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FINAL REPORT

SHIPSHEWANA LAKE RESTORATION FEASIBILITY STUDY

Submitted to:

SHIPSHEWANA COMMUNITY LAKE IMPROVEMENT ASSOCIATION

Submitted by:

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EXECUTIVE SUMMARY

Located in LaGrange County, Shipshewana Lake has a surface area of 202 acres, a mean depth of 6.7 ft., and a 4,675 acre watershed. Most of the drainage from the predominently agricultural watershed enters the lake through two ditches: Cotton Lake Ditch on the south shore, and the smaller Mud Lake Ditch to the west. Since the late 1970s, the water quality and general condition of Shipshewana Lake has declined dramatically. The Indiana Department of Environmental Management (IDEM) calculated an Indiana Lake Classification System (ILCS) Eutrophication Index (EI) value of 51 (on a scale of 0 to 75) for the lake (IDEM, 1986). Currently, Shipshewana Lake appears to be in the most extreme stages of eutrophication. All lake uses have been severely impaired; swimming has been banned, boating is hampered by algae scums and clumps of bottom material buoyed by gas bubbles, and fishing has declined precipitously.

The objectives of this feasibility study were to assess the current eutrophication-related problems of Shipshewana Lake, identify the sources of the problems and their relative contributions, and develop recommendations for a restoration program that will provide a reasonable probability of success in improving the quality of the lake.

The lake water quality data collected were characteristic of shallow productive lakes. An ILCS EI value of 53 was calculated from the data, indicating that there has been a deterioration in the lake's trophic status. Surficial sediments were observed to be primarily composed of silt/clay with a significant organic content. There was a distinctly flocculant layer at the surface of the lake bottom that appeared to consist largely of dead algae cells. This unconsolidated flocculant material represents a significant source of internal nutrient loading to the lake.

Cotton Lake and Mud Lake Ditches appear to be significant sources of sediment and nutrient loading to Shipshewana Lake. Agricultural and urban non-point source pollution is the principle source of nutrients

entering the lake. A significant component of this pollution consists of animal wastes that are not being adequately controlled in the watershed. In addition, livestock access to streams is resulting in stream bank erosion and deposition and transport of wastes directly into the streams.

The urban area in and around the town of Shipshewana appears to be a significant source of nutrient contamination. Within this subbasin, a flea market, livestock auction house, and fertilizer plant are the most probable sources of significant discharges. There may be some leakage from the town sanitary sewer system or septic fields, as indicated by fecal coliform/fecal streptococcus ratios characteristic of human waste.

Restoration of Shipshewana Lake must include a significant reduction in external nutrient loading to the lake along with a reduction in available internal nutrients in the lake. Implementation of Best Management Practices (BMPs) throughout the watershed should begin with an extensive education program designed to make all farmers, businessmen, and residents aware of the issues surrounding the decline of Shipshewana Lake and the activities that result in nutrient contamination of runoff. The next step should be providing guidance in selection and implementation of appropriate practices, with emphasis on animal waste management, erosion control, and fertilizer contamination. Consideration should be given to construction of artificial wetlands, or similar treatment facilities at the mouths of the two ditches that discharge into the lake.

An over-winter lake drawdown is recommended to consolidate the loose organic sediments, reduce nutrient availability from these sediments, and provide some preventative action against the development of nuisance aquatic weeds as water quality improves in the future. Drawing the lake down by approximately 8 ft. will expose most of the organic sediments and allow a deep pool to remain for fish. Limited physical removal of sediment should be considered in certain areas where the organic material is especially thick. Installation of a water control structure at the outlet of the lake should also be considered.

It may be possible to take no in-lake actions and realize a significant long-term reduction in internal nutrients through washout. Under significantly reduced external loading, the lake will begin to export nutrients until a new equilibrium is reached between nutrient inputs and losses. The relatively short detention time of the lake (i.e., 2-3 months) should expedite this process. It is possible that this new trophic condition will be satisfactory for renewed use of the lake.

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SECTION 1. INTRODUCTION AND BACKGROUND

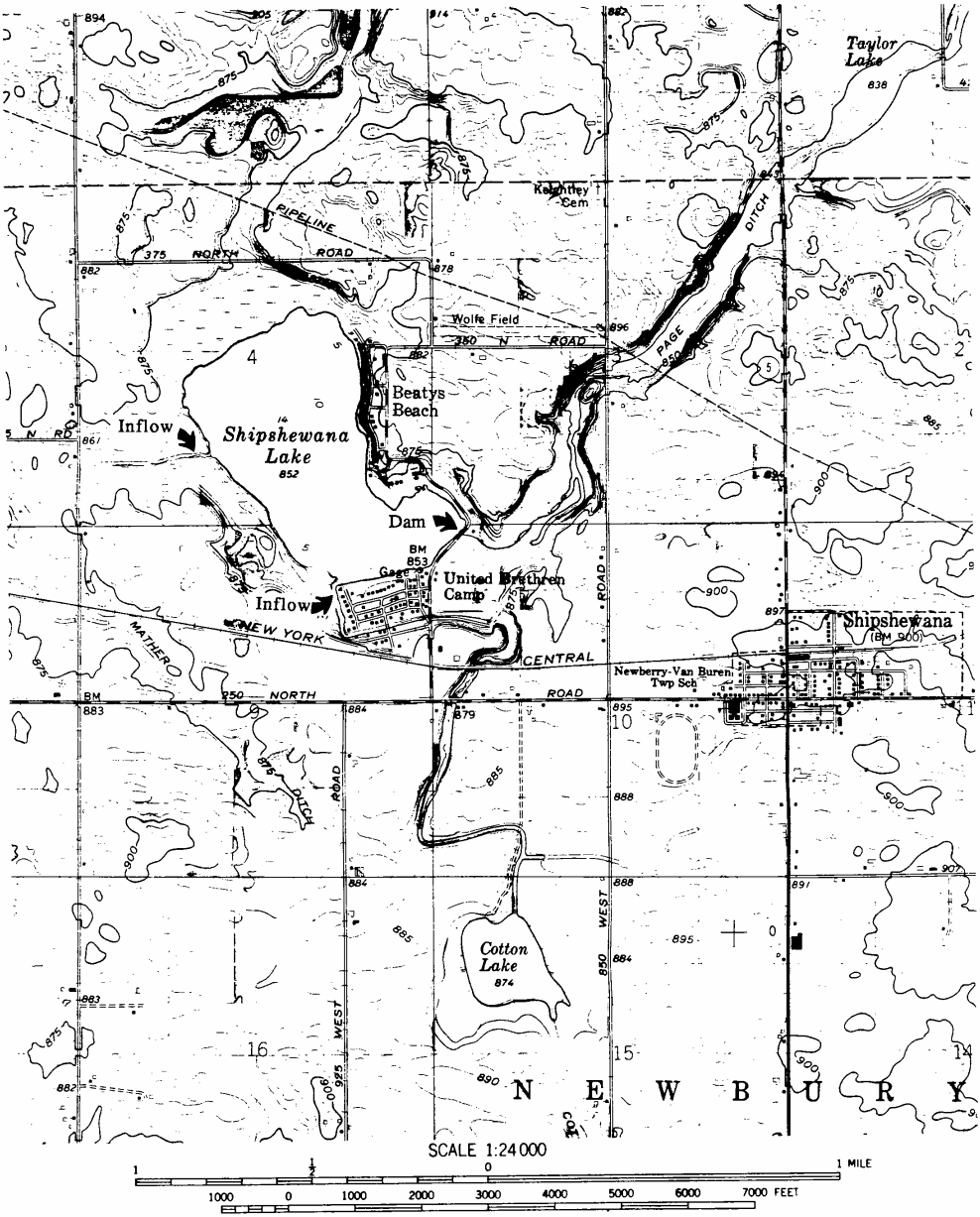
1.1 SHIPSHEWANA LAKE AND WATERSHED

Located in LaGrange County, Shipshewana Lake has a surface area of 202 acres (Figure 1). The shores of the lake are heavily developed with single family residences and a youth camp. There is a state-owned public access site with a cement boat ramp on the south shore. The 4,675 acre watershed is predominantly agricultural, and most of the drainage enters the lake through two ditches: Cotton Lake Ditch on the south shore, and the smaller Mud Lake Ditch to the west. The lake discharges into Page Ditch through a sheet-pile dam on the eastern shore that was constructed in the early 1960s.

The lake has always been relatively shallow (i.e., mean depth of 6.7 ft. and maximum depth of 14 ft.), with a hard bottom of marl and sand. Aerial photographs taken in 1938 indicate that the lake was entirely surrounded by wetlands, except for the eastern shore which was forested (Grant 1988). At that time, Cotton Lake Ditch discharged into a large wetland area adjacent to the outlet of the lake. The watershed consisted of approximately 1,875 acres of cropland, with residential development limited to a few cottages on the southern-most shore of the lake.

By 1965 the eastern shore of Shipshewana Lake was fully developed with residential housing, and Cotton Lake Ditch had been diverted into the lake to provide lake access to land owners along the ditch. This diversion added 2,300 acres to the total watershed area, including 87 acres in the town of Shipshewana. Cotton Lake Ditch drains through two ponds (the Fish Ponds), the larger of which has a surface area of 5 acres, while the smaller pond is approximateky one acre.

The most recent available aerial photograph, taken in 1986, shows the development of the western shore of the lake where a marsh previously existed at the mouth of Mud Lake Ditch. The marsh was drained and filled with dredged material from adjacent marsh and the lake. In addition,



Portion of the U.S.G.S Shipshewana quadrangle showing the location of Shipshewana Lake.

several channels had been excavated around the lake to provide lake access to new development.

Significant features in the watershed include two facilities in the town of Shipshewana that draw upwards of 30,000 visitors and tourists to the area weekly between May and September: a cattle and horse auction facility, and a very large flea market. The town of Shipshewana has a sanitary sewer system. The sewage treatment plant discharges into Page Ditch, downstream of Shipshewana Lake. Stormwater runoff is by sheet flow, street gutters, and storm sewers that eventually discharge into Sarah Davis Ditch (Figure 1). The surrounding farming community is predominantly Amish, and farming techniques are typical of those commonly practiced in the late 1800s. Horse drawn vehicles are common and ubiquitous throughout the community.

1.2 NATURE OF THE PROBLEM

Since the late 1970s, the water quality and general condition of Shipshewana Lake has declined dramatically. The lake was classified as a Class Three lake (i.e., lowest quality, advanced eutrophic) by the Indiana Department of Environmental Management (IDEM) in the Indiana Lake Classification System and Management Plan (1986). This classification was based, in part, on a total phosphorus (TP) concentration of 0.045 mg/l and a Secchi disc transparency of 3.0 ft. A Eutrophication Index value of 51 was calculated for the lake, on a scale of 0 - 75. The lake was defined as being in the IV-A Lake Management Group: relatively shallow lakes that have the potential for being restored through dredging, bottom sealing, or sediment consolidation.

Shipshewana Lake appears to be in the most extreme stages of eutrophication. Massive blooms of blue-green algae have become common during the growing season. Secchi disc transparency has declined to approximately 0.5 ft. The hard lake bottom has been overlain by a thick and unconsolidated layer of organic sediment. Reducing (i.e., anoxic) conditions persist in this layer and in the water column above it during the peak growing season, as evidenced by total depletion of dissolved

oxygen (DO) below depths of 6 feet, and floating masses of bottom sediment buoyed by gases produced by anoxic decomposition. All lake uses have been severely impaired; swimming has been banned, boating is hampered by algae scums and clumps of bottom material buoyed by gas bubbles, and fishing has declined precipitously. The lake drains into Page Ditch, and eventually into the Pigeon River. These receiving streams undoubtedly suffer significant impairments as a result of the elevated nutrient and algae concentrations being discharged into them from Shipshewana Lake.

1.3 STUDY OBJECTIVES

The objectives of this feasibility study were to assess the current eutrophication-related problems of Shipshewana Lake, identify the sources of the problems and their relative contributions, and develop recommendations for a restoration program that will provide a reasonable probability of success in improving the quality of the lake. This effort included a compilation of available historic water quality, land use, and hydrologic data (Section 2.1); a field survey and sampling program (Section 2.2); an analysis and evaluation of all lake and watershed information (Section 3); an identification of appropriate technological solutions (Section 4); and a presentation of conclusions and recommendations (Section 5).

SECTION 2. DATA COLLECTION

This section presents the data that were compiled and collected for this investigation, including bathymetry, water quality, sediment composition, and land use.

2.1 HISTORICAL DATA

Several sources of historical data were identified during this investigation. A comprehensive survey of the lakes in LaGrange County, including Shipshewana Lake, was conducted in 1988 by Mr. William Grant of the LaGrange County Health Department (Grant 1988). Included in the results of the survey were 1) a description of the historical development of Shipshewana Lake and its immediate surroundings, 2) a discussion of land use in the watershed, and 3) a summary of water quality measurements collected from previous studies of the Lake. Water quality values included results of samples collected in 1975 and 1986 (by Dr. Peter Hippensteel of Tri-State University, Angola, IN) and in May, June, July, and August 1988 (by Mr. Bill Grant, LaGrange County Health Department). Water quality measurements were also made in Shipshewana Lake by the IDEM in 1973 and 1987 (pers. comm. from J.L. Winters to G. Doxtater, Sept. 1988).

