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FINAL REPORT

LITTLE BARBEE LAKE FEASIBILITY/DESIGN STUDY

Submitted To:

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EXECUTIVE SUMMARY

International Science & Technology, Inc. (IS&T) has provided technical services to the Barbee Lakes Property Owners Association in conducting a Feasibility/Design Study of Little Barbee Lake, Kosciusko County, Indiana. The study was funded through the Indiana Department of Natural Resources Lake Enhancement Program (LEP).

The objectives of the Feasibility Study were three-fold:

- Assess the current condition of the lake and establish a baseline against which future changes can be measured.
- Identify potential threats to the well-being of the lake.
- Recommend lake and/or watershed management practices that minimize such threats.

To meet these objectives, four separate phases of the study were necessary. First, all relevant background information, including maps, previously collected water chemistry data, copies of correspondence, and biological data, were collected and reviewed. This information was critical to understand the current status of knowledge on the lake. Second, lake surveys were conducted to collect data on water quality, abundance of algae, depth of sediments at the tributary inlets, sediment chemistry, water depths, and aquatic plant distribution. Third, a watershed survey was conducted. This involved compilation of land use information for use in constructing a land use map of the entire watershed. In addition, the watershed survey involved the application of a computer model that predicted sediment and nutrient transport from the watershed. The land use map and computer model results will be important tools for controlling and reducing the influx of nutrients to Little Barbee Lake, and for identifying key problem areas. The fourth phase of the study involved the analysis of all data that had been collected, and development of recommendations that would have the greatest probability of improving the quality of this resource.

For the Design component of the project, engineering plans and specifications for two construction projects were developed: dredging of the Stonebruner-Putney Ditch channel and mouth, and stabilization of a reach of the Putney Ditch inflow. Separate bid packages were provided to the Barbee Lakes Property Owners Association for contracting these projects. The plans for the dredging project specify the areal extent of the dredging and the quantity of material to be removed from the lake. In addition, plans for construction of a containment basin to dry or dewater the sediments are provided. The property on which the basin is to be constructed is private. Permission was obtained from the owner to use the site for as long a period of time as necessary. Specifications included in the Design section of the report cover all aspects of both construction and dredging. This includes all documents required by the IDNR Lake Enhancement Program for construction projects.

Much of the information contained in this report is of a technical nature, and, like a report in any scientific field, may contain unfamiliar terms and information. An effort has been made to reduce the complexity of the report wherever possible, because it is intended to serve all those concerned about the future of Little Barbee Lake. To clarify one concept that underlies the very nature of this study and the problems seen in the lake, a definition of eutrophication is in order. This term describes the natural aging process of lakes, in which the lake is gradually filled with marsh vegetation, then becomes a swale, and eventually a wooded area. This may take many hundreds of years, depending on the physical characteristics of the lake and the degree of man's intervention in the process.

Like many lakes that have agricultural watersheds, eutrophication of Little Barbee Lake has been accelerated due to the addition of vital plant nutrients in runoff. Under normal conditions, these nutrients, primarily nitrogen and phosphorus, are in short supply, and come mainly from biological sources. Decaying plants and animals, weathering of watershed soils, and atmospheric inputs are the major natural sources of lake nutrients. The relatively deep soils of the midwest are characteristically rich in nutrients. The lakes in this area of the country are naturally more productive than areas with shallow soils, and rocky lake bottoms. In the case of Little Barbee, addition of nutrients from the watershed has been in excess of the quantities normally present in the lake. A decrease in clarity, absence of dissolved oxygen in the deeper areas, and abundance of blue-green algae are all evidence of the effects of nutrient enrichment on the lake. This study documented these and other problems in the lake and watershed.

Management strategies recommended in this report are based on the most current understanding of the relationship between water quality and non-point source pollutants, i.e., those pollutants coming from diffuse sources in the watershed. In terms of restoration, reductions of sediment associated nutrients will be the key to restoring the lake. In addition to the obvious benefit of increased lake depth, dredging of the Stonebruner-Putney Ditch channel and mouth will reduce the nutrient contribution of sediments in this area of the lake. However, the recommended long-term strategy is to treat the problems at their source: upland areas within the Stonebruner-Putney Ditch watershed. Application of best management practices (BMPs) at key problem areas will go farthest and be the most cost-effective method of restoring the lake.

The Little Barbee Lake Property Owners Association is encouraged to pursue funding for BMP implementation through the newest component of the LEP, the Lake Watershed Land Treatment Program (LWLTP). This program provides cost sharing and incentives to land users for applying practices on their land that reduce the amount of sediment and nutrients from agricultural sources entering a T-by-2000 Lake Enhancement project lake. In addition to this program, a project recently initiated by the SCS is focusing in part on the Little Barbee Lake watershed. This study, conducted on the northern Tippecanoe River drainage basin, is designed to accelerate BMP application through increased educational and technical assistance to land users. Prior to conducting other restoration activities, an evaluation of the success of this project and of land treatment activities is recommended. Over the next few years, a volunteer monitoring program would supply the information necessary to gage the effectiveness of upland controls and to determine whether additional measures are warranted.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Concluded)

LIST OF TABLES

TABLE		PAGE

LIST OF FIGURES

SECTION 1. INTRODUCTION

This report is the outcome of the Feasibility component of a Feasibility/Design Study conducted on Little Barbee Lake by International Science & Technology, Inc. (IS&T) for the Barbee Lakes Property Owners Association. The project was performed and funded under the provisions of the State of Indiana "T by 2000" Lake Enhancement Program (LEP). The LEP was established to ensure the continued viability of Indiana's public access lakes by controlling sediment related problems such as erosion and nutrient enrichment. The objectives of studies conducted under this program are to characterize the lake and surrounding watershed, identify water quality related problems, present alternative solutions, and recommend the most appropriate restoration strategies. The ultimate objective of the program is to restore the well being of the lakes through development of specific plans of action for restoration (Design Phase) and installation of the required control measure as appropriate (Construction Phase or Land Treatment Program).

The Feasibility component of the project included collection of historical data on the lake, current water quality and biological data, land use analysis, and computer simulation of sediment and nutrient transport. Recommendations for management of the lake and watershed were also elements of the Feasibility Study.

Incorporation of a Design component was a result of earlier work on Little Barbee Lake (Hippensteel, 1989) that identified the need for dredging of the Stonebruner-Putney Ditch inflow channel and mouth. The objective of the Design component of the study was to provide the Barbee Lakes Property Owners Association with bid ready documents (contract documents and engineering plans) for this project, and to develop recommendations for erosion and sediment control and stream stabilization. The Project Manuals and accompanying plans submitted separately with this report are the products of the Design Study.

1.1 LITTLE BARBEE LAKE

Little Barbee Lake is located in Kosciusko County, near the town of North Webster, Indiana (Figure 1). The lake has a surface area of 74 acres, a maximum depth of 26 feet and mean depth of 13 feet. The lake bottom consists primarily of sand, muck and marl (IDNR, 1972). Little Barbee Lake is part of the Barbee Lake chain, a cluster of seven inter-connected natural lakes in the Grassy Creek branch of the Tippecanoe watershed. Little Barbee is situated between Big Barbee Lake upstream and Irish Lake downstream in the chain. The outlet from the downstream most lake in the seven lake chain flows into Tippecanoe Lake. The two major inputs to Little Barbee Lake are the outflow from Big Barbee Lake and Stonebruner-Putney Ditch. Stonebruner-Putney Ditch enters the lake on the south shore. The watershed of this ditch consists of 2,641 acres (Hippensteel, 1989) of predominantly agricultural land.

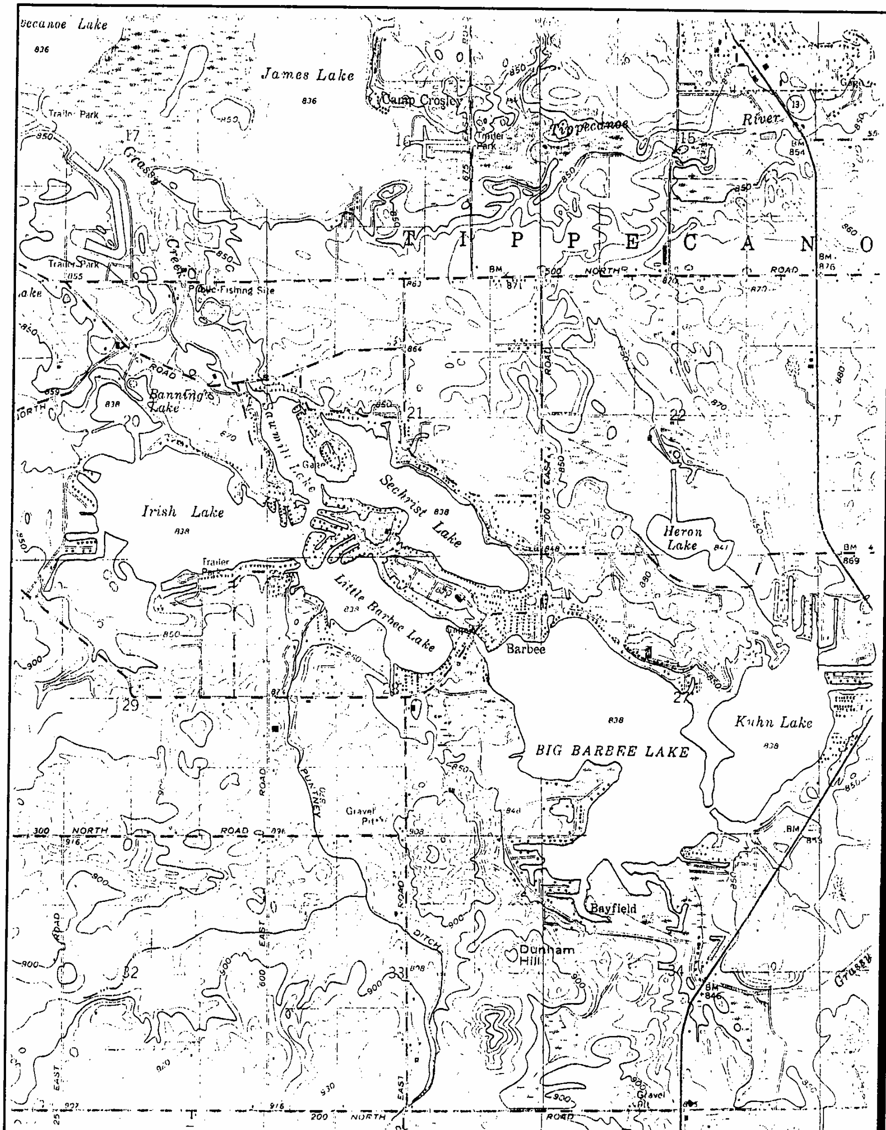

Figure 1. Portion of the North Webster, Indiana quadrangle showing the location of Little Barbee Lake.

Total watershed acreage for Little Barbee Lake, including the Stonebruner-Putney Ditch and Big Barbee Lake watersheds, is 27,345 acres. Corn, soybeans and wheat are the principal crops; and hogs, cattle and poultry are the primary livestock produced in the Little Barbee Lake watershed.

Residential development was sparse around the shores of Little Barbee Lake in the 1920's, however by the 1940's the eastern shore of the lake had become well developed with single family residences and weekend cottages. Residential development continued during the 1950's, encroaching on wetland areas on the west end of Little Barbee Lake (IDNR, 1988). By 1965, aerial photography (IDNR, 1965) showed residential development completely surrounding the lake, except for a small section of the south shore. Currently, the shores of Little Barbee Lake are completely developed for residential use. A 1972 fisheries survey conducted by the Indiana Department of Natural Resources (IDNR) documented 135 homes along the lake shore. The survey also noted that canals had been constructed for residential development along the north shore. Data collected in 1980 documented 154 homes along the lake shore (Hippensteel, 1989). The majority of the residences are now occupied year round.

Geologically, the Little Barbee Lake watershed is composed of Devonian age bedrock; largely limestone, dolomite and black shale. Unconsolidated deposits consist of sand and gravel outwash, and glacial till in hummocky moraine form. The glacially formed lake is the result of the advance and retreat of the Saginaw and Erie lobes of the main glacier that extended southwest from the Lake Erie and Saginaw Bay Basins, during the Wisconsonian period of glaciation (14,000 to 22,000 years ago). The effect of this glaciation on north-central Indiana is evidenced by the moraine topography, with interspersed lakes, bogs, and glacial drainage troughs and plains (Clark, 1980).

The soils surrounding Little Barbee Lake have been described by the Soil Conservation Service (SCS) as ranging from depressional to steep, and well drained to poorly drained. The two major soil associations found in this area are the Houghton-Palms and the Riddles-Wawasee Associations.

The Houghton-Palms Association occurs in lands immediately surrounding the lake. This association is typically comprised of very poorly drained, mucky soils, with level to depressional topography. The surface drainage pattern is poorly defined and ponding in low areas is common during wet periods. These soils are severely limited as sites for residential development, although large areas adjacent to lakes have been filled and developed for urban use.

The Riddles-Wawasee Association predominates in the Stonebruner-Putney Ditch watershed. This association is characterized by level to strongly sloping topography, with knobs, broad ridges and narrow depressions, and moderately well defined surface drainage patterns. This association is used primarily for cultivated crops such as corn and soybeans.

1.2 NATURE OF THE PROBLEM

Sediment and nutrient loading have been identified as the predominant water quality impairments to Little Barbee Lake (Hippensteel, 1989). The total phosphorus (TP) concentrations in the lake have increased from 0.03 mg/L in 1973 (Kosciusko Co. Health Dept., 1973) to 0.08 mg/L in 1975 and 1983, and 0.12 mg/L in 1988 (Hippensteel, 1989). TP concentrations of water entering Little Barbee Lake from Stonebruner-Putney Ditch have been reported to vary from 0.04 to 0.23 mg/L (Hippensteel, 1989).

In 1986, Little Barbee Lake was placed in Trophic Class Three and given a Eutrophication Index (EI) value of 56 by the Indiana Department of Environmental Management (IDEM) as noted in the Indiana Lake Classification System and Management Plan (1986). This index value was based on data collected by the Indiana State Board of Health (ISBH) in 1975. A recent re-evaluation of this data by IDEM gives the lake an EI value of 59, but does not change the Trophic Class of the lake (Harold BonHomme, pers. comm.). In an investigation of Kosciusko County lakes in 1988, Hippensteel (1989) found that, with the exception of Ridinger Lake, Little Barbee Lake had the highest EI value of all the lakes in the Barbee Lake Chain. Lakes in Trophic Class Three are in an advanced state of eutrophication, and commonly produce nuisance algal blooms during the summer months. Other characteristics include high water column and tributary nutrient concentrations, oxygen depletion below the thermocline in mid to late summer, and low water clarity.

The IDEM EI value placed Little Barbee Lake in the Lake Management Group VII-B. Lakes belonging to the Group VII category rank intermediate among all of the lakes surveyed by IDEM. Management strategies for restoring lakes in this category focus on limiting nutrient inputs. These strategies include phosphorus removal for wastewater treatment plants in the drainage basin, septic tank maintenance programs, protection of wetland areas, erosion control, and establishment of buffer corridors for streams adjacent to the lake and tributary streams. Selected in-lake restoration techniques include sediment consolidation, nutrient inactivation and dilution/flushing.

Erosion from agricultural land in the Stonebruner-Putney Ditch watershed has resulted in significant sediment deposition in the lower reaches of the ditch, extending into the lake. The resultant loss in cross-sectional area of the ditch channel has contributed to stream bank degradation during storm events. Water depth in the ditch has been reduced significantly during the past 10 years due to sediment deposition (pers. comm., Barbee Lakes Property Owners Assoc., 1989). Additionally, a submerged sandbar has developed at the mouth of the ditch, extending approximately 150 yards into the lake.

1.3 FEASIBILITY STUDY OBJECTIVES

The objective of the feasibility component of the project was to fully assess the current conditions in the lake and watershed with respect to sedimentation and water quality. Based on this assessment, a plan for implementing appropriate mitigative strategies was developed. The mitigative techniques chosen were those having the greatest probability of success in improving the overall quality of the lake.

Four phases of activity were necessary to meet the project objectives. First, all relevant information pertaining to the lake and watershed (e.g., USGS topographic maps, aerial photographs of the lake and watershed, previous water quality and fisheries studies, and hydrologic, geologic and soil data) was collected and reviewed. This information was used to understand the physical setting of the lake, and the current status of knowledge regarding sedimentation and water quality problems.

The second phase of the study involved collection of field data. Water samples and in-situ (in-lake) chemical and physical data were collected from the lake and from Stonebruner-Putney Ditch. Sediment characteristics, algal community composition, and bathymetric data were also collected. These data provided the most recent evaluation of the chemical, biological and physical conditions in the lake.

A survey of the watershed was the third phase of the study. Areas of excessive nutrient and sediment loading were identified by using the Agricultural Non-Point Source Pollution (AGNPS) computer simulation developed by the U.S. Department of Agriculture. The watershed survey was critical in addressing problems at their source, and for developing the most appropriate mitigative strategies.

The final phase of this project was to develop recommendations to mitigate the problems observed in this study and in prior studies. The methods used in each phase of the project, and the results of the study are presented in the sections that follow.

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SECTION 2. HISTORICAL DATA

The following section describes the historical data collected for this study. This information included water quality data, fisheries surveys, aquatic plant surveys, soils data, land use and hydrological data. Several state and county agencies as well as universities, were contacted in pursuit of this information.

2.1 WATER QUALITY

Table 1 presents a summary of historical water quality data collected on Little Barbee Lake. Table 2 lists the sources of this information, including the Indiana Department of Natural Resources (IDNR), the

Table 1. Little Barbee Lake historic water quality data.

DATE	LOCATION	SOURCE	TP (mg/L)	OP (mg/L)	NO_3-N (mg/L)	NH_3-NO (mg/L)	SURF. DO (mg/L)	SECCHI (ft)
6-72	mid-lake	IDNR					9.00	8.5
1-73	mid-lake	Kosc. Co. HD		0.03	2.4			
7-75	mid-lake	ISBH	0.08	0.06	1.0	0.4		5.0
6-80	mid-lake	IDNR						5.0
8-83	mid-lake	Tri-State	0.08		1.4			4.6
7-84	mid-lake	Tri-State						6.6
6-88	mid-lake	IDNR						7.5
8-88	mid-lake	Tri-State	0.12					5.0
1990	mid-lake	IN Univ./IDEM	0.28	0.4	1.23	2.3		2.3

Kosciusko County Health Department, the Indiana State Board of Health (ISBH), Tri-State University (Angola, Indiana), and Indiana University/IDEM (joint effort coordinated by Bill Jones at the School of Public and Environmental Affairs (SPEA). A review of the data reveals an apparent increase in total phosphorus (TP) concentration in Little Barbee Lake. All of the TP values exceed the concentration used by EPA to define a eutrophic lake, 0.025 mg/L. The data represent water column averages. It is interesting to note that although TP concentrations are indicative of poor water quality, the secchi disk transparencies do not reflect highly eutrophic conditions.

Table 3 presents a summary of historical water quality data collected on Stonebruner-Putney Ditch. Data sources include ISBH and Tri-State University. It is apparent that TP concentrations in Stonebruner-Putney Ditch are variable, ranging from a low of 0.04 mg/L to a high of 0.23 mg/L. The variability in TP concentrations is most likely dependent upon a combination of several factors, including prevailing watershed activities, storm events and stream flow.

A discussion of water quality in the Barbee Lakes was included in the IDNR fishery surveys of 1980 and

Table 2. Little Barbee Lake historical data summary.

DATE	AGENCY	DESCRIPTION
197?	Kosciusko Co. Health Dept.	Bacteriological Survey
1972	IDNR	Fish Management Report
1973	Kosciusko Co. Health Dept.	Lake Survey Data
1975	ISBH	Lake Survey Data
1980	IDNR	Fish Management Report
1980	Kosciusko Co. Health Dept.	Bacteriological Survey
1983	Tri-State Univ.	Lake Survey Data
1983	Kosciusko Co. Health Dept.	Well Water Analysis
1984	Tri-State Univ.	Lake Survey Data
1984	Kosciusko Co. Health Dept.	Bacteriological Survey
1985	Tri-State Univ.	Water Quality Data - Inflowing Streams
1985	ISBH	Correspondence - Lake Condition
1988	IDNR	Fish Management Report
1989	Tri-State Univ.	Highly Erodible Soils Map
1989	Tri-State Univ.	Preliminary Investigation of the Lakes of Kosciusko County
1989 Indiana	USDA-SCS	Soil Survey of Kosciusko County,
1990	IN Univ./IDEM	Volunteer Monitoring Program

1988. The 1980 survey described Little Barbee Lake as being thermally stratified at the time of the

Table 3. Stonebruner-Putney Ditch historic water quality data.

DATE	SOURCE	TP (mg/L)	OP (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)
7-75	ISBH	0.14	0.13	5.8	0.2
3-85	Tri-State Univ.	0.23	0.7		
5-85	Tri-State Univ.	0.05			
4-86	Tri-State Univ.	0.04			
7-88	Tri-State Univ.	0.15			

survey (June 1980), with the thermocline located between 14 and 18 feet. At that time, the lake had adequate dissolved oxygen to support fish (5.0 mg/L DO or greater) to a depth of 15 feet. The 1988 fishery survey stated that the water quality of Little Barbee Lake was the poorest of the seven lakes in the system. This evaluation was based primarily on the Secchi disk transparencies, which averaged approximately six feet.

Bacteriological surveys of Little Barbee Lake were conducted by the Kosciusko County Health Department in 1980, 1984 and at an unknown date prior to 1980. A bacteriological survey was also conducted on well water in the Barbee Lake Chain in 1983. Prior to 1980, four sites along the shores of Little Barbee Lake were sampled for total and fecal coliform analyses. The results of that survey showed no fecal coliform, however total coliform bacteria was measurable at all four sites, with the lowest count being 50 colonies per 100 ml of sample. The IDEM standard for fecal coliform is 200 colonies per 100 ml. In September 1980, the county surveyed Little Barbee Lake again. Five sites along the shoreline were sampled for fecal coliform. All five sites exhibited positive fecal coliform growth, however. During a third survey, conducted in May of 1984, eight of nine sites sampled in the Barbee Lake chain tested positive for fecal coliform. In August of 1983, 17 wells in the Barbee Lake chain were analyzed for fecal and total coliform. Well depths ranged from 12 to 176 feet. Two of the 17 samples exhibited positive fecal coliform growth, and two showed positive total coliform growth. Fecal coliform was present in two wells of 68 and 21 foot depths. Total coliform growth was measurable in two wells with depths of 21 and 12 feet. It should be noted that "positive fecal coliform" does not necessarily indicate unacceptable results.

Indiana State Board of Health (ISBH) correspondence, dated July 1985, noted that direct septic tank drainage to the lakes in the Barbee Chain had never been observed, nor were there any significant violations of the fecal coliform bacteria standards, established by the State, in the tests conducted by the Kosciusko County Health Department. Due to the heavily developed shoreline, the correspondence noted the probability of septic tank leachate reaching the lake.

In May 1985, sediment cores were taken from five sites in the Barbee Lakes by Tri-State University. The cores were described as consisting of typical marl lake sediment. Three of the five cores had parts of snail shells interspersed throughout the core, and two consisted of muck type sediments at the top of the core to a depth of five inches. One core had a high percentage of sand and small pebbles.

2.2 FISH POPULATION SURVEYS

Fish population surveys of the Barbee Lakes were conducted by IDNR in 1972, 1980 and 1988. Species documented in these reports and their relative abundance are listed in Table 4.

