Illinois State Water Survey Division

SURFACE WATER SECTION
AT THE
UNIVERSITY OF ILLINOIS

SWS Contract Report 396

SEDIMENT MANAGEMENT FOR HORSESHOE LAKE AND ITS WATERSHED, ALEXANDER COUNTY, ILLINOIS

by

Ming T. Lee, Nani G. Bhowmik, Paul B. Makowski, Donald S. Blakley,
Raman K. Raman, William C. Bogner, and William P. Fitzpatrick

Prepared for the
Illinois Department of Conservation
Contract No. 1-5-39782

Champaign, Illinois
August 1986

Illinois Department of Energy and Natural Resources

Funding for this work was partially provided through the Illinois Department of Conservation and U.S. Fish and Wildlife Service Federal Aid in Sport Fish Restoration and Federal Aid in Wildlife Restoration project number FW-11-R.

CONTENTS

SEDIMENT MANAGEMENT FOR HORSESHOE LAKE AND ITS WATERSHED, ALEXANDER COUNTY, ILLINOIS

by
Ming T. Lee, Nani G. Bhowmik, Paul B. Makowski, Donald S. Blakley,
Raman K. Raman, William C. Bogner, and William P. Fitzpatrick

INTRODUCTION AND OBJECTIVES

The Illinois State Water Survey has conducted a diagnostic investigation and feasibility study of sediment management for Horseshoe Lake, Alexander County, for the Illinois Department of Conservation through a grant from the U.S. Fish and Wildlife Service. Because of the need to restore and maintain the lake environment, an applied research investigation was formulated and organized into the following five components:

1. Determination of the rate at which sedimentation is progressing at Horseshoe Lake
2. Analysis of pertinent water quality parameters
3. Development of necessary lake hydrologic data
4. Identification of major sources of sedimentation, using sediment budget analysis techniques
5. Development and evaluation of various sediment management plans on the basis of the gathered data and existing information

This report presents the results of these five components of the study. A separate report, Sedimentation Rates in Horseshoe Lake. Alexander County. Illinois (Bogner et al., 1985) was published as State Water Survey Contract Report 364 in June 1985.

Acknowledgments

This investigation, sponsored and financially supported by the Illinois Department of Conservation and the U.S. Fish and Wildlife Service, Department of Interior, was conducted under the general supervision and guidance of Stanley A. Changnon, Jr. (Chief Emeritus), Richard Schicht (Acting Chief), and Michael L. Terstriep (Surface Water Section Head), Illinois State Water Survey. The Horseshoe Lake Task Force of the Illinois

Department of Conservation provided general guidance for this investigation. Jim Mick administered the project; Michael Carter coordinated the project; Don Garver performed the macrophyte survey and provided the past sediment survey data; Bill Boyd reviewed reports and made many valuable suggestions; Russell Garrison provided assistance in the field; Bill Collins provided lake historical information; Guy Sternburg provided data and maps; Brian Small assisted the lake shore monument survey; Andy West served as a representative of the Nature Preserves Commission and many other Horseshoe Lake Conservation Area staff assisted in monument and ground-water well installation.

The Soil Conservation Service, under the general guidance of John Eckes, State Conservationist, and Steve Black, Assistant State Conservationist, provided the soil loss assessment in the watershed. The field work and analyses were conducted by Kenneth E. Wolfe, Area Agricultural Engineer; Gary Barnett, District Conservationist; and Robert H. Zinszer, Area Conservationist.

William Westcott, Inter-Survey Geotechnical Laboratory, performed analyses of sediment samples for unit weights and particle size distribution. Walter Lembke, Professor of Agricultural Engineering, provided guidance on sediment analysis.

A number of Water Survey staff members were extremely helpful in this investigation. Mike Demissie originally formulated the stream diversion alternatives and assisted in their hydrologic evaluation; Judy Marsh assisted in data analysis; Kevin Davie assisted in the lake sedimentation survey; Mark Grinter helped install equipment; William H. Zehrt helped in data analysis; John Brother, William Motherway, Jr., and Linda Riggin prepared the illustrations; Kathleen Brown typed the drafts and final report; and Gail Taylor edited the final report.

Study Area

Location

Horseshoe Lake lies within the Horseshoe Lake State Fish and Wildlife Management Area, two miles south of Olive Branch, IL, and 15 miles northwest of Cairo, IL, in Alexander County. Figure 1 shows the regional location.

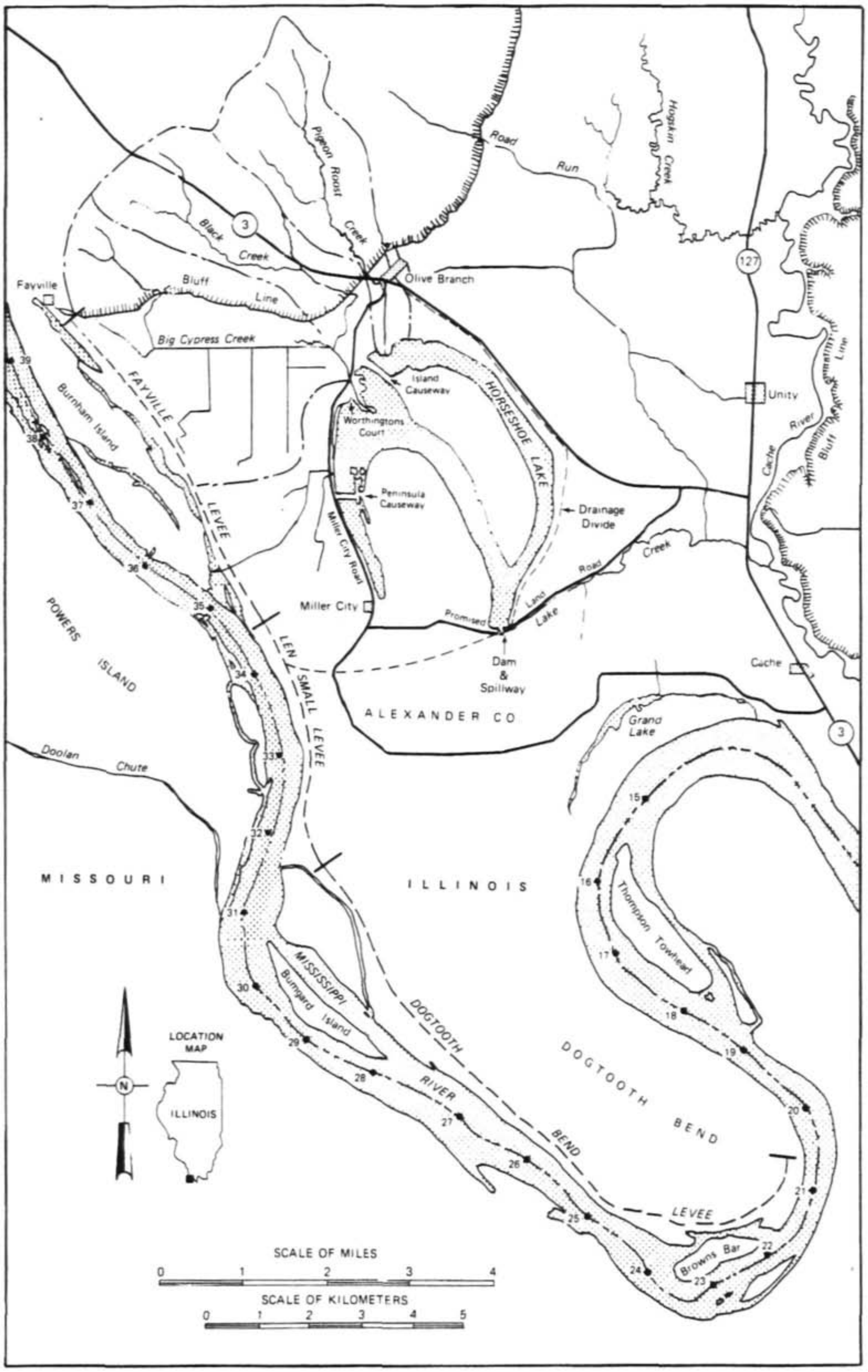


Figure 1. Location map for Horseshoe Lake, Alexander County, Illinois

Characteristics

The Horseshoe Lake State Fish and Wildlife Management Area is a floodplain wetland. It is located on the floodplain of the Mississippi River (Lee and Stall, 1976, 1977; Lee, 1979, 1982; Bellrose et al., 1983). The area occupies 9570 acres, which includes the 2007-acre Horseshoe Lake, and exhibits wetland characteristics common to more southerly wetland environments. Many of these characteristics, such as rare species of plants and animals, cannot be found in more northern latitudes of the state. A detailed description of these characteristics may be found in the IDOC Master Management Plan for Horseshoe Lake (IDOC, 1972).

Wetland habitat similar to that at Horseshoe Lake is commonly found along the Mississippi River. Oxbow lakes are remnants of river channels that were abandoned as the river migrated laterally through its floodplain. Horseshoe Lake is a prime example of this type of shallow-water, oxbow lake habitat.

The primary sources of recharge for oxbow lakes may be seasonal flooding by rivers and/or continuous supply from tributary streams which empty into the lake. Horseshoe Lake receives its water from both of these sources. The two streams which provide a continuous supply of water to the lake are Black Creek, which drains an area of 9.86 square miles west and northwest of the lake and originates in the Sante Fe Hills and the Big Cypress Swamp; and Pigeon Roost Creek, which originates in the Gilson Hills north of the lake and drains an area of 3.78 square miles (figure 1). Both streams are subject to flash flooding during intense rainfall and are the primary source of water and sediment for the lake. The Mississippi River, which floods Horseshoe Lake on an average of two out of every three years, is a secondary but important source of water for the lake.

Oxbow-lake hydrologic characteristics such as sources and amount of recharge, flooding frequency, and storage capacity influence the floral and faunal characteristics of the area and the type of habitat available for biological communities inhabiting the wetland. If the area is managed for specific interests, whether state or private, the management objectives may be formulated on the basis of these biotic characteristics. At Horseshoe Lake, the following management objectives have been implemented: to provide a winter refuge for the Illinois flock of the Mississippi Valley population of migratory Canadian geese; to preserve the natural character of the area; to provide for fishing, hunting, camping, and sightseeing activities; to provide forest management; and to preserve the Horseshoe Lake Island Nature Preserve and the Horseshoe Lake Forest Nature Preserve (IDOC, 1972).

History

Pre-State Ownership. Southern Illinois is well known for the abundant remnants of ancient cultures which once occupied this area. From before 8000 B.C. through 1500 A.D. the region experienced at least four major cultural periods: the Paleo-Indian, the Archaic, the Woodland, and the Mississippian. There are at least 15 recorded archeological sites within the immediate lake vicinity that represent three of the four above-mentioned periods (Cobb and Jefferies, 1983).

Tools and weapons recovered from the Black Creek watershed indicate the presence of ancient hunting and camping tribes as far back as 1500 B.C. Within the conservation area there are sites that have been identified as a Woodland camp and a Late Woodland village (IDOC, 1972). The location of the Late Woodland village on the shoreline of the lake indicates that the lake was being used at least 1100 years ago. The density of sites in the immediate vicinity of the lake is greater than in outlying areas, which suggests ancient use of the waterway and shows the early historical significance of this unique resource.

From pre-historic times through the 18th century the area was traversed by Indians, hunters, trappers, and explorers. Such noted historical figures as the Spanish explorer de Soto (14th century), French explorers Marquette and Joliet (15th century), and George Rogers Clark (18th century) possibly passed through or near the area.

In 1803, the federal government purchased southern Illinois from the Kaskaskia Indians, who controlled the area after the Revolutionary War (Hutchison, 1984). Illinois gained statehood in 1818, and in 1827 the federal government transferred the land to Alexander County. Sometime between 1900 and 1904, the county sold the area to Dr. F. M. Harrel of Cairo, Illinois. Harrel attempted to drain the lake for two years but was unsuccessful; however, the lake nearly dried up several times while under

Harrel's ownership due to drought conditions (John M. Mattingly, personal communication to R. J. Bushee, State Water Survey, 1934).

Harrel owned the lake through 1920. Between 1905 and 1920, he purchased the Horseshoe Lake island from C. P. Lawrence. In the early 1920s, A. P. Green of Indiana purchased the lake and the island property from Harrel for one dollar. Under Green's ownership, Horseshoe Lake was used as a private duck hunting club. The island supported several small orchards but was primarily used for hay production and pasture.

During these pre-state-ownership years, Horseshoe Lake existed as a shallow bottomland cypress swamp and was highly dependent on annual precipitation and river floodwaters for its water. Black Creek was the only stream feeding the lake, while Pigeon Roost Creek flowed parallel to the northeast and east side of the lake to the Richland Slough, and eventually into the lower Cache River. Pigeon Roost Creek was diverted into Horseshoe Lake sometime prior to 1927, possibly in conjunction with construction of old Illinois Route 3.

The southwest arm of the lake, known locally as the Miller City arm, was in forage crops prior to state ownership. Other areas within the lake were logged for the cypress and tupelo lumber as evidenced by remnant stump fields in the Worthington's Court area, north of the spillway, and on both sides of the island causeway (figure 1).

Access to the island and the peninsula was by primitive causeways known as "corduroy roads." They were constructed by laying cypress logs horizontally and side by side to create a road surface which had the ribbed appearance of corduroy cloth. The lack of trees in the northern part of the lake is partially due to this construction.

The island and surrounding area supported many homesteads. Raising of livestock, hay production, and logging were economic staples for the homesteaders around Horseshoe Lake prior to state ownership.

State Ownership. In 1927, the state of Illinois began purchasing properties in the Horseshoe Lake area with the intent of establishing a state conservation area. As described in the files of the Illinois Department of Conservation, an initial purchase of 49.05 acres on the Horseshoe Lake island was made in April 1927, and property acquisition continued throughout the rest of the year. The majority of the private land holdings belonged to A. P. Green, who sold approximately 3176 acres to the state by the end of 1927. This acreage included both the Horseshoe Lake island and the lake. By the end of 1927 nearly 3600 acres of land and water had been relinquished to state control. After the lake had been acquired, plans were formulated to stabilize the lake pool.

In 1929 the Illinois Department of Conservation completed construction of a stop-log spillway and dam at the intersection of Lake Creek and Promised Land Road at the southern tip of Horseshoe Lake (figure 1). This was the first attempt to stabilize the lake pool. The wooden spillway was structurally adequate to withstand hydrostatic pressure exerted by impounded water; however, the design did not take into account the pressure exerted on the structure by Mississippi River floodwater flowing over the spillway into the lake. Consequently, in the spring of 1930, the spillway was washed into the lake by incoming floodwater. Horseshoe Lake drained and lay partially dry for one year (Horseshoe Lake Chamber of Commerce, 1983).

In 1930 construction of a controllable concrete spillway was started. This spillway was completed in 1931, just prior to the first attempt at stocking fish in the lake. In 1933 retaining walls were added to the dam. The walls extended east and west from the spillway wing walls and were 2 feet higher than normal lake pool elevation.

The controllable spillway functioned for eight years before being altered to a fixed concrete structure in 1939 (IDOC, 1972). The 1939 spillway was not tied in to a sea level datum, but current calculations based on the original spillway blueprints indicate that the 1940 elevation was approximately 322 feet mean sea level (msl).

After final spillway construction was completed, the lake level rose approximately 4.5 feet above its pre-1939 stage. This rise in elevation inundated over 600 acres of topographically low land adjacent to the lake. Included in this acreage were the areas known as Worthington's Court and the Miller City arm (figure 1). Although the majority of the flooded land belonged to the state, several private holdings were also flooded. Some of these properties are still under private ownership and are still under water. Prior to stabilizing the lake pool at a higher elevation, the state secured flood easements.

Black Creek Modifications. In the mid-1940s, the area north of the mouth of Black Creek was a privately owned duck hunting club. By the early

1960s this property and much of the current holdings had been acquired by the state through direct purchase or other methods of land transferral, which allowed development of the state park facilities. By the early 1960s it became evident to the state and local citizens that the main channel of Black Creek was becoming log-choked and silted in. In 1963 the channel was dredged by the IDOC to within 500 feet of the lake. The last 500 feet of dense vegetation and shallow water was then blasted open and dredged. The purpose of this operation was to promote better drainage and to provide continued access to the lake for property owners along this stretch of the creek (Bill Collins, IDOC, personal communication, 1984).

Levee Modifications. Prior to 1969 only portions of the Mississippi River levee system had been completed. The completed levees in the Horseshoe Lake area functioned as barriers to overland flow in Dogtooth Bend south of the lake. This area, which is primarily cropland, experienced severe scour and fill prior to construction of the Len Small Levee in 1943 and the Dogtooth Bend Levee prior to 1943 (U.S. Army Corps of Engineers, 1984). The northern end of the levee system, the Fayville Levee, was not completed until 1969.

Pre-1969 Mississippi River floodwaters periodically entered Horseshoe Lake via an overland flow route originating near Fayville, Illinois, passing through the Big Cypress Swamp, and entering the lake in the Big Pocket-Worthington's Court area (Russell Garrison, Horseshoe Lake Conservation Area Refuge Manager, personal communication, 1984). Upon completion in 1969, the Fayville Levee System effectively prevented this overland flow to the lake. Local residents attribute the aggradation of the Black Creek delta and general siltation of the Big Pocket-Worthington's Court area to the completion of the levee. This hypothesis is based on the assumption that the velocity of flow entering the lake via the overland flood route was fast enough to maintain incoming sediment in suspension, to scour the lake bottom in this area, and to carry this material in suspension through the lake and out over the spillway. Currently there are no available data to substantiate this hypothesis, as no velocity measurements or sediment samples were taken during these flooding episodes.

Waterfowl Management. Waterfowl management at Horseshoe Lake began soon after the Illinois Department of Conservation took possession in 1927.

In 1928, the management area supported its first significant population of geese, approximately 1000 birds (Horseshoe Lake Chamber of Commerce, 1983). By 1939 the conservation area harbored a winter flock of over 100,000 birds (Kennedy and Lewis, 1977). From 1940 to 1950 the population at Horseshoe Lake fluctuated around the 1939 high. Between 1955 and 1965 the goose population increased significantly, and by 1965 the Mississippi Valley population had surpassed 200,000 geese. New waterfowl management policies initiated in the Mississippi Flyway during the 1960s prompted an average 10 percent per year population growth through 1969, when the census stabilized near 300,000 geese.

Population increases in 1976 and 1977 led to a record Mississippi Valley census of over 500,000 geese in 1978 (Thornburg, 1982). Between 1978 and 1981 the goose population declined due to poor breeding conditions in the northern breeding grounds. By 1981 this decline began to reverse and by 1984 the IDOC census indicated a population in excess of 350,000 birds. Of this number, 125,000 geese were harbored in the Horseshoe Lake State Fish and Wildlife Management Area in January 1985.

Geologic and Climatic Setting

Physiography and Geology. The Horseshoe Lake State Fish and Wildlife Management Area lies at the intersection of two major physiographic provinces: the Salem Plateau Section of the Ozark Plateau, and the Coastal Plain Province (figure 2). These two provinces overlap within the upper Horseshoe Lake watershed.

The Salem Plateau is part of the regionally uplifted Ozark Plateau and occupies the northern two-thirds of Alexander County, Illinois (Harris, et al. 1977), including portions of the upland watershed of Horseshoe Lake.

In the upper watershed, the Ozark-type topography is less extreme than in northern areas of the plateau. Local relief is less than 300 feet between valley bottoms and divides, and low hills with moderately steep slopes characterize the region. Bluff exposures are not dominant although they are present. Chert-gravel bed streams drain the low hills and are significant features of the Ozark-type geology. The combination of lithology and topography causes many of the creeks to behave like streams in arid and semi-arid regions: they are ephemeral, and flow rigorously only in direct response to large rainfalls (Ritter, 1975).

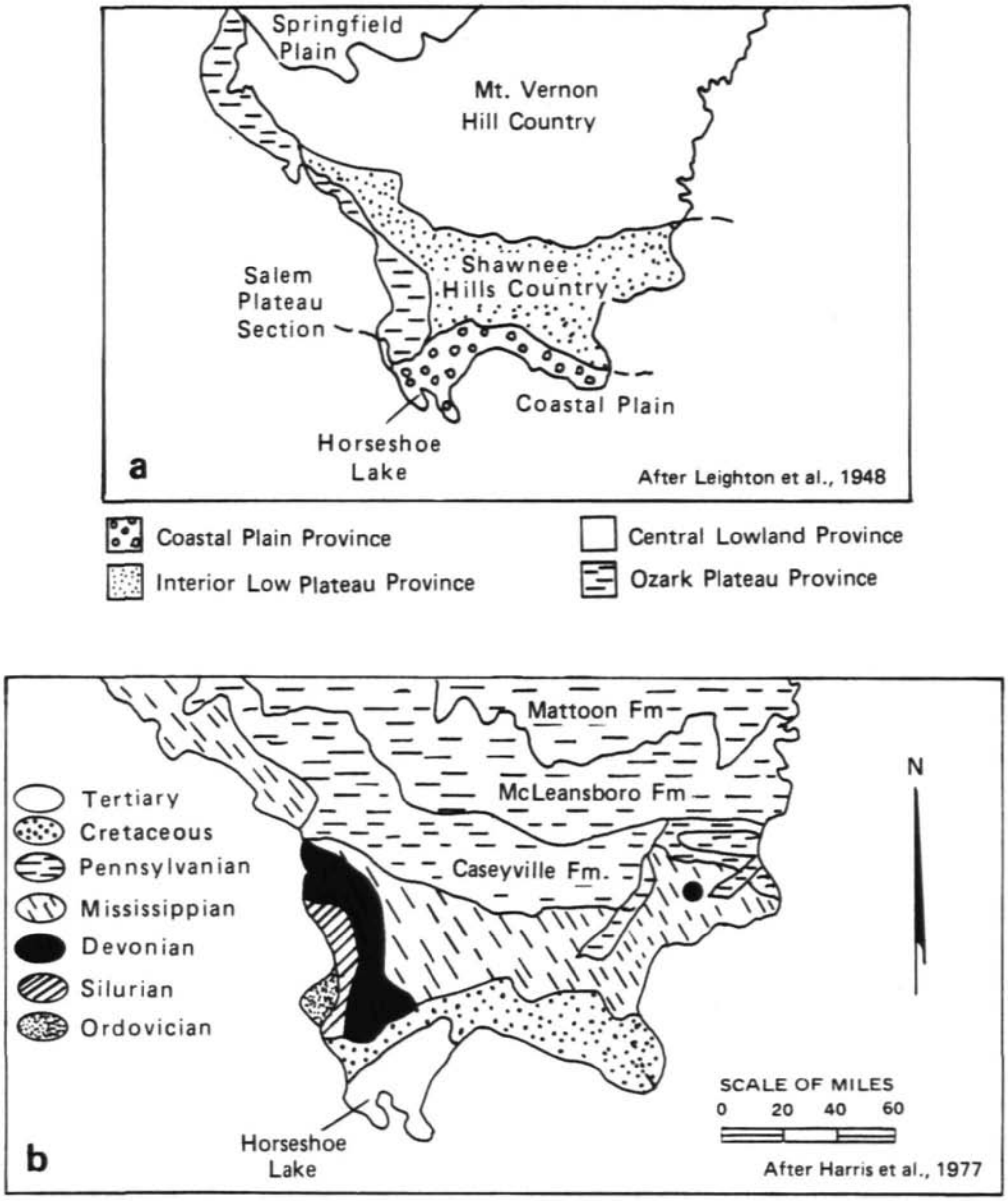


Figure 2. a) Physiography and b) bedrock of the Horseshoe Lake area

The chert gravel transported in these streams is derived from local bedrock formations. In the Horseshoe Lake watershed, lower Devonian limestone and chert formations are overlain by cherty Cretaceous gravels and thin Quatenary loess deposits. Devonian exposures are limited. Upper Paleozoic and lower Mesozoic formations are not present; therefore a major hiatus occurs between the Cretaceous and Devonian formations. No igneous rocks are known to be exposed in this area.

The Cretaceous gravels overlying the lower Devonian bedrock in the upper Horseshoe Lake watershed represent the overlapping of the Coastal Plain Province with the southern boundary of the Salem Plateau Section. All of the lower Mississippi River Valley and a portion of the lower Ohio River Valley are part of the Coastal Plain Province.

Topographically, the Coastal Plain is a broad alluvial plain characterized by meander scrolls, terrace deposits, wetland areas, and oxbow lakes such as Horseshoe Lake. Relief is generally very low except at floodplain boundaries where bedrock bluffs may exhibit vertical relief. The floodplain surface is flat to gently rolling in areas containing ridge and slough sequences. The lower Horseshoe Lake watershed exhibits all of these characteristics.

Underlying the lower Horseshoe Lake watershed is 50 to 200 feet of floodplain alluvium (Pryor, 1958). This alluvium consists of vertical accretions of clay, silt, sand, and gravel, although the lateral continuity of these sequential accretions may be disrupted by point bar, channel, and natural levee deposits. Overbank gravel lobes deposited on the floodplain surface during floodplain construction may be preserved in the stratigraphic record (Wolman and Leopold, 1967), but rapid migration by the river through its floodplain may rework the overbank gravel sequences before they can be permanently preserved. Normally the alluvial deposits coarsen with depth, although the overbank gravel deposits, if preserved, may disrupt this sequence.

The floodplain alluvium beneath the Horseshoe Lake area rests on Tertiary and Cretaceous marine deposits. Generally, the depth to these formations increases south from Olive Branch, Illinois. These marine deposits represent a period of marine regression to the south as indicated in part by their southward dip. Underlying this regressive sequence are Lower Paleozoic Formations of Ordovician and Lower Devonian age. No Lower

Mesozoic or Upper Paleozoic units are reported in the stratigraphic column beneath Horseshoe Lake, indicating that a major hiatus may occur at the Cretaceous and Lower Devonian contact, as it does in the upper watershed.

More detailed discussions of the floodplain and bedrock stratigraphy under the Horseshoe Lake area are given by Pryor (1956) and Harris et al. (1977).

Climate. Horseshoe Lake is located near the extreme southern tip of Illinois between the Ohio and Mississippi Rivers. Due to this geographical location, the area has a temperate humid climate similar to that of Kentucky and southern Missouri. The two large rivers in the area can influence local climatological patterns.

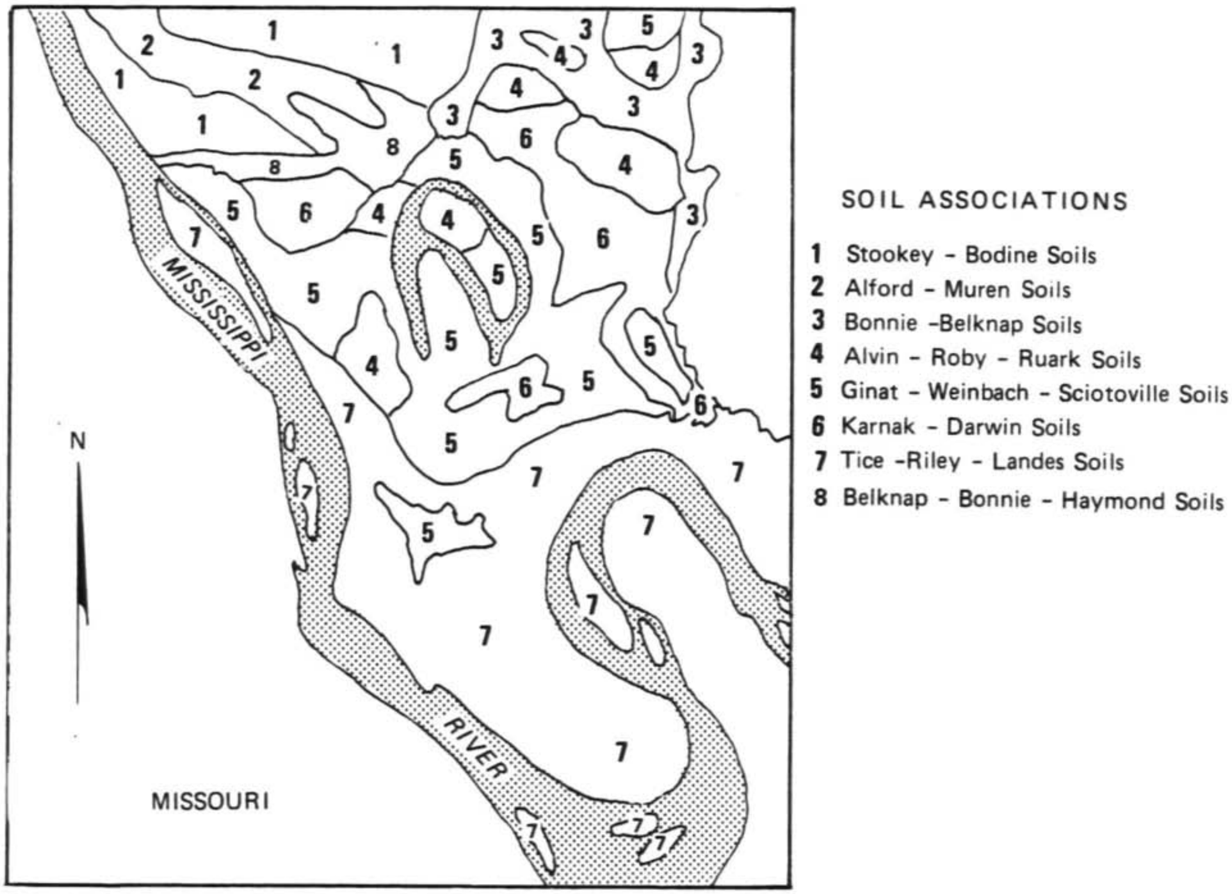
Table 1 provides basic climate information for the Horseshoe Lake vicinity, based on the Narrative Climatological Summary and the statistical summary from the National Oceanic Atmospheric Administration (NOAA, 1983) for Cairo, Illinois. Averages presented are long-term averages.

Soils. Soils in the Horseshoe Lake watershed are generally silty loams which have developed in bottomland alluvium, on remnant terrace deposits, and in upland loess deposits. Problems commonly associated with these soils include low fertility, erodibility, and poor drainage. Figure 3 shows a generalized soil association map of the southern half of Alexander County, which includes the Horseshoe Lake watershed, and table 2 provides a legend and description of the soil associations.

Land Use. The Horseshoe Lake watershed, including the area of the lake, covers 15,116 acres. The upland watershed is forested but contains small cropland and pasture acreages. Some hillside farming is evident. The lowland watershed is primarily agricultural land with row cropping as the standard practice. A small percentage of the lowland watershed is forested, primarily in the state-owned management area and in Big Cypress Swamp. The wide diversity of environments and communities present within the watershed provides the background for the many varied and distinct floral and faunal species present.

Table 1. Climatic Summary for the Horseshoe Lake Area

Absolute temperature range	-16 F (Low) - January 1918 106 F (High) - August 1930
Average growing season	222 days
Average number heating degree days	3913 per year
Average number cooling degree days	1807 per year
Average number thunderstorm days	53 per year
Normal annual precipitation	47.12 inches
Average seasonal snowfall	10 inches
Driest period	July through October
Wettest month	March
Driest month	October



Modified from Allen, 1968. Originally adapted from USDA Generalized Soils Map.

Figure 3. Soil associations near the Horseshoe Lake area

Table 2. Soil Map Descriptions*

1)	Stookey-Bodine Soils	Deep, permeable, generally weakly developed soils, and shallow, cherty soils; steep and very steep
2)	Alford-Muren Soils	Deep, moderately permeable soils; rolling to steep
3)	Bonnie-Belknap Soils	Light colored, medium- and moderately fine-textured, poorly drained, strongly acid bottomland soils
4)	Alvin-Roby-Ruark Soils	Deep, loamy soils; generally have moderately fine-textured subsoil; a coarse- to fine-textured substratum; level to sloping stream terraces
5)	Ginat-Weinbach-Sciotoville Soils	Deep; fine-textured or moderately textured substratum; level to sloping stream terraces
6)	Karnak-Darwin Soils	Light colored and moderately dark colored, fine-textured, very poorly drained, slightly to medium acid bottomland soil
7)	Tice-Riley-Landes Soils	Soils of the Darwin Alluvial land - Riley Association; moderately dark colored moderately fine-textured bottomland; sandy; strata often will vary from poorly-drained loamy fine sand to silty clay
8)	Belknap-Bonnie-Haymond Soils	Light colored, medium-textured poorly- to well-drained, strongly to slightly acid bottomland soil

*Adapted from Allen (1968), and U.S. Soil Conservation Service and Illinois Agricultural Extension Service (1968).

DIAGNOSTIC ANALYSES

This section of the report is divided into four subsections, which describe the methods and results of the first four components of this study: the lake sedimentation survey, water quality analyses, hydrologic analyses, and sediment analyses. The results and analyses discussed in these four subsections form the basis for the feasibility analyses presented in the next section.

Lake Sedimentation Survey

Methods and Data Sources

The lake sedimentation survey methods developed by the Water Survey and other water and soil research agencies are generally most suitable for use in man-made lake impoundments. In these lakes, a definite date of origin can be defined for the lake on the basis of the date of construction of the closing structure. The thickness of sediment which accumulates from the time of closing to the time of a survey can be readily measured in the field by use of a spud bar, sounding pole, or core sampler driven through the sediment. The depth of penetration of the pole indicates the depth at which the accumulated sediment interfaces with the original soil material. At this interface, the character of the soil material will change substantially, generally becoming both coarser and denser.

The origin of Horseshoe Lake is neither completely natural nor completely artificial. Because of this dual character, the analysis of the sedimentation rate requires both direct and indirect methods of analyzing sedimentation in the lake. Three basic data sources were used in analyzing the sedimentation rate of the lake.

1) Aerial photography was used to study changes in the physical features of the lake, the Black and Pigeon Roost Creek deltas, drainage of sections of the lake, expansion-reduction in tree stands in the lake, and construction of causeways and other structures in and around the lake.

2) Two previous surveys of the lake were conducted by IDOC personnel: a 1951 survey by O. M. Price (Price, 1980) and a 1980 survey by Don Garver (Conlin, 1981). The analysis of these surveys is limited due to a lack of information on the 1951 survey and the limited detail of the 1980 survey.

3) The 1984 survey by the Water Survey is the third basic data resource. This survey provides the basis for analyzing sedimentation in the lake from 1951 to 1984 (with some analysis for the 1980 to 1984 period) and for establishing a well documented survey pattern for future surveys of the lake.

Aerial Photography. A review of available aerial photographs for the region was made. The University of Illinois library files were used to obtain photographs dating back to 1938. The years for which photographs are available are 1938, 1950, 1956, 1959, 1965, and 1971. These photographs were used to make observations of historical changes in the Horseshoe Lake area.

A review of the photographs indicates that the tributary deltas did not grow appreciably in area over the years 1938-1971. Major losses of trees in the lake were observed over the period 1938-1950 due to construction and logging activities. The Miller City arm of the lake south of the causeway to the peninsula was farmed at least as far back as 1950. Earlier and later photographs show this area inundated with lake water.

1951 O.M. Price Survey. In January and February 1951, O. M. Price of the Illinois Department of Conservation conducted a survey of Horseshoe Lake to determine the water volume of the lake. He surveyed 224 cross sections: 158 from the dam, up the east side of the island to the island causeway; and 66 from the south tip of the island up the west side of the island to the island causeway.

A base map of Price's survey showing the location of selected cross sections was prepared in 1980. Also in 1980, these selected cross sections were plotted (Price, 1980). No written report was prepared to describe this survey, but interviews with Mr. Price in 1984 indicate that the following procedures were used:

- Water depths were determined from the elevation of the spillway crest.
- Location around the lake was determined using two traverse lines. One of the traverse lines ran from the dam, up the east shore of the lake to a point just east of the Pigeon Roost Delta. The other traverse line ran up the west side of the island, starting from the

southern tip, to the island causeway (actually the northern tip of the island; the causeway did not exist in 1951).

- Location on cross section lines was determined by estimation of distance and magnetic bearing.
- No cross sections were run in the western portion of the lake from the Black Creek Delta into the Miller City branch of the lake. It was noted that this area was shallow but could be traversed by boat.

1980 Don Garver Survey. In 1980, Don Garver of the Illinois Department of Conservation resurveyed depths on 18 cross sections from Price's survey. Three to seven depth measurements were made on each cross section to determine loss of depth. Cross sections were relocated by eye and distances were estimated.

Figure 4 shows the results of this survey as presented by Conlin (1981) in an internal DOC memo. These results were also used as the basis of a 1981 Bureau of Natural Resources report regarding the siltation problem at Horseshoe Lake.

1984 ISWS Lake Sedimentation Survey. During the period March to August 1984, the Water Survey conducted a detailed resurvey of Horseshoe Lake. Nine of Price's cross sections were relocated approximately and surveyed. In addition, five additional cross sections were surveyed to complete the Miller City branch of the lake and a radial survey was made of the areas immediately west of the island causeway and immediately south of Worthington's Court (figure 5).

The survey methods used were the standard methods used by the Water Survey in its lake sedimentation program. Cross-section ends were temporarily located using 2-inch-square wooden hubs. These were later replaced by concrete survey markers for permanent identification. Horizontal location on each cross section was determined by using a Hewlett Packard 3805 distance meter.

Depth of water and thickness of sediment deposits were measured using a 2-inch-diameter aluminum sounding pole with an 8-inch-diameter shoe to indicate the top surface of the soft sediments. To make a measurement, the pole was first lowered into the water until the sounding shoe rested on the top surface of the sediment. At this point, the water depth was measured.

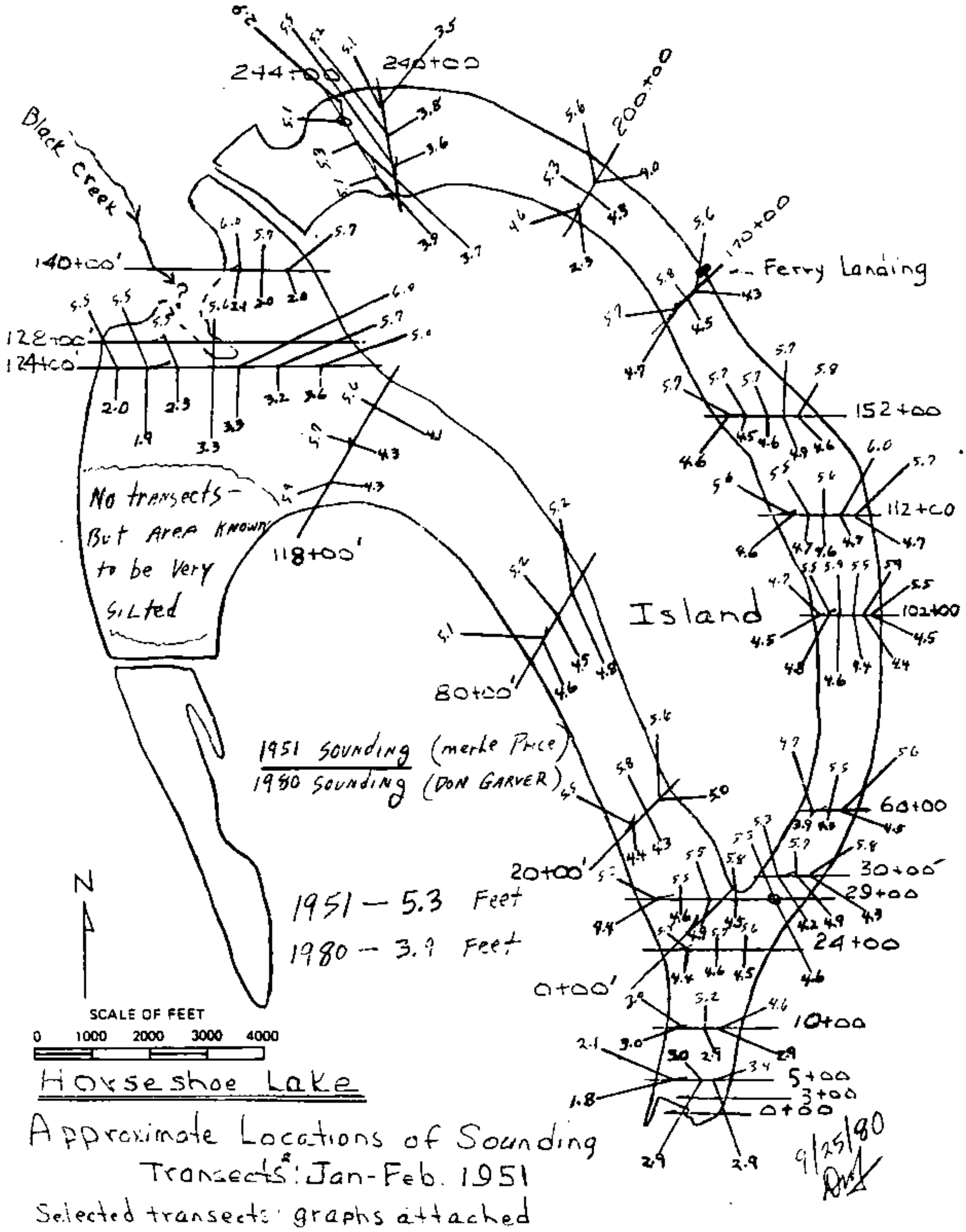


Figure 4. Summary of 1951 and 1980 surveys of Horseshoe Lake (Reproduction of map presented by Conlin, 1981)

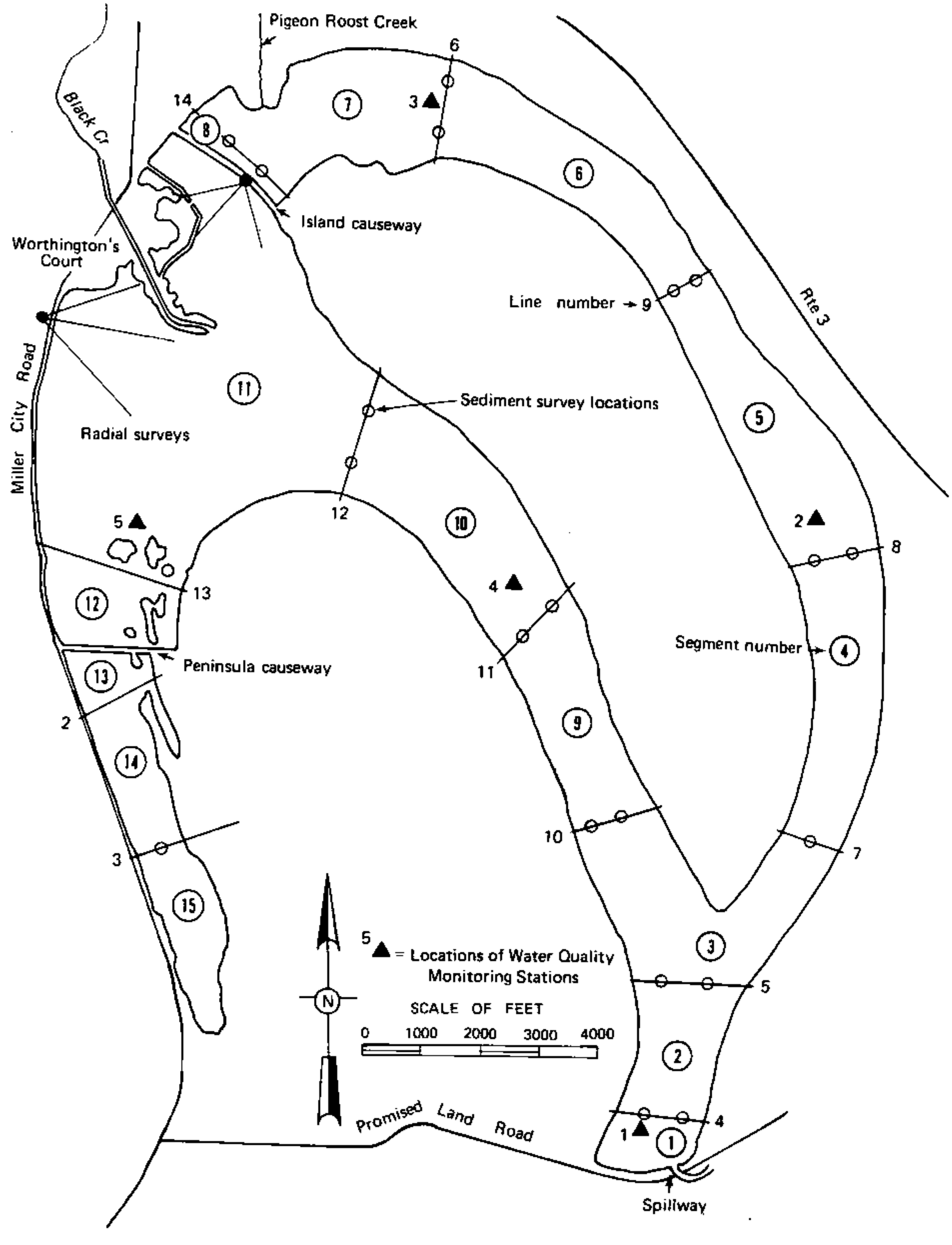


Figure 5. 1984 survey plan for Horseshoe Lake

The sounding pole was then manually pushed through the accumulated sediment to the point of refusal, where another measurement was made of the combined water and sediment depth. All depths were later adjusted to the common datum of the spillway elevation. During this surveying, any other points of interest were noted in the field book. These notes might include changes in the consistency of the sediments with depth or width, changes in the physical condition of sediments brought up on the sounding pole, tree lines, etc.

The radial surveys (figure 5) near the Black Creek delta were conducted in a slightly different manner. In these areas, a pivot point was established and used to survey radial sections of the delta region. Also, no penetration measurements were made to determine sediment thickness.

Following the survey, the end points of each cross section were accurately located by R.A. Nack & Associates, a consulting engineering firm. This survey was designed to determine both the horizontal location of each range end and the mean sea level elevation at each point.

Also following the survey, samples of the accumulated sediments were collected for the following analyses:

1) unit weight of in situ sediments
2) particle sizes of the sediments
3) nutrient content of the sediments

The locations where these samples were collected are also indicated in figure 5.

All unit weight samples and the below-surface particle size and nutrient samples were taken using a piston-type core sampler. Surface samples for particle size and nutrients were taken using a 6-inch Ekman dredge.

Results

The results of the 1951 and 1984 surveys were analyzed using an average depth method for determining lake volumes. The following procedures were used:

1) All depth measurements were adjusted to the spillway level.

2) 1984 cross sections were plotted on standard graph paper.

3) 1951 and 1980 depth measurements were adjusted to fit onto the 1984 plots.

4) Cross-sectional areas were determined by digitizing the cross sections.

5) Surface areas were digitized from 7.5-minute U.S. Geological Survey quadrangle maps.

6) Segmental volumes were determined using the formula:

$$V = A \times \sum_{i=1}^{n} (E_i/W_i)/n \qquad (1)$$

where

V = the segment volume
A = the segment area
E_n = the cross-sectional areas of the lines bounding the segment
W_n = the corresponding widths of the lines
n = the number of lines bounding a segment
i = the segment number

In segment 11 near the Black Creek delta, this method was adjusted slightly to account for the radial surveys conducted.

7) The total volume of the lake was then determined by summing the segmental volumes.

