INVESTIGATIONS INTO ECOLOGICAL AND SOCIOLOGICAL DETERMINANTS OF LAND-USE DECISIONS - A STUDY OF INLAND LAKE WATERSHEDS IN NORTHERN MICHIGAN[1]

TECHNICAL REPORT NO. 1

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I. STATEMENT OF OBJECTIVES - Need for Research

Northern Michigan's land and water resources have long been held in economic and aesthetic esteem, and for just such reasons, subject to exploitative pressure from the human element, eager to live, work and play in such scenic and naturally abundant surroundings. Further, with today's modern society enjoying increased leisure time, greater mobility and affluence, our prime environmental resources as well as those of Wisconsin, Minnesota and other scenic, water-rich areas are faced with heavy and growing pressure from man's activities.

Michigan's sparsely populated northland becomes correspondingly attractive to urban dwellers as cities increase in population, pollution and crime. Consequently, lakes and rivers important to the north's unique ecology become highly desirable as "get-away" spots; increasing the danger of rapid "cultural eutrophication", an unnatural and man-made speeding up of a water body's pollution and aging process.

Canals and wetland filling projects appear in an effort to capitalize on and cater to the area's influx of population, both seasonal and permanent. Often such land developments are not planned with area ecology in mind. Proposed sewage systems may be inadequate; the wetlands may be of primary importance to a lake or river's "health", integrity and virtual existance.

New industry may be lured to the area in a race for increased tax base and employment opportunities, with little thought for proper placement or control.

The recreation industry provides products and places for play and the instigation to use them. However, snowmobiles, trail bikes and other off-the-road recreational vehicles are used irresponsibly; tearing up vital dune grass, disturbing wildlife habitat and shattering the serenity of the woods in all seasons.

Highly aware of these and other environmental, economic and recreational problems, northern scenic areas are struggling to provide adequate legislative, planning and consulting resources to their communities. There is an unquestioned necessity in these areas to "demonstrate creative rather than destructive skills if we are to replicate nature or to manage it (McHarg, 1971)." Fortunately, in Northern Michigan's threatened environment, there is opportunity to take creative and preventive action; action which is less costly than rehabilitative programs in the long run, both monetarily as well as aesthetically.

As evidence of north-area community and governmental readiness and need for action, a recent (1972) amendment was made to the Michigan Inland Lakes and Streams Act of 1965, giving the Department of Natural Resources control over major modifications of shoreline and submerged lands. Also, the Michigan Department of Natural Resources has established an Office of State Land Use Planning to identify areas of critical environmental concern, Northern Michigan among them.

Wisconsin, in a recent Supreme Court decision, (Just vs. Marinet Co.), upheld legislation which may be seen as representing a new environmental ethic in its societal protection of natural values. Also, the Upper Great Lakes Regional Commission along with Wisconsin's Department of Natural Resources recently completed a five-year program of research and implementation in lake renewal and rehabilitation, related policy issues, and public awareness education.

However, as much as there is now the needed trend toward organized zoning regulations, land-use advisory boards and conscientious legislation, planning commissions and the like, such organizations cannot function effectively without facts. They need water quality data, sewage systems advisement, soil analysis, and knowledge of land use characteristics; as well as a meter of the public attitude toward lakeland pollution and progress toward rectifying it. They need to know: Where is the major recreational opportunity in the area? How much human impact can that area withstand? Where is the agricultural heartland? Where are the best forest locations? Where are the best sites for urbanization? It is here that the University of Michigan Biological Station can intercede with historical, aquatic, terrestrial and social data accumulated from our program concerned with ecological and sociological determinations of land-use decisions.

Our program objectives relate to Northern Michigan's land use problems on three separate yet integrated levels: aquatic, terrestrial and social. Thus far, our study has allowed for accumulation of valuable data in all three areas. It may be noted, however, that more information has been collected in aquatic sections; stemming from the fact that aquatic research was included in the pilot program, whereas social and terrestrial research areas have been more recently implemented.

With progression of the study, nutrient budget analysis of specific inland watersheds have come to demand close cooperation between the aquatic and terrestrial portions of the study. Social science research has found it necessary to integrate both aquatic and terrestrial resources into assessing lake and river property owners' perception of their environment. Both the terrestrial and social science areas have been augmented by additional historical research, and to the social science area has been added the resources of CRUSK (Center for Research and Utilization of Scientific Knowledge), part of the University's Institute for Social Research complex. Such a resource will give much needed assistance in putting scientific knowledge across to potential users in understandable terms.

Our public information scientist has been established as a community consulting resource and has already felt a great demand for his services.

The Biological Station has also had the opportunity to present factual testimony at several land-use hearings conducted by the Michigan Department of Natural Resources with respect to development proposals in the study area. Part of the data used in the presentations were taken from NSF/RANN research projects, and seemed to have positive impact in forestalling less desirable proposals.

It has become apparent that the research we have been pursuing and the progressive results we are obtaining, included herewith, are of great value and in demand; not only in northern Michigan but also for other like environments in the North Central states and perhaps other world areas, providing land-use planning precedents, factual reports and valuable reference sources.

II. DESCRIPTION OF STUDY AREA

Many of Michigan's most beautiful lakes, possessing great potential for development, are found in the Inland Water Route region of northern lower Michigan. The region is named for a series of navigable waterways leading, by way of interconnecting rivers, through Crooked, Pickerel, Burt, Mullett and Black Lakes to the Straits of Mackinac and finally to the St. Lawrence Seaway.

Economically and ecologically important since early times, the Inland Water Route was first used by Indians and fur traders. Today it is maintained for recreational navigation by the U. S. Lake Survey. Its watershed, encompassing a land area of 3,783 km^2 (1,461 mi^2), is drained principally by the Crooked, Maple, Sturgeon, Pigeon, Black and Cheboygan rivers. This includes lakes in most of Cheboygan and Emmet counties and portions of Charlevoix, Montmorency, Otsego and Presque Isle counties *(figure 1)*. The lakes range in size from tiny ponds and bogs to Mullett, Burt and Black Lakes; fourth, fifth and eighth largest lakes, respectively, in the state. The lakes, rivers and wetlands of this watershed are inter-woven and often interdependent. Therefore, change on one body of water may easily and rapidly affect others.

The population of the Inland Water Route region is predominately rural. The largest towns range from 3,000 to 6,000 and county populations range from 5,250 to 18,300 individuals *(Table 1)*. However, about 20 percent of the population of

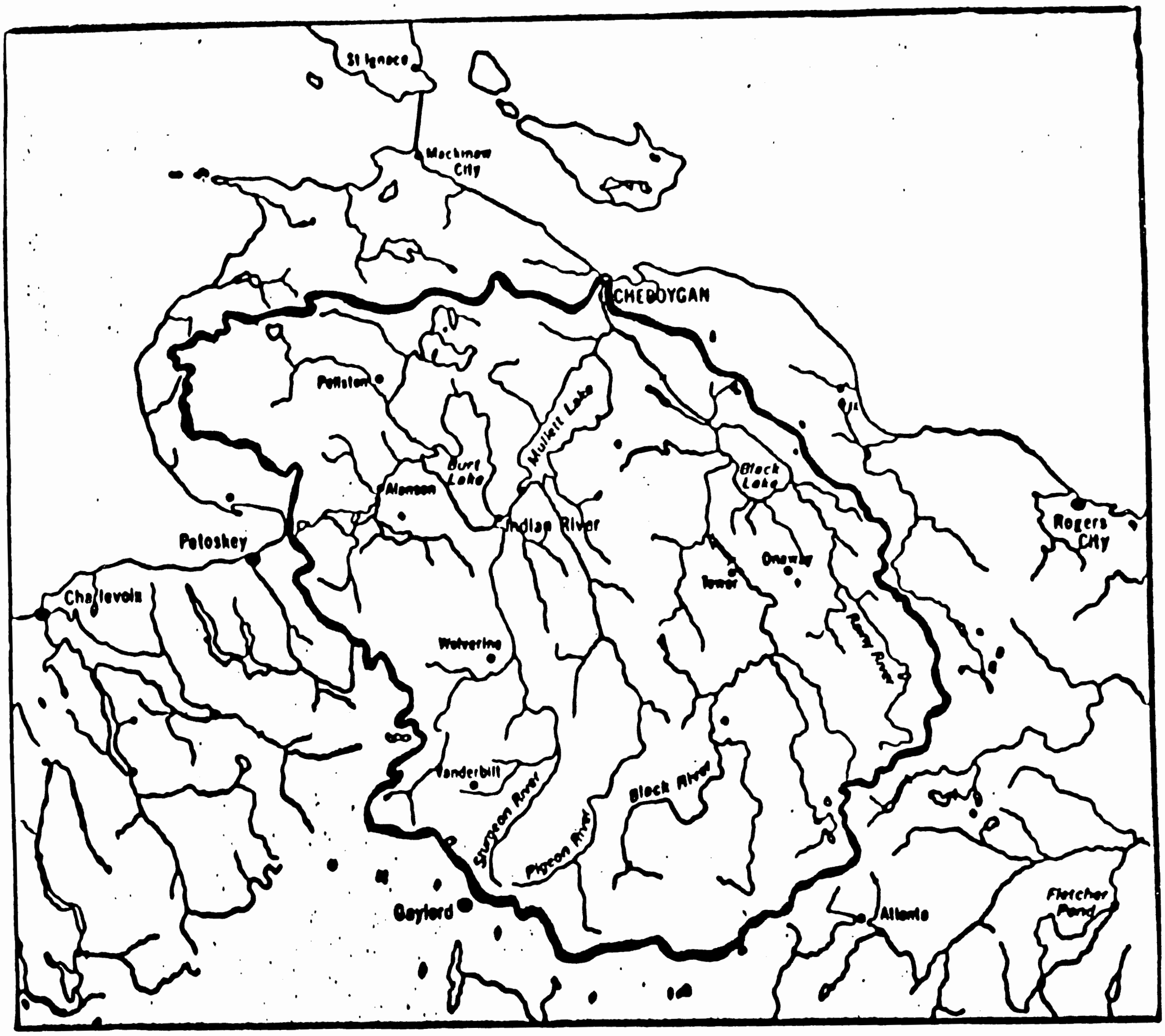

FIGURE 1 THE AREA OF NORTHERN MICHIGAN KNOWN AS THE INLAND WATER ROUTE REGION CONSTITUTES THE DRAINAGE BASIN OF THE CHEBOYGAN RIVER

TABLE 1 SELECTED STATISTICS ON THE POPULATION AND NATURAL RESOURCES OF MICHIGAN COUNTIES IN THE INLAND WATER ROUTE REGION OF NORTHERN MICHIGAN[1]

STATISTIC	STATE OF MICHIGAN	CHEBOYGAN COUNTY	EMMET COUNTY
HUMAN POPULATION			
No. of people (1970)	8,875,083	16,573	18,331
Increase in past 10 yrs. (%)	13.4	13.9	15.3
Population in urban areas	6,555,773	5,553	6,342
Percent in urban areas	73.8	33.5	34.6
HOUSING			
Total Units	2,954,570	8,924	8,904
Year Round (%)	2,841,827 (96.2)	5,974 (66.9)	6,818 (76.6)
Seasonal (%)	112,743 (3.8)	2,924 (33.1)	2,086 (23.4)
LAND USE			
Total area - Acres	37,267,240	510,720	305,208
Inland Water - Acres (%)	899,504 (2.4)	49,472 (9.7)	10,560 (3.5)
Land surface (%)	36,367,736 (97.6)	461,248 (90.3)	294,720 (96.5)
Forest	18,900,200 (52.0)	337,200 (73.1)	186,700 (62.0)
Agriculture	11,947,603 (32.7)	54,847 (11.9)	56,907 (19.3)
Transportation	1,149,296 (3.2)	14,319 (3.1)	10,369 (3.5)
Recreation	611,489 (1.7)	2,293 (0.5)	8,532 (2.9)
Urbanization	1,086,146 (3.0)	2,035 (0.4)	1,766 (0.6)
Other	2,673,002 (7.4)	50,554 (11.0)	34,446 (11.7)
WATER			
Inland Water Bodies			
Total Number	35,068	344	272
Total Acreage	840,867	51,358	10,412
Bodies of Water > 200 acres	595	10	8
Miles of streams	36,071	420	98
Miles of Great Lakes shoreline	2,187	36	68

TABLE 1 (continued) SELECTED STATISTICS ON THE POPULATION AND NATURAL RESOURCES OF MICHIGAN COUNTIES IN THE INLAND WATER ROUTE REGION OF NORTHERN MICHIGAN[1]

STATISTIC	PRESQUE ISLE CO.	CHARLEVOIX COUNTY	OTSEGO COUNTY	MONTMORENCY COUNTY
HUMAN POPULATION				
No. of people (1970)	12,836	16,541	10,422	5,247
Increase in past 10 yrs. (%)	-2.1	23.2	38.1	18.6
Population in urban areas	4,275	6,488	3,012	---
Percent in urban areas	33.3	39.2	28.9	0
HOUSING				
Total Units	5,706	7,617	5,150	4,830
Year Round (%)	4,387 (76.9)	6,233 (81.8)	4,672 (90.7)	3,360 (69.6)
Seasonal (%)	1,319 (23.1)	1,384 (18.2)	478 (9.3)	1,470 (30.4)
LAND USE				
Total area - Acres	433,920	288,640	344,320	362,880
Inland Water - Acres (%)	19,264 (4.4)	23,552 (8.2)	6,784 (2.0)	7,744 (2.1)
Land surface (%)	414,656 (95.6)	265,088 (91.8)	337,536 (98.0)	355,136 (97.9)
Forest	289,200 (69.7)	161,700 (61.0)	251,000 (74.4)	287,000 (80.8)
Agriculture	95,521 (23.0)	51,109 (19.3)	46,052 (13.6)	28,351 (8.0)
Transportation	9,326 (2.5)	8,983 (3.4)	9,120 (2.7)	6,776 (1.9)
Recreation	786 (0.2)	11,081 (4.2)	489 (0.1)	486 (0.1)
Urbanization	2,152 (0.5)	4,015 (1.5)	1,261 (0.4)	431 (0.0)
Other	17,671 (4.3)	28,200 (10.6)	29,614 (8.8)	32,392 (9.1)
WATER				
Inland Water Bodies				
Total Number	229	97	378	248
Total Acreage	15,504	23,415	7,281	12,100
Bodies of Water > 200 acres	8	6	4	12
Miles of streams	301	215	198	306
Miles of Great Lakes shoreline	72	22	0	0

[1]Source: Michigan State University Cooperative Extension Service

Canada and the United States lives within 500 miles of the region *(figure 2)*. Consequently, the main economic base of the region consists of services to the tourist industry... an "industry" that creates a seasonal influx in the area almost triple its year-round population.

Less than 100 of the area's 1,000 inland water bodies are larger than 20 acres with suitable shoreline for development. Approximately twenty of these are already developed to some degree with additional potential for future development *(Table 2)*. Seasonal dwellings are more prevalent than year-round housing compared to elsewhere in the state. In addition, the past decade has seen an increasing tendency for summer homes to be converted to year-round dwellings, as well as a boom of new construction on lakeshores. Lakeshore housing is predominately single family, with septic tank and drain field sewage disposal. Back-lotting is infrequent and cluster-type dwelling units are practically non-existent.

Each lake is being studied closely for a more detailed, individual description of characteristics and sensitivity to human impact. Progress in that respect is included in the "Morphometric Features" section of this report.

There are several lakes included in the study in addition to those which are developed that are entirely state or privately owned and have no human development on their shores. Several lakes are also being examined whose watersheds lie adjacent to the Inland Water Route, but which empty directly into

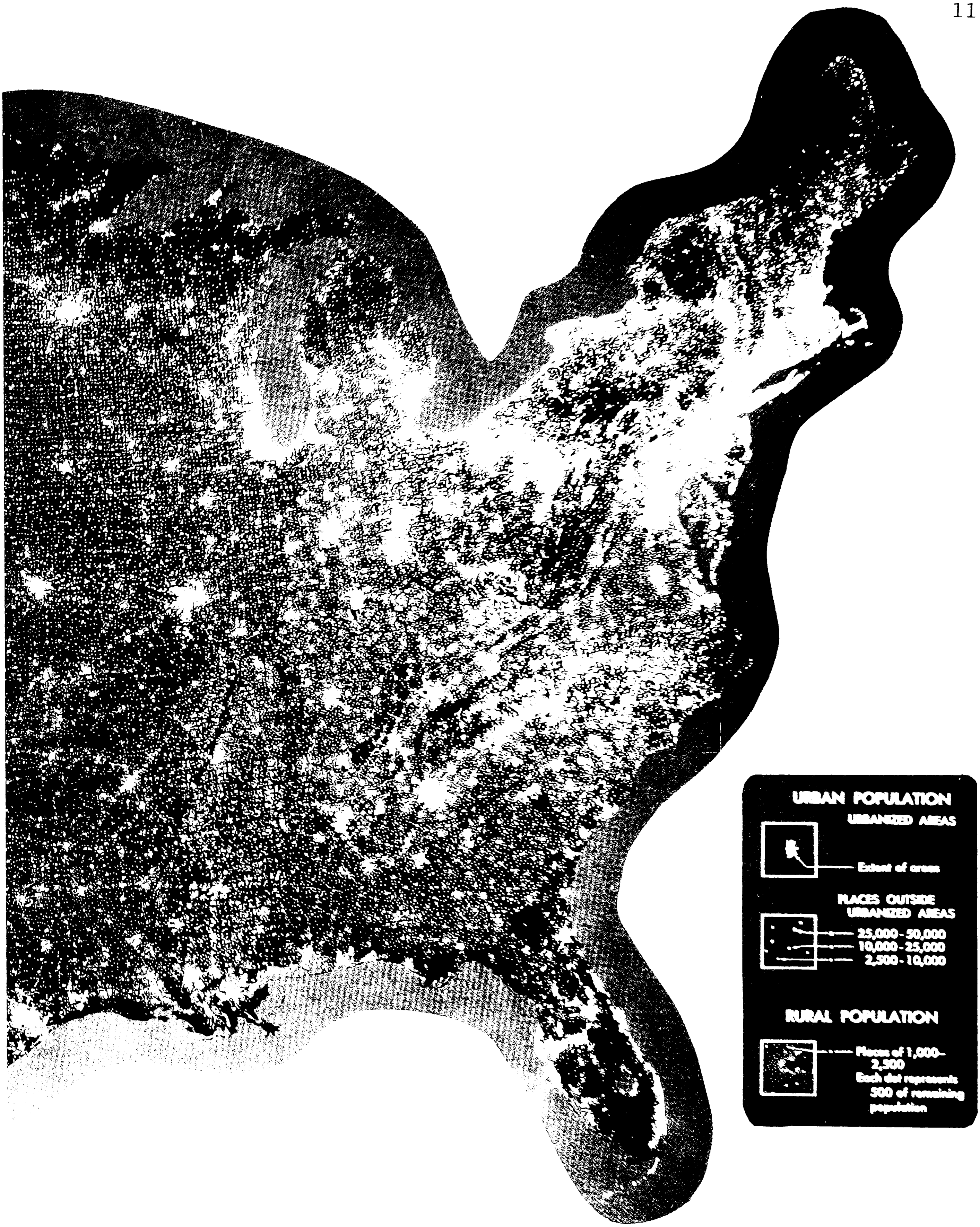

FIGURE 2 POPULATION DISTRIBUTION, URBAN AND RURAL, IN THE UNITED STATES: 1970. PREPARED BY GEOGRAPHY DIVISION, BUREAU OF CENSUS, U.S. DEPARTMENT OF COMMERCE

TABLE 2 ESTIMATED NUMBER OF DWELLING UNITS ON THE SHORES OF LAKES AND RIVERS IN THE STUDY AREA

LAKE[1]	DWELLING UNITS	RIVER	DWELLING UNITS
Mullet	1,043	Black	172
Burt	715	Indian	162
Walloon	628	Cheboygan	146
Black	609	Crooked	78
Paradise	364	Sturgeon	51
Crooked	317		
		TOTAL:	609
Douglas	270		
Pickerel	122		
Long	91	GRAND TOTAL:	5,092
Twin	68		
Wildwood	54		
Round	53		
Munro	48		
Larks	36		
Silver (Wilmot Twp.)	26		
Lance	22		
Devereaux	17		
TOTAL:	4,483		

[1]There are 21 other lakes in the study area that are either state owned and have no dwelling units, or are privately owned and have one dwelling unit on their shores.

the Straits of Mackinac. Because of this variety of lake types, each exhibiting different degrees of development, the Inland Water Route is proving to be an ideal study area.

The Inland Water Route land surface is predominately forested, with much of the former agricultural land now standing idle *(Table 1)*. Such unused farm land is often for sale in large tracts, making it easily acquirable by real estate profiteers. There also remains an abundance of undeveloped natural shoreline land on many lakes.

With regard to access, the area has been serviced to date by the north-south I-75 expressway, completed ten years ago and affording a direct route to the north for millions of people from the southern Great Lakes industrial megalopolis. Two years ago, legislation was passed requiring the Transportation Planning Department to upgrade highways US 31, US 131 and US 23 *(figure 3)*. Such highway improvements, especially if carried to an expressway status, could result in a funneling of even greater amounts of people into northern Michigan, and could also create adverse impact on important environmental areas the highways bisect.

The study area, in general, may be described as one of great natural beauty and resource. It contains many unique and important ecosystems that must be considered irreplaceable and therefore carefully approached for management and development by using the most complete and accurate information and methods available.

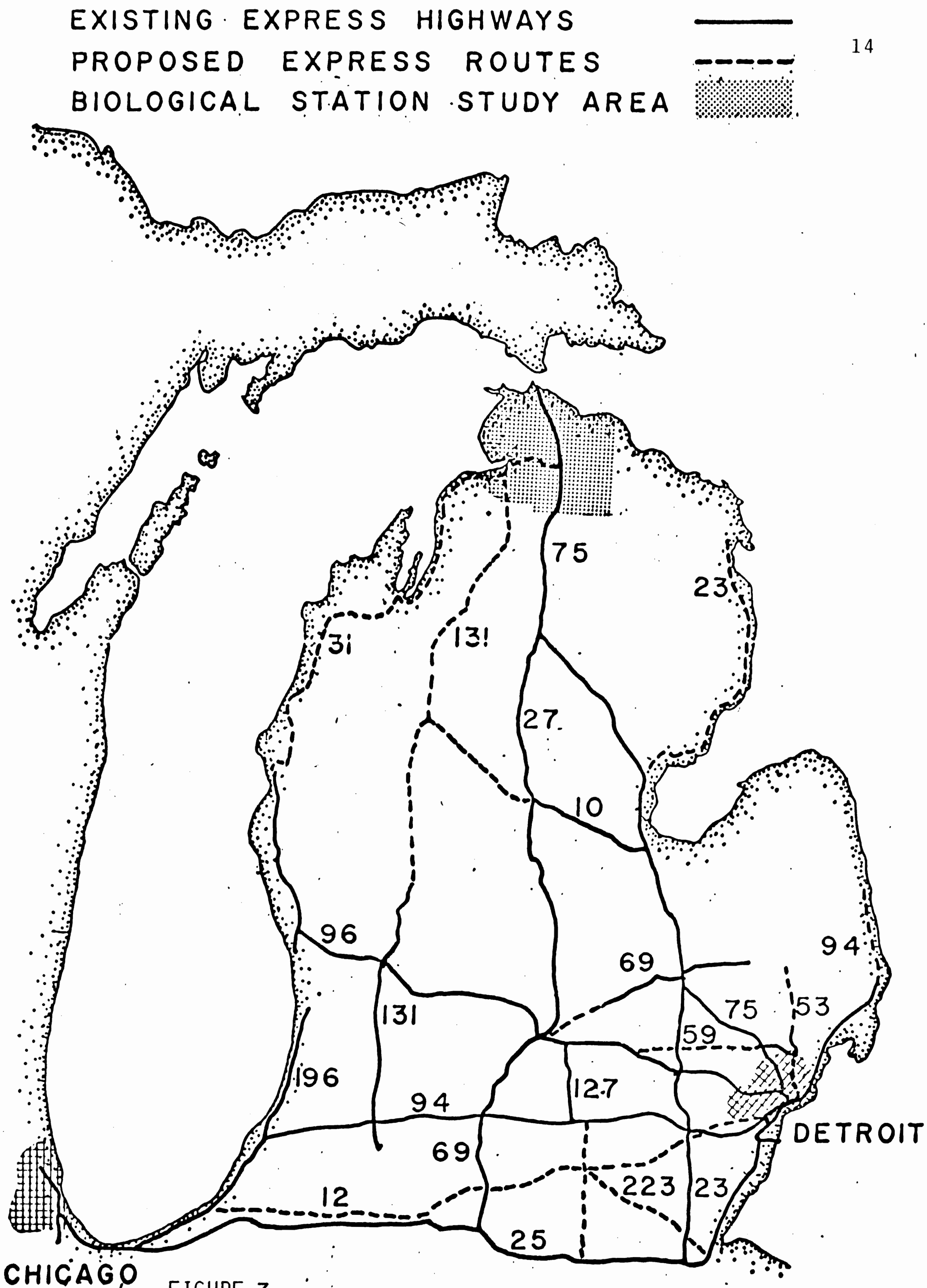

FIGURE 3 PRESENTLY EXISTING AND PROPOSED EXPRESS ROUTES TO AND THROUGH NORTHERN MICHIGAN

III. METHODS AND MATERIALS

A. AQUATIC

For an in-depth, working description of water bodies in the study area, data has been amassed describing the members of three variable vectors (morphometric features, physical-chemical parameters and biological parameters). As this data is correlated, a concise hyperdimensional picture of a lake's individuality emerges. This provides the project with an integrated, functional view of lake characteristics such as external form, water chemistry and biological communities.

MORPHOMETRIC FEATURES

Values for twelve morphometric parameters have been determined for 38 northern Michigan lakes. Seven of the parameters involve direct measurements: maximum depth, maximum length, maximum width, shoreline length, surface area, watershed area and volume. Five other parameters were derived from values of several of the direct measurements: mean depth, mean width, shoreline development factor, volume development factor and ratio of watershed area to lake area.

Values for six of the direct measurements were determined from hydrographic maps of the lakes. The seventh watershed area was determined from U. S. Geological Survey topographical maps. Most of the maps were compiled under the auspices of the Institute for Fisheries Research of the Michigan Department of Natural Resources and the U. S. Army Corps of Engineers Lake Survey. Data for Silver Lake (Koehler Township, Cheboygan County) was derived from a map commissioned by the Boy Scouts of America who own all the land surrounding the lake. A map produced by a University of Michigan Biological Station class project was used to measure Livingston Bog's (Cheboygan County) morphometric parameters. Wildwood Lake (Cheboygan County) was mapped by RANN program staff at the Biological Station specifically for the purpose of this investigation.

Descriptions of the various measurements and their respective derivations follow. Definitions of morphometric parameters are those given by Welch (1948):

Maximum depth is the greatest depth known for a lake. This parameter was obtained by examining a map of the lake to find the greatest depth contour or sounding (in meters).

Maximum length is the length of a line connecting the two most distant points of the shoreline without crossing land, except for islands. The position of this line was determined for each lake and then drawn on a map. The map was then projected onto a gridded screen using an opaque projector, such that the scale of the map and the maximum length line were both visible. The map was enlarged five times its original size in this manner. A map measuring wheel was then run along the scale projection line. The resultant reading on the dial of the map measuring wheel was divided into the length of the scale line to obtain a conversion ratio. Then the wheel was run along the projection of the maximum length line. The resultant dial reading was multiplied by the conversion ratio to determine the actual maximum length (in kilometers).

Maximum width is the length of a line connecting two extreme points of the shoreline such that the line lies within 15° of being perpendicular to the maximum length line. Maximum width (in kilometers) was determined in the manner described for maximum length.

Shore length[1] is the actual length of the shoreline. The perimeter of each lake was measured on a projection of the map with a map measuring wheel. The conversion ratio obtained for the maximum length was used to convert the dial reading on the wheel to actual shore length (in kilometers).

Surface area is the area of a lake bounded by its shoreline. This definition explicitly regards islands as part of the surface area (Welch, 1948). The value for this parameter was in most cases given in the title block of the map for each lake. Where surface area was not given, a unit area using the map scale was graphically constructed, and its outline traced with a Gelman compensating polar planimeter. The unit area was divided by the corresponding planimeter reading to obtain a conversion ratio. The planimeter

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[1]The maximum length, maximum width and shore length were determined for each lake at the same time. The projector was allowed to reach equilibrium temperature (one-half hour warm-up time) to eliminate changes of scale over time.

reading, derived from tracing the shore length of the lake, was multiplied by the conversion ratio to obtain actual surface area (in hectares).

Watershed area is defined here as the area bounded by the highest elevation which continuously surrounds a particular lake without including other lakes. This definition provides an approximation of the area of land which provides surface and ground water input to each lake. Ground water flow was assumed to flow with surface contours. Accurate determinations of watershed areas must await further intensive work to determine actual ground water flow patterns. The watershed area for each lake was traced from U. S. Geologic Survey quadrangle maps (1:62,500 scale) on to blank paper. A piece of paper delineating each watershed was cut out with a pair of scissors. The measurement of actual area obtained by passing a piece of paper of unit area (related to the 1:62,500 scale) through a Hayasahi Denko Automatic Area Meter, Model AAM5 was then accordingly divided into the unit area to obtain a conversion factor. After all cut-out watersheds were passed through the area meter, each resultant area measurement was multiplied by the conversion factor to devise the appropriate watershed areas in hectares.

Volume is the amount of water contained in the lake described by its shoreline. A Gelman planimeter was used to trace the shoreline (the zero contour line), and each successively deeper contour line, thereby obtaining a reading proportional to the area delineated by each contour line. The volume of water bounded between each contour interval was approximated by the formula for volume of a truncated cone:

$$\text{Volume} = \frac{D}{3} \left(A_1 + A_2 + \sqrt{A_1 A_2}\right), \text{ where}$$

D = the difference in depth between the two contour intervals involved

A_1 = the area bounded by the upper contour line

A_2 = the area bounded by the lower contour line

Summing the volumes contained between each contour gives the total volume for the lake (in cubic meters).

Having made the foregoing direct measurements for each lake, the following five parameters were derived for each lake:

Mean depth is the volume of a lake divided by its surface area (in meters).

Mean width is the surface area of a lake divided by its maximum length (in kilometers).

Shore development factor is the shore length of a lake divided by two times the square root of π times its area. Twice the square root of π times the area of a lake is equivalent to the circumference of a circle having the same area as the lake. The rounder a lake is, the closer its shore length will be to a circumference of a circle of given area, and the closer its shore development factor will be to 1.0, the theoretical minimum. Conversely, the more irregularly shaped the lake and/or convoluted the shoreline, the longer the shore length in reference to the theoretical circumference and the higher its shore development factor.

Volume development factor is three times the mean depth of a lake divided by its maximum depth. Since mean depth was derived from a lake's volume divided by its area, the expression for volume development describes the ratio of the volume of the lake to the volume of a cone with a basal area equal to the lake's surface area, and a height equal to the maximum depth of the lake. A volume development factor of 1.0 for a lake would indicate that, overall, the basin would be close to the shape of a cone. A factor lower than one would indicate that the shape of the basin is more convex than a cone, whereas a factor higher than one would indicate the general shape to be more concave.

The ratio of watershed area to lake area was simply obtained by dividing its watershed area by the lake surface area.

PHYSICAL-CHEMICAL PARAMETERS

Water quality data has been obtained on most Cheboygan and Emmet County lakes on a quarterly basis since fall, 1972. Limnological data has been collected mostly at a limnetic station at the deepest portion of the lakes. Each basin was sampled in multi-depression lakes. Twenty-five lakes (32 basins) were sampled in fall, 1972. Collections were made from only nine lakes during winter, 1973, because of unusually early ice break-up conditions.

The water chemistry laboratory at the Biological Station's Stockard Lakeside Laboratory became fully outfitted and operational during spring, 1973. Since that time, quarterly water quality surveys have been conducted on 38 lakes in the two-county area.

In order to study the adequacy of obtaining water quality samples from lakes on a quarterly basis, Douglas Lake was sampled weekly in 1972-73 and bi-weekly in 1973-74. This phase of our investigation was enhanced by a modern digital meteorlogical station installed at the Biological Station with funds provided by the University of Michigan.

A Boston Whaler, obtained with National Science Foundation funds, has been employed for access to the largest lakes (Black, Mullett, Burt, Crooked, Pickerel and Walloon) in the study area. Small rowboats have been used on all other lakes.

A snowmobile and sled have been utilized for lake access during winter.

Physical, chemical and biological data were obtained during each lake sampling trip. Temperature profiles were recorded at one meter intervals at central lake stations using a Whitney resistance thermometer. Light transparency was measured with a standard zoom diameter all-white Secchi disc. Light penetration measurements were obtained with a submarine photometer fitted with Weston photocells during both summer and winter surveys. Percent light transmission with depth and the extinction coefficient (k) were calculated from the photometer readings. Turbidity was measured with a Hellige turbidimeter also during summer and winter sampling trips. Turbidity measurements were expressed in mg/ℓ as SiO_2. Color of the water was estimated with a Forel-Ule color comparator.

Water chemistry samples were obtained with a three liter Kemmerer water bottle. Samples were obtained from three to five depths at each station depending upon temperature profile characteristics. Water samples for titriometric chemistry, pH and conductivity were placed in 300 ml B.O.D. bottles and samples for nutrient chemistry were placed in pre-washed and rinsed 8 oz. polyethylene bottles. Water for chlorophyll a analyses were stored in 250 ml glass-stoppered bottles. A 5% solution of $MgCO_3$ suspension was added to each bottle in the field. All water samples were stored in dark containers and iced down when warranted.

Upon arrival of the samples at Stockard Lakeside Laboratory, tests for dissolved oxygen, alkalinity, pH, conductivity, chlorophyll a and ammonia-nitrogen were performed immediately. The remaining water samples were stored in a refrigerator at 3°C and chemical tests were run as soon as possible. Dissolved oxygen was determined titriometrically using the azide modification of the Winkler method (APHA 1971, Method 218B). Total alkalinity was also measured titriometrically using bromcresol green-methyl red mixed indicator (APHA 1971, Method 102). Determination of pH prior to January, 1974 was conducted on a Beckman Model N pH meter and after that date on a Beckman Model H-5 pH meter. Specific conductance was measured on an Industrial Instruments Model RC-16B2 Conductivity Bridge. Final readings were expressed in μmhos/cm at 25°C. Magnesium, sodium, calcium and potassium were determined on a Perkin-Elmer Model 305 Atomic Absorption Spectrophotometer (EPA 1971). Chloride was measured on the Beckman model H-5 expanded scale pH meter fitted with a salt bridge and a Beckman chloride electrode (APHA 1971). The remaining chemical tests (ammonia-nitrogen, nitrate-nitrogen, soluble-phosphorus, total phosphorus and silica) were all determined colorimetrically on a Beckman DB-GT Spectrophotometer. Total-phosphorus and soluble-phosphorus were measured using a hybrid method of Gales et al. (1966) for digestion, and Schmid and Ämbuhl (1965) for neutralization and color development. Ammonia-nitrogen and nitrate-nitrogen were determined by the methods of Solorazano (1969) and Müller and Widemann (1955), respectively. Silica was measured using the heteropole blue method (APHA 1971, Method 151). All chemical data was reported in mg/ℓ except nitrogen and phosphorus compounds which were reported as μg/ℓ.

The volume of water samples generated by the aquatic sampling program together with samples collected by the wetlands and terrestrial sections of the program became too large to be handled by the aforementioned manual techniques. Beginning with the fall, 1974 lake survery, a Technicon Dual Channel Autoanalyzer II was obtained for the program by University of Michigan funds. This instrument has allowed us to automate our chemistry laboratory and has replaced the Beckman DB-GT Spectrophotometer in our operations.

BIOLOGICAL PARAMETERS

Samples for chlorophyll a as a measure of standing crop of phytoplankton and net tows for zooplankton were routinely obtained during the quarterly water quality surveys. Chlorophyll a samples were filtered through a 0.45μ membrane filter, extracted with 90% spectrophotometric grade acetone and determined fluorometrically on a Turner Model III Fluorometer (Strickland and Parsons 1968). Plankton tows were taken at all central lake stations using a No. 20 mesh 0.25m diameter cylinder-cone plankton net. The net was towed from the bottom to the surface at approximately 0.5 m/sec. In shallow ponds and bog lakes, either a 10 m oblique plankton tow was taken, or a series of casts with a 3 liter capacity horizontal Van Dorn bottle were filtered through the plankton net. The samples were treated with carbonated water (club soda) for narcotization (Gannon and Gannon, in press) and then with 5% buffered formalin for preservation.

In the laboratory, the samples were examined for species composition and relative abundance of zooplankton Crustacea and Rotifera. Crustacean zooplankton were analyzed by placing a 10 ml aliquot from the sample into a chambered counting cell (Gannon 1971) and examining the organisms under a stereozoom microscope at 20 to 140x. Any organisms requiring greater magnification to be identified were mounted on a slide and observed under a compound microscope at 100 to 400x. Crustacean zooplankton were identified according to Yeatman (1959) for cyclopoid copepods; Wilson (1959) for calanoid copepods; Brooks (1957) for *Daphnia;* Goulden (1968) for *Moina;* Deevey and Deevey (1971) for *Eubosmina;* and Brooks (1959) for the remaining Cladocera. Rotifers in the plankton were analyzed by concentrating aliquots, placing them in a 5 ml plexiglass chamber, putting a cover glass over the chamber, and observing the organisms under a compound microscope at 100x. Species that could not be identified in the chamber were pipetted onto a glass slide, a cover slip was put in place, and the specimen observed under the microscope at 400 or 1,000x. When the mouth parts (trophi) needed to be examined, a drop of 5% sodium hypochlorite (household bleach) was placed on the specimen to dissolve body tissues, leaving only the sclerotized trophi available for identification. Rotifers were identified according to Voigt (1957) and Edmondson (1959).

Rooted aquatic plants were qualitatively collected during summer, 1974 and quantitave studies on benthic macro-invertebrates were initiated in summer, 1973. In addition, an inventory of fish species composition in lakes of the study area was compiled from data files of the Michigan Department of Natural Resources. None of this information has been analyzed in detail at this time; therefore, these data will not be discussed in this report.

DATA STORAGE, RETRIEVAL AND MANIPULATION

One of the long range goals of the RANN program at the University of Michigan Biological Station is to devise a lake-ranking system based on sensitivity to certain degrees of human impact. Understanding the associative structure of the lakes based on static interpretations of the parameters being measured is a first step toward that goal.

In their study of 55 Florida lakes, Shannon and Brezonik (1972) used a variety of analytic techniques to elicit structure in their multivariate data base, and to reduce its dimensionality. Seventy percent of the variance in the data could be explained on the first axis computed in a principal components analysis. That axis was defined to be a "eutrophication" scale. Using the multivariate data available for each lake, the value of the first principal component was computed and used to rank each lake on the "eutrophication" scale. This ordination was compared to the results of a clustering analysis performed on the data base. The results of the two techniques were shown to corroborate one another. Other aspects of the structure of the data base, such as the contribution of independent sets of variables to the "eutrophication" function were developed, using canonical correlation and multivariate regression techniques.

The general analytic approach described above was considered to be a good model for the initial efforts involving the data base being built at the University of Michigan Biological Station. The methods involved in implementing the analyses and other associated goals are described hereafter.

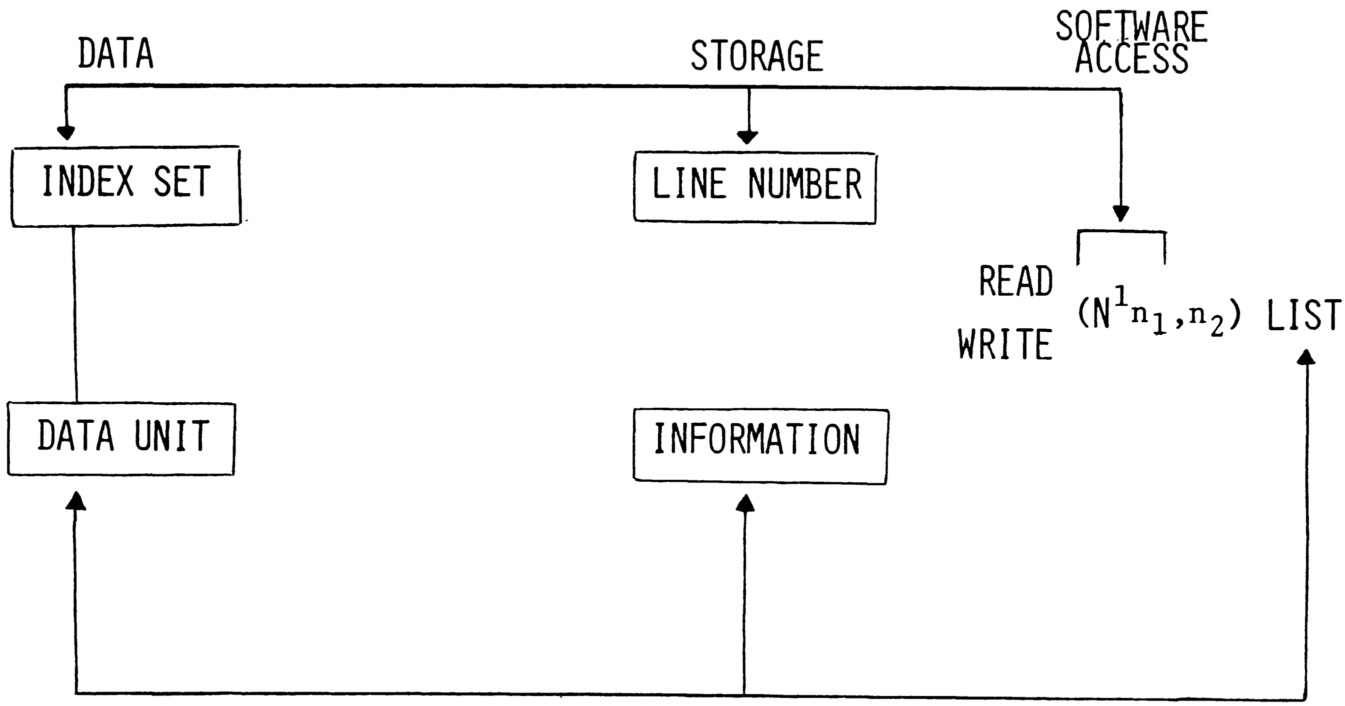
Several requirements needed to be met in the design of a data base structure suitable for results being generated by the RANN program. First, applicability to the wide variety of limnological variables being measured was needed. Second, compatibility was necessary between our system and the data file structure used with the IBM 360/67 machinery and operating system, called the Michigan Terminal System (MTS), at the University of Michigan Computing Center. Third, ease and consistency of access and manipulation by special purpose software routines was required.

A limnological datum can be considered as dichotomous, consisting of : 1) a value, or set of values mutually dependent on one another, to be called the <u>data unit</u>, and 2) the set of necessary descriptors of the data unit, which distinguishes it from each and every other data unit, to be called the <u>index set</u>. This concept ties directly to data file organization in MTS, wherein a line of information (data unit) is identified and separated from other lines of information by a unique line number (index). The Fortran IV programming language, as implemented in MTS (University of Michigan Computing Center 1971; 1973), offers direct access input/output statements with analogous structure. For example:

$$\text{READ } (N^1 n_1 \, , n_2) \text{ LIST}$$

$$\text{WRITE } (N^1 n_1 \, , n_2) \text{ LIST}$$

LIST is the data unit with n_2 being a description of its structure and $N^1 n_1$ being a unique description of its location in the data storage structure. N^1 is the name of the data file and n_1 is the line number in the file (index) associated with the data unit. The conceptual unity of the general data base structure is as follows:



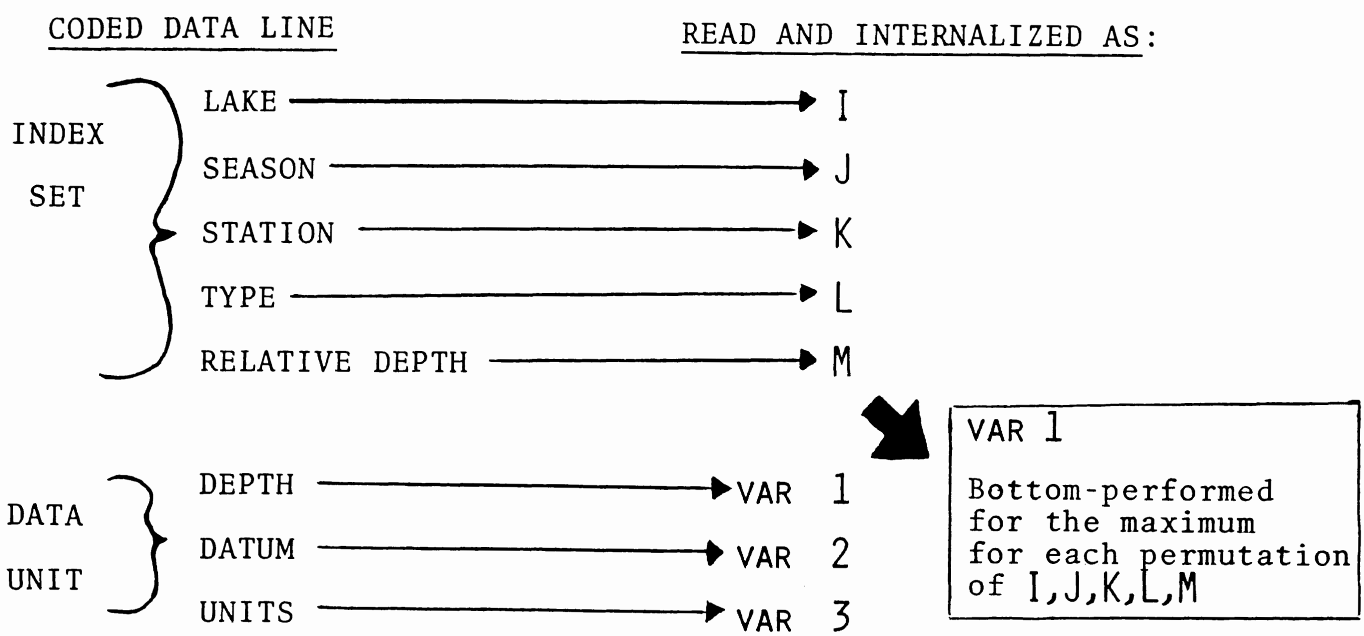
To date, three types of information, (physical, chemical and morphological parameters) have been integrated into the data structure.

It is necessary to specify the lake, season, location in the lake (station), type of measurement, and depth associated with the physical or chemical measurement in order to describe each piece of information sufficiently. For purposes of compatability with the MTS system, where zero and fractional values are unsuitable indices in the software, the depth of each reading and the units of measurement were considered to be part of the data unit. It was necessary that relative depth be substituted for absolute depth as the index vector. The relative depth was described as an ordinal value with 01 and 02 being the first and second samples in a vertical sampling set, sequentially to the last (bottom) sample in the profile. The value of the bottom-most relative depth was replicated as another type of data unit, with an index set comprised of lake, season, station and type of data.

