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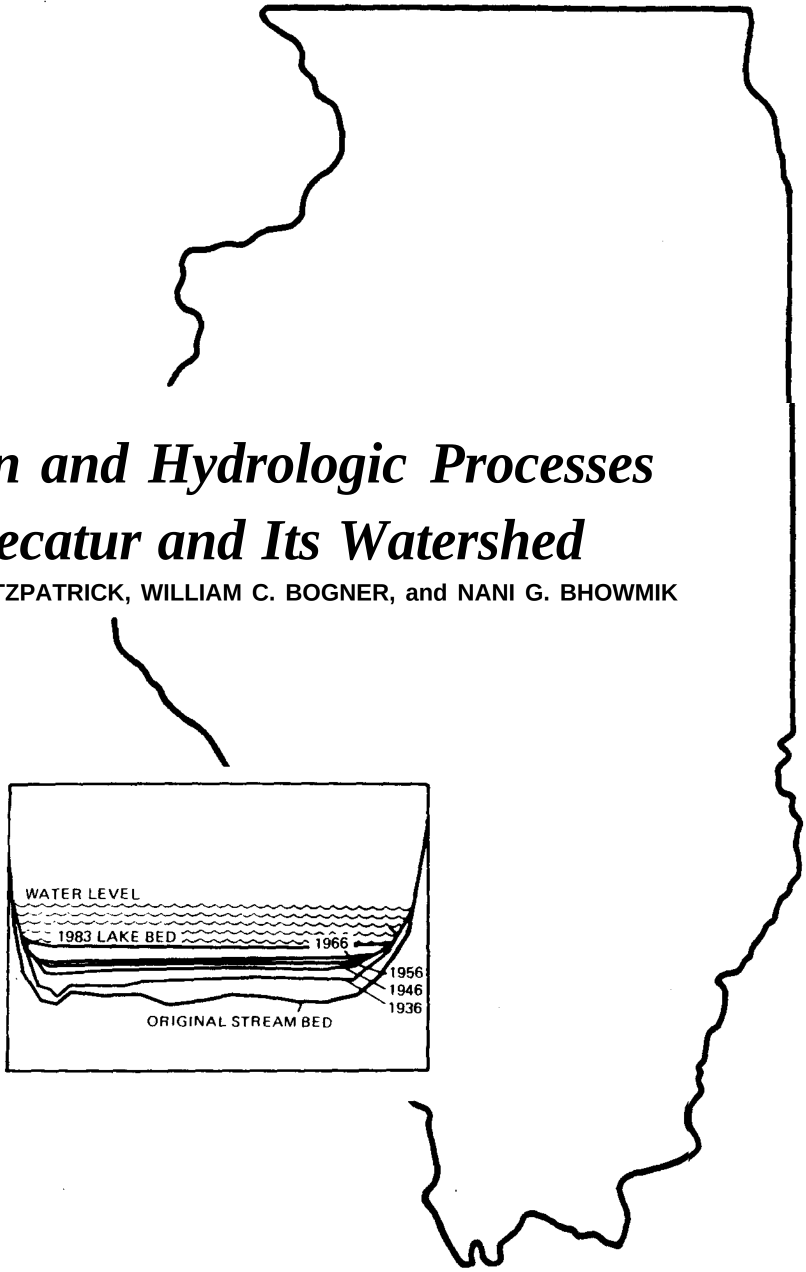
REPORT OF INVESTIGATION 107

STATE OF ILLINOIS

ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

Sedimentation and Hydrologic Processes in Lake Decatur and Its Watershed

by WILLIAM P. FITZPATRICK, WILLIAM C. BOGNER, and NANI G. BHOWMIK



ILLINOIS STATE WATER SURVEY

CHAMPAIGN

1987

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by WILLIAM P. FITZPATRICK, WILLIAM C. BOGNER, and NANI G. BHOWMIK

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Indexing Terms: Bank erosion, erosion, hydrographic surveying, hydrology, Lake Decatur, lake sedimentation, particle size, reservoir sedimentation, sedimentation, trap efficiency, unit-weight density, Upper Sangamon River.

STATE OF ILLINOIS
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CONTENTS

PAGE

Appendices

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SEDIMENTATION AND HYDROLOGIC PROCESSES IN LAKE DECATUR AND ITS WATERSHED

by William P. Fitzpatrick, William C. Bogner, and Nani G. Bhowmik

ABSTRACT

One of the end products of erosion is the accumulation of sediment in lakes and reservoirs, which results in the degradation and impairment of use of these water bodies. Lake Decatur, a water supply reservoir in the Upper Sangamon River watershed in east-central Illinois, has lost one-third of its storage capacity to sedimentation since its construction in 1922. The lake has been surveyed six times (in 1931-1932, 1936, 1946, 1956, 1966, and 1983) for the purpose of determining sediment accumulation rates. These surveys represent the most extensive investigation of reservoir sedimentation in Illinois.

This report presents the results of the last survey as well as an analysis of previous surveys and investigations. It includes a compilation of information on the history of the lake and on the physical and geological characteristics of the Upper Sangamon watershed. Changes in reservoir storage capacity over time and the temporal, spatial, and geotechnical variations in sediment deposition are analyzed. Also presented is an analysis of the relative contribution of sediment from various areas of the watershed.

Over a 61-year period (1922-1983) Lake Decatur lost 9100 acre-feet of storage capacity through the accumulation of 9,830,000 tons of sediment. On the average each acre of watershed delivered 21.4 tons of soil to the lake over this 61 -year period. Rates of sediment accumulation have generally decreased over time. The highest annual rate was for the period 1936-1946 (0.36 tons per acre), the lowest annual rate was observed for the period 1946-1956 (0.17 tons per acre), and the annual rate for the period 1966-1983 (0.26 tons per acre) was near the 61-year annual average of 0.27 tons per acre. The 15% of the watershed area nearest the lake contributed approximately one-half of the sediment in the lake.

INTRODUCTION

This report is a product of the continuing long-term research of the Illinois State Water Survey (ISWS) into the process of lake and reservoir sedimentation in Illinois. The purpose of the report is to document the regional characteristics of the watershed, the pattern of sedimentation in Lake Decatur, and the nature of the sediment in the lake, and to assess the relative contribution of sediment from major source areas.

This report presents the results of the 1983 sedimentation survey of Lake Decatur, which was a cooperative project between ISWS and the City of

Decatur. Lake Decatur is the water supply reservoir for the city and is the sole source of water for the city's industries and 100,000 residents. The basic purpose of this survey was to determine the current volume of Lake Decatur and to calculate the past rates of volume loss and sediment accumulation. The lake was surveyed five times previously, in 1931-1932, 1936, 1946, 1956, and 1966. The 1983 survey was conducted during the period June through August.

The previous surveys of Lake Decatur provide some of the most complete documentation available of lake sedimentation processes in Illinois. This report presents an analysis of the data from the earlier surveys.

Some of the information presented in this report was previously published in Illinois State Water Survey Contract Report 342, Sedimentation Survey of Lake Decatur, Decatur, Illinois (Bogner et al., 1984).

Scope

This report presents information regarding the following areas:

1) History, geology, hydrology, and climatology of the Upper Sangamon River basin watershed

2) Past surveys of Lake Decatur

3) The 1983 lake survey

4) Lake bed sediment characteristics

5) Sources of sediment to Lake Decatur

Acknowledgments

This research project was conducted as part of the authors' regular duties at the Illinois State Water Survey under the administrative guidance of Stanley A. Changnon, Chief Emeritus; Michael L. Terstriep, Head of the Surface Water Section; and Nani G. Bhowmik, Assistant Head. Misganaw Demissie provided invaluable guidance in the analysis of the results and preparation of the report. Kurt Johnson and Barry Klepp, students at the University of Illinois, assisted in field data collection, data organization, and calculations of lake volumes. William Westcott, under the direction of Michael V. Miller, performed the analysis of sediment samples for unit weight and particle size. Figures and illustrations for this report were prepared by William Motherway, Jr., and John Brother, Jr. Gail Taylor edited the report, and Kathleen Brown typed the rough drafts and the camera-ready copy.

Partial funding for this study was provided by the City of Decatur. Particular appreciation is expressed to Don Gibson, City of Decatur; Ron Lewis, Lake Maintenance; Brad Brown, Decatur Lake Police; and the citizens of the City of Decatur.

DAM AND RESERVOIR

History of Decatur Waterworks

The first public water supply for the residents of Decatur, built in the early 1830s, was a shallow public well near what is now Lincoln Square. Several other wells were finished in the following years, but their water capacity was insufficient for the growing population and industries of Decatur. The city population grew from less than 100 in 1830 to over 7000 by 1870. In 1871 the city council voted $30,000 in bonds for the construction of a pumping station and related equipment on the Sangamon River. The new installation provided a capacity of one million gallons a day (1 MGD). The raw waters of the Sangamon proved to be too turbid, so an infiltration gallery was constructed in the bed of the river to filter the river water through sand and gravel. To keep up with the demands of the growing city, a wood dam was built in 1878 across the river near the present low dam (a few hundred feet downstream of the current city dam).

By 1884 the city's pumpage capacity had increased to 7 MGD. A new pumping station was built in 1909 at a cost of $225,000, and in 1913 a new filter plant was under construction.

The old wood low dam was replaced in 1910 by a new low dam of concrete with a spillway elevation of 595 feet msl (mean sea level). Later, in 1920, the A. E. Staley Co. built its own dam 100 feet downstream of the Staley Bridge, constructed to alleviate periodic shutdowns at the Staley Company's corn processing plant due to water shortages at the city's waterworks. The Staley dam was used to augment the municipal water supply as well as to supply the Staley plant until the new city dam was completed in 1922, at which time the Staley dam was removed.

The new city dam and reservoir cost approximately $2 million. Of this amount, the city paid $725,000 and the rest was financed by the Decatur Water Supply Company, a quasi-public company established to issue bonds to cover the remaining costs and to administer the new lake and dam. The Decatur Water Supply Company was dissolved in 1932 when the last of the bonds were retired, and the ownership of the lake was turned over to the City of Decatur. The location of Lake Decatur and its watershed is shown in figure 1.

At the same time that the population and industries of Decatur continued to grow and place new demands on the city waterworks, Lake Decatur was being reduced in capacity by sedimentation. By 1956, the lake had lost approximately 30% of its volume. In 1956, a set of hydraulically controlled bascule gates was installed on top of the spillway segment of the city dam to raise the storage capacity of the lake by providing a means of varying the spillway elevation between 610 and 615 feet msl.

The city's water treatment capabilities have been expanded over the years. The main water treatment plant, just north of the city dam, has been enlarged several times and has a capacity of 28 MGD. A new plant was built in 1975, near Rea's Bridge, at a cost of $8 million. The new North Water

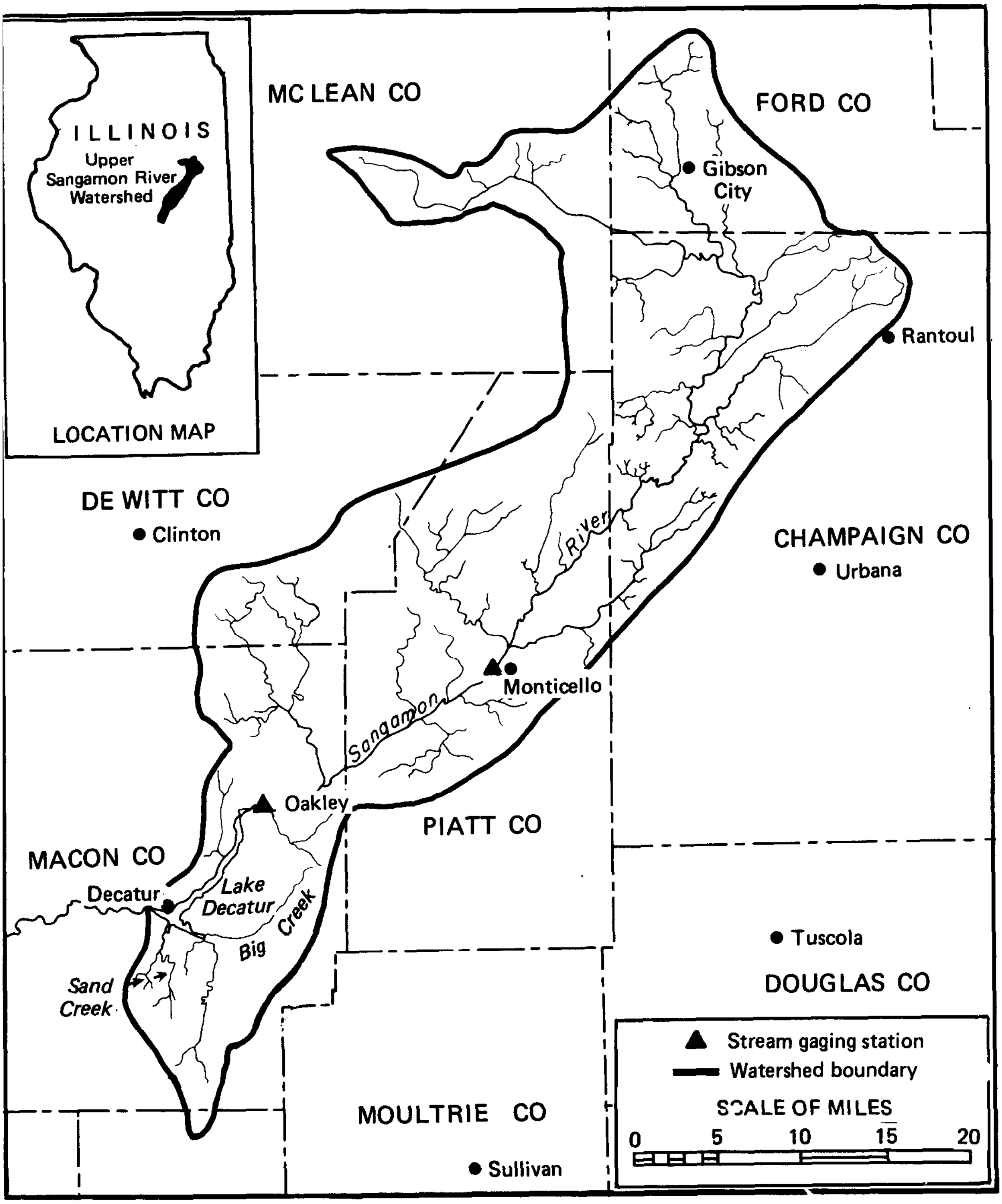


Figure 1. Location of Lake Decatur, showing watershed boundary and Monticello gaging station

Treatment Plant has an installed capacity of 12 MGD, which can be expanded to 24 MGD.

The North Water Treatment Plant was situated near the upper end of the lake in anticipation of the construction of a new flood control and water supply reservoir, the Oakley/Springer project, proposed by the U.S. Army Corps of Engineers. The Oakley/Springer dam was to be built just north of Rea's Bridge and would have provided several tens of thousands of acre-feet of storage that would have supplied the city's needs well into the next century. In the late 1970s, however, Congress ceased appropriating money to the project and it was deauthorized.

Several reservoir projects have been proposed over the years to increase the municipal water supply of Decatur: Big Creek, Sand Creek, Friends Creek, and others. For one reason or another these projects were not built, and Lake Decatur remains the sole source of potable water for the city.

Decatur Dam and Reservoir

The city dam at Lake Decatur has a total length of approximately 1900 feet extending north and south across the Sangamon River Valley. The dam consists of three segments: the concrete spillway segment in the middle, which is 480 feet long, 28 feet in height above the bottom of the original river channel, 4 feet thick at the top, and 14 feet thick at the base; and two earth-filled sections on either end of the spillway, each having a length of about 675 feet and a freeboard of approximately 22 feet between the spillway crest and the top of the end sections (Brown et al., 1947).

The original spillway elevation was 610 feet msl. The set of moveable gates installed atop the spillway section in 1956 is capable of raising the pool elevation to 615 feet; however, the pool is normally maintained at 613.5 feet. The upstream end segments of the dam have slopes of 2.5 to 1 and are faced with concrete slabs. The upstream face of the spillway section is vertical.

A flushing conduit of 3 by 4 feet was built into the spillway section at a depth of 15 feet below the crest. The total cost of the dam construction was $940,000. Other costs, including land purchase and clearing, road and bridge relocation, and riprapping, brought the original cost up to $2,013,840 (Brown et al., 1947).

Lake Decatur covers the entire floodplain of the Sangamon River and encroaches on the bluffs and slopes of the valley. The old floodplain is approximately 1/2 mile wide and was occupied by a winding river channel 100 to 200 feet across and about 5 to 10 feet deep. The submerged river channel has been completely buried in much of the lake as the fine silts washed into the lake have settled out in the deeper, quiet portions of the lake. The original maximum depth of the lake at the dam was approximately 28 feet in the old river channel and about 16 feet over the old floodplain. Currently the maximum depth is 17 feet at the dam and over 20 feet deep at a scour hole in the lake bed below Staley Bridge (below elevation 613).

The lake forms an inverted "T" shape (see figure 1) where the valley of the Sangamon River takes a right angle turn from a southwest orientation to a northwest direction at the junction of the major tributary, Big Creek, about 1-1/2 miles upstream of the dam. The only other major tributary of the lake is Sand Creek, which joins the lake at the "T" from the southwest. The lake is bounded by bluffs of up to 70 feet and steep slopes which are most noticeable along the southern shore of the Big Creek tributary and along the shoreline of the main lake on its upper part.

Pre-Dam Valley Topography

Before the construction of the city dam, the valley of the Sangamon River at Decatur was occupied by the meandering course of the river. Parcels of farmland on the floodplain are bordered by the river and the valley walls, as shown in figure 2. The map of the valley shown in figure 2 was obtained from the Water Survey's files. It was undated and drawn sometime prior to 1918 as indicated by a handwritten note on the original.

The floodplain of the Sangamon River occupied the entire valley floor and averaged about 1/2 mile wide. The valley walls are composed of Illinoian and Wisconsinan glacial till and are capable of holding near vertical bluffs, as can be seen in the southwestern portion of the map in figure 2.

The twisting course of the river shown in figure 2 is a result of the low gradient and high sediment load of the river. In this figure one can see the cut-off meanders and side channels which are typical of the Sangamon River. In the area shown by the pre-dam map, the river traveled 8.7 miles from the north railroad bridge to the county bridge in the southwest, a valley distance of 5.8 miles.

In figure 2 the old bridges and levees of the pre-dam valley can be seen. Of the six highway bridges shown in this figure which crossed the valley, four were maintained in service when the valley was inundated. The Maffit and Cowford Bridges were abandoned.

Shoreline Usage and Recreation

Land use along the shore of Lake Decatur varies from highly developed urban areas, to public parks and clubs, to undeveloped woodlands. Developed areas including parks, clubs, and residential areas encompass over 90% of the total shoreline. The southern shore is dominated by single family housing, while the northern shores are generally wooded and less developed.

Lake Decatur provides a focal point for recreation in the area. Nine city parks are on the lake shore, of which the largest are Nelson, Faries, and Big Creek Parks. Approximately 10 private/semi-private clubs also occupy the lakeshore. These clubs cover a wide range of interests ranging from Boy Scout and Girl Scout camps to the Decatur Country Club and the Yacht Club.

Major recreational activities on the lake are boating, water-skiing, sailing, and fishing. In 1983 approximately 2600 boat licenses were issued by the city for Lake Decatur. The number of boat licenses averages about one

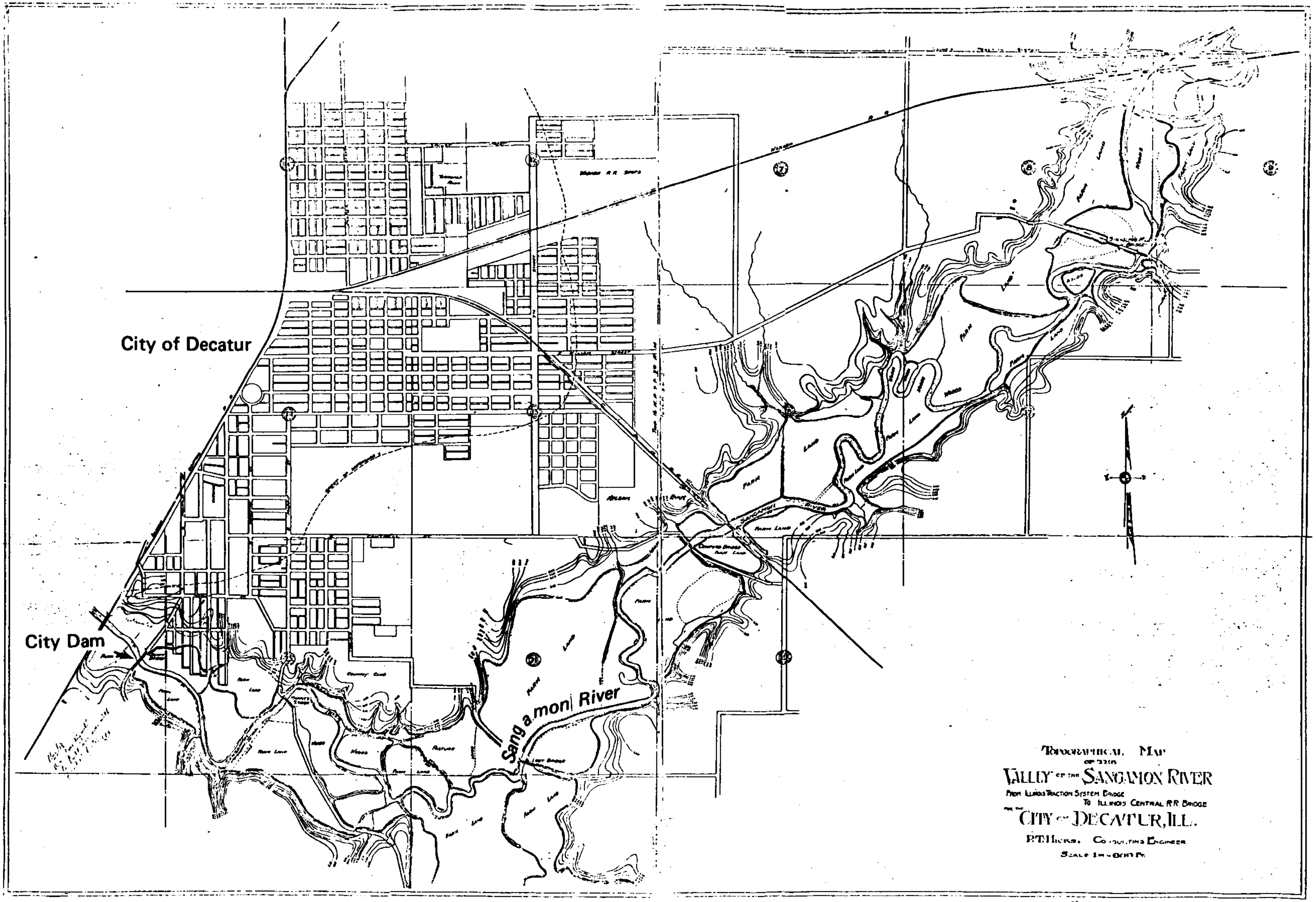


Figure 2. Valley of the Sangamon *River before construction of Lake Decatur*

per 40 people for the city population of 100,000. In 1983, 420 dock permits (individual and multiple) were issued by the city for the lakefront property owners and tenants.

Water Quality

The water quality of Lake Decatur is considered fair to moderate. The lake has high concentrations of nitrates and total dissolved solids, and it has had periodic problems with turbidity and bacterial contamination (IEPA, 1978).

Thirty-one Illinois lakes were sampled in 1973 for the USEPA national eutrophication survey. Lake Decatur ranked 28 out of 31 in overall trophic quality (USEPA, 1975), and was classified as eutrophic by the USEPA. A eutrophic lake is one that exhibits any of the following characteristics: algal blooms, excessive aquatic weeds, oxygen deficiencies, or a shift in species composition of aquatic fauna to forms that can tolerate low concentrations of dissolved oxygen. Most of these problems have been seen in Lake Decatur.

PHYSICAL AND GEOLOGICAL CHARACTERISTICS OF THE WATERSHED

Climate

The climate of the Decatur region is classified as humid continental. Typical features of the climate are the great variations in temperature and precipitation between months and years (Changnon, 1964; NOAA, 1982). The seasons of the year in the watershed range from warm to hot summers and cool to cold winters. On the average, weather fronts move through the region 25 to 30 times a year, causing abrupt changes in weather conditions.

Average annual precipitation from 1951 to 1980 was 39.12 inches; it has been as high as 60.58 inches (in 1927) and as low as 25.10 inches (in 1914). Thunderstorms account for approximately 41% of the average annual precipitation, and snowfall is 5% of the total. Precipitation during the months of April to September is normally 60% of the annual total. June is the wettest month and February the driest. The heaviest 24-hour rainfall on record is 4.76 inches on June 2, 1975. Thunderstorms occur on the average of 45 days of the year with hail occurring on 2 to 3 days, sleet on 6 days, and freezing rain on 4 days. Snowfalls of 1 inch or more in 24 hours normally occur 6 times a year. July is normally the warmest month and January the coldest. Temperature extremes on record are 113 degrees Fahrenheit on July 14, 1954, and -24 degrees Fahrenheit on February 13, 1905. The average growing season is 173 days from the last frost in late April to the first frost in mid-October. The average annual number of heating degree days from 1951 to 1980 was 5453. The average annual number of cooling degree days over the same period was 1175.

Physiography and Geology

The Upper Sangamon River and Lake Decatur are situated in the Till Plains section of the Central Lowland physiographic province, as shown in figure 3. The Till Plains section covers approximately 80% of Illinois and is generally characterized by broad till plains which are mostly in a youthful erosion stage, in contrast to the Dissected Till Plains on the older drift-sheets to the west as in eastern Iowa and extreme western Illinois. The Upper Sangamon watershed is located on the Bloomington Ridged Plain subdivision of the Till Plains section. The Bloomington Ridged Plain is characterized by low broad morainic ridges with intervening wide stretches of relatively flat or gently undulatory ground moraine (Leighton et al., 1948).

The Sangamon River Valley dates back to the Sangamon interglacial period which followed the Illinoian glaciers approximately 100,000 years ago. When the ice sheets of the Illinoian glacial epoch melted, they left behind a relatively flat ground moraine composed of clay till with scattered pebble and sand lenses. A relatively broad and shallow valley was carved into the ground moraine by the waters draining from the retreating ice and the newly exposed land surface (Leighton, 1923).

Figure 4 shows the valley strata as compiled from well borings and test pits made as part of engineering studies carried out before the Decatur dam was built. In this figure the bedding of glacial till, sand, and gravel can be seen. The strata shown in figure 4 are the end products of countless erosion and deposition cycles which alternately cut into and filled the valley. These cycles were the result of glacial processes which destroyed old drainage systems and reworked the regional topography.

The upper surface of the Illinoian till was shaped by the newly created Sangamon River. The river drained the retreating Illinoian ice front and carved the valley down into the till. Leighton (1923) found an old soil surface (6-8 inches deep) on top of Illinoian till, as well as oxidated and leached zones of till below. The soil surfaces indicate a relatively long period of exposure before burial by deposits from the next glacial period. Leighton interpreted the sand and gravel layers between the two tills, seen in figure 4, as the outwash deposits from the advancing ice front of the Wisconsinan glaciers.

The Wisconsinan period followed the Sangamon interglacial period. The ice sheets of the Wisconsinan glacier advanced out of the northeast as a result of climatic changes which cooled the region. The outwash deposits of the early Wisconsinan were overridden by the ice sheet. Later melting cycles eroded the outwash deposits and laid down unsorted till composed mostly of clay with some pebbles and boulders. The glacial till was deposited over most of the area that the ice sheet had occupied, leaving a flattened topography with the river valleys smoothed over. The Sangamon Valley was almost buried by the till of the Wisconsinan glaciers. As the ice front retreated to the northeast, meltwaters recarved the valley (Leighton, 1923).

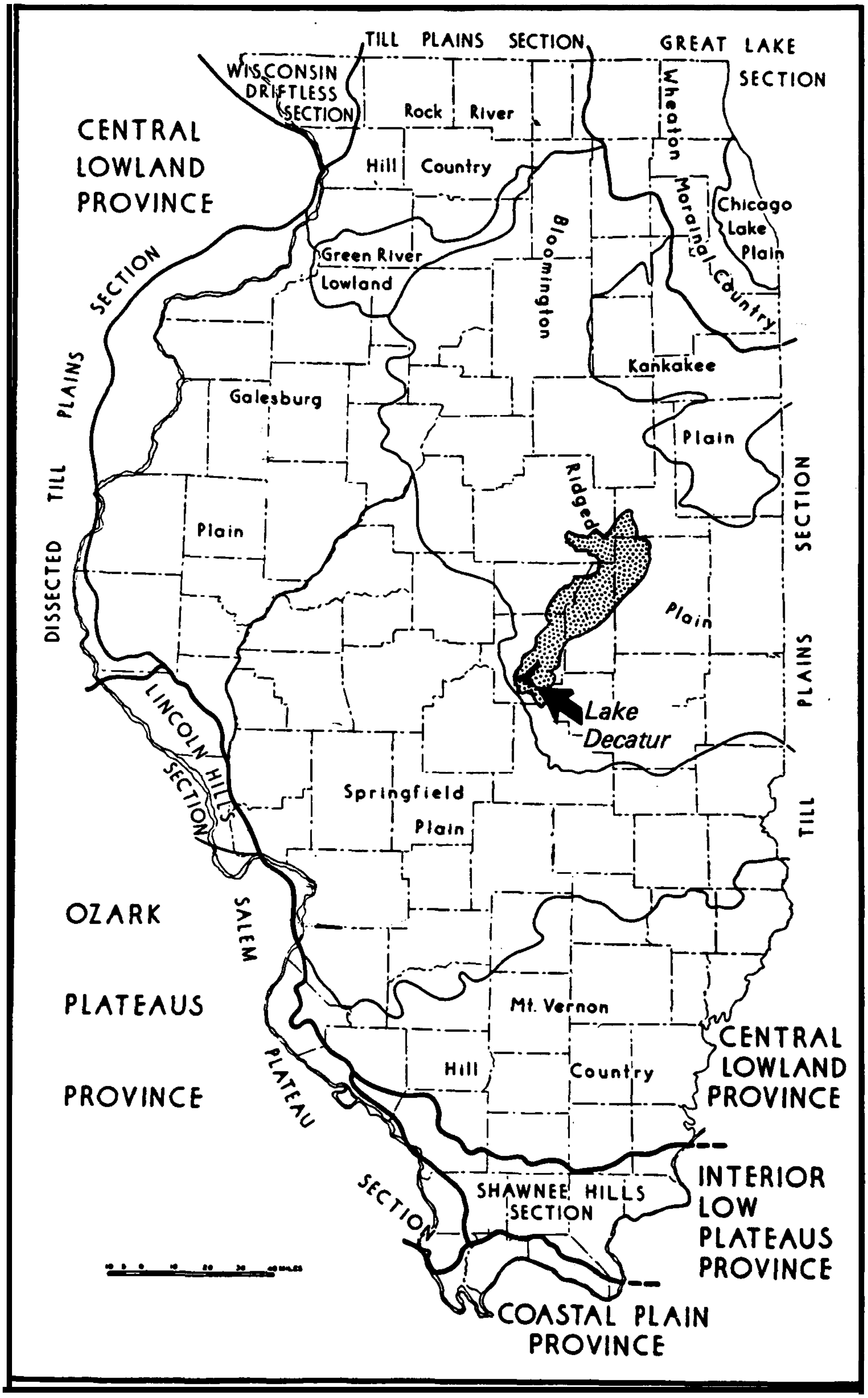


Figure 3. Physiographic divisions of Illinois

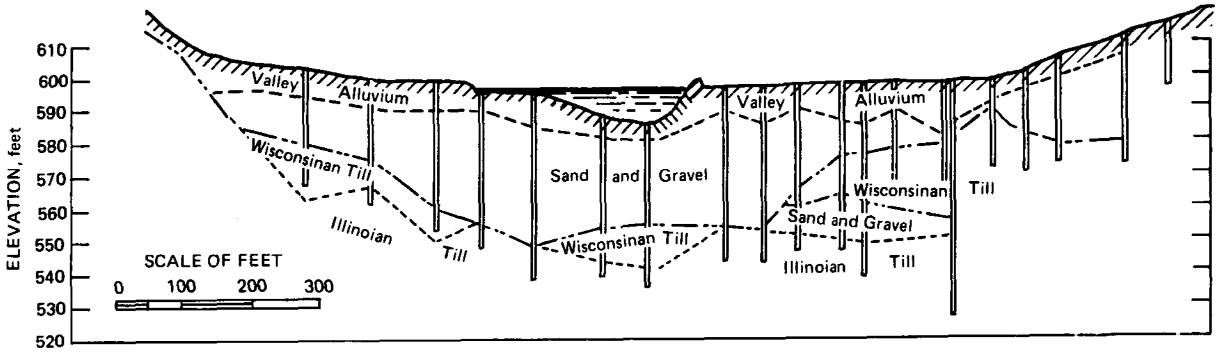


Figure 4. Stratigraphic cross section of the Sangamon River near Decatur

The discontinuous layers of Wisconsinan Till shown in figure 4 are the result of the erosion and downcutting of the post-Wisconsinan Sangamon River. The river cut the valley bottom to an elevation of approximately 540 feet, which was 50 feet deeper than the pre-dam valley. The extensive erosion and downcutting carved the valley to the level of the top of the till surface shown in figure 4. When the Wisconsinan glaciers retreated out of the watershed, the flow carried by the Sangamon River decreased; the river adjusted to the reduced flow by aggrading the valley floor. It deposited a large sand and gravel layer on top of the Wisconsinan till as shown in figure 4. Recent deposits of silt and clay were laid by the river on the floodplain between the valley walls, as indicated by the valley alluvium shown in figure 4.

