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SEDIMENTATION INVESTIGATION OF LAKE SPRINGFIELD,
SPRINGFIELD, ILLINOIS

by

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Prepared for
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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. It presents the results of an investigation of sedimentation in Lake Springfield, Springfield, Illinois. The lake has been surveyed to determine its storage capacity, its capacity loss rate, the pattern of sediment deposition in the lake, and the nature of the sediment. The latest survey was conducted under a cooperative agreement between the City of Springfield and ISWS during the summer of 1984. The lake was previously surveyed in 1948 and 1977. The 1977 survey of the lake determined a capacity loss of 11 percent of the original 1934 volume. A reconnaissance survey was conducted in 1965.

Lake Springfield is the largest municipally-owned lake in Illinois, covering over 4000 acres and encompassing 59,900 acre-feet (20 billion gallons) of storage in 1934 (at normal pool elevation of 560 feet msl). It was created by impoundment of the Sugar Creek tributary of the Sangamon River.

Lake Springfield and its watershed are located in central Illinois south of the City of Springfield as shown in figure 1. The two major streams flowing into the lake are Sugar Creek and Lick Creek, which join at the upper end of the lake. The lake's water storage is replenished by runoff from its 265-square-mile-watershed. In addition to providing a catchment for runoff that resupplies the lake storage, the watershed also contributes sediment which is entrained by runoff water and carried to the lake. Rainfall and other forms of precipitation act as the initiators of fluvial erosion, sediment transport, and deposition processes which are constantly at work in the watershed.

Figure 2 is a photograph showing one of the effects of sedimentation in a lake. This photograph was taken looking downstream from the boat launch located a few hundred feet north of Glasser Bridge (figure 3). The area

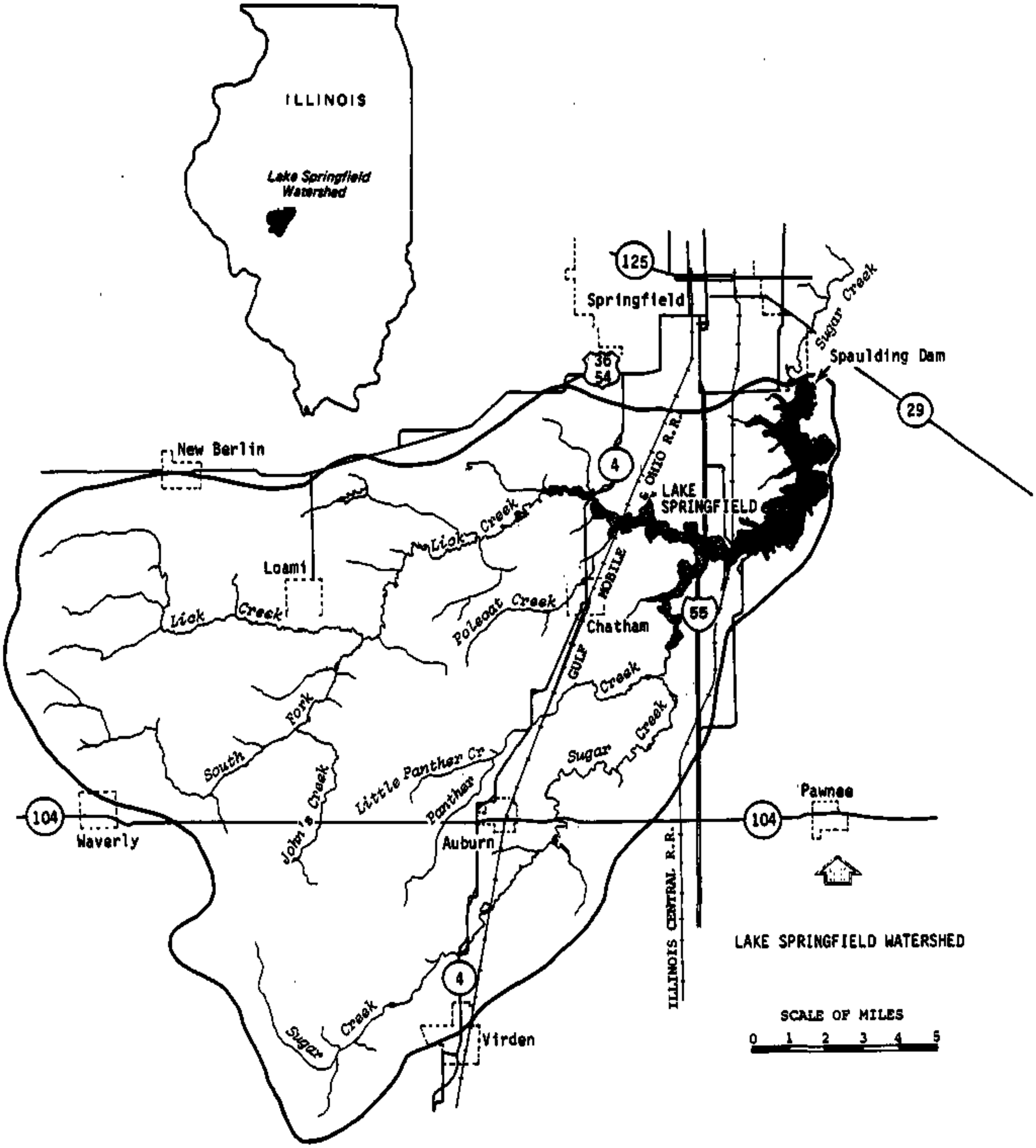

Figure 1. Location map of Lake Springfield and its watershed

Figure 2. View of Lake Springfield, looking downstream from the Glasser Bridge boat launch (water level is 3 feet below normal pool, exposing a mud flat overgrown with aquatic weeds)

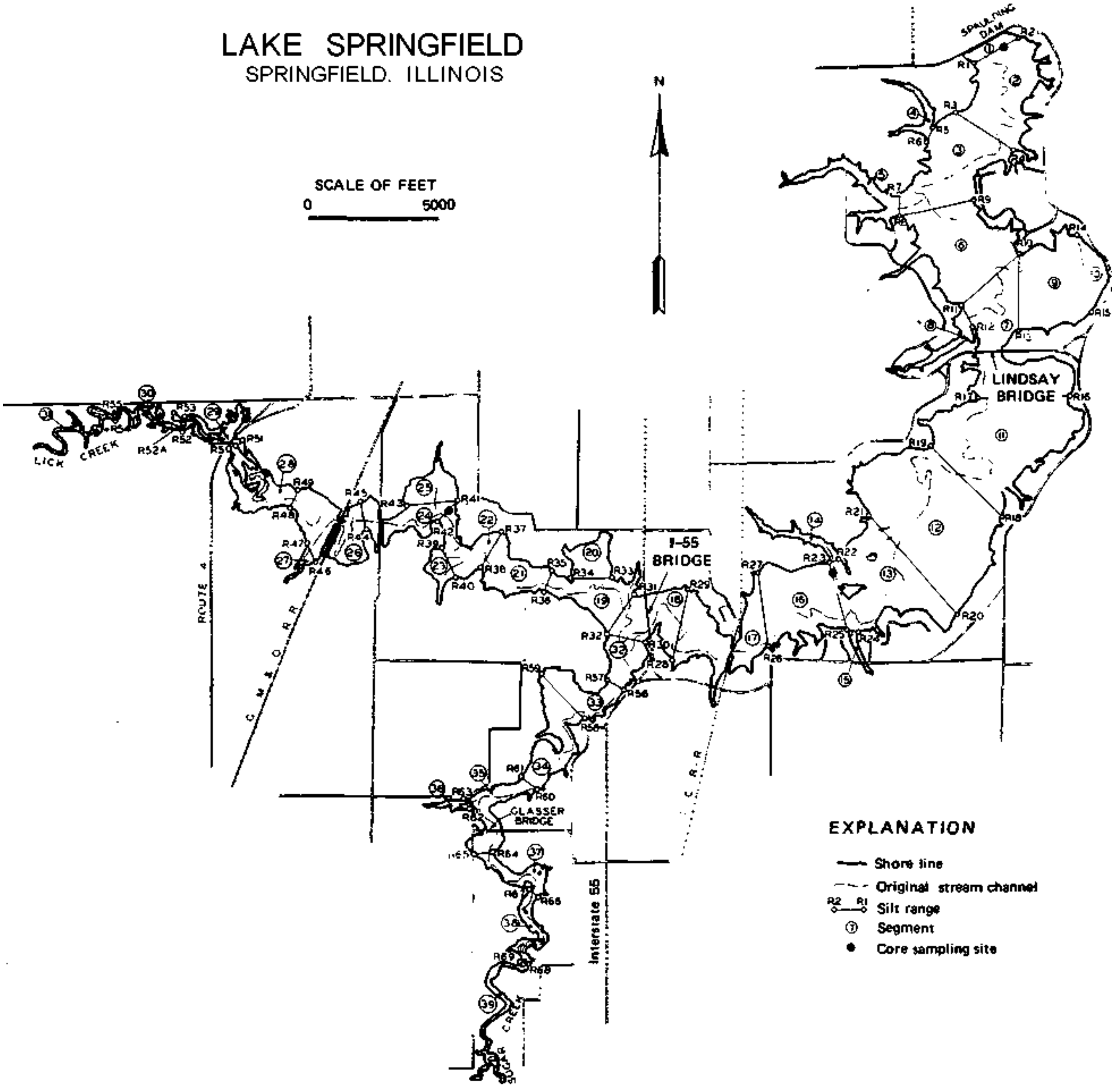

Figure 3. Map of Lake Springfield, showing the location of the survey ranges, lake segments, and core sampling sites

shown in the photograph between the tree lines is an upstream area of the lake that has lost two-thirds of its average depth due to sediment accumulation. Where there once was a wide and fairly deep area of the lake this photograph shows an area of mud flat overgrown with lily pads and weeds that were exposed by the lake drawdown of 3 feet. The lake in this area at the time this photograph was taken (November 20, 1984) was reduced to a shallow stream channel flowing over the mud flat as can be seen in the background. This area of the lake in 1934 averaged approximately 6 feet deep, while currently it averages less than 2 feet at normal pool.

The area shown in this photograph is typical of the upstream areas of the lake that are currently unusable for most recreation activities and obviously provide little storage. This type of impairment of use of the upstream areas will become worse over time as areas such as that shown in the photograph fill with sediment and no longer trap and hold incoming sediment to the degree they did in the past. The result will be that the mud flats and noxious weed growth areas will propagate and migrate downstream, occupying larger areas of the lake over time and further reducing both the water storage capacity of the lake and recreational activities on the lake.

Acknowledgements

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, and Michael L. Terstriep, Head of the Surface Water Section. Misganaw Demissie provided invaluable guidance in the analysis of the results and preparation of the report. Scott Schutte, Bob Cunningham, and Adam Giganti, employees of the Springfield City Water Light and Power Company (CWLP), assisted in field data collection. William H. Zehrt, student of engineering at the University of Illinois, assisted in data organization and calculation. Lake bed sediment samples were analyzed at the Inter-Survey Geotechnical Laboratory by William Westcott and Becky Roeper under the direction of Michael V. Miller. 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.

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DAN AND RESERVOIR

History of the Springfield Waterworks

The city of Springfield was chartered in 1840 with a population of approximately 2500. The city's first public water supply, consisting of four hand pumps placed one on each corner of the town square, was installed in 1845. In 1848 and 1853 the hand pumps were upgraded, but their capacity was inadequate for the growing city. A private company was organized in 1857 for the purpose of finding and developing artesian wells to supplement the city's supply. The project was a failure and was abandoned two years later. In 1860 the city purchased the private water works company and made plans to bring water to the city from the Sangamon River. In 1866 work started on a pumphouse and infiltration gallery at the Sangamon River. Over the next 40 years the water works were expanded by additional pumphouses, new water mains, and enlarged infiltration galleries and wells in the river bottom. To augment the water supply during low flow on the river, a dam was built in 1908 across the Sangamon River. In 1912 a new well field was installed together with a 10-mgd pump.

The well fields and river intakes were inadequate for the city's demands, and in 1930 bonds were issued for the construction of a lake and water purification plant. The new lake was constructed by damming Sugar Creek, a tributary of the Sangamon River. The lake was completed in 1935 at a cost of $2.5 million. One year later the city's new purification plant at the lake was finished.

Spaulding Dam

Spaulding Dam (figure 3) extends in a northeast-southwest direction across the valley of Sugar Creek. The dam is 1900 feet long and has a spillway elevation of 560 feet msl. The lake's water level is controlled by a set of five moveable gates 8 feet in height installed into the spillway located at the southwest end of the dam.