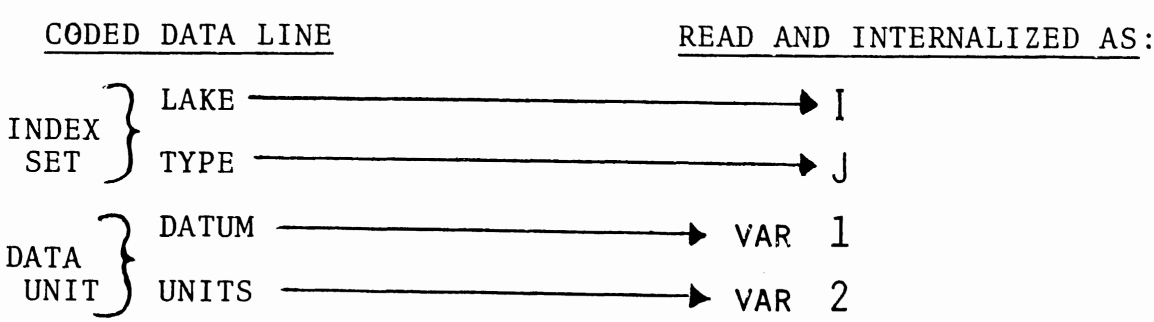
The complete specification of a piece of morphometric data simply requires a lake and type description with the data unit being the value of the parameter and units of measurement.

All physical, chemical and morphometric data were coded and typed on punched paper tape using a 33ASR tele-typewriter terminal. Details of the index sets and coding appear in Appendix A. The index set and data unit for both physical and chemical data are equivalent so these data can be treated the same in the data base structure. However, since both the morphometric parameters and "bottom" samples have different data unit structure and index sets, it was necessary to differentiate those parameters in the data base structure. This was done by assigning these data to a different file on MTS. No systemic problem occured since the Fortran direct access statement includes the name of the file to be read.

A routine was written in Fortran IV to read coded data and place it in the data storage structure. The reading process for the physiochemical data was as follows:



The morphometric data were read as follows:



After the reading of a coded data line, an index number would be computed from the index set according to the type of data:

Physical/chemical $INDEX\ P = M + (L - 1) \times 40 + (K - 1) \times 1{,}000 + (J - 1) \times 5{,}000 + (J - 1) \times 50{,}000$

Bottom $INDEX\ B = L + (K - 1) \times 25 + (J - 1) \times 125 + (J - 1) \times 125$

Morphometric $INDEX\ M = J + (I - 1) \times 12$

The above indices are used in the direct access input-output statements to describe the line number of the file to be read into or written on. In fact, INDEX is 10^3 times the actual MTS line number. Bottom data were to be put in a file described by the number 4, physical and chemical by 5 and morphometric by 6. The various data were put in the proper location in the data structure according to the following statements:

Physical: WRITE (5' INDEX P, 100) VAR 1, VAR 2, VAR 3

Bottom : WRITE (4' INDEX B, 101) VAR 1

Morphometric: WRITE (6' INDEX M, 102) VAR 1, VAR 2

where 100, 101 and 102 are statements defining format of the data.

Once a data base is organized coherently, implementation of access and manipulation using software routines is possible. A small set of programs were written to meet several important needs critical to storage, retrieval and manipulation of water quality data. First, retrieval of data or subsets of data by RANN staff was required. Second, a need for organizing and printing neatly tabulated data for documentation purposes and dissemination to user groups was deemed important. Third, it was necessary to develop specialized subsets of data for presentation to analytical programs.

A conversational data retrieval system was written in Fortran IV to meet the first requirement. The basic design criterion was to reduce external complexity so that users need not be experienced with computer operations in order to retrieve data. In order to achieve that criterion, the program was written to recognize simple intuitive key words used to describe the data to be retrieved. Another portion of the program detects classes of input errors and prompts the user for corrections. Once a list of key word descriptors has been read from the terminal input and assigned internal values, an index number is computed and a file number assigned for the direct access read statement. The retrieval program performs a WRITE operation to the terminal (see Appendix B for complete usage descriptions).

The second requirement was met by writing two programs for printing tabular data, one for morphometric data and the other for physicochemical data. The output of the morphometric data printing program (MOUT) was designed so that the entire morphometric data base would be presented on one printed page. Using Fortran iteration statements, J is incremented 12 times for each time I is incremented once, from I = 1 to 48, i.e., the number of basins to be described. After each increment, the INDEX defined by the combination of I and J is computed. Then the indexed datum is read from the morphometric file and the data is printed sequentially on the printer page.

The physicochemical data tabular printing program (POUT) uses the same type of iterative direct-read procedure with an improvement in speed and efficiency made possible by the bottom data file. As I, J, K and L are incremented, and index is computed for a direct read on the bottom data file to determine how many measurements were made for that combination of indices. If a relative depth is not found for a particular index, the iteration continues without performing further nonproductive steps. If a relative depth is present, then the value of the maximum relative depth is used to specify the number of sequential readings of the physicochemical data file. This should occur after having indexed to the first position (relative depth) for a particular data type, station, season and lake. A buffer area designed to fit on one printer page is filled with all physical and chemical data existing for one lake, season and station and is then printed. This procedure continues with successive increments for each lake, season and station. Our current output from POUT results in over 300 pages of information.

The INDEXed direct-read concept was central to all the programs written in support of the third requirement, the development of data manipulation capabilities. A series of programs were written to partition and restructure the data base to suit requirements of the analytical procedures. One routine was used to partition the data base into four separate seasonal data sets, each containing the data obtained at the central station of each lake. Data collected during May and June 1973 went into a Spring 1973 data set (SPR 73); data collected during July and early August into a Summer 1973 set (SUM 73); and data collected in late September and October 1973 went into a fall 1973 data set (FALL 73). The Winter 1974 (WIN 74) data set was composed of data collected during February and March 1974. Assembling these data sets resulted in a balanced yearly representation of time-varying parameters.

In order to remove the effect of the variability in maximum depth, numbers of samples, and depths of samples from lake to lake/season to season, a specialized program was designed. It substitutes one depth-corrected representative parameter for all the values contained in each vertical profile series. Using this, four new data sets were generated from those developed in the previous step.

Each depth-corrected value was derived by trapezoidally integrating the parameter over its corresponding vertical profile, and then dividing the result by the total depth sampled, as described in the following equation:

$$A_{ij} = \left(\sum_{i=1}^{i=IMAX-1} 1/2 \; (Z_{(i+1)_j} - Z_{ij}) \; (D_{(i+1)_j} + D_{ij}) \right) \div \sum_{i=1}^{i=IMAX-1} (Z_{(i+1)_j} - Z_{ij})$$

where i = relative depth index
j = parameter index
IMAX = number of measurements in the profile
Z = depth for indexed relative depth and parameter
D = data value for indexed depth and parameter
A = depth-corrected value

Depth profiles are not obtained for Secchi depth and color measurements, so these data were directly transferred to the new data files by the program. Another exception had to be made for light penetration data where one computed value, the vertical extinction coefficient (k), could represent most of the information contained in light transmission profiles with depth. The extinction coefficient (k), is derived from the equation $I = I_o e^{-kx}$ which describes the attenuation of light with depth, I_o being the surface light intensity and I being the intensity at depth x. As the program read percent light transmission data, it was passed to a least squares regression subroutine rather than to the integration procedure. The vertical extinction coefficient K_j for each lake j was computed from the light penetration data by the subroutine according to the following equation:

$$K_j = \frac{n_j \sum_{i=1}^{i=n_j} Z_{ij} \ln D_{ij} - \sum_{i=1}^{i=n_j} Z_{ij} \sum_{i=1}^{i=n_j} D_{ij}}{n_j \sum_{i=1}^{i=n_j} Z_{ij}^2 - \left(\sum_{i=1}^{i=n_j} Z_{ij}\right)^2}$$

where i = relative depth index
j = lake index
Z_{ij} = depth for relative depth in lake j
D_{ij} = percent light transmission at relative depth i and lake j
n_j = number of light data points in lake j

The K values were then passed to the appropriate locations in the new data files.

Yearly means, ranges and standard deviations for the data types were calculated using the depth-corrected data in all four seasonal data files as the sample population. Seasonal statistics were calculated by regarding the data gathered within each individual sampling season as being a separate population (Table 3). The values in Table 3 were calculated with the descriptive statistics routine contained in MIDAS (Michigan Interactive Data Analysis System), developed and supported by the University of Michigan Statistical Research Laboratory (Fox and Guire 1973).

Units of measure and order of magnitude for each parameter vary widely. Linear analytical compounds derived from such data would have little obvious meaning. To obviate this problem, standardization of the variables was performed according to the equation

$$Z_{ij} = \frac{\bar{x}_j - x_{ij}}{s_j}$$

where i = index defining the particular lake and season
j = index of data type
x_j = yearly mean for variable j (from Table 3)
s_j = yearly standard deviation of variable (from Table 3)
x_{ij} = value of variable j for a particular season i, and
Z_{ij} = standardized value of variable j for a particular lake and season

In addition to generating four seasonal depth-corrected standardized data files, the program averaged each parameter as measured in each lake over the four seasons. It then passed the results through the standardization subroutine

TABLE 3A. DESCRIPTIVE STATISTICS ON WATER QUALITY PARAMETERS - YEARLY COMPOSITE (FALL 1973 - WINTER 1974)

Variable	Mean	STD DEV	Minimum	Maximum
SECCHI (m)	3.81	2.17	.50	10.00
TEMP (m)	12.43	7.05	.32	25.02
LITE PEN (-K)	1.57	1.59	.11	7.33
TURBID (mg/ℓ)	1.07	1.30	0.	8.38
PH	7.76	0.82	4.75	9.20
DISS O2 (%SAT)	77.48	25.96	9.50	136.00
ALKALIN (mg/ℓ)	114.76	56.21	.90	272.07
CONDUCT (μmhos/cm)	239.85	111.47	11.80	581.00
CA (mg/ℓ)	29.23	15.18	.73	84.50
MG (mg/ℓ)	10.87	5.54	.15	24.69
K (mg/ℓ)	0.69	0.25	.10	1.40
NA (mg/ℓ)	2.88	5.95	.21	66.75
CHLORO-a (mg/m^3)	28.11	50.90	.49	266.81
SIO2 (μg/ℓ)	1950.90	1567.90	4.00	6217.50
PHOS-SOL (μg/ℓ)	16.28	30.22	0.	299.02
PHOS-TOT (μg/ℓ)	24.56	41.47	0.	366.17
NO3-N (μg/ℓ)	122.65	171.00	3.83	1592.50
NH3-N (μg/ℓ)	114.15	227.73	1.00	1324.00
PHAEOPIG (mg/m^3)	5.22	12.25	0.	58.30
COLOR (F-U)	14.87	4.24	5.00	21.00

TABLE 3B. DESCRIPTIVE STATISTICS ON WATER QUALITY PARAMETERS - SPRING 1973

Variable	Mean	STD DEV	Minimum	Maximum
SECCHI (m)	3.83	2.12	1.00	10.00
TEMP (m)	13.33	4.28	7.12	24.82
PH	7.87	.82	4.83	8.41
DISS O2 (%SAT)	88.05	18.39	35.00	111.50
ALKALIN (mg/ℓ)	112.57	54.12	.90	200.99
CONDUCT (μmhos/cm)	229.73	102.98	16.60	397.00
CA (mg/ℓ)	27.15	13.66	.93	58.80
MG (mg/ℓ)	9.02	5.00	.38	15.76
K (mg/ℓ)	.59	.22	.25	1.20
NA (mg/ℓ)	2.07	2.42	.26	11.35
SIO2 (μg/ℓ)	1009.90	988.28	6.25	3371.30
PHOS-SOL (μg/ℓ)	6.87	5.09	2.23	20.40
PHOS-TOT (μg/ℓ)	9.17	8.57	2.75	50.14
NO3-N (μg/ℓ)	106.95	116.77	14.00	612.50
NH3-N (μg/ℓ)	39.47	100.63	1.00	563.56
COLOR (F-U)	14.80	4.89	5.00	21.00

TABLE 3C. DESCRIPTIVE STATISTICS ON WATER QUALITY PARAMETERS - SUMMER 1973

Variable	Mean	STD DEV	Minimum	Maximum
SECCHI (m)	3.71	1.89	1.00	7.50
TEMP (m)	20.25	4.14	9.94	25.02
LITE PEN (-K)	1.29	1.42	.11	6.69
TURBID (mg/ℓ)	1.29	1.55	.05	8.38
PH	8.03	.82	5.34	9.20
DISS O2 (%SAT)	86.25	24.56	31.94	136.00
ALKALIN (mg/ℓ)	100.82	49.72	1.23	167.75
CONDUCT (µmhos/cm)	222.32	103.20	11.80	397.43
CA (mg/ℓ)	30.11	14.43	1.44	54.43
MG (mg/ℓ)	12.04	5.97	.36	22.60
K (mg/ℓ)	.61	.22	.10	1.14
NA (mg/ℓ)	2.20	1.83	.29	8.97
SIO2 (µg/ℓ)	2052.00	1605.50	55.33	5756.50
PHOS-SOL (µg/ℓ)	18.93	47.49	5.10	299.02
PHOS-TOT (µg/ℓ)	31.03	58.39	8.15	366.17
NO3-N (µg/ℓ)	75.33	54.74	9.95	279.55
NH3-N (µg/ℓ)	66.76	185.15	5.50	1114.90
COLOR (F-U)	14.87	4.11	6.00	21.00

TABLE 3D. DESCRIPTIVE STATISTICS ON WATER QUALITY PARAMETERS - FALL 1973

Variable	Mean	STD DEV	Minimum	Maximum
SECCHI (m)	3.69	2.14	.50	9.50
TEMP (m)	13.07	3.24	6.57	18.06
PH	7.77	.88	4.75	8.46
DISS O2 (%SAT)	81.06	24.45	19.50	114.00
ALKALIN (mg/ℓ)	112.32	52.55	2.60	181.77
CONDUCT (µmhos/cm)	237.74	108.32	21.50	463.71
CA (mg/ℓ)	23.84	11.28	1.02	45.00
MG (mg/ℓ)	10.59	5.03	.38	18.55
K (mg/ℓ)	.70	.22	.30	1.39
NA (mg/ℓ)	2.78	3.36	.40	17.30
SIO2 (µg/ℓ)	2368.30	1703.90	61.27	6217.50
PHOS-SOL (µg/ℓ)	21.64	29.73	5.25	174.10
PHOS-TOT (µg/ℓ)	35.37	53.18	7.60	339.07
NO3-N (µg/ℓ)	84.73	88.93	14.61	491.65
NH3-N (µg/ℓ)	46.86	104.45	6.20	647.16
COLOR (F-U)	15.54	3.88	5.00	21.00

TABLE 3E. DESCRIPTIVE STATISTICS ON WATER QUALITY PARAMETERS - WINTER 1974

Variable	Mean	STD DEV	Minimum	Maximum
SECCHI (m)	4.04	2.57	.50	10.00
TEMP (m)	2.81	.99	.32	5.96
LITE PEN (-K)	1.85	1.72	.21	7.33
TURBID (mg/ℓ)	.87	.99	0.	3.95
PH	7.40	.67	5.15	8.05
DISS O2 (%SAT)	55.28	22.20	9.50	91.00
ALKALIN (mg/ℓ)	132.55	64.48	3.50	272.07
CONDUCT (μmhos/cm)	268.47	127.69	19.80	581.00
CA (mg/ℓ)	35.69	18.31	.73	84.50
MG (mg/ℓ)	11.84	5.80	.15	24.69
K (mg/ℓ)	.86	.25	.53	1.40
NA (mg/ℓ)	4.34	10.85	.21	66.75
CHLORO-a (mg/m^3)	25.11	50.90	.49	266.81
SIO2 (μg/ℓ)	2354.60	1515.00	4.00	5275.00
PHOS-SOL (μg/ℓ)	17.56	21.95	0.	123.25
PHOS-TOT (μg/ℓ)	22.61	18.65	0.	87.00
NO3-N (μg/ℓ)	220.75	281.35	3.83	1592.50
NH3-N (μg/ℓ)	299.17	326.57	11.50	1324.00
PHAEOPIG (mg/m^3)	5.22	12.25	0.	58.30
COLOR (F-U)	14.19	4.08	7.00	21.00

to form a data base composed of YEARLY depth-corrected standardized averages for each parameter and lake, sampled consistently from season to season. The five data files in this form were the bases for all subsequent analysis, with minor reformatting done to orient the data to suit particular input requirements for each particular analytical program.

The following analyses were performed on each of the five data sets:

Correlation coefficients: The correlation matrix was calculated and used in each of the other analyses mentioned, but the programs involved do not print the matrix as part of their output. To enable direct examination of pair-wise correlations, the CORRELATE routine contained in MIDAS was used to generate the matrices (Fox and Guire 1973).

Principal components: The PRINCOM routine contained in MIDAS was used to compute the first three principal components. If disparate magnitudes and units of measurement are involved in an analysis, the method of calculating the eigenvalues of a correlation matrix derived from sample data expressed as unit variances is preferred to the covariance matrix procedure (Morrison 1967). Appropriate modes were specified for the PRINCOM routine. Values for the first three principal components derived from the YEARLY data set were computed for each lake using its descriptive data in the yearly file. These values were then assembled in a data file, and are shown in Table 4.

TABLE 4. VALUES OF THE FIRST THREE PRINCIPAL COMPONENTS CALCULATED FROM A MATRIX OF YEARLY AVERAGE VALUES OF 16 PARAMETERS FOR 36 LAKES

	COMPONENT				COMPONENT		
Lake	First	Second	Third	Lake	First	Second	Third
Arnott	-1.73	-3.30	-1.33	Mud	-2.15	-1.06	-1.32
Black	-1.40	0.04	-0.40	Spring	-3.37	-2.08	-1.95
Bryant's	5.37	-0.70	-1.25	Mullett	-1.75	0.08	0.69
Burt	-1.92	0.21	0.66	Munro	0.22	0.17	0.50
Carp	0.58	0.38	-0.75	Osmun	-0.14	1.06	-0.34
Cochran	1.10	1.40	0.42	Pickerel	-1.56	-0.43	-0.18
Crooked	-1.54	-0.33	-0.38	Roberts	0.11	1.06	-0.25
Devereaux	2.18	0.96	1.07	Round	-1.16	-0.24	-0.06
Dog	1.70	0.63	-1.70	Silver-C	-0.47	0.50	2.73
French Farm	-0.83	0.72	-0.11	Silver-B	-1.70	0.77	1.29
Hoop	5.54	-0.79	-0.97	Twin-A	-2.72	0.91	1.61
Larks	-0.58	-0.22	0.41	Twin-D	-1.90	0.64	1.06
Lancaster	-0.81	-1.99	-1.12	Twin-G	-1.80	0.15	1.36
Lance	1.40	-5.06	2.20	Twin-Isol.	1.08	1.58	1.19
Livingston	5.22	0.23	-1.76	Vincent	3.46	1.84	-0.11
Long	0.06	-0.04	1.02	Weber	3.36	1.55	0.57
McLavey	-0.09	0.90	-0.58	Wildwood	0.16	0.09	-0.19
Mud Bog	0.51	0.46	-1.49	Wycamp	-1.80	-0.29	-0.85
				Stoney Cr.	-0.77	-0.56	-1.62

<u>Clustering</u>: A clustering program written by Goldstein and Grigal (1972) was used to obtain an approximate, one-dimensional initial reduction of the hyperdimensional relationships existing between and among the lakes. Values from a correlation matrix calculated as a product of a column centered data matrix and its transpose were used as similarity coefficients by the clustering method. The program starts with each lake being in a separate group. The pair of groups having the highest value in the correlation matrix are joined to form one group. A single, unweighted average value is computed for each parameter for the new group using the data values for the two old groups from the data matrix. These two sets of values in the data matrix are replaced by the one set of newly computed values. A new correlation matrix is computed from the reduced data matrix, and the procedure is repeated. After as many iterations as there are lakes, all lakes will be included in one group.

In addition to the five basic data sets, a clustering was performed on the data set comprised of values for the first three principal components of the YEARLY data set. A three-dimensional physical model was built, with each of the three axes of the model corresponding to a principal component. The values of the components for each lake, taken from Table 4, were used to position the lake in the model. The groups produced at the eight-group level by the clustering program, using the principal component data, were differentiated on the physical model by marking the members of each group with an identifying color coded map pin.

B. TERRESTRIAL

The terrestrial section of the Northern Michigan Environmental Research Program has progressed on three fronts: nutrient analyses of ground water, an inventory of lake shoreline soils, and compilation of a nutrient (nitrogen and phosphorus) budget for selected lakes in the study area. Most progress has been made on the ground water analyses. Consequently, it is appropriate to discuss the methods and results for those analyses in separate sections. Soils and nutrient budget data, however, are both preliminary and, therefore, their methods and results will be discussed together as progress to date in the Results and Discussion section of this report.

Site Selection

Ground water was analyzed from 200 wells located throughout Cheboygan and Emmet Counties *(figure 4)*. We attempted to sample ground water under a variety of land usages. Samples were obtained in the predominately agricultural Black River valley (A), the marshy Indian River area (B), the upland cattle grazing lands in northern Emmet County (C), in an area known to have high nutrient loading from the spray effluent of the Harbor Springs sewage treatment facility (D), and a relatively undisturbed forested area (E). In addition, Long, Devereaux, Cochran and Silver (Wilmont Township) Lakes were specified as areas of particular interest. One hundred and sixty wells were selected from these areas. The remaining 40 wells were randomly selected from surrounding areas (X) to determine background levels moving into and out of the study region *(figure 4)*.

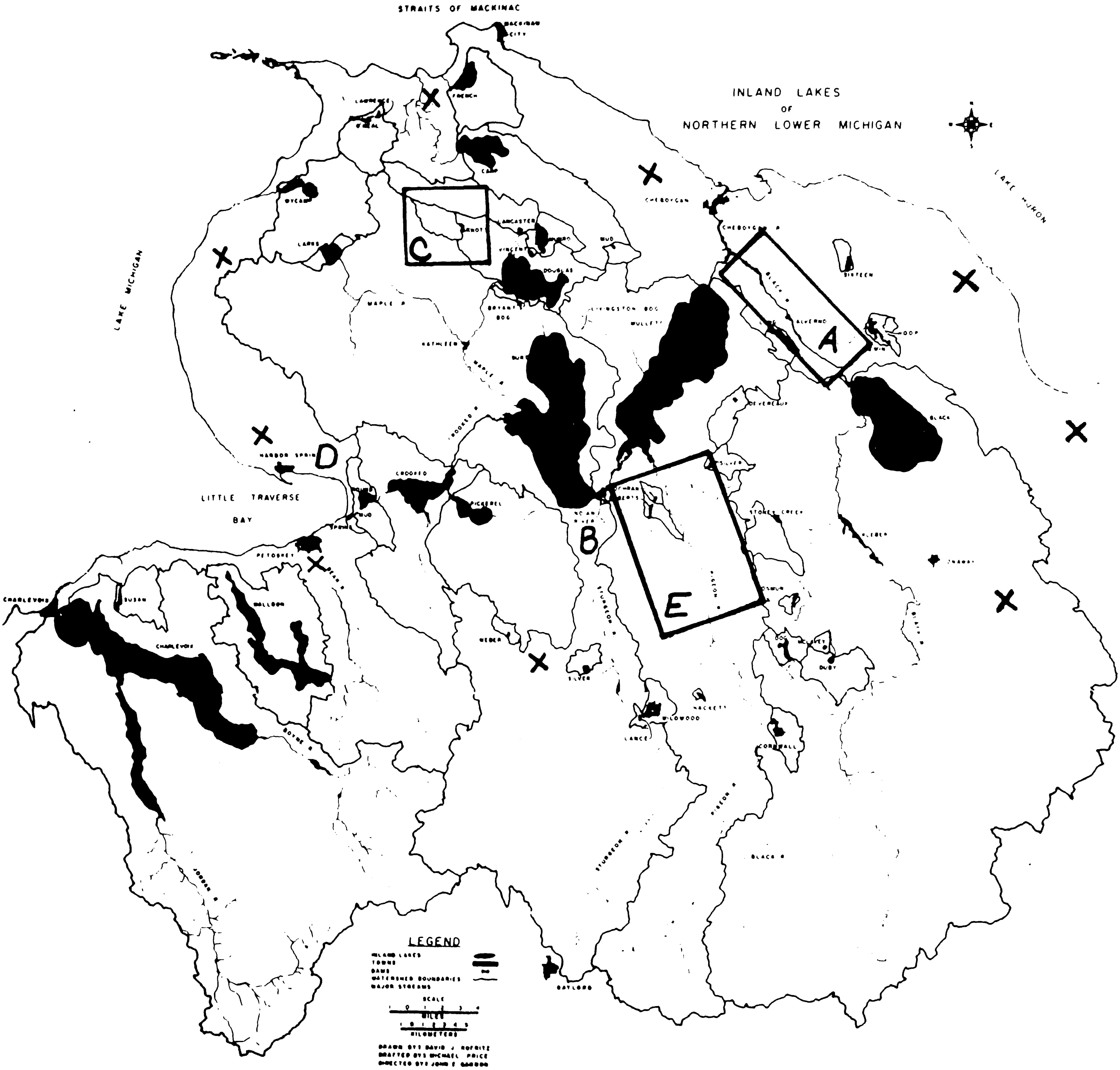


FIGURE 4 The major sampling areas in the ground water survey. A = agricultural orchards-mixed farms, B=urban development, C= agricultural farms, D=spray effluent plant area, E=forested. (NOTE: X referes to background sampling areas outside major study area)

Specific wells in these study areas were selected primarily from well drillers' logs that are on file at State of Michigan Health Department district offices in Petoskey and Cheboygan. These logs give information on well location, depth, size and the strata through which the well was drilled. In addition to those chosen from well logs, a number of wells at State of Michigan agencies (state parks, etc.) were selected for sampling. It was also necessary to choose a number of wells by direct field observation in north-central Emmet County. This was an area considered necessary for study, but for which no well logs were available. Information about depth of these wells, and perhaps the year in which they were drilled, was obtained directly from the well owners.

We generally avoided choosing more than two or three wells per section (one mi^2). Wells were chosen by examination of the categorized areas on the map and matching well locations given in the logs. The remaining wells outside of the main sample areas were chosen similarly, but were widely separated.

During the actual course of the sampling process, an additional 13 wells were added to the list. These were wells of specific interest to the local user community. Thus, a total of 250 wells were made available for analyses by early summer. Actual sampling began in June, 1974. Approximately 200 out of the 250 wells were sampled each month during June, July and August.

All sample bottles were washed prior to sample collection with 4N sulfuric acid and rinsed in deionized water. The majority of the samples were taken directly from the inside or outside water faucet of a household or business. Duplicate samples were taken from each location. The faucet was turned on and let run one minute prior to collecting the sample. The bottles were rinsed out twice in the tap water before the actual collection was made. It should be noted that standard iron pipe used in well construction rusts on prolonged contact with moisture, thus reducing concentrations of orthophosphate-phosphorus. However, water quality tests on iron versus plastic pipe by Tabatabai and Fenton (1974) observed no effect of iron pipe on nitrate-nitrogen concentration. Experiments at our laboratory have shown little reduction in cation concentrations due to iron pipe deterioration providing the water was allowed to flow freely through the pipe for one minute prior to sampling.

A few samples were taken directly from the outlet pipes of artesian or flowing wells. Additional samples were taken where it was possible to obtain both a sample from the faucet and also from either a flowing well bypass pipe, or between the well pump and the system's storage tank. This allowed some comparisons to be made between the content of the water as it came out of the well, either naturally or pumped, and its content after it had been through a water storage and pressure system.

After collection, the bottles were put on ice in a styrofoam cooler. All samples were frozen within six hours after collection, stored and analyzed within two months.

During the collection process, the well owners were asked if their water system included any kind of pressure/storage tank; whether or not the water was treated or filtered in any way; and what type, or types, of piping existed in the plumbing system. Notation was also made of the general land-use patterns in the immediate vicinity of the well.

Because of logistical problems during the winter months and redundancy of values in some areas, it was decided to reduce the number of wells sampled by 75 percent after the summer sampling period. Consequently, 50 wells will be sampled in September, November and February. A full sampling program will start again in April, prior to spring thaw. The final choice of the 50 wells was based on a number of factors. Summer data information was used to locate areas that exhibited higher nutrient levels, as well as those that seemed to be quite low in all values. In addition, wells were chosen from areas of interest to the local user community.

A review of the 1974 data will be utilized in decisions on the number and areas of sampling for the 1975-76 program. Focus will be placed on those areas where the aquatic and terrestrial sections of this study need to integrate their efforts, and also on those areas of specific community interest.

Lab Analyses

Cation analyses (calcium, magnesium, potassium and sodium) were completed following standard procedures of atomic absorption spectrophotometry (Perkin-Elmer 1973). A Technicon autoanalyser was used to analyze nitrate-nitrogen, ammonia-nitrogen, orthophosphate-phosphorus, iron and chloride. Nitrate was analyzed by the Greis-Ilsovay reaction and is reported as nitrate-nitrogen (EPA 1971). The Berphelot reaction was used to analyze ammonia-nitrogen (EPA 1971). After manual digestion, phosphorous was analyzed using the molybdate reaction, and iron by the persulfate oxidation technique (EPA 1971). Chloride analyses followed standard techniques (EPA 1971). Twenty percent of the total samples were selected randomly for filtering through a 0.45μ pore size filter in order to test for possible increases in nutrient values due to particulates. The test showed no significant difference in levels ($p < 0.05$) between filtered and unfiltered samples. The filtration will be continued as a check on one percent of the new samples.

C. SOCIAL

Definition of the Population to be Studied

The universe sampled included heads-of-household and their spouses occupying housing units (HU's) around the inland lakes and rivers of Emmet and Cheboygan Counties; in addition, households on those portions of two lakes that overlap adjacent counties (Presque Isle and Charlevoix) were also included. We designed our study to include residents who live near, although not directly adjacent to, the water's edge, as well as riparians. Direct experience of the study staff as well as discussion with area officials, scientists, and interested citizens led us to believe that backlot development was extensive and expanding, that it accounted for a significant portion of recent development around the waterways, and that such property would likely be the site of a large part of future development activity. River residents were included in our population since it was presumed that one of the chief attractions of their property is its accessibility to the lakes (as well as the whole inland waterway in three of five cases), and because their activities--e.g., dredging and filling, fishing, sewage treatment--impact the lakes. Again, as with the decision to include backlotters, the decision to include river residents was arrived at based on staff experience and consultation with scientists, officials and interested citizens familiar with the region.

Estimating the Number of Housing Units

We looked long and hard but were unable to find a pre-existing count of HU's for the lakes or rivers. We began by contacting area planning officials; this exercise turned up some 1972 sewer authority maps for two of the study lakes, with small boxes allegedly representing houses, and inventories of housing on selected Emmet County lakes which were of unknown reliability. We contacted regional electric companies for estimates of hook-ups on the lakes, but all we could get from this source was the field engineer's best guess. Census data did not distinguish lake from non-lake property, so was of little help although a guess for Cheboygan County lakes based on census data by an area planner turned out to be remarkably close to our final estimate. Geological Survey topographic maps of the area indicate houses, but were made in 1957 and so were far out of date. For Cheboygan County we attempted to draw a count from the tax rolls, but the buildings were neither adequately mapped nor described. Many of the tax maps were in very rough shape, and the process of moving from the tax map to the legal description of the property, with a judgment to be made as to whether any given assessment indicated a building, was excessively cumbersome.

Finally, we struck on the notion of using aerial photographs of the lakes. Of the several possibilities, we found most current and usable the 24" x 24" blow-ups of the

August, 1973, Agriculture Stabilization and Conservation Service (ASCS) flyover of the region. The scale of these prints is 1":660'. As the pictures were taken with trees and other vegetation in full growth, counting residential structures was often quite challenging. In many cases, all we could go by were the docks extending out into the lakes, or driveway traces. Due to time constraints it was necessary to press four different staff members into service in counting lake and river-oriented structures. Although some of us were more conservative or liberal in our estimates, the variation was not striking in the cases where we re-counted each other's work.

We counted structures, using the criteria to be mentioned in the next section, between readily identifiable geographical points, such as a road intersection, the tip of a peninsula, stream mouths, or extreme vegetational discontinuities, as when old field growth abruptly gave way to heavy woods or an orchard abutted cleared land.

Delineation of Study Area

Since we wanted to capture as much as possible of what we believed was significant backlot development, while avoiding asking water-related questions of people who couldn't be expected to answer them intelligently, we finally decided to include in our sampling frame all HU's within one-quarter mile of the water's edge. With the quarter-mile distance as our basic criterion, we added the following refinements.

1. In the case of lakes, where a primary road (a road which carries more traffic than that generated by the properties confronting it) ran within the quarter-mile zone roughly parallel to the lake (most of the lakes in the area are ringed by such through-traffic roads), we included both the waterfront HU's and those backlot HU's with driveway access to the road.

2. For lakes, if more than one primary road existed, we took only waterfront HU's and those backlot units with driveways onto the primary road nearest the water.

3. In the case where a village or town was located on the lake, we included only those houses directly abutting the water's edge. Although none of the lake-fronting villages in our sample are legally incorporated, we followed this "waterfront-only" ruling in several cases where, based on experience and the advice of others familiar with the area, it would have been inappropriate to adhere to our other criteria. Specifically, we counted waterfront properties only for the villages of Walloon Lake (Walloon Lake); Conway and Oden (Crooked Lake); Carp Lake

(Paradise Lake); Indian River (Burt Lake); Topinabee, Mullet Lake and Aloha (Mullet Lake).

4. For rivers we decided to include all HU's within one-quarter mile of the water's edge, provided there was some physical access to the river in evidence, such as a path or road, boat ramp or dock.

5. Where rivers flow through villages, towns, or other dense housing, we took only riparian properties. This rule was followed in dealing with the villages of Alanson (Crooked River) and Indian River (Indian and Sturgeon Rivers).

6. We specifically excluded from our universe those dwellings on the Cheboygan River within the city limits of Cheboygan, the only incorporated city, in our study area, that has inland waterway frontage.

Following these rules, we counted structures on the aerial photograph enlargements, and arrived at the estimates presented in *Table 2*.

Sampling

We wanted to compare the responses of people in households along several dimensions--small versus big lakes; lakes versus rivers; relatively oligotrophic versus eutrophic lakes; Emmet versus Cheboygan Counties--and to look at attitudes and behavior while considering several of these dimensions simultaneously. Thus, in order to minimize the impact of error variance on our analysis, we required a relatively large number of interviews. From these as well as budgetary considerations, we decided to aim for a sample of approximately 800 interviews. Assuming an 80 percent response rate, we would need to attempt interviews at 1000 HU's. Our final sampling rate was 1/4.9.

For several reasons, we decided to divide our total population into clusters and sample on that basis rather than interviewing at every n^{th} house. In the first place, we wanted to carry out some micro-neighborhood analyses, and these would have been virtually impossible without cluster sampling. Secondly, we wished to avoid having to list the entire population, both because of time and money constraints and because of the arousal of interest we anticipated it might cause in the area. Finally, we felt that by clustering we could assure a coverage rate (HU's located by interviewers) of close to 100 percent. We recognized the potential distorting effect that pre-knowledge of the questionnaire by some of the respondents might have, but it was our judgment that this consideration did not outweigh the ones favoring a clustering approach. As it turned out, an unexpected advantage of cluster sampling in this case was that during the course of the summer our interviewers soon became neighborhood fixtures, and satisfied respondents would voluntarily inform them as to the whereabouts of other householders--something very useful in a setting where people come and go as irregularly and frequently as they do in the lake recreation community. Finally, in many cases an interviewer would approach a house, and be welcomed immediately, often before he had even introduced himself, because the respondent had heard about the study from the neighbors. Needless to say, in a few cases the advance warning may have scared off the respondent, but since the nonresponse rate in our study was so close to the 20 percent anticipated, it seems doubtful that this was an important effect.

We decided that for purposes of our planned micro-neighborhood analyses, clusters of from 12 to 15 housing units would be best. In that case we would have on the order of 100 clusters to distribute around the lakes and rivers we wanted to study. In order to get down to geographically identifiable groups of 12 to 15 structures, it was necessary in many cases to return to the aerial photos and search for cluster-defining geographical features, since the first round counting had left us with numerous groups of one hundred or more cottages stretched along the shore. In quite a few cases it was impossible to break the segment down by this method, with the result that the entire group had to be listed.

In order to insure the possibility of examining the relationships of selected study variables to water quality conditions, the sample was stratified according to a ranking supplied by the Biological Station limnologist.

Listing

In ten whirlwind days at the end of May, two of the staff members listed and mapped every housing unit (except for motels and hotels, in which case only the owner's unit was taken) in the selected segments. For each HU, an identifying description was provided, and its approximate location was indicated on a segment map. The segments were numbered--100 series for Cheboygan County; 200 series for Emmet County lakes; 300 series for rivers--and plotted on a large map of the region.

The listing process disclosed the impact on our estimates of the tree coverage at the time of the aerial photographs. The lakes and rivers for which structures were estimated from the aerial photographs showed field-listed structures to be more numerous than we estimated by an average ratio of 1.28 to 1. In many instances we had fallen far short of the actual number of HU's; in a few cases, for example, we had estimated about 20 and actually found 60 HU's. In the case of these large listings, the segments were subsampled.

Selecting the Respondent

We listed approximately 1220 HU's. For every listing we made up a coversheet with a pre-designated respondent, either the head of the household or the wife, alternately throughout the sample. At the end of a week's training, the interviewers were assigned segments, on the criterion of geographic proximity, and corresponding maps, listing sheets and coversheets.

The interviewer's sampling task was as follows. He had to locate the sample segment and verify the accuracy of the listing. For each structure he had first to determine the number of housing units. Basically, a housing unit is a room or group of rooms in which the occupants live and eat apart from any others, and which has a separate entrance and kitchen facilities.[2] Short-term motels, hotels, camps, overflow cabins, tent quarters, recreational vehicles and institutional quarters were excluded, except for motel, hotel or institution owners', resident managers' or other employees' housing units.

Once he had determined which structures contained housing units, the interviewer was to attempt an interview with the designated respondent at all occupied housing units. To eliminate a housing unit because it was unoccupied, the interviewer was supposed to try to obtain an interview on three separate occasions, well spaced by time of day, day of week, and month of the summer. In fact, as our interviewers were returning again and again to their segments, and occupation was usually readily discernible, most of those housing units which we decided were unoccupied had been observed throughout the summer. Final calls in most cases were not made until

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[2] This definition differs slightly from that of the Census Bureau, which specifies <u>either</u> a separate entrance <u>or</u> cooking facilities. We purposefully tightened the criterion in order to minimize the potential influence of overflow cabins, bunkhouses and other such unusual dwellings.

the last week or two of the summer.[3]

In occupied housing units the interviewer was to begin by identifying the head of the household, or his wife, as pre-designated by the coversheet. We anticipated there would be numerous instances of multiple family residence, and therefore provided the interviewers with the following rules for determining the "head in residence":

1. If the owner of the property is in residence, he/she is the head.

2. If there is one person in the primary family unit, he/she is the head.

3. If there is one married couple in the household, then the husband is the head.

4. In cases where there is more than one family unit, ask:

    "Which man (or woman) knows the most about this place, that is, who can best answer some questions about this place?"

    If your informant can single out one person in response to this question, then that person is the

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[3]Vacant HU's were thus defined in practice as HU's without indications of active habitation (e.g., cars, laundry, landscaping changes) on three calls. This procedure for determining vacancy differs from that of the Census Bureau, which decides on the basis of one call. We adopted this approach because of the extreme irregularity of summer home use by seasonal residents. To get the same number of interviews following Census Bureau procedures would have required far more extensive listing.

head. If the informant cannot single out one person, go to rule number 5.

5. Ask, "Which one of you is older?". Person who is the oldest is the head.

We also assumed that in a recreation-resort context during the summer months there might be difficulties in finding the designated respondent at home. Insofar as possible our goal was to interview an equal number of husbands and wives, but as budgetary considerations would not permit infinite call backs, we settled on the following rules.

1. If the designated respondent was temporarily away--e.g., fishing, shopping, visiting neighbors--we attempted to make an appointment for an interview.

2. If, on the third attempt, the interviewer still had not contacted the designated respondent, he was instructed to take the spouse.

3. If the designated respondent was to be absent for an extended period--e.g., husband remaining in Detroit to work while wife and child(ren) vacationed--the interviewer was instructed to take the spouse.

While we were unable to provide an exhaustive set of contingencies for respondent selection, we supplied the interviewers with the following list of examples and instructed them to contact the field supervisor if they encountered other situations.

(a) if "Wife" is indicated and the head is unmarried, you are to interview the head;

(b) if "Wife" is indicated and the head of the household is a female, you are to interview her;

(c) if the "Head" is indicated but he is unavailable after three calls, an interview with the wife is preferable to a nonresponse;

(d) if the "Wife" is indicated, but she is unavailable after three calls, an interview with the head is preferable to a nonresponse;

(e) if the "Head" is indicated but is unavailable after three calls and has no wife (listed) <u>and</u> there is a married couple living in the HU (listed on the listing box), an interview with the husband is preferable to a nonresponse;

(f) if the "Wife" is indicated but is unavailable after three calls and has no husband (listed) <u>and</u> there is a married couple living in the HU (listed on the listing box), an interview with the wife is preferable to a nonresponse.

IV. RESULTS AND DISCUSSION - PROGRESS TO DATE

A. AQUATIC

NATURAL RESOURCE INVENTORY

One of the most urgent needs in any natural resource management program aimed at preserving long-term water quality in inland lakes is an accurate, up-to-date natural resource inventory. The natural resource data base for the Inland Water Route region is incomplete, with limited available data scattered in many obscure places. Persons responsible for natural resource management in the region strongly feel that a complete natural resource inventory is urgently needed in order that management decisions can be based upon facts, not just intuition.

The objective of Phase I of our project is to compile a natural resource inventory for the lakes and their watersheds in northern lower Michigan and to put it in a form most useful to natural resource managers at local, regional and state levels of government. Progress on this portion of the project has been excellent and is near completion. A general description of the natural features (geography, geology, soils, vegetation, climate, and history of land-use) of the study area is being prepared as a semi-technical report geared to the general public (see Information Utilization Section of this report). A detailed watershed map has been constructed for lakes in the study area, and land-use classification within each watershed is being categorized and mapped using remote sensing techniques. The University of Michigan Biological

Station has launched a joint project with Bendix Aerospace Systems Division on a contract with NASA to utilize ERTS satellite data for land-use classification in northern lower Michigan. Data on human riparian population in the study area is being compiled from various sources, the most important of which are lakeshore resident interviews conducted during this project (see Social Science section of this report).

The main emphasis of our investigations has focused on an inventory of limnological characteristics of the inland lakes in Cheboygan and Emmet Counties. Work completed to date includes lake mapping, computations of morphometric data, and the collection and analyses of nearly two years of quarterly water quality data on 38 lakes. This phase of our work will be completed following the winter survey, 1975.

Compilation of data into technical reports for natural resource managers is currently underway, and a series of semi-technical reports on each lake is planned for the general public. Summaries of the morphometric and physicochemical characteristics of lakes in the study area are included in the next sections.

<u>Lake Watersheds</u>

The limnologist interested in lake problems cannot limit his investigation just to lake water. Impact on the water body, no matter whether it originates naturally or culturally, comes primarily from the watershed. It is surprising that detailed watershed maps do not exist for most lakes in northern Michigan, including those in the study area. Consequently, we prepared watershed boundary maps for all lakes within the Inland Water Route region (*figure 5*). These maps have already proven invaluable in the interpretation of limnological data and in discussion of environmental problems with the local public as well as natural resource managers in township, county, regional, and state governmental agencies (see Information Utilization section of this report).

Most of the land area in northern lower Michigan drains eventually into the Inland Water Route lakes; Pickerel, Crooked, Burt, Mullet, and Black Lakes (*figure 5*). These lakes are all interconnected by rivers. Water moving through this system finally flows through the Cheboygan River and empties into Lake Huron. Exceptions are Charlevoix, Susan, Walloon, Wycamp, O'Neal, Lawrence, Carp, and French Farm Lakes which drain directly into Lake Michigan, and Lake Sixteen which drains directly into Lake Huron. A general northwest to southeast orientation of many of the smaller watersheds can be observed, since this was the major direction of glacial activity in the region thousands of years ago. (*figure 5*).

It is most important, from a natural resource management point of view, to realize that the extent and configuration of the drainage basin has little or no relation to the morphology and morphometry of the lake ba-

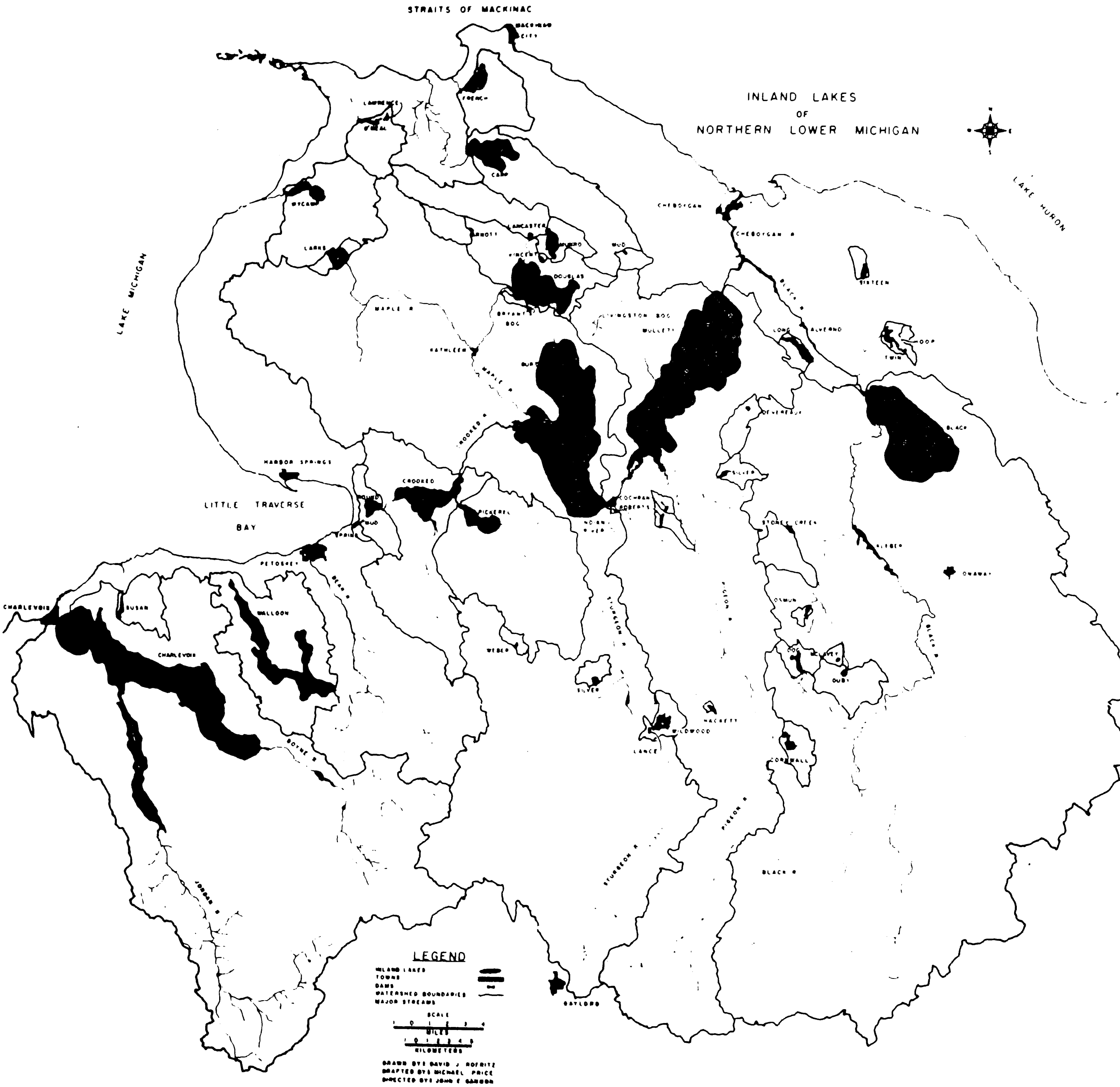

FIGURE 5 Watersheds of inland lakes in northern lower Michigan. The heavy lines trace the watershed boundaries and the thin lines trace the course of major streams.

sin itself. Some of the smallest lakes (e.g., Lancaster Lake) have large watersheds and conversely, some large lakes have small watersheds (e.g., Walloon Lake). Depending upon drainage and seepage patterns, some lakes (e.g., Burt, Mullett, and Black Lakes) are located in the northernmost portion of their watersheds, while others (e.g., Carp and Susan Lakes) are found in the western portion of their watersheds, while still others (e.g., Douglas and Lancaster Lakes) are located in the eastern portion of their watersheds. Some small drainage (e.g., Twin, Cochran, and Osmun Lakes) and small seepage lakes (e.g., Weber, Silver in Wilmot Township, and Vincent Lakes) drain only a small area of land near the lakeshore. On the other hand, some of the largest lakes (e.g., Burt, Mullett, and Black Lakes) drain vast areas of northern lower Michigan, encompassing parts of five counties.

