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Big Long Lake, Lake of the Woods, McClish Lake, Pretty Lake

A Study for their Improvement, Restoration and Protection...

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Lake and River Enhancement Section
Division of Fish and Wildlife/IDNR
402 W. Washington Street, W-273
Indianapolis, IN 46204

Big Long Lake, Lake of the Woods, McClish Lake, Pretty Lake...

A Study for their Improvement, Restoration and Protection...

Prepared for:

Big Long Lake Association
Lake of the Woods/ McClish Lake Association
Pretty Lake Association

DeKalb, LaGrange, Noble, and Steuben Counties, Indiana

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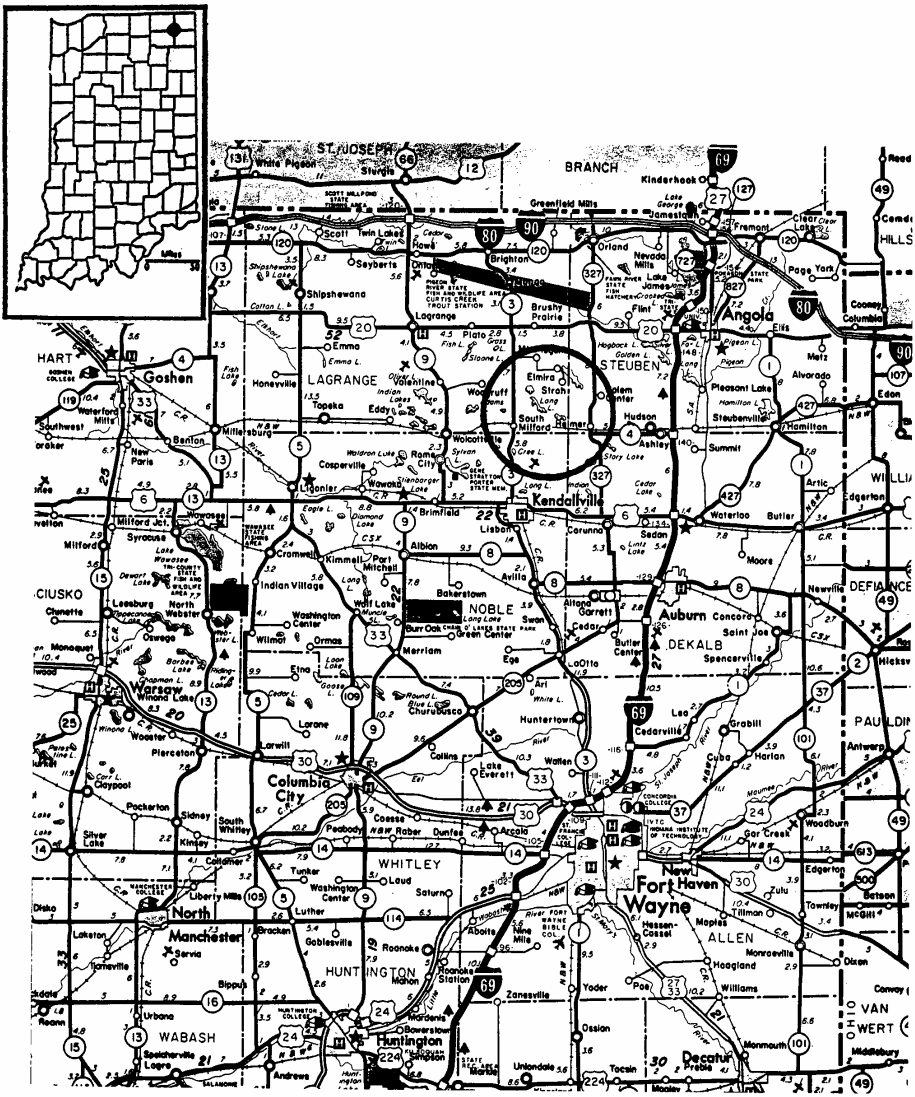
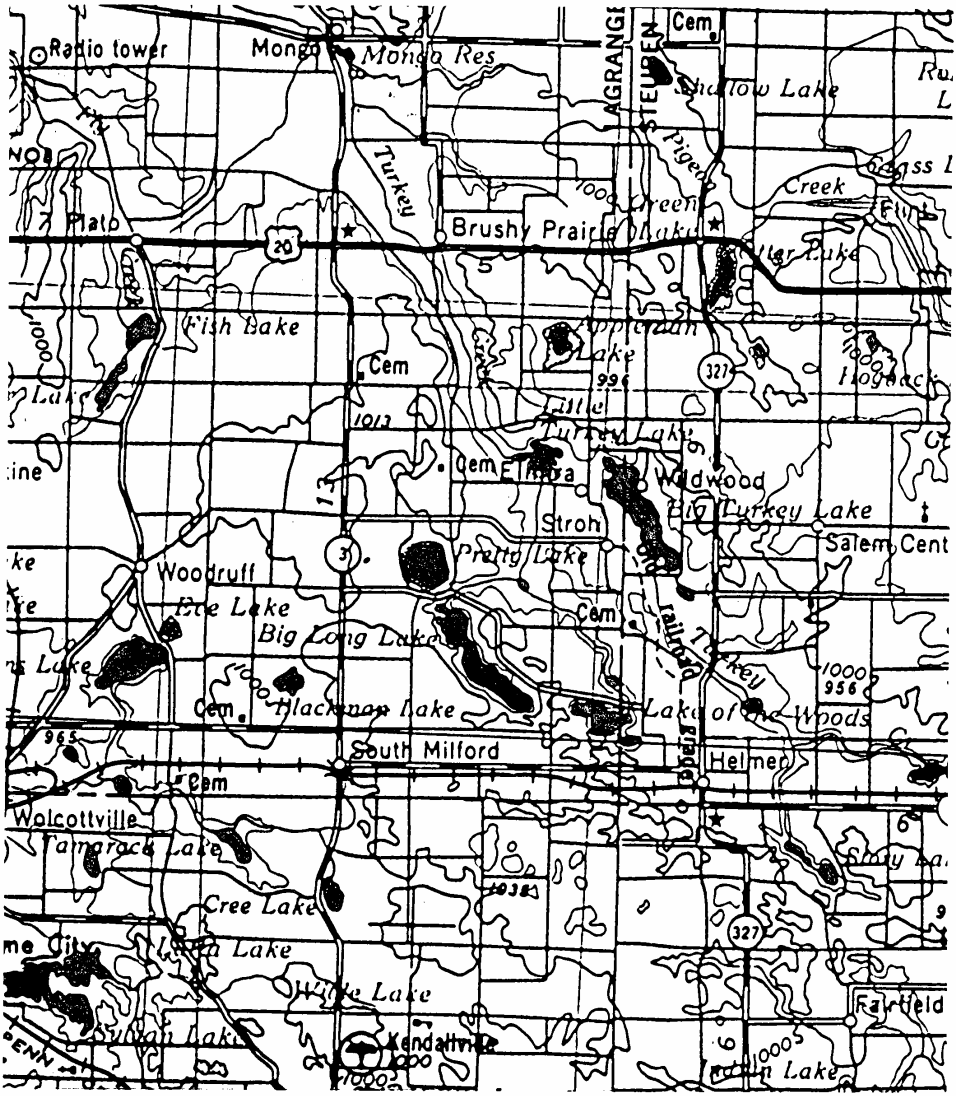
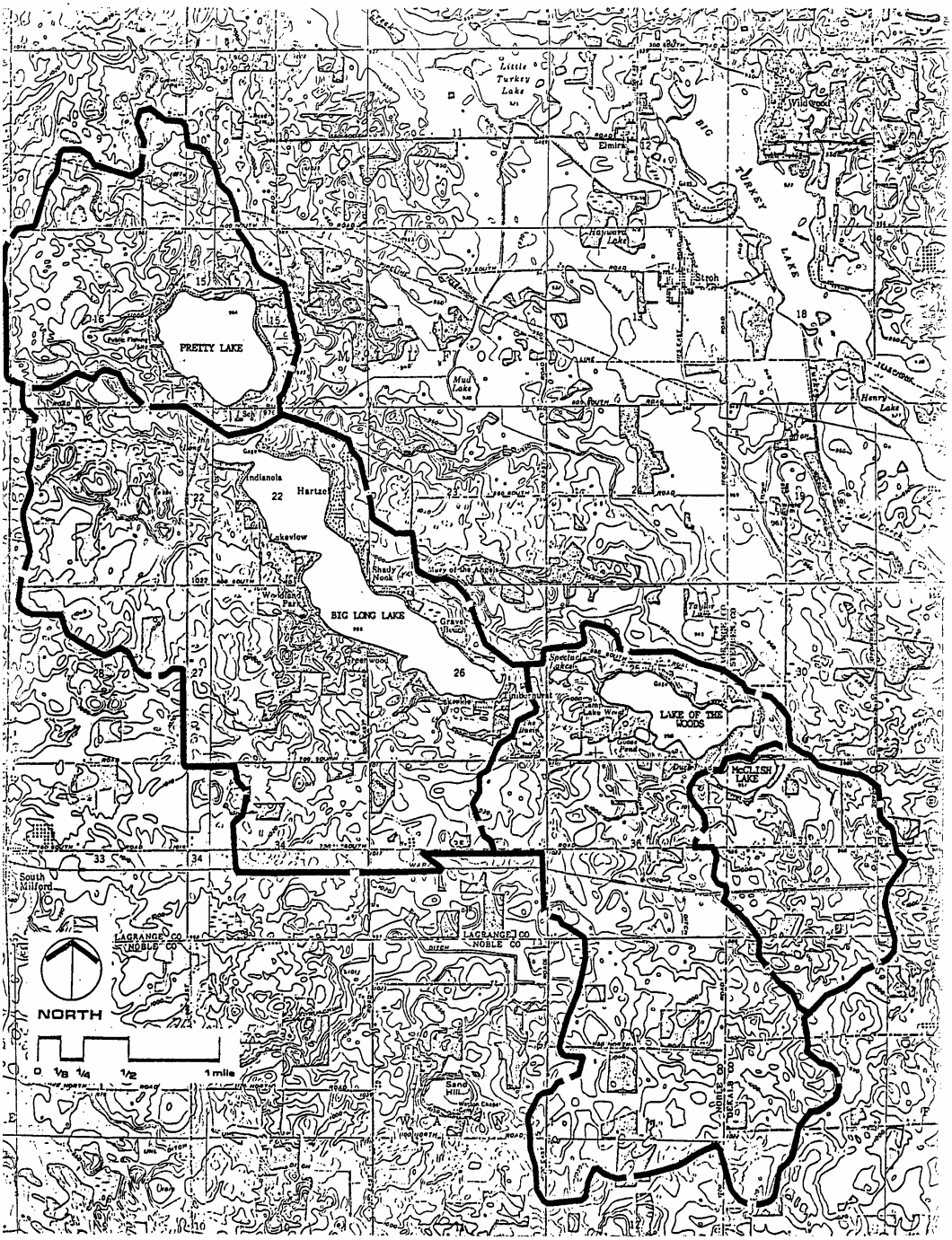


Regional Location Map


Radio tower
Mongo
Mongo Res
Cem
Shallow Lake
Turkey
Creek
Plato
Brushy Prairie
Fish Lake
Cem
Little Turkey Lake
Cem
Wildwood
Big Turkey Lake
Stroh
Salem Cent
Woodruff
Pretty Lake
Eve Lake
Big Long Lake
Cem
Cem
Blackman Lake
Lake of the Woods
South Milford
Helmer
Cem
Wolcottville
Tamarack Lake
Cree Lake
Lake
Wide Lake
Fairfield
Kendallville
Indian Lake

Area Map



Study Area Map

Color infrared aerial photograph of the Pretty Lake watershed. Photo date - September, 1987.

Color infrared aerial photograph of the Big Long Lake, Lake of the Woods and McClish Lake watershed. Photo date - September, 1987.

Big Long Lake

EXECUTIVE SUMMARY

Big Long Lake is a Class One water body in LaGrange County. A Class One lake is a lake of highest water quality, which rarely support macrophyte and/or algae in serious concentrations (IDEM, 1986). Historical data suggest that eutrophication symptoms were evident in the lake as early as 1930, but the process appears to have accelerated in the past two decades. The most pronounced biological changes took place following 1972, when ciscos were extirpated, the overall quality of the fishery declined, and aquatic macrophytes expanded progressively to pose management problems in the late 1980's. The most serious macrophyte problems occur in waters less than 5 feet deep and are attributed to the exotic species Eurasian watermilfoil. Algal blooms dominated by blue-green algae are common during summer.

The principal contributing factors for the eutrophication of Big Long Lake have been identified as nutrients and sediments from watershed sources and delivered by ditches. Sediment eroded from the watershed has been responsible for pronounced basin infilling of nearshore areas near ditch mouths especially in the north and south end of the lake.

Conservation tillage has been identified as one of the most effective methods of controlling erosion due to agricultural practices. Thus, continued and expanded use of conservation tillage systems in conjunction with addressing drainage issues on a cost-benifit basis, and implementation of the constructed options is strongly advised.

Lake residents can further control sediment and nutrient loading by monitoring lake front development for adequate erosion control, and existing development for adequate septic treatment. A lake watch program could be a viable approach to meeting this task.

INTRODUCTION

Big Long Lake (figure page iii), LaGrange County, is a 365 acre lake with a maximum and mean depth of 82 feet and 40 feet, respectively. Legal lake level is 955 feet and is controlled by a concrete dam at the outlet stream leading to Mud Lake. The lake has no permanent named inlets, but three major drainage ditches discharge into the lake. One ditch drains agricultural and wetland areas west of the lake and discharges at the northwestern corner of the lake. The other two ditches drain agricultural areas and discharge to the lake at its southwestern corner.

The present study was initiated because of lake residents' concerns regarding a reduction in the quality of the fishery, increased submergent weed and algal growth, and observation of siltation associated with delivery of erosion products from the watershed especially during early spring rains.

The current chapter is designed to define the current water quality of Big Long Lake and to determine whether current values represent a marked decline in water quality within the historical past. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on water quality for Big Long Lake. The second section summarizes the water quality analyses conducted as part of the present study and compares values to earlier studies. The third and final section details our sediment studies at Big Long Lake where we were interested in determining the extent of basin infilling in the historical past as well as changes in phosphorus loading to the lake. Management implications of our analysis of past and current water quality will be discussed later in this report.

Historical Water Quality

Historical Database

A total of 14 separate studies were conducted on Big Long Lake between 1925 and 1989 for which data were available (Table B1). The Indiana Department of Natural Resources (DNR) constructed a bathymetric map for Big Long Lake in 1925, but collection of water quality data on the lake did not begin until 1930 with the investigation of Will Scott of Indiana University. The Indiana Department of Natural Resources surveyed the fish community 2 times (1975 and 1984) and included data on water chemistry and macrophytes. As a follow up to the study by Frey (1955) on cisco distributions, the Department of Natural Resources collected fish and/or physical/chemical data on four occasions from 1972 through 1988 for assessing the status of cisco populations in the lake. The Indiana Department of Environmental Management (IDEM) visited the lake once in the mid-1970's to collect

Table B1. Chronology of Investigations at Big Long Lake

1925	Indiana Department of Natural Resources. Construction of bathymetric map for Big Long Lake.
1930	Indiana University. Survey of physical/chemical parameters, phytoplankton and zooplankton. Published by Scott (1931).
1955	Indiana University. Status report on cisco. Published by Frey (1955).
1972	Indiana Department of Natural Resources. Temperature and dissolved oxygen profiles for assessing cisco population.
1973	Indiana Department of Environmental Management. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
1974	Indiana Department of Natural Resources. Dissolved oxygen profile and gill netting in "cisco layer" to assess status of cisco population. Published by Gulish (1974).
1975	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1976	Indiana Department of Environmental Management. Survey of physical/chemical parameters in outlet stream.
1984	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1987	Indiana Department of Natural Resources. Survey of physical/chemical parameters.
1988	Indiana Department of Natural Resources. Assessment of cisco population.
1988	Indiana University. Survey of physical/chemical parameters by William Jones.
1988	LaGrange County Health Department. Survey of physical/chemical parameters by William Grant.
1989	Indiana University. Survey of physical, chemical, and biological parameters for construction of IDEM eutrophication index.

water chemistry and biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state. William Grant of the LaGrange County Health Department collected physical/chemical data in 1988. Finally, Indiana University recently (1988, 1989) collected data on the lake to assess whether the IDEM eutrophication index for the lake has changed since the mid-1970's.

Physical/Chemical Parameters

A total of twelve physical and chemical parameters have been measured at Big Long Lake at a frequent enough intervals to be useful in delineating historical trends (Table B2). Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer at Big Long Lake, it is likely that they reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature. Thus, it is only valid to make interyear comparisons for individual months (Table B2, Figure B1). As expected, June Secchi values were greater than for any summer month and were roughly comparable between the two years (1984, 1988) for which data were available. July values for both 1988 and 1989 were lower than any June data, but 1988 was 10 feet greater than reported for 1989. We feel that this is a direct consequence of the serious drought of 1988 whereby runoff and associated nutrient loading to lakes in northern Indiana was minimal and resulted in lower phytoplankton populations and thus increased water clarity than observed during "normal" years. August values were comparable between 1975 and 1988 as were September values between 1973 and 1989 (Table B2). On the basis of Secchi data alone, it does not appear that the trophic state of Big Long Lake has changed markedly since at least 1973.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production. A good measure of the degree of eutrophication is provided by the extent of water column anoxia (absence of oxygen) in mid summer (Table B3). Pronounced water column anoxia is evident by at least June in Big Long and extends throughout the summer stratified period. There is a trend toward a vertical expansion of the anoxic zone within the water column as summer progresses. Although the historical database is not extensive, it appears that serious water column anoxia was evident as early as 1930 and was roughly comparable to that observed in the late 1980's. Midsummer mean oxygen values in the water column of Big Long Lake historically remained above 5.0 mg/L prior to 1988, but were below that value during both 1988 and 1989 suggesting fairly eutrophic conditions (Table

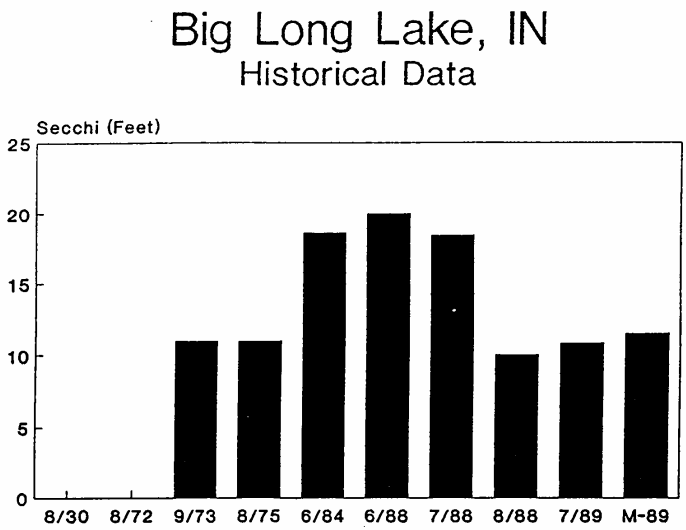


Figure B1. Historical Secchi Disk Readings in Big Long Lake for the Period 1930-1989. M-89 is the mean for September and October 1989.

Table B2. Historical Changes in Physical and Chemical Parameters at Big Long Lake for the Period 1973-1989. Mean 1989 is the Mean of September and October 1989 Samplings.

Big Long Lake Historical Data		Aug.30	Aug.72	Sept.73	Aug.75	June 84	May 88	July 88	Aug.88	July 89	Mean 1989
Secchi	feet			11	11	18.6	20	18.4	10	10.82	11.5
Mean Dissolved Oxygen	mg/L	2.1	5.2	8.4		6.6	7	3.4		2.7	2.9
Conductivity	umhos/cm							270		270	280
Alkalinity	mg/L as CaCO3					145.9		119.8		152	121.5
pH						9		7.6		7.6	
Total Phosphorus	mg/L			0.07					0.18	0.21	0.14
Ortho Phosphorus	mg/L			0.06			0.03			0.09	0.035
Nitrate-N	mg/L			<.1			1.2	0.526		0.53	0.35
Ammonia-Nitrogen	mg/L			0.35				0.113		0.1	0.395
Total Kjeldahl N	mg/L										0.85
Organic-Nitrogen	mg/L			0.5				0.768		0.81	0.455

Table B3. Historical Records of Water Column Anoxia in Big Long Lake, IN

Observation		Initial Depth of <1 mg/L Dissolved Oxygen
June:		
1984		50 feet
July:		
1975		15 feet
1988		42 feet
1989		52 feet
August:		
1930	North Basin	26 feet
	South Basin	26 feet
1972		19 feet
September:		
1989		23 feet
October:		
1989		26 feet

B2). The historical data suggest that deep water deoxygenation during summer has characterized Big Long Lake since at least 1930, but may have intensified recently.

Alkalinity is a measure of the carbonate buffering capacity of lakes and can be a useful parameter for assessing changes in watershed delivery of erosion products through human activities. Oscillations in alkalinity values for Big Long Lake since 1984 do not yield any apparent trend that can be related to changes in watershed management practices (Table B2, Figure B2). It is interesting to note, however, that July 1988 was lower than July 1989 and possibly reflects reduced farm runoff during the drought of 1988. Such an interpretation is consistent with the higher Secchi value recorded for the same month reflecting lower algal production.

Although the database is rather limited, total phosphorus concentrations in Big Long Lake during 1988 and 1989 appear to be 3-4 times greater than reported in 1975 (Figure B3, Table B2). Ortho phosphorus values as well as nitrogen parameters, however, did not display a significant trend for the period (Table B2). The remaining physical and chemical parameters measured at Big Long Lake were sampled so infrequently as to be of little value in delineating past trends in water quality.

Microbiology

Neither the LaGrange County Health Department nor the Indiana State Board of Health had any historical microbiological data from Big Long Lake.

Phytoplankton

Phytoplankton samples have been collected three times since 1930. Will Scott (1931) collected zooplankton and phytoplankton samples from discrete intervals of the water column at two stations during August 1930. The Indiana Department of Environmental Management sampled phytoplankton during September 1973, but detailed data were missing from the departmental files. The final survey of phytoplankton was by Indiana University in July 1989, but details were not provided.

Algal abundance in the north and south basins of Big Long Lake during August 1930 was estimated at 5,225/mL and 4,714/mL, respectively (Table B4). Clathrocyctis (Anacystis or Microcystis in current taxonomy) was the dominant taxon in both basins with Lyngbya and Dinobryon as the principal subdominants. The dominance of the algal assemblage of the lake in 1930 by blue-green algae was suggestive of a moderate degree of production with a likely trophic state being within the mesotrophic range.

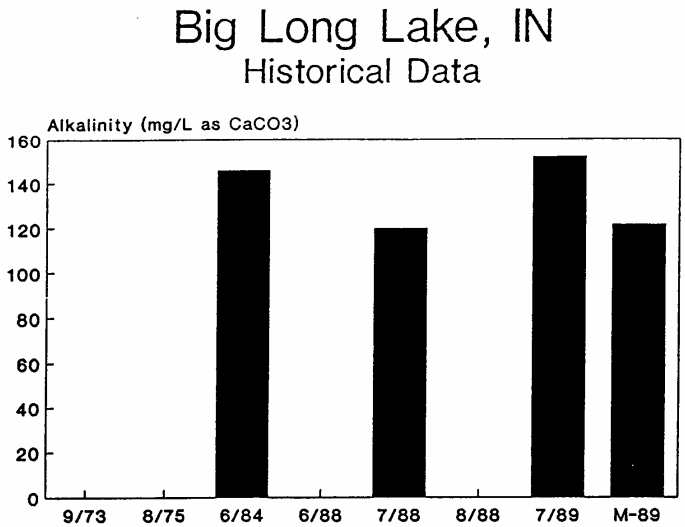


Figure B2. Historical Alkalinity Readings in Big Long Lake for the Period 1973-1989. M-89 is the mean for September and October 1989.

Big Long Lake, IN
Historical Data

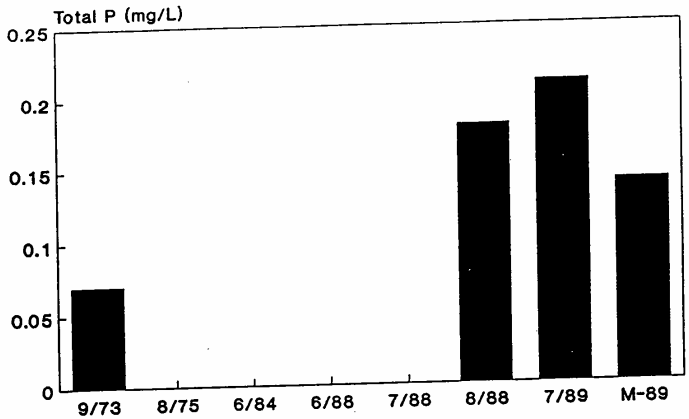


Figure B3. Historical Total Phosphorus Concentrations in Big Long Lake for the Period 1973-1989. M-89 is the mean for September and October 1989.

The blue-green alga Lyngbya was the dominant taxon in September 1973, but estimates of total algal abundance were unavailable. Finally, algal abundance for July 1989 was estimated at between 1,000-2,000/mL. All the database is limited, the phytoplankton assemblage of Big Long Lake appears to have changed little in either dominance or overall abundance since at least 1930.

Macrophytes

The macrophyte (aquatic plant) community was examined in 1975 and 1984 as part of Indiana Department of Natural Resources fish surveys (Table B5). Plant taxonomic composition was identical for the two surveys. Submergent macrophytes were the most taxonomically diverse plant community with most species being pondweeds.

Macrophytes appear to have been common to a depth of ten feet in 1975, but the DNR survey felt that aquatic plants were not a problem at Big Long Lake. By 1984 macrophyte growth was considered abundant along the south shore to a depth of eight feet, but was still not considered a serious management problem. Most recently, Grant (1988) noted that lake residents in recent years have noticed an increase in macrophyte abundance and have implemented a chemical control program to manage it. From the limited database, it appears that macrophyte abundance in Big Long Lake has been increasing progressively since at least 1975 to the point of posing a management problem.

Fish

The Indiana Department of Natural Resources surveyed the fish community of Big Long Lake in 1975 and 1984. Because standard fish assessment techniques are not effective for fish inhabiting deeper portions of the water column, a separate survey of cisco populations was conducted in 1974 and possibly in other years. All DNR surveys were based on electrofishing, gill net, and trap collections as follows:

1974	Standard and Vertical Gillnets in "Cisco Layer"	
1975	Electrofishing:	1.5 hrs night
	Gillnets:	3 for 72 hrs = 216 hrs total effort
1984	Electrofishing:	1.5 hrs night
	Gillnets:	3 for 72 hrs = 216 hrs total effort
	Traps:	3 for 72 hrs = 216 hrs total effort

A listing of the individual species caught and the contribution of each to total fish abundance and weight caught during the 1975 and 1984 DNR surveys are provided in Tables B6 and B7, respectively. The most abundant fish

Table B4. Phytoplankton and Zooplankton Abundances and Concentrations of Dissolved Gases in the North and South Basins of Big Long Lake on 20 August 1930. Table from Scott (1931).

KEY: (D) Depth, (T) Temperature, (O) Oxygen, (CO_2) Carbon Dioxide, (Cb) Carbonates

LAKE: LONG LAKE (N. Basin)
Date: 8/20/30

Plankton					Dissolved Gases					
Species	0-5	5-10	10-15	15-20	D	T	O	%	CO_2	Cb
Ceratium	51	34	8		S	23.8	4.43		—1.0	23.2
Dinobryum	209	4,364	665		2	23.8	4.51		—2.4	23.2
Aneura	8	4			4	23.5	4.43		—2.4	23.2
Polyarthra		4.2			6	21.3	4.85		—1.4	23.2
Hexarthra	8									
Noltholca	8		4		8	13.3	1.95		.4	30.4
Daphnia	6.4	19	2.4		10	10.5	.35		1.2	29.8
					12	10	.17		1.0	30.8
					15	9.4	.05		.6	30.8
Diaptomus	37	12								
Cyclops	15	52	6.4		18	8.8	.05		1.4	32.2
Nauplii	55	115	2.4							
Melosira	4	64	17							
Fragillaria	4	4								
Asterionella										
Anabena	170	81	8							
Clathrocystis	4,535	2,905	401							
Oscillatoria	89	76	25							
Lyngbya	341	746	17							

LAKE: LONG LAKE (S. Basin) (LaGrange)
Date: 8/20/30

Plankton					Dissolved Gases						
Species	0-5	5-10	10-15	15-21	D	T	O	%	CO_2	Cb	pH
Ceratium	140	42	8.5	2	S	23.8	5.03		—1.6	23.8	8.3
Dinobryum	311	759	657	106	2	23.8	5.15		—1.6	22.6	8.3
Aneura		8.5			4	23.5	5.13		—1.2	23.2	8.3
Polyarthra					6	21.6	4.51		—1.0	23.6	8.3
Asplanena	4										
Noltholca				4	8	12.7	1.53		1.0	29.6	7.5
Daphnia	8	.8	12	1.6	10	10.5	.31		1.0	29.8	7.1
Leptodera	.8				12	10	.34		2.0	29.8	7.1
					15	9.0	.08		2.0	30.2	7.1
Diaptomus	16	4	1.6	.8							
Cyclops	24	18	12	1.6							
Nauplii	98	55	23	1.6							
					22	8.8	.065		2.2	31.2	7.1
Melosira	8	21	17								
Fragillaria	38	12	65	4							
Asterionella											
Anabena	234	55	12								
Clathrocystis	3,549	1,267	652	251							
Oscillatoria	123	38	34	25							
Lyngbya	311	499	136	25							

Table B5. Species Composition of the Macrophyte Community of Big Long Lake for 1975 and 1984.

Species	Common Name	1975	1984
SUBMERGENTS:			
Chara spp.	chara	X	X
Myriophyllum spp.	water milfoil	X	X
Potomogeton illinoensis	Illinois pondweed	X	X
Potomogeton pectinatus	sago pondweed	X	X
Potomogeton richardsonii	Richardson's pondweed	X	X
Potomogeton zosteriformis	flatstem pondweed	X	X
EMERGENTS:			
Decodon verticillatus	swamp loosestrife	X	X
Typha latifolia	common cattail	X	X
FLOATING LEAVED:			
Nuphar advena	spatterdock	X	X

caught in the 1975 was bluegill (22%) followed by warmouth (19%) and yellow bullhead (16%). The rank ordering based on abundance was altered for the 1984 survey with yellow perch (22%), lake chubsucker (14%) and largemouth bass (10%) dominating the catch in decreasing order. The rank ordering of fish taxa expressed as a percent of total fish weight for the 1975 survey was bluegill (17%), yellow bullhead (15%), and bowfin (13%), while in 1984 the ordering changed to brown bullhead (20%), yellow bullhead (16%), and lake chubsucker (11%).

Bluegill, warmouth, and yellow perch declined in both abundance and weight of total fish caught from the 1975 to 1984 surveys, while lake chubsucker and yellow perch increased (Figure B4). The growth rates of most species were average to above average in 1975, and the recreational fishery of Big Long Lake was considered good. By 1984, however, growth rates of yellow perch and largemouth bass were below average, and the percent of yellow perch, largemouth bass, and bluegill populations considered harvestable were lower than in 1975. Overall, the DNR felt that the quality of the fishery declined between 1975 and 1984.

The cisco inhabits deeper portions of the water column and is often missed by routine fishery survey techniques employed by the DNR. This fish species requires cold well oxygenated water and is therefore sensitive to deoxygenation of the lower water column associated with increasing eutrophication. Ciscos were rare in Big Long Lake in 1955 (Frey 1955), but by 1972 were considered rare or absent from the lake and the species had not been reported from the lake for several years (Gulish 1974). Additional surveys in 1975 and 1988 using sampling methodologies specifically designed to maximize the likelihood of catching ciscos failed to yield any specimens, leading DNR to conclude that the species had been extirpated from the lake.

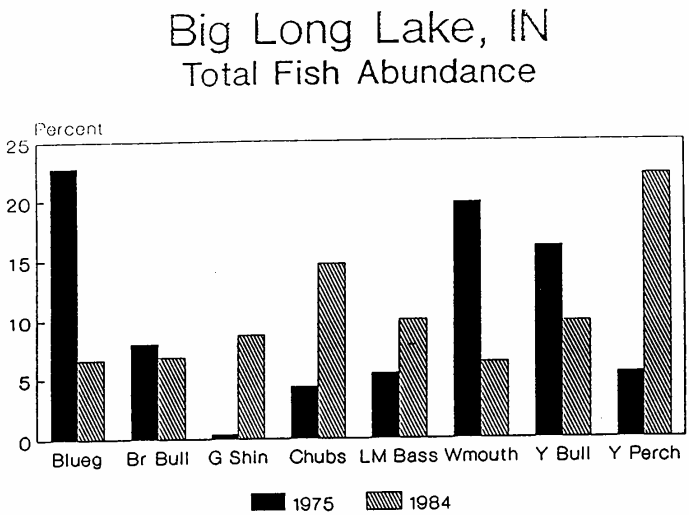
The historical fishery data support the contention that water quality in Big Long Lake has been declining since at least 1955. Although no water quality data were available for the lake during the period (mid 1950's to early 1970's) when cisco populations were being extirpated, the decline in the quality of the lake's fishery between 1975 and 1984 corresponded with a two to three fold increase in total phosphorus in the lake.

Table B6. Importance of Individual Fish Species in Big Long Lake During 1975 and 1984 Expressed as a Percent of Total Fish Abundance Caught in DNR Surveys.

	1975	1984
Black Bullhead	2.6	
Black Crappie	1.5	
Bluegill	22.8	6.6
Bowfin	1.7	1.2
Brown Bullhead	8	6.8
Golden Shiner	0.4	8.7
Grass Pickeral	1.1	2
Green Sunfish	3.7	2
Hybrid Sunfish		0.1
Lake Chubsucker	4.3	14.7
Largemouth Bass	5.4	10
Pumpkinseed	2.6	7.2
Redear	3.7	1.9
Rock Bass		0.1
Spotted Gar	1.1	0.6
Warmouth	19.8	6.3
Yellow Bullhead	16.1	9.8
Yellow Perch	5.4	22.1

Table B7. Importance of Individual Fish Species in Big Long Lake During 1975 and 1984 Expressed as a Percent of Total Fish Weight Caught in DNR Surveys.

	1975	1984
Black Bullhead	4.4	
Black Crappie	1.8	
Bluegill	17.6	3.2
Bowfin	13.1	11.6
Brown Bullhead	11.9	20.3
Golden Shiner		4.3
Grass Pickeral	0.7	1.5
Green Sunfish	0.8	0.6
Hybrid Sunfish		0.1
Lake Chubsucker	3.1	11.8
Largemouth Bass	11.2	10.6
Pumpkinseed	0.8	2.3
Redear	2.1	1.8
Rock Bass		0.2
Spotted Gar	3.2	3.7
Warmouth	10.8	2.7
Yellow Bullhead	15.3	16.4
Yellow Perch	2.7	9.2



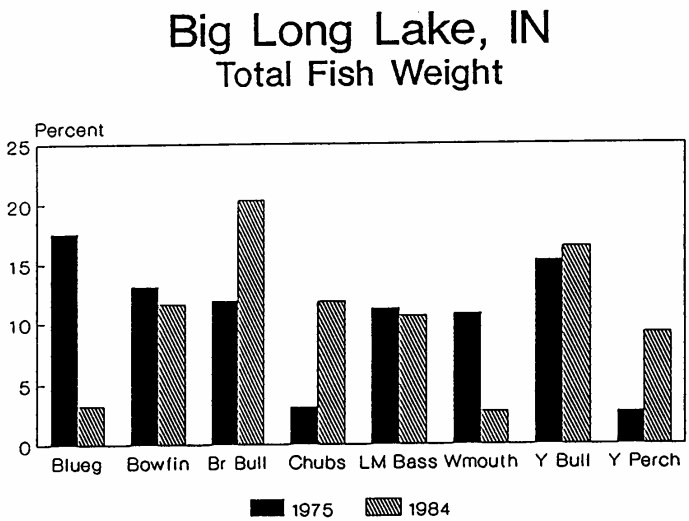


Figure B4. Changes in the Percentage Contribution of Select Species to Total Fish Abundance and Weight in Big Long Lake for 1975 and 1984.

Current Water Quality

Methods

Water quality parameters were collected during 1989 on 15 September and 5 October. A single sampling station was established in the central basin of Big Long Lake near the point of maximum water depth. (Figure B5). Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc and a Licor photometer. Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column where a Kemmerer bottle was used to collect water at each meter of the water column. All analyses were performed in certified laboratories according to EPA techniques (EPA-600/14-79-020, Methods for Chemical Analysis of Water and Wastes, Revised March 1983). Chemical parameters analyzed included conductivity, alkalinity, ammo nia, total Kjeldahl nitrogen, nitrate/ nitrite nitrogen, ortho phosphorus, and total phosphorus. Data for physical and chemical parameters for Big Long Lake during the 1989 survey are presented in Table B8.

Two phytoplankton samples were collected with a #20 Wisconsin plankton net (76 um) on each sampling date. One tow was taken from 5 feet depth to the surface, and a second five foot tow was taken to include the beginning of the thermocline. All plankton samples were preserved with Lugol's solution and returned to the laboratory for analysis. Plankton counts utilized Utermohl chambers and were performed with the aid of an inverted microscope.

Physical/Chemical Parameters

Temperature. The water columns of northern Indiana lakes greater than approximately five meters deep remain thermally stratified throughout most of the year. As a result of density-temperature relationships, complete mixing of the water column from top to bottom occurs only when water temperature reaches a uniform 4oC, the maximum density of water. This occurs twice a year in temperate lakes (spring and fall) associated with seasonal climatic changes. The length of the mixing period depends on the rapidity of climate change and can vary from a few days to less than a month. Lakes displaying two mixing periods per year are termed dimictic.

During the stratified period, the water column of Indiana lakes is divided into three zones based on temperature-density relationships. The uppermost well mixed zone is termed the epilimnion and extends from the surface to a depth roughly approximating the lower depth of wave action. The lowermost portion of the water column is the hypolimnion, a zone of density-isolated water that mixes with surface waters

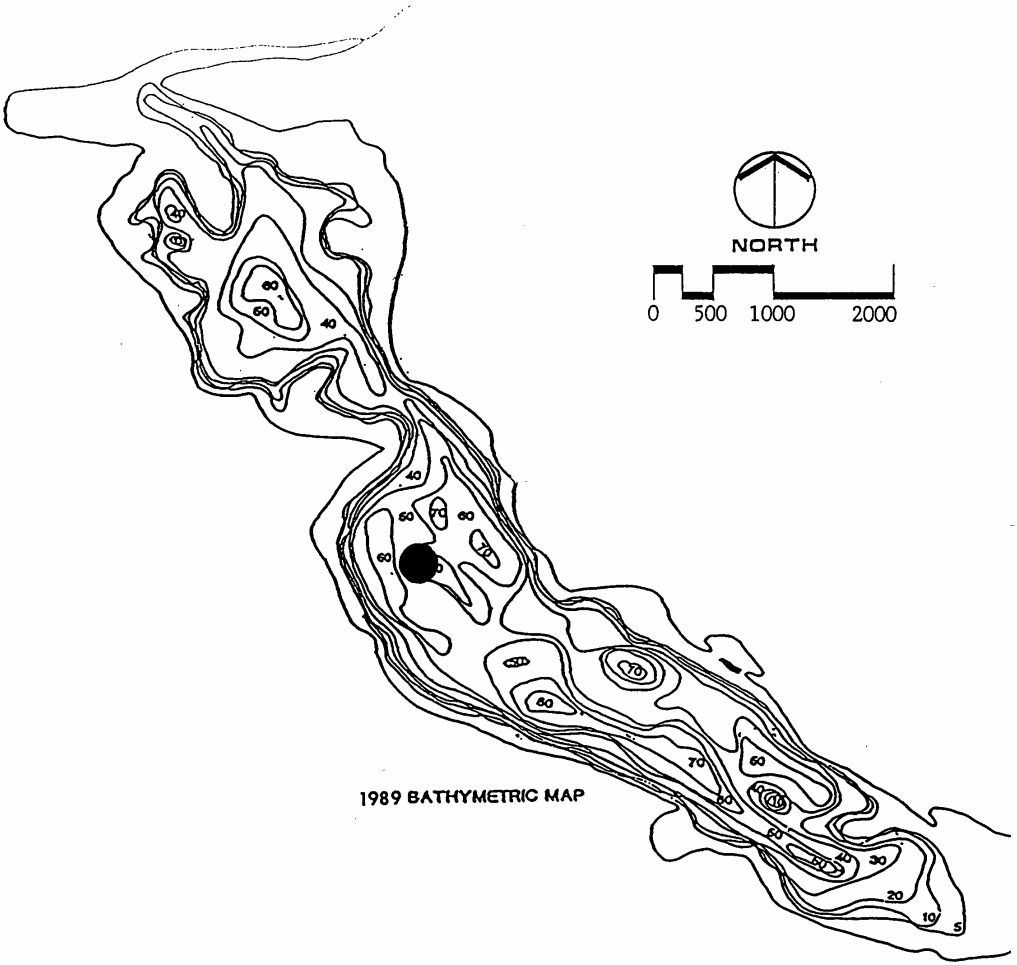


Figure B5. Station Utilized for 1989 Limnological Investigations.

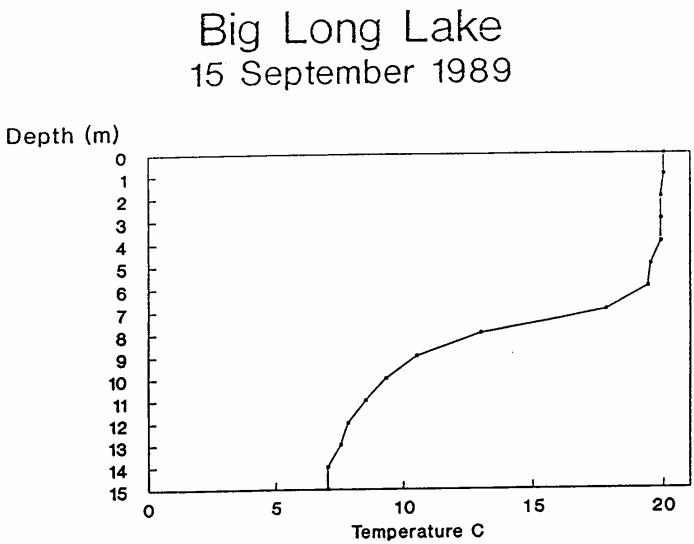
only during the short mixing periods. The portion of the water column that is transitional between the epilimnion and hypolimnion is termed the metalimnion. That one meter of the metalimnion displaying the greatest temperature change is called the thermocline.

Water column profiles clearly demonstrated that Big Long Lake was thermally stratified during both September and October 1989 (Figure B6). The thermocline was between seven and eight meters during September but moved deeper to 9-10 meters by October as the lake began to cool in the initial stages of stratification breakdown characteristic of fall. Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

Pronounced water column deoxygenation was noted during both September and October 1989 (Figure B7). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). The lake was essentially anoxic below a depth of 7 meters during September and 8 meters three weeks later in October. The slight increase in mean dissolved oxygen between September and October reflects the seasonal expansion in the depth of the epilimnion prior to the breakdown of stratification during fall (Figure B8). Mean water column values for 1989 were lower than all previous surveys with the exception of August 1930 (Tables B2 and B4).

Historically, Big Long Lake has displayed severe deoxygenation of the water column as early as June (Table B3). Severe anoxia was evident as early as 1930, the extent of which was similar to that observed during the 1970's and 1980's. It is likely that water column anoxia in Big Long is not entirely a result of trophic state but in part is dictated by the morphometry of the lake. The linear shape of the lake combined with its depth likely restrict the ability of wind action to mix the lake completely to the bottom.

Secchi Disc Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae and/ or sediment suspended in the water column to block light transmission. Visual inspection on our sampling dates



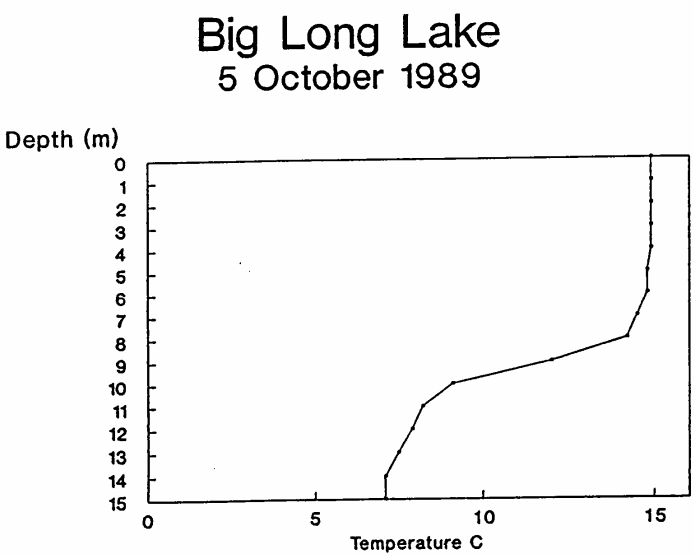
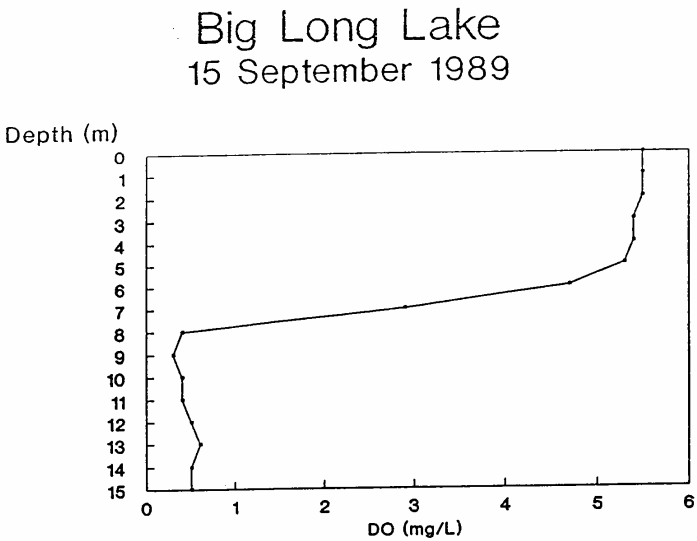


Figure B6. Water Column Temperature Profiles for Big Long Lake During September and October 1989.



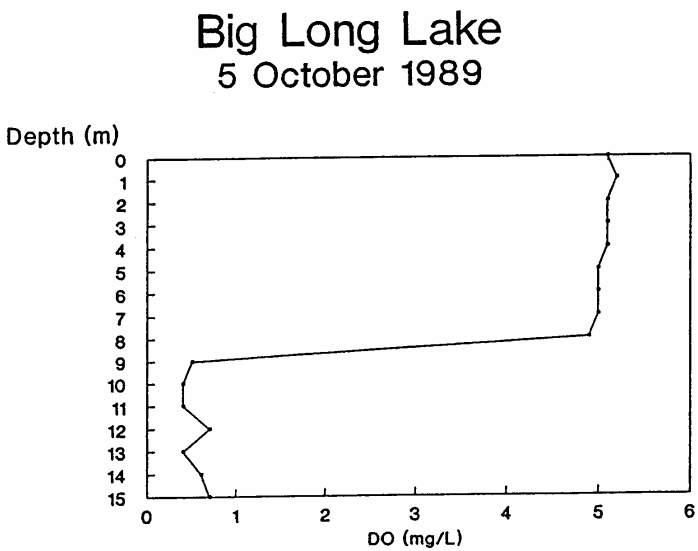


Figure B7. Dissolved Oxygen Profiles for Big Long Lake During September and October 1989.

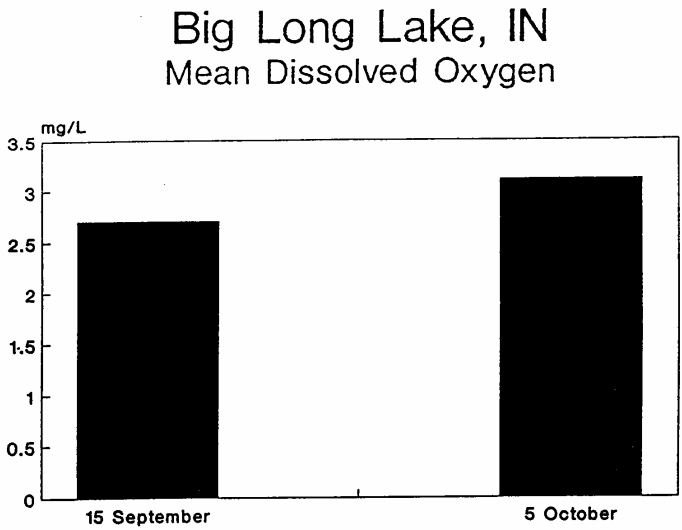


Figure B8. Mean Dissolved Oxygen Concentrations in the Water Column of Big Long Lake During September and October 1989.

suggested that Secchi depth was controlled by algae rather than sediment. Thus, the shallower the Secchi depth during summer, the more productive (eutrophic) a lake is presumed to be. Secchi transparency was similar during September (11.7 feet) and October (11.3 feet) 1989 (Figure B9). The 1989 values were nearly identical wit h the eleven feet recorded in September 1973. Based on a comparison of late summer Secchi values, it does not appear that water clarity has changed appreciably since at least 1973.

Ammonia. Ammonia values for Big Long Lake during September (0.35 mg/L) and October (0.44 mg/L) 1989 (Figure B10) were comparable those reported for the lake since at least 1973 (Table B2).

Nitrite-Nitrate. As with ammonia, nitrite-nitrate nitrogen concentrations were greater during October (0.5 mg/L) than September (0.2 mg/L) 1989 (Figure B10). The 1989 values were comparable to those reported for the lake since at least 1973.

Kjeldahl Nitrogen. Unlike the previous two nitrogen components, Kjeldahl nitrogen values were greater in September (1.3 mg/L) than October (0.4 mg/L) 1989 (Figure B10). Based on all three nitrogen components, it does not appear that nitrogen concentrations in Big Long Lake have changed appreciably since at least 1973.

Total Phosphorus. Total phosphorus concentrations were greater during September (0.17 mg/L) than October (0.11 mg/L) 1989 (Figure B11). The 1989 total phosphorus values for Big Long Lake were similar to values reported for the 1980's (0.18-0.21 mg/L), but were markedly greater than the 0.07 mg/L reported for September 1973 (Table B2).

Ortho Phosphorus. As noted for total phosphorus, ortho phosphorus concentrations were greater in September (0.05 mg/L) than October (0.02 mg/L) 1989 (Table B8). Ortho phosphorus value for Big Long Lake for both dates in 1989 were comparable to those reported for the lake since at least 1973 (Table B2).

Nitrogen:Phosphorus Ratios. The ratio of total nitrogen to total phosphorus can be useful in delineating which of these two essential nutrients is limiting primary production in lakes. Numerous authors (Baker et al. 1981, Kratzer and Brezonik 1981, Canfield 1983) have proposed that N:P ratios less than 10 suggest nitrogen limitation, while those greater than 10 suggest phosphorus. The N:P ratios in Big Long Lake were 76 in September and 36 in October 1989. These values suggest that the lake is phosphorus limited throughout the year but becomes less so by the end of the growing season.

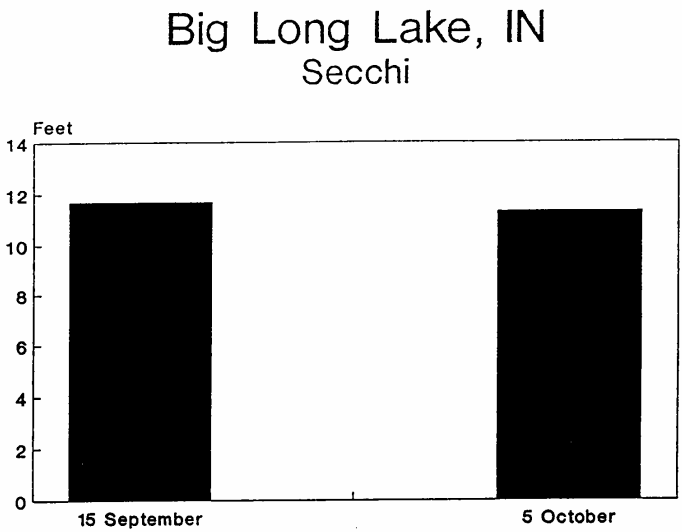
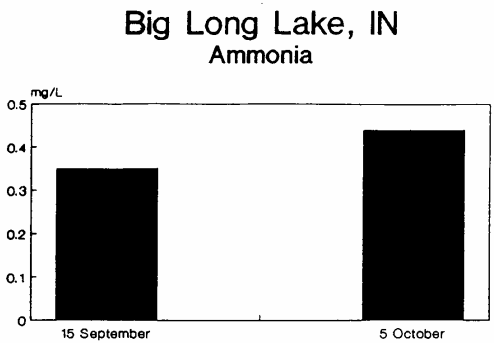
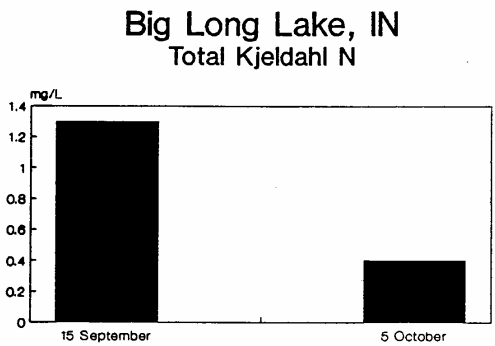


Figure B9. Secchi Disk Transparency for Big Long Lake During September and October 1989.





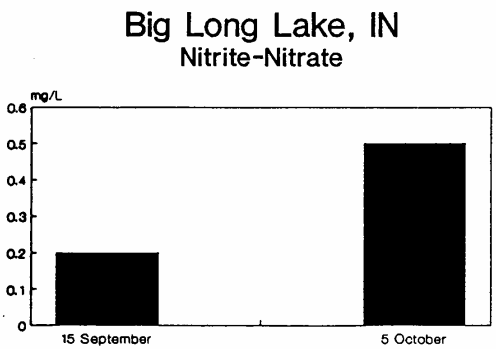


Figure B10. Concentrations of Ammonia, Total Kjeldahl Nitrogen, and Nitrite-Nitrate for Big Long Lake During September and October 1989.

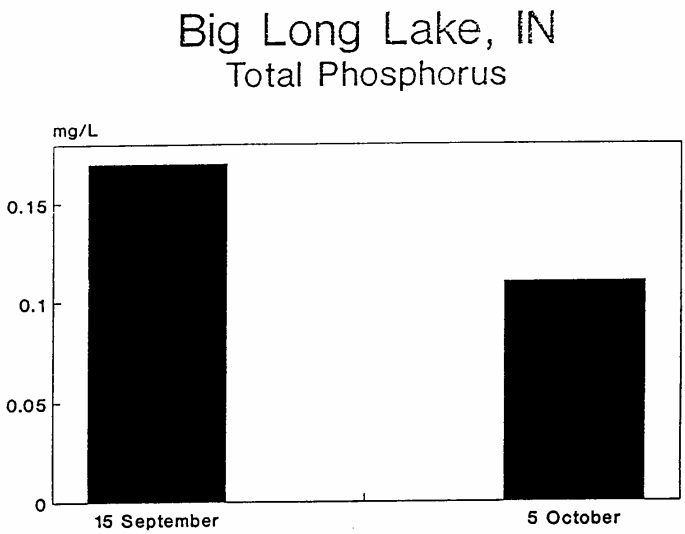


Figure B11. Total Phosphorus Concentrations for Big Long Lake During September and October 1989.

Alkalinity and Conductivity. As noted for phosphorus and most nitrogen parameters, alkalinity was greater during September (128 mg/L) than October (115 mg/L) 1989 (Figure B12). A similar parameter, conductivity, remained unchanged between September and October (Table B8). Values for both parameters were comparable to those reported for the lake since at least the early 1980's (Table B2).

Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll concentrations were measured during both September (1.5 mg/m3) and October (3.6 mg/m3) 1989 (Figure B13 and Table B9). There are no historical data for comparison with the 1989 survey.

Table B8. Physical and Chemical Parameters for the 1989 Survey of Big Long Lake.

Big Long Lake Chemistry	1989	15 September	5 October	
Secchi	feet	11.7	11.3	
Mean Dissolved Oxygen	mg/L	2.7	3.1	
Ammonia	mg/L	0.35	0.44	
Total Kjeldahl N	mg/L	1.3	0.4	
Nitrite-Nitrate	mg/L	0.2	0.5	
Total Phosphorus	mg/L	0.17	0.11	
Ortho Phosphorus	mg/L	0.05	0.02	
Conductivity	umho/cm	280	280	
Alkalinity	mg/L	128	115	
Chlorophyll a	mg/m3	1.5	3.6	
Mean Temperature	Celsius	14.2	12.0	
Total Coliform	mpn/100ml	40.0	0.6	=<1

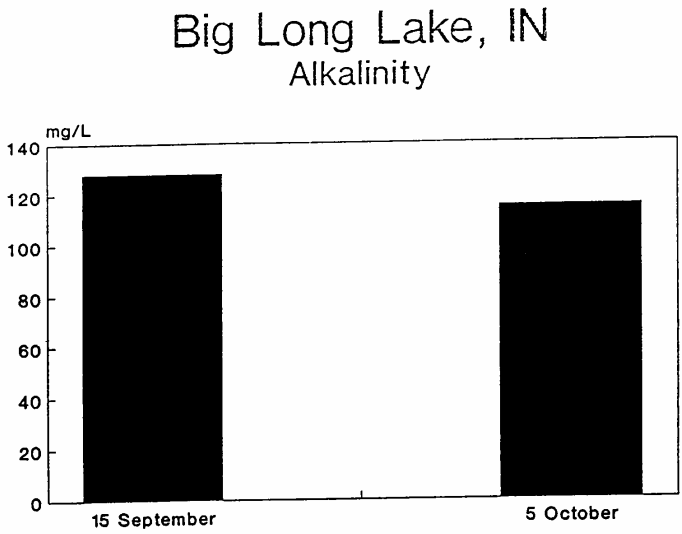


Figure B12. Alkalinity Values for Big Long Lake During September and October 1989.

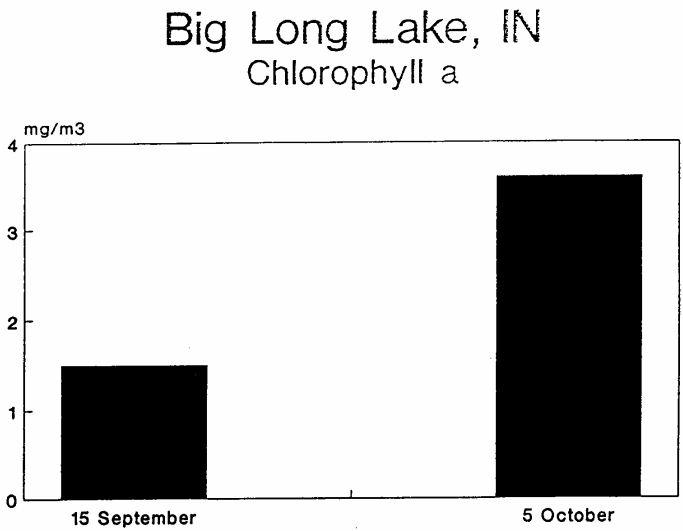


Figure B13. Chlorophyll Concentrations for Big Long Lake During September and October 1989.

Table B9. Phytoplankton Composition for Big Long Lake During September and October 1989.

	15 September		5 October	
	S	T	S	T
Ceratium	447	205	638	236
Fragilaria	285	152	569	156
Lyngbya	222	35	232	80
Oscillatoria	139	35	75	34
Melosira	85	87	106	87
Asterionella	74	77	168	65

S = algal units/mL calculated from a vertical tow from a depth of five feet to the surface.

T = algal units/mL calculated from a five foot vertical tow that includes the thermocline.

IDEM Trophic State Index

Mr Harold BonHomme of the Indiana Department of Environmental Management (IDEM) devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined.

The 1973 eutrophication index for Big Long Lake was calculated by the Indiana Department of Environmental Management as 33, thus assigning the lake to the category of intermediate water quality, Class Two. Parameters for the 1989 index calculation were identical to those used for the 1973 index. Based on our September and October samplings, we have calculated the 1989 IDEM eutrophication index for Big Long Lake as 13 (Table B10). Our calculation is somewhat lower than the 19 calculated for July 1989 by W. Jones of Indiana University, but also places the lake in the category of best water quality, Class One.

The phytoplankton assemblage during September and October of 1989 was dominated numerically by Ceratium with Fragilaria and Lyngbya as the principal subdominants (Table B10). All three taxa were components of the plankton in August 1930 (Table B4), but only Lyngbya was a major contributor to total plankton abundance. The overall group composition of the p lankton appears to have changed little since 1930 with dinoflagellates and blue-green algae sharing dominance, while diatoms are the principal subdominant group.

On the basis of IDEM eutrophication indices alone, it appears that the lake is less productive in 1989 than in 1973. It must be remembered that the IDEM index is based on parameters collected for the water column in open water sections of the lake, and like all indices, does not include the extent and productivity of aquatic macrophytes. Historical evidence suggests that the extent of aquatic macrophytes in Big Long Lake has been expanding over at least the last decade. Expanding macrophyte abundance is often associated with reduced nutrient and algal abundance in open water areas as the vegetated littoral zone successfully competes with open water phytoplankton for nutrients (Canfield et al. 1983). The fact that the eutrophication index indicates an improvement in water quality during the past 16 years is likely associated with concurrent expansion of macrophytes. Other lines of evidence presented in this report suggest no such reduction in the degree of eutrophication.

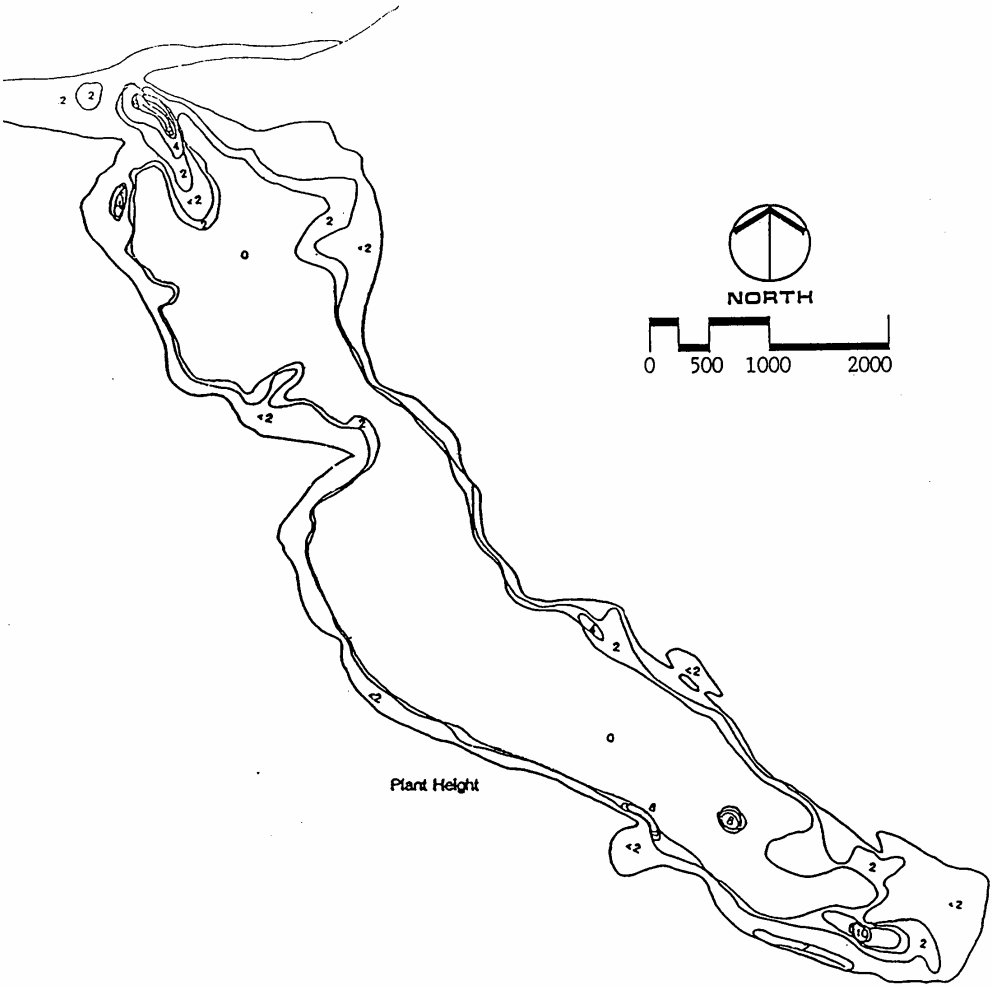


Figure B24. The Height of Aquatic Macrophytes in Big Long Lake in 1989 by Two Foot Height Increments.

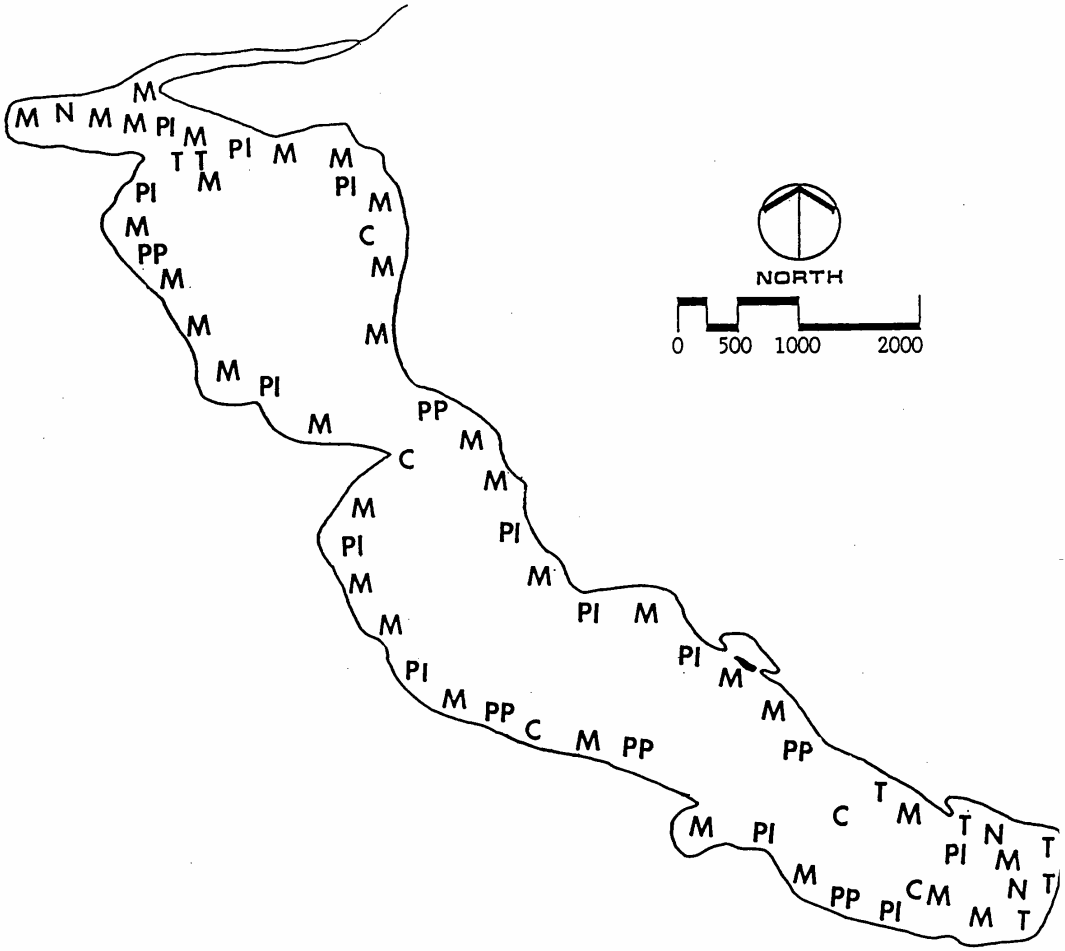


Figure B25. Distribution of Major Plant Taxa in Big Long Lake in 1989. Plants were: Chara (C), Myriophyllum (M), Nuphar (N), Potamogeton illinoensis (PI), Potamogeton pectinatus (PP), and Typha (T).

Fish

The Raytheon fathometer data recorded from the 32 cross lake transects were also used to provide a qualitative assessment of the fish community of Big Long Lake. Echos of fish in the water column appeared on all fathometer recordings, and these were used to assess total fish abundance and the depth distribution of the population for the lake.

Total fish abundance in open water areas of Big Long Lake was estimated at 7/1000 feet of fathometer transect. The greatest density of fish (20% total abundance) was at a depth of 3-6 feet (1-2 meters) with the second greatest density at 6-10 feet (2-3 meters) (Figure B26). Fish avoided depths shallower than 3 feet (1 meter), the area of highest temperatures, and greater than 23-26 feet (7-8 meters). The latter depth interval was the thermocline, below which oxygen values quickly fell to less than 1 mg/L. Only 16% of the fish tabulated were found below the thermocline. It must be noted, however, that oxygen is only one of many factors controlling fish distributions. Macrophytes such as found at lake depths less than 10 feet provide a prime habitat for both feeding and reproduction and are a major contributing factor to fishery production.

Bathymetric Map and Lake Infilling

The Indiana DNR published a bathymetric map of Big Long Lake based on a survey of 1925 (Figure B27). Depth contours were constructed at five foot intervals for the lake. The current study constructed an updated bathymetric map for 1989 based on fathometer recordings obtained from 32 lake transects (Figure B28). With the exception of the five foot depth contour, the 1989 map was constructed using a ten foot contour scheme.

A comparison of the depth configurations for 1925 and 1989 is provided in Figure B29. The 0-5 foot contour in 1925 comprised approximately 107 acres, an area larger than displayed by an other single contour. The second largest contour was the 30-40 foot contour (57 acres). The deepest section of the lake (greater than 80 feet) was less than 2 acres. The 0-5 foot contour still displayed the largest aerial extent in 1989 (110 acres), and the 30-40 foot interval (52 acres) was still the second most important contour. The deep water zone (greater than 80 feet) in 1989 had approximately the same area as reported in 1925.

Sedimentation patterns for the past 64 years can be delineated through comparison of the aerial extent of individual contours for 1925 and 1989 (Figure B29). The aerial extent of the two shallowest depth contours (0-5, 5-10 feet) increased since 1925 by 3% and 21%, respectively.

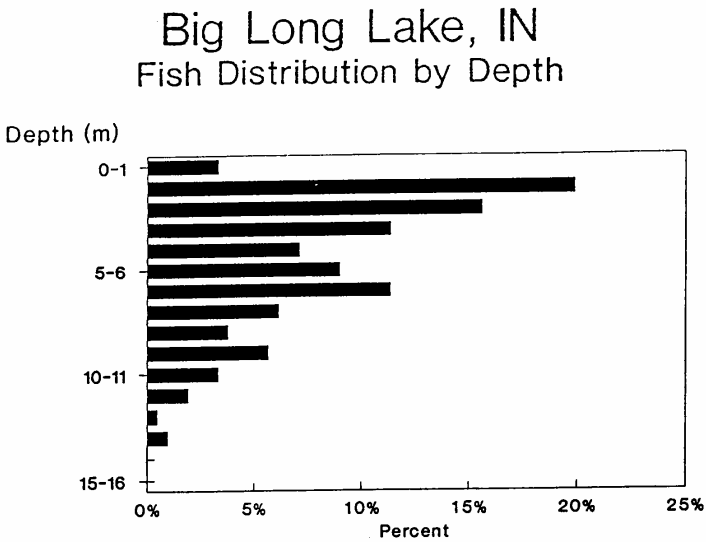


Figure B26. Semi-Quantitative Estimate of Fish in Big Long Lake in September 1989 Expressed as Number of Individuals Per 1000 Feet of Fathometer Transect and Partitioned According to Water Depth.

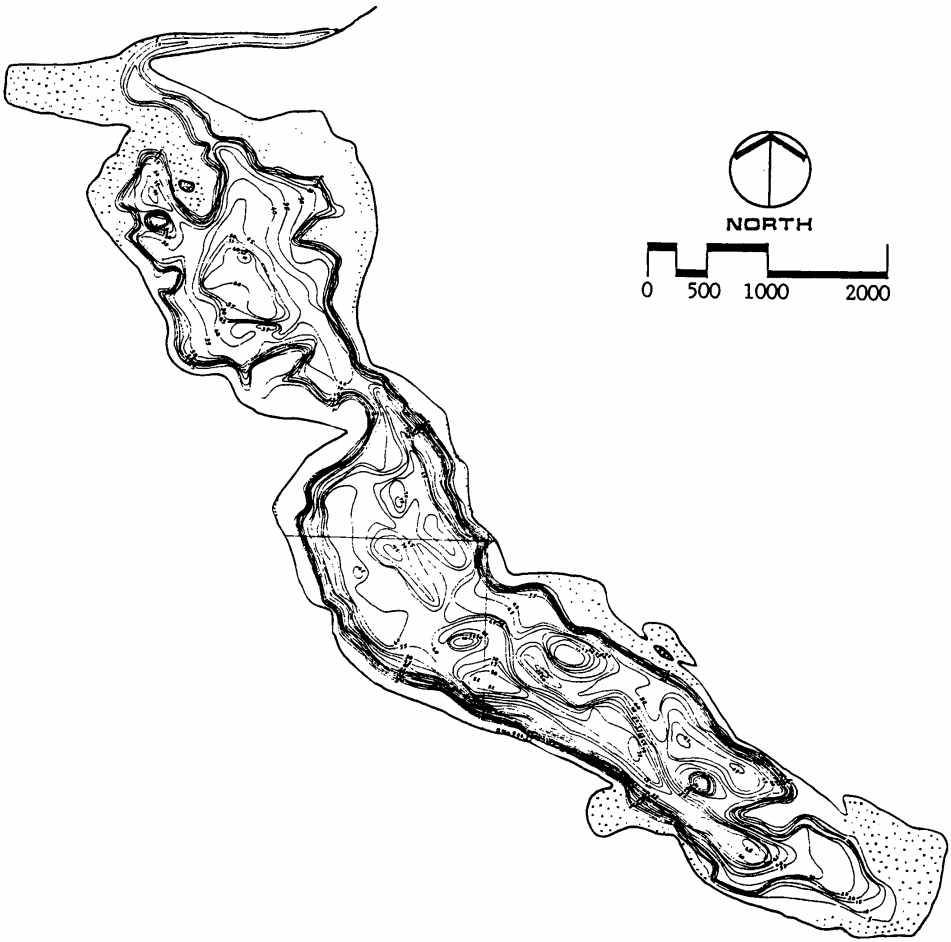


Figure B27. Bathymetric Map of Big Long Lake from 1925.

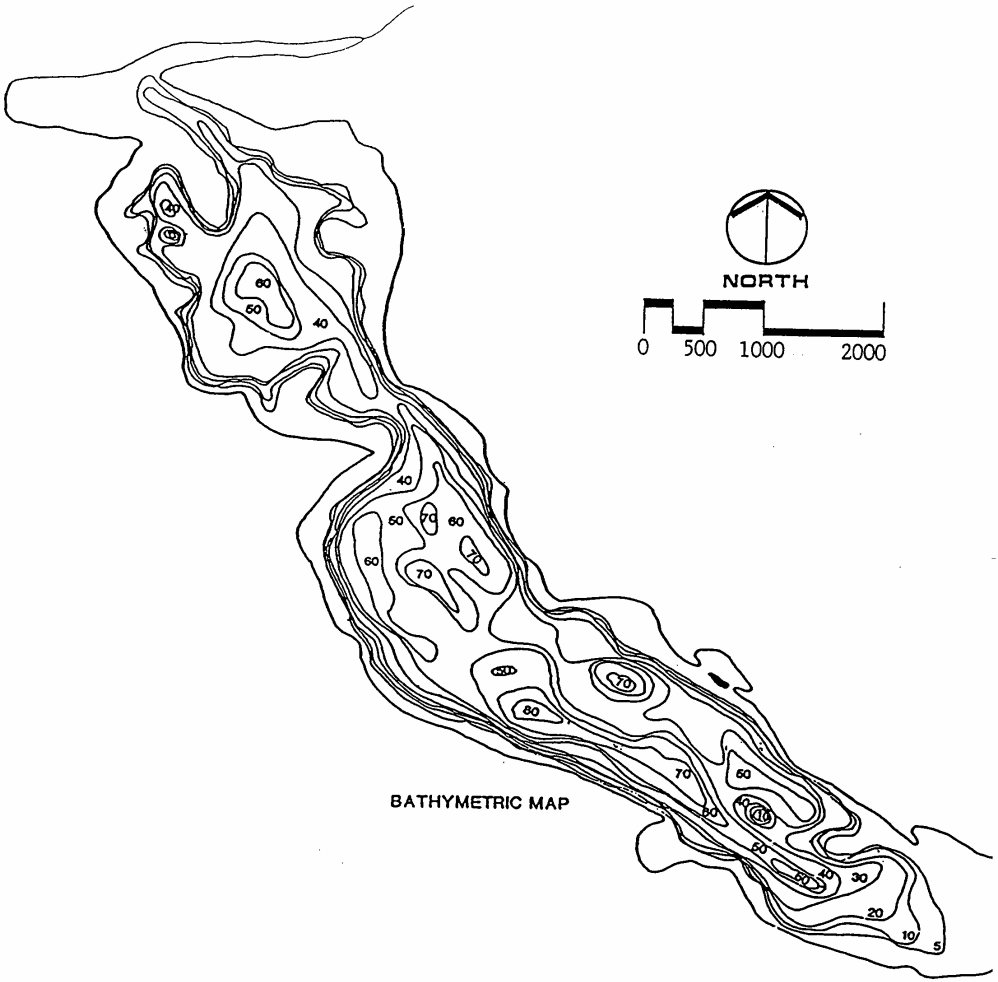
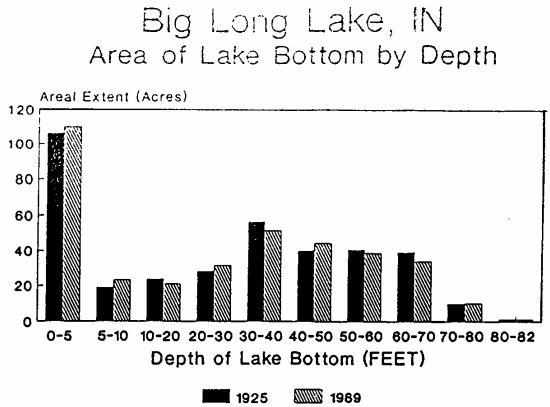
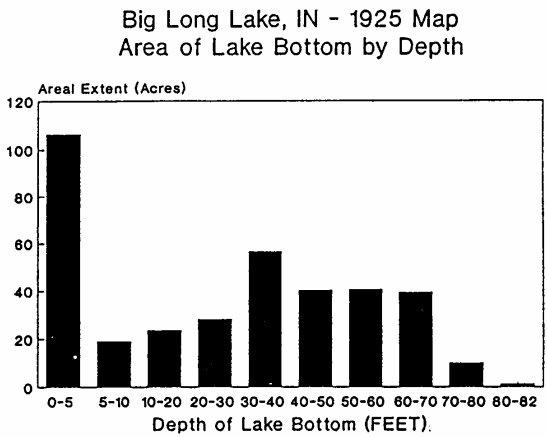


Figure B28. Bathymetric Map of Big Long Lake from 1989.





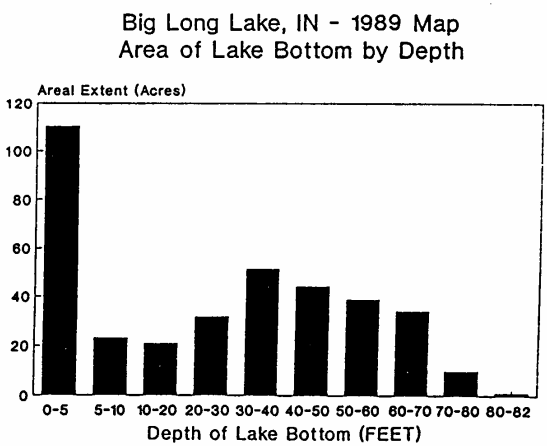


Figure B29. Comparison of the Depth Distribution Within Big Long Lake for 1925 and 1989.

No consistent pattern was evident for depth intervals from 10 feet to 70 feet, but those areas deeper than 70 feet did not change appreciably in areal extent between 1925 and 1989.

Infilling of nearshore areas was not uniform throughout Big Long Lake between 1925 and 1989. The most pronounced sedimentation has taken place at the south end of the lake where the 0-5 foot and 5-10 foot contours have expanded markedly and become colonized by thick stands of submergent macrophytes.

It is clear that basin sedimentation is strongly controlled by stream input of watershed erosion products. Two unnamed ditches enter Big Long Lake at its south end where sedimentation appears to be greatest. Both ditches were sampled in the current investigation and designated as BL3 and BL4. Both ditches drain watershed segments devoted to agriculture, and the ditch designated as BL3 was dredged during 1989 approximately 0.5 miles above our sampling location. Although residents reported that the ditch at the northwest corner of Big Long Lake (BL2) delivers silt ladened water during spring and early summer, we were unable to associate such watershed delivery with increased lake basin sedimentation. Due to the proximity of the inlet to the lake outlet, it appears that most of this sediment load is directed toward the outlet stream. Two other contributors to lake infilling, motor boating and shoreline erosion, are not considered to be important factors for the observed pattern of sedimentation in Big Long Lake.

Sediment Studies

Sediment Contaminants

A piston coring device equipped with a clear plexiglass tube was used to collect a one-meter core from the center of the northern basin of Big Long Lake. This technique permitted examination of the core to insure that the sediment-water interface was not disturbed during the coring operation. The core was extruded in 10 cm sections and placed in labelled plastic bags. All core material was kept cool at 4o C until analyzed. Prior to analysis, the 0-10 cm interval was thoroughly mixed and extracted for metal and organic contaminant analyses. This upper most interval provided sufficient material for our investigation.

The metals and organics data are presented in Table B11. Iron and calcium were the highest metals found in the sediments, but none of the metals analyzed were considered to be above background levels for comparable regions of northern Indiana. Similarly, extremely low concentrations were found for all organics, with most being at or below detection limits.

Table B11. Concentrations of Metals and Organic Chemical Contaminants in Surface Sediments of Big Long Lake.

METALS	ug/g dry wgt	ORGANICS	ug/g dry wgt
% Solids	6.1	2,4,5-T	<0.130
Ag	<24	2,4,5-TP (Silvex)	<0.109
Al	6390	2,4-D	<0.770
Ba	80	2,4-DB	<0.580
Be	<2	B-BHC	<0.018
B	15	D-BHC	<0.009
Cd	3	Methoxychlor	<0.380
Ca	17700	Toxaphene	<0.500
Cr	56	4,4'-DDD	<0.023
Cu	18	4,4'-DDE	<0.006
Fe	30400	4,4'-DDT	<0.025
Pb	64	A-BHC	<0.006
Mg	4130	Aldrin	<0.008
Mn	502	Chlordane	<0.029
Mo	108	Dieldrin	<0.004
Na	62	Endosulfan I	<0.030
Ni	42	Endosulfan II	<0.006
Sr	26	Endosulfan sulfate	<0.139
Ti	156	Endrin aldehyde	<0.049
V	23	Endrin	<0.012
Zn	53	G-BHC (Lindane)	<0.008
		Heptachlor epoxide	<0.177
		Heptachlor	<0.006
		PCB's	<0.140

Sediment Core Profiles

A sediment core was collected from the center of the northern basin of Big Long Lake (Figure B30) by means of the same piston coring device described in the previous section of this report. As always, the plexiglass tubing permitted inspection of the core to insure that the sediment-water interface was left undisturbed during the coring operation. Only the core which we felt absolutely met this requirement was saved for analysis. The total core length collected was 58 cm.

The core was extruded within two hours of collection and sectioned at 1 cm intervals with each sample being placed in a plastic bag for storage. All samples were then kept at 4o C until analyzed. In addition to wet weight for select core levels, organic content was calculated as the difference in weight between the wet weight and that after drying at 100o C for 24 hrs. Inorganic content was calculated from the weight difference of the sample dried at 100o C for 24 hrs and ashed at 500o C for one hour. Phosphorus was determined by the standard ascorbic acid colorimetric method using filtrate collected from an HCl digestion of the sediment sample.

Water content of the Big Long core displayed little stratigraphic variation and remained at approximately 95% throughout (Figure B31). The notable exception was at a depth of 4 cm which was 83% water.

The percentage of sediment dry weight contributed by the inorganic fraction remained at 66 to 70% throughout the length of the core with the remainder being the organic fraction (Figure B32). It is normal for Indiana lakes of intermediate trophic state to deposit in excess of 50 cm of sediment in one hundred years (Crisman 1987). The slight variability in the percentage of inorganic and organic matter in the Big Long core suggests that the relative contribution of each has changed little in the past 100 years. Such an interpretation, however, does not imply that the annual sedimentation of these parameters has remained constant for the past century. Given that no charge was included for 210-Pb dating in our budget and this parameter was to be used only if a pronounced stratigraphy was noted, we have not included such a dating technique. Instead, we have relied on indirect estimation of sedimentation in Big Long Lake via comparison of current and historical bathymetric maps and the extent of recent basin infilling.

In situations such as Big Long Lake where the percentage of inorganic and organic matter does not change appreciably along the length of a sediment core, it is conventional to express total phosphorus concentrations as a function of the total dry weight of sediment at a particular depth in the

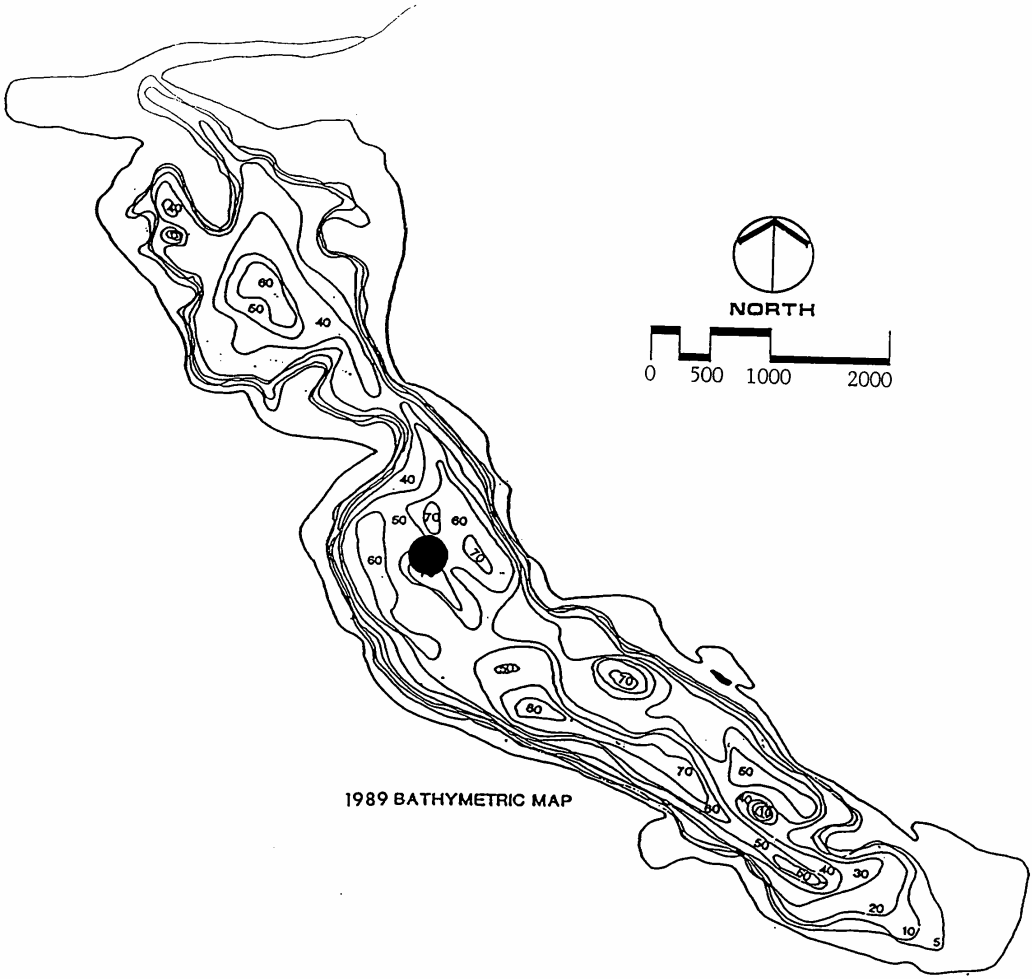


Figure B30. Site of Sediment Core Collection in Big Long Lake During 1989.

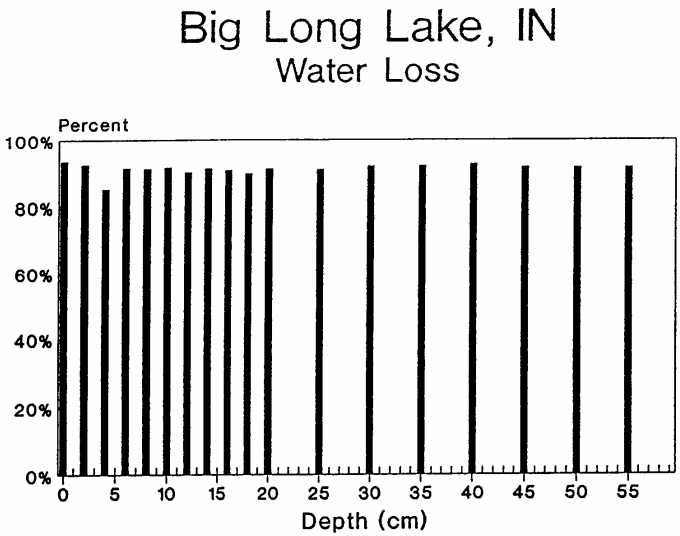
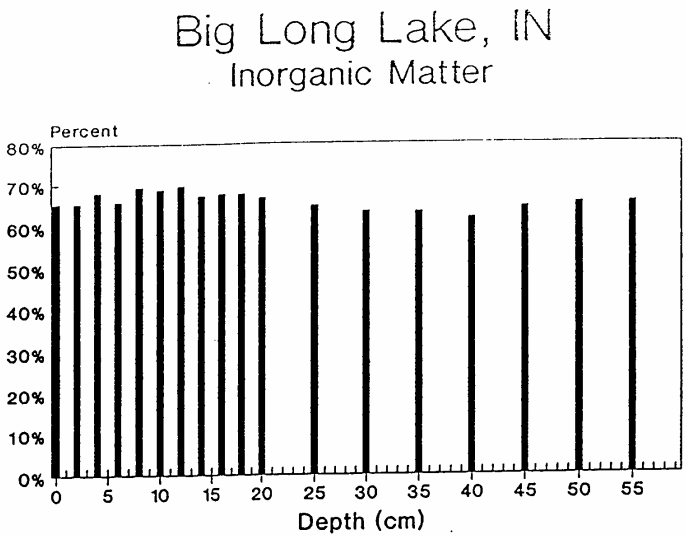


Figure B31. Profile of Percent Water in the Sediment Core From Big Long Lake.



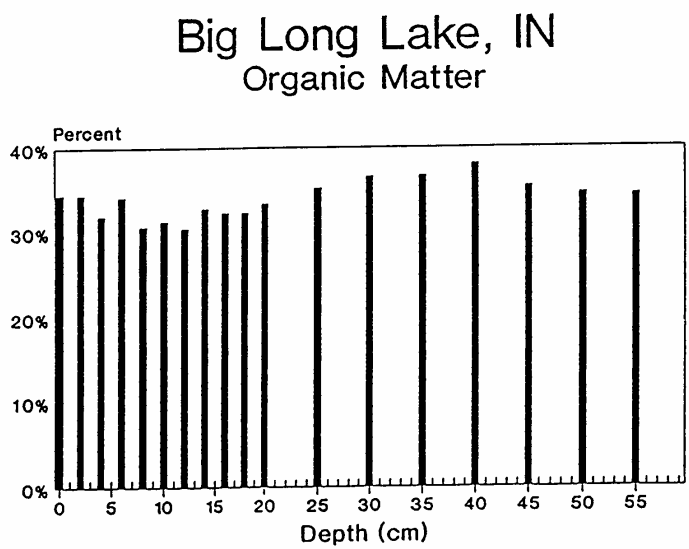
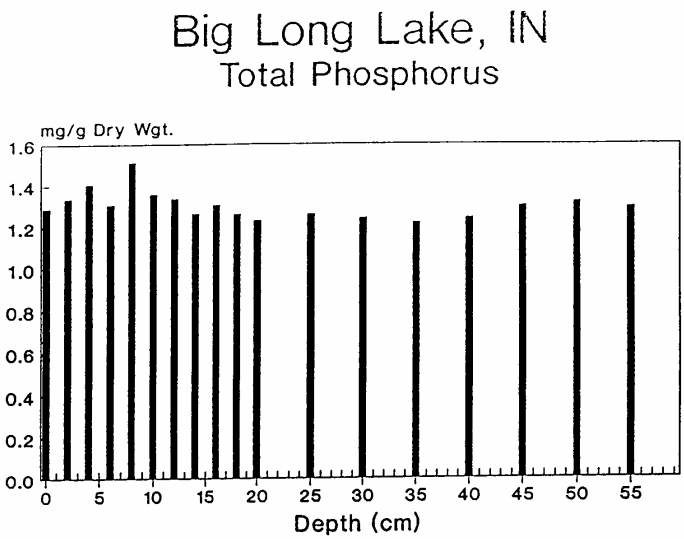


Figure B32. Profiles of Percent Organic and Inorganic Matter in the Sediment Core From Big Long Lake.

core. Total phosphorus concentrations displayed little stratigraphic variability and ranged from 1.2 to 1.5 mg/g sediment dry weight (Figure B33). The range of phosphorus values reported from Big Long Lake is only slightly greater than reported (0.7-1.4 mg P/ g sediment dry weight) comparably eutrophic Lake of the Woods (18 IDEM index) and Pretty Lake (13 IDEM index) and was within the range (0.9-2.8 mg P/g sediment dry weight) reported for much more eutrophic Indiana lakes including Bruce (33 IDEM index), Nyona (54 IDEM index), and South Mud (49 IDEM index) (Crisman et al. 1990, Eviston et al. 1990). The enrichment of phosphorus in the sediments of Big Long Lake reflects both the fact that the sediments of this lake displayed both higher water (90% versus 75-85%) content (increased soupiness) and higher organic (30-40% versus 10-23%) than any of the other five lakes just mentioned. It appears that the great depth of Big Long coupled with its morphometrically related resistance to wind mixing result in the lake being efficient at trapping nutrients in its deep water sediments. This is beneficia l for lake management because nutrients entering such lakes are likely to be less available for repeated recycling within the lake once taken up by plankton or macrophytes.

The relationship between total phosphorus and sediment organic matter percentage for the Big Long core is presented in Figure B33. Total phosphorus per gram of sediment dry weight remained relatively constant throughout the core length, while the percentage contribution of organic matter to total sediment dry weight declined from 40 cm to the top of the core. This trend suggests that phosphorus entering Big Long Lake recently may not be as readily available for algal and macrophyte growth as in the past.



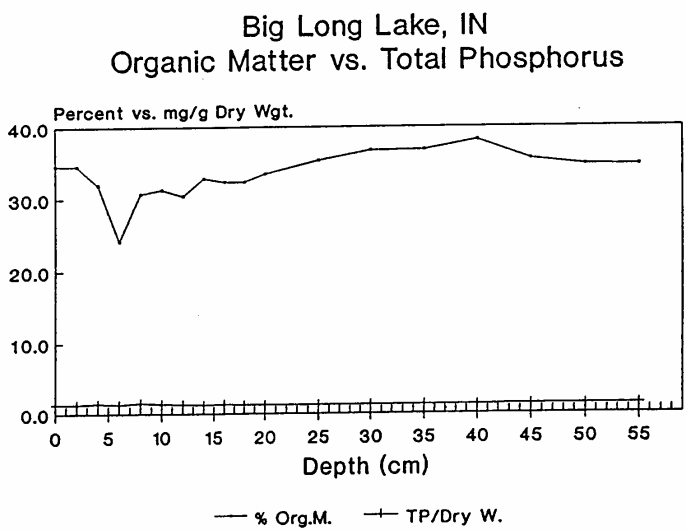


Figure B33. Profile of Total Phosphorus Concentrations and Comparison of Profiles of Organic Matter Percent and Total Phosphorus/Gram Sediment Dry Weight for Sediment Core From Big Long Lake.

