ASSESSMENT OF WATERSHED-LAKE INTERACTIONS INFLUENCING THE CULTURAL EUTROPHICATION OF LITTLE CROOKED & CROOKED LAKES, INDIANA

PREPARED BY: THOMAS L. CRISMAN

ASSISTANCE BY: WILLIAM R. DEMOTT
PAUL M. STEWART
AND
EARTH SOURCE INC.

SUBMITTED TO: CROOKED LAKE PROPERTY OWNERS ASSOCIATION

FOR: INDIANA LAKE ENHANCEMENT PROGRAM
DIVISION OF SOIL CONSERVATION
INDIANA DEPARTMENT OF NATURAL RESOURCES

APRIL 1993

EXECUTIVE SUMMARY

Crooked Lake is one of the true natural gems of Indiana. It has historically possessed some of the best water quality in the state and is characterized as being one of the last lakes to have a population of ciscos, a fish characteristic of deep cold lakes of good to excellent water quality. In recent years, however, the cisco population has progressively declined to a point that it is near to extirpation in the lake. The purpose of the present study was to collect and interpret all past data on interconnected Crooked and Little Crooked Lakes, to assess current conditions of both the lakes and their watershed, and to make recommendations aimed at preserving and/or improving water quality in both lakes.

A number of parameters have shown changes concurrent with the decline in cisco populations. Most notable is the reduction in the vertical extent of the deep oxygen layer in the water column considered essential for the survival of ciscos. The principal factor responsible for the deep oxygen layer is the production of oxygen as a byproduct from the photosynthetic activity of the blue-green alga Oscillatoria rubescens. It is clear that the Oscillatoria population is stressed via a reduction in light availability at depth in Crooked Lake. The cause for this shading of deeper sections of the water column is from a combination of increased algal productivity in surface waters of the lake and increased turbidity of the water column from fine sediments delivered from the watershed during rain events. The IDEM eutrophication index has increased progressively for both Little Crooked and Crooked Lakes since the mid 1970's indicating expanding algal populations in surface waters. In addition, investigators from the IDNR have observed that cisco kills occur following major rain events and increased turbidity in the water column.

While it is clear that reduction of the extent of the deep oxygen layer from reduced photosynthetic activity of Oscillatoria rubescens populations due to light reduction from increased lake eutrophication and inorganic turbidity has played an important role in stressing cisco populations, increased predation pressure associated with past stocking programs for brown trout have also impacted cisco populations negatively. It appears that much of the most pronounced eutrophication of both Crooked and Little Crooked Lakes was prior to the early 1960's, there is also a signal from the paleolimnological, historical, and current data that the lakes have become even more eutrophic since at least the mid 1970's. Today, Crooked Lake is assigned to Class II, the intermediate category of water quality according to IDEM standards, while Little Crooked Lake is Class III, the category of worst water quality.

Bathymetric and paleolimnological data as well as 1990 investigations of inlet streams demonstrated that Little Crooked Lake is receiving a heavy load of sediment and nutrients from the northern portion of its watershed associated with agricultural and construction activities. Sediments have filled much of the deepest portion of the lake and a delta of highly flocculent has formed at the stream mouth at the northwestern corner of the lake. The impact of the watershed disturbance is not limited to the Little Crooked basin alone, but clear evidence was found that at least the eastern basin of Crooked Lake is also affected via transport through the canal between the two lakes.

The management plan for Crooked Lake and Little Crooked Lake must integrate both lake and watershed management options. Without such an approach the lakes will continue to decline in water quality. Even though the new regional sewer system will minimize residential inputs to the system, it appears that other watershed activities have had as serious if not more serious impact on the lakes historically. Specific recommendations for development of a watershed-lake management plan include a reduction in sediment loading from inlets along the northern shore of Little Crooked Lake via conservation tillage and waterway sediment trapping options and blockage of tile fields in old field areas of the Crooked Lake Nature Preserve. In-lake management recommendations include strict adherence to limitations imposed on lake residents regarding removal of shallow water vegetation in front of their properties, proper maintenance of septic tanks until the regional sewer system is completed, and discontinuance of stocking of brown trout into the lake in order to reduce predation pressure on ciscos. Lake residents should be encouraged to discontinue all lawn fertilization.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Crooked Lake and Little Crooked Lake, Whitley and Noble Counties (Figure 1), form the headwaters of the Tippecanoe River and are separated by a small channel and wetland. The easternmost and smaller (15 acres) of the two (Little Crooked) lakes has a maximum depth of 50 feet and a mean depth of 20 feet. Approximately 80% of the shoreline is ringed with residences. Little Crooked had an IDEM eutrophication index of 32 in 1975 placing it in Class Two waters, those of intermediate water quality. Flow from this basin is westward to Crooked Lake.

Crooked Lake (206 acres) is truly one of the gems of Indiana lakes. Not only is it one of the deepest (maximum 108 feet, mean 43.9 feet), but it is also one of the least productive lakes in the state. The 1975 IDEM eutrophication index was only 3, placing the lake in the category of best water quality (Class One). Only one of the public lakes and reservoirs in Indiana had better water quality than Crooked Lake in 1975. Unfortunately, an investigation by IDEM in 1987 found that the eutrophication index had increased during the twelve year period to 12. While still considered Class One, the results suggest that Crooked Lake is undergoing cultural eutrophication. Legal lake level is 905 feet and is controlled by a concrete sill on the outlet (Tippecanoe River) leading to Big Lake.

Crooked Lake is also distinguished biologically. The DNR manages Crooked Lake Nature Preserve, a 100 acre tract consisting of an island in Crooked Lake, a wetland and upland habitats. Perhaps the most distinctive feature of Crooked Lake is the presence of the cisco (Coregonus artedii), a cold water whitefish characteristic of deep oligotrophic lakes. This fish has long been noted as an good biotic indicator of excellent water quality because of its restricted oxygen and temperature requirements, and its decline could be an indicator of worsening water quality. In 1955, 41 Indiana lakes maintained cisco populations, but this was reduced to only 23 by 1975 associated with advancing cultural eutrophication in many lakes. Recently, additional lakes appear to have either lost or are in danger of loosing their ciscos forever. Such is also the case at Crooked Lake.

The cisco population of Crooked Lake has displayed clear evidence of stress since at least 1980. Two major cisco kills have been reported: summer and fall (June-October) of 1981 following a historically high period of rainfall and fall of 1986. The DNR has documented a progressive decline in both cisco harvest and fishing pressure at Crooked Lake to the point that individuals have been essentially absent from surveys after 1986 Since 1981, the population has shifted progressively to older individuals and little

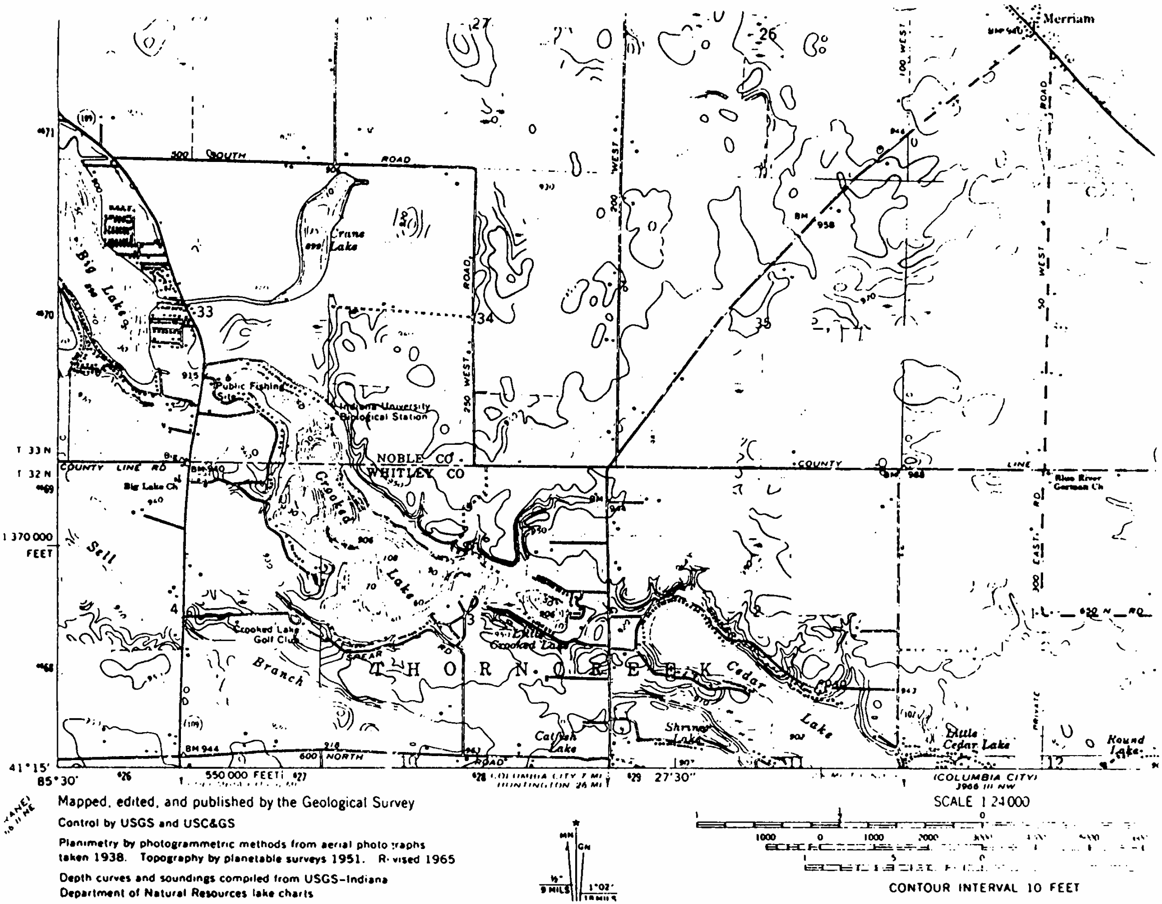


Figure 1. Topographic map showing location of Crooked and Little Crooked Lake

recruitment has been documented. The cisco is clearly stressed in Crooked Lake and on the brink of extirpation. Indeed, improvements in the management of both watershed and lake are needed to ensure that the population does not become extirpated.

As stated earlier, declining cisco populations are extremely good early warning signals of advancing cultural eutrophication in lakes. Unfortunately, the cause for the reduction of cisco in Crooked Lake has not been clearly identified. In spite of its relatively small watershed, numerous investigators have suggested that recent increased delivery of eroded sediment from the watershed is a prime candidate. The 1981 fish kill followed a period of historically high rainfall in the late spring. The DNR survey of 1981 suggested that increased delivery of suspended sediments from the watershed during this time increased turbidity in the lake thereby shading out the deep water plate of algae considered essential for the existence of cisco in the lake. It was also suggested that a study was needed to quantify nutrient and sediment inputs into the lake, identify their sources, and eliminate the problem. Jed Pearson of the Indiana DNR performed a follow-up study of watershed nutrient loading in 1989 and examined the three major inlets to the lake. Of these, an inlet draining agricultural land and entering Little Crooked Lake contributed approximately 80% of the combined phosphorus and nitrogen loading to the Crooked Lake system. Pearson noted that following his survey, the farm inlet was dredged and resulted in severe erosion of channel banks and bottom.

Further evidence for the impact of eroded sediment from the watershed on the clarity of Crooked Lake is the detailed examination of Secchi transparency for the lake conducted by W. DeMott of Indiana-Purdue University of Fort Wayne during 1989. Dr. DeMott noted that the lowest Secchi disk values for 1989 were during May following major storm events. In spite of its relatively small size, it appears that the Crooked Lake watershed is contributing sufficient sediment to have a major impact on the lake and its biota.

The historical database for Crooked Lake is extensive. Although earlier studies exist, there has been a wealth of investigations at the lake since the 1960's by the DNR and university faculty and their graduate students. No one has attempted to synthesize this database in order to trace the recent history of water quality in Crooked Lake.

Our comprehensive investigation of Crooked Lake and its watershed was designed to address the following questions:

1. What is the current water quality of Crooked and Little Crooked Lakes?

2. What are the major factors responsible for current water quality?

3. How has water quality changed historically and when did it begin to become progressively worse?

4. Can we identify the past watershed/lake practices that promoted an accelerated decline in water quality and can these factors be ranked as to their importance in the process?

5. How can we effectively eliminate or significantly reduce watershed loading of nutrients and sediments to the lake?

6. What is the most cost effective way to manage/ restore the lake?

The analytical approach followed was designed to specifically address these questions. Our project investigated the watershed and lake together. We gathered data on current water quality and land use practices, delineated historical changes in both and proposed management alternatives both for controlling watershed loading of nutrients and sediments into the lake and for management/restoration of the lake. Throughout our investigation, we made every effort to cooperate with county and state agencies as well as the lake association in order not to "reinvent the wheel" with our study. Such close cooperation insured that our study provided the most cost effective approach to lake and watershed management. In addition, we felt strongly that public relations were a very important part of our study, and we worked closely with the lake association to organize public meetings to discuss in open forum the nature of our project and how the public can be involved in the process. The success of lake management and restoration depends on strong public support, and we worked with the local association in a supportive manner.

Historical Water Quality

Historical Database

A total of 42 separate studies were conducted on Crooked Lake between 1930 and 1990 for which data were available (Table 1). Collection of water quality data on the lake began in 1930 with the investigation of Will Scott of Indiana University, and D.G. Frey assessed the cisco populations in 1955. Detailed water quality surveys of the lake did not begin until 1963-64 when Robert G. Wetzel of Indiana University conducted detailed investigations of factors controlling phytoplankton production in the lake. The Indiana DNR conducted fifteen studies between 1969 and 1990 on a variety of limnological aspects including fish and macrophyte communities, status of ciscos, water chemistry, and watershed loading of nutrients. The Indiana Department of Environmental Management (IDEM) visited the lake 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, and did follow up assessments of trophic state in 1987 and 1990. The 1990 data were collected under the supervision of Bill Jones of Indiana University. Finally, numerous university investigations have focused on Crooked Lake. Allan Konopka of Purdue University examined phytoplankton populations, Anthony Iovino of Indiana University examined benthos populations, B. Higgins and J. Morris of Indiana University studied zooplankton populations, and most recently Bill DeMott and Michael Stewart of IPFW have begun examination of various limnological aspects of the lake.

Physical/Chemical Parameters

Three physical and chemical parameters have been measured at Crooked (Table 2) and Little Crooked (Table 3) Lakes at frequent enough intervals to be useful in delineating historical trends. 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 the summer at Crooked Lake, it is likely that they largely 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 (Tables 2 and 3). It was impossible to compare Secchi values historically for any single month, but the amount of inter year variability for the summer growing period as a whole was not considered great. On the basis of Secchi data alone, it does not appear that the trophic state of Crooked or Little

Table 1. Chronology of Investigations at Crooked Lake

1930	Indiana University. Survey of physical/chemical parameters, phytoplankton and zooplankton. Published by W. Scott (1931).
1952	United States Geological Survey. Construction of bathymetric map for Crooked Lake.
1955	D.G. Frey. Assessment of status of ciscos in Crooked Lake. Published in Invest. Indiana Lakes and Streams.
1963	R.G. Wetzel. Measurement of algal productivity and controlling factors. Published by Wetzel (1965) in Mem. Ist. Ital. Idrobiol..
1963	R.G. Wetzel. Survey of water chemistry and interaction with phytoplankton. Published by Wetzel (1966) in Verh. Internat. Verein. Limnol..
1966	B.E. Higgins Study of cisco food preferences in Crooked Lake. Published as a Ph.D. dissertation at Indiana University.
1966	J.S. Morris. Investigation of winter populations of four species of cladoceran zooplankton in the genus Daphnia. Published as a M.S. thesis at Indiana University.
1969	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition. Published by Hudson (1969)
1971	J.S. Morris. Investigation of environmental variables, especially photoperiod, on four species of cladoceran zooplankton in the genus Daphnia. Published as a Ph.D. dissertation at Indiana University.
1972	Indiana Department of Natural Resources. Survey of physical/chemical parameters. Published by Taylor (1972).
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).

1974 Indiana Department of Environmental Management. Comparison of oxygen conditions in northeastern Indiana lakes where cisco populations have been reported historically. Unpublished manuscript by H. BonHomme (1974).

1975 A.J. Iovino. Survey of benthic invertebrates. Published as a Ph.D. dissertation, Indiana University.

1975 Indiana Department of Environmental Management. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.

1978 J. Hetrick and M. Balestra. Unpublished study of the feeding habits of yellow perch and brown trout in Crooked Lake.

1979 Indiana Department of Natural Resources. Trout and cisco management investigations. Published by Pearson and Whittlesey (1979).

1980 A. Konopka. Physiology of the blue-green alga *Oscillatoria rubescens* in the metalimnion of Crooked Lake. Published in Appl. Environm. Microbiol..

1981 Indiana Department of Natural Resources. Study of trout harvest, growth, movements, food habits, and mortality. Published by Pearson (1981).

1981 A. Konopka. Investigation of the effects of temperature, oxygen, and pH on populations of the blue-green alga *Oscillatoria rubescens* in the metalimnion of Crooked Lake. Published in Appl. Environm. Microbiol..

1981 Indiana Department of Natural Resources. Study of cisco deaths at Crook Lake and survey of oxygen levels.

1982 A. Konopka. Study of vertical migration patterns of the blue-green alga *Oscillatoria rubescens* in Crooked Lake. Published in Br. Phycol. J..

1982 A. Konopka. Physiological ecology of the blue -green alga *Oscillatoria rubescens* in the metalimnion of Crooked Lake. Published in Limnol. Oceanogr.

1982 Crooked Lake Association. Sampling for fecal coliform bacteria and nutrients in inlet streams to Crooked and Little Crooked Lakes during September.

1982 Indiana Department of Natural Resources. Survey of cisco populations. Published by Pearson (1982).

1982 Indiana Department of Natural Resources. Examination of cisco-oxygen relationships in Crooked Lake and other northern Indiana lakes. Published by Pearson (1982).

1983 Crooked Lake Association. Sampling for fecal coliform bacteria and nutrients in inlet streams to Crooked and Little Crooked Lakes.

1983 A. Konopka. Epilimnetic and metalimnetic patterns in algal productivity in Crooked Lake. Published in Can. J. Fish. Aquat. Sci..

1983 Indiana Department of Natural Resources. Survey of cisco populations. Published by Pearson (1983).

1983 A. Konopka, K. Brown and C. Lovell. Feeding activities of zooplankton in Crooked Lake. Published by Water Resources Research Center, Purdue University.

1984 Crooked Lake Association. Sampling for fecal coliform bacteria and nutrients in inlet streams to Crooked and Little Crooked Lakes.

1984 Indiana Department of Natural Resources. Survey of oxygen and cisco populations. Published by Pearson (1984).

1985 Indiana Department of Natural Resources. Survey of cisco populations. Published by Pearson (1985).

1986 Indiana Department of Natural Resources. Survey of cisco populations. Published by Pearson (1986).

1987 Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition. Published by Pearson (1987).

1987	Indiana Department of Environmental Management. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index.
1988	Indiana Department of Natural Resources. Survey of cisco populations. Published by Pearson (1987).
1989	W. DeMott. Collection of detailed Secchi disc data from Crooked and Little Crooked Lakes.
1989	G. Bruce and G. Boehme. Collection of Secchi disc data from Crooked Lake for July-September as part of IDEM Indiana Volunteer Lake Monitoring Program.
1990	Indiana University. IDEM funded survey of physical, chemical, and biological parameters for construction of IDEM eutrophication index.
1990	Indiana Department of Natural Resources. Water quality measurements of three streams flowing into Little Crooked and Crooked Lakes. Published by Pearson (1990).
1990	G. Bruce and G. Boehme. Collection of Secchi disc data from Crooked Lake for July-September as part of IDEM Indiana Volunteer Lake Monitoring Program.
1991	G. Bruce and G. Boehme. Collection of Secchi disc data from Crooked Lake for July-September as part of IDEM Indiana Volunteer Lake Monitoring Program.

Table 2. Historical limnological data for Crooked Lake.

Crooked Lake, IN Historical Data		1963/ 1964	Aug. 1969	Aug. 1972	June 1978	Aug. 1978	July 1987	Aug. 1987	Sept. 1987	June 1989	July 1989	Aug. 1989	Sept. 1989	May 1990	June 1990	July 1990	Aug. 1990	Oct. 1990	May 1991	June 1991	July 1991	Aug. 1991	Sept. 1991	Oct. 1991
Secchi	feet		16.0	7.5			14.6	9.4	9.6	11	9.8	8.8	7.5	16.5	8	9	10.2	8.9	13	8.5	12.8	11	7.3	10
Mean Dissolved Oxygen	mg/L			6.1	7.8	9.6	6.4	4.6	5.0									4.5						
Alkalinity	mg/L			149.5			111.5																	
pH		8.3		8.1		7.7	8.8																	
Conductivity	umhos/cm	224																						
Total Phosphorus	mg/L							0.065										0.075						
Ortho Phosphorus	mg/L																	0.061						
Nitrate-N	mg/L																	0.02						
Ammonia-Nitrogen	mg/L																	0.12						
Organic-N	mg/L																	0.52						
Chlorophyll	mg/m3																	2.2						

Table 3. Historical limnological data for Little Crooked Lake.

Little Crooked Lake, IN Historical Data		1963/ 1964	Aug. 1969	Aug. 1972	July 1990	Oct. 1990
Secchi	feet			8.5	9.5	1.7
Mean Dissolved Oxygen	mg/L		10.9	4.5	2.6	2.5
Alkalinity	mg/L		116	188	149.64	
pH		8.0		7.9	7.7	
Conductivity	umhos/cm	259			410	
Total Phosphorus	mg/L				0.036	0.215
Ortho Phosphorus	mg/L				0.01	0.2
Nitrate-N	mg/L				0.989	0.075
Ammonia-Nitrogen	mg/L				0.054	1.5
Organic-N	mg/L				1.14	0.71
Chlorophyll	mg/m3					4.1

Crooked 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 (Tables 2 and 3). Although Crooked historically has maintained oxygen throughout the water column during summer, Little Crooked has been displaying anoxia in the water column beginning at least by July and extending throughout the growing season (Table 4). Although the historical record is weak, it appears that such anoxia has been common in Little Crooked since at least 1972.

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 Crooked Lake since 1969 do not yield any apparent trend that can be related to changes in watershed management practices (Tables 2 and 3). The remaining physical and chemical parameters measured at Crooked Lake were sampled so infrequently as to be of little value in delineating past trends in water quality.

Microbiology

Neither the Whitley and Noble County Health Departments nor the Indiana State Board of Health had any historical microbiological data from Crooked Lake. The lake association did collect microbiological data from inlet streams during the 1980's (appendix E), but no data from within the lake were included.

Phytoplankton

Phytoplankton samples have been collected periodically since 1930. Will Scott (1931) collected zooplankton and phytoplankton samples from discrete intervals of the water column during July and August 1930. The Indiana Department of Environmental Management sampled phytoplankton during August 1975, but detailed data were missing from the departmental files. The most recent survey of phytoplankton was by Indiana University in July 1990, but details were not provided. In addition to these surveys, Wetzel during 1963-1964 assessed lake productivity and Konopka during the 1980's investigated factors controlling *Oscillatoria* in the lake. Detailed references for these investigations are provided at the end of this report.

Algal abundance in the surface waters of Crooked Lake during

Table 4. Historical records of water column anoxia in Crooked and Little Crooked Lakes.

Observation	Initial Depth of <1 mg/L Dissolved Oxygen
June:	
C 1978	No Anoxia
July:	
C 1987	No Anoxia
LC 1990	7 feet
August:	
LC 1969	No Anoxia
LC 1972	20 feet
C 1972	100 feet
C 1978	No Anoxia
C 1987	No Anoxia
October:	
C 1990	No Anoxia
LC 1990	26 feet

July 1930 was estimated at 2,359/mL and at 920/mL during July of that year (Table 5). Clathrocystis was the dominant taxon with Ceratium, Oscillatoria and Fragilaria as the principal subdominants. The presence of blue-green algae was suggestive of a moderate degree of production. Algal abundance in surface waters of Crooked Lake for October 1990 was estimated at 153/mL and at 169/mL in Little Crooked. The assemblages in both lakes were dominated by blue-green taxa. The phytoplankton database for Crooked Lake is limited and not from comparable seasons. Thus, it is difficult to assess whether the phytoplankton assemblage of Crooked Lake has increased in abundance since 1930.

Macrophytes

The macrophyte (aquatic plant) community was examined two times (1969 and 1987) as part of Indiana Department of Natural Resources fish surveys (Table 6). Plant taxonomic composition was nearly identical for the two surveys. Submergent macrophytes were the most taxonomically diverse plant community with pondweeds displaying the greatest number of species. Both surveys noted that macrophytes were of limited distribution in Crooked Lake and were not considered a management problem.

Fish

The Indiana Department of Natural Resources surveyed the fish community of Crooked Lake three times between 1969 and 1987. All DNR surveys were based on a combination of electrofishing, gill net, and trap collections, the details of which are presented in Table 7. In addition to the detailed surveys, spot checks for ciscos were also conducted periodically.

A listing of the individual species caught and the contribution of each to total fish abundance and weight caught during the three DNR surveys are provided in Tables 8 and 9, respectively. Largemouth bass was the most abundant fish caught in 1969 (24%) but was replaced by bluegill in 1978 and 1987 (31% and 38%). The second most abundant fish in the surveys were bluegill (19%) in 1969, cisco (18%) in 1978, and largemouth bass (23%) in 1987. On a weight basis, ciscos dominated the 1978 surveys (33%) and largemouth bass (25%) dominated the 1987 survey.

Fish stocking into Crooked Lake has been practiced by the Indiana DNR since at least the early 1970's and was likely conducted by residents prior to that. Fish known to have been stocked into the lake include brown trout, rainbow trout, and lake trout.

Table 5. Phytoplankton and zooplankton abundances and concentrations of dissolved gases in Crooked Lake in 1929 and 1930. Table from Scott (1931). Key: (D) depth, (T) temperature, (O) oxygen, (CO_2) carbon dioxide, (Cb) carbonates.