At the end of the Wisconsinan period, approximately 10,000 years ago, the valley took on its present appearance. The valley averaged l/2 mile wide between the bluffs, and the floodplain was divided by the meandering course of the river. As can be seen in figure 5, the valley walls are composed of till of the Wedron and Glasford Formations (Bergstrom and Piskin, 1974). These tills are pebbly clay and were laid down by the Wisconsinan and Illinoian glaciers, respectively.

Pleistocene deposits above the bedrock range up to 300 feet thick and consist of till, sand, and gravel. Figure 5 shows the major Pleistocene formations: the Banner, Glasford, and Wedron, which resulted from the Kansan, Illinoian, and Wisconsinan glacial stages, respectively. These formations of pebbly clay till are interbedded with discontinuous layers of sand and gravel.

The major feature of the bedrock surface is an old valley which drained east-central Illinois prior to the glacial epochs. This valley is known as the Mahomet Valley and is located 200 - 300 feet below the current ground surface. The main valley lies in an east-west orientation, is approximately 8 miles wide, and passes under the central portion of the watershed, as shown in figure 5. The Mahomet Valley stretches across eastern Illinois from approximately Hoopeston in the east to Havana in the west. It was the course of a major river that had laid sand and gravel deposits across the floor of

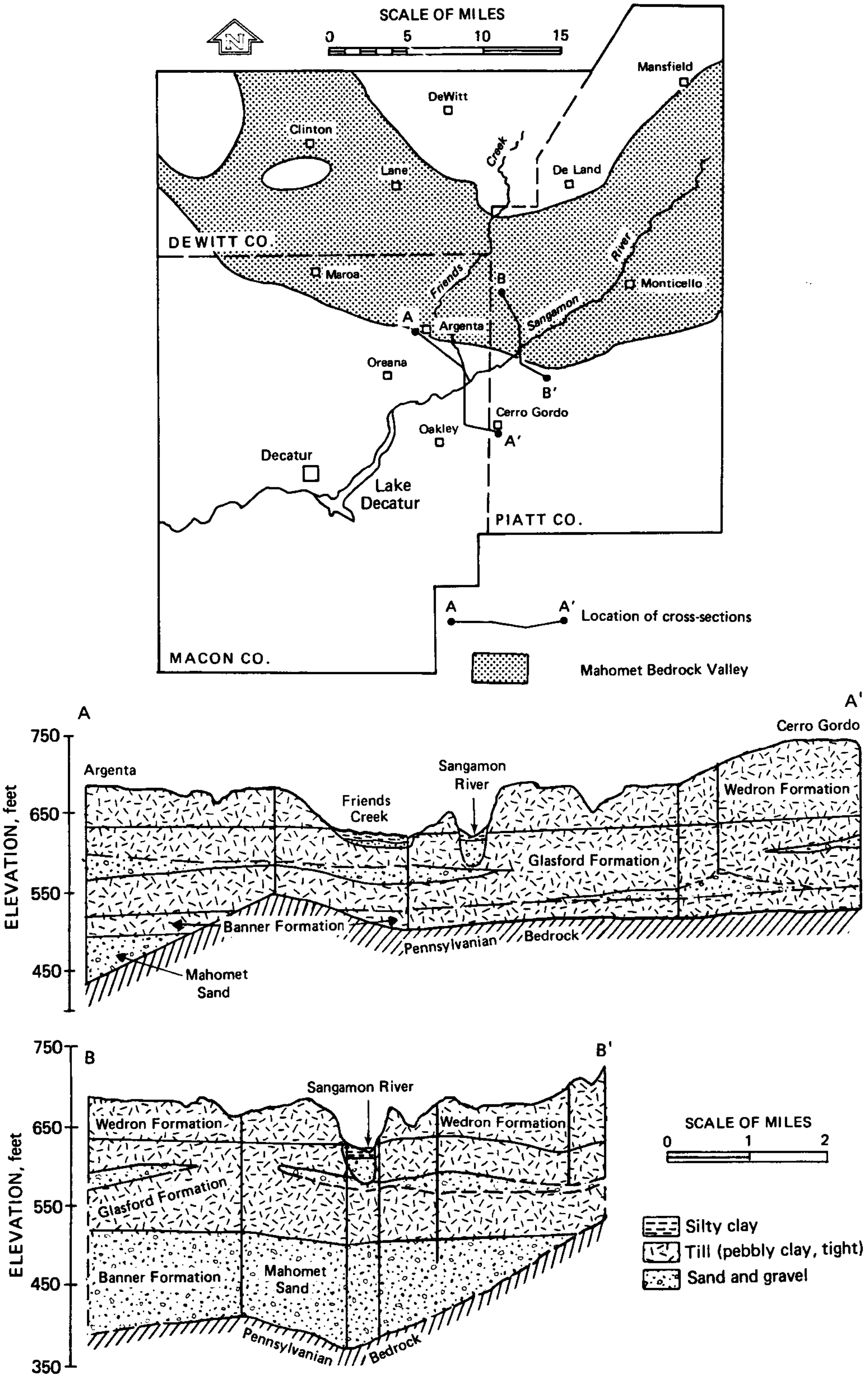


Figure 5. Geologic components of the Upper Sangamon River, showing the Mahomet Valley Aquifer

the old valley and is now buried beneath glacial till (Stephenson, 1966). The valley was filled and destroyed by glacial deposits starting with the Kansan glaciers approximately l/2 million years ago. These sands and gravels are now an important source of groundwater for the communities that overlie the buried valley.

The regional topography was also shaped by the glacial activity of the Pleistocene ice ages and by the streams that developed on the glacially deposited materials after the retreat of the ice sheets. Pleistocene and recent deposits consist of glacial till, wind-blown loess, and river deposits. Prominent large-scale features of the area are the roughly concentric moraines, shown in figure 6, which lie in a northwest to southeast orientation and include the Shelbyville, Cerro Gordo, Champaign, Leroy, Bloomington, and Normal Moraines.

The western boundary of the Lake Decatur/Upper Sangamon River watershed is the Shelbyville Moraine, which lies in a north-south orientation through Dewitt, Macon, and Shelby Counties . This moraine separates the surficial glacial deposits of the older Illinoian deposits to the south and west and the younger Wisconsinan deposits to the north and east.

Glacial deposits are relatively thick and completely conceal the underlying bedrock topography. Fluvial processes are responsible for the higher reliefs of the watershed. Steep slopes are found along the major streams of the watershed such as the Sangamon, Friends Creek, and Big Creek. These slopes are in contrast to the generally flat areas which make up the majority of the land surfaces.

The bedrock under the watershed is of Pennsylvanian age (310 - 280 million years old) through Macon, Piatt, and McLean Counties. Older strata lie beneath the glacial deposits in Champaign and Ford Counties in the eastern portion of the watershed. The bedrock of the western portion is the Pennsylvanian system which is characterized by thin layers of sandstone, limestone, shale, and coal of the Bond and Modesto Formations (Willman et al., 1967). These rocks were deposited in shallow continental seas which repeatedly inundated the region, and in the coastal swamps which occupied the area between the periods of inundation.

The bedrock of the eastern portion of the watershed ranges in age from Silurian to Pennsylvanian (approximately 435 to 280 million years old). The LaSalle anticline trending in a north-south direction has uplifted rocks as old as the Silurian in Champaign and Ford Counties. Under the thick blanket of Wisconsinan glacial till and moraines the dominant rock types are the Silurian dolomites and Devonian limestones in southern Ford and northwestern Champaign Counties. Younger formations that contribute to the bedrock surface in the two counties are the Mississippian limestones and shales of the Kinderhookian and Valmeyerian Formations, and the Pennsylvanian limestone, shale, and coal measures of the Spoon, Carbondale, and Modesto Formations (Willman et al., 1967).

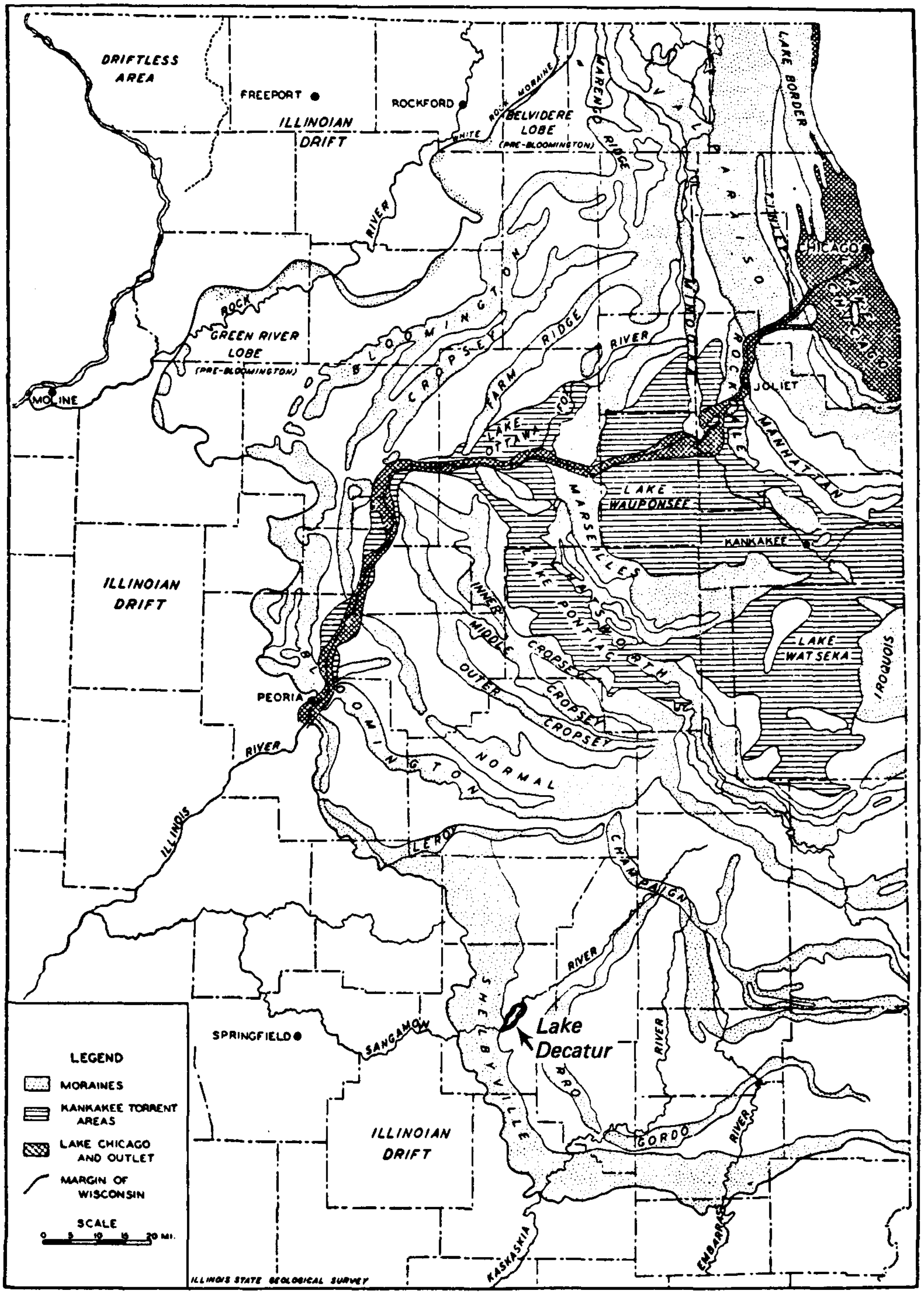


Figure 6. Surficial deposits of northern Illinois

Soils

The Upper Sangamon watershed has been divided into five types of soil areas by the Soil Conservation Service (1983) to delineate the major soil environments. The areal distribution of the major soil types is shown in figure 7. The soil areas are described as follows:

Area 1 - This area, which is the largest of the areas, covers 59% of the watershed and contains the most productive soils of the watershed. This area groups together the nearly level prairie soils that formed in 40 to greater than 60 inches of loess and the loam of glacial till on the uplands. Major soils are the poorly drained Drummer and Sable silty clay loams and the somewhat poorly drained Flanagan and Ipava silt loams. These soils have a high organic content and a high resistance to drought. They are very fertile and are the highest producing soils of the watershed. For this reason area 1 is used mostly for row crops.

Area 2 - This area encompasses 12% of the watershed and consists of nearly level to sloping prairie soils that were formed in less than 20 inches of loess and the silty clay loam glacial till on the uplands. Soil groups of this area are the Vanna silt loam on the slopes up to 12% and the Elliott silt loam and Ashkum silty clay loam on the flat areas. Most of the area is devoted to cultivated crops although the productivity is not as high as in area 1.

Area 3 - This area encompasses the forest soils formed on the uplands in loess and loam glacial till of less than 40 inches. Area 3 covers 13% of the watershed. Major soil types are the Birkbeck and Xenia silt loams on 2 to 5% slopes and the Russell and Miami silt loams on 2 to 25% slopes. Most of this area is used for cultivated crops although these are the least productive soils of the watershed.

Area 4 - Major soils of this area are the Brenton and Elburn silt loams and the Drummer silty clay loam. These soils formed in 24 to 60 inches of loess underlain by sand and gravel on stream terraces. Most of the area is level and is used for cultivated crops. Productivity is high and similar to that of area 1. Area 4 covers 13% of the total watershed.

Area 5 - This area consists of level, dark colored soils on floodplains. Major soils are the Sawmill and Colo silty clay loam and the Lawson and Ross silt loam. These soils were formed in the alluvial deposits of floodplains and are very fertile and productive. Most of this area is used for pasture, hay, and woodlands, with smaller areas used for cultivated crops. This area covers less than 3% of the watershed.

Agricultural Land Use

Row crops are the largest land use in the Upper Sangamon/Lake Decatur watershed, covering approximately 87% of the total area in 1982 (Soil Conservation Service, 1983). Historically the watershed has shown a trend towards increasing row crop acreage, as can be seen in figure 8, which shows

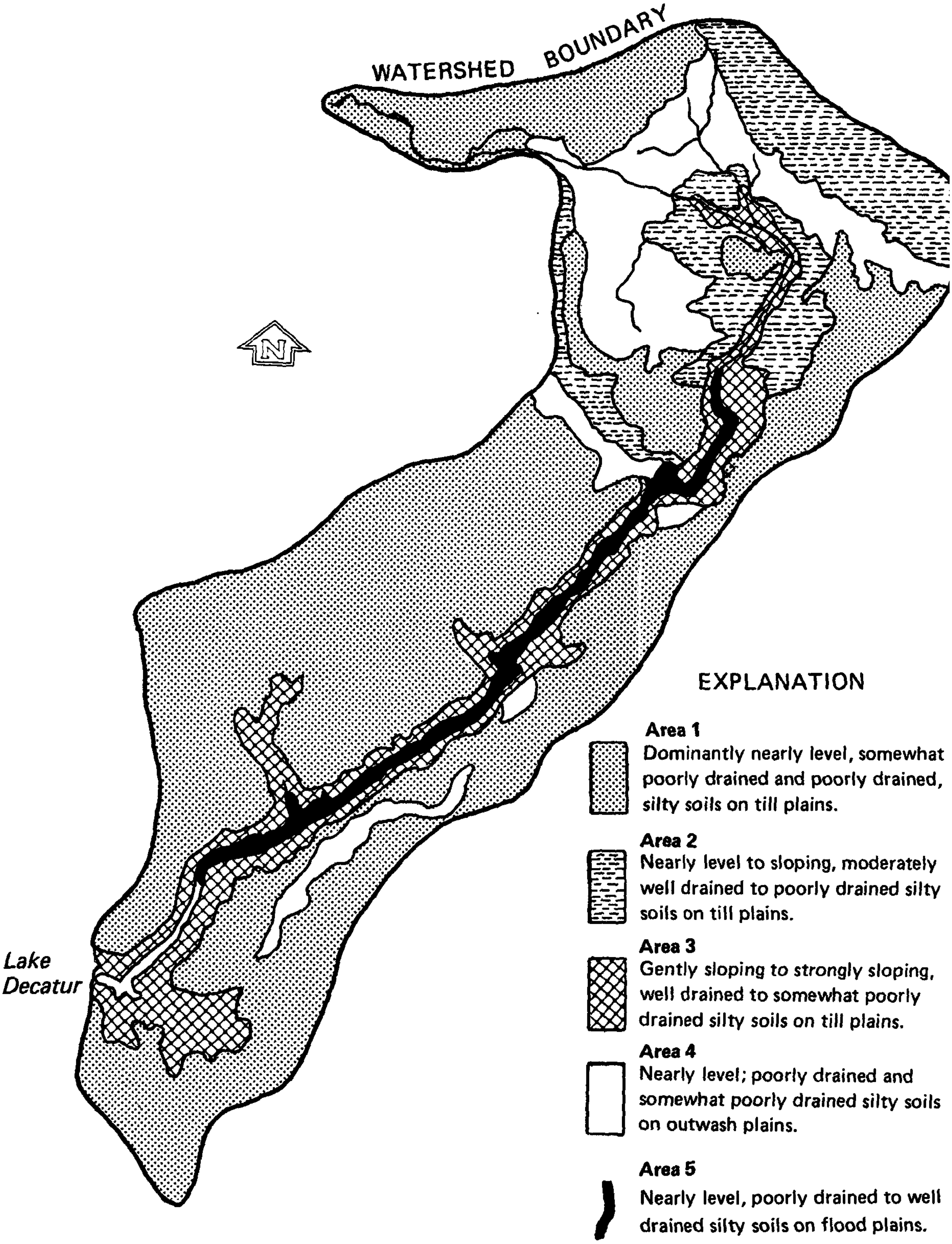


Figure 7. Major soil types of the Upper Sangamon River watershed

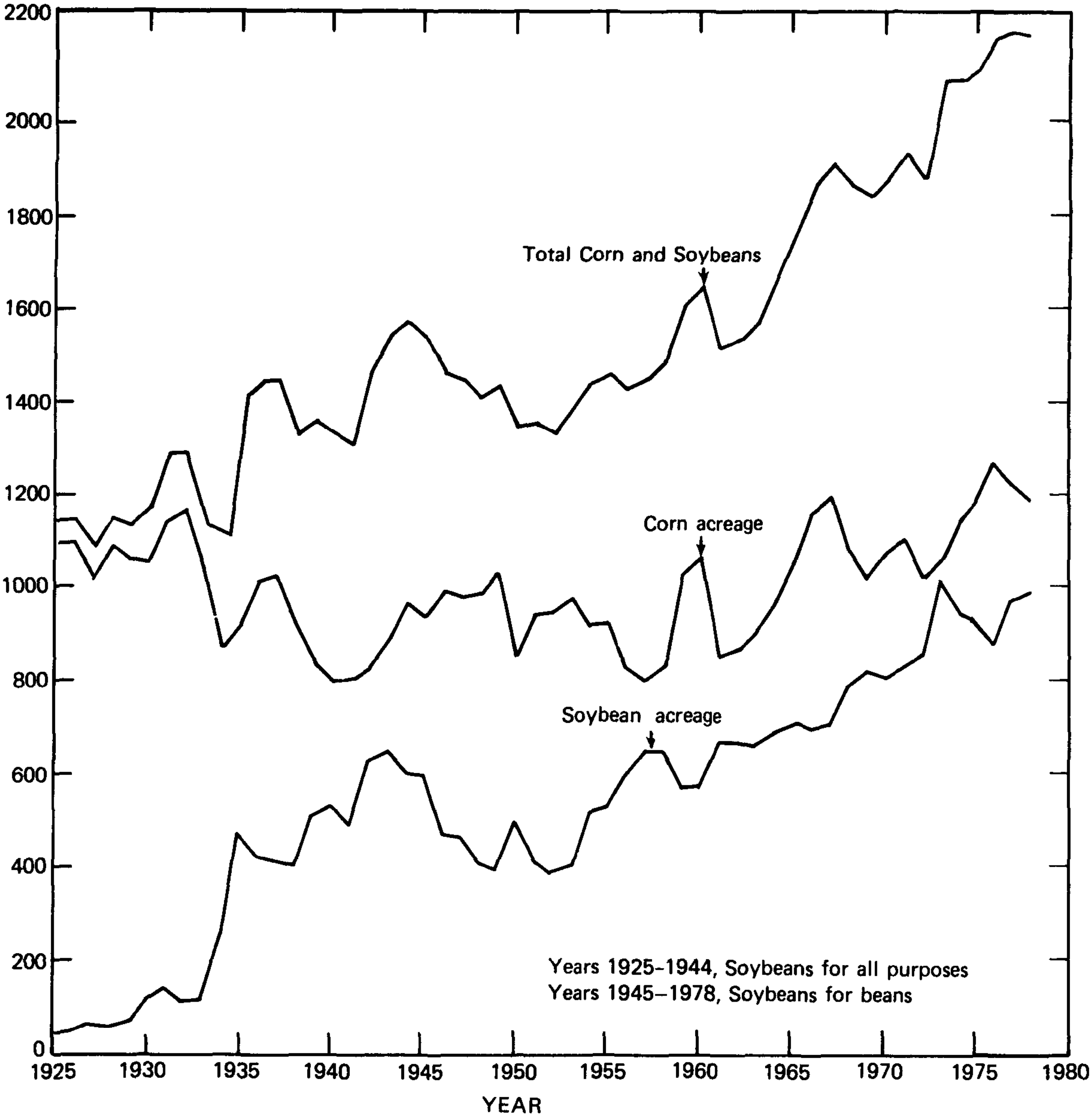


Figure 8. Row crop production (corn and soybeans) in *the Upper* Sangamon *River watershed*

the acreage devoted to corn and soybeans in the six major counties of the watershed (Macon, Piatt, Dewitt, McLean, Ford, and Champaign Counties). The data presented in figure 8 were compiled from publications of the Illinois Cooperative crop reporting service. Row crops covered over one million more acres in 1978 than they did in 1925, a total increase of over 91% or an average annual increase of 1.7%. Major increases in total corn and soybean acreage occurred in the years 1927-1937, 1941-1944, 1952-1960, 1961-1967, and 1972-1978. Soybeans showed a relatively consistent trend overall towards increasing acreage with the exception of a 200,000-acre decline in the late 1940s and early 1950s. The early 1930s (1933-1935) showed an abrupt increase in soybean acreage of 350,000 acres. Corn plantings peaked in 1932 at 1,174,000 acres, a number not reached again until 1967. The largest rates of increase in the total acreage given to corn and soybeans occurred in the mid-1930s, early 1940s, mid-1960s, and early 1970s.

To assess the effects of land use trends on the sedimentation of Lake Decatur, the yearly total acreage in corn and soybeans was computed for the time periods prior to the last five sedimentation surveys of the lake. The totals are presented in table 1. The lake sedimentation surveys will be described later.

From table 1 it is seen that the largest increase in corn and soybean acreage occurred during lake survey period 5 (1967-1983) as represented by the acreage values for this period up to 1978, the last available data. Period 2 (1937-1946) showed the second largest percentage increase in total acreage for corn and soybeans. The only period with a decrease in the total acreage given to these crops was period 3 (1947-1956), which showed a slight decrease of about 30,000 acres.

Historical events help to explain the overall changes in land use in the watershed. Period 1 (1925-1936) showed an increase of nearly 6% in corn and soybean acreage, which was expected considering that soybeans had recently been introduced to the area and provided an attractive new cash crop during the depression era. Period 2 (1937-1946) included the years of World War II and the resulting efforts of farm operators to increase production of food, fiber, and oil crops. An examination of figure 8 shows an increase in both corn and soybean acreage between the years 1941-1944. Following 1944, acreage of both crops decreased, more dramatically for soybeans than for corn. Period 3 (1947-1956) shows a decrease in total acreage for the first six years and an increase in the last four years, primarily due to increased soybean plantings. Period 4 (1957-1966) and period 5 (1967-1978) both show

Table 1. Six-County[1] Acreage in Corn and Soybeans Averaged per Year over Survey Periods

Sedimentation survey period	Years	Average yearly total corn and soybeans (acres/year)	Percent increase over previous period
1	1925-1936	1,215,600	+5.7*
2	1937-1946	1,444,290	+18.8
3	1947-1956	1,413,360	-2.1
4	1957-1966	1,620,430	+14.7
5	1967-1978	2,026,675	+25.1

* Compared with 1925 total of 1,149,700 acres

[1] Macon, Piatt, Dewitt, McLean, Ford, and Champaign Counties

an overall trend toward increased plantings in both crops. These years were not only periods of increasing row crop acreage but also periods of dramatic increases in yields for both crops. Average yields for corn and soybeans were 73 and 31 bushels per acre respectively in 1957. Yields in 1978 averaged 126 and 39 bushels per acre for corn and soybeans respectively (Illinois Cooperative Crop Reporting Service).

Erosion and Conservation

Gross Erosion Rates

Gross erosion rates are an estimate of the soil loss in a watershed. Their purpose is to quantify the degradation of agricultural lands and to serve as a tool in planning land management strategies. Gross erosion rates are useful in assessing the magnitude of problem areas, i.e., the proportion of a watershed that may be eroding beyond its capacity to regenerate.

Gross erosion values do not predict the amount of sediment leaving a watershed. The quantity of sediment leaving a watershed is known as the sediment yield. Due to the very complex interaction of erosion, transport, and deposition processes, only a portion of the total eroded sediment actually is transported out of a watershed. The ratio of sediment yield to gross erosion is the sediment delivery ratio. This value will be discussed in the section, "Delivery Ratio, Sediment Yield, and Trap Efficiency."

An erosion assessment made by the Soil Conservation Service for the Lake Decatur watershed indicated that the most significant source of sediment in the watershed is sheet and rill erosion. It has been estimated that 93% of the total erosion in the watershed is from this source (Soil Conservation Service, 1983). The areas of highest erosion are located along the outer boundaries of the watershed and along the streams where the steepest slopes are found. Croplands make up 88% of the total watershed area and contribute 98% of the sheet and rill erosion (table 2). Critical areas, those having annual gross erosion greater than 10 tons/acre, make up only 6% of the watershed area but contribute 23% of the total sheet and rill erosion. In contrast, the areas devoted to pasture, woodland, and miscellaneous uses make up 12% of the watershed area and contribute less than 2% of the total sheet and rill erosion. It has been estimated that 166,200 acres of cropland (28% of the total) are eroding at rates in excess of the annual soil tolerance level of 5 tons per acre (Soil Conservation Service, 1983). Channel and gully erosion have been estimated at 185,000 tons of sediment per year. Total gross erosion including channel, gully, sheet, and rill erosion from this watershed amounts to 2,646,000 tons per year.

Table 3 presents a summary of the estimated gross erosion by regional source areas for 1983 in the Lake Decatur watershed as compiled by the Soil Conservation Service (1983). From this table it can be seen that for all areas listed the average annual gross erosion rates are within the range of 4 to 5 tons per acre. These per-area erosion rates are similar; however, the impacts of the different areas on the rate of sedimentation in Lake Decatur are very dissimilar. The section "Sources of Sediment to Lake Decatur" will delineate the per-area impact of each of these source areas.

Table 2. Sheet and Rill Erosion Sources by Land Use for the Upper Sangamon River Watershed
(Soil Conservation Service, 1983)

	Total acres	Total tons	% of tonnage	Average (tons/acre)	% of total acreage
Cropland 0-5 tons/acre/yr	349,600	966,100	39	2.76	60
Cropland 5-10 tons/acre/yr	128,900	879,300	36	6.82	22
Cropland 10+ tons/acre/yr	37,300	576,300	23	15.45	6
Pasture	23,100	16,300	0.6	0.71	4
Woodland	20,800	15,800	0.6	0.76	3
Miscellaneous	27,800	6,800	0.3	0.25	5
Total		2,460,600			

Table 3. Erosion Source by Watersheds
(Soil Conservation Service, 1983)

Source	Area in acres	% total area	Gross erosion (tons)	Average gross erosion (tons/acre/yr)
Total watershed	593,400	100.0	2,645,840	4.5
Sangamon River above Monticello	352,000	59.3	1,540,740	4.4
Sangamon River below Monticello	241,514	40.7	1,105,100	4.6
Main stem*	149,244	25.2	690,250	4.6
Bluff watersheds	37,960	6.4	155,510	4.1
Big and Sand Creeks	54,400	9.2	259,250	4.8

*Main stem of Sangamon River between Monticello and 13.5 miles above city dam, including Friends Creek

Conservation Efforts

Conservation efforts in the watershed have been credited with reducing the rate of sedimentation in Lake Decatur (ISWS, 1957). This is a difficult parameter to quantify in the study of watershed erosion and lake sedimentation. It is impossible to document all the conservation efforts of the past or present, since the individual efforts of landowners and operators have not usually been recorded over the years. However, this section outlines some of the large-scale efforts undertaken towards soil conservation.

Soil and water conservation districts were first organized in the 1930s. One of the first efforts was the Erosion Control Demonstration Project in McLean County, established in 1933 by the Soil Conservation Service in cooperation with the University of Illinois. This project was successful in demonstrating effective methods of soil conservation and became a forerunner of future conservation districts. The information presented here on the conservation districts of the 1930s and 1940s is summarized from Brown et al. (1947).

In the early 1940s conservation districts were established in all the counties of the watershed. By 1946, 87% of the watershed was included in organized districts. These districts were formed to provide technical, educational, and financial assistance to local landowners for the purpose of maintaining the productivity of the soil and reducing the denudation of farmland. Assistance to the districts in the watershed was provided by a variety of sources including the City of Decatur, the University of Illinois, the USDA, and others. Initially, progress was slow. In 1946 307 farms had formulated complete conservation plans with about one-half of the plans implemented. The new practices covered approximately 2% of the watershed and included activities such as contour plowing, terracing, waterways, and diversions.

The Soil Conservation Service (1983) reported that in 1982 conservation practices were needed on 47% of the watershed in order to reduce all gross erosion values to below 5 tons per acre per year. This acreage included 19% of the watershed area on which gross erosion values were already below the 5 tons per acre standard but which were interspersed with acreage that did not meet the standards. This indicates that a great deal of work remains to be done in soil conservation activities.

