LONG LAKE - WAUSHARA COUNTY

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LONG LAKE
WAUSHARA COUNTY

INTRODUCTION

Many lakes throughout Wisconsin are undergoing aging (eutrophication) accelerated by cultural activities in the watershed. The resultant problems -- prolific weed growth, nuisance algal blooms, deteriorating fisheries, impaired water quality and sediment infilling -- pose a serious threat to the utilization of these lakes. International concern has stimulated considerable research on the nature and causes of the lake aging process, including the development of various control techniques. Although lake degradation and its causes have received substantial attention, and some lake rehabilitation approaches have been described, the field of lake management is still as much a state-of-the-art as it is a science.

Approaches to lake restoration fall into two general categories: (1) methods to limit fertility and/or sedimentation in lakes, and (2) procedures to manage the consequences of lake aging. Nutrient or sediment limitation techniques treat underlying causes of lake problems. Techniques for managing the consequences of lake aging enhance the usability of lakes. Many techniques used in lake restoration do not readily fall into a single category as, for example, inlake plant and animal harvesting, which affect both species population directly (managing a consequence) and nutrient content within a lake. Often, a combination of both approaches is essential to a successful lake management effort.

There are many difficulties associated with remedial efforts. Lakes are complicated ecosystems and the ability to predict the response of lake systems to various treatments is as yet limited. Moreover, each lake has its own "unique personality," which frustrates attempts to transfer results from one lake to another that appears to have similar problems. There are also time constraints associated with lake renewal programs. The public wants prompt action and immediate results. This is seldom possible. A certain amount of pretreatment information is required to formulate a well-founded remedial program.

In 1974, the State of Wisconsin enacted a law (Chapter 33 of the State Statutes) that enabled lake communities to approach lake restoration by creating a special purpose unit of government called a lake district. These lake districts can enlist the technical and financial assistance of the Department of Natural Resources in an effort to improve or protect lake water quality.

Long Lake property owners formed a lake district in 1978 and applied for both technical and financial assistance from the Department. The study of Long Lake and its watershed was initiated in 1979.

OBJECTIVES

The immediate objectives of the one-year "feasibility study" at Long Lake were to define:

1. a water budget,
2. a nutrient budget,
3. a characterization of inlake chemistries, biological processes, and sediments,
4. a set of lake management alternatives, including prediction of the lake response to each alternative.

Northern Lake Service, a consulting firm under contract with the lake district, collected the data which are evaluated in this report prepared by the Office of Inland Lake Renewal.

FEASIBILITY STUDY RESULTS

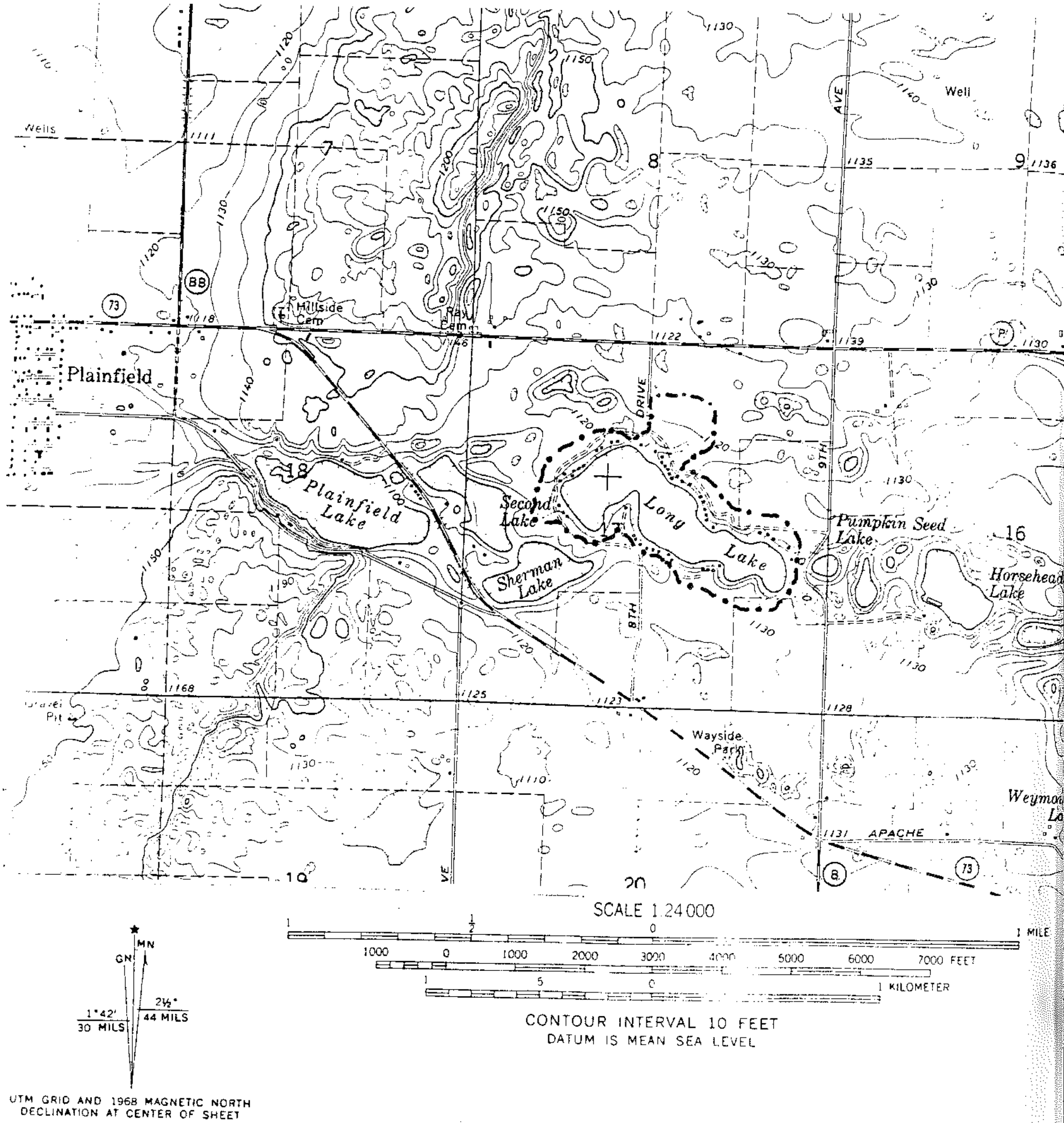
Physical Characteristics of Lake and Watershed

The physical characteristics of Long Lake and associated watershed are presented in Table 1.

TABLE 1
PHYSICAL CHARACTERISTICS OF LONG LAKE (WAUSHARA COUNTY)

Watershed Size (direct drainage)	86 acres	34.8 hectare
Lake Area (A)	52 acres (1979)	21 hectare
Ratio of Watershed Area to Lake Area	1.7:1	
Average Annual Outflow	0.25 cubic feet per sec	
Annual Outflow Volume	180 acre-feet/year	222,894 cubic meters/year
Lake Volume (V)	208 acre-feet	257,000 cubic meters
Maximum Depth	6 feet	1.8 meters
Mean Depth (V/A)	4 feet	1.2 meters
Water Residence Time	1.16 years	

The surface watershed draining to Long Lake is approximately 86 acres (Figure 1). Land usage within this area is 74.5 acres (30.1 hectares) forest and 11.5 acres (4.7 hectare) urban. Long Lake is surrounded with pitted outwash and is touched by an end moraine deposit to the west. It is a kettle type lake formed by some ice blocks buried in an outwash stream from the glacier some 10-14,000 years ago. The unconsolidated glacial material is deposited on a Cambrian Age sandstone about 100 feet below the lake's surface. Soils which are around the lake include Plainfield loamy sand, Burkhardt sandy loam and Richford loamy sand.



LEGEND

—•— Watershed Boundary (Direct Drainage)

FIGURE 1

SURFACE WATERSHED MAP OF LONG LAKE - WAUSHARA COUNTY

The regional groundwater flow pattern is generally from the north toward the south. The local groundwater pattern was determined by the installation of three observation wells combined with eight wells installed by U.S. Geological Survey. In general, the groundwater is flowing into the lake only along the north shore near the public access (Site A, Figure 2) and out of the lake along the rest of the lake basin (see Figure 2). The groundwater flowing into the lake during the study year was estimated at 10 acre-feet/year and the groundwater outflow at 50 acre-feet/year.

Water Budget

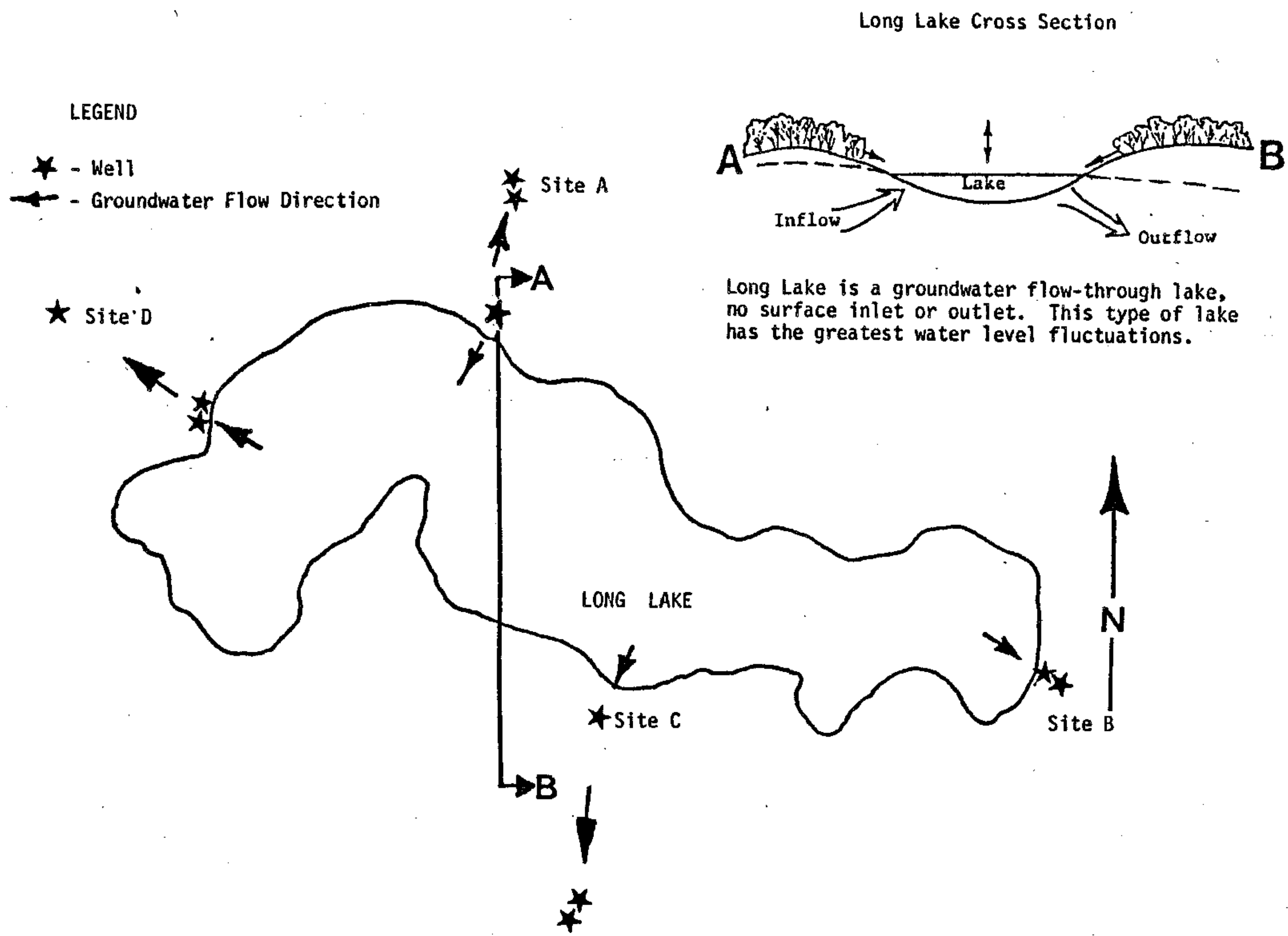
As summarized in Table 2, the primary water sources to Long Lake consist of atmospheric precipitation on the lake surface, surface water runoff and groundwater infiltration. Water losses are dominated by evaporation and groundwater outflow. The lake water level was about the same at the start and the end of the study. Consequently, the impact of inlake water storage changes was minimal. The best estimate of the water flushing rate through Long Lake was therefore 1.16 years or 0.25 cubic feet per second.

TABLE 2
WATER BUDGET FOR LONG LAKE, WAUSHARA COUNTY

		Acre-feet/year	Percent
1. Inflow			
Atmospheric (Precipitation on the lake)		140	77
Watershed (Surface Runoff)		30	17
Groundwater		10	6
	TOTAL	180	100
2. Outflow			
Atmospheric (Evaporation off the lake)		130	72
Groundwater		50	28
	TOTAL	180	100

Phosphorus Budget

Generally, lakes are considered a product of their watershed, i.e., the nutrients that contribute to the growth of aquatic plants are mainly derived from runoff and erosion in the watershed. In an attempt to understand the importance of the processes occurring in Long Lake, a nutrient budget was calculated to describe the amount of phosphorus reaching the lake over the course of a year. From a nutrient control and management perspective, phosphorus is the key element of concern. Nitrogen influx to the lake can occur from a variety of uncontrollable sources, i.e., fixation of atmospheric



GROUNDWATER FLOW DIRECTIONS DURING 1980 AT LONG LAKE - WAUSHARA COUNTY
FIGURE 2

nitrogen by some algae or by direct atmospheric input. Phosphorus, however, is not a volatile element and is usually transported to lakes via surface runoff (snow melt in the spring or heavy rainfalls), through the groundwater (including septic tank leachate), and as dust, leaves, or dissolved in rainfall from the atmosphere. Phosphorus is also the more easily controlled element; therefore, further discussion about nutrients will only involve phosphorus.

TABLE 3
PHOSPHORUS BUDGET TO LONG LAKE, WAUSHARA COUNTY

SOURCE		lbs/yr.	(kg/yr)	Percent
1. Inflow				
Atmospheric		9.7	4.4	41
Watershed (Surface Runoff)		8.4	3.8	35
Groundwater (Natural Background)		0.2	0.1	1
Groundwater (Septic Systems)		5.5	2.5	23
	TOTAL	23.8	10.8	100
2. Outflow				
Groundwater		0.9	0.4	100
3. Net Retained in the Lake Water, Plants and Sediment		22.9	10.4	96

The following data sources, extrapolations and assumptions were used in the process of constructing the phosphorus budget (Table 3):

1. The amount of phosphorus contributed from the atmosphere was determined using an export coefficient (0.21 kg/ha/yr) for a bulk precipitation station at Stevens Point, Wisconsin.

2. Surface runoff was calculated using phosphorus export coefficients of 0.5 kg/ha/yr and 0.05 kg/ha/yr for the urban and forest land use types, respectively.

3. Groundwater flow into and out of the lake was measured by the use of a series of observation wells installed and monitored during the course of the study. An average phosphorus concentration in the groundwater was 0.020 mg/l-P for the inflow and 0.050 mg/l-P for the outflow.

4. The septic system contributions were calculated using these assumptions: 1) the loading of phosphorus to the lake can be represented by the equivalent of five permanent houses located on the continuous inflow side of the lake (this includes an adjustment for houses in the transitional zone that contribute phosphorus during inflow periods) 2) total phosphorus loading to the soil absorption fields was 3.1 kg-P per year, and 3) the soils retained 80 percent of the phosphorus.

Figure 3 illustrates the trophic position of the lake based upon this budget estimate of phosphorus inputs to Long Lake. The three major trophic classifications represented in the figure are: Oligotrophic (limited nutrients in the lake--no algae problems), Mesotrophic (moderate amounts of nutrients in the lake water--occasional algae problem), and Eutrophic (a nutrient-rich lake with expected algae problems).

Inlake Water Quality

Table 4 contains the spring water chemistry data.

The water quality of Long Lake is good, and the alkalinity and pH values indicate that the lake is buffered and not susceptible to any problems from acid rain (Figure 4).

Nitrogen and phosphorus are the most important elements in terms of lake fertility. There is generally a good correlation between phosphorus and nitrogen in solution and the productivity of the open water part of the lake. Phosphorus has, however, become the element of most concern in studies of lake eutrophication. It is usually the limiting element in the growth of aquatic plants. The phosphorus concentration in Long Lake during the spring of 1980 was 0.02 mg/l. At this concentration, there should be no serious prolonged algae problems. Phosphorus does, however, tend to accumulate in lake sediments where it can be utilized by macrophytes such as are found in Long Lake.

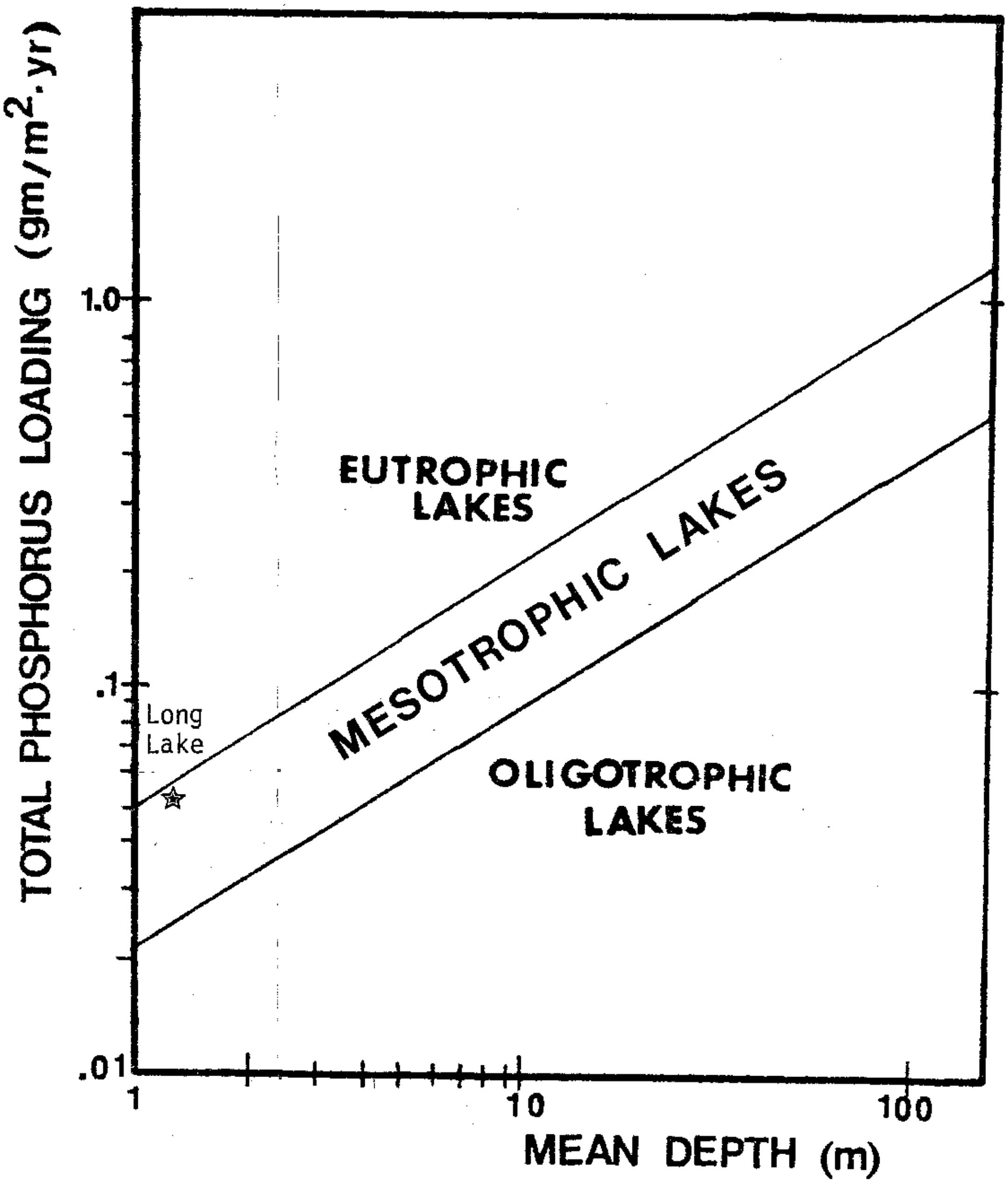


FIGURE 3

THE POSITION OF LONG LAKE - WAUSHARA COUNTY IN THE TROPHIC CONTINUUM BASED ON A PHOSPHORUS LOADING ESTIMATE.