Big Long Lake, The Watershed

The Big Long Watershed

The approach of this part of the study is to specifically address the effect of the watershed on the Lake (Figure B34). After preliminary investigation, the method was to target the area(s) of highest concern. The task was to build upon the 1988 study, A Preliminary Investigation of Twenty-Four Lakes, LaGrange County, Indiana by William Grant, LaGrange County Health Department. The study is quite extensive regarding Lake water quality, but had only general observations about the watershed. Basically, our study had to start from the beginning to discover how this watershed was contributing to challenges in this lake system. The concerns to be identified in the watershed were as follows:

a. Nutrient contribution to the Lake;
b. What are the probable sources;
c. How can sediment be reduced;
d. What are the intrinsic values of the watershed, and
e. How can the sources of sediment/nutrients be managed to reduce impacts to the lake?

This feasibility study included the use of the following resources:

a. Reconnaissance of the entire watershed by site visits on several occasions;
b. Walking tours of some private property areas that could not be properly observed from public areas;
c. Aerial photographs (County Surveyor);
d. Aerial photographs (USDA - Soil Conservation Service, 1972 and 1973);
e. Aerial color infrared photographs (NAPP, 1987);
f. United States Geological Survey (USGS) quadrangle maps;
g. United States Fish and Wildlife Service, National Wetland Inventory maps;
h. USDA - SCS Soil Surveys of DeKalb (1982), LaGrange (1980), Noble (1977) and Steuben (1981) Counties Indiana;
i. DeKalb, LaGrange, Noble, and Steuben Counties records: Auditor, Surveyor, Treasurer, etc:,
j. Various meetings and/or telephone conversations with State & County agencies, local property owners and;
k. A Preliminary Investigation of Twenty-Four Lakes, LaGrange County, Indiana, 1988, by William Grant, LaGrange County Health Department.

The main purpose of this investigation was to target the area(s) which would be the highest priority(ies) for land treatment systems for trapping nutrients and sediments in the watershed. These constructed solutions may consist of land treatment, settling basins, constructed wetlands, sediment traps, ponds, or shallow water habitat areas, etc. These terms are descriptive of similar broad-scale land treatment concepts that would reduce nutrient and sediment loading to the Big Long Lake system. Other upland agricultural practices such as terracing, grassed waterways, conservation tillage, and proper animal waste disposal are all vital methods to improving the water quality of the lake. These practices, are discussed later in this section. Methods of land treatment and applications will be recommended for problem areas. Local SCS and ASCS offices have been appraised of the areas felt to be contributing excessive amounts of sediment and nutrients (see watershed tour). The goal of this feasibility study is to focus on the site(s) of greatest potential: to most benefit the lake system in sediment and nutrient control, in the shortest time; and to attempt to identify the process to create this system and its costs. The final considerations that would evaluate the feasibility and/or priority of such constructed projects would then be up to the Lake Association leadership. Discussions with the Soil Conservation Service county offices indicated the awareness of problems with soils and agricultural practices above the lake. The SCS has pledged to help the Lake Association in any way possible including technical support, and initiating discussions with owners of properties which are contributing intolerable amounts of sediment, nutrient, and animal waste runoff. The SCS would be important support on the larger constructed solutions, and could be of prime responsibility to encourage and/or design the other <u>upland</u> <u>practices</u> and structures.

Natural Features

The Big Long watershed falls in the Northern Lakes Natural Region (Homoya et al, 1985). This Natural Region is comprised of numerous fresh water lakes of glacial origin. Natural community types common to this region include bog, marsh, lake, sedge meadow, prairie and various deciduous forest types. The aquatic communities may be characterized by the presence of bulrush, marsh fern, cattails, pond weeds, spatterdock, Virginia arrow-arum, orchids, tamarack and various species of sedges. The typical forest community which at one time covered over half of this natural region is dominated by oak (chiefly, red oak) and hickory. Other notable species include black, silver, sugar, and red maples; beech; American and red elm; green ash and cottonwood. Cisco (*Coregonus artedii*) a specie of State special concern was last reported in Big Long Lake in 1974. Although once common to many lakes in northern Indiana, it is now believed that the cisco has been extirpated in Big Long (IDNR 1989). State endangered plants reported in Big Long Lake vicinity include Beck water-marigold (*Bidens Beckii*), and three species of pondweed: Fries' pondweed (*Potamogeton Friessi*), flat leaf pondweed (*P. Robbinsii*), and Richardson's pondweed (*P. Richardsonii*).

Techniques useful in preserving these natural features include:

a. Avoid relocation of natural stream channels

b. Avoid building close to wooded ravines or stream banks.

c. Preserve natural vegetation adjacent to water areas.

d. Avoid construction in, or drainage of, wetlands.

e. Avoid the use of on-site septic systems near the lake or near drainages where there is potential for saturated soils.

Watershed Tour--impressions by visual survey

Big Long Lake and Watershed

The purpose of this section is to express in narrative form the observations and general visual impressions that were made during site tours of the watersheds and review of color infrared and other aerial photographs. The intent is to provide a perspective that may be fresh and to stimulate residents to make their own continuing observations.

Prior to our detailed watershed tours, we examined several aerial photographs of the Lake and watershed. The purpose of this was to identify potential problem areas not likely to be observed from the ground in order that they could be checked in the field. Aerial photographs were also used to help us focus on the "big picture". This allowed us to understand the watershed interaction as a whole before we broke it down into its smallest components (Figure B34).

The lakes proper are discussed in detail in the front of this report.

1. The unique land form of the lake and the surrounding relatively high land is among the first items striking the viewer. Most of the lake shoreline is bordered by embankments that rise 20 to 50 feet above the water. Some of this impression is probably the result of the artificially high lake level. (See lake contour maps which indicate very flat, probably former wetland or shallow submergent, ring around the entire lake.)

2. As noted by (Grant, 1989) many seasonal homes are now year-round homes. In addition, many new homes have recently been built, replacing some of the older cottages. More new homes are being planned. This trend was noted on the south shore areas of Lakeside and Greenwood. Several new roads including 1050E have been constructed.

3. Five or more deep ravines enter the southwest shore of the lake which drain the upland watershed to the southwest. Most of these are natural drainageways. One notable exception is the draw that crosses 1000E south of the lake. A section of this 'stream' has been ditched (recently) west of the road. East of the road, fresh bank side cutting is apparent. (Certainly this project should be reconsidered, or modified to incorporate bank stabilization measures, as it seems to be improving only a limited area of farm drainage problems.)

4. A large, quality wooded tract (FOR) occurs in Section 27. Much of this land has steep topography. Preservation of this woods would be very important. Certainly, development in this area would create a major sedimentation problem, even with great care in construction.

5. Several emergent and scrub/shrub wetland depressions (Wt) occur throughout Sections 27, 34, and 35. Some of these can be seen along Road 700S.

6. Nearly all of the rolling upland of the Big Long watershed is in crop production.

7. Animal operations and pastured lands observed are labelled (An). Animal operations in the Big Long watershed do not appear to be problem sediment and nutrient sources.

8. In Section 28, west of road 900E, is some recent wetland ditching. Although it appears outside of the watershed boundary, it is suspected to be altering the wetland to the east and, under certain conditions, may contribute flow to the east.

9. Also in Section 27 is a large camp ground operation. As a summertime seasonal operation with weekend use peaks, surface runoff and sanitary wastewater should be monitored. It was noted that the agricultural land adjacent to the camp ground was to be in long term hay-pasture.

10. In the small portion of Section 28 in the watershed, some fall chisel plowed land and a couple of dry dams were observed. It is recommended that vegetative filters be placed around dry dams to intercept sediment. Some brown water appeared flowing in the swale into Section 21.

11. Section 21, west of Big Long Lake has seen a great deal of change in recent history. This area also comprises the single most direct watershed contribution to Big Long Lake. A former wetland near the curve in 900E is now a pond with a ditch that bypasses. Obviously, some filtering ability has been lost. To the west of this site are some new roads with scattered homesites. Whether by design or accident, this area remains to have good cover and most of the wetlands remain intact. Hopefully, these features can be maintained, even if more homes are added. (It was anticipated that the worse watershed conditions would be found here.)

12. Also in Section 21, Northwest Quarter, and into Section 22, are a couple of constructed option opportunities. One is associated with the ditched drainageway discussed above. However, several homes are near water level at this location. A second area, although small, could easily be restored to be more effective at sediment removal.

13. Most of the land area of Section 22 drains through an existing wetland depression (Wt) about midway between 500S and 600S. This area should remain undrained, and, perhaps enhanced. Properly planned, wetland improvements could address the runoff from a very critical area including Sections 21, 22, and 28--about 1,000 acres. Part of this 'sub-shed' is in a long-term pasture (P) rotation.

14. Continuing around the north and to the east, the outlet structure and Public Access (P.A.) is encountered. This outlet is relatively near, and opposite, the major inflow discussed above. It is suspected that short-circuting of flow occurs from the inlet to the west, and the outlet. This would account for basin infilling in this area.

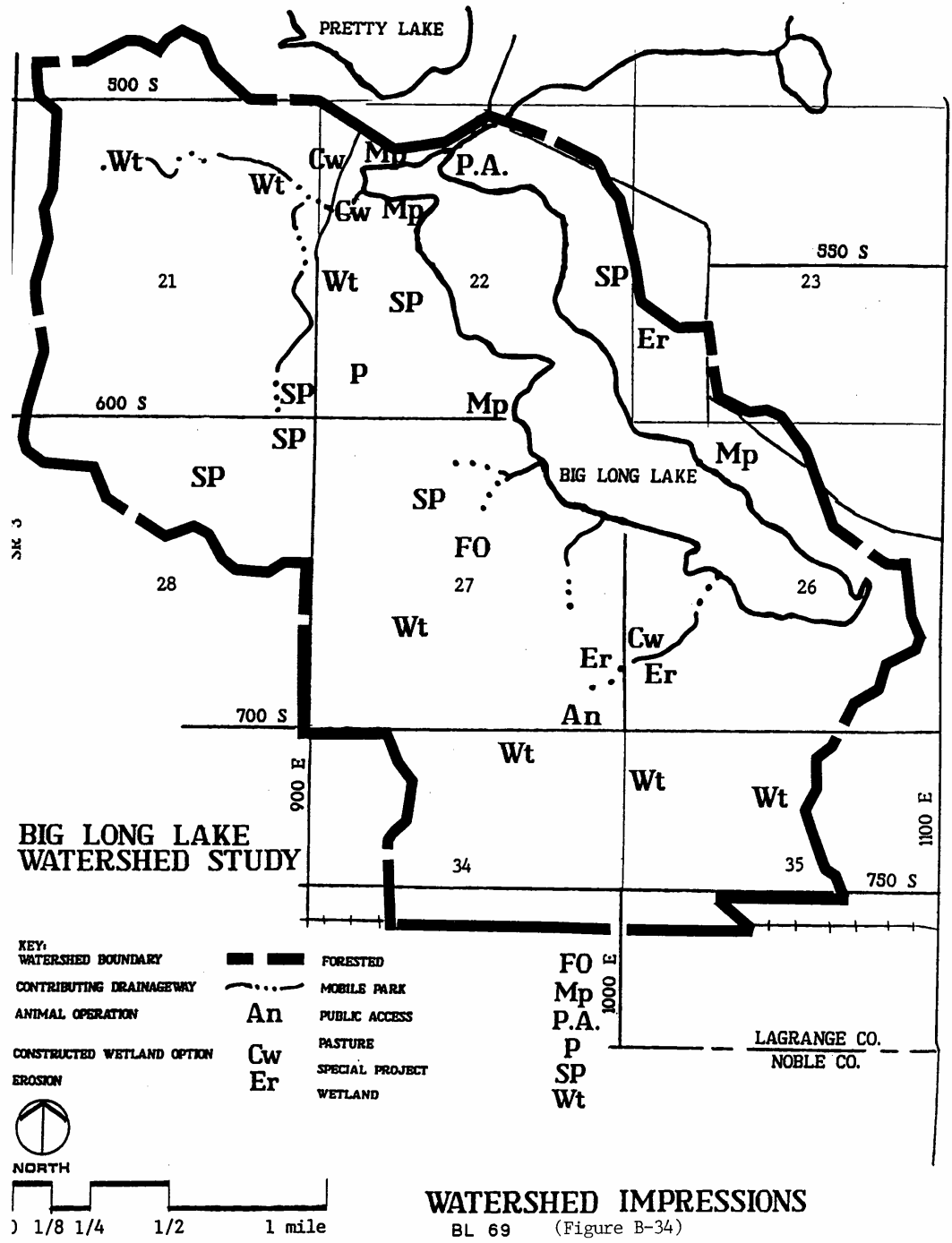
15. Most of the northeast shore, Section 22, is moderately developed. The upland watershed on this side is relatively narrow, generally less than one-quarter mile. Much of the agricultural portion is in no-till winter wheat. A critical eroded area is noted (Er). Its proximity to the lake adds to the concern. Rill and gully erosion is apparent. Further management of this area may involve: grade & bank stabilization, grassed waterways, and permanent vegetation field borders.

16. At the extreme southeast corner of the Lake (in the 'Timberhurst' area) are several homes, some recent, on very low soils. It is reported that a cluster system, located in suitable soils, will be used for waste treatment. A wetland shoreline has been surrounded by a channel for boat access to the lake. This has likely substantially reduced the effectiveness of this filtering edge of the lake. A feasible solution may be to require a permanent vegetative buffer/filter strip along the southeast shore. A buffer strip would partially filter runoff from adjacent residential lands.

17. Several mobile parks (Mp) occur around Big Long Lake. Concerns about sanitary wastes are usually warranted at these sites because they may have older systems, or are simply overloaded by these higher density developments. (We have learned that at least one park is being renovated, and at least one other is under mandate.)

18. An overview of these observations for Big Long Lake suggests that, simply by comparative input, the uplands and farmland are the greatest contributor of sediment. The steepness of gradient, and therefore increased velocity, is the apparent key to the degradation of this lake. Lakefront development has caused many of the usual problems, but these should be addressed on an individual parcel by parcel basis.

19. In 1989 several Special Projects (SP) were initiated by the LaGrange County Soil Conservation Service. These Special Projects include: long-term corn/hay rotations; long-term hay pasture; conservation, no-till, and upland chisel plow; rill and gully stabilization; and grassed waterways with dry dams.



WATERSHED IMPRESSIONS

BL 69 (Figure B-34)

Photospectroscopy

Aerial photography is an intricate tool for use in many topographic and natural resource applications.

In doing a land use study using aerial photography, several items must first be considered to provide the most accurate detailed information possible in obtaining the desired data.

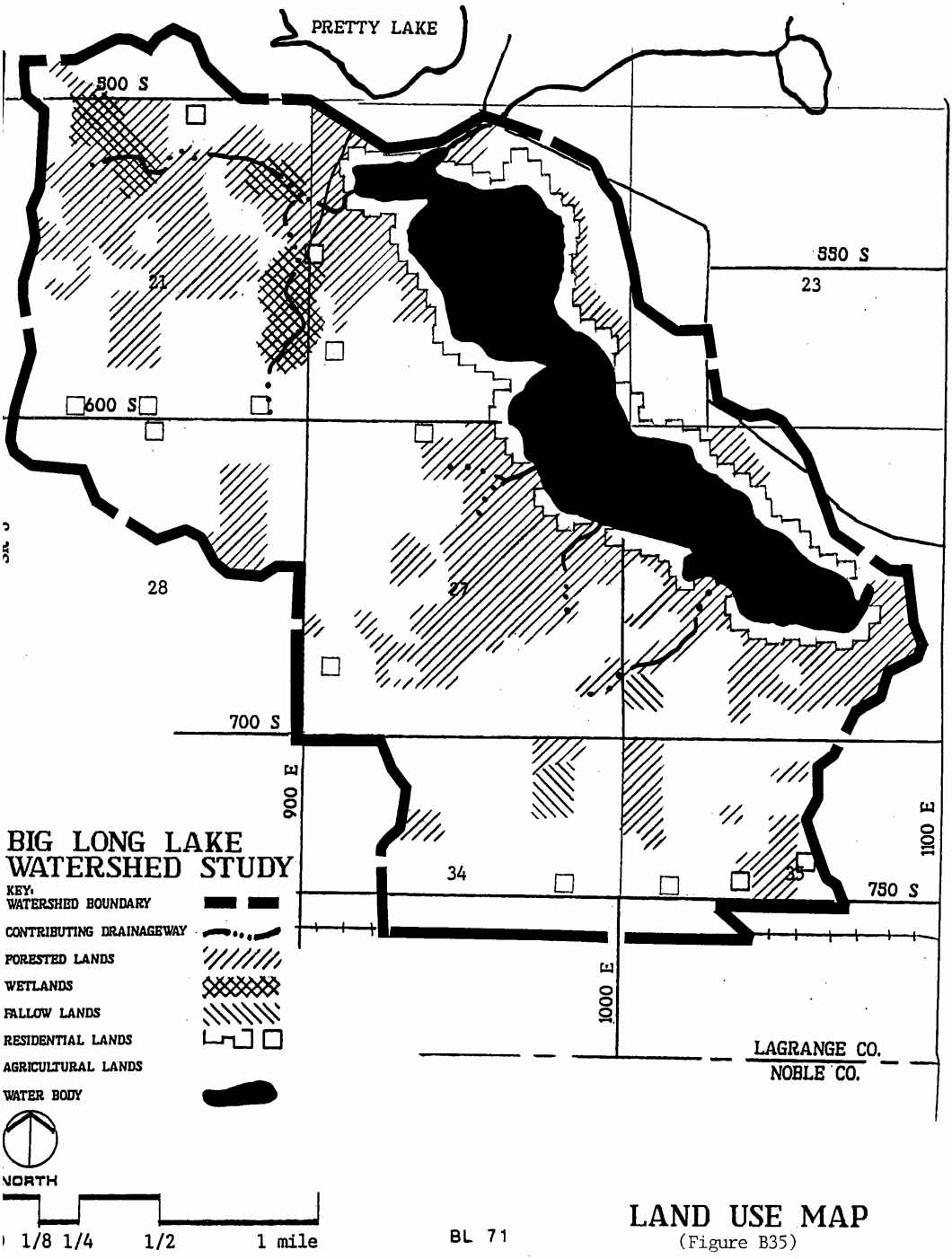
First, and probably most important in doing a study of primarily agricultural usage, the "type" of photograph used is important. For the most part, two "types" of photographs exist: 1) those taken in the visible spectrum, and 2) those taken in ultraviolet or infrared spectrum of light. Since all living organisms emit energy in the electromagnetic spectrum and since our study is based primarily in an agricultural watershed area, color infrared photography was used.

This type of photography delineates plants through size, density, and respiration, by photographing specific intensities of electromagnetic radiation emitted. Fallow lands, lake and wetlands appear as grey or black areas on the photo.

Second, the date in which the photographs were taken is an important consideration in the determination of the results and comparison to current trends.

Month and day play a factor in the interpretation of the types of vegetation and wetlands described. An extreme example of this would be trying to distinguish agricultural usage on a photo taken in July compared to the same photo taken in December. The day is also a factor because of previous weather conditions. According to the USDC, National Weather Service, 1.8 inches of rain fell over the project area in the 4 weeks prior to the photo date, this was 0.8 inches below normal, however this deviation was not sufficient to alter normal land use cover types. The photographs used for this study were taken on the September 4, 1987 fly-over at a scale of 1:40000 (Figure page v).

In doing the land use study of the Big Long Lake watershed, the entire watershed was laid out on the photographs using a transparency. The size of an overlay grid (1 acre) was then calculated, drawn, and then placed over the photos. From there the watershed was divided into the following land use categories: Agriculture; Big Long Lake; Fallow; Forested (woodlots); Residential; and Wetlands. Results of the study are shown in watershed summary, Table B12. Land use is graphically represented in Figure B35.



LAND USE MAP
(Figure B35)

BIG LONG LAND-USE SUMMARY TABLE		
Cover Type	Acres	% of Total
Agriculture	1796.6	63.5
Big Long Lake	388.0	13.7
Fallow	23.9	0.8
Forested (woodlots)	431.6	15.3
Residential	140.6	5.0
Wetlands	46.4	1.6
Total Watershed Area	2827.1	99.9

Table B12. Big Long Land-Use Summary

Geology

The Big Long watershed is primarily underlain by bedrock of the Coldwater Shale Formation (Gray 1987). The Coldwater Shale Formation consists of 90 to 350 feet of gray shale laid down in the lower Mississippian Period of the Paleozoic Era (about 350 million years ago). The southern tip of the Big Long watershed is underlain by the Ellsworth Shale Formation, 340 feet of mostly green shale with some black shale nearer the lower facie. The Ellsworth Shale was laid down during the lower Mississippian and upper Devonian period of the Paleozoic Era (about 355 million years ago).

The shale deposits of the Big Long area are covered by over 200 feet of partially lithophied to unconsolidated glacial deposits (Gray 1989). The most recent glaciation occurred some 12,000 years ago during the Wisconsinan Advance. The Big Long watershed is comprised of sediments deposited from the Huron-Saginaw Lobe of the Wisconsinan Ice Sheet (Hill 1986). This material is dominated by loam till of the Trafalgar Formation which includes large areas of severely eroded drift, and dead-ice land forms...Big Long Lake! For further discussion on surface geology, see Soils.

Topography

The watershed of Big Long Lake is best described as a morainal topography. Morainal topography is a general term used to describe areas of irregular mounds and ridges which are the result of glacial drift. Glacial drift are deposits of outwash streams and unsorted sand and gravel tills. The highest point in the Big Long watershed is 1035 feet above sea level in the southwest corner of the watershed, and the lowest point, at the lake is 955 feet above sea level.

Relief throughout the watershed is characterized as flat to somewhat depressional to the west, moderately to steeply sloping near the lake. Slopes range from 0 to 14 percent in the majority of the watershed, to an extreme of 45 percent near the south west side of the lake.

Severe slopes

The length and steepness of slopes are major factors in assessing the probable erosion risks of an area. On steep or long slopes, runoff water accumulates in channels where increased flows produce greater erosive forces. Level or flat lands produce shallow overland flows over a larger area, this decreases the erosive forces of runoff.

The intent of this study-map (Figure B36) is to further illustrate the fabric of the land forms in the watershed. Areas with severe slopes comprise 1,237 acres or 44 percent of the Big Long watershed. Severe slopes detailed in this study range from 10 to 45 percent. The majority of the severe slope areas occur along the western shore of Big Long Lake. Much of the agricultural land in the northwest quarter of the watershed also exhibit large areas with severe slopes. This study provides further evidence where land management emphasis should be. This graphic also substantially matches the worst conditions of Highly Erodible Lands discussed later in the report. In general, areas mapped as having severe slopes should not be in agricultural crop production, or should be in a conservation tillage program. Some of these sloped areas nearer the lake are too steep for development without special care, if at all.

Soils

The soils of the Big Long watershed are grouped in the Wawasee-Hillsdale-Conover Association by the LaGrange County Soil Survey. This association is further characterized as moderately drained, nearly level to strongly sloping areas, with course to medium grained soils of glacial till plains and moraines.

The association is approximately 30 percent Wawasee and similar soils, and 17 percent Hillsdale soils, 14 percent Conover soils, and 39 percent other minor soil inclusions.

According to the LaGrange County Soil Survey (1980), The well drained Wawasee and Hillsdale soils are on knobs, breaks between drainages, and on level till plains. Low water availability is a major limiting factor of the Hillsdale soils. The poorly drained Conover soils occur on broad flats and along drainageways. Conover soils are limited by saturated conditions.

Table B10. IDEM Eutrophication Index for Big Long Lake in 1989.

	Parameter	Value	Eutrophy Points
I.	Total Phosphorus	0.14 ppm	3
II.	Soluble Phosphorus	0.03 ppm	1
III.	Organic Nitrogen	0.45 ppm	0
IV.	Nitrate	0.35 ppm	2
V.	Ammonia	0.39 ppm	1
VI.	Dissolved Oxygen Saturation @ 5 feet	56%	0
VII.	Dissolved Oxygen (% of water column with >0.1 ppm DO)	100%	0
VIII.	Light Penetration (Secchi Disk)	11.5 feet	0
IX.	Light Transmission (% at Three Feet)	52 %	2
X.	Total Plankton		
	Vertical Tow (5 ft to Surface)	1,520 cells/mL	2
	Blue-green Dominance	No	0
	Vertical Tow (Thermocline)	625 cells/mL	0
	Blue-green Dominance	No	0
	> 100,000 cells/mL	No	0
		1989 IDEM Index	11

Stream Sampling

Methods

At each station, two, 1-liter water samples were collected from the upper 15 cm of the water column. Water samples were analyzed for: calcium carbonate alkalinity, specific conductivity, pH, total nitrogen, total phosphorus and color. In addition to water quality measurements, stream flow was calculated using a General Oceanics mechanical flowmeter and a visual survey was conducted of stream and basin characteristics.

Stream Chemistry

Four stream/ditch stations were sampled during the 1989 survey (Figure B14). Station BL1 was on the outlet stream for Big Long Lake. Samples were collected on the north side of County Road 500 S. Station BL2 was the site for the unnamed stream that discharges to Big Long Lake at its northwestern corner (northwest ditch). Samples were collected on the south side of County Road 525 S. This section of the watershed consists of rolling terrain draining into an extensive wooded wetland prior to discharging into Big Long Lake via the stream.

The two remaining stream stations were located on unnamed ditches entering the lake at its southwestern corner. Located 0.25 miles west of County Road 1050 E, station BL3 was on an unnamed ditch (southwest ditch) that drains a rolling section of the watershed that is both wooded and devoted to agriculture. This ditch was "cleaned" during the summer of 1989. The final site BL4 was approximately 1/8 mile east of County Road 1050 E on unnamed ditch near its mouth in Big Long Lake. This ditch enters the lake just south of the unnamed ditch represented by station BL3 and drains a segment of the watershed that is primarily rolling and wooded, with little cultivation.

Water chemistry data for all four stations were collected on 18 January 1990. Flow was detectable at only BL1 (11.53 cfs), the outlet stream for Big Long Lake, and BL3 (4.02 cfs) (Figure B15).

There were only minor differences in the pH (5.8-6.3) of the stream stations (Figure B16). Both alkalinity and conductivity (Figure B17) were lowest at the outlet (BL1), intermediate and roughly comparable at BL2 and BL3, and highest at BL4. It is obvious that the lake is trapping carbonates associated with primary production and sedimentation.

Nitrite/nitrate concentrations were barely detectable (0.01 mg/L) at the lake outlet (BL1) but were one to two

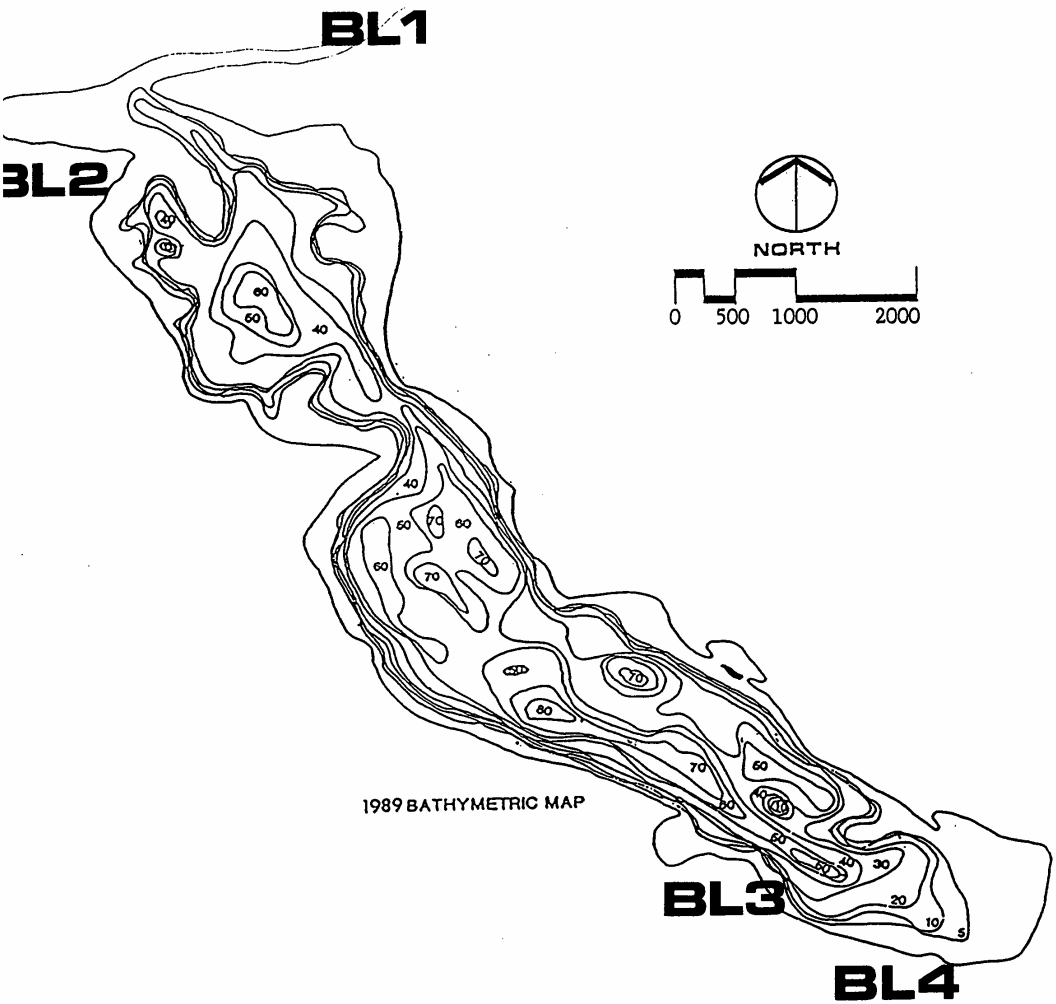


Figure B14. Stream Sampling Stations for 1989 Investigation.

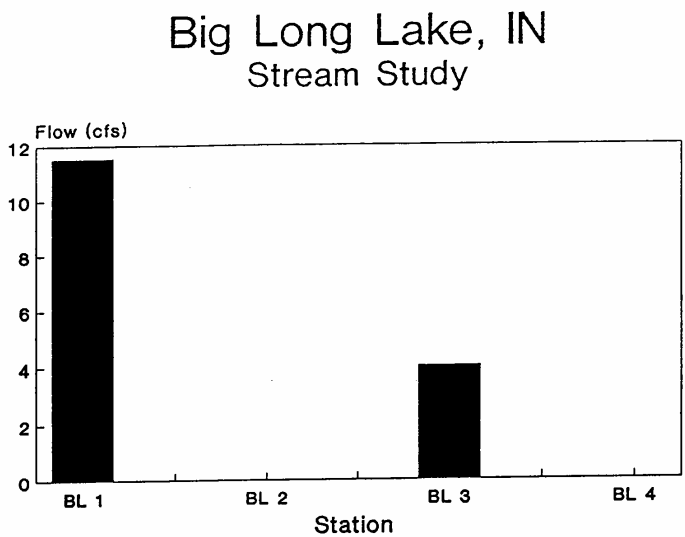


Figure B15. Flow in Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.

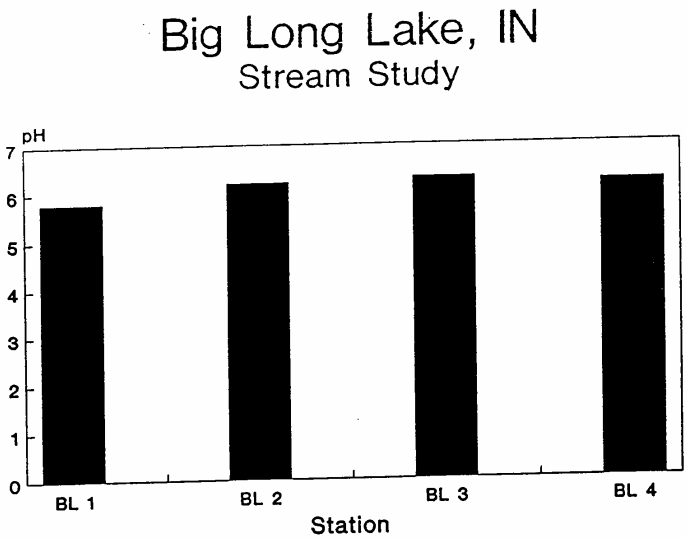
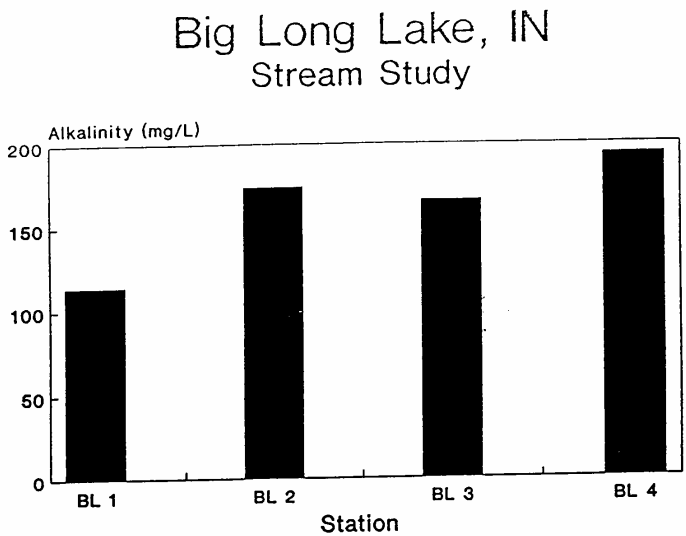


Figure B16. pH Values for Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.



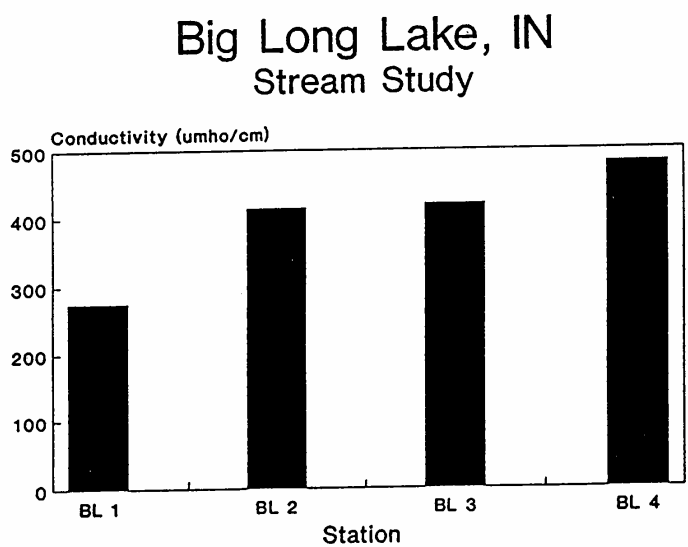


Figure B17. Alkalinity and Conductivity Values for Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.

orders of magnitude greater (0.84-1.95 mg/L) for the three ditch stations (Figure B18). It appears that the lake is effectively trapping nitrogen loading from the watershed.

Unlike nitrogen, total phosphorus was greater for the lake outlet than for the inlet streams (Figure B19), but interstation differences were minimal (0.15-0.23 mg/L). Ortho phosphorus, on the other hand, was 0.5 to 3.5 times lower for the outlet and inlet stations (Figure B19). All of the total phosphorus found at stations BL2 and BL3 was contributed by ortho phosphorus.

Finally, total suspended solids were greatest for the two ditches entering the lake at the southwestern corner (BL3 and BL4). Interstation differences were relatively minor (4-9 ppm), and values likely reflect inorganic rather than organic turbidity given the time of year (Figure B20).

Microbiology

A water sample for total coliform analysis was collected on both 15 September and 5 October at the water quality station in the central basin of Big Long Lake. Samples were analyzed within eight hours of collection. The analyses followed the state approved membrane filter procedure and counts have been expressed as most probable numbers (mpn), a standard way of estimating bacterial numbers. The concentration of total coliform bacteria was 40 mpn/100 mL during September 1989 but dropped to 0.6 mpn/100 mL three weeks later on 5 October (Figure B21). All bacteria counts at Big Long Lake during 1989 were well within state standards.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic macrophytes in Big Long Lake. A total of 32 transects spanning the width of the lake were used as the data base. The plant survey was conducted in September 1989 and thus represents summer plant extents. Plant biovolume is defined as the percent of the water column at a given location in the lake that is filled with plant biomass. Thus, it is a measure of the extent of macrophyte infestation throughout the lake system.

The aerial distribution of plant biovolume in Big Long Lake is presented in Figure B22, and the percentage of lake area represented by individual biovolume increments is presented in Figure B23. For convenience, biovolume has been expressed in increments of 20% of water column infestation. Macrophytes generally were restricted to water depths less than 20 feet deep, thus limiting plant growth in the lake to near shore areas. Given the morphometry of the basin, a majority of the lake bottom (53%) was considered void of vegetation.

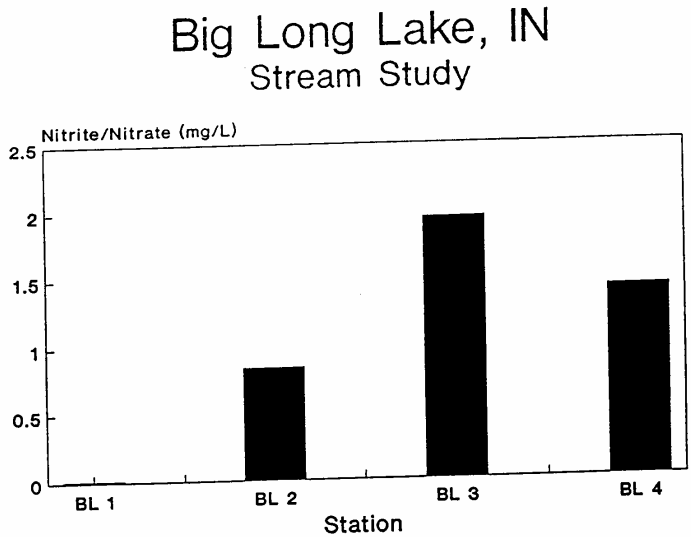
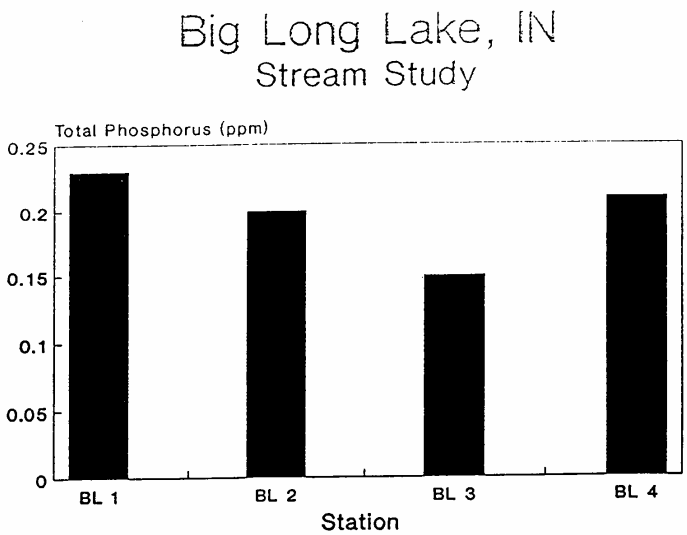


Figure B18. Nitrite/Nitrate Values for Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.



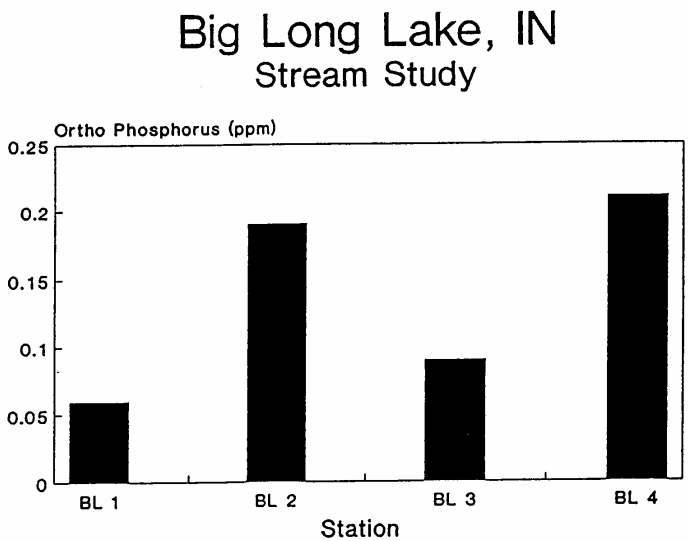


Figure B19. Total Phosphorus and Orthophosphorus Values for Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.

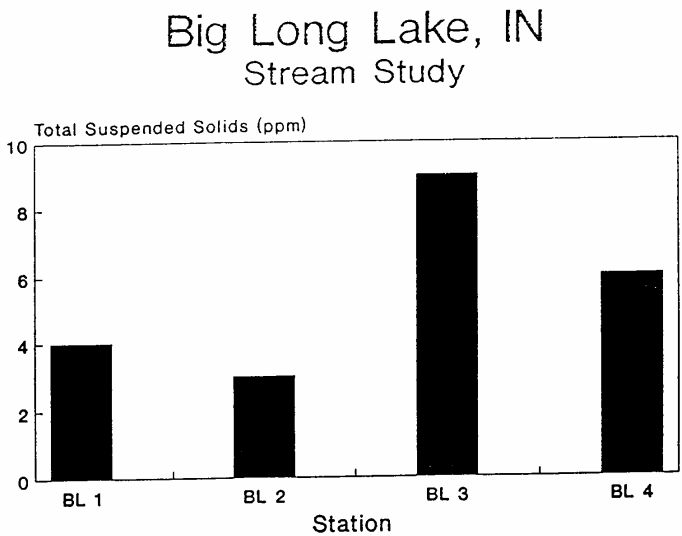


Figure B20. Total Suspended Solids Values for Three Ditches Draining the Big Long Lake Watershed For 18 January 1990. Station BL1 is the Lake Outlet.

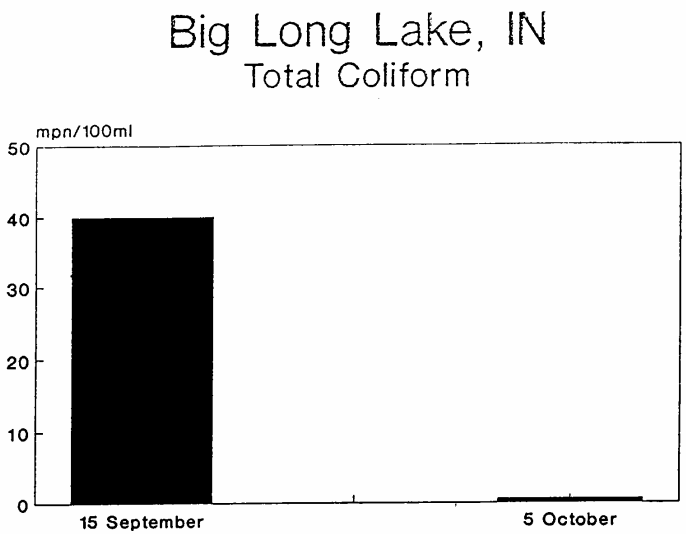


Figure B21. Total Coliform Bacteria Values for Big Long Lake During September and October 1989.

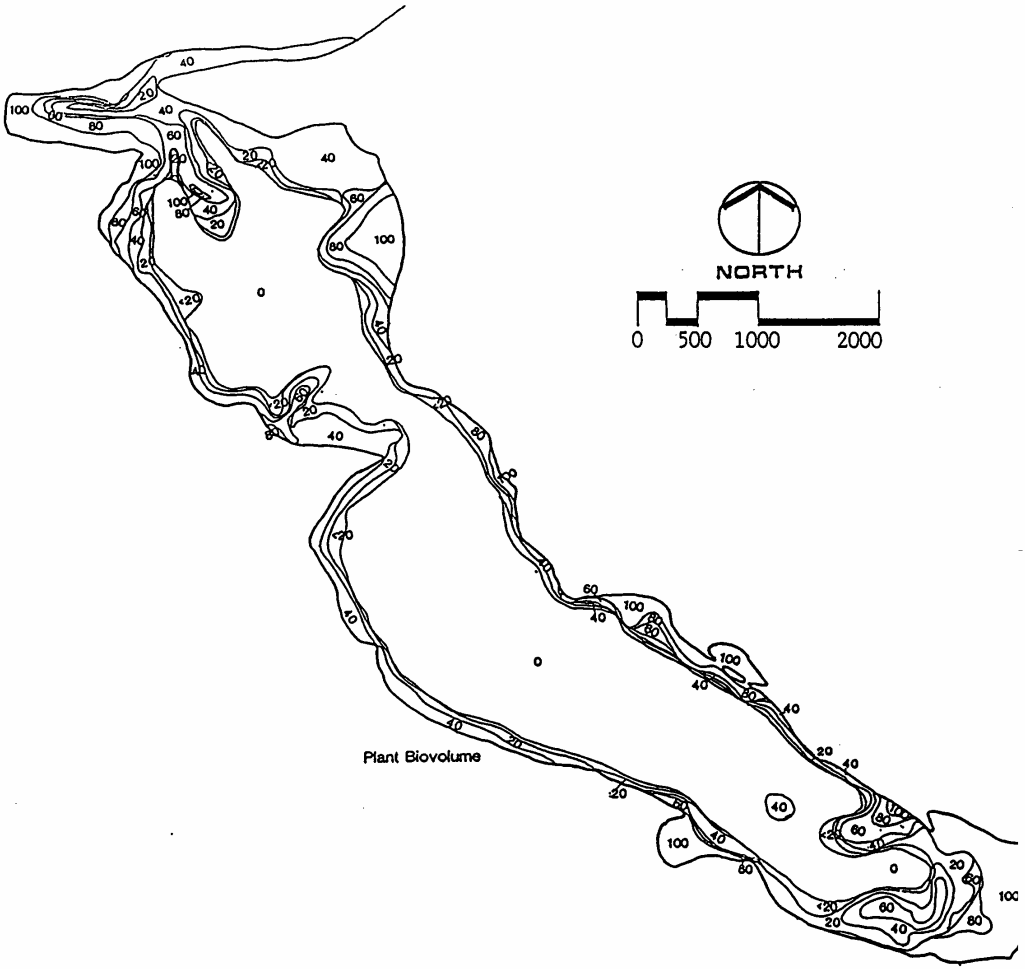


Figure B22. Distribution of Aquatic Macrophyte Biovolume in Big Long Lake for 1989.

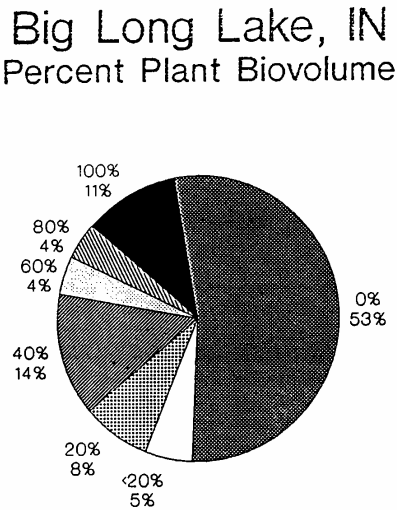


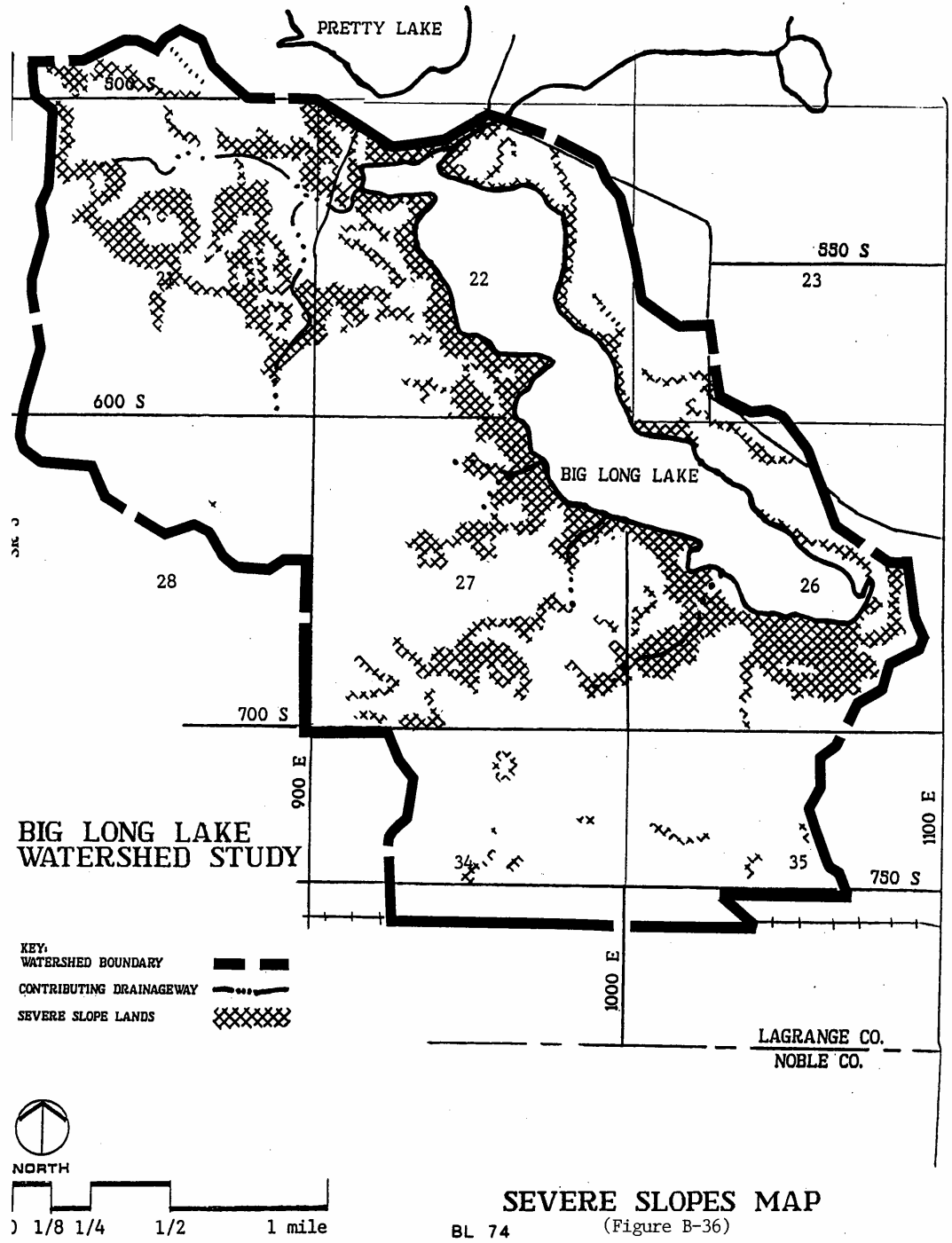
Figure B23. The Distribution of Plant Biovolume in Big Long Lake Expressed as a Percent of Water Column Infestation. For Each Pie Segment, the Upper Percent is the Biovolume and the Lower is the Percent of Lake Area Represented by the Interval.

Areas of 100% water column infestation were aerially limited (11% of lake area) and were found principally at the mouths of inlet streams and ditches. The greatest extent of the 100% areas was at the extreme southern and northern ends of the lake with secondary areas found in bays along the eastern and western shores. The areas of 80% infestation accounted for only 4% of lake area, with most being adjacent to the 100% areas but in somewhat deeper water. Only 15% of the total vegetated littoral zone infested 80-100% of the water column of Big Long Lake. The remaining 85% of the littoral zone displayed less than 80% biovolume, with the 40% of the zone (14% of total lake) being between 40% and 60% biovolume.

Our work at other Indiana lakes (Eviston and Crisman 1988, Crisman et al. 1990, Eviston et al. 1990) has demonstrated that the public perceives a macrophyte problem only when plant biovolume exceeds 80% of the water column. Following this reasoning, only 15% of the surface area of Big Long Lake could be characterized as having management problems with macrophytes. Such areas appear to be limited to water depth less than 10-15 feet with the most serious problems in nearshore areas less than 5 feet deep. The depth distribution of macrophytes is controlled both by basin morphometry and pronounced light limitation below 10 feet water depth. It appears that plants have colonized most available sites, and it is suggested further eutrophication of Big Long Lake will not likely result in a pronounced exacerbation of macrophyte problems beyond current levels.

The height of macrophyte growth throughout Big Long Lake is depicted in Figure B24. Most of the vegetated littoral zone of Big Long Lake was characterized by plant heights less than 2 feet tall with the second most important plant height interval being 2-4 feet. Only isolated pockets of plant growth between 4 and 10 feet tall were noted. Such a distribution of plant heights suggests a pronounced morphometric limitation to macrophyte growth.

In addition to looking at the distribution of plant biomass in Big Long Lake, a qualitative survey was made to determine the distribution of the major plant species in the system (Figure B25). The exotic species, Eurasian watermilfoil (*Myriophyllum spicatum*), shared dominance of the vegetated littoral zone with Illinois pondweed (*Potamogeton illinoensis*) and sago pondweed (*Potamogeton pectinatus*). It appears that all three species are contributors to near shore macrophyte management problems with watermilfoil being of particular concern. Dense submergent and floating-leaved plant growth (principally *Nuphar* spp.) near stream and ditch inlets is likely serving a beneficial purpose in trapping some of the nutrients and silt delivered from the watershed.



SEVERE SLOPES MAP
(Figure B-36)

BL 74

Other minor soil inclusions in this association are the Boyer, Chelsea, Metea, and Martinsville which are found in areas similar to that of the major soils of the association. The Whitaker soils are located on slightly lower areas; Rensselaer soils are located in depressions and drainages; and Houghton soils are in deep depressions and low lying areas.

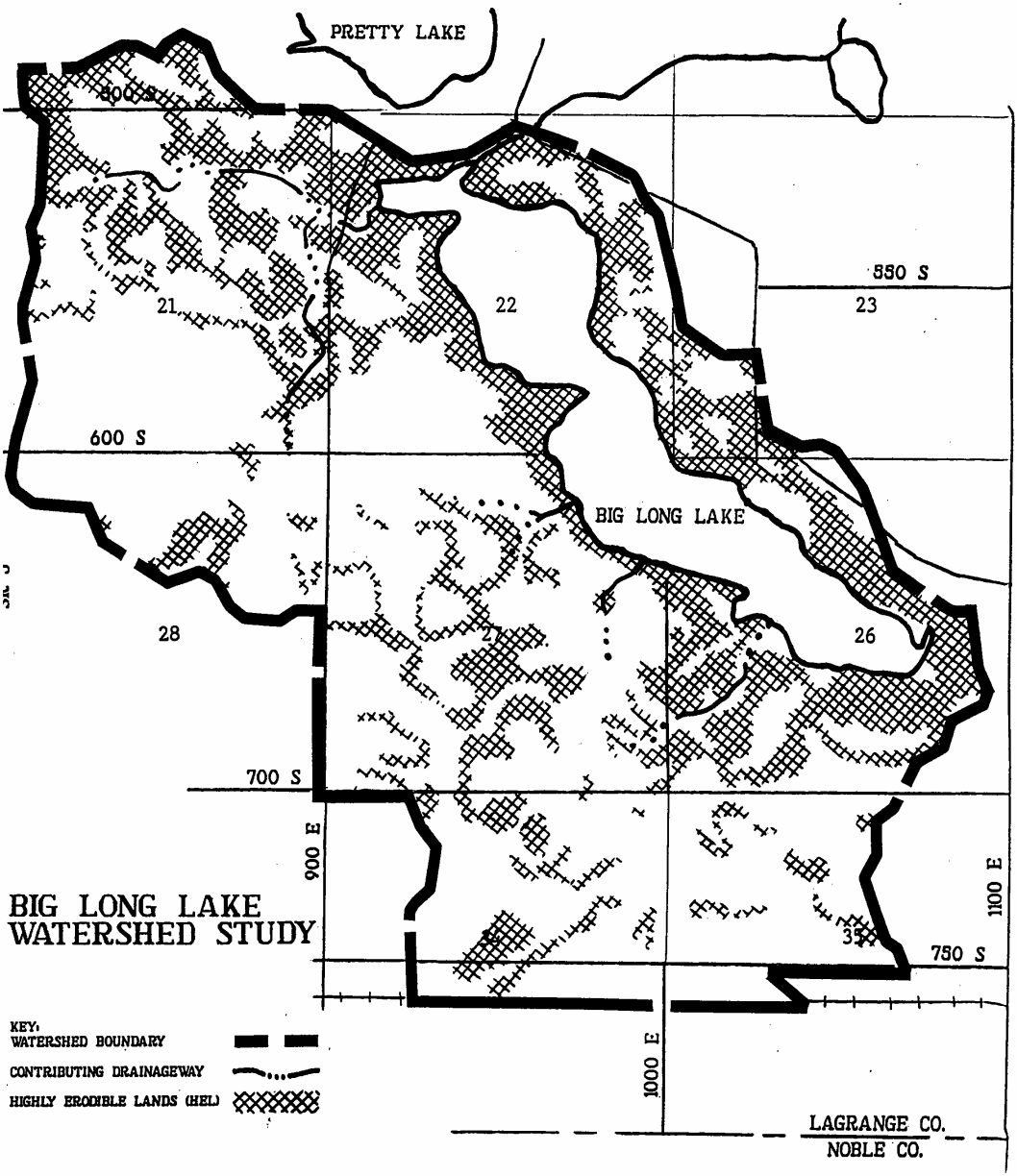
Highly Erodible Land

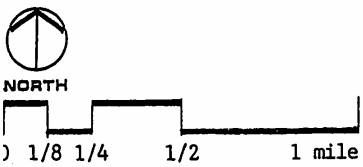
Highly erodible lands, or HEL are determined based on dominant slope length, percent slope and soil texture determined for each soil unit in each county. The purpose of identifying areas containing HEL is to display the origin of potential sediment sources so that the study may target areas of general concern. Using the Soil Survey of LaGrange County prepared by the USDA-SCS issued in 1980, and data provided by the local SWCD and SCS offices, soils of the HEL designation were mapped as shown in Figure B37. The following highly erodible soils occur within the Big Long watershed (Table B13).

Boyer loamy sand, 6 to 12% slopes
Chelsea fine sand, 6 to 12% slopes
Hillsdale sandy loam, 6 to 12% slopes
Metea loamy sand, 6 to 12% slopes
Wawasee fine sandy loam, 6 to 12% slopes
Wawasee fine sandy loam, 12 to 18% slopes
Wawasee loam, 6 to 12% slopes
Wawasee loam, 12 to 18% slopes

Table B13. **Highly Erodible Land (HEL) soils of the Big Long watershed.**

The Big Long watershed was first analyzed to determine the total extent of HEL map units in the watershed. The Big Long watershed is comprised of approximately 946 acres (33.5%) of HEL. The study area was then further divided to determine the extent of HEL currently in crop production. Highly Erodible Land in agricultural production are of greater concern to the overall water quality of Big Long Lake because these lands are more susceptible to erosive forces than HEL with established permanent vegetative cover. Approximately 41% (390 acres) of the total HEL occur in agricultural land-use areas, and are considered to be directly contributing sediment to Big Long Lake. The HEL study was based strictly on HEL map units, it does not take into account non-HEL map units which may have inclusions of HEL soils. Target sediment sources were located using the HEL map and aerial photos, and will be discussed further in latter sections of this report.





HIGHLY ERODIBLE LANDS MAP (HEL)

BL 76 (Figure B-37)

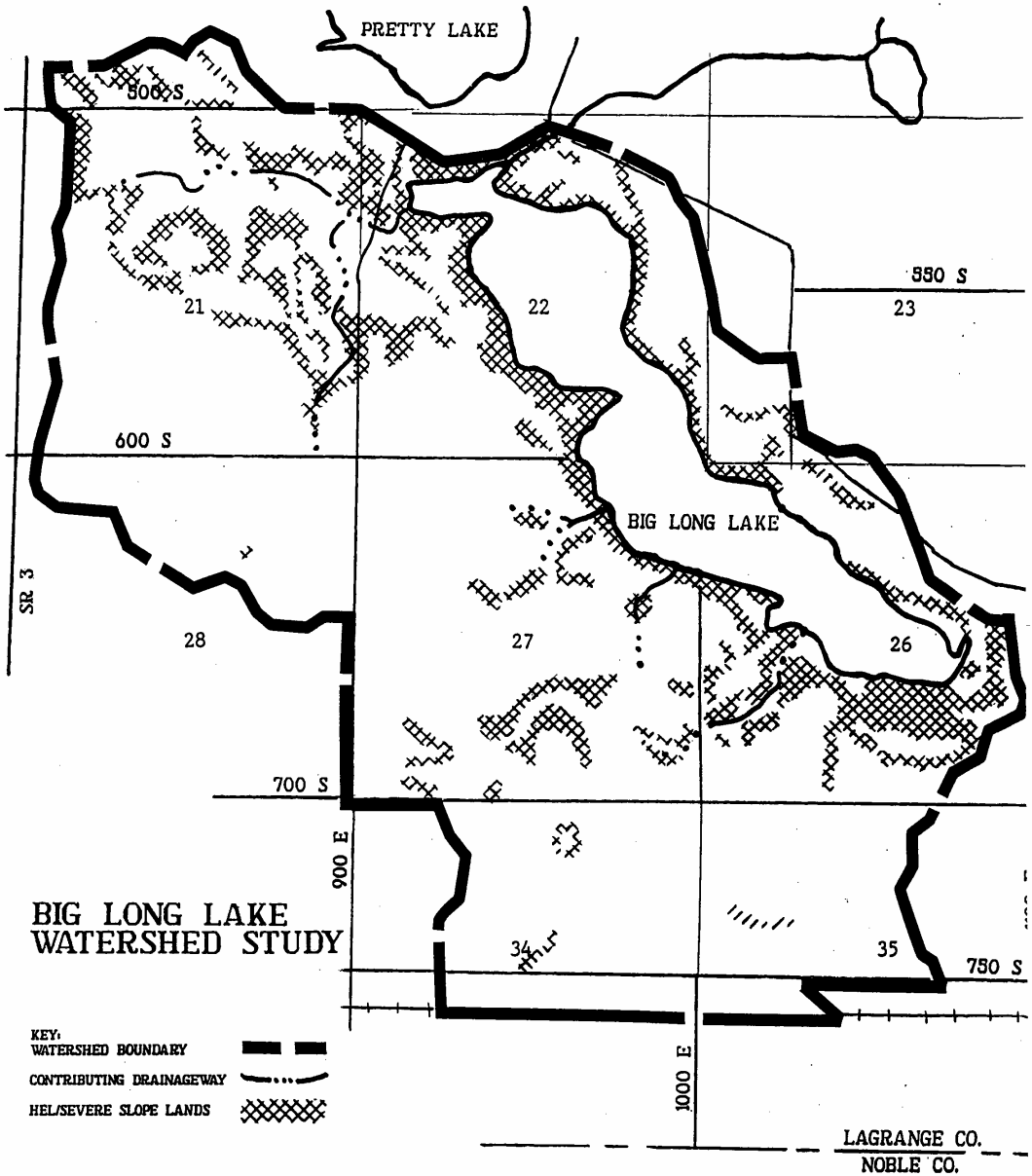
Highly Erodible Lands Overlays

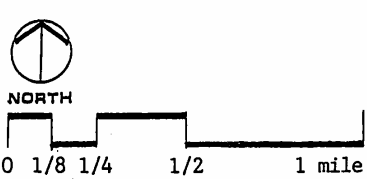
The intent of this HEL/Severe Slope Overlay (Figure B38) is to emphasize the areas of the watershed where severe erosion problems are likely to occur. The areas defined in the Agricultural Lands/HEL/Severe Slope Overlay (Figure B39) were in crop production as of 1987. The 159 acres, detailed in this overlay represent the worst case HEL areas of the Big Long watershed. Much of this land is adjacent to open drains or ditches which facilitate the transport of eroded soils to the Lake. For this reason, those areas present the greatest sedimentation threat to Big Long Lake. Every effort should be made to enlist those lands into CRP or related land treatment programs (grassed waterways, filter strips, sediment control basins, etc.). It must be noted that in the past year, 1989, several of these critical erosion areas have been enlisted into the Conservation Reserve Program or other special projects initiated by the SCS. This is a good start, but it is apparent from the HEL/severe slope overlay that the majority of the critical erosion areas of the watershed have not been fully addressed. These lands should not be in agricultural crop production with out properly implemented sediment control measures.

Erosion: Causes and Prevention

Erosion of soil is primarily caused by the force of raindrops striking the ground, and, secondly, by the force of water flowing in rills or channels. As rain falls on unprotected ground it breaks small particles of soil free. These soil particles are then carried away by sheets of water. Naturally, as the intensity of rainfall increases, velocity and volume (flow) of runoff increases, thus potential soil erosion increases. Types of soil erosion probable or noted in the Big Long watershed:

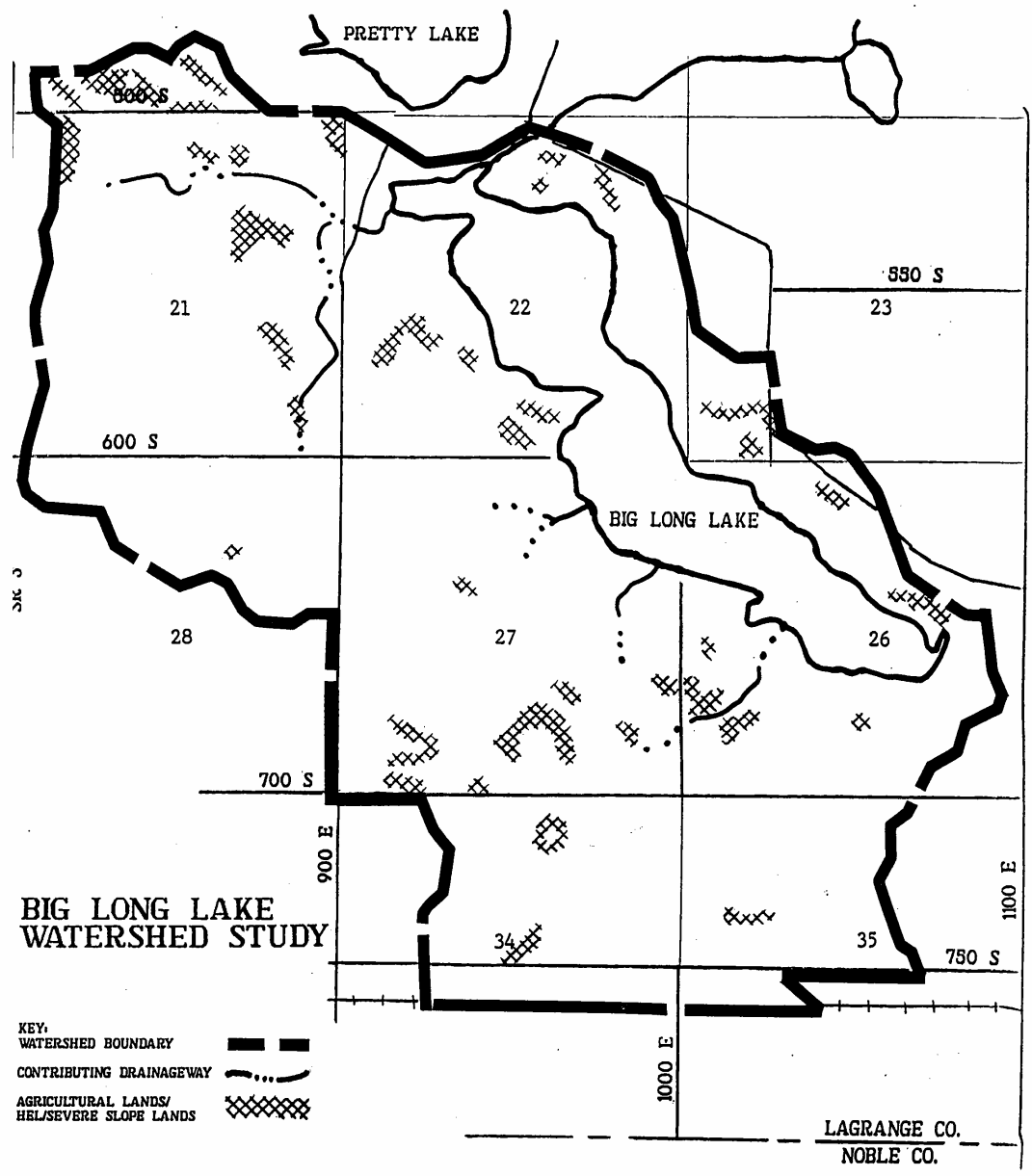
1. Raindrop (or splash) erosion due to the impact of rain on unprotected land.
2. Sheet erosion or overland flow causes exposed soil to be suspended by the action of the flowing water, this is common on sloping to nearly level unprotected land.
3. Rill and gully erosion is the result of concentrations of runoff water in riverlates. Rill erosion may cut several inches into the topsoil. Gully erosion, resulting from unmaintained rills or drainages, may cut several feet into the surface.
4. Streambank and channel erosion causes a scouring of stream bottom and undercutting of stream banks.
5. Wind erosion, similar to sheet erosion, is caused by the turbulent force of the wind over unprotected land.

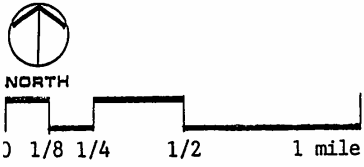




BL 78

HEL/SEVERE SLOPES OVERLAY
(Figure B-38)





BL 79

AGRICULTURAL LANDS/
HEL/SEVERE SLOPES
OVERLAY
(Figure B-39)

The erosion potential of a given area may be determined by four criteria: 1) soils; 2) surface cover; 3) topography; and 4) climate.

An understanding of soils, and the factors involved in making soil more susceptible to erosion include: soil texture, soil structure, soil content of clay or organic material, and soil permeability. Maintaining adequate surface cover, either in the form of vegetative cover or crop residue, is important in reducing soil loss.

The realization is that soil is a valuable resource, and particles are difficult and expensive to recover once erosion has begun. **Prevention is easier than correction!**

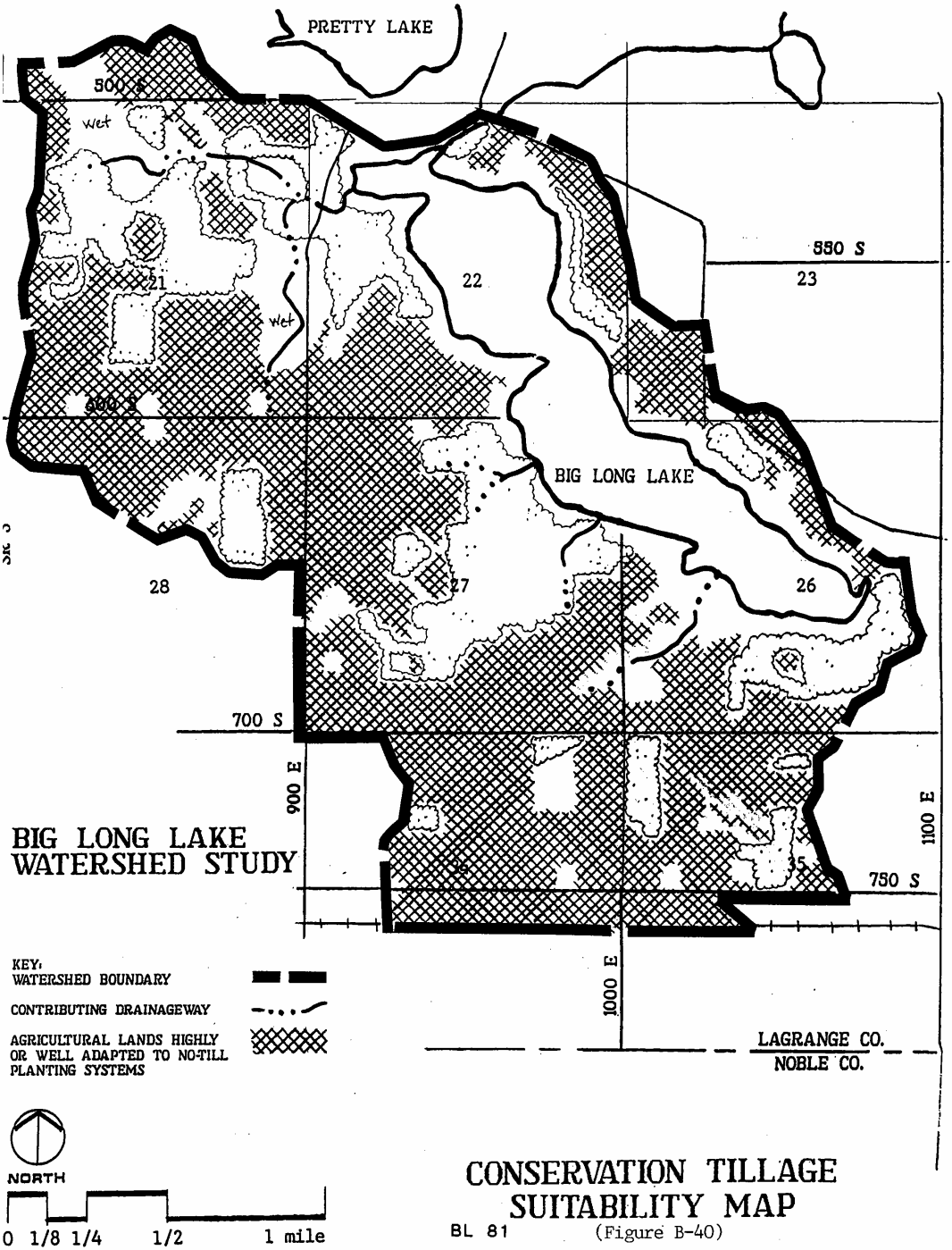
Useful concepts in erosion prevention and control:

a. Maintain natural vegetative cover wherever possible.
b. Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes.
   Row cropping should be done perpendicular to slope.
c. Divert runoff from severely sloping areas.
d. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.
e. Stabilize drainage areas immediately following any construction or "maintenance".
f. Leave natural buffer areas along streams and ditches.
g. Stabilize stream bank or ditch escarpments.
h. Utilize sediment ponds below feed lots and "open" sloping lands.
i. Construct and maintain sediment control structures prior to construction of any lake or waterfront development.
j. Implement applicable conservation tillage method.

Conservation Tillage

There are several methods of tillage currently utilized in corn and bean production: moldboard plow, chisel plow, large blade (deep) disc harrow, small blade (shallow) disc harrow, ridge-till, and no-till. Fall moldboard and chisel plowing are still frequently used by Indiana farmers, however, conservation tillage systems are becoming more widely excepted due to improved yields, and greater savings of soil, water, and money.

The no-till conservation tillage/planting system has been identified as one of the most effective conservation practice available to farmers in Indiana (AY-210). The Suitability for Conservation Tillage overlay (Figure B40) indicate 95% to 98% of the agricultural lands in the Big Long watershed are well to highly adapted to no-till conservation tillage systems. Agricultural lands depicted as unsuitable for no-till (3%) in the Big Long watershed include soils which are too wet or slopes greater than 12%. Lands in the Big Long watershed noted as unsuitable to no-till should be in permanent cover.



CONSERVATION TILLAGE SUITABILITY MAP

BL 81 (Figure B-40)

Development on Saturated Soils

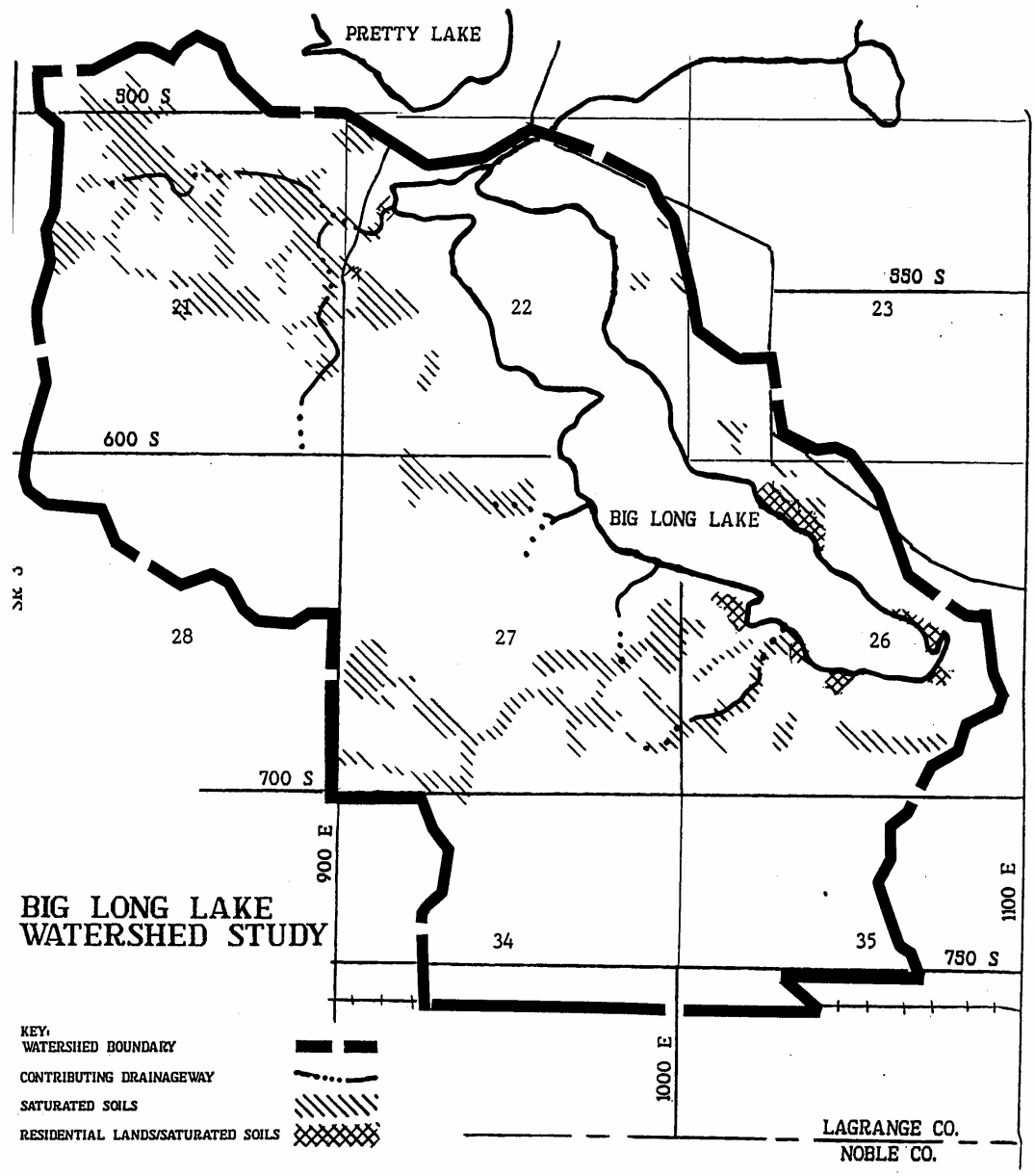
The goal of this study was to estimate potential septic system inefficiencies. Inadequate septic systems have been documented to contribute raw sewage (nutrients) to a lake (Grant 1988). Using data collected on saturated soils (Table B14) and comparing it with building records from 1959, projections were established indicating septic systems that were likely to be located in saturated soils (Figure B41). The assumption was made that septic tank-type systems are in place for those residences located on saturated soils. General septic system efficiencies are based on the need for well drained soils necessary for proper treatment of sewage effluent. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well drained soils. It should be noted that seasonal fluctuations in the water table of poorly drained soils were not taken into account. Varying water table elevations and waste loading would be responsible for fluctuations in treatment success. Localized fecal coliform values likely increased due to a substantial increase in the summer population around the lake and fluctuations in the water table as well as residences situated on steeply sloping areas or, watershed residences with septic systems that outlet directly into ditches.

The findings of this study (Figure B42), indicate a static trend in building on saturated soils. In 1959, on Big Long Lake, 6 of the 280 homes (2%) were located on saturated soils. Current building records for Big Long Lake at the time this study demonstrated a similar ratio: 17 of 850 homes (2%) were located on saturated soils. Review of the remaining developable lands around Big Long indicate future trends will greatly favor development on saturated soils.

Possible approaches to meet the future disposal needs with the objective of maintaining or improving water quality would include: 1) Lake-wide or County-wide sanitary sewer system, 2) mound type septic systems and/or 3) pumping to suitable septic/drain field locations and 4) any of the above in combination with a constructed wetland or pond/wet meadow system. The cluster system currently used by residents of the Timberhurst area is an excellent method of waste treatment.

Although treatment is certainly not limited to the management approaches discussed above, it was determined that these methods of waste treatment would effectively meet the goals of sewage disposal.

Residences must take on the responsibility of maintaining their own waste disposal systems. Drain fields must be inspected regularly and septic tanks must be pumped on a regular schedule.



BL 83

SATURATED SOILS/
RESIDENTIAL LANDS
OVERLAY
(Figure B-41)

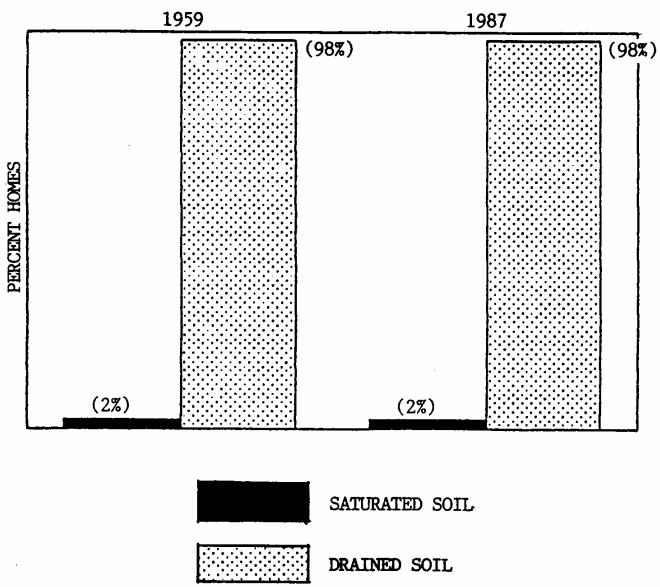
Further study is recommended for those residential areas noted in the Saturated Soils/Residential Lands Overlay, as well as lake homes situated in steeply sloping areas. A study could be developed utilizing a septic leachate detector or preferably, septic dye test.

If it is determined that an engineering study should be undertaken for a new wastewater treatment system, the method and site selection should consider tertiary treatment using a constructed wetland system.

Table B14. **Poorly drained soils of the Big Long Area.** Adapted from USDA-SCS Indiana Technical Guide, 1988.

CONOVER loam
HOUGHTON muck, ponded
RENSSELAER loam
UDORTHENTS loamy
WALLKILL silt loam

Figure B42. **Profiles of Residences Located on Saturated Soils; Trends based on 1959/1987 building records.**



Hydrology

The Big Long watershed is a sub-drainage basin to the Lake Michigan Basin. The main water supply comes from ground water stored in the sand and gravel deposits of the Wisconsin till aquifer. According to the LaGrange County Soil Survey, the watershed of Big Long receives an average annual precipitation of 32.9 inches with a standard deviation of 6.7 inches. July tends to be the wettest month with an average precipitation of 3.8 inches. On average, February is the driest month with a precipitation mean of 1.6 inches. The greatest basin drainage gradient is 60.3 foot/mile occurring in the southwest quarter of the watershed. According to the 1979 Cowardin et al classification system, water regimes range from temporary to semi-permanent. Fifty-six percent of the wetlands located in the Big Long watershed are of seasonal water regimes. Ninety-eight percent are small, less than ten acre, palustrine wetlands (Table B15). Palustrine wetlands are defined here as wetlands less than 20 acres in size, averaging less than 6 foot in depth, and dominated by trees, shrubs, and/or emergent vegetation (Mitsch and Gosselink, 1986).

It is estimated that 71% of the wetlands in the Lake Michigan Basin have been lost (Hamilton 1965). Losses are primarily attributed to drainage for agricultural production. The following table is intended to illustrate the types of wetlands remaining in the Big Long watershed, and focus attention on preserving these natural filters.

Table B15. **Big Long watershed water regime characteristics**

Palustrine	Occurrence	%Totals
Less Than 10 Acres	134	98
More Than 10 Acres	3	2
Totals	137	100
Cover-Type		
Emergent	86	63
Forest	33	24
Scrub/Shrub	18	13
Totals	137	100
Water Regime		
Temporary	1	1
Saturated	3	2
Seasonal	77	56
Semi-permanent	5	4
Unknown	51	37
Totals	7	100

Computer Modelling: Hydrology

The focus of the study, a computer model using SEDIMOT-II, (Warner, 1983) was used to project storm runoff, and hydrographs for 5, 25, and 100 year storm events. Data used for the computer model was derived in part from the land use study. Cover types for each segment of the subwatershed were assessed using color infrared aerial photographs, soil input was supplied by the USDA-Soil Conservation Service, and slope segments were determined using information from the US Geological Survey. Results of this study were used to predict sediment removal ability of proposed control structures located on the 'northwest ditch', and 'southwest ditch' near Big Long Lake using the Surface Loading Rate formula (SLR), (Barfield 1987).

The hydrology modeling techniques used in the SEDIMOT-II program are divided into two major areas:

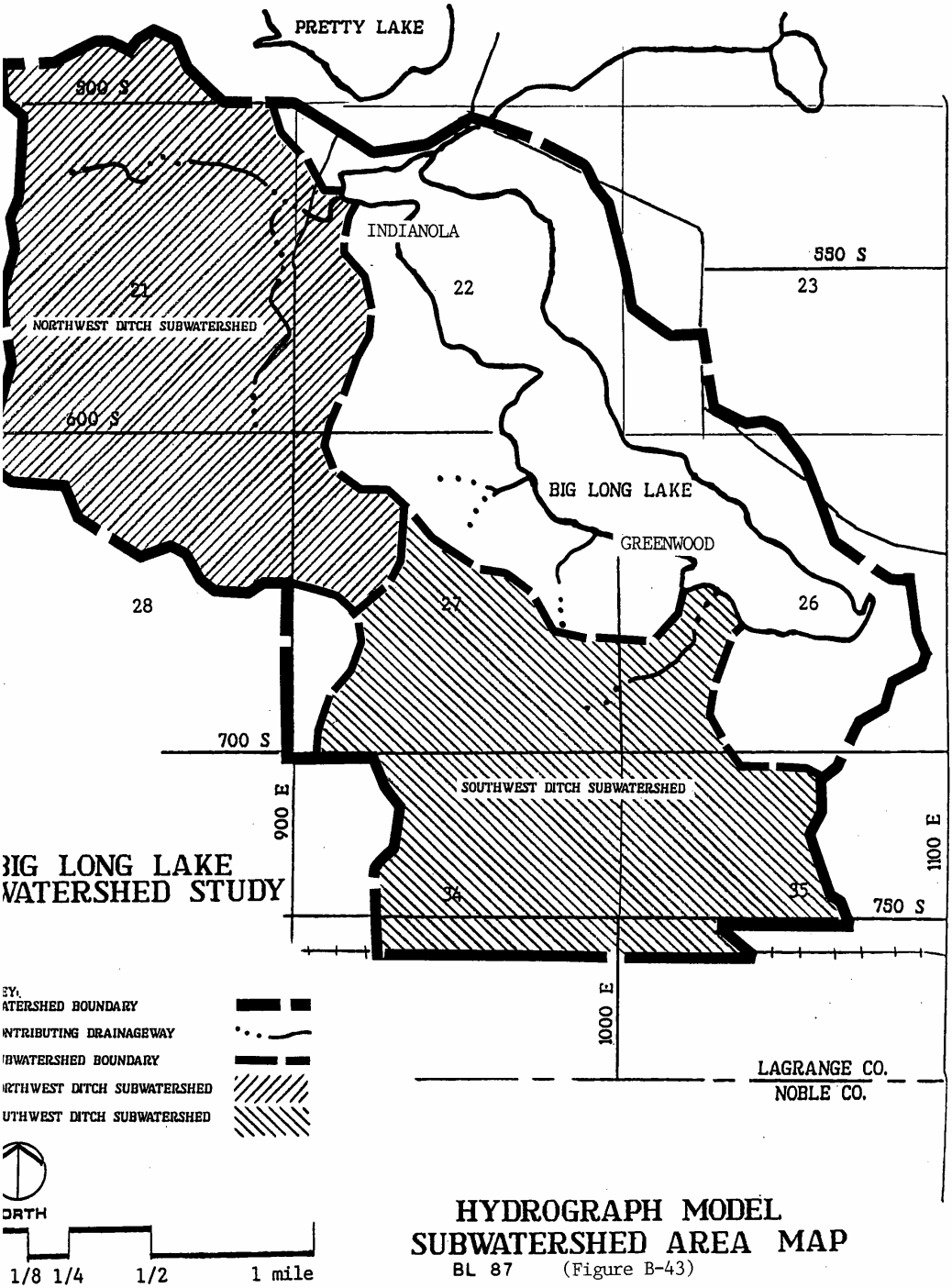
1) Rainfall Component. The rainfall component uses a given rainfall depth for a specific storm event, converted into a temporal storm pattern (storm duration over a given geographical area and time) because a large portion of the rainfall may occur over a small period of time with fluctuations in intensity.

2) Runoff Component. The runoff component determines the depth of rainfall in 0.1 hour increments given a 24 hour storm event (TR-55, 1986). The runoff is distributed over a period of time according to predicted rainfall. The runoff component is then used to determine hydrographs (watershed runoff over time) at specific locations throughout the watershed.

Factors involved in SEDIMOT-II include: storm type, event type, in this case runs were made using rainfall depths from a 2 year, 25 year, and 100 year storm events, soil types, vegetative cover types, basin relief, drainage area, and length of drainage segment. A summary of hydrology input data and SLR formula is presented in Appendix E.

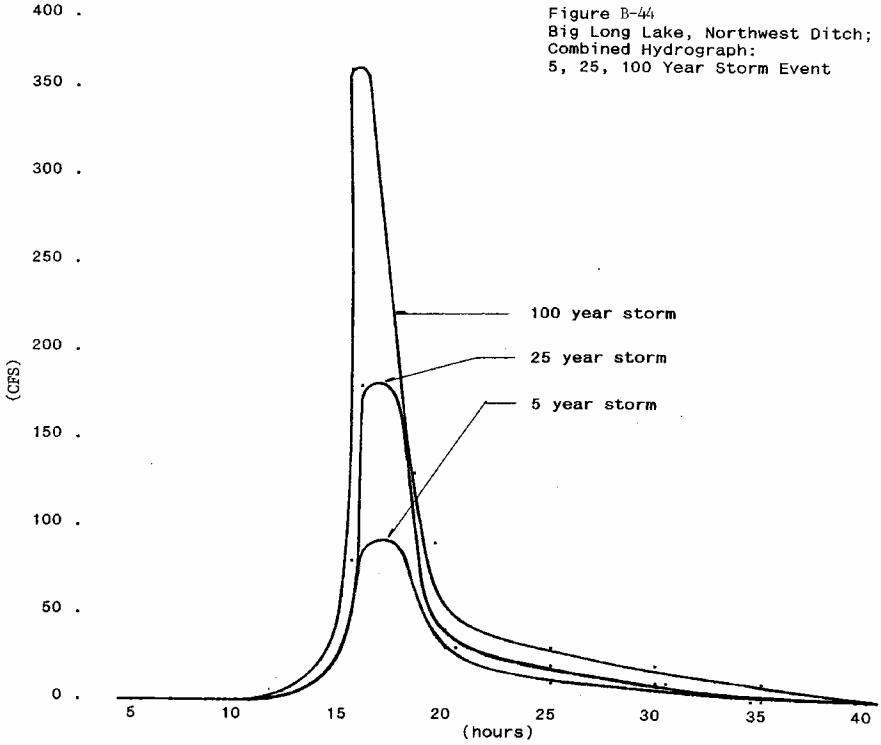
Northwest Ditch

The northwest ditch flows into Big Long Lake just north of the Indianola Division (Figure B43). The northwest ditch drains the largest single land area of the Big Long watershed, about 970 acres. The residents of Big Long Lake often point to the northwest ditch as the source of 'brown' water which often clouds the north basin of the Lake. For this reason, the northwest ditch subwatershed was targeted for an indepth study of hydrology. Hydrographs for the northwest ditch are presented in Figure B44. Additional data are presented in the Northwest Ditch Subwatershed Summary, Table B16.



HYDROGRAPH MODEL
SUBWATERSHED AREA MAP
BL 87 (Figure B-43)

Figure B-44
Big Long Lake, Northwest Ditch;
Combined Hydrograph:
5, 25, 100 Year Storm Event



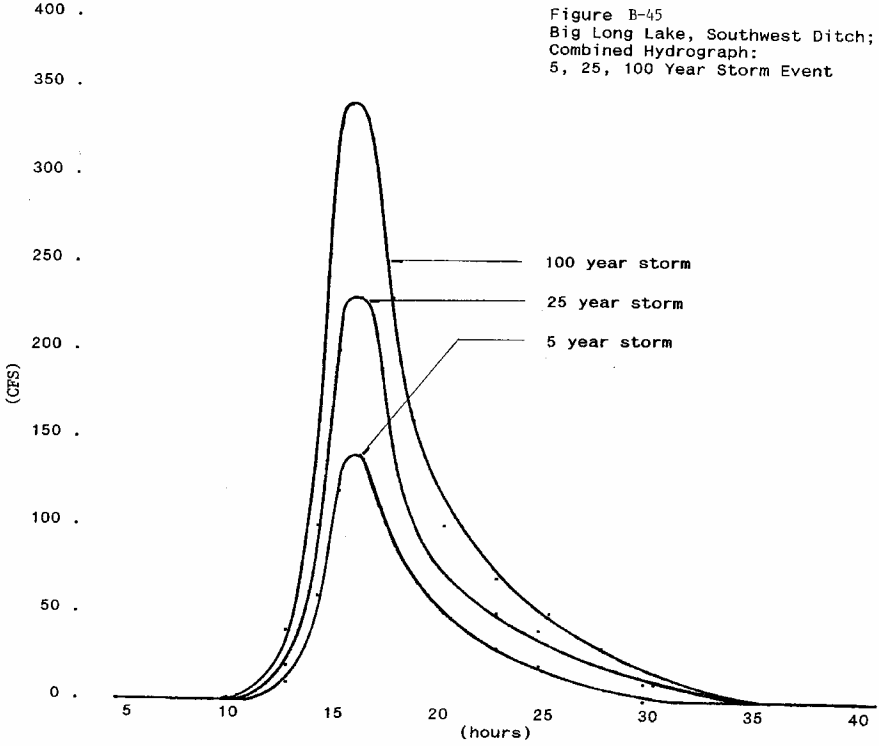
NORTHWEST DITCH SUBWATERSHED SUMMARY	
Drainage Area	971.00 acres
Runoff Volume:	
5 Year Storm	69.29 acre-feet
25 Year Storm	114.54 acre-feet
100 Year Storm	165.82 acre-feet
Peak Inflow Rate (from Hydrograph):	
5 Year Storm	169.71 cfs
25 Year Storm	276.47 cfs
100 Year Storm	393.28 cfs
Mean Flow Rate (from Hydrograph):	
5 Year Storm	26.62 cfs
25 Year Storm	34.13 cfs
100 Year Storm	37.55 cfs
Pool Capacity	30.30 acre-feet
Detention Time of Flow:	
5 Year Storm	13.77 hours
25 Year Storm	10.74 hours
100 Year Storm	9.76 hours

Table B16. Northwest Ditch Subwatershed Summary

Southwest Ditch

The Southwest ditch flows into Big Long Lake just south of the Greenwood Division (Figure B43). The southwest ditch drains the second largest single land area of the Big Long watershed, about 900 acres. Stream sampling for Big Long Lake, 18 January 1990, showed the southwest ditch to have the highest total suspended solids and nutrients (mg/l) of those sampled. The high sediment and nutrient load may in part be attributed to the recent (1989) cleaning of an upper section of the ditch. The southwest ditch subwatershed was targeted for an indepth study of hydrology. Hydrographs for the southwest ditch are presented in Figure B45. Additional data are presented in the Southwest Ditch Subwatershed Summary, Table B17.

Figure B-45
Big Long Lake, Southwest Ditch;
Combined Hydrograph:
5, 25, 100 Year Storm Event



SOUTHWEST DITCH SUBWATERSHED SUMMARY	
Drainage Area	900.00 acres
Inflow Runoff Volume:	
5 Year Storm	70.57 acre-feet
25 Year Storm	117.14 acre-feet
100 Year Storm	169.44 acre-feet
Peak Inflow Rate:	
5 Year Storm	138.55 cfs
25 Year Storm	236.40 cfs
100 Year Storm	343.56 cfs
Mean Flow Rate:	
5 Year Storm	38.62 cfs
25 Year Storm	52.42 cfs
100 Year Storm	67.70 cfs
Pool Capacity	17.22 acre-feet
Detention Time of Flow:	
5 Year Storm	5.39 hours
25 Year Storm	3.97 hours
100 Year Storm	3.08 hours

Table B17. Southwest Ditch Subwatershed Summary

Sediment and Nutrient Removal

In order to quantify the effectiveness of a control structure or constructed/enhanced wetland in removing sediments and nutrients, it is first necessary to develop a concept design for the site. Using the conceptual designs presented later in this report, a flow model was developed. Flow models are used to determine a particular hydraulic characteristic for a given site at a given point in time. In this case, flow models are used to determine the surface loading rate (SLR). The SLR is used to derive the position of a particle (sediment) with a given diameter, within a system at any given point. With this information, a settling velocity can be predicted for particles entering a system based on particle size, distance and time. The predicted sediment removed is determined by the size of particles equal or larger to that of the design settling velocity.