The irregular boundaries of lake watersheds in no way resemble the predominately rectangular boundaries of political units of government responsible for natural resource management in the study area. For example, a lake may lie in one county and its watershed may lie almost entirely in an adjacent county. Some townships may be located far away from a particular lake but nevertheless be part of that lake's watershed. The largest lakes in the study area have watersheds that encompass dozens of townships and several counties. It is critically important that township and county officials responsible for natural resource management be aware of watershed boundaries and use this information in land-use decision making. Since lake watersheds cross so many political boundaries, it is important to realize that regional or even state-wide coordination of land-use planning will be necessary if long-term environmental quality is to be maintained in the face of increasing human development and impact in northern lower Michigan. A detailed watershed map such as presented in Figure 5 can be one of the most important tools available to the land-use planner. We are currently in the process of preparing a booklet for natural resource managers, presenting the watershed map together with a series of transparent overlay maps depicting political boundaries and present land-use characteristics of the study area (see Information Utilization section of this report).

Morphometric Features of Lakes

Morphometric characteristics of lake basins can also be valuable information for the natural resource manager. Some basic morphological and morphometric features of lakes are important determinants in the sensitivity of a given water body to adverse change by human impact. Basically, these features are extremely simple, but have never been effectively utilized by natural resource managers in land-use planning involving inland lakes. Large lakes usually have a greater capacity to withstand human development than small lakes simply because of the dilution factor available in the greater volume of water. Shallow lakes generally can withstand human development better than deep lakes due to a combination of morphometric and chemical factors. In shallow lakes that do not thermally stratify in summer, phosphorus precipitates into the sediments and is unavailable for incorporation into biological and geochemical cycling within the aquatic ecosystem. In deeper lakes, which do thermally stratify and where oxygen depletion occurs in the hypolimnion, phosphorus is released from the sediments and becomes available for cycling within the lake.

Hardness of the water is also an important factor here. Coprecipitation of phosphorus occurs in hard water lakes having high amounts of calcium carbonate. Such coprecipitation does not readily occur in soft water lakes. Consequently, soft water lakes are more susceptible to nutrient loading than hard water lakes.

Shoreline length in relation to surface area of the lake, and the ratio of land surface in the watershed area to lake surface area are important morphometric features which have bearing on sensitivity of lakes to change. The shoreline development factor is a simple morphometric parameter which has been used by limnologists to characterize the shorelines of lakes for many decades. It compares the length of the shoreline of a lake to that of a circle having the same area as the lake. Lakes which have an irregular shoreline featuring many prominent bays, points and other shoreline projections have a higher shoreline development factor than those lakes with simple shorelines most resembling a circle. In general, lakes with higher shoreline development factors have greater potential for over-development by humans because they have longer shorelines relative to the surface area of the lake. Also, lakes with larger shoreline development factors are often in a more advanced state of eutrophy due to the existence of productive littoral areas in shallow, protected embayments. Depending upon soil types and ground water characteristics, lakes with large watershed areas relative to lake surface area have greater sensitivity to adverse change by human impact than lakes with small watersheds.

Another salient feature of lake sensitivity is the flushing rate or water renewal time. This is the amount of time it takes to flush out an existing volume of lake water and replace it with inflowing water. Lakes with fast flushing times (rapidly flowing influent and effluent streams) can usually maintain higher water quality in the face of adverse human impact than can lakes with slow flushing times. Drainage lakes normally have faster flushing times than seepage lakes.

An approximate calculation of the flushing rate of drainage lakes can be made by dividing the lake volume by the flow rate at the outlets. This information can be readily obtained by a natural resource management agency with a simple flow meter for stream flow measurements, and a hydrographic map of the lake from which lake volume can be calculated. Flushing rates for seepage lakes are more difficult to obtain since detailed information on ground water characteristics is required.

The following is a brief account of the basic morphometric features of the lakes in the study area. Emphasis will be placed on those morphometric features having value in determining the relative sensitivity of these lakes to adverse change by human impact. Those lakes within the Inland Water Route watershed will be discussed first, followed by those lakes in the study area which drain directly into Lake Michigan and the Straits of Mackinac.

The Crooked Lake Watershed

Crooked Lake, Emmet County, has a long history of development and is currently one of the most populated lakes in the study area, sustaining 317 dwelling units on its shores (*Table 2*). It has the fourth highest shoreline development factor (2.96) in the study area. Crooked Lake is relatively large (surface area of 960 ha) and moderately deep (mean and maximum depths of 3.0 and

18.6 m, respectively) (*Table 5*). It is aptly named since its shoreline is extremely irregular (*figure 5*). Its immediate watershed is large (11,194 ha) and since Round, Mud, and Pickerel Lakes drain into Crooked Lake, it has a total watershed of 26,409 ha. Crooked Lake has been identified as the lake most seriously affected by human impact within the study area. In order to alleviate nutrient loading problems, a sewer line is currently being installed along the north shore and plans have been made to sewer the south shore also.

Round Lake, Emmet County, is situated at the westernmost portion of the Inland Water Route watershed. It lies close to Little Traverse Bay and the city of Petoskey (*figure 5*). It is separated from Little Traverse Bay by a series of sand dunes. The lake is relatively small (surface area of 133.2 ha) and shallow (mean and maximum depths of 1.6 and 4.1 m, respectively) (*Table 5*). Its epithet is proper since the lake is rather round as revealed by a low (1.26) shoreline development factor. We estimate that a total of 65 dwelling units are located along its shores. Its watershed is not large (1,551 ha) and includes tiny Mud Lake located to the southwest. Mud Lake is very small (surface area of 6.0 ha) and shallow (mean and maximum depths of 0.8 m and 3.0 m, respectively)(*Table 5*).

TABLE 5

MORPHOMETRIC DATA FOR SELECTED NORTHERN MICHIGAN LAKES

LAKE	MAX DEPTH	MEAN DEPTH	MAX LENGTH	MAX WIDTH	MEAN WIDTH	SHORE LENGTH	SURFACE AREA	WATERSHED AREA	VOLUME	SDF	VDF	AREA RATIO
ARNOTT	15.20	3.70	0.50	0.30	0.20	1.30	9.40	933.00	35096.00	1.20	0.70	99.26
BLACK	15.20	7.70	10.50	6.10	3.90	28.70	4052.00	136554.00	313882624.00	1.30	1.50	33.70
BRYANTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BURT	22.20	12.00	15.70	7.80	4.42	52.30	6848.00	101388.00	826446336.00	1.80	1.60	14.81
CARP	4.60	1.20	4.60	2.90	1.70	14.30	760.00	6752.00	10358982.00	1.50	0.80	8.88
CHARLEVO	37.20	17.00	21.20	4.20	3.25	90.20	6800.00	73541.25	1.17	3.10	1.37	10.81
COCHRAN	4.60	1.70	0.50	0.30	0.20	1.30	11.00	218.00	187115.00	1.10	1.10	19.82
CORNWALL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1102.00	0.0	0.0	0.0	0.0
CROOKED	18.60	3.00	5.60	3.10	1.70	29.70	960.00	11194.00	29488464.00	2.96	0.50	11.66
DEVEREAU	6.10	3.10	0.50	0.37	0.28	1.47	14.00	1009.00	437270.31	1.10	1.53	72.07
DOG	2.40	1.10	1.70	0.90	0.50	5.71	76.00	770.00	815786.19	1.83	1.38	10.13
DUBY	3.70	1.10	0.69	0.56	0.39	1.95	26.40	1958.80	307098.50	1.06	0.90	74.20
FRENCH F	3.00	0.90	2.80	1.30	0.80	7.30	234.00	3067.00	2060698.00	1.30	0.90	13.11
HACKETT	2.10	1.30	0.50	0.27	0.24	1.29	11.80	53.40	150767.00	1.05	1.86	4.53
HOOP	9.50	3.70	0.26	0.16	0.12	0.67	2.88	141.00	112359.75	1.10	1.20	48.96
SIXTEEN	1.80	0.55	1.37	0.51	0.39	3.30	52.00	275.30	292993.81	1.28	0.92	5.29
LARKS	2.40	0.80	1.94	1.89	1.26	6.26	242.00	413.00	1866543.00	1.13	0.99	1.71
LANCASTE	17.40	2.90	0.70	0.50	0.30	1.70	20.80	3692.00	613154.00	1.10	0.50	177.50
LANCE	24.40	5.20	0.64	0.25	0.16	1.42	9.80	835.00	517081.19	1.27	0.64	85.20
LIV. BOG	1.80	1.00	0.06	0.02	0.01	0.14	0.09	0.0	965.20	1.30	1.70	0.0
LONG	19.50	7.00	3.57	0.67	0.45	8.66	160.00	416.00	11311422.00	1.92	1.08	2.60
MCLAVEY	3.60	1.35	0.43	0.30	0.23	1.20	9.60	226.60	130887.50	1.10	1.10	23.60
MUD BOG	1.00	1.00	0.60	0.40	0.17	2.20	10.28	439.00	100000.00	1.93	3.00	42.70
MUD-EMCO	3.00	0.80	0.58	0.17	0.10	1.24	6.00	0.0	47148.10	1.43	0.81	0.0
SPRING	2.70	0.70	0.53	0.07	0.06	1.17	2.80	139.30	20463.30	1.91	0.78	49.75
MULLETT	42.70	11.20	16.20	6.30	4.20	45.10	6652.00	64767.00	756373248.00	1.60	0.80	9.74
MUNRO	4.60	1.00	2.80	1.30	1.00	7.20	277.60	925.00	2948022.00	1.20	0.70	3.33
OSMUN	3.00	0.72	0.98	0.40	0.17	2.39	16.40	174.00	117666.69	1.66	0.72	10.61
PICKERAL	21.30	3.90	4.10	1.70	1.10	10.60	427.24	13664.00	17149920.00	1.40	0.50	31.98
ROBERTS	1.20	0.60	1.10	0.30	0.20	2.60	21.40	473.00	118016.00	1.60	1.30	22.10
ROUND	4.10	1.60	1.67	1.35	0.80	5.17	133.20	1551.00	2124864.00	1.26	1.14	11.64
SILVER-C	27.40	11.20	0.70	0.70	0.40	1.00	30.80	523.00	3360000.00	1.00	1.20	16.98
SILVER-B	9.80	3.40	1.14	0.49	0.28	2.86	31.44	661.00	1091755.00	1.43	1.04	21.02
TWIN-A	7.60	3.70	0.44	0.15	0.11	1.25	5.32	459.00	185102.69	1.60	1.50	86.28
TWIN-B	10.70	4.10	0.77	0.22	0.14	2.30	10.84	459.00	449375.31	1.96	1.14	42.34
TWIN-C	12.20	4.90	0.62	0.38	0.19	2.08	11.72	459.00	592587.69	1.70	1.20	39.16
TWIN-D	7.60	4.20	0.43	0.27	0.12	1.29	5.36	459.00	208954.50	1.63	1.65	85.63
TWIN-E	13.70	4.80	0.96	0.24	0.17	2.70	16.32	459.00	768642.69	1.90	1.05	28.13
TWIN-F	6.10	2.50	0.34	0.12	0.11	0.87	3.72	459.00	92917.19	1.23	1.23	123.39
TWIN-G	22.30	8.10	0.76	0.73	0.33	2.60	25.00	459.00	2025976.00	1.47	1.08	18.36
TWIN-ISO	9.10	4.00	0.34	0.21	0.18	1.00	5.68	459.00	239024.81	1.15	1.32	80.81
TWIN-TOT	22.30	5.55	2.68	0.73	0.32	14.10	84.00	459.00	4562581.00	4.30	0.75	5.46
DOUGLAS	27.10	5.47	6.12	3.65	2.47	25.12	1510.00	5651.00	82671888.00	1.82	0.61	3.74
VINCENT	6.90	3.00	0.47	0.36	0.30	1.36	12.32	39.00	377751.00	1.10	1.30	3.17
WALLOON	30.50	8.80	10.10	4.00	1.70	44.30	1728.00	9170.00	154197072.00	3.00	0.90	5.31
WEBER	12.20	6.10	0.60	0.30	0.20	1.50	11.40	306.00	701517.00	1.20	1.50	26.84
WILDWOOD	5.50	1.90	1.55	1.27	0.58	9.32	89.60	877.30	1716053.00	2.78	1.04	9.79
WYCAMP	2.10	0.40	2.50	2.30	1.00	10.80	256.80	6321.00	1090564.00	1.90	0.60	24.61
STONEY C	0.0	0.0	0.0	0.0	0.0	0.0	76.00	1523.20	0.0	0.0	0.0	20.04

A VALUE OF 0.0 INDICATES MISSING DATA - - - UNITS ARE METERS FOR DEPTHS, KM FOR LENGTHS AND WIDTHS, HECTARES FOR SURFACE AND WATERSHED AREAS, AND CUBIC METERS FOR VOLUMES - - - SDF'S,VDF'S, AND AREA RATIOS ARE UNITLESS

STOP 0
EXECUTION TERMINATED

Only a few dwelling units are located on the shoreline of Mud Lake, but highway M-131 traverses near its western shore, and is becoming heavily developed with commercial establishments.

A small seepage lake, known as Spring Lake, is located next to Mud Lake. It is small (2.8 ha in surface area) and shalllow (mean and maximum depths of 0.7 m and 2.7 m, respectively). It has a small watershed of 139 ha (*Table 5*). There are no dwellings on its shores, but commercial development is encroaching near the lake on its south and west sides.

Pickerel Lake, Emmet County, is located southeast of Crooked Lake and flows into it by way of the short Pickerel-Crooked Channel (*figure 5*). Pickerel Lake is about one-half as large as Crooked Lake and is slightly deeper (*Table 5*). A large segment of the Pickerel Lake shoreline is in state ownership and the remainder of the shoreline is only moderately developed with 122 dwelling units (*Table 2*). The watershed of Pickerel Lake encompasses 13,664 ha. Although nutrient loading from cultural sources has not been identified as a problem in Pickerel Lake, its south shore is slated for a sewer along with the south shore of Crooked Lake.

<u>The Burt Lake Watershed</u>

Water from Round, Crooked and Pickerel Lakes flows eventually through the Crooked River to Burt Lake. The

Sturgeon and Maple Rivers are major tributaries to Burt Lake, in addition to Crooked River *(figure 5)*. Burt Lake, Cheboygan County, is the fourth largest lake in the state and has a surface area of 6,848 ha *(Table 5)*. It is relatively deep with mean and maximum depths of 12.0 m and 22.2 m respectively *(Table 5)*. It has several large bays and therefore has a relatively high shoreline development factor. It also has the longest shoreline (52.3 km) of all lakes in the study area except Lake Charlevoix, and therefore has potential for heavy human development. Besides a large tract of land on the north shore which is controlled by the University of Michigan Biological Station, most of the shoreline is in private ownership. A total of 879 dwelling units have been estimated to be located on its shores *(Table 2)*. The watershed of Burt Lake covers a large portion of the northern tip of the lower peninsula of Michigan. The proximal watershed (101,388 ha) includes the drainage area of the Maple River to the west of the lake and the Sturgeon River to the south. In addition, the drainage basin of Burt Lake includes the watersheds of Larks, Arnott, Lancaster, Vincent, Munro and Douglas Lakes to the north and west, and Silver, Weber, Lance and Wildwood Lakes south of the lake *(figure 5)*. Consequently, Burt Lake's total watershed area is 140,181 ha.

Larks Lake, Emmet County, is moderately large (242 ha in surface area) and extremely shallow (mean depth is only 0.8 m and maximum depth only 2.4m)*(Table 5)*. It is nearly circular in size which is reflected in its low shoreline development factor (1.10). It has a small watershed (surface area of 413 ha) and drains by way of Brush Creek into the West Branch of the Maple River and thence into Burt Lake. Larks Lake is sparsely populated with 44 dwelling units located mostly along the southern shore and northeastern portion of the lake (*Table 2*).

Douglas Lake, Cheboygan County, is the fifth largest (surface area of 1,509.3 ha) lake in the study area. It is a multiple ice-block kettle lake, with seven major depressions in the basin. It is moderately deep with a maximum depth of 26.7 m and a mean depth of 5.4 m (*Table 5*). The University of Michigan Biological Station controls over 50 percent of the shoreline mostly along the eastern and southern portions of the lake. The western end of the lake is extensively developed with 332 residential second-homes. Its immediate watershed boundary lies extremely close to the southern and eastern edges of the lake and most of the land area in the watershed lies northwest of the lake (*figure 5*). The immediate watershed is 5,651 ha but Munro, Lancaster, Vincent and Arnott Lakes also drain into Douglas Lake so that the total watershed area of Douglas Lake is 10,307 ha. The Douglas Lake drainage area is part of the Burt Lake watershed, since the east branch of the Maple River flows from Douglas Lake to its confluence with the west branch of the Maple River and then into Burt Lake.

Munro Lake, Cheboygan County, is similar in its morphometric features to Larks Lake in that it is moderate in size (277.6 ha in surface area) and extremely shallow (mean and maximum depths, 1.0m and 4.6 m, respectively) *(Table 5)*. It is an oblong lake with simple shoreline features and a low shoreline development factor (1.20). Cottage development is sparce (59 dwelling units) and is mostly constructed in the southeastern corner of the lake. Its watershed area is relatively small (925 ha) and it drains by way of a tiny creek into adjacent Lancaster Lake.

Lancaster Lake, Cheboygan County, is a small (20.8 ha surface area) but deep (mean and maximum depths of 2.9 m and 17.4 m, respectively) kettle lake *(Table 5)*. It is nearly circular with very low human development (five dwelling units) on its shores. In spite of its small size, it has an extremely large swampy watershed encompassing 3,692 ha northwest of the lake. The drainage area for Lancaster Lake is 177.5 times larger than the surface area of the lake. Lancaster drains into Douglas Lake by way of Bessey Creek *(figure 5)*.

Arnott Lake, Emmet County, has similar morphometric features to Lancaster Lake. It is small (9.4 ha in surface area) and deep (mean and maximum depths of 3.7m and 15. 2m respectively). Its watershed area (933 ha) is over 99 times larger than the surface area of the lake *(Table 5)*. Arnott Lake is almost entirely surrounded by a cedar swamp and only one summer cottage is located on its shore. The lake drains by swampland seepage into Douglas Lake.

Vincent Lake, Cheboygan County, is a small (12.32 ha in surface area) seepage lake, located southwest of Munro Lake and north of Douglas Lake. It is shallow (less than 7 m deep) with a false bottom of fine, flocculent silts in addition to an encroaching shoreline. Only a summer children's camp is located on its southeastern shore. Vincent Lake's watershed is small (39 ha) in area and is only three times larger than the surface area of the lake *(Table 5)*.

Bryant's Bog, Cheboygan County, is located only a few hundred meters from the shore of Douglas Lake. It is a tiny northern bog lake in late stage hydrarch succession. The mat surrounding the lake contains typical bog plants, but is also anchored with large trees occuring near the open water portion of the lake. It has less than 0.05 ha of open water and is only one meter deep. The original basin was slightly less than one ha in area and was about 15 m deep (Welch 1936a). Nearly all large trees on the bog mat have died in recent years, presumably due to abnormally high water levels (Schwintzer, in press). Several dwellings are found close to the western and northern edges of the bog.

Four lakes (Silver, Weber, Lance and Wildwood) are located in the southern portion of Cheboygan County in Burt Lake's watershed *(figure 5)*. Silver Lake is an almost perfectly circular seepage lake (shoreline development factor of 1.00). It is relatively small

(30.8 ha in surface area) and is one of the deepest lakes (mean and maximum depth of 11.2 m and 27.4 m, respectively). It has a relatively small watershed (523 ha in area). Human development is moderately heavy with approximately 32 dwelling units located on its shores (*Tables 2 and 5*).

Weber Lake is a small oval-shaped seepage lake. It has a surface area of 11.4 ha and is moderately shallow (mean and maximum depths of 6.1 and 12.2 m, respectively) (*Table 5*). Its watershed encompasses an area of 306 ha. The lake is entirely state-owned and supports a state forest campground.

Lance Lake is a small but deep kettle lake. It has a surface area of only 9.8 ha but has a mean depth of 5.2 m and a maximum depth of 24.4 m (*Table 5*). Its watershed encompasses an area of 835 ha. Development is heavy along the shoreline, with 22 dwelling units counted (*Table 2*). Lance Lake is drained by a small creek, through swampland, into the Sturgeon River.

Wildwood Lake is an artificial lake that was created ten years ago for second home development purposes by damming up a small creek. The lake has a surface area of 89.6 ha and an extremely irregular shoreline (shoreline development factor of 2.78). It is extremely shallow with a mean depth of only 1.9 m and a maximum depth of 5.5 m (*Table 5*). Human development is currently light, with about 66 dwelling units on its shores. Wildwood Lake drains into and is part of Lance Lake's watershed.

The Mullett Lake Watershed

Mullett Lake is the fifth largest lake (surface area of 6,652 ha) in the State of Michigan, and the deepest lake (maximum depth of 42.7 m and mean depth of 11.2 m) in the study area (*Table 5*). The western shore is nearly straight, but the eastern side has a number of points and bays (shoreline development factor is 1.60). The proximal watershed of Mullett Lake, including the extensive drainage area of the Pigeon River, south of the lake, is 64,769 ha. Water flows from Burt Lake into the south end of Mullett Lake by way of the Indian River. Hence, the lake is the receiving water body for drainage of water from most of the Inland Water Route watershed, encompassing a total area of 207,381 ha). The village of Indian River is located midway between the two lakes and is the fastest growing urban area in Cheboygan County. The village is the proposed site of a junction between two major north-south freeways, so human development in the area is expected to increase sharply in the near future. The largest inland cattail marsh is located at the mouth of the Indian River at Mullett Lake and is currently threatened by dredge and fill development. Mullett Lake has the second longest shoreline (45.1 km) in the study area and supports the largest number of dwelling units (1,283) (*Tables 2 and 5*). Water from

Mullett Lake flows out of the north end through the Cheboygan River, past the city of Cheboygan and then empties into Lake Huron *(figure 5)*.

Small lakes in the study area that are part of the Mullett Lake watershed are Devereaux, Silver (Koehler Township), Cochran, Roberts, Cornwall Flowage and Livingston Bog.

Devereaux Lake is a small (14 ha in surface area) seepage lake located east of Mullett Lake in Cheboygan County. It is a shallow (mean and maximum depths of 3.1 and 6.1 m, respectively) round kettle lake that appears to have a perched water table. Water level fluctuations from year to year are greater in Devereaux Lake than in any other water body in the study area. During the past few years of abnormally high water levels in the Great Lakes region, water levels in Devereaux Lake have been so high that upland vegetation surrounding the lake has been inundated and killed. There are currently 17 dwelling units on Devereaux Lake, all constructed during the past decade. The watershed of Devereaux Lake encompasses an area of 1,009 ha*(Tables 2 and 5)*.

Silver Lake, Koehler Township, Cheboygan County, is located south of Devereaux Lake. Silver Lake is small (31.4 ha in surface area) and shallow (mean and maximum depths of 3.4 m and 9.8 m, respectively *(Table 5)*. The lake is privately owned by the Detroit Area Boy Scout Council. It is used only during the summer for a children's camp. Silver Lake is drained by Silver Creek which flows into the Little Pigeon River and then empties into Mullett Lake.

Cochran and Roberts Lakes are located southeast of the village of Indian River. The lakes are known locally as "twin lakes" since they lie in such close proximity to one another. Limnologically, the epithet,"twin lakes", is a misnomer. Cochran Lake is a small seepage lake, while Roberts Lake is a small flowage created by damming up Twin Lakes Creek. Cochran Lake has a surface area of 11.0 ha and is a shallow, round kettle lake with mean and maximum depths of 1.7 m and 4.6 m, respectively *(Table 5)*. Roberts Lake is oblong in shape, small (21.4 ha in surface area), and extremely shallow (mean and maximum depths of 0.6 and 1.2, respectively). Both lakes are entirely in state ownership.

Another flowage on Cornwall Creek is part of the Mullett Lake watershed. Cornwall Creek was recently dammed up, creating a water body of approximately 90 ha. Its maximum depth is about 5.5 m. The flowage has not been mapped, so detailed morphometric data is unavailable. The watershed of Cornwall Creek Flowage drains an area of about 1,000 ha. The flowage drains through Cornwall Creek into the Pigeon River and then into Mullett Lake.

Livingston Bog is located west of Mullett Lake *(figure 5)*. It is a tiny lake with classical terrestrial plant communities normally associated with northern bogs.

The original basin was about one ha in surface area and had a maximum depth of approximately 9 m. The open water zone today is slightly less than 0.1 ha in surface area and has a maximum depth of 1.8 m above the false bottom *(Table 5)*.

<u>The Black Lake Watershed</u>

The proximal watershed of Black Lake (Cheboygan and Presque Isle Counties) encompasses a large area of 136,554 ha. Including watersheds of smaller lakes within the Black River drainage basin, the Black Lake watershed has a total area of 139,548 ha. The largest part of the watershed is drained by the Upper Black and Rainy Rivers which are the major inlet to Black Lake. The outlet to Black Lake is the Lower Black River which flows into the Cheboygan River and then into Lake Huron *(figure 5)*.

Black Lake is the eighth largest lake in Michigan and the third largest in the study area. It has a surface area of 4,052 ha. It is a broad, moderately deep lake with a mean depth of 7.7 m and a maximum depth 15.2 m *(Table 5)*. The lake is mostly round with only one prominent point at the mouth of the Upper Black River. The shoreline of Black Lake is 28.7 km long and is moderately developed, with dwelling units estimated to number 749 *(Table 2)*.

South of part of the Upper Black River Watershed and Black Lake are four water bodies (Osmun, McLavey, Dog Lakes and Stoney Creek) that are included in our study area. Osmun Lake is a small (surface area of 16.4 ha) and shallow (mean and maximum depths of 0.7 m and 3.0 m, respectively) water body with several small islands and a shoreline liberally covered with rushes (*Table* 5). Only one seasonal cottage is located on the shores of this privately owned lake. McLavey Lake is similarly a small (9.6 ha in surface area) and shallow (mean and maximum depths of 1.35 m and 3.6 m, respectively) seepage lake with only one dwelling unit on its shores. Osmun and McLavey Lakes both have small watersheds of 174 ha and 226 ha, respectively (*Table* 5).

Both Dog Lake and Stoney Creek are flowages. Dog Lake is 76 ha in extent and drains through McMasters Creek and eventually into the Upper Black River. Typical of most flowages in the area, it is shallow with mean and maximum depths of 1.1 m and 2.4 m, respectively. Stoney Creek Flowage has not been mapped, so morphometric data are mostly unavailable. It has a water surface area of 76 ha and drains a land surface of 1,523 ha. It is extremely shallow with water depth normally less than one meter throughout.

Two reservoirs, Kleber and Tower Ponds, are located on the Upper Black River. We have included Kleber Pond in our study area. Kleber Pond was formed by the construction of a hydroelectric power dam on the Upper Black River. It has a surface area of 72 ha and a maximum depth of about 10 m. The reservoir has not been hydrographically mapped, so detailed morphometric data are unavailable. Kleber Pond is sparsely dotted with seasonal cottages.

Another hydroelectric reservoir, Alverno Pond, is located on the lower Black River north of Black Lake. Alverno Pond has a surface area of 46 ha, maximum depth of about 5 m, and is moderately developed with dwellings. It is located in the most fertile agricultural valley in Cheboygan County.

Three water bodies (Long, Hoop and Twin Lakes) are located in the drainage area of the lower Black River. Long Lake is aptly named. It is 3.8 km long and has a mean width of only 0.45 km. It has three depressions, the deepest of which is 19.5 m. Long Lake encompasses an area of 160 ha and has a relatively small watershed (416 ha in area). It has a long shoreline (8.7 km) relative to the surface area of the lake. Therefore, it has a comparatively high shoreline development factor (1.6). Human population on Long Lake is moderately dense with 112 dwelling units on its shores *(Tables 2 and 5)*.

The name "Twin Lakes" implies two lakes of similar dimensions lying in close proximity to one another. For Twin Lakes, Cheboygan County, this is certainly a misnomer. Twin Lakes is actually a chain of seven small interconnecting basins separated from one another by narrow channels. An eighth isolated basin lies east of the interconnected depressions. Although it has no surface connection to the chain of lakes, it nevertheless is considered part of the Twin Lakes group. The Twin Lakes basins have a total surface area of 84 ha. Most depressions are from 10 to 12 m deep and the deepest basin has a maximum depth of 22.3 m. The shoreline is extremely irregular and therefore the Twin Lakes chain has the highest shoreline development factor (4.3) of any lake in the study area *(Table 5)*. Twin Lakes is sparsely dotted with 84 dwelling units. Its watershed is relatively small, encompassing an area of 459 ha. Twin Lakes is drained by Owens Creek which empties into the Lower Black River just north of Black Lake.

Hoop Lake is a bog lake located near the Twin Lakes chain. Hoop Lake has a typical floating mat of vegetation characteristic of boreal bogs. In contrast to Bryant's and Livingston Bogs, Hoop Lake is larger and deeper. It has a surface area of 2.9 ha and mean and maximum depths of 3.7 m and 9.5 m, respectively *(Table 5)*. Hoop Lake has a small watershed of 53 ha. It is entirely state-owned with no development anywhere in its watershed.

The Walloon Lake Watershed

Walloon Lake, Emmet and Charlevoix Counties, empties directly into Lake Michigan by way of its outlet, Bear Creek *(figure 5)*. The lake is large (1,728 ha in surface area) and deep (mean and maximum depths of 8.8 m and 30.5 m, respectively) *(Table 5)*. There are four major depressions in Walloon Lake; three are near 30 m deep, while the fourth is 15.6 m deep. The shoreline is irregular with long narrow embayments known locally as "arms". Walloon Lake has 44.3 km of shoreline and has the second highest shoreline development factor (3.0) in the study area *(Table 5)*. The lake has a comparatively small watershed of 9,170 ha. Walloon Lake is heavily populated with 772 dwellings along its shores *(Table 2)*.

The Carp Lake Watershed

Carp Lake, Emmet and Cheboygan Counties, is located north of Douglas Lake. It is a large (surface area of 760 ha) and shallow (mean and maximum depths of 1.2 and 4.6 m, respectively) lake, heavily populated with 448 dwellings on its shores *(Tables 2 and 5)*. Its large watershed (6,752 ha in surface area) lies southeast of the lake and consists mostly of wetlands. Carp Lake drains into the Straits of Mackinac by way of Carp Lake River *(figure 5)*.

Mud Lake Bog, Cheboygan County, is located in the Carp Lake Watershed. It is a broad (surface area of 10.3 ha) and shallow (one meter deep throughout) bog lake. One residence has been constructed near its shores.

The Wycamp Lake Watershed

Wycamp Lake is a flowage in northwestern Emmet County. It empties into Lake Michigan by way of Wycamp

Creek. The lake has a surface area of 257 ha and is shallow, with depths less than 2 m throughout. The lake has a watershed area of 6,321 ha, most of which is state-owned *(Table 5)*. Only one seasonal dwelling is located on its shores.

The French Farm Lake Watershed

This flowage is located north of Carp Lake near the Straits of Mackinac. It empties into the Straits by way of French Farm Creek. French Farm Lake has morphometric features similar to Wycamp Lake. It is 234 ha in size and is shallow (less than 3 m deep) throughout. Its watershed covers 3,067 ha of land, most of which is state-owned *(Table 5)*. There is no human development on its shores.

Water Quality Characteristics

Salient limnological features of lakes in the study area will be discussed here with emphasis on physicochemical characteristics. For the sake of brevity, lengthy tabular data of limnological parameters will not be included. Instead, important features will be gleaned from the data file and discussed verbally. For the sake of discussion, the lakes have been grouped according to water hardness, color and depth. Those lakes with alkalinity greater than 80 mg/ℓ and having marked marl deposits will be defined here as hard-water lakes. Conversely, those lakes with alkalinity below 80 mg/ℓ and not exhibiting marl deposition will be termed soft-water lakes. Those lakes which are deep enough to thermally stratify during summer are termed deep lakes, while those lakes that remain essentially homothermous during summer are called shallow lakes. The majority of lakes in the study area are shallow or deep hard-water lakes. There are no deep soft-water lakes but a considerable number of shallow soft-water ones. Some lakes are noticeably stained with brown humic materials. These include boreal bog lakes as well as shallow and deep lakes receiving drainage from boggy and marshy wetlands. The lake types range from morphometrically and chemically oligotrophic water bodies to a wide range of mesotrophic lakes to classical dystrophic bog lakes in late stage hydrarch succession. However, the area lacks any truly eutrophic lakes.

Deep Hard-water Lakes

Walloon Lake is perhaps the most oligotrophic lake in the study area. The lake has four basins; three deep basins (maximum depths of 24.4, 27.4 and 30.5 m, respectively) that are freely interconnected. The fourth basin, the North Arm, is only 16 m deep and is separated from the rest of the lake by a narrow sill. The North Arm exhibits limnological characteristics considerably distinct from the rest of the lake.

The three main basins of Walloon Lake have all the features normally attributed to oligotrophy. Water color is a deep emerald green (VIII to X on the Forel-Ule

Color Scale) and light penetrates deeply. Secchi disc depths range from 3.5 m during summer, to 5.5 m in fall, and 9.0 m during winter. The euphotic zone consists of a large volume of the lake with depths of the one percent light transmission recorded at 14 m during summer and 18 m during winter. All three basins thermally stratify during summer with the thermocline beginning at about 9 to 10 m. Oxygen distribution with depth is clinograde during summer with saturation dropping from 50 percent at the top of the hypolimnion to 6 percent at the bottom. The water is highly buffered with alkalinity of over 120 mg/ℓ (as $CaCO_3$) with calcium concentrations of over 30 mg/ℓ recorded throughout the main portion of the lake. Both phosphorus and nitrogen concentrations are extremely low (zero to 6 µg/ℓ of total phosphorus and less than 200 µg/ℓ nitrate-nitrogen during summer). Light marl encrustations are observable throughout the shallow portions of the lake.

The North Arm of Walloon Lake exhibits lower light penetration, greater oxygen depletion in the hypolimnion, higher pH, alkalinity, conductivity, and nutrient content than the rest of the lake. Secchi disc transparency is 2.0 m during summer and the compensation depth for photosynthesis is 7.5 m, approximately half that of the main portion of the lake. Alkalinity and conductivity values are higher in the North Arm, approximately 10 mg/ℓ and 40 µmhos, respectively. Total phosphorus concentrations are approximately two times higher. The isolated nature of the North Arm, coupled with its lesser volume and higher human population density are undoubtedly important factors in the observed water quality differences between the North Arm and the rest of Walloon Lake.

Silver Lake (Wilmot Township) has the appearance and characteristics of a limestone sink lake. It lies in a bowl-shaped depression and is almost perfectly round, with the deepest spot (27.4 m) near the center of the lake. Light penetrates further into Silver Lake than any other water body in the study area. The water is a brilliant emerald green color (V-VI on the F-U Color Scale), with Secchi disc depths recorded at 6 to 7 m in summer and 10 m during winter. The depth of one percent light transmission is 17 to 18 m during ice-free conditions. The lake thermally stratifies in summer with the thermocline extending from about 7 to 15 m. Because of the clarity of the water, the depth of photosynthetic activity extends well into the thermocline. Consequently, Silver Lake is characterized by a pronounced dissolved oxygen maximum in the thermocline. Oxygen concentrations are supersaturated (over 120 percent) in the thermocline during summer. Dissolved oxygen is present in the bottom waters year-round. The water of Silver Lake is highly buffered, with pH ranging from 8.2 to 8.5 in the epilimnion during summer. Alkalinity (100-130 mg/ℓ) and calcium concentrations (30-42 mg/ℓ) are both high. Marl deposits on sediments and macrophytes are prominent throughout the littoral zone. Phosphorus concentrations (generally less than 20 μg/ℓ total phosphorus) are typically low for such a marl lake. However, nitrate-nitrogen concentrations (usually less than 125 μg/ℓ) were also low. Silver Lake has heavy cottage development on its shores and back-lotting is also common. In spite of heavy human impact, Silver Lake appears to be maintaining its predominately oligotrophic character. Coprecipitation of phosphorus with calcium carbonate into the sediments seems to be an important factor in the continued good water quality condition of Silver Lake.

The Inland Water Route Lakes (Pickerel, Crooked, Burt and Mullett) understandably exhibit many similar limnological characteristics, since they are all interconnected by relatively large and rapidly flowing river systems. Of these, Pickerel Lake has the lowest population density on its shores and, in many respects, has the highest water quality in the four lake chain. Water color is yellowish-green (X to XV on the F-U Color Scale). Secchi disc depths range from 2.5 m during spring bloom conditions to 6.0 m during winter. The euphotic zone is relatively deep, with the light compensation zone (depth of one percent light transmittance) vascillating slightly from 8 to 10 m year-round. The lake thermally stratifies, the thermocline ranging from

9 to 16 m during mid-summer. Dissolved oxygen conditions in the hypolimnion drop under ten percent saturation during summer but remain high (greater than 50 percent saturation) during winter stagnation. Alkalinity (140-180 mg/ℓ), calcium (near 40 mg/ℓ), and pH (7.5 to 8.5) are high and marl deposition is evident. Typical of marl lakes, phosphorus concentrations (generally less than 10 μg/ℓ total phosphorus) are low. Nitrogen concentrations (nitrate-nitrogen ranging from 25 μg/ℓ in epilimnetic waters to over 200 μg/ℓ in hypolimnetic waters) are relatively high. Silica levels are 2.5 to 4.5 mg/ℓ year-round.

Crooked Lake, as mentioned previously, is known to have noticeably declined in water quality due to human impact on its shores. Some of the oldest resort settlements in the study area are located on Crooked Lake. Many cottages were built prior to the time when septic tanks were required for sewage disposal. Swimming beaches have been intermittently closed due to high coliform bacteria counts during the past few years. The lake is subject to noticeable phytoplankton blooms, a phenomenon not common in most lakes in the study area. The principal investigator once sampled the lake in July and observed a bloom of *Dinobryon* with Secchi disc transparency reduced to 0.7 m. He returned a few days later to find Secchi disc transparency increased to 2.0 m and no evidence of the recent plankton bloom. Crooked Lake thermally stratifies during summer with the thermocline ranging from 8 to 12 m. Water color is green (XVI on the F-U Color Scale), and turbid from phytoplankton. During summer, 1973, light transparency was good with a Secchi disc depth of 4 m and the compensation depth for photosynthetic activity at 12 m. However, Secchi disc depth was 2.8 m and the compensation depth at 8 m during summer, 1974. Dissolved oxygen concentrations were low in the hypolimnion during summer with no oxygen at the bottom in both years. Oxygen saturation at the bottom during winter was near 50 percent in 1973 and 60 percent in 1974. Marl deposits are evident throughout the littoral zone in Crooked Lake. Alkalinity and pH are similar to that found in Pickerel Lake. However, nutrients are generally slightly higher in Crooked Lake than in Pickerel Lake.

Although Burt Lake is more than six times larger than Crooked Lake and contains nearly three times more water by volume, limnological features of the two lakes are similar. Burt Lake thermally stratifies during summer, with the thermocline ranging from 10 to 15 m. The depth of one percent light transmission is about 10 m during summer. Secchi disc transparency is about 4 m in summer and 7 m during winter. Dissolved oxygen concentrations become low (one to 20 percent saturation) in the hypolimnion, but depleted conditions have not been observed. Dissolved oxygen in the bottom waters during winter remains above 60 percent saturation.

All measured chemical parameters are generally similar in Crooked and Burt Lakes year-round.

Mullett Lake is the receiving body for most of the Inland Water Route region's waters. In spite of its large watershed and the high human population density along its shores, Mullett Lake's water quality condition has remained good. The large volume of this, the deepest lake in the study area, is an important factor in diluting any nutrient loads entering the lake from its vast watershed. The mid-summer thermocline in Mullett Lake extends from 10 to 20 m. Secchi disc depths range from 4 m in summer to 7 m in winter. The photosynthetic compensation zone is at 12 m in this lake. Dissolved oxygen remains high throughout the water column year-round. Bottom oxygen concentrations remain near 50 percent saturation during summer and 70 percent during winter. Values for pH range from 8.5 at the surface to 7.8 near bottom during summer. Alkalinity and specific conductance values are near 150 mg/ℓ and 300 μmhos, respectively. Calcium is about 40 mg/ℓ and marl deposition is prevalent especially on rocky points and shoals. Total phosphorus concentrations (near 20 μg/ℓ) are low but are generally slightly higher than in Burt Lake. Nitrate-nitrogen values (35 μg/ℓ in epilimnetic waters and near 130 μg/ℓ near bottom during summer) are similar to those found in Pickerel, Crooked and Burt Lakes.

Black Lake also has an extremely large drainage basin and heavy cottage development, but like Mullett Lake, its large surface area and volume appear to be important factors in the continued maintenance of its good water quality. Since Black Lake has a maximum depth of only 15 m and the fetch of the wind over the lake surface is long, summer stratification is probably a temporary phenomenon. Under warm and calm weather thermal stratification develops, as was apparent during our sampling trip in summer, 1973, when a thermocline was observed to begin at a depth of 10 m. However, in summer 1974, homothermous conditions were observed. Apparently, Black Lake stratifies temporarily during periods of calm weather and is repeatedly turned over during windy weather throughout the summer. Water in Black Lake is a lightly stained, brownish-green color (XIX on the F-U Color Scale) apparently due to both high biomass of diatoms in the water column and to the presence of humic materials washed in from the lake's extensive watershed. Secchi disc depths between 3.0 and 4.5 m have been recorded and the photosynthetic compensation depth occurs at 8 m during summer. The lake probably does not stratify long enough for oxygen depletion to occur in the bottom waters. Lowest values recorded near bottom were 12 percent saturation during summer and 31 percent in winter. Other Black Lake chemical parameters are similar to those observed in Mullett Lake.

Physiochemical characteristics of Douglas Lake have been previously described by Welch (1927; 1945), Welch and Eggleton 1932; 1935) and Tucker (1957a). The most prominent feature of the limnology of Douglas Lake is that each basin within the lake exhibits different physiochemical characteristics according to their depth and exposure to predominant winds. Welch called this phenomenon "submerged depression individuality". For brevity, only data for South Fishtail Bay of Douglas Lake will be discussed here.

South Fishtail Bay is the depression in Douglas Lake most protected from wind action. Consequently, it warms up sooner in the spring, stratifies earlier in the summer, and turns over later in the fall than does the rest of the lake. The thermocline in the bay extends from about 7 to 15 m during mid-summer. Water color (XV-XVII on the F-U Color Scale) is lightly stained with brown humic materials. The compensation depth for photosynthetic activity is about 10 m throughout summer. In contrast to the lakes mentioned previously, a large portion of the hypolimnion is devoid of oxygen from late summer until fall overturn. Oxygen also becomes depleted near the bottom during winter stagnation. The lake waters are highly buffered with alkalinity (120 to 130 mg/ℓ) and calcium (32 mg/ℓ). Marl deposition on firm substrates and on aquatic macrophytes is evident. The pH ranges from 8.5 in surface waters to 7.5 near bottom during summer. Phosphorus concentrations are extremely low (one to 20 μg/ℓ). Likewise, nitrogen is low during summer (nitrate-nitrogen usually under 100 μg/ℓ), at times reaching values near zero in the upper water. Both phosphorus and nitrogen compounds increase with depth during summer, presumably due to depletion by phytoplankton in epilimnetic waters and regeneration by microbial activity in hypolimnetic waters. A similar pattern is noted with silica, but concentrations in the upper waters rarely drop below 2 mg/ℓ.

Submerged depression individuality reaches its greatest expression in the study area in Twin Lakes. The basins in this chain are so distinctly separated from one another and exchange of water between them is so slow, that they essentially can be treated as separate ecosystems. Basin "A" is fairly representative of most depressions 8 to 13 m deep in the Twin Lakes chain, while basin "G" is the most distinctive depression since it is considerably deeper (22.3 m) than the rest.

Basin "A" of Twin Lakes has a maximum depth of 7.6 m and a surface area of 5.3 ha. It is sufficiently shallow so that summer stratification is weakly developed (surface and bottom temperatures of about 23 and 16^{o} C, respectively). The basin is typical of marl lakes with emerald green color (VII-X on the F-U Color Scale), high alkalinity (160 to 170 mg/ℓ), pH (8.2 to 8.4) and calcium (greater than 50 mg/ℓ). Light penetration is excellent, with the Secchi disc still visible on bottom. The entire basin is covered with extensive deposits of marl. Oxygen concentration remains near saturation throughout the water column during ice-free condition and has not been observed to drop below 60 percent saturation during winter. Coprecipitation of phosphorus with calcium carbonate is undoubtedly occuring in this basin. Total phosphorus concentrations are below 16 μg/ℓ year-round. Nitrate-nitrogen values are also low, usually below 150 μg/ℓ year-round. Silica concentrations (2.5 to 3.5 mg/ℓ) are similar to those found in the aforementioned lakes.

Basin "G" is not only deeper than other depressions in the Twin Lakes chain but is 25 ha in surface area. It is therefore two to five times larger than the others. Thermal stratification occurs in this basin throughout summer, with the thermocline extending from 6 to 11 meters. Color is only slightly greener (F-U Color Scale value of XII) than in the rest of the Twin Lakes chain. Secchi disc depths of 6 to 8 m are recorded year-round. The depth of one percent light transmission is 14 m during summer. Dissolved oxygen becomes depleted near the bottom during summer and winter (3 and 34 percent saturation, respectively). However, zero oxygen conditions have not been observed during any season in this basin. Other chemical parameters are similar for basins "A" and "G", except that greater nitrogen, phosphorus, and silica values are found in the bottom waters of basin "G" during winter, presumably due to regeneration.

Long Lake is another multidepression lake featuring three basins, but they are interconnected at a deep level and have similar limnological features. Discussion here will center on basin "A", the deepest (19.5 m) depression in the lake. This basin thermally stratifies during summer, with the thermocline extending from 6 to 14 m.

Water color is light greenish yellow (X-XIV on the F-U Color Scale). Light penetration is good, with Secchi disc depths ranging from 2.5 in summer to 8.3 in winter. Depth of one percent light transmittance is 11.5 m during summer. Dissolved oxygen depletion occurs in the hypolimnion during summer and winter, but values less than two percent saturation near the bottom have not been observed. Alkalinity (98 to 120 mg/ℓ), calcium (25 to 40 mg/ℓ), and pH (8.6 in surface waters and 7.3 near bottom) are in similar concentrations to those found in the aforementioned lakes. Marl deposition is apparent but not extensive in littoral areas of Long Lake. Total phosphorus values are normally less than 10 μg/ℓ in upper waters and reach over 40 μg/ℓ near bottom during both summer and winter stagnation periods. Nitrate-nitrogen values are usually less than 50 μg/ℓ during ice-free months and are approximately three times higher during winter. Silica (< 0.6 mg/ℓ) is much lower than in other deep hard-water lakes, perhaps because Long Lake has one of the smallest watersheds of any lake in the study area.