Dillon + Rigler

TABLE 4
INLAKE SPRING WATER CHEMISTRY DATA FOR LONG LAKE - WAUSHARA CO.

DATE	4/30/79		3/18/80		3/19/80		4/14/80		4/15/80	
SOURCE	A		C		B		C		B	
Depth (Feet)	0	6	0	5	0	5	0	4.5	0	--
Reactive Phosphorus	< .005	< .005	--	--	< .004	< .004	--	--	< .004	--
Total Phosphorus	--	--	.013	.016	.02*	.02*	.013	.019	.02*	--
Total Nitrogen	.85	.79	.96	.79	1.0	1.04	.90	.74	1.02	--
Organic Nitrogen	.70	.64	.82	.76	.90	1.0	.77	.73	1.0	--
Ammonia Nitrogen	.13	.12	.04	.00	.05	.03	.13	.00	< .02	--
Nitrate and Nitrite -N	.02	.03	.10	.03	.05	< .02	.00	.01	< .02	--
Calcium	10	9	--	--	12	13	--	--	--	--
Magnesium	7	4	--	--	8	9	--	--	6	--
Sodium	< 1	< 1	--	--	1	1	--	--	< 1	--
Potassium	< .5	< .5	--	--	.8	.8	--	--	.6	--
Manganese	< .03	< .03	--	--	--	--	--	--	.16	--
Iron	.16	.16	--	--	--	--	--	--	.1	--
Conductivity (umohs)	131	115	--	--	150	160	83	80	100	--
Chloride	< 1	1	--	--	< 2	< 2	--	--	< 2	--
Alkalinity (as $CaCO_3$)	36	35	54	54	56	64	42	36	38	--
Lab pH (units)	7.3	7.3	7.9	7.6	7.8	8.0	8.34	8.2	7.2	

NOTES: All analyses reported in mg/l except where noted.
< = less than

SOURCE

A - DNR - Bureau of Research - Delafield Lab.
B - DNR - Bureau of Research - State Lab of Hygiene.
C - NORTHERN LAKE SERVICE - Long Lake Feasibility Study

* Highest spring total phosphorus

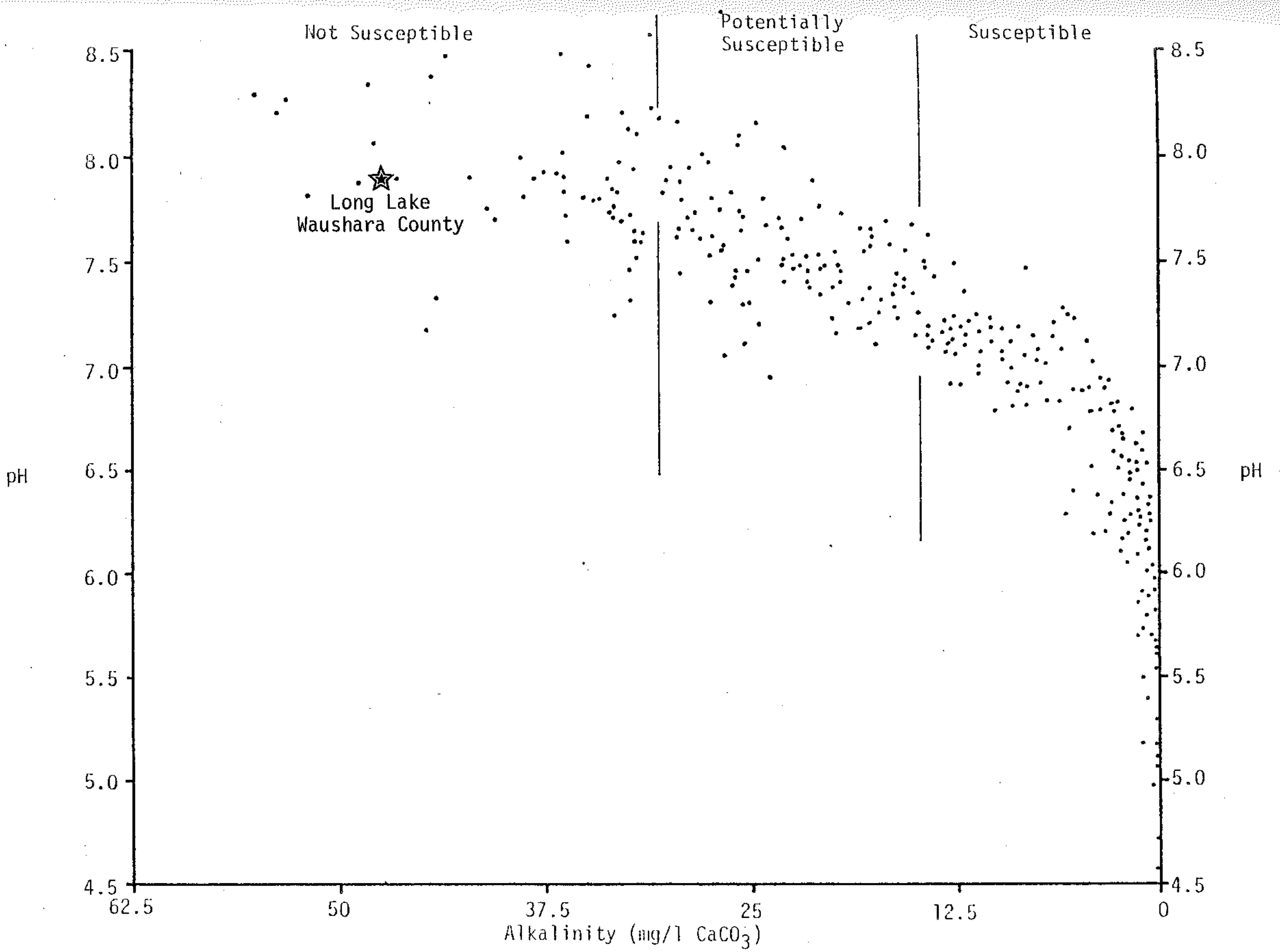


FIGURE 4
THE ALKALINITY AND pH VALUES OF 350 NORTHERN WISCONSIN LAKES WITH AN INDICATION OF THEIR SUSCEPTIBILITY TO ACID RAIN

Dissolved Oxygen

Dissolved oxygen is essential to the metabolism of all aquatic organisms, hence the dynamics of oxygen in lakes is a basic determinant in their distribution and growth.

The lake is semi-protected from the wind; however, it apparently is mixed throughout the open water period due to its shallow depth. In the absence of an ice cover, wind action at the surface creates water currents that cause complete circulation from top to bottom. Consequently, there are no oxygen depletions at any depth in the summer.

Over winter, the lake is not mixed by the wind because of the ice cover. The aquatic life is, therefore, dependent upon the dissolved oxygen stored in the water. During mild winters with little snow cover, sunlight penetrates through the snow and ice to plants which use carbon dioxide and produce oxygen. This happened in 1980. The lowest reading noted during the study period was 7.4 mg/l at 6 feet in February, 1980, although lower levels may have occurred for short periods. But, in years when the snow cover is thicker and where respiration greatly exceeds oxygen production, the oxygen can be depleted causing the fish to die. Winter fish kills have occurred frequently in the past at Long Lake due to low winter oxygen levels. Winter dissolved oxygen, ice, and snow measurements are shown in Table 5.

TABLE 5
DISSOLVED OXYGEN FOR LONG LAKE - WAUSHARA COUNTY

DATE	ICE THICKNESS (FEET)	SNOW THICKNESS (FEET)	SAMPLE DEPTH (FEET)	DISSOLVED OXYGEN (mg/l)	DATA SOURCE
3/4/59	--	--	0 4	0.0 0.0	A
2/2/62	1.8'	3.5'	2 3.5	0.4 0.0	A
2/18/63	1.7'	2.4'	2 3.5	0.4 0.0	A
1/7/65	1.0'	2.0'	1.5	0.0	A
2/8/74	1.9'	0.3'	2.5 4.5 6.5	11.6 8.0 7.4	A
2/8/77	1.7'	0.4'	2.5 4	0.2 0.0	A
1/22/79	1.0'	0.8'	2 3.5	0.2 0.0	A
2/22/80	1.6'	--	0 2 4 6	11.8 11.4 7.6 7.4	B
3/18/80	1.8'	--	2 4 5	8.5 8.8 8.8	B
3/19/80	1.6'	0.0'	0 7	8.4 8.6	C

SOURCE
A - DNR-Area Fish Manager
B - Northern Lake Service
C - DNR - Bureau of Research

Inlake Trophic Status

The basis for the trophic status concept is that lake water quality problems are caused largely by, or associated with, increased nutrient concentrations in the lake. As indicated earlier, phosphorus will generally be the nutrient of concern. Figure 5 shows a sequence of cause and effect events which would occur under conditions where phosphorus was limiting. An increase in lake phosphorus concentration would cause an increase in primary productivity (as measured by chlorophyll a). Simultaneously there would be decreases in Secchi disc visibility (higher turbidity) and dissolved oxygen in the bottom waters or at night (respiration exceeds production). Nitrogen to phosphorus ratios greater than 15 suggest phosphorus is the limiting element. In Long Lake, the nitrogen to phosphorus ratios were always greater than 30 during the growing season. Therefore, phosphorus is apparently the limiting nutrient and Carlson's Trophic State Index can be used to illustrate the trophic status of the lake.

The Carlson index ranges from zero to 100 and can be computed from Secchi disc, chlorophyll a or total phosphorus data. A low index, zero to 40, is a relative measure of the most nutrient "poor" (oligotrophic) lakes, whereas the higher numbers are indicative of more fertile lakes. The larger the number the more fertile the lake. Equations 1-3 are used in this approach.

(1) $\text{T.S.I. (Secchi disc)} = 60 - 33.2 \text{ Log}_{10} \text{ SD}$

(2) $\text{T.S.I. (Chlorophyll } \underline{a}) = 36.25 + 15.5 \log_{10} \text{Chl -a}$

(3) $\text{T.S.I. (Total phosphorus)} = 60 - 33.2 \log_{10} \frac{40.5}{TP}$

Figure 6 illustrates the "Trophic State Index" for Long Lake during the course of the feasibility study.

The trophic characterization of Long Lake is representative of a mesotrophic to slightly eutrophic body of water. This is in general agreement with the expectations based on nutrient loading to the lake (see Figure 3). The degree of eutrophy is not considered aesthetically detrimental, although some usage problems would be anticipated.

Biological Characteristics - Algae

Algae (Phytoplankton) are microscopic plants that occur throughout all lakes. Together with the larger attached aquatic plants (macrophytes), algae are the primary foundation of the aquatic food chain that ultimately culminates in predator fish populations. Phytoplankton have the ability to combine light energy from the sun and inorganic nutrients of carbon, phosphorus, and nitrogen, plus minor elements, to construct new biolgocial material (sugars, proteins, etc.). The process by which this occurs is called photosynthesis. From the process of photosynthesis, organic material is formed to be utilized by the small animals (e.g., zooplankton) in lakes. These herbivorous animals are preyed upon by larger animals such as fish.

FIGURE 5

CONCEPTUAL SEQUENCE OF CAUSE AND EFFECT RELATIONSHIPS IN LAKE EUTROPHICATION PROCESS (from Porcella et al., 1979)

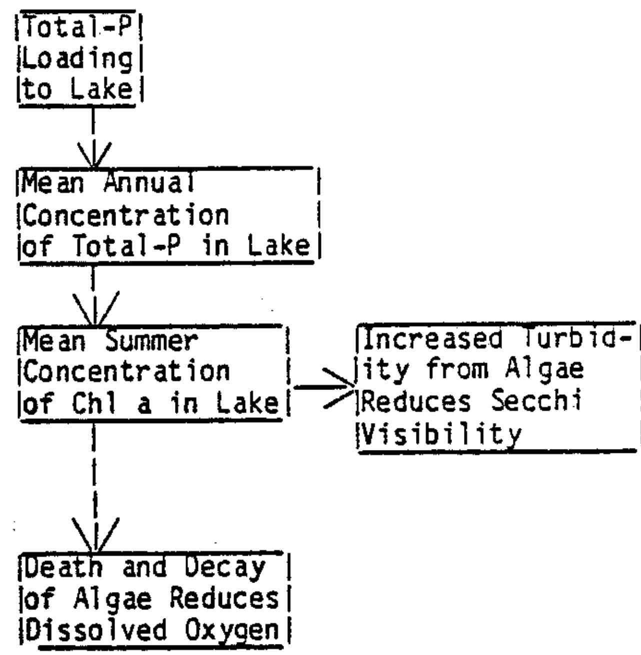
Variables

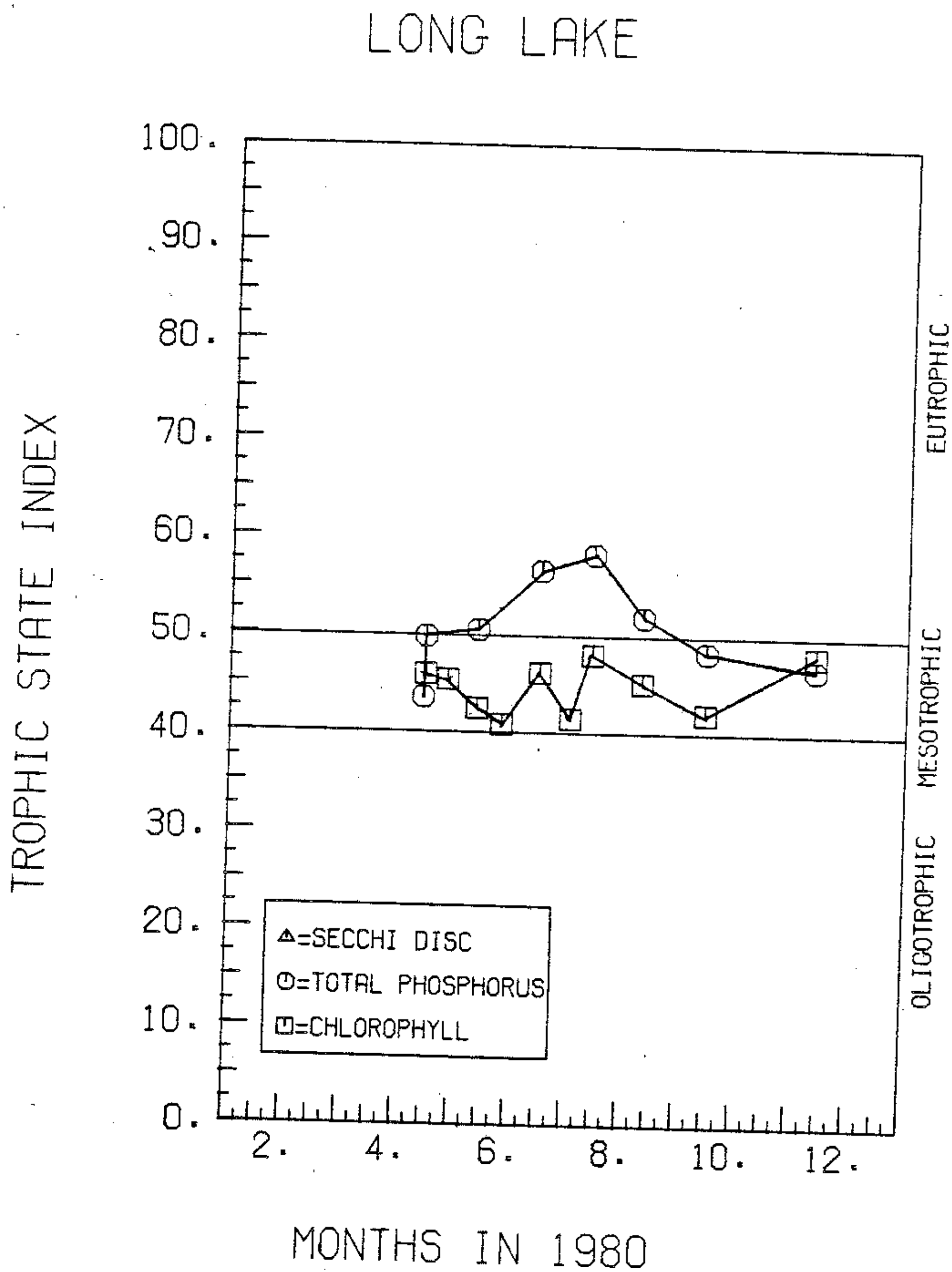
Total Phosphorus Input Loading

Total Phosphorus Concentration

Chlorophyll *a* Concentration
Secchi Depth

Dissolved Oxygen Concentration





TROPHIC STATE INDEX (TSI) FOR LONG LAKE - WAUSHARA COUNTY

FIGURE 6

Algae are classified, in part, according to their respective pigmentation. All algae contain at least the basic photosynthetic pigment chlorophyll a. This pigment imparts a green color to the algae. The major taxonomic groupings found in Long Lake consist of blue-green algae, green algae, and chrysophytes.

Blue-green algae are so named because the cells contain, in addition to chlorophyll, a pigment called phycocyanin which gives them a dark green tinge. When blue-green algae become abundant, some species will float on the water surface and cause unsightly mats that wash up on the shore. In severe cases, a blue-green paint-like effect is associated with blooms of these algae. In general, the more nutrient-rich a lake, the more often blue-green algae are dominant in the population. Blue-green species are present in Long Lake; however, densities are not high enough to be of concern.

Green algae contain only chlorophyll pigment. When green algae become abundant they might display a green cast to the water. Green algae are generally more desirable than blue-green algae because they are more readily eaten by zooplankton. Consequently, green algae seldom become abundant enough to form scums or mats. The dominant algae in Long Lake during the growing season was a green species (Figure 7). The biomass, as measured by chlorophyll a, reached a peak of 6 mg/m^3 during July, with a summer mean of 3.3 mg/m^3. This concentration suggests no apparent problems during the summer of 1980. Eutrophic lakes have a mean summer chlorophyll concentration of 10 mg/m^3 or greater and often have peaks of 25-200 mg/m^3.