Lake volumes were calculated for three dates:

1) 0000 represents the lake volume based on the maximum penetration of pole through the 1984 sediments.
2) 1951 represents the lake volume based on the survey conducted in 1951. (Where no survey data were collected in 1951, the volume from (1) was used.)
3) 1984 represents the lake volume based on the water depths measured in 1984.

The results of this analysis are presented in table 3. The 1984 water volume in Horseshoe Lake at the spillway level was 5947 acre-feet. Sediment accumulation during the period 1951 to 1984 was 2808 acre-feet.

Table 3. Horseshoe Lake - Alexander County
Summary of Lake Sedimentation Results

Segment[1]	1984 Volume (acre-feet)	Sediment volumes (acre-feet)			Sediment tonnages (1000 tons)			Unit weights (pounds per cubic foot)		
		1951-1984	0000-1951[2]	0000-1984[3]	1951-1984	0000 -1951[2]	0000 -1984[3]	Area (acres)	1951-1984	0000-1951
1	49.2	7.1	26.2	33.3	2.3	18.5	20.8	21.1	14.9	32.5
2	265.8	62.6	162.9	225.5	20.3	115.3	135.6	82.3	14.9	32.5
3	606.7	183.0	545.7	728.7	55.4	324.5	379.9	160.5	13.9	27.3
4	533.5	160.3	569.3	729.6	28.6	249.2	277.8	138.2	8.2	20.1
5	733.4	243.3	697.4	940.7	45.6	264.3	309.9	180.2	8.6	17.4
6	498.4	266.2	393.5	659.7	64.9	144.8	209.7	147.9	11.2	16.9
7	347.7	319.0	138.5	457.5	123.7	151.1	274.8	150.5	17.8	50.1
8	19.8	23.9	-	23.9	11.9	-	11.9	10.9	22.9	-
9	449.9	107.9	397.6	505.5	36.0	224.3	260.3	113.6	15.3	25.9
10	708.6	192.3	574.9	767.2	66.2	411.7	477.9	183.1	15.8	32.8
11	1395.9	950.7	631.8	1582.5	468.0	836.6	1304.6	601.7	22.6	60.8
12	105.8	110.3	-	110.3	87.7	-	87.7	65.3	36.5	-
13	42.6	38.4	-	38.4	30.5	-	30.5	26.3	36.5	-
14	99.4	79.4	-	79.4	63.1	-	63.1	64.1	36.5	-
15	90.7	63.2	-	63.2	50.2	-	50.2	61.3	36.5	-
Total	5947	2808	4139	6946	1154	2740	3894	2007		
		Average unit weight (pounds per cubic foot)			18.9	30.4	25.7			

Drainage area 23.72 square miles
15,177 acres

Area excluding lake 13,170 acres

Sediment delivery to lake 2.58 tons/acre

Note: 0000 represents the maximum penetration of the sounding pole in 1984. No date can be applied.

[1] Refer to figure 5 for segment location

[2] Accumulated sediment up to 1951

[3] Accumulated sediment up to 1984

Thus 32 percent of the 1951 water volume was filled with sediment during the period 1951-1984.

The maximum penetration of the sounding pole in 1984 indicated that 6946 acre-feet of unconsolidated sediments had accumulated in the lake. The date of origin of these sediments cannot be determined on the basis of the physical measurement techniques of this survey.

Particle Size Analysis. Samples of the lake bed sediment were taken for laboratory analysis of the particle size distribution of the material. A total of 57 samples were obtained from sediment cores and surface samples. This analysis is based on the laboratory results for 48 of the samples, which are presented in appendix 1.

The lake bed sediments in Horseshoe Lake are predominantly clay. The simple averages of the 48 samples are: 70 percent clay, 25 percent silt, and 6 percent sand. The results indicate a trend of increasing clay concentration from upstream to downstream in samples from the lake bed. This is usually the case and has been observed in other lake studies (Bogner et al., 1984; Eakin, 1939; Heinemann, 1962). The distribution of sediment particles in a lake is determined by the carrying capacity of the inflowing entraining waters. As sediment-laden water flows into a lake, its velocity decreases and its ability to entrain sediment is reduced. The entraining water responds to the reduced velocity and reduced carrying capacity by dropping the particles with the largest mass out of suspension first and by continuing to release sediment, of decreasing mass, as the velocity diminishes. The result of this process is that the gravels and sands are concentrated in upstream areas, and silts and clays in the downstream portions of the lake.

Soil Nutrient Analysis. Samples of the 1984 Horseshoe Lake sediments were collected for standard soil nutrient analysis. The results of this analysis by the University of Illinois Agronomy Laboratory are presented in appendix 2. With the assistance of Professor Walter Lembke, an analysis of the soil tests was made to evaluate the possibility of applying the sediments to agricultural land.

The nutrient analysis of the Horseshoe Lake sediments indicates that these sediments would be beneficial to the productivity of the native soil. Due to the high clay contents of the sediments, an application of these sediments mixed into a lighter textured soil by chiselling would be the optimum method from an agricultural standpoint.

Phosphorus and potassium levels are sufficient for agricultural production although phosphorus applications would be necessary in order to maintain yields. The high organic content of the sediments should contribute to the agricultural value of the sediment.

Unit Weight Analysis. In order to determine the weight of sediment in Horseshoe Lake, both volume and unit weight of the accumulated sediments are required. To determine unit weight, samples of the accumulated sediments were collected using a 2-inch-diameter core sampler. This sampler takes cores of the sediment up to 3 feet in length. These samples can then be subsampled by removing sections of known length from the core in order to define changes in sediment density with depth.

Forty-eight of these subsamples were collected from Horseshoe Lake. They were weighed to determine wet weight and dried at 105° Centigrade until there was no further weight reduction.

From this analysis, water content as percent of solid material, as well as unit weight, could be determined. These values are given in appendix 1 with a summary of sample locations. These results were used in conjunction with the sediment volumes on a segmental basis to determine the weight of the deposited sediment. Sample unit weights from the top of the sediment cores were applied to the 1951 to 1984 sediment accumulation volume. Sample unit weights from the bottom of the cores were applied to the pre-1951 sediment accumulation volume. These unit weights were applied on the basis of field observation of a distinct change in composition of the sediments at a point approximately corresponding to this surveyed break.

The calculated sediment tonnages with their corresponding unit weights are given in table 3. This analysis indicates that 1.15 million tons of sediment accumulated in Horseshoe Lake from 1951-1984. The average unit weight of these sediments is 18.9 pounds per cubic foot. Pre-1951 unconsolidated sediment deposits were just under 2.74 million tons with an average unit weight of 30.4 pounds per cubic foot. Combined unconsolidated sediment deposits were 3.89 million tons with an average unit weight of 25.7 pounds per cubic foot.

The unit weights of the sediment deposits in Horseshoe Lake are much lower than those of sediments in other Illinois lakes. The unit weight of unconsolidated sediments at Horseshoe Lake varied from a low of 8.2 pounds per cubic foot to 36.5 pounds per cubic foot. The range in other Illinois lakes would be expected to be approximately 25 to 45 pounds per cubic feet.

The likely reason for these unusually low unit weights is the high organic content of the sediments and also the high clay content (as per Heinemann, 1962; Bogner et al., 1984). The organic content of Horseshoe Lake sediment samples ranges from 10.2 percent to 17.5 percent by weight. In contrast, the organic content of sediments in two man-made Illinois impoundments (Kothandaraman and Evans, 1983a, 1983b) was much lower than these values, reaching a high of 11.2 percent at deep water sampling sites and a high of 7.9 percent at shallower sites. These figures indicate that the organic load to Horseshoe Lake may be much higher than the organic load to man-made Illinois lakes.

On the basis of this information it is estimated that of the sediment deposited since 1951, approximately 10 percent or 117,000 tons is of organic origin. Table 4 shows the estimated organic content of sediments throughout the lake and corresponding tonnages.

Sedimentation Rates. The general analysis of in-lake sedimentation rates emphasizes the volume of material accumulating in the lake. This sediment effectively displaces the lake water, reducing water volume through reductions in both depth and area. The volume of accumulated material is readily measured by using the techniques described previously in this report.

This volume cannot be extended directly to watershed land areas due to changes in the unit density weight of the sediments. Soil as it exists in the field (dried, packed) has a unit weight of approximately 95 pounds per cubic foot. The volume of sediment accumulated in Horseshoe Lake from 1951 to 1984 had an average unit weight of 18.9 pounds per cubic foot. With these unit weights, it is apparent that the sediments in the lake occupy approximately 5 times more volume in the lake than they would as watershed soil.

For these reasons, two types of sedimentation rates will be used in this report. Volume-based rates will be used for sediment accumulation in

Table 4. Organic Content of Horseshoe Lake Sediments

Segment	1951-1984 sediment weight (1000 tons)	1984 organic content (%)	1951-1984 organic weight (1000 tons)
1	2.3	11.9	0.27
2	20.3	11.9	2.42
3	55.4	12.4	6.87
4	28.6	16.7	4.78
5	45.6	16.3	7.43
6	64.9	14.0	9.09
7	123.7	10.7	13.24
8	11.9	9.3	1.11
9	36.0	11.7	4.21
10	66.2	11.5	7.61
11	468.0	9.4	43.99
12	87.7	7.1	6.23
13	30.5	7.1	2.17
14	63.1	7.1	4.48
15	50.2	7.1	3.56
	1154.4		117.46

the lake, and mass or tonnage rates will be used for rates of delivery from a source area.

A total of 2808 acre-feet of sediment accumulated in Horseshoe Lake from 1951 to 1984. This is an average annual accumulation of 78.6 acre-feet of sediment. If this rate continues, the water volume of the lake will be completely displaced by sediment by the year 2060. One-half of the 1984 water volume will be lost by 2022. These estimates are based on the current sedimentation rate; however, the current rate may not be fully applicable to determining when the lake will be completely filled with sediment. As sediment accumulates in the lake, it changes the hydrologic characteristics of the system, and there will probably be a reduction of the proportion of the total sediment delivered that settles within the lake.

The 1951 to 1984 sedimentation rate in Horseshoe Lake indicates that the average depth of the lake is decreasing by 0.039 feet or 0.47 inches per year. Figure 6 shows the average annual loss of depth for each segment of the lake. These accumulation rates show generally decreasing sediment accumulation rates in the lake from north to south. This decrease is expected since the major portion of the sediment will settle out near the sources (Black and Pigeon Roost Creeks) with lower rates as the distance from the source increases.

An unexpected observation is that the east branch of the lake has higher rates of sedimentation than the central branch. This branch is affected primarily by flows from Pigeon Roost Creek, while the central branch of the lake is affected primarily by Black Creek. Due particularly to its larger size, the impact of Black Creek was expected to be greater than that of Pigeon Roost Creek. The cause of the lower sediment accumulation rates in the middle branch of the lake may be the flushing action of Mississippi floodwaters which passed through the lake prior to the closing of the river levees in 1969. If these flows completely flushed the middle branch of the lake from 1951-1969, the accumulation of sediment in segments 9, 10, and 11 is from the 15-year period of 1969 to 1984 rather than the 34-year period of 1951 to 1984. This would increase the accumulation rates in these segments by nearly 125 percent for the period 1969 to 1984. This impact would also be significant in segments 1, 2, and 3.

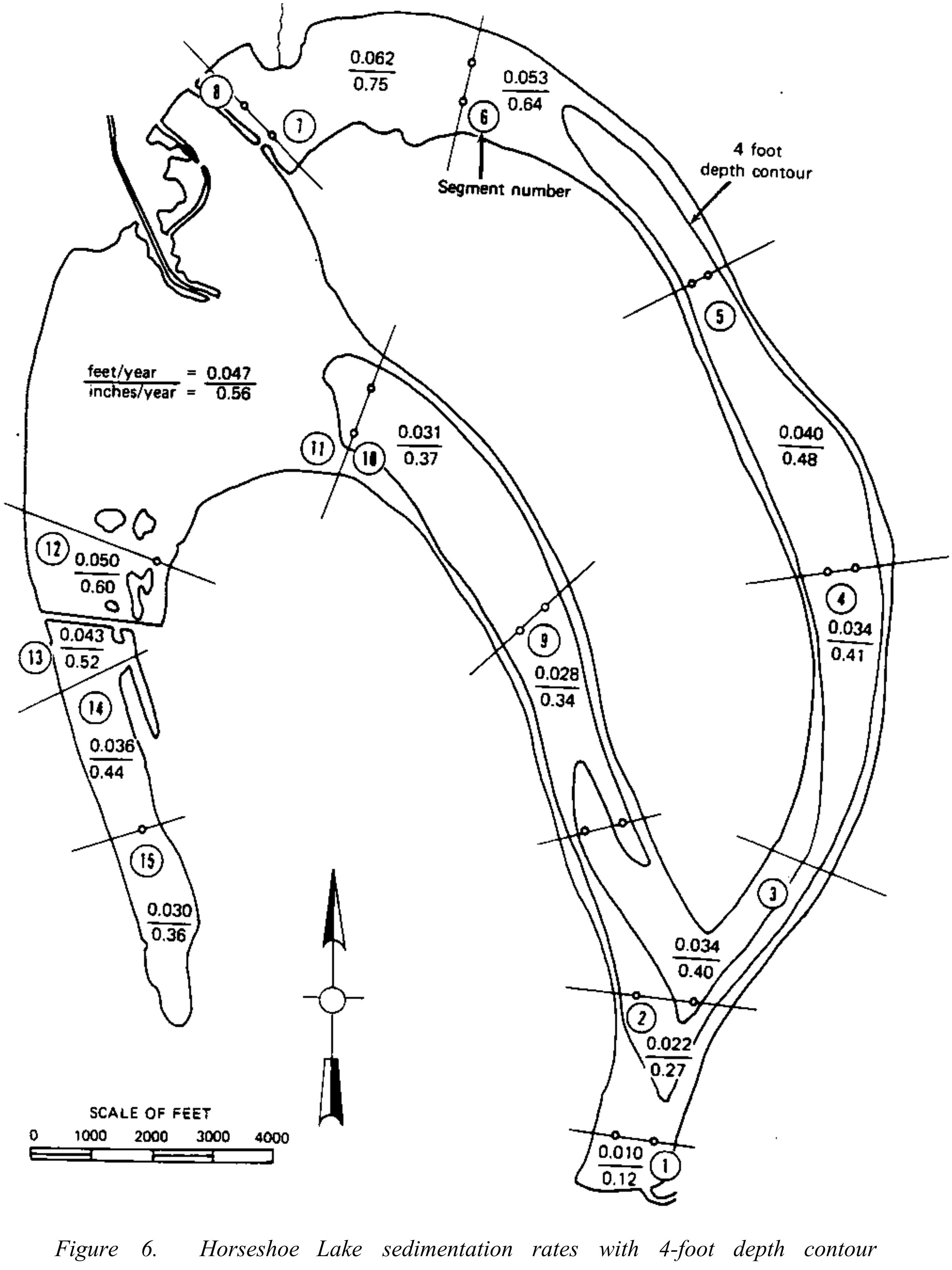


Figure 6. Horseshoe Lake sedimentation rates with 4-foot depth contour

The 1,154,000 tons of sediment which accumulated in Horseshoe Lake from 1951 to 1984 correspond to an accumulation rate of 33,900 tons per year or 2.58 tons per watershed acre per year. This figure includes the sediment input from the watershed as well as the large mass of organic material accumulated directly in the lake from plant detritus and animal droppings (biological sources). It does not take into account sediment inputs to the lake as a result of Ohio River and Mississippi River backwaters. Water samples collected by the Water Survey in spring 1984 indicate that this source contributes less than 1 percent of the total sediment budget of the lake.

Organic inputs to the lake average 3400 tons per year or 1.72 tons per lake acre per year. Subtracting the annual organic input from the total sediment accumulation in the lake yields 30,500 tons per year of non-organic sediment accumulation or 2.32 tons per watershed acre per year.

It should not be expected that these rates will remain constant. Over the years, significant changes can occur in the lake-stream-watershed system. For example, changes in watershed land use might change erosion rates, stream channelization or diversion might reduce sediment delivery to the lake, and continuing accumulation of sediment in the lake will almost certainly change patterns of deposition in the lake. Modifications of this type have occurred previously in the system and can happen in the future. Initiating a program of lake sedimentation monitoring is a first step in the evaluation of the impact these modifications will bring.

Water Quality Analyses

One of the major objectives of this investigation is an assessment of the water quality characteristics of the lake waters. The detailed and extensive data gathered during this study can serve as background information for gauging any changes in lake water quality conditions resulting from subsequent implementation of a lake and watershed management plan.

Methods

To assess the current conditions of the lake, certain physical, chemical, and biological characteristics of the lake were monitored from

March 1984 to March 1985. The lake was monitored on a once-a-month basis. Although six sampling locations in the lake were initially selected, the one in the Miller City arm of the lake proved to be inaccessible due to very shallow water depths. Therefore five lake stations were used for routine sample collections and monitoring purposes. The locations of these lake stations are shown in figure 5.

In-situ observations for water temperature, dissolved oxygen, and secchi disc transparencies were made at all the stations. An oxygen meter, Yellow Spring Instrument Company model 54, with a 50-foot probe, was standardized in lake surface water. Dissolved oxygen content was determined by the modified Winkler method as outlined by the American Public Health Association et al. (1980). Temperature and dissolved oxygen measurements were obtained in the water column at 1-foot intervals commencing from the surface of the lake.

For measuring secchi disc transparencies, an 8-inch-diameter secchi disc with black and white quadrant markings attached to a calibrated line was used. The disc was lowered until it disappeared from view, and the depth of immersion of the disc was noted. The disc was lowered farther and then raised slowly until it reappeared. Again the depth of immersion was noted. The average of these two observations was recorded as the secchi disc readings.

Water samples for chemical analyses were obtained from each station at 1 foot below the surface. For ammonia and nitrate determinations, water samples were filtered at the lake site through 0.45-micrometer millipore filters to prevent biomodification of the dissolved nitrogen forms. Surface water samples were obtained for phytoplankton identification and enumeration. Water samples in a volume of 380 ml were collected for algal identification and enumeration, preserved with 20 ml of formalin at the time of collection, and stored at room temperature until examined. All the samples were shipped through UPS to the State Water Survey's Water Quality Section at Peoria, Illinois, for analyses. The samples for chemical analysis were kept refrigerated until the analyses were performed.

Laboratory analyses were performed to determine total suspended and dissolved solids, volatile suspended solids, turbidity, pH, alkalinity, total and dissolved phosphorus, nitrate-nitrogen, and ammonia-nitrogen.

The methods and procedures involved in these determinations are given in table 5.

For algal identification and enumeration, the sample was thoroughly mixed and a 1-ml aliquot was pipetted into a Sedgwick Rafter Cell. A differential interference contrast microscope equipped with a 10X or 20X eyepiece, 20X or 100X objective, and a Whipple disc was used for identification and counting purposes. Five short strips were counted. The algae were identified as to species and were classified into five main groups: blue-greens, greens, diatoms, flagellates, and others. For enumeration, blue-green algae were counted by trichomes. Green algae were counted by individual cells except for Actinastrum, Coelastrum, and Pediastrum, which were recorded by each colony observed. *Scenedesmus* was counted by each cell packet. Diatoms were counted as one organism regardless of their grouping connections. For flagellates, a colony of Dinobryon or a single cell of Ceratium was recorded as a unit. Dimensions of the individual species of algae were determined using a wide-field Filar Micrometer eyepiece after calibrating it with a Leitz stage micrometer.

A macrophyte survey of the lake was conducted by Donald M. Garver of IDOC on September 12, 1984. The results are included later in this section.

In-situ sediment oxygen demand (SOD) rate determinations were made at stations 1 to 4. Station 5 was inaccessible because of low water level. In-situ measurement of sediment oxygen demand rates consists essentially of confining a known volume of water over a given bottom area. For this investigation, a small box-type sampler 12 × 7 × 6 inches in size, made of 3/16-inch welded steel plate, was used. The dissolved oxygen (DO) drop within the confined waters was monitored with a galvanic cell oxygen probe equipped with a stirrer. The stirrer-probe combination was implanted internally in the sampler. The details regarding the sampler, field procedures, and SOD rate evaluation techniques have been given by Butts and Evans (1979).

Table 5. Analytical Procedures

pH	Glass electrode method with portable Metrohm-Herisau meter (model E588)
Alkalinity	Potentiometric method; titration with standard sulfuric acid solution to an end point pH of 4.3
Turbidity	Nephelometric method, using Turner Fluorometer, model 110; Formazin used as a standard
Total solids	Residue on evaporation overnight on a steam bath at 103-105°C
Suspended solids	Dry weight of solids retained on gooch crucible with fiberglass filter
Suspended volatile solids	Loss on ignition of suspended solids at 550°C in a muffle furnace for 1 hour
Total phosphorus	Sample was digested with sulfuric-nitric acid mixture and determined by ascorbic acid method
Total dissolved phosphorus	Sample was first filtered through 0.45 μm filter paper, digested with sulfuric acid mixture, and determined by ascorbic acid method
Ammonia-N	Phenate method
Nitrate-N	Chromotropic method

Results

Physical Characteristics

Temperature and Dissolved Oxygen. The thermal stratification of deep lakes, impoundments, and reservoirs in the temperate zone is a natural phenomenon. Even very shallow lakes (5 to 10 feet) under certain conditions are known to exhibit thermal gradients of 6°C in 5 feet of water (Hill et al., 1981a, 1981b). Most of the physical, chemical, and biological characteristics of impounded waters are functions of temperature. Closely related to temperature variation in lake water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. Together, these two interrelated forces are capable of creating strata of water of vastly differing characteristics.

Where the depth of an impoundment or lake is significant, the thermal stratification acts as an effective barrier to wind-induced mixing. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion mechanism. As a result, when the benthic sediments exert a high demand, the oxygen resources of the hypolimnetic zone are quickly exhausted, and anoxic conditions prevail in the lake bottom waters during the warm summer months. Hill et al. (1981a) reported this to be true even in a lake with a 5-foot depth (Lake Ellyn).

The dissolved oxygen and temperature profiles for stations 1, 3, and 5 are shown respectively in figures 7a, 7b, and 7c. Because the water depths at these stations were 4 feet or less except during May 1984, the temperatures in the water columns were very nearly uniform. Maximum water temperatures were reached in the lake during June and July, and the highest recorded temperature was 31.2°C for station 5 on July 16, 1984.

The water depth at station 1 was 9 feet during the May 1984 sampling and monitoring of the lake. At this time, the Mississippi River floodwaters were backing into the Horseshoe Lake system. There were correspondingly significant increases in water depths at all the other stations also.

Even though the lake remained well mixed as evidenced by the temperature data, significant gradient in the dissolved oxygen concentrations existed between the surface and deeper waters during the summer months (June to August). During this period, the surface waters

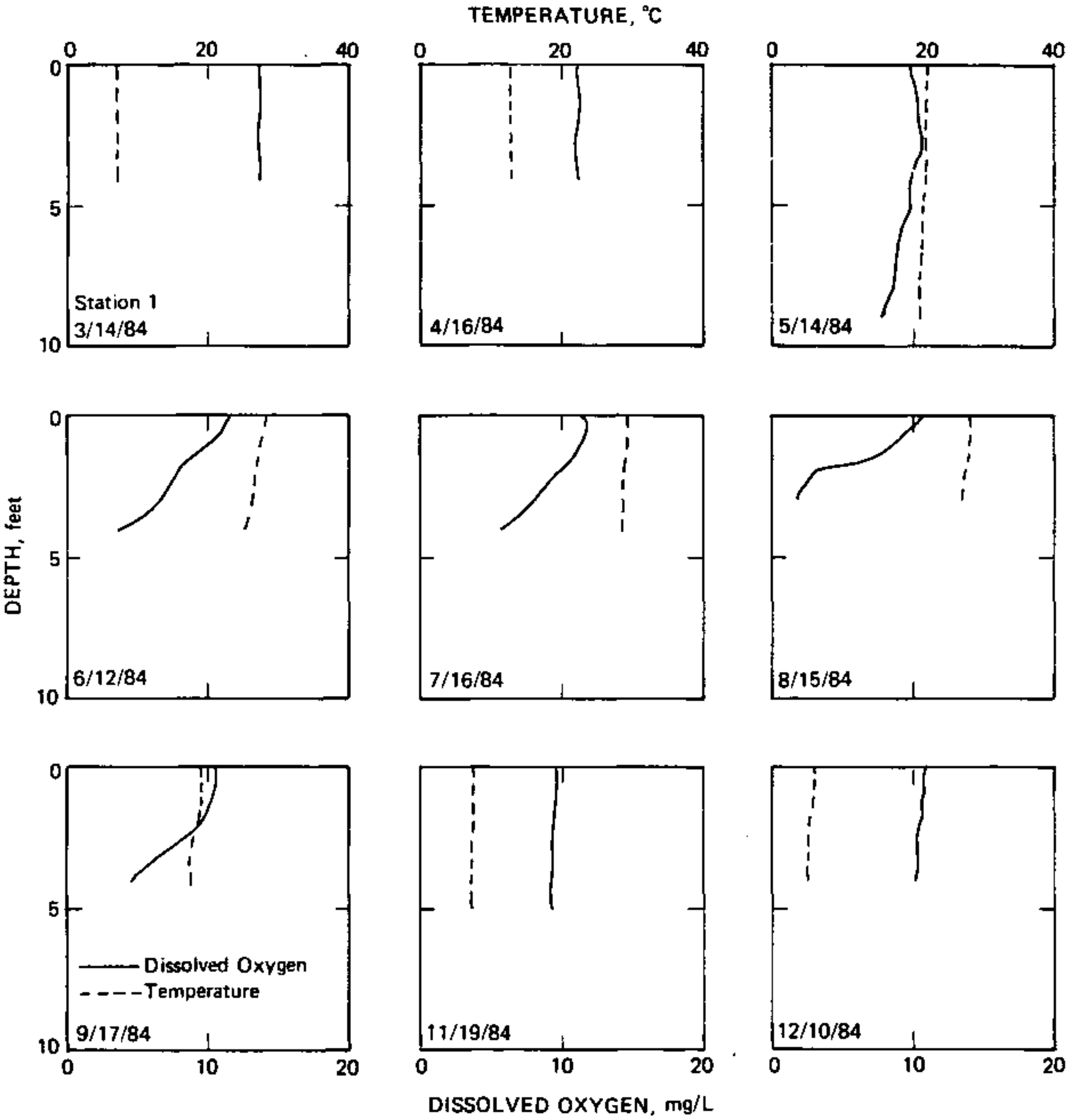


Figure 7a. Dissolved oxygen and temperature profile at station 1

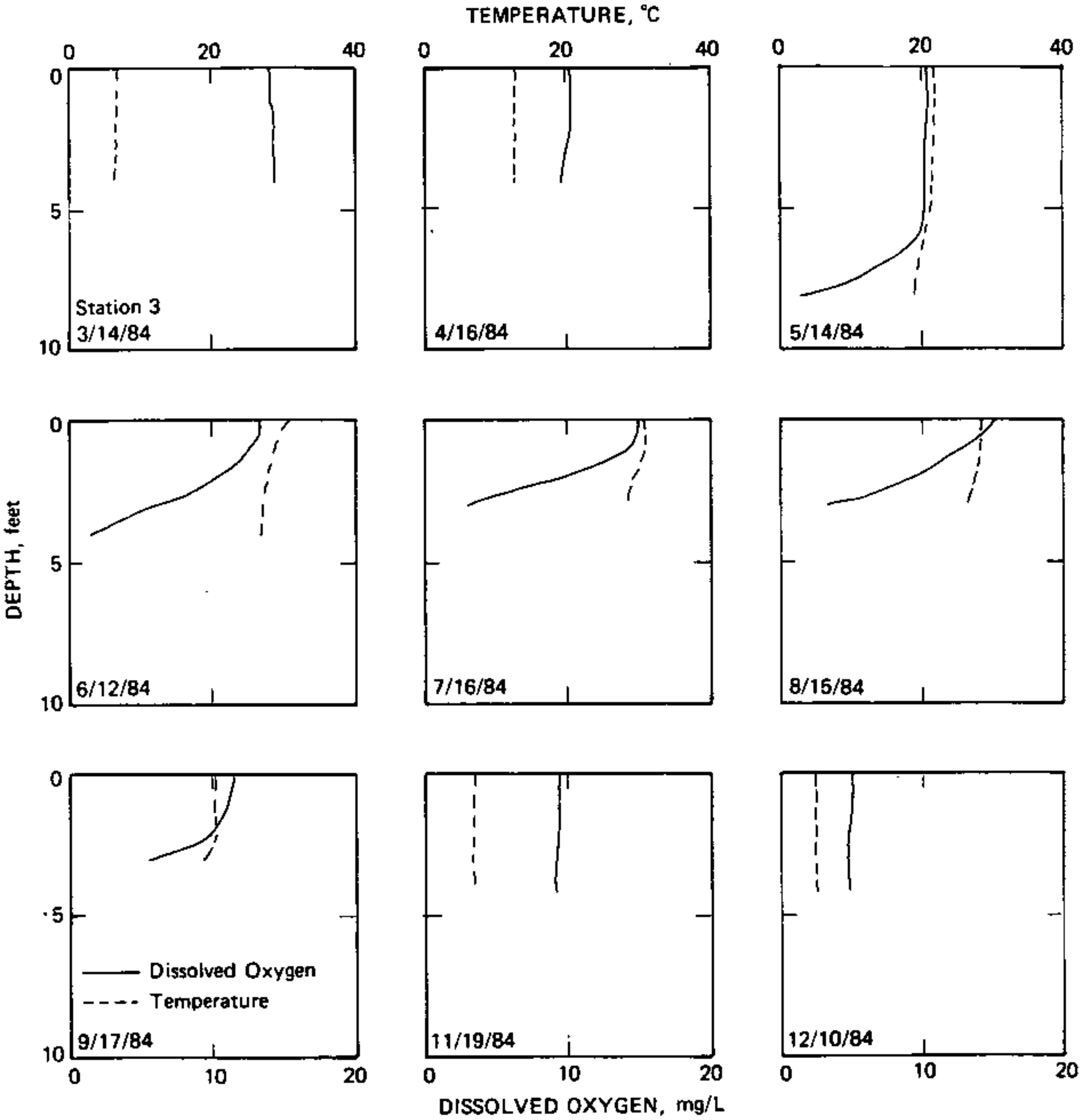


Figure 7b. Dissolved oxygen and temperature profile at station 3

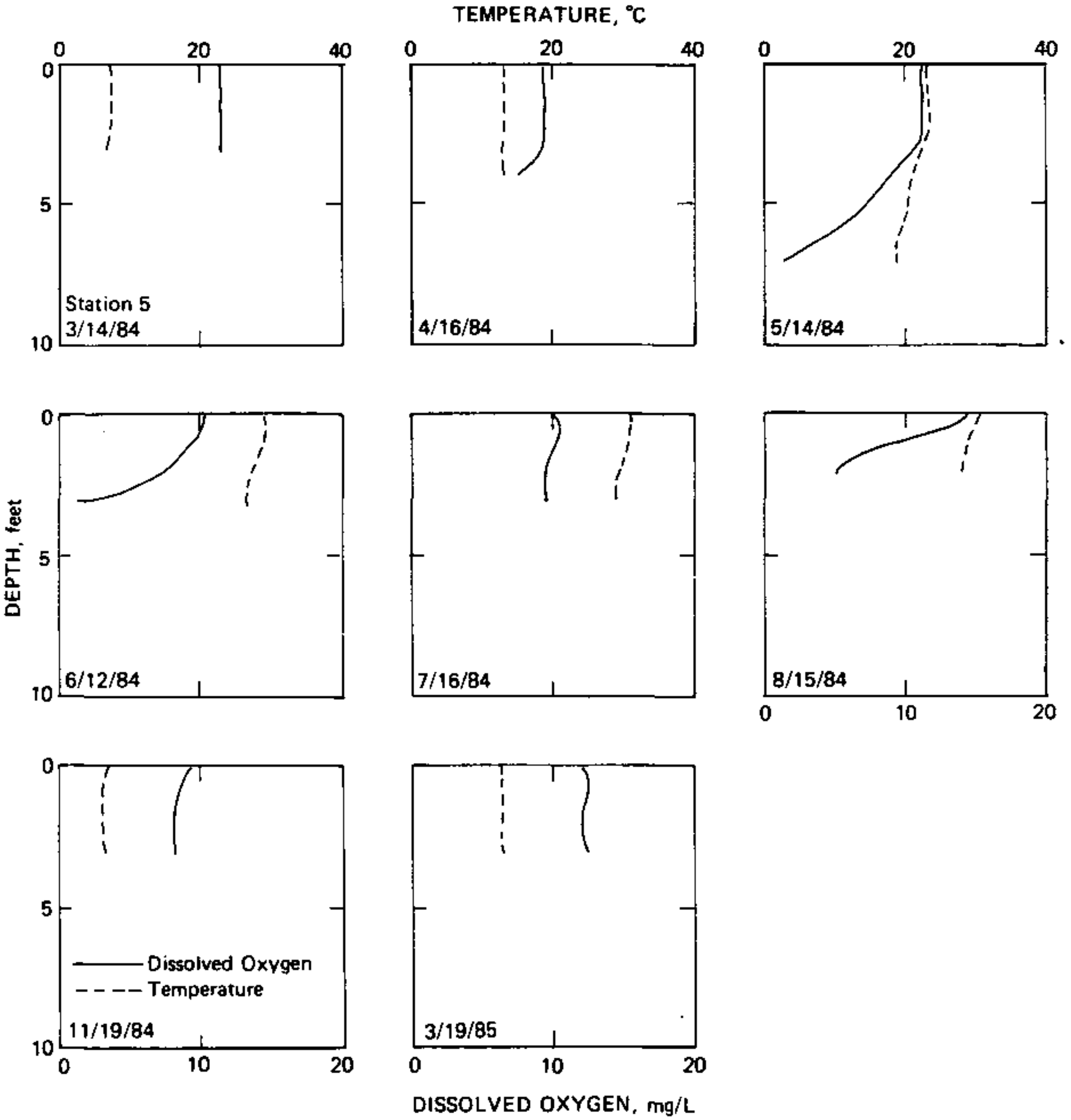


Figure 7c. Dissolved oxygen and temperature profile at station 5

exhibited supersaturated conditions due to profuse algal growths in the lake. At the same time, the near bottom waters were practically anoxic. This is because the oxygen demands exerted by the organically rich bottom sediments at the elevated summer temperatures were much higher than the rates at which oxygen was replenished from the atmosphere. A similar phenomenon was reported by Hill et al. (1981a) for Lake Ellyn. Except during the summer months, the dissolved oxygen conditions in the lake were uniform at each station. The observed dissolved oxygen and temperature data for all five stations are included in appendix 3.

Secchi Disc Transparencies. Secchi disc visibility is a measure of the lake water transparency or its ability to allow light transmission. Even though the secchi disc transparency is not an actual quantitative indication of light transmission, it serves as an index and a means of comparing similar bodies of water or the same body of water at different times. Since changes in water color and turbidity in a deep lake are generally caused by aquatic flora and fauna, transparency is often related to this entity. However, in shallow lakes with depths less than 10 feet, the transparency values are affected by inorganic particulate matter in addition to the organic matter. Autochthonous sources of particulate matter include bottom sediment disturbance by wind action and by bottom feeding fish such as carp and catfish. Erosion from the watershed during intense rainstorms is the primary allochthonous source of particulate matter to small lakes.

In terms of water clarity, Horseshoe Lake is not unlike other shallow lakes in Illinois. The temporal variations in secchi disc readings for stations 1, 2, and 3 are shown respectively in figures 8a, 8b, and 8c along with the temporal variations for several other water quality characteristics. A summary of all the water quality data collected during this investigation for all the stations is given in table 6. All the raw data collected during this investigation are included in appendix 4.

The mean secchi disc values for the stations varied from 19 inches to 23 inches. The maximum water clarity of 42 inches was observed for station 1 on May 14, 1984 when the Mississippi River water was backing into Horseshoe Lake. The water depth at station 1 was 9 feet during this period, whereas it was usually only 4 feet. All other stations exhibited similar elevated secchi disc readings on this date, though not to the same

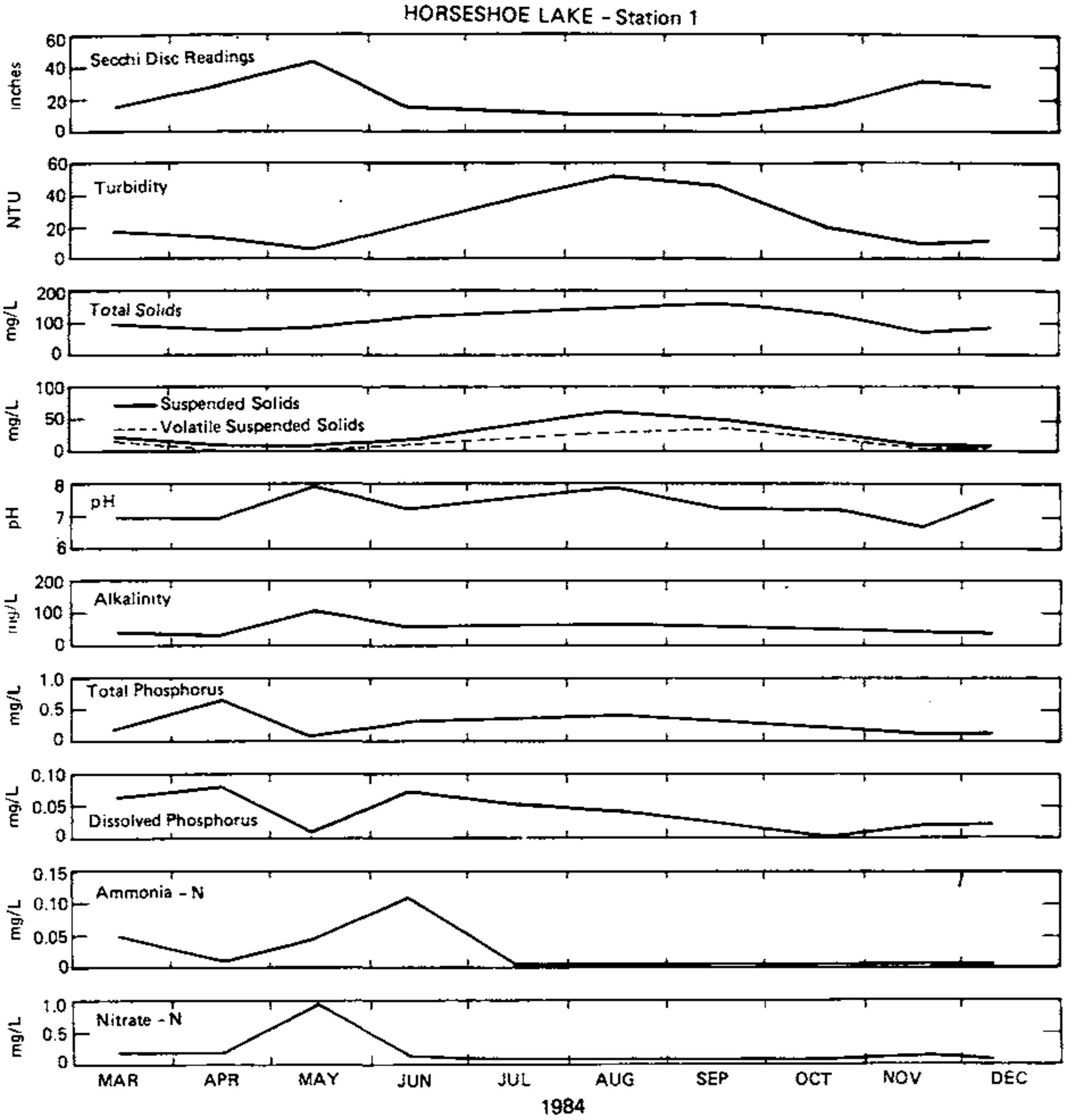


Figure 8a. Water quality characteristics at station 1

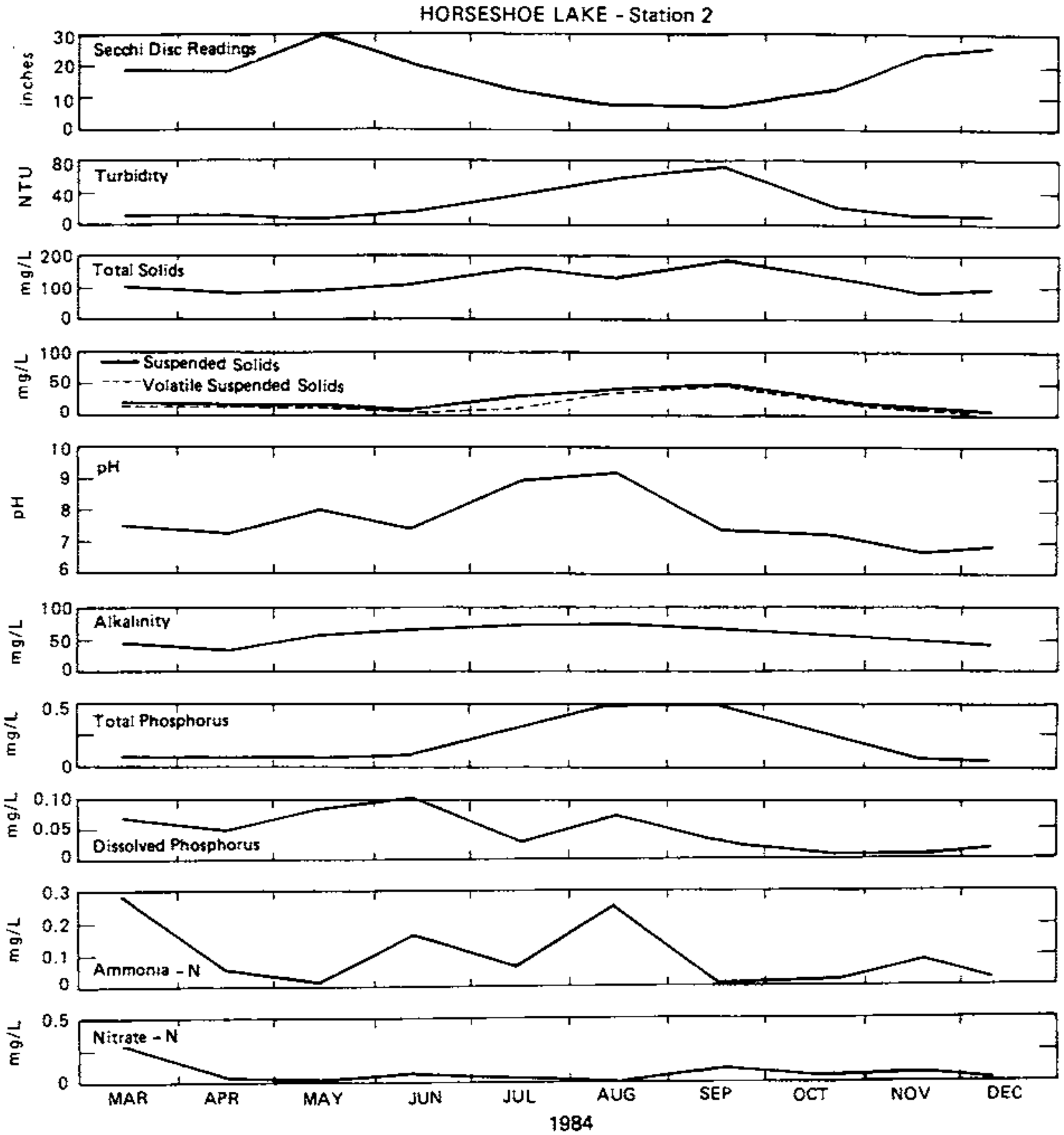


Figure 8b. Water quality characteristics at station 2

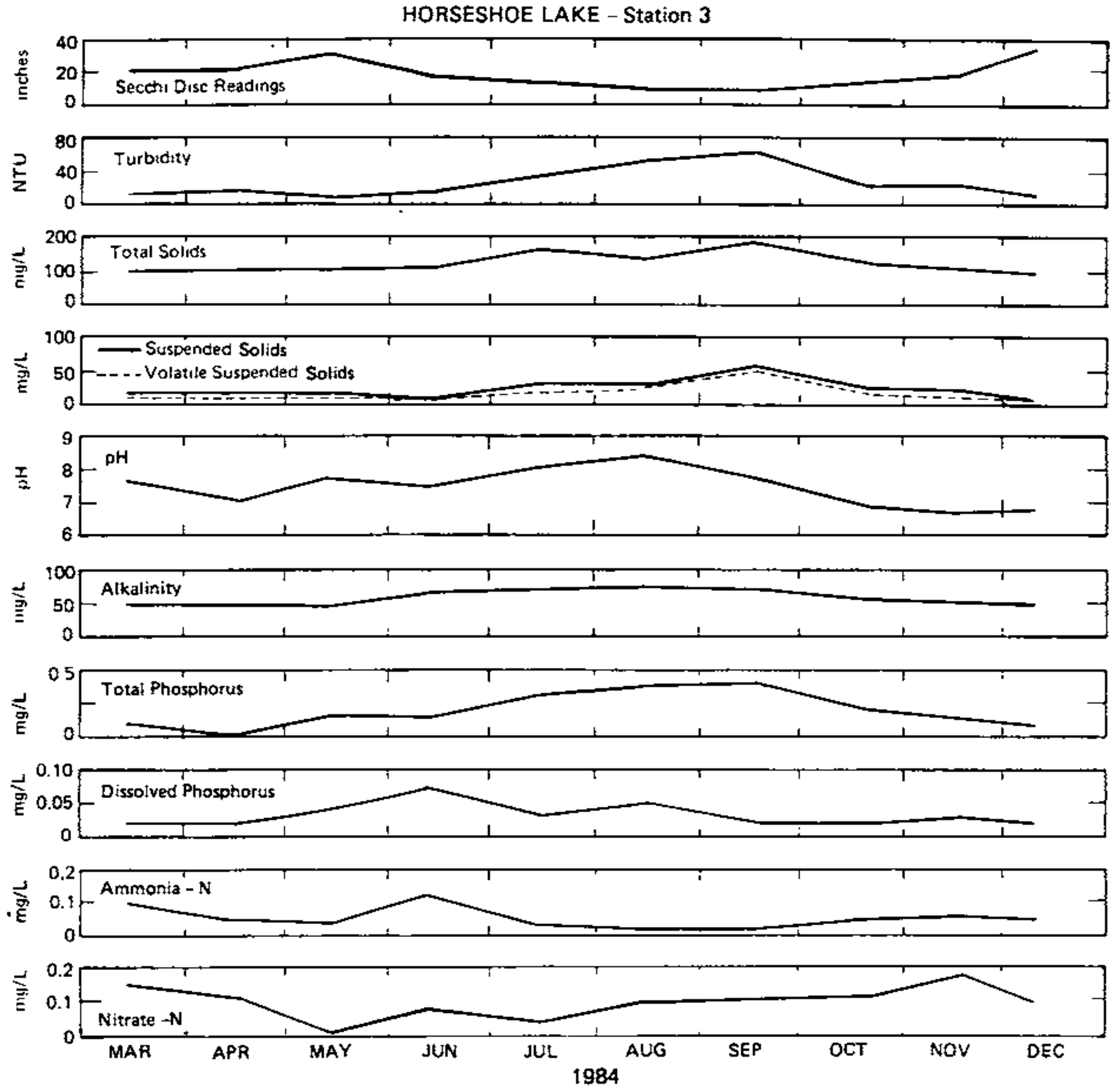


Figure 8c. Water quality characteristics at station 3

Table 6. Summary of Water Quality Characteristics in Horseshoe Lake

Parameters	Station 1			Station 2			Station 3		
	No. of observations	Mean	Range	No. of observations	Mean	Range	No. of observations	Mean	Range
Secchi readings	11	19	10-42	11	19	7-30	10	20	9-33
Turbidity	10	21	7-51	11	26	10-75	11	25	11-63
Total solids	10	109	75-165	11	120	86-187	11	124	104-187
Suspended solids	10	23	6-60	11	22	8-56	11	22	6-58
Volatile suspended solids	10	15	0-36	11	18	8-52	11	16	6-50
pH	10		6.7-7.9	11		6.7-9.2	11		6.7-8.4
Alkalinity	10	53	34-105	11	56	37-76	11	58	48-76
Total phosphate-P	10	0.25	0.07-0.63	11	0.22	0.10-0.45	11	0.20	0.03-0.40
Total dissolved phosphate-P	11	0.04	0.00-0.08	11	0.05	0.01-0.10	11	0.03	0.02-0.07
Ammonia-N	11	0.04	0.01-0.11	11	0.09	0.01-0.29	11	0.05	0.02-0.12
Nitrate-N (Dissolved)	11	0.18	0.06-0.93	11	0.08	0.03-0.32	11	0.10	0.01-0.18

Parameters	Station 4			Station 5		
	No. of observations	Mean	Range	No. of observations	Mean	Range
Secchi readings	11	20	12-33	9	23	15-37
Turbidity	11	22	12-36	8	17	9-25
Total solids	11	106	74-146	8	91	67-123
Suspended solids	11	20	9-44	8	15	6-27
Volatile suspended solids	11	12	5-30	8	8	4-16
pH	11		6.7-7.8	8		6.6-7.6
Alkalinity	11	52	31-83	8	45	29-64
Total phosphate-P	11	0.18	0.10-0.30	8	0.13	0.08-0.22
Total dissolved phosphate-P	11	0.05	0.02-0.11	9	0.06	0.02-0.11
Ammonia-N	11	0.08	0.01-0.29	9	0.08	0.01-0.17
Nitrate-N (Dissolved)	11	0.15	0.01-0.81	9	0.11	0.03-0.24

Units of measurement: Secchi readings - inches; turbidity - NTU; pH - dimensionless; others - mg/L extent as station 1. The mean and range of values found in Horseshoe Lake were similar to the values for another lake, Horseshoe Lake in Madison County, reported by Hill et al. (1981b).