Table 1 presents a summary of historical water quality data collected on Shipshewana Lake by the Indiana Department of Natural Rresources (IDNR), IDEM, and the LaGrange County Health Department. Although the data are inconsistent with respect to parameters reported, there is a very well defined trend of decreasing Secchi disc depth between 1973 and 1988. Total phosphorus concentrations have approximately tripled and total nitrogen has increased by an order of magnitude over this period.

There have been some limited investigations by the LaGrange County Health Department into the possibility of septic fields contaminating the ground and surface water in the watershed. Although many septic tanks are located at or below the water table, no conclusive data have been collected on levels of contamination.

TABLE 1. SHIPSHEWANA LAKE HISTORIC SURFACE WATER QUALITY DATA

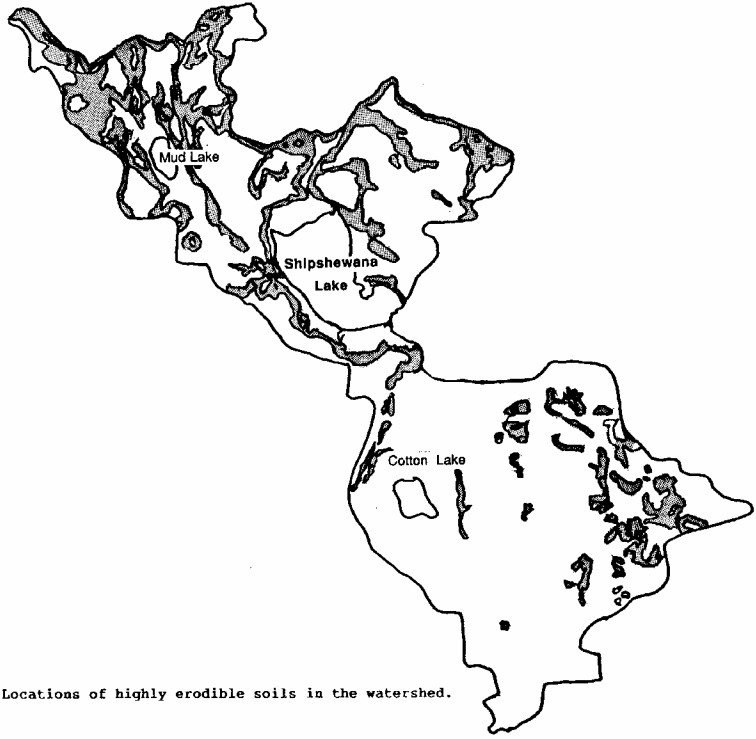
DATE	LOCATION	SOURCE	TP mg/L	PO mg/L	NO_3 mg/L	NH_4 mg/L	TN Mg/L	Fecal Colif. #/100 ml	Fecal Strep 100 ml	DO	Secchi ft
Sept 1973	mid lake	IDEM	0.045	–	0.1	0.7	0.2	–	–	–	3.0
1975	mid lake	IDNR	–	–	–	–	–	–	–	–	3.0
June 1983	mid lake	IDNR	–	–	–	–	–	–	–	7.2	2.5
1986	mid lake	IDNR	–	0.8	–	–	–	–	–	8.0	1.5
July 1987	mid lake	IDNR	0.18		0.1	0.1	1.9	–	–	–	1.5
June 1988	mid lake	IDNR	0.38	0.17	0.0	–	–	–	–	9.1	1.0
July 1988	mid lake	IDNR	0.14	0.02	–	–	–	10	31	10.2	0.5

Fish surveys were conducted in 1968, 1975, and 1983 by IDNR. Included in the 1983 survey report are some water quality measurements and a list of common species of aquatic plants found in Shipshewana Lake at the time of the survey. The 1983 survey concluded that "Shipshewana Lake is relatively shallow and extremely productive," and the high concentrations of nutrients maintained in the lake are "producing excessive algae blooms that are becoming a nuisance." An interesting observation recorded during this survey was that I+ age class for all of the major game species (i.e., black crappie, yellow perch, bluegill, and largemouth bass) were either missing or very scarce. No explanation for this recruitment failure was given. The plant survey concluded that aquatic vegetation was abundant along the shore and in isolated areas of the lake, and did not pose a detriment to the fishery.

The Soil Conservation Service has done extensive mapping of soil types around the Lake, including a survey of erodible soils. Figure 2 presents locations of highly erodible soils in the Shipshewana Lake watershed. It can be seen from this figure that the majority of erodible soils are in the northern portion of the watershed, and particularly the Mud Lake Ditch subbasin.

2.2 FIELD SURVEY

International Science & Technology, Inc. (IS&T) personnel conducted a survey of Shipshewana Lake and watershed on September 13-16, 1988 to provide information required for a detailed assessment of the current conditions in and around the lake. Samples were collected to analyze lake and inflow stream water quality, sediment organic matter, and zooplankton and phytoplankton species and abundance. A bathymetric survey and an aquatic plant survey also were conducted, and land use patterns in the watershed were examined and mapped.



Locations of highly erodible soils in the watershed.

2.2.1 Field Sampling Methods

A bathymetric survey of Shipshewana Lake was conducted using a recording fathometer (Lowrance "Eagle") operated from a pontoon boat. A survey grid of north-south and east-west transects was laid out using a 175 ft. grid spacing (Figure 3). The fathometer was tuned to allow differentiation between the surface of the unconsolidated organic sediment and the hard bottom (Figure 4). Fathometer paper records were digitized and stored in IBM-PC compatible data files for analysis using a contour mapping software package ("SURFER").

Stream velocity was measured in the Cotton Lake inflow immediately downstream of the Fish Ponds (Figure 1) with a Marsh-McBirney digital flowmeter. Stream flow was estimated from the velocity data by the cell velocity method. It was not possible to measure flow in the Mud Lake inflow stream due to low flow conditions.

In-situ water quality parameters were measured at six in-lake stations: four stations located on a mid-lake transect and a station located at the mouth of each of the inflow streams (Figure 5). In-situ profile measurements of temperature and dissolved oxygen were made with a YSI dissolved oxygen meter at 0.5 m intervals from the water surface to immediately above the sediment surface. Secchi disk depth and total water depth were also recorded at each station.

Water samples were collected at the surface and mid-depth with a 6-L Van Dorn sampler at each lake station. Samples were placed in clean, rinsed, labeled, 4-L Cubitainer containers and stored at 4 ^{o}C in the dark. Samples were subsequently shipped to the IS&T analytical laboratory via overnight express air freight. The samples were received at the laboratory within 24 hours of collection.

Water quality samples were also collected at seven stations on the Cotton Lake inflow stream and one station in Mud Lake (Figure 6). Because of the low flow conditions, additional stations located along the Mud Lake inflow stream did not have sufficient water for sample collection during the September 13-16 field trip. However, grab samples

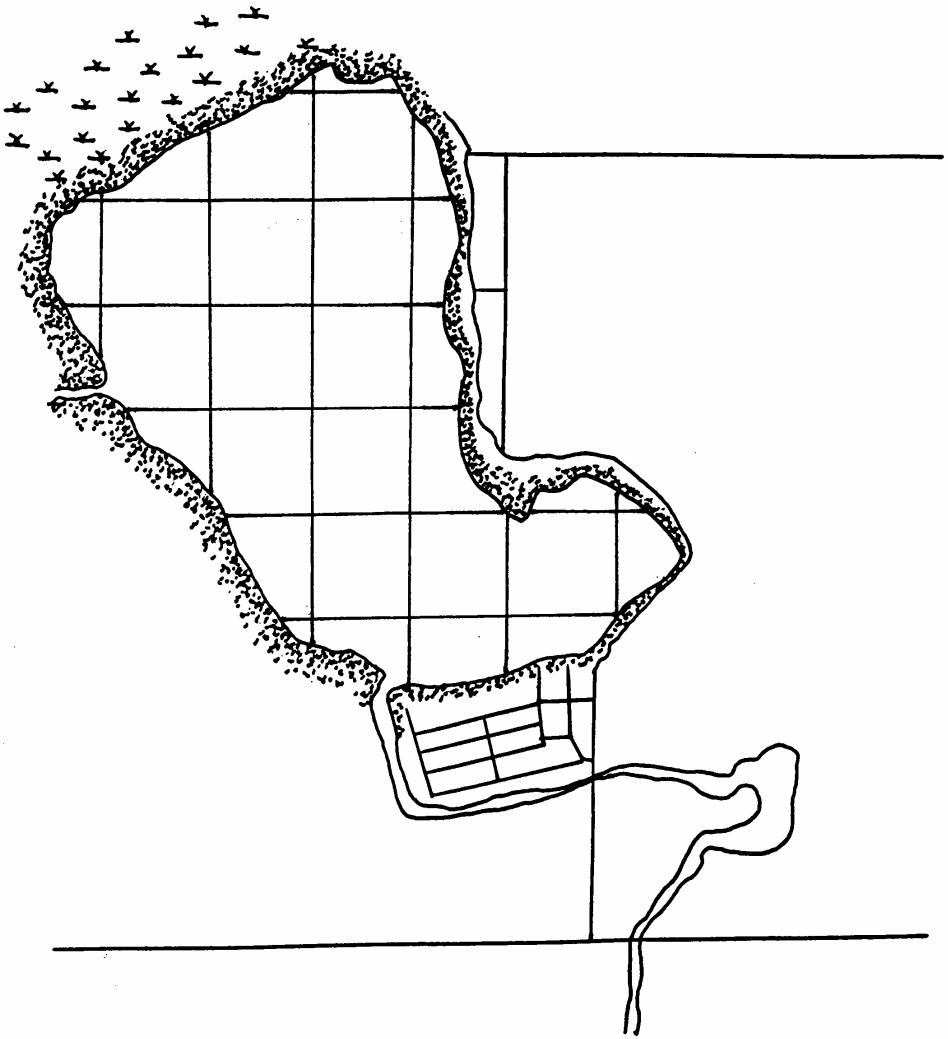


Figure 3. Layout of the transects used for the bathymetric survey.

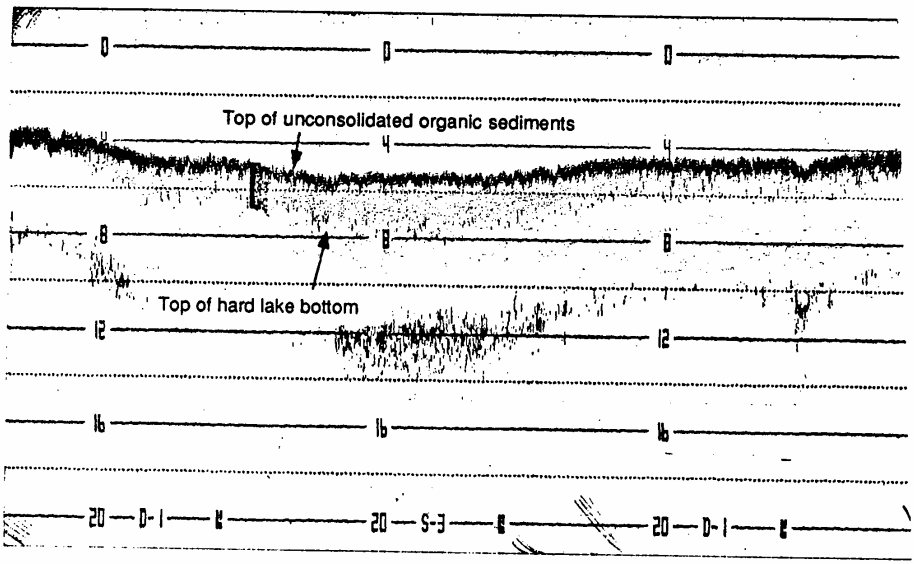


Figure 4. Example of a fathometer record showing the differentiation between the unconsolidated organic sediments and the hard lake bottom.

