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Illinois State Water Survey Division
SURFACE WATER SECTION

SWS Contract Report 444

WATER, SEDIMENT, AND NUTRIENT BUDGETS OF LAKE SPRINGFIELD. SPRINGFIELD, ILLINOIS

FINAL REPORT

by William P. Fitzpatrick and Laura L. Keefer

Prepared for the City of Springfield

Champaign, Illinois
March 1988

ENR *Illinois Department of Energy and Natural Resources*

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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 processes of hydrology and pollutant transport in Illinois waters. It presents the results of a two-year field monitoring project to assess the hydrologic, sediment, and nutrient budgets of the watershed of Lake Springfield. This research investigation was conducted under a cooperative cost-sharing agreement between the City of Springfield and the ISWS. This report summarizes the results and findings of the monitoring period May 15, 1985 through May 14, 1987. The data and findings of the first year of the project have been published in ISWS Contract Report 408, "Hydrologic Investigation of the Watershed of Lake Springfield." The data and results presented here are the result of further data collection and analysis and supersede ISWS Contract Report 408.

Lake Springfield is the largest municipally owned lake in Illinois, covering 6.6 square miles and encompassing 52,200 acre-feet (17 billion gallons) of storage in 1984 (at normal pool elevation of 559.35 feet msl). The lake is the primary source of potable water for the City of Springfield. It was constructed in 1934 by the impoundment of Sugar Creek, a tributary of the Sangamon River.

The lake and its watershed are located in central Illinois south 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 and other pollutants which are entrained by runoff water and carried to the lake. Rainfall and other forms of precipitation act as the initiators of

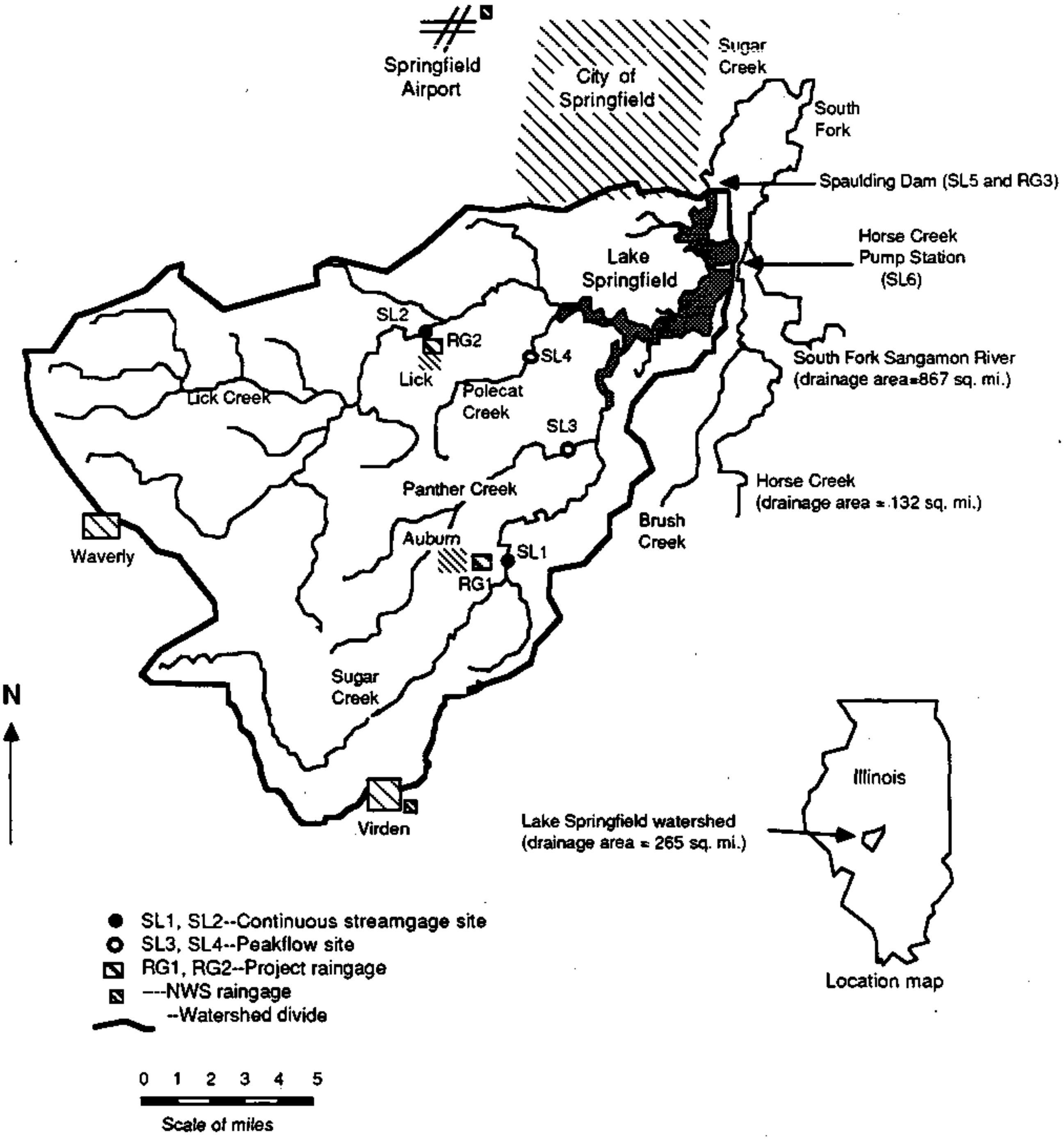

Figure 1. Map of the Lake Springfield watershed

fluvial erosion, sediment and pollutant transport, and deposition processes which are constantly at work in the watershed.

Runoff waters are delivered to the lake by tributary streams, of which the largest, as shown in figure 1, are Sugar, Lick, Panther, and Polecat Creeks. These streams, in addition to the unnamed tributaries, are the principal agents of water, sediment, and nutrient transport to the lake. The ISWS investigation of sedimentation in the lake (Fitzpatrick et al., 1985) documented an overall loss of 13 percent of lake water storage capacity since 1934 due to sediment accumulation. This investigation described many of the effects of sediment transport to the lake, such as the loss of more than 50 percent of the volume of upstream areas of the lake, noxious aquatic weeds, and impaired recreational and aesthetic uses.

Figure 2 is a photograph of water samples obtained on June 3, 1985, from flowing tributaries of the lake and from Lake Springfield at Spaulding Dam (see figure 1). These samples were taken after a 2-inch rainfall on the watershed. The turbidity of the water is caused by the transport of sediment and nutrients eroded from agricultural and urban lands in the watershed. The sample obtained from Lake Springfield at the dam is clear because of the relatively large volume of the lake, which allows entrained sediment and nutrients to settle out.

Figure 3 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 4). The area shown in the photograph between the tree lines is an upstream area of the lake that has lost two-thirds of its average depth because of sediment accumulation. Where there once was a wide and fairly deep area of the lake, this photograph shows a mud flat area overgrown with lily pads and weeds that were exposed by the lake drawdown of 3 feet. At the time this photograph was taken (November 20, 1984), the lake in this area was reduced to a shallow stream channel flowing over the mud flat as can be seen in the background. In 1934 the average depth of this area of the lake was approximately 6 feet, while currently the average depth is less than 2 feet at normal pool.

The area shown in figure 3 is typical of the upstream areas of the lake that are currently unusable for most recreation activities and

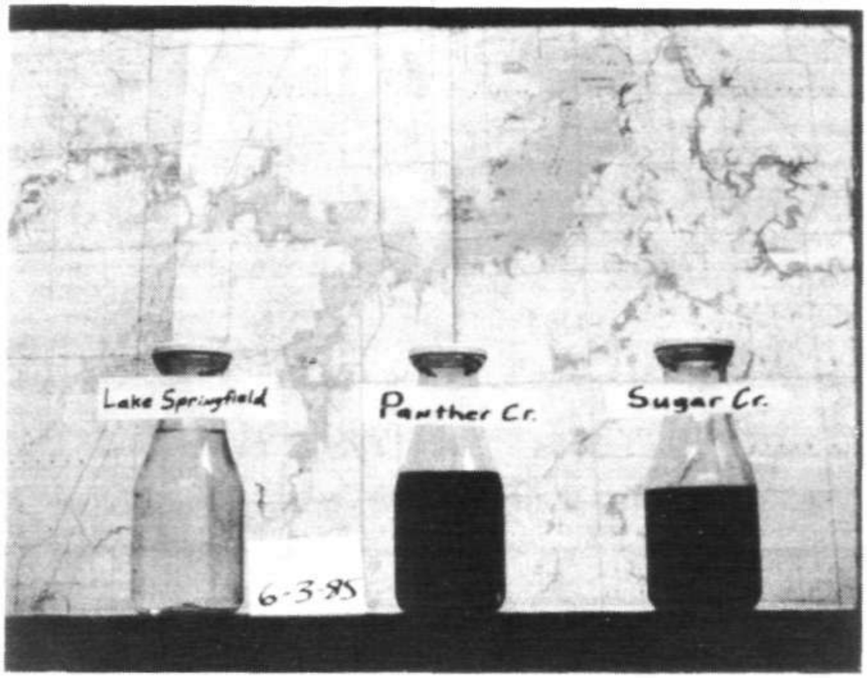

Figure 2. Photograph of water samples taken from Lake Springfield at Spaulding Dam, Panther Creek, and Sugar Creek on June 3, 1985 (The photograph shows the relative concentrations of sediment in the water samples and demonstrates the sediment trapping ability of the lake; the inflowing creeks were much higher in sediment concentration than the outflowing water of the lake)

Figure 3. 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)

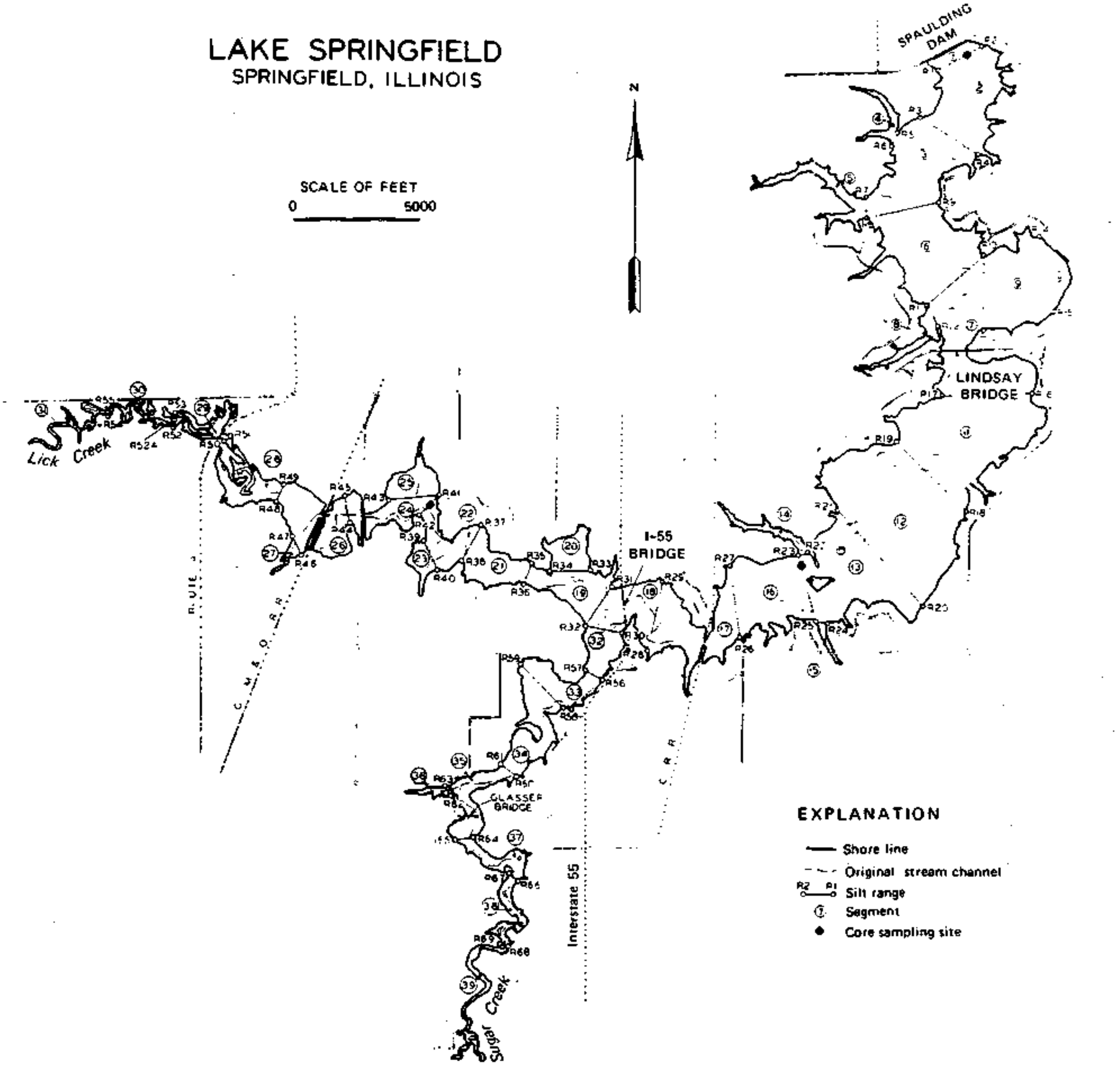

Figure 4. Lake Springfield

obviously provide little water 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.

This project was undertaken to provide the City of Springfield with management information necessary for cost-effective control of the inflow and accumulation of sediment and pollutants in the lake. The goals of this investigation were:

- To determine the hydrologic budget of the lake
- To determine the sediment, nitrogen, and phosphorus budgets
- To identify the source areas of the watershed that contribute disproportionate quantities of pollutants to the lake

The goals of this project were achieved through field monitoring of the major flowing tributaries of the lake and the outflow of the lake at the dam. Existing data on the lake and watershed were reviewed, and the standard analytical techniques developed by the ISWS and other organizations were used to determine the hydrologic and flow constituent parameters. These procedures will be presented later in this report. The most important aspect of this investigation is its use of detailed in-field measurements of flow and transport. These measurements provide an accurate assessment of these parameters and greatly improve the precision of the final results.

Acknowledgments

This research project was conducted as part of the authors' regular duties at the Illinois State Water Survey under the administrative guidance of Richard G. Semonin, 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. Paul B. Makowski wrote many of the computer programs used for data analysis. William H. Zehrt, student of engineering at the University of Illinois, assisted in data collection and organization. Suspended sediment samples were analyzed at the Inter-Survey Geotechnical Laboratory by William Westcott and Becky Roeper under the direction of Michael V. Miller. Water quality sample analysis was performed at the Water Quality Section laboratory in Peoria, Illinois, by David L. Hullinger. Kathleen Brown, Becky Howard, and Tammy Warnes typed the rough drafts and camera-ready copy.

Partial funding for this study was provided by the City of Springfield. Particular appreciation is expressed to James Buckler, Thomas Skelly, and William A. Brown, City Water, Light and Power (CWLP), for their cooperation and assistance.

BACKGROUND

Springfield Waterworks and Lake Springfield

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 waterworks 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 (million gallons per day) 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 the damming of 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 4) extends in a northeast-southwest direction across the valley of Sugar Creek. The dam is 1900 feet long and has a spillway elevation of 559.35 feet msl (Crawford, Murphy and Tilly, Consulting Engineers, 1965). The lake's water level is controlled by a set of five movable gates 8 feet in height installed into the spillway located at the southwest end of the dam.

Lake Characteristics

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 4. Figure 4 shows the ranges across the lake used to measure sediment accumulation, and it also shows the original stream channels of the valley.

The reservoir is used 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 559 feet msl at Spaulding Dam.

The soils of the watershed formed in loess deposits up to 8 feet thick, which are underlaid by Illinoian drift. 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. On the average, 50 thunderstorms occur during the year and snowfalls of 1 inch or more occur 8 days of the year.

Earlier Investigations of Sedimentation and Gross Erosion

The Water Survey has conducted four studies to determine the lake's volume loss and sediment accumulation rates. These studies were conducted in the years 1948, 1965, 1977, and 1984. Table 1 summarizes the results of these investigations (Fitzpatrick et al., 1985).

Table 1. Summary of Storage Capacity Loss, Sediment Deposition Rates, and Average Depth in Lake Springfield

Period ending this year	Storage capacity loss rate per year (acre-feet)	Storage capacity loss rate per year (million gallons)	Sediment deposition rate per year (tons)	Lake average depth (feet)
1934	---	----	-------	14.4
1948	186	60.6	146,000	13.7
1965	135	44.0	129,000	13.2
1977	142	46.3	118,000	12.8
1984	157	51.2	121,000	12.5
1934-1984	154	50.2	130,000	----

An earlier investigation (1952) of the sedimentation of Lake Springfield showed that the total gross erosion in the lake's watershed was 600,000 tons per year. The sediment deposited in the lake averaged 1.03 tons per acre per year. The investigators recommended that the City of Springfield undertake a cooperative erosion control program with the local soil and water conservation agencies and provide financial assistance to landowners for the purpose of controlling non-point sources of sediment in the watershed (Stall et al. , 1952),.

A report on the sediment and soil loss in three Illinois watersheds (the Lake Springfield, Lake Taylorville, and Lake Vermilion watersheds) was published in 1977 by the ISWS (Lee and Stall, 1977). The average gross erosion in the Lake Springfield watershed was reported to be 3.96 tons per acre per year, and the total gross erosion in the watershed was 655,398 tons per year. The work associated with this project was summarized by the Illinois Environmental Protection Agency (1978).

OVERVIEW OF WATER, SEDIMENT, AND NUTRIENT BUDGET DEVELOPMENT

A water budget of a lake is a bookkeeping procedure that relates the various components of inflow, outflow, and change in storage within the lake. A water budget aids in assessing the sources of inflow and losses to the system and also facilitates the assessment of the sediment and nutrient budgets of the lake. The sediment and nutrient budgets are impacted by the water budget in that fluvial transport is the principal mode of transport of sediment and nutrients to and from the lake.

Water Budget

Figure 5 is a schematic diagram of the water budget of the lake, which shows the various components of inflow and outflow that are taken into account in this analysis. The components are runoff to the lake, precipitation on and evaporation from the lake surface, municipal uses including water supply and power plant usage, spillway overflow, pumpage to the lake, and losses to ground water. Two components not shown but addressed in this study are dam and spillway gate leakage, and changes in the lake's storage.

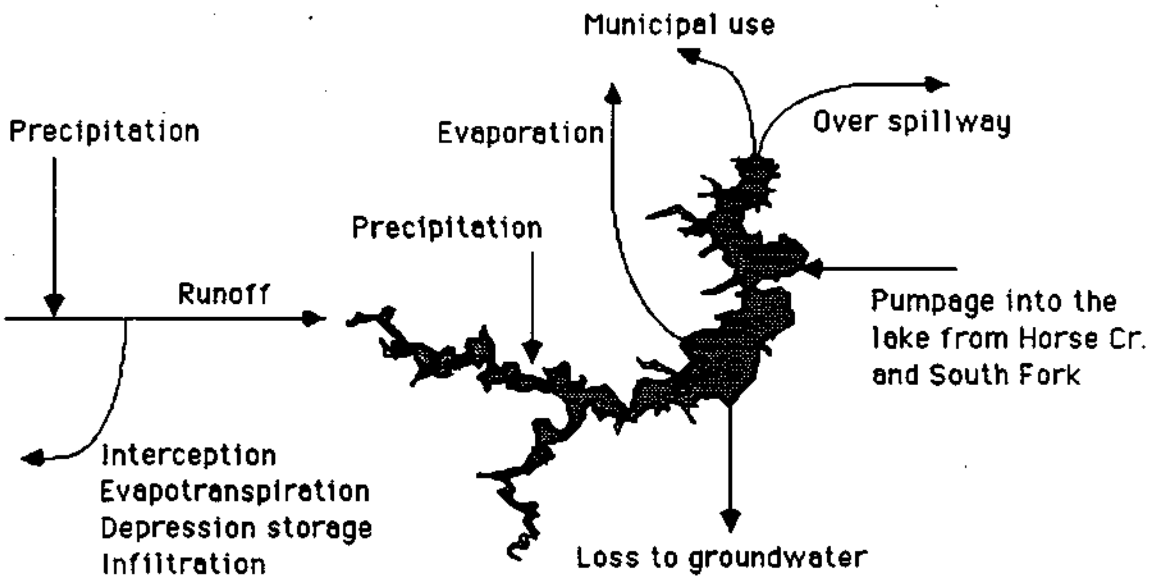

Figure 5. Schematic diagram of the water budget of Lake Springfield

The water budget of Lake Springfield may be expressed by the following equation:

Inflow = Outflow ± change in lake storage

Inflow is the sum of the water contributed by the sources of water to the lake: Lick, Sugar, Panther, and Polecat Creeks; the direct unnamed tributaries of the lake; and the pumpage into the lake from Horse Creek.

Outflow is the sum of the water lost from the lake because of spillway overflow, dam and spillway gate leakage, municipal water supply, power plant usage, loss to ground water, and net evaporation (gross evaporation less direct precipitation) from the lake.

Change in storage is the difference in the quantity of water held by the lake at the start and end of the time period considered. This parameter is a function of reduced capacity due to sedimentation and the fluctuation in the lake pool level, i.e., the amount of water in the lake.

To quantify the inflow of water to the lake, field monitoring stations were designed and installed on the streams flowing into the lake. These stations were operated throughout the monitoring year, and detailed calibration measurements were performed to assure that accurate data were obtained from their records.

City Water, Light and Power (CWLP) provided data on the water withdrawn from the lake for municipal water supply and power plant usage as well as the operation records of the Horse Creek pump station and the lake's spillway.

This component of the project is discussed in greater detail in the data collection and budget development sections.

Sediment Budget

The sediment budget is constructed in a manner similar to that for the water budget in that it considers the sources and losses of sediment in the lake system. The transport of sediment is determined by the concentration of sediment in the flow and the quantity of the flow over time. Field monitoring of the concentration of sediment in the inflowing tributaries of the lake and in the outflow from the lake was used to determine the loading or transport of this parameter. This monitoring was performed by detailed field measurements of the variation of concentrations within the stream cross sections and along the stream lengths during various flow conditions throughout the year. Automated water samplers were used to provide samples during periods when personnel were unavailable for direct sampling. The methods of monitoring the sediment concentration over time are discussed in the section "Data Collection."

Nutrient Budget

The nutrient budget was determined in a similar manner to that for the sediment budget. Samples were obtained for laboratory analysis throughout the monitoring year. Simultaneous sampling of sediment concentration and the various nutrient constituents allowed the correlation of the various parameters so that the transport to and from the lake could be determined from the accumulated data sets. The data collection and budget development sections of this report present more details on this component of the investigation.

Point sources are not addressed in this analysis because a review of the major point source contributors, such as the municipal sewage treatment plants of Chatham and Auburn, indicated that on an annual basis their contribution is very small. During extreme low-flow periods the proportion of nutrients contributed by point sources may be significant, but in light of the quantities of nutrients transported during high flows, the low-flow values are insignificant.

DATA COLLECTION

The purpose of field data collection was to provide basic data on the quantities of water, sediment, and nutrients transported over time by the inflowing tributaries of Lake Springfield and by the outflow of the lake at the dam (including municipal and power plant uses). These data were essential to determining the water, sediment, and nutrient budgets of the lake.

In order to obtain this information a data collection system and procedures were developed for the Lake Springfield watershed. The approach was as follows: (1) decide on the type of data needed, (2) select appropriate sites to obtain the data, and (3) select the necessary instrumentation to measure and sample the variables. The data needed were the temporal and spatial distribution of the quantity of water delivered to and flowing out of the lake, and the concentrations of sediment and nutrients in the various inflow and outflow sources. Monitoring sites on the inflowing tributaries, and the instrumentation used there, were selected so that the information obtained from the measurements would accurately reflect the processes occurring in the inflowing tributaries. Five sites were selected for regular monitoring: four on the inflowing tributaries and one at the lake's spillway. Other locations were monitored as needed, such as the Horse Creek pump station which the city operates to provide supplemental inflow to the lake from the adjacent drainage basin.

Two primary monitoring sites were installed on the largest tributaries of the lake. These sites were equipped with continuous stream-gaging stations which measure the stage (water level) of the streams. Also installed at these sites were automated water samplers to provide discrete samples at regular intervals (generally every 6 to 8 hours) while the creeks were flowing. These sites were installed on Sugar and Lick Creeks, which together drain 183 square miles of the total watershed area of 258 square miles (excluding the lake area), or 71 percent of the total.