Turbidity. High turbidity affects the aesthetic quality of water. Its origins are generally considered to be municipal and industrial wastes; clastic materials derived from the drainage basin; soil erosion resulting from agricultural practices and urban and highway development; sediments in shallow lakes stirred by wind, waves, and high-speed boating activities; and detrital remains of algae and aquatic and terrestrial plants and animals. However, in the case of Horseshoe Lake, some of these causative agents are absent, including industrial wastes, urban development, and high-speed boating activities.

Since the turbidity measurement is based on the scattering of light, turbidity is a function not only of the number of particles (silt, clay, or algae) but also of the shape and size of the particles and of the water color. Figure 8 reveals the inverse correlation between the secchi disc readings and the turbidity values for stations 1, 2, and 3. The mean turbidity values for the lake ranged from 17 to 26 NTU with a maximum observed value of 75 NTU at station 2. The turbidity values increased in the lake during summer months, primarily because of algal blooms in the lake. The mean turbidity and range of values observed for this Horseshoe Lake (Alexander County) are about twice as high as the values reported by Hill et al. (1981b) for the other Horseshoe Lake (Madison County).

Total Solids, Suspended Solids, and Volatile Suspended Solids. Total solids, as presented here, include total dissolved solids and suspended solids. In natural waters, the dissolved solids consist mainly of carbonates, bicarbonates, sulfates, chlorides, phosphates, and nitrates of calcium, magnesium, sodium, and potassium with traces of iron, manganese, and other substances. The constituent composition of these minerals is to a large extent dependent on the geochemistry of the area contributing to the surface water or ground-water resource. The amount of suspended solids found in impounded waters is small compared with the amount found in streams because solids tend to settle to the bottom in lakes. However, in shallow lakes this aspect is greatly modified by wind and wave action and by the type and intensity of use to which these lakes are subjected.

All salts in solution change the physical and chemical nature of the water and exert an osmotic pressure. Some have physiological as well as toxic effects. However, possible synergistic or antagonistic interactions between mixed salts in solution may cause the effects of salts in combination to be different from those of salts occurring separately.

The suspended sediment concentrations for Horseshoe Lake (table 6) were found to be half or less than half of the values reported for Horseshoe Lake (Madison County) and for Nippersink Lake, a shallow glacial lake in the Fox Chain of Lakes (Hill et al., 1981b). However, the waters of Horseshoe Lake (Madison County) were found to be highly mineralized with mean dissolved solids varying from 532 to 711 mg/L in different sampling sites (ibid). The dissolved mineral content for Horseshoe Lake (Alexander County) was only about one-fifth of the values reported by Hill et al. (1981b). The suspended matter in the lake is predominantly volatile and consequently organic in nature (figure 8). In general, organic matter constitutes 60 to 80 percent of the suspended matter found in the lake waters.

Chemical Characteristics

pH and Alkalinity. It is generally considered that pH values above 8.0 in natural waters are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition. Photosynthesis by aquatic plants uses carbon dioxide, removing it from bicarbonate, when no free carbon dioxide exists in the water medium. Decomposition and respiration tend to reduce pH and increase bicarbonates.

The alkalinity of a water is its capacity to accept protons and is generally imparted by bicarbonate, carbonate, and hydroxide components. The species makeup of alkalinity is a function of pH and mineral composition. The carbonate equilibrium, in which carbonate and bicarbonate ions and carbonic acid are in equilibrium, is the chemical system present in natural waters.

The range of pH observed for Horseshoe Lake (table 6 and figure 8) was 6.6 to 9.2. This was much less than the range of 6.7 to 10.4 reported for Horseshoe Lake (Madison County) by Hill et al. (1981b). Also the mean alkalinity values observed during this investigation were only about half the values reported for the Madison County Horseshoe Lake. In spite of high densities of algal growth in the lake during summer months, the pH values did not increase and the alkalinity values did not decrease (figure 8), as would normally be the case. As the sediment oxygen demand in this lake is extremely high, as will be discussed in detail subsequently, the mineralization of the lake bottom organic sediments under anaerobic conditions at the mud-water interface appears to counteract the effects of algal blooms. Decomposition under anoxic conditions tends to depress the pH and increase the alkalinity values.

Phosphorus. Phosphorus as phosphate may occur in surface waters or ground waters as a result of leaching from minerals or ores, natural processes of degradation, or agricultural drainage. Phosphorus is an essential nutrient for plant and animal growth and, like nitrogen, it passes through cycles of decomposition and photosynthesis.

Because phosphorus is essential to the plant growth process, it has become the focus of attention in the entire eutrophication issue. With phosphorus being singled out as probably the most limiting nutrient and the one most easily controlled by removal techniques, various facets of phosphorus chemistry and biology have been extensively studied in the natural environment. To prevent biological nuisance, the Illinois Pollution Control Board (1979) stipulates, "Phosphorus as P shall not exceed 0.05 mg/L in any reservoir or lake with a surface area of 20 acres or more or in any stream at the point where it enters any reservoir or lake."

Unlike nitrate-nitrogen, phosphorus applied as fertilizer is held tightly to the soil. Most of the phosphorus carried into streams and lakes from runoff over cropland will be in the particulate form. On the other hand, the major portion of phosphate-phosphorus emitted from municipal sewer systems is in a dissolved form. This is true of phosphorus generated from anaerobic degradation of organic matter in the lake bottom. Consequently, the form of phosphorus -- particulate or dissolved --is indicative of its source to a certain extent.

From his experience with Wisconsin lakes, Sawyer (1952) concluded that aquatic blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus are in excess of 0.3 and 0.01 mg/L, respectively. These critical levels for nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature.

A summary of the observations for total and dissolved phosphate-phosphorus in the lake is given in table 6. Temporal variations in phosphorus content in the lake are depicted in figures 8a, 8b, and 8c. Even the lowest observed total phosphorus was 3 to 10 times higher than the critical value suggested by Sawyer (1952). The mean dissolved phosphorus levels in the lake varied from 0.03 to 0.06 mg/L. These phosphorus concentrations pertain to the near surface water samples. However, the phosphorus levels in the near bottom waters during summer months would have been significantly higher due to the mineralization of the organic-rich bottom sediments in the lake.

The ratios of mean dissolved phosphorus to total phosphorus for the lake varied from 0.15 at station 3 to 0.28 at station 4. Only station 5 exhibited a high ratio of 0.46. The values for stations 1 to 4, ranging from 0.15 to 0.28, compared well with similar values reported for Horseshoe Lake in Madison County (Hill et al., 1981b). This indicates that on an average 72 to 85 percent of the phosphorus in the lake waters is in particulate form.

Nitrogen. Nitrogen in natural waters is generally found in the form of nitrate, organic nitrogen, and ammonia-nitrogen. Nitrate's are the end product of the aerobic stabilization of organic nitrogen, and as such they occur in polluted waters that have undergone self-purification or aerobic treatment processes. Nitrates also occur in percolating ground waters. Ammonia-nitrogen, a constituent of the complex nitrogen cycle, results from the decomposition of nitrogenous organic matter. Ammonia-nitrogen can also result from municipal and industrial waste discharges to streams and rivers.

The concerns about nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because traditional water treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/L in public water supplies. Second, a concentration in excess of 0.3 mg/L is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1952).

Nitrogen is one of the principal elemental constituents of amino acids, peptide, proteins, urea, and other organic matter. Various forms of nitrogen -- for example, dissolved organic nitrogen and inorganic nitrogen such as ammonium, nitrate, nitrite, and elemental nitrogen -- cannot be used to the same extent by different groups of aquatic plants and algae.

Vollenweider (1968) reports that in laboratory tests, the two inorganic forms of ammonia and nitrate are as a general rule used by planktonic algae to roughly the same extent. However, Wang et al. (1973) reported that during periods of maximum algal growth under laboratory conditions, ammonium-nitrogen was the source of nitrogen preferred by plankton. In the case of higher initial concentrations of ammonium salts, yields were noted to be lower than with equivalent concentrations of nitrates (Vollenweider, 1968). This was attributed to the toxic effects of ammonium salts. The use of nitrogenous organic compounds has been noted by several investigators, according to Hutchinson (1957). However, Vollenweider (1968) cautions that the direct use of organic nitrogen by plankton has not been definitely established, citing that not one of 12 amino acids tested with green algae and diatoms was a source of nitrogen when bacteria-free cultures were used. However, the amino acids were completely used up after a few days when the cultures were inoculated with a mixture of bacteria isolated from water. He has opined that in view of the fact that there are always bacterial fauna active in nature, the question of the use of organic nitrogen sources is of more interest to physiology than to ecology.

The mean and range of values for ammonia-nitrogen and nitrate-nitrogen in the lake are included in table 6, and the temporal variations in these parameters are shown in figures 8a, 8b, and 8c. Mean inorganic nitrogen (total of ammonia-nitrogen and nitrate-nitrogen) varied in the lake from 0.15 mg/L at station 3 to 0.23 mg/L at station 4, with all the other stations having values in between. These values are about half to three-fourths of the critical value for readily available nitrogen suggested by Sawyer (1952) from the perspective of lake eutrophication. The ammonia-nitrogen values observed in Horseshoe Lake were within the limits stipulated by the IPCB and did not reach levels which could be toxic to sports fisheries.

Mineral Content. Table 7 shows the results of chemical analyses performed for a few anions and cations in Horseshoe Lake samples for selected dates during 1984. The waters of the lake are relatively soft (hardness: approximately 55 mg/L as $CaCO_3$) compared to the lakes in the northern part of the state (hardness approximately 250 mg/L as $CaCO_3$). The chloride and sulfate concentrations were low except during the period when the Mississippi River backed into the lake (May 1984). The values for chloride, sulfate, and hardness were much higher during May 1984 than during April and June 1984. The Mississippi River water generally had beneficial effects on the water quality characteristics of the lake, including improved clarity, reduced suspended sediments, and reduced turbidity.

The values for heavy metals measured indicated that they were well within IPCB's standards for general water quality except for iron, which exceeded the standard of 1.0 mg/L in 5 out of 13 observations.

Table 8 shows some of the results of analyses of water quality characteristics of the lake reported by the Illinois Environmental Protection Agency. The values shown in table 6 are in good agreement with the IEPA observations except those for nitrate-nitrogen.

Sediment Oxygen Demand. The results of the sediment oxygen demand (SOD) measurements in the lake are given in table 9. Included in the table, for purposes of comparison, are the results for Horseshoe Lake in Madison County, which is also an oxbow lake of the Mississippi River and is of similar size and depth to Horseshoe Lake in Alexander County. The station locations for the Madison County lake can be found in the report by Hill et al. (1981b).

The sediments of the Alexander County lake at stations 1, 3, and 4 exhibit similar oxygen uptake rates, while the rate for sediments at station 2 is significantly higher. All the SOD rates corrected to 25°C for the Alexander County Horseshoe Lake are higher than the highest rate observed in the Madison County lake. The rates of sediment oxygen demand at 25°C were computed using the following equation:

$$SOD_T = SOD_{25} (1.047^{T-25}) \quad (2)$$

Table 7. Concentrations of a Few Anions and Cations in Horseshoe Lake Samples on Selected Dates

Stations	Chloride. mg/L			Sulfate. mg/L			Hardness mg/L			Iron. mg /L		
	4/16	5/14	6/12	4/16	5/14	6/12	4/16	5/14	6/12	8/15	9/17	10/22
1	1.4	10.8	0.0	11.0	40.0	9.0	54.0	159.0	53.0	0.77	1.16	0.69
2	1.2	2.4	2.0	12.0	16.0	9.0	56.0	76.0	70.0	0.89	1.17	0.79
3	1.2	1.0	1.6	15.0	9.0	10.3	66.0	66.0	75.0	1.20	1.26	0.93
4	0.4	6.0	2.0	14.0	29.0	9.3	46.0	116.0	76.0	0.60	1.04	0.97
5	0.2	1.8	1.6	12.0	17.0	9.5	46.0	80.0	68.0	-	-	0.83

Stations	Manganese, mg/L			Lead. mg/L			Zinc. mg/L		
	8/15	9/17	10/22	8/15	9/17	10/22	8/15	9/17	10/22
1	0.43	0.48	0.29	<0.014	<0.014	<0.014	0.008	0.012	0.018
2	0.58	0.76	0.42	<0.014	<0.014	<0.014	0.021	0.019	0.015
3	0.50	0.63	0.27	<0.014	<0.014	<0.014	0.014	0.025	0.018
4	0.32	0.53	0.22	<0.014	<0.014	<0.014	0.020	0.024	0.014
5	-	-	0.12	-	-	<0.014	-	-	0.020

Note: All the data were collected in 1984.

Table 8. Water Quality Data Reported by the Illinois EPA*

Parameters	Lake stations (6/7/79) 1 (1)	2 (3)	3 (5)	Lake stations (8/29/79) 1 (1)	2 (3)	3 (5)
Secchi readings	18	15	15	8	7	10
Turbidity	10	18	22	24	48	32
Suspended solids	34	50	39	44	95	49
Volatile suspended solids	17	17	13	26	60	22
pH	7.4	7.6	7.3	8.5	8.6	7.7
Alkalinity	50	45	50	40	45	40
Total phosphate-P	0.32	0.36	0.25	0.35	0.51	0.34
Dissolved phosphate-P	0.09	0.08	0.06	0.03	0.10	0.03
Ammonia-N	0.04	0.07	0.17	0.01	0.01	0.01
Nitrate-N	0.02	0.01	0.01	0.00	0.00	0.00
Chloride	3	3	3	4	4	3
Sulfate	7	8	7	5	5	5
Iron	0.84	0.97	1.20	1.10	2.00	1.60
Manganese	0.48	0.46	0.41	0.65	0.92	0.43
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Note: Lake station designations within parentheses indicate the sampling sites selected for this investigation that are closest to the lake sites for which the IEPA reported water quality data

Secchi readings - inches; turbidity - NTU; pH - dimensionless; others - mg/L

*Provided by Marion office, Illinois EPA

Table 9. Results of In-situ Measurements of Sediment Oxygen Demand Rates

Stations	Alexander Co. lake (8/16/84) Ambient temp. °C	SOD rates, $g/m^2/d$* Ambient temp. °C	 25°C	Madison Co. lake (8/30/78) SOD rates g/m2/d* at 25°C
1	28.0	5.10	4.46	
2	27.5	7.27	6.58	3.92
3	26.8	5.26	4.85	2.40
4	28.0	4.47	4.04	2.50
7				3.50
8				3.96

* 3-5 $g/m^2/d$ is classified as a significant organic enrichment of the bottom sediments on the basis of 100 SOD measurements made in Illinois by the Water Quality Section, Illinois State Water Survey

where

SOD_T = sediment oxygen demand at any temperature, T°C

SOD_{25} = sediment oxygen demand at 25°C

On the basis of approximately 100 SOD measurements in Illinois streams and lakes, the Water Quality Section has subjectively classified SOD rates into pollutional classes. Rates falling between 3.0 and 5.0 grams per square meter per day indicate a significant organic enrichment of the bottom sediments. The results of the SOD measurements are not surprising because the lake serves as a wintering habitat for a large number of waterfowl.

Biological Characteristics

Algae. The total algal counts and the species distribution of algae found in the lake during May to October 1984 are shown in table 10. Except for the observations at station 5 during August and October, algal counts in the lake were found to be of bloom proportions (>500 cts/ml). The algal counts found in the lake are comparable to the values reported for the Madison County lake for the corresponding periods (Hill et al., 1981b).

The relative dominance of algal types found in the lake is shown in table 11. In May, diatoms appear to be the dominant species in the lake. In June and July green algae dominate, and in the later part of the summer blue-green algae begin to dominate. Blue-green algae create unsightly conditions in the lake by forming algal scum under quiescent lake conditions.

The significant influences of algae in the lake on water transparency and corresponding suspended solids and turbidity were documented previously.

Macrophytes. The results of the macrophyte survey made on September 12, 1984, by Donald M. Garver of the Illinois Department of Conservation are shown in figure 9. Two species of rooted vegetation -- American lotus and coontail -- were the dominant macrophyte species in the lake. Their areal extent is delineated in figure 9.

Lotus grows profusely in the northwest sector of the lake. It is most prevalent north of Wicker Dump Road in the Ben Worthington Resort Area, in the delta of Black Creek, and northwest of the island road. Lotus growth was formerly present in approximately 3 acres of the lake south of the

Table 10. Algal Types and Densities in Horseshoe Lake

Station 1

Dates	BG	G	D	F	T
5/14/84		450	1160		1610
6/12/84					
7/16/84	3620	21160	4670	890	30340
8/15/84	9980	27930	3990		41900
9/17/84	18380	12390	2470		33240
10/22/84	13440	5040	3730	420	22630

Station 2

Dates	BG	G	D	F	T
5/14/84		550	1400		1950
6/12/84	800	810	240	140	1990
7/16/84	2730	18640	1890	890	24150
8/15/84	14700	25880	2260		42840
9/17/84	23260	1365			24620
10/22/84	15020	1890	2570	50	19530

Station 3

Dates	BG	G	D	F	T
5/14/84	90	530	1360	40	2020
6/12/84	580	27830	1000		29410
7/16/84	3200	13550	5410		22160
8/15/84	9980	34440			44420
9/17/84	29450	2100			31550
10/22/84	5570	3310	4670	840	14390

Station 4

Dates	BG	G	D	F	T
5/14/84		770	630	470	1870
6/12/84		31550	890	370	32810
7/16/84	1110	1200	410	60	2780
8/15/84	5670	12290	2150	160	20270
9/17/84	15020	4930	5410	410	25770
10/22/84	1060	570	590		2220

Station 5

Dates	BG	G	D	F	T
5/14/84		820	700		1520
6/12/84		18480	1000	370	19850
7/16/84	240	470	60		770
8/15/84		380			380
9/17/84					
10/22/84	100	20	70	10	200

Note: BG = blue-greens; G = greens; D = diatoms; F = flagellates; T = total

Table 11. Relative Dominance of Algal Types in Horseshoe Lake (Percent of total)

	Station 1					Station 2				
Dates	BG	G	D	F	T	BG	G	D	F	T
5/14/84		28.0	72.0		100		28.2	71.8		100
6/12/84					100	40.2	40.7	12.1	7.0	100
7/16/84	11.9	69.7	15.5	2.9	100	11.3	77.2	7.8	3.7	100
8/15/84	23.8	66.7	9.5		100	39.3	60.4	5.3		100
9/17/84	55.3	37.3	7.4		100	94.5	5.5			100
10/22/84	59.4	22.3	16.5	1.8	100	76.9	9.7	13.2	0.3	100

	Station 3					Station 4				
Dates	BG	G	D	F	T	BG	G	D	F	T
5/14/84	4.5	26.2	67.3	2.0	100		41.2	33.7	25.1	100
6/12/84	2.0	94.6	3.4		100		96.2	2.7	1.1	100
7/16/84	14.4	61.2	24.4		100	39.9	43.2	14.7	2.2	100
8/15/84	22.5	77.5			100	28.0	60.6	10.6	0.8	100
9/17/84	93.3	6.7			100	58.3	19.1	21.0	1.6	100
10/22/84	38.7	23.0	32.5	5.8	100	47.7	25.7	26.6		100

	Station 5				
Dates	BG	G	D	F	T
5/14/84		53.9	46.1		100
6/12/84		93.1	5.0	1.9	100
7/16/84	31.2	61.0	7.8		100
8/15/84		100			100
9/17/84					100
10/22/84	50.0	10.0	35.0	5.0	100

Note: BG = blue-greens; G = greens; D = diatoms; F = flagellates; T = total

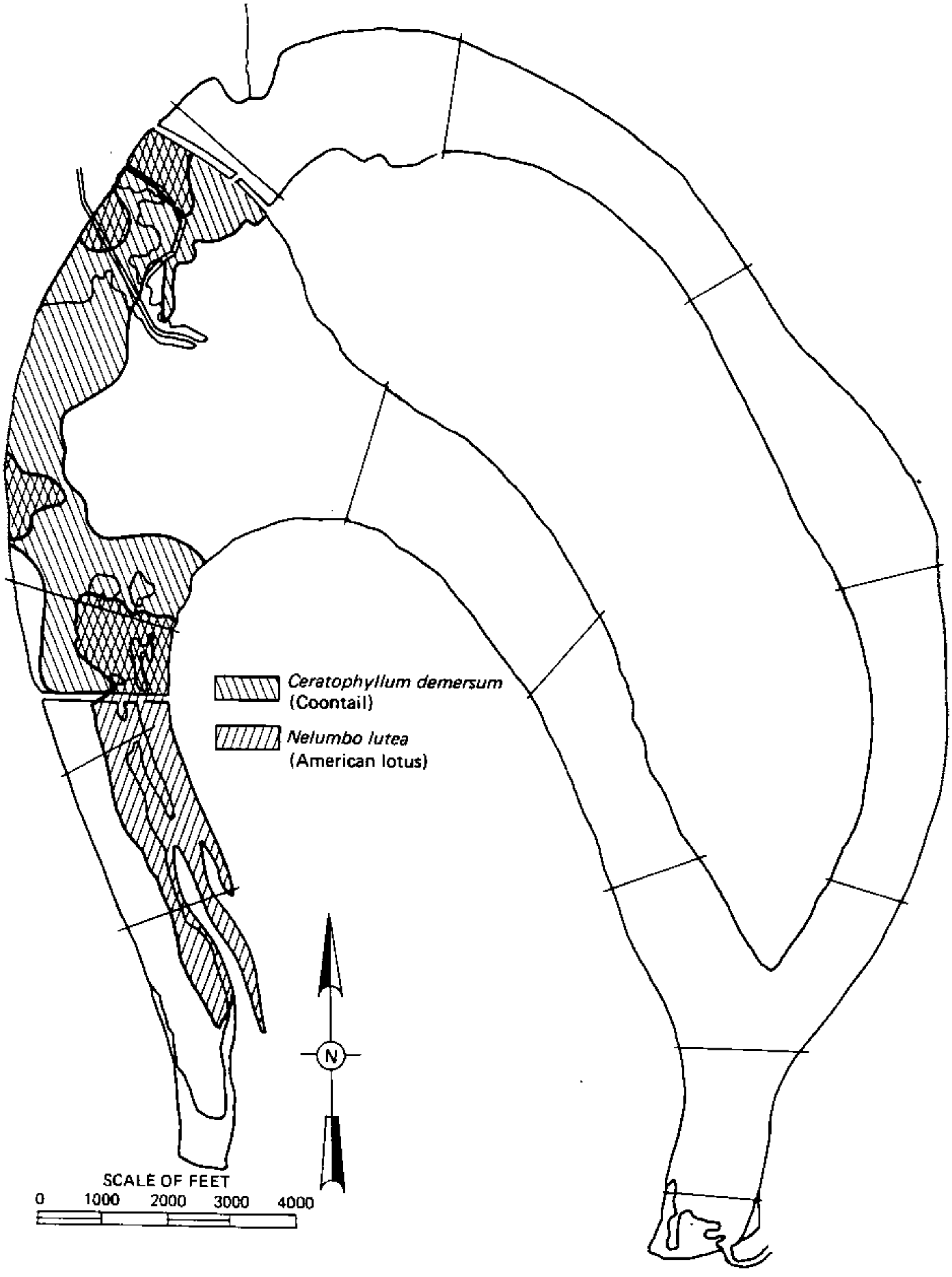


Figure 9. Types and areal extent of macrophytes in Horseshoe Lake

ferry landing and in 1 acre near the dam. These two areas were chemically treated and the lotus was eliminated over a period of several years. Lotus growth is present in very small patches in various areas of the lake which are not shown in figure 9, because in all cases the growths extend less than 5 feet from the shoreline.

Coontail is present principally in the northwest sector of the lake between the island road and Wicker Dump Road. Coontail also grows in various other areas of the lake in small patches within 5 feet of the shoreline.

Table 12 lists other species of vegetation found in the lake on the date of this survey and indicates their relative abundance. The growth areas of all emergent species other than lotus were confined to the immediate shoreline. Donald Garver reports that the less abundant species which are confined to shoreline growth areas have not increased significantly in density or diversity within the last 20 years.

Summary

Horseshoe Lake in Alexander County was monitored to assess its water quality characteristics from March 1984 to March 1985 on a once-a-month basis. In-situ observations for dissolved oxygen, temperature, and secchi disc readings and sample collections for chemical and biological analyses were made at five locations in the lake during this period.

As the lake is very shallow, temperatures were found to be uniform through the water column at any given time. However, dissolved oxygen concentrations tend to exhibit a significant gradient during summer months, from supersaturated conditions near the surface to totally anoxic conditions near the bottom. The lake's sediment oxygen demand rates ranged from 4.04 to 6.58 $mg/m^2/d$ at 25°C. These high rates, combined with the fact that the average volatile fraction of the suspended solids was very high (average: 68 percent), are indicative of very high organic enrichment of the bottom sediments.

In terms of water clarity, Horseshoe Lake is not unlike other shallow lakes in Illinois. The mean secchi disc values for the stations varied from 19 to 23 inches. The lake exhibited highest clarity when the Mississippi River floodwaters backed up into the lake system during the early part of May 1984. The mean turbidity values for the lake ranged from

Table 12. Relative Abundance of Macrophytes in Horseshoe Lake

Ceratophyllum demersum	(Coontail)	1
Nelumbo lutea	(American lotus)	1
Pontederia cordata	(Pickerel weed)	3
Jussiaea repens	(Creeping water primrose)	3
Sagittaria latifoloa	(Common arrowhead)	4
Typha latifolia	(Common cattail)	4
Pianthera americana	(American water-willow)	4
Potamogeton nodosus	(American pondweed)	5
Polygonum fluitans Eaton	(Water smartweed)	5

Note: 1 = abundant; 2 = common; 3 = present; 4 = limited; 5 = very limited

17 to 26 NTU. The dissolved mineral content of the lake was only about one-fifth of that reported for Horseshoe Lake in Madison County. The suspended matter in the lake was predominantly volatile and consequently organic in nature.

The pH values of the lake samples varied from 6.6 to 9.2. The alkalinity varied from 29 to 105 mg/L as $CaCO_3$. These values were about half the values reported for the Madison County Horseshoe Lake.

The mean phosphorus values ranged from 0.03 to 0.06 mg/L, which is much higher than the commonly reported critical level of 0.01 mg/L from the eutrophication perspective. However, the inorganic nitrogen concentrations (nitrate-nitrogen plus ammonia-nitrogen) measured for the lake samples were below the critical level of 0.3 mg/L for nitrogen.

The waters of the lake were relatively soft (hardness: 55 mg/L as $CaCO_3$) compared to the lakes in the northern part of the state. The concentrations of chloride and sulfates were very low. The values for heavy metals indicated that they were within the Illinois Pollution Control Board standards for general water quality except in the case of iron.

The lake experienced algal blooms with densities greater than 500 cts/ml during late spring and summer months. American lotus and coontail were the predominant rooted vegetation in the lake during September 1984.

Hydrologic Analyses

The watershed of Horseshoe Lake was monitored from January 1984 through April 1985. Data were collected on precipitation, lake stage, stream stage, discharge, and ground-water levels. When possible, long-term records were used to compare the period of monitoring to the long-term period. Collection of these data was necessary to construct a hydrologic budget.

The construction of a hydrologic budget is an important first step before sediment loading may be assessed. The general utility of any lake depends on the quantity of water in the lake at any time as well as its physical and chemical quality. Without a hydrologic budget a clear and specific lake and watershed management alternative cannot be proposed.

Methods

A hydrologic budget is based on a solution of the following: the inflow minus the outflow equals the change in storage. Whether the inflow or the outflow is greater will determine if the change in storage is a positive or negative quantity. As shown in figure 10, there are a number of components of inflow and outflow that are taken into account in the hydrologic budget (Lee, 1979; Makowski and Lee, 1983).

The first step of the hydrologic budget is to identify components. The most obvious component is precipitation. Precipitation contributes the major part of the inflow, directly or indirectly. A portion of the precipitation that falls on the ground may be lost to interception, evapotranspiration, depression storage, and infiltration, which may be collectively referred to as "losses." Some of the precipitation lost to infiltration may return to the lake as ground-water inflow. The portion of the precipitation which is not part of these losses enters the lake as runoff. Precipitation which falls on the lake will experience no losses and therefore is a direct contribution to the inflow. Inflow may also come from pumpage into the lake, ground-water flow, backwater, or other sources.

Outflow in the hydrologic budget can include evaporation, flow over the spillway, transpiration, and losses mentioned previously. Ground water may contribute to either the inflow or the outflow depending on the location of the water table with respect to the lake level.

The hydrologic system of Horseshoe Lake is quite complex. The lake is shallow with a large surface area compared to the watershed area, and is subject to periodic flooding by the Mississippi River. The watershed consists of two different parts: a steep bluff area which contributes runoff quickly, and a flat wetland area that contributes runoff slowly. The wetland can also serve to store excess water within its system.

Results

The individual components of the hydrologic budget will be discussed in the following order: precipitation, runoff, backwater, ground water, evaporation, lake water level, and transpiration.

Precipitation. Precipitation initiates the inflow process to the lake, directly or indirectly. Precipitation, in the context of this

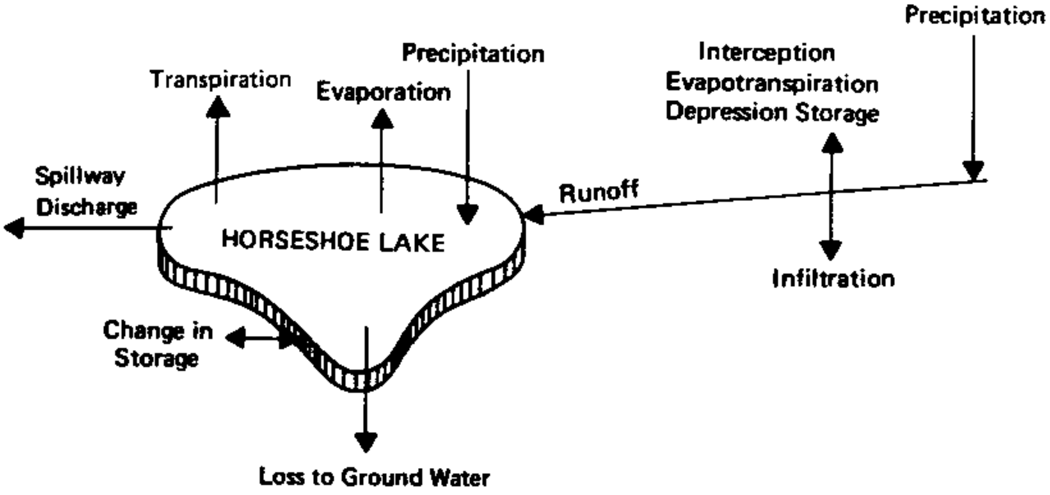


Figure 10. Components of the hydrologic budget of Horseshoe Lake

report, is either rain or snow, although the significant precipitation events are usually rain in this part of the state.

Two precipitation gages were operated by Illinois State Water Survey (ISWS) personnel and one was operated by the National Weather Service (NWS) as seen in figure 11. Thirteen months of data were collected. The daily totals are presented in appendix 5.

Long-term and monthly precipitation data were collected for Cairo, Illinois. From January 1984 through April 1985 the precipitation was 10.74 inches, or 17 percent, above normal. When only the part of the monitoring period from April 1984 through April 1985 is considered, the precipitation is 13.29 inches, or 22 percent, above normal. The majority of this above-average precipitation fell during three months: October and December 1984, and April 1985. The largest precipitation deficit occurred during three months: January, June, and August 1984. The monthly precipitation values are presented in table 13. Variations in the precipitation recorded for the gages are due to differences in spatial distribution of precipitation and to missing data. To accurately describe the amount of precipitation that fell on the watershed and to account for missing data, the daily precipitation amounts, recorded at the three gages located on the watershed, were averaged.

Monthly precipitation summaries are useful in assessing an average condition, although rainfall may vary greatly within a month. Individual precipitation events can yield valuable information. The frequency with which precipitation can be expected to be equaled or exceeded is used to assess the magnitude of the precipitation that fell on the watershed. The return interval, usually having the unit of years, is the reciprocal of the probability. By using regionalized results of Huff and Neill (1970) and Huff (1974), along with the precipitation that was recorded by ISWS gages (NWS data were daily amounts), the recurrence intervals of the events can be calculated. Recurrence intervals were assigned for the entire event duration as well as for the maximum 5-, 30-, and 60-minute precipitation amounts. Only recurrence intervals above a 2-year frequency could be found for events with durations above 60 minutes. The results are presented in appendix 6. Recurrence intervals of 2.81 and 2.78 years were computed for an event occurring on December 21, 1984. For the two ISWS stations, recurrence intervals of 3.14 and 2.29 years were found for an event of

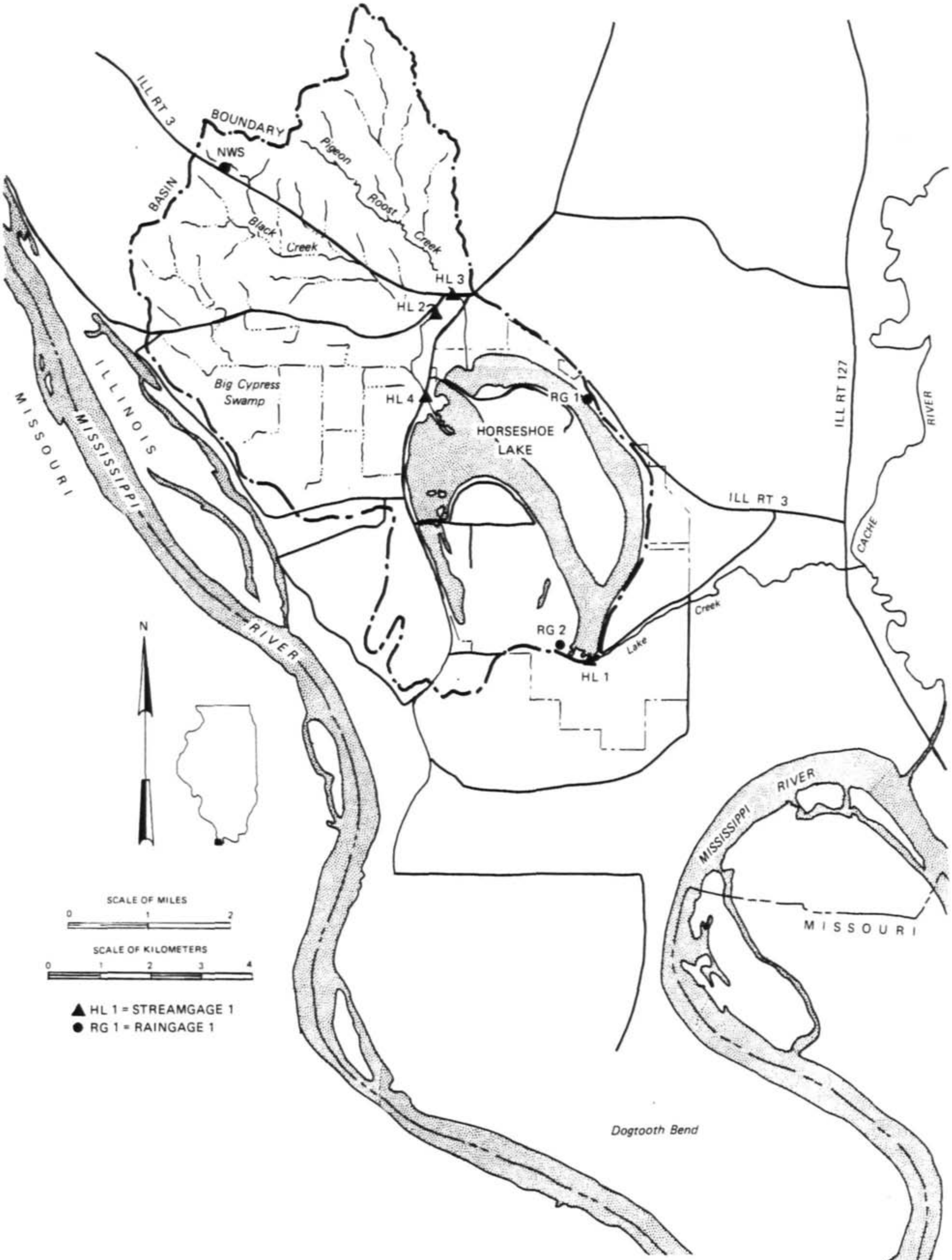


Figure 11. Locations of monitoring stations

Table 13. Monthly Precipitation
(Inches)

Date	Cairo precip.[1]	Departure from normal	RG1[2]	RG2[3]	NWS[4] Olive Branch	Averaged precip.
1984						
January	1.25	-2.22			1.33	1.33
February	3.16	-0.26			3.97	3.97
March	4.89	-0.07			6.36	6.36
April	6.40	1.96	0.13*	1.48*	4.94	4.33
May	4.88	-0.02	2.55*	5.00	4.50	4.15
June	1.71	-2.65	2.06	1.57	1.93*	2.10
July	5.79	1.83	1.23*	3.46	2.74	2.89
August	1.05	-2.92	0.86	0.94	1.35	1.05
September	4.40	0.90	5.37	5.80	4.98	5.41
October	7.89	5.35	11.77	10.08	9.80*	10.67
November	4.33	0.36	4.34*	4.97	7.41	6.19
December	10.07	5.91	5.91*	7.58	5.98*	7.98
1985						
January	*	*	0.90*	1.31*	1.52	1.64
February	3.27	-0.15	2.61*	2.31*	4.19	4.03
March	4.83	-0.13	5.07*	5.12*	5.66	5.75
April	7.29	2.85	5.29	5.85	6.53	5.99
Totals	71.21	+10.74	48.09	55.46	69.00	73.84

[1] National Oceanic and Atmospheric Administration data
[2] RG1 is located along the east arm of the lake
[3] RG2 is located near the spillway
[4] NWS is located along Route 3 in the northwest portion of the watershed

* Missing or incomplete data

April 26, 1985. These data suggest localized intense precipitation. The highest concentration of intense precipitation fell from the middle of September through the middle of November 1984 and again in late March through April 1985. However, the month of December 1984 experienced only one exceptional rainfall. The remainder of the monthly surplus was a result of almost daily precipitation.

Runoff. The portion of the precipitation that falls on the land surface and is not lost to interception, evapotranspiration, depression storage, or infiltration will enter the lake as runoff. Runoff may enter the lake by a defined stream channel or directly overland. Since it is not feasible to monitor every source of runoff into the lake, four locations were selected as monitoring sites. Three sites were on the two major tributaries, Pigeon Roost Creek and Black Creek. One site was located at the spillway of the lake.

The location of the monitoring sites must satisfy certain hydraulic and hydrologic criteria. The hydrologically suitable sites situated very near the lake proved to be poor hydraulic sites due to the backwater of the lake, which caused variable stage-discharge relationships. Therefore the sites had to be moved upstream. Their locations are shown on figure 11. Black Creek at Fayville Road was designated as HL2 and Pigeon Roost Creek was called HL3. These sites had continuous stage recorders. The site on Black Creek at Miller City Road, referred to as HL4, had no recorder, although stage was recorded periodically. The stage at the spillway, HL1, was collected daily.

No long-term runoff data are available for comparison in this part of the state. The small drainage areas of these watersheds further compound the data analysis problem. The distances between the nearest long-term stations and the site of investigation are excessive, and spatial differences in runoff are quite large; therefore the data from the nearest long-term stations are not useful for comparison purposes.

The monthly runoff values are presented in table 14 and the daily values in appendix 7. Also presented in table 14 are the runoff ratios. A runoff ratio (runoff divided by precipitation) indicates the amount of precipitation that results in runoff. The average watershed precipitation values computed in the previous section were used. A low runoff ratio signifies high losses and generally occurs in summer when the soil is dry,

Table 14. Monthly Runoff
(Inches)

	HL1			HL2		HL3		HL4	
Date	Flow over the spillwav	Backwater	Runoff	Runoff	Runoff ratio	Runoff	Runoff ratio	Runoff	Runoff ratio
1984									
March*	1.920	0	1.920	2.334		2.994		1.651	
April	1.888	1.726	0.162	1.365	.28	1.611	.33	2.046	.41
May	8.731	3.183	5.548	1.664	.42	1.616	.41	2.686	.68
June	0.330	0	0.330	0.144	.07	0.067	.03	.234	.11
July	0.003	0	0.003	0.154	.05	0.097	.03	.251	.09
August	0.000	0	0.000	0.001	.00	.009	.01	.012	.01
September	0.000	0	0.000	0.080	.01	0.091	.02	.135	.02
October	0.226	0	0.226	1.742	.16	0.886	.08	2.661	.25
November	1.676	0	1.676	3.354	.54	2.625	.42	5.168	.83
December	2.928	0	2.928	5.074	.63	3.933	.49	6.011	.76
1985									
January	2.755	0	2.755	0.410	.25	0.165	.10	2.129	**
February	2.618	0.200	2.418	3.234	.80	2.807	.70	5.013	**
March	6.859	3.281	3.578	2.987	.44	2.901	.42	2.216	.14
April	4.856	0	4.856	2.225	.37	2.294	.38	5.181	.86
Totals				24.768	.35	22.096	.30	35.394	.53
Area (acres)	15177			2348		2227		6314	

HL1 - Horseshoe Lake spillway
HL2 - Black Creek at Fayville Road Bridge
HL3 - Pigeon Roost Creek at Route 3 Bridge
HL4 - Black Creek at Miller City Road Bridge

* Incomplete data for month
** Influenced by backwater

evapotranspiration potential is great, and foliage is present. Conversely, high runoff ratios occur when the soil is saturated or frozen, evapotranspiration potential is minimal, and foliage is absent.

Stage-discharge relationships were determined at HL2 and HL3 by numerous measurements. In addition to these measurements, hydraulic computations were made from stream cross sections that supplemented actual discharge measurements. The stage-discharge relationship at HL1 was developed from the spillway geometry.

As mentioned previously, no continuous discharge records were available for Black Creek at the Miller City Road bridge due to backwater influence of the lake. Therefore, in order to obtain flows at HL4, the discharge measurements at this site were related to the continuous record at HL2, which represents roughly one-third of the HL4 watershed. The HL2 watershed is steep whereas the majority of the HL4 watershed is relatively flat, made up mostly of the Big Cypress Swamp. This difference precludes a computation based on a unit area. Therefore, the method described below was used.

A least squares regression using the periodic discharge measurements made at HL4 were used in conjunction with flows at HL2. Since HL2 constitutes one-third of the HL4 watershed, there should be a correlation between the runoff at the two sites. To account for attenuation of flow, various combinations of hourly data were used as independent variables to generate flows at HL4. The residuals were investigated and a stepwise correlation was used to eliminate variables. Runoff data for HL4 were then computed by using the regression equation and runoff data at HL2.

The Pigeon Roost and Black Creek watersheds are adjacent and share similar topography, so the differences between the runoff values are not significant. The drainage areas are also similar, so the 12 percent differences in the amount of runoff recorded at each site as seen in table 14 are attributed to precipitation and minor watershed differences. The highest runoff ratios occurred in November 1984 through May 1985.

In table 14 the runoff results for HL1 are significantly different from those at the other sites. This is because there was flow into the lake from the Mississippi River backwater. This was accounted for by providing three columns for HL1 in table 14: flow over the spillway, backwater, and runoff. Flow over the spillway is the flow out of the lake (outflow), backwater is flow into the lake (inflow), and runoff is the summation of flow over the spillway and backwater. No runoff ratios were calculated for HL1 since a portion of water leaving the lake entered the lake as backwater flooding and is not runoff from the watershed.

The results of the runoff computation for HL4 are also presented in table 14. The daily results as shown in appendix 7 indicate that the peak runoff at HL4 is similar in magnitude to the peak at HL2. This is because the peak flow from the bluff area moves quickly through the stream system. Rather than peak runoff receding quickly at HL4, the flow stays elevated as the flow from the Big Cypress Swamp area begins its contribution albeit more slowly. This causes the runoff at HL4 to continue long after the flow at HL2 has ceased. The runoff from one month can continue into another month due to this time lag, which can affect the runoff ratio in some cases.

The HL4 watershed definitely contributes a higher portion of runoff than does either HL2 or HL3. This may result from two factors. The first is that the ground-water level may be coincident to the ground surface in the area of Big Cypress Swamp. This would cause a continuous base flow. The second cause may relate to the Mississippi River. When the Mississippi River is in flood stage, the water can seep under the levee and recharge the ground water or flow directly into the stream system. In addition, if the floodwaters from the Mississippi River rise significantly they can enter Big Cypress Swamp. After the floodwaters recede, the water that entered the area drains slowly.

As was done with precipitation, recurrence intervals were assigned to runoff events to gage their magnitude. By using a regionalized technique (Curtis, 1977), recurrence intervals may be compiled for the monitored watersheds. Since HL2 and HL3 were monitored continuously, only these stations could be analyzed.