Lake Springfield

The building of the lake required the clearing of 4300 acres of the valley bottom. In addition a saddle dam was built 2 miles south of Spaulding Dam to raise the drainage divide between Horse Creek and Sugar Creek. During construction of the lake, roads and railroad fills were riprapped as protection against wave erosion.

The stream channel of the pre-dam Sugar Creek was entrenched to a depth 10 feet below the valley floor, which was relatively flat and averaged about one-half mile wide. The original maximum depth of the lake in the old stream channel at the dam was 35 feet, and the average depth on the valley bottom at the dam was 25 feet.

The reservoir is approximately 12 miles in length extending south and west from the dam. It has a "Y" shape formed by the inundated valleys of Sugar and Lick Creeks, which join together in the upstream portion of the lake as shown in figures 1 and 3. Figure 3 is a detail map of Lake Springfield showing the ranges across the lake used to measure sediment accumulation. This figure also shows the original stream channels of the valley.

The reservoir is utilized as the source of the city's drinking water and also for boiler and cooling water for the city's coal-fired electrical power plant. The city's water treatment plant and power plant are located along the lakeshore south of the dam.

PHYSICAL CHARACTERISTICS OF THE WATERSHED

The watershed is located south of Springfield, Illinois, in Sangamon, Morgan, and Macoupin Counties. The watershed area covers 265 square miles and is primarily a level- to gently-sloping plain which is incised in the lower portions by the valleys of Sugar and Lick Creeks. The streams in the upper portions of the watershed are shallow and less pronounced. Elevations vary from 700 feet msl at Waverly, Illinois, to 560 feet msl at Spaulding Dam.

The soils of the watershed formed in loess deposits up to 8 feet thick, which are underlain by Illinoian drift. The average gross erosion has been estimated as 3.96 tons per acre per year or a total of 601,000 tons per year for the watershed (Lee and Stall, 1977). The land use has been estimated as

88 percent cropland, 8 percent pasture, 1 percent woodland, and 2 percent other (Lee and Stall, 1977).

The climate of the Springfield region is typically continental with warm summers and fairly cold winters. The following local climate data are summarized from NOAA (1983). Annual precipitation averaged 35.47 inches for the period 1944 to 1983. Yearly extremes in precipitation were 48.12 inches in 1981 and 23.98 inches in 1953. Snowfall averaged 24.6 inches per year. The average annual temperature was 53.2°F and the extremes were 112°F in July 1954 and -24°F in February 1905. The average numbers of degree days for the period 1951 to 1980 were 5654 heating and 1165 cooling degree days. Thunderstorms occur 50 days of the year on the average, and snowfalls of 1 inch or more occur 8 days of the year.

EARLIER INVESTIGATIONS

Earlier surveys of Lake Springfield provide the basis of comparison for determining the loss of water storage capacity and the sediment accumulation. The lake was previously surveyed in 1948 and 1977, and a reconnaissance survey was conducted in 1965. This section describes the results and methods of the previous surveys.

Improvements in field data collection and analytical methods available to this investigation have allowed the recalculation of the results of previous investigations. The results of this recalculation supersede those presented in earlier reports and will be referred to later in this report.

1948 Survey

The Illinois State Water Survey and the Soil Conservation Service performed the first survey of the lake in 1948. This survey was part of a larger-scale project to assess the extent of sedimentation and capacity loss in Illinois reservoirs. A total of 38 ranges were established across the lake for the measurement of sediment accumulation and water depths. The range ends on shore were marked with concrete monuments for the purpose of accurate relocation in future surveys. The lake was divided into 39 segments, each of which was bounded by two ranges and by the lakeshores. These segments were then used to calculate the volumes of water and sediment in each portion of the lake.

The 1948 lake bed topography was determined by measuring the water depth along the length of the ranges at 50-foot intervals. The horizontal position of the sounding points was determined by single-angle triangulation with a telescopic alidade. Soundings of the water depth were made with a bell-shaped 5-pound aluminum sounding weight with a base diameter of 5 inches and a height of 6 inches. At intervals of every 100 feet the thickness of the sediment was measured with a spud bar (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 easily penetrate the sediment. 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 may 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 are 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 bottom.

On shallow ranges an alternate method of measuring the sediment depth was used. This method involved using a wood sounding pole to measure the water depth at the top of the sediment, and then pushing the pole through the sediment to the firmer old soil of the pre-dam valley. The results of this method were checked by the use of the spud bar at selected sites.

The 1948 sediment volume and lake storage capacity calculations were based on methods developed by the Soil Conservation Service (Eakin, 1936). The lake bed elevations for the years 1934 and 1948 were plotted and 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 lake bed sediment was sampled to determine the average density of the material. Ten samples were collected from the lake bed sediments using a

4-inch by 1-1/4-inch pipe nipple. These samples were difficult to collect due to the thin sediment layers in many parts of the lake and the loose consistency of the sediments in general. The samples were placed in jars of known volume and weight and then heated to remove all moisture. The sample weight was divided by the sample volume to determine a weight per unit volume or density.

The results of the 1948 survey were published by the Illinois State Water Survey (Stall, 1949; Stall et al., 1952). This survey found an average annual capacity loss rate of 0.30 percent, or a 1934-1948 loss of 4.36 percent. A sediment accumulation of 2659 acre-feet with an average unit-weight density of 42.6 pounds per cubic foot was reported.

1965 Reconnaissance Survey

This reconnaissance survey of the lake was initiated to determine if the sedimentation rate of the lake had increased over the years since the first survey. A total of 80 soundings were taken on 10 of the 38 ranges using a sounding pole. The relative rates of sediment deposition along the measured ranges were used to indicate the capacity loss and sediment accumulation of the whole lake for the period 1948-1965.

The results of the 1965 reconnaissance were published by the ISWS in a letter report (Stall, 1965). Although this report acknowledged that the results of this reconnaissance were less accurate than the results of the 1948 survey, they do give a general indication of the changes in deposition since the previous survey. This reconnaissance indicated a reduction in the rate of sedimentation since 1948. The author determined an annual capacity loss of 0.17 percent per year for the period 1948-1965, which is just over half that of the earlier period. This reduction was attributed to the drought of the 1950s, which lowered the lake level as much as 12 feet, resulting in drying and compaction of the sediment. The sediment thus had less volume and therefore occupied less of the lake's storage capacity. The author also determined that over the period 1948-1965, 98,368 tons of sediment, or 5786 tons per year, had accumulated in the reservoir.

1977 Survey

The 1977 sedimentation survey was conducted as part of a research grant from the Illinois Institute for Environmental Quality under Section 208 of the Water Pollution Control Act amendments of 1972 (P.L. 92-500). The purpose of this research was the evaluation of nonpoint sources of pollution of surface waters. In addition to the lake sedimentation survey, detailed analyses of watershed erosion rates were made using the Universal Soil Loss Equation, and a program of stream and lake sediment quality sampling was conducted in Lake Springfield and its watershed. The results of these components were presented in Bogner, 1977; Lee and Stall 1977; and IEPA, 1978.

The 1977 survey was conducted in January, February, and July 1977. During January and February the deep water cross sections of the lake south of R9-R8 were surveyed up to cross section R35-R36 on the Lick Creek arm and R58-R59 on the Sugar Creek arm of the lake (figure 3). These cross sections were surveyed through ice cover of up to 30 inches. The remainder of the cross sections including R1-R2, R3-R4, and R5-R6 were surveyed in July 1977 through open water.

All sounding measurements, whether through ice or open water, were made using a 2-inch-diameter sounding pole. This pole was extendable in 8-foot sections up to 32 feet and was marked in tenths of feet. During the summer a sounding shoe was attached to the bottom of the pole to improve precision of measurements. The winter survey did not utilize this sounding shoe due to the increased difficulty in preparing an ice hole for the 8-inch-diameter shoe.

The 1977 survey resurveyed the cross sections monumented for the 1948 survey. In cases where monuments were not recovered, location of the range end was determined visually and horizontal angle measurements were made to document the line as surveyed. In the upstream portion of the lake, it was not always possible to document the line chosen by horizontal angle. In these cases, as much site description as possible was determined in order to document the surveyed line.

All horizontal measurements during the winter survey were determined by a standard surveying traverse. The survey crew maintained line by having the trailing tape man align the leading tape man with the range end/goal. In this way, sounding measurements were taken at regular 100-foot intervals.

During the summer survey, horizontal control was maintained using a metered cable on all cross sections except R3-R4, which was surveyed using stadia distance measurements.

The volume for the 1977 survey was calculated using the methods of the Soil Conservation Service (SCS, 1968). The results of the 1948 survey were re-evaluated but were not changed for the report.

The results of the 1977 survey showed that sedimentation rates in Lake Springfield had decreased slightly from the period 1934 to 1948 to the period 1965 to 1977. The 1965 to 1977 sedimentation rate was found to be 0.29% per year compared to a rate of 0.30% per year for the period 1934 to 1948. Total accumulated sediment in 1934 to 1977 was 7561 acre-feet with an average unit weight density of 39.0 pounds per cubic foot.

1984 RESERVOIR SEDIMENTATION SURVEY

The 1984 hydrographic survey of Lake Springfield began in the spring of 1984. 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 for the 1984 survey.

Surveying and Sampling Techniques

The equipment used for the 1984 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 theodolite
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 Citizens Band radios
12) Electric trolling motor and marine battery
13) Sample storage jars and plastic bags
14) Miscellaneous items: field books, pencils, camera, spatula, concrete survey monuments, post hole digger, machetes, survey ribbon, etc.

The hydrographic survey was conducted by measuring the depth of the lake bed along 37 of the 38 range lines previously established across the lake (figure 3) . 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 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 1984 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 one-third 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.

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 lakeshores, and the shore station equipment operator used the EDM to determine the sounding boat's position while sampling. Soundings were obtained using the same aluminum pole and sediment shoe used in the cable method. Sounding intervals were 25 to 100 feet.

The sounding crew consisted of three persons: the boat operator/reflector handler, the sounding man, and the cable handler. For the shore station method the cable handler was replaced by a surveyor who was stationed on shore to operate the EDM, record data, and communicate with the rest of the crew via two-way radio.

Figure 4 is a photograph of a depth measurement being taken on Lake Springfield. The horizontal coordinates of the workboat at the site of the measurement were determined by a surveying station located on the lakeshore. This picture shows the sounding man reading the present depth of the lake using a sounding pole, while the data recorder notes the readings and observations. The reflector handler is not shown in this picture. Lindsay Bridge, located 3 miles south of the dam, can be seen in the background of figure 4. The piers of the bridge show the markings (dark horizontal lines) of the lake surface at normal pool. On the date this photograph was taken the lake level was 3 feet below spillway elevation as can be seen in figure 4.

Following the sounding of the lake cross sections, samples of the lake bed sediments were collected to determine 1) particle size distribution, 2) unit weight density, and 3) changes in the sediment over the length of the core samples. During this survey, bottom sediments were collected from 44 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 using the dredge sampler, which scooped up the top 2 to 4 inches of the lake bed sediment. Core samples were taken using a 3-foot-long, 2-inch-diameter sampler which was lowered to the lake bed from the workboat using ropes and

Figure 4. Lake Springfield at Lindsay Bridge, showing survey crew measuring water depth (lake pool elevation on 10/23/84 was 557 feet msl; normal pool is 560 feet msl)

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 density 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 sediment particle sizes.

Hydrographic Characteristics

Data collected during the 1984 sedimentation survey were analyzed to determine changes in the cross-sectional areas of the lake, to develop a 1984 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 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 1984. The survey data were used to generate cross-sectional topographic profile plots of the lake bed. The data from previous surveys were added to the 1984 plots to provide a graphic presentation of the aggradation of the lake bed over time. These profiles were constructed on the basis of the field data which recorded the horizontal distance from shore markers (survey monuments) at each sounding point and the elevation of the lake bed as measured by sounding.

