THE UNIVERSITY OF MICHIGAN
Biological Station

A Water Quality Survey of Munro Lake, Michigan

Technical Report No. 7

by

G. Winfield Fairchild (Instructor)
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and
The Limnology students at the
University of Michigan Biological Station

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Douglas Lake

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 inquiries to: The University of Michigan Biological Station, Pellston, Michigan 49769 (Phone 616-539-8406).

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INTRODUCTION

The riparian residents of Munro Lake, Cheboygan County, Michigan have been concerned in recent years with the water quality and sediment build up in their lake. In particular, the Munro Lake Association has begun exploring techniques of preventing the periodic winter kill of fish in the lake, and is considering the possibility of dredging. Lake management measures such as these demand considerable ecological study if they are to achieve the results desired. The limnology class at the University of Michigan Biological Station accordingly conducted a study of the lake during the summer of 1978. The report which follows includes physical, chemical and biological information concerning the present state of Munro Lake, and specifically addresses two questions concerning the lake's possible future:

1.) What might be the effects of increased housing development along the lakeshore?

2.) What might be the effects of dredging upon water quality in the lake?

A major purpose of the report is a thorough documentation of the present condition of the lake, hence the fairly technical nature of much of what is included herein.

In compiling this report, the class drew extensively upon published and unpublished information from a RANN study (Gannon and Paddock, 1974) of the watersheds of Emmet and Cheboygan Counties and wishes also to acknowledge the generous technical support and advice of Art Gold, researcher in residence at the Biological Station. In addition, we would like to thank many of the lakeshore residents for their help in providing information about the lake.

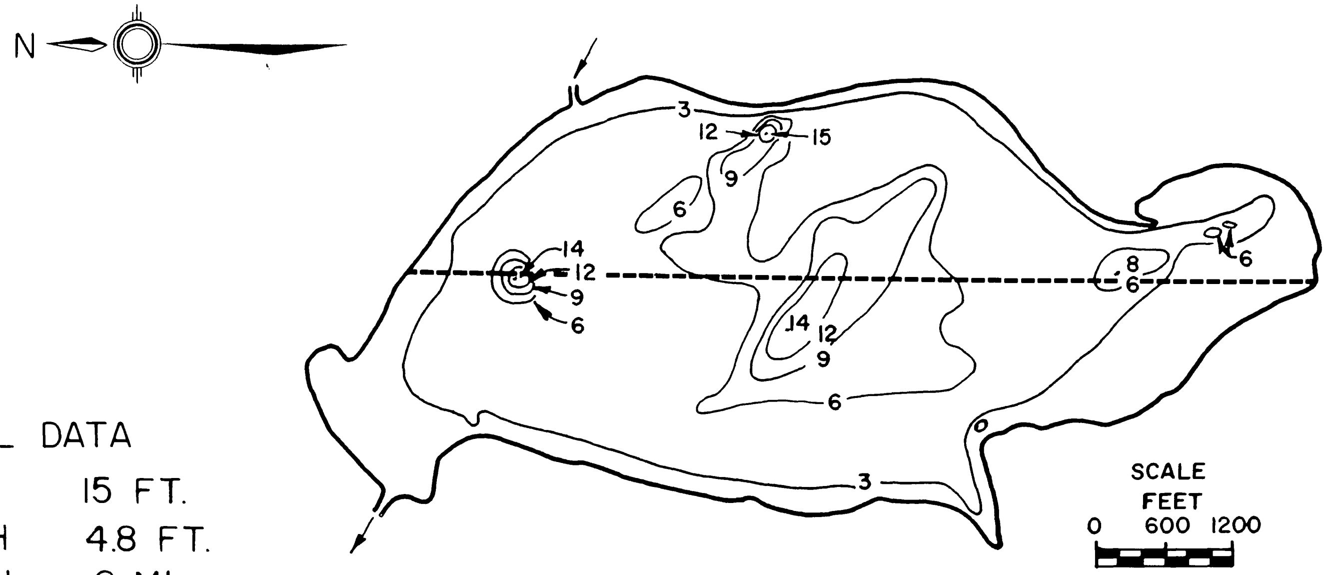
MORPHOMETRIC FEATURES

Munro Lake, located in Cheboygan County, Michigan (N 45° 37', W 84° 41') is a shallow, hardwater lake of glacial ice block origin. The lake has a maximum length of 1.7 miles, and a surface area of 529 acres; compared to its large areal size, however, Munro Lake's mean depth is only 4.8 feet, and none of the lake's several basins exceed 15 feet in depth (Fig. 1).

The present shallow nature of Munro Lake is the result of a gradual filling in of its basins since their formation during the final Pleistocene glacial advance some 12,000 years ago (Dorr and 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 pipe joined together with plumbers fittings. The cores were taken at four locations on the lake on July 25, 1978 (Fig. 2). The sediments at the surface of all four cores consisted of a flocculent organic material which only gradually became more compacted with depth. Highly compressed sediments beneath this flocculent material were reached in cores I,II, and IV, suggesting that the original lake basin lay at or close to these depths. No such sediments were found in core III, and the large central basin undoubtedly was considerably deeper than the 23 feet penetrated by the coring device used.

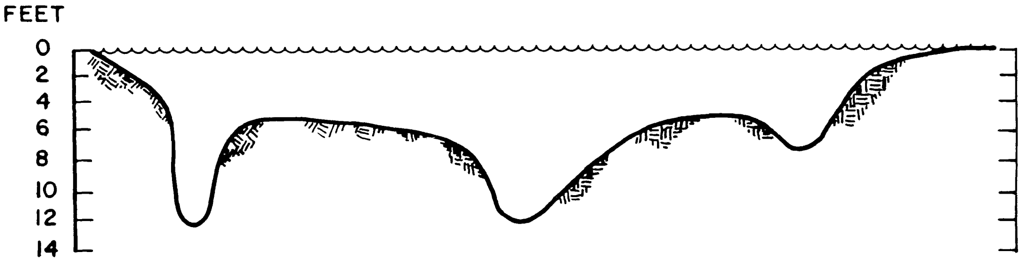
MUNRO LAKE
MORPHOMETRIC FEATURES

(Fig. 1)



PHYSICAL DATA

MAXIMUM DEPTH	15 FT.
AVERAGE DEPTH	4.8 FT.
MAXIMUM WIDTH	.8 MI.
MAXIMUM LENGTH	1.7 MI.
SHORELINE	4.5 MI.
SURFACE AREA	529 ACRES
WATERSHED AREA	2280 ACRES
VOLUME	110,000,000 CU.FT.
SHORELINE DEVELOPMENT FACTOR	1.2