Table 4. Fish species and relative abundance in the Barbee Lakes. (IDNR Fish Management Reports)

COMMON NAME	SCIENTIFIC NAME	1972	1980	1988
Bluegill	Lepomis macrochirus	29.5%	30.3%	55.7%
Bullheads	Ictalurus spp.	1.6%	2.2%	1.2%
Channel Catfish	Ictalurus punctatus	**	0.1%	4.5%
Crappies	Pomoxis spp.	3.2%	9.3%	2.0%
Largemouth Bass	Micropterus salmoides	12.5%	3.6%	9.5%
Smallmouth Bass	Micropterus dolomieui	**	0.1%	0.1%
Yellow Perch	Perca flavescens	9.9%	12.9%	4.5%
Northern Pike	Esox lucius	**	0.2%	0.2%
Rainbow Trout	Salmo gairdnerii	**	**	1.0%
Walleye	Stizostedion vitreum	**	**	0.2%
White Bass	Roccus chrysops	0.1%	0.1%	0.8%
Other Sunfish		11.4%	16.4%	10.3%
Suckers		4.4%	16.6%	3.8%
Gizzard Shad	Dorosoma cepedianum	6.9%	0.9%	4.1%
Gar		1.2%	1.3%	1.0%
Carp	Cyprinus carpio	2.2%	0.7%	0.2%
Minnows		14.7%	3.5%	0.7%
Other nongame fish		2.4%	1.9%	0.5%

** species not found

The 1980 survey found 76 percent of the fish collected to be game fish. The major game species included bluegill (Lepomis macrochirus), yellow perch (Perca flavescens), black crappie (Pomoxis nigromaculatus), redear (Lepomis microlophus), and largemouth bass (Micropterus salmoides). The dominant nongame species were the white sucker (Catostomus commersoni), spotted sucker (Minytrema melanops) and lake chubsucker (Erimyzon sucetta). Overall, the survey report concluded that the Barbee Lakes supported a medium quality sport fishery. Short term recommendations for maintaining and improving this fishery included mechanical weed control (raking and pulling) along channels, docks and beach areas, a continuation of septic system dye-testing along the shoreline, and initiation of stocking programs for channel catfish (Ictalurus punctatus), tiger muskellunge (Esox spp.), and rainbow trout (Salmo gairdnerii) in the Barbee Lakes. The suggested long-term fish management efforts included in-lake nutrient inactivation, reduction of nutrient inputs, assessing the need for harvest restrictions (size limits) and evaluating the proposed stocking programs.

The 1988 survey found the Barbee Lakes to support a stable warm-water fishery. The dominant game fish included bluegill, largemouth bass, crappie and perch, with bluegill dominating the overall catch. Gizzard shad (Dorosoma cepedianum) and white sucker were the major forage fish collected during the survey. Noted improvements to the fishery included the successful stocking of channel catfish, initiated in 1981 at Irish Lake, and an increase in the natural reproducing population of white bass (Roccus chrysops). A greater number of larger bluegill (6 - 7 inches) were collected in 1988 compared to previous surveys, but fewer 8 inch and larger Bluegills were found. The 1988 survey report concluded that the Barbee Lakes provide adequate fishing for bluegill and largemouth bass, and that there had been no decline in fishing interest over the past two decades. The survey recommendations included the application of stricter bass harvest regulations to improve bass size structure, continuation of catfish stocking on a triennial basis and continuation of rainbow trout stocking. Recommendations for future management efforts included implementation of aquatic weed control for submergent vegetation near docks and beaches, curtailing future shoreline development, protection of existing shoreline and wetland areas, and continuation of periodic septic system dye-testing.

2.3 AQUATIC PLANT SURVEY

Documentation of aquatic plants found in the Barbee Lakes was included in the IDNR fish population surveys of 1980 and 1988. Both surveys found milfoil (Myriophyllum spp.) and Chara (Chara spp.) to be the dominant aquatic vegetation in the lakes, with coontail (Ceratophyllum demersum) and curly-leaf pondweed (Potamogeton crispus) also commonly found. The dominant emergent aquatic plants were cattail (Typha spp.) and water lilly (Nymphaea spp.). By 1988, spatterdock (Nuphar spp.) had also become a dominant emergent plant. Milfoil was noted in the 1988 survey as being most prevalent in the artificial channels and along the shoreline of Little Barbee, Big Barbee and Sawmill Lakes. The 1988 survey also noted that submergent vegetation is chemically treated on an annual basis in many areas of the lakes in the Barbee chain.

2.4 ERODIBLE SOILS

Areas of highly erodible soils in the Little Barbee Lake watershed were identified from reports published by the Kosciusko County Soil and Watershed Conservation Districts. These reports, produced in cooperation with the SCS and other agencies, identify areas with high proportions of sheet, rill, and gully erosion. An additional source of information was a map of erodible soils in Kosciusko County prepared by Dr. Peter Hippensteel (Tri-State University, Angola, IN).

2.5 LAND USE

Historically, the majority of the land in Kosciusko County has been utilized for agriculture, with grain farming and livestock production the primary farming activities. According to a 1941 land use report for the county, the main crops grown were corn, soybeans and wheat. Data obtained from the Conservation Technology Information Center (CTIC) for 1984 and 1988 showed the majority of the crop land in Kosciusko County to be used for corn production, followed by soybeans and small grain crops (such as wheat, rye, barley, oats, etc.). In 1984, conservation tillage practices were utilized on 45 percent of the active cropland in the county. The primary type of conservation tillage practiced in 1984 was mulch-till, where the total soil surface is disturbed just prior to planting and weed control is accomplished using a combination of herbicides and/or cultivation. At least 30 percent of the soil surface is left covered by residue after planting to reduce soil erosion by water and wind. CTIC data for 1988 indicate conservation tillage to be practiced on 49 percent of the active cropland in Kosciusko County. Once again, mulch-till was the primary type of conservation tillage, with no-till accounting for 10 percent of the conservation tillage practiced. No-till conservation tillage leaves the soil undisturbed prior to planting. Planting is done in a narrow seedbed created by a planter or drill and weed control is accomplished using herbicides (CTIC, 1989).

2.6 SIGNIFICANT NATURAL AREAS AND ENDANGERED OR THREATENED SPECIES

Significant natural areas, and endangered and threatened species in the Little Barbee Lake watershed were identified by the IDNR Division of Nature Preserves. The Division of Nature Preserves has a database of information pertaining to natural areas and endangered species and can identify locations of their occurrence by USGS quadrangle map, giving latitude and longitude coordinates. There were no natural areas identified in the Little Barbee Lake watershed, however the mudpuppy (Necturus maculosus) was noted to be of "special concern". The mudpuppy record is from Sechrist Lake, but it could be found in Little Barbee Lake because the two lakes are connected. Table 5 contains the location of this specie as identified by quadrangle.

Table 5. Significant natural areas and endangered/threatened species in the Little Barbee Lake watershed.

USGS QUADRANGLE	SPECIES COMMON NAME	SPECIES SCIENTIFIC NAME	STATUS	LATITUDE	LONGITUDE
North Webster	Mudpuppy	Necturus maculosus	SSC	411737	854301

Status:

SE = endangered
SR = rare
WL = watch list

ST = threatened
SCC = special concern
# = observed prior to 1960

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SECTION 3. METHODS

This section of the report describes the methods used to complete the Feasibility component of the project. The data collection efforts were divided into two sub-tasks: (1) a lake survey, and (2) a watershed survey. These subtasks are described below.

3.1 LAKE SURVEY

IS&T personnel conducted a survey of Little Barbee Lake during the late summer and fall of 1989 to collect the information required for a detailed assessment of the current conditions in the lake and watershed. Samples were collected to analyze lake and tributary water quality, phytoplankton species and abundance, and sediment nutrient concentrations. A bathymetric survey of the Stonebruner-Putney Ditch mouth and surrounding area was also conducted. The methods used for sample collection and other components of the field survey are described below.

3.1.1 In-situ Measurements

In-situ water quality, water samples and phytoplankton were collected on 24 August 1989 at one in-lake station located at the deepest part of the lake (Figure 2). In-situ profile measurements of temperature, dissolved oxygen and pH were made using a Hydrolab "Surveyor II" Environmental Data System. Measurements were recorded at the surface, at a depth of three feet, four feet, and at two foot increments to the lake bottom. Secchi disk transparency was measured on the shaded side of the boat. The Secchi disk was lowered until it disappeared, and then raised until it reappeared. The average of these two depths was reported as the Secchi disk depth. Percent light transmission was recorded at three feet using a Martek Model XMS transmissometer. This instrument was calibrated, on the lake, prior to use.

3.1.2 Chemical Measurements

Water samples were collected at the surface, mid-depth (12 ft.), and approximately one (1) foot above the lake bottom (22 ft.) using a 6-L (6.6 quart) vertical Van Dorn water sampler. All in-lake water samples were collected at the same location as the in-situ data. Samples for nutrient analysis were poured directly from the Van Dorn into clean 4-L Cubitainer containers. Aliquots collected for fecal coliform analysis were poured into sterilized, 100 ml Whirlpak containers. Separate aliquots were also collected for chlorophyll a analysis. All samples were immediately placed in coolers and stored at 4°C prior to shipment to the IS&T analytical laboratory. Analyses were begun within 24 hours of collection. Table 6 lists the analytes measured in the water samples and the methods used to conduct the analyses.

In addition to the water samples, quality assurance samples were also collected in the field and included in the shipment to the analytical laboratory. These samples consisted of a blank (deionized water that was poured into the Van Dorn and then into a Cubitainer) and a duplicate sample. The blank sample was used

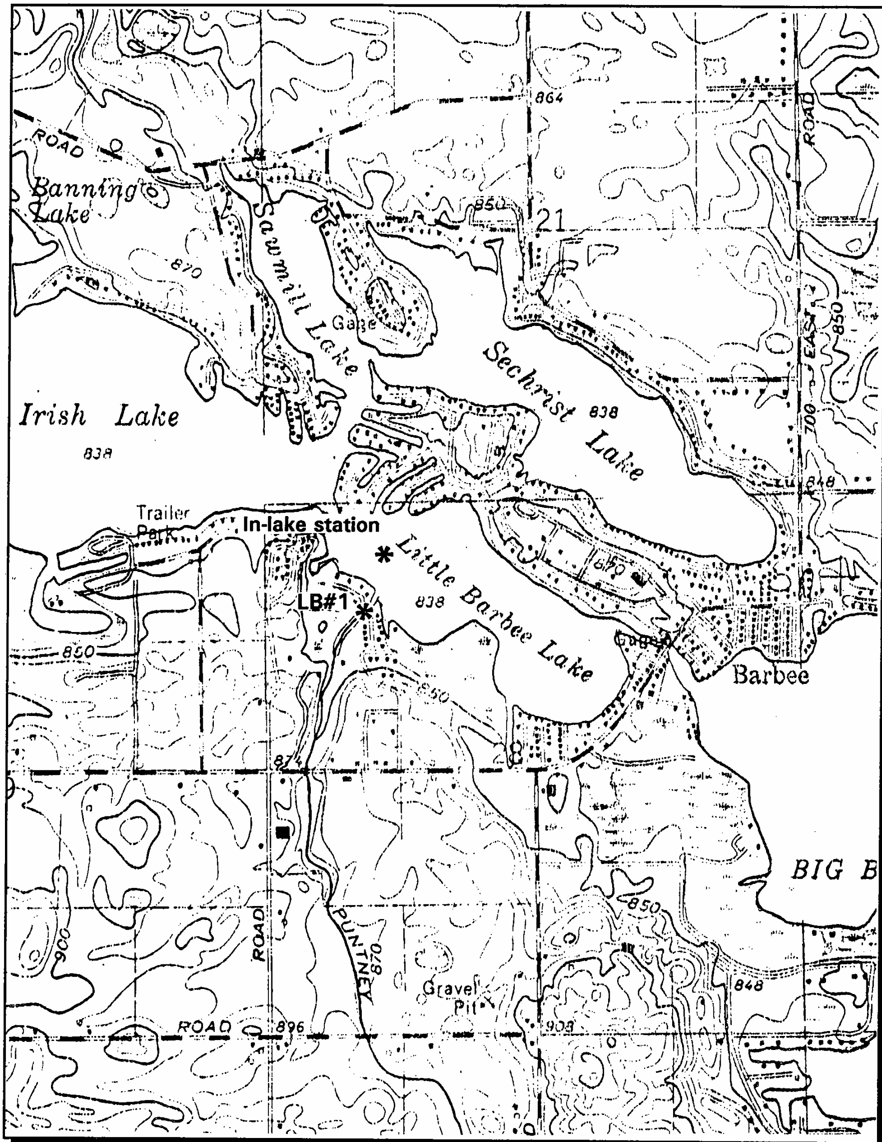

Figure 2. In-lake and tributary sampling locations.

Table 6. Chemical parameters and analytical methods used in evaluating the Little Barbee Lake water samples.

PARAMETER	INSTRUMENT OR METHOD	REFERENCE
Chlorophyll a (Chla)	Spectrophotometer	Standard Methods, 16th ed.
Fecal Coliform	Incubation, visual count	Standard Methods, 16th ed.
Ammonia ($N\text{-}NH_4$)	Flow Injection Analysis	EPA 350.1
Nitrate (NO_3)	Flow Injection Analysis	EPA 383.2
Total Kjeldahl Nitrogen (TKN)	Flow Injection Analysis	EPA 351.2
Ortho Phosphorus (OP)	Flow Injection Analysis	EPA 365.1
Total Phosphorus (TP)	Flow Injection Analysis	EPA 365.1
Total Suspended Solids (TSS)	Gravimetric	EPA 160.2
Temperature	In-situ Hydrolab Surveyor II	
Dissolved Oxygen (DO)	In-situ Hydrolab Surveyor II	
pH	In-situ Hydrolab Surveyor II	

to evaluate potential contamination due to field procedures (e.g. nutrient or bacteria residues in the sampler or in the sample bottles). The duplicate sample, obtained from a second water sample collection at one of the three (3) depths, provided a measure of variability within the water column.

A water quality sample was also collected from Stonebruner-Putney Ditch following a storm event on 15 November 1989. The location of this sample site is shown in Figure 2. One grab sample was collected from this tributary by immersing a clean, rinsed and labeled 1-L Cubitainer into the stream at mid-channel. The tributary sample was placed on ice and shipped to the IS&T analytical laboratory within 24 hours of collection. Samples were analyzed for all of the parameters listed in Table 6, with the exception of fecal coliform.

3.1.3 Biological Sample Collection

Two vertical plankton tows were taken using an 80μ mesh plankton net with an opening of one foot. The first tow was from a depth of five (5) feet to the surface. The second tow was from a depth of 20 feet and included the thermocline. The plankton samples were immediately preserved with Lugol's solution and stored in labeled, opaque bottles. Phytoplankton were identified to species and enumerated using the settling chamber-inverted microscope technique as described by H. Utermöhl (Sournia, 1972).

3.1.4 Sediment Sample Collection

A sediment survey was conducted in the lake and in Stonebruner-Putney Ditch. A total of seven (7) sediment samples were collected from this tributary along a transect running from a point 100 feet upstream from the tributary mouth to a point in the lake 100 feet downstream from the mouth, and along a second transect encompassing the width of the shoal. The transects and sample numbers assigned to each location are shown in Figure 3. The samples were spaced approximately 50 feet apart. In silty areas the cores were obtained with a Wildco K-B sediment core sampler. Where a hard sediment bottom prevented the use of this corer, a Petite Ponar dredge was utilized to obtain the sediment sample. These samples were immediately placed in 250 ml containers and shipped in coolers via overnight courier to the IS&T laboratory. The top three (3) inches of sediment were analyzed for total phosphorus (TP) and Total Kjeldahl Nitrogen (TKN). Additionally, particle size analyses were conducted on samples two through seven to assess the likelihood of sediment resuspension.

As a second element of the sediment survey, sediment probings were conducted at each sediment sampling station. A sediment probe was used to detect the depth to the sediment surface and to detect the probe refusal depth, or the depth to which the probe may be pushed into the sediments without meeting resistance. This information was then used to provide an indication of the depth of recently deposited sediment.

3.1.5 Bathymetric Survey

Using electronic surveying equipment, a bathymetric survey was conducted at the mouth of Stonebruner-Putney Ditch. Survey points were chosen so as to include the entire shoal area of the tributary, and to fully characterize the bottom contours of the lake at this site. A Digital Electronic Measuring device (DEM) was used to obtain elevations of the lake bottom at the survey points. All elevation measurements were tied into a USGS benchmark. A contour mapping software package ("SURFER") was used to

develop a contour map of the ditch and mouth area from elevations and coordinate data.
Estimates of the amount of sediment deposition at the mouth of Stonebruner-Putney Ditch were made by comparing a 1965 hydrographic survey (IDNR, 1965) with the 1989 IS&T survey. The volume of water contained in the Stonebruner-Putney Ditch tributary region was determined using the following equation (Wetzel and Likens, 1979):

$$V=\frac{h}{3}\,(A_1+A_2+\sqrt{A_1A_2})$$

where:
V = volume
h = depth of stratum
A_1 = area of upper surface
A_2 = area of lower surface

Estimates of changes in lake sediment accumulation were obtained by comparing the volume of water within the area surveyed in 1989 with the volume in the same area of the 1965 survey. The 1989 data were corrected for the lake level at which the 1965 survey was referenced.

3.2 WATERSHED SURVEY

Characterization of the current conditions in the Little Barbee Lake watershed was oriented toward identifying the principal sources of sediment and nutrient loading within the Stonebruner-Putney Ditch watershed. Components of this survey included:

- Hydrologic characterization
- Land use delineation
- Erodible soil evaluation
- Sediment/nutrient modeling

3.2.1 Hydrologic Data

The principal hydrologic parameter of interest in developing a restoration strategy for Little Barbee Lake is the hydraulic retention time. This is defined as the length of time required for the entire volume of the lake to be replaced with "new" water from runoff and direct precipitation. The information used in calculating the residence time included the lake volume, average annual runoff for the Little Barbee Lake watershed, annual rainfall, and evaporation from the surface of the lake.

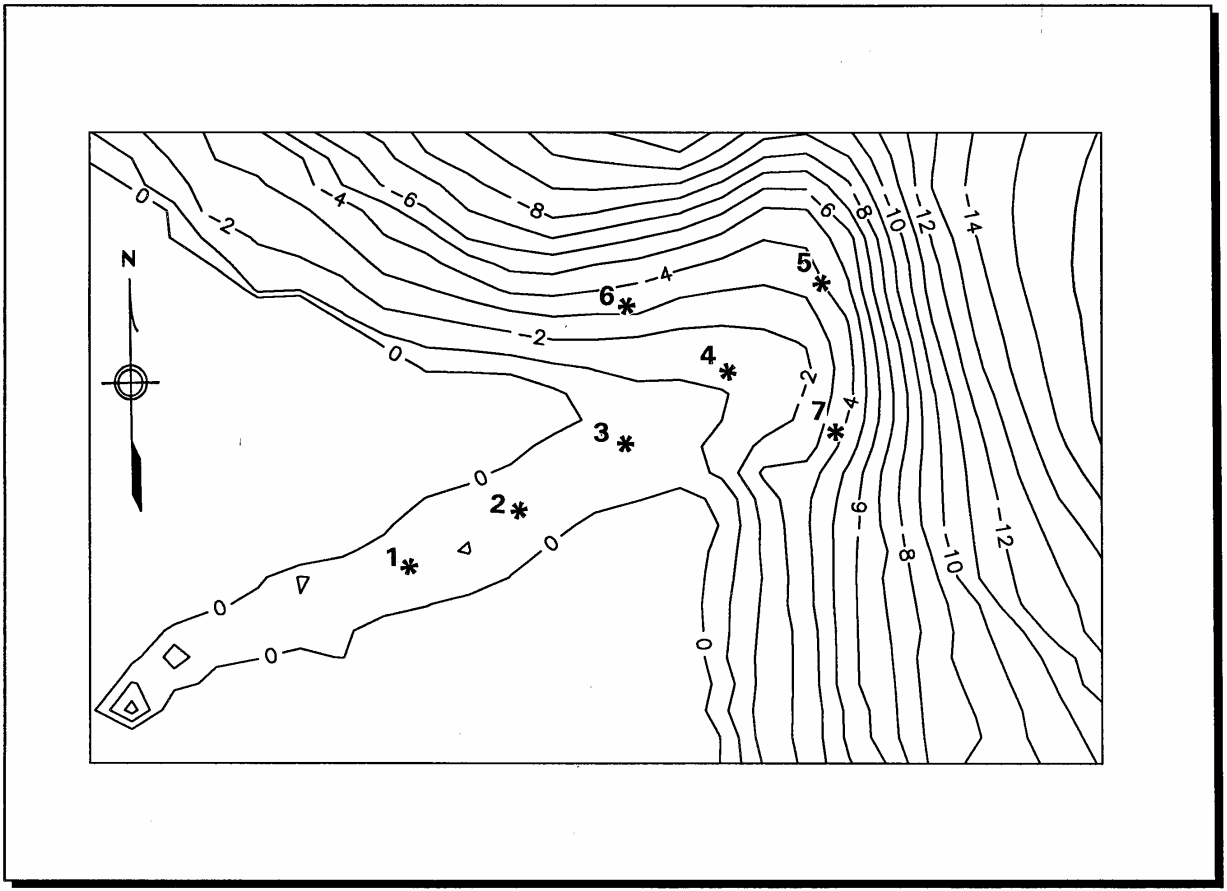

Figure 3. Transect location for the Little Barbee Lake sediment survey (1" = 55.26 ft).

3.2.2 Land Use Delineation

Major land use patterns in the Little Barbee Lake watershed were identified using recent (1985) aerial photographs (1:2000 scale) of the lake and watershed, USGS topographic maps (1:24,000 scale), and site reconnaissance. Several steps were necessary to develop the final land use map of the entire watershed.

First, the watershed boundary was outlined on topographic maps and digitized into IBM-PC compatible data files along with key geographical features (e.g., lake shorelines, streams, roads and towns). Land use within the watershed was delineated using aerial photographs, and assigned to one of sixteen (16) unique land use categories. The land use types used are shown in Table 7. The border of each land use type was digitized into IBM-PC compatible data files. These files were overlain onto the watershed boundary and geographical feature data files. Coverage maps and tabular summaries of land use in the watershed, as well as the data files to produce them, were developed using IS&T proprietary software. The results of this task were used as input parameters for modeling sediment and nutrient loading to the watershed (Section 3.2.4).

Table 7. Land use categories designated in the watershed survey.

1. Water Surface
2. Wetlands (including approximate stream corridors)
3. Forest (tree groups larger than 0.25 acre)
4. Open Land/Vacant Lots (no structures or livestock)
5. Pasture (grazed lands)
6. Row Crops (corn, beans, etc.)
7. Non-row Crops (wheat, hay, etc.)
8. Orchard
9. Feedlot
10. Low Density Residential/Rural (1 dwelling/acre)
11. Medium Density Residential (2-5 dwellings/acre)
12. High Density Residential (6 or more dwellings/acre)
13. Commercial/Industrial (industrial parks, malls)
14. Institutional (schools, parks, golf courses)
15. Bare/Unseeded Ground (construction sites)
16. Resource Extraction (borrow pits, timber sites)

3.2.3 Erodible Soils Evaluation

The Kosciusko County Soil and Water Conservation District (SWCD) has prepared a detailed analysis of

These studies were the primary sources of information used in characterizing the extent of erodible soils within the watershed.

3.2.4 Sediment/Nutrient Modeling

Information on land use, climate, soils and hydrology were combined to provide input parameters for use in the Agricultural Non-Point Source Pollution Model (AGNPS), a system developed by the U.S. Department of Agriculture-Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service. The PC-based model was designed to simulate the sediment and nutrient contributions from watersheds under predefined hydrologic conditions. AGNPS operates on a grid basis and requires that the watershed be divided into a series of discrete squares, or

Table 8. Input parameters used in the AGNPS model [1].