LAKE: CROOKED (Whitley)
Date: 7/30/29

Plankton						Dissolved Gases					
Species	0-5	5-10	10-15	15-20		D	T	O	%	CO_2	Cb
Ceratium	602	217	17	42		S	26.7	5.84	103	0	22.92
Dinobryum	4					2	26.1	5.89	103	0	22.44
Aneura			4.2			4	23.9	6.11	103	0	23.42
Polyarthra						6	21.1	4.44		2.44	23.18
Noltholca	34										
Asplancna	5			4		8	16.7	.30		6.82	27.56
Hexarthra	8	4									
Daphnia	8	3	2.4	3.2		10	13.3	.61		5.02	28.54
						12	11.7	1.33		4.88	26.84
						15	10.9	.87		6.34	27.56
Diaptomus	10	3	2.4								
Cyclops	1.6	7	2.4	3.8							
Nauplii	4	8	4.2	4.2		20	10.6	0		7.80	28.78
						21	10.6	0		5.84	28.78
Corethra				18							
Melosira	34	64	140	128							
Fragillaria	516	166	51	51							
Asterionella	85	136	51	4							
Anabena											
Clathrocyctis	866	507	264	183							
Oscillatoria	162	42	29	34							
Lyngbya											

LAKE: CROOKED (Whitley)
Date: 8/15/30

Plankton						Dissolved Gases					
Species	0-5	5-10	10-30	13-30		D	T	O	%	CO_2	Cb
Ceratium	55	42	4			S	26.1	5.56		—1.4	25.8
Dinobryum	8					2	25	5.54		—1.0	25.8
Aneura			166			4	24.4	5.28		—1.0	25.8
Polyarthra	102		46			6	21.6	5.28		—1.6	25.8
Noltholca		12.8	17			8	13.5	5.15		—1.0	25.2
Daphnia	.8	2.4	1.6			10	10	8.40	10S	—1.4	29.0
Holopedium	4	4	.8			12	8.5	7.29		—1.0	29.2
						15	7.5	4.76		0	23.2
Diaptomus	21	10	9.6								
Cyclops	22	12	29.6								
Nauplii	11.2	2	61			20	6.6	4.0		1.0	27.2
Melosira		4.2				25	6.1	3.23		1.0	23.6
Fragillaria	8.5	4.2									
Asterionella											
Anabena						30	6.1	1.63		2.4	23.6
Clathrocyctis	785	1,147	354								
Oscillatoria	64	29	13								
Lyngbya											

Table 6. Historical data on macrophyte composition.

Crooked Lake
Macrophytes

Species	Common Name	1969	1987
SUBMERGENTS:			
Ceratophyllum demersum	coontail	X	X
Chara spp.	chara	X	X
Decodon verticillatus	water willow	X	
Elodea canadensis	elodea	X	
Juncus effusus	soft rush	X	
Myriophyllum heterophyllum	water milfoil	X	X
Najas flexilis	bushy pondweed	X	
Potamogeton nodasus	american pondweed		X
Potomogeton pectinatus	sago pondweed	X	
Vallisneria americana	wild celery / eelgrass	X	X
EMERGENTS:			
Peltandra virginica	arrow arum	X	X
Pontederia cordata	pickeral weed	X	X
Sagittaria latifolia	arrowhead	X	X
Scirpus spp.	bulrush		X
Typha latifolia	common cattail	X	X
FLOATING LEAVED:			
Nuphar advena	spatterdock	X	X
Nymphaea tuberosa	waterlily	X	X
Potamogeton natans	pondweed	X	

Table 7. Historical DNR Fish Sampling in Crooked Lake, IN.

1969

Electrofishing:	2 hrs night
Gillnets:	4 for 48 hrs = 192 hrs total effort
Traps:	1 for 48 hrs =48 hrs total effort
Seine Hauls:	4

1978

Electrofishing:	1.25 hrs night
Traps:	3 for 96 hrs = 288 hrs total effort

1987

Electrofishing:	1 hr night
Gillnets:	3 for 48 hrs = 144 hrs total effort
Traps:	4 for 48 hrs = 192 hrs total effort

Table 8. Historical data on fish abundance expressed as percent of total fish abundance from IDNR survey.

Crooked Lake % Total Fish Abundance	1969	1978	1987
Black Bullhead	0.2		
Black Crappie	3.5	0.9	
Blackchin Shiner		0.1	
Bluegill	19.8	31.5	38.5
Bluntnose Minnow			0.3
Bowfin	0.5	0.1	0.8
Brook Silverside		0.3	1.1
Brown Bullhead		0.5	2.5
Brown Trout		3.3	
Cisco		18.3	
Golden Shiner	0.2	0.4	0.2
Grass Pickeral	0.5	0.8	2.1
Green Sunfish	0.7	1.7	0.3
Hybrid Sunfish		0.7	0.2
Lake Chubsucker	9.6	8.4	2.9
Largemouth Bass	24.2	1.8	23.1
Longnose Gar			2.5
Rainbow Trout			0.8
Pumpkinseed	10.7	3.1	2.3
Redear	1.2	5.0	12.7
Rock Bass	8.2	4.4	2.1
Spotted Gar	0.9	1.3	0.8
Warmouth	10.7	7.1	5.2
Yellow Bullhead	0.7	0.9	0.5
Yellow Perch	8.4	9.5	5.2

Table 9. Historical data on fish weight expressed as percent of total fish weight from IDNR surveys.

Crooked Lake Fish Weight	1978	1987
Black Bullhead		
Black Crappie	0.7	
Bluegill	12.5	18.0
Bowfin	1.9	8.3
Brown Bullhead	2.4	1.7
Brown Trout	6.4	
Cisco	33.4	
Golden Shiner	0.1	0.1
Grass Pickeral	0.7	1.3
Green Sunfish	0.7	0.1
Hybrid Sunfish	0.6	
Lake Chubsucker	8.4	2.8
Largemouth Bass	1.7	25.7
Longnose Gar		11.2
Pumpkinseed	1.2	1.0
Rainbow Trout		2.6
Redear		13.6
Rock Bass	2.0	1.3
Spotted Gar	7	2.5
Warmouth	3.7	2.8
Yellow Bullhead	2.9	1.2
Yellow Perch	10.3	5.5

Ciscos were considered common in Crooked Lake in 1954, 1975, and 1988. The population, however, has been experiencing difficulties recently (Figure 2). Lake turbidity was elevated following a six inch rain in June 1981 and resulted in the first reported cisco and trout die off in Crooked Lake. This kill continued throughout the summer and early fall of 1981 and DNR estimated that two-thirds of the cisco population in the lake had been killed. Given the stress to the cisco population, it was suggested at the time that brown trout not be stocked further to the lake to reduce predation on ciscos. It was further suggested that declining water quality was at least partly responsible for the observed decline in cisco. Subsequent fish surveys 1982-1988 noted that the cisco population consisted predominately of larger, older females. By 1985, Pearson felt that the cisco population in Crooked Lake was on the verge of collapse. A second cisco kill followed in September 1986 after a month of above average rainfall and presumably increased erosion from the watershed.

Ciscos require cold well oxygenated water and are therefore sensitive to deoxygenation of the lower water column associated with increasing eutrophication. The historical cisco data suggest that water quality in Crooked Lake may have been declining recently. Although the limited historical water chemistry database does not indicate this trend, inherent sensitivity of the cold water fishery to reduced dissolved oxygen conditions in the lower water column may be an early warning indicator of slowly degrading water quality.

Current Water Quality

Methods

Sampling locations for current water quality data for Crooked and Little Crooked Lakes collected on 12-13 October 1990 are shown in Figure 3. 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 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). Data for physical and chemical parameters are presented in Table 10.

Phytoplankton were collected with a #20 Wisconsin plankton net equipped to open and close at discrete depth intervals. Two samples were collected at each lake. The first was a

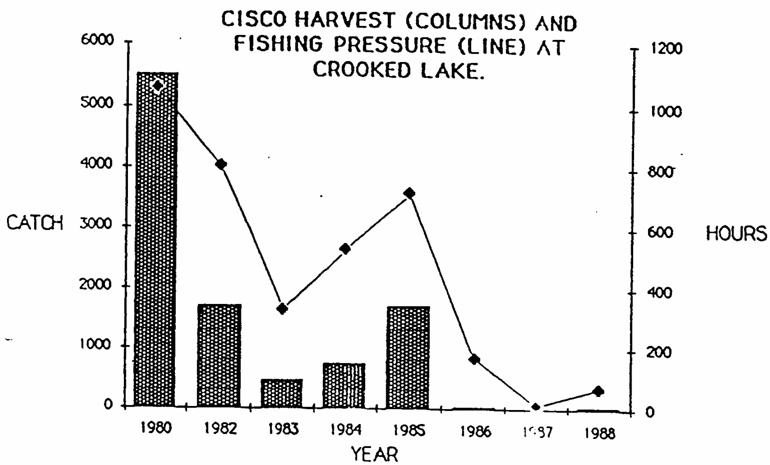


Figure 2. Cisco harvest and fishing pressure at Crooked Lake. From Pearson (1990).

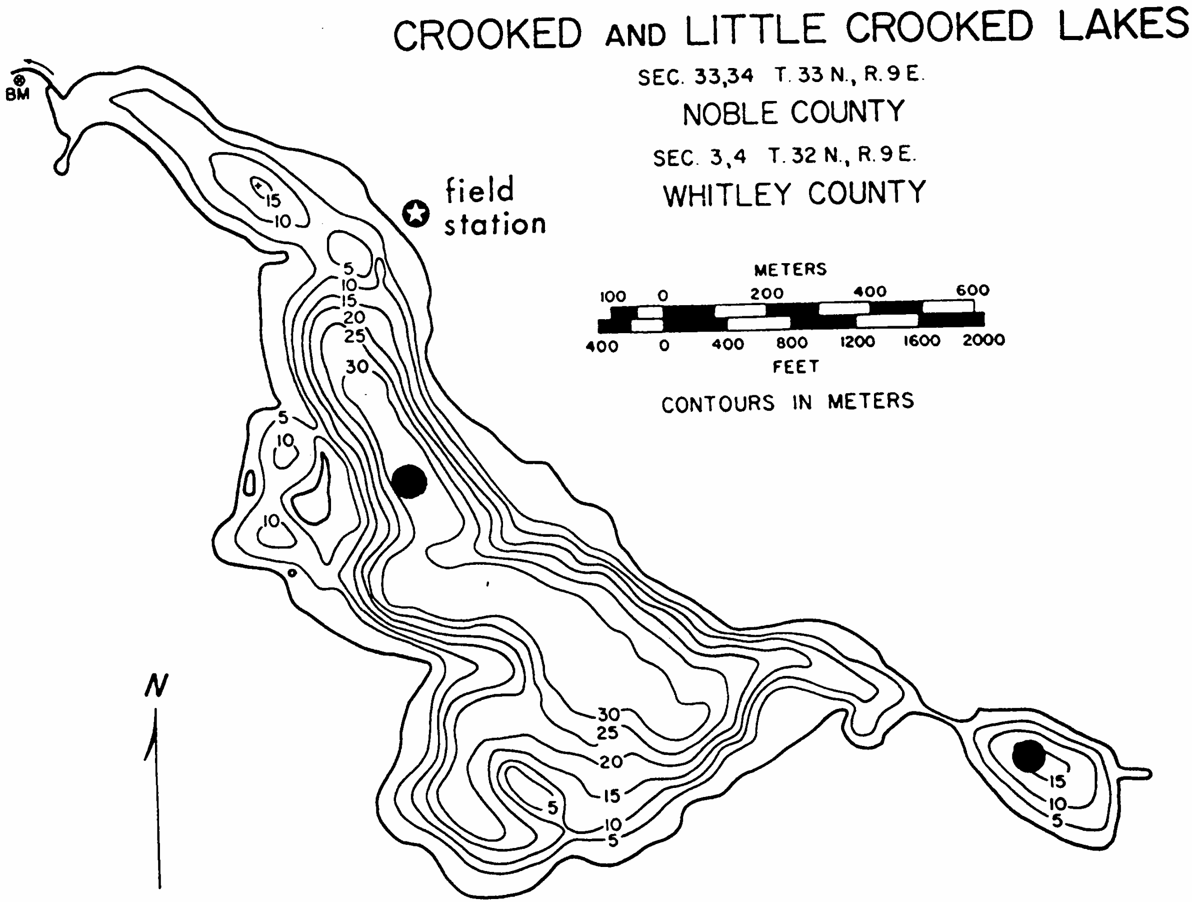


Figure 3. Sampling stations for 1990 limnological parameters

Table 10. Water chemistry for Crooked and Little Crooked Lakes in 1990.

Little- and Crooked Lake, IN 1990		L.C.+ 7-2	L.C.* 10-13	C.* 10-12
Secchi	feet	9.5	1.7	8.9
Mean D.O.	mg/L	2.6	2.5	4.5
Ammonia	mg/L	1.53	1.5	0.12
Organic-N	mg/L	1.40	0.71	0.52
Nitrate	mg/L	0.989	0.075	0.02
Total Phosphorus	mg/L	0.036	0.215	0.075
Ortho Phosphorus	mg/L	0.01	0.2	0.061
Conductivity	umho/cm	410.0		
Alkalinity	mg/L	149.64		
Chlorophyll-a	ug/L		4.1	2.2
pH		7.7		
Temperature	C	8.5	9.5	8.4

+ Data by Indiana University

* Data by B. DeMott and M. Stewart

vertical haul through the water column from a depth of five feet to the surface, and the second was a five foot vertical haul that spanned the thermocline. Both collections were specified for calculation of the IDEM Eutrophication Index. Alcohol preserved samples were settled in Utermohl chambers and counted using 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 $4^{o}C$, 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.

The water column profiles clearly demonstrated that both Crooked and Little Crooked Lakes were thermally stratified during October 1990 (Figure 4). The thermocline was between six and seven meters in Little Crooked and between eight and nine meters in Crooked.

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).

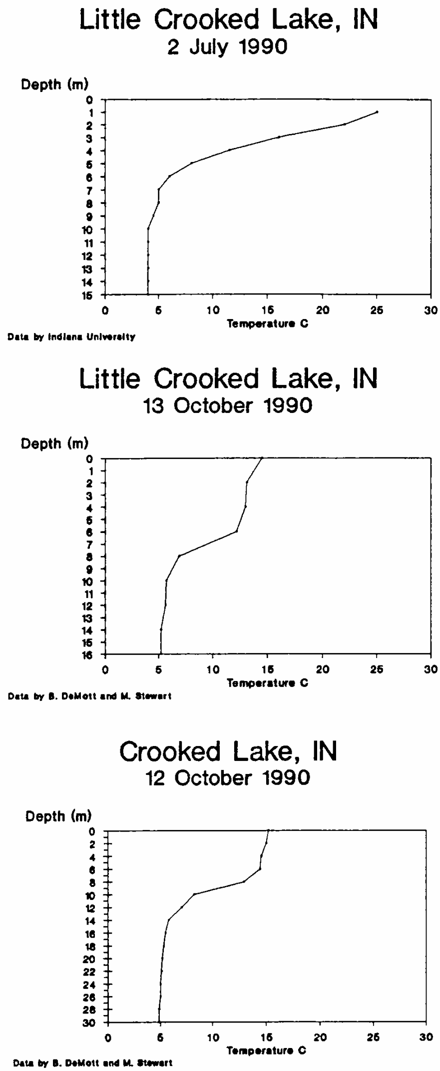


Figure 4. Temperature profiles for 2 July and 12-13 October 1990.

Pronounced water column deoxygenation was noted in both Crooked and Little Crooked during October 1990 (Figure 5). 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). While Little Crooked was essentially anoxic below depths of six meters, Crooked was essentially oxygenated throughout the water column. The pronounced zone of increased oxygen concentrations between 12 and 20 meters depth in the water column of Crooked Lake was likely the result of pronounced algal photosynthetic activity in this zone. Such algal plates are common in Crooked Lake and are related to the distribution of the blue-green alga Oscillatoria rubescens.

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 suspended in the water column to block light transmission. Thus, the shallower the Secchi depth during summer, the more productive (eutrophic) a lake is presumed to be. The 1990 Secchi value for Crooked (8.7 feet) was within the range reported for late summer since at least since 1972. The 1.7 feet Secchi reported for Little Crooked in October 1990 was the lowest value reported in this lake since at least 1969. The value for Crooked Lake is characteristic of lakes of moderate to good water quality, while that of Little Crooked Lake is comparable to moderately eutrophic systems. Care should be taken, however, to compare data collected in October with those from the height of the growing season (summer).

Nitrogen Forms. The October 1990 ammonia values for Crooked and Little Crooked were 0.12 mg/L and 1.5 mg/L, respectively. The value for Little Crooked is considered high for Indiana lakes and may reflect flushing of watershed sources into the lake via the major inlet. As nitrogen is one of the major nutrients driving primary production in lakes, ammonia values should be monitored closely in the future to determine if a trend is clear and the ultimate source for the nitrogen imput. Nitrite-nitrate nitrogen concentrations for these lakes were 0.02 and 0.07 mg/L, and organic nitrogen values were 0.52 and 0.71 mg/L, respectively. No pre 1990 historical data were available for any of these parameters.

Phosphorus Forms. Total phosphorus concentrations in October 1990 in Crooked and Little Crooked were 0.07 and 0.21 mg/L, respectively, while ortho phosphorus values were 0.06 and 0.2 mg/L. No pre 1990 historical data were available for any of these parameters. It is interesting to note that most of the phosphorus in both lakes was in the biologically readily available form. As with ammonia, ortho phosphorus concentrations should be monitored closely to note trends

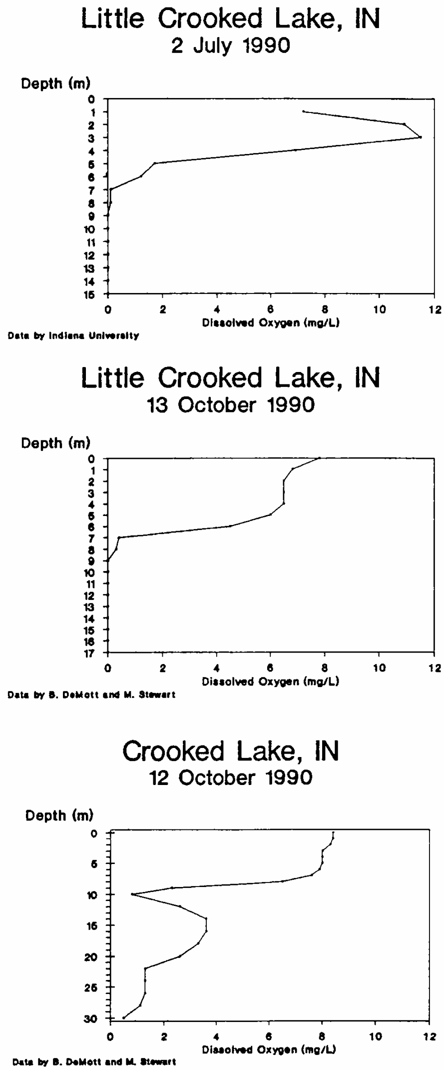


Figure 5. Dissolved oxygen profiles for 2 July and 12-13 October 1990.

and possible sources. It should be taken as a warning that aquatic productivity in the lake and associated trophic state may increase if values for these nitrogen and phosphorus parameters remain high.

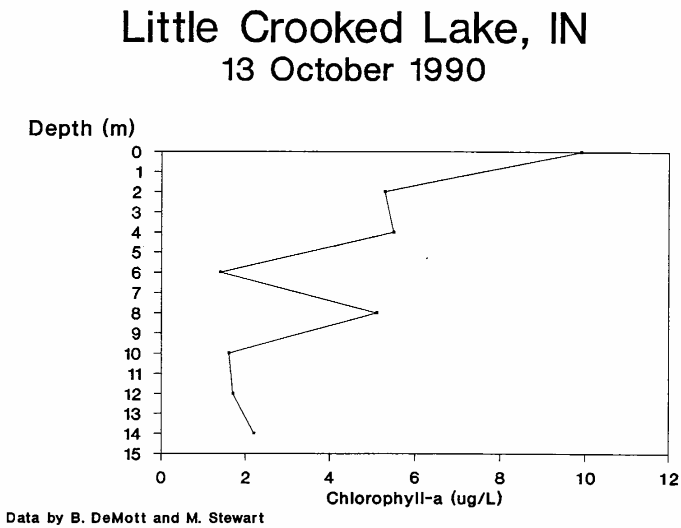
Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake (Figure 6). Chlorophyll concentrations during October 1990 in Crooked Lake remained relatively constant in the upper 6 meters of the water column, decreased progressively to 20 meters, then remained relatively constant at low values. In contrast, chlorophyll values in Little Crooked Lake decreased progressively in the upper 6 meters of the water column, displayed a major peak at 8 meters, then declined toward the lake bottom. The peak of chlorophyll at 8 meters is likely due to an algal plate at that level. Mean water column values of chlorophyll during October 1990 were 2.2 mg/m^3 and 4.1 mg/m^3 for Crooked and Little Crooked, respectively. There are no historical data for comparison with the 1990 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 1975 eutrophication index for Crooked and Little Crooked Lakes were calculated by the Indiana Department of Environmental Management as 3 and 32, respectively, thus assigning Crooked to the category of best water quality, Class One and Little Crooked to that of intermediate water quality, Class Two. Parameters for both the 1987 and 1990 index calculations were identical to those used for the 1975 index. Although no data were available for Little Crooked Lake, the 1987 index value of 12 assigned Crooked Lake to Class One, the category of best water quality.

Based on our October samplings, we have calculated the 1990 IDEM eutrophication index for Crooked Lake as 40 (Table 11) and for Little Crooked Lake as 54 (Table 12). Our calculation for Little Crooked is comparable to the 56 calculated for July 1990 by W. Jones of Indiana University. Our 1990 values assigned Crooked to the category of intermediate water quality, Class Two, and Little Crooked to the category of worst water quality, Class Three. Thus, on the basis of the eutrophication index alone, both lakes have



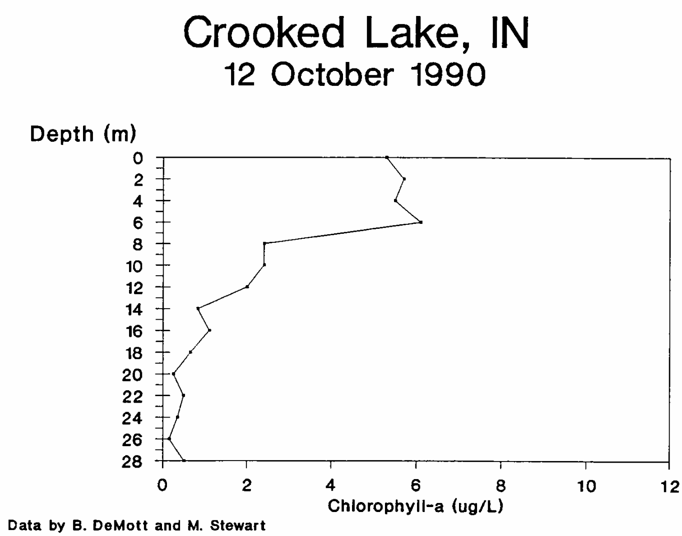


Figure 6. Chlorophyll profiles for 12-13 October 1990.

Table 11. IDEM Eutrophication Index for Crooked Lake in 1990.

	Parameter	Value	Eutrophy Points
I.	Total Phosphorus	0.07 ppm	3
II.	Soluble Phosphorus	0.06 ppm	3
III.	Organic Nitrogen	0.52 ppm	2
IV.	Nitrate	0.02 ppm	0
V.	Ammonia	0.12 ppm	0
VI.	Dissolved Oxygen Saturation @ 5 feet	100%	0
VII.	Dissolved Oxygen (% of water column with >0.1 ppm DO)	90%	0
VIII.	Light Penetration (Secchi Disk)	8.9 feet	0
IX.	Light Transmission (1% at Three Feet)	34 %	3
X.	Total Plankton		
	Vertical Tow (5 ft to Surface)	153,600 cells/mL	10
	Blue-green Dominance	Yes	5
	Vertical Tow (Thermocline)	169,000 cells/mL	4
	Blue-green Dominance	Yes	5
	> 100,000 cells/mL	Yes	5
		1990 IDEM Index	40

Table 12. IDEM Eutrophication Index for Little Crooked Lake in 1990.

	Parameter	Value	Eutrophy Points
I.	Total Phosphorus	0.21 ppm	4
II.	Soluble Phosphorus	0.2 ppm	4
III.	Organic Nitrogen	0.71 ppm	2
IV.	Nitrate	0.07 ppm	0
V.	Ammonia	1.5 ppm	4
VI.	Dissolved Oxygen Saturation @ 5 feet	100%	0
VII.	Dissolved Oxygen (% of water column with >0.1 ppm DO)	44%	3
VIII.	Light Penetration (Secchi Disk)	1.7 feet	6
IX.	Light Transmission (1% at Three Feet)	4.5 %	4
X.	Total Plankton		
	Vertical Tow (5 ft to Surface)	104,000 cells/mL	10
	Blue-green Dominance	Yes	5
	Vertical Tow (Thermocline)	169,000 cells/mL	2
	Blue-green Dominance	Yes	5
	> 100,000 cells/mL	Yes	5
		1990 IDEM Index	54

become progressively more productive in the past 15 years with the greatest change having taken place in Crooked Lake. It should be noted, however, that eutrophication indices are subject to great variation especially in relatively clean water lakes such as Crooked Lake depending on the season samples were taken and interyear variability in climate that might affect the frequency and severity of storm events and water column mixing events. Finally, while most parameters were within limits observed earlier, the elevated 1990 index for Crooked Lake resulted in major increases in both ortho phosphorus and plankton values.

Macrophytes

A raytheon recording fathometer was used to estimate the biovolume of aquatic macrophytes in both lakes. A total of 16 transects in Crooked and 9 transects in Little Crooked spanning the width of each lake were used as the data base. The survey of Crooked Lake was limited to the eastern portion of the basin because it was felt that that portion of the basin would have experienced the greatest impact from possible delivery of sediment and nutrients from Little Crooked Lake. The plant survey was conducted in August 1990 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 Crooked and Little Crooked Lakes is presented in Figure 7, and the percentage of lake area represented by individual biovolume increments is presented in Figure 8. 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 (79% Crooked, 72% Little Crooked) was considered void of vegetation.