Shallow Hard-water Lakes

Larks, Munro, and Round Lakes exhibit many similar limnological characteristics. They are typical shallow marl lakes, with deposits of calcium carbonate evident on firm substrates and aquatic macrophytes. Sediments in deeper waters are silty and cream-colored, consisting largely of a calcium carbonate floc. Water color in all three lakes is light green (VIII-XV on the F-U Color Scale) and is extremely clear, with the Secchi disc visible to the bottom. Larks Lake is the clearest, with 50 percent of surface irradiance reaching the bottom. Round Lake is the most turbid, with only 7 percent reaching the bottom during summer. Dissolved oxygen concentrations are near saturation throughout most of the volume of all three lakes during ice-free months. Some depletion (10 percent saturation) occurs near bottom in Munro Lake during summer. Oxygen depletion is evident under the ice in all three lakes. Winter oxygen saturation values near the bottom range from 75 percent in Larks Lake to 50 percent in Round Lake to less than 30 percent in Munro Lake. Winterkill is known to occur in Munro Lake during long winters of heavy snowfall. All three lakes are highly buffered with calcium carbonate. Values for pH range from 8.3 to 8.7 in summer and 7.5 to 7.8 in winter. Alkalinity values of 100 to 110 mg/ℓ are observed during summer while concentrations increase to over 150 mg/ℓ in Round and Munro Lakes, and over 200 mg/ℓ in Larks Lake during winter. Likewise, calcium concentrations rise from near 30 mg/ℓ in summer to 37 mg/ℓ in Munro Lake, and over 50 mg/ℓ in Round and Larks Lakes during winter. These data indicate that some calcium carbonate is going back into solution during winter. Total phosphorus is low (less than 20 μg/ℓ) in all three lakes during summer, and only a slight increase in concentration (30 to 50 μg/ℓ) occurs in Round Lake during winter. Nitrate-nitrogen concentrations are also low (less than 100 μg/ℓ) in all three lakes during ice-free conditions, but triple during winter.

Carp Lake is turbid and green in color from a high standing crop of phytoplankton. Secchi discs of greater than 2 m are rarely observed. Although the lake is only 4.6 m deep, light penetration does not occur to the bottom. The compensation depth for photosynthetic activity is at 3.5 m during summer. The lake is sufficiently large and shallow enough that wind-generated currents undoubtedly mix it completely. Consequently, dissolved oxygen conditions are near saturation throughout the water column during ice-free conditions. Most of the water column remains high in oxygen during winter except nearest the bottom, where saturation drops to 40 percent. Marl deposition is present in Carp Lake but is not as extensive as in the aforementioned shallow lakes. Alkalinity ranges from near 100 mg/ℓ in summer to over 120 mg/ℓ in winter. Likewise, calcium increases from 27 to 37 mg/ℓ from summer to winter. Phosphorus (7 to 37 μg/ℓ total phosphorus) and nitrogen (60 to 100 μg/ℓ) are low year-round.

Spring and Mud Lakes are extremely productive water bodies that appear to have been influenced by past human activities. A formerly active brewery stood near the shores of Spring Lake and undoubtedly used the lake for dumping of high nutrient wastes. Both Mud and Spring Lakes are close to the city of Petoskey, one of the oldest towns in the study area and one that is currently exhibiting rapid growth. We are in the process of assessing past and present impacts of human development on these two lakes. Photosynthetic activity from both aquatic macrophytes and phytoplankton drive oxygen levels to supersaturation (up to 140 percent) and pH levels to 9.2 in Spring and Mud Lakes during the warmest months of the year. Water color in both lakes is green (XII-XVIII on the F-U Color Scale) and the Secchi disc is visible to the bottom in these shallow water bodies. Marl deposition is evident on aquatic macrophytes but there does not appear to be a build-up of marl in the sediments of either lakes. Nutrient regeneration in both lakes during winter is dramatic. Alkalinity rises from approximately 150 mg/ℓ in summer to nearly 300 mg/ℓ during winter. Values for pH drop from well over 8.5 in summer to 7.6 in winter. Calcium concentrations are two to three times higher in winter (60 to 90 mg/ℓ) than in summer (26 to 42 mg/ℓ). Silica concentrations triple between summer (1.0 to 1.5 mg/ℓ) and winter (3 to 5 mg/ℓ). Total phosphorus values are low (9 to 16 μg/ℓ) in summer, but are six times higher in Spring Lake and three times higher in Mud Lake during winter. Summer values for nitrate-nitrogen range from 76 to 122 μg/ℓ in Spring Lake, and near 50 μg/ℓ in Mud Lake. Concentrations are fifteen times higher in Spring Lake and 20 times higher in Mud Lake during winter.

Wildwood Lake, in its short nine year existence as an artificial lake, has been beset with serious environmental problems mainly expressed in profuse growths of aquatic macrophytes. Nutrients are probably still leaching out of the submerged soils of the former Bradley Creek valley and are undoubtedly being augmented by leachate from septic tank drainfields along the sandy lakeshore. Water color is yellowish green with light brownish stain (XVI to IXX on the F-U Color Scale). Light penetrates to the bottom throughout the lake. The Secchi disc usually disppears from view just before the bottom (4 m). Most of the volume of Wildwood Lake is saturated with dissolved oxygen during ice-free months except near the mud-water interface, where values less than 70 percent saturation have been observed. High rates of dissolved oxygen consumption by decomposition and respiration processes are reflected by low oxygen concentrations (45 percent saturation near surface and 13 percent near bottom) under the ice. Some local residents say that winterkill of fish has occurred at least three times in Wildwood Lake, but there are no records to substantiate this claim. Summer pH values range from 8.3 at the surface to 7.9 near bottom. Alkalinity is near 120 mg/ℓ while calcium concentrations are about 35 mg/ℓ. Marl encrustation is visible on aquatic macrophytes but there is no observable deposition on the sediments. Summer values for nitrate-nitrogen (40 μg/ℓ) and silica (0.3 mg/ℓ) are low, but values for total phosphorus (45 μg/ℓ) are high in comparison with other hard-water lakes in the study area. Considerable regeneration of these nutrients is indicated during winter, with mean values of 200 μg/ℓ, 1.4 mg/ℓ and 58 μg/ℓ observed for nitrate-nitrogen, silica, and total phosphorus respectively.

In contrast to Wildwood Lake, Silver Lake (Koehler Township) receives relatively little human impact, and water quality conditions are excellent. Silver Lake is a marl lake with lightly turbid emerald green green water (IX to X on the F-U Color Scale) Secchi disc depth is 4 to 6 m during ice-free months, and the depth of one percent light transmission (8m) is reached near the bottom (9.8 m). Dissolved oxygen saturations near bottom remain above 70 percent saturation year-round. Alkalinity averages 140 mg/ℓ, and calcium concentration is near 40 mg/ℓ. Values for pH above 8.3 are common throughout ice-free months. Calcium carbonate is visible on aquatic macrophytes, and marl deposits constitute a major portion of sediments. Total phosphorus (14 μg/ℓ) and nitrate-nitrogen (50 μg/ℓ) are low during summer. Phosphorus concentrations remain essentially the same year-round, while nitrate-nitrogen doubles during winter. Silica concentrations are relatively high (3.8 mg/ℓ) and do not change significantly with seasons.

Osmun and McLavey Lakes also receive little human impact and are in good water quality condition. Color of both lakes is only slightly stained with brown humic materials (XVI-XIX on the F-U Color Scale). Light penetration is excellent, with the Secchi disc visible on the bottom. Thirty-nine percent of surface illumination reaches the bottom in Osmun Lake, and two percent reaches the bottom in McLavey Lake. Dissolved oxygen remains near saturation through the entire water column in both lakes during ice-free conditions and remains high throughout winter. Alkalinity (90 mg/ℓ) and calcium (about 26 mg/ℓ) concentrations are lower than the aforementioned shallow hardwater lakes, but pH values are commonly above 8.2 in both Osmun and McLavey Lakes during summer. Some marl is observed on aquatic macrophytes in both lakes, but no marl deposition is observed in recent sediments of McLavey Lake. It also does not appear to be a major fraction of bottom muds in Osmun Lake. Phosphorus (11 to 12 μg/ℓ total phosphorus) and nitrogen (45 to 57 μg/ℓ nitrate-nitrogen) are low in both lakes during summer and decreases in winter. Silica concentrations (2.5 to 2.8 mg/ℓ in Osmun Lake and 3.0 to 4.0 mg/ℓ in McLavey Lake) remain approximately the same year-round in both lakes.

The remaining lakes are all impoundments for wildlife management or hydroelectric purposes. Wycamp, French Farm, and Roberts Lakes were natural lakes that had dams constructed at their outlets to stabilize water levels, presumably for the enhancement of wildlife production. Kleber and Alverno Ponds are hydroelectric reservoirs on the Upper and Lower Black Rivers, respectively.

French Farm and Wycamp Lakes both have firm substrates throughout which support growths of submergent and emergent vegetation. Sediments in Roberts Lake are soft and flocculent, with vegetation mostly confined to the periphery of the lake. Light penetration is good, with the Secchi disc visible on bottom in all three lakes. Over 20 percent of surface illumination reaches bottom in each lake. Dissolved oxygen is near saturation during ice-free months and remains high in winter in all three lakes. Alkalinity, pH, and calcium are high and major nutrients are low in these lakes, similar to the pattern observed in most marl lakes in the study area. Marl deposition is prevalent in all three lakes, especially in Roberts Lake where sediments are predominately a calcium carbonate floc. Nutrients generally remain low year-round. The only significant exception is a ten-fold increase in nitrate-nitrogen from summer to winter in Wycamp Lake.

Both Alverno and Kleber Ponds have physicochemical characteristics similar to those observed in Black Lake. They are highly buffered ecosystems with high alkalinity, calcium, pH, and relatively low nutrient concentrations. Dissolved oxygen remains high throughout the water column in both reservoirs year-round. Rapid flushing rates are undoubtedly important in sustaining good water quality conditions in Alverno and Kleber Ponds.

Brown Hard-water Lakes

Six lakes in the Inland Water Route region are hard-water lakes, but in contrast to those mentioned previously, these lakes are all deeply stained with brown humic materials (XX to XXI on the F-U Color Scale). Three of them (Arnott, Lancaster and Lance Lakes) are deep kettle lakes. Two (Cornwall and Stoney) are flowages that mostly drain boggy wetlands and have therefore attained a brown water character. The other (Mud Lake Bog) has an acid-forming mat of bog vegetation, but the open water is decidedly basic.

Arnott and Lancaster Lakes appear to be in very early stages of hydrarch succession, progressing toward dystrophy. Both lakes are surrounded by encroaching shrub-like vegetation characteristic of northern bogs. Lance Lake may have had a similar appearance at one time, but it is surrounded by lawns and cottages now. All three lakes have soft, flocculent sediments from shore to shore. The brown-stained waters in these lakes extinguish illumination quickly. The compensation depth for photosynthetic activity during summer is 3, 4, and 5 m in Arnott, Lancaster and Lance Lakes, respectively. Secchi depths are rarely over 3 m during ice-free months. Since these lakes are small, deep and protected from wind action, they thermally stratify early in the spring and remain stratified until late in the fall. The thermocline develops and remains at a shallow depth. Therefore, each of these lakes have a large hypolimnion relative to the epilimnion. Productivity in these lakes is high, as indicated by frequent phytoplankton blooms during ice-free months. We have observed large pulses of blue-green algae in Arnott and Lancaster Lakes and phenomenal blooms of *Ceratium* in Lance Lake. Under such conditions, it is not surprising that hypolimnetic oxygen deficits are high in these lakes. Dissolved oxygen concentrations are zero throughout most of the hypolimnion in Lance Lake by mid-summer. Oxygen decreases throughout the hypolimnion to near zero at the bottom of Arnott and Lancaster Lakes in summer. During winter stagnation, dissolved oxygen generally ranges from near 50 percent saturation under the ice to under 20 percent near bottom. Lowest oxygen values near bottom recorded for these lakes during winter were 0.6 percent for Arnott Lake in 1973 and 2.0 for Lance Lake in 1974. Values for pH generally range from 8.2 at the surface to 7.3 at the bottom during summer.

All chemical parameters measured in Arnott, Lancaster and Lance Lakes increase with depth during stratified conditions except dissolved oxygen and pH. Alkalinity is high and averages 160 mg/ℓ in these lakes. Calcium (44 to 48 mg/ℓ) is especially high in Arnott Lake, and also relatively high in Lancaster (32 mg/ℓ) and Lance (26 to 46 mg/ℓ). Some marl encrustation is observable on aquatic macrophytes in the littoral zone, but no accumulation is apparent in the sediments. The hypolimnion of these lakes acts as a nutrient sink during thermally stratified periods, with redistribution into upper waters occurring during spring and fall overturn. Total phosophorus concentrations (approximately 20 μg/ℓ) are low in the epilimnion of all three lakes during summer. Values near bottom increase slightly (23 μg/ℓ) in Arnott Lake, rise approximately ten times (240 μg/ℓ) in Lancaster Lake, and increase dramatically (1,370 μg/ℓ) in Lance Lake. Similar increases, but of less magnitude, occur from surface to bottom in each of these lakes during winter. Nitrate-nitrogen concentrations average 80 μg/ℓ in Arnott Lake and 125 μg/ℓ in Lancaster Lake. There is little variance with depth during summer. However, nitrate-nitrogen increases from 10 μg/ℓ and the surface to almost 100 μg/ℓ near bottom in Lance Lake during summer. Concentrations of nitrate-nitrogen increase in winter approximately two to three times over summertime values. Silica is high in all three lakes. Silica in Arnott Lake is approximately 2.5 mg/ℓ during summer and varies little with depth. However, silica increases dramatically with depth in both Lancaster (3.2 mg/ℓ at the surface to 5.0 mg/ℓ near bottom) and Lance (0.7 mg/ℓ to 6.4 mg/ℓ) Lakes. Regeneration of silica is indicated in all three lakes by higher values during winter then in summer.

Since Stoney Creek Flowage is generally less than one meter deep throughout, it is mostly choked with submergent and emergent aquatic vegetation. Even though its waters are highly stained, light penetration in these shallow waters is good. Dissolved oxygen is obviously high during ice-free conditions but drops to near 20 percent saturation during winter. Alkalinity (150 mg/ℓ), pH (7.9), and calcium (54 mg/ℓ) are all high during summer and, except for pH (7.2), remain so year-round. Total phosphorus (16 μg/ℓ) and nitrate-nitrogen (140 μg/ℓ) are low during summer and do not change significantly in winter. Silica is high (3.2 mg/ℓ) year-round.

Cornwall Creek Flowage is deeper (5.5 m) than Stoney Creek Flowage but nevertheless supports an abundant growth of aquatic macrophytes. The Secchi disc depth is three meters, with two percent of surface illumination reaching the bottom during summer in Cornwall Creek Flowage. Dissolved oxygen remains high throughout the water column year-round. Alkalinity (125 mg/ℓ), pH (7.9) and calcium (37 mg/ℓ) are relatively high year-round. Total phosphorus (6 μg/ℓ) nitrate-nitrogen (80 μg/ℓ) and silica (1.2 mg/ℓ) are low during summer. A fivefold increase in total phosphorus and a twofold increase in silica occurs during winter.

Mud Lake Bog is a most unusual bog lake in the Inland Water Route region. Welch (1936b) studied the lake for many years and wrote, "the lake is, then, a unique situation in which the open water (the lake itself) maintains a high alkalinity, although margined completely by a bog mat supersaturated with water which is acid in reaction... From all external signs an observer would expect this bog lake to have the same acid character as do the innumerable other northern so-called Sphagnum bog lakes". Welch (1936b) surmised that the basic character of the water had its origin through chemical reactions in the lake basin itself. However, there are limestone outcrops in the drainage basin and underground seepage of high alkaline water into the lake that should not be discounted.

Since Mud Lake Bog is only one meter deep, light penetrates to the false bottom in spite of heavy absorption by brown humic materials. The Secchi disc is barely visible at the mud-water interface. Five percent of surface illumination reaches this zone. Dissolved oxygen remains high throughout the water column during ice-free conditions. However, dissolved oxygen drops to near zero under mid-winter ice. We have recorded pH values from 8.0 to 8.8, while Welch (1936b) reported that pH occasionally reached 9.4 in Mud Lake Bog during summer. Alkalinity (100 to 120 mg/ℓ) and calcium concentrations (29 mg/ℓ) are similar to those found in more typical hard-water lakes in the study area. However, no marl encrustations are visible in Mud Lake Bog. Phosphorus (19 µg/ℓ total-phosphorus) and nitrogen (136 µg/ℓ nitrate-nitrogen) are low during summer and remain so year-round. However, silica (3.1 mg/ℓ) concentrations are relatively high.

Brown Soft-water Lakes

This grouping of lakes includes three acid Sphagnum bogs in the study area and one flowage surrounded by bog vegetation. The bogs have the appearance of classic boreal bog lakes, featuring typical zonation of vegetation surrounding the open water, false bottom, and acid pH. However, they do not correspond to the classical definition of dystrophy since they appear to be highly productive. They support a large biomass of phytoplankton and zooplankton throughout the growing season. Additional research will be required before we fully understand how these bogs function with apparent high productivity in a soft-water medium.

Bryant's and Livingston Bogs are limnologically similar in many respects. They are both small and shallow with deeply stained brown water. The Secchi disc is barely visible at the mud-water interface (one meter deep). For reasons not fully understood, dissolved oxygen concentrations, even at the surface on a warm summer's day, are never near saturation. Values greater than 75 percent are rarely recorded at the surface and drop to 50 percent and lower near bottom. There is a significant diurnal flux in dissolved oxygen, with values throughout the water column dropping as much as 50 percent at night during summer. Under ice cover, oxygen concentrations drop near zero. The pH in both bogs is approximately 5.7, and alkalinity is extremely low. There is no detectable alkalinity in the surface waters of these bogs, and bottom values are near 3 mg/ℓ during summer. All measured cations are extremely low. For example, calcium is near 1.5 mg/ℓ and silica is approximately 0.1 mg/ℓ in both bogs. However, phosphorus and nitrogen are relatively high. Total phopshorus averages 87 μg/ℓ and 33 μg/ℓ, and nitrate-nitrogen is 158 μg/ℓ and 280 mg/ℓ in both Bryant's and Livingston Bogs, respectively. Slight increases in these nutrients are observed during winter. Hoop Lake differs from Bryant's and Livingston Bogs in that it is deeper (9.5 m) and thermally stratified during summer. Otherwise, Hoop Lake exhibits similar chemical characteristics to the smaller bogs and also supports a large biomass of plankton. A phenomenal bloom of *Dictyosphaerium* colored the water green in Hoop Lake during summer, 1973. The thermocline ranges from 2 to 5 m during mid-summer. Light is extinguished rapidly in the dark stained waters of Hoop Lake, with the Secchi disc disappearing at 2 m. Dissolved oxygen ranges from near 75 percent saturation at the surface to zero throughout most of the hypolimnion. A similar profile of dissolved oxygen with depth is observed during winter. Summer values for pH range from 6.0 at the surface to 4.7 near the false bottom during summer. They drop to near 5.0 throughout the water column in winter. Alkalinity ranges from zero to 1.8 mg/ℓ during summer and from zero to 10 mg/ℓ in winter. All measured cations are extremely low. Silica is less than 0.5 mg/ℓ in summer and less than 0.9 mg/ℓ in winter, while calcium is near 1 mg/ℓ year-round.

Dog Lake is a natural boggy wetland area which was normally kept flooded by beaver dams. The beaver dams have been replaced by a cement dam to stabilize the water level. The waters of Dog Lake are as deeply stained with brown humic materials as the aforementioned bogs, and the Secchi disc just disappears at the bottom. Dissolved oxygen is near saturation throughout the water column during summer, but drops under 35 percent saturation in winter. Values for pH are near 8.0 in summer and drop to 6.6 in winter. Cations and anions are low during ice-free conditions and change little over winter.

Unstained Soft-water Lakes

Water in the following seepage lakes is chemically soft and is not noticeably stained from humic and tannic materials.

Cochran and Devereaux Lakes are physicochemically similar. Both lakes have clear water (X-XIV on the F-U Color Scale) with good light penetration. The Secchi disc is normally visible on bottom with 14 percent of surface illumination reaching the bottom sediments in Cochran Lake. The Secchi disc depth in Devereaux Lake is 3.5 m, with 9 percent of surface illumination reaching the bottom. Light penetration is sufficiently good and bottom sediments sufficiently firm that aquatic macrophytes grow throughout both of these lakes. Dissolved oxygen remains near saturation in the entire water column of Cochran Lake during ice-free conditions. However, some oxygen depletion (78 percent saturation) occurs near bottom in Devereaux Lake during summer. Oxygen depletion (approximately 50 percent saturation) occurs in both lakes under ice cover. Alkalinity is 65 mg/ℓ in Cochran Lake and 45 mg/ℓ in Devereaux Lake during summer. Values for pH are 8.4 in Cochran Lake and 7.8 in Devereaux Lake in summer. Cations and anions are low in both lakes. Calcium is 21 mg/ℓ in Cochran Lake and 16 mg/ℓ in Devereaux Lake. Total phosphorus is generally under 25 μg/ℓ and nitrate-nitrogen is near 50 μg/ℓ in both lakes. Silica is under 0.3 mg/ℓ. Concentrations of major nutrients during winter are only slightly higher than those values observed in summer.

Isolated Basin of Twin Lakes, although it is only a few hundred yards from the Twin Lakes chain, is limnologically distinct from the interconnected basins.

The waters of Isolated Basin are twice as soft as waters in the Twin Lakes chain. Light penetrates deeply into the clear waters of Isolated Basin. The Secchi disc disappears at about 6 m, and 15 percent of surface illumination often reaches the bottom during ice-free conditions. Dissolved oxygen remains high throughout the water column, with only slight depletion (78 percent saturation) occurring near bottom during ice-free periods. Oxygen concentrations under ice-cover range from 60 percent saturation near surface to 17 percent near the bottom. Values for pH are near 8.0 during summer, and drop to 7.2 in winter. Alkalinity averages 70 mg/ℓ in summer and rises to 86 mg/ℓ in winter. Calcium averages 21 mg/ℓ year-round. Silica concentrations (0.1 mg/ℓ) are very low in summer. Some regeneration of silica is indicated during winter, as concentrations range from 0.2 mg/ℓ at the surface to 0.6 mg/ℓ at the bottom. Total phosphorus (11 to 23 μg/ℓ) and nitrate-nitrogen (25 μg/ℓ) are extremely low in summer and even lower in winter.

Vincent Lake today bears little resemblance to the acid bog lake investigated by Jewell and Brown (1929) and Welch (1938a) in the early 1920's. It has retrogressed to a slightly basic soft-water lake. Brown stain from humic materials is gone from Vincent Lake today (XIV to XVI on the F-U Color Scale). The Secchi disc disappears at 3 m and 9 percent of surface illumination reaches the bottom. The sediments are still soft and flocculent, retaining the false bottom character of the former bog lake. Dissolved oxygen remains near saturation throughout the water column in ice-free periods, but decreases under ice cover from 90 percent saturation near surface to 38 percent near bottom. Values for pH average 7.7 during summer and drop to 6.0 in winter. Alkalinity (6 mg/ℓ) and calcium (3 mg/ℓ) are extremely low in summer. Calcium remains essentially the same during winter, while alkalinity rises from 9 mg/ℓ near surface to 22 mg/ℓ near bottom. Total phosphorus (22 μg/ℓ), nitrate-nitrogen (49 μg/ℓ), and silica (0.1 mg/ℓ) are all low during ice-free conditions and do not rise appreciably during winter.

Weber Lake was studied by Hooper (1954) who was interested in the unusual limnological characteristics of this lake. It has the appearance of many other hard-water lakes in the study area, but its waters are extremely soft. Hooper (1954) surmised that the lake basin's ground water influence is sealed from the surrounding area except for seepage from an adjacent bog. Color of the water in Weber Lake is bluish-green (X to XVI on the F-U Color Scale). The Secchi disc is visible at 4 m during ice-free conditions, and 7 percent of surface illumination reaches the bottom. Dissolved oxygen remains high (above 80 percent saturation) during summer and does likewise in winter, except near bottom where depletion occurs (4 percent saturation). Values for pH range from 8.3 near surface to 7.9 near bottom in summer. They drop about 1.0 throughout the water column in winter. Alkalinity is extremely low in summer (13 mg/ℓ) and increases only slightly (21 mg/ℓ) in winter. Calcium is low (3.8 mg/ℓ) during summer but increases (over 5.0 mg/ℓ) in winter. Total phosphorus (20 μg/ℓ) and nitrate-nitrogen (10 μg/ℓ) are low in summer and generally remain so in winter. Silica concentrations are extremely low (0.06 mg/ℓ) in summer and range from near zero at the surface to 0.3 mg/ℓ during winter.

LAKE RANKING BASED UPON SENSITIVITY TO HUMAN IMPACT

The average limnologist, after a brief visit to a lake and analysis of several water quality parameters, can usually venture a vague opinion about the sensitivity of the water body to human impact. There is no question that certain lakes have greater capacity to withstand human development than others. It is critically important, however, that this information be quantified and built into the resource management of inland lake watersheds. Not all lakes should be treated the same in zoning ordinances and land-use plans as they are today. Lakes that are more sensitive to human impact should be zoned more stringently than lakes that have the capacity to withstand more human development. There is an urgent need for a problem-oriented lake classification or ranking system that will indicate the relative sensitivity of a lake to degradation by human impact.

Lakes have defied classification for centuries. Each lake has its own unique attributes. Consequently, simple classification systems that disregard their inherent complexities have not been useful to natural resource management. On the other hand, complicated, lengthy classification schemes become unwieldy, gain little general acceptance, and are soon forgotten. Therefore, ranking a series of lakes with reference to their sensitivity to change by human influences appears to offer more utility to natural resource management than lake classification.

It has been the second objective of our project to design such a lake ranking system based upon sensitivity of lakes to adverse change by human impact. Such a ranking system would be of interest in the comparison of lakes. It would also be useful in communicating water quality information to natural resource managers and the general public. Officials responsible for natural resource management at both county and state levels of government have already expressed enthusiastic interest in the lake sensitivity ranking concept. In order to devise such a lake ranking scheme, our research efforts have been moving forward on several parallel fronts, including: 1) analyses of past limnological data 2) analyses of paleolimnological indicators of change 3) ranking of lakes based upon present water quality 4) and detection of early indicators of lake change in the structure and composition of biological communities.

Historical Perspectives

Our knowledge of the eutrophication process in inland lakes has been greatly enhanced by analyzing long series of limnological data for a particular lake. Our understanding of recent water quality changes in Lake Erie and Washington in the United States, and several important lakes in Europe, is largely due to the fact that limnological data had been collected over a time period of many decades on those water bodies. Consequently, one of our first tasks on this project was to locate, compile and analyze all old limnological data available for lakes in the study area.

It was readily apparent from the onset of this research program that there is an appalling lack of data useful in the interpretation of changes in lakes of northern lower Michigan. Most data was collected by Paul Welch and his students at the

University of Michigan Biological Station. However, their efforts were mostly concentrating on Douglas Lake and a few other lakes in the vicinity of the Biological Station. Other data was obtained from the files of the Fish Division of the Michigan Department of Natural Resources. These data, consisting usually of a few temperatures, dissolved oxygen, pH, and alkalinity measurements, were taken irregularly and incidently during lake inventories and fish surveys. Besides the fact that these data were obtained so irregularly, lack of uniformity in personnel and methodology render these data of dubious value. More recent data has been collected on a routine basis on a few lakes in the study area by the Michigan Water Resources Commission. Although these data are more accurate and complete, this agency's monitoring program has been in operation only a few years. Therefore, these data are not useful at this time for historical perspectives. Many lakes in the study area had never been investigated limnologically before the initiation of the RANN program at the Biological Station.

The most detailed and lengthy series of limnological data are available for Douglas Lake. Records of Welch, Eggleton, and others date back to 1911. The bulk of these data have never been analyzed to detect long term trends in changes in water quality. Analyses of these data are currently being conducted by RANN program staff. The only data in this series previously scrutinized was summer hypolimnetic oxygen deficits. Bazin and Saunders (1971) detected a slow but prolonged change in the eutrophication of Douglas Lake (*figure 6*). They sur-

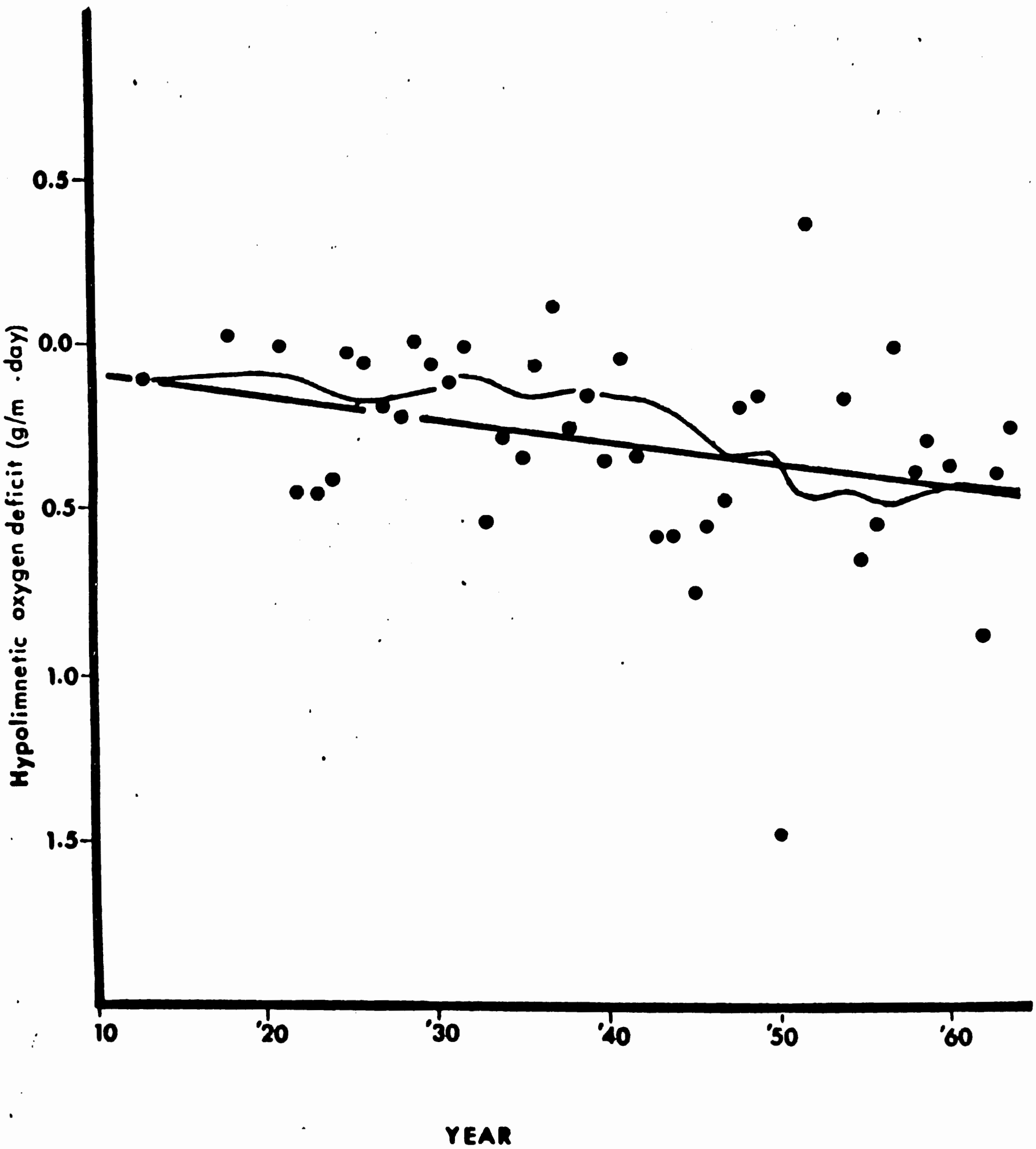

FIGURE 6 ANNUAL HYPOLIMNETIC OXYGEN DEFICIT IN DOUGLAS LAKE. THE STRAIGHT LINE REPRESENTS THE LINE OF BEST FIT BY LINEAR REGRESSION. THE SMOOTH CURVE REPRESENTS AN EXPONENTIALLY SMOOTHED ONE-YEAR FORECAST WITH A=0.05 (from Bazin and Saunders 1971).

mised that (the) "...rate of increase in hypolimnetic oxygen depletion is too rapid to reflect natural eutrophication of Douglas Lake. Therefore, if eutrophication has occurred, it must be the result of human effects". They concluded that the massive deforestation which occurred in the area from 1879 through 1920 accelerated nutrient inputs into the lake from its watershed. The continued trend of increasing hypolimnetic oxygen deficits in more recent years is more difficult to explain (Bazin and Saunders 1971). It is the purpose of one phase of the RANN program to use diatoms in Douglas Lake sediments as paleolimnological indicators in order to better understand recent changes in lake history (see next section).

Vincent Lake is another water body studied extensively by personnel at the University of Michigan Biological Station. Welch (1938a) called Vincent Lake a retrograding bog. During the early 1920's, this lake was a typical northern bog lake with brown stained, acidic (pH of about 4.3) water surrounded by a mat of Sphagnum and other bog plants. The pH of Vincent Lake suddenly increased to about 6 in 1925, presumably due to the effects of deforestation and a lowering of the ground water table. The increase in the alkaline nature of the lake has continued. Values for pH of near neutrality were reached in 1945 and have continued to the present. Typical bog vegetation has disappeared from the periphery of the lake.

Slight but possibly significant increases in pH, alkalinity, and conductivity have been noted in some lakes in the study area. These trends may indicate an increase in productivity of these water bodies. Specific conductance in Munro

Lake has risen from 175 μmhos/cm in 1945 to over 200 μmhos/cm in 1974. Alkalinity has increased in Cochran Lake from 55 mg/ℓ in 1945 to 68 mg/ℓ in 1974. Likewise, pH has risen from 8.0 to 8.7 in the same time period. Alkalinity and pH have risen similarly in Weber Lake during the past three decades. Such trends on these lakes and others are currently being analyzed more riogorously by RANN program staff at the Biological Station.

<u>Paleolimnological Indicators of Change</u>

The technique of lake coring is an established one which has been used to reconstruct the history of bodies of water. Only in the past few years has this paleolimnological technique been used to interpret the recent history of lakes. Our use of lake coring is to establish the diatom component of the algal assemblages of the recent past, approximately 150 years. Our initial investigation is focused on Douglas Lake. Core samples obtained from South Fishtail Bay of the lake cover a time interval starting with the present and ending with a short period prior to Caucasian man's settlement in the area. This will allow us to establish the status of the lake prior to man's disturbance of the forest and its subsequent response, including response to events such as development.

Two cores have been selected from five taken for subsamples for pollen and diatom analysis. A series of pollen preparations are being examined for correlation of the depth (= time) intervals with known terrestrial events. Approximately 1500 diatom preparations have been made and are being examined for 1) floristic composition and 2) population assemblage.

The floral list for Douglas Lake exceeds 300 diatom taxa at present and approximately one-third of the population analysis has been completed.

With a physical one-fourth of the core having been examined, we have found that 28 taxa comprise anywhere from 89 to 96 percent of the assemblages (*Table 6*). The assemblage at the surface is dominated by eight taxa (1.0%), two of which are major contributors (10.0%) and six of which are minor contributors (10.0%) (*figure 7*). The two major dominants are *Melosira granulata gamma status* (#21) and *Fragilaria crotonensis* (#16), which make up 52.9 to 69.8 percent of the assemblage. The six minor dominants make up 26.2 to 36.1 percent of the assemblage and are *Cyclotella michiganiana* (#9), *C. stelligera* (#11), *Asterionella formosa* (#5), *Tabellaria fenestrata* (#28), *Synedra ulna var. chaseana* (#27), and *Melosira granulata alpha status* (#20).

Two of the minor dominants are noteworthy: *C. stelligera* and *M. granulata alpha status*. These two taxa are forms frequently associated with eutrophic waters (Cholnoky 1968 and Huber-Pestalozzi 1942). Both taxa are abundant at the surface of the Douglas Lake core and decrease in frequency as older levels are examined (*figure 7*). *Melosira granulata alpha status* has disappeared from the count and returned only in small amounts (0.03%). The other minor dominants (and major dominants) are, for the most part, eurytopic taxa with exceptions being *C. michiganiana* and *S. ulna var. chaseana*.

TABLE 6 SPECIES COMPOSITION OF PREDOMINANT DIATOMS IN THE UPPER ONE-THIRD OF A SEDIMENT CORE FROM SOUTH FISHTAIL BAY, DOUGLAS LAKE

TAXON

1. *Achnanthes biasolettiana*
2. *A. linearis*
3. *A. minutissima*
4. *Amphora perpusilla*
5. *Asterionella formosa*
6. *Cyclotella comta*
7. *C. glomerata*
8. *C. kutzingiana*
9. *C. michiganiana*
10. *C. operculata*
11. *C. stelligera*
12. *Cymbella microcephala*
13. *Fragilaria brevistriata*
14. *F. construens*
15. *F. construens var. minuta*
16. *F. crotonensis*
17. *F. pinnata*
18. *Gomphonema intricatum var. pumila*
19. *Mastigloia smithii var. lacustris*
20. *Melosira granulata* α-*status*
21. *M. granulata* γ-*status*
22. *Navicula radiosa var. tenella*
23. *Stephanodiscus minutus*
24. *S. niagarae*
25. *Synedra delicatissima*
26. *S. filiformia var. exilis*
27. *S. ulna var. chaseana*
28. *Tabellaria fenestrata*

According to Stoermer and Yang (1970) *S. ulna var. chaseana* is dominant in the offshore oligotrophic waters of Lake Michigan. This species is not numerically abundant in the nutrient-rich waters of Green Bay of Lake Michigan, and its distribution outside of the Great Lakes area is little known. According to available data from Douglas Lake, its occurence is stable throughout the levels examined. *Cyclotella michiganiana* is recorded as being dominant in the offshore waters of Lake Michigan and often becomes abundant in areas receiving some degree of nutrient enrichment (Stoermer and Yang 1970). *Cyclotella michiganiana* is the dominant *Cyclotella* species in Douglas Lake at the present time and has been throughout the time interval examined so far (*figure 7*).

On the basis of this data one may conclude that Douglas Lake has only recently (approximately 40 years) started to show a significant increase in pollution-tolerant forms. Also, from the limited data available, we surmise that the lake is undergoing a trophic change at the present time. We hypothesize that although removal of the pine forest may have had some influence on the lake trophic level, the response of the algal flora "points a finger" at man's recreational development of the lake.

When complete, the population analysis will establish what the lake was like prior to Caucasian man's "civilized" activities. It will also show what effect, if any, the cutting of the forest and the alteration of the drainage systems had on the lake. Finally, it will show how the lake responded fol-

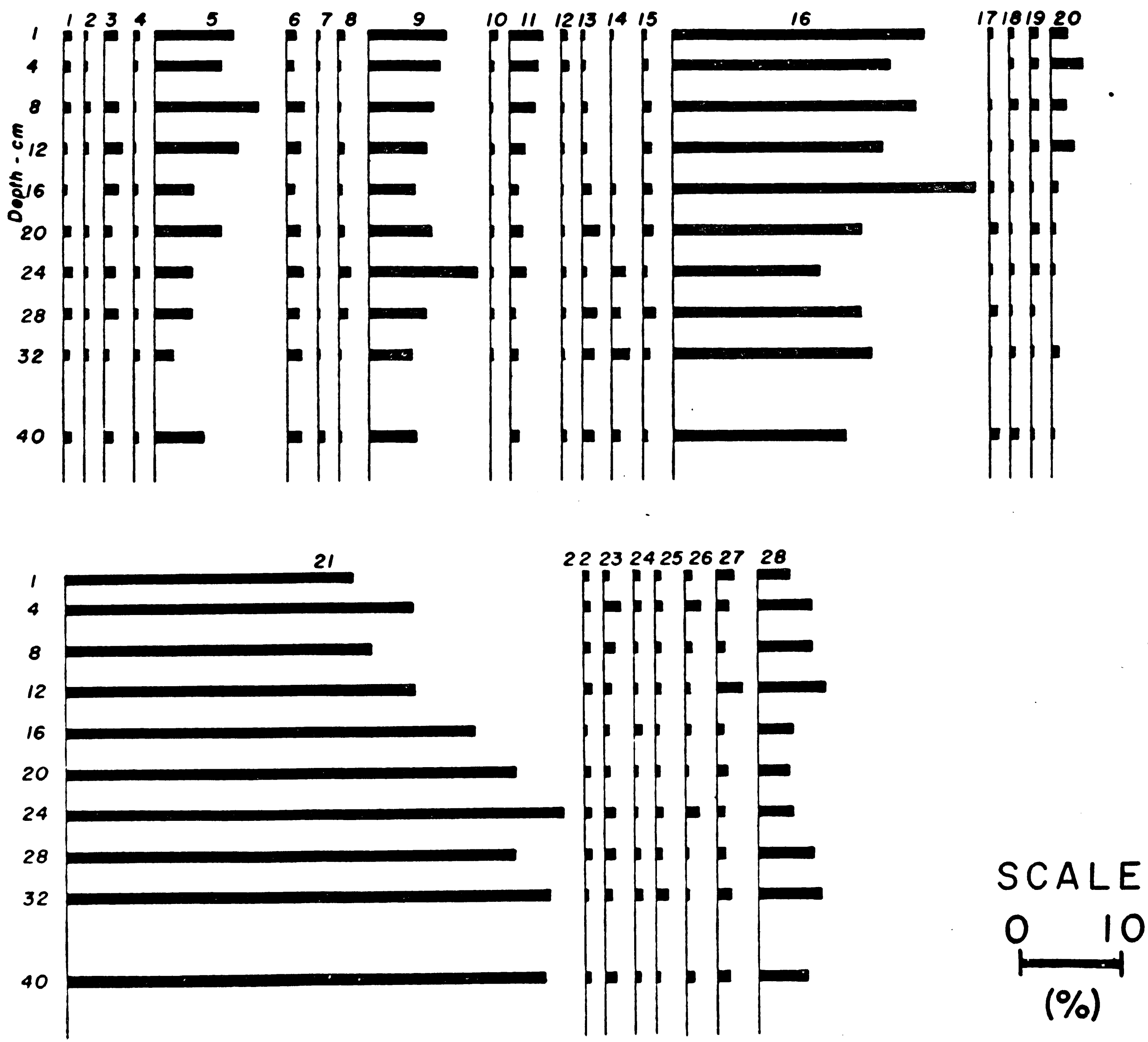

FIGURE 7 CONPOSITION (IN PERCENT) OF SELECTED DIATOM TAXA IN THE UPPER THIRD OF A SEDIMENT CORE FROM SOUTH FISHTAIL BAY, DOUGLAS LAKE. NUMBERS REFER TO SPECIFIC DIATOM TAXA AS LISTED IN TABLE 6.

lowing the disturbance and the subsequent commercial development. The information generated can be utilized by natural resource management agencies in establishing guidelines for lake development on the basis of the history of the lake's response to the past events along its shore and drainage area.

Lake Ranking

In order to specify the water quality state of a lake, it is necessary to describe the lake in terms of a large number of limnological parameters. Inasmuch as ranking is a linear ordination, the dimensionality of the information contained in a set of parameters must be reduced to a linear approximation to allow ranking of lakes by water quality. Such a reduction involves understanding the correlative structure of the parameters, either on a determinate or statistical level. In our initial efforts to quantitatively rank lakes by their water quality characteristics, we have collated a portion of our data base and employed it in a multivariate statistical analysis modeled after Shannon and Brezonik (1972).

The analytical techniques require each lake to be described with a singular value for each parameter. Such singular values were derived, but with an undetermined loss of information. For example, a singular depth-corrected value derived from a vertical profile of measurements for dissolved oxygen may be less ecologically meaningful than a simple binary statement of whether or not hypolimnetic oxygen depletion exists.

Light penetration data as it varies with depth can be explained by a monotonic function with constant slope, k. In general, however, depth cannot be included in the information content of a singular value because the vertical distribution of few limnological parameters can be described by a monotonic function. However, for purposes of this analysis, quantitative singular depth-corrected values for the parameters appear to carry sufficient information.

It was not possible to include the complete set of parameters being measured for each lake. Only those parameters for which data had been incorporated in the computer storage and retrieval system could be implemented at this time. Furthermore, only one year of seasonal and yearly average values could be included. Prior to the expiration of the current grant period, all the data gathered during two years of complete seasonal sampling will be available for analysis. The preliminary nature of the results must be noted in assessing the progress of the analytical efforts to date.

No *a priori* assumption can be made regarding which seasonal data set will contain the most useful information for lake ranking purposes. Seasonal idiosyncrasies, such as algal blooms or ice melt dilution, reduce the already low probability that one measurement of a parameter will be a representative value. Hence the data set containing yearly averaged values for the parameters is regarded to be the most representative quantitative description of present water quality. Performing the analyses on each of the seasonal data sets was deemed necessary for the purpose of elucidating correlative structure among those lakes and parameters which were not sampled consistently from season to season. These data also permit us to investigate seasonally time-varying relationships among the parameters, and to explore relative seasonal information content.

Each of the analytical programs discussed here computes and uses the correlation matrix as a base for its particular computational procedure. In addition to their transparent role in the formal hypothesis generating routines, correlation coefficients can also be valuable in directing the water quality investigator to specific problems. For example, acid bog waters are generally known to be low in productivity. Using such an assumption, one might expect positive correlation between chlorophyll a and pH in such lakes. However, we obtained a significant negative correlation between these two parameters in brown-stained bog waters. Either the bog lakes in the study area are supporting a large biomass of phytoplankton in very soft waters, or we may be obtaining positive interference in the fluorometric measurement of chlorophyll a by a normal constituent of these bog waters. We are currently investigating this problem.

The first three principal components calculated from the YEARLY data set are described in Table 4. Those first three principal components explain nearly 75 percent of the variance in that data set, as evidenced by an examination of the eigenvector coefficients. The most important parameters (coefficients greater than 0.3) for each component are as follows:

FIRST component - 40% of variance	SECOND component - 13% of variance
Magnesium	Temperature
pH	Dissolved Oxygen
Alkalinity	Potassium
Conductivity	Total Phosphorus
Calcium	Soluble Phosphorus

THIRD component - 12% of variance

Secchi Depth
Nitrates
Color

An underlying concept described by each component is suggested by its particular combination of predominant variables. For example, the association of variables used in deriving values for the first component suggests that such values lie along a "Hardness" axis. Similarly, the second and third components can be regarded to be "Lake Metabolism" and "Bog - ness" measures, respectively.

It can be seen, however, that each of the three components separately do not explain sufficient variance in the data for any one to be used to describe the present water quality of the lakes in the study group. This suggests that the results of the clustering analyses will be useful in formulating a specific multidimensional model to be used in rating lake water quality.

The dendrograms in figures 8 through 12 were derived using our seasonal and yearly data sets as input. For consistency of presentation, the lakes are clustered at the eight-group level, with each group separated vertically by a small space. The polarity of the junctions are such that in the two groups being paired, the one having the greatest within-group similarity lies above the other. If only one lake is contained in a group, it lies below the junction.