TITLE	DESCRIPTION
Cell Number	ID number of current cell
Receiving Cell	ID of cell receiving outflow from current cell
SCS Curve Number	Relates runoff mass to rainfall mass (inches)
Field Slope	Mean slope of fields (%)
Slope Shape	Indicates concave, convex or uniform slope shape
Slope Length	Indicates average field slope length (feet)
Channel Slope	Mean slope of stream channel (%)
Side Slope	Mean slope of stream channel banks (%)
Roughness	Manning's Roughness Coefficient for channels
Soil Erodibility	K-Factor from Universal Soil Loss Equation
Crop Practice	C-Factor from Universal Soil Loss Equation
Conservation Practice	P-Factor from Universal Soil Loss Equation
Surface Condition	Indicates degree of land surface disruption
Aspect	Principal drainage direction
Soil Texture	Indicates sand, silt, clay or peat
Fertilization	Indicates level of added fertilizer
Incorporation	Indicates % of fertilizer left on soil after storm
Point Source Flag	Indicates presence/magnitude of any point source
Gully Source	Override estimate of gully erosion magnitude
COD	Level of chemical oxygen demand generated
Impoundment Flag	Indicates presence/absence of terrace systems
Channel Flag	Indicates presence/absence of defined streams

[1] Parameters represent estimated conditions within each cell.

cells. Twenty-two input parameters, covering a wide range of physical and chemical characteristics are assigned to each cell (Table 8). Sediment and nutrients are routed through the watershed; their concentrations in each cell being a function of upstream loading and the unique cell attributes, which can either increase or diminish the non-point pollution load. Sediment, nutrient, and hydrologic characteristics may be summarized for any cell along the flow path and at the watershed outlet. The model also allows the user to highlight cells with specific characteristics, such as high sediment phosphorus. In addition, land use and other characteristics may be hypothetically altered to determine the effect of future changes on sediment and nutrient loading. The model provides estimates for single precipitation events only, so the user must define a "design storm" for the analysis.

The accuracy and precision of the model results are directly proportional to the cell size used. Smaller cell sizes allow greater precision and thus greater confidence in the model output. The developers of the AGNPS model recommend a cell size of 40 acres for watersheds greater than 2000 acres, however IS&T used a 10-acre cell size for the Stonebruner-Putney Ditch watershed. Although smaller cell sizes mean greater numbers of cells, the four-fold increase in precision of the model results outweighed the additional labor required for data entry.

Each AGNPS cell was characterized according to the parameters listed in Table 8. The design storm chosen was a two year, 24-hour event. This is defined as the largest storm that can be expected to occur once every two years, based on a 30 year period of record. For Little Barbee Lake, this was a 2.7 inch rainfall (U.S. Department of Commerce, 1966). Nutrient, sediment and runoff maps were produced using the AGNPS Graphical Interface System.

3.2.5 Stream Channel Characterization

An evaluation of the Putney Ditch channel was conducted in November 1989. The purpose of this evaluation was to analyze stream bank stability and classify the stream according to the major variables that control channel geomorphology. The Rosgen Stream Classification System (Rosgen, 1986) was used in this effort. This system categorizes stream channels according to gradient, sinuosity, width/depth ratio, dominant size of channel materials, valley confinement, and landform features including dominant soils and stability. Field application of this system involves measurement of gradient, width, and depth under bankfull conditions. The term "bankfull" refers to the flows which form, maintain, and shape stream channels. These flows occur on a frequency of one to two years, and dictate the elevation at which persistent vegetation can survive. The parameters measured are key components in determining the suitability of stream habitats. In classifying a given stream or reach of stream, the Rosgen system provides a basis for comparison of streams in widely different geographic areas. For example, resource managers in Indiana can refer to a stream's classification when describing problems to colleagues in other regions of the country, thus providing a common point of reference.

The Rosgen system is also an important tool for assessing the stability of stream channels to watershed alterations, such as changes in flow regime, sediment supply, or increased floodplain confinement. It has also proven valuable as a tool in selecting applicable restoration techniques and in locating and predicting the effectiveness of stream habitat improvement strategies. Putney Ditch was classified using the Rosgen System to evaluate bank stability, sediment supply, and capacity to transport sediment to Little Barbee Lake, and as a tool in developing stabilization measures.

SECTION 4. RESULTS AND DISCUSSION

4.1 LAKE SURVEY

This investigation included in-situ, chemical and biological water quality measurements; sediment analyses; and bathymetric mapping. These data were used to summarize conditions in the lake and assess its current trophic status.

4.1.1 In-situ Measurements

In-situ water quality measurements are presented in Figures 4a-4c and Table 9. These data indicate that

Table 9. Little Barbee Lake in-situ water quality measurements. (24 August 1989)

DEPTH (ft.)	TEMP (C)	DO (mg/L)	pH	% TRANS. @3 ft.	SECCHI DISK (ft)
0.0	24.7	9.63	8.3		2.62
3.0	24.7	9.60	8.3	14.3	
4.0	24.7	9.53	8.3		
6.0	24.6	9.42	8.3		
8.0	24.6	9.37	8.3		
10.0	24.5	9.40	8.3		
12.0	23.8	2.57	7.8		
14.0	23.5	0.40	7.5		
16.0	21.8	0.07	7.4		
18.0	19.8	0.05	7.2		
20.0	17.6	0.06	7.2		
22.0	15.7	0.04	7.2		
23.0	bottom				

Little Barbee Lake was thermally stratified at the time of sampling, with the thermocline (the zone of maximum decrease in temperature) at approximately 12 feet.

Dissolved oxygen (DO) concentrations were between 9.63 and 9.40 mg/L from the surface to a depth of ten (10) feet. All readings from the surface through (10) feet were supersaturated. The oxygen concentrations dropped sharply from 10 to 12 feet, with anoxic conditions from this depth to the lake bottom. The clinograde DO profile (Figure 4b) is generally indicative of productive, eutrophic lakes.

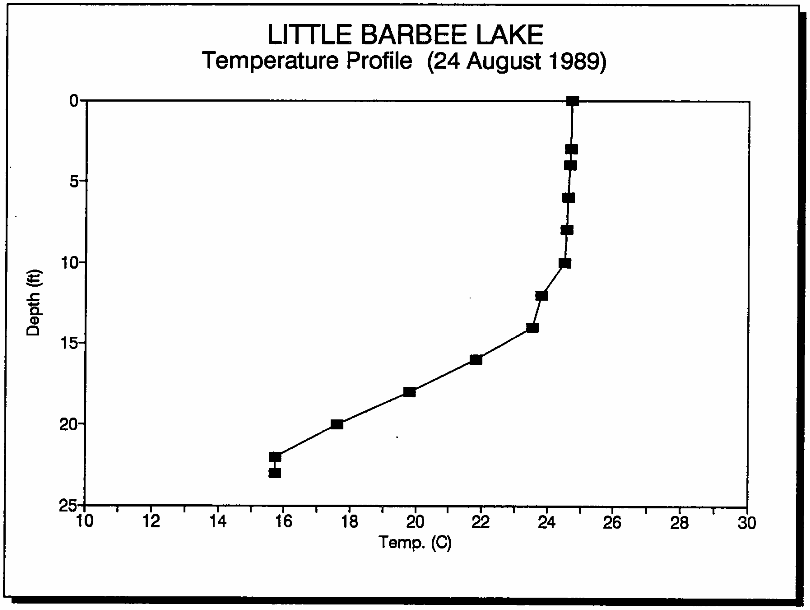

Figure 4a. In-situ temperature profile for Little Barbee Lake (24 August 1989).

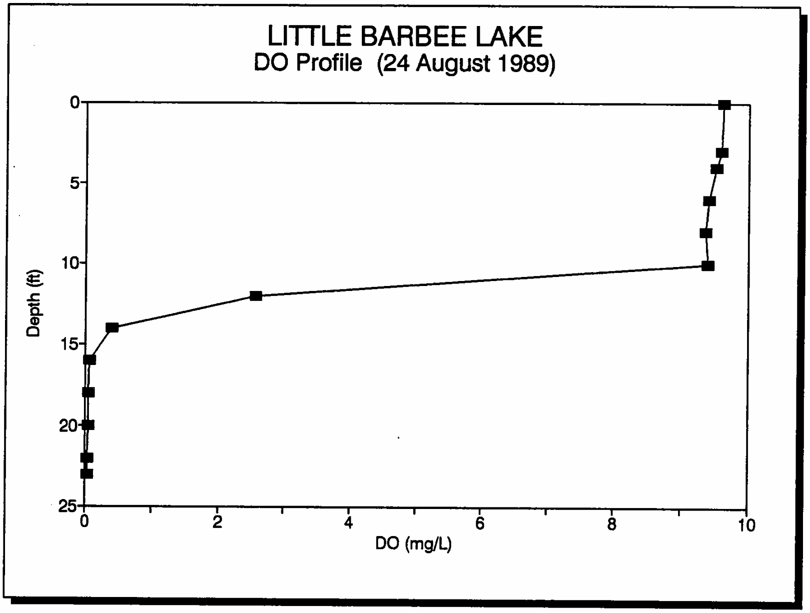

Figure 4b. In-situ DO profile for Little Barbee Lake (24 August 1989).

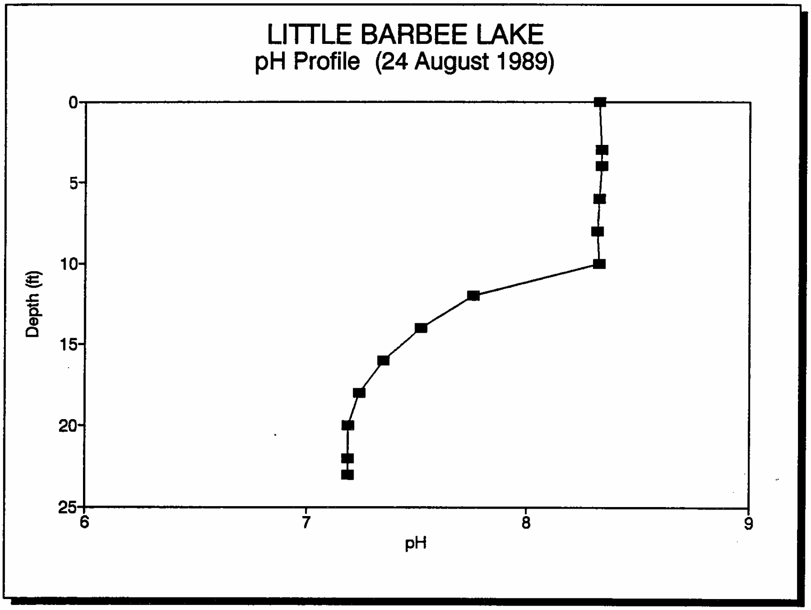

Figure 4c. In-situ pH profile for Little Barbee Lake (24 August 1989).

The pH distribution in the water column exhibited a pattern representative of a productive stratified lake, with values above the thermocline higher than those below. The pH values above the thermocline were constant at 8.3. Below the thermocline, values ranged from 7.8 to 7.2. The higher pH values in the upper ten feet of water are a result of the photosynthetic utilization of carbon dioxide (CO_2), a weak acid. As CO_2 is utilized by green plants and algae, its concentration in the water column is reduced. This acts to increase pH in the surface waters of the lake.

4.1.2 Chemical Measurements

Water quality analyses were conducted on both in-lake samples and a storm event tributary sample are presented in Tables 10 and 11, respectively. Results for both types of samples collected are discussed below.

In-Lake Samples

Higher concentrations of TP, OP, TKN, $N\text{-}NH_4$, and TSS were found in sample collected at the bottom of Little Barbee Lake than in either the mid-depth or surface samples. These data reflect nutrient release from the lake sediments, and are indicative of eutrophic conditions. The high TSS concentration in the bottom sample may also indicate disturbance of the bottom sediments during sampling. Such a disturbance may have contributed to the higher nutrient concentrations in the bottom sample.

The ratio of total nitrogen to total phosphorus (N:P) is often used to evaluate the relative importance of these two algal nutrients, which are quickly taken up in their soluble forms (i.e., ortho-phosphorus and nitrate). Algae characteristically consume phosphorus in excess of immediate physiological requirements. Nitrogen is rarely limiting (i.e., the first to be used completely following continued growth) in freshwater systems due to its abundance in the atmosphere and availability through nitrogen fixation by blue-green algae. Although the concentrations of the soluble forms, therefore, are not necessarily indicative of available supply, the ratio of the total nutrient concentrations can be used to assess which nutrient will be limiting to plant growth (Welch, 1980). Development of specific long-term management strategies is often dependent on which of these two nutrients is limiting to the aquatic resource.

As a general rule, if the N:P ratio is 17 or greater, phosphorus is most likely the limiting nutrient. N:P ratios less than 13 are usually indicative of nitrogen limitation (Cooke, et. al., 1986). Either nitrogen or phosphorus may be limiting when ratios are between 13 and 17. The N:P ratios of the surface (23.1) and mid-depth (21.6) samples indicate Little Barbee Lake was phosphorus limited at the time of sampling.

Table 10. Little Barbee Lake water quality results for in-lake samples.

SAMPLE ID	SAMPLE DEPTH (ft)	DATE COLLECTED	TIME COLLECTED	CHL a (mg/m^3)	FECAL COLIFORM (#/100ml)	$N\text{-}NH_4$ (mg/L)	NO_3 (mg/L)	TKN (mg/L)	OP (mg/L)	TP (mg/L)	TSS (mg/L)
LB-SURF	0.0	08/24/89	13:45	27.39	60	<0.005	0.165	0.783	0.027	0.041	0.3
LB-MID	12.0	08/24/89	13:55	26.33	12	<0.005	0.126	0.887	<0.005	0.047	1.5
LB-BOTM	22.0	08/24/89	14:05	6.41	0	2.860	0.146	3.900	0.066	0.578	19.0

CHL a = Chlorophyll a
FECAL COLIFORM = Fecal Coliform Bacteria
$N\text{-}NH_4$ = Ammonia
NO_3 = Nitrate
TKN = Total Kjeldahl Nitrogen
TSS = Total Suspended So
TP = Total Phosphorus
OP = Ortho Phosphorus
< = Value Lower than Detection Limit

Table 11. Water quality results for Stonebruner-Putney Ditch.

SAMPLE ID	DATE COLLECTED	TIME COLLECTED	CHL a (mg/m^3)	$N\text{-}NH_4$ (mg/L)	NO_3 (mg/L)	TKN (mg/L)	OP (mg/L)	TP (mg/L)	TSS (mg/L)
LB-#1	11/15/89	11:30	145.25	0.622	1.902	2.519	0.127	0.598	121.2

CHL a = Chlorophyll a
$N\text{-}NH_4$ = Ammonia
NO_3 = Nitrate
TKN = Total Kjeldahl Nitrogen
OP = Ortho Phosphorus
TP = Total Phosphorus
TSS = Total Suspended Solids

Storm Event Samples

The storm sample from Stonebruner-Putney Ditch was collected on 15 November, 1989, during a storm of moderate intensity. Rainfall during this 24-hour period was 1.21 inches, less than half the maximum amount (2.4 inches) that can be expected to occur on a frequency of one year (U.S. Dept. of Commerce, 1966). Rainfall during the 24 hours prior to the date of sample collection was 0.06 inches. Precipitation data were recorded at the Warsaw, IN airport.

Nutrient (TP, OP, TKN, NO_3) and total suspended solids (TSS) levels, in general, were higher in this tributary than in Little Barbee Lake during summer stratification. Both OP (0.127 mg/L) and NO_3 (1.902 mg/L) values were much higher. The TP concentration (0.598 mg/L) was roughly equivalent to the concentrations observed in the hypolimnetic sample from Little Barbee, and almost 15 times higher than TP in the lake surface sample. The TSS levels found in Stonebruner-Putney Ditch following this storm event were far greater than the values found in the water column of the lake. The observed TSS concentration (121 mg/L), in combination with the elevated nutrient concentrations, indicate that this tributary is contributing significantly to the sediment and nutrient loading to Little Barbee Lake.

4.1.3 Biological Measurements

The results of the Chla analyses indicate that the greatest amount of photosynthetic activity was occurring between the surface and twelve feet. The pigment concentration observed in the surface (27.39 mg/m^3) and mid-depth samples (26.33 mg/m^3) suggests highly productive waters. As expected, the Chla concentration in the bottom sample dropped sharply as light and temperature became limiting to phytoplankton.

The results of phytoplankton identification and enumeration for Little Barbee Lake showed a diverse algal community of 35 species representing 5 classes (Table 12). The algal community was dominated by blue-greens, which comprised approximately 86 percent of the 5 foot tow and 72 percent of the 20 foot tow (Figures 5a and 5b). Numerically, the dominant algal specie was the blue-green algae Anabaena flosaquae. Other numerically important species included the green algae Melosira granulata, and the blue-greens Oscillatoria planctonica, Anabaena planctonica, and Aphanocapsa pulchra. Blue-green algal dominance is often associated with eutrophic conditions.

Moderately high counts of fecal coliform bacteria were found in the surface and mid-depth water column samples. The highest fecal count (60 colonies per 100 ml of sample) occurred in the surface sample. This may have been the result of the rain event which occurred the evening prior to sampling. All three samples had counts well below the IDEM standard for whole body contact recreation in lakes and reservoirs (i.e., 400 colonies per 100 ml sample). It is not possible to identify the source of fecal contamination from the available data. However, possible sources include waterfowl, septic system overflow, and animal waste including pet droppings.

Table 12. Little Barbee Lake phytoplankton identification and cell count/ml (24 August 1989).

	CELLS PER SAMPLE	
	5 FT. TOW	20 FT. TOW
Sample Volume Total (ml)	121.0	178.0
Volume of sample settled for ident. (ml)	1.0	1.0
SPECIES		
Chlorophyta(green algae)		
Ankistrodesmus convolutus	107,000	
Ankistrodesmus falcatus	*	
Chlamydomonasglobosa	438,000	
Closteriopsis longissima	107,000	
Crucigenia tetrapedia	584,000	430,000
Gloeocystis major	*	
Pediastrum simplex v duodenarium	584,000	860,000
Sphaerocystis Schroeteri	*	*
Staurastrum sp	*	
Total Chlorophyta cells per sample	1,606,000	1,504,000
Total Chlorophyta cells per ml settled	13,273	8,450
Chrysophyta (diatoms,chrysophytes,etc.)		
Cyclotella sp < 10u	146,000	
Dinobryon sociale	292,000	537,000
Fragilaria crotonensis	*	*
Melosira granulata	30,700,000	10,000,000
Melosira sp	5,990,000	13,000,000
centric diatoms < 10u	430,000	
pennate diatoms > 25u	146,000	1,500,000
Total Chrysophyta cells per sample	37,274,000	25,467,000
Total Chrysophyta cells per ml settled	308,049	143,074
Euglenophyta (euglenoids)		
Trachelomonas charkowiensis	*	
Total Euglenophyta cells per sample	0	0
Total Euglenophyta cells per ml settled	0	0

Table 12. **Little Barbee Lake phytoplankton identification and cell count/ml. (24 August 1989 - concluded).**

	CELLS PER SAMPLE 5 FT. TOW	20 FT. TOW
Sample Volume Total (ml)	121.0	178.0
Volume of sample settled for ident. (ml)	1.0	1.0
SPECIES		
Pyrrophyta (yellow-browns)		
Ceratium hirudinella	*	1,400,000
Cryptomonas brevis	146,000	
Cryptomonas erosa	146,000	215,000
Cryptomonas phaseolus	292,000	
Cryptomonas pusilla	107,000	
Total Pyrrophyta cells per sample	584,000	1,722,000
Total Pyrrophyta cells per ml settled	4,826	9,674
Cyanophyta (blue-greens)		
Anabaena flosaquae	43,200,000	
Anabaena planctonica	27,900,000	752,000
Aphanocapsa delicatissima	15,200,000	
Aphanocapsa pulchra	16,600,000	10,400,000
Aphanothece gelatinosa	*	
Aphanizomenon flosaquae	24,700,000	
Coelosphaerium kuetzingianum	12,400,000	*
Chroococus dispersus	13,100,000	
Lyngbya birgei	6,280,000	19,800,000
Merismopedia punctata	4,090,000	
Merismopedia tenuissima	1,720,000	
Microcystis aeruginosa	24,700,000	
Oscillatoria limnetica	3,800,000	7,950,000
Oscillatoria planctonica	28,800,000	
Oscillatoria tenuis	20,000,000	
blue-green monads	22,200,000	11,600,000
blue-green filaments	2,150,000	
Total Cyanophyta cells per sample	242,970,000	74,372,000
Total Cyanophyta cells per ml settled	2,008,011	417,822
Total phytoplankton cells per sample	282,434,000	103,065,000
Total phytoplankton cells per ml settled	2,334,148	579,020

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

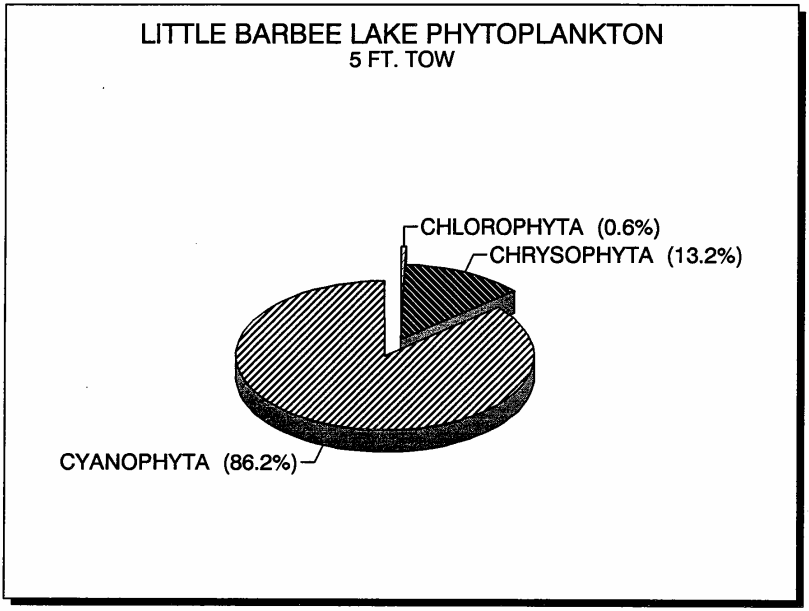

Figure 5a. Percentages of phytoplankton classes represented in Little Barbee Lake 5 foot tow.

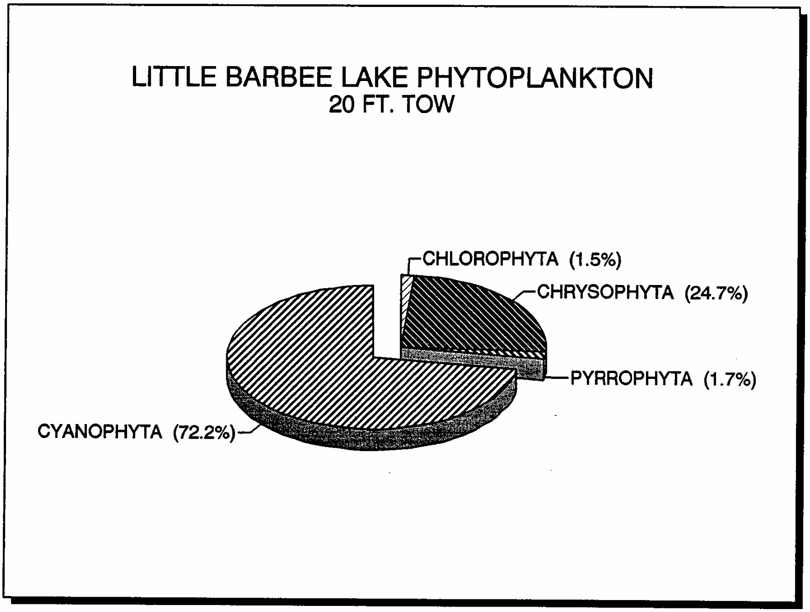

Figure 5b. Percentages of phytoplankton classes represented in Little Barbee Lake 20 foot tow.