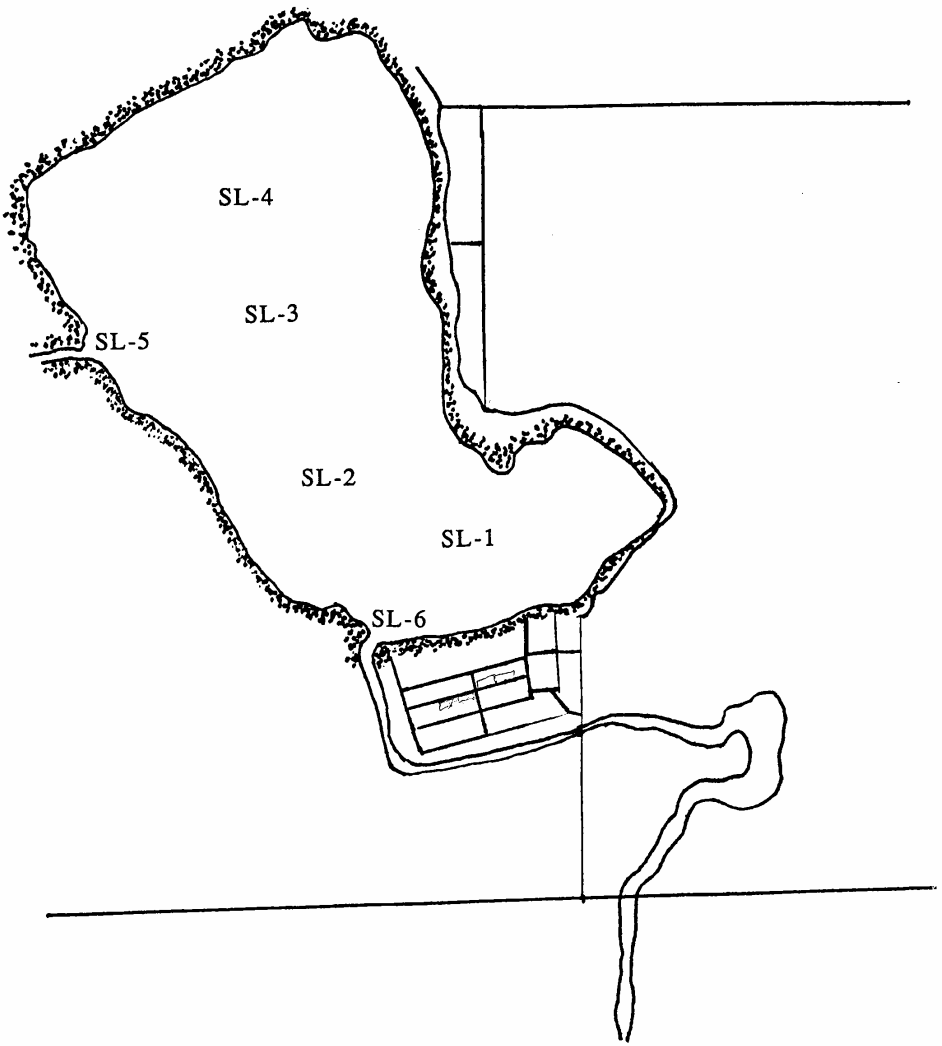
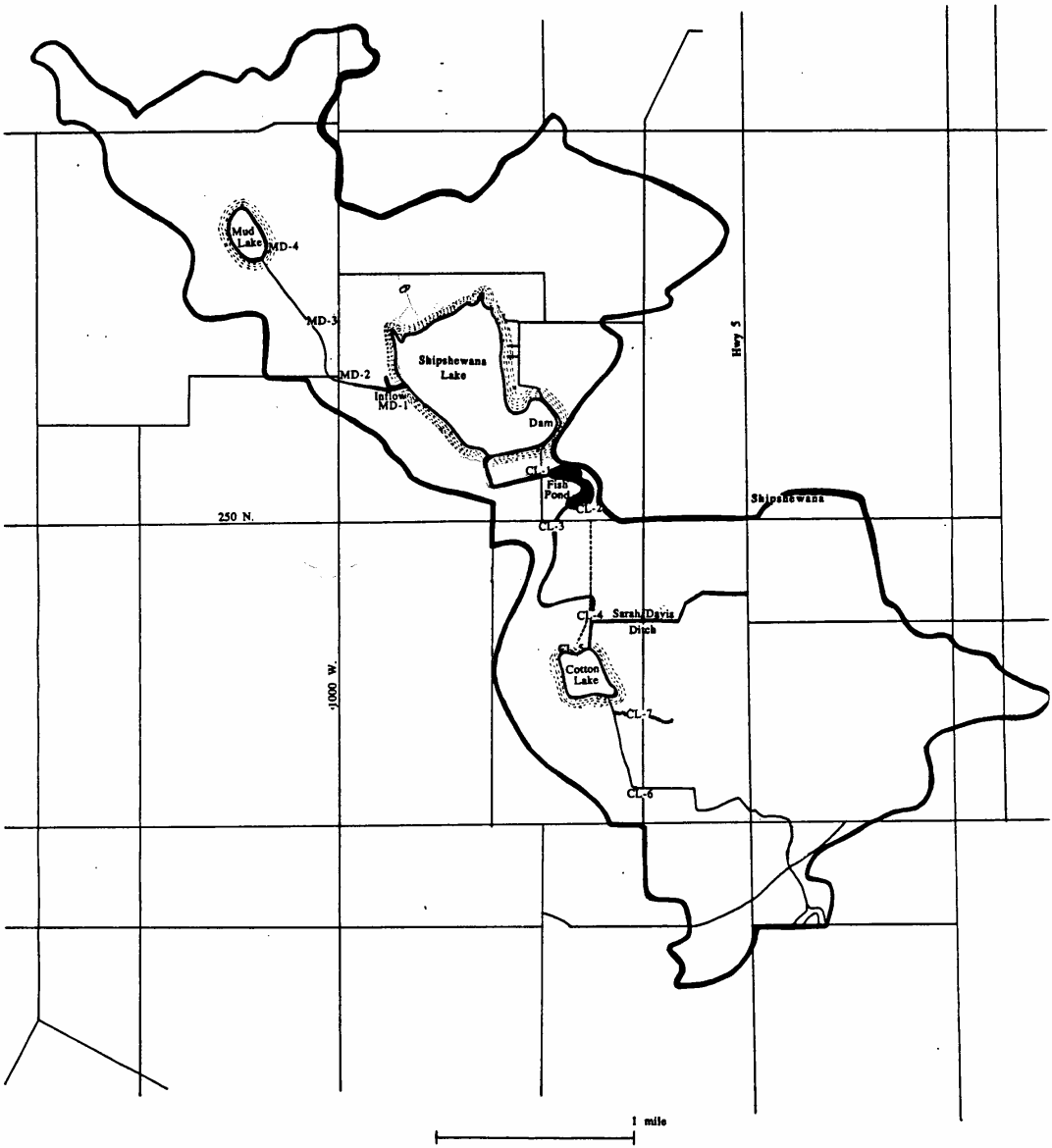


Figure 5. Locations of in-lake sampling stations.



Locations of stream sampling stations.

were collected by Mr. Bill Grant (LaGrange County Health Department) after a rainstorm and subsequent rise in stream level on September 20 at two stations on the Mud Lake inflow (MD-1 and MD-2), and at one Mud Lake inflow station (MD-1) on October 18 during significant rainfall.

Laboratory water quality analyses (total phosphorus, soluble phosphorus, nitrate, ammonia, total suspended solids, conductivity, chlorophyll a, pheophytin, fecal coliform, and fecal streptococcus) were conducted at the IS&T analytical laboratory in Sterling, VA, using the methods listed in Table 2.

Plankton samples were collected at in-lake stations SL-1, SL-2, SL-3, and SL-4. Whole water samples were collected for phytoplankton identification, preserved in Lugol's solution and stored in amber glass jars. Vertical zooplankton tows were collected using half-meter 63u-mesh plankton nets towed from a depth of 5 feet to the lake surface. Phytoplankton and zooplankton were identified to species and enumerated using the settling chamber-inverted microscope technique (Sournia 1972).

Sediment cores were taken at in-lake stations (SL-1, SL-2, SL-3, and SL-4), photographed, and divided into visibly distinct layers. The depth of each layer was measured in the field and analyzed in the laboratory for sand, silt, and organic matter content.

A visual aquatic plant survey of Shipshewana Lake was conducted to quantify the distribution of floating and rooted aquatic macrophytes. Plant species were collected and identified, and distributions plotted on a map of the lake and adjacent wetland areas.

Land use information in the Shipshewana Lake watershed was collected by several methods. A large copy of a recent aerial photograph of the lake and watershed was taken to a town meeting of people living around the lake. The attendees were asked to locate activities (such as farms, factories, drainage areas, etc.) that may affect water quality in the lake or drainage streams. This provided invaluable information about land use patterns in the watershed. A visual reconnaissance was also conducted of the Cotton Lake and Mud Lake subbasins, with particular attention given to potential erosion or nutrient pollution problems. All

TABLE 2. CHEMICAL PARAMETERS AND ANALYTICAL METHODS

PARAMETER	INSTRUMENT OR METHOD	REFERENCE
Total phosphorus	Flow Injection Analysis	EPA 365.1
Soluble phosphorus	Flow Injection Analysis	EPA 365.1
Nitrate	Ion Chromatography	EPA 429
Ammonia	Flow Injection Analysis	EPA 350.1
Chlorophyll a	Spectrophotometer	Standard Methods, 16th ed.
Pheophytin	Spectrophotometer	Standard Methods, 16th ed.
Total suspended solids	Gravimetric	EPA 160.2
Fecal coliforms	Incubation, visual count	Standard Methods, 16th ed.
Fecal streptococcus	Incubation, visual count	Standard Methods, 16th ed.

land use information was compiled onto a map of the Shipshewana Lake watershed.

2.2.2 Field Sampling Results

Bathymetry. The bathymetric map produced for this study indicates that water depth in Shipshewana Lake reaches a maximum of 12 feet at mid-lake (Figure 7). A map produced by IDNR in 1957 showed similar depth contour lines, but indicated that maximum water depth was 14 feet. A comparison of the depth to the flocculant layer and the depth to hard bottom yielded an estimate of the depth, distribution, and volume of organic sediment in the lake. The resulting organic sediment depth map shows that the average depth of unconsolidated sediment is 1.7 ft., with thicknesses of four to five feet in some areas of the Lake (Figure 8). Areas with no sediment build-up may indicate the location of springs in the lake. Volume estimates indicate that approximately 14.9 million cubic feet (or 551,000 cubic yards) of unconsolidated organic matter is present in Shipshewana Lake (Table 3).

Water Quality. In-situ water quality measurements are presented in Figure 9 and Table 4. These data indicate that Shipshewana Lake was well-mixed throughout the water column when the samples were collected. Dissolved oxygen was above saturation at all points within the water column with the exception of the sediment-water interface. There was no evidence of a thermocline at any station. Water clarity was quite low; Secchi disk depth ranged from 0.5 to 0.7 ft. (0.15 to 0.20 m).

Water quality analytical results for the in-lake samples indicated that the four mid-lake stations (SL-1, SL-2, SL-3, and SL-4) had similar values for most parameters (Table 5). Surface samples had consistently higher values of total phosphorus (TP), soluble phosphorus (PO_4), nitrate-nitrite (NO_3-NO_2), and ammonia (NH_3), but lower total suspended solids (TSS) values, than did mid-depth samples at the four mid-lake stations. The two stations at the mouths of the inflow streams, SL-5 and SL-6, had slightly higher ammonia and chlorophyll a values than did the mid-lake stations. The low measurement of pheophytin in relation

Figure 7. Bathymetric map of Shipshewana Lake. Depths are shown in feet.

Figure 8. Map of organic sediment thickness as determined by the fathometer records. Depths are shown in feet.

TABLE 3. SHIPSHEWANA LAKE SEDIMENT VOLUME ESTIMATES

Sediment Depth (ft)	Sediment Volume Ft^3	Yd^3
0-1	795,140	29,450
1-2	5,964,945	220,924
2-3	6,092,825	225,660
3-4	1,905,295	70,566
4-5	128,430	4,757
TOTALS	14,886,635	551,357
Acres	196.9	

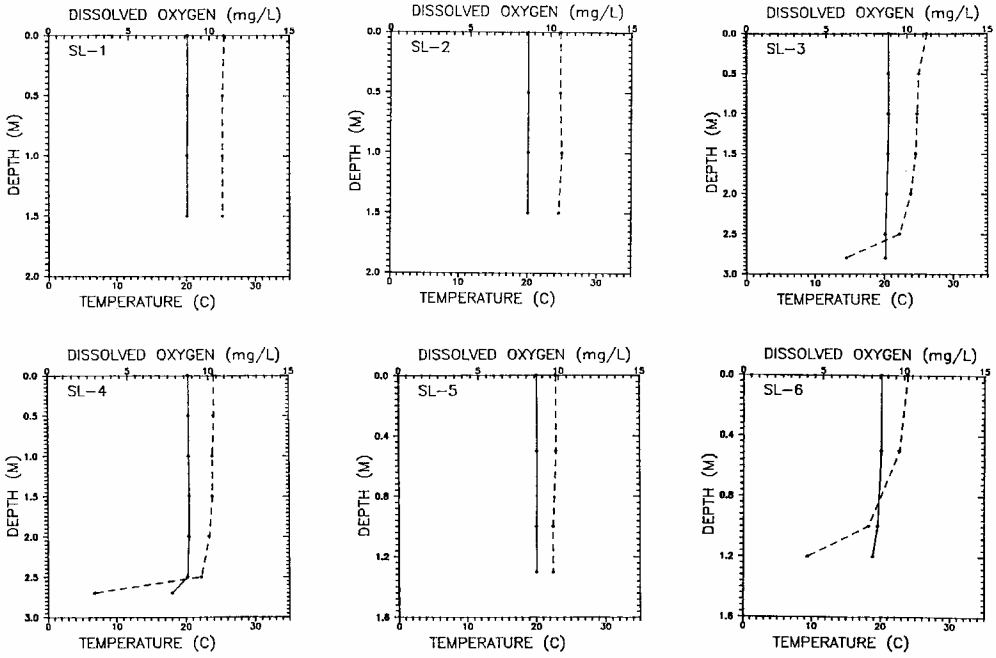


Figure 9. Temperature (solid) and dissolved oxygen (dashed) profiles observed at the in-lake stations.