Nutrients are removed from a system in two basic ways: 1) by biotic processes in which they are utilized by plants and bacteria or; 2) by physical processes. Nutrients often travel through a system bonded to particulate matter, thus, as sediments are settled out, so are the nutrients attached to them. Sedimentation is the settling out of soil particles which have been transported by air or water. Sedimentation occurs when the velocity of the transport medium **(water)** is slowed adequately and for a sufficient period of time (detention time) to allow for the soil particles to settle out. Larger, heavier particles require high velocities of runoff to be transported and are quick to settle out. Smaller, lighter soil particles are transported by suspension or by moving (tumbling) along the surface. Fine silts and clay materials are generally transported in suspension. These smaller soil particles are difficult to recover once eroded. Substantially lower velocities and greater detention times are required to settle these particles out.

Specific site design would be necessary to predict the actual amounts of sediments and nutrients transported through a system or to quantify the amount removed by a specific control structure. It is possible, however, to relate sediment removal efficiencies using the SLR, with data from the concept plan and mean flow reported for the 5 year return storm. Findings of this model indicate that sediment equal to, or greater than 0.006 mm (fine silt) will settle out of the system in both the northwest ditch and the southwest ditch constructed options. Particle size based on a mean specific gravity of 2.65.

Results from the Wilson Ditch constructed wetland site (near Culver, Indiana), designed by **Earth Source Inc.**, showed mean total phosphorous was reduced 90%, while mean total nitrogen (nitrate/nitrite) was reduced 85% during the 1988 summer monitoring program. Mean total phosphorous was reduced 60% and mean total nitrogen was reduced 65% during the 1988 winter monitoring program.

Constructed Wetland Habitat

Potential exists for the construction of sediment/nutrient control structures to increase the overall wildlife habitat and production capabilities for the Big Long area.

Primary fisheries production in Big Long Lake could benefit greatly by increased wetlands. Virtually all sport fish production is dependent on wetlands, either for spawning, cover or planktonic food production. Pike and sunfishes are major benefactors of increased wetland spawning area. They spawn in the wetlands and then return to the lake proper.

Increased wetlands will draw waterfowl away from areas of moderate human use. Productivity is likely to increase while the "nuisance factor" decreases. Song birds are drawn to wetlands for a number of reasons: nesting structure provided by persistent emergent vegetation (cattails); security cover; and food production. Species such as the Great Blue Heron, Yellow Rail, Great White Egret, and Yellow-headed Blackbird (which are all state threatened, rare or of special concern) will locate near wetlands for many of the same reasons as their avian counter parts.

Fur-bearing animals like beaver, mink and muskrat depend on wetlands primarily for food, security cover and den sizes.

Muskrats will likely be the first fur-bearer to colonize a shallow constructed wetland. These prolific mammals do well in areas which have low water flow and emergent aquatic vegetation such as cattails. If muskrat den/foraging activity strays from or damages the constructed wetland and wetland structures it may become a nuisance, therefore, populations will require careful monitoring and controlled.

The mink is one of the most prized furbearers associated with wetlands. The habitat requirements of the mink are similar to those of the muskrat with one exception, the mink is a carnivore. Thus, mink population will usually mirror changes in muskrat population.

The beaver is another valued furbearer likely to colonize a constructed wetland in the Big Long area. Again, if den/dam building activity strays from the constructed wetland it may become a nuisance, therefore, beaver populations will also require careful monitoring.

In summary, a constructed wetland is capable of increasing and supporting a diverse number of habitants. It should be noted that a constructed wetland is also constructed habitat. By design, these areas may attract species of special interest, through planned inclusions of required habitat components.

Constructed Wetlands as a Watershed Management Practice

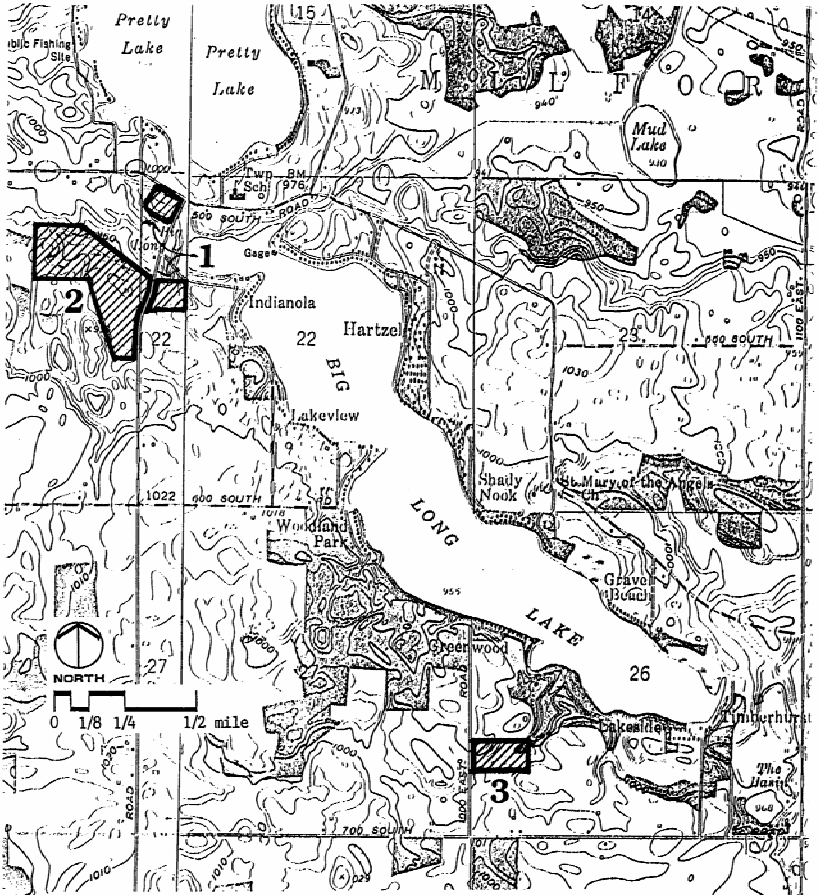
For more than 50 years, wetlands have been identified as water purifying systems for natural lakes (van der Valk, et al 1978). Wetland vegetation, benthic organisms, and soils perform as traps, at least seasonally, for nutrients, suspended sediments, metals, pathogens, and many agricultural chemicals (Kadlec and Kadlec 1978). Thus, during the course of the Big Long watershed study, a primary objective was to identify opportunities for nutrient/sediment trap target sites on contributing ditches and tiles identified as loading excessive nutrtients and sediments to the lake (Figure B46). The primary criteria in selecting these sites were: location, topography, flow rates, soils, feasibility, current land use, size, environmental concerns, and sediment/nutrient loading characteristics of the drainage basin. As each site is considered for development, an evaluation should be made of the status of erosion control/land treatment above each proposed site, and goals set for timetables, land acquisition, fund raising, final design and construction.

Each site is described in the following text with a conceptual plan for illustration. Cost range estimates and priority recommendations are discussed in later sections of this report.

Project Descriptions: Big Long Lake

Northwest Ditch - Constructed Option 1.

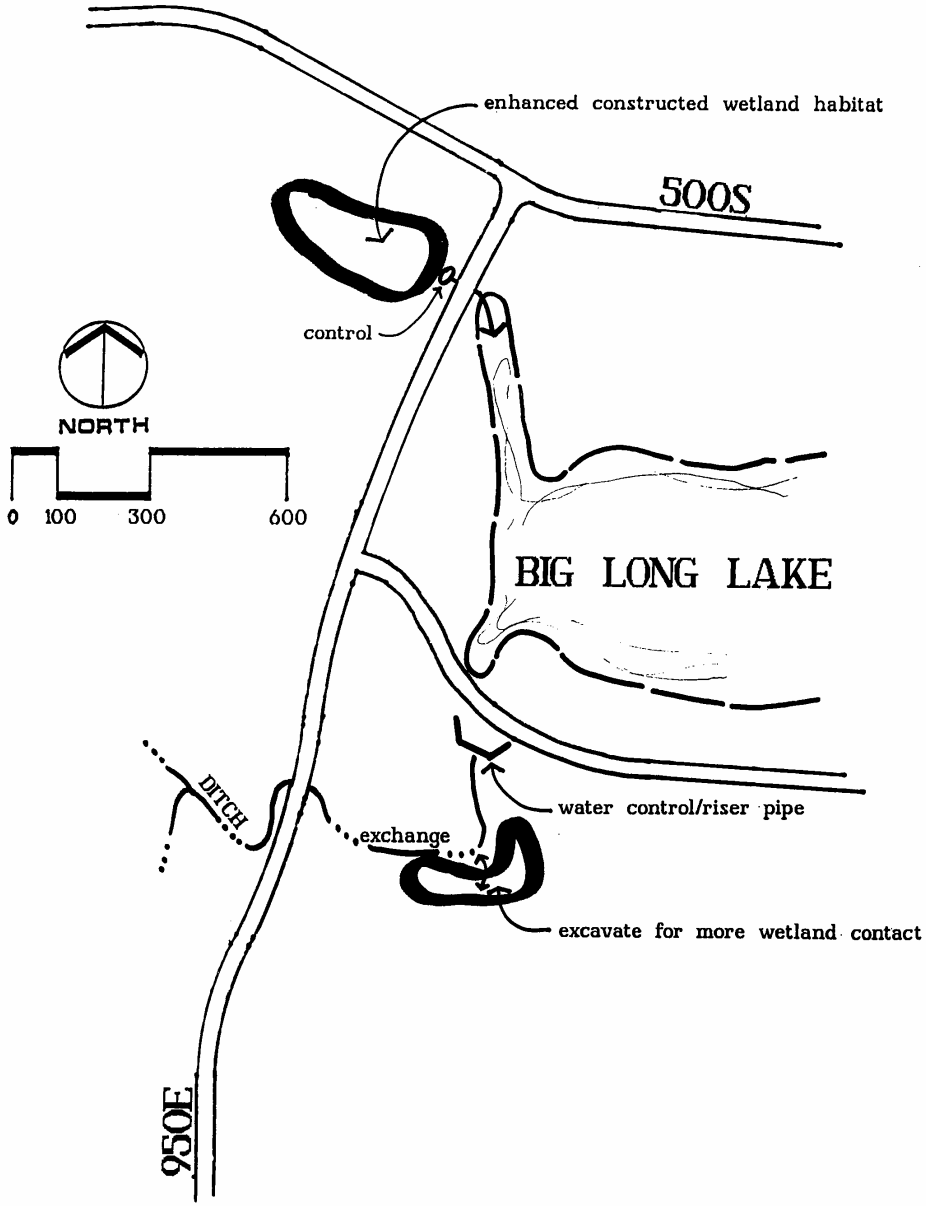
Two project sites at the northwest end of Big Long Lake are illustrated with this option, Figure B47. The important ditch inflowing from the south was examined for constructed wetland opportunities. Several nearby upstream properties have been improved in recent years at grades close to the stream flow. In order to construct a nutrient/sediment trapping system on this ditch segment, it was determined that some excavation and enhancement of an existing wetland near the inlet was the best approach. The concept indicates shallow excavation of a portion of this site to increase the stream contact with the wetland. Some flow abatements would likely be a part of final design. In addition, the large culvert under the road at the inlet would have an extension with a water control feature. This option should be considered in tandem with Constructed Option 2. The wetland near the southeast intersection of 500S and 900E intercepts a small, but highly erodible, subwatershed. This is a wetland enhancement/ restoration opportunity that could be easily accomplished with minor earthwork and a control structure, but may also include more comprehensive enhancement which would increase wildlife habitat and native plant diversity.



Constructed Options Location Map

BIG LONG LAKE (Figure B-46)

Earth·Source Inc



Constructed Option 1

Northwest Ditch
BIG LONG LAKE

(Figure B-47)

Earth·Source Inc

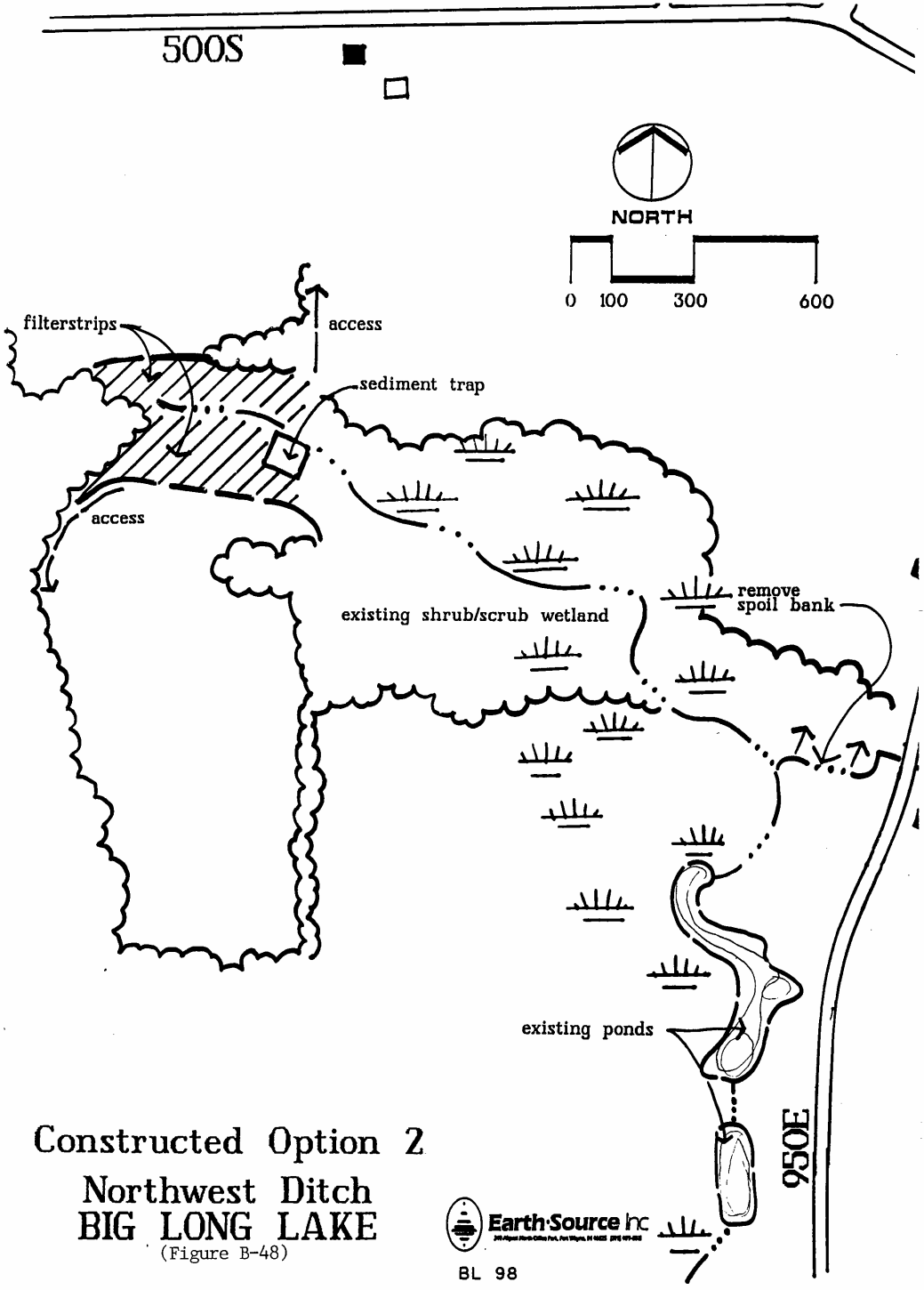
Northwest Ditch - Constructed Option 2.

This illustration (Figure B48), includes several suggestions that will protect and improve the existing (channelized) shrub/scrub wetland's ability to remove sediments and nutrients.

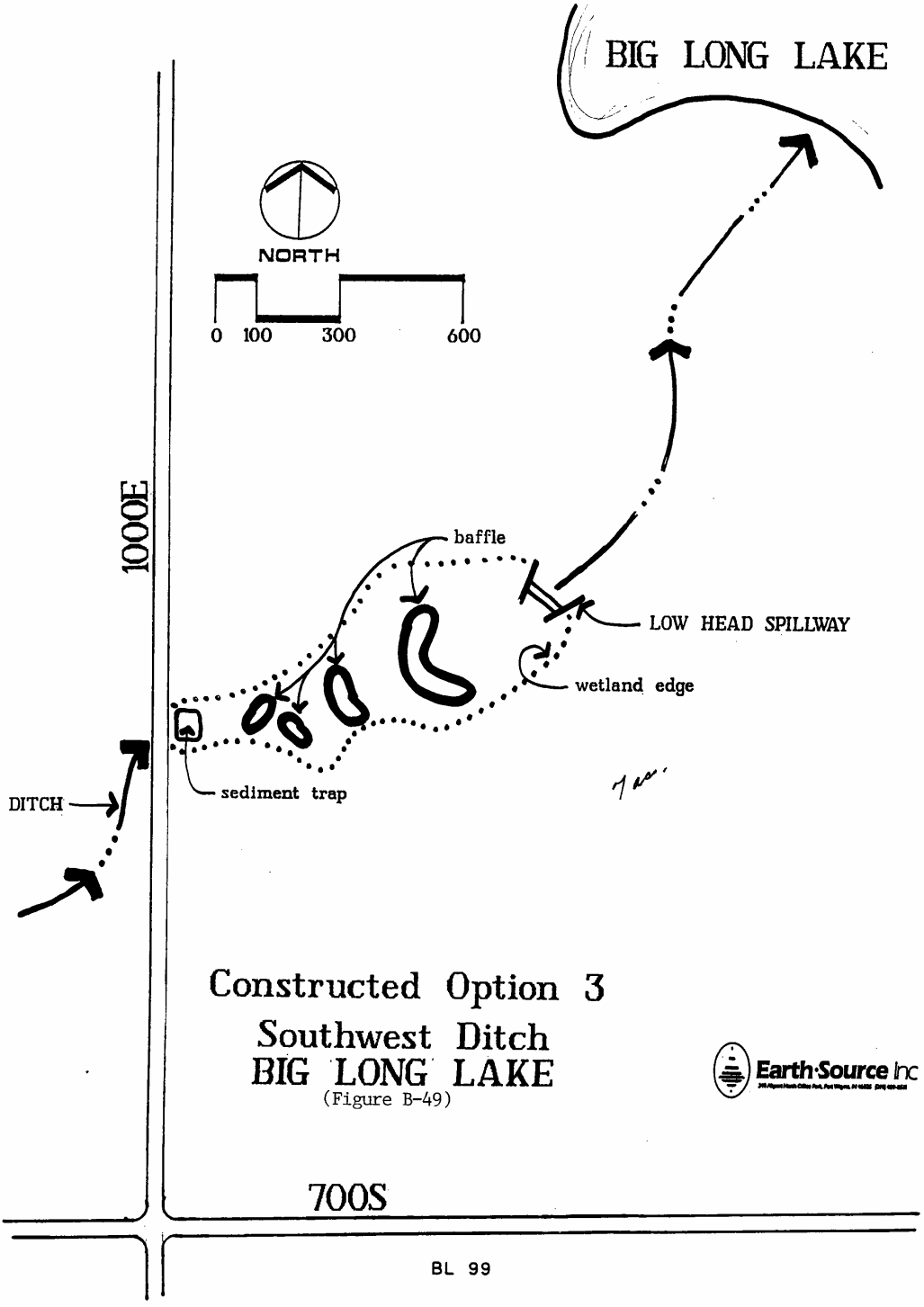
Starting nearest 950E: The existing ditch is channelized along the edge of the wetland with a spoil bank on the wetland side. Removal of the spoil bank would increase detention time and contact with the existing wetland. Continuing northwest to above the wetland, a sediment trap is suggested to intercept flow from the erodible upland above. The cropland on each side of this drainageway is recommended for broad filterstrips of permanent cover which will stabilize edge as well.

Southwest Ditch - Constructed Option 3.

This site, located on the east side of 1000E, intercepts significant areas of naturally erodible and agricultural lands (Figure B49). This is a very important site because of its ability to control an important source of nutrients and sediments to the lower end of Big Long Lake and also moderate stream velocities downstream, thus reducing streambank erosion thorough the forested area. The concept illustrates a low head spillway, diversion baffles (or islands), and an upstream sediment trap. Approximately 7 acres would be within the new constructed wetland edge. Among many other benefits, excellent wildlife habitat potential would result.



Constructed Option 2
Northwest Ditch
BIG LONG LAKE
(Figure B-48)



Constructed Option 3
Southwest Ditch
BIG LONG LAKE
(Figure B-49)

Cost Estimates for Constructed Options

The following estimates are offered to represent the anticipated cost factors for construction of suggested sites. For final design and construction documents, an allowance of 15% to 20% of construction cost should be added to these estimates. Additional cost of services should be added for bidding, construction monitoring and construction administration if required by the funding agencies. Other additional cost items not included in these estimates are as follows: 1. Land cost (if any); 2. Attorney's fees to prepare land agreements; 3. Property line surveys or descriptions; 4. Preparation of permits such as to the Department of the Army, IDNR Division of Water, County Drainage Boards, Indiana Department of Environmental Management; 5. Operation and maintenance of sites and access thereto.

Priority recommendations (Very High (1), High (2), Moderate (3), etc.) have been made based upon the need, feasibility, accessibility of the site, and other considerations discussed in previous sections. The Lake Association should not be discouraged from pursuing and implementing lower priority constructed options, while higher priority sites are under consideration or in process.

Northwest Ditch - Constructed Option 1.

Cost items include excavation; soil fill; water control outlet structure; rock; fabric, and erosion control materials; and sediment trap.

Estimated Cost Range: $24,000 - 32,000

Priority Recommendation: High (2)

Enhanced Wetland

Cost items include minor control structure, optional excavation/earthwork for increased detention time and enhancement of wetland habitat.

Estimated Cost Range: $5,000 - 10,000.

Priority Recommendation: Moderate to High (4)

Constructed Option 2.

Cost items include minor clearing, excavation, restoration, spreading soils, and disposal of excess materials for spoil bank removal, sediment trap excavation, and filter strips.

Estimated Cost Range: $7,000 - 10,000

Priority Recommendation: High (3)

Southwest Ditch - Constructed Option 3.

Cost items include sediment trap, baffles/islands, clearing, excavation, control structure/embankment, restoration, and erosion control materials.

Estimated Cost Range: $75,000 - 125,000

Priority Recommendation: Very High (1)

Permitting

Beyond property ownership, many governmental agencies may have jurisdiction over private property. For example, drainage may be regulated by the County Surveyor. Water issues, particularly construction in a floodway, is regulated by the Indiana Department of Natural Resources Division of Water, and the United States Department of the Army, Corps of Engineers. Excavation below legal lake level, 955.0 foot, mean sea level datum, or any ditch modification within 0.5 miles of the Lake, will require authorization by the IDNR, Division of Water, Lake Section. The Corps of Engineers will require permitting and Water Quality Certification by the IDEM, Office of Water Management for construction in wetland areas. The Corps of Engineers (and the Divisions of Water) may require permitting if any construction impounds water. A list of different agency contacts, addresses, and telephone numbers may be found in appendix B.

Conclusions & Recommendations

Conclusions and Recommendations

BIG LONG LAKE

Water Quality

Water quality trends for open water stations of Big Long Lake were delineated from individual physical-chemical and biological parameters. The composition of the midsummer phytoplankton assemblage during 1989 resembled that of 1930 with blue-green algae sharing dominance with dinoflagellates. The lake has been characterized by extensive anoxia in the lower water column during summer since at least 1930. Total phosphorus is the only standard physical-chemical parameter used to define trophic state that suggests decreased water quality since the early 1970's. The 3-4 fold increase in this parameter between 1973 and 1989 should be interpreted cautiously because of the scant temporal database and the fact that the IDEM eutrophication indices calculated separately for two investigations during 1989 suggest an improvement of water quality in Big Long Lake from Class Two (intermediate water quality) in 1973 to Class One (best water quality) in 1989. As the eutrophication index is calculated from parameters collected in open water, recent expansion in littoral macrophytes may have increased the trapping efficiency of phosphorus by the littoral zone resulting in an index falsely indicating declining productivity in the lake ecosystem. Finally, in addition to declining growth rates and species compositional shifts that DNR feels suggest a reduction in the quality of the fishery since at least 1975, the apparent extirpation of the cisco, a fish intolerant of depleted oxygen in the water column, during the early 1970's likely results from a reduction in water quality.

The vegetated littoral zone appears to have increased progressively in its luxuriance and possibly areal extent since at least 1975. Although the DNR reported expansion of macrophytes between 1975 and 1984, only recently have they been considered a serious enough management problem to necessitate a chemical control program funded by lake residents. It is likely that many of the inconsistencies noted in the trends of individual water quality parameters discussed above may be directly related to a recent expansion of the littoral zone thereby increasing its role as a trap for nutrients. It is suggested that water quality has not improved at Big Long Lake, rather the productivity base has merely shifted towards macrophytes rather than algae.

While both septic and stream drainage have contributed to the eutrophication of Big Long Lake, the latter is likely of greater overall magnitude. It is recommended that residents make a concerted effort to have their drain fields inspected regularly and to keep their septic tanks pumped.

Residents can reduce nutrient loading to the lake by using phosphate-free detergents for both clothes and dishes. Simple irrigation of lawns using lake water will provide sufficient nutrients to sustain lawn growth. Such simple modification of practices can reduce the contribution each resident makes to the phosphorus and nitrogen loading of the lake.

Water quality improvement in Big Long Lake must address both watershed and in-lake management issues. Implementation of in-lake management practices may provide short term relief from near shore macrophyte problems and other manifestations of eutrophication but will not provide a long term solution without addressing nutrient and sediment inputs to the lake from the watershed. It is suggested that no long term in-lake management solutions be implemented until nutrient and sediment loading from the watershed is reduced dramatically.

Macrophytes

Although the extent and richness of the vegetated littoral zone appears to have increased progressively since at least 1975, macrophytes were not considered serious enough of a problem to warrant a chemical control program until the late 1980's. Macrophytes appear to be confined mostly to water less than 10-15 feet deep in Big Long Lake. Assuming that macrophyte problems are manifested only when plant biovolume exceeds approximately 80% of the water column, only 17% of the surface area of Big Long Lake would be classified as having management problems with macrophytes. A majority of this area is concentrated at the north and south ends of the lake near ditch and stream entry points. Approximately 53% of the lake's bottom is considered entirely free of vegetation with an additional 40% having plant biovolume occupying between 40% and 60% of the water column. Most of the plant biovolume is in water less than four feet deep and is contributed primarily by milfoil (Myriophyllum). Most stands of macrophytes are less than two feet tall.

A number of techniques can be implemented to control problem macrophytes (Crisman 1986, Moore and Thornton 1988). Excessive growth can be cut mechanically and removed from the lake. Although some nutrients can be removed from the lake, this is no permanent solution because roots and seeds are left intact, and finding a suitable site for disposal of the cut material is often difficult. Residents could continue the chemical control program as in previous years. This is merely a stop gap measure that can do more harm than good. Nutrients released from decaying vegetation enter the water column and can promote phytoplankton blooms. Numerous cases exist of excessive chemical treatment that shifts lakes to algal dominance and a whole new range of management problems (Crisman 1987).

Any weed control at Big Long Lake must be approached cautiously. The best way to insure that algal problems do not follow macrophyte problems is to avoid overly zealous complete control of macrophytes in the lake. Although extensive macrophyte growth is rather aerially restricted in the lake, it is greatest near the mouths of ditches and tiles. Excessive removal of macrophytes from such areas could reduce the kidney effect offered by the vegetated littoral zone and speed the delivery of nutrients to open water areas possibly promoting enhancement of phytoplankton populations.

Fish

Although only two detailed surveys have been conducted, the DNR felt that the quality of the fishery in Big Long Lake declined between 1975 and 1984. During the period, yellow perch increased in abundance, bluegill decreased, and the growth rates of most species declined. Perhaps the most significant fishery change observed in the lake has been the loss of ciscos, a fish requiring cold well oxygenated waters, during the 1970's. Ciscos were rare in the lake as early as 1955, rare or absent by 1972, and considered extirpated by 1975. While never a recreationally important species in the lake, the progressive loss of ciscos clearly indicates that eutrophication of Big Long Lake has been accelerating during the past two decades.

A majority of the fish in Big Long Lake are restricted to water depths of 3-5 feet during midsummer due to serious oxygen depletion in deeper waters. It is likely that attempts at fishery management will be only marginally successful until nutrient loading to the lake is reduced significantly. It is recommended that lake residents encourage the State of Indiana to provide additional funding support for periodic survey of the fish community of the lake by the DNR.

Basin Infilling

Big Long Lake has experienced moderate basin infilling during the past 64 years. The depth contours displaying the greatest incremental increase during the period were 0-5 feet and 5-10 feet, which increased in aerial extent by 3% and 21%, respectively. On a lake wide basis, greatest basin infilling was observed at the north end between the major inlet and the lake outlet and in the south end offshore from the mouths of two major ditch systems. It appears that such sedimentation has not been accompanied by a change in the relative proportion of inorganic and organic matter in the sediment. It is obvious that a majority of the sedimentation in Big Long Lake is directly related to ditch input of watershed sediment especially during spring rain events. We were able to find no evidence to suggest that shoreline

erosion was a major factor in observed patterns of sedimentation in Big Long Lake. Homeowners, however, should inspect their shoreline for evidence of erosion, be encouraged to leave a fringe of emergent vegetation along the entire length of their lake front to serve as an erosion barrier and make appropriate repairs immediately. Boaters should be encouraged to reduce speed when near shore in order to minimize wave generation and subsequent erosion of shoreline areas.

It is recommended that in addition to watershed management practices discussed later, aquatic plants at the mouths of ditches should be left intact as a nutrient and sedimentation barrier. Removal of such plant growth will speed delivery of both parameters into the lake thus accelerating both basin infilling and eutrophication.

BIG LONG WATERSHED

It is apparent that nutrient and sediment loading from the Big Long watershed is the present cause of cultural eutrophication in Big Long Lake. It is also apparent that the lake has met the increased availability of nutrients by the expansion of shoreline submergent macrophytes and increased frequency of algal blooms. While land treatment has been initiated in several areas of the watershed, substantial measures in watershed protection remain. Considerable watershed loading could be prevented by simply implementing conservation tillage programs in applicable areas. Additional consideration to sediment control must be placed on future ditch cleaning and drainage projects in the watershed. Furthermore, local government and lake residents bear the responsibility of controlling the fashion in which continued development pressure impacts the lake. Existing 'homes' must be modernized to include adequate septic disposal, new development must include an adequate erosion control plan.

I. The Lake:

A. Residents must undertake the responsibility of maintaining their own waste disposal systems. Drain fields should be inspected regularly and septic tanks should be pumped on a regular schedule. Avoid the use of on-site septic systems near areas which have been identified as containing saturated soils, or near areas with drainage gradients (steep slopes) too great for adequate septic treatment. The latter is perceived to be the greatest problem around Big Long.

B. If fertilization for lakefront lawns is desired, residents should consider using lake water for irrigation/fertilization of lawns (lake water will provide ample nutrients) or, use fertilizers low in phosphorous (0.5% liquid; 3.0% granular). Finally, fertilizer should be applied only during the growing season, April-October. (Note: an IDNR permit may be required for pumping out public waters)

C. The Lake Association should take an active role in monitoring future development: lakefront and watershed. Development monitoring could be accomplished by the formation of a 'Lake Watch Committee'. Lakefront development should consider setbacks from the lake, septic suitability, and must incorporate adequate sediment control measures. Watershed development (commercial) must be made aware of potential sediment and/or nutrient sources to the Lake, and like lakefront development, incorporate adequate sediment control measures. Sediment control structures such as erosion control mats, silt fences, straw bale filters, and sediment basins must be installed prior to any construction or development which would impact the Lake. The Lake Association should also promote the establishment of a county-wide erosion control plan.

II. The Watershed:

A. The land-use or cropping practice of areas mapped as having highly erodible lands or severe slopes should be carefully considered. Much of this land should be in a conservation tillage program, or, in some cases should not be in agricultural crop production. Some of these sloped areas nearer the lake are too steep for development. Those areas defined in the HEL/severe slope study should maintain natural buffer areas or filter strips along ditches or open drainageways.

The 159 acres, detailed in Agricultural Lands/HEL/severe slope overlay represent the worst case, or highest erosion threat areas of the Big Long watershed. Much of this land is adjacent to open drains or tiles which facilitate the transport of eroded soils to the Lake. For this reason, those areas present the greatest sedimentation threat to Big Long Lake. Every effort must be made to enlist these areas into conservation tillage, CRP or related land treatment programs. Lands in the Big Long watershed noted as unsuitable to no-till should be in permanent cover.

Other land treatment practices, especially stream/ditch bank stabilization, should be pursued. This could be accomplished by establishing grassed ditch borders (filter strips), and, in more extreme cases, structural

or riprapped solutions. Excavate and maintain sediment traps that may be located at easily accessible intervals, such as near roads. (Other various Conservation Practices are listed in Appendix C. These practices will be detailed in individual farm Conservation Plans, as required by the 1985 Farm Bill to be implemented by 1995).

B. Consider the Constructed Options as described in that Section of this report. Priority should be given to constructed options on the southwest and northwest ditches respectively.

C. Stabilize streambank or ditch escarpments. Allow native vegetation to establish on stream banks. Retain on one side during 'maintenance'. The need for selective ditch cleaning should be carefully weighed against possible impacts to the Lake.

D. Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes.

E. Divert runoff from severely sloping areas.

F. Avoid spreading animal waste during the winter or near direct drainageways unless it can be incorporated IMMEDIATELY.

III. **General recommendations:**

Encourage preservation of remaining upland forest, wetlands and upland depressions. Land owners must be made aware of Federal regulations protecting wetlands.

Avoid relocation (straightening) of natural stream channels.

Avoid building close to wooded ravines or streambanks.

Preserve natural vegetation adjacent to water areas, such as remaining in-lake wetlands at stream inflows. The extreme south end also has some good wetland shore areas that also should be preserved.

Avoid construction in, bypassing of, or drainage of, wetlands.

Maintain natural vegetative cover wherever possible.

Stabilize drainage areas immediately following any construction or "maintenance". Quick vegetative cover and streambank protection is essential to erosion control.

Lake of the Woods

EXECUTIVE SUMMARY

Lake of the Woods is a Class One water body in LaGrange-Steuben Counties. A Class One lake is a lake of highest water quality, which rarely support macrophyte and/or algae in serious concentrations (IDEM, 1986). Historical data suggest that eutrophication has been increasing progressively during the past two decades. The most pronounced biological changes took place following 1972, when ciscos were extirpated, the overall quality of the fishery declined, and oxygen conditions became such that trout populations can no longer be maintained in the lake year round. Algal blooms dominated by blue-green algae are common during summer.

The principal contributing factors for the eutrophication of Lake of the Woods have been identified as nutrients and sediments from watershed sources and delivered by ditches. Sediment eroded from the watershed has been responsible for pronounced basin infilling of nearshore areas near ditch mouths especially in the west and east end of the lake.

Conservation tillage has been identified as one of the most effective methods of controlling erosion due to agricultural practices. Thus, continued and expanded use of conservation tillage systems in conjunction with addressing drainage issues on a cost-benifit basis, and implementation of the constructed options is strongly advised.

Lake residents can further control sediment and nutrient loading by monitoring lake front development for adequate erosion control. A lake watch program could be a viable approach to meeting this task. Septic leachate from lake front homes on Lake of the Woods and McClish Lake is suspected of contributing highly to the decline in water quality of Lake of the Woods. Residents must undertake the responsibility of monitoring and maintaining their own waste disposal systems.

No in-lake management recommendations are proposed for Lake of the Woods. Macrophytes are not likely to pose management problems in the lake if eutrophication progresses further due to limitations of light and basin morphometry. If watershed practices are implemented to reduce nutrient and sediment loading to the lake, it is likely that the trophic state of Lake of the Woods will decrease accordingly.

INTRODUCTION

Lake of the Woods (figure page iii), LaGrange-Steuben County, is a 136 acre lake with a maximum and mean depth of 84 feet and 40.2 feet, respectively. Legal lake level is 956.45 feet, but the lake lacks a control structure on the unnamed outlet stream leading to Taylor Lake. The lake has three unnamed permanent inlets. One stream enters Lake of the Woods at the west end and is the outlet from the two small interconnected Spectacle Lakes. The small segment of the watershed drained by this stream is mostly uncultivated and consists of swamp forest. A second stream connects Goose Pond with Lake of the Woods along the middle of the latter's south shore. Goose Pond is essentially a semi-connected bay of Lake of the Woods and drains a small wooded segment of the watershed. The third and final unnamed inlet is the outlet of McClish Lake through Duck Pond. This large section of the watershed is primarily devoted to row crop agriculture.

Maumee Ditch drains the greatest portion of the Lake of the Woods watershed and enters the lake at its southwest corner. While a majority of the watershed drained by this ditch is devoted to row crops and pasture, the area in the immediate vicinity of the lake is forested and swampy. The outlet for Lake of the Woods is located at the eastern end of the lake and flows north into Taylor Lake.

The present study was initiated because of lake residents' concerns regarding algal blooms, a reduced quality fishery and observation of siltation associated with delivery of erosion products from the watershed especially during early spring rains.

The current chapter is designed to define the current water quality of Lake of the Woods and to determine whether current values represent a marked decline in water quality within the historical past. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on water quality for Lake of the Woods. The second section summarizes the water quality analyses conducted as part of the present study and compares values to earlier studies. The third and final section details our sediment studies at Lake of the Woods where we were interested in determining the extent of basin infilling in the historical past as well as changes in phosphorus loading to the lake. Management implications of our analysis of past and current water quality will be discussed later in this report.

Historical Water Quality

Historical Database

A total of 11 separate studies were conducted on Lake of the Woods between 1955 and 1990 for which data were available (Table W1). The earliest study was a report on the status of the cisco population in the lake. The United States Geological Survey (USGS) constructed a bathymetric map for Lake of the Woods in 1958, but detailed water quality surveys of the lake did not begin until 1972. The Indiana Department of Natural Resources surveyed the fish community 6 times between 1972 and 1988 and included data on water chemistry and macrophytes for several years. The Indiana Department of Environmental Management (IDEM) visited the lake once in the early 1970's to collect water chemistry and biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state. Indiana University collected data on the lake during 1989 to assess whether the IDEM eutrophication index for the lake has changed since the mid-1970's. Finally, local lake residents organized a Secchi disk monitoring program in 1989-90 in order to document basin siltation during heavy rain events.

Physical/Chemical Parameters

A total of thirteen physical and chemical parameters have been measured at Lake of the Woods at a frequent enough interval to be useful in delineating historical trends (Table W2). Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer at Lake of the Woods, it is likely that they mostly reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature. Thus, it is only valid to make interyear comparisons for individual months (Table W2, Figure W1). The July 1989 reading of 1.4 feet was 80% lower than the July 1977 value, while September 1989 was 45% lower than the mean of September 1973 and 1984. On the basis of historical Secchi data alone, it appears that the trophic state of Lake of the Woods has changed markedly since at least 1972-1973.

Mr. Robert Fuess recently organized a citizen based Secchi disk monitoring program for Lake of the Woods that collected data on 13 dates between 8 October 1989 and 10 June 1990. Three stations were monitored on each date: Station 001 (center of the lake at the deepest point), Station 002 (approximately 50 feet offshore from the mouth of the Maumee Ditch), and Station 003 (approximately 50 feet offshore from the mouth of the McClish Lake inlet). Interstation

Table W1. Chronology of Investigations at Lake of the Woods.

1955	Indiana University. Status report on cisco. Published by Frey (1955).
1958	United States Geological Survey. Construction of bathymetric map for Lake of the Woods.
1972	Indiana Department of Natural Resources. Temperature and dissolved oxygen profiles for assessing cisco population.
1973	Indiana Department of Environmental Management. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
1974	Indiana Department of Natural Resources. Dissolved oxygen profile and gill netting in "cisco layer" to assess status of cisco population. Published by Gulish (1974).
1975	Indiana Department of Natural Resources. Assessment of cisco populations.
1977	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1984	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1988	Indiana Department of Natural Resources. Assessment of cisco populations.
1989	Indiana University. Survey of physical, chemical, and biological parameters for construction of IDEM eutrophication index.
1989-90	Lake Residents. Citizen Secchi disk monitoring program.

Table W2. Historical Changes in Physical and Chemical Parameters at Lake of the Woods for the Period 1972-1989. Mean 1989 is the Mean of September and October 1989 Samplings.

Historical Data		Aug.1972	Sept.1973	July 1977	Sept.1984	July 89	Mean-1989
Secchi	feet	6.5	9.5	7	11	1.4	6
Mean Dissolved Oxygen	mg/L	2.5	4.8	6	8		3.8
Conductivity	umhos/cm					395	412.5
Alkalinity	mg/L as CaCO3	136.8		188.1	163	202.1	159
pH		9		9	9.2		
Cl	mg/L		13				
SO4	mg/L		59				
Total Phosphorus	mg/L		0.124			0.029	0.275
Ortho Phosphorus	mg/L		<0.03			0.002	0.025
Nitrate-N	mg/L		<0.1			1.6	0.9
Ammonia-Nitrogen	mg/L		0.64			0.91	0.595
Total Kjeldahl N	mg/L						1
Organic-Nitrogen	mg/L		0.52			0.65	0.4
Chlorophyll	mg/m3						6.2

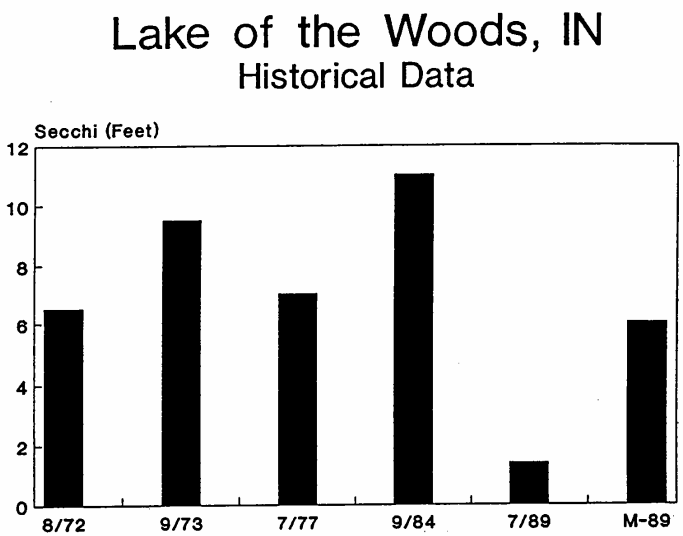


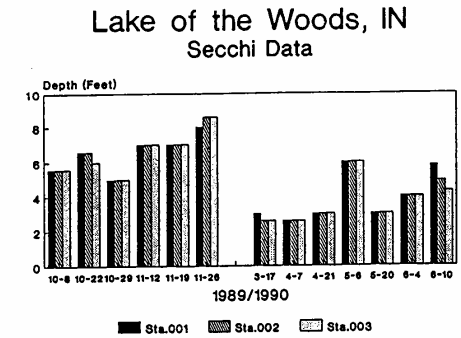
Figure W1. Historical Secchi Disk Readings in Lake of the Woods for the Period 1972-1989. M-89 is the mean for September and October 1989.

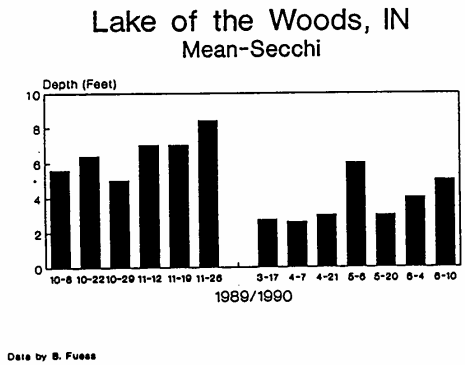
variability was not great for either individual dates or when expressed as a mean for the entire study period (Figure W2). Pronounced variability was noted, however, in mean lake Secchi values between individual sampling dates (Figure W2). The lowest Secchi values reported from October 1989 through June 1990 were for 17 March, 7 and 21 April, and 20 May 1990. The first three dates were during the period of spring runoff from the watershed. Secchi values increased between 21 April and 5 May, but decreased by 50% over the next 15 days associated with several days of heavy rains. It is highly unlikely that such low spring time Secchi values result from increased phytoplankton biomass, but are a direct reflection of watershed erosion and delivery of silt ladened water during rain events.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production. A good measure of the degree of eutrophication is provided by the extent of water column anoxia (absence of oxygen) in mid summer (Table W3). Pronounced water column anoxia is evident by at least July in Lake of the Woods and extends throughout the summer stratified period. Although the historical database is not extensive, it appears that serious water column anoxia was evident as early as 1972, but as evidenced by September data, may have become progressively worse to the present. A majority of previous estimates of midsummer mean oxygen values in the water column of Lake of the Woods historically remained below 5.0 mg/L (Table W2). The historical data suggest that deep water deoxygenation during summer has characterized Lake of the Woods since at least 1972.

Depth profiles of dissolved oxygen in lakes normally display a progressive decline in values with increasing depth, the extent of which is usually directly proportional to lake trophic state. High values in surface waters result from wind mixing action, atmospheric diffusion, and phytoplankton photosynthesis, while reduced values in deeper stratified waters reflect decomposition rates and morphometric constraints to total water column mixing during the circulation periods of spring and fall. In some lakes, however, this generalized pattern of reduced oxygen with increasing depth is interrupted by a horizontal zone of increased oxygen deep within the water column. The resulting oxygen profiles are termed heterograde oxygen curves and are usually produced by a layer or plate of dense actively photosynthesizing phytoplankton.

Heterograde oxygen curves were reported at Lake of the Woods in the early 1970's, but even then their temporal stability throughout the year was weak (Table W4). Since 1973 a heterograde curve has been reported only once (July 1989), and its vertical extent was less than three feet (one





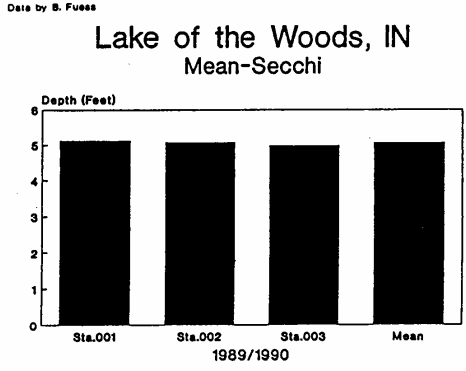


Figure W2. Results of the Citizen Based Secchi Disk Monitoring Program of November 1989 - June 1990. Stations Were 001 (Center of Lake), 002 (Offshore From Mouth of Maumee Ditch) and 003 (Offshore From Mouth of McClish Lake Inlet).

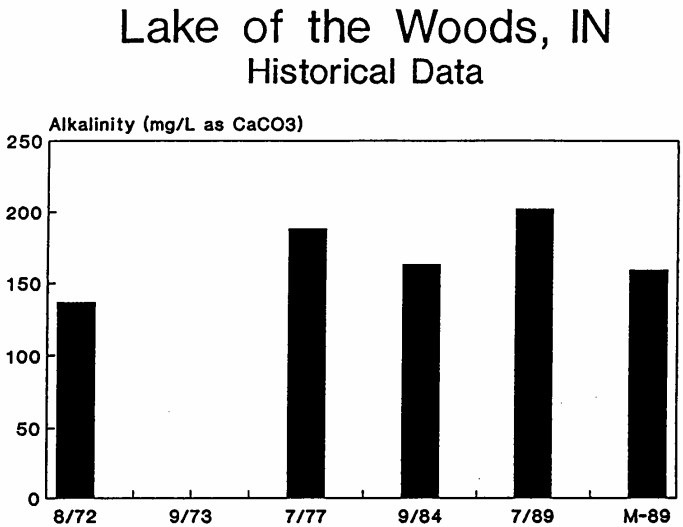


Figure W3. Historical Alkalinity Readings in Lake of the Woods for the Period 1972-1989. M-89 is the mean for September and October 1989.

Table W3. Historical Records of Water Column Anoxia in Lake of the Woods, IN

Observation		Initial Depth of <1 mg/L Dissolved Oxygen
<u>July</u>:		
1977		24 feet
1989		55 feet
<u>August</u>:		
1972	(8/10)	24 feet
	(8/25)	19 feet
<u>September</u>:		
1973		No Anoxia
1984		24 feet
1989		19 feet
<u>October</u>:		
1989		22 feet

Table W4. Depth to Positive Heterograde Oxygen Zone in Lake of the Woods.

Date	Depth to Zone (Feet)	Thickness of Zone (Feet)	Max. DO in Zone (mg/L)	Temp. Range Within Zone (°C)
July:				
1977	Not Present			
1989	13	<3	13.5	22 - 22
August:				
8/10/1972	Not Present			
8/25/1972	10	5	12.6	21 - 24
September:				
1973	13	3	11.6	18 - 22
1984	Not Present			
1989	Not Present			
October:				
1989	Not Present			

meter). Coupled with the trend established for Secchi transparency, these data suggest that light transmission in the water column of Lake of the Woods has declined to such an extent since the early 1970's that the deep water phytoplankton plate responsible for the zone of high oxygen at depth in the water column of the lake has been eliminated. As will be discussed later, positive heterograde oxygen curves are considered essential for the survival of cisco, a cold-water, oxygen sensitive fish, in most northern Indiana lakes (Gulish 1974). The DNR reported that ciscos were common in Lake of the Woods in both 1955 and 1975, but the fish was considered extirpated in the lake by 1988.

Alkalinity is a measure of the carbonate buffering capacity of lakes and can be a useful parameter for assessing changes in watershed delivery of erosion products through human activities. Oscillations in alkalinity values for Lake of the Woods since 1972 do not yield any apparent trend that can be related to changes in watershed management practices (Table W2, Figure W3).

Although the database is rather limited, total phosphorus concentrations in Lake of the Woods in September-October 1989 were 2.2 times greater than reported during September 1973 (Figure W4, Table W2). Unfortunately, the database for this parameter is too scant to delineate any significant historical trend. The remaining physical and chemical parameters measured at Lake of the Woods were sampled so infrequently as to be of little value in determining past trends in water quality.

Microbiology

Neither the LaGrange County Health Department nor the Indiana State Board of Health had any historical microbiological data from Lake of the Woods.

Phytoplankton

Phytoplankton samples have been collected twice (1973, 1989) at Lake of the Woods. The Indiana Department of Environmental Management sampled phytoplankton during September 1973. Algal abundance was estimated at 49,000/mL in surface waters (0-5 feet), with mean water column abundance at 55,500/mL. The following algal taxonomic composition was noted:

Algal Group	Genus
Diatoms	Asterionella
	Synedra
Greens	Tribonema
Blue-Greens	Aphanizomenon
Dinoflagellates	Ceratium

Tribonema was the numerical dominant in surface waters (35,000/mL), while Aphanizomenon was the principal taxon in waters deeper than 16 feet (54,000/mL). The most recent survey of phytoplankton was by Indiana University in July 1989. Although taxonomic data were not provided, blue-green algae did not numerically dominate the phytoplankton assemblage. Total algal abundance in surface waters (0-5 feet) was 500-1,000/mL but increased to 1,000-2,000/mL at the thermocline.

Macrophytes

The macrophyte (aquatic plant) community was examined twice (1977, 1984) as part of Indiana Department of Natural Resources fish surveys (Table W5). Plant taxonomic composition was identical for the two surveys. Submergent macrophytes were the most taxonomically diverse plant community with most species being pondweeds. Emergent and floating-leaved plant communities consisted of two species each.

Both the 1977 and 1984 DNR surveys noted that vegetation extended to a depth of approximately six feet, was dominated by species of pondweeds, and was not considered a management problem. It was concluded that basin morphometry and depth controlled the aerial extent of macrophytes in Lake of the Woods.

Lake of the Woods, IN
Historical Data

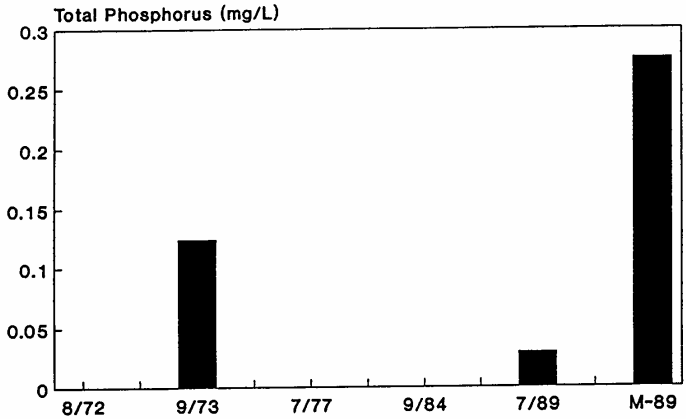


Figure W4. Historical Total Phosphorus Concentrations in Lake of the Woods for the Period 1973-1989. M-89 is the mean for September and October 1989.

Table W5. Species Composition of the Macrophyte Community of Lake of the Woods for 1977 and 1984.

Species	Common Name	1977	1984
SUBMERGENTS:			
Ceratophyllum demersum	coontail	X	X
Chara spp.	chara	X	X
Elodea canadensis	elodea	X	X
Najas flexilis	bushy pondweed	X	X
Najas marina	spiny najas	X	X
Najas minor	brittle najas	X	X
Potomogeton amplifolius	bass weed	X	X
Potomogeton foliosus	leafy pondweed	X	X
Potomogeton pectinatus	sago pondweed	X	X
Potomogeton pusillus	fine leaf pondweed	X	X
Potomogeton richardsonii	Richardson's pondweed	X	X
Vallisneria americana	eel grass	X	X
EMERGENTS:			
Lythraceae sp.	swamp loosestrife	X	X
Peltandra virginica	arrow arum	X	X
FLOATING LEAVED:			
Nuphar advena	spatterdock	X	X
Nymphaea tuberosa	white water lily	X	X

Fish

The Indiana Department of Natural Resources surveyed the fish community of Lake of the Woods three times between 1974 and 1984. The sampling methodologies for the DNR surveys were:

1974	Standard and vertical gillnets in "cisco layer"	
1977	Electrofishing:	1 hr night
	Gillnets:	3 for 96 hrs = 288 hrs total effort
1984	Electrofishing:	1 hr night
	Gillnets:	5 for 48 hrs = 240 hrs total effort

A listing of the individual species caught and the contribution of each to total fish abundance and weight caught during the 1977 and 1984 DNR surveys are provided in Tables W6 and W7, respectively. Largemouth bass was the numerical dominant in both the 1977 and 1984 surveys and together with the second most abundant fish, bluegill, increased in representation between the two surveys (Figure W5). The abundance of the other two principal subdominants, yellow bullhead and yellow perch, declined during the same period. As noted for abundance, largemouth bass was dominant fish of both surveys on a weight basis, and its overall contribution increased between 1977 and 1984 (Figure W5). Yellow perch also increased its contribution to total weight during the same period, while both bluegill and bowfin decreased. Two taxa commonly posing management problems, gizzard shad and carp, were either absent or a minor component of the fish fauna of Lake of the Woods.

The cisco inhabits deeper portions of the water column and is often missed by routine fishery survey techniques employed by the DNR. This fish species requires cold well oxygenated water and is therefore sensitive to deoxygenation of the lower water column associated with increasing eutrophication. Ciscos were common in Lake of the Woods in 1955 (Frey 1955), 1972 (Gulish 1974), and 1975. A follow up survey in 1988 using sampling methodologies specifically designed to maximize the likelihood of catching ciscos failed to yield any specimens, leading DNR to conclude that the species had been extirpated from the lake between 1975 and 1988.

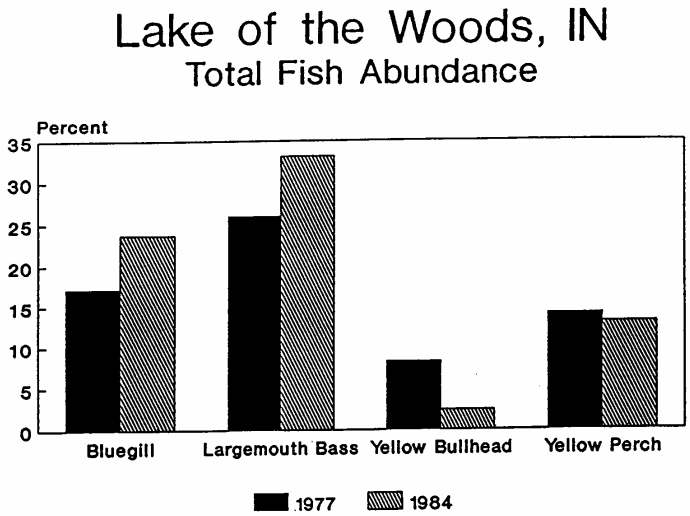
An active fish stocking program has been ongoing at Lake of the Woods since at least 1975 (Table W8). Only rainbow trout were stocked in 1975 and 1976, but beginning in 1977, both rainbow and brown trout were released. Fish stocking has occurred at approximately two year intervals since 1978.

Table W6. Importance of Individual Fish Species in Lake of the Woods During 1977 and 1984 Expressed as a Percent of Total Fish Abundance Caught in DNR Surveys.

	1977	1984
Black Crappie	2.1	1.7
Bluegill	17.2	23.7
Bowfin	2.4	0.3
Brown Trout	7.1	
Carp		0.2
Channel Catfish		0.2
Grass Pickeral	0.6	1.3
Green Sunfish	7.4	9.2
Lake Chubsucker	0.6	1.5
Largemouth Bass	26	33.1
Northern Pike	0.3	
Pirate Perch		0.2
Pumpkinseed	0.9	1
Rainbow Trout		2
Redear	0.6	0.5
Warmouth	10.7	7.1
White Sucker	1.8	2.5
Yellow Bullhead	8.3	2.4
Yellow Perch	14.2	13.1

Table W7. Importance of Individual Fish Species in Lake of the Woods During 1977 and 1984 Expressed as a Percent of Total Fish Weight Caught in DNR Surveys.

	1977	1984
Black Crappie	2.0	2.9
Bluegill	10.7	8.6
Bowfin	15.8	5.2
Brown Trout	11.3	
Carp		2.5
Channel Catfish		1.7
Grass Pickeral	0.4	0.7
Green Sunfish	1.4	2.5
Lake Chubsucker	0.3	0.9
Largemouth Bass	19.4	33.9
Northern Pike	3.1	
Pumpkinseed	0.4	0.1
Rainbow Trout		7.2
Redear	0.7	0.5
Warmouth	4.9	3.8
White Sucker	8.1	8.0
Yellow Bullhead	9.0	5.1
Yellow Perch	12.7	16.2



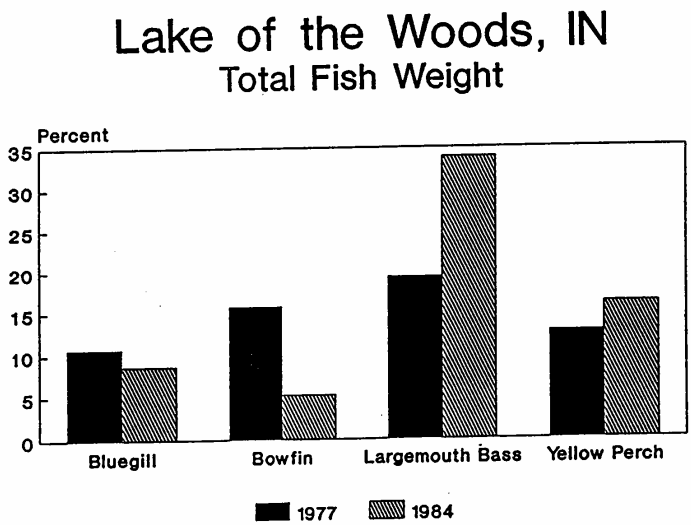


Figure W5. Changes in the Percentage Contribution of Select Species to Total Fish Abundance and Weight in Lake of the Woods in 1977 and 1984.

Table W8. History of Fish Stocking at Lake of the Woods, IN for the Period 1975-1984.

YR	Rainbow Trout	Brown Trout
1975	1,500	
1976	1,000	
1977	500	500
1978	500	
1979		
1980	500	500
1981		
1982	500	500
1983		
1984	500	

The 1977 DNR fishery survey was initiated because of a major cisco die off during 1976. The results this survey suggested that the oxygen regime of the lake was insufficient for a viable cisco population but was sufficient for trout. It was recommended that rainbow and/or brown trout be stocked annually. In spite of the likely extirpation of cisco in the lake, the fishery was considered good.

A major decline in the fishery of Lake of the Woods was noted between 1977 and 1984. By the latter year, overall fish production was considered low, and it was concluded that the lake provided only limited sport fishing opportunities for warm water species. While ciscos were likely extirpated from the lake, conditions in 1984 were considered only marginal for supporting trout year round. It was recommended that trout stocking be undertaken only during spring. No other fishery management was proposed.

The historical fishery data, especially for the cold water fauna, suggest that water quality in Lake of the Woods has declined recently. The inherent sensitivity of the cold water fishery to reduced dissolved oxygen conditions in the lower water column leading to loss of cisco and marginal conditions for trout on a year round basin are clear early warning indicators of degrading water quality.

Current Water Quality

Methods

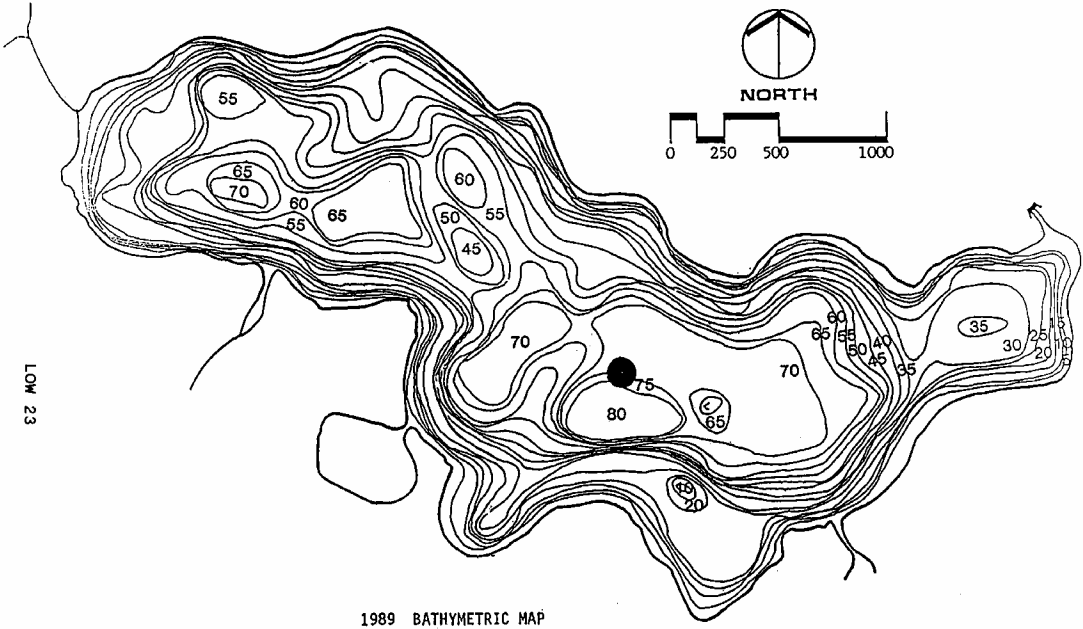
Water quality parameters were collected during 1989 on 16 September and 5 October. A single sampling station was established in the center of Lake of the Woods near the point of maximum water depth (Figure W6). Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc and a Licor photometer. Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column where a Kemmerer bottle was used to collect water at each meter of the water column. All analyses were performed in certified laboratories according to EPA techniques (EPA-600/14-79-020, Methods for Chemical Analysis of Water and Wastes, Revised March 1983). Chemical parameters analyzed included conductivity, alkalinity, nitr ate/nitrite nitrogen, total Kjeldahl nitrogen, ammonia, total phosphorus, and ortho phosphorus. Data for physical and chemical parameters for Lake of the Woods during the 1989 survey are presented in Table W9.

Two phytoplankton samples were collected with a #20 Wisconsin plankton net (76 um) on each sampling date. One tow was taken from 5 feet depth to the surface, and a second five foot tow was taken to include the beginning of the thermocline. All plankton samples were preserved with Lugol's solution and returned to the laboratory for analysis. Plankton counts utilized Utermohl chambers and were performed with the aid of an inverted microscope.

Physical/Chemical Parameters

<u>Temperature.</u> The water columns of northern Indiana lakes greater than approximately five meters deep remain thermally stratified throughout most of the year. As a result of density-temperature relationships, complete mixing of the water column from top to bottom occurs only when water temperature reaches a uniform 4oC, the maximum density of water. This occurs twice a year in temperate lakes (spring and fall) associated with seasonal climatic changes. The length of the mixing period depends on the rapidity of climate change and can vary from a few days to less than a month. Lakes displaying two mixing periods per year are termed dimictic.

During the stratified period, the water column of Indiana lakes is divided into three zones based on temperature-density relationships. The uppermost well mixed zone is termed the epilimnion and extends from the surface to a depth roughly approximating the lower depth of wave action. The lowermost portion of the water column is the hypolimnion, a zone of density-isolated water that mixes with surface



1989 BATHYMETRIC MAP

Figure W6. Station Utilized for 1989 Limnological Investigations.

Table W9. Physical and Chemical Parameters for the 1989 Survey of Lake of the Woods.

Lake of the Woods	1989	16 September	5 October
Secchi	Feet	5.6	6.33
Mean Dissolved Oxygen	mg/L	3.1	4.6
Ammonia	mg/L	0.45	0.74
Total Kjeldahl N	mg/L	1.2	0.8
Nitrite-Nitrate	mg/L	0.4	1.4
Total Phosphorus	mg/L	0.28	0.27
Ortho Phosphorus	mg/L	0.03	0.02
Conductivity	umho/cm	405	420
Alkalinity	mg/L	158	160
Chlorophyll a	mg/m3	4.4	8.0

waters only during the short mixing periods. The portion of the water column that is transitional between the epilimnion and hypolimnion is termed the metalimnion. That one meter of the metalimnion displaying the greatest temperature change is called the thermocline.

Water column profiles clearly demonstrated that Lake of the Woods was thermally stratified during both September and October 1989 (Figure W7). The thermocline was between five and six meters during September but moved deeper to 7-8 meters by October as the lake began to cool in the initial stages of stratification breakdown characteristic of fall.

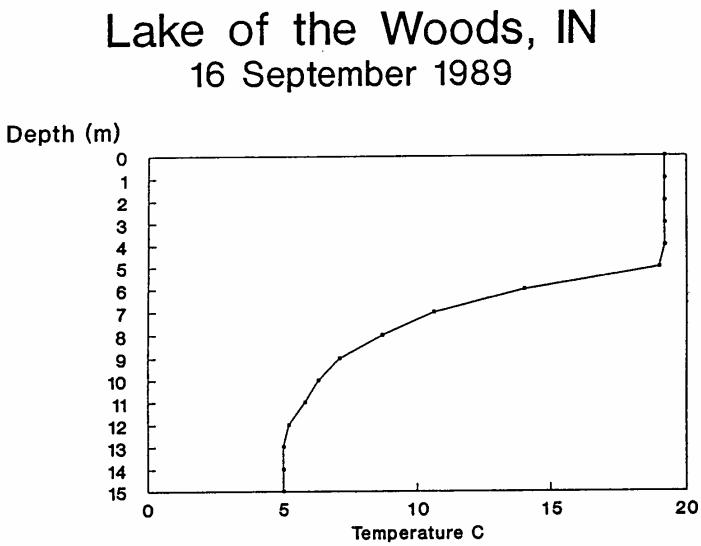
Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

Pronounced water column deoxygenation was noted during both September and October 1989 (Figure W8). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). The lake was essentially anoxic below a depth of 5 meters and 6 metered during September and October, respectively.

Mean oxygen values for the water column on both dates of 1989 were less than 5 mg/L (Figure W9). Mean water column dissolved oxygen for September 1989 (3.1 mg/L) was lower than values for the same month during 1973 (4.8 mg/L) and 1984 (8 mg/L) (Table W2). No historical data for October were available.

Historically, Lake of the Woods has displayed severe deoxygenation of the water column as early as July (Table W3). Severe anoxia was evident by at least 1972, but both the extent and temporal duration has increased markedly to the present.

Secchi Disc Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae and/or sediment suspended in the water column to block light transmission. Field observations on each of the two sampling dates suggested that Secchi depths in Lake of the Woods on those dates were controlled mainly by phytoplankton biomass. Thus,



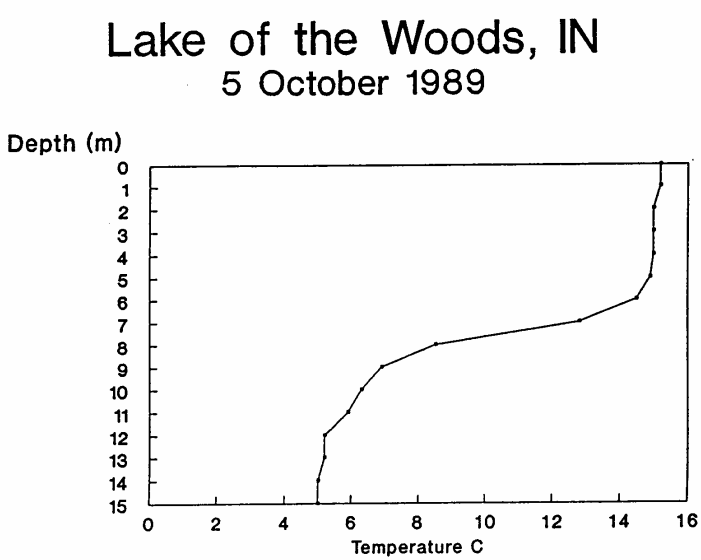
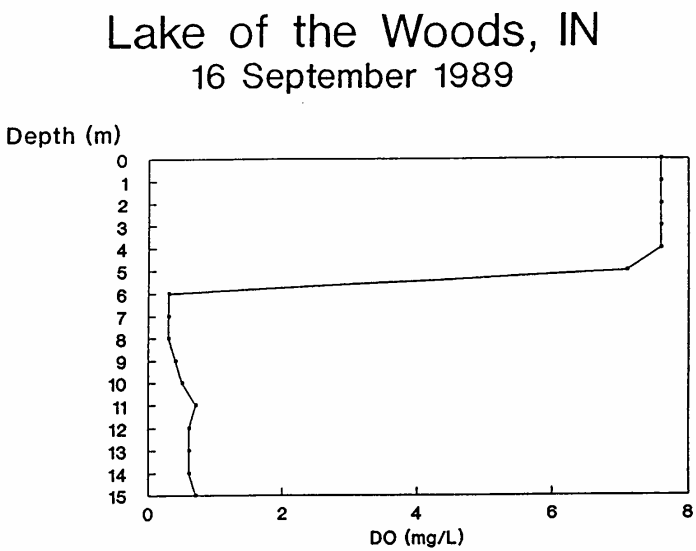


Figure W7. Water Column Temperature Profiles for Lake of the Woods During September and October 1989.



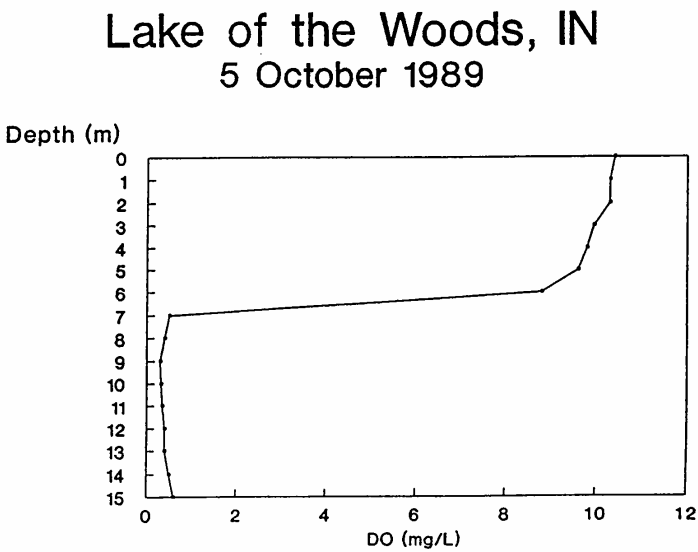


Figure W8. Dissolved Oxygen Profiles for Lake of the Woods During September and October 1989.

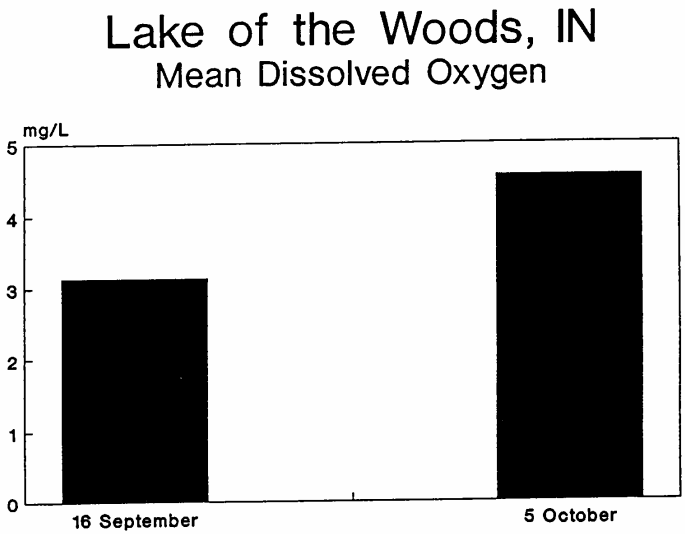


Figure W9. Mean Dissolved Oxygen Concentrations in the Water Column of Lake of the Woods During September and October 1989.

the shallower the Secchi depth during summer, the more productive (eutrophic) a lake is presumed to be. Secchi transparency was similar during September (5.6 feet) and October (6.3 feet) 1989 (Figure W10). The September 1989 value was 41% and 49% lower than the September reading for 1973 and 1984, respectively (Table W2). Such a historical comparison of late summer Secchi values suggests that water clarity has changed appreciably in the past decade.

Ammonia. Ammonia values for Lake of the Woods during September (0.45 mg/L) were lower than October (0.74 mg/L) 1989 (Figure W11). The mean for September-October 1989 (0.59 mg/L) was lower than reported for July 1989 (0.91 mg/L) but comparable to September 1973 (0.64 mg/L) (Table W2).

Nitrite-Nitrate. As with ammonia, nitrite-nitrate nitrogen concentrations were greater during October (0.4 mg/L) than September (1.4 mg/L) 1989 (Figure W11). The historical database was insufficient for comparison.

Kjeldahl Nitrogen. Unlike the previous two nitrogen components, Kjeldahl nitrogen values were greater in September (1.2 mg/L) than October (0.8 mg/L) 1989 (Figure W11). No historical values were found.

Total Phosphorus. Total phosphorus concentrations were similar during September (0.28 mg/L) and October (0.27 mg/L) 1989 (Figure W12). The September 1989 total phosphorus value for Lake of the Woods was 2.2 times greater than reported for September 1973 (Table W2).

Ortho Phosphorus. As noted for total phosphorus, ortho phosphorus concentrations were comparable during September (0.03 mg/L) and October (0.02 mg/L) 1989 (Table W9). Ortho phosphorus value for Lake of the Woods for both dates were comparable to values reported for September 1973 (0.03 mg/L) (Table W2).

Nitrogen:Phosphorus Ratios. The ratio of total nitrogen to total phosphorus can be useful in delineating which of these two essential nutrients is limiting primary production in lakes. Numerous authors (Baker et al. 1981, Kratzer and Brezonik 1981, Canfield 1983) have proposed that N:P ratios less than 10 suggest nitrogen limitation, while those greater than 10 suggest phosphorus. The N:P ratios in Lake of the Woods were 42 in September and 29 in October 1989. These values suggest that the lake is phosphorus limited throughout the year.

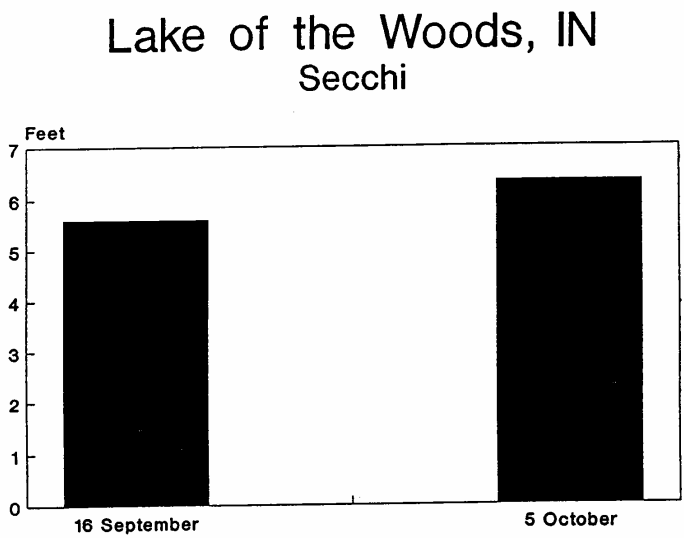
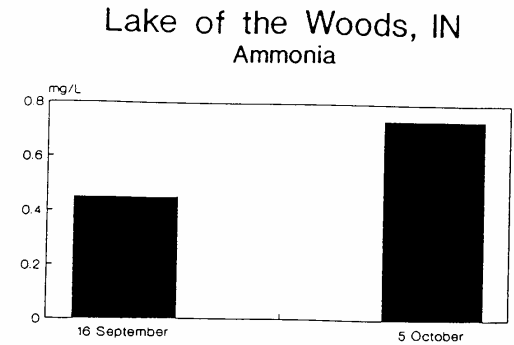
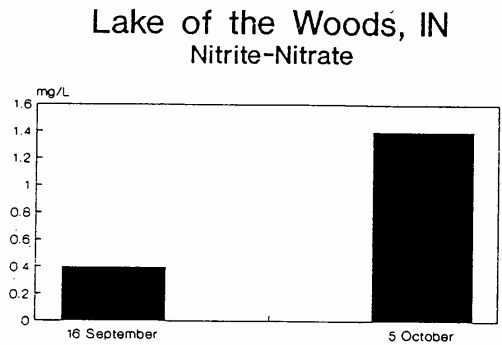


Figure W10. Secchi Disk Transparency for Lake of the Woods During September and October 1989.





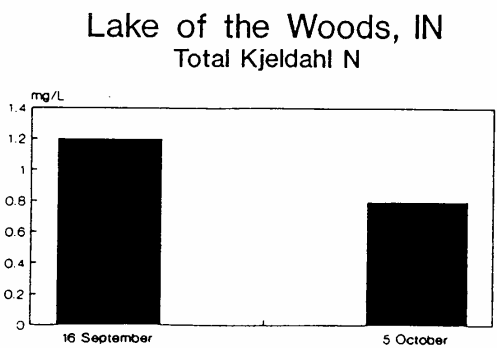


Figure W11. Concentrations of Ammonia, Nitrite-Nitrate and Total Kjeldahl Nitrogen for Lake of the Woods During September and October 1989.

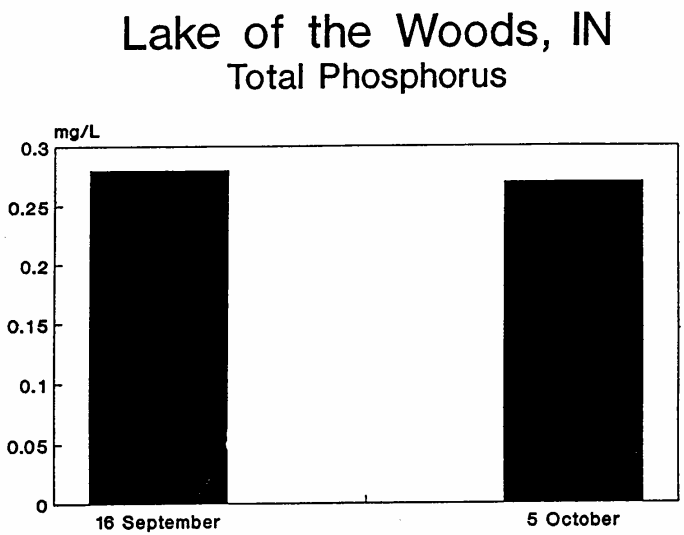


Figure W12. Concentrations of Total Phosphorus for Lake of the Woods During September and October 1989.

Alkalinity and Conductivity. Alkalinity values were comparable during September (158 mg/L) and October (160 mg/L) 1989 (Figure W13). A similar parameter, conductivity, also remained unchanged between September and October (Figure W13). Values for alkalinity were comparable to those reported for the lake since at least the early 1970's (Table W2).

Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll concentrations were measured during both September (4.4 mg/m3) and October (8.0 mg/m3) 1989 (Figure W14). There are no historical data for comparison with the 1989 survey.

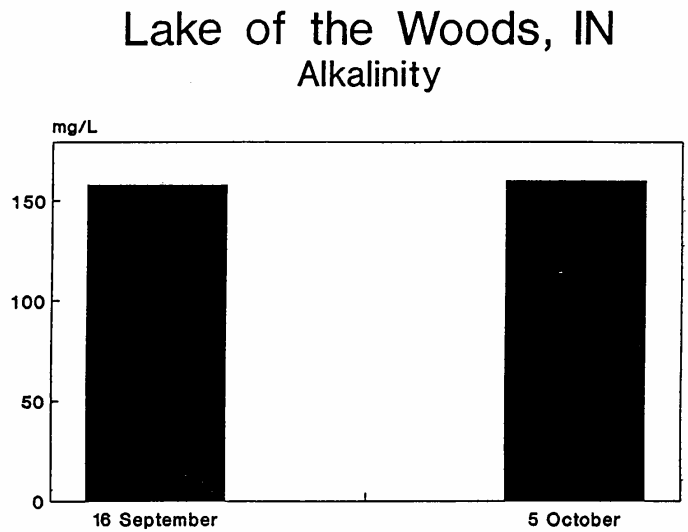
IDEM Trophic State Index

Mr Harold BonHomme of the Indiana Department of Environmental Management (IDEM) devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined.

The 1973 eutrophication index for Lake of the Woods was calculated by the Indiana Department of Environmental Management as 18, thus assigning the lake to the category of best water quality, Class One. Parameters for the 1989 index calculation were identical to those used for the 1973 index. Based on our September and October samplings, we have calculated the 1989 IDEM eutrophication index for Lake of the Woods as 18 (Table W10). While our index calculation assigns Lake of the Woods to Class One, W. Jones of Indiana University calculated a eutrophication index of 29 based on parameters collected during July 1989. The latter index would place the lake in the category of intermediate water quality, Class Two.

The phytoplankton assemblage during September and October of 1989 was dominated numerically by Tribonema with Fragilaria as the principal subdominant (Table W11). Tribonema was also dominant numerically during September 1973.

On the basis of IDEM eutrophication indices alone, it appears that the lake has changed little between 1973 and 1989. It must be remembered that the IDEM index is based on parameters collected for the water column in open water sections of the lake, and like all indices, does not include the extent and productivity of aquatic macrophytes.



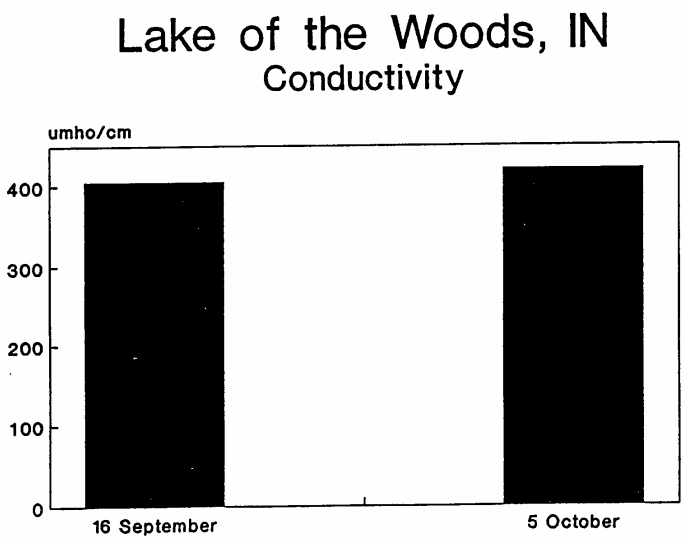


Figure W13. Conductivity and Alkalinity Values for Lake of the Woods During September and October 1989.

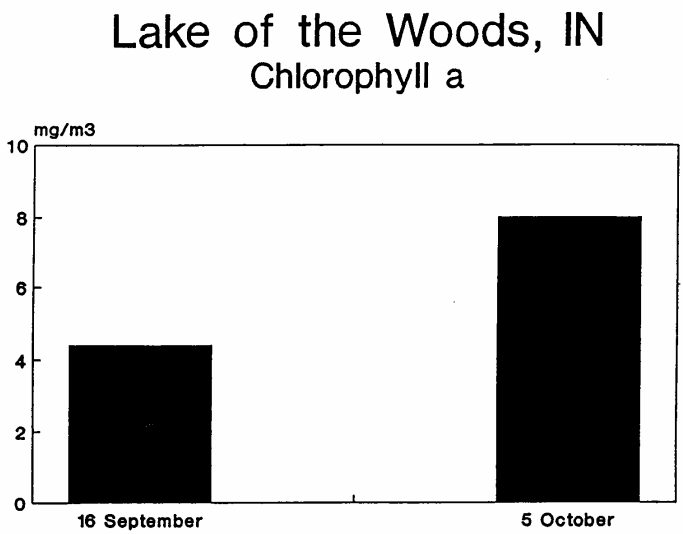


Figure W14: Chlorophyll Concentrations for Lake of the Woods During September and October 1989.

Table W10. IDEM Eutrophication Index for Lake of the Woods in 1989.

	Parameter	Value	Eutrophy Points
I.	Total Phosphorus	0.27 ppm	4
II.	Soluble Phosphorus	0.02 ppm	0
III.	Organic Nitrogen	0.40 ppm	0
IV.	Nitrate	0.9 ppm	3
V.	Ammonia	0.6 ppm	3
VI.	Dissolved Oxygen Saturation @ 5 feet	92%	0
VII.	Dissolved Oxygen (% of water column with >0.1 ppm DO)	100%	0
VIII.	Light Penetration (Secchi Disk)	5.9 feet	0
IX.	Light Transmission (1% at Three Feet)	35%	3
X.	Total Plankton		
	Vertical Tow (5 ft to Surface)	2,526 cells/mL	3
	Blue-green Dominance	No	0
	Vertical Tow (Thermocline)	2,220 cells/mL	2
	Blue-green Dominance	No	0
	> 100,000 cells/mL	No	0
		1989 IDEM Index	18

Table W11. Phytoplankton Composition for Lake of the Woods During September and October 1989.

	16 September		5 October	
	S	T	S	T
Tribonema	988	761	873	836
Fragilaria	765	549	832	769
Ceratium	218	495	521	238
Asterionella	122	185	322	299
Aphanizomenon	69	36	343	272

S = algal units/mL calculated from a vertical tow from a depth of five feet to the surface.

T = algal units/mL calculated from a five foot vertical tow that includes the thermocline.

Expanding macrophyte abundance is often associated with reduced nutrient and algal abundance in open water areas as the vegetated littoral zone successfully competes with open water phytoplankton for nutrients (Canfield et al. 1983). Given that there is no evidence for a major expansion in macrophytes in recent years, it is suggested that the relatively constant eutrophication index indicates no real acceleration in eutrophication in Lake of the Woods since at least 1973.

Stream Sampling

Methods

At each station, two, 1-liter water samples were collected from the upper 15 cm of the water column. Water samples were analyzed for: calcium carbonate alkalinity, specific conductivity, pH, total nitrogen, total phosphorus and color. In addition to water quality measurements, stream flow was calculated using a General Oceanics mechanical flowmeter and a visual survey was conducted of basin characteristics.

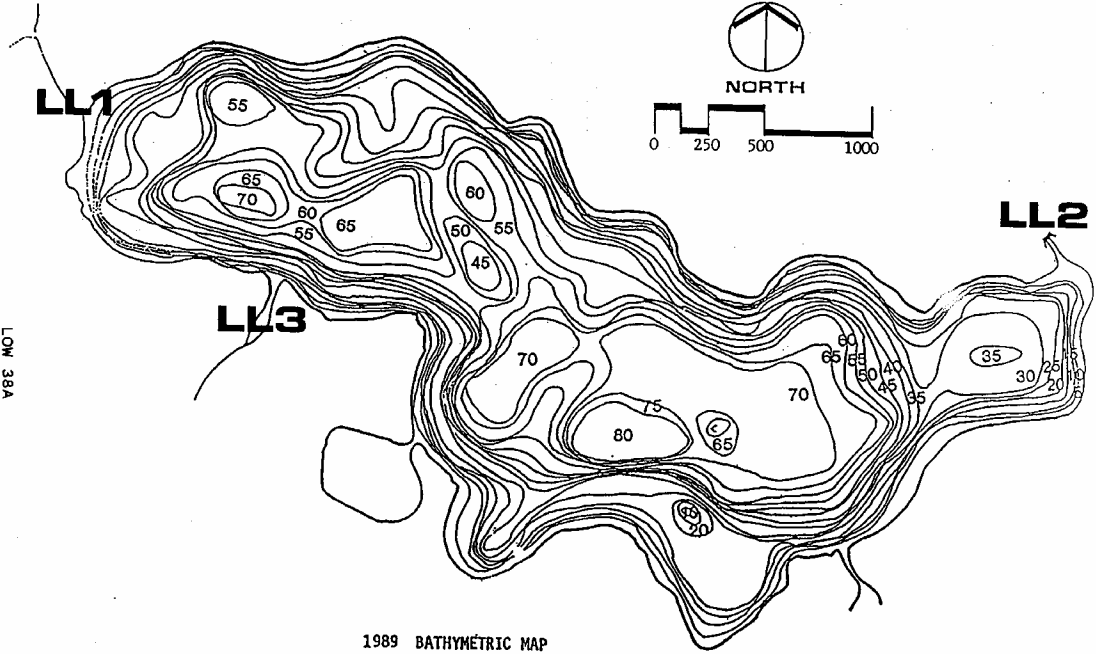
Stream Chemistry

Three stream/ditch stations were sampled during the 1989 survey (Figure W15). Station LL1 was on the stream that drains into Lake of the Woods at its west end and is the outlet stream for the two interconnected Spectacle Lakes.

Samples were collected approximately 200 feet upstream from the stream mouth. The small segment of the watershed drained by this stream is mostly uncultivated and consists of swamp forest. Station LL3 was on the Maumee Ditch that enters the Lake of the Woods along its southwestern shore. Samples were collected approximately 200 feet from the stream mouth. While a majority of the large watershed area drained by this ditch is devoted to row crops and pasture, the area in the immediate vicinity of the lake is forested and swampy. The third sampling site at Lake of the Woods was the outlet stream (LL2) approximately 1/8 mile downstream from the control structure. The outlet stream is at the northeast corner of the lake and drains into Taylor Lake.

Water chemistry data for all three stations were collected on 18 January 1990. Flow was detectable at only LL3, Maumee Ditch, (12.08 cfs) and LL2, the outlet stream for Lake of the Woods (14.56 cfs) (Figure W16).

There was little difference in the pH of the Spectacle Lake outlet (6.4) and the Lake of the Woods outlet (5.5) (Figure W17). Both alkalinity and conductivity (Figure W18) were lowest at the outlet (LL2) and highest Maumee Ditch (LL3). It is obvious that the lake is trapping carbonates associated with primary production and sedimentation.



1989 BATHYMETRIC MAP

Figure W15. Stream Sampling Stations for 1989 Investigation.

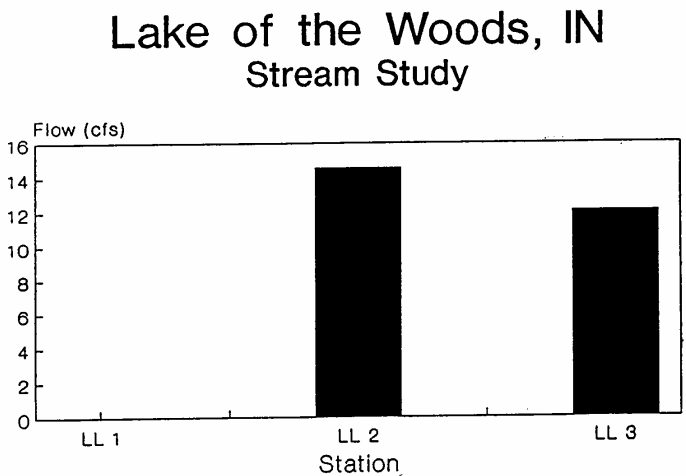


Figure W16. Flow in Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.

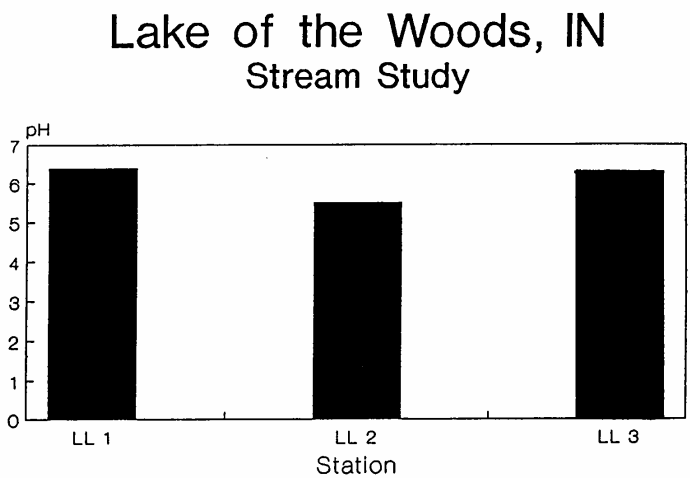
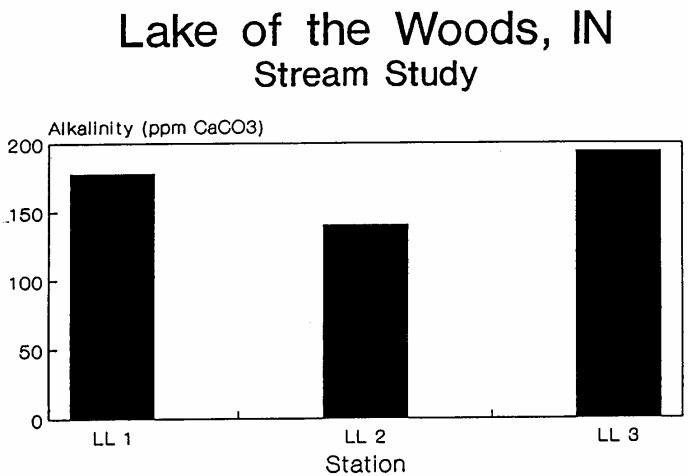


Figure W17. pH Values for Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.



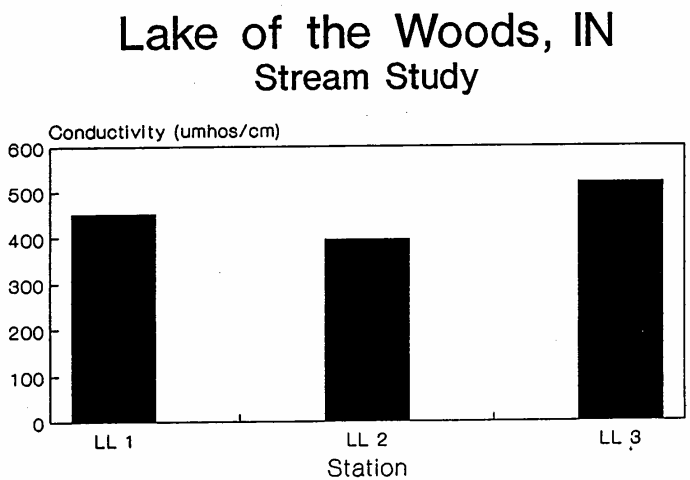


Figure W18. Alkalinity and Conductivity Values for Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.

While both the Spectacle Lake outlet and Lake of the Woods outlet had comparable values (0.07 and 0.18 mg/L, respectively), nitrite/nitrate was two orders of magnitude greater (3.25 mg/L) for the Maumee Ditch (Figure W19). It appears that the lake is effectively trapping nitrogen loading from the watershed. Like nitrogen, total and ortho phosphorus were roughly comparable between the Spectacle Lake and Lake of the Woods outlets and greatest for the Maumee Ditch (Figure W20). Ortho phosphorus contributed all of the total phosphorus value for site LL3.

Finally, the value total suspended solids (TSS) was approximately double in the Maumee Ditch (13 ppm) those of the Spectacle Lake outlet (6 ppm) and Lake of the Woods outlet (4 ppm) (Figure W21). It is felt that all TSS values likely reflect inorganic rather than organic turbidity given the time of year.