Range 9-8. Range 9 - 8 is located 1 .5 miles above Spaulding Dam, as shown in figure 3. The cross-sectional plot is shown in figure 5. At this cross

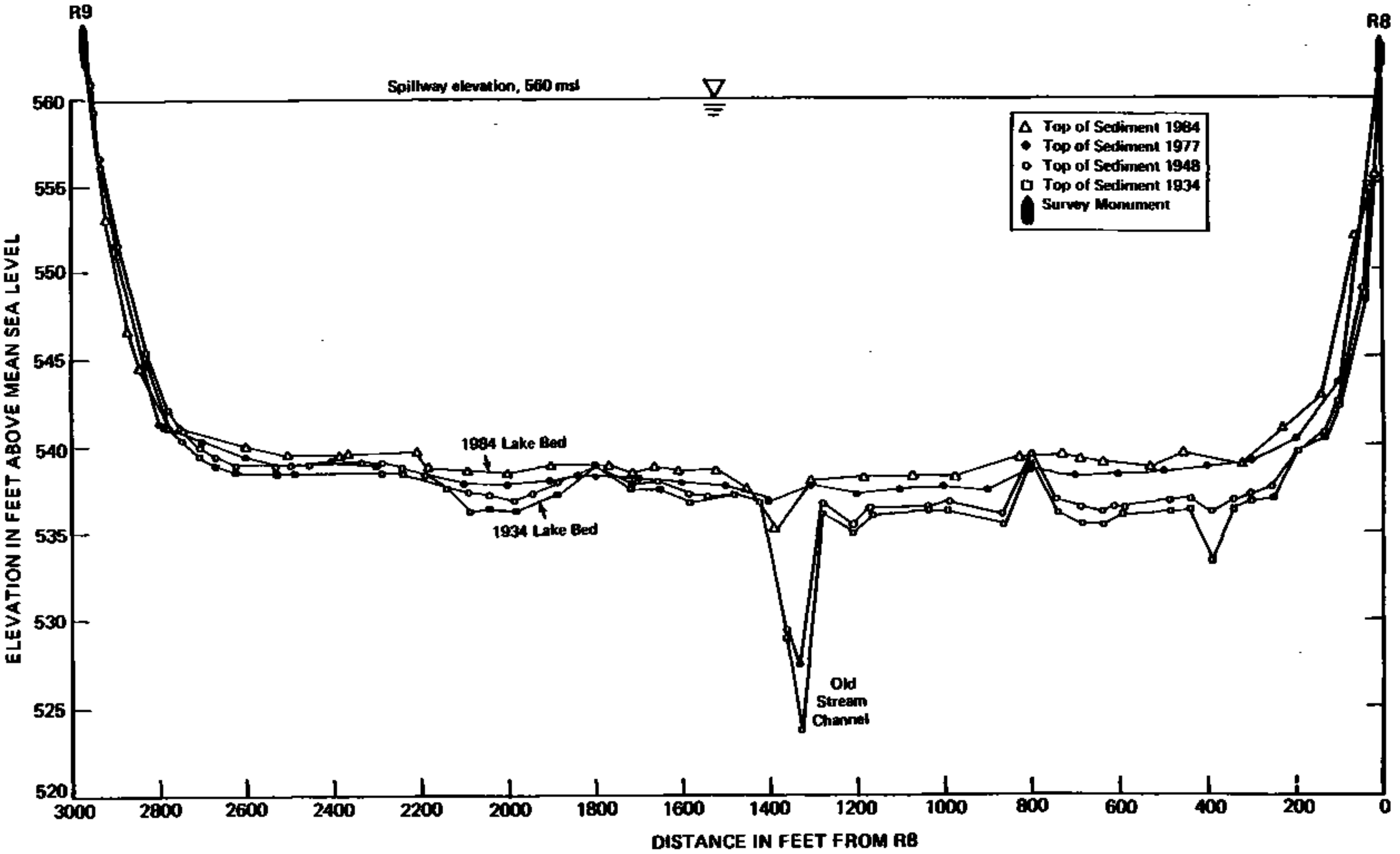

Figure 5. Cross-sectional plot of the lake bed topography at Range 9-8, showing the accumulation of sediment over the 50 years since the lake's construction

section it can be seen how the old stream channel has been completely buried by accumulated sediment. This is typical of the downstream portions of the lake. On the old floodplain of the valley, deposited sediment averaged less than 3 feet whereas in the old channel it was as much as 13 feet. This cross section is a good example of sedimentation processes where the lake's maximum depth is decreasing faster than its average depth over time. Currently the maximum depth at this cross section is 23 feet and the average depth is 20 feet.

Range 32-31. This cross section (figure 6) is located 6.8 miles upstream of Spaulding Dam in the Lick Creek arm of the lake just upstream of the junction of the Sugar Creek arm as shown in figure 3. The old stream channels at this location have been completely buried by sedimentation. Sediment thickness at this cross section ranges from 14 feet in the old stream channel to an average of 3 feet on the old valley bottom.

Range 60-61. This is a range in the upstream portion of Sugar Creek. This cross section is located 8.4 miles upstream of Spaulding Dam. The profile of this cross section is shown in figure 7. This profile shows that the average thickness of sediment is 4 feet on the valley bottom and 12 feet in the old channel. It can be seen in figure 7 that the old channel is buried by sediment; however, the depression in the 1977 and 1984 plots near the old channel indicates that inflowing waters have tended to follow a path close to the old channel and have kept this area relatively deep.

Hydrographic Map

The cross-sectional depth soundings obtained during the 1984 survey were used to generate a hydrographic map of the lake. This map is presented in figure 8 and represents the bed topography as it can be inferred from the 1984 survey data. The map was drawn with a contour interval of 5 feet.

From this map, it is seen that the deepest portion of the lake is the downstream region near Spaulding Dam. The shallowest regions are the upstream areas in the Sugar and Lick Creek arms of the lake. Throughout most of the lake the old stream channels have filled with sediment, smoothing over the topography.

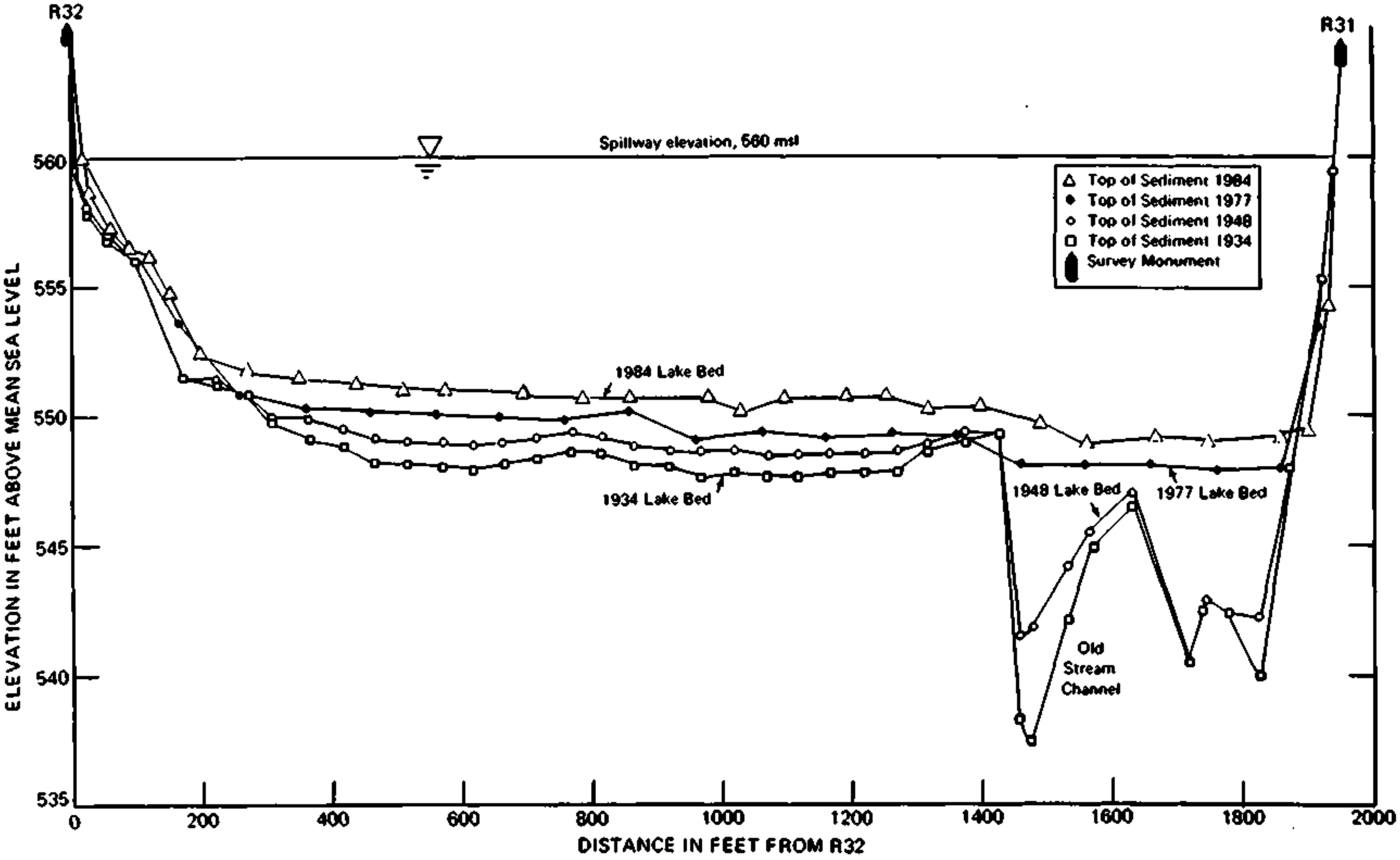

Figure 6. Cross-sectional plot of the lake bed topography at Range 32-31$_t$ showing the accumulation of sediment over the 50 years since the lake's construction

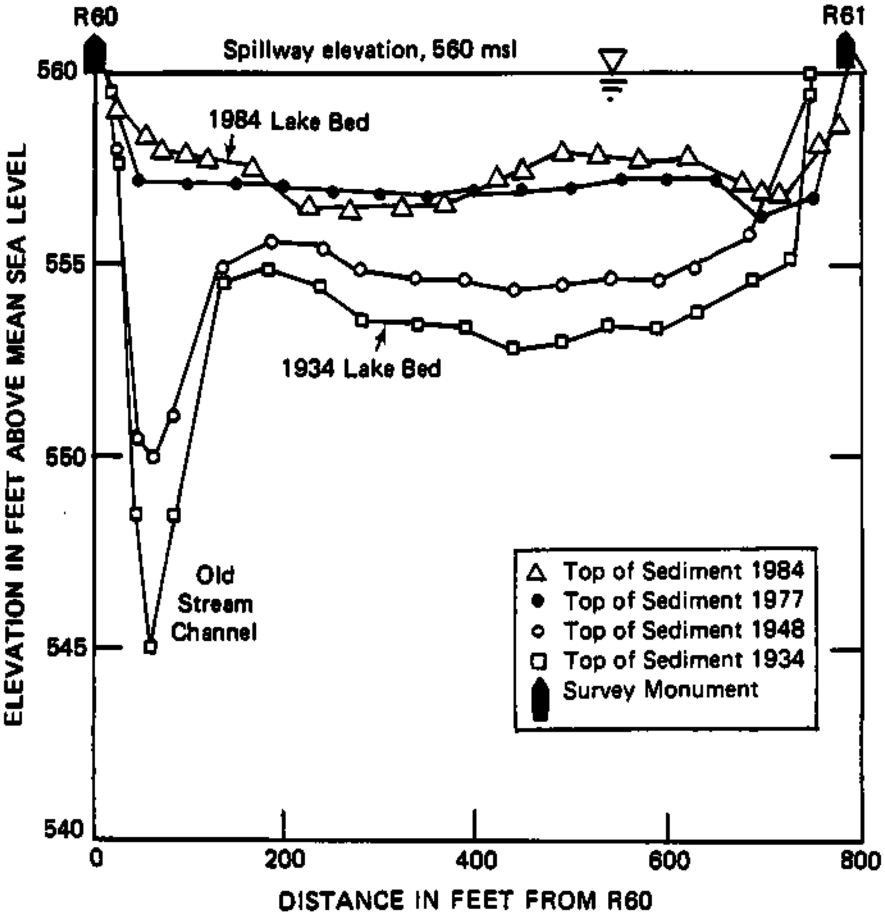

Figure 7. Cross-sectional plot of the lake bed topography at Range 60-61, showing the accumulation of sediment over the 50 years since the lake 's construction

