Illinois State Water Survey Division

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LAKE DREDGING IN ILLINOIS AND A PRELIMINARY ASSESSMENT OF PRE-DREDGING CONDITIONS AT LAKE SPRINGFIELD

by

Nani G. Bhowmik, William P. Fitzpatrick, John Helfrich, and Edward C. Krug

Final Report Submitted to the
Illinois Department of Energy and Natural Resources

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ABSTRACT

Illinois lakes serve as a major sink of the sediment and pollutants transported by streams. Sediments and pollutants accumulate in lakes and cause use impairement due to volume loss, shallowness, turbidity, habitat destruction, eutrophication, taste and odor problems, and loss of aesthetic values. Lake dredging is a technique for removing accumulated sediments and rehabilitating lost lake resources. Although lake dredging has been performed in the past on Illinois lakes, these projects have been on a relatively small scale. The amount of lake dredging is expected to increase in the future as older lakes experience cumulative use impariment over time. This research project documented past dredging programs in Illinois and assessed the potential effects of lake dredging on Lake Springfield, one of the state's largest man-made water supply lakes. The city of Springfield plans to dredge 2.7 million cubic yards of sediment from their lake over the period 1987 through 1989. This is the largest dredging project to date in the state and represents the scale of future dredging projects anticipated at other lake sites in the state. This research analyzed lakebed sediments obtained prior to dredging activities in Lake Springfield for trace metal, organic chemistry, and physical characteristics for a preliminary assessment of the potential pollution problems that could occur as a result of dredging. The results show detectable levels of organic insecticides, herbicides, and trace metals in the lakebed sediments; however, the concentrations of these constituents are relatively low. This research concluded from the observed concentrations of contaminants in the sediments of Lake Springfield that disturbance of these sediments by dredging (using conventional dredging techniques to minimize resuspension) could cause some localized elevated turbidity levels. However, there is little evidence that the contaminants in the sediment could cause measurable contamination of the water in the lake. Further research is needed to measure the actual release of contaminants to the lake water during the dredging operation in order to more accurately assess the effects of dredging on the use of the lake and the lake's water quality.

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INTRODUCTION

Erosion and sedimentation are natural processes that can not be stopped or eliminated. However, when these processes become excessive they impact many human uses of water. Sedimentation in Illinois lakes and sediment transported by Illinois streams have been recognized as the major water resources problems in Illinois.

Illinois lakes serve as a major sink of the sediment and pollutants carried by streams. Quantifying the sedimentation rates in Illinois lakes not only shows the rate of capacity loss of the lakes, but may also indicate the relative changes in the sediment yield from the watersheds because of natural variations and/or human activities.

In the early 1930s, realizing the potential impact of sedimentation on the state's surface water impoundments, the Illinois State Water Survey in cooperation with other interested agencies pioneered the use of lake sedimentation surveys in Illinois as a means of evaluating lake conditions. This program evolved from the Water Survey's long-standing involvement in investigating the quantity and quality of the state's water resources. Illinois may thus possess one of the longest lake sedimentation survey programs in the nation. Over the years, the Water Survey has accumulated records from approximately 180 surveys of more than 130 lakes in Illinois. Figure 1 shows the locations of the surveyed lakes. As can be seen, most of these lakes are located in the western and southern parts of the state, where ground water either is not available or cannot be exploited economically. Approximately 15 backwater lakes along the Illinois River have also been surveyed. The original emphasis in the lake sedimentation surveys was on the capacity losses of the lakes as a result of silt deposition. However, in recent years the program has been extended to include analyses of water and sediment quality as well as sources of the sediment.

Results of the studies have shown that Illinois lakes are losing their capacities at the rate of 0.2 to 5% per year. Figure 2 is a plot showing capacity losses of Illinois lakes surveyed since 1930. At least 12 of these lakes are losing their capacities at a rate of more than 2% per year. If this rate continues, they will lose 50% of their capacities in about 25 years.