The placement of these stations along Sugar and Lick Creeks was determined by field reconnaissance of the bridge crossings over the creeks. The bridge crossings over the creeks immediately upstream of the lake could not be used because of the hydraulics of the interaction of the lake's backwater with the flow in the creeks. The interaction of backwater and flow would have interfered with the calibration of stream stage to stream discharge that was used to convert the stage record to stream discharge. By the process of elimination, beginning at the lake and progressing upstream on the creeks, the final sites were selected primarily by rejecting bridge crossings unsuitable for this type of monitoring due to backwater effects, turbulence generated by piers or bends in the creeks, and dangerous working conditions.

The final sites selected are shown in figure 1.

Hydrology

An accurate understanding of the processes of streamflow occurring in the watershed is essential to determining the hydrologic, sediment, and nutrient budgets of the lake. Streamflow is the vehicle that transports the various constituents of flow such as sediment and nutrients, and therefore it requires careful and precise measurements.

Stream Stage

Stage, which is a measurement of the elevation of the stream surface, is a function of the flow area and velocity of a stream. A stage record will allow determination of the quantity of water carried by the stream by application of a site-specific stage-to-discharge calibration curve. With detailed calibration the information on stage can be used to determine the flow area, average velocity, average depths, and other parameters related to stream hydrology.

Figure 1 shows the locations of the stream monitoring sites in the watershed. It can be seen in this figure that of the total of five sites, two are continuous recording streamgaging stations, two are peak stage recorder stations, and one is a spillway monitoring station. The latter station, which is located at the dam spillway (SL5), is operated by CWLP as a regular part of their waterworks operation.

The two continuous recording streamgaging stations are located on Sugar Creek (SL1) and Lick Creek (SL2), which are the largest of the lake's inflowing streams. Figure 6 is a photograph of the Lick Creek gaging station and shows the equipment installed at these sites. These streamgaging sites were equipped with continuous water level recorders that continuously monitored the stage of the streams. A photograph of the continuous recorder installed on Lick Creek is shown in figure 7. The water level recorders were basically a float and pulley system attached to a strip chart. Water level changes in the stream raised or lowered the recorder float attached to the strip chart pen, causing a calibrated change in the pen position on the strip chart and recording the elevation and change of the stream's water level. From these recorders a continuous output of the streamwater level was obtained for use in determining the quantity of water moving through the stream channel. The "Streamflow" section in this report discusses the procedure used to convert the stream stage record to stream discharge.

The gaging stations used in the project were designed and built by the ISWS for this investigation. They were installed in May 1985. The water level recorders were Leupold-Stevens Type A instruments and were

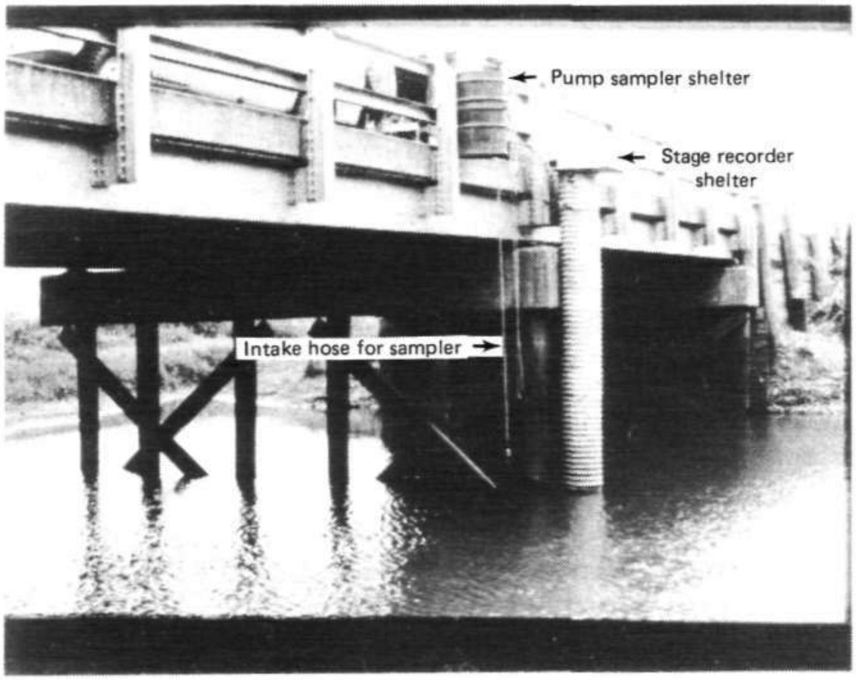

Figure 6. Project monitoring site SL2 at Lick Creek at Curran Road (The photograph shows the equipment shelters for the continuous stage recorder and the automated pump sampler)

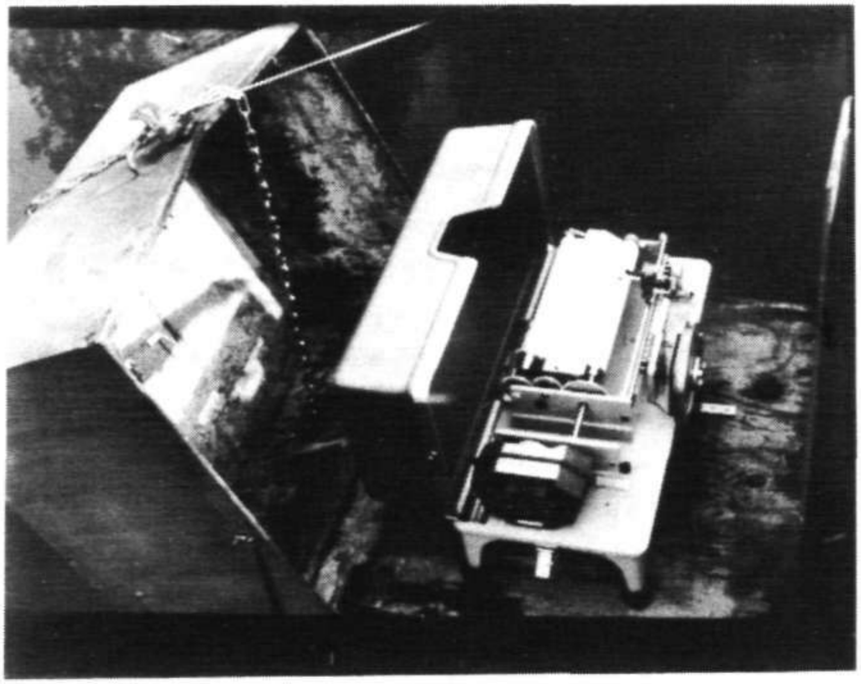

Figure 7. Continuous stream stage recorder installed at Lick Creek (SL2)

driven by battery-operated quartz clocks. As shown in figure 6, the recorders were housed in an ISWS gage security shelter designed for protection from the weather and vandalism. The float and pulley system was enclosed within a culvert pipe stilling well (figure 6) that was used to dampen the wave oscillations of the water surface and protect the float system from debris carried by the stream.

The station design was typical of the ISWS temporary gaging station design. The water level recorder was enclosed in a security shelter attached to the railing of the bridge and totally supported by the bridge. The culvert pipe stilling well beneath the recorder and shelter was independently supported and was designed to break away in the event of an ice jam, logjam, or debris pile striking the gage structure.

The two peak stage recorders were located on Panther (SL3) and Polecat (SLA) Creeks (figure 8). These recorders provided measurements of the maximum elevation that the stream surface reached during a storm/runoff event. The recorders, which were built and installed by the ISWS in May 1985, were constructed of 3-inch-diameter PVC pipe and a removable cedar rod that was placed into the pipe. The recorders were installed vertically in the stream channel and surveyed into to provide a known elevation of the pipe and rod. The rod was placed inside the pipe together with powdered cork, and the pipe was covered by a PVC cap. When the stream rose to the elevation of the pipe, inlet holes allowed water to flow into the pipe and caused the cork to rise by floating on the water surface. Cork will continue to float up within the pipe as long as the stream is rising. When the stream falls, cork adheres to the wood rod at the elevation of the highest water level and provides a measurable mark on the rod. The peak elevation marks were measured during each site visit and recorded on the project site visit log sheets.

An electronic sonar distance meter was used to measure the stage at the Panther and Polecat Creek sites. Readings were made as part of the regular weekly site visits and during storm/runoff event sampling. Stage was measured by placing the meter at a known datum on the bridge, from which it transmitted a sonar signal downward to the streamwater surface. The water surface reflected the signal back to the meter and the distance was calculated from the lag time between transmission and return, calibrated for the effect of air temperature on the speed of sound. The

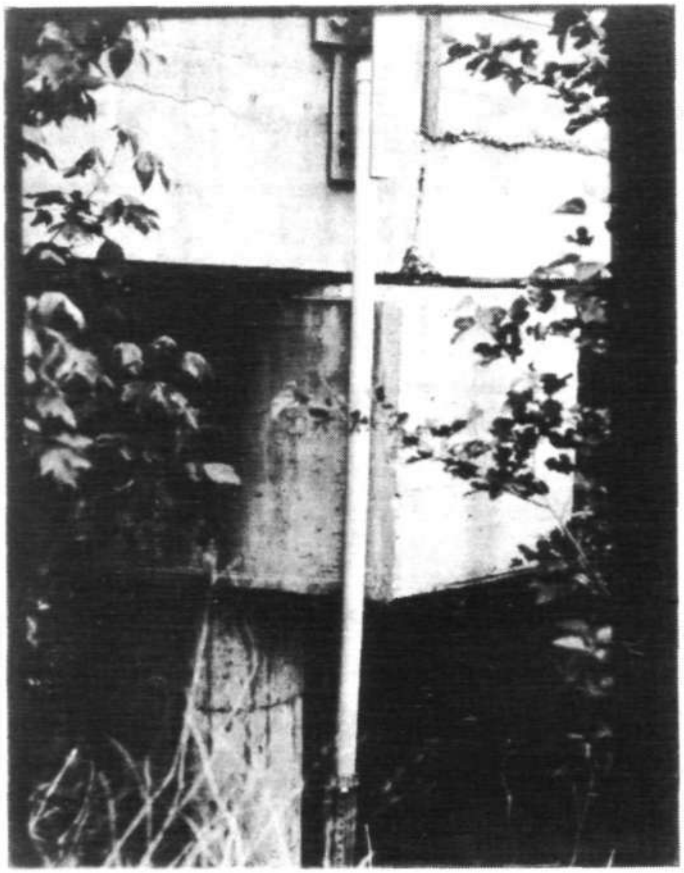

Figure 8. Project monitoring site SL4 at Polecat Creek at Highway 4, Chatham, IL (The photograph shows a crest gage installed on the bridge pier, used to record maximum stream stage)

instrument used was an Exact Technologies Corporation Dimensional Measurement Computer with a resolution of 1 inch over a range up to 50 feet.

Stream stage was also measured with a fiberglass surveying level rod. The level rod was lowered to the stream surface from a known datum on the bridge, and the reading was subtracted from the bridge datum to obtain the stage elevation.

Stream Velocity

The measurement of velocities within a stream cross section was necessary for determining stream discharge and developing a site-specific stage-to-discharge calibration. The instrument used to measure stream velocity was a rotating bucket current meter. This instrument was a standard Price-type meter, which had a rotor with six cone-shaped cups mounted on a vertical stainless steel shaft. The meter was calibrated by the manufacturer to a standard rating table in which the number of rotations of the rotor over time corresponds to a specific velocity.

The current meter was attached to a 30-pound weight to keep it from drifting in the current and was suspended into the stream from the bridge with a cable/winch/crane assembly. A discussion of the use of this meter to measure discharge is presented below.

Streamflow

The gaging stations installed on Sugar and Lick Creeks provided basic data on the stage of these creeks over time. When a stage-to-discharge calibration is applied, the stage data can be converted to flow. The stage-to-discharge calibration was developed by several detailed field measurements of the stream discharge at several stages. The discharges were plotted with corresponding stages, and a stage-to-discharge curve was developed for each site.

The stream discharge measurement techniques used were developed by the USGS (Buchanan and Somers, 1969) and the American Society for Testing and Materials (standard practice for Open-Channel Flow Measurement of Water by Velocity-Area Method, designation: D 3858-79).

Stream discharge was determined by subdividing a cross section of the stream at the bridge into partial sections approximately 10 feet wide. The average velocity of the flow at each partial section was measured and multiplied by the flow area of that partial section. The sum of the individual partial section discharges determined the stream discharge. A standard rotating bucket mechanical velocity meter was used to measure point velocities in the stream.

The velocity meter, suspended by a cable/winch/crane assembly, was lowered into the stream at the midpoint of each partial section. A depth gage built into the winch read the total depth of the stream at the midpoint of the partial section. This depth was recorded and later used to calculate the flow area of the partial section. Velocity measurements were then made at the vertical in the midpoint of the partial section. The meter was positioned beneath the water surface at 0.2 and 0.8 of the total depth (for total depths greater than 2.0 feet) or at 0.6 of the total depth (for total depths less than 2.0 feet). The velocity of the stream at the measured points was recorded and used to calculate the average velocity of the partial section. The partial section discharge was then calculated by multiplying by the flow area.

Other information recorded and used to calculate the stream discharge included information on total stream width, velocity vector normal to the cross section, channel geometry, bed forms, and other variables pertinent to the measurement accuracy.

Streamflow in the creeks of the watershed not equipped with continuous stage recorders was determined by extrapolation of the flow monitored at the gaging stations. In addition, the secondary monitoring sites at Panther and Polecat Creeks were visited weekly for sampling and stage measurement. These sites also had peak stage recorders that provided the peakflow elevation that occurred between site visits. Stage-to-discharge curves were developed for these sites by field discharge measurements. The stage record obtained from weekly visits and the peak stage recorders were used together with extrapolated discharge-per-watershed-area data from the gaging stations to develop a continuous record of the flow at these sites.

Stage data provided by the gaging station strip charts were entered into the University of Illinois CYBER computer system by digitizing the pen trace on the charts into x- and y-coordinates. The digitized data were then interpreted by computer programs developed by the ISWS to provide a data set for hourly stage. The hourly stage data files were then run through programs which converted the stage to discharge by using specific stage-to-discharge curves developed for each station. The output discharge data files provided hourly stream discharge data that were later used to develop daily sediment and nutrient transport data.

The Springfield waterworks has a supplemental source of water in the adjacent drainage basin of Horse Creek (figure 1). Water from Horse Creek is delivered to the lake by the Horse Creek pump station (SL6) located on the eastern shore of Lake Springfield as shown in figure 1. The pump station is operated when the lake level falls below elevation 558 msl, when anticipated inflow will be insufficient to raise the lake level, and/or at the discretion of the city's waterworks. The pump station has a rated pumpage capacity of 72 MGD. The records of the amount of water pumped into the lake and the concentration of sediment and nutrients were maintained by CWLP. The operational records of the pump station and the results of analyses of samples of the pumped water were provided to the ISWS.

CWLP provided data to the ISWS on the quantity of water leaving the lake through spillway overflow and spillway gate and dam leakage, and on the quantity used by the City of Springfield for municipal water supply and power plant operation.

Sediment

Sediment Concentration

The concentration of sediment in the flow carried by the inflowing creeks and in the flow leaving the lake via spillway overflow was determined by sediment concentration sampling. Many methods were used in this project to sample the suspended sediment concentration of the inflowing and outflowing waters of Lake Springfield. The methodology used at each location was determined by the flow characteristics at the site. Four methods were used to sample the concentration of sediment: iso-kinetic depth-integrated, iso-kinetic depth- and width-integrated, dip sampling, and automated pump sampling.

The first two methods employed a US DH-59 iso-kinetic water sampler developed by the USGS. The US DH-59 is a streamlined bronze casting 15 inches long and 24 pounds in weight. The sampler is of a depth-integrating design by which water flows into the instrument at the same velocity as the immediate stream velocity, and therefore iso-kinematically. The value of this instrument is that with skilled use the water and sediment (or other flow constituent) sample will represent the average concentration of the sediment carried by the stream at the sampled portion of the stream.

A weighted bottle holder was used for dip sampling, which was the method used to sample the suspended sediment concentration of the lake water and of the streams during low flow. This method was used when the distribution of sediment in the water was uniform. The spillway of the lake was sampled through this method since the variations in the-concentration of suspended sediment at the spillway were very small.

The pump sampling method was used at the Lick and Sugar Creek gage stations to provide samples over time throughout a storm/runoff event. The pump sampler used was an Instrument Specialties Corporation (ISCO) model 1680 automated sampler. This instrument was programmable for sampling volume and time and provided the flexibility needed for sampling the streamflow for sediment concentration throughout runoff events. This instrument was used to complement the in-field data collection effort and allowed samples to be obtained when field personnel were working at other locations.

The pump sampler 1680 was configured to provide a maximum of 28 discrete samples between site visits and servicing. As shown in figure 6 the sampler was mounted on the bridge site directly above the thalweg (main channel) of the stream. An intake hose was suspended from the sampler and into the streamflow. At preset time intervals, the sampler would pump air through the intake line to purge any water left from previous samples, and it would then pump a set quantity of water into one of the 28 sample bottles. The pumping mechanism is a peristaltic pump designed to minimize possible sample contamination. The model 1680 was usually programmed to collect a sample every 6 hours, with an 8-hour cycle used during low-flow periods.

The intake of the sampler was allowed to hang free into the streamflow at a depth of 1 to 2 feet below the stream surface. As the stream stage would rise, the velocity of the water would pull the intake downstream slightly and maintain the 1- to 2-foot submergence depth. The free-hanging intake also helped prevent the accumulation of debris on the intake. On a weekly basis the sampler was serviced and checked for malfunctions and contamination. In addition, simultaneous samples of the streamflow for suspended sediment concentration made by using the depth- and width-integrated technique were compared with the model 1680 samples to calibrate the sampling bias of the pump samplers.

Sediment Transport

This section discusses the techniques and methods used to determine the instantaneous average concentration of sediment in a stream. The budget development section presents the techniques used to determine the transport of sediment over time, which incorporate the variables of changing sediment concentration and flow.

Particles carried by streamflow are not distributed uniformly throughout the flow area. Because of this, most methods of sampling for concentration will produce a bias in the final analysis if calibrations are not performed. The transport of sediment in a stream is a function of the average concentration of sediment in the streamflow and the quantity of streamflow. To determine the loading or transport of sediment in a stream, the variations in the concentration of sediment with respect to the stream width and depth must be understood. Flow conditions, channel geometry, tributary confluences, velocity distributions, and many other factors will affect the vertical and lateral distribution of particles carried by a stream. Basically a sampling procedure must provide a means of assessing the average concentration of sediment in the stream with respect to the stream velocity, as well as a means of calibrating other sampling methods, such as dip samples, to determine the average sediment concentration. The methods used in this project were developed by the USGS (Guy and Norman, 1970) and are proposed practices of the American Society of Testing and Materials Committee D-19 (water) and Subcommittee D-19.07 (sediment) (ASTM, 1982).

This project used the iso-kinetic depth-integrating sampler (the US DH-59) and the equal width increment technique. In this method the stream cross section was divided into four or five partial sections, and the midpoint of each partial section was sampled by lowering the US DH-59 sampler to the stream bottom and back to the surface at a constant rate to provide a depth-integrated sample. The sample from each partial section would then represent the average concentration at that partial section. The actual sediment discharge was determined by combining the average concentration with the average water discharge at each partial section. In order to calibrate the relative bias of sampling one partial section, the deviation of the partial section sediment concentration from the average was used to provide the calibration factor. In a similar manner the bias of using a dip or pump sampler was determined. This procedure was most effective if several calibrations were performed over several different flow conditions.

Another method for calibrating non-integrated sampling methods -- the width-integrated technique -- was also used in this study. This technique was similar to the equal width increment method except that the average concentration of sediment in the stream cross section was determined by integrating samples from all partial sections into a single bottle or by summing the net weight of the sediment in individual samples (partial section depth-integrated) and dividing by the sum of the net weight of water in the sample set. The calibration factor was then determined by examining the deviation of a single partial-section sample from the average, or the deviation of a sample obtained by a non-integrated technique such as a pump sampler.

Depth-integrated sampling was performed weekly at each monitoring site during elevated flow conditions when the stream depth was greater than 2 feet.

Sediment concentration samples obtained with the automated pump samplers were also calibrated for sample bias caused by evaporation. This was a concern because a sample obtained by the pump sampler may sit inside the instrument for a week before it is retrieved, capped, and shipped to the laboratory. Evaporation standards were inserted into the pump sampler bottle tray at each weekly site visit. The standards were retrieved on the next visit, capped, and sent to the laboratory for weighing. The calibration factor for evaporation was 0.001 per day with a standard deviation of 0.0005. Considering the other systematic and random sources of error, this was determined to be insignificant and was not applied to the data set.

A sample that represents the average concentration of sediment carried by the stream at the time of sampling allows direct determination of the sediment transported at the time of sampling if the stream discharge is known. A major difficulty of this type of field measurement is that of calibrating the accuracy of the concentration sample with respect to the average concentration of the streamflow. Various methods of sampling for concentration would result in differing biases.

The instantaneous load of sediment carried by the creeks at the monitoring sites was determined by multiplying the instantaneous water discharge by the calculated instantaneous average sediment concentration. This procedure was performed for each concentration sample. The result was a series of instantaneous loading representing the range of flow conditions. The technique of determining the changes in loading over the period between sampling times is discussed in the budget development section.

Nutrients

Nutrient Concentration

Nutrients in the form of nitrogen and phosphorus were sampled by using the dip method. The following parameters were determined from the nutrient samples: total phosphorus, dissolved phosphorus, total Kjeldahl nitrogen, total ammonia nitrogen, dissolved nitrate nitrogen, and dissolved ammonia nitrogen. Sampling bottles were prepared by the ISWS water quality laboratory. One-liter bottles were used for raw samples, and 200-milliliter bottles were used for filtered samples. The filtered samples were used to assess the dissolved parameters, and the raw water samples were used for the other parameters. Samples were obtained by dipping the bottles into the streamflow from the streambank. This method was preferred to other methods because it reduces sample contamination that may occur from transferring the sample between containers (i.e., from DH-59 glass bottles to the nutrient bottles). The nutrient samples are perishable and susceptible to contamination.

The liter bottle was dipped in the streamflow to obtain a raw water sample. From this raw sample, a filtered sample was obtained by withdrawing 200 milliliters and filtering it through a 45-micron filter. The filter was used to remove all particles and biological organisms which might react with the sample and cause the various forms of nitrogen and phosphorus to convert to other forms (i.e., particulate and dissolved). Filtering and preparation of the samples was performed in the field immediately after sampling for quality assurance and to reduce sample degradation. The samples were then placed on ice and kept cold until delivered to the ISWS water quality laboratory.

Nutrient Transport

Nutrient sampling required on-site filtration and preparation, and therefore these samples could not be obtained by using automated equipment. For this reason, and because of the high cost of this type of analysis, nutrient samples were obtained less frequently than sediment concentration samples. To provide a data set on the concentration of nutrients over time, the correlation of the nutrient parameters with sediment load was examined. Makowski et al. (1986b) and Lee et al. (1983) have shown that many stream water quality parameters exhibit a good correlation with suspended sediment loads. In addition water discharge was also examined for correlation to nutrient loads. This type of correlation analysis was performed on the nutrient samples obtained in this study, and the correlations developed were used to develop a record of the transport of the nutrient parameters over time.

Precipitation

Precipitation was monitored at several locations in the area of the watershed. The City of Springfield maintains a raingage at the city's water treatment plant located near Spaulding Dam. The U.S. National Weather Service has a meteorology station at Capital Airport approximately 6 miles north of Lake Springfield and at Virden, Illinois, which is on the south edge of the watershed as shown in figure 1. In addition three raingages were placed in the watershed as can be seen in figure 1. Raingage RG3 was installed at the City of Springfield Property Management Center located on the east shore of the lake near Spaulding Dam. RG1 and RG2 were installed in the towns of Auburn and Lick, respectively. The raingage sites were chosen to provide broad area coverage of the watershed and also to facilitate time-efficient data collection site visits. The sites therefore were selected for their proximity to the project's gaging station sites. They were instrumented with Belfort Universal Recording Rain Gages (weighing type). The project raingages were installed in September and October 1985.

DEVELOPMENT OF WATER, SEDIMENT, AND NUTRIENT BUDGETS

The water, sediment, and nutrient budgets were developed primarily from data on streamflow and the suspended and dissolved concentrations of materials transported by streamflow. Precipitation was monitored and analyzed for the purpose of documenting the distribution of precipitation over the study period and determining the magnitude of precipitation events.

Precipitation Analysis

Precipitation in the Lake Springfield area averaged 96 percent of the 40-year mean value for the period May 1985 through May 1987 (table 2). In each of the monitoring years, the percentage of the long-term average was 96 percent. Precipitation data for this analysis was obtained from CWLP and the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) climatological data summaries (NOAA, 1985, 1986 and 1987). The 40-year mean precipitation amounts are the average values for the period 1944 through 1983 at the Capital Airport NWS station (NOAA, 1983).