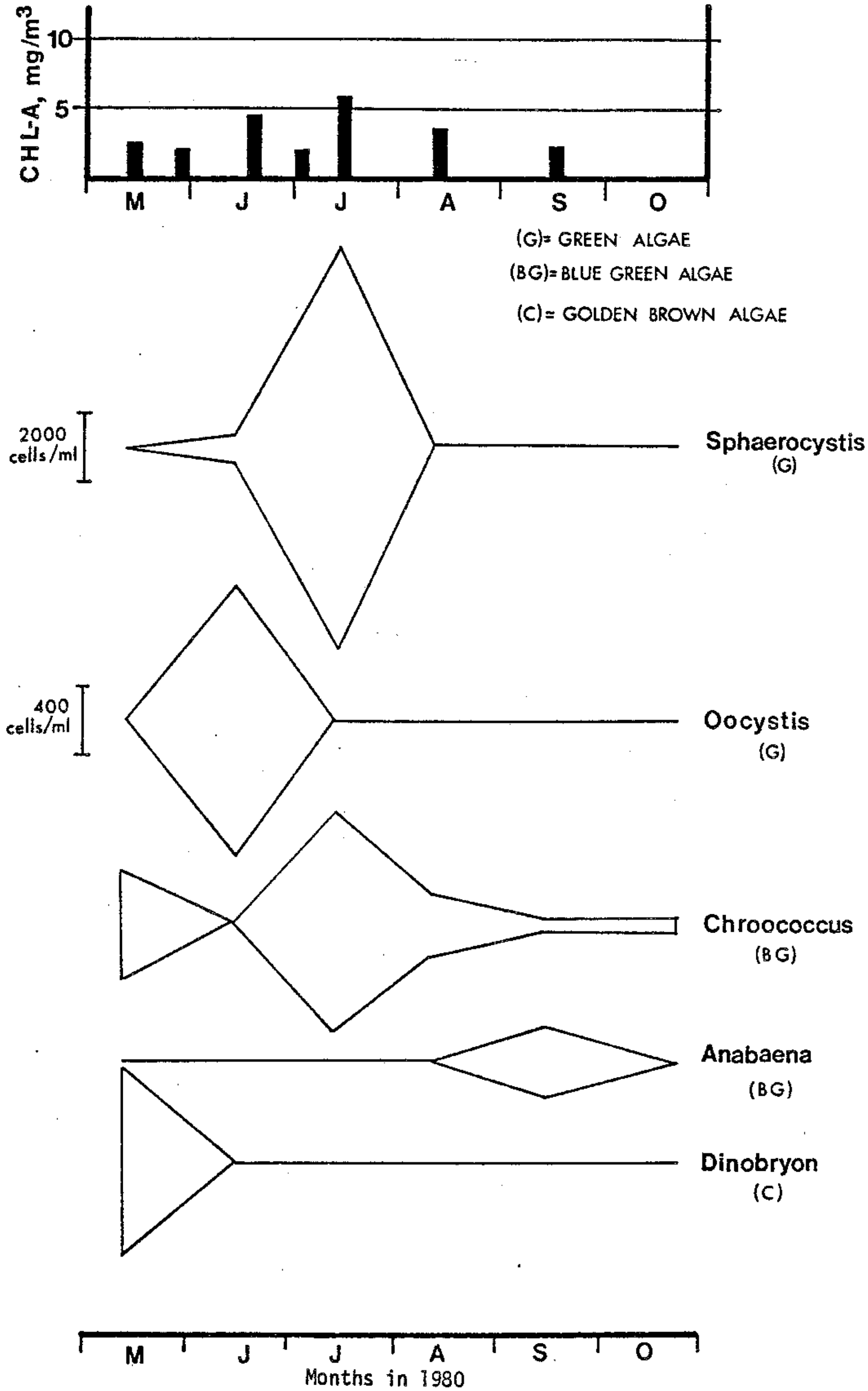
Chrysophytes (golden brown algae) have a distinctive golden-brown color. Many of these organisms are motile (capable of movement). As shown in Figure 7, these species are generally more abundant in spring and are greatly reduced later.

Biological Characteristics - Macrophytes (attached aquatic plants)

Aquatic plants attached to the lake sediment are called macrophytes and play an important role in lake ecosystems. A zone of macrophytes extending around the near-shore areas offers habitat for fish and wildlife. Many aquatic insects inhabit beds of macrophytes and are an important source of fish food. The root systems are helpful in stabilizing the near-shore sediments from erosion. But macrophytes can, if excessive, become a detriment to the development of a good sport fishery, and interfere with swimming, boating, etc.

An aquatic plant survey was conducted in mid-July, 1980. A species list for the lake is given in Table 6 and the most prevalent species are illustrated in Figure 8.

Over 20 species of aquatic plants were found in Long Lake, indicating a diverse community. The total area of weed growth in July was approximately 52 acres, or nearly the entire lake (Figure 9). Submergent species dominated the plant community with nearly 33 acres, while the floating leaf and emergent communities covered 14 and 5 acres of the lake, respectively. Because of the good water clarity, growth was possible down to the lake bottom, approximately 6 feet.



ALGAL DISTRIBUTION IN LONG LAKE - WAUSHARA COUNTY

FIGURE 7

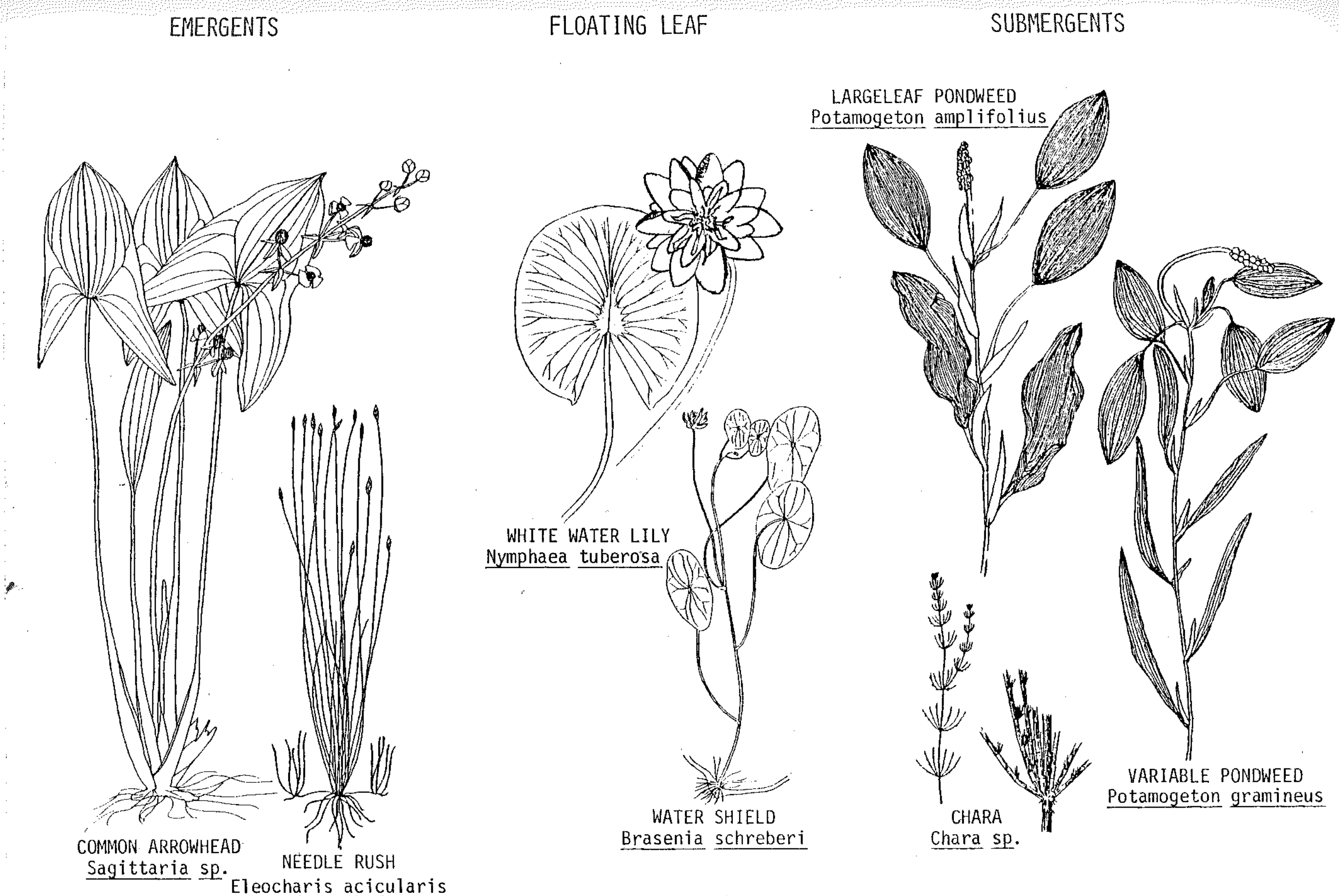


FIGURE 8

MOST FREQUENTLY OCCURRING MACROPHYTES IN LONG LAKE - WAUSHARA COUNTY

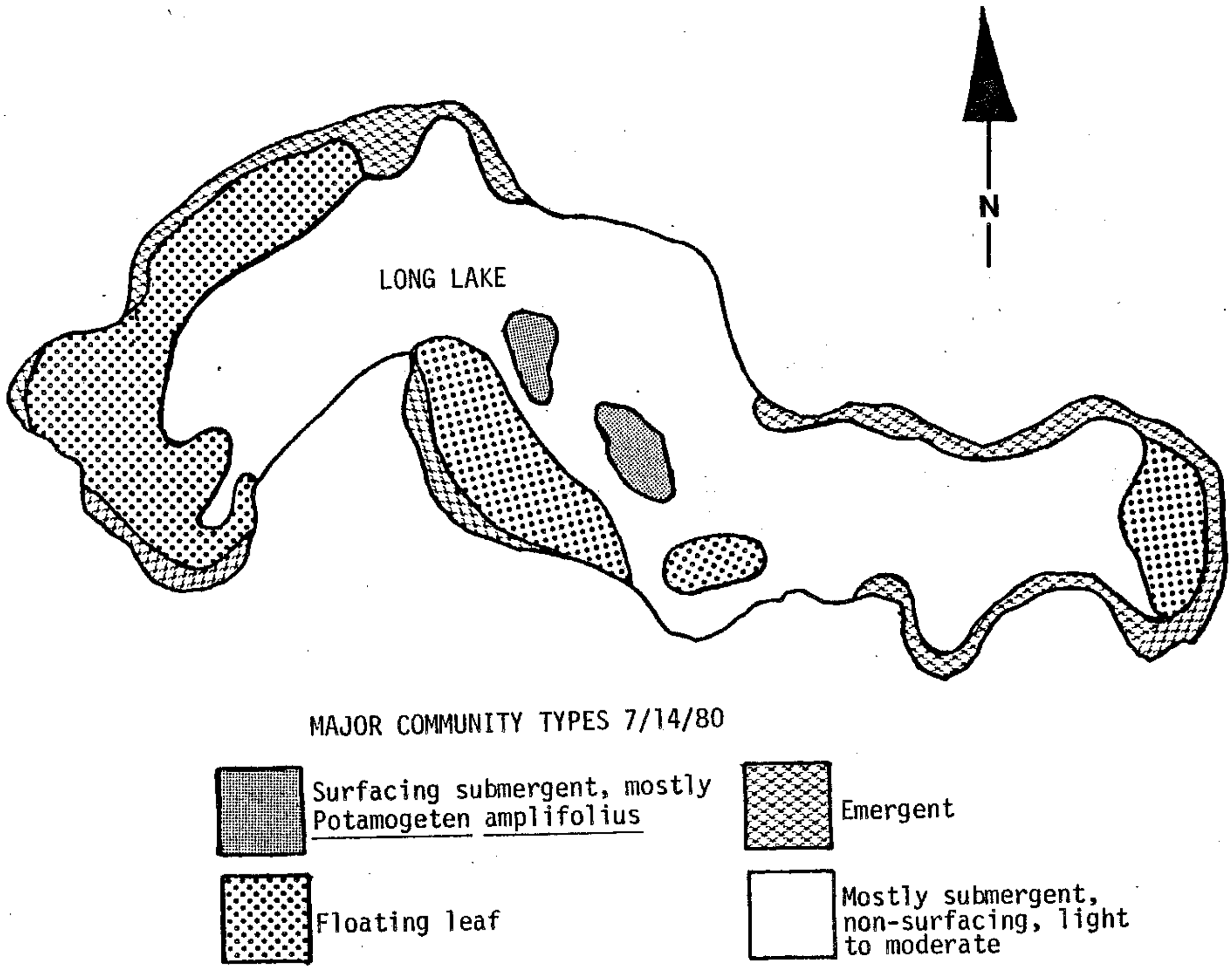


FIGURE 9

MACROPHYTE MAP FOR LONG LAKE - WAUSHARA COUNTY

The plant community provides fish and wildlife with a variety of habitat for reproduction, protection of the young, and food production. Most of the species shown in Table 6 are beneficial to fish or wildlife.

TABLE 6
MACROPHYTES PRESENT IN LONG LAKE, WAUSHARA COUNTY, 1980

Emergent Plants	Common Name	Percent* Frequency Occurrence
Eleocharis acicularis	Needle rush	23%
Sagittaria sp.	Arrowhead	16%
Dulichium arundinaceum	Three-way sedge	--
Scirpus sp.	Bulrush	--
Juncus sp.	Rush	--
Carex sp.	Sedge	--
Floatingleaf Plants		
Nymphaea sp.	White water lily	25%
Brasenia Schreberi	Watershield	25%
Nuphar sp.	Yellow water lily	--
Submergent Plants		
Potamogeton gramineus	Variable pondweed	35%
Chara sp.	Stonewort	27%
Potamogeton amplifolius	Largeleaf pondweed	23%
Elodea canadensis	Waterweed	12%
Potamogeton foliosus	Leafy pondweed	10%
P. praelongus	Whitestem pondweed	--
P. Richardsonii	Claspingleaf pondweed	--
Myriophyllum sp.	Milfoil	--
Megalodonta Beckii	Water marigold	--
Polygonum sp.	Smartweed	--
Isoetes sp.	Quillwort	--

*only percent frequencies of 10% or more shown.

In terms of recreational usage, weeds are now excessive in most parts of the lake. Past attempts at control have involved herbicides (e.g., endothal in 1967 and 1969, Silvex in 1967, and sodium arsenite in 1955) but two other techniques might be considered in the future--harvesting or dredging. Either method could be utilized to increase the lake's recreational usability.

Fish

The extensive areas with weed growth contribute to frequent winterkills, precluding the development of a self-sustaining sport fishery. Long Lake has had a fairly long history of fish stocking, starting in 1948, which normally has followed winterkill years. Low dissolved oxygen (D.O.) conditions often occur under winter ice and only the most tolerant species (such as bullheads) are able to survive in any numbers. Good to fair spawning habitat exists for northern pike, largemouth bass, and bluegills; however, a sustained sport fishery for these species is not possible until the periodic winterkills are eliminated. In addition, even if adequate D.O. levels are provided, additional steps will be necessary to maintain a balanced and productive fish population.

The existing imbalance in the fishery might be corrected by treatment with a piscicide followed by restocking. Installation of an aeration system would then provide for the survival of these fish through the winter. Utilization of one of the two previously discussed weed control measures might also be considered.

TABLE 7
FISH STOCKED IN LONG LAKE - WAUSHARA COUNTY

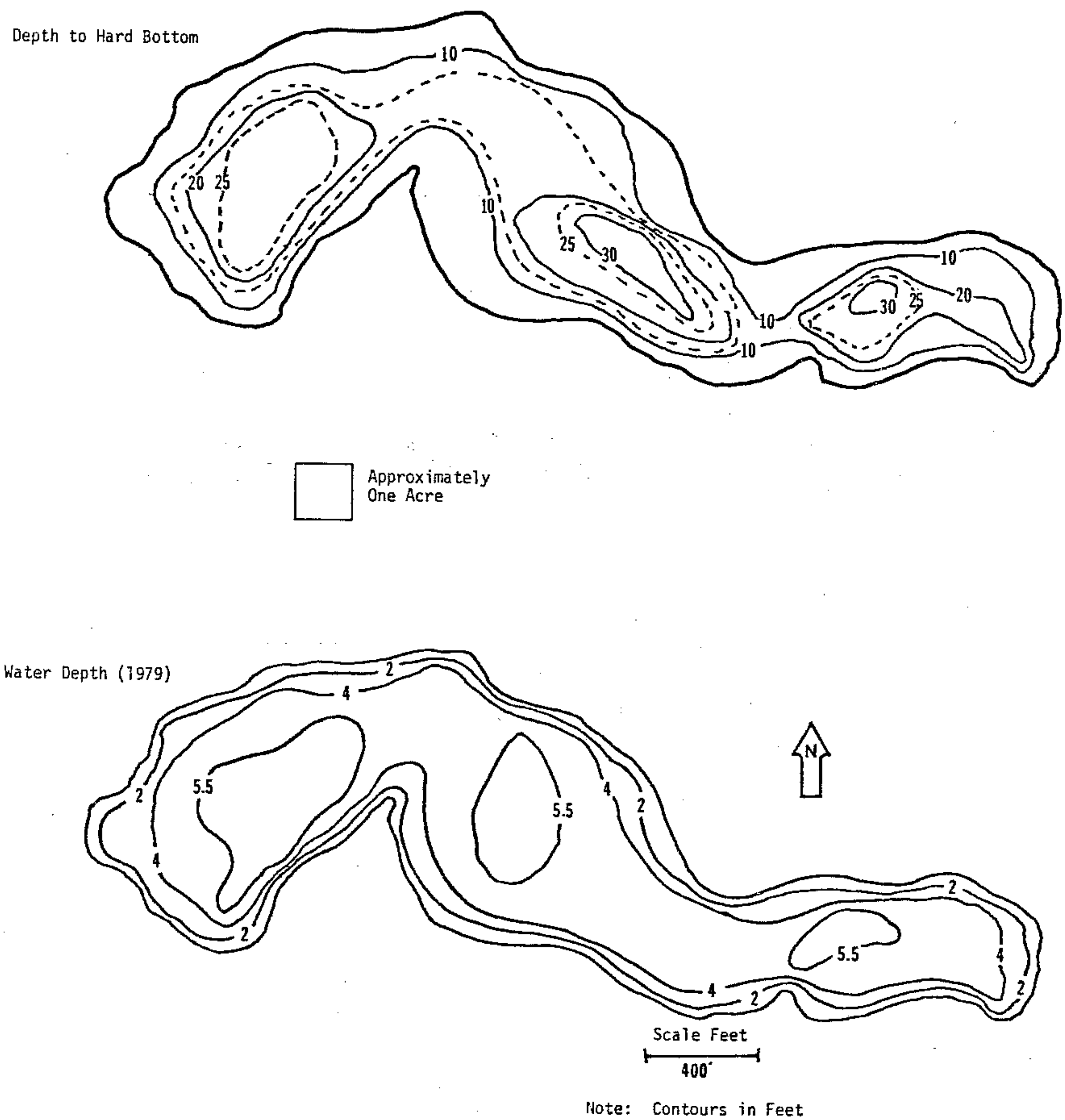
YEAR	LARGE MOUTH BASS	BLUE-GILL	NORTHERN PIKE FRY	WALLEYE			YELLOW PERCH		
				FRY	FINGER-LING	ADULT	EGG	YOUNG	ADULT
1960			15,000	74,000			1,000,000		
1961	6,500			75,000	38,400		750,000	375	4
1962	6,500	400	25,000			750			
1965									62
1974	3,500	2,000	175,000						
1977		1,158	20,000					2,000	
1978	3,500	2,000	20,000						1,000
1979	3,500								

Lake Sediments

The extent of the soft sediments in Long Lake was determined by probing during the winter of 1979-80. Water depth and depth to hard bottom maps were produced from this data (Figure 10). These show that the sediments vary in thickness from near zero along the edges to over 24.5 feet thick in the middle and at the east and west ends of the lake. The total volume of soft sediments is about 727,000 cubic yards.