Areas of greater than 80% water column infestation were aerially limited to areas immediately along the shore in Crooked, especially along the east shore. Only 5% of Crooked exhibited greater than 60% plant biovolume. In contrast, plant communities failed to display greater than 60% biovolume in Little Crooked, and only 4% of lake area was characterized by greater than 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

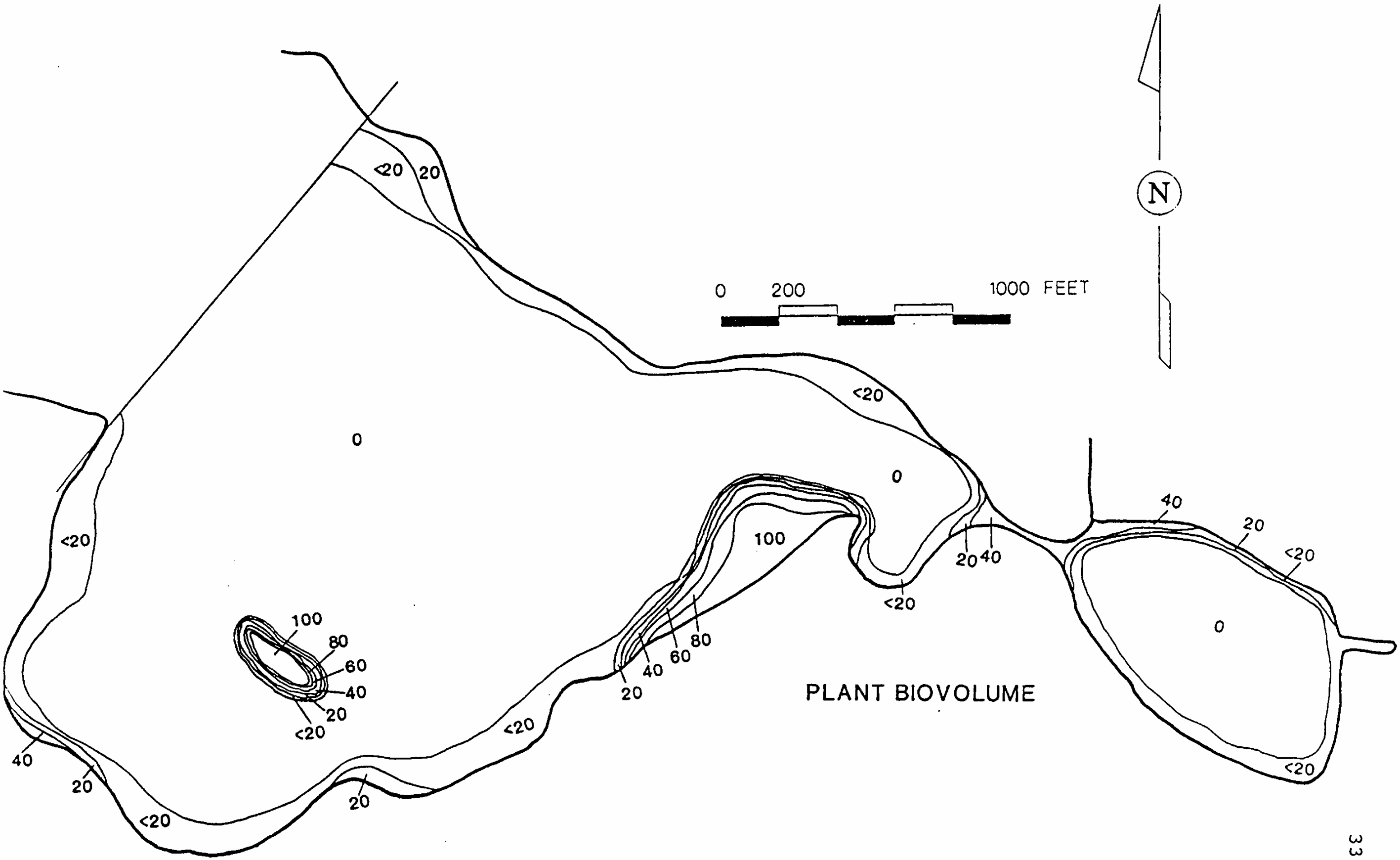
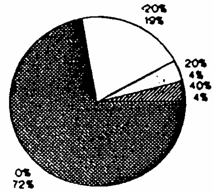
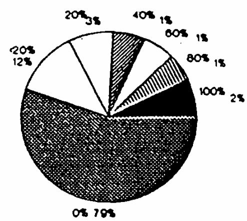


Figure 7. Distribution of plant biovolume.

Little Crooked Lake, IN
Percent Plant Biovolume



Crooked Lake, IN
Percent Plant Biovolume



Little- and Crooked Lake, IN
Percent Plant Biovolume

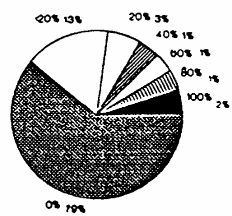


Figure 8. Distribution of percent plant biovolume.

this reasoning, neither Crooked nor Little Crooked have a macrophyte problem. The depth distribution of macrophytes is controlled both by basin morphometry and pronounced light limitation below 10 feet water depth. It is suggested that further eutrophication of Crooked Lake could result in a pronounced exacerbation of macrophyte problems beyond current levels, but only in nearshore areas.

In addition to examining the distribution of plant biomass in Crooked and Little Crooked Lakes, a qualitative survey was made to determine the distribution of the major plant species in the system (Figure 9). The plant assemblage of Crooked is rich in species of pondweeds (Potomogeton), with the principal secondary submergent in the basin being the macroalga Chara. Patches of spatterdock (Nuphar) and waterlily (Nymphaea) were found along the entire shore. Pondweeds were poorly represented in Little Crooked and the submergent flora was dominated by filamentous algae and Myriophyllum. As in Crooked, patches of spatterdock and waterlilies characterized the shoreline.

Fish

The Raytheon fathometer data recorded from the 16 and 9 cross lake transects for Crooked and Little Crooked, respectively, were also used to provide a qualitative assessment of the fish community. 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 basins.

Total fish abundance in open water areas of Crooked Lake was estimated at 25/1000 feet of fathometer transect, while the estimate for Little Crooked was 116/1000 feet. The greatest density of fish in Crooked (21% total abundance) was at a depth of 0-1 feet (0.3 meter) with the second greatest density (12%) at 12-13 feet. (Figure 10). The greatest density of fish in Little Crooked (39% total abundance) was at a depth of 6-7 feet (2 meter) with the second greatest density (19%) at 5-6 feet. Fish avoided depths deeper than 20-21 feet (7 meters) in Crooked and 15-16 feet (4 meters) in Little Crooked. Below these depths, oxygen values declined sharply. 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.

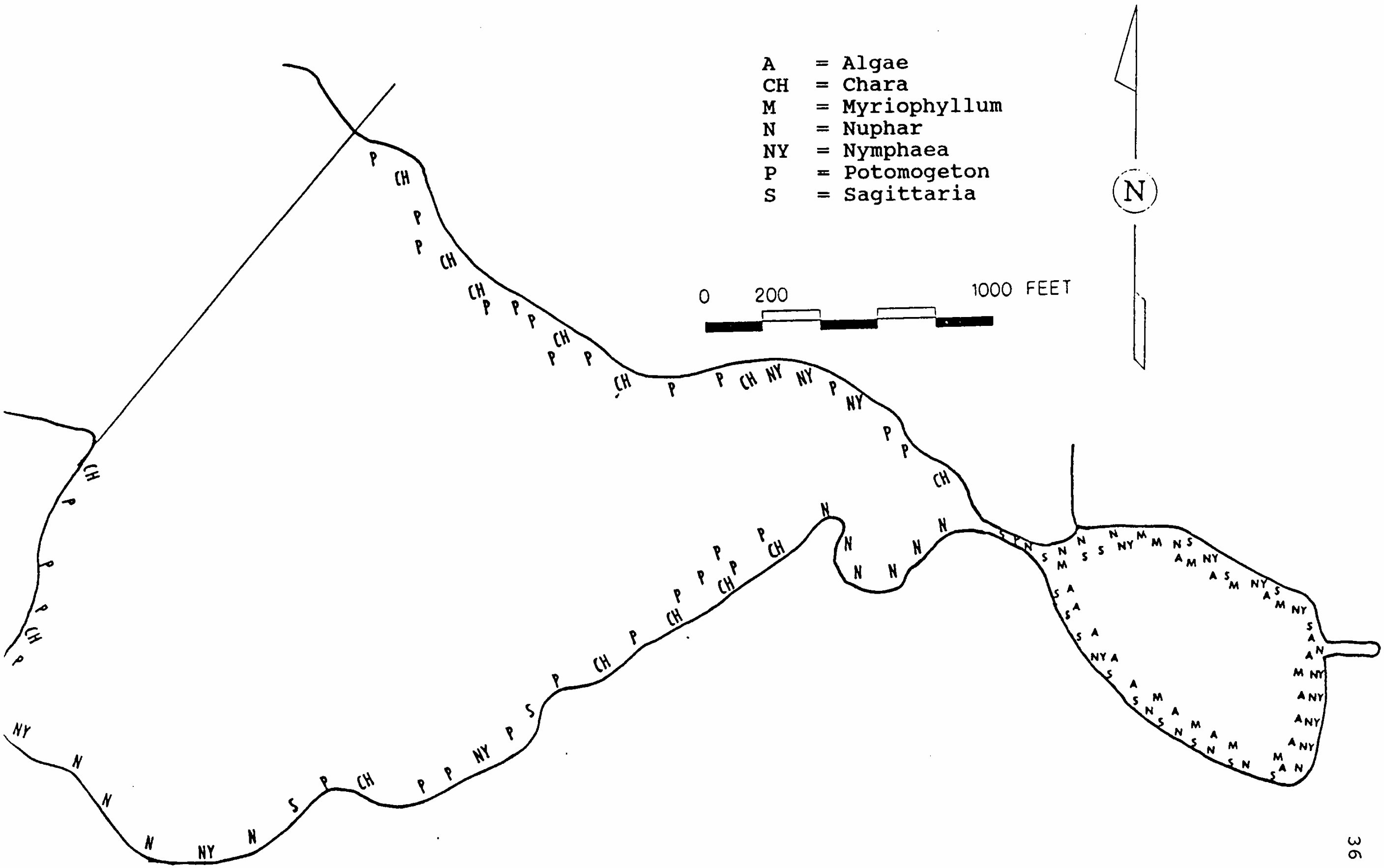


Figure 9. Distribution of plant taxa.

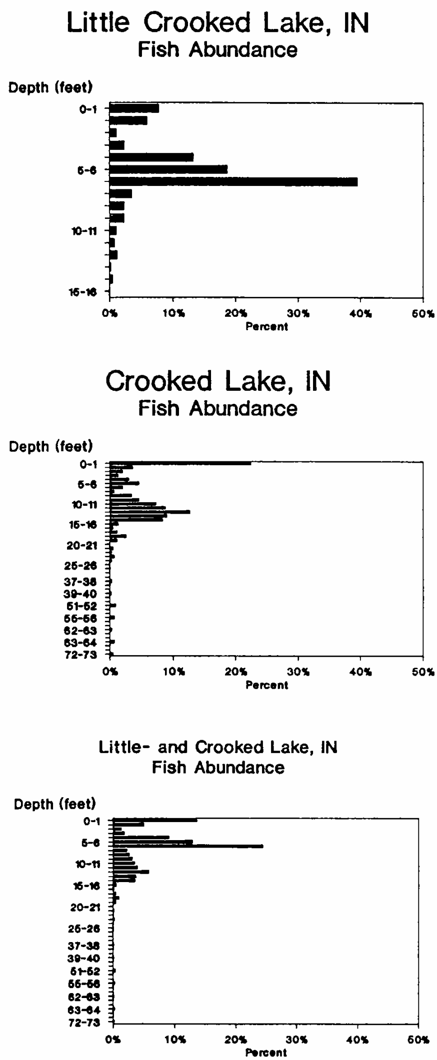


Figure 10. Fish abundance by depth.

Bathymetric Map and Lake Infilling

The United States Geological Survey published a bathymetric map of Crooked and Little Crooked Lakes based on a survey of 1952 (Figure 11). Depth contours were constructed at five foot intervals for the lake. The current study constructed an updated bathymetric map for 1990 based on fathometer recordings obtained from 16 lake transects from Crooked and 9 transects from Little Crooked (Figure 12). Following convention established by the 1952 map, five foot contours were constructed for the 1990 map.

A comparison of the depth configurations in Crooked for 1952 and 1990 is provided in Figure 13. The 0-5 foot contour in 1952 comprised approximately 15 acres, an area larger than displayed by an other single contour. The second largest contour were the 30-35 and 105-110 foot contours (8 acres). As in 1952, the 0-5 foot contour displayed the largest aerial extent in 1990 (15 acres), but the 100-105 foot contour (10 acres) was the second most important contour. The deep water zone (greater than 105 feet) in 1990 had all but disappeared.

A comparison of the depth configurations in Little Crooked for 1952 and 1990 is provided in Figure 14. The 0-5 foot contour in 1952 comprised approximately 2.8 acres, an area larger than displayed by an other single contour. The second largest contour was the 25-30 foot contour (1.5 acres). The deepest section of the lake (greater than 50 feet) was less than one acre. As in 1952, the 0-5 foot contour displayed the largest aerial extent in 1990 (2.9 acres), but the 30-35 foot contour (2.2 acres) had become the second most important contour. The deep water zone (greater than 50 feet) in 1990 was greatly reduced in aerial extent. It is possible, however, that some pockets of this zone remain and were missed by the positioning of our bathymetric profiles. A more detailed survey of both lakes was beyond the scope of the present study.

Sedimentation patterns for the past 38 years can be delineated through comparison of the aerial extent of individual contours for 1952 and 1990 (Table 13). The aerial extent of the 100-105 foot contour in Crooked Lake increased by 119% between 1952 and 1990. The depths in this basin showing the second greatest increase in aerial extent were 95-100 and 40-45 feet, which increased by 85% and 22%, respectively. In addition to the loss of areas greater than 105 feet, depth intervals showing the greatest loss in extent in Crooked were 75-80 (24%), 85-90 (23%) and 50-55 (14%).

The aerial extent of the 30-35 foot contour in Little Crooked Lake increased by 75% between 1952 and 1990. The

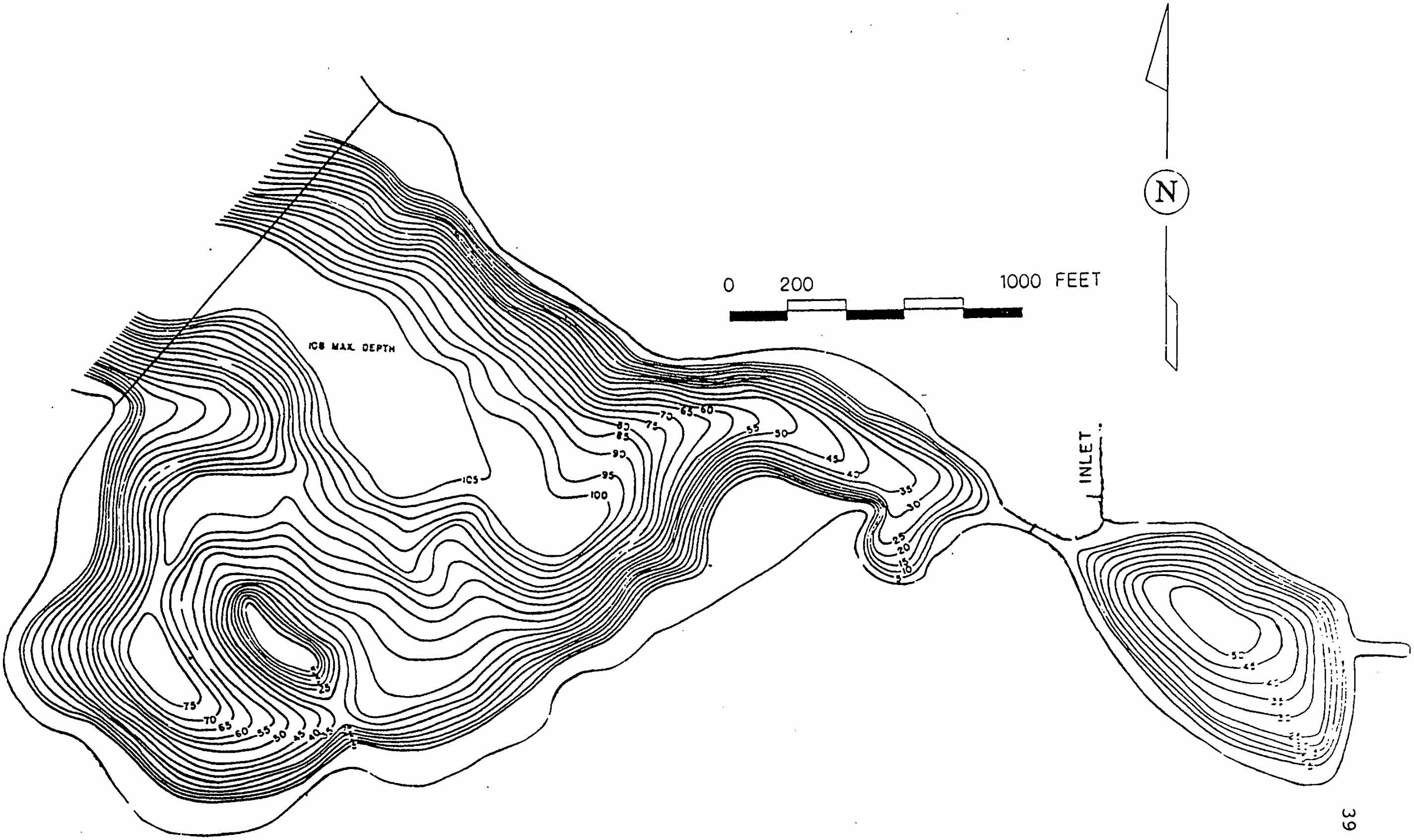


Figure 11. Bathymetric map for Crooked Lake 1952.

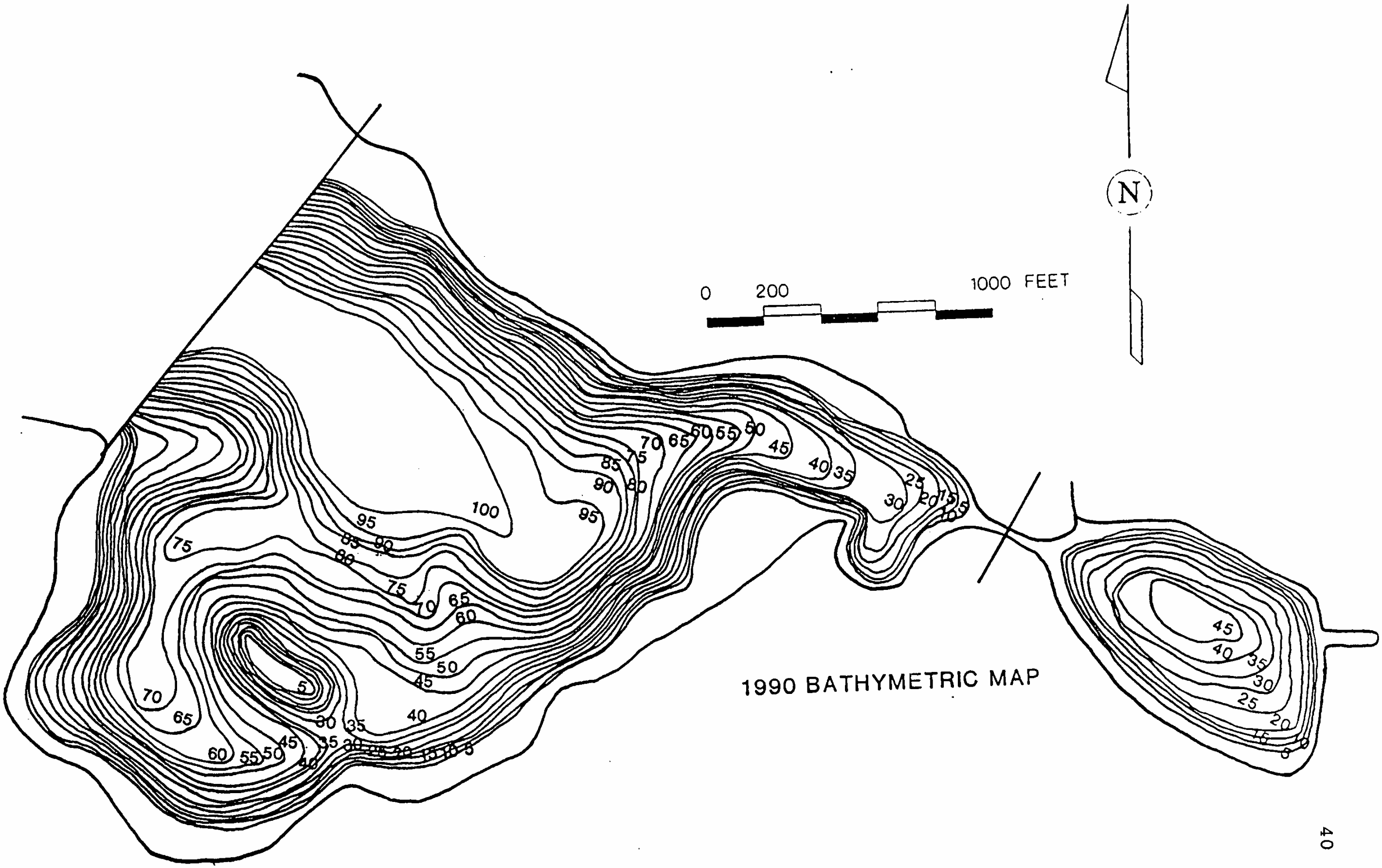
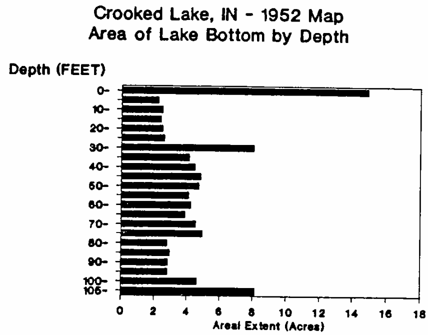
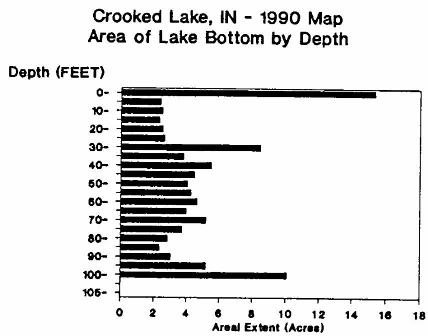


Figure 12. Bathymetric map for Crooked Lake 1990.





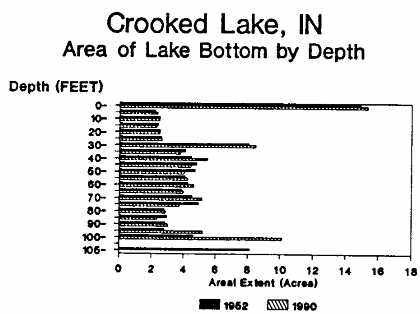
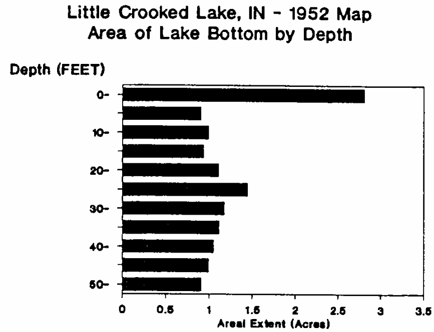
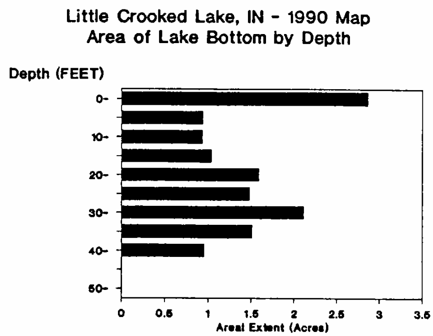


Figure 13. Aerial extent of individual depth contours in 1952 and 1990 expressed in five foot intervals.





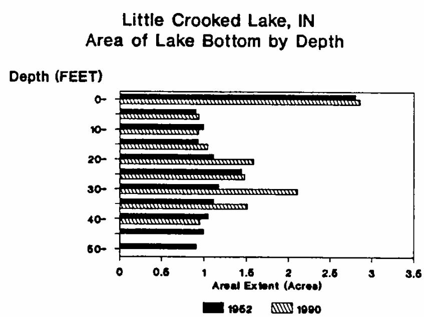


Figure 14. Aerial extent of individual depth contours in 1952 and 1990 expressed in five foot intervals.

Table 13. Percent change in the extent of individual depth contours between 1952 and 1990.

Lake Depth	Little C. Change	Crooked L. Change	Combined Change
0-5	+ 3.6%	+ 2.7%	+ 2.8%
5-10	0.0%	+ 9.1%	+ 6.5%
10-15	- 10.0%	0.0%	- 2.9%
15-20	+ 11.1%	- 4.2%	0.0%
20-25	+ 45.5%	0.0%	+ 13.9%
25-30	+ 7.1%	0.0%	+ 2.5%
30-35	+ 75.0%	+ 4.9%	+ 15.2%
35-40	+ 36.4%	- 7.3%	+ 1.9%
40-45	0.0%	+ 22.2%	+ 16.4%
45-50	- 100.0%	- 6.3%	- 22.4%
50-55	- 100.0%	- 14.9%	- 28.6%
55-60	------	+ 4.9%	
60-65	------	+ 9.5%	
65-70	------	+ 2.6%	
70-75	------	+ 15.6%	
75-80	------	- 24.5%	
80-85	------	+ 3.6%	
85-90	------	- 23.3%	
90-95	------	+ 3.5%	
95-100	------	+ 85.7%	
100-105	------	+ 119.6%	
105-108	------	- 100.0%	

depths in this basin showing the second greatest increase in aerial extent were 20-25 and 35-40 feet, which increased by 45% and 36%, respectively. Depth intervals showing the greatest loss in extent in Little Crooked were 45-50 (100%), 50-55 (100%) and 10-15 (10%).

Infilling of nearshore areas was not uniform throughout Crooked and Little Crooked Lakes between 1952 and 1990. The most pronounced sedimentation has taken place in the deep water areas at the southeastern end of Crooked and those areas in closest proximity to the channel leading to Little Crooked Lake. Sedimentation in Little Crooked has been most severe in the deepest portion of the basin and at the northwestern and southeastern corners of the lake. It is clear that basin sedimentation is strongly controlled by watershed erosion products. Two other contributors to lake infilling, motor boating and shoreline erosion, are possibly contributing factors for the observed pattern of sedimentation in both lakes but were beyond the scope of the current study.