By using watershed parameters such as area, slope, rainfall intensity and an areal factor, recurrence intervals of 2, 5, 10, 25, 50, and 100 years may be calculated (Curtis, 1977). The recurrence intervals for peak runoff at HL2 and HL3 (table 15) indicate that the stations show general agreement at peak flows. Each site had three instantaneous peak runoff events above a 2-year recurrence interval. Average daily runoff is plotted against time in figure 12 for HL2 and HL3. As with the peak flows, each

Table 15. Recurrence Intervals of Peak Runoff at HL2 and HL3

	HL2		HL3	
Date	Peak runoff (cfs)	Recurrence interval (years)	Peak runoff (cfs)	Recurrence interval (years)
3/28/84	459.8	Less than 2	570.1	2.3
12/21/84	652.0	2.8	599.3	2.5
3/30/85	584.9	2.3	635.5	2.3
4/27/85	540.6	2.0	457.2	Less than 2

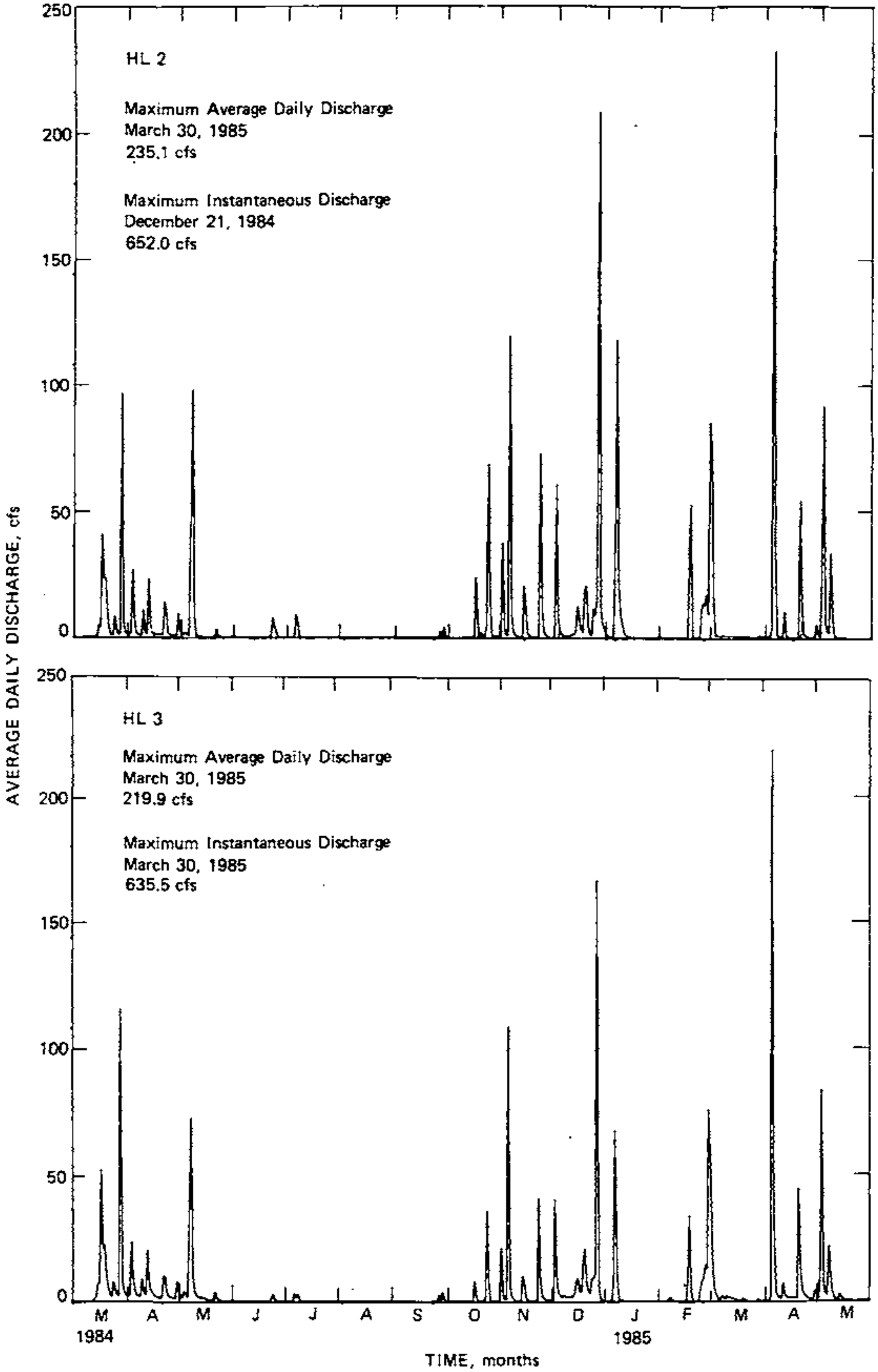


Figure 12. Daily discharge hydrographs for stations HL2 and ELS

site experienced approximately the same number of peaks, but the respective magnitudes are different. Figure 13 presents flow duration curves for HL2 and HL3. Again average daily flow values were used. The flow duration results for both sites look similar. From approximately 50 to 100 percent of the time the streams have no flow. The average daily discharge above 25 cfs is exceeded at HL2 and HL3 5 and 4 percent of the time, respectively.

Approximately 35 percent of the watershed was not monitored at all, and approximately 35 percent of the watershed is monitored continuously. The remaining 30 percent is situated in the HL4 watershed. The unmonitored portion of the watershed must be accounted for in order for a hydrologic budget to be constructed. The Horseshoe Lake watershed, as described previously, is basically made up of two distinct parts. The bluff area is monitored by HL2 and HL3 and may be characterized as having streams with rapid runoff. The remaining portions of the watershed are wetlands, and in the area west of the lake the ground water manifests itself as the baseflow. The watershed at HL4 consists of both types, bluff and wetland. These parts must be separated to provide meaningful results. If the unmonitored part of HL4 is referred to as UM4, then the following relation is assumed:

$$Q_{UM4} = [6314 \cdot Q_{HL4}) - 2348 \cdot (Q_{HL2})]/3966 \qquad (3)$$

where

Q_{UM4} = monthly runoff at UM4 in inches

Q_{HL4} = monthly runoff at HL4 in inches

Q_{HL2} = monthly runoff at HL2 in inches

The drainage areas of HL4, HL2, and the unmonitored portion of HL4 are 6314, 2348, and 3966 acres, respectively.

If this unmonitored runoff accounted for at HL4 could be spread out over the entire watershed (except the lake), the runoff into the lake could be estimated. As with the similar assumption explained previously, the equation becomes:

$$Q = [2227\ Q_{HL3} + 6314\ Q_{HL4} + 4629\ Q_{UMW}]/13,170 \qquad (4)$$

where Q is the runoff (in inches) into the lake. The drainage areas of HL2, HL4, the unmonitored portion of the watershed, and the entire watershed (excluding the lake) are 2227, 6314, 4629, and 13,170 acres, respectively. The runoff values are presented in table 16.

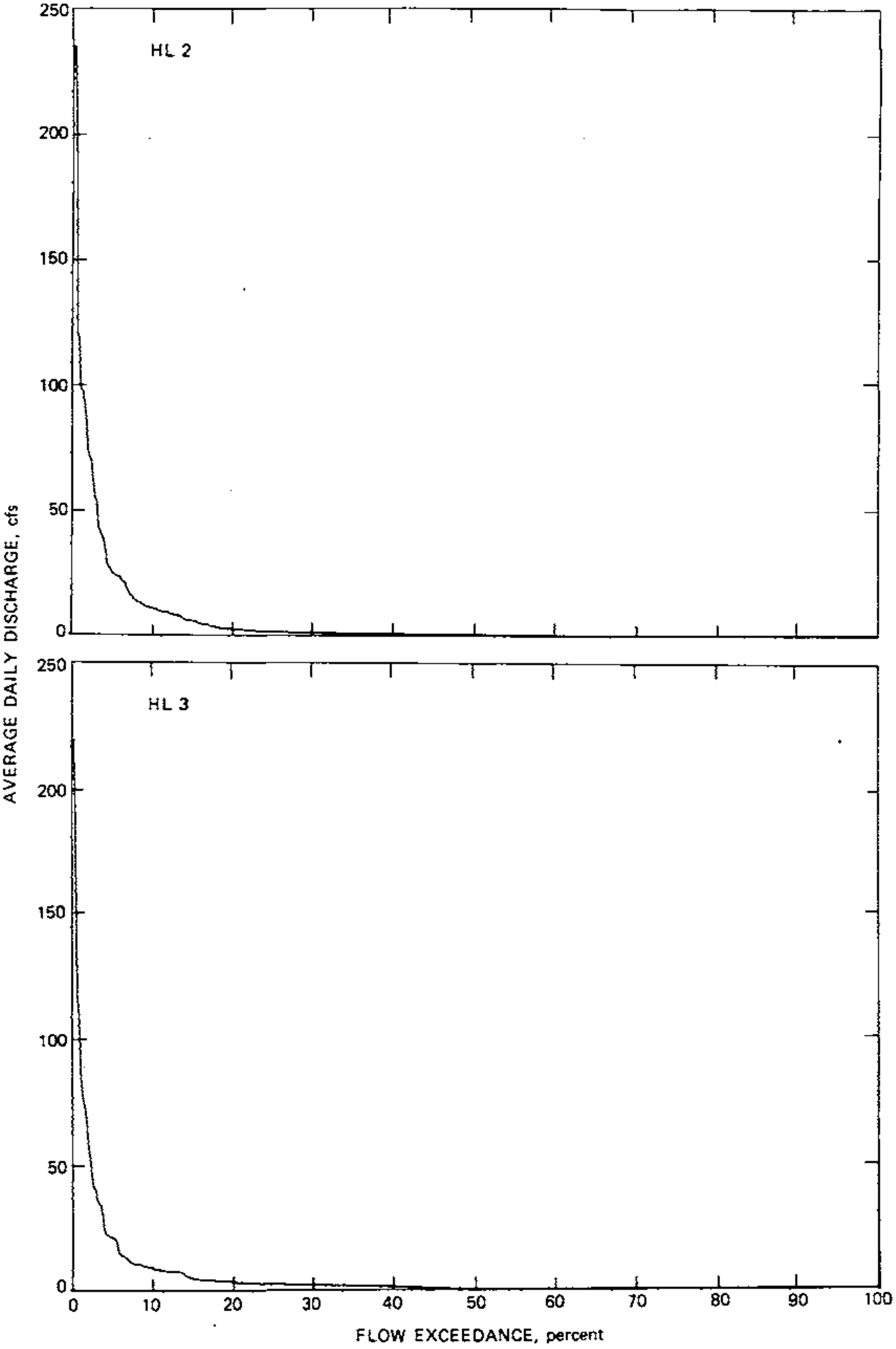


Figure 13. Flow duration curves for stations HL2 and HL3

Table 16. Watershed Runoff
(Inches)

Date	HL4	HL2	Unmonitored portion of HIT (UM4)*	HL3	Unmonitored watershed UMW	Total average runoff
1984						
April	2.046	1.365	2.449	1.611	2.449	2.114
May	2.686	1.664	3.291	1.616	3.291	2.718
June	.234	.144	.287	.067	.287	.224
July	.251	.154	.308	.097	.308	.245
August	.012	.001	.018	.009	.018	.014
September	.135	.080	.168	.091	.168	.139
October	2.661	1.742	3.205	.886	3.205	2.552
November	5.168	3.354	6.242	2.625	6.242	5.115
December	6.011	5.074	6.566	3.933	6.566	5.855
1985						
January	2.129	.410	3.147	.165	3.147	2.155
February	5.013	3.234	6.066	2.807	6.066	5.010
March	2.126	2.987	1.760	2.901	1.760	2.172
April	5.181	2.225	6.931	2.294	6.931	5.308
Total	33.743	22.434	40.438	19.102	40.438	33.621
Drainage area (acres)	6314	2348	3966	2227	4629	13170

*The portion of the watershed which is upstream of monitoring station HL4, but outside the subwatershed HL2

Backwater. Horseshoe Lake is a natural oxbow lake. As such it is subject to inflow not only from the watershed but from the Mississippi River, which originally formed the lake. Horseshoe Lake is situated approximately 15 miles upstream from the confluence of the Mississippi River with the Ohio River. Because elevated stages on either the Ohio or Mississippi River may cause the inundation of Horseshoe Lake, the backwater flooding is quite complex. The complexity is because if the stage of either river is above normal, it will influence the other such that the backwater effects will be felt upstream, thereby exacerbating potential flood conditions. In past flood studies, only the effects of runoff from the watershed were considered, and the interaction of the rivers was ignored.

Horseshoe Lake drains into Lake Creek, which flows into the lower Cache River, which discharges into the Mississippi River. At the mouth of the lower Cache River, the Mississippi River drains approximately 713,000 square miles and has an average flow of 189,000 cubic feet per second (cfs) (U.S. Army Corps of Engineers, 1978). The Mississippi River routinely backs up the lower Cache River and eventually into Horseshoe Lake if the flood is severe. The Mississippi River regularly floods the Dogtooth Bend area, and during floods exceeding a 10-year recurrence interval the river may break the spur dike. The floodwaters then flood most of the area (U.S. Corps of Engineers, 1984). Before the levees and spur dikes were built west of Horseshoe Lake and along Dogtooth Bend, the Mississippi River cut across the bend to rejoin itself further downstream as may be seen in figure 1. Though the levee construction curtailed flow, floodwaters still enter the lake.

The 1973 flood stage on the Mississippi River reached an elevation of 343.43 feet msl, the 1983 flood stage was 344.19 feet msl, and the 1984 maximum stage was 336.7 feet msl at Thebes, Illinois. Prior to the continual period of record the maximum flood elevation of 345.14 feet msl occurred in 1844. During the period of monitoring, the Mississippi River floodwaters flowed into Horseshoe Lake on five separate occasions: April 6-11, 1984; April 27-May 1, 1984; May 7-18, 1984; March 1-5, 1985; and March 8-10, 1985. Lake elevations at these times were, respectively, 322.47, 322.54, 325.66, 323.64, and 323.59 feet msl. During the 1973 flood the maximum lake elevation was reported by local observers to be roughly 338.5 feet msl.

Since there are so many independent variables, there is no direct correlation between river stage and the water level in Horseshoe Lake. However, data suggest that there probably was flow into the lake during at least 15 of the last 26 years. The data from the USGS gage at Thebes, Illinois, were used. The amount of flow entering was estimated from the collected data. Staff gages were located in Lake Creek and in Horseshoe Lake. The head differential together with the spillway and dam geometry allowed an estimation of the backwater inflow. This estimate is only an approximation because the backwater inflow can enter the lake by routes other than solely over the spillway, especially at high stages.

Ground Water. The bottom and sides of Horseshoe Lake are pervious. Because the lining of the lake is permeable, the level of the ground water is important. If the ground-water level is above the lake level, water will flow into the lake; if the ground-water level is below the lake level, water will flow from the lake.

Local well log data were used as the source of ground-water elevations as well as the type of material that lies below the ground surface. These well log records were obtained from the Illinois State Water Survey's (ISWS) Ground Water Section files. There were 25 well logs available for the immediate area of the lake. Of these, 17 well logs were from an approximate elevation of 318 feet mean sea level (msl) and 8 well logs corresponded to the current spillway elevation of 321.4 feet msl.

The available data suggest that the regional ground-water surface flows from the bluffs in the northwest near the Mississippi River to the lower Cache River in the southeast. The surface of the ground-water table appears to be coincident with the land surface in the area of Big Cypress Swamp. The regional ground-water level dips so as to be below the spillway elevation. The average ground water surface, in the area of the lake, was 314.3 feet msl. Since the spillway elevation is 321.41 feet msl, a net outflow from the lake to the ground water should be expected. The net difference between the average lake level (321.41 feet msl) and the ground water (314.3 feet msl) is 7.1 feet. The lake sedimentation survey indicated that the average depth of the lake is 2.96 feet. Therefore, the average elevation of the lake bottom is 318.4 feet msl.

Beneath the lake a clay layer extends to a depth of 30 to 40 feet. This clay is underlain by sands and gravels. The material is not homogeneous since there are lenses of sand and gravel interspersed throughout its depth. For computational purposes a value of 30 feet of clay was assumed. Since the ground surface is approximately 330 feet msl, the clay bottom should be at an elevation of about 300 feet msl. The distance which water must travel from the average lake bottom through the clay to the sand and gravels below is 18.4 feet. It was estimated that this clay has a hydraulic conductivity, K, equal to 0.005 gallons per day per square foot (gpd/ft^2) (Walton, 1965; Freeze and Cherry, 1979).

The hydraulic gradient, i, is the net difference between the lake level and ground water divided by the distance the water has to travel or 7.1 feet/18.4 feet, which is 0.386 feet per foot. Using Darcy's equation,

$$q = k \cdot i \cdot a \tag{5}$$

where

k = hydraulic conductivity, gallons per day per square foot
a = surface area of the lake, square feet
i = hydraulic gradient, feet per foot
q = discharge, gallons per day,

the discharge from the lake to the ground water is 168,675 gallons per day (gpd), or 0.26 cubic feet per second (cfs), or .0031 inches per day. The monthly discharge in inches is shown in table 17.

The results of the hydraulic computation indicate that there is little interaction between the lake and the ground water. If there was significant flow out of the lake, the lake should have periodically gone dry (before the dam was built). However, the records indicate that the lake has never gone dry. As was mentioned in the "History" section of this report, the landowner who owned the lake between about 1900 and 1920 "...started to drain the lake but gave up the attempts after two years. While he owned the property the lake became almost dry several times during extended droughts...." (John J. Mattingly, personal communication to R.J. Bushee, State Water Survey, 1934). This letter referred to a time before the spillway was constructed.

Evaporation. Monthly pan evaporation data were obtained from the National Weather Service (NWS) for Dixon Springs for the period

Table 17. Lake Evaporation and Seepage to Ground Water (Inches)

	Evaporation			
Date	Normal Carbondale	Actual Dixon Springs	Departure	Seepage to ground water
1984				
March	2.03	1.53	-0.50	.096
April	3.42	2.79	-0.63	.093
May	4.74	4.20	-0.54	.096
June	5.18	5.40	0.22	.093
July	5.62	4.98	-0.64	.096
August	4.94	4.26	-0.68	.096
September	3.70	3.61	-0.09	.093
October	2.36	1.68	-0.68	.096
November	1.29	1.29	0.00	.093
December	0.72	*	*	.096
1985				
January	0.74	*	*	.096
February	1.02	*	*	.087
March	2.03	1.91	-0.12	.096
April	3.42	3.54	0.12	.093
Totals	41.21	35.19	-3.54	1.320

*Not collected

corresponding to the months of data collection. Monthly pan to lake coefficients were used (Roberts and Stall, 1967) to estimate the evaporation from Horseshoe Lake. The long-term evaporation data were obtained for Carbondale (Roberts and Stall, 1967). The results are presented in table 17. No data were collected from December 1984 through February 1985 because the water in the pan was frozen. The evaporation amounts should be low. During the data collection period, evaporation appeared to be below normal by 3.54 inches or 9 percent.

Lake Water Level. The lake water level or stage was recorded daily by Department of Conservation (IDOC) personnel. Stage was also recorded periodically by the State Water Survey (ISWS) field person during sediment sampling. Stage was measured by means of a staff gage located near the spillway. The stage is converted to mean sea level (msl) since 6.07 feet on the staff gage equals 321.41 ft msl (the spillway crest elevation).

The fluctuation in stage over time is presented in figure 14. The maximum stage of 10.32 feet was recorded on May 11-14, 1984. As with the other very high stages the cause was backwater from the Mississippi River. By comparison, precipitation produces relatively minor increases in the stage. The rainfall which occurred on December 21, 1984, resulted in a 0.9-foot rise in the stage, while the March 30, 1985, event resulted in a 1.0 foot rise.

The trend in stage appears to be cyclic based on one year's data. The stage rises from the winter to the spring and peaks with the backwater flooding. The summer and early autumn months experience a drop in stage so that the lake level falls below the spillway. The stage then again rises to the winter levels. In this period of data collection the stages fluctuated 4.70 feet: from 4.25 feet above the spillway to 0.45 feet below the spillway.

Transpiration. The water that is absorbed by root systems of plants and that does not remain in the plant tissues is discharged to the atmosphere as vapor through transpiration. Transpiration is the principal mechanism by which precipitation falling on the ground is returned to the atmosphere. When the water budget of a lake is determined, transpiration and evaporation are linked together as evapotranspiration. Due to the

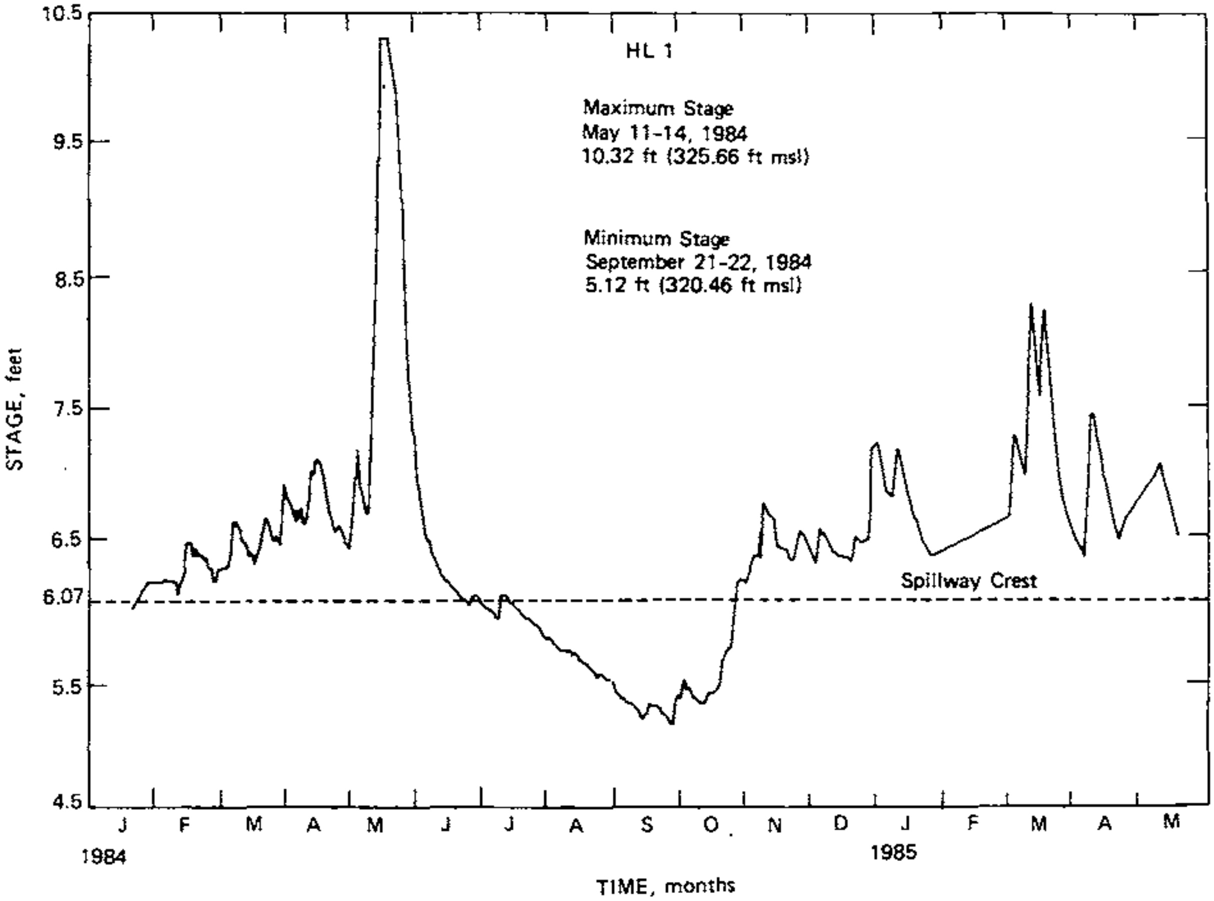


Figure 14. Water level at Horseshoe Lake, January 1984 through May 1985

number of aquatic plants in and around Horseshoe Lake, transpiration is a separate component.

Since few data are available on transpiration, this component was estimated from a water budget. Any surplus of water was assumed to be transpired by the plants. The monthly amounts were tied to the monthly percentage of the annual amount of water evaporated. Plants transpire water depending on the amount of water available. Transpiration by deep rooted plants might create a temporary deficit to be made up at a later date.

Hydrologic Budget

The hydrologic budget for Horseshoe Lake may be expressed as follows:

$$\Delta S = D + R - L - T - E - I - Q + M \tag{6}$$

where

D = direct precipitation on the lake
R = precipitation on the watershed subject to losses
L = watershed losses due to interception, depression storage, evapotranspiration, and infiltration
T = transpiration
E = evaporation from the surface of the lake
I = flow from the lake to ground water
Q = flow over the spillway
M = backwater from the Mississippi River
ΔS = increase (+) or decrease (–) in the lake storage

When watershed losses are extracted from precipitation on the watershed, a value for runoff is obtained.

The values used in the hydrologic budget were obtained from the previous sections. A brief explanation of the components of the hydrologic budget follows.

Precipitation is divided into two parts: the portion which falls on the lake, and the portion which falls on the land surface, which is subject to losses due to interception, depression storage, evapotranspiration, and infiltration.

If the ground water level is higher than the surface of the lake, water flows into the lake, but if the surface of the lake is higher than the ground-water level, water flows out of the lake. The latter is the case at Horseshoe Lake.

Flow over the spillway and lake storage are interdependent. The water level of the lake may be below the spillway elevation when outflows exceed inflows. A positive change in the total indicates that inflow exceeds outflow and the lake is filling, while a negative total indicates that outflow exceeds inflow and the lake is emptying. For the Horseshoe Lake hydrologic budget, a monthly period was used. These monthly surpluses and deficits in the monthly totals were summed to the accumulated totals. When the accumulated totals are positive, the lake level is above the spillway and when these totals are negative, the lake level is below the spillway. A hydrologic budget is presented for Horseshoe Lake in table 18. The components of the budget can be measured in inches and millions of cubic feet. Inches represent a volume over an area but may not be comparable with the other components which represent differing areas. To allow direct comparison cubic feet are used.

As shown in table 18 the plus signs designate flow into the system and the minus signs indicate flow out of the system. The main inflow is runoff, while the main outflow is flow over the spillway. Lake evaporation amounts are less than the direct precipitation on the lake.

Loss to ground water from the lake is nearly negligible. It was included in the hydrologic budget for comparison with other components. The ground-water loss from the lake is assumed to be uniform and constant throughout the year. Backwater from the Mississippi River, on the other hand, is periodic. When backwater conditions exist, the flow can be substantial.

The hydrologic budget explains the cyclic nature of the fluctuating stage within Horseshoe Lake as may be seen in figure 14 and table 18. A low stage occurs in the summer which rises slowly to peak with the occurrence of backwater flooding. The stage is lowest in late summer and early autumn. The precipitation was above average during the monitoring period, although the excess fell only from October 1984 through April 1985. The period before the summer of 1984 was dry, but the backwater flooding kept the stage above the spillway crest. The lake level fell by about 1 foot during the summer of 1984.

Table 18. Hydrologic Budget for Horseshoe Lake - April 1984 through April 1985

	Runoff (+)		Precipitation over lake (+)		Evaporation (–)		Transpiratlon(–)		Loss to ground water (–)		Backwater from Mississippi River (J)		Flowr over spillway (–)		Total	Accumulated total
Date	Inches	ft^3×10^6	inches	it^3×10^6	inches	ft^3×10^6	inches	ft^3×10^6	inches	ft^3×10^6	inches	ft^3×10^6	inches	ft^3×10^6	ft^3×10^6	ft^3×10^6
1984																
April	2.114	101.06	4.33	35.99	2.79	20.33	3.65	26.23	0.093	0.68	1.726	95.09	1.888	104.01	76.44	76.44
Nay	2.718	129.94	4.15	28.85	4.20	30.60	5.47	40.22	0.096	0.70	3.183	175.36	8.731	481.01	-217.00	-140.56
June	0.224	10.71	2.10	15.23	5.40	39.34	7.06	51.58	0.093	0.68	0.0	0.0	0.330	18.18	-83.77	-224.33
July	0.245	11.71	2.89	21.05	4.98	36.28	6.53	47.21	0.096	0.70	0.0	0.0	0.003	0.16	-51.59	-275.92
August	0.014	0.67	1.05	10.42	4.26	31.04	5.57	40.22	0.096	0.70	0.0	0.0	0.0	0.0	-63.64	-339.56
September	0.139	6.64	5.41	39.41	3.61	26.30	4.70	34.10	0.093	0.68	0.0	0.0	0.0	0.0	-15.03	-354 59
October	2.552	122.00	10.67	77.88	1.68	12.24	2.21	15.74	0.096	0.70	0.0	0.0	0.226	12.45	158.61	-195.98
November	5.115	244.53	6.19	45.10	1.29	9.40	1.68	12.24	0.093	0.68	0.0	0.0	1.676	92.34	174.97	-21.01
December	5.855	279.91	7.98	57.92	0.72*	5.24	0.96	6.99	0.096	0.70	0.0	0.0	2.928	161.31	163.81	142.80
1985																
January	2.155	103.02	1.64	11.88	0.74*	5.39	0.96	6.99	0.096	0 70	0.0	0.0	2.755	151.78	-49.89	92.91
February	5.010	239.51	4.03	29.36	1.62*	11.80	2.11	15.74	0.087	0.63	0.200	11.02	2.618	144.23	107.49	200.40
March	2.172	103.84	5.75	49.76	1.91	13.92	2.50	18.36	0.096	0.70	3.281	180.76	6.859	377.88	-84.37	116.03
April	5.308	253.76	5.99	43.64	3.54	25.79	4.61	33.22	0.093	0.68	0.0	0.0	4.856	267.53	-29.82	86.21
Totals	33.621	1607.30	62.18	453.00	36.74	267.67	48.01	183.60	1.244	8.93	8.39	462.23	32.87	1810.882		86.21

*Long-term average assumed

Sediment Analyses

The watershed of Horseshoe Lake was monitored from April 1984 through April 1985. Data were collected on suspended sediment concentration as well as on the components discussed in the hydrologic analyses section. A lake sedimentation survey was done in 1984. The gross erosion was assessed by the Soil Conservation Service in 1984.

Methods

The sediment budget was constructed in a manner similar to the construction of the hydrologic budget. The sources of sediment were identified and accounted for in a bookkeeping procedure. The main source of sediment to Horseshoe Lake is the watershed. The Mississippi River can also be a contributor of sediment when its waters back up into the lake. The only outflow of sediment from the lake is over the spillway. The difference between the amount of sediment that enters the lake and the amount that leaves the lake is the quantity which is deposited in the lake.

The first step in the construction of the sediment budget is to identify the components of sedimentation. The erosion process begins when raindrops dislodge soil particles and transport them across the surface of the ground in a process known as sheet erosion. The concentration of sheet flow results in rill erosion. As rills merge, gullies may form. Sheet, rill, and gully erosion are collectively referred to as gross erosion, which is a component of the sediment budget.

When the sediment reaches the stream the sediment can be transported as suspended or bed load. There is a fine distinction between what is considered bed load and what is suspended load. Bed load moves by rolling, sliding, or saltation (hopping). The suspended load is continuously supported by the turbulence of the fluid. Wash load is differentiated from suspended load since the sediment which makes up the wash load is finer than that found on the bed of the stream. The wash load is therefore dependent on the available supply of sediment particles in the watershed (Graf, 1971). The sediment budget for Horseshoe Lake was based on monitoring of only the suspended sediment portion, which includes the wash load.

The streambed and banks can be additional sources of sediment. To determine the contributions of bank erosion to the sediment budget of a lake, an evaluation of the location, cause, and extent of bank erosion must be performed. The first step in this evaluation is a field inspection of the eroded sites during which observations of the existing conditions are made and initial measurements of important hydraulic parameters are recorded. Due to the short duration of this investigation, it was not possible to quantify the extent of the sediment contribution. However, a qualitative assessment of locations, causes, and extent of bank erosion was accomplished for Pigeon Roost Creek and Black Creek. On-site field inspections were made at accessible locations along each stream. Topographic maps, aerial photographs of the watershed, and field reconnaissance were used to identify accessible locations. Once identified, sites were visited and basic hydraulic geometry parameters were noted such as width, depth, meander pattern, human disturbances, vegetation, and land use.

Deposition of sediment can occur as a result of any of the components discussed. Deposition will occur when water loses energy and so no longer can support the sediment. Once sediment is in a stream, deposition can take place inside a meander loop or further downstream as a point bar.

Results

The individual components of the sediment budget will be discussed in the following order: gross erosion, suspended sediment load, streambank erosion, and lake sedimentation.

Gross Erosion. The gross erosion is the long-term average soil loss rates in the watershed for specific combinations of physical and land management conditions. The soil loss rates were assessed by the Soil Conservation Service (SCS), using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The soil loss equation is:

$$A = RKSLCP \tag{7}$$

where

A = average soil loss rate in tons per acre per year
R = rainfall factor
K = soil erodibility factor
S = steepness factor
L = slope-length factor

C = cropping factor

P = support practice factor

The gross erosion is an average soil loss and is not the same as the amount of sediment that is delivered to a stream. The amount of sediment delivered to a stream (the sediment yield) is equal to or less than the gross erosion due to deposition en route. The sediment yield divided by the gross erosion is the sediment delivery ratio. The amount of sediment which enters the stream may not be the quantity which enters the lake due to deposition which may occur in the stream en route.

Gross erosion was assessed by the Soil Conservation Service (SCS) for the Pigeon Roost Creek watershed, Black Creek watershed, and the remaining watershed which was not included in either the Pigeon Roost Creek or Black Creek watershed. For each watershed the computation of soil loss rates was performed in two parts: cropland, and pasture and woodland. The average amount of sediment delivered to the stream was assessed and ranged from 0.56 to 0.89 with an average value of 0.76.

The pasture and woodland portion of the gross erosion was assumed to be generated mostly by gully erosion. Since gullies are connected directly to streams, it was assumed that the sediment delivery ratio was equal to 1.

The results of the SCS erosion study are presented in table 19. The Black Creek watershed has the highest rates of both gross erosion and sediment yield from cropland. Pigeon Roost Creek has slightly lower rates of gross erosion and sediment yield. The areas outside the Pigeon Roost and Black Creek watersheds have the lowest rates.

The total gross erosion rate for the entire watershed was calculated as 3.33 tons per acre per year, and the annual sediment yield was 2.62 tons per acre. The sediment delivery ratio was estimated as 0.79 for the watershed. The cropland contributes 82.2 percent of the gross erosion and 77.4 percent of the estimated sediment yield. The study was based on a sample composed of approximately 24 percent of the watershed.

Suspended Sediment Load. Suspended sediment was monitored at four sites: HL1, HL2, HL3, and HL4. For location refer to figure 11. Suspended sediment load, or simply load, is dependent on suspended sediment concentration and runoff discharge. In equation form:

$$Qs = Cs \cdot Q \cdot .00269 \qquad (8)$$

Table 19. Erosion in the Horseshoe Lake Watershed

		Gross Erosion		SDR*	Sediment yield		Percent of area sampled
		(tons/acre)	(tons)		(tons/acre)	(tons)	
Black Creek	Cropland	11.93	26,580	0.71	8.48	18,893	
	Pasture & woodland	1.0	4,086	1.0	1.0	4,086	
	Total	4.86	30,666	0.75	3.64	22,979	20.3
Pigeon Roost Creek	Cropland	8.21	3,727	0.81	6.65	3,019	
	Pasture & woodland	1.0	1,966	1.0	1.0	1,966	
	Total	2.35	5,693	0.88	2.06	4,985	19.8
Other	Cropland	2.63	7,998	0.81	2.14	6,508	
	Pasture & woodland	1.0	2,225	1.0	1.0	2,225	
	Total	1.94	10,223	0.86	1.66	8,733	30.4
Total	Cropland	6.69	38,305	0.74	4.96	28,420	
	Pasture & woodland	1.0	8,277	1.0	1.0	8,277	
	Total	3.33	46,582	0.79	2.62	36,697	24.0

*Sediment delivery ratio

where

Qs = suspended sediment load in tons per day (T/d)

Cs = suspended sediment concentration in milligrams per liter (mg/L)

Q = runoff discharge in cubic feet per second (cfs)

The results of the monthly data are presented in table 20. Daily totals are presented in appendix 8. The monthly loads were obtained by the summation of the daily loads.

A method similar to that used in the runoff section was employed to calculate the suspended sediment load from the 35 percent of the watershed that was not monitored. The portion of the watershed of HL4 that is not monitored by HL2 should be representative of the unmonitored watershed at least on an annual basis. The computations and results are presented in table 21.

In table 20 the loads at HL1 are presented as 1) outflow, 2) backwater, and 3) net total. The total amount of sediment that was measured as leaving the lake at HL1 was termed the outflow. When the backwater reverses and flows into the lake carrying sediment with the floodwaters, this is the backwater contribution. The net total is the amount of sediment that left the lake above what came in during the backwater flooding. This assumes that 100 percent of the Mississippi River sediment left the lake. This net total could be an amount of sediment flushed out of the lake when the floodwaters receded or the amount of sediment that came from the watershed which was not deposited in the lake. For example, in April 1984 99.6 percent of the sediment leaving the lake had entered in the backwater from the Mississippi River, but in October 1984 all the sediment that left the lake had entered from the watershed. Of the total amount measured for the period of data collection 19 percent of the amount leaving by the spillway had entered the lake due to backwater from the Mississippi River. The sediment that enters by backwater flooding is not deposited in the lake due to the small size of the sediment and the short residence time.

Figure 15 shows the average daily discharge plotted against the average daily suspended sediment load for HL1, HL2, and HL3. A regression line based on least squares is presented for each station. The spillway (HL1) has two sets of points and two regression lines used to differentiate

Table 20. Monthly Suspended Sediment Loads

Date	HL1				HL2		HL3		HL4	
	Outflow (+) (tons)	Outflow (+) (tons/acre)	Backwater (–) (tons)	Net total (tons)	(tons)	(tons/acre)	(tons)	(tons/acre)	(tons)	(tons/acre)
1984										
April	51.9	0.004	51.7	0.2	227.0	0.097	128.1	0.058	290.4	0.046
May	628.3	0.048	96.9	531.4	765.7	0.326	428.7	0.193	4588.5	0.727
June	39.6	0.003	0.0	39.6	5.5	0.002	1.2	0.001	28.1	0.004
July	0.3	0.000	0.0	0.3	7.9	0.003	1.6	0.001	31.8	0.005
August	0.0	0.000	0.0	0.0	0.0	0.000	0.0	0.000	1.5	0.000
September	0.0	0.000	0.0	0.0	4.1	0.002	1.4	0.001	17.2	0.003
October	4.0	0.000	0.0	4.0	343.8	0.146	60.3	0.027	130.5	0.021
November	30.5	0.002	0.0	30.5	340.5	0.145	42.9	0.019	492.8	0.078
December	44.7	0.003	0.0	44.7	1394.6	0.594	1098.1	0.493	2984.5	0.473
1985										
January	44.8	0.003	0.0	44.8	161.1	0.069	174.1	0.078	100.8	0.016
February	49.0	0.004	3.9	45.1	1230.8	0.524	2894.4	1.300	235.6	0.037
March	144.7	0.011	65.8	78.9	1137.2	0.484	857.5	0.385	2587.8	0.410
April	109.4	0.008	0.0	109.4	89.7	0.038	75.4	0.034	1979.6	0.314
Total	1147.2	0.086	218.3	928.9	5707.9	2.430	5763.7	2.590	13469.1	2.134

HL1	Horseshoe Lake spillway
HL2	Black Creek at Fayville Road
HL3	Pigeon Roost Creek at Route 3
HL4	Black Creek at Miller City Road

Table 21. Monthly Suspended Sediment Load from the Watershed

			Unmonitored portion of HL4 (UM4)*				Unmonitored watershed UW		Total suspended sediment load	
Date	HL4 (tons)	HL2 (tons)	(tons)	(tons/acre)	HL3 (tons)	HL4 (tons)	(tons)	(tons/acre)	(tons)	(tons/acre)
1984										
April	290.4	227.0	327.9	.083	128.1	290.4	384.2	.083	295.8	.022
May	4588.5	765.7	7758.4	1.956	428.7	4588.5	9054.3	1.956	5454.7	.414
June	28.1	5.5	48.0	.012	1.2	28.1	55.5	.012	33.2	.002
July	31.8	7.9	45.9	.012	1.6	31.8	55.5	.012	35.0	.003
August	1.5	0.0	2.4	.001	0.0	1.5	4.6	.001	2.3	.000
September	17.2	4.1	25.0	.006	1.4	17.2	27.8	.006	18.2	.001
October	130.5	343.8	4.2	.001	60.3	130.5	4.6	.001	74.4	.006
November	492.8	340.5	583.0	.147	42.9	492.8	680.5	.147	482.7	.037
December	2984.5	1394.6	3925.8	.990	1098.1	2984.5	4582.7	.990	3227.2	.245
1985										
January	100.8	161.1	65.1	.016	174.1	100.8	74.1	.016	103.8	.008
February	235.6	1230.8	}3093.0	.780	2894.4	235.6	}3610.6	.780	3257.1	.247
March	2587.8	1137.2			857.5	2587.8				
April	1979.6	89.7	3098.5	.781	75.4	1979.6	3615.2	.781	2232.5	.170
Total	13,469.1	5707.9	18,977.2	4.785	5763.7	13,469.1	22,149.8	4.785	15,216.9	1.155
Area	6314	2348	3966		2227	6314	3966		13,170	

*UM4 = [6314 (HL4) - 2348 (HL2)]/3966

Total load = [2227 (HL3) + 6314 (HL4) + 4629 (UW)]/13,170

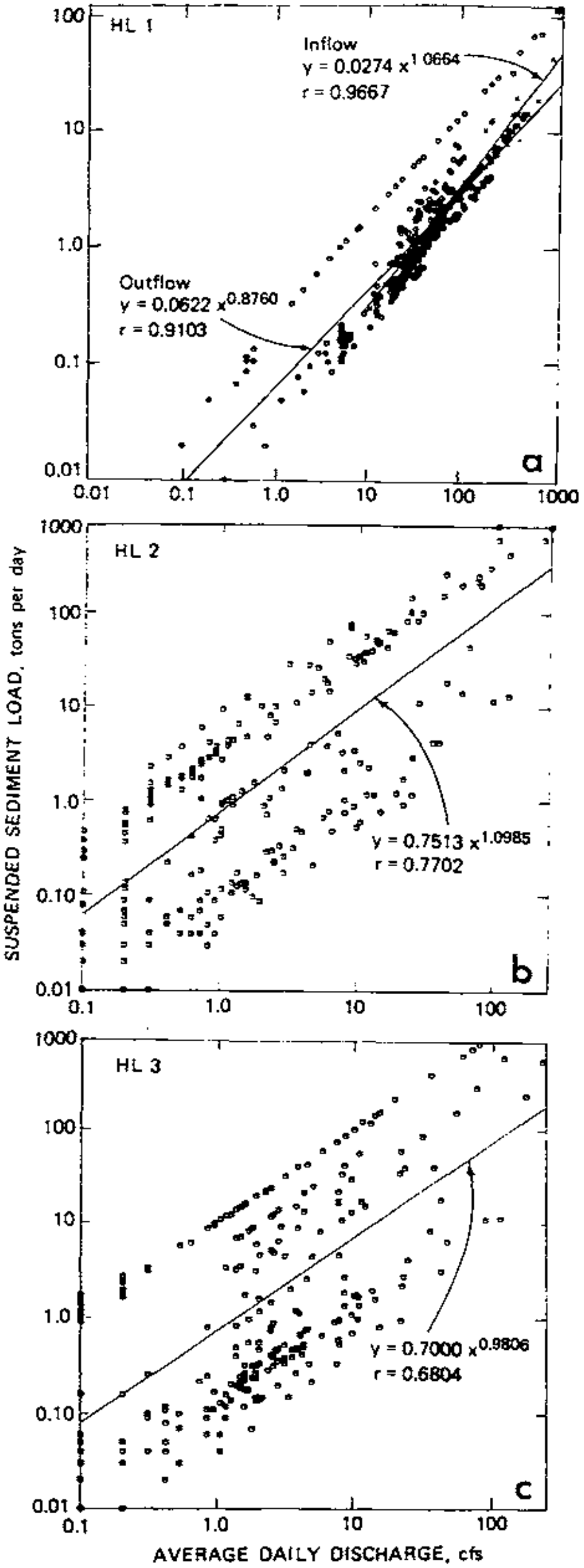


Figure 15. Relationship between suspended sediment load and daily discharge, stations HL1, HL2, and HL3

between the inflow caused by backwater flooding and the outflow from the lake.

The regression lines are flatter for HL1 than for either HL2 or HL3; however, this is not easily detected from the plots because HL1 has a different scale to accommodate the range of points. The intercept is also smaller, so that for a comparable discharge, HL1 will pass a lower load than either HL2 or HL3. For example, a 10-cfs discharge at HL2 will be carrying a 9.4 tons/day suspended sediment load according to the regression equation, while HL1 will pass 0.5 tons/day. This shows the amount of sediment that can be deposited in the lake.

The inflow line for HL1 (spillway) in figure 15 is slightly higher than the outflow line because the discharges resulting from backwater are high. However, because of the limited amount of data, this can not be generalized to the entire range of discharges.

At HL1 there is an upper series of points which are parallel to the outflow regression line above the cluster of points below (figure 15). These points indicate the flow reversal that occurred immediately after the backwater flooding from the Mississippi River in May 1984. Apparently the backwater flooding resuspends sediment within the lake, which is then flushed out of the lake during the flow reversal.

No clear pattern may be seen in figure 15 for stations HL2 and HL3.

Streambank Erosion. The severity of bank erosion along Pigeon Roost and Black Creeks intensifies from the uplands downstream to the lake. The numerous feeder creeks draining the upland areas are braided gravel bed streams. Channels are poorly defined and a braided pattern is evidenced by small, intermittently coalescing channels separated by in-channel gravel bars. Bank erosion in these areas is minor as most erosion occurs as sheet and rill erosion, and prominent streambanks to confine flow are minimal.

As the feeder creeks enter the upland valleys to form the principal tributaries (Pigeon Roost and Black Creeks), the channels exhibit characteristics common to Ozark-type streams. Channels become wider, sinuosity increases, and gravel bar development dominates the streams. Chert-gravel bed material dominates the locally transported load as loess-derived fines are transported further downstream as suspended load. Gravel deposits occur along the shallow streams as small lobes and sheets deposited on the floodplain during overbank flow. Streambanks are generally low (3 to 6 feet), steep, and heavily vegetated. Bank erosion is minimal except where vegetation has been removed and land has been tilled to the bank crest. At these locations, lower bank scour, upper bank failure, and gully entrenchment into farmland are moderate to severe.

Proceeding downstream through the tributary valleys to Olive Branch, channels become more sinuous. The gravel sediment load begins to decrease as the silt, sand, and clay load begins to dominate. Streambanks are generally vertical to steeply sloped on outside meanders and moderately sloped on inside bends and adjacent to ripples. Bank erosion along these stream lengths is moderate to severe and manifests itself primarily on outside bends of meander sequences where undercutting and scour promote upper bank slab failure (figure 16). Where field drainage intersects the streambank, headward gullying is the dominant erosional feature (figure 17).