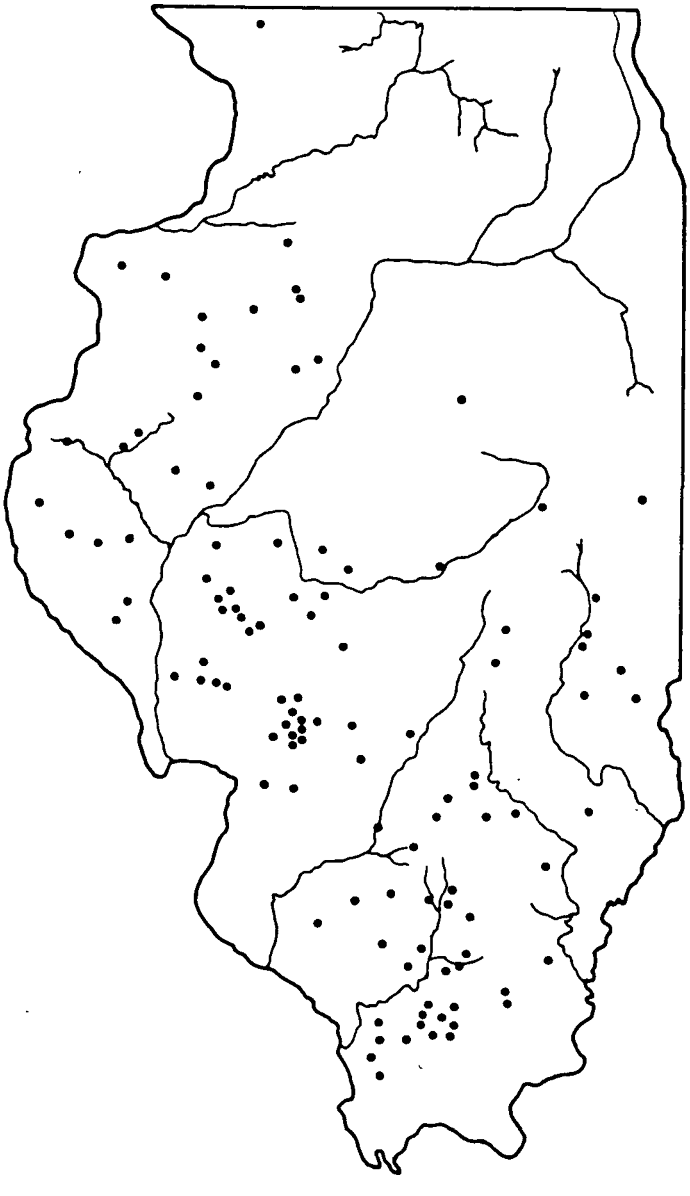

Figure 1. Locations of lake sedimentation surveys in Illinois

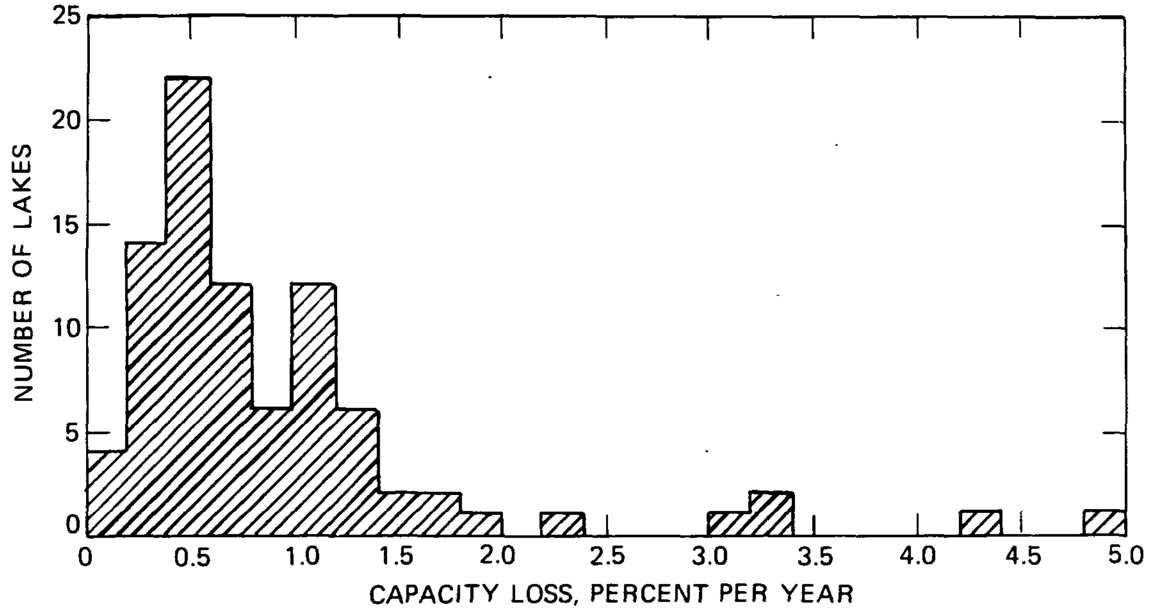

Figure 2. Capacity losses of Illinois lakes

The Water Survey's lake sedimentation program was extremely active during the 1950s and early 1960s (figure 3). During this period, several major reservoir watershed studies were conducted in cooperation with other local, state, and federal agencies. However, since the mid-1960s the Water Survey's effort has been considerably reduced because of limited state support. As a matter of fact, during the period 1967-1970 and during 1973 not a single lake sedimentation survey was conducted in Illinois.

Many cities and communities are now proposing to dredge their lakes to increase their storage capacities, in the hope of preventing shortages of water for domestic supplies. Two such projects are now being implemented in the central part of the state. In June 1987, the city of Springfield started to dredge a portion of the Sugar Creek arm that is almost full of sediment except for a small channel (figure 4). In Lake Decatur, a small area will be dredged to demonstrate the feasibility of dredging within this lake environment.

Figures 5 and 6 show the sedimentation patterns of Lake Springfield and Lake Decatur, respectively (Fitzpatrick et al., 1985, 1987). Both illustrations indicate the high sedimentation near the upper reaches of these lakes.

Recognizing the importance of lake dredging in Illinois and its potential long-term impact on the state's vital water resources, the Illinois Department of Energy and Natural Resources funded a research project to evaluate the pre-dredging conditions at Lake Springfield, including the levels of metals and organics in the sediment. The project was conducted from mid-April through June 30, 1987. This report summarizes the findings of this project.

Acknowledgments

The research project reported here was partially funded by a grant from the Illinois Department of Energy and Natural Resources (ENR). Linda Vogt of the ENR Research and Planning Section is the Project Coordinator and has been extremely helpful in all aspects of this project. W.C. Bogner, an engineer with the Water Survey, prepared the section on the history of twelve lake dredging projects in Illinois. Becky Howard typed the report drafts and camera-ready copy. Particular appreciation is expressed to Thomas Skelly and James Buckler, Springfield City Water, Light & Power Company (CWLP), for their assistance in project planning and coordination and for reviewing the project reports.

PREVIOUS LAKE DREDGING PROJECTS IN ILLINOIS

Lake dredging for the purpose of increasing the depth and/or volume of existing reservoirs has seen limited use in Illinois. Twelve lake dredging projects have been documented from the Water Survey lake file data. Table 1 presents information on these lake dredging