4.1.4 Trophic State Assessment

The biological, chemical and physical characteristics of a lake can be incorporated into an index number to describe its trophic state. Historically, trophic classifications have been based on the division of the trophic continuum into a series of classes. Traditional systems divide the continuum into three classes (i.e., oligotrophic, mesotrophic and eutrophic), but frequently offer no clear delineation of these divisions. Calculating a trophic state index allows a quantitative description of the degree of eutrophication in a lake, and provides a basis for numerically comparing the lake's trophic status over a period of time and for comparing its trophic state against that of other lakes.

There are several numerical trophic classification systems currently used within the scientific community. A previous trophic state assessment of Little Barbee Lake was conducted using the BonHomme Eutrophication Index and is documented in the Indiana Lake Classification System and Management Plan (IDEM, 1986). The index was developed by Harold BonHomme of IDEM. Index points are assigned based on diverse chemical, physical and biological measurements in the lake. A lake may receive a Eutrophication Index (EI) number ranging from 0 to 75, with values near 0 being the least eutrophic.

Another numerical index that is widely reported in the literature for trophic state assessment is the Carlson Trophic State Index (TSI). Carlson (1977) based his index on algal biomass using the log transformation of Secchi disk transparency, a physical measurement, as an estimate of biomass. Since Chla and TP concentrations are often correlated with transparency, a TSI number may also be calculated from these biological and chemical measurements. All three measurements are taken from surface waters where phytoplankton productivity is at its peak. The equations used for computing the Carlson TSI are:

$$TSI(SD) = 60 - (14.41 \ln SD) \tag{1}$$

Where:

TSI(SD) = TSI based on Secchi disk transparency
SD = Secchi transparency (meters)

$$TSI(Chla) = (9.81 \ln Chla) + 30.6 \tag{2}$$

Where:

TSI(Chla) = TSI based on chlorophyll concentration
Chla = Chlorophyll a (mg/m^3)

Where:

$$TSI(TP) = (14.42 \ln TP) + 4.15 \quad (3)$$

TSI(TP) = TSI based on total phosphorus concentration
TP = Total phosphorus (mg/m^3)

The Carlson TSI classifies lakes on a scale of 0 to 100, with each major scale division (i.e., 10, 20, 30, ...) representing a doubling in algal biomass. Under ideal circumstances, the three separate TSI values should be similar, however the index values will exhibit some variability. This variability reveals basic differences in the ecological functioning of the aquatic system. The accuracy of Carlson's TSI based on Secchi disk measurement alone is diminished by the presence of non-algal particulate matter or highly colored water. The index number derived from the Chla values, when available, is best for estimating algal biomass, and priority should be given for its use as a trophic state indicator (Carlson, 1977).

A BonHomme Eutrophication Index (EI) number was calculated for Little Barbee Lake using the water quality and biological data collected during the 24 August 1989 field survey. A breakdown of the points assigned for each of the EI criteria is shown in Table 13. The number of points assigned was based on a newly revised scale developed by the IDEM staff. This revision allows comparison of current EI values with those based on data collected by the ISBH in the 1970's. There is a source of uncertainty in this EI calculation that should be noted. The phytoplankton sample from the thermocline was collected in a manner inconsistent with the technique used by BonHomme. A closed sample from the thermocline only, rather than a vertical tow from the thermocline to the surface, is the method used on lakes previously sampled by IDEM. Based on the recommendations of Mr. BonHomme (pers. comm.), the data collected from the 5 foot tow was used to estimate the phytoplankton count in the thermocline.

Previously, the IDEM calculated an EI number of 56 for Little Barbee Lake. A re-evaluation of the original data used for this calculation resulted in an EI number of 59 (BonHomme, pers. comm.). The EI number based on data collected 24 August 1989 was also 59, placing the lake in the Class Three trophic category. Although the newly calculated EI value was the same as that calculated in the 1970's, a significant increase in TP and $N\text{-}NH_4$ concentrations was noted. Decreases in concentration were seen for OP and NO_3, as well as a decrease in the dissolved oxygen saturation value at five feet.

Calculation of the Carlson TSI was based on the Chla and TP concentrations in the surface waters, as well as the Secchi disk transparency of Little Barbee Lake. Table 14 presents the results of these calculations. The range of TSI values was between 58 and 63. Lakes with TSI numbers between 50 and 60 are characterized by decreased water transparency, increased macrophyte growth, and anoxic hypolimnia during the summer months. These lakes are experiencing accelerated eutrophication. As TSI values increase to the range of 60 to 70, blue green algae become dominant and algal scums are probable (Carlson 1979).

Table 13. BonHomme Eutrophication Index calculations for Little Barbee Lake.

Parameter and Range	Range Value	Range Observed	Point Value
Total Phosphorus (mg/L)			
Observed Mean: 0.22 mg/L			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3		0
0.20 to 0.99	4	X	4
Greater than 0.99	5		0
Soluble Phosphorus (mg/L)			
Observed Mean: 0.03 mg/L			
At least 0.03	1	X	1
0.04 to 0.05	2		0
0.06 to 0.19	3		0
0.20 to 0.99	4		0
1.00 or more	5		0
Organic Nitrogen (mg/L)			
Observed Mean: 0.90 mg/L			
At least 0.05	1		0
0.60 to 0.80	2		0
0.90 to 1.90	3	X	3
2.0 or more	4		0
Nitrate (mg/L)			
Observed Mean: 0.15 mg/L			
At least 0.30	1		0
0.40 to 0.80	2		0
0.90 to 1.90	3		0
2.0 or more	4		0
Ammonia (mg/L)			
Observed Mean: 1.0 mg/L			
At least 0.30	1		0
0.40 to 0.50	2		0
0.60 to 0.90	3		0
1.0 or more	4	X	4
Percent oxygen saturation at 5 feet			
Observed Value: 116%			
114% or less	0		0
115% to 119%	1	X	1
120% to 129%	2		0
130% to 149%	3		0
150% or more	4		0

Table 13. BonHomme Eutrophication Index calculations for Little Barbee Lake (concluded).

Parameter and Range	Range Value	Range Observed	Point Value
Percent of Water Column with at least 0.10 mg/L of DO			
Observed Value: 69%			
28% or less	4		0
29% to 49%	3		0
50% to 65%	2		0
66% to 75%	1	X	1
76% to 100%	0		0
Secchi Disk Transparency			
Observed Value: 3 feet			
5 feet or less	6	X	6
Greater than 5 feet	0		0
Light Transmission at 3 feet			
Observed Value: 14%			
0% to 30%	4	X	4
31% to 50%	3		0
51% to 70%	2		0
71% or greater	0		0
Total Plankton from 5 foot Tow (#/L)			
Number of Organisms per Liter: 2,540,000			
Less than 4,700/L	0		0
4,701/L to 9,500/L	1		0
9,501/L to 19,000/L	2		0
19,001/L to 28,000/L	3		0
28,001/L to 57,000/L	4		0
57,001/L to 95,000/L	5		0
95,001/L or more	10	X	10
Blue-green dominance	5	X	5
Total Plankton from Thermocline Tow (#/L)			
Number of Organisms per Liter: 2,540,000			
Less than 9,500/L	0		0
9,501/L to 19,000/L	1		0
19,001/L to 47,000/L	2		0
47,001/L to 95,000/L	3		0
95,001/L to 190,000/L	4		0
190,001/L to 285,000/L	5		0
285,001/L or more	10	X	10
Blue-green dominance	5	X	5
Population of 950,000 or more	5	X	5
			==
INDEX VALUE			59

Table 14. Carlson Trophic State Index calculations for Little Barbee Lake.

SAMPLE DATE	SECCHI DISK (m)	TSI (SD)	CHLOROPHYLL (mg/m3)	TSI (Chla)	TP (mg/m3)	TSI (TP)
08/24/89	0.8	63	27.4	63	41	58

A comparison of the calculated TSI values shows that Secchi disk and Chla based values are equivalent, and greater than the TP based value. This would indicate that light attenuation was dominated by algae, and the lake was phosphorus limited on the date of sampling (Carlson, 1983).

Both the BonHomme EI and the Carlson TSI classify Little Barbee Lake as moderately eutrophic at the time of sampling. It should be noted that the data used to construct these indices are derived from a single sampling event and are only representative of lake conditions on a single day in mid-summer. Better representation of trophic state could be attained through increased lake monitoring throughout the summer growing season. Such high resolution sampling was beyond the scope of this investigation.

4.1.5 Sediment Sample Results

The results of the analyses on sediment samples collected from Stonebruner-Putney Ditch are shown in Table 15. The samples were collected 21 November 1989. For comparison purposes, this table also

Table 15. Little Barbee Lake sediment sample analyses.

SAMPLE ID	DATE COLLECTED	TIME COLLECTED	TP (mg/Kg)	TKN (mg/Kg)	% SAND	% SILT	% CLAY
SB - #1	11/21/89	16:14	220	57			
SB - #2	11/21/89	16:20	180	50	98.0	2.0	0.0
SB - #3	11/21/89	16:30	380	200	96.0	4.0	0.0
SB - #4	11/21/89	16:40	670	340	92.0	8.0	0.0
SB - #5	11/21/89	16:45	2,800	2,050	72.0	22.0	6.0
SB - #6	11/21/89	16:55	320	78	96.0	4.0	0.0
SB - #7	11/21/89	17:00	270	200	96.0	4.0	0.0
IDEM Background Level			610	1,500			

shows mean background concentrations of TP and TKN in sediments at 83 sites throughout Indiana, surveyed by IDEM from 1985 to 1987 (Indiana 305B Report, 1986-1987). These mean values represent sediment concentrations at sites upstream of all known point sources of pollution, including industrial discharges and combined sewer overflows. As such, they are considered to represent unpolluted lake and stream sediments statewide. The IDEM provides these estimates because no criteria for sediment concentrations of nutrients and priority pollutants have been established by the state or federal government. As guidelines for interpreting sediment data, IDEM has defined four levels of concern: low, medium, high, and unknown. Low concern is defined as 2-10 times background levels, medium concern as 10-100 times background, and high concern as any concentration greater than 100 times background.

Using the IDEM guidelines, all results obtained are in the low concern category. The maximum factor by which a parameter exceeded the background level was 4.5 for TP in sample #5. This sample was located along the Stonebruner-Putney Ditch inflow, approximately 100 feet into the lake. A TP concentration of 2,800 mg/kg was measured at this site. Sediment TKN concentrations were also highest in this sample, measuring 2,050 mg/kg or 1.4 times the background level.

The results of the particle size analyses indicated that sand was the dominant particle size for all six samples, comprising from 72 to 98 percent of the total sediment composition. Resuspension following a disturbance to the lake bottom, such as dredging, would therefore be expected to have minimal and short term effects on water clarity.

Accurate measurement of sediment depth, through the use of a sediment probe, was not possible. The sediment probe met no resistance when inserted the maximum distance (i.e., 10 feet) into the sediment at each of the seven (7) sampling locations. From this information it can then be postulated that sediment depth at the mouth of Stonebruner-Putney Ditch is greater than 10 feet.

4.1.6 Bathymetric Survey

A bathymetric map of the mouth of Stonebruner-Putney Ditch is shown in Figure 6. Sediment accumulation in this area was determined using the method described in Section 3.1.5. The calculations indicate a minor decrease in sediment volume. Within the 0.93 acres surveyed, a decrease of 0.7 acre-feet was found. The decrease in sediment volume should not be attributed to an actual change in the rate of sedimentation. It is most likely due to measurement error that resulted from comparison of the 1965 map, produced at five foot contour intervals, with the 1989 map, which was plotted at one foot intervals. The small change in sediment volume within the area surveyed is a strong indication that the sediment bar at the mouth of Putney Ditch has remained relatively unchanged over the last 25 years.

No historical data or maps were available showing the depths of the canal leading into the lake. The measurements taken during the 1989 survey showed a maximum depth of two feet in the sea-walled portion of the canal. Discussion with local residents indicates that the depth of the canal has decreased

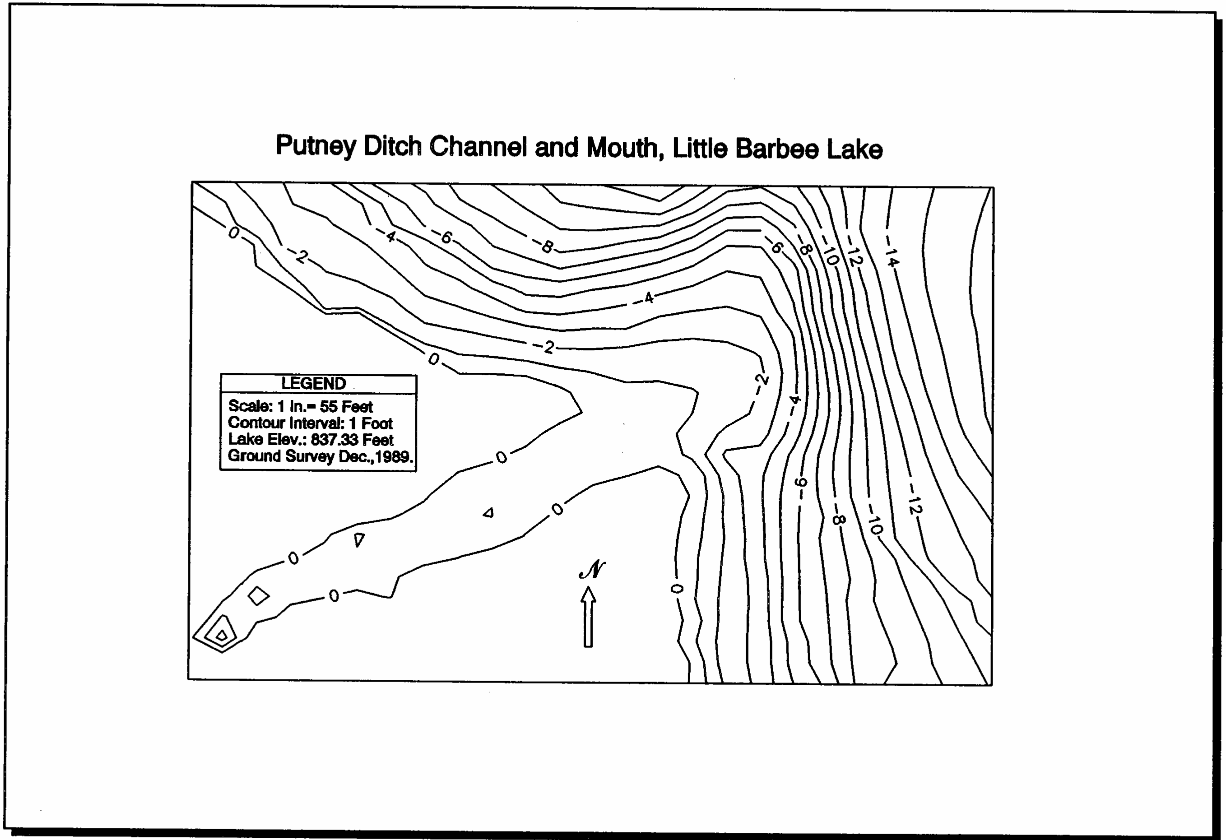

Figure 6. Bathymetric map of Little Barbee Lake at Stonebruner-Putney Ditch.

significantly (six to eight feet) during the last 10 to 15 years.

4.2 WATERSHED SURVEY

The watershed survey examined hydrology, land use, and erodible soils within the Stonebruner-Putney Ditch drainage basin. The AGNPS model served as an important tool for integrating the effects of these factors on nutrient and sediment loading to the lake and interpreting their significance.

4.2.1 Hydrologic Results

With respect to lake restoration, the principal hydrologic parameter of interest in characterizing Little Barbee Lake is the hydraulic residence time. This is defined as the length of time required for the entire volume of the lake to be replaced with "new" water from runoff and direct precipitation. This parameter defines how dynamic the system is and how responsive a lake will be to changes in nutrient loading.

For this study, hydraulic residence time was computed as the ratio of lake water volume to the net annual inflow water volume from Stonebruner-Putney Ditch The formula used in calculating retention time (τ) is as follows:

$$\tau=\frac{V}{R+P-E} \tag{4}$$

Where:
τ = Hydraulic retention time (years)
V = Lake volume (acre-feet)
R = Average annual runoff (acre-feet/year)
P = Precipitation (acre-feet/year)
E = Evaporative losses (acre-feet/year)

In addition to runoff from the watershed, the lake receives direct input from precipitation, and loses water volume through evaporation from the lake surface. Average annual runoff (R) was determined by multiplying the area of the Stonebruner-Putney Ditch watershed by the average annual runoff value of 12.38 inches (1.03 feet) reported for the Tippecanoe River at Oswego, IN (USGS 1988). Average annual rainfall for the Kosciusko and Whitley County area is 36 in/year (USGS, 1988). Thus, direct precipitative input (P) to the lake was estimated to be 222 acre-feet per year. Evaporative losses (E) from lake surfaces in northern Indiana are approximately 32 inches/year (Geraghty et. al., 1973) or approximately 198 acre-feet for Little Barbee Lake. Thus, there is a net increase of four inches (0.33 feet), or approximately 24 acre-feet of water added to the lake annually (i.e., the difference between direct precipitative input and evaporative losses).

Based on these data, the hydraulic residence time for Little Barbee Lake was calculated to be 0.35 years (128 days). Intermediate water residence times, such as this, provide adequate time for algae to assimilate the available nutrients, and to grow and accumulate within the water body. The addition of runoff from the Big Barbee Lake sub-watershed would reduce the residence time considerably. The lake, however, is chiefly influenced by runoff from the Stonebruner-Putney Ditch watershed.

Based on a retention time of 128 days, Little Barbee Lake will have a moderately rapid response to a reduction in external nutrient loading. However, flushing of nutrient rich bottom water will be incomplete during summer stratification. Following fall turnover, the accumulated sediment nutrients will be subject to reduction by flushing effects, as released nutrients are washed out of the system.

4.2.2 Land Use Characterization

One of the most influential factors governing the quality of a surface water body is the nature of land use in the drainage basin. Land use characterization within the Stonebruner-Putney Ditch watershed of Little Barbee Lake was critical in determining the input parameters for the AGNPS model. The different land use categories and corresponding percentages of areal coverages are listed in Table 16. A land use map is presented in Figure 7.

Table 16. Land use percentages for the Stonebruner-Putney Ditch watershed of Little Barbee Lake.

CATEGORY	PERCENT OF WATERSHED
Water	2.5
Wetlands	2.1
Forest	9.4
Open	2.1
Pasture	0.4
Row Crops	73.7
Non-row Crops	3.5
Orchards	0.1
Feedlots	0.0
Low Density Residential	3.1
Medium Density Residential	2.6
High Density Residential	0.0
Commercial	0.2
Institutional	0.0
Bare/Unseeded Ground	0.0
Resource Extraction	0.3

The primary land use within the watershed is row crop agriculture, which accounted for 74% of the total acreage. Blocks of row crops were found uniformly dispersed throughout the entire drainage basin. This large percentage of land presents the greatest potential source of sediment and nutrient loading to Little Barbee Lake. Forested land comprised 9.4% of the watershed area and was found throughout the drainage basin, while non-row crop agriculture accounted for 3.5% of the total watershed area. Wetland areas, 2% of the drainage basin, were found along the south and west shores of Little Barbee Lake, and in the central and southern portions of the Stonebruner-Putney Ditch watershed.

The three residential use categories together accounted for only 5.7% of the watershed area. Areas of low density residential use (i.e., one unit per acre) were found throughout the watershed, while areas of medium density residential use (i.e., two to five units per acre) were concentrated along the shores of Little Barbee Lake. There were no areas of high density (i.e., six or more units per acre) residential use identified.

4.2.3 Erodible Soils Evaluation

The "Northeast Indiana Erosion Study" (USDA, 1988) cited loss of soil productivity, prevention of small plant growth, and contribution of soil to ditches as three primary problems associated with soil erosion. The study identified major erosion problem areas and rates of erosion in 14 counties in northeastern Indiana, including Kosciusko County. Problem areas are defined in the reports as areas "with a predominance of land that is eroding substantially in excess of rates at which it will maintain its' productivity". The results of the USDA report were used to identify problem areas in the Little Barbee Lake watershed.

The USDA estimate of soil erosion in Kosciusko County was 9.9 tons/acre/year (291 yd^3/acre/year): 5.8 tons (155 yd^3) from sheet and rill erosion, 3.1 tons (83 yd^3) from wind, and one ton (27 yd^3) from gully erosion. The Stonebruner-Putney Ditch portion of the watershed would therefore contribute approximately 26,150 tons (698,000 yd^3) of sediment per year.

In a preliminary investigation of Kosciusko County lakes, Hippensteel (1989) evaluated erodible soils in the Stonebruner-Putney Ditch watershed. This study identified specific highly erodible soil types and their location, rather than the more broadly defined problem areas in the USDA study. A total of 714 acres (27%) of the Stonebruner-Putney Ditch watershed were found to contain highly erodible soil types. Areas of highly erodible soils are contiguous with portions of the Stonebruner-Putney Ditch shoreline, and are found throughout the western and central portions of that watershed. Highly erodible soils are also found along the northeast shore and contiguous with the canals on the northwest shore of Little Barbee Lake (Hippensteel, 1989).

4.2.4 Sediment and Nutrient Modeling

Prior to running the AGNPS model, it was necessary to divide the watershed into a grid of equal areas, called "cells". This grid was prepared by subdividing each 640-acre section of the USGS 1:24,000 topographic map, into four 160-acre cells. These cells were then further subdivided to yield a total of 64 10-acre cells per section. This method allowed referencing of cells to Range and Township boundaries. The AGNPS cell grid for the Little Barbee Lake watershed is shown in Figure 8. The watershed contains 259 10-acre cells.

Data characterizing the physical features of the cells were utilized by the model to describe the sediment and nutrient contributions of each cell. This information was used to identify cells that were responsible for disproportionately high sediment and nutrient loading. Four categories of AGNPS output were evaluated in describing the pertinent export features: (1) sediment yield, (2) cell erosion, (3) nutrient loading, and (4) hydrology. The AGNPS model was run on one distinct scenario: a U.S. Weather Bureau defined, type two, two-year, 24-hour storm during the Spring growing season.

Sediment Yield and Erosion

Sediment yield from each AGNPS cell is the amount of sediment, in tons, that leaves a cell at its downstream edge. This yield represents the sediment generated inside the cell as well as the sediment generated upstream, and sediment deposition within the cell. Therefore, sediment yield is calculated as the sediment generated within the cell, plus upstream contributions, minus deposition.

Cell erosion refers to the amount of sediment that is produced by the storm event within an individual cell, rather than the cumulative amount passing through the cell. It is useful in identifying the cells that experience the greatest amount of internal erosion. The most important factors contributing to erosion within a given cell are soil erodibility (i.e., K-factor) and land slope. Land use, water flow velocity, and the presence/absence of agriculture or unmitigated construction generally produce higher erosion losses than areas consisting of forests or wetlands. Watershed cells with comparatively high sediment yield and cell erosion are displayed in Figures 9 and 10, respectively.