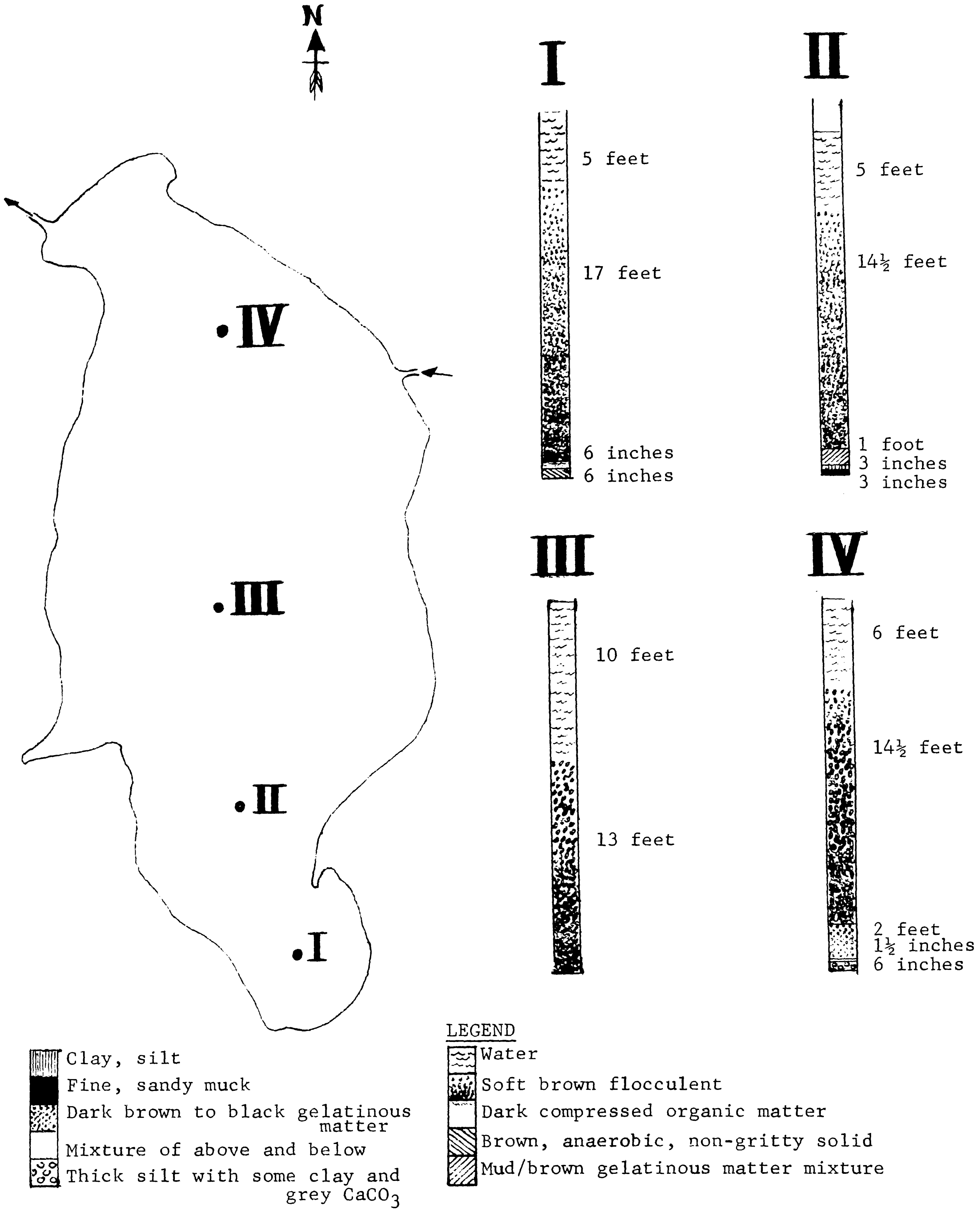


Fig. 2 Location and sediment analysis of cores taken from Munro Lake, July 7, 1978.

PHYSICO-CHEMICAL MEASUREMENTS

The shallow nature and comparatively large size of Munro Lake result in virtually continuous wind-driven mixing of the entire water column (Fig. 3). Thus, not only are water temperatures closely alligned to fluctuating air temperatures, but these temperatures are quite uniform from the surface to the sediments. High dissolved oxygen concentrations in most of the water column also reflect this mixing (Table I). When ice does not cover the lake, oxygen concentrations can be expected to maintain high saturation values, reflecting diffusion from the atmosphere as well as oxygen production through photosynthesis.

Table I. Chemical Measurements, July 7, 1978

Depth (ft.)	D.O. ppm	% Sat.	pH	Free CO_2 (ppm)	HCO_3 (ppm)	CO_3 (ppm)
2	8.8	108	8.6	0	94	4
5	8.8	108	8.7	0	92	6
8	8.8	108	8.8	0	92	6
11 (sediments)	.2	3	8.6	0	94	4

Depth (ft.)	Total Alk. ppm	Hardness (as ppm $CaCO_3$)	Turbidity (as ppm SiO_2)	Chlorophyll-*a* ($mg\text{-}m^{-3}$)
2	98	108	2.6	4.44
5	98	112	3.2	5.74
8	98	112	2.3	87.81
11	98	120	1.5	32.03

Munro Lake is a moderately hardwater lake due to high concentrations of calcium (Ca) and magnesium (Mg) ions in the