Microbiology

A water sample for total coliform analysis was collected on both 16 September and 5 October at the water quality station in the center Lake of the Woods. Samples were analyzed within eight hours of collection. The analyses followed the state approved membrane filter procedure and counts have been expressed as most probable numbers (mpn), a standard way of estimating bacterial numbers. The concentration of total coliform bacteria was 20 mpn/100 mL during September 1989 but declined to 5 mpn/100 mL three weeks later on 5 October (Figure W22). All bacteria counts at Lake of the Woods during 1989 were well within state standards.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic macrophytes in Lake of the Woods. A total of 20 transects spanning the width of the lake were used as the data base. The plant survey was conducted in September 1989 and thus represents summer plant extents. Plant biovolume is defined as the percent of the water column at a given location in the lake that is filled with plant biomass. Thus, it is a measure of the extent of macrophyte infestation throughout the lake system.

The aerial distribution of plant biovolume in Lake of the Woods is presented in Figure W23, and the percentage of lake area represented by individual biovolume increments is presented in Figure W24. For convenience, biovolume has been expressed in increments of 20% of water column infestation. Macrophytes generally were restricted to water depths less than 20 feet, thus limiting plant growth in the lake to near shore areas. Given the morphometry of the basin, a large area of the lake bottom (70%) was considered void of vegetation.

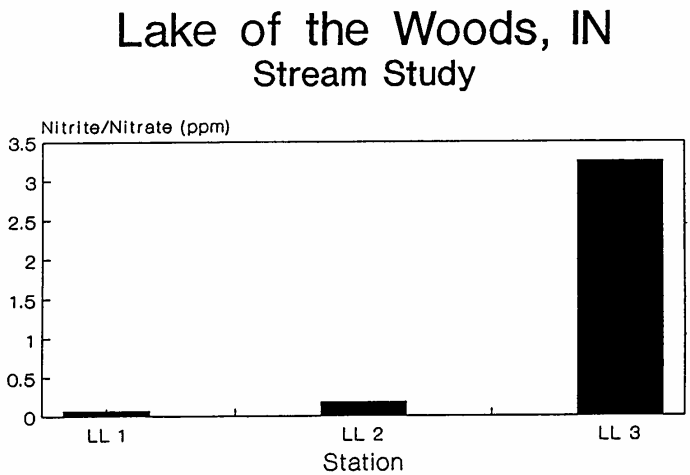
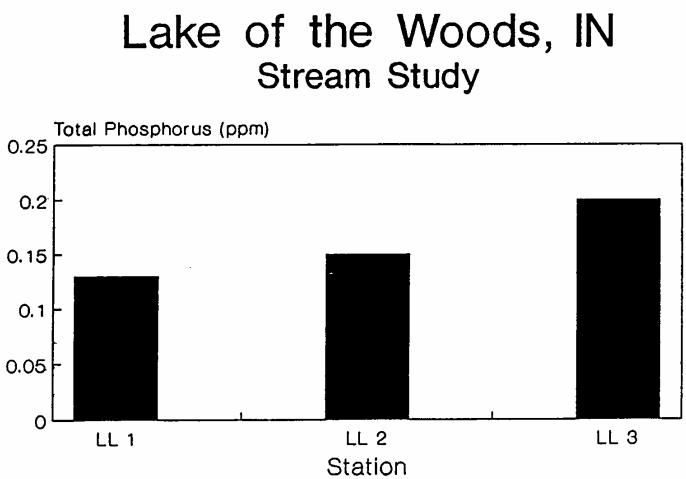


Figure W19. Nitrite/Nitrate Values for Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.



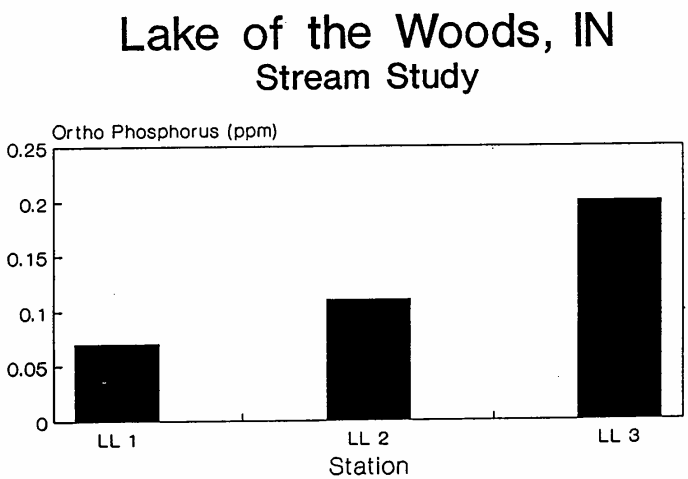


Figure W20: Total Phosphorus and Orthophosphorus Values for Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.

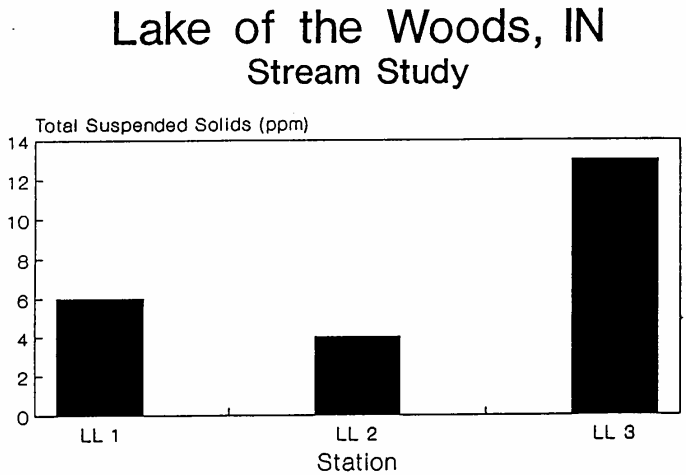


Figure W21. Total Suspended Solids Values for Two Ditches Draining the Lake of the Woods Watershed For 18 January 1990. Station LL2 is the Lake Outlet.

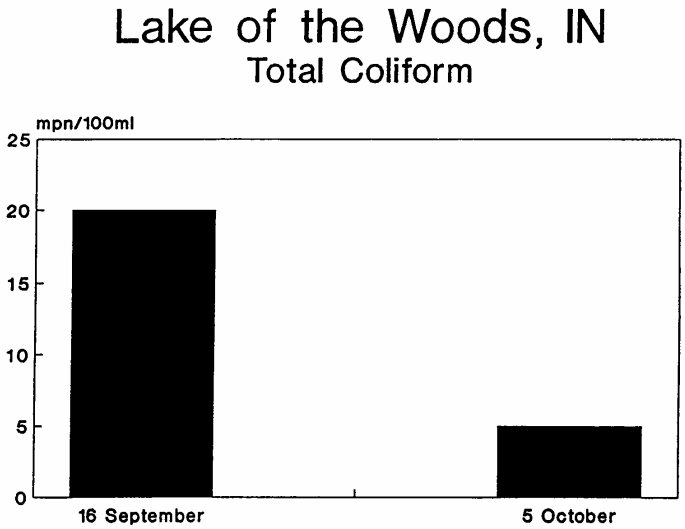


Figure W22. Total Coliform Bacteria Values for Lake of the Woods During September and October 1989.

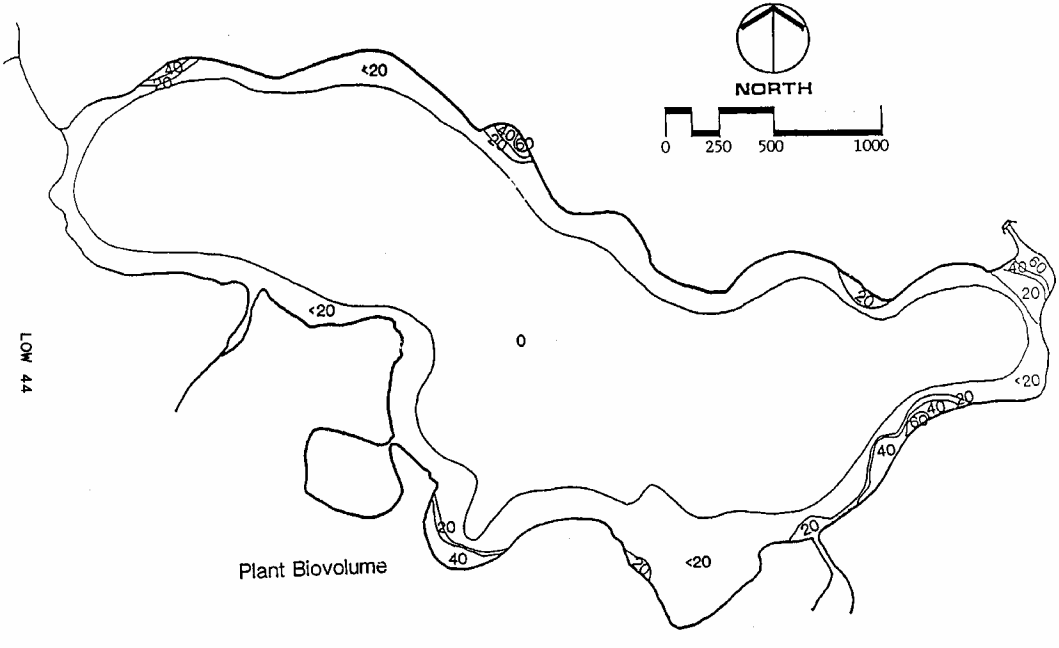


Figure W23. Distribution of Aquatic Macrophyte Biovolume in Lake of the Woods for 1989.

Lake of the Woods, IN
Plant Distribution by Depth

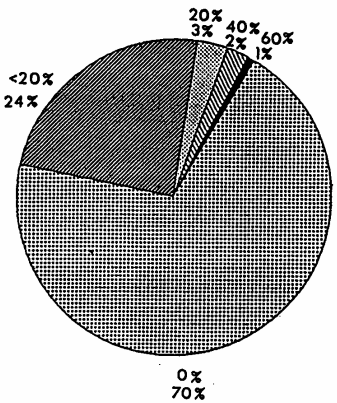


Figure W24. The Distribution of Plant Biovolume in Lake of the Woods Expressed as a Percent of Water Column Infestation.

Areas of 100% and 80% water column infestation were essentially absent from Lake of the Woods, and 60% infestation represented only 1% of lake surface area. The remaining 90% of the vegetated littoral zone (27% of total lake area) was characterized by less than 40% biovolume, with 80% of the zone (24% of total lake area) being less than 20%.

Our work at other Indiana lakes (Eviston and Crisman 1988, Crisman et al. 1990, Eviston et al. 1990) has demonstrated that the public perceives a macrophyte problem only when plant biovolume exceeds 80% of the water column. Following this reasoning, Lake of the Woods is essentially free of management problems with macrophytes. The depth distribution of macrophytes in Lake of the Woods is controlled both by basin morphometry and pronounced light limitation below 10 feet water depth. It is suggested further eutrophication of Lake of the Woods is not likely to result in a pronounced exacerbation of macrophyte problems beyond current levels.

The height of macrophyte growth throughout Lake of the Woods is depicted in Figure W25. Most of the vegetated littoral zone of Lake of the Woods was characterized by plant heights less than 2 feet tall with the second most important plant height interval being 2-4 feet. Only a single pocket of plant growth between 4 and 8 feet tall was noted in a cove along the northern lake shore. The observed distribution of plant heights in Lake of the Woods suggests a pronounced morphometric and light limitation to macrophyte growth.

In addition to looking at the distribution of plant biomass in Lake of the Woods, a qualitative survey was made to determine the distribution of the major plant species in the system (Figure W26). The submergent species, coontail (Ceratophyllum demersum), shared dominance of the vegetated littoral zone with eel grass (Vallisneria americana), and three species of pondweeds (leafy pondweed, sago pondweed, Richardson's pondweed). Richardson's pondweed (Potamogeton Richardsonii) is listed as a State endangered plant.

Fish

The Raytheon fathometer data recorded from the 20 cross lake transects were also used to provide a qualitative assessment of the fish community of Lake of the Woods. Echos of fish in the water column appeared on all fathometer recordings, and these were used to assess total fish abundance and the depth distribution of the population for the lake.

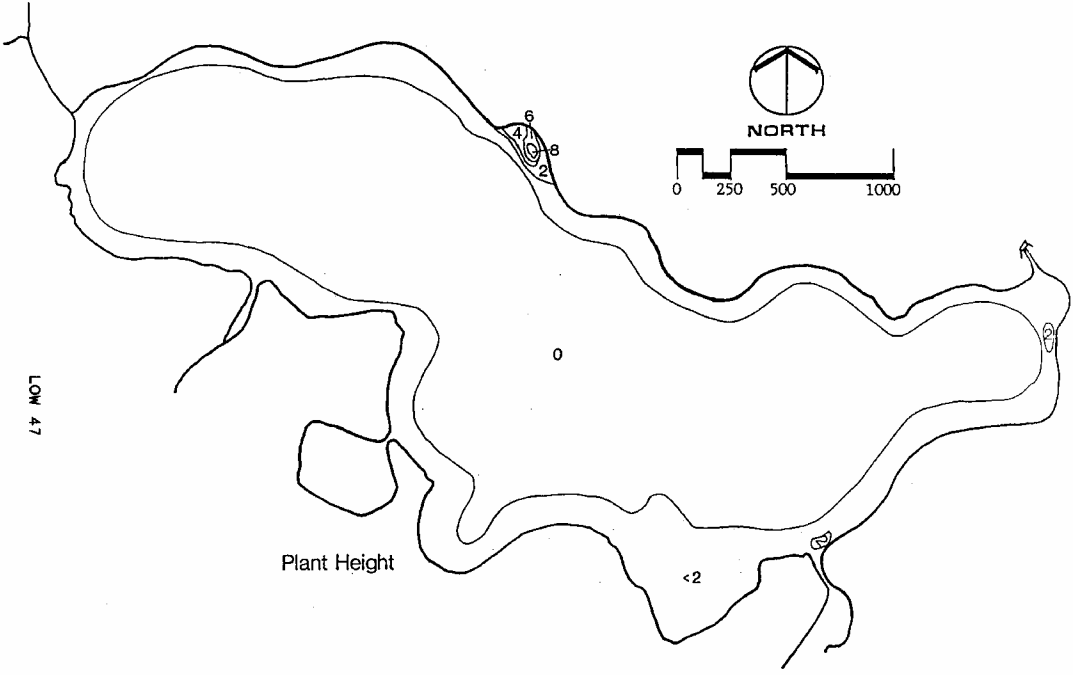


Figure W25. The Height of Aquatic Macrophytes in Lake of the Woods in 1989 by Two Foot Height Increments.

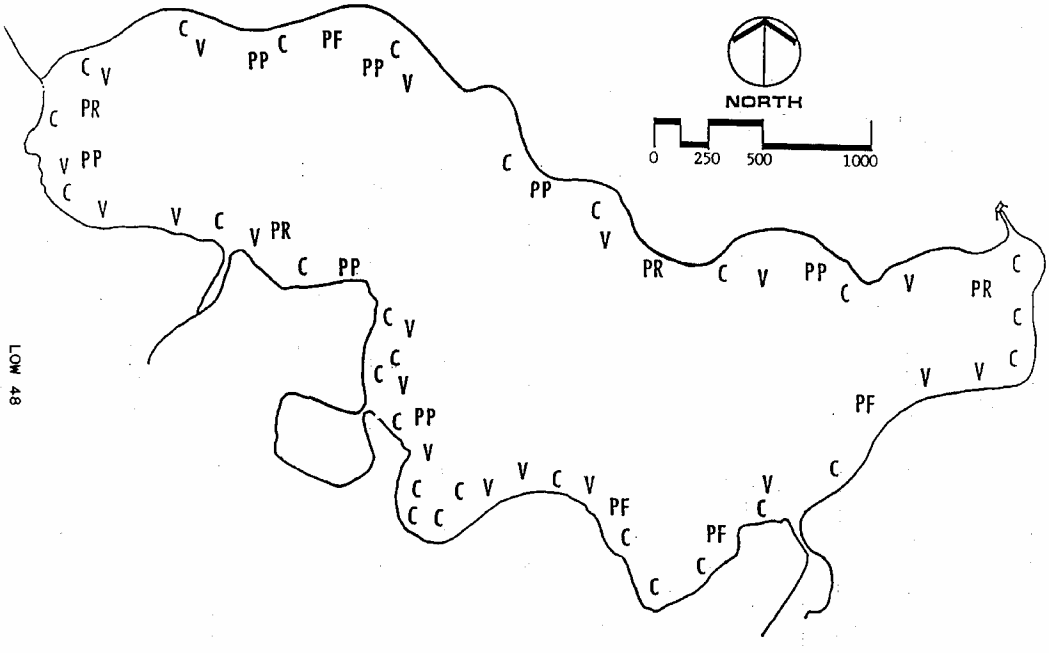


Figure W26. Distribution of Major Plant Taxa in Lake of the Woods in 1989. Plants were: Ceratophyllum (C), Potamogeton foliosus (PF), Potamogeton pectinatus (PP), Potamogeton richardsonii (PR), and Vallisneria (V).

Total fish abundance in open water areas of Lake of the Woods was estimated at 7/1000 feet of fathometer transect. The greatest density of fish (36% total abundance) was at a depth of 16-19 feet (5-6 meters) with the second greatest density at 3-6 feet (1-2 meters) (Figure W27). Fish avoided depths shallower than 3 feet (1 meter), the area of highest temperatures, and deeper than 16-19 feet (5-6 meters). The latter depth interval was the thermocline, below which oxygen values quickly fell to less than 1 mg/L. Only 12% of the fish tabulated were found below the thermocline. It must be noted, however, that oxygen is only one of many factors controlling fish distributions. Macrophytes such as found at lake depths less than 10 feet provide a prime habitat for both feeding and reproduction and are a major contributing factor to fishery production.

Bathymetric Map and Lake Infilling

The United States Geological Survey published a bathymetric map of Lake of the Woods based on a survey of 1958 (Figure W28). Depth contours were constructed at five foot intervals for the lake. The current study constructed an updated bathymetric map for 1989 based on fathometer recordings obtained from 20 lake transects (Figure W29).

Following convention established by the 1958 map, five foot contours were constructed for the 1989 map.

A comparison of the depth configurations for 1958 and 1989 is provided in Figure W30. The 70-75 foot contour in 1958 comprised approximately 18 acres, an area larger than displayed by an other single contour. The second largest contour was the 0-5 foot contour (17 acres). The deepest section of the lake (greater than 80 feet) was less than 3 acres. The 0-5 foot contour replaced the 70-75 foot contour as the contour displaying the greatest aerial extent in 1989 (20 acres), with the 70-75 foot contour being the second most important contour following a reduction in area to 13 acres. The deep water zone (greater than 80 feet) in 1989 comprised approximately 2 acres.

Sedimentation patterns for the past 31 years can be delineated through comparison of the aerial extent of individual contours for 1958 and 1989 (Figure W30). The aerial extent of the shallowest depth contour (0-5 feet) increased by 18% between 1958 and 1989. Conversely, 20-25, 50-55, and 70-75 foot contours displayed the greatest percentage decrease in extent during the 31 year period, 37%, 8%, and 28%, respectively. Those contours deeper than 75 feet either remained unchanged or decreased slightly during the same period.

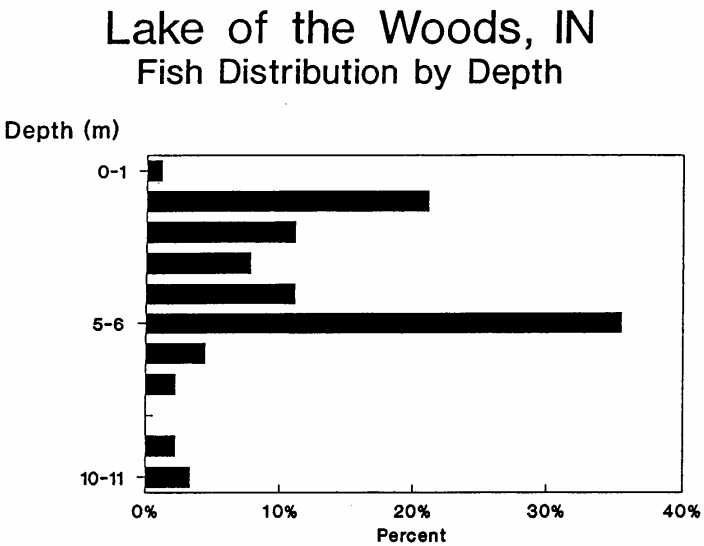


Figure W27. Semi-Quantitative Estimate of Fish in Lake of the Woods in September 1989 Expressed as Number of Individuals Per 1000 Feet of Fathometer Transect and Partitioned According to Water Depth.

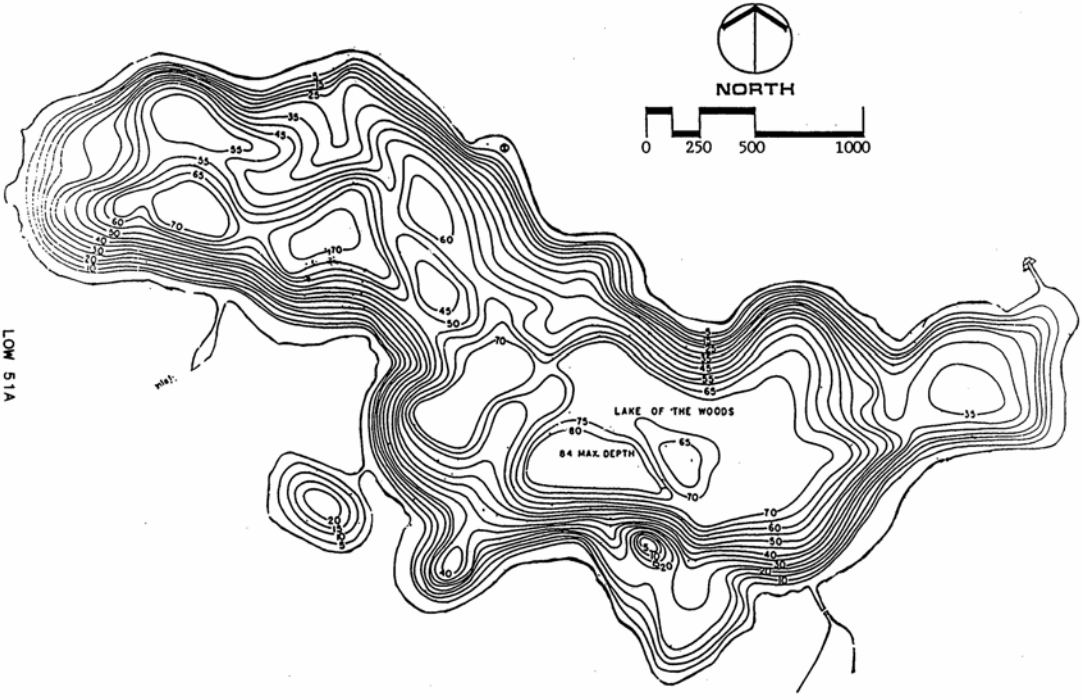


Figure W28. Bathymetric Map of Lake of the Woods from 1958

LOW 51A

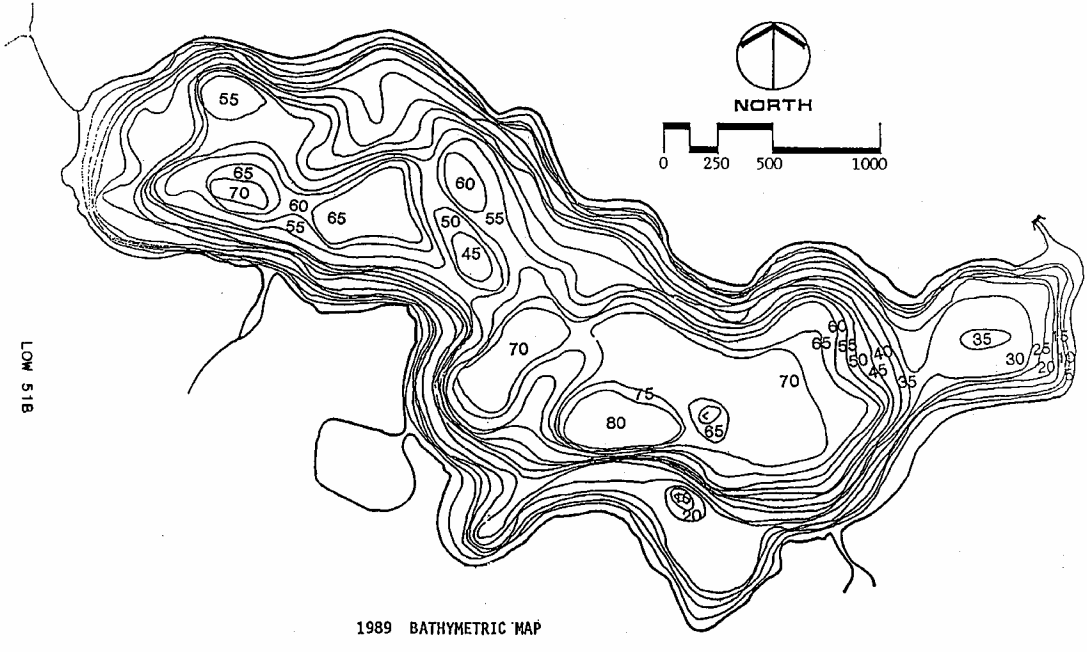
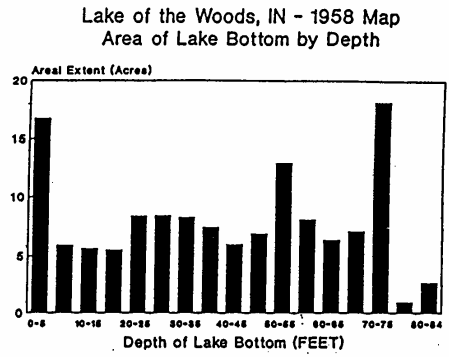
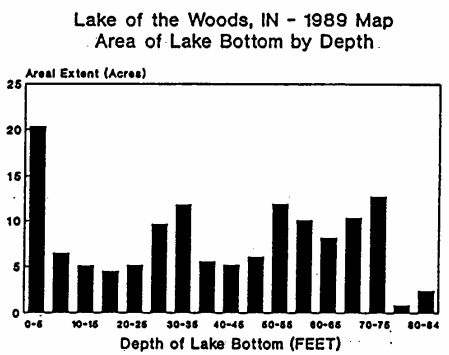


Figure W29. Bathymetric Map of Lake of the Woods from 1989.





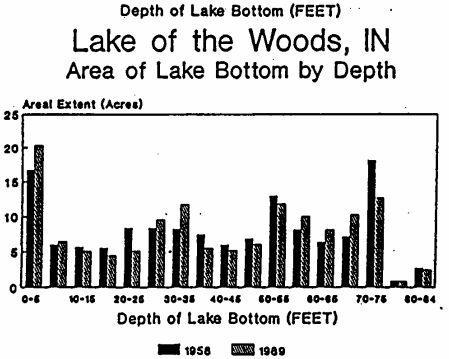


Figure W30. Comparison of the Depth Distribution Within Lake of the Woods for 1958 and 1989.

Infilling of nearshore areas was not uniform throughout Lake of the Woods between 1958 and 1989. The most pronounced sedimentation has taken place in the western third of the basin immediately offshore from the Maumee Ditch and the Spectacle Lake outlet and at the eastern end of the lake between the outlet from McClish Lake and the Lake of the Woods outlet.

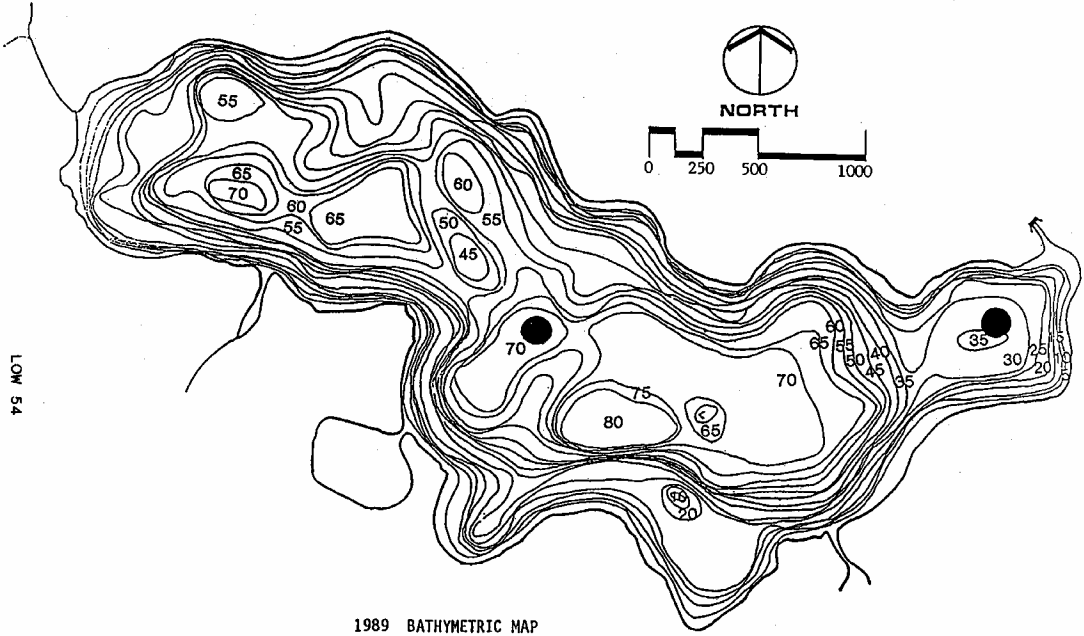
It is clear that basin sedimentation is strongly controlled by stream input of watershed erosion products. Most of the recent sedimentation in Lake of the Woods has been immediately offshore from the major inlets to the basin. Residents have reported that all three ditches deliver silt ladened water during spring and early summer. Two other contributors to lake infilling, motor boating and shoreline erosion, are not considered to be important factors for the observed pattern of sedimentation in Lake of the Woods.

Sediment Studies

Sediment Core Profiles

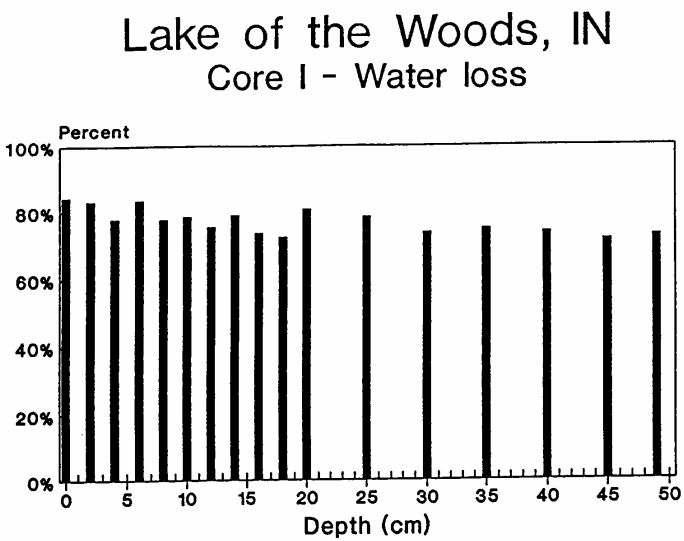
Two sediment cores were collected from Lake of the Woods (Figure W31). Core I (49 cm long) was collected from near the center of Lake of the Woods, an area considered to integrate the watershed loadings delivered by the Spectacle Lake outlet and Maumee Ditch. Core II (35 cm long) was situated near the lake outlet and thus would be most heavily influenced by loading from McClish Lake and its watershed. Both cores were collected by a piston coring device equipped with a clear plexiglass tube. This technique permitted examination of the cores to insure that the sediment-water interface was not disturbed during the coring operation. Each core was extruded within two hours of collection and sectioned at 1 cm intervals with each sample being placed in a plastic bag for storage. All samples were then kept at 4oC until analyzed. In addition to wet weight for select core levels, organic content was calculated as the difference in weight between the wet weight and that after drying at 100oC for 24 hrs. Inorganic content was calculated from the weight difference of the sample dried at 100o C for 24 hrs and ashed at 500o C for one hour. Phosphorus was determined by the standard ascorbic acid colorimetric method using filtrate collected from an HCl digestion of the sediment sample.

Water content of the two cores was similar (approximately 80%), and little stratigraphic variation was noted in either (Figure W32). Core I near the Maumee Ditch, however, did display a slight increase in water content in the most recently sediments. Organic content in both cores (Figure W33) ranged between 9% and 14%, with the surficial sediments in both being slightly more organic than deeper in the profile. The highest organic content was noted in core I collected near the mouth of the Maumee Ditch.



1989 BATHYMETRIC MAP

Figure W31. Sites of Sediment Core Collection in Lake of the Woods During 1989.



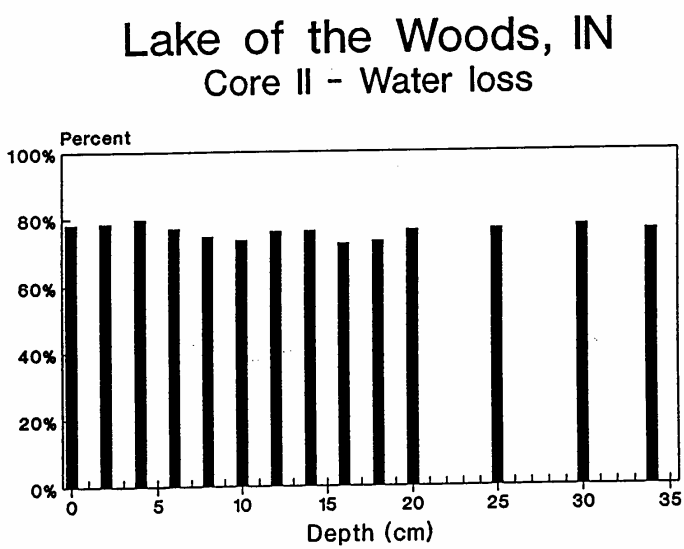
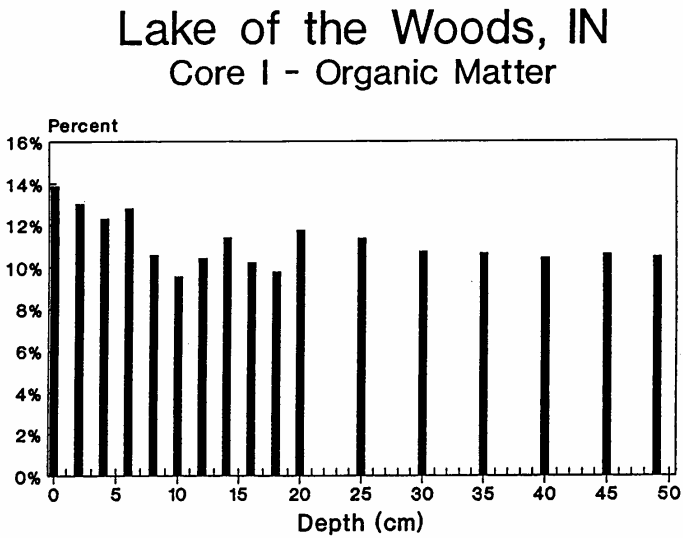


Figure W32. Profile of Percent Water in the Sediment Cores From Lake of the Woods.



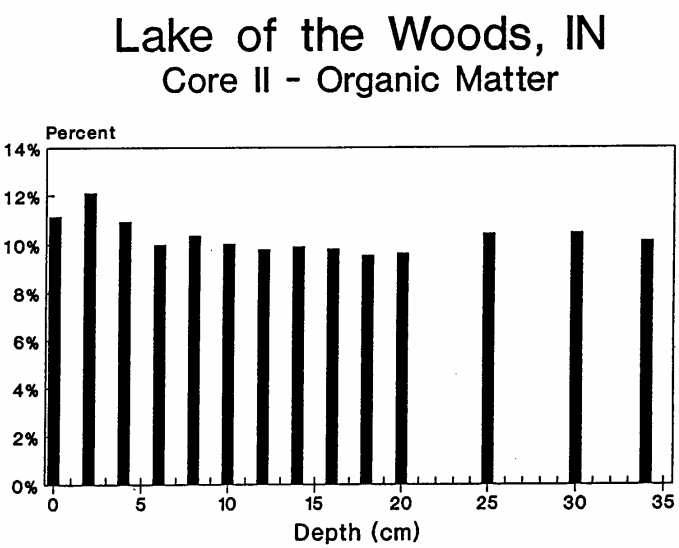


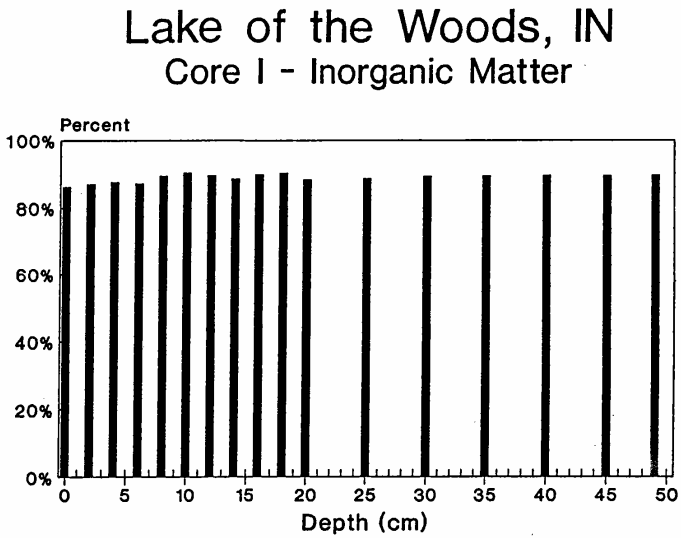
Figure W33. Profile of Percent Organic Matter in the Sediment Cores From Lake of the Woods.

The percentage of sediment dry weight contributed by the inorganic fraction remained at 80% to 87% throughout the length of both cores core (Figure W34). The percentage of inorganic matter found at Lake of the Woods is somewhat high for Indiana lakes of comparable trophic state and likely reflects that fact that this lake is receiving high sediment loads from the watershed. It is normal for Indiana lakes of intermediate trophic state to deposit in excess of 50 cm of sediment in one hundred years (Crisman 1987).

The slight variability in the percentage of inorganic and organic matter in the Lake of the Woods cores suggest that the relative contribution of each has changed little in at least the past 100 years. Increased organic deposition in the upper 1 cm of the core does not necessarily mean that the erosion rate has decreased. Rather, it suggests that lake productivity actually accelerated in the recent past associated with an increased percentage of year round residences and application of chemical fertilizers throughout the watershed. Given that no charge was included for 210-Pb dating in our budget and this parameter was to be used only if a pronounced stratigraphy was noted, we have not included such a dating technique.

In situations such as Lake of the Woods where the percentage of inorganic and organic matter does not change appreciably along the length of a sediment core, it is conventional to express total phosphorus concentrations as a function of the total dry weight of sediment at a particular depth in the core. Total phosphorus concentrations were greatest in the most recently deposited sediments (upper 10 cm) of both cores (Figure W35). Below this depth little stratigraphic variability was noted. The range of phosphorus values reported from Lake of the Woods are within the range displayed by cores from more eutrophic Indiana lakes including Bruce, Nyona, and South Mud (Crisman et al. 1990, Eviston et al. 1990).

The relationship between total phosphorus and sediment organic matter percentage for the Lake of the Woods cores is presented in Figure W36. Total phosphorus per gram of sediment dry weight remained increased in the surface sediments of both cores, while the percentage contribution of organic matter to total sediment dry weight remained constant. This trend suggests that phosphorus entering Lake of the Woods recently may not be as readily available for algal and macrophyte growth as in the past and may be associated with the inorganic sediment fraction.



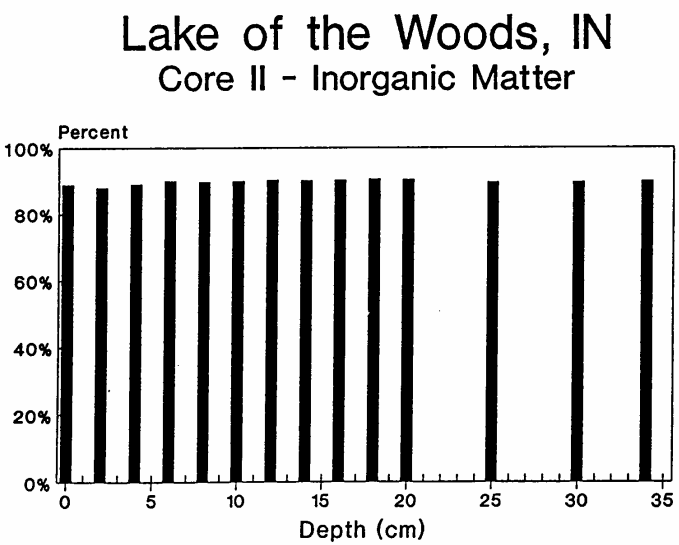
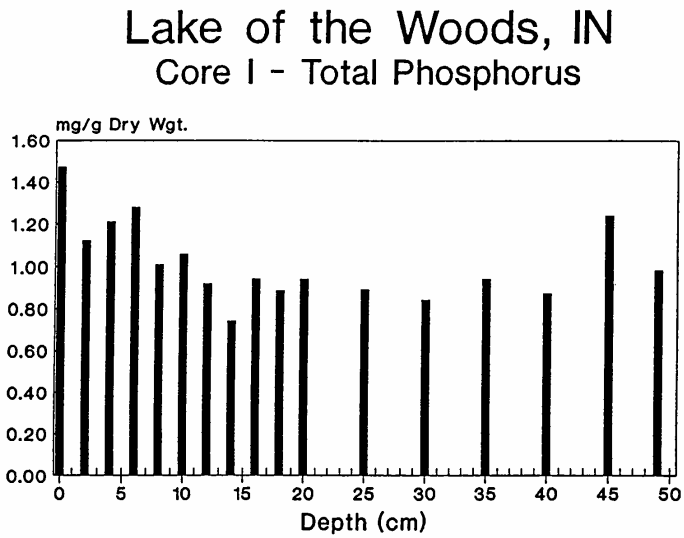


Figure W34. Profile of Percent Inorganic Matter in the Sediment Cores From Lake of the Woods.



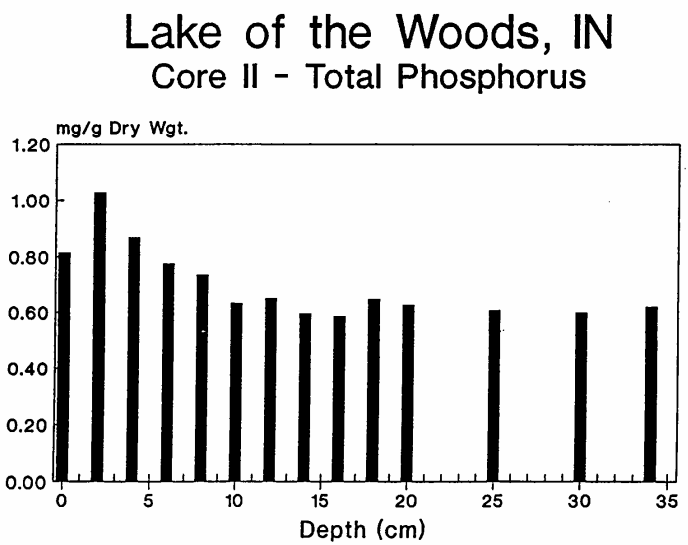
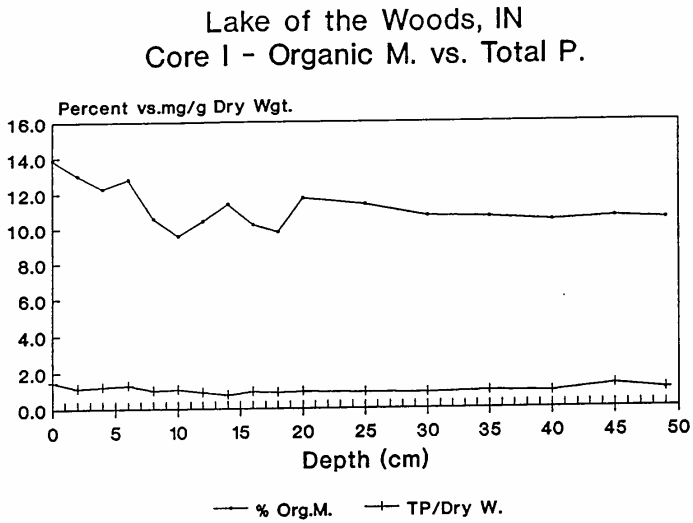


Figure W35. Profile of Total Phosphorus Concentrations for Sediment Cores From Lake of the Woods.



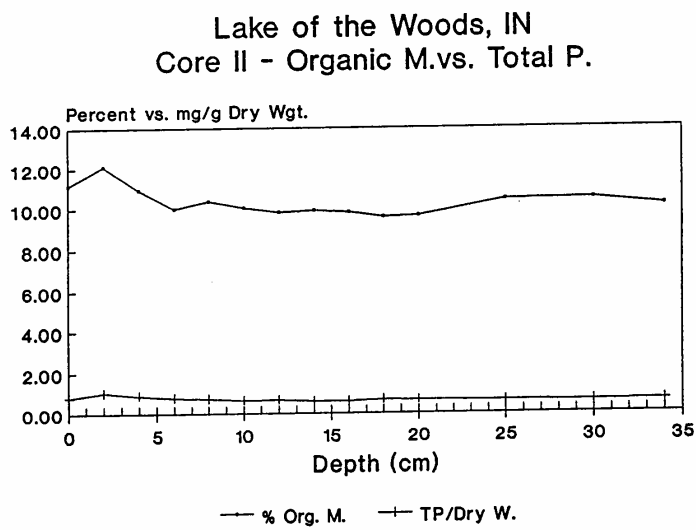


Figure W36. Comparison of Profiles of Organic Matter Percent and Total Phosphorus/Gram Sediment Dry Weight for Sediment Cores From Lake of the Woods.

Lake of the Woods, The Watershed

The Lake of the Woods Watershed

The approach of this part of the study is to specifically address the effect of the watershed on the Lake. After preliminary investigation, the method was to target the area(s) of highest concern. Our study had to discover how this watershed was contributing to challenges in this lake system. The concerns to be identified in the watershed were as follows:

a. Nutrient contribution to the Lake;
b. What are the probable sources;
c. How can sediment be reduced;
d. What are the intrinsic values of the watershed, and
e. How can the sources of sediment/nutrients be managed to reduce impacts to the lake?

This feasibility study included the use of the following resources:

a. Reconnaissance of the entire watershed by site visits on several occasions;
b. Walking tours of some private property areas that could not be properly observed from public areas;
c. Aerial photographs (County Surveyor);
d. Aerial photographs (USDA - Soil Conservation Service, 1972 and 1973);
e. Aerial color infrared photographs (NAPP, 1987);
f. United States Geological Survey (USGS) quadrangle maps;
g. United States Fish and Wildlife Service, National Wetland Inventory maps;
h. USDA - SCS Soil Surveys of DeKalb (1982), LaGrange (1980), Noble (1977) and Steuben (1981) Counties Indiana;
i. DeKalb, LaGrange, Noble, and Steuben Counties records: Auditor, Surveyor, Treasurer, etc:,
j. Various meetings and/or telephone conversations with State & County agencies, local property owners.

The main purpose of this investigation was to target the area(s) which would be the highest priority(ies) for land treatment systems for trapping nutrients and sediments in the watershed. These constructed solutions may consist of land treatment, settling basins, constructed wetlands, sediment traps, ponds, or shallow water habitat areas, etc. These terms are descriptive of similar broad-scale land treatment concepts that would reduce nutrient and sediment loading to the Lake of the Woods system. Other upland agricultural practices such as terracing, grassed waterways, conservation tillage, and proper animal waste disposal are all vital methods to improving the water quality of the lake. These practices, are discussed later in this section. Methods of land treatment and applications will be

recommended for problem areas. Local SCS and ASCS offices have been appraised of the areas felt to be contributing excessive amounts of sediment and nutrients or that would otherwise benefit from programs beyond the scope of the Lake Enhancement Program (see watershed tour). The goal of this feasibility study is to focus on the site(s) of greatest potential; to most benefit the lake system in the shortest time; and to attempt to identify the process to create this system and its costs. The final considerations that would evaluate the feasibility and/or priority of such constructed projects would then be up to the Lake Association leadership. Discussions with the Soil Conservation Service county offices indicated the awareness of problems with soils and agricultural practices above the lake. The SCS has pledged to help the Lake Association in any way possible including technical support, and initiating discussions with owners of properties which are contributing intolerable amounts of sediment, nutrient, and animal waste runoff. The SCS would be important support on the larger constructed solutions, and could be of prime responsibility to encourage and/or design the other upland practices and structures.

Natural Features

The Lake of the Woods watershed falls in the Northern Lakes Natural Region (Homoya et al, 1985). This Natural Region is comprised of numerous fresh water lakes of glacial origin. Natural community types common to this region include bog, marsh, lake, sedge meadow, prairie and various deciduous forest types. The aquatic communities may be characterized by the presence of bulrush, marsh fern, cattails, pond weeds, spatterdock, Virginia arrow-arum, orchids, tamarack and various species of sedges. The State endangered, Richardson's pondweed (Potamogeton Richardsonii) was identified as one of the dominant species in our aquatic plant survey for Lake of the Woods. The typical forest community which at one time covered over half of this natural region is dominated by oak (chiefly, red oak) and hickory. Other notable species include black, silver, sugar, and red maples; beech; American and red elm; green ash and cottonwood. Cisco (Coregonus artedii) a specie of State special concern was last reported in Lake of the Woods in 1975, and by 1988 was believed to be extinct (IDNR 1989).

Techniques useful in preserving these natural features include:

a. Avoid relocation of natural stream channels

b. Avoid building close to wooded ravines or stream banks.

c. Preserve natural vegetation adjacent to water areas.

d. Avoid construction in, or drainage of, wetlands.

e. Avoid the use of on-site septic systems near the lake or near drainages where there is potential for saturated soils.

Watershed Tour--impressions by visual survey

Lake of the Woods and Watershed

The purpose of this section is to express in narrative form the observations and general visual impressions that were made during site tours of the watersheds and review of color infrared and other aerial photographs. The intent is to provide a perspective that may be fresh and to stimulate residents to make their own continuing observations.

Prior to our detailed watershed tours, we examined several aerial photographs of the Lake and watershed. The purpose of this was to identify potential problem areas not likely to be observed from the ground in order that they could be checked in the field. Aerial photographs were also used to help us focus on the "big picture". This allowed us to understand the watershed interaction as a whole before we broke it down into its smallest components (Figure W37).

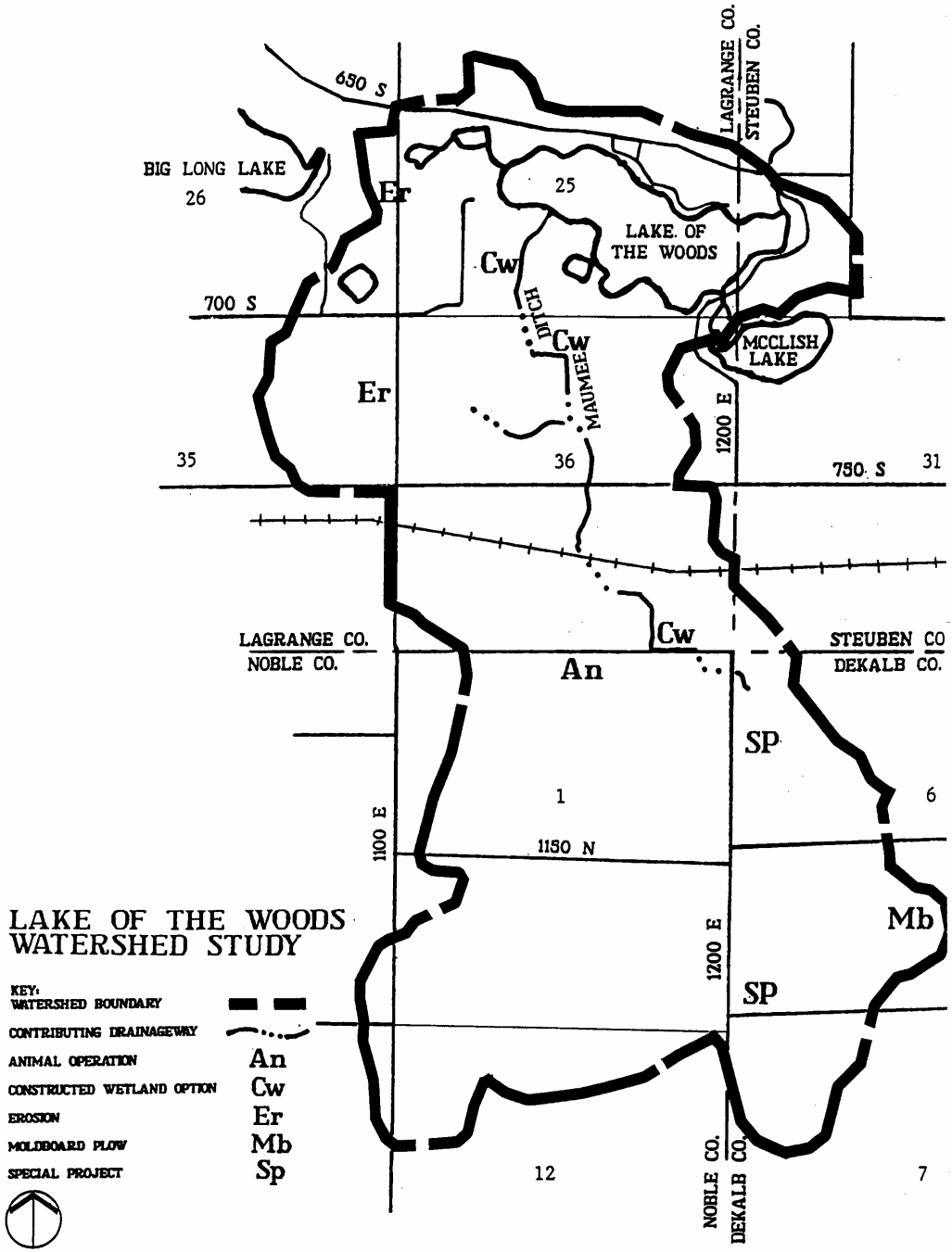
1. The third largest lake in this study, the Lake of the Woods exhibits some of the best and worst conditions for water quality effects in the lake.

2. 'Best' conditions are the substantial natural condition of the western and southern shores of the lake. About 40% of this lake is 'undeveloped', probably because of the lowness of this area. Features of this zone includes the 'Goose Pond', Camp Lakewood, and Spectacle Lakes. Another best condition is that McClish Lake is serving as a nutrient and sediment trap for about a fourth of Lake of the Woods' watershed.

3. Conditions of concern to the lake proper are the closeness to the lake and the apparent lowness of the residential development around the lake. This occurs mainly on the southeast shore.

4. Other concerns are the eroded (Er) areas from Sections 35 and 26. The drainageway along road 1100E was flowing with sediment when noted. About eighty feet of fall occurs in one mile to the lake from Section 35.

5. The main contributor of water to Lake-of-the-Woods is the Maumee Ditch. Nearest the lake, it runs through a quality forested wetland area, unfortunately, flow is confined to the ditch. Constructed options (Cw) on the ditch are to be investigated in the north edge of Section 36, and Section 25. Another good site appears in the southeast corner of Section 36. Deep stream cuts occur between the railroad grade and to the north of 750S. The open ditch ends at 1200E.



WATERSHED IMPRESSIONS
(Figure W-37)

Consideration of these two general locations would intercept both the upland cropland and the high erosion potential nearer the lake.

6. A 'fertile' hog operation (An) is located on the LaGrange/Noble County Line, and contributes directly to the Maumee Ditch. This needs to be intercepted and/or managed properly! Management could involve: implementation of animal waste management practices, diverting ditch flow from animal operations, livestock exclusion-fence livestock out of the ditches, establish permanent vegetative filter strips between livestock and open waterways.

7. The Noble and DeKalb Counties farm land in Sections 1, 6, 7, and 12 is relatively flat and appears to be well managed in corn-hay rotation. It is expected that sediment borne nutrient contribution by tile drainage would be the greatest concern from this land.

8. A small portion of Section 6 (south central) is utilizing moldboard (Mb) tillage in corn production. No-till cultivation is recommended for this area.

9. The opportunity exists at the head of the Maumee Ditch, to divert flow from tile drainage into an existing wetland located at the southeast corner of Section 36. The Maumee Ditch currently parallels the south and west borders of this wetland section. Many of the tiles above the head of the Maumee Ditch, Section 6, are in a state of disrepair, directly contributing sediments and nutrients into the ditch. Recent Special Projects (SP) initiated by the SCS in this area have included conservation tillage; corn-hay rotations; and riser pipes over dilapidated tiles. The objective of future projects in this area should be to minimize tile-water borne sediment by repair or replacement of broken tiles.

10. Returning to the extreme east end of the lake, there is about a fifteen acre field and gravel borrow area which should be managed for sediment control.

Photospectroscopy

Aerial photography is an intricate tool for use in many topographic and natural resource applications.

In doing a land use study using aerial photography, several items must first be considered to provide the most accurate detailed information possible in obtaining the desired data.

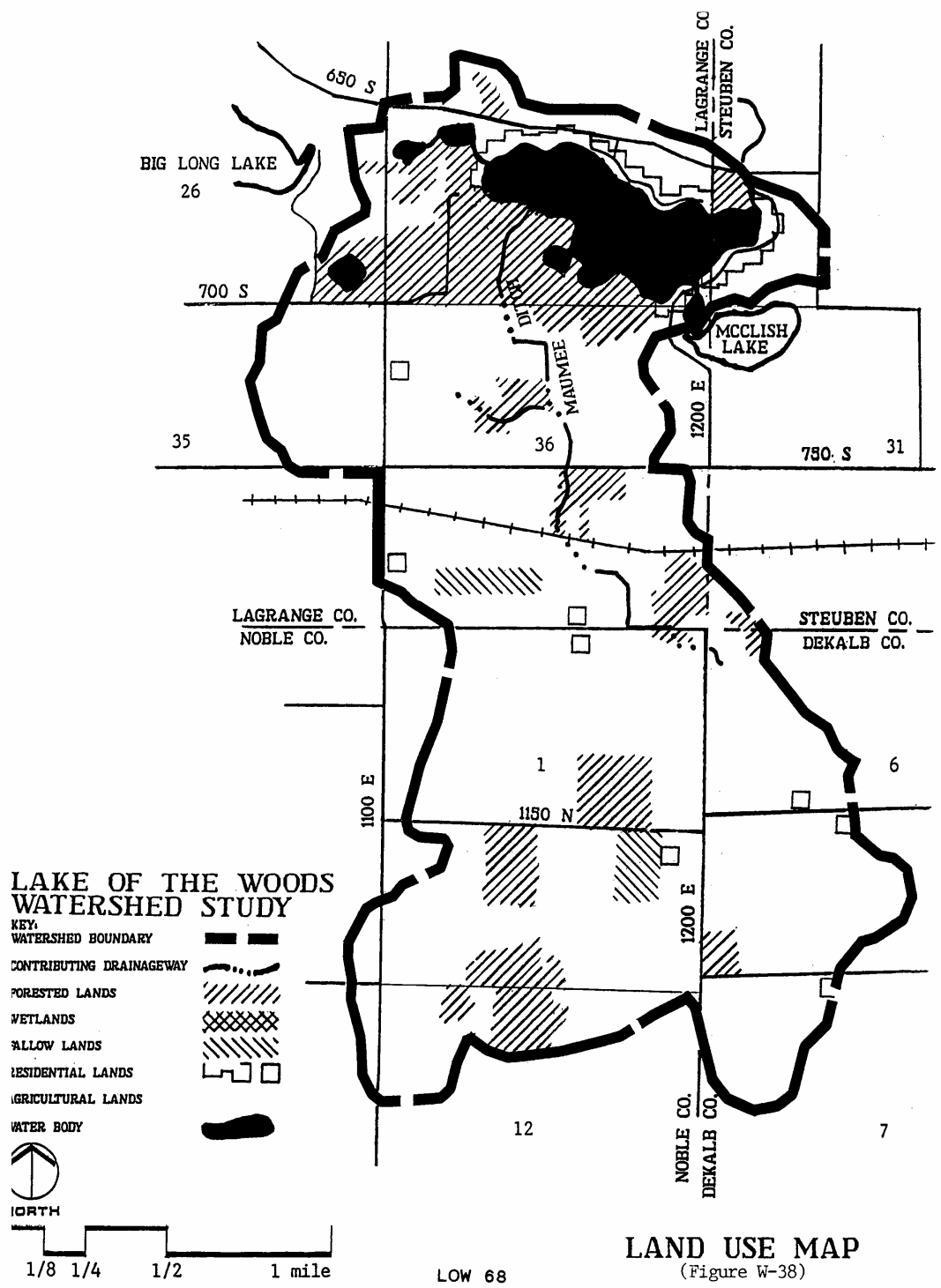
First, and probably most important in doing a study of primarily agricultural usage, the "type" of photograph used is important. For the most part, two "types" of photographs exist: 1) those taken in the visible spectrum, and 2) those taken in ultraviolet or infrared spectrum of light. Since all living organisms emit energy in the electromagnetic spectrum and since our study is based primarily in an agricultural watershed area, color infrared photography was used.

This type of photography delineates plants through size, density, and respiration, by photographing specific intensities of electromagnetic radiation emitted. Fallow lands, lake and wetlands appear as grey or black areas on the photo.

Second, the date in which the photographs were taken is an important consideration in the determination of the results and comparison to current trends.

Month and day play a factor in the interpretation of the types of vegetation and wetlands described. An extreme example of this would be trying to distinguish agricultural usage on a photo taken in July compared to the same photo taken in December. The day is also a factor because of previous weather conditions. According to the USDC, National Weather Service, 1.8 inches of rain fell over the project area in the 4 weeks prior to the photo date, this was 0.8 inches below normal, however this deviation was not sufficient to alter normal land use cover types. The photographs used for this study were taken on the September 4, 1987 fly-over at a scale of 1:40000 (figure page v).

In doing the land use study of the Lake of the Woods watershed, the entire watershed was laid out on the photographs using a transparency. The size of an overlay grid (1 acre) was then calculated, drawn, and then placed over the photos. From there the watershed was divided into the following land use categories: Agriculture; Fallow; Forested (woodlots); Lake of the Woods; Residential; and Wetlands. Results of the study are shown in watershed summary, Table W12. Land use is graphically represented in Figure W38.



LOW 68

LAND USE MAP
(Figure W-38)

LAKE OF THE WOODS LAND-USE SUMMARY TABLE		
Cover Type	Acres	% of Total
Agriculture	1193.6	55.9
Fallow	44.9	2.1
Forested (woodlots)	506.9	23.7
Lake of the Woods	133.0	6.2
Residential	208.6	9.8
Wetlands	44.9	2.1
Total Watershed Area	2134.9	99.8

Table W12. **Lake of the Woods Land-Use Summary**

Geology

The Lake of the Woods watershed is underlain by bedrock of the Coldwater Shale Formation (Gray 1987). The Coldwater Shale Formation consists of 90 to 350 feet of gray shale laid down in the lower Mississippian Period of the Paleozoic Era (about 350 million years ago). The west central and southern tip of the Lake of the Woods watershed is underlain by the Ellsworth Shale Formation, 340 feet of mostly green shale with some black shale nearer the lower facie. The Ellsworth Shale was laid down during the lower Mississippian and upper Devonian period of the Paleozoic Era (about 355 million years ago).

The shale deposits of the Lake of the Woods area are covered by over 200 feet of partially lithophied to unconsolidated glacial deposits (Gray 1989). The most recent glaciation occurred some 12,000 years ago during the Wisconsinan Advance (Hill 1986). The Lake of the Woods watershed is comprised of sediments deposited from the Huron-Saginaw Lobe of the Wisconsinan Ice Sheet. This material is dominated by areas of loam till and mixed drift. The more complex till of the area consists of stratified drift in chaotic form. For further discussion on surface geology, see Soils.

Topography

The watershed of Lake of the Woods is best described as a morainal topography. Morainal topography is a general term used to describe areas of irregular mounds and ridges which are the result of glacial drift. Glacial drift are deposits of outwash streams and unsorted sand and gravel tills. The highest point in the Lake of the Woods watershed is 1042 feet above sea level in the southwest corner of the watershed. The lowest point is 950 feet above sea level at the lake.

Relief throughout the watershed is characterized as flat to rolling to the south, moderately to steeply sloping in the north central region of the watershed, and rolling to depressional near the lake. Slopes range from 0 to 20 percent.

Severe slopes

The length and steepness of slopes are major factors in assessing the probable erosion risks of an area. On steep or long slopes, runoff water accumulates in channels where increased flows produce greater erosive forces. Level or flat lands produce shallow overland flows over a larger area. This decreases the erosive forces of runoff.

The intent of this study-map (Figure W39) is to further illustrate the fabric of the land forms in the watershed. Areas with severe slopes comprise 338 acres or 16% of the Lake of the Woods watershed. Severe slopes detailed in this study range from 10 to 20 percent. The majority of the severe slope areas occur southwest of Lake of the Woods. Much of this is agricultural land. This study provides further evidence where land management emphasis should be. This graphic also substantially matches the worst conditions of Highly Erodible Lands and will be discussed later in the report.

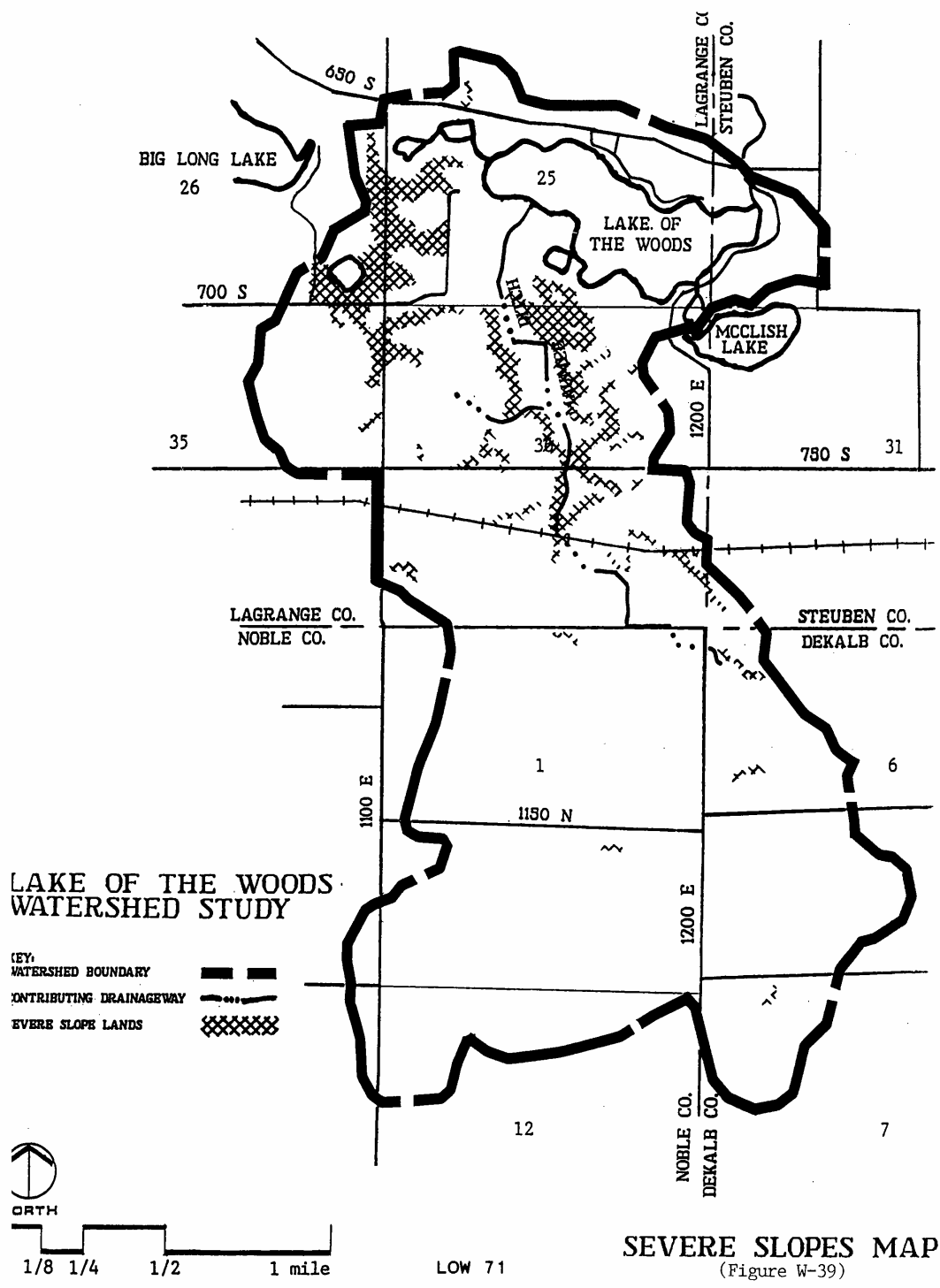
In general, areas mapped as having severe slopes should not be in agricultural crop production, or should be in a conservation tillage program.

Soils

The soils of the Lake of the Woods watershed are grouped in the: Strawn-Conover Association by the DeKalb County Soil Survey; the Wawasee-Hillsdale-Conover Association by the LaGrange County Soil Survey; the Miami-Riddles-Brookston Association by the Noble County Soil Survey; and the Kosciusko-Ormas-Boyer Association by the Steuben County Soil Survey. In general, the associations are characterized as moderately drained, nearly level to strongly sloping areas, with deep course to moderately fine grained soils of glacial till plains and moraines.

Overall, the associations are dominated by: Brookston, Hillsdale, Kosciusko, Miami, Oshtemo, and Wawasee soils.

The well drained Hillsdale, Kosciusko, Miami, Oshtemo, and Wawasee soils are on knobs, breaks between drainages, and on moderately sloping to level till plains. The poorly to very poorly drained Brookston soils occur on flats, depressional areas in uplands, and in drainageways.



SEVERE SLOPES MAP
(Figure W-39)

Highly Erodible Land

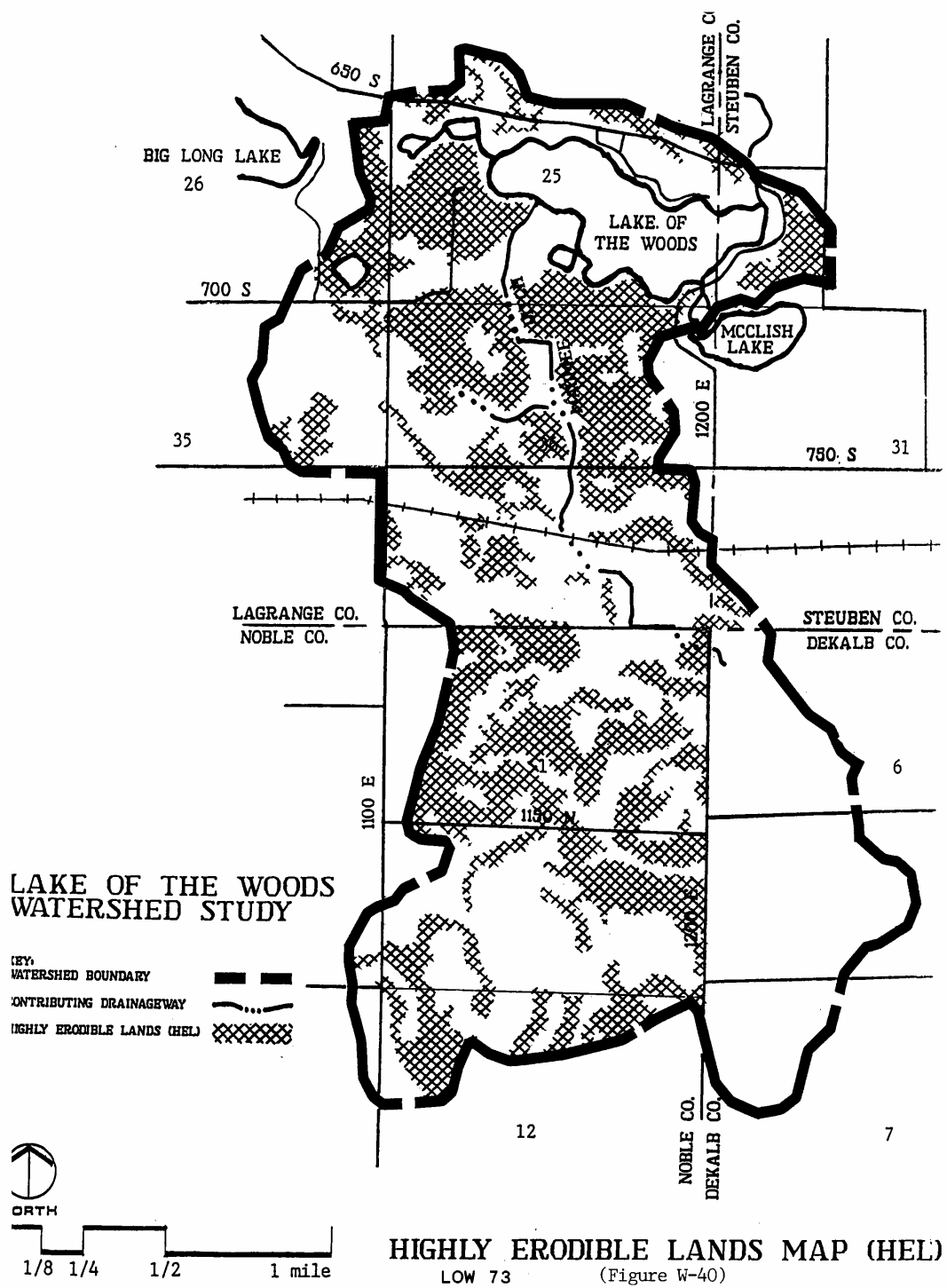
Highly erodible lands, or HEL are determined based on dominant slope length, percent slope and soil texture determined for each soil unit in each county. The purpose of identifying areas containing HEL is to display the origin of potential sediment sources so that the study may target areas of general concern. Using the Soil Survey of LaGrange County prepared by the USDA-SCS issued in 1980, and data provided by the local SWCD and SCS offices, soils of the HEL designation were mapped as shown in Figure W40.

The following highly erodible soils occur within the Lake of the Woods watershed (Table W13).

Boyer loamy sand, 6 to 12% slopes
Chelsea fine sand, 6 to 12% slopes
Hillsdale sandy loam, 6 to 12% slopes
Metea loamy sand, 6 to 12% slopes
Wawasee fine sandy loam, 6 to 12% slopes
Wawasee fine sandy loam, 12 to 18% slopes
Wawasee loam, 6 to 12% slopes
Wawasee loam, 12 to 18% slopes

Table W13. **Highly Erodible Land (HEL) soils of the Lake of the Woods watershed.**

The Lake of the Woods watershed was first analyzed to determine the total extent of HEL map units in the watershed. The watershed is comprised of approximately 824 acres (38.6%) of HEL. The study area was then further divided to determine the extent of HEL currently in crop production. HEL in agricultural production are of greater concern to the overall water quality of Lake of the Woods because these lands are more susceptible to erosive forces than HEL with established permanent vegetative cover. Approximately 72% (605 acres) of the total HEL occur in agricultural land-use areas, and are considered to be directly contributing sediment to Lake of the Woods. The HEL study was based strictly on HEL map units, it does not take into account non-HEL map units which may have inclusions of HEL soils. Target sediment sources were located using the HEL map and aerial photos, and will be discussed further in latter sections of this report.



HIGHLY ERODIBLE LANDS MAP (HEL)

LOW 73 (Figure W-40)

Highly Erodible Lands Overlays

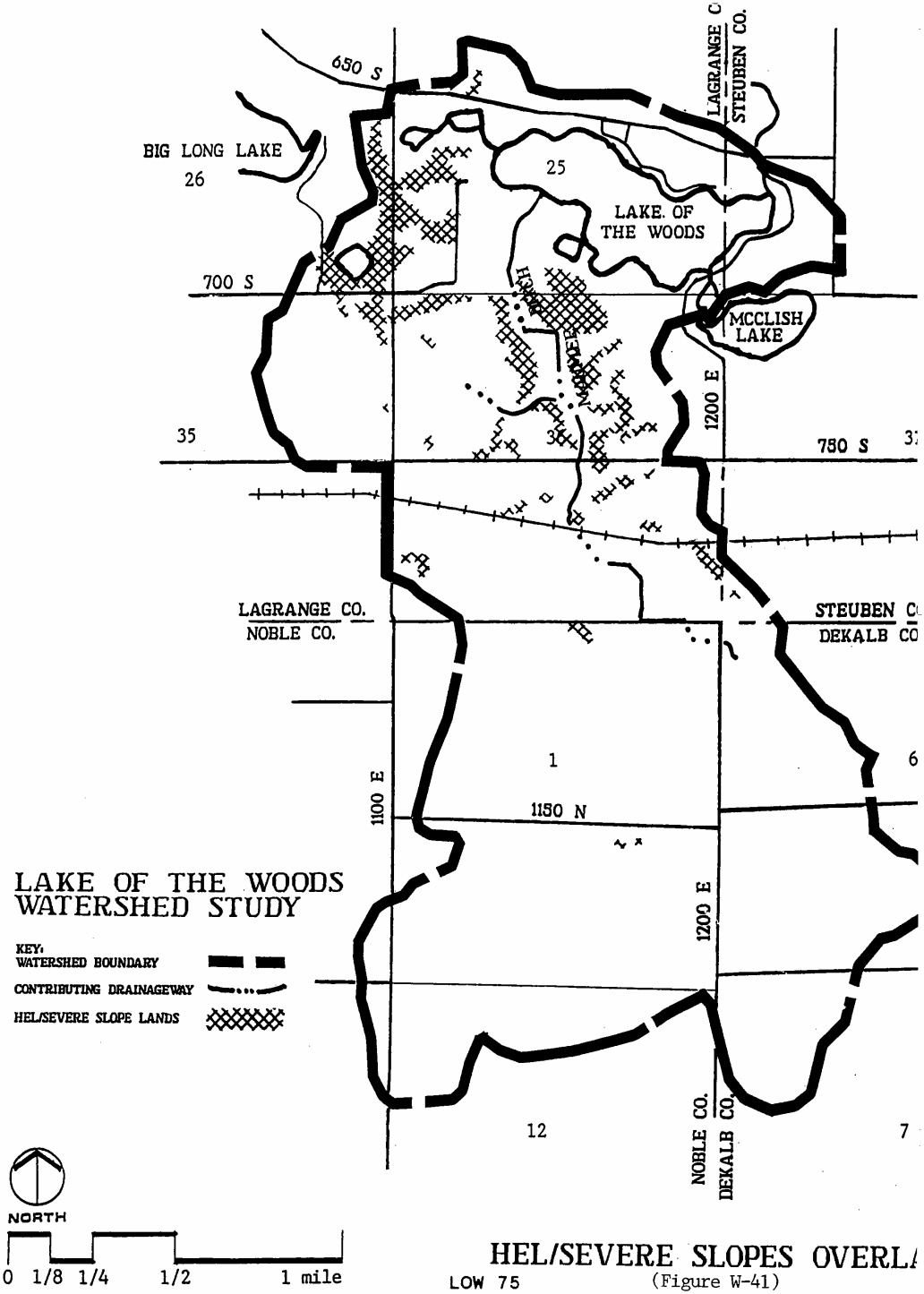
The intent of this HEL/Severe Slope Overlay (Figure W41) is to emphasize the areas of the watershed where severe erosion problems are likely to occur. The areas defined in the Agricultural Lands/HEL/Severe Slope Overlay (Figure W42) were in crop production as of 1987. The 101 acres, detailed in this overlay represent the worst case HEL areas of the Lake of the Woods watershed. The majority of these lands are adjacent to the Maumee Ditch which facilitate the transport of eroded soils to the lake. For this reason, those areas present the greatest sedimentation threat to Lake of the Woods. Every effort should be made to enlist those lands into CRP or related land treatment programs (grassed waterways, filter strips, etc.). It should be noted that in the past year, 1989, several areas in the southeast portion of the watershed, head of the Maumee Ditch have been enlisted into special programs offered by the SCS. This is a good start, but it is apparent from the HEL/severe slope overlay that the majority of the critical erosion areas of the watershed have not been fully addressed. These lands should not be in agricultural crop production.

Erosion: Causes and Prevention

Erosion of soil is primarily caused by the force of raindrops striking the ground, and, secondly, by the force of water flowing in rills or channels. As rain falls on unprotected ground it breaks small particles of soil free. These soil particles are then carried away by sheets of water. Naturally, as the intensity of rainfall increases, velocity and volume (flow) of runoff increases, thus potential soil erosion increases.

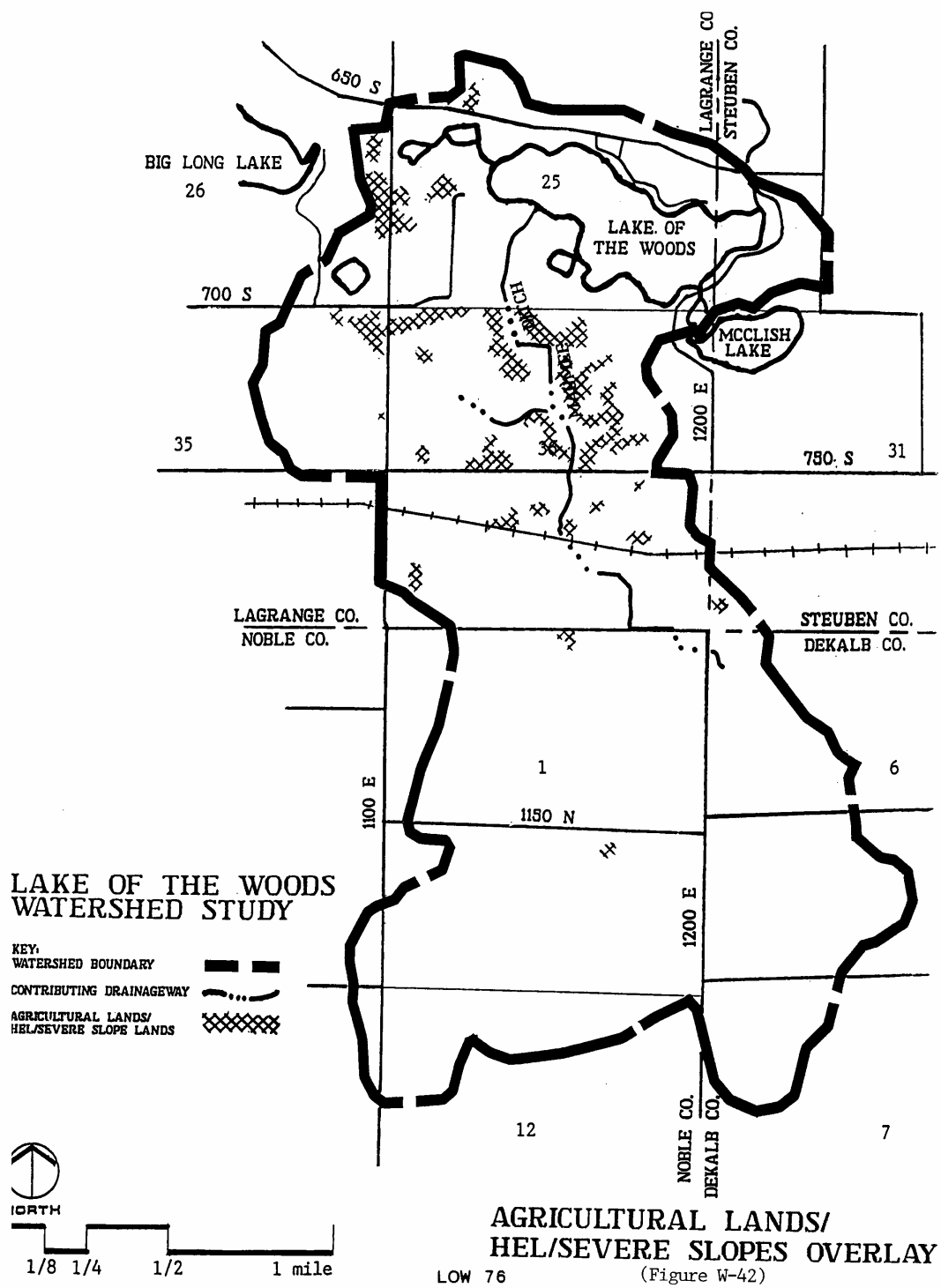
Types of soil erosion probable or noted in the Big Long watershed:

1. Raindrop (or splash) erosion due to the impact of rain on unprotected land.
2. Sheet erosion or overland flow causes exposed soil to be suspended by the action of the flowing water, this is common on sloping to nearly level unprotected land.
3. Rill and gully erosion is the result of concentrations of runoff water in riverlates. Rill erosion may cut several inches into the topsoil. Gully erosion, resulting from unmaintained rills or drainages, may cut several feet into the surface.
4. Streambank and channel erosion causes a scouring of stream bottom and undercutting of stream banks.
5. Wind erosion, similar to sheet erosion, is caused by the turbulent force of the wind over unprotected land.



HEL/SEVERE SLOPES OVERLA

LOW 75 (Figure W-41)



AGRICULTURAL LANDS/
HEL/SEVERE SLOPES OVERLAY
(Figure W-42)

The erosion potential of a given area may be determined by four criteria: 1) soils; 2) surface cover; 3) topography; and 4) climate.

An understanding of soils, and the factors involved in making soil more susceptible to erosion include: soil texture, soil structure, soil content of clay or organic material, and soil permeability. Maintaining adequate surface cover, either in the form of vegetative cover or crop residue, is important in reducing soil loss.

The realization is that soil is a valuable resource, and particles are difficult and expensive to recover once erosion has begun. **Prevention is easier than correction!**

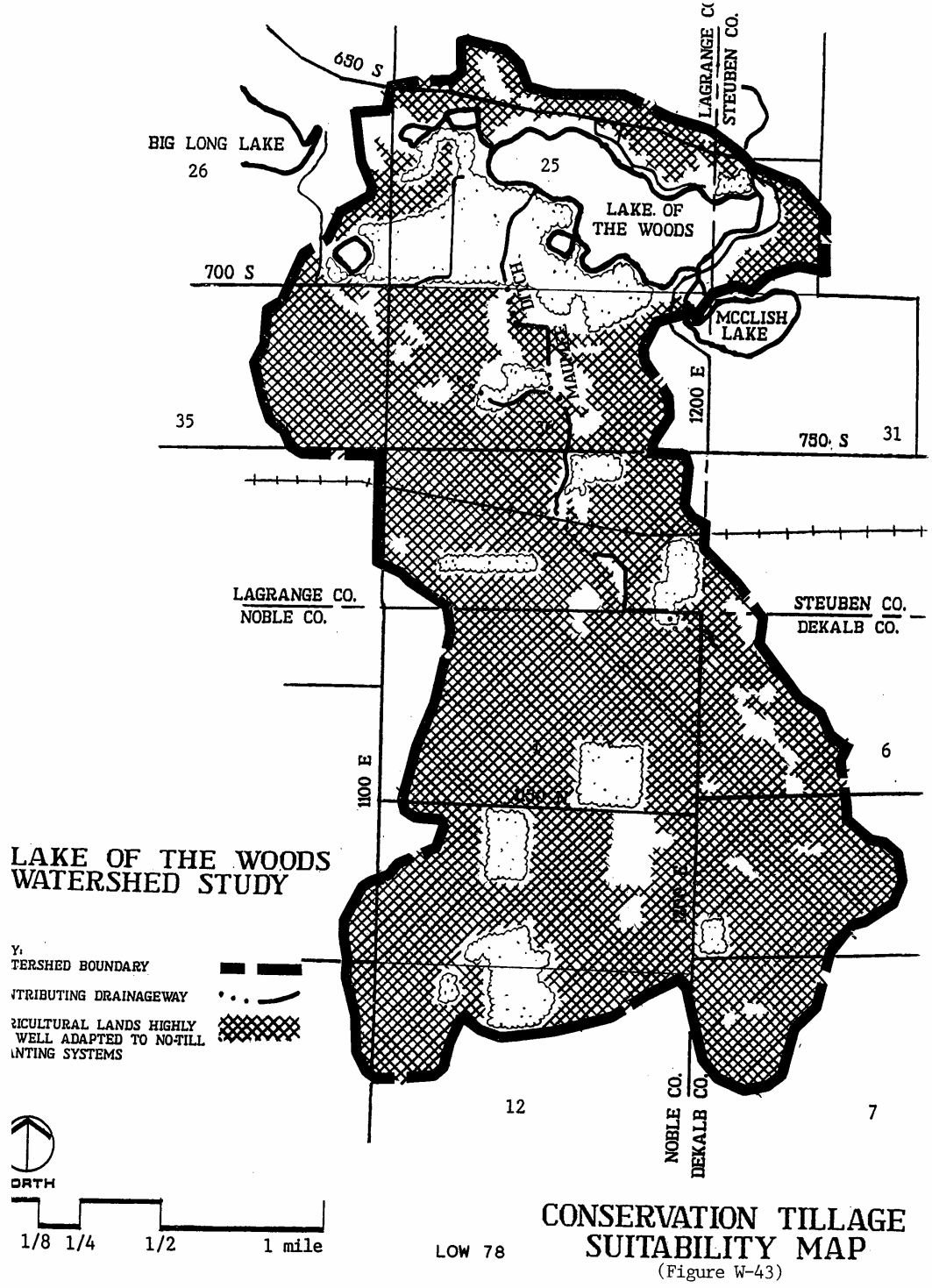
Useful concepts in erosion prevention and control:

a. Maintain natural vegetative cover wherever possible.
b. Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes.
   Row cropping should be done perpendicular to slope.
c. Divert runoff from severely sloping areas.
d. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.
e. Stabilize drainage areas immediately following any construction or "maintenance".
f. Leave natural buffer areas along streams and ditches.
g. Stabilize stream bank or ditch escarpments.
h. Utilize sediment ponds below feed lots and "open" sloping lands.
i. Construct and maintain sediment control structures <u>prior</u> to construction of any lake or waterfront development.
j. Implement applicable conservation tillage method.

Conservation Tillage

There are several methods of tillage currently utilized in corn and bean production: moldboard plow, chisel plow, large blade (deep) disc harrow, small blade (shallow) disc harrow, ridge-till, and no-till. Fall moldboard and chisel plowing are still frequently used by Indiana farmers, however, conservation tillage systems are becoming more widely excepted due to improved yields, and greater savings of soil, water, and money.

The no-till conservation tillage/planting system has been identified as one of the most effective conservation practice available to farmers in Indiana (AY-210). The Suitability for Conservation Tillage overlay (Figure W43) indicate 92% to 97% of the agricultural lands in the Lake of the Woods watershed are well to highly adapted to no-till conservation tillage systems. Agricultural lands depicted as unsuitable for no-till (5%) in the Lake of the Woods watershed include soils which are too wet or slopes greater than 12%. Lands noted as unsuitable to no-till should be in permanent cover.



CONSERVATION TILLAGE SUITABILITY MAP
(Figure W-43)

Development on Saturated Soils

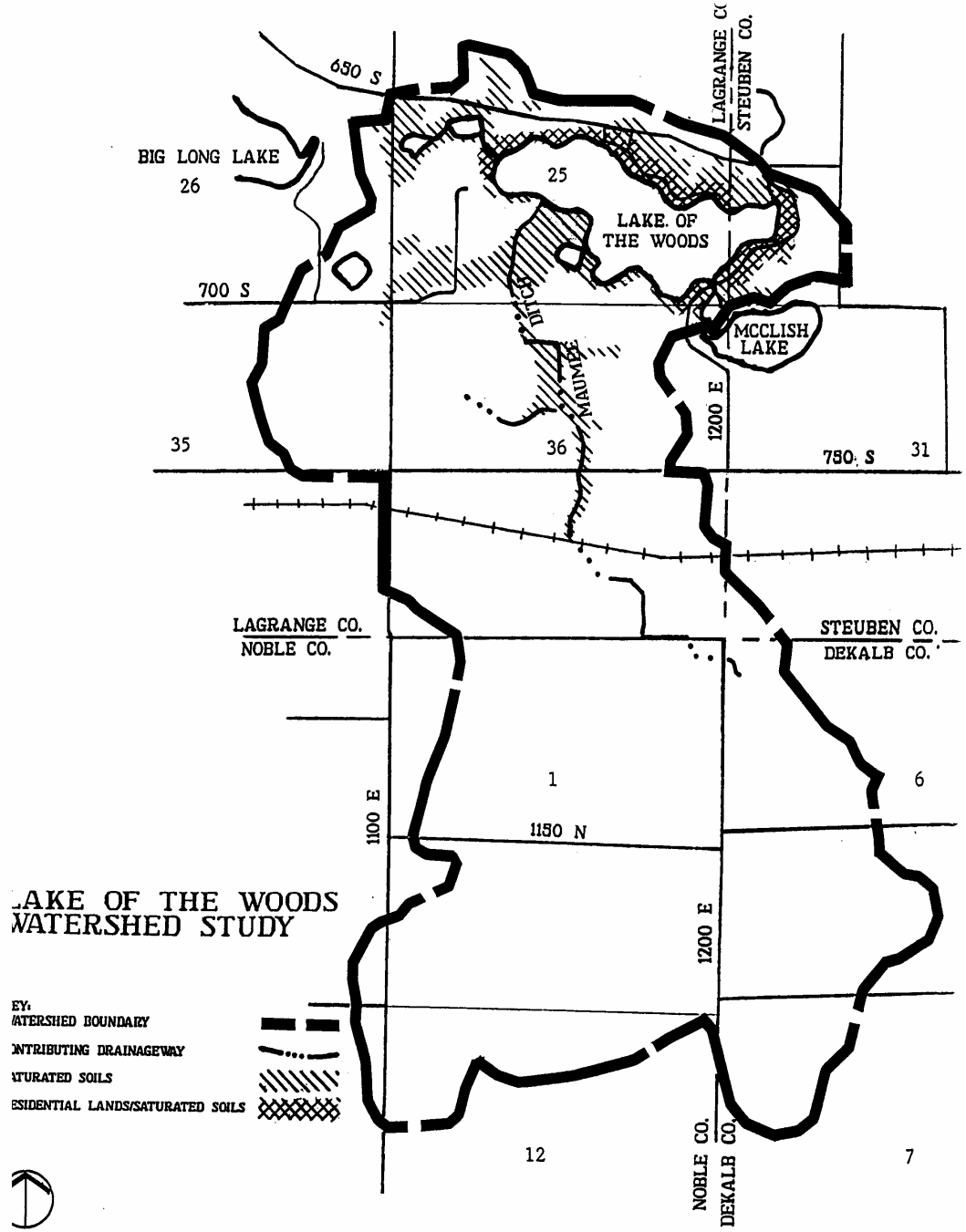
The goal of this study was to estimate potential septic system inefficiencies. Ineffective septic systems have been documented to contribute excessive amounts of nutrients to a lake. Using data collected on saturated soils (Table W14) and comparing it with building records from 1959, projections were established indicating septic systems that were likely to be located in saturated soils (Figure W44).

The assumption was made that septic tank-type systems are in place for those residences located on saturated soils. General septic system efficiencies are based on the need for well drained soils necessary for proper treatment of sewage effluent. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well-drained soils. It should be noted that seasonal fluctuations in the water table of poorly drained soils were not taken into account. Varying water table elevations and waste loading would be responsible for fluctuations in treatment success. Localized fecal coliform values likely increased due to a substantial increase in the summer population around the lake and fluctuations in the water table as well as residences in the watershed with septic systems that outlet directly into ditches.

The findings of this study (Figure W45) indicate a continued trend towards building on saturated soils. In 1959, on Lake of the Woods, 89 of the 101 homes (88%) were located on saturated soils. Building records from 1987 for Lake of the Woods demonstrated a high, but some what reduced ratio of 138 of 164 homes (84%) were located on saturated soils. The shore of Lake of the Woods is entirely comprised of saturated soils, this suggests that future trends will greatly favor development on saturated soils.

Possible approaches to meet the future waste disposal needs with the objective of maintaining or improving water quality would include: 1) Lake-wide sanitary sewer system, 2) mound type septic systems and/or 3) pumping to suitable septic locations and 4) any of the above in combination with a constructed wetland or pond/wet meadow system.

The **first**, likely most effective and costly method of waste handling would entail the construction of a lake community-wide, sanitary sewer system with off-site waste treatment. The **second** method, a mound type septic system would involve raising the septic tank and drain field above the saturated soil allowing for aerobic treatment of the sewage effluent. The **third** method of waste treatment, is a procedure which involves pumping the waste effluent to an area with soils suitable for use in septic tank systems.