TABLE 4. SHIPSHEWANA LAKE IN-SITU WATER QUALITY MEASUREMENTS.
Measurements recorded 13 September 1988.

SAMPLE ID	TIME	DEPTH (m)	TEMP (c^o)	DO mg/L	% SAT.	SECCHI DISK DEPTH
SL-1	0855	Surface	20.2	10.9	118%	0.2
		0.5	20.2	10.8	117%	
		1.0	20.1	10.8	117%	
		1.5	20.1	10.8	117%	
SL-2	0945	Surface	20.0	10.6	115%	0.2
		0.5	20.1	10.6	115%	
		1.0	20.1	10.7	116%	
		1.5	20.1	10.5	114%	
SL-3	1020	Surface	20.6	11.2	123%	0.2
		0.5	20.6	10.7	118%	
		1.0	20.6	10.6	116%	
		1.5	20.5	10.5	115%	
		2.0	20.3	10.2	111%	
		2.5	20.1	9.5	103%	
		2.75	20.1	6.2	31%	
SL-4	1100	Surface	20.4	10.3	112%	0.2
		0.5	20.4	10.3	112%	
		1.0	20.4	10.2	111%	
		1.5	20.5	10.2	112%	
		2.0	20.4	10.0	109%	
		2.5	20.2	9.5	103%	
		2.7	18.0	2.9	31%	
SL-5	1130	Surface	20.1	9.8	107%	0.15
		0.5	20.1	9.8	107%	
		1.0	20.0	9.6	104%	
		1.3	20.0	9.6	104%	
SL-6	1150	Surface	20.0	10.2	111%	0.2
		0.5	20.0	9.7	105%	
		1.0	19.5	7.8	84%	
		1.2	18.8	4.0	43%	

TABLE 5. SHIPSHEWANA LAKE WATER QUALITY RESULTS FOR IN-LAKE STATIONS. TP=total phosphorus, SOL P=soluble phosphorus, NO_3=nitrate, NH_3=ammonia, TSS=total suspended solids, COND=conductivity, CHLA-chlorophyll a, PHEO=pheophytin, FECAL COL=fecal coliform, FECAL STREP=fecal streptococcus

SAMPLE ID	TIME COLLECTED	SAMPLE CODE	DATE COLLECTED	TP mg/l	SOL P. mg/l	NO_3 mg/l	NH_3 mg/l	TSS mg/l	COND uS	CHL A	PHEO	FECAL COL.	FECAL STREP	
SL-1	08:55	Surf	13 Sept. 88	0.108	0.014	3.414	0.932	23.3	272	89.58	1.91	0!	0!	
SL-2	09:45	Surf	13 Sept. 88	0.086	0.015	1.081	0.891	35.0	270	85.44	8.01	0!	0!	
SL-3	10:25	Surf	13 Sept. 88	0.091	0.015	0.637	0.737	47.0	290	97.45	0.00	0!	0!	
SL-4	11:00	Surf	13 Sept. 88	0.081	0.010	0.732	0.823	36.6	279	93.45	0.00	0!	0!	
SL-5	11:30	Surf	13 Sept. 88	0.108	0.016	0.589	1.153	43.3	278	117.48	0.00	0!	0!	
SL-6	11:50	Surf	13 Sept. 88	0.123	0.017	1.128	0.943	55.0	290	140.57	0.00	0!	0!	
BLANK			13 Sept. 88	0.006	0.020	0.005	0.130	2.0	3.0	1.47	4.70	0!	0!	
SL-1	08:55	Mid	13 Sept. 88	0.093	0.004	0.613	0.355	50.0	276	NR	NR	NR	NR	
SL-2	09:45	Mid	13 Sept. 88	0.075	0.014	1.037	0.724	45.0	279	NR	NR	NR	NR	
SL-3	10:25	Mid	13 Sept. 88	0.089	0.014	0.670	0.889	40.0	275	NR	NR	NR	NR	
SL-4	11:00	Mid	13 Sept. 88	0.065	0.016	0.746	0.748	40.0	276	NR	NR	NR	NR	

NA = Information Not Available
NR = Not requested
! = Results confirmed by reanalysis

to chlorophyll a (CHLA) indicates that most of the algal cells found in the samples were alive.

Table 6 presents water quality data for the stations located along the Cotton Lake and Mud Lake inflow streams. Nutrient levels (TP, PO_4, NO_3-NO_2, and NH_3) were generally higher in the inflow streams than in Shipshewana Lake. Observed TP levels were higher in the Cotton Lake inflow stream than either Mud Lake inflow or Shipshewana Lake. The sample collected at Cotton Lake (Station CL-5) had the highest TP measured in any water sample during this study (0.200 mg/L). However, the sample collected during a rainstorm from Mud Lake inflow stream station MD-2 exhibited the highest concentration of PO_4 observed (0.630 mg/l). Mud Lake (MD-4) appeared to contain relatively low levels of nutrients.

Bacteriological. Fecal coliform or fecal streptococcus cells were not found at any of the in-lake stations (Table 5). Fecal coliform and fecal streptococcus cells were found in all Cotton Lake and Mud Lake inflow station samples (Table 6). In most of the samples, cell concentrations were within the range considered normal for unpolluted raw surface water. High numbers were found at Mud Lake inflow station MD-1 during a significant rainfall on October 18th. The suggested water quality standard for general recreation use (not intended for swimming) is a maximum of 2000 counts (EPA 1986), well below the 12,300 counts recorded from this sample.

Streamflow. Streamflow at the Cotton Lake Ditch ouflow immediately downstream of the Fish Ponds (Station CL-1) was estimated to be 0.43 cubic feet per second (0.012 cubic meters per second). This reading was taken during relatively low flow conditions.

Phytoplankton. Results of phytoplankton identification and enumeration showed that the algal community in Shipshewana Lake in September 1988 was dominated numerically by bluegreens (particularly *Microcystis aeruginosa* and *Aphanizomenon flos-aquae*). However, the algal community was relatively diverse, with a total of 39 species in 6 classes represented

TABLE 6. WATER QUALITY RESULTS FOR COTTON LAKE AND MUD LAKE INFLOW STREAMS. Labels as defined in Table 4. FC/FS=fecal coliform/fecal streptococcus ratio.

SAMPLE ID	TIME COLLECTED	DATE COLLECTED	TP mg/l	SOL P. mg/l	NO_3 mg/l	NH_3 mg/l	TSS mg/l	COND µS	CHL A	PHEO	FECAL COL.	FECAL STREP	FC/FS
CL-1	10:40	15 Sept. 88	0.145	0.061	0.896	0.806	10.0	468	46.99	2.50	90	12	7.5
CL-2	09:35	15 Sept. 88	0.117	0.053	3.330	1.571	2.8	505	58.74	0.00	60	10	6
CL-3	09:35	15 Sept. 88	0.145	0.129	4.909	2.184	14.2	560	17.13	0.00	148	130	1.1
CL-4	10:06	15 Sept. 88	0.144	0.094	10.988	3.263	5.0	578	39.25	0.00	160	187	0.9
CL-5	10:45	15 Sept. 88	0.200	0.147	0.011	0.797	20.0	454	272.0	0.00	18	0	-
CL-7	09:20	15 Sept. 88	0.007	0.012	5.990	1.634	00.0	639	2.09	0.00	82	4	20.5
MD-4	13:05	15 Sept. 88	0.016	0.015	0.804	0.840	2.5	73.0	5.34	1.70	65	84	0.8
MD-1	11:10	20 Sept. 88	0.013	0.082	13.97!	4.797	320	874	75.29	2.51	100	600	0.2
MD-2	11:00	20 Sept. 88	0.050	0.630	0.005!	1.452	110	570	30.28	0.00	120	300	0.4
MD-1	NA	18 Oct. 88	NA	NA	NA	NA	22	482	3.74	2.99	12,300	32,200!	0.4

NA = Information Not Available
NR = Not requested
! = Results confirmed by reanalysis

in the lake samples (Table 7). Other numerically important species included the green algae Scenedesmus quadricauda and the bluegreens Microcystis aeruginosa var. ichthyoblable, Anabaena spiroides, and Oscillatoria rubescens. Bluegreen algae dominance typically indicates eutrophic, nutrient enriched conditions (Wetzel 1975).

Zooplankton. The zooplankton community was also relatively diverse, with the cladoceran Bosmina longirostris numerically dominating the samples at all four in-lake stations (Table 8). Cladocera feed primarily on phytoplankton; however, bluegreen algae species abundant in Shipshewana Lake are unpalatable or indigestible to many cladocera (Porter 1973; 1975). Other, less abundant, algae species (especially green algae) are the probable food source in Shipshewana Lake for many of the zooplankters.

Sediment Samples. The sediment analysis indicated that organic matter was a major portion of the sediment at all in-lake stations with the exception of station SL-3 (Table 9). This station was located near the deepest section of the Lake, and much of the bottom layer appeared to consist of a marl type of sediment, with little of the dark brown or gray organic matter observed at the other stations. As suggested earlier, this type of sediment, with little organic matter intermixed or overlaid on the surface, may indicate the location of a spring. However, neither the water quality nor temperature profiles indicate differences at station SL-3 when compared to the other mid-lake stations.

Aquatic Vegetation. The aquatic vegetation survey documented a healthy mixture of aquatic macrophyte species, with two types of floating-leafed water lilies (Nuphar advena and Nymphaea odorata) predominating in the Lake, and a shrubby swamp located at the northern end of the lake (Figure 10). Fragments of coontail (Ceratophyllum demersum) and water milfoil (Myriophyllum sp.) were present in the shallow nearshore waters in some places, but were not attached and growing at the time of this survey late in the growing season. Spatterdock (Nuphar advena) was observed growing along a shallow berm created by the dredging of the wetlands area on the west side of the Lake.

TABLE 7. SHIPSHEWANA LAKE PHYTOPLANKTON IDENTIFICATION AND NUMBER/ML.
Samples collected September 13, 1988

	SL-1	SL-2	SL-3	SL-4
Chlorophyceae (green algae)				
Chlamydomonas spp.	*	256.7	577.6	513.4
unicellular green (7u)	64.2	64.2	64.2	64.2
Pediastrum boryanum	*			
Pediastrum tetras	*	*		
Pediastrum simplex	*	*	*	449.3
Pediastrum duplex	*		*	*
Coelastrum microporum	*	*	256.7	256.7
Oocystis parva	*	128.4	64.2	128.4
Oocystis pusilla	256.7	128.4	385.1	385.1
Chodatella (*Lagerheimia*) *longiseta*	*			128.4
Ankistrodesmus falcatus	64.2		64.2	
Kirchneriella subsolitaria		*		
Tetraedron caudatum	64.2			128.4
Tetraedron trigonium	64.2	320.9	192.5	320.9
Scenedesmus quadricauda	1989.6	3144.9	2118.0	3016.5
Crucigenia heterocanthum	*	*	*	*
Bacillariophyceae (diatoms)				
Melosira granulata	256.7	128.4	256.7	64.2
Melosira distans	192.5	*	64.2	*
Cyclotella spp.? 3u	64.2	8		
5-10u		64.2	128.4	64.2
10u	192.5	*	64.2	*
Stephanodiscus sp.	*	*	*	
Meridion circulare	128.4			
Navicula sp.		*		
Nitzschia sp.	*			
small pennate	64.2	*	64.2	
Dinaphyceae (dinoflagellates)				
Gymnodinium sp.	64.2	64.2		*
Ceratium hirundinella[a]	.0144	.0073	.0170	.0141
Cryptophyceae (cryptomonads)				
Cryptomonas marsonni	*	128.4	64.2	*
Cryptomonas erosa (& *ovalis*?)	*	64.2	128.4	320.9
Cyanophyta (bluegreens)				
Chroococcus dispersus	*	256.7	*	*
Microcystis aeruginosa	169309	369361	323984	217830
var. *flos-aquae*	*	*	*	
var. *ichthyoblable*	192.5	3209.0	3850.9	3337.4
Microcystis incerta	*	*	*	*
Anabaena spiroides	*	*	2246.0	9627.0
Aphanizomenon flos-aquae	20153	32347	24620	40819
Oscillatoria rubescens	3080.7			

TABLE 7. SHIPSHEWANA LAKE PHYTOPLANKTON IDENTIFICATION AND NUMBER/ML. Samples collected September 13, 1988 (concluded)

	SL-1	SL-2	SL-3	SL-4
Desmidiaceae[b]				
Cosmarium spp.	320.9	385.1	320.9	641.8
Total cells/ml	196521	410052	359542	269432
# mls subsampled	3	3	3	3
# grids counted	50	50	50	50

* Species was found during scans of the subsample but not seen during the actual count.

a This is a large species present in low numbers. Since it was caught in the zooplankton net, counts of it were made when the zooplankton were counted. These numbers are based on counts of 2 - 4 one milliliter subsamples of the 200 ml zooplankton samples.

b *Staurastrum quadricuspidatum* empty shells were frequently seen, and only one or two may have had cell material in them.