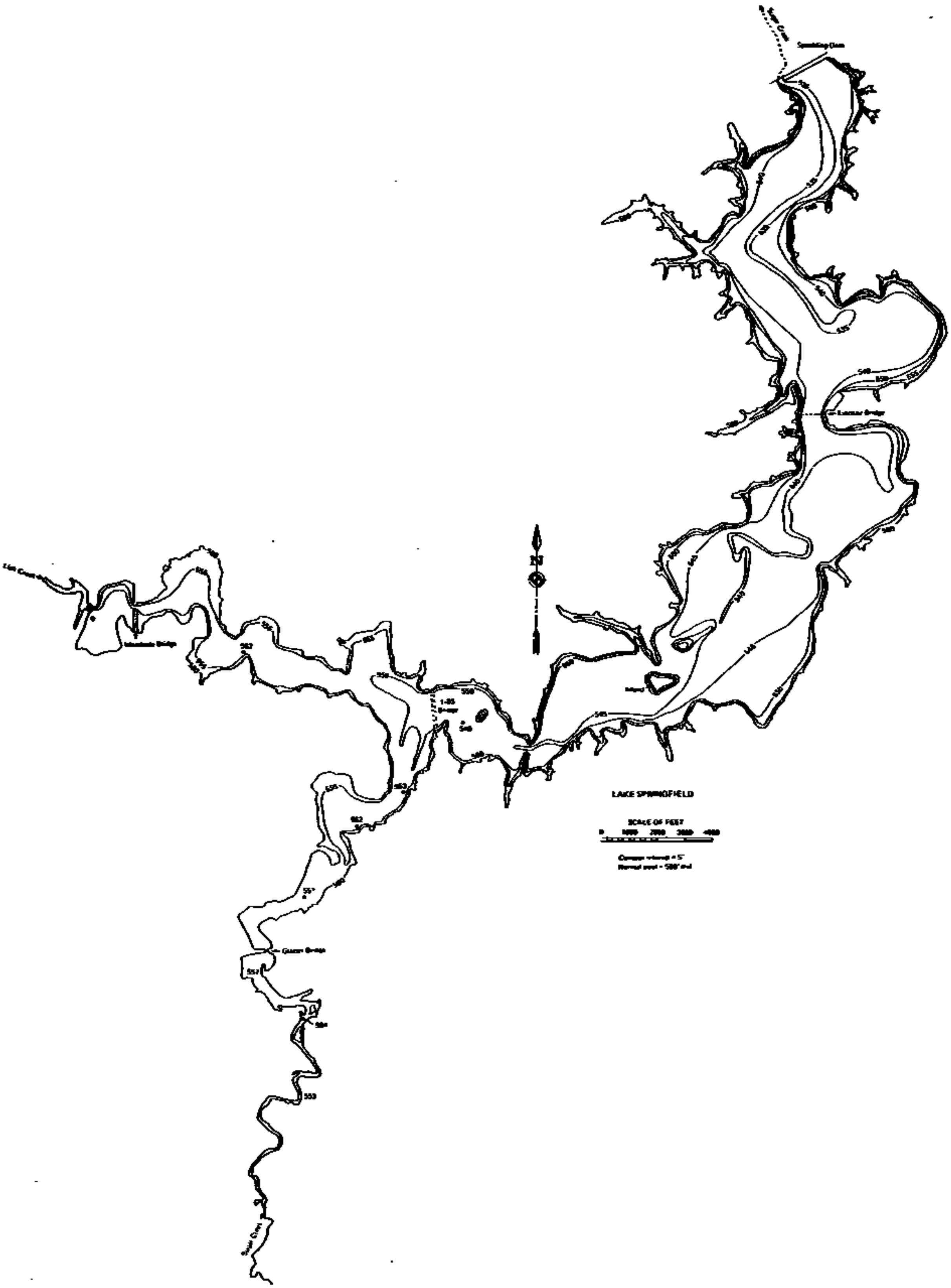

Figure 8. 1984 hydrographic map of Lake Springfield

Stage-Area and Stage-Capacity Relationships

The hydrographic map (figure 8) developed from the 1984 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 tor each increase in stage as follows (SCS, 1968):

$$V = L/3\ CA_L + /A_L \ x\ A_u + A_u) \qquad (1)$$

where

V = the capacity between the 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 9. This figure can be used to readily determine the capacity or area of the lake for a given stage below 560 msl.

The stage capacity curve indicates the importance of the top few feet of the lake to the water supply capability of the lake. The top foot of the lake (560 feet msl) represents a storage capacity of approximately 4000 acre-feet or 1300 million gallons. In contrast, 1 vertical foot of storage at the 550-foot msl level represents only 2700 acre-feet or 880 million gallons and at the 540-foot msl level only 900 acre-feet or 290 million gallons.

LAKE BED SEDIMENT CHARACTERISTICS

This section presents the results of analyses of the geotechnical characteristics of Lake Springfield'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.

The accumulated sediments of Lake Springfield were analyzed for three factors: 1) unit weight dry density, 2) particle size distribution, and 3)

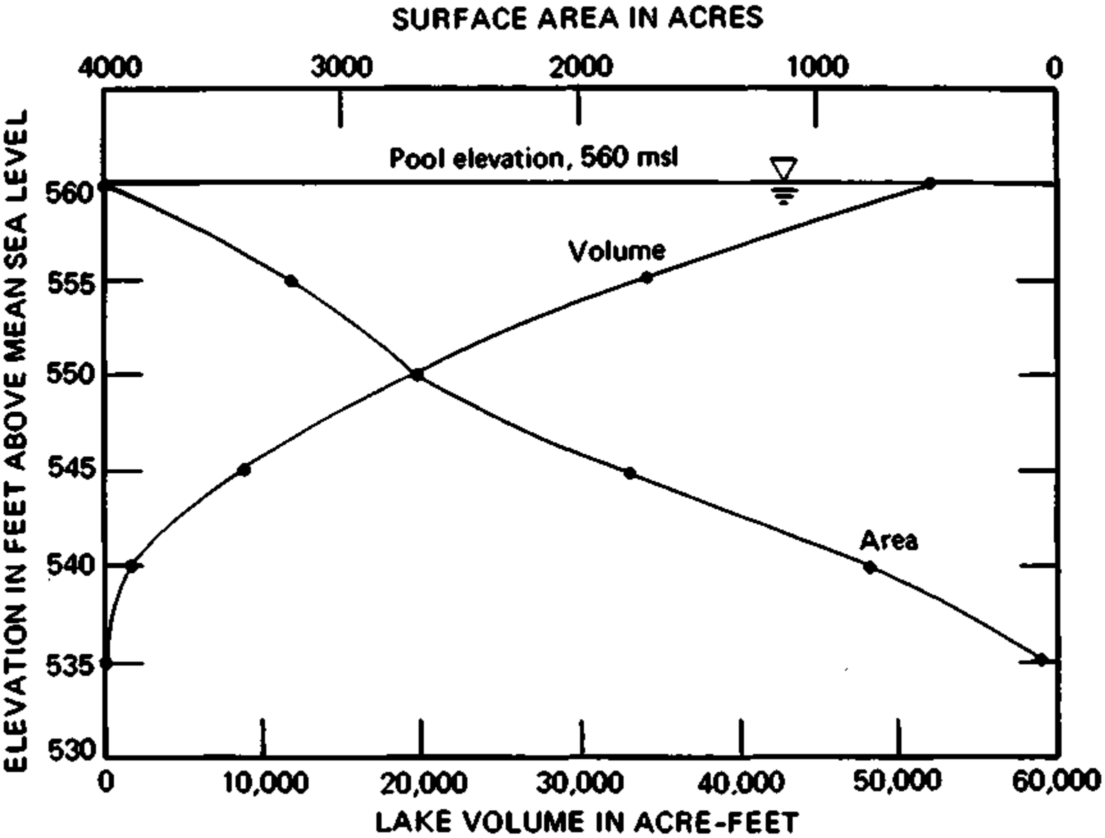

Figure 9. Stage-area-volume curves of Lake Springfield in 1984, showing the changes in lake volume and area that occur at various pool elevations

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 74 samples collected from Lake Springfield are presented in Appendix 1. The dry density of the sediment varies from 20 to 78 pounds per cubic foot. The average density of the lake bed sediment in 1984 was 38.6 lb/ft^3. In general the unit weight densities are lowest near the dam and highest in the upstream reaches of the lake. Table 1 presents the average unit weight density used for each lake segment to calculate the total sediment weight in the lake in 1984. 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 prior to the lake construction, recognized by the old root zone layer, generally larger particle sizes, and usually a very consolidated texture.

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 inflowing streams enters Lake Springfield, it slows drastically and can no longer maintain its sediment load. As the water enters the lake, the sediment particles initially will drop from suspension. As the water moves further down the lake it slows even more, and the lower density sediments settle to the bottom. Near the dam, mostly finer particles are deposited.

The unit weight densities in the upper portions of the lake are also affected by the periodic exposure to drying and compaction during times of low water levels. Lake Springfield has frequent pool level drawdowns caused by the demands of the water treatment plant during periods of low inflow from

Table 1. Sediment Unit Weights, Lake Springfield, 1984
(In pounds per cubic foot)

Segment no.	Unit weight	Segment no.	Unit weight
1	29.2	21	37.7
2	25.3	22	42.8
3	24.8	23	38.5
4	45.6	24	58.7
5	54.1	25	53.5
6	27.7	26	65.2
7	39.8	27	65.0
8	42.6	28	65.0
9	27.6	29 L	65.0
10	31.3	30 L	65.0
11	35.1	31	65.0
12	31.2	32	31.6
13	32.6	33	40.7
14	46.1	34	45.3
15	43.6	35	59.9
16	35.8	36	65.0
17	40.4	37	65.0
18	37.2	38	65.0
19 L	39.6	39	65.0
20 L	49.6		

Lick Creek reservoir arm
Sugar Creek reservoir arm

its watershed. As a result aeration and compaction of lake sediment occur more frequently in the shallow upstream areas.

In general the density of sediment in the 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/ft3 and varies with different proportions of particle sizes and organic concentrations. The maximum density of sediments sampled in Lake Springfield was 78 lb/ft3. This sample was from the Sugar Creek arm where the sediment had been exposed to drying during droughts. The least dense samples were obtained from areas of the lake that have remained submerged since construction of the lake in 1934. The continual saturation of sediments near the dam has retarded consolidation and compaction due to the interstitial pressure and buoyancy of water between sediment particles. A density of 20 lb/ft^3 was measured in a sample obtained approximately one-half mile upstream of the dam. 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/ft3; however, the fluid nature of the material precluded sampling using the techniques available to this study.

Particle Size

The lake sediment in Lake Springfield is predominantly clay. The simple averages of all particle size samples are: 66% clay, 33% silt, and 1% sand. Appendix 1 lists the results of particle size analyses of 45 lake bed samples. These results show a general trend towards an increasing proportion of clay from upstream to downstream in the lake. Samples from the ranges near Spaulding Dam have proportions of clay as high as 89%. A trend of decreasing particle size in the downstream direction has been observed in other reservoirs (Heinemann, 1962; Eakin, 1936) .

Sediment Core Samples

Lake bed sediment core samples were obtained at a variety of sites throughout Lake Springfield, and three 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 here 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, and the surveyed lake bed elevations obtained from the present and past surveys of the lake.

The locations of the core samples presented in this section are shown in figure 3. The core sample from cross section 1-2, presented in figure 10, shows the type of material that predominates in the lake bed. The sediments are predominantly uncompacted silty clay of a fairly uniform distribution. Density is low and averages approximately 30 pounds per cubic foot. This core was taken from above the old valley bottom floodplain 500 feet upstream of the dam 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 23 feet. The depositional rate at this site has slowed in the last 7 years as can be seen in figure 10. Of the 1.2 feet of sediment depth sampled, most of the sediment was deposited over the period 1934-1977.

The core sample in figure 11 was obtained from range 23-25, located in the middle portion of the lake approximately 5 miles upstream of the dam. The sediments in this portion of the lake are uncompacted silty clays with a low concentration of sand. The density of the material averages 30 pounds per cubic foot due to the continual saturation of the sediment since deposition. The current water depth at this site is over 12 feet and these sediments have not been exposed to aeration and compaction. The sediment is fairly uniform in particle size and density with respect to depth of burial, indicating that the type of sediment delivered to this site has not changed over time. The gas pockets observed in the sediment core are due to gas produced by the decomposition of organic matter. The rate of deposition has changed over time, as can be seen in figure 11. The depth of sediment represented by the time period 1934 to 1948 (14 years) is approximately equal to the depth deposited over the period 1948 to 1977 (29 years), indicating a difference in the yearly deposition rate at this site.