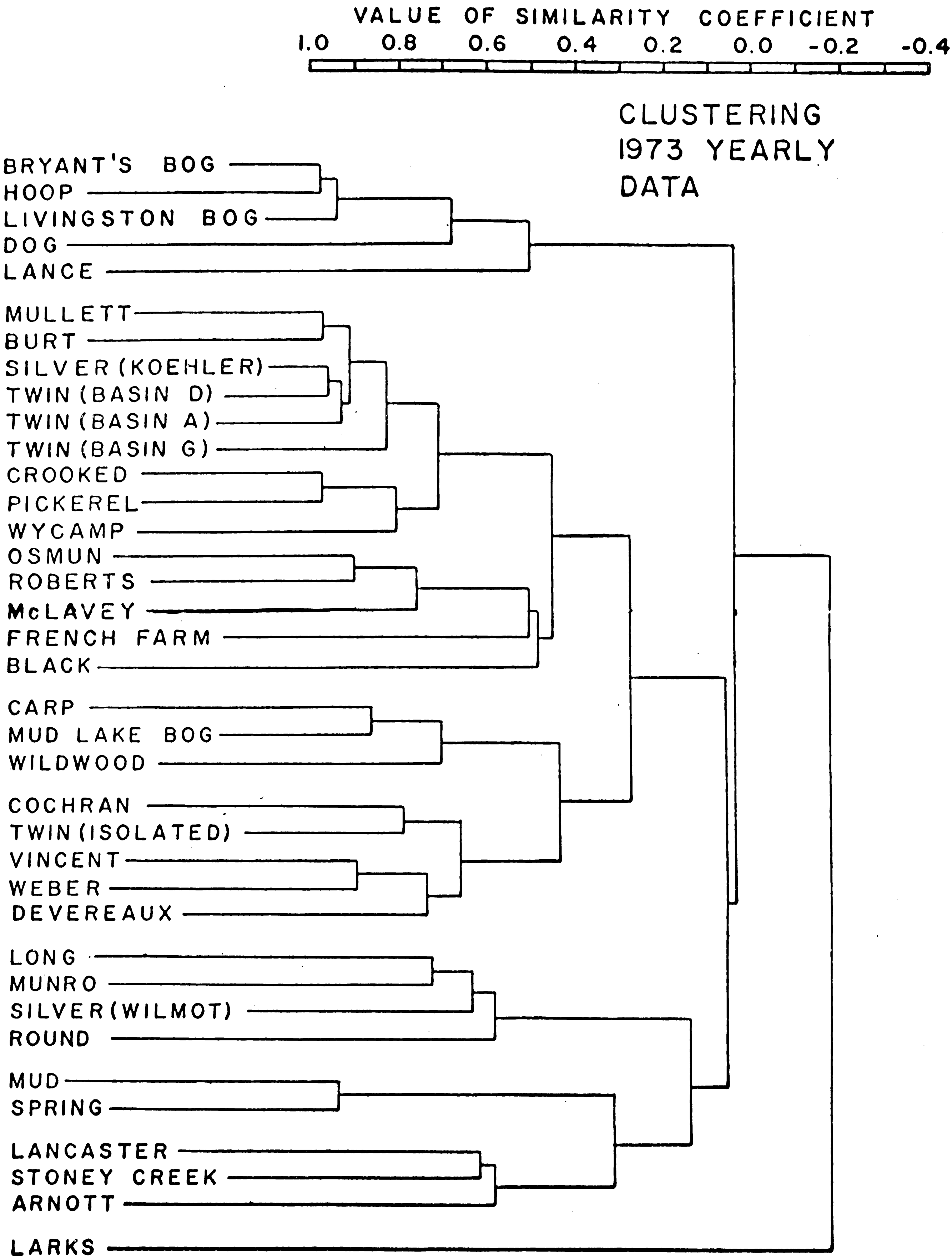

FIGURE 8 CLUSTER ANALYSIS OF LAKES BASED UPON YEARLY DATA

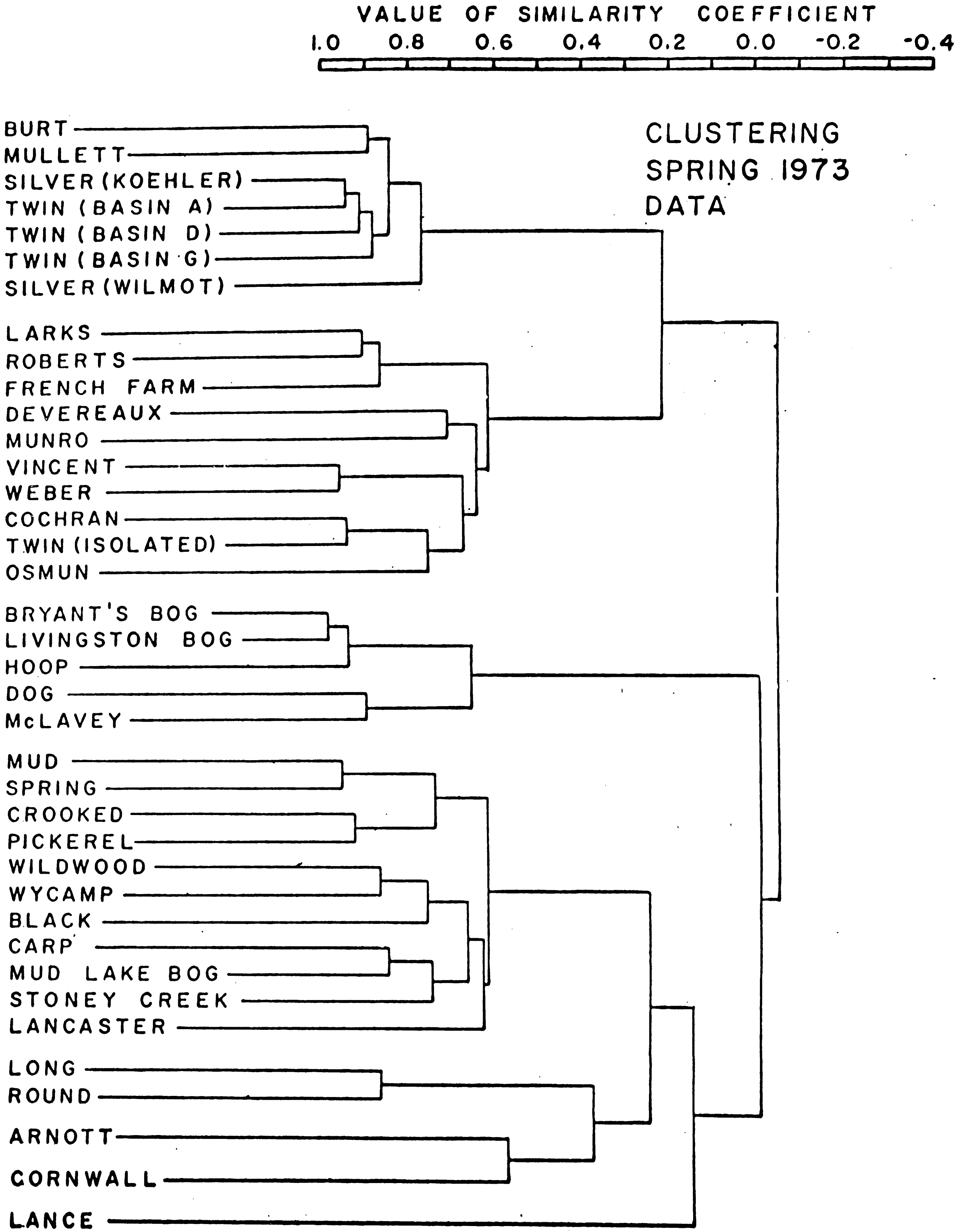

FIGURE 9 CLUSTER ANALYSIS OF LAKES BASED UPON SPRING DATA

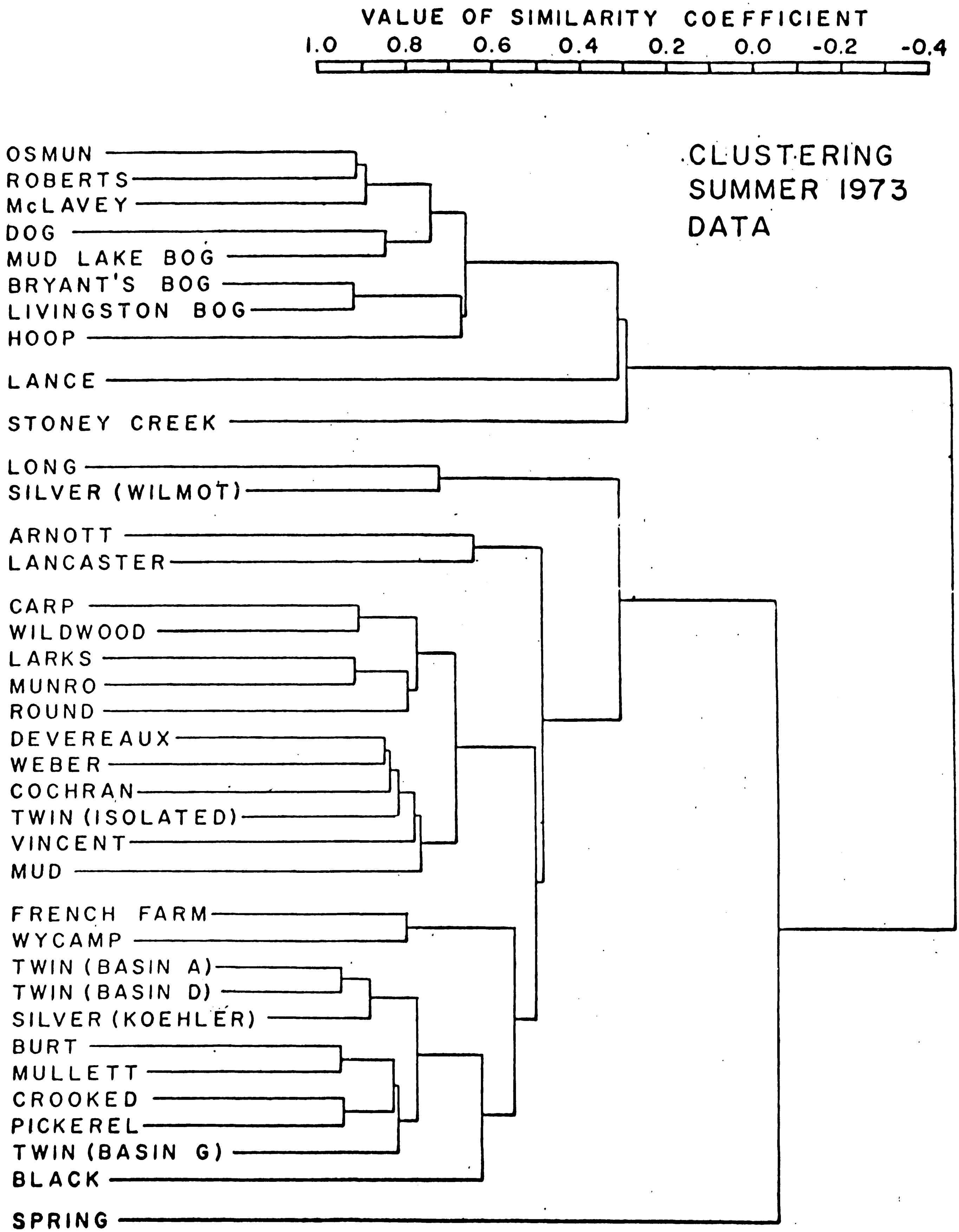

FIGURE 10 CLUSTER ANALYSIS OF LAKES BASED UPON SUMMER DATA

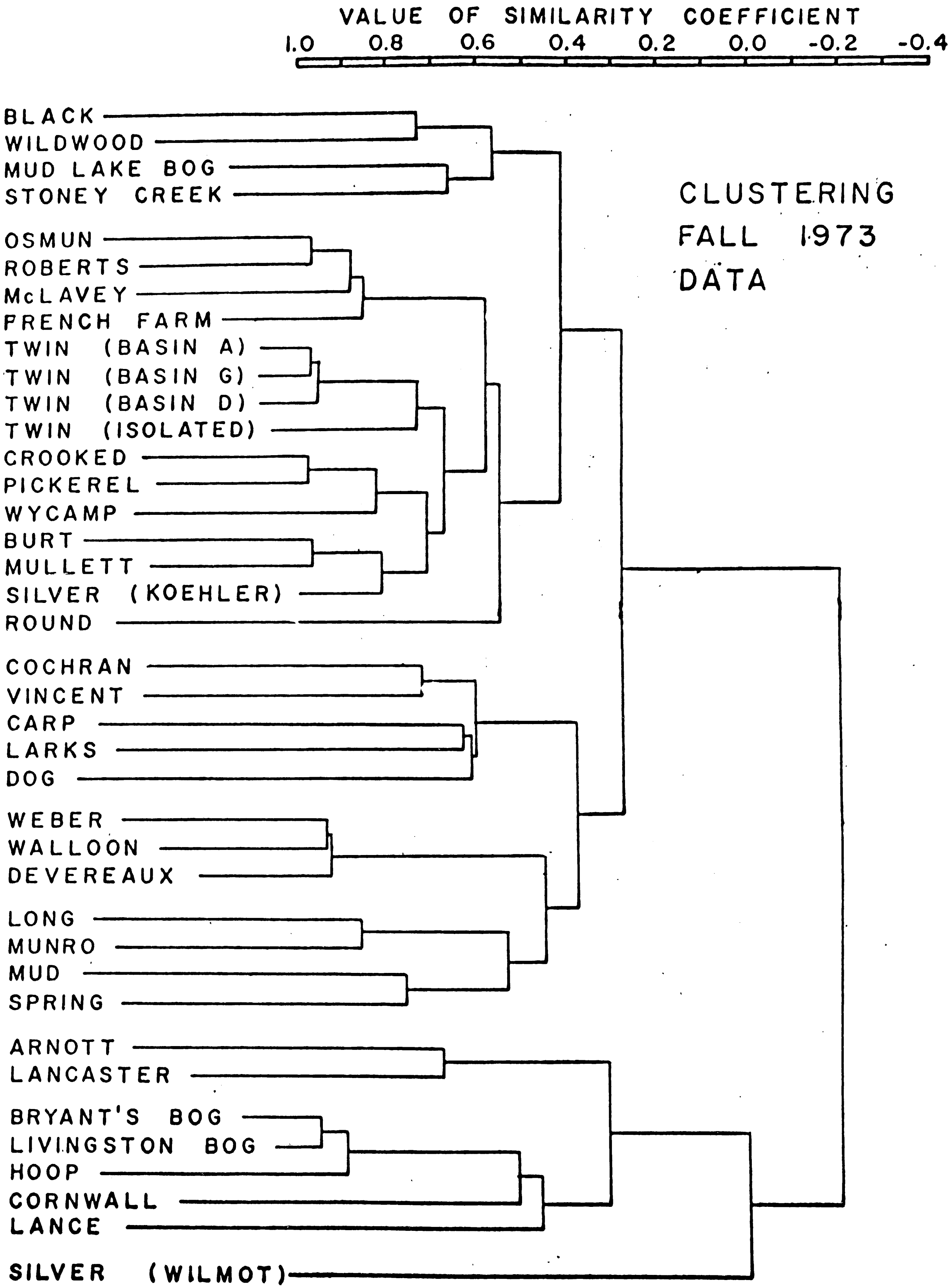

FIGURE 11 CLUSTER ANALYSIS OF LAKES BASED UPON FALL DATA

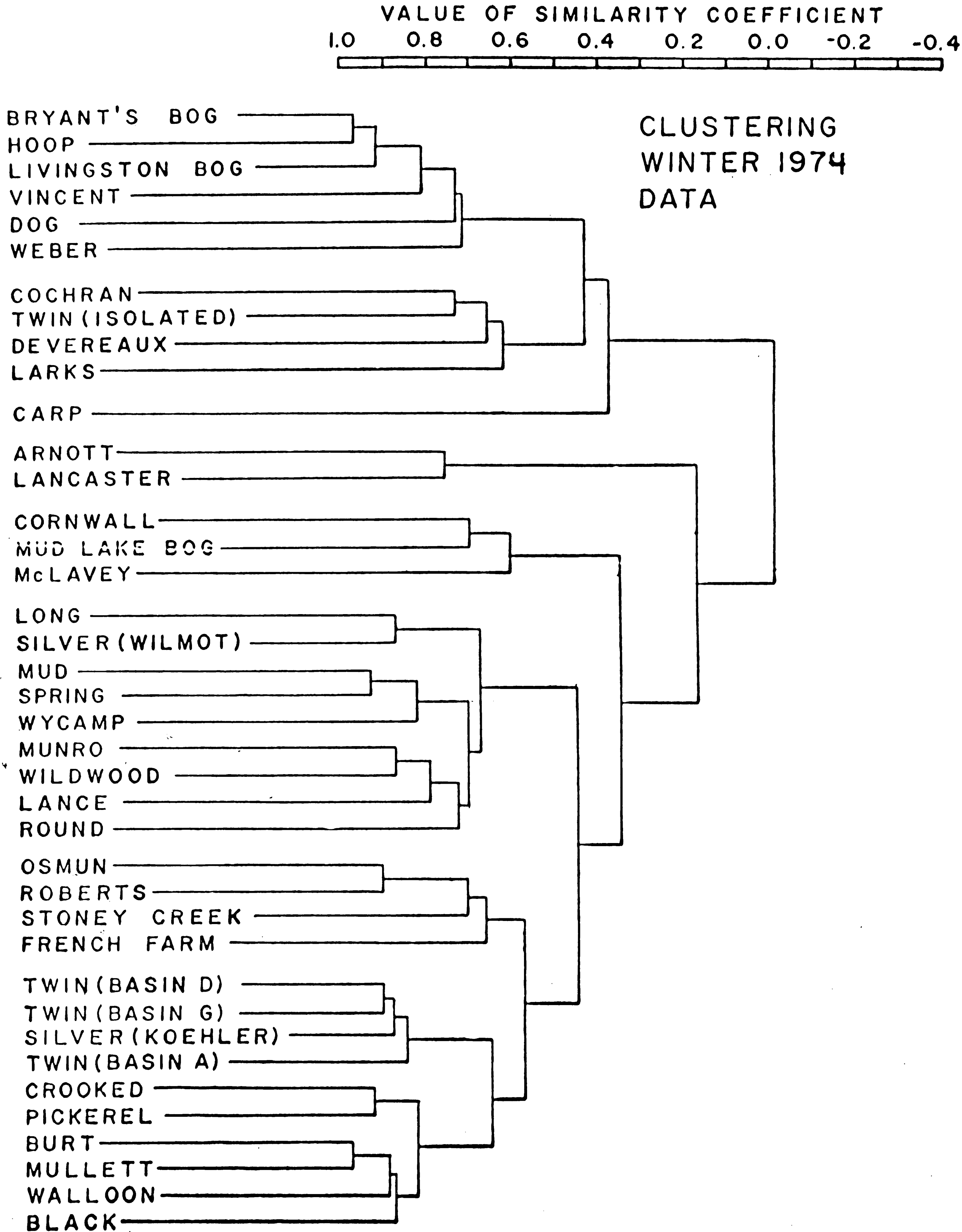

FIGURE 12 CLUSTER ANALYSIS OF LAKES BASED UPON WINTER DATA

The sensitivity of the clustering routine to variance in the data set becomes apparent (*figures 8 through 12*). Associations at the eight-group level are not equivalent. That the clustering routine may yield equivalent groupings at some level, regardless of season, is suggested by the observation that certain groupings, which occur at very high values for the similarity coefficient, can be found in each of the dendrograms. The brown-stained lakes (Livingston, Bryant's, Hoop and Lance) generally cluster together independently of the seasonal nature of the data. Likewise, the several basins of Twin Lakes associate well. Mud Lake and Spring Lake, which could be considered to be two basins in one lake, also group together consistently. Burt and Mullett also group together, as do Crooked and Pickerel Lakes. Since these groups of lakes are proximal to one another in the Inland Water Route, such groupings appear to have ecological significance. Furthermore, Crooked, Pickerel, Burt and Mullett Lakes cluster together at a higher level consistently from season to season.

Although these intuitively sound groupings appear in all dendrograms, the other lakes associated with such a group generally do not remain consistent, nor do such groups have equivalent within-group similarity from season to season. It is important to note that based upon yearly data (*figure 8*), the grouping of lakes corresponded most closely to intuitive ranking of these lakes by limnologists involved in the NSF-RANN program. Further analysis is therefore required to determine at which group level, if any, a clustering routine will generate equivalent clustering structures from data sets compiled during different seasons. The first step in that effort is to establish the ecological meaningfulness of the groupings resulting from the particular clustering algorithm used.

When the similarity coefficient is high, lake groupings have occurred which agree with groupings that were initially perceived by experienced observers at the Biological Station. At lower values of the similarity, a comparison between analytically derived clusters and those perceived by an experienced observer fail, due to the observer's inability to assess objectively and *in toto* the complete range of parameters involved. However, if an observer was able to define and implement his intuitive clustering algorithm using many parameters, such a comparison could be made, with the assumption that the closer an analytically derived structure agrees with the experienced observer's intuition, the more ecologically significant the result of the analysis.

A concise representation of each lake's position in hyper-dimensional space might help an observer in assessing the similarity of a group of lakes, but for more than three dimensions a construct is physically and conceptually intractable. Consequently, we performed a cluster analysis of lakes represented in the YEARLY data set using three principal components as descriptive parameters *(figure 13)*. The associations at the eight-group level were color-coded on a physical model constructed in three dimensions *(figure 14)*. An examination of the physical model shows that the clustering routine does not form spheroidal clusters, probably as a consequence of the particular new group location procedures used in the routine. Another consequence of this procedure

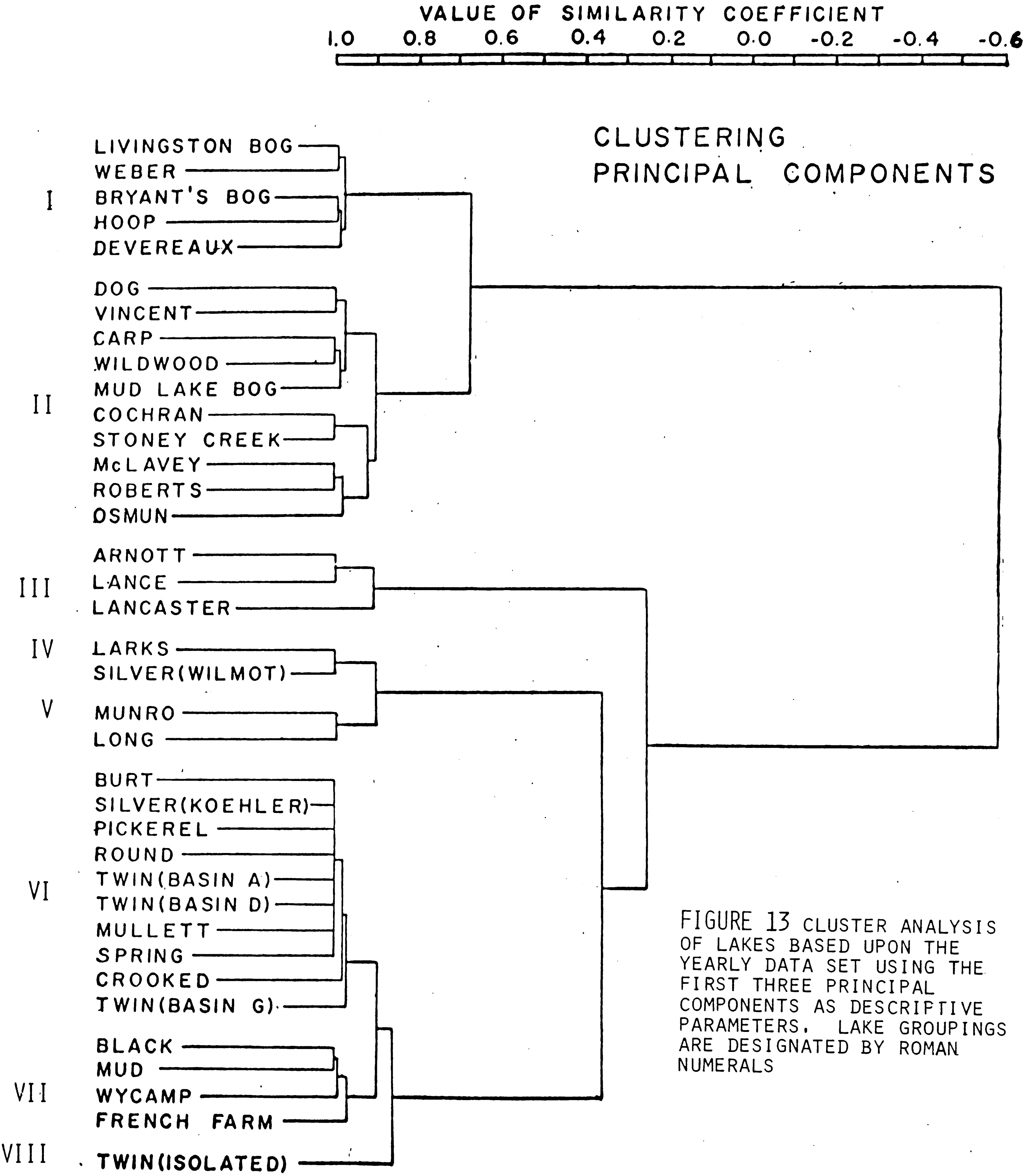

FIGURE 13 CLUSTER ANALYSIS OF LAKES BASED UPON THE YEARLY DATA SET USING THE FIRST THREE PRINCIPAL COMPONENTS AS DESCRIPTIVE PARAMETERS. LAKE GROUPINGS ARE DESIGNATED BY ROMAN NUMERALS

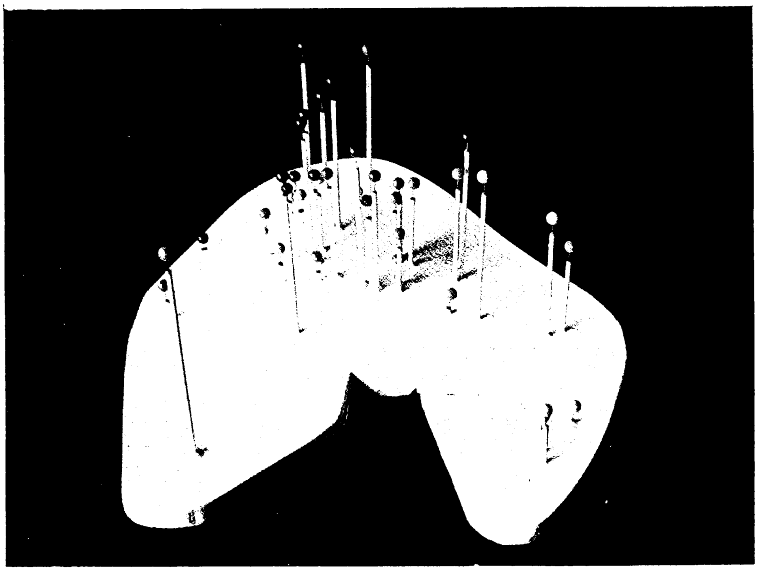

FIGURE 14. A PHYSICAL MODEL OF LAKE POSITION AS DESCRIBED BY VALUES FOR THE FIRST THREE PRINCIPAL COMPONENTS. GROUPS OF LAKES, AS FOUND IN FIGURE 13, ARE COLOR CODED AS FOLLOWS: GROUP I - LIGHT BLUE; II - LIGHT GREEN; III - YELLOW; IV - LAVENDER; V - DARK BLUE; VI - RED; VII - PINK; AND VIII - DARK GREEN.

is that once a lake is included in a group, its position in the p-dimensional space is not retained, and the lake is not available for comparing to other groups as they develop. Work will have to be done to improve the algorithm used by the clustering routine so that alternative groupings can be compared and maximized.

In summary, it has been shown that a limited data base has been developed and applied in an analytical program initially modeled after an approach used by Shannon and Brezonik (1972) in a somewhat similar ecological study of Florida lakes. The eventual goal of our analyses is to rank lakes on the basis of present water quality. The results of the analysis to date have been presented, with a discussion of their implications for the continuing effort. The testing of methods and closer definition of the orientation of the analytical approach can be regarded as completion of a major step necessary to the success of the RANN program at the University of Michigan Biological Station.

Early indicators of water quality change

We are encouraged by our preliminary results in ranking lakes based upon present water quality characteristics. The next step, and a most important one, will be to incorporate rate process information into our ranking scheme. In order to rank lakes in terms of their sensitivity to change, we must have information on rates of change. However, data on limnological rate processes is difficult to obtain. Agencies responsible for water quality monitoring rarely have the time, manpower, or funds to conduct even simple experiments on primary productivity rates in a large number of lakes. Another approach, and one that is more applicable to a water quality monitoring agency, is to establish early indicators of lake change in biological community structure. Since organisms can be considered integrators of the environment in which they live, they should be good indicators of changing environmental conditions. However, our current knowledge of indicator species has not been useful in allowing us to detect early changes in water quality. Obnoxious growths of the blue-green alga, *Anaebena*, or the benthic green alga, *Cladophora*, are certainly indicators of advanced eutrophy, but do not act as early-warning signals. It is our contention that indicators in biological community structure may be more valuable in detecting early signs of change in water quality. We are currently analyzing data on community structure of Protozoa, Rotifera and Crustacea for early indicators of change.

Protozoa

Investigations on various aspects of the colonization of artificial substrates (polyurethane foam) by freshwater protozoans during the period June 1972 through October 1974 were supported, in part, by funds from the NSF-RANN Grant awarded to the University of Michigan Biological Station. The work during this period was an exploration of invasion rate problems that had grown out of earlier studies. The first investigation using polyurethane foam substrates for these studies were undertaken during summer, 1967 by Cairns et al. (1969). The results of this work supported the MacArthur-Wilson Equilibrium Model, even though the number of protozoan species did not reach a true equilibrium in eight weeks. Failure to do so suggested that the eight week period during which the investigation was carried out was not long enough to allow equilibrium to be achieved.

As a follow-up investigation, Cairns, Dickson and Yongue (1971) began their study approximately seven weeks earlier (immediately following ice-off) in order to allow additional time for equilibrium to be reached. This study showed that the number of species found in substrates between 46 and 95 days old oscillated about a mean of 19.76 species. This mean was 33% lower than the mean for 37 to 43 day-old units (polyurethane foam substrates) of the previous study.

Those results lead to a study of the relationship between number of protozoan species and duration of habitat immersion (Cairns, Yongue and Boatin 1973). Polyurethane foam units (substrates) were placed at weekly intervals at the surface of the epilimnion of Douglas Lake from 11 July 1970 to 8 August 1970. At the time of the first sampling on 14 August 1970, units had been immersed 32, 25, 18, 11 and 4 days, respectively. A record sampling was carried out on 27 September 1970. The average number of species during the first sampling ranged between an average of 39.5 and 63.5 species. At the second sampling the number of species ranged between 28 and 34 species. In both cases the indication was that the colonization rate as well as number of colonizing species had shifted over the previous years.

A second investigation was conducted during summer, 1970 to determine the relation between colonization in the benthic area and colonization at the surface. The results showed that colonization was significant as early as 3.5 days (22 species average) and was relatively stable from 14 days on (46.5 species average). It also indicated that numbers and kinds of species that colonized polyurethane substrates were very much alike both at the surface and in the benthic area. Those results suggested that the rate of colonization might be much the same both vertically and horizontially throughout the lake.

No site-specific distortions were noted thus far, which indicates the method had considerable merit. The gradual increase in invasion rate over the study period suggests a profound change is occuring in the lake, the most likely explanation for which is eutrophication.

The investigation during summer, 1973 is covered in Cairns and Yongue (1974). Much more extensive data was obtained during summer, 1974 and is currently being analyzed. The methods and procedures were the same as in the 1973 studies, but the distribution of the substrates was designed to detect an epicenter for the eutrophication process (e.g. septic tank drainage) and its effects on Protozoan colonization rate.

The first study in this series to receive NSF-RANN support was initiated during the summer, 1972. This study was undertaken to investigate protozoan colonization rates at different depths in Douglas Lake (Cairns and Yongue 1974). Three series of polyurethane substrates were placed in the lake. Two of these were anchored in 6.5 m of water and the third in 20.5 m of water. The first two series contained substrates at the surface and at depths of 1.5, 3.0, 4.5 and 6.0 m. The third series had substrates suspended at depths of 6, 11, 12, 13, 14, 15, 18 and 20 m. Sampling was carried out weekly during the summer period up to 10 August. Sampling of Series II included 20 October which was after the fall overturn, and again on 20 June 1973. Series III was also sampled on 20 October. No clear differences in pattern related to depth of colonization or species diversity was evident in the surface to 6 m substrates. During the summer stagnation period, the number of species colonizing deeply submerged substrates (11 to 20 m) was lower than that of those in the epilimnion, but after the overturn the numbers were quite similar. Series III disappeared, presumably due to vandalism, before spring, 1973. However, Series II which remained intact showed an evident increase in number of species at a 20 June 1973 sampling. This suggested that the rate of colonization in this lake was, indeed, climbing.

Before the 1972 summer session, one of our colleagues (B. C. Parker) posed the question that substrate color might have an effect on colonization rates. During the 1972 session, substrates in colors, ranging from red to purple, including white, were placed in the lake and sampled weekly. No difference was detected. These substrates remained in the lake through the 1974 summer session . Samplings were carried out during 1973 and 1974, so data was gathered on substrates that had remained in the lake for one and two years. This data is being analyzed with similar data from other studies.

During the 1973 summer session, sets of polyurethane substrates were distributed into twelve widely scattered sites around the perimeter of Douglas Lake. The sites chosen represented as diverse habitat types as could be found in the lake. Weekly samplings were made. This study was carried out to further test the suggestion that the whole lake is represented by a common protozoan community structure. This data was organized and is now being analyzed for overlaps of species through space, time and taxonomy.

In addition, sets of substrates were sampled daily for 14 days so that the rate of colonization during this period could be determined. It had been previously established that stable communities were developed in 14 days. This was repeated in 1974 and the data for both periods is being amassed and analyzed.

Planktonic Rotifera

Rotifers in lakes belong to the Class Monogonata and Class Bdelloidea. Both groups have been studied rather extensively in Europe, although the monogonates are better known. The monogonates exist in a variety of habitats from terrestrial mosses to the smallest temporary ponds to the largest lakes. They are found throughout the lacustrine ecosystem including the limnetic zone, among littoral vegetation and in psammolittoral habitats. The Bdelloidea also exist in a diversity of habitats. However, they are predominately benthic and, therefore, are absent from the limnetic zone of lakes. They are common bottom dwellers in lakes and are only occasionally collected in plankton samples. Rotifers obtained in collections from the limnetic zone normally include both eulimnetic and eulittoral species. Littoral forms are collected most often from shallow, weedy lakes, but occasionally they occur in net tows taken from the limnetic zone of large, deep lakes. Some species, such as *Monostyla lunaris* and *Brachionus* spp., appear adapted to both littoral and planktonic existence.

Basic descriptive information on the species composition and distribution of planktonic rotifers of inland lakes throughout North America is sorely lacking. Rotifers have been neglected in most zooplankton investigations because of difficult and uncertain taxonomic problems. In addition, inherent problems in identification exist due to their small size (100 to 300 μ long). Contraction and distortion of the body after fixation with common preservatives often makes identification to the species level exceedingly difficult if not impossible. Fortunately, more recent literature on rotifer taxonomy (Ahlstrom 1943; Carlin 1943; Voigt 1957; and Edmondson 1959) has clarified some basic problems in the identification of many common species and has been successfully utilized in two recent investigations on the Laurentian Great Lakes (Nauwerck 1972; Stemberger 1973).

The importance of rotifers in aquatic ecosystems should not be overlooked. Nauwerck (1972) has estimated that rotifer biomass may occasionally equal that of the crustacean zooplankton from his investigations in Lake Ontario. Hillbricht-Ilkowska (1967) noted rapid population turnover rates for *Keratella cochlearis* , and the same is undoubtedly true for other species as well. Consequently, at least certain species or groups of species have the capability to respond rapidly to environmental change, and therefore, should be useful as indicators of lake change.

Early studies on the rotifers in Michigan lakes were conducted by Jennings (1894, 1896, 1900 and 1904). He briefly listed 160 species of planktonic and littoral rotifers collected in a few inland lakes in the Grand Traverse Bay area and included records of rotifers from the Great Lakes region in general. Campbell (1941) did a thorough investigation on vertical distribution of rotifers. He recorded 29 species in the plankton of Douglas Lake, Cheboygan County. Beach (1960) recorded 34 species in a study of rotifers in the Ocqueoc River system, Presque Isle County. The most recent investigation on rotifers in Michigan was conducted by Prins and Davis (1966). They found 25 species in the Kalamazoo River while studying the effects of pollutants on rotifer abundance.

Since rotifers have been inadequately studied in North America, rotifer inventory will provide new information on the distribution of species in different lake types. Species that are restricted in their ecological requirements will be useful as indicators of lake trophic states. Consequently, these species will be valuable in the design of a functional lake ranking scheme presently in progress at the Biological Station. An analysis of species diversity will be made from these data to explore the value of the diversity index as an independent variable for use in our lake ranking endeavors. Furthermore, species association coefficients will be analyzed to determine any relationships of rotifer community structure to lake trophic conditions.

Our initial emphasis has focused on species composition of planktonic rotifers in the lakes of the Inland Water Route region. Species lists for most of the 38 lakes surveyed for rotifers have been completed for three sampling seasons. Analyses on samples from the fourth season (summer, 1973) are currently in progress. Over 110 species have been reported thus far. About 60 species are planktonic, while the rest are associated with littoral habitats (Table 7). Twenty-five of the linmetic species are new records for Michigan lakes.

Although our analyses are incomplete at this time, some significant patterns exist in species distribution with regard to water quality. The most promising indicator for oligotrophy is *Synchaeta asymmetrica*. This species was first reported for North America from Lake Michigan (Stemberger 1973). *Synchaeta lakowitziana* and *Notholca squamula* have been observed only in oligotrophic and mesotrophic lakes during winter months, but may also be found in the cold hypolimnetic waters of deep lakes during summer stratification. *Asplanchna herricki* has been found thus far only in mesotrophic lakes. No clear indicators of eutrophy are apparent at this time, although *Filinia longiseta* and *Brachionus* spp. may prove important species in eutrophic lakes during summer (Pejler 1957, Hakkari 1972). *Keratella ticinensis* and *Ploesoma lynceus* have consistently appeared only in acidic lakes and bogs. *Keratella ticinensis* is synonymous with *K. quadrata* var. *curvicornis* of Ahlstrom (1943) and may be a new North American record. *Keratella taurocephala*, another acidobiont, is also common in dystrophic lakes in the study area.

Polyarthra vulgaris and *Keratella cochlearis* were present in nearly every water body sampled. Other ubiquitous species were *P. remata*, *Synchaeta stylata*, *K. crassa*, *K. earlinae*,

TABLE 7 LIST OF ROTIFERS COLLECTED FROM 38 LAKES IN NORTHERN LOWER MICHIGAN

CLASS - Monogonata

ORDER - Ploima

FAMILY - Brachionidae
SUBFAMILY - Brachioninae

* *Anureopsis fissa* (Gosse)
* *A. fissa f. navicula* Rousselet
* *Brachionus quadridentatus* Hermann
* *B. angularis* Gosse
* *Euchlanis triguetra* Ehrbg.
* *E. meneta* Meyers
* *E. dilatata* Ehrbg.
* *E. oropha* Gosse
* *E. incisa* Carlin
Kellicottia bostoniensis (Rousselet)
K. longispina (Kellicott)
Keratella cochlearis (Gosse)
K. cochlearis f. tecta (Gosse)
× *K. crassa* Ahlstrom
K. earlinae Ahlstrom
K. hiemalis Carlin
K. quadrata (O. F. Müller)
× *K. serrulata* var. *curvicornis* Rylov
× *K. taurocephala* Myers
× *K. testudo* (Ehrbg.)
** *K. ticinensis* (Callerio)
* *Lophocharis salpina* (Ehrbg.)
* *Macrochaeta subquadratus* Perty
* *Mytilina ventralis* (Ehrbg.)
* *M. ventralis* var. *brevispina* Ehrbg.
* *M. ventralis* var. *macrocantha* (Gosse)
Notholca acuminata (Ehrbg.)
N. foliacea (Ehrbg.)
N. labis Gosse
× *N. squamula* (O. F. Müller)
N. striata (O. F. Müller)
* *Platyias patulus* (O. F. Müller)
* *Trichotria pocillum* O. F. Müller
* *T. tetractis* (Ehrbg.)

SUBFAMILY - Colurinae

* *Lepadella acuminata* (Ehrbg.)
* *L. erhrenbergi* (Perty)
* *Lepadella* spp.
* *Squatinella tridentata* (Fresenius)

(continued)

FAMILY - Lecanidae

* *Lecane luna* (O. F. Müller)
* *L. flexilis* (Gosse)
* *L. leotina* (Turner)
* *L. tudicola* Harring and Myers
* *L. ploenensis* (Voigt)
* *L. ohioensis* (Herrick)
* *L. intrasinuata* (Olofsson)
* *Lecane* spp.
Monostyla lunaris Ehrbg.
* *M. quadridentata* Ehrbg.
* *M. bulla* Gosse
* *M. crenata* Harring
* *M. hamata* Stoke
* *Monostyla* spp.

FAMILY - Notommatidae

* *Cephalodella tenuiseta* var. *americana* Donner
* *Cephalodella* spp.

FAMILY - Trichocercidae

* *Trichocerca bicristatus* (Gosse)
* *T. birostris* (Minkiwicz)
* *T. capucina* (Wierzejski and Zacharias)
T. cylindrica (Imhof)
* *T. inermis* ? (Linder)
* *T. lata* (Jennings)
* *T. longiseta* (Shrank)
* *T. mucosa* (Stokes)
× *T. multicrinis* (Kellicott)
* *T. parvula* (Carlin)
T. porcellus (Gosse)
* *T. pusilla* (Jennings)
* *T. relicta* ? Donner
× *T. rousseleti* (Voigt)
× *T. similis* (Wierzejski)
* *T. tenuior* (Gosse)
* *Trichocerca* spp.

FAMILY - Gastropidae

× *Ascomorpha agilis* var. *americana* de Beauchamp
A. ecuadis Perty
× *A. saltans* Bartch
Chromogaster ovalis (Bergandal)
Gastropus hyptopus (Ehrbg.)
G. stylifer Imhof

FAMILY - Tylotrochidae

Tylotrocha monopus (Jennings)

(continued)

FAMILY - Asplanchnidae

× *Asplanchna brightwelli* Gosse
A. herricki de Guerne
× *A. girodi* de Guerne
A. priodonta Gosse
× *A. sieboldi* (Leydig)

FAMILY - Synchaetidae

Ploesoma hudsoni (Imhof)
P. lenticulare Herrick
P. lynceus (Ehrbg.)
P. truncatum (Levander)
× *Polyarthra dolichoptera* Idelson
P. euryptera Wierzejski
× *P. major* Burckhardt
× *P. remata* Skorikov
P. vulgaris Carlin
** *Synchaeta asymmetrica* Koch-Althaus
× *S. lakowitziana* Lucks
× *S. oblonga* Ehrbg.
S. pectinata Ehrbg.
S. stylata Wierzejski
S. tremula (O. F. Müller)
Synchaeta sp.

ORDER - Flosculariacea

FAMILY - Testudinellidae

Filinia longiseta (Ehrbg.)
× *Filinia terminalis* (Plate)
× *Pompholyx sulcata* Hudson
* *Testudinella patina f. trilobata* Anderson
* *Testudinella* spp.

FAMILY - Hexarthridae

Hexarthra mira (Hudson)

FAMILY - Flosculariidae

× *Ptygura libera* Meyers

FAMILY - Conochilidae

× *Conochiloides coenobasis* Skorikov
C. dossuarius (Hudson)
× *C. natan* (Seligo)
Conochilus unicornis Rousselet
C. hippocrepis (Shrank)

(continued)

ORDER - Collothecacea

FAMILY - Collothecidae

Collotheca mutabilis (Hudson)
C. pelagica Rousselet
Collotheca spp.

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*littoral species

ˣpreviously not recorded in Michigan

**new North American record

Kellicottia longispina, *Conochilus unicornis*, *Collotheca mutabilis*, *Asplancha priodonta* and *Gastropus stylifer*. These species are not useful indicators of lake trophic states since they are found in a widerange of environmental conditions. They are mentioned here because they contribute significantly to the biomass of zooplankton in the lakes under investigation.

Rotifers currently are not utilized as water quality indicators in North American lakes. However, many species have proven to be useful indicators of lake trophic states in Europe (Berzins 1949; Pejler 1957; and Hakkari 1972). We have found many of these species to be good indicators for lakes in our study area. In addition, we have noted several other species that heretofore have not been utilized as indicator organisms. We are encouraged by the results of this investigation, because rotifers appear to offer a presently untapped biological resource for lake quality assessment. However, investigations must proceed on several fronts to further define the role of rotifers as indicators of lake trophic condition. First, species diversity as well as community structural characteristics will be analysed. Second, quantitative data will be accrued on rotifer populations. Presence and absence data may not be sufficient to adequately evaluate lake trophic condition. For example, *Filinia longiseta* may be present in very low abundance since its resting eggs hatch irregularly but at short intervals during the year. When ecological conditions are optimal, the population of this species increases rapidly (Gilbert 1974). Knowledge of life history, seasonal distribution, and ecological requirements are essential for evaluating the significance of the appearance of a given species in a lake and its characterization as an indicator organism.

Crustacea

Crustacean zooplankton have long been recognized as important constituents of the biological community in lakes. These micro-crustaceans belonging to the Cladocera and Copepoda are not only abundant, but are also significant links in food web dynamics and energy flow pathways in the aquatic ecosystem. Because they are larger (600 to 3,000 μ long) than rotifers, the micro-crustaceans have received much more attention. Although the taxonomy of at least the limnetic micro-Crustacea is well-known and numerous papers have been published on their ecology in inland lakes, Cladocera and Copepoda have not been used extensively as indicator organisms.

Few species of Cladocera or Copepoda are characteristic of a given lake type. Two species of *Bosmina*, one characteristic of oligotrophy and the other of eutrophy, have been utilized as indicator organisms in Europe. However, these species have not been used in North America due to taxonomic confusion in the genus *Bosmina* that existed until the recent revision by Deevey and Deevey (1971). *Chydorus sphaericus* is often noted to appear as a common plankter in eutrophic waters where extensive blue-green algal blooms are prevalent. However, the gross appearance of the algal bloom is a better indicator of eutrophic conditions than the inconspicuous cladoceran. If a zooplankter is to be useful as an indicator, its presence or disappearance should be an early-warning signal to advancing eutrophy.

Examining structure of the crustacean zooplankton community may be more fruitful than looking for indicator species of environmental change. Gliwicz (1969) observed higher proportions of cladocerans and rotifers and lower proportions of calanoid copepods in Polish lakes of higher eutrophy. A similar situation is found in the Great Lakes. In the eutrophic waters of Green Bay, rotifers and cladocerans are relatively more abundant than calanoid copepods; whereas in the oligotrophic offshore waters of Lake Michigan, calanoid copepods are proportionately more abundant. Monitoring the relative proportions of calanoid copepods to cladocerans and rotifers may be a useful ratio in indicating changes in water quality of lakes (Gannon 1972).

Our objectives in investigating crustacean zooplankton in the inland lakes of northern lower Michigan are to 1) examine the species composition in lakes of the study area with special reference to any species or groups of species that may indicate trophic condition of the lakes, and 2) compile quantitative data on percent composition of major groups of plankters in order to test the hypothesis that the ratio of calanoid copepods to cladocerans, and perhaps to rotifers as well, may be useful in characterizing trophic state. Our analyses of species composition are nearly completed while quantitative counts for percent composition are progressing well at this time. Our investigation is the most intensive study on zooplankton ever conducted in northern Michigan lakes. Previous studies in the area are few and have usually resulted in simple lists of organisms, often only to the generic level (Gorham 1931, Welch 1936 a, 1936 b, 1938 a, 1938 b; Chandler 1937; Hooper 1954).