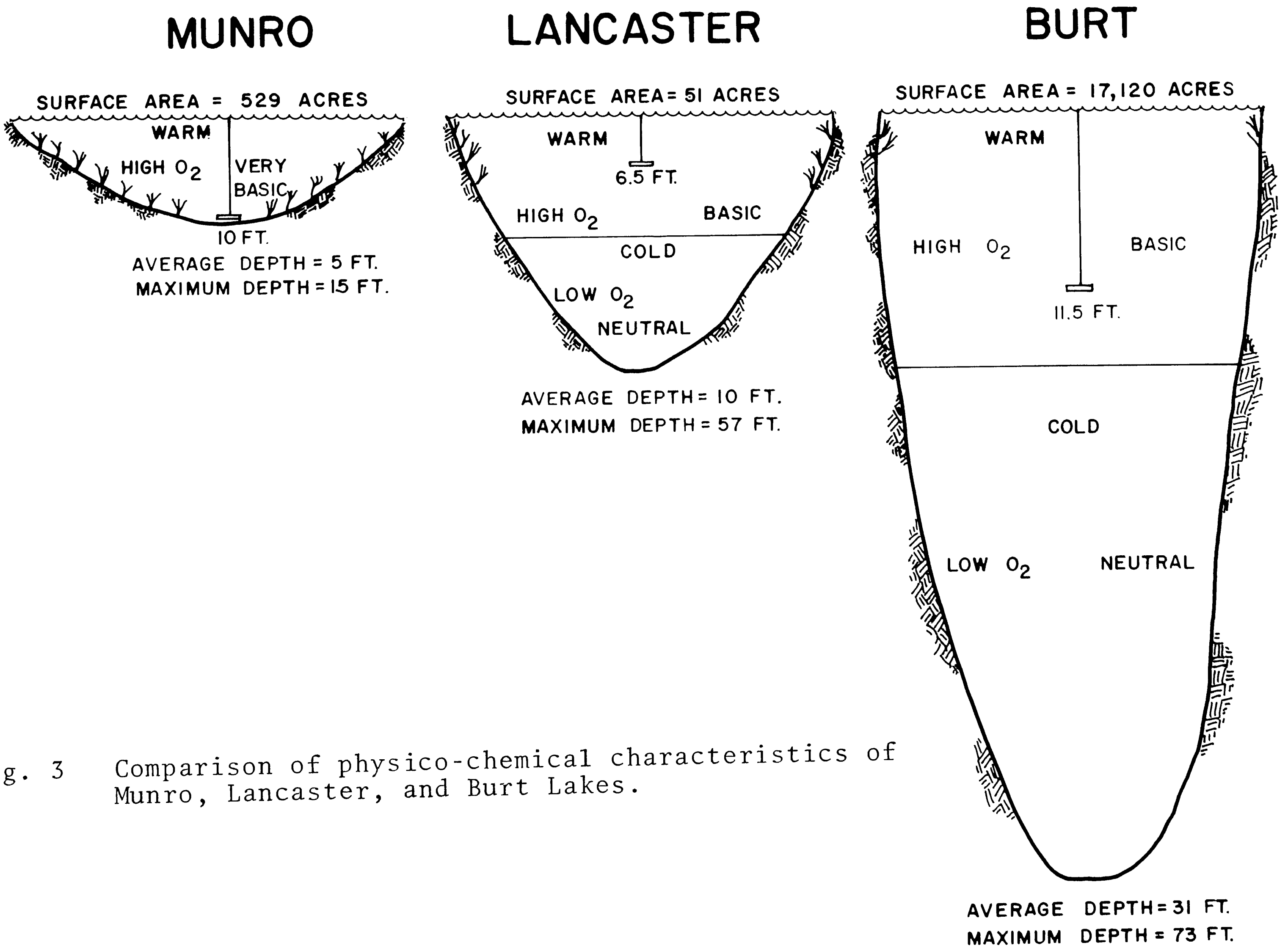


Fig. 3 Comparison of physico-chemical characteristics of Munro, Lancaster, and Burt Lakes.

soils of its watershed. The high alkalinity values, which measure the combined concentrations of free carbon dioxide (CO_2), bicarbonate ions (HCO_3^-) and carbonate ions ($CO_3^=$), are also characteristic of hardwater lakes in this area. The sources of input of alkalinity to Munro Lake are carbon dioxide from the atmosphere as well as various carbonates from its watershed. High pH (basicity) of the water results in particularly high relative concentrations of carbonate ions (Cole 1975), and this frequently combines with calcium and precipitates out of the water as a flocculent yellowish or grayish material known as marl. Munro Lake is not unique in its marl production; Douglas Lake, Larks Lake, Carp Lake, and many of the other lakes of this region also have marly bottom material. Marl covers most of the sandy eastern shore of Munro Lake to a depth of only a few inches. In the more protected or deeper portions of the lake, however, the marl is kept in suspension together with fine particles of organic origin.

Table II. Five decades of measurements of Munro Lake (from Welch, and Gannon, unpublished data.

Date	Source	pH	Total Alkalinity (ppm)	mhos-cm^{-1} Conductivity
23 July 43	Welch	8.4	105	175
21 July 36	"	8.0	101	185
28 July 37	"	8.0	97	190
2 July 40	"	8.1	90	180
8 Aug. 49	"	8.5	101	190
10 Aug. 49	"	8.2	121	220
Summer 73	Gannon	8.3	92	216
Summer 74	"	8.5	99	204
7 July 78	Fairchild	8.7	98	217

These properties, although they vary seasonally to some extent, are seen to have remained essentially constant over the past 44 years (Table II). Conductivity, an expression of the total numbers of ions present in the water and thus an indication of nutrient input into the lake, has shown a gradual increase since measurement was first begun over four decades ago. This increase is probably a consequence of increased housing development along the lakeshore.

The concentrations of particular ions in the lake were measured in 1973 and 1974 (Table III), using a Perkin-Elmer Atomic Absorption Spectrophotometer and Technicon Autoanalyzer II.

Table III. Ion Concentrations in Munro Lake, 1973-4 (Gannon, unpublished data)

	Spr 73	S 73	F 73	W 74	Spr 74	S 74
Ca (ppm)	24.8	27.3	19.8	37.1	29.5	23.2
Mg (ppm)	7.3	14.0	10.0	13.7	7.5	9.3
K (ppm)	0.7	0.7	0.8	1.2	0.7	0.7
Na (ppm)	1.1	1.2	1.1	1.8	1.1	1.3
SiO_2 (ppm)	45.	390.	328.	620.	87.	210.
PO_4-P (ppb)	5.2	12.2	10.2	19.3	2.0	4.5
Total-P (ppb)	10.0	18.9	13.9	22.6	12.0	8.5
NO_3-N (ppb)	103.	50.	32.	152.	130.	52.
NH_3-N (ppb)	263.	14.6	30.3	487.	241.	109.
avail. N/avail. P	70.	5.3	6.1	33.1	185.	35.8

The primary producers of Munro Lake, the aquatic vascular plants and algae, each require slightly differing concentrations of these ions. The micronutrients Ca, Mg, K and Na are needed only in small quantities, and are not believed to be limiting to plant production in Munro Lake. Silica (SiO_2) is needed in abundance by the dominant algae of the lake, the diatoms. These are typically most abundant during the Spring (Cole 1975), and appear to reduce the SiO_2 concentrations in Munro Lake at that time (Table III).

The macronutrients, available nitrogen (NH_3-N and NO_3-N) and available phosphorus (PO_4-P) are needed by primary producers in much larger quantities and are therefore generally limiting to plant growth in lakes of this region. Natural algal communities are known to utilize Nitrogen and Phosphorus in the ratio 12:1 to 14:1 (Cole 1975). Diatoms in particular are known to "luxury consume" large quantities of available Phosphorus in the Spring when they are abundant, and appear to reduce substantially the concentration of available Phosphorus in Munro Lake during the Spring (Table III). The generally high "available N/available P" ratio (Table III) suggests that Munro Lake's algal production is usually limited primarily by the availability of Phosphorus.

Light penetration in Munro Lake is very high. Secchi depth measurements exceeded 10 feet, and indicate a substantial amount of light at the bottom, providing sufficient energy for photosynthesis by rooted aquatic vegetation, which is accordingly abundant in most of the lake.

The apparent color of the water was documented using a Forel-Ule color scale (Hutchinson 1967). The scale reading of 14 represents a yellow-green color, probably caused by light scattering from the abundant diatoms, as well as other particles, in the lake.

TROPHIC STATUS

Lakes undergo a process of "aging", termed eutrophication. Sedimentation causes a filling in of the basin, and algal and vascular plant production gradually increases. The end result is usually a wetland. The rates of eutrophication appear to differ substantially according to the particular lake involved; the process may be affected considerably by the size and chemical characteristics of the watershed, the degree of protection and depth of the lake basin, and the kinds of plants along the lake margin. Thus, lakes all display unique characteristics. Limnologists have nonetheless attempted to classify lakes into certain broad categories. A commonly used classification system, with some of the characteristics which define each category, is presented in Table IV.

Table IV. Features contrasting Oligotrophic and Eutrophic Lakes (after Cole 1975)

Oligotrophic	Eutrophic
deep and steep banked	shallow; broad litteral zone
blue or green water	green to yellowish or brownish green
high light penetration	limited light penetration
water poor in plant nutrient	plant nutrients, and Ca^{++}, abundant
sediments low in organic matter	very organic sediments

oxygen abundant at all depths at all times	oxygen usually depleted in deeper water
vascular plants not abundant	vascular plants abundant
low phytoplankton densities	high phytoplankton densities
profundal benthos diverse	profundal benthos consisting of only a few oxygen-tolerant species

Lakes showing intermediate characteristics are usually termed "mesotrophic". Thus, the process of eutrophication involves gradual progression from an initially oligotrophic state to a more mesotrophic, and finally eutrophic condition.