If all the proposed conservation practices were implemented, the SCS estimates that the gross erosion in the watershed would be reduced by 35% (Soil Conservation Service, 1983). One method of reducing erosion is conservation tillage. Fields planted in continuous corn and managed with conservation tillage showed soil losses 58% less than fields with conventional tillage in Missouri claypan soil (Burwell and Kramer, 1983).

General statistics on conservation tillage compiled from No-Till Farmer magazine’s annual acreage survey show that in the years 1973 through 1981 there was a 133% increase in acreage planted with minimum tillage, a 6% increase for no-till, and an 11% decrease in conventional tillage for the “corn belt” states of Illinois, Indiana, Iowa, Missouri, and Ohio (Christensen and Magleby, 1983). In 1981 conservation tillage methods were used on 1/3 of the harvested cropland in the "corn belt" (Moldenhauer et al., 1983). These statistics indicate that farm operations are accepting and applying new technologies and methods for the reduction of soil erosion.

Sangamon River

The Sangamon River drains 925 square miles of watershed upstream of the dam at Lake Decatur. The river empties into Lake Decatur and resupplies the water storage of the reservoir. Excess water delivered to the lake passes over the dam and is carried downstream by the river channel below the dam.

The Sangamon River is a meandering stream approximately 100 feet in width and 5- to 10-feet deep. The river flows over alluvial deposits laid by the river in a valley 1/2 mile wide. The main stem of the river flows 241 miles from its headwater near Ellsworth in McLean County to the Decatur Dam. The river slope is 1.7 feet per mile and has a total fall of 420 feet.

The sediment load of the river is predominantly silt and clay; however, throughout most of its length the river bed is composed of sand and gravel. Annually the river and its tributaries deliver approximately 200,000 tons of sediment to Lake Decatur.

The flow of the Sangamon River is monitored by the U.S. Geological Survey at a gaging station located in the City of Monticello, as shown in figure 1. This station is approximately 25 miles upstream of the city dam and monitors the drainage from 59% of the total watershed of Lake Decatur. The station at Monticello has a period of record extending back to 1915. Another gaging station also operated by the USGS is located near the town of Oakley. This station has a period of record extending back to 1951. Complete records were kept for the years 1951 to 1956. Since 1956 the record has been maintained during high flows. The Oakley station is located approximately 13.5 miles upstream of the dam at Decatur and monitors the drainage from 84% of the total watershed.

The flow analysis that follows was performed for the records from the Monticello station. An analysis was not performed for the records from the Oakley station because the length and detail of the records from Oakley are not as extensive and the Oakley station is located in the backwater of the lake during elevated flow on the Sangamon River.

Average Discharge

The average volume of flow or discharge at Monticello is 406 cubic feet per second (cfs) or 260 MGD. This is determined by dividing the total quantity of water that has flowed past the Monticello station by the total period of record. The discharge computed on an annual basis is presented in figure 9. From figure 9 it can be seen that the annual discharge varies considerably from a maximum of 1105 cfs (714 MGD) in 1927 to a low of 68 cfs (44 MGD) in 1934.

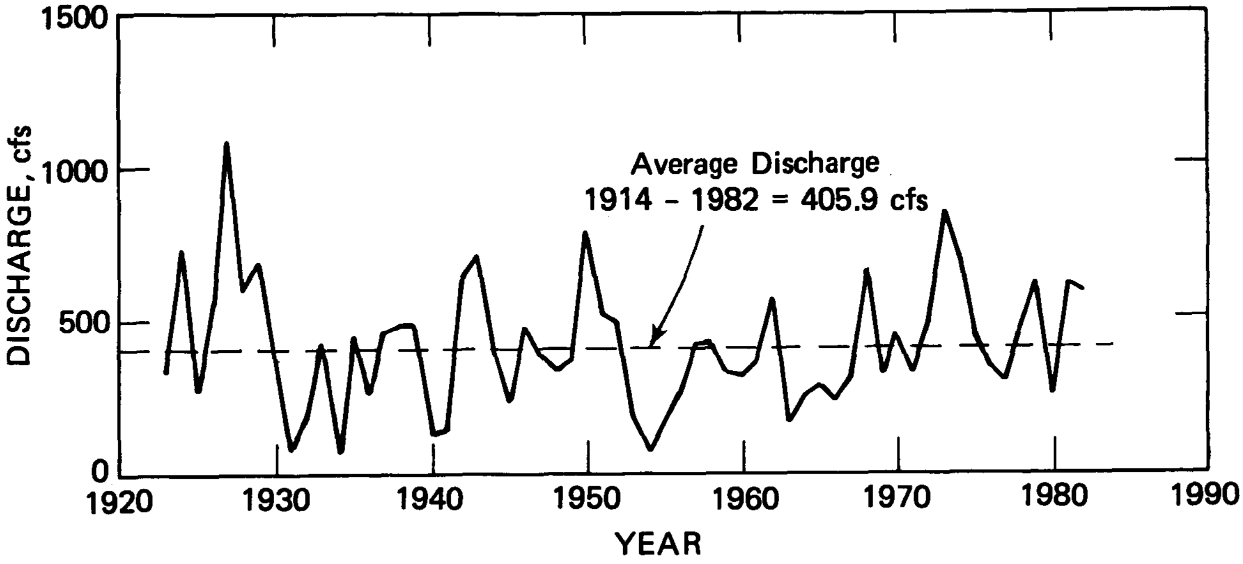


Figure 9. Average annual discharge of the Sangamon River at Monticello

An average annual discharge of 406 cfs is the equivalent of 10 inches of water from the watershed area. The long-term average annual precipitation is 39 inches; therefore, the Sangamon River drains 26% of the precipitation falling on the watershed. The remaining 74% of the average annual precipitation is used by plants and animals, is lost to evaporation, or infiltrates into ground-water aquifers.

High and Low Flows

The peak and lowest flows measured for each year at the Monticello station are presented in figure 10. The low flow record shown in figure 10a points up the need for a water storage reservoir at Decatur. The current daily demand for water at Decatur is approximately 18 MGD. If the daily demand is scaled down to the proportion of the total watershed area monitored at Monticello, it becomes 10.6 MGD or 16 cfs. From figure 10 it can be seen that the low flow of the river would have provided a sufficient quantity of water to meet the daily demands of the City of Decatur in only 11 of the 61 years of record.

The high flow record at Monticello presented in figure 10b shows the peak flow for each year of record. The years of major floods are shown by the larger peaks of the graph. A flood frequency analysis of the annual peak floods was performed for the Sangamon River at Monticello using methods prescribed by the U.S. Water Resources Council (USWRC, 1976). The results of this analysis, presented in figure 11, indicate that the 100-year recurrence interval discharge is 20,200 cfs. The maximum recorded discharge for the

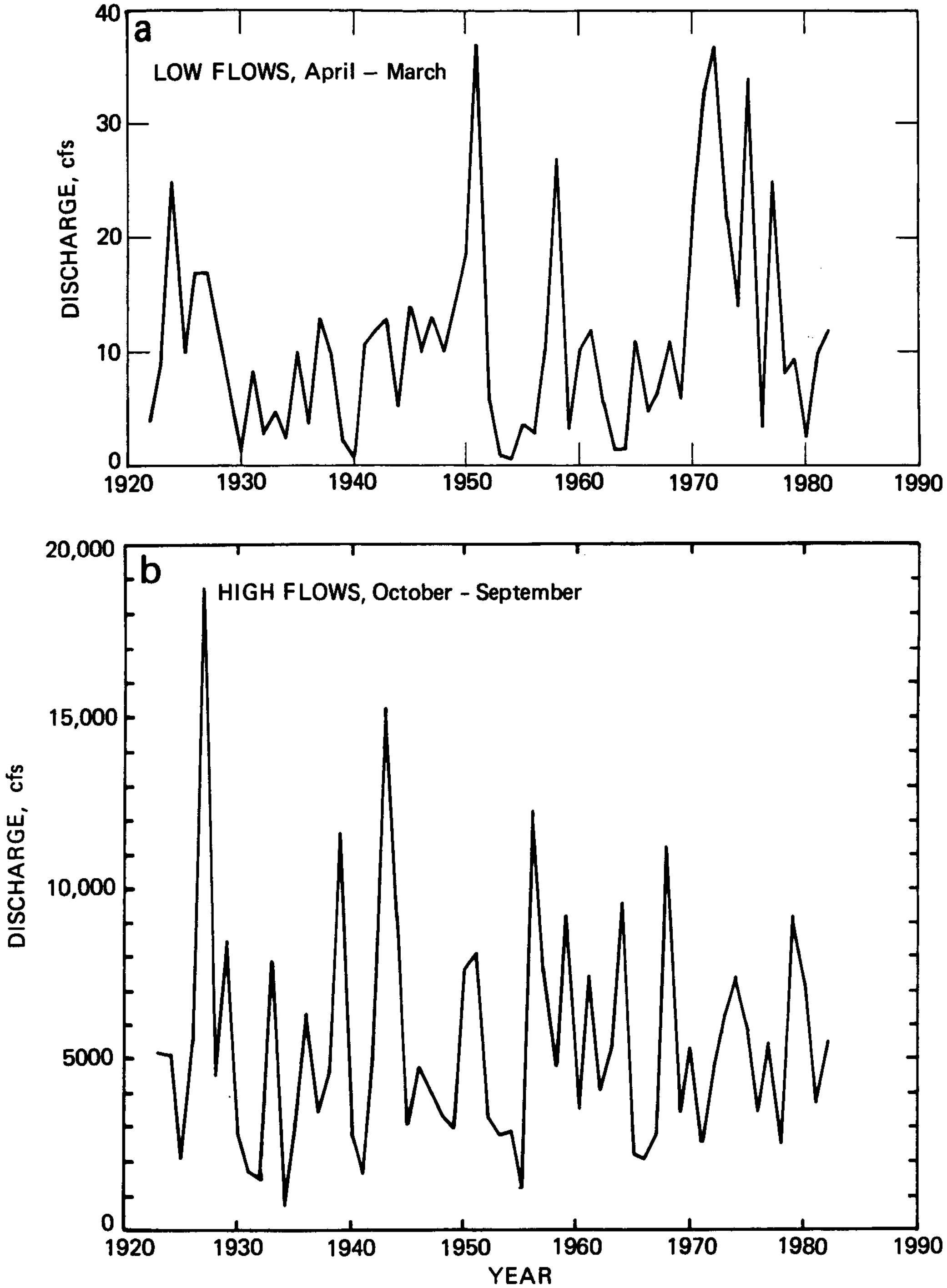


Figure 10. High and low flows for the Sangamon River at Monticello

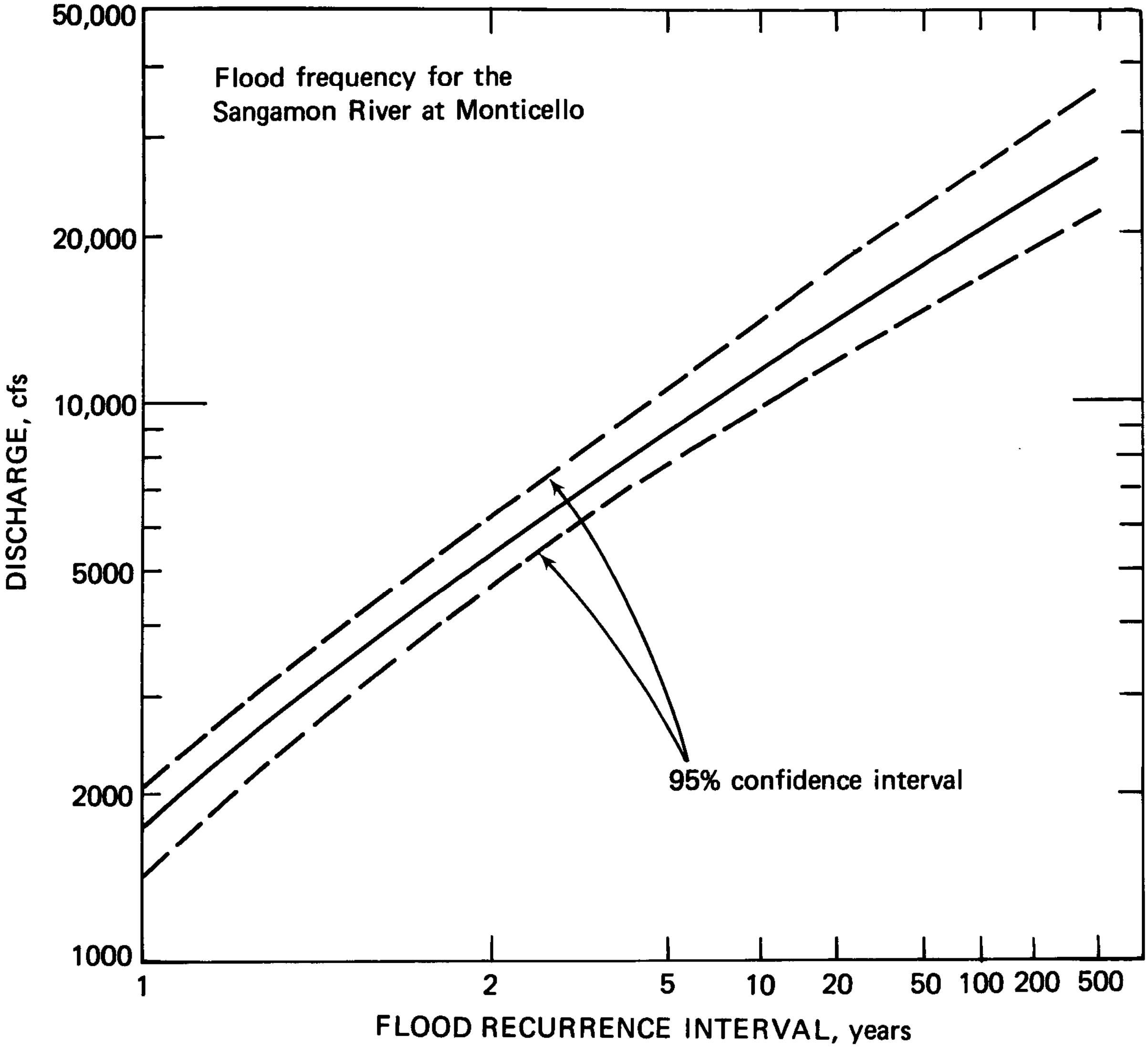


Figure 11. Flood recurrence interval for the Sangamon River at Monticello

Sangamon River at Monticello was 18,700 cfs on October 4, 1926. This value corresponds to a recurrence interval of 65 years.

The peak flow record was compared with Lake Decatur's sedimentation record in order to examine the correlation of these parameters. The results of this comparison are presented in the section "Factors Influencing the Variability of Sedimentation Rates in Lake Decatur."

PRE-1983 SURVEYS, METHODS, AND RESULTS

The study of reservoir sedimentation is an examination of the changes over time in the accumulation of sediment and the aggradation of the lake bed. An important factor in this study is a comparison of past survey results with results of the present survey to assess the quantitative change in the sedimentation rates of the lake. A total of seven lake sedimentation surveys including the present one are described. The results presented in this section are those reported in the original survey reports. Where results differ from those in the presentation of the 1983 results, they represent either minor computational differences or errors in the presentation of the earlier results. In all cases, the 1983 results supersede earlier reports.

1930 Reconnaissance Survey

The City of Decatur recognized in the late 1920s that their new lake was being reduced in size due to sedimentation. A preliminary study of the rate of sedimentation and bank erosion was carried out in 1930, under the direction of F. L. Washburn, Engineer for Macon County. The results showed sedimentation averaging 1 to 2 feet in Sand Creek and the upper reaches of the main lake above Rea's Bridge. Several small bays and inlets had been filled with sediment, and bank erosion had removed up to 35 feet of shoreline in some areas.

1931-1932 Survey

The findings of the 1930 survey led the Illinois State Water Survey in cooperation with the Decatur Water Supply Company to begin a more thorough study of sedimentation in the lake in 1931-1932. The purpose of this new study was to determine the 1931-1932 elevations of the lake bed and then to resurvey in a few years to determine the rate of sedimentation based on the changes in elevation and volume over the time interval. Prior to 1931 no topographic map or cross sections of sufficient precision were available to allow the direct determination of the sedimentation rates in the flooded valley. The largest-scale map made of the river valley prior to lake construction was the 1918 “Topographical Map of the Valley of the Sangamon River from Illinois Traction System Bridge to Illinois Central Railroad Bridge for the City of Decatur, Illinois" by P. T. Hicks, Consulting Engineer , shown in figure 2. The contour interval of 5 feet and the scale of 1 inch to 600 feet were not of sufficient precision to allow direct calculation of sedimentation rates. As a result, during the 1931-1932 survey, benchmark ranges were established that could be used in the future for comparison of the changes in lake bed elevations.

In the 1931-1932 survey, 55 ranges were established across the lake for the measurement of sediment accumulations and water depths. The range ends on shore were marked with concrete monuments or iron pipes for the purpose of accurate relocation for future surveys. One emphasis of the 1931-1932 survey was to assess the effects of the bridge crossings on the hydraulics of flow and the sedimentation pattern within the lake. Twenty ranges were established within a distance of 1/2 mile around the railroad bridges south of Faries Park. Fifteen ranges were located within a distance of 1/3 mile near Rea's Bridge. Other areas of emphasis were the Staley and Sand Creek Bridges. In areas away from the bridge crossings the ranges were spaced at intervals of 3/4 to 1 -1/4 miles.

In the 1931-1932 survey, the sounding boat was positioned along the range line using a cable. A steel cable was fastened on shore at both ends of the range line, and the horizontal distance across the lake was measured using floats attached to the cable at 5-foot intervals. Soundings were made using a 1-pound sounding lead 5 inches in diameter, which was suspended on a wire.

Sediment measurement procedures for the 1931-1932 survey were described as follows by Glymph and Jones (1937):

> Silt depths were determined with a special silt sampler, consisting of a 3-foot length of thin iron tubing, 4 inches in diameter, and closed at the upper end. This was lowered to the lake bottom by attaching successive sections of threaded iron pipe. Samples were obtained by forcing the tube solidly into the bottom sediment. If the silt was penetrated and the subsilt material was sufficiently coherent to seal the bottom of the tube, a complete section or core of the sediment was obtained. A number of slots one-half inch wide and five inches long in the walls of the tube permitted inspection of the sample at any level.

In the 1931-1932 survey, silt measurements were made only in the upper part of the lake above the William Street Bridge and near the mouths of Sand and Big Creeks. Silt measurements were not made in the old river channel because the sediment depth exceeded the length of the sampler.

The results of the 1931-1932 survey showed no unusual delta deposits on the upper end of the lake; however, both Sand and Big Creeks had small deltas. The absence of a delta on the Sangamon was attributed to the fine silts and clay carried by that river which are held in suspension by the incoming water well into the lake. The maximum sediment deposits of 4 feet were found in the old river channel above Rea's Bridge. Deposits in the lake averaged approximately 1 to 2 feet on the old floodplain above Rea's Bridge. Below Rea's Bridge, the deposits were difficult to measure due to the depth limitations of the core sampler. Since the sampler operated in water depths of less than 12 feet, no estimate of the sediment depth below Rea's Bridge was made (Gerber, 1932).

The results of the 1931-1932 survey were not published; however, the findings of the investigators did help to outline the need for a more intensive assessment of the problem.

1936 Survey

A resurvey of the lake was performed in 1936. The emphasis of this survey was to map the total sediment in the lake by determining the original valley depth and the 1936 lake bed depth across each range line.

The 1936 survey was performed under a cooperative agreement between the Water Survey and the Illinois Agricultural Experiment Station under the direction of Louis M. Glymph, Jr., and Victor H. Jones.

A spud bar was used to measure the depth of the deposited sediment below the current lake bed. The spud bar is a steel rod with triangular grooves machined at 0.1-foot intervals, forming a series of cups opening upward along the length of the bar. The cups open to the top of the bar, allowing the bar to penetrate the sediment easily. The bar is dropped vertically through the water and into the sediment and old soil of the valley. Each cup on the spud bar retains a sample of the sediment at the point of maximum penetration, i.e., the cups grab a sample when the direction of travel of the bar is reversed and the sampler is pulled out of the lake bed.

When the spud bar is retrieved from the lake bed, the sample cups are examined for texture differences which indicate the old soil of the valley. Root zones, coarser particles, and color differences identify the old valley bottom. The depth and elevation of the old soil is determined by measuring the distance along the spud bar between the top of the current lake bed and the first sample of the old soil. The depth measured by the spud bar is subtracted from the lake bed elevation to determine the elevation of the old valley.

The 1936 survey established 14 special shore-line ranges to study the importance of bank erosion in reservoir sedimentation. In addition, 13 end sections of regular ranges were measured in detail to establish the shore profile. This survey also used the range-line method. Forty-nine ranges were used, of which 24 had been established previously for the survey of 1931-1932 (Glymph and Jones, 1937).

In 1936 the sounding boat was positioned in the lake using a cut-in method of range-line intersection employing a plane table and alidade. Where it was impractical to establish plane table stations for positioning the boat, the cable method was used. Soundings were made using a 5-pound aluminum bell-shaped sounding weight with a base diameter of 5 inches and a height of approximately 6 inches. This sounding bell was developed by the Soil Conservation Service and was calibrated with the sounding weight used in the 1931-1932 survey.

Sounding stations along the range lines were generally 50 feet apart. At every third station, sediment depth was measured using the spud bar or core sampler. The core sampler used in 1931-1932 was used for this survey in areas where the water depth was less than 12 feet and the sediment thickness was less than 3 feet. In areas of deep water and/or thick sediment a spud bar was used to sample the lake bed and determine the original valley elevation.

Cross sections of the lake were plotted showing the original valley elevations, the 1931-1932 lake bed, and the 1936 lake bed. The plotted cross sections were planimetered to determine the cross-sectional areas of the water and sediment for each survey. The cross-sectional areas were combined with planimetered segment surface areas and entered into the prismoidal formula (as will be described in the analysis of the 1983 survey) to yield segment volumes of the lake for the original, 1931-1932, and 1936 conditions. No estimate of the weight of sediment was made in 1936.

The preliminary results of the 1936 survey were published by the USDA, Soil Conservation Service (Glymph and Jones, 1937). The authors determined a rate of volume loss in the reservoir of 1.0% per year. The sediment tended to accumulate in the deeper and quieter portions of the lake, especially in the old river channel through the main lake. The upstream portion of the lake showed no typical delta deposits and the river channel was free of accumulated sediment. The authors attributed this to the uniformly fine sediment washed into the lake by the Sangamon River. Smaller side channels and backwater areas on the upstream end of the lake were noted to have accumulated as much as 4 feet of sediment.

Bank erosion was recognized to be a contributing factor in reservoir sedimentation, but estimates of the amount of sediment from bank erosion were not made.

1946 Survey

In 1946, 39 of the 49 sedimentation ranges used during the 1936 survey were resurveyed by the Water Survey. The ranges omitted in 1946 were the extreme upstream ranges on the Sangamon River, the Big Creek tributary, and the Sand Creek tributary. An examination of these ranges in 1946 indicated that no sediment deposition had occurred there due to the scouring action of the inflowing streams. In these upper reaches, the lake is confined to the old stream channel with no overbank floodplain flow.

The 1946 survey used the same survey methods as the 1936 survey. The sounding boat was positioned in the cross section using a cut-in method of positioning by employing a plane table - alidade system. Depth measurements were made using a cast aluminum sounding weight.

Lake sedimentation rates are determined by comparing the original lake bed elevations with the present sediment surface. During the 1946 survey, selected points were measured for comparison with the original elevations as measured in 1936. It was found that these measurements were generally within 0.1 to 0.2 feet of the 1936 elevations.

The 1946 lake and sediment volumes were calculated using methods developed by the Soil Conservation Service (Eakin, 1936). The lake bed elevations were plotted for the years 1922, 1936, and 1946, and these plots were used to determine cross-sectional areas of water and sediment for each year. The volume of each segment of the lake was calculated using the prismoidal formula.

The unit weight analysis of the deposited sediment for the 1946 survey as well as that for the 1936 survey were of limited use. In both surveys, lake sediment samples were collected using the spud sampler and the pipe sampler from the 1936 survey. Samples were collected by combining material contained in the spud cups or by scooping material from the pipe sampler. These samples were placed in jars of known volume and heated to remove all moisture. The weight of the sample was then divided by the jar volume to determine a volume weight or unit weight. These samples were easily biased by the degree of packing used when the sediment material was placed in the sampling jar. Unit weight of deposited sediment is best determined by using undisturbed sediment samples.

The results of the 1946 survey were published by ISWS (Brown et al., 1947). This report documented a 25% loss in volume of the lake from 1922 to 1946. The average annual capacity loss from 1936 to 1946 was 1.2% compared to the 1.0% rate determined for the period 1922-1936. The authors found a tentative correlation between the increases in row crop production in the watershed and the increase in the rate of sedimentation in Lake Decatur.

The lake sediment samples collected in 1936 and 1946 were analyzed during the 1946 study to determine particle size distribution, organic carbon, total nitrogen content, and apparent unit weights. These samples showed similar particle size characteristics, organic carbon, and total nitrogen content to the typical prairie soils, and it was concluded that the source of the lake sediment was sheet erosion from the upland prairie soils.

The authors estimated the trap efficiency of the reservoir to be 78% based on turbidity records, flow records at Monticello, and the weight of the deposited sediment in the years 1936 to 1946.

Bank erosion along the shore of the lake was estimated to be 35.5 acre-feet or 1.5% of the total deposited sediment within the lake.

The total weight of sediment was estimated to be 2,650,000 tons for the period 1936 to 1946 with an average unit weight of 51.5 pounds per cubic foot. This value was recognized to represent only a very gross estimate of the total sediment weight due to the limitations of the sediment sampling methods.

1956 Survey

The 1956 survey was conducted by the Water Survey at the same time that the new bascule spillway gates, which allowed the pool elevation to vary from 610 msl to 615 msl, were being positioned on the spillway. During this survey, 30 of the previously established ranges were surveyed. In addition, seven new cross sections were established upstream from the previously established cross sections to provide full coverage of the lake area at the new spillway elevation. The sedimentation survey was conducted using a sounding pole for depth measurements and a plane table - alidade method for horizontal locations.

During the 1956 survey, no measurements of the original bed elevations were taken. The 1956 measured bottom elevations were compared to the elevations of the original bed surveyed in 1936. The lake capacity was determined using the Soil Conservation Service methods (Eakin, 1936). The original (1922) volume of the lake as determined in the 1936 survey was used for comparative purposes.

The 1956 survey was the first survey of the lake in which undisturbed samples of the accumulated sediment were collected. Core samplers with 2.875-inch-diameter barrels were used. A total of 93 samples were cut from the sediment cores varying in length from 4 to 4.2 inches. Depth of sampling was as much as 7 feet.

Results of the 1956 survey were published in a Letter Report by ISWS (1957). This report noted a considerable reduction in the volumetric sedimentation rate from the two earlier periods, which was attributed primarily to the drought of the early 1950s. The impact of the drought was two-fold. Initially, the lake bed was exposed to prolonged dry periods which compacted the deposited sediment due to dehydration. Second, during the drought, the inflow to the lake was very low which contributed toward a substantial reduction in sediment brought to the lake. The authors hypothesized that the reduction of the sedimentation rate was also due to increased erosion control measures in the watershed.

Total depletion of lake storage capacity during the period 1946 to 1956 was estimated to be 771 acre-feet. This was about 77 acre-feet per year for ten years. Capacity loss rates of 198 acre-feet per year and 236 acre-feet per year were observed for the 1922-1936 and 1936-1946 periods, respectively.

1966 Survey

The 1966 sedimentation survey was conducted by the Water Survey using a sounding pole for water depth measurement and a plane table and alidade for horizontal control. No measurements of sediment thickness were made. The 37 cross sections used in the 1956 survey were resurveyed.

Water and sediment volumes were recalculated for all previous surveys, but no adjustments in the results were made. The 1966 water volume of the lake was determined for both the 610 msl spillway elevation and the 613 msl normal pool elevation maintained by the moveable spillway gates.

The sediment unit weight analysis for the 1966 survey report (Stall and Gibb, 1966) was the most thorough up to that time. Although no analysis of these unit weights was published, a thorough review of all survey results was made based on unit weight sampling for the 1956 and 1966 surveys, The results of these analyses indicated that the average unit weights for each survey year were as follows:

1936	40.5 pounds per cubic foot
1946	40.5 pounds per cubic foot
1956	44.9 pounds per cubic foot
1966	46.9 pounds per cubic foot

These results were based on estimates for the 1936 and 1946 surveys, and on sediment sampling for the 1956 and 1966 surveys.

The results of the 1966 survey showed that during the period 1956 to 1966 Lake Decatur had lost 1031 acre-feet of storage, for an average annual rate of 103 acre-feet. This rate was above the drought-affected rate determined for the period 1946 to 1956 but was still considerably lower than the rates of the 1922-1936 and 1936-1946 periods.

1983 RESERVOIR SEDIMENTATION SURVEY

The 1983 hydrographic survey of Lake Decatur began in the spring of 1983. Past reports on the lake, old survey field books, maps, newspaper clippings, and other related materials were obtained from the Water Survey files and the University of Illinois library during this survey. These sources as well as field reconnaissances of the lake and watershed were used to develop the methodology used in the 1983 survey.

Surveying and Sampling Techniques

The equipment used for the 1983 survey field data collection was selected on the basis of the precision and accuracy needs of this type of hydrographic survey. Preference was given to equipment of simple and reliable design.

The workboats were chosen for their shallow draft and stability. A 14-foot tri-hull ABS plastic boat was used for sounding and sampling. This boat was mated with a 10- or 20-horsepower outboard motor depending on the water depth in the work area and distance from the launch site. A 12-foot flat bottom jon-boat, coupled with a 10-horsepower motor, was used for the very shallow upper reaches of the lake.

The basic data collection equipment used in this survey was as follows:

1) 2-inch-diameter aluminum sounding pole in 8-foot sections with marked 0.1-foot graduations

2) Sediment shoe for the sounding pole

3) Hewlett-Packard model electronic distance measuring device (EDM)

4) Polypropylene cable of 1/4-inch diameter

5) Cable meter to measure distance along the cable

6) Automatic level and theodite

7) Stadia rod and range poles

8) 2-inch-diameter by 3-foot-long core sampler

9) Ekman "clam-shell" type dredge

10) Measuring and examination board for sediment cores

11) Two-way radios

12) Electric trolling motor and marine battery

13) Sample storage jars and plastic bags

14) Miscellaneous items: field books, pencils, camera, spatula, ice hole cutter, concrete survey monuments, post hole digger, machetes, survey ribbon, etc.

Some of the above equipment will be described in more detail in the next section.

The hydrographic survey of the lake was conducted by sounding the 37 ranges surveyed in 1956 and 1966. These range lines are shown in figure 12, along with some of the additional range lines surveyed previously. The original numbering system was retained for consistency. Of the 43 plan segments shown in figure 12, some of the smaller segments (17-19, 27-28, 34-35, and 42-43) were combined for the 1956, 1966, and 1983 surveys, resulting in a total of 38 segments.

Depth measurements were made over the side of the workboat by lowering the sounding pole with a sediment shoe at its end. The sediment shoe is constructed so that it "floats" on the water/sediment interface and is free to slide up and down the sounding pole as the pole is pushed into the top of the lake bed. When the pole is raised up from the bottom, limiting guides at its base catch the sediment shoe, resulting in a distinct clicking sound. When this sound is heard, the depth of the pole in the water is measured by means of marked graduations in tenths of a foot along the pole. Depth readings use the water surface as a temporary datum and these readings are later converted into lake bed elevations by subtracting the depth readings from the lake surface elevations.

Two methods of horizontal positioning were used in the 1983 survey: the cable and the shore station methods. Both methods required that the sounding boat be positioned in the lake along the range line at a known distance from the range markers.