A core sample from an upper portion of the lake (Range 41-42) is shown in figure 12. This core was obtained from the Lick Creek arm of the lake 8.4 miles above the dam. The sediment in this core is typical of the upstream deposits of the lake. The material in the core has an increasing density

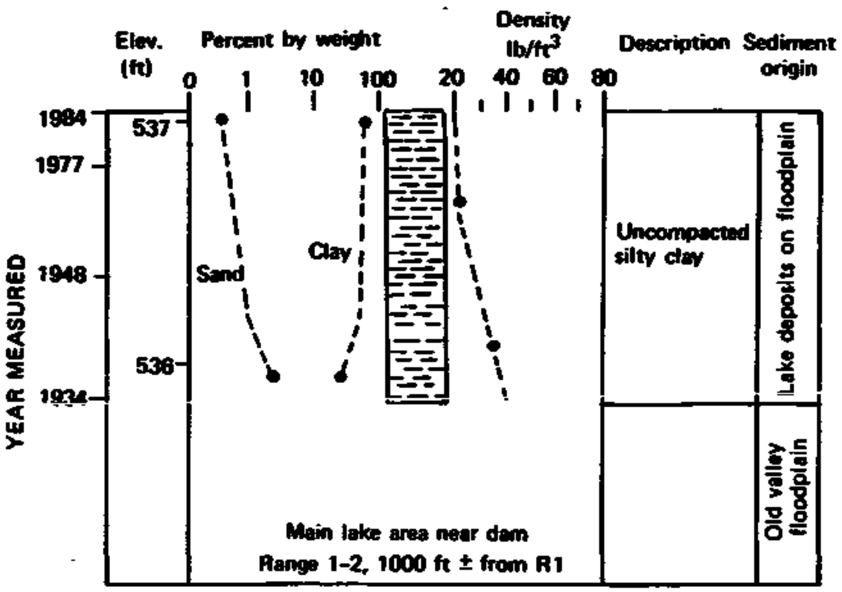

Figure 10. Geotechnical analysis of a Lake Springfield sediment core sample from Range 1-2, showing changes in sediment particle size and density with depth (Also shown are the past lake bed surface elevations at the sample site)

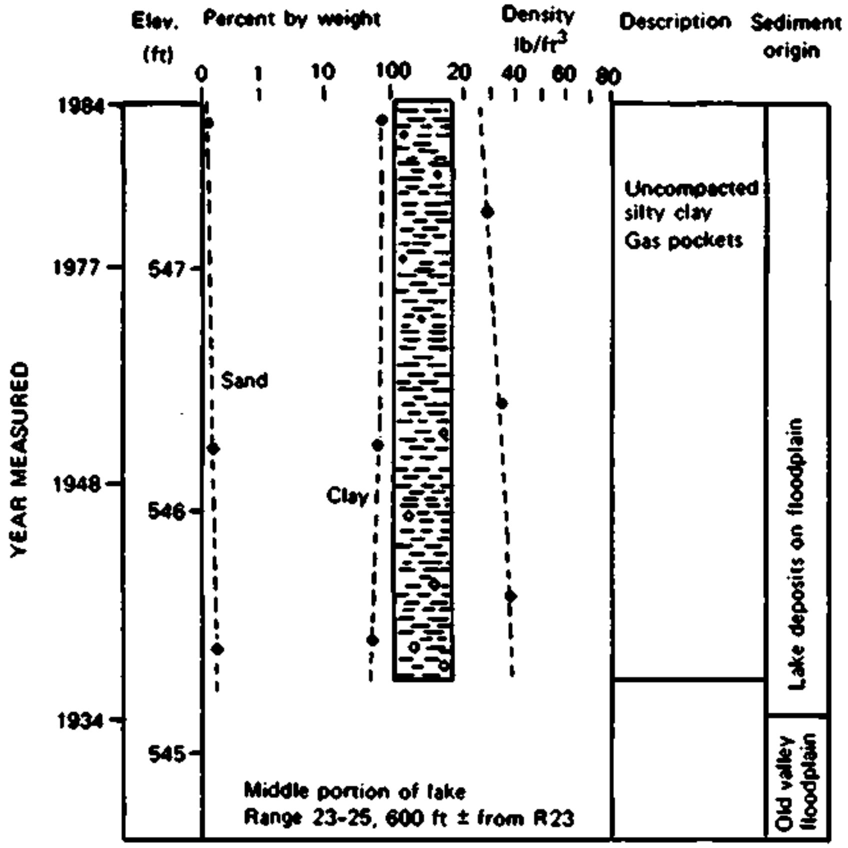

Figure 11. Geotechnical analysis of a Lake Springfield sediment core sample from Range 23-25, showing changes in sediment particle size and density with depth (Also shown are the past lake bed surface elevations at the sample site)

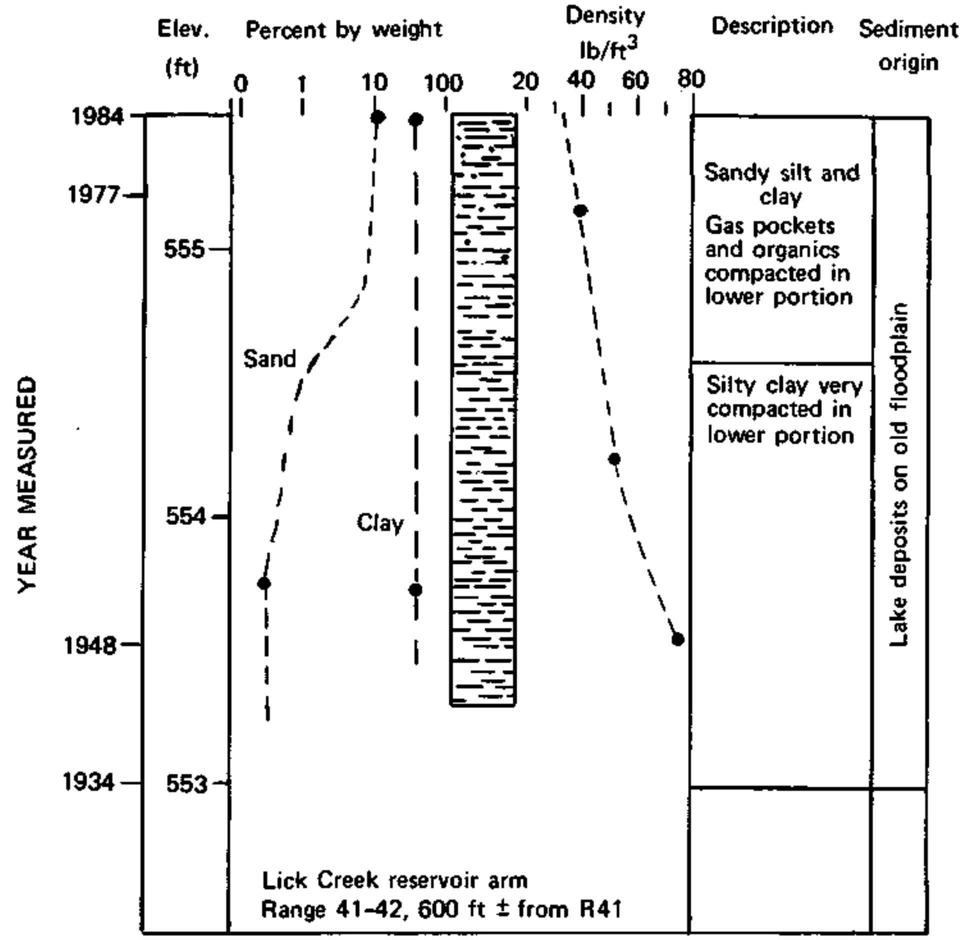

Figure 12. Geotechnical analysis of a Lake Springfield sediment core sample from Range 41-42, showing changes in sediment particle size and density with depth (Also shown are the past lake bed surface elevations at the sample site)

with depth and ranges from 40 pounds per cubic foot at the top to 73 pounds per cubic foot in the lower portion. This portion of the lake has been dewatered due to lake drawdown many times over the years and as a result the sediments are denser than the material in the deeper portions of the lake. The current water depth at normal pool is less than 5 feet. In figure 12 it can be seen that the sand concentration increases towards the top of the core, indicating that the depositional area of sand in the lake has moved downstream over the years as the extreme upstream portions of the lake have filled with sediment. Lick Creek enters the lake 3 miles upstream of this sampling site, and much of the original volume of the lake in this area is now filled with sediment, reducing the volume available to trap incoming sediment. As a result heavier materials such as sand are carried further downstream into the lake.

SEDIMENTATION RATES

The amount of sediment in a lake or reservoir is usually described either as sediment volume or sediment mass. The sediment volume corresponds to the water storage capacity loss in a lake or reservoir. In contrast the sediment mass, as measured by the sediment tonnage, is a measurement not dependent on the degree of compaction and is therefore a parameter that can be used to assess the relative sediment accumulation in various lakes and reservoirs. The weight of sediment in a lake indicates the rate of sediment inflow from a watershed and therefore provides an estimate of the rate of erosion of the watershed soils.

This present investigation of the sedimentation of Lake Springfield includes a reassessment of the earlier surveys of the lake. The review of the earlier surveys of 1948 and 1977 and the 1965 reconnaissance survey was undertaken to provide a consistent analysis of the changes over time in the sedimentation rates of the lake. The methodology of computing the lake volume used in this study is consistent with that used in earlier investigations. The revisions of the results of the earlier studies are due to improvements in methods of measuring distances and surface areas available to this investigation. The sediment mass or weight analysis employed in this study is basically a refinement of earlier methods and has the advantages of improved sediment sampling techniques and a much larger data set related to the changes in sediment density both areally and with the depth of burial.

Reservoir Capacity Loss Rates

The volume of sediment accumulation in a reservoir is generally determined as the loss in water storage capacity of the lake over a period of time. The volume of sediment will then be the difference between the original volume of the reservoir and the volume of the reservoir at the time it is surveyed.

The water storage capacity of Lake Springfield was calculated for the years 1934, 1948, 1965, 1977, and 1984. The methods used are detailed in the SCS National Engineering Handbook Section 3, Chapter 7 (SCS, 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 1984 survey sounded 37 of the original 38 range lines, which are shown in figure 3. These range lines were used to divide the lake into segments for the purpose of calculating total volume and volume loss in each segment of the lake.

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. The full text of Primoid is given in Appendix 2.

Table 2 gives the volume of each segment of the reservoir for 1934 and the 1948, 1977, and 1984 surveys. The differences between these volumes indicate the increased volume of sediment in a given segment and the corresponding

Table 2. Lake Springfield Volume in Acre-feet by Segments, 1934-1984, with 1984 Sediment Tonnages:

Segment number	Volume in acre-feet 1934	1948	1977	1984	1984 sediment tonnage (kilotons)
1	580	562	531	528	33
2	4323	4197	3953	3908	229
3	4914	4792	4547	4443	248
4	172	171	160	158	14
5	486	472	448	443	50
6	5302	5171	4932	4831	284
7	6319	6157	5904	5829	396
8	318	311	294	271	44
9	4170	4059	3980	3886	171
10	505	495	485	469	24
11	6805	6663	6467	6420	294
12	7392	7202	6921	6859	362
13	4180	4018	3752	3707	324
14	164	152	128	141	23
15	72	70	62	62	10
16	2720	2598	2416	2388	259
17	2427	2297	2111	2033	347
18	1432	1346	1184	1101	261
19	1308	1210	1009	949	298
20	306	294	262	249	61
21	728	666	533	524	168
22	575	517	406	394	145
23	139	114	78	76	53
24	571	506	399	393	210
25	219	197	162	155	74
26	531	403	316	316	278
27	29	16	3	3	37
28	223	145	93	97	179
29	67	50	31	29	53
30	91	68	38	34	81
31	48	34	17	19	41
32	594	541	451	402	132
33	582	522	416	358	199
34	884	767	527	460	419
35	345	264	140	124	284
36	26	15	1	1	35
37	158	103	43	44	162
38	128	74	49	45	117
39	93	50	36	31	88
Total	59,926	57,289	53,285	52,180	6,487

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.

The 1965 segmental volumes of the lake are not presented in table 2. This is because the 1965 reconnaissance survey lacked the detail of measurement of the other surveys and therefore only a rough estimate of the total lake volume was made. This estimate of the 1965 volume is presented in table 3.

Table 3 presents a summary of the changes over time, calculated by this investigation, in the lake storage capacity, capacity loss rate, annual percent volume loss, and average depth for the years 1934, 1948, 1965, 1977, and 1984. As can be seen, Lake Springfield lost 7700 acre-feet of storage in the 50 years before 1984. This value represents approximately 13 percent of the original lake capacity. The annual capacity loss rate has varied from a high of 186 acre-feet to as low as 135 acre-feet. The 50-year average rate was 154 acre-feet or 50 million gallons per year. The average yearly loss is equivalent to 0.26 percent of the lake's original capacity, as shown in table 3. At this constant rate the lake will reach its half-life (half of its original volume and depth) approximately 140 years from now. Also shown in table 3 is the average depth of the lake for the years of survey. From table 3 it can be seen that the lake averaged 14.4 feet deep in 1934. In 1984 it averaged 12.5 feet, a loss of 1.9 feet. The total average reduction in the lake depth is equivalent to 0.4 inches per year.