A more recently proposed system of classification, termed the Trophic State Index, attempts to rank lakes on the basis of single easily measured lake characteristics. Three such characteristics are winter (or early spring) phosphorus concentrations, summer chlorophyll-*a* concentrations (a measure of algal biomass), and summer Secchi depth (Carlson 1977). The high light penetration and limited depth of Munro Lake make Secchi depth measurement an inaccurate one, the Secchi disk entering the flocculent sediments while still readily visible from the surface. The variability of winter and spring phosphorus concentrations in Munro Lake similarly makes a reliable estimate of the lake's Trophic State Index difficult. Estimates of summer chlorophyll-*a* concentrations were accordingly chosen as the basis for the evaluation of a Trophic State Index for Munro Lake.

Chlorophyll-*a* measurements were taken using a Turner Model III Fluorometer. Chlorophyll-*a* concentration was related to Trophic State Index (TSI) using the equation:

$$\mathrm{TSI} = 10(6 - \log_2 \frac{7.7}{(\mathrm{chl}\text{-}a)^{.68}}) \quad \text{(Carlson, 1977)} \quad (1)$$

Low TSI values thus typify oligotrophic lakes; values exceeding 54 are, in contrast, usually associated with eutrophic lakes.

Munro Lake can be seen to correspond more closely in its physical and chemical characteristics to a eutrophic lake. Its shallow basin, yellow-green water, abundant P and N, the highly organic nature of its sediments, and the presence of large stands of aquatic vascular plants, all conform to the characterization of eutrophy. When rated against other lakes of this region on the basis of its chlorophyll-*a* content, Munro Lake has been described (Stemberger, unpublished data) as mesotrophic (Fig. 4). However, this assessment is based upon concentrations of chlorophyll-*a* just beneath the surface. Our data suggest that Munro Lake possesses unusually high amounts of chlorophyll-*a* near the interface between the water column and the flocculent false bottom of the lake (Table I). If these four chlorophyll-*a* measurements are averaged, the resultant TSI assumes a value of 65, certainly very high for lakes in this region and more in concert with the observed eutrophic characteristics of the lake. Results from the Self-Help Program (Inland Lake Self-Help Program Annual Report, 1977) for Munro Lake for 1977 were an average of 21.3 mg m^{-3} chlorophyll-*a*, which also confers a high TSI of 60, again supporting the classification of Munro Lake as a eutrophic lake.

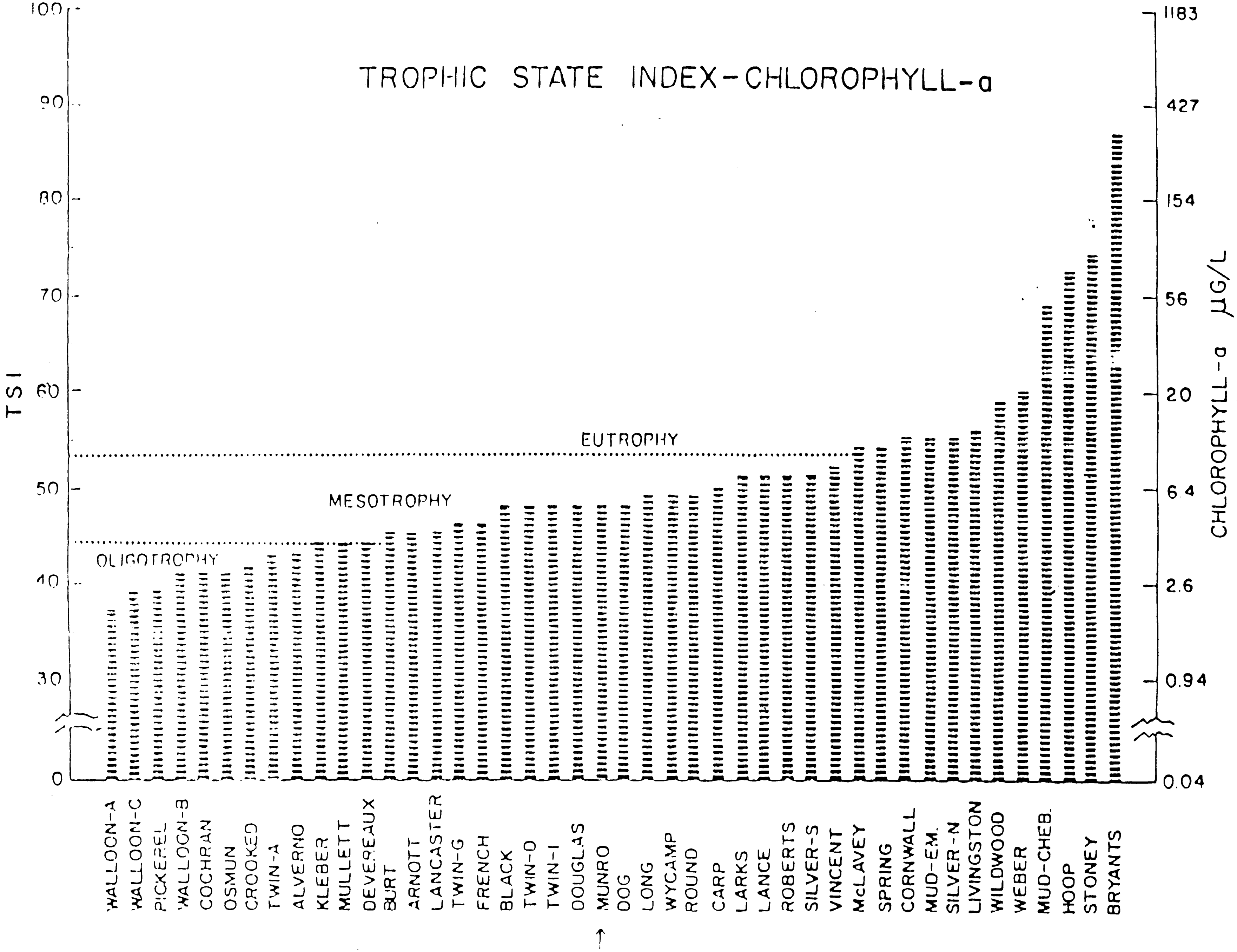


Fig. 4 Trophic, State Index, based on chlorophyll-*a* concentration for lakes of Northern Lower Michigan (Stemberger, unpublished data).

FISH PRODUCTION

A generalized food-web diagram of Munro Lake (Fig. 5) emphasizes the dual importance of the aquatic vascular plants and phytoplankton as bases of fish production. The phytoplankton were dominated by the colonial diatom *Fragilaria crotonensis*, which comprised 84% of total algal abundance. Other genera found in the lake are listed in Table V. The dominance of diatoms is indicative of hardwater lakes with sufficient SiO_2 (Hutchinson, 1967).