SATURATED SOILS/
RESIDENTIAL LANDS OVERLAY

LOW 80 (Figure W-44)

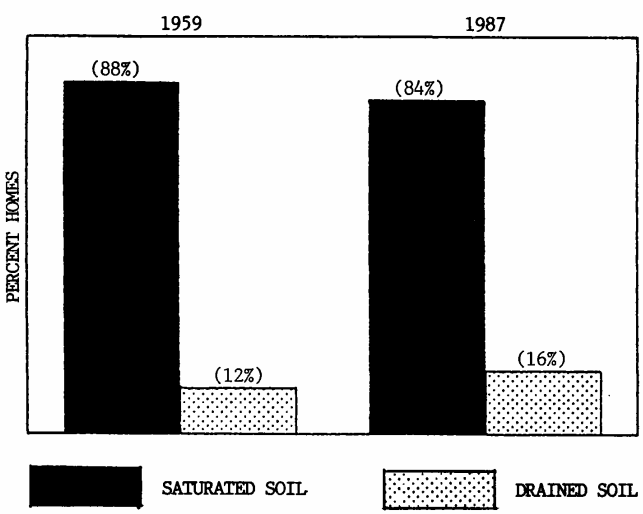
Although treatment is certainly not limited to the management approaches discussed above, it was determined that these methods of waste treatment would effectively meet the goals of sewage disposal.

Residences must take on the responsibility of maintaining their own waste disposal systems. Drain fields must be inspected regularly and septic tanks must be pumped on a regular schedule. Further study is recommended for those residential areas noted in the Saturated Soils/Residential Lands Overlay. A study could be developed utilizing a septic tank dye. If it is determined that an engineering study should be undertaken for a new wastewater treatment system, the method and site selection should consider tertiary treatment using a constructed wetland system.

Table W14. **Poorly drained soils of the Lake of the Woods area.** Adapted from USDA-SCS Indiana Technical Guide, 1988.

CONOVER loam	RENSSELAER loam
EDWARDS muck	SEBEWA loam
HOUGHTON muck	UDORTHENTS loamy
HOUGHTON muck, ponded	WALLKILL silt loam
PITS gravel	

Figure W45. **Profiles of Residences Located on Saturated Soils; Trends based on 1959/1987 building records.**



Hydrology

The Lake of the Woods watershed is a sub-drainage basin to the Lake Michigan Basin. The main water supply comes from ground water stored in the sand and gravel deposits of the Wisconsin till aquifer. The watershed of Lake of the Woods receives an average annual precipitation of 33.5 inches with a standard deviation of 6.3 inches. July tends to be the wettest month with an average precipitation of 3.8 inches. On average, February is the driest month with a precipitation mean of 1.7 inches. The average basin drainage gradient in the Lake of the Woods watershed is 29.4 feet/mile. The Maumee Ditch channel gradient is 22.4 feet/mile. According to the 1979 Cowardin et al classification system, water regimes range from temporarily flooded to permanent. Sixty percent of the wetlands located in the watershed are of seasonal water regimes. Ninety-one percent are small, less than ten acre, palustrine wetlands (Table W15). Palustrine wetlands are defined here as wetlands less than 20 acres in size, averaging less than 6 foot in depth, and dominated by trees, shrubs, and/or emergent vegetation (Mitsch and Gosselink, 1986).

It is estimated that 71% of the wetlands in the Lake Michigan Basin have been lost (Hamilton 1965). Losses are primarily attributed to drainage for agricultural production. The following table is intended to illustrate the types of wetlands remaining in the Lake of the Woods watershed, and focus attention on preserving these natural filters.

Table W15. **Lake of the Woods watershed water regime characteristics**

Palustrine	Occurrence	%Totals
Less Than 10 Acres	50	90.9
More Than 10 Acres	5	9.1
Totals	55	100.0
Cover-Type		
Emergent	34	61.8
Forest	16	29.1
Scrub/Shrub	3	5.5
Open Water	2	3.6
Totals	84	100.0
Water Regime		
Temporary	3	5.4
Saturated	4	7.3
Seasonal	33	60.0
Semi-permanent	3	5.4
Permanent	1	1.8
Unknown	11	20.0
Totals	84	99.9

Computer Modelling: Hydrology

The focus of the study, a computer model using SEDIMOT-II, (Warner, 1983) was used to project storm runoff, and hydrographs for 5, 25, and 100 year storm events. Data used for the computer model was derived in part from the land use study. Cover types for each segment of the subwatershed were assessed using color infrared aerial photographs, soil input was supplied by the USDA-Soil Conservation Service, and slope segments were determined using information from the US Geological Survey. Results of this study were used to predict sediment removal ability of proposed control structures located on the Maumee Ditch above the Lake of the Woods using the Surface Loading Rate formula (SLR), (Barfield 1987).

The hydrology modeling techniques used in the SEDIMOT-II program are divided into two major areas:

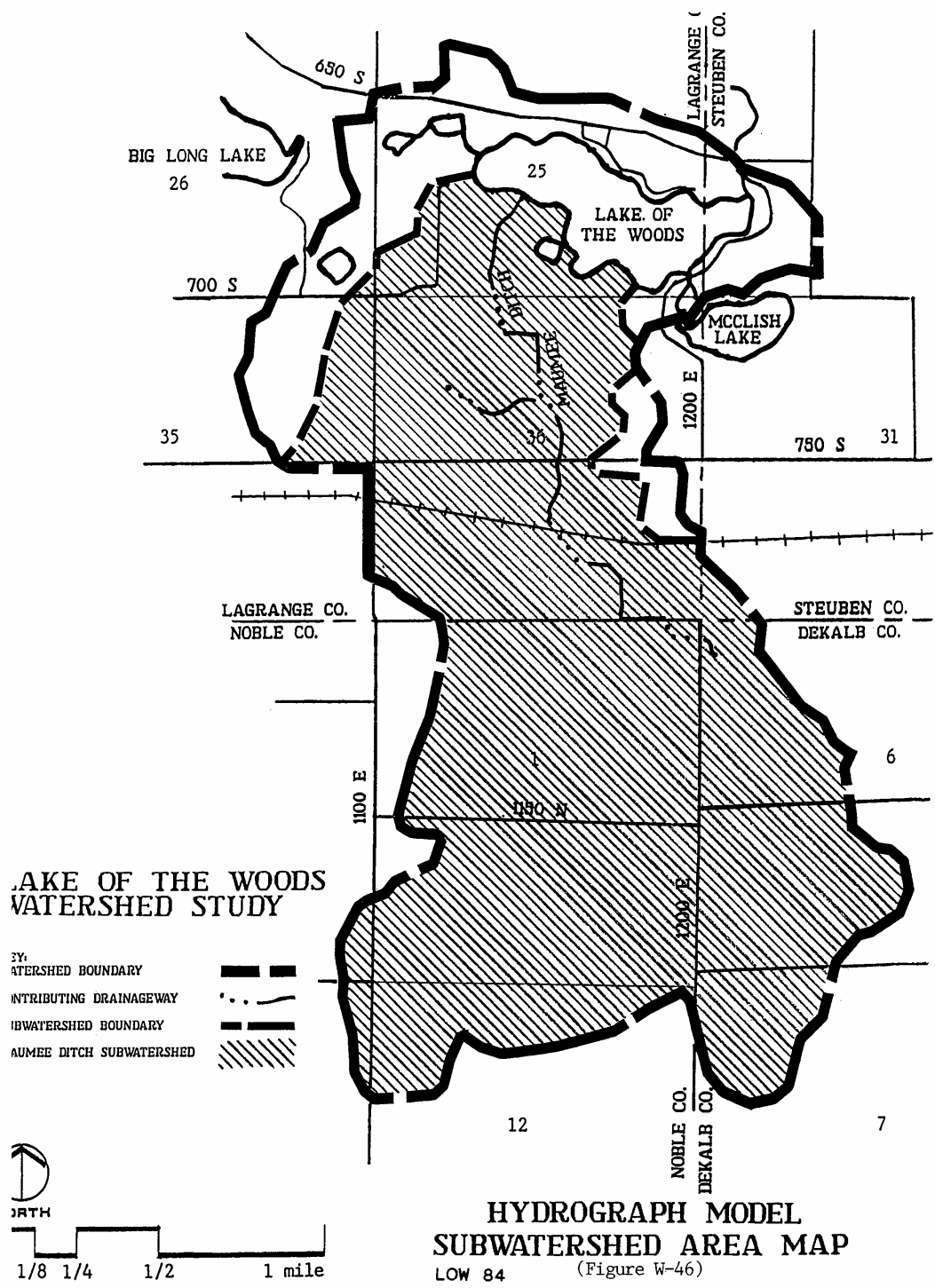
1) Rainfall Component. The rainfall component uses a given rainfall depth for a specific storm event, converted into a temporal storm pattern (storm duration over a given geographical area and time) because a large portion of the rainfall may occur over a small period of time with fluctuations in intensity.

2) Runoff Component. The runoff component determines the depth of rainfall in 0.1 hour increments given a 24 hour storm event (TR-55, 1986). The runoff is distributed over a period of time according to predicted rainfall. The runoff component is then used to determine hydrographs at specific locations throughout the watershed.

Factors involved in SEDIMOT-II include: storm type, event type, in this case runs were made using rainfall depths from a 2 year, 25 year, and 100 year storm events, soil types, vegetative cover types, basin relief, drainage area, and length of drainage segment. A summary of hydrology input data and SLR formula is presented in Appendix E.

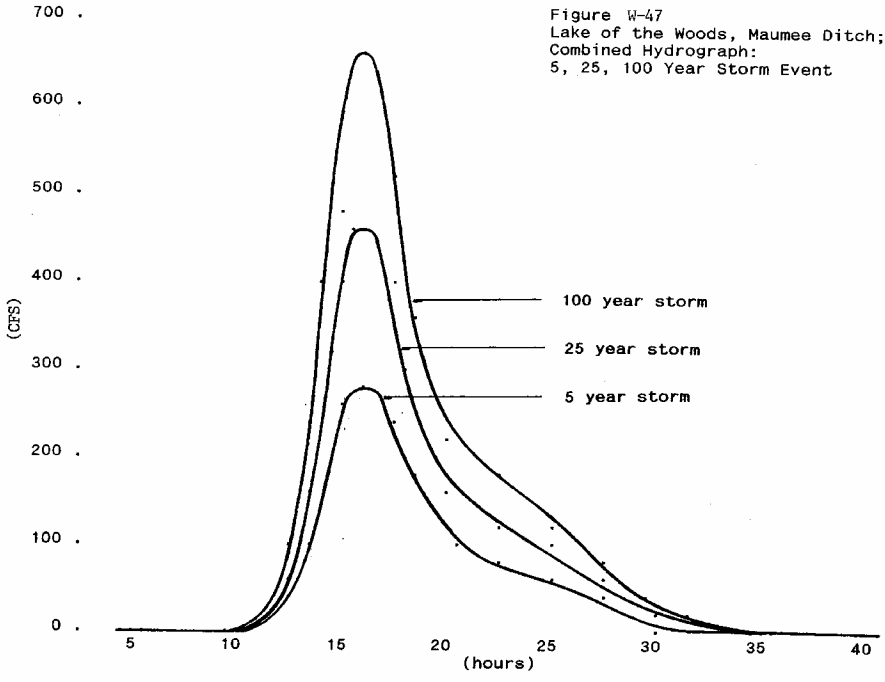
Maumee Ditch

The Maumee Ditch flows into Lake of the Woods between the Goose Pond to the south, and Camp Lake Wood to the north (Figure W46). The Maumee Ditch subwatershed is by far the largest drainage basin of the Lake of the Woods watershed. The Ditch and tile network drains over 1800 acres of land. Stream sampling for Lake of the Woods, 18 January 1990, showed the Maumee Ditch to have the greatest flow, total suspended solids and nutrients (mg/l) of those sampled. For this reason, the Maumee Ditch subwatershed was targeted for an indepth study of hydrology. Hydrographs for the Maumee Ditch are presented in Figure W47. Additional data are presented in the Maumee Ditch Subwatershed Summary Table W16.



HYDROGRAPH MODEL
SUBWATERSHED AREA MAP
LOW 84 (Figure W-46)

Figure W-47
Lake of the Woods, Maumee Ditch;
Combined Hydrograph:
5, 25, 100 Year Storm Event



MAUMEE DITCH SUBWATERSHED SUMMARY	
Drainage Area	1833.00 acres
Runoff Volume:	
5 Year Storm	170.37 acre-feet
25 Year Storm	273.62 acre-feet
100 Year Storm	387.42 acre-feet
Peak Inflow Rate (from Hydrograph):	
5 Year Storm	284.83 cfs
25 Year Storm	466.26 cfs
100 Year Storm	666.46 cfs
Mean Flow Rate (from Hydrograph):	
5 Year Storm	57.39 cfs
25 Year Storm	74.37 cfs
100 Year Storm	98.55 cfs
Pool Capacity	46.23 acre-feet
Detention Time of Flow:	
5 Year Storm	9.75 hours
25 Year Storm	7.52 hours
100 Year Storm	5.68 hours

Table W16. Maumee Ditch Subwatershed Summary

Sediment and Nutrient Removal

In order to quantify the effectiveness of a control structure or constructed/enhanced wetland in removing sediments and nutrients, it is first necessary to develop a concept design for the site. Using the conceptual designs presented later in this report, a flow model was developed. Flow models are used to determine a particular hydraulic characteristics for a given site at a given point in time. In this case, flow models are used to determine the surface loading rate (SLR). The SLR is used to derive the position of a particle (sediment) with a given diameter, within a system at a any given point. With this information, a settling velocity can be predicted for particles entering a system based on particle size, distance and time. The predicted sediment removed is determined by the size of particles equal or larger to that of the design settling velocity.

Nutrients are removed from a system in two basic ways: 1) by biotic processes in which they are utilized by plants and bacteria or; 2) by physical processes. Nutrients often travel through a system bonded to particulate matter, thus, as sediments are settled out, so are the nutrients attached to them. Sedimentation is the settling out of soil particles which have been transported by air or water. Sedimentation occurs when the velocity of the transport medium **(water)** is slowed adequately and for a sufficient period of time (detention time) to allow for the soil particles to settle out. Larger, heavier particles require high velocities of runoff to be transported and are quick to settle out. Smaller, lighter soil particles are transported by suspension or by moving (tumbling) along the surface. Fine silts and clay materials are generally transported in suspension. These smaller soil particles are difficult to recover once eroded. Substantially lower velocities and greater detention times are required to settle these particles out.

Specific site design would be necessary to predict the actual amounts of sediments and nutrients transported through a system or to quantify the amount removed by a specific control structure. It is possible, however, to relate sediment removal efficiencies using the SLR, with data from the concept plan and mean flow reported for the 5 year return storm. Findings of this model indicate that sediment equal to, or greater than 0.004 mm (very fine silt) will settle out of the system in the Maumee Ditch constructed option. Particle size based on a mean specific gravity of 2.65.

Results from the Wilson Ditch constructed wetland site (near Culver, Indiana), designed by **Earth Source Inc.**, showed mean total phosphorous was reduced 90%, while mean total nitrogen (nitrate/nitrite) was reduced 85% during the 1988 summer monitoring program. Mean total phosphorous was reduced 60% and mean total nitrogen was reduced 65% during the 1988 winter monitoring program.

Constructed Wetland Habitat

Potential exists for the construction of sediment/nutrient control structures to increase the overall wildlife habitat and production capabilities for the Lake of the Woods area.

Primary fisheries production in Lake of the Woods could benefit greatly by increased wetlands. Virtually all sport fish production is dependent on wetlands, either for spawning, cover or planktonic food production. Pike and sunfishes are major benefactors of increased wetland spawning area. They spawn in the wetlands and then return to the lake proper.

Increased wetlands will draw waterfowl away from areas of moderate human use. Productivity is likely to increase while the "nuisance factor" decreases. Song birds are drawn to wetlands for a number of reasons: nesting structure provided by persistent emergent vegetation (cattails); security cover; and food production. Species such as the Great Blue Heron, Yellow Rail, Great White Egret, and Yellow-headed Blackbird (which are all state threatened, rare or of special concern) will locate near wetlands for many of the same reasons as their avian counter parts.

Fur-bearing animals like beaver, mink and muskrat depend on wetlands primarily for food, security cover and den sizes.

Muskrats will likely be the first fur-bearer to colonize a shallow constructed wetland. These prolific mammals do well in areas which have low water flow and emergent aquatic vegetation such as cattails. If muskrat den/foraging activity strays from or damages the constructed wetland and wetland structures it may become a nuisance, therefore, populations will require careful monitoring and controlled.

The mink is one of the most prized furbearers associated with wetlands. The habitat requirements of the mink are similar to those of the muskrat with one exception, the mink is a carnivore. Thus, mink population will usually mirror changes in muskrat population.

The beaver is another valued furbearer likely to colonize a constructed wetland in the Lake of the Woods area. Again, if den/dam building activity strays from the constructed wetland it may become a nuisance, therefore, beaver populations will also require careful monitoring.

In summary, a constructed wetland is capable of increasing and supporting a diverse number of habitants. It should be noted that a constructed wetland is also constructed habitat. By design, these areas may attract species of special interest, through planned inclusions of required habitat components.

Constructed Wetlands as a Watershed Management Practice

For more than 50 years, wetlands have been identified as water purifying systems for natural lakes (van der Valk, et al 1978). Wetland vegetation, benthic organisms, and soils perform as traps, at least seasonally, for nutrients, suspended sediments, metals, pathogens, and many agricultural chemicals (Kadlec and Kadlec 1978). Thus, during the course of the Lake of the Woods watershed study, a primary objective was to identify opportunities for nutrient/sediment trap target sites on contributing ditches and tiles identified as loading excessive nutrients and sediments to the lake (Figure W48). The primary criteria in selecting these sites were: location, topography, flow rates, soils, feasibility, current land use, size, environmental concerns, and sediment/nutrient loading characteristics of the drainage basin. As each site is considered for development, an evaluation should be made of the status of erosion control/land treatment above each proposed site, and goals set for timetables, land acquisition, fund raising, final design and construction.

Each site is described in the following text with a conceptual plan for illustration. Cost range estimates and priority recommendations are discussed in later sections of this report.

Project Descriptions: Lake of the Woods

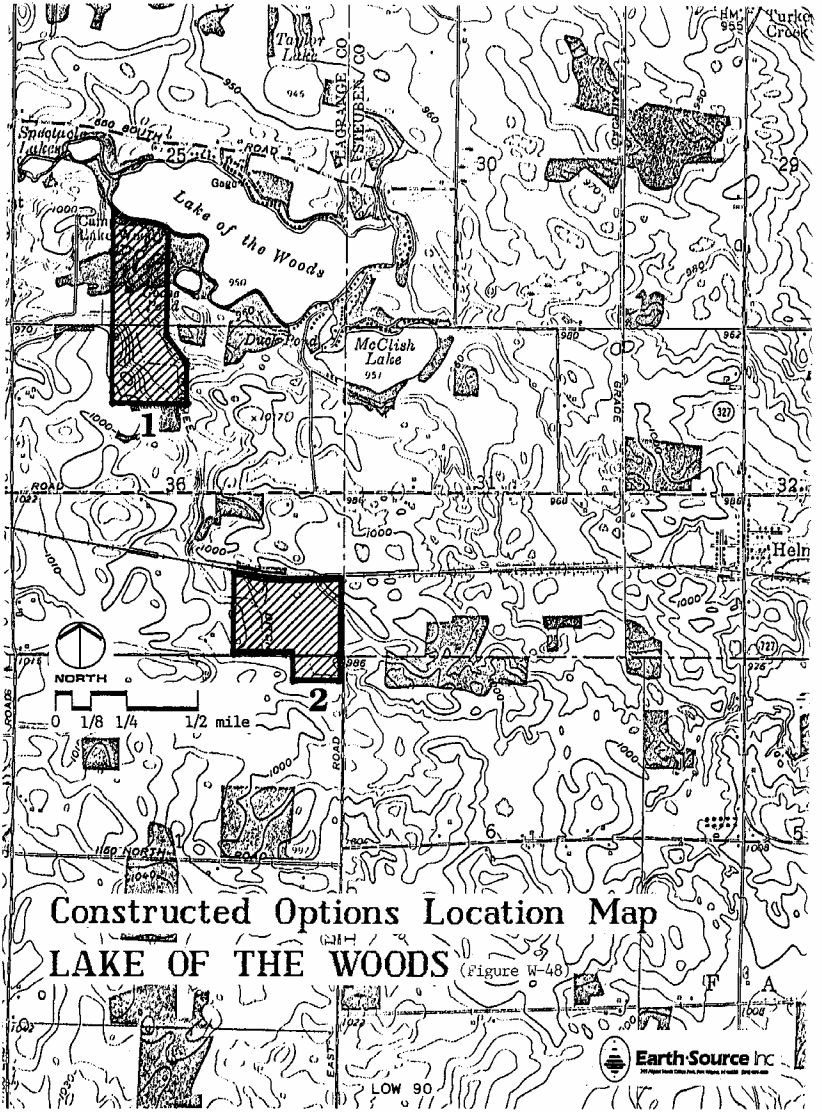
Maumee Ditch: Constructed Option 1

The Maumee Ditch and associated tiles, drain the largest single land area of this study. Flows related to the Maumee Ditch carry the greatest volume of sediments and nutrients of any tributary in the study area.

Due to the complex nature of this project, construction will be discussed as a whole or Master Plan, and, then divided into three possible phases.

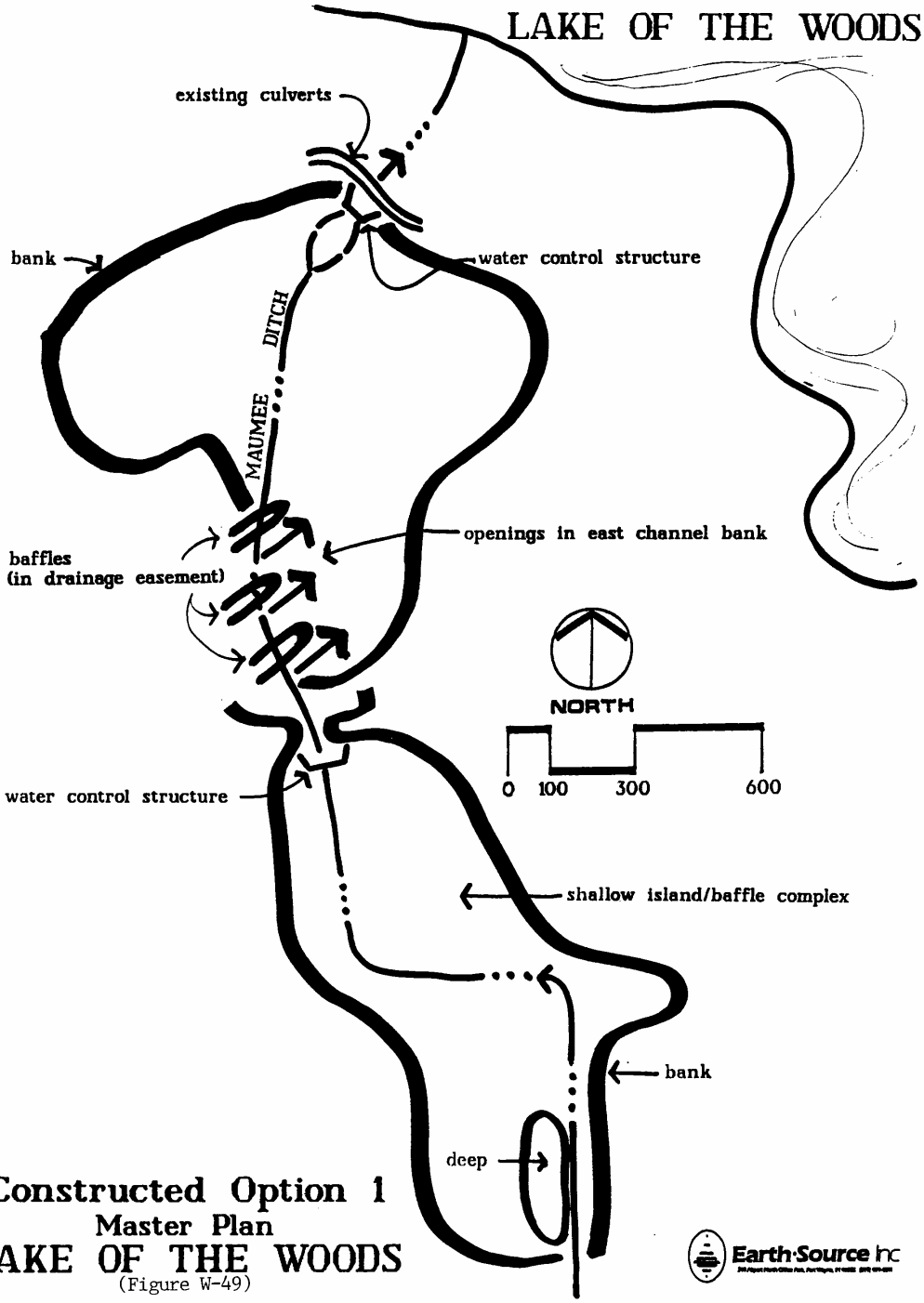
Maumee Ditch: Constructed Option 1 - Master Plan

This 35 acre site (Figure 49) would include: 1) A water control structure and excavated channel bank openings for temporary inundation of an existing forested - scrub/shrub wetland complex near the lake. At the present time this wetland complex is partially drained by the Maumee Ditch; and 2) Excavation of several deep pools, flow diversion baffles, islands, maintainable sediment traps, and extensive emergent shallow water complex approximately 1600 feet south of the lake. A water level control structure with spillway would provide the water management of this wetland system.



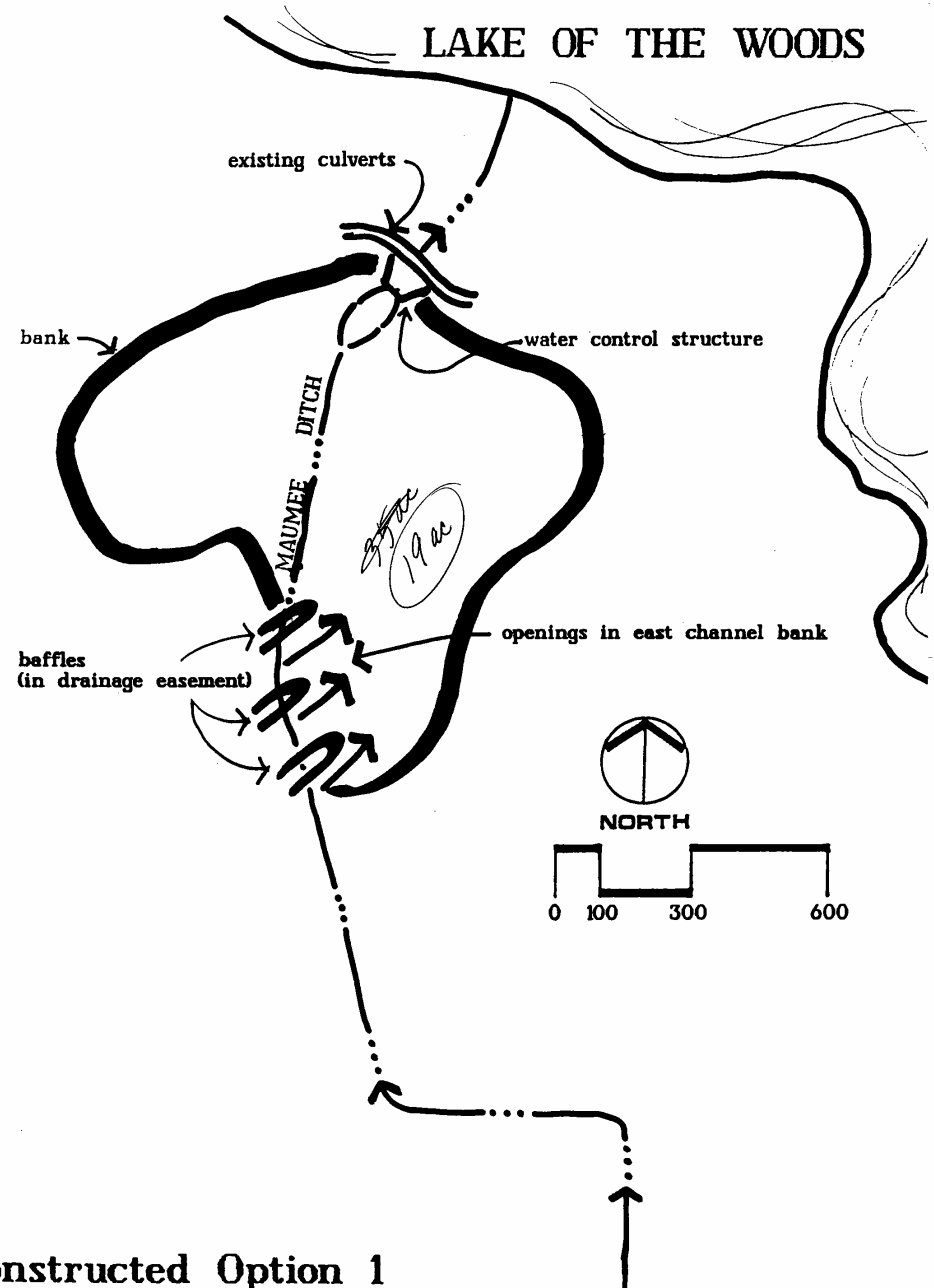
Constructed Options Location Map

LAKE OF THE WOODS (Figure W-48)



Constructed Option 1
Master Plan
LAKE OF THE WOODS
(Figure W-49)

Earth·Source Inc



Constructed Option 1
Phase I
LAKE OF THE WOODS
(Figure W-50)

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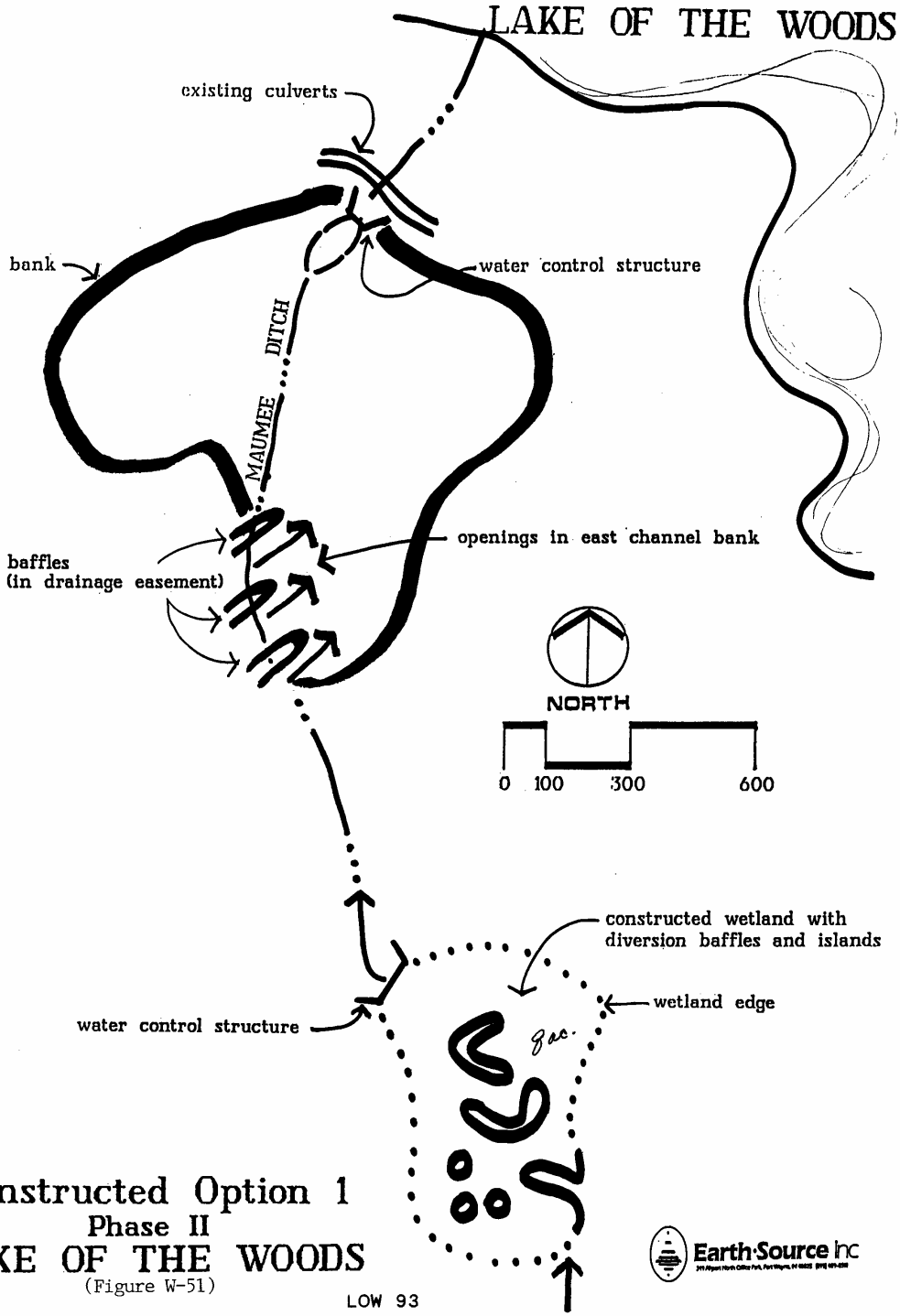

Constructed Option 1
Phase II
LAKE OF THE WOODS
(Figure W-51)

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Maumee Ditch: Constructed Option 1 - Phase 1

This opportunity (Figure W50) consists of excavating openings in the east channel spoil bank (within the drainage easement) and diverting flow into approximately 19 acres of the existing scrub/shrub and forested wetland complex. A water control structure will allow for management of water levels in this management section of the Maumee Ditch and wetland associated with this site.

Additional enhancements of the wetland may be considered for habitat improvement and increased residence time if final design study warrants.

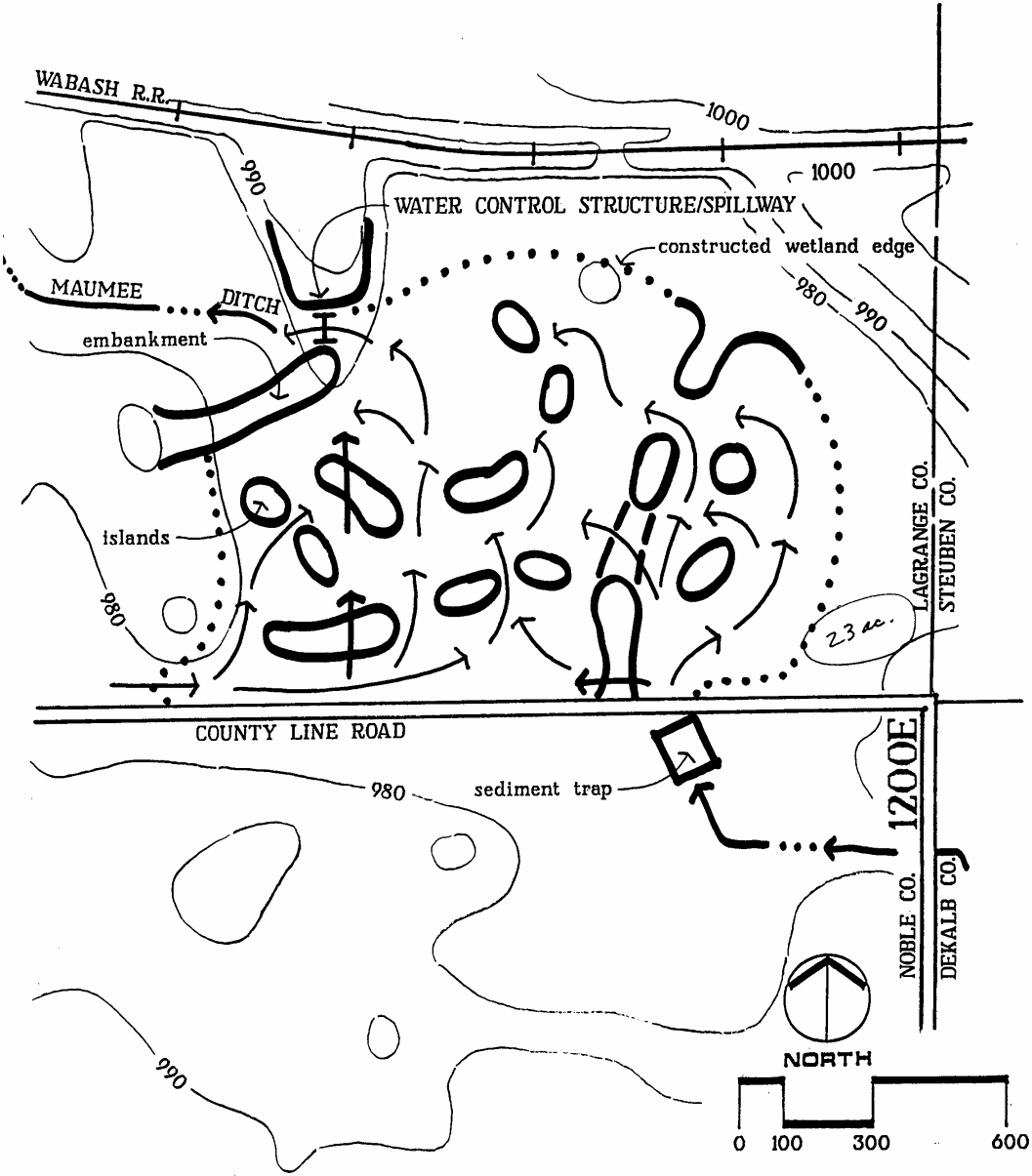
Maumee Ditch: Constructed Option 1 - Phase 2

Phase 2, an approximate 8 acre site about 800 foot upstream from the Phase 1 site is considered an opportunity for a constructed wetland. Features of this concept (Figure W51) would include water level control structure and spillway, diversion baffles, islands, and sediment traps. The existing flow would be diverted from the channel and spread over the constructed wetland site. The site is currently in crop/hay production. Ditch profiles and surrounding topography obtained in the design phase would reveal the final site definition and the extent of excavation necessary to accomplish this phase.

Maumee Ditch: Constructed Option 2.

This option (Figure 52) would consist of rerouting the head water of the Maumee Ditch through a restored scrub/shrub wetland area. This site would also receive flow from an extensive dilapidated tile complex which drains more than 640 acres above the Maumee Ditch. This 23 acre site would include deep pools, flow diversion baffles, islands, and maintainable sediment traps. A water level control structure with spillway would provide the water management of this wetland system.

Constructed Option 2 is considered to be an integral part of the constructed/restored wetland treatment system above the Lake of the Woods. Ultimately, implementation of Constructed Option 1 in conjunction with Construction Option 2 will greatly benefit the lake.



Constructed Option 2

Maumee Ditch

LAKE OF THE WOODS

(Figure W-52)

Earth·Source Inc

LOW 95

Cost Estimates for Constructed Options

The following estimates are offered to represent the anticipated cost factors for construction of suggested sites. For final design and construction documents, an allowance of 15% to 20% of construction cost should be added to these estimates. Additional cost of services should be added for bidding, construction monitoring and construction administration if required by the funding agencies. Other additional cost items not included in these estimates are as follows: 1. Land cost (if any); 2. Attorney's fees to prepare land agreements; 3. Property line surveys or descriptions; 4. Preparation of permits such as to the Department of the Army, IDNR Division of Water, County Drainage Boards, Indiana Department of Environmental Management; 5. Operation and maintenance of sites and access thereto.

Priority recommendations (Very High (1), High (2), Moderate (3), etc.) have been made based upon the need, feasibility, accessibility of the site, and other considerations discussed in previous sections. The Lake Association should not be discouraged from pursuing and implementing lower priority constructed options, while higher priority sites are under consideration or in process.

Constructed Option 1, Phase 1:

Cost items include openings (excavation) in east channel bank, baffles, water control/outlet structure.

Estimated Cost Range: $40,000 - 80,000

Constructed Option 1, Phase 2:

Cost items include excavation, channel piping, baffles/islands, water control/outlet structure, restoration, erosion control materials, and fence.

Estimated Cost Range: $75,000 - 125,000

Constructed Option 1, Master Plan:

Cost items include excavation for sediment traps, channel openings, channel piping, baffles/islands, water control/outlet structures, restoration, erosion control materials, perimeter embankments; and fence.

Estimated Cost Range: $165,000 - 280,000

Priority Recommendation: Very High (1)

The Constructed Option 1 Master Plan includes construction of Phase 1 and Phase 2.

Constructed Option 2.

Cost items include sediment trap excavation, channel piping, earth work for baffles/islands and embankment, water control/outlet structure, restoration, erosion control materials, and fence.

Estimated Cost Range: $130,000 - 175,000

Priority Recommendation: High (2)

Permitting

Beyond property ownership, many governmental agencies may have jurisdiction over private property. For example, drainage may be regulated by the County Surveyor. Water issues, particularly construction in a floodway, is regulated by the Indiana Department of Natural Resources Division of Water, and the United States Department of the Army, Corps of Engineers. Excavation below legal lake level, 956.45 foot, mean sea level datum, or any ditch modification within .5 miles of the Lake, will require authorization by the IDNR, Division of Water, Lake Section. The Corps of Engineers will require permitting and Water Quality Certification by the IDEM, Office of Water Management for construction in wetland areas. The Corps of Engineers (and the Divisions of Water) may require permitting if any construction impounds water. A list of different agency contacts, addresses, and telephone numbers may be found in appendix B.

Conclusions & Recommendations

Conclusions and Recommendations

LAKE OF THE WOODS

Water Quality

Water quality trends for open water areas of Lake of the Woods were delineated from individual physical-chemical and biological parameters. The lake has been characterized by extensive anoxia in the lower water column during summer since at least 1972. Both a doubling in total phosphorus values between 1973 and 1989, and reductions in Secchi transparency for July (1977 versus 1989) and September (1973-84 versus 1989) of 80% and 45%, respectively suggest that water quality has decreased since the early 1970's. This interpretation is supported by an increase in the IDEM eutrophication index from 18 in 1973 to 22-29 in 1989 suggesting a shift from Class One (best water quality) to Class Two (intermediate water quality) within the past 16 years. Finally, in addition to declining quality in warm water sport fish populations, cisco, a fish intolerant of depleted oxygen in the water column, was apparently extirpated in the lake between 1975 and 1988, and oxygen conditions after 1984 became insufficient to support trout populations on a year round basis.

The vegetated littoral zone is rather restricted in Lake of the Woods and appears not to have expanded in response to progressive eutrophication. No management recommendations for aquatic macrophytes have ever been made by DNR for this lake.

While both septic and ditch drainage have contributed to the eutrophication of Lake of the Woods, the latter is likely of greater overall magnitude. It is recommended that residents make a concerted effort to have their drain fields inspected regularly and to keep their septic tanks pumped. Residents can reduce nutrient loading to the lake by using phosphate-free detergents for both clothes and dishes. Simple irrigation of lawns using lake water will provide sufficient nutrients to sustain lawn growth. Such simple modification of practices can reduce the contribution each resident makes to the phosphorus and nitrogen loading of the lake.

Water quality improvement in Lake of the Woods is linked critically with implementation of watershed management practices that significantly reduce nutrient and sediment loading. Reduction in watershed contributions of both will likely lead to a reduction in trophic state in the lake. No in-lake management practices are proposed for Lake of the Woods.

Macrophytes

The extent and richness of the vegetated littoral zone appears not to have been altered during progressive eutrophication, and macrophytes have never been considered a serious enough of a problem to warrant implementation of a management program. Most vegetation in Lake of the Woods is confined mostly to water less than 10 feet deep. Assuming that macrophyte problems are manifested only when plant biovolume exceeds approximately 80% of the water column, none of the surface area of Lake of the Woods would be classified as having management problems with macrophytes. Approximately 70% of the lake's bottom is considered entirely free of vegetation with an additional 24% having plant biovolume occupying less than 20% of the water column. Most of the plant biovolume is in water less than four feet deep and is contributed primarily by coontail, pondweeds, and eelgrass. Most stands of macrophytes are less than two feet tall. Macrophyte extent in Lake of the Woods is controlled by light availability and basin morphometry, and it is unlikely that macrophyte problems would accompany further eutrophication of this lake. Currently, no management program for macrophytes is needed in Lake of the Woods.

Fish

While DNR considered the fishery of Lake of the Woods to be good prior to 1977, overall quality declined between 1977 and 1984 prompting DNR to conclude that the lake offered only limited sport fishing opportunities for warm water species. While oxygen concentrations had declined to a level insufficient to support trout populations on a year round basis, perhaps the most significant fishery change observed in the lake has been the loss of ciscos, a fish requiring cold well oxygenated waters. All surveys reported that ciscos were common in the lake prior to 1975, but failure to capture any specimens in later surveys has prompted DNR to conclude that this species was extirpated in the lake between 1975 and 1988. While never a recreationally important species in the lake, the progressive loss of ciscos clearly indicates that eutrophication of Lake of the Woods has been accelerating during the past two decades.

A majority of the fish in Lake of the Woods are restricted to water depths of 16-19 feet during midsummer due to serious oxygen depletion in deeper waters. It is likely that attempts at fishery management will be only marginally successful until nutrient loading to the lake is reduced significantly. It is recommended that lake residents encourage the State of Indiana to provide DNR with continued funding for conducting periodic surveys of the fish community in Lake of the Woods.

Basin Infilling

Lake of the Woods has experienced moderate basin infilling during the past 31 years. The depth contour displaying the greatest incremental increase during the period was 0-5 feet, which increased in aerial extent by 18%. On a lake wide basis, greatest basin infilling was observed in the western one-third of the lake near the mouths of Maumee Ditch and the inlet from Spectacle Lakes and at the eastern end of the lake between the McClish Lake inlet and the lake outlet. It appears that such sedimentation has not been accompanied by a change in the relative proportion of inorganic and organic matter in the sediment. It is obvious that a majority of the sedimentation in Lake of the Woods is directly related to ditch input of watershed sediment especially during spring rain events. We were able to find no evidence to suggest that shoreline erosion was a major factor in observed patterns of sedimentation in Lake of the Woods. Homeowners, however, should inspect their shoreline for evidence of erosion, be encouraged to leave a fringe of emergent vegetation along the entire length of their lake front to serve as an erosion barrier and make appropriate repairs immediately. Boaters should be encouraged to reduce speed when near shore in order to minimize wave generation and subsequent erosion of shoreline areas.

It is recommended that in addition to watershed management practices discussed later, aquatic plants at the mouths of ditches should be left intact as a nutrient and sedimentation barrier. Removal of such plant growth will speed delivery of both parameters into the lake thus accelerating both basin infilling and eutrophication.

LAKE OF THE WOODS WATERSHED

It is apparent that nutrient and sediment loading from the Lake of the Woods watershed and Lake shore have not decreased over recent history. In fact, water quality studies in the Lake suggest that watershed loading has increased since 1984. The Lake has met the increased availability of sediments and nutrients with an increased frequency of algal blooms reduced quality fishery, and observation of siltation associated with delivery of erosion products from the watershed. Successful restoration of Lake of the Woods is dependent on curtailing the flow of nutrients and sediment bonded nutrients to the lake from the watershed, and in addressing septic leachate, a large probable source of nutrients. For this reason, priority must be given to land treatment of critical watershed areas, one or more of the constructed options, and further study of potential septic problems.

I. Lake Residents:

A. Septic leachate from lake front homes on Lake of the Woods and McClish Lake is suspected of contributing highly to the decline in water quality of Lake of the Woods. Residents must undertake the responsibility of maintaining their own waste disposal systems. Drain fields should be inspected regularly and septic tanks should be pumped on a regular schedule. Avoid the use of on-site septic systems near areas which have been identified as containing saturated soils, and relocate systems currently situated in saturated soils. The Lake Association should consider engaging an engineering study for a lake-wide sanitary sewer district which considers several alternative methods of waste treatment. Also, the Lake Association should voice support of County efforts to establish a County-wide sanitary sewer district.

B. If fertilization for lakefront lawns is desired, residents should consider using lake water for irrigation/fertilization of lawns (lake water will provide ample nutrients) or, use fertilizers low in phosphorous (0.5% liquid; 3.0% granular). Finally, fertilizer should be applied <u>only</u> during the growing season, April-October. (Note: an IDNR permit may be required for pumping out public waters)

C. The Lake Association should take an active role in monitoring future development: lakefront and watershed. Development monitoring could be accomplished by the formation of a 'Lake Watch Committee'. Lakefront development should consider setbacks from the lake, septic suitability, and must incorporate adequate sediment control measures. Watershed development (commercial) must be made aware of potential sediment and/or nutrient sources to the Lake, and like lakefront development, incorporate adequate sediment control measures. Sediment control structures such as erosion control mats, silt fences, straw bale filters, and sediment basins must be installed <u>prior</u> to any construction or development which would impact the Lake. The Lake Association should also promote the establishment of a county-wide erosion control plan.

II. The Watershed:

A. The land-use or cropping practice of areas mapped as having highly erodible lands or severe slopes should be carefully considered. Much of this land should be in a conservation tillage program, or, in some cases should not be in agricultural crop production. Those areas defined in the HEL/severe slope study should maintain natural buffer areas or filter strips along ditches.

The 101 acres, detailed in Agricultural Lands/HEL/severe slope overlay represent the worst case, or highest erosion threat areas of the Lake of the Woods watershed. Much of this land is adjacent to the Maumee Ditch, open drains or tiles which facilitate the transport of eroded soils to the Lake. For this reason, those areas present the greatest sedimentation threat to Lake of the Woods. Every effort must be made to enlist these areas into conservation tillage, CRP or related land treatment programs. Lands in the Lake of the Woods watershed noted as unsuitable to no-till should be in permanent cover.

As illustrated by the 'Conservation Tillage Suitability Map', the ballance of the watershed is well adapted to conservation/no-tillage methods. This area represents the major overall export of sediments and nutrients from the watershed. Other land treatment practices, especially stream/ditch bank stabilization, should be pursued along the Maumee Ditch. This could be accomplished by establishing grassed ditch borders (filter strips), and, in more extreme cases, structural or riprapped solutions. In addition, the tile complex ahead of the Maumee Ditch must be repaired or effectively blocked and abandoned in those areas where tile has broken down. Excavate and maintain sediment traps that may be located at easily accessible intervals, such as near roads. (Other various Conservation Practices are listed in Appendix C. These practices will be detailed in individual farm Conservation Plans, as required by the 1985 Farm Bill to be implemented by 1995).

B. Consider the Constructed Options as described in that Section of this report. Priority should be given to constructed options on the Maumee Ditch, as well as those identified for McClish Lake.

A monitoring program should be implemented in the upstream segments of the Maumee Ditch. Upstream monitoring would more precisely locate sediment and nutrient loading areas of this subwatershed so that specific management practices could be implemented, as well as prioritize the Maumee Ditch Constructed Options. Samples should be analyzed for total phosphorus, ortho-phosphorus, total nitrogen, nitrate/nitrite, total suspended solids, coliform and streptococcal bacteria.

C. Stabilize streambank or ditch escarpments. Allow native vegetation to establish on stream banks. Retain on one side during 'maintenance'. The need for selective cleaning or maintenance of the Maumee Ditch should be carefully weighed against impacts to Lake of the Woods.

III. General recommendations:

Encourage preservation of remaining upland forest, wetlands and upland depressions. Landowners must be made aware Federal regulations protecting wetlands. Avoid relocation (straightening) of natural stream channels.

Avoid building close to wooded ravines or streambanks.

Preserve natural vegetation adjacent to water areas, such as remaining in-lake wetlands at stream inflows. The southwest end also has some good wetland shore areas that should be preserved.

Avoid construction in, bypassing of, or drainage of, wetlands and maintain natural vegetative cover wherever possible.

Stabilize drainage areas immediately following any construction or "maintenance". Quick vegetative cover and streambank protection is essential to erosion control.

Row cropping should be done perpendicular to slope. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained. Divert runoff from severely sloping areas.

Get livestock out of open ditches and ditch banks, perhaps, by helping landowners find financial assistance to fence and construct filter strips. Also, Filter strip or otherwise intercept runoff from animal feedlots.

Utilize sediment ponds below feed lots and "open" sloping lands.

Avoid spreading manure during the winter or near direct drainageways unless it can be incorporated IMMEDIATELY.

Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes. Divert runoff from severely sloping areas.

Wind erosion is thought to be a minor factor in soil loss of the Lake of the Woods watershed, however, soil loss could be further limited by use of wind breaks or perennial grass buffers with a north-south orientation.

McClish Lake

EXECUTIVE SUMMARY

McClish Lake is undergoing progressive cultural eutrophication and changes in the IDEM eutrophication index suggest a reduction of 33% in water quality in the past sixteen years. Although a limnological survey was not funded as part of the current investigation, three recent observations are of note and deserve further attention. First, the lake has lost (1988-1989) the deep water high oxygen layer noted in all previous surveys. This layer is produced by a plate of photosynthesizing algae. Second, populations of cisco, a fish requiring cold well oxygenated water, have declined since 1975 and massive summer kills of this species were observed in both 1988 and 1989. Third, the citizen based Secchi monitoring program on the lake during 1989-1990 documented pronounced reductions in water clarity following periods of major rainfall and associated delivery of silt from the watershed.

The results of our limited investigation of McClish Lake suggest that increased delivery of watershed erosion products since approximately 1984 has shaded out the phytoplankton layer producing the deep water oxygen layer resulting in severe stress to cisco populations. Unfortunately, we did not collect a database sufficient to make specific management recommendations on the lake itself, but have concentrated instead on management options for the watershed.

One of the contributing factors suggested for the eutrophication of McClish Lake have been identified as nutrients and sediments from watershed sources and delivered by ditches and tiles.

Conservation tillage has been identified as one of the most effective methods of controlling erosion due to agricultural practices. Thus, continued and expanded use of conservation tillage systems in conjunction with addressing drainage issues on a cost-benifit basis, and implementation of the constructed options and filter strips is strongly advised.

Septic leachate from lake front homes is suspected of contributing highly to the decline in water quality of both McClish Lake and Lake of the Woods. Residents must undertake the responsibility of monitoring and maintaining their own waste disposal systems.

Lake residents can further control sediment and nutrient loading by monitoring lake front development for adequate erosion control and re-evaluating the fertilizer requirements (if any) for lake front homes. A resident lake watch program could be a viable approach to meeting this task.

INTRODUCTION

McClish Lake (figure page iii), LaGrange-Steuben County, is a 35 acre lake with a maximum and mean depth of 57 feet and 34.6 feet, respectively. Legal lake level is 951.03 feet, but the lake lacks a control structure on the unnamed outlet stream flowing through Duck Pond to Lake of the Woods. The lake has no permanent inlet streams, but does receive watershed runoff via tile fields. One point discharge enters McClish Lake via a 12 inch tile at the southwestern corner of the lake. The segment of the watershed drained via this tile system is rolling and under cultivation. The second point source discharge to the lake is a tile located along the eastern shore of the lake and drains a rolling watershed segment devoted primarily to row crops and pasture.

The present study was initiated because of lake residents' concerns regarding algal blooms, ongoing massive mortality of ciscos during midsummer, and observation of siltation associated with delivery of erosion products from the watershed especially during early spring rains. Unfortunately, limnological investigations in McClish Lake were not included in the current project funded as part of the Indiana Lake Enhancement Program. Monitoring of tile discharges was funded as part of the investigation for the Lake of the Woods - McClish Lake watershed.

As a service to the residents of McClish Lake, we monitored temperature, dissolved oxygen, and Secchi transparency at a single station in the lake concurrent with our sampling program on Lake of the Woods. Unfortunately, we were not able to include additional parameters for which we would have incurred a major analytical cost. For the three parameters measured as well as ciscos, we have attempted to discuss present each in a historical context in order to determine whether current values represent a marked decline in water quality within the historical past. Management implications of our analysis of past and current water quality will be discussed later in this report.

METHODS

Three limnological parameters were monitored during 1989 on 16 September and 5 October. A single sampling station was established in the center of McClish Lake Woods near the point of maximum water depth. (Figure M1). Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc.

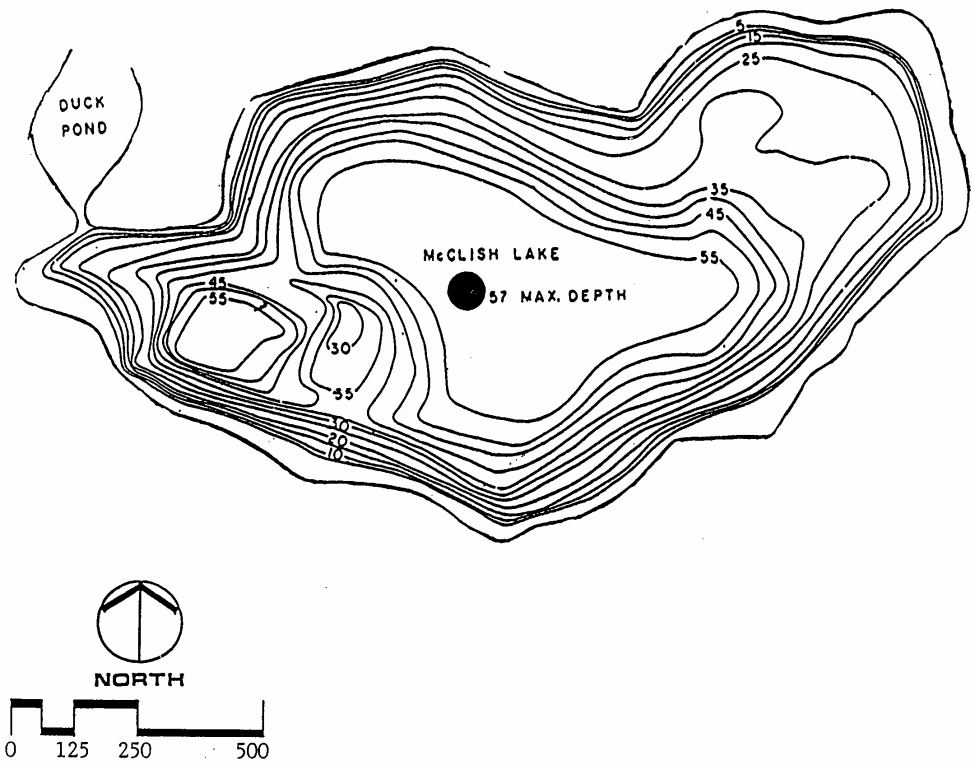


Figure M1. Station Utilized for 1989 Limnological Investigations.

TEMPERATURE

The water columns of northern Indiana lakes greater than approximately five meters deep remain thermally stratified throughout most of the year. As a result of density-temperature relationships, complete mixing of the water column from top to bottom occurs only when water temperature reaches a uniform 4oC, the maximum density of water. This occurs twice a year in temperate lakes (spring and fall) associated with seasonal climatic changes. The length of the mixing period depends on the rapidity of climate change and can vary from a few days to less than a month. Lakes displaying two mixing periods per year are termed dimictic.

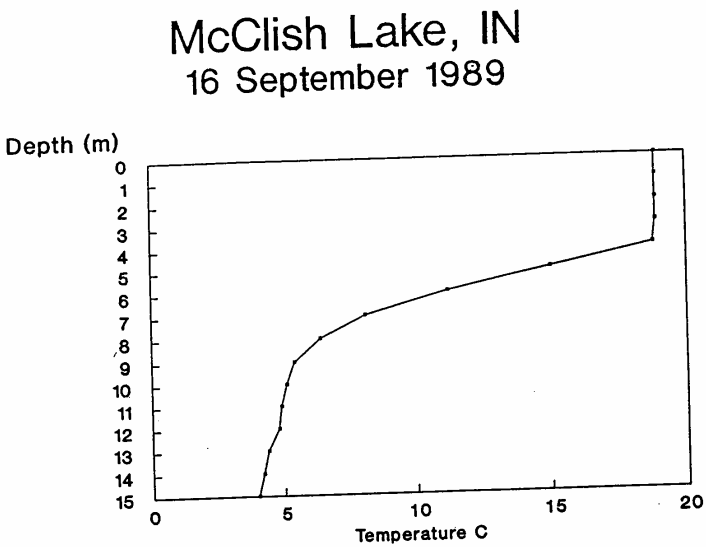
During the stratified period, the water column of Indiana lakes is divided into three zones based on temperature-density relationships. The uppermost well mixed zone is termed the epilimnion and extends from the surface to a depth roughly approximating the lower depth of wave action. The lowermost portion of the water column is the hypolimnion, a zone of density-isolated water that mixes with surface waters only during the short mixing periods. The portion of the water column that is transitional between the epilimnion and hypolimnion is termed the metalimnion. That one meter of the metalimnion displaying the greatest temperature change is called the thermocline.

Water column profiles clearly demonstrated that McClish Lake was thermally stratified during both September and October 1989 (Figure M2). The metalimnion was extensive during both months, extending between four and nine meters in September and five and nine meters in October. The thermocline was between five and six meters during September but moved deeper to 6-7 meters by October as the lake began to cool in the initial stages of stratification breakdown characteristic of fall.

DISSOLVED OXYGEN

Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

Pronounced water column deoxygenation was noted during both September and October 1989 (Figure M3). As expected,



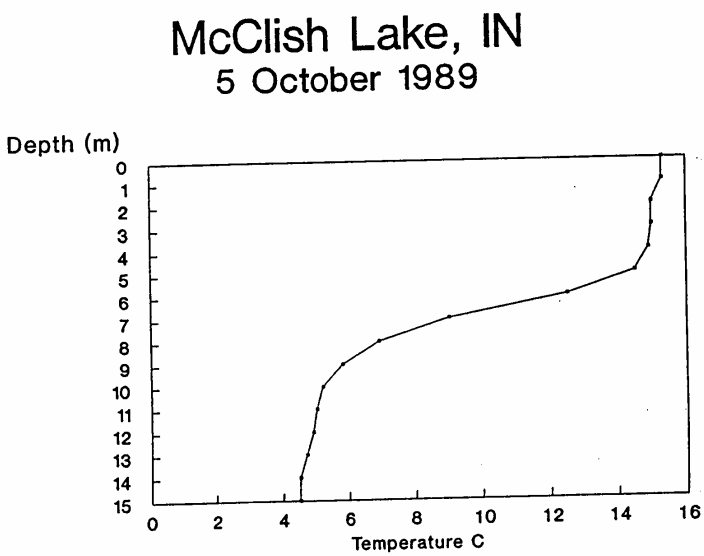
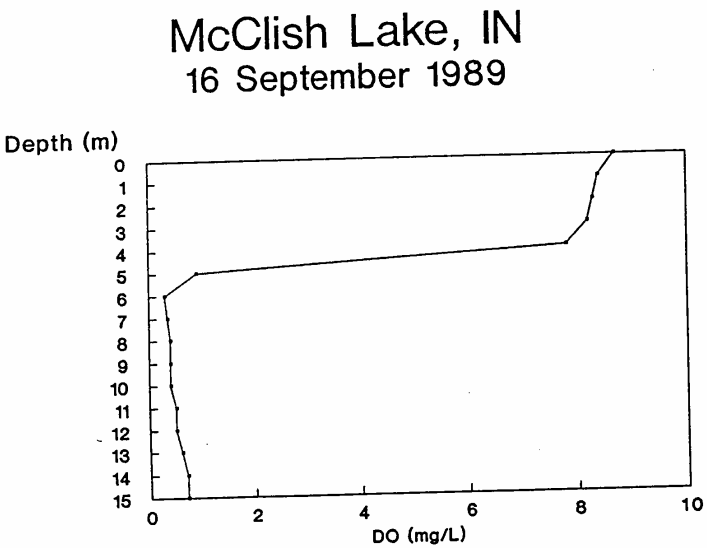


Figure M2. Water Column Temperature Profiles for McClish Lake During September and October 1989.



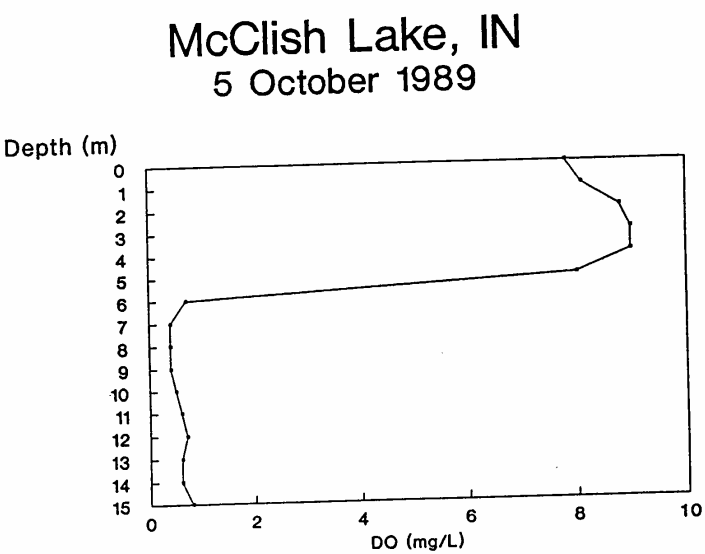


Figure M3. Dissolved Oxygen Profiles for McClish Lake During September and October 1989.

the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). The lake was essentially anoxic below a depth of 4 meters and 5 meters during September and October, respectively. Mean oxygen values for the water column on both dates of 1989 were less than 5 mg/L (Figure M4).

As noted above, depth profiles of dissolved oxygen in lakes normally display a progressive decline in values with increasing depth, the extent of which is usually directly proportional to lake trophic state. High values in surface waters result from wind mixing action, atmospheric diffusion, and phytoplankton photosynthesis, while reduced values in deeper stratified waters reflect decomposition rates and morphometric constraints to total water column mixing during the circulation periods of spring and fall. In some lakes, however, this generalized pattern of reduced oxygen with increasing depth is interrupted by a horizontal zone of increased oxygen deep within the water column. The resulting oxygen profiles are termed heterograde oxygen curves and are usually produced by a layer or plate of dense actively photosynthesizing phytoplankton.

Heterograde oxygen curves were reported consistently at McClish Lake in all surveys of the lake conducted from at least 1952 through 1988 (Table M1). A representative positive heterograde oxygen curve for August 1972 is presented in Figure M5. Heterograde curves were present during July 1988 and 1989, but they were thinner and less well oxygenated than in any previous survey for the month. Although data are lacking for late summer 1988, heterograde oxygen curves were absent during both September and October 1989. These data suggest that light transmission in the water column of McClish Lake has declined to such an extent since the early 1970's that the deep water phytoplankton plate responsible for the zone of high oxygen at depth in the water column of the lake has been eliminated. As will be discussed later, positive heterograde oxygen curves are considered essential for the survival of cisco, a cold-water, oxygen sensitive fish, in most northern Indiana lakes (Gulish 1974). Cisco populations appear to have declined markedly between 1975 and 1988, and massive fish kills of the species were noted during the summers of both 1988 and 1989.

SECCHI

Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer at McClish Lake, it is likely that they mostly reflect algal biomass rather than suspended inorganic

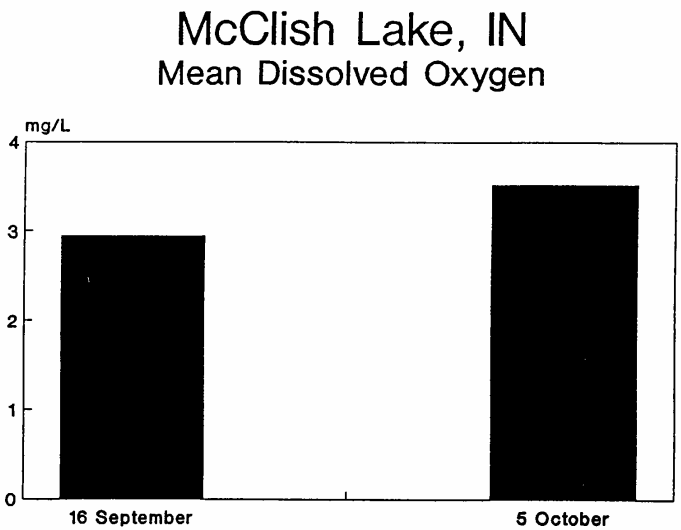


Figure M4. Mean Dissolved Oxygen Concentrations in the Water Column of McClish Lake During September and October 1989.

Table M1. Depth to Positive Heterograde Oxygen Zone in McClish Lake.

Date	Depth to Zone (Feet)	Thickness of Zone (Feet)	Max. DO in Zone (mg/L)	Temp. Range Within Zone (^{o}C)
June:				
1961	10	13	18.5	11 - 19
July:				
1960	10	6	15.8	16 - 19
1961	16	6	24.7	11 - 15
1962	16	10	28.9	
1988	10	3	12.6	24 - 25
1989	10	6	12.1	19 - 23
August:				
1953	16	10	17.0	
1960	13	6	16.9	13 - 18
1961	16	10	32.2	
September:				
1973	9	6	18.0	13 - 22
1989	Not Present			
October:				
1989	Not Present			
November:				
1952	16	10	16.9	

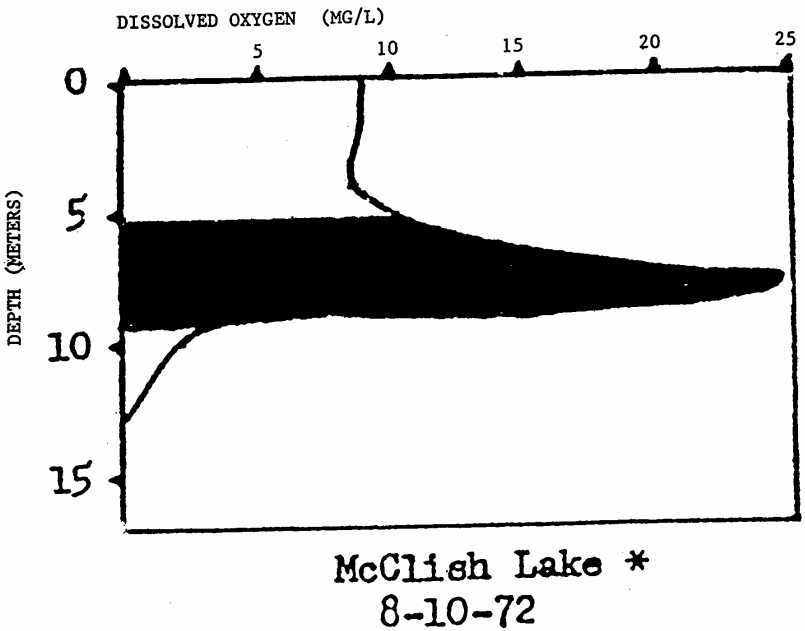


Figure M5. Positive Heterograde Oxygen Curve for McClish Lake on 10 August 1972. Figure Adapted from Gulish (1974).

sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature.

Secchi readings during September and October 1989 were 6.75 feet and 6.60 feet, respectively (Figure M6). Although no historical values for the month of October were found, the September 1989 value was lower than that reported for September 1973 (8.77 feet) by the IDEM. Indiana University reported a Secchi value of 8.86 feet during July 1989, well within the historical value range of 9.50 feet in 1979 and 8.12 feet in 1988 reported by DNR and Indiana University, respectively. On the basis of historical Secchi data alone, it appears that the trophic state of McClish Lake has not changed appreciably since at least 1973.

Mr. Robert Fuess recently organized a citizen based Secchi disk monitoring program for McClish Lake that collected data on 12 dates between 5 October 1989 and 7 June 1990. Three stations were monitored on each date: Station 001 (center of the lake at the deepest point), Station 002 (center of the lake at the southwest end), and Station 003 (approximately 100 feet offshore from the mouth of the field tile at the southeast end of the lake). On 11 of the 12 dates sampled, the lowest Secchi value was reported from the southeastern station near the tile inlet. Interstation variability was not great between the other two stations during most of the sampling period (Figure M7). Such trends are also clearly shown through comparison of mean Secchi values for individual stations (Figure M7).

Pronounced variability was especially evident for mean lake Secchi values between individual sampling dates (Figure M8). The lowest Secchi values reported from October 1989 through June 1990 were for 15 April, and 16 and 24 May 1990. All three dates were during the period of spring runoff from the watershed. Approximately one inch of rain fell immediately before 15 April, two inches in the four days prior to 16 May and an additional one inch prior to 24 May. Suspended silt was observed on all three sampling dates. It is interesting to note that water clarity increased by 181% between 15 April and 1 May and by 601% between 24 May and 30 May, periods lacking any significant rainfall. It is highly unlikely that such low spring time Secchi values result from increased phytoplankton biomass, but are a direct reflection of watershed erosion and delivery of silt ladened water during rain events.

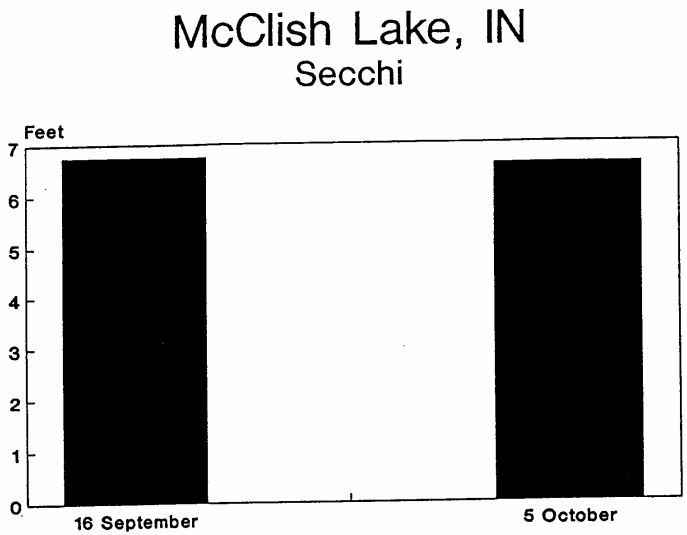
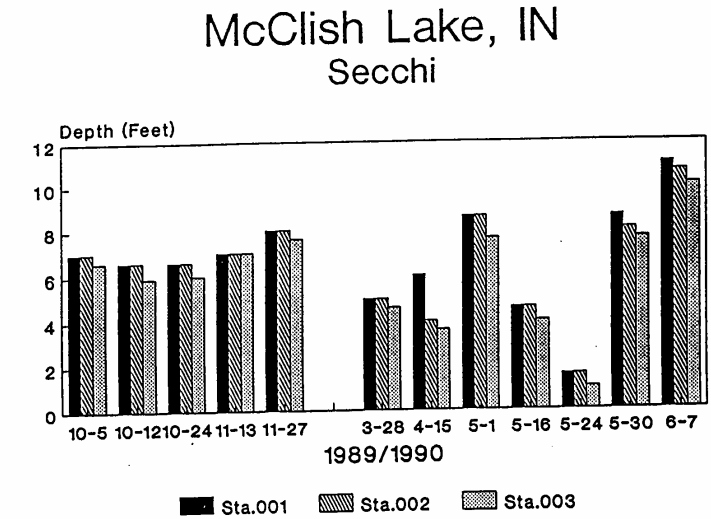
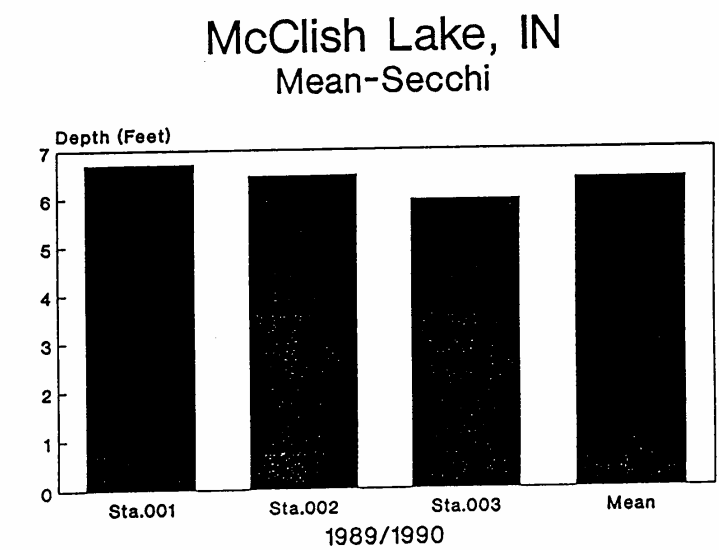


Figure M6. Secchi Disk Transparency for McClish Lake During September and October 1989.



Data by B. Fuess



Data by B. Fuess

Figure M7. Results of Individual Stations from the Citizen Based Secchi Disk Monitoring Program of October 1989 - June 1990. Stations Were 001 (Center of Lake), 002 (Center of Lake at Southwest End) and 003 (Offshore From Tile Inlet at Southeast Corner of McClish Lake).

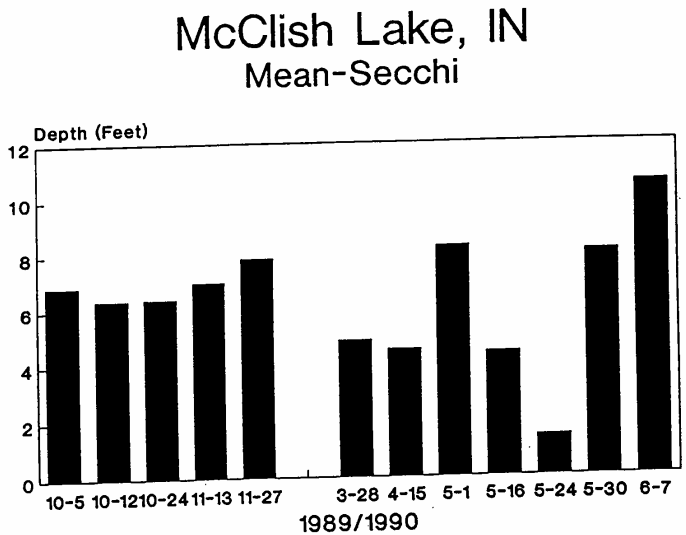


Figure M8. Mean Lake Data for Individual Dates of the Citizen Based Secchi Disk Monitoring Program of October 1989 - June 1990. Stations Were 001 (Center of Lake), 002 (Center of Lake at Southwest End) and 003 (Offshore From Tile Inlet at Southeast Corner of McClish Lake).

IDEM EUTROPHICATION INDEX

Mr Harold BonHomme of the Indiana Department of Environmental Management (IDEM) devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined.

The 1973 eutrophication index for McClish Lake was calculated by the Indiana Department of Environmental Management as 18, thus assigning the lake to the category of best water quality, Class One. Using identical parameters, Indiana University calculated an index of 24 based on data collected during July 1989. While still considered Class One, the 1989 value of 24 is extremely close to the upper limit (25) of this trophic state category. On the basis of the eutrophication index alone, it appears that the condition of McClish Lake has declined by 33% in the past 16 years. It must be remembered, however, that the degree of change observed at McClish Lake in the past 16 years may be within the range of expected variability of such parameters, and a detailed study is needed to determine whether observed changes in the eutrophication index truly represent changes in trophic state.

FISH: CISCO

The cisco inhabits deeper portions of the water column and is often missed by routine fishery survey techniques employed by the DNR. This fish species requires cold well oxygenated water and is therefore sensitive to deoxygenation of the lower water column associated with increasing eutrophication. Ciscos were common in McClish Lake in 1955 (Frey 1955), 1972 (Gulish 1974), and 1975 (DNR). A follow up survey in 1988 using sampling methodologies specifically designed to maximize the likelihood of catching ciscos did not yield many specimens, leading DNR to conclude that the species was now rare in the lake.

Mr. Robert Fuess reported that a major cisco kill began in McClish Lake during mid August 1988 and extended through at least Labor Day. Residents on the Labor Day weekend "were picking up dead and dying ciscos on their beaches by the bucket full". Mike Walterhouse (1988) and Jed Pearson of the Indiana DNR observed 21 dead ciscos when they visited the lake on 14 September 1988 and noted that the kill appeared to have been extensive. Walterhouse wrote in his report "another cisco lake gone?". No other fish species were part of the 1988 kill. A cisco kill was also observed during the

summer of 1989 but was not as extensive as that of 1988. It is entirely possible that the species has been extirpated from McClish.

DITCH SAMPLING

METHODS. At each station, two, 1-liter water samples were collected from the upper 15 cm of the water column. Water samples were analyzed for: calcium carbonate alkalinity, specific conductivity, pH, total nitrogen, total phosphorus and color. In addition to water quality measurements, stream flow was calculated using a General Oceanics mechanical flowmeter and a visual survey was conducted of stream and basin characteristics.

DITCH CHEMISTRY

Two ditch stations were sampled during the 1989 survey (Figure M9). Station ML1 sampled the tile entering the lake along the southwestern shore. Samples were collected approximately 150 feet upstream from discharge point along the lake shore. The segment of the watershed drained by this point source is mostly cultivated. Station ML2 was at the mouth of the tile that drains into McClish Lake at its southeast corner. Samples were collected on the west side of McClish Road. This watershed segment is used for row crops and pasture.

Water chemistry data for both stations were collected on 18 January 1990. Flow was detectable at only ML1 (0.31 cfs) (Figure M10). There was little difference in pH between ML1 (6.2) and ML2 (6.5). Both alkalinity and conductivity were greater at the southeast tile (Figure M11).

Unlike alkalinity and conductivity, nitrite/nitrate nitrogen (Figure M12) and both total and ortho phosphorus (Figure M13) were greater in the southwest tile (ML1). Finally, the value total suspended solids (TSS) was 3.7 times greater in the southwest tile (26 versus 7 ppm). It is felt that all TSS values likely reflect inorganic rather than organic turbidity given the time of year.

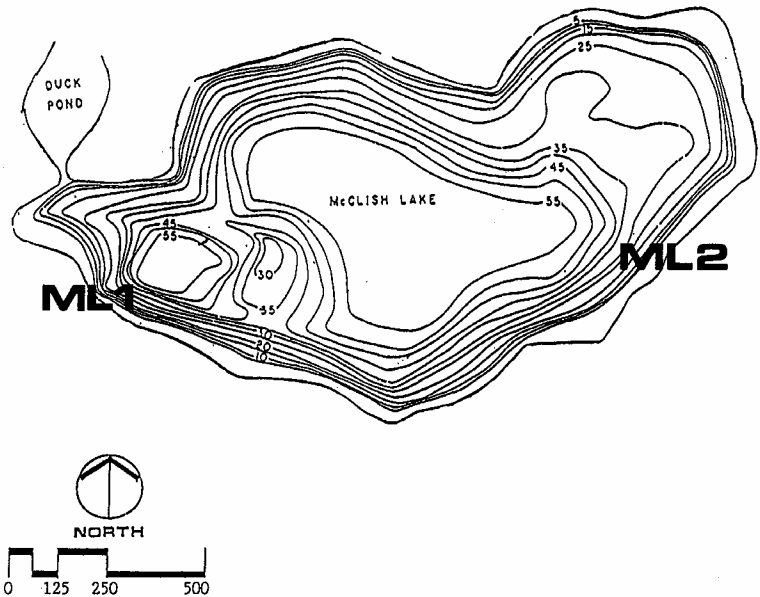


Figure M9. Stream Sampling Stations for 1989 Investigation

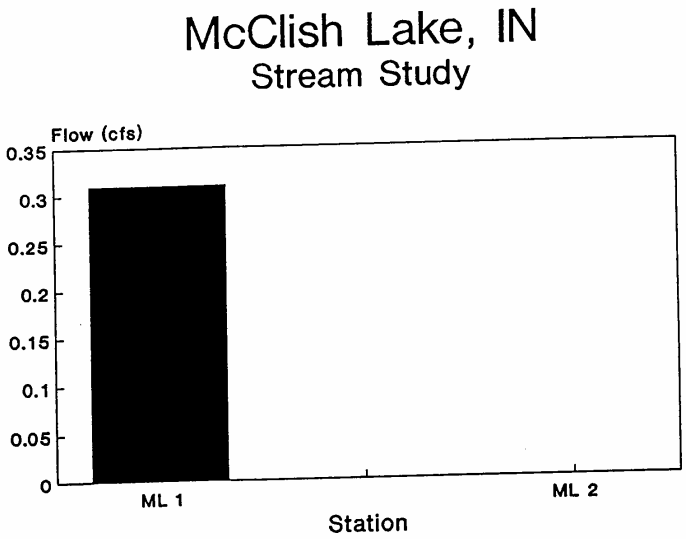
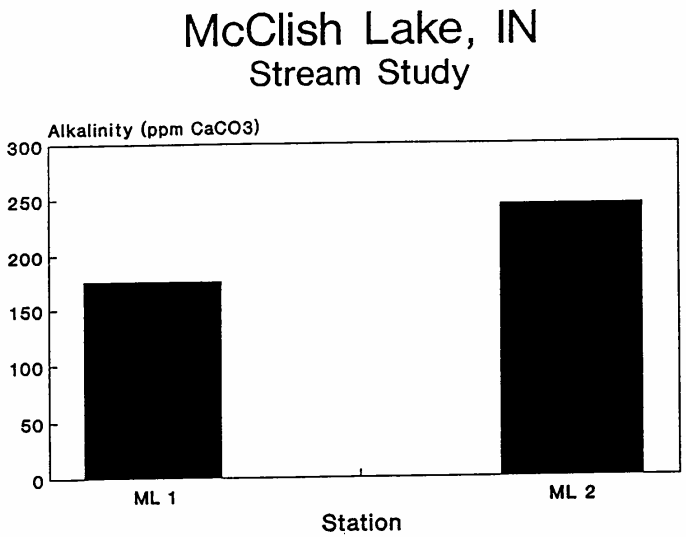


Figure M10. Flow in Two Tiles Draining the McClish Lake Watershed For 18 January 1990.



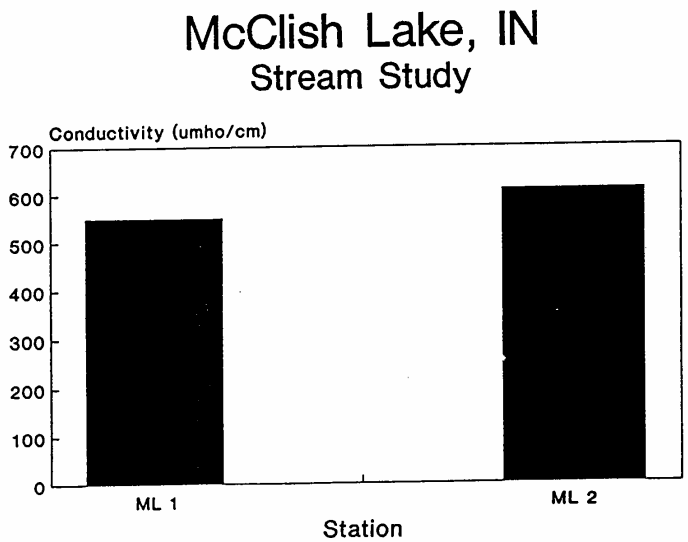


Figure M11. Alkalinity and Conductivity Values for Two Tiles Draining the McClish Lake Watershed For 18 January 1990.

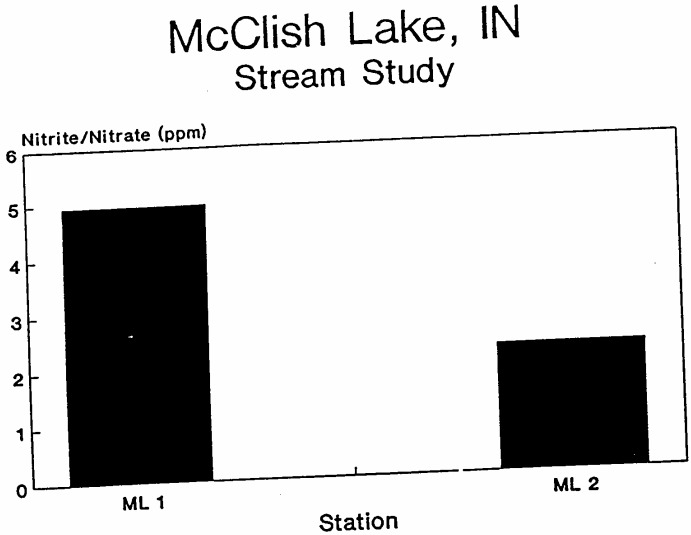
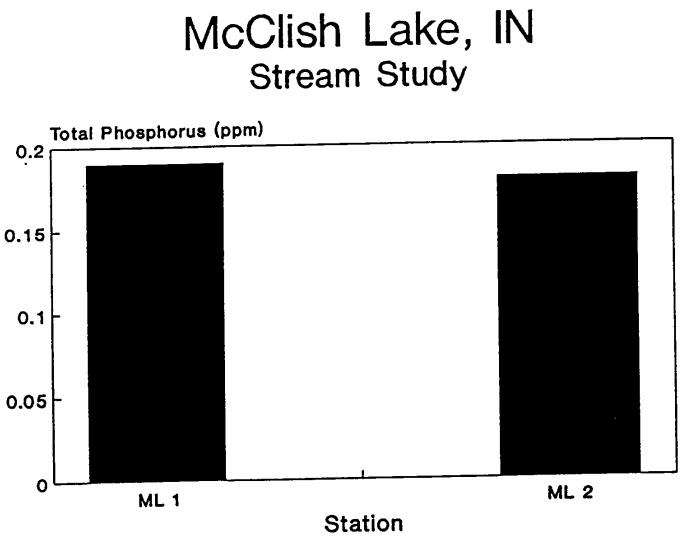


Figure M12. Nitrite/Nitrate Values for Two Tiles Draining the McClish Lake Watershed For 18 January 1990.



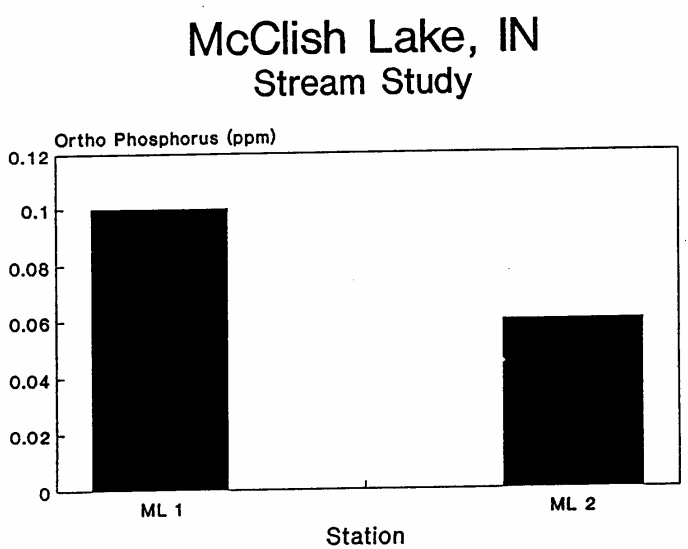


Figure M13. Total Phosphorus and Orthophosphorus Values for Two Tiles Draining the McClish Lake Watershed For 18 January 1990.

McClish Lake, The Watershed

The McClish Lake Watershed

The approach of this part of the study is to specifically address the effect of the watershed on the Lake. After preliminary investigation, the method was to target the area(s) of highest concern. Our study had to discover how this watershed was contributing to challenges in this lake system. The concerns to be identified in the watershed were as follows:

a. Nutrient contribution to the Lake;
b. What are the probable sources;
c. How can sediment be reduced;
d. What are the intrinsic values of the watershed, and
e. How can the sources of sediment/nutrients be managed to reduce impacts to the lake?

This feasibility study included the use of the following resources:

a. Reconnaissance of the entire watershed by site visits on several occasions;
b. Walking tours of some private property areas that could not be properly observed from public areas;
c. Aerial photographs (County Surveyor);
d. Aerial photographs (USDA - Soil Conservation Service, 1972 and 1973);
e. Aerial color infrared photographs (NAPP, 1987);
f. United States Geological Survey (USGS) quadrangle maps;
g. United States Fish and Wildlife Service, National Wetland Inventory maps;
h. USDA - SCS Soil Surveys of DeKalb (1982), LaGrange (1980), Noble (1977) and Steuben (1981) Counties Indiana;
i. DeKalb, LaGrange, Noble, and Steuben Counties records: Auditor, Surveyor, Treasurer, etc:,
j. Various meetings and/or telephone conversations with State & County agencies, local property owners.

The main purpose of this investigation was to target the area(s) which would be the highest priority(ies) for land treatment systems for trapping nutrients and sediments in the watershed. These constructed solutions may consist of land treatment, settling basins, constructed wetlands, sediment traps, ponds, or shallow water habitat areas, etc. These terms are descriptive of similar broad-scale land treatment concepts that would reduce nutrient and sediment loading to the McClish Lake system. Other upland agricultural practices such as terracing, grassed waterways, conservation tillage, and proper animal waste disposal are all vital methods to improving the water quality of the lake. These practices, are discussed later in this section. Methods of land treatment and applications will be

recommended for problem areas. Local SCS and ASCS offices have been appraised of the areas felt to be contributing excessive amounts of sediment and nutrients or that would otherwise benefit from programs beyond the scope of the Lake Enhancement Program (see watershed tour). The goal of this feasibility study is to focus on the site(s) of greatest potential; to most benefit the lake system in the shortest time; and to attempt to identify the process to create this system and its costs. The final considerations that would evaluate the feasibility and/or priority of such constructed projects would then be up to the Lake Association leadership. Discussions with the Soil Conservation Service county offices indicated the awareness of problems with soils and agricultural practices above the lake. The SCS has pledged to help the Lake Association in any way possible including technical support, and initiating discussions with owners of properties which are contributing intolerable amounts of sediment, nutrient, and animal waste runoff. The SCS would be important support on the larger constructed solutions, and could be of prime responsibility to encourage and/or design the other upland practices and structures.

Natural Features

The McClish Lake watershed falls in the Northern Lakes Natural Region (Homoya et al, 1985). This Natural Region is comprised of numerous fresh water lakes of glacial origin. Natural community types common to this region include bog, marsh, lake, sedge meadow, prairie and various deciduous forest types. The aquatic communities may be characterized by the presence of bulrush, marsh fern, cattails, pond weeds, spatterdock, Virginia arrow-arum, orchids, tamarack and various species of sedges. The typical forest community which at one time covered over half of this natural region is dominated by oak (chiefly, red oak) and hickory. Other notable species include black, silver, sugar, and red maples; beech; American and red elm; green ash and cottonwood. McClish Lake's cisco (*Coregonus artedii*) population, a specie of State special concern was last reported in good number in 1975. A 1988 IDNR Fisheries survey of McClish Lake determined that cisco were now rare (IDNR 1989).

Techniques useful in preserving these natural features include:

a. Avoid relocation of natural stream channels

b. Avoid building close to wooded ravines or stream banks.

c. Preserve natural vegetation adjacent to water areas.

d. Avoid construction in, or drainage of, wetlands.

e. Avoid the use of on-site septic systems near the lake or near drainages where there is potential for saturated soils.

Watershed Tour--impressions by visual survey

McClish Lake and Watershed

The purpose of this section is to express in narrative form the observations and general visual impressions that were made during site tours of the watersheds and review of color infrared and other aerial photographs. The intent is to provide a perspective that may be fresh and to stimulate residents to make their own continuing observations.

Prior to our detailed watershed tours, we examined several aerial photographs of the Lake and watershed. The purpose of this was to identify potential problem areas not likely to be observed from the ground in order that they could be checked in the field. Aerial photographs were also used to help us focus on the "big picture". This allowed us to understand the watershed interaction as a whole before we broke it down into its smallest components (Figure M14).

1. McClish is the smallest lake of the group studied. A variety of nice homes and seasonal cottages ring almost the entire lake.

2. It becomes quickly apparent that this relatively small lake is in the poorest condition of those studied. Watershed sediments are flowing into and filling the lake from many sources. The main inflow from the center of Section 31 carries an important sediment load; and field runoff from the east, although much tilled, was observed to be a significant contributor. Each of these inflows must be considered for high priority land management if the deterioration of the lake is to be slowed.

3. A tile entering the southwest shore visibly carries very brown sediment laidend water probably from open-broken tiles over the hill to the west (southwest corner of Section 25). A dry dam or constructed wetland is recommended for this prominent sediment source. Utilizing a simple riser pipe located nearest the lake on the broken tile (with either option) would effectively reduce sediment loading to the lake.