The total sediment yield into Little Barbee Lake, from the Stonebruner-Putney Ditch watershed, during the modeled storm was calculated at 6,003 tons. The amount of sediment yielded from each cell in the watershed ranged from 0.01 to 244 tons, with the greatest yield occurring along the Stonebruner-Putney Ditch inflow (e.g., cells #2, 4, 9, 19, 30, 31, 44, 58, 59, and #76) to a distance approximately 0.2 miles south of County Road 300 North (Figure 9). The sediment yield from these cells was in excess of 200 tons. A large portion of the sediment yield was contributed to Stonebruner-Putney Ditch by its western branch. The dominant land use within this area is row crop agriculture.

The cell with the highest sediment yield to Little Barbee Lake, 244 tons, was cell #19 located

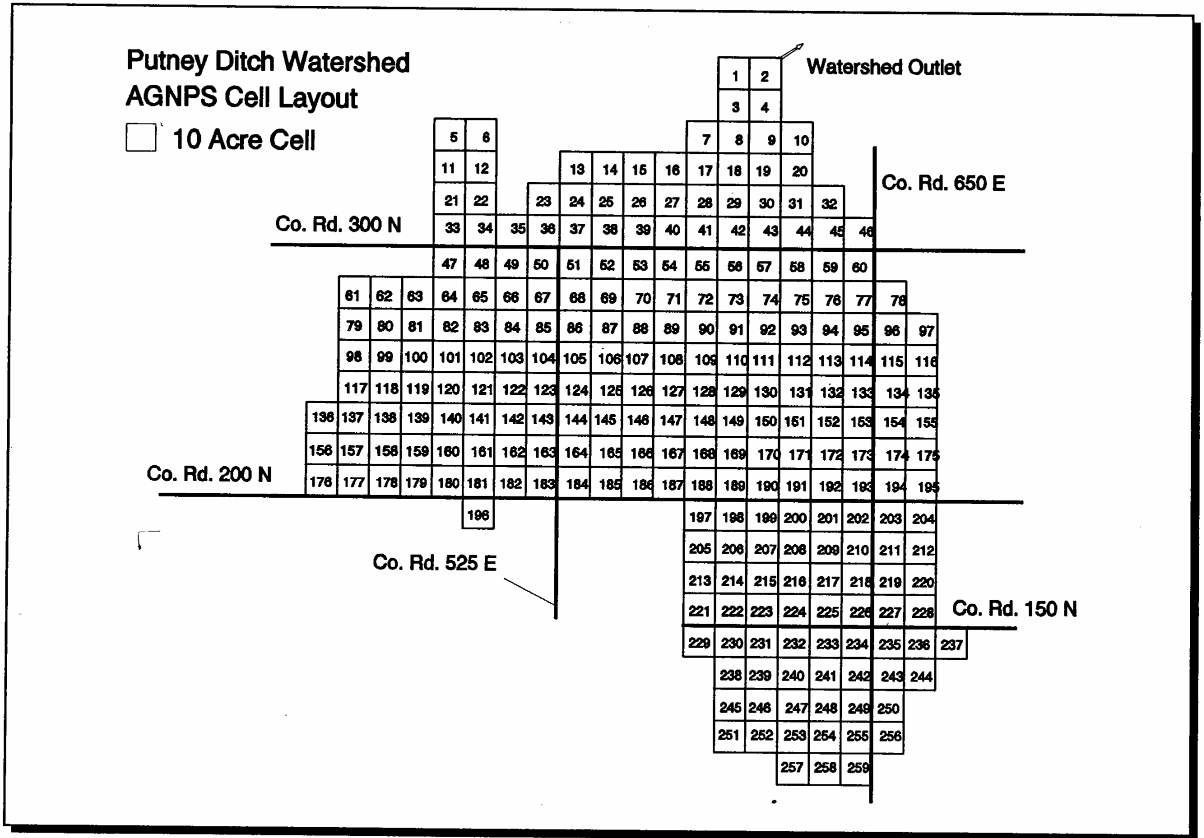

Figure 8. AGNPS cell layout for the Putney Ditch watershed.

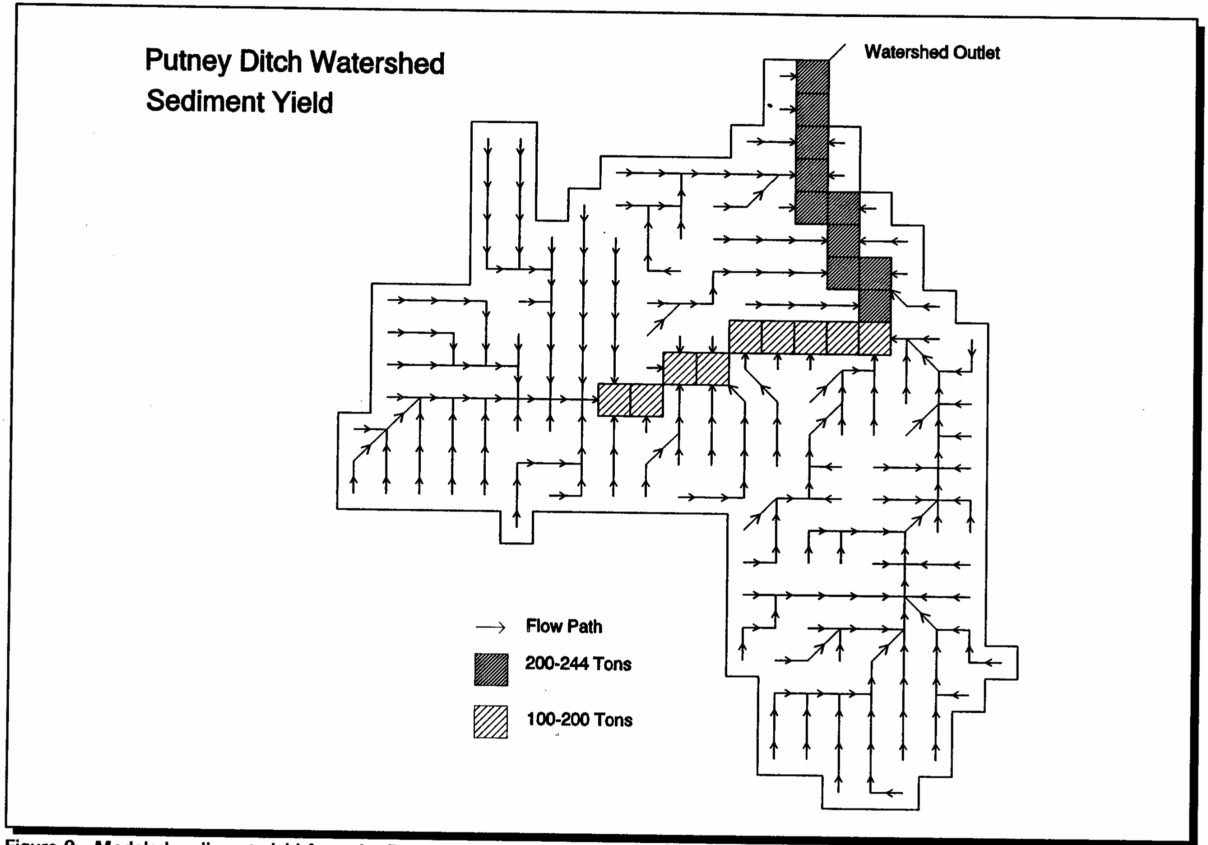

Figure 9. Modeled sediment yield from the Putney Ditch watershed.

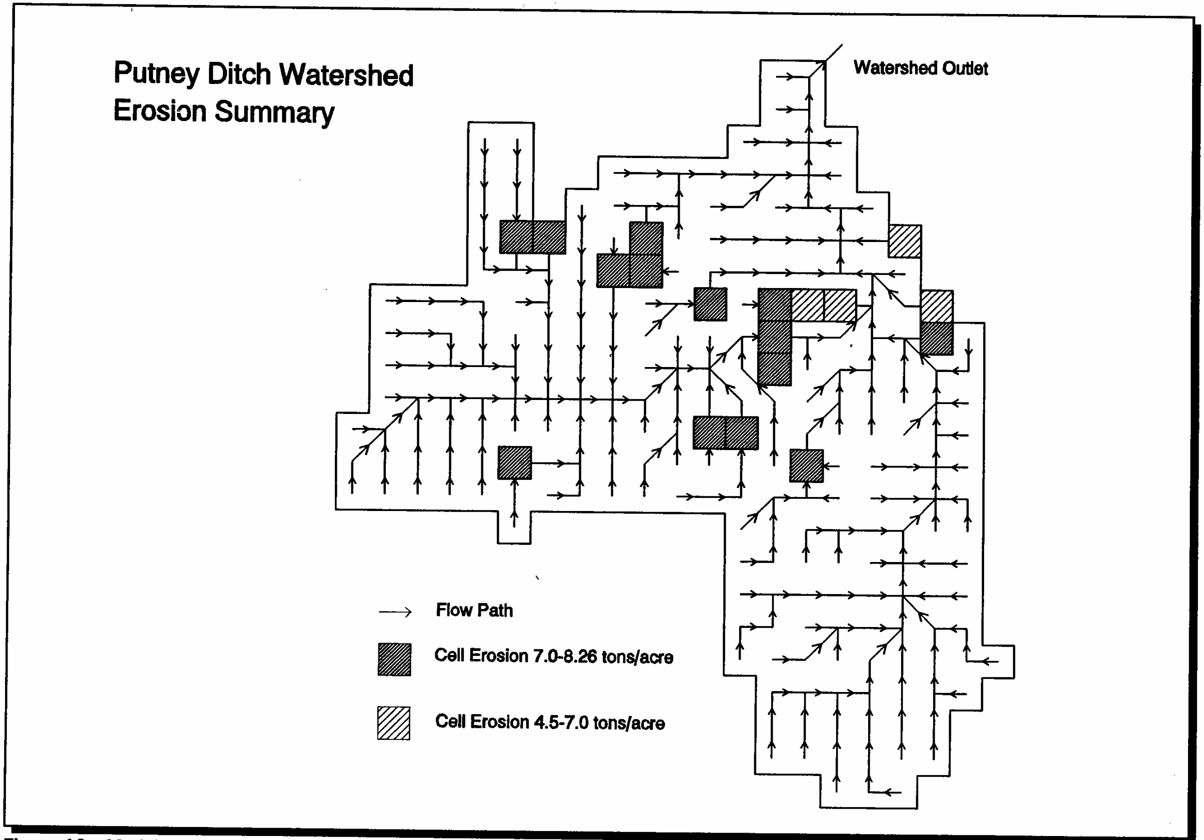

Figure 10. Modeled erosion for the Putney Ditch watershed.

along Stonebruner-Putney Ditch, approximately 0.5 miles south of the inflow to Little Barbee Lake. The western boundary of this cell is County Road 600 East. The 2,510 acre drainage area of cell #19 includes all high yield cells identified above, with the exception of cells #2, 4, and #9 which are located downstream of cell #19. The amount of sediment entering cell #19 from upstream sources was 248 tons, a significantly greater amount than that generated within the cell (20 tons). Sediment deposition in cell #19 was nine percent. Cell #9 receives the outflow from cell #19, and is located directly north of that cell. Cell #9, characterized as wooded acreage, also had a high sediment yield (236 tons). The majority of the sediment yield from this cell was generated from upstream sources, with a four percent sediment deposition rate within the cell. Cell #4 receives the runoff from cell #9, and is located immediately north of cell #9. Cell #4 flows into cell #2, which is the watershed outlet to Little Barbee Lake. Both cells #4 and #2 have high sediment yields (231 and 226 tons, respectively), the majority of which was generated from upstream sources. Cell #4 is characterized as wooded acreage, while land use in cell #2 is residential. Sediment deposition rates in both cells #4 and #2 was low.

Other areas of higher sediment yield were located along the western branch to Stonebruner-Putney Ditch. Cell #93, located approximately 1000 feet east of County Road 600 East and 1500 feet south of County Road 300 North, receives drainage from the western 41% of the watershed. This cell contributed 127 tons of sediment to Stonebruner-Putney Ditch during the design storm. Comparatively, cell #95, representing the southern portion of the watershed (790 acres) contributed 91 tons of sediment to the ditch.

Cell erosion figures for the 2 year, 24-hour storm ranged from no sediment production to 8.26 tons per acre. The average value for all cells in the watershed was 1.98 tons/acre. As indicated in Figure 10, cells exhibiting higher erosion rates (greater than 3.5 tons/acre) were generally located in the central and western portion of the watershed. The highest rate of erosion (i.e., 8.26 tons/acre) was observed in eleven watershed cells: cells #35, 38, 51, 52, 71, 96, 110, 147, 148, 161, and #170. The land use in each of these cells was designated as straight row crop agriculture, with each cell having a land slope of 9%, and a soil erodibility factor of 0.28. Two of these cells, #51 and #170, contain stream channels. Cell #51, located immediately south of County Road 300 North and east of County Road 535 East, contains the headwaters of an intermittent stream flowing south, into the western branch of Stonebruner-Putney Ditch. The southwest branch of Stonebruner-Putney Ditch flows through cell #170, located approximately 1000 feet north of County Road 200 North and east of County Road 600 East.

Cells #29, 46, 74, 75, 78, 231, and #255 all displayed erosion rates greater than 3.5 tons/acre. The land use within these cells was designated as row crop agriculture. Land slopes of these cells ranged from 4% to 9%, and soil erodibility factors ranged from 0.17 to 0.37.

Nutrient Loading

The AGNPS model supplied estimates for both soluble and sediment-bound nitrogen and phosphorus concentrations in runoff from the watershed. Soluble forms of both nutrients are readily available to aquatic vegetation and phytoplankton, whereas the sediment-bound fractions are not likely to have an immediate biological effect. Maps showing cells within the watershed that contributed relatively greater amounts of these nutrients are contained in the following sections.

Nitrogen Loading

Using the cumulative data generated by the AGNPS model, it was possible to ascertain the cell yield of total nitrogen (i.e., the sum of soluble N and sediment-bound N) from the watershed during the design storm. Areas of higher soluble nitrogen loading are shown in Figure 11. Areas of greater soluble nitrogen loadings were located in the west central portion of the watershed. Cells with high sediment-bound nitrogen loadings were in both the western and southern portions of the watershed (Figure 12). The total nitrogen input from the Stonebruner-Putney Ditch watershed was 5,025 pounds, or 1.94 pounds/acre. Approximately 80% of this amount, 4,040 pounds, was in the form of soluble nitrogen. A total nitrogen loading of 2,279 pounds (2.11 pounds/acre) was calculated for the western branch of Stonebruner-Putney Ditch. This stream drains a total of 1080 acres in the western portion of the watershed. The southern branch of Stonebruner-Putney Ditch has a drainage area of 790 acres and contributed a total nitrogen load of 1,888 pounds (2.39 pounds/acre) to the ditch during the design storm.

Soluble nitrogen generated within individual cells ranged from 0.04 pounds/acre to 4.96 pounds/acre. Values of 4.96 pounds/acre were observed in cells #72, and #106. These cells represent areas of row crop agriculture and have soil erodibility factors of 0.28. Cell #72 is located 1000 feet south of County Road 300 North, and approximately 1000 feet west of County Road 600 East. Cell #106 is located 0.4 miles south of County Road 300 North and 1000 feet east of County Road 525 East.

Sediment-bound nitrogen generated within individual cells ranged from 0.01 to 3.08 pounds/acre. The highest value was observed in cell #144, a cell characterized as a fallow, open field. This cell is located immediately east of County Road 525 East and 0.2 miles north of County Road 200 North, and has a soil erodibility factor of 0.32.

Phosphorus Loading

Phosphorus loading to Little Barbee Lake was also modeled using AGNPS. The data generated were used to determine the cell yield of total phosphorus during the design storm. As with the nitrogen loading, excessive soluble phosphorus loads occurred in the west-central portion of the watershed, while high sediment-bound phosphorus loads were found in both the western and southern portions. The total phosphorus (i.e., both soluble and sediment-bound P) input from the Stonebruner-Putney Ditch watershed was 1,295 pounds, or 0.50 pounds/acre. Of this amount, approximately 62% (803 pounds) was in the soluble form. A total phosphorus input of 605 pounds was calculated for the western portion of the drainage basin, while the southern portion contributed 506 pounds to Stonebruner-Putney Ditch.

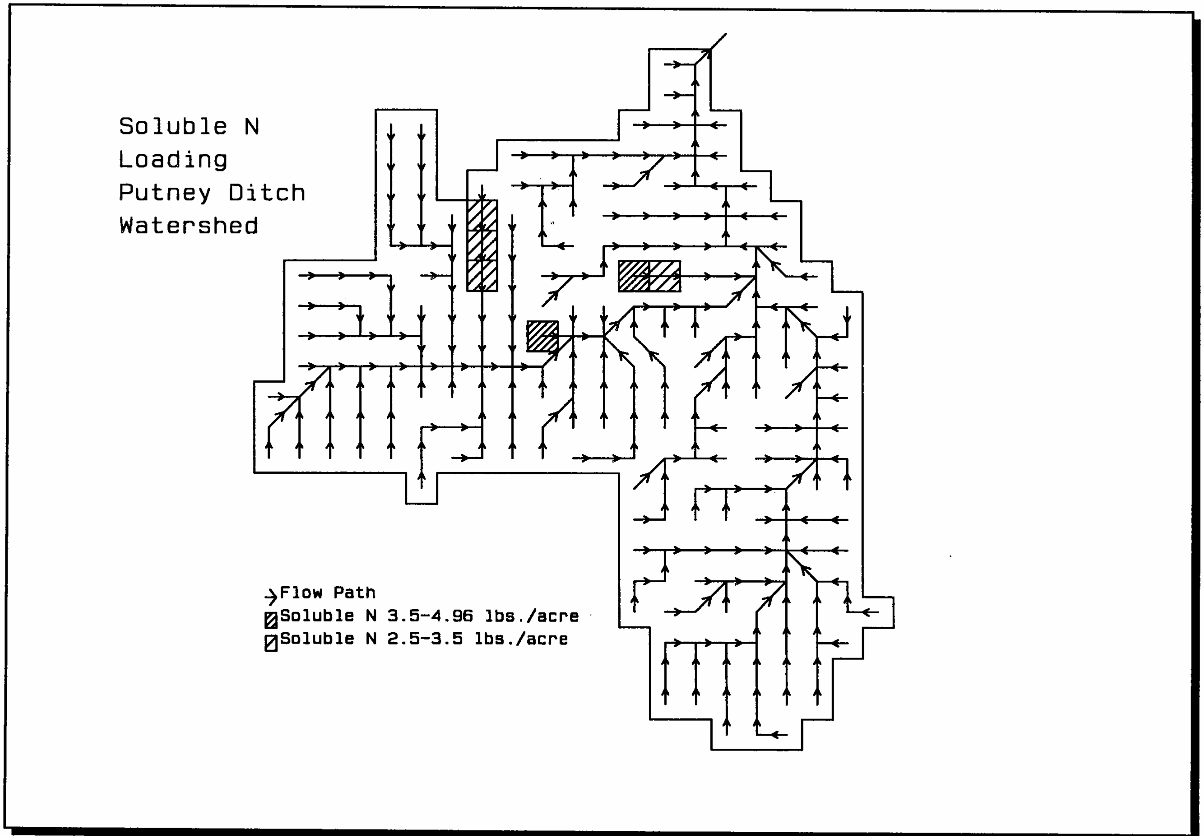

Figure 11. Modeled soluble nitrogen loading for the Putney Ditch watershed.

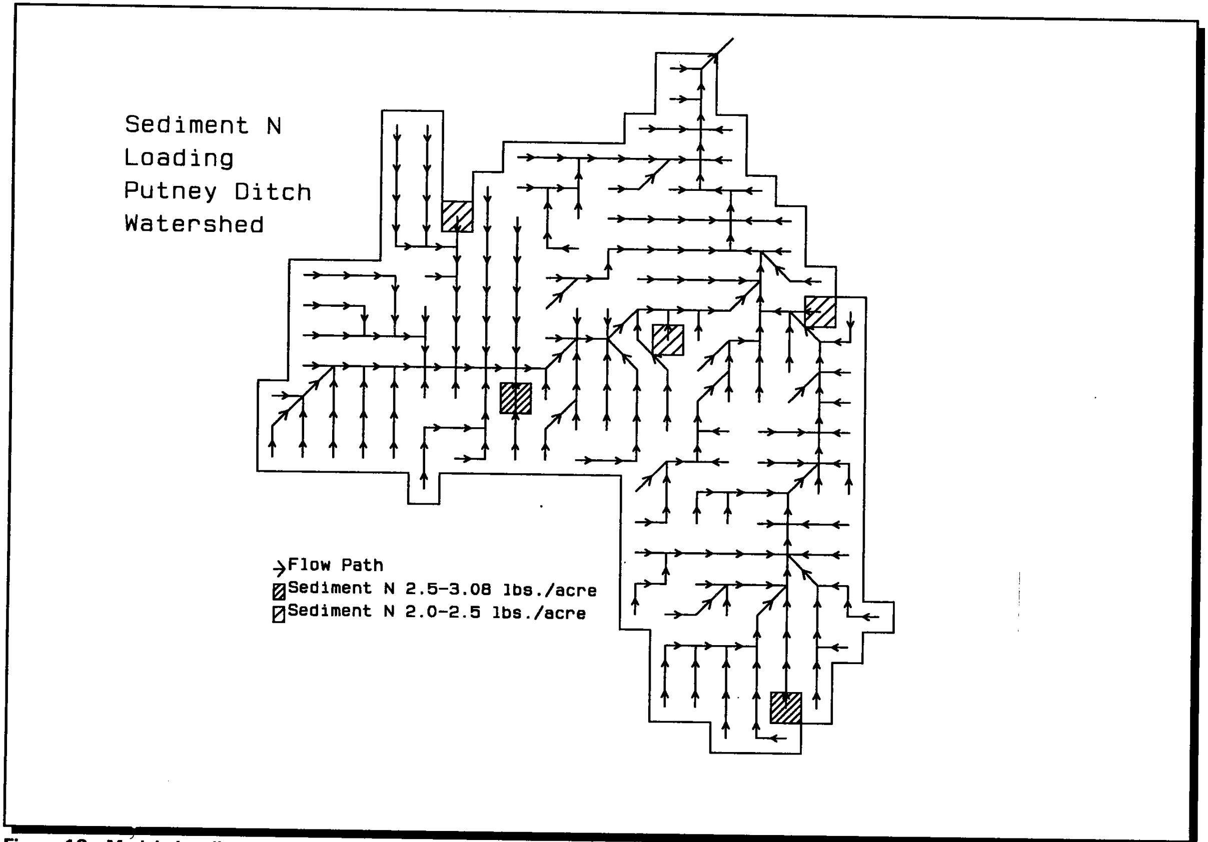

Figure 12. Modeled sediment nitrogen loading for the Putney Ditch watershed.

Soluble phosphorus values generated by the model for the design storm ranged from 0.00 to 1.03 pounds/acre. Cells within the watershed contributing disproportionately greater soluble phosphorus are shown in Figure 13. Cell #72 and #106 had the highest soluble nitrogen values.

The results of sediment-bound phosphorus loading are shown in Figure 14. Sediment-bound phosphorus exhibited a range of 0.01 to 1.54 pounds/acre. Cell #144 generated the highest sediment phosphorus loading of any cell in the watershed. This 10-acre area also generated the highest sediment-bound nitrogen value. Cells 35, 96, 110, and 255 showed sediment-bound phosphorus loading rates in excess of 1.0 pounds/acre. In all four cells, row crop agriculture is the primary land use, and land slopes within the cells range from 4% to 9%. Cells with moderately high sediment phosphorus loading (0.85 pounds/acre or greater) were interspersed throughout the watershed. Land use in these cells is agricultural, and soil erodibility factors range from 0.28 to 0.32.