The cable method was used to sound approximately half of the ranges. This method involved stretching a 1/4-inch polypropylene cable across the lake and measuring the horizontal distance between the range markers using a cable meter. Soundings of the current lake bottom were made at 25- to 100-foot intervals. Two factors limited the use of this method: the range length was limited to less than 1500 feet due to the cable length; and areas of high boat traffic precluded the use of the cable due to the possible danger of accidents.

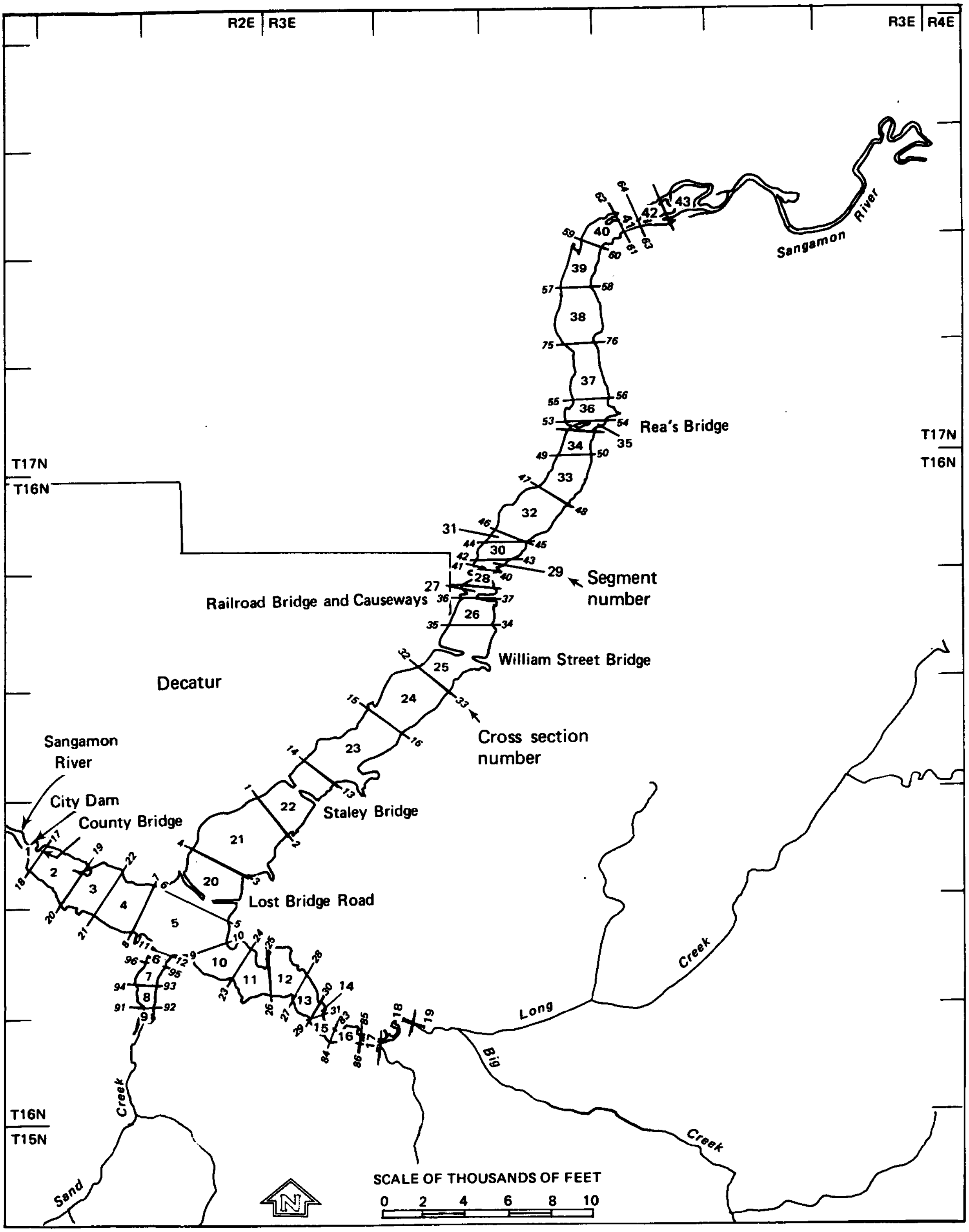


Figure 12. Plan view of Lake Decatur, showing cross section and segment locations

The second survey method (shore station method) employed a Hewlett-Packard electronic distance measuring device (EDM) which uses an infrared light beam reflected off a mirrored prism carried on the workboat, to measure the boat distance from the shore station. Through this method, lines of sight were cleared between range stations on opposite lake shores, and the shore station equipment operator used the EDM to determine the sounding boat’s position while sampling. Soundings were obtained by using the same aluminum pole and sediment shoe used in the cable method. Sounding intervals were 25 to 150 feet and usually were more widely spaced than in the cable method owing to the much larger distances across the lake.

The sounding crew consisted of three persons: the boat operator/data recorder, the sounding man, and the reflector/cable handler. This last individual would switch between duties depending on the type of survey method used. An additional person was required on shore for the shore station method to operate the EDM and communicate with the rest of the crew via two-way radio.

Following the sounding of all lake cross sections, samples of the lake bed sediments were collected to determine 1) particle size distribution, 2) unit weights, and 3) changes in the sediment over the length of the core samples. During this survey, bottom sediments were collected from 38 sites.

Two types of samplers were used for lake sediment sampling, an Ekman "clam-shell" type dredge and a core sampler. Surface samples were obtained by using the dredge sampler, which scooped up the top 2 to 4 inches of the lake bed sediment. Core samples were taken by using a 3-foot-long, 2-inch-diameter sampler which was lowered to the lake bed from the workboat with ropes and then driven into the sediment by means of a sliding lead weight built into the top of the core sampler and operated by ropes from the workboat. The cores were extruded onto a core measuring board in the workboat and examined for sand content, organics, compaction, and changes in color and texture over the length of the sample. Portions of the sample were then removed for later analyses to determine the unit weight and particle size distributions.

Generally unit weight samples were cut from the core at the upper, middle, and lower third of the core. Multiple unit weight analyses for each core allowed the calculation of accumulated sediment weights for lake sediments whose density could vary with depth. Particle size samples were also taken from the core samples and from the dredged samples for estimation of the areal distribution of particle sizes.

Following the sampling of lake bed sediment, the efforts of field data collection were directed towards depth sounding the Sangamon River at six cross sections upstream of the lake up to the Oakley Bridge, 13.5 miles upstream of the city dam. The bridge sections within the lake were also measured to determine the impacts of the bridge causeways on the sediment deposition pattern. A shoreline and bluff reconnaissance survey was also undertaken to determine areas of high bank erosion.

Concurrent with the latter field data collection, related data necessary for a generalized analysis were gathered. Data on lake water level records, rainfall records, stream discharge, stream sediment discharge, watershed land use, and soils were among the types of data assembled from various sources to aid in the analysis of the 1983 survey.

Analyses of Data

Data collected during the 1983 sedimentation survey were analyzed to determine the variations within the cross-sectional areas of the lakes, to develop a 1983 hydrographic map, to develop the stage-volume and stage-area relationships, and to determine the lake bed sediment characteristics including textures, unit weights, and particle size distributions. Other analyses consisted of the determination of the sedimentation rates both volumetrically and on the basis of the weight of the deposited sediment. A brief analysis was also made of the interrelationship between the delivery rate of sediment and the sediment yield and trap efficiency.

Cross-Sectional Profiles

A total of 37 cross sections were surveyed in 1983, and the data collected from these cross sections were compared with the cross-sectional data collected in previous surveys. Some of the typical cross-sectional plots are described here. Their locations are shown in figure 12.

Range 7-8: Range 7-8 is located 1.2 miles above the city dam, as shown in figure 12. The cross-sectional plot is shown in figure 13. At this cross section it can be seen how the old river channel is completely covered by the accumulated sediment. An old side channel of the Sangamon River shown on the left of the plot is also completely covered with deposited sediment. Variations in the original lake bed were as much as 12 feet, whereas presently it has been smoothed over and varies by only about 2 feet across most of the range line. The 4-foot peak in the lake bed near the shore at Monument 7 is the result of dredging and fill for a private harbor construction. The 1922 lake bed surface shows an old natural levee approximately 1 foot above the floodplain. This levee is the result of overbank flows of the pre-dam Sangamon River, when the river would overflow its channel and the overbank flow would diminish in velocity and drop out some of the sediment it carried. The result of this process is the development of a natural levee along the river bank.

Range 15-16: This cross section is located 4.1 miles upstream of the dam on the main body of the lake (figure 12). Figure 14 shows a plot of this cross section for various surveys. The most noticeable feature of the cross-sectional plot shown in figure 14 is the five old river channels (numbered in the figure from upstream to downstream), which are the result of four tight meander bends of the old river. The meander pattern at this location can be seen in the pre-dam valley map of figure 2. The old flow pattern of the pre-dam river at this cross section was as follows: at channel 1, the flow came from upstream and hence as the cross section is

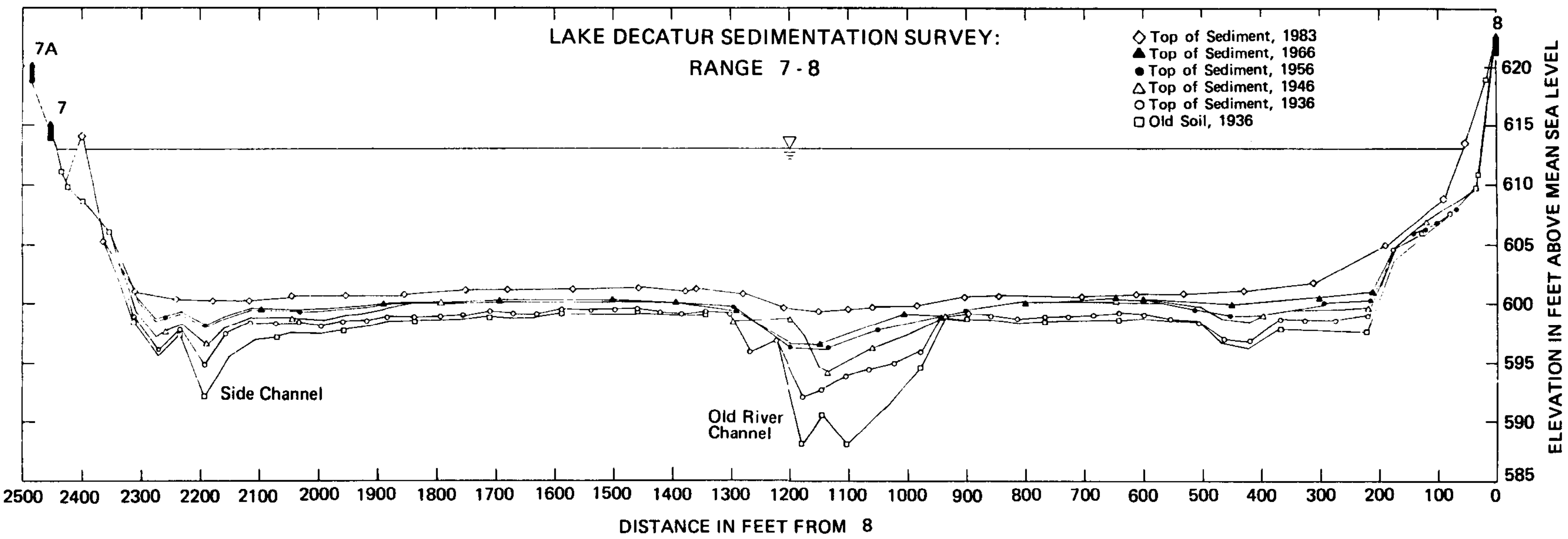


Figure 13. Lake Decatur cross section 7-8

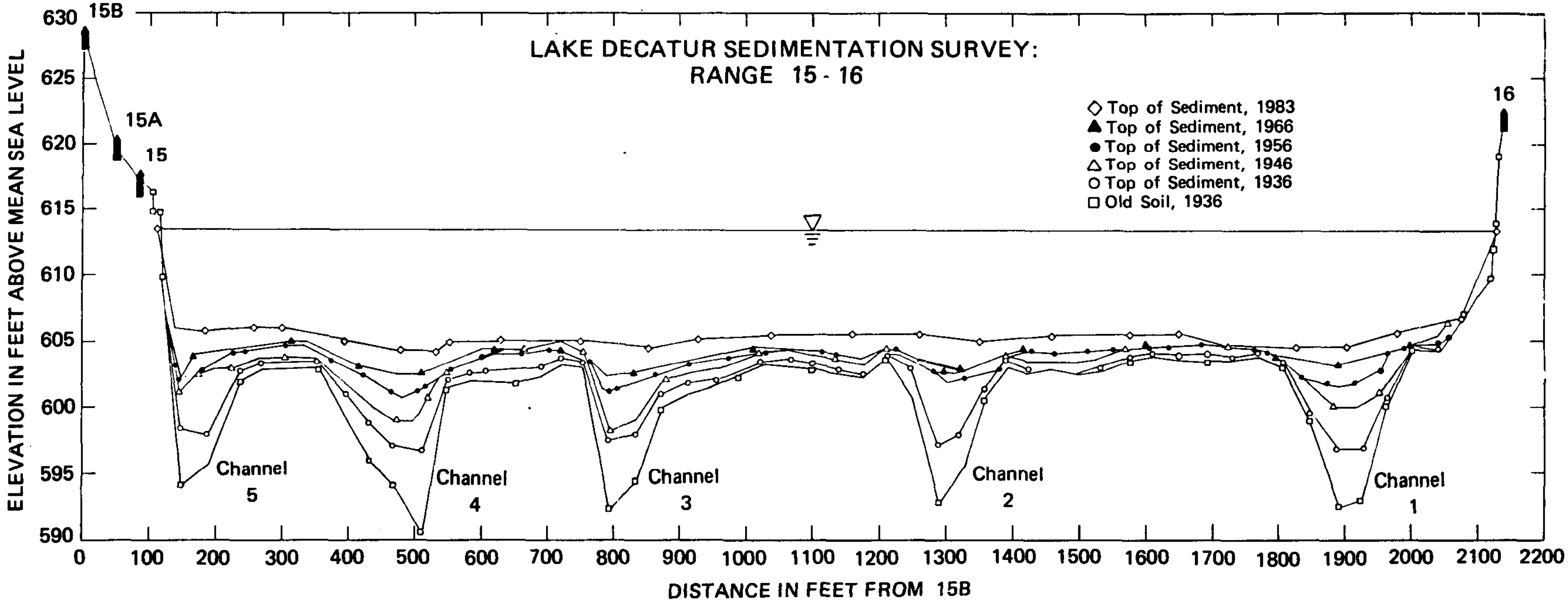


Figure 14. Lake Decatur cross section 15-16

orientated "came out of the graph." After channel 1, the river flowed south and west a few hundred feet, took a sharp bend to the left, and flowed back through channel 2. After channel 2, the river flowed north and east before turning left again and flowing back through the cross section in channel 3. Similarly, for channel 4, the river flowed through channel 3, took a turn to the left, flowed through channel 4, and after another turn flowed back through channel 5.

Between 1922 and 1983 the maximum depth decreased 14 feet from 22.5 feet to 8.5 feet. The highest sedimentation rates occurred within the old channels; the floodplain valley experienced a relatively low sedimentation rate. It is apparent that the 1983 topography is much more subdued than the 1922 topography at this cross section. Other features of this location are the relatively low near-shore bluffs of the valley in contrast to the next cross section at range 44-45, discussed below.

Range 44-45: This cross section is located 6.1 valley miles from the city dam (figure 12). The original channel of this cross section (figure 15) is located against the valley bluff near the right shoreline. Natural overbank levee deposits are seen on the left side of the channel. The maximum depth below 613 msl decreased from 19 feet in 1922 to approximately 5 feet in 1983. The bulk of the sediment at this cross section was deposited in the old channel during the period 1922-1946, whereas sediment deposition in the period 1966-1983 was more evenly distributed across the range line.

Range 75-76: This is one of the upstream cross sections located 8.2 miles from the city dam (figure 12). Cross-sectional plots for this range are shown in figure 16. A noticeable feature of this cross section is the high bluff on the left shore which rises 50 feet above the lake with a near-vertical face. This bluff has eroded back 40 feet since 1936 and is the most severe area of lakeshore erosion. By contrast the shore on the other side has filled in approximately 30 feet over the same period.

This cross section is located approximately 1-1/2 miles downstream from the junction of the Sangamon River and the upstream section of the lake. Figure 16 shows how the Sangamon River flow has continued to follow the old river channel in the lake, as evidenced by the presence of the channel in 1983 on the left side of the figure. Except for this depression on the old channel, the bed elevations of this cross section became fairly flat between 1922 and 1983. An old natural levee approximately 2 feet above the floodplain is present near the right bank of the river channel.

Range 27-28: This cross section is shown in figure 17. It is located 2.9 miles upstream of the dam in the Big Creek arm of the lake (figure 12). From figure 17, it can be seen that the bed topography has flattened over the years; the old channel has been filled and the sediment has feathered out near the shore. The channel shown in this plot was formerly occupied by the Big Creek tributary of the Sangamon River (figure 12). It can be seen that the deepest part of the cross section is still close to the old river channel and is about 1 foot deeper than the surrounding river bed. The channel has not yet been completely obliterated by the deposited sediments because of the high velocity of the incoming flow from Big Creek, which has kept this area

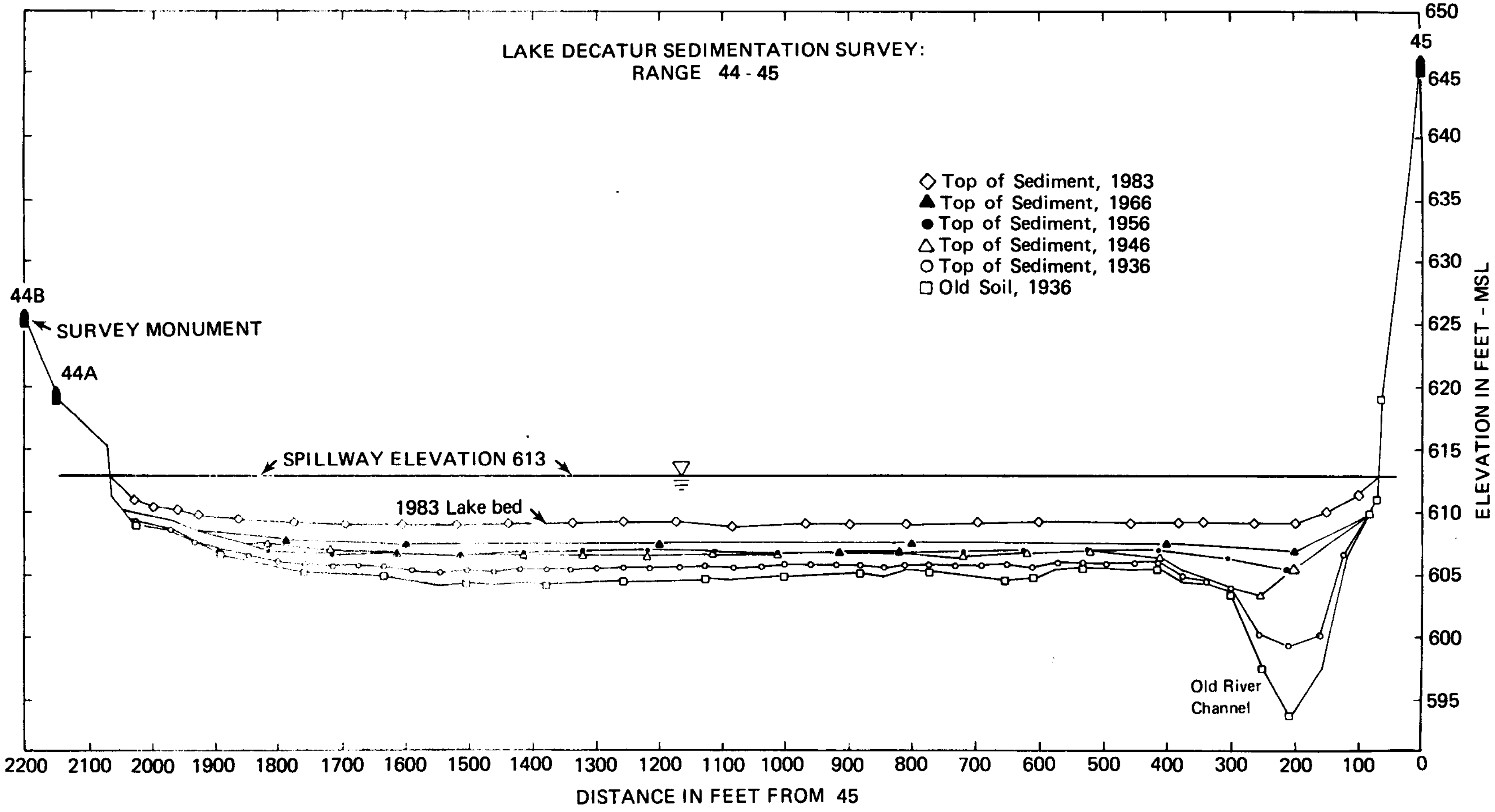


Figure 15. Lake Decatur cross section 44-45

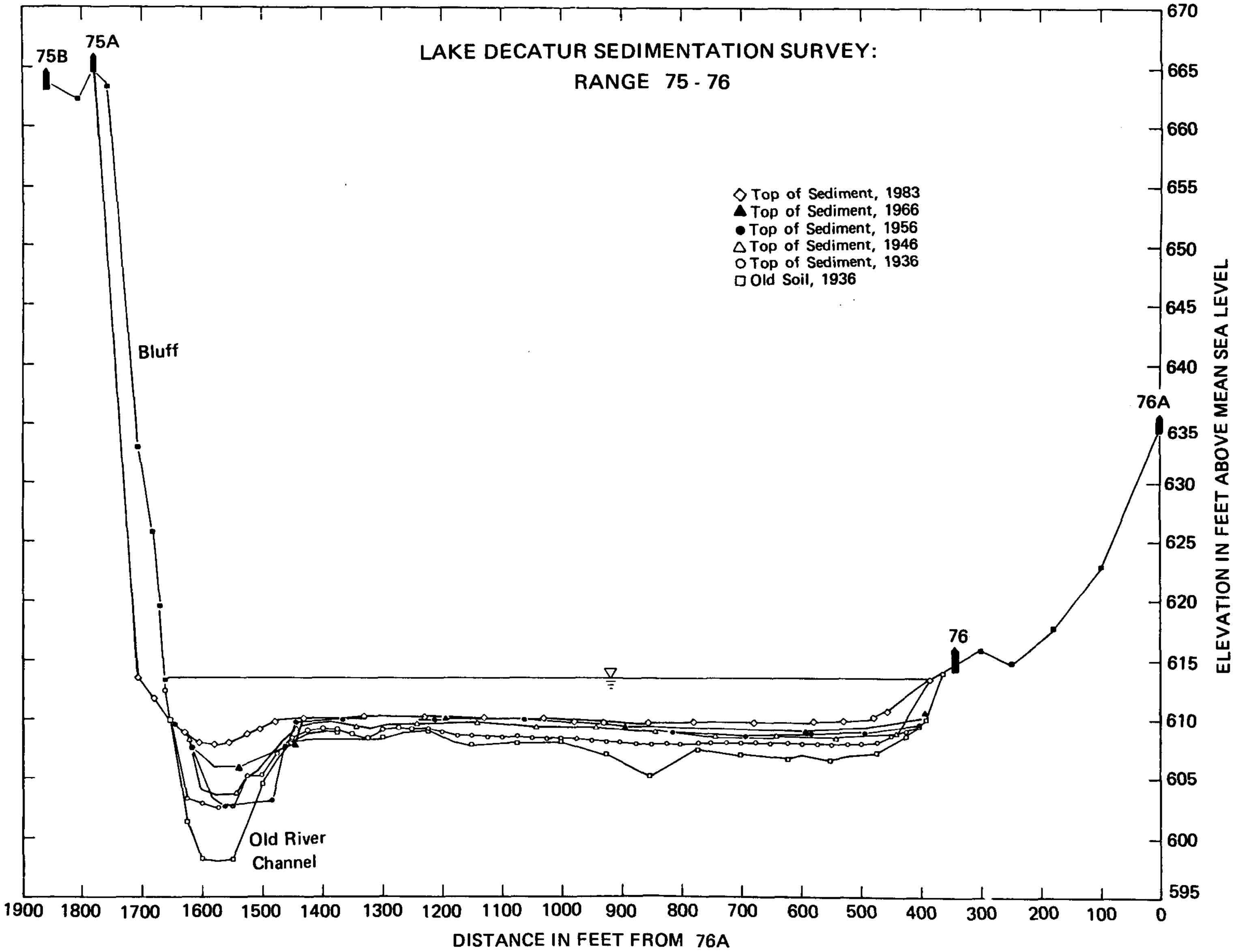


Figure 16. Lake Decatur cross section 75-76

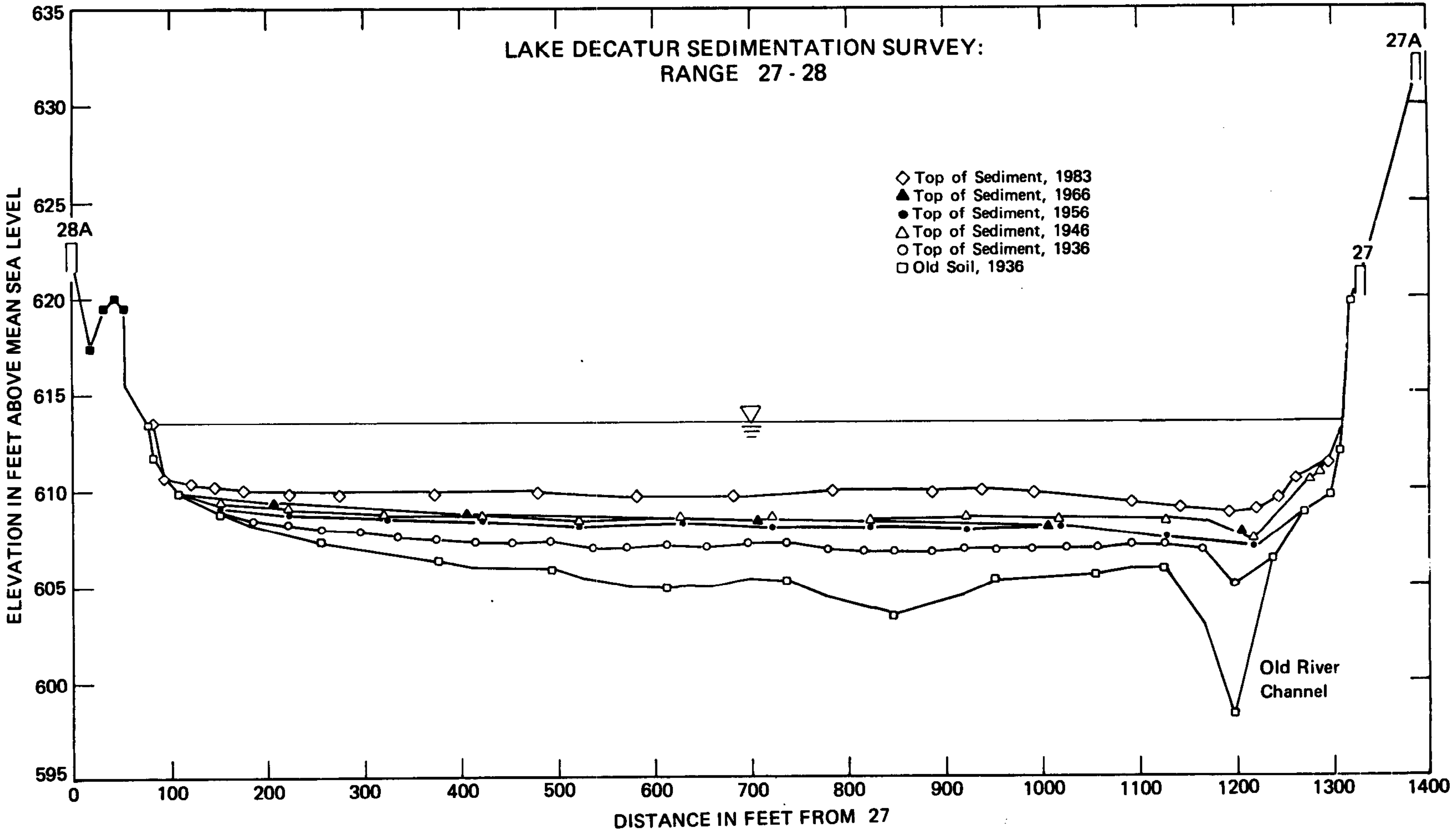


Figure 17. Lake Decatur cross section 27-28

relatively deep by eroding the deposited sediment. Lake bed aggradation reduced the maximum depth below 613 msl from 14.5 feet in 1922 to 4.0 feet in 1983. An old natural levee and side channel can be seen to the left of the old channel in figure 17.

Range 95-96: This cross section is located on the Sand Creek arm of the lake 1.7 miles upstream of the city dam (figure 12). Figure 18 shows that this cross section had no well-developed channel in 1922. Sand Creek, which flowed through this cross section, had a high sediment load and relatively low average discharge, and as a result the stream wandered back and forth across the width of the valley with no defined channel. In 1922, the maximum depth was over 10 feet; currently it is less than 5 feet. This range lost an average of 3 feet of depth during the first 24 years after the dam was constructed and lost approximately 2-1/2 feet of depth between 1946 and 1983.

Some general observations can be made concerning these cross-sectional plots :

1) Lake-deposited sediment tends to smooth over the old river valley topography.

2) Sediment thickness is greatest in the old river channel.

3) The sediment thickness tends to feather out near shore.

4) Over time the maximum depth of water at each cross section decreases faster than the average depth.

5) The lake bed elevations from the years 1946 and 1956 are coincident across most of the cross sections. This results from the relatively low sedimentation rate of the time period between the two surveys.

Hydrographic Map

The cross-sectional depth soundings obtained during the 1983 lake survey were used to generate a hydrographic map of the lake. This map is presented in figure 19 and represents the bed topography as can be inferred from the 1983 data. The map was drawn with a contour interval of 4 feet. The contours shown by dashed lines represent a supplemental interval of 2 feet.

From this map, it is seen that the deepest part of the lake is the downstream region near the dam. This area represents a great deal of the total lake volume and therefore a high percentage of the water storage. In figure 19, it is seen that the old river channel portion of the lake bed has been filled in throughout much of the lake. The river channel bottom was originally at 582 feet msl at the dam in 1922. Currently the bed elevation is 596 feet msl near the dam. A bed elevation of 590 feet was measured beneath the Staley Bridge. This is interpreted to be the result of localized scour produced by water moving through the causeway openings.

