**State Water Survey Division**
SURFACE WATER SECTION
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# SEDIMENTATION RATES IN HORSESHOE LAKE, ALEXANDER COUNTY, ILLINOIS

*by*

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## INTRODUCTION

In 1984 the Illinois State Water Survey conducted a sedimentation survey of Horseshoe Lake in Alexander County, Illinois. This survey is part of a diagnostic/feasibility study being conducted by the Water Survey for the Illinois Department of Conservation to determine means of reducing depth loss in the lake due to sediment inputs from the watershed.

The various components of this study include:

1) The lake sedimentation survey
2) A water quality analysis of the lake
3) An inflow-outflow hydrologic analysis of the lake
4) Determination of a sediment budget for the lake
5) A feasibility study for the management of sediment in the lake and upland watershed

This report presents the results of the lake sedimentation survey. These results are necessary to the performance of the other research components, which will be reported on at a later date.

Acknowledgments

This research project was conducted as part of the authors' regular duties at the Water Survey under the administrative guidance of Stanley A. Changnon, Jr., Chief; Michael L. Terstriep, Head of the Surface Water Section; and Nani G. Bhowmik, Assistant Head of the Surface Water Section. Ming T. Lee is principal investigator for this project. William Westcott performed the analyses of sediment samples for unit weights and particle sizes. Some of the illustrations for this report were computer-generated on an Apple Macintosh Personal Computer and the others were prepared by William Motherway, Jr., Linda Riggin, and John Brother, Jr. Gail Taylor edited the report, and Kathleen Brown and Pamela Lovett typed the rough drafts and camera ready copy.

This study was partially funded by the Illinois Department of Conservation through a grant from the U.S. Fish and Wildlife Service.

## BACKGROUND

### Physical Characteristics of the Area

Horseshoe Lake is located in Alexander County, Illinois, 2 miles south of Olive Branch, Illinois, and 15 miles northwest of Cairo. The lake is a 2007-acre natural oxbow lake located in the Mississippi River valley near the confluence of the Ohio River with the Mississippi. The lake is subject to backwater flooding due to high stages in either the Mississippi or Ohio. Figure 1 shows the general location of the lake, as well as most of the features mentioned in this section.

Horseshoe Lake has an upland drainage area of 20.6 square miles excluding the surface area of the lake. The two principal streams, Black Creek (9.86 square miles) and Pigeon Roost Creek (3.78 square miles), originate in the valley bluffs and then flow across the floodplain before entering the lake.

Horseshoe Lake State Conservation Area is a unique natural area reminiscent of southern cypress swamps found in the lower Mississippi River valley. It lies at the northern limit of this type of environment and has many characteristics which cannot be found in northern latitudes.

Total acreage for the conservation area is 9558.01 acres, which includes the 2007-acre Horseshoe Lake (Illinois Department of Conservation, 1983). The

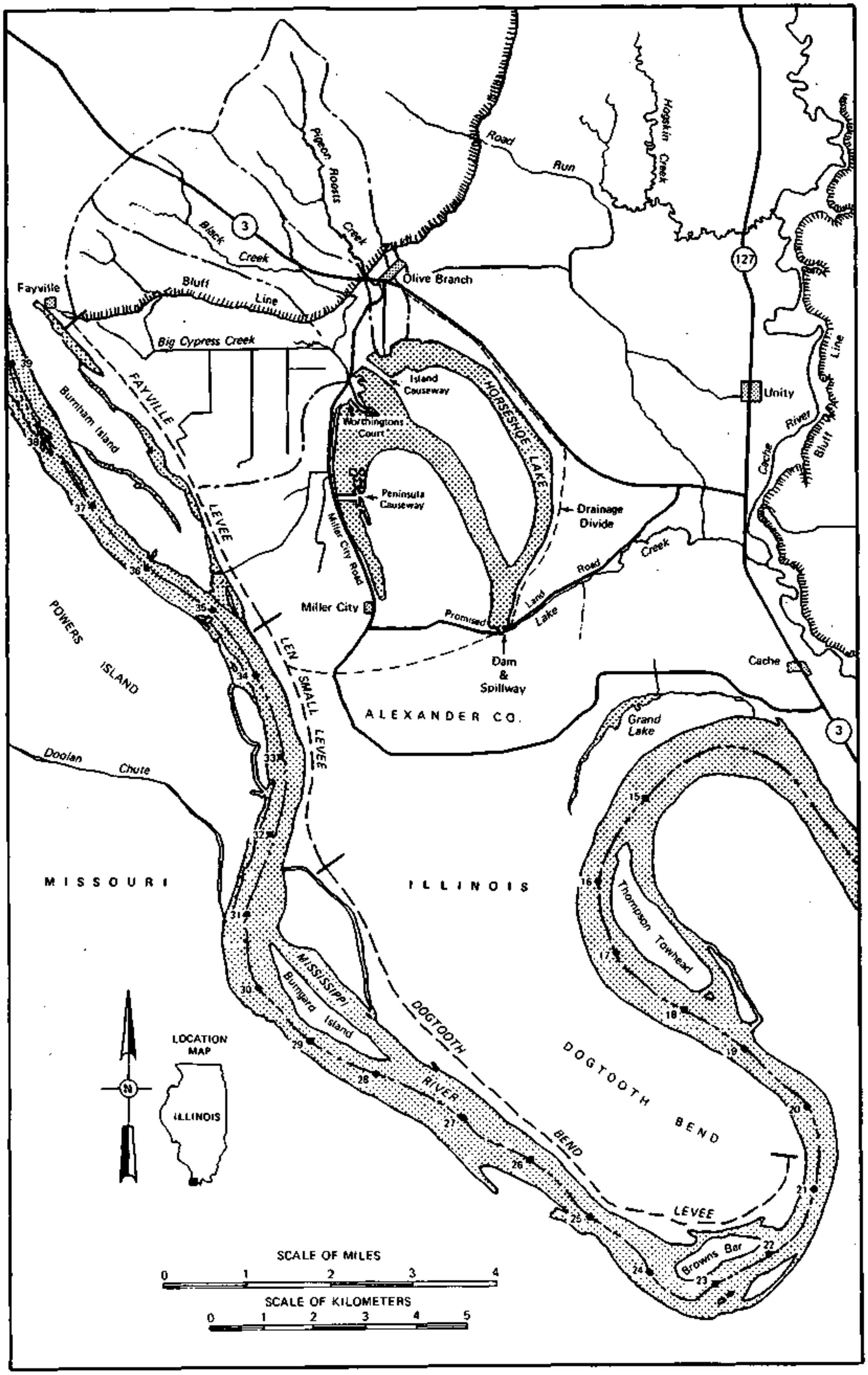


*Figure 1. Location map for Horseshoe Lake, Alexander County, Illinois*

Horseshoe Lake Nature Preserve and Horseshoe Lake Forest Nature Preserve comprise 492.0 acres of the total holdings (IDOC, 1983). These preserves are characteristically swampy and support bottomland forest vegetation.

Several aquatic environments exist within the state-owned area including Lake Creek (a small tributary to the Cache River), several intermittent swamps, and Horseshoe Lake proper. Common bottomland and aquatic vegetation found in these areas includes the tree species Bald Cypress, Swamp Cottonwood, White Oak, Elm, and Tulip Poplar, and the aquatic plants Buttonbush, Lotus, Duckweed, Coontail, and Water Primrose (IDOC, 1972).

The faunal community is largely dominated by the wintering Canada Goose, Branta canadensis, throughout the fall and winter seasons. Mammals indigenous to the area include the Whitetail Deer, Red and Gray Fox, Muskrat, Beaver, Fox Squirrel, and Gray Squirrel. Notable reptiles include the Cottonmouth Snake, assorted water snakes (Natrix sp.) and various species of turtles. The lake provides habitat for many species of rough fish and game fish. Some of the more common fishes are the Carp, Sucker, Channel Catfish, Black Bass, Bluegill, Redear Sunfish, and Crappie (IDOC, 1972).