Hydrology

The AGNPS model was used to examine the hydrologic inputs to Little Barbee Lake for the design storm conditions. Runoff values for the individual cells ranged from 0.18 to 1.34 inches. Watershed cells producing runoff greater than or equal to 1.00 inches (i.e., 75% of the peak runoff observed) are displayed in Figure 15. The greatest runoff volume, 1.34 inches, was produced in cells 60, 72, 106, and 130. These cells are located primarily in the central portion of the watershed.

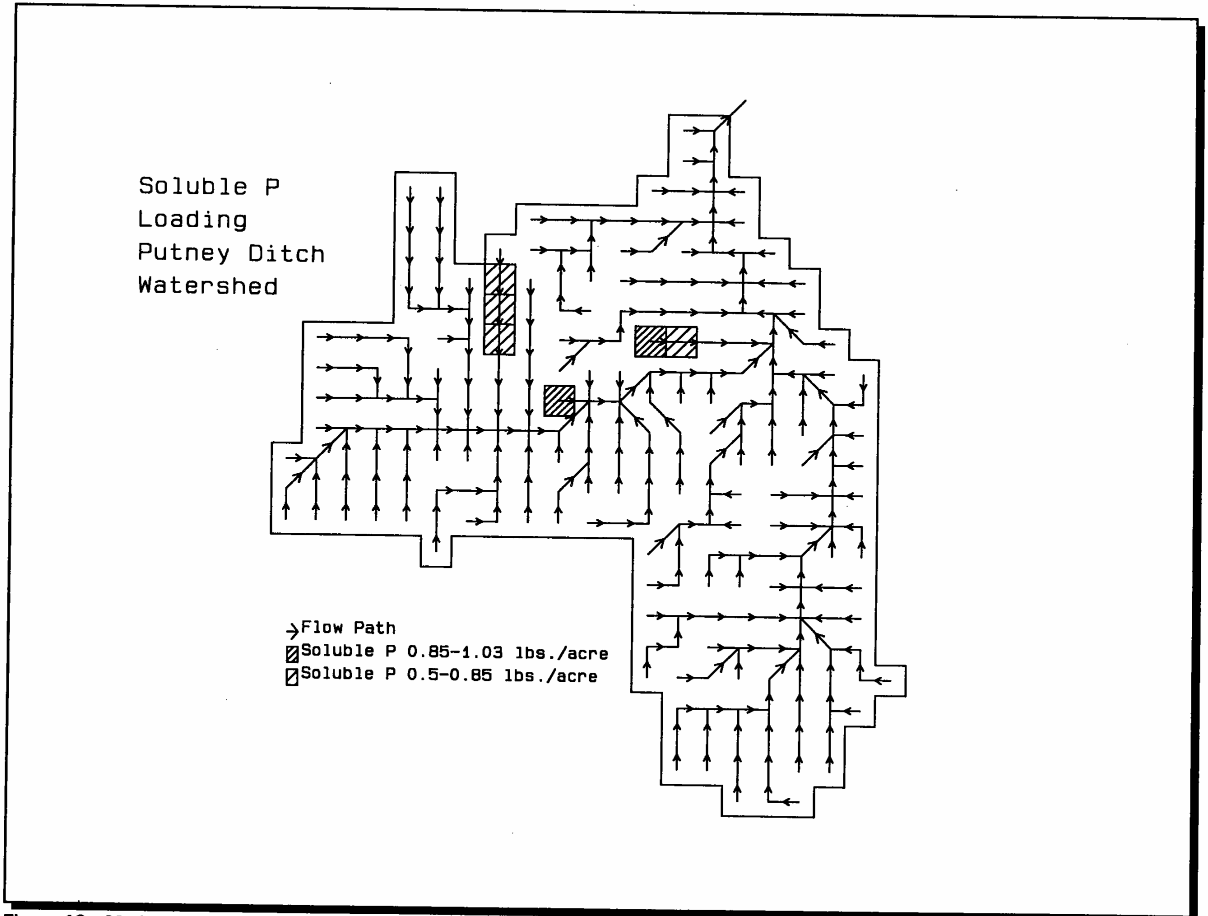

Figure 13. Modeled soluble phosphorus loading for the Putney Ditch watershed.

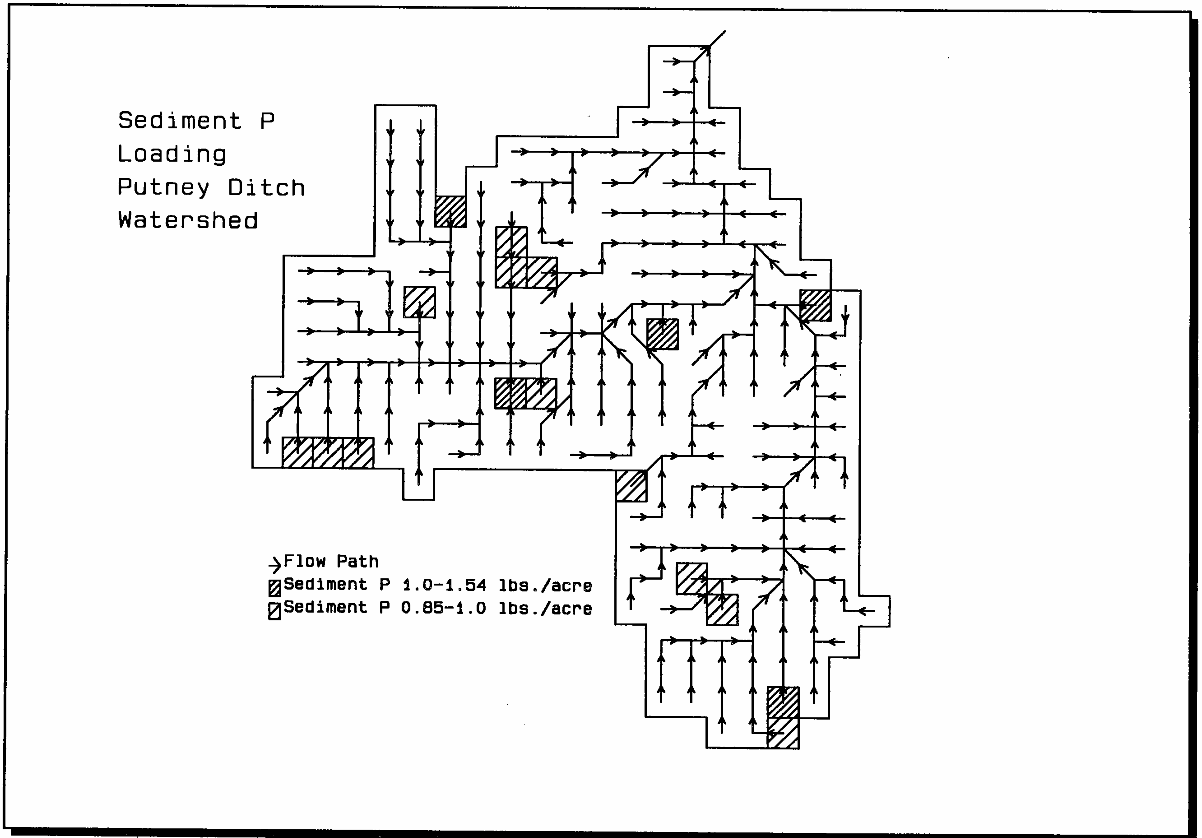

Figure 14. Modeled sediment phosphorus loading for the Putney Ditch watershed.

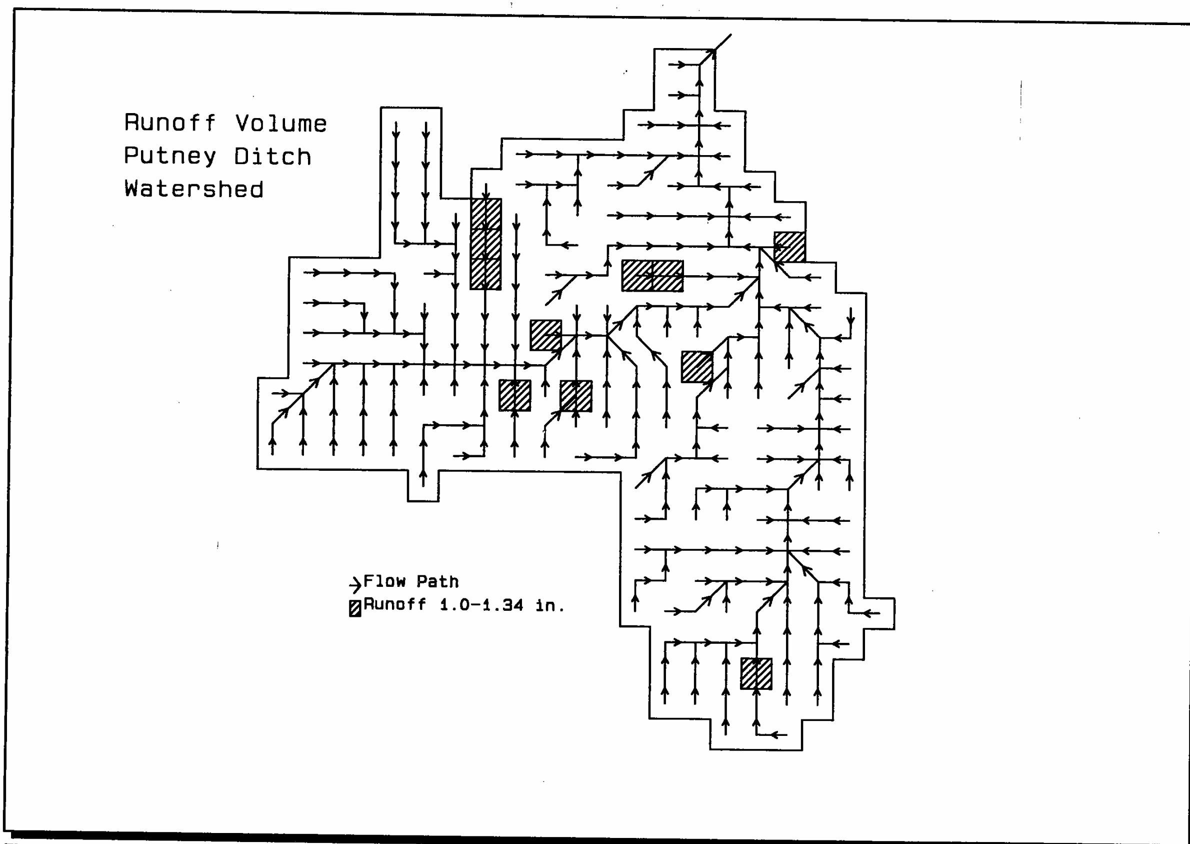

Figure 15. Predicted runoff for the Putney Ditch watershed during the modeled storm.

4.2.5 Stream Channel Characterization

The objective of this aspect of the project was to characterize the major tributary to Little Barbee Lake, Putney Ditch, with respect to channel stability, sediment supply, and sediment transport, and, if necessary, to recommend stabilization measures based on the field observations. The tributary was surveyed in November of 1989 using the Rosgen Stream Classification System, as described in Section 3.2.5. Based on the field survey, the stream was classified as a C-3 channel with the following average characteristics:

- Slope: 0.9%
- Width: 14 feet
- Depth: 1.3 feet
- Dominant Particle Size: small gravel
- Sinuosity: > 1.8
- Confinement: slight.

In contrast to streams with higher gradient and larger particle size bed material, streams in this category have slopes less than one percent, width to depth ratios of 10 or greater, and sinuosity of 1.8 to 2.4. The latter term refers to the ratio of the length of the stream to the length of the valley. In the case of Putney Ditch, the total length of the stream is almost twice that of the valley length, which indicates a meandering pattern.

C-3 streams are easily destabilized by excess sediment. The response to an increase in sediment loading is the formation of in-channel bars and lateral adjustment, i.e., bank erosion. This process adds even more sediment, creating similar conditions downstream. A serious example of this process was observed in Putney Ditch approximately 500 feet downstream of McKenna Road. Until it is stabilized, this section of the stream will be a significant source of sediment to Little Barbee Lake. The erosion that is occurring here will accelerate as the banks supply more sediment to the stream. Restoration of the natural channel geometry and stabilization using native materials from the immediate area is recommended for this section (see Section 8).

In terms of biological resources, C-3 streams usually provide good habitat for fish and aquatic invertebrates. The size of the streambed material is coarse and variable enough to provide a variety of habitat conditions suitable for spawning, feeding, and resting. Due to greater width to depth ratios, these streams may have a shortage of deep water areas during summer low flows. Areas that do not have sufficient depth at low fl^w can be enhanced with habitat improvement measures such as low profile deflectors or bank imbedded boulders. Both of these measure create pool conditions at low flows.

Streams form and maintain channels capable of carrying the runoff volume that occurs approximately annually. When this annual, or bank-full flow occurs, the majority of sediment that is transported on an annual basis is moved through the system. At flows less than three-fourths bank-full, the stream does not move appreciable amounts of sediment. A "stable" stream is one in which sediment supply is in balance with the stream's ability to carry the bank-full load without degradation of the banks, or a change in gradient or slope. This situation, in which a balance exists between sediment supply and transport, is considered an equilibrium condition. Establishment of a stream type allows one to determine whether specific stream reaches are out of line, or out of equilibrium, with the stream as a whole.

If a change in sediment supply or volume of runoff occurs, the stream system is thrown out of equilibrium. For example, if construction activities in the watershed increase the amount of sediment entering the stream, there must be adjustments to the physical characteristics of the stream to allow the bank-full volume to be carried. The most common adjustment in low gradient streams, common in northern Indiana, is bank erosion. The process of adjusting to the increased sediment load forces the stream to erode the outside bank, which in turn "carves out" more sediment from the bank itself, particularly if the bank material consists of erodible soils. Given the natural meandering pattern of streams, this process cannot be confined to a single location, and continues as a kind of chain reaction in which downstream outside banks are sequentially eroded as more material is added at every turn of the stream. Thus, the original sediment added to the stream is multiplied many times in the process of accelerating downstream erosion. The process of "recovery" to an equilibrium condition may take many years, during which the stream channel is carrying excess sediment to the receiving water body.

Streambank stabilization refers to measures that are designed to protect eroding streambanks, and reduce or prevent excessive transport of sediment to the receiving water body. Stabilization is usually accomplished with some form of revetment, or bank reinforcement. Riprap or gabions are two commonly used structural methods to stabilize streambanks. Riprap is rock that is sized to stay in position in the face of expected waters velocities. Placement of riprap requires that slopes be no steeper than 1:1 (one foot rise to one foot of run). In many cases, this requirement makes riprap an impractical alternative due to steep banks that would require extensive excavation to achieve a 1:1 slope. If access to a site is limited, riprap installation also requires construction of roads to accommodate trucks and heavy equipment. Gabions are prefabricated wire baskets that are filled with rocks. They solve the problem of steep banks because they can be stacked vertically. However, road access is also required for installation, and gabions are much more expensive than riprap.

In contrast to structural materials, revetments can also be constructed from native materials such as tree root wads and rocks. This approach has several advantages over the above mentioned techniques and is strongly recommended in lieu of riprap or gabions. Materials can usually be obtained on-site at a fraction of the cost. In addition, the root wads can be installed into vertical banks, and the extending root fans provide good habitat and hiding places for fish. Road access is not necessary, because the only equipment that is required is a back-hoe mounted on tracks and able to move in the stream channel itself. Finally, the natural appearance of the stream is maintained.

Based on the field reconnaissance conducted on the Putney Ditch channel, streambank stabilization on the section mentioned above is recommended. An extended meander in this section is eroding a high, steep bank on the right side of the valley (looking downstream). Stabilization using native materials, and restoration of the natural channel geometry in this area is recommended approach. Section 8 of this report provides further detail on this recommendation.

SECTION 5. SEDIMENT AND NUTRIENT CONTROL

Sedimentation and the associated increase in nutrient loading is the major problem that is currently effecting Little Barbee Lake. The Design component of this project focuses on removal of the majority of sediment that has built up over the years in the Putney Ditch channel and mouth. This will be a significant benefit to the lake both in terms of water quality and increased recreational use. However, as with any dredging project, the improvement will be short-lived without corresponding measures in the watershed. The following section is a discussion of the types of BMP's (agricultural practices designed to reduce erosion and nutrient loading) expected to have the greatest role in reducing nutrient concentrations and sediment inputs to the lake and to Putney Ditch. Section 5.1 focuses on erosion control techniques that will reduce both nutrient and sediment transport to streams. The techniques described are primarily aimed at reducing loading from agricultural areas, however urban erosion control is also discussed. Section 5.2 provides an overview of best management practices (BMPs) for nutrient reduction specific to agricultural areas. This section also includes recommended maintenance procedures for lawns adjacent to the lake. Section 5.3 discusses applicable in-lake restoration techniques. With the exception of dredging, in-lake restoration procedures are not recommended at this time. This section is intended to provide background information on these techniques to the Barbee Lakes Property Owners Association.

5.1 EROSION CONTROL

This section provides an overview of agricultural BMP's that have been developed for erosion control on cropland, pastures, and streambanks. Within the Putney Ditch watershed, erosion control is especially important on lands adjacent to or near Stonebruner-Putney Ditch. The AGNPS model showed high sediment yield along the entire length of this tributary.

Although not classified specifically as lake restoration techniques, erosion control practices maintain productivity on the land, reduce costs of fertilizers and pesticides, and ultimately benefit receiving streams and lakes. The Soil Conservation Service has published design criteria for a variety of BMP's, including those discussed below. This agency has and will continue to provide guidance to individual farmers and land owners in selection and implementation of BMP's. The following summary is drawn from a manual developed by the U.S. EPA, in conjunction with the North American Lake Management Society (NALMS), entitled The Lake and Reservoir Restoration Guidance Manual, published in 1988. Other sources of information include technical publications received through extension services and the SCS.

5.1.1 Agricultural Erosion Control

Conservation Tillage

Erosion in agricultural areas of the watershed can be significantly reduced by conservation tillage practices. The objective of this type of BMP is to protect soil from wind and water erosion by increasing the amount of crop residue. No till farming, where the topsoil is left essentially undisturbed year round, and minimum tillage are forms of this BMP. The effectiveness of these practices in reducing sediment loss and runoff is considered fair to excellent, depending on the degree of tillage reduction (USEPA, 1988). Phosphorus in runoff can be greatly reduced with conservation tillage, however nitrogen concentrations are largely unaffected. In fact, total nitrogen and herbicide concentrations may increase in groundwater as a result of no till practices, a potential negative side effect. Fertilizer management and integrated pesticide management should accompany conservation tillage practices.

Contour Farming/Stripcropping

Contour plowing and contour stripcropping are effective in reducing soil loss on farm land with a 2-8 percent, and 8-15 percent slope, respectively. Both practices require plowing along the natural contours. In stripcropping, grasses or other close growing crops are planted between row crops, such as corn or soybeans.

Streamside Management/Buffer Strips

Vegetation planted between a stream and plowed field (a buffer strip) is extremely effective in reducing both nutrient and sediment inputs, and in protecting riparian habitat. This is a very cost effective practice. Once established a buffer strip will maintain itself indefinitely. Parameters that determine the effectiveness of filter strips include filter width, slope, vegetation type, and application rate of fertilizers.

Other Erosion Control Practices

Management of pasture lands to prevent overgrazing, thereby reducing soil compaction and runoff, is important in an overall sedimentation control plan. Stream banks should be fenced to prevent access to cattle and destruction of soft banks. Crop rotation, terracing, and soil stabilization are also effective in reducing sediment inputs to streams.

5.1.2 Urban/Residential Erosion Control

Control of erosion due to development or construction activities must be a component of a watershed-wide approach to reduce future sedimentation in Little Barbee Lake. Factors that influence the type and amount of erosion include the nature and extent of vegetative cover, topography; and the frequency, and intensity of rainfall events.

Vegetative cover plays a critical role in controlling erosion by absorbing the impact of falling rain, holding soils together, increasing the retention capacity of soils, and slowing runoff velocity. Evapotranspiration by plant cover also aids in reducing erosion by removing water from soils between rainfall events.

Topographic characteristics (i.e., slope, size, and shape) of the drainage basin have a strong influence on the amount and rate of runoff. Changes to site topography resulting from development can have a significant impact on the quantity of runoff, and therefore sediment, that is generated.

The characteristics of surface and subsurface soils are fundamental to the resistance of soils to erosive forces, and to the nature of the sediment that results from erosion. Soils with high sand and silt content are normally the most highly erodible. Increasing organic and clay content result in decreased erodibility, however these soils are more easily transported.

In general, the following practices may be applied to control erosion due to land development activities within the Putney Ditch watershed. These practices are not presented in detail. An excellent source of further information specific to Indiana is the Hoosier Heartland Resource Conservation and Development Council's Urban Development and Planning Guide (HHRCDC, 1985). Another recently developed document is designed to provide Indiana Counties and local governments with a model erosion control ordinance (HERPICC, 1989). This document, entitled "A Model Ordinance for Erosion Control on Sites With Land Disturbing Activities" was developed by a task group composed of engineers, planners, university professors, SCS personnel, and County Commissioners from across the State of Indiana. HERPICC, the Highway Extension and Research Project for Indiana Counties and Cities, is a Purdue University Extension Service that administered the project. Copies of the ordinance may be obtained by writing HERPICC at:

Civil Engineering Building
Purdue University
West Lafayette, IN 47907
(800) 428-7639.

Phased Construction

Phasing construction activities minimizes the extent of land disrupted at one time, reducing the sediment load to a receiving stream or lake during a given storm event. If multiple structures are to be built over an extended period, the entire area slated for development may not have to be cleared at once.

Road Stabilization

Several practices are available to minimize erosion and sediment transport due to traffic in construction areas. These include stabilization of freshly graded road surfaces with gravel and installation of gravel pads at entrances to construction sites. The latter serve to reduce the amount of sediment carried off-site on tires of construction vehicles.

Sediment Barriers

Various types of barriers may be placed in the path of runoff to detain sediment and decrease flow velocities. These barriers, consisting of hay or geotextile filter fabric, are placed across or at the toe of slopes. Sediment barriers are also effective in protecting storm drain inlets from construction site runoff.

Sediment Traps and Basins

Temporary basins may be constructed to contain flows long enough for sediment to settle out. These basins are characteristically simple, often consisting of a small pond formed by an earthen dike, with a gravel lined outlet.

Establishment of Vegetative Cover

Planting of fast growing grasses and other plants provides a means for quickly stabilizing disturbed areas. The choice of plant type will depend on the intended permanency of the cover. Mulching with straw and other fibrous materials will aid in establishment of protective vegetation. This in itself will reduce erosion and runoff on disturbed areas.

For future developments in the watershed, an erosion and sediment control plan should be developed to address the potential problems resulting from the particular activity. The plan should clearly present the anticipated erosion and sedimentation problems that are likely to result, and the measures that will be taken to mitigate them. Both narrative and graphical sections should be included. The narrative section should include the following:

- Brief description of the project
- Existing conditions (physical features, slope, etc.)
- Description of adjacent areas that may be impacted
- Summary of soil characteristics
- Identification of problem areas (high slope, erodible soils, etc.)
- Erosion and sediment control measures to be used
- Description of post construction stabilization and practices, including measures to control storm water runoff
- Storm water runoff concerns and impacts
- Inspection and maintenance schedules planned
- Calculations used in design of basins, waterways, and other structural controls.

Graphical materials in the site plan should provide the necessary maps and related materials, including:

- Vicinity map showing site location
- Current elevation contours
- Existing vegetation types and locations
- Soils
- Critical erosion areas
- Existing drainage patterns
- Proposed contours after grading
- Limits of clearing and grading
- Location of erosion and sediment control practices
- Detailed drawings of structural practices to be used

The final plan should be subject to approval of a county or local planning board or similar group, and should provide comprehensive documentation of the erosion and sediment control strategies to be applied in the development of the site.