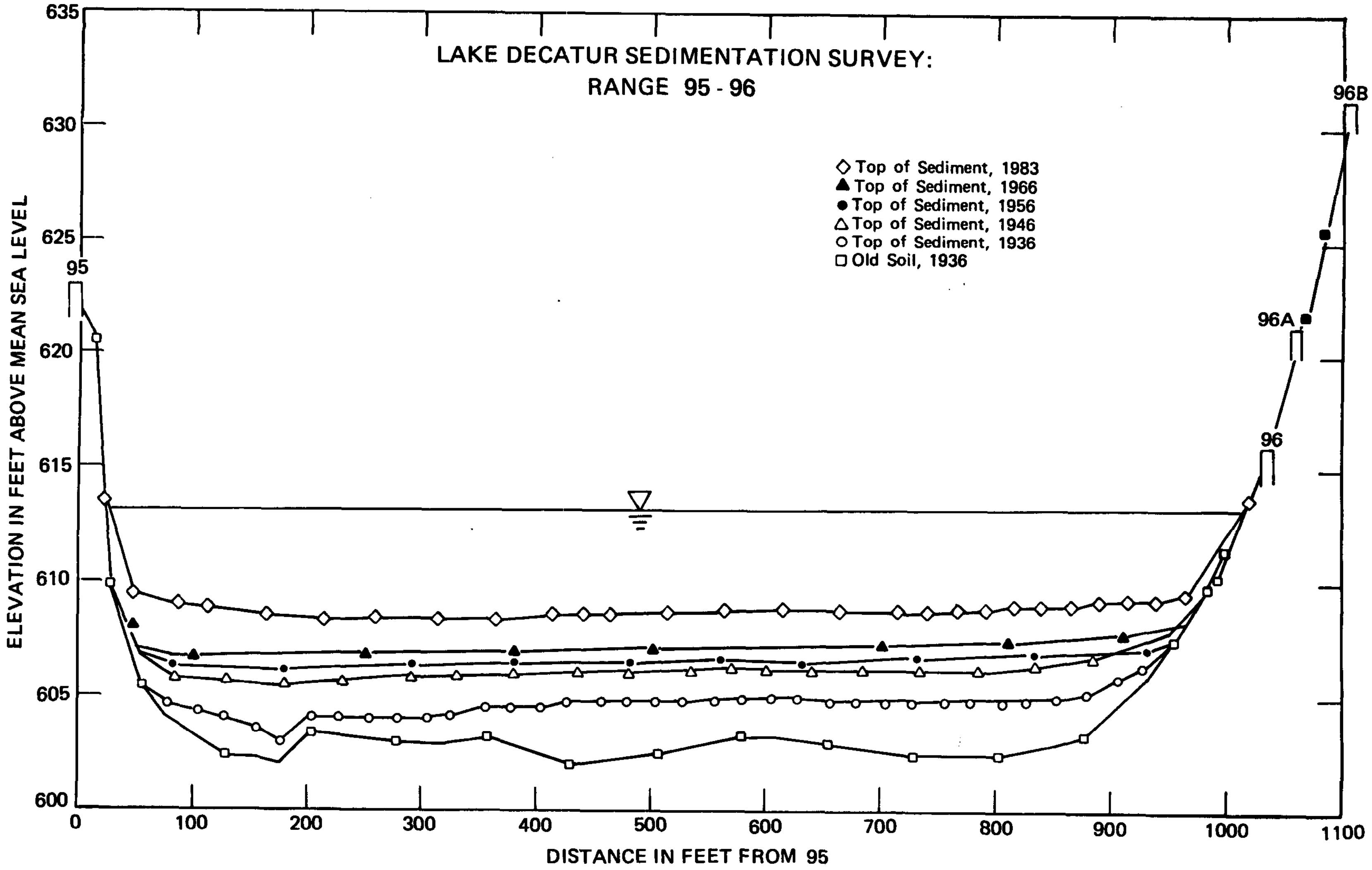


Figure 18. Lake Decatur cross section 95-96

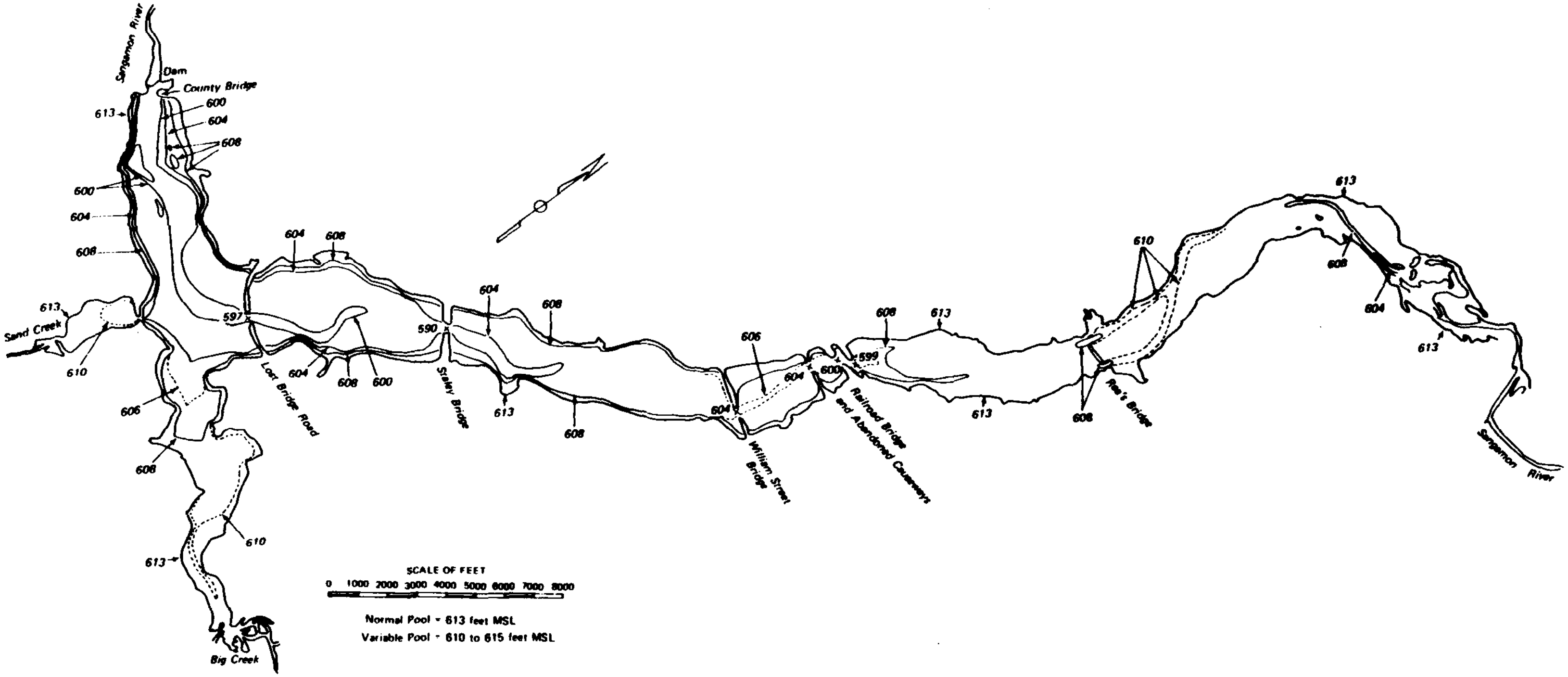


Figure 19. Hydrographic map of Lake Decatur, 1983
(Four-foot contour interval; dashed lines represent supplemental 2-foot contour interval)

Stage Area and Stage Capacity Relationships

The hydrographic map (figure 19) developed from the 1983 survey data was used to analyze the relationship between water level or stage in the lake and the capacity and area of the lake.

The shoreline elevation of the lake at each stage was digitized and the area was calculated from these values. These areas were then used to calculate the incremental water capacity for each increase in stage as follows (SCS, 1968):

$$V = {}^{L}/3\ (A_L + \sqrt{A_L \times A_u} + A_u) \qquad (1)$$

where

V = the capacity between two water surfaces in acre-feet

L= the distance between the two water surfaces in feet

A_L = the area of the lower surface in acres

A_u = the area of the upper surface in acres

The sum of all incremental volumes below a surface is the capacity for that stage. The stage vs. area and stage vs. capacity relationships are plotted in figure 20. This figure can be used to readily determine the capacity or area of the lake for a given stage below 613 msl. This relationship will change with time as sedimentation reduces the lake volume.

Delivery Ratio, Sediment Yield, and Trap Efficiency

The total yearly gross erosion in the watershed of Lake Decatur has been estimated as 2,646,000 tons (SCS, 1983). This value represents the total sheet/rill and channel/gully erosion in the watershed. The gross erosion averages out to 4.5 tons per acre per year. Most of the eroded sediment is moved only a short distance from its source. The sediment that is carried out of the watershed is known as the sediment yield.

The sediment yield to Lake Decatur has two components: 1) the sediment deposited in the lake, and 2) the sediment carried over the spillway and transported downstream. The first component is measured by the lake sediment surveys and the second component is estimated by the trap efficiency of the reservoir. The trap efficiency is the amount of sediment held by the reservoir divided by the total sediment which enters the lake.

Brune (1953) developed a curve which estimates the trap efficiency of a reservoir on the basis of the capacity/inflow ratio. From Brune's curve the trap efficiency of Lake Decatur is approximately 78% for 1983. Applying this value to the average yearly lake sediment accumulation rate of 162,000 tons for the period 1966 to 1983 results in a sediment yield of 208,000 tons per year. Dividing the yield by the gross erosion results in a delivery ratio of 7.9%, which is lower than previous estimates. The total sediment yield of 208,000 tons per year works out to an average value of 0.35 tons per acre of

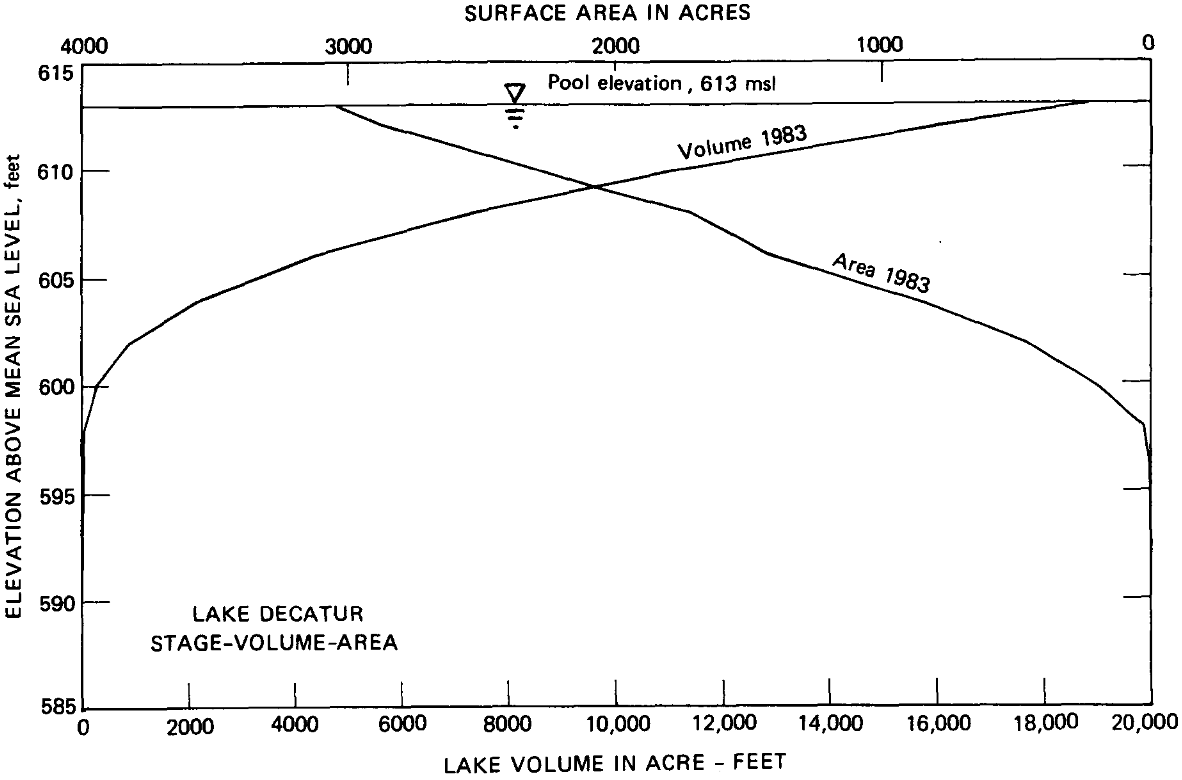


Figure 20. Stage-volume-area curves for Lake Decatur

Table 4. Sediment Yield in the Lake Decatur Watershed

Period	Lake sediment yield (tons/acre/year)	Trap efficiency (percent)	Total sediment delivery (tons/acre/year)
1922-1936	0.29	78	0.37
1936-1946	0.36	76	0.47
1946-1956	0.17	74	0.23
1956-1966	0.28	80	0.35
1966-1983	0.26	78	0.33
1922-1983 average	0.27	77	0.35

watershed per year. Table 4 lists the calculated sediment yields for the time intervals between surveys of the lake.

The sediment yields presented in table 4 show much higher rates during the earlier survey periods than in the period 1966-1983. The trap efficiency decreased over the years from 1922-1956 and peaked in the 1956-1966 period due to the raising of the spillway in 1956 and the resulting increased lake volume. From table 4 it is seen that the highest sedimentation rate occurred in the period 1936-1946 and the lowest rate in 1946-1956.

Bridge Causeways, Scour Holes, and Sand Distribution

Lake Decatur is crossed by eight bridges over its length. The two major effects of these bridges are: 1) localized lake bed scouring at the bridge crossings, and 2) increased concentration of larger particles in the lake bed sediment downstream of the bridge crossings. Both of these phenomena are the result of the type of bridge construction and the effect of the bridges on the flow of water through the lake.

The eight bridges (operational and abandoned) crossing Lake Decatur are all of similar construction, employing two causeways built into the lake from opposite shores and joined by a center bridge span 200 - 300 feet long. Rea's Bridge is different from the others in that it has three causeways joined by two bridge spans. The bridge spans and the openings between the causeways allow the conveyance of incoming waters, especially high flows, through the lake. The locations of the bridges crossing the lake are shown in figure 12. Three of the bridges are located in the lower portion of the lake starting 200 feet upstream of the dam; their average distance apart is 8000 feet. Three bridges, two of them abandoned, are railroad bridges grouped 300 feet apart in the middle portion of the lake. The William Street Bridge is slightly downstream of the railroad bridges, and the eighth bridge, Rea's Bridge, is located in the upstream portion of the lake.

Localized lake bed scouring occurs at the causeway openings beneath the bridges. These openings act as funnels where the incoming waters of the Sangamon River which have spread out over the lake's width and depth are constricted and concentrated into a small cross-sectional area. The effects of localized scouring may be better seen in a profile of the lake bed. Figure 21 is the thalweg profile of Lake Decatur for 1983. In this figure the maximum depth as measured at each cross section and bridge crossing is plotted with the valley distance from the dam. The valley distance was measured along the centerline of the lake from the dam upstream to the Sangamon River. In this figure it can be seen that the bridge scour holes range in depth from 2 feet deep at Lost Bridge to 11 feet at Staley Bridge.

The occurrence of the bridge crossings probably has little effect overall on the rate of sedimentation in Lake Decatur. However, the coincidence of localized scour and abrupt reduction in cross-sectional area indicates the effect that human activity can have on localized sedimentation rates within the lake.

The scouring action at the causeway openings has affected the distribution of sediment particle sizes in the lake bed. Figure 22 shows the percent of sand by weight in surface samples of lake bed material, plotted according to the valley distance from the dam. It can be seen in this figure that there is a repetitive pattern of sand concentration in the lake bed surface samples. Upstream of the bridge crossings sand averages less than 1% by weight, whereas downstream of the bridges the concentration of sand increases to an average of 15% by weight. The correlation of sand concentration to bridge location is the result of the constricting effect of the bridge causeways and the resulting increased water velocity and local scour. It is speculated that during periods of low flow into the lake the

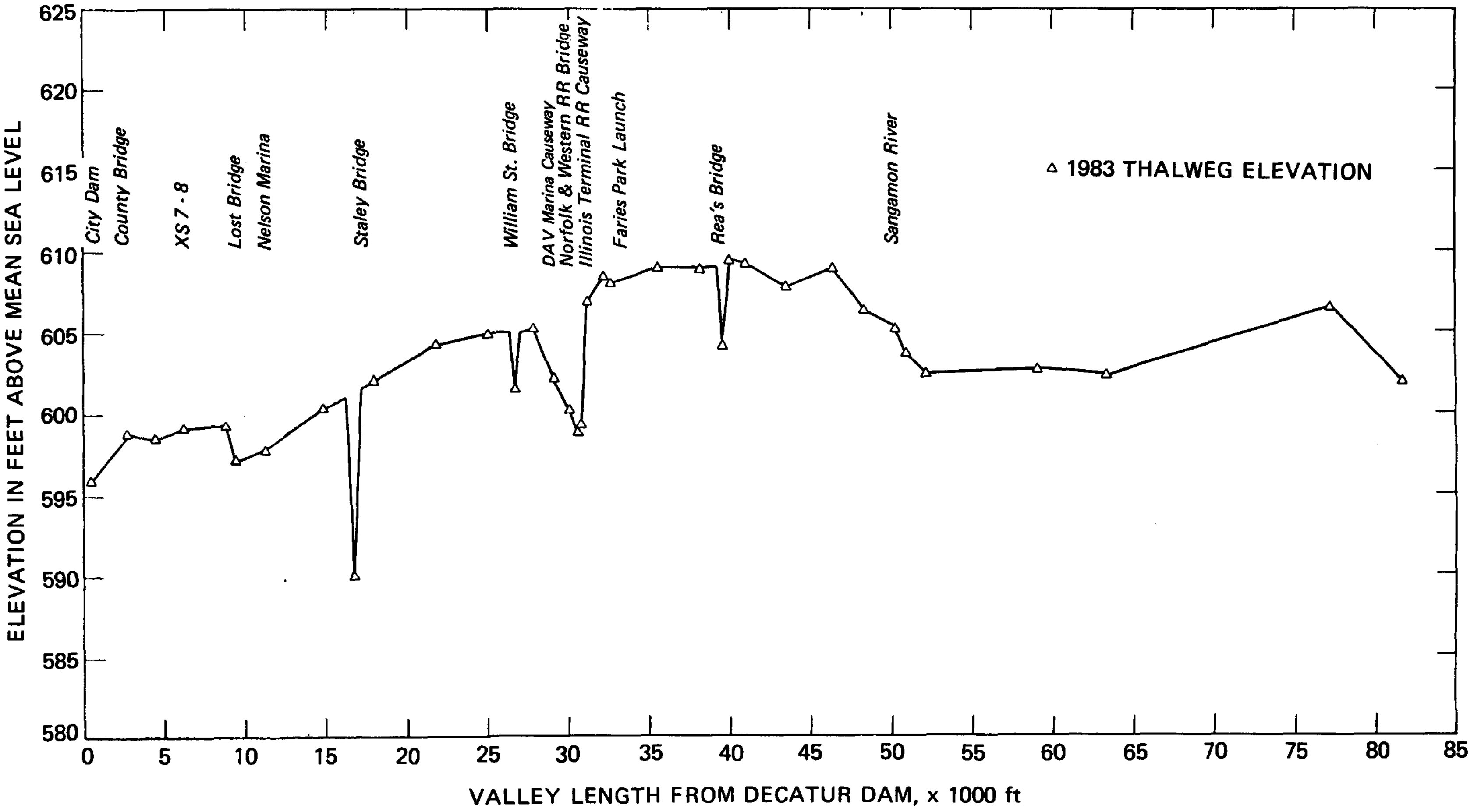


Figure 21. Thalweg profile of Lake Decatur, 1983

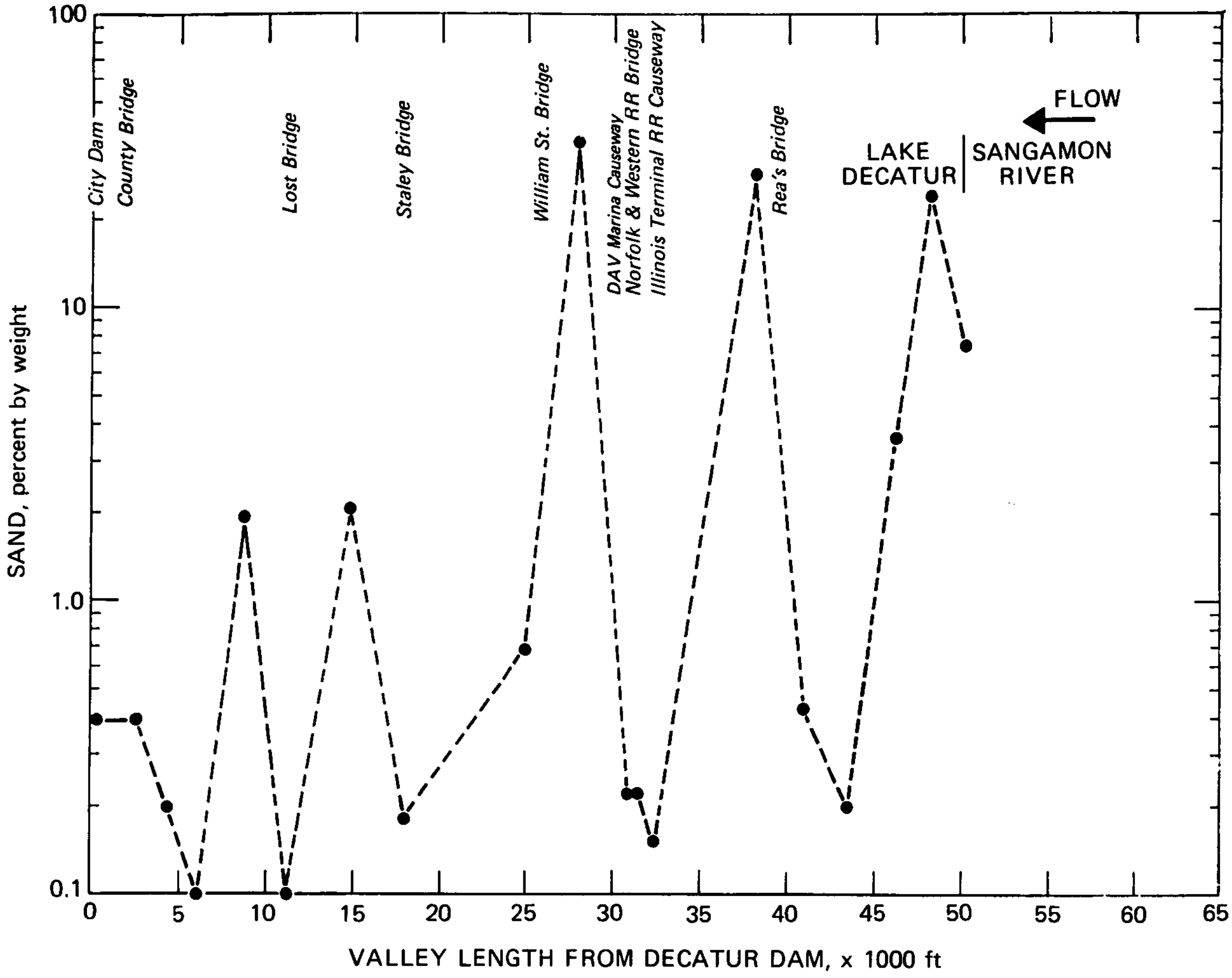


Figure 22. Surficial sand concentrations at selected locations, Lake Decatur, 1983

water velocity at the bridge openings is at a minimum. As a result sedimentation is fairly uniform throughout the lake, and sediment is deposited directly from the water column onto the lake bed in the deep quiet portions of the lake as well as at the scour holes. Additionally, the slopes of the scour holes may deposit sediment in the hole by mass movement of sediment downslope.

The enrichment of sand downstream of the bridges is believed to occur during periods of high flow. During high flow the scour holes are cleaned out by the water currents through the causeway openings. Heavier particles such as sand and gravel are carried only a relatively short distance by the currents and are deposited just downstream of the scour holes, where the energy of the entraining waters diminishes and can no longer carry the sand and gravel. Lighter particles of silt and clay are held in suspension by waters of less energy and are therefore carried further into the lake from the bridges. The effect of this process over the years is an enrichment in the concentration of sand particles downstream of bridges.

An exception to the pattern of high sand concentrations downstream of the bridges is seen in figure 22 at the William Street Bridge, where the pattern is reversed. At this location sand was at a higher concentration upstream of the bridge. This exception to the pattern is probably due to the proximity of the railroad bridge causeways which occur approximately 3000 feet upstream of the William Street Bridge. It is believed that the railroad causeways constrict and regulate the flow of water to the William Street Bridge. The north railroad causeway set has a cross-sectional area of 1500 square feet (below 613 msl), whereas the William Street Bridge has a cross-sectional area of 2700 square feet. It is expected that the volume of water that passes through the railroad causeways would not produce the velocities necessary to scour the William Street causeway opening. This is shown in figure 21, where the scour hole at the railroad causeways is twice as deep as that at William Street.

The high concentration of sand seen downstream of the bridges may be the result of the fill used to build the bridge causeways. If the causeway fills are eroding, the sand downstream of the bridges may have originated there.

LAKE BED SEDIMENT CHARACTERISTICS

This section presents the results of detailed analyses of the sediment characteristics of Lake Decatur’s bed materials. The purpose of this effort was to quantify temporal and spatial changes in the lake bed sediments with regard to density, particle size, and depositional environment of the lake bed materials. This effort was undertaken to 1) assess the nature of the lake bed sediment, and 2) correlate the examined parameters with the results of other studies of lake sedimentation.

Five general areas of sediment analysis presented below are:

1) Changes in sediment bulk dry density (unit weight) with distance from the dam

2) The relation of depth of sediment to bulk dry density

3) Changes in the particle size distribution with distance from the dam

4) The relation of bulk dry density to particle size

5) The relation of particle size, density, and sediment field descriptions at specific sampling points

The accumulated sediments of Lake Decatur were analyzed for three factors: 1) unit weight dry density, 2) particle size distribution, and 3) changes in sediment texture over depth and distance. Sampling methodologies were described in a previous section.

Density

Unit weight analysis provides an estimate of the bulk dry density of sediment. The unit weights of 84 samples collected from Lake Decatur are presented in Appendix 1. The dry density of the sediment varies from 25 to 83 pounds per cubic foot. The average density of the lake bed sediment in 1983 was 49.6 lb/ft^3. In general the unit weight densities are lowest near the dam and highest in the upstream reaches of the lake. Table 5 presents the average unit weight density used for each lake segment to calculate the total sediment weight in the lake in 1983. The unit weight of the sediment in each lake segment was determined by averaging the density for the bounding cross sections of each segment.

Three types of textures were observed in the lake sediment: 1) the top very saturated light grey sediment, which was very loose and uncompacted; 2) the older and more compacted sediments, which grade from slightly compacted and loose in the upper portion of the column to consolidated and firm in the older and deeper portions (this is the most abundant part of the core, generally starting 0.3 to 0.4 feet below the lake bed and continuing down to the original valley soils); and 3) the original valley soils that formed

Table 5. Average Sediment Unit-Weights, Lake Decatur
(in pounds per cubic foot)

Segment	Unit weight	Segment	Unit weight
1	31.3	22	48.6
2	33.8	23	40.8
3	34.2	24	41.8
4	32.4	25	39.9
5	43.6	26	40.0
6 s	48.1	27-28	40.6
7 s	67.3	29	42.0
8 s	67.3	30	42.1
9 s	82.7	31	43.2
10 B	51.9	32	49.0
11 B	54.0	33	55.0
12 B	52.2	34-35	63.9
13 B	57.8	36	70.5
14 B	66.6	37	68.3
15 B	67.9	38	69.8
16 B	71.7	39	68.8
17-19 B	74.4	40	62.9
20	38.8	41	64.7
21	45.3	42-43	67.7

S = Sand Creek reservoir arm
B = Big Creek reservoir arm

prior to the lake construction, recognized by the old root zone layer, generally larger particle sizes, and usually a very consolidated texture. The old soil layer was usually absent from cores taken in the lake because the depth of the accumulated sediments exceeded the sampling depth of the core sampler.

These unit weights show a general decreasing trend from the upper end of the lake to the dam. This is to be expected in lake sedimentation studies (Heinemann, 1962; Bogner, 1983) and results from the progression of sediment particle deposition in the lake. As the moving water of the Sangamon River enters Lake Decatur, it slows drastically and can no longer maintain its sediment load. As the water enters the lake, the heavier sediment materials tend to drop from suspension first. As the water moves further down the lake it slows even more, and the lower density sediments settle to the bottom. At the dam, only the least dense materials will still be carried by the water to either be settled out in the lake near the dam or pass over the spillway.

The unit weights in the upper segments of the lake are also affected by the periodic exposure to drying and compaction during times of low water levels. Lake Decatur is a public water supply lake and the pool level is frequently lowered by the demands of the water treatment plants during periods of low flow on the Sangamon River. As a result the aeration and resulting compaction of lake sediment occurs more frequently in the shallow upstream lake segments.

In table 5, variations from the trend of increasing density from the dam to upstream can be observed in several segments, such as segments 4, 5, 17-19, 20, 23, and 32. These variations from the overall trend are attributed to inputs of larger particles of sediment from tributaries of the lake and the presence of sand in lake sediments downstream of bridges.

Other lake sedimentation studies have shown a trend of increasing sediment unit weight density with depth below the lake bed (Heinemann, 1962). At specific cross sections increasing density with depth is observed in Lake Decatur. Figure 23 is a plot of density versus depth at selected sites in the lake. It can be seen in this figure that density generally increases with depth; however, the relation between the two variables is unpredictable. For cross section 1-2 the sediment density doubles with a 1-foot increase in depth, but at cross section 17-18 the density varies little with depth.

In general the density of sediment in a lake bed will increase with time and increasing depth of burial. There is, however, a maximum density that the sediments can attain. This density is approximately 100 lb/ft^3 and varies with different proportions of particle sizes and organic concentrations. The maximum density of sediments sampled in Lake Decatur was 83 lb/ft^3. This sample was from sediment on the upstream portion of the Sand Creek reservoir arm, which was originally laid as above-pool-level delta deposits prior to the raising of the spillway in 1956. The least dense samples were obtained from areas of the lake that have remained submerged since the construction of the lake in 1922. The continual saturation of sediments in the near-dam portion of the lake has retarded consolidation and compaction due to the interstitial pressure and buoyancy of water between

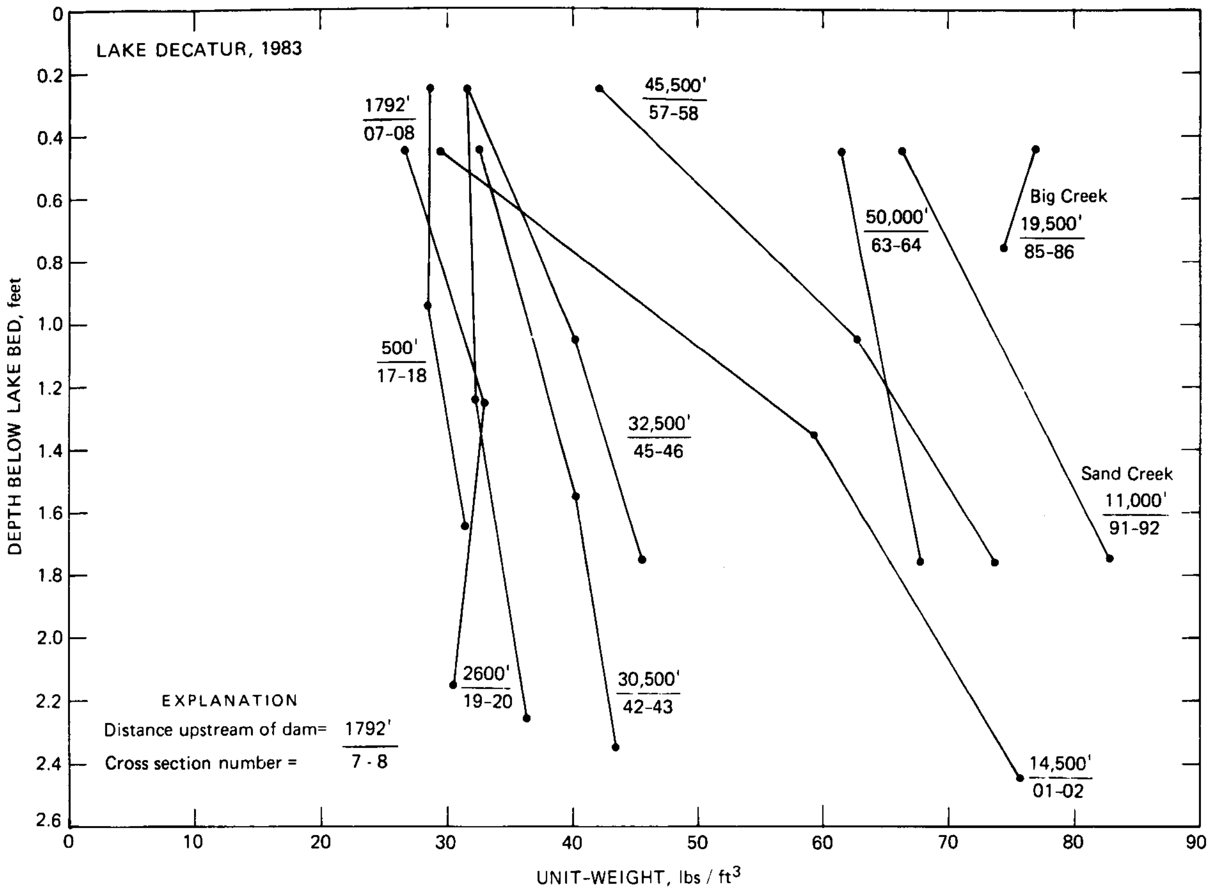


Figure 23. Density versus depth, Lake Decatur, 1983

sediment particles. A sediment density of 25 lb/ft^3 was measured approximately 1.5 miles from the dam in material that was predominantly clay and deposited on the lake bed within the last 10 years. The least dense material is the sediment in the top inch of the lake bed in the deep areas near the dam. This material probably has a range of dry weight densities of less than 20 lb/ft^3; however, the fluid nature of the material precluded sampling using the techniques available to this study.