The precipitation data used in this analysis was obtained from stations located throughout the Lake Springfield area (figure 1). The exact amount of precipitation that fell on the lake's watershed, which covers 265 square miles, can only be estimated from the available data obtained from three points in the area. In addition the various stations of the Airport, Virden, and CWLP's spillway station provide records of varying length and detail which can further complicate the determination of long-term averages and record amounts. The analysis of the precipitation data below is intended to be a brief overview of the events that occurred during the study period. Record amounts and long-term averages discussed below refer to the data from the Airport station since it has the most extensive record of over 40 years.

January 1986 was the driest month of the two-year study period. The amount of precipitation at the Airport was 0.04 inches, which was only 2 percent of the 40-year mean amount. Over the study period the Airport station recorded two new monthly records during November 1985 and September 1986. November 1985 was the wettest month of the study period with an

Table 2. Monthly Precipitation in the Lake Springfield Area, May 15, 1985 through May 14, 1987, and 40-year Record Monthly Amounts
(Values in parentheses are monthly totals)

	NWS Airport	NWS Virden	CWLP Spaulding Dam	NWS 40-year mean	Average Virden and Airport	Maximum monthly rainfall totals (40-year record NWS Airport)		
							Amount	Year
May 15-31, 85	0.33 (1.75)	0.11 (3.42)	0.08 (1.80)	2.24 (4.08)	0.22 (2.59)	May	6.37	1974
Jun-85	6.16	6.89	6.10	3.95	6.53	Jun.	8.87	1960
Jul-85	2.95	1.31	2.70	3.16	2.13	Jul.	10.76	1981
Aug-85	6.03	5.22	5.00	3.06	5.63	Aug.	8.37	1981
Sep-85	0.64	0.33	0.80	3.35	0.49	Sep.	7.73	1970
Oct-85	3.08	1.85	5.40	2.63	2.47	Oct.	6.15	1955
Nov-85	6.94	9.61	9.40	2.39	8.28	Nov.	4.71	1983
Dec-85	2.43	3.01	3.10	2.15	2.72	Dec.	8.94	1982
Jan-86	0.04	0.03	0.00	1.97	0.04	Jan.	5.67	1949
Feb-86	1.80	2.03	2.10	2.03	1.92	Feb.	4.43	1951
Mar-86	1.45	1.03	0.97	3.11	1.24	Mar.	7.89	1973
Apr-86	1.57	1.00	2.45	3.59	1.29	Apr.	9.91	1964
May 1-14, 86	0.73 (2.56)	1.65 (3.68)	0.29 (2.20)	1.84 (4.08)	1.19 (3.12)			
Year I total	34.15	34.07	38.39	35.47	34.11			
				Percent of 40-year mean -	96%			
May 15-31, 86	1.83	2.03	1.91	2.24	1.93			
Jun-86	6.23	1.46	4.66	3.95	3.85			
Jul-86	5.39	4.34	7.00	3.16	4.87			
Aug-86	1.13	0.94	1.10	3.06	1.04			
Sep-86	8.57	6.06	5.01	3.35	7.32			
Oct-86	3.63	3.64	3.65	2.63	3.64			
Nov-86	1.95	2.93	1.14	2.39	2.44			
Dec-86	1.40	1.61	1.05	2.15	1.51			
Jan-87	1.46	no data	1.37	1.97	1.46			
Feb-87	0.73	no data	0.80	2.03	0.73			
Mar-87	2.08	no data	1.25	3.11	2.08			
Apr-87	2.59	no data	2.55	3.59	2.59			
May 1-14, 87	0.38 (0.56)	0.78 (0.99)	0.75 (0.75)	1.84 (4.08)	0.58 (0.78)			
Year II total	37.37	missing data	32.24	35.47	34.01			
				Percent of 40-year mean =	96%			

average precipitation (Airport and Virden stations) of 8.28 inches. The November 1985 rainfall at the Airport (6.94 inches) was three times the 40-year mean and exceeded the November record of 4.71 inches set in 1983. September 1986 was also a wet month: the precipitation at the Airport was 8.57 inches, which was two and one-half times the 40-year mean and exceeded the monthly record of 7.73 inches set in 1970 (table 2). The average amount for September 1986 was 7.32 inches (Airport and Virden stations), which was nearly one inch less than the average amount (Airport and Virden stations) for November 1985. June and August 1985 and July and October 1986 were also wet months, but precipitation fell below the record amounts. During the two-year study period (encompassing 25 months) the 40-year mean amounts were exceeded in 8 months, and amounts less than the 40-year mean were experienced in 17 months (figure 9).

Daily precipitation was fairly well distributed with respect to time and no new records were set (table 3). The highest daily precipitation amount was 4.23 inches at the Airport station on September 20, 1986. This was less than the record for the month of 5.12 inches set in 1959 and well below the highest daily amount for any day of 6.12 inches, set in December 1982. Only one daily precipitation amount during the study period exceeded the 2-year recurrence interval for the region presented in Technical Letter 13 of the Water Survey (ISWS, 1970). The 4.23 inches of precipitation on September 20, 1986 exceeded the 10-year one-day precipitation of 4.0 inches but was below the 25-year one-day precipitation amount of 5.1 inches.

The distribution of precipitation was variable across the watershed area, and as a result the runoff of water, sediment, and nutrients varied considerably among the basins of Lick, Sugar, Panther, and Polecat Creeks for any given time period. For example, the daily rainfall on June 3, 1985 was 1.89 inches at Virden, 2.09 inches at Spaulding Dam, and only a trace amount at the airport. Monthly precipitation also showed considerable variation between sites (figure 10). Differences in monthly totals can vary by 3 or more inches between stations as shown in figure 10.

The three precipitation monitoring sites installed in the watershed for this project are located in Auburn, Illinois, in Lick, Illinois, and at the City of Springfield Property Management Center (PMC) located near Spaulding Dam. These sites were not used in this monthly analysis because they did not have the long-term data of the NWS stations. These project

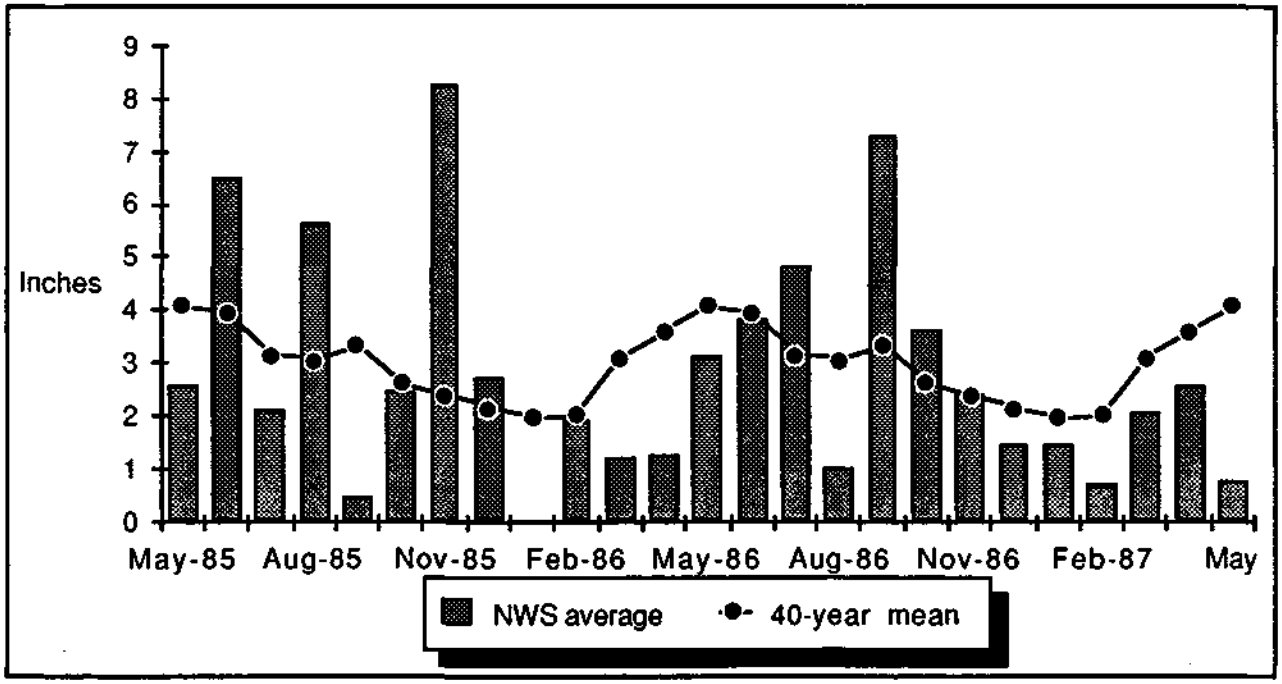

Figure 9. Monthly precipitation averages at the Airport and Virden NWS stations, May 15, 1985 - May 14, 1987, and 40-year mean precipitation at the Airport

Table 3. Highest Daily and Monthly Precipitation Measured during 2-Year Study Period, and 40-year Record Amounts
(In inches)

	Highest one-day precipitation during 2-year study period				40-year record	
Month	Airport	Year	Virden	Year	Airport	Year
Jan	0.54	1987	0.01	1986*	2.78	1975
Feb	0.63	1987	0.73	1986*	1.89	1976
Mar	0.56	1986	0.36	1986*	2.84	1972
Apr	1.65	1987	0.55	1986*	4.45	1979
May	1.25	1986	2.15	1985	2.48	1975
Jun	2.46	1985	2.40	1985	4.73	1958
Jul	1.80	1986	1.87	1986	4.43	1981
Aug	1.89	1985	1.35	1985	4.79	1956
Sep	4.23	1986	2.01	1986	5.12	1959
Oct	1.28	1986	1.11	1986	3.51	1973
Nov	1.48	1985	1.66	1985	2.46	1964
Dec	1.43	1985	1.86	1985	6.12	1982

*Virden station was not reporting during Jan-April, 1987

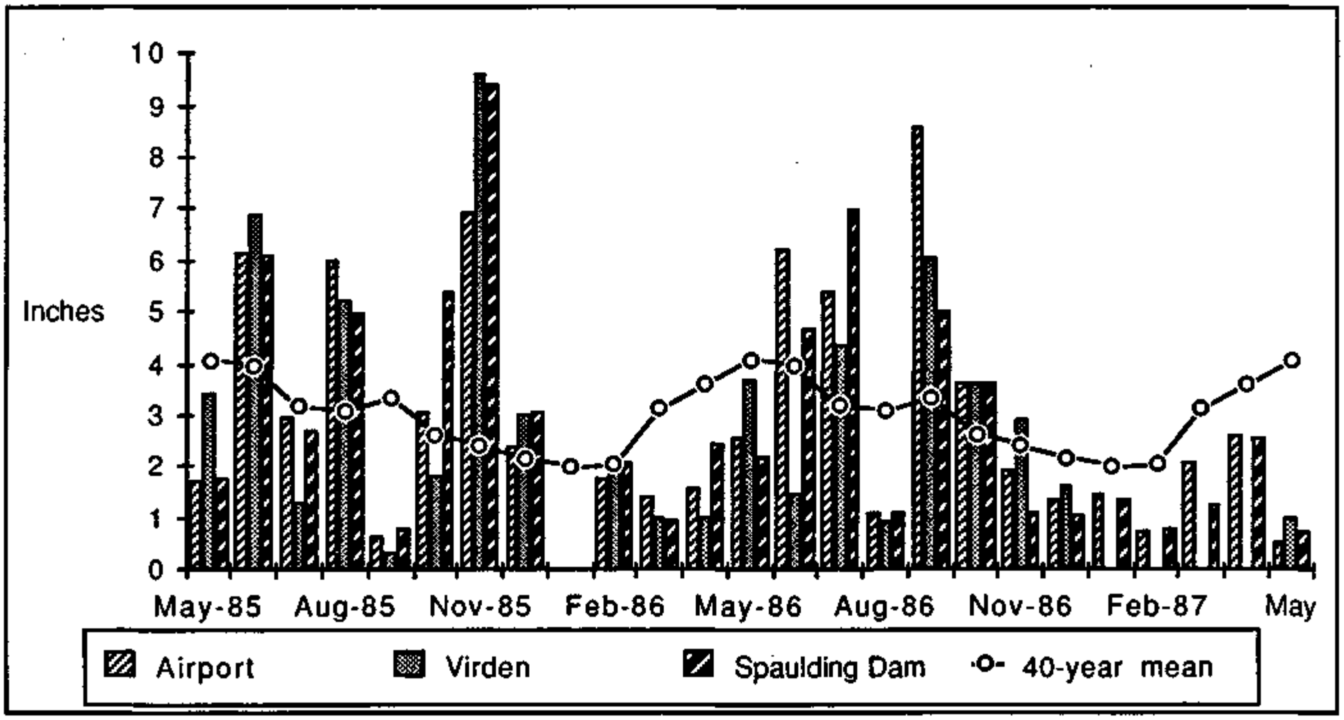

Figure 10. Monthly precipitation in the Lake Springfield area, May 1985 - May 1987

precipitation stations were used in the more detailed analysis of specific runoff events presented later in this report.

Water Budget

Streamflow to the Lake

Streamflow was determined for all the inflowing tributaries of the lake. The lake's watershed was divided into five basins, and the data from the streamgaging sites were used to determine the flow records of the inflowing tributaries. The continuous streamgages located on Sugar and Lick Creeks provided a record of the streamflow in these basins. The peak-flow records obtained from the stream crest gages and the measurements made during the site visits were used to assess the flows in Panther and Polecat Creeks. The flow from the unmeasured areas of these individual creeks downstream of the gaging sites was determined by proportioning the unit-area flow determined for each gaging site to the total drainage area of the individual creeks. Table 4 lists the five basins draining into the lake, the total drainage area of the basins, and the area of the basins monitored by the project's gaging sites.

It can be seen from table 4 that the gaging sites monitored 70 percent of the lake's total drainage area and therefore allowed a good assessment of the total flow to the lake and a determination of the hydrologic budget of the lake. In addition, accurate flow records were necessary for determining the loading of sediment and nutrients to the lake. Since the loading of sediment and nutrients changes quickly with respect to time, streamflow, and concentration, it was necessary to construct hourly streamflow records for all the individual basins of the lake's watershed. These hourly records were used with the instantaneous sediment and water quality concentration data to determine the loading of these parameters.

Sugar and Lick Creeks. Hourly streamflow records were determined for the gaged portions of Sugar and Lick Creeks on the basis of the continuous records of stream stage and the in-field measurements of the relationship of stage to discharge at the individual sites.

Streamflow was determined for the total drainage areas of Sugar and Lick Creeks by proportioning the per-unit-area flow measured at the gaging site to the total drainage area for these creeks.

Table 4. Basins Draining into Lake Springfield
(Drainage areas, gage type, and percent of basin area gaged)

Basin	Total drainage area (sq. mi)	Gaged area (sq. mi)	Percent of basin area gaged	Gage type
Sugar Creek	64	49.17	77%	Continuous
Lick Creek	119	99.64	83%	Continuous
Panther Creek	24	23.42	97%	Peak
Polecat Creek	10	7.29	74%	Peak
Direct tributaries of the lake	41	0	0%	None
Total	258*	179.52	70%	

*Total area excluding the area of the lake (6.6 square miles)

Polecat and Panther Creeks. Hourly streamflow records were determined for these sites by examining the per-unit-area flow relationship of these sites with the continuous records obtained at the Sugar and Lick Creek streamgaging sites. Panther Creek was observed to behave in a one-to-one per-unit-area flow relationship with the Sugar Creek site on a daily and monthly basis. This creek showed some deviation from this relationship on an hourly basis, but in general the long-term averages agreed very well. Polecat Creek's peak flow and instantaneous flow record agreed well with those for Sugar Creek on a per-unit-area basis for high and moderate flow, but consistently showed a disproportionately high base low flow of 0.5 cfs (cubic feet per second). The Polecat Creek hourly record therefore was developed by adding the observed baseflow to a per-unit-area proportion of flow to the Sugar Creek site. The baseflow rate of 0.5 cfs was due to the nature of the drainage basin of Polecat Creek, which receives runoff from the urban areas of Chatham, Illinois.

Direct unnamed tributaries of the lake. This area included the many unnamed tributaries that flow directly into Lake Springfield and were not accounted for in the other tributary areas. The method used to generate the flow record for Polecat Creek was used to determine the hourly flow from this area. The per-unit-area flow observed in Sugar Creek was proportioned to the area represented by these small tributaries. The observed baseflow from Polecat Creek (0.5 cfs) was proportioned to the area drained by these tributaries [(drainage from the direct tributaries) ÷ (drainage from Polecat Creek) x 0.5 cfs] and then added to the hourly flows for this area in order to generate the final flow values. This baseflow value was added because the basins of the direct unnamed tributaries and that of Polecat Creek are similar in land use and size.

Pumpage into the Lake from Horse Creek

The pump station was operated periodically over four months during the study period. The records of the pump station operation were supplied by CWLP and were used to determine the quantity of inflow to the lake from this source.

Water Use and Outflow from the Lake

Lake Spillway Discharge. The spillway of Lake Springfield discharges excess water from the lake. Normally the control gates on the spillway are kept in the raised position at 559.35 msl. During periods of high inflow the gates are lowered in order to keep the lake pool level near 559.35 msl. CWLP maintains records of the lake level and spillway gate settings. From these records and the spillway design rating curves, the flow over time was calculated.

Municipal Water Use. The quantity of water withdrawn by the city for potable and power plant use was provided for this analysis by CWLP.

Lake Evaporation. Lake evaporation is determined by estimating the gross evaporation from the lake and subtracting the direct precipitation that fell on the lake's surface to generate the net evaporation. Evaporation values are measured in units of inches, similar to measurements of rainfall. Total volumes of evaporation, like rainfall, are calculated by multiplying the depth by the area considered. Gross evaporation was determined by the methods of Roberts and Stall (1967), in which pan evaporation data provided by the National Weather Service is adjusted by a coefficient that accounts for the different effects of the relatively large volume in the lake as compared with the volume in a shallow pan. Roberts and Stall provided monthly pan-to-lake coefficients which were used to generate the measured gross lake evaporation values shown in table 5. The

Table 5. Evaporation from Lake Springfield, May 15, 1985 - May 14, 1987

Year I	Measured gross lake evaporation Springfield area* (adjusted pan) (inches)	Average lake evaporation Springfield area (inches)**	Rainfall average Virden and Springfield (inches)	Net lake evaporation (gross evap. minus avg. rainfall) (inches)	Estimated evaporation due to thermal discharge (inches)	Total net lake evaporation (inches)
May 15-31,85	3.92	2.58	0.22	3.70		
Jun-85	5.19	5.69	6.53	-1.33		
Jul-85	5.30	6.35	2.13	3.17		
Aug-85	4.64	5.18	5.63	-0.98		
Sep-85	4.44	3.67	0.49	3.95		
Oct-85	2.46	2.33	2.47	0.00		
Nov-85	no data	1.07	8.29	-7.22		
Dec-85	no data	0.48	2.72	-2.24		
Jan-86	no data	0.48	0.04	0.45		
Feb-86	no data	0.78	1.92	-1.14		
Mar-86	no data	1.81	1.24	0.57		
Apr-86	no data	3.12	1.29	1.84		
May 1-14, 86	2.95	2.13	1.19	1.76		
Totals in inches	36.64	35.67	34.11	2.53	13.57	16.10
Million gallons	4211	4099	3920	291	1560	1851

Table 5. Evaporation from Lake Springfield May 15, 1985 - May 14, 1987
(Concluded)

Year II	Measured gross lake evaporation Springfield area* (adjusted pan) (inches)	Average lake evaporation Springfield area (inches)**	Rainfall average Virden and Springfield (inches)	Net lake evaporation (gross evap. minus avg. rainfall) (inches)	Estimated evaporation due to thermal discharge (inches)	Total net lake evaporation (inches)
May 15-31, 86	2.12	2.58	1.93	0.19		
Jun-86	6.19	5.69	3.845	2.34		
Jul-86	6.61	6.35	4.865	1.74		
Aug-86	5.69	5.18	1.035	4.65		
Sep-86	4.17	3.67	7.315	-3.14		
Oct-86	3.90	2.33	3.635	0.27		
Nov-86	no data	1.07	2.44	-1.37		
Dec-86	no data	0.48	1.505	-1.03		
Jan-87	no data	0.48	1.46	-0.98		
Feb-87	no data	0.78	0.73	0.05		
Mar-87	no data	1.81	2.08	-0.27		
Apr-87	4.26	3.12	2.59	1.67		
May 1-14, 87	3.58	2.13	0.58	3.00		
Totals in inches	41.12	35.67	34.01	7.11	13.57	20.69
Million gallons	4726	4099	3909	818	1560	2378

* Total measured gross lake evaporation includes regional average values for months of missing data

** Monthly values averaged where available, Virden station had no data Jan. 1987-April 1987

NWS pan evaporation data are read for only part of the year. For periods when the data was not provided, the average monthly long-term records were used. Gross evaporation from Lake Springfield removes on the average over 4 billion gallons from the lake each year. During extremely dry years this loss to the lake can have significant impact on the lake level and the available raw water supply. The measured monthly gross lake evaporation and the long-term average monthly gross evaporation vary in a cyclic pattern over the course of a year (figure 11). In general the highest evaporation rates occur in the month of July and the lowest in the months of December and January. Gross evaporation rates start out low in January and tend to increase through spring and summer, peaking in the month of July and then decreasing through the late summer and fall and reaching a minimum during the month of December. Both Year I and Year II showed higher gross evaporation rates than the long-term averages (table 5 and figure 11). Year I had a gross evaporation rate approximately 1 inch higher than average, and the Year II rate was nearly 5-1/2 inches higher. These higher gross rates occurred during the periods that had less than average rates of rainfall.