TABLE 8. SHIPSHEWANA LAKE ZOOPLANKTON IDENTIFICATION AND NUMBER/LITER.
Samples collected September 13, 1983

	SL-1	SL-2	SL-3	SL-4
Copepoda				
nauplii	5.77	5.35	12.56	6.28
diaptomid copepodids	0.34	0.17	0.51	0.51
Diaptomus oregonensis	present	0.08	present	present
cyclopoid copepodids	3.40	2.80	5.43	2.72
Cyclops sp.	0.85	0.17	1.19	0.34
Cladocera				
Diaphanosoma brachyurum	0.34	0.59	0.85	0.17
Bosmina longirostris	64.52	53.57	147.19	136.16
Daphnia rosea	0.17	0.08	present	0.17
Chydorus sphaericus	2.38	1.36	7.13	4.75
Alona monocantha			present	
Rotifera				
Filina terminalis	9.34	11.63	20.37	9.51
Polyarthra vulgaris	1.87	0.42	1.19	0.51
*Keratella cochlearis**	2.87	0.34	0.68	present
Euchlanis sp.			present	
Trichocerca sp.	0.34	0.25	0.34	0.51
Brachionus calyciflorus	present		0.17	
Miscellaneous zooplankton				
Chaoborus larvae		present		
Chironomid larvae	present			

"Present" indicates the species was seen in a scan of the sample..
**Keratella serrulata* was present in very low numbers and was counted with *K. cochlearis*.

TABLE 9. IN-LAKE STATION SEDIMENT CORES. Depth, percent organic matter, percent sand, and percent silt/clay of each visually distinct layer.

STATION	VISUAL LAYER	DEPTH (cm)	% ORGANIC MATTER	SAND %	SILT/CLAY %	REMARKS
SL-1	Surface	10	28.18	18.11	53.71	Entire core uniformly brown-gray; top layer more flocculant than bottom; appeared largely organic.
	Bottom	21	38.27	24.64	37.09	
SL-2	Surface	3	29.41	14.22	56.37	Top layer gray-green, very flocculant, and primarily dead algae; mid-layer gray, fine grained, and more compacted; bottom dark brown with identifiable plant fragments.
	Middle	26	32.04	7.61	60.35	
	Bottom	8	49.79	45.42	4.79	
SL-3	Surface	16	10.27	2.52	87.21	Top layer sand and some organic matter; no flocculant material; bottom entirely marl.
	Bottom	9	9.62	5.31	85.07	
SL-4	Surface	20	30.83	4.43	64.74	Only one visible layer; uniformly brown-gray; top more flocculant than bottom; appeared largely organic.

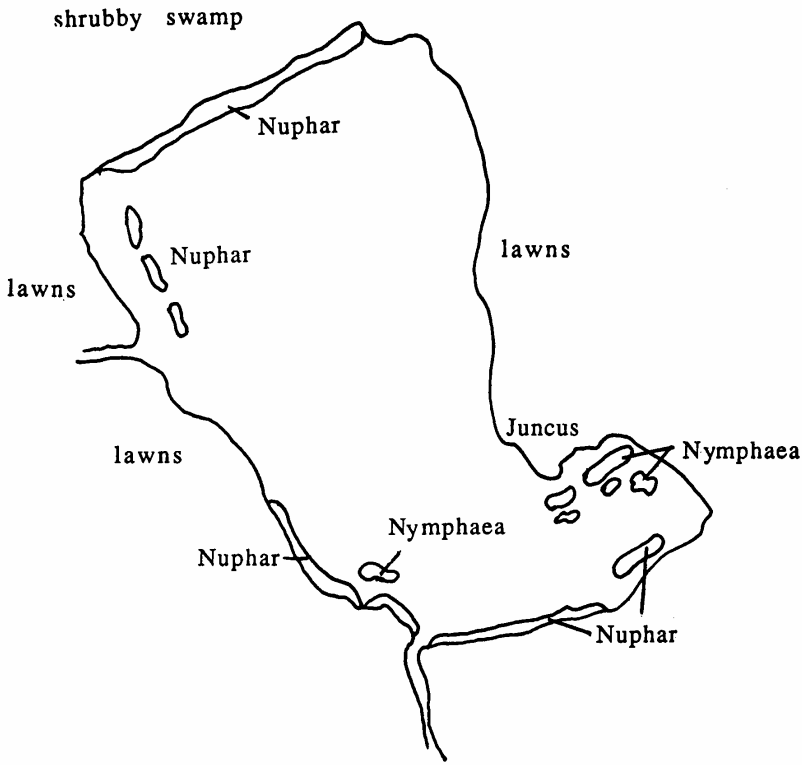


Figure 10. Map of aquatic vegetation observed on Shipshewana Lake.

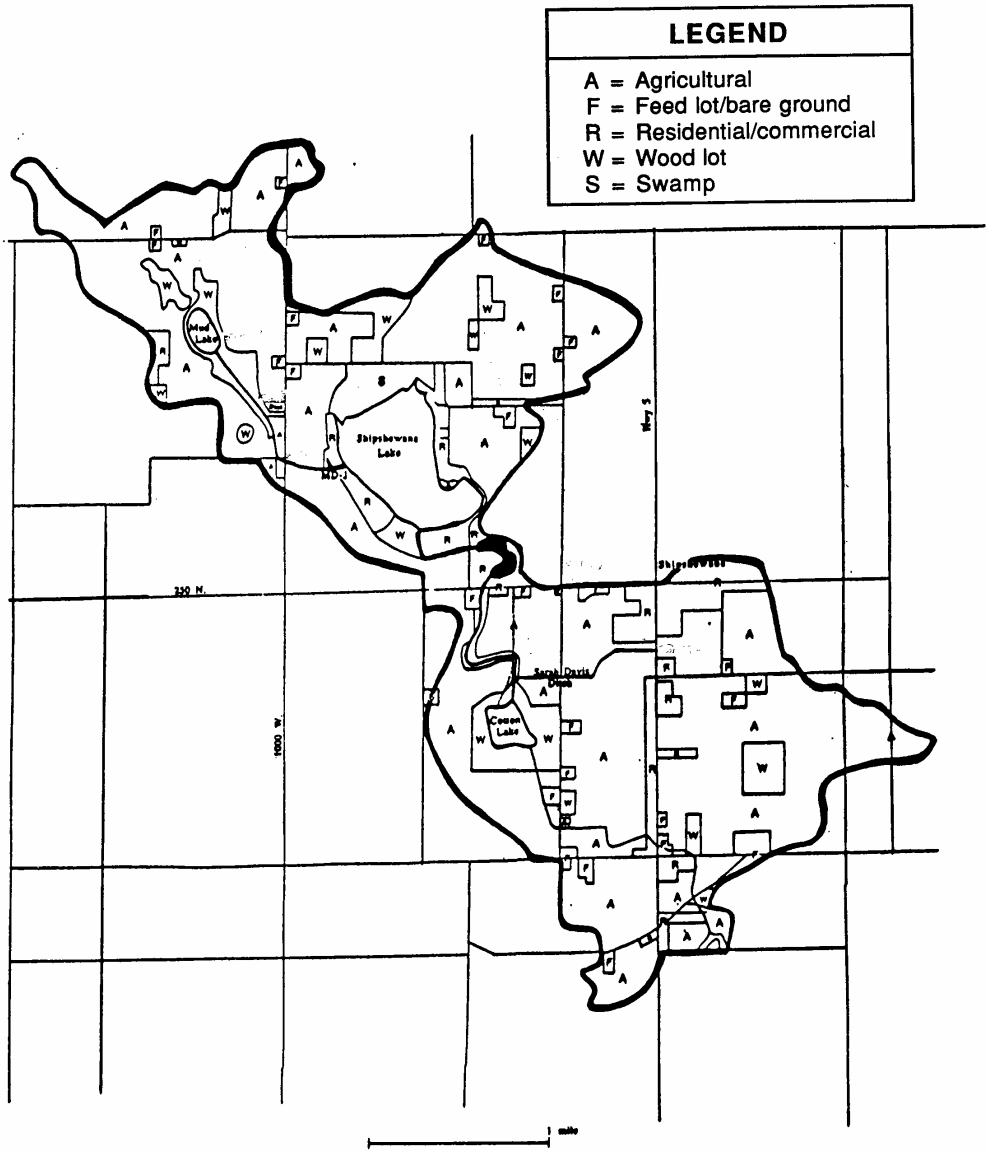
Land Use. The land use map produced from the large-scale aerial photograph and input from local residents shows the extent of agricultural development in Shipshewana Lake watershed (Figure 11). It is estimated that 3,635 acres (78 percent) of the land in the watershed is agricultural cropland, 200 acres (4 percent) is feedlot or bare ground livestock holding areas, 410 acres (9 percent) is residential or urban, and 425 acres (9 percent) is forested.

The watershed reconnaissance identified several specific features and activities that represent possible sources of nutrient loading to Shipshewana Lake. In the Cotton Lake watershed, drainage from the town of Shipshewana (in particular, the livestock auction and flea market) is directed via storm drains to Sarah Davis Ditch. This stormwater probably contributes significantly to the excessive nutrient loading observed in Cotton Lake inflow stream water quality.

The livestock holding pens at the auction facility are covered. The pens are kept clean by scraping up accumulated manure and hauling it to a land application site outside of the watershed. In addition, the livestock holding areas are periodically swept. These areas are not hosed down, or otherwise washed. Runoff from the facility is discharged into the town's stormwater sewers, from which it is discharged eventually into Cotton Lake Ditch via Sarah Davis Ditch.

Overland flow from a fertilizer sales and handling plant located close to the Fish Ponds was also identified as a possible source of nutrient contamination during rainstorms. In addition, there is a home on a septic tank adjacent to the nothernmost of the two Fish Ponds.

Mud Lake appears to be a relatively healthy shallow lake, with clear water and nutrient concentrations not indicative of excess loading. However, immediately downstream of Mud Lake, several farming and agricultural practices appear to be severely affecting stream water quality. A duck farm is located adjacent to Mud Lake inflow, and effluent from the feed lots and hatching and raising barns flows through



Summary of land use in the Shipshewana Lake watershed.

a small cement holding tank and into the stream. The cement tank was observed to be full of solids and in need of maintenance. Other farming practices observed within the Mud Lake inflow subbasin that may affect water quality include uncontrolled runoff from bare ground livestock and horse holding pens and direct assess to the stream by livestock.

In addition to specific potential sources of nutrients, several general conditions and land use practices were observed in the watershed that are likely to contribute to excessive nutrient loading to the lake. These include poor stream bank protection and limited animal waste management.

As a final observational note, the popularity of horse-drawn conveyances in the watershed may present an additional, albeit relatively small source of nutrients. Although horses are common on the street of Shipshewana, there appears to be an active effort to remove manure on a frequent basis by both the town and private merchants who maintain their own parking lots.

SECTION 3. DISCUSSION

This section presents an evaluation and discussion of the data that were collected and reviewed for this study. The objective was to develop a clear definition of the current conditions in Shipshewana Lake and the mechanisms that have been responsible for these conditions.

3.1 TROPHIC INDEX ASSESSMENT

The Indiana Lake Classification System (ILCS) provides a mechanism for quantifying the current trophic status of Shipshewana Lake. An ILCS Eutrophication Index (EI) value of 53 was calculated for Shipshewana Lake using the water quality data collected during the field survey. Table 10 presents the details of the calculation.

There is one source of uncertainty in the EI calculation that should be noted. The samples for total organic nitrogen (TON) were destroyed in shipment. This is one of the parameters required for the index value calculation. Fortunately, the structure of the EI is such that a reasonably confident score may be estimated by inference from the other nitrogen constituents. Specifically, the mean NH3 concentration was observed to be 0.85 mg/l. TON includes NH3, plus other organic forms of nitrogen (e.g., particulate). Therefore, TON must be equal to or greater than 0.85 mg/l. Historical data (Table 1) indicate that total nitrogen, which is the sum of TON plus nitrates and nitrites, is typically 3.5 to 19 times greater than NH3. Under these circumstances, the TON component of the EI has two possible scoring ranges: 0.9 - 1.9, and >1.9 mg/l. Conservatively, it may be confidently assumed that TON falls within the lower range, and this assumption was used in calculating the index value. The index value would have been one point higher, or 54, if TON were actually in the higher range.