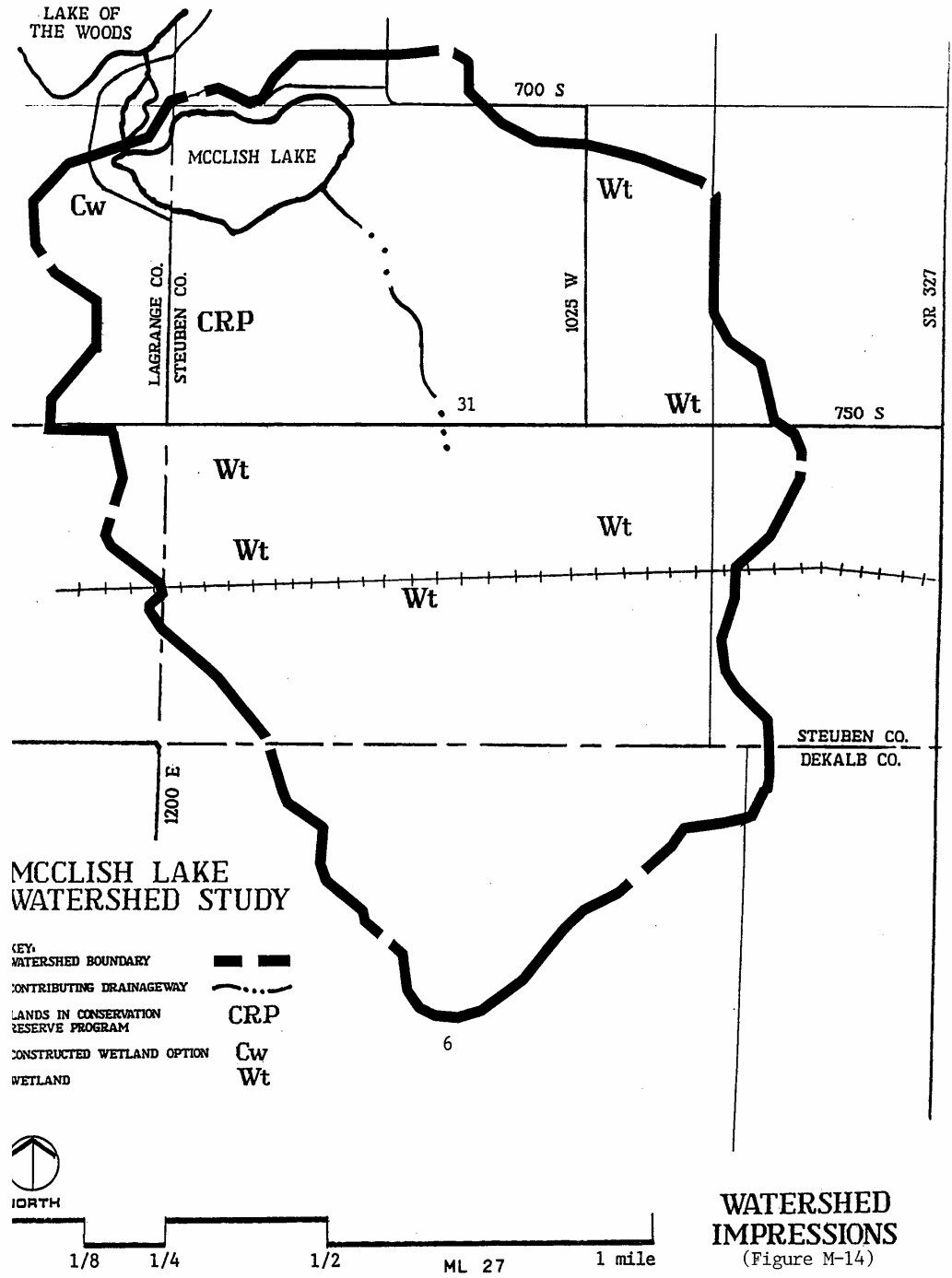
4. The upland watershed is very rolling, but has several nice wetland depressional areas that could be enhanced or preserved.

5. Almost all of the watershed for McClish Lake is in Steuben County.

6. The area west of the main inlet to McClish (Section 31) has recently been enlisted into the Conservation Reserve Program (CRP).

7. The southwest portion of the McClish watershed (Section 6) is in long term hay rotation.

8. Generally, there is a lot of watershed and development pressure on such a small lake that apparently has no good remaining buffers of filtering system. Addressing each of the inflows and intensive, if not total, conservation land treatment of this watershed is critical. This is crucial not only to McClish, but also to Lake of the Woods, which will soon show (if not already) the adverse effects in McClish Lake.



WATERSHED IMPRESSIONS
(Figure M-14)

Photospectroscopy

Aerial photography is an intricate tool for use in many topographic and natural resource applications.

In doing a land use study using aerial photography, several items must first be considered to provide the most accurate detailed information possible in obtaining the desired data.

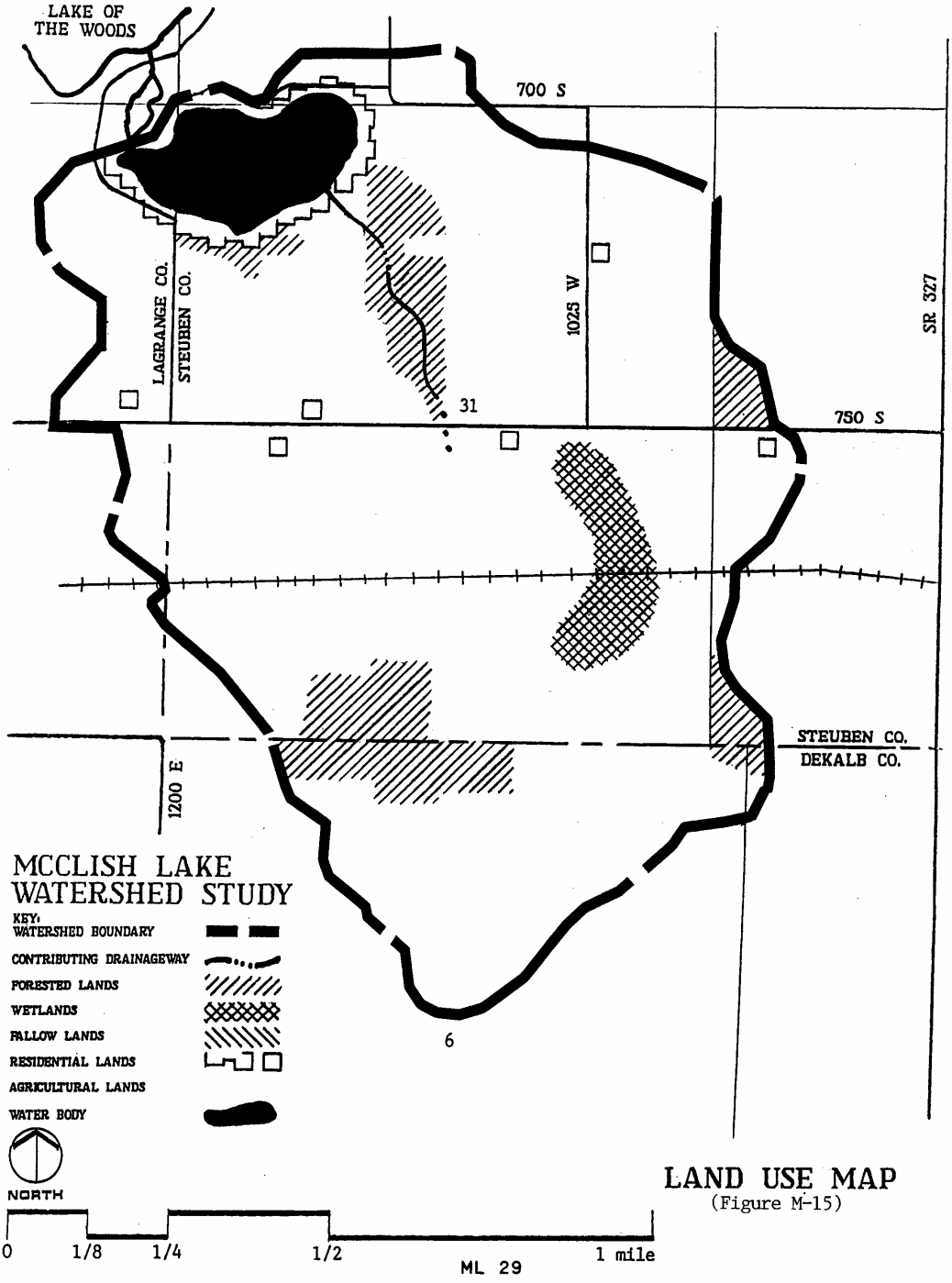
First, and probably most important in doing a study of primarily agricultural usage, the "type" of photograph used is important. For the most part, two "types" of photographs exist: 1) those taken in the visible spectrum, and 2) those taken in ultraviolet or infrared spectrum of light. Since all living organisms emit energy in the electromagnetic spectrum and since our study is based primarily in an agricultural watershed area, color infrared photography was used.

This type of photography delineates plants through size, density, and respiration, by photographing specific intensities of electromagnetic radiation emitted. Fallow lands, lake and wetlands appear as grey or black areas on the photo.

Second, the date in which the photographs were taken is an important consideration in the determination of the results and comparison to current trends.

Month and day play a factor in the interpretation of the types of vegetation and wetlands described. An extreme example of this would be trying to distinguish agricultural usage on a photo taken in July compared to the same photo taken in December. The day is also a factor because of previous weather conditions. According to the USDC, National Weather Service, 1.8 inches of rain fell over the project area in the 4 weeks prior to the photo date, this was 0.8 inches below normal, however this deviation was not sufficient to alter normal land use cover types. The photographs used for this study were taken on the September 4, 1987 fly-over at a scale of 1:40000 (figure page v).

In doing the land use study of the McClish Lake watershed, the entire watershed was laid out on the photographs using a transparency. The size of an overlay grid (1 acre) was then calculated, drawn, and then placed over the photos. From there the watershed was divided into the following land use categories: Agriculture; Fallow; Forested (woodlots); McClish Lake; Residential; and Wetlands. Results of the study are shown in watershed summary, Table M2. Land use is graphically represented in Figure M15.



LAND USE MAP
(Figure M-15)

McCLISH LAND-USE SUMMARY TABLE		
Cover Type	Acres	% of Total
Agriculture	533.0	73.7
Fallow	0.0	0.0
Forested (woodlots)	41.0	5.7
McClish Lake	33.0	4.6
Residential	66.0	9.1
Wetlands	50.0	6.9
Total Watershed Area	723.0	100.0

Table M2. McClish Lake Land-Use Summary

Geology

The McClish Lake watershed is underlain by bedrock of the Coldwater Shale Formation (Gray 1987). The Coldwater Shale Formation consists of 90 to 350 feet of gray shale laid down in the lower Mississippian Period of the Paleozoic Era (about 350 million years ago).

The shale deposits of the McClish area are covered by over 200 feet of partially lithophied to unconsolidated glacial deposits (Gray 1989). The most recent glaciation occurred some 12,000 years ago during the Wisconsinan Advance. The McClish Lake watershed is comprised of sediments deposited from the Huron-Saginaw Lobe of the Wisconsinan Ice Sheet (Hill 1986). This material is dominated by glacial outwash fan deposits of sand, gravel, and loam till of the Trafalgar Formation. The more complex till of the area consists of stratified drift in chaotic form. The Trafalgar Formation includes large areas of severely eroded drift, and dead-ice land forms...McClish Lake! For further discussion on surface geology, see Soils.

Topography

The watershed of McClish Lake is best described as a morainal topography. Morainal topography is a general term used to describe areas of irregular mounds and ridges which are the result of glacial drift. Glacial drift are deposits of outwash streams and unsorted sand and gravel tills. The highest point in the McClish watershed is 1013 feet above sea level at the southern corner of the watershed. The lowest point is 951 feet above sea level at the lake. Relief throughout the watershed is characterized as rolling to strongly slopping to the southwest, flat to somewhat depressional to the east, and rolling to flat near the lake. Slopes range from 0 to 12 percent.

Severe slopes

The length and steepness of slopes are major factors in assessing the probable erosion risks of an area. On steep or long slopes, runoff water accumulates in channels where increased flows produce greater erosive forces. Level or flat lands produce shallow overland flows over a larger area. This decreases the erosive forces of runoff.

The intent of this study-map (Figure M16) is to further illustrate the fabric of the land forms in the watershed. Areas with severe slopes comprise 89 acres of the McClish Lake watershed. Severe slopes detailed in this study range from 10 to 12 percent. This study provides further evidence where land management emphasis should be. This graphic also substantially matches the worst conditions of Highly Erodible Lands and will be discussed later in the report.
Areas mapped as having severe slopes should not be in agricultural crop production without conservation tillage.

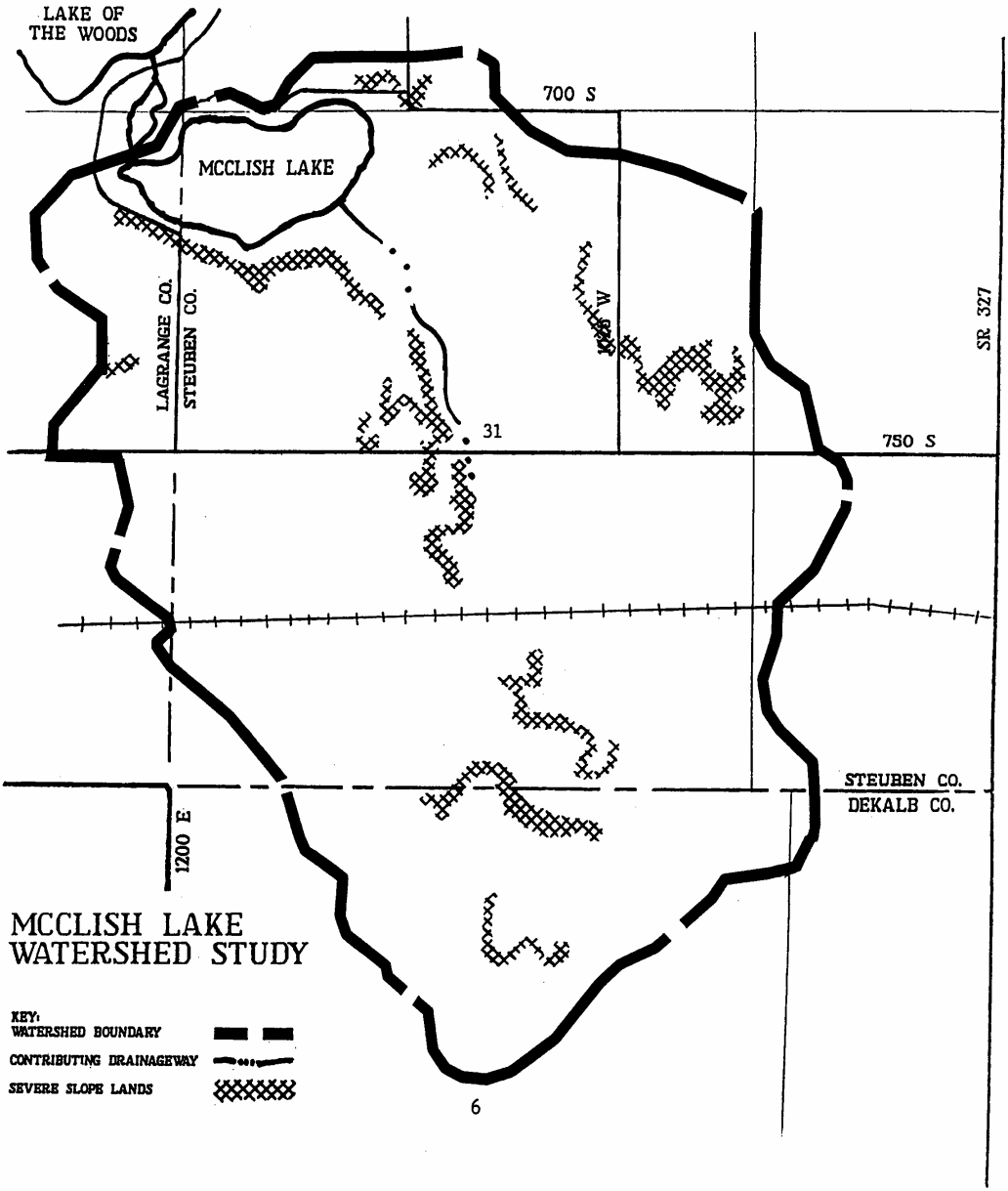
Soils

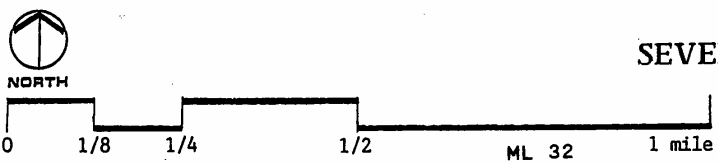
The soils of the McClish Lake watershed are grouped in the Kosciusko-Ormas-Boyer Association by the Steuben County Soil Survey. This association is further characterized as deep, sandy loam soils over sand and gravel of glacial outwash plains and moraines, moderately to well drained, with nearly level to strongly sloping areas.

The association is approximately 35 percent Kosciusko soils, 15 percent Ormas soils, 14 percent Boyer soils, with the remaining 36 percent other minor soil inclusions.

According to the Steuben County Soil Survey (1981), the major components of this association are well drained. The Kosciusko and Ormas soils are found in nearly level to moderately sloping areas, and the Boyer soils occur in generally steeper areas.

Other minor soil inclusions in this association are the Carmi, Casco, and Oshtemo soils which are similar to Kosciusko and Boyer soils, and the poorly drained Cohoctah, Millgrove, and Riverdale soils found in slightly lower areas, depressions and drainages.





ML 32

SEVERE SLOPES MAP
(Figure M-16)

Highly Erodible Land

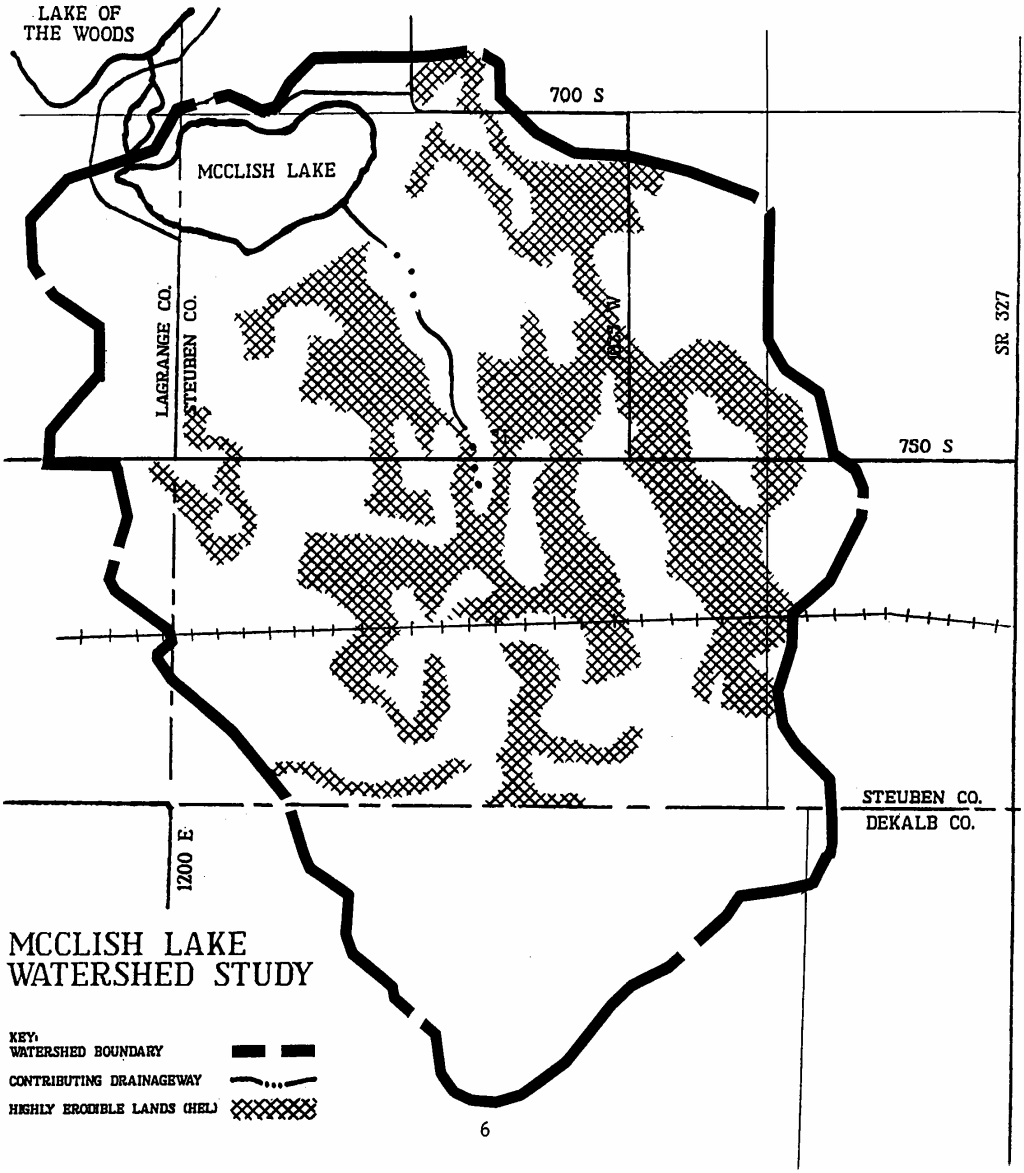
Highly erodible lands, or HEL are determined based on dominant slope length, percent slope and soil texture determined for each soil unit in each county. The purpose of identifying areas containing HEL is to display the origin of potential sediment sources so that the study may target areas of general concern. Using the Soil Surveys of DeKalb, LaGrange, and Steuben Counties, prepared by the USDA-SCS, and data provided by the local SWCD and SCS offices, soils of the HEL designation were mapped as shown in Figure M17.

The following highly erodible soils occur within the McClish Lake watershed (Table M3).

Boyer loamy sand, 6 to 12% slopes
Chelsea fine sand, 6 to 12% slopes
Hillsdale sandy loam, 6 to 12% slopes
Metea loamy sand, 6 to 12% slopes
Wawasee fine sandy loam, 6 to 12% slopes
Wawasee fine sandy loam, 12 to 18% slopes
Wawasee loam, 6 to 12% slopes
Wawasee loam, 12 to 18% slopes

Table M3. **Highly Erodible Land (HEL) soils of the McClish Lake watershed.**

The McClish Lake watershed was first analyzed to determine the total extent of HEL map units in the watershed. The watershed is comprised of approximately 211 acres (29.2%) of HEL. The study area was then further divided to determine the extent of HEL currently in crop production. HEL in agricultural production are of greater concern to the overall water quality of McClish Lake because these lands are more susceptible to erosive forces than HEL with established permanent vegetative cover. Approximately 92% (195 acres) of the total HEL occur in agricultural land-use areas, and are considered to be directly contributing sediment to McClish Lake. The HEL study was based strictly on HEL map units, it does not take into account non-HEL map units which may have inclusions of HEL soils. Target sediment sources were located using the HEL map and aerial photos, and will be discussed further in latter sections of this report.



NORTH

0 1/8 1/4 1/2 1 mile

ML 34

HIGHLY ERODIBLE LANDS MAP (HEL)

(Figure M-17)

WATERSHED MANAGEMENT

Highly Erodible Lands Overlays

The intent of this HEL/Severe Slope Overlay (Figure M18) is to emphasize the areas of the watershed where severe erosion problems are likely to occur. The areas defined in the Agricultural Lands/HEL/Severe Slope Overlay (Figure M19) were in crop production as of 1987. The 31 acres, detailed in this overlay represent the worst case HEL areas of the McClish Lake watershed. Much of this land is adjacent to open ditches, and represent the greatest sedimentation threat to McClish Lake. Every effort should be made to enlist those lands into CRP or related land treatment programs (grassed waterways, filter strips, etc.). In 1989, one of these critical erosion areas west of the main inlet to McClish Lake was enlisted into the CRP. This is a good start, but it is apparent from the HEL/severe slope overlay that the majority of the critical erosion areas of the watershed have not been fully addressed. These lands should not be in agricultural crop production.

Erosion: Causes and Prevention

Erosion of soil is primarily caused by the force of raindrops striking the ground, and, secondly, by the force of water flowing in rills or channels. As rain falls on unprotected ground it breaks small particles of soil free. These soil particles are then carried away by sheets of water. Naturally, as the intensity of rainfall increases, velocity and volume (flow) of runoff increases, thus potential soil erosion increases.

Types of soil erosion probable or noted in the Big Long watershed:

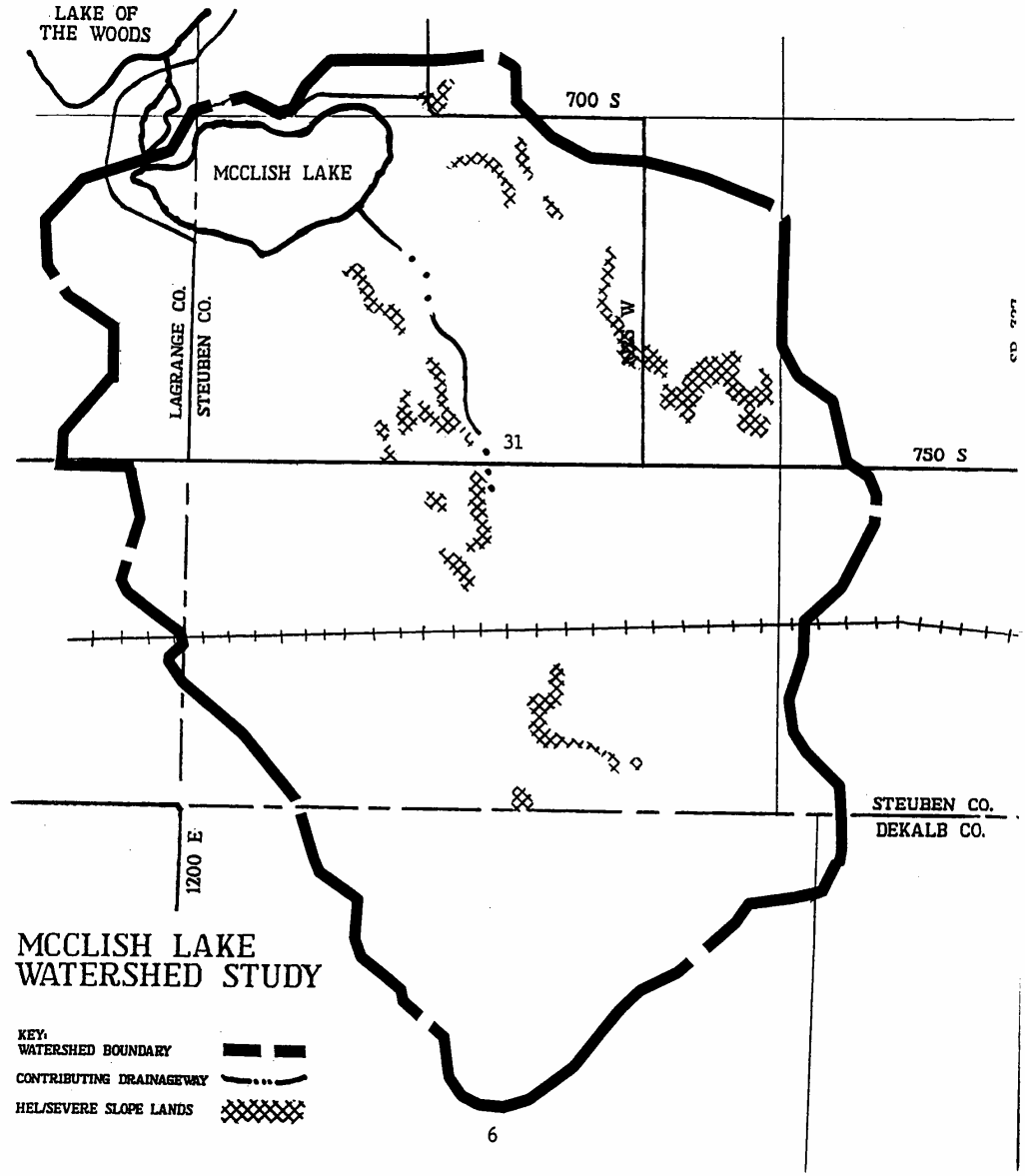
1. Raindrop (or splash) erosion due to the impact of rain on unprotected land.

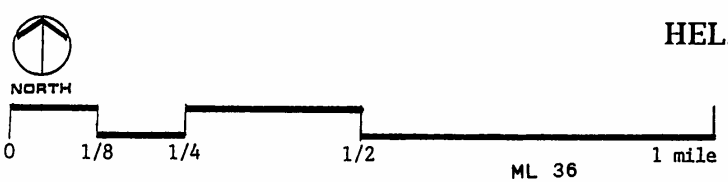
2. Sheet erosion or overland flow causes exposed soil to be suspended by the action of the flowing water, this is common on sloping to nearly level unprotected land.

3. Rill and gully erosion is the result of concentrations of runoff water in riverlates. Rill erosion may cut several inches into the topsoil. Gully erosion, resulting from unmaintained rills or drainages, may cut several feet into the surface.

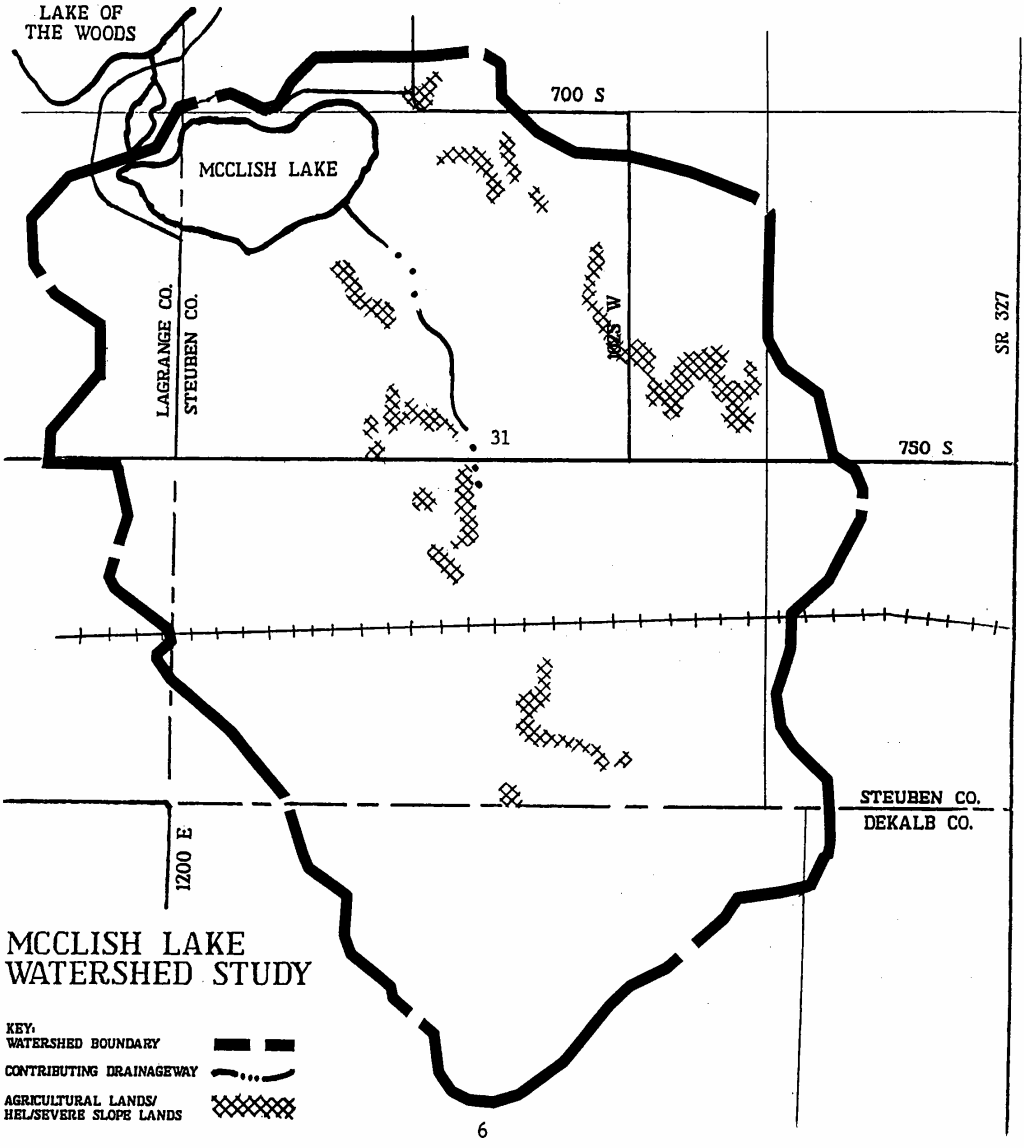
4. Streambank and channel erosion causes a scouring of stream bottom and undercutting of stream banks.

5. Wind erosion, similar to sheet erosion, is caused by the turbulent force of the wind over unprotected land.



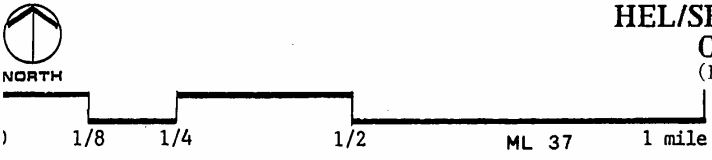


HEL/SEVERE SLOPES OVERLAY
(Figure M-18)



AGRICULTURAL LANDS/ HEL/SEVERE SLOPES OVERLAY

(Figure M-19)



The erosion potential of a given area may be determined by four criteria: 1) soils; 2) surface cover; 3) topography; and 4) climate.

An understanding of soils, and the factors involved in making soil more susceptible to erosion include: soil texture, soil structure, soil content of clay or organic material, and soil permeability. Maintaining adequate surface cover, either in the form of vegetative cover or crop residue, is important in reducing soil loss.

The realization is that soil is a valuable resource, and particles are difficult and expensive to recover once erosion has begun. **Prevention is easier than correction!**

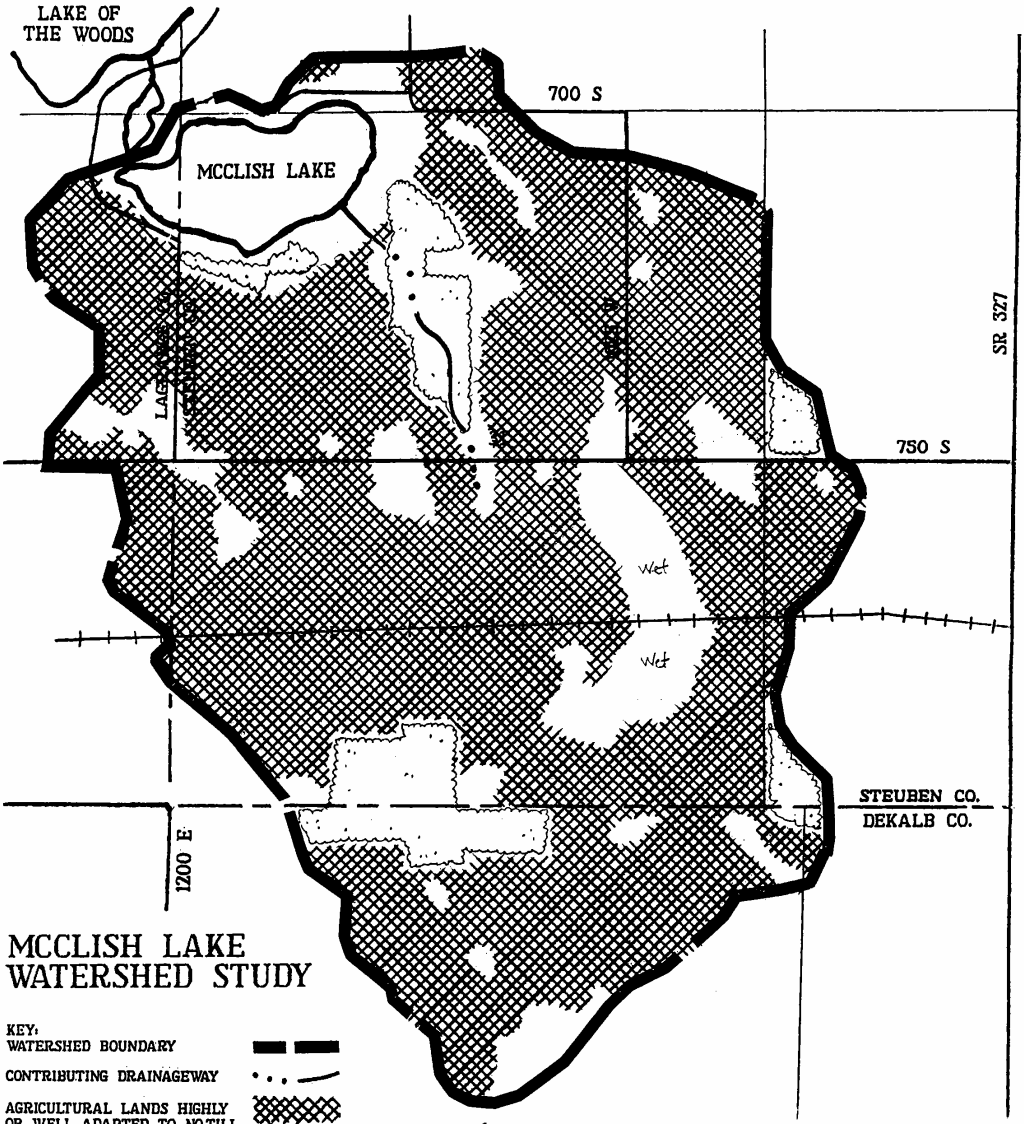
Useful concepts in erosion prevention and control:

a. Maintain natural vegetative cover wherever possible.
b. Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes.
   Row cropping should be done perpendicular to slope.
c. Divert runoff from severely sloping areas.
d. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.
e. Stabilize drainage areas immediately following any construction or "maintenance".
f. Leave natural buffer areas along streams and ditches.
g. Stabilize stream bank or ditch escarpments.
h. Utilize sediment ponds below feed lots and "open" sloping lands.
i. Construct and maintain sediment control structures <u>prior</u> to construction of any lake or waterfront development.
j. Implement applicable conservation tillage method.

Conservation Tillage

There are several methods of tillage currently utilized in corn and bean production: moldboard plow, chisel plow, large blade (deep) disc harrow, small blade (shallow) disc harrow, ridge-till, and no-till. Fall moldboard and chisel plowing are still frequently used by Indiana farmers, however, conservation tillage systems are becoming more widely excepted due to improved yields, and greater savings of soil, water, and money.

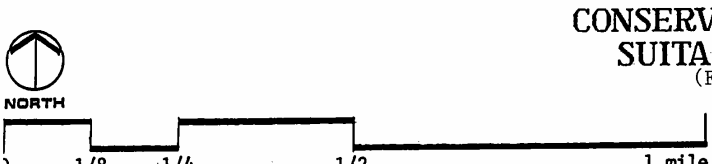
The no-till conservation tillage/planting system has been identified as one of the most effective conservation practice available to farmers in Indiana (AY-210). The Suitability for Conservation Tillage overlay (Figure M20) indicate 85% to 90% of the agricultural lands in the McClish Lake watershed are well to highly adapted to no-till conservation tillage systems. Agricultural lands depicted as unsuitable for no-till (13%) in the McClish Lake watershed include soils which are too wet or slopes greater than 12%. Lands noted as unsuitable to no-till should be in permanent cover.



6

CONSERVATION TILLAGE SUITABILITY MAP

(Figure M-20)



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Development on Saturated Soils

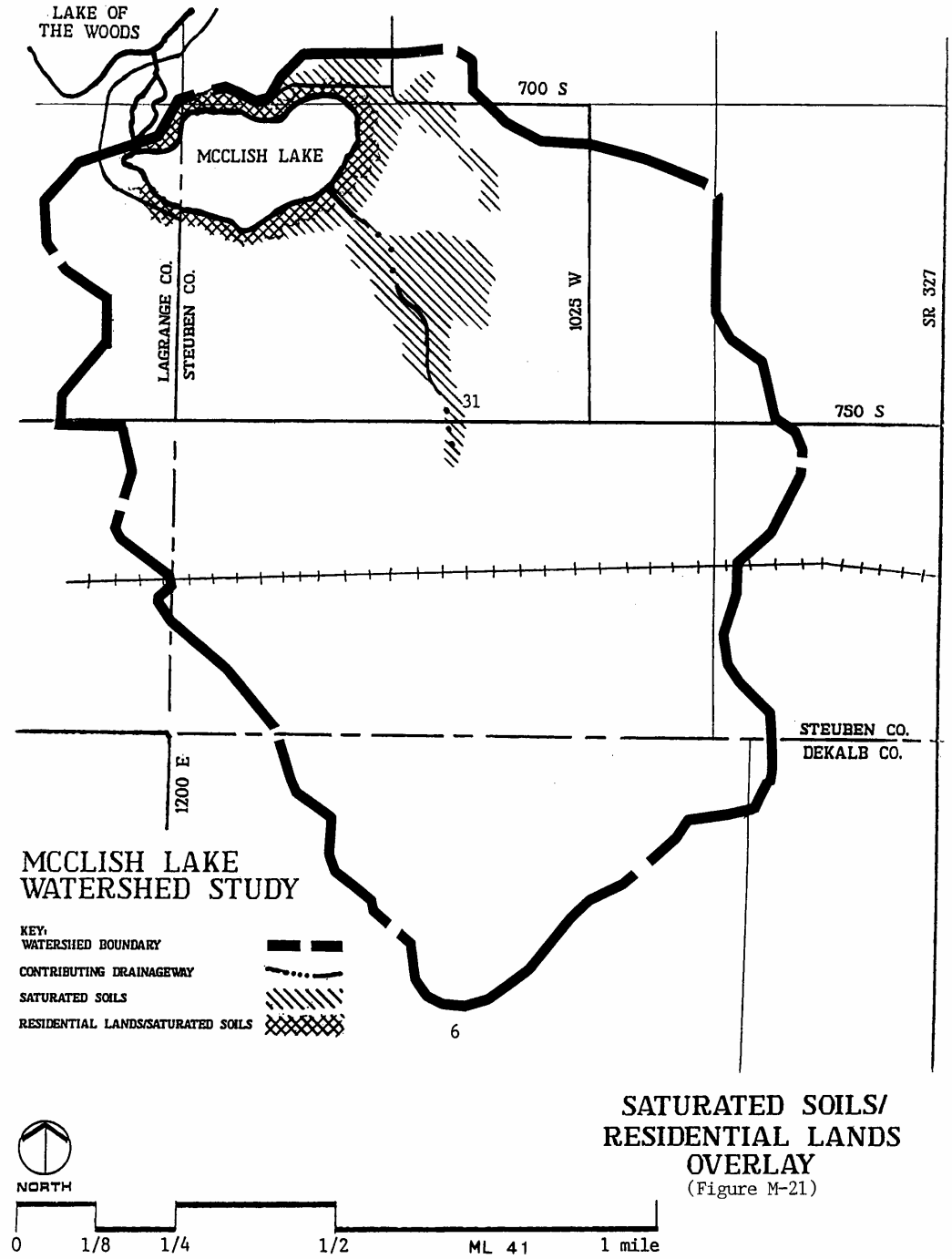
The goal of this study was to estimate potential septic system inefficiencies. Ineffective septic systems have been documented to contribute excessive amounts of nutrients to a lake and likely share greatly in the cause of a poor overall water quality rating. Using data collected on saturated soils (Table M4) and comparing it with building records from 1959 and 1987 (incomplete), projections were established indicating septic systems that were likely to be located in saturated soils (Figure M21).

The assumption was made that septic tank-type systems are in place for those residences located on saturated soils. General septic system efficiencies are based on the need for well drained soils necessary for proper treatment of sewage effluent. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well drained soils. It should be noted that seasonal fluctuations in the water table of poorly drained soils were not taken into account. Varying water table elevations and waste loading would be responsible for fluctuations in treatment success. Localized fecal coliform values likely increased due to a substantial increase in the summer population around the lake and fluctuations in the water table as well as residences in the watershed with septic systems that outlet directly into ditches.

The findings of this study indicate a constant trend towards building on saturated soils. In 1959, on McClish Lake, 36 of the 36 homes (100%) were located on saturated soils. Building records available from 1987 indicated that all homes constructed since 1959 on McClish Lake were also located on saturated soils.

Possible approaches to meet the current or future waste disposal needs with the objective of maintaining or improving water quality would include: 1) Lake-wide sanitary sewer system, 2) mound type septic systems and/or 3) pumping to suitable septic locations and 4) any of the above in combination with a constructed wetland or pond/wet meadow system.

The **first**, likely most effective and costly method of waste handling would entail the construction of a lake community-wide sanitary sewer system with off-site waste treatment. The **second** method, a mound type septic system would involve raising the septic tank and drain field above the saturated soil allowing for aerobic treatment of the sewage effluent. The **third** method of waste treatment, is a procedure which involves pumping the waste effluent to an area with soils suitable for use in septic tank systems.



SATURATED SOILS/ RESIDENTIAL LANDS OVERLAY
(Figure M-21)

Although treatment is certainly not limited to the management approaches discussed above, it was determined that these methods of waste treatment would effectively meet the goals of sewage disposal.

Residences must take on the responsibility of maintaining their own waste disposal systems. Drain fields must be inspected regularly and septic tanks must be pumped on a regular schedule. Further study is strongly recommended for those residential areas noted in the Saturated Soils/ Residential Lands Overlay. A study should be developed utilizing a septic leachate detector or preferably, a septic tank dye. It is further recommended that all inlets to McClish Lake be sampled for Fecal Coliform bacteria, Streptococcal bacteria, and bacteria ratios, in order to discern specific areas of sub-watershed contribution of human and animal waste.

If it is determined that an engineering study should be undertaken for a new wastewater treatment system, the method and site selection should consider tertiary treatment using a constructed wetland system.

Table M4. **Poorly drained soils adjacent to McClish Lake.** Adapted from USDA-SCS Indiana Technical Guide, 1988.

EDWARDS MUCK
HOUGHTON MUCK, undrained
METEA, loamy sand
MILLGROVE, loam
PITS, gravel
RENSSELAER, loam
UDORTHENTS, loamy
WASHTENAW, silt loam

Hydrology

The McClish Lake watershed is a sub-drainage basin to the Lake Michigan Basin. The main water supply comes from ground water stored in the sand and gravel deposits of the Wisconsin till aquifer. The watershed of McClish Lake receives an average annual precipitation of 33.5 inches with a standard deviation of 5.2 inches. July tends to be the wettest month with an average precipitation of 3.6 inches. On average, February is the driest month with a precipitation mean of 1.6 inches. The average basin drainage gradient in the McClish Lake watershed is 46.8 feet/mile. According to the 1979 Cowardin et al classification system, eighty percent of the wetlands located in the watershed are of seasonally flooded water regimes. Eighty-eight percent are small, less than ten acre, palustrine wetlands (Table M5). Palustrine wetlands are defined here as wetlands less than 20 acres in size, averaging less than 6 foot in depth, and dominated by trees, shrubs, and/or emergent vegetation (Mitsch and Gosselink, 1986).

It is estimated that 71% of the wetlands in the Lake Michigan Basin have been lost (Hamilton 1965). Losses are primarily attributed to drainage for agricultural production. The following table is intended to illustrate the types of wetlands remaining in the Lake of the Woods watershed, and focus attention on preserving these natural filters.

Table M5. **McClish Lake watershed water regime characteristics**

Palustrine	Occurrence	%Totals
Less Than 10 Acres	31	88.5
More Than 10 Acres	4	11.4
Totals	55	99.9
Cover-Type		
Emergent	25	71.4
Forest	9	25.7
Scrub/Shrub	1	2.8
Totals	35	99.9
Water Regime		
Seasonal	28	80.0
Unknown	7	20.0
Totals	35	100.0

Constructed Wetlands as a Watershed Management Practice

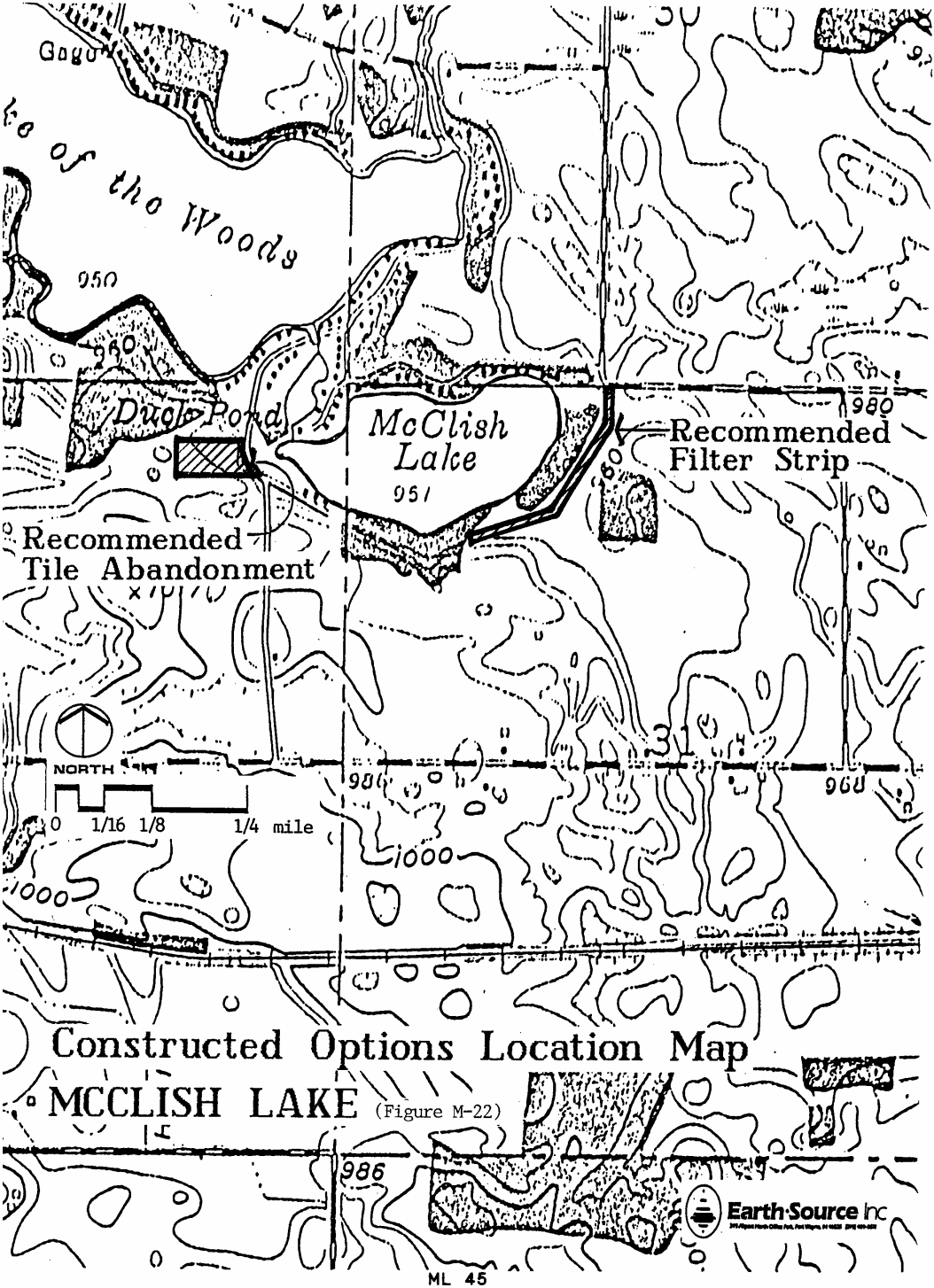
For more than 50 years, wetlands have been identified as water purifying systems for natural lakes (van der Valk, et al 1978). Wetland vegetation, benthic organisms, and soils perform as traps, at least seasonally, for nutrients, suspended sediments, metals, pathogens, and many agricultural chemicals (Kadlec and Kadlec 1978). Thus, during the course of the McClish watershed study, a primary objective was to identify opportunities for nutrient/sediment trap target sites on contributing ditches and tiles identified as loading excessive nutrients and sediments to the lake (Figure M22). Indeed, the Lake Enhancement Program considers constructed wetlands as one of the most effective management options. The primary criteria in selecting these sites were: location, topography, flow rates, soils, feasibility, current land use, size, environmental concerns, and sediment/nutrient loading characteristics of the drainage basin. As each site is considered for development, an evaluation should be made of the status of erosion control/land treatment above each proposed site, and goals set for timetables, land acquisition, fund raising, final design and construction.

Each site is described in the following text with a conceptual plan for illustration. Cost range estimates and priority recommendations are discussed in later sections of this report.

Project Descriptions: McClish Lake

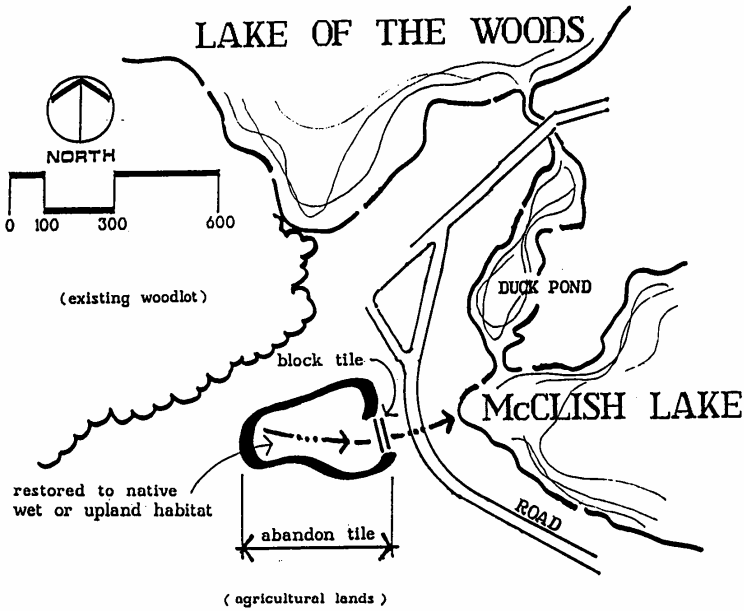
Southwest Tile Abandonment.

This site (Figure M23), is a small (3-5 acres), but important opportunity to halt a direct sediment and nutrient input to McClish Lake. Although the site has been in hay production in recent years, some feed grain cropping was observed on aerial photos from previous years. The problem is an open tile section in an old field tile which outlets directly into McClish Lake. Fine silt and suspended clay particles in this tile inflow are characteristic of those which block water column light transmission and lead to cisco kills. On January 18, 1990, the distinctive sediment plume from this inlet was readily visible over one-third of McClish Lake, the Duck Pond, and entering Lake of the Woods. Local residents report this sediment plume to be a common occurrence following any moderate rainfall event. Undoubtedly this inlet is one source of water quality problems and the 'declining' cisco fishery. The site shown on the concept plan is an upland depression in close proximity to the lake. The recommendation is to block and/or stand pipe the tile at the east edge of the depression, and abandon the old tile section to the west. This approach is typical to some U.S. Fish and Wildlife Service wetland restorations. USF&W has indicated that this would be a priority site due to existing



Constructed Options Location Map

MCCLISH LAKE (Figure M-22)



RECOMMENDED TILE ABANDONMENT

(Figure M-23)

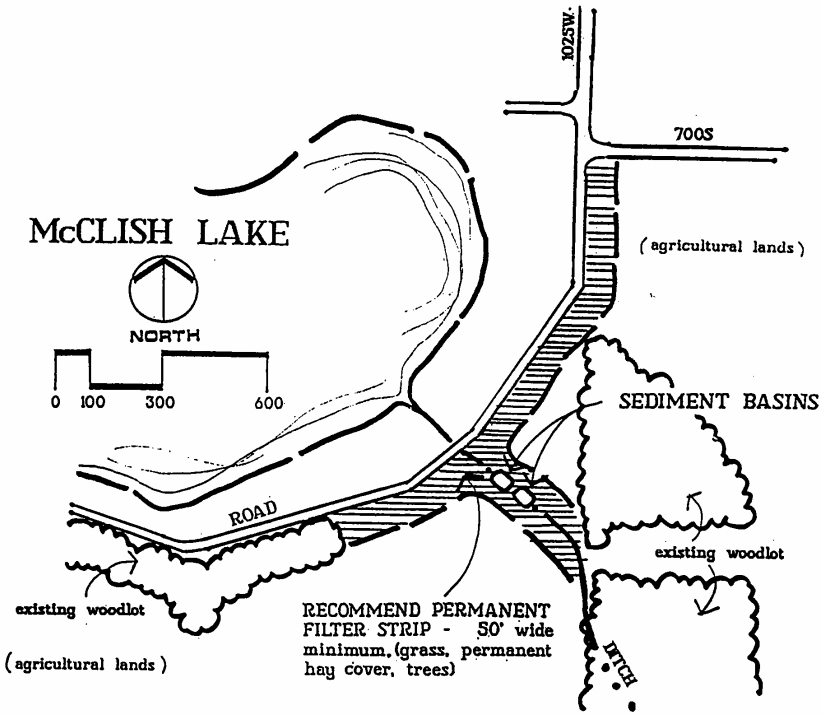
wildlife and water quality impacts and benefits attributed to this type of project. The depression may revert to native wetland or mesic upland habitat. Some planting assistance may target habitat type and aid in establishment of a very function and attractive area.

Filter Strip.

A permanent vegetated filter strip is suggested for the southeast side of the lake including the ditch bank (Figure M24). Some of this land is in crop production, and although in conservation tillage, its close proximity to the lake is an important factor in this recommendation. During rain events, sediment-laden run-off has been observed washing across the road, in roadside ditches, and directly entering open drainages to the lake. A permanent buffer of grass/hay, and/or trees/shrubs can be planted for cover.

Sediment Basins.

In the ditch southeast of McClish Lake (Figure M24), a sediment basin is suggested. With sedimentation identified as a major problem in McClish Lake, this site near the Lake will intercept a principal inflow to the Lake. As discussed elsewhere in this report, land treatment of agricultural land must be the primary approach to the protection of McClish Lake. Appropriate site(s) for constructed wetland opportunities were not found in this subwatershed. This project concept plan illustrates a series of excavated sediment basins. Final design planning should take into consideration: storm events, fabric and rock linings, site access, maintenance, and proper alignment.



RECOMMENDED FILTER STRIP

(Figure M-24)

Cost Estimates for Constructed Options

The following estimates are offered to represent the anticipated cost factors for construction of suggested sites. For final design and construction documents, an allowance of 15% to 20% of construction cost should be added to these estimates. Additional cost of services should be added for bidding, construction monitoring and construction administration if required by the funding agencies. Other additional cost items not included in these estimates are as follows: 1. Land cost (if any); 2. Attorney's fees to prepare land agreements; 3. Property line surveys or descriptions; 4. Preparation of permits such as to the Department of the Army, IDNR Division of Water, County Drainage Boards, Indiana Department of Environmental Management; 5. Operation and maintenance of sites and access thereto.

Priority recommendations, in this case both Very High (1), have been made based upon the need, feasibility, accessibility of the sites, and other considerations discussed in previous sections. The Lake Association should pursue all possible opportunities for implementation of these high priority constructed options.

Tile Abandonment.

Cost items include excavation for tile drain intercept; drop pipe; erosion control materials; and restoration plantings.

Estimated Cost Range: $2,300 - 4,200.

Priority Recommendation: Very High (1)

Filter Strips and Sediment Basin.

Cost items include grade and site preparation, excavation, and seed/plant materials.

Estimated Cost Range: $12,000 - 20,000

Priority Recommendation: Very High (1)

Permitting

Beyond property ownership, many governmental agencies may have jurisdiction over private property. For example, drainage may be regulated by the County Surveyor. Water issues, particularly construction in a floodway, is regulated by the Indiana Department of Natural Resources Division of Water, and the United States Department of the Army, Corps of Engineers. Excavation below legal lake level, or any ditch modification within 0.5 miles of the Lake, will require authorization by the IDNR, Division of Water, Lake Section. The Corps of Engineers will require permitting and Water Quality Certification by the IDEM, Office of Water Management for construction in wetland areas. The Corps of Engineers (and the Divisions of Water) may require permitting if any construction impounds water. A list of different agency contacts, addresses, and telephone numbers may be found in appendix B.

Conclusions & Recommendations

CONCLUSIONS AND RECOMMENDATIONS

McCLISH LAKE

McClish Lake is undergoing progressive cultural eutrophication. While the IDEM eutrophication index value of 18 in 1973 placed the lake in Class One (best water quality), Indiana University calculated an index value of 24 in 1989, one point from being assigned to Class Two (intermediate water quality). In the sixteen year period, water quality declined by approximately 33%. It appears that eutrophication has been associated mostly with expanding phytoplankton populations. The degree of change observed at McClish Lake in the past 16 years may be within the range of expected variability of such parameters, and a detailed study is needed to determine whether observed changes in the eutrophication index truly represent changes in trophic state.

The most serious biological changes in the lake have been associated with the loss of a positive heterograde oxygen profile in the lake. Such oxygen profiles are defined by a zone of elevated oxygen values at depth resulting from photosynthetic activity of a layer (plate) of phytoplankton. The vertical and temporal extent of this oxygen rich layer was greatly reduced between 1973 and 1988, and it was totally lacking during the late summer and early fall of 1989.

Ciscos, a fish requiring cold well oxygenated waters, were considered common in McClish Lake from at least 1955 to 1975. By 1988, however, this species was considered rare. A massive fish kill of ciscos occurred during the late summer and early fall of 1988, and a smaller kill was noted during the summer of 1989. The loss of ciscos appears to be directly linked to the obliteration of the positive heterograde oxygen curve characterizing McClish Lake prior to 1988.

The loss of the heterograde oxygen curve and the phytoplankton plate that produces it appears directly linked to a reduction in water clarity in McClish Lake. A heterograde oxygen curve was present in the lake during July 1989 when water clarity was similar to that reported in the late 1970's. By September 1989, however, water clarity was approximately 25% lower than reported during the 1970's and the heterograde oxygen curve was absent. It appears that the phytoplankton plate became shaded out during the late summer of 1989 and likely 1988 leading to loss of the oxygen sensitive ciscos.

The citizen based Secchi monitoring program of 1989 - 1990 clearly demonstrated a 200-600% reduction in water clarity following rainfall events and observed that such periods were accompanied by noticeable suspended silt in the water column. The delivery of suspended silt to McClish Lake appears to have increased recently associated with

installation of drain fields in the watershed in 1984 and 1987 with water delivery directly to the lake. We suggest that the loss of the heterograde oxygen curve and associated stress to cisco populations is a direct consequence of delivery of watershed derived erosion products to the lake and not related to a major increase in lake trophic state. No lake management plan will be successful at McClish Lake until watershed delivery of inorganic sediments and nutrients is greatly reduced. Our unfunded investigations at McClish Lake were sufficient only to demonstrate that a problem exists, but not detailed enough to formulate a sound management plan for the lake. A number of proven techniques can be implemented to alleviate management problems associated with cultural eutrophication (Crisman 1986, Moore and Thornton 1988), but specific recommendations for McClish Lake are not possible without a detailed investigation of the lake. Instead, our recommendations focus on ways to reduce watershed loading of nutrients and sediments to the lake basin.

McCLISH LAKE WATERSHED

It is apparent that nutrient and sediment loading from the McClish Lake watershed and Lake shore have not decreased over recent history. In fact, water quality studies in the Lake suggest that watershed loading has increased over the past 6 years. McClish Lake has met the increased availability of sediments and nutrients with increased frequency of algal blooms, and more striking, the loss of the lakes' cisco fishery. Successful restoration of McClish Lake is dependent on curtailing the flow of nutrients and sediment bonded nutrients to the lake from the watershed, and in addressing septic leachate, a large probable source of nutrients entering McClish Lake. For this reason, priority must be given to land treatment of critical watershed areas; one or more of the constructed options; and further study of potential septic problems.

I. Lake Residents:

A. Septic leachate from lake front homes is suspected of contributing highly to the decline in water quality of McClish Lake. Residents must undertake the responsibility of maintaining their own waste disposal systems. Drain fields should be inspected regularly and septic tanks should be pumped on a regular schedule. Avoid the use of on-site septic systems near areas which have been identified as containing saturated soils, and relocated systems currently situated in saturated soils. The Lake Association should consider a lake-wide sewer inspection using either a septic dye test or septic leachate detector, areas defined in the saturated soils

study are of primary concern. The Lake Association should also consider engaging an engineering study for a lake-wide sanitary sewer district which considers several alternative methods of waste treatment.

B. If fertilization for lakefront lawns is desired, residents should consider using lake water for irrigation/fertilization of lawns (lake water will provide ample nutrients) or, use fertilizers low in phosphorous (0.5% liquid; 3.0% granular). Fertilizer should be applied <u>only</u> during the growing season, April-October. (Note: an IDNR permit may be required for pumping out public waters)

C. The Lake Association should take an active role in monitoring future development: lakefront and watershed. Development monitoring could be accomplished by the formation of a 'Lake Watch Committee'. Lakefront development should consider setbacks from the lake, septic suitability, and must incorporate adequate sediment control measures. Watershed development must be made aware of potential sediment and/or nutrient sources to the Lake, and like lakefront development, incorporate adequate sediment control measures. Sediment control structures such as erosion control mats, silt fences, straw bale filters, and sediment basins must be installed <u>prior</u> to any construction or development which would impact the Lake. The Lake Association should also promote the establishment of a county-wide erosion control plan.

II. The Watershed:

A. The land-use or cropping practice of areas mapped as having highly erodible lands or severe slopes should carefully considered. Much of this land should be in a conservation tillage program, or, in some cases should not be in agricultural crop production. Those areas defined in the HEL/severe slope study should maintain natural buffer areas or filter strips along ditches or open drainageways.

The 31 acres, detailed in Agricultural Lands/HEL/severe slope overlay represent the worst case, or highest erosion threat areas of the McClish Lake watershed. Much of this land is adjacent to open drains or broken tiles which facilitate the transport of eroded soils to the Lake. Every effort must be made to enlist these areas into conservation tillage, CRP or related land treatment programs. Lands in the McClish watershed noted as unsuitable to no-till should be in permanent cover.

As illustrated by the 'Conservation Tillage Suitability Map', the balance of the watershed is well adapted to conservation/no-tillage methods. This area represents the major overall export of sediments and nutrients from the watershed. Other land treatment practices, especially stream/ditch bank stabilization, should be pursued along the Southeast Ditch inlet. This could be accomplished by establishing grassed ditch borders (filter strips), and, in more extreme cases, structural or riprapped solutions. Excavate and maintain sediment traps that may be located at easily accessible intervals, such as near roads, as discussed in the Constructed Options section. (Other various Conservation Practices are listed in Appendix C. These practices will be detailed in individual farm Conservation Plans, as required by the 1985 Farm Bill to be implemented by 1995).

B. Consider all Constructed Options as described in that Section of this report: a) intercept the southwest tile drainage. b) construct nutrient/sediment trapping systems (filter strip and sediment traps) on the southeast tile/ditch. Priority should be given to all Constructed Options, as they not only will improve the water quality and fishery of McClish Lake, but Lake of the Woods as well.

III. General recommendations:

Encourage preservation of remaining upland forest, wetlands and upland depressions. Avoid building close to wooded ravines or streambanks. Avoid construction in, bypassing of, or drainage of, wetlands and maintain natural vegetative cover wherever possible. Land owners must be made aware Federal regulations protecting wetlands.

Avoid relocation (straightening) of natural stream channels. Stabilize drainage areas immediately following any construction or "maintenance". Quick vegetative cover and streambank protection is essential to erosion control.

Row cropping should be done perpendicular to slope. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.

Get livestock out of open ditches and ditch banks, perhaps, by helping landowners find financial assistance to fence and construct filter strips. Also, Filter strip or otherwise intercept runoff from feedlots.

Avoid spreading manure during the winter or near direct drainageways unless it can be incorporated IMMEDIATELY.

Pretty Lake

EXECUTIVE SUMMARY

Pretty Lake is a Class One water body in LaGrange County. A Class One lake is a lake of highest water quality, which rarely support macrophyte and/or algae in serious concentrations (IDEM, 1986). Historical data suggest that lake trophic state has not changed appreciably during the past two decades. Although the lake appears not to have experienced recent progressive eutrophication, oxygen conditions declined during the early 1980's to a level no longer able to support trout populations year round. Algal blooms dominated by blue-green algae are common during summer.

The principal factors controlling the trophic state of Pretty Lake have been identified as nutrients and sediments from watershed sources and delivered by ditches. Sediment eroded from the watershed has been responsible for pronounced basin infilling of nearshore areas near ditch mouths especially in the west and north end of the lake.

Conservation tillage has been identified as one of the most effective methods of controlling erosion due to agricultural practices. Thus, continued and expanded use of conservation tillage systems in conjunction with addressing drainage issues on a cost-benifit basis, and implementation of the constructed options and filter strips is strongly advised.

Lake residents can further control sediment and nutrient loading by monitoring lake front development for adequate erosion control and re-evaluating the fertilizer requirement of lake front home. A lake watch program could be a viable approach to meeting this task.

No in-lake management recommendations are proposed for Pretty Lake. Macrophytes are not likely to pose management problems in the lake if eutrophication progresses further due to limitations of light and basin morphometry. If watershed practices are implemented to reduce nutrient and sediment loading to the lake, it is likely that the trophic state of Pretty Lake will decrease accordingly.

INTRODUCTION

Pretty Lake (figure page iii), LaGrange County, is a 184 acre lake with a maximum and mean depth of 84 feet and 25.7 feet, respectively. Legal lake level is 965.5 feet and is controlled by a concrete dam in 150 feet from the lake in the outlet stream leading to Turkey Lake. The lake has no permanent named inlets, but two major drainage ditches discharge into the lake. One ditch drains agricultural land west of the lake and discharges into the channel at the public access site on the western shore of the lake. The second ditch drains a segment devoted primarily to cultivation and animal operations and discharges to the lake along its north shore.

The present study was initiated because of lake residents' concerns regarding increased submergent weed growth especially in the vicinity of the two channels dug along the western shore in 1948 and 1949 and observation of siltation associated with delivery of erosion products from the watershed especially during early spring rains.

The current chapter is designed to define the current water quality of Pretty Lake and to determine whether current values represent a marked decline in water quality within the historical past. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on water quality for Pretty Lake. The second section summarizes the water quality analyses conducted as part of the present study and compares values to earlier studies. The third and final section details our sediment studies at Pretty Lake where we were interested in determining the extent of basin infilling in the historical past as well as changes in phosphorus loading to the lake. Management implications of our analysis of past and current water quality will be discussed later in this report.

Historical Water Quality

Historical Database

A total of 19 separate studies were conducted on Pretty Lake between 1930 and 1989 for which data were available (Table P1). Collection of water quality data on the lake began in 1930 with the investigation of Will Scott of Indiana University. The United States Geological Survey (USGS) constructed a bathymetric map for Pretty Lake in 1956, but detailed water quality surveys of the lake did not begin until 1963 as part of a cooperative effort between the USGS and Indiana University. Part of this investigation focused reconstructing the terrestrial vegetation and lake trophic state for the past 14,000 years. The Indiana

Table P1. Chronology of Investigations at Pretty Lake

1930	Indiana University. Survey of physical/chemical parameters, phytoplankton and zooplankton. Published by Scott (1931).
1956	United States Geological Survey. Construction of bathymetric map for Pretty Lake.
1963	United States Geological Survey. Detailed examination of dissolved oxygen and temperature profiles during fall stratification breakdown. Published by Ficke (1965).
	United States Geological Survey. Detailed examination of phytoplankton, dissolved oxygen, and pH profiles during fall stratification breakdown. Published by Lipscomb (1966).
	Indiana University. Detailed examination of primary productivity for 1963 and 1964. Some data on physical/chemical parameters. Published by Wetzel (1966, 1970).
1964	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1970	Indiana Department of Natural Resources. Dissolved oxygen profile.
	Michigan State University. Paleolimnological reconstruction of the trophic history of Pretty Lake for the past 14,000 years. Published by Wetzel (1970).
1972	Indiana Department of Environmental Management. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
	Indiana Department of Natural Resources. Survey of physical/chemical parameters.
1973	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1974	Indiana Department of Natural Resources. Survey of physical/chemical parameters.

1974 Indiana University. Paleoecological reconstruction of the vegetational history of the Pretty Lake area for the past 14,000 including calculation of sedimentation rates in the lake. Published by Williams (1974)

1979 Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.

1983 Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.

1985 Indiana Department of Natural Resources. Survey of fish community and physical/chemical parameters.

1988 Indiana University. Survey of physical/chemical parameters by William Jones.

1988 LaGrange County Health Department. Survey of physical/chemical parameters by William Grant.

1989 Indiana University. Survey of physical, chemical, and biological parameters for construction of IDEM eutrophication index.

Department of Natural Resources surveyed the fish community 5 times between 1964 and 1985 and included data on water chemistry and macrophytes for most years. The Indiana Department of Environmental Management (IDEM) visited the lake once in the early 1970's to collect water chemistry and biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state. William Grant of the LaGrange County Health Department collected some physical/chemical data. Finally, Indiana University recently (1988, 1989) collected data on the lake to assess whether the IDEM eutrophication index for the lake has changed since the mid-1970's.

Physical/Chemical Parameters

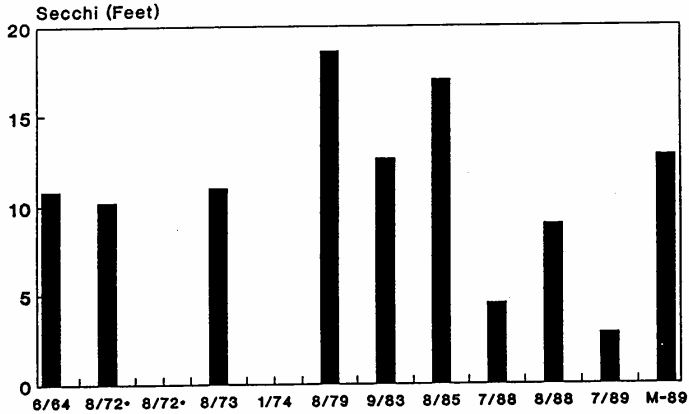
A total of thirteen physical and chemical parameters have been measured at Pretty Lake at a frequent enough intervals to be useful in delineating historical trends (Table P2). Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer at Pretty Lake, it is likely that they reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response to steadily increasing temperature. Thus, it is only valid to make interyear comparisons for individual months (Table P2, Figure P1). A majority of Secchi values collected for Pretty Lake were for August, and the most recent value, 1988 (9 feet), was somewhat lower than the range (10.8-18.6 feet) reported for the past 25 years. On the basis of Secchi data alone, it does not appear that the trophic state of Pretty Lake has changed markedly since at least 1972.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production. A good measure of the degree of eutrophication is provided by the extent of water column anoxia (absence of oxygen) in mid summer (Table P3). Pronounced water column anoxia is evident by at least July in Pretty Lake and extends throughout the summer stratified period. There is a trend toward a vertical expansion of the anoxic zone within the water column as summer progresses. Although the historical database is not extensive, it appears that serious water column anoxia was evident as early as 1930 and was roughly comparable to that observed in the late 1980's. A majority of previous estimates of midsummer mean oxygen values in the water column of Pretty Lake historically remained below 5.0 mg/L (Table P2). Such values normally suggest fairly eutrophic conditions, but for Pretty Lake are likely a reflection of the depth of this relatively small lake. The historical data suggest that deep water deoxygenation during summer has characterized Pretty Lake since at least 1930.

Table P2. Historical Changes in Physical and Chemical Parameters at Pretty Lake for the Period 1964-1989. Mean 1989 is the Mean of September and October 1989 Samplings.

Pretty Lake, Historical Data		June 1964	29.Aug.1972	31.Aug.1972	Aug.1973	Jan.1974	Aug.1979	Sept.1983	Aug.1985	July 1988	Aug.1988	July 1989	Mean 1989
Secchi	feet	10.8	10.2		11		18.6	12.6	17	4.5	9	2.8	12.8
Mean Dissolved Oxygen	mg/L	7.2	2.4		3.4		3.85	6	3.1	5.3			2.5
Conductivity	umhos/cm	227.5								285		325	315
Alkalinity	mg/L as CaCO3	130	136.8	120.7	153.9	146	144.5	154.4	171.6	126.7		141	133
Mean Temperature	F	55.2	54.5		55.8		54.1	54.2	53.2	65.2			54.5
pH		8.7	9	8.3	9	8.1	9	9.2	9	8.5		7.4	
Ca (CaCo3)	mg/L					76							
Total Phosphorus	mg/L			0.3		0.04					0.05	0.01	0.44
Ortho Phosphorus	mg/L									<.01			0.025
Nitrate-N	mg/L					<0.1				0.385		0.337	
Ammonia-Nitrogen	mg/L									0.242		0.026	0.31
Total Kjeldahl N	mg/L												1.1
Organic-Nitrogen	mg/L									0.806		1.376	
Nitrite-Nitrate	mg/L												0.55
Chlorophyll	mg/m3												3.3

Pretty Lake, IN
Historical Data



*29. and 30. August 1972

Figure P1. Historical Secchi Disk Readings in Pretty Lake for the Period 1964-1989. M-89 is the mean for September and October 1989.

Table P3. Historical Records of Water Column Anoxia in Pretty Lake, IN

Observation	Initial Depth of <1 mg/L Dissolved Oxygen
June:	
1964	No Anoxia
July:	
1970	26 feet
1973	60 feet
1988	39 feet
1989	62 feet
August:	
1930	29 feet
1963	30 feet
1972	25 feet
1979	57 feet
1985	42 feet
September:	
1963	28 feet
1983	29 feet
1989	24 feet
October:	
1963	38 feet
1989	25 feet
November:	
1963	39 feet

Alkalinity is a measure of the carbonate buffering capacity of lakes and can be a useful parameter for assessing changes in watershed delivery of erosion products through human activities. Oscillations in alkalinity values for Pretty Lake since 1964 do not yield any apparent trend that can be related to changes in watershed management practices (Table P2, Figure P2). It is interesting to note, however, that July 1988 was lower than July 1989 and possibly reflects reduced farm runoff during the drought of 1988. Such an interpretation is consistent with the higher Secchi value recorded for the same month reflecting lower algal production.

Although the database is rather limited, total phosphorus concentrations in Pretty Lake fail to display any significant historical trend (Figure P3, Table P2). The remaining physical and chemical parameters measured at Pretty Lake were sampled so infrequently as to be of little value in delineating past trends in water quality.

Microbiology

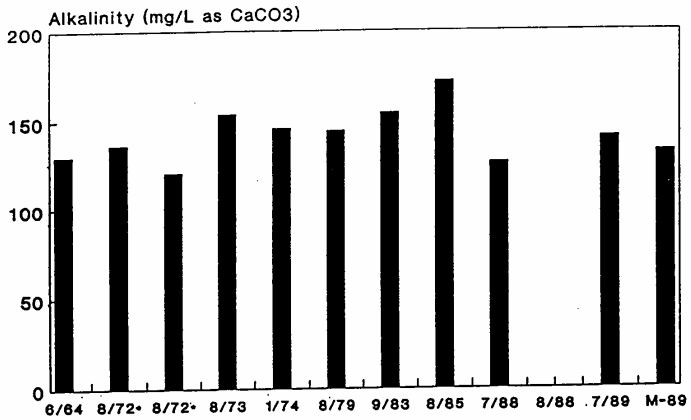
Neither the LaGrange County Health Department nor the Indiana State Board of Health had any historical microbiological data from Pretty Lake.

Phytoplankton

Phytoplankton samples have been collected four times since 1930. Will Scott (1931) collected zooplankton and phytoplankton samples from discrete intervals of the water column during August 1930. The USGS collected phytoplankton from discrete intervals of the water column throughout the fall of 1963 (Lipscomb 1966). The Indiana Department of Environmental Management sampled phytoplankton during August 1972, but detailed data were missing from the departmental files. The final survey of phytoplankton was by Indiana University in July 1989, but details were not provided. Algal abundance in the surface waters of Pretty Lake during August 1930 was estimated at 9,775/L (9.7/mL) (Table P4). Fragilaria was the dominant taxon with Ceratium and Dinobryon as the principal subdominants. The presence of several taxa of blue-green algae was suggestive of a moderate degree of production.

The blue-green alga Aphanizomenon was the dominant genus throughout the fall of 1963 with diatoms being the principal subdominants. The dinoflagellate Ceratium was the dominant taxon in August 1972, but estimates of total algal abundance were unavailable. Finally, algal abundance for July 1989 was estimated at less than 1,000/mL. All the database is limited, the phytoplankton assemblage of Pretty Lake appears to have changed little in either dominance or overall abundance since at least 1930.

Pretty Lake, IN
Historical Data



*29. and 30. August 1972

Figure P2. Historical Alkalinity Readings in Pretty Lake for the Period 1964-1989. M-89 is the mean for September and October 1989.

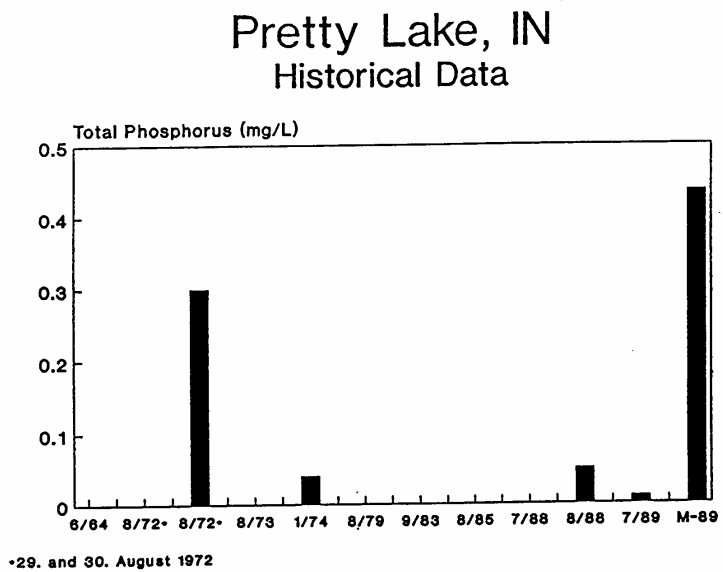


Figure P3. Historical Total Phosphorus Concentrations in Pretty Lake for the Period 1964-1989. M-89 is the mean for September and October 1989.

Table P4. Phytoplankton and Zooplankton Abundances and Concentrations of Dissolved Gases in Pretty Lake on 20 August 1930. Table from Scott (1931).

KEY: (D) Depth, (T) Temperature, (O) Oxygen, (CO_2) Carbon Dioxide, (Cb) Carbonates

LAKE: PRETTY
Date: 8/18/30

Plankton					Dissolved Gases					
Species	0-5	5-10	10-15	15-20	D	T	O	%	CO_2	Cb
Ceratium	2,948	102	72	128	S	23.8	5.18		—2.4	26.8
Dinobryum	1,966	42	25	34	2	23.8	5.24		—1.4	27.6
*	106	68		25						
Anoura	264	12	4	5.6	4	23.3	5.16		—1.6	27.8
Hexarthra	17	12.8	4.2							
Polyarthra					6	21.8	4.64		— .8	27.8
Noltholca	8.5	1.6	8.5	8						
					8	14.7	1.62		.4	32.2
Asplancna	21	8.5								
Daphnia	12	3.2	1.6		10	10	.85		1.0	33.0
					12	9.4	.45		1.0	32.6
					15	8.8	.35		1.0	31.8
Diaptomus	44	4	2.4	.8						
Cyclops	18	12	3.2	1.6						
Nauplii	332	50	10.4	4	20	8.3	.03		1.0	32.2
Melosira	12	29	21	17	24.5	8.3	.04		1.0	31.8
Fragillaria	4,083	334	162	98						
Asterionella	4	4		4.2						
Anabena	42			4						
Clathrocyctis	563	742	115	102						
Oscillatoria	132	29	12	4						
Lyngbya	25	1,036	55	81						

Primary Productivity

R.G. Wetzel conducted a detailed investigation of phytoplankton production in Pretty Lake from May 1963 to December 1964 (Wetzel 1966, 1970). As expected, algal production was greatest during the summer and was mostly restricted to the upper eight meters of the water column (Figure P4). Annual mean primary productivity for the study period was estimated at 305-440 mg C/m2/day averaged for the whole water column (Wetzel 1966). Such values were considered low to moderate for comparable marl lakes in Indiana.

Macrophytes

The macrophyte (aquatic plant) community was examined four times from 1964 to 1983 as part of Indiana Department of Natural Resources fish surveys (Table P5). Plant taxonomic composition was identical for the last three of the four surveys. Submergent macrophytes were the most taxonomically diverse plant community with most species being pondweeds.

The macroalga Chara was the dominant plant in 1964. Although most areas less than eight feet deep were covered by this plant, it grew close to the substrate and was not considered to be a problem. The channels that were dredged along the west shore of the lake in 1948 and 1949 were completely choked with submergent vegetation in 1964, while only limited nearshore areas elsewhere were considered to have macrophyte problems. No wide scale macrophyte program was recommended for the lake. All later surveys (1973, 1979, 1983) noted that Chara was the dominant plant in shallow zones of the lake with the exception of the channels along the western shore which were completely choked with water milfoil. It was suggested that a control program was needed only in the channels. All studies emphasized that aquatic macrophytes for the most part were restricted to depths less than 10 feet with most of the lake bottom being weedless.

Fish

The Indiana Department of Natural Resources surveyed the fish community of Pretty Lake five times between 1964 and 1985. All DNR surveys were based on a combination of electrofishing, gill net, and trap collections, the details of which are presented in Table P6.

A listing of the individual species caught and the contribution of each to total fish abundance and weight caught during the five DNR surveys are provided in Tables P7 and P8, respectively. The contribution of four species to total fish abundance tended to increase progressively after 1964 (Figure P5). The most pronounced increase for bluegill was after 1979, while that for yellow perch and largemouth bass was post 1973. The extremely low abundance for the

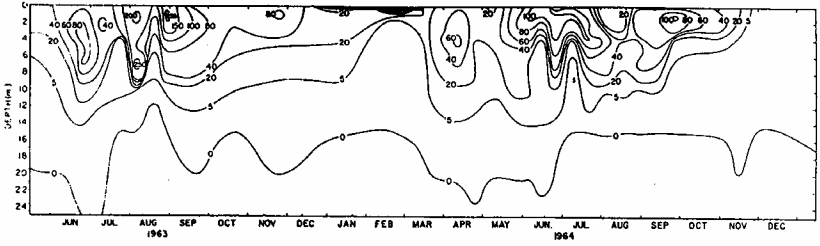


Figure P4. Isopleths of Rates of Primary Production ($mgC/m^3/day$) in Pretty Lake During 1963-1964. Figure Taken from Wetzel (1970).

Table P5. Species Composition of the Macrophyte Community of Pretty Lake for the Period 1964-1983.

Species	Common Name	1964	1973	1979	1983
SUBMERGENTS:					
Ceratophyllum demersum	coontail	X	X	X	X
Chara spp.	chara	X	X	X	X
Elodea canadensis	elodea	X	X	X	X
Myriophyllum spp.	water milfoil	X	X	X	X
Najas flexilis	bushy pondweed	X			
Potomogeton amplifolius	bass weed	X			
Potomogeton crispus	curly leaf pondweed	X	X	X	X
Potomogeton foliosus	leafy pondweed	X	X	X	X
Potomogeton illinoensis	Illinois pondweed	X	X	X	X
Potomogeton natans	floating leaf pondweed	X			
Potomogeton pectinatus	sago pondweed	X			
Potomogeton pusillus	fine leaf pondweed	X			
Potomogeton robbinsii	Robbin's pondweed	X			
Potomogeton strictifolius	fine leaf pondweed	X			
Potomogeton zosteriformis	flatstem pondweed		X	X	X
Ranunculus spp.	aquatic buttercup	X			
EMERGENTS:					
Eleocharis rostellata	spike rush	X			
Equisetum spp.	scouring rush	X			
Juncus effusus	soft rush	X			
Polygonum spp.	water smartweed	X			
Pontederia cordata	mud plantain	X	X	X	X
Pontederia cordata cf. taenia	mud plantain	X			
Scirpus americanus	three-square bulrush	X			
Scirpus sylvaticus	bulrush	X			
Typha latifolia	common cattail	X	X	X	X
FLOATING LEAVED:					
Nuphar advena	spatterdock	X	X	X	X
Nuphar microphyllum	water shield	X			
Nymphaea odorata	water lily	X	X	X	X

Table P6. Historical DNR Fish Sampling in Pretty Lake, IN.

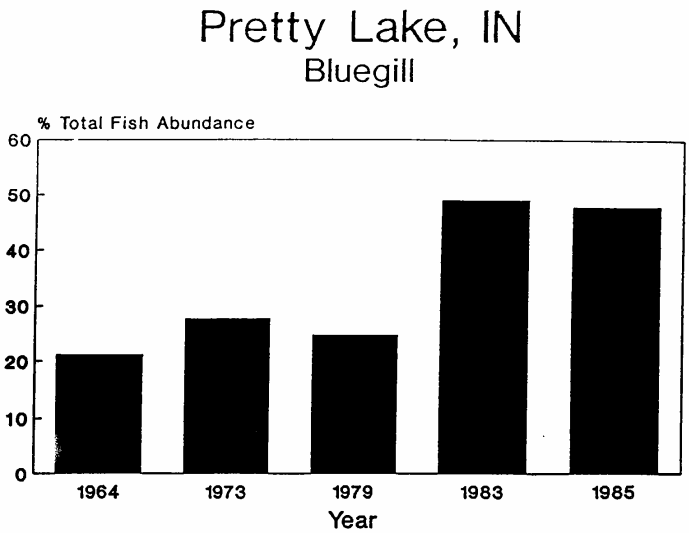
1964	Electrofishing:	8 hrs night
	Gillnets:	5 for 96 hrs = 384 hrs total effort
	Traps:	20 for 96 hrs = 1920 hr total effort
1973	Electrofishing:	2 hrs night
	Gillnets:	3 for 72 hrs = 216 hrs total effort
1979	Electrofishing:	1 hr night
	Gillnets:	3 for 96 hrs = 288 hrs total effort
	Traps:	3 for 96 hrs = 288 hrs total effort
1983	Electrofishing:	1 hr night
	Gillnets:	4 for 72 hrs = 288 hrs total effort
	Traps:	3 for 72 hrs = 216 hrs total effort
1985	Gillnets:	4 for 48 hrs = 192 hrs total effort

Table P7. Importance of Individual Fish Species in Pretty Lake During the Period 1964-1985 Expressed as a Percent of Total Fish Abundance Caught in DNR Surveys.

	1964	1973	1979	1983	198
Black Bullhead	0.3				
Black Crappie	0.5	0.7	1.3	0.9	
Bluegill	21.2	27.8	24.8	49.1	47.
Bowfin	0.2	0.2	0.5	0.5	
Brook Stickleback	0.1				
Brown Bullhead	0.5	1.2	1.8	2.4	2.
Brown Trout				0.1	
Golden Shiner	0.3	0.7	1.3	0.3	
Grass Pickeral	0.6	0.2	0.3	1	
Green Sunfish	7.6	9.3	3.4	3.1	
Lake Chubsucker	1.4	9.3	0.8	2.1	
Largemouth Bass	7.2	5.3	11	13.5	1.
Northern Pike	2.9	0.5	0.7	0.3	4.
Pumpkinseed	0.8	2.9	2.1	1.6	2.
Rainbow Trout	0.1	3.2			
Redear	38.3	6.8	16.9	8.6	4.
Rock Bass	3.9	3.6	6.9	1.6	5.
Smallmouth Bass	0.1				
Walleye	0.6				
Warmouth	5.2	15.9	7	3.1	
White Sucker				0.2	
Yellow Bullhead	3.2	8.1	9.2	3.4	10.
Yellow Perch	4.6	3.9	12.1	7.9	13.

Table P8. Importance of Individual Fish Species in Pretty Lake During 1979 and 1983 Expressed as a Percent of Total Fish Weight Caught in DNR Surveys.

	1979	1983
Black Bullhead		
Black Crappie	2.2	1.3
Bluegill	8.3	24.3
Bowfin	5.9	8.7
Brown Bullhead	4.9	11.9
Brown Trout		0.5
Golden Shiner	0.6	0.2
Grass Pickeral	0.3	1.3
Green Sunfish	0.9	0.5
Hybrid Sunfish		
Lake Chubsucker	0.5	1.1
Largemouth Bass	16.1	17.1
Northern Pike	4.6	5.2
Pumpkinseed	0.5	0.7
Redear	14.9	11.7
Rock Bass	5.5	1.7
Spotted Gar		
Warmouth	5.5	2.8
White Sucker		2.3
Yellow Bullhead	19.8	3.3
Yellow Perch	9.9	5.4



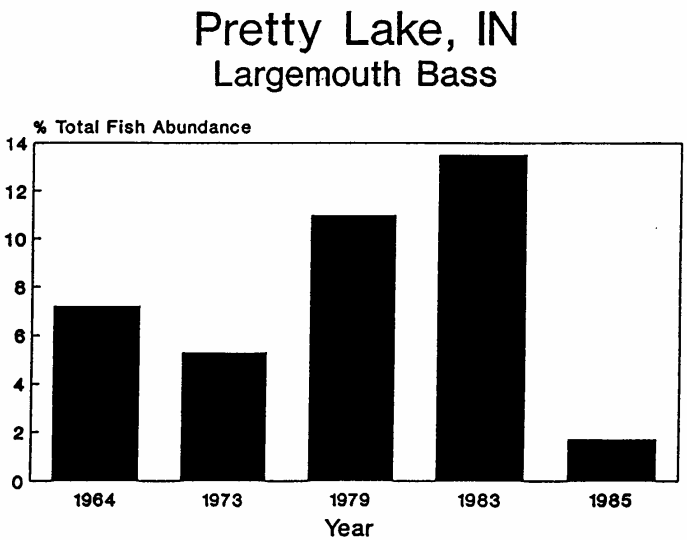


Figure P5. Changes in the Percentage Contribution of Select Species to Total Fish Abundance in Pretty Lake for the period 1964-1985.

latter species in 1985 may be a reflection of the somewhat reduced sampling effort by DNR in that year. Yellow bullhead displayed the earliest period of increase, post 1964. Unlike the previous four species, redear sunfish displayed a progressive decline in abundance from 1964 to 1985 (Figure P5).

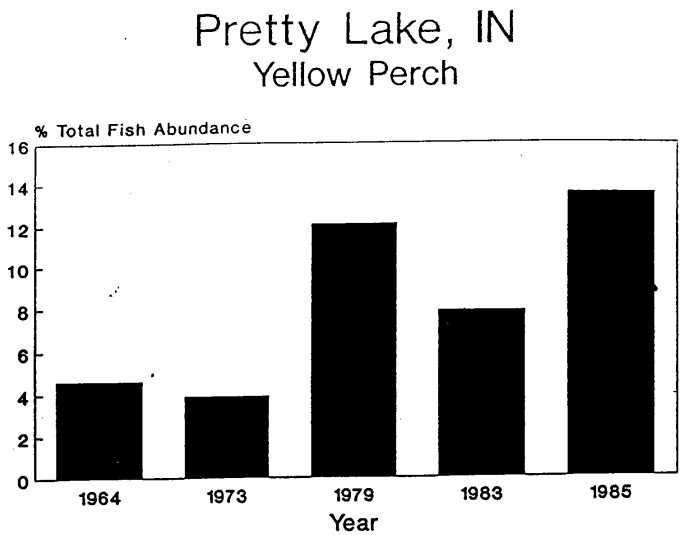
With the exception of 1964, when redear was the major contributor to total fish abundance, bluegill have been the most abundant taxon in Pretty Lake, contributing in excess of 25% of fish caught in DNR surveys (Figure P6). The contribution of redear progressively declined following 1964 as yellow perch and yellow bullhead increased to be the most important subdominants on the basin of abundance. By 1983, bluegill was the principal contributor to both total abundance and weight of the survey catch.

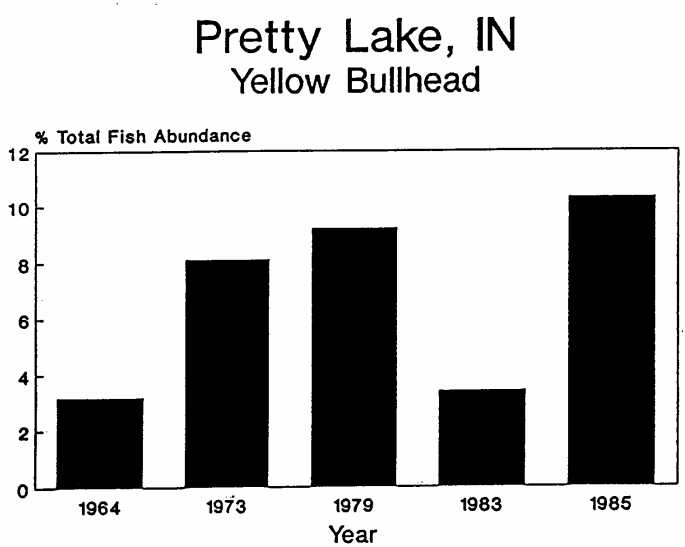
An active fish stocking program has been ongoing at Pretty Lake since at least 1952 (Table P9). During the 1950's and 1960's, a broad stocking effort for bluegill, smallmouth bass, largemouth bass, rainbow trout and walleye was undertaken, emphasis concentrated solely on rainbow and brown trout in the 1970's and 1980's. Trout have been stocked each year since 1964.

The 1964 DNR survey noted that Pretty Lake was noted for its yellow perch fishery in the 1930's and its bluegill and redear fishery in the 1940's. By 1964, the lake was noted for its bluegill, redear and rainbow trout due to the active stocking effort for the latter. The DNR surveys of 1964, 1973, 1979 concluded that the fishery of Pretty Lake was good. While the warm water fishery of the lake was still considered good in 1983, concern was being expressed for the trout populations. Extensive trout die offs were noted during the exceptionally hot summer of 1983. Creel census indicated that 333 of the 1000 brown trout released in April were caught by anglers by June with 98% of the harvest occurring within two weeks of stocking. On the other hand, only 0.6% of the 1,500 rainbow trout stocked during fall 1982 were caught during the creel census period of April-June 1983. It was unknown whether the stocked fish died prior to April or were caught.