Table 3. Changes Over Time in Lake Storage Capacity, Annual Capacity Loss Rates, and Average Depths, Lake Springfield

Period ending this year	Lake storage capacity (acre-feet)	Lake capacity loss rate per year (acre-feet)	Percent loss per year	Average depth (feet)
1934	59,900	-	-	14.4
1948	57,300	186	0.31%	13.7
1965	55,000	135	0.22	13.2
1977	53,300	142	0.24%	12.8
1984	52,200	157	0.26%	12.5
1934-1984	-	154	0.26%	-

The capacity loss rate has varied over time as shown in table 3. The highest loss rate of 186 acre-feet per year was measured for the period 1934-1948. The rate for the next period was 135 acre-feet per year. This reduction is attributed partially to increases in the drawdown of the lake's pool caused by drought and water supply demands that occurred after 1948, which have compacted the deposited sediment. Major drawdowns of 12 feet in 1954 and 6 feet in 1977 and 1984 have resulted in aeration and compaction of the lake sediment. This compaction of the sediment does not reduce the total weight of the deposited sediment. However, it reduces its volume and correspondingly increases available storage.

Figure 13 shows the percent volume loss by segments from 1934-1984. 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 Sugar and Lick Creek reservoir arms have lost more than 30 percent of their volumes. Segments with the lowest percentages of volume loss are found in the deep portions of the lake near the dam.

Figure 14 shows the current proportion of total lake storage capacity contained in major subareas of the lake. It can be seen in this figure that the Lick and Sugar Creek reservoir arms contain less than 10 percent of the total lake storage. Together the mid-lake and downstream areas contain over 90 percent of the total storage. Also shown in this figure is the proportion of the original 1934 volume of the lake contained in the subareas. By comparing the 1934 and 1984 proportional volumes it can be seen that the reservoir arms have lost their volumes at a higher rate than the mid-lake and downstream areas.

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

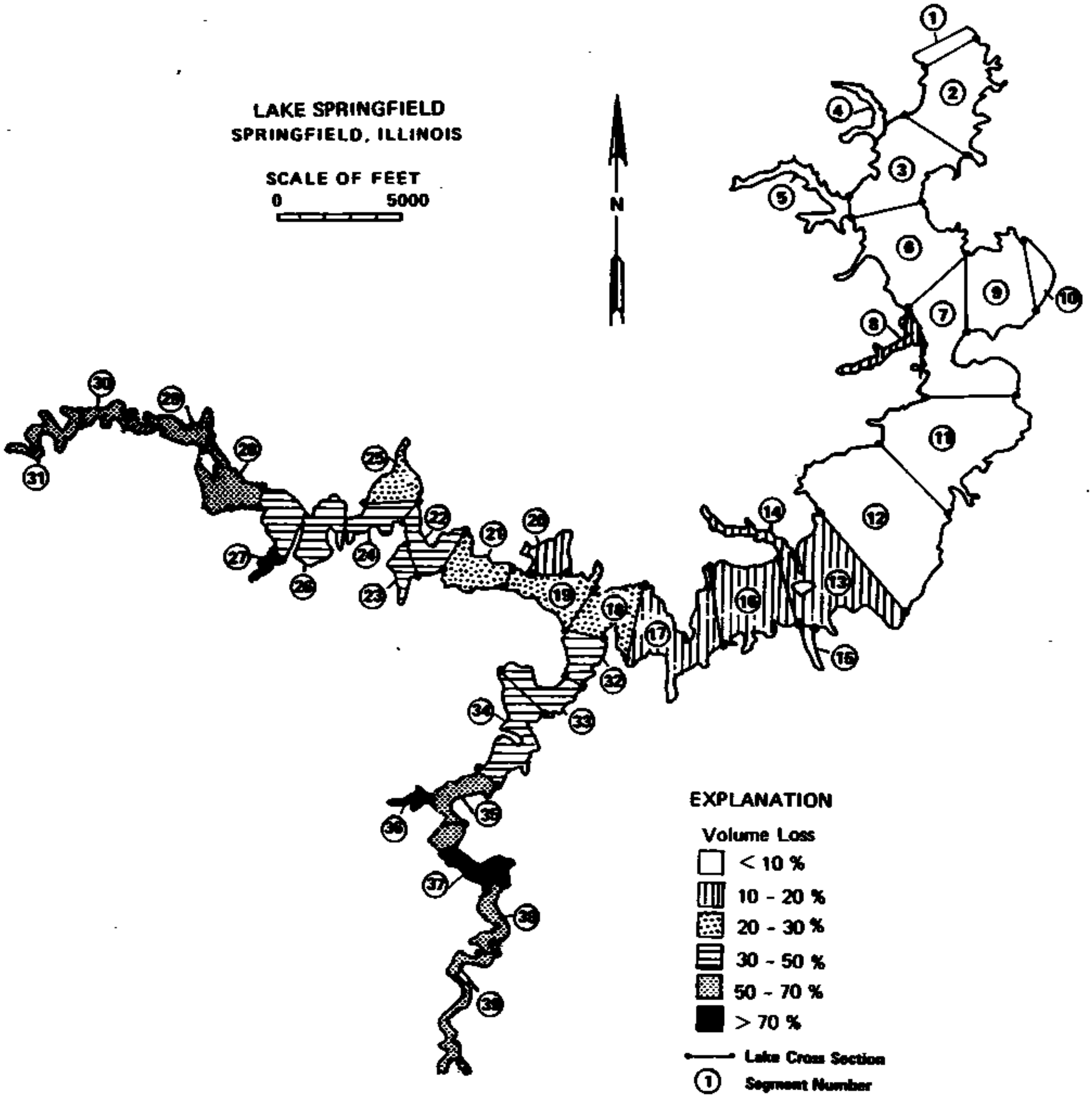

Figure 13. Percent loss of original volume in Lake Springfield due to sediment accumulation from 1934 to 1984, by segments

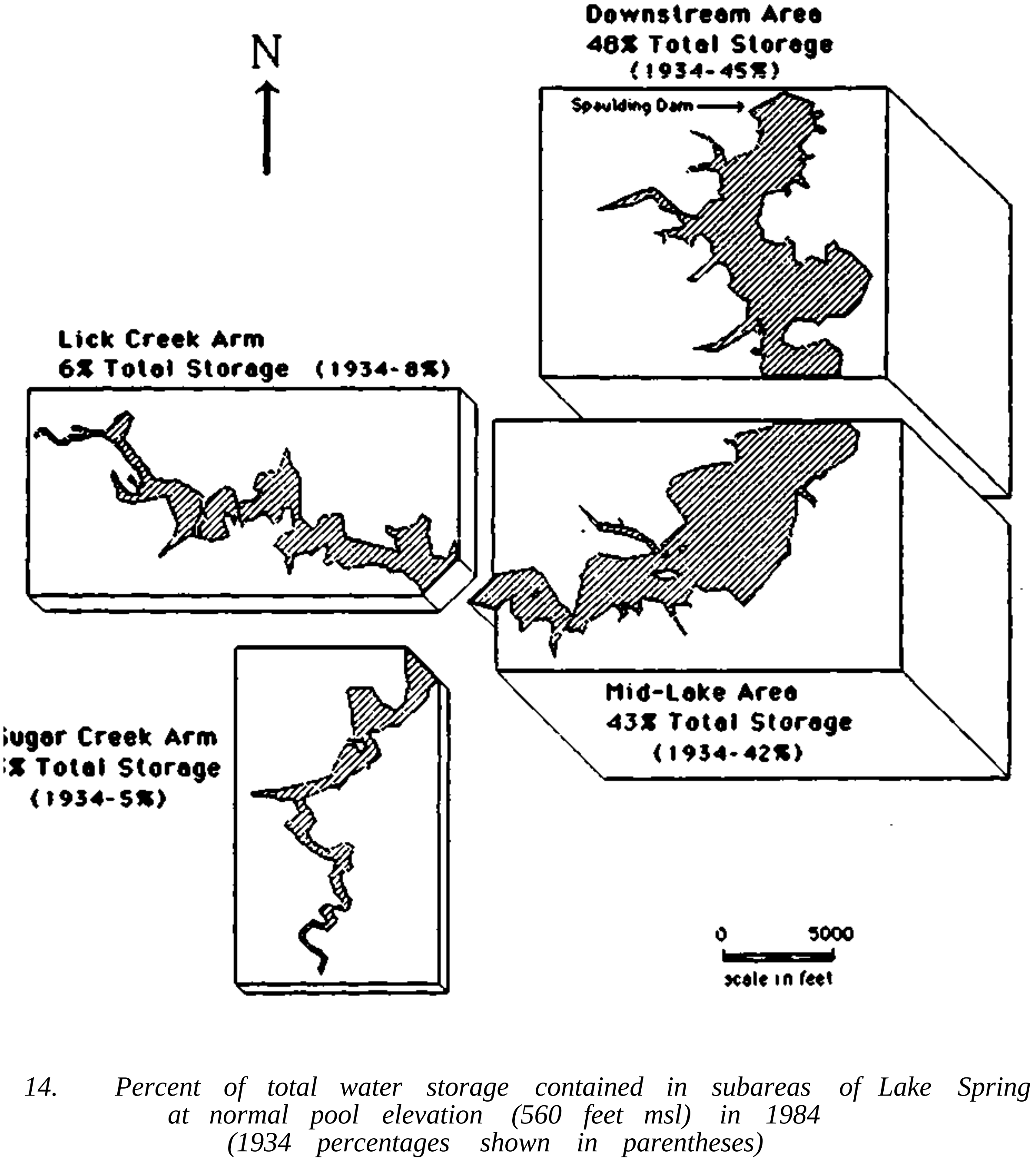

Figure 14. Percent of total water storage contained in subareas of Lake Springfield at normal pool elevation (560 feet msl) in 1984 (1934 percentages shown in parentheses)

calculation of the sedimentation rates by weight provides the data necessary to determine the amount of material washed into the lake based on the dry weight of the sediments. This allows a better assessment of the changes in the rate of sediment inflow over time.

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.

The weight of sediment accumulated in Lake Springfield from 1934 to 1984 was determined on the basis of segmental sediment volumes as described earlier and unit weight of the sediment as determined by the 1984 sediment sampling. Unit weights determined for sediment samples collected in 1984 were applied to the appropriate segmental sediment volumes (table 1).

Sediment weight in 1977 and 1984 was calculated for each lake segment by using equation 1. The total weight of sediment in the reservoir is the sum of the segmental weights:

$$T = (21.78)\ MV \qquad (2)$$

where

T = the segmental sediment weight in tons
21.78 = conversion factor
M = the segmental unit weight in pounds per cubic foot
V = the segmental sediment volume

The weight of the sediment in the lake for each survey year was determined on the basis of a detailed analysis of the exposure of sediments to drying and compaction. The average unit weight density of lake sediments for each survey year is given in table 4. The increase in unit weight from 1948 to 1965 resulted from the drought of 1953-1954 which lowered the lake pool 12 feet and compacted the previously deposited sediment.

The total amount of sediment in Lake Springfield in 1984 was 7700 acre-feet, representing 6.5 million tons. To bring this number into perspective, 7700 acre-feet is equivalent to the volume of a building that occupies an area 100 feet by 100 feet and is 6.4 miles high. The weight of sediment in the lake is equivalent to the weight of 4.3 million average size automobiles (3000 pounds each). Further, if the total weight of sediment is divided by the time it took to be deposited on the lake bed, the daily

Table 4. Average Unit Weight Density of Lake Bed Sediment

Year	Pounds per cubic foot
1918	35.4
1965	39.8
1977	39.1
1984	38.6

average rate is equivalent to 236 average sized automobiles being dumped into the lake every day. These figures are presented to highlight the magnitude of the process of lake sedimentation, and, by corollary, the magnitude of the quantity of eroded material that has washed off this primarily agricultural watershed.

The annual sedimentation rates for Lake Springfield are summarized in table 5. Table 5 also shows the storage capacity loss rate and the average weight of sediment deposited in the lake for each acre of watershed. In table 5 it can be seen that the weight of sediment deposited in the lake has varied over time. The highest rate of deposition (146,000 tons per year) was calculated for the period 1934 to 1948. In contrast, the lowest rate occurred over the period 1965 to 1977. In table 5 it can be seen that the rate of sediment deposition has decreased over time. The weight of sediment deposited over the periods 1965 to 1977 (118,000 tons/year) and 1977-1984 (121,000 tons/year) differs by 3 thousand tons or less than 3 percent. As shown in table 5, the sediment deposition rate over the last 19 years has been much below the 50-year average.

A comparison of the capacity loss and sediment accumulation rates given in table 5 indicates the importance of analysis based on the volumetric and mass accumulation of sediment. The highest capacity loss rate corresponds to the highest sediment deposition rate; however, the lowest storage capacity loss rate did not occur during the period of lowest sediment deposition rate. This discrepancy is due to the changes in the density of the sediment, caused primarily by drawdowns in the lake surface due to droughts and water supply demands. As discussed previously, the drought of the 1950's resulted in a drawdown of 12 feet and in the aeration and compaction of the sediment in the lake. It is due to this compaction of

Table 5. Annual Sedimentation Rates in Lake Springfield

Period	Storage capacity loss rate (acre-ft/yr)	Weight of sediment, tons (per year)	Tons of sediment per acre of watershed*
1934-1948	186	146,000	0.88
1948-1965	135	129,000	0.78
1965-1977	142	118,000	0.71
1977-1984	157	121,000	0.73
1934-1984	154	130,000	0.79

*Watershed area excluding lake = 165,366 acres

sediment that the period 1948 to 1965 had the lowest capacity loss rate at the same time that it had the second highest rate of total sediment deposition by weight.