Sediment Studies

Sediment Core Profiles

A piston coring device equipped with a clear plexiglass tube was used to collect cores from Little Crooked and in Crooked both at the eastern end of the basin immediately offshore from the channel leading from Little Crooked and at the western end of the basin (Figure 15). Coring sites were selected both to integrate basin conditions and to provide signals of watershed disturbance. We selected sites that were deep enough to provide an undisturbed record while still being feasible to core from a boat. Attempts to obtain cores from the northeastern corner of Little Crooked Lake were thwarted due to the extremely flocculent nature of the sediment in areas near the inlet. Our coring technique permitted examination of the cores to insure that the sediment-water interface was not disturbed during the coring operation. The cores were 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 4^{o} C until analyzed. One cm^3 sediment samples from select core levels were placed in small porcelain crucibles of known dry weight, and wet weight of the sediment was measured using a Mettler analytical balance. Water loss (% water) was calculated after reweighing the samples following dessication for 24 hours at 100^{o} C. Inorganic and organic fractions were determined by weight loss following ignition at 550^{o} C for one hour. Samples were allowed to cool to room temperature in a dessicator before

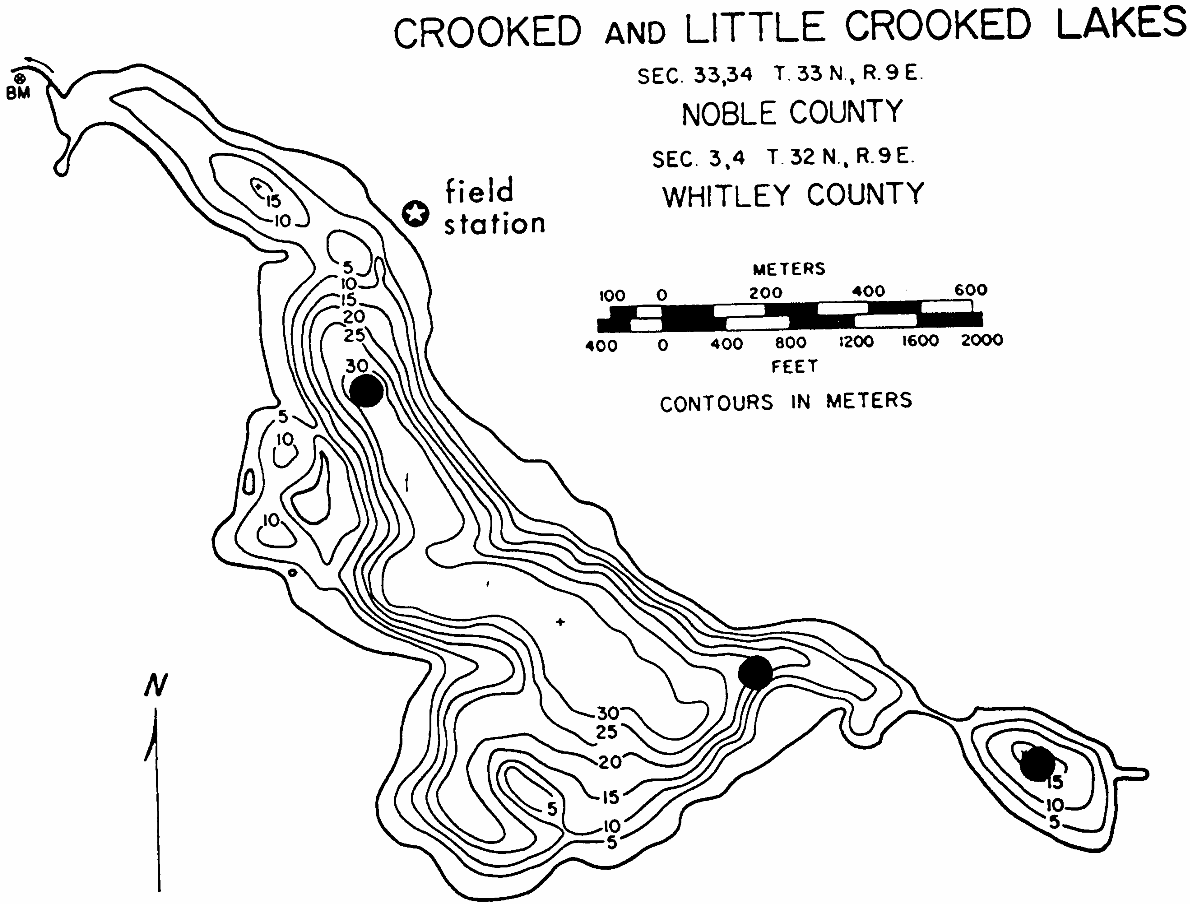


Figure 15. Location of sediment coring sites.

weighing.

Determination of total phosphorus for select core levels utilized the ignition method of Anderson (1976). Inorganic residue from the loss on ignition analysis just described was washed into a 200 mL beaker using 25 mL of 1N HCl and boiled for 15 minutes on a hot plate. Each sample was then diluted to 100 mL, and orthophosphate was measured by the ascorbic acid method (APHA 1985) using a Bausch and Lomb spectrophotometer equipped with a 1 cm light path. For the latter analyses, reagent blanks were run after every five sediment samples.

Each of the sediment cores were dated utilizing state of the art ^{210}Pb and ^{137}Cs methodology. ^{210}Pb and ^{137}Cs concentrations were measured by direct gamma assay using a coaxial N-type, intrinsic-germanium detector (Princeton Gamma Tech). This type of detector counts over a large range of gamma energies and can be used for simultaneous measurement of supported and unsupported ^{210}Pb or other gamma-emitting radioisotopes of environmental interest (Appleby et al. 1986, Nagy 1988. An outer shield (0.95 cm steel), main shield (10.1 cm lead), and an inner lining (0.05 cm cadmium + 0.15 cm copper) were used to reduce background radiation at the germanium detector.

Samples for isotope analysis were dried at 100^{o} C for 24 hours, pulverized by mortar and pestle, weighed, and placed in small plastic petri dishes (#1006, Falcon, CA). Core sections were combined (up to 4 cm) to obtain an adequate sample weight (generally > 3 grams). Petri dishes were sealed with plastic cement and left for 14 days to equilibrate radon (^{222}Rn) with radium (^{226}Ra). Counting times varied from 14 to 45 hours depending on sample weight; small samples needed to be counted longer to minimize uncertainty. Blanks were counted for every two samples to determine background radiation. Standards were run with the same frequency to track efficiency (counts/gamma) and calculate a ^{226}Ra conversion factor (pCi/cps).

Sample spectra were analyzed for activity in the 46.5 keV for ^{210}Pb, and activities at 295 keV (^{214}Po), 352 keV (^{214}Pb) and 609 keV (^{214}Bi) representing uranium series peaks were used to compute supported levels of ^{210}Pb. Calculation of ^{210}Pb dates followed the constant rate of supply model (Appleby and Oldfield 1978), which is able to quantify changing sedimentation rates.

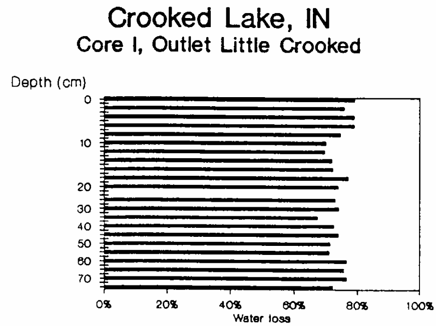
Water content of sediment cores is measured as a measure of the degree of flocculation of the sediment profile. In shallow water areas such information on the depth of the flocculent layer is extremely important as a measure of the likelihood of sediment resuspension via natural waves and boating activities. Water content of the Little Crooked Lake core increased from approximately 52% at its base to 80% in the most recently deposited sediments (Figure 16). In contrast, the water content of the core from eastern Crooked Lake at the outlet from Little Crooked displayed little stratigraphic varability and remained at greater than 70% along most of its length. The western Crooked core also displayed little variability and remained at greater than 80%.

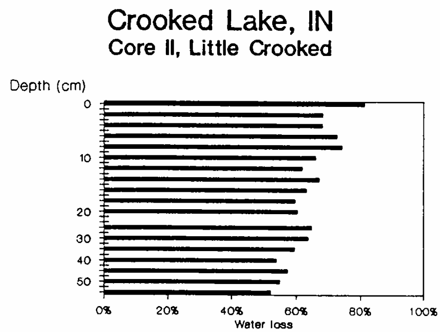
The more compact nature of the Little Crooked core is clearly related to the fact that the sediments were the most inorganic dominated of the lake cores (Figures 17 and 18). The second most inorganic sediments were found in the eastern Crooked core near the inlet from Little Crooked, while the western Crooked core displayed the least inorganic sediment content. The idea that the shift to a more inorganic dominated sediment in Little Crooked and the eastern end of Crooked is the result of increased delivery of watershed erosion products is supported by the previously discussed comparison of 1952 and 1990 bathymetric maps.

Total dry sediment accumulation rate based on ^{210}Pb profile dating increased progressively in Little Crooked from the mid 1800's into the early 1960's, after which it fluctuated but tended to decrease progressively to the present (Figure 19). A similar pattern was displayed by the western Crooked core. In both cores, there is a tendency for sedimentation rates during the 1960's and early 1970's to remain at the high values prior to declining to the present.

A good ^{210}Pb dated profile was not obtained from the eastern Crooked core, and the profile appeared to be somewhat disturbed near its bottom. Instead, we have used ^{137}Cs as a dating tool to give a rough approximation of recent sedimentation in this core. ^{137}Cs is produced via atomic fusion, and its deposit over the earth's surface has been directly related to the period of atmospheric testing of nuclear weapons following World War II. Peak deposition of this material was during the late 1960's and 1970's. The profiles for ^{137}Cs from all three cores suggest that approximately 20 cm of sediment was deposited in Little Crooked Lake after the 1960's, compared with 10-12 cm in both the eastern and western Crooked Lake cores (Figure 20). Although a good ^{210}Pb profile as not apparent in the eastern Crooked core, the correspondence between the eastern and western Crooked cores for their ^{137}Cs profiles suggests that in spite of increased delivery of inorganic rich sediments from Little Crooked to the eastern basin of Crooked, intra Crooked deposition patterns have likely been similar during the past two decades. Unfortunately, the eastern Crooked profile does not warrant further detailed interpretation.

The accumulation of organic sediments in Little Crooked increased progressively from the mid 1800's to peak core





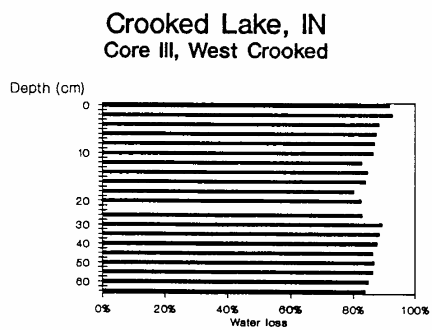


Figure 16. Profiles of sediment percent water.

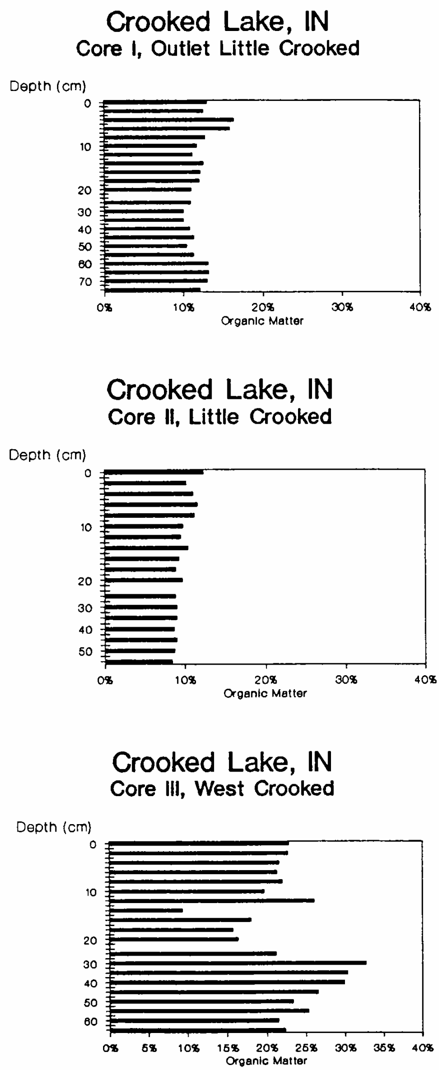


Figure 17. Profiles of sediment percent organic matter.

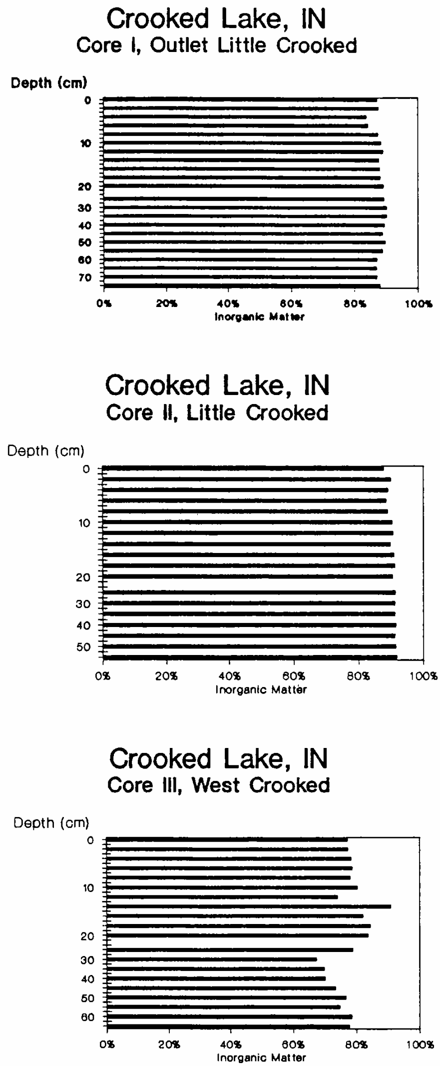
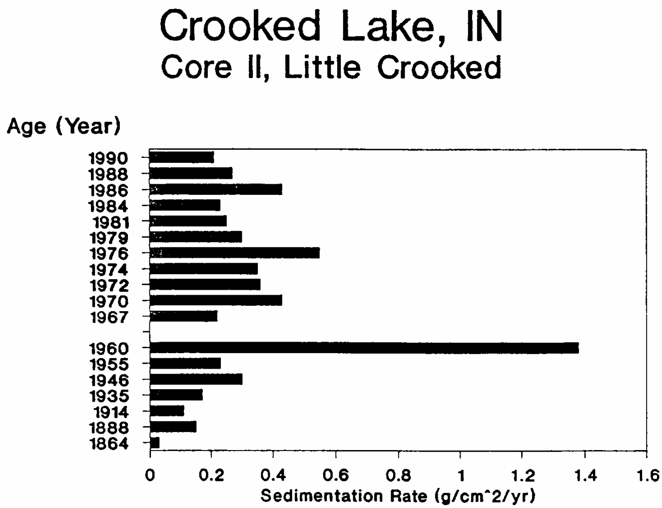


Figure 18. Profiles of sediment percent inorganic matter.



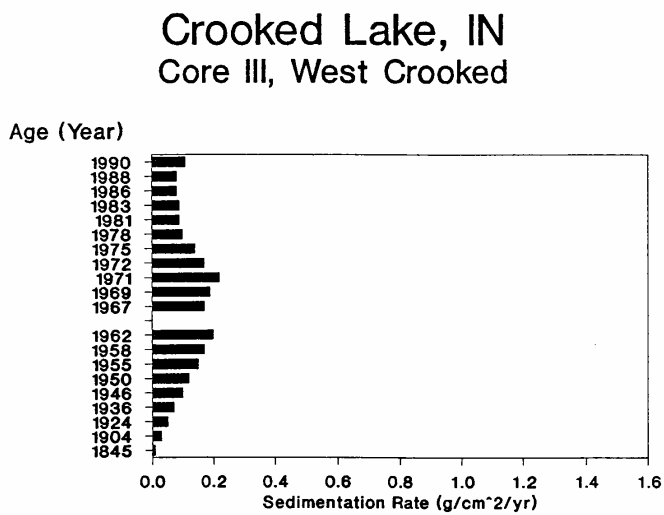


Figure 19. Profiles of sedimentation rate of dry matter.

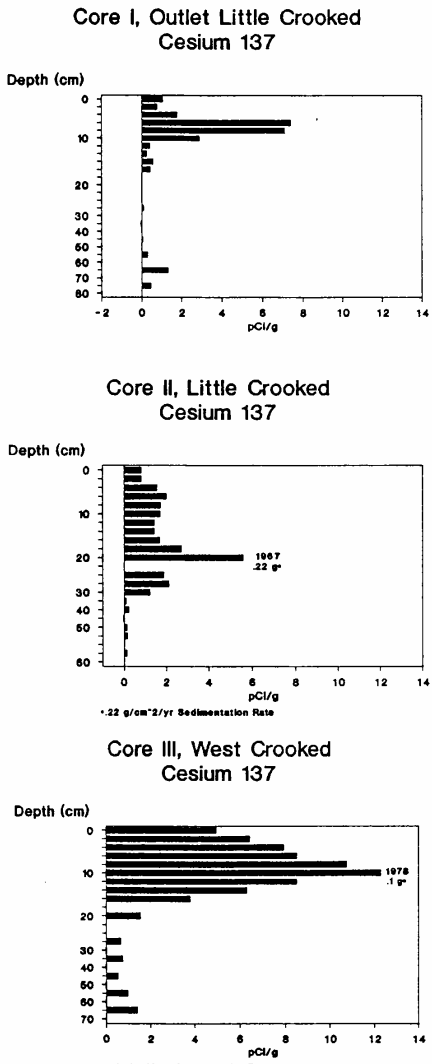


Figure 20. Profiles of ^{137}Cs in sediment cores.

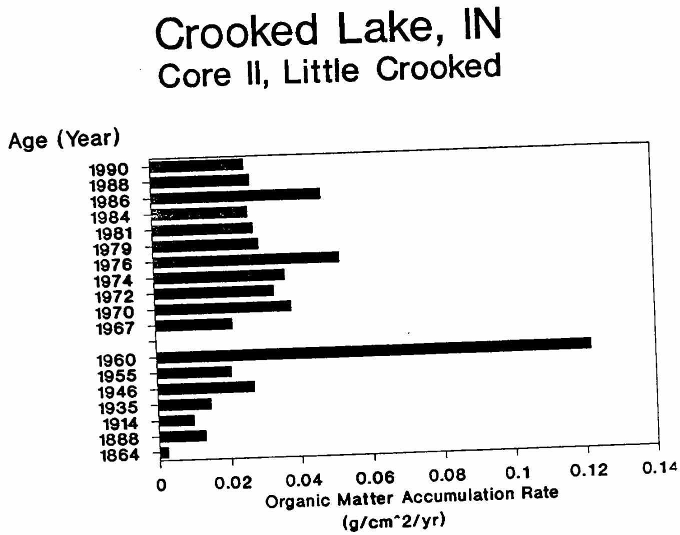
values during the early 1960's (Figure 21). Accumulation rates remained high during the 1960's and 1970's, after which they declined progressively to the present. Organic sedimentation rates in west Crooked increased progressively from the mid 1800's until the late 1950's, after which they declined slightly and remained relatively constant to the late 1970's. Following a further decline in the late 1970's, rates have remained relatively constant to the present.

Inorganic accumulation rates in Little Crooked increased progressively from the mid 1800's to the 1960's after which they have declined progressively to the present (Figure 22). Inorganic accumulation rates also increased progressively in western Crooked from the mid 1800's through 1960, but they remained relatively constant at high levels into the early 1970's. Values declined during the early 1970's and have remained a constant but low level from 1980 to the present. It is interesting to note that overall inorganic accumulation rates in the western Crooked core were smaller than those of Little Crooked Lake and are a reflection of the fact that Little Crooked Lake is a smaller basin and impacted greatly by sediments delivered via inlets from the northern portion of its watershed. The western Crooked site is not near any major inlet.

Total phosphorus concentrations in the Little Crooked core remained constant throughout most of the profile except in the most recently deposited sediments where they increased slightly (Figure 23). Total phosphorus concentrations in the eastern Crooked core declined progressively from the core bottom to 20 cm, above which they increased to the surface. A similar pattern is shown by the western Crooked core except that the mid core decline in phosphorus values occurs at 10 cm. In all three cores, the total phosphorus profiles parallel those of percent organic matter suggesting that most of the phosphorus entering the two lakes is in a biologically available form (Figure 24).

Total phosphorus accumulation rates in Little Crooked increased progressively from the mid 1800's to the early 1960's, declined into the early 1980's and remained relatively constant to the present (Figure 25). A similar historical trend is demonstrated by the western Crooked core except that accumulation rates of phosphorus at the latter site were less than half those of Little Crooked.

It appears that the major eutrophication period in the recent history of both Little Crooked and Crooked Lakes was prior to the early 1960's when the delivery of inorganic sediment and total phosphorus increased markedly. Although interyear variability was noted after this period, the annual accumulation rate of phosphorus actually declined in both lakes during the 1970's. There is a suggestion, however, in both cores of increased deposition of phosphorus



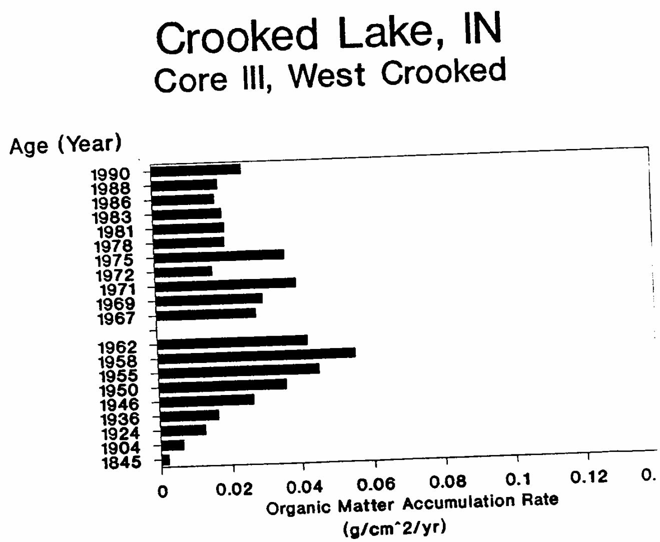
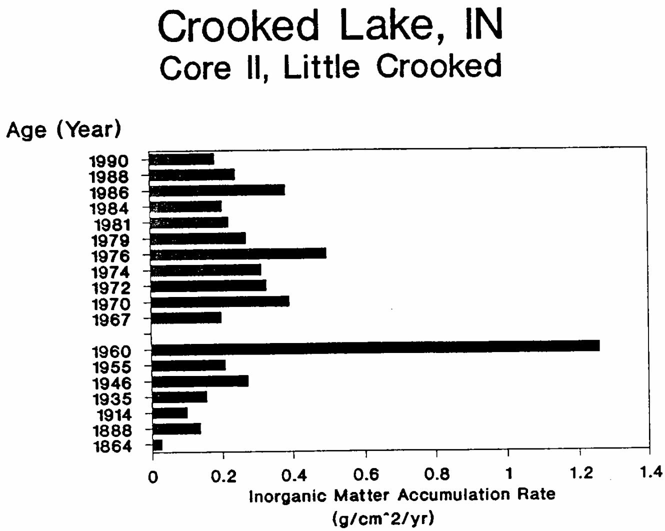


Figure 21. Profiles of organic matter accumulation rates.



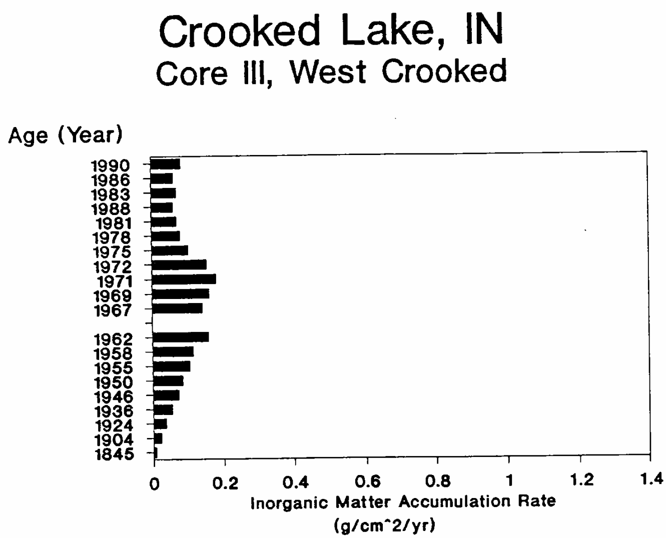
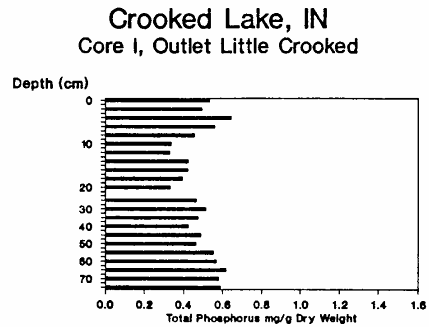
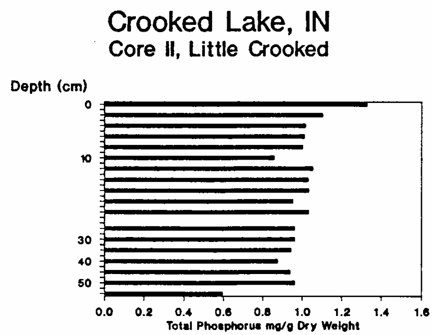


Figure 22. Profiles of inorganic matter accumulation rates.





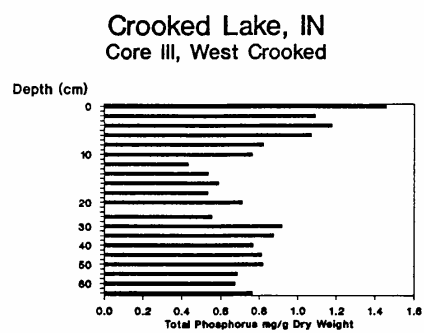


Figure 23. Profiles of total phosphorus concentrations.

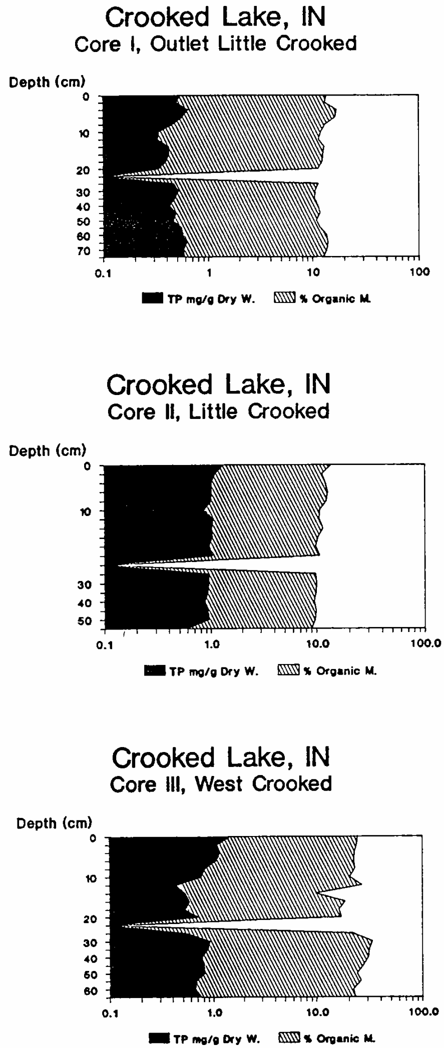
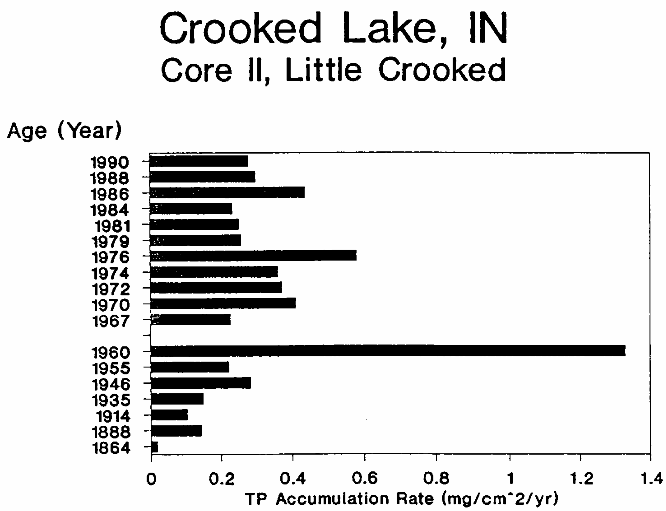


Figure 24. Profiles of total phosphorus versus organic matter.