A total of 65 species of Cladocera and Copepoda have been observed in the lakes of the Inland Water Route region (Table 8). Thirty of these species are limnetic while 35 are characteristic of the littoral zone. Many species were common to the majority of lakes regardless of trophic state. *Epischura lacustris*, *Cyclops bicuspidatus thomasi*, *Mesocyclops edax*, *Bosmina longirostris*, and *Diaphanosoma leuchtenbergianum* occurred in 85 percent of the lakes. Species occuring in over 50 percent of the lakes were *Diaptomus minutus*, *D. oregonensis*, *Cyclops vernalis*, *Tropocyclops prasinus mexicanus*, *Chydorus sphaericus*, *Daphnia galeata mendotae*, *D. retrocurva*, and *Ceriodaphnia lacustris*. Even those species with more limited distributions did not show any relationship to trophic status of the lakes. As we expected, crustacean zooplankton were not good indicators of trophic conditions of lakes in study areas. However, several aspects of community structure appear worth pursuing further. First, we have noted that those lakes which appear oligotrophic to the experienced observer generally have higher numbers of limnetic species in summer than more eutrophic lakes. We are currently analyzing these data with statistical scrutiny. It appears at this time that more oligotrophic ecosystems do indeed have higher species diversity than eutrophic ones. A drop in the number of limnetic species during comparable mid-summer periods may indicate environmental change. Second, calanoid copepods appear to be relatively more abundant than other limnetic micro-crustaceans in more oligotrophic ecosystems. Consequently, we are encouraged that a simple ratio of calanoid copepods to other major groups of limnetic zooplankters may be useful in characterizing lakes in the study area.

TABLE 8 LIST OF CRUSTACEAN PLANKTON FROM 38 LAKES IN NORTHERN LOWER MICHIGAN

CALANOID COPEPODA

Diaptomus minutus Lilljeborg
Diaptomus oregonenis Lilljeborg
Diaptomus reighardi Marsh
Epischura lacustris S. A. Forbes

CYCLOPOID COPEPODA

Cyclops bicuspidatus thomasi S. A. Forbes
**Cyclops varicans rubellus* Lilljeborg
**Cyclops venustoides bispinosus* Yeatman
Cyclops vernalis Fischer
**Ectocyclops phaleratus* (Koch)
**Eucyclops agilis* (Koch)
**Eucyclops speratus* (Lilljeborg)
**Macrocyclops albidus* (Jurine)
Mesocyclops edax (S. A. Forbes)
Mesocyclops leuckarti (Claus)
Orthocyclops modestus (Herrick)
**Paracyclops affinis* (Sars)
**Paracyclops fimbriatus poppei* (Rehberg)
Tropocyclops prasinus mexicanus Kiefer

CLADOCERA
FAMILY - Bosminidae

Bosmina longirostris (O. F. Müller)
Eubosmina coregoni (Baird)
Eubosmina tubicen (Brehm)

FAMILY - Chydoridae

**Acroperus harpae* Baird
**Alona affinis* (Leydig)
**Alona costata* Sars
**Alona guttata* Sars
**Alona quadrangularis* (O. F. Müller)
**Alona setulosa* Megard
**Alonella excisa* (Fischer)
**Alonella nana* (Baird)
**Camptocercus rectirostris* Schodler
**Chydorus ovalis* Kurz
**Chydorus sphaericus* O. F. Müller
**Eurycercus lamellatus* (O. F. Müller)
**Graptoleberis testudinaria* (Fischer)
**Leydigia quadrangularis* (Leydig)

(continued)

Monospilus dispar Sars
Pleuroxus procurvus Birge
Pleuroxus striatus Schodler
Pleuroxus uncinatus Baird

FAMILY - Daphnidae

Ceriodaphnia lacustris Birge
Ceriodaphnia quadrangula O. F. Müller
Daphnia ambigua Scourfield
Daphnia catawba Coker
Daphnia dubia Herrick
Daphnia galeata mendotae Birge
Daphnia longiremis Sars
Daphnia parvula Fordyce
Daphnia pulex Leydig emend. Richard
Daphnia pulicaria Forbes emend. Hrbacek
Daphnia retrocurva Forbes
Daphnia rosea Sars emend. Richard
Daphnia schødleri Sars
Scapholebris kingi Sars
Simocephalus exspinosus (Koch)
Simocephalus serrulatus (Koch)
Simocephalus vetulus Schodler

FAMILY - Holopedidae

Holopedium gibberum Zaddach

FAMILY - Leptodoridae

Leptodora kindtii (Focke)

FAMILY - Macrothricidae

Drepanothrix dentata (Euren)
Ilyocryptus spinifer Herrick
Ophryoxus gracilis Sars
Streblocerus serricaudatus (Fischer)

FAMILY - Polyphemidae

Polyphemus pediculus (L.)

FAMILY - Sididae

Diaphanosoma leuchtenbergianum Fischer
Sida crystallina (O. F. Müller)

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*littoral species

B. TERRESTRIAL

The objective of the terrestrial portion of the Northern Michigan Environmental Research Program is to evaluate impact of specific land use patterns on nutrient cycling in the watersheds of northern lower Michigan. Empahsis during the current grant period was focused on nutrient characteristics of ground water. Since movement of nutrients in ground water largely depends on soil types, initial efforts to analyze soil characteristics along critical lake shorelines have begun. As our program progressed and we interacted with scientists of the aquatic and social section as well as the user community, we realized how important knowledge of nutrient cycling is to sound land use decision-making processes in the area. It became apparent that to best integrate our efforts with the major objectives of the RANN program at the Biological Station and to meet the needs of the user community, terrestrial research must focus on nutrient budget calculations in the various watersheds in the study area. In the following three sections (ground water, soils and nutrient budgets) we discuss our progress to date and present some preliminary analyses of data.

GROUND WATER NUTRIENT ANALYSES

The purpose of this portion of our program was to make initial determinations of nutrient levels in ground water in the Inland Water Route region. This work was the first step toward the long-term process of monitoring ground water and providing data critical to knowledge of nutrient cycling. This information will serve as a baseline for future research and will be used as an indicator of nutrient overloading of specific soil types by surface land use activities.

Ground water

Data presented here are preliminary results from June samples only. July through September samples are analyzed but are in the process of data reduction and analyses. The values obtained show a great deal of variation over the range of wells sampled *(figures 15 through 23)*. Nitrate-nitrogen (NO_3-N) ranges from zero to 9,219 ppb.[4] Ammonium-nitrogen (NH_4-N) shows a range of from zero to 1,693 ppb. Total dissolved phosphates (PO_4-P) range from zero to 530 ppb. Dissolved iron (Fe) goes from zero to 3,300 ppb. Chlorides (Cl) range from zero to 75 ppm; sodium (Na) from 1.0 to 125.0 ppm; potassium (K) from 0.2 to 3.4 ppm; magnesium (Mg) from 1.2 to 63.0 ppm; and calcium (Ca) from 2.8 to 121.0 ppm.

Although these ranges are very wide in most cases, the majority of the values for most of the categories fall within narrow bounds. For instance, the majority of the potassium values fall between 0.5 and 1.5 ppm. The greatest majority of magnesium values fall between 15.0 and 30.0 ppm. A large percentage of the calcium values fall between 15.0 and 45.0 ppm, and most sodium values fall below 30 ppm. Chlorides generally fall between zero and 10 ppm, and almost all the phosphates fall below 40 ppb. The nitrate, ammonium, and iron values vary widely over the range. This was expected

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[4] 1,000 parts per billion (ppb) = 1,000 μg/ℓ = 1 part per million (ppm) = 1 mg/ℓ

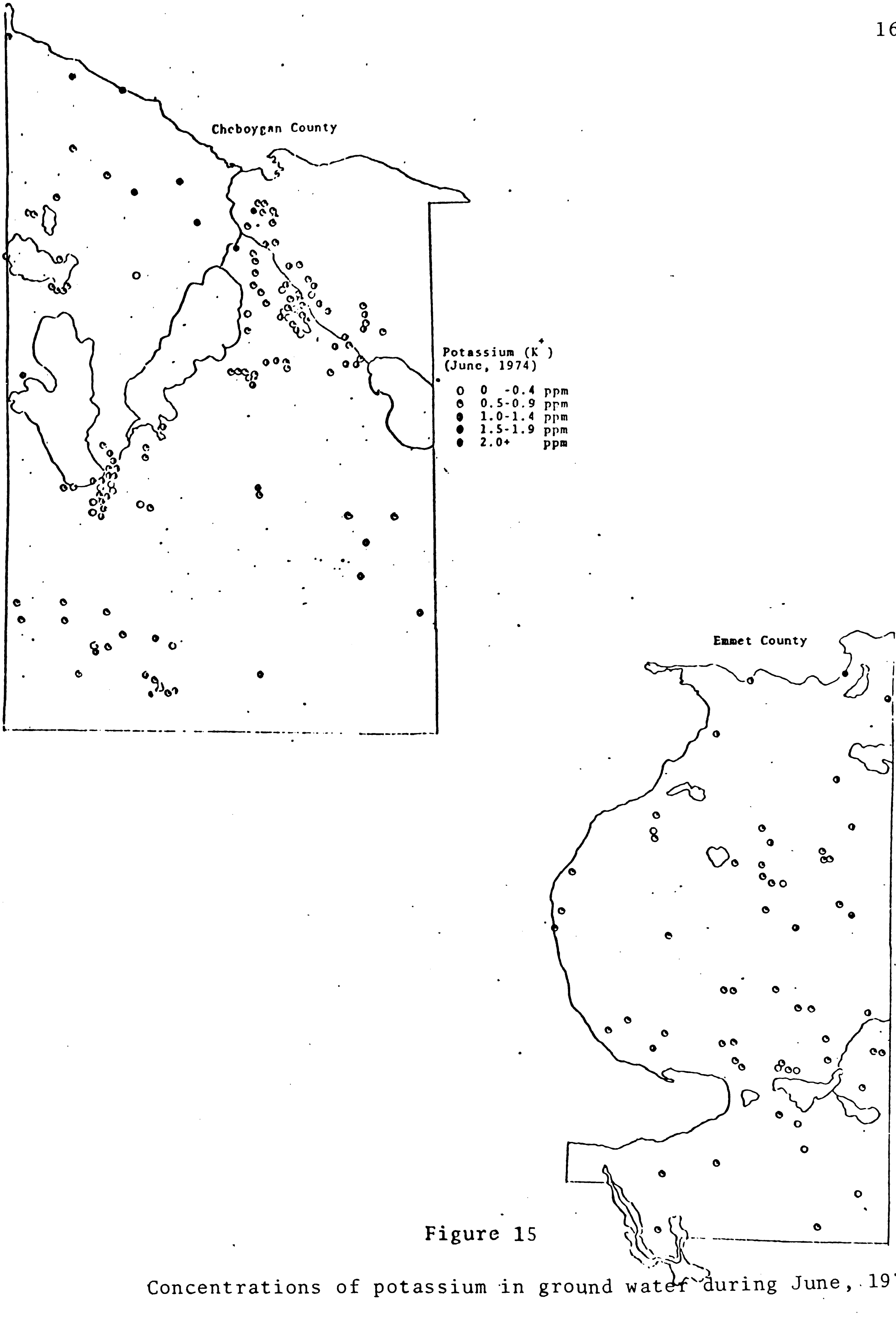


Figure 15

Concentrations of potassium in ground water during June, 1974

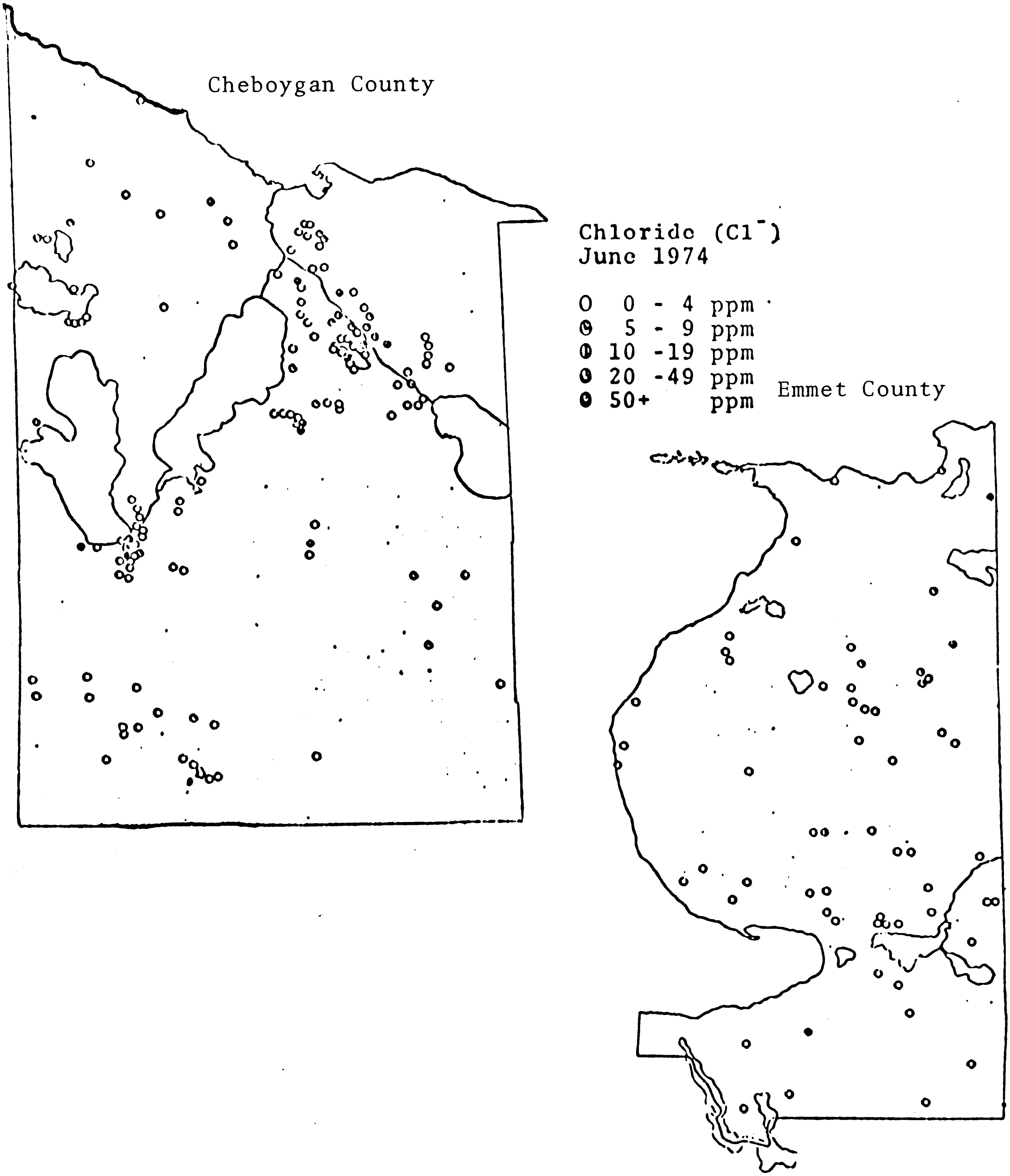


Figure 16

Concentrations of chloride in ground water during June, 1974

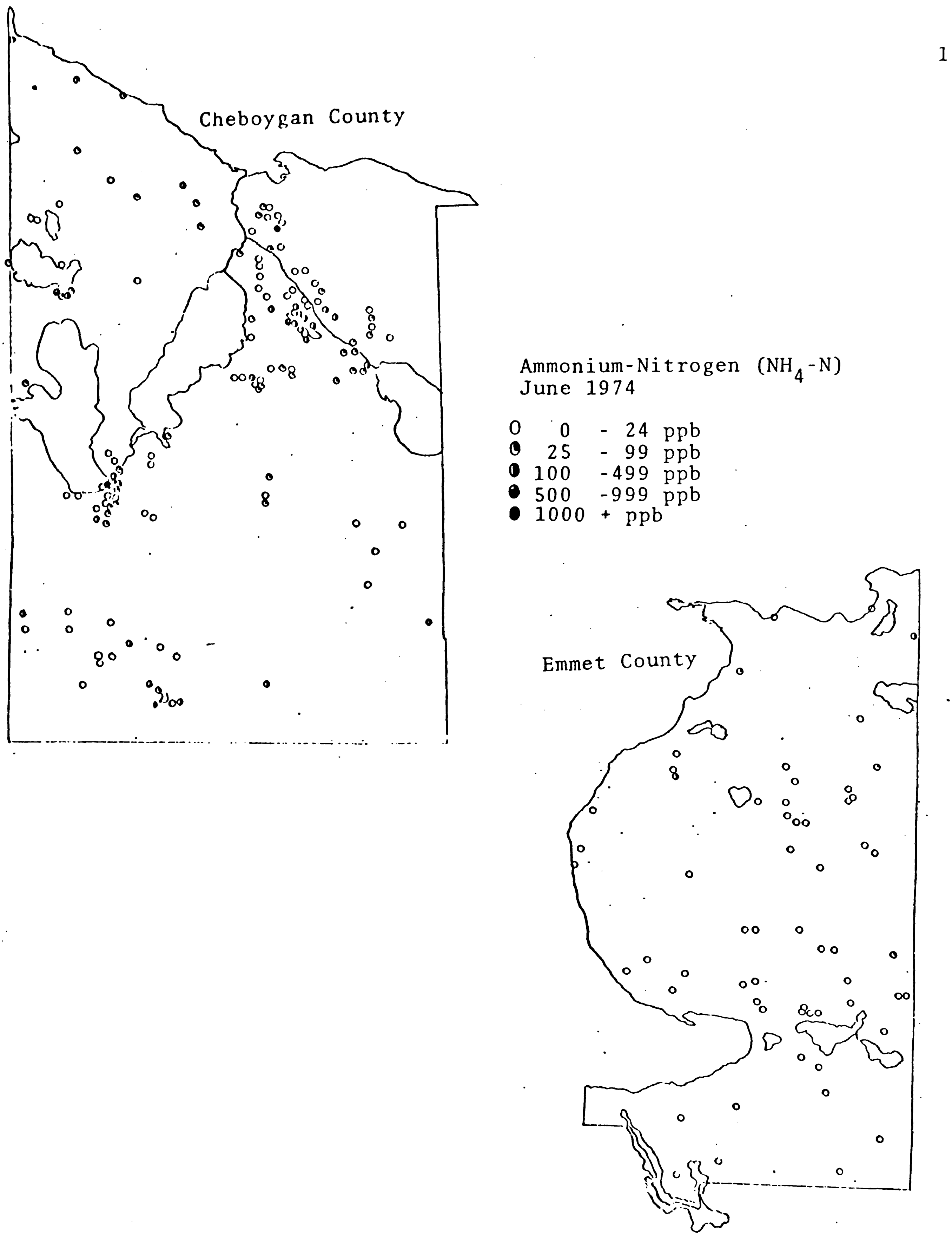
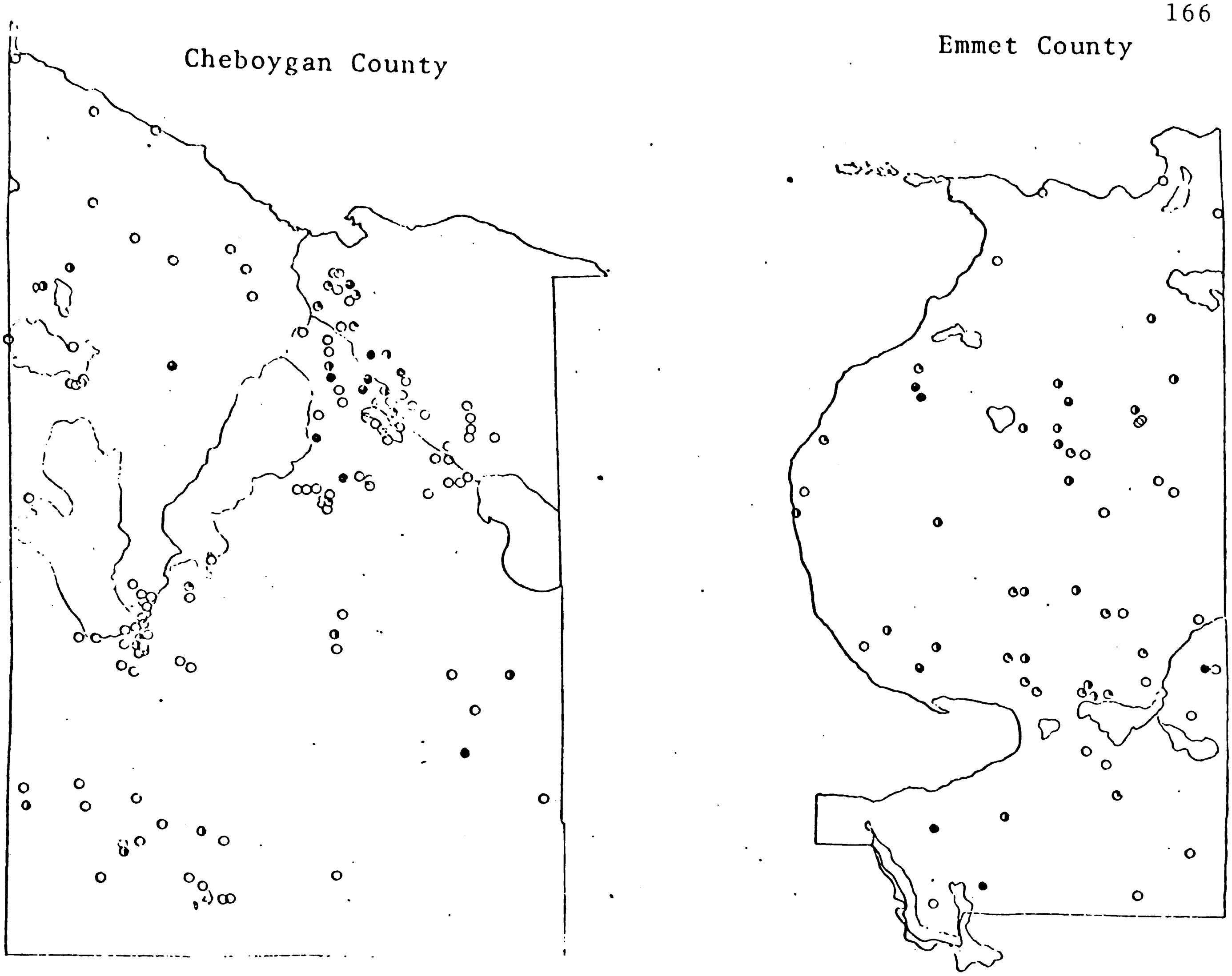


Figure 17

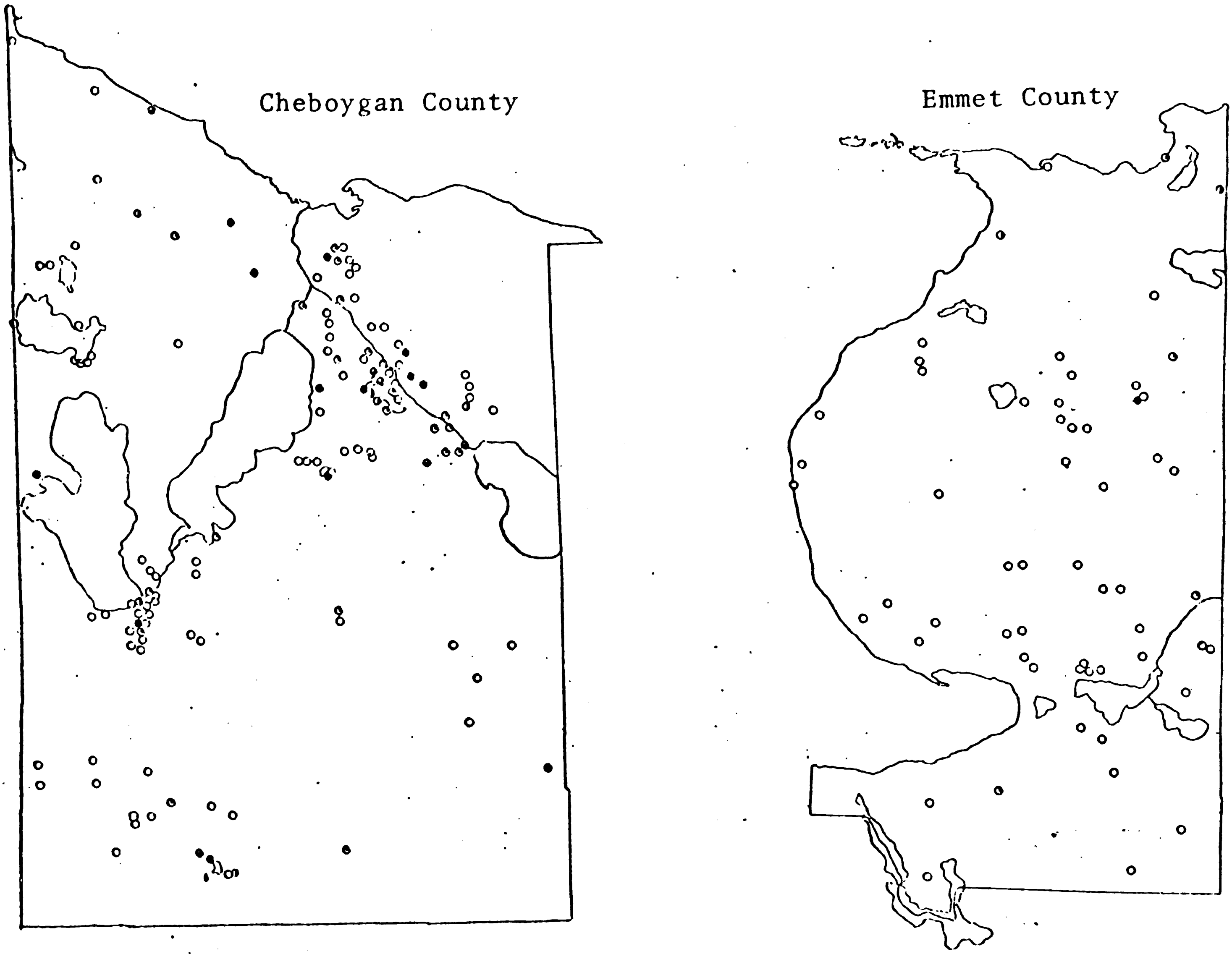
Concentrations of ammonium-nitrogen in ground water during June, 1974



Nitrate-Nitrogen (NO_3-N)
June 1974

○	0- 499 ppb
◔	500- 999 ppb
◑	1000- 1999 ppb
◕	2000- 3999 ppb
●	4000+ ppb

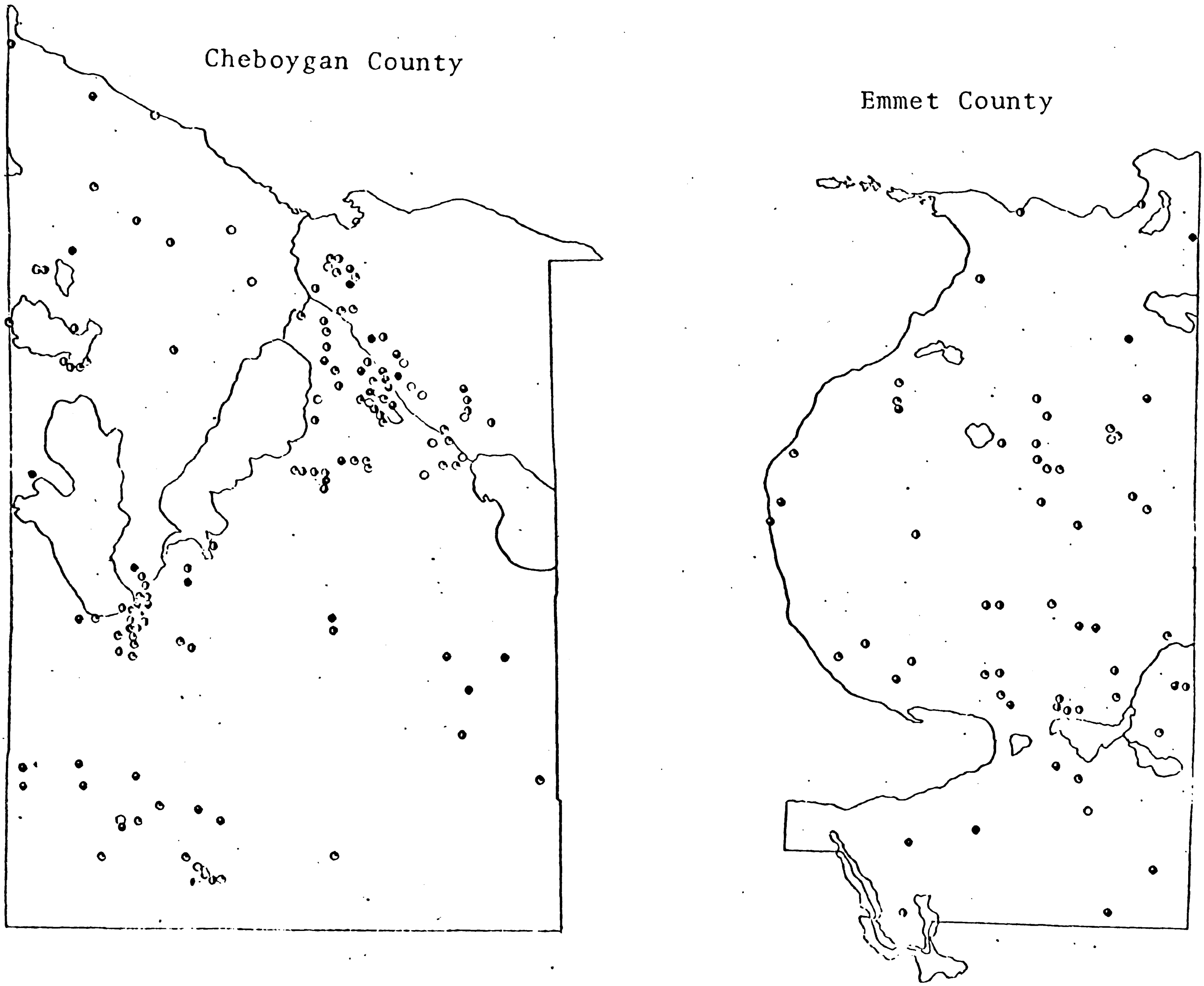
Figure 18
Concentrations of nitrate-nitrogen in ground water during June, 1974



Sodium (Na)
June 1974

O	0- 9 ppm
◔	10- 19 ppm
◑	20- 29 ppm
◕	30- 39 ppm
●	40+ ppm

Figure 19
Concentrations of sodium in ground water during June, 1974

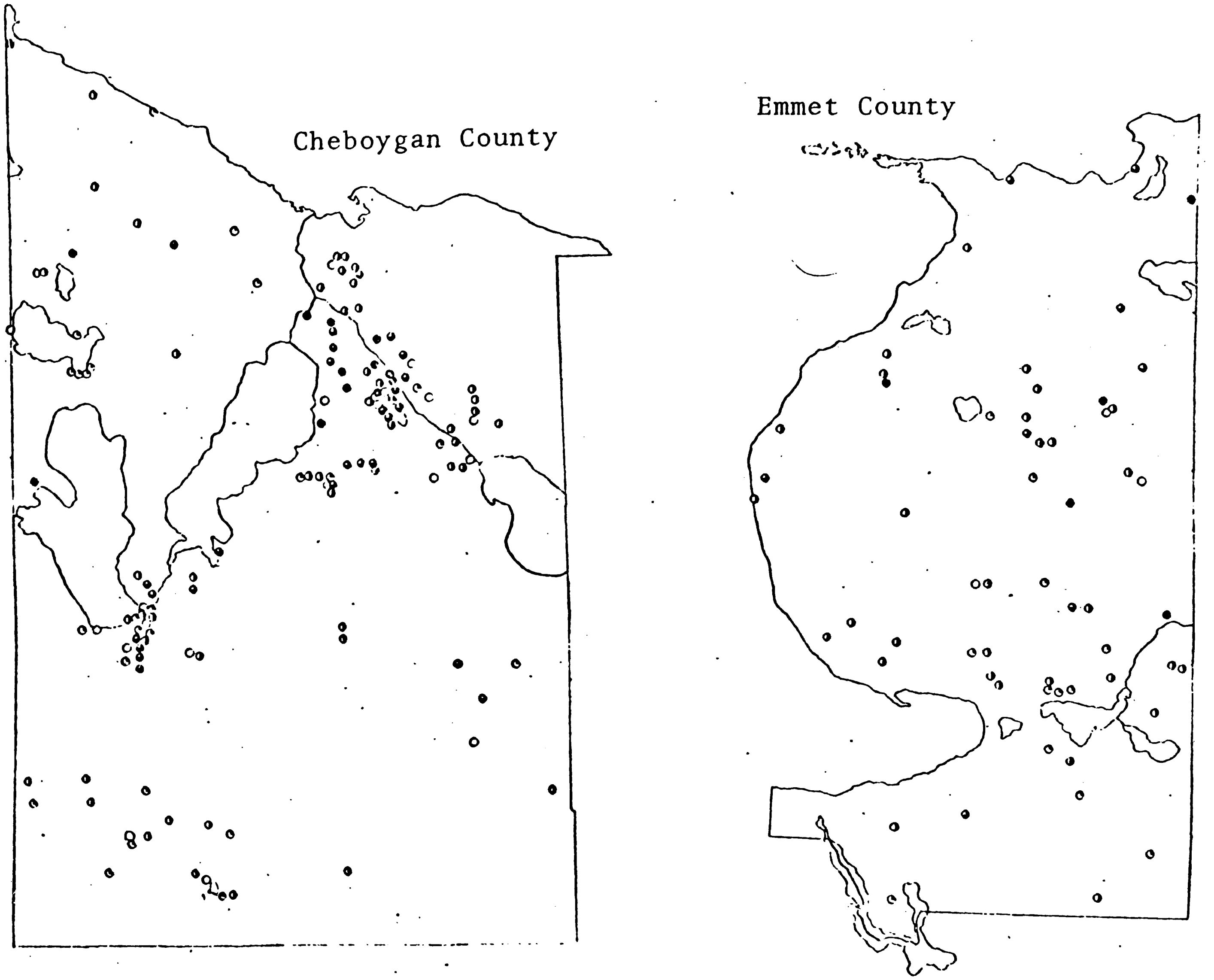


Calcium (Ca^+)
June 1974

O	0 -14 ppm
◐	15 -29 ppm
◑	30 -39 ppm
◕	40 -49 ppm
●	50+ ppm

Figure 20

Concentrations of calcium in ground water during June, 1974



Magnesium (Mg+)
June 1974

- O 0 - 9 ppm
- 10 -14 ppm
- 15 -19 ppm
- 20 -24 ppm
- 25+ ppm

Figure 21

Concentrations of magnesium in ground water during June, 1974

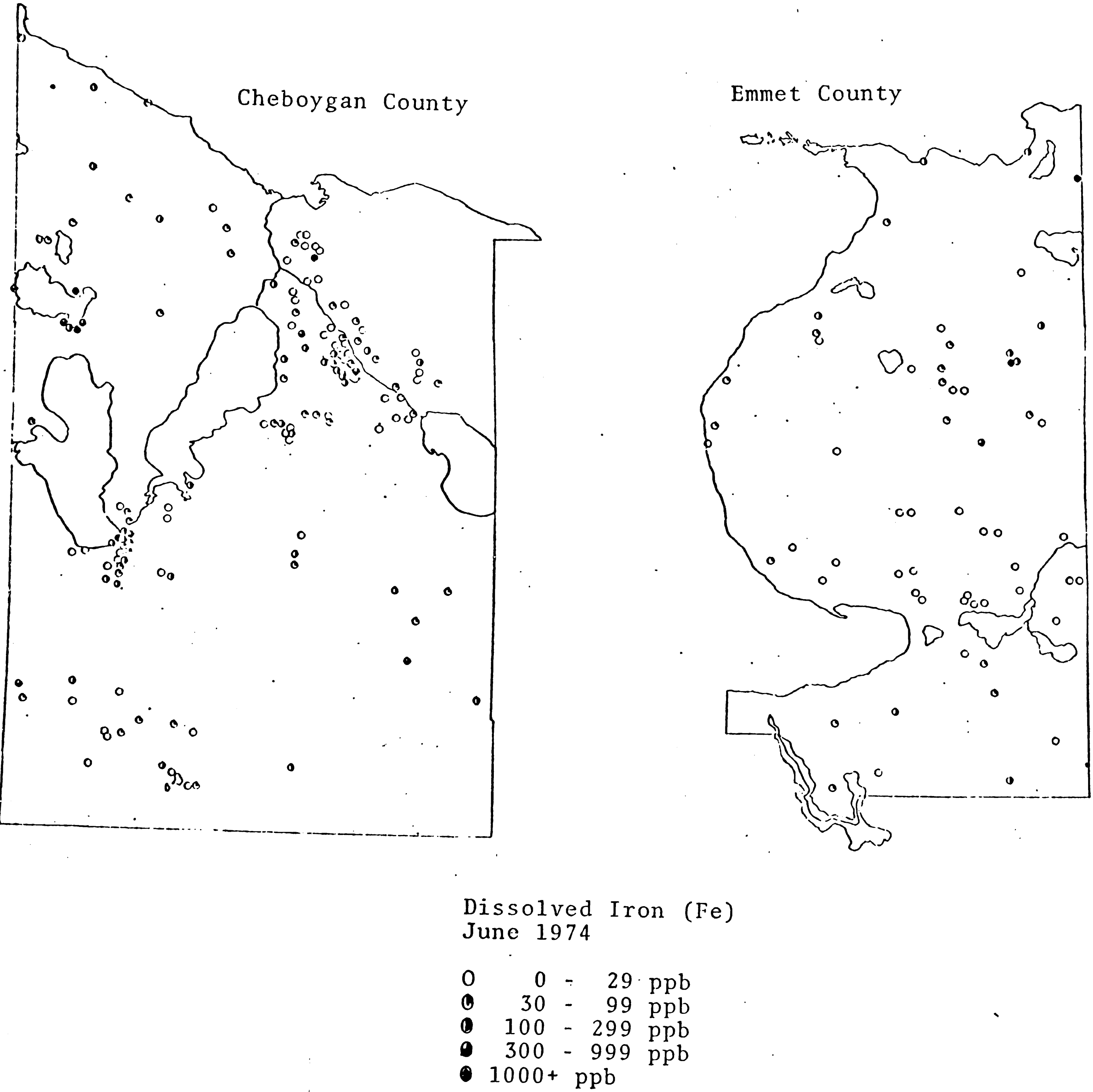
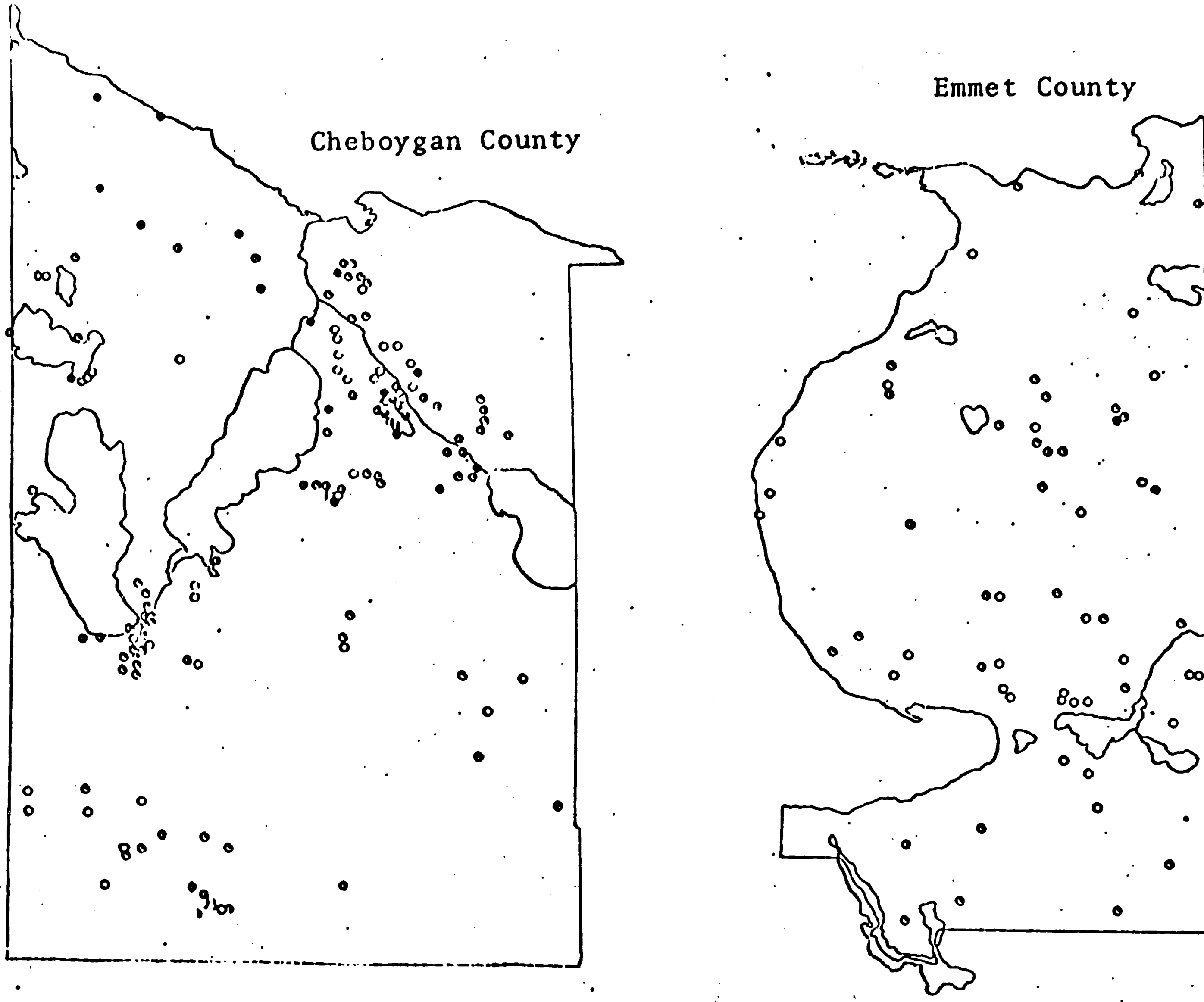


Figure 32

Concentrations of dissolved iron in ground water during June, 1974



Dissolved Phosphorus (PO_4)
June 1974

0 0 - 9 ppb
0 10 - 19 ppb
0 20 - 49 ppb
0 50 - 99 ppb
0 100+ ppb

Figure 23
Concentrations of dissolved phosphorus in ground water during June, 1974

of iron due to the type of construction material used in the pipes and storage tanks. Further analyses on nitrogen values are needed and currently in progress. Before any inferences can be drawn from the data, it is necessary to compare the range of nutrient values found in the study area with the safety standards for drinking water. Such a comparison reveals that all values determined in June for Ca, Cl, PO_4-P, NO_3-N, K, Mg and Na, did not exceed health safety standards (*Table 9*). The only nutrient that exceeded the recommended World Bank (1974) safety levels in a few areas was the NH_4-N form of nitrogen. It should be noted that the U. S. Department of Health has not set specific standards for the NH_4-N form of nitrogen. However, excessive amounts (10 ppm of NO_3-N in water supplies) have been shown to be hazardous to infant health (U. S. Department of Health 1962).

In Cheboygan County, only 15 percent of the wells showed NO_3-N values higher than 1,000 ppb (*figures 15 through 23*). Most of these did occur in areas of active or abandoned farming and grazing. However, no implications can be made at this time since many other wells in these areas did not register high levels of NO_3-N. Nitrate-nitrogen levels near Indian River, an area encompassing a village and an extensive marshland, were mostly very low. The few wells showing higher NO_3-N values varied considerably with respect to depth.

Almost 50 percent of the wells sampled in Emmet County exhibited NO_3-N values higher than 1,000 ppb. These wells were concentrated in the north central part of the county, and near Harbor Springs. It is of interest to note that some

TABLE 9

A comparison of the range of nutrient values found in the June 1974 ground water survey in northern lower Michigan with safety standards for drinking water

Parameter	Range of Values in Michigan study - June, 1974 ppm	Maximum concentration allowed in public drinking water (Drinking Water Standards) ppm
NO_3-N	0 - 9	10
NH_4-N*	0 - 1.6	0.5
PO_4-P* (total dissolved)	0 - .04	100
Cl	0 - 75	250
Fe	0 - 3.3**	0.3
Ca*	15 - 45	200
Mg	15 - 30	150
K	0.2 - 3.4	340+
Na	1 - 125	135+

*Limits for NH_4-N, PO_4-P, and Ca are from World Bank Report 1974. The remaining Standards are from U.S. Department of Health 1962

**These high values are suspect and may be due to the type of pipe (iron) used in sampling

+Taste threshold of cation in form of KCl and NaCl of the deeper wells (over 200 ft. deep) in the northern parts of the county had abnormally high NO_3-N levels ranging from 3,300 ppb to 4,400 ppb.

Our preliminary analyses have not revealed any pattern between substrate type and NO_3-N concentrations. Wells drilled in limerock usually had NO_3-N values considerably lower than 1,000 ppb.

There appeared to be no pattern in the ammonium values. The same was true for the dissolved iron levels. The highest phosphate readings came mostly from northern Cheboygan County, but those were few. There were some variations in the sodium and chloride values, but no specific patterns emerged with just one month's data. An area of specific interest to the local community was an area of known well water contamination from a road salt stockpile near Indian River. Our preliminary data indicates that a salt incursion in the Indian River aquifer at about 80 ft. is still moving northeast, since wells on the edge of that incursion show significantly higher Na and Cl levels than the surrounding area. There are also a few high sodium and/or chloride readings at various points that lie adjacent to major paved highways.

Data from ground water samples indicate that there exists considerable variability in nutrient levels. There is also an indication that wells in Emmet County have higher NO_3-N values than those in Cheboygan County. Higher concentrations in both counties are mostly in areas of agriculture or urbanization. However, immediate cause and effect conclusions should not be inferred since wells exist in these areas which are low in NO_3-N. All residential wells tested met U.S. public health safety standards during the June sampling period.

It is difficult to determine any direct relationships between surface land-use activities and ground water quality in the study area at this time. Information on ground water flow patterns is critically needed and will be analyzed during the next phase of the project. Not much is known about soil permeability and percolation rates in different areas. Many of these wells penetrate through clay strata, which indicates that percolation into the water table or into aquifers from the surface may be inhibited. For instance, water tested from a well 239 feet deep in Cheboygan County showed low values for all parameters tested including NO_3-N (1.5 ppb) even though this well is in the barnyard on an active cattle ranch which has been in operation since about 1870.

Values for Mg and Ca generally are high and many well owners did, indeed, speak of hard water. This would be expected from ground water originating in glacial till which includes a high degree of calcareous material.

Data from the other sampling periods undoubtedly will augment some of the tentative patterns derived from one month's data, as well as delineate other patterns for nutrients in the ground water of the study area. When more data is analyzed, a firmer baseline for ground water nutrient values can be established. From this base, future observations can be made to detect increases or decreases from base level, and to correlate these changes with changes in the land and water use patterns in the region. In addition, comparisons of average values can be made with those already monitored in the lake waters by the aquatic section of the project.

Our progress to date in ground water sampling in Emmet and Cheboygan Counties is merely a first step. It should, however, provide a base for further research, both in studying the ground water itself, and in studying ways in which changes in the ground water may reflect changes in land use patterns. This information may provide early indicators of problems arising from overloading the capacity of the land and certain types and intensiveness of land useage.