An EI value of 51 was reported by IDEM (1986) for Shipshewana Lake. The current value of 53 indicates that there has been a deterioration in the lake's trophic status. This substantiates the qualitative

TABLE 10. ISBH LAKE EUTROPHICATION INDEX
Shipshewana Lake - 9/13/88

PARAMETER AND RANGE	RANGE VALUE	RANGE OBSERVED	POINTS
Total Phosphorus (mg/l)			
At least 0.03	1		0
0.04 - 0.05	2		0
0.06 - 0.19	3	x	3
0.2 - 0.99	4		0
Greater than 0.99	5		0
Soluble Phosphorus (mg/l)			
Less than 0.03	0	x	0
At least 0.03	1		0
0.04 - 0.05	2		0
0.06 - 0.19	3		0
0.2 - 0.99	4		0
Greater than 0.99	5		0
Organic Nitrogen (mg/l)			
At least 0.5	1		0
0.6 - 0.8	2		0
0.9 - 1.9	3	x	3
Greater than 1.9	4		
Nitrate (mg/l)			
At least 0.3	1		0
0.4 - 0.8	2		0
0.9 - 1.9	3	x	3
Greater than 1.9	4		0
Ammonia (mg/l)			
At least 0.3	1		0
0.4 - 0.5	2		0
0.6 - 0.9	3	x	3
Greater than 0.9	4		
Percent Saturation DO @ 5 ft.			
115	0		0
115 - 119	1	x	1
120 - 129	2		0
130 - 149	3		0
Greater than 149	4		0
Percent of water column with DO 0.1 ppm			
29	4		0
29 - 49	3		0
50 - 65	2		0
66 - 75	1		0
76 - 100	0	x	0

TABLE 10. ISBH LAKE EUTROPHICATION INDEX
Shipshewana Lake - 9/13/88 (concluded)

PARAMETER AND RANGE	RANGE VALUE	RANGE OBSERVED	POINTS
Secchi Transparency			
Five feet or less	6	x	6
Percent Light Transmission at 3 ft			
0 - 30	4	x	4
31 - 50	3		0
51 - 70	2		0
71 - 100	0		0
Total Plankton per ml			
Vertical tow from 5 ft.			
500	0		0
500 - 1,000	1		0
1,000 - 2,000	2		0
2,000 - 3,000	3		0
3,000 - 6,000	4		0
6,000 - 10,000	5		0
Greater than 10,000	10	x	10
Blue-Green Dominance?	5	x	5
Vertical tow from 5 ft. incl. thermocline			
1,000	0		0
1,000 - 2,000	1		0
2,000 - 5,000	2		0
5,000 - 10,000	3		0
10,000 - 20,000	4		0
20,000 - 30,000	5		0
Greater than 30,000	10	x	10
Blue-Green Dominance?	5	x	5
100,000	5		0
	Total Eutrophy Score		53

observations provided by residents of the surrounding community that the condition of the lake has declined.

3.2 HYDROLOGIC CONDITIONS

The principal hydrologic parameter of interest in evaluating the trophic status of Shipshewana Lake and developing a restoration strategy is hydraulic detention time. This is defined as the average time required for the volume of the lake to be completely replaced, and may be estimated from annual runoff, watershed area, and lake volume.

The U.S. Geological Survey has published average annual runoff data for the 48 coterminous states. The region containing LaGrange County has an average annual runoff of approximately 12.5 inches. Thus, the 4,625 acre Shipshewana Lake watershed may be expected to produce approximately 4,670 ac-ft. of runoff annually. In addition, the lake will receive approximately 38 in. of direct rainfall annually, and lose approximately 26.4 in. in evaporation. Based on a mean depth of 6 ft. and a surface area of 202 acres, Shipshewana Lake has a volume of approximately 1210 ac-ft. Thus, the lake's detention time was estimated to be approximately 0.24 yr., or about 88 days. This is a relatively short detention time.

Short detention times in lakes result in rapid flushing and retention of a relatively smaller fraction of total nutrient loading than would be retained in similar lakes with longer detention times (Reckhow, et al. 1979). From the perspective of lake restoration, this means that Shipshewana Lake is likely to have a relatively rapid response to a reduction in external nutrient loading. Moreover, accumulated sediment nutrients will be subject to reduction by flushing effects as released nutrients are washed out of the system and not replaced by external loads.

3.3 WATER QUALITY

The in-situ water quality data indicate that Shipshewana Lake was generally well mixed and not thermally stratified when sampled. The observed water column temperature and dissolved oxygen profiles are

characteristic of relatively shallow productive lakes strongly influenced by wind mixing. Supersaturation of the water column reflects a highly productive algal population. The surficial organic sediments appear to be highly reduced and anoxic, as indicated by qualitative observations of the black color, sulfurous odor, and presence of gas bubbles in these sediments.

The nutrient concentrations observed in the water samples are characteristic of eutrophic systems. The mean TP concentration for in-lake stations (i.e., SL-1, SL-2, SL-3, and SL-4) was relatively high (0.090 mg/l) while the mean PO_4 concentration was near the detection limit (0.010 mg/l). These data indicate that most of the phosphorus in the water column was in particulate form, probably as algal biomass, and that phosphorus is the limiting nutrient. It is noteworthy that the recent historical data indicated TP concentrations significantly higher (0.38 mg/l in June 1988) than those observed during this investigation. Spatial and temporal variability in water quality parameters reflect the fundamental instability of eutrophic systems (Barica 1980). Seasonal and transient meteorological effects serve as driving influences on these lakes. Therefore, observed nutrient concentrations are expected to be inherently variable over relatively short periods of time.

The mean NH_3 and NO_3-NO_2 concentrations at the in-lake stations were 0.85 mg/l and 1.47 mg/l, respectively. Significant concentrations of these soluble forms of nitrogen indicate that nitrogen is not the limiting nutrient to algal growth in Shipshewana Lake. This substantiates the conclusion that phosphorus is the limiting nutrient in the lake.

The high nutrient concentrations observed at the stations along Cotton Lake Ditch indicate that this stream represents a significant source of phosphorus and nitrogen to Shipshewana Lake, even under low flow conditions. Several likely sources of nutrients were identified during the watershed reconnaissance, including livestock auction and flea market facilities in the town of Shipshewana, and a fertilizer plant adjacent to the Fish Ponds. However, runoff from these sources enters

the inflow stream downstream of Cotton Lake. The very high levels of TP (0.2 mg/l) present in Cotton Lake and the emerald green color of the water observed during the site visit (indicating a concentrated bloom of bluegreen algae) imply a significant nutrient source upstream of Cotton Lake. Interestingly, the upstream station (CL-7) data showed relatively low TP and PO_4 concentrations, and relatively high NO_3-NO_2 and NH_3 concentrations. The sample appeared to be dominated by soluble forms of nitrogen; TSS and CHLA were very low. Much of the land upstream of Cotton Lake is agricultural, although there is also a mobile home camp within the subbasin. The data are insufficient to characterize the source of the contamination conclusively, but there appears to be a very significant source of nutrients in the upper reaches of the Cotton Lake subbasin.

Mud Lake Ditch is another significant source of nutrients to Shipshewana Lake, but primarily under storm flow conditions. At low flow conditions, the discharge from the ditch was negligible and Mud Lake (MD-4) had relatively low nutrient concentrations and suspended solids. In contrast, the storm samples collected in the lower reaches of the ditch on September 20 had very high nutrient and suspended solids concentrations. In particular, concentrations of the soluble nitrogen fractions (NH_3 and NO_3-NO_2) were the highest observed in any sample (4.80 mg/l and 14.0 mg/l, respectively).

Although the base flow fecal coliform and fecal streptococcus cell counts were relatively low, the ratios of fecal coliform to fecal streptococcus (FC/FS) may provide information on possible sources of pollution (Table 6). A ratio greater than 4.1 is considered indicative of pollution derived from domestic wastes (human) whereas ratios less than 0.7 suggest pollution due to nonhuman sources (Metcalf & Eddy 1979). Ratios between 0.7 and 4.4 usually indicate wastes of mixed human and animal sources. Using these values as a guide, the Cotton Lake inflow would appear to be affected primarily by human wastes in and immediately downstream of the Fish Ponds and in the upper part of the watershed. Those portions of the stream between Cotton Lake and the Fish Ponds (including Sarah Davis Ditch) appear to be contaminated by a

mixture of human and animal wastes. Because of the low cell counts involved in calculating the ratios, any inferences must be interpreted as being suggestive, but not conclusive.

The Mud Lake Ditch discharge FC/FS ratios indicate that significant contamination is occurring under storm flows, probably from poultry wastes. It is significant that the total numbers of fecal coliform and fecal streptococcus were very high at the MD-1 station on October 18.

3.4 ALGAE POPULATIONS

The phytoplankton data indicate that Shipshewana Lake has a highly productive algae population, dominated by blue-green species. This is typical of highly eutrophic systems. Although the observed water column data indicate nearly complete oxygenation throughout the water column, the presence of such a productive and diverse algal community presents a serious threat of a population bloom-collapse cycle (Mericas, et al 1985). Under optimum environmental and meteorological conditions, such as a prolonged period of clear skies, warm temperatures, and calm winds, algae populations reach very high concentrations which are not sustainable under normal conditions. When conditions change, with the passage of a weather system for example, the unstable population collapses, resulting in a near-complete deoxygenation of the water column as the algal biomass decomposes. In addition to the impacts on aquatic organisms, these bloom-collapse events present aesthetic problems such as odors and unsightly scums. Although there is no evidence of toxic effects in Shipshewana Lake, certain blue-green species, including *Anabaena sp.* and *Aphanizomenon flos-aquae* present the potential for toxic effects.

3.5 LAKE SEDIMENTS

The lake sediment core visual and analytical data indicate that the surficial sediments in Shipshewana Lake are primarily composed of silt/clay with a significant organic content. The cores taken at SL-1, SL-2, and SL-4, had a mean organic content of 34.8 percent. This is on

the lower end of the range of organic content reported by Wedepohl et. al. (1983) for seven glacial lakes in Wisconsin. There was a distinctly flocculant layer at the surface of each of these cores that appeared to consist largely of dead algae cells. This type of unconsolidated flocculant material typically contains large concentrations of nitrogen and phosphorus.

The very low organic content observed at the SL-3 station is probably indicative of a spring in that area of the lake. The heterogeneity of organic sediment in the lake is evident from the variability among stations. In addition, a comparison of the location of SL-3 and the organic sediment depth map (Figure 8) indicates that substantial differences may occur within close proximity. Again, springs in the bottom of the lake would account for this variability. Unfortunately, precise definition of the locations and flow of springs in the lake was beyond the scope of this investigation.

The observed characteristics of the surficial sediments in Shipshewana Lake indicate that they are probably a significant source of internal nutrient loading, especially under the anoxic conditions that appear to predominate at the sediment-water interface. With a significant reduction in external nutrient loading, this internal nutrient source may be sufficient to sustain eutrophic conditions, albeit less severe than currently exist in the lake. Any restoration effort must address the problem of significant sediment nutrient release.

3.6 LAND USE

The review of land use in the watershed revealed several specific activities and general practices that represent potential sources of nutrient loading to Shipshewana Lake. The identification of these specific nutrient sources is based on the nature of the activities at each location and literature data on nutrient loading associated with those types of land use. Sampling and quantification of specific nutrient sources was beyond the scope of this investigation, and is not anticipated as being required to define a restoration strategy. However,

an effective restoration of the lake must address and control the impact of these activities and practices on nutrient loading.

3.6.1 Identified Nutrient Sources

The high concentrations of nutrients in Cotton Lake Ditch appear to be the result of stormwater drainage from the town of Shipshewana (e.g., Sarah Davis Ditch) and the agricultural lands within the southern half of the Shipshewana Lake watershed. The major identified nutrient sources include runoff from the livestock auction facility, the fertilizer plant, and the flea market. It must be emphasized that these facilities have been identified because of their relative size. It would be incorrect to conclude that these three facilities are the sole source of nutrient contamination in this subbasin.

Several thousand head of cattle and horses pass through the auction facility in Shipshewana each week between May and September. On the average, cattle excrete between 0.07 and 0.09 lb. of phosphorus and 0.37 to 0.43 lb. of nitrogen per 1,000 lb. live weight (SCS 1975). Horses excrete more phosphorus (0.12 lb. per 1,000 lb.) and less nitrogen (0.3 lb. per 1,000 lb.). Very significant amount of nutrients are being deposited on the floors of the facility annually as manure and urine. The current waste management practice involves collecting manure from the livestock holding areas and hauling it off for land application. It is unclear how this practice affects liquid wastes and the smaller particulate material that is not picked up in the scraping process. It may be assumed that a large fraction of this residual material is ultimately washed off during rain storms and transported to Shipshewana Lake in stormwater. Dust, oil and grease, spilled food, and other litter from the public areas and parking lots of the auction facility will also be in stormwater runoff from this site.

The fertilizer plant (Figure 11) is a farm supply operation that sells and handles agricultural chemicals, including fertilizers and pesticides. Many of these materials are in liquid form, and are dispensed from tanks. These tanks are filled and washed on-site. All

surface runoff, including washwater, flows into the Fish Ponds via a drainage tile. Transient nutrient loading from this site is potentially very high. Such loading is expected to be very variable, depending on the times of the year when the various chemical are being applied.

Sanitary waste facilities at the flea market are connected to the town sewer system. Weekly traffic through this facility can reach 40,000 people. The pollutants associated with this level of traffic include spilled food matter, oil and grease from automobiles, and dust. Litter and surface pollutants that are not collected as trash will be transported by stormwater runoff to Sarah Davis Ditch, and into the lake.