From Olive Branch to the lake, Black Creek has been rerouted and channelized. Bank erosion and channel entrenchment are at their maximum along this portion of the creek. The channel depth increases to approximately 12 feet, and widths range from 16 to 23 feet near Olive Branch. At the confluence of Black Creek and Big Cypress Ditch the channel widens to 32-39 feet. Upstream of this confluence Black Creek banks are moderately to steeply sloping to a height of 10-12 feet. Downstream of the confluence streambanks are low and gently sloping, and channel depth decreases. The stream channel may be aggrading at this location. This stream segment is influenced by lake backwater and shows minor bank erosion.

Along the upstream channelized section, bank failure is common. Remnant slump scars are evident along both banks. Scars and deposits indicate slab failure, and rotational slumps and bank scour are the dominant erosion types. It appears the failures are episodic as a function of major storm events which created near bankfull stages. The channel is log-choked from trees succumbing to bank failure, which in turn exacerbates bank erosion by directing flow around the fallen trees into the banks.

From north of Route 3 to Horseshoe Lake, Pigeon Roost Creek exhibits its most severe bank erosion. Entering Olive Branch, the creek becomes extremely sinuous for a short distance. Remnant slumps are present which apparently resulted from undercutting on outside bends. Banks are steeply

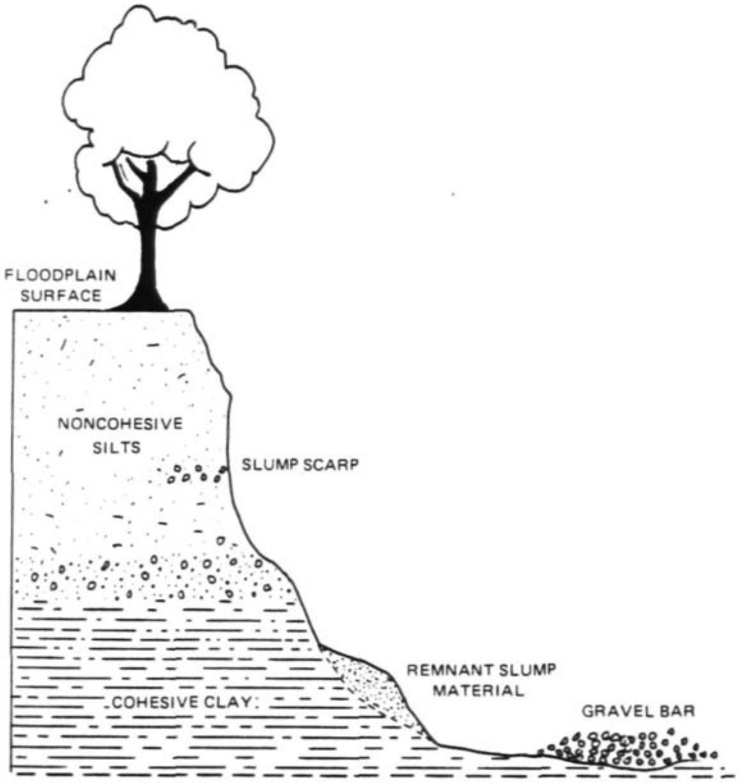


Figure 16. Typical bank profile of lower valley streams in the Horseshoe Lake watershed

Figure 17. Incipient gully development along Black Creek

sloped and are vegetated by small trees and brush. Channel depth is approximately 6-10 feet and widths range from 10-16 feet.

From the Route 3 bridge to Horseshoe Lake, the creek has been diverted and channelized. The southwest bank downstream of the bridge is protected by a concrete retaining wall for a short distance. The opposite bank is not protected near the bridge and is experiencing minor erosion. From Route 3 to Miller City Road bank erosion appears to be moderate as banks are well vegetated.

At Miller City Road the creek encounters a major bottleneck where it passes through a concrete box culvert under the road. The flow is severely restricted during major storm events and the culvert tends to trap channel debris, which exacerbates the constriction. The creek exhibits a near 3-foot drop at this location from the upstream to the downstream side of the culvert. Downstream of the culvert the channel bottom is scoured and a pool has developed which is subject to extreme turbulence during high flows. The most severe bank erosion along Pigeon Roost Creek occurs at this location (figures 18-20).

The northeast bank, just downstream of the Miller City Road culvert on Pigeon Roost Creek, has retreated within 6 feet of residential dwellings near the creek at one point. Banks are nearly vertical, up to 10 feet high, and the channel approaches 32 feet in width across the pool. Undercutting and parallel retreat of the northeast bank appear to be taking place. Bank stabilization along this segment has been attempted by emplacement of concrete and gravel riprap and junk cars. Just past the critical curvature of the bend the local efforts seem to have temporarily stabilized the banks.

From this location to the lake, the ditch is relatively straight. Numerous pool and riffle sequences exist with maximum pool depths near 3 feet and distances between riffles approaching 65 feet. The channel width narrows to approximately 14 feet, and the steeply sloped banks generally reach 12 feet in height. Slab failure scars line both banks of this segment to the point where backwater from the lake influences the stream. Below this point the banks are generally of low to moderate heights, well vegetated, and stable.

In summary, three distinct features within the lower Horseshoe Lake watershed appear to exacerbate bank erosion. Where larger tributaries of

Figure 18. Flow entering Miller City Road culvert (Note proximity of water surface to the top of the culvert)

Figure 19. Water exiting Miller City Road box culvert

Figure 20. Bank erosion below Miller City Road box culvert

Pigeon Roost and Black Creeks enter the main streams, meandering and bank erosion intensify for a short distance. Bank erosion is severe on outside bends of the meander pattern.

In Olive Branch, changes in land use, increased runoff, and removal of bank vegetation has increased the potential for bank erosion.

At locations where the natural drainage has been channelized, straightened, redirected, or altered by structures or channel debris, bank erosion intensifies. Immediately upstream and downstream of flow confining or constricting structures, as on Pigeon Roost Creek below Miller City Road, bank erosion may be particularly severe.

Streambank erosion within the Horseshoe Lake watershed may be qualitatively characterized as moderate. Pigeon Roost Creek exhibits the most severe bank erosion. Bank erosion along Big Cypress Ditch, a major tributary to Black Creek, is minor.

Although the qualitative average of bank erosion in the watershed is moderate, locations where bank erosion is severe do exist on Pigeon Roost and Black Creek. These locations, as identified on figure 21, exist along the lower stream segments, primarily from the village of Olive Branch downstream to Horseshoe Lake. Bank scour, undercutting, and various forms of bank failure appear to be the erosion processes operating at these locations.

The effect of these processes on the sediment budget of Horseshoe Lake may be minimal to moderate as the bank erosion is episodic, depending upon seasonal storm frequency and intensity. Sediment contributions are greater during periods of frequent, intense precipitation which causes stream stages to fluctuate between low and bankfull stages, thus promoting periods of more severe erosion. A detailed discussion of bank erosion mechanics has been given by Bhowmik and Schicht (1980).

Lake Sedimentation. The lake sedimentation rates are discussed in a previous section. These rates are equivalent to a long-term record of data. Because Horseshoe Lake is a natural lake and its date of origin cannot be determined, a 1951 survey was used as a reference.

In addition to the sediment entering the lake from the watershed and the Mississippi River, an organic component which accumulates directly in the lake was identified. This organic component is composed of plant and animal remains. Only the sediment portion will be considered with respect

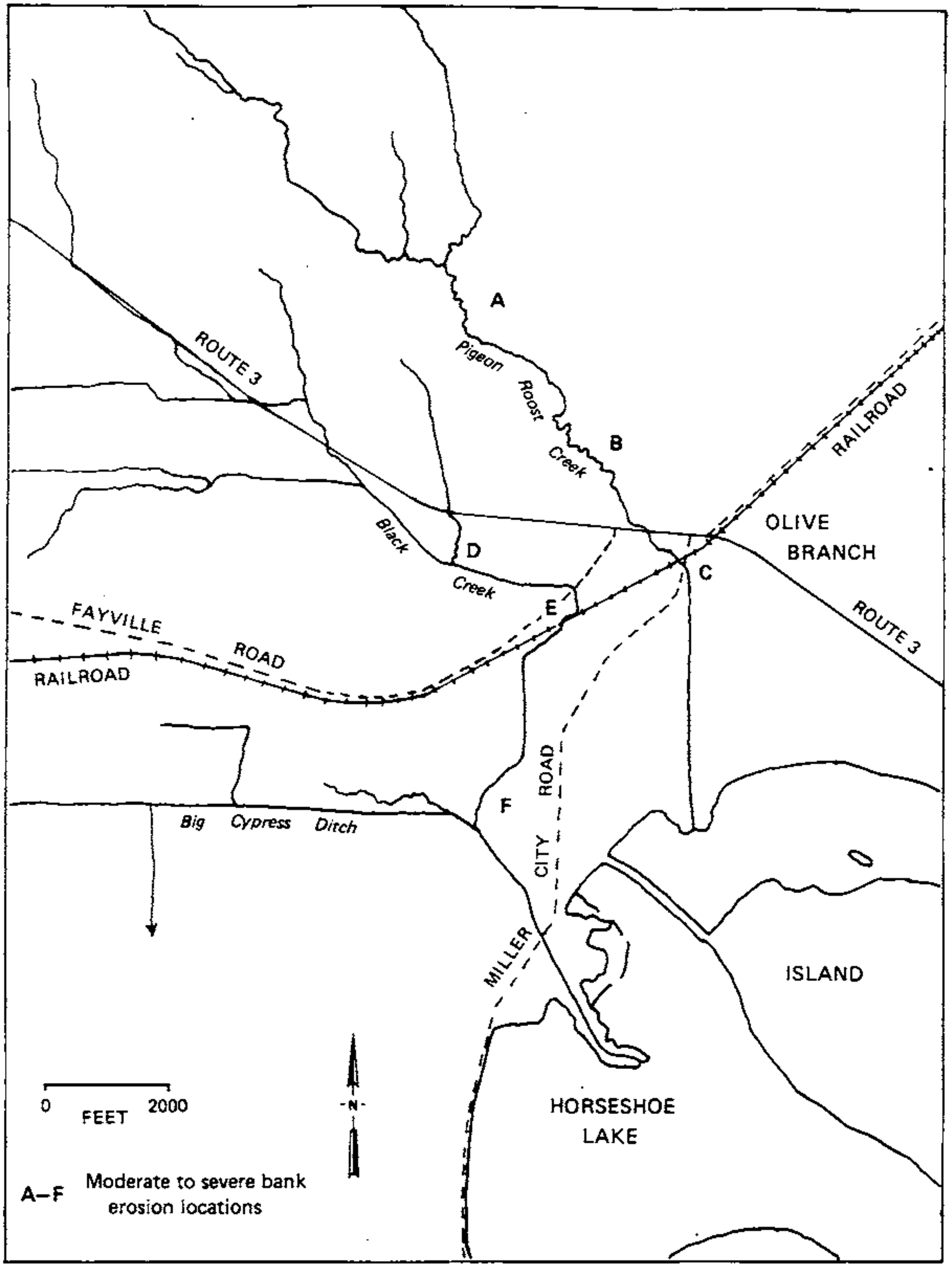


Figure 21. Bank erosion sites in the lower Horseshoe Lake watershed

to the sediment budget, although the organic portion constitutes about 10 percent of the total sediment found in the lake. The total sediment accumulation is 30,500 tons per year or 2.32 tons per acre of watershed for the 34-year period from 1951 through 1984..

Sediment Budget

The sediment budget is presented in table 22. During the time of monitoring 14,288 tons of suspended sediment were deposited in Horseshoe Lake. This is equivalent to 1.085 tons per acre of watershed. The lake has a trap efficiency of 94 percent based on the measured inflow and outflow of sediment. That is, 94 percent of the sediment that enters the lake remains in the lake. The delivery ratio from the watershed is the annual sediment input to the lake divided by the gross erosion. In Horseshoe Lake the watershed delivery ratio is 0.36 based upon the gross erosion values furnished by the SCS and the amount of sediment measured.

The Mississippi River backwater makes up about 1.4 percent of the total sediment inflow to the lake although it constitutes about 20 percent of the sediment leaving the lake. This suggests that sediment deposited in the lake from the backwater is negligible since the sediment particles are much smaller than the watershed sediment. Additionally, the backwater might serve to resuspend the sediment deposited in the lake, especially near the spillway. This may be seen from table 20, which shows that in June 1984, after a backwater event, more sediment left the lake than was transported into it.

The 34-year average annual sedimentation rate determined by the lake sedimentation survey, excluding the organic component, was 30,500 tons. The amount of sediment deposited in the lake during the study was 13,200 tons per year or 43 percent of the long-term annual sediment accumulation within the lake. There are several possible reasons why the long-term lake sedimentation is higher than that which was measured. The total load is composed of suspended sediment and bed load, but only the suspended sediment load was measured. The bed load can be from 5 to 25 percent of the measured suspended load (Simons and Senturk, 1977). In Illinois the value of 15 percent is commonly used, which would make the total load 15,200 tons.

Also, most of the sediment load is transported during events. It was found from smaller watersheds that 98 percent of the annual load is

Table 22. Suspended Sediment Budget for Horseshoe Lake

Date	Watershed (+) (tons)	Mississippi River backwater (+) (tons)	Outflow over spillway (–) (tons)	Deposited in lake (tons)	Deposited in lake (tons/acre)
1984					
April	295.8	51.7	51.9	295.6	.022
May	5454.7	96.9	628.3	4923.3	.374
June	33.2	0.0	39.6	-6.4	-.000
July	35.0	0.0	.3	34.7	.003
August	2.3	0.0	0.0	2.3	.000
September	18.2	0.0	0.0	18.2	.001
October	74.4	0.0	4.0	70.4	.005
November	482.7	0.0	30.5	452.2	.034
December	3227.2	0.0	44.7	3182.5	.242
1985					
January	103.8	0.0	44.8	59.0	.004
February					
March	3257.1	69.7	193.7	3133.1	.238
April	2232.5	0.0	109.4	2123.1	.161
Total	15,216.9	218.3	1147.2	14,288.0	1.085
Average annual	14,046.4	201.5	1059.0	13,188.9	1.001

transported in about 5.9 percent of the time (Makowski et al., 1986). If the larger events are not monitored, the annual load can be underestimated.

Also not reflected in the sediment budget was the contribution of the streambed and banks. Although streambed and bank erosion is not severe on the Horseshoe Lake watershed, if this component had been included in the sediment budget it would have increased the gross erosion amount.

The sedimentation survey brought out the fact that there is a significant organic input to the lake from both plants and animals. This input is made directly to the lake and cannot be measured within the tributaries.

Direct comparison between the long-term sedimentation rate obtained from the lake survey and the short-term monitoring results should take the following facts into account. Sedimentation rates of lakes do not remain constant. They gradually decrease over time as the trap efficiency decreases. Over the years, as reflected in the lake sedimentation survey, changes can occur in the watershed that have an effect on the sediment reaching the lake, such as construction activities on the watershed, stream channelization, changes in land use, and land management. Also significant are climatic factors such as the amount of precipitation, antecedent moisture conditions, and precipitation intensity. With one year of data it is difficult to know whether the period of monitoring was above normal, below normal, or normal. A minimum of three years of data are necessary to make that judgment.

FEASIBILITY STUDY

In order to find ways to extend the useful life of Horseshoe Lake, a number of schemes for sediment input control and sediment removal were investigated. The results of the investigation are presented here. However, these results do not take the place of detailed design and cost estimates. They are intended to be used only as a basis for comparison between alternatives. For actual implementation, much more detailed design and cost analyses will be required.

There are several assumptions that are used throughout the discussion of alternatives. First, although soil studies were not performed, it was assumed that the soil was suitable for fill or foundations. Second, the same 5-year recurrence interval for precipitation and runoff was used for design. The 5-year recurrence interval was selected since it would provide adequate protection and yet not be excessive. The proposed plans were based on the peak flow rate. Finally, the plans did not consider backwater flooding by the Mississippi River.

The unit prices for the cost determinations were obtained from various sources such as local contractors, the Illinois Department of Transportation (IDOT), and the U.S. Corps of Engineers (USCOE). Costs for acquisition of land were not considered. It was assumed that, for comparable costs, the project had a 40-year life. All monetary figures represent present worth. Future cash outlays were computed to present worth by using a 7.125 percent discount rate. Only basic economic optimizations were performed.

The management alternatives are of two main types. One type limits future sediment input to the lake, while the other increases the depth within the lake. It is foreseen that any solution will require at least one alternative of each type so that sediment delivered to the lake will be curtailed while additional depth is achieved. Discussion is limited to the sediment delivered from the watershed and does not touch on the organic input to the lake.

Management Alternatives

Watershed Management

The gross erosion assessment indicated that the croplands in the Black Creek and Pigeon Roost Creek watersheds have annual gross erosion rates as high as 11.93 and 8.21 tons per acre per year, which are about twice the soil tolerance levels. The local Soil Conservation Service staff (personal communication, 1985) estimates that these can be reduced to about 40 to 60 percent of the present rates.

Since watershed management would require full and long-term cooperation of the landowners in the watershed, this alternative will be difficult to accomplish within a short time. Therefore, the watershed management alternative was not included as an alternative for cost comparison. However, it is recommended that the Illinois Department of

Conservation and the Soil Conservation Service formulate a cooperative effort to reduce the amount of soil loss from the watershed.

In-Stream Sediment Management

Channel Diversion. The channel diversion alternatives would decrease future sediment delivery to Horseshoe Lake. This would be accomplished by diverting the major sources of sediment, Pigeon Roost and Black Creeks, during high flows. Pigeon Roost and Black Creeks do not follow their natural course, especially in the lower reaches. A map from the late 19th century shows that Pigeon Roost Creek did not enter Horseshoe Lake but flowed directly to Lake Creek. The diversion of the creeks around Horseshoe Lake is therefore an obvious alternative.

Four diversion schemes were investigated:

1) Diversion of Pigeon Roost Creek to Black Creek (the combined flow would then proceed west through Big Cypress Swamp to the Mississippi River)
2) Diversion of Black Creek to Pigeon Roost Creek along the approximate path of the old Pigeon Roost Creek channel along Route 3 to Lake Creek in the area of the Poor Farm
3) Diversion of Pigeon Roost Creek to Black Creek, then along the western edge of the lake (east of Miller City Road) and then east to Lake Creek
4) Diversion of Pigeon Roost Creek to Black Creek along the western edge of the lake (east of Miller City Road) into the Miller City arm of the lake, which would be used as a sedimentation basin

Several assumptions were made with respect to the channel diversions. The first was that the channel cross-sectional shape was trapezoidal with 1:2 side slopes. Secondly, the channel was assumed to be lined with soil so a Manning's roughness coefficient of 0.025 was used. Third, the channel would have to be protected in certain areas where the local velocities are excessive; therefore the channel alternatives were designed so that channel maintenance should be minimal. Design velocities were around 3 to 4 feet per second (fps) which should be adequate to keep the channel clear of sediment. Though no maintenance or maintenance costs are included, routine maintenance should be expected. The final assumption concerned the depth of flow within the channel cross section. The water surfaces were matched at the upstream and downstream ends. With the water surface established, the depth of flow was kept within a 5- to 10-foot range with a 10 percent freeboard added to this depth. The topographic information was obtained from a U.S. Geological Survey (USGS) 7.5-minute map.

The two main sources of sediment to Horseshoe Lake were identified as Pigeon Roost Creek and Black Creek. The other sources are less significant. The concept behind the diversion scheme is to divert the sediment-laden water from the lake. The sediment diverted from the lake should have a negligible effect on the receiving streams downstream. The highest amount of sediment is transported during storm events, and the lower flows carry comparatively little sediment. Therefore, a diversion structure could be placed in the stream channel so that high flows would be diverted around the lake and low flow routed into the lake. All of the flow can not be diverted from the lake since the creeks are the principal source of water to the lake. The operation of this structure could be either automatic or manual.

Because the lake depth is of paramount importance, maintaining water flow into the lake is the overriding consideration. It must be acknowledged that a certain amount of sediment-laden water will be diverted into the lake to maintain lake levels. The operation of the diversion structure would be dependent on the lake level. For example, if the lake level were high, the entire flow could be diverted away from the lake. If the lake level were low, more water might be diverted into the lake although this would also deliver additional sediment to the lake. Proper management would therefore be essential to the diversion scheme.

For example, if flows with suspended sediment loads above 10 tons per day had been diverted away from the lake for the period of data collection, there would have been 15 days on which flow would not have entered the lake. In this 15-day period, approximately one-third of the monitored flow and 96 percent of the monitored sediment would have been diverted away from the lake.

Pigeon Roost and Black Creeks are comparatively small and as such have runoff-sediment load relationships that vary widely. The sediment load is dependent on variable factors such as season, rainfall intensity, and rainfall amount. The runoff-sediment load relationship was presented in figure 15. As may be seen in this figure, low flows transport minor quantities of sediment and most of the sediment is transported during high flows. Additionally, more sediment is transported during the rising limb of the flood hydrograph than the falling limb. Management of the diversion is critical, and a balance must be found between keeping the sediment out of the lake and letting adequate water into the lake.

The fourth diversion alternative is different from the other alternatives in that it would not decrease inflow to the lake. This alternative would divert water to the Miller City arm of the lake, which would be used as a sedimentation basin. The sediment-laden water would enter the Miller City arm, permitting the sediment time to settle and allowing relatively sediment-free water to enter the main part of the lake. This idea could possibly be extended to the other diversion alternatives by using a diversion in conjunction with a sedimentation basin. The highly sediment-laden water could be diverted from the lake while the moderately sediment-laden water could be detained so that the sediment could settle before the water entered the lake. The diversion of the sediment-laden water from the sedimentation basins could add to the longevity of the basins and keep dredging costs down.

1. Diversion to the Mississippi River. This alternative would route Pigeon Roost Creek through a diversion structure located in Black Creek (figure 22). The flow of the drainage through Big Cypress Swamp would be reversed to a point just before the levee. From this point on a pump station would be used to pump the flow over the levee to the Mississippi River. The slope of the channel through Big Cypress Swamp would not be fixed as in the other alternatives but would be determined on the basis of the level to which the water must be pumped and the depth of the diversion channel.

An alternative to diverting Pigeon Roost Creek at Price's Landing, as shown in figure 22, would be to divert the flow at the abandoned Chicago and Eastern Illinois railroad. This will not be discussed since the Price's Landing diversion collects the agricultural drainage south of the railroad and is somewhat shorter.

It was found that pumping costs are higher than channel excavation costs. To reduce costs it was decided to make the stream channel larger so it could store some of the peak flow and reduce the pumping requirements. In this fashion the pump capacity could be reduced by one-half. However,

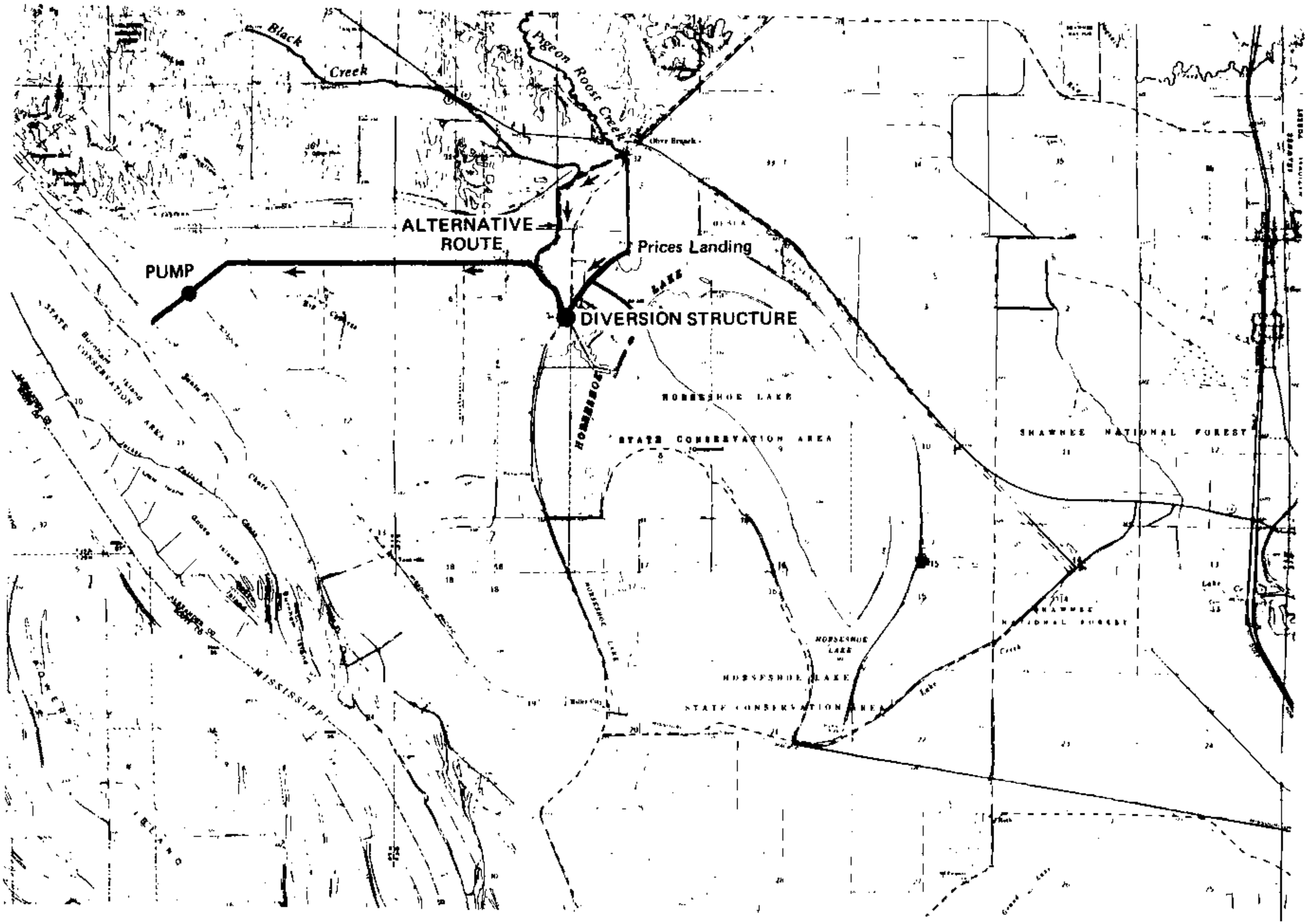


Figure 22. Diversion to the Mississippi River

this storage might allow some sedimentation within the channel and increase the cost and frequency of maintenance.

The advantages of this alternative are that the adjacent farms in Big Cypress Swamp would be drained better when the pump is operating, and future sediment inflow to the lake could be reduced. The disadvantages are the possibility of draining Big Cypress Swamp, the high operation and maintenance costs, the lack of gain in the depth of the lake, and the fact that hydrologic inflow to the lake would be affected.

The diversion channel from Pigeon Roost Creek to Black Creek would be 3500 feet in length and would have a bottom width of 20 feet and a depth of 8.4 feet at design discharge. From the diversion structure to the pump station the channel would be 16,200 feet long, 40 feet wide at the base, and 8.4 feet deep at design discharge. The pumping capacity would be 930 cubic feet per second (cfs).

The first cost of the pump station and appurtenant material would be $11.18 million ((USCOE, personal communication). The present worth operation (power) cost for a 40-year project life would be $0.66 million. The cost of the channel would be $1.56 million. The other costs including bridge replacement (IDOT, personal communication) and diversion structure (IDOC, personal communication) amounts to $0.36 million. The total cost of this alternative would be $13.76 million. A cost summary may be seen in table 23.

2. Diversion along Route 3 to Lake Creek. This alternative would take the entire Black Creek flow to a control structure in Pigeon Roost Creek. The channel would then travel a path along the old channel of Pigeon Roost Creek, which, for the most part, has been completely obliterated, to join Lake Creek just west of Route 3 as shown in figure 23. The area near Lake Creek and Route 3 is known as the Poor Farm area due to frequent flooding. This alternative should not cause significant sedimentation above present levels in the Poor Farm area.

There are a number of variations of this route. The diversion of Black Creek to Pigeon Roost Creek could be located at the abandoned Chicago and Eastern Illinois railroad. This scheme would not collect the Big Cypress Swamp drainage. Another variation is that east of Route 3 the channel could parallel Route 3. There should be little difference in length between this alternative and the one detailed.

Table 23. Estimated Cost of the Diversion to the Mississippi River (1985 values in millions of dollars)

Item	Cost
Pump station	11.18
Pump station operation and maintenance	0.66
Channel excavation	1.56
Diversion structure	0.12
Bridge reconstruction	0.24
Total	13.76

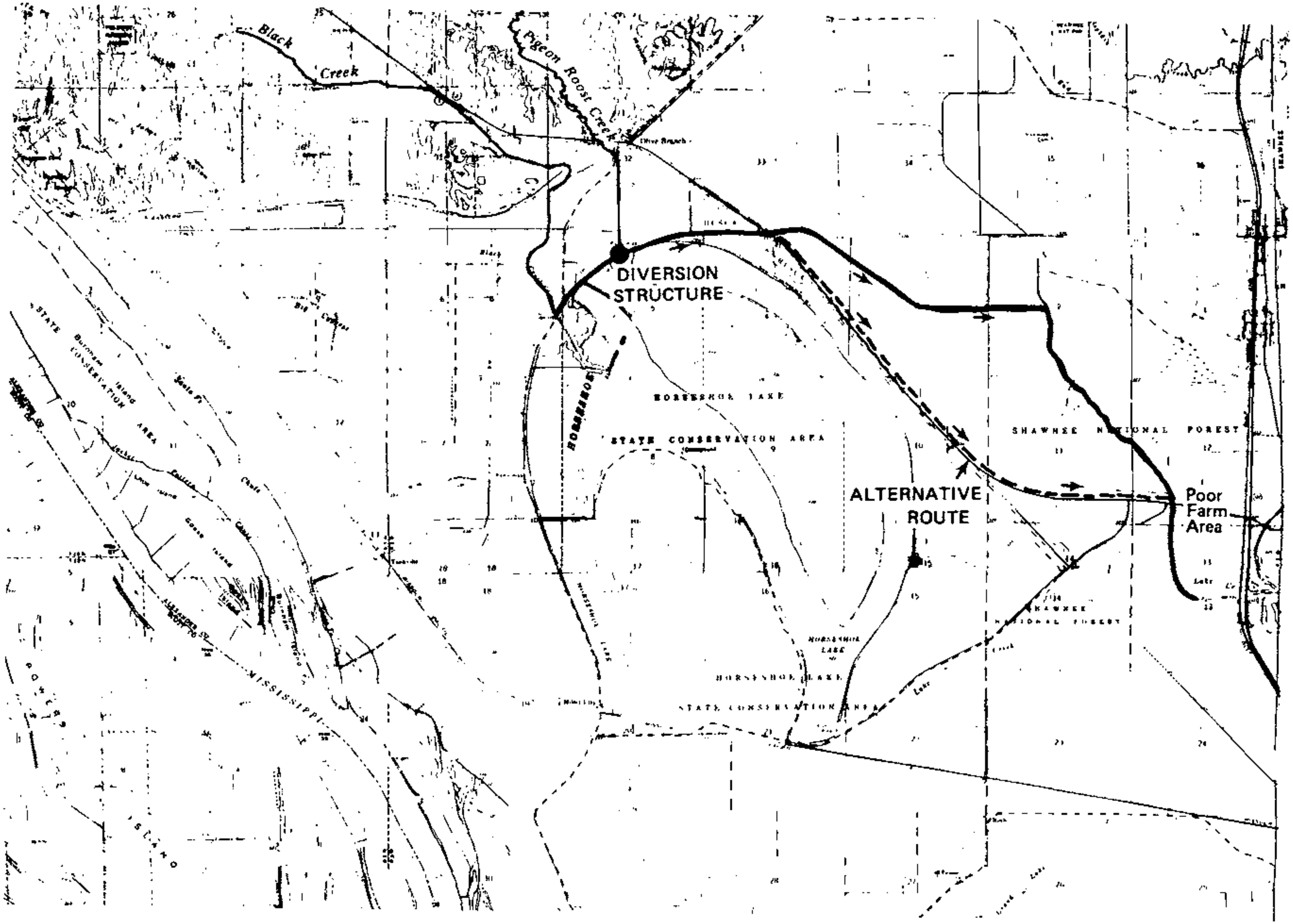


Figure 23. Diversion along Route 3 to Lake Creek

The advantage to this alternative is that it would reduce future sedimentation of Horseshoe Lake. The disadvantages are that it would affect the hydrologic input to the lake and there would be no gain in depth of the lake.

The diversion channel from Black Creek to Pigeon Roost Creek would have a length of 3500 feet, bottom width of 25 feet, and a water depth of 7.0 feet at peak flow. From the diversion structure to Lake Creek the length of the channel would be 27,000 feet, with a bottom width of 45 feet, and a depth of 8.1 feet at peak flow.

The cost of constructing the channel would be $1.26 million (Denny Construction Company, Anna, Illinois, personal communication). Approximately 5 bridges would have to be constructed or reconstructed. The cost of the bridges (IDOT, personal communication) diversion structure (IDOC, personal communication), and tree removal (Denny Construction Company, personal communication) would be $1.36 million for a total cost of $2.62 million. A summary of the costs may be seen in table 24.

3. Diversion through Miller City Arm to Lake Creek. This diversion would take the flow from Pigeon Roost Creek to Black Creek. The combined flow would then be located within the lake just east of Miller City Road and would head east along the abandoned Missouri Pacific Railroad to Lake Creek. This alternative can be seen in figure 24. In formulating the route of this alternative, it was felt that the diversion should be on Illinois Department of Conservation (IDOC) property as much as possible. This route also would allow the drainage west of the lake to be diverted away from the lake.

The advantages of this alternative are that future sediment input into the lake would be minimized, and agricultural drainage west of the lake could be prevented from entering the lake. The disadvantages are that many trees in the path of the diversion would be lost, and access to the lake from the west bank along Miller City Road would be disrupted. A portion of the lake would be displaced by the diversion channel. As with the other diversion schemes, this diversion would adversely affect the hydrologic input to the lake and there would be no gain in depth.

The diversion channel from Pigeon Roost Creek to Black Creek would have a length of 3500 feet, a bottom width of 20 feet, and a depth of water of 8.4 feet at peak discharge. From the diversion structure to Lake Creek

Table 24. Estimated Cost of the Diversion along Route 3 to Lake Creek
(1985 values in millions of dollars)

Item	Cost
Bridge reconstruction	1.24
Channel construction	1.26
Diversion structure	0.10
Tree removal	0.02
Total	2.62

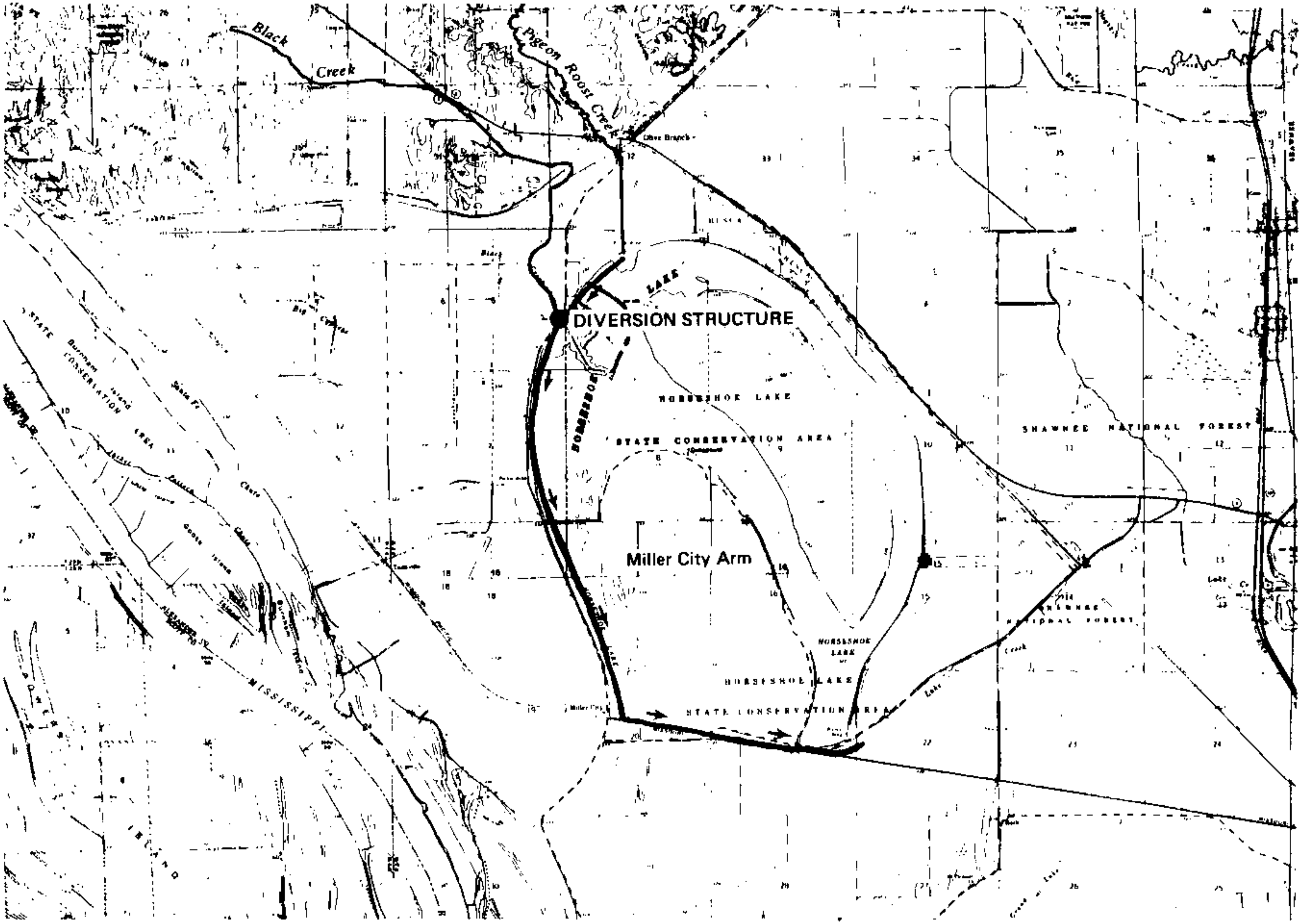


Figure 24. Diversion through Miller City arm to Lake Creek

the length of the channel would be 25,000 feet, with a bottom width of 50 feet and a depth of 8.3 feet at peak discharge.

In addition to the channel construction, Lake Creek would have to be cleared to provide additional flow capacity. Even though the watershed area of Lake Creek would remain the same, the peak flow would increase since the attenuation effect of the lake would be removed.

The cost of the channel diversion (Denny Construction Company, personal communication) would be $1.31 million. The other costs, including bridge construction (IDOT, personal communication), diversion structure (IDOC, personal communication), and tree removal (Denny Construction Company, personal communication) would be $0.65 million for a total cost of $1.96 million. A cost summary is provided in table 25.

4. *Diversion to Miller City Arm Sedimentation Basin.* This alternative is similar to the previous scheme. The difference between the alternatives is that instead of conveying the flow through the Miller City arm of the lake to Lake Creek as in the previous alternative, the diversion would stop at the southern end of the Miller City arm. This alternative may be seen in figure 25. The flow, once in the Miller City arm, would continue north to join the lake above the peninsula causeway by flowing over a spillway. The Miller City arm would then become a sedimentation basin.

One additional advantage of this alternative is that there would be little effect on the hydrologic budget in that all flow would enter the lake. As with the previous alternative the agricultural drainage west of the lake would be collected and future sediment inflow to the lake would be minimized. The disadvantages of this alternative are: periodic dredging about once every 10 years would be required; spoil sites would have to be designated; in the path of the diversion the stand of trees would be lost, as would some in the Miller City arm due to dredging; access to the lake from the west side would be limited; the lake would lose some area due to the diversion channels; and recreational value of the Miller City arm would be lost.

The diversion from Pigeon Roost Creek to the Black Creek delta would be 3500 feet in length with a bottom width of 20 feet and a depth of 8.4 feet at design discharge. From the diversion structures to the southern

Table 25. Estimated Cost of the Diversion through Miller City Arm to Lake Creek
(1985 values in millions of dollars)

Item	Cost
Bridge reconstruction	0.36
Channel construction	1.31
Diversion structure	0.12
Tree removal	0.17
Total	1.96

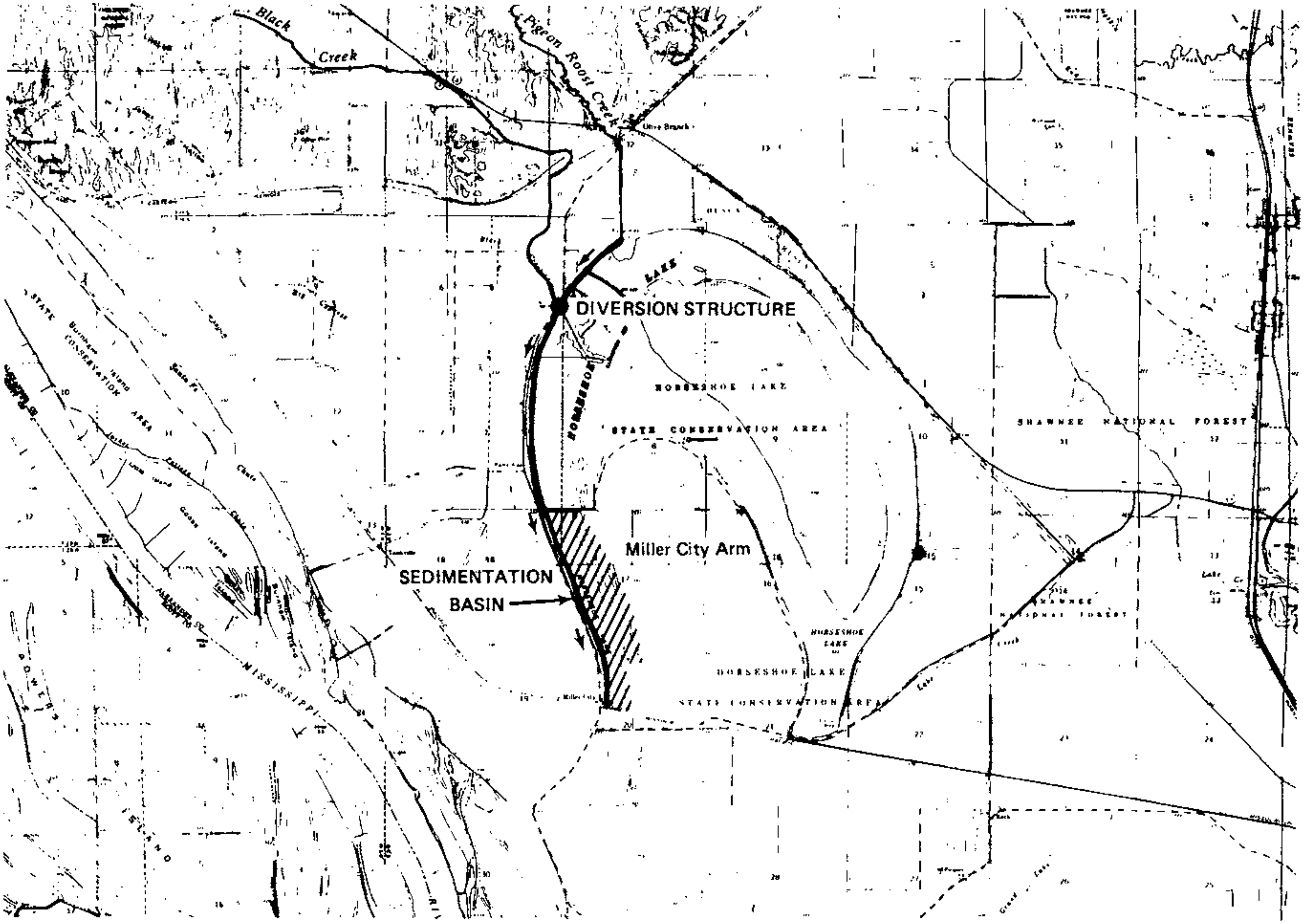


Figure 25. Diversion to Miller City arm sedimentation basin

end of the Miller City arm the length would be 8000 feet, the bottom width would be 50 feet, and the depth would be 8.3 feet at design discharge.

The diversion channel would have a cost of $0.91 million (Denny Construction Company, personal communication). The sedimentation basin construction would be $0.05 million (Denny Construction Company, personal communication). The other costs including bridges (IDOT, personal communication), diversion structure (IDOC, personal communication), and tree removal (Denny Construction Company, personal communication) come to $0.53 million. Assuming a 40-year life, the sedimentation basin would need to be dredged three times. As determined by cost estimates for Lake Springfield (Cochran & Wilken, Inc., 1985), the present cost of dredging would be $3.72 million. The project would have a total cost of $5.21 million. A summary of costs is presented in table 26.

Reduction in dredging costs would be accomplished by combining this scheme with alternative 3; that is, to carry the diversion to Lake Creek and still use the sedimentation basin. During low lake levels, all the flow would go through the sedimentation basin to the lake. When the lake levels were high, the sedimentation basin could be bypassed completely.

In-Lake Management

Raising the Lake Level. The most obvious alternative to gain depth in the lake is to raise the spillway. There are two alternatives available: 1) raising the existing spillway and 2) replacing the spillway entirely. Both these alternatives must start from the same question: what is the future pool elevation?

To determine the future height of the spillway, the adjacent topography was investigated. The only available map was the USGS 7.5-minute topographic map. The present elevation of the spillway is 321.41 feet mean sea level (msl). The lake level should be at least 1 foot below the point where flooding would occur. A significant elevation with respect to road elevations is 325 feet msl as determined from the field survey and the topographic map. Therefore, normal pool would be 323.50 feet msl, which would provide a 2-foot increase in the depth of the lake.