Sediments were collected at three sites in the lake. The analytical results are shown in Figure 11. Sediments in Long Lake are highly flocculent, and organic in nature, comprised of only 7 percent solids. Because of this and the shallow characteristic of the lake, high powered boats could mix the sediment into the lake waters. The no wake restriction on Long Lake was, therefore, a wise management decision.

LONG LAKE, WAUSHARA COUNTY



WATER DEPTH AND DEPTH OF SOFT SEDIMENT IN LONG LAKE - WAUSHARA COUNTY

Figure 10

SEDIMENT CORE ANALYSIS

Core	Percentage I	Percentage II	Percentage III
% Water	95.3	91.4	92.2
% Solids	4.7	8.6	7.8
% Nitrogen	2.5	1.7	2.3
% Phosphorus	0.019	0.016	0.037

*On a dry weight basis

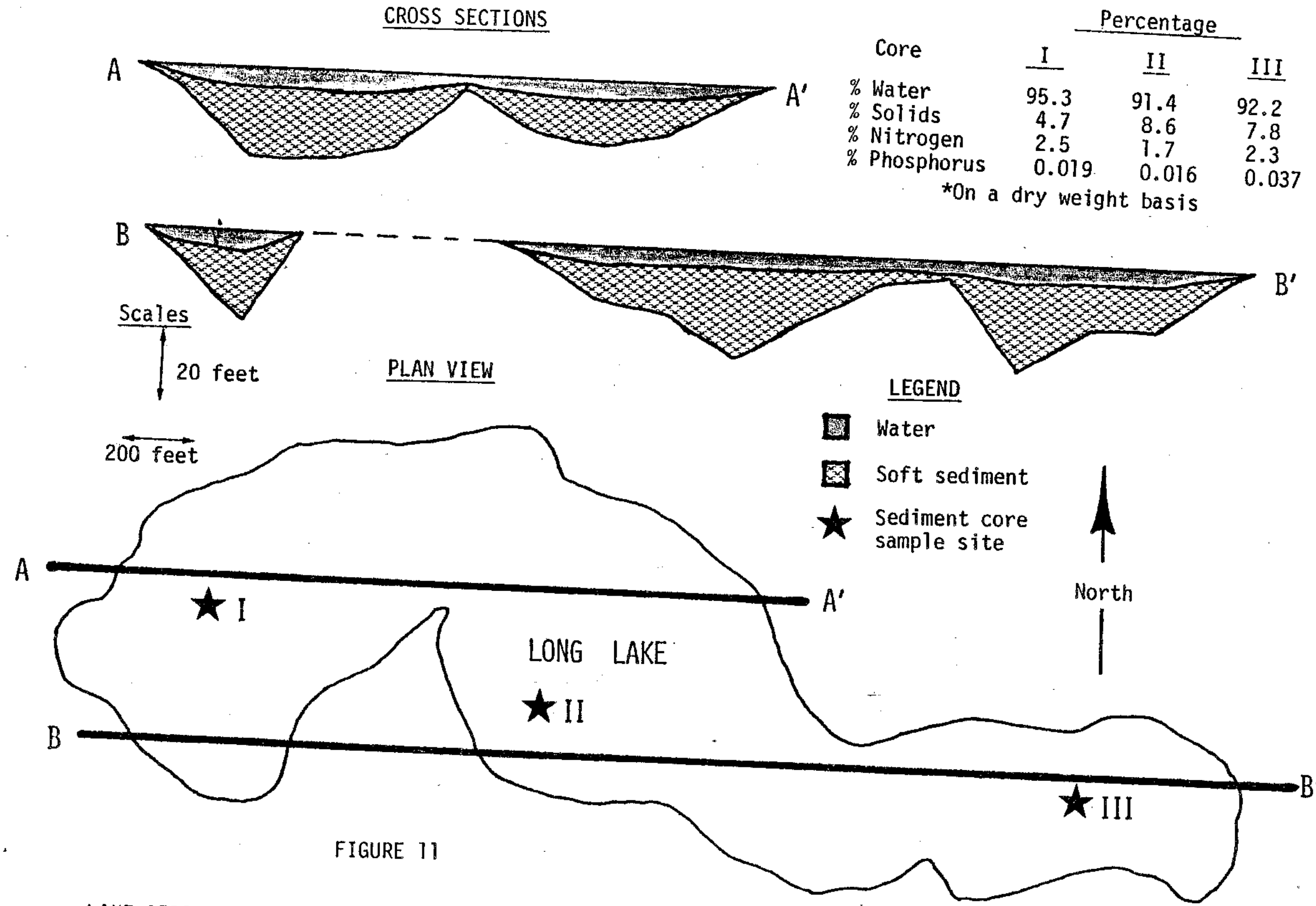


FIGURE 11

LAKE SEDIMENT COMPOSITION, CROSS SECTIONS, AND PLAN VIEW FOR LONG LAKE - WAUSHARA COUNTY

The sediment material appears to have been derived autochthonously (produced within the lake). As described earlier, the surface drainage area to the lake is very small, 86 acres, with a watershed to lake ratio of 1.7:1. No large direct sources of organic material which could have contributed to formation of this sediment can be found, either today or historically. The lake does not, at this time, receive large inputs of either nutrients or sediments. The infilling process was apparently a long one, measured in terms of thousands of years.

LAKE LEVEL FLUCTUATIONS AND IRRIGATION

Although the present study was not designed to specifically determine the effect of irrigation on the lake level, considerable interest has been expressed by people around Long Lake. Data collected during the study and by other researchers have therefore been used in an attempt to address this concern.

Long Lake is land-locked with neither inflow nor outflow streams (e.g., groundwater flow through; Figure 2). This type of lake can have a widely fluctuating water level that corresponds to groundwater level changes. If regional groundwater levels are affected by irrigation, then the lake level should show a corresponding change. Therefore, this type of lake is at least potentially susceptible to irrigation pumping effects on groundwater. However, Long Lake's water level fluctuated only 0.9 feet during the study year (Figure 12). Monitoring information for 12 other Wisconsin lakes of the flow-through type showed annual fluctuations of 0.85 to 3.28 feet (Table 8).

TABLE 8: Range of lake-level fluctuations (from: Wisconsin Lake levels, Their Ups and Downs. Novitzki and Devaul, USGS).

Lake type	Fluctuation during period of record (ft)	Average annual fluctuation (ft)	Maximum annual fluctuation (ft)	Minimum annual fluctuation (ft)	Period of Record
GROUNDWATER FLOWTHROUGH					
Devils	10.91	3.28	6.31	1.83	1937-74
North (Holden)	10.14	1.56	3.70	.49	1937-75
Shell	6.05	1.43	2.74	.61	1936-74
Cedar	5.81	1.18	1.98	.34	1936-74
Anvil	5.10	1.00	1.84	.50	1936-74
Rib	4.77	1.78	3.93	.78	1936-64
Boot	4.43	.90	1.60	.38	1936-64
Pine	4.24	1.30	2.75	.53	1936-75
Silver	4.01	1.03	2.12	.27	1936-64
Wheeler	3.86	.85	1.35	.38	1936-74
Pine	3.48	1.17	1.90	.58	1936-64
Beaver	2.50	.96	1.57	.42	1933-67

LONG LAKE - WAUSHARA COUNTY

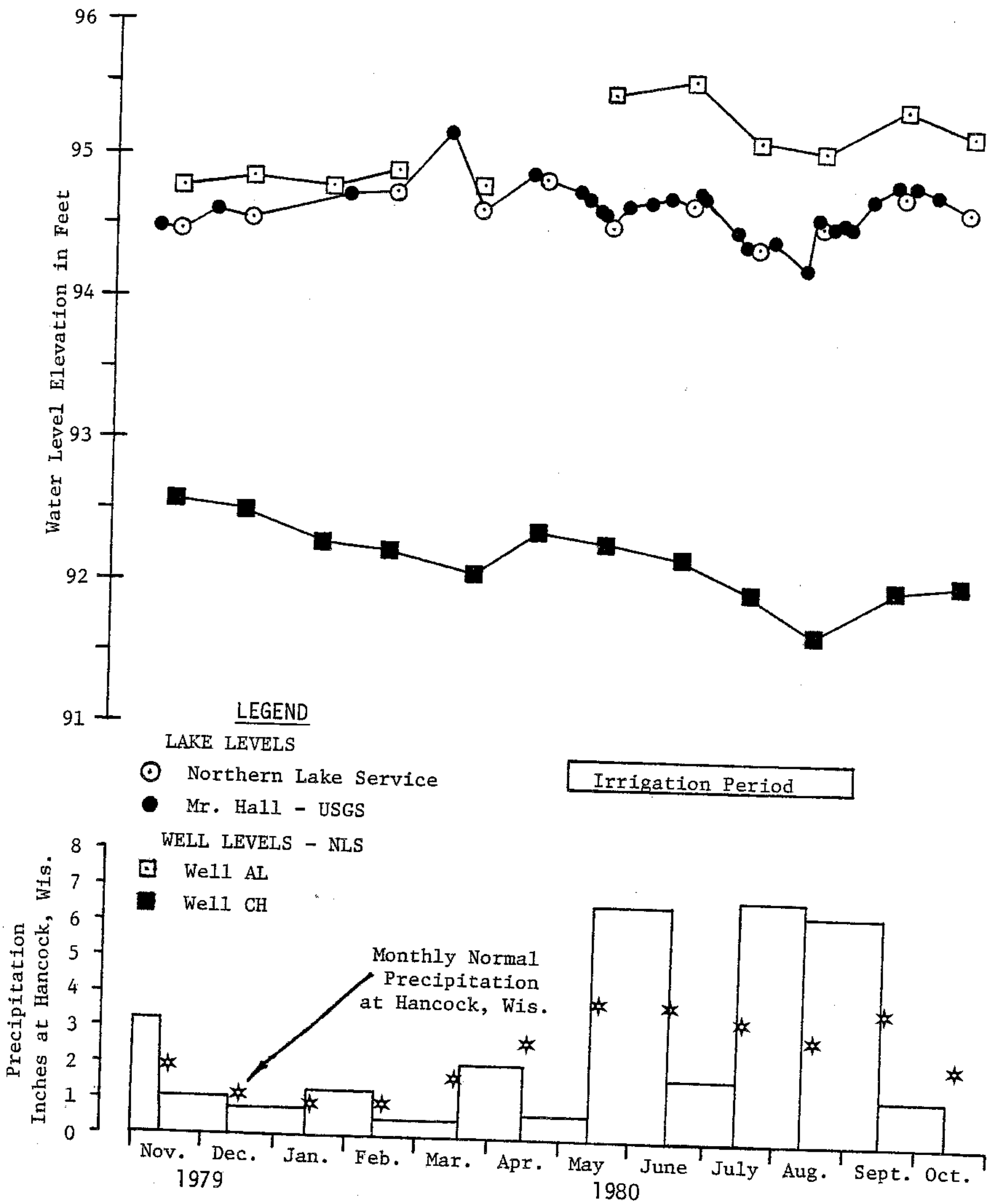


FIGURE 12
PRECIPITATION AND WATER LEVELS AT LONG LAKE

The largest impact irrigation could have on lake level is if the water were pumped directly out of the lake. Presently, this is not occurring. The next greatest impact would occur if high capacity irrigation wells were so close that their drawdown cones would reach the lake. Figure 13 shows an example of drawdown cones from a study conducted elsewhere. The contour lines show the drawdown cones during pumping July 16, 1974. The local effect didn't extend more than a quarter of a mile. Pumping was not occurring on May 14 or October 22. High capacity irrigation pumping is not known to be present within a quarter mile of the lake.

However, irrigation pumping could also have a long term regional effect on groundwater levels. This impact can be assessed by examining any change in the location of the groundwater divide. The Wisconsin River - Wolf River groundwater divide near Long Lake has been approximately determined twice, once in about 1957 and also in 1965 (Figure 14). There was a shift over the eight year period (Figure 14). This suggests that some groundwater depletion has occurred on the Wisconsin River side of the divide; however, between 1957 and 1979 there has been a land use change in the area, involving reforestation with pine trees (Figure 15). The annual evapotranspiration rates for pine trees and grassland is 19.4 and 16 inches, respectively. Therefore, the increased water uptake by the trees may be a factor in the relocation of the groundwater divide. The Lake District may wish to determine the divide's location again in the near future.

The permeability of the ground around Long Lake was also reviewed in case the Lake District considers pumping water into the lake at some time in the future. Cross sections were drawn through Long Lake to show this permeability (Figure 16). The material appears highly permeable and a well to augment the lake level may have very little effect. A recent study of this alternative The Effects of Using Groundwater to Maintain Water levels of Cedar Lake, Wisconsin by McLeod, 1980, concludes that "90 percent of pumped water was either recycled from the lake to the well or otherwise lost as seepage from the lake." It would probably be greater than 90 percent at Long Lake.

MANAGEMENT ALTERNATIVES

The management alternatives presented here are designed to provide information and direction to the Lake District for possible future management efforts. The following alternatives will address: 1) watershed activities; 2) lake deepening by dredging; 3) macrophyte (weed) control; 4) aeration; and 5) lake level and irrigation.

These alternatives are not all-inclusive, nor are they mutually exclusive. The residents of Long Lake must decide which alternative, if any, they may wish to pursue. The Lake District should consider its needs and priorities in formulating a management plan.

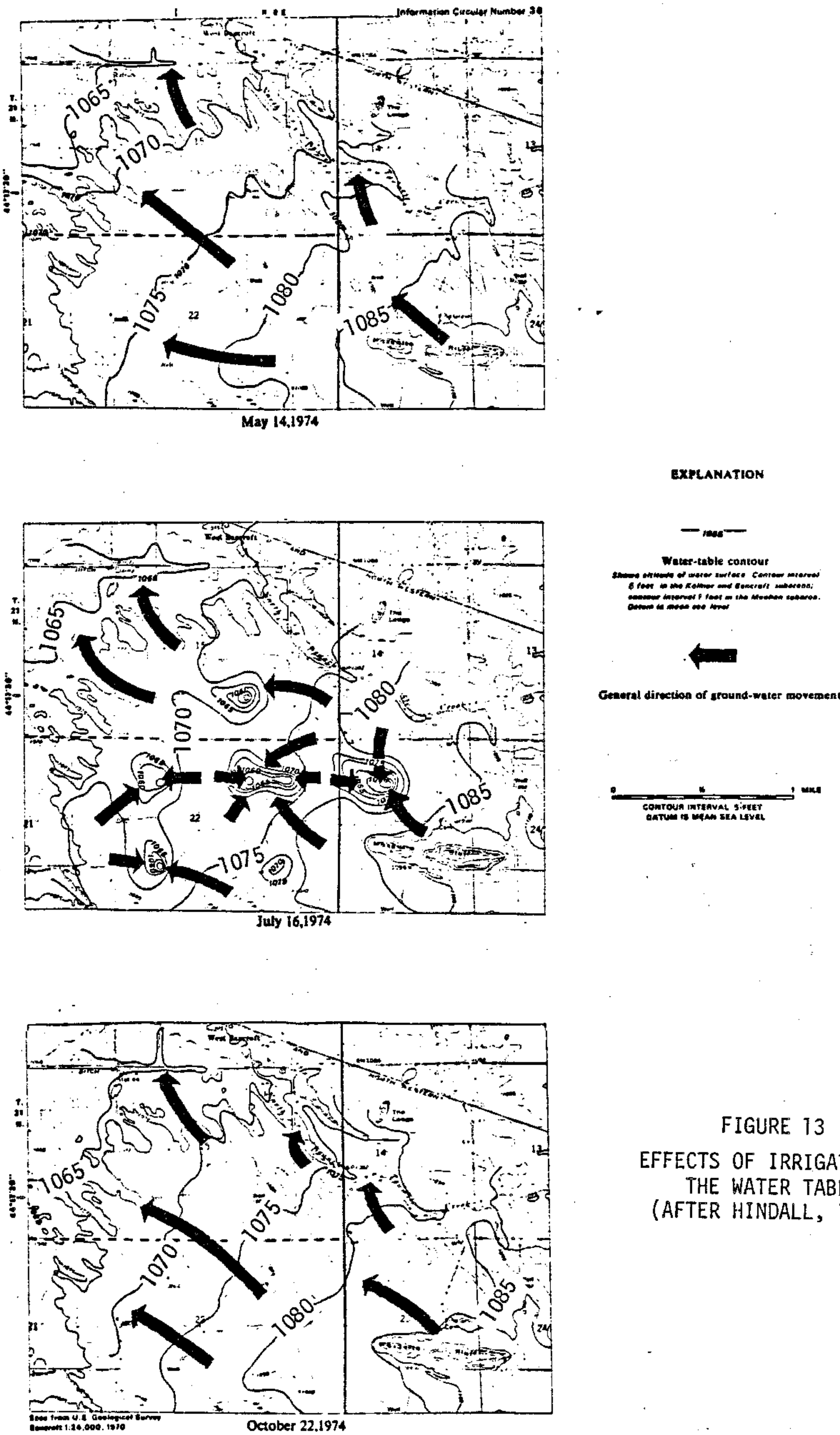


FIGURE 13

EFFECTS OF IRRIGATION ON THE WATER TABLE (AFTER HINDALL, 1978)