## Area Functions

The Horseshoe Lake Conservation Area serves several functions. The primary function is to serve as a winter refuge for the Illinois flock of the Mississippi Valley population of migratory Canada geese. Annually, over 20,000 hunters use the public hunting area and the surrounding privately owned clubs. Fishing is the number one outdoor sport at Horseshoe Lake during the spring and summer months. Fishing, camping, and sightseeing activities account for approximately 200,000 visitor days annually (IDOC, 1972).

## Ancient History

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, Archaic, Woodland, and Mississippian. There are at least 15 recorded archeological sites within the immediate lake vicinity that represent the last three of the 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 which have been identified as a Woodland camp (circa 1000 - 200 B.C.) and a Late Woodland village (circa 400 - 900 A.D.) (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.

## Pre-State Ownership

Prior to 1927, Horseshoe Lake existed as a shallow bottomland cypress swamp and was highly dependent for its water upon annual precipitation and flooding by the Mississippi River. Before the state purchased the lake and constructed a dam, portions of the wetland would regularly dry up during July and August (Horseshoe Lake Chamber of Commerce, 1983).

The southwest corner of the lake, currently known as the Miller City arm, was farmed before the dam was constructed. Access to the Horseshoe Lake island and the peninsula was by primitive causeways known as "corduroy" roads after their cypress and tupelo log construction (R. Garrison, IDOC, personal communication, 1984). The lack of trees in the northern portion of the lake is partially due to this construction. Other areas in and around the lake which are void of standing timber are evidence of the early timber harvesting in the area. Logging occurred in several areas which are now covered by water. Remnant stump fields are located just north of the Horseshoe Lake spillway, in the Worthington Court area, and just east and west of the island causeway.

Before 1927, the local economy was largely dependent upon mining, logging, and agricultural activities. Remnants of several abandoned silica and gravel operations can be seen in the lake's vicinity. Agriculture is still the economic leader in the area, and timber harvesting has declined considerably.

## State Ownership

Land and Lake Acquisition. In 1927 the state of Illinois began purchasing properties in the Horseshoe Lake area, with the intent of establishing a state conservation area. 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 Mr. A. P. Green of Indiana, who sold approximately 3176 acres to the state during 1927. This acreage included both the Horseshoe Lake island and the lake proper. By the end of 1927 approximately 3500 acres of land and water had been relinquished to state control.

During the years since 1927, the state has continued to purchase land adjacent to the lake. Throughout the 1950's and into the early 1960's most of the current holdings were acquired. The largest total acreage purchased in any year was the 1927 acquisition. Another major transaction occurred in 1952 when approximately 1775 acres were acquired. The current acreage within the conservation area exceeds 9500 acres (IDOC files).

Spillway History. 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 had a V-form pointing into the lake, which could withstand normal hydraulic pressures associated with impounded water. However, the spillway design did not take into account the velocity and pressure exerted on the structure by Mississippi River backwater flowing into the lake over the spillway. 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).

The need for a more stable spillway was recognized by DOC engineers, and in 1930 construction commenced on a controllable bottom discharge spillway. This was completed in 1931 just prior to the first attempt at stocking fish in the lake. The spillway functioned for approximately eight years. A 2-foot-high retaining wall was added to this structure in 1933. It extended east and west from the existing spillway wing walls.

The controllable spillway was replaced by a fixed concrete overflow spillway in 1939 (IDOC, 1972). The elevation of this spillway was not tied in to a standard datum. At the time the surveyors chose an arbitrary datum and proceeded with construction based on it. The original blueprints of the spillway indicate that the 1940 elevation was approximately 322 feet MSL. The 1984 survey of the lake region determined the spillway elevation to be 321.41 feet MSL.

Following completion of the 1939 spillway and dam construction, the lake level was approximately 4.5 feet higher than the uncontrolled, pre-development lake. Due to this increase in water level, approximately 640 acres of topographically low lands adjacent to the lake were inundated. Included in this acreage were the areas known as Worthington's Court and the Miller City arm. 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 (IDOC files).

Levee Construction. Horseshoe Lake is generally subject to annual flooding by the Mississippi River as river backwater enters the lake due to reversed flow over the spillway. Until 1969, floodwater entered the lake in two ways – river backwater entered the lake over the spillway, and direct overbank flow followed the course of Big Cypress Creek (a tributary to Black Creek) into the Black Creek delta area in the northwest corner of the lake (figure 1).

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

Local residents have suggested that prior to 1969 the velocity and flow of the floodwater passing through the Black Creek delta area were great enough to flush this portion of the lake, thereby counteracting normal deltaic sedimentation processes. Residents suggest that the aggradation of the Black Creek delta was not a problem until after the Fayville Levee was completed.

Modifications. In the mid-1940's, the delta area of Black Creek (figure 1) was owned by a Mr. Milar. During this period a series of small levees were built in the vicinity of the delta to enclose a private duck hunting club (B. Collins, IDOC, personal communication, 1984).

In 1963 the main channel of Black Creek was dredged by the Department of Conservation. The purpose of this dredging was to deepen the channel to improve drainage as well as access to the main body of the lake by people who owned private cabins along this stretch of the creek (B. Collins, IDOC, 1981).

The causeway to the island was constructed in 1961 along the same route occupied by the corduroy road in the early 1900's. A second causeway to the peninsula (Wicker Place) was built in 1963. It also followed the route of an earlier corduroy road.

Goose Population and Management. The primary purpose of the Horseshoe Lake State Conservation Area is to provide wintering habitat for the Illinois flock of the Mississippi Valley population of the migratory Canada goose, *Branta canadensis interior* (IDOC, 1972). The geese migrate from the James Bay and Hudson Bay breeding grounds in northern Ontario and begin arriving at Horseshoe Lake in late September. ' The end of the southward fall migration occurs near the middle of December.

Prior to 1928 the Horseshoe Lake area supported a minute wintering goose population. The majority of the flock was dispersed along the Mississippi River from Chester, Illinois, to Cairo, Illinois. Hunting was unmanaged at this time and large goose kills were the rule. In 1918 this relatively unmanaged hunting began to decline as a result of the passage of the Migratory Bird Treaty Act, which established federal rules and regulations to govern the taking of migratory waterfowl.

Soon after the state purchased the Horseshoe Lake island and began catering to the flock, the geese began using this protected area. In 1928 the island supported its first significant population, approximately 1000 birds (Horseshoe Lake Chamber of Commerce, 1983). With subsequent land purchases, declining Mississippi River habitat (due to U.S. Army Corps of Engineers flood protection projects), increasing refuge habitat, and protection from increasing hunting pressure, the Illinois flock began to concentrate in the Horseshoe Lake refuge and surrounding area. By 1939 the conservation area was harboring a winter flock of over 100,000 birds (Kennedy and Lewis, 1977).

Since the Horseshoe Lake Refuge was the first and only refuge in the southern tip of the state, practically all of the Illinois flock was concentrated there. This concentration of birds in one easily accessible area produced increased hunting pressure near the refuge, and the Illinois flock suffered greatly. By 1916 only 22,000 geese of an estimated Mississippi Valley population of 53,000 were wintering at Horseshoe Lake. Due to this severe depletion of a valuable natural resource over a 7~year period, the entire Mississippi Flyway was closed to goose hunting for the fall 1946 season.