The flooded areas that would be caused by this alternative are shown in figure 26. Little adjacent area would be flooded due to the steepness

Table 26. Estimated Cost of the Diversion to Miller City Arm Sedimentation Basin
(1985 values in millions of dollars)

Item	Cost
Bridge reconstruction	0.24
Channel construction	0.91
Diversion structure	0.12
Tree removal	0.17
Sedimentation basin construction	0.05
Dredging of sedimentation basin	3.72
Total	5.21

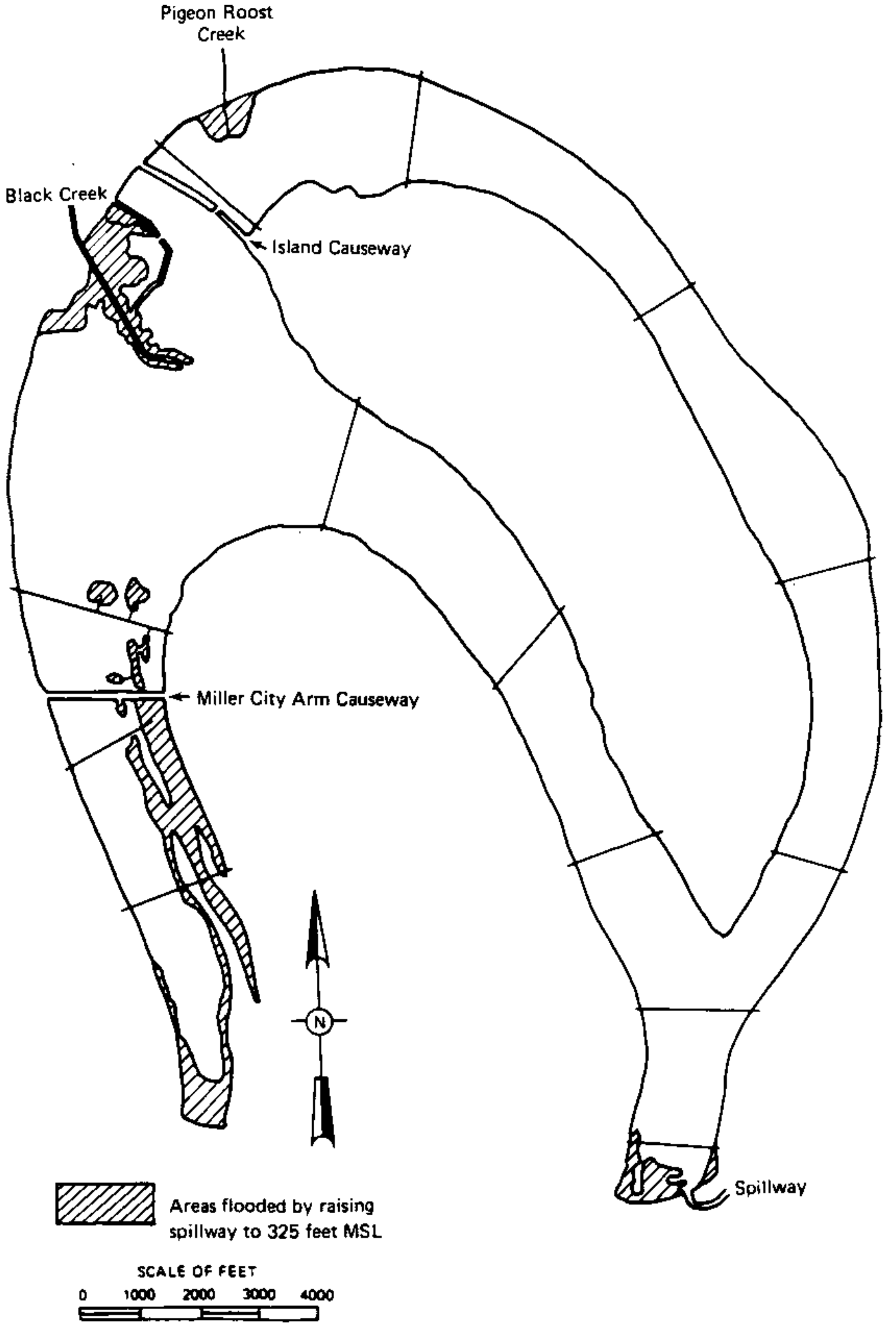


Figure 26. Areas that would be flooded as a result of raising the spillway

of the banks of the lake. Not shown on this map is the flooding in the Big Cypress Swamp area. This wetland area has complicated drainage patterns.

The first alternative to be discussed is the raising of the old spillway by 2 feet, keeping the length of the spillway the same. The disadvantage to this alternative is the insufficient capacity of the spillway. The insufficient size is important because it would not allow the runoff to pass quickly through the lake, and as a result the lake level would increase. If the spillway is raised by 2 feet it follows that future lake levels would increase by 2 feet during flood events. Figure 27 provides a stage-discharge curve for the existing spillway length with a crest at 323.50 feet msl, showing the 2-, 5-, 10-, and 25-year recurrence intervals for runoff. This figure also shows various elevations of points near the lake. A 2-year runoff event would flood an extensive area. The only choice would be to raise the roads that are affected.

The advantages to this alternative are that the depth of the lake would be increased and there would be little effect on the hydrologic budget. A disadvantage is that, as just discussed, the small discharge capacity of the dam would cause frequent flooding. Also, this alternative, by itself, would not prevent sedimentation; the backwater flooding of the Mississippi River would be reduced (see "Preventing Backwater Flow from the Mississippi River" section); and there might be adverse impacts on the vegetation in the nature preserve.

The costs of this alternative would be minimal. It is suggested that the dam be raised to an elevation of 330 feet msl to prevent backwater flows and high lake levels from scouring the dam. Additional protection of the dam could prevent scouring from backwater stages above 330 feet msl. Currently excess flow can pass over the dam.

It was assumed that the spillway was structurally sound so that the spillway height could be raised by the addition of flashboards. The spillway and dam restoration would cost about $0.13 million. The other costs, mainly raising the roads above a 2-year recurrence interval runoff event and restoring positive drainage to the area south of the Miller City arm, would be $0.73 million for a total cost of $0.86 million (Denny Construction Company, personal communication). A cost summary is given in table 27.

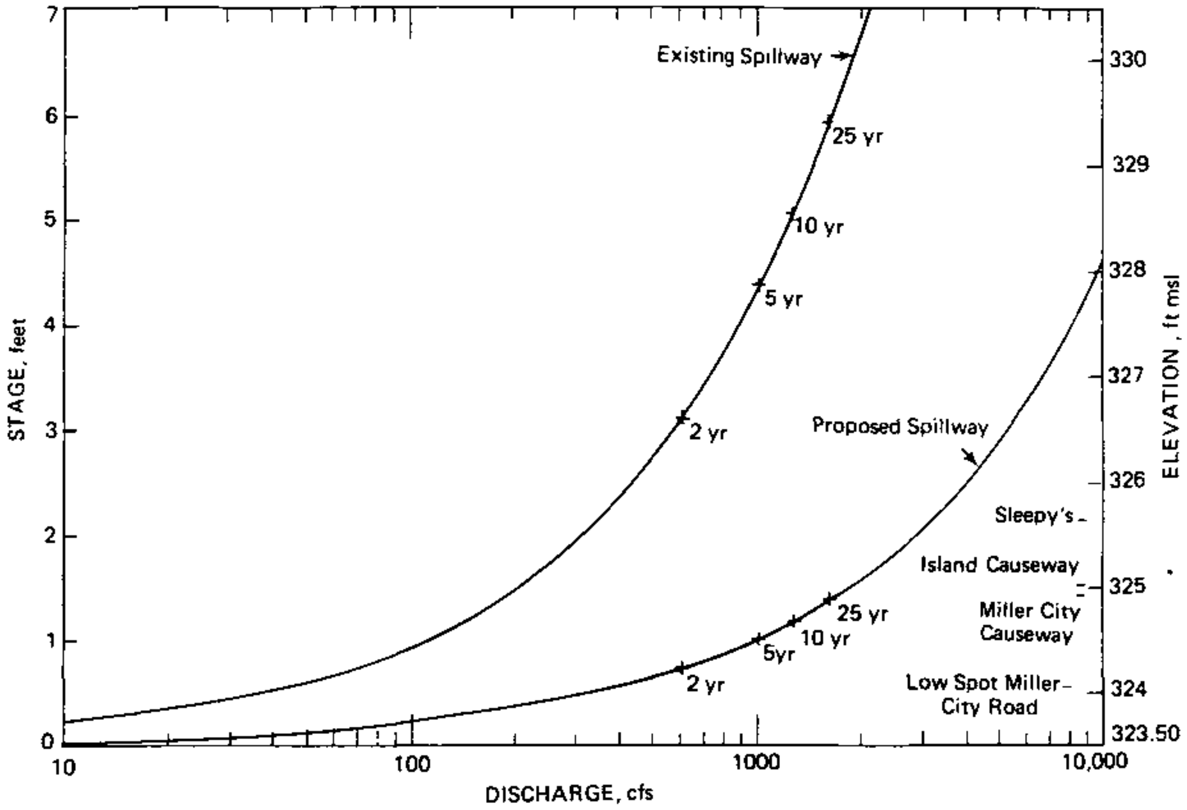


Figure 27. Stage-discharge relationships for existing and proposed spillways

Table 27. Estimated Cost of Raising the Spillway (Old Spillway)
(1985 values in millions of dollars)

Item	Cost
Raising of dam and spillway	0.13
Raising of roads above a 2-year flood	0.71
Restoring positive drainage south of lake	0.02
Total	0.86

The second spillway alternative is to totally reconstruct the dam and spillway. A spillway designed for a 5-year recurrence interval was used since this spillway design would not cause significant flooding. A gate could be included to provide a variable control for the lake level (though it was not considered for the cost estimate). The site would be at the location of the existing structure. The stage-discharge relationship of the larger spillway is also plotted on figure 27. From this figure it can be seen that the enlarged spillway capacity would reduce the lake elevation during flood events. For a flood with a 25-year recurrence interval, the proposed spillway would result in a lake elevation below 325 feet msl, whereas with the existing spillway the same runoff would result in a lake elevation of almost 329.5 feet msl.

The advantages of this alternative are that the lake level may be varied if a variable control is provided, there would be little effect on the hydrologic budget, and the large spillway capacity would limit the rise of water within the lake. A disadvantage is that future sedimentation would still occur. Also, there is a possibility that vegetation in the nature preserve would be adversely impacted. The backwater flooding would be reduced unless the gate structure is used to allow Mississippi River water into the lake if desired.

The major cost of this alternative is $0.85 million for raising the spillway to 323.5 feet msl and the dam to 330 feet msl (Denny Construction Company, personal communication). This estimate is based on the cost of concrete for a gravity dam. The other costs are raising roads above a 2-year flood and restoring positive drainage south of the Miller City arm of the lake, which amounts to $0.18 million (Denny Construction Company, personal communication). The total cost of the project is $1.03 million. A summary of costs for this alternative is presented in table 28.

Mentioned earlier were the possible adverse effects on the vegetation in the nature preserve that might result from raising the water level. It was found that the tree mortality is high and could possibly be attributed to the construction of the spillway. Starting in May 1985 wells were placed on the island nature preserve and water levels there and in the lake have been monitored.

Separating Delta Areas for a Sedimentation Basin. This scheme would combine the watersheds of Pigeon Roost Creek and Black Creek in a

Table 28. Estimated Cost of Raising the Spillway (New Spillway)
(1985 values in millions of dollars)

Item	Cost
Raising of dam and spillway	0.85
Raising of roads above a 2-year flood	0.16
Restoring positive drainage south of lake	0.02
Total	1.03

sedimentation basin constructed in the north end of the lake. The suspended sediment would then be allowed to drop out before the flow enters the lake. The sedimentation basins would have to be dredged periodically.

This scheme is presented in figure 28. The watersheds of Pigeon Roost Creek and Black Creek would be combined by levees or causeways in the lake. One levee would run north-south and be located east of Pigeon Roost Creek, and the other would run east-west south of the Black Creek delta. To allow flow out of the sedimentation basin, one or two small outlets would be constructed on either or both levees to allow circulation within the lake.

To total about 7500 linear feet, the levees would probably be 8 feet in height and have a 4-foot top width and a 1:2 side slope. The outlet structure(s) (one was assumed) would be designed to pass the flow slowly to allow maximum sedimentation. The structure would be 25 feet in length. The banks of the levees adjacent to the spillway(s) would be riprapped to prevent scour.

This sedimentation basin would have to be dredged periodically. For computation it is assumed that the long-term sedimentation rate found in the lake sedimentation survey will continue. The basin is 271 acres in size. The basin would fill with about 1.25 inches of sediment per year. Therefore, 875,000 cubic yards of sediment would have to be removed every 20 years.

The advantages to this alternative are that future sediment inflow would be prevented or at least significantly reduced, and there would be little effect on the hydrologic budget since the runoff from the tributaries does not adversely affect the lake level.

The disadvantages are that periodic dredging would be required; therefore spoil areas would be required and the recreational value of the north end of the lake would be negatively impacted by lack of both access and depth. Due to the small capacity of the spillway from the sedimentation basin, flooding would be possible at upstream areas, especially in Big Cypress Swamp. This alternative would not provide for an additional gain in depth in the lake outside of the sedimentation basin.

Assuming a 40-year period, the sedimentation basin would have to be dredged once. Assuming a 7.125 percent discount rate, the dredging would cost $2.16 million on the basis of cost estimates for Lake Springfield

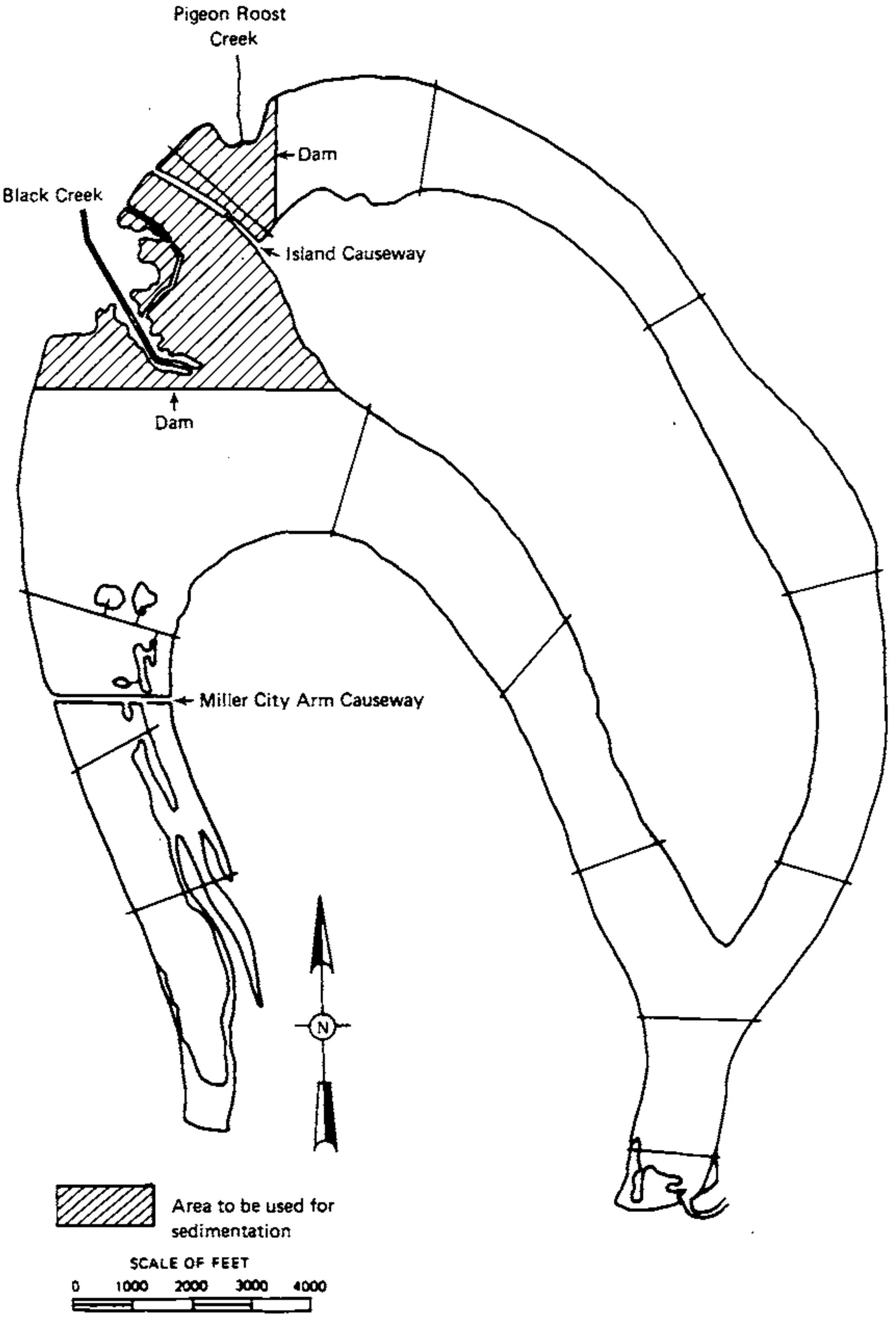


Figure 28. Proposed sedimentation basin in the north end of the lake

(Cochran & Wilken, Inc., 1985). The construction of the sediment basin would cost $0.22 million (Denny Construction Company, personal communication). The total cost for this alternative would be $2.38 million. A summary of costs is presented in table 29.

Reduction in dredging costs could be accomplished by combining this alternative with a diversion. The highest sediment flows would be diverted around the sedimentation basin, and lower sediment flow could pass through the sedimentation basin. If the lake level was low, all flow would go into the sedimentation basin and then into the lake. When the lake level was high, all flow could bypass the sedimentation basin.

Preventing Backwater Flow from the Mississippi River. Periodically the floodwaters of the Mississippi River enter Horseshoe Lake. More details may be found in the "Hydrologic Analyses" section, "Backwater" subsection. Prior to field monitoring it was hypothesized that floodwaters transport a great deal of sediment and then deposit it in the lake.

The water that enters the lake from the Mississippi River can cause backwater effects. Therefore, the water quality records of the Mississippi River were used. The floodwaters of the Mississippi River were assumed to back into the Cache River, then into Lake Creek, and then over the spillway into the lake. The suspended sediment is highest during peak flows. During Water Year 1983 (October 1, 1982 - September 30, 1983), the minimum, maximum, and mean suspended sediment concentrations of the Mississippi River at Thebes were 71, 1060, and 439 mg/L, respectively (Stahl et al., 1983).

However, during the field monitoring, floodwater which was backed into the lake was clearer than lake water. A number of suspended sediment concentration samples were collected from below the spillway, from the east arm of the lake, and from stations HL2, HL3, and HL4. The respective results were 11.6, 13.5, 2068, 1300, and 840 mg/L. These data clearly indicated that the Mississippi River water was clearer than the water of the tributaries. This was believed to be because the Mississippi River backwater traveled overland at very low velocities that allowed the sediment in suspension to drop out. The Mississippi River backwater contributed 1.4 percent to the sediment budget, but only a small fraction of this 1.4 percent was actually deposited in the lake.

Table 29. Estimated Cost of Separating Delta Areas for a Sedimentation Basin
(1985 values in millions of dollars)

Item	Cost
Sedimentation basin construction	0.22
Dredging of sedimentation basin	2.16
Total	2.38

With these results it was decided that the backwater does more good than harm by providing a large inflow to the lake, and that it should not be prevented from entering the lake.

Therefore no cost estimation was performed for this alternative.

Draining and Refilling the Lake. This management option would consist of completely draining the lake in order to expose the accumulated sediment to physical compaction and natural oxidation. Compaction would occur due to removal of buoyant forces from the saturated sediment. Some of this compaction would be permanent and would result in a 25 to 50 percent decrease in the volume of the exposed sediment. The exposure period should be at least one year.

Natural oxidation would then reduce the organic content of the sediment and therefore its bulk. This reduction of the bulk of the exposed sediment would result in another 25 to 50 percent reduction in volume. Therefore there would be a total sediment volume reduction of up to 75 percent.

Advantages of this option would include an increase in depth, sediment/water quality improvements, exposure of sediments for selected dry dredging, and water level drawdown for dam/spillway reconstruction.

Disadvantages of this option would include loss of boating facilities for at least one year, disruption of the present fish population, the need for a reestablishment period for the fish population, goose population disruption, and odor problems.

Costs required for this option would be $0.85 million for reconstruction of the dam and spillway (see the "Raising the Lake Level" alternative).

Constructing a Segmental Water Level Control System. This alternative would involve the construction or modification of water level control structures in the lake to allow surcharging and dewatering of sections of the lake as separate units. The purpose of the compartmentalization would be to allow individual water level management of each "compartment" to provide dewatering and/or water depth increases. The advantage of the compartments would be to reduce the impact of dewatering on the fishery of the lake by providing a seed stock of native fish.

Advantages of this option would include increased management alternatives, reduced impacts from dewatering, localized increases in depth, and induced water circulation.

Disadvantages of this option would include possible reduction of fish migration routes, a partial loss of fishery, reduced fish access to shallow water spawning, and possible adverse impacts of high/low water stages.

Costs of this option would include $0.85 million for reconstruction of the dam and spillway, $4 million for an 1100-foot inflatable dam, and $0.05 million each for modification of the two causeway structures. The total cost would be $4.95 million.

Lake Dredging. Dredging implies the complete removal of accumulated sediments from all or portions of the lake. Areas suitable for dredging should be coordinated for optimal environmental benefits.

From an engineering perspective, open lake areas with no trees or stumps and at least 2 to 3 feet of water would be desirable dredging sites. Table 30 gives the results of a dredge site feasibility analysis for 16 possible sites (see figure 29). This analysis is based on sediment thickness, tree stands, and stump field locations, as well as site accessibility.

Spoil areas could be located on the Horseshoe Lake island, on the peninsula east of the Miller City arm of the lake, or elsewhere if space could be made available. On the basis of the unit weights determined in the sedimentation survey, the sediment would compact over time to one-third of its in-lake volume. Thus dredging 100 acres or 5 percent of the lake to increase the depth by 5 feet would require 170 acre-feet of sediment disposal volume or 34 acres to a depth of 5 feet, assuming that 1 cubic foot of dewatered sediment will consolidate to 0.34 cubic foot of dry sediment.

Advantages of dredging would include an increase in water depth, recovery/recycling of soil nutrients, decreased aquatic weed growth, and improved sediment/water quality.

Disadvantages of dredging would include disruption of the lake system, loss of spoil disposal areas, and formation of non-continuous stagnant pools.

As indicated in figure 29 and table 30, approximately 50 percent of Horseshoe Lake is dredgible. The initial dredging depth would be 5 feet.

Table 30. Potential Increase in Lake Volume due to Dredging

Dredge site	Area in acres	Average depth original (ft)	Average depth 1984 (ft)	Change in average depth (ft)	Dredge volume* (ac-ft)
A	99	3.3	1.6	1.7	167
B	87		-2.3	2.	174
C	50		-2.3	2.	99
D	44	4.0	1.8	2.2	96
E	39	6.7	2.8	3.9	153
F	67	9.0	3.9	5.0	333
G	149	9.6	4.2	5.4	806
H	95	9.0	3.8	5.2	494
I	48	7.5	3.7	3.8	182
J	147	8.0	3.8	4.2	616
K	75	8.6	4.0	4.6	346
L	29	8.0	3.9	4.1	118
M	67	6.0	3.1	2.9	193
N	30	3.9	2.3	1.6	48
0	48	3.1	1.6	1.5	72
P	61	2.5	1.5	1.0	61
Total	-1100				3958

*To original lake bed

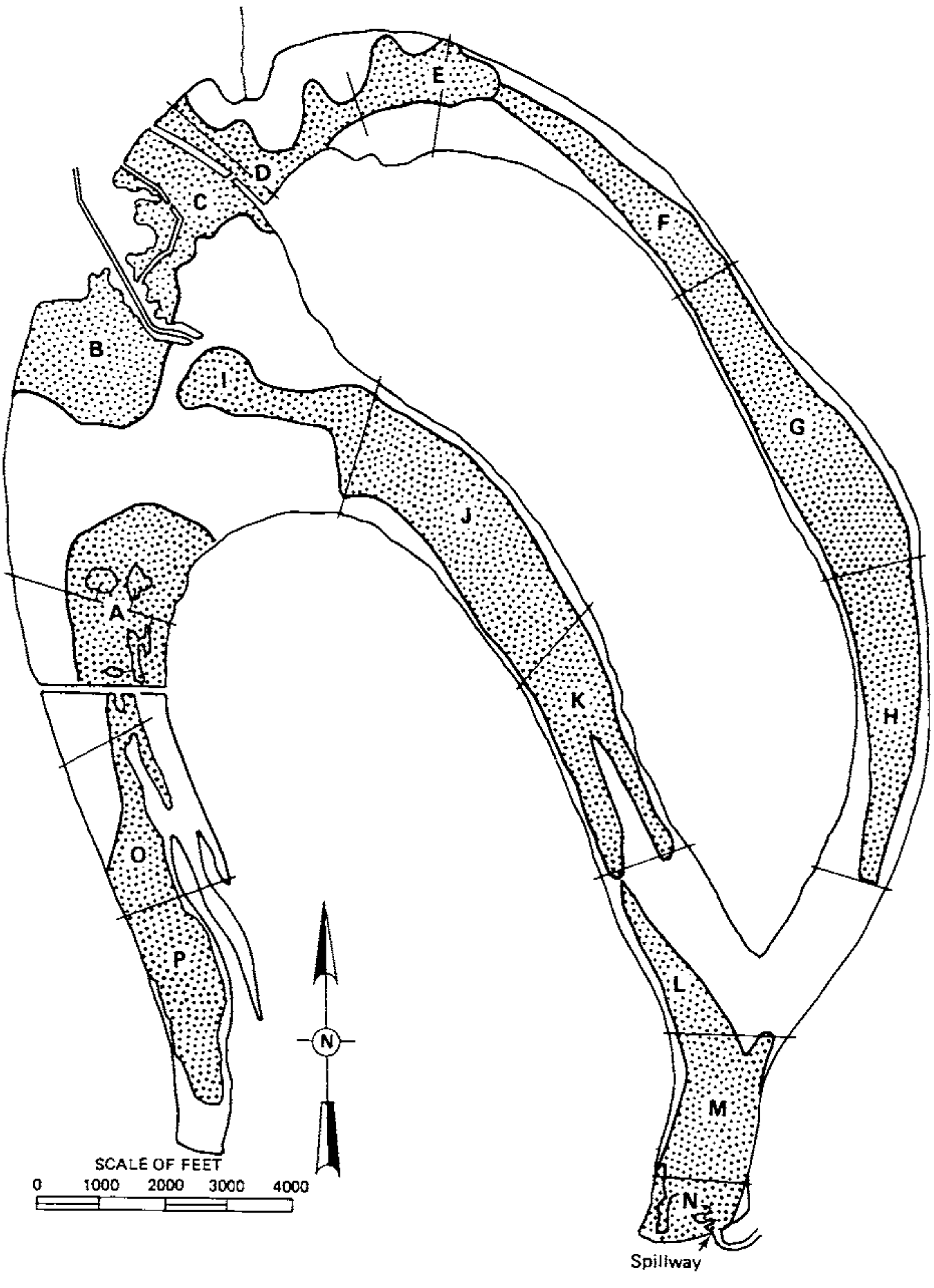


Figure 29. Potential dredging sites

On the basis of the analysis of dredging feasibility performed for Lake Springfield by Cochran & Wilken, Inc. (1985), one year of dredging of 50 percent of Horseshoe Lake would cost $40 million. One year of dredging of 10 percent of the lake would cost $8 million. Continual maintenance dredging of 2.5 percent of the lake per year would cost $2 million per year over an initial 20-year period. Because the sedimentation rate of approximately 0.5 inches per year would result in 1 foot or less of sediment accumulation over a 20-year period, subsequent annual costs would be $0.4 million per year.

The "Do Nothing" Alternative. Under this alternative, no action would be taken. No monetary costs are involved in this alternative. The environmental impacts are known. This alternative would not add depth in the lake or prevent future sediment from entering the lake. The recreational value of the lake would decline and, due to a natural eutrophication process, the lake would completely fill up with sediment.

Summary. The costs of the feasible alternatives are summarized in table 31. The available cost comparison suggests that the least-cost alternatives are raising the lake water level and draining and refilling the lake. The channel diversion through the Miller City arm is the least-cost in-stream management alternative. No cost estimation was made for watershed management because it cannot be considered to be a feasible solution in the short term.

SUMMARY AND RECOMMENDATIONS

The Illinois State Water Survey has conducted a diagnostic and feasibility study of sediment management for Horseshoe Lake, Alexander County, Illinois, for the Illinois Department of Conservation through a grant from the U.S. Fish and Wildlife Service. This study was organized in five components:

1. Determination of the sedimentation rate at Horseshoe Lake
2. Analysis of pertinent lake water quality parameters
3. Development of a lake hydrologic budget
4. Identification of major sources of sedimentation, using sediment budget analysis techniques

Table 31. Estimated Cost of Alternatives
(1985 values in millions of dollars)

Alternatives	Channel	Dredging	Pump	Sediment basin	Spillway and dam	Other*	Total cost
Diversion to Mississippi River	1.56	-	11.84	-	-	0.36	13.76
Diversion along Rte. 3 to Lake Creek	1.26	-	-	-	-	1.36	2.62
Diversion through Miller City Arm	1.31	-	-	-	-	0.65	1.96
Using Miller City Arm as sed. basin	0.91	3.72	-	0.05	-	0.53	5.21
Raising lake level without new dam and spillway	-	-	-	-	0.13	0.73	0.86
Raising lake level with new dam	-	-	-	-	0.85	0.18	1.03
Separating delta areas	-	2.16	-	0.22	-	-	2.38
Draining-refilling lake	-	-	-	-	0.85	-	0.85
Segmental water level control	-	-	-	-	0.85	4.10	4.95
Lake dredging	-	40	-	-	-	-	40

*Other: Includes raising roads, tree removal, bridge construction, modification of causeway structures, and restoring drainage

5. Development and evaluation of various sediment management plans on the basis of the gathered data and existing information.

A data collection and evaluation program was conducted from January 1984 to May 1985. Three stream gaging stations and two raingages were established to measure rainfall, runoff, and suspended sediment loads in the watershed. The lake water quality was monitored monthly at five locations. The water quality parameters monitored were dissolved oxygen, temperature, secchi disc transparencies, pH, alkalinity, turbidity, total solids, suspended solids, suspended volatile solids, total phosphorus, total dissolved phosphorus, ammonia-nitrogen, and nitrate-nitrogen. Additionally, a lake sedimentation survey was performed to determine the sedimentation rate.

The results of the lake sedimentation survey indicated that a total of 2808 acre-feet of sediment accumulated in Horseshoe Lake from 1951 through 1984, which represents an annual sedimentation rate of 78.6 acre-feet. If this rate continues, 50 percent of the lake will be displaced by sediment by the year 2022, and the entire lake will be displaced by sediment by 2060. In terms of depletion of water depth, the sedimentation survey indicated that the lake is losing its depth at a rate of 0.47 inches per year. The results also showed that the sediment accumulation generally decreased from north to south, and that the east branch of the lake has a higher rate of sedimentation than the central branch. The main reason for the lower sedimentation rate at the middle branch may be the flushing action of Mississippi floodwaters, which passed mainly through the middle branch of the lake prior to the closing of the river levee (Fayville Levee). In terms of sediment weight, 1,154,000 tons of sediment were deposited from 1951 to 1984, or 33,900 tons per year, or 2.58 tons per acre per year from the watershed.

The lake water quality study indicated that temperatures were uniform through the water column at any given time. However, the dissolved oxygen concentrations tend to exhibit a significant gradient during summer months from supersaturated conditions near the surface to totally anoxic conditions near the bottom. The lake's sediment oxygen demand rates ranged from 4.04 to 6.58 milligrams per square meter per day at 25°C. These high rates, combined with the fact that the average volatile fraction of the suspended solids was very high (average: 68 percent), are indicative of a very high organic enrichment of the bottom sediments. The mean secchi disc values varied from 19 inches to 23 inches. The mean turbidity values for the lake ranged from 17 to 26 NTU. The suspended matter in the lake was predominantly volatile and consequently organic in nature. The mean phosphorus values ranged from 0.03 to 0.06 mg/L, which is much higher than the commonly reported critical level of 0.01 mg/L from the eutrophication perspective. However, the inorganic nitrogen concentrations were below the critical level of 0.3 mg/L for nitrogen. The lake experienced algal blooms with densities greater than 500 counts/ml during late spring and summer months.

The 13-month hydrologic budget of Horseshoe Lake was established. The inflows consist of 62 inches of direct rainfall on the lake, 34 inches of runoff from the watersheds, and 8.4 inches of Mississippi River backwater. The outflows consist of 37 inches of lake evaporation, 1.2 inches of infiltration to the ground water, and 33 inches of flow over the spillway. There was a net gain of water at the end of April 1985.

Similarly, the sediment budget for the same period was also developed. The sediment yield delivered to Horseshoe Lake was assessed as 15,200 tons from its watersheds, 218 tons from the Mississippi River backwater, and 1,147 tons that passed over the spillway. Consequently, it was estimated that 14,288 tons deposited in the lake. This value is below the long-term annual average sedimentation rate (excluding the organic component) of 30,500 tons determined by the 1984 sediment survey.

On the basis of the feasibility study, the following recommendations are made:

1. Watershed management has the potential to reduce the gross erosion to the level of 40 percent of the current. However, in order to achieve this, a long-range plan and full cooperation of the landowners in the watershed are absolutely necessary. The Illinois Department of Conservation is seeking technical assistance from the Soil Conservation Service to develop a detailed conservation plan to accomplish this alternative.

2. The in-stream management techniques that were considered included four stream diversion alternatives. From the preliminary cost estimate, the most economic alternative is to divert the flow through the Miller City

arm. The cost estimation considers only engineering and construction aspects. Further information on local landowner reaction and other environmental impacts would need to be obtained. The alternatives of diverting the streamflows west to the Mississippi River and to Lake Creek are considered costly due to high pumping costs and the long distance of the new proposed channels.

3. In-lake management could include both raising the lake level and increasing the water depth by removing sediment. The most economic alternatives are draining and refilling the lake and raising the lake water level. Raising the lake water level may be the most desirable alternative; however, further evaluation is needed to determine the impacts on the cypress trees of additional water depth. To meet this need, ground-water monitoring was initiated in May 1985 and is still continuing. Preliminary results show that the lake water level and ground-water table adjacent to the lake are closely related. A public hearing and a survey are recommended to seek the reactions of local residents regarding raising the water level.

4. This study is based on one year of field data and previously available data. One year of field data may not be representative of the long-term records which are required to develop a sound management plan. The accuracy of all the management alternatives is strongly dependent upon the long-term hydrologic data. To enhance and refine the management plan, the continuation of field monitorings is recommended.

5. It should be noted that the cost estimations for this study were derived only for the purpose of comparing alternatives. To arrive at detailed design and construction costs, additional cost computation is required.

REFERENCES

Allen, James S., 1968. Alexander County surface water resources. Illinois Department of Conservation, Division of Fisheries.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1980. Standard methods for the examination of water and wastewater, fifteenth edition.

Bellrose, F.C., S.P. Havera, F.L. Paveglio, Jr., and D.W. Steffeck, 1983. The fate of lakes in the Illinois River Valley. Illinois Natural History Survey, Champaign, Illinois, Biological Notes No. 119.

Bogner, W.C., W.P. Fitzpatrick, and N.G. Bhowmik, 1984. Sedimentation survey of Lake Decatur, Decatur, Illinois. Illinois State Water Survey Contract Report 342.

Bogner, W.C., W.P. Fitzpatrick, and D.S. Blakley, 1985. Sedimentation rates in Horseshoe Lake, Alexander County, Illinois. Illinois State Water Survey Contract Report 364.

Butts, T.A., and R.L. Evans, 1979. Sediment oxygen demand in a shallow oxbow lake. Illinois State Water Survey Circular 136, 38 p.

Cobb, Charles R. , and Richard W. Jefferies, 1983. Archeological investigations at the Milar Site, Alexander County, IL. Research Paper No. 40, Center for Archeological Investigations, Southern Illinois University at Carbondale.

Cochran & Wilken, Inc., 1985. Engineering report, Lake Springfield sediment removal project. Springfield, IL.

Conlin, Mike, 1981. IDOC office memorandum to Ray Norbut and Bruce Clark. Subject: Horseshoe Lake - Alexander County. January 9.

Curtis, G.W., 1977. Techniques for estimating magnitude and frequency of floods in Illinois. U.S. Geological Survey Water Resources Investigations 77-117, Champaign, IL.

Eakin, Henry M., 1936. Silting of reservoirs. Revised by Carl B. Brown, 1939. Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C., Technical Bulletin 524.

Freeze, R.A., and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, NJ.

Graf, W.H., 1971. Hydraulics of sediment transport. McGraw-Hill Book Company, New York, New York.

Harris, Stanley E., Jr., William C. Harrell, and Daniel Irwin, 1977. Exploring the land and rocks of Southern Illinois. Southern Illinois University Press, Carbondale, IL.

Heinemann, Herman G. , 1962. Volume-weight of reservoir sediment. Proceedings ASCE, Journal of Hydraulics Division 88: 181-197.

Hill, T.E., D.L. Hullinger, and V. Kothandaraman, 1981a. Physical, chemical, and biological water quality characteristics of Lake Ellyn. Illinois State Water Survey Contract Report 274, 25 p.

Hill, T.E., R.L. Evans, and J.S. Bell, 1981b. Water quality assessment of Horseshoe Lake [Madison County, Illinois]. Illinois State Water Survey Contract Report 249, 82 p.

Horseshoe Lake Chamber of Commerce Bulletin, 1983.

Huff, F.A., 1974. Calculation of 5-minute to 60-minute rainfall occurring 1, 2, 3, 4, and 5 times per season. Illinois State Water Survey, Unpublished, Champaign, IL.

Huff, F.A., and J.C. Neill, 1970. Rainfall frequencies. Illinois State Water Survey Technical Letter 13, Champaign, IL.

Hutchinson, G.E., 1957. A treatise on limnology, volume 1: geography, physics, and chemistry. John Wiley and Sons, Inc., New York, 1015 p.

Hutchison, Max D., 1984. Lower Cache preservation plan. Natural Land Institute, Rockford, IL.

Illinois Department of Conservation, 1972. Management plan for Horseshoe Lake conservation area, Alexander County, IL.

Illinois Pollution Control Board, 1979. Water pollution regulations of Illinois, 52 p. plus amendments through July 1, 1979.

Kennedy, David, and Ernie Lewis, 1977. In search of the Canada Goose. Great Lakes Living Press, 1977.

Kothandaraman, V., and R.L. Evans, 1983a. Diagnostic-feasibility study of Johnson Sauk Trail Lake. Illinois State Water Survey Contract Report 312.

Kothandaraman, V., and R.L. Evans, 1983b. Diagnostic-feasibility study of Lake Le-Aqua-Na. Illinois State Water Survey Contract Report 313.

Lee, M.T., 1979. Inflow hydrology of Horseshoe Lake, Madison County, Illinois. Contract Report to Illinois Department of Conservation.

Lee, M.T., 1982. Sediment conditions in Sanganois Conservation Area, Cass and Mason Counties, Illinois. Illinois State Water Survey Contract Report 290.

Lee, M.T. and J.B. Stall, 1976. Sediment conditions in backwater lakes along the Illinois River. Illinois State Water Survey Contract Report 176A.

Lee, M.T., and J.B. Stall, 1977. Sediment conditions in backwater lakes along the Illinois River. Illinois State Water Survey Contract Report 176B.

Leighton, M.M., G.E. Ekblaw, and L. Horberg, 1948. Physiographic divisions of Illinois. Journal of Geology, 56(1).

Makowski, P.B., and M.T. Lee, 1983. Sediment and hydrologic budgets for the Lake of the Woods Watershed, Champaign County, Illinois. Illinois State Water Survey Contract Report 309, Champaign, IL.

Makowski, P.B., M.T. Lee, and M. Grinter, 1986. Hydrologic investigation of the Highland Silver Lake watershed: 1985 progress report. Illinois State Water Survey Contract Report 380.

National Oceanic and Atmospheric Administration (NOAA), 1983. Narrative climatological summary and statistical summary for Cairo, Illinois.

Price, O.M., 1980. Horseshoe Lake approximate location of sounding transects: January - February, 1951. IDOC file document.

Pryor, W.A., 1956. Ground water geology in southern Illinois, A preliminary geologic study. Illinois State Geological Survey Circular 212.

Pryor, Wayne A., 1958. Geological report on the occurrence of groundwater in the Horseshoe Lake area, Alexander County. Illinois State Geological Survey.

Ritter, Dale F., 1975. Stratigraphic implication of coarse-grained gravel deposited as overbank sediment, southern Illinois. Journal of Geology, Vol. 83, p. 645-650.

Roberts, W.J., and J.B. Stall, 1967. Lake evaporation in Illinois. Illinois State Water Survey Report of Investigation 57.

Sawyer, C.N., 1952. Some new aspects of phosphate in relation to lake fertilization. Sewage and Industrial Wastes, 24{6}: 768-776.

Simons, D.B., and F. Senturk, 1977. Sediment transport technology. Water Resources Publications, Fort Collins, Colorado.

Stahl, R.L., K.K. Fitzgerald, T.E. Richards, and P.D. Hayes, 1983. Water resources data, Illinois, Water Year 1983, Vol. 1. Illinois except Illinois River Basin. U.S. Geological Survey Water Data Report IL-83-1, Champaign, IL.

Thornburg, Dennis, 1982. The Canada Goose flock in Illinois. From Selected Papers in Illinois History. Third Annual Illinois History Symposium, Illinois State Historical Society.

U.S. Army Corps of Engineers, 1978. Special flood hazard information study, Mississippi River, Mile 0.0 to Mile 160.7. Department of the Army, St. Louis, MO.

U.S. Army Corps of Engineers, 1984. Initial evaluation report on the water resources problems of the streams and tributaries in Alexander and Pulaski Counties, Illinois. Department of the Army, St. Louis, MO.

U.S. Soil Conservation Service and Illinois Agricultural Extension Service, 1968. Soil survey of Alexander and Pulaski Counties, Illinois.

Vollenweider, R.A., 1968. Scientific fundamentals of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organization for Economic Cooperation and Development, Paris, DAS/CSI/68-27, 159 p.

Walton, W.C., 1965. Ground-water recharge and runoff in Illinois. Illinois State Water Survey Report of Investigation 48, Champaign, IL.

Wang, W.C, W.T. Sullivan, and R.L. Evans, 1973. A technique for evaluating algal growth potential in Illinois surface waters. Illinois State Water Survey Report of Investigation 72, 16 p.

Wischmeier, W.H. , and D.D. Smith, 1978. Predicting rainfall erosion losses. A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook, No. 537.

Wolman, M.G., and L.B. Leopold, 1967. River flood plains - some observations on their formation. U.S. Geological Survey Professional Paper 282-C, p. 87-109.