5.2 WATERSHED NUTRIENT REDUCTION

In addition to causing nuisance algae and other water quality problems in the lake, excessive nutrient loading can result in groundwater contamination and human health effects. Erosion control measures will decrease sediment bound nutrient loading, however a reduction in the transfer of soluble fractions of phosphorus, and particularly nitrogen must also be a management priority. Animal wastes and fertilizers are two key sources of soluble nutrients in the watershed. The section below focuses on BMP's designed specifically to reduce soluble inputs. Animal wastes from feedlots and confinement areas, application of animal manures as fertilizers, and commercial fertilizers themselves are primary sources of soluble nitrogen and phosphorus. BMP's for pasture management and stream protection are also described.

5.2.1 Animal Production and Keeping

The need for confinement of animals in feed lots or holding facilities, as opposed to open pastures, results in highly concentrated runoff. Summaries of several BMP's that have been designed to address problems associated with confinement areas on the following pages.

Roofing

On the average, the Putney Ditch watershed receives over three feet of rainfall per year. This means that for each acre of open confinement area, close to a million gallons of contaminated water are generated on an annual basis. Washdown water may equal this amount. Roofing confinement areas allows separation of clean runoff from contaminated slab runoff. Roof gutters and a water collection system greatly reduce the amount of water that must be treated.

Location

The amount of pollutants entering a stream decreases with distance from the source. The distance where zero pollution enters a waterway has been estimated to be 98 to 393 feet, depending on soil characteristics, grass type, and density of cover (Novotny and Chesters, 1981). Confinement areas should be built up and graded away from a ditch or stream. Animals should be fenced no closer than the top of the grade. The ditch slope should have a grass cover, and the runoff from the storage facility should be retained.

Washdown Water

BMP's for the use of washdown water focus on recycling and reduction in the quantity of water used. Substituting higher water pressure for volume and scraping manure prior to hosing minimizes water usage.

Manure Storage Lagoons

Farms with a limited capacity for liquid manure storage must frequently spread the lagoon contents on pasture land to prevent overflow. This often results in ponding of the liquid waste during periods when the ground is saturated, e.g., following snowmelt in the spring. Manure applied under these conditions is likely to flow off of the field and into a waterway. Installation of a solids separator ahead of the lagoon increases the capacity of the lagoon and lengthens the period between cleaning. In addition, odor problems are reduced.

5.2.2 Manure Application to Pastures

Although no data are available for the Putney Ditch watershed, it is probable that a large percentage of manure that is produced from animal production is returned to the land. There is general agreement that manure can and should be used in crop production to increase yields and fertility. However, water quality degradation will occur without proper management of manure application. Proper timing of application (i.e., during non-saturated conditions), application to land with minimal slope, addition of manure in quantities equal to crop requirements, and avoidance of soil compaction during the application process will minimize problems due to manure application.

5.2.3 Fertilizer Management

Application of fertilizers in quantities equal to crop needs will greatly reduce nutrient enrichment of aquatic resources due to agricultural operations. Reducing the loss of nutrients to the groundwater or air is dependent on proper soil testing, and establishment of realistic yield goals. Knowledge of the contribution that legumes, manure, and crop rotation make to soil nitrogen and phosphorus levels is critical to determining proper application rates.

Nitrogen

Over-application of nitrogen has been recognized as a significant problem in agricultural areas throughout the country. Although some degree of over-application is necessary given significantly less than 100% uptake efficiencies, current research on this problem points to a lack of consideration of alternative sources of nitrogen, such as manure or alfalfa, in calculating the quantity of fertilizer necessary for a given yield (Granatstein, 1988). Nitrate in soils in excess of crop requirements results in groundwater contamination, as well as increasing eutrophication of surface waters. Nitrogen "credits", i.e., a reduction in the amount of nitrogen necessary due to carryover from previous crops (legumes) or to crop rotation result in both cost benefits to farmers and improved water quality. Examples of nitrogen credits, in terms of pounds/acre N for previous legume crops, are shown in Table 17. This information is taken from material published in a University of Wisconsin Extension Bulletin (Granatstein, 1988). The Kosciusko

Table 17. Nitrogen credits for previous legume crops (from Granatstein, 1988).

CROP	N CREDIT
Forages	
Alfalfa	40 lb. N/ac. plus 1 lb. N/ac. for each percent legume in stand.
Red Clover	Use 80% of alfalfa credit.
Soybeans	1 lb. N/ac. for each bu/ac. of beans harvested up to a maximum credit of 40 lb. N/ac.
Green Manure Crops	
Sweet Clover	80-120 lb. N/ac.
Alfalfa	6-100 lb. N/ac.
Red Clover	50-80 lb. N/ac.
Vegetable Crops	
Peas, snapbeans, limabeans	10-20 lb. N/ac.

County SWCD District Conservationist, Sam St. Clair, can provide additional information on nitrogen management.

Phosphorus

Phosphorus is not as mobile a nutrient as nitrogen, and will tend to remain in the soil for longer periods of time. Erosion will reduce soil phosphorus levels, however in many cases, phosphorus levels will have built up over the years, and continued, or "maintenance applications", may not be economically justified (Granatstein, 1988). As with nitrogen, the rate of application of commercial phosphorus fertilizers can be reduced or even eliminated when fertility credits from manure are accounted for. A program of regular soil testing combined with maintenance of proper soil pH is essential to avoid over application of phosphorus.

Timing of application is also a key factor in reducing the quantity of fertilizers that reach ground or surface waters. In general, application in the fall results in significant runoff and loss during the non-growing season. Spring pre-plant application is recommended.

5.2.4 Septic Systems

Homes on septic systems within the watershed, and more importantly, on the lakeshore, may be a source of nutrients. No data were collected during the Feasibility Study that indicated this, however a detailed septic system survey was beyond the scope of the project. The following paragraphs offer general guidance on installation, use, and maintenance of septic systems.

Proper Location

The features governing appropriate placement of septic systems include proper soils and adequate buffer distances between the drain field and sensitive areas. Information is available from both the SCS and USGS concerning the suitability of various soils and geologies for drain field construction. These agencies should be consulted prior to installing any new system. The Indiana Department of Environmental Management should also be contacted to determine the most recent limitations concerning minimum distance of the drain field from drinking supplies, lakes, drainage ditches, etc.

Regular Inspection and Maintenance

A septic tank should be inspected at least once per year to assess the rate of solids accumulation. If these materials build up, they will be transferred with the waste to the drain field, resulting in clogged soil pores. This condition results in a reduction of permeability, and eventually construction of a new drain field. Septic system maintenance should involve inspection of "Tee-joints" and distribution boxes, since these parts are especially prone to shifting that can lead to uneven dispersal of waste water into the drain field. Material removed from the tank should be discharged at a treatment plant. Periodic inspection and pumping will avoid this expense.

Drain Field Protection

Trees should not be allowed to grow on top of the drain field. Tree roots can penetrate the field, diminishing its efficiency. Vehicular traffic should also be prevented, since this will cause compaction of the leach field soils.

Proper Use

Solids, greases, or toxic materials should not be disposed of in septic systems. Solids, such as paper towels and disposable diapers, add to the overall load of the system, decreasing efficiency and increasing maintenance costs. Fats, oils, and greases can solidify in the system and create blockages. Toxic materials (e.g., paints, motor oil, pesticides) are not decomposed by septic systems and can leach out into groundwater, contaminating wells and eventually reaching lakes and streams. In addition, these materials can kill the beneficial bacteria responsible for decomposing normal septic system wastes.

Additives

Authorities agree that under most circumstances, chemical and biological additives are not needed to accelerate decomposition in the septic field. Under extreme use situations however, these additives may be helpful. Caution must be observed when using these products since some additives will actually inhibit decomposition. Products containing more than one percent of the following chemicals should not be used:

- **Halogenated hydrocarbons:** trichloroethane, trichloroethylene, methylene chloride, halogenated benzenes, carbon tetrachloride;

- **Aromatic hydrocarbons:** benzene, toluene, naphthalene;

- **Phenol derivatives:** trichlorophenol, pentachlorophenol, acrolein, acrylonitrile, benzidine.

A good reference with information on septic system design and maintenance is found in Perkins (1989).

5.2.5 Park and Lawn Maintenance

The following paragraphs provide a summary of maintenance procedures to reduce nutrient inputs to Little Barbee Lake from surrounding lawns and park area. The following "common sense" procedures will minimize nutrient concentration in runoff from these areas.

Grass and Leaves

Grass clippings should be allowed to remain on the lawn following mowing unless excessive thatch build-up occurs. This will reduce the need for artificial nutrients. In addition, this will have a beneficial effect on the nationwide waste disposal problem, as bagged grass or leaves comprise 15-20% of all substances placed in landfills (Hugo, 1990). Raked leaves should not be disposed in or near the lake or its tributaries. Instead, they should be bagged and transported to a compost area away from any water flow path. If a compost area is used, runoff should not be allowed to reach the lake or tributaries.

Trash Receptacles

The number of trash cans and dumpsters should be sufficient to handle all trash deposited between collections. The containers should be cleaned with plain water directed from a spray nozzle. Disinfectants should be used sparingly and not allowed to drain onto the ground. Rinse water containing disinfectant must be properly disposed of.

Holes should not be drilled in the bottom of trash barrels to afford better drainage. Water percolating through these containers is high in nutrient and bacterial content, and should be avoided. Trash cans should be covered and not left open. Spring-loaded lids are recommended, and open topped drums should be avoided. Rusty receptacles should be replaced promptly. Trash cans should be placed as far as possible from the lake.

Fertilizers and Chemicals

Application of fertilizers should be avoided or minimized. These products will enhance the growth of algae and macrophytes in the lake if they are present in runoff. Application of other chemicals, such as pesticides and herbicides, should be carefully controlled and avoided if possible. Alternatives to chemical treatment should be investigated.

Automobile Traffic

The exhaust from internal combustion engines is high in metal, hydrocarbon, and nutrient content. So called "tailpipe drippings" are a major source of nutrients in urban watersheds. Drains and waterways along roads and parking lots should be situated so as not to channel runoff directly into the lake or its tributaries. Ideally, stormwater runoff should be routed to a treatment facility (or holding pond). If this is not feasible, runoff should be routed across large, vegetated areas prior to being allowed to enter the lake or its tributaries.

Education Centers

Recreational users of Little Barbee Lake should be educated on issues surrounding the lake and its care. Broad-based nature exhibits or storyboards on specific problems, such as why fisherman should not clean their catch in or near the lake (entrails can lead to elevated bacteria counts and reduction in dissolved oxygen) would promote understanding of water quality issues. These types of exhibits could be placed at the public access sites to the Barbee Lakes.

5.3 IN-LAKE RESTORATION

The problems identified in Little Barbee Lake stem from both nutrient enrichment and sedimentation. Although nutrients may be contributed as a result of near-shore activities, watershed inputs largely determine both in-lake nutrient concentrations and sedimentation rates. As stated earlier, implementation of the BMP's previously described is considered the most effective strategy to restore the lake. The treatment of problems similar to those experienced in Little Barbee Lake through in-lake techniques has been successful, however in most cases the lakes are smaller or have longer retention times (Cook et al., 1986). However, the results of this study do not point to the need for in-lake measures at this time. Moreover, in-lake techniques, particularly those designed specifically to reduce nutrient concentrations, would be short-lived without corresponding measures in the watershed. These practices, such as no-till farming and animal waste management, will go farthest and be the most cost-effective solutions to long-term improvement in water quality. A combination of watershed BMPs and stream stabilization should be the primary tools to reduce sediment and nutrient levels in Little Barbee Lake.

Recognizing that there may be a need in the future to consider in-lake techniques, the following section describes four treatment methods that are routinely used in lakes and reservoirs across the country. This information is presented for background purposes only.

5.3.1 Aquatic Plant Harvesting

A reduction in internal nutrient loading is an indirect benefit of aquatic plant harvesting. The direct benefits relate primarily to increased recreational use of the lake. However, nutrient removal and protection of the pelagic zone from nutrients released during macrophyte decay may also result from harvesting. If nutrient income is low to moderate and weed density is high, as much as 50 percent of the net annual phosphorus loading could be removed through intensive harvesting (USEPA, 1988). Mechanical harvesting, however, is energy and labor intensive. Additionally, plants may fragment and spread the infestation. It is recommended that floating barrier systems be utilized during harvesting to curtail the spread of buoyant plant fragments, and aid in their collection.

The objective of aquatic plant harvesting is to cut and remove nuisance growths of rooted aquatic plants and associated filamentous algae. The most common means of harvesting is accomplished through the use of a mechanical weed harvester; a maneuverable, low-draft barge designed with one horizontal and two vertical cutter bars, a conveyor to remove cut plants to a holding area on the machine, and another conveyor to rapidly unload plants. Harvesters vary in size and storage capacity, with cutting rates ranging from about 0.2 to 0.6 acres per hour depending on the size of the machine. Disposal of the cut materials is usually not a problem. Because aquatic plants are more than 90 percent water, their dry bulk is comparatively small. Additionally, farmers and lakeshore residents will often use the cut weeds as mulch and fertilizer.

Most harvesting operations are effective at producing a temporary relief from nuisance plants, and in removing organic matter and nutrients. In some cases, however, plant regrowth can be very rapid (days or weeks). Conyers and Cooke (1983) and Cooke and Carlson (1986) found that a slower method of lowering the cutter blade approximately one inch into the soft sediments would produce a season-long control of milfoil by tearing out the plant roots (USEPA, 1988). This harvesting method is only effective when sediments are soft and the length of the cutter bar (usually 5 - 6 ft.) can reach into the mud.

Contracted harvesting costs in the Midwest range from $135 to $300 per acre. Unless there are large areas in need of harvesting on a regular basis, contract harvesting, as opposed to purchase of a harvester, is usually the most cost effective method. The cost of a machine with a five foot capacity (capable of harvesting a five foot swath) ranges from $35,000 to $50,000. Labor, fuel, insurance, disposal charges, and machinery downtime must also be factored into the total annual costs of a harvesting program (USEPA, 1988).

5.3.2 Artificial Circulation

Artificial circulation is a lake restoration technique that is designed to eliminate thermal stratification and density barriers by increasing circulation within the lake. This results in oxygenation of bottom waters, improved fisheries habitat, and, in theory, a reduction in nutrient availability by oxidizing formerly anoxic lake sediments. Cowell et al. (1987) evaluated this technique on a Florida lake using a multiple inversion aeration system. Significant reductions in turbidity, pH, alkalinity, total nitrogen, hydrogen sulfide, and iron were found in this study. Secchi disk transparency also increased significantly. This method has also been shown to control blue green algae blooms by shifting the algal community from blue-green dominated to the more desirable green algae dominated. Blue green algae are more buoyant, and thus have a competitive advantage over green algae during stratified conditions (Lorenzen, 1977). Rapid vertical mixing of the water column reduces this advantage. A marked reduction in blue green algae, and a 70% increase in the number of green algae species was demonstrated in the Florida lake mentioned above (Cowell et al., 1987). However, the results of Cowell's study are for a soft water lake, and not directly comparable to the moderate to high alkalinities typical of midwestern lakes. A direct benefit to fisheries in terms of improved habitat quality, and extended habitat area would be the only result that could confidently be expected if such a system were installed in Little Barbee Lake. Although some degree of reduction in internal nutrient release could be expected, the large watershed to lake area ratio would limit the effectiveness of such a system for this objective. Proper sizing of an aeration system, i.e., adequate air flow to completely destratify the lake, is critical to the success of this method.

In practice, an aeration system employs porous ceramic diffusers, similar to large scale aquarium air stones, or perforated plastic pipe to transfer pumped air from the surface to the lake bottom. Reaeration is accomplished through direct transfer within the water column, and, to a greater extent, by the forced movement of bottom waters to the lake surface. A commercially installed aeration system for Little Barbee Lake may cost upwards of $100,000. However, the equipment can usually be purchased and self-installed for less than 50% of the commercial cost.

5.3.3 Phosphorus Precipitation/Inactivation

The terms phosphorus precipitation or inactivation refer to the removal of phosphorus from the water column (precipitation) or the reduction of phosphorus release from the lake sediments (inactivation). These two in-lake restoration techniques both involve the use of aluminum sulfate (alum) to chemically bind and remove phosphorus. The two techniques differ only in the dose applied. In phosphorus precipitation, the aluminum sulfate is added in a quantity sufficient to remove only the phosphorus present in the water column. The alum quickly becomes aluminum hydroxide, which adsorbs and essentially sweeps the water clean of phosphorus. If the alum is added in a sufficiently large dose, inactivation of phosphorus in the sediments of the lake occurs in addition to phosphorus precipitation. The aluminum hydroxide that settles on the bottom of the lake forms a barrier that greatly reduces the transport of phosphorus to the overlying water. This level of treatment has been shown to be highly effective in reducing the water column phosphorus concentration for long periods of time, reducing the phosphorus content of groundwater seeping into the lake, and in bringing about a measurable and lasting improvement in trophic state.

As pointed out in the majority of the literature available on this treatment method, alum treatment should not be conducted unless it is preceded by efforts to reduce phosphorus inputs from the watershed. Estimates in the literature of the period of effectiveness for this treatment, assuming that the dose is sufficient to neutralize the sediments, range from five to 10 years for a single application.

The negative effects of an alum application relate chiefly to the potential toxicity of dissolved aluminum, which is toxic to fish. However, this problem only occurs if the alkalinity in the lake is insufficient to buffer the effects of the alum, which is acidic due to the sulfate ion. Low initial alkalinity that is further reduced by the alum can result in a drop in pH. Dissolved aluminum is present (and therefore toxic) below a pH of 6.0, and becomes the dominant form of aluminum at a pH 5.5 to 5.0. At a pH greater than this (pH 6 to 8) studies have shown that deleterious effects of alum treatment are minimal and short-lived. Documented adverse effects of the treatment include a reduction in species diversity of plankton in treated lakes, and, in laboratory tests, mortality of Chironomid insect larvae. The reduction in species diversity occurred in West Twin Lake, Ohio, and was attributed to the physical effects of the floc that settled on the lake bottom, the change in species diversity from blue-green to green algae, and the increased clarity of the water which may have increased predation on zooplankton by fish (Cook et al., 1986). The laboratory tests that showed mortality of Chironomidae were chronic tests, i.e., conducted over a long period of time. These tests showed that a typically applied dose of alum can cause mortality in a common lake insect larvae in a laboratory situation. The researchers pointed out that in-lake conditions might mitigate the observed effects. Another study of four alum treated lakes in Wisconsin showed no damage to invertebrate populations during several years of monitoring (Cook et al., 1986).

The increased clarity of the water following alum treatment often results in increased plant growth, another potential negative factor. However, this is usually a manageable problem, and may act to improve fish habitat in lakes where frequent algal blooms have kept macrophyte growth to a minimum.

The most common recommendation to managers regarding application of alum is to closely monitor pH during the treatment process, and to cease the treatment if the pH falls below 6.0. For Lake of the Woods, it is anticipated that the alkalinity would be more than sufficient to maintain a pH greater than 6.0 during and following an alum application. Alkalinities reported in the 1982 study ranged from 140 to 165 mg/L $CaCO_3$. However, for proper dose determination, alkalinities in each major strata of the lake, e.g., the 15 to 20 foot contour interval, should be determined prior to the application. In practice, the lake is divided in into several zones, based on depth, and the dose corresponding to the alkalinity of the particular zone is then applied.

The simplest method of alum application is to apply a dry form over the back of a moving boat. However, a slurried form has major advantages, the greatest being more rapid dissolution. This form of alum requires either an on-board pump to slurry the dry alum with lake water, or a specially made barge designed to load and apply liquid alum directly. The later is the most efficient method of treatment.

The success of an alum treatment is defined by decreased algal standing crop (commonly measured by Chla) and a decreased phosphorus concentration following treatment. A monitoring program during and immediately following the application is essential to gage the response of the lake and to provide the data necessary to interpret the changes in water quality.

Costs of alum application are largely dependent on labor costs and method of application. Discussion of costs and dose determination with Sweetwater Consultants, a Pennsylvania based firm specializing in alum application, indicates that for lakes with alkalinities in the range of 150 mg/L $CaCO_3$ (the expected alkalinity for Little Barbee Lake), a quantity of 500 gallons of slurried aluminum sulfate should be applied per surface acre of the lake to be treated. Most applications treat the area (volume) from 10 feet to the lake bottom. However, assuming that the entire 74 acres of Little Barbee Lake was to be treated, a quantity of 37,000 gallons of slurried alum would be required. Sweetwater's estimate of the application costs, including the cost of the alum itself, ranges from \$0.80 to \$1.00 per gallon, for a total cost of \$29,600 to \$37,000.

For further information on firms experienced in alum application, and general information on lake management and restoration, the Little Barbee Lake Property Owners Association is encouraged to contact and join the North American Lake Management Society (NALMS). This organization is a nationwide non-profit group dedicated to effective lake management, and can be reached at the following address:

NALMS
c/o University of Florida
Research and Technology Park
One Progress Blvd., Box 27
Alachua, FL 32615
(904) 462-2554

The EPA Lake and Reservoir Restoration Guidance Manual (1990), Monitoring Lake and Reservoir Restoration (1990), and Cook et al. (1986), are excellent sources of information on alum treatment. The latter reference is the most thorough source, and includes detailed information on dose determination.

5.3.4 Dredging

In the absence of widespread watershed controls, i.e., agricultural practices designed to reduce erosion in the watershed, dredging of the mouths of inlet streams or canals is sometimes necessary. However, the costs of dredging are often prohibitive, and the technique itself seldom receives financial assistance under state or federal projects because it is a short-term treatment, and does not address the sedimentation problem at the source, i.e., erosion from upland areas. In most cases, dredging is limited to the stream channel and the portion of the inlet in the immediate vicinity. The only real advantage of dredging is improved access and greater depth, however a reduction in the rate of nutrient release from the sediments may be a secondary benefit. The disadvantages of dredging in most cases outweigh the benefits. In addition to the high cost, there is the requirement for separate disposal areas, excessive turbidity in the immediate vicinity, and the probable need to redredge the same area within several years if upland controls are not implemented.

In general, there are two types of dredging commonly used on freshwater lakes: mechanical and hydraulic dredging. Mechanical dredges consist of a dragline or backhoe operated from shore or from a barge platform. The shore based operation is most common, however maneuverability s much greater if the dredge is operated on a barge. Dump trucks are necessary to offload the dredged material for either shore based or barge based mechanical dredging. For the latter, a second barge is necessary to hold the dredge material prior to transfer to a truck for disposal. The primary advantage of mechanical dredging is the high solids content of the dredge material. Disadvantages include excessive turbidity at the dredge site and a relatively slow rate of removal. Costs of mechanical dredging are approximately $5.00 per cubic yard, assuming a relatively short hauling distance, good access to the site for heavy equipment, and no disposal costs, e.g., landfill costs.

Hydraulic dredges are the most common machines used in 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 sediment, the loosened material is sucked into the pipe in the form of a slurry. The slurry pipe extends from the barge to a disposal site, where a settling basin is required to dewater the material. The advantages of hydraulic dredging include relatively high removal rates, high cost efficiencies, and minimum impact on the shoreline. Disadvantages include the need for containment basins for dewatering the dredge material. The latter will often require that several acres of land near the dredge site be utilized for a period of one to two years. Relatively high turbidity, and the need for a suitable pipeline route from the lake to the dewatering basin are also potential problems. Maximum pumping distance with this technique is approximately one mile. Greater distance is possible, however in-line pumps are required which greatly increase the cost of the operation. Costs of hydraulic dredging range between $2.00 to $3.00 per cubic yard of material removed. This does not include construction of sedimentation basins.