The discrepancy between the capacity loss rates and the weight of deposited sediment highlights the need for detailed analysis of both of these parameters in order to assess the changes over time in the lake's usefulness as a water supply reservoir. The weight of sediment deposited over a time interval in the past will not change; however, the volume of that sediment will change due to factors such as pool drawdowns and hence will impact the available storage of the lake. The scouring of lake bed sediment, resuspension, and transport of the material over the dam can occur in a lake and this will change the mass of sediment remaining. However, since this phenomenon is of minor importance for large lakes, it can be neglected in this instance and the sediment deposited over any given time period can be considered to remain in the lake forever.

The reduction in sediment delivery to the lake indicated by the reduced rate of increase of sediment weight in the lake might result from a number of factors, including but not limited to improvements in soil conservation in the watershed, changes in rainfall and/or streamflow patterns, or changes in the hydraulics of the stream-lake system. Evaluation of these influences is beyond the scope of the present study and would require a more detailed analysis of watershed sediment loads.

TRAP EFFICIENCY, WATERSHED EROSION, AND SEDIMENT SOURCES

Reservoir Trap Efficiency

The trap efficiency of a lake is a measure of the proportion of the total sediment load carried into the lake that is deposited. Brune (1953) and Dendy (1974) have developed methods of estimating the trap efficiency of lakes and reservoirs based on the ratio of average yearly inflow to the storage capacity. Based on these methods, it is estimated that the 1984 trap efficiency of Lake Springfield is about 95%. This value is an approximation of the average proportion of sediment that will settle in the lake in an average year.

The 1984 survey determined that 6.5 million tons of sediment has been deposited in the lake since 1934, an average rate of 130 thousand tons per year. The trap efficiency ratio can be used to estimate the total amount of sediment delivered to the lake. The total sediment accumulation of 6.5 million tons divided by the trap efficiency of 95% yields the estimate that 6.8 million tons have been delivered. The estimated long-term average rate of sediment delivery to the lake is 137,000 tons per year.

Sedimentation Rates and Watershed Erosion

The amount of sediment in Lake Springfield would equal 0.21 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 Springfield has passed through the lake and been 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 0.22 inches of soil per watershed acre (weighted long-term reservoir trap efficiency is 95%). The 50-year lake sedimentation rate (in-lake sediment) represents 39.3 tons of soil for each acre of watershed. Correcting for the reservoir trap efficiency, the total sediment delivered to Lake Springfield since its construction represents 41.3 tons of soil for each acre of watershed. The average annual rate of delivery is 0.79 tons per acre or 0.004 inches per acre of watershed.

Sources of Sediment

The principal source of sediment to Lake Springfield is the 258 square miles **of watershed** (excluding **the** lake area) drained by Sugar and Lick Creeks and **their tributaries.** Additional sources are Horse Creek water pumped into Lake Springfield to augment the lake storage, aerosol deposition, intentional construction fills, and litter. These additional sources are minor in comparison to sediment carried by Sugar and Lick Creeks and their tributaries and will not be considered in this analysis.

A method of performing a rough assessment of the relative contribution of sediment from major sources is to examine the depositional patterns within the lake. Lake Springfield had 6.5 million tons of sediment in 1984. Of this total 1.7 million tons had been deposited in the Lick Creek reservoir arm and 1.4 million tons in the Sugar Creek reservoir arm. If these values are divided by the watershed area, they will provide an estimate of the per-area input of sediment from each source for the period of record. The Lick Creek arm receives drainage from approximately 135 square miles and the Sugar Creek arm from 100 square miles of watershed. Therefore the annual per-area input of sediment (deposited in the reservoir arms) for the period 1934 to 1984 is 0.39 tons per acre for the Lick Creek arm and 0.45 tons per acre for the Sugar Creek arm. In contrast the annual average sediment deposition for the whole lake is 0.79 tons per acre, indicating that much of the sediment delivered by Sugar and Lick Creeks is not deposited in the arms of the reservoir but is carried into the main lake. This method indicates that Sugar Creek appears to be contributing more sediment per watershed area than Lick Creek, although it must be stressed that these values are only rough estimates. The only definitive method of assessing the per-area inputs of sediment is by intensive monitoring of the flow of sediment and water within each watershed.

It is recommended that a data collection and analysis program be initiated for this watershed to determine the relative sediment contribution of the three major subareas of the total watershed: Lick Creek, Sugar Creek, and direct drainage to the lake. This program should include an assessment of the hydrologic and sediment budgets of the lake as well as instream monitoring of the flow of water and sediment in Sugar and Lick Creeks and their tributaries. The results of this program will allow the targeting of areas of the watershed for the purpose of applying soil conservation measures to reduce sediment input to the lake in a cost effective way.

COMPARISON OF VOLUME LOSSES IN LARGE ILLINOIS RESERVOIRS

Table 6 lists the volume loss rates for Lake Springfield and other Illinois reservoirs with storage capacities greater than 10,000 acre-feet. The capacity loss rates of these large reservoirs range from 1.02 to 0.15 percent per year. It can be seen in this table that Lake Springfield, with a 50-year capacity loss rate of 0.26 percent, has one of the lowest rates of capacity loss. It can also be seen that there is a poor correlation between watershed size and capacity loss. For example, Lake Lou Yeager's watershed is approximately half the size of Springfield's, yet its capacity loss rate is four times higher. The Rend Lake watershed is nearly twice the size of Springfield's and its loss rate is almost 60 percent higher. All the reservoirs listed in this table have similar watershed land uses, primarily agricultural.

The lake and reservoir sedimentation investigation program at the Illinois State Water Survey is currently examining the interrelationship of many factors affecting the process of sedimentation. The goal of this study is to determine the effect of the interaction of variables such as watershed size, land use, topography, soils, and distribution of precipitation on the

Table 6. Sedimentation in Illinois Reservoirs
(Storage capacity greater than 10,000 acre-feet)

Reservoir	Drainage area (sq mi)	Original storage capacity (acre-feet)	Period	Percent loss per year
Carlyle*	2680	280,595	1967-1976	.53
Shelbyville*	1054	207,820	1969-1980	.37
Decatur	925	27,900	1921-1983	.53
Rend*	488	184,675	1970-1980	.41
Springfield	265	59,900	1934-1984	.26
Crab Orchard	196	70,746	1940-1951	.44
Lou Yeager	115	15,837	1965-1977	1.02
Mattoon	56	13,160	1958-1980	.52
Little Grassy	15	26,116	1941-1951	.15

*Multiple use pool, non-flood control

rate of sedimentation in lakes and reservoirs, and to be able to predict rates of sedimentation. However, field measurements are essential to determine **the** exact rate of capacity loss of Illinois lakes.

SUMMARY

A sedimentation survey of Lake Springfield was conducted in 1984 to determine the present capacity of the lake, as well as the sedimentation rates over the period since the lake's construction and the three prior surveys conducted in 1948, 1965, and 1977. Sedimentation rates determined in 1948, 1965, and 1977 surveys have been changed to conform to the methods of analysis used in the present survey.

Lake Springfield's watershed encompasses a total of 265 square miles. Land use is primarily agricultural row crops owing to the fertile soil formed in loess deposits and the moderate slopes of the land. The climate is typically continental with warm summers and cold winters. Over the period 1944-1983 precipitation has averaged approximately 35 inches; however, annual extremes have deviated from the average by over 35 percent.

In 1984 Lake Springfield had a storage capacity of 52,200 acre-feet (17 billion gallons). This value represents a decrease of storage of 13 percent since 1934. In 1984 there were 7700 acre-feet of sediment in the lake, representing 6.5 million tons. The sedimentation and capacity loss rate have varied over the time intervals between the surveys of 1948, 1965, 1977, and 1984. Table 5 summarizes the results of this investigation of the lake. The highest capacity loss rate occurred over the period 1934 to 1948 and averaged 186 acre-feet per year. This capacity loss rate corresponds to the highest sediment tonnage accumulation rate of 146,000 tons per year. Later time periods show lower rates with respect to both the tonnage of accumulation and capacity loss. Figure 15 summarizes the sedimentation and capacity loss measured for each period. In this figure it can be seen that the rates over the period 1977 to 1984 are near the 50-year average. The capacity loss rate over this period is slightly higher than the 50-year average and the weight of sediment deposited is less than the average.

The rate of water storage capacity loss for Lake Springfield is well below the average for large Illinois reservoirs, as shown in table 6. On the average Lake Springfield has lost 0.26 percent of its storage capacity

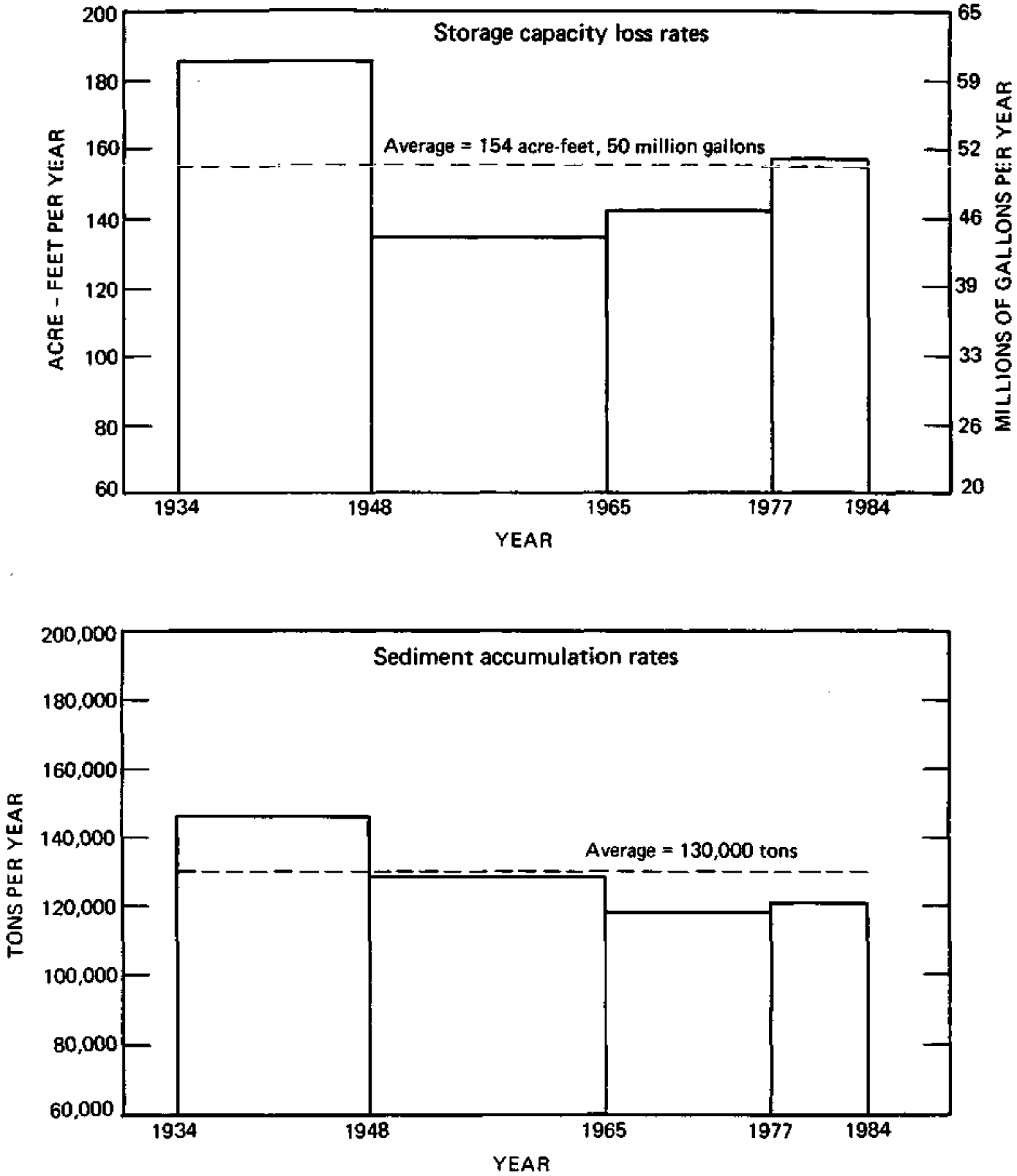

Figure 15. Summary plots of sedimentation rates in Lake Springfield: total storage capacity loss per time period in acre-feet and million gallons per year, and sediment accumulation rates per time period in tons per year

annually over the past 50 years. The average rate for large Illinois reservoirs (original storage capacities greater than 10,000 acre-feet) is 0.47 percent per year.