The rooted aquatic vascular plants were distributed according to water depth and substrate type. Sandy, marl covered sediments near shore were found to be utilized primarily by emergent vegetation, including the bulrushes *Scirpus acutus* and *S. americanus*, several sedges (*Carex spp.*) and flowering rushes (*Juncus spp.*). Patches of small submergent plants, *Chara sp.* and *Najas flexilis*, were also abundant. Shallow protected areas with more flocculent sediments contained a diverse community of the water milfoil *Myriophyllum exalbescens*, the pondweeds *Potamogeton gramineus* and *P. natans*, the bur reed *Sparganium angustifolium*, and the fragrant water lily *Nymphaea odorata*. *P. natans* and *P. praelongus* were the chief forms of vegetation in the center of the lake, dominating the shallower and deeper areas respectively. There is high agreement between the distribution of the emergent plants and the presence of firm marly sand sediments. The distribution of pond-

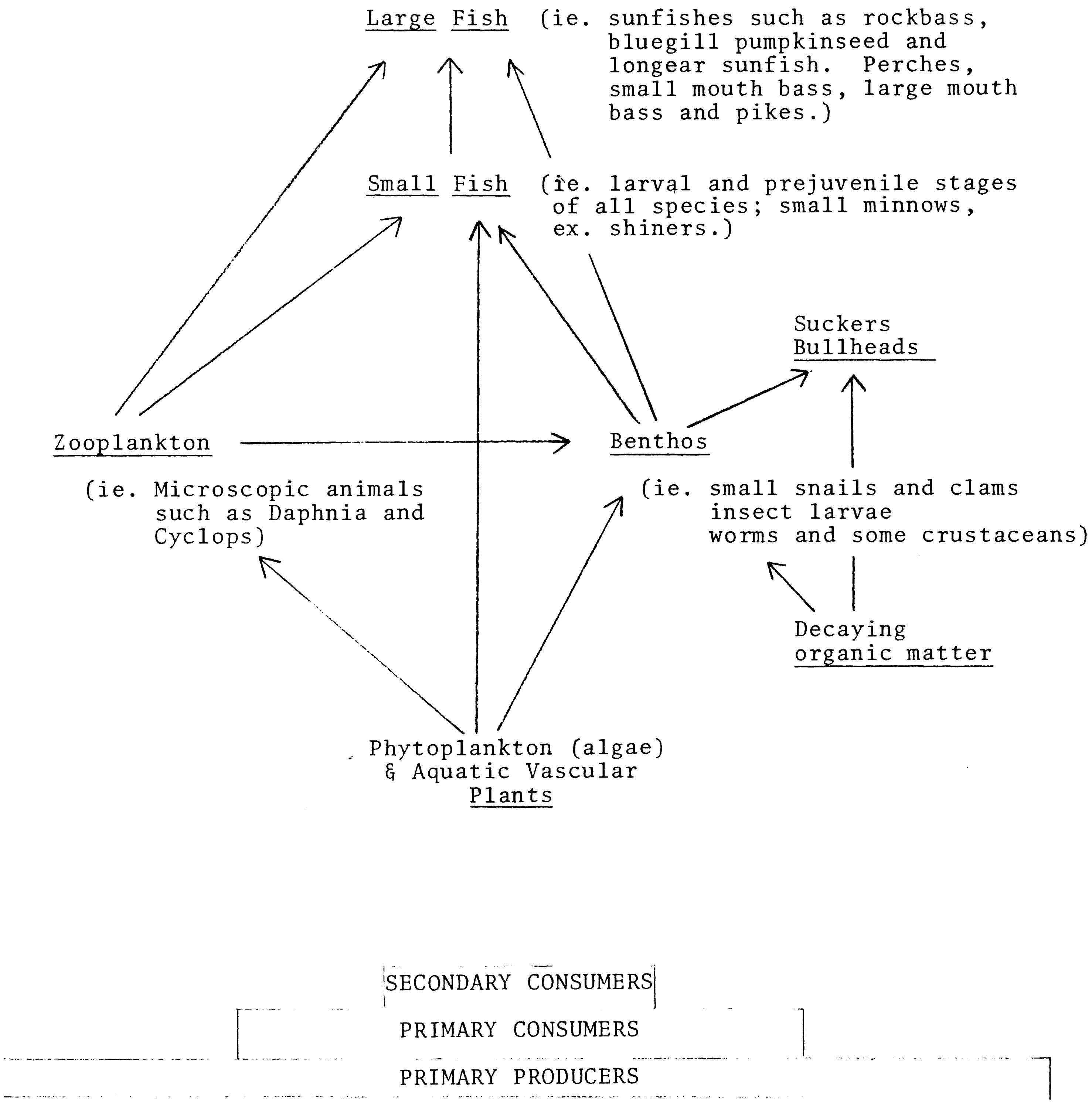


Fig. 5 Food Web Diagram of Munro Lake

weeds is similarly highly correlated with the presence of flocculent organic sediments in the lake. The aquatic vascular plants, together with their attached algae (periphyton) serve both as attachment and as a food source for a diverse invertebrate community which is ultimately utilized by fish. The vascular plants in fact constitute the only firm substrate capable of supporting these organisms in the central portion of the lake. Most of the benthic productivity in Munro Lake, however, undoubtedly occurs along the lake margins. The majority of benthic organisms collected were aquatic insects associated with sandy substrates in the lake.

The zooplankton, which constitute the principal consumers of algae in Munro Lake, and are in turn heavily utilized by most of the fish species, consisted mainly of rotifers and small crustacean species (Table V). The generally small size of the species present reduces their visibility to fish and is a commonly observed effect of a large fish population in a shallow lake with good visibility to the bottom.

The relatively low fishing pressure and high productivity of Munro Lake result in high quality fishing for lake residents. As shown by a Department of Natural Resources survey of the lake in 1968 (Table VI), the average sizes of all major fish species in Munro Lake exceeded state averages. Whereas periodic winter kills do occur, they apparently have not occurred with sufficient frequency to shift the fish community away from the present dominance by pike and centrarchid fishes (bass, sunfish) to a community dominated by fish more tolerant of low oxygen concentration such as brown bullheads and white suckers.

Table V. Genera of Plankton found in Munro Lake, July 7, 1978

PHYTOPLANKTON

CHLOROPHYTA

Chlorococcum
Coelastrum
Cosmarium
Scenedesmus
Sphaerocystis
Staurastrum

CHRYSOPHYTA

Amphipleura
Amphora
Asterionella
Cyclotella
Cymbella
Diatoma
Fragilaria
Navicula
Nitzchia
Pinnularia
Stauroneis
Synedra
Tabellaria

CYANOPHYTA

Anabáena
Chroococcus
Gloeocapsa
Gomphosphaeria
Merismopedia

PYRROPHYTA

Ceratium

ZOOPLANKTON

ROTIFERS

Asplanchna
Collotheca
Conochiloides
Conochilus
Hexarthra
Keratella
Lecane
Polyarthra
Trichocerca

CRUSTACEA

Bosmina
Ceriodaphnia
Cyclops
Diaphanosoma
Diaptomus
Holopedium

Table VI. Principal Fish Species of Munro Lake (from DNR survey, 7-24-68).