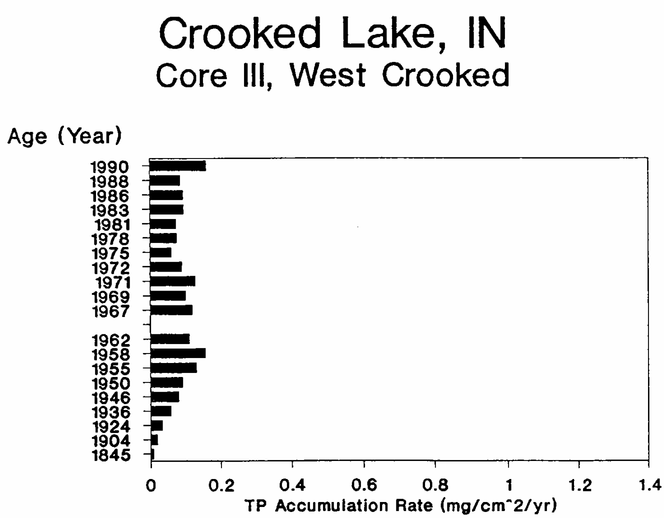


Figure 25. Profiles of total phosphorus accumulation rates.

in Little Crooked after 1984 and in western Crooked after 1981. It must be pointed out that during the post 1981 period signalling the progressive loss of ciscos in Crooked Lake, total phosphorus and inorganic matter accumulation rates in the lake were lower than reported during the 1960's and early 1970's.

THE CROOKED LAKE WATERSHED

INTRODUCTION

The approach of this part of the study is to specifically address the effect of the watershed on the lake. After preliminary investigation, the chosen method was to identify general area(s) of highest concern, and suggest possible methods of remediation. 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. What are the probable nutrient sources;
b. What are the probable sediment sources; and
c. How can sediment/nutrient sources be managed or reduced to mitigate impacts to the lake?

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

The Noble and Whitley County USDA-SCS offices were appraised of the areas felt to be contributing exessive amounts of sediment and nutrients or that would benefit from programs beyond the scope of this Lake Enhancement Program in meetings held in February and May 1991. The Whitley County Soil and Water Conservation District has pledged to help the Lake Association and watershed landowners 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.

NATURAL FEATURES

The Crooked Lake watershed falls in the Northern Lakes Natural Region (Homoya et al. 1985). This Natural Region is comprised of numerous freshwater lakes of glacial origin. Natural comunity 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.

Review of element occurence, or, endangered species records maintained by the IDNR, Division of Nature Preserves indicate that several State listed (endangered, threatened, rare, special concern, or watch list) plant and animal species have been documented from Crooked Lake and its watershed. These include the cisco (Coregonus artedii), liver elimia snail (Goniobasis livescens), four species of pondweed (Potamogeton Freiesii, P. praelongus, P. Robbinsii and P. strictifolius), lesser bladder wort (Utricularia minor), and Illinois hawthorn (Crataegus prona) to name a few. The area is also home to the Crooked Lake Nature Preserve, a 100 acre site located along the northeast shore (Figure 26). The Nature Preserve is comprised of several cover-types such as forested, old field succession to scrub/shrub, seep and marsh wetland systems. Techniques useful in preserving the natural features of the lake and watershed include:

a. Avoid relocation of natural stream channels. Relocation hastens the removal of runoff by increasing the velocity of flow. This in turn increases the erosive force of the stream and prevents settling of material.

b. Avoid building close to wooded ravines or stream banks. Encroachment on steep banks weakens the stability of the slope, thus increasing the risk of erosion. Building too close to ravines and stream banks also infringes upon the riparian zone, a valuable habitat in limited supply.

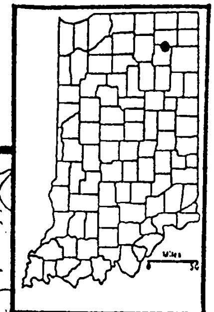
c. Preserve natural vegetation adjacent to water areas. In addition to providing valuable habitat, vegetation adjacent to water areas provides an excellent baffle and nutrient/sediment filter (minimum of 66′ is recommended).

d. Avoid construction in, or drainage of, wetlands. Wetlands provide habitat for more endangered species than

Crooked Lake Nature Preserve

County: Whitley, Noble
Size: 100 acres

Map: Merriam 7.5' Quad
Ownership: Nature Preserves-IDNR
Acres, Inc.



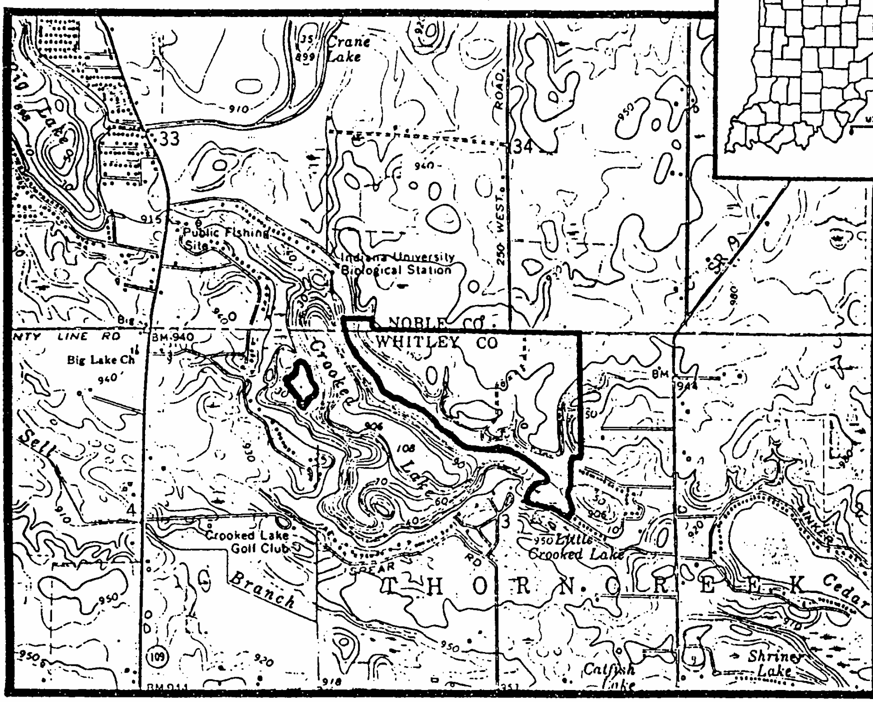


Figure 26. Location of Crooked Lake Nature Preserve.

any other cover-type. Wetlands are also active filters of watershed generated sediment and nutrients as well as natural reservoirs for flood storge and prevention.

PHOTOSPECTROSCOPY

LAND-USE. 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, denisty, and respiration, by photographing specific intensities of electromagnetic radiation emitted. On the photo, fallow lands, lake and senescent vegetation appear as grey or black; active or vigorously growing vegetation appear as varying hues of red.

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, about 1.5 inches of rain fell over the project area in the 4 weeks prior to the photo date, this was 0.8 inches below normal, with the driest period occurring the week the photograph was taken. This rainfall deviation was not of sufficient amount or duration to alter normal land use cover types. The photographs used for this study were taken on the August 20, 1987 fly-over at a scale of 1:20,000 (Figure 27).

In doing the land use study of the Crooked Lake watershed, the entire watershed was laid out on the photographs using a transparency. The size of an overlay grid (5 acres) was then calculated, drawn, and then placed over the photos. From there, the watershed was divided into the following land use categories:

Figure 27. Color infrared aerial photograph of the Crooked Lake watershed. Photo date 20 August 1987.

* Agriculture
* Forested Wetlands
* Public Access
* Waterbodies
* Forested
* Golf Course
* Residential
* Wetlands

Results of the study are shown in Table 14. Land use is graphically represented in Figure 28.

LAND-USE TRENDS. For the purpose of this study, aerial photographs from 1951, 1964, 1972, 1981, and 1987 were examined to determine trends in land-use within the Crooked Lake watershed (Figure 29).

Historically, there have likely been few major changes in land-use in the Crooked Lake watershed. The primary land use in the watershed is agricultural, however, this appears to be declining. Minor shifts in the type of agricultural land use have been frequent due to the varying demands of the world market.

The Crooked Lake watershed has witnessed a continued and constant decline in the aerial coverage of land in agricultural crop production, from 463 acres in 1951 to 297 acres in 1987. Corresponding with this decline in crop land from 1951 to 1981 was a marked increase in residential land use (25 acres 1951 to 113 acres in 1981). Residential land use appeared to top out in 1981. Crop land, however, continued to decrease between 1981 and 1987. The shift in recent years is attributed to conversion to wetland and woodland brought about by USDA Conservation Reserve Programs offered beginning in the mid 1980's as well as the dedication of the Crooked Lake Nature Preserve.

According to the Whitley County SCS, projected agricultural land-use trends in the Crooked watershed are not expected to change significantly. Recent trends in agricultural practices have included the shift towards conservation programs. Eighty four percent (250.2 acres) of the agricultural land in the wateshed is in no-till or Conservation Reserve Programs (CRP). It was noted, however, that farmers needed to maintain more crop residue.

Contrary to the general trend of wetland and woodland conversion in Indiana, the coverage of wetland and woodland in the Crooked Lake watershed was fairly constant between 1951 and 1981. As indicated above, the acreage of both wetlands and woodlands actually increased between 1981 and 1987. While this is a good indicator for improved conditions (water quality and erosion) from the watershed, it is important to realize that the CRP is a 10 year program. Much of the land currently in CRP is 4 to 6 years into the program. What will be done with this land when it comes out of CRP? This should be monitored, and efforts made to keep

Table 14. Crooked Lake land use summary.

CROOKED LAKE LAND-USE SUMMARY TABLE

Cover Type	Acres	% of Total
AGRICULTURE	298.6	30.9
FORESTED	291.5	30.2
GOLF COURSE	46.4	4.8
PUBLIC ACCESS	2.9	0.3
RESIDENTIAL	107.3	11.1
WATERBODIES	203.0	21.0
WETLANDS:		
EMERGENT WETLANDS	9.7	1.0
FORESTED WETLANDS	7.1	0.7
WATERSHED TOTAL	966.5	100.0

CROOKED LAKE WATERSHED STUDY
LAND USE

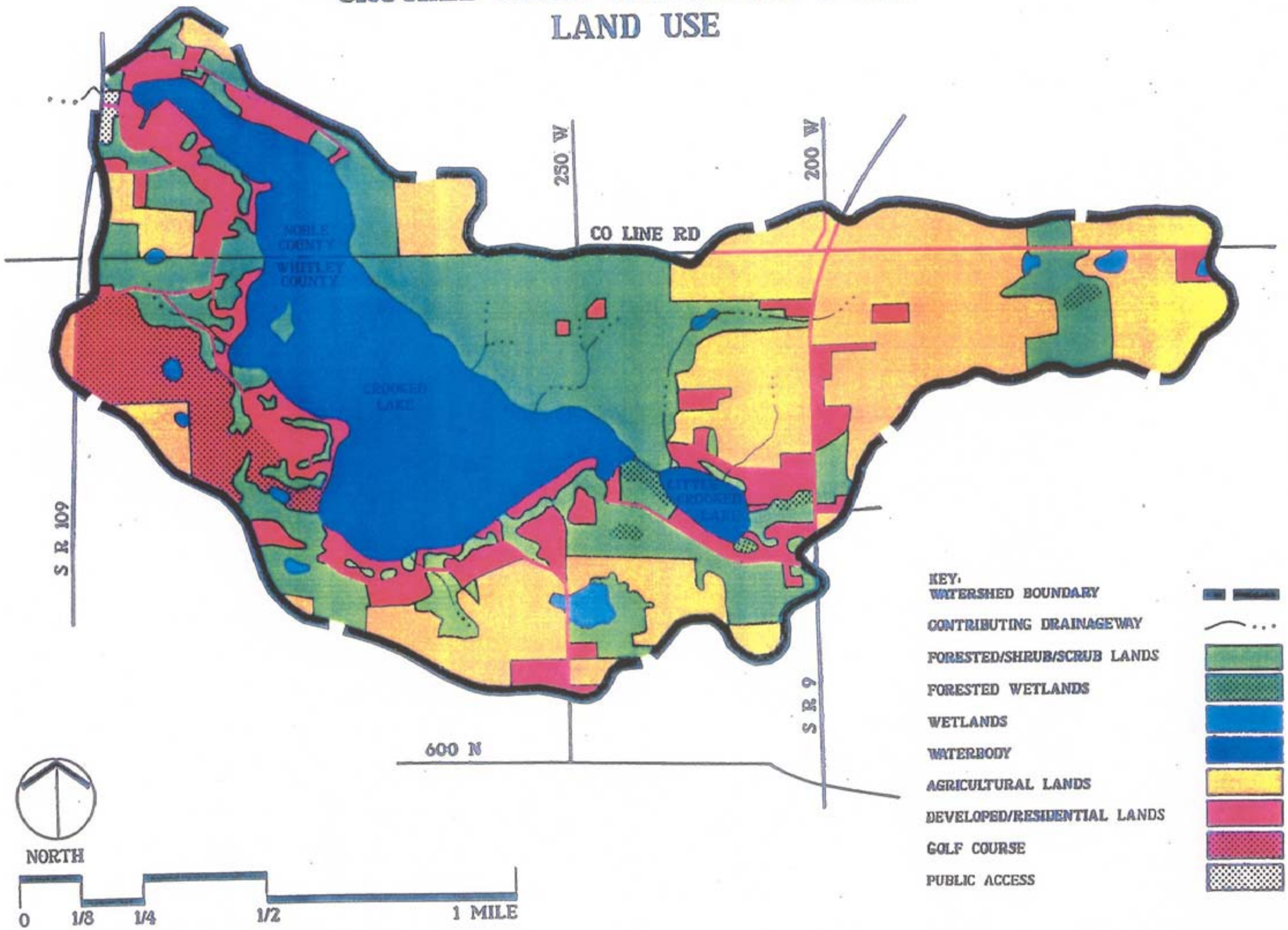


Figure 28

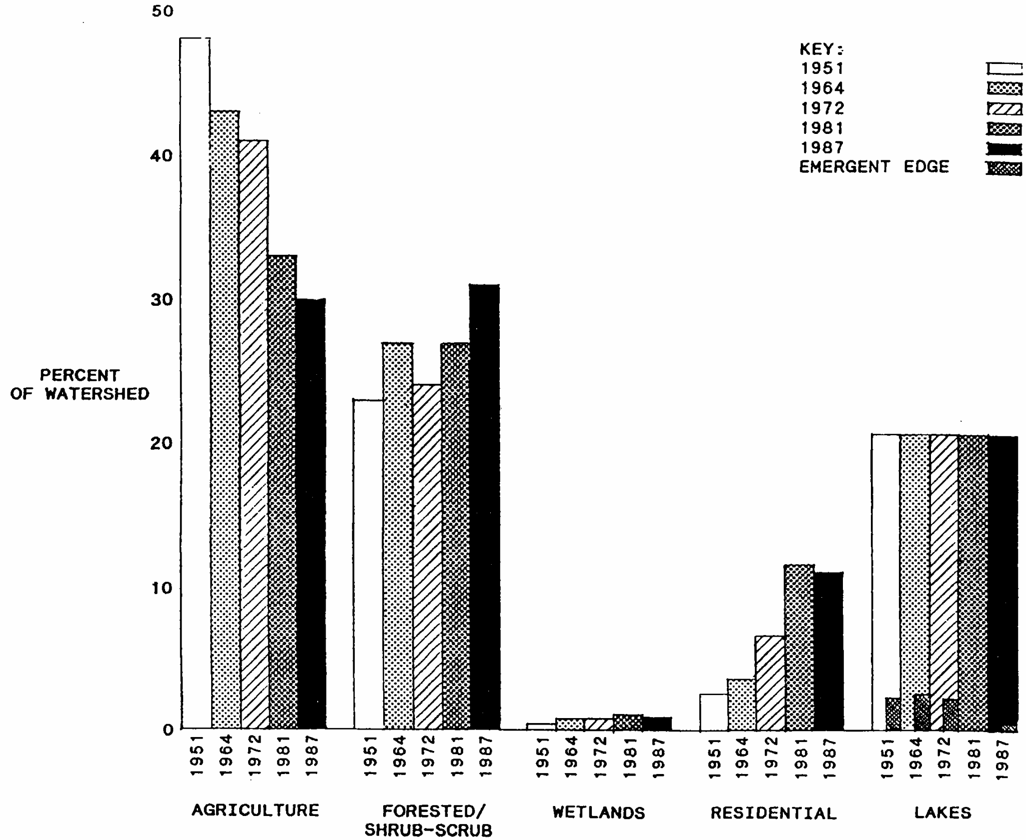


Figure 29. Land-use trends for the Crooked Lake watershed as noted from 1951, 1964, 1972, 1981 and 1987.

these lands in a natural state, or at a minimum, in conservation tillage.

The most striking "land-use" change actually occurred within the shores of Crooked Lake. From 1951 to 1972 approximately 18% (34 acres) of the total lake area was comprised of emergent (wetland) vegetation.

By 1981 and 1987, the emergent vegetation in Crooked Lake had all but disappeared. One possible explanation for the loss in emergent fringe could be a change in the lake level. In 1948, the legal level of Crooked Lake was established at 905.69 feet (msl). According to monitoring records provided by IDNR Division of Water (IDNR 1990), Crooked Lake has short duration (hours-days) fluctuations in lake level, varying a total of 2.25 feet between 1943 and 1990. The normal lake level remained fairly constant over the 47 year monitoring period, thus, water level fluctuation was likely not the reason for the loss in emergent fringe.

Another more plausible explanation for the loss in fringe might be explained in the fact that residential use around Crooked Lake nearly doubled between 1972 and 1981. Factors involved with increased residential usage may include increased septic leachate; increased sedimentation (construction, shoreline erosion, motor boats, etc.) or increased (localized) use of aquatic herbicides. Although we were not able to find supporting evidence for increased herbicide use in our research, it is likely that an increase in lake users may have prompted a shift in the perceived lake use.

It is interesting to note, when queried about when the water quality of Crooked Lake appeared to decline, many lake residents responded "the early 1980's". Two potential causes for declining water quality during the early 1980's may be identified from a changing land-use perspective: 1) increased residential usage; and 2) a loss in emergent wetland fringe within the lake (possibly related to the former). Other watershed factors customarily responsible for declining water quality were either improving (less land in crop production) or had been in place for a number of years (the golf course).

GEOLOGY

BEDROCK. The Crooked Lake watershed is underlain by bedrock of the Antrim Shale Formation (Gray 1987). This formation consists mainly of black shale, with some gray shale and limestone lower in the formation. The Antrim Shale was laid down in the mid to upper Devonian Period of the Paleozoic Era (about 375 million years ago).

Quarternary. The shale deposits of the Crooked Lake area are covered by up to 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 glacial deposits of the Crooked Lake watershed are derived from northwestern limits of the Ontario-Erie Lobe of the Wisconsinan Ice Sheet. In addition to the common mixed drift and till glacial deposits, the watershed contains areas of stratified drift in linear form. This is characteristic of unique ice forms, such as collapsed sub-ice tunnels and collapsed open ice channels.

Hydrology. The Crooked Lake watershed is a sub-drainage basin to the Tippecanoe River which is part of the larger Wabash River basin. The main water supply comes from ground water stored in the sand and gravel deposits of the Wisconsin till aquifer. The watershed of Crooked Lake receives an average annual precipitation of 36.9 inches with a standard deviation of 9.4 inches.

Soils. The soils of the Crooked Lake watershed are grouped into two categories by the Noble and Whitley County Soil Surveys: 1) In Noble County, th Morley-Blount Association is listed as the dominant soil association. 2) In Whitley County, the Morley-Glynwood Association, is listed as the dominant soil association. Morley soils are typically deep, moderately drained, and frequently occur on hillsides and drainageways. The Glynwood soils are similar to Morley soils, however, they are generally located lower on hillsides and flatter situations. Blount soils are also deep, but rather poorly drained and usually on flats with slopes generally less than 4 percent.

In general, the Morley-Blount Association is characterized as soils well suited for agricultural land-use. According to the Whitley County Soil Survey, the Morley-Glynwood Association is best adapted for recreational use. Both associations are susceptible to extreme erosion problems and are often limited by wetness, which makes septic suitability a high concern in residential areas.

TOPOGRAPHY. The watershed of Crooked 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. Drift is a collective term referring to any glacially generated sediment. The hill and valley landforms of the Crooked Lake watershed are difficult to convert to agricultural production which is responsible for the many wetlands and wooded lands throughout the area.

The highest point in the Crooked Lake watershed is 985 feet above sea level located at the northeastern tip of the watershed. The lowest point in the watershed is about 797 feet msl (bottom elevation) in the eastern basin of Crooked Lake. The mean basin drainage gradient between the 3 primary inflows in the Crooked Lake watershed is 77.7 feet/mile.

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 rills or 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. Slopes in the Crooked Lake watershed range from about 0 to as much as 43 percent.

The intent of the Severe Slope study-map (Figure 30 is to illustrate further the fabric of the land forms in the watershed. Areas with severe slopes comprise 181 acres or 19% of the Crooked Lake watershed. Severe slopes detailed in this study range from 10 to 43 percent. The majority of severely sloping areas occur around the lake and along contributing drainageways. 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 this report.

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 Noble and Whitley Counties, and data provided by the SCS offices (Table 15), soils of the HEL designation were mapped as shown in Figure 31.

The Crooked Lake watershed was first analyzed to determine the total extent of HEL map units in the watershed. The HEL soils of the watershed comprise approximately 577 acres or 60% of watershed area. The study area was then further divided to determine the extent of HEL currently in crop production. HEL in agricultural production are generally of greater concern to the overall water quality of a lake because these lands are more susceptible to erosive forces than HEL with established permanent vegetative cover. The exception to this is HEL along steep sided ravines and drainages. While the HEL study was based strictly on HEL map units supplied by the USDA Soil Conservation Service, it does not take into account non-HEL map units which may have inclusions of HEL soils.

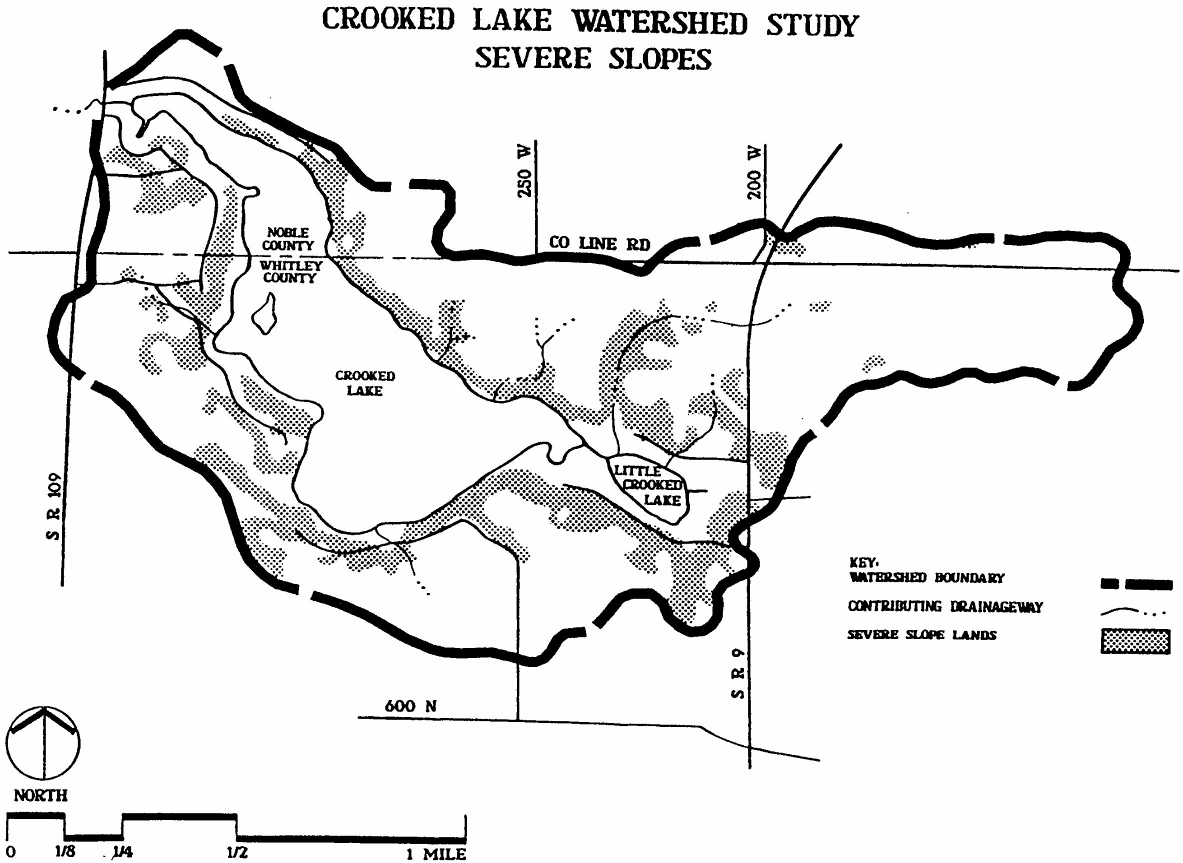

CROOKED LAKE WATERSHED STUDY
SEVERE SLOPES
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
250 W
200 W
CO LINE RD
S R 109
S R 9
600 N
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
SEVERE SLOPE LANDS
NORTH
0
1/8
1/4
1/2
1 MILE

Figure 30.