The sediment deposited in Lake Springfield is primarily clay. The simple averages of all samples are: 66% clay, 33% silt, and 1% sand. The average density of the sediment in 1984 was 38.6 pounds per cubic foot.

The upstream areas of the lake have lost a greater proportion of their original volume than the downstream areas, as shown in figure 13. Currently over 90% of the storage capacity of the lake (at normal pool) is contained in the lake segments downstream of the Interstate Bridge (figure 3), as shown in figure 14.

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Appendix 1. Lake Springfield Sediment Particle Size and Unit Weight Analysis

Appendix 1

Range	Depth below lakebed to midpoint of sample (feet)	% Sand	% Silt	% Clay	Density (lb/ft3)
01-02 North	0.05	0.55	26.35	73.10	
01-02 South	0.10	0.55	30.23	69.22	
	0.35				23.3
	0.95				35.0
	1.12	4.45	47.92	47.63	
03-04 East	0.05	0.12	14.49	85.39	
	0.35				20.0
	1.15				24.1
	1.35	0.12	10.49	89.39	
	1.95				24.0
	2.15	0.21	19.96	79.83	
05-06	0.35				45.4
	1.15				45.8
07-08	0.05	0.18	52.40	47.42	
	0.45				54.1
08-09 East	0.35				24.3
	1.45				28.8
08-09 West	0.05	0.09	19.98	79.93	
	0.45				23.2
	1.35				29.4
10-11 South	0.65				32.8
10-13 South	0.05	0.21	19.46	80.33	
	0.65				23.2
11-12	0.05	0.30	35.39	64.31	
	0.35				41.8
	1.15				43.4
	1.35	0.24	27.44	72.32	
14-15 South	0.05	0.15	18.47	81.38	
	0.45				23.4
	1.55				39.2
16-17 East	0.35				46.6
16-17 West	0.10	0.58	30.82	68.60	
	0.55				40.1
18-19 East	0.10	0.06	22.77	77.17	
	1.25				33.7
18-19 West	0.35				24.6
	1.05				30.6
20-21 East	0.10	0.27	26.93	72.80	
	0.55				33.0
20-21 West	0.10	0.68	22.35	76.97	
	0.55				34.3
22-23	0.10	0.18	40.93	58.89	
	0.35				39.6
	0.95				42.4
	1.85				56.4

Appendix 1 (continued)

Range	Depth below lakebed to midpoint of sample (feet)	% Sand	% Silt	% Clay	Density (lb/ft^3)
23-25 North	0.10	0.09	21.98	77.93	
	0.45				28.0
	1.25				31.2
	1.15	0.21	26.45	73.34	
	2.05				32.9
	2.25	0.09	36.97	62.94	
23-25 South	0.45				29.2
	1.75				39.8
24-25	0.10	0.06	47.47	52.47	
	0.35				**42.7**
	1.55				**44.4**
26-27 North	0.75	0.30	23.93	75.77	
	0.95				**31.7**
	1.65				**76.8**
26-27 South	0.25				24.8
	0.85	**0.15**	**18.97**	**80.88**	
	1.05				**35.8**
28-29 North	0.10	0.05	24.84	75.11	
	0.45				**25.7**
	1.45	**0.32**	**25.81**	**73.87**	
	1.65				**33.1**
	1.95	**0.21**	**27.10**	**72.69**	
28-29 South	0.45				28.6
	1.25				**48.8**
	1.65				**71.0**
30-31	**0.35**				**29.1**
30-32	**0.10**	**0.15**	**30.95**	**68.90**	
31-32	**0.10**	**0.12**	**25.97**	**73.91**	
	0.65				**27.1**
	1.65				**34.0**
33-34	**0.10**	**0.33**	**22.93**	**76.74**	
	0.45				**29.2**
	1.25				**70.0**
35-36	**0.10**	**4.14**	**35.47**	**60.39**	
	0.35				**30.4**
	1.15	**0.088**	**32.97**	**66.94**	
	1.35				**35.2**
	1.95				**51.3**
	2.15	**0.60**	**-26.44**	**72.96**	
37-38	0.45				33.9
	1.35				**35.7**
	1.85	**0.18**	**34.94**	**64.88**	
	2.05				**39.9**
39-40	0.10	0.03	26.99	72.98	
	0.35				36.4
	1.45				45.2
	2.35				34.0

Appendix 1 (concluded)

Range	Depth below lakebed to midpoint of sample (feet)	% Sand	% Silt	% Clay	Density (lb/ft^3)
41-42	0.10	11.57	37.14	51.29	
	0.35				39.5
	1.25				48.3
	1.75	0.50	46.77	52.73	
	1.95				72.6
44-45	0.10	2.11	35.73	62.16	
	0.25				58.1
	0.75'	4.51	57.29	38.20	
	1.15				74.8
48-49	0.10	14.07	49.85	36.08	
	1.75	4.54	62.52	32.94	
56-57	0.10	0.03	32.99	66.98	
	0.35				30.0
	1.55				35.7
58-59	0.10	0.06	44.15	55.79	
	0.45				33.3
	1.25				38.3
	1.45	0.15	33.95	65.90	
	2.25				77.7
	2.45	3.88	64.40	31.72	
58-59 Bay	0.45				38.0
	1.65				37.8
	1.95				35.1
	2.55				40.1
60-61	0.10	0.16	46.02	53.82	

Appendix 2. Primoid — A FORTRAN program for the Calculation of Lake Storage Capacity, Sediment Volume and Sediment Weight Using the Dobson Prismoidal Formula

```
      PROGRAM PRIMOID (INPUT,OUTPUT)
      INTEGER TOTSEG, TOTYR
      DIMENSION W2(11),VOL(101,11),TOTVOL(11),E2(11),SEDVL(101,11),
     $WGT(101,11),TOTWGT(11),TOTSD(11)
      DATA TOTVOL/11*0.0/,TOTWGT/11*0.0/,TOTSD/11*0.0/
      1N=5
      I0UT=6
C
C
C        PRIMOID— A FORTRAN PROGRAM FOR THE CALCULATION OF LAKE
C           VOLUMES USING THE DOBSON PRISMOIDAL FORMULA
C
C
C                          BY
C                      BILL BOGNER
C                          AND
C                      KURT JOHNSON
C
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
C     LAKE BETWEEN SURVEY YEARS AND FOR THE TOTAL PERIOD OF EXISTEN
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+           )/130680
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 TOO 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         W1           THE WIDTH OF THE DOWNSTREAM CROSS
C                                   SECTION, FEET
C
C          W2         W2           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,TOTYR
      WRITE(IOUT,206)TOTSEG,TOTYR
C
C
C
C    BASIC PHYSICAL PARAMETERS ARE READ IN TO DESCRIBE THE LAKE CROSS
C    SECTIONS AND SEGMENTS. THESE PARAMETERS ARE ISEG (THE SEGMENT ID)
C    E2, A, APRIME, W2, TPUW, BTMUW, ICOMP, AND H3. TPUW AND BTMUW
C    ARE THE UNIT WEIGHTS FOR THE TOP ONE FOOT OF SEDIMENT AND THE
C    REMAINING BOTTOM LAYER OF SEDIMENT RESPECTIVELY.
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.
```

```
C
C
C
      READ(IN,108)(W2(IYR),E2(IYR),IYR=1,TOTYR)
      WRITE(IOUT,208)(W2(IYR),E2(IYR),IYR=1,TOTYR)
      DO 10 NSEG=l,TOTSEG
         DO 11 IYR=1,TOTYR
         Wl=W2(IYR)
         E1=E2(IYR)
         READ(IN,100)ISEG,E2(IYR),A,APRIME,W2(IYR),
     1    TPUW,BTMUW,1COMP,H3
         WRITE(10UT,200)ISEG,E2(IYR),A,APRIME,W2(IYR),
     1    TPUW,BTMUW,ICOMP,H3



      THE VALUES OF APRIME AND ICOMP GUIDE THE PROGRAM THROUGH THE
      CALCULATION OF EACH SEGMENTAL VOLUME. A NEGATIVE VALUE FOR APRIME
      INDICATES THAT THE SEGMENT VOLUME SHOULD BE CALCULATED USING THE
      AVERAGE END AREA METHOD WITH A LENGTH SUBSTITUTED FOR THE SURFACE
      AREA IN THE INPUT DATA.



      IF(APRIME.EQ.0..AND.ICOMP.LT.0.)THEN
            VOL(ISEG,IYR)=El*A/2./660./66.
            ICOMP=ICOMP*(-l)
            ELSE IF(APRIME.EQ.O.)THEN
          VOL(ISEG,IYR)=(El+E2(IYR))*A/2./660./66.
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
        ELSE IF(ICOMP.GE.O) THEN
               VOL(ISEG,IYR)=((APRIME/3.)*(E1+E2(IYR)
                )/(Wl+W2(IYR)))+((A/3.)*(El/Wl+
               E2(IYR)/W2(IYR)))
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.O) THEN
         VOL(ISEG,IYR)=((APRIME+A)/3.0)*E1/W1
      ICOMP=ICOMP*(-l)
      ENDIF



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:

               H3* E2/130680

C        IS ADDED INTO THE SEGMENT REPRESENTED BY THE ABSOLUTE VALUE
C        OF ICOMP.
C
C
C
      IF(ICOMP.NE.0)THEN
      VOL(ICOMP,IYR)=VOL(ICOMP,IYR)+H3*E1/130680
      TOTVOL(IYR)=TOTVOL(IYR)+H3*E1/130680
      ENDIF
      TOTVOL(IYR)=TOTVOL(IYR)+VOL(ISEG,IYR)
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
         CALL  WGHT  (VOL(ISEG,1),VOL(ISEG,IYR),A,TPUW,
     $BTMUW,SEDVL(ISEG,IYR),WGT(ISEG,IYR),TOTWGT(IYR))
      TOTSD(IYR)=TOTSD(IYR)+SEDVL(ISEG,IYR)
   11        CONTINUE
   10        CONTINUE
C
C
C
C     OUTPUT AND FORMAT STATEMENTS
C
C
C
      WRITE(IOUT,215)
      WRITE(IOUT,216)
      WRITE(IOUT,217)
```

```
        WRITE(I0UT,218)
        DO  22  NSEG=l,TOTSEG
             WRITE(IOUT, 214)NSEG, (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=l,TOTSEG
             WRITE(I0UT,211)NSEG,(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   F0RMAT(/2X,I3,6X,F8.2,2X,F8.2,4(4X,F8.2,2X,F8.2))
  213        FORMAT('        1948                 1977
     $    1984')
  210 FORMAT(' SEGMENT   SEDIMENT  SEDIMENT    SEDIMENT  SEDIMENT    SED
     $IMENT  SEDIMENT')
  219 FORMAT('1'//)
  212 FORMAT(' NUMBER     VOLUME    WEIGHT      VOLUME    WEIGHT      VO
     $LUME    WEIGHT')
  214 FORMAT(/2X,I3,8X,F8.2,5(5X,F8.2))
  215 FORMAT('1'//36X, "LAKE SPRINGFIELD"//42X, "WATER VOLUME IN ACRE FEET
     $"/)
  216 FORMAT(//8X,4(5X,'********'))
  217 FORMAT(/' SEGMENT',7X,'1934',9X,'1948',9X,'1977',9X,'1984')
  218 FORMAT(' NUMBER ',4(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(215)
  206 FORMAT('1',15,'SEGMENTS',5X,15,'YEARS')
  100 FORMAT(15,F10.0,2(F5.1),1F5.0,2F5.1,15,F5.0)
```

```
  200  FORMAT(/15,F10.0,'SQ.FT.',2(F5.1,'ACRES',3X),3F5.0,15,F5.0)
  108 F0RMAT(10(F5.0,F10.0))
  208 FORMAT(10(F5.0,'FEET',F10.0,'SQ.FT.'))
      END
C
C
C
C
C
C
C
      SUBROUTINE WGHT (OLDVL,PRESVL,AREA,BTMUW,TPUW,SDVL.WT.TTWGT)
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
         SDVL=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
```

```
   IF(SDVL.GT.AREA)THEN
      WT=(SDVL-AREA)*BTMUW+(TPUW*AREA)
   ELSE
      WT=SDVL*TPUW
   ENDIF
      WT=(WT*43560.0/2000.0/1000.0

RETURN
END
```