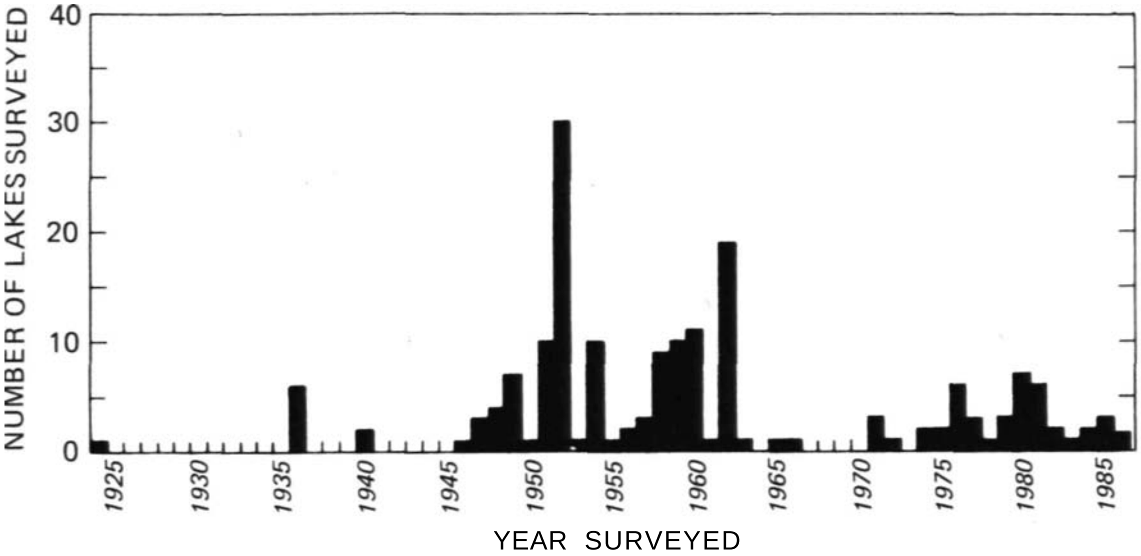

Figure 3. History of lake sedimentation surveys

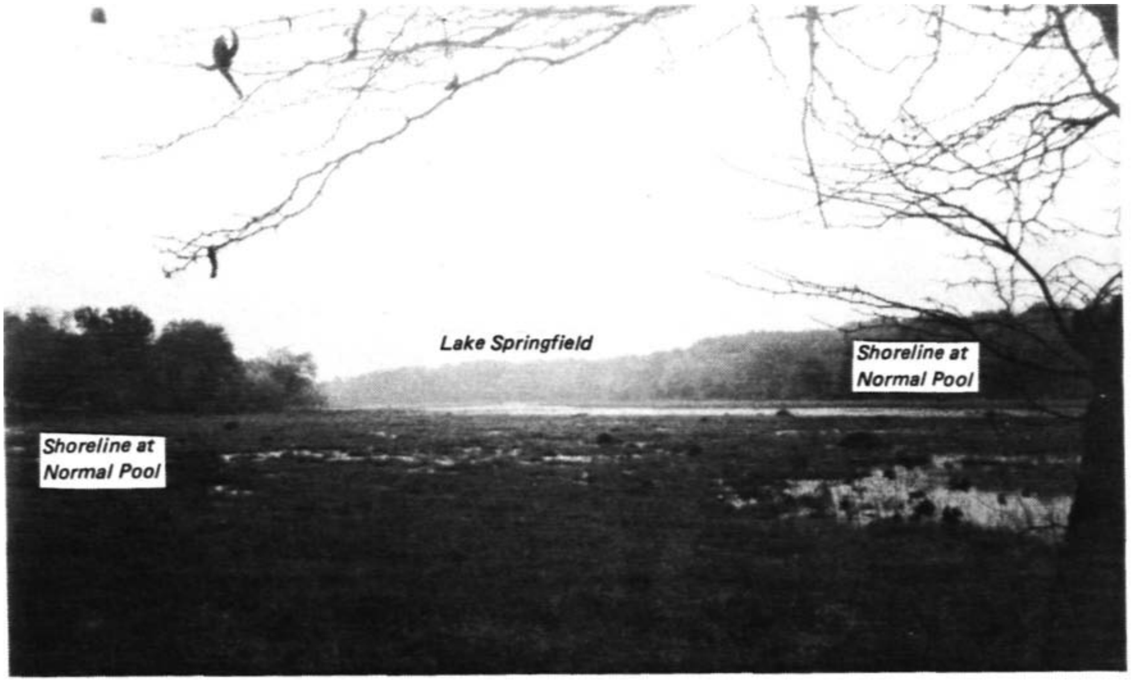

Figure 4. View of Lake Springfield's Sugar Creek arm, looking downstream from the Glasser Bridge boat launch (water level is 3 feet below normal pool, exposing a mud flat overgrown with aquatic weeds)