Between 1947 and 1950, an attempt was made to split the Illinois flock by creating three new waterfowl management areas. Two of the three new refuges were successful in drawing portions of the flock away from the Horseshoe Lake area. This helped reduce the huge concentration of birds in any particular location, thereby dispersing some of the hunting pressure. These two refuges were the Crab Orchard National Wildlife Refuge near Carbondale, Illinois, and the Union County State Wildlife Refuge near Ware, Illinois. The third refuge, Mermet Lake State Conservation Area in Massac County, was unsuccessful in drawing a portion of the Horseshoe Lake goose flock. Mermet was successful, however, in providing quality wetland habitat for ducks.

From 1950 through 1957 the Mississippi Valley goose population steadily increased to approximately 275,000 birds, where it stabilized until the mid-1960's. In the mid-1960's new hunting and harvest management policies were initiated within the flyway, which allowed the population to increase to 300,000 geese by 1969 (Kennedy and Lewis, 1977). During these years of evolving management techniques, the Horseshoe Lake portion of the Illinois flock increased and decreased proportionally, generally holding approximately 40 percent of the flock (J. Golden, IDOC Region V Wildlife Biologist, personal communication, 1984). Continued responsible management allowed the Mississippi Valley population to grow to a record high of over 500,000 birds by 1977. Since 1977, the Mississippi Valley population has declined to the current population of approximately 375,000 geese, of which approximately 100,000 to 125,000 were expected to rest at the Horseshoe Lake State Conservation Area during the fall and winter of 1984 (J. Golden, 1984).

## GEOLOGIC AND CLIMAT0L0GIC SETTING

### Physiography and Geology

Physiographically the Horseshoe Lake region is classified as the northernmost occurrence of the Coastal Plain Province, which encompasses most of the lower Mississippi River downstream of the lake. The Coastal Plain in Illinois includes the southern ti'p of the state and is underlain by Cretaceous and Tertiary sediments which overlap the older Paleozoic rocks to the north (Leighton et al., 1948).

Topographically the region is dominated by the Mississippi River and by the valley bluffs, which are principally lower Devonian limestone and cherts. These bluffs were carved by the downcutting of the Mississippi River and the simultaneous regional uplift of the Ozark Dome. The floodplain of the Mississippi River between its bluffs is principally sand and gravel valley fill deposited by the river. McKay et al. (1979) estimated that the thickness of the valley fill is greater than 115 feet along the valley axis. In general the valley fill coarsens with depth, with the lower portions being coarse gravel. These coarse gravels are a major aquifer of the region.

Below the valley fill are Tertiary and Cretaceous deposits, which are generally unconsolidated clay, sand, and gravel. Together these deposits are approximately 300 feet thick.

The Paleozoic rocks beneath the younger deposits are principally Devonian and Mississippian limestone and dolostone. The regional dip of the Paleozoic rocks in the area is to the northeast, whereas the Tertiary and Cretaceous rocks have a southern dip. The regional dip of these rocks results from tilting, folding, and faulting, some of which is associated with the Ozark Dome uplift. This uplift has lifted pre-Cambrian granites (which occur many thousands of feet beneath Horseshoe Lake) to the surface in southern Missouri.

A stratigraphic cross section of the recent valley alluvium at Horseshoe Lake is presented in figure 2. This cross section was developed from logs for test wells (figure 2) drilled near the lakeshore, on the island, and on the peninsula. The wells indicated on the island and peninsula were used to define the stratigraphy of these two areas but do not fall on the stratigraphic cross section line. Based on these data the layer of clay beneath the lake is speculated to be a clay plug deposited as lake deposits.

The clay layer beneath the lake isolates the waters of the lake from ground waters, resulting in a perched water level in the lake. In figure 2 the ground water levels, as measured when the wells were drilled, are shown

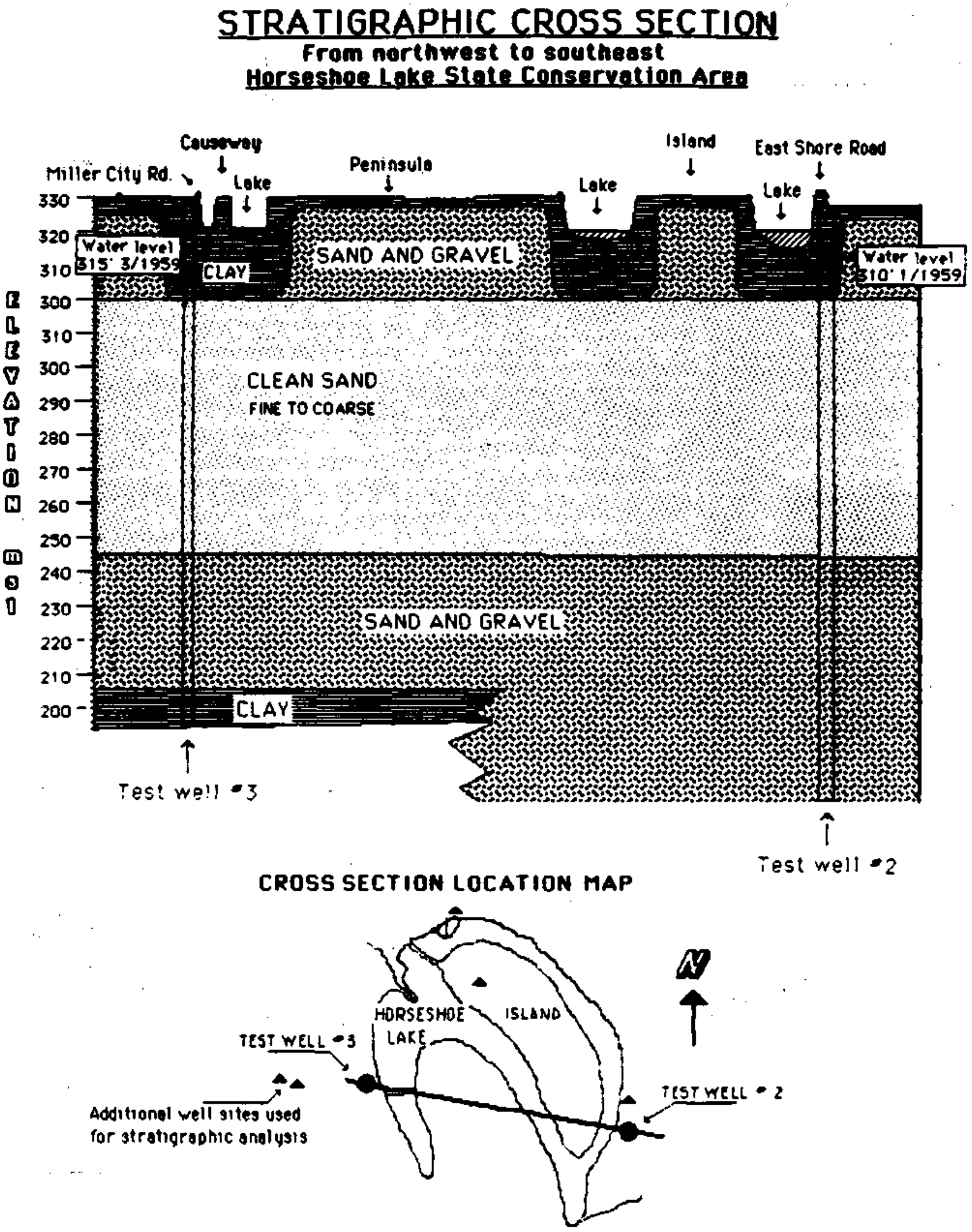


*Figure 2. Stratigraphic cross section of Horseshoe Lake*

on the stratigraphic cross section. The deepest portion of the lake is approximately at elevation 317 whereas the static ground-water levels were measured at elevations 310' and 315' msl, indicating that the movement of water between the lake and the ground is negligible. This hypothesis is also supported by the fact that the lake has never completely dried up even during prolonged dry periods when the ground-water table would have been below the level measured when the test wells were drilled.