Net lake evaporation (table 5) was determined by subtracting monthly rainfall from the measured monthly gross lake evaporation. The rainfall values used in this analysis were the averages of the NWS stations at Springfield Airport and Virden, IL. Net evaporation from Lake Springfield is also affected by the thermal discharge from the city's power plant. Forced evaporation due to thermal discharge was estimated at 1560 million gallons per year (R.W. Beck and Associates, 1984). This value is equivalent to 13.57 inches of loss from the lake surface. Therefore the total net lake evaporation used in this study for Lake Springfield is the sum of the measured gross evaporation plus the evaporation due to thermal discharge less the direct precipitation on the lake (table 5). The long-term average gross evaporation for the Springfield area is 35.67 inches and the long-term average for precipitation is 35.47 inches. The long-term average net evaporation is thus 0.20 inches, which indicates that average gross evaporation and average rainfall are nearly equal for lakes in the area. Net evaporation tends to vary over time depending on the quantity of rainfall and gross evaporation (figure 12). In general, net evaporation follows similar trends to those of gross evaporation, tending to peak in

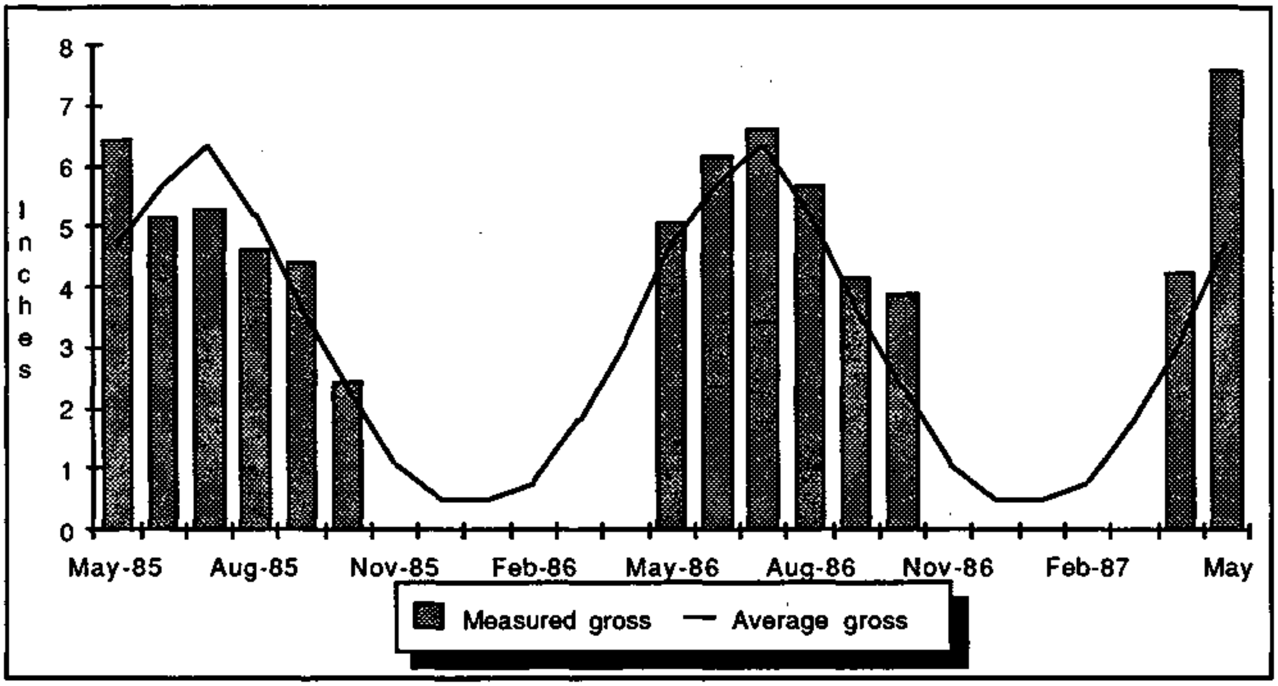

Figure 11. Measured and average gross lake evaporation, Lake Springfield, May 1985 - May 1987

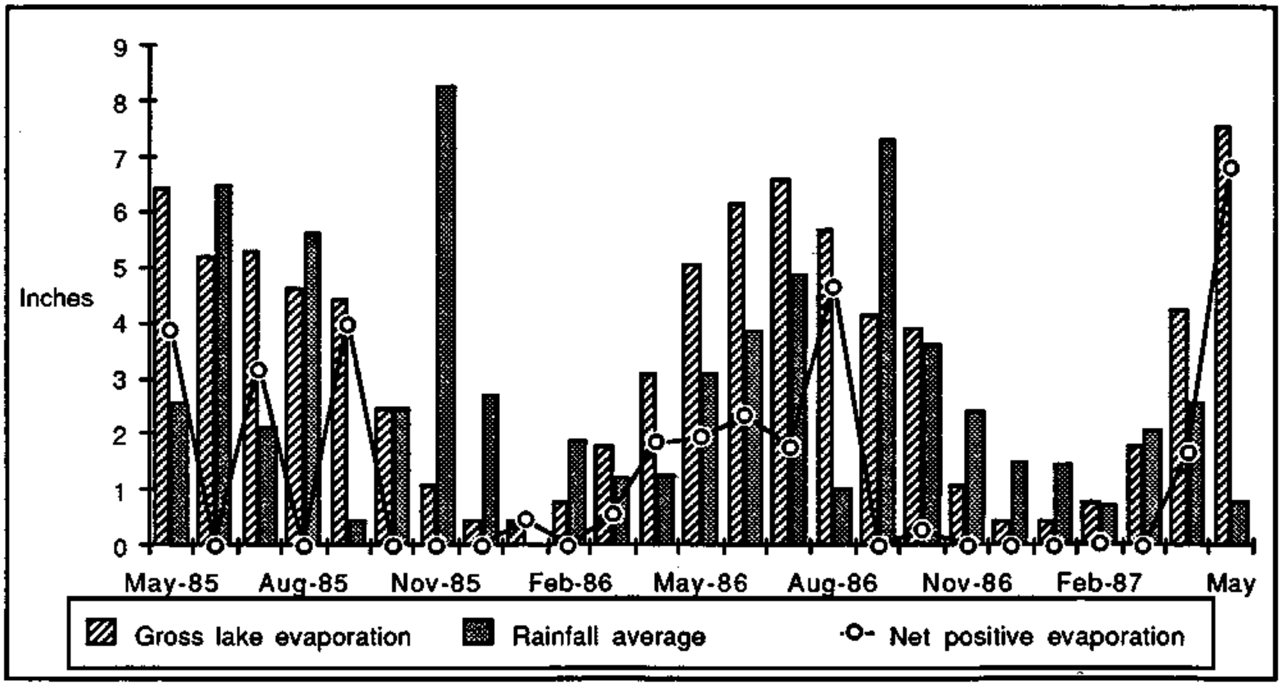

Figure 12. Monthly rainfall, and gross and net positive lake evaporation, May 1985 - May 1987

the summer months and to decline to near zero in the winter months. The quantity of water lost from the lake due to total net evaporation was determined to be 1851 million gallons in Year I and 2378 million gallons in Year II.

Lake Seepage and Spillway Gate and Dam Leakage. The amount of flow out of the lake due to seepage from the lake's dam and spillway was determined from the data provided to the Water Survey by CWLP. This value was 0.7 MGD. The quantity of water lost to seepage from the bottom and sides of the lake was considered to be insignificant (Makowski et al., 1986a) and was not considered in this analysis.

Change in Storage

Change in storage is the difference in the quantity of water held by the lake at the start and end of the time period considered. Two factors are considered in this analysis: change in lake level, and lake volume lost to sediment deposition. Lake level records are maintained by CWLP on a daily basis. Volume loss due to sediment deposition was determined by comparing the total inflow of sediment from the watershed with the quantity leaving the lake by water withdrawal (municipal use and power plant) and carried by flow over the spillway.

Year I. For Year I (May 15, 1985 - May 14, 1986) the lake surface started at 560.18 feet msl and ended at 560.21 feet msl. Therefore the lake held 0.03 foot of water more at the end of Year I. The lake's stage capacity curve (Fitzpatrick et al., 1985) estimates the total volume of the top 1 foot of lake storage as 4000 acre-feet or 1300 million gallons. The net change in the quantity of water held at the end of Year I is therefore 40 million gallons. Sediment deposition during Year I was measured as the equivalent of approximately 16 million gallons. Subtracting the increase in storage due to a higher lake level at the end of Year I from the storage replaced by sedimentation results in a total change in storage of positive 24 million gallons, an overall gain in water in the lake over this time period.

Year II. The overall change in lake level for Year II (May 15, 1986-May 14, 1987) was from 560.21 feet at the start of the period to 560.04 feet at the end, a net change of -0.17 foot. This drop in lake level is equivalent to 222 million gallons. Volume loss due to sediment deposition was measured as the equivalent of approximately 8 million gallons. The net change in storage is therefore negative 214 million gallons, an overall loss of water in the lake over this time period.

Lake Springfield Water Budget

Water Inflow. During the two-year study period over 88 billion gallons of water flowed into Lake Springfield (table 6). The detailed water budget is presented in the appendix. During Year I, over 51 billion gallons flowed into the lake and during Year II, 37 billion gallons entered the lake. The long-term average annual inflow rate to Lake Springfield, obtained from the Streamflow Assessment Model (STREAM) (Knapp et al., 1985a, 1985b), is 44 billion gallons. The two-year study period average yearly inflow of 44 billion gallons was therefore equal to the long-term average, with Year I's total above the average and Year II's total below the average

The computed water budgets (table 6) of the two-year study period show differences in the total amounts of inflow and outflow, which under ideal conditions should balance. The two-year difference between inflow and outflow amounts to 540 million gallons or 0.6% of the total inflow. The individual differences amount to 6.7 percent for Year I and 7.8 percent for Year II. These differences are expected and result from the accumulation of errors generated in each step of the process of developing the budgets. The sources of the errors are varied and can include rounding errors in computation, errors associated with field measurement, and variations in stream flow and withdrawal unaccounted for in the computation process. The values of inflow and outflow were not adjusted to distribute the differences because the individual errors in quantifying each of the variables are not consistent and cannot be proportionally distributed. For example, field measurements of discharge over time are usually accepted as having an associated error of 10 percent. The exact magnitude and direction of the measurement errors for any given individual component of the budget cannot be directly assessed because of the variables operating in a natural stream system. Therefore individual component errors of 10 percent are assumed, and the resulting errors shown in the final budget are considered reasonable and acceptable.

Table 6. Summary Water Budget of Lake Springfield, May 15, 1985 - May 14, 1987 (In million gallons)

Inflow categories (percent of total watershed area)

	Lick Creek (45%)		Sugar Creek (24%)		Direct Tribs. (15%)		Panther Creek (9%)		Polecat Creek (4%)		Pumpage from Horse Creek (0%)	
Year I* amount and percent of total inflow	19503	38%	14247	28%	9219	18%	5390	11%	2311	5%	473	1%
Year II** amount and percent of total inflow	18301	49%	8432	23%	5504	15%	3191	9%	1415	4%	244	1%

Outflow

	Spillway discharge		Dam & gate leakage		Municipal usage		Power plant usage		Net evaporation		Change in lake storage	
Year I* amount and percent of total outflow	35944	75%	258	1%	7816	16%	1825	4%	1851	4%	24	0%
Year II** amount and percent of total outflow	28341	71%	258	1%	7384	18%	1825	5%	2378	6%	-214	-1%

	Year I*	Year II**	Two-year total
Inflow total	51143	37087	88230
Outflow total	47718	39972	87690
Difference	3425	2885	540
Percent difference	6.7%	7.8%	0.6%

*Year I = May 15, 1985 - May 14, 1986
**Year II = May 15, 1986 - May 14, 1987

The amounts of water contributed by the individual sources of inflow to the lake have varied between the two years of study (table 6 and figure 13). Lick Creek's flow to the lake declined by approximately one billion gallons from Year I to Year II. Lick Creek's percentage of the total, however, increased by 11 percent over this same time period. It contributed 38% of the total inflow in Year I and 49% of the inflow during Year II. The increase of the percentage of inflow contributed by Lick Creek is due to the patterns of precipitation across the watershed area during the study periods, in that this tributary received more precipitation during the Year II period than the other watershed areas. The other tributaries of the lake also show variations in the percentages of total inflow contributed from one year to the next (table 6). These variations are expected and are due to the complex interaction of factors affecting streamflow such as precipitation, soil moisture, evaporation, transpiration, depression storage, infiltration, and land use. Given similar geologic, climatic, and land use conditions, the proportions of total inflow should tend to even out with time. Year II represented a more even distribution of streamflow in the lake's watershed than occurred in Year I. In Year II, the relative percent of total inflow was much closer to the relative percent of the areas drained by each tributary of the lake (table 6 and figure 13).

All of the inflowing tributaries experienced changes in the quantity of flow and the percentage of the total flow over time. Sugar and Lick Creeks, being the largest of the tributaries of the lake, have shown the greatest range of change. The total inflow and that contributed by both of these tributaries are shown in figure 13. Variations in the percent of inflow contributed by each of the inflow sources can be seen in table 6. The Horse Creek pump station contributed approximately 1 percent of the total in each of the study years. Polecat Creek, Panther Creek, and the direct tributaries of the lake contributed amounts that varied by approximately 1 to 2 percent over the study period. All of the tributaries of the lake contributed inflow within a range of plus or minus 5 percent of the proportion of the watershed they drain.

Water Outflow. Total water outflow for the two years of the study has been approximately 88 billion gallons (table 6). Year I was a wetter

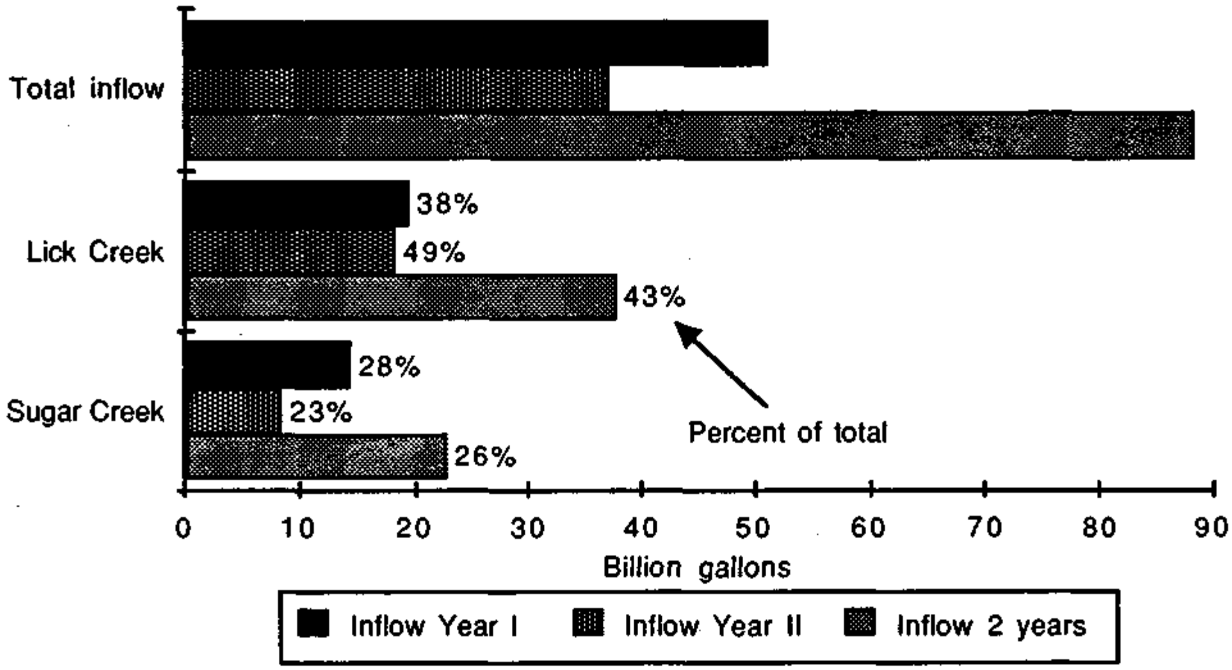

Figure 13. Water inflow to Lake Springfield by source area, May 1985 - May 1987

year than Year II. Outflows from the lake in Year I and Year II were approximately 48 billion gallons and 40 billion gallons, respectively. As expected, the quantities of outflow observed for these two years parallel the respective amounts of inflow (Year I had a much higher inflow than Year II).

Of the various categories of outflow, power plant use and dam and gate leakage remained the same for the two study years (table 6). Spillway discharge and municipal use decreased from Year I to Year II. Net evaporation was the only category of outflow that increased in the second year when compared to the first. The data for municipal use was supplied by CWLP, and the change from one year to the next was probably due to changes in water demand from the industries and population served. Dam and gate leakage and power plant use were expected to remain about the same over the two years since these were based on average daily rates of loss to the lake that were applied to both years. The change in the amount of water loss due to spillway discharge from Year I to Year II was also expected due to the reduced inflow to the lake in the second year compared to the first.

Spillway discharge is the single largest category of outflow for both years, accounting for 75 and 71 percent of the total outflow for Year I and Year II, respectively (table 6 and figure 14). Spillway overflow occurs when the lake's storage volume is filled and the excess inflow is discharged over the spillway. Municipal use is the second largest category of outflow from the lake (table 6). Although the actual quantity of water withdrawn for municipal use decreased by over 400 million gallons in Year II, the proportion of outflow represented by this category increased in relation to the other categories. This is because Year II had less total outflow than Year I, and the amount of municipal use, although decreasing slightly, represented a greater demand on the lake in the dryer Year II period.

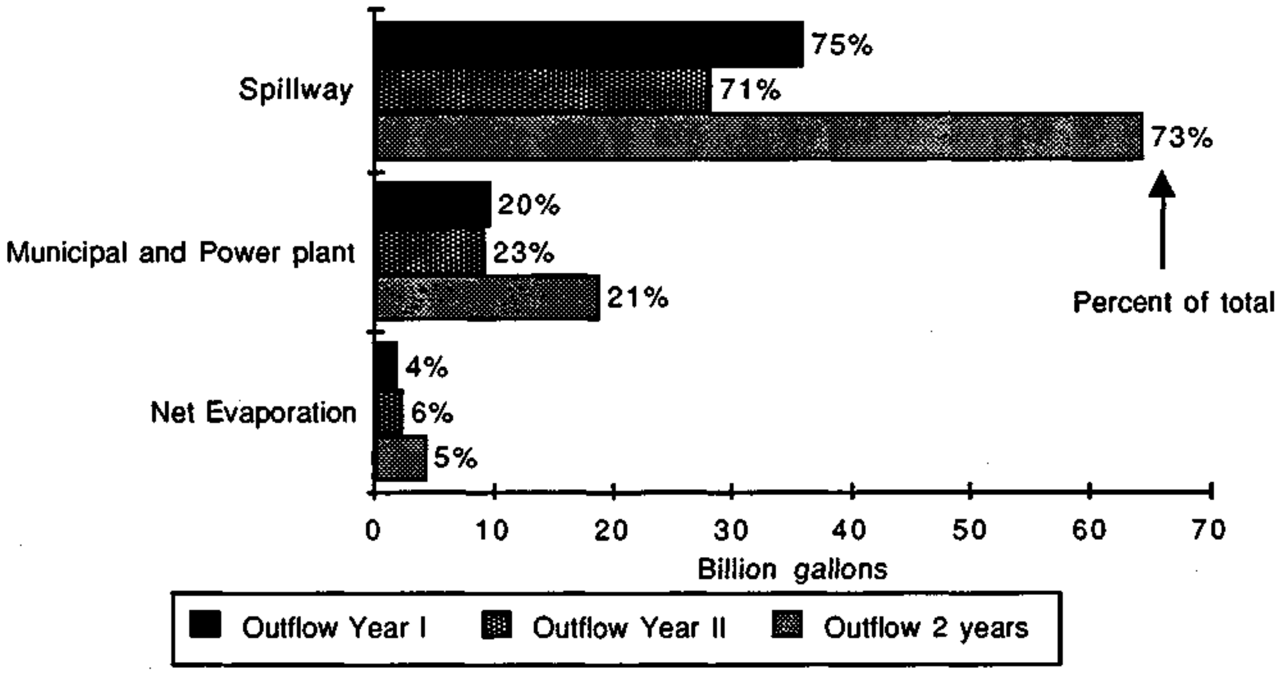

Figure 14. Water outflow from Lake Springfield by category, May 1985 - May 1987

Sediment Budget

Suspended Sediment Transport to the Lake

The analysis of the transport (loading) of sediment over time was performed by using streamflow, sediment concentration data and the statistical relationships between observed instantaneous sediment loading and streamflow. Streamflow data provided a record of the total amount of water, sediment, nutrients, and other flow constituents moving past a given stream cross section. The amount of any specific parameter carried by the stream is the product of the total flow and the concentration of the parameter. For example, a stream flowing at 1000 cubic feet per second and transporting sediment at a concentration of 10,000 parts per million (1 percent) is transporting 10 cubic feet of sediment per second. This explanation is intended to provide a very basic picture of the mechanism of stream transport calculation and does not address the many other variables that must be considered in this type of investigation such as measurement error, sampling bias, density changes in water due to suspended material and temperature, and many other factors.

The total load of sediment to the lake from its watershed is divided into two basic components: suspended load and bed load. Suspended load is carried in the majority of the stream's cross-sectional area and is readily measured by using the standard techniques developed by the Water Survey and other organizations. The bed load, however, which is composed of the components of total load that are carried along or near the streambed, is difficult to sample and quantify because any instrument placed at the streambed boundary will change the flow conditions and the resulting transport of sediment. The technique used to estimate this parameter is discussed in the section on bed load.

Sugar and Lick Creeks. These sites are Sugar Creek at Highway 104 at Auburn, Illinois (SL1), and Lick Creek at Curran Road near Lick, Illinois (SL2), as shown in figure 1. As discussed earlier, these sites were instrumented with automated water samplers and continuous streamgage recorders.

Daily suspended sediment loading was calculated by using a method developed previously (Lee et al., 1983). This method calculates the loading of the stream on the basis of the instantaneous concentration of sediment over a time interval bounded by the time-midpoint between previous and succeeding instantaneous samples. Figure 15 demonstrates the application of this method.

Interpreted data points were extrapolated and added to the sediment concentration data set in order to apply automated sampler and point sample calibration to the average streamflow sediment concentration. Additional interpreted points were added (figure 15a) to fill in missing portions of important high flow periods, i.e., the breakpoint of a rising limb of a hydrograph where the automated sampler or on-site sampling had missed the initial change in sediment concentration. This is an important part of the analysis of the hydrograph, sediment concentration over time, and sediment loading, and is necessary in interpreting stream loading in rapidly changing conditions.

Figure 15b demonstrates the technique of dividing the record into time periods of average sediment concentrations. The time periods of average concentration are then multiplied by the average quantity of water flow occurring in the individual periods to determine the period loading of sediment. Daily sediment load is determined by the sum of the period loading in each day as shown in figure 15c.

In the course of monitoring the concentration of sediment over time for the two-year study period, over 5000 sediment concentration samples were obtained from the Sugar and Lick Creek monitoring sites. Of this number, 1046 were selected for laboratory analysis. The samples for analysis were chosen on the basis of the observed concentration and the specific flow conditions in the creeks at the time represented by each sample. Calibration and interpretive points were generated and the sediment concentration data set was analyzed by means of the University of Illinois CYBER computer program developed by the Water Survey for sediment load calculation. The sediment loading output data set presents the total amount of sediment transported by Sugar and Lick Creeks at the gaging sites for each day of the monitoring year.

The daily loads at each of the gaging stations were used to generate the total loading from Sugar and Lick Creeks at the points where they empty into the lake. This procedure was accomplished by proportioning the measured load at the gaging stations according to the proportion of the total watershed of the creeks monitored. The results of the area proportioning method for extrapolating sediment concentration and loading

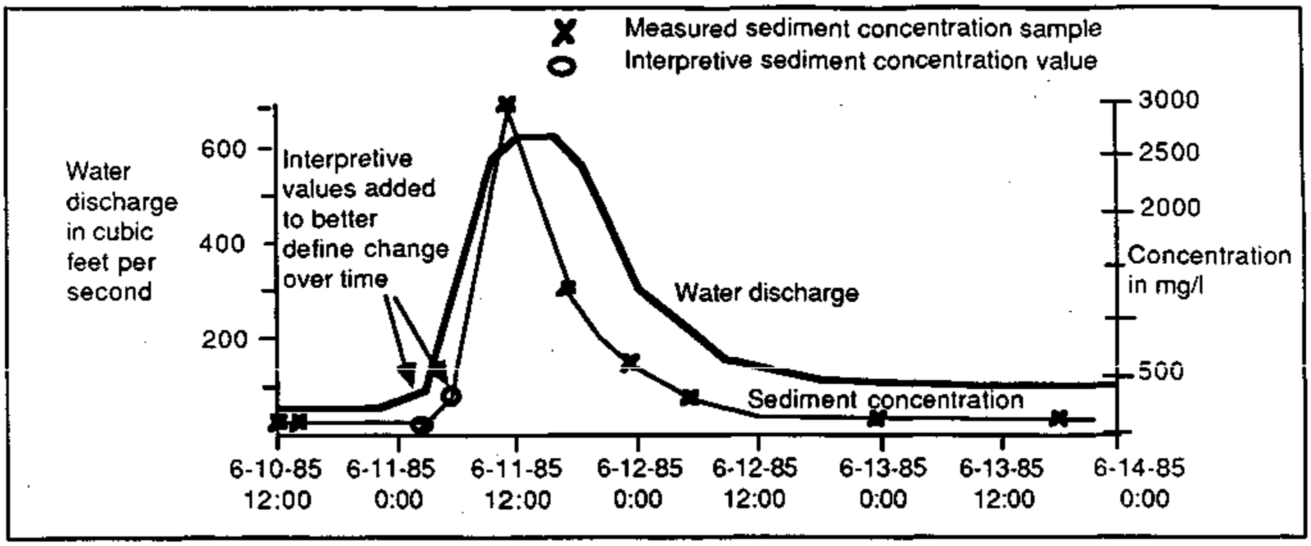

Figure 15a. Water discharge and sediment concentration values for runoff event on June 10-14, 1985, at Sugar Creek, Auburn, Illinois

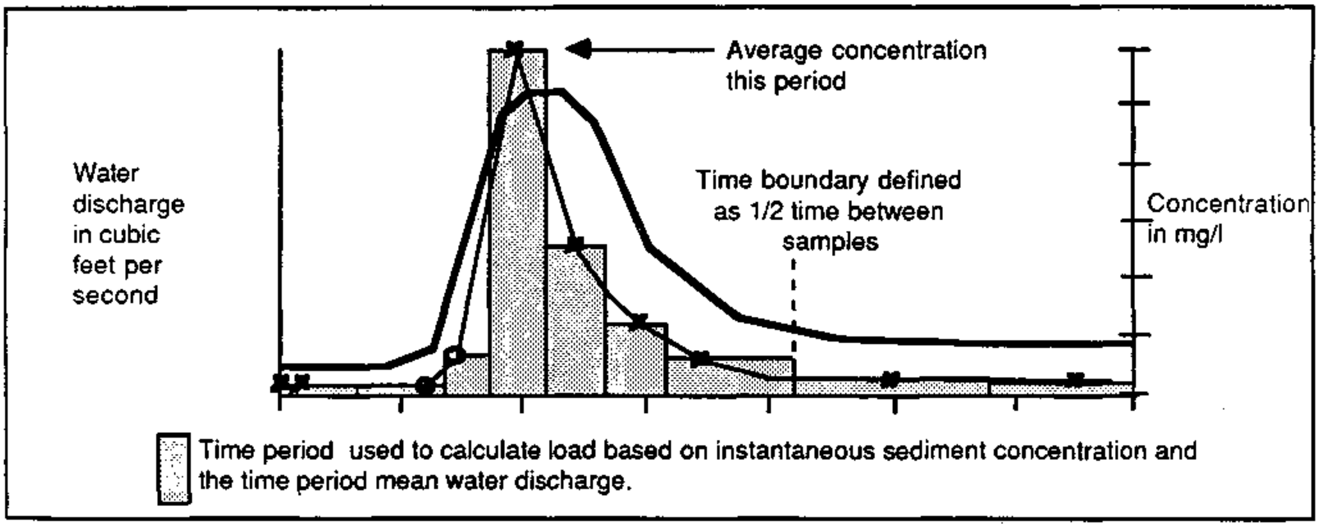

Figure 15b. Concentration and discharge record from figure 15a, divided into time periods in which the concentration value represents the mean concentration of the period

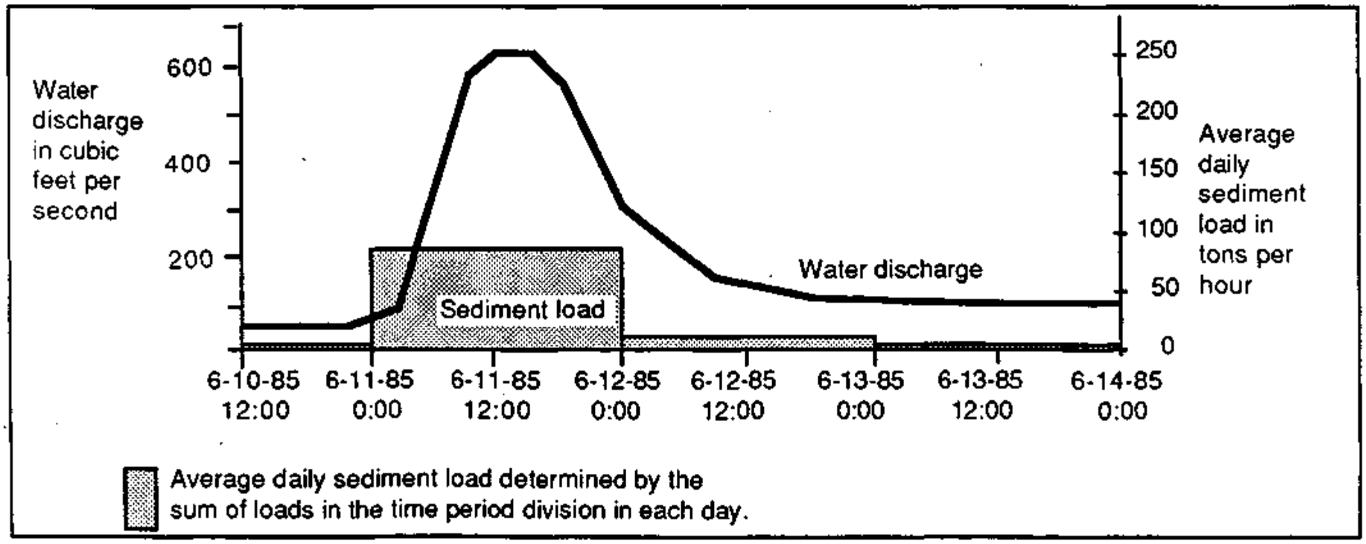

Figure 15c. Calculated daily sediment load values. The period mean concentrations shown in figure 15b are multiplied by the period mean water discharge and a constant to determine tons per period. The average daily sediment load is determined by the sum of the loads per time period in each day.

were verified by data from samples obtained from locations in the creeks downstream of the gages.