Particle Size

The lake sediment in Lake Decatur is predominantly clay. The simple averages of all particle size samples are: 57% clay, 36% silt, and 7% sand. Appendix 1 lists the results of particle size analyses of 40 lake bed samples. These results show a general trend towards increasing silt and clay from upstream to downstream in the lake. This trend is seen in the main stem of the lake as well as in the Big and Sand Creek tributary arms. A trend of increasing particle size towards the upstream has been observed in other reservoirs (Heinemann, 1962; Eakin, 1936).

There is a correlation between the particle size distribution and the unit weight density of lake sediments (Heinemann, 1962). Figure 24 is a plot of the percent of clay by weight and the unit weights of Lake Decatur bed material samples. These data were developed from the particle size and unit-weight density analyses. Surface particle size samples taken at 0.1 foot of depth were combined with unit weights of lake bed measured at the

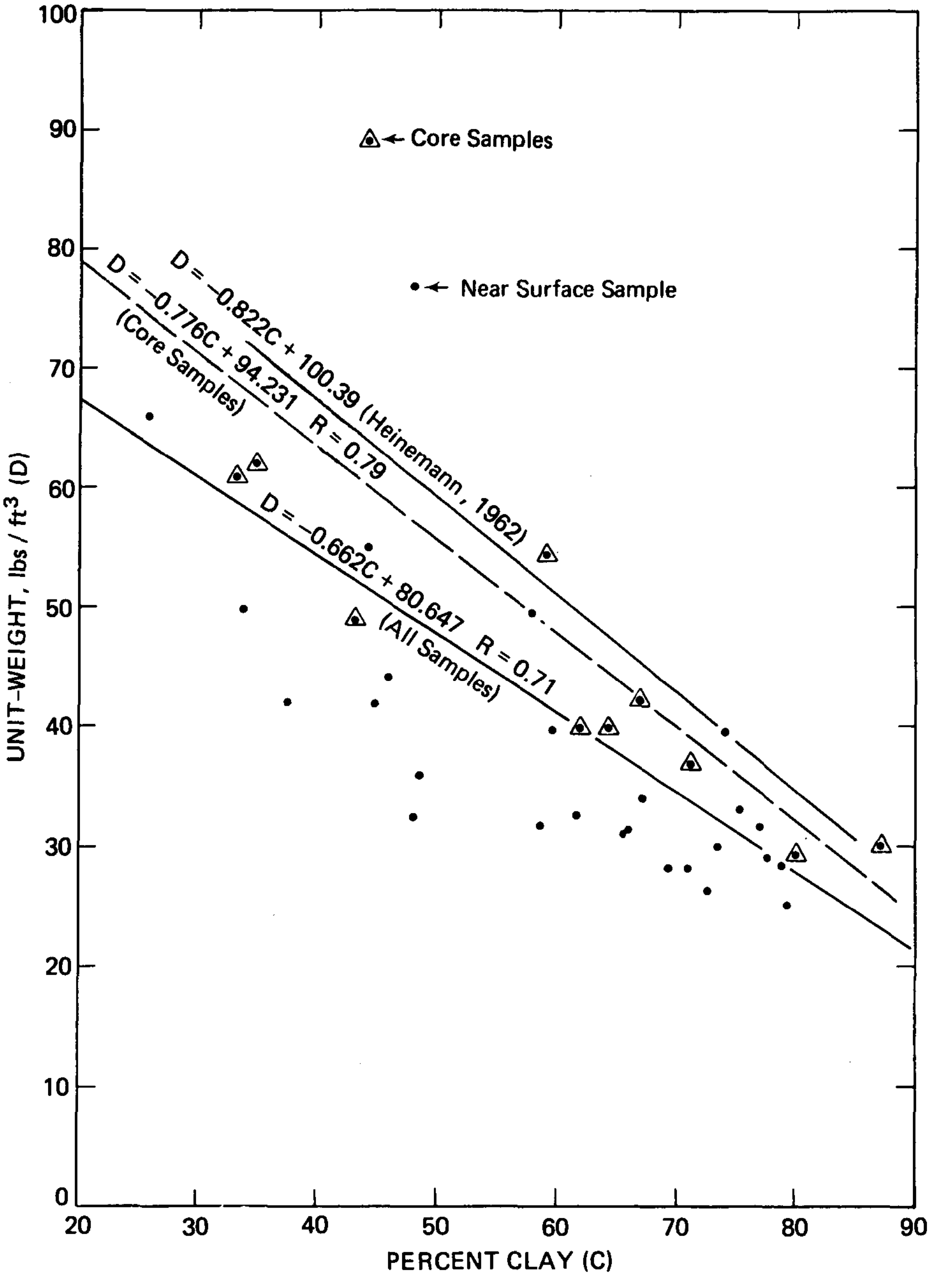


Figure 24. Correlation of percent clay and unit-weight density in lake bed sediments

closest depth. That is, the nearest available unit weight was combined with the particle size data point within 0.5 foot. If the difference in depth of sample between the two parameters was greater than 0.5 foot, a linear interpolation was used to determine corresponding densities. Where interpolation was impossible due to a lack of bracketing data points, careful extrapolation of the measured densities was made. This extrapolation was based on the slope of the density vs depth relation at individual sites for the deepest data points available. The two parameters are related by equation 2, which has a correlation coefficient of .71 with a standard error of estimate of 10.56 for 37 samples. In equation 2, D is the unit weight density in pounds per cubic foot and C_1 is the percent by weight of the sample less than .004 millimeters in diameter, the upper size limit of the Wentworth size class for clay.

$$D = -.662\ C_1 + 80.65 \qquad (2)$$

This regression was developed from the data presented in Appendix 1, where the particle size analysis and unit-weight results are listed by segment number and sample depth. Heinemann (1962) found a similar relationship between percent clay and unit weight density in 236 samples he studied from Sabetha Lake in Kansas. His regression, shown in equation 3, was based on particle size analysis where the upper size limit of clay was defined at .002 millimeters and therefore C_2 is the percent by weight of particles less than .002 millimeters.

$$D = -.822\ C_2 + 100.39 \qquad (3)$$

Equations 2 and 3 are plotted in figure 24, and a similar trend is observed, i.e., as the proportion of clay increases the density decreases. As defined, C_2 is less than C_1. Therefore, the weight percent of clay in a sample will always be less when defined by C_2 (percent by weight less than .002 mm) than when defined by Cl (percent by weight less,than .004 mm). Therefore it is expected that the plot of equation 2 would predict a higher density for a given C-value than the plot of equation 3. In figure 24 this is not the case; the plot of equation 3 is above equation 2 throughout the graph. The disparity between the expected and the observed plots of the equations is probably due to: 1) the size of the sample populations; and 2) the depth of the samples. Heinemann's 236 samples ranged from 0.6 to over 5.0 feet below the lake bed whereas the 37 samples from Lake Decatur averaged only 0.6 foot below the bed. The depth of the sample is expected to change the unit weight density due to compaction by the weight of the overlying sediment. This was observed in Lake Decatur and in Sabetha Lake. In figure 24 the dashed regression line represents the relationship of percent clay and density for the deeper core samples from Lake Decatur. It is seen in both the regression line plot and the scatter plot of data points that for a given percentage of clay the densities of the core samples are at the higher limits of the range of unit weight densities. It is inferred that the relation of percent clay to density in Lake Decatur would agree better with Heinemann's regression if the average sample depth was deeper and the sample population was larger.

Sediment Core Samples

This section presents and discusses lake bed sediment core samples obtained at a variety of sites throughout Lake Decatur. Six core samples were selected for detailed analysis. The sampling sites represent typical sediment depositional environments in the lake and range from near-dam locations to the headwaters of the lake.

The core samples are described for percent sand and clay by weight, unit weight density, sediment type, sediment origin, and past lake bed surface elevations. The information on these cores was obtained from field descriptions, laboratory analysis of particle size distributions and unit weight density, regression analysis of clay versus density in equation 2, and the surveyed lake bed elevations obtained from the present and past surveys of the lake.

The locations of the core samples discussed in this section are shown in figure 25. Four of the cores are from the main body of Lake Decatur, and two are from reservoir arms of the lake.

The core sample from cross section 7-8, presented in figure 26, shows the type of material that predominates in the lake bed. The sediments are silt and clay of a fairly uniform distribution. Density is low and averages approximately 30 pounds per cubic foot. This core was taken from the area of the lake formerly occupied by the old Sangamon River channel and exhibits the type of uniform texture of sediment found in the deeper quiet portions of the lake. Currently the water depth at this site is approximately 13 feet. The depositional rate of this site has accelerated in the last 17 years as can be seen in figure 26. Of the 2.5 feet of sediment depth sampled, three-quarters of the depth represents the last 17 years and the lower one-quarter represents the previous 20 years.

The core sample from cross section 1-2 shown in figure 27 was taken on the old floodplain of the valley and shows the variety of sediments associated with the shallow portions of the lake. This core penetrated the sediment to below the pre-dam valley bottom into the old river deposits. The older and deeper portions of the core show a higher concentration of sand than the newer and shallower portions. Unit weight density increases with depth in this core, ranging from 30 to 80 pounds per cubic foot. The densest sample was from the old river deposits. With the exception of the time period 1946-1956, the depositional rate at this site is fairly uniform. The period 1946-1956 was a time of reduced sedimentation throughout the lake that has been attributed to droughts of the period (Stall and Gibb, 1966).

A break in the core and a layer of root hairs and organics was observed at elevation 600.5 msl. This was attributed to the boundary between the old valley floor and the newer lake deposits.

The cores from the upstream portion of Lake Decatur shown in figures 28 and 29 are from cross sections 61-62 and 49-50. The core from 61-62 penetrated the sediment to below the 1946 lake bed surface. This core is mostly silt and clay with some organics. Sand percentages of the sediment

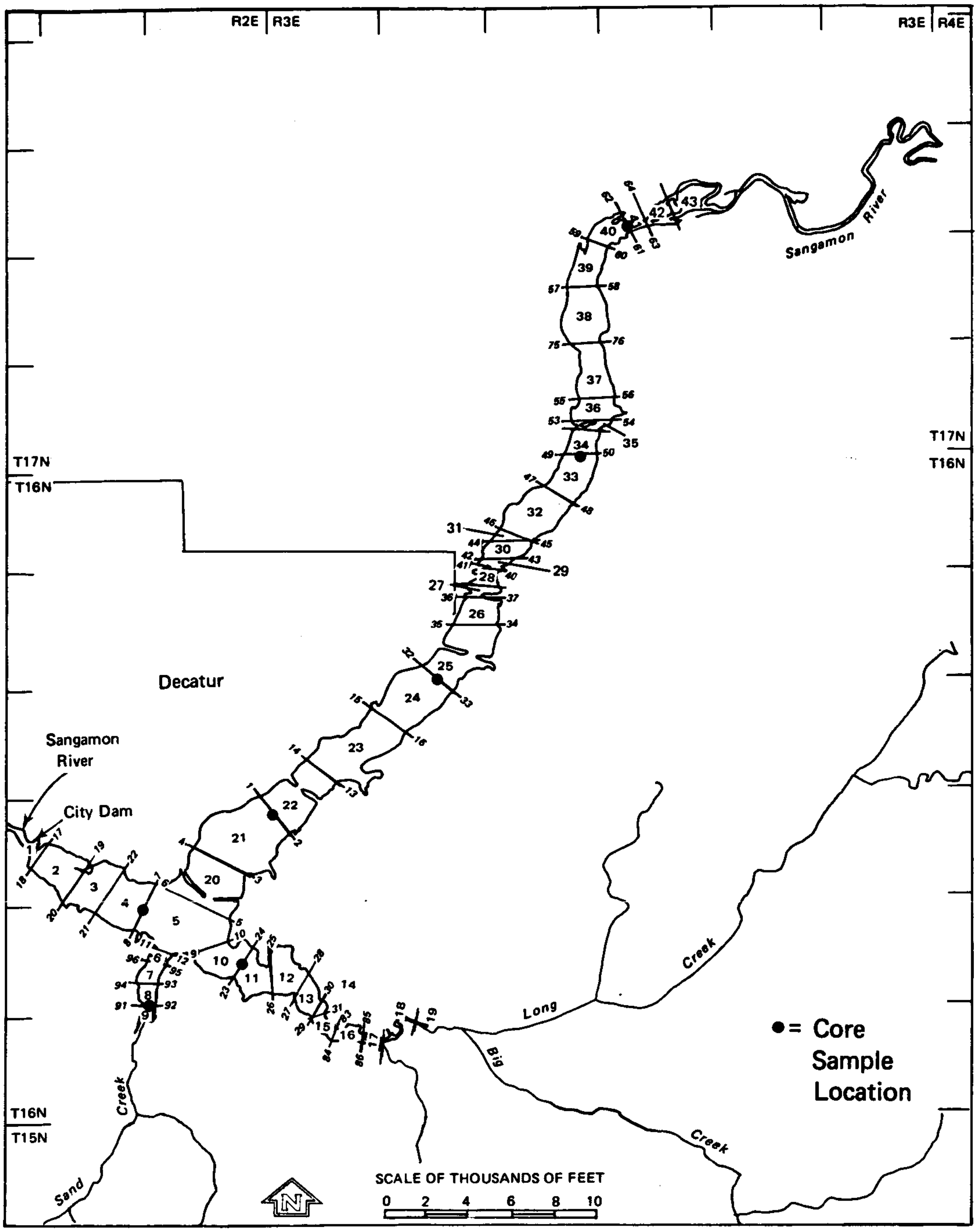


Figure 25. Sediment core sample locations in Lake Decatur

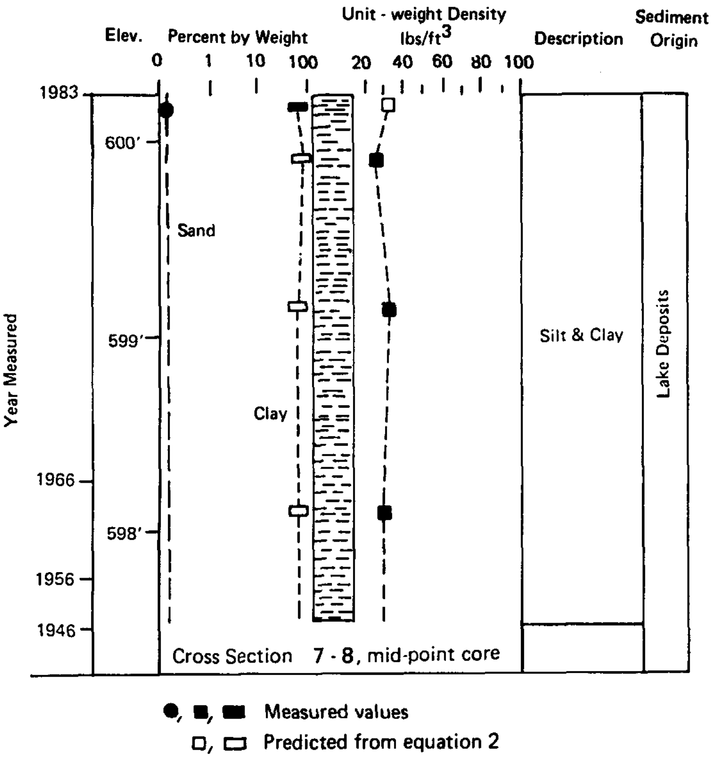


Figure 26. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at mid-point of cross section 7-8, Lake Decatur, 1983

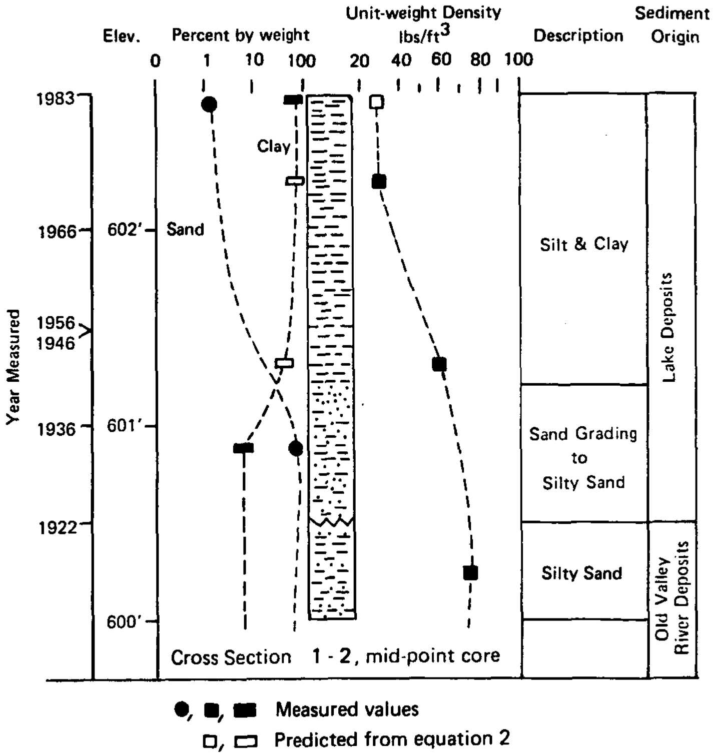


Figure 27. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at mid-point of cross section 1-2, Lake Decatur, 1983

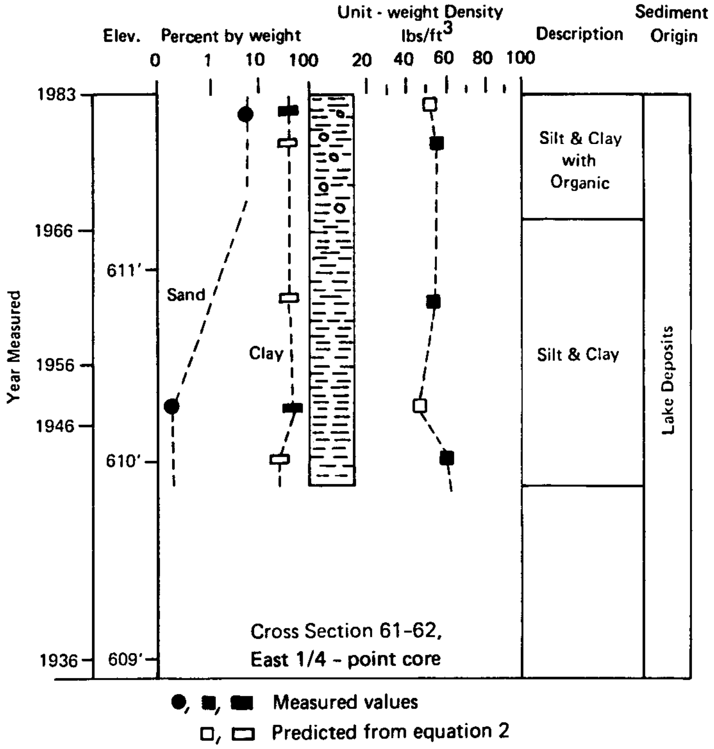
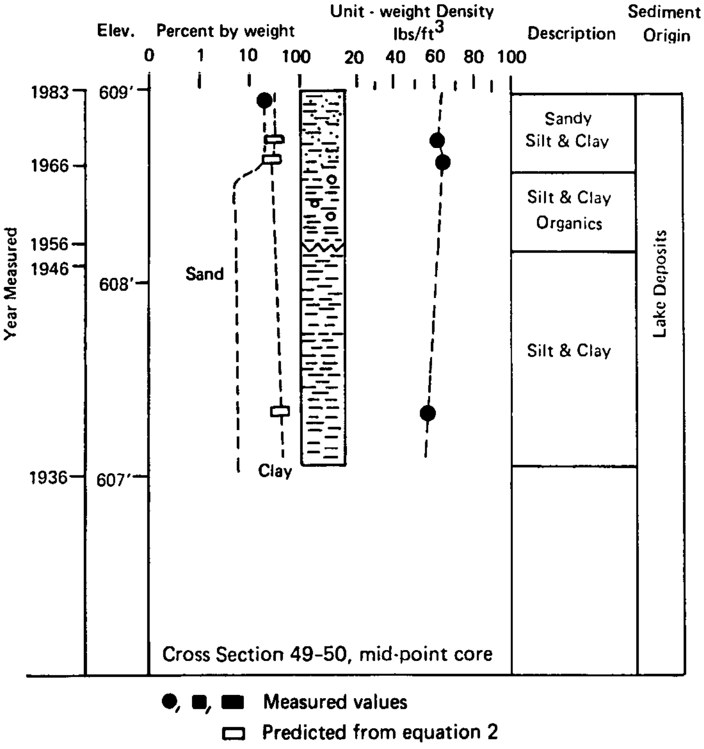


Figure 28. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at east 1/4-point of cross section 61-62, Lake Decatur, 1983

Figure 29. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at mid-point of cross section 49-50, Lake Decatur, 1983



are low, and the unit weight density increases slightly with depth, averaging approximately 60 pounds per cubic foot. The core from 49-50 was obtained just south of Rea's Bridge. The sediment texture grades from sandy silt and clay to all silt and clay. The percentage of sand in the sediment drops off at 0.5 foot below the current lake bed surface. A break in the core just above elevation 608 msl was identified as an aerated layer of silt which was exposed during the 1954-1955 drought and the resulting lowering of the lake level. The unit weight density in this core decreases with depth. Apparently this is the result of increasing clay concentration which decreases the density. The sediments from both upstream cores were lake deposits as the core sampler could not reach the lower sediments from the pre-1922 valley.

The remaining cores were taken in the two tributary arms of the lake. The core from the Big Creek arm at 23-24 (figure 30) shows a higher percentage of sand than was seen in the main lake core samples. An aerated layer was identified in this core as the 1954-1955 lake bed elevation. The core from 91-92 (figure 31) was obtained at the upstream cross section of the Sand Creek arm. This core shows the greatest variability of sediment types of all the samples. The maximum depth of this core was to an approximate elevation of 610 msl. As a result the sediments have periodically been exposed to drying and compaction as indicated by the relatively high unit weight densities.

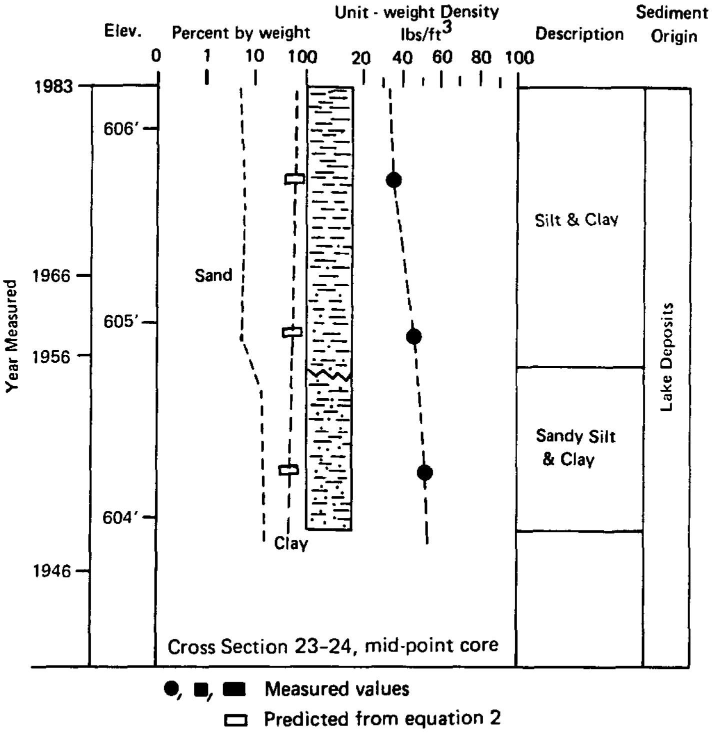


Figure 30. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at mid-point of cross section 23-24, Lake Decatur, 1983

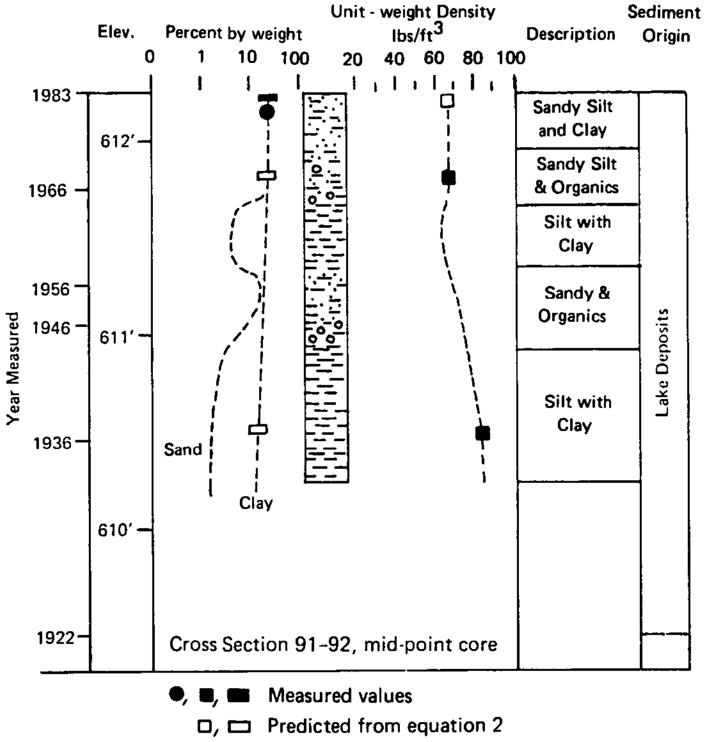


Figure 31. Particle size distribution, unit-weight density, and description of lake bed sediment, and chronographic plot of past lake bed surfaces, at mid-point of cross section 91-92, Lake Decatur, 1983

SEDIMENTATION RATES

Sedimentation Rates by Volume

The reservoir volumes for 1922, 1936, 1946, 1956, 1966, and 1983 were determined using the prismoidal formula as described by the Soil Conservation Service (1968). Basically, the volume of the reservoir is determined as the sum of a series of segmental volumes derived from surface area, cross-sectional area, and cross section width of each segment and cross section.

The 1983 survey sounded 37 range lines. These range lines were used to divide the lake into 38 segments for the purpose of calculating total volume and volume loss in each segment of the lake. As discussed previously, in 1936 the lake was subdivided into 50 segments. The later surveys combined some of the smaller segments into larger segments but retained the original numbering system for consistency. The segment numbers are shown in figure 12.

Lake segments are subdivisions of the lake, each of which is bounded by two roughly parallel range lines and by the two shorelines. End ranges are used for segments which terminate at the mouth of a tributary of the lake. Segments which contain end ranges are generally triangular in shape; the apex represents a cross-sectional area of zero at the intersection of the lacustrine and riverine environment.

The ranges are measured cross sections with a known cross-sectional area for each year of survey. Using the cross-sectional areas of the ranges, the volume of each segment is calculated for each survey-year and the difference in volume from year to year represents the amount of accumulated sediments.

To facilitate the calculation of the volumes as well as the weight of the deposited sediment, the program Primoid was developed on the CDC Cyber system at the University of Illinois. This program was written specifically for the Lake Decatur project but could readily be adapted for other lakes. The full text of Primoid is given in Appendix 2.

The results of these calculations are given in table 6. As stated previously, the effective spillway elevation of Lake Decatur was increased in 1956 from 610 to 615 msl. An elevation of 613 msl was chosen as a representative lake level based on prevailing conditions. All surveys, including the pre-1956 surveys, have been adjusted to this elevation for purposes of comparative analysis. These results show that the storage capacity of the reservoir at an elevation of 613 msl was reduced from 27,900 acre-feet in 1922 to 18,800 acre-feet in 1983. This represents a total volumetric deposition of 9100 acre-feet.

Sediment accumulation rates in the lake were determined on the basis of the 1922 capacity at 613 msl. The sediment accumulation from 1922 to 1983 amounted to 32.6% of the 1922 capacity (at 613 msl) or an average annual accumulation of 0.53% per year. This accumulation resulted in an average deposition of 2.96 feet of sediment on the reservoir bed or an average bed accretion of 0.05 feet per year.

Table 6. Capacity of the Lake, Capacity Loss Rate, and Average Depth, Lake Decatur

Period ending this year	Lake storage capacity (acre-feet)	Lake capacity loss rate per year (acre-feet)	Percent loss per year	Average depth (feet)
1922	27900	-	-	9.0
1936	25100	197	0.71	8.1
1946	22700	240	0.86	7.3
1956	22200	50	0.18	7.2
1966	20800	140	0.50	6.7
1983	18800	118	0.42	6.0
1922-1983	-	149	0.53	-

Table 7 gives the volume of the reservoir segments in 1922 and at the time of the 1936, 1946, 1956, 1966, and 1983 surveys. The differences between these volumes indicate the increased volume of sediment in a given segment and the corresponding decrease in water volume. In some cases, there is a net reduction of sediment in a segment over a period of time. This might result from consolidation of the sediment due to drying (as during the early 1950s) or from localized scour or dredging.

Figure 32 shows the percent volume loss by lake segments from 1922-1983. From this figure it can be seen that the segments which have lost more than half of their volumes are located in the upstream portions of the lake. Most of the segments in the Sand and Big Creek reservoir arms have lost more than 50% of their volume. Segments with the least amount of percent volume loss are found in the deep portions of the lake near the dam.

Sedimentation Rates by Weight

The determination of the volume of sediment that has accumulated over time is useful in that it provides a general picture of the available water storage of the lake. The extrapolation of the previous volume loss rates is needed to estimate the future available storage. The application of previous lake volume analysis to predict future volume loss is limited by the fact that the density of sediment deposits changes with time and the newer deposits change the volume of the previously deposited sediment. In general the sedimentation rate over time will increase both the volume and mass of lake sediment and correspondingly decrease available water storage. The calculation of the sedimentation rates by weight provides the data necessary to determine the amount of material washed into the lake on the basis of the dry weight of the sediments. This allows a better assessment of the changes in the rate of sediment inflow over time. Once the sedimentation rates by dry weight are determined, a more detailed analysis of watershed erosion and delivery ratios is possible. This section will delineate the methods used for the calculation of the sedimentation rates by dry weight.

Unit weight analysis provides an estimate of the relative density of sediment. The unit weights of 84 samples collected from Lake Decatur are presented in Appendix 1. The dry density of the sediment varies from 25 -to 83 pounds per cubic foot. In general the unit weights are lowest near the dam and highest at the upstream reaches of the lake. Table 5 presents the average unit weight density used for each lake segment to calculate the total sediment weight in the lake in 1983. The unit weight of the sediment in each lake segment was determined by averaging the density for the bounding cross sections of each segment.