## Geomorphology

The topography and surficial geology of the valley bottom of the Mississippi River in the vicinity of Horseshoe Lake are the result of erosional, sediment transport, and depositional processes operating over millions of years. The most significant agents of these processes are the Mississippi River and its tributaries. The bedrock walls of the valley were exposed as the result of downcutting by the river in response to the regional uplift associated with the Ozark Dome. The valley bluffs in the area, which range up to 300 feet above the river, helped to preserve the records of past stages of the river in the form of terrace deposits along the slopes. The valley bottom between the bluffs varies in width from less than 1 mile wide at a point 3 miles northwest of Horseshoe Lake to 15 miles wide at the lake. The ridges, sloughs, backwaters, and wetlands on the valley bottom are remnants of past channels of the river.

Horseshoe Lake is located on the floodplain of the Mississippi River in extreme southern Illinois (figure 3). The lake is classified as a cut-off meander, oxbow lake created when the Mississippi River abandoned its channel in this area. The Mississippi River is a meandering stream which wanders across its floodplain between the valley bluffs, abandoning old channels and

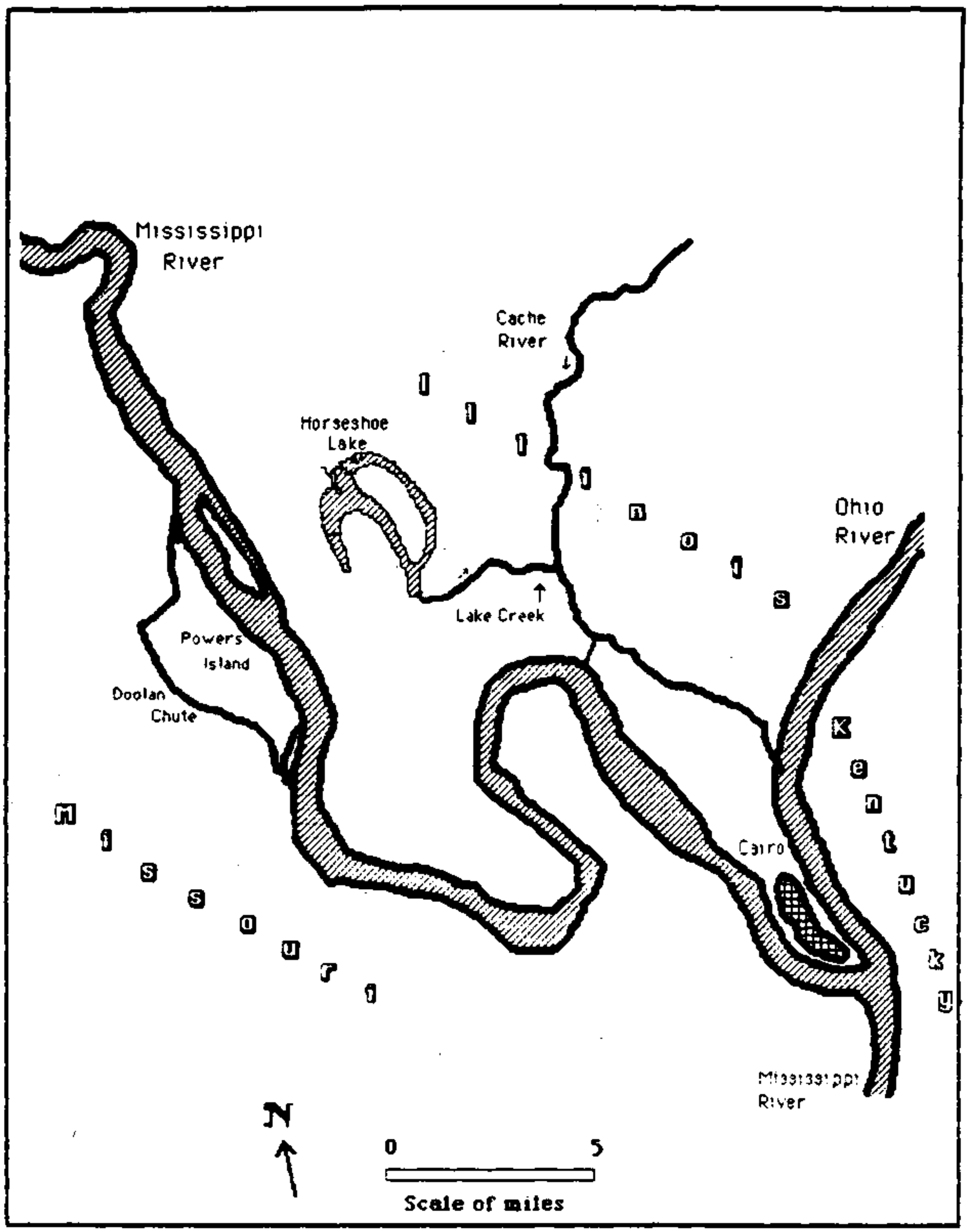


*Figure 3. Present geomorphic setting of Horseshoe Lake*

carving new ones and in the process moving countless tons of sediment and reshaping the land.

Age of the Lake. The formation of the Horseshoe meander loop of the Mississippi River, its abandonment, and formation of the oxbow lake occurred after the last glacial period, the Wisconsinan, approximately 10,000 years ago. Although the glacial ice sheets *never* advanced into the Horseshoe Lake area, the effects of the melting ice sheets did impact the Mississippi River. Glacial periods were times of channel and floodplain aggradation in the Mississippi valley due to the high sediment loads, principally sand and gravel, carried by streams draining the ice sheets. Currently the river has entrenched *or* downcut into the old deposits of the Late Wisconsinan period. The maximum elevation of valley aggradation is recorded by remnants of terrace deposits in the Mississippi River Valley and its tributaries. The terrace deposits of the Late Wisconsinan glacial period have been observed at elevations 50 feet above the current normal stages of the Mississippi and Ohio Rivers (Flint, 1941; Alexander and Prior, 1968). Terrace deposits of the Cache Valley, to the east of Horseshoe Lake, have been radiocarbon dated in the range of 13,000 to 6000 years before the present (Alexander and Prior, 1968). Radiocarbon dates and the terrace deposit elevations suggest that the Horseshoe Lake region was completely inundated either by the waters of the Mississippi River or by channel/floodplain deposits prior to the end of the Wisconsinan Period.

Archeological investigations of the prehistoric settlements in the region indicate that habitation of the shores of Horseshoe Lake may have occurred as far back as the Mid-Archaic Period 6000 to 3000 B.C. (Cobb and Jefferies, 1983).

On the basis of geological and archeological indications and in the absence of radiometric dates of the Horseshoe Lake sediments it is speculated that the lake was formed approximately 6000 years ago.

Origin of the Lake. Regionally, the ridges and sloughs of the valley floodplain are relics of past courses of the Mississippi River. These features were formed as point-bar and channel deposits as the Mississippi River wandered across its floodplain. The Mississippi River has occupied this area since the Early Tertiary (Flint, 1941) approximately 65 million years ago. Since that time, the river has occupied every portion of the valley bottom, changing its course by meandering. The valley bluffs were formed by simultaneous regional uplift and the downcutting of the river.

The patterns of ridges and sloughs in the Horseshoe Lake area provide indications of chronological changes in the positions of past courses of the Mississippi River. A basic premise of using ridge and slough patterns to analyze chronological events is the principle of. superposition and truncation. Basically this principle states that if a series of ridges is truncated by another series of ridges, the first series is the older. That is, the first series had to be deposited before it could be eroded and the second series deposited. This principle also applies to sloughs.