Polecat and Panther Creeks. Sediment loading in these tributaries of Lake Springfield was monitored at the peakflow streamgage sites shown in figure 1. Instantaneous sediment load data were obtained at these sites on Panther and Polecat Creeks during the weekly site visits. A total of 175 measurements were performed in which stream stage was determined and sediment concentration samples were obtained. For each site the stage data were converted into instantaneous discharge through the stage-to-discharge relationship measured at each site. The instantaneous discharge data were then used to calculate the instantaneous sediment discharge. For each site these two parameters were plotted and a regression equation relating the instantaneous sediment and water discharges was determined by a least square fit. Very low flow and no-flow data points were not considered in the regression analysis. The relationships between these parameters for Panther and Polecat Creeks are as follows:

Panther Creek: $Q_s = 0.00341\ (Q_w)^{1.259}$ $r = 0.808$ for 63 observations

Polecat Creek: $Q_s = 0.000851\ (Q_w)^{1.749}$ $r = 0.870$ for 75 observations

Q_s = instantaneous sediment discharge (tons per hour)
Q_w = instantaneous water discharge (cubic feet per second)
r = correlation coefficient

These regression equations were used to determine the daily loading of sediment of these two creeks at the point at which they empty into Lake Springfield.

The regression equations indicate the relative amounts of sediment per unit area that each of these creeks transports. Panther Creek showed a higher loading per unit area than Polecat Creek. This was observed in the field and was verified by calculations of instantaneous loading. The two watersheds differ in land use. Panther Creek's watershed is primarily in row crops with large areas of pasture located along the creek. Polecat Creek's watershed is row-cropped, but has large urban areas (principally the city of Chatham) that contain large impervious surfaces of rooftops and streets, and grassed lawns. Also, Polecat Creek's stream channel is smaller and less entrenched and has considerably less bank erosion than Panther Creek. The pasture areas of Panther Creek were observed in field reconnaissance to have areas of gully and bank erosion and therefore were expected to contribute large amounts of sediment to the creek.

Direct Tributaries of the Lake. This area of Lake Springfield's watershed includes the many unnamed tributaries that flow directly into the lake. These small tributaries range in size from several square miles to a few hundred acres and drain watersheds that have many land uses including row crops, woodlands, and urban/suburban areas. Polecat Creek is the smallest of the watersheds directly monitored for this project and was chosen for the purpose of indicating the behaviors of the small tributaries of the lake. Therefore the flow and transport relations observed for Polecat Creek were applied to the direct tributary areas.

Horse Creek Pump Station. In addition to providing extra water to the lake, the operation of the pump station also contributes sediment. The quantity of sediment delivered to the lake from this source was determined from the pumping records of CWLP and the results of periodic sediment concentration sampling at the pump intakes.

Suspended Sediment Transport from the Lake

Lake Spillway. Weekly sediment concentration samples were used together with the data set for spillway discharge to determine the quantity of sediment leaving the lake over the spillway gates. The concentration of sediment in the lake water is fairly constant over time because of the buffering effect of the large lake volume in relation to the average inflow of water. Weekly sampling provided a good measure of the changes over time, and each sample was used to determine the time-weighted monthly average concentration. Monthly average concentrations were then multiplied by monthly flow to determine monthly load values.

Municipal Water Supply, Power Plant Usage, and Spillway Gate and Dam Leakage. Water use and spillway gate and dam leakage values were supplied by CWLP. Sediment concentration values were determined on the basis of the time-weighted average monthly concentration of samples obtained at the lake's spillway. Sediment discharge from the lake was determined from the product of the total monthly water use and leakage, and the average monthly sediment concentration.

Bed Load to the Lake

This parameter was estimated independently of the determination of suspended load transport because of the complex and difficult nature of directly measuring bed load in natural streams. The bed load is that portion of the total load of a stream that is transported in contact with, or very close to, the bed of a stream.

Graf (1971) described the difficulty of determining bed load in natural streams from predictive equations, noting that the available equations are based on small-scale flume studies and site-specific field conditions, which severely limits their application to natural systems that vary from the hydraulic and sediment conditions under which the equations were developed. He indicated further that disagreements of up to 100 percent in the results of the various equations are not uncommon and that the applicability of these equations to field determinations remains an educated guess.

Direct measurement of bed load is difficult because of equipment limitations. The Helley-Smith bed load sampler is currently the only portable instrument developed for measuring bed load. This instrument uses a mesh bag to filter particles from the streamflow and therefore is limited to capturing particles larger than the mesh size (generally 0.25 mm). Finer mesh bags tend to clog and reduce the filtering efficiency.

A sediment budget study of the upper Mississippi River showed that the ratio of bed load to suspended load varied from between 6 and 26 percent on the six streams studied. The average value was 11 percent (Nakato, 1981). A value of 10 percent is used in this analysis on the basis of field observations of the relatively small streambed particle sizes, low streambed gradients, and relatively moderate to low streamflow velocities.

Lake Springfield Sediment Budget

Over 61,000 tons of sediment were delivered to Lake Springfield over the two-year study period (table 7). In Year I 40,407 tons were delivered to the lake, and in Year II 20,899 tons were delivered. The reduction from Year I to Year II corresponds to the 27 percent reduction in water runoff to the lake observed over this same period.

Table 7. Summary Sediment Budget of Lake Springfield, May 15, 1985 - May 14, 1987 (in tons)

	Inflow categories (percent of total watershed area)					
	Lick Creek(45%)	Sugar Creek(24%)	Direct Tribs.(15%)	Panther Creek(9%)	Polecat Creek (4%)	Pumpage from Horse Creek(0%)
Year I* amount and percent of total inflow	17523 43%	14596 36%	4842 12%	2176 5%	953 2%	317 1%
Year II** amount and percent of total inflow	12321 59%	5678 27%	1465 7%	1052 5%	297 1%	86 0%

	Outflow			
	Spillway discharge		Non-spillway outflow	
Year I* amount and percent of total outflow	2416	83%	492	17%
Year II** amount and percent of total outflow	1008	74%	362	26%

	Year I*	Year II**	Two-year total
Total to lake	40407	20899	61306
Total from lake	2908	1370	4278
Net sediment deposited	37499	19529	57028
Trap efficiency	93%	93%	93%

*Year I = May 15, 1985 - May 14, 1986
**Year II = May 15, 1986 - May 14, 1987

The summary sediment budget for the two-year study period is presented in table 7. This table shows the amount of sediment delivered and the percent of the yearly total contributed by each source area. Lick Creek, the largest tributary of the lake, contributed the greatest amount of sediment to the lake of all the source areas. The two largest tributaries of Lick and Sugar Creeks together contributed nearly 82 percent of the total two-year inflow of sediment from an area which represents 69 percent of the lake's watershed. The smaller source areas of sediment (Panther and Polecat Creeks and the direct tributaries of the lake) contributed sediment at a rate per area less than that of Lick and Sugar Creeks as shown in table 7. The monthly values for each of the inflow and outflow categories are presented in the appendix.

Figure 16 is a plot of the monthly water runoff to the lake, total monthly sediment inflow, and monthly rainfall (average of Capitol Airport and Virden stations) for the period May 15, 1985 through May 14, 1987. It can be seen in this figure that sediment inflow is primarily a function of the magnitude of water runoff to the lake. The months of high sediment inflow were June, November, and December 1985; May 1986; and April 1987, which correspond to the highest runoff months. These five months accounted for over 76 percent of the total sediment inflow over the two-year study period. February and December 1986 and February 1987 all had relatively high snowmelt runoff but relatively low sediment inflow because snowmelt runoff generally carries less sediment during gradual warming periods.

Monthly water runoff and sediment inflow correspond poorly to monthly rainfall (figure 16). Many factors besides the amount of rainfall contribute to sediment transport and water runoff, including ground moisture, evapotranspiration potential, and temperature. This relationship highlights the need for actual field monitoring to accurately assess runoff and sediment transport.

Lake Springfield Sediment Trap Efficiency

The trap efficiency of a lake is a measure of the proportion of total sediment carried into the lake that is deposited within the lake. Brune (1953) and Dendy (1974) have developed methods of estimating the trap efficiency of lakes and reservoirs from the ratio of average yearly inflow to storage capacity. On the basis of these methods, it was estimated that

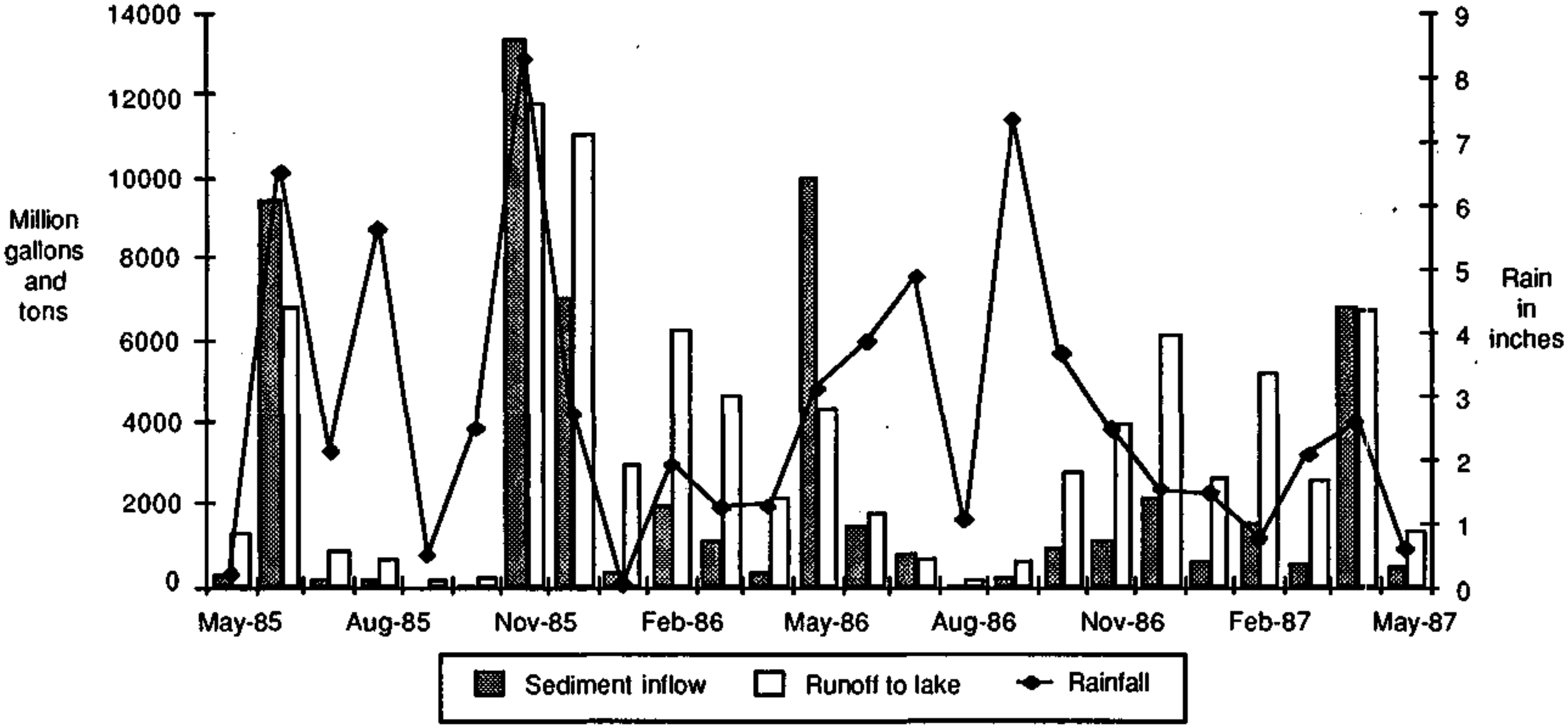

Figure 16. Monthly sediment inflow, water runoff to the lake, and rainfall, Lake Springfield, May 15, 1985 - May 14, 1987

the average trap efficiency of Lake Springfield is 95 percent (Fitzpatrick et al., 1985). This value is a long-term average and is not intended to reflect the trap efficiency of the lake each year, since the inflow and outflow of sediment and water will vary depending on many variables such as storm intensities, lake pool levels, ground conditions, and evapotranspiration. In each of the two years of monitoring the measured sediment trap efficiency of the lake was 93 percent (table 7).

Sediment Deposition in Lake Springfield

The amount of sediment deposited in the lake from all sources excluding lakeshore erosion was 57,028 tons over the two-year study period May 15, 1985 through May 14, 1987 (table 7). The 1984 sedimentation survey of the lake determined that the average density of sediment deposited over the period 1977 to 1984 was 771 tons per acre-foot of sediment. Applying this value results in a net lake volume loss of 74.0 acre-feet or 24.1 million gallons for the two-year study period. The values of volume loss for the two study years were 15.8 million gallons in Year I and 8.3 million gallons in Year II.

Nutrient Budget

Nitrogen and phosphorus are the two principal limiting nutrients of biological activity in aquatic systems. These nutrients in excessive amounts can cause nuisance algae and aquatic plant blooms and severely limit the usefulness of a water supply source for human consumption. Nutrients are delivered to streams and lakes from many sources such as topsoil erosion, fertilizers, animal wastes, sewage discharge, biological activity, and atmospheric deposition.

This investigation monitored and determined the budgets of the following forms of nitrogen and phosphorus: total Kjeldahl nitrogen, dissolved nitrate nitrogen, total and dissolved phosphorus, and ammonia nitrogen.

Total Kjeldahl nitrogen is a measurement of the sum of the organic and ammonia forms of nitrogen in both the dissolved and particulate forms.

Dissolved nitrate nitrogen is the most readily available form of nitrogen for algae and other aquatic plant use. It is an oxidized component of the nitrogen cycle and is the product of the biological conversion of more reduced forms such as ammonia and nitrite. The Illinois Pollution Control Board has set a limit for this nutrient of 10 mg/l for public water supplies.

Total phosphorus is the sum of the dissolved and particulate forms of phosphorus. The Illinois Pollution Control Board has set a limit of 0.05 mg/l total phosphorus for lakes and reservoirs.

Dissolved phosphorus is that fraction of total phosphorus that is dissolved in the water or attached to suspended particles that will pass through a 45-micron filter.

Total ammonia nitrogen is a measure of the reduced form of nitrogen in aquatic environments. Ammonia is toxic to aquatic organisms in elevated concentrations and is converted to more oxidized forms that can be used by aquatic plants in the presence of oxygen. For general use waters, the Illinois Pollution Control Board specifies an upper limit of ammonia of 15 mg/l.

Nutrient Transport to the Lake

The transport of various nutrients in the monitored streams of the watershed was analyzed by means of periodic field sampling of the concentration of these constituents at various flow conditions and levels of sediment concentrations. In order to understand the variations of nutrient concentrations over time and to be able to predict nutrient concentrations for time intervals when samples were not obtained, the data were examined for correlations of nutrient loads, sediment loads, and water discharge. This statistical analysis of correlations was performed because the data set on nutrient concentrations was limited due to the cost and time-consuming process of obtaining and processing these samples in the field.

Instantaneous nutrient loads were best correlated with water discharge in the smaller tributaries of Panther and Polecat Creeks and the direct tributaries of the lake. Instantaneous nutrient load data from the larger tributaries of Lick and Sugar Creeks were observed to be best correlated with water discharge for the dissolved nutrient parameters and with sediment load for the parameters of ammonia, Kjeldahl nitrogen, and total phosphorus.

The tributaries of Sugar and Lick Creeks had the most extensive data set on measured sediment concentrations and water discharge. The decision to relate the nutrient parameters of ammonia, Kjeldahl nitrogen, and total phosphorus to sediment loading at these sites was based on the results of the correlation analysis and the fact that the larger sites had a fairly extensive sediment concentration record. Sugar and Lick Creeks had 494 and 552 sediment concentration samples, respectively, over the two-year study period. Sediment load was determined on the basis of measured sediment concentration data. These samples were well distributed with respect to time and flow conditions and provided a good data set for relating nutrient concentration over time. The smaller sites of Panther and Polecat Creeks had 92 and 83 sediment concentration samples respectively over the two-year study period. Since the sediment concentration data set from these sites is relatively small, water discharge was used to predict the sediment loads based on the correlation of these variables. The errors of using water discharge to predict sediment and then sediment to predict nutrient loads would have been cumulative and larger than the error of predicting nutrient loads based on water discharge alone.

The equation variables developed for each parameter and each site and the correlation coefficients of the equations are shown in table 8. In general the equations developed show a relatively good statistical agreement between predicted and observed results.

The regression equations correlating water discharge and the loadings of sediment and nutrients were used to develop data sets on the daily loading of each of the nutrient parameters to the lake from the flowing tributaries. The loading of nutrients to the lake from the Horse Creek pump station was determined from field samples of nutrient concentrations obtained during the pump station operation.

The equations developed for Sugar and Lick Creeks tend to have higher correlation coefficients than those developed for the other sites (table 8). This is due to the magnitude of the variables considered: the larger tributaries tend to have higher water discharges and loads than the smaller tributaries, and therefore the error between the predicted and observed data will tend to be less compared to the magnitude of the observed data. For example, an error of one ton per hour between the predicted and observed values will be more significant in a stream

Table 8. Site-Specific Correlation Coefficients of Regression Analysis between Water Discharge (Qw), Sediment Discharge (Qs), and Various Nutrient Water Quality Parameter Discharges

Regression equation: aX^b

Tributary	Independent variable X	Dependent variable Y	Slope b	Intercept a	Sample size	Correlation coefficient r
Sugar Cr.	Qw	Dissolved nitrate-N	1.407	1.18E-04	32	0.895
	Qw	Dissolved phosphorus	1.047	9.40E-06	32	0.909
	Qs	Ammonia-N	0.735	2.00E-03	28	0.920
	Qs	Kjeldahl-N	0.802	1.12E-02	27	0.958
	Qs	Total phosphorus	0.706	3.56E-03	32	0.961
Lick Cr.	Qw	Dissolved nitrate-N	1.368	7.00E-05	34	0.820
	Qw	Dissolved phosphorus	1.050	8.13E-06	34	0.905
	Qs	Ammonia-N	0.884	1.10E-03	30	0.945
	Qs	Kjeldahl-N	0.897	5.52E-03	33	0.910
	Qs	Total phosphorus	0.897	2.25E-03	30	0.979
Panther Cr.	Qw	Dissolved nitrate-N	1.192	4.99E-04	31	0.947
	Qw	Dissolved phosphorus	1.324	2.33E-06	31	0.841
	Qw	Ammonia-N	1.233	8.11E-06	27	0.849
	Qw	Kjeldahl-N	1.268	3.27E-05	26	0.720
	Qw	Total phosphorus	1.355	6.21E-06	31	0.814
Polecat Cr. and direct tribaries	Qw	Dissolved nitrate-N	1.901	9.31E-05	33	0.932
	Qw	Dissolved phosphorus	0.846	6.07E-06	33	0.561
	Qw	Ammonia-N	1.098	7.89E-06	29	0.816
	Qw	Kjeldahl-N	1.023	4.98E-05	27	0.795
	Qw	Total phosphorus	1.049	1.07E-05	33	0.685

Qw = water discharge in cubic feet per second
Qs = sediment discharge in tons per hour
Y = nutrient discharge in tons per hour

transporting four tons per hour than in a stream transporting 15 tons per hour.

Nutrient Transport from the Lake

The amounts of the various nutrient parameters transported out of the lake were determined by multiplying the average monthly concentration of the nutrients by the monthly flow over the spillway and the amount of water used for municipal supply. The relatively large volume of the lake buffered the variations in the concentrations of nutrients and sediment at the spillway.

Thirty-two nutrient samples were obtained from the lake at the spillway over the course of the two-year study period. In addition 61 dissolved nitrate and 16 phosphorus concentration sample results were provided by CWLP.

Lake Springfield Nutrient Budget

Table 9 lists the quantities of nutrients delivered to and carried out of the lake for the two-year study period. The monthly values for each of the inflow and outflow categories are presented in the appendix.

Most of the phosphorus samples obtained at the lake spillway exceeded the Illinois Pollution Control Board (IPCB) general use standard. Forty-seven out of forty-eight samples were above the 0.05 mg/l standard. The lowest concentration measured was 0.05 mg/l on June 17, 1986. The highest concentration of phosphorus measured was 0.26 mg/l on September 8, 1986. The concentrations of nitrate were all within the IPCB standard for water supplies of 10 mg/l. The 35 ammonia concentration measurements were all below the IPCB limit of 15 mg/l.