The DNR survey of 1985 noted that for the third year in a row summer dissolved oxygen and temperature conditions were considered marginal for trout survival. Again, fall stocked trout harvest was poor compared to that of spring stocked individuals. It was concluded that the lake could no longer support trout populations on a year round basis.

The historical fishery data, especially for the cold water fauna, suggest that water quality in Pretty Lake may be declining recently. Although the limited historical water chemistry database does not indicate this trend, inherent





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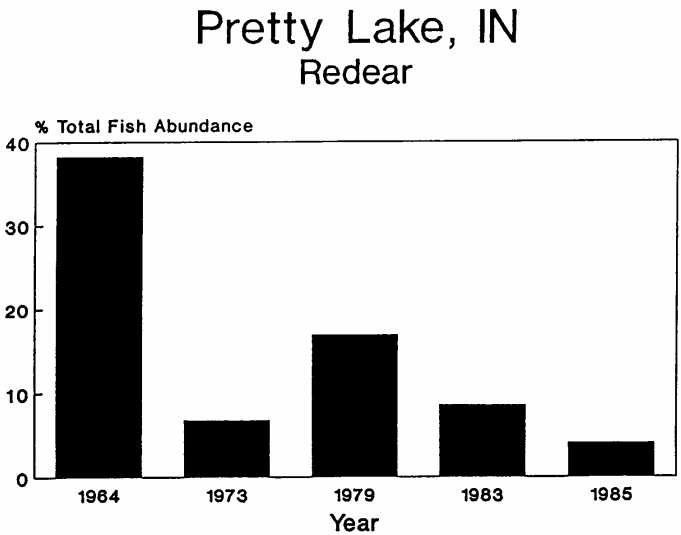

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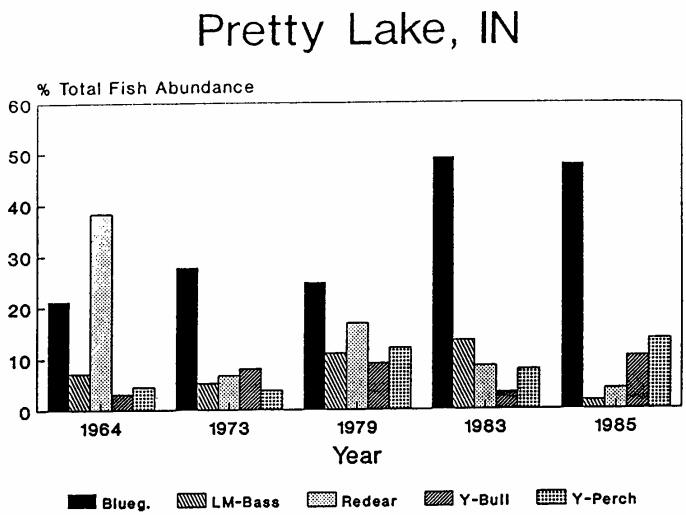


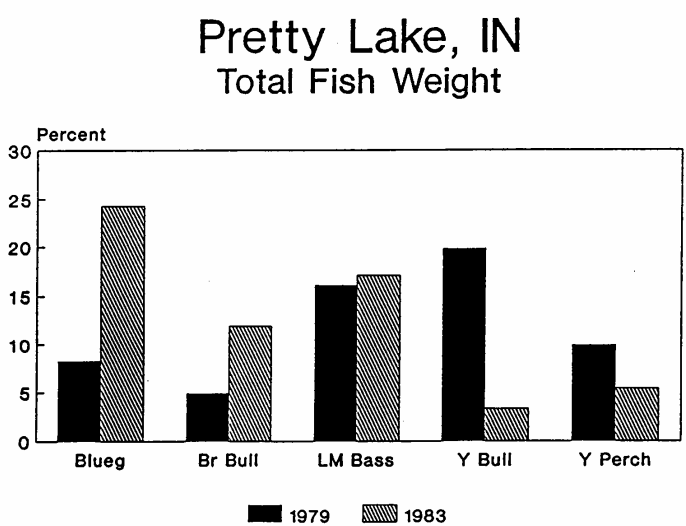


Figure P6. Changes in the Percentage Contribution of Select Taxa to Total Fish Abundance and Weight in Pretty Lake for the period 1964-1985.

Table P9. Records of Fish Stocking at Pretty Lake, IN for the Period 1952-1985.

YR	Bgill	S.M.Bass	L.M.Bass	R. Trout	Walleye
1952				152	
1953				258	
1954				250	
1955	1,100	500	3,000	315	
1956	2,957	750	500	150	
1957				1,050	
1958		465	700	1,620	
1959		487	1,472	1,600	
1960		1,125	2,000	1,500	
1961		1,000		2,600	
1962				2,600	
1963				2,000	
1964				1,000	2,500
1965				1,000	2,150
1973		2,000			150
1975				2,000	
1976				2,000	
				2,000 B	
1977				2,000	
1978				2,000	
1980				2,000	
1981				2,000 B	
1982				1,500	
				1,800 B	
1983				1,500	
				1,000 B	
1984				2,500	
1985				1,000 B	

B = Brown Trout

sensitivity of the cold water fishery to reduced dissolved oxygen conditions in the lower water column may be an early warning indicator of slowing degrading water quality.

Current Water Quality

Methods

Water quality parameters were collected during 1989 on 15 September and 5 October. A single sampling station was established in the center of Pretty Lake near the point of maximum water depth (Figure P7). Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc and a Licor photometer. Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column where a Kemmerer bottle was used to collect water at each meter of the water column. All analyses were performed in certified laboratories according to EPA techniques (EPA-600/14-79-020, Methods for Chemical Analysis of Water and Wastes, Revised March 1983). Chemical parameters analyzed included conductivity, alkalinity, ammonia, total Kjeldahl nitrogen, nitrate/ nitrite, ortho phosphorus, and total phosphorus.
Data for physical and chemical parameters for Pretty Lake during the 1989 survey are presented in Table P10.

Two phytoplankton samples were collected with a #20 Wisconsin plankton net (76 um) on each sampling date. One tow was taken from 5 feet depth to the surface, and a second five foot tow was taken to include the beginning of the thermocline. All plankton samples were preserved with Lugol's solution and returned to the laboratory for analysis. Plankton counts utilized Utermohl chambers and were performed with the aid of an inverted microscope.

Physical/Chemical Parameters

Temperature. The water columns of northern Indiana lakes greater than approximately five meters deep remain thermally stratified throughout most of the year. As a result of density-temperature relationships, complete mixing of the water column from top to bottom occurs only when water temperature reaches a uniform 4oC, the maximum density of water. This occurs twice a year in temperate lakes (spring and fall) associated with seasonal climatic changes. The length of the mixing period depends on the rapidity of climate change and can vary from a few days to less than a month. Lakes displaying two mixing periods per year are termed dimictic.

Table P10. Physical and Chemical Parameters for the 1989 Survey of Pretty Lake.

Pretty Lake	1989	15 September	5 October
Secchi	Feet	12.4	13.1
Mean Dissolved Oxygen	mg/L	2.6	2.4
Ammonia	mg/L	0.13	0.49
Total Kjeldahl N	mg/L	1.7	0.5
Nitrite-Nitrate	mg/L	0.2	0.9
Total Phosphorus	mg/L	0.68	0.19
Ortho Phosphorus	mg/L	0.03	0.02
Conductivity	umho/cm	310	320
Alkalinity	mg/L	133	133
Chlorophyll a	mg/m3	3.1	3.5

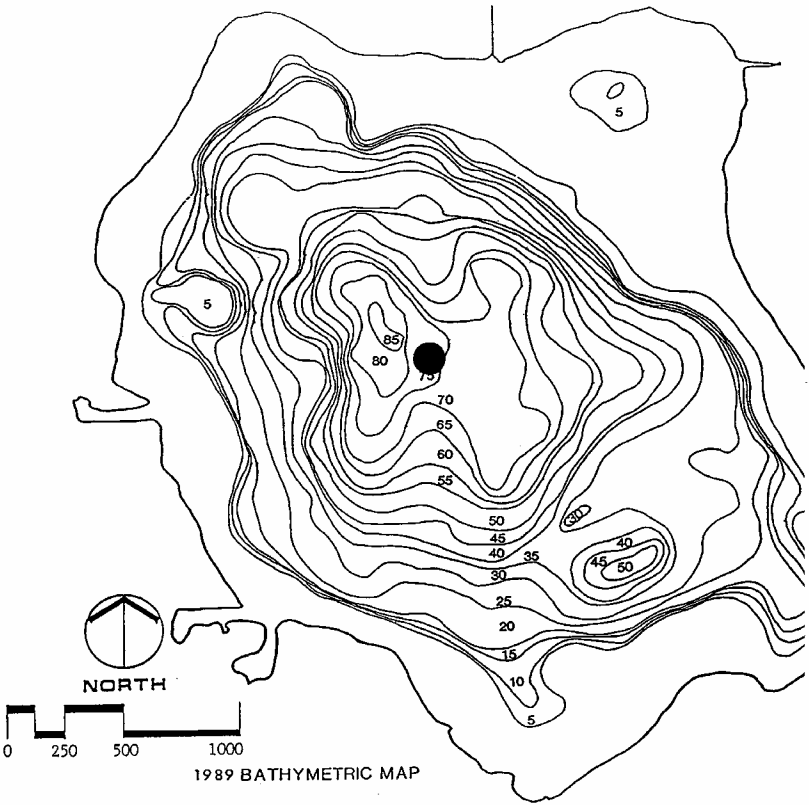


Figure P7. Station Utilized for 1989 Limnological Investigations.

During the stratified period, the water column of Indiana lakes is divided into three zones based on temperature-density relationships. The uppermost well mixed zone is termed the epilimnion and extends from the surface to a depth roughly approximating the lower depth of wave action. The lowermost portion of the water column is the hypolimnion, a zone of density-isolated water that mixes with surface waters only during the short mixing periods. The portion of the water column that is transitional between the epilimnion and hypolimnion is termed the metalimnion. That one meter of the metalimnion displaying the greatest temperature change is called the thermocline.

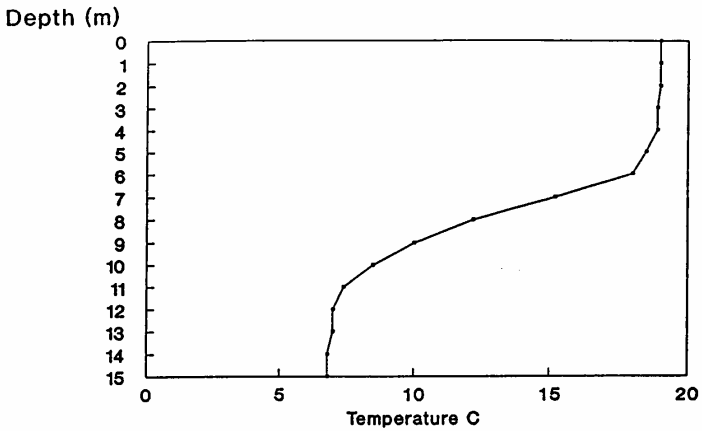
Water column profiles clearly demonstrated that Pretty Lake was thermally stratified during both September and October 1989 (Figure P8). The thermocline was between seven and eight meters during September but moved deeper to 9-10 meters by October as the lake began to cool in the initial stages of stratification breakdown characteristic of fall.

Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

Pronounced water column deoxygenation was noted during both September and October 1989 (Figure P9). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). The lake was essentially anoxic below a depth of 7 meters during both months.

Mean oxygen values for the water column on both dates of 1989 were less than 3 mg/L (Figure P10). Mean water column dissolved oxygen for our 1989 survey was comparable to that of the end of August 1972, but was lower than reported during September 1983 (Table P2). No other historical data for the compara ble season were available for comparison.

Historically, Pretty Lake has displayed severe deoxygenation of the water column as early as July (Table P3). Severe anoxia was evident as early as 1930, the extent of which was similar to that observed during the 1970's and 1980's. It is likely that water column anoxia in Pretty is not entirely a result of trophic state but in part is dictated by the



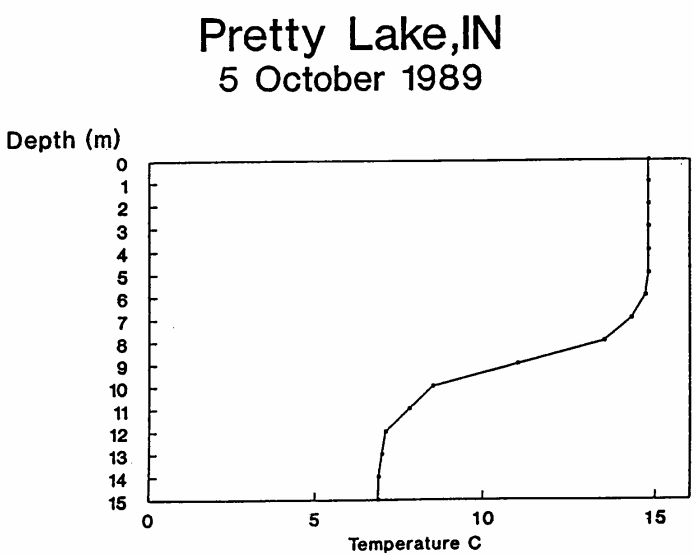
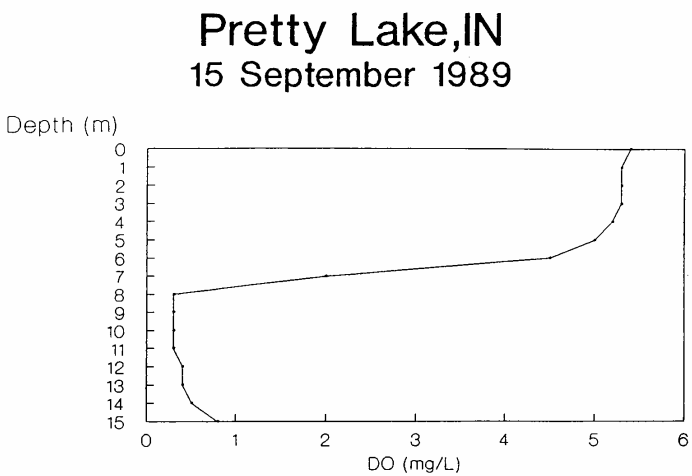


Figure P8. Water Column Temperature Profiles for Pretty Lake During September and October 1989.



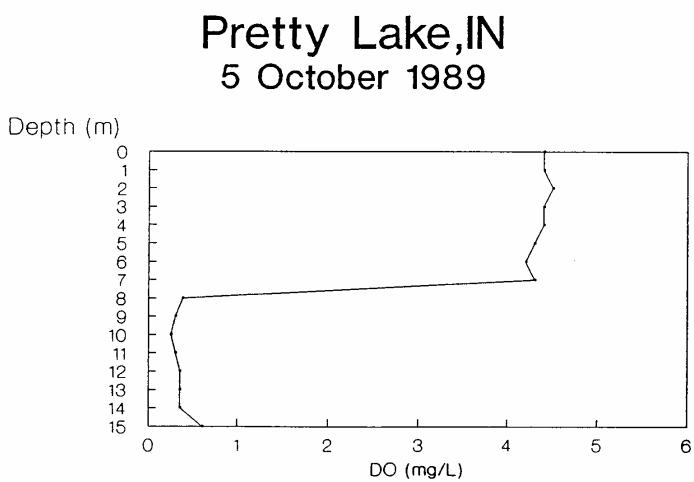


Figure P9. Dissolved Oxygen Profiles for Pretty Lake During September and October 1989.

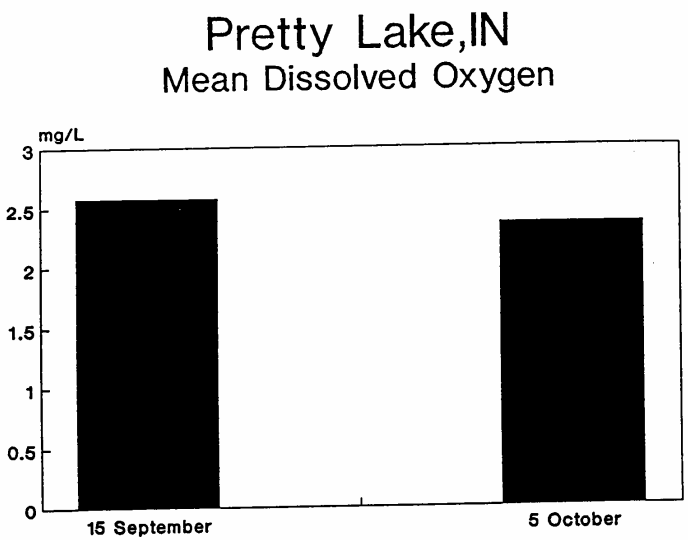


Figure P10. Mean Dissolved Oxygen Concentrations in the Water Column of Pretty Lake During September and October 1989.

morphometry of the lake. The small surface area of the lake combined with its depth likely restrict the ability of wind action to mix the lake completely to the bottom.

Secchi Disc Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae and/or sediment suspended in the water column to block light transmission. Field observations on both sampling dates suggested that algae were the prime controlling factor over Secchi values. Thus, th e shallower the Secchi depth during summer, the more productive (eutrophic) a lake is presumed to be. Secchi transparency was similar during September (12.4 feet) and October (13.1 feet) 1989 (Figure P11). The 1989 values were nearly identical with the 12.6 feet recorded in September 1983 and slightly deeper than the 10.2 feet found at the end of August 1972 (Table P2). Based on a comparison of late summer Secchi values, it does not appear that water clarity has changed appreciably since at least 1972.

Ammonia. Ammonia values for Pretty Lake during September (0.13 mg/L) were lower than October (0.49 mg/L) 1989 (Figure P12). No historical data exist for comparable months.

Nitrite-Nitrate. As with ammonia, nitrite-nitrate nitrogen concentrations were greater during October (0.9 mg/L) than September (0.2 mg/L) 1989 (Figure P12). The historical database was insufficient for comparison.

Kjeldahl Nitrogen. Unlike the previous two nitrogen components, Kjeldahl nitrogen values were greater in September (1.7 mg/L) than October (0.5 mg/L) 1989 (Figure P13).

Total Phosphorus. Total phosphorus concentrations were greater during September (0.68 mg/L) than October (0.19 mg/L) 1989 (Figure P13). The 1989 total phosphorus values for Pretty Lake were higher than reported for the lake (0.1-0.3 mg/L) since at least 1972 (Table P2).

Ortho Phosphorus. As noted for total phosphorus, ortho phosphorus concentrations were greater in September (0.03 mg/L) than October (0.02 mg/L) 1989 (Table P10). Ortho phosphorus value for Pretty Lake for both dates in 1989 were comparable to those reported for the lake in 1988, the only year for which this parameter was available (Table P2).

Nitrogen:Phosphorus Ratios. The ratio of total nitrogen to total phosphorus can be useful in delineating which of these two essential nutrients is limiting primary production in lakes. Numerous authors (Baker et al. 1981, Kratzer and Brezonik 1981, Canfield 1983) have proposed that N:P ratios less than 10 suggest nitrogen limitation, while those greater than 10 suggest phosphorus. The N:P ratios in Pretty

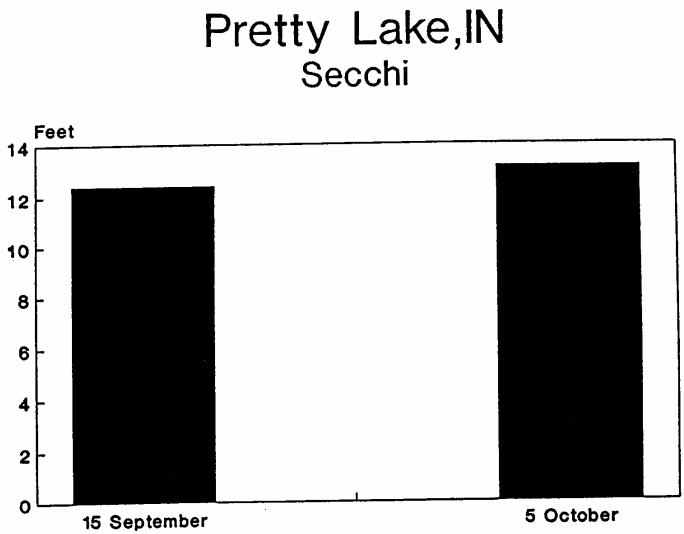
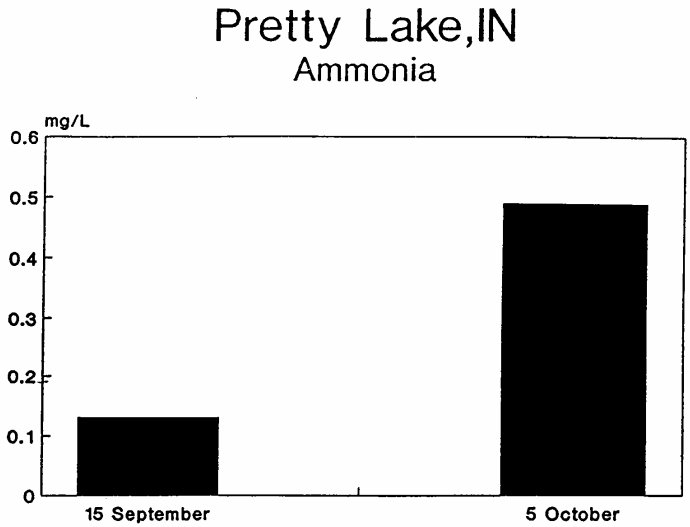


Figure P11. Secchi Disk Transparency for Pretty Lake During September and October 1989.



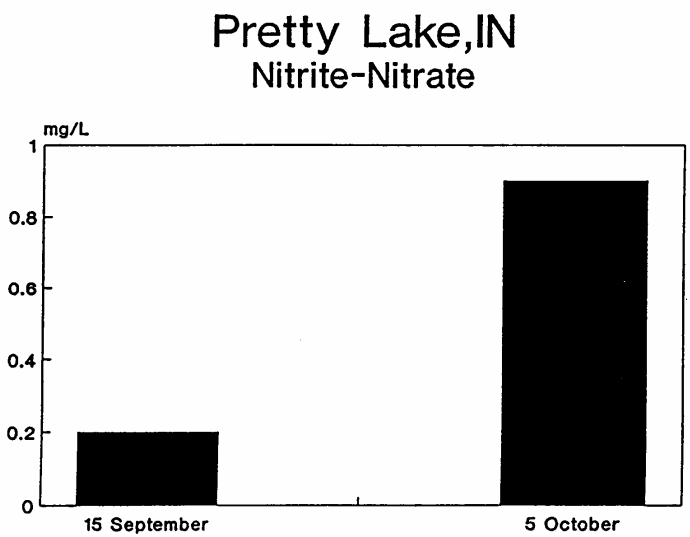
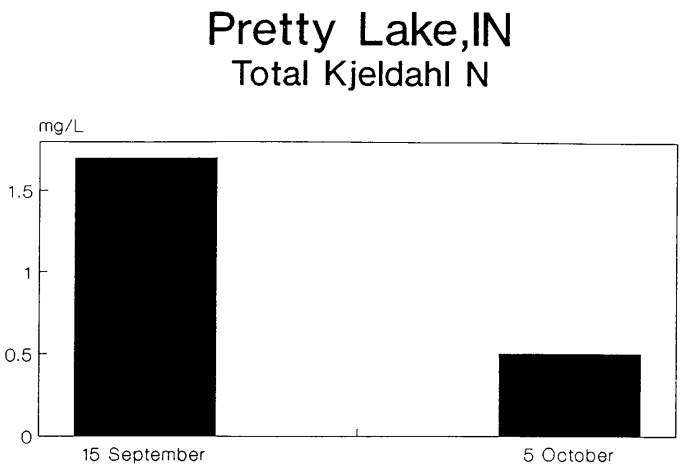


Figure P12. Concentrations of Ammonia and Nitrite-Nitrate Nitrogen for Pretty Lake During September and October 1989.



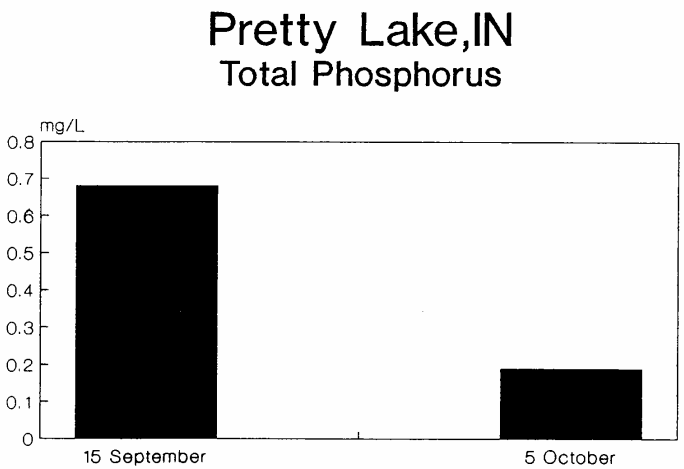


Figure P13. Concentrations of Total Kjeldahl Nitrogen and Total Phosphorus for Pretty Lake During September and October 1989.

Lake were 25 in September and 26 in October 1989. These values suggest that the lake is phosphorus limited throughout the year.

Alkalinity and Conductivity. Alkalinity was identical (133 mg/L) during both September and October 1989 (Figure P14). A similar parameter, conductivity, also remained unchanged between September and October (Figure P14). Values for both parameters were comparable to those reported for the lake since at least the mid 1960's (Table P2).

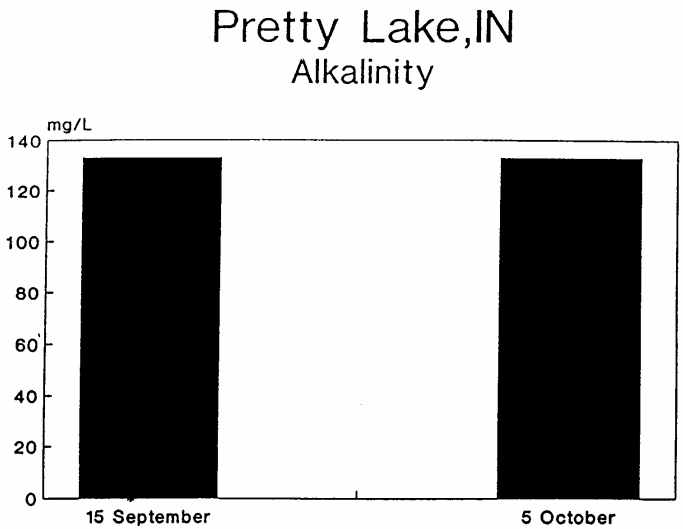
Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll concentrations were measured during both September (3.1 mg/m3) and October (3.5 mg/m3) 1989 (Figure P15). There are no historical data for comparison with the 1989 survey.

IDEM Trophic State Index

Mr Harold BonHomme of the Indiana Department of Environmental Management (IDEM) devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined.

The 1972 eutrophication index for Pretty Lake was calculated by the Indiana Department of Environmental Management as 25, thus assigning the lake to the category of best water quality, Class One. It is interesting to note, however, that if the index had been one point greater, the lake would have been assigned to Class Two, lakes of intermediate water quality. Parameters for the 1989 index calculation were identical to those used for the 1973 index. Based on our September and October samplings, we have calculated the 1989 IDEM eutrophication index for Pretty Lake as 13 (Table P11). Our calculation is comparable with the 14 calculated for July 1989 by W. Jones of Indiana University and places the lake in the category of best water quality, Class One.

The phytoplankton assemblage during September and October of 1989 was dominated numerically by Fragilaria with Ceratium and Lyngbya as the principal subdominants (Table P12). All three taxa were components of the plankton in August 1930 (Table P4) and the assemblage was dominated by Fragilaria and secondarily by Ceratium. The overall group composition of th e plankton appears to have changed little since 1930 with diatoms as the dominants and dinoflagellates and blue-green algae as the principal subdominant groups.



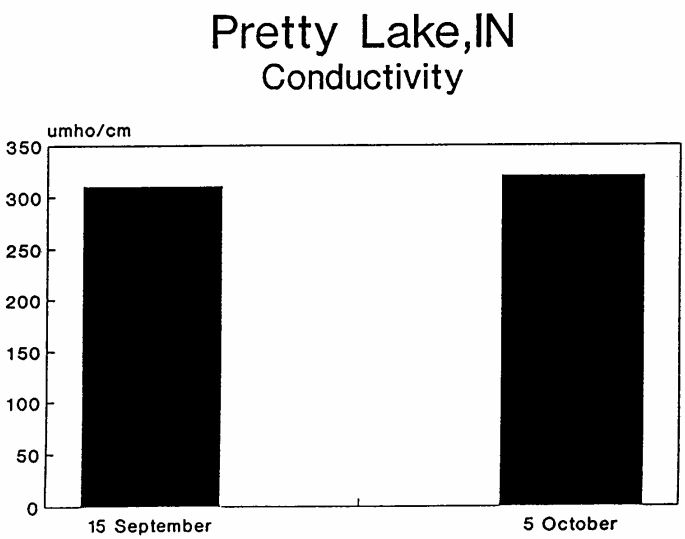


Figure P14. Conductivity and Alkalinity Values for Pretty Lake During September and October 1989.

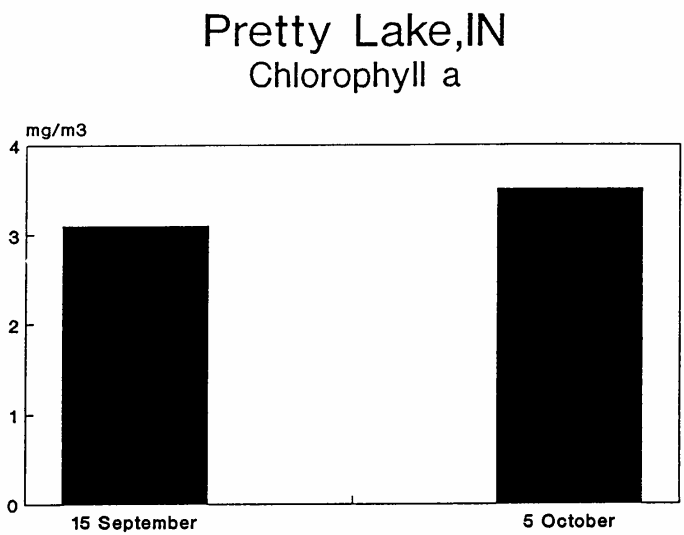


Figure P15. Chlorophyll Concentrations for Pretty Lake During September and October 1989.

Table P11. IDEM Eutrophication Index for Pretty Lake in 1989.

	Parameter	Value	Eutrophy Points
I.	Total Phosphorus	0.44 ppm	4
II.	Soluble Phosphorus	0.02 ppm	0
III.	Organic Nitrogen	0.79 ppm	2
IV.	Nitrate	0.55 ppm	2
V.	Ammonia	0.31 ppm	1
VI.	Dissolved Oxygen Saturation @ 5 feet	57%	0
VII.	Dissolved Oxygen (% of water column with >0.1 ppm DO)	100%	0
VIII.	Light Penetration (Secchi Disk)	12.8 feet	0
IX.	Light Transmission (1% at Three Feet)	62 feet	2
X.	Total Plankton		
	Vertical Tow (5 ft to Surface)	1,750 cells/mL	2
	Blue-green Dominance	No	0
	Vertical Tow (Thermocline)	900 cells/mL	0
	Blue-green Dominance	No	0
	> 100,000 cells/mL	No	0
		1989 IDEM Index	13

Table P12. Phytoplankton Composition for Pretty Lake During September and October 1989.

	15 September		5 October	
	S	T	S	T
Fragilaria	667	223	846	482
Ceratium	444	187	749	271
Lyngbya	162	103	178	86
Melosira	140	125	143	182
Microcystis	107	85	64	56

S = algal units/mL calculated from a vertical tow from a depth of five feet to the surface.

T = algal units/mL calculated from a five foot vertical tow that includes the thermocline.

On the basis of IDEM eutrophication indices alone, it appears that the lake is less productive in 1989 than in 1972. It must be remembered that the IDEM index is based on parameters collected for the water column in open water sections of the lake, and like all indices, does not include the extent and productivity of aquatic macrophytes. Expanding macrophyte abundance is often associated with reduced nutrient and algal abundance in open water areas as the vegetated littoral zone successfully competes with open water phytoplankton for nutrients (Canfield et al. 1983). The fact that the eutrophication index indicates an improvement in water quality during the past 17 years is likely associated with concurrent expansion of macrophytes. Other lines of evidence presented in this report suggest no such reduction in the degree of eutrophication.

Stream Sampling

Methods

At each station, two, 1-liter water samples were collected from the upper 15 cm of the water column. Water samples were analyzed for: calcium carbonate alkalinity, pH, color, specific conductivity, total nitrogen, and total phosphorus. In addition to water quality measurements, stream flow was calculated using a General Oceanics mechanical flowmeter and a visual survey was conducted of the basin characteristics.

Stream Chemistry

Three stream/ditch stations were sampled during the 1989 survey (Figure P16). Station PL1 was on the tile that drains into Pretty Lake in the excavated channel by the public access site. Samples were collected on the east side of County Road 900 E at the point were the tile discharges into the channel. The section of the watershed drained by this tile complex is rolling much of which is highly erodible land and mostly under cultivation. Station PL2 sampled the ditch entering Pretty Lake along the north shore. Samples were collected on the north side of County Road 425 S approximately 300 yards from the mouth of the ditch. This rolling segment of the watershed was mostly used for pasture with several animal operations, much of the remainder of the area is under cultivation. The third sampling site at Pretty Lake was the outlet stream (PL3) just below the control structure. The outlet stream is at the northeast corner of the lake and drains toward Turkey Lake.

Water chemistry data for all three stations were collected on 18 January 1990. Flow was detectable at only PL2 (4.02 cfs) along the western lake shore and PL3, the outlet stream for Pretty Lake (3.37 cfs) (Figure P17).

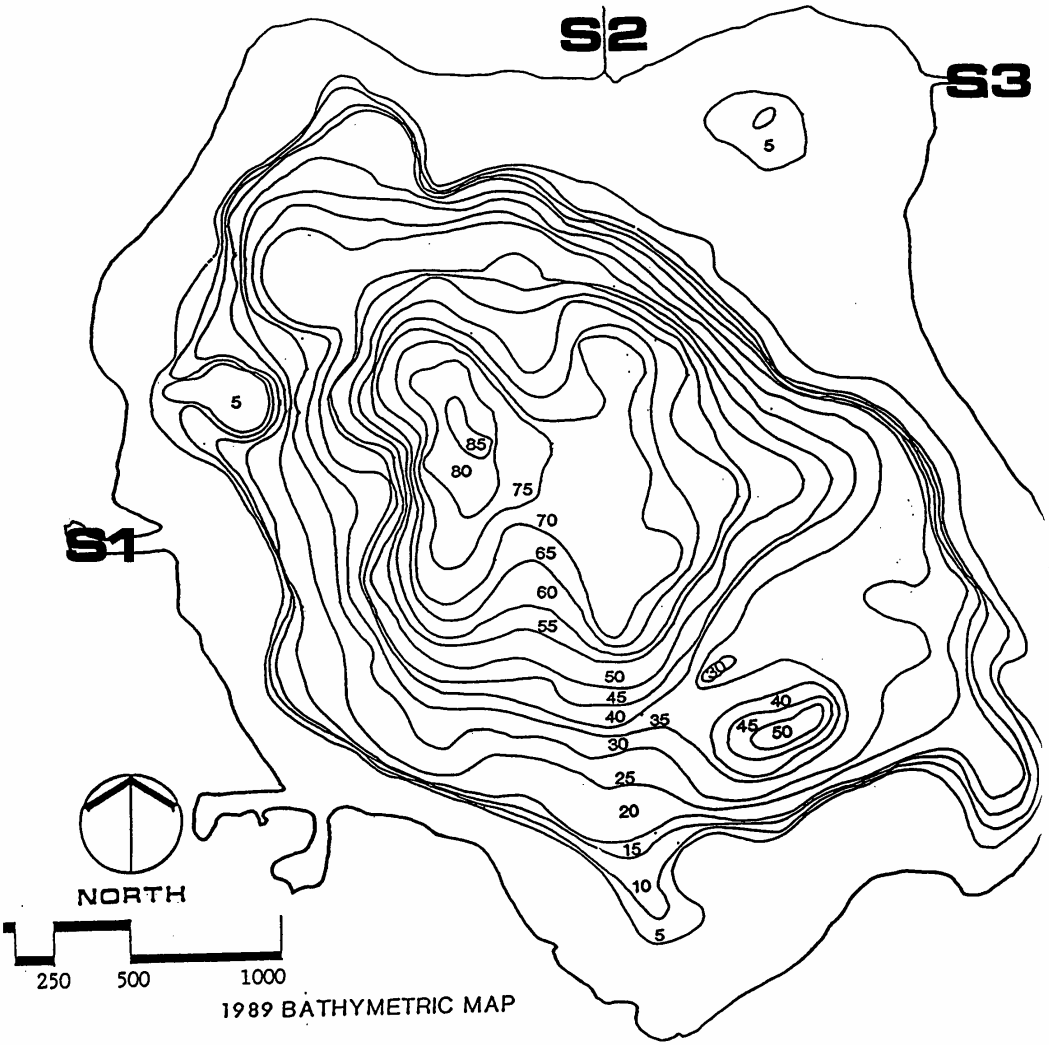


Figure P16. Stream Sampling Stations for 1989 Investigation.

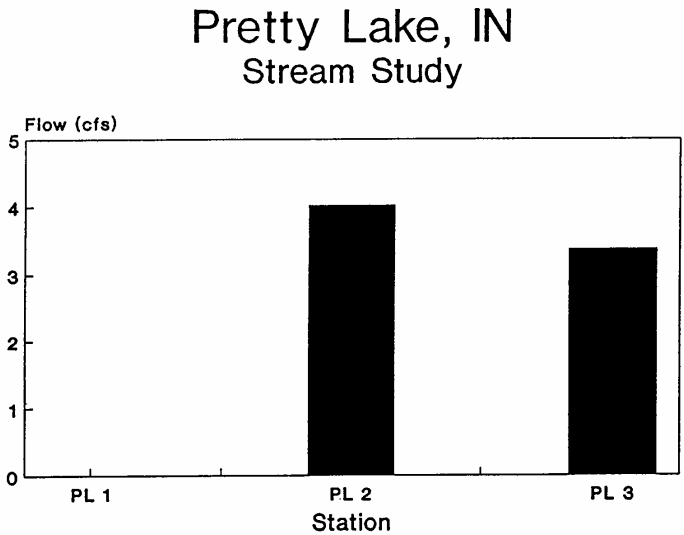


Figure P17. Flow in Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.

There were only minor differences in the pH (5.5-6.4) of the stream stations (Figure P18). Both alkalinity and conductivity (Figure P19) were lowest at the outlet (PL3) and highest at PL1 for alkalinity and at PL2 for conductivity. It is obvious that the lake is trapping carbonates associated with primary production and sedimentation.

Nitrite/nitrate was barely detectable (0.05 mg/L) at the lake outlet (PL3) but were two orders of magnitude greater (3.57-5.27 mg/L) for stations PL1 and PL2 (Figure P20). It appears that the lake is effectively trapping nitrogen loading from the watershed.

Like nitrogen, total and ortho phosphorus were lower for the lake outlet than for the inlets (Figure P21). Of the two inlets, total phosphorus was greatest (1.17 mg/L) in the west shore tile (PL1), while ortho phosphorus was greatest (0.18 mg/L) for the north shore ditch (PL2).

Finally, total suspended solids (TSS) were greatest for the north shore ditch (44 ppm), while the west shore tile (PL1) and the lake outlet (PL3) were identical at 7 ppm (Figure P22). It is felt that all TSS values likely reflect inorganic rather than organic turbidity given the time of year.

Microbiology

A water sample for total coliform analysis was collected on both 15 September and 5 October at the water quality station in the center of Pretty Lake. Samples were analyzed within eight hours of collection. The analyses followed the state approved membrane filter procedure and counts have been expressed as most probable numbers (mpn), a standard way of estimating bacterial numbers. The concentration of total coliform bacteria was 0.6 mpn/100 mL during September 1989 but rose to 28 mpn/100 mL three weeks later on 5 October (Figure P23). All bacteria counts at Pretty Lake during 1989 were well within state standards.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic macrophytes in Pretty Lake. A total of 16 transects spanning the width of the lake were used as the data base. The plant survey was conducted in September 1989 and thus represents summer plant extents. Plant biovolume is defined as the percent of the water column at a given location in the lake that is filled with plant biomass. Thus, it is a measure of the extent of macrophyte infestation throughout the lake system.

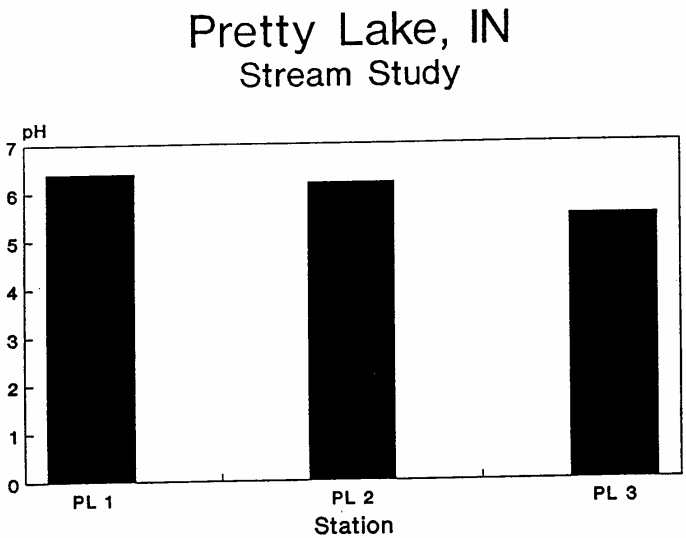
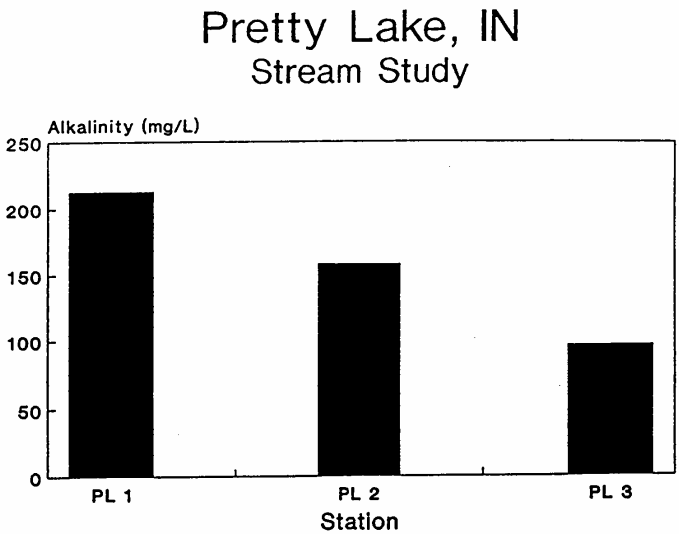


Figure P18. pH Values for Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.



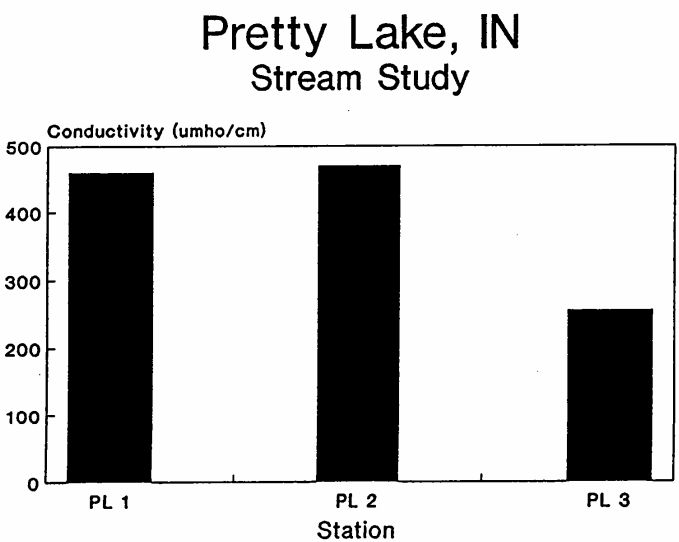


Figure P19. Alkalinity and Conductivity Values for Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.

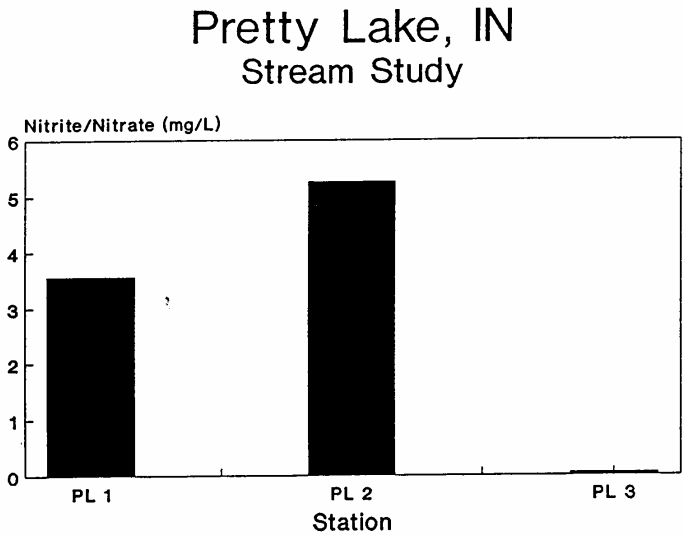
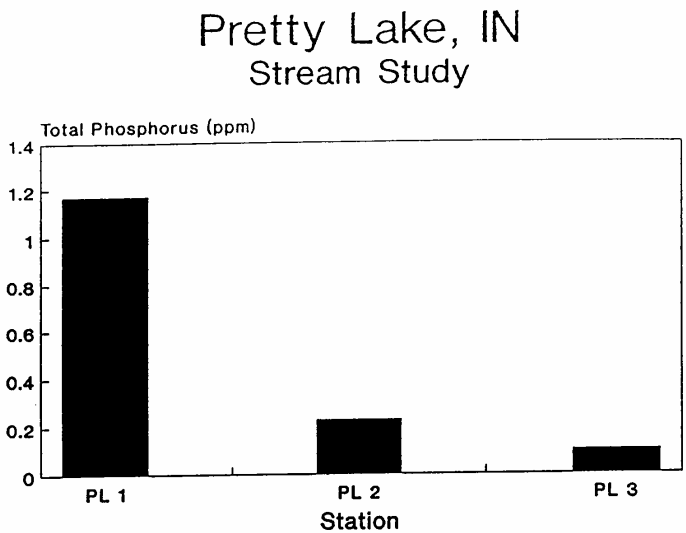


Figure P20. Nitrite/Nitrate Values for Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.



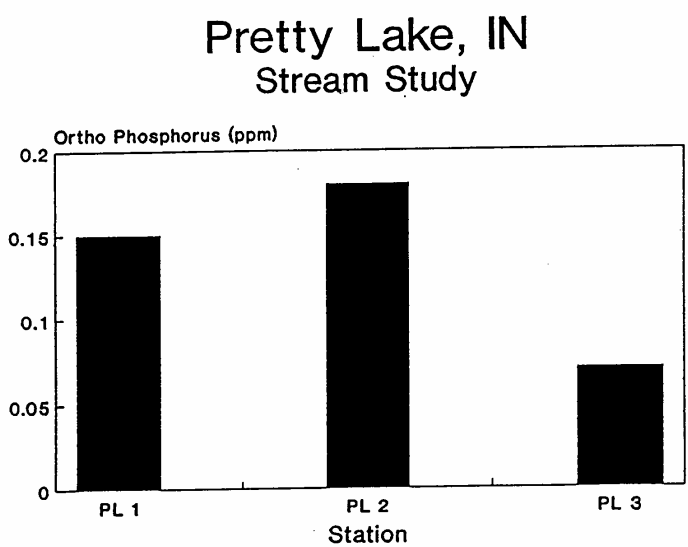


Figure P21. Total Phosphorus and Orthophosphorus Values for Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.

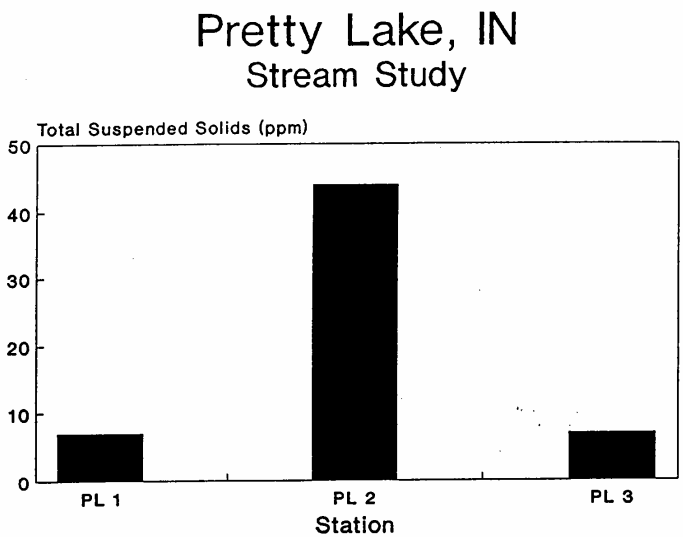


Figure P22. Total Suspended Solids Values for Two Ditches Draining the Pretty Lake Watershed For 18 January 1990. Station PL3 is the Lake Outlet.

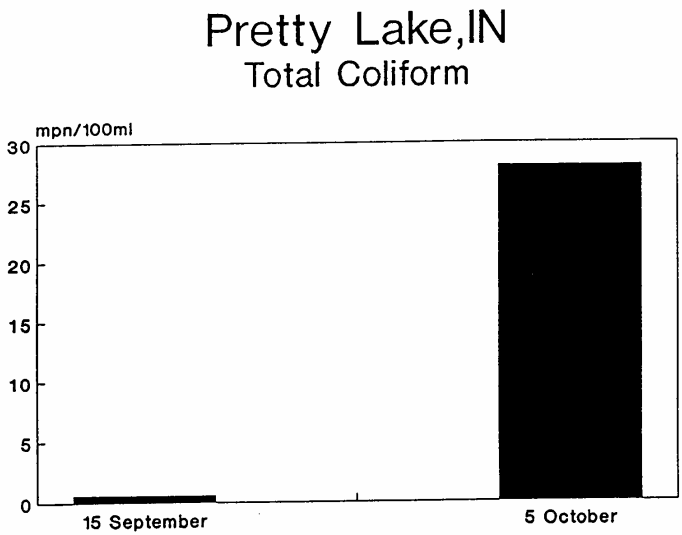


Figure P23. Total Coliform Bacteria Values for Pretty Lake During September and October 1989.

The aerial distribution of plant biovolume in Pretty Lake is presented in Figure P24, and the percentage of lake area represented by individual biovolume increments is presented in Figure P25. For convenience, biovolume has been expressed in increments of 20% of water column infestation. Macrophytes generally were restricted to water depths less than 20 feet, thus limiting plant growth in the lake to near shore areas. Given the morphometry of the basin, a large area of the lake bottom (32%) was considered void of vegetation.

Areas of 100% and 80% water column infestation were aerially limited to the canals along the western shore. The only area of 60% biovolume was along the shore of the northeast corner of the lake near the outlet. This biovolume interval represented the greatest extent of macrophytes in Pretty Lake proper and was characteristic of only 1% of the lake's surface. The remaining 99% of the littoral zone displayed less than 60% biovolume, with 31% of the zone being between 20% and 40% biovolume.

Our work at other Indiana lakes (Eviston and Crisman 1988, Crisman et al. 1990, Eviston et al. 1990) has demonstrated that the public perceives a macrophyte problem only when plant biovolume exceeds 80% of the water column. Following this reasoning, the western shore canals and perhaps the northeastern corner of the lake could be characterized as having management problems with macrophytes. Such areas appear to be limited to water depth less than 5 feet. The depth distribution of macrophytes is controlled both by basin morphometry and pronounced light limitation below 10 feet water depth. It is suggested further eutrophication of Pretty Lake could result in a pronounced exacerbation of macrophyte problems beyond current levels.

The height of macrophyte growth throughout Pretty Lake is depicted in Figure P26. Most of the vegetated littoral zone of Pretty Lake was characterized by plant heights less than 2 feet tall with the second most important plant height interval being 2-4 feet. Only isolated pockets of plant growth between 4 and 6 feet tall were noted. Such a distribution of plant heights suggests a pronounced morphometric and light limitation to macrophyte growth.

In addition to looking at the distribution of plant biomass in Pretty Lake, a qualitative survey was made to determine the distribution of the major plant species in the system (Figure P27). The exotic species, Eurasian watermilfoil (*Myriophyllum spicatum*), shared dominance of the vegetated littoral zone with chara, and Illinois pondweed (*Potamogeton illinoensis*). It appears that most of the near shore macrophyte management problems result from watermilfoil. It should be noted, however, that such dense submergent and floating-leaved plant growth (principally *Nuphar* spp.) near stream and ditch inlets is likely serving a

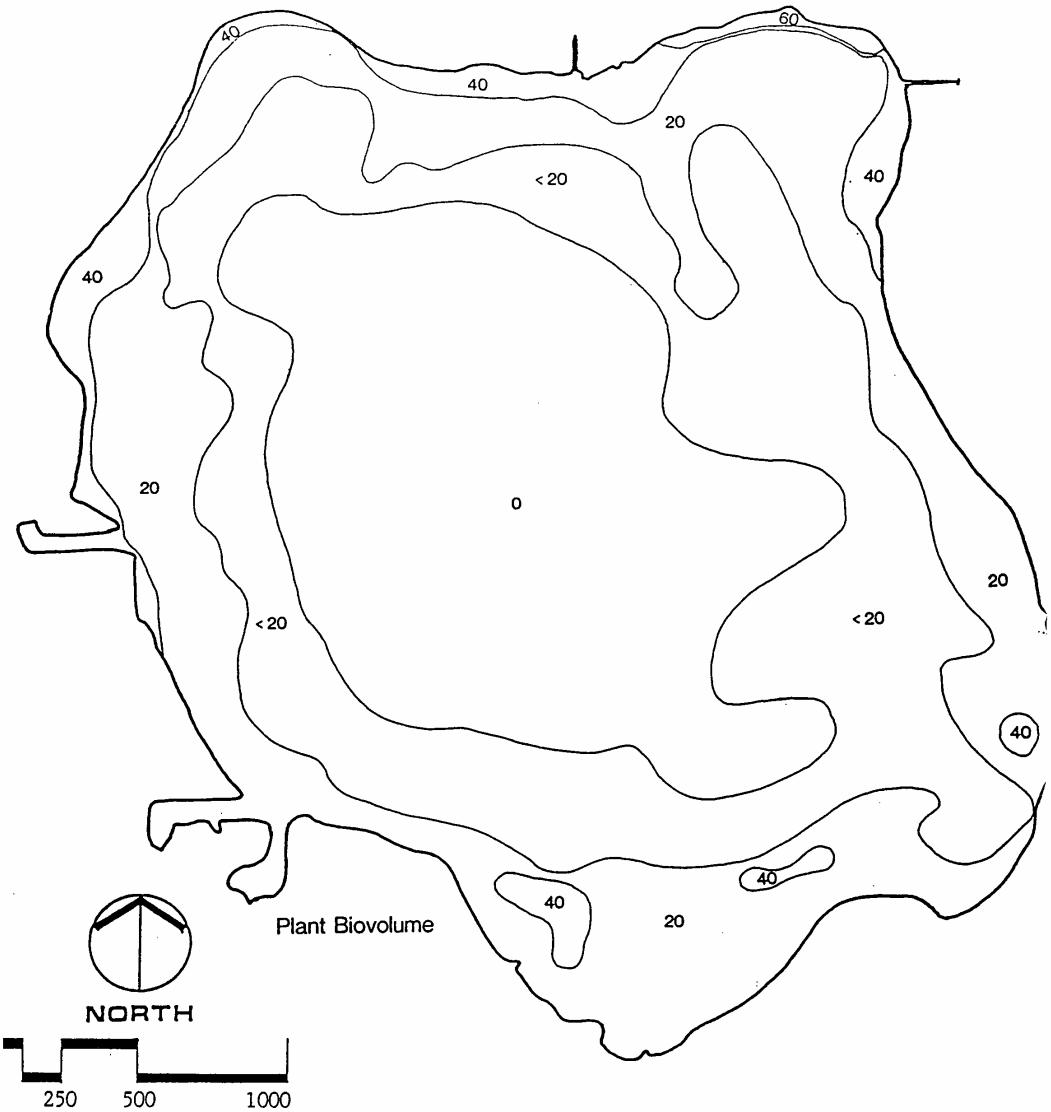


Figure P24. Distribution of Aquatic Macrophyte Biovolume in Pretty Lake for 1989.

Pretty Lake, IN
Percent Plant Biovolume

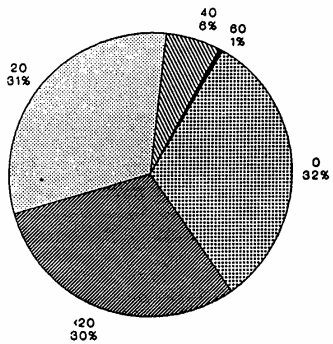


Figure P25. The Distribution of Plant Biovolume in Pretty Lake Expressed as a Percent of Water Column Infestation.

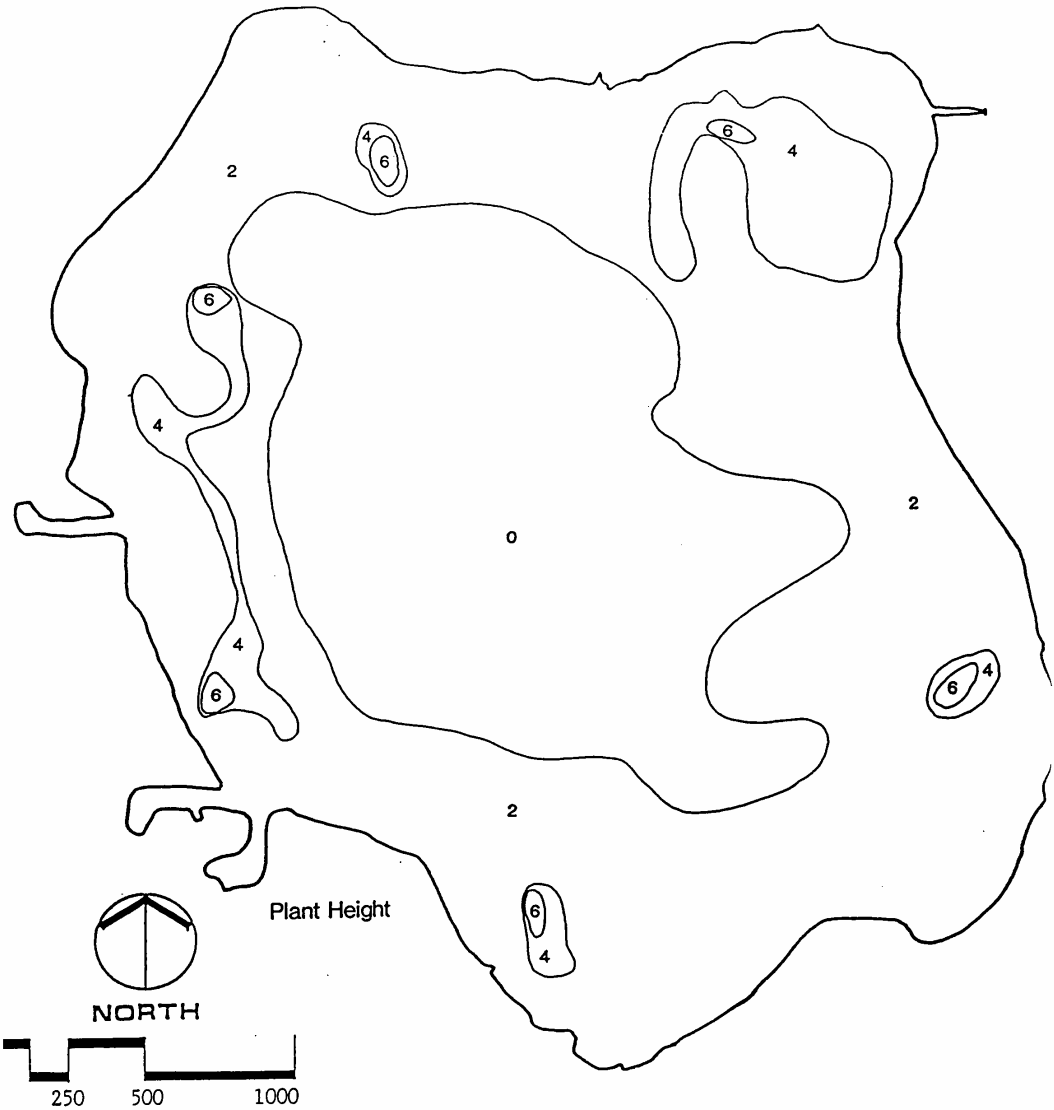


Figure P26. The Height of Aquatic Macrophytes in Pretty Lake in 1989 by Two Foot Height Increments.

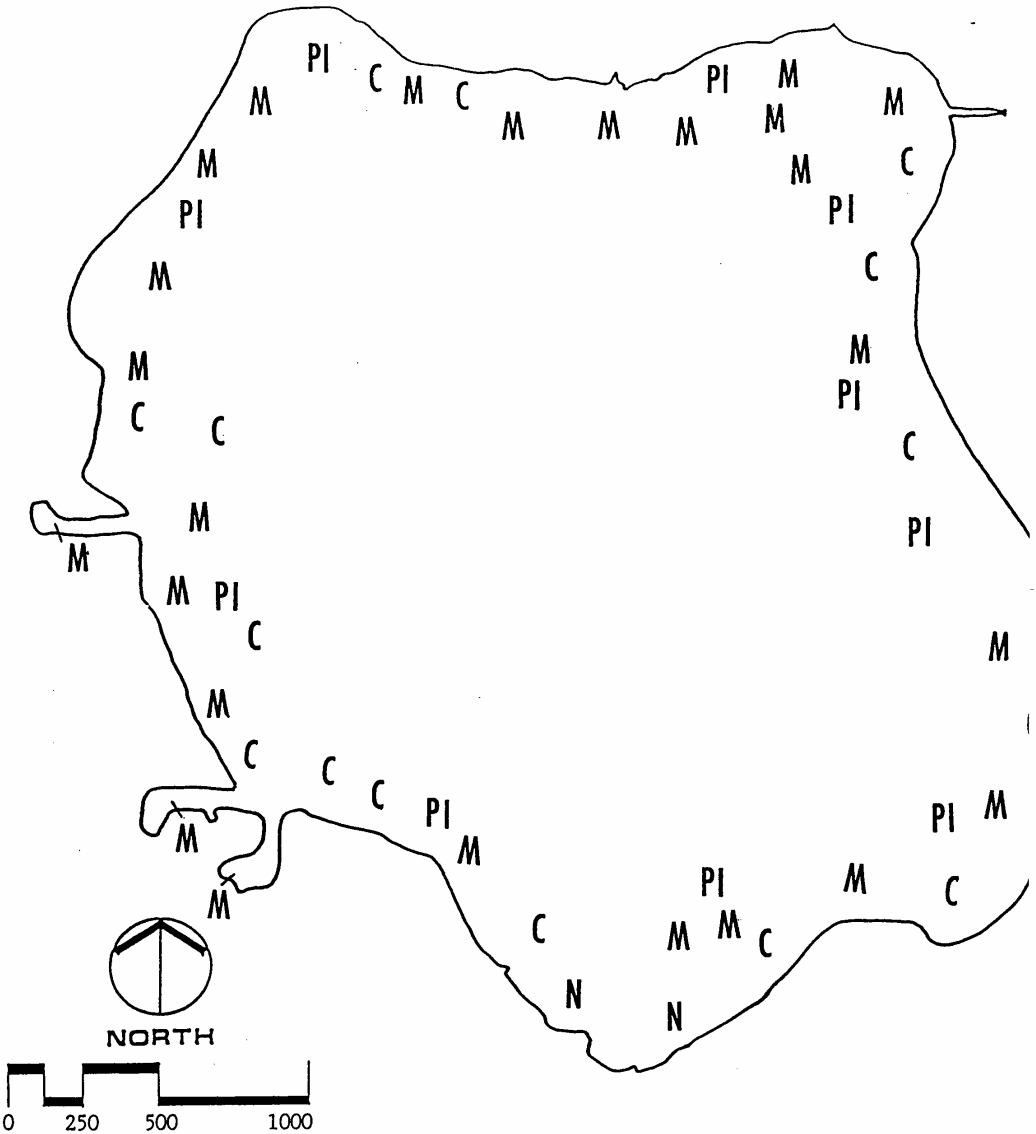


Figure P27. Distribution of Major Plant Taxa in Pretty Lake in 1989. Plants were: Chara (C), Myriophyllum (M), Nuphar (N), and Potamogeton illinoensis (PI).

beneficial purpose in trapping some of the nutrients and silt delivered from the watershed.

Fish

The Raytheon fathometer data recorded from the 16 cross lake transects were also used to provide a qualitative assessment of the fish community of Pretty Lake. Echos of fish in the water column appeared on all fathometer recordings, and these were used to assess total fish abundance and the depth distribution of the population for the lake.

Total fish abundance in open water areas of Pretty Lake was estimated at 7/1000 feet of fathometer transect. The greatest density of fish (20% total abundance) was at a depth of 16-19 feet (5-6 meters) with the second greatest density at 13-16 feet (4-5 meters) (Figure P28). Fish avoided depths shallower than 3 feet (1 meter), the area of highest temperatures, and deeper than 23-26 feet (7-8 meters). The latter depth interval was the thermocline, below which oxygen values quickly fell to less than 1 mg/L. Only 19% of the fish tabulated were found below the thermocline. It must be noted, however, that oxygen is only one of many factors controlling fish distributions. Macrophytes such as found at lake depths less than 10 feet provide a prime habitat for both feeding and reproduction and are a major contributing factor to fishery production.

Bathymetric Map and Lake Infilling

The United States Geological Survey published a bathymetric map of Pretty Lake based on a survey of 1956 (Figure P29). Depth contours were constructed at five foot intervals for the lake. The current study constructed an updated bathymetric map for 1989 based on fathometer recordings obtained from 16 lake transects (Figure P30). Following convention established by the 1956 map, five foot contours were constructed for the 1989 map.

A comparison of the depth configurations for 1956 and 1989 is provided in Figure P31. The 0-5 foot contour in 1956 comprised approximately 56 acres, an area larger than displayed by an other single contour. The second largest contour was the 5-10 foot contour (24 acres). The deepest section of the lake (greater than 80 feet) was less than 2 acres. The 0-5 foot contour still displayed the largest aerial extent in 1989 (68 acres), but the 5-10 foot contour had been replaced by the 30-35 foot interval (15 acres) as the second most important contour. The deep water zone (greater than 80 feet) in 1989 had approximately the same area as reported in 1956.

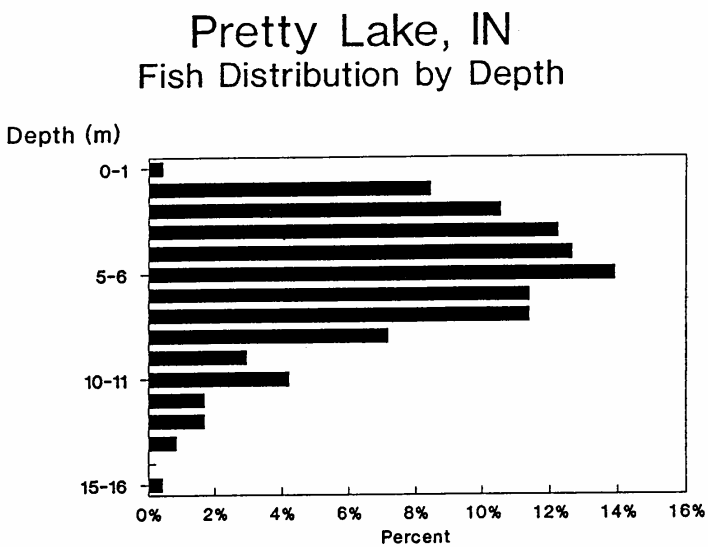


Figure P28. Semi-Quantitative Estimate of Fish in Pretty Lake in September 1989 Expressed as Number of Individuals Per 1000 Feet of Fathometer Transect and Partitioned According to Water Depth.

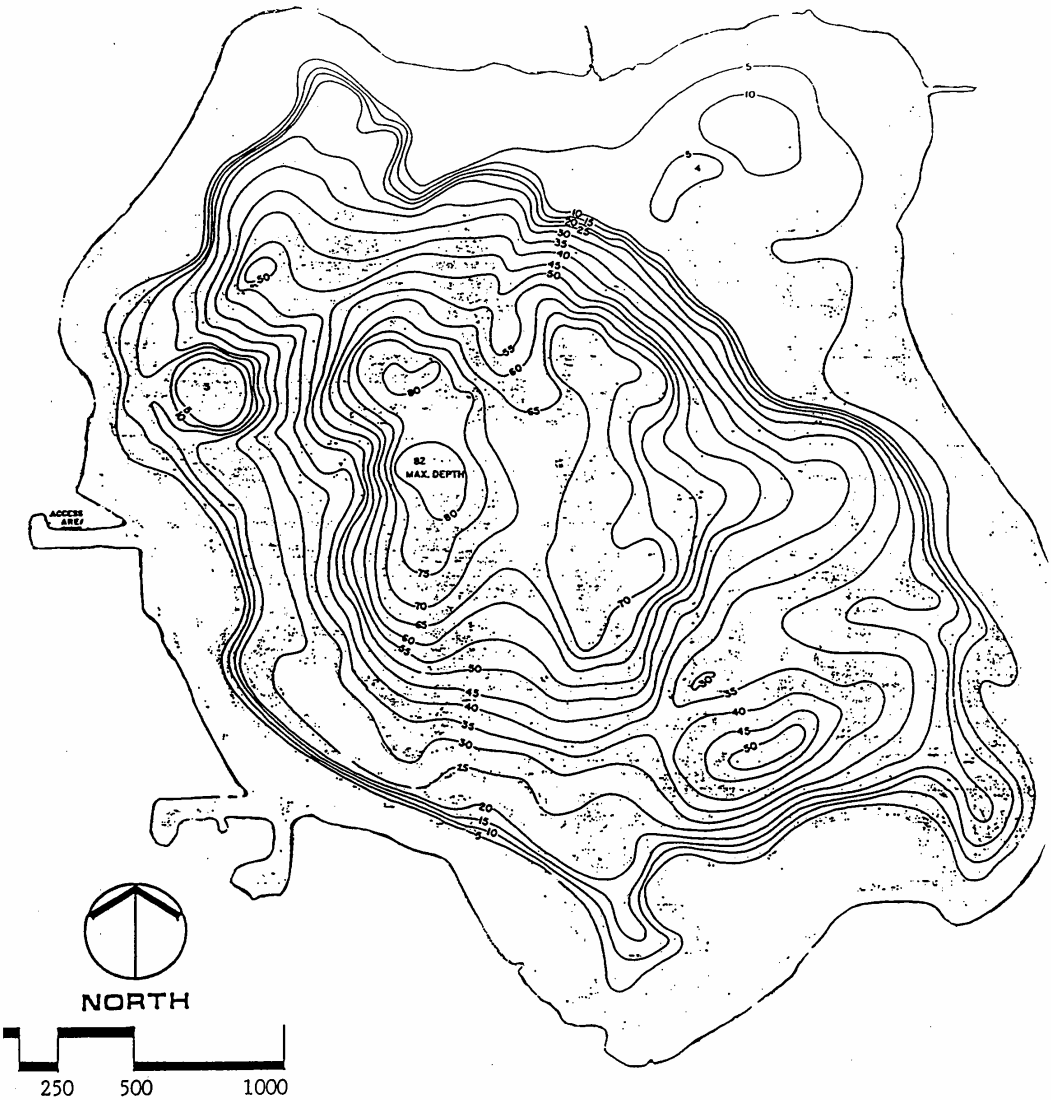


Figure P29. Bathymetric Map of Pretty Lake from 1956.

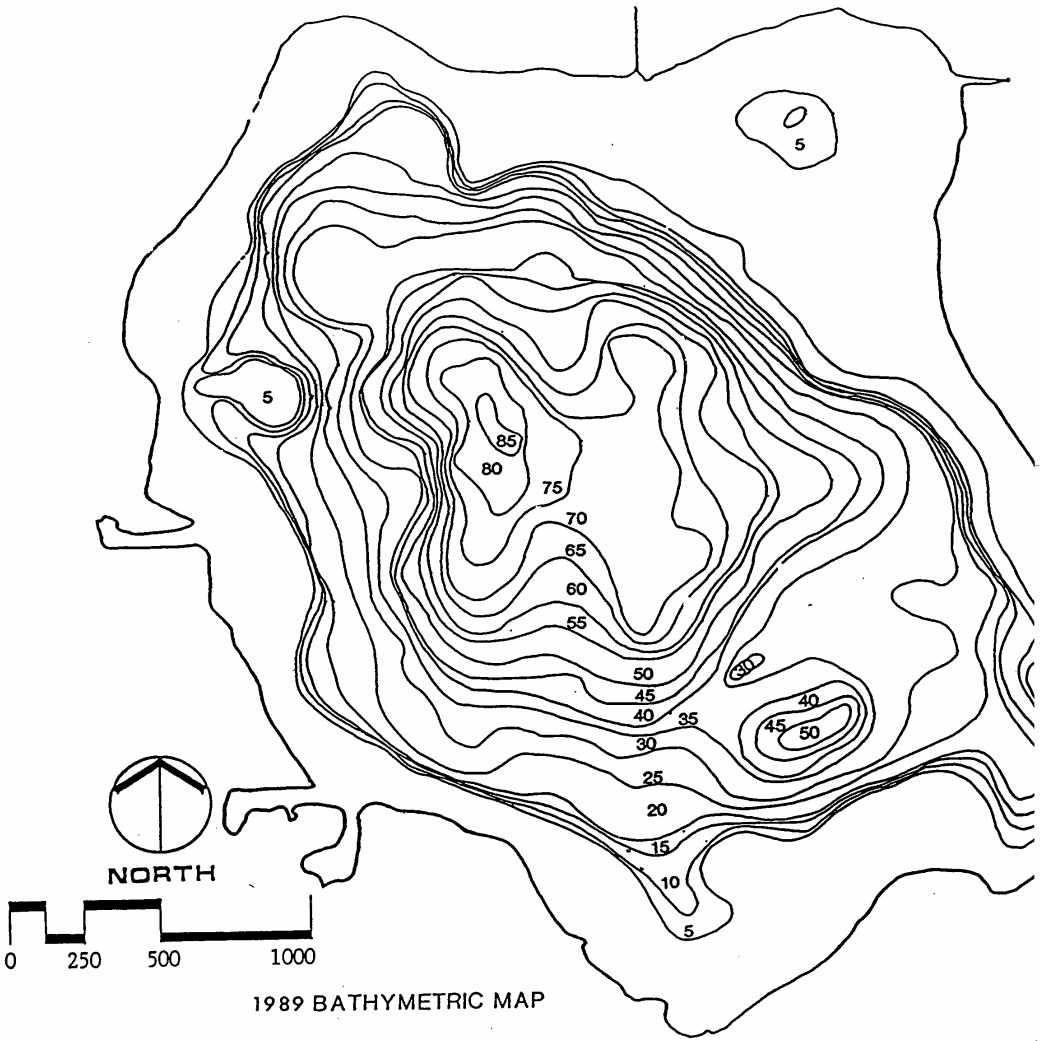
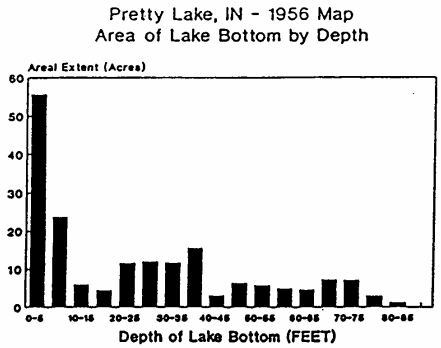
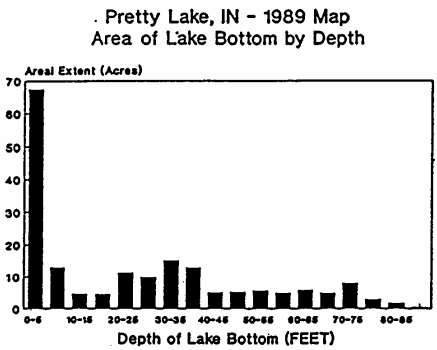


Figure P30. Bathymetric Map of Pretty Lake from 1989.





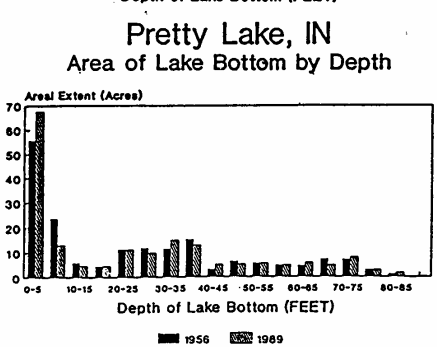


Figure P31. Comparison of the Depth Distribution Within Pretty Lake for 1956 and 1989.

Sedimentation patterns for the past 33 years can be delineated through comparison of the aerial extent of individual contours for 1956 and 1989 (Figure P31). The aerial extent of the shallowest depth contour (0-5 feet) increased by 21% between 1956 and 1989. This increase was largely at the expense of the 5-10 and 10-15 foot intervals which decreased by 45% and 23%, respectively, during the same time period. No consistent pattern was evident for deeper depth intervals, differences between 1956 and 1989 were not considered extensive.

Infilling of nearshore areas was not uniform throughout Pretty Lake between 1956 and 1989. The most pronounced sedimentation has taken place at the northeastern corner of the lake and along the western shore in the vicinity of the excavated channels.

It is clear that basin sedimentation is strongly controlled by stream input of watershed erosion products. Most of the recent sedimentation in Pretty Lake has been immediately offshore from the unnamed ditches entering the lake at its northeast corner (PL2) and along the western shore in the dredged channel (PL1). Both inlets drain watershed segments devoted to agriculture, and residents have reported that both inlets deliver silt ladened water during spring and early summer. Two other contributors to lake infilling, motor boating and shoreline erosion, are not considered to be important factors for the observed pattern of sedimentation in Pretty Lake.

Sediment Studies

Sediment Core Profiles

A piston coring device equipped with a clear plexiglass tube was used to collect a 56 cm core from the center of Pretty Lake (Figure P32). This technique permitted examination of the core to insure that the sediment-water interface was not disturbed during the coring operation. The core was extruded within two hours of collection and sectioned at 1 cm intervals with each sample being placed in a plastic bag for storage. All samples were then kept at 4o C until analyzed. In addition to wet weight for select core levels, organic content was calculated as the difference in weight between the wet weight and that after drying at 100o C for 24 hrs. Inorganic content was calculated from the weight difference of the sample dried at 100o C for 24 hrs and ashed at 500o C for one hour. Phosphorus was determined by the standard ascorbic acid colorimetric method using filtrate collected from an HCl digestion of the sediment sample.

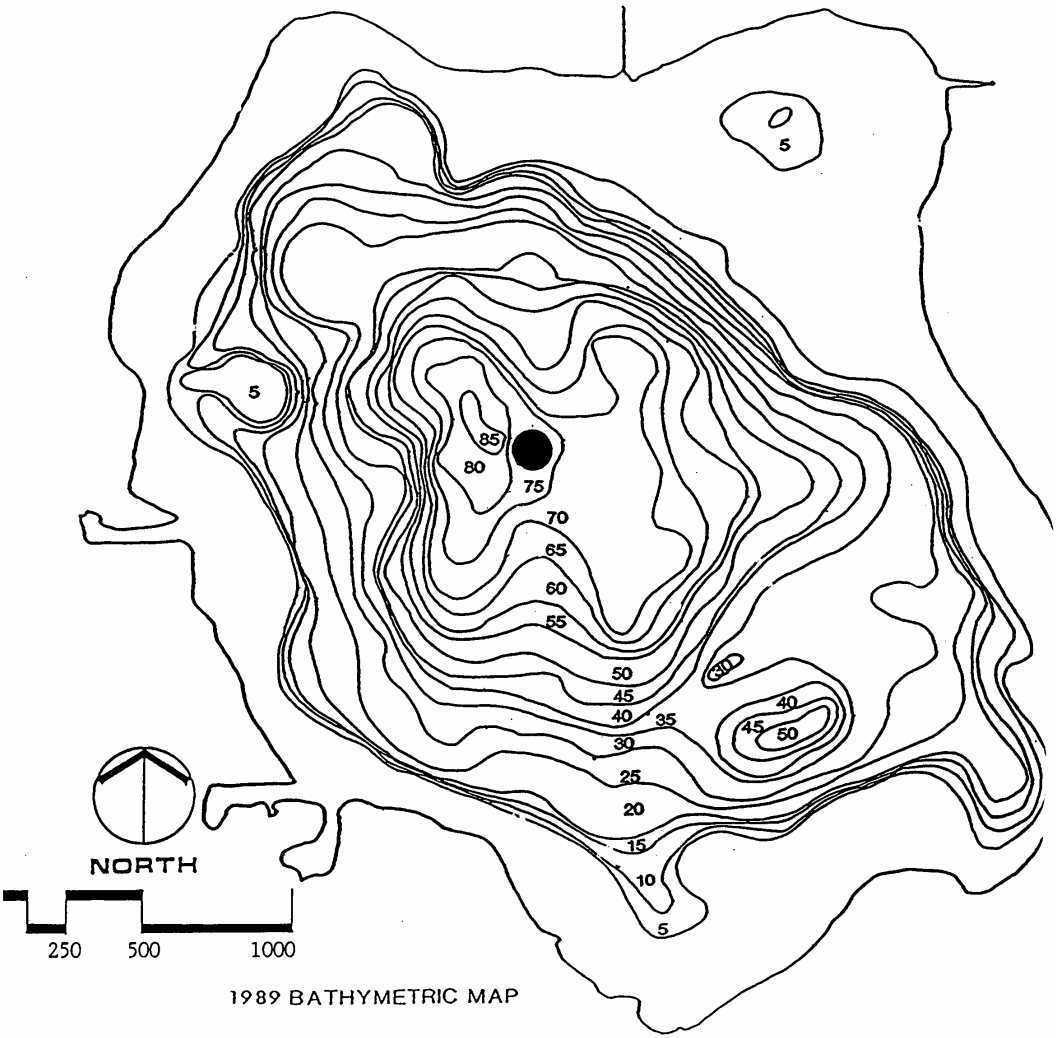


Figure P32. Site of Sediment Core Collection in Pretty Lake During 1989.

Water content of the Pretty Lake core displayed little stratigraphic variation and remained at approximately 85-90% throughout (Figure P33). The percentage of sediment dry weight contributed by the inorganic fraction remained at 78 to 85% throughout the length of the core with the remainder being the organic fraction (Figure P34). The percentage inorganic matter found at Pretty Lake is somewhat high for Indiana lakes that are as comparably unproductive and likely reflects that fact that this lake is actively depositing marl. It is normal for Indiana lakes of intermediate trophic state to deposit in excess of 50 cm of sediment in one hundred years (Crisman 1987). Detailed carbon-14 dating of cores collected from a location near the 1989 core yielded an annual sedimentation rate of 0.07 cm/year for the past 720 years (Williams 1974). Applying this sedimentation rate, the 56 cm core collected during 1989 represents the past 800 years of lake history. Clearing of the watershed forest by European settlers that occurred approximately 159 years ago would be recorded in the core at a depth of 11.13 cm.

The slight variability in the percentage of inorganic and organic matter in the Pretty Lake core suggests that the relative contribution of each has changed little in at least the past 100 years. Organic content of the core was greatest at 8-14 cm and likely represents a period immediately following land clearance for agriculture in the early 1800's. Organic content decreased progressively from 10 cm to 3 cm the increased again in the top centimeter. It is suggested that following an initial pulse in lake productivity following European land clearance (14-10 cm), watershed erosion continued to accelerate to at least the early 1950's. Increased organic deposition in the upper 1 cm of the core does not necessarily mean that the erosion rate has decreased. Rather, it suggests that lake productivity actually accelerated in the past 42 years associated with an increased percentage of year round residences and application of chemical fertilizers throughout the watershed. Given that no charge was included for 210-Pb dating in our budget and this parameter was to be used only if a pronounced stratigraphy was noted, we have not included such a dating technique. Instead, we have relied on the dating profile published by Williams (1974) for a comparable core and indirect estimation of sedimentation in Pretty Lake via comparison of current and historical bathymetric maps and the extent of recent basin infilling.

In situations such as Pretty Lake where the percentage of inorganic and organic matter does not change appreciably along the length of a sediment core, it is conventional to express total phosphorus concentrations as a function of the total dry weight of sediment at a particular depth in the core. Total phosphorus concentrations displayed little stratigraphic variability and with one exception ranged from 0.65 to 0.95 mg/g sediment dry weight (Figure P35). The

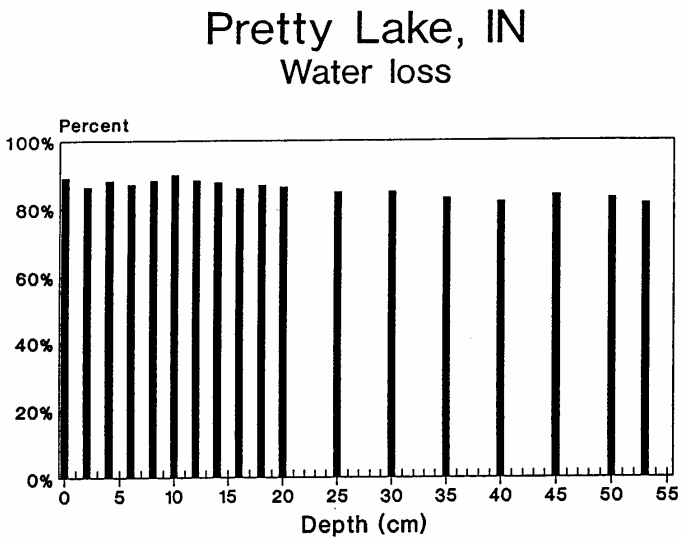
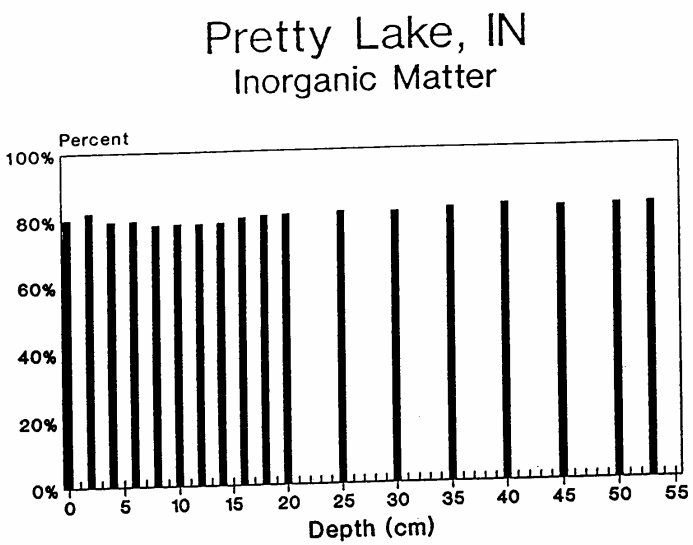


Figure P33. Profile of Percent Water in the Sediment Core From Pretty Lake.



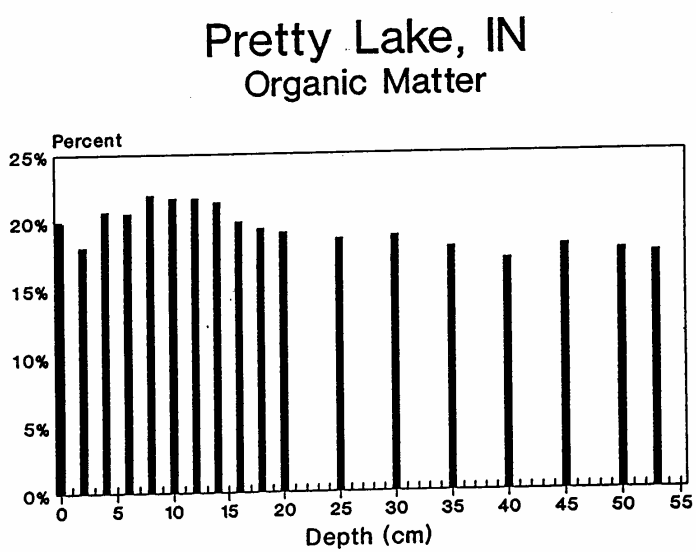
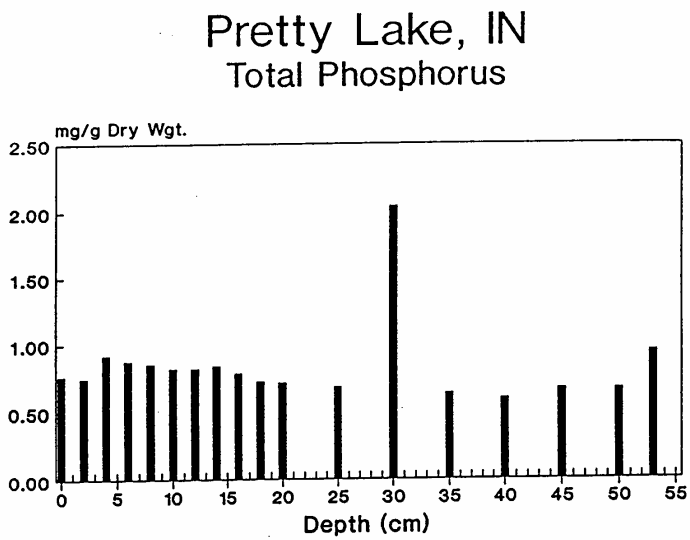


Figure P34. Profiles of Percent Organic and Inorganic Matter in the Sediment Core From Pretty Lake.



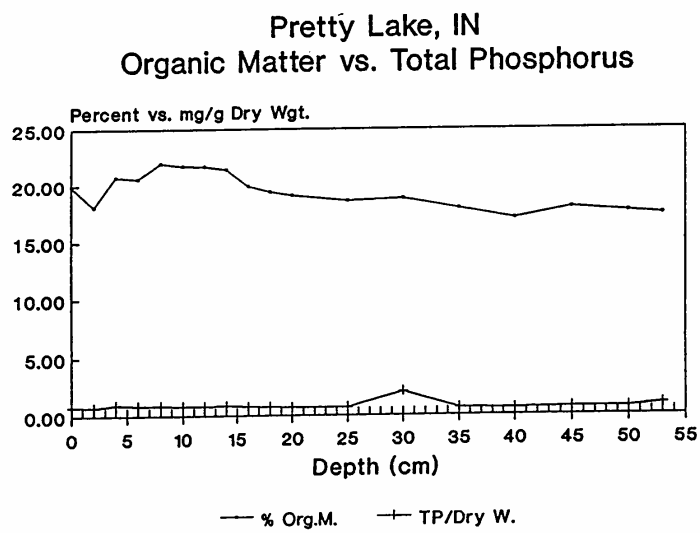


Figure P35. Profile of Total Phosphorus Concentrations and Comparison of Profiles of Organic Matter Percent and Total Phosphorus/Gram Sediment Dry Weight for Sediment Core From Pretty Lake.

exception, 2.1 mg/g at 30 cm likely represents a deposition episode over 400 years ago. The range of phosphorus values reported from Pretty Lake are lower than those of more productive Indiana lakes including Bruce, Nyona, and South Mud (Crisman et al. 1990, Eviston et al. 1990).

The relationship between total phosphorus and sediment organic matter percentage for the Pretty Lake core is presented in Figure P35. Total phosphorus per gram of sediment dry weight remained relatively constant throughout the core length, while the percentage contribution of organic matter to total sediment dry weight declined from 10 cm to the top of the core. This trend suggests that phosphorus entering Pretty Lake recently may not be as readily available for algal and macrophyte growth as in the past and may be associated with the inorganic sediment fraction.

Pretty Lake, The Watershed

The Pretty Lake Watershed

The approach of this part of the study is to specifically address the effect of the watershed on the Lake. After preliminary investigation, the method was to target the area(s) of highest concern. The task was to build upon the 1988 study, A Preliminary Investigation of Twenty-Four Lakes, LaGrange County, Indiana by William Grant, LaGrange County Health Department. The study is quite extensive regarding Lake water quality, but had only general observations about the watershed. Basically, our study had to start from the beginning to discover how this watershed was contributing to challenges in this lake system. The concerns to be identified in the watershed were as follows:

a. Nutrient contribution to the Lake;
b. What are the probable sources;
c. How can sediment be reduced;
d. What are the intrinsic values of the watershed, and
e. How can the sources of sediment/nutrients be managed to reduce impacts to the lake?

This feasibility study included the use of the following resources:

a. Reconnaissance of the entire watershed by site visits on several occasions;
b. Walking tours of some private property areas that could not be properly observed from public areas;
c. Aerial photographs (County Surveyor);
d. Aerial photographs (USDA - Soil Conservation Service, 1972 and 1973);
e. Aerial color infrared photographs (NAPP, 1987);
f. United States Geological Survey (USGS) quadrangle maps;
g. United States Fish and Wildlife Service, National Wetland Inventory maps;
h. USDA - SCS Soil Surveys of DeKalb (1982), LaGrange (1980), Noble (1977) and Steuben (1981) Counties Indiana;
i. DeKalb, LaGrange, Noble, and Steuben Counties records: Auditor, Surveyor, Treasurer, etc:,
j. Various meetings and/or telephone conversations with State & County agencies, local property owners and;
k. A Preliminary Investigation of Twenty-Four Lakes, LaGrange County, Indiana, 1988, by William Grant, LaGrange County Health Department.

The main purpose of this investigation was to target the area(s) which would be the highest priority(ies) for land treatment systems for trapping nutrients and sediments in the watershed. These constructed solutions may consist of land treatment, settling basins, constructed wetlands, sediment traps, ponds, or shallow water habitat areas, etc. These terms are descriptive of similar broad-scale land treatment concepts that would reduce nutrient and sediment loading to the Pretty Lake system. Other upland agricultural practices such as terracing, grassed waterways, conservation tillage, and proper animal waste disposal are all vital methods to improving the water quality of the lake. These practices, are discussed later in this section.
Methods of land treatment and applications will be recommended for problem areas. Local SCS and ASCS offices have been appraised of the areas felt to be contributing excessive amounts of sediment and nutrients or that would otherwise benefit from programs beyond the scope of the Lake Enhancement Program (see watershed tour). The goal of this feasibility study is to focus on the site(s) of greatest potential; to most benefit the lake system in the shortest time; and to attempt to identify the process to create this system and its costs. The final considerations that would evaluate the feasibility and/or priority of such constructed projects would then be up to the Lake Association leadership. Discussions with the Soil Conservation Service county offices indicated the awareness of problems with soils and agricultural practices above the lake. The SCS has pledged to help the Lake Association in any way possible including technical support, and initiating discussions with owners of properties which are contributing intolerable amounts of sediment, nutrient, and animal waste runoff. The SCS would be important support on the larger constructed solutions, and could be of prime responsibility to encourage and/or design the other upland practices and structures.

Natural Features

The Pretty Lake watershed falls in the Northern Lakes Natural Region (Homoya et al, 1985). This Natural Region is comprised of numerous fresh water lakes of glacial origin. Natural community types common to this region include bog, marsh, lake, sedge meadow, prairie and various deciduous forest types. The aquatic communities may be characterized by the presence of bulrush, marsh fern, cattails, pond weeds, spatterdock, Virginia arrow-arum, orchids, tamarack and various species of sedges. The typical forest community which at one time covered over half of this natural region is dominated by oak (chiefly, red oak) and hickory. Other notable species include black, silver, sugar, and red maples; beech; American and red elm; green ash and cottonwood. There have been no recent reports of rare or endangered plants or animals in Pretty Lake or the Pretty Lake watershed.

Techniques useful in preserving these natural features include:

a. Avoid relocation of natural stream channels

b. Avoid building close to wooded ravines or stream banks.

c. Preserve natural vegetation adjacent to water areas.

d. Avoid construction in, or drainage of, wetlands.

e. Avoid the use of on-site septic systems near the lake or near drainages where there is potential for saturated soils.

Watershed Tour--impressions by visual survey

Pretty Lake and Watershed

The purpose of this section is to express in narrative form the observations and general visual impressions that were made during site tours of the watersheds and review of color infrared and other aerial photographs. The intent is to provide a perspective that may be fresh and to stimulate residents to make their own continuing observations.