Figure 4 is a map of the region showing the major ridge and slough axes. In this figure it can be seen that the oldest Mississippi River channel that flowed through the Horseshoe Lake area flowed in an east-west direction. This is apparent from the series of ridges and sloughs to the south of the old east-west channel, immediately west of the current lake location. This series overlaps the series marking the older east-west channel and is therefore younger than the latter. These ridges and sloughs indicate that the Mississippi River channel migrated to the south by outside bank meandering,

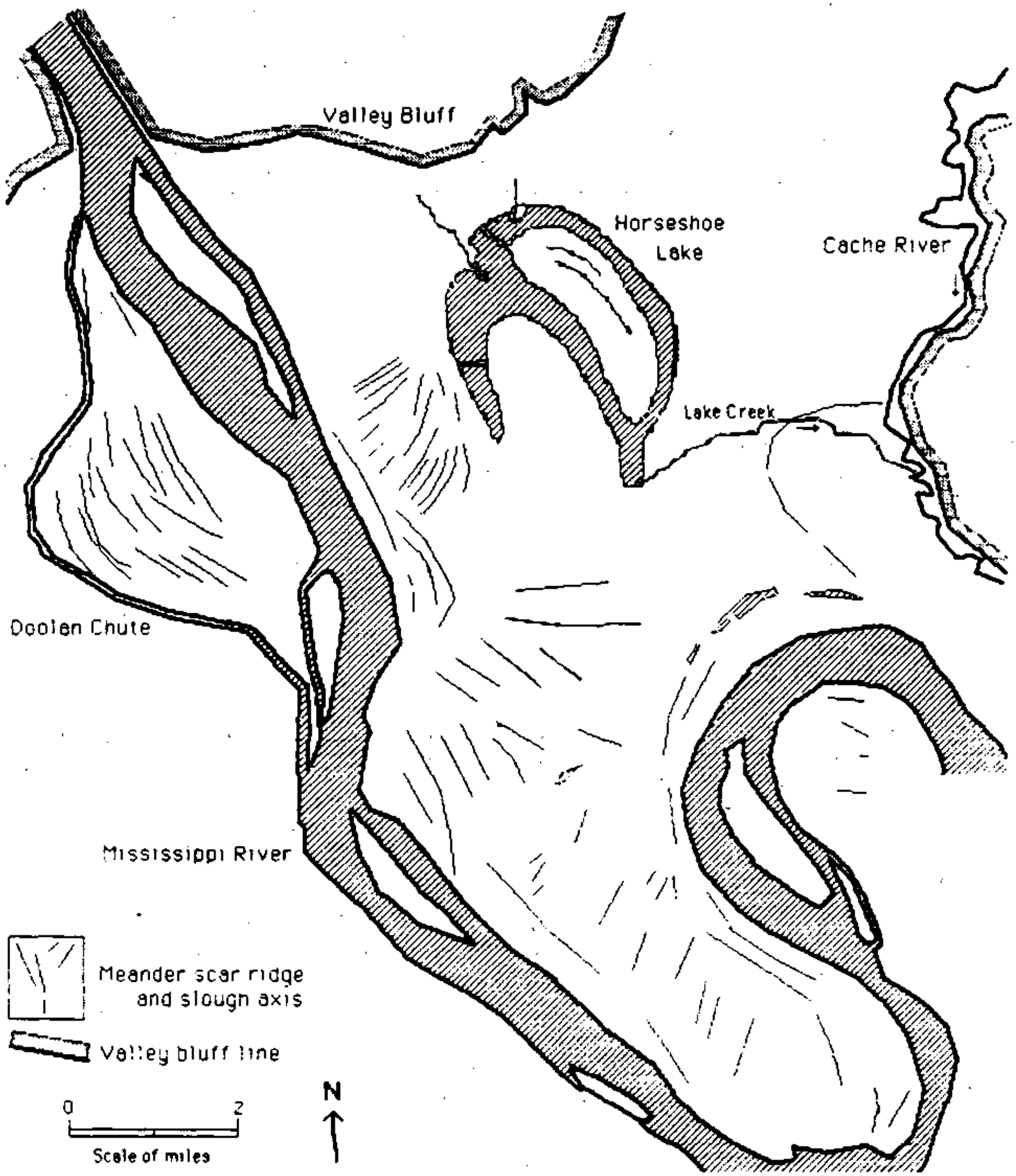


*Figure 4. Mississippi River meander soars near Horseshoe Lake*

and before the Horseshoe Lake meander loop was abandoned, the upstream channel of the meander loop had a north-south orientation. The Horseshoe meander loop was abandoned by the Mississippi River when the two arms of the meander loop met. This occurred in the vicinity of the current river channel south of Powers Island as shown in figure 5. The sequence of events in the migration of the Mississippi River and the formation of Horseshoe Lake are summarized in this figure. At the time the Horseshoe Lake meander loop was abandoned, the main channel of the Mississippi River was located west of Powers Island, approximately 3 miles west of its current location. Later the Mississippi River abandoned the channel west of Powers Island and carved the present course of the river in the vicinity of Horseshoe Lake.

## Climate

The following analysis is based on the Narrative Climatological Summary and the statistical summary from the National Oceanic and Atmospheric Administration (NOAA, 1983) for Cairo, Illinois.

Cairo and Horseshoe Lake are located at the extreme southern tip of Illinois between the Ohio and Mississippi Rivers. The area has a temperate climate more typical of Kentucky and southern Missouri than of Illinois.

The absolute temperature range of -16° Fahrenheit in January 1918 to 106° Fahrenheit in August 1930 is slightly modified by the influence of the two large rivers. The average growing season from the last freeze in spring to the first freeze in the fall is 222 days. The average annual number of heating degree days is 3913, and the average annual number of cooling degree days is 1807.

Normal annual precipitation for Cairo is 47.12 inches, considerably more than in central and northern Illinois. Most of the excess falls during the winter and spring months; summer rainfall is approximately the same here