Nutrient Deposition in Lake Springfield

The majority of the nutrients delivered to the lake were deposited on the lakebed or held within the water column over the two-year study period. Nutrients are removed from the lake water by the process of settling (sedimentation) and biological uptake. Table 9 lists the quantities of the measured nutrient parameters delivered to the lake, the amounts leaving the lake, the amounts trapped by the lake, and the average inflow and outflow concentrations. Most of the nutrient parameters behaved similarly to

Table 9. Summary Nutrient Budget of Lake Springfield, May 15, 1985 - May 14, 1987

	Inflow (tons)	Outflow (tons)	Deposited (tons)	Trap efficiency	Average inflow concentration (mg/l)	Average outflow concentration mg/l
Total phosphorus	79.4	39.2	40.2	51%	0.22	0.11
Dissolved phosphorus	29.6	20.5	9.1	31%	0.08	0.06
Dissolved nitrate nitrogen	3079.9	815.8	2264.1	74%	8.36	2.30
Ammonia nitrogen	48.3	63.4	-15.1	-31%	0.13	0.18
Kjeldahl nitrogen	271.2	222.1	49.1	18%	0.74	0.63
Year I (May 15, 1985 - May 14, 1986)						
Total phosphorus	49.5	23.7	25.8	52%	0.23	0.12
Dissolved phosphorus	17.5	12.5	5.0	29%	0.08	0.06
Dissolved nitrate nitrogen	2173.9	583.0	1590.9	73%	10.18	3.02
Ammonia nitrogen	30.2	40.7	-10.5	-35%	0.14	0.21
Kjeldahl nitrogen	171.1	128.3	42.8	25%	0.80	0.66
Year II (May 15, 1986 - May 14, 1987)						
Total phosphorus	29.9	15.5	14.4	48%	0.19	0.10
Dissolved phosphorus	12.1	8.0	4.1	34%	0.08	0.05
Dissolved nitrate nitrogen	906.0	232.8	673.2	74%	5.85	1.45
Ammonia nitrogen	18.1	22.7	-4.6	-25%	0.12	0.14
Kjeldahl nitrogen	100.1	93.8	6.3	6%	0.65	0.58

sediment in that the quantities delivered to the lake are greater than the amounts leaving the lake. Ammonia nitrogen is an exception: 15 tons more ammonia were recorded leaving than entering. This is due to processes of the nitrogen cycle in aquatic environments in which decomposing nitrogeneous organic matter releases ammonia into the water column.

DISCUSSION

Flow Duration

Flow duration analysis classifies the daily flows during a period and ranks them according to the portion of the period during which a particular discharge was equaled or exceeded. The flow duration graph is a statistical probability analysis of the recurrence rate of one-day flows measured over a given period. Two flow duration curves are presented in figure 17: the thirty-year STREAM Model flow duration and the flow duration observed over the two-year study period. The flow duration plots (figure 16) can be used to determine the recurrence rate of various flow rates or the flow rate at various recurrence frequencies. For example, the median flow rate (i.e., the quantity of flow equaled or exceeded 50 percent of the time) was 120 cfs (77.6 million gallons per day) over the two-year study period. The long-term 30-year median flow rate was 49 cfs (31.7 million gallons). The difference in the two medians is due to routine variations in the annual distribution of streamflow. The difference between the long-term and the two-year medians was caused by a greater frequency of low and medium flows over the study period as compared to the 30-year record.

The flow duration graph can also be used to determine the percent time that a given discharge was equaled or exceeded. For example, the graph (figure 17) can be used to estimate the number of days that streamflow to the lake was sufficient to supply the city's water demand. The two-year average daily water use over the study period was 25.8 million gallons per day (40 cubic feet per second) for both municipal consumption and power plant use. Based on the flow record over the same time period, streamflow to the lake would have been sufficient to supply this amount 71 percent of the time or 259 days per year. The water storage of the lake was needed to supply the municipal consumption and power plant use on 106 days per year over the two-year study period. Based on the 30-year long-term record, streamflow to the lake would be expected to supply municipal

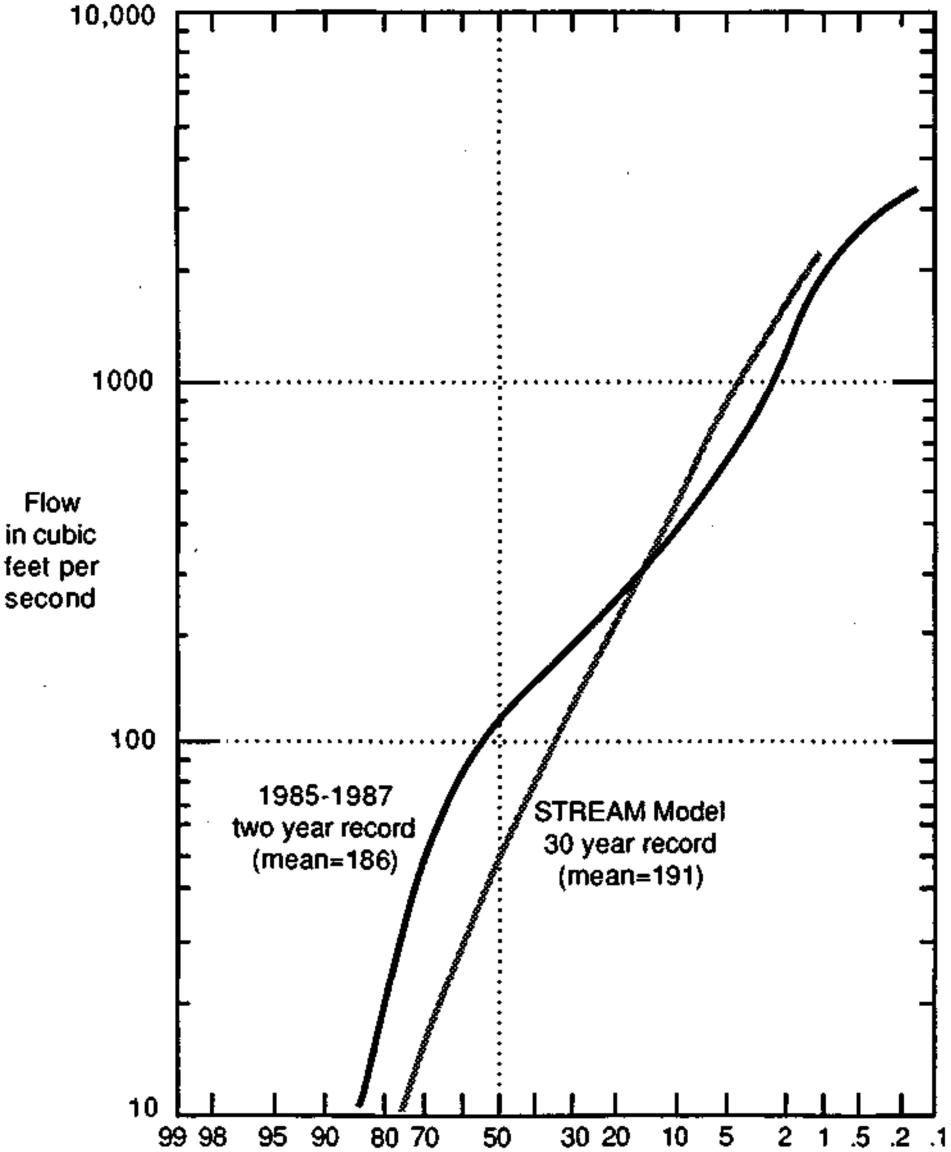

Figure 17. Flow duration at Lake Springfield

need 55 percent of the time or 201 days per year. This analysis of the number of days that streamflow would supply the city's needs was based on the average daily water use by the city and does not account for fluctuations in the daily use or the effects of evaporation. However, the flow duration analysis can be used to highlight the function of a reservoir in a water supply system: the reservoir serves to store water during abundant flow conditions to provide water during dry periods.

The difference between the long-term and two-year records for the recurrence rate of flows equal to or greater than 40 cfs is due to the greater frequency of moderate flows over the two-year study period when compared to the average. This observation also explains the higher median flows observed during the study period. In general the two-year study period had a greater occurrence of low and medium flows than the long-term record, and a less frequent occurrence of high flows. The average daily inflow rate (total inflow divided by the number of days) over the two-year study period was 196 cfs (120 million gallons), which is nearly equal to the 30-year long-term average inflow rate of 191 cfs (123 million gallons).

Long-Term Averages

To assess the relative significance of the results of the two years of monitoring, the available long-term records were examined. Precipitation records were obtained from the local climate data for Capital Airport (NOAA, 1983). The sedimentation investigation of Lake Springfield (Fitzpatrick et al., 1985) was used to determine Lake Springfield's average sediment inflow and deposition rates. The Streamflow Assessment Model (STREAM) was used to determine the mean yearly and peak daily flood flows to the lake (Knapp et al., 1985a, 1985b). Long-term data on the inflow and deposition rates of nutrients to the lake are not available.

The 40-year average yearly precipitation was 35.47 inches.

The sedimentation investigation of Lake Springfield determined that the average yearly sediment deposition in the lake from 1934 to 1984 was 130,000 tons per year. This investigation also determined a long-term average lake trap efficiency of 95 percent, which indicates that the long-term average yearly inflow of sediment to the lake was 137,000 tons.

The STREAM model is the product of a regional study which examined the long-term records of streamgaging data of the area, including records of streamflow from the Lick and Sugar Creek watersheds. The model was run for the Lake Springfield watershed; the output value for the mean yearly inflow to the lake was 44,123 million gallons per year, and the average yearly (2-year recurrence) peak daily flood flow to the lake was 2166 million gallons per day. The 2-year recurrence peak daily flood flow is the maximum daily flow to the lake over the course of the year that will be exceeded on the average in 50 percent of the years.

Precipitation during Year I was 4 percent below normal and runoff was 16 percent above the long-term average, as shown in table 10. Table 10 is a summary of the results of this two-year monitoring project and the long-term record on a yearly basis. The high runoff for Year I was due to the distribution of precipitation over the year. The high precipitation amounts of November 1985 (6.94 and 9.61 inches at Capital Airport and Virden respectively), which were two to three time the average for the month (2.39 inches), fell on saturated and frozen ground conditions, resulting in a relatively high runoff rate. The distribution of precipitation through the year also helped to reduce sediment transport, sediment deposition, and lake volume loss. Precipitation and the resulting runoff were concentrated in the summer and winter months. Winter is a period of reduced erosion potential because of frozen ground and temporary water storage as ice in the fields. In addition, no daily precipitation amount records were set and the stream system was able to drain the watershed without excessive flooding. The precipitation that occurred during the summer months generally was well distributed over time, and the established vegetative cover helped to reduce erosion and sediment transport.

The second year of monitoring was slightly dryer than the first with respect to precipitation, which was 96 percent of the long-term average. Runoff was much less than in the Year I period and amounted to only 84 percent of the long-term average. The gross evaporation rate for the Year II period was 4.48 inches higher than during the Year I period. In addition, the precipitation during Year II tended to be more evenly distributed with respect to time, especially during the summer months, when compared with precipitation in the Year I period, which would tend to increase the use of available moisture by growing plants in the watershed

Table 10. Comparison of Measured Values from the Two-year Study Period to the Long-Term Averages (Percentages of the long-term amounts in parentheses)

	Long term	Year I	Year II
Precipitation (inches)*	35.47	34.11 (96%)	34.01 (96%)
Runoff (million gallons)	44.12	51.14 (116%)	37.09 (84%)
Sediment transport (tons)	137,000	40,407 (29%)	20,899 (15%)
Sediment deposition (tons)	130,000	37,499 (29%)	19,529 (15%)
Lake volume loss (million gallons)	50	15.9 (32%)	8.3 (17%)
Gross lake evaporation (inches)	35.67	36.64 (103%)	41.12(115%)

*Average of Airport and Virden NWS stations compared to the long-term record at the airport and to reduce runoff. The relatively low runoff observed over the Year II period is one of the principal causes of the relatively low sediment transport and lake volume loss rates.

Sediment deposition in the lake and the resulting lake volume loss measured in each of the monitoring years were well below the long-term averages. The long-term average rate of sediment transport determined by the 1984 sedimentation investigation of the lake was based on measurements made at intervals ranging from 7 to 17 years over the 50-year period preceding 1984. Because the time intervals between measurements were relatively long, they were likely to include runoff events well in excess of the yearly average daily flood flow and, as a result, to include very high-magnitude sediment transport events that were much higher than those measured during this two-year study period.

Storm of November 18-21. 1985

One of the largest storm and runoff events of the two-year study period occurred on November 18-21, 1985. Over the 4-day period the precipitation totals at Capital Airport and Virden were 2.21 and 2.78 inches, respectively. The precipitation, runoff, and sediment loading that occurred on these dates at the Sugar Creek gage at Auburn are shown in figure 18. In this figure the event start time is 13:00 on November 18, 1985. The precipitation plot is cumulative starting from the event start time. The precipitation data were from the project raingage RG1 in Auburn.

Typical characteristics of runoff and loading can be seen in figure 18. In the plot of runoff it can be seen that the curve of flow over time changes faster (i.e., has a higher slope) on the rising portion of the curve than the falling portion. Sediment and nutrient loading respond in a similar manner, increasing quickly at the start and slowly falling towards the end of the event. The effects of the two precipitation events were cumulative in that the runoff of the first rainfall was still draining out of the watershed when the second rainfall occurred and the result was a maximum peakflow that was much higher in the second portion than the first portion of the event.

The responses of streamflow and loading to precipitation can be seen in this figure. On the afternoon of November 18 over 1 inch of rain produced a moderate runoff that peaked at 17 million gallons per hour on

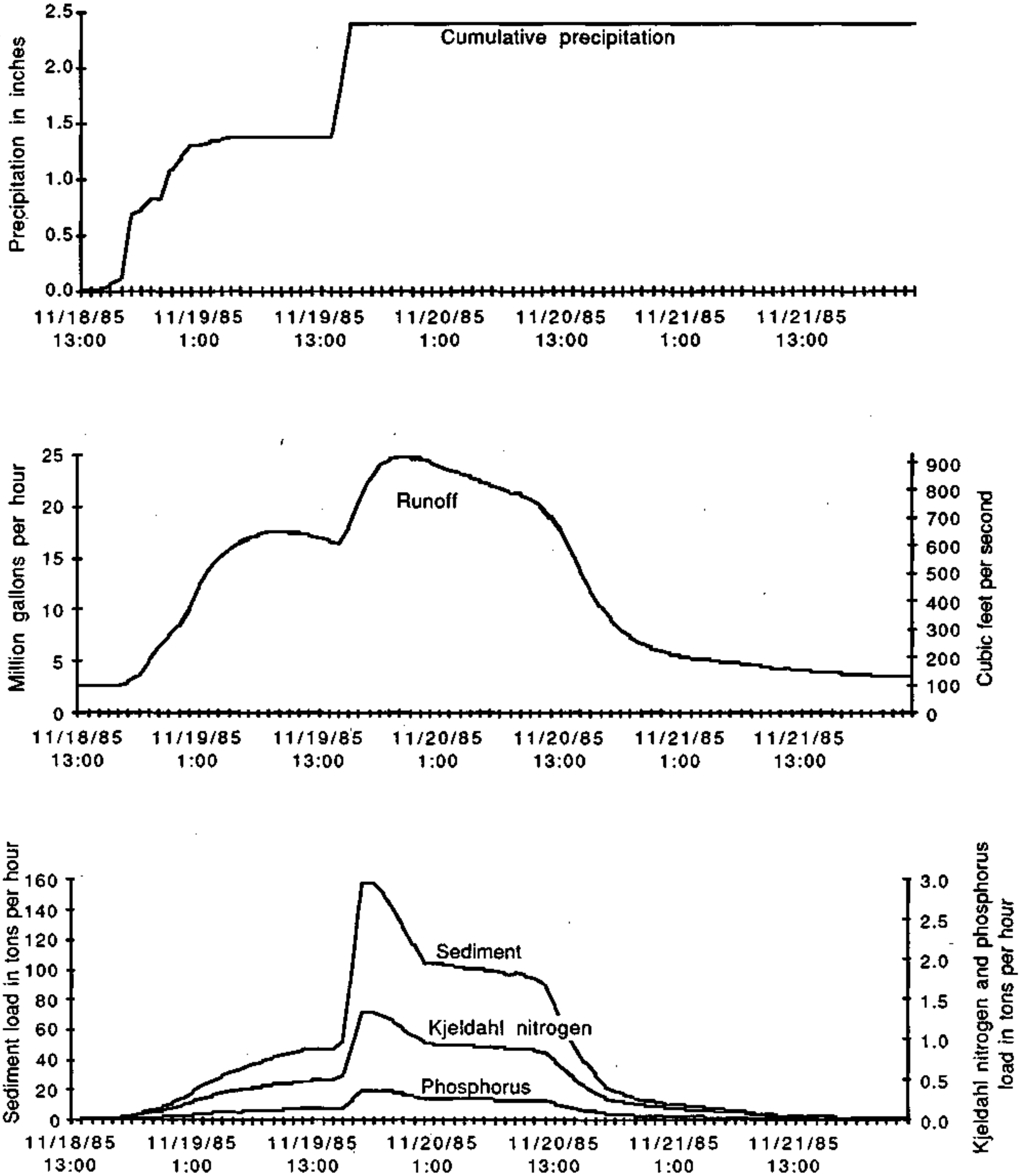

Figure 18. Precipitation, runoff, and loadings of sediment, Kjeldahl nitrogen, and phosphorus, Sugar Creek at Auburn, Illinois, November 18-21, 1985

the morning of November 19 and began to recede by the early afternoon. In the mid-afternoon of November 19 another storm occurred in the area, dropping over an inch of rain in two hours. Sugar Creek responded to the rainfall almost immediately due to saturated ground conditions, and a very sharp increase in runoff was recorded. The peak caused by this additional rainfall was 25 million gallons per hour. The increase in runoff corresponded to abrupt increases in sediment and nutrient loading. Runoff increased by 50 percent but the sediment load jumped by over 200 percent from 45 to 160 tons per hour. Similar increases were observed in the nitrogen and phosphorous loading.

The capacity of the stream to transport sediment and nutrients increases faster at higher flow conditions. The record of this storm shows that higher runoff events move a disproportionate quantity of sediment and nutrients when compared with moderate events. For example, Sugar Creek will transport many more pollutants during a single day of 25-million-gallons-per-hour flow than it would during five days of 5-million-gallons-per-hour flow. This relationship is very important in that the bulk of the yearly total loading to the lake can occur within a few major runoff events.

Variability of Sediment Transport Rates

This section presents the results of an analysis of the larger storm/runoff events with respect to sediment transport to the lake.

Highest Daily Sediment Transport Rate

Rainfall, runoff, and pollutant transport are not directly associated. A single large storm event can move great quantities of sediment and pollutants disproportionately to the total rainfall and runoff amounts. The highest daily sediment transport rate of the two-year study period occurred on April 14, 1987. On this date 4231 tons of sediment were delivered to the lake by a water inflow of 1448 million gallons. This runoff event was caused by a rainfall of 1.65 inches on April 13 and 0.52 inches on April 14, 1987. The sediment delivered to the lake on April 14, 1987 caused an estimated lake volume loss of 1.66 million gallons. In contrast to this single day the total sediment delivery to the lake for

Year II of the study period excluding April 1987 was 14,097 tons and the resulting volume loss was 5.5 million gallons.

In order to bring the magnitude of sediment transport that occurred on April 14, 1987 into perspective, a daily transport rate of 4231 tons is equivalent to dumping 2821 average-sized automobiles (3000 pounds each) into the lake in a single day. This is an average of 114 automobiles an hour or one every 31 seconds. The sediment delivery rate measured on April 14, 1987 is the equivalent of losing 69,000 gallons of lake storage every hour. These figures are presented to demonstrate the disproportionate contribution of a single storm, during which vast quantities of sediment and pollutants can be delivered to the lake in a short period of time.

Figure 19 presents plots of the precipitation at the Airport, water runoff to the lake, and sediment transport to the lake over the two-year study period. The larger storm events in the lake's watershed over the two-year study period were responsible for the bulk of sediment delivered to the lake, whereas the smaller storms that accounted for the bulk of water runoff tended to produce relatively low rates of sediment and pollutant transport. Watershed treatment and lake operations strategies which address these larger storm/runoff events would have the greatest impact in reducing sediment and pollutant transport to the lake and in reducing lake volume loss.

Sources of Sediment and Nutrients to Lake Springfield

This section summarizes the loading of sediment and nutrients to Lake Springfield on a total and per-area basis in order to examine the sources that contribute disproportionate quantities to the lake. For this analysis Lake Springfield's watershed is divided into six areas: Lick, Sugar, Panther, and Polecat Creeks, the direct unnamed tributaries of the lake, and diverted flow from the Horse Creek basin adjacent to the lake.

The per-area contributions of sediment to the lake by the various source areas over the two-year study period are shown in table 11 and figure 20. The largest source of sediment to the lake is Lick Creek. Lick Creek delivered nearly half of the total sediment to the lake from an area that represents 45 percent of the total watershed area (table 11). Sugar Creek was the largest contributor of sediment to the lake on the basis of tons per square mile. The two largest tributaries of the lake, Lick and

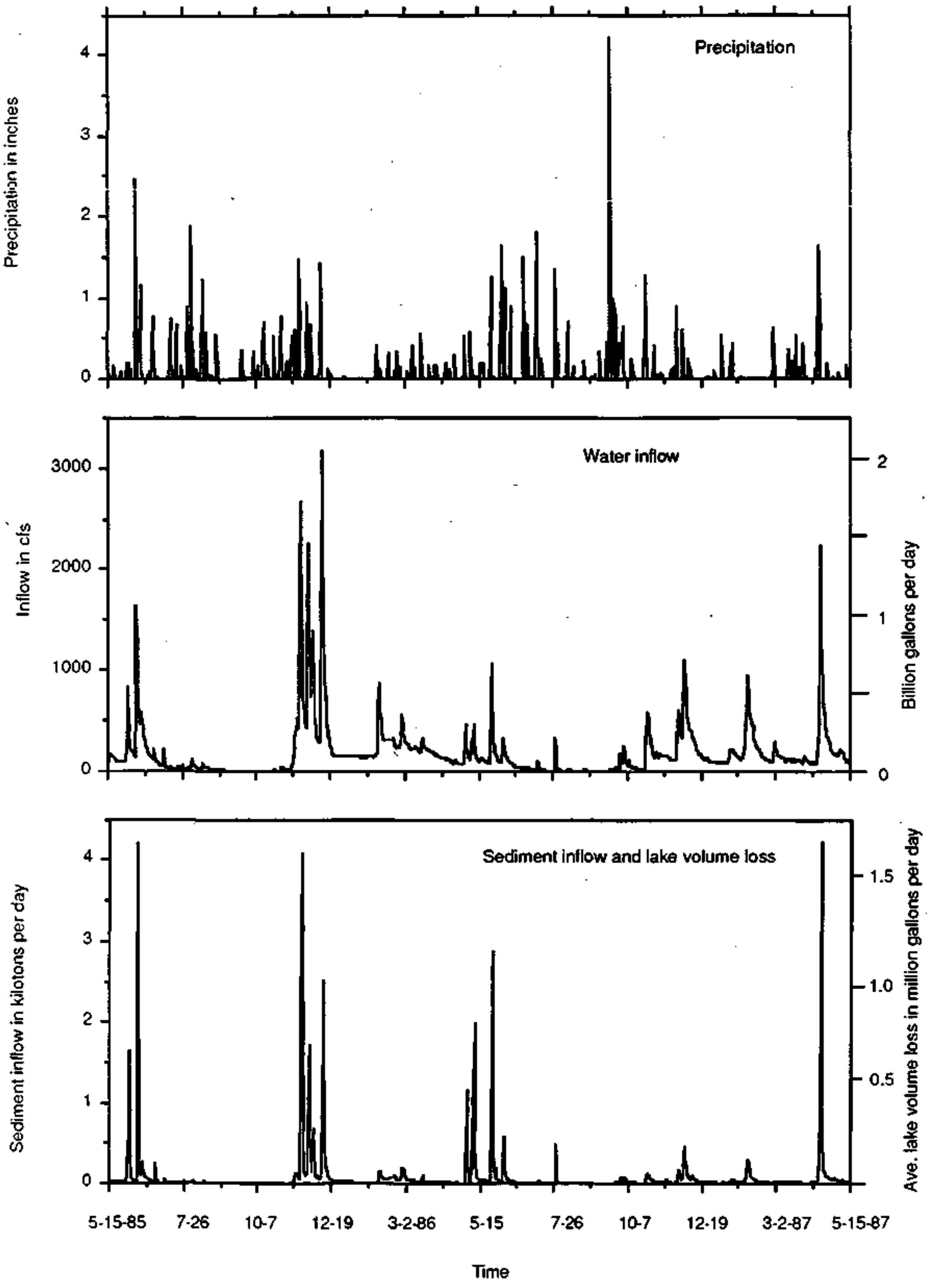

Figure 19. Precipitation at the NWS Airport station, water and sediment inflow, and volume loss in Lake Springfield, May 15, 1985 - May 14, 1987

Table 11. Sediment and Nutrient Delivery to Lake Springfield by Source Area, May 15, 1985 - May 14, 1987