Many factors can affect the density of lake sediment and its resulting volume: aeration of the lake bed due to low water levels can compact sediment, different particle sizes occupy different volumes, the weight of sediment above a given point can increase compaction, and other factors such as organic content and rate of sediment input may affect sediment density.

Table 7. Lake Decatur Volume in Acre-feet by Segments, 1922-1983, with 1983 Sediment Tonnages

Segment number	Volume in acre-feet						1983 sediment tonnage (kilotons)
	1922	1936	1946	1956	1966	1983	
1	263	249	240	236	206	189	51
2	1120	1060	1020	1050	963	902	161
3	1250	1160	1110	1120	1080	1010	178
4	1700	1570	1490	1440	1400	1280	301
5	2830	2640	2430	2390	2300	2100	689
6	89	75	64	62	57	46	45
7	224	179	140	131	115	75	218
7	88	89	62	60	52	26	141
9	59	37	26	28	26	11	86
10	674	621	560	544	511	459	244
11	578	509	439	413	391	326	297
12	532	431	340	344	323	249	322
13	259	195	148	159	140	110	187
14	29	21	16	17	13	11	26
15	101	63	52	49	42	40	90
16	100	60	52	46	39	38	96
17-19	120	79	72	65	45	41	127
20	2140	2020	1920	1890	1830	1740	334
21	2850	2700	2540	2520	2440	2300	540
22	1660	1560	1450	1450	1380	1290	392
23	2120	1930	1760	1690	1590	1440	603
24	1580	1430	1300	1250	1180	1060	480
25	1280	1170	1050	1050	978	900	327
26	438	400	347	353	325	302	118
27-28	394	352	302	297	269	258	120
29	159	140	118	116	103	94	60
30	301	266	219	218	192	164	126
31	120	106	90	87	76	65	52
32	1020	862	712	666	595	478	576
33	589	488	395	354	324	256	398
34-35	425	347	277	253	225	181	340
36	359	289	224	211	190	152	317
37	562	459	376	366	332	277	425
38	632	489	423	385	339	291	517
39	343	256	229	195	161	153	285
40	219	179	166	149	124	108	151
41	104	94	87	81	68	56	68
42-43	530	492	452	433	355	297	344
Total	27900	25100	22700	22200	20800	18800	9830

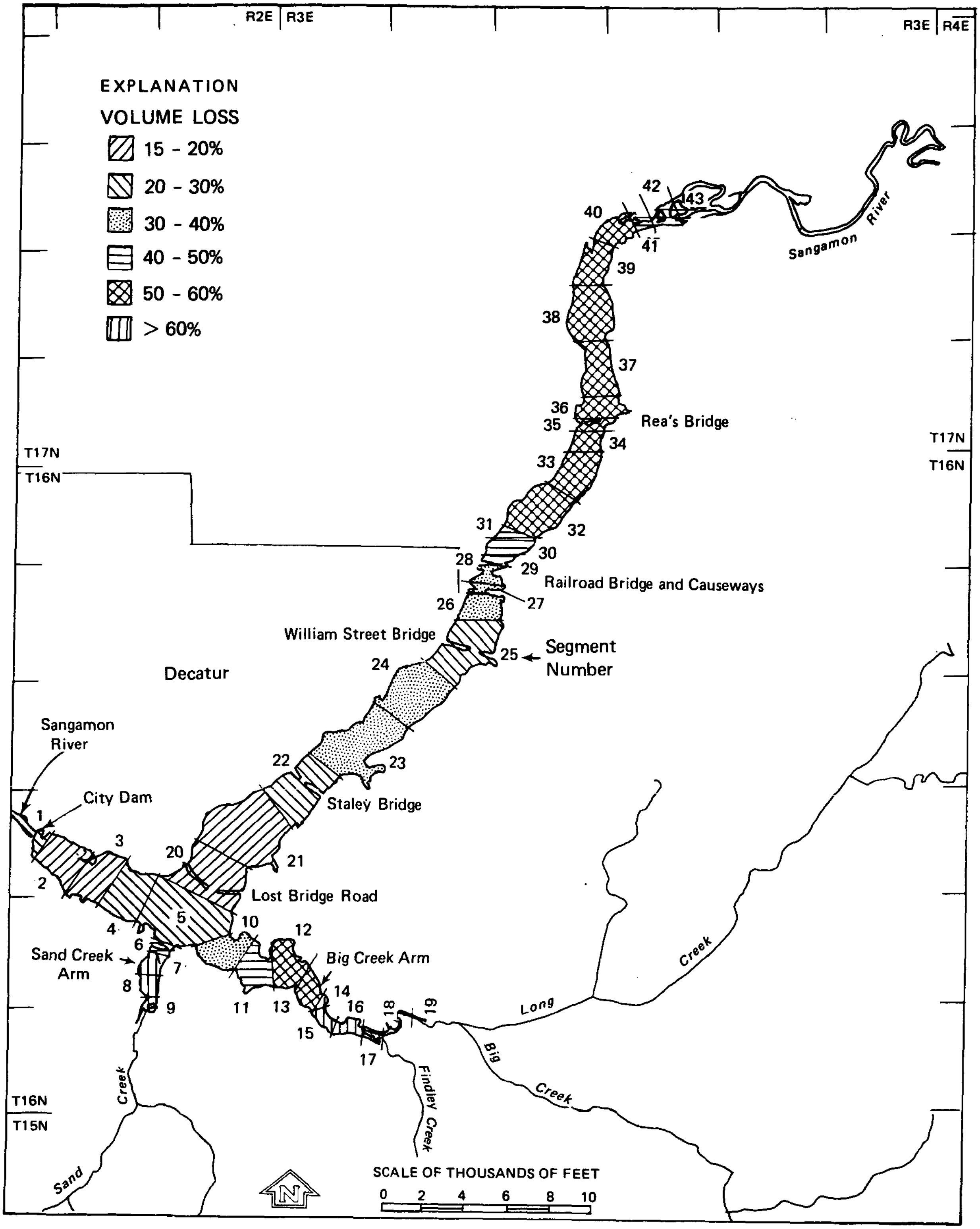


Figure 32. Percent loss of volume in Lake Decatur by segments, 1922-1983

The weight of sediment accumulated in Lake Decatur from 1922 to 1983 was determined on the basis of segmental sediment volumes as described earlier and unit weight of the sediment as determined by the 1983 sediment sampling program. Unit weights determined for sediment samples collected in 1983 were applied to the appropriate segmental sediment volumes. In general, the samples were collected at the midpoint of each cross section, and the unit weight for a segment was determined by averaging the unit weights of the two bounding cross sections.

Sediment weight was calculated for each lake segment by using equation 4. The total tonnage of sediment in the reservoir is the sum of the segmental tonnages :

$$T = (21.78)\ M\forall \tag{4}$$

where

T= the segmental sediment tonnage

21.78 = a unit conversion factor

M = the segmental unit weight in pounds per cubic foot

$\forall$ = the segmental sediment volume

Sedimentation Rates and Watershed Erosion

The amount of sediment in Lake Decatur would equal 0.09 inches of soil if the material were distributed across the watershed area (at an in-field density of 100 pounds per cubic foot). Some of the sediment delivered to Lake Decatur has passed through the lake and was carried over the spillway. If this material is added to the amount of in-lake sediment, the total sediment delivered to the lake amounts to 0.12 inches of soil per watershed acre (weighed long-term reservoir trap efficiency is 77%). The 61-year lake sedimentation rate (in-lake sediment) represents 16.5 tons of soil for each acre of watershed. Correcting for the reservoir trap efficiency, i.e., the sediment carried out of the lake by high flows, the total sediment delivered to Lake Decatur since its construction represents 21.4 tons of soil for each acre of watershed.

SOURCES OF SEDIMENT TO LAKE DECATUR

The principal source of sediments to Lake Decatur is the 920 square miles of watershed (excluding the lake area) drained by the Sangamon River above the Lake Decatur dam. The only measurable non-watershed sediment source to the lake is lakeshore bank erosion. Other very minor sediment sources will not be considered in this analysis. These minor sources include aerosol depositions, intentional construction fills, litter, etc.

Thus the major portion of the sediment in the lake was deposited as a result of the combined processes of soil erosion, sediment transport, and deposition in the watershed, stream systems, and lake. These forces do not operate uniformly throughout the watershed. The impact of various sediment source areas on sedimentation in Lake Decatur will therefore depend on the complex interactions of these three forces.

This section will estimate the relative amounts of sediment deposited in the lake by sub-watersheds or source areas of Lake Decatur sediment. The source areas of sediment and sub-watersheds of Lake Decatur examined in this section are 1) lakeshore erosion, 2) the Big and Sand Creek watersheds, which empty directly into Lake Decatur, 3) the small unnamed watersheds that drain the bluffs around Lake Decatur and flow directly into the lake, 4) the Sangamon River watershed above Monticello, and 5) the Sangamon River and its tributaries below Monticello and above Lake Decatur (see figure 33).

Lakeshore Bank Erosion

Earlier studies estimated the volume of sediment in Lake Decatur generated by lakeshore erosion. Brown et al. (1947) determined that over the 10 years preceding their report 1.5% of the total sediment in the lake was derived from lakeshore erosion.

In the 1983 survey a field reconnaissance of the lakeshore was conducted, and surveyed lake cross sections were used to calculate the area of lakeshore eroded. The volume of material removed by erosion between surveyed cross sections was calculated by using the average end area method. The distances along the lakeshore used to calculate the volumes of eroded material were determined from field observations. A summary of the magnitude and extent of lakeshore erosion is presented in figure 34. The total estimated erosion over the years 1936-1983 is 81 acre-feet of the original on-site bank materials. Applying an in situ density of 95 pounds per cubic foot yields 168,000 tons of bank material washed into the lake. Dividing by the time span of the data (47 years) yields 3600 tons per year. The total amount of sediment currently in the lake is 9.83 million tons, as shown in table 7. This value converts to an annual rate of 161,000 tons. The comparison of the annual sedimentation rates for lakeshore erosion and total sediment provides an estimate that 2.2% of the total yearly sediment deposited in the reservoir is the result of lakeshore bank erosion.

The value of 2.29 of the total lake sediment contributed by bank erosion must be qualified. This number is a conservative estimate based on the lakeshore areas with measurable erosion. It is expected that just about every portion of shoreline has lost some material to erosion; however, no estimate was made of the quantity of material lost in these areas with less severe erosion.

The areas of the most severe lakeshore bank erosion, as shown in figure 34, are the south shore approximately 1/2 mile upstream of the dam and the west shore bluff upstream of Rea's Bridge. The west shore approximately 1 mile upstream of Rea's Bridge was estimated to have contributed 58% of the total bank material eroded from 1936-1983. This area has a 70-foot-high

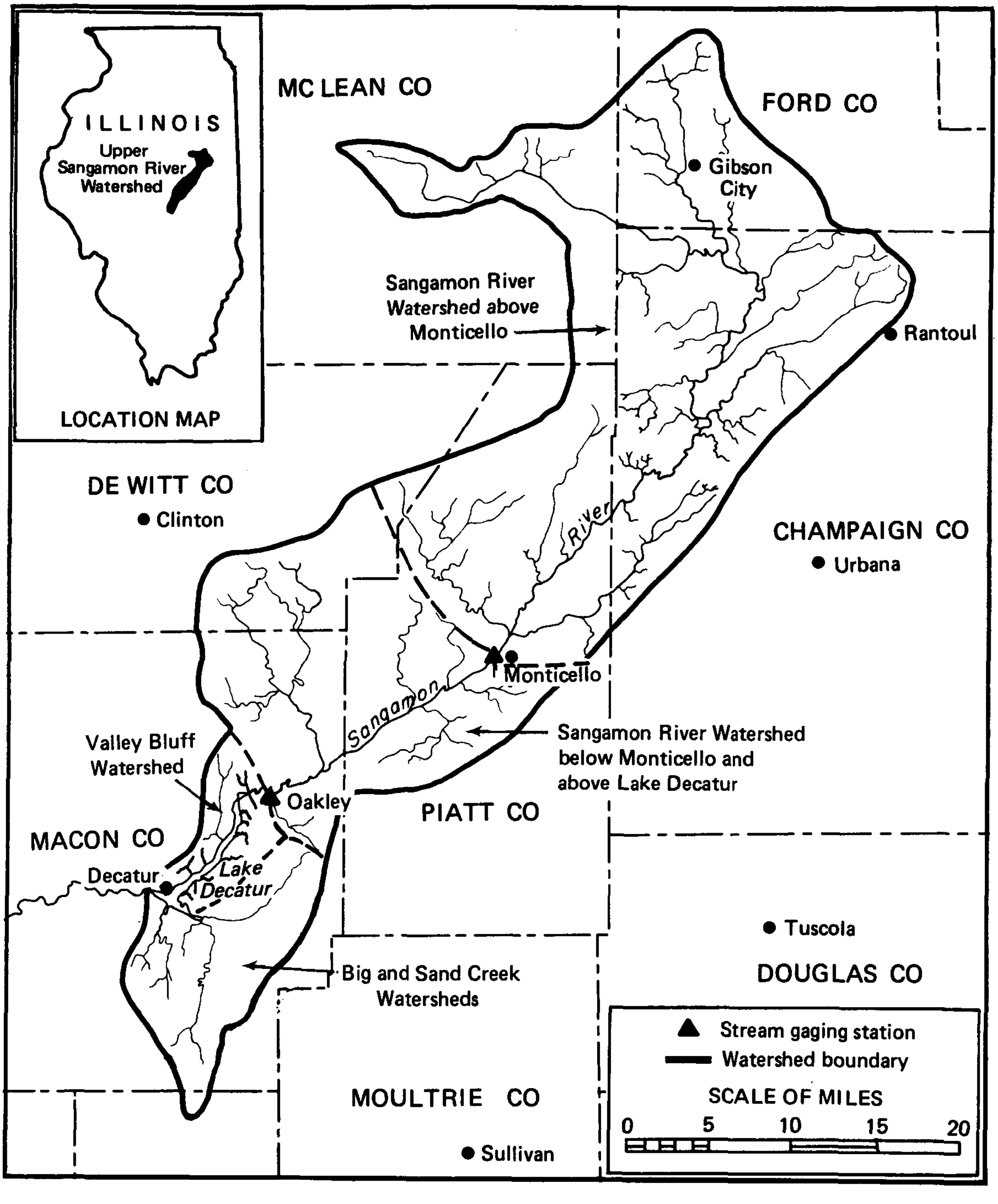


Figure 33. Location of Lake Decatur and the Upper Sangamon River watershed, showing the major source areas of sediment to Lake Decatur

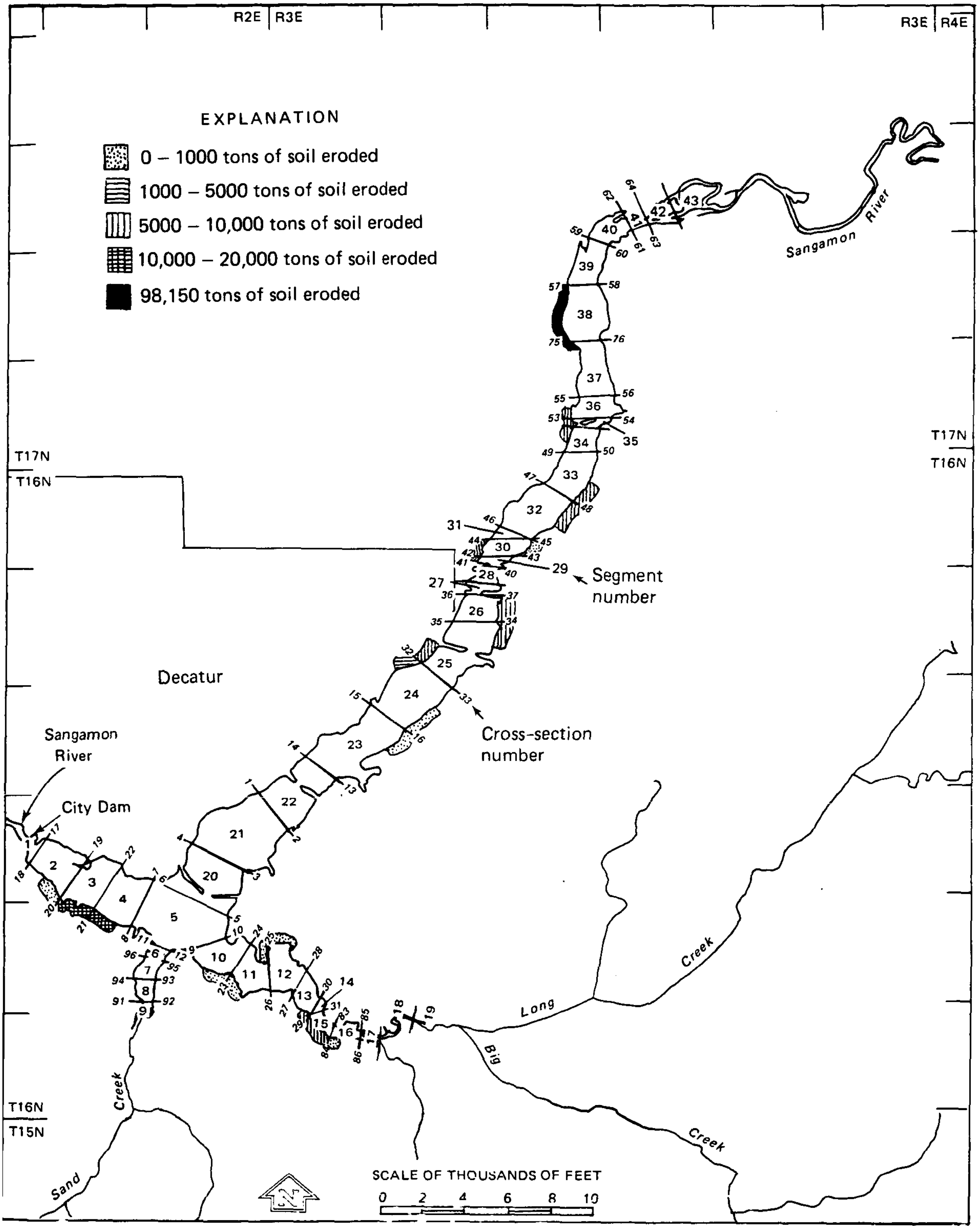


Figure 34. Lake Decatur lakeshore erosion, 1936-1983

bluff that was estimated to have eroded back as much as 40 feet over the 47 years of data. Other major areas of lakeshore bank erosion are the east shore opposite Faries Park; the west and east shore downstream and upstream of the William Street Bridge, respectively; and the south upstream shore of the Big Creek tributary arm.

The areas discussed above are the major contributors of eroded bank material and are coincident with steep valley bluffs. Other areas of lakeshore with more gentle slopes are also susceptible to bank erosion from waves; however, these areas have been armored with riprap and the banks appeared to be stable.

Big and Sand Creek Watersheds

The two major tributaries of the lake are Big and Sand Creeks. For this discussion the term Big Creek will refer to Long, Findley, and Big Creeks, which come together at the headwater of the Big Creek arm of the lake. To estimate the total amount of sediment delivered by these tributaries, we will assume that each of the two tributary arms of the lake can be considered as a separate subreservoir. Further, if we assume that the sediment in place in the two major arms of the reservoir was deposited from the tributaries emptying into the reservoir arm, we will have the means of estimating relative sedimentation rates.

In this assumption reservoir trap efficiency is neglected for each subreservoir. It is believed that some of the sediment that leaves the subreservoirs is partially replaced by sediment deposited from Sangamon River water that mixes with the Big and Sand Creek tributary waters in the subreservoirs.

The two subreservoirs examined in this section are the Big Creek subreservoir which is the arm of Lake Decatur containing segments 10 through 19, shown in figure 34; and the Sand Creek subreservoir containing lake segments 6 through 9.

In 1922, the year of the lake's construction, the two subreservoirs contained 10.4% of Lake Decatur's volume. In 1983 these subreservoirs contained 7.6% of the total volume. Table 8 presents the long-term average annual percent volume loss and the watershed sediment yields for each subreservoir and Lake Decatur. From this table it can be seen that the annual percent volume loss rate in the subreservoirs, when compared with that of Lake Decatur, is 100% higher for the Sand Creek subreservoir and 50% higher for the Big Creek subreservoir. Table 8 lists the long-term average annual sediment yield to Lake Decatur and the subreservoirs.

From table 8 it can be seen that in general the smaller the watershed, the higher the sediment yield rate per unit area. The 61-year annual sediment yield rates for Lake Decatur and the Big Creek and Sand Creek subreservoirs are 0.27, 0.50, and 0.90 tons per acre, respectively. The annual rate for Sand Creek is over three times higher than the rate for Lake Decatur, and the rate for Big Creek is nearly twice as high as that for the

Table 8. 61-year Volume Loss Rate and Watershed Sediment Yield to Lake Decatur and the Big Creek and Sand Creek Subreservoirs

	1922 volume (acre-feet)	% volume loss per year	Watershed area (acres)	Watershed sediment yield (tons/acre/year)
Lake Decatur	27,860	0.5	592,000	0.27
Big Creek	2,392	0.8	45,430	0.50
Sand Creek	495	1.1	8,970	0.90

main lake. The sediment in the Big and Sand Creek subreservoirs represents 14 and 5% of the total Lake Decatur amount, respectively. The sediment in these subreservoirs, 19% of Lake Decatur's total, was deposited in an area of the lake that in 1922 encompassed 10.4% of Lake Decatur's volume.

The lake and subreservoir volume loss rates and watershed sediment yields for the time intervals between lake surveys are shown in figure 35. This figure illustrates the disproportionate sedimentation rates for the subreservoirs as compared with Lake Decatur. The sedimentation rates, shown by the percent of original volume plot, were fairly constant for Lake Decatur and the Big Creek subreservoir over the 27 years preceding this study. Over this same period the sedimentation rate for Sand Creek accelerated, increasing approximately 75% in the last 17 years of the 27-year period. The cause of the accelerated sedimentation for the Sand Creek subreservoir is unknown , but it most likely reflects changes in land use or management practices. The variability in the rates of sedimentation in the lake and subreservoirs, and hence the erosion and transport rates on the watersheds, illustrate the complex nature of sedimentation studies.

In comparing figure 35 with table 8 it can be seen how the sediment yields of the watersheds have deviated from the average. For the last 17-year period the sediment yield of Sand Creek was 97% of the 61-year average, whereas the sediment yield of Big Creek was 70% and that of Lake Decatur was 96%.

The sediment yield plots in figure 35 show that with the exception of the "dry years" of 1946-1956, the yield rate for Lake Decatur has been fairly consistent over time. The rate for Lake Decatur has varied by 30%, whereas the rate for Sand Creek has varied by over 60%. The difference in the variation in the yield rate per area is expected; the watershed of Lake Decatur is 66 times larger than that of Sand Creek and due to its larger size it moderates the rate changes better than the smaller watersheds. The subdued changes in sedimentation rates in Lake Decatur as compared with the subreservoirs can also be seen in the percent of original volume plot in figure 35. The changes in the slope of the lines in this plot are the greatest for the Sand Creek subreservoir, less for the Big Creek subreservoir, and the least for Lake Decatur.

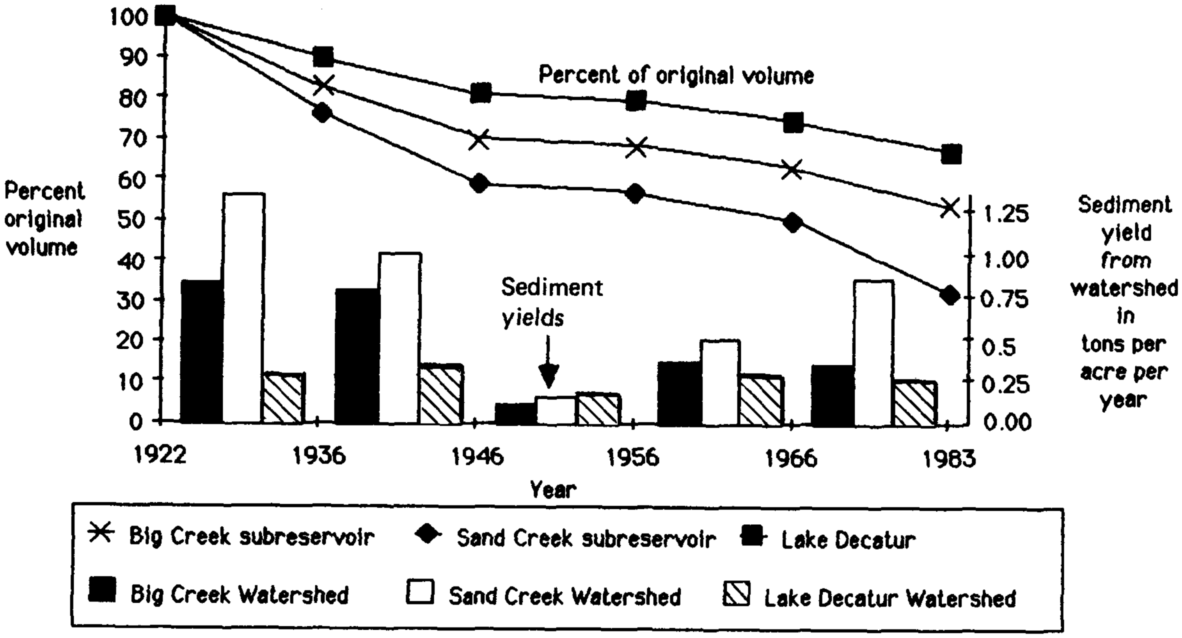


Figure 35. Percent of original volume and watershed sediment yield, Lake Decatur and the Big Creek and Sand Creek subreservoirs, 1922-1983

It is inferred from these data that in general smaller watersheds have higher variability in sediment yield rates than larger watersheds. In summary, a general conclusion concerning watershed size and sediment yield rates is that as watershed size decreases, sediment yield per unit area increases and the variability in the rate over time increases.

Valley Bluff Watersheds

Approximately 60 square miles of the Lake Decatur watershed are drained by small tributaries that empty directly into the lake. These small tributaries drain the valley bluffs around the lakeshore and the high ground behind the bluffs. The headwaters of these tributaries range from 50 to 100 feet above the lake surface, and the stream lengths average approximately one mile. The drainage areas range from a few hundred acres to several square miles. Much of the area drained by these unnamed streams is located in the valley bluffs with steeper slopes than Big or Sand Creeks.

In order to assess the relative contribution of sediment from the small valley bluff watersheds, the assumption was made that the average annual rate of sediment per watershed area is higher on the valley bluff watersheds than on Big or Sand Creeks. These bluff watersheds have gradients that exceed 100 feet per mile and generally have very short transport distances to the lake. For this study the 61-year sediment yield rate is estimated to be 1.25 tons per acre per year.

The current sediment yield rate was estimated to be 0.94 tons per acre per year (SCS, 1983). It is expected that, as was shown for the Big and Sand Creek watersheds, the long-term sediment yield rate is greater than the current rate. Applying the estimated 61-year sediment yield rate to the watershed area for the period of time since the lake's construction will allow an estimate of the proportion of total sediment in Lake Decatur from this area. The area drained by the bluff watersheds is 37,960 acres. Therefore the average yearly sediment yield is 47,450 tons. The 61-year total is estimated to be 2.9 million tons or 29% of the 9.83 million tons of sediment in Lake Decatur.

Sangamon River above Monticello

To determine the relative contribution of sediment by the Sangamon River, an analysis of instream sediment load was made for the Sangamon River at Monticello and was extended to the Sangamon River at the Lake Decatur Dam.

The discharge of the Sangamon River has been monitored by the U.S. Geological Survey since 1915 at the city of Monticello, Illinois. Since October 1980, the Monticello gaging station has been included in the State Water Survey's Instream Sediment Monitoring Program. Under this program, sediment discharge of the Sangamon River at Monticello has been monitored on a bi-weekly basis. A 2-year record of field data was used to develop a relationship between suspended sediment transport and water discharge for the Monticello station.

The analysis of the Sangamon River sediment transport proceeded in the following manner:

1) A regression analysis of the Instream Sediment Monitoring Program field data for the Sangamon River at Monticello was made (sediment transport curve) (Bonini et al., 1983).

2) From the sediment transport curve and the daily flow duration table of the Monticello station, an annual sediment transport rate analysis was made for the Monticello station.

On the basis of this analysis, the sediment discharge past the Monticello gaging station during the period 1923-1982 was 4.39 million tons. Not all the sediment passing the Monticello gaging station actually reaches Lake Decatur. A portion of the material is lost in transit primarily as channel and floodplain deposition. In their 1983 report, SCS predicted a delivery ratio of 63% from Monticello to Lake Decatur. That is, they predicted that 63% of the sediment passing Monticello actually reaches Lake Decatur. Thus sediment delivery to the lake from the Monticello station is 2.77 million tons.

Finally, allowing for a trap efficiency of 78% for Lake Decatur, the amount of accumulated sediment in the lake that originated above Monticello is 2.16 million tons or 22% of the 9.83 million tons of sediment in Lake Decatur.

Sangamon River below Monticello and above Lake Decatur

The flow of the Sangamon River is monitored by the USGS at a bridge near Oakley, Illinois. This station is 13.5 miles upstream of the dam at Lake Decatur and is considered in this study to be the headwater of the lake. Oakley monitors the flow from 774 square miles of the Sangamon River watershed. The period of record at this station is continual for the years 1951-1956 and fragmentary since 1956. The fragmentary record includes monitoring only during high flow on the river. Currently no sediment monitoring data are available for this station.

The Oakley station monitors 84% of the Lake Decatur watershed and is a key station in any evaluation of the sources of the sediments in the lake. A flow duration curve for the station was synthesized to fill in the gaps in the discharge record since 1956 since only high flows were monitored over this period. This information was combined with the continuous record at Oakley representing the years 1950 to 1956 to yield a complete discharge record from 1950 to 1982. This continuous record was then entered into the sediment discharge relationship developed for the Monticello station to yield a value for the total quantity of sediment transported past the Oakley station during the period 1950-1982. The results indicate that the sediment yield to the lake for the area included in the watershed from Monticello to Oakley is 1.21 times the total sediment yield from the watershed above Monticello. Therefore, based on the estimated 22% of the total lake sediment from above Monticello, the area below Monticello and above Oakley yields 27% of the sediment in Lake Decatur.

The results of this analysis are presented in table 9, which summarizes all of the estimated sediment yields by source area. From table 9 it is seen that the relative impact of a sediment source area is related both to the size of the source area and its distance from the lake. Thus, the source area with the largest yield per unit area is the bluff watersheds which are actually the summation of a group of small watersheds draining directly into the lake. Conversely, the source area with the lowest yield per unit area is

Table 9. Sources of Sediment to Lake Decatur: Estimated Proportion of Total Lake Sediment and Sediment Yield by Source Area

Source	Percent lake watershed area	Percent total lake sediment	Yield to lake (tons/acre/year)
All sources	100	100	0.27
Sangamon River above Monticello	59	22	0.10
Sangamon River below Monticello and above lake	25	27	0.29
Bluff watersheds	6	29	1.25
Big and Sand Creeks	9	19	0.56
Lakeshore erosion	-	2	-

the area above Monticello, which at 550 square miles is the largest area considered in this analysis and also the most remote from the lake.

It is emphasized that these values are only estimates and should not be interpreted as definitive evaluations of sediment loads from the various source areas.

FACTORS INFLUENCING THE VARIABILITY OF SEDIMENTATION RATES IN LAKE DECATUR

Lake sedimentation is a process that can be viewed as the end product of three general forces: erosion, sediment transport, and deposition. Some of the variables that affect these forces are as follows:

1) Erosion rates are influenced by such factors as topography, geology, soil types, land use, land cover, and volume, rate, and type of precipitation.

2) Transport of sediment is influenced by channel slope, channel shape, channel roughness, amount of overbank flow, and volume and rate of runoff .