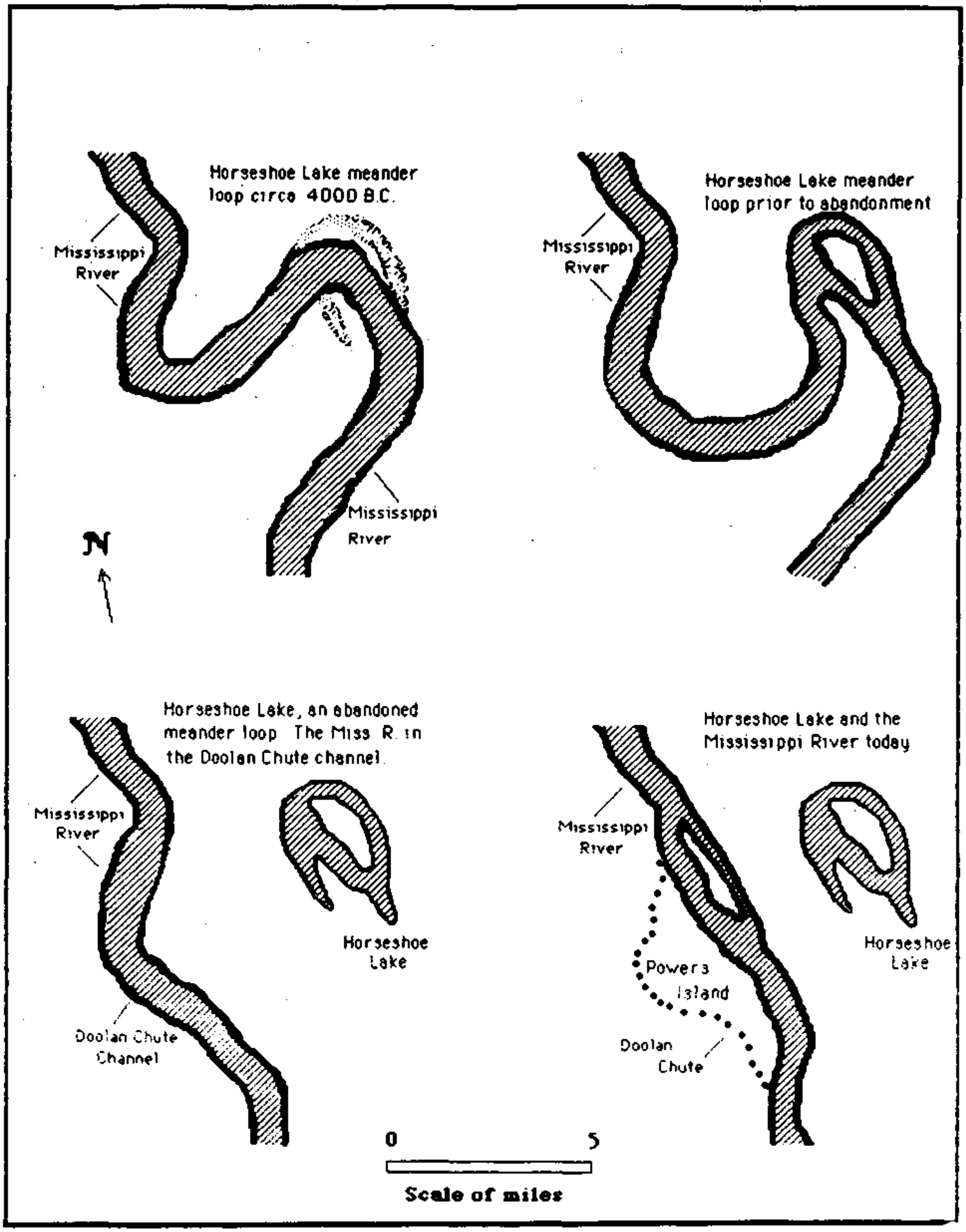


*Figure 5. The evolution of Horseshoe Lake*

as in areas further north. July through October is the driest period. The wettest single month is March, while the driest is October.

The average winter has only occasional light snows. The ground remains bare most of the time, and only about 15 days per season have a snow cover of 1 inch or more. The seasonal average snowfall for the entire local period of record is 10 inches, but half of the winters have less than 7.3 inches, and one-third of the winters have less than 5 inches.

Cairo has a long-term average of 53 thunderstorm days per year, but the number of damaging wind and hail storms is not large.

## LAKE SEDIMENTATION SURVEY METHODS

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 based on 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 have been used in analyzing the sedimentation rate of the lake.

1) Aerial photography has been 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 have been 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 utilized 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 have not grown 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 P.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. A total of 224 cross sections were surveyed: 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 estimated.

Figure 6 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 Lake Sedimentation Survey

During the period March to August 1981, 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 7).

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 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. When making 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. 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

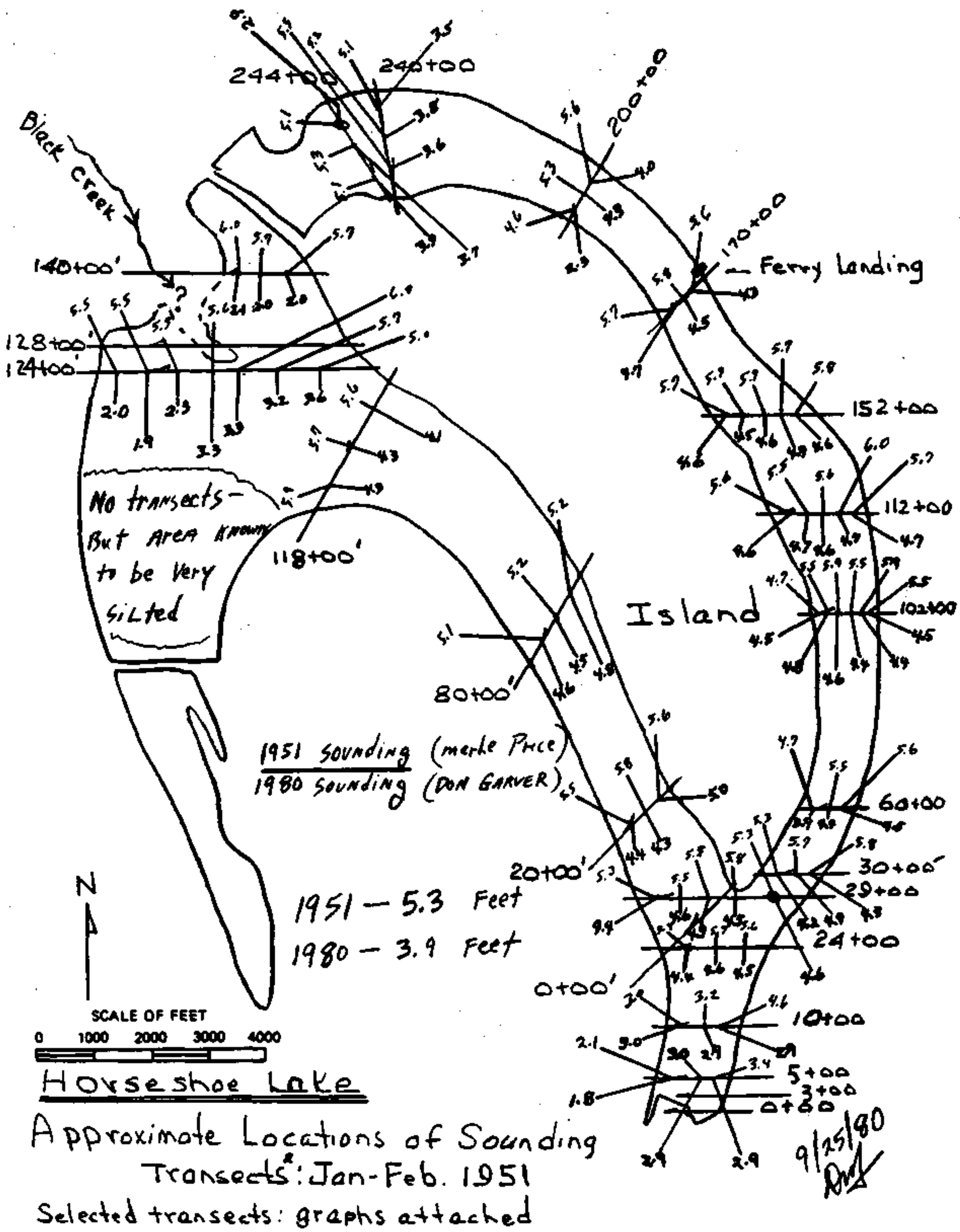


*Figure 6. Summary of 1951 and 1980 surveys of Horseshoe Lake (Reproduction of map presented by Conlin, 1981)*