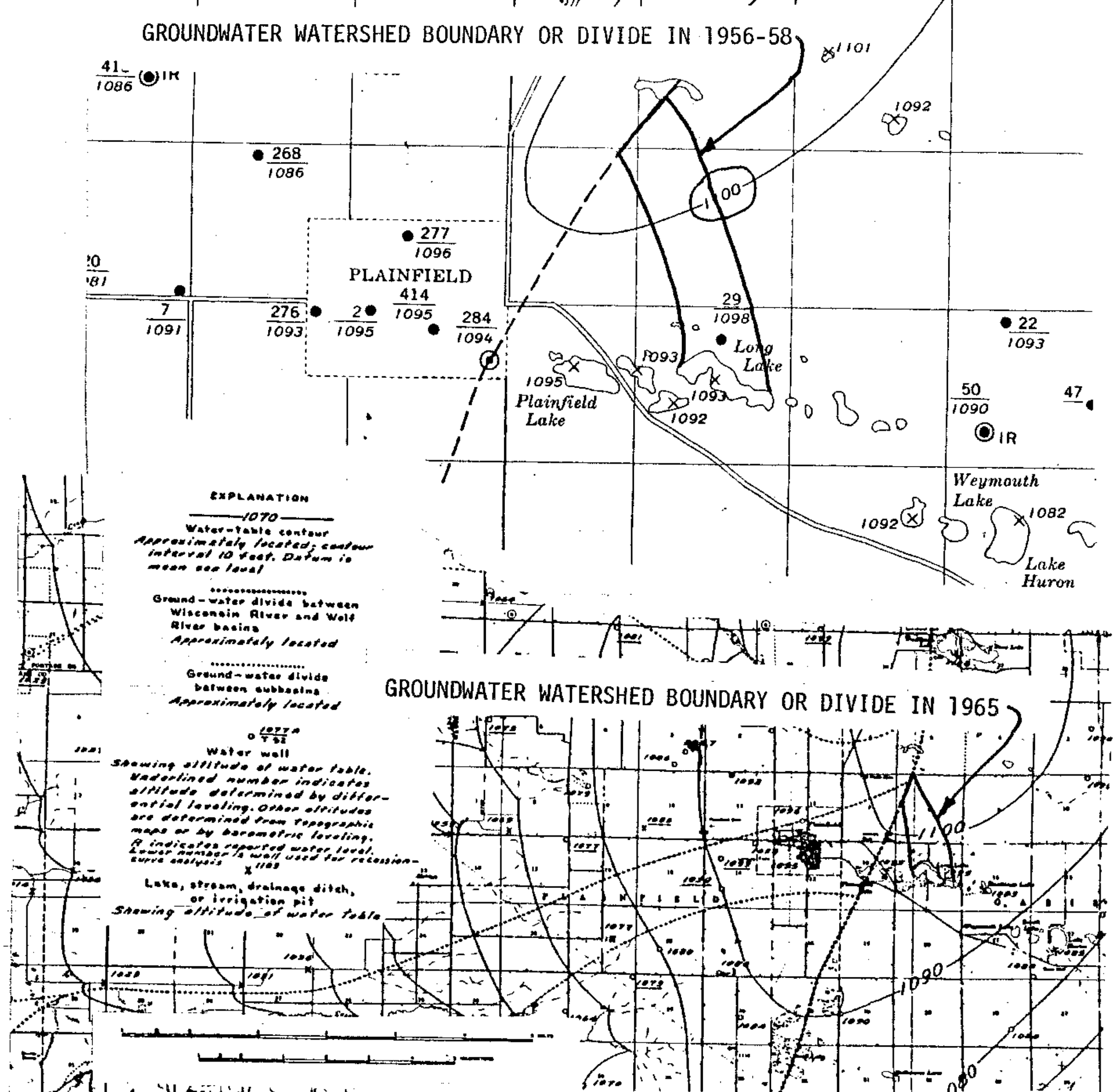


FIGURE 14

GROUNDWATER WATERSHED FOR LONG LAKE - WAUSHARA COUNTY
FROM SUMMERS, 1965 AND WEEKS AND STANGLAND, 1971

EXPLANATION

——— 1100 ———
Water-table contour
Contour interval 20 feet; datum is mean sea level

• • • • • • • • •
Approximate western limit of area of flowing wells, except for Wild Rose area

◉ M
High-capacity well
M, *municipal or industrial well;* IR, *irrigation well;* F, *flowing well. Pumped at rate of 100 gpm or more, 1956-58*

⊙
High-capacity irrigation pit
Pumped at rate of 100 gpm or more, 1956-58

●
Low-capacity well
D, *destroyed well;* F, *flowing well. Includes high-capacity wells used only for emergency supply*

Spring

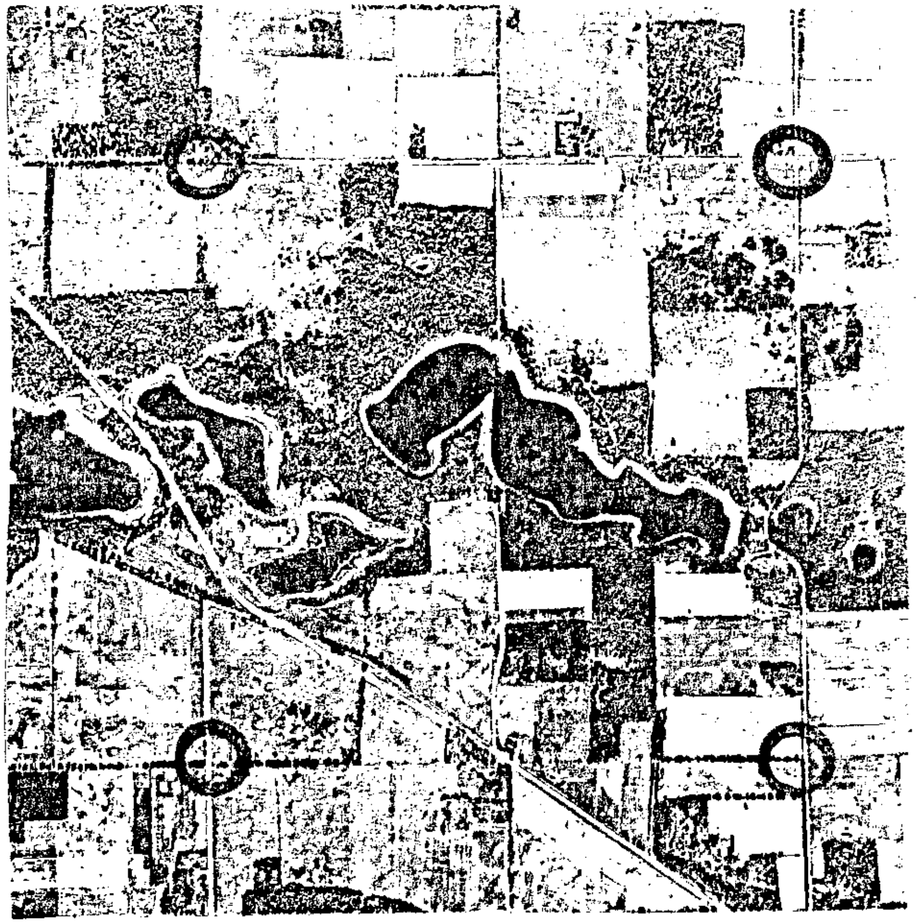
424
1059
Upper figure is well or spring number; lower figure, where shown, is altitude of water table

× 1086
Altitude at water table at spring stream, pond, marsh, lake, or quarry

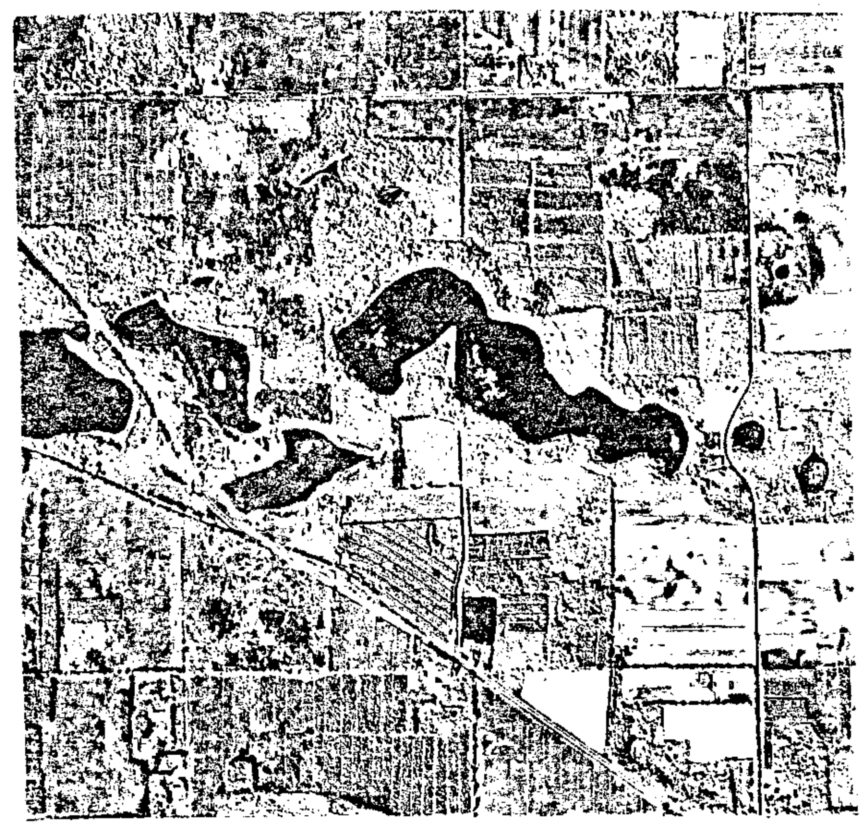
⚒
Quarry

24
Streamflow measuring site

▲
Stream site at which water was collected for chemical analysis



October 12, 1957



August 29, 1979

FIGURE 15

AIR PHOTOS SHOWING THE REFORESTATION THAT HAS OCCURRED NEAR LONG LAKE - WAUSHARA COUNTY

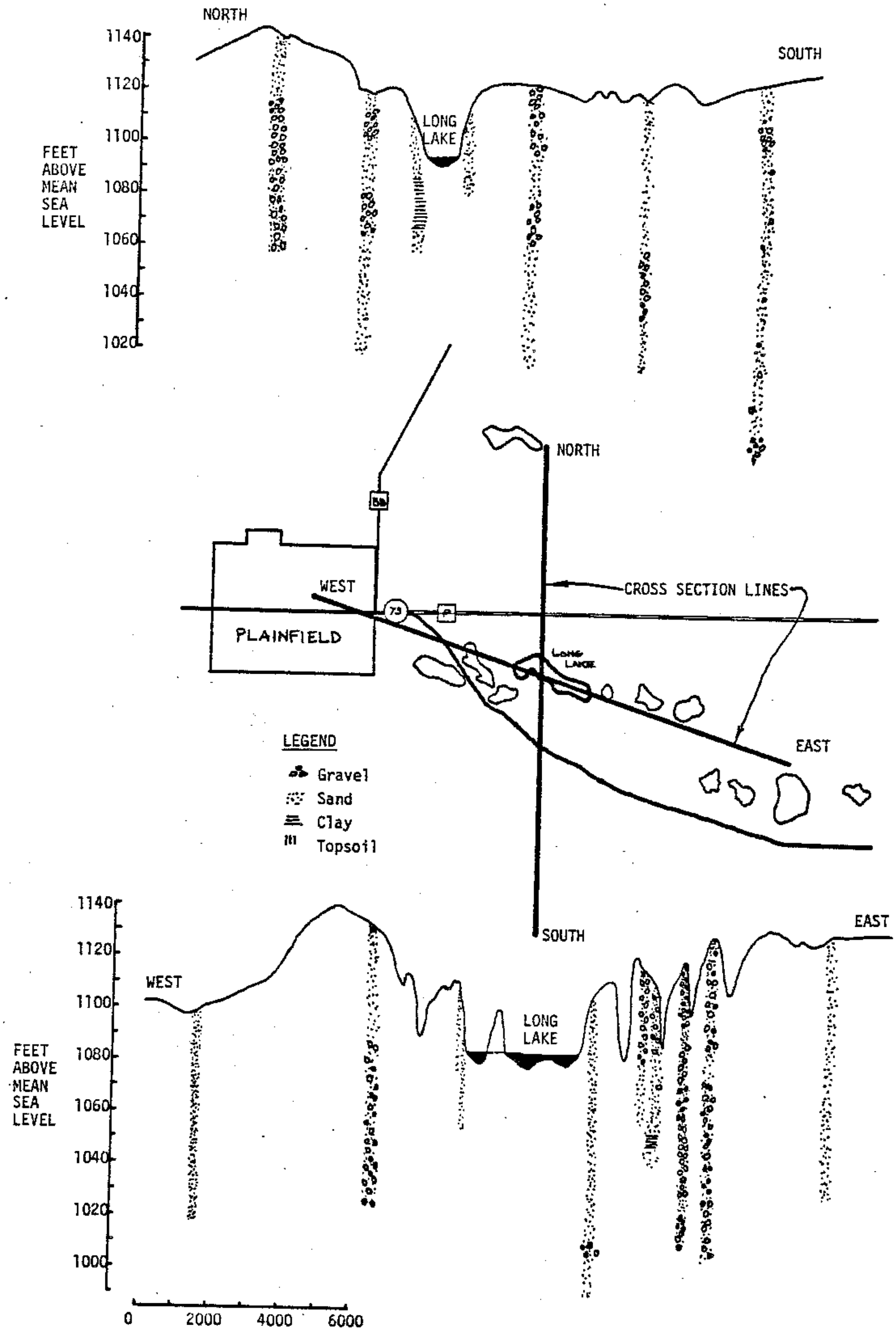


FIGURE 16

WELL LOG CROSS-SECTIONS NEAR LONG LAKE - WAUSHARA COUNTY

Watershed Practices

The water quality of Long Lake is generally quite good. Unfortunately, the primarily natural infilling process has left the lake with a shallow water depth, but great volumes of highly organic sediment. Rooted vegetation has been able to establish itself throughout the lake because of suitable substrate and good water clarity.

Protection activities for Long Lake would be designed to minimize nutrient inputs as a means of preventing possible future algal problems. Even though there is no evidence that restriction of nutrients to a lake will reduce macrophyte growth, it would still be good practice and conceivably could help reduce the lake's weed problem.

At present, surface water runoff from the defined watershed does not pose a serious problem. The watershed is not only small but is mostly forested the highly permeable soils help to promote infiltration. The major concern the Lake District might have in the immediate watershed would be to insure that any future activities will be undertaken in an environmentally sound manner.

1. Control of Soil Erosion From Construction Sites About Lake

The most effective method of controlling erosion and sedimentation is careful site planning. Well established and well maintained vegetation is a major deterrent to soil erosion because it shields the soil from raindrop impact and increases flow friction (resistance). Root systems may increase soil porosity, permitting greater water infiltration and reinforcing the soil mass. Stems, stalks, leaves, and roots break up flow patterns, increase flow friction, and cause deposition of some soil particles. Plants also remove water from the soil by transpiration, so the soil can absorb more water, potentially decreasing the amount of runoff. It is important to recognize that planting and maintenance of vegetation is practical only on slopes flatter than three horizontal to one vertical. Mature sod cover will almost completely prevent water erosion in many circumstances. Mature forests reduce water erosion to as little as one-thousandth of the rate on unprotected disturbed soils. Accordingly, every effort should be made to disturb as little existing vegetation as possible, and to reestablish good cover as soon as possible after grading.

Measures to minimize soil loss should be used if the soil is to remain exposed for more than 30 days. Protective measures must be installed prior to or during active construction, not after.

Fast-growing annual and perennial grasses may be used on partially completed construction projects to protect them from erosion for short periods of time. Completion of final grading during seasons unfavorable for permanent vegetative stabilization may necessitate temporary structural surface stabilization. Certain areas such as drainageways, cut and fill slopes, borrow pit areas, excavations and soil stockpiles often require immediate structural surface stabilization, although this need may be temporary.

Permanent vegetative stabilization should be long-lived and require minimal care or maintenance. Grasses and legumes are generally superior to shrubs and ground covers, because of their more complex root systems. The selection of plant material should be based upon specific site growth expectancies, the purpose of the planting, and foreseeable assured level of maintenance activities. Any representation that a particular plant material is proper for a given slope, soil condition, and maintenance expectancy should be viewed skeptically unless the performance of comparable installations in the general area provides certainty.

The more fertile surface layer of the soil, if present, is usually removed and stockpiled during grading activities. Typically, exposed subsurface layers are less fertile, have lower organic matter content, and are more susceptible to erosion than surface soil horizons. For this reason, the physical and chemical properties of newly exposed soils should be considered. The principal chemical factors are nutritive elements such as nitrogen, phosphorus, magnesium, potassium, and occasionally certain trace elements. Systematic soil analyses of various horizons performed during the site investigation can be helpful in estimating the plant requirements and the proper application of fertilizers and other conditioning materials. For plant growth, factors such as soil texture, soil drainage, porosity, degree of aeration, structure, degree of compaction, soil temperature, slope gradient, available nutrients, and exposure to the sun and wind must be carefully considered.

Prior to establishment of permanent vegetation, a protective layer of mulching is an important erosion control measure because it: 1) protects the soil against erosion; 2) prevents seeds, fertilizer, and other soil additives from washing away; 3) improves capacity for rainfall infiltration into the soil; 4) prevents wide variations in soil temperature, 5) encourages retention of moisture by reducing surface evaporation, and 6) shields delicate young plants. The most common mulch materials are hay, small grain straw, wood chips, jute matting, glass fiber netting, plastic and asphalt emulsions, and various paper products. Most fiber mulches require immediate anchoring to prevent dispersal. Using plastic sheeting as mulch is unwise because direct sunlight may cause it to kill seeds and plants. The UW-Extension can provide guidance on such activities. The present Waushara County agent is Milo Olson, 414-787-4631, Ext. 220.

2. <u>Control of Nutrients/Sediments in Overland Flow During Storm Events</u>

Although few properties at Long Lake have developed lawns right down to the water's edge, those that do might be modified by the reintroduction of locally common vegetation. It is recommended that a strip of land paralleling the shoreline and extending inland from the water a minimum of 20 feet (buffer zone), be allowed to develop with vegetation. This can be accomplished by the selective planting of terrestrial species observed growing in this zone at other sites around the lake where development has not yet occurred. In surveying the surrounding habitats for selection of the species to be incorporated, attention should be paid to the comparison and contrast of the two areas with respect to soil type, moisture content, depth of water table, and slope.

In selecting species for incorporation in the buffer zone, a combination of deep-rooted and shallow-rooted plants should be considered for optimal drainage interception as well as inclusion of a suitable mixture of ground species. This will, ideally, result in a three-storied complex of tall trees, shorter trees and shrubs, and ground level vegetation, such as ferns, creepers, and grasses. When selecting the species to be used, their relative compatibility to one another must be considered (see Appendix I for suggested woody plant species).

While much of the nutrient uptake by the vegetative buffer strip may be expected to return in leaf fall at the onset of winter, any interruption of the flow of nutrients to algae and weeds during the spring and summer growing season helps. Raking of the fallen leaves for decomposition in a compost pile set well back from the shore will further help reduce the nutrient loading to the lake.

Homeowners appear to take considerable pride in their lawns. This same pride, when applied to the lake property setting, could be redirected towards the more environmentally beneficial ramifications of vegetative buffer strip landscaping.

3. Lawn Fertilization

Lawn fertilizers should be judiciously applied. As phosphates from lawn fertilizers migrate through soils as a result of over-fertilization, available sites for phosphorus attachment on soil grains are occupied. When this occurs in the zone of septic system leachate, the effluent phosphates from domestic wastes are transported into the groundwater, increasing the possibility of transport to the lake. The soil retention capacity for phosphate is a finite function and once the phosphate sites are occupied, their value is negated as a sorption area for phosphorus. Care must be exercised in lawn fertilization.

If a lake property owner feels that lawn fertilization is necessary, soil samples should be analyzed to determine the exact nutrient requirement, and excessive application should be discouraged. University of Wisconsin Extension should be able to supply the names of soil testing laboratories that routinely conduct soil analyses.