Table 15. Highly erodible land (HEL) soils of the Crooked Lake watershed.

BLOUNT silt loam, 1 to 4% slopes
GLYNWOOD loam, 3 to 6% slopes
MORLEY loam, 3 to 6% slopes
MORLEY loam, 6 to 12% slopes
MORLEY loam, 12 to 20% slopes
MORLEY loam, 20 to 30% slopes
MORLEY clay loam, 5 to 12% slopes
MORLEY clay loam, 12 to 20% slopes

CROOKED LAKE WATERSHED STUDY
HIGHLY ERODIBLE LANDS (HEL)

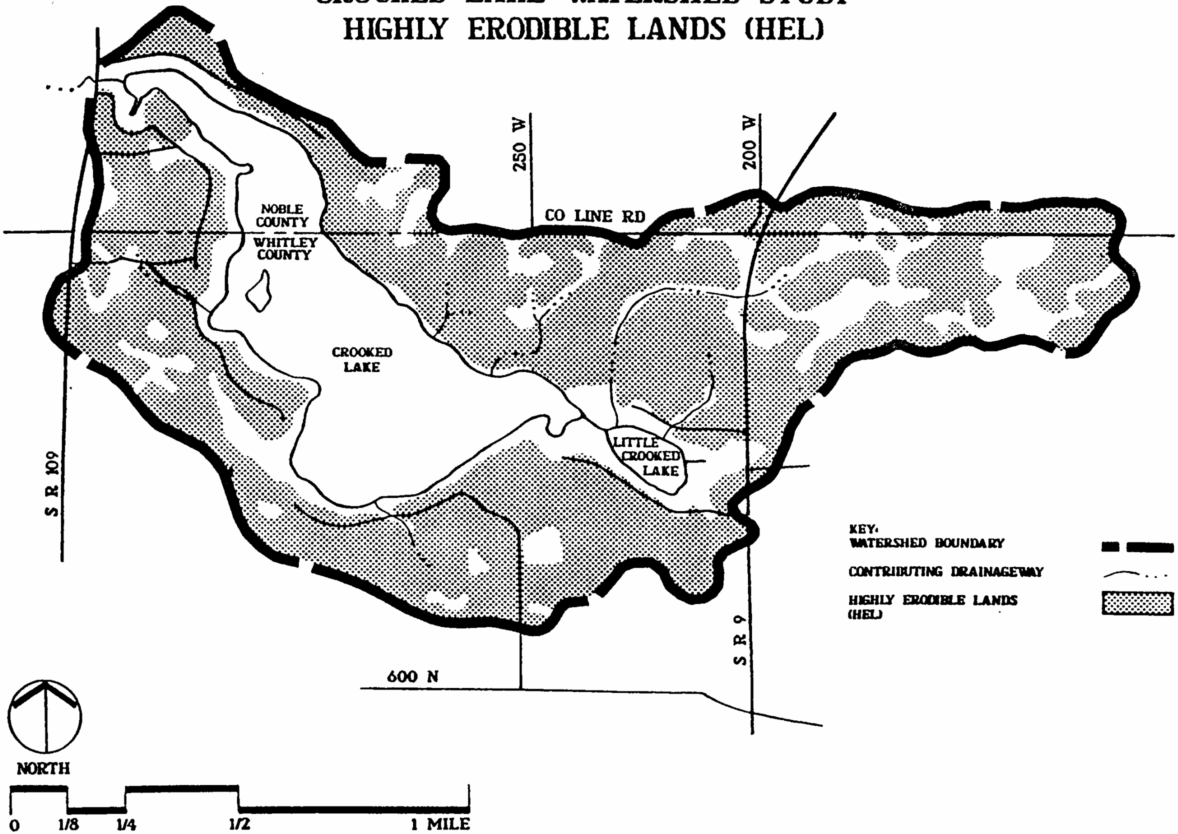


Figure 31.

WATERSHED MANAGEMENT

HIGHLY ERODIBLE LANDS OVERLAYS. The intent of this HEL/Severe Slope Overlay (Figure 32) is to emphasize the areas of the watershed where severe erosion problems are likely to occur. The 163 acres, detailed in the HEL/Severe Slope Overlay represent the worst case HEL areas of the Crooked Lake watershed. The majority of these lands are near or adjacent to the lake or large contributing drainages. It is likely that the worst case area is along the "Farm Ditch" (Pearson 1990) where steep banks combine with HEL and high flows to produce excessive erosion. Grade stabilization techniques or more advanced biotechnical solutions should be implemented in this area.

The 25 areas defined in the Agricultural Lands/HEL/Severe Slope Overlay (Figure 33) were in crop production as of 1987. The HEL/Severe Slope Agricultural lands shown in the south and west regions of the watershed were not in CRP nor conservation tillage programs at the time of this study. Every effort should be made to enlist those lands into CRP, conservation tillage or other land treatment programs (grassed waterways, filter strips, field borders, etc.).

EROSION: CAUSES AND PREVENTION

Erosion of soil is primarily caused by the force of raindrops striking the ground, and, secondarily 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 (Eviston et al. 1990). Types of soil erosion probable or noted in the Crooked Lake watershed are:

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.

CROOKED LAKE WATERSHED STUDY
HEL/SEVERE SLOPES OVERLAY

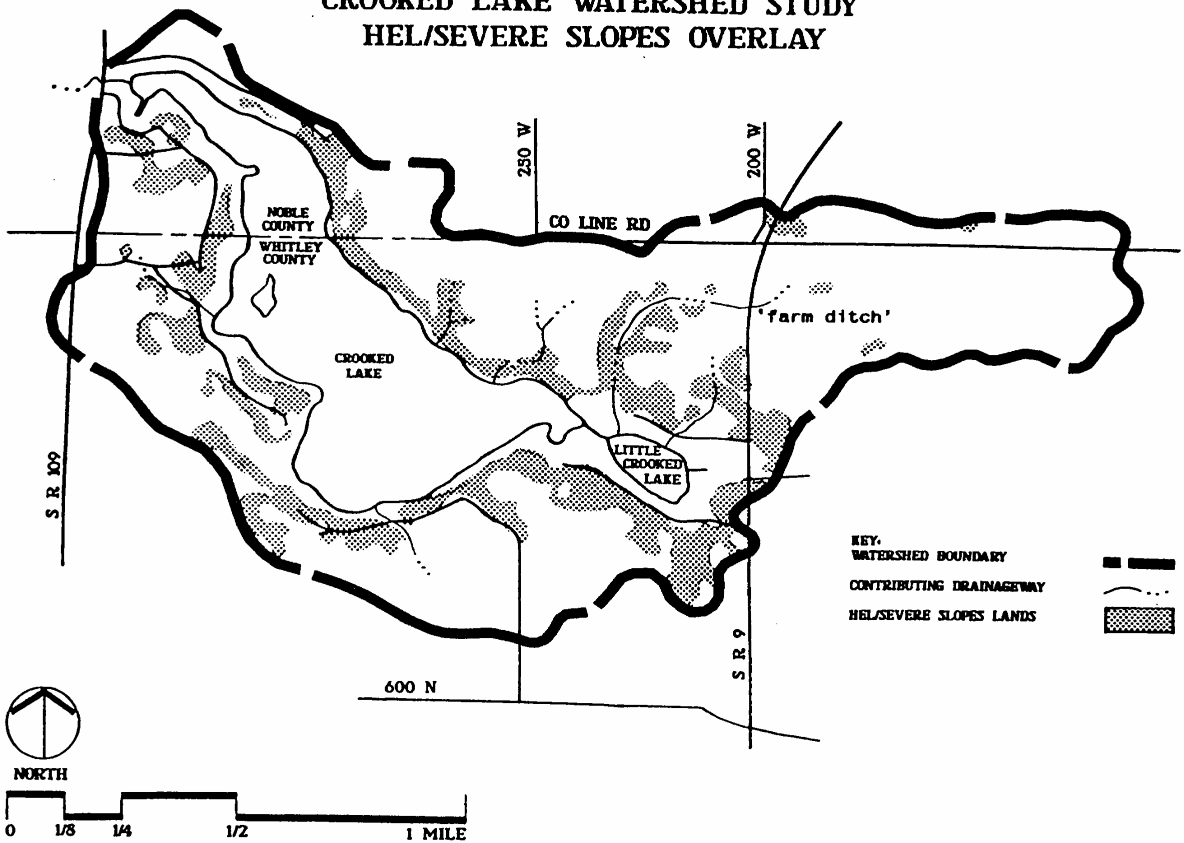


Figure 32.

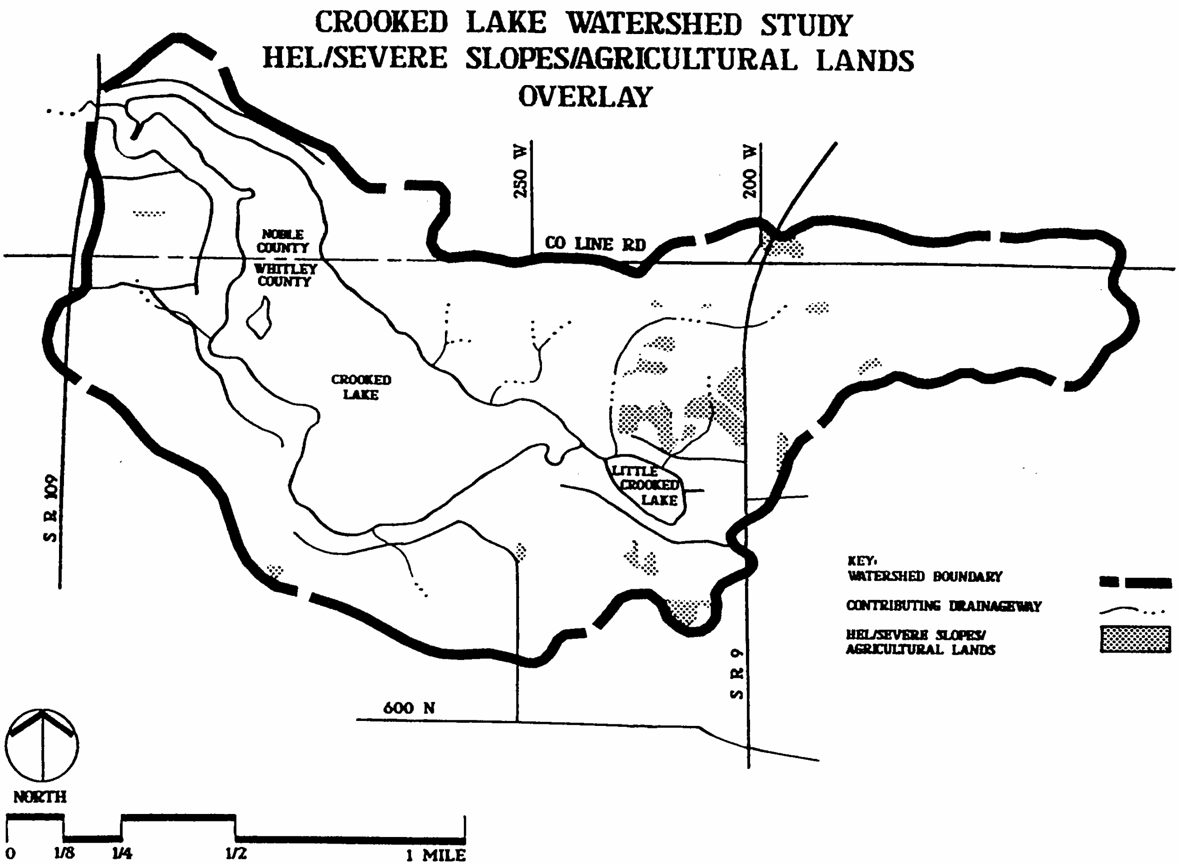

CROOKED LAKE WATERSHED STUDY
HEL/SEVERE SLOPES/AGRICULTURAL LANDS
OVERLAY
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
S R 109
S R 9
600 N
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
HEL/SEVERE SLOPES/
AGRICULTURAL LANDS
NORTH
0
1/8
1/4
1/2
1 MILE

Figure 33.

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.

! PREVENTION IS EASIER THAN CORRECTION !

Useful concepts in erosion prevention and control:

a. Maintain vegetative cover wherever possible

   Natural vegetative cover is the best protection against raindrop erosion and the best binder of soil particles.

b. Protect sloping areas.

   Vegetation is difficult to establish and maintain once the slopes have been eroded.

c. Divert runoff from severely sloping areas

   Flow over sloping areas increases the velocity of runoff, thus increasing the likelihood of erosion.

d. Row cropping should be done parallel to slope contour.

   Contour farming in effect breaks up the slope length into shorter segments (terraces), thus decreasing the threat of both sheet and rill erosion.

e. Utilize multiple cropping or landscaping parallel to slope contour when natural cover is not maintained.

   Multiple cropping breaks up long slope lengths and slows overland flows by effectively creating a series of filters.

f. Stabilize drainage areas immediately following any construction or "maintenance".

   This presents erosion of unprotected land.

g. Leave natural buffer areas along streams and ditches.

   Vegetation adjacent to open water couses provides an excellent baffle and nutrient/sediment filter (minimum of 66 feet is recommended).

h. Stabilize stream bank or ditch escarpments.

Utilize natural vegetation and/or biotechnical methods to protect against natural bank erosion and undercutting.

Biotechnical methods are defined here as the use of mechanical (riprap, fabric) and natural (grass, willow) means to secure unstable soils and embankments.

i. Utilize sediment ponds below "open" sloping lands.

This traps runoff borne pollutants ahead of drainage systems where they are difficult or impossible to recover.

j. Construct and maintain sediment control structures prior to construction of any lake or waterfront development.

This will prevent the unnecessary discharge of construction generated sediments directly into the lake.

k. Implement applicable conservation tillage method.

Conservation tillage is viewed as the most effective method of preventing erosion due to agricultural practices.

CONSERVATION TILLAGE. There are several methods of tillage currently utilized in corn and soybean production: moldboard plow, chisel plow, large blade (deep) disc harrow, small blade (shallow) disc harrow, ridge-till, and no-till. Conservation tillage systems are becoming more widely accepted due to improved yields, greater savings of soil (and soil bound nutrients), water, and money.

The no-till conservation tillage/planting system has been identified as one of the most effective conservation practices available to farmers in Indiana. Using the Soil Survey of Noble and Whitley Counties (USDA-SCS, 1977 and 1990, respectively), soils and tillage data provided by local SWCD and SCS offices (AY-210), and watershed data generated by this report, an overlay was prepared graphically representing agricultural lands which are well or highly adapated to no-till conservation tillage/planting (Figure 34). The Suitability for Conservation Tillage overlay indicates that a majority of the agricultural lands in the Crooked Lake watershed are moderately to highly adapted to no-till conservation tillage systems.

SEPTIC STUDIES. Ineffective septic systems have been documented to contribute excessive amounts of nutrients to a

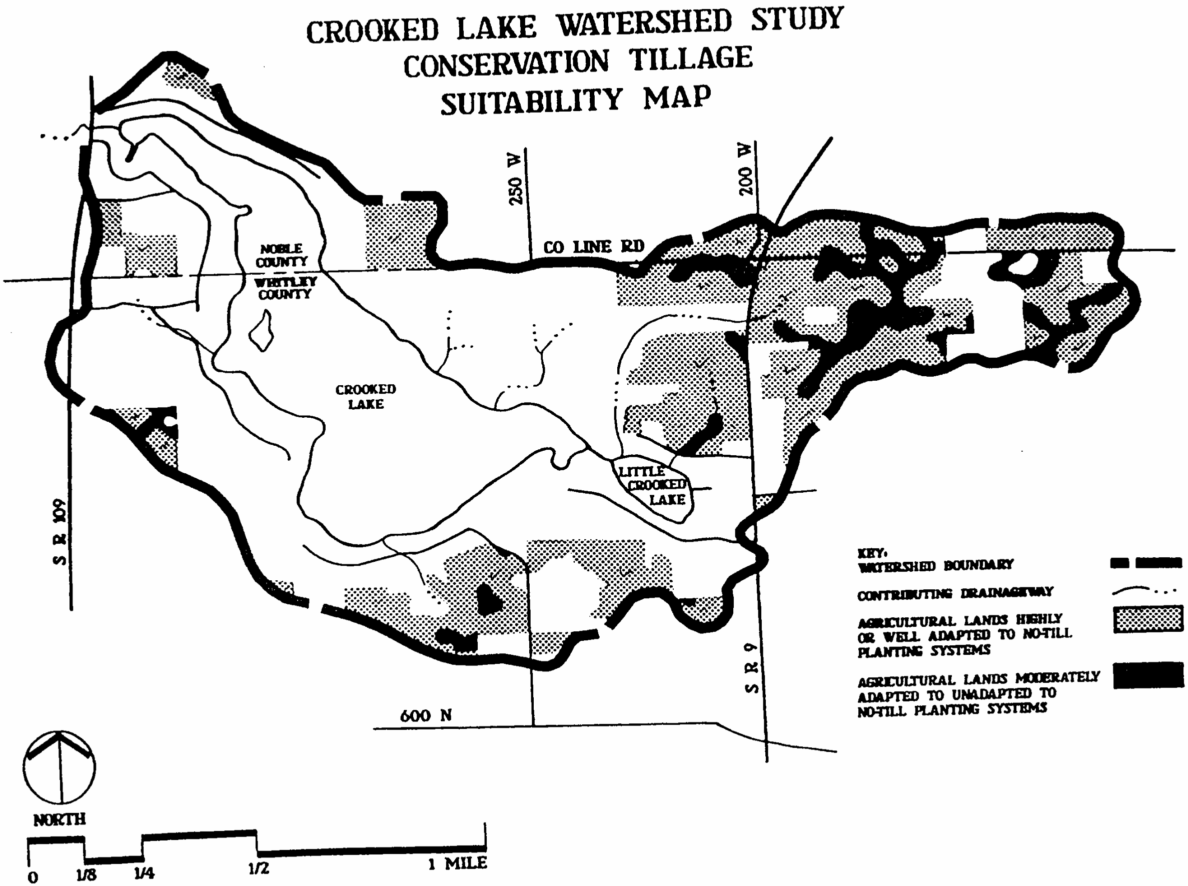

CROOKED LAKE WATERSHED STUDY
CONSERVATION TILLAGE
SUITABILITY MAP
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
S R 109
S R 9
600 N
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
AGRICULTURAL LANDS HIGHLY OR WELL ADAPTED TO NO-TILL PLANTING SYSTEMS
AGRICULTURAL LANDS MODERATELY ADAPTED TO UNADAPTED TO NO-TILL PLANTING SYSTEMS
NORTH
0
1/8
1/4
1/2
1 MILE

Figure 34.

lake. This is supported by the Coliform Bacteria data collected in the lake during the early 1980's (Appendix E). Initially, the goal of this study was to estimate potential septic system inefficiencies based solely on the likelihood of septic systems located in saturated soils. Upon further investigation of lake residences, it was determined that homes located on steep slopes also posed a potential septic leachate problem (Earth Source Inc. 1990).

In general, septic system efficiencies are based on the need for sewage effluent to be in contact with well drained soils (and the organisms residing on these soils) of sufficient duration to provide adequate treatment. The raw sewage is decomposed by organisms requiring aerobic respiration, thus requiring well-drained soils. The assumption (1990) was made that septic tank-type systems are in place for those residences around Crooked Lake. 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.

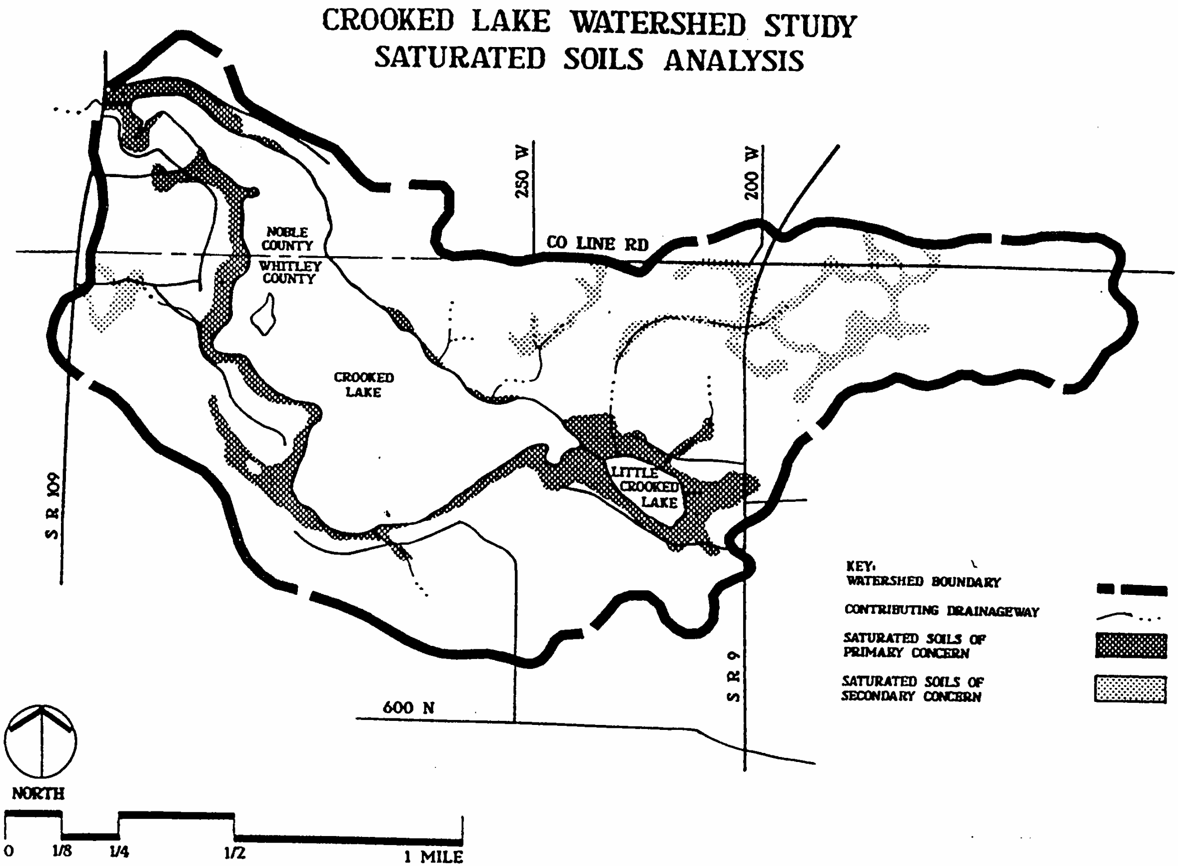
Using data collected on saturated soils (USDA-SCS 1988, Table 16), USGS topography, and comparing it with building information obtained from 1951, 1964, 1972, 1981, and 1987 aerials (the existing data base of the Noble and Whitley County Sanitarians Offices were not sufficient to determine the age of specific septic systems) trends were established indicating residences of **primary concern**: septic systems that were located in saturated soils or on slopes too great to provide adequate treatment; and, residences of **secondary concern**: septic systems that were likely to be located in saturated soils or on slopes too great to provide adequate treatment (Figures 35 and 36).

The findings of this study, based on a summation of data (Figures 37 and 38), indicate an upward trend toward building in saturated soils or on steep slopes. This trend is especially evident between 1972 and 1981. As of 1987, the Crooked Lake shore was nearly completely developed. Seventy-three of the 127 homes (57.5%) were located in saturated soils or steep slopes of primary concern. An additional 33 homes (26.0%) were situated in areas of secondary concern (areas likely to provide inadequate septic treatment).

The findings of this study support the need for the proposed Tri-Lakes Regional Sewer District (TRSD). The TRSD engineered by Philip L. Schnelker Inc., will serve the Tri-Lakes, Little Crooked and Crooked Lakes. Improvements to the sanitary sewer system will include installation of sanitary

Table 16. Poorly drained soils of the Crooked Lake area. Adapted from USDA-SCS Indiana Technical Guide (1988).

COESSE silty clay loam	EDWARDS muck, drained
HOUGHTON muck, drained	MARTISCO muck, drained
MARSH	MERMILL loam
MILFORD silty clay loam	MUSKEGO muck
PEWAMO silty clay loam	SARANAC silty clay loam
SHOALS silt loam	WALLKILL silty clay loam
WASHTENAW silt loam	



CROOKED LAKE WATERSHED STUDY
SATURATED SOILS ANALYSIS
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
S R 109
S R 9
600 N
NORTH
0
1/8
1/4
1/2
1 MILE
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
SATURATED SOILS OF PRIMARY CONCERN
SATURATED SOILS OF SECONDARY CONCERN

Figure 35.

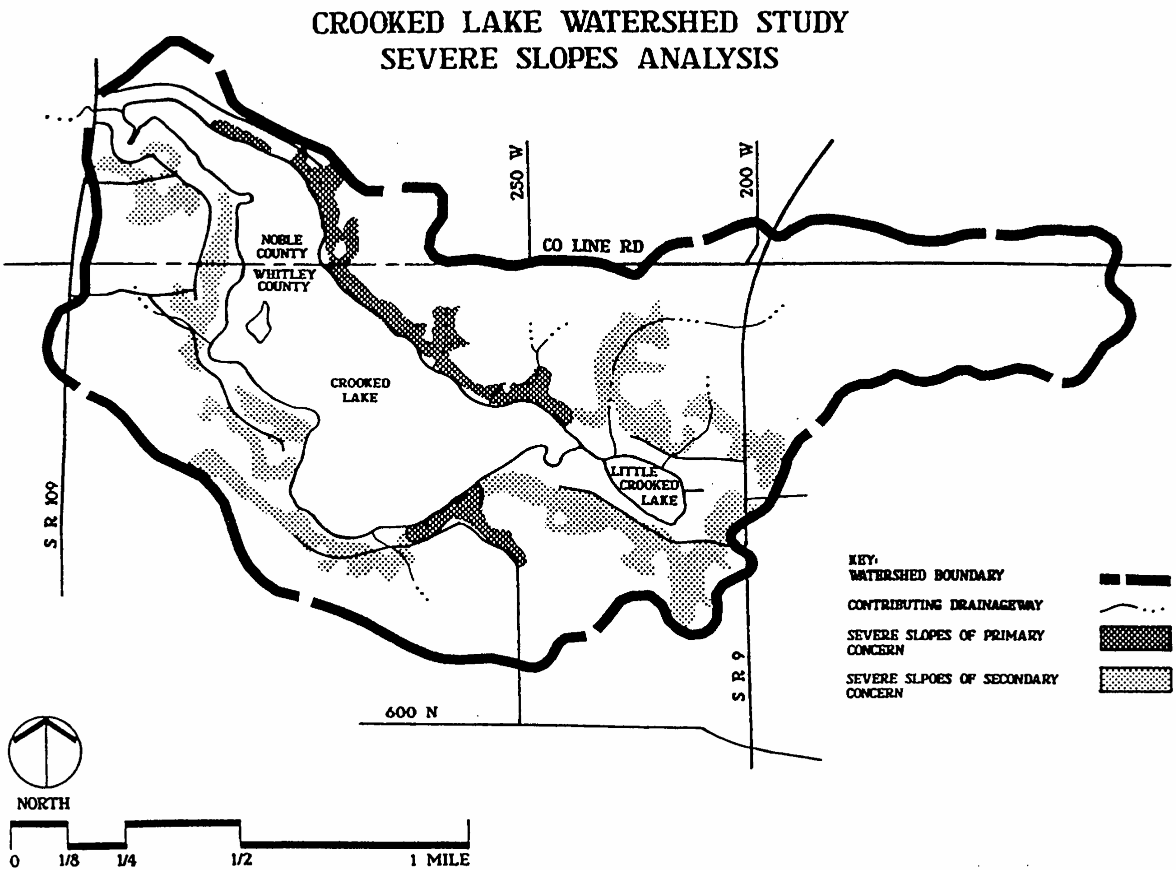

CROOKED LAKE WATERSHED STUDY
SEVERE SLOPES ANALYSIS
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
S R 109
S R 9
600 N
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
SEVERE SLOPES OF PRIMARY CONCERN
SEVERE SLPOES OF SECONDARY CONCERN
NORTH
0
1/8
1/4
1/2
1 MILE

Figure 36.