The Mud Lake subbasin appears to contribute a much lower nutrient load to Shipshewana Lake under base flow conditions than the Cotton Lake subbasin. Base flow was observed to be very low, preventing the collection of water samples along most of the length of the stream. This condition is typical during summer and autumn months. However, flow and nutrient loads were observed to increase substantially during the sampled storms. A major source of nutrient and fecal contamination in the ditch appears to be a duck farm adjacent to the MD-3 station (Figure 11). The farm consists of hatching and raising barns, and a bare-ground outdoor feed lot which typically contains between 5,000 and 10,000 adult ducks. The lot has a cement drainage trough which also serves as a watering trough for the ducks. A constant low flow of water is maintained in the trough using well water. The drainage water from the trough is directed into a small cement holding tank, and the overflow is then discharged into Mud Lake Ditch. The settling pond was almost full during the September site visit, and was observed to be generally ineffective in removing excessive particulate matter. The discharge to the ditch was observed to be very heavily contaminated with duck wastes. Based on a daily TP excretion rate of 0.62 lb. per 1,000 ducks (SCS 1975), this single facility has a potential daily contribution to Shipshewana Lake of 3.1 lb.-P.

3.6.2 Land Use Practices

The erosion data presented in Figure 2 indicate that the Mud Lake subbasin has the highest percentage of highly erodible soils. Erosion controls throughout the Shipshewana Lake watershed appeared to be very limited, especially with respect to stream bank erosion. Sheet erosion in the watershed is only slight to moderate due to the Amish style of farming (Wayne Stanger, pers. comm.). Much of the length of each of the inflow streams is fenced, primarily due to the steep banks of the streams themselves. However, along both Cotton Lake and Mud Lake Ditches, sites were observed where livestock had been allowed access to the banks of the stream, creating erosive conditions and allowing raw animal wastes to enter the streams.

Animal waste appears to be a significant source of nutrients in surface runoff in the watershed. The animals of concern include horses, hogs, poultry, and cattle. Table 11 presents a summary of daily nutrient excretion rates for a variety of common livestock animals. These values are for raw excreta, and therefore are higher than the actual loads that would be delivered to receiving waters. However, the potential magnitude of nutrient loading from large concentrations of these animals can be appreciated from the data.

An unusually large number of horses are present in the Shipshewana Lake watershed, principally due to the Amish influence in the community. The watershed is unique in that horse-drawn conveyances and agricultural machines are a mainstay of the local economy. As a result, significant quantities of manure are deposited on roadways in and around the town. The current management of these wastes involves a voluntary system of regular sweeping of parking lots and parking areas. The collected wastes are generally placed in garbage recepticles and disposed of outside of the watershed. Any residual material not removed during this process will be washed off by stormwater and enter the receiving waters.

Livestock waste management practices, other than those discussed above, appear to be very limited in the watershed. The few settling

TABLE 11. BEST MANAGEMENT PRACTICES AVAILABLE FOR THE CONTROL OF URBAN RUNOFF (Cooke, et al., 1986).

SOURCE CONTROLS:

- Increased Infiltration
- Retention
- Erosion Control
- Street Sweeping
- Fertilizer Management

REDUCTION IN DELIVERY TO RECEIVING WATERS:

- Stormwater rerouting
- Infiltration and Sedimentation Basins
- Flow Equalization
- Physical, Chemical, and Biological Treatment

ponds, or similar management practices observed were under-designed and/or poorly maintained. The watershed is predominantly agricultural and relatively large in comparison to the lake. Therefore, although the nutrient contribution of a few animals on an individual farm may be numerically small, the cumulative effect is significant.

SECTION 4. IDENTIFICATION OF POTENTIAL SOLUTIONS

This section presents a discussion of technological solutions that are available for addressing the nutrient enrichment problems in Shipshewana Lake. The discussion is organized with respect to position in the system: Section 4.1 focuses on land and watershed management techniques that will reduce nutrient loading to, and transport in, the streams; and Section 4.2 discusses strategies for in-lake restoration, including sediment removal and in-situ treatment methods. It must be recognized that in-lake restoration efforts will be futile without a significant and permanent reduction in external nutrient loading.

4.1 WATERSHED MANAGEMENT

There are several specific areas in watershed management that must be addressed to reduce nutrient loading to Shipshewana Lake. These include erosion control, runoff control and treatment, and animal waste management. All of the techniques and practices are representative of best management practices (BMPs). Although BMP development is an emerging science, there is a substantial amount of pertinent design information available regarding the technologies discussed.

4.1.1 Erosion Control

A crucial area in which erosion control practices are needed is stream bank protection and stabilization. The observed access of livestock to sections of streams results in destabilization of the stream banks and deposition or transport of animal wastes directly into the stream waters. Fencing stream banks to exclude livestock is simple and relatively inexpensive. In addition to fence construction, there may be some costs associated with providing alternative sources of water to the animals. The benefits will include reduced stream bank erosion and prevention of the direct entry of raw animal wastes into the streams.

Additional erosion control and soil conservation practices should be promoted and instituted to the extent practical in the watershed. These

practices should include conservation cropping and tillage, critical area planting, terracing, and grade stabilization. It is beyond the scope of this investigation to describe in detail the gamut of possible BMPs, since applicability is very site specific. However, the Soil Conservation Service (SCS) has published design criteria and provides guidance to individual farmers and land owners in the selection and implementation of erosion control measures.

4.1.2 Runoff Control

Stormwater runoff from any developed urban area will be contaminated by dust, animal waste, oil and grease, lawn fertilizers, and a wide range of other materials that are deposited on the ground or buildings and washed off by rainfall or snowmelt.

Contaminated runoff is a serious problem in the watershed, especially in the Cotton Lake Ditch subbasin. This conclusion is based on observations of the lack of stormwater management controls, the nature of land use in the watershed, and the nutrient concentrations observed in the stream water samples. The sources of contamination are diverse, ranging from street litter (including manure) to agricultural chemicals associated with the fertilizer plant.

BMPs for the control of urban stormwater may be separated into source controls and reduction of delivery to receiving waters. Table 11 lists several types of practices and technologies that are commonly used in managing urban runoff. The most applicable practices for the Shipshewana Lake watershed include erosion control, street sweeping, and control of lawn fertilizer application. Porous pavement, which promotes infiltration, may be suitable as a means of stabilizing existing unpaved parking areas and minimizing runoff.

The treatment of contaminated urban stormwater may be accomplished by employing wet and dry stormwater detention ponds, grassed waterways, sedimentation basins, and artificial wetlands as mechanisms for pollutant removal. Diversion techniques may also be used to reroute contaminated

flows away from the critical waterway to another receiving water with a greater assimilative capacity. Some combination of these and other approaches will provide a practical means of significantly reducing surface runoff nutrient loading.

Management of contaminated runoff from commercial operations, such as the flea market, the fertilizer plant, and the livestock auction facility must begin with minimization of contamination. In the case of the flea market and public areas of the livestock auction facility, this can take the form of improved litter collection, stabilization of bare ground surfaces, and containment and routing of stormwater flows through grassed areas and sediment basins.

At a facility like the fertilizer plant, contamination control should begin with chemical handling and management practices that minimize spills and other concentrated releases to the environment. In addition, the control of chemical dusts and aerosols, and the diversion of surface runoff through grassed buffers and sedimentation ponds will minimize the discharge of chemical contaminants. Perhaps the most technologically complex control for this facility would be the treatment of tank washwater. This material cannot be discharged into the Shipshewana Lake system without significant impairments. It may be possible to discharge the washwater into the the town sanitary sewage system, if the capacity is available. Otherwise, some form of detention and treatment will be required (e.g., lagoons or land application).

Historically, the discharges from Cotton Lake Ditch and Mud Lake Ditch flowed through marshland prior to entering Shipshewana Lake. The dredging and rerouting of these ditches that occurred in the early 1960s removed the sediment and nutrient trapping effects that these marsh areas provided. Construction of artificial wetland treatment systems or sediment traps at the discharges of the two ditches would serve to removed suspended pollutants from, and improve water quality in the discharges prior to entry into the lake. As an example of an innovative treatment system that might be considered, Figure 12 shows a wetland installation designed to alternately treat stormwater flows during

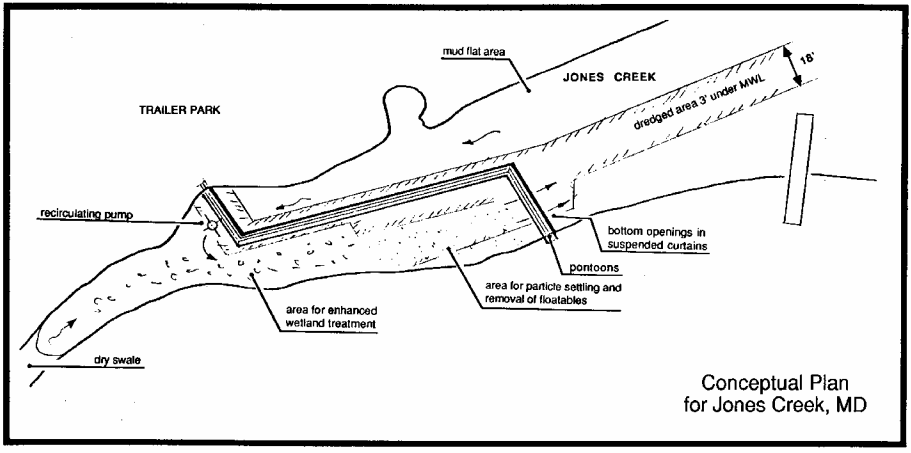


Figure 12. Conceptual plan for an innovative enhanced wetland treatment facility that may be applicable to Shipshewana Lake. Storm runoff is treated by wetland plant uptake and sedimentation prior to discharge. During dry periods, the recirculating pump draws water from the receiving body for treatment.

runoff events, and recirculate and treat polluted lake water under base flow conditions (Karl Dunkers, pers. comm.).

The costs of implementing BMPs are very dependent on site specific conditions. Some indication of relative costs may be obtained from the data presented in Table 12.

4.1.3 Animal Waste Management

Animal waste management appears to be a significant problem throughout the watershed. There was evidence of fecal contamination in every stream sample collected for this investigation. The two areas of particular concern are Sarah Davis Ditch and the lower end of Mud Lake Ditch. Sarah Davis Ditch appears to be receiving animal and human wastes at base flow in spite of control measures in the subbasin. Although storm flow samples were not collected, it is likely that such flows will have very high concentrations of nutrient and bacteriological contaminants. Mud Lake Ditch is heavily contaminated with duck wastes during storm events.

The general principle of proper animal waste management and control centers on minimization of contamination and adequate treatment of contaminated flows. Contamination may be minimized by maintaining vegetated buffer areas between livestock and receiving waters, improved waste collection systems, and containment of runoff from intensive livestock holding areas. Strategies such as land application and construction of lagoons and ponds are the best means for treating contaminated runoff. The SCS Agricultural Waste Management Field Manual (1975) is an excellent reference for basic guidance in implementing on-site waste management practices.

4.2 LAKE RESTORATION

The significant volume of flocculant organic sediment in Shipshewana Lake represents a large store of readily available nutrients that will continue to cycle into the water column regardless of what controls are

TABLE 12. TYPICAL COSTS OF SELECTED URBAN BMPS (SCHUELER 1987).

MANAGEMENT PRACTICE	SIZE	COST (1985 $)
Dry Pond/Extended Detention Basin	50,000 ft^3	$18,700
Wet Pond	50,000 ft^3	20,400
Infiltration Trench	3,600 ft^3	4,600
Grit Separators	n/a	7,500
Grassed Swales	15 ft. x 150 ft.	750
Wetland Planting	5 ac.	10,000

placed on external loading. The options that are available to deal with this internal loading include physical removal, chemical treatment, and physical consolidation. An alternative course of no action is also possible.

4.2.1 Sediment Removal

The technologies available for sediment removal may be classified as either wet or dry: dry techniques require drawing the lake down, or otherwise exposing and partially dewatering the sediments; wet techniques are constructed in-situ with the sediments submerged.

All dry sediment removal techniques are similar in that they involve draining the water body sufficiently to allow heavy machinery to be used in physically removing the exposed sediment. The major advantage of this approach is that it allows the sediment to partially dewater and consolidate. Thus, the removed material has a relatively high solids content and can be efficiently moved over roads by truck. In addition, there is excellent control over the quantity and location of sediments removed and relatively little sediment resuspension occurs.

The major disadvantages of dry sediment removal include cost and logistic limitations. Because the material is trucked over roads, the cost per cubic yard removed tends to be higher than hydraulic dredging techniques. Getting heavy machinery in and out of the work site is often a problem in highly developed shoreline areas or where access roads are inadequate. The construction of plank roads is often required for moving heavy machinery over soft lake sediments. The transporting process often results in a lot of mud being deposited on the roads between the shoreline and the disposal area. This can present a serious public relations problem where a large volume of material is being removed over a period of several months.

Wet sediment removal techniques involve either scooping up bottom material in buckets that are subsequently emptied into a barge or truck for transport to a disposal area, or suspending the material in a slurry

and transporting it through a pipe to an impounded disposal area for dewatering.

Bucket dredges consist of a dragline or backhoe operated from a barge platform and a second barge is used to hold the dredged material. When the second barge is full, it is moved to a shore site where the spoil is transferred to a truck for disposal. The advantages include a relatively high solids content and a high degree of manuverability. The disadvantages include turbidity in the lake from resuspension of bottom sediments and relatively low rates of removal.

Hydraulic dredges are the most common machines used in large-scale wet dredging operations. The dredge consists of a cutter head mounted on the end of a suction pipe suspended from a barge. As the cutter head dislodges sediments, the loosened material is sucked into the pipe in the form of a slurry. The slurry pipe extends from the barge to the shoreline, and from there to the disposal area. A settling basin is required at the disposal area to allow settling of the suspended particulate material and return of the remaining, or "return" water to either the lake or some other receiving system.