Species	Age Class	Number Collected	Mean Length (inches)	State Avg. (inches)
Northern Pike	I	6	15.9	15.6
	II	3	17.8	19.4
	III	11	22.8	22.2
	IV	1	26.6	24.6
Bluegill	VIII	2	9.3	8.5
	X	1	9.7	9.2
Pumpkinseed	II	1	4.3	4.1
Rock Bass	II	2	5.5	4.5
Largemouth Bass	III	2	10.8	10.6
Yellow Perch	II	23	6.2	6.1
	III	7	7.3	7.0
	IV	7	8.5	8.0
	V	2	9.7	9.0

NUTRIENT LOADING

The high chlorophyll-*a* values and abundant aquatic vascular plants in Munro Lake indicate a generally high rate of nutrient flow into the lake. Since available phosphorus appeared to be the nutrient most limiting to plant growth (Table III), the sources and rates of phosphorus flow into the lake were examined.

The conceptual framework for the phosphorus loading analysis summarized here is provided by Dillon and Rigler (1975). Their model permits the prediction of both the winter (or early spring) phosphorus concentration and summer mean chlorophyll-*a* value of a lake based upon an assessment of the land use and extent of its watershed, as well as the morphometric characteristics of the lake itself:

$$[P] = \frac{L(1-R)}{\bar{z}\ p} \qquad \text{(Dillon \& Rigler 1975)} \quad (2)$$

In their model, [P] = the predicted concentration of winter (or early Spring) phosphorus, L = the total phosphorus "loading" expressed on a yearly basis, R = the fraction of this loading which is not lost in the outflow, $\bar{z}$ = the mean depth of the lake, and p = the flushing rate, expressed as a fraction of the total lake volume.

Values for Munro Lake which were used in this model are summarized in Table VII. These values were derived from previous studies of hydrology and land use in this region and must be considered as rough estimates rather than direct measurements. Use of the model nonetheless permits some significant general conclusions, and directs attention to particular areas of concern in maintaining the present water quality in Munro Lake.

Yearly loading (L) of phosphorus was estimated as the sum of inputs from groundwater originating in various land use types within the watershed, from direct precipitation, and from septic tanks along the lakeshore. In order to obtain estimates of phosphorus loading due to groundwater input, a land use map of the Munro Lake watershed was prepared using infra-red satellite photographs of the region, together with information from a survey of portions of the watershed accessible by car (Fig. 6). This map was then used to obtain areal estimates of "MOSTLY AGRICULTURAL," "FOREST," and "URBAN" land. Phosphorus loading values were then applied using estimates by Omernik (1976). An estimated 57% of the watershed is characterized as "MOSTLY AGRICULTURAL" land, a designation which includes heavily fertilized cropland as well as fallow fields and rangeland used for grazing. This component of the watershed contributes the majority ($\simeq$ 65%) of the phosphorus entering the lake as groundwater. "FOREST" comprises 37% of the watershed but contributes only another 22% of the total. The remaining 13% of watershed loading originates from the lawns, gardens, etc. associated with residences around the lake, designated as "URBAN." This figure does not include septic tank runoff, however, which is considered separately. Groundwater supply of phosphorus from the watershed (J_b) is thus estimated at 101.6 $kg \cdot yr^{-1}$, or 58% of total input (Table VII).