4. Wastewater Disposal Systems

An important water source for the lake is groundwater seepage and with it comes 24 percent of the nutrient load, primarily wastewater derived. However, not all the homes around the lake contribute nutrients to it through the groundwater, some being located in regions of groundwater outflow. Those located in regions of groundwater inflow and transitional zones contribute the major share of the nutrients to the lake via groundwaters. The groundwater flow directions were shown in Figure 2.

The Lake District is encouraged to support activities which help to minimize the impact of these systems. It is suggested that: 1) the private wastewater disposal systems be pumped or maintained on a regular basis, 2) water use be kept low and such conveniences as garbage disposals or automatic dishwashers be discouraged, 3) conversion of seasonal cottages to permanent residences be done with waterwater disposal system capacity kept in mind, 4) the use of low phosphorus or phosphorus-free detergents be considered, and 5) establishment of vegetative buffer strips be encouraged (see Appendix I for detail).

Dredging

It appears the primary problem facing the Lake District is the shallow lake depth. Large scale dredging of the lake would provide the most dramatic results, especially upon the lake's rooted aquatic vegetation. Winterkills and their impact upon the lake's fishery may also be controlled. Unfortunately, dredging can be quite expensive and location of adequate disposal sites is often a difficult task.

The total amount of "soft" or accumulated sediment within Long Lake is approximately 727,000 cubic yards. Removal of this material would expose the lake's original sand bottom and would deepen the lake down to 30 feet. Weed growth would be eliminated from the resultant area deeper than 12 feet (Figure 10). Macrophyte densities would, in addition, be reduced over sand bottom as compared to the present muck. However, some vegetation must be maintained in the lake for fish and wildlife habitat. The near shore areas (emergents) shown in Figure 9 should be left intact. These areas total about 5 acres. Exceptions could be made where necessary for boat access to and from shore and to provide areas for swimming. Nevertheless, this region is important and future lake management should include its protection.

Of course removal of all the soft sediment is not necessary to provide some improvement. For example, a worthwhile project might involve dredging a five acre area to a depth of 20 feet in the western end (removal of 121,000 cubic yards) coupled with deepening to 8-10 feet in the rest of the basin. Increased depth would thereby be provided throughout the lake with macrophytes eliminated in the 20 foot deep area. Further macrophyte control could be achieved by deepening to 12-15 feet instead of 8-10 feet; however, the bottom sediments might then go anoxic, resulting in nutrient release into the water column. Greater nutrient availability would lead to more algae in the lake.

Other possible benefits of dredging would be an increase in lake volume and accessibility, and potentially an increased groundwater flow into the lake. It is likely that an increase in lake volume would also aid in minimizing fish winterkill problems by both increasing initial mass of dissolved oxygen available in the lake prior to ice cover and by decreasing the oxygen demand from the sediments.

Disposal of sediment must be accomplished in an environmentally acceptable manner. However, this material is probably a good soil conditioner and application to agricultural lands would be a realistic consideration.

Hydraulic dredging involves a cutterhead and pump to remove sediments. Because much water is pumped with the sediments, construction of one or more large holding ponds is usually necessary to settle out the dredged material. The water can then be returned to the lake or disposed of in some other manner. Spray irrigation of the carriage water has been successful in some situations.

Dredging and disposal would require approvals from the Department of Natural Resources (DNR) District Headquarters at Green Bay and approval by the U.S. Army Corps of Engineers. Local government may also have to be contacted for permission to use a particular area for sediment disposal. Moreover, the dredging permit would generally require that any water returned to the lake or other surface or groundwaters meet certain water quality standards. This means that if the dredging alternative is selected, further investigation will be necessary. Some of the required information includes:

1. Location and volume of sediment to be removed;
2. More accurate determination of depth of soft sediment in the specific location of planned removal;
3. Location of the dredge disposal areas,
4. Specific plans for the containment facility,
5. Determination of additional sediment chemical and physical characteristics, and
6. Anticipated environmental effects of the dredging project.

Contact should be made with the Inland Lake Coordinator, DNR District Headquarters at Green Bay, and this office, early in the planning stages of a dredging project.

Various factors influence dredging costs, including project size, method of removal, type of material to be dredged, distance to disposal sites and availability of contractors. Unit costs on current dredging projects range from $2.00 to $2.50 per cubic yard of material removed.

MACROPHYTE CONTROL

1. Herbicides

Herbicide application is included as a management option because of its extensive usage elsewhere and its past use on Long Lake. Nevertheless, treatment throughout the lake is not recommended for many reasons, including: 1) treatments have to be repeated annually or more frequently, 2) only near shore areas can be treated effectively, 3) mounting environmental concern regarding the addition of any toxic substance to public waters, 4) organic sediments continue to accumulate, and 5) increased oxygen demand and nutrient availability for algal growth occur during the decomposition process. In addition, each herbicide is effective against some species but not others. Control of a diverse macrophyte community requires usage of more than one type of herbicide.

If endothal were used, most of the species would be controlled; however, *Chara* would quickly invade the "new" area. If endothal and $CuSO_4$ were used, control would be achieved; however, it would be expected that eventually *Elodea* or some other tolerant species will invade the "new" area. This would necessitate the usage of other or additional chemicals. Chemical treatment generally ranges from $150 to $300 per acre and would not be eligible for cost-sharing under the Inland Lake Renewal program. If used, a permit would be required from the Department of Natural Resources Area Office in Oshkosh.

2. Macrophyte Harvesting

If macrophyte control continues to be the management strategy, harvesting would be the preferred approach. Harvesting has several advantages over herbicides, including: 1) discrete areas can be treated anywhere in the lake, 2) plant biomass and nutrients are removed from the lake, and 3) all species present will be controlled. Retreatment will still be required annually, and adequate control may necessitate cutting an area more than once each summer. Some problems unique to harvesting versus herbicides are as follows: 1) initially high equipment cost, 2) the need to remove and dispose of the cut plants, and 3) the continued presence of macrophytes below the effective cutting depth. Nevertheless, these do not outweigh the advantages.

Harvesting would remove all species present. Also, the soft bottom may allow penetration of the cutting bar to the root depth. Operators of harvesting equipment at Phantom lakes report that they are cutting and removing the whole plants (including roots) and are not getting immediate regrowth. This may be possible at Long Lake.

If weed control were attempted in a large percentage of the lake, harvesting would definitely be preferred (unless dredging is economically practical) because of its beneficial impact on nutrient release/removal, sediment infilling/organic sediment accumulation, and sediment oxygen demand/D.O. depletion rate in winter. Costs will depend upon the equipment selected, but a small harvester can be obtained for about $15,000. Macrophytes can be cut and removed from 1-4 acres per day, depending on abundance. Disposal techniques include application to cropland or gardens, which have proven to be beneficial elsewhere.

Raking or some similar technique might also be considered, especially around special usage shoreline areas. However, some vegetation must be maintained in the lake for fish and wildlife habitat. The near shore areas (emergents) shown in Figure 9 should be left intact. These areas total about 5 acres. Exceptions could be made where necessary for boat access to and from shore and to provide areas for swimming. Nevertheless, this region is important and future lake management should include its protection.

A few private companies advertise macrophyte harvesting services. Prices vary between companies and will be influenced by lake location and macrophyte density. Anticipated costs would, however, be $200-$300 per acre. Disposal of the macrophytes is usually, but not always, included in the service available.

Because they are considered cosmetic approaches which treat the symptoms rather than the cause of the problem, state cost-sharing is generally not available for chemical or mechanical weed control practices.

Aeration

It appears an important problem facing Long Lake is maintenance of a sport fishery. Artificial aeration and the subsequent lake mixing it induces during the late fall and winter months is a method of preventing oxygen depletion. When ice cover forms, it blocks atmospheric oxygen from dissolving in the lake water. As plants and algae in the lake decay, they consume oxygen. If this oxygen consumption is greater than that resupplied to the lake by plant photosynthesis, then eventually all the lake's winter storage of oxygen will be depleted. If the period of ice cover is prolonged or if light is prevented from penetrating into the lake by heavy snow cover, the possibility of this occurring is increased and winter fishkills will be a consequence.

Various methods of aerating a lake are available. One approach is to couple a shore air blower or compressor (30-40 cubic feet per minute with 8 PSI pressure for Long Lake) with perforated tubing that is laid along the lake's bottom. The air escaping through the perforations will transport the warm bottom waters (in the winter) to the lake surface. The ice will eventually be eroded and an open water area will be maintained throughout the winter. Atmospheric oxygen can then be dissolved into the water and can replenish that used up by the decaying organic material.

This type of system might also be used during the fall and early winter months only to reduce the duration of ice cover and maximize the dissolved oxygen concentrations in the water prior to ice formation. Operation of the system during this period only may be sufficient to prevent winterkill, although some experimental testing would be necessary. The estimated equipment cost would be $7,000 with a monthly operating cost of approximately $100.

A second approach is to aerate the water outside of the lake's boundaries. Cascade aeration systems are used for this purpose. Lake water is pumped to the top of a ramp and allowed to cascade downwards, being reaerated in the process. This reaerated water is then allowed to flow back into the lake. An advantage of this type of system over the diffused air injection design is that open water areas (and the necessary protective barriers) are minimized during the wintertime, often an important consideration for a lake that is heavily used for winter recreation. A disadvantage is that it is more energy-intensive, thus much more expensive to operate.

Installation and operation of any aeration system will require approval from the Department of Natural Resources (DNR) District Headquarters at Green Bay.

If the Lake District is interested in this lake management approach, the Office of Inland Lake Renewal should be contacted for technical assistance in the design of an appropriate system. Financial assistance is also available for purchase, installation, and the first year of operation.

Lake Level and Irrigation

Changes in groundwater systems are slow. The development of irrigation near the lake is a relatively new demand on this system. The potential of regional effects from irrigation pumping exist, but these are hard to identify among the changes in recharge and levels brought about by climatic and land use changes. Long Lake has had a fairly long record of lake level measurements from various sources, and groundwater levels in wells installed around the lake have been monitored by the United States Geological Survey (USGS). However, the USGS no longer is funding the monitoring of well and lake levels at Long Lake. Mr. Hall has continued monitoring the lake level on his own time, but the Lake District may find it advantageous to continue monitoring the well and lake levels, including Plainfield Lake. The time of most notable effect due to irrigation would be in dry years so the most intensive monitoring should occur then, but information from wetter years would also be useful. The Office of Inland Lake Renewal can advise the Lake District in establishing a monitoring program.

Do Nothing

If no controls or management plans are implemented, what is the future of Long Lake? The answer is that its characteristics would likely change little from its present state, unless intense urbanization would occur.

The lake's water quality is dominated by its physical characteristics. To date, urbanization has not greatly accelerated the eutrophication process. The lake will continue to fill in gradually, probably at a rate of less than 0.5 cm/year. The fishery would continue to be dominated by species such as bullheads which can tolerate the low winter dissolved oxygen levels.

THE NEXT STEPS

Office of Inland Lake Renewal staff members are available to discuss the results and implications of this study further with the Lake District. The District must then decide what management strategy, if any, to pursue. Once a basic plan has been decided upon, assistance will also be provided in its implementation. Financial aid is presently available from the State for eligible projects at rates up to 80 percent of the actual cost to a maximum of $230,000.

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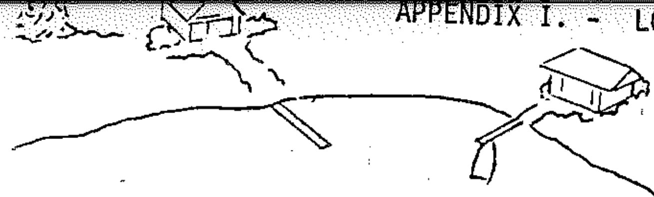

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A Riparian's Guide For Self-Help Inland Lake Water Quality Management

by
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Michigan State University 1976.
Currently Environmental Resources Unit
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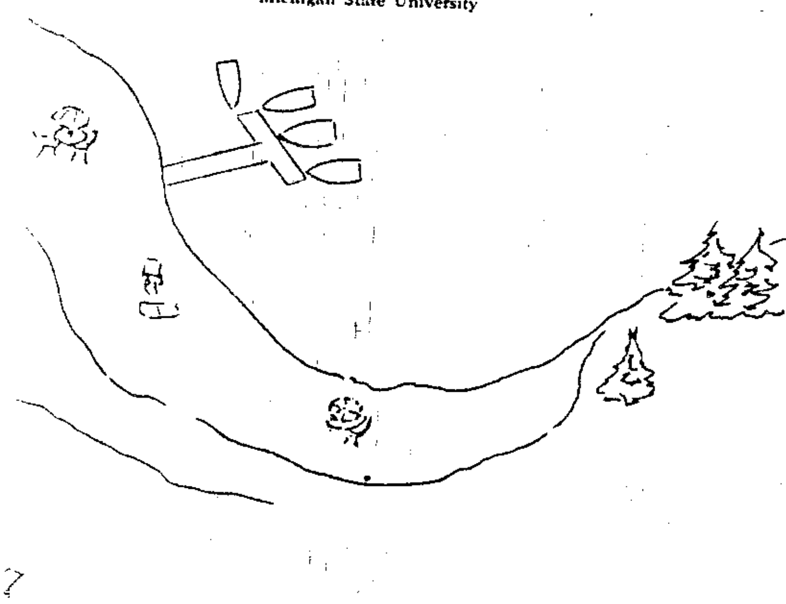


MICHIGAN STATE UNIVERSITY

ON-SITE SEPTIC TANK DISPOSAL OF HOUSEHOLD EFFLUENT

Introduction

In addition to the criteria used in the selection o lake property, as mentioned in Chapter I, the owne has a continuous responsibility to use and maintain th holding in such a way as to not contribute to th degradation of the lake.

A major factor of recreational lake degradation in Michigan is the enrichment and contamination of the waters by sewage effluent draining through the ground and into the lake from faulty septic tank systems.

Because many recreational lakes are in rural areas, municipal sewage systems are infrequent. Therefore, the riparian's responsibility for the safe disposal of household wastes is imperative. This chapter is intended to provide the property owner with an insight into the principles of septic tank operations. This information should assist in the optimal selection and maintenance of the on-site disposal process.

In some instances the soils and topography of the setting may significantly reduce the efficiency of septic tank systems no matter how carefully installed. Therefore, further information is provided for modifications and use procedures which will help reduce the environmental damage of the system under such circumstances. Next, in situations where the septic tank system is altogether inappropriate, alternative disposal methods are discussed. Finally, to lessen the impact of effluents on lake water quality, a system of vegetative buffer plantings is discussed.

Waste disposal by the septic tank-drain field system came into widespread use in this country during the post World War II period when the return of large numbers of GIs coincided with economic recovery and precipitated the building boom of the late 1940s and early 1950s. Housing developments and individual home sites expanded at a faster rate than public sewage disposal facilities, and individual on-site sewage disposal systems filled the gap. The most popular of these was the septic tank-drain field system. This consists of a large settling tank which initially receives waste-laden household waters. Here much of the solid material settles out as sludge, and bacterial decomposition of organic material begins.

Most septic tanks have a holding time of about 24 hours. The relatively clarified water from the septic tank then flows from here to the tile field, or subsurface ground distribution system. The intent here is to trickle the effluent in as wide a dispersal pattern as is feasible to allow the bacteria of the soil and the soil matrix itself to serve as a filtration system.

The actual efficiency of a septic tank, however, is extremely variable depending upon the capacity of the facility, frequency of use, slope of the land, soil type, size of the disposal site, depth to groundwater, and proximity of the system to wells, streams, or lakes.

Design Principle of On-Site Septic Tank Systems

The system consists of two basic components, a holding tank to settle out solids and initiate anaerobic bacterial decomposition of organic compounds and a distribution system for effluent waste water, usually either a dry well, seepage bed, or tile field. In each distribution system the objective is to use the surrounding soil to filter and disperse the waste water from the septic tank. In the soil layer, natural bacterial populations continue the decomposition of the effluent while the soil structure itself is relied upon, by a physical filtering process, to entrap any remaining suspended material and bacteria contained in the wastes. These same soil particles also absorb much of the phosphates derived from the waste water. The result is purified water. This purified water is then safely available for use when it reemerges in streams or lakes and is withdrawn some distance away by drinking water wells.

Suitability to Recreational Lake Settings

As it turns out, the area surrounding popular recreational lakes rarely meets the criteria appropriate to the ideal functioning of on-site septic tank disposal systems. Nitrates and chloride ions are not effectively removed under even the best conditions. Often housing lots are too small to allow adequate removal of phosphates or bacterial organisms before the effluent enters the lake or groundwater system.

Nitrates and, particularly, phosphates derived from such sewage are important nutrients associated with plant growth. When they drain into lake waters because of inadequate treatment of wastes, proliferation of algae and aquatic weeds can result, with an associated decline in the recreational potential of the lake.

Septic tank effluent may also foster the entrance of bacterial and viral contaminants from human feces to those same lake waters, or to drinking water wells with attendant potential health hazards to local residents and swimmers. Dr. Walter N. Mack has demonstrated the presence of polio virus in well water in one instance in Michigan associated with septic tank contamination of groundwater.(7)

At present, regulations determining the design and location of residential septic tank disposal systems are established by individual sanitary codes set by each Michigan county. The State Public Health Department authority applies only to larger-scale disposal systems generating 10,000 gallons per day or associated with housing developments built since 1968. Consequently, the individual lake resident, contemplating construction or modification of an on-site sewage system, must comply with the standards of that county.

Most Michigan counties require a minimum setback of 50 feet of both septic tank and drainage area from any well or surface water as a public health safety measure. This distance, however, may not adequately prevent the entrance of nutrients into these facilities. Ellis and Childs (4) recorded an instance of phosphate travel greater than 100 feet to Houghton Lake from a septic system. The embayment area of the lake in front of the suspect septic system was observed to support an unusually dense aquatic weed growth suggestive of localized enrichment. The generally existing sanitary codes pertaining to minimum setback requirements, together with the frequency of sandy soils adjoining many Michigan lakes in which rapid percolation test rates may quite often be obtained, create a condition permitting potential entrance of significant nutrient loading to these lakes.

In addition, many existing home sites of 10 years or older may often have saturated drain fields which in the past may have adequately intercepted phosphates, but now, due to clogging of the subsoil surfaces by organic matter, are contributing considerable phosphate to the lakes.(3)

This nutrient source from septic systems surrounding each lake together with lawn fertilizer runoff constitutes a cause of lake degradation which can be remedied by responsible landowners themselves.

Optimal Criteria for New Septic Tank Installations

Where a community sewage system is not available, individuals contemplating purchase should first consult the local county sanitary code to determine the suitability of the proposed site for septic tank disposal. This consultation should be made and a satisfactory soil percolation test completed before any sales agreement is signed. In addition, the conscientious buyer should strive to exceed existing minimum standards by incorporating as many of the recommendations as possible.

Septic Tank

Install the largest practical septic tank possible. Generally the smallest acceptable size has a 750 gallon capacity, while larger tanks are required as the number of bedrooms and household occupants increases. The cost is not considerably greater for a 1,000 gallon capacity tank, and the margin of safety with respect to increased retention time is worth the expense. For larger homes, multiple tanks in series may be required, and here, too, it is wise to install the largest capacity practical. If a garbage grinder is part of the household plumbing, additional capacity is indicated. Steel septic tanks should be avoided as they are susceptible to corrosion and leakage. Concrete tanks should be preferred as they are sturdier and less prone to leakage. The following table provides a guide to minimum tank sizes which should be installed.