Based on the above mentioned costs for hydraulic dredging, the cost of dredging approximately 5,000 cubic yards from the Putney Ditch mouth would be approximately $15,000.00. This is the quantity of material calculated for removal during this Feasibility Study. The cost of construction of a containment basin to dewater (dry) the sediments would be approximately equal to the dredging costs, which would result in a total project cost of $30,000 to $40,000.

SECTION 6. LONG-TERM MONITORING

A long-term water quality and sediment monitoring program would provide a basis for detecting changes in the water quality of Little Barbee Lake. The objective of such a program would be to assess the condition of the lake, over time, and draw conclusions regarding future changes that may be observed. Additionally, if a decline in water quality should occur, and the causes are not immediately evident, the data collected under this program would provide the level of detail required for a professional lake manager to analyze the situation.

A monitoring program could be implemented for Little Barbee Lake utilizing volunteers from both the Barbee Lakes Property Owners Association as well as land owners in the watershed. A similar volunteer program is currently underway at Shipshewana Lake in LaGrange County, Indiana. This section describes the basic components of a monitoring program that could be conducted by volunteers, with assistance from a local analytical laboratory. The program is described in two parts: data collection and data interpretation.

6.1 DATA COLLECTION

The core of the monitoring program would be the routine collection of water quality and sediment depth measurements. The collection of storm flow samples from the tributaries to the lake is also recommended, however, this would be a more difficult task given the unpredictability of sampling frequency.

6.1.1 Lake Water Quality

Water quality monitoring should include both in-situ measurements and laboratory analyses of water samples. In-lake measurements and samples should be collected from a single station at the deepest location in the lake. These measurements should be collected on a regular basis, such as the first Monday of each month, and at approximately the same time of day (i.e., early afternoon). In-situ measurements should include Secchi disk transparency, and temperature and dissolved oxygen profiles. The instrumentation required for these measurements may be purchased for between $850 and $1,000.

Water quality samples should be collected at the surface, mid-depth and approximately one foot above the bottom of the lake. Samples should be analyzed for total phosphorus, total nitrogen and chlorophyll a. A suitable Van Dorn-type water sampler may be purchased for approximately $400. Analytical costs will be dependent on the laboratory used; however, given the similarity in costs among most analytical laboratories, the level of quality assurance that the lab uses should be the determining factor in deciding which laboratory to use. The recommended detection limits, and methods of analyses for lake samples are shown in Table 18. Although the lab need not necessarily be involved in the U.S. EPA Contract Laboratory Program (CLP), it should be able to provide a level of quality assurance and quality control

Table 18. Water quality parameters and analytical requirements for lake samples.

Parameter	Detection Limit	Method No. EPA	SM[1]
Total Phosphorus	0.010 mg/L	365.1	424F
Dissolved Reactive Phosphorus	0.010 mg/L	365.1	424F
Ammonia Nitrogen	0.020 mg/L	350.3	
Nitrite+Nitrate Nitrogen	0.050 mg/L	353.3	
Total Kjeldahl Nitrogen	0.050 mg/L	351.2	420B
Total Suspended Solids	1.000 mg/L	160.2	209C
Chlorophyll a	0.100 mg/L		1002G

Chlorophyll a analyses to be corrected for pheophytin.

[1] APHA - *Standard Methods for the Examination of Water and Wastewater*

that meets CLP guidelines.

6.1.2 Tributary Storm Samples

Because sediment and nutrient loading is the primary issue of concern, a basic program of tributary storm sampling is recommended. In sampling storm runoff there is a compromise between the ideal, which would involve flow-weighted samples collected throughout each storm hydrograph, and the practical constraints of limited funds to support the program. Flow-weighted sampling is very expensive, requiring sophisticated automatic monitoring and control packages, and substantial labor to maintain the equipment. In contrast, grab samples may be collected manually and only require some sort of sampling container. The disadvantage of grab samples is that they only represent a single moment in the storm hydrograph, and pollutant concentrations are known to vary significantly throughout the duration of a storm. However, the consistent collection of many grab samples over a period of time can provide a basis for comparison among tributaries and detection of large changes in loading though time.

Collection of storm flow samples should be at, or just before the peak flow. The storm event sample should be collected from the Putney Ditch mouth (about 100 feet upstream of the lake). Additional sampling stations may be necessary to determine the impact of local disturbances, such as construction activities; or downstream of point sources, such as feedlots or suspect tile drains. At a minimum, the storm samples should be analyzed for total suspended solids, total phosphorus and total nitrogen.

6.1.3 Sediment Accumulation

To monitor the success of the restoration measures outlined in this study, i.e., the stream stabilization and watershed BMPs, water depths in the vicinity of the Putney Ditch mouth should be measured on a quarterly basis following the dredging project. This can be accomplished very inexpensively using a graduated pole with a wide base, such as a coffee can lid, to ensure that measurements are made at the top of the sediment layer. For deeper areas, a calibrated line (preferably a chain) can be slowly dropped from a boat to the lake bottom.

Sediment monitoring stations should be established on a transect (an imaginary line) running down the sea-walled portion of the channel to a point about 200 feet into the lake. The measurements should be made at 50 foot intervals (starting at the downstream-most bridge over the ditch). Initially, the stations should be located using surveyor's instruments, so that subsequent measurements are taken at the same location each time. Lake surface elevation should be recorded for each round of station measurements to ensure that all measurements are referenced to a common horizontal datum. The Kosciusko County Surveyor may be able to assist the Barbee Lakes Property Owners Association in establishing the sediment monitoring program.

6.2 DATA MANAGEMENT

A single individual, or small group of individuals, should be responsible for all data collection and records maintenance to ensure that the monitoring is conducted reliably and consistently. Consistency of technique and analytical methods is essential to minimize random variability in the data and maximize the value of the collected information in detecting changes over time.

Standardized data forms should be developed and used for all field measurements and sample collection. The forms should be simple, but complete, and as easy to use in the field as possible. Both the in-situ data, and the results from the analytical laboratory should be entered into a PC-based database. There are numerous software packages available that provide the necessary features for ease of maintenance, statistical analyses, and graphics.

6.3 DATA INTERPRETATION

The monthly data generated by this program will provide a general characterization of Little Barbee Lake. There are some simple methods for presenting the data that will allow local lake managers to utilize the data and draw some basic conclusions.

Graphic plots of the water quality and sediment data should be maintained as a basic interpretive tool. Water quality time-series data plots can be used to visually detect seasonal trends, long-term trends, and differences in extreme values between years. Fitting a simple linear regression through time-series data will often allow the detection of a long-term increase or decrease in a measured parameter (i.e., Secchi disk transparency or depth to sediment). Such a trend would be revealed by a regression slope that is statistically significantly different from zero.

Water quality parameters may be evaluated in terms of annual statistics. A simple example would be the examination of the average annual Secchi disk transparency along with the range of transparencies observed during the year. A trend of decreasing annual means and minimum transparencies would suggest that either suspended sediment or algae concentrations are increasing. Additionally, the Carlson trophic state index (TSI) could be applied to the monthly water quality data collected on the lake. A more representative trophic state assessment could be obtained by examination of the TSI values observed over a period of time. A good limnological text, such as Wetzel (1983) will provide more detailed interpretive guidance than can be provided within the scope of this investigation.

SECTION 7. SUMMARY

Based on the results of the watershed analyses, lake and tributary sampling, and visual observations, the following is a summary of the adverse impacts to Little Barbee Lake that relate to sedimentation and nutrient enrichment:

- Nutrients from upland sources within the Putney Ditch watershed have resulted in accelerated eutrophication of Little Barbee Lake. Conditions are not expected to improve until BMPs are widely implemented in the watershed.

- Total nutrient concentrations in water samples collected near the bottom of the lake were very high, suggesting that nutrient release from the sediments could be significant.

- Areas adjacent to the main branch of Putney Ditch should be priorities for the Lake Enhancement Program's Land Treatment Program. Sediment yield from AGNPS cells near this tributary was high.

- An area along Putney Ditch approximately 500 feet downstream of McKenna Road was very unstable, and is a current source of sediment to Little Barbee Lake. Stabilization of this section of the channel is recommended.

- Storm samples collected at the mouth of Putney Ditch had very high total phosphorus levels. This may be attributed to a combination of watershed inputs and the contribution of nutrients from the sediments in this area.

- The BonHomme Eutrophication Index value for Little Barbee Lake (59) was higher than three other Kosciusko County Lakes sampled by IS&T on the same day in August, 1989. (Ridinger, Winona, and Pike Lakes). The EI for Ridinger Lake was 42, for Winona Lake 48, and for Pike Lake 40. Greater water column nutrient concentrations, abundance of blue-green algae, and the larger number of algal cells counted were the major factors in the higher EI value.

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SECTION 8. RECOMMENDATIONS

The results of this study indicate that water quality problems in Little Barbee Lake stem from sediment and associated nutrient inputs from the watershed. The planned dredging of the Putney Ditch channel and mouth will immediately improve access to the lake, and will reduce nutrient inputs from sediments in this area. The cost effectiveness of the dredging operation will be greatly increased if best management practices are implemented on priority areas; those lands that are near Putney Ditch or its tributaries. The AGNPS model data set developed during this study can be used to further evaluate problem areas. In addition, it can be used test the effectiveness of best management practices by hypothetically altering current land use characteristics, re-running the model, and then evaluating changes in nutrient and/or sediment concentrations downstream.

The recommendations for improvement of this resource center on reduction of non-point source pollutants (sediment and nutrients) from the watershed. Effective waste water management is also of critical importance. This applies to both septic systems and feedlot point sources. In order of importance to water quality in Little Barbee Lake, a brief outline of management strategies is presented below:

8.1 UPLAND BEST MANAGEMENT PRACTICES

- Encourage the use of agricultural BMPs, e.g., conservation tillage, contour farming, buffer strips, and animal waste management. The SCS and SWCD representatives are a valuable source of information and assistance.

- Implement effective erosion control in residential areas and at construction sites. This can be accomplished with city and/or county ordinances.

- Enact and enforce appropriate zoning and development planning regulations for controlling the production of off-site pollutants.

- Encourage measures to reduce the inputs of lawn fertilizers and other pollutants from properties adjacent to the lake.

- Wetlands in the Little Barbee Lake watershed are a critical resource, and every effort should be made to preserve them. For landowners wishing to restore drained wetland areas, a U.S. Fish and Wildlife Service (USFWS) Program now provides funds and technical resources for wetland restoration. The USFWS office in Bloomington coordinates this program, however the Kosciusko County District Conservationist, Sam St. Clair, is familiar with the program's requirements and has worked with the USFWS on wetland restoration projects in the county.

The long-term benefit of the planned dredging project on the Putney Ditch channel and mouth, and the Putney Ditch stabilization project, will be enhanced by efforts to implement BMPs in the watershed. The Barbee Lakes Property Owners Association is encouraged to pursue funding for upland controls through the Lake Enhancement Program's Lake Watershed Land Treatment Program (LWLTP). This component of the LEP provides cost share assistance to land users for applying practices that reduce inputs of sediment and nutrients from agricultural sources. Applications for funding under this program are submitted by the local Soil and Water Conservation District for a given project area, e.g., the Putney Ditch watershed, as opposed to a specific practice.

Application of upland BMPs through the LWLTP will be complemented by a Soil Conservation Service project recently started in the Northern Tippecanoe River watershed. The objective of this project is to accelerate implementation of BMP's through increased education and technical assistance to land users.

Problems resulting in nutrient enrichment are much more effectively treated at their source. During the next few years, the effectiveness of upland BMPs should be assessed through a volunteer monitoring program.

8.2 IN-LAKE TECHNIQUES

In-lake restoration techniques are not recommended at this time. However, if the degree of BMP implementation is not sufficient to effect an improvement in water quality over a period of time (e.g., three to four years), in-lake techniques can be used to accelerate improvement in lake water quality. These measures are aimed at improvement in existing conditions within a short period of time, e.g., a single growing season. However, the potential effects of runoff from activities higher in the Barbee Lake chain on water quality in Little Barbee Lake limits the available in-lake options. Weed harvesting and lake aeration are two management tools that would confidently be expected to benefit the lake despite contributions of nutrients and runoff from lakes higher in the Barbee chain.

Harvesting of aquatic plants that are causing navigational and recreational problems should be on an as-needed basis. The objective should not be to eradicate the plants, because a well established aquatic plant community will reduce water column nutrients and thus limit the growth of phytoplankton. In addition, they provide valuable fisheries habitat and act to filter nutrients at tributary mouths.

Discussion with area fisheries biologists and environmental professionals is recommended if the Barbee Lakes Homeowners Association is considering an aeration system. Aeration should be viewed primarily as a method to improve fisheries habitat, and, potentially, to reduce internal nutrient loading to the lake. As mentioned in Section 5.3.2, proper sizing of the aeration system is critical to the success of this technique.

8.3 STREAMBANK STABILIZATION

As discussed in Section 4.2.5, streambank stabilization is recommended for a steep, eroding section of the Putney Ditch streambank, approximately 500 feet downstream of McKenna Road. The material provided in the Design Study Project Manual - Putney Ditch Stream Stabilization, contains details of the existing condition of the channel in this area, and the same area following the proposed stabilization project. These drawings and the associated bid documents are provided separately to allow the Barbee Lakes Property Owners Association to solicit separate bids for construction of the native material revetments that are recommended, as opposed to a contract that would combine the proposed dredging and stabilization projects.

The recommendation to stabilize the Putney Ditch streambank was made with full consideration of other measures that would also be expected to reduce the Putney Ditch sediment load, and ultimately the quantity of sediment and associated nutrients reaching the lake. In particular, a sedimentation basin just upstream of McKenna Road was considered. This was a measure that was discussed early in the project, and although IS&T and design engineers from ETA, Inc. initially supported this as a viable solution, further analysis led to the conclusion that a sedimentation basin would not be the best approach, both technically and financially, to the sedimentation problem. An analysis of bank stability and sediment transport capacity that was conducted by Mr. James R. Gracie of Brightwater Consultants was a key component of the watershed survey, and led all of the technical personnel involved in the project to re-evaluate the sedimentation basin approach and focus instead on restoring bank stability, thereby reducing the sediment load due to continual and increasing erosion of the banks downstream of McKenna Road.

The drawings and specifications contained in the Bid Package were also products of the bank stability analysis mentioned above, conducted by Brightwater Consultants. Due to the past experience of this firm in the use of native materials for streambank stabilization, and the first-hand knowledge of the proposed project, IS&T recommends that Brightwater Consultants or a firm similarly qualified in the use of native materials for streambank stabilization be involved as Inspector for the Putney Ditch stabilization project. Although the use of native materials is becoming more widely employed, only a few construction firms in the country have experience with this technique. Use of a firm with this type of experience would ensure that the drawings are interpreted correctly, and that construction would be properly supervised.

8.4 FUTURE ACTION

At the present time, the recommended course of action is to proceed with the dredging and streambank stabilization projects as soon as possible. The Barbee Lakes Property Owners Association should allow adequate time to evaluate the success of these projects and upland controls as they are implemented, prior to expending additional funds. A significant improvement in the quality of Little Barbee Lake is a high probability as a result of these projects, and through the assistance now possible to landowners via the LEP land treatment program, the SCS Tippecanoe Project, and the general increase in knowledge concerning BMPs brought about by these programs.

SECTION 9. PERMITS

Prior to initiating any lake restoration project, the BLPOA is strongly encouraged to discuss the planned project(s) with the State and Federal agencies responsible for permitting these types of projects. The U.S. Army Corps of Engineers, Louisville District, is responsible for administering Section 404 of the Clean Water Act, which governs all activities that involve the discharge of dredged or fill material to waters of the United States. Any project involving dredging, filling, shoreline or streambank stabilization, or other work near or in any lake or waterway requires evaluation by the Corps to determine whether an individual Section 404 Permit will be required, or whether the proposed project falls under an existing permit, called a Nationwide Permit. The latter does not result in public notice of the proposed project. For an individual Section 404 permit, the Corps distributes a public notice of the of the proposed activity to all affected landowners, after which there is a 30 day period for public comment on the project. Plans and descriptions of the project must accompany a Section 404 Permit Application. For Section 404 permit inquiries and requests, information can be obtained from the Louisville District Corps at the following address:

Mrs. Pat Rucker
U.S. Army Corps of Engineers
Operations and Readiness Division
P.O. Box 59
Louisville, Kentucky 40201
(502) 582-5607.

On receipt of a permit application, the Corps notifies the Indiana Department of Environmental Management (IDEM) of the proposed project, and of their action on the permit request. Granting of a Section 404 Permit is dependent on the issuance of an IDEM Section 401 Water Quality Certification, an authorization to proceed with the project. In most cases, a Water Quality Certification need not be applied for separately, however discussion with IDEM indicates that for a project involving return of water to a lake from an upland sedimentation basin, a Water Quality Certification is necessary despite the fact that the project falls under a Corps of Engineers Nationwide Permit, which does not require an application. A Water Quality Certification can be obtained from IDEM if their review of the permit application, maps, plans, and other pertinent information is satisfactory. A period of two months is usually required for the review process.

For projects on public, natural lakes in Indiana that involve excavating, filling in, or otherwise changing the lake area or depth, a State of Indiana Department of Natural Resources permit is required. This permit application (Form 43008, Permit Application for Construction In or On a Public Freshwater Lake or Lake Michigan), can be obtained by contacting IDNR at the following address:

IDNR Division of Water

2475 Directors Row
Indianapolis, IN 46241
(317) 232-5661.

Plans and a description of the project should accompany the permit application. Discussion with Brian Balsley, IDNR Division of Water, indicates that permit review takes approximately 60 days.

For streambank stabilization work on Putney Ditch, an individual Section 404 Permit may be required. Excavation and replacement of bank material, as opposed to removal of the material to an upland site, may be grounds for requiring a separate 404 Permit. The Louisville District Corps will need to carefully review the plans for streambank stabilization. An IDNR Construction in a Floodway Permit, obtained from the Division of Water at the above address, will be required for work involving streambank stabilization on Putney Ditch. In addition to this permit, a "Permit Application for Ditch Projects" may also be required. This is an IDNR permit that applies to work on a ditch or drain having a bottom depth lower than the normal water level of a freshwater lake of 10 acres or more and within one-half mile of the lake.

In addition to contacting the State and Federal agencies mentioned above, the BLPOA should also contact the Kosciusko County Surveyor, Mr. Richard Kemper, to ensure that he is fully informed of any activity planned or proposed on a regulated drain, e.g., Putney Ditch. Mr. Kemper can be contacted at the following address:

Kosciusko County Surveyor
Room 25, First Floor
Courthouse
100 West Center Street
Warsaw, IN 46580.

9.1 SUMMARY OF PERMIT REQUIREMENTS

The proposed dredging and streambank stabilization projects on Putney Ditch have been discussed with all of the above-named agencies, including the Louisville District Corps. For the dredging project, guidance from the Louisville District is that a separate 404 Permit is not required, and that the project falls under an existing Nationwide Permit because the dredged material will be deposited at an upland site that is diked, and not built on a wetland. The Corps will officially acknowledge this in writing to the BLPOA following review of the project plans. A Water Quality Certification from IDEM is required to authorize return of water from the sedimentation basin to the lake. An IDNR Division of Water Public Freshwater Lake Permit is also required for the dredging activity. In addition to the permit application, issuance of this permit will require a letter describing the project in addition to a copy of the map showing the channel and proposed extent of dredging on the Putney Ditch channel and mouth. Approximately 60 days will be required to review and grant the permit.

For the streambank stabilization project, further review by the Corps of the plans and extent of the project will be necessary to determine whether a separate 404 is necessary or if the project will be covered by an existing Nationwide Permit. In addition to the Corps requirements, this project will require a IDNR Construction in a Floodway Permit, and possibly a Ditch Project permit. Both of these permits are administered by the IDNR Division of Water. The permit applications for the proposed dredging and streambank stabilization projects have been provided to the Barbee Lakes Homeowners Association.

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HERPICC, 1989. A model ordinance for erosion control on sites with land disturbing activities. Highway Extension and Research Project for Indiana Counties and Cities, Purdue University. West Lafayette, IN. 18 p.

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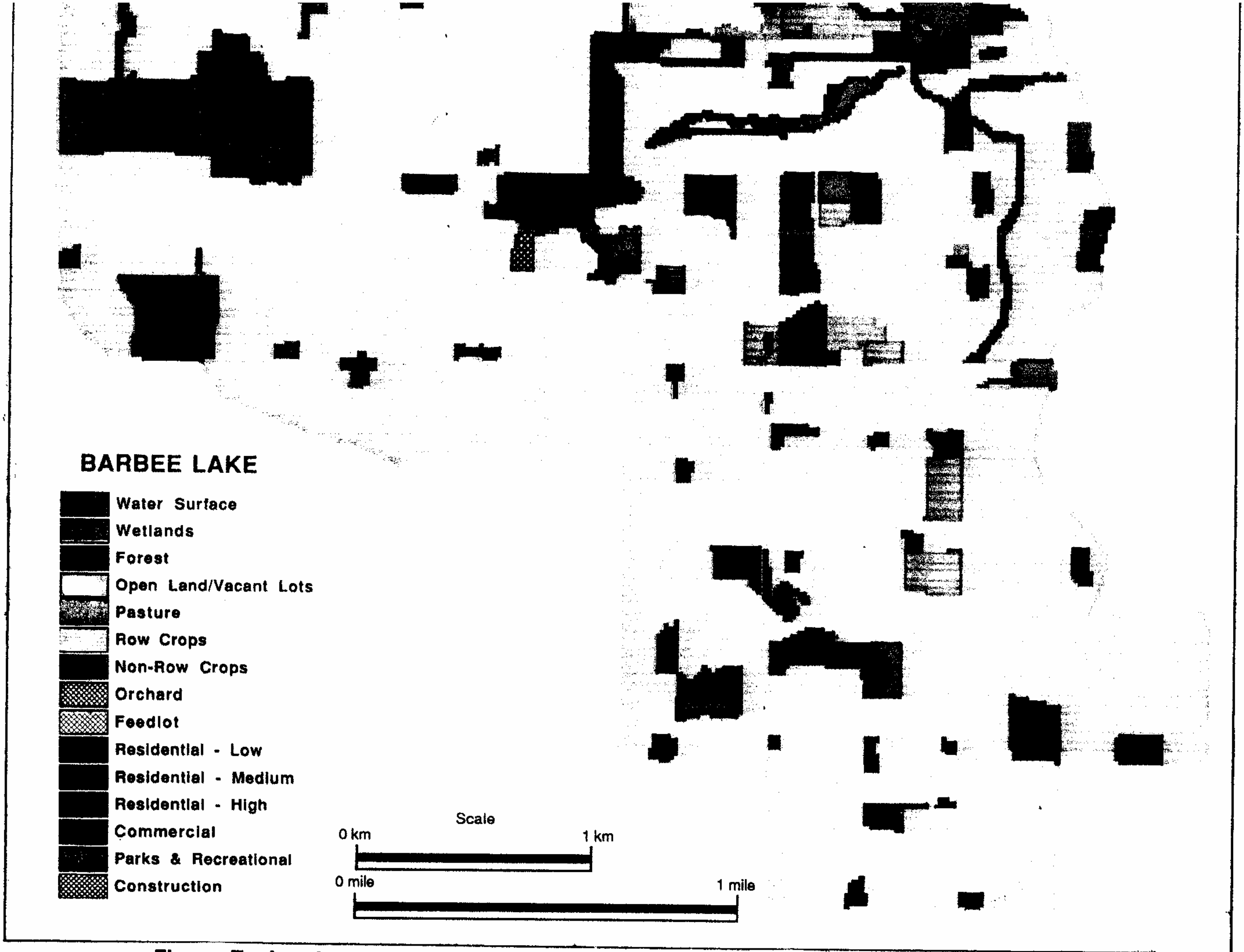

Figure 7. Land use in the Stonebruner-Putney Ditch watershed.