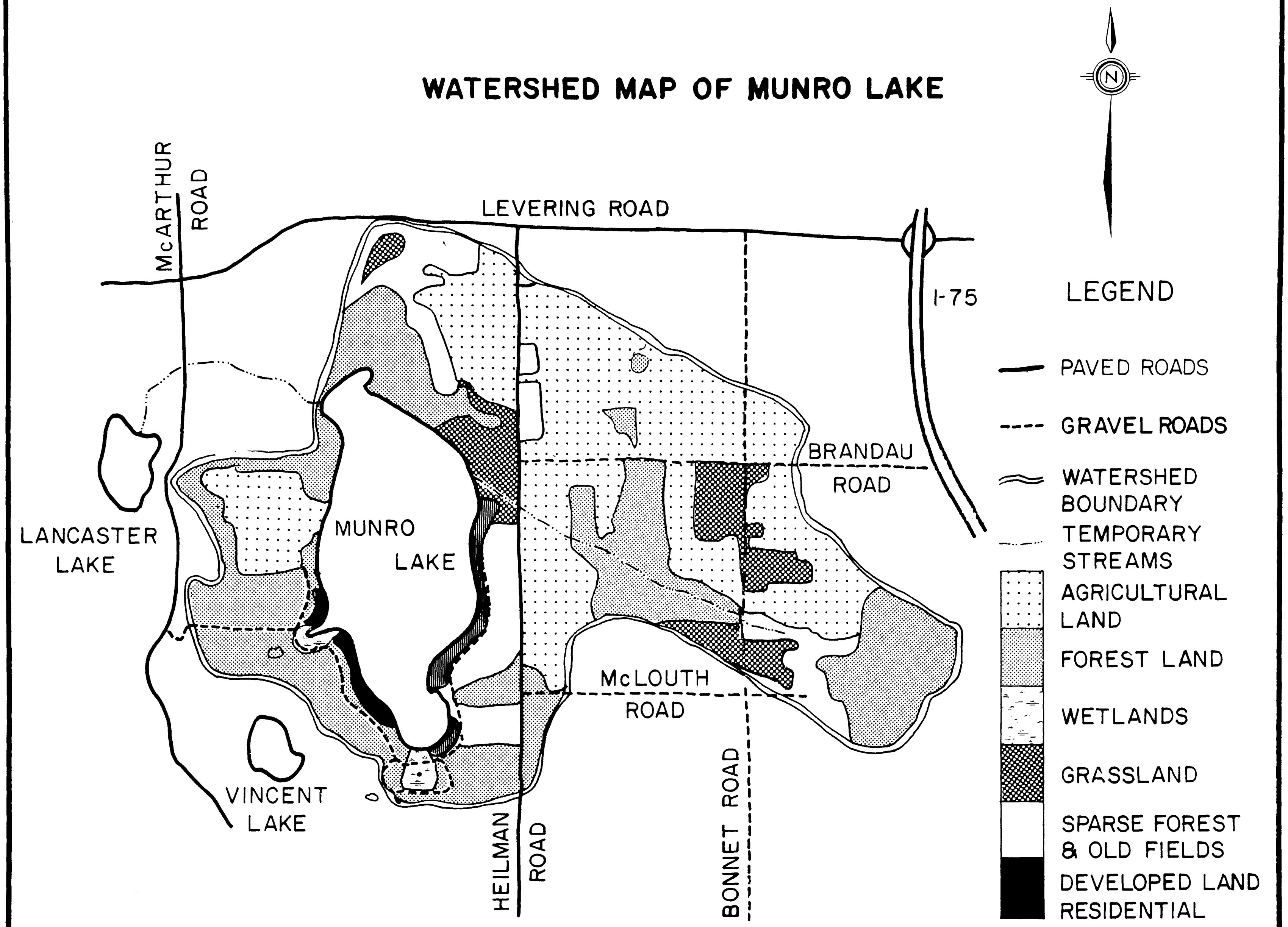


Fig. 6 Land use within the Munro Lake Water

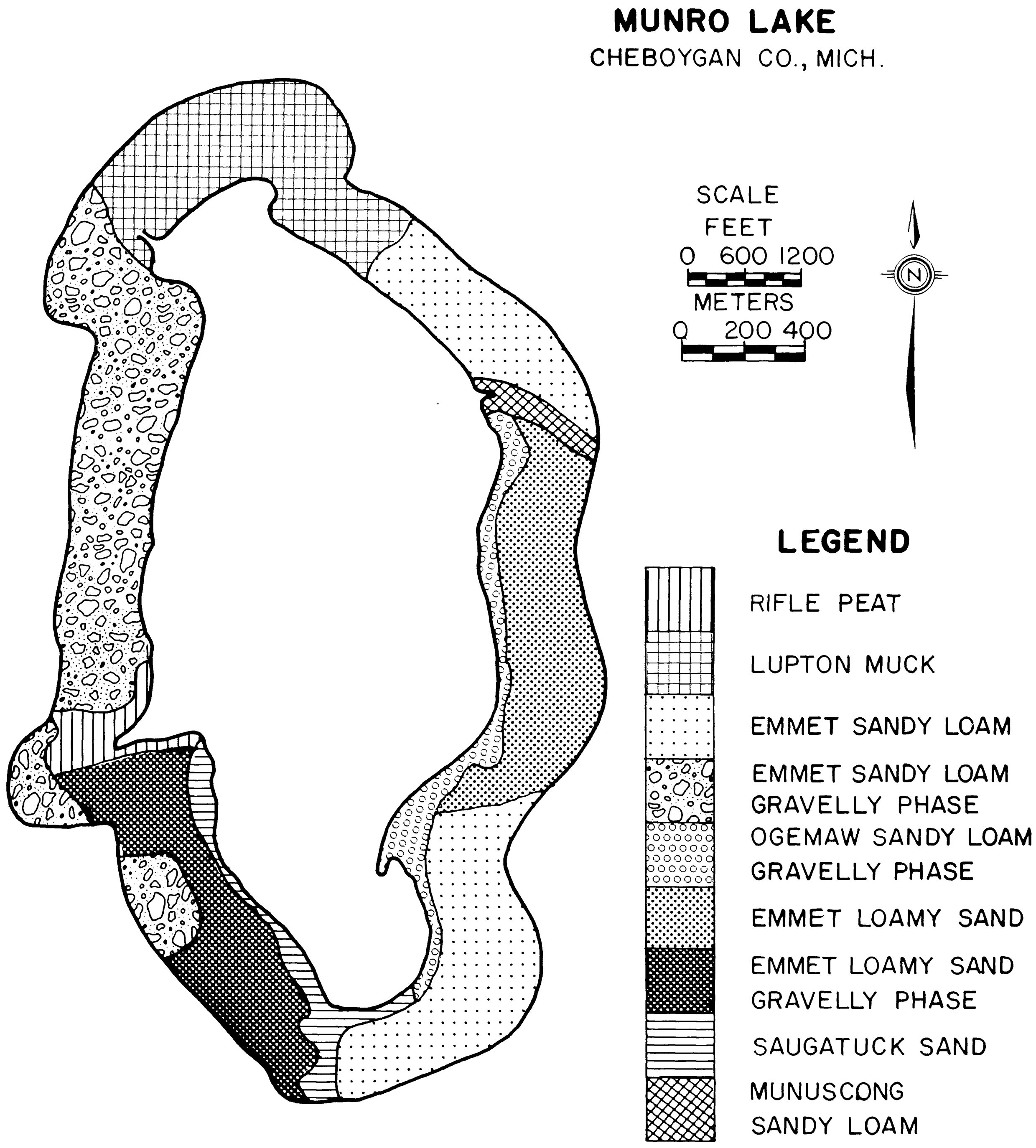


Fig. 7 Soil types to a distance of 1000 ft. from the lakeshore.

The second most important source of phosphorus loading was found to occur through direct wet and dryfall precipitation. Approximately 30% of total yearly loading to Munro Lake enters the lake directly from the atmosphere.

In order to assess the effects of septic tanks upon phosphorus loading in Munro Lake, the class assumed a total of 56 temporary and 4 permanent residences on the lake. The number of year-round residents was estimated at 10. Temporary residents' use of septic tanks on the lake was evaluated by assuming the average summer residence to contain 2 people for 3 months of the year, or an equivalence of .5 people per year per cottage. Septic tanks are known to receive about .8 kg P per year per user (Dillon & Rigler 1975). That portion of the phosphorus not retained in the drainfield or otherwise trapped by the soil or its vegetation enters the lake. Most of the cottages on Munro Lake are seen to be situated on Ogemaw Sandy Loam, Gravelly Phase (Fig. 7) which has poor phosphorus retention (Foster et al., 1939). Septic treatment was therefore estimated to remove only 30% of phosphorus entering as household wastes and human excrement. Nonetheless, the contribution of septic tank effluents to total phosphorus loading is estimated at 21.3 $kg\text{-}yr^{-1}$, only 12% of total loading at the present time.

Munro Lake's relatively shallow morphometry is disadvantageous with regard to nutrient loading, since there is relatively little water to dilute these incoming plant nutrients. The lake has a rapid flushing rate (p), however, and empties an estimated 77% of its water volume each year, much of it to Lancaster Lake. Thus, much of the incoming phosphorus is exported out of the lake.

Based upon these estimates, the Dillon and Rigler model predicted a winter (or early spring) phosphorus concentration of 8.2 mg m^{-3} which underestimates the only actual winter measurement of phosphorus of 22.7 mg m^{-3} taken on the lake (Winter, 1974, Gannon, unpublished data). The model may also be used to predict summer chlorophyll-*a* concentration, using the equation:

$$\log_{10} [\text{chl-}a] = 1.45 \log_{10} [P] - 1.14 \quad \text{(Dillon and Rigler)} \quad (3)$$

The predicted value of 1.5 mg m^{-3} chlorophyll-*a* also grossly underestimates the actual concentrations measured by the class, and by the Michigan Self Help Program as discussed previously.

Munro Lake is subject to an additional source of phosphorus loading not included in the Dillon and Rigler model, that provided by regeneration of phosphorus from the lake sediments. Its shallow basin morphology results in periodic wind driven resuspension of the flocculent silt of the lake bottom, and subjects organically bound phosphorus trapped in these sediments to mineralization through bacterial decay. This phosphorus is thus made available for uptake by algae, and may greatly enhance over-all primary productivity.

Phosphorus release from the sediments is also facilitated by the presence of anoxic conditions at the sediment-water interface. Phosphorus, which is trapped in the sediments when oxygen is present, escapes to the water column when this oxygen is depleted, especially during winters of heavy ice and snow cover. This phosphorus likewise contributes to increased algal growth (Wetzel, 1975).

A significant portion of the total nutrient loading and high productivity observed in Munro Lake may therefore be due to the internal cycling of phosphorus within the lake itself. While the sediments of deeper, oligotrophic lakes serve as nutrient "traps," retaining organically bound phosphorus, the sediments of shallow, highly productive lakes such as Munro Lake are frequently subject to both resuspension and anoxia, and release much of their phosphorus to the water column. Reducing external phosphorus loading from the watershed can be expected to have little immediate effect upon reversing the eutrophication process in such lakes.