LAKE SHORELINE SOILS

Soils serve as reservoirs, channels and filters for precipitation which enters streams, lakes and ground water aquifers. During some rainstorms and conditions of rapid snowmelt, and as results of disturbances and intensive land use, soils contribute large quantities of suspended solids and dissolved substances to water moving over and through them. As the rooting media for naturally-occurring and man-planted vegetation, and as the recipients of a large variety of household, urban, industrial and agricultural wastes, soils act as chemical reactors and living filters. Water passes through them and interacts with roots, wastes and by-products of soil, and chemical and biological processes. These processes dictate that any evaluations of relationships between land use and lake water quality must include considerations of soil properties within watersheds, especially along stream banks and shorelines. As a first step in providing soils information for this investigation, we have developed a framework for compiling existing data for soils adjacent to the lakes of the study area. This framework permits modification and addition of data for individual soil units as such data is accrued through field and laboratory investigations.

Information sources and compilation

Basic maps and information for soils of Cheboygan and Emmet Counties are contained in soil survey reports (Foster *et al*. 1939 for Cheboygan; Alfred *et al*. 1973 for Emmet County). Additional detailed soil maps for some sections of each county are contained on aerial photos on file in county offices of the U. S. Soil Conservation Service (S. C. S).

The initial processes of delineating soils along lakeshores and estimating the length and proportion of each shoreline occupied by individual soil types was begun by Mazur (1973), who compiled data for fourteen lakes in Cheboygan and seven lakes in Emmet County. Mazur used the 1939 Cheboygan County Soil Survey Report and advanced field sheets for the Emmet County survey. This information for Cheboygan County is being converted to make the 1939 information comparable with current soil series designations. Additional up-dated information and data not compiled by Mazur is being obtained from the Soil Conservation Service photo files and soil survey reports.

Soils interpretations sheets from S. C. S. for each soil series provide general horizon characteristics and physical and chemical properties which relate to land use. Additional data on the suitabilities of the soils as waste disposal sites are contained in reports by Ellis and Erickson (1969) and Schneider and Erickson (1972).

Pertinent data for shoreline soils are being compiled in a format for punching on 80-column computer data cards. The intent is to provide data which can be statistically correlated by multiple regression or other techniques with land use, lake water quality and well log data being compiled in other phases of this study. The plan for data type and format is outlined in Table 10. The framework and compilation of data in computer-compatible form will provide a flexible basis for integration and correlation of existing soils data with other land and water information. It also permits addition of more data as it becomes available.

Current and Future Work

Existing data are being compiled on the form described. Additional delineation of soils series for lakes not included by Mazur will be made. The completion of this work during the current grant period will provide basic soil information for use by other segments of the study and by planning personnel in Cheboygan and Emmet counties.

The logical next phase of this work is to plan for the correlation of soils data with data on land use patterns and lake water quality. Such correlations will be the basis for hypotheses regarding interactions between land uses and soils as they influence lake water quality. Testing of hypotheses advanced will, of necessity, be initially constrained to detailed considerations of alternative pathways for the functioning of feasible cause and effect relationships; *e.g.* phosphate sources in land use around a given lake, phosphate sorption potentials of lakeshore soils and phosphate concentrations

TABLE 10 Description and format of soils data to be punched onto computer cards. Two or more cards will be used for each shoreline series.

Column Number(s)	Item description, format and data source
CARD 1	
1	County Number: 1 = Cheboygan 2 = Emmet
2-3	Lake designation: 00 (As designated in Appendix A)
4-8	Soil Series and Slope Code: 00000 (Soil Survey Legend for Michigan, Jan. 1969, and Soil Survey Reports)
9-11	Shoreline length, in miles: 00.0 (Mazur, 1973 and supplement)
12-14	Percent of total shoreline occupied by soil type: 00.0 (Mazur, 1973 and supplement)
15-16 17-18 19-20 21-22 23-24 25-26	Thickness in inches, for each soil horizon, provision made for 6 horizons: 00 (SCS Interpretations and Soil Series Descriptions sheets)
27-28 ↓ 35-36	SCS texture (coded) for each horizon: 00
37-39 40-42 43-45 46-48 ↓ 70-72	Permeability range in inches/hour and minutes/inch, for each of the top 3 horizons: 00.0 (SCS)
73-74 75-76 77-78	pH (average of range given) for each of the top 3 horizons: 0.0 (SCS)
79-80	Available for additional identification

(continued)

Column Number (s)	Item description, format and data source
CARD 2	
1-9	Identification as on columns 1-9 of Card 1
10-13	Phosphate (PO_4=) soprtion capacity in pounds/ acre 6" thickness; midpoint of range specified: 0000. (Schneider and Erickson, 1972)
14-80	Limitations (coded for: none, slight, moderate, severe, very severe) and suitabilities (coded for: not suitable, very poor, poor, fair, fair to good, good) for use of soils for septic systems, cottages, picnic areas, campsites, *etc*. Also, permeability, pH and PO_4 sorption data for additional horizons

in the lake water. Complexities of possible ground water contributions and lake sediment chemistry are recognized as typical of additional necessary considerations in reaching conclusions regarding land-water interactions.

Rigorous testing of hypotheses will be dependent on availability of existing "control" and "treatment" situations in the study area and on future research. An alternative approach will be to utilize simulation models being developed in International Biological Programme (I. B. P) research to examine watersheds of our study area. The results of this portion of our study are the first step in preparing to apply the I. B. P. models as they become available.

A PRELIMINARY NITROGEN AND PHOSPHORUS BUDGET FOR SELECTED WATERSHEDS

Almost every form of human activity has the effect of increasing the amounts of nutrients entering ground and surface waters. The importance of nutrient budgets cannot be overstated. Without a knowledge of which nutrient sources contribute significantly to the system and which do not, it is impossible to determine which sources need to be regulated in order to maintain good quality surface and ground water.

The purpose of this phase of the terrestrial research of the Northern Michigan Environmental Research Project was to make an initial contribution toward developing nitrogen (N) and phosphorus (P) budgets for many of the lakes studied by the aquatic sections in Emmet and Cheboygan Counties, and to point out information gaps that will have to be filled before complete budgets are to be calculated in the next phase of the project.

It is well known that man's activities greatly influence water quality in the ecosystem. Agricultural activity causes increased erosion of soil left unprotected by plant cover. The eroded soil contains nutrients which may end up in surface waters. Fertilizers applied to the land in excess of amounts taken up by the harvested crop can leach through the soil into the ground water, and eventually into surface water. Livestock operations produce, as a by-product, large amounts of manure which must be disposed of. Year-round manure disposal by land spreading results in manure being applied to frozen soil. Since such spread cannot be absorbed into frozen ground, winter rains, and spring snow melt washes it into nearby water ways.

Urbanization is a very significant source of nutrient input to surface water. The excretory products of a large number of people in a relatively small area leads to a disposal problem and commonly results in nutrient water pollution. Effluent from sewage treatment plants is generally dumped directly into a nearby lake or stream with predictable degradation of water quality. In unsewered areas, drainage from septic tanks can contaminate ground water with nutrients, particularly nitrates, which can then find their way into surface waters. Urban storm sewers contribute a greater nutrient load than is generally believed. Large percentages of urban areas are paved and, consequently, impervious. The nutrients contained in the rain falling onto roof tops, sidewalks, streets, and parking lots, as well as the nutrients contained in the materials found in these places, i.e. dust, leaves, etc. wash directly into storm sewers, and into surface waters. Lush green lawns are requently the result of overfertilization, the excess leaching into ground water, streams and/or lakes.

Recreation can also be a significant contribution of nutrients. Drainage from the septic tanks of lake and stream resort homes may be the most prominent enrichment source for many waters, particularly in small, highly developed lakes. Besides residences, commercial establishments such as lakeside motels, hotels, rental cabins, ski lodges, etc. are also served by septic tanks, with the same results. Even seemingly innocuous pastimes such as hiking, camping and canoe portaging can often cause the erosion of nutrient rich lake and stream bank soil into these waters.

The importance of any individual nutrient source to a lake cannot be assessed except in light of a relatively complete nutrient budget which includes an evaluation of land use, in the lake's watershed. The following sections give our preliminary estimates of nutrient loading for a group of selected lakes in Northern Lower Michigan.

Nutrient Input by Precipitation

Precipitation and dry fall onto water surface can contribute significant amounts of N and P to lakes. To estimate the significance of this source requires accurate measurements of nutrients in rain, snow, and dust fall. The tremendous variation from one location to another, due to the effects of urban areas, industry, agriculture, etc. (Chapin and Uttormark 1973) makes extrapolation of data from one site to another quite difficult. Sampling of precipitation and dry fall in the Emmet-

Cheboygan Counties area is now being determined on an annual basis and will be used in refinement of future budgets.

According to a cartographic representation of data from 60 sites across the United States (Junge, 1958), the Emmet-Cheboygan County area receives about 2.0 kg/ha/year of inorganic nitrogen. However, this estimate does not include dry fall contributions and, due to sampling procedures, may also exclude the first few minutes of some precipitation events, a time during which inorganic N concentrations are highest (Gambell and Fisher, 1964). Consequently, Chapin and Uttormark (1973) feel the Junge's estimate may be three to four times too low.

Precipitation plus dust fall in rural west central Wisconsin contributed about 5.6 kg/ha/yr of inorganic N (Hoeft et al. 1972). Pecor et al. (1973) calculated a loading of 4.5 kg/ha/yr from precipitation onto Houghton Lake, Michigan. It is not clear from the authors' description of their experimental procedure how much dry fall was included in their precipitation samples.

Data from Wisconsin (Kluesener, 1972; Hoeft et al. 1972) indicates that organic N loadings from precipitation and dry fall are about equal to inorganic N loadings. For the purposes of an initial estimate of N and P loadings into 29 of the lakes in the study area, a fairly conservative 5.3 kg/ha/yr of inorganic N and a similar amount of organic N is assumed. It is also assumed that about 50 percent of this organic N will be available for uptake by aquatic plants. Consequently, a total of 7.9 kg/ha/yr of available N is estimated to fall on the lake surfaces from precipitation and dry fall.

There is limited data in the literature for atmospheric P contributions. Pecor et al. (1973) calculated that precipitation added 0.18 kg/ha/yr of total P to Houghton Lake. Kluesener (1972) estimated 0.25 kg/ha/yr entered Lake Wingra, Wisconsin from this source. In addition, Kluesener reported that dry fall contributed an additional 0.78 kg/ha/yr of total P. It is not known how much of this P is available for plant growth. Much of the P in precipitation and dry fall comes from dust generated over land surfaces (Chapin and Uttormark 1973), and is unavailable for uptake by plants in this form.

For the purposes of this initial estimate, it is assumed that about 0.35 kg/ha/yr of available P falls on the surfaces of the lakes in Emmet and Cheboygan Counties in precipitation and dry fall. Based upon these data, preliminary estimates of N and P loadings from precipitation are listed in Table 11. A series of precipitation stations have been established in Emmet and Cheboygan Counties to provide a more accurate estimate of nutrient inputs in the watershed areas during the next phase of the project.

Nutrient Input by Stream Drainage

There is a paucity of water quality and flow data for the Northern Lower Michigan area. Data for five representative streams in the study area were provided by the Michigan Water Resources Commission. The streams were not influenced by any major municipal or industrial effluent discharge. This data was used to calculate the contributions of soluble inorganic

TABLE 11 AVAILABLE N AND P PRECIPITATION AND DRY FALL FOR SELECTED LAKES IN NORTHERN LOWER MICHIGAN

Lakes	Surface area (ha)	kg available N/year	kg available P/year
Arnott	9.4	74	3
Black	4052	31,929	1418
Burt	6848	53,962	2397
Carp	760	5989	266
Cochran	11	87	4
Crooked	960	7565	336
Devereaux	14	110	5
Dog	76	599	27
Douglas	1374	10,827	481
French Farm	234	1844	82
Hoop	2.9	23	1
Larks	242	1907	85
Lancaster	21	164	7
Lance	10	77	3
Long	160	1261	56
Mud Lake Bog	10	81	4
Mullett	6652	52,417	2328
Munro	278	2187	97
Osmun	16	129	6
Pickerel	427	3367	150
Roberts	21	169	7
Round	133	1050	47
Silver, Wilmot Twp.	31	243	11
Silver, Koehler Twp.	31	243	11
Twin Lakes	84	662	29
Vincent	12	97	4
Walloon	1728	13,617	605
Weber	11	90	4
Wycamp	257	2024	90

P, total P, inorganic N and organic N from streams into the lakes.

The amount of P available from run-off for aquatic plant uptake lies between the values for soluble ortho-P and total P (Lee 1973). The average soluble ortho-P and total P loadings from the five area rivers was estimated to be 0.02 and 0.07 kg/ha/yr, respectively. A mean value of 0.05 kg/ha/yr of "available" P was estimated to be contributed from undisturbed watersheds draining into lakes in Emmet and Cheboygan Counties.

Inorganic and organic nitrogen inputs were calculated to be 0.43 and 0.80 kg/ha/yr. All of the inorganic N, and 50 percent of the organic N was assumed to be available, giving an estimated total of 0.83 kg/ha/yr of "available" N from these watersheds.

As a comparison, the amount of N and P contributed to Houghton Lake, Michigan from inflowing streams was 0.40, 0.74 and 0.04 kg/ha/yr of inorganic N, organic nitrogen and total P, respectively (Pecor et al. 1973).

The watershed areas coupled with N and P loadings for 29 lakes in the study area are given in Table 12. While the land use patterns in the drainage area of the lakes under consideration are generally quite similar, local variations due to intensive livestock production, heavily fertilized orchards, erosion and municipal effluent disposal, etc. could produce nutrient input of a much higher magnitude. A refinement will be made of our nutrient loading estimates in the next phase of the project. We will take into account local variations and land use patterns. Examples of different input values that

TABLE 12 ESTIMATED N AND P LOADINGS FOR LAKES FROM WATERSHEDS IN EMMET AND CHEBOYGAN COUNTIES, MICHIGAN

Lakes	Immediate Watershed (ha)	Available N loading kg/year	Available P loading kg/year
Arnott	933	774	43
Black	136,554	113,223	6223
Burt	101,388	84,051	4621
Carp	6752	5598	308
Cochran	218	181	10
Crooked	11,194	9281	510
Devereaux	1009	836	46
Dog	770	638	36
Douglas	5651	4685	66
French Farm	3067	2543	140
Hoop	141	117	6
Larks	413	343	19
Lancaster	3692	3061	168
Lance	835	692	38
Long	416	345	19
Mud Lake Bog	439	364	20
Mullett	64,767	53,701	2952
Munro	925	767	42
Osmun	174	144	8
Pickerel	13,664	11,329	623
Roberts	473	392	22
Round	1551	1286	71
Silver, Wilmot Twp.	523	434	24
Siver, Koehler Twp.	661	548	30
Twin Lakes	459	380	21
Vincent	39	32	2
Walloon	9170	7603	408
Weber	306	254	14
Wycamp	6321	5241	288

might be expected from various land uses are presented in Table 13. This data, in lieu of actual measurements of all sources of nutrients, along with a knowledge of the lake's drainage basin size, populations, stream flow rates and water quality, precipitation inputs, hydrology and land use patterns could be used to construct a simple simulation model of nutrient transport in the key watershed areas.

It should be noted that increasing development of marshlands will also present water quality problems in the study area. As the organic soils of the marshes are exposed to oxygen, because of water drainage, large quantities of nutrients will be released due to rapid oxidation of organic matter. A further analyses on nutrient content in marshes and its importance in the study area is given by Schwintzer (see Wetlands Section). Contact with the Houghton Lake Marshland RANN Project (Kadlec and Richardson 1974) has also provided invaluable information on marsh ecosystems and their role in effecting water quality.

<u>Septic Tank Drainage</u>

Currently, all lakeshore residences on the inland lakes of Emmet and Cheboygan Counties are served by septic tanks. Only the north shore of Crooked Lake is soon to be serviced by a sewer. Drainage from these septic systems may be the single most important source of nutrients to many lakes, especially the small and highly developed ones.

The average human is estimated to excrete up to 5.4 kg of N and 0.5 kg of P per year (Van Nuran 1948, McCarty *et al.*

TABLE 13 NITROGEN AND PHOSPHORUS CONTENTS OF VARIOUS NUTRIENT SOURCES* (from Brezonik 1973)

Source	N	P
NATURAL		
	1.5-3.4	.83-.86
Forest run-off	1.3-5.0	.084-.18
Forest percolation water	0.54	.034
Swamp and marsh run-off	?	?
Meadowland and runn-off	?	?
Precipitation on lake surface	.58/.18-.98	.044/.015-.060
Aquatic birds	.48-.95	.09-.18
Leaves and pollen	?	?
CULTURAL		
Domestic sewage	39.4	0.80
AGRICULTURAL AREAS		
Pasture	8.5	0.18
	1-5	0.15-0.75
Cropland	5-120	0.22-1.0
Farm animals, feedlots	?	?
URBAN RUN-OFF	8.8	1.1
SEPTIC TANKS	?	?
MARSH AND LANDFILL DRAINAGE	?	?

*All units in kg/ha/yr except rain fall (g/m^2-lake area-year), birds (kg/duck-yr.), and domestic sewage (kg/capita-yr.). (from Brezonik, 1973)

1967, Vollenweider 1968). This material, along with other wastes containing N and P, give lakeshore septic systems a high potential for nutrient pollution of lake waters. The average input into four septic systems was estimated by Walker *et al.* (1973a) to be 8.2 kg of N per person per year, indicating that about 67 percent of the N entering septic systems comes from human excreta. However, Vollenweider (1968) states that almost all of the N in sewage comes from human excreta, and that domestic sewage averages about 5.4 kg of N per person/year. Therefore, the loadings calculated by Walker *et al.* may be somewhat high. Ellis and Childs (1973) estimate the input of P to household septic systems to be about 0.45 kg of P per person/year for households lacking washing machines. Automatic washers and phosphate-containing detergents raise this value to about 1.6 kg of P per person/year.

To estimate the N and P contributions of lakeshore septic systems it was assumed that, on the average, each lakeshore residence was occupied for 50 percent of the year by a family of four, and that half of these residences have washing machines. Assuming an input of 5.4 kg of N and 0.5 kg of P per person per year, and an additional 1.0 kg of P per person per year for those residences with washing machines, it was calculated that each residence supplies 10.9 kg of N and 2.1 kg of P to lakeshore septic systems each year. These estimates will be revised as information on family size and length of residence becomes available from the Social Science section of this project. Using recent aerial photos of Emmet and Cheboygan Counties and the published soil surveys of the counties, the number of residences within 45.7 m of the shores of the inland lakes in two counties was estimated.

Field checks by RANN project personnel showed a 28 percent underestimate of residences by the aerial photos. Adjustments were made for all lakes. An analysis of the type of soil present at each residence was completed during summer, 1974. This provided a base for calculating total N and P soil absorption capacity around each lake.

Just how much of the N and P load from lakeshore septic tanks actually reaches the lakes is an extremely difficult problem to resolve. It has been found that 75 to 85 percent of the total N in septic tank effluents is in the NH_4-N form (Bouma *et al*. 1972, Walker *et al*. 1973a, Dudly and Stevenson 1973).

In a typical septic tank drain field the effluent runs from a perforated pipe or tile line into a shallow bed of gravel, and then into the soil. After a system has been in use for a few months, an organic "crust" forms at the gravel-soil interface. This retards the movement of the liquid into the soil (Bouma *et al*. 1972). The result is that the soil below the drain field is unsaturated with water, and contains air in the larger pore spaces. Under these conditions, NH_4-N is readily nitrified to NO_3-N. In well drained soils, with at least three feet of unsaturated soil between the bottom of the gravel bed (typically two feet below soil surface) and the water table, essentially all of the NH_4-N is converted to NO_3-N.

As several studies have shown (Bouma *et al*. 1972, Walker *et al*. 1973b, Dudly and Stevenson 1973) this NO_3-N is very soluble, mobile, and leaches readily through the soil profile to the ground water. Assuming that the ground water is moving toward the lake, it is likely that about 85 percent of the N entering the septic system will eventually find its way into the lake as an available plant nutrient. The remaining 15 percent is tied up in organic forms in the soil, and in the sludge that forms in the bottom of the septic tank itself.

In poorly drained soils, the process of nitrification is not complete, and some of the remaining NH_4-N may be absorbed onto the negatively charged soil surfaces (Bouma _et_ _al_. 1972, Dudly and Stevenson 1973). A "typical" septic tank effluent might contain 35 ppm of NH_4-N (Dudly and Stevenson 1973), 100 ppm of Na, 35 ppm of Ca, and 20 ppm of Mg (Ellis 1973). These cations would compete with the NH_4^+ except in organic soils, which typically have a high cation exchange capacity.

In the absence of oxygen, the NO_3 ion is the first alternative electron acceptor utilized by bacteria in respiration processes (Keeney 1972). In the process of dentrification, NO_3-N is converted to gaseous N and lost from the system. It is likely that, in a poorly drained soil, considerable organic material will still be present in the effluent when it reaches the water table. Further decomposition of this material under saturated conditions will quickly exhaust any oxygen present and lead to denitrification Just how much N would be lost from the effluent in this manner would depend on many things. However, it has been shown that most of the N can be removed from effluents if denitrification can be made to occur continuously (Bouma _et_ _al_. 1972, Bouwer 1970, Erickson _et_ _al_. 1971, 1972) Under conditions of fluctuating water table, which occurs in many of the soils surrounding lakes, the NO_3-N present in the flooded portion of the soil profile will be lost by denitrification.

In the estimation of the actual nutrient loading from septic tank effluent into nearby lakes it was assumed that in well-drained soils, 85 percent of the N in the effluent was reaching the lakes. In poorly drained soils, and soils with seasonably high water tables, their value was estimated at 50 and 65 percent, respectively. These values will be further clarified in the next phase of the project.

The fate of effluent phosphorus in the soil is considerably more complicated. Most soils have the capacity to fix considerable amounts of phosphate. This occurs by a variety of processes including chemical precipitation by soluble Fe, Al and Mn; and fixation by silicate clays (Buckman and Brady 1969).

In a new septic system, it has been observed that essentially all of the P in the effluent is fixed by the soil within a few feet of the septic drain field (Bouma et al. 1972, Dudly and Stevenson 1973, Ellis and Childs 1973). In older systems however, the capacity to fix P is reduced as the soil becomes saturated; in which case the P moves quite readily through the soil to the ground water, and then into the lake in the case of a lake shore septic system.

Schneider and Erickson (1972), using much of the data derived by Ellis and Erickson (1969), have rated many of the soils of Michigan as to their capacity to adsorb P, with the intent that this information could be used to help predict the fate of P from septic systems built in these soils. Ellis and Childs

(1973) demonstrated a relationship between the movement of P away from the septic tank drain field and the phosphorus adsorbing capacity of the soil as derived in the laboratory by Schneider and Erickson (1972) and Ellis and Erickson (1969). Phosphate moved farther, and reached the lake in a shorter period of time, in soils with low P-adsorbing capacities. In some soils with high P-adsorbing capacities, much less movement was found. A complicating factor is the ability of a P-saturated soil to regenerate its P-adsorbing capacity over a period of time. Just how many times this can occur, and how long it takes is unknown, and no doubt varies from soil to soil (Ellis and Erickson 1969, Ellis 1973).

When a soil is saturated with water, as below the water-table, the diffusion of oxygen into the soil is very slow. Oxygen depletion by microbial respiration occurs in these saturated soils. Under these conditions, P becomes much more mobile in the soil, and more phosphorus is found in readily extractable forms. This is thought to be due to the reduction of ferric iron to ferrous iron with a consequent loss of part of the soils' P-adsorbing capacity (Patrick and Mahapatra 1968, Antie _et al_. 1970, Patrick 1964, Syers _et al_. 1973). Consequently, less P is adsorbed from septic tank effluent by soils below the water table (Ellis and Childs 1973). With the preceding information as background and with cognizance of all the variables and uncertainties involved, the following initial set of conditions are assumed:

1. An average septic system in our study area receives 10.9 kg and 2.1 kg P/yr.

2. An average system consists of 23.2 m^2 (a reasonable size according to the Cheboygan County sanitary code).
3. A bottom bed of gravel an average of 0.9 m from the water table (0.6 m is required in Cheboygan County, 1.2 m in Emmet County).
4. A seepage bed distance of 15.2 m from the lakeshore as required by Cheboygan County Sanitary Code.
5. Phosphorus from effluent remains in the top 1.5 m of the ground water as it moves toward to the lake (Bouma et al. 1972, Dudley and Stevenson 1973).
6. Effluent fans out so that the affected area is 9.1 m wide at the lake shore (Bouma et al. 1972, Dudley and Stevenson 1973).
7. Soil P-adsorbing capacity is in the medium range, $1.7 \times 10^{-11} \times$ kg P/m^3 of soil (Schneider and Erickson 1972).
8. Soil P-adsorption capacity is regenerated once, and half of this capacity is reusable a second time (Ellis and Erickson 1969).
9. Phosphorus moves straight down through the soil to the ground water, then moves laterally to the lake.
10. Below the water table, the soil has only 50 percent of the P-adsorbing capacity of the soils above the water table.

With the preceding information as a base we have calculated how long the soil would absorb P, and consequently, how long it would be before all P from the septic tank was essentially all running into the lake or ground water. Under typical lakeshore soils found in the study area, the effluent would move through 21.2 m^3 of drainfield with a P-adsorbing capacity of 1.76×10^{-1} kg of P/m^3, of which half of this amount is used twice. After passing through the drainfield soil, the effluent would pass through 198.2 m^3 of natural seepage soil with a P-adsorbing capacity of 8.8×10^{-2} kg/m^3 of which half is used twice. Thus, 31.8 kg of P would be adsorbed by the soil, or essentially all of the P from the system for 15 years. Soils with other P-adsorbing capacities are given below:

P adsorbing capacity of mineral soils (kg/m^3)	Yrs. to saturation
Very low (1.2×10^{-1})	<10
low (1.4×10^{-1})	12
high (1.76×10^{-1})	19
Very high (2.4×10^{-1})	>20

In a poorly drained organic soil, these times of saturation would be somewhat reduced. Ellis and Childs (1973) found that on a poorly drained organic soil with extremely low P-adsorbing capacity, a loading of 3.2 kg/yr for five years caused the soil to be completely saturated with P, and that P was running essentially unchecked directly into the lake 9.1 m away.

It is not generally known how old the septic systems are around the lakes in Emmet and Cheboygan Counties. However, information on age of dwellings will be obtained by the social science section. This data will be used to refine our estimate of nutrient loading. It is also known that a large number of the older systems do not meet the requirements for distance above the water table or distance from the lake shore. This factor will be taken into account in the next phase of the project. However, for the purposes of estimating the present loading of P from lakeshore septic systems, the following assumptions were made:

Drainage	P-adsorbing capacity	Percent of P from each septic system that reaches the lake
Good	high, very high	25
Good	medium	45
Good	low, very low	65
Poor	high, very high	35
Poor	medium	55
Poor	low, very low	75

It must be remembered that eventually, all the soils receiving effluent will become P-saturated, and then all of the P will pass through the soil. For the purposes of these estimates it was further assumed that ground water movement was into instead of away from all the lakes under consideration. Ground water movement away from a lake would mean, of course, that none of the septic tank effluent would move into the lake.

By comparing soil characteristics along lake shores in Cheboygan and Emmet Counties with P-adsorbing capacity of these soil types (Schneider and Erickson 1972), we estimated percentages of N and P in the effluent from septic systems located on these soils that would reach the adjacent lake. From these percentages and the adjusted count of residences on these soil types, we calculated the actual loading of N and P to each lake from lakeside septic systems (Table 14). We also calculated the potential loading, i.e., all the N and P entering the septic systems each year (Table 14).

TABLE 14 CONTRIBUTIONS OF N AND P FROM SELECTED LAKESHORE SEPTIC SYSTEMS

Lakes	Estimated number of residences	Potential Loading		Estimated Actual Loading N		Estimated Actual Loading P	
		kg N/yr	Kg P/yr	Kg/yr	%potential	Kg/yr	potential
Mullett*	1038	13,553	2654	10,131	75	1575	59
Burt*	929	11,910	2332	7692	65	1516	65
Walloon	787	8567.5	1678	6711	78	729	43
Black	682	7426.2	1454	5392	73	808	56
Paradise	309	3363.8	659	2657	79	232	35
Crooked	391	4256.5	834	2947	69	361	43
Douglas	251	2732	535	1696	62	273	51
Pickerel	120	1306	256	811	62	131	51
Long	106	1154	226	854	74	94	42
Twin	81	882	173	710	81	57	33
Round	47	1941	100	266	52	59	59
Munro	63	685.8	134	399	58	84	63
Larks	36	392	77	242	62	34	44
Silver	45	489.9	96.0	401	82	28	29
Lance	26	283	55.3	142	50	42	75
Devereaux	26	283	55.3	225	80	18	33

*This data includes contributions to Burt Lake from septic systems along the Sturgeon (65 residences), and Crooked Rivers (100 residences), and to Mullett Lake from 207 residences along the Indian River

As indicated earlier, these loadings are a first estimate. To further quantify these values, a sampling program will be undertaken in the next phase of the project. Ground water and/or inshore lake water samples taken adjacent to houses on various soil types will be used to gain more insight into the actual effect of soil type on N and P contributions from septic tank effluent.

Total N and P loadings for the lakes as calculated to date are presented in Tables 15 and 16 . The values for runoff and drainage, i.e. nutrients coming from the watershed in stream flow, are based only on the immediate watershed, i.e., the watershed immediately surrounding that lake, and do not include nutrients which pass out of one lake and into another. Calculations of flow from one lake to another are currently under way and will be presented in the next phase of the report. The next stage of the project will also concentrate on a refined nutrient budget with the aquatic section. Included in this investigation will be dye tracer studies from septic tanks, analyses of stream flow in key transfer areas, a study on ground water movement near certain key indicator lakes in the watersheds. An outline of nutrient loading capabilities will also be calculated for each lake. This information will be essential to local community decision makers. Their decisions on the need for curtailing development in sensitive areas will be predicated on the aquatic section's ranking system and an index of nutrient loading capacity.

TABLE 15. TOTAL OF N SOURCES TO LAKES FROM IMMEDIATE WATERSHEDS IN NORTHERN LOWER MICHIGAN (KG N/YEAR)

Lakes	Precipitation and Dry Fall	Runoff and Drainage	Lake & Stream Side Septic Tanks	TOTAL
Arnott	74	744	--	848
Black	31,924	113,223	5,397	151,529
Burt	53,962	84,051	7,698	145,711
Carp	5,989	5,598	2,659	14,246
Cochran	87	181	--	268
Crooked	7,565	9,281	2,950	19,796
Devereaux	110	836	226	1,172
Dog	599	638	--	1,237
Douglas	10,827	4,685	1,698	17,210
French Farm	1,844	2,543	--	4,387
Hoop	23	117	--	140
Larks	1,907	343	242	2,492
Lancaster	164	3,061	--	3,225
Lance	77	692	142	911
Long	1,261	345	854	2,460
Mud Lake Bog	81	364	--	445
Mullett	52,417	53,701	10,140	116,258
Munro	2,187	767	399	3,353
Osmun	129	144	--	273
Pickerel	3,367	11,329	812	15,508
Roberts	169	392	--	561
Round	1,050	1,286	266	2,602
Silver, Wilmot Twp.	243	434	401	1,078
Silver, Koehler Twp.	243	548	--	791
Twin Lakes	662	380	711	1,753
Vincent	97	32	--	129
Walloon	13,617	7,603	6,717	27,937
Weber	90	254	--	344
Wycamp	2,024	5,241	--	7,265

TABLE 16. TOTAL OF P SOURCES TO LAKES FROM IMMEDIATE WATERSHEDS IN NORTHERN LOWER MICHIGAN (KG P/YEAR)

Lakes	Precipitation and Dry Fall	Runoff and Drainage	Lake & Stream Side Septic Tanks	TOTAL
Arnott	3	43	--	46
Black	1,418	6,223	809	8,450
Burt	2,397	4,621	1,518	8,536
Carp	266	308	232	806
Cochran	4	10	--	14
Crooked	336	510	361	1,207
Devereaux	5	46	18	69
Dog	27	35	--	62
Douglas	481	66	273	820
French Farm	82	140	--	222
Hoop	1	6	--	7
Larks	85	19	34	138
Lancaster	7	168	--	175
Lance	3	38	42	83
Long	56	19	94	169
Mud Lake Bog	4	20	--	24
Mullett	2,328	2,952	1,576	6,856
Munro	97	42	84	223
Osmun	6	8	--	14
Pickerel	150	623	131	904
Roberts	8	22	--	--
Round	47	71	59	177
Silver, Wilmot Twp.	11	24	28	63
Silver, Koehler Twp.	11	30	--	41
Twin Lakes	29	21	57	107
Vincent	4	2	--	6
Walloon	605	418	729	1,752
Weber	4	14	--	18
Wycamp	90	288	--	378

C. WETLANDS

RELATIONSHIP OF WETLANDS TO LAKE WATER QUALITY

Wetlands (marshes, swamps, bogs, and meadows) are important in determining quality of lake waters and seasonal flow rates into the lakes. In addition, they affect the quality and quantity of stream flow and ground water. They improve water quality by filtering out wastes and breaking them down, through microbial action, into simple inorganic compounds which can be taken up by the vegetation. Wetlands also regulate the seasonal flow of water by storing water temporarily during periods of high input due to snow-melt and rainfall,and discharging it during periods of low input. The effectiveness of individual wetlands in performing these functions depends on many characteristics including size, location, soil, vegetation, and relationship to the regional water table.

Our initial work focused on determining the impact of nearby homes and cottages on a bog ecosystem. Bogs make up a significant fraction of the wetlands in northern lower Michigan and may be especially sensitive to the growing pressure of man's activities.

In summer, 1972,we studied Bryant's Bog, a small peat bog located near Douglas Lake, because 1) the vegetation of the bog is undergoing major changes involving the death of most of the trees 2) cottages and houses have been built near the south and west sides of the bog in recent years 3) it had been hypothesized that the vegetation changes were related to the cottages and homes 4) aspects of this bog had been intermittently studied by staff or students of the Biological Station from 1917 to the present. Thus Bryant's Bog appeared to provide a good example of man's impact on one type of wetlands of importance to northern Michigan: a boreal bog.

To date, the following has been accomplished:

1) The bog was mapped and the present map compared to the one made in 1926 (*figure 24*). It was found that a small section of the western edge of the bog had been artificially filled with sand and gravel.

2) The open water areas in maps prepared in 1926, 1955, 1963, and 1972 were compared. Filling of the bog lake was shown to be a slow and irregular process with an average advance of the floating mat into the open water of 0.05 m (0.15 ft) per year.

3) The elevation difference between the water level of the open water in Bryant's Bog and the surface of Douglas Lake was the same as that measured in 1926, showing that bog drainage was unaffected by the construction of the nearby houses and cottages.

4) The vegetation data gathered by plant ecology classes under the direction of Dr. F.C. Gates between 1917 and 1954 has been summarized. The vegetation gradually changed from relatively open bog shrub communities to closed bog conifer communities.

5) The vegetation of the bog was sampled and described in terms of frequency, density, and dominance of the plant species present. Permanent plots were established to permit detailed analysis of vegetation

STATUS OF WETLANDS SURVEY, Emmet & Cheboygan Counties, Michigan
August 1974

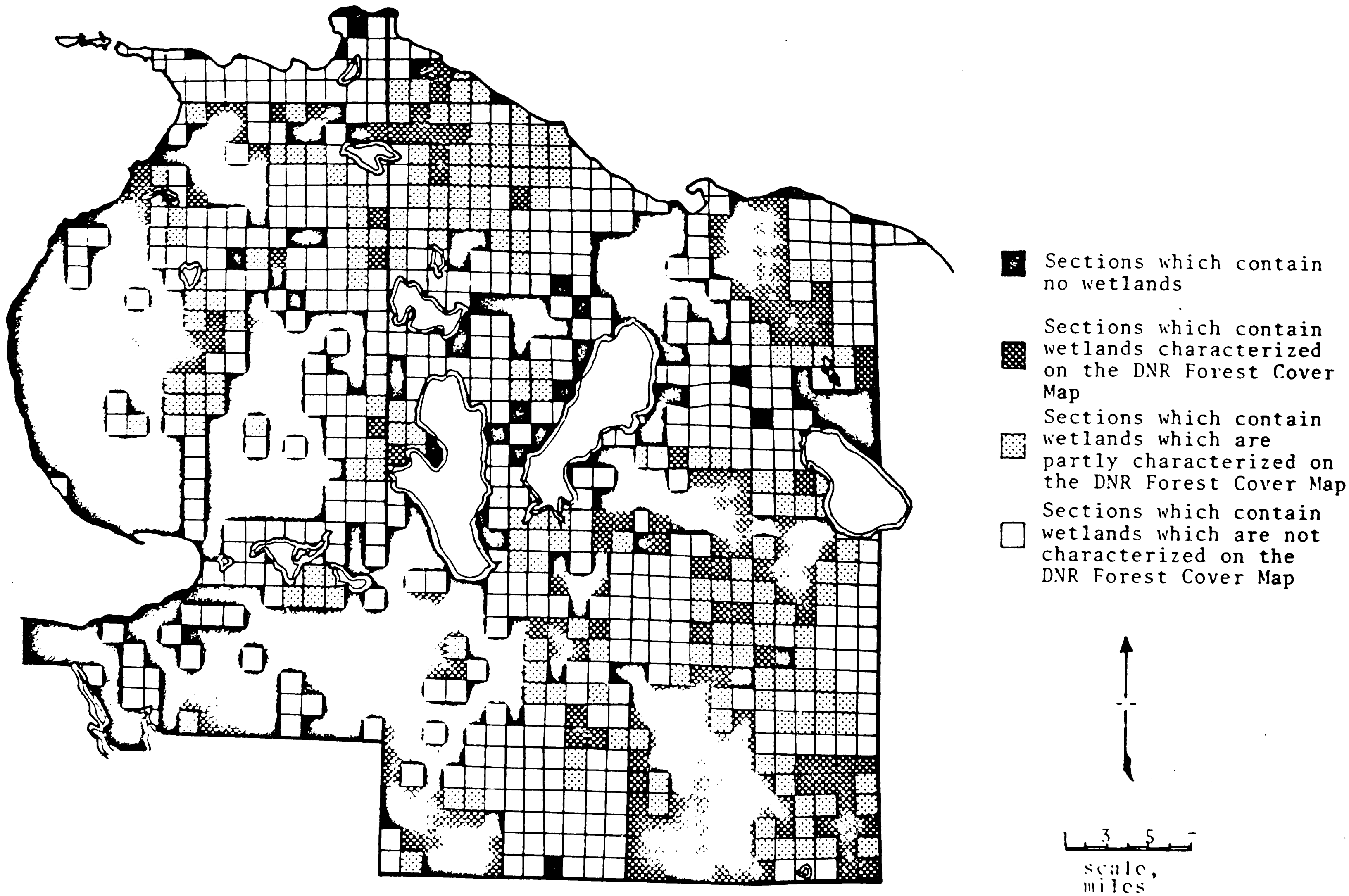


FIGURE 24

changes following the gradual decay of the dead trees now standing.

6) It was tentatively concluded that the changes in the bog were not due to man's activities but instead were caused by unusually high water levels due to natural causes responsible for the high water levels encountered throughout the region in recent years.

The study of Bryant's Bog was completed in summer, 1973 and the results were reported in an article entitled "Vegetation Changes in a Small Michigan Bog from 1917 to 1972" which has been accepted for publication by The American Midland Naturalist.

During summer, 1973, we shifted the focus of our work to finding the contributions of existing wetlands of all types (marshes, swamps, bogs, and meadows) to the maintenance of the present high water quality in the lakes of this region. This information is essential to the development of feasible management strategies for the maintenance of lake water quality.

The following procedure was adopted to study the relationships between the wetlands and lake water quality and to determine the contribution of the wetlands to lake water quality:

1) Determine the extent and location of the wetlands.
2) Characterize wetlands with respect to: a) soil type b) vegetation type c) presence and nature of inlets and outlets d) connection to regional ground water e) relationship to rivers and lakes, and f) chemical and bacteriological characteristics of waters flowing into and out of the wetlands.

3) Evaluate the importance of each wetland for water quality in related lakes.

Step 1, determination of extent and location of wetlands, was begun in summer, 1973 and continued during summer, 1974. The Forestry Division of the Michigan Department of Natural Resources (DNR) has already mapped the forest cover of wetlands owned by the State of Michigan and administered by the Forestry Division. This includes almost all of the publicly owned wetlands. Blueprints of these forest cover maps were obtained through the DNR. Each township is mapped on a separate sheet at a scale of 4 in. = 1 mile. Each sheet includes a base map of the entire township showing section lines, streams, lakes, roads, and settlements. The forest cover (including nonforested types of cover such as open bog and bare rock) of areas owned by the State of Michigan and administered by the Forestry Division is superimposed on the base map.

Extent and location data for wetlands in the two-county area was taken from U.S. Geological Survey 1:62,500 scale topographic maps. The topographic maps were optically enlarged and projected onto the forest cover maps and the outline of the wetlands traced onto the forest cover maps. The extent of DNR owned, Forestry Division administered wetland area and total wetland area was then determined with a planimeter. Forest cover maps are unavailable for a very small number of townships because they contain no DNR owned, Forestry Division administered land. The extent of the wetlands in these townships was determined by planimeter from USGS topographic maps.

The results of this survey are shown in Table 17. Emmet County contains 108.8 km^2 (42 mi^2) of wetlands making up 9.1 percent of its total land area. The State of Michigan owns almost half of these wetlands. Cheboygan County contains 308.2 km^2 (119 mi^2) of wetlands making up 14 percent of its total land area. The State of Michigan owns almost half of these wetlands. Public ownership of such a large fraction of the wetland area will facilitate the retention of these wetlands in their present state.

The present status of the wetland survey on a section-by-section basis is shown in Figure 24. In Emmet County, 53 percent of the sections contain no wetlands, 6 percent contain wetlands completely cover-mapped, 8 percent contain wetlands partially cover-mapped, and 33 percent contain wetlands that have not been cover-mapped. In Cheboygan County only 24 percent of the sections contain no wetlands, 20 percent contain completely cover-mapped wetlands, 18 percent contain partially cover-mapped wetlands, and 38 percent contain wetlands that have not been cover-mapped.

Step 2, characterization of wetlands, began in summer, 1974. Representative sites for each of the major wetland vegetation types found in the area (*Table 18*) were selected and sampled for dissolved chemicals in the groundwater at a depth of 15 to 30 cm (6 to 12 in) below the surface. The samples from one site were completely analyzed during the summer, while samples from the remaining sites were analyzed for pH, alkalinity, and dissolved oxygen on the day of collection. A subsample was frozen for further analysis during the winter.

TABLE 17

Extent and Ownership of Wetlands in Emmet and Cheboygan Counties, Michigan in 1974

	Emmet Co.	Cheboygan Co.	Both Counties
Total land area* - 1 km^2 (mi^2)	1191.4 (460)	2066.8 (798)	3258.2 (1258)
Total wetlands - km^2 (mi^2)	108.8 (42)	308.2 (119)	417.0 (161)
Total wetlands as percent of land area (%)	9.1	14.9	12.8
State owned+ wetlands - km^2 (mi^2)	51.8 (20)	152.8 (59)	204.6 (79)
State owned+ wetlands as percent of total wetlands (%)	48.6	49.5	49.0

*not including inland water

+land owned by the State of Michigan and administered by the Forestry Division of the Department of Natural Resources

TABLE 18

Dissolved Chemical Sampling: Sites and Schedule 1974

Vegetation type	Site location	Number of samples taken summer, 1974
Open bog	Mud Lake Bog	4
	Gates' Bog	3
	Bryant's Bog	4
Conifer swamp	Mud Lake Bog	3
	Pleasantview Swamp	3
	Reese's Bog	3
Hardwood swamp	Maple Bay Swamp	3
	Crooked River	3
Alder thicket	Pleasantview Swamp	3
Sedge meadow	Indian River Spreads	3
	Crooked River	3
Cattail marsh	Indian River Spreads	3
	Cheboygan Marsh	3

The same dissolved chemicals are being measured in wetland groundwater, terrestrial ecosystems and the lakes to help determine whether the wetlands are sources or sinks for dissolved chemicals.

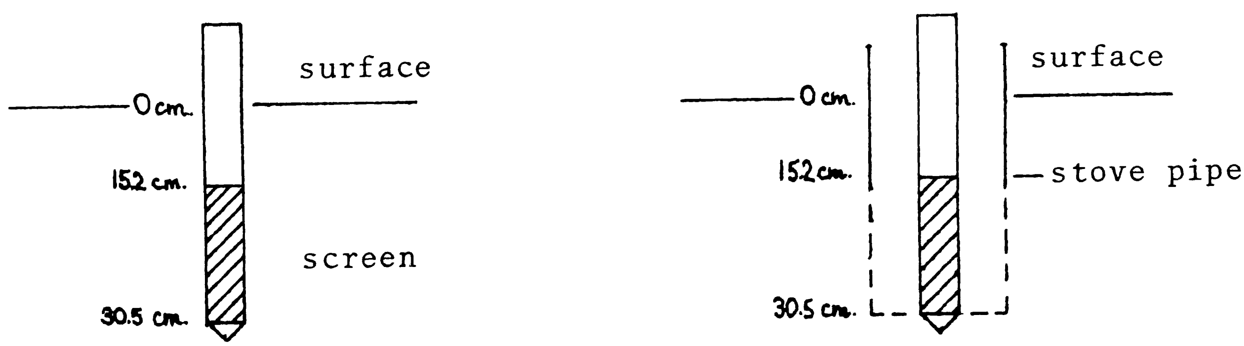
The sample sites were distributed among the major vegetation types to determine whether there is a correlation between the vegetation type and the concentration of one or more of the dissolved chemicals in the groundwater near the surface. If such relationships are found, the vegetation could be used as a crude indicator of the dissolved chemicals in the groundwater near the surface in the two-county study area. This would greatly facilitate preliminary surveys of the effects of particular wetlands on lake water quality in connection with land use planning and could be used to help select sample sites for detailed studies.

The following methods are used in collecting groundwater samples at each site, 15.2 to 30.5 cm below the soil surface. The points at which the individual samples are taken at each site are selected visually as being representative of the site (judgement sample). At each point, all vascular plant species present within a radius of approximately 6 m (20 ft) are recorded. A commercial well point with a 15.2 cm (6 in) long intake screen is placed into the ground so that the top of the screen is 15.2 cm (6 in) below the surface and the bottom is 30.5 cm (12 in) below the surface. If the soil is wet and loose, the well point is pushed gently to the desired depth.

If the soil is dense or dry at the surface, a piece of stovepipe is driven into the ground to a depth of 30.5 cm (12 in), the soil inside the pipe removed, the pipe pulled up to a depth of 15.2 cm (6 in), and the well point placed in the center of the hole so that it is firmly seated. The collection train is then assembled as shown in Figure 25. Water is pumped from the well until it flows clear. Duplicate samples are then collected for analysis for 1) dissolved oxygen 2) alkalinity and pH, and 3) dissolved chemicals. The samples for dissolved chemicals are collected in 8 oz. polyethylene bottles which are immediately put on ice. They are filtered through a millipore filter (0.45μ) in the laboratory as soon as possible, but always within 12 hours of collection, and then frozen until time permits further analysis. Dissolved oxygen, alkalinity, and pH measurements are completed in the laboratory within 12 hours of collection.