3) Sediment deposition is influenced by the shape, capacity, and depth of the reservoir as well as by outflow rates, existence of either living or dead vegetation, and exposure of sediments to drying and compaction (Bogner, 1983).

Many of these variables are constant over time, and others are very dynamic and constantly changing. The ultimate goal of the study of lake sedimentation is to determine the effect of the interaction of these variables and to be able to accurately predict rates of lake sedimentation. Currently this goal has not been achieved. The best conceptual and mathematical models developed for determining past and future rates of lake sedimentation provide only rough qualitative estimates. These rough estimates are clearly inadequate to meet the needs of a municipality concerned with managing and planning water supplies. For this reason field mapping of water supply reservoirs is imperative.

For this study many of the variables that influence the forces of erosion, transport, and deposition have been examined. As part of the background documentation of the characteristics of the watershed, sections of this report have documented the changes over time in variables such as intensity of land use (row crop acreage), precipitation and streamflow (average flows, high and low flows), land management (conservation efforts), and reservoir trap efficiency. Two factors were found to correlate with the sedimentation record in Lake Decatur. These are increases in land use for corn and soybean acreage and peak flow in the Sangamon River.

A qualitative relationship was observed between corn and soybean acreage in the six major counties of the watershed and the lake's sedimentation rate. In figure 8 it can be seen that major increases in corn and soybean acreage occurred in the mid-1930s, the early 1940s, the mid-1960s, and the early 1970s. These periods coincide with the four highest lake sedimentation rates. The period 1946 to 1956 showed an overall decrease in corn and soybean acreage in the watershed and also had the lowest sedimentation rate. Beyond this very qualitative relationship the correlation of corn and soybean acreage to sedimentation rates becomes poor. For example, the period 1966-1983 had the largest increase in total acreage of all the survey periods but the second lowest lake sedimentation rate.

The flow records of the Sangamon River were examined to determine correlations with sedimentation rates in Lake Decatur. Four factors were examined related to streamflow: average annual discharge, period peak discharge, average peak discharge, and the three highest yearly peak discharges for each period. The best correlation with lake sedimentation was observed for the three highest yearly peak discharges.

The sum of the three highest peak discharges at the Monticello station for each period is presented with the annual sedimentation rate in Lake Decatur in table 10. It can be seen in this table that the ranking of sedimentation rates agrees with the ranking of the sum of the three highest discharges for three of the five time periods. Further examination of the flow records indicated that this relationship could be improved. The highest peak discharge of the period 1946-1956 occurred 15 days before the 1956 lake survey began. It is probable that much of the sediment generated by this storm-discharge event did not reach the lake prior to the 1956 survey. This storm-discharge event was the third highest peak annual flow in the last 61 years. The flow was calculated to have been 12,300 cfs or 8 billion gallons per day. It was decided to shift this peak flow ahead to the period 1956-1966 and re-examine the correlation.

The adjusted values for the sum of each periods' three highest flows are shown in table 10. The results show a good correlation between this variable

Table 10. Lake Decatur Sedimentation Rates and Flow of the Sangamon River at Monticello, Illinois: Sum of the Three Highest Annual Peak Discharges per Survey Period

Period	Lake sedimentation (tons/acre/year)	Three highest annual peak discharges (1000 cfs)	Adjusted three highest annual peak discharges (1000 cfs)*
1922-1936	0.29	35.1	35.1
1936-1946	0.36	36.2	36.2
1946-1956	0.17	28.0	20.5
1956-1966	0.28	26.4	31.1
1966-1983	0.26	27.8	27.8

* Adjustment made to shift highest peak discharge for 1946-56 period (which occurred 15 days before the 1956 lake sedimentation survey began) to 1956-66 period

and yearly sedimentation rates in Lake Decatur. A regression analysis between these two factors showed a correlation coefficient of 95%; however, the data set is quite small and much more work remains to be done before this correlation is proposed as a predictive tool.

A more detailed examination of the variables discussed above and others may yield better correlations and ultimately determine the exact causes and effects of lake sedimentation processes. However, this effort is beyond the scope and resources of this investigation.

SUMMARY

Overview of the Study Area

Dam and Reservoir

Lake Decatur is a man-made reservoir located in the City of Decatur, Macon County, Illinois. The reservoir was built in 1922 to insure a reliable source of potable water to the growing city. The lake was created by impounding the flow of the Sangamon River behind a dam with a crest 28 feet above the river bottom and a length of 1/3 mile across the river valley.

The city dam at Decatur created a lake with a volume of approximately 20,000 acre-feet and an area of 4.4 square miles. Subsequent construction in 1956 raised the effective dam crest and increased the area to 4.8 square miles and the volume to 28,000 acre-feet (excluding accumulated sediment).

In addition to impounding water for the lake, the city dam also created a sediment trap where the sediment load of the Sangamon River and its tributaries could no longer pass through the valley in the same manner as occurred prior to the dam. As a result the lake has lost much of its water-storing capability due to the accumulated sediment displacing available storage.

Watershed

The drainage area of the Sangamon River and its tributaries upstream of the dam at Decatur is 925 square miles. This watershed extends into portions of seven counties in east-central Illinois. The regional climate is favorable to agriculture; the growing season averages 173 days and the annual rainfall averages 39 inches. The prairie soils were formed on glacial till and loess deposits and are very productive. The watershed topography is flat to gently rolling and well suited to mechanized agriculture.

Historically the trend in the watershed land use is towards increasing row crop acreage, currently encompassing 87% of the land area. The historical trend in soil and water conservation is towards increasing application of new methods and technologies to reduce erosion. Currently, the average gross erosion in the watershed is 4.5 tons of soil per acre per year.

Sangamon River

This river drains 925 square miles upstream of the dam at Decatur and has a main-stem length of 241 miles. The river is a low gradient stream (1.7 feet per mile) which wanders across its valley bottom forming meanders and side channels. The bed of the river is predominantly sand and gravel, whereas the sediment load of the river is mainly silt and clay. Annually the river delivers approximately 200,000 tons of sediment to the lake, of which 22% on the average flows through the lake and passes over the dam.

The flow of the river is quite variable, with an average daily discharge to the lake of 439 mgd (680 cfs). The flows measured at Monticello, encompassing 60% of the watershed area, range from a maximum of 1200 mgd (18,700 cfs) to a minimum of 0.1 mgd (0.2 cfs).

Results

The 61 years of record of sedimentation in Lake Decatur provided by the surveys of 1936, 1946, 1956, 1966, and 1983 have documented a long-term volume loss rate of 0.53% per year. Currently the lake has lost one-third of its original volume (1922 volume at spillway elevation 613 msl). Rates of volume loss have varied from 0.18% per year (1946-1956) to 0.86% per year (1936-1946). The rate over the past 17 years was 0.42% per year, which is less than the long-term average.

Currently there is 9100 acre-feet of sediment in the lake, representing 9.83 million tons of material. The long-term average rate is 160,000 tons of accumulation per year. Rates have varied from 210,000 tons per year (1936-1946) to 100,000 tons per year (1946-1956). The rate over the past 17 years was 150,000 tons per year.

The volumetric and tonnage rates discussed above indicate that the sedimentation rate over the past 17 years is less than the long-term average. By inference this indicates that the watershed erosion rates over the past 17 years were also less than the long-term average.

Table 11 summarizes the annual rates of sedimentation in Lake Decatur for each survey period. The rates presented in table 11 are shown graphically in figure 36.

The sediment in Lake Decatur is predominantly clay. The averages of all samples are: 57% clay, 36% silt, and 7% sand. Currently the average dry-weight density is approximately 50 pounds per cubic foot.

Table 9 summarizes the sources of sediment to Lake Decatur by watershed area.

Table 11. Annual Sedimentation Rates in Lake Decatur

Period	Storage capacity loss rate (acre-feet)	Tons of sediment	Tons of sediment per acre of water shed
1922-1936	200	170,000	0.29
1936-1946	240	210,000	0.36
1946-1956	50	100,000	0.17
1956-1966	140	170,000	0.28
1966-1983	120	150,000	0.26
1922-1983	150	160,000	0.27

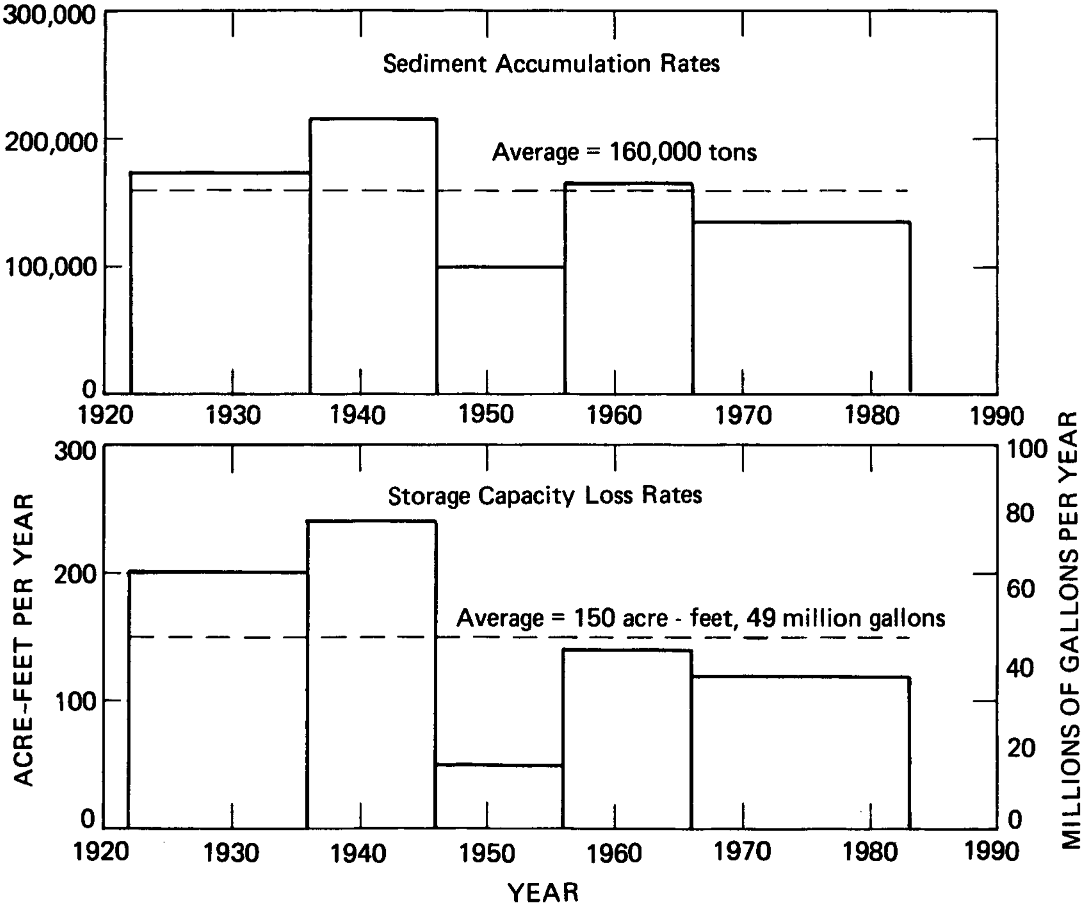


Figure 36. Summary plots of sedimentation rates in Lake Decatur: sediment accumulation rates per time period in tons per year, and total storage capacity loss per time period in acre-feet and million gallons per year

The proportions of Lake Decatur's lake bed sediment from each watershed area were determined on the basis of the best information currently available. These values are estimates, the accuracy of which can be increased only by further study of the watershed of Lake Decatur. Basic data collection efforts in the watershed related to streamflow and stream sediment load would be invaluable in any study to determine the actual and relative sediment contribution from different watershed areas.

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Appendix 1. Lake Decatur Particle Size and Unit Weight Analysis

Appendix 1. Lake Decatur Particle Size and Unit Weight Analysis

X-Section	Depth below lake bed to mid-pt. of sample (ft)	Percent by weight			Density lb ft^3
		Clay	Silt	Sand	
17-18	0.1	78.78	20.83	0.39	
	0.25				28.53
	0.95				28.29
	1.2	80.05	19.45	0.50	
	1.65				31.33
19-20	0.1	76.95	22.65	0.40	
	0.25				31.56
	1.25				32.20
	2.25				36.18
21-22	0.1	73.29	26.51	0.20	
	0.35				29.98
	1.35				32.17
07-08	0.1	72.44	27.47	0.09	
	0.35				26.54
	1.25				32.67
	2.15				30.28
11-12	0.1	65.53	34.26	0.21	
	0.35				31.29
	1.35				33.58
	2.55				44.33
95-96	0.1	48.41	51.48	0.11	
	0.35				36.28
	2.35				51.77
91-92	0.1	25.75	44.01	30.24	
	4.5				66.32
	1.75				82.73
09-10	0.1	66.95	32.92	0.13	
	0.35				33.96
	0.65				42.84
	0.85				51.17
23-24	0.45				34.09
	1.25				46.01
	1.95				52.65
25-26	0.75				55.44
27-28	0.1	37.38	62.11	0.51	
	0.55				42.11
	0.85				43.96
27-28	1.55				48.96
	1.6	43.22	56.36	0.42	
29-30	0.45				49.72
	1.25				64.13
	1.55				66.63
83-84	0.1	57.68	40.50	1.82	
	0.15				49.47
	0.65				69.09
	1.15				65.41

Appendix 1. Continued

X-Section	Depth below lake bed to mid-pt. of sample (ft)	Percent by weight Clay	Silt	sand	Density $\frac{lb}{ft^3}$
85-86	0.1	47.87	48.19	3.94	
	0.45				76.83
	0.75				74.37
5-6	0.1	73.94	24.12	1.94	
	0.35				39.41
	0.85				46.28
	1.35				65.01
3-4	0.1	79.36	20.59	0.05	
	0.45				25.33
	1.4	87.12	12.37	0.51	
	1.75				31.23
1-2	0.1	77.70	20.21	2.09	
	0.45				29.31
	1.35				59.28
	1.8	7.06	7.87	85.07	
	2.45				75.52
13-14	0.1	70.67	29.15	0.18	
	0.25				28.23
	1.15				37.86
15-16	0.1	69.32	30.57	0.11	
	0.25				28.19
	1.05				31.63
	1.75				43.69
32-33	0.1	65.56	33.76	0.68	
	0.45				31.33
	1.2	64.24	34.26	1.50	
	1.65				39.92
34-35	0.1	48.10	21.21	30.69	
	0.25				32.40
	1.2	44.08	54.88	1.04	
40-41	0.1	75.15	24.63	0.22	
	0.45				33.08
	1.25				34.36
	1.6	71.18	28.48	0.34	
	2.05				40.56
42-43	0.1	61.89	38.06	0.23	
	0.45				32.64
	1.55				40.25
	2.0	66.76	33.06	0.18	
	2.35				43.39
44-45	0.1	58.49	41.36	0.15	
	0.25				31.80
	1.15				37.86
	1.8	61.86	37.81	0.33	
	2.05				40.86

Appendix 1. Concluded

X-Section	Depth below lake bed to mid-pt. of sample (ft)	Percent by weight			Density $\frac{lb}{ft^3}$
		Clay	Silt	Sand	
45-46	0.25				31.46
	1.05				40.08
	1.75				45.44
47-48	0.35				36.01
	1.15				52.55
49-50	0.1	49.95	42.18	7.87	
	0.1	26.97	23.17	49.86	
	0.25				62.72
	0.35				64.67
	1.65				57.36
55-56	0.1	49.64	49.93	0.43	
	0.35				39.78
	1.4	34.93	42.72	22.35	
	1.75				70.53
75-76	0.1	44.83	54.97	0.20	
	0.35				41.87
	0.95				46.85
	1.65				66.12
57-58	0.1	45.78	50.56	3.66	
	0.25				44.13
	1.05				62.72
	1.4	33.43	63.51	3.06	
	1.75				73.50
59-60	0.1	33.74	41.75	24.51	
	0.15				49.75
	1.35				64.17
61-62	0.1	44.42	47.99	7.59	
	0.25				54.87
	1.05				53.52
	1.6	54.44	45.31	0.25	
	1.85				61.61
63-64	0.45				61.51
	1.75				67.71

Appendix 2. Primoid -- A FORTRAN Program for the Calculation of Lake Volumes on the Basis of the Dobson Prismoidal Formula

```
      PROGRAM PRIMOID (INPUT,OUTPUT)
      INTEGER TOTSEG,TOTYR
      DIMENSION  A(101),W(101),APRIME(101),VOL(101,6),TOTVOL(6),
     $TPUW(101),BTMUW(101),SEDVL(101,6),WGT(101,6),TOTWGT(6),TOTSD(6)
      DATA TOTVOL/6*0.0/,TOTWGT/6*0.0/
      IN=5
      IOUT=6
C
C
C         PRIMOID-- A FORTRAN PROGRAM FOR THE CALCUIATION OF LAKE
C            VOLUMES USING THE DOBSON PRISMOIDAL FORMULA
C
C
C                             BY
C                         KURT JOHNSON
C                            AND
C                         BILL BOGNER
C
C
C     PRIMOID CALCULATES THE VOLUME OF A LAKE FOR A GIVEN NUMBER OF
C     SURVEY YEARS. FOLLOWING THE VOLUME CALCULATION, PRIMOID
C     DETERMINES THE VOLUME AND TONNAGE OF SEDIMENT ACCUMULATION IN THE
C     LAKE BETWEEN SURVEY YEARS AND FOR THE TOTAL PERIOD OF EXISTENCE OF
C     THE LAKE.
C
C     THE CALCULATION IN THIS PROGRAM IS BASED ON THE DOBSON PRISMOIDAL
C     FORMULA FROM SOIL CONSERVATION SERVICE(1968):
C
C                 V=(A´/3)*((E1+E2)/(W1+W2))+(A/3)*(E1/W1+E2/W2)+
C                    (H3*E3+H4*E4+  ..........)/1306 80
C
C     THESE SYMBOLS ARE REPRESENTED BY THE FOLLOWING VARIABLE ARRAYS
C     AND ARE DESCRIBED AS FOLLOWS:
C
C
C
C         SYMBOL   VARIABLE   DESCRIPTION
C           V           VOL        THE TOTAL SEGMENT VOLUME,ACRE-FEET
C
C           A´          APRIME     THE QUADRILATERAL AREA OF THE SEGMENT
C                                  FORMED ON TWO SIDES BY THE RANGE ENDS
C                                  AND ON THE OTHER TWO SIDES BY LINES
C                                  DRAWN FROM THE INTERSECTION OF THE
C                                  RANGE LINES AND CREST CONTOUR, ACRES
C
C           A           A          THE MEASURED SEGMENT AREA OF THE
C                                  RESERVOIR, ACRES
C
C           E1          E2         THE CROSS-SECTIONAL AREA OF WATER
C                                  ALONG THE DOWNSTREAM RANGE OF THE
```

```
C                                  SEGMENT FOR A SURVEY YEAR, SQ. FEET
C
C        E2         E1             THE CROSS-SECTIONAL AREA OF WATER
C                                  ALONG THE UPSTREAM RANGE OF THE
C                                  SEGMENT FOR A SURVEY YEAR, SQ. FEET
C
C        W1         W2             THE WIDTH OF THE DOWNSTREAM CROSS
C                                  SECTION, FEET
C
C        W2         W1             THE WIDTH OF THE UPSTREAM CROSS
C                                  SECTION, FEET
C
C     H3,H4,...     H3             THE PERPENDICULAR DISTANCE FROM THE
C                                  RANGE ON A TRIBUTARY TO THE JUNCTION
C                                  OF THE TRIBUTARY ON THE MAIN STREAM;
C                                  OR IF THIS JUNCTION IS OUTSIDE THE
C                                  SEGMENT, TO THE POINT WHERE THE
C                                  THALWEG OF THE TRIBUTARY INTERSECTS
C                                  THE DOWNSTREAM RANGE, FEET
C
C
C
C
C     THE HISTORY OF THE LAKE SURVEYS IS DESCRIBED BY THE FOLLOWING
C     VARIABLES WHICH SERVE AS THE BASIC PROGRAM PARAMETERS:
C
C        TOTSEG-- THE TOTAL NUMBER OF SEGMENTS USED IN THE VOLUME
C                 CALCULATION
C
C        TOTYR-- THE NUMBER OF YEARS FOR WHICH SURVEY DATA WILL BE
C                SUPPLIED
C
C
C
      READ(IN,106)TOTSEG
      READ(IN,106)TOTYR
C
C
C
C     BASIC PHYSICAL PARAMETERS ARE READ IN TO DESCRIBE THE LAKE CROSS
C     SECTIONS AND SEGMENTS. THESE PARAMETERS ARE CONSIDERED TO BE
C     NON-VARIABLE IN THIS PROGRAM. CONDITIONS IN OTHER LAKES MAY
C     INVALIDATE THIS ASSUMPTION. THESE PARAMETERS ARE, W, A, APRIME,
C     TPUW, AND BTMUW. TPUW AND BTMUW ARE THE UNIT WEIGHTS FOR THE TOP
C     ONE FOOT OF SEDIMENT AND THE REMAINING BOTTOM LAYER OF SEDIMENT
C     RESPECTIVELY.
C
C
C
      READ(IN,108) W(1)
```

```
      DO 5 NSEG=2,TOTSEG
         READ(IN,107)A(NSEG),APRIME(NSEG),W(NSEG),TPUW(NSEG),BTMUW(NSEG)
    5 CONTINUE
C
C
C
C     FOR EACH SURVEY YEAR(NYR) DATA ARE INPUT FOR CALCULATING EACH
C     SEGMENT VOLUME AND THE CALCULATION IS MADE.
C
C
C
      DO 10 IYR=1,TOTYR
         READ(IN,106)NYR
         READ(IN,100)ISEG,E1,ICOMP,H3
         DO 11 NSEG=2,TOTSEG
            E2=E1

C
C
C     ICOMP IS USED TO DESCRIBE COMPLICATED SEGMENTS WHICH ARE EITHER THE
C     FIRST SEGMENT OF A TRIBUTARY BRANCH OR AN END SEGMENT WHICH IS
C     DEFINED BY ONLY ONE CROSS SECTION. IN THIS CASE, CALCULATIONS TAKE
C     PLACE IN THE SECOND AND THIRD IF STATEMENTS. SINCE RESERVOIRS END
C     WITH A TRIBUTARY, THERE WILL BE NO UPSTREAM CROSS SECTION FOR THE
C     FINAL SEGMENT. THE PROGRAM INSERTS A NEGATIVE NUMBER IN ICOMP.
C
C
C
            IF(NSEG.EQ.TOTSEG)THEN
              ICOMP=(-1)
              ISEG=NSEG
              NSEGM1=ISEG-1
              GO TO 8
            ENDIF
C
C
C
C     THE SEGMENT NUMBER, CROSS-SECTIONAL AREA, ICOMP, AND H3 ARE READ IN.
C
C
C
            READ(IN,100)ISEG,E1,ICOMP,H3
            ISEG=ISEG+1
            NSEGP1=ISEG+1
            NSEGM1=ISEG-1
C
C
C
C     ICOMP CAN HAVE THREE TYPES OF VALUES:
C     -----IF ICOMP IS GREATER THAN OR EQUAL TO ZERO,THE SEGMENT VOLUME
```

```
C           IS CALCULATED USING THE STANDARD TWO CROSS SECTION FORMULA
C           PRESENTED ABOVE.
C
C
C
    8         IF(ICOMP.GE.0) THEN
                VOL(ISEG,IYR)=((APRIME(ISEG)/3.)*(E1+E2
     $        )/(W(ISEG)+W(NSEGM1)))+((A(ISEG)/3.)*(E1/W(ISEG)+
     $       E2/W(NSEGM1)))
C
C
C
C     ----IF ICOMP IS NEGATIVE,THE SEGMENT OCCURS AT THE UPSTREAM END OF
C         THE MAIN BODY OF THE LAKE OR OF A TRIBUTARY BRANCH. THIS VOLUME
C         WILL BE CALCULATED USING ONLY ONE CROSS SECTION.
C
C
C
              ELSE IF(ICOMP.LT.0) THEN
                VOL(ISEG,IYR)=((APRIME(ISEG)+A(ISEG))/3.0)*E2/W(NSEGM1)
             ICOMP=ICOMP*(-1)
             ENDIF
C
C
C
C     ----IF ICOMP IS NON-ZERO AND AN H3 VALUE IS GIVEN, THE SEGMENT IS
C         THE FIRST SEGMENT OF A TRIBUTARY BRANCH AND THE VOLUME:
C
C               H3* E2/1306 80
C
C         IS ADDED INTO THE SEGMENT REPRESENTED BY THE ABSOLUTE VALUE
C         OF ICOMP.
C
C
C
             IF(ICOMP.NE.0)THEN
             ICOMP=ICOMP+1
             VOL(ICOMP,IYR)=VOL(ICOMP,IYR)+H3*E2/1306 80
             ENDIF
   11        CONTINUE
   10        CONTINUE
C
C
C
C     FOR EACH SURVEY YEAR,THE TOTAL VOLUME OF THE RESERVOIR IS
C     DETERMINED BY SUMMING THE SEGMENTAL VOLUMES FOR THAT SURVEY YEAR.
C            TOTVOL - AN ARRAY WHICH WILL RECEIVE THE TOTAL
C               VOLUME OF WATER CONTAINED IN THE RESERVOIR
C               FOR EACH YEAR A SURVEY WAS CONDUCTED.
C
```

```
C
C
      DO 14 IYR=1,TOTYR
      DO 15 NSEG=2,TOTSEG
            TOTVOL(IYR)=TOTVOL(IYR)+VOL(NSEG,IYR)
   15 CONTINUE
   14 CONTINUE
C
C
C
C     THE SUBROUTINE WGHT WILL CALCULATE THE VOLUME AND WEIGHT OF SEDIMENT
C     IN EACH SEGMENT AS WELL AS THE TOTAL WEIGHT ACCUMULATED IN THE
C     RESERVOIR.TO CALCULATE THE WEIGHT USING ONLY ONE UNIT WEIGHT, TPUW
C     SHOULD BE REPLACED BY BTMUW IN THE CALL STATEMENT.
C
C
C
      DO 12 IYR=2,TOTYR
      DO 13 NSEG=2,TOTSEG
         CALL WGHT (VOL(NSEG,1),VOL(NSEG,IYR),A(NSEG),BTMUW(NSEG),
     $TPUW(NSEG),NSEGM1,SEDVL,WGT,NSEG,IYR,TOTWGT(IYR))
C
C
C
C
  13     CONTINUE
           TOTSD(IYR)=TOTVOL(1)-TOTVOL(IYR)
  12  CONTINUE
C
C
C
C     OUTPUT AND FORMAT STATEMENTS
C
C
C
      WRITE(IOUT,215)
      WRITE(IOUT,216)
      WRITE(IOUT,217)
      WRITE(IOUT,218)
      DO 22 NSEG=2,TOTSEG
         NSEGM1=NSEG-1
         WRITE(IOUT,214)NSEGM1,(VOL(NSEG,IYR),IYR=1,TOTYR)
   22 CONTINUE
      WRITE(IOUT,223)
      WRITE(IOUT,221)(TOTVOL(IYR),IYR=1,TOTYR)
      WRITE(IOUT,224)
C
C
C
      WRITE(IOUT,219)
```

```
      WRITE(IOUT,225)
      WRITE(IOUT,213)
      WRITE(IOUT,210)
      WRITE(IOUT,212)
      DO 17 NSEG=2,TOTSEG
         NSEGM1=NSEG-1
         WRITE(IOUT,211)NSEGM1,(SEDVL(NSEG,IYR),WGT(NSEG,IYR),IYR=2,
     $TOTYR)
   17 CONTINUE
      WRITE(IOUT,223)
      WRITE(IOUT,222)(TOTSD(IYR),TOTWGT(IYR),IYR=2,TOTYR)
      WRITE(IOUT,224)
C
C
C
C
  211  FORMAT(/2X,I3,6X,F8.2,2X,F8.2,4(4X,F8.2,2X,F8.2))
  213 FORMAT(´                        1936                  1946
     $    1956                   1966                  1983´)
  210 FORMAT(´ SEGMENT   SEDIMENT  SEDIMENT    SEDIMENT  SEDIMENT    SED
     $IMENT  SEDIMENT    SEDIMENT  SEDIMENT    SEDIMENT  SEDIMENT´)
  219 FORMAT(´1´//)
  212 FORMAT(´ NUMBER      VOLUME    WEIGHT      VOLUME    WEIGHT      VO
     $LUME    WEIGHT      VOLUME    WEIGHT      VOLUME    WEIGHT´)
  214  FORMAT(/2X,I3,8X,F8.2,5(5X,F8.2))
  215  FORMAT(´1´//36X,´LAKE DECATUR´//42X,´WATER VOLUME IN ACRE FEET.´/)
  216  FORMAT(//8X,6(5X,´********´))
  217  FORMAT(/´  SEGMENT´,7X,´1922´,9X,´1936´,9X,´1946´,9X,´1956´,9X,´196
     $6´,9X,´1983´)
  218 FORMAT(´ NUMBER ´,6(5X,´********´))
  221  FORMAT(/´ SUBTOTAL´,4X,F8.2,5(5X,F8.2))
  222  FORMAT(/´   SUBTOTAL´,1X,F8.2,2X,F8.2,4(4X,F8.2,2X,F8.2))
  223  FORMAT(/´  *************´)
  224  FORMAT(/´  ********************************************************
     $**************************************************************´)
  225  FORMAT(/36X,´ACCUMULATED SEDIMENT´//42X,´WEIGHT IN KILOTONS´/42X,´
     $VOLUME IN ACRE FEET´//)
  106  FORMAT(I4)
  100 FORMAT(2X,I2,40X,F13.2,14,F5.0)
  107 FORMAT(43X,F7.2/43X,F7.2/20X,F8.2/20X,F8.2,14X,F8.2)
  108 FORMAT(20X,F7.2)
      END
C
C
C
C
C
C
C
C
      SUBROUTINE  WGHT  (OLDVL,PRESVL,AREA,BTMUW,TPUW,NSEGM1,SEDVL,WGT,
```

```
     $NSEG,IYR,TOTWGT)
      DIMENSION  SEDVL(101,6),WGT(101,6)
C
C             OLDVL -IS THE VOLUME OF WATER IN THE SEG
C                MENT NSEG DURING 1922.
C
C
C             PRESVL - IS THE VOLUME OF WATER IN THE SEG-
C                NSEG DURING IYR.
C
C
C             AREA - IS THE SURFACE AREA OF NSEG.
C
C
C             BTMUW - IS THE DEEPER UNIT WEIGHT OF SEDI-
C                MENT IN NSEG.
C
C
C             TPUW - IS THE UPPER UNIT WEIGHT OF SEDI-
C                MENT IN NSEG.
C
C
C
C
C                THE SEDIMENT VOLUME IS CALCULATED.
C
C
C
C
         SEDVL(NSEG,IYR)=OLDVL-PRESVL
C
C
C
C                IF THE SEDIMENT VOLUME IS LESS THAN
C             THE SEGMENT´S AREA THEN THE SEDIMENT
C             VOLUME IS MULTIPLIED BY THE TOP UNIT
C             IN ORDER TO CALCULATE THE SEGMENT´S
C             SEDIMENT WEIGHT.
C
C
C
         IF(SEDVL(NSEG,IYR).GT.AREA)THEN
            WGT(NSEG,IYR)=(SEDVL(NSEG,IYR)-AREA)*BTMUW
            WGT(NSEG,IYR)=(TPUW*AREA)+WGT(NSEG,IYR)
         ELSE
            WGT(NSEG,IYR)=SEDVL(NSEG,IYR)*BTMUW
         ENDIF
            WGT(NSEG,IYR)=(WGT(NSEG,IYR)*43560.0/2000.0)/1000.0
      TOTWGT=TOTWGT+WGT(NSEG,IYR)
      RETURN
      END
```