Table VII. Summary Statistics for Dillon & Rigler's (1975) Phosphorus-Loading Model as Applied to Munro Lake

A. Parameter Used

Symbol	Parameter	Value	Source
A_o	lake surface area	2.14×10^6 m^2	
$\bar{z}$	lake mean depth	1.44 m	
V	lake volume	3.12×10^6 m^3	
A_d	lake drainage area	7.08×10^6 m^2	
r	total annual unit runoff	.29 m yr^{-1}	Pentland (1968)
Pr	mean annual precipitation	.794 m yr^{-1}	Richardson <u>et al.</u> (1978)
Ev	mean annual lake evaporation	.624 m yr^{-1}	Pecor <u>et al.</u> (1973)
Nc	number of seasonal cottages	56	
N_d	number of permanent homes	4	
R_s	septic field retention coefficient	0.3	adapted from Foster <u>et al.</u> (1939)
L_{pr}	phosphorus loading from precipitation	2.5×10^{-6} kg m^{-2} yr^{-1}	Gannon (1978)

B. Watershed Characterization (P export values adapted from Omernik, 1976)

Land Use	Area (km^2)	P export (Kg Km^{-2} yr^{-1})	P supply (Kg yr^{-1})
Mostly agricultural	4.01	16.3	65.4
Forest	2.65	8.6	22.8
Urban	0.42	31.7	13.4

Total P supply from drainage basin (J_d) = 101.6

C. Equations for the calculation of other parameters

Symbol	Parameter	Equation
Q	total outflow volume	$Q = A_d \cdot r + A_o\,(Pr-Ev) = 2.4 \times 10^6\ m^3\ yr^{-1}$
P	flushing rate	$p = Q/V = .77\ yr^{-1}$
q_s	areal water load	$q_s = Q/A_o = 1.1\ m\ yr^{-1}$
R	lake retention coefficient	$R = 0.426\ EXP(-0.271\ q_s) + 0.574\ EXP(-0.00949\ q_s) = 0.89$
N_{cy}	number of capital-years at lake	$N_{cy} = 0.5 \cdot Nc + 2.5 \cdot N_d = 38$
J_a	P supplied to lake from cottages	$J_a = 0.8 \cdot N_{cy}\,(1-R_s) = 21.3\ kg\ yr^{-1}$
J_{pr}	P supplied to lake from precipitation	$J_{pr} = L_{pr} \cdot A_o = 53.5\ kg\ yr^{-1}$
J_t	total P supplied to lake	$J_t = J_d + J_{pr} + J_a = 176.4\ kg\ yr^{-1}$
L	total P loading per unit of lake surface	$L = J_t/A_o = 82.4\ mg\ m^{-2}\ yr^{-1}$
[P]	predicted winter P concentration	$[P] = \dfrac{L(1-R)}{\bar{z}p} = 8.2\ mg\ m^{-3}$

CONCLUSIONS

I. Dredging

Munro Lake has been described as a eutrophic lake with high productivity and good fishing, but also with the extensive weed beds and occasional winter kills which accompany the latter stages of lake aging. The lake has accordingly been a source of some concern to the shoreline residents; an aerator was placed in the lake during the winter of 1978 to help prevent winter kill, and the lake association had begun to explore the possibility of dredging as a means of temporarily reversing the eutrophication process.

The limnology class addressed the question of dredging Munro Lake from the viewpoint of what effects the removal of sediments might have upon water quality and organisms in the lake. The problems of what sort of dredging equipment to use, what to do with the sediments, and how to finance such a project were not considered directly. However, the class strongly felt that only the removal of the flocculent silt characteristic of the central basins, Turtle Bay near the outflow stream to Lancaster Lake, and the southern end of the lake should be considered.

Potential changes in the lake were estimated in relation to dredging out this silt either to the underlying glacial till in shallower areas, or to a depth of 12 feet in the deeper basins. The effects of dredging to greater depths were not considered in detail, although the results would predictably be very different. The following effects are predicted following dredging:

1.) The sediment type in the central portion of the lake would remain flocculent and highly organic. Sediment cores taken at 4 stations on the lake indicate that the silt extends far deeper than 12 feet below the water surface in most of this area. Silt would be expected to recede somewhat from shallower, near-shore areas.

2.) Because of the lake's large surface area, dredging to a depth of 12 feet would probably not change the complete circulation of gases and nutrients throughout the water column. The presence of oxygen at the sediment-water interface during most of the year, considered critical to nutrient "trapping" by the sediments, should not be substantially altered.

3.) Chemical characteristics of the water, such as pH, alkalinity, hardness, and conductivity, should not be affected greatly by dredging.

4.) Light penetration to the bottom would remain sufficiently high to permit the regrowth of aquatic vascular plants. In particular, Potamogeton praelongus could be expected to eventually recolonize the central portion of the lake; its tolerance of low light levels and rapid growth would probably still permit growth to the surface of the lake in late summer.

5.) During the first several years following dredging, noxious algal blooms could be expected, due to (1) increased availability of nutrients from the disturbed bottom, and (2) the temporary absence of rooted aquatic vascular plants, which compete with the algae for these nutrients.

6.) Due to the increased water volume, depletion of oxygen under the ice by respiring plants and animals would be reduced. The periodic winter kills of Munro Lake accordingly would occur less frequently.

The general conclusion of the class was that the probable cost and temporary disturbances created by dredging in the fashion proposed outweighed the minimal improvement in the lake's water quality which would result. In particular, it was felt that better alternatives were available to reduce the occurrence of fish winter kills.

II. Nutrient Loading

An analysis of P-loading into Munro Lake, based upon Dillon and Rigler's (1975) model, supported the following conclusions:

1.) Runoff from the various land use types in the Munro Lake watershed constituted 58% of the total P loading into the lake from external sources, contributing an estimated 101.6 Kg P to the lake per year. Of this amount, about 2/3 was attributed to agricultural sources.

2.) Approximately 37% of the watershed is not presently utilized for either agricultural or home development. These lands contribute only 22% of the P loading from the watershed. Their presence in the watershed is therefore highly desirable and helps to limit the overall P loading to Munro Lake.

3.) Residential development has apparently had minimal impact upon the lake to date. Gradually increasing conductivity values in the lake since the 1930's are indicative of slight increases in overall nutrient addition to the lake, and are probably related to increased numbers of cottages during the past several decades. In general, the contributions of residential portions of the watershed (lawns, etc.) and the effluent from septic tanks along the lakeshore, are small, and were estimated as 8% and 12% of the total P loading (J_t) to the lake, respectively.

4.) Much of the phosphorus supporting the high productivity of Munro Lake may be due to internal recycling from the sediments. While difficult to quantify, the existence of substantial P regeneration from the sediments is supported by the underestimations of P and chlorophyll-a concentrations provided by the Dillon and Rigler model, as well as by our knowledge of the importance of this process in shallow, eutrophic lakes.

The comparatively small watershed and limited residential development around Munro Lake presently help to keep the lake relatively clean despite its naturally eutrophic state. The lake is highly productive, with good fishing, and yet at the same time retains remarkable water clarity, without the noxious algal blooms which often accompany shallow and highly developed lakes. Whereas dredging the lake appears to be financially impractical, the present water quality in Munro Lake can at least be maintained by careful planning in the future development of its watershed.

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