Preliminary results for some properties of the ground water are given in Table 19. Results for most of the dissolved chemicals are not yet available because the samples have not been completely analyzed. The pH values showed that all open bog sites were strongly acid, while the pH in the remaining vegetation types was near neutrality. The alkalinity in open bog sites was zero while in the remaining vegetation types it ranged from 75 to 180 mg/l $CaCO_3$ with no discernible relationship between vegetation type and alkalinity. In Maple Bay Swamp and in the sedge meadow on the Crooked River, one sample of the three had a very high alkalinity of 430 mg/l $CaCO_3$.

A. Placement of Well Point



B. Collection Train

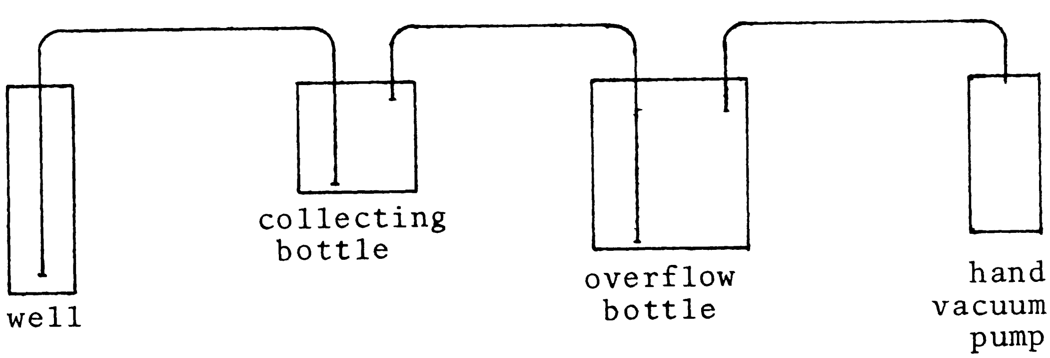


FIGURE 25 PROCEDURE FOR GROUNDWATER SAMPLE COLLECTION

TABLE 19

Preliminary Report of Wetland Ground Water Characteristics: Summer 1974*

Vegetation Type	Site Location	Date Sampled	pH	Alkalinity mg/ℓ as $CaCO_3$	Temp. °C	Diss. Oxygen mg/ℓ
Open bog	Mud Lake Bog	7/19	4.3	0.0	18.9	0.0
	Gates' Bog	8/15	3.8	0.0	13.9	-
	Bryant's Bog	7/15	4.3	0.0	18.9	0.0
Conifer swamp	Mud Lake Bog	7/26	7.0	129	16.1	0.05
	Pleasantview Swamp	8/6	6.7	139	15.0	-
	Reese's Bog	8/12	7.4	150	15.6	0.05
Hardwood swamp	Maple Bay Swamp	8/16	6.4	75	15.6	-
	Crooked River	8/1	6.8	199	16.7	0.11
Alder thicket	Pleasantview Swamp	8/13	6.8	137	16.1	0.0
Sedge meadow	Indian River Spreads	8/8	6.4	180	18.9	0.0
	Crooked River	7/31	6.5	127	17.2	0.2
Cattail marsh	Indian River Spreads	8/9	8.3	144	23.3	4.0
	Cheboygan Marsh	7/29	7.2	149	21.7	0.5

*all values are averages for three samples except for the open bog at Mud Lake and Bryant's Bog where values are averages for four samples

These extreme values are not included in the average values given in Table 19. The high values may be due to the presence of marl at the 15.2 to 30.5 cm (6-12 in) depth in the soil.

All sites except the cattail marsh had very low concentrations of dissolved oxygen. Several were totally anaerobic while all of the others contained less than 0.25 mg/1. Dissolved oxygen values were not obtained at some sites because very slow flow rates from the saturated soil into the well made the collection of samples uncontaminated with atmospheric oxygen extremely difficult and excessively time consuming. The dissolved oxygen values for the Cheboygan Marsh were surprisingly low, since by midmorning the photosynthetic activity of the abundant phytoplankton could be expected to replace oxygen depleted during the night.

The preliminary results indicate that with respect to the parameters studied, the open bog has unique pH and alkalinity values and that the presence of open bog vegetation may be used as a crude indicator of low pH and zero alkalinity. No apparent relationships exist between the remaining vegetation types and any of the parameters examined.

D. SOCIAL

Work on the social science portion of the Northern Michigan Environmental Program began in January, 1974 and has progressed according to schedule over the ten-month period which has elapsed. Our initial task aimed at expanding the study objectives set forth in the original proposal. This was accomplished by means of a more extensive assessment of the problems facing the region. Although we were familiar with many of the concerns of northern Michigan residents as a result of our early work during the pilot phase of the program, we continued to conduct meetings with people in the two-county area and others concerned about its future growth and development. Beginning in early winter and continuing through the summer months, a series of meetings were held with the program's User Committee, representatives of several lake associations; the Steering Committee,made up of professionals and technical personnel who could evaluate technical aspects of the research and finally, with staff members of the Water Resources Commission and the Land Use Planning Division of the Department of Natural Resources in Lansing. At the same time we were able to review other studies covering similar problem areas and explore various facets that could conceivably be investigated as part of our study.

As a result of the meetings and the more extensive literature review, new insights were gained as to the additional subject areas that might be investigated and some specific questions that might be addressed. Two issues which emerged were the public's perception of the role of local government in planning and managing growth and development; and perceptions of the environmental, economic and social impacts of different types of regional growth.

A discussion of each phase of the survey follows.*

SAMPLING

During the initial phase of the project, careful attention was given to the specific population that would be investigated. It should be noted that during the proposal development stage modifications were made in our approach to sampling based on comments of the NSF/RANN review committee. Rather than selecting a sample of 100 households from each of the large lakes in the region, a probability sample proportional to size of all lakes was selected. In this way, we will be able to characterize responses for the entire study area as well as make between-lake comparisons. Further modifications were made after commencing work. Specifically, we decided that in addition to inland lake residents, we would investigate the attitudes and behavior of people living on or visiting the navigable rivers in the two-county area. This procedure would allow us to include responses from people living in places undergoing rapid development. These people are also lake-oriented since the rivers in the region provide access to nearly all lakes. Our sample design enables us to compare responses of people on the major lakes with each other as well as with people along the rivers.

In addition to comparing lake and river residents, we were also interested in comparing responses of people living on different types of lakes. The lakes may be differentiated from each other by their size and depth, water quality, and the particular political jurisdiction (county) within which each falls. The objective of between lake comparisons according to these specific characteristics guided our approach to sample design.

As a first step in designing the sample, we needed an estimate of the total number of households around each lake and river in the two-county area. Using aerial photographs provided by USDA Agricultural Stabilization and Conservation Service, household counts were recorded for each lake and river. These counts were then mapped and divided into segments of approximately 12, 24, or 36 depending on the location of identifiable landmarks on the photographs. It had been determined earlier that sampling, interviewing and objective data collection would take place in clusters of 12 housing units so as to minimize study costs and have a substantial base for certain cluster comparisons on specific responses.

Working with the sketch maps depicting clusters containing 12 or multiples of 12 housing units, a sample across all lakes and rivers in the two-county area was drawn with the objective of gathering approximately 800 interviews. This probability sample identified the specific lakes and rivers and the segments on each of them from which our interviews would be taken. The housing units in the selected clusters were then listed in detail by driving through the area and counting houses. In this way, we were able to obtain a precise number of households on the ground and, at the same time, identify precisely the location, address or other identifying characteristics for the interviewers. With these detailed listings, the sample was then revised and listing sheets were prepared for approximately 1220 households. This represents roughly 20 percent of the total number of households around the lakes and rivers in the two-county area. After taking into account vacancies and estimated refusals,the sample of 1300 households was expected to yield approximately 800 interviews.

DESIGNING THE INSTRUMENTS

After our initial meetings with the user groups, the steering committee, lake association members and the DNR representatives, we began to design the questionnaire and the instruments to be used in collecting environmental data. Given the variety of topics that were to be investigated, our first task was to design a sequence of questions for each of the different groups that would fall in our sample. Specifically, the major groups of respondents whose attitudes and behaviors we were interested in identifying were year-round owners, seasonal owners, year-round renters and seasonal renters. The first part of our questionnaire, therefore, was designed to classify respondents according to these different tenure status. From that point, questions followed the major topical areas we wanted to understand for each group. For owners, these included people's assessments of community services and taxes, their feelings about their particular neighborhood and lake conditions, their attitudes toward local government, their assessment of their individual dwelling and the land associated with it and, finally, their use of leisure and non-leisure time. For renters who were seasonal, we asked about their reasons for coming to northern Michigan, their use of the area during non-summer months and their expectations for acquiring property in the future. Additional background characteristics covering all respondents were also obtained.

The first draft of the questionnaire was pretested in early May. Thirty questionnaires were administered to people living in southeastern Michigan who either a) owned property on a lake or river in northern Michigan in places other than Emmet and Cheboygan counties, b) had visited a cottage or home in northern Michigan, or c) were living on a lake or river in southeastern Michigan. The purpose of the initial pretest was to examine the suitability and sequencing of the specific questions that we had designed. Following the pretest, the questionnaire was revised and condensed. Two weeks later a second pretest questionnaire was administered to residents on lakes in Emmet and Cheboygan counties in locations outside of our sample segments. Additional revisions were made as a result of this effort. A final questionnaire was sent to the printers on June 7, one week prior to the beginning of our interviewer training.

In addition to the household questionnaire, data was collected on 1) characteristics of the residential properties covered by the household sample 2) the availability of specific recreation facilities, convenience shopping, public access sites and major commercial centers 3) characteristics of the lakes and rivers determined by the limnologists, and 4) rates of growth in various parts of our study area. Growth rates are based on 1960 and 1970 census data and records of septic tank permits issued in Emmet and Cheboygan counties for the period from 1970 to 1974.

Procedures were developed for gathering and quantifying the above data so they could be analyzed in connection with responses elicited from our sample of households.

CONDUCTING INTERVIEWS

After finalizing of the questionnaire we began to identify, hire and train people living in the two-county area as our interviewers. Contacts with local clergy, school superintendents and advertisements in several newspapers produced nearly 40 applicants. Beginning on June 10, 27 area residents began a one-week period of intensive training on interviewing procedures and questionnaire administration. Toward the end of that week sample listings of households were distributed to interviewers based on proximity to their place of residence. From June 15 through August 28, 829 interviews were conducted from our sample.

CODE DEVELOPMENT AND DATA PREPARATION

Shortly after the interviewing began, the research staff prepared draft codes for the questionnaire. The codes were completed after reviewing the first 50 or so questionnaires that were returned by our interviewers. When about 200 questionnaires were accumulated, six coders were trained and began the process of coding. As of mid-October, all questionnaires had been coded. Keypunching is now in process. At the same time, environmental data was timed to coincide with the completion of interview coding.

NEXT STEPS DURING THE GRANT PERIOD

During the next five months of the initial grant period, major efforts will be devoted to the analysis and interpretation of our data. We are allowing the period from 15 October to 15 November for building our computer files covering environmental data, lake characteristics, and individual responses. By early December, we expect to have initial runs covering descriptive characteristics of the population. These data will be presented in the Environmental Program's newsletter scheduled for early next year. Essentially, information will be available on the proportion of owners, renters and year-round seasonals who are living in the two-county areas and on each of the lakes and rivers. We will also know who moved to these areas in northern Michigan from different parts of the state and the reasons they came. Descriptive data will also be available on characteristics of residential properties including their size, market value, etc. Other descriptive information on people's use of time and their attitudes towards specific environmental and growth issues will be covered in the newsletter. The period from December through February will be devoted to further data analysis and initial writing of a first technical report. During this period, it is anticipated that meetings will take place with individuals from the users group who potentially will have urgent need for our findings. We hope that the meetings will help in determining the direction for our subsequent analysis. At the same time, the meetings will inform various users of the data about their potential with respect to planning and management.

V. UTILIZATION

BACKGROUND

The goal of our research program is to maintain and improve environmental and environmentally related social quality in northern Michigan and elsewhere, insofar as our research is applicable. The success of this goal depends as much upon the utilization of knowledge as it does upon the development of new information by project research. Therefore, this program has always had a very strong utilization effort since its application in June, 1972.

Northern Michigan is essentially a homogeneous region. It is a rural, sparsely populated area with small cities and towns, scattered farms, many lakes and wooded areas. The economy has always been relatively depressed compared to the richer farm lands to the south. It has for generations been the summer "playground" for the more affluent from the urban centers in lower Michigan and adjacent states. Although much of the economy in northern Michigan is geared to these "summer people" as they are locally termed, and much of the commercial property is either owned by or oriented to these non-residents, the regional "decision-makers" or "influentials" are still dominated by local people. Communications with these local decision-makers and citizens at all levels has been our primary utilization effort to date. We have continually asked these people for guidance to areas of greatest need while encouraging them to use our project information as it becomes available. We are firmly convinced that the utilization of new natural resource information will not occur, in this region at least, without local acceptance of the project. Citizens from northern Michigan have always had a basic distrust of governments, management schemes and information originating from "down-state". This is an attitude that prevails in many predominantly rural areas in the United States. It is their belief, often justified, that they are being manipulated for the benefit of those who do not reside permanently in the region. Recognizing this attitude early, we have continually stressed local relationships of the project. We have worked hard at developing a climate of acceptance, credibility and receptivity among local citizens for our project and its information. This does not mean we have ignored the regional and state natural resource managers, but the primary effort to date has been to build a strong local foundation of acceptance upon which we expect to build and diffuse informational links to the other, more widespread "users".

This effort has involved all menbers of the project staff, but by necessity it centered around those living and working at the Biological Station on a permanent basis. For the first year, this local effort was led by Dr. John E. Gannon. John had the great advantage of being intimately familiar with the region and its people through years of residence and study. He was therefore quickly able to establish rapport and communications with the local citizens. He developed many excellent contacts with which we have been able to build upon. With the second year of the project, utilization effort was formally assigned to our Public Information Scientist, William L. Foster. Mr. Foster also had the decided advantage of being a local resident for years. Prior to his assignment on this project he was a well respected teacher of biology at a local high school. Bill was able to pick up easily on the lines of communication already existent and he soon developed many new contacts as the program progressed.

Although we can point to numerous examples of "utilization" already spawned by this project, (several will be described in detail later in this report), the primary effort to date has been one of communication leading to a receptive climate for eventual utilization of the scientific information just now being made available by the research programs. During the remaining, final efforts of the project, stress will be placed upon this utilization of knowledge from the research program, and communication efforts will ease. These efforts will be guided by the Center for Research on Utilization of Scientific Knowledge (CRUSK) of the Institute of Social Research of the University of Michigan.

From the progress to date, we are confident that our utilization efforts will be highly successful, especially in the local region. We have the advantage of working in a region with a relatively sparse population, who have an awareness of the dangers of environmentally degrading development to a generally high quality natural environment. Our ultimate objective is to present this region as a "model" to which other regions with similar problems can refer. Efforts and results to date are reported below:

USER COMMITTEE

One of the first jobs of the Public Information Scientist was to compile an organized list of potential "users" of natural resource information. Over 300 names, positions, addresses and telephone numbers were assembled, including county, city, township and village officers; State Department of Natural Resources staff; lake association representatives and interested and influential citizens.

This list was distributed to project staff to aquaint them with these "decision-makers" and to provide quick reference for contact. A revision of this list is now underway in response to new appointments, recent elections and a better understanding of area influentials. From this list we developed our "User Committee" composed of carefully selected representatives. Each person selected has a specific role in natural resource decision making processes. This 36 person committee has township officers, county commissioners, planning commissioners, zoning administrators, district sanitarians, extension directors, state foresters, biologists, soil conservationists, water resource managers, county and regional planners, lake association officers and interested and influential citizens.

This Committee was asked, individually and as a group, to interact with our project staff. We looked to this Committee for guidance and direction on research problem selection and utilization procedures. In fact, our current research objectives were formulated largely upon comments and criticisms received at the earliest "User" meeting, during the pilot phase of this project.

Several all-day meetings with this Committee were held at the Biological Station. The format always included ample time for discussion and comments by the Committee members. This "feedback" to our project scientists from people concerned with practical resource management problems has proved invaluable. These meetings also acted as excellent focal points for future communications and, perhaps most importantly, it gave the resource managers a chance to interact with a scientific project during its formative stages.

One unforeseen but extremely significant spinoff of these meetings was the interaction between resource manangers, officials, and citizens of the two counties and regional commissions. Despite close geographic proximity at the very tip of northern lower Michigan, apparently very little real communication existed. Those in attendance quickly realized that environmental problems do not follow political boundaries. Planners, extension agents, sanitarians, commissioners, etc. started to interact and communicate on these regional problems in a new and constructive manner.

A "Field Day" was held in August, 1974 to inform the "User Committee" more fully about our research program. This day was designed to emphasize field work by giving each person a chance to experience field data gathering processes.

This Committee has been the single most important communicative avenue between the project and users. It has been vital to the project in many ways, especially in guidance, stimulation and personal contacts leading to assistance and cooperation. We plan to continue this Committee as well as strengthen and broaden its membership. Future meetings are already planned for 1975.

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

Excellent rapport and communication has developed between this project and the DNR Water Quality Appraisal Section. Mr. John Robinson, Chief of the Section, and Dr. Dennis Tierney, Supervisor of the Inland Lake Management Group have visited the Station many times and we have met with them in Lansing at their offices several times. These groups in the State DNR are viewing our project with great interest, particularly in as much as it may provide them with a model for future inland lake quality water appraisal efforts throughout the entire state. As a means to further communications between our project and the DNR, we actively encouraged location of a DNR staff member at the Station's Lakeside Laboratory. Early in 1974, Mr. Remy

Pattyn came to the Station to begin the establishment of a "Self-Help" program for water quality appraisal of inland lakes. (Briefly, the DNR "Self-Help" program is one in which local governments or lake association members will use, under DNR guidance, monitoring equipment to determine the water quality of their lake. Guidance takes several forms and includes seminars, instructive booklets and lay-oriented lake environmental publications. The community must agree to participate for a minimum of three years.) The placement of a DNR officer at our facility was a milestone in cooperative efforts between our groups and greatly facilitated communication.

The Office of Land Use of the State of Michigan has been an important contact at the state level. We have met with Mr. Carl Hosford, Director of the Office and his staff on several occasions. A recent publication of the State Land Use Office spelled out the relationship between our efforts...

> ...The Department of Natural Resources and the University of Michigan are cooperating in several areas of land-use research. The Departments' land agency is a member of the Steering Committee for the University of Michigan's Northern Michigan Environmental Research Program studying varous physical land capabilities and social attitudes in Emmet and Cheboygan counties...

A very important aspect of our communication effort has been interaction with DNR resource managers at the regional level. Steady contact and cooperation has been established with the regional Wildlife Habitat Biologist, Mr. Jeffery C.

Greene, stationed in our study area. He has attended all our "User" meetings and stops by our offices for informal discussions when in the vicinity. To better understand some of his responsibilities and management tools, several of our staff members participated in deer management surveys held on Biological Station property.

Mr. Greene called our attention to an area that needed ecological investigations. State biologists had identified a 100 acre cattail marsh in our study area (at the mouth of the Cheboygan River in the city of Cheboygan) as one of the most extensive cattail marshes on the Great Lakes. The land was in mixed public-private ownership and a request for a dredge permit along with questions from public and private groups as to its use brought to attention the need for an immediate baseline natural history and water quality study. Within days our Public Information Scientist was able to coordinate an effort that placed two graduate students in the marsh for an eight week, concentrated natural history study. Mr. Robert Thobaben and Mr. Douglas Woodby presented three papers and a series of short reports to the DNR covering the birds, mammals, macrophytes, algae water quality and productivity of the area. Project scientists advised and guided the two graduate students on various aspects of their study. A local newspaper editor, Mr. J.W. Cohoe, was invited by the Public Information Scientist to accompany the graduate students through the marsh on one their morning field trips, thereby initiating a series of articles and photographs as the project progressed. As a result of these articles in the Cheboygan News, awareness of both our project and the marsh's diverse, productive habitat was enhanced.

Also at the regional level we are in contact on a routine basis with Mr. Ed Ecker, forester and Mr. Mason Shouder, fisheries biologist, as well as local conservation officers.

UPPER GREAT LAKES REGIONAL COMMISSION

We have recently established contact with the Upper Great Lakes Regional Commission, a Federal agency concerned with northern Michigan, Wisconsin and Minnesota. Through meetings with Mr. Alex Laggis, Michigan liaison and the Governor's representative, we have begun plans to jointly sponsor (with the Department of Natural Resouces) an "Inland Lakes Conference" to be held in northern Michigan. This conference would bring together all agencies and organizations concerned with Michigan inland lakes, to develop a concerted research and management effort for these extremely important natural systems. Tentatively planned for spring, 1975, the conference will be the first in what we hope to be a series of similar meetings.

REGIONAL PLANNING AND DEVELOPMENT COMMISSIONS

From the very beginning of the project, regional planning and development commissions have been involved with our research efforts. Because of our geographic location (at the tip of lower Michigan) our research area is split into two regional development commisions. Cheboygan county is included in the Northeast Regional Planning and Development Commission and Emmet county is a part of the Northwest Commission. George Byelich, natural resource planner and Jon Mersman, regional planner of the Northeast Commission, have participated substantially in the project design as a result of numerous contacts. Mr. Gregory Piaskowski, associated planner of the Northwest Commission, has attended our "User Committee" meetings and maintains routine communications with our staff.

CHEBOYGAN COUNTY

The most important contact in Cheboygan county has been Mr. Carl Burgtorf, zoning administrator. His insights into the county's communication pathways and urgent environmental concerns have been invaluable. Carl also took the time to give us a detailed plan for project involvement in Cheboygan county.

Regular monthly meetings have been held with the Cheboygan County Technical Advisory Committee. This committee makes recommendations on environmental matters to the Cheboygan County Board of Commissioners and other local governing bodies which may request assistance. In addition to representatives from this project, the committee consists of the local Sanitarian; a representative from the Northeast Regional Planning and Development Commission; County Extension Administrator; County Zoning Administrator; Soil Conservationist; State Forester;

County Roads Engineer and the Chairperson of the Board of County Commissioners.

We have also been in close contact with State Health Department District No. 4 in Cheboygan county through Sanitarian Michael Kavanaugh. He is familiar with our project and we have helped him in our water chemistry laboratory with quickly needed fluorometric determinations. His input at "User" meetings have been substantial.

The project staff were invited to give a presentation before the Cheboygan County Board of Commissioners. From this early contact, we have asked Mr. Ralph Hammer, Chairperson of the Rivers and Watercourses Committee, to represent the Commission on the "User Committee". As our information resources grow, we plan to ask for another presentation to the fifteen member board.

EMMET COUNTY

Contact was made with Ms. Ann Smith, Emmet County Commissioner, when she attended our August 1, 1974 "Field Day". Also contacted was a newly elected commissioner, Ms. Pauline Mengebier, who has indicated interest in our project and plans to attend future "User" meetings. A presentation to the entire eleven person board is planned for spring, 1975.

Mr. Max Putters, Emmet county planner, has followed our project closely. His comments have been especially helpful since he is a professional planner, one of the very few in the region.

State Health Department District No. 3 regulates Emmet county. Sanitarian William M. Henne and Environmentalist Ward Bollinger have been involved with our project from the first "User" meeting. We have been able to assist them several times with chemical determinations that could not have been obtained through their normal channels.

TOWNSHIPS

The townships are truly the "grass roots" of decision-making in Michigan, with many dedicated but often untrained officials making important land-use decisions. Our research areas include 32 townships (19 in Cheboygan county; 13 in Emmet). Most of them have some lake frontage under their jurisdiction and all exist in various lake watersheds. Even though county-wide zoning ordinances exist in the two counties, townships may supercede (for better or worse) the county ordinances with their own ordinances, or they may accept the county's as their own.

An attempt to organize concentrated communication with all 32 townships was not deemed feasible, so a diffusion approach was attempted. We began to work with a few townships to help with immediate problems or with townships that expressed specific interest in our project. Future plans call for a workshop specifically geared to townships and natural resource problems. This workshop would probably be in cooperation with the Michigan Township Association.

Individual township contact began with Munro township which contains all of Douglas Lake and three other study lakes. Contacts of long standing were renewed with township supervisor, Carl Bonnett, a pioneer of the area. Regular attendance and a representation at all township meetings was initiated. At these meetings, the supervisor and board always were willing to give the Public Information Scientist the floor for progress reports from the Biological Station.

Other townships have become informed of our project through various contacts. By the invitation of the Pickerel-Crooked Lakes Improvement Association, we made presentations to Little Field and Little Traverse Township Boards in Emmet county. These two townships have jurisdiction over the Crooked Lake shoreline. They were therefore interested in our water quality studies and pleased with the fact that a project of such applied nature was in progress. These townships have been faced with serious land-use decisions because several large developers have sought approvals from them for various development projects.

The Nunda Township Board in Cheboygan county, faced with land-use decisions in conjuction with Wildwood Lake, have followed and expressed genuine interest in the project.

LAKE ASSOCIATIONS

There are 20 associations in the study area that are comprised of lakefront property owners concerned about the improvement and protection of their lake and surrounding environment. As with townships, it was deemed unfeasible to work with all of them. Instead, working relationships were established with associations requesting information, and preliminary contact was made with the remainder. Special activities which have been carried out with several associations are discussed below.

We have worked closely with the Douglas Lake Improvement Association for several years through the Founder, Mr. Lynn Kellogg and officers, Mr. F. Johnson and Mr. J. Day. We conducted several meetings with these gentlemen during summer, 1974. Since the Biological Station is a member of the association, we have a close working relationship with other members. This experience should greatly help when working with other associations.

The Douglas Lake Improvement Association was the first association to print, verbatim, our initial "Lakeland Report" in their newsletter to 200 members. A "coffee" was held for association members in late August, 1974 to create a more personalized communication with "our neighbors".

In September, 1974, Dr. Christopher Sower (Social Scientist at Michigan State University and Chairperson of the Ecology Committee for the Pickerel-Crooked Lakes Association) came to our project for help. A new sewer was to be constructed on the north shore of Crooked Lake and then linked with the city of Harbor Springs sewage treatment system. It was general knowledge that the water quality of Crooked Lake was below average and, at first, the new sewer system appeared to alleviate environmental degradation eliminating ineffective septic tanks. However, the association expressed concern that the new sewer might cause greater problems by opening up wetland areas not presently available for building because of strict enforcement of sanitary codes in Emmet county . The association visualized the impact of new development in wetland areas adding to the already crowded waters of Crooked Lake. They wanted information on water quality and wetlands, and eventually decided to print an informative booklet entitled "Will We Save Our Lakes? The Time for Decision is Now!". We contributed a section on water quality based upon our studies and a statement on the importance of wetlands to lake ecology. Contacts with the association continued through the spring of 1974 when the committee members were able to make the presentation themselves. It is important to note that after helping them get started, they "carried the ball" and continued to present their own case for wetland protection.

Wildwood Lake is the only lake in our study area created expressly for shoreline development purposes. Because of a poorly conceived and excuted plan by the lake developers, the residents have serious lake problems. Even before residents became offficially organized, they were individually asking for advice about rehabilitation and restoration of their lake. At our urging, they formed an official organization to better enable themselves to have a systematic and united approach to their problems. Project staff met with them several times. Some information on Wildwood Lake gathered by the project was given to the property owners at their request.

Black Lake Association, one of the oldest and strongest lake associations in the state, has followed the project closely from its beginning. The importance of continued contact with this association lies in the fact that it provides the opportunity for total communication with shoreline property owners of a major lake in our study area. We have made numerous presentations to that association and we hosted a tour of our research facility for the Black Lake Association in the fall of 1974.

The other major lakes in the region are represented by several associations each. We hosted several coffee discussions for Burt and Mullett Association representatives to talk over common problems.

THE MICHIGAN LAKE AND STREAM ASSOCIATION

The Michigan Lake and Stream Association is dedicated to the conservation and improvement of Michigan's inland waters. Individual lake associations, including many in our study area, are members of this state-wide organization. This association has become effective in encouraging formation of lake associations by riparians and in assisting them with solutions to common problems. We have established close contact with two regional vice-presidents having responsibility for lakes and lake associations in our study area and we have given presentations repeatedly at their regional meetings in northern lower Michigan. Dr. John Gannon has taken part in their annual meeting during the past two years.

The Michigan Lake and Stream Association publishes the quarterly magazine "Michigan Riparian". Ms. Mary Vanderlaan of the project staff published a two-part series on inland lake zoning in the magazine and we are preparing another article concerning our project next spring.

BONNETT WASTE DISPOSAL PROJECT

One of the more unique interactions in which we were able to directly apply research for immediate need came when one of our "User Committee" members, Mr. Charles Bonnett, asked our advice on a solid waste disposal project. Besides being one of the most successful farmers in Cheboygan county, Mr. Bonnett is active in township and county projects and is Cheboygan county's Soil Conservation District Chairperson, a member of the Cheboygan County Road Commission and is on the Planning Commission. He has been quite concerned about solid waste disposal problems. Consequently, he designed an experiment to see if paper sludge waste from the Charmin Paper Mill in Cheboygan could be of use on farm lands. The sludge is now being dumped in a sanitary land fill. With the assistance of Dr. Lee Jacobs, soil scientist at Michigan State University, Mr. Bonnett is testing whether or not the sludge will increase yield in one of his cornfields. We are co-operating on the study by analyzing water swmples in an adjacent pond in order to detect any adverse changes in water quality due to the sludge application. Results from the first season have yet to be fully analyzed but plans are underway to continue the experiment in this unique and cooperative effort.

HEARINGS

At various times, our project scientists and staff have been called upon to make presentations at water quality and land-use hearings. Both private citizens and resource managers made the original contacts with our staff. Following are reports of our factual testimony.

Tamarack Development is a planned development of condominiums (96 units) on 520 feet of the north arm of Walloon Lake. Since the Bear Creek Township Board and the Walloon Lake Association expressed concern over the proposed development, a hearing to express views was held. At the invitation of one of the members of the "User Committee", project scientist Dr. John Gannon presented a statement on water quality and explained the high shoreline development factor on Walloon Lake. At the present time, approval for the plan is pending.

Our research staff, at the request of Cheboygan County Zoning Administrator, Carl Burgtorf, made statements at a hearing on a planned development of Mud Lake in the Indian River marsh area. Out testimony was primarily concerned with the impact of the development on the marsh and therefore on Mullett Lake downstream. The outcome is pending, but the testimony did lead to a cordial meeting with the developer at the Biological Station and his interest in our further work on the environment of the proposed area.

LAKE KATHLEEN

Lake Kathleen is an impoundment on the Maple River, Emmet county (figure 5). It was created for development purposes by the owner who wished to ring the lake with a number of homes and build a golf course on its' shores. With full cooperation of the owner, program personnel at the Biological Station and a team of limnology students launched an intensive study on the lake during the summer of 1973. Our objectives were to provide baseline data on water quality of Lake Kathleen with special emphasis on its sensitivity to change by human impact, and to critique the owner's plans for development of the area from an environmental viewpoint.

A written report containing our findings was submitted to the owner. Subsequent meetings were held by the owner with people involved in natural resource management in Emmet county. This is one of the first times natural resource managers were consulted before a development was started. They remarked that most of the time they are called in <u>after</u> environmental damage had occurred due to poor planning. No new development has been initiated at Lake Kathleen to date, but this is one of the first occasions where carefully prepared information in environmental sensitivity has gone into plans for a future recreational development in northern Michigan!

TWIN LAKES

Our attention was drawn to a state forest campground problem on Twin Lakes, Cheboygan county, by concerned residents of the area. The first state campground was built on "Isolated Basin" many years ago. It was officially abandoned long ago, although campers continued to use the old site and the soil banks developed serious erosion problems. A second campground was built on basin "A" of the Twin Lakes chain. Serious erosion problems due to human activity occurred there also and that campground site was abandoned in late May, 1974. No attempt was made to stabilize erosion and restore vegetation on the two abondoned sites. A third site was recently constructed on basin "C" and was opened to the public during Memorial Day weekend, 1974. We joined local residents in their concern about degredation of water quality in Twin Lakes from increased silt and nutrient loading through run off and seepage from the badly eroded campgrounds. Based upon our water quality studies on Twin Lakes, we were able to prepare a report on the water quality status of Twin Lakes with special reference to the sensitivity of this water body by human impact. We concluded that erosion control measures should be initiated immediately to restore the land to its inherent beauty and safeguard water quality of this fragile aquatic resource. Present practices of building a campground, watching it erode, abandoning it, and building a new one down the shoreline do not seem to be in accordance with the sound land-use planning. The DNR has since announced allotment of $3000 for soil erosion abatement and reseeding of at least one of the old campground sites.

ENVIRONMENTAL ASSOCIATIONS

We placed environmental "activitists" on the "User Committee" as a deliberate attempt to further communications with local resource managers and the various environmental groups. We have also initiated a unique approach for contacting these groups. Since local environmentalists are generally interested in recreational activities such as hiking, cycling, ski touring and bird watching, we have invited them to the 10,000 acre Biological Station for outings. The Cheboygan Cross County Ski Club and the Little Traverse Group of the Sierra Club (Petoskey) have had a joint cross country ski tour on our grounds accompanied by Biological Station staff. These outings have given us an opportunity to informally discuss our project. We also hosted a joint meeting with the Petoskey Regional Audubon Society and the Little Traverse Group of the Sierra Club in May, 1974 for a day of hiking and exploring, followed by a pot luck dinner in the evening and a presentation of our project by two of the project scientists. Approximately 100 people were in attendance.

FIELD CONTACTS

Contacts with the general public through field personnel can not be underestimated. The 28 people conducting the social science interviews came in contact with several thousand people during the survey of 829 residents. Mr. Chris Hansen, in collecting over 200 residential water samples, provided important public information contact. When residents showed special interest in our project, they were given a project summary. Since the beginning of lake sampling, field and survey teams have come in contact with scores of interested lake residents. Through this kind of communication, rapport has built up as they see and are able to feel a part of the research action. It was quite surprizing to note how quickly news of the project spread through the community, simply by word-of-mouth.

THE MEDIA

Communications with the general public through the media has been both excellent and extensive. The Public Information Scientist has developed fine contacts with editors, reporters, and broadcasters. Four local newspapers, three radio stations and two regional television channels have carried material about the project.

OTHER CONTACTS

As time permitted, numerous talks and speeches have been given to local groups, club and societies. Groups are toured through the Biological Station and countless requests for information are received and responded to by the project staff, but primarily by the Public Information Scientist.

Initially, such activities were given relatively high priority by the staff, but as awareness of the project increased in the region, less time was given to general communications and more time was centered on specific contacts.

PUBLICATIONS

In order to facilitate dissemination of project progress and findings, the following non-technical publications have been created:

1. Project Summary: "Northern Michigan Environmental Research Program"

   A five page, stiff-cover report, summarizing our project. Written for the interested citizen. Five hundred copies were printed and over 450 have been distributed.

2. Newsletter: "Lakeland Report"

   This publication, the first of a series, was designed to interest the general public, especially the water-oriented resident. Distribution was directed through lake associations for inclusion in their fall newsletters. To this date, over 500 have been circulated with an expected audience of 1,000. The news media have also used portions of the report in featured articles.

3. Informational Reports:

   A series of reports exploring man and his environment in northern lower Michigan. The series will provide background information for use in future land-use considerations. Drafts of the first two reports on natural features of the region and history of land-use in the area have been prepared.

VI. CREDITS AND ACKNOWLEDGEMENTS

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VIII. APPENDICES

APPENDIX A

APPENDIX A

CODING INSTRUCTIONS FOR RANN DATA INDICES

LAKE:

Arnott	01	Spring	25
Black	02	Mullett	26
Bryant's Bog	03	Munro	27
Burt	04	Osmun	28
Carp	05	Pickerel	29
Charlevoix	06	Roberts	30
Cochran	07	Round	31
Cornwall Creek	08	Silver (Cheboygan Co.)	32
Crooked	09	Silver (BSA)	33
Devereaux	10	Twin - A	34
Dog	11	Twin - B	35
Duby	12	Twin - C	36
French Farm	13	Twin - D	37
Hackett	14	Twin - E	38
Hoop	15	Twin - F	39
Sixteen	16	Twin - G	40
Larks	17	Twin (Isolated)	41
Lancaster	18	Vincent	42
Lance	19	Walloon	43
Livingston Bog	20	Weber	44
Long	21	Wildwood	45
McLavey	22	Wycamp	46
Mud Lake Bog	23	Stoney Creek	47
Mud (Emmet Co.)	24	Twin (Total)	48

DATE:

Fall 72	1	Winter 74	6
Winter 73	2	Spring 74	7
Spring 73	3	Summer 74	8
Summer 73	4	Fall 74	9
Fall 73	5		

STATION: If only one station, enter 1
If more than one, number consecutively from 1

TYPE: Physicochemical parameters

Secchi Depth and Color	01	Potassium	11
Temperature	02	Sodium	12
Light Penetration	03	Chloride	13
Turbidity	04	Chlorophyll *a*	14
pH	05	SiO_2	15
Dissolved Oxygen	06	Soluble PO_4	16
Alkalinity	07	Total PO_4	17
Conductivity	08	NO_3-N	18
Calcium	09	NH_3-N	19
Magnesium	10	Phaeopigments	20

RELATIVE DEPTH: Number from 01 consecutively up to 39. 01 should represent the first reading or sample in a series (usually at a specific depth of 0 meters) at a specific lake, time and station. 02 should represent the second reading or sample in that series, 03 the third, etc. The specific depth related to the relative depth will be entered in the respective DATA section of the log.

TYPE: Morphological parameters

Maximum Depth	01
Mean Depth	02
Maximum Length	03
Maximum Width	04
Mean Width	05
Shoreline Length	06
Surface Area	07
Watershed Area	08
Volume	09
Shoreline Development Factor	10
Volume Development Factor	11
Watershed Area/Surface Area Ratio	12

DATA ENTRY: PHYSICAL & CHEMICAL

SPECIFIC DEPTH:
Enter depth in meters of sample or reading. Use 1 digit (or decimal) per column. Make sure that the relative depth index is appropriate for this depth.

DATUM:
Enter datum, using 1 digit (or decimal) per column.

UNITS:
Enter units of measure appropriate to the datum. Abbreviate to 4 characters or less.

NOTE
When transcribing Secchi Depth & Color, enter Color (Arabic Numerals) in the Specific Depth field, the Secchi reading in the Datum field, and M (to right) in the Units field

DATA ENTRY: MORPHOLOGICAL

The procedure is the same as for physical and chemical data entry, except that only Datum and Units are appropriate.

APPENDIX B

APPENDIX B

INSTRUCTIONS FOR USE OF RANN - A CONVERSATIONAL DATA RETRIEVAL SYSTEM

RANN, a conversational data retrieval system written in FORTRAN IV, was created to help cope with the problems of storage, manipulation, and accessibility that are associated with the large quantities of water quality data being collected, collated, or otherwise compiled as a result of the NSF-RANN program at the University of Michigan Biological Station.

Each piece of data has been stored on computer files, with each type of data indexed as follows:

Physical/Chemical:Lake,Station,Date(Season),TypeofData,Depth(Relative)

Morphological:Lake,TypeofData

(See APPENDIX A for a detailed description of the parameters and the associated indexing system.)

The user initiates a data retrieval session using the command RUN RANN. The computer will then ask for indices. The user then enters a string of parameter keywords which specify the datum(a) to be retrieved.

The first keyword in the list should describe if physical/chemical or morphological data is to be retrieved. Keywords for these are PHYsical, CHEmical, and MOrphological, respectively. The whole word may be used, or just the capitalized, underlined portion (smallest significant abbreviation).

If either PHY or CHE is specified, it must be followed by a string of five (5) parameter keywords, one (1) from each of the following categories: lake, station, date, phys/chem data type, and relative depth. See Tables I through V for descriptions of these parameter keywords. If MO is specified, it must be followed by a lake parameter keyword, and a morphological data type parameter keyword (See Tables I and VI).

General "grammatical" rules are as follows:

1. A comma must follow each parameter keyword.
2. There must be no blank spaces between a comma and the following parameter keyword.
3. There must be no blanks between a comma and the preceding parameter keyword unless it happens to be part of a smallest significant abbreviation, such as MUD (Mud Lake Bog)
4. The parameter keywords may be in any order in the list.

A special keyword, ALL, is available to enable the user to specify an array to be retrieved. If specifying PHY/CHE data, ALL may be substituted for one (1) of the required parameter keywords. The system will then retrieve data for the entire range of the keyword replaced, the other parameters remaining constant. For example, the input list PHY,BURT,1,ALL,TEMP,SUM73 will retrieve the temperature profile obtained for Burt Lake (Central Station) during summer, 1973. If MO data is being specified, ALL may be substituted for either or both parameter keywords, with results equivalent to those obtained when used with PHYS/CHEM data.

Output from the system is as follows:

PHY/CHE Data:

5 Integer Numbers   Depth   Data   Units (if any)

Lake Index, Date Index, Station Index, Type Index, Rel Dep Index

MO Data:

2 Integer Numbers (Lake Index, Type Index)	Data	Units (if any)

If no data exists for the parameters specified, nothing will be printed. Abbreviations of units employed appear in Table VII. (See Appendix A for identification of the particular index numbers)

Misspellings, underspecification, and overspecification are detected by the system, and generate the printing of an appropriate error comment. Input errors which do not fall neatly into one of those categories will be detected, but the ensuing error comment might not elucidate the problem.

To terminate a retrieval session, enter a dash (-) instead of a parameter keyword list. If, at any time, the user wants to stop the program while it is retrieving data, the BREAK button on the terminal keyboard should be pushed. After the "Attention Interrupt" message has been printed, the BRK-RLS button (which will be illuminated) on the upper right hand side of the terminal should be pushed. If additional data retrieval is necessary, RUN RANN must be given again.

An example of a computer print-out of physical chemical data appears in Table VIII. The print-out of the morphometric data appears in the Text (Table 5).

TABLE I LAKE PARAMETER KEYWORDS

ARNott
BLack
BRyant's Bog
CARp
CHArlevoix
COChran
CORnwall
CRooked
DEvereaux
DOG
DUby
FRench Farm
HAckett
HOop
LANCAster
LANCE
LARks
LIVingston Bog
LOng
MClavey
MUD lake Bog
MUD-emmet Co.
MULlett

MUNro
Osmun
PIckerel
ROBerts
ROUnd
SILVER-BSA
SILVER-Cheboygan Co.
SIXteen
SPRing
STone Creek
TWIN-A
TWIN-B
TWIN-C
TWIN-D
TWIN-E
TWIN-F
TWIN-G
TWIN-Isolated
*TWIN-Total (*Appropriate only for morphological data)
VIncent
WALloon
WEber
WILdwood
WYcamp

TABLE II DATE PARAMETER KEYWORDS

FALL72
WIN73
SPR73
SUM73

FALL73
WIN74
SPR74
SUM74
FALL74

TABLE III STATION PARAMETER KEYWORDS

1
2
3 (Must consist of one and only one digit)
4
5

TABLE IV RELATIVE DEPTH PARAMETER KEYWORDS

01
02
etc.
... (Must consist of two and only two digits)
....
....
38
39
or,

Special Relative Depth Parameter Keywords:

Surf - Equivalent to 0.0 meters

Bottom - Equivalent to the greatest depth for which a piece of data was obtained for a specified lake, date, station, and physical or chemical data type

TABLE V PHYSICAL/CHEMICAL DATA TYPE PARAMETER KEYWORDS

ALKalinity
CAlcium
CHLorophyll-a
CL (Chloride)
CONductivity
DO (Dissolved Oxygen)
K (Potassium)
LIGht Penetration
MG (Magnesium)
NA (Sodium)
NH3-n
NO3-n
PH
PHAeopigments
PHOS-Soluble
PHOS-Total
SEcchi (Output includes color)
SIO2 (Silica)
TEmperature
TUrbidity

TABLE VI MORPHOLOGICAL DATA TYPE PARAMETER KEYWORDS

AREa ratio	(Lake Area ÷ Watershed Area)
MAX-Depth	
MAX-Length	
MAX-Width	
SDf	(Shoreline Development Factor)
SHorelength	
SURFAce area	
VDf	(Volume Development Factor)
VOlume	
WATershed area	

TABLE VII COMMON UNITS ABBREVIATIONS

PPM: Parts per million
PPB: Parts per billion
%SAT: Percent saturation
%TRN: Percent light transmission
C: Degrees Centigrade
M: Meters
MG/L: Milligrams per liter
CUBM: Cubic meters
SQKM: Square kilometers
KM: Kilometers
HECT: Hectares
CUKM: Cubic Kilometers

APPENDIX C

PRELIMINARY DATA FROM THE SURVEY OF LAKE-ORIENTED RESIDENTS

TABLE 1

Household Characteristics of Northern Michigan Residents, by County
(percentage distribution of respondents)

Household Characteristics	Cheboygan	Emmet	Presque Isle	Charlevoix	All
Second Home Owners	51	46	41	57	49
Year-round Residents[a]	31	36	26	15	31
Vacationers[b]	18	18	33	28	20
TOTAL	100%	100%	100%	100%	100%
Number of Respondents	501	214	39	72	826

[a] Year-round residents include owners, renters and those who neither own nor rent.

[b] Vacationers include seasonal renters and those seasonal residents who neither own nor rent.

TABLE 2

Primary Residence of Second Home Owners and Vacationers, by County[1]

(percentage distribution of respondents)

Permanent Residence	Cheboygan	Emmet	Presque Isle	Charlevoix	ALL
Michigan	73	58	87	45	68
Wayne (Detroit)	22	17	42	12	
Oakland and Macomb	18	14	17	11	
Ingham, Eaton and Clinton (Lansing)	7	6	0	4	
Washtenaw, Livingston, Monroe	4	1	4	2	
Bay, Saginaw and Midland	3	2	14	4	
Emmet, Cheboygan, Presque Isle	3	5	3	5	
Calhoun, Kalamazoo, and Jackson	4	2	0	2	
Other Michigan counties	12	11	7	5	
Ohio	12	20	10	16	14
Indiana	5	13	0	20	8
Florida	4	1	0	5	3
Other states	5	8	3	14	7
	100%	100%	100%	100%	100%
All second home owners and vacationers	317	126	29	56	528

[1]Figures do not include the 46 respondents who are seasonal respondents who are seasonal residents, using the waterfront residence as their main voting address.

TABLE 3

Impact of the Energy Crisis on Vacation Plans of Second Home Owners and Vacationers

	Percent of Respondents Reporting Energy Crisis Influenced Plans[1]	Number of Respondents
Second Home Owners	24	97
Vacationers	17	28
ALL	22	125

[1] The question was: "Would you say that the cost and availability of gasoline influenced your vacation plans this summer quite a bit, somewhat, or not at all?" Figures represent respondents who answered "quite a bit" or "somewhat".

TABLE 4

Attitudes Toward Growth and Development
by Household Characteristics
(percentage distribution of respondents)

Amount of Growth and Development Desired[1]	Second Home Owners	Year-round Residents	Vacationers	ALL
A Great Deal	3	7	1	4
Some (or) a Little	69	72	72	71
None at All	28	21	27	25
	100	100	100	100
Number of Respondents	396	253	158	807

[1]The question was: "How much growth and development would you personally like to see in this area -- a great deal, some, a little, or none at all?"

TABLE 5

Reasons People Like to be in Northern Michigan[1]
(percent of 2011 reasons given)

Peace and quiet of area, solitude, not crowded; away fron city problems, crime, traffic, noise	24
Water and lakes, inland waterway, Great Lakes	13
Natural setting; outdoors, trees and animals, the country	11
Recreation opportunities, skiing, sailing, hunting, fishing, etc.	11
Climate, weather	10
Clean air and water	8
Familiarity with area: lived here all my life, have visited area frequently	7
The people; friends, family	3

[1]The question was: "First of all, what do you like about your being here in this part of northern Michigan?"

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