	Lick Creek	Sugar Creek	Direct tributaries	Panther Creek	Polecat Creek	Horse Creek	Watershed total (average)
Drainage area							
square miles	119.4	63.8	40.8	24.1	9.8	---	258
Sediment							
Total kilotons	29844	20274	6307	3228	1250	403	61306
Tons per sq. mi.	250	318	155	134	128	---	238
Kjeldahl nitrogen							
Total kilotons	105.2	90.4	31.7	32.1	7.6	4.2	271.2
Tons per sq. mi.	0.88	1.42	0.78	1.33	0.78	---	1.05
Dissolved nitrate-N							
Total kilotons	689.6	673.3	1162.3	328.5	219.3	6.9	3079.9
Tons per sq. mi.	5.78	10.55	28.49	13.63	22.38	---	11.94
Dissolved phosphorus							
Total kilotons	14.5	9.6	1.9	2.6	0.2	0.8	29.6
Tons per sq. mi.	0.12	0.15	0.05	0.11	0.02	---	0.11
Ammonia nitrogen							
Total kilotons	21.0	12.2	6.3	6.7	1.3	0.8	48.3
Tons per sq. mi.	0.18	0.19	0.15	0.28	0.13	---	0.19
Phosphorus							
Total kilotons	43.0	18.6	7.5	8.5	0.0	1.8	79.4
Tons per sq. mi.	0.36	0.29	0.18	0.35	0.00	---	0.31

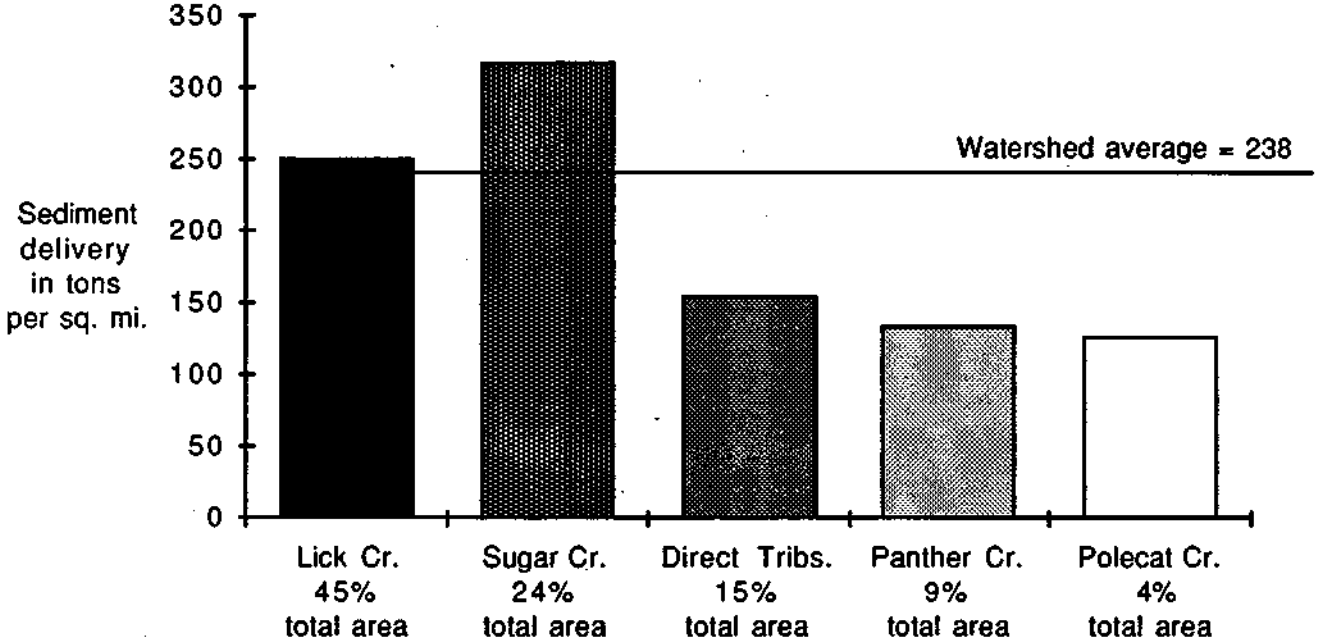

Figure 20. Sediment delivery to Lake Springfield by source area, May 15, 1985 - May 14, 1987

Sugar Creeks, delivered sediment at rates that were 5 and 34 percent higher, respectively, than the average rate for the watershed (figure 20). These rates indicate that a reduction in the per-area contribution of sediment from the drainage areas of Lick and Sugar Creeks would have the largest impact in reducing sedimentation and volume loss in the lake.

Lick and Sugar Creeks are also the largest contributors of Kjeldahl nitrogen to the lake (table 11). The areas of Sugar and Panther Creeks are the largest contributors on a unit-area basis. The amounts of Kjeldahl nitrogen delivered to the lake by Sugar and Panther Creeks were 1.42 and 1.33 tons per square mile, respectively, over the two-year study period and are well above the watershed average of 1.05 tons per square mile. The other source areas contributed at rates well below the watershed average rate.

The smaller drainage areas of the lake are the largest contributors of dissolved nitrate nitrogen. Panther and Polecat Creeks and the direct tributaries contributed nitrate to the lake at a rate in excess of the watershed average. The rates per square mile from Polecat Creek and the direct tributaries were approximately twice the watershed average. Together the areas of Panther and Polecat Creeks and the direct tributaries account for 56 percent of the dissolved nitrate inflow from an area which represents only 28 percent of the lake's watershed (table 11 and figure 21). Nitrate is the largest total nutrient delivered to the lake. The quantity of nitrate flowing into the lake is seven times higher than the total quantities of other nutrients monitored, which indicates that this parameter is a significant portion of the lake's nutrient load.

The two forms of phosphorus, total and dissolved, were seen to behave similarly in terms of largest total and highest per-area inflow rates. The principal sources of phosphorus to the lake are the areas of Lick and Sugar Creeks. Polecat Creek and the direct tributaries were the smallest contributors in terms of total amounts and rate per square mile.

The ammonia nitrogen contribution from the Panther Creek area was the highest rate per square mile of all source areas for this parameter. Other areas of the lake's watershed contributed larger total amounts, but these were less than or equal to the watershed average.

The nutrient and sediment delivery rates presented here are the measured values for this two-year monitoring period and may or may not

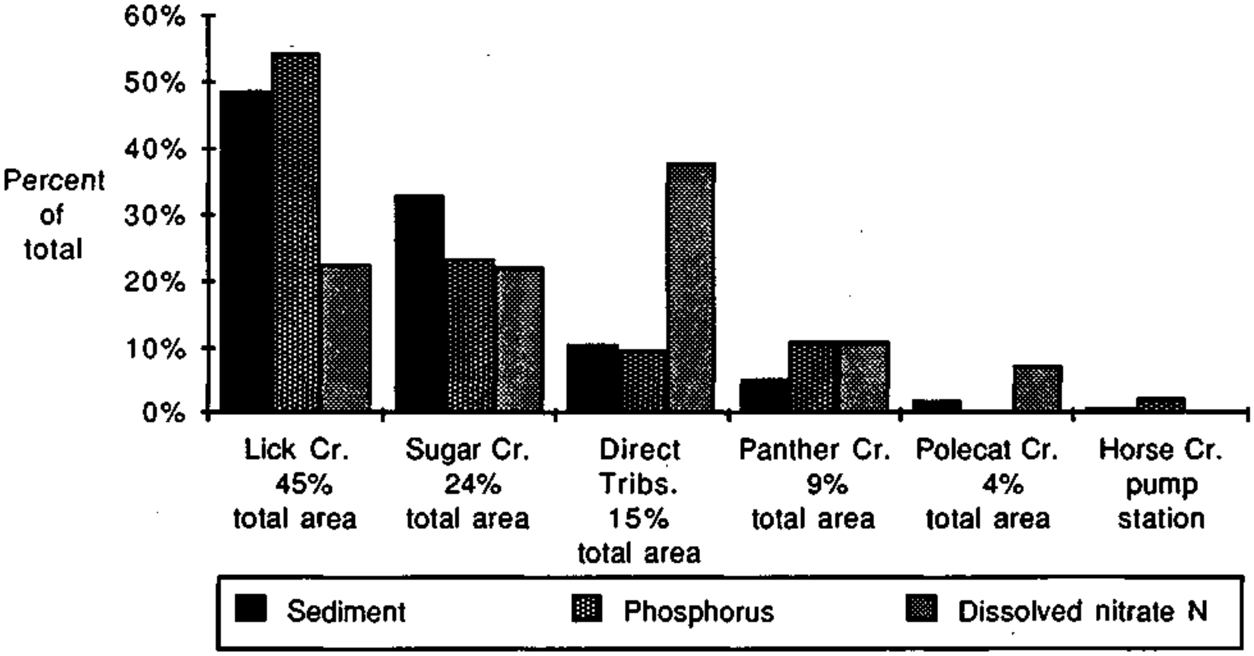

Figure 21. Percent of total sediment, phosphorus, and nitrate delivered to Lake Springfield by various source areas

reflect the long-term averages for these areas in terms of delivery per unit area. Many types of localized events including land disturbances due to construction activities, agricultural chemical mishandling or spill, or isolated localized storms could skew the relation of the findings of the monitoring to the long-term rates. However, the results are important in that they indicate trends of relative contribution of sediment and nutrients to the lake, and they should be valuable in determining the targeting of land treatment measures in the future.

Limiting Nutrients

The inflow of nutrients to the lake promotes nuisance algae blooms which can increase water treatment costs due to taste and odor problems and can also reduce the recreational and aesthetic value of the lake. The ratio of inorganic nitrogen to dissolved phosphorus is used to determine the limiting nutrient of the lake. A ratio of 15 of inorganic nitrogen to dissolved phosphorus is considered the value below which the lake is nitrogen limiting and above which the lake is phosphorus limiting. Based on the samples obtained over the study period, the limiting nutrient was nitrogen for 283 days or 41 percent of the time and phosphorus for 405 days or 59 percent of the time (figure 22). In figure 22 it can be seen that the ratio of inorganic nitrogen to dissolved phosphorus varies over the course of time. In general nitrogen is the limiting nutrient during summer and early autumn.

Control of Sediment and Pollutant Inflow to Lake Springfield

Erosion, transport, and deposition are natural processes that can be accelerated or reduced by human activities. Conceptually the costs of unchecked erosion are fairly apparent and include the loss of productive agricultural soils, reduced efficiency of stream channels to convey flood flow, destruction of aquatic habitat, diminished water resources, and many others. From the perspective of managing Lake Springfield for water supply storage, fishery and other aquatic habitats, recreational uses, and aesthetic benefit, the reduction of sediment and pollutant inflow to the lake and the reduction of deposition in the lake are of great importance. Four general techniques of managing sediment and pollutant transport and deposition are 1) control at the source by watershed land treatment; 2)

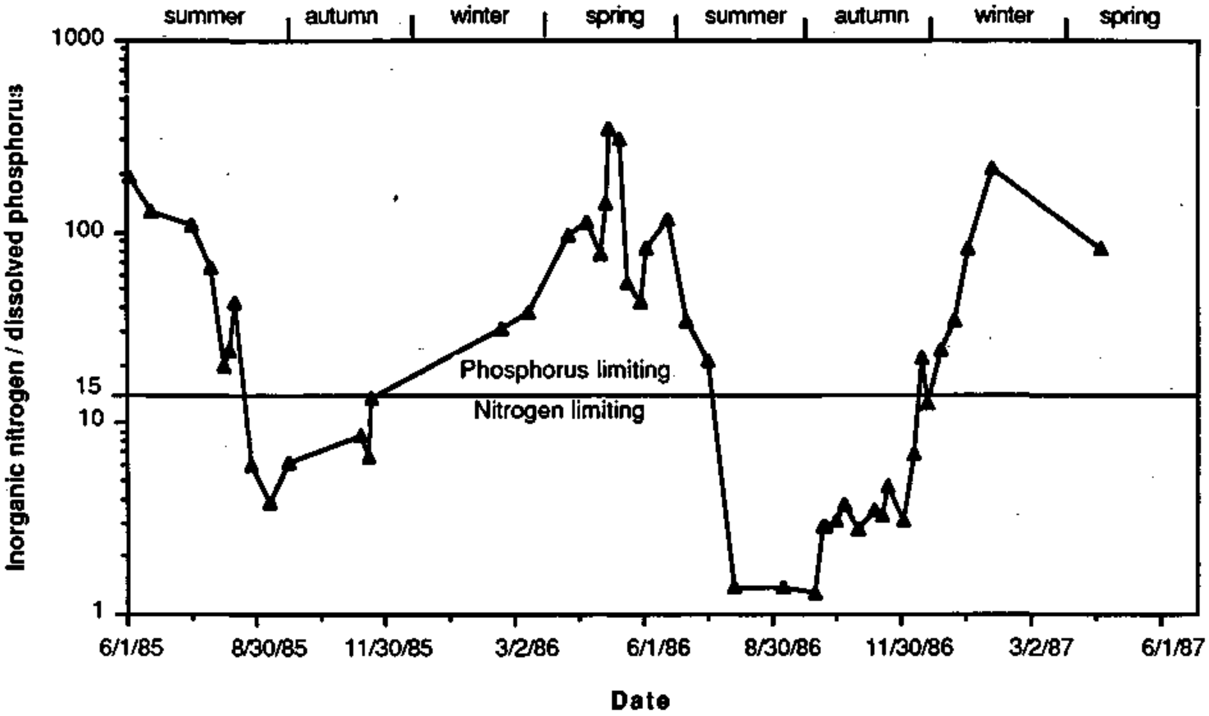

Figure 22. Limiting nutrients in Lake Springfield as measured by the ratio of inorganic nitrogen to dissolved phosphorus (All samples are from the lake surface near the dam)

control prior to delivery to the lake by retention structures; 3) control in the lake by desiccation, isolation, and/or dredging; and 4) diversion of sediment and pollutant flow around the lake. The section below briefly presents and discusses some of these techniques to highlight some possible options. The selection of future courses of action that the city may follow will require much more detailed examinations of costs and benefits that are beyond the scope of this report.

Sediment and Pollutant Control at Source

Watershed Land Treatment. This technique of sediment/pollutant management can have the added benefits of increasing agricultural productivity as well as reducing off-site damage to stream channels and riparian habitat. We recommend that the city continue to cooperate and assist the efforts of various agencies concerned with erosion control from agricultural areas. Each effort should be examined for the potential benefit to the lake and reviewed in light of the actual expected reduction in sediment and pollutant loading to the lake. Areas of the watershed closest to the lake will tend to have greater efficiency in delivering eroded materials to the lake than distant areas. Also watershed areas directly adjacent to major water sources such as bottomland pastures will tend to deliver higher percentages of eroded materials than upland areas. Various areas of the watershed have been identified in this report as disproportionately higher contributors of sediment and pollutants as compared to other areas. On the average, erosion in these areas should be addressed to achieve the greatest reduction on the basis of acreage treated.

Construction activities adjacent to the lake should be watched for excessive soil disturbance, exposed bare soil left for extended periods, soil stockpiles, and denuded high slope areas around the lakeshore. Eroded materials from these areas will tend to have delivery ratios to the lake of up to 100 percent and will aggravate problems related to shallowness, aquatic plant control, turbidity, and volume loss in the more heavily used and important areas of the lake. The lakeshore areas tend to have large areas of mowed lawns, which can contribute quantities of nutrients from wash-off of fertilizers and lawn clippings and can also contribute quantities of pesticides and herbicides directly into the city's raw water supply. Public education as to the detrimental effects of improper landscape practices on land around the lake would be a good step in reducing pollutant loading from these areas. Recent efforts towards reduced mowing on city-owned properties and prairie restoration activities on vacant properties have benefits in terms of both wildlife habitat and reduced loadings of sediment and other pollutants to the lake.

Stream Channel Stabilization. Materials eroding from streambanks tend to have very high delivery ratios, which result in a high percentage of the eroding materials being delivered to the lake. A one-mile stretch of stream with an eroding bank three feet high, eroded back three feet, can deliver enough sediment to the lake to reduce the lake's storage capacity by one million gallons. General observation of various stream channels in the watershed (a small sampling of the total of over one hundred miles of channels) indicates that most of the channels are stable and in good condition. A field reconnaissance of the stream channels, especially those near the lake and in areas on high slopes, could identify problem areas and allow targeting of preventive measures to reduce their contribution to the lake.

Lakeshore Stabilization. Lakeshore erosion can eat away valuable land around the lake and will aggravate problems related to shallowness, aquatic plant control, turbidity, and volume loss in the more heavily used areas of the lake. In addition, the reworking of eroded lakeshore materials by waves and currents will tend to cause the material to occupy a greater volume in the lake then in place on the shore. Eroded lakeshore materials can increase in volume by two times once in the lake and can be a significant factor in lake volume loss. The city's riprap program, which has continued since the lake's construction, has been effective in lakeshore erosion control and the program should be continued.

Sediment and Pollutant Control Instream

The primary technique of instream control of the transport of sediment and pollutants is to allow the streamflow to pass through an area where sediment and pollutants are allowed to settle out from the streamflow. What this technique requires is an area of sufficient volume and cross-sectional flow area that streamflow velocities are greatly reduced. Lakes and wetlands provide this function naturally. The sedimentation surveys of the lake and the results of this project have demonstrated that Lake Springfield is an efficient trap for sediment and pollutants. Lake Springfield has an average long-term trap efficiency of 95 percent, which is a measure of the quantity of sediment trapped by the lake compared to the quantity of sediment delivered. If the streamflow that now enters the lake were first passed through a lake of the same size as Lake Springfield, the amount of sediment delivered to Lake Springfield would be reduced by 95 percent. The upper portions of Lake Springfield (the Lick and Sugar Creek arms of the lake) have trapped approximately 50 percent of the sediment delivered to the lake (Fitzpatrick et al., 1985); therefore, if the volume of the upper portion of the lake is maintained by dredging, this area should continue to serve as an efficient sediment trap and help to preserve the storage volume of the deeper downstream areas.

Sedimentation basins could be constructed in the stream channels above the lake to trap inflowing sediment and pollutants. The upper portion of the lake (areas upstream of the I-55 bridge) originally contained a volume of 2.5 billion gallons (7800 acre-feet), which indicates that if retention structures totaling this storage volume were constructed upstream of the lake, they could trap about half of the inflowing sediment. These figures are presented to give a quick overview of the sizing and function of sediment retention structures and do not take into consideration important factors related to operation and design that could greatly affect the efficiency and cost of these structures.

In-Lake Control of Sediment and Pollutant Accumulation

Dredging is the principal technique of removing large quantities of sediment from a lake. The city's current dredging program will remove 2.7 million cubic yards (500 million gallons) of sediment from the lakebed. In addition to increasing the volume of the lake, dredging will restore the lost depth in the upper portions of the lake and enhance the fishery and recreational and aesthetic uses of these areas. The removal of sediment from the upper portion of the lake will also restore the sediment trapping ability of these areas and help to prolong the uses of the deeper downstream areas.

Lost lake volume caused by sediment accumulation can be controlled by desiccation or drying of the material to increase its density and reduce the volume that the sediment occupies within the lake. The compaction of sediment by drying has limits in application in that the material can be compacted only up to a certain limit (dependent on particle size distribution and organic content), and the drying process requires that the lake pool level be drawn down for prolonged periods. Intentional drawdown of the pool for sediment compaction may be an inadvisable option in the management of a water supply lake.

Pollutant isolation by capping of the sediments has been used in cases where pollutants contained in the sediment were released in sufficient quantities to severely impact the quality of the overlying waters. This phenomenon has not been observed in Lake Springfield. The capping of the bottom sediment by placing a clay layer on top of the lakebed would cause a significant loss in total water storage of the lake.

Diversion of Streamflow

To reduce the inflow of sediment and pollutants to the lake, excess water inflow not necessary to replenish the water storage of the lake could be diverted to streams in adjacent watersheds. During times when the lake level is at spillway elevation, inflow to the lake is compensated by water overflow at the spillway. Therefore during flood periods the lake will capture significant quantities of sediment and pollutants carried by inflow that is not necessary to replenish the lake's water supply storage. Diversion of streamflow would require construction of diversion channels through an adjacent drainage divide, enlargement of existing channels that would convey new levels of flood flows, and construction of control structures to direct flow to either the lake or the diversion channel. An advantage of this option is that it would provide lake managers great flexibility in controlling the large quantities of sediment and pollutants carried into the lake during major floods.

SUMMARY

This report presents the results of a two-year field monitoring project to assess the hydrologic, sediment, and nutrient budgets of the watershed of Lake Springfield. This report is a summary of the results and findings of the monitoring period May 15, 1985 through May 14, 1987.

This project was undertaken in order to measure and quantify the hydrologic and transport processes that affect the use of Lake Springfield. The information gathered as part of this investigation will provide data that will be valuable for resource management and will provide for more informed and cost-effective management decisions on matters such as lake rehabilitation, water quality control, and land treatment to reduce the degradation of the lake's water resources.

Lake Springfield's watershed encompasses a total of 265 square miles. Land use is primarily agricultural row crops owing to the fertile soil formed on 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 averaged approximately 35 inches; however, annual extremes have deviated from the average by over 35 percent (±12 inches).

Lake Springfield has lost over three billion gallons of water storage (13 percent of the original volume) over the period 1934 to 1984 due to sediment and pollutant transport to the lake. On the average the lake has lost 50 million gallons of storage per year due to the deposition of 130,000 tons of sediment a year. The upstream areas of the lake have experienced higher volume loss rates and use impairment than the downstream portions of the lake.

The long-term average watershed gross erosion and sediment delivery rates are 3.96 and 0.79 tons per acre per year respectively. The long-term average watershed sediment delivery ratio (sediment delivery divided by gross erosion) is 20 percent.

Over the course of the study period (May 15, 1985 through May 14, 1987) precipitation was 96 percent of normal. The Year I period (May 15, 1985 through May 14, 1986) precipitation (34.11 inches) was 96 percent of normal (35.47 inches), with unusually large amounts of precipitation occurring in November and December 1985 that contributed to the above-average runoff, which was 16 percent above normal for the year. The Year

II period (May 15, 1986 through May 14, 1987) precipitation (34.01 inches) was 96 percent of normal with one-half of the rain occurring during the period June through September 1986. Most of the rainfall during the Year II period occurred during the peak of the crop growing season and peak evaporation periods, resulting in low runoff rates to the lake. Stream flow during Year II was 16 percent below normal.

Sediment transport to the lake during the two-year study period was below the fifty-year average rate. The transport rates were 40,407 and 20,899 tons for the Year I and Year II periods, respectively, which were 29 and 15 percent of the fifty-year average rate, respectively. These low sediment transport rates were due principally to the lack of major flood events and the relatively low amounts of precipitation. The highest daily flood measured over the two-year period corresponded to the expected average annual (two-year recurrence) flood. Daily precipitation amounts were also well distributed; only one daily amount (4.23 inches on September 20, 1986) exceeded the 10-year one day amount, and it occurred after a period of very dry conditions in the watershed and resulted in a relatively low runoff and sediment transport rate.

The lake volume loss over the Year I period was 15.9 million gallons, a loss rate of 0.09 percent per year. This rate was 32 percent of the long-term average. Volume loss for the Year II period was 8.3 million gallons or 17 percent of the fifty-year average. Volume loss is directly associated with the quantity of sediment deposited, and the low volume loss rates of the two-year study period were due to the same factors that produced the low sediment inflow and deposition rates.

Most of the phosphorus samples obtained at the lake spillway exceeded the Illinois Pollution Control Board (IPCB) general use standard. Forty-seven out of forty-eight phosphorus samples exceeded the Illinois Pollution Control Board (IPCB) general use standard of 0.05 mg/l standard. The concentrations of nitrate were all within the IPCB standard for water supplies of 10 mg/l. Ammonia nitrogen concentration samples were all below the IPCB limit of 15 mg/l.

The limiting nutrient in the lake over the two-year study period was usually phosphorus, due to the relatively large quantities of nitrogen delivered to the lake from the watershed. The lake was seen to be phosphorus limiting on 405 days (59 percent of the time) and nitrogen limiting on 283 days (41 percent of the time) over a 688-day period for which data was available.

The median water inflow rate (middle value of all observations) to the lake over the two-year study period was approximately 78 million gallons per day. The average water inflow rate (total sum of inflow divided by number of observations) was 120 million gallons per day. The median sediment inflow rate was approximately 15 tons per day. The average rate was 84 tons per day. Comparing the average to the median rate, it can be seen that the averages are much above the median, indicating a significant effect on the daily average of events or days with very high sediment and water inflow rates. This is expected and is a result of the relatively large number of low-flow days compared to high-flow days (i.e., low-flow periods account for the majority of days, but the sum of the flows occurring in low-flow periods is less than that occurring during high flows).