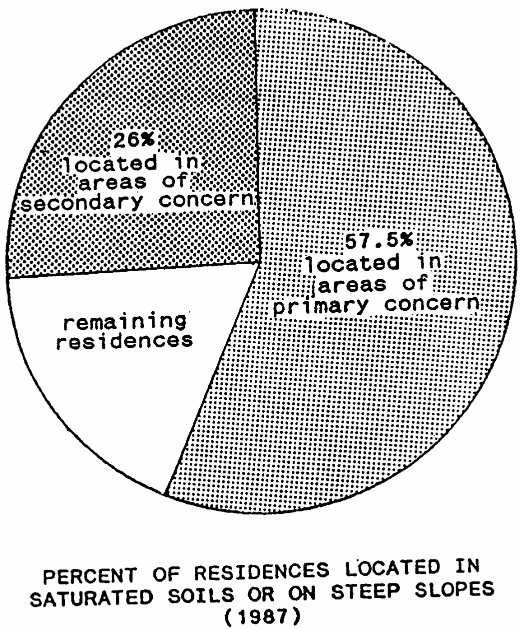


Figure 37. Lake residences septic suitability profiles; trends based on 1951, 1964, 1972, 1981 and 1987 aerials.

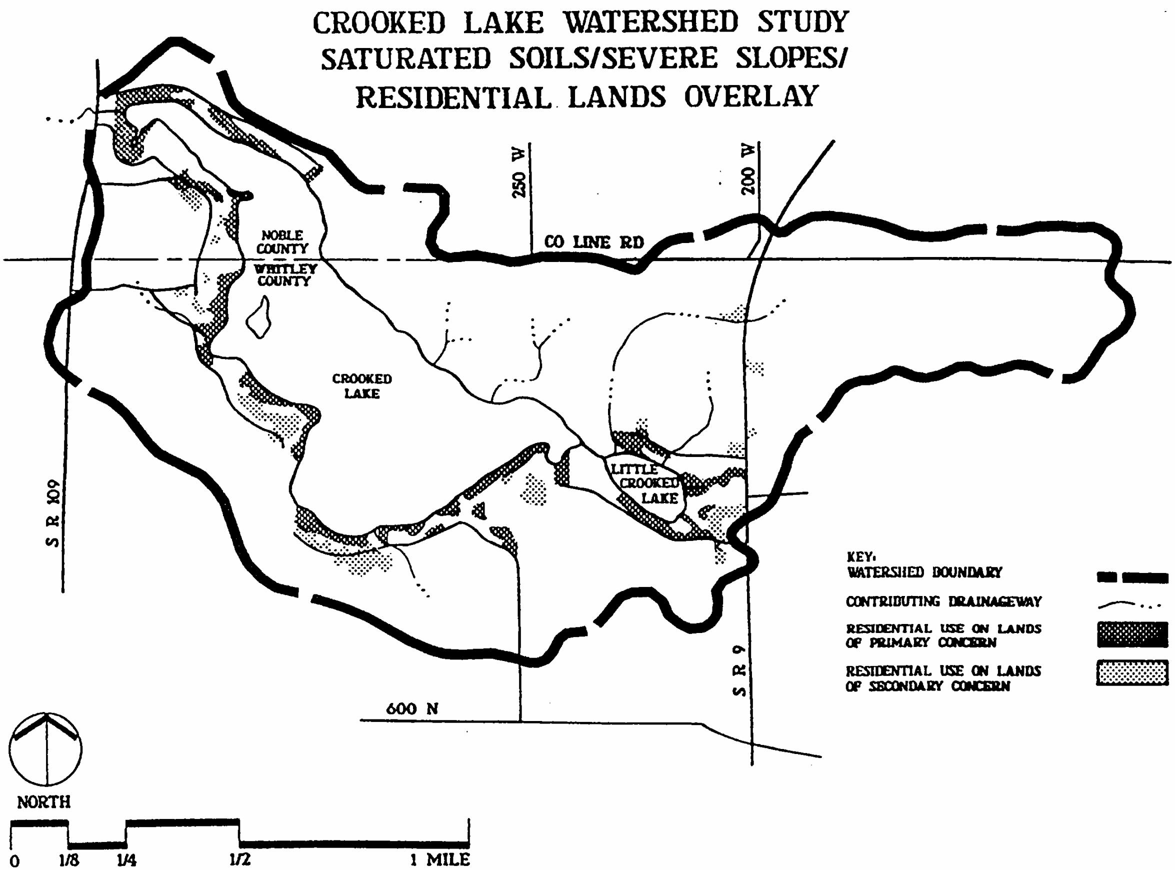

CROOKED LAKE WATERSHED STUDY
SATURATED SOILS/SEVERE SLOPES/
RESIDENTIAL LANDS OVERLAY
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
S R 109
S R 9
600 N
KEY:
WATERSHED BOUNDARY
CONTRIBUTING DRAINAGEWAY
RESIDENTIAL USE ON LANDS OF PRIMARY CONCERN
RESIDENTIAL USE ON LANDS OF SECONDARY CONCERN
NORTH
0
1/8
1/4
1/2
1 MILE

Figure 38.

sewer and appurtenances, vacuum collection staitons and a waste treatment facility to be located south of the Tri-Lakes. Engineering for the system was completed in 1990, construction of the system is slated to begin in January of 1992, with the system operational by 1993.

Although treatment is not limited to the management approach discussed above, this method of waste treatment should effectively meet the goals of sewage disposal.

Until the sanitary sewer system is operational, 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.

WATERSHED TOUR: CROOKED 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 fresh perspective and to stimulate residents to make their own continuing observations. It must be noted that the watershed tour narrative only depicts events or situations which are readily observable from public roads or areas. Areas not accessible during our watershed tours were analyzed using air photo interpretation in an attempt to tie together the watershed recommendations and draw further conclusions.

Prior to our 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, or, ground truthed in the field. This allowed us to understand the watershed interaction as a whole before breaking it down into smaller components. Many of the following notes and observations are keyed to Figure 39.

1. Crooked Lake is one of the deepest and cleanest lakes in Indiana. Traditionally, because of its high water quality, this lake has been the home of a significant population of cisco. This fish, dependent on cool, clear, highly oxygenated water to survive and reproduce, is becoming increasingly rare in Indiana. Indeed, the cisco population is even decreasing in number in this lake. It is easy to understand the concern people have for the water quality of the lake and changes in the watershed that may have caused a decline in water quality.

2. The watershed for Crooked Lake and its associate Little Crooked Lake is very small, its boundary ranging only 1/8 to 3/4 of a mile in distance from the shoreline.

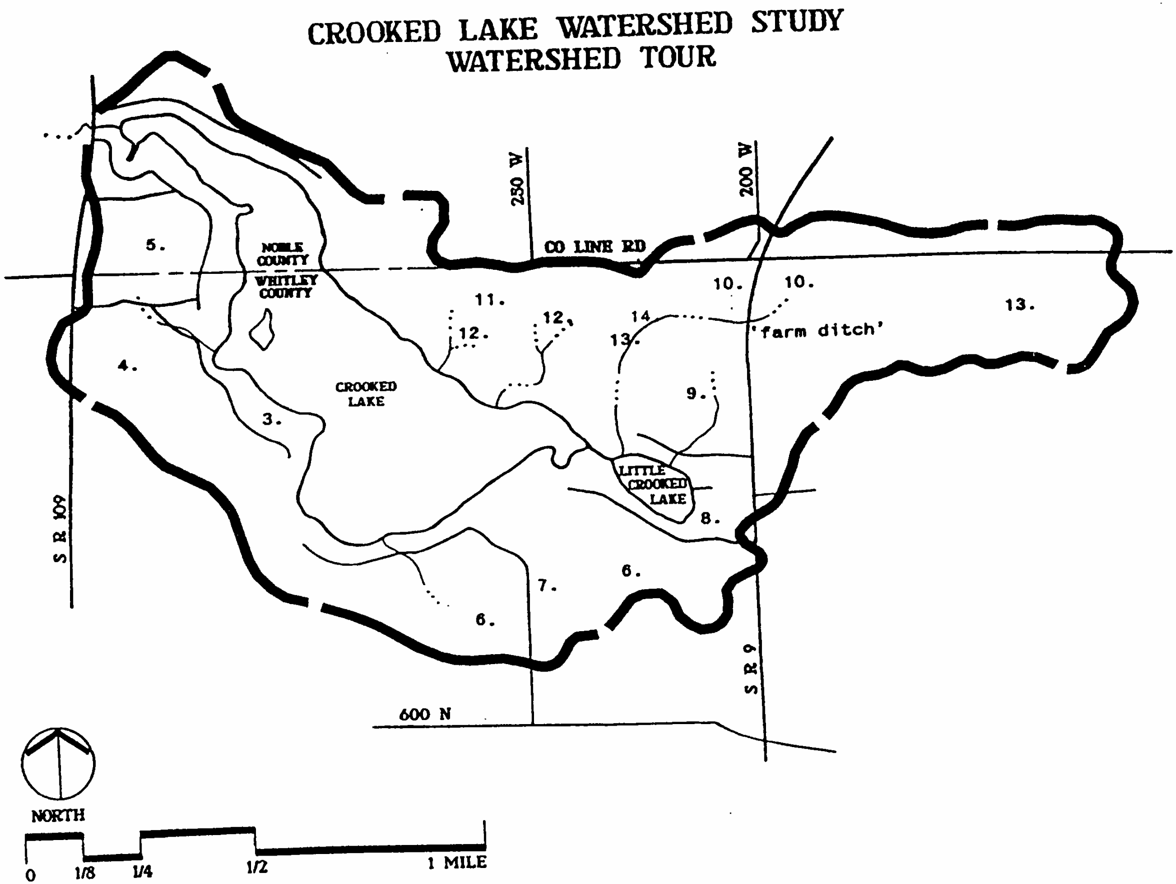

CROOKED LAKE WATERSHED STUDY
WATERSHED TOUR
250 W
200 W
CO LINE RD
NOBLE COUNTY
WHITLEY COUNTY
CROOKED LAKE
LITTLE CROOKED LAKE
'farm ditch'
S R 109
S R 9
600 N
NORTH
0
1/8
1/4
1/2
1 MILE
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14

Figure 39.

Pollutants entering the lake system do not have to travel far from their sources. This implies that water quality problems must be tackled at their sources rather than somewhere between the source and the lake.

3. Starting at the outlet from Crooked Lake and traveling counter-clockwise, much of the east and south shoreline of the lake is developed with cottages and permanent homes, the majority of this development taking place between 1972 and 1981. Many of the homes appeared to be located on saturated soils. As discussed in the preceding Septic Studies section, older septic systems may be working inefficiently, and thus, contributing nutrient loads directly to the lake. Residents must take responsibility for maintaining their septic systems until the Tri-Lakes Regional Sewer District is operational.

4. Behind the residences on the east side of the lake is a 9-hole golf course. Several (3 or 4) intermittent streams and ditches flowed from the course into the lake. After a significant rain event, the water flow in these channels was relatively clean of sediments. Nutrients may be flowing from the course after fertilizer applications. However, after checking with the golf professional in charge of the course, it was determined that fertilizer was only applied twice a year (spring and fall). The total annual quantity of nitrogen applied is 500 pounds on the fairways only. Dacthal, a pre-emergent crabgrass herbicide is also applied in the spring. It is doubtful, at this application rate, that the golf course is a major contributor of nutrients to the lake as the fertilizer application levels are considered minimal for turf maintenance. However, should fertilizer application increase, care should be taken to prevent transport of nutrients to the lake.

5. A small agricultural field located north of the golf course is in grain crops and may be a small contributor of sediment and nutrients to the lake. The swale that drains the field flows through a lawn area which may filter some pollutants, however, this agricultural field should be enlisted into a conservation tillage program.

6. Another larger agricultural field is located south of the lake near Spear Road. The swale that drains this field flows through a wooded thicket. Conservation tillage practices are recommended for these two fields to further reduce sediment and nutrient loading of the lake.

7. A very nice wetland complete with beaver and wood ducks occurs near Spear Road. This wetland captures runoff from the surrounding agricultural lands before it flows

into the lakes. This wetland is an asset to the lake worth preserving.

8. Little Crooked Lake is developed on the north and south shorelines with cottages and permanent homes. Again, some of these houses may have poorly working septic systems that could contribute nutrients directly to the lake. Residents must take responsibility for maintaining their septic systems until the Tri-Lakes Regional Sewer District is operational.

9. An agricultural field north of Little Crooked Lake was in the CRP, and the water that flows through its swale was visibly clean. The water quality of runoff would likely decrease if this field were taken out of CRP.

   The status of lands in the Conservation Reserve Program should be monitored to avoid possible water quality problems which may occur if the lands are put back into production.

10. At the northeast end of the watershed, two agricultural fields in grain crops (on either side of SR 9 south of the County Line Road) apparently contribute flow both overland and in tiles to a steeply-wooded ravine that enters Little Crooked Lake. Even though the ravine flows through woods, and the fields are in conservation tillage (no-till), after substantial rain events, water in the channel was turbid. The swales in the fields could be in grass with adequate buffers.

11. The Crooked Lake Nature Preserve covers much of the north shoreline of Crooked Lake. This shoreline, with its emergent vegetation edge and its wooded hillside reminds us of what the entire shroeline once looked like.

12. Two intermittent streams flowed through the wooded ravines of the nature preserve. The smaller stream flows into Crooked Lake and after a rain event its waters were turbid. Some stream bank cutting was observed in the stream. The deep and steeply sloped ravine was wooded but the ground cover (herbaceous plants and leaf litter) was sparse.

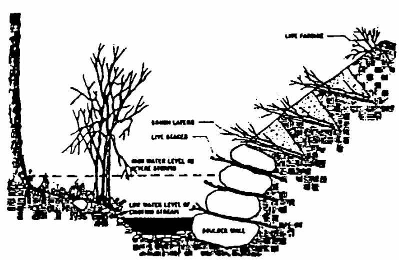
    Every effort should be made to incorporate bank stabilization mechanisms within the eroding channel areas of the Nature Preserve.

    It is apparent that the channel is receiving large amounts of water from the upland. Even though the CRP fields above this ravine have not been cultivated since 1978, the probable tile drainage network is pumping significant amounts of water (and sediment?) into the intermittent stream.

Efforts should be made to intercept (block) the tile drains located within the old field areas of the Nature Preserve. This would reduce the input of runoff to the ditches, and aid in the "restoration" of the old field areas of the Nature Preserve.

13. The other intermittent stream that flows through the eastern-most part of the Nature Preserve is part of the drainage system mentioned in item #10 above. This stream as it enters Little Crooked Lake was carrying a major amount of sediments after a substantial storm event. Extensive stream bank cutting and erosion of the ravine were observed as the stream rushed through its meanders in the Tall Trees Memorial Grove of the Nature Preserve. It is apparent that even though this revine has been here for centuries, significant changes have occurred to it in the recent past and present. This stream is accepting much greater volumes of water now than it has historically. Added water and sediment from tiles and swales from agricultural fields above the ravine have overloaded the capacity of the stream causing severe bank cutting and sediment transport. This sediment laden water flows directly into Little Crooked Lake not far from the mouth of Crooked Lake.

It is unlikely that any major constructed options, to slow or detail flow, could be seriously considered within the Nature Preserve (although biotechnical bank stabilization has been used in other nature preserves). Measures must be taken to slow the water and sediment loss above the ravine outside the Nature Preserve.



Detail of stabilized streambank, with rock wall, live stakes, brush layers, and a fascine at top of bank

In addition to the structure and sediment trap recently installed on a disturbed section of "farm ditch", a series of in-stream check dams or weirs could further slow run-off and increase in-stream sedimentation carried from this agricultural drainage area. Grassed waterways and conservation tillage practices may also help slow runoff from the agricultural lands. A constructed option site may also exist on the west side of SR 9, 1/8 mile south of County Line Road. This could increase the residence time for a significant volume of runoff and substantially reduce the peak flow of water and sediment into the ravine.

14. A small impounded pond was noted in the farm ditch, east of the Nature Preserve. The relatively narrow pond is oriented along the stream course. Due to the ponds configuration, it is likely short circuited or flushed during high flow events. The sediment trapping and nutrient filtering function of this pond could be improved by increasing the surface area of the pond, pulling back the banks at the inflow and outflow and planting these new shallow water areas with emergent vegetation (cattails/rushes). The addition of shallow water emergent areas at the inlet and outlet would increase filtering of sediments and nutrients by slowing the velocity of incoming run-off and forcing it through a vegetative filter.

    Also, the outlet structure of this pond appears to be in need of repair. Additional recent watershed disturbances including construction of State Road 9 and dredging of the inlet to Little Crooked Lake have likely impacted water both Crooked and Little Lakes.

CONCLUSIONS AND RECOMMENDATIONS

STUDY CONCLUSIONS

Crooked Lake is one of the true natural gems of Indiana. It has historically possessed some of the best water quality in the state and is characterized as being one of the last lakes to have a population of ciscos, a fish characteristic of deep cold lakes of good to excellent water quality. In recent years, however, the cisco population has progressively declined to a point that it is near to extirpation in the lake.

A number of parameters have shown changes concurrent with the decline in cisco populations. Most notable is the reduction in the vertical extent of the deep oxygen layer in the water column considered essential for the survival of ciscos. The principal factor responsible for the deep oxygen layer is the production of oxygen as a byproduct from the photosynthetic activity of the blue-green alga Oscillatoria rubescens. It is clear that the Oscillatoria population is stress via a reduction in light availability at depth in Crooked Lake. The cause for this shading of deeper sections of the water column is from a combination of increased algal productivity in surface waters of the lake and increased turbidity of the water column from fine sediments delivered from the watershed during rain events. The IDEM eutrophication index has increased progressively for both Little Crooked and Crooked Lakes since the mid 1970's indicating expanding algal populations in surface waters. In addition, investigators from the IDNR have observed that cisco kills occur following major rain events and increased turbidity in the water column.

While it is clear that reduction of the extent of the deep oxygen layer from reduced photosynthetic activity of Oscillatoria rubescens populations due to light reduction from increased lake eutrophication and inorganic turbidity has played an important role in stressing cisco populations, increased predation pressure associated with past stocking programs for brown trout have also impacted cisco populations negatively. It appears that much of the most pronounced eutrophication of both Crooked and Little Crooked Lakes was prior to the early 1960's, there is also a signal from the paleolimnological, historical, and current data that the lakes have become even more eutrophic since at least the mid 1970's. Today, Crooked Lake is assigned to Class II, the intermediate category of water quality according to IDEM standards, while Little Crooked Lake is Class III, the category of worst water quality.

Bathymetric and paleolimnological data as well as 1990 investigations of inlet streams demonstrated that Little

Crooked Lake is receiving a heavy load of sediment and nutrients from the northern portion of its watershed associated with agricultural and construction activities. Sediments have filled much of the deepest portion of the lake and a delta of highly flocculent has formed at the stream mouth at the northwestern corner of the lake. The impact of the watershed disturbance is not limited to the Little Crooked basin alone, but clear evidence was found that at least the eastern basin of Crooked Lake is also affected via transport through the canal between the two lakes.

The management plan for Crooked Lake and Little Crooked Lake must integrate both lake and watershed management options. Without such an approach the lakes will continue to decline in water quality. Even though the new regional sewer system will minimize residential inputs to the system, it appears that other watershed activities have had as serious if not more serious impact on the lakes historically. Specific recommendations for development of a watershed-lake management follow.

RECOMMENDATIONS FOR THE CROOKED LAKE WATERSHED

1. A plan should be developed to intercept or block the tile drains within old field areas of the Crooked Lake Nature Preserve. In addition, there is a great need to incorporate bank stabilization mechanisms within the eroding channel areas of the Nature Preserve.

2. Conservation tillage systems. Conservation tillage systems appear to be the best agricultural land-use management practice for the Crooked Lake area. As demonstrated by the Suitability for Conservation Tillage overlay, 100% of the agricultural lands in the Crooked Lake watershed are moderately to highly adapted to no -till conservation tillage systems. The majority of conservation tillage applications require only selective (target specific) herbicide and insecticide chemical controls. The fact is, the cost of chemical treatment is so high and the margin of profit so low, that many producers under treat their crops. The use of insecticides is further reduced when the producer uses crop rotation in the management plan. In addition, conservation tillage yields less run-off than agricultural lands not utilizing con-till. Thus, less run-off of applied chemicals results from crop lands utilizing conservation tillage. There is a need to implement Conservation tillage systems on the agricultural lands that have not yet converted to con -till.

3. Bank stabilization. Erosion (bank under cutting) due to high flows and unprotected ditch banks identified in the steep sided drainages of the Nature Preserve and "farm ditch" is responsible for a portion of the sediment delivered to Crooked Lake. Through incorporation of erosion control materials and grass or woody species assemblages, the eroding banks could be stabilized in addition to providing in-stream filtering of sediments and nutrients. Cost estimates for erosion control materials and installation range from $1.10-1.85 per square yard. Installed grass mixes start around $0.50 per square yard and willow whips about $13.50 per square yard. For comparison, rip-rap starts at about $25.00 per square yard. In summary, a number of erosion control measures including instream check dams, grassed waterways, a constructed option site, and conservation tillage practices are all options to consider for installation in the Crooked Lake watershed.

4. Maintain and improve recent corrective measures taken along the "farm ditch" to reduce sediment and nutrient flow to Little Crooked Lake. These include the IDEM cost shared project for a grade stabilization structure to reduce stream head cutting and the bank stabilization and and seeding near the stream outlet to Little Crooked Lake.

5. Monitor agricultural lands currently in CRP and attempt to keep them in CRP.

6. Septic care and maintenance. Until the Tri-Lakes Regional Sewer District is operational, residences must take on the responsibility of maintaining their own wast disposal systems. Drain fields must be inspected regularly and septic tanks must be pumped on a regular schedule.

<u>RECOMMENDATIONS FOR CROOKED AND LITTLE CROOKED LAKES</u>

1. Strong support should be given to the IDNR shoreline management strategy for Crooked Lake. Current limitations for Crooked Lake residents to alter shorelines or chemic ally treat macrophytes in nearshore areas should be adhered to if not strengthened. It was observed in the current study that much of the emergent vegetation along the shore has been eliminated within the past decade. Not only does such vegetation provide fish breeding grounds and protection of young, but it also acts both as a kidney to absorb nutrients coming from the watershed and as a buffer against pronounced shoreline erosion.

2. Stocking of brown trout should not take place until a clear picture of the predation impact of this species on ciscos is developed. It appears that predation from brown trout has played a part in the demise of the cisco population in Crooked Lake.

3. Shoreline residences should refrain from use of fertilizers for their lawns. Given the soil structure of the area, it is likely that much of the nutrients are leached directly into the lake. When coupled with the fact that much of the shoreline vegetation has been removed and no longer acts as a nutrient trap, these nutrients become available for algal growth in the open water areas of the lake.

4. Measures exist for increasing the dissolved oxygen content of the deep waters (hypolimnion) of lakes. These concentrate on the use of pumps to aerate artifically the lake. Foremost among these techniques are total water column aeration and hypolimnetic aeration. Total water column aeration places an air diffuser pipe on the bottom of the lake and allows air bubbles to diffuse upward through the water column. While this will aerate the deep portions of the lake, water temperature of the hypolimnion is raised substantially as surface and deep waters are mixed in the process. Given that ciscos require both well oxygenated and cold waters, this technique would not promote cisco populations in Crooked Lake. The second aeration technique, hypolimnetic aeration, air lifts deep waters to the surface, aerates them, then pumps them back to the depth from which they came. The waters are thus aerated without increasing the temperature of the bottom waters. Both types of aeration devices, however, have only been proposed for small lakes shallower than Crooked Lake and are definitely not a cost effective option for lakes the size and depth of Crooked Lake. To date, there are no effective oxygenation methods that could be used in Crooked Lake.

REFERENCES

American Public Health Association (APHA). 1985. Standard Methods for the Examination of Water and Wastewater. 16th Edition, APHA, Washington, D.C.. 1268 pp.

Andersen, J.M. 1976. An ignition method for determining total phosphorus in lake sediments. Water Res. 10:329 -331.

Appleby, P.G. and F. Oldfield. 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported 210-Pb to the sediment. Catena 5:1-8.

Appleby, P.G., P.J. Nolan, D.W. Gifford, M.J. Godfrey, F. Oldfield, N.J. Anderson, and R.W. Battarbee. 1986. ^{210}Pb dating by low background gamma counting. Hydrobiologia 143:21-27.

Binford, M.W. and M. Brenner. 1986. Dilution of ^{210}Pb by organic sedimentation in lakes of different trophic states, and application to studies of sediment-water interactions. Limnol. Oceanogr. 31(3): 584-595.

BonHomme, H. 1974. A comparison of dissolved oxygen concentrations as existing in some northeastern Indiana lakes which are or were cisco lakes in the past. Indiana Department of Environmental Management. 6 pp.

Crisman, T.L. 1986. Eutrophication control with an emphasis on macrophytes and algae. pp. 200-239. IN: N. Polunin (ed.). Ecosystem Theory and Application. Wiley Press.

Crisman, T.L. 1987. History of cultural eutrophication at Lake Manitou, Indiana and prospects for its management. Lake Manitou Association. 103 pp.

Crisman, T.L. 1990. Sylvan Lake, Indiana: A final feasibility report. Sylvan Lake Improvement Association. 124 pp.