Appendix 1

Sediment Sample Locations and Geotechnical Analyses

Sample Location and Geotechnical Analysis
Horseshoe Lake - Alexander County

	Sample Number[2]						**Particle Size Distribution**[3]		
Location[1]	Unit weight	Particle size	Nutrient	Depth below lake bed to midpoint of sample (feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
12-S-836	1			1.35	52.4	1.77			
	2			0.3	14.8	3.90			
		1		1.2			55	44	1
		2		0.15			80	19	1
			1	1.0					
12-S-1580	3			1.95	27.0	2.70			
	4			1.15	17.1	3.96			
		3		1.1			81	18	1
		4		0.2			78	21	1
			2	1.65					
			3	S					
11-S-579		5		0.15			85	14	1
		6		2.15			86	13	1
			4	1.85					
	5			1.55	27.3	2.67			
	6			0.55	17.5	3.94			
			5	S					

[1] Format for location L-E-d: L = line number; E = end surveyed from; d = distance in feet of sample point from E

[2] Nutrient samples split from P.S. samples

[3] Percent sand > 64μ; 64μ > percent silt > 4μ; percent clay < 4μ

	Sample Number[2]			Depth below lake bed to midpoint of sample			Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient	(feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
11-S-1111	7			1.65	24.4	3.00			
		7		1.85					
		8		0.6			92	7	1
			6	1.35					
	8			0.45	13.6	4.46			
			7	0.15					
10-S-412	9			1.75	26.2	2.78			
	10			0.85	15.4	4.18			
			8	1.1					
			9	S					
		9		2.05			91	8	1
		10		1.55			89	10	1
		11		S			83	16	1
10-S-1095	11			1.145	25.6	2.78			
	12			0.35	14.6	4.36			
			10	0.6					
			11	S					
		12		1.2					
		13		0.1			81	18	1

	Sample Number[2]			Depth below lake bed to midpoint of sample			Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient	(feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
5-W-508	13			1.25	29.0	2.52			
	14			0.45	14.2	4.45			
			12	0.7					
		14		1.95			86	14	0
		15		1.0					
			13	0.2					
		16		0.1			97	2	1
5-W-1464	15			1.45	35.9	2.19			
	16			0.45	15.5	4.17			
		17		1.25					
			44	0.8					
			14	S					
		18		0.25			90	8	2
4-E-348	17			0.85	61.0	1.59			
		19		0.55			78	21	0
		56		S			70	26	4
			15	0.1(S)					

	Sample Number[2]			Depth below lake bed to midpoint of sample (feet)			Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient		Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
4-E-974	18			0.55	68.2	1.48			
			17	S					
		20		0.3			82	17	0
		21		0.1 (S)			71	24	5
			16	0.1					
7-E-439	27			0.65	9.8	5.51			
	28			2.15	19.6	3.38			
		22		1.85			96	1	2
		23		S			78	19	1
			18	1.55					
			19	S					
8-E-503	29			0.35	6.5	7.18			
	30			1.75	25.2	3.00			
		24		1.45			84	9	7
		25		S			92	7	2
			20	1.15					
			21	S					

	Sample Number[2]			Depth below lake bed to midpoint of sample			Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient	(feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
8-E-996	31			0.55	8.4	6.29			
	32			1.85	15.4	4.30			
			22	1 .55					
		26		1.25					
		55		S			78	20	2
			23	S					
6-E-503	33			0.55	16.4	3.95			
	34			2.05	21.6	3.12			
		57		1.75					
		29		S			67	31	2
			24	1.45					
			25	S					
6-E-1185	35			0.55	9.1	5.64			
	36			1.85	77.7	1.42			
		28		1.55					
		27		S			62	26	13
			45	S					

	Sample Number[2]			Depth below lake bed to midpoint of sample (feet)			Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient		Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
9-W-652	37			0.25	8.1	6.77			
	38			1.75	12.4	5.16			
			46	1.45					
		30		1.15			72	26	2
			26	S					
		31		S					
9-W-328	39			0.75	11.3	5.04			
	40			2.15	16.6	3.98			
		32		1.85			72	16	12
		33		S			94	3	3
			27	1.55					
			28	S					
14-N-900	19			1.55	64.5	1.52			
	20			0.45	26.3	2.64			
		35		1.05			66	32	2
			29	0.95					
		36		S			52	47	0
			30	S					

	Sample Number[2]			Depth below lake bed to midpoint of sample			**Particle Size Distribution**[3]		
Location[1]	Unit weight	Particle size	Nutrient	(feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
14-N-1517	21			1.25	64.2	1.48			
			31	1.0					
			32	S					
	22			0.35	19.5	3.24			
		37		1.40			46	21	33
		38		S			59	41	1
		39		0.6			62	35	3
AE642	45			0.95	72.4	1.45			
	46			0.55	59.8	1.57			
			33	0.75					
		40		1.15			45	55	1
		41		S			58	41	0
			34	S					
AE534	23			1.65	78.6	1.38			
	24			0.65	75.8	1.37			
			35	0.9					
		42		1.05			17	21	61
		43		S			60	28	12
		44		1.45			33	11	56
			47	S					

	Sample Number[2]						Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient	Depth below lake bed to midpoint of sample (feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
ΔW1717		45		0.65			81	18	1
		46		S			68	32	0
		47		1.45			63	33	4
	25			B	21 .6	3.16			
	26			T	63.3	1 .56			
			36	1 .00					
			37	S					
ΔW1072	47			1.15	61.4	1.53			
	48			0.35	23.2	2.82			
		48		0.95					
		50		0.75			55	44	1
			38	0.6					
		49		S			53	47	1
			39	S					
13-S-200	42			1.25	70.5	1.43			
	43			0.35	36.5	2.18			
		51		1.5			48	52	0
		52		S			34	66	0
			40	0.65					
		58		0.55			39	61	1
			41	S					

	Sample Number[2]						Particle Size Distribution[3]		
Location[1]	Unit weight	Particle size	Nutrient	Depth below lake bed to midpoint of sample (feet)	Unit weight	Water content	Percent of clay	Percent of silt	Percent of sand
2-W-400	41			0.85	76.6	1.38			
	44			0.35	66.3	1.48			
		53		1.05			57	40	3
		54		S			83	4	13
			42	0.65					
			43	S					

Appendix 2

Soil Nutrient Sample Analyses

Nutrient Sample Analysis
Horseshoe Lake - Alexander County

Sample number	P_1 (lbs/ac)	P_2 (lbs/ac)	K (lbs/ac)	Ca (lbs/ac)	Mg (lbs/ac)
1	51	96	460	4690	1210
2	50	90	568	5430	1380
3*	107	215	824	5757	1320
4	46	74	528	5960	1680
5*	54	215	1012	6600	1360
6	28	45	356	5430	1360
7*	49	146	952	6820	1570
8	126	164	794	5540	1190
9*	51	93	490	5757	1260
10	40	60	592	6180	1340
11*	176	192	668	6820	1260
12	37	68	490	6500	1490
13*	41	74	636	6500	1360
14*	96	164	888	6500	1340
15*	138	215	776	6280	1380
16	74	215	904	8620	2020
17*	154	215	568	6180	1380
18	40	59	444	5860	1360
19*	87	164	786	6710	1280
20	57	85	428	6280	1280
21*	85	146	762	6080	1300
22	23	36	340	6390	1210
23*	78	176	754	5960	1340
24	42	78	482	6180	1380
25*	103	215	616	5110	1065
26*	96	154	660	6280	1280
27	25	46	512	6710	1360
28*	82	192	684	5757	1150
29	56	132	498	5330	1170
30*	100	215	436	4160	937
31	54	126	468	5110	1260
32*	70	215	512	4790	1130
33	93	215	388	4160	1075
34*	85	192	506	5540	1260
35	90	146	268	3090	682
36	59	176	636	5640	1620
37*	90	215	754	7030	1230
38	43	132	444	4900	1130
39*	85	215	482	4580	1065
40	68	164	592	6710	1340
41*	164	176	762	3200	703
42	82	215	716	6280	1300

Sample number	P_1 (lbs/ac)	P_2 (lbs/ac)	K (lbs/ac)	Ca (lbs/ac)	Mg (lbs/ac)
43*	120	215	936	5330	1044
44	34	53	444	6080	1510
45*	64	146	512	5430	1022
46	24	47	460	6820	1230
47*	70	164	644	4470	1022

*sediment surface sample

Appendix 3

Dissolved Oxygen and Temperature Observations

Dissolved oxygen, temperature observations in Horseshoe Lake, station 1

Depth	3/14/84		4/16/84		5/14/84		6/12/84		7/16/84		8/15/84	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	13.8	6.7	11.1	13.3	9.9	22.1	11.5	28.3	11.3	29.4	10.5	28.1
1	13.8	6.7	11.2	13.5	10.1	22.1	9.9	27.5	11.2	29.3	8.0	28.1
2	13.8	6.6	11.2	13.5	10.1	21.9	7.7	26.8	9.6	29.0	2.7	27.4
3	13.8	6.6	11.1	13.5	10.9	21.8	5.6	26.4	8.4	28.8	1.8	27.2
4	13.8	6.5	11.1	13.5	9.8	21.7	3.4	25.8	5.3	28.4	--	--
5	--	--	--	--	9.8	21.6	--	--	--	--	--	--
6	--	--	--	--	8.9	21.4	--	--	--	--	--	--
7	--	--	--	--	8.7	21.4	--	--	--	--	--	--
8	--	--	--	--	8.0	21.1	--	--	--	--	--	--
9	--	--	--	--	6.7	21.0	--	--	--	--	--	--

Depth	9/17/84		10/22/84		11/19/84		12/10/84		3/18/85	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	10.3	19.4	7.2	15.1	9.8	7.8	10.9	6.0	11.8	12.2
1	10.2	19.5	--	--	9.6	7.8	10.8	6.0	12.2	12.2
1.5	--	--	6.7	14.9	--	--	--	--	--	--
2	9.8	19.1	--	--	9.6	7.8	10.6	5.5	11.9	12.0
3	6.7	17.8	6.7	14.9	9.6	7.8	10.6	5.5	12.0	12.0
4	4.7	17.8	--	--	9.6	7.8	10.3	5.0	11.2	12.0
5	--	--	--	--	9.6	7.8	--	--	--	--

D.O. - mg/l
Temperature - degrees Celsius

Dissolved oxygen, temperature observations in Horseshoe Lake, station 2

Depth	3/14/84		4/16/84		5/14/84		6/12/84		7/16/84		8/15/84	
feet	D.O..	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	14.0	7.2	11.2	13.7	11.2	21.8	11.9	30.9	13.3	29.9	11.5	28.2
1	14.0	7.2	11.2	13.7	11.5	21.8	11.7	30.6	12.9	30.1	11.0	27.8
2	14.1	16.5	11.2	13.8	11.4	21.7	8.6	29.0	10.5	29.7	4.5	27.3
3	14.1	6.4	11.1	13.8	10.1	21.4	6.4	28.0	5.9	29.0	2.9	27.1
4	13.9	5.9	11.1	13.9	7.8	20.5	3.2	27.5	2.0	28.7	0.8	27.0
5	13.6	5.9	11.1	13.9	6.7	20.2	0.1	26.9	--	--	--	--
6	--	--	--	--	6.5	19.9	--	--	--	--	--	--
7	--	--	--	--	4.7	19.6	--	--	--	--	--	--
8	--	--	--	--	4.2	19.5	--	--	--	--	--	--
9	--	--	--	--	3.3	19.4	--	--	--	--	--	--

Depth	9/17/84		10/22/84		11/19/84		12/10/84		3/18/85	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	10.7	21.8	7.9	16.5	10.4	7.8	11.3	5.0	11.6	12.0
1	6.9	20.8	--	--	10.0	7.8	11.1	5.0	11.4	12.0
1.5	--	--	7.7	16.3	--	--	--	--	--	--
2	6.0	20.6	--	--	10.0	7.8	11.0	5.0	11.4	12.0
3	4.6	20.5	6.8	16.0	10.0	7.8	11.0	5.0	11.4	12.0
4	3.0	20.6	--	--	10.0	7.8	11.0	5.0	11.4	11.8
5	--	--	--	--	9.9	7.8	--	--	11.0	11.8

D.O. - mg/l
Temperature - degrees Celsius

Dissolved oxygen, temperature observations in Horseshoe Lake, station 3

Depth	3/14/84		4/16/84		5/14/84		6/12/84		7/10/84		8/15/84	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	14.0	7.2	10.2	13.2	10.1	21.4	13.4	30.2	15.0	30.3	15.0	28.3
1	14.2	6.9	10.1	13.3	10.5	21.4	12.8	29.0	14.9	30.4	13.0	28.1
2	14.3	6.7	10.1	13.4	10.5	21.4	10.3	27.9	9.0	29.6	3.5	27.8
3	14.4	6.6	10.0	13.5	10.5	21.3	5.8	27.2	2.9	28.6	3.5	27.0
4	14.5	6.5	9.9	13.5	10.4	21.2	1.4	26.7	--	--	--	--
5	--	--	--	--	10.2	21.2	--	--	--	--	--	--
6	--	--	--	--	10.0	21.0	--	--	--	--	--	--
7	--	--	--	--	7.2	20.3	--	--	--	--	--	--
8	--	--	--	--	1.3	19.1	--	--	--	--	--	--

Depth	9/17/84		10/22/84		11/19/84		12/10/84		3/18/85	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	11.4	20.5	6.9	15.1	9.7	6.9	9.8	5.0	11.2	13.0
1	11.4	20.5	--	--	9.5	6.9	--	5.0	11.2	13.0
1.5	--	--	6.6	15.1	--	--	9.8	--	--	--
2	10.4	20.2	--	--	9.5	6.9	9.8	5.0	11.4	12.0
3	5.2	19.5	4.7	14.9	9.5	6.9	9.6	5.0	11.6	11.5
4	--	--	--	--	9.5	6.9	10.0	5.0	10.8	11.2

D.O. - mg/l
Temperature - degrees Celsius

Dissolved oxygen, temperature observations in Horseshoe Lake, station 4

Depth	3/14/84		4/16/84		5/14/84		6/12/84		7/16/84		8/15/84	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	12.3	6.8	8.9	13.4	13.0	21.7	9.9	29.1	9.5	29.0	11.5	28.1
1	12.4	6.7	8.7	13.5	13.5	21.7	9.6	28.4	9.5	29.0	11.3	28.0
2	12.4	6.7	8.5	13.5	13.6	21.7	9.3	27.6	9.3	29.0	7.5	27.2
3	12.3	6.7	8.5	13.6	13.6	21.5	7.2	27.2	7.9	28.8	5.5	27.0
4	12.3	6.7	8.6	13.7	11.0	20.3	3.9	26.4	4.2	28.5	0.8	26.9
5	11.5	6.6	8.6	13.7	6.4	20.0	0.7	26.1	--	--	--	--
6	--	--	--	--	4.9	19.4	--	--	--	--	--	--
7	--	--	--	--	3.3	19.1	--	--	--	--	--	--
8	--	--	--	--	2.2	18.8	--	--	--	--	--	--
9	--	--	--	--	1.3	18.7	--	--	--	--	--	--

Depth	9/17/84		10/22/84		11/19/84		12/10/84		3/18/85	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	8.5	20.6	7.0	15.4	10.2	7.5	10.0	5.0	11.9	13.0
1	8.3	20.5	--	--	10.1	7.5	9.9	5.0	11.8	12.5
1.5	--	--	7.0	15.4	--	--	--	--	--	--
2	8.0	20.2	--	--	10.0	7.5	9.9	5.0	11.4	12.0
3	7.3	20.0	6.9	15.4	9.8	7.5	9.7	4.5	11.6	11.8
4	--	--	--	--	9.9	7.5	9.4	4.5	11.2	11.5
5	--	--	--	--	--	--	--	--	10.6	11.2

D.O. - mg/l
Temperature - degrees Celsius

Dissolved oxygen, temperature observations in Horseshoe Lake, station 5

Depth	3/14/84		4/16/84		5/14/84		6/12/84		7/16/84		8/15/84	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0	11.5	7.5	9.5	13.5	11.3	22.7	10.2	28.6	10.3	31.2	14.4	30.3
1	11.5	7.5	9.4	13.5	11.4	22.6	9.7	28.3	10.1	31.0	8.6	28.8
2	11.6	7.1	9.3	13.5	11.3	22.5	7.5	27.1	9.2	29.9	5.0	28.0
3	11.5	7.1	9.2	13.5	11.0	22.3	1.3	26.7	9.5	29.3	--	--
4	--	--	7.7	13.5	8.6	21.2	--	--	--	--	--	--
5	--	--	--	--	7.2	20.6	--	--	--	--	--	--
6	--	--	--	--	5.4	19.8	--	--	--	--	--	--
7	--	--	--	--	1.1	19.3	--	--	--	--	--	--

Depth	9/17/84		10/22/84		11/19/84		12/10/84		3/18/85	
feet	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.
0			7.1	15.2	9.2	7.0			12.1	12.8
1			--	--	8.6	6.5			12.2	12.5
1.5	Inaccessible		6.6	15.2	--	--	Inaccessible		--	--
2			--	--	8.5	6.5			12.0	12.5
3			--	--	8.4	6.5			12.2	12.5

D.O. - mg/l
Temperature - degrees Celsius

Appendix 4

Physical and Chemical Characteristics of Surface Waters

Physical and chemical quality characteristics of surface waters at station 1 in Horseshoe Lake

Parameters	3/14/84	4/16/84	5/14/84	6/12/84	7/16/84	8/15/84
Secchi disc readings	15.00	24.00	42.00	15.00	13.00	10.00
Turbidity	18.00	13.00	7.00	22.00	-9.00	51.00
Total solids	106.00	82.00	94.00	118.00	-9.00	144.00
Suspended solids	25.00	13.00	8.00	19.00	-9.00	60.00
Suspended volatile solids	18.00	0.00	2.00	15.00	-9.00	30.00
pH	7.07	6.98	7.85	7.23	-9.00	7.91
Alkalinity	38.00	34.00	105.00	53.00	-9.00	66.00
Total phosphorus - P	.18	.63	.07	.30	-9.00	.40
Total dissolved phosphorus - P	.06	.08	.01	.07	.05	.04
Total ammonia - N	.05	.01	.05	.11	.03	.04
Dissolved nitrate - N	.17	.20	.93	.12	.08	.06

Parameters	9/17/84	10/22/84	11/19/84	12/10/84	3/18/85
Secchi disc readings	10.00	17.00	30.00	28.00	10.00
Turbidity	45.00	20.00	10.00	12.00	14.00
Total solids	165.00	121.00	75.00	88.00	100.00
Suspended solids	50.00	26.00	10.00	6.00	16.00
Suspended volatile solids	36.00	20.00	7.00	6.00	13.00
pH	7.25	7.20	6.70	7.50	7.58
Alkalinity	62.00	52.00	42.00	39.00	43.00
Total phosphorus - P	.34	.22	.12	.12	.14
Total dissolved phosphorus - P	.02	0.00	.02	.02	.03
Total ammonia - N	.02	.02	.03	.04	.03
Dissolved nitrate - N	.10	.06	.12	.06	.08

Physical and chemical quality characteristics of surface waters at station 2 in Horseshoe Lake

Parameters	3/14/84	4/16/84	5/14/84	6/12/84	7/16/84	8/15/84
Secchi disc readings	24.00	24.00	30.00	20.00	12.00	8.00
Turbidity	12.00	12.00	11.00	15.00	39.00	60.00
Total solids	106.00	86.00	96.00	108.00	168.00	138.00
Suspended solids	17.00	16.00	14.00	8.00	30.00	42.00
Suspended volatile solids	15.00	11.00	10.00	8.00	10.00	40.00
pH	7.50	7.27	7.95	7.44	8.99	9.20
Alkalinity	46.00	37.00	56.00	66.00	72.00	76.00
Total phosphorus - P	.14	.14	.13	.19	.33	.45
Total dissolved phosphorus - P	.07	.05	.08	.10	.03	.07
Total ammonia - N	.29	.06	.02	.17	.07	.26
Dissolved nitrate - N	.32	.06	.03	.07	.05	.03

Parameters	9/17/84	10/22/84	11/19/84	12/10/84	3/18/85
Secchi disc readings	7.00	13.00	24.00	26.00	17.00
Turbidity	75.00	23.00	13.00	10.00	11.00
Total solids	187.00	137.00	89.00	100.00	102.00
Suspended solids	56.00	26.00	14.00	8.00	13.00
Suspended volatile solids	52.00	26.00	11.00	8.00	12.00
pH	7.35	7.15	6.67	6.88	7.63
Alkalinity	68.00	56.00	52.00	46.00	46.00
Total phosphorus - P	.45	.25	.13	.10	.14
Total dissolved phosphorus - P	.03	.01	.01	.02	.03
Total ammonia - N	.01	.02	.08	.02	.01
Dissolved nitrate - N	.11	.06	.09	.05	.06

Physical and chemical quality characteristics of surface waters at station 3 in Horseshoe Lake

Parameters	3/14/84	4/16/84	5/14/84	6/12/84	7/16/84	8/15/84
Secchi disc readings	21.00	22.00	30.00	17.00	12.00	9.00
Turbidity	13.00	15.00	11.00	16.00	36.00	51.00
Total solids	106.00	104.00	104.00	109.00	168.00	140.00
Suspended solids	17.00	14.00	16.00	7.00	31.00	30.00
Suspended volatile solids	14.00	7.00	10.00	7.00	19.00	28.00
pH	7.65	7.07	7.80	7.45	8.08	8.35
Alkalinity	49.00	48.00	48.00	68.00	72.00	76.00
Total phosphorus - F	.12	.03	.14	.17	.32	.38
Total dissolved phosphorus - F	.02	.02	.04	.07	.03	.05
Total ammonia - N	.10	.05	.04	.12	.03	.02
Dissolved nitrate - N	.16	.12	.01	.08	.04	.10

Parameters	9/17/84	10/22/84	11/19/84	12/10/84	3/18/85
Secchi disc readings	9.00	-9.00	18.00	33.00	30.00
Turbidity	63.00	22.00	25.00	14.00	13.00
Total solids	187.00	128.00	110.00	104.00	106.00
Suspended solids	58.00	26.00	23.00	6.00	15.00
Suspended volatile solids	50.00	17.00	9.00	6.00	10.00
pH	7.75	6.93	6.74	6.80	7.63
Alkalinity	72.00	54.00	51.00	50.00	55.00
Total phosphorus - P	.40	.21	.16	.10	.13
Total dissolved phosphorus - P	.02	.02	.03	.02	.03
Total ammonia - N	.02	.05	.06	.05	.04
Dissolved nitrate - N	.11	.12	.18	.10	.03

Physical and chemical quality characteristics of surface waters at station 4 in Horseshoe Lake

Parameters	3/14/84	4/16/84	5/14/84	6/12/84	7/16/84	8/15/84
Secchi disc readings	18.00	19.00	33.00	24.00	17.00	12.00
Turbidity	22.00	24.00	12.00	14.00	18.00	25.00
Total solids	106.00	92.00	95.00	97.00	141.00	106.00
Suspended solids	22.00	19.00	16.00	9.00	22.00	18.00
Suspended volatile solids	12.00	5.00	10.00	9.00	6.00	18.00
pH	7.19	6.90	7.81	7.21	7.80	7.39
Alkalinity	32.00	31.00	83.00	60.00	66.00	70.00
Total phosphorus - P	.15	.10	.11	.20	.22	.26
Total dissolved phosphorus - P	.09	.04	.07	.11	.02	.03
Total ammonia - N	.04	.01	.29	.19	.10	.03
Dissolved nitrate - N	.16	.81	.09	.11	.05	.04

Parameters	9/17/84	10/22/84	11/19/84	12/10/84	3/18/85
Secchi disc readings	12.00	14.00	28.00	20.00	28.00
Turbidity	36.00	26.00	14.00	28.00	21.00
Total solids	146.00	109.00	74.00	100.00	101.00
Suspended solids	44.00	27.00	11.00	13.00	19.00
Suspended volatile solids	30.00	16.00	7.00	10.00	8.00
pH	7.65	7.01	6.69	6.72	7.46
Alkalinity	64.00	48.00	40.00	36.00	37.00
Total phosphorus - P	.30	.22	.12	.16	.18
Total dissolved phosphorus - P	.02	.02	.02	.03	.05
Total ammonia - N	.04	.01	.04	.10	.08
Dissolved nitrate - N	.08	.01	.10	.14	.06

Physical and chemical quality characteristics of surface waters
at station 5 in Horseshoe Lake

Parameters	3/14/84	4/16/84	5/14/84	6/12/84	7/16/84	8/15/84
Secchi disc readings	15.00	21.00	31.00	17.00	20.00	24.00
Turbidity	25.00	20.00	9.00	21.00	14.00	11.00
Total solids	92.00	86.00	82.00	100.00	123.00	80.00
Suspended solids	21.00	12.00	13.00	14.00	13.00	10.00
Suspended volatile solids	13.00	5.00	6.00	13.00	5.00	4.00
pH	6.98	6.82	7.63	7.14	7.50	7.50
Alkalinity	29.00	30.00	52.00	56.00	56.00	64.00
Total phosphorus - P	.14	.08	.11	.12	.17	.12
Total dissolved phosphorus - P	.11	.08	.07	.07	.04	.04
Total ammonia - N	.01	.08	.17	.11	.02	.06
Dissolved nitrate - N	.24	.18	.07	.11	.06	.03

Parameters	9/17/84	10/22/84	11/19/84	12/10/84	3/18/85
Secchi disc readings	-9.00	21.00	37.00	-9.00	19.00
Turbidity	-9.00	-9.00	12.00	-9.00	23.00
Total solids	-9.00	-9.00	67.00	-9.00	100.00
Suspended solids	-9.00	-9.00	6.00	-9.00	27.00
Suspended volatile solids	-9.00	-9.00	4.00	-9.00	16.00
pH	-9.00	-9.00	6.62	-9.00	7.35
Alkalinity	-9.00	-9.00	36.00	-9.00	34.00
Total phosphorus - P	-9.00	-9.00	.10	-9.00	.22
Total dissolved phosphorus - P	-9.00	.02	.04	-9.00	.05
Total ammonia - N	-9.00	.04	.15	-9.00	.05
Dissolved nitrate - N	-9.00	.17	.11	-9.00	.06

Appendix 5

Monthly Rainfall Summaries

Illinois State Water Survey
Horseshoe Lake Project
Monthly Rainfall Summary

RAIN GAGE	DATE MOYR	DAYS													MONTHLY TOTAL
RF.1	0484	DY01	DY10	MD	MD	MD	MD	MD	MD	MD	MD	MD	MD		
RF.1		DY11	DY20	MD	MD		0.01	0.02			0.02	0.04			
RF.1		DY21	DY30	MD	MD						0.04				0.13
RF.1	0584	DY01	DY10	0.02					2.18	0.31	0.01	0.02	0.01		
RF.1		DY11	DY20			0.21		*MD	*MD	*MD	*MD	*MD	MD		
RF.1		DY21	DY31	MD	*MD	*MD	*MD	*MD	MD	MD	MD	*MD	*MD	*MD	2.55
RF.1	0684	DY01	DY10		0.02	0.02	0.04				0.02	0.03	0.09		
RF.1		DY11	DY20	0.05	0.04	0.01	0.21	0.02	0.03	0.03	0.04		0.02		
RF.1		DY21	DY31	0.71	0.29	0.51		0.02	*MD	*MD	*MD	*MD	*MD		2.06
RF.1	0784	DY01	DY10	*MD	MD	*MD	MD		0.29		0.01	0.02			
RF.1		DY11	DY20					0.12	0.03	0.56					
RF.1		DY21	DY31						0.14		0.02	0.03	0.01		1.23
RF.1	0884	DY01	DY10		0.16	0.03	0.02		0.03						
RF.1		DY11	DY20	0.04							0.37		0.01		
RF.1		DY21	DY31		0.14							0.06			0.86
RF.1	0984	DY01	DY10		0.02	0.21					0.02	0.72			
RF.1		DY11	DY20	0.88											
RF.1		DY21	DY31		1.31	1.19	0.20	0.77		0.05					5.37
RF.1	1084	DY01	DY10				*MD	0.02	1.02	0.23			0.38		
RF.1		DY11	DY20	0.55	0.11	2.10	0.31	0.17	0.66		0.34	0.84	2.41		
RF.1		DY21	DY31	0.05	0.15			0.26			1.72		0.08	0.37	11.77
RF.1	1184	DY01	DY10	1.95		*MD	*MD	*MD				0.79			
RF.1		DY11	DY20					0.13		MD	MD	*MD			
RF.1		DY21	DY31						0.14	1.33					4.34
RF.1	1284	DY01	DY10		0.11			0.05	0.29	0.36	0.02	0.04			
RF.1		DY11	DY20		0.01	0.65	0.32			0.03	0.53		0.65		
RF.1		DY21	DY31	2.76			0.09					*MD	MD	MD	5.91
RF.1	0185	DY01	DY10	*MD	*MD	MD	*MD	MD	*MD	MD	*MD	*MD	*MD		
RF.1		DY11	DY20							0.21	0.04	*MD	MD		
RF.1		DY21	DY31	MD	MD					0.36			0.29	*MD	0.90
RF.1	0285	DY01	DY10	MD	MD	MD	MD	MD	MD	MD	MD		1.31		

RF.1		DY11	DY20	0.06	0.21						0.09				
RF.1		DY21	DY28	0.01	1.36	0.88									2.61
RF.1	0385	DY01	DY10	0.22			0.26			*MD	MD	MD	MD		
RF.1		DY11	DY20	MD		0.43						*MD	*MD		
RF.1		DY21	DY31	MD	MD					0.12		0.57	3.40	0.07	5.07
RF.1	0485	DY01	DY10				*MD	0.52					0.03		
RF.1		DY11	DY20				1.16					*MD	*MD		
RF.1		DY21	DY30	MD	MD	0.70			1.49	1.17			0.22		5.29
RF.2	0484	DY01	DY10	MD	MD	MD	MD	MD	MD	MD	MD	MD	MD		
RF.2		DY11	DY20	MD	MD		0.06					0.21	0.03		
RF.2		DY21	DY30	0.74	0.11							0.50	0.02		1.48
RF.2	0584	DY01	DY10	0.01	0.03	0.40		0.05	1.71	1.58		0.01	0.03		
RF.2		DY11	DY20		0.02	0.18							0.26		
RF.2		DY21	DY31	0.02					0.17	0.51	0.02				5.00
RF.2	0684	DY01	DY10			0.01	0.02						0.45		
RF.2		DY11	DY20	0.03	0.05			0.06					0.20		
RF.2		DY21	DY31	0.09	0.24	0.38	0.01	0.03							1.57
RF.2	0784	DY01	DY10		0.03		2.08	0.02	0.42	0.01	0.03	0.01			
RF.2		DY11	DY20					0.32	0.03	0.18					
RF.2		DY21	DY31						0.23	0.03	0.03	0.02	0.02		3.46
RF.2	0884	DY01	DY10		0.05		0.30	0.01	0.03						
RF.2		DY11	DY20								0.35	0.02	0.02		
RF.2		DY21	DY31		0.12							0.04			0.94
RF.2	0984	DY01	DY10			0.25	0.03					1.02			
RF.2		DY11	DY20	1.28											
RF.2		DY21	DY31		1.09	1.22	0.26	0.60		0.05					5.80
RF.2	1084	DY01	DY10					0.01	0.81	0.18			0.41		
RF.2		DY11	DY20	0.08	0.11	1.47	0.03	0.19	0.74		0.20	0.93	2.37		
RF.2		DY21	DY31	0.07	0.14			0.12			1.85		0.04	0.33	10.08
RF.2	1184	DY01	DY10	1.56								0.08			
RF.2		DY11	DY20					0.13		0.06	1.67				
RF.2		DY21	DY30						0.14	1.33					4.97
RF.2	1284	DY01	DY10		0.16	0.02		0.04	0.02	0.31	0.10	0.04			
RF.2		DY11	DY20		0.03	0.44	0.38			0.03	0.12	0.16	0.49		
RF.2		DY21	DY31	2.95			0.05						0.75	1.49	7.58
RF.2	0185	DY01	DY10			0.06		0.37		0.04					
RF.2		DY11	DY20							0.16	0.04		MD		
RF.2		DY21	DY31	MD	MD					0.22	0.07		0.35		1.31
RF.2	0285	DY01	DY10	MD	MD	MD	MD	MD	MD	MD	MD		1.06		

RF.2		DY11 DY20	0.09	0.09						0.09				
RF.2		DY21 DY28		1.16	0.88									2.31
RF.2	0385	DY01 DY10	0.21			0.30				0.51	MD	MD		
RF.2		DY11 DY20	MD		0.34							*MD		
RF.2		DY21 DY31	*MD	0.34					0.14		0.36	2.73	0. 19	5.12
RF.2	0485	DY01 DY10					0.51				0.03	0.03		
RF.2		DY11 DY20	0.03			1.00								
RF.2		DY21 DY30	MD	MD	0.73			2.03	1.49			0.27		5.85
RF.3	0484	DY01 DY10			0.86	0.36				0.07	0.59			
RF.3		DY11 DY20.		0.79		0.18	0.01	0.02				0.09		
RF.3		DY21 DY30	0.67	0.35	0.04						0.79	0.12		4.94
RF.3	0584	DY01 DY10			0.24	0.23	0.07	0.87	1.50					
RF.3		DY11 DY20			0.24									
RF.3		DY21 DY31	0.93		0.13			0.15	0.13	0.01				4.50
RF.3	0684	DY01 DY10	*MD	MD	MD	MD	*MD	*MD	*MD	MD	MD	MD		
RF.3		DY11 DY20	MD	MD	MD	MD	MD	MD		0.14	0.05			
RF.3		DY21 DY30	1.00	0.01	0.73									1.93
RF.3	0784	DY01 DY10	0.01			0.41	1.42	0.23						
RF.3		DY11 DY20					0.04		0.13					
RF.3		DY21 DY31						0.12	0.05	0.33				2.74
RF.3	0884	DY01 DY10	0.03								0.09			
RF.3		DY11 DY20			0.08					0.84				
RF.3		DY21 DY31		0.31										1.35
RF.3	0984	DY01 DY10			0.16						0.92			
RF.3		DY11 DY20	1.13											
RF.3		DY21 DY30		0.29	1.45	0.40	0.14	0.42	0.04	0.03				4.98
RF.3	1084	DY01 DY10						0.79	0.17					
RF.3		DY11 DY20	0.49	0.14	MD	MD	MD	MD	*MD	MD	MD	MD		
RF.3		DY21 DY31		0.02	0.18	0.01	0.17			1.61	0.03	0.15	0 .15	3.81
RF.3	1184	DY01 DY10	2.52	0.01			0.08					1.08		
RF.3		DY11 DY20	0.01				0.14			1.77	0.18			
RF.3		DY21 DY30						0.30	1.32					7.41
RF.3	1284	DY01 DY10		0.35			0.55				0.17			
RF.3		DY11 DY20		0.02	0.56	0.46	0.02			0.53	0.19	0.21		
RF.3		DY21 DY31	2.85			0.07		*MD	MD	0.MD	*MD	MD	MD	5.98
RF.3	0185	DY01 DY10	*MD	*MD	MD	*MD	MD					0.10		
RF.3		DY11 DY20							0.22	0.03	0.11			
RF.3		DY21 DY31							0.47	0.01		0.26	0 .32	1.52
RF.3	0285	DY01 DY10	0.13	0.08			0.07					0.63		

RF.3		DY11	DY20	0.62					0.11						
RF.3		DY21	DY28	0.01	1.40	0.40	0.74								4.19
RF.3	0385	DY01	DY10	0.25			0.25				0.09		0.18		
RF.3		DY11	DY20	0.02		0.33	0.08								
RF.3		DY21	DY31	0.19	0.25		0.02			0.12			2.54	1.36	5.66
RF.3	0485	DY01	DY10					0.73		0.01					
RF.3		DY11	DY20	0.06			0.89	0.86							
RF.3		DY21	DY30			0.85	0.27		0.58	2.15	0.02		0.11		6.53

GAGE	LOCATION
1	BEHIND FIELD OFFICE (EAST ARM OF LAKE)
2	BY SPILLWAY
3	NWS STATION IN THE BLUFFS (NORTH END OF WATERSHED)

NOTE: MD IS MISSING DATA

*MD IS MISSING DATA WITH NO SIGNIFICANT PRECIPITATION

Appendix 6

Recurrence Intervals of Precipitation

Recurrence Intervals of Precipitation

DATE	GAGE	DURATION	TOTAL		MAX 5 MIN		MAX 30 MIN		MAX 60 MIN	
DYMOYR	NO	MIN	DEPTH	RI	DEPTH	RI	DEPTH	RI	DEPTH	RI
14 484	1	635.0	.03	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
18 484	1	470.0	.03	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
19 484	1	544.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
14 484	2	778.0	.06	-5.00	.00	-4.00	.02	-4.00	.02	-4.00
19 484	2	473.0	.02	-5.00	.01	-4.00	.01	-4.00	.01	-4.00
20 484	2	715.0	.03	-5.00	.00	-4.00	.02	-4.00	.02	-4.00
21 484	2	1233.0	.74	-5.00	.18	.50	.39	.43	.40	.32
22 484	2	555.0	.11	-5.00	.01	-4.00	.03	-4.00	.05	-4.00
29 484	1	166.0	.03	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
29 484	1	134.0	.01	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
30 484	1	704.0	.02	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
29 484	2	190.0	.23	-5.00	.03	-4.00	.12	-4.00	.19	-4.00
29 484	2	253.0	.27	-5.00	.04	-4.00	.15	-4.00	.24	-4.00
30 484	2	555.0	.03	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
6 584	1	100.0	.25	-5.00	.11	.20	.24	.20	.24	-4.00
6 584	1	876.0	1.94	-5.00	.24	1.06	.82	1.68	1.40	2.31
2 584	2	411.0	.25	-5.00	.01	-4.00	.06	-4.00	.10	-4.00
3 584	2	281.0	.18	-5.00	.02	-4.00	.07	-4.00	.08	-4.00
5 584	2	770.0	.05	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
6 584	2	133.0	.62	-5.00	.10	-4.00	.35	.35	.53	.53
6 584	2	1219.0	1.12	-5.00	.28	1.42	.57	1.06	.66	.96
7 584	1	1014.0	.31	-5.00	.04	-4.00	.16	-4.00	.28	-4.00
9 584	1	377.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
13 584	1	172.0	.21	-5.00	.04	-4.00	.12	-4.00	.17	-4.00
7 584	2	392.0	1.55	-5.00	.22	.85	.64	1.24	.88	1.36
9 584	2	722.0	.04	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
12 584	2	325.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
13 584	2	186.0	.18	-5.00	.04	-4.00	.13	-4.00	.15	-4.00
20 584	2	210.0	.12	-5.00	.01	-4.00	.04	-4.00	.05	-4.00
20 584	2	116.0	.11	-5.00	.05	-4.00	.10	-4.00	.10	-4.00
20 584	2	718.0	.05	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
26 584	2	217.0	.11	-5.00	.01	-4.00	.03	-4.00	.06	-4.00
26 584	2	137.0	.06	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
27 584	2	319.0	.48	-5.00	.03	-4.00	.14	-4.00	.24	-4.00
27 584	2	931.0	.05	-5.00	.01	-4.00	.02	-4.00	.02	-4.00
2 684	1	592.0	.02	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
2 684	1	728.0	.02	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
3 684	1	768.0	.02	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
3 684	2	823.0	.03	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
4 684	1	389.0	.02	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
8 684	1	595.0	.03	-5.00	.00	-4.00	.00	-4.00	.00	-4.00
9 684	1	608.0	.02	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
10 684	1	1081.0	.12	-5.00	.02	-4.00	.07	-4.00	.08	-4.00
10 684	2	372.0	.45	-5.00	.06	-4.00	.20	-4.00	.29	-4.00
11 684	2	346.0	.03	-5.00	.00	-4.00	.02	-4.00	.02	-4.00
11 684	1	372.0	.03	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
12 684	1	295.0	.03	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
13 684	1	385.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00

continued

DATE	GAGE	DURATION	TOTAL		MAX 5 MIN		MAX 30 MIN		MAX 60 MIN	
DYMOYR	NO	MIN	DEPTH	RI	DEPTH	RI	DEPTH	RI	DEPTH	RI
14 684	1	106.0	.19	-5.00	.05	-4.00	.15	-4.00	.18	-4.00
15 684	1	674.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
16 684	1	623.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
17 684	1	290.0	.03	-5.00	.00	-4.00	.02	-4.00	.02	-4.00
12 684	2	265.0	.05	-5.00	.01	-4.00	.02	-4.00	.03	-4.00
15 684	2	200.0	.06	-5.00	.00	-4.00	.02	-4.00	.04	-4.00
18 684	1	96.0	.04	-5.00	.02	-4.00	.03	-4.00	.03	-4.00
19 684	1	519.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
21 684	1	124.0	.71	-5.00	.30	.90	.58	.44	.68	.42
22 684	1	69.0	.29	-5.00	.12	-4.00	.28	-4.00	.29	-4.00
23 684	1	398.0	.51	-5.00	.12	-4.00	.33	-4.00	.40	-4.00
25 684	1	334.0	.02	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
19 684	2	391.0	.20	-5.00	.05	-4.00	.18	-4.00	.19	-4.00
21 684	2	143.0	.09	-5.00	.01	-4.00	.05	-4.00	.07	-4.00
22 684	2	137.0	.24	-5.00	.03	-4.00	.11	-4.00	.20	-4.00
23 684	2	210.0	.38	-5.00	.04	-4.00	.19	-4.00	.29	-4.00
24 684	2	690.0	.04	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
1 784	2	1079.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
4 784	2	167.0	1.11	-5.00	.16	-4.00	.65	.59	.98	.98
4 784	2	329.0	.99	-5.00	.14	-4.00	.34	-4.00	.49	.23
6 784	1	150.0	.29	-5.00	.17	.20	.26	-4.00	.26	-4.00
8 784	1	548.0	.03	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
6 784	2	192.0	.42	-5.00	.14	-4.00	.36	-4.00	.39	-4.00
7 784	2	265.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
8 784	2	699.0	.04	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
15 784	1	691.0	.15	-5.00	.06	-4.00	.10	-4.00	.11	-4.00
17 784	1	152.0	.56	-5.00	.18	.23	.43	.25	.52	.25
15 784	2	643.0	.35	-5.00	.10	-4.00	.29	-4.00	.31	-4.00
17 784	2	126.0	.18	-5.00	.02	-4.00	.08	-4.00	.14	-4.00
26 784	1	59.0	.02	-4.00	.00	-4.00	.01	-4.00	-1.00	-1.00
26 784	1	208.0	.12	-5.00	.03	-4.00	.08	-4.00	.10	-4.00
27 784	1	638.0	.02	-5.00	.00	-4.00	.00	-4.00	.01	-4.00
29 784	1	703.0	.04	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
26 784	2	106.0	.09	-5.00	.01	-4.00	.05	-4.00	.07	-4.00
26 784	2	121.0	.14	-5.00	.02	-4.00	.08	-4.00	.11	-4.00
27 784	2	259.0	.03	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
28 784	2	79.0	.03	-5.00	.00	-4.00	.03	-4.00	.03	-4.00
29 784	2	684.0	.04	-5.00	.01	-4.00	.01	-4.00	.01	-4.00
2 884	1	79.0	.16	-5.00	.03	-4.00	.12	-4.00	.16	-4.00
3 884	1	73.0	.03	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
4 884	1	124.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
6 884	1	368.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
2 884	2	76.0	.05	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
4 884	2	121.0	.30	-5.00	.08	-4.00	.21	-4.00	.28	-4.00
5 884	2	670.0	.04	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
11 884	1	133.0	.04	-5.00	.02	-4.00	.03	-4.00	.03	-4.00

continued

DATE	GAGE	DURATION	TOTAL		MAX 5 MIN		MAX 30 MIN		MAX 60 MIN	
DYMOYR	NO	MIN	DEPTH	RI	DEPTH	RI	DEPTH	RI	DEPTH	RI
18 884	1	254.0	.37	-5.00	.12	-4.00	.23	-4.00	.27	-4.00
19 884	1	699.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
22 884	1	634.0	.14	-5.00	.02	-4.00	.06	-4.00	.08	-4.00
18 884	2	287.0	.35	-5.00	.14	-4.00	.25	-4.00	.31	-4.00
19 884	2	790.0	.04	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
22 884	2	567.0	.12	-5.00	.01	-4.00	.03	-4.00	.05	-4.00
29 884	1	135.0	.06	-5.00	.02	-4.00	.04	-4.00	.05	-4.00
29 884	2	172.0	.04	-5.00	.01	-4.00	.04	-4.00	.04	-4.00
2 984	1	974.0	.23	-5.00	.02	-4.00	.04	-4.00	.06	-4.00
2 984	2	608.0	.25	-5.00	.01	-4.00	.04	-4.00	.07	-4.00
4 984	2	237.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
8 984	1	479.0	.74	-5.00	.15	-4.00	.41	.24	.46	.21
11 984	1	359.0	.88	-5.00	.16	-4.00	.34	-4.00	.46	.21
8 984	2	301.0	1.02	-5.00	.25	.46	.69	.70	.74	.48
11 984	2	418.0	1.28	-5.00	.09	-4.00	.26	-4.00	.42	-4.00
22 984	1	1407.0	2.50	-5.00	.32	1.81	.77	1.62	.80	1.31
24 984	1	374.0	.20	-5.00	.03	-4.00	.05	-4.00	.09	-4.00
25 984	1	166.0	.77	-5.00	.23	1.25	.53	1.10	.71	1.18
22 984	2	1467.0	2.32	-5.00	.22	1.19	.52	1.07	.69	1.14
24 984	2	543.0	.26	-5.00	.03	-4.00	.06	-4.00	.09	-4.00
25 984	2	209.0	.60	-5.00	.17	.71	.31	.35	.40	.40
27 984	1	242.0	.05	-5.00	.00	-4.00	.02	-4.00	.03	-4.00
27 984	2	206.0	.05	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
51084	1	311.0	.19	-5.00	.02	-4.00	.08	-4.00	.12	-4.00
61084	1	373.0	.85	-5.00	.17	.67	.38	.57	.48	.60
71084	1	288.0	.23	-5.00	.01	-4.00	.06	-4.00	.09	-4.00
101084	1	522.0	.38	-5.00	.03	-4.00	.08	-4.00	.11	-4.00
111084	1	97.0	.55	-5.00	.18	.83	.48	1.00	.56	.87
51084	2	855.0	.82	-5.00	.13	.33	.27	.28	.35	.32
71084	2	251.0	.19	-5.00	.01	-4.00	.06	-4.00	.09	-4.00
101084	2	541.0	.41	-5.00	.02	-4.00	.08	-4.00	.11	-4.00
111084	2	103.0	.08	-5.00	.02	-4.00	.06	-4.00	.07	-4.00
121084	1	87.0	.10	-5.00	.02	-4.00	.07	-4.00	.09	-4.00
121084	1	784.0	.79	-5.00	.07	-4.00	.19	-4.00	.27	.21
131084	1	256.0	1.32	-5.00	.31	1.75	.61	1.27	.67	1.10
141084	1	509.0	.25	-5.00	.04	-4.00	.14	-4.00	.19	-4.00
141084	1	189.0	.06	-5.00	.01	-4.00	.03	-4.00	.05	-4.00
141084	1	667.0	.17	-5.00	.04	-4.00	.07	-4.00	.09	-4.00
161084	1	256.0	.66	-5.00	.21	1.13	.38	.57	.45	.52
181084	1	149.0	.05	-5.00	.02	-4.00	.04	-4.00	.05	-4.00
181084	1	450.0	1.13	-5.00	.23	1.22	.42	.71	.77	1.26
201084	1	254.0	1.08	-5.00	.19	1.00	.47	.97	.58	.93
121084	2	136.0	.07	-5.00	.01	-4.00	.03	-4.00	.05	-4.00
121084	2	738.0	.37	-5.00	.03	-4.00	.09	-4.00	.15	-4.00
131084	2	257.0	1.14	-5.00	.22	1.19	.63	1.32	.66	1.09
141084	2	139.0	.03	-5.00	.01	-4.00	.03	-4.00	.04	-4.00

continued

DATE DYMOYR	GAGE NO	DURATION MIN	TOTAL DEPTH	 RI	MAX 5 MIN DEPTH	 RI	MAX 30 MIN DEPTH	 RI	MAX 60 MIN DEPTH	 RI
141084	2	660.0	.19	-5.00	.01	-4.00	.05	-4.00	.08	-4.00
161084	2	270.0	.74	-5.00	.18	.83	.43	.77	.46	.54
181084	2	123.0	.06	-5.00	.01	-4.00	.05	-4.00	.07	-4.00
181084	2	378.0	1.07	-5.00	.20	1.06	.63	1.32	.74	1.22
201084	2	168.0	.95	-5.00	.23	1.25	.60	1.26	.74	1.21
201084	1	594.0	1.33	-5.00	.14	.39	.28	.30	.48	.59
211084	1	799.0	.05	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
221084	1	337.0	.15	-5.00	.02	-4.00	.07	-4.00	.10	-4.00
251084	1	206.0	.26	-5.00	.11	.25	.23	.23	.24	-4.00
201084	2	681.0	1.42	-5.00	.08	-4.00	.25	.24	.35	.31
211084	2	297.0	.07	-5.00	.00	-4.00	.02	-4.00	.04	-4.00
221084	2	332.0	.14	-5.00	.02	-4.00	.06	-4.00	.10	-4.00
251084	2	215.0	.12	-5.00	.03	-4.00	.11	-4.00	.11	-4.00
281084	1	776.0	1.72	-5.00	.19	.92	.43	.79	.62	1.04
301084	1	158.0	.08	-5.00	.03	-4.00	.07	-4.00	.08	-4.00
311084	1	286.0	.37	-5.00	.11	.26	.21	-4.00	.27	.21
11184	1	155.0	.28	-5.00	.04	-4.00	.12	-4.00	.18	-4.00
11184	1	408.0	1.67	-5.00	.32	1.81	.65	1.36	.79	1.29
281084	2	829.0	1.85	-5.00	.23	1.24	.48	1.01	.63	1.05
301084	2	170.0	.04	-5.00	.01	-4.00	.02	-4.00	.03	-4.00
311084	2	336.0	.33	-5.00	.05	-4.00	.16	-4.00	.18	-4.00
11184	2	157.0	.28	-5.00	.07	-4.00	.16	-4.00	.19	-4.00
11184	2	337.0	1.28	-5.00	.25	1.38	.50	1.05	.56	.85
91184	1	135.0	.79	-5.00	.21	1.13	.34	.43	.42	.45
151184	1	224.0	.13	-5.00	.02	-4.00	.06	-4.00	.09	-4.00
91184	2	168.0	.08	-5.00	.00	-4.00	.02	-4.00	.04	-4.00
151184	2	296.0	.13	-5.00	.03	-4.00	.06	-4.00	.08	-4.00
171184	2	1453.0	1.55	-5.00	.12	.28	.24	.24	.30	.24
261184	1	166.0	.12	-5.00	.02	-4.00	.06	-4.00	.10	-4.00
261184	1	991.0	1.35	-5.00	.02	-4.00	.12	-4.00	.21	-4.00
21284	1	279.0	.11	-5.00	.02	-4.00	.04	-4.00	.06	-4.00
261184	2	202.0	.12	-5.00	.01	-4.00	.07	-4.00	.10	-4.00
261184	2	1154.0	1.35	-5.00	.02	-4.00	.12	-4.00	.22	-4.00
21284	2	239.0	.16	-5.00	.02	-4.00	.07	-4.00	.13	-4.00
51284	1	315.0	.05	-5.00	.00	-4.00	.02	-4.00	.03	-4.00
61284	1	530.0	.29	-5.00	.01	-4.00	.05	-4.00	.08	-4.00
71284	1	396.0	.36	-5.00	.03	-4.00	.15	-4.00	.19	-4.00
81284	1	157.0	.02	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
91284	1	93.0	.04	-5.00	.01	-4.00	.02	-4.00	.03	-4.00
31284	2	328.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
51284	2	269.0	.04	-5.00	.00	-4.00	.01	-4.00	.03	-4.00
61284	2	243.0	.02	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
71284	2	472.0	.31	-5.00	.02	-4.00	.06	-4.00	.09	-4.00
81284	2	159.0	.10	-5.00	.02	-4.00	.05	-4.00	.09	-4.00
91284	2	111.0	.04	-5.00	.01	-4.00	.04	-4.00	.04	-4.00
121284	1	532.0	.35	-5.00	.02	-4.00	.08	-4.00	.13	-4.00