High-flow events contribute significant quantities of sediment and nutrients to the lake. A rainfall and runoff event on April 14, 1987 caused nearly 20 percent of the measured sediment inflow and volume loss for the Year II period. Watershed land treatment and lake management strategies which address the larger storm/runoff events would have the most significant impact in reducing sediment and pollutant inflow to the lake, as well as the use impairment caused by sediment and pollutant accumulation in the lake.

On the basis of the data obtained over the two-year study period, the most significant sources of sediment to the lake in terms of total amounts and tons per square mile are the two largest tributaries of the lake: Sugar and Lick Creeks. These two areas, which represent 69 percent of the watershed area, accounted for 82 percent of the total sediment inflow. Lick Creek's contribution of sediment to the lake on a per-area basis is 5 percent above the watershed average. Sugar Creek's contribution of sediment to the lake is 34 percent higher than the watershed average. A reduction in the per-area input of sediment from the Sugar Creek area would have the greatest impact on reducing sedimentation and volume loss in the lake.

The principal sources of phosphorus in terms of total input to the lake are the Sugar and Lick Creek basins. The highest contributors on a per-area basis were Lick and Panther Creeks, indicating that a reduction in the per-area contribution of these sources would produce the greatest impact in reducing the inflow of this nutrient to the lake.

Dissolved nitrate nitrogen is the single largest category of nutrients measured over this two-year study. The quantity of nitrate nitrogen flowing into the lake is seven times higher than the sum of all other forms of nutrients measured. The single largest source of nitrate to the lake is the unnamed direct tributaries of the lake, which accounted for 38 percent of the total inflow. The direct tributaries of the lake were also the largest contributors of nitrate on a per-area basis. Measures to control this pollutant in the watershed would have the greatest impact if applied to the small unnamed direct tributaries of the lake.

The data gathered as part of this project will be valuable in tracking future events related to sedimentation, volume loss, and nutrient inflow to the lake. The analytical techniques used for this project will be applicable in assessing water, sediment, and nutrient budgets in future years. We recommend that the city continue to operate the gage network established for this project and use the data presented as part of this analysis to follow the effect on the lake of future storm and runoff events, especially the larger floods. The established gage network can provide accurate data on the quantity of water flowing into the lake, and the relationships of water discharge to sediment and nutrient loads can be used to estimate the inflows of these parameters. The relationships observed between water discharge and sediment and nutrient loads are based on the observations of only two years of data and therefore will produce some uncertainty in predicting future events, especially if substantial changes occur in watershed land treatment, land use, and land management. Future analyses of volume loss in the lake, dredging needs, and pollution control will benefit from continued operation of the gage network and the water flow data provided by the gaging stations.

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APPENDIX. WATER, SEDIMENT, AND NUTRIENT BUDGETS

WATER BUDGET OF LAKE SPRINGFIELD
May 14, 1985 - May 15, 1987
(in million gallons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Outflow Spillway Discharge	Outflow dam and gate leakage	Outflow municipal usage	Outflow power plant usage	Outflow evapor- ation	Outflow change in lake storage
1985	May*	318	451	294	171	75	0	696	12	403	85		
	Jun	2303	2101	1352	795	333	0	5206	21	6S3	15C		
	Jul	116	338	226	128	62	0	331	22	767	155		
	Aug	70	279	188	106	53	0	0	22	715	155		
	Sep	10	17	20	6	12	106	0	21	706	150		
	Oct	0	11	17	4	12	164	0	22	641	155		
	Nov	4903	3079	1977	1165	484	203	8882	21	592	150		
	Dec	4700	2932	1883	1109	462	0	9890	22	623	155		
1986	Jan	794	983	638	372	161	0	1226	22	604	155		
	Feb	2557	1714	1104	648	273	0	4865	20	546	140		
	Mar	1880	1292	835	489	209	0	3991	22	590	155		
	Apr	696	693	452	262	116	0	0	21	625	150		
	May	2643	774	505	293	129	0	3583	22	588	155		
	Jun	873	405	268	153	72	0	2318	21	746	150		
	Jul	472	99	73	38	25	0	0	22	749	155		
	Aug	145	9	16	3	11	0	0	22	696	155		
	Sep	146	73	56	27	21	244	0	21	673	150		
	Oct	1554	581	381	220	99	0	0	22	678	155		
	Nov	1937	920	597	348	151	0	2794	21	530	150		
	Dec	3248	1320	854	500	213	0	5203	22	556	155		
1987	Jan	1049	728	475	276	122	0	2414	22	557	155		
	Feb	2384	1284	829	486	207	0	4253	20	500	140		
	Mar	1129	663	434	251	112	0	1505	22	543	155		
	Apr	3359	1550	1000	586	248	0	6264	21	567	150		
	May*	518	383	249	145	64	0	864	10	322	70		
Totals:		37804	22679	14723	8581	3726	717	64285	516	15200	3650	4210	-190
Year I:		19503	14247	9219	5390	2311	473	35944	258	7816	1825	1851	24
Year II:		18301	8432	5504	3191	1415	244	28341	258	7384	1825	2378	-214

Inflow total:	88230
Outflow total:	87690
Difference:	540
% difference:	0.61%

	Inflow Totals		Outflow Totals	Yearly error:
Year I:	51143	Year I:	47718	6.70%
Year II:	37087	Year II:	39972	-7.78%

*partial month

SEDIMENT BUDGET, LAKE SPRINGFIELD
May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow other than spillway leakage	Outflow monthly total
1985	May*	103	119	36	42	8	0	308	17	12	29
	Jun	2160	5342	655	302	129	0	8588	181	21	202
	Jul	54	55	34	31	7	0	181	15	39	54
	Aug	41	70	14	22	3	0	150	0	37	37
	Sep	4	1	0	1	0	37	43	0	48	48
	Oct	0	2	0	1	0	47	50	0	37	37
	Nov	4038	5476	1577	537	307	233	12168	649	51	700
	Dec	3000	1198	1472	490	287	0	6447	1020	87	1107
1986	Jan	49	75	93	100	19	0	336	62	29	91
	Feb	906	351	285	210	57	0	1809	265	44	309
	Mar	506	167	150	141	31	0	995	166	26	192
	Apr	144	85	55	66	12	0	362	0	46	46
	May	8296	660	67	75	14	0	9112	167	46	213
	Jun	1108	156	27	35	6	0	1332	80	26	106
	Jul	582	134	7	8	2	0	733	0	26	26
	Aug	51	2	0	0	0	0	53	0	24	24
	Sep	73	60	8	7	2	86	236	0	39	39
	Oct	540	204	66	61	14	0	885	0	52	52
	Nov	631	140	109	98	22	0	1000	58	15	73
	Dec	1135	382	230	160	46	0	1953	144	23	167
1987	Jan	382	64	62	70	13	0	591	66	21	87
	Feb	673	275	218	156	44	0	1366	156	29	185
	Mar	239	105	50	62	11	0	467	46	27	73
	Apr	2189	3195	484	221	95	0	6184	305	37	342
	May*	227	113	35	38	7	0	420	27	12	39
Year I:											
Bedload:		1593	1327	440	198	87	N.A.	3645	N.A.	N.A.	N.A.
Susp. load:		15930	13269	4402	1978	866	317	36762	2416	492	2908
Total load:		17523	14596	4842	2176	953	317	40407	2416	492	2908
Year II:											
Bedload:		1120	516	133	96	27	N.A.	1892	N.A.	N.A.	N.A.
Susp. load:		11201	5162	1332	956	270	86	19007	1008	362	1370
Total load:		12321	5678	1465	1052	297	86	20899	1008	362	1370
TOTAL LOAD:		29844	20274	6307	3227	1250	403	61306	3424	854	4278

Total to lake = 61306
Total from lake = 4278
Net sediment deposited = 57028

Trap efficiency = 93.0%

Note: N.A. = not applicable.
TOTAL LOAD = Two year total.

PHOSPHORUS BUDGET, LAKE SPRINGFIELD
May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow Power & Water Plants Dam/Gate Leakage	Outflow Monthly Total
1985	May*	0.2	0.2	0.1	0.1	0.0	0.0	0.6	0.2	0.2	0.4
	Jun	3.1	3.6	0.6	0.8	0.0	0.0	8.1	1.5	0.3	1.8
	Jul	0.1	0.2	0.1	0.1	0.0	0.0	0.5	0.1	0.3	0.4
	Aug	0.1	0.2	0.1	0.0	0.0	0.0	0.4	0.0	0.5	0.5
	Sep	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.5	0.5
	Oct	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.5	0.5
	Nov	5.6	4.0	1.0	1.6	0.0	0.8	13.0	4.1	0.5	4.6
	Dec	4.1	1.5	0.9	1.5	0.0	0.0	8.0	4.5	0.5	5.0
1986	Jan	0.1	0.2	0.3	0.2	0.0	0.0	0.8	0.8	0.7	1.5
	Feb	1.4	0.6	0.5	0.5	0.0	0.0	3.0	4.0	0.6	4.6
	Mar	0.9	0.4	0.4	0.3	0.0	0.0	2.0	2.7	0.5	3.2
	Apr	0.3	0.3	0.2	0.2	0.0	0.0	1.0	0.0	0.3	0.3
	May	10.6	1.2	0.2	0.2	0.0	0.0	12.2	1.2	0.3	1.5
	Jun	1.7	0.4	0.1	0.1	0.0	0.0	2.3	0.6	0.2	0.8
	Jul	0.9	0.2	0.0	0.0	0.0	0.0	1.1	0.0	0.3	0.3
	Aug	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.7	0.7
	Sep	0.1	0.1	0.0	0.0	0.0	0.4	0.6	0.0	0.8	0.8
	Oct	0.9	0.4	0.2	0.2	0.0	0.0	1.7	0.0	0.6	0.6
	Nov	1.1	0.3	0.3	0.2	0.0	0.0	1.9	1.7	0.4	2.1
	Dec	1.8	0.6	0.4	0.4	0.0	0.0	3.2	2.7	0.3	3.0
1987	Jan	0.7	0.2	0.2	0.2	0.0	0.0	1.3	0.7	0.2	0.9
	Feb	1.1	0.5	0.4	0.4	0.0	0.0	2.4	1.1	0.2	1.3
	Mar	0.5	0.3	0.2	0.1	0.0	0.0	1.1	0.6	0.2	0.8
	Apr	3.2	1.3	0.5	0.6	0.0	0.0	5.6	2.3	0.3	2.6
	May*	0.5	0.2	0.1	0.1	0.0	0.0	0.9	0.3	0.2	0.5
Year I:											
Bedload:		2.2	1.2	0.4	0.5	0.0	N.A.	4.4	N.A.	N.A.	N.A.
Susp. Load:		22.3	11.8	4.3	5.4	0.0	1.4	45.2	18.2	5.5	23.7
Total Load:		24.5	13.0	4.7	5.9	0.0	1.4	49.6	18.2	5.5	23.7
Year II:											
Bedload:		1.7	0.5	0.3	0.2	0.0	N.A.	2.7	N.A.	N.A.	N.A.
Susp. Load:		16.8	5.1	2.5	2.4	0.0	0.4	27.2	10.9	4.6	15.5
Total Load:		18.5	5.6	2.8	2.6	0.0	0.4	29.9	10.9	4.6	15.5
TOTAL LOAD:		43.0	18.6	7.5	8.6	0.0	1.8	79.5	29.1	10.1	39.2

Total to lake = 79.5
Total from lake = 39.2
Net deposited = 40.3

Trap efficiency = 50.7%

Note: N.A. = not applicable.
TOTAL LOAD = Two year total.

DISSOLVED PHOSPHORUS, LAKE SPRINGFIELD
May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow power & water plants dam/gate leakage	Outflow Monthly Total
1985	May*	0.1	0.2	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2
	Jun	0.9	0.9	0.2	0.3	0.0	0.0	2.3	0.6	0.1	0.7
	Jul	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
	Aug	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.2
	Sep	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.3
	Oct	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.2	0.2
	Nov	2.0	1.4	0.2	0.5	0.1	0.3	4.5	1.5	0.2	1.7
	Dec	2.0	1.3	0.2	0.5	0.1	0.0	4.1	1.6	0.2	1.8
1986	Jan	0.3	0.4	0.1	0.1	0.0	0.0	0.9	0.6	0.5	1.1
	Feb	1.0	0.7	0.2	0.2	0.0	0.0	2.1	3.2	0.5	3.7
	Mar	0.7	0.5	0.1	0.1	0.0	0.0	1.4	2.0	0.4	2.4
	Apr	0.2	0.3	0.1	0.1	0.0	0.0	0.7	0.0	0.1	0.1
	May	1.0	0.3	0.1	0.1	0.0	0.0	1.5	0.5	0.1	0.6
	Jun	0.3	0.2	0.0	0.0	0.0	0.0	0.5	0.2	0.1	0.3
	Jul	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.1
	Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4
	Sep	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.5	0.5
	Oct	0.6	0.2	0.1	0.1	0.0	0.0	1.0	0.0	0.4	0.4
	Nov	0.7	0.4	0.1	0.1	0.0	0.0	1.3	1.3	0.3	1.6
	Dec	1.3	0.6	0.1	0.1	0.0	0.0	2.1	2.0	0.2	2.2
1987	Jan	0.4	0.3	0.1	0.1	0.0	0.0	0.9	0.2	0.1	0.3
	Feb	0.9	0.5	0.1	0.1	0.0	0.0	1.6	0.2	0.0	0.2
	Mar	0.4	0.3	0.1	0.0	0.0	0.0	0.8	0.2	0.1	0.3
	Apr	1.3	0.7	0.1	0.2	0.0	0.0	2.3	0.8	0.1	0.9
	May	0.2	0.2	0.0	0.0	0.0	0.0	0.4	0.1	0.1	0.2
Total:		14.5	9.6	1.9	2.6	0.2	0.8	29.6	15.1	5.4	20.5
Year I:		7.6	6.0	1.2	1.9	0.2	0.6	17.5	9.6	2.9	12.5
Year II:		6.9	3.6	0.7	0.7	0.0	0.2	12.1	5.5	2.5	8.0

Total to lake =	29.6
Total from lake =	20.5
Net deposited =	9.1
Trap efficiency =	30.7%

NITRATE BUDGET, LAKE SPRINGFIELD

May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow Power & Water Plants, Dam/Gate Leakage	Outflow Monthly Total
1985	May*	3.5	7.8	5.3	5.1	1.1	0.0	22.8	13.4	9.9	23.3
	Jun	45.4	72.7	133.5	33.0	25.0	0.0	309.6	60.6	11.5	72.1
	Jul	0.6	5.8	5.8	3.8	1.2	0.0	17.2	3.7	7.4	11.1
	Aug	0.3	3.6	1.9	2.8	0.4	0.0	9.0	0.0	2.8	2.8
	Sep	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	1.2	1.2
	Oct	0.0	0.1	0.0	0.1	0.0	0.4	0.6	0.0	1.0	1.0
	Nov	120.3	143.1	346.8	55.9	64.5	1.2	731.8	31.3	0.8	32.1
	Dec	114.0	129.6	332.9	51.4	61.9	0.0	689.8	127.8	12.7	140.5
1986	Jan	7.5	18.9	13.9	12.0	2.8	0.0	55.1	25.8	16.6	42.4
	Feb	42.1	44.8	48.2	24.1	9.3	0.0	168.5	113.8	16.8	130.6
	Mar	24.9	27.9	23.3	16.6	4.6	0.0	97.3	82.7	16.2	98.9
	Apr	6.5	12.0	7.9	8.0	1.6	0.0	36.0	0.0	12.9	12.9
	May	54.3	14.0	9.9	9.2	2.0	0.0	89.4	37.0	9.0	46.0
	Jun	10.5	6.2	3.8	4.4	0.8	0.0	25.7	15.6	5.8	21.4
	Jul	6.3	1.4	1.0	1.0	0.2	0.0	9.9	0.0	1.5	1.5
	Aug	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.1	0.1
	Sep	0.9	1.4	1.3	0.9	0.3	5.3	10.1	0.0	0.3	0.3
	Oct	24.9	12.1	10.5	7.3	2.1	0.0	56.9	0.0	1.1	1.1
	Nov	28.0	19.6	17.6	11.7	3.5	0.0	80.4	3.9	1.0	4.9
	Dec	59.7	34.3	40.2	18.3	7.7	0.0	160.2	11.7	2.1	13.8
1987	Jan	11.4	13.1	9.1	8.6	1.9	0.0	44.1	14.3	4.0	18.3
	Feb	39.8	33.3	37.7	17.9	7.2	0.0	135.9	35.5	5.5	41.0
	Mar	12.5	11.2	7.2	7.6	1.5	0.0	40.0	14.2	6.4	20.6
	Apr	69.8	53.1	99.2	24.1	18.6	0.0	264.8	58.7	7.0	65.7
	May*	5.6	7.2	5.3	4.6	1.1	0.0	23.8	8.4	3.8	12.2
Total:		689.6	673.3	1162.3	328.5	219.3	6.9	3079.9	658.4	157.4	815.8
Year I:		385.1	472.8	924.0	217.1	173.3	1.6	2173.9	470.1	112.9	583.0
Year II:		304.5	200.5	238.3	111.4	46.0	5.3	906.0	188.3	44.5	232.8

Total to lake = 3079.9
Total from lake = 815.8
Net deposited = 2264.1

Trap efficiency = 73.5%

AMMONIA BUDGET, LAKE SPRINGFIELD
May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow Power & Water Plants Dam/Gate Leakage	Outflow Monthly Total
1985	May*	0.1	0.1	0.1	0.1	0.0	0.0	0.4	0.2	0.2	0.4
	Jun	1.5	2.4	0.5	0.6	0.1	0.0	5.1	2.5	0.3	2.8
	Jul	0.1	0.1	0.1	0.1	0.0	.0.0	0.4	0.2	0.6	0.8
	Aug	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.3	0.3
	Sep	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.3
	Oct	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.3
	Nov	2.8	2.6	0.9	1.1	0.2	0.2	7.8	10.3	0.8	11.1
	Dec	2.0	0.9	0.8	1.0	0.2	0.0	4.9	11.5	0.8	12.3
1986	Jan	0.1	0.1	0.2	0.2	0.1	0.0	0.7	1.1	0.6	1.7
	Feb	0.7	0.4	0.4	0.5	0.1	0.0	2.1	3.6	0.5	4.1
	Mar	0.4	0.2	0.3	0.3	0.1	0.0	1.3	3.7	0.8	4.5
	Apr	0.1	0.1	0.2	0.1	0.0	0.0	0.5	0.0	1.1	1.1
	May	5.2	0.7	0.2	0.2	0.0	0.0	6.3	1.8	0.5	2.3
	Jun	0.8	0.2	0.1	0.1	0.0	0.0	1.2	0.5	0.6	1.1
	Jul	0.4	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.7	0.7
	Aug	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.3
	Sep	0.1	0.1	0.0	0.0	0.0	0.2	0.4	0.0	0.3	0.3
	Oct	0.5	0.2	0.1	0.1	0.0	0.0	0.9	0.0	0.3	0.3
	Nov	0.5	0.2	0.2	0.2	0.1	0.0	1.2	1.4	0.3	1.7
	Dec	0.9	0.4	0.3	0.3	0.1	0.0	2.0	2.9	0.4	3.3
1987	Jan	0.3	0.1	0.2	0.2	0.0	0.0	0.8	2.1	0.6	2.7
	Feb	0.5	0.3	0.3	0.3	0.1	0.0	1.5	2.8	0.4	3.2
	Mar	0.2	0.2	0.2	0.1	0.0	0.0	0.7	1.1	0.5	1.6
	Apr	1.6	1.5	0.4	0.5	0.1	0.0	4.1	4.6	0.6	5.2
	May*	0.2	0.1	0.1	0.1	0.0	0.0	0.5	0.7	0.3	1.0
Year I:											
Bedload:		1.1	0.7	0.4	0.4	0.1	N.A.	2.7	N.A.	N.A.	N.A.
Susp. Load:		11.0	7.3	3.7	4.1	0.8	0.6	27.5	33.9	6.8	40.7
Total Load:		12.1	8.0	4.1	4.5	0.9	0.6	30.2	33.9	6.8	40.7
Year II:											
Bedload:		0.8	0.4	0.2	0.2	0.0	N.A.	1.6	N.A.	N.A.	N.A.
Susp. Load:		8.1	3.8	2.0	2.0	0.4	0.2	16.5	17.1	5.6	22.7
Total Load:		8.9	4.2	2.2	2.2	0.4	0.2	18.1	17.1	5.6	22.7
TOTAL LOAD:		21.0	12.2	6.3	6.7	1.3	0.8	48.3	51.0	12.4	63.4

Total to lake = 48.3
Total from lake = 63.4
Net deposited = -15.1

Trap efficiency = -31.2%

Note: N.A. = not applicable.
TOTAL LOAD = Two year total.

KJELDAHL NITROGEN BUDGET, LAKE SPRINGFIELD
May 15, 1985 - May 14, 1987
(in tons)

Year	Month	Inflow Lick Creek	Inflow Sugar Creek	Inflow Direct Tribs.	Inflow Panther Creek	Inflow Polecat Creek	Inflow Horse Creek	Inflow Monthly Total	Outflow Spillway	Outflow Power & Water Plants Dam/Gate Leakage	Outflow Monthly Total
1985	May*	0.5	0.9	0.5	0.4	0.1	0.0	2.4	2.2	1.3	3.5
	Jun	7.7	19.0	2.7	3.0	0.7	0.0	33.1	10.8	2.2	13.0
	Jul	0.3	0.6	0.4	0.3	0.1	0.0	1.7	1.1	3.5	4.6
	Aug	0.2	0.7	0.4	0.2	0.1	0.0	1.6	0.0	2.4	2.4
	Sep	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.8	0.8
	Oct	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.0	0.7	0.7
	Nov	13.8	20.5	4.0	5.4	1.0	1.6	46.3	21.1	3.5	24.6
	Dec	10.1	6.4	3.8	4.9	0.9	0.0	26.1	23.5	3.7	27.2
1986	Jan	0.3	0.8	1.2	1.0	0.3	0.0	3.6	4.2	3.2	7.4
	Feb	3.5	2.5	2.2	2.1	0.5	0.0	10.8	19.8	2.9	22.7
	Mar	2.1	1.4	1.6	1.4	0.4	0.0	6.9	13.4	2.1	15.5
	Apr	0.7	0.9	0.9	0.6	0.2	0.0	3.3	0.0	1.1	1.1
	May	25.9	4.5	1.0	0.7	0.2	0.0	32.3	13.7	2.8	16.5
	Jun	4.2	1.3	0.5	0.3	0.1	0.0	6.4	7.8	3.4	11.2
	Jul	2.2	0.9	0.1	0.1	0.0	0.0	3.3	0.0	3.4	3.4
	Aug	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.9	1.9
	Sep	0.4	0.4	0.1	0.1	0.0	1.4	2.4	0.0	1.9	1.9
	Oct	2.3	1.5	0.7	0.6	0.2	0.0	5.3	0.0	1.9	1.9
	Nov	2.6	1.2	1.2	1.0	0.3	0.0	6.3	5.5	1.7	7.2
	Dec	4.4	2.5	1.7	1.6	0.4	0.0	10.6	9.8	1.7	11.5
1987	Jan	1.6	0.6	0.9	0.7	0.2	0.0	4.0	5.7	1.7	7.4
	Feb	2.6	2.0	1.6	1.5	0.4	0.0	8.1	9.9	1.5	11.4
	Mar	1.1	1.0	0.8	0.6	0.2	0.0	3.7	3.5	1.7	5.2
	Apr	7.8	11.7	2.0	2.2	0.5	0.0	24.2	14.4	1.7	16.1
	May*	1.0	0.9	0.5	0.4	0.1	0.0	2.9	2.1	0.9	3.0
Year I:											
Bedload:		5.5	5.6	1.8	2.0	0.4	N.A.	15.3	N.A.	N.A.	N.A.
Susp. Load:		54.9	56.0	18.1	19.6	4.4	2.8	155.8	99.9	28.4	128.3
Total Load:		60.4	61.6	19.9	21.6	4.8	2.8	171.1	99.9	28.4	128.3
Year II:											
Bedload:		4.1	2.6	1.1	1.0	0.3	N.A.	9.0	N.A.	N.A.	N.A.
Susp. Load:		40.7	26.2	10.7	9.5	2.5	1.4	91.0	68.6	25.2	93.8
Total Load:		44.8	28.8	11.8	10.5	2.8	1.4	100.0	68.6	25.2	93.8
TOTAL LOAD:		105.2	90.4	31.7	32.0	7.6	4.2	271.1	168.5	53.6	222.1

Total to lake = 271.1
Total from lake = 222.1
Net deposited = 49.0

Trap efficiency = 18.1%

Note: N.A. = not applicable.
TOTAL LOAD = Two year total.