Location of the septic tank for easy inspection accessibility and cleaning is usually required by law, and is an additionally good family health and lake management practice. The resident should consider this in planning any landscaping or structural modifications of the residence. Under no circumstance should any structures of considerable weight or vehicle parking areas be located above or near either septic tank or drain field.

Dosage Chamber

An additional feature which, if properly designed and installed, can increase the efficiency of the system is the incorporation of a dosage (or dosing) tank between the septic tank and tile field (or seepage bed). It is equipped with either an automatic syphon or pump so that when the level in the chamber reaches a predetermined point, the water in the chamber is emptied into the drainage system. The dosage chamber is intended to retain effluent until a sufficient amount appropriate to the distribution capacity of the drainage field is reached. It then releases this measured amount to the distribution system. In this manner, the receiving soils are allowed some opportunity to drain and dry out between the wetting cycles, as opposed to a less interrupted flow of effluent when the drainage bed is connected directly to the septic tank.

The dosage chamber is particularly helpful in reducing massive "slugs" of effluent to the soil during periods of peak use such as weekend visitors or extensive use of washers or other large-volume water uses. The incorporation of a dosage chamber in the system, in effect, "buys time" for the soil to absorb and filter the household effluent.

Drain Field

Common drain fields used in Michigan are the tile field, seepage bed, and dry well. While all of these systems leave much to be desired with respect to lake communities, the tile field is usually least damaging(17)(12) and should be preferred to either of the other alternatives. This method of subsurface disposal incorporates the largest surface area exposure of the soil to effluent and thus offers the most promise of nutrient and bacterial interception before the effluent water enters the water table or surface water system.

RECOMMENDED MINIMUM SIZE SEPTIC TANKS

Adapted from Vogt and Boyd, 1973

House Size	Tank Capacity Without Garbage Grinder	Tank Capacity With Garbage Grinder
2 bedrooms or less	1-750 gallon	1-1000 gallon
3 bedrooms	1-900 gallon	2-750 gallon
4 bedrooms	1-1000 gallon	1-1000 gallon plus 1-500 gallon

For each additional bedroom the tank capacity must be increased by 400 gallons. Remember, both the septic tank and tile field must be expanded if additional bedrooms are later added to the house.

Local codes will often stipulate the maximum length and minimum space between trenches for the tile field. Ideally, the run for each trench should be no more than 100 feet with a minimum space of 4 feet between trenches(17). More often, however, the size of the drain field will simply be stated as a minimum number of square feet based on the number of bedrooms in the home, slope of the land, and results of the percolation test. The longer the time for water to go down in the percolation test, the more area required for the tile field. It is generally reasonable to expect to need a minimum of about 225 square feet of absorption field for a three bedroom home(17). Residents near the lake shore should allow even more space, as soil absorption capacity is even more critical.

In considering local requirements, it is important to recognize that these laws, primarily designed to protect well-water supplies, are inadequate with respect to the special conditions of the lake environment. The spacing and percolation requirements appropriate to a large, remote lot in an upland setting may be completely ineffective when applied to small, sandy, lake shore lots. Thus, as a general rule, the lake property owner should try not only to meet, but to exceed local code requirements.

The required percolation test as a major determinant of soil suitability for a tile field and its necessary size has been criticized as being inadequate for measuring soil infiltration capacity(3)(5). Bouma states the field percolation test method overestimates the infiltrative capacity of the soil once an operating tile field is installed. Healy and Laak further suggest that size and shape of the hole as well as weather condition at the time of the test also affect the results.

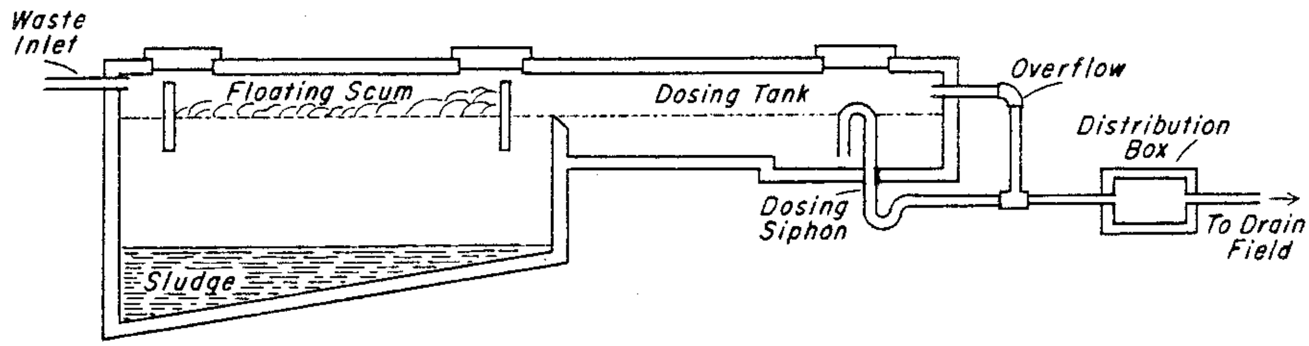


Illustration of the dosing chamber (or tank) with dosing siphon presented in schematic form. Adapted from "Manual of Septic-Tank Practice," 1963 by U.S. Dept. of Health, Education and Welfare (Publication number 526) p. 51.

However, since the percolation test remains a basic indicator of tile field suitability and size, several tests should be conducted throughout the general area in which the proposed field will be located, and then the tile field should be installed larger than the size anticipated as adequate on the basis of the percolation tests. An alternative to a percolation test in Lenawee County is to have the contractor dig a soil profile with a backhoe. This, together with site evaluation by County Health Department representatives, determines septic tank and drain field requirements of the individual property.

Once the size of the proposed drain field is determined, the resident should allow sufficient space on the property to later install a second tile field of the same size. Depending upon soil type and intensity of use of the septic system, the tile field will eventually decline in efficiency due to clogging of the soil spaces with an organic residue or "crust" on the trench walls. This is caused by the trapping of fine suspended material still in the septic tank effluent as well as an organic mat resulting from metabolic activity of aerobic bacterial organisms degrading the effluent at the soil-water interface(3). The life of the tile field will be variable, but generally effective water treatment should not be expected to last more than 10-15 years.

If the resident can afford it at the time of construction, a duplicate tile field should be installed along with the initial one. Both should be connected to the septic tank with a valve system. This makes it possible to alternate from one tile field to the other every few years, thus allowing the soil in the unused tile field to "dry out" and recover its infiltrative capacity. Standing water, the odor of sewage, or soggy sod above the tile field indicate degeneration of the field and the need for remedial action. The continued existence of a clogged drain field constitutes a direct health hazard and also insures the contamination and enrichment of nearby surface waters during unusually wet periods.

Criteria for Tile Field Installation

The septic system should be set as far as possible (in accordance with existing sanitary code requirements) from any well or surface water. In other words the resident should try to exceed, as much as possible, the minimum setback distances. When possible the tile field should be located on the far side of any slope leading toward the lake or well site. It is still possible, however, for effluent to collect beneath the leach field and drain back into the lake, or to intercept groundwater flowing toward the lake or well due to hydrostatic pressures independent of the surface contours. Nonetheless, the effort should be made to set the drain field(s) as far back as possible.

Once the location is selected and approved by the local sanitarian, the trench construction may be initiated. Depth and fill requirements are also covered in most codes and many counties may require inspection of the tile field before it is covered. The bottom of the tile trenches should be at least 4-6 feet above the water table at its highest level of the year and the tiles set no more than ½ inch apart in a level run. A plastic, perforated drainage pipe is also available and should be installed in accordance with local sanitation codes. Michigan State University Cooperative Extension Bulletin Number S77 provides an excellent guide to the homeowner with respect to the field construction and septic system maintenance.

Precautions Regarding Operation of On-Site Disposal Systems

To reduce the damaging potential of the lake front septic system, follow a policy of water conservation. The less flushed into the system, the less its chance of contaminating groundwater or the lake. Such a policy does not call for stringent water rationing, simply a little restraint and common sense. Similarly, the septic system is intended to accommodate the disposal of bodily wastes and, ideally, should be limited to this purpose only.

Try to avoid appliances which constitute an unnecessary burden to the system in terms of sediments, organic material, and volume of flushing water. Instead of using garbage disposals, alternate disposal methods should be used such as garbage pickup service or landfill disposal. By the same token, even where not specifically prohibited, home laundries should also be avoided. Washing machine or dishwater effluent is often heavily laden with phosphate detergents which, even if biodegradable, place a strain on the system. If a washing machine is in use on the property, wash loads should always be a full load of laundry so unnecessary volumes of water are not flushed through the system.

Similarly, avoid once-a-week "wash days" to prevent massive slugs of water from entering the system, thereby reducing the exposure time of effluent to soil filtration. Instead, full wash loads should be done at intervals spaced throughout the week. (The same rationale applies to the use of automatic dishwashers.) Care should be exercised not to overload the system when visitors are entertained. Often the strain imposed on the household hot water heater will help curtail such abuses to the system, but again a little common sense to space out baths, dishwashing, etc. helps.

Moderate use of bowl cleaners and cleansing compounds should not adversely effect the bacterial cultures of the system, but the toilet should not be used as a common receptacle for large amounts of caustics, grease, oils, or volatile compounds. Nor should sanitary napkins or disposable diapers be flushed into the tank as these products break down into cellulose fibers which may accumulate at the soil interface of the tile field or, if intact, can clog plumbing or drain tiles. The same caution obviously applies to plastic products, paper towels, and cigarette butts.

The septic tank itself should be pumped by a licensed septic tank service about every other year depending upon the extent of use. Whenever the tank is pumped, it is wise to leave some sludge in the bottom to help restart the bacterial action.

In addition to the operational precautions mentioned above, the resident can also reduce the nutrient input from the property to the lake by landscaping to prevent erosion, avoiding the direct runoff of storm water to the lake, and leaving a strip of natural vegetation along the lake shoreline. The plants which naturally occur at the water's edge often have root systems which help stabilize the bank and also take up some of the nutrient laden groundwater which would otherwise enter the lake.

In this respect, lawn fertilization should also be held to a minimum, if practiced at all. Any fertilizer not taken up by the grass will drain into the lake and further contribute to aquatic weed problems and algal blooms. [Residents who feel a lush lawn is imperative should fertilize only during the spring growing season. A soil test by the County Cooperative Extension Service should first be made, and fertilizer applied strictly in accordance with the resultant recommendations.]

Investigation for Septic Tank Infiltration of Lake Waters

The individual property owner as well as the lake association can test a septic system for possible leakage by periodically flushing a fluorescein dye down the drain. These dyes serve as tracers of the path of the water from the system. They are commercially produced, harmless to the water or environment, and produce a bright red or green color. If a septic system is discharging directly to the lake, a noticeable color plume will usually result within a few to 24 hours. The dyes are often prepackaged in gelatin packets or as tablets in household size doses. Companies providing the dye preparations may be located through advertisements in sanitary engineering and water management journals, or via the regional public health department, county sanitarian, or plumbing supply company.

If a dye test indicates leakage, the septic system should be inspected and the problem corrected. This may entail anything from simply pumping the septic tank for repair, or replacement of tank or tile field. It should be noted that the dye test is not a definitive indicator of septic system efficiency. A positive test does not necessarily constitute proof of contamination (any more than a negative test implies absolute safety), but it does indicate the need for a careful investigation of the area to ascertain the nature of the discharge. In this respect, the assistance of the local sanitarian or a licensed septic tank serving company may be required.

From the standpoint of good lake management, the dye test is most effective if conducted regularly as a community project sponsored by the local property owners or lake association. An ideal time is Independence Day, Labor Day, or Memorial Day when the largest number of residents is expected. In relatively crowded lake communities, it may be necessary to organize sequential testing of adjacent homes or follow-up dye tests to determine which individual systems caused the positive results in a particular area of the lake. Any such project, to be successful, requires considerable preplanning, including the diplomatic education of residents with respect to environmental and civic responsibility. An attitude of positive co-operation is essential if any indicated remedial follow-up action is to be successful.

ALTERNATIVES TO SEPTIC TANK DISPOSAL SYSTEMS

Currently there are three technologically feasible alternatives to the use of septic tank drain field systems. These are aeration chambers, holding tanks, and municipal sewage systems.

The aeration chamber consists of an elaboration on the basic septic tank wherein air is pumped into the standing tank effluent to introduce more oxygen. Digestion is more completely accomplished by aerobic bacteria as opposed to the anaerobic system of the traditional septic tank. The resultant effluent released to the tile field imposes considerably less strain on the soil biota and is lower in suspended solids and BOD. However, the nutrient component remains a factor of the dispersed effluent, and its ramifications in terms of potential lake enrichment are still viable.

Conversion to holding tanks entails the likely expansion of the holding capacity of the existing septic tank. (The impact of holding tank capacity restrictions can be reduced by installation of devices to reduce the amount of water used to flush the toilet each time it is used. This may consist of plastic inserts commercially marketed under the trade-name "Little John" or by placing a plastic jug full of water in the toilet tank to reduce its holding capacity and thus, the amount of water used for flushing.) However, all effluent is pumped from the tank by a contract disposal service, and the liquid waste and sludge is taken either to a municipal sewage treatment plant or approved land surface disposal site. This option would involve an expense to the residents for subscribing to a disposal service — Wisconsin studies indicate the cost to be about $1,000 per year for a family of four(12) — and the constraint of judicious use of water to reduce the frequency of pumpage. It is feasible however, to envision an arrangement whereby the preexisting tile field could be incorporated as a back-up system in case of tank overflow.

Accompanying such a system would have to be some form of regulatory or economic constraint to prevent abuse of the "back-up privilege." Otherwise some residents could ostensibly subscribe to the philosophy and function of holding tank operations, while in reality simply continuing their original septic tank-drain field system. Perhaps establishment of flat-rate haulage with regularly scheduled pumping for each subscriber would accomplish this. This would be similar to the system practiced by home heating oil companies where each customer is scheduled for service to keep that household's oil tank properly supplied.

The holding tank option has the added benefit of providing the incentive to local residents and local government alike to initiate the construction of a municipal sewage system. In all likelihood, annual costs to residents on a sewer line would eventually be less than the pumpage fees associated with a holding tank. While the township or county would benefit by no longer needing to contend with large scale land disposal sites; problems of groundwater contamination, licensing and administration of the haulers, and winter maintenance of disposal facilities would still exist. If the disposal site is an existing sewage treatment plant, increased use of the holding tank system will probably necessitate its expansion anyway. A note of caution: the lake community considering a sewage project should also plan for stringent development ordinances to prevent possible overdevelopment of the area as a consequence of the new sewer facilities.

An alternate approach is an on-site waste disposal authority. This idea is being developed at the University of Wisconsin-Madison. In this instance a local municipal authority would be created with assessment powers which could purchase the septic tank systems of all member households. Assessments on the properties provide the authority with the necessary funds for the purchases and operation. Thereafter, all responsibility for operation and maintenance of the systems would rest in the authority rather than with individual home owners. Ostensibly, the authority would have greater financial resources than any individual householder and could operate the systems in the most environmentally responsible manner. Its responsibilities would include the replacement or improvement of failing systems including conversion to holding tanks where indicated.

Another option to septic tank-drain field systems still in the early marketing stages is the use of self-contained disposal systems such as propane incinerator toilets and a variety of more recently developed self-contained systems such as the "Clivus Multrum" dry toilet based on the concept of organic material composting, or mineral oil recycling flush systems in which the oil is cleaned and reused while heavier wastes carried by it settle out in a holding tank.

The advantage of these systems over regular flush toilet plumbing is the reduced liquid volume of the wastes which, in turn, reduces the frequency of required pumping of the holding tank. Unfortunately, installation of the systems ranges from about $800 to $4,000 and often involves maintenance and operation costs for recycling pumps and filters in addition to propane and/or pumpage fees. Pumping of these tanks, however, is required far less frequently than with a standard holding tank system.

For the individual riparian who can afford the initial expense, this option, if proven to be hygienically and aesthetically acceptable, may prove superior in long-run costs and environmental risks to the interim septic holding-tank approach. It must be noted, however, that these self-contained units, while showing great potential, remain to be proven technically effective or publicly acceptable.

Consequently, the holding tank option seems an appropriate short-term interim measure for providing relief to lake eutrophication. It also provides the needed incentive (including possible help in gaining federal support) to establish more permanent measures, such as municipal sewage treatment facilities. Eventually, the self-contained disposal systems may provide the answer to residential pollution of surface waters, but this option is yet to be sufficiently developed and tested.

THE USE OF VEGETATIVE BUFFER STRIPS TO REDUCE THE IMPACT OF SEPTIC TANK EFFLUENTS ON LAKE WATER QUALITY

Irrespective of on-site sewage disposal method, an additional way to limit nutrient input to the lake is to preserve a natural strip of phreatophitic ("moisture loving"), woody vegetation along the water's edge. This buffer zone of indigenous plants will help stabilize the lake shore as a precaution against erosion. It will intercept some of the nutrients which would otherwise enter the lake by surface runoff or such subsurface drainage as household drain fields.

This interception is accomplished by nutrient uptake via the root systems, with subsequent conversion of at least part of these nutrients by the tree's or shrub's tissues. This interruption and partial retention of effluent nutrients in shoreside trees and shrubs is a preferable alternative to the direct entrance of these nutrients to the lake where they may contribute to aquatic weed and algal growth. While much of the nutrient uptake by the vegetative buffer strip may be expected to return in leaf fall at the onset of winter, any interruption of the flow of effluent nutrients to algae and weeds during the spring and summer growing seasons helps. Raking of the fallen leaves for decomposition in a compost pile set well back from the shore (preferably on the reverse slope) will further help reduce the nutrient loading of the lake.

If the lake lot is just being developed, the owner should leave as wide a strip of undisturbed vegetation as possible, particularly if a relatively steep slope is involved. In addition to heightened water quality protection, this practice also increases the aesthetics of the lake by preserving its natural appearance and provides the resident with more leisure time since less yard maintenance is required. In fact, the less the natural vegetation of the home site is disturbed, the better, so long as the initial cover is natural and thriving.