continued

DATE	GAGE	DURATION	TOTAL		MAX 5 MIN		MAX 30 MIN		MAX 60 MIN	
DYMOYR	NO	MIN	DEPTH	RI	DEPTH	RI	DEPTH	RI	DEPTH	RI
131284	1	888.0	.63	-5.00	.03	-4.00	.12	-4.00	.19	-4.00
161284	1	631.0	.03	-5.00	.00	-4.00	.01	-4.00	.01	-4.00
181284	1	276.0	.46	-5.00	.02	-4.00	.11	-4.00	.17	-4.00
181284	1	105.0	.07	-5.00	.02	-4.00	.04	-4.00	.06	-4.00
121284	2	514.0	.27	-5.00	.01	-4.00	.06	-4.00	.08	-4.00
131284	2	805.0	.58	-5.00	.01	-4.00	.08	-4.00	.13	-4.00
171284	2	296.0	.03	-5.00	.00	-4.00	.01	-4.00	.02	-4.00
181284	2	350.0	.47	-5.00	.02	-4.00	.12	-4.00	.16	-4.00
181284	2	92.0	.06	-5.00	.01	-4.00	.03	-4.00	.06	-4.00
181284	2	257.0	.08	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
191284	2	112.0	.14	-5.00	.03	-4.00	.11	-4.00	.13	-4.00
201284	1	1354.0	3.41	2.81	.32	1.80	.63	1.31	.81	1.33
241284	1	377.0	.09	-5.00	.01	-5.00	.03	-5.00	.05	-4.00
201284	2	1413.0	3.44	2.78	.18	.91	.57	1.19	.82	1.34
241284	2	304.0	.05	-5.00	.00	-5.00	.01	-5.00	.03	-4.00
301284	2	625.0	.75	-5.00	.01	-5.00	.09	-5.00	.17	-4.00
311284	2	1390.0	1.49	-5.00	.05	-5.00	.17	-5.00	.29	.42
3 185	2	243.0	.06	-5.00	.00	-5.00	.01	-5.00	.02	-4.00
5 185	2	399.0	.37	-5.00	.02	-5.00	.08	-5.00	.14	-4.00
7 185	2	544.0	.04	-5.00	.00	-5.00	.01	-5.00	.01	-4.00
17 185	1	176.0	.21	-5.00	.03	-5.00	.12	-5.00	.16	-4.00
18 185	1	171.0	.04	-5.00	.00	-5.00	.02	-5.00	.02	-4.00
17 185	2	430.0	.16	-5.00	.00	-5.00	.02	-5.00	.05	-4.00
18 185	2	117.0	.04	-5.00	.01	-5.00	.04	-5.00	.04	-4.00
27 185	1	452.0	.36	-5.00	.02	-5.00	.08	-5.00	.12	-4.00
30 185	1	527.0	.29	-5.00	.01	-5.00	.04	-5.00	.06	-4.00
27 185	2	453.0	.22	-5.00	.01	-5.00	.04	-5.00	.08	-4.00
28 185	2	274.0	.07	-5.00	.00	-5.00	.02	-5.00	.03	-4.00
30 185	2	877.0	.35	-5.00	.01	-5.00	.04	-5.00	.08	-4.00
10 285	1	1821.0	1.37	-5.00	.02	-5.00	.09	-5.00	.19	.21
12 285	1	240.0	.21	-5.00	.02	-5.00	.11	-5.00	.15	-4.00
10 285	2	1287.0	1.15	-5.00	.02	-5.00	.10	-5.00	.15	-4.00
12 285	2	388.0	.09	-5.00	.01	-5.00	.03	-5.00	.07	-4.00
18 285	1	374.0	.09	-5.00	.00	-5.00	.02	-5.00	.03	-4.00
21 285	1	982.0	1.37	-5.00	.05	-5.00	.30	-5.00	.52	1.11
23 285	1	436.0	.88	-5.00	.07	-5.00	.23	-5.00	.36	.72
18 285	2	437.0	.09	-5.00	.00	-5.00	.01	-5.00	.02	-4.00
21 285	2	1089.0	1.16	-5.00	.21	-5.00	.36	-5.00	.49	1.07
23 285	2	559.0	.88	-5.00	.11	-5.00	.33	-5.00	.45	1.03
1 385	1	283.0	.22	-5.00	.01	-5.00	.06	-5.00	.09	-4.00
4 385	1	506.0	.26	-5.00	.01	-5.00	.03	-5.00	.06	-4.00
1 385	2	409.0	.21	-5.00	.01	-5.00	.04	-5.00	.07	-4.00
4 385	2	526.0	.30	-5.00	.03	-5.00	.10	-5.00	.15	-4.00
8 385	2	459.0	.51	-5.00	.09	-5.00	.21	-5.00	.31	.48
13 385	1	653.0	.43	-5.00	.01	-5.00	.05	-5.00	.09	-4.00
13 385	2	577.0	.34	-5.00	.01	-5.00	.05	-5.00	.09	-4.00y

concluded

DATE	GAGE	DURATION	TOTAL		MAX 5 MIN		MAX 30 MIN		MAX 60 MIN	
DYMOYR	NO	MIN	DEPTH	RI	DEPTH	RI	DEPTH	RI	DEPTH	RI
27 385	1	241.0	.12	-5.00	.01	-4.00	.05	-4.00	.08	-4.00
21 385	2	1402.0	.34	-5.00	.01	-4.00	.03	-4.00	.06	-4.00
27 385	2	171.0	,14	-5.00	.01	-4.00	.08	-4.00	.11	-4.00
29 385	1	281.0	.58	-5.00	.16	.40	.28	.24	.39	30
30 385	1	1296.0	3.47	3.14	.24	1.08	.55	1.02	.86	34
29 385	2	177.0	.36	-5.00	.14	.27	.21	-4.00	.25	-4.00
30 385	2	1543.0	2.92	-5.00	.24	1.08	.35	.35	.43	.37
5 485	1	244.0	.52	-5.00	.07	-4.00	.16	-4.00	.28	-4.00
10 485	1	157.0	.03	-5.00	.00	-4.00	.02	-4.00	.03	-4.00
5 485	2	366.0	.51	-5.00	.13	.24	.21	-4.00	.30	.20
10 485	2	446.0	.06	-5.00	.00	-4.00	.02	-4.00	.03	-4.00
14 485	1	448.0	.80	-5.00	.02	-4.00	.11	-4.00	.21	-4.00
14 485	1	261.0	.36	-5.00	.11	-4.00	.20	-4.00	.23	-4.00
14 485	2	636.0	.86	-5.00	.02	-4.00	.10	-4.00	.19	-4.00
14 485	2	344.0	.14	-5.00	.00	-4.00	.03	-4.00	.05	-4.00
23 485	1	565.0	.70	-5.00	.17	.46	.35	.35	.39	.30
26 485	1	66.0	.22	-5.00	.05	-4.00	.19	-4.00	.22	-4.00
26 485	1	1173.0	2.44	-5.00	.21	.78	.50	.82	.61	.80
23 485	2	666.0	.73	-5.00	.15	.34	.34	.33	.36	.26
26 485	2	113.0	.31	-5.00	.10	-4.00	.14	-4.00	.28	-4.00
26 485	2	1297.0	3.21	2.29	.37	2.51	.51	.87	.68	1.02
30 485	1	204.0	.14	-5.00	.02	-4.00	.06	-4.00	.07	-4.00
30 485	1	590.0	.83	-5.00	.23	1.02	.35	.35	.48	.44
1 585	1	70.0	.31	-5.00	.10	-4.00	.24	-4.00	.30	.20
2 585	1	363.0	.11	-5.00	.01	-4.00	.05	-4.00	.06	-4.00
6 585	1	327.0	.12	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
7 585	1	170.0	.09	-5.00	.01	-4.00	.03	-4.00	.06	-4.00
7 585	1	255.0	.06	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
30 485	2	293.0	.21	-5.00	.01	-4.00	.08	-4.00	.11	-4.00
30 485	2	387.0	1.17	-5.00	.25	1.17	.47	.69	.67	1.00
1 585	2	76.0	.23	-5.00	.07	-4.00	.20	-4.00	.22	-4.00
2 585	2	316.0	.06	-5.00	.01	-4.00	.03	-4.00	.04	-4.00
6 585	2	502.0	.12	-5.00	.00	-4.00	.03	-4.00	.05	-4.00
7 585	2	218.0	.09	-5.00	.01	-4.00	.04	-4.00	.05	-4.00
7 585	2	302.0	.09	-5.00	.00	-4.00	.03	-4.00	.05	-4.00

NOTE: -1. = EVENT LESS THAN 60 MIN
-2. = EVENT LESS THAN 30 MIN
-3. = EVENT LESS THAN 5 MIN
-4. = EVENT WITH RI OF LESS THAN 5 PER YEAR
-5. = EVENT WITH RI OF LESS THAN ONCE IN 2 YEARS
RI = RECURRENCE INTERVAL, YEARS
DEPTH HAS UNITS OF INCHES

Appendix 7

Mean Daily Discharge

Horseshoe Lake -- Alexander County
Illinois State Water Survey

Mean Daily Discharge at the Spillway
(Units of cubic feet per second)

```
MO  1  YR 84  day 01-10  -9999.9 -9999.9 -9999.9 -9999 .9 -9999 .9 -9999.9 -9999.9 - 9999.9 -9999.9 -9999.9
              day 11-20  -9999.9 -9999.9 -9999.9 -9999 .9 -9999 .9 -9999.9 -9999.9 - 9999.9      .0      .6
              day 21-31      1.2     1.8     2.4     3 .0     3 .7     5.3     5.3      5.3     5.3     5.3

Monthly Total     44.97

MO  2  YR 84  day 01-10      5.3     5.3     6.6     6.3     5.9     5.6     5.3     5.3      .8     4.2
              day 11-20      7.2    10.7    32.1    32.1    32.1    21.5    27.5    21.7    22.4    21.5
              day 21-29     18.1    19.0    12.5    11.5     5.3     5.9    12.5    12.5    12.5

Monthly Total    389.48


MO  3  YR 84  day 01-10     12.7    14.2    15.8    27.3    51.9    51.5    47.7    44.3    34.1    31.7
              day 11-20     29.2    21.5    23.2    20.5    16.9    22.3    26.7    34.7    46.0    55.1
              day 21-31     51.4    44.1    35.4    33.9    36.4    33.4    39.6    82.6    88.9    78.5    73.0

Monthly Total   1224.46


MO  4  YR 84  day 01-10     65.8    57.3    64.4    57.0    63.8    31.9   -62.0  -114.9  -173.8    23.2
              day 11-20    -88.4     3.6    58.7    60.0    78.0    77.4    74.1    59.9    52.9    44.0
              day 21-30     42.8    47.0    45.0    40.2    31.6    24.4    11.9  -205.6  -197.4  -169.7

Monthly Total    103.08


MO  5  YR 84  day 01-10     94.1   101.2    91.1    75.3    63.8    68.8   107.8  -392.1  -344.3  -914.4
              day 11-20   -378.4     0.0     0.0     0.0     0.0     0.0     0.0     0.0   340.1   695.1
              day 21-31   1050.0  1000.1   573.4   398.5   231.9   197.6   166.4   102.5    85.7    70.3    53.4

Monthly Total   3537.94
```

```
MO  6  YR 84  day 01-10     37.7    34.0    30.1    22.7    19.3    16.1    11.8     8.0     7.5     5.8
              day 11-20      5.0     3.9     2.8     2.0     1.5      .5      .1     0.0     0.0     0.0
              day 21-30       .0      .2      .6      .5      .1     0.0     0.0     0.0     0.0     0.0

Monthly Total     210.19

MO  7  YR 84  day 01-10      0.0     0.0     0.0      .1      .4      .6      .5      .1     0.0     0.0
              day 11-20      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 21-31      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0

Monthly Total       1.66


MO  8  YR 84  day 01-10      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 11-20      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 21-31      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0 .0

Monthly Total       0.00


MO  9  YR 84  day 01-10      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 11-20      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 21-30      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0

Monthly Total       0.00


MO 10  YR 84  day 01-10      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
              day 11-20      0.0     0.0     0.0     0.0     0.0     0.0     0.0      .3     2.1     3.8
              day 21-31      5.5     6.6     6.5     5.4     5.1     9.2    13.6    18.0    21.5    21.5    25 .2

Monthly Total     144.36
```

```
MO 11  YR 84  day 01-10     28.3   73.3   68.0   62.8   58.4   56.7   51.5   33.2   27.6   27.1
              day 11-20     26.6   26.0   24.7   19.3   17.8 . 19.0   27.0   35.0   41.4   38.9
              day 21-30     36.1   32.0   27.8   23.6   19.5   17.4   28.5   43.5   39.2   38.6

Monthly Total   1068.70


MO 12  YR 84  day 01-10     34.8   31.0   27.1   23.3   22.3   21.4   20.5   20.2   19.9   19.5
              day 11-20     18.6   17.7   23.7   36.6   34.6   32.6   31.2   32.4   34.4   39.7
              day 21-31    135.4  192.4  200.6  201.4  167.6  134.1  104.8   88.0   85.6   83.1   90.7

Monthly Total   2025.11


MO  1  YR 85  day 01-10    141.7  182.5  164.6  143.7  122.7  101.8   83.0   73.8   62.8   54.9
              day 11-20     51.3   44.4   37.6   31.5   28.2   25.1   22.6   20.8   21.8   22.8
              day 21-31     23.9   24.9   25.9   27.0   28.0   29.0   30.1   31.1   32.1   33.2   34.2

Monthly Total   1756.96


MO  2  YR 85  day 01-10     35.2   36.3   37.3   38.3   39.4   40.4   41.4   42.5   43.5   44.5
              day 11-20     45.6   46.6   47.6   48.7   49.7   50.7   51.8   52.8   53.8   54.9
              day 21-28     55.9   60.9  124.9  230.0  201.4   95.4  -10.6 -116.7

Monthly Total   1542.17

MO  3  YR 85  day 01-10   -222.7 -499.9 -642.6   27.4  246.4  446.0  304.4 -339.9 -387.3  458.8
              day 11-20    282.0  465.7  369.4  295.1  222.2  159.4  110.6   86.5   73.3   63.7
              day 21-31     54.5   47.9   41.4   36.6   31.9   28.6   25.7   22.3   59.0  102.0  312.9

Monthly Total   2281.25


MO  4  YR 85  day 01-10    312.9  274.7  222.9  187.4  156.2  112.2  102.0   89.1   76.2   63.2
              day 11-20     50.3   42.6   35.5   40.2   47.0   53.8   58.8   63.2   67.7   72.1
              day 21-30     76.6   81.0   85.4   89.9   94.3   98.8  103.2  107.7  109.7  121.8

Monthly Total   3096.54
```

```
MO  5  YR 85  day 01-10    134.0  145.2  115.5  102.0   89.6   79.5   69.6   59.7   49.8   39.9
              day 11-20  -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9
              day 21-31  -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9 -9999.9

Monthly Total    884.60
```

Horseshoe Lake -- Alexander County
Illinois State Water Survey

Mean Daily Discharge at Gaging Station #2
(Units of cubic feet per second)

```
MO 03 YR 84   day 01-10      MD     MD     MD     MD     MD     MD     MD     MD     MD     MD
              day 11-20      MD     MD     .3     .8    4.9    4.2   41.1   23.4   23.3    8.2
              day 21-31     2.4     .9     .7    8.5    3.0    1.0    1.5   97.4    5.9    1.5    1.1

Monthly Total      230.2


MO 04 YR 84   day 01-10      .9    2.1   27.1    7.5    2.0    1.0     .8     .8   10.9    1.9
              day 11-20     1.3   23.3    4.3    1.7    1.4    1.2    1.1    1.0    1.0    1.0
              day 21-30    14.3   10.2    1.7    1.0     .8     .8     .7     .6    9.6    2.8

Monthly Total      134.7


MO 05 YR 84   day 01-10     1.5    1.4    1.8    1.3     .7   42.8   98.8    8.5     .7     .5
              day 11-20      .4     .3     .2     .2     .2     .1     .1     .0     .0    3.5
              day 21-31      .2     .2     .2     .1     .1     .1     .1     .1     .1     .0     .0

Monthly Total      164.2


MO 06 YR 84   day 01-10      .0     .0     .0     .0     .0     .0     .0    0.0    0.0    0.0
              day 11-20     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
              day 21-30     7.8    4.1    2.2     .1     .0     .0     .0     .0     .0     .0

Monthly Total       14.2
```

```
MO 07 YR 84   day 01-10      .0    0.0    0.0    9.2    5.8     .1     .1     .0     .0     .0
              day 11-20      .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 21-31      .0     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

Monthly Total      15.2


MO 08 YR 84   day 01-10      .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 11-20      .0     .0     .0     .0     .0     .0     .0     .0     .0    ..0
              day 21-31      .0     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

Monthly Total        .1


MO 09 YR 84   day 01-10      .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 11-20      .4     .0     .0     .0    0.0    0.0    0.0    0.0    0.0    0.0
              day 21-30     0.0     .0    2.7     .2    4.2     .2     .0     .0     .0    0.0

Monthly Total       7.9


MO 10 YR 84   day 01-10     0.0    0.0    0.0    0.0    0.0     .2     .1     .0     .0     .0
              day 11-20      .1     .0   24.2    6.4     .2    2.1     .6     .2    6.0   69.4
              day 21-31    15.8     .7     .5     .2     .6     .3     .2   38.0    3.8    1.2    1.0

Monthly Total     171.8


MO 11 YR 84   day 01-10   120.4    9.1    2.4    1.2     .6     .3     .2     .1   20.9   11.3
              day 11-20     1.8     .7     .3     .2     .1     .1     .0   73.6   10.5    2.4
              day 21-30     1.0     .5     .2     .1     .1     .1   61.5    6.9    2.8    1.2

Monthly Total     330.9
```

```
MO 12 YR 84    day 01-10      .6      .9      .6      .7      .9     1.2     1.5     2.8    12.8     7.8
               day 11-20     3.3     2.4    18.6    21.0     4.6     1.9      .9    11.7     9.2    15.7
               day 21-31   209.8    12.1     5.8     3.4     1.5      .7      .3      .2      .1    28.4   119.2

Monthly Total      500.5


MO 01 YR 85    day 01-10    21.8     9.1     5.5     2.2      .9      .4      .2      .1      .1      .0
               day 11-20      .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
               day 21-31      .0      .0      .0      .0      .0      .0      .0      .0      .0      .0      .0

Monthly Total       40.4


MO 02 YR 85    day 01-10      .0      .0      .0      .0      .0      .0      .0      .0      .0    26.2
               day 11-20    53.6      .3      .1      .1      .0      .0    10.9    13.7    13.3    17.5
               day 21-28     9.7    86.3    70.8    12.9      .9      .9      .9      .9

Monthly Total      319.0


MO 03 YR 85    day 01-10      .9      .8      .8      .7      .7      .7      .7      .6      .6      .6
               day 11-20      .5      .5      .5      .5      .5      .4      .4      .4      .3      .3
               day 21-31      .5     1.2      .6      .5      .4      .4      .5      .5     4.4   235.1    39.4

Monthly Total      294.7


MO 04 YR 85    day 01-10     1.1      .4      .3      .2    10.7      .7      .3      .2      .1      .1
               day 11-20      .0      .0      .0    55.0    10.1     1.3      .8      .5      .4      .4
               day 21-30      .3      .3     5.5     2.1      .4    24.6    92.8     6.0     2.6     2.3

Monthly Total      219.5


          N0TE:MD IS MISSING DATA
```

Horseshoe Lake -- Alexander County
Illinois State Water Survey

Mean Daily Discharge at Gaging Station #3
(Units of cubic feet per second)

MO 03 YR 84	day 01-10	MD	MD	MD	MD	MD	MD	MD	MD	MD	MD	
	day 11-20	MD	MD	1.0	1.7	7.2	7.2	52.4	20.7	22.0	10.6	
	day 21-31	5.3	2.9	1.8	7.9	4.7	2.6	2.3	116.3	7.6	3.5	2.4
Monthly Total	280.1											
MO 04 YR 84	day 01-10	1.9	2.4	23.5	9.4	4.1	2.5	1.9	1.8	8.9	4.0	
	day 11-20	2.7	20.2	7.3	4.2	3.2	2.3	1.9	1.6	1.3	1.3	
	day 21-30	10.1	9.8	3.8	2.3	1.7	1.5	1.4	1.2	8.0	4.3	
Monthly Total	150.7											
MO 05 YR 84	day 01-10	1.8	1.5	3.9	3.3	1.8	33.7	72.9	10.2	4.0	2.4	
	day 11-20	1.7	1.4	1.6	1.3	1.1	.7	.4	.4	.3	3.7	
	day 21-31	1.3	.8	.3	.1	.1	.1	.2	.1	.1	.1	.1
Monthly Total	151.2											
MO 06 YR 84	day 01-10	.1	.1	.1	.1	.0	.0	.0	.0	.0	.2	
	day 11-20	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	
	day 21-30	1.5	2.6	.9	.0	.0	.0	.0	.0	.0	.0	
Monthly Total	6.3											

```
MO 07 YR 84   day 01-10       .0     .0     .0    3.3    1.9    2.9     .2     .1     .0     .0
              day 11-20       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 21-31       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

Monthly Total        9.1


MO 08 YR 84   day 01-10       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 11-20       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 21-31       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0

Monthly Total         .8


MO 09 YR 84   day 01-10       .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 11-20       .1     .0     .0     .0     .0     .0     .0     .0     .0     .0
              day 21-30       .0     .2    2.6     .4    3.8     .5     .0     .0     .0     .0

Monthly Total        8.5


MO 10 YR 84   day 01-10       .0     .0     .0     .0     .0     .1     .0     .0     .0     .0
              day 11-20       .0     .0    8.0    2.4     .0     .3     .1     .0    1.9   35.7
              day 21-31      7.6     .1     .1     .0     .1     .0     .0   21 .2    2.9    1.1     .8

Monthly Total       82.9


MO 11 YR 84   day 01-10    109.3    5.5    1.6     .9     .3     .1     .1     .1   10.0    7.3
              day 11-20      1.2     .4     .2     .1     .2     .1     .1   40 .6    7.3    1.8
              day 21-30      1.1     .8     .5     .4     .5    1.0   40.4    8 .0    3.5    2.3

Monthly Total      245.6
```

MO 12 YR 84	day 01-10	1.6	2.3	2.3	1.5	1.8	2.0	1.9	2.6	7.4	9.2	
	day 11-20	4.4	3.5	14.4	20.7	7.1	4.6	3.1	9.0	9.0	11.3	
	day 21-31	167.7	4.6	.8	.2	.0	.0	.0	.0	.0	7.0	67.7
Monthly Total	368.0											
MO 01 YR 85	day 01-10	10.8	.9	.1	.3	.2	.1	.3	.1	.1	.1	
	day 11-20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
	day 21-31	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	1.5
Monthly Total	15.4											
MO 02 YR 85	day 01-10	.0	.0	.0	.0	.0	.0	.0	.0	.0	12.4	
	day 11-20	34.2	3.6	.1	.1	.0	.0	4.2	8.1	9.4	14.5	
	day 21-28	13.3	76.2	57.6	18.5	5.5	2.9	1.4	.2			
Monthly Total	262.6											
MO 03 YR 85	day 01-10	2.3	2.1	1.0	2.1	1.8	1.5	1.3	1.1	.9	.5	
	day 11-20	.3	.1	1.2	.8	.1	.1	.1	.1	.1	.1	
	day 21-31	.2	.9	.2	.1	.1	.1	.2	.1	2.3	219.9	29.7
Monthly Total	271.4											
MO 04 YR 85	day 01-10	3.6	1.9	1.4	1.3	7.2	2.6	1.5	1.4	1.5	1.5	
	day 11-20	1.4	1.4	1.3	44.7	12.8	4.0	2.4	1.8	1.4	1.0	
	day 21-30	.3	.1	4.0	3.5	1.1	13.4	84.2	6.8	2.9	2.2	
Monthly Total	214.6											

NOTE: MD IS MISSING DATA

Horseshoe Lake -- Alexander County
Illinois State Water Survey

Mean Daily Discharge at Gaging Station #4
(Units of cubic feet per second)

```
MO 03  YR 84  DAY 01-10      MD      MD      MD      MD      MD      MD      MD      MD      MD      MD
              DAY 11-20      MD      MD      MD      MD      MD      MD      MD      MD      MD      MD
              DAY 21-31      MD      MD      MD      MD      MD      MD     3.0   144.6   136.5   112.2    41.7

Monthly Total     438.0


MO 04  YR 84  DAY 01-10     6.6     4.6    47.1    46.8    42.6    21.5     7.9     4.1    17.7    18.1
              DAY 11-20    16.0    34.4    41.2    32.6    23.3     7.1     5.5     4.9     4.6     4.4
              DAY 21-30    15.1    37.9    30.4    26.9     7.5     4.0     3.4     3.1    13.4    10.2

Monthly Total     542.7


MO 05  YR 84  DAY 01-10    15.8    12.3     6.6     6.7     5.3    54.4   190.8   189.5   138.1    59.9
              DAY 11-20     5.1     1.8     1.4     1.1     1.0      .7      .6      .4      .3     4.6
              DAY 21-31     5.1     4.3     2.6      .8      .7      .6      .5      .5      .5      .4      .1

Monthly Total     712.4


MO 06  YR 84  DAY 01-10      .1      .1      .1      .1      .1      .1      .1      .1      .1      .1
              DAY 11-20      .1      .1      .1      .1      .1      .1      .1      .1      .1      .1
              DAY 21-30     7.6    15.1    16.6    13.2     5.8     1.2      .1      .1      .1      .1

Monthly Total      62.0
```

MO 07 YR 84	DAY 01-10	.1	.1	.1	3.9	26.8	16.3	15.7	1.0	.2	.1	
	DAY 11-20	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	
	DAY 21-31	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
Monthly Total	66.5											
MO 08 YR 84	DAY 01-10	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	
	DAY 11-20	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	
	DAY 21-31	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
Monthly Total	3.1											
MO 09 YR 84	DAY 01-10	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	
	DAY 11-20	.7	.7	.6	.3	.1	.1	.1	.1	.1	.1	
	DAY 21-30	.1	.1	4.1	4.0	7.0	7.6	4.8	4.0	.1	.1	
Monthly Total	35.8											
MO 10 YR 84	DAY 01-10	.1	.1	.1	.1	.1	.3	.5	.4	.3	.2	
	DAY 11-20	.2	.2	15.2	49.3	32.7	32.3	5.2	3.3	13.3	65.0	
	DAY 21-31	136.0	93.0	76.9	5.0	1.9	1.8	1.6	42.0	59.9	45.9	22.8
Monthly Total	705.8											
MO 11 YR 84	DAY 01-10	130.3	186.4	140.6	95.5	8.2	3.6	1.9	1.1	14.4	50.5	
	DAY 11-20	38.1	35.5	6.5	2.3	1.1	.7	.5	99.4	113.3	93.2	
	DAY 21-30	50.2	8.4	3.1	1.5	.9	.6	79.3	92.7	77.0	33.9	
Monthly Total	1371.0											

```
MO 12  YR 84  DAY 01-10      8.4    4.3    3.1    2.9    3.4    3.8    4.8    6.8   18.5   33.4
              DAY 11-20     29.6   25.6   34.0   60.3   53.6   40.2   16.8   19.5   29.9   36.0
              DAY 21-31    315.2  318.6  255.1  129.3   17.5    9.5    4.6    2.2    1.2   40.6   65.6

Monthly Total     1594.6


MO 01  YR 85  DAY 01-10    225.9  175.6  107.0   27.7   14.4    6.8    2.8    1.4     .7     .4
              DAY 11-20       .2     .1     .1     .1     .1     .1     .1     .1     .1     .1
              DAY 21-31       .1     .1     .1     .1     .1     .1     .1     .1     .1     .1     .1

Monthly Total      564.8


MO 02  YR 85  DAY 01-10       .1     .1     .1     .1     .1     .1     .1     .1     .1   17.9
              DAY 11-20    124.9   93.9   81.0   18.1     .4     .2    9.7   31.1   44.2   60.3
              DAY 21-29     58.3  133.6  212.0  215.1  146.6   72.9    6.7    1.9     .1
Monthly Total     1329.8


MO 03  YR 85  DAY 01-10      3.8    3.7    3.5    3.4    3.2    3.1    3.0    2.9    2.7    2.6
              DAY 11-20      2.5    2.3    2.2    2.2    2.2    2.0    1.9    1.8    1.7    1.6
              DAY 21-31      1.6    3.1    3.1    3.1    2.3    1.9    1.9    2.0    4.6  301.2  210.6

Monthly Total      587.9


MO 04  YR 85  DAY 01-10    297.8  172.3   12.6    1.5   11.9   16.6   12.6    8.7    1.2     .7
              DAY 11-20       .4     .2     .1   49.6   92.4   71.5   60.4    6.4    2.8    2.1
              DAY 21-30      1.7    1.5    5.7   11.6    9.0   26.6  174.8  152.4  130.4   38.8

Monthly Total     1374.3
```

NOTE: MD=MISSING DATA

Appendix 8

Mean Daily Suspended Sediment Loads

Horseshoe Lake Project -- Alexander County
Illinois State Water Survey

Mean Daily Suspended Sediment Load at the Spillway

(Units of tons per day)

MO 1 YR 84	day 01-10	MD	MD	MD	MD	MD	MD	MD	MD	MD	MD	
	day 11-20	MD	MD	MD	MD	MD	MD	MD	MD	0.00	.03	
	day 21-31	.05	.08	.10	.13	.16	.23	.22	.22	.22	.21	.21
Monthly Total	1.86											
MO 2 YR 84	day 01-10	.21	.20	.19	.17	.15	.13	.12	.11	.02	.09	
	day 11-20	.15	.22	.93	1.39	1.85	1.55	2.35	1.64	1.46	1.19	
	day 21-29	.81	.80	.50	.43	.18	.19	.37	.34	.30		
Monthly Total	18.02											
MO 3 YR 84	day 01-10	.28	.27	.53	1.32	3.26	3.99	3.40	2.85	1.95	1.59	
	day 11-20	1.26	.78	.93	.90	.80	1.14	1.47	2.05	1.89	2.06	
	day 21-31	2.30	2.30	2.11	2.27	2.71	2.73	3.53	8.31	7.99	6.20	4.98
Monthly Total	78.14											
MO 4 YR 84	day 01-10	3.78	2.67	2.31	2.00	2.19	1.07	-2.03	-3.69	-5.44	.76	
	day 11-20	-3.08	.13	2.27	2.44	3.32	3.44	3.44	2.90	2.66	2.30	
	day 21-30	2.32	2.63	2.61	2.41	1.95	1.55	.79	-13.52	-12.92	-11.06	
Monthly Total	.17											

MO 5 YR 84	day 01-10	6.11	6.54	5.86	4.83	3.57	3.29	4.01	-15.16	-15.23	-45.56	
	day 11-20	-20.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.04	73.46	
	day 21-31	116.83	116.87	70.21	51.02	30.99	27.51	24.09	15.41	13.37	11.36	8.92

Monthly Total 531.37

MO 6 YR 84	day 01-10	6.47	6.00	5.45	4.21	3.67	3.14	2.35	1.63	1.56	1.24
	day 11-20	1.09	.87	.64	.46	.35	.12	.02	0.00	0.00	0.00
	day 21-30	0.00	.05	.14	.11	.02	0.00	0.00	0.00	0.00	0.00

Monthly Total 39.60

MO 7 YR 84	day 01-10	0.00	0.00	0.00	.02	.07	.11	.09	.02	0.00	0.00	
	day 11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	day 21-31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Total .31

MO 8 YR 84	day 01-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	day 11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	day 21-31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Total 0.00

MO 9 YR 84	day 01-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	day 11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	day 21-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Total 0.00

MO 10 YR 84	day 01-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	day 11-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.01	.06	.11	
	day 21-31		.18	.18	.15	.17	.29	.41	.51	.58	.54	.59

```
Monthly Total   3.95

MO 11  YR 84  day 01-10     .64   1.84   1.88   1.90   1.92   1.84   1.66   1.06    .87    .85
              day 11-20     .82    .80    .75    .58    .53    .56    .78   1.00   1.17   1.09
              day 21-30    1.00    .88    .75    .63    .51    .45    .73   1.11    .98    .96

Monthly Total  30.54

MO 12  YR 84  day 01-10     .85    .75    .65    .55    .52    .49    .46    .45    .44    .42
              day 11-20     .40    .37    .49    .74    .69    .64    .60    .62    .64    .73
              day 21-31    2.91   4.18   4.40   4.46   3.75   3.03   2.39   2.02   1.99   1.94   2.14

Monthly Total  44.69


MO  1  YR 85  day 01-10    3.38   4.39   3.99   3.51   3.03   2.53   2.08   1.87   1.60   1.41
              day 11-20    1.33   1.16    .99    .84    .75    .68    .61    .56    .59    .62
              day 21-31     .65    .68    .71    .74    .77    .80    .83    .86    .90    .93    .96

Monthly Total  44.76


MO  2  YR 85  day 01-10     .99   1.02   1.05   1.08   1.12   1.15   1.18   1.22   1.25   1.28
              day 11-20    1.31   1.35   1.38   1.41   1.45   1.48   1.52   1.55   1.58   1.62
              day 21-28    1.65   1.80   3.72   6.90   6.07   2.89   -.32  -3.58

Monthly Total  45.13


MO  3  YR 85  day 01-10   -6.87 -15.51 -20.05    .86   7.77  14.15   9.71 -10.90 -12.49  14.88
              day 11-20    9.19  15.26  12.17   9.78   7.40   5.34   3.72   2.93   2.49   2.18
              day 21-31    1.87   1.65   1.44   1.28   1.12   1.01    .91    .79   2.10   3.62  11.11

Monthly Total  78.90
```

```
MO  4  YR 85  day 01-10   11.10    9.74    7.90    6.64    5.53    3.97    3.61    3.15    2..70   2.23
              day 11-20    1.78    1.51    1.25    1.42    1.66    1.90    2.07    2.23    2 .39   2.54
              day 21-30    2.70    2.85    3.01    3.16    3.32    3.47    3.63    3.79    3 .85   4.28

Monthly Total 109.40
```

```
                         Horseshoe Lake Project -- Alexander County
                                Illinois State Water Survey

                    Mean Daily Suspended Sediment Load at Gaging Station #2
                                 (Units of tons per day)

3 84 day 01-10   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
3 84 day 11-20   -1.00   -1.00     .01     .03   28.41   30.52  279.05  156.94  112.26   37.16
3 84 day 21-31   10.74    4.05    2.79   81.39   30.58    9.94   13.69  908.66   53.67   13.37    4.08

Monthly Total 1777.4


4 84 day 01-10     .40     .76   12.07    3.51     .93     .45     .68    4.45   60.46   10.92
4 84 day 11-20    7.02  110.85    4.26    1.66    1.35    1.16    1.07     .99     .96     .52
4 84 day 21-30     .83     .64     .10     .06     .05     .05     .04     .04     .56     .18

Monthly Total  227.0


5 84 day 01-10     .12     .14     .17     .13     .19   19.83  652.62   75.59    6.37    3.99
5 84 day 11-20    3.08    2.43     .01     .01     .01     .01     .01     .00    0.00     .53
5 84 day 21-31     .09     .07     .07     .04     .04     .04     .04     .04     .03    0.00    0.00

Monthly Total  765.7


6 84 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
6 84 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
6 84 day 21-30    2.24    2.12    1.14     .03    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    5.5


7 84 day 01-10    0.00    0.00    0.00    3.70    4.14     .08     .03    0.00    0.00    0.00
7 84 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
7 84 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    7.9
```

```
8 84 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
8 84 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
8 84 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    0.0


9 84 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
9 84 day 11-20     .23    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
9 84 day 21-30    0.00     .02    1.43     .12    2.17     .14    0.00    0.00    0.00    0.00

Monthly Total    4.1


10 84 day 01-10    0.00    0.00    0.00    0.00    0.00     .01     .01     .00    0.00    0.00
10 84 day 11-20     .01     .00    1.25     .51     .01    5.13    1.88     .38   15.93  240.71
10 84 day 21-31   70.46    1.84     .04     .02     .17     .09     .05    4.51     .49     .14     .12

Monthly Total  343.8


11 84 day 01-10   14.32     .94     .23     .11     .06     .03     .02     .01    1.85    1.25
11 84 day 11-20     .17    1.10     .95     .57     .30     .30     .06  216.58   32.73    7.34
11 84 day 21-30    2.89    1.38     .47     .11     .08     .08   47.80    5.60    2.25     .96

Monthly Total  340.5


12 84 day 01-10     .44     .67     .44     .07     .09     .11     .14     .27    1.23     .80
12 84 day 11-20     .33     .24    1.31     .98     .22     .09     .04    2.43   31.64   46.52
12 84 day 21-31  657.97   42.79   19.66   11.89    5.12    2.64    1.23     .77     .49  109.12  454.83

Monthly Total 1394.6
```

```
1 85 day 01-10   89.14   35.29   21.52    8.63    3.39    1.63     .84     .39     .25    0.00
1 85 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
1 85 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total  161.1


2 85 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00   90.69
2 85 day 11-20  216.90    1.61     .39     .30    0.00    0.00   40.87   53.08   51.31   67.49
2 85 day 21-28   37.28  331.73  269.68   55.45    3.58    3.47    3.47    3.47

Monthly Total 1230.8


3 85 day 01-10    3.32    3.09    3.03    2.88    2.70    2.70    2.58    2.32    2.32    2.28
3 85 day 11-20    1.93    1.93    1.93    1.93    1.86    1.54    1.54    1.54    1.34    1.16
3 85 day 21-31    1.88    4.74    2.18    1.83    1.54    1.54    1.90    1.89   15.65  893.30  166.83

Monthly Total 1137.2


4 85 day 01-10    4.64    1.76    1.00     .60   41.11    2.73     .64     .06     .04     .02
4 85 day 11-20    0.00    0.00    0.00   15.49    2.73     .18     .11     .07     .05     .05
4 85 day 21-30     .04     .04     .71     .30     .06    3.13   12.64     .83     .35     .31

Monthly Total   89.7


5 85 day 01-10    4.53    1.10     .09     .07     .06     .05     .04     .03     .03     .01
5 85 day 11-20   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
5 85 day 21-30   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00

Monthly Total    6.0
```

```
                         Horseshoe Lake Project -- Alexander County
                                 Illinois State Water Survey

                  Mean Daily Suspended Sediment Load at Gaging Station #3
                                   (Units of tons per day)

3 84 day 01-10   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
3 84 day 11-20   -1.00   -1.00     .04     .07   17.36   22.71  156.57   60.69   40.64   17.90
3 84 day 21-31    8.62    4.72    3.28   43.16   26.20   14.60   12.22  592.57   35.02   15.85    5.11

Monthly Total 1077.3


4 84 day 01-10     .34     .40    4.30    1.79     .78     .47     .57    6.30   30.92   14.10
4 84 day 11-20    9.63   35.83    4.81    2.72    2.09    1.51    1.21    1.01     .86     .51
4 84 day 21-30    1.73    1.83     .68     .42     .32     .27     .25     .21    1.41     .80

Monthly Total  128.1


5 84 day 01-10     .27     .18     .43     .40     .32    8.72  286.18   57.66   22.30   13.00
5 84 day 11-20    9.39    7.56    8.72    7.30    3.55     .22     .12     .11     .09    1.17
5 84 day 21-31     .41     .25     .10     .05     .03     .03     .05     .04     .03     .03     .03

Monthly Total  428.7


6 84 day 01-10     .03     .03     .03     .03     .01    0.00    0.00    0.00    0.00     .03
6 84 day 11-20     .03    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
6 84 day 21-30     .33     .48     .17     .01    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    1.2


7 84 day 01-10    0.00    0.00    0.00     .48     .48     .54     .04     .01    0.00    0.00
7 84 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
7 84 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    1.6
```

```
8 84 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
8 84 day 11-20    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
8 84 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

Monthly Total    0.0


9 84 day 01-10    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00     .00    0.00
9 84 day 11-20     .02    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
9 84 day 21-30    0.00     .03     .49     .08     .70     .10     .01    0.00    0.00    0.00

Monthly Total    1.4


10 84 day 01-10    0.00    0.00    0.00    0.00    0.00     .02     .00    0.00    0.00    0.00
10 84 day 11-20    0.00    0.00    1.94     .92    0.00     .26     .06     .00    1.66   41.09
10 84 day 21-31   11.36     .16     .01    0.00     .02     .00    0.00    2.28     .34     .12     .09

Monthly Total   60.3

11 84 day 01-10   11.85     .68     .18     .11     .04     .01     .01     .01    1.02     .99
11 84 day 11-20     .14     .04     .01     .01     .01     .01     .01    3.24     .61     .15
11 84 day 21-30     .09     .06     .03     .02     .03     .06   18.64    2.82    1.23     .79

Monthly Total   42.9


12 84 day 01-10     .57     .76     .82     .12     .14     .15     .14     .20     .55     .72
12 84 day 11-20     .34     .27     .84     .98     .34     .22     .15    1.13   13.78   15.92
12 84 day 21-31  236.81    4.67     .82     .16     .25    0.00    0.00    0.00    0.00   76.87  740.36

Monthly Total 1098.1
```

```
1 85 day 01-10  125.82    9.94    1.20    3.29    2.02    1.10    3.47    1.77    1.10    1.10
1 85 day 11-20     .12    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
1 85 day 21-31    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    6.46   16.70

Monthly Total  174.1


2 85 day 01-10     .30    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00  120.36
2 85 day 11-20  391.80   41.63    1.43     .94    0.00    0.00   44.46   89.13  103.16  159.24
2 85 day 21-28  146.08  838.34  626.18  218.46   61.39   33.03   15.59    2.83

Monthly Total 2894.4


3 85 day 01-10   24.93   23.23   11.52   22.38   20.42   17.00   14.81   12.72   10.40    6.00
3 85 day 11-20    3.22    1.59   13.00    9.13    1.10    1.10    1.10    1.10    1.10    1.10
3 85 day 21-31    2.42   10.28    1.70    1.10    1.10    1.10    1.77    1.68    5.45  546.67   87.27

Monthly Total  857.5


4 85 day 01-10    9.29    4.80    3.68    3.39   18.20    6.78    1.81     .21     .23     .23
4 85 day 11-20     .22     .21     .20    6.72    2.03     .55     .32     .24     .19     .13
4 85 day 21-30     .04     .01     .52     .49     .16    1.66   11.46     .94     .39     .29

Monthly Total   75.4


5 85 day 01-10    2.87    1.41     .49     .24     .11     .05     .36     .24     .07     .00
5 85 day 11-20   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
5 85 day 21-30   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00

Monthly Total    5.8
```

```
                    Horseshoe Lake Project -- Alexander County
                           Illinois State Water Survey

               Mean Daily Suspended Sediment Load at Gaging Station #4
                              Units of tons per day

3 84 day 01-10   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
3 84 day 11-20   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00
3 84 day 21-31   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   -1.00   56.06  125.15  102.05   43.26

Monthly Total  326.5


4 84 day 01-10    2.37    1.57   16.31   16.73   15.13    7.84    2.92    9.41   39.31   41.19
4 84 day 11-20   36.24   46.07    4.33    3.42    2.49     .75     .58     .51     .48    1.00
4 84 day 21-30    3.71    9.98    7.97    7.10    2.01    1.04     .88     .81    3.40    4.87

Monthly Total  290.4


5 84 day 01-10    3.30    2.53    1.34    1.38    1.86   29.79 1066.86 1659.30 1210.69  541.64
5 84 day 11-20   45.88   15.56     .17     .11     .10     .07     .06     .04     .03     .47
5 84 day 21-31    2.39    1.98    1.24     .37     .30     .26     .21     .19     .18     .14      .09

Monthly Total 4588.5


6 84 day 01-10     .05     .04     .04     .04     .04     .04     .04     .04     .04     .04
6 84 day 11-20     .04     .04     .04     .04     .04     .04     .04     .04     .04     .04
6 84 day 21-30    2.77    6.63    7.89    6.41    2.83     .62     .06     .05     .05     .05

Monthly Total   28.1


7 84 day 01-10     .05     .05     .05    1.10   13.38    7.86    7.56     .58     .11     .05
7 84 day 11-20     .05     .05     .05     .05     .05     .05     .05     .05     .05     .05
7 84 day 21-31     .05     .05     .05     .05     .05     .05     .05     .05     .05     .05      .05

Monthly Total   31.8
```

```
8 84 day 01-10     .05      .05      .05      .05      .05      .05      .05      .05      .05      .05
8 84 day 11-20     .05      .05      .05      .05      .05      .05      .05      .05      .05      .05
8 84 day 21-31     .05      .05      .05      .05      .05      .05      .05      .05      .05      .05      .05

Monthly Total    1.5


9 84 day 01-10     .05      .05      .05      .05      .05      .05      .05      .05      .05      .05
9 84 day 11-20     .34      .32      .29      .14      .05      .05      .05      .05      .05      .05
9 84 day 21-30     .05      .06     1.92     1.91     3.26     3.71     2.32     1.96      .07      .05

Monthly Total   17.2


10 84 day 01-10     .05      .05      .05      .03      .01      .04      .07      .06      .05      .02
10 84 day 11-20     .03      .03     1.72     7.20     4.59     7.96     1.93     1.15     4.59    13.34
10 84 day 21-31   28.37    14.80     7.33      .51      .24      .23      .24     8.13    11.99     9.15     6.55

Monthly Total  130.5


11 84 day 01-10   25.33    39.50    29.78    20.75     1.77      .78      .41      .23     2.52    11.04
11 84 day 11-20    8.09     7.46     1.40      .49      .24      .14      .10    19.80    23.32    19.10
11 84 day 21-30   10.61     1.77     3.83     3.19     1.80     1.29   103.95    66.54    54.94    32.60

Monthly Total  492.8


12 84 day 01-10    6.09     3.08     2.23      .27      .32      .35      .45      .62     1.68     3.10
12 84 day 11-20    2.75     2.40     3.26     6.05     5.42     4.09     1.74     5.94    73.72    85.88
12 84 day 21-31 1117.16   729.25   580.49   303.00     3.15     1.70      .82      .39      .21     7.01    31.87

Monthly Total 2984.5
```

```
1 85 day 01-10   40.13    31.19    19.37     4.99     2.58     1.22      .51      .24      .13      .07
1 85 day 11-20     .04      .02      .02      .02      .02      .02      .02      .02      .02      .02
1 85 day 21-31     .02      .02      .02      .02      .02      .02      .02      .02      .02      .02      .02

Monthly Total  100.8


2 85 day 01-10     .02      .02      .02      .02      .02      .02      .02      .02      .02     2.76
2 85 day 11-20   22.07    16.74    14.41     3.43      .07      .04     1.65     5.45     7.78    10.63
2 85 day 21-28   10.33    23.28    37.13    38.28    26.29    13.16     1.25      .69

Monthly Total  235.6


3 85 day 01-10     .68      .65      .63      .60      .57      .55      .53      .50      .48      .46
3 85 day 11-20     .44      .41      .40      .39      .39      .36      .34      .32      .31      .28
3 85 day 21-31     .28      .54      .54      .54      .42      .34      .33      .36    15.17  1146.07  1413.92

Monthly Total 2587.8


4 85 day 01-10 1087.18   645.75    49.81      .61     1.73     2.48     1.88     1.34      .15      .07
4 85 day 11-20     .04      .03      .05    18.58    36.52    20.76    13.94     1.51      .63      .31
4 85 day 21-30     .25      .22      .82     1.76     1.36     4.49    33.05    29.31    24.98    -1.00

Monthly Total 1979.6
```