The advantages of hydraulic dredging include relatively high removal rates, high cost efficiencies, and minimum impact on the shoreline. The disadvantages include generally high levels of turbidity in the lake, the requirement for a suitably large and nearby disposal area, and the need for a suitable pipeline route from the lake to the disposal area.

The bathymetric survey data provided an estimate of 551,000 cubic yards of organic material in the lake. Typical dredging costs reported in the literature range between $2 and $5 per cubic yard, depending on the method of removal. If it is assumed that removal of 75 percent of the accumulated organic material will sufficiently reduce internal nutrient storage, dredging of Shipshewana Lake will cost between $750,000 and $2.06 million dollars. This estimate does not include land costs that may be associated with disposal, or the cost of post-dredging monitoring.

4.2.2 Chemical Oxidation

Oxidation of the organic material in lake sediments serves to reduce the availability of nutrients in this material. Several in-situ sediment oxidation techniques are available, the most successful of which involves the injection of calcium nitrate and other chemicals, such as lime into the sediments.

Lake restorations using calcium nitrate sediment treatment rely on the stimulation of biochemical denitrification. The principle objective is to inactivate sediment phosphorus through nitrate-induced reactions, but a related effect of the treatment is anaerobic sediment oxidation through denitrification. Cooke (1986) noted that in shallow lakes with high pH and temperature, the necessary chemical reactions may not take place to inactivate phosphorus. The RIPLOX technology uses calcium nitrate in conjunction with lime and ferric chloride to enhance the reactions. An important note is that nitrate treatments have been found to have no significant effect on sediment consolidation, and may result in an increase in sediment thickness.

Specific doses required for nitrate application are very dependent on local conditions. However, treatment costs typically range between $0.74 and $1.33 per square meter of lake bottom. For Shipshewana Lake, this may be projected to an estimated cost of between $600,000 and $1.08 million.

4.2.3 Sediment Consolidation

Sediment consolidation through water level drawdown offers a possible alternative to dredging as a means of increasing lake depth (Wedepohl, et al. 1983). This technique is relatively new and not fully proven, but appears to be particularly well suited to highly organic sediments (Wedepohl 1983; Cooke et al. 1986). In practice, the lake level is drawn down to below the surface of the sediments, removing the buoyant support of the water, and the sediments are consolidated under their own weight. After a period of drying, the lake level is restored.

The sediment consolidation process is irreversible, and a net increase in depth results. Although it is commonly assumed that the sediments will be oxidized upon exposure to the air, studies indicate that no significant oxidation occurs during the drying (Cooke, et al. 1986). However, nutrient release from the sediments is generally diminished with their consolidation.

The most common application of lake level drawdown is in aquatic weed control, where nuisance plants are exposed to freezing and desiccation, or other harsh environmental conditions. Small populations of coontail and water milfoil were observed in Shipshewana Lake during the September site survey. Residents of the lake have indicated that these plants are readily observable in the early Spring, and less apparent later in the season when the algae are most abundant. A reduction in algal density and increase in light penetration in the lake probably would result in a proliferation of nuisance aquatic weeds. Thus, an ancillary benefit of drawing the lake down for sediment consolidation would be the inhibition of macrophyte growth.

A drawdown of Shipshewana Lake will require excavation machinery for digging the drainage channels, dump trucks for hauling excavated material, a disposal site for the removed material, and labor. An estimate of the costs was developed based on certain assumptions regarding excavation requirements and operating costs. It was assumed that a 4 ft. deep and 12 ft. wide channel 3,000 ft. long will be required to drain the lake into Page Ditch. Cooke, et al. (1986) cite costs for a lake drawdown and bulldozer excavation of a small lake in New York state at approximately $5.66/cubic yard. If it is assumed that machinery, operating, and labor costs for the Shipshewana Lake drawdown will be approximately $5.00/cubic yard, the cost may be estimated at $26,700.

4.2.4 Aeration

Internal oxygen demand from organic sediments and highly productive algal populations can result in complete deoxygenation of the water column at certain times of the day (e.g., pre-dawn hours). Mechanical

aerators may be used under these circumstances to supplement natural oxygen transfer processes and maintain aerobic conditions in the water column. Artificial aeration in a shallow lake may also resuspend a significant amount of loose bottom material, and promote the oxidation of this material. There have been some investigations into the effectiveness of aeration as a means of sediment consolidation (Wedepohl 1983). In general, it has been reported that aeration with air alone is not effective in promoting sediment consolidation. The addition of a strong oxidant, such as ozone or hydrogen peroxide significantly improves the performance of sediment aeration systems. However, the additional costs involved in obtaining the oxidants are usually prohibitive. Typical costs for sediment oxidation of organic sediments using ozonation are in the range of $15.00 per cubic yard, or approximately $6 million to treat 75 percent of the sediment in Shipshewana Lake.

Mechanical aeration may have a role in maintaining aerobic conditions during a lake drawdown. Normally, a small pool of water will remain in the deepest areas of the lake. This pool is subject to high oxygen demand from disturbed sediments and concentrated fish populations. A mechanical aerator may be required to offset these demands.

4.2.5 Phosphorus Inactivation

Chemical precipitation and inactivation of phosphorus may be used as a means of effectively reducing the availability of sediment phosphorus to the overlying water column. This is accomplished by treating the lake with aluminum sulfate (alum) to form a precipitate which tightly binds phosphorus by sorbtion and entrapment (Cooke, et al. 1986). Large doses will result the sealing of the surface of the lake sediments and an inhibition of phosphorus cycling over many years. This technique has been very successful in many deep lakes, but the responses in shallow lakes have been variable. It has been suggested that wind mixing in shallow lakes disrupts the alum floc, exposing unsealed sediments to the water column. Cooke et al. (1986) conclude that dredging, drawdown, and aquatic weed harvesting may be more effective in controlling internal phosphorus in shallow lakes.

4.2.6 Microbial Inoculation

There are a number of commercial microbial products available that are marketed as treatments for organic lake sediments. Questions regarding the use and effectiveness of these products are often raised during restoration studies. For that reason, a brief discussion is appropriate.

The theory behind microbial lake treatment products is that they contain unique combinations of bacteria and other microorganisms that are particularly effective at decomposing organic lake sediments, but are rarely found in the lake environment. Several researchers have investigated the claims and effectiveness of these products (Gremillion and Mericas 1988; Cooke, et al. 1986; Szewczyk 1984; Hanson 1981). All of the published evidence by independent investigators indicates that these commercially marketed microbial lake treatments have no significant effect on either lake sediment thickness or nutrient release.

4.2.7 "No Action" Alternative

In any feasibility study, there will be the available option of doing nothing. In the case of Shipshewana Lake, a complete "no action" policy will result in further deterioration in the ecological condition of the lake; eutrophication will progress, leading to the eventual filling in of the lake and conversion to a marsh.

The hydrologic conditions in the lake are such that a modified "no action" strategy may result in a long-term improvement in lake water quality. The detention time in Shipshewana Lake is relatively short (i.e., 0.24 yr., or approximately 88 days). If external loading can be significantly reduced, the short detention time will result in internal nutrients being washed out of the system. Over a period of years, the net internal store of nutrients would be reduced, accompanied by reductions in water column nutrients and generally improved trophic conditions. The uncertainties in this scenario are in the level of

reduction in external loading necessary and the rate of nutrient washout from the lake. Nutrient export will be a function of external load and internal sediment nutrient release. Unfortunately, the available data are insufficient to develop even a simple annual nutrient budget model to project likely response.

SECTION 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Shipshewana Lake is suffering from excessive nutrient enrichment and is rapidly moving from eutrophic to hypereutrophic conditions. The evidence for this lies in elevated nutrient concentrations found in the lake, the increasing frequency and severity of algal blooms, the dominance of blue-green algae in these blooms, and the observed increase in the lake's Eutrophication Index score. A significant layer of flocculant organic sediment is resulting in accelerated nutrient cycling between the sediments and water column, and generally anaerobic conditions on the lake bottom.

Agricultural and urban non-point source pollution is the principle source of nutrients entering the lake. A significant component of this pollution consists of animal wastes that are not being adequately controlled in the watershed. The most severe individual animal waste problem observed was at the duck farm on Mud Lake Ditch where the existing waste settling tank was observed to be full to capacity. In addition, livestock access to streams is resulting in stream bank erosion and deposition and transport of wastes directly into the streams.

The urban area in and around the town of Shipshewana appears to be a significant source of nutrient contamination. Within this subbasin, the flea market, livestock auction house, and fertilizer plant appear to be the most probable sources of significant discharges. In addition, there may be some leakage from the town sanitary sewer system or septic fields, as indicated by fecal coliform/fecal streptococcus ratios.

Restoration of Shipshewana Lake must include a significant reduction in external nutrient loading to the lake along with a reduction in available internal nutrients in the lake. This may be accomplished through an integrated program of implementation of agricultural and urban best management practices throughout the watershed and mitigation measures in the lake. Of the in-lake alternatives, the most economical

and likely to succeed will be a drawdown to promote sediment consolidation and inhibit nuisance macrophyte development. Limited mechanical dredging may be possible while the lake level is down, and will be beneficial to the lake.

It may be possible to take no in-lake actions and realize a significant long-term reduction in internal nutrients through washout. Under significantly reduced external loading, the lake will begin to export nutrients until a new equilibrium is reached between nutrient inputs and losses. It is possible that this new trophic condition will be satisfactory for renewed use of the lake.

5.2 RECOMMENDATIONS

A restoration of Shipshewana Lake is warranted by the current eutrophic conditions and the impairment to recreational uses that these conditions have caused. The restoration should include a combination of reduction in external nutrient load and internal nutrient cycling.

Implementation of BMPs throughout the watershed should begin with an extensive education program designed to make all farmers, businessmen, and residents aware of the issues surrounding the decline of Shipshewana Lake and the activities that result in nutrient contamination of runoff. Once the population has been made aware of the nature of the problem, the next step should be providing guidance in selection and implementation of appropriate management practices. Emphasis should be placed on animal waste management, erosion control, and fertilizer contamination. This program should be conducted in conjunction with the County Conservationist's office and the SCS.

Wetland areas historically existed at the mouths of Cotton Lake Ditch and Mud Lake Ditch. Serious consideration should be given to construction of artificial wetlands at the mouths of these two discharges. Such wetlands will serve to further reduce sediment and nutrient loading to the lake through treatment of the ditch discharges.

In-lake restoration efforts should only begin after the implementation of controls in the watershed. Premature in-lake mitigation efforts are likely to be undone by continued loading from the watershed. An over-winter lake drawdown is recommended to consolidate the loose organic sediments, reduce nutrient availability from these sediments, and provide some preventative action against the development of nuisance aquatic weeds as water quality improves in the future. Drawing the lake down by approximately 8 ft. will expose most of the organic sediments and allow a deep pool to remain for fish.

A certain amount of dredging will be required to provide a drainage channel between the deepest part of the lake and the lake outlet. While the excavation machinery is on-site for this dredging, additional limited physical removal of sediment should be considered in accessible areas where the organic material is especially thick. An additional construction activity that should be considered is the installation of a water control structure at the outlet of the lake that would allow periodic drawdowns in the future for lake maintenance (e.g., weed control, fisheries renovations, and dredging).

5.3 FUTURE ACTIONS

Consistent with the structure of the Indiana Lake Enhancement Program, the next step in the restoration process should be a Design Study, followed by implementation of the restoration activities.

5.3.1 Design Study

A Design Study should be conducted with the following objectives:

- Identify and design site specific BMPs for the major sources of nutrient contamination in the watershed (i.e., livestock auction, flea market, fertilizer plant, livestock holding areas). This should be done in close cooperation with the District Conservationist and the SCS.

- Design artificial wetlands, sediment traps, or similar treatment systems for the discharges of Cotton and Mud Lake Ditches.

- Design and plan a lake drawdown to provide a reduction in lake level of approximately 8 ft. This plan should include specifications for the excavation required for adequate drainage, opportunistic dredging that might be conducted in association with the drawdown, disposal of the excavated material, construction of an outlet structure to facilitate future drawdowns, and permits that may be required.

- Conduct an environmental impact assessment of downstream effects of an extended drawdown of Shipshewana Lake.

- Investigate funding options available to support the restoration implementation.

- Prepare and submit application packages for permits and funding.

5.3.2 Restoration Implementation

The restoration effort should begin with implementation of BMPs for controlling contaminated runoff throughout the watershed. It will probably take several years for most of the individual landowners, businessmen, and farmers to construct on-site controls. During this period all regional facilities, such as detention ponds, wetlands, and sediment traps should be constructed.

A drawdown of Shipshewana Lake should be conducted after most of the watershed controls have been put into operation. The drawdown should be scheduled to begin in September or October to allow the lake to fully drain and the exposed sediments to dry prior to the onset of Winter snow and ice cover. All excavation, dredging, and construction should be scheduled for this period as well. The lake should be allowed to refill in the following Spring. The available hydrologic information indicates that the lake will refill within 2 to 3 months.

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