Crisman, T.L. and W.B. Eviston. 1989. Lakes of the Four Seasons: A study for improvement, restoration, and protection. LOFS Property Owner's Association, Crown Point, IN. 114 pp.

Crisman, T.L., W.B. Eviston, and E.P. Ellingson. 1990. A study for the improvement, restoration, and protection of Nyona Lake and South Mud Lake. Nyona Lake Lions Club, Fulton County, Indiana. 214 pp.

Earth Source Inc. 1990. Shorewood Forest: Lake Louise, A study for the improvement, restoration, and protection. Shorewood Forest Property Owners Association, Porter County, Indiana. 133 pp.

Earth Source Inc. 1990. Big Long Lake, Lake of the Woods, McClish Lake, Pretty Lake: A study for the improvement, restoration and protection. Big Long Lake Association, Lake of the Woods/McClish Lake Association, Pretty Lake Association, DeKalb, LaGrange, Noble and Steuben Counties, Indiana. 372 pp.

Eviston, W.B. and T.L. Crisman. 1988. The cultural eutrophication of Koontz Lake, Indiana: Causes, consequences, correction. Koontz Lake Environmental Enhancement Committee. 117 pp.

Frey, D.G. 1955. Distribution ecology of the cisco (Coregonus artedii) in Indiana. Investigations of Indiana Lakes and Streams 4:177-228.

Gray, H.H. 1987-1989. Bedrock and Quarternary Geology of Indiana. Indiana Geological Survey. Bloomington, IN.

Gulish, W.J. 1974. Distribution and abundance of cisco on the Fawn and Pigeon River watersheds. Division of Fish and Wildlife, Indiana Department of Natural Resources, Indianapolis. 20 pp.

Gulish, W.J. 1975. A summary of Indiana cisco investigations 1971-1974. Indiana Department of Natural Resources.

Hetrick, J. and M. Balestra. 1978. A comparative study of the feeding habits of yellow perch and brown trout in Crooked Lake, Indiana. Unpublished report. 10 pp.

Higgins, B.E. 1966. Food selection by the cisco, Coregonus artedii (Le Sueur), in Crooked Lake (Noble-Whitley Co.), Indiana. Ph.D. Dissertation, Indiana University, Bloomington, IN.

Hill, J.R. 1986. The Geology of Indiana. Unofficial publication of the Indiana Geological Survey. Bloomington, IN.

Homoya, M.A., D.B. Abrell, J.R. Aldrich, and T.W. Post. 1985. The Natural Regions of Indiana. Proceedings of the Indiana Academy of Sciences 94:245-266.

Hudson, G. 1969. Fish management report Crooked Lake, Whitley County. Indiana Department of Natural Resources. 6 pp.

Indiana Department of Environmental Management. 1986. Indiana Lake Classification System and Management Plan. IDEM, Indianapolis. 112 pp.

Indiana Department of Environmental Management. 1989. Nonpoint source assessment report. IDEM, Indianapolis, IN.

Iovino, A.J. 1975. Extant chironomid larval populations and the representativeness and nature of their remains in lake sediments. Ph.D. Dissertation, Indiana University, Bloomington, IN. 54 pp.

Konopka, A. 1980. Physiological changes within a metalimnetic layer of Oscillatoria rubescens. Appl. Environ. Microbiol. 40:681-684.

Konopka, A. 1981. Influence of temperature, oxygen, and pH on a metalimnetic population of Oscillatoria rubescens. Appl. Environ. Microbiol. 42:102-108.

Konopka, A. 1982. Buoyancy regulation and vertical migration by Oscillatoria rubescens in Crooked Lake, Indiana. Br. Phycol. J. 17:427-442.

Konopka, A. 1982. Physiological ecology of a metalimnetic Oscillatoria rubescens population. Limnol. Oceanogr. 27:1154-1161.

Konopka, A. 1983. Epilimnetic and metalimnetic primary production in an Indiana hardwater lake. Can. J. Fish. Aquat. Sci. 40:792-798.

Konopka, A., K.M. Brown and C.R. Lovell. 1983. Selective feeding by zooplankton: implications for lake productivity. Technical Report 161. Water Resources Research Center, Purdue University, West Lafayette, Indiana.

Lake, J. 1977. Environmental impact of land use on water quality. Final technical report on the Black Creek project. J. Morrison (ed.). EPA-905/9-77-007-B. U.S. Environmental Protection Agency, Washington, D.C.. 280 pp.

Livingstone, D.A. 1955. A lightweight piston sampler for lake deposits. Ecology 36:137-139.

Moore, L. and K. Thornton (eds.). 1988. The Lake and Reservoir Restoration Guidance Manual. EPA 440/5-88-002. U.S. Environmental Protection Agency, Washington, D.C.. 185 pp.

Morris, J.S. 1966. A study of winter factors associated with the occurrence of four species of Daphnia in one lake. M.S. Thesis, Indiana University, Bloomington, IN.

Morris, J.S. 1971. A study of the effect of environmental variables, particularly photoperiod, on four coexisting Daphnia species. Ph.D. Dissertation, Indiana University, Bloomington, IN.

Nagy, J.W. 1988. Simultaneous determination of supported and unsupported ^{210}Pb concentrations in lake-bottom sediments using low-energy, high-purity germanium gamma-ray spectroscopy. M.S. project, University of Florida.

Pearson, J. 1981. Trout harvest, growth, movements, food habits, and mortality at Crooked Lake. Indiana Department of Natural Resources. 42 pp.

Pearson, J. 1982. Cisco die-off at Crooked Lake and declines in oxygen concentrations at other northeast Indiana lakes in 1981. Indiana Department of Natural Resources. 9 pp

Pearson, J. 1982. Cisco population decline at Crooked Lake. Indiana Department of Natural Resources. 10 pp.

Pearson, J. 1983. Further notes on the cisco decline at Crooked Lake. Indiana Department of Natural Resources. 7 pp.

Pearson, J. 1984. Collapse of the cisco fishery at Crooked Lake. Indiana Department of Natural Resources. 21 pp.

Pearson, J. 1985. Cisco status at Crooked Lake. Indiana Department of Natural Resources. 10 pp.

Pearson, J. 1986. Cisco population status, harvest, and brood fish collection at Crooked Lake. Indiana Department of Natural Resources. 13 pp.

Pearson, J. 1987. Crooked Lake fish survey report. Indiana Department of Natural Resources. 14 pp.

Pearson, J. 1988. Spot check survey of ciscos in Crooked Lake. Indiana Department of Natural Resources. 4 pp.

Pearson, J. 1990. Water quality in three Crooked Lake inlets. Indiana Department of Natural Resources. 9 pp.

Pearson, J. and D. Whittlesey. 1979. Trout and cisco management at Crooked Lake, Noble-Whitley Counties, Indiana. Indiana Department of Natural Resources. 26 pp.

Robbins, J.A. and D.N. Edgington. 1975. Determination of recent sedimentation rates in Lake Michigan using Pb -210 and Cs-137. Geochim. Cosmochim. Acta 39: 285-30

Scott, W. 1931. The lakes of northeastern Indiana. Investigations of Indiana Lakes and Streams 2:61-145.

Steinhart, G.C., D.R. Griffith, and J.V. Mannering (AY-210). Adaptability of tillage-planting systems to Indiana soils. Agronomy Department, Purdue University. 15 pp.

Taylor, M. 1972. Crooked Lake fish survey report. Indiana Department of Natural Resources. 4 pp.

USDA, Soil Conservation Service. 1981. Soil survey of Noble County, Indiana. 117 pp.

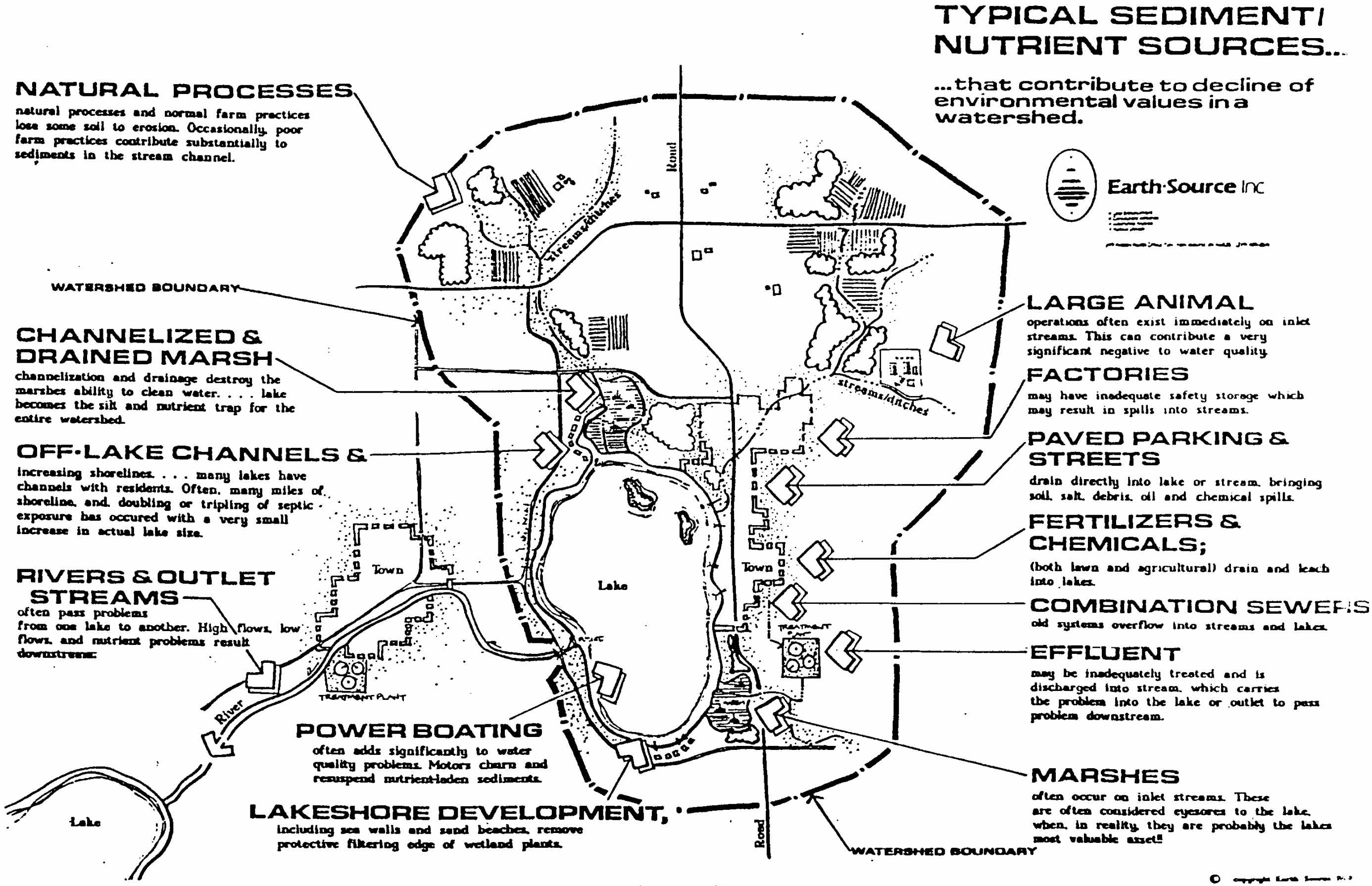
USDA, Soil Conservation Service. 1981. Soil survey of Whitley County, Indiana. 183 pp.

USDA, Soil Conservation Service. 1988. Sec. II-11/88- Indiana Technical Guide.

Wetzel, R.G. 1966. Productivity and nutrient relationships in marl lakes of northern Indiana. Verh. Internat. Verein. Limnol. 16:321-332.

APPENDIX A

Typical Sediment & Nutrient Sources


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.
WATERSHED BOUNDARY
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!
WATERSHED BOUNDARY
Road
streams/ditches
streams/ditches
Town
Town
Lake
Lake
River
TREATMENT PLANT
Road

APPENDIX B

Federal, State & Local Contacts

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

US Army Corps of Engineers
20 Massachusetts Ave., NW
Washington, D.C. 20314
(202) 272-0169

US Fish & Wildlife Service
18th & C Streets, NW
Washington, D.C. 20240
(202) 343-4646

USDA-SCS
Noble County
R.R. 1, Box 16
Albion, IN 46703
(219) 636-7682

IDNR
Division of Water
2475 Directors Row
Indianapolis, IN 46241
(317) 232-4160

IDNR
Div. of Soil Conservation
402 W. Washington Street
Room 265
Indianapolis, IN 46204
(317) 233-3870

IDNR
Div. of Fish & Wildlife
402 W. Washington Street
Room W274
Indianapolis, IN 46204
(317) 232-4080

EPA, Region V
230 S. Dearborn Street
Chicago, IL 60604
(312) 353-2079

US Army Corps of Engineers
Louisville District
P.O. Box 59
louisville, KY 40201-0059
(502) 582-5607

US Fish & Wildlife Service
Bloomington Field Office
718 N. Walnut Street
Bloomington, IN 47401
(812) 334-4267

USDA-SCS
Whitley County
1919 E. Business Rt 30
Columbia Ctiy, IN 46725
(219) 244-6780

IDEM
Office of Water Management
Chesapeake Building
105 South Meridian Street
Indianapolis, IN 46206
(317) 232-8476

IDNR
Div. of Nature Preserves
402 W. Washington Street
Room 267
Indianapolis, IN 46204
(317) 232-4052

Earth Source Inc (consultant)
349 Airport North Office Park
Fort Wayne, IN 46825
(219) 489-8511

APPENDIX C

Various Conservation Practices...

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

Various Conservation Practices...

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 Oridnance	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

Past Inlet Sampling Results

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763

B. C. Bruce
691-3546
461-1220

Attn: John Tolby

CROOKED LAKE ASSOCIATION
RURAL ROUTE 9
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 10-[illegible]-82
[illegible]
[illegible]

Map attached (last page)

L A B O R A T O R Y   R E P O R T

SAMPLE ID: LOCATION A, RECEIVED 9/7/82
PCS SAMPLE NUMBER: 2532481

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.52
ORGANIC NITROGEN, MG/L N	2.1
AMMONIA NITROGEN, MG/L	0.27
NITRATE NITROGEN, MG/L N	2.0
TOTAL SUSPENDED SOLIDS, MG/L	310
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	110,000

SAMPLE ID: LOCATION B, RECEIVED 9/7/82
PCS SAMPLE NUMBER: 2532482

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.18
ORGANIC NITROGEN, MG/L N	1.8
AMMONIA NITROGEN, MG/L	0.38
NITRATE NITROGEN, MG/L N	0.9
TOTAL SUSPENDED SOLIDS, MG/L	56
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	1700

SAMPLE ID: LOCATION C, RECEIVED 9/7/82
PCS SAMPLE NUMBER: 2532483

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.24
ORGANIC NITROGEN, MG/L N	2.3
AMMONIA NITROGEN, MG/L	2.7
NITRATE NITROGEN, MG/L N	1.0
TOTAL SUSPENDED SOLIDS, MG/L	4.0
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	<100

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S BOX 17
LAOTTO, INDIANA 46763

CROOKED LAKE ASSOCIATION
RURAL ROUTE [illegible]
COLUMBIA CITY, INDIANA [illegible]

L A B O R A T O R Y   R E P O R T

SAMPLE ID: LOCATION D, RECEIVED 7/7/82
PCS SAMPLE NUMBER: 2532434

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.04
ORGANIC NITROGEN, MG/L N	0.86
AMMONIA NITROGEN, MG/L	0.16
NITRATE NITROGEN, MG/L N	<0.5
TOTAL SUSPENDED SOLIDS, MG/L	6.0
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	1100

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763
TELEPHONE (219) 637-3137

CROOKED LAKE ASSOCIATION
RURAL ROUTE 9
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 4-4-83
PAGE: 1
PCS PROJECT NUMBER: 4269

LABORATORY REPORT

SAMPLE ID: LOCATION A, 3/27/83
PCS SAMPLE NUMBER: 1225372

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.44
ORGANIC NITROGEN, MG/L N	2.0
AMMONIA NITROGEN, MG/L	0.25
NITRATE NITROGEN, MG/L N	2.0
TOTAL SUSPENDED SOLIDS, MG/L	190
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	4400

SAMPLE ID: LOCATION B, 3/27/83
PCS SAMPLE NUMBER: 1225373

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.06
ORGANIC NITROGEN, MG/L N	0.80
AMMONIA NITROGEN, MG/L	0.08
NITRATE NITROGEN, MG/L N	<0.25
TOTAL SUSPENDED SOLIDS, MG/L	16
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	<91

SAMPLE ID: LOCATION C, 3/27/83
PCS SAMPLE NUMBER: 1225374

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.22
ORGANIC NITROGEN, MG/L N	1.2
AMMONIA NITROGEN, MG/L	0.33
NITRATE NITROGEN, MG/L N	1.0
TOTAL SUSPENDED SOLIDS, MG/L	86
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	<91

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763
TELEPHONE (219) 637-3137

CROOKED LAKE ASSOCIATION
RURAL ROUTE 9
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 4-4-83
PAGE: 2
PCS PROJECT NUMBER: 4269

L A B O R A T O R Y   R E P O R T

SAMPLE ID: LOCATION D, 3/27/83
PCS SAMPLE NUMBER: 1225375

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	1.2
ORGANIC NITROGEN, MG/L N	1.9
AMMONIA NITROGEN, MG/L	0.77
NITRATE NITROGEN, MG/L N	2.8
TOTAL SUSPENDED SOLIDS, MG/L	280
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	2000

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763
TELEPHONE (219) 637-3137

MR. GEORGE BRUCE
CROOKED LAKE ASSOCIATION
RURAL ROUTE 9
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 9-1-83
PAGE: 1
PCS PROJECT NUMBER: 4269

LABORATORY REPORT

SAMPLE ID: LOCATION A, RECEIVED 8/5/83
PCS SAMPLE NUMBER: 1397274

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	1.4
ORGANIC NITROGEN, MG/L N	3.0
AMMONIA NITROGEN, MG/L	0.62
NITRATE NITROGEN, MG/L N	3.2
TOTAL SUSPENDED SOLIDS, MG/L	510
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	17,000

SAMPLE ID: LOCATION B, RECEIVED 8/5/83
PCS SAMPLE NUMBER: 1397275

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	<0.50
ORGANIC NITROGEN, MG/L N	1.4
AMMONIA NITROGEN, MG/L	0.70
NITRATE NITROGEN, MG/L N	0.8
TOTAL SUSPENDED SOLIDS, MG/L	120
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	700

SAMPLE ID: LOCATION C, RECEIVED 8/5/83
PCS SAMPLE NUMBER: 1397276

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.90
ORGANIC NITROGEN, MG/L N	2.0
AMMONIA NITROGEN, MG/L	0.82
NITRATE NITROGEN, MG/L N	2.4
TOTAL SUSPENDED SOLIDS, MG/L	300
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	26,000

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763

TELEPHONE (219) 637-3137

MR. GEORGE BRUCE
CROOKED LAKE ASSOCIATION
RURAL ROUTE 9
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 9-1-83
PAGE: 2
PCS PROJECT NUMBER: 4269

LABORATORY REPORT

SAMPLE ID: LOCATION D, RECEIVED 8/5/83
PCS SAMPLE NUMBER: 1397277

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	1.4
ORGANIC NITROGEN, MG/L N	2.1
AMMONIA NITROGEN, MG/L	0.50
NITRATE NITROGEN, MG/L N	2.0
TOTAL SUSPENDED SOLIDS, MG/L	590
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	81,000

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S, BOX 17
LAOTTO, INDIANA 46763
TELEPHONE (219) 637-3137

MR. GEORGE BRUCE
CROOKED LAKE ASSOCIATION
RURAL ROUTE 3
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 1-9-84
PAGE: 1
PCS PROJECT NUMBER: 4269

LABORATORY REPORT

SAMPLE ID: LOCATION A, RECEIVED 11/28/83
PCS SAMPLE NUMBER: 2328937

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	<0.50
ORGANIC NITROGEN, MG/L N	<0.25
AMMONIA NITROGEN, MG/L	<0.25
NITRATE NITROGEN, MG/L N	<1.0
TOTAL SUSPENDED SOLIDS, MG/L	3.6
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	100

SAMPLE ID: LOCATION B, RECEIVED 11/28/83
PCS SAMPLE NUMBER: 2328938

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	<0.50
ORGANIC NITROGEN, MG/L N	0.90
AMMONIA NITROGEN, MG/L	<0.25
NITRATE NITROGEN, MG/L N	<1.0
TOTAL SUSPENDED SOLIDS, MG/L	9.8
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	<100

SAMPLE ID: LOCATION C, RECEIVED 11/28/83
PCS SAMPLE NUMBER: 2328939

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	0.60
ORGANIC NITROGEN, MG/L N	2.2
AMMONIA NITROGEN, MG/L	0.30
NITRATE NITROGEN, MG/L N	<1.0
TOTAL SUSPENDED SOLIDS, MG/L	420
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	1800

POLLUTION CONTROL SYSTEMS INCORPORATED
COUNTY ROAD 550 S., BOX 17
LAOTTO, INDIANA 46763

TELEPHONE (219) 637-3137

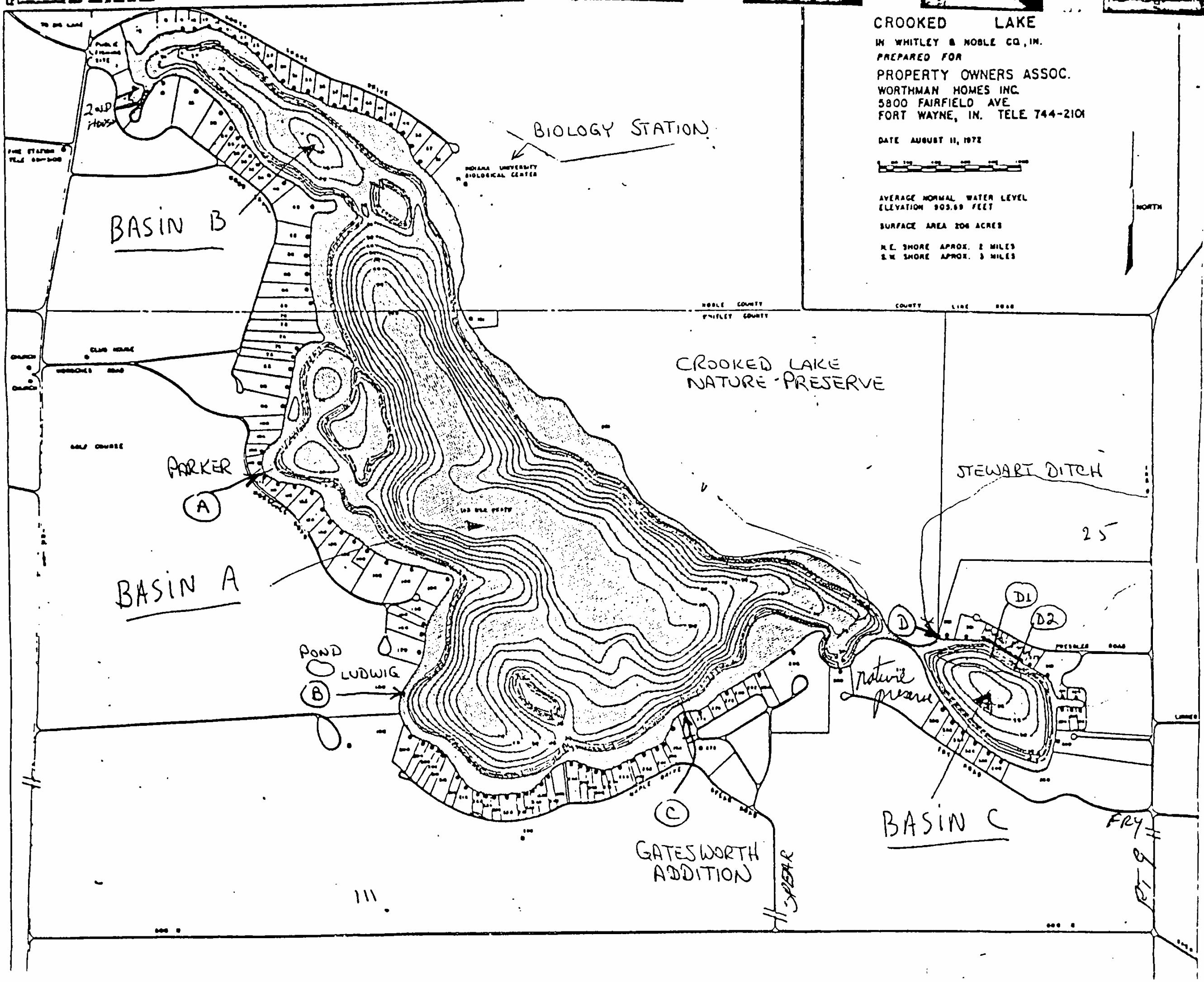
MR. GEORGE BRUCE
CROOKED LAKE ASSOCIATION
RURAL ROUTE 8
COLUMBIA CITY, INDIANA 46725

DATE OF REPORT: 1-9-84
PAGE: 2
PCS PROJECT NUMBER: 4269

L A B O R A T O R Y   R E P O R T

SAMPLE ID: LOCATION D, RECEIVED 11/28/83
PCS SAMPLE NUMBER: 2328740

ANALYTICAL DETERMINATION	ANALYTICAL RESULT
TOTAL PHOSPHORUS, MG/L P	<0.50
ORGANIC NITROGEN, MG/L N	2.0
AMMONIA NITROGEN, MG/L	0.35
NITRATE NITROGEN, MG/L N	1.0
TOTAL SUSPENDED SOLIDS, MG/L	9.8
FECAL COLIFORM BACTERIA, ORGANISMS/100 ML	100



CROOKED LAKE
IN WHITLEY & NOBLE CO., IN.
PREPARED FOR
PROPERTY OWNERS ASSOC.
WORTHMAN HOMES INC.
5800 FAIRFIELD AVE.
FORT WAYNE, IN. TELE 744-2101
DATE AUGUST 11, 1972
AVERAGE NORMAL WATER LEVEL
ELEVATION 903.69 FEET
SURFACE AREA 206 ACRES
N.E. SHORE APROX. 2 MILES
S.W. SHORE APROX. 3 MILES
NORTH
BIOLOGY STATION
INDIANA UNIVERSITY BIOLOGICAL CENTER
BASIN B
2ND House
NOBLE COUNTY
WHITLEY COUNTY
COUNTY LINE ROAD
CROOKED LAKE NATURE PRESERVE
PARKER
A
BASIN A
STEWART DITCH
25
D
D1
D2
POND
LUDWIG
B
nature preserve
C
GATESWORTH ADDITION
BASIN C
FRY
SPEAR