Prior to our detailed watershed tours, we examined several aerial photographs of the Lake and watershed. The purpose of this was to identify potential problem areas not likely to be observed from the ground in order that they could be checked in the field. Aerial photographs were also used to help us focus on the "big picture". This allowed us to understand the watershed interaction as a whole before we broke it down into its smallest components (Figure P36).

1. Pretty Lake is well-suited to its name. With gentle slopes on the western shores, and higher bluffs on the eastern shore, this apparently deep lake is --well--Pretty. From small simple older cottages, to larger homes, to newer ranch style homes, the pride and concern for this lake is obvious. However, the entire lake is ringed with these homes. Can the lake continue to sustain its visible good quality under this pressure?

2. A relatively small, directly-contributing watershed surrounds the lake. The cropland west of the lake had been planted with a no-till drill.

3. The Public Access is located on the west side of the lake.

4. Several minor inlets and swales enter the lake on the west. Some are carrying sediments, but from small areas (2 to about 10 acres). Much of the runoff entering the lake from these inlets and swales is ponded ahead of the lake. This allows for sedimentation of larger particles prior to entering the lake. A permanent vegetation filter strip is recommended in this area to further slow runoff ahead of the Lake.

5. Northwest of the lake, the watershed has seen some recent changes. Previously considered non-contributing, lands (including wetlands) have been ditched to connect with the lake. This is the major inlet into Pretty Lake, emptying into a large weed bed (where fishing is good!). This entire drainage system should be critically reviewed. A large wetland at the southeast corner of Section 9 has been open ditched in an attempt to crop farm some of this area.

6. Two animal operations (An) are located north of 400 South, in Section 9. The ditches adjacent to these operations receive direct runoff from the animal operations. These areas must be managed properly. Management could involve: implementation of animal waste management practices, diverting ditch flow from animal operations, livestock exclussion-fence livestock out of the ditches, establish permanent vegetative filter strips between livestock and open waterways.

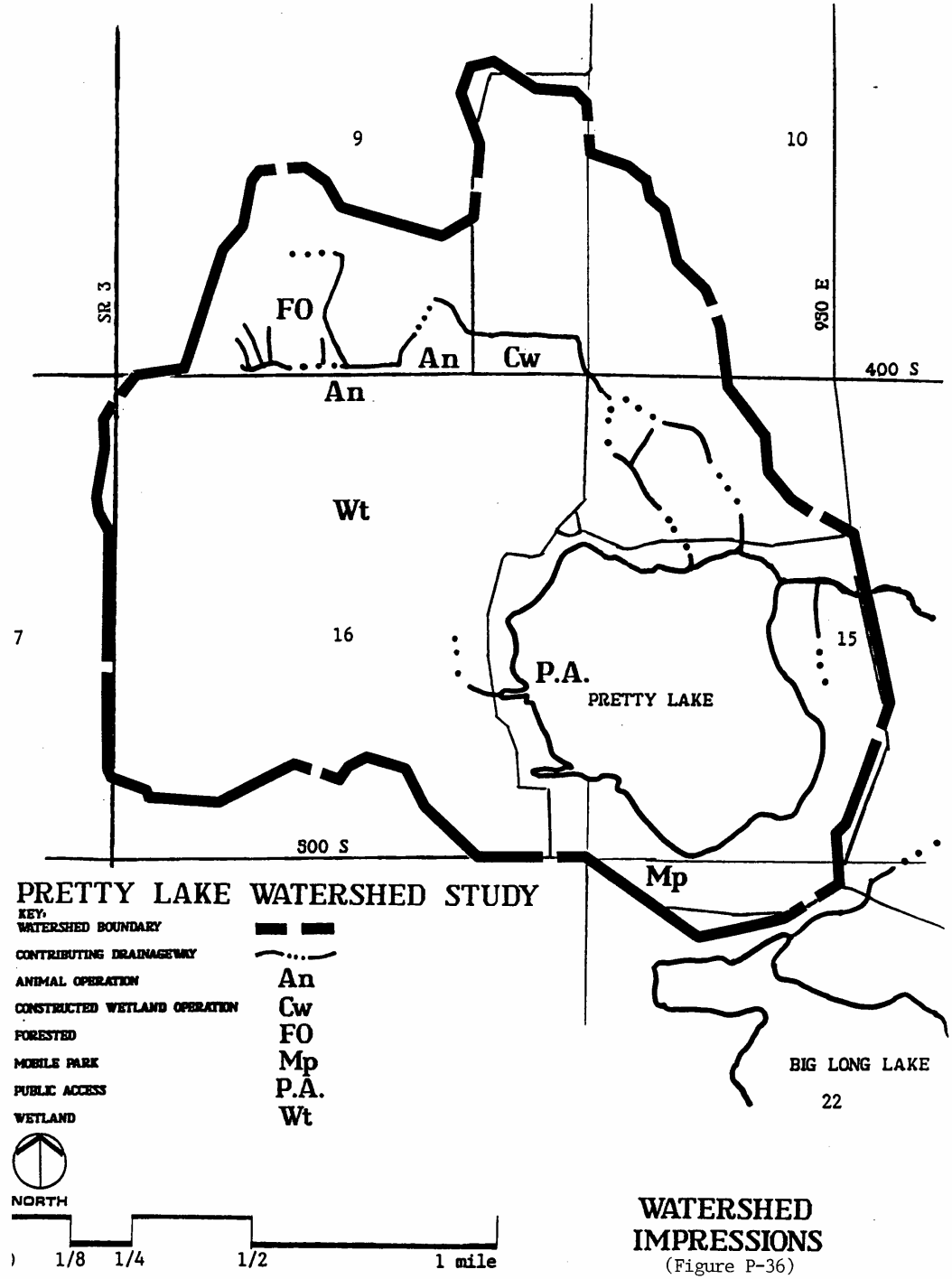
7. The surface drainage in northern half (approximate) of Section 9 has been routed (ditch modification) to the northeast, out of the Pretty Lake watershed. Although this area of the wathershed was previously considered to be non-contributing (HEL, sediment) to Pretty Lake, due to drainage modification, it is no longer a part of the Pretty Lake watershed.

8. A forested wetland (FO) exists in the southwest quarter of Section 9, but has again been connected by open ditch into the Pretty Lake system. What about closing this section of ditch, or opening a portion of the levee to re-inundate the forested area?

9. The opportunity exist to restore the drained wetland located at the southeast corner of Section 9. Restoration of this wetland would intercept the highest sediment and nutrient loading segment of the Pretty Lake watershed. This management strategy is further discussed in the Constructed Options section of this report.

10. Returning to the lake, another small flow from the wooded area in the northeast is noted. The outlet is also located in the northeast corner.

11. Hopefully, the lake portion of this study will reveal evidence of the rate of deterioration of the lake--and, hopefully, will be very low. It is suspected that problems can be dated to the ditching to the north.



WATERSHED IMPRESSIONS
(Figure P-36)

Photospectroscopy

Aerial photography is an intricate tool for use in many topographic and natural resource applications.

In doing a land use study using aerial photography, several items must first be considered to provide the most accurate detailed information possible in obtaining the desired data.

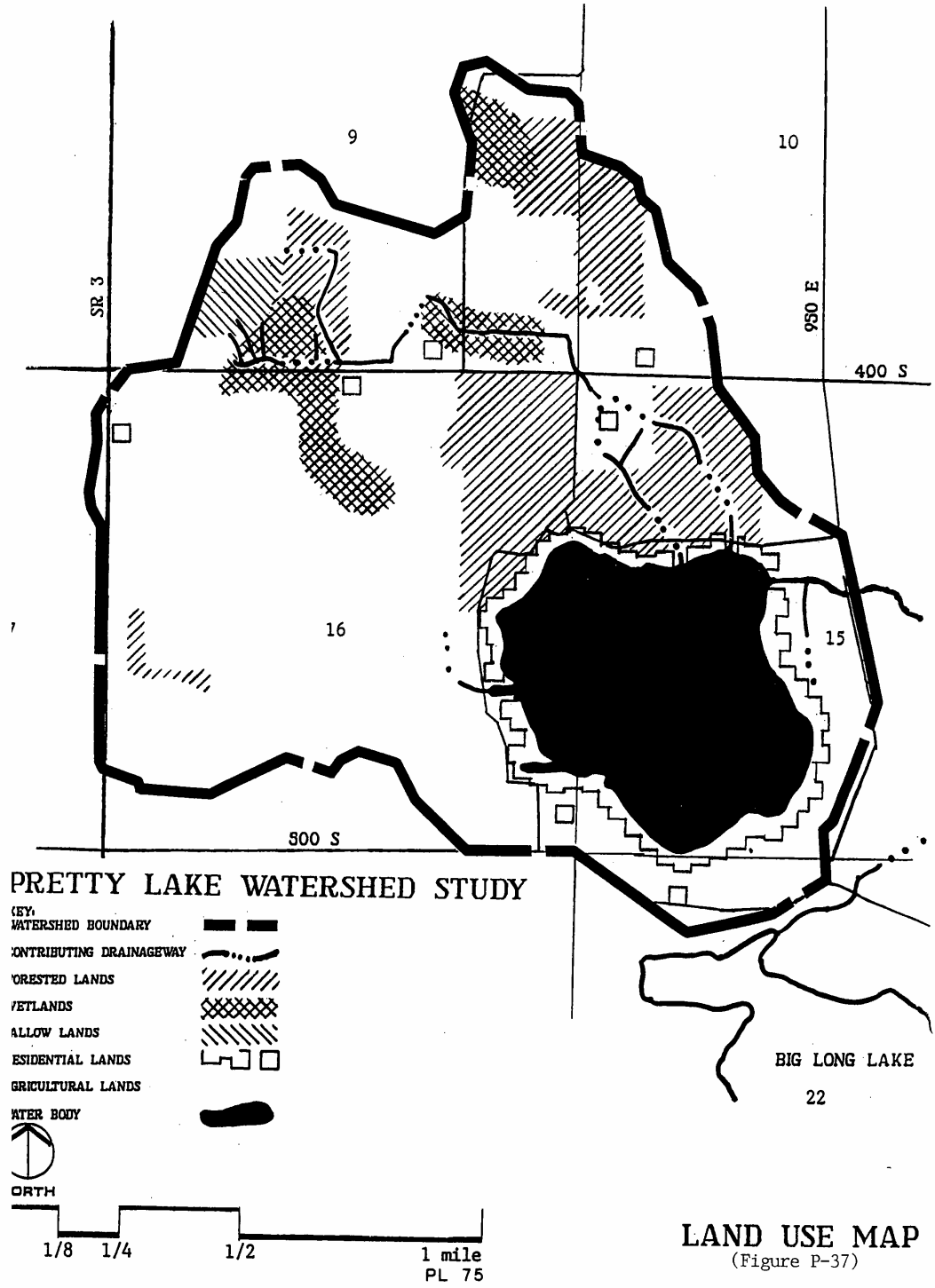
First, and probably most important in doing a study of primarily agricultural usage, the "type" of photograph used is important. For the most part, two "types" of photographs exist: 1) those taken in the visible spectrum, and 2) those taken in ultraviolet or infrared spectrum of light. Since all living organisms emit energy in the electromagnetic spectrum and since our study is based primarily in an agricultural watershed area, color infrared photography was used.

This type of photography delineates plants through size, density, and respiration, by photographing specific intensities of electromagnetic radiation emitted. Fallow lands, lake and wetlands appear as grey or black areas on the photo.

Second, the date in which the photographs were taken is an important consideration in the determination of the results and comparison to current trends.

Month and day play a factor in the interpretation of the types of vegetation and wetlands described. An extreme example of this would be trying to distinguish agricultural usage on a photo taken in July compared to the same photo taken in December. The day is also a factor because of previous weather conditions. According to the USDC, National Weather Service, 1.8 inches of rain fell over the project area in the 4 weeks prior to the photo date, this was 0.8 inches below normal, however this deviation was not sufficient to alter normal land use cover types. The photographs used for this study were taken on the September 4, 1987 fly-over at a scale of 1:40000 (figure page iv).

In doing the land use study of the Pretty Lake watershed, the entire watershed was laid out on the photographs using a transparency. The size of an overlay grid (1 acre) was then calculated, drawn, and then placed over the photos. From there the watershed was divided into the following land use categories: Agriculture; Fallow; Forested (woodlots); Pretty Lake; Residential; and Wetlands. Results of the study are shown in watershed summary, Table P13. Land use is graphically represented in Figure P37.



LAND USE MAP
(Figure P-37)

PRETTY LAKE LAND-USE SUMMARY TABLE		
Cover Type	Acres	% of Total
Agriculture	468.7	41.7
Fallow	35.1	3.1
Forested (woodlots)	241.4	21.5
Pretty Lake	184.0	16.4
Residential	118.9	10.6
Wetlands	75.9	6.7
Total Watershed Area	1124.0	100.0

Table P13. Pretty Lake Land-Use Summary

Geology

The Pretty Lake watershed is underlain by bedrock of the Coldwater Shale Formation (Gray 1987). The Coldwater Shale Formation consists of 90 to 350 feet of gray shale laid down in the lower Mississippian Period of the Paleozoic Era (about 350 million years ago).

The shale deposits of the Pretty Lake area are covered by over 200 feet of partially lithophied to unconsolidated glacial deposits (Gray 1989). The most recent glaciation occurred some 12,000 years ago during the Wisconsinan Advance (Hill 1986). The Pretty Lake watershed is comprised of sediments deposited from the Huron-Saginaw Lobe of the Wisconsinan Ice Sheet. This material is dominated by loam till of the Trafalgar Formation which includes large areas of severely eroded drift, and dead-ice land forms...Pretty Lake! For further discussion on surface geology, see Soils.

Topography

The watershed of Pretty Lake is best described as a morainal topography and areas of thin loamy till over morainal topography. Morainal topography is a general term used to describe areas of irregular mounds and ridges which are the result of glacial drift. Glacial drift are deposits of outwash streams and unsorted sand and gravel tills. The highest point in the Pretty Lake watershed is 1027 feet above sea level in the northern most point of the watershed, and the lowest point is 964 feet above sea level at the outlet of Pretty Lake.

Relief throughout the watershed is characterized as rolling to depressional. Slopes range from 0 to 12 percent.

Severe slopes

The length and steepness of slopes are major factors in assessing the probable erosion risks of an area. On steep or long slopes, runoff water accumulates in channels where increased flows produce greater erosive forces. Level or flat lands produce shallow overland flows over a larger area. This decreases the erosive forces of runoff.

The intent of this study-map (Figure P38) is to further illustrate the fabric of the land forms in the watershed. Areas with severe slopes comprise 252 acres or 22% of the Pretty Lake watershed. Severe slopes detailed in this study range from 10 to 12 percent. The majority of the severe slope areas occur in the north half of the watershed. This study provides further evidence where land management emphasis should be. This graphic also substantially matches the worst conditions of Highly Erodible Lands and will be discussed later in the report. In general, areas mapped as having severe slopes should not be in agricultural crop production without conservation tillage.

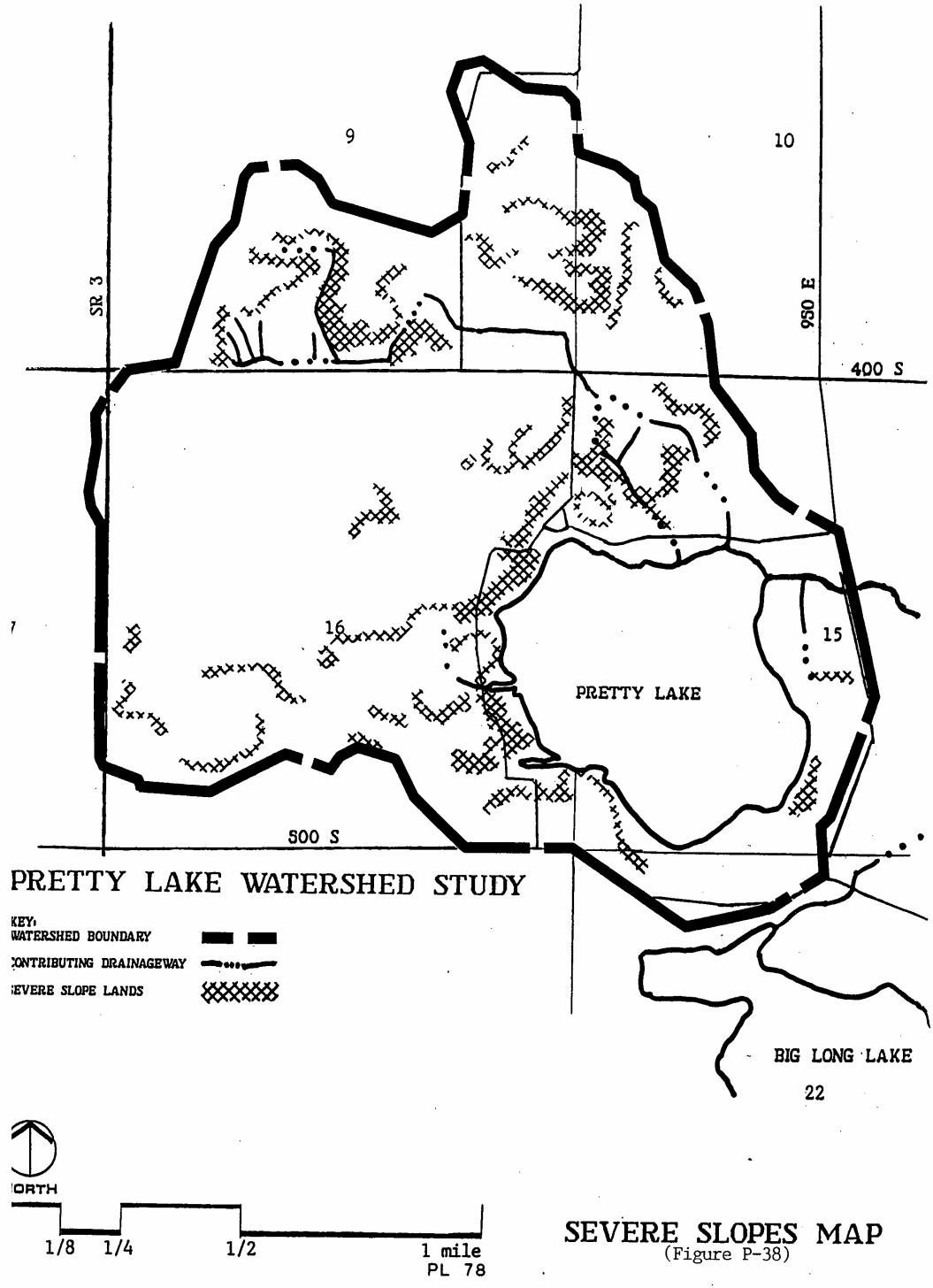
Soils

The soils of the Pretty Lake watershed are grouped in the Wawasee-Hillsdale-Conover Association by the LaGrange County Soil Survey. This association is further characterized as moderately drained, nearly level to strongly sloping areas, with course to medium grained soils of glacial till plains and moraines.

The association is approximately 30 percent Wawasee and similar soils, and 17 percent Hillsdale soils, 14 percent Conover soils, and 39 percent other minor soil inclusions.

According to the LaGrange County Soil Survey (1980), The well drained Wawasee and Hillsdale soils are on knobs, breaks between drainages, and on level till plains. Low water availability is a major limiting factor of the Hillsdale soils. The poorly drained Conover soils occur on broad flats and along drainageways. Conover soils are limited by saturated conditions.

Other minor soil inclusions in this association are the Boyer, Chelsea, Metea, and Martinsville which are found in areas similar to that of the major soils of the association. The Whitaker soils are located on slightly lower areas; Rensselaer soils are located in depressions and drainages; and Houghton soils are in deep depressions and low lying areas.



SEVERE SLOPES MAP
(Figure P-38)

Highly Erodible Land

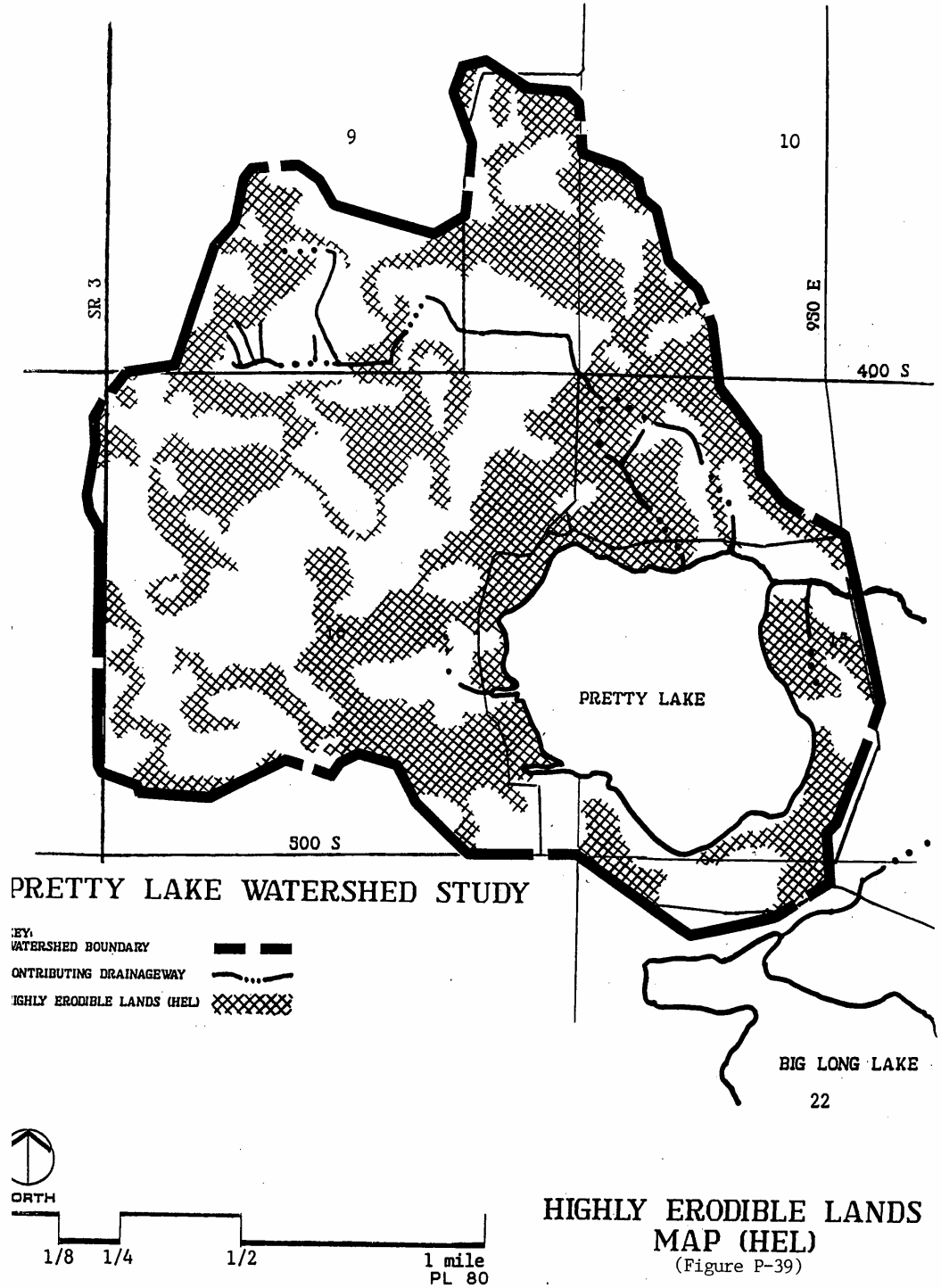
Highly erodible lands, or HEL are determined based on dominant slope length, percent slope and soil texture determined for each soil unit in each county. The purpose of identifying areas containing HEL is to display the origin of potential sediment sources so that the study may target areas of general concern. Using the Soil Survey of LaGrange County prepared by the USDA-SCS issued in 1980, and data provided by the local SWCD and SCS offices, soils of the HEL designation were mapped as shown in Figure P39.

The following highly erodible soils occur within the Pretty Lake watershed (Table P14).

Boyer loamy sand, 6 to 12% slopes
Boyer loamy sand, 12 to 18% slopes
Chelsea fine sand, 6 to 12% slopes
Hillsdale sandy loam, 6 to 12% slopes
Metea loamy sand, 6 to 12% slopes
Oshtemo loamy sand, 6 to 12 % slopes
Wawasee fine sandy loam, 6 to 12% slopes
Wawasee fine sandy loam, 12 to 18% slopes
Wawasee loam, 6 to 12% slopes

Table P14. **Highly Erodible Land (HEL) soils of the Pretty Lake watershed.**

The Pretty Lake watershed was first analyzed to determine the total extent of HEL map units in the watershed. The Pretty Lake watershed is comprised of approximately 516 acres (45.9%) of HEL. The study area was then further divided to determine the extent of HEL currently in crop production. HEL in agricultural production are of greater concern to the overall water quality of Pretty Lake because these lands are more susceptible to erosive forces than HEL with established permanent vegetative cover. Approximately 59% (306 acres) of the total HEL occur in agricultural land-use areas, and are considered to be directly contributing sediment to Pretty Lake. The HEL study was based strictly on HEL map units, it does not take into account non-HEL map units which may have inclusions of HEL soils. Target sediment sources were located using the HEL map and aerial photos, and will be discussed further in latter sections of this report.



HIGHLY ERODIBLE LANDS MAP (HEL)
(Figure P-39)

WATERSHED MANAGEMENT

Highly Erodible Lands Overlays

The intent of this HEL/Severe Slope Overlay (Figure P40) is to emphasize the areas of the watershed where severe erosion problems are likely to occur. The areas defined in the Agricultural Lands/HEL/Severe Slope Overlay (Figure P41) were in crop production as of 1987. The 66 acres, detailed in this overlay represent the worst case HEL areas of the Pretty Lake watershed. Much of this land is adjacent to open drains or ditches which facilitates the transport of eroded soils to the Lake. For this reason, those areas present the greatest sedimentation threat to Pretty Lake. Every effort should be made to enlist those lands into CRP or related land treatment programs (grassed waterways, filter strips, etc.). It is apparent from the HEL/severe slope overlay that the majority of the critical erosion areas of the watershed have not been fully addressed. These lands should not be in agricultural crop production.

Erosion: Causes and Prevention

Erosion of soil is primarily caused by the force of raindrops striking the ground, and, secondly, by the force of water flowing in rills or channels. As rain falls on unprotected ground it breaks small particles of soil free. These soil particles are then carried away by sheets of water. Naturally, as the intensity of rainfall increases, velocity and volume (flow) of runoff increases, thus potential soil erosion increases.

Types of soil erosion probable or noted in the Pretty Lake watershed:

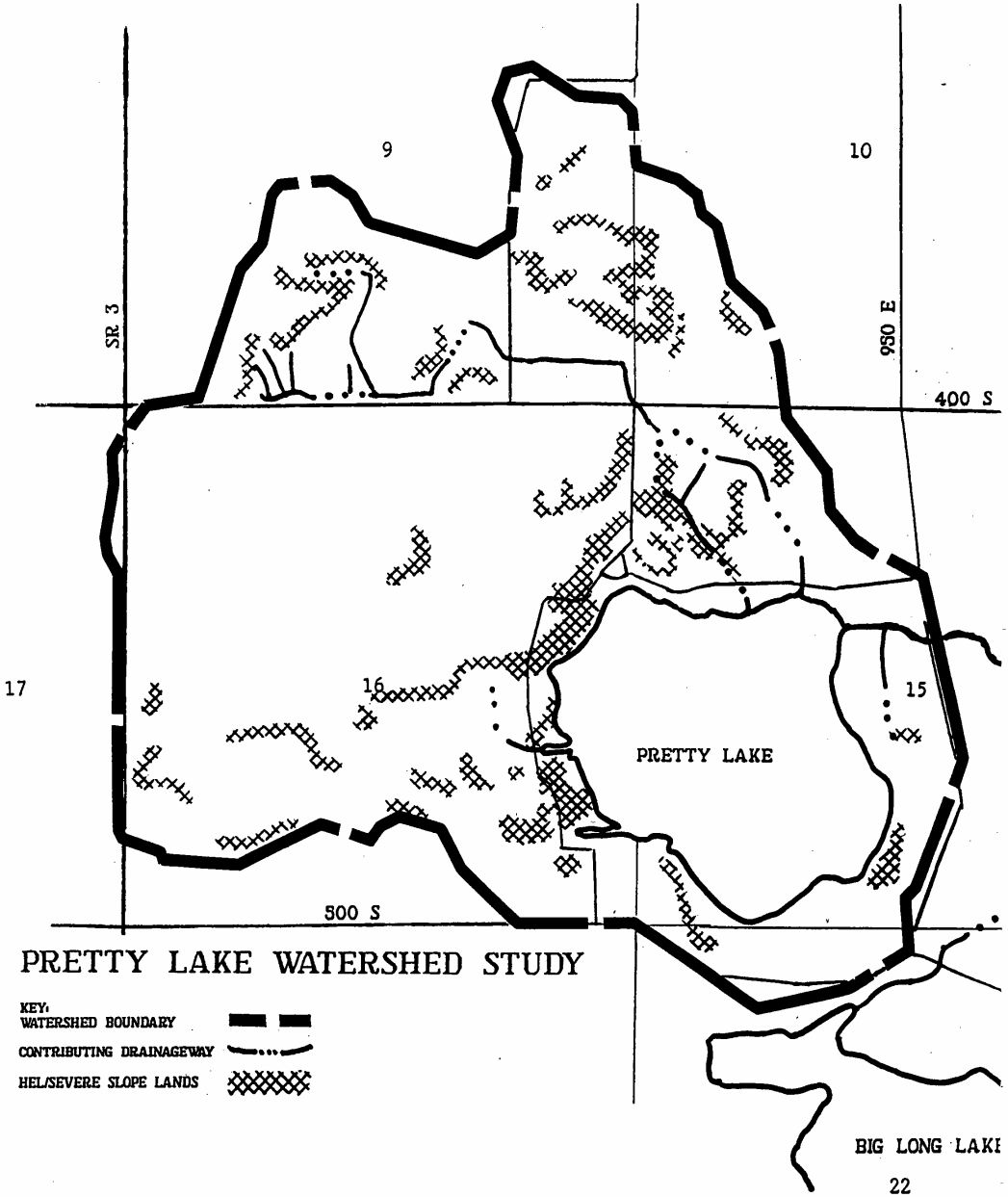
1. Raindrop (or splash) erosion due to the impact of rain on unprotected land.

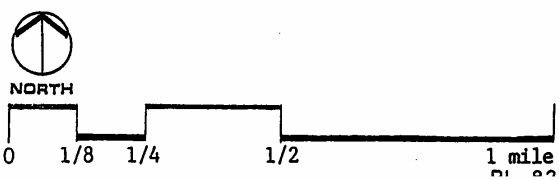
2. Sheet erosion or overland flow causes exposed soil to be suspended by the action of the flowing water, this is common on sloping to nearly level unprotected land.

3. Rill and gully erosion is the result of concentrations of runoff water in riverlates. Rill erosion may cut several inches into the topsoil. Gully erosion, resulting from unmaintained rills or drainages, may cut several feet into the surface.

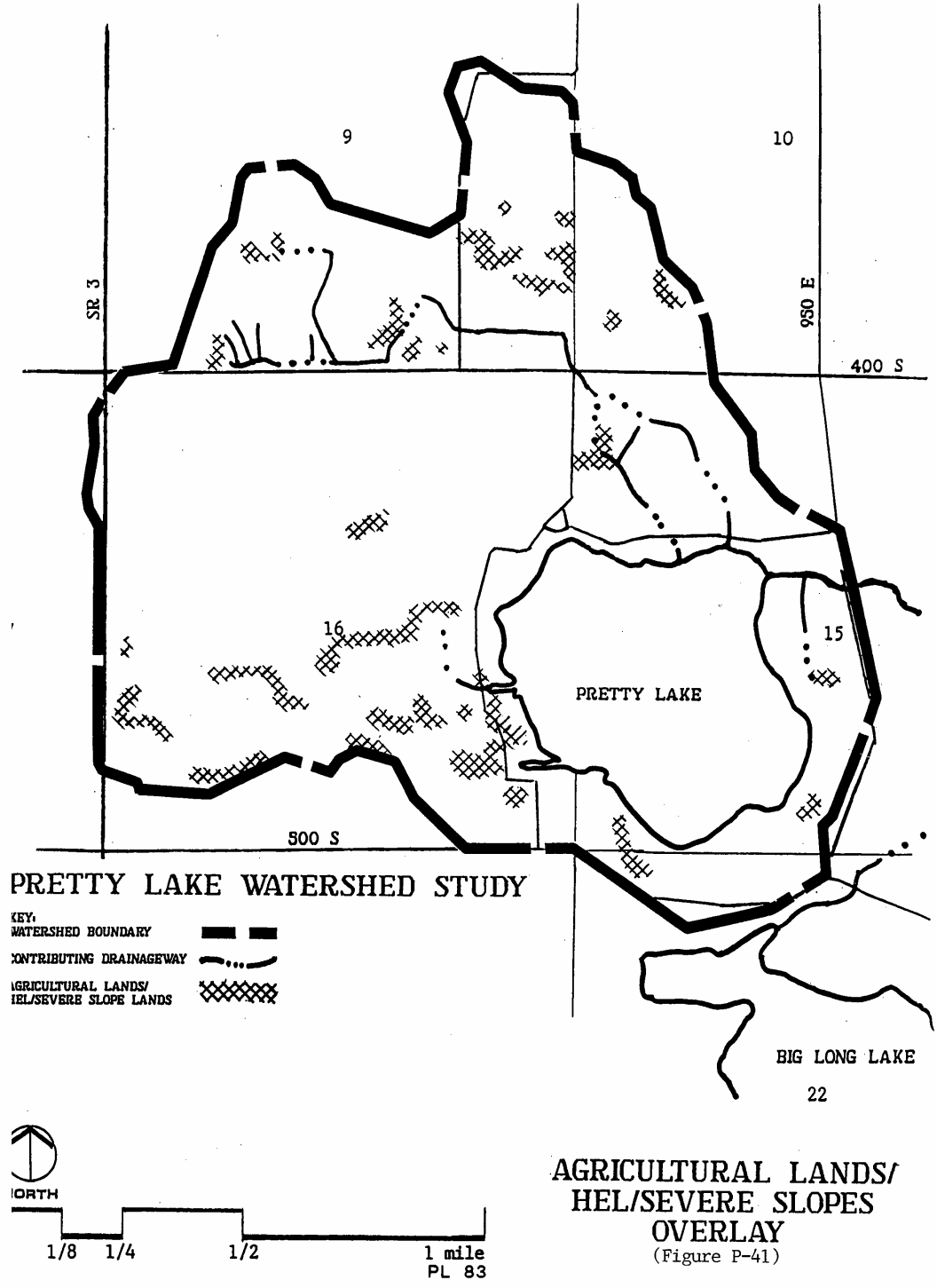
4. Streambank and channel erosion causes a scouring of stream bottom and undercutting of stream banks.

5. Wind erosion, similar to sheet erosion, is caused by the turbulent force of the wind over unprotected land.





HEL/SEVERE SLOPES OVERLAY
(Figure P-40)



AGRICULTURAL LANDS/
HEL/SEVERE SLOPES
OVERLAY
(Figure P-41)

The erosion potential of a given area may be determined by four criteria: 1) soils; 2) surface cover; 3) topography; and 4) climate.

An understanding of soils, and the factors involved in making soil more susceptible to erosion include: soil texture, soil structure, soil content of clay or organic material, and soil permeability. Maintaining adequate surface cover, either in the form of vegetative cover or crop residue, is important in reducing soil loss.

The realization is that soil is a valuable resource, and particles are difficult and expensive to recover once erosion has begun. **Prevention is easier than correction!**

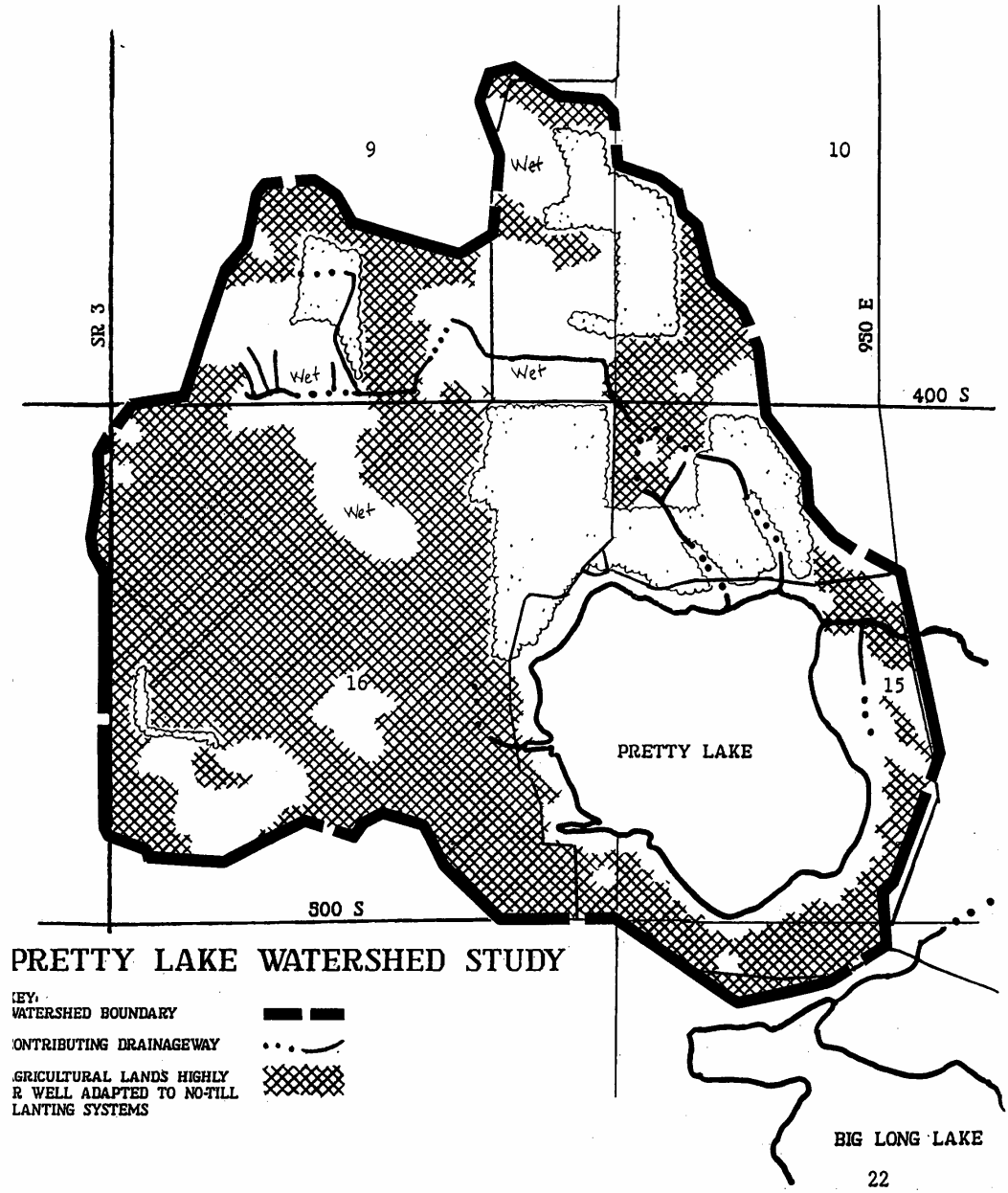
Useful concepts in erosion prevention and control:

a. Maintain natural vegetative cover wherever possible.
b. Protect sloping areas. Vegetation is difficult to establish and maintain on eroded slopes.
   Row cropping should be done perpendicular to slope.
c. Divert runoff from severely sloping areas.
d. Break up long slope lengths by multiple cropping or landscaping when natural cover is not maintained.
e. Stabilize drainage areas immediately following any construction or "maintenance".
f. Leave natural buffer areas along streams and ditches.
g. Stabilize stream bank or ditch escarpments.
h. Utilize sediment ponds below feed lots and "open" sloping lands.
i. Construct and maintain sediment control structures <u>prior</u> to construction of any lake or waterfront development.
j. Implement applicable conservation tillage method.

Conservation Tillage

There are several methods of tillage currently utilized in corn and bean production: moldboard plow, chisel plow, large blade (deep) disc harrow, small blade (shallow) disc harrow, ridge-till, and no-till. Fall moldboard and chisel plowing are still frequently used by Indiana farmers, however, conservation tillage systems are becoming more widely excepted due to improved yields, and greater savings of soil, water, and money.

The no-till conservation tillage/planting system has been identified as one of the most effective conservation practice available to farmers in Indiana (AY-210). The Suitability for Conservation Tillage overlay (Figure P42) indicate 75% to 80% of the agricultural lands in the Pretty Lake watershed are well to highly adapted to no-till conservation tillage systems. Agricultural lands depicted as unsuitable for no-till (22%) in the Pretty Lake watershed include soils which are too wet or slopes greater than 12%. Lands noted as unsuitable to no-till should be in permanent cover.



CONSERVATION TILLAGE SUITABILITY MAP

(Figure P-42)

Development on Saturated Soils

The goal of this study was to estimate potential septic system inefficiencies. Ineffective septic systems have been documented to contribute excessive amounts of nutrients to a lake. Using data collected on saturated soils (Table P15) and comparing it with building records from 1959, projections were established indicating septic systems that were likely to be located in saturated soils (Figure P43).

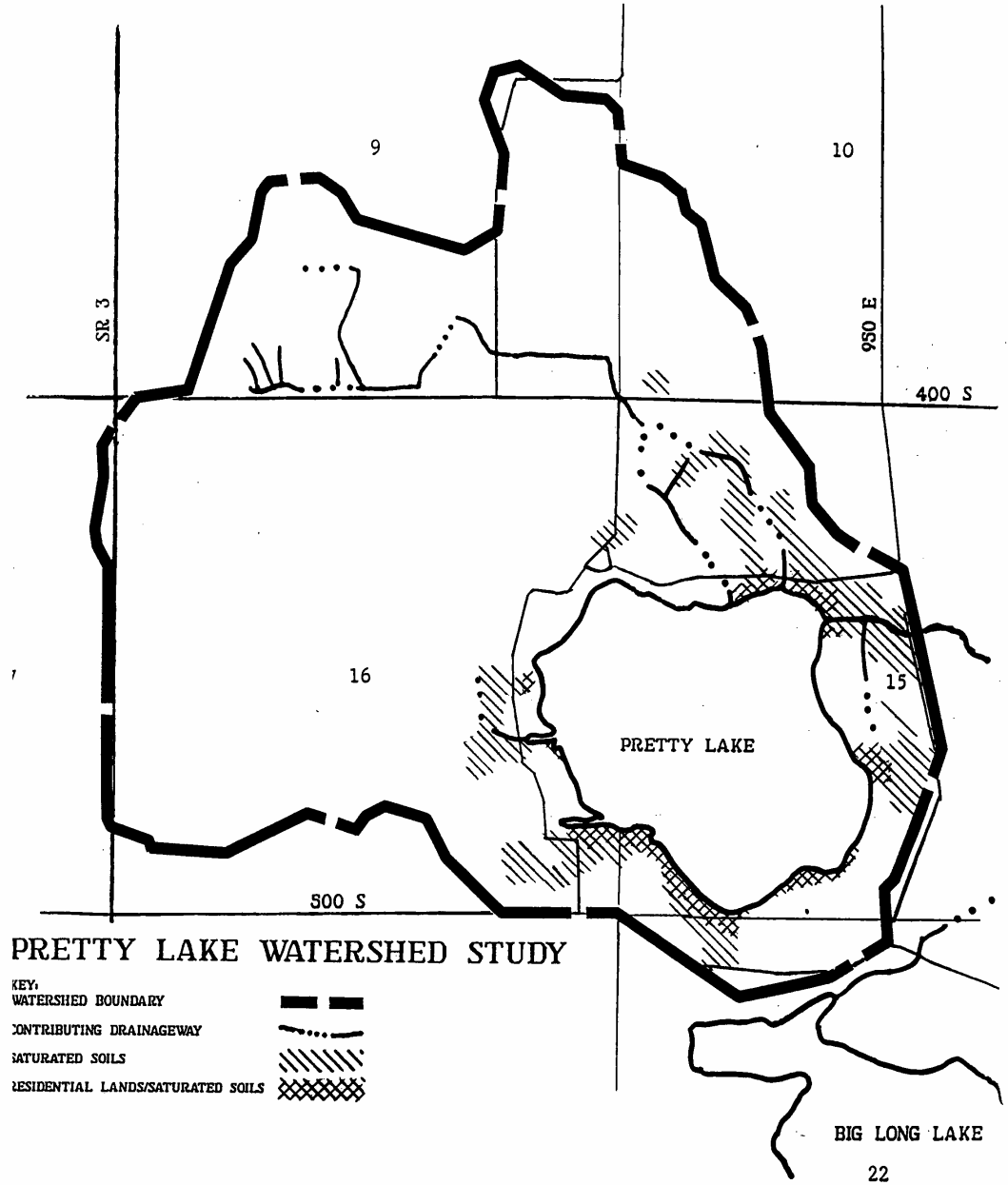
The assumption was made that septic tank-type systems are in place for those residences located on saturated soils. Septic system efficiencies are based on the need for well drained soils necessary for proper treatment of sewage effluent. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well drained soils. It should be noted that seasonal fluctuations in the water table of poorly drained soils were not taken into account. Varying water table elevations and waste loading would be responsible for fluctuations in treatment success. Localized fecal coliform values likely increased due to a substantial increase in the summer population around the lake and fluctuations in the water table as well as residences in the watershed with septic systems that outlet directly into ditches.

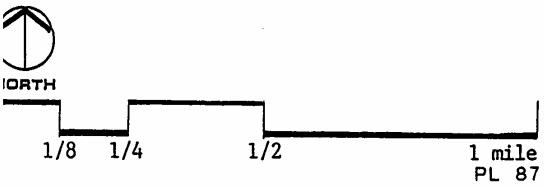
The findings of this study (Figure P44) indicate a trend towards building on saturated soils. In 1959, on Pretty Lake, 51 of the 132 homes (39%) were located on saturated soils. Building records for Pretty Lake in 1987 demonstrated an increase in the number of home located on saturated soils, 89 of 170 homes (52%) were located on saturated soils.

Possible approaches to meet the current and future waste disposal needs with the objective of maintaining or improving water quality would include: 1) Lake-wide or County-wide sanitary sewer system, 2) mound type septic systems and/or 3) pumping to suitable septic locations and 4) any of the above in combination with a constructed wetland or pond/wet meadow system.

Although treatment is certainly not limited to the management approaches discussed above, it was determined that these methods of waste treatment would effectively meet the goals of sewage disposal.

Residences must take on the responsibility of maintaining their own waste disposal systems. Drain fields must be inspected regularly and septic tanks must be pumped on a regular schedule. Further study is recommended for those residential areas noted in the Saturated Soils/Residential Lands Overlay. A study could be developed utilizing a septic tank dye.





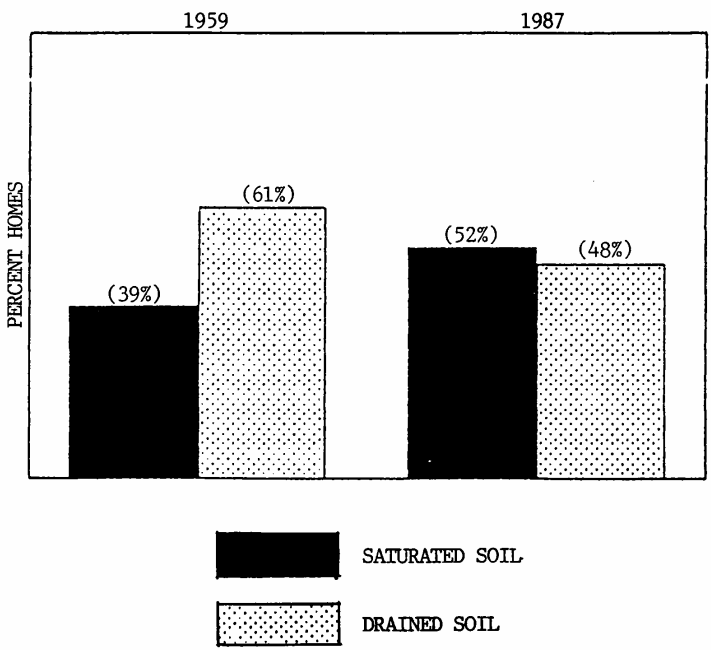
SATURATED SOILS/
RESIDENTIAL LANDS
OVERLAY
(Figure P-43)

If it is determined that an engineering study should be undertaken for a new wastewater treatment system, the method and site selection should consider tertiary treatment using a constructed wetland system.

Table P15. **Poorly drained soils of the Pretty Lake Area.** Adapted from USDA-SCS Indiana Technical Guide, 1988.

CONOVER loam
HOUGHTON muck
RENSSELAER loam
UDORTHENTS loamy

Figure P44. **Profiles of Residences Located on Saturated Soils; trends based on 1959/1987 building records.**



Hydrology

The Pretty Lake watershed is a sub-drainage basin to the Lake Michigan Basin. The main water supply comes from ground water stored in the sand and gravel deposits of the Wisconsin till aquifer. According to the LaGrange County Soil Survey, the watershed of Pretty Lake receives an average annual precipitation of 32.9 inches with a standard deviation of 6.7 inches. July tends to be the wettest month with an average precipitation of 3.8 inches. On average, February is the driest month with a precipitation mean of 1.6 inches. The greatest basin drainage gradient in the watershed is 110.9 feet/mile along the main inlet ditch. According to the 1979 Cowardin et al classification system, water regimes range from temporary to semi-permanent. Fifty-five percent of the wetlands located in the watershed are of seasonal water regimes. Eighty-eight percent are small, less than ten acre, palustrine wetlands (Table P16). Palustrine wetlands, defined here as wetlands less than 20 acres in size, averaging less than 6 foot in depth, and dominated by trees, shrubs, and/or emergent vegetation (Mitsch and Gosselink, 1986).

It is estimated that 71% of the wetlands in the Lake Michigan Basin have been lost (Hamilton 1965). Losses are primarily attributed to drainage for agricultural production. The following table is intended to illustrate the types of wetlands remaining in the Big Long watershed, and focus attention on preserving these natural filters.

Table P16. **Pretty Lake watershed water regime characteristics**

Palustrine	Occurrence	%Totals
Less Than 10 Acres	74	88.1
More Than 10 Acres	10	11.9
Totals	84	100.0
Cover-Type		
Emergent	44	52.4
Forest	17	20.2
Scrub/Shrub	21	25.0
Open Water	2	2.4
Totals	84	100.0
Water Regime		
Temporary	4	4.8
Saturated	5	5.9
Seasonal	46	54.8
Semi-permanent	9	10.7
Unknown	20	23.8
Totals	84	100.0

Computer Modelling: Hydrology

The focus of the study, a computer model using SEDIMOT-II, (Warner, 1983) was used to project storm runoff, and hydrographs for 5, 25, and 100 year storm events. Data used for the computer model was derived in part from the land use study. Cover types for each segment of the subwatershed were assessed using color infrared aerial photographs, soil input was supplied by the USDA-Soil Conservation Service, and slope segments were determined using information from the US Geological Survey. Results of this study were used to predict sediment removal ability of proposed control structures located on the main inlet to the north of Pretty Lake using the Surface Loading Rate formula (SLR), (Barfield 1987).

The hydrology modeling techniques used in the SEDIMOT-II program are divided into two major areas:

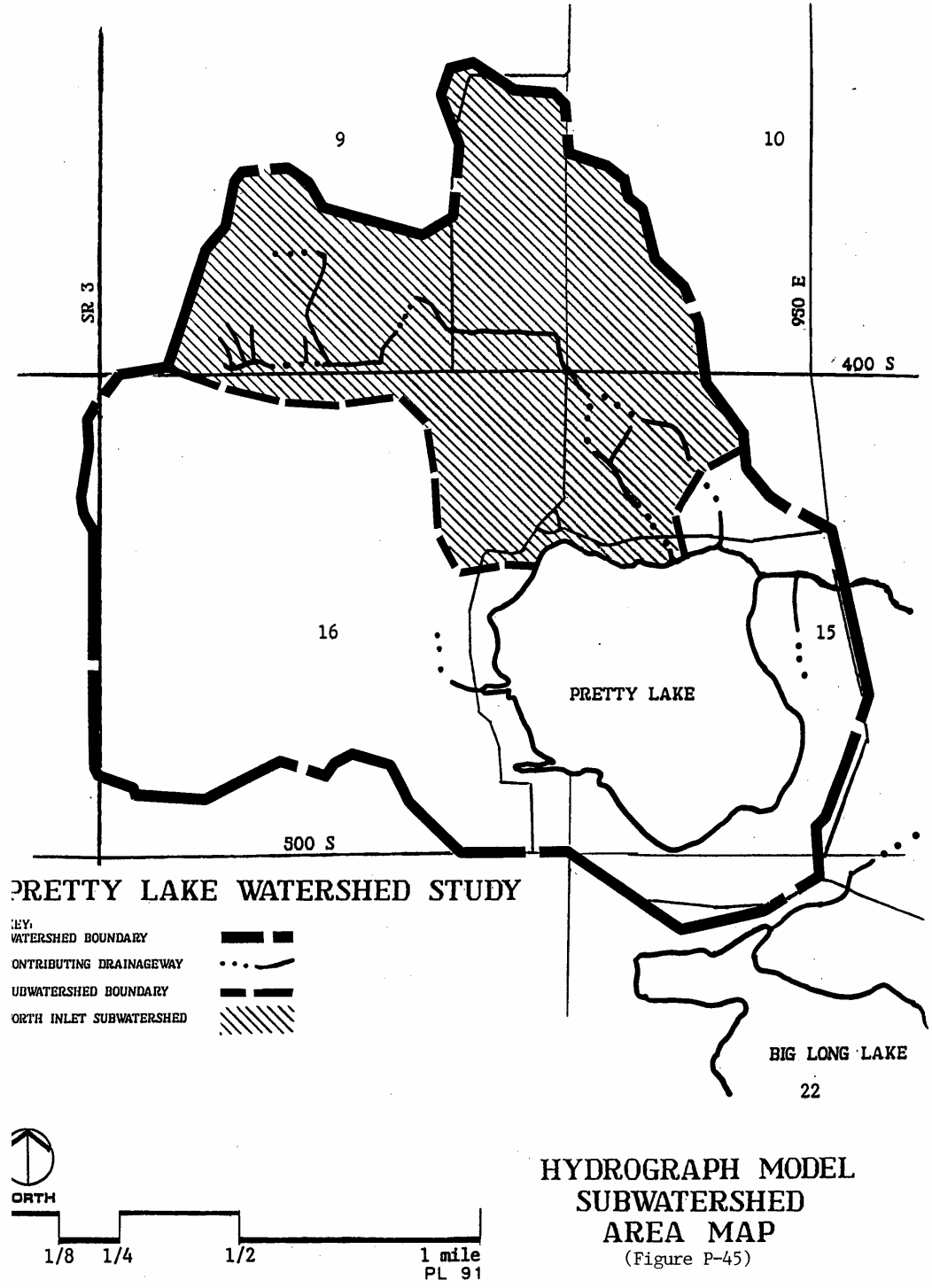
1) Rainfall Component. The rainfall component uses a given rainfall depth for a specific storm event, converted into a temporal storm pattern (storm duration over a given geographical area and time) because a large portion of the rainfall may occur over a small period of time with fluctuations in intensity.

2) Runoff Component. The runoff component determines the depth of rainfall in 0.1 hour increments given a 24 hour storm event (TR-55, 1986). The runoff is distributed over a period of time according to predicted rainfall. The runoff component is then used to determine hydrographs (watershed runoff over time) at specific locations throughout the watershed.

Factors involved in SEDIMOT-II include: storm type, event type, in this case runs were made using rainfall depths from a 2 year, 25 year, and 100 year storm events, soil types, vegetative cover types, basin relief, drainage area, and length of drainage segment. A summary of hydrology input data and SLR formula is presented in Appendix E.

North Inlet

The north inlet flows into Pretty Lake about 800 feet east of County Road 900E, and just south of County Road 425S. (Figure P45). The north inlet drains the largest single drainage area of the Pretty Lake watershed, about 425 acres. Due to the size of the north inlet drainage area, and length of the inlet ditch section the north inlet subwatershed was targeted for an indepth study of hydrology. Hydrographs for the north inlet are presented in Figure P46. Additional data are presented in the North Inlet Subwatershed Summary, Table P17.



HYDROGRAPH MODEL
SUBWATERSHED
AREA MAP
(Figure P-45)

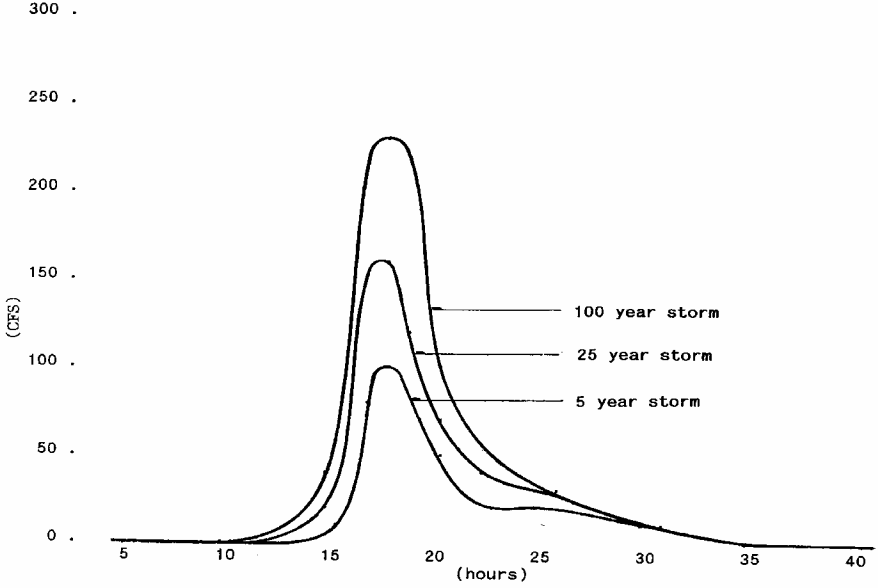


Figure P-46. Pretty Lake, North Inlet; Combined Hydrograph: 5, 25, 100 Year Storm Event

NORTH INLET SUBWATERSHED SUMMARY	
Drainage Area	427.00 acres
Runoff Volume:	
5 Year Storm	39.58 acre-feet
25 Year Storm	62.86 acre-feet
100 Year Storm	88.58 acre-feet
Peak Inflow Rate (from Hydrograph):	
5 Year Storm	102.63 cfs
25 Year Storm	163.33 cfs
100 Year Storm	231.95 cfs
Mean Flow Rate (from Hydrograph):	
5 Year Storm	26.97 cfs
25 Year Storm	34.23 cfs
100 Year Storm	39.63 cfs
Pool Capacity	37.88 acre-feet
Detention Time of Flow:	
5 Year Storm	16.99 hours
25 Year Storm	13.39 hours
100 Year Storm	11.56 hours

Table P17. North Inlet Subwatershed Summary

Sediment and Nutrient Removal

In order to quantify the effectiveness of a control structure or constructed/enhanced wetland in removing sediments and nutrients, it is first necessary to develop a concept design for the site. Using the conceptual designs presented later in this report, a flow model was developed. Flow models are used to determine a particular hydraulic characteristic for a given site at a given point in time. In this case, flow models are used to determine the surface loading rate (SLR). The SLR is used to derive the position of a particle (sediment) with a given diameter, within a system at a any given point. With this information, a settling velocity can be predicted for particles entering a system based on particle size, distance and time. The predicted sediment removed is determined by the size of particles equal or larger to that of the design settling velocity.

Nutrients are removed from a system in two basic ways: 1) by biotic processes in which they are utilized by plants and bacteria or; 2) by physical processes. Nutrients often travel through a system bonded to particulate matter, thus, as sediments are settled out, so are the nutrients attached to them. Sedimentation is the settling out of soil particles which have been transported by air or water. Sedimentation occurs when the velocity of the transport medium (water) is slowed adequately and for a sufficient period of time (detention time) to allow for the soil particles to settle out. Larger, heavier particles require high velocities of runoff to be transported and are quick to settle out. Smaller, lighter soil particles are transported by suspension or by moving (tumbling) along the surface. Fine silts and clay materials are generally transported in suspension. These smaller soil particles are difficult to recover once eroded. Substantially lower velocities and greater detention times are required to settle these particles out.

Specific site design would be necessary to predict the actual amounts of sediments and nutrients transported through a system or to quantify the amount removed by a specific control structure. It is possible, however, to relate sediment removal efficiencies using the SLR, with data from the concept plan and mean flow reported for the 5 year return storm. Findings of this model indicate that sediment equal to, or greater than 0.003 mm (fine silt) will settle out of the system in both the northwest ditch and the southwest ditch constructed options. Particle size based on a mean specific gravity of 2.65.

Results from the Wilson Ditch constructed wetland site (near Culver, Indiana), designed by Earth Source Inc., showed mean total phosphorous was reduced 90%, while mean total nitrogen (nitrate/nitrite) was reduced 85% during the 1988 summer monitoring program. Mean total phosphorous was reduced 60% and mean total nitrogen was reduced 65% during the 1988 winter monitoring program.

Constructed Wetland Habitat

Potential exists for the construction of sediment/nutrient control structures to increase the overall wildlife habitat and production capabilities for the Pretty Lake area.

Primary fisheries production in Pretty Lake could benefit greatly by increased wetlands. Virtually all sport fish production is dependent on wetlands, either for spawning, cover or planktonic food production. Pike and sunfishes are major benefactors of increased wetland spawning area. They spawn in the wetlands and then return to the lake proper.

Increased wetlands will draw waterfowl away from areas of moderate human use. Productivity is likely to increase while the "nuisance factor" decreases. Song birds are drawn to wetlands for a number of reasons: nesting structure provided by persistent emergent vegetation (cattails); security cover; and food production. Species such as the Great Blue Heron, Yellow Rail, Great White Egret, and Yellow-headed Blackbird (which are all state threatened, rare or of special concern) will locate near wetlands for many of the same reasons as their avian counter parts.

Fur-bearing animals like beaver, mink and muskrat depend on wetlands primarily for food, security cover and den sizes.

Muskrats will likely be the first fur-bearer to colonize a shallow constructed wetland. These prolific mammals do well in areas which have low water flow and emergent aquatic vegetation such as cattails. If muskrat den/foraging activity strays from or damages the constructed wetland and wetland structures it may become a nuisance, therefore, populations will require careful monitoring and controlled.

The mink is one of the most prized furbearers associated with wetlands. The habitat requirements of the mink are similar to those of the muskrat with one exception, the mink is a carnivore. Thus, mink population will usually mirror changes in muskrat population.

The beaver is another valued furbearer likely to colonize a constructed wetland in the Pretty Lake area. Again, if den/dam building activity strays from the constructed wetland it may become a nuisance, therefore, beaver populations will also require careful monitoring.

In summary, a constructed wetland is capable of increasing and supporting a diverse number of habitants. It should be noted that a constructed wetland is also constructed habitat. By design, these areas may attract species of special interest, through planned inclusions of required habitat components.

Constructed Wetlands as a Watershed Management Practice

For more than 50 years, wetlands have been identified as water purifying systems for natural lakes (van der Valk, et al 1978). Wetland vegetation, benthic organisms, and soils perform as traps, at least seasonally, for nutrients, suspended sediments, metals, pathogens, and many agricultural chemicals (Kadlec and Kadlec 1978). Thus, during the course of the Pretty Lake watershed study, a primary objective was to identify opportunities for nutrient/sediment trap target sites on contributing ditches and tiles identified as loading excessive nutrients and sediments to the lake (Figure P47). The primary criteria in selecting these sites were: location, topography, flow rates, soils, feasibility, current land use, size, environmental concerns, and sediment/nutrient loading characteristics of the drainage basin. As each site is considered for development, an evaluation should be made of the status of erosion control/land treatment above each proposed site, and goals set for timetables, land acquisition, fund raising, final design and construction.

Each site is described in the following text with a conceptual plan for illustration. Cost range estimates and priority recommendations are discussed in later sections of this report. It must be noted that Constructed Options 1 and 2 are considered here as a series. Development of Constructed Option 1 would increase the filtering function of Constructed Option 2 by increasing the time of (runoff) concentration above site 2, thus, longer wetland contact with flows.

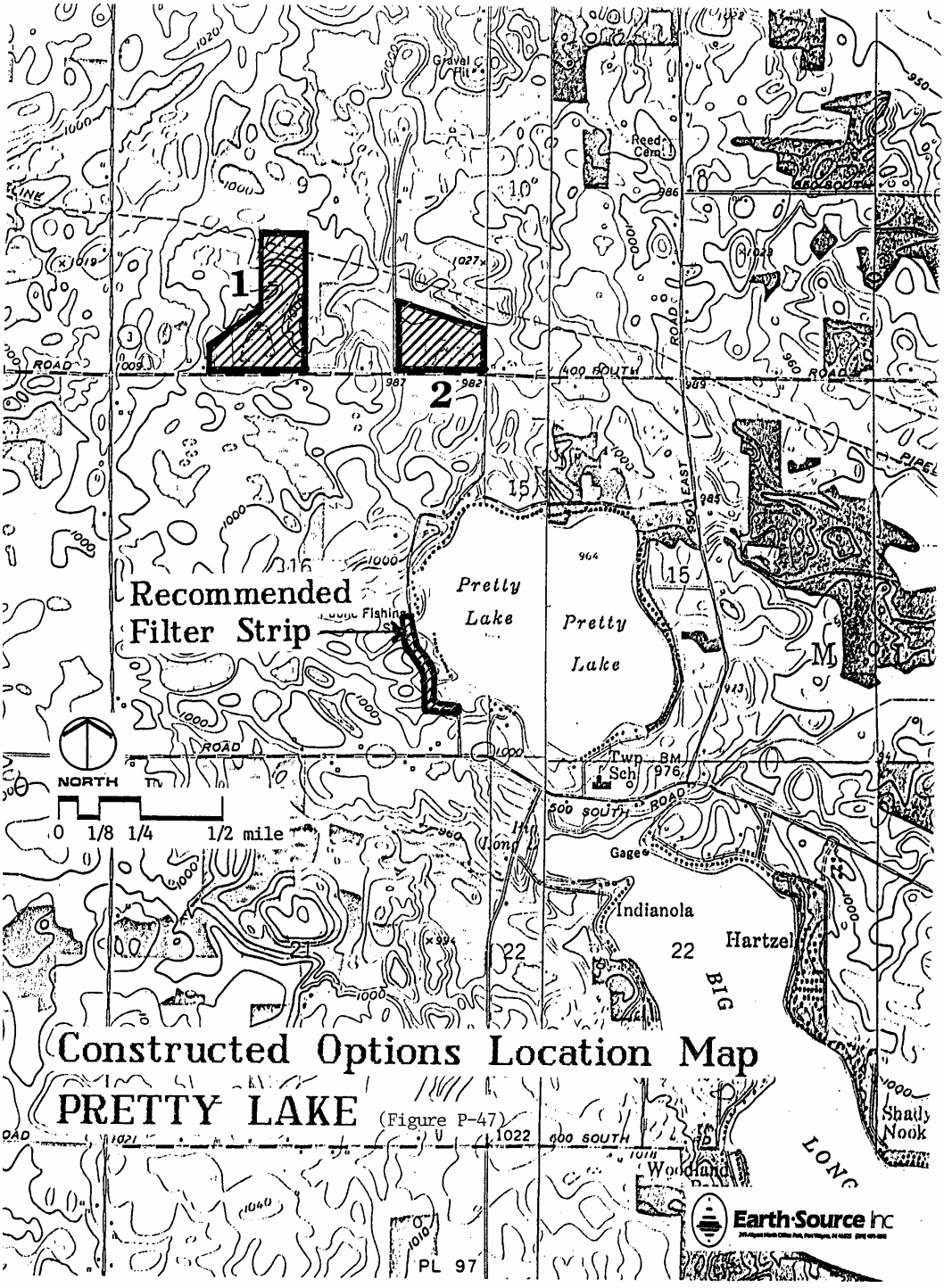
Project Descriptions: Pretty Lake

Constructed Option 1.

This opportunity (Figure P48), consist of excavating openings through ditch and spoil banks into an existing forested wetland at locations to be selected in final design. Upland agricultural lands to the northwest would be filtered more effectively if allowed to enter this woodland as it once did naturally. Upland drainage may be diverted directly into and through the woodland before entering the ditch, and/or, via bank openings to grade with woodland elevation. Depending upon the ditch profile, diversion baffles may be needed to divert flow into the woodland.

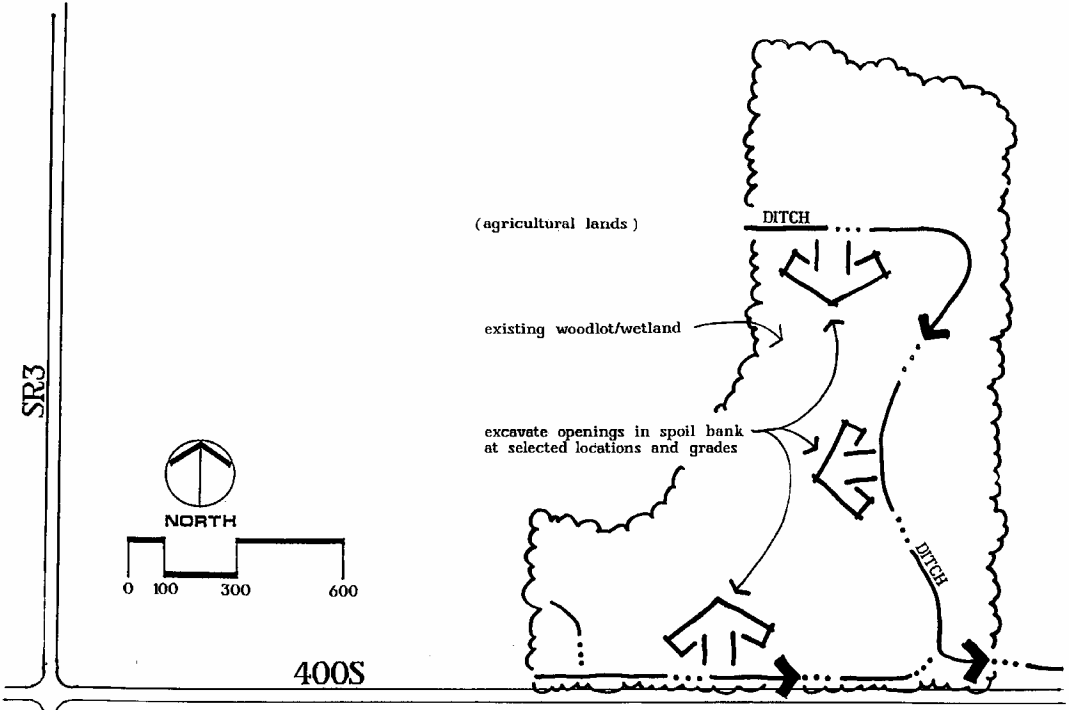
Constructed Option 2.

This site (Figure P49), would substantially consist of wetland restoration of a wetland which is entirely ditched, part of which is successfully converted to cropland. Elevations and ditch profiles observed suggest that some shallow excavation will be necessary over part of the site in order to achieve design objectives. Excavated materials can



Constructed Options Location Map

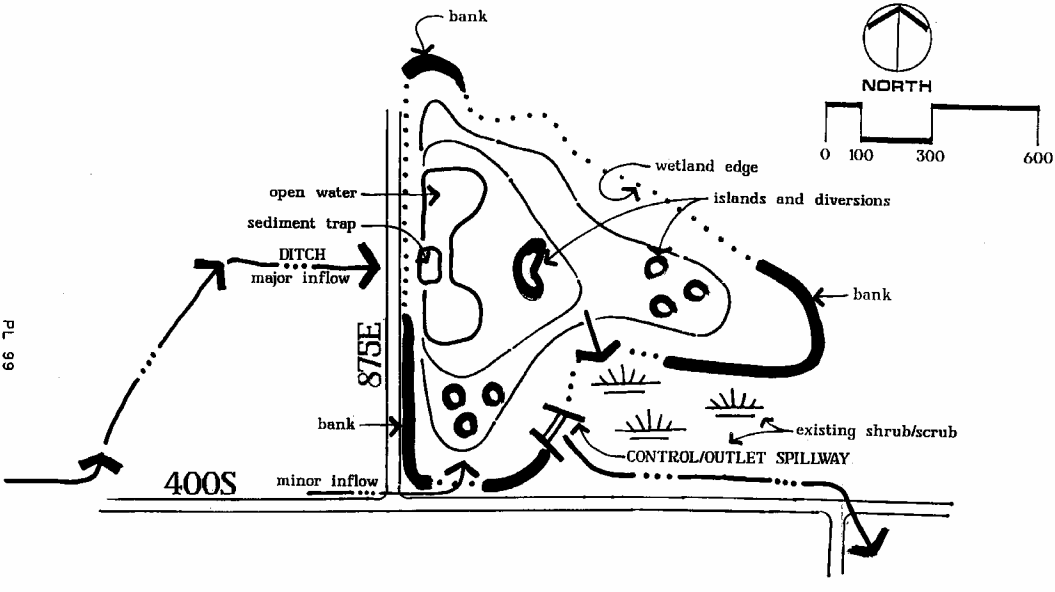
PRETTY LAKE (Figure P-47)



Constructed Option 1
PRETTY LAKE

Earth-Source Inc

PL 98



Constructed Option 2
PRETTY LAKE
(Figure P-49)

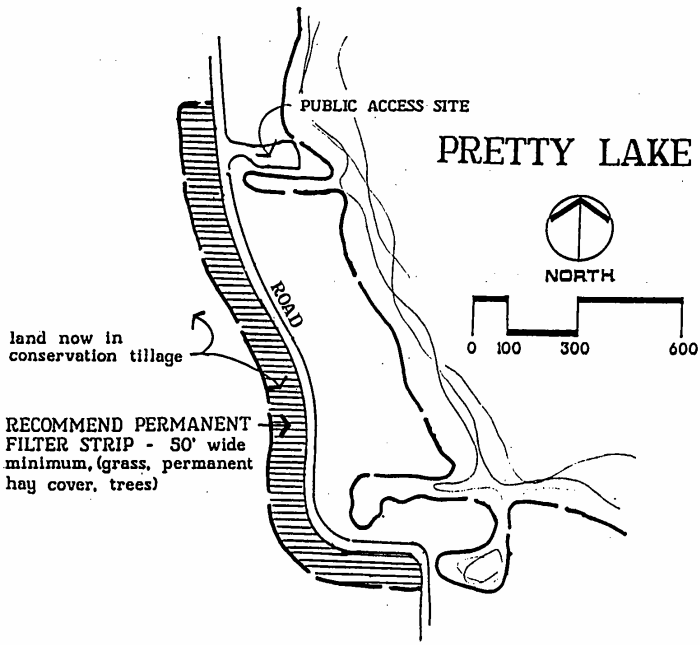
Earth·Source Inc

be placed in islands, baffles, and a perimeter bank/levee. A water level control/outlet spillway will maintain water levels at normal and high flows. A strong correlation exists between adverse changes in Pretty Lake water quality and the ditching of this wetland section. This Constructed Option should be considered a high priority for the protection of Pretty Lake, as it intercepts animal operations, and a large portion of the directly contributing agricultural lands to the west and north, including highly erodible agricultural lands.

A filter strip similar to that discussed below is recommended along the ditch channel in this constructed option site. The filter strip would serve as a temporary bank stabilization and limited erosion control strategy in the interim between design and construction of the wetland phase of this option.

Filter Strip:

This project would result in establishment of permanent vegetative cover bordering agricultural land at close westerly proximity to the lake (Figure P50). Although this land appears to be in minimum or conservation tillage at this time, runoff (overland flow) from this agricultural area, much of which is highly erodible land, is effecting the lake. This is can be readily observed following any rainfall event. Permanent vegetation could include grass, and tree/shrub plantings.



RECOMMENDED FILTER STRIP

(Figure P-50)

Cost Estimates for Constructed Options

The following estimates are offered to represent the anticipated cost factors for construction of suggested sites. For final design and construction documents, an allowance of 15% to 20% of construction cost should be added to these estimates. Additional cost of services should be added for bidding, construction monitoring and construction administration if required by the funding agencies. Other additional cost items not included in these estimates are as follows: 1. Land cost (if any); 2. Attorney's fees to prepare land agreements; 3. Property line surveys or descriptions; 4. Preparation of permits such as to the Department of the Army, IDNR Division of Water, County Drainage Boards, Indiana Department of Environmental Management; 5. Operation and maintenance of sites and access thereto.

Priority recommendations (Very High (1), High (2), Moderate (3), etc.) have been made based upon the need, feasibility, accessibility of the site, and other considerations discussed in previous sections. The Lake Association should not be discouraged from pursuing and implementing lower priority constructed options, while higher priority sites are under consideration or in process.

Constructed Option 1.

Cost items include excavation; earth spreading, and erosion control materials; and restoration of disturbed area.

Estimated Cost Range: $10,000 - 15,000

Priority Recommendation: Moderate to High (3)
Priority recommendation is dependent upon construction of Option 2 and success of land treatment above site.

Constructed Option 2.

Cost items include sediment trap, baffles/islands, clearing, excavation, water control structure, outlet spillway, embankment, sediment trap, fence, restoration, and erosion control materials.

Estimated Cost Range: $130,000 - 170,000

Priority Recommendation: Very High (1)

Constructed Option 2: Filter Strip.

Cost items include grade preparation, seed/plant materials.

Estimated Cost Range: $500 - 2,000

Priority Recommendation: Moderate

Filter Strip.

Cost items include grade preparation, seed/plant materials.

Estimated Cost Range: $500 - 2,000

Priority Recommendation: High (2)

Permitting

Beyond property ownership, many governmental agencies may have jurisdiction over private property. For example, drainage may be regulated by the County Surveyor. Water issues, particularly construction in a floodway, is regulated by the Indiana Department of Natural Resources Division of Water, and the United States Department of the Army, Corps of Engineers. Excavation below legal lake level, 965.9 foot, mean sea level datum, or any ditch modification within .5 miles of the Lake, will require authorization by the IDNR, Division of Water, Lake Section. The Corps of Engineers will require permitting and Water Quality Certification by the IDEM, Office of Water Management for construction in wetland areas. The Corps of Engineers (and the Divisions of Water) may require permitting if any construction impounds water. A list of different agency contacts, addresses, and telephone numbers may be found in appendix B.

Conclusions & Recommendations

CONCLUSIONS AND RECOMMENDATIONS

PRETTY LAKE

Water Quality

Water quality trends for open water areas of Pretty Lake were delineated from individual physical-chemical and biological parameters. The lake has been characterized by extensive anoxia in the lower water column during summer since at least 1930. Based on an examination of the historical physical and chemical database, it appears that the trophic state of Pretty Lake has changed little since at least 1964 and possibly earlier. In fact, the IDEM eutrophication index decreased from 25 in 1972 to 13-14 in 1989 suggesting an improvement in water quality for this Class One (best water quality) lake. Although the lake has been characterized as having an overall good fishery that historically has been supplemented through an active stocking program, oxygen conditions after 1981-83 became insufficient to support trout populations on a year round basis.

The vegetated littoral zone is rather restricted in Pretty Lake and appears to have expanded in recent years only in the constructed channels along the western shore eutrophication. No management recommendations for aquatic macrophytes have ever been made for the lake proper by DNR.

While both septic and ditch drainage have contributed to the eutrophication of Pretty Lake, the latter is likely of greater overall magnitude. It is recommended that residents make a concerted effort to have their drain fields inspected regularly and to keep their septic tanks pumped. Residents can reduce nutrient loading to the lake by using phosphate-free detergents for both clothes and dishes. Simple irrigation of lawns using lake water will provide sufficient nutrients to sustain lawn growth. Such simple modification of practices can reduce the contribution each resident makes to the phosphorus and nitrogen loading of the lake.

Water quality improvement in Pretty Lake is linked critically with implementation of watershed management practices that significantly reduce nutrient and sediment loading. Reduction in watershed contributions of both will likely lead to a reduction in trophic state in the lake. No in-lake management practices are proposed for Pretty Lake.

Macrophytes

The extent and richness of the vegetated littoral zone appears not to have been altered during at least the past two decades, and macrophytes have never been considered a

serious enough of a problem to warrant implementation of a management program except in the constructed channels along the western shore. Most vegetation in Pretty Lake is confined mostly to water less than 10 feet deep. Assuming that macrophyte problems are manifested only when plant biovolume exceeds approximately 80% of the water column, none of the surface area of Pretty Lake would be classified as having management problems with macrophytes. Approximately 32% of the lake's bottom is considered entirely free of vegetation with an additional 62% having plant biovolume occupying less than 20% of the water column. Most of the plant biovolume is in water less than four feet deep and is contributed primarily by watermilfoil, pondweeds, and chara. Most stands of macrophytes are less than two feet tall. Macrophyte extent in Pretty Lake is controlled by light availability and basin morphometry, and it is unlikely that macrophyte problems would accompany further eutrophication of this lake. Currently, no management program for macrophytes is needed in Pretty Lake except in the channels along the western shore. Even there, it is suggested that only spot spraying with herbicides or mechanical removal of plant biomass be done only in those areas needed to be cleared to permit boat traffic to dock. Extensive plant removal could reduce the kidney effect of the vegetation in the canal and increase nutrient loading to the lake proper.

Fish

Pretty Lake was noted for its yellow perch in the 1930's, its bluegill and redear in the 1940's, and its bluegill, redear and rainbow trout by 1964 due to an active stocking program for both rainbow and brown trout. While all past DNR surveys have considered the fishery of Pretty Lake to be of good overall quality, oxygen concentrations in the early 1980's declined to a level insufficient to support trout populations on a year round basis.

A majority of the fish in Pretty Lake are restricted to water depths of 16-19 feet during midsummer due to serious oxygen depletion in deeper waters. It is likely that attempts at fishery management will be only marginally successful until nutrient loading to the lake is reduced significantly. It is recommended that lake residents encourage the State of Indiana to provide additional funding for the DNR to continue periodic surveying of the fish community of Pretty Lake.

Basin Infilling

Pretty Lake has experienced moderate basin infilling during the past 33 years. The depth contour displaying the greatest incremental increase during the period was 0-5 feet, which increased in aerial extent by 21%. On a lake wide basis,

greatest basin infilling was observed along the western shore immediately in from the constructed channels and at the northeast corner of the lake. It appears that such sedimentation has not been accompanied by a change in the relative proportion of inorganic and organic matter in the sediment. It is obvious that a majority of the sedimentation in Pretty Lake is directly related to ditch input of watershed sediment especially during spring rain events. We were able to find no evidence to suggest that shoreline erosion was a major factor in observed patterns of sedimentation in Pretty Lake. Homeowners, however, should inspect their shoreline for evidence of erosion, be encouraged to leave a fringe of emergent vegetation along the entire length of their lake front to serve as an erosion barrier and make appropriate repairs immediately. Boaters should be encouraged to reduce speed when near shore in order to minimize wave generation and subsequent erosion of shoreline areas.

It is recommended that in addition to watershed management practices discussed later, aquatic plants at the mouths of ditches should be left intact as a nutrient and sedimentation barrier. Removal of such plant growth will speed delivery of both parameters into the lake thus accelerating both basin infilling and eutrophication.

PRETTY LAKE WATERSHED

It is apparent that nutrient and sediment loading from the Pretty Lake watershed is the present cause of cultural eutrophication in the Lake. A ditch relocation project in the northern reaches of the watershed (early to mid 1980's) diverted flow from Pretty Lake to the Turkey Lakes. This project effectively reduced the total drainage area of the Pretty Lake watershed by approximately 40%. Even though watershed drainage area has been reduced, watershed loading of sediments and nutrients does not appear to have changed since 1980. While land treatment has been initiated in limited sections of the watershed, substantial measures in watershed protection remain to be implemented. Considerable watershed loading could be prevented by simply implementing conservation tillage programs in applicable areas. Tiled fields to the west of the Lake must be maintained or repaired so that tile borne sediments do not continue to be piped directly into the Lake. The main inlet at the north end of Pretty Lake must be protected. Our recommendations for this area are presented in the Constructed Options section of this report. Furthermore, lake residents bear the responsibility of controlling the fashion in which re-development pressure impacts their lake. Existing 'homes' must be modernized to include adequate septic disposal; new development must include an adequate erosion control plan.

I. Lake Residents:

A. Residents must undertake the responsibility of maintaining their own waste disposal systems. Drain fields should be inspected regularly and septic tanks should be pumped on a regular schedule. Avoid the use of on-site septic systems near areas which have been identified as containing saturated soils.

B. If fertilization for lakefront lawns is desired, residents should consider using lake water for irrigation/fertilization of lawns (lake water will provide ample nutrients) or, use fertilizers low in phosphorous (0.5% liquid; 3.0% granular). Fertilizer should be applied <u>only</u> during the growing season, April-October. (Note: an IDNR permit may be required for pumping out public waters.)

C. The Lake Association should take an active role in monitoring future development: lakefront and watershed. Development monitoring could be accomplished by the formation of a 'Lake Watch Committee'. Lakefront development should consider setbacks from the lake, septic suitability, and must incorporate adequate sediment control measures. Watershed development must be made aware of potential sediment and/or nutrient sources to the Lake, and like

lakefront development, incorporate adequate sediment control measures. Sediment control structures such as erosion control mats, silt fences, straw bale filters, and sediment basins must be installed <u>prior</u> to any construction or development which would impact the Lake. The Lake Association should also promote the establishment of a county-wide erosion control plan.

II. The Watershed:

A. The land-use or cropping practice of areas mapped as having highly erodible lands or severe slopes should be carefully considered. Much of this land should be in a conservation tillage program, or, in some cases should not be in agricultural crop production. Some of these sloped areas nearer the lake are too steep for development. Those areas defined in the HEL/severe slope study should maintain natural buffer areas or filter strips along ditches or open drainageways.

   The 66 acres, detailed in Agricultural Lands/HEL/severe slope overlay represent the worst case, or highest erosion threat areas of the Pretty Lake watershed. Much of this land is adjacent to open drains or tiles which facilitate the transport of eroded soils to the Lake. For this reason, those areas present the greatest sedimentation threat to Pretty Lake. Every effort must be made to enlist these areas into conservation tillage, CRP or related land treatment programs. Lands in the Pretty Lake watershed noted as unsuitable to no-till should be in permanent cover.

   Other land treatment practices, especially stream/ditch bank stabilization, should be pursued. This could be accomplished by establishing grassed ditch borders (filter strips), and, in more extreme cases, structural or riprapped solutions. Excavate and maintain sediment traps that may be located at easily accessible intervals, such as near roads. (Other various Conservation Practices are listed in Appendix C. These practices will be detailed in individual farm Conservation Plans, as required by the 1985 Farm Bill to be implemented by 1995).

B. Consider the Constructed Options as described in that Section of this report.

C. Stabilize streambank or ditch escarpments. Allow native vegetation to establish on stream banks. Retain on one side during 'maintenance'. The need for selective ditch cleaning should be carefully weighed against possible impacts to the Lake.

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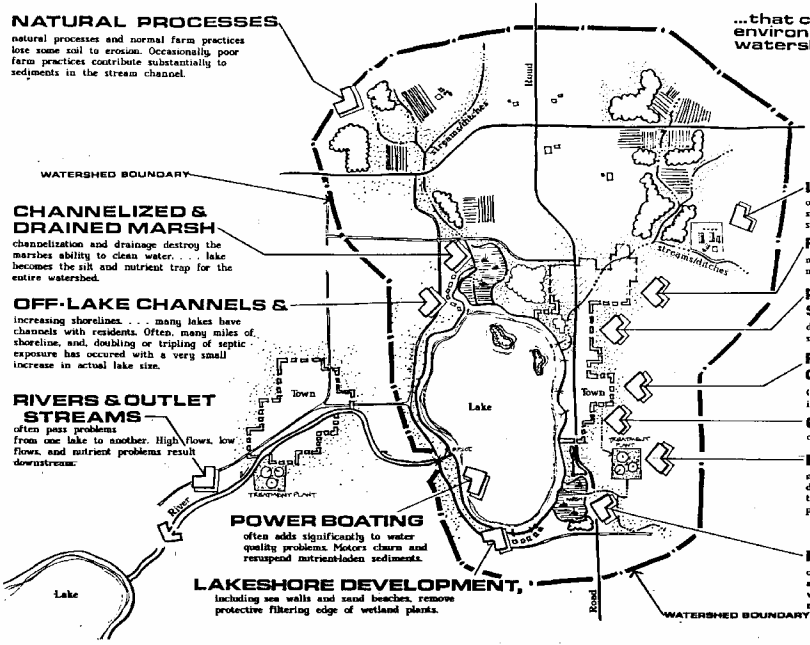
Appendix

APPENDIX A

TYPICAL SEDIMENT/ NUTRIENT SOURCES...

...that contribute to decline of environmental values in a watershed.

Earth·Source Inc



NATURAL PROCESSES

natural processes and normal farm practices lose some soil to erosion. Occasionally, poor farm practices contribute substantially to sediments in the stream channel.

CHANNELIZED & DRAINED MARSH

channelization and drainage destroy the marshes ability to clean water. . . . lake becomes the silt and nutrient trap for the entire watershed.

OFF-LAKE CHANNELS &

increasing shorelines. . . . many lakes have channels with residents. Often, many miles of shoreline, and, doubling or tripling of septic exposure has occured with a very small increase in actual lake size.

RIVERS & OUTLET STREAMS

often pass problems from one lake to another. High flows, low flows, and nutrient problems result downstream.

POWER BOATING

often adds significantly to water quality problems. Motors churn and resuspend nutrient-laden sediments.

LAKESHORE DEVELOPMENT,

including sea walls and sand beaches, remove protective filtering edge of wetland plants.

LARGE ANIMAL

operations often exist immediately on inlet streams. This can contribute a very significant negative to water quality.

FACTORIES

may have inadequate safety storage which may result in spills into streams.

PAVED PARKING & STREETS

drain directly into lake or stream, bringing soil, salt, debris, oil and chemical spills.

FERTILIZERS & CHEMICALS;

(both lawn and agricultural) drain and leach into lakes.

COMBINATION SEWERS...

old systems overflow into streams and lakes.

EFFLUENT

may be inadequately treated and is discharged into stream, which carries the problem into the lake or outlet to pass problem downstream.

MARSHES

often occur on inlet streams. These are often considered eyesores to the lake, when, in reality, they are probably the lakes most valuable asset!!

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APPENDIX B

The following is a list of Federal, State and local agency contacts which may be useful in obtaining further information or permit requirements.

EPA
Wetland Protection Section
401 M Street SW
Washington, D.C. 20460
(202) 382-5043

EPA, Region V
230 S. Dearborn Street
Chicago, IL 60604
(312) 353-2079

US Army Corps of Engineers
20 Massachusetts Ave., NW
Washington, D.C. 20314
(202) 272-0169

US Army Corps of Engineers
Detroit District
P.O. Box 1027
Detroit, MI 48231
(313) 226-6773

US Fish & Wildlife Service
18th & C Streets, NW
Washington, D.C. 20240
(202) 343-4646

US Fish & Wildlife Service
Bloomington Field Office
718 N. Walnut Street
Bloomington, IN 47401
(812) 334-4267

IDNR
Division of Water
2475 Directors Row
Indianapolis, IN 46241
(317) 232-4160

IDEM
Office of Water Management
Chesapeake Building
105 South Meridian Street
Indianapolis, IN 46206
(317) 232-8476

IDNR
Div. of Soil Conservation
FLX1 Building
Purdue University
West Lafayette, IN 47907
(317) 494-8383

IDNR
Div. of Fish & Wildlife
607 State Office Building
Indianapolis, IN 46204
(317) 232-4080

Earth Source Inc. (consultant)
349 Airport North Office Park
Fort Wayne, IN 46825
(219) 489-8511

APPENDIX C

Various Conservation Practices and Values,
and Degree of Difficulty for Implementation

Conservation Plans	Required by the 1985 Farm Bill
Land Adequately Treated	Normal
Conservation Cropping System	Difficult
Critical Area Planting	Moderately Difficult
Crop Residue Management	Difficult
Diversions	Difficult
Farmstead Windbreak	Normal
Feedlot Windbreak	Normal
Field Windbreak	Normal
Field Border	Very Difficult
Grade Stabilization	Moderately Difficult
Grassed Waterway	Difficult
Holding Ponds & Tanks	Easy
Livestock Exclusion	Moderately Difficult
Livestock Watering Facility	Moderately Difficult
Minimum Tillage	Difficult
Pasture & Hayland Management	Difficult
Pasture & Hayland Planting	Difficult
Pond	Easy
Recreation Area Improvement	Normal
Sediment Control Basin	Difficult
Stream Channel Stabilization	Moderately to Very Difficult
Streambank Protection	Moderately Difficult
Stripcropping	Very Difficult
Surface Drains	Difficult
Terraces, Gradient	Very Difficult
Terraces, Parallel	Very Difficult
Tile Drains	Difficult
Tree Plantings	Very Difficult
Wildlife Habitat Management	Moderately Difficult
Woodland Harvesting	Moderately Difficult
Woodland Improvement	Difficult

Adapted from Final Report on the Black Creek Project;
Allen County (Indiana) Soil and Water Conservation District.

APPENDIX D

PRACTICE	EFFECTIVENESS	LONGEVITY	CONFIDENCE	APPLICABILITY	POTENTIAL NEGATIVE IMPACTS	CAPITAL COST	O&M COST
Addition of Tertiary Treatment	E	E	E	E	E	F	F
Construction of Sedimentation Basins at Inlets to Lake	G	E	G	G	G	F	F
AGRICULTURAL PRACTICES							
—Conservation Village	F-E	G	G	G	F	F	F
—Contour Farming	F-G	P	F	G	E	E	E
—Pasture Management	F-G	E	E	G	E	E	E
—Crop Rotation	F-G	G	G	G	E	E	E
—Terraces	F-G	G	G	G	E	F	G
—Animal Waste Management	E	E	E	E	E	F	F
—Grass Waterways	E	E	G	G	E	G	E
—Buffer Strips	E	E	E	E	E	G	E
—Diversion of Runoff	G	G	F-G	F	E	F	G
CONSTRUCTION CONTROLS							
—Erosion Control Ordinance	E	E	E	E	E	E	E
—Runoff Control Ordinance	E	E	E	E	E	E	E
—Field Inspections	E	E	E	E	E	E	E

Legend: E = Excellent G = Good F = Fair P = Poor

SOURCE: The Lake and Reservoir Restoration Guidance Manual, USEPA

APPENDIX E

INPUT PARAMETERS FOR SEDIMOT-II

HYDROLOGY DATA

STORM TYPE:	SCS TYPE II
RAINFRALL DEPTH:	3.50 INCHES (5-YEAR)
	4.50 INCHES (25-YEAR)
	5.50 INCHES (100-YEAR)
STORM DURATION:	24.00 HOURS
TIME INCREMENT:	0.10 HOURS
HYDROLOGIC SOIL GROUP:	B/C

LAND USE:	RUNOFF CURVE NUMBER:
AGRICULTURE -ACTIVE	71-88
AGRICULTURE -OTHER	72-81
FORESTED	55-73
PASTURELAND	49-61
RESIDENTIAL	74
WETLAND	30

APPENDIX F

Physical and Chemical Parameters for the 1990 Inlet Survey.

STATION	ALKALINITY (mg/L CaCO3)	pH	SPECIFIC CONDUCTIVITY (umho/cm)	NITROGEN: NITRATE/ NITRITE (mg/L)	TOTAL: PHOSPHORUS (mg/L)	ORTHO-PHOSPHORUS (mg/L)	TOTAL SUSPENDED SOLIDS (mg/L)
BL 1	114.00	5.8	275.00	0.01	0.23	0.06	4.00
BL 2	174.00	6.2	415.00	0.84	0.20	0.19	3.00
BL 3	166.00	6.3	420.00	1.95	0.15	0.09	9.00
BL 4	194.00	6.2	480.00	1.41	0.21	0.21	6.00
LL 1	178.00	6.4	452.00	0.07	0.13	0.07	6.00
LL 2	140.00	5.5	395.00	0.18	0.15	0.11	4.00
LL 3	194.00	6.3	520.00	3.25	0.20	0.20	13.00
ML 1	176.00	6.2	550.00	4.95	0.19	0.10	26.00
ML 2	244.00	6.5	610.00	2.29	0.18	0.06	7.00
PL 1	212.00	6.4	460.00	3.57	1.17	0.15	7.00
PL 2	158.00	6.2	470.00	5.27	0.23	0.18	44.00
PL 3	96.00	5.5	255.00	0.05	0.10	0.07	7.00
CL 1	0.0	5.5	1.30	0.00	0.22	0.05	0.00

BL = BIG LONG LAKE
ML = McCLISH LAKE
CL = QA/QC SAMPLE

LL = LAKE OF THE WOODS
PL = PRETTY LAKE