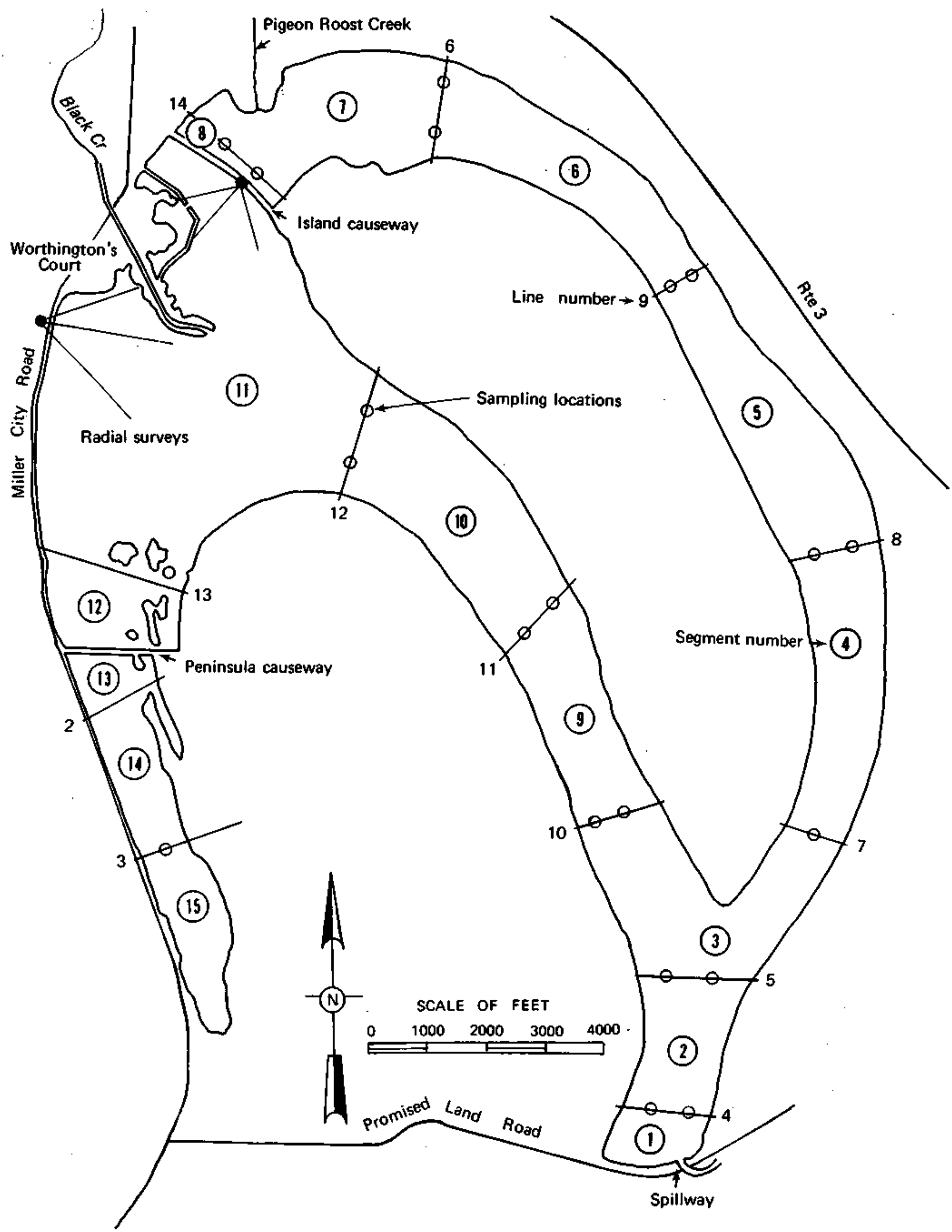


*Figure 7. 1984 survey plan for Horseshoe Lake*

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 7) 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 of these samples are also indicated in figure 7.

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. A summary of sampling locations and results of the analyses are presented in appendix 1.

## ANALYSES OF DATA

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:

$$\forall = A \times \Sigma(E_n/W_n)/n$$

where

$\forall$ = the segment volume

A = the segment area

$E_n$ = the cross-sectional areas of the lines pounding the segment

$W_n$ = the corresponding widths of the lines

n = the number of lines bounding a segment

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 1. The 1984 water volume in Horseshoe Lake at the spillway level is 5947 acre-feet. Sediment accumulation during the period 1951 to 1984 was 2808 acre-feet. Thus 32% of the 1951 water volume was filled with sediment during the period 1951-1984.

The maximum penetration of the sounding pole in 1984 indicates that 6946 acre-feet of unconsolidated sediments have 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. The results are presented in appendix 1.

The lake bed sediments in Horseshoe Lake are predominantly clay. The simple averages of the 48 samples are: 70% clay, 25% silt, and 6% 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-lagen water flows into a lake, its velocity decreases and its ability to

Table 1. Horseshoe Lake - Alexander County
Summary of Lake Sedimentation Results

| Segment[1] | 1984 Volume (acre-feet) | Sediment volumes (acre-feet) | | | Sediment tonnages (1000 tons) | | | Area (acres) | Unit weights (pounds per cubic foot) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1951-1984 | 0000-1951[2] | 0000-1984[3] | 1951-1984 | 0000-1951[2] | 0000-1984[3] | | 1951-1984 | oooo-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 8 for segment location

[2] Accumulated sediment up to 1951

[3] Accumulated sediment up to 1984

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 reduction in weight.

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 1981 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 1. This analysis indicates that 1.15 million tons of sediment accumulated in Horseshoe Lake from 1951-1981. Average unit weight of these sediments is 18.9 pounds per cubic foot. Pre-1951 unconsolidated sediment deposits were just under 2.71 million tons with an average unit weight of 30.1 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 very low in comparison to those of sediments of other lakes in Illinois. The unit weight of unconsolidated sediments at Horseshoe Lake varied from a low of 6.5

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% to 17.5% 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% at deep water sampling sites and a high of 7.9$ 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.

Based on this information it is estimated that of the sediment deposited since 1951, approximately 10$ or 117,000 tons is of organic origin. Table 2 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 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

Table 2. 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 | | 117.4 |

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 when analyzing sediment accumulation in the lake, and mass or tonnage rates will be used to analyze rates of delivery from a source area.

A total of 2808 acre-feet of sediment accumulated in Horseshoe Lake during the period 1951 to 1984. This averages out to an 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 were determined on the basis of 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 rate of sedimentation of Horseshoe Lake indicates that the average depth of the lake is decreasing by 0.039 feet or 0.47 inches per year. Figure 8 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 mostly im-