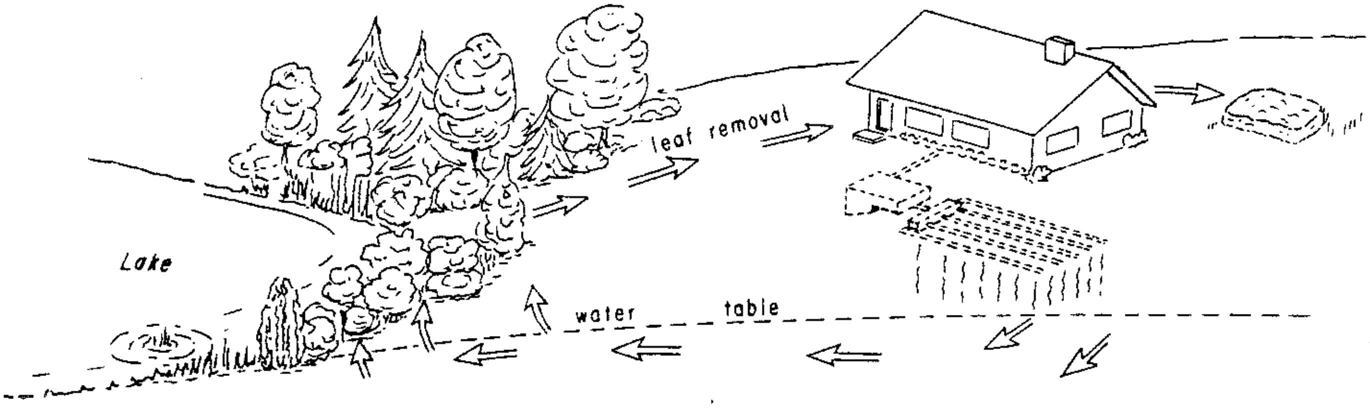
Where the property has already been extensively developed, the sculptured, manicured lawns right down to the water's edge should be modified by the reintroduction of locally common phreatophytic vegetation. This can be accomplished by the selective planting of terrestrial species observed growing in this zone at other sites around the lake where development has not yet occurred.

In surveying the surrounding habitats for selection of the species to be incorporated, attention should be paid to the comparison and contrast of the two areas with respect to soil type, moisture content, depth of water table, and slope. In selecting species for reintroduction, the assistance of the Department of Natural Resources regional forester can be invaluable. The accompanying guide to typical phreatophitic trees and shrubs found in Michigan may also be helpful.

In selecting species for incorporation in the buffer zone, a combination of deep-rooted and shallow-rooted plants should be considered for optimal drainage interception as well as inclusion of a suitable mixture of ground species. This will, ideally, result in a three-storied complex of tall trees, shorter trees and shrubs, and ground level vegetation, such as ferns, creepers, and grasses. When selecting the species to be used, their relative compatibility to one another must be considered.

The following table gives examples of tree and shrub compatibility, so the appropriate combination of canopy and understory species can be planted. This may entail planting some species at different seasons or time intervals to allow for differing growth rates. Similarly, the ultimate size of the plants should be considered with respect to their potential for screening unsightly structures on the property or the possibility that they would obstruct a preferred view. Cooperating personnel of the Michigan State University Extension Service in the Department of Horticulture and School of Urban Planning and Landscape Architecture may be approached for assistance in planning the best positioning of the species selected.

Once the choice of species is made, the appropriate plants must be acquired. Some of the species included in the accompanying list of suggestions may be ob-



The concept of the vegetative buffer zone, showing up take septic tank effluent from the ground water system is diagrammed here. The nutrients are theoretically intercepted by the root system of the shrubs, trees, and other plants and retained in their structure and leaves. Leaves should be raked and composted away from the lake shore to prevent release of phosphates to the lake upon their decomposition.

tained from the Michigan Department of Natural Resources Forestry Department under their wildlife planting program. Again, the regional forester should be of assistance in this respect. (An additional benefit of the buffer zone plantings is that most of the species listed are of direct benefit to wildlife and may enhance the natural aesthetics of the setting.) Stock obtained from the Department of Natural Resources will be of seedling size; if larger specimens are desired they may, in many cases, be purchased from local nurseries. Care should be taken to avoid the introduction of exotic species which may disrupt the local ecology. Similarly, wild species should not be removed from public land, as this is a violation of state law.

American homeowners appear to take considerable pride in their lawns, as indicated by the large market in home gardening supplies. This same pride, when applied to the lake property setting, however, must be redirected toward the more environmentally beneficial ramifications of vegetative buffer strip landscaping.

Suggested Woody Plant Species which May Be Appropriate To Lake Front Buffer Zone Planting

Reference: Fowell, H. A. 1965. Silvics of forest trees of the United States Agriculture Handbook #271. USFS, Dept. Agri., USGPO, Wash., D.C., 762 pp.

Ash, Black – All of Michigan.
Soil: Most common in peat, but also clays and sands or clay till; prefers high water table or standing water.
Associated trees and shrubs:
Trees – American elm, red maple, white cedar, birch, spruce, hemlock, tamarack.
Shrubs – Alder, dogwood, sumac, blueberry, holly.
Growth conditions: Tallest of record is 79 feet in Wisconsin.

Ash, Green – All of Michigan.
Soil: Common on bottomlands, loams with neutral pH to slightly alkaline; successful plantings on spoil banks of strip mines; common in alluvial soils of river and stream banks.
Associated trees: Sugarberry, American elm, aspen, sugar maple, basswood, black willow, sycamore, box elder, red maple.
Growth conditions: 1-3 feet per year in first 6 or 7 years; intolerant to moderately tolerant.
Roots: "Fourth most extensive root system of all species studied" (Agri. Handbook #271 p. 188); trees 38 feet tall had roots 48 feet laterally and 3.6 feet downward; about equally distributed within top 3 feet of soil; highly resistant to wind damage.

Ash, White – All of Michigan except western Upper Peninsula.
Soil: Most common on fertile soils with high nitrogen content and moderate to high calcium content; grows best on moderately well-drained soils; rarely found in swamps, but tolerant of temporary flooding; rarely found in bottom lands where air drainage is poor.
Associated trees and shrubs:
Trees – White pine, northern red oak, basswood, red maple, sugar maple, hemlock, beech, birch, black cherry, elm.
Shrubs – Downy serviceberry, paw paw, American hornbeam, flowering dogwood, witchhazel, E. hophornbeam, dockmackie.
Growth conditions: 3-5 years to reach breast height; about 35-40 feet tall in 20 years; shades tolerant when young, but becomes intolerant with maturity; pioneer species but can survive in climax canopy.

Aspen, Bigtooth – All of Michigan.
Soil: Well-drained, sandy soils; needs water table lower than 18 inches from surface for adequate aeration; found along streams and lakes.
Associated trees and shrubs:
Trees – Quaking aspen, balsam poplar, paper birch, red maple (these most common).
Shrubs – Chokeberry (*Prunus virginiana*), downy serviceberry (*Amelanchier arborea*), sweet fern

(*Comptonia peregrina*), prairie willow (*Salix humilus*).

Ground cover — Blueberries (*Vaccinium* spp), checkerberry wintergreen (*Eaultheria procumbens*), dwarf bush honeysuckle (*Diervilla lonicera*) eastern bracken (*Pteridium latiusculum*) and blackberry (*Rubus* spp).

Growth conditions: Medium-sized tree usually not more than 30-40 feet tall; rapid growth until 40 years old; short-lived for about 60-70 years; highly intolerant.

Roots: Very shallow; good effluent interception probably, but subject to windthrow and topping; popular wildlife food of whitetail deer, beaver, grouse, porcupine.

Aspen, Quaking — All of Michigan.

Soil: Wide variety, but least successful in coarse sands; usually poor in sands because of low moisture and nutrient level (may do very well at lake sides with effluent).

Associated trees and shrubs:

Trees — Birch, white spruce, black spruce, jack pine.

Shrubs — Hazel, alder, raspberry.

Roots: 39-60 inches deep.

Basswood — All of Michigan.

Soil: Loams, sandy loam, silt loam with clay subsoil; should have minimum silt plus clay content of 35% and 3% organic matter in upper 7 inches of soil profile; pH 5.5-7.3; fairly sensitive to microclimate; apparently not "wet soil" tolerant, but leaves have high phosphorus and nitrogen content suggesting that it would take up effluent.

Associated trees: Paper birch, white pine, northern red oak, white ash, white pine, hemlock, yellow birch, sugar maple, beech, black cherry, white oak.

Growth conditions: About 5-12 or 18 inches per year; fastest growth in first 20 years; reaches 140+ feet tall.

Roots: Deep, widely spread system of strong lateral roots.

Beech, American — All of Michigan.

Soil: Preference is loamy soil with a high humus content; requires considerable water — 10 inches per year for growth and transpiration; will grow where water table is within 6-10 inches of surface, but is less tolerant than red maple or sweetgum; has shallower root system on poorly drained soils.

Associated trees: Sugar maple, yellow birch, basswood, black cherry, red spruce, hickory, oak.

Growth conditions: About 1 foot per year for first 40 years; mature height 60-80 feet; maximum 120 feet; very tolerant, similar to sugar maple.

Roots: Larger expanse of surface roots; thin bark makes it subject to fungal infection.

Birch, Paper — North and central Michigan.

Soil: Glacial soils, especially tills and outwash; generally requires well-drained soil; grows best in stands.

Associated trees: Jack pine, balsam fir, black spruce, yellow birch, aspen, sugar maple, white spruce, red spruce, white ash.

Growth conditions: Sensitive seedlings; mature trees — 70 feet tall; short-lived, 70-75 years; heavy mortality.

Birch, Yellow — All of Michigan.

Soil: Grows well on loams from good to poorly drained.

Associated trees and shrubs:

Trees — Hemlock, sugar maple, beech, red spruce, white cedar, basswood, black ash, white ash, aspen, white birch.

Shrubs — Mountain maple, dogwood (alternate leafed), ground hemlock.

Growth conditions: Rapid growth with moderate overhead sunlight; 8-10 feet in 6 years; about 50 feet high when mature.

Cedar, Red — Southern Michigan (Eastern red cedar)

Soil: Neutral to slightly acid soils; pH 4.7 - 7.8, but not very tolerant of upper pH.

Associated trees: Pine, oak.

Growth conditions: 40-50 feet tall; slow growth; rate of growth closely associated with water supply.

Roots: Seedlings have deep tap root, apparently maintained with maturity.

Cedar, White — Central and northern Michigan.

Soil: Best in neutral or alkaline soils especially of limestone origin; well-drained, but also grows in swamps.

Associated trees and shrubs:

Trees — White spruce, black spruce, red spruce, yellow birch, balsam fir, white pine, tamarack, red maple, American elm, aspen, sugar maple, basswood.

Shrubs — Red-osier dogwood, willow, chokecherry, cranberry, alder.

Growth conditions: Seedlings require constant summer moisture; medium size tree commonly 40-50 feet tall, 2-3 feet diameter; 28 feet tall in 40 years on good site.

Roots: Shallow, subject to windthrow.

Cherry, Black — Michigan Lower Peninsula.

Soil: Loamy to gravelly soils with silty to clayey subsoils; well-drained.

Associated trees: Sugar maple, white pine, northern red oak, white ash, hemlock, beech, yellow birch.

Growth conditions: Very rapid growth first 45-50 years; maximum height may reach 100 feet but is usually 80 feet or less; intolerant, common in canopy openings.

Roots: Predominantly spreading and shallow, usually restricted to upper 2 feet of soil; easily windthrown.

Dogwood, Flowering — Central and southern Michigan.

Soil: Upland to deep moist soils; common along streambanks; do better on light soils than heavy ones; foliage high in mineral nutrients, hence significant in soil improvement; litter decomposes rapidly; especially good source of calcium; leaves concentrate flourine; range 40 to 100 ppm with site and season.

Associated trees: Oak-hickory forests, red maple, yellow poplar, white ash, beech, black gum.

Growth conditions: Maximum size 40 feet tall; in north is a many-branched shrub; very shade tolerant.

Hemlock, Eastern — Central to Upper Peninsula of Michigan.

Soil: Grows well in peat and muck soils and also on sandy loams in lake states.

Associated trees: White pine, yellow birch, yellow poplar, aspen, white spruce, paper birch, tamarack, sycamore.

Growth conditions: 16 feet in 40 years in Michigan; maximum — 60 feet in 140 years; highly tolerant of shading, but causes stunted growth.

Locust, Black — Not natural to Michigan, but has been introduced.

Soil: Does well on poor soils, but is a legume and with litter it produces significant nitrogen in the soil and environment (soluble nitrate occurs with rapid decomposition of locust litter).

Associated trees: Hardwood, yellow poplar, maple.

Growth conditions: Very rapid growth – 75 feet in 50 years; maximum height is 40-100 feet.

Roots: Extensive, shallow root system.

Maple, Red – All of Michigan.

Soil: Wide variety of soil; common along small, sluggish streams.

Associated trees: Black ash, American elm, aspen, paper birch, yellow birch, black spruce, sugar maple, beech, basswood.

Growth conditions: Rapid growth in early life; 3-3.5 inches dbh in 10 years; mature trees are 60-90 feet high.

Roots: Shallow or deep tap root, depending on weight; shade tolerant.

Maple, Silver – Central and southern Michigan.

Soil: Variety of soils, common on low, well-drained, river bottom land; sometimes along low lake shores.

Associated trees: American elm, red maple, basswood, sycamore, river birch, cottonwood, black ash.

Growth conditions: Rapid growth, especially in first 50 years; 70-120 feet high; moderately intolerant.

Maple, Sugar – All of Michigan.

Soil: All types; thrives on fertile, well-drained sites, especially loams; pH range 3.7-7.3; best is 5.5-7.3.

Associated trees and shrubs:

Trees – Beech, yellow birch, basswood, red spruce, red maple, hemlock, white spruce.

Shrubs – Beaked hazel, Atlantic leatherwood, scarlet elder, American elder, pagoda dogwood, dwarf honeysuckle, raspberry, blackberry.

Growth conditions: About 1 foot per year; at age 30 may be 35-40 feet tall; very tolerant of shade.

Roots: Deep and branching.

Oak, Northern Red – All of Michigan.

Soil: Soils range from clay to loamy sands, and from deep stone free to rocky, shallow soils; needs moist substratum within 1-4 feet of surface; best sites are fine, textured soils with high water table.

Associated trees and shrubs:

Trees – Ash, aspen, birch, cherry, elm, fir, hickory, maple, oak, pine, spruce, basswood, sycamore, northern white cedar, black locusts, and more.

Small trees – Flowering dogwood, holly, hornbeam, hophornbeam, redbud, pawpaw, sassafras, serviceberry, percimmon.

Shrubs – Greenbrier (*Smilax* spp.), Hydrangea, mountain laurel (*Kalmia latifola*), rhododendron, and witch hazel (*Hamamelis virginiana*).

Growth conditions: Maximum 70-90 feet tall with 2-3 feet dbh; slow growth rate; intermediate tolerance.

Roots: Deep tap root.

Oak, Swamp White – Lower southern Michigan.

Soil: Commonly found in wet lowlands.

Associated trees: All trees common to wet or moist sites; basswood, black ash, hickory, pin oak, red maple, northern red oak, silver maple, sweetgum, sycamore, yellow poplar, white ash, willow.

Growth conditions: 60-70 feet high; fairly rapid growth; 2-3 feet dph; intermediate intolerance with seedlings able to start in shade.

Roots: Shallow root system.

Pine, Red – Central and northern Michigan including Upper Peninsula.

Soil: Grows well in poorer soils; studies of litter in lake states show it to be high in phosporus and nitrogen.

Associated trees and shrubs:

Trees – Jack pine, eastern white pine, quaking aspen, bigtooth aspen, scrub oak, maple, black cherry, balsam fir, black spruce.

Shrubs – Canada blueberry (*Vaccinium canadense*), lowbush blueberry (*Arctostaph-ylos uva-ursi*), prairie willow (*Salix humilis*), American hazel (*Corylus americana*), beaked hazel (*C. Cornuta*), striped maple (*Acer pensylanicum*), dwarf bush honeysuckle (*Diervilla lonicera*), Jerseytea ceanothus (*Ceanothus americanus*), American fly honeysuckle (*Lonicera canadensis*).

Growth conditions: About 1 foot per year for first 60 years; live 100+ years.

Roots: Like white pine, very extensive root system; in some cases tap root may go down 9 feet or more.

Pine, White – All of Michigan.

Soil: Grows on variety of soils but most commonly associated with well drained sandy soils.

Associated trees and shrubs:

Trees – Northern red oak, white ash, hemlock, paper birch, red maple, pin cherry, sugar maple, beech, yellow birch, balsma fir, white spruce, white cedar.

Shrubs – *Oxalis, Mitchella, Aralia, Arisaema, Dennstaedtia, Cornus, Maianthemum, Pteridium.*

Growth conditions: Rapid growth – 20 inches annually; long-lived, up to 200 years; old trees may be 200 feet tall; tolerance: may be shaded out by aspens, oaks, maples and eventually die; but can dominate birches (thin leaf cover).

Roots: Form and distribution varies with soil characteristics; normally only vestige of a tap root with 3-5 large roots spread laterally outward and downward; gives tree firm anchor in soil; mass of smaller lateral roots spread from the major laterals; high concentrations of nitrogen, organic matter, and exchangeable bases stimulate formation of a concentration of fine roots.

Poplar, Balsam – All of Michigan.

Soil: Common along lake borders; excellent growth on sandy, gravelly soils; needs much moisture.

Associated trees and shrubs:

Trees – Balsam fir, aspen, white spruce, paper birch, black ash, red maple, tamarack.

Shrubs – Speckled alder (*Alnus rugosa*), American green alder (*A. crispa*), red-osier dogwood (*Cornus stolinfera*), bunchberry dogwood (*C. canadensis*), mountain maple (*Acer spicatum*), bearberry honeysuckle (*Lonicera involucrate*), beaked hazel (*Corylus cornuta*), American cranberry bush (*Viburnum trilobum*).

Growth conditions: Rapid growth during first 40-50 years – up to 70 feet tall; Short-lived; less shade tolerant than common associates: white spruce, balsam fir, northern white cedar, black ash, red maple; but equally intolerant as quaking aspen and paper birch; will not grow well in competition with other species unless it is dominant.

Poplar, Yellow – Lower central and southern Michigan.

Soil: Well-drained, loose textured soils; requires high nitrogen content and, consequently, often found with black locust.

Associated trees: Beech, sugar maple, black gum, dogwood, hickory.

Growth conditions: 120 feet tall in 50-60 years with dbh 18"-24"; very fast growth, but intolerant.

Roots: Rapidly growing, deeply penetrating tap root plus many strongly developed, wide spreading lateral roots.

Sycamore, American – Central and southern Michigan.

Soil: Excellent along lakes; tolerant of groundwater fluctuactions.

Associated trees: Black elm, red maple, silver maple, black willow (moderately intolerant).

Growth conditions: Fast growing throughout its life, only black willow is faster; 70 feet in 17 years.

Roots: Widely spread, strongly branched roots.

Tamarack – All of Michigan.

Soil: Variety of soils; high moisture tolerance; common on lake shores.

Associated trees and shrubs:

Trees – N. white cedar, red maple, black ash, aspen, black spruce, white spruce.

Shrubs – Alder, red-osier, dogwood, cranberry, birurnum.

Growth conditions: Seedlings need abundant light and constant water level – should not be shaded in early growth stages; relatively slow growth – 3 feet in 5 years; 16 feet in 15 years; 60+ feet in 45 years

Roots: Shallow, compact system, usually 1-2 feet deep; grows well if water table is 18 inches deep.

Willow, Black – Southern and central Michigan.

Soil: Flourishes in very wet areas; needs abundant and continuous supply of moisture during growing season; grows in almost any soil.

Associated trees and shrubs:

Trees – Black spruce, river birch, sycamore, red maple, locust, red mulberry.

Shrubs – Buttonbush, swamp privet.

Growth conditions: Very rapid growth, reaches 30-60 feet in north but short-lived.

Roots: Tends to have relatively shallow, extensive root systems.

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