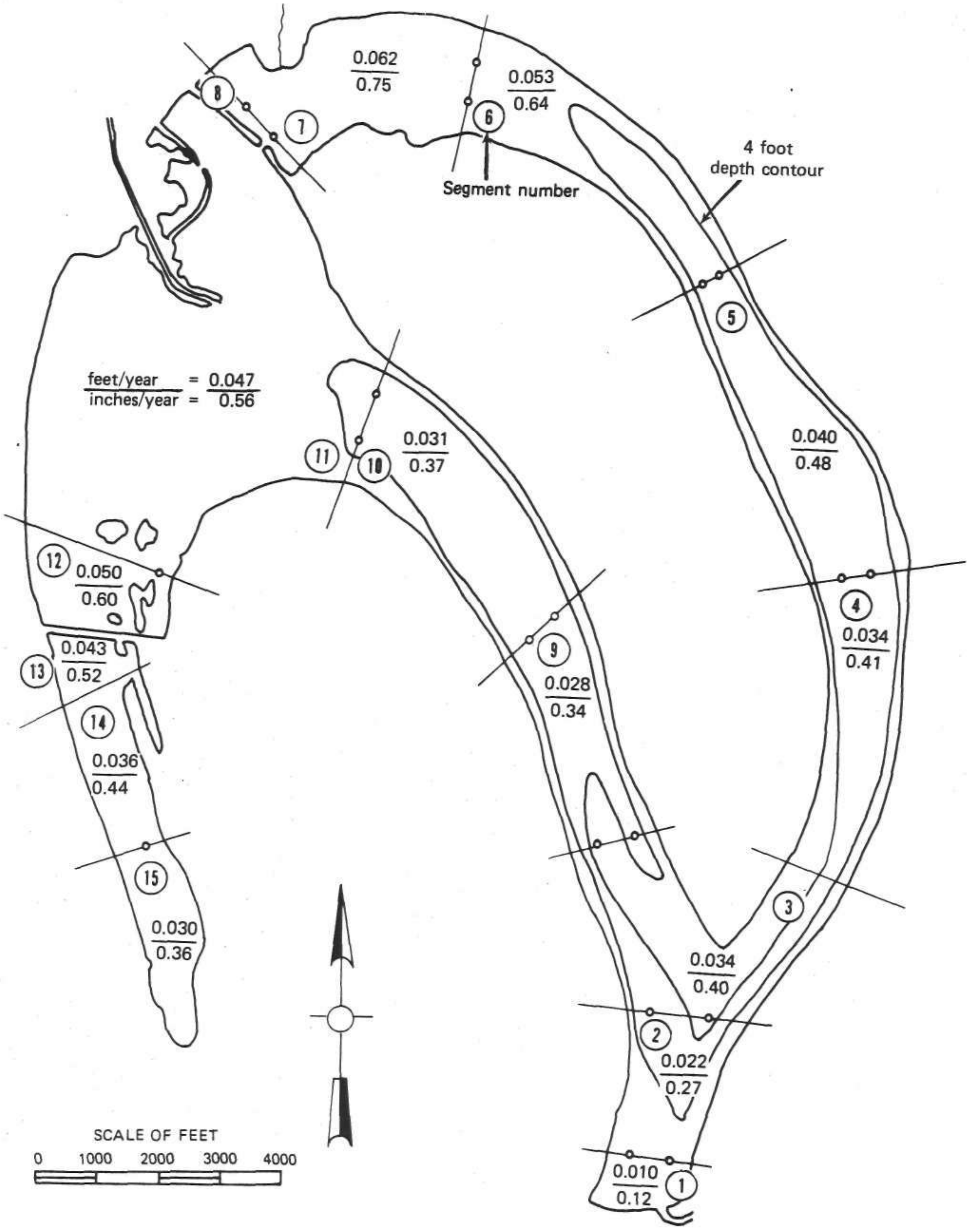


*Figure 8. Horseshoe Lake sedimentation rates with 4-foot depth contour*

pacted by flows from Pigeon Roost Creek while the central branch of the lake is mostly impacted by Black Creek. Due particularly to its larger size, the impact of Black Creek was expected to be greater than that of Pigeon Roost. 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% for the period 1969 to 1981. This impact would also be significant in segments 1, 2, and 3.

The 1,150,000 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% of the total sediment budget of the lake.

Organic inputs to the lake average 3500 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 30,400 tons per year of non-organic sediment accumulation or 2.31 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.

## SUMMARY

Horseshoe Lake is a 2007-acre natural oxbow lake located in Alexander County at the southern tip of Illinois. The lake is subject to backwater flooding due to high stages on either the Ohio *or* Mississippi Rivers. The lake has direct drainage from 23.7 square miles of upland watershed.

The lake is owned by the Illinois Department of Conservation and is managed primarily as a winter refuge for migratory Canada geese. Additional use of the lake for fishing, camping, and sightseeing has been impacted in recent years by sediment accumulations in the lake.

Physiographically, the Horseshoe Lake region is classified as the northernmost occurrence of the Coastal Plain Province which encompasses most of the lower Mississippi River downstream of the lake. The topography of the area is dominated by the Mississippi River and the valley bluffs. The valley width varies from less than 1 mile to 15 miles between 300-foot-high bluffs.

The Horseshoe Lake area has a temperate climate with temperatures ranging from -16° Fahrenheit to 106° Fahrenheit. Average annual precipitation is 47.12 inches.

A 1984 sedimentation survey was conducted as part of a diagnostic/feasibility study being conducted by the Water Survey for the Illinois Department of Conservation. The cross-sectional profiles surveyed during the 1984 survey were compared to cross sections surveyed in 1951 by Department of Conservation personnel. Profiles were developed on the basis of measurements of water depth and thickness of sediment deposits.

These profiles were used to determine the 1981 water volume of Horseshoe Lake at normal pool elevation, sediment accumulations from 1951 to 1984, and the total volume of unconsolidated sediments in the lake. These results, presented in table 1, show a 1984 water volume of 5947 acre-feet, sediment accumulation of 2808 acre-feet from 1951 to 1984, and 6946 acre-feet of unconsolidated sediment in the lake.

The weight of sediment that accumulated in the lake from 1951 to 1984 and the total weight of unconsolidated sediment in the lake were determined on the basis of samples collected in 19.84. These results show that 1,154,000 tons of sediment accumulated in the lake from 1951 to 1984. Total weight of unconsolidated sediment in the lake was 3|894,000 tons in 1984.

Analysis of particle sizes of the sediments in Horseshoe Lake shows a preponderance of clay materials. The simple averages of all sediment samples analyzed were 70% clay, 25% silt, and 6% sand.

Analysis of the organic content of the Horseshoe Lake sediments shows that the organic input to the lake is very high. It is estimated that 10% of the sediment material is of organic origin. This high organic input is a result of large goose populations and the large stands of Cypress and Tupelo trees in the lake.

A determination of sedimentation rates in Horseshoe Lake showed that the water volume of the lake is being replaced by sediment at the rate of 78.6 acre-feet per year. This represents a loss of average depth in the lake of about 0.5 inches per year.

Sediment is accumulating in the lake at a rate of 2.31 tons per acre of watershed per year. Average annual accumulation of organic material in the lake is approximately 1.72 tons per acre of lake per year.

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# Appendix 1

## Sample Location and Geotechnical Analysis

Sample Location and Geotechnical Analysis
Horseshoe Lake - Alexander County

| | 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 |
| 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 | | 1.4 | | | 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 (feet) | | | Particle Size Distribution3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Location[1] | Unit weight | Particle size | Nutrient | | 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 | | | 1.45 | 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] | | | | | | Particle Size Distribution | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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) | | | | | |

| Location[1] | Sample Number[2] | | | Depth below lake bed to midpoint of sample (feet) | Unit weight | Water content | Particle Size Distribution[3] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unit weight | Particle size | Nutrient | | | | 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 | 4 |
| | | | 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 | | | | | |

| Location[1] | Sample Number[2] Unit weight | Particle size | Nutrient | Depth below lake bed to midpoint of sample (feet) | Unit weight | Water content | Particle Size Distribution[3] 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 | | | | | |

| Location[1] | Sample Number[2] Unit weight | Sample Number[2] Particle size | Sample Number[2] Nutrient | Depth below lake bed to midpoint of sample (feet) | Unit weight | Water content | Particle Size Distribution[3] Percent of clay | Particle Size Distribution[3] Percent of silt | Particle Size Distribution[3] 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 | | | | | |

| Location[1] | Sample Number[2] Unit weight | Particle size | Nutrient | Depth below lake bed to midpoint of sample (feet) | Unit weight | Water content | Particle Size Distribution[3] 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 | | | | | |

| Location[1] | Sample Number[2]: Unit weight | Sample Number[2]: Particle size | Sample Number[2]: Nutrient | Depth below lake bed to midpoint of sample (feet) | Unit weight | Water content | Particle Size Distribution[3]: Percent of clay | Particle Size Distribution[3]: Percent of silt | Particle Size Distribution[3]: Percent of sand |
|---|---|---|---|---|---|---|---|---|---|
| AW1717 | | 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 | | | | | |
| AW1072 | 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] | | | Depth below lake bed to midpoint of sample | | | Particle Size Distribution | | |
|---|---|---|---|---|---|---|---|---|---|
| Location[1] | Unit weight | Particle size | Nutrient | (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

Nutrient Sample Analysis

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