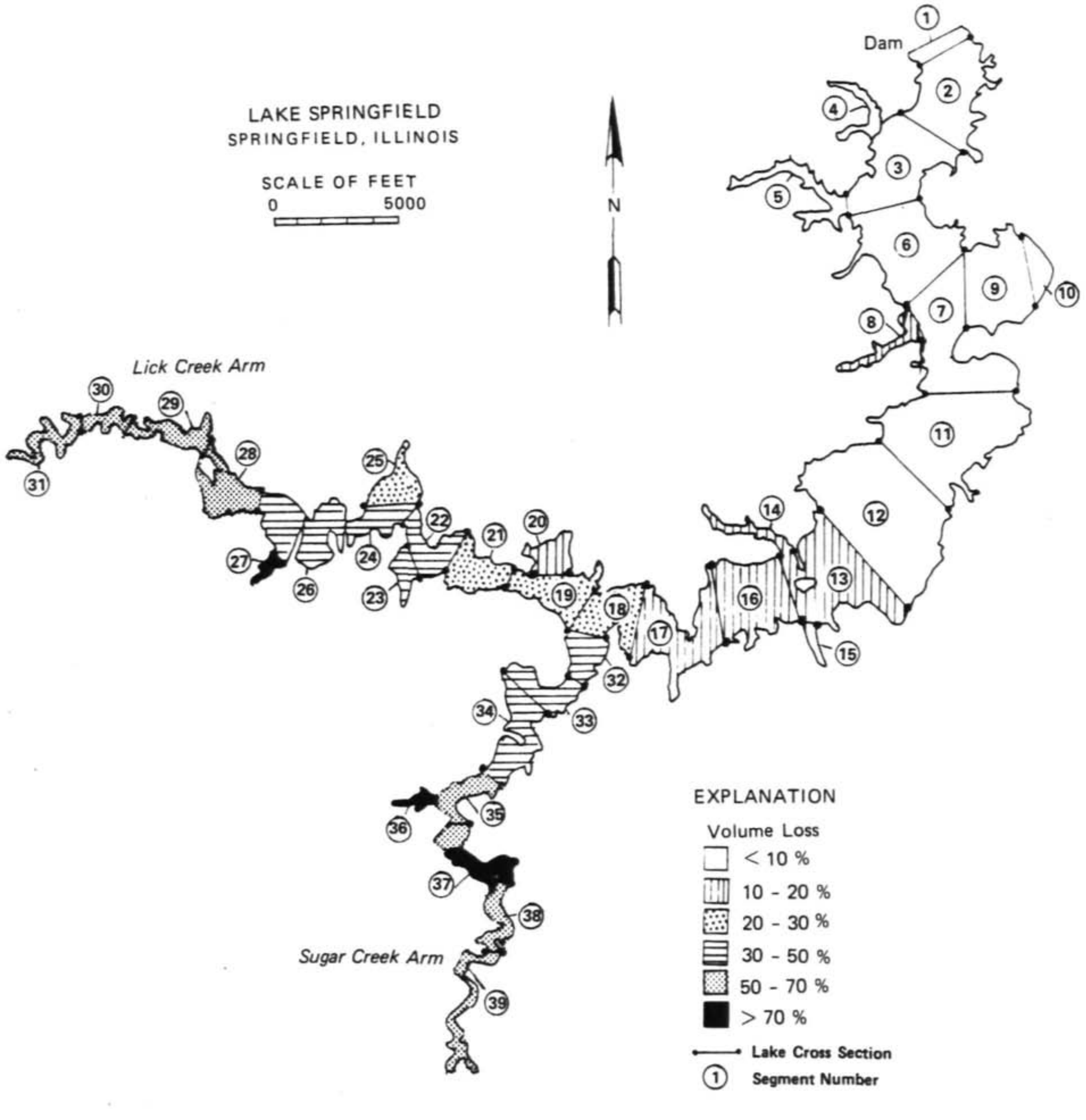

Figure 5. Volume loss in Lake Springfield between 1934 and 1984

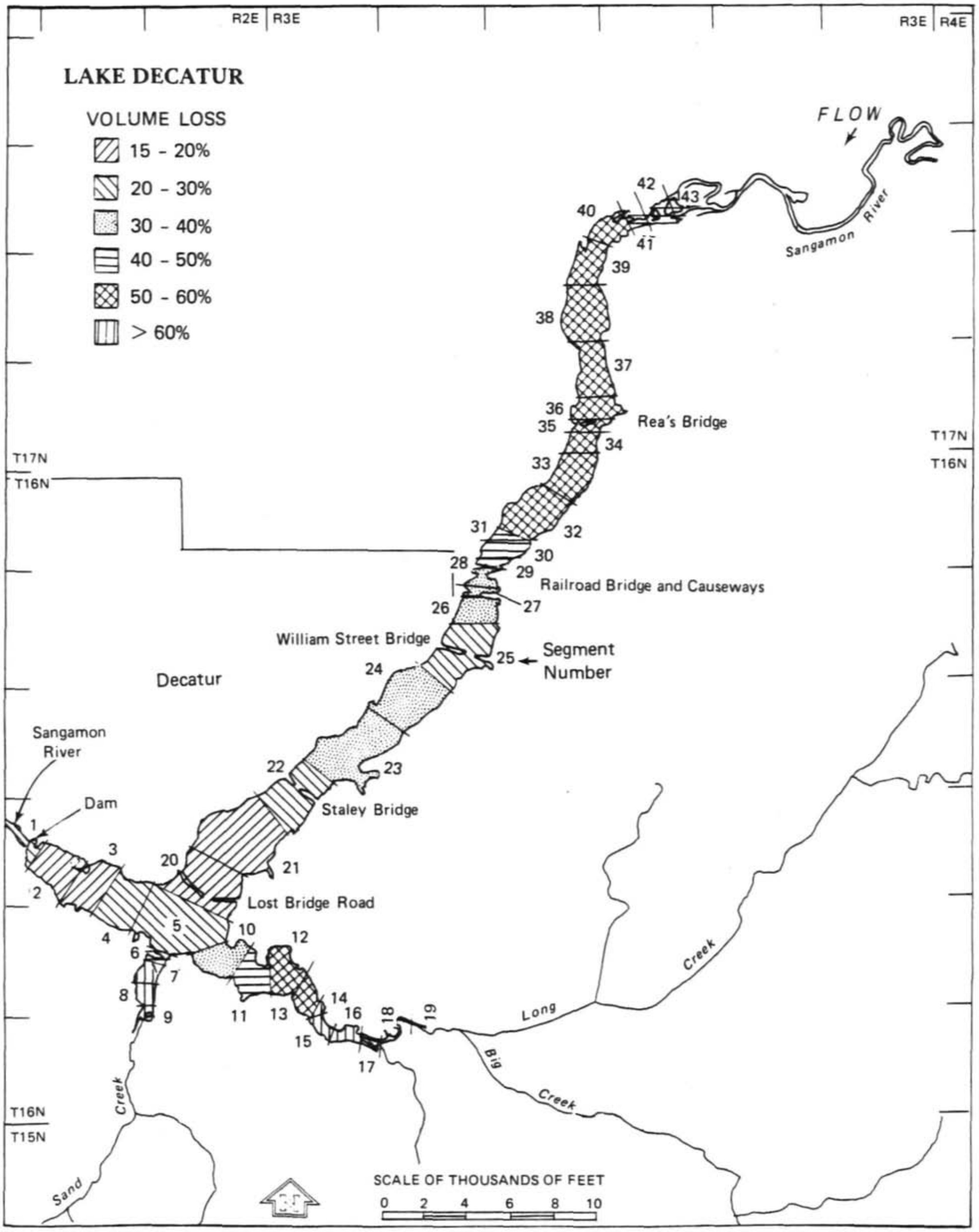

Figure 6. Volume loss in Lake Decatur between 1922 and 1983

Table 1. Previous Lake Dredging Projects in Illinois

	Year constructed	Original capacity (million gallons)	Year dredged	Volume dredged (thousand cubic yards)
Water supply lakes				
Spring Lake-Macomb	1927	200	1951	270
Carlinville	1938	560	1968-1972	108
Paris	1905	175	1972-1981	284+
Oakland	1937	38	1972-1975	95
Paradise	1907	665	1980	2.3
Recreational lakes				
Old Pittsfield	1924	109	1951	NA
Spring Lake-Mahomet	1956	NA	1976-1980	NA
Apple Canyon Lake	1969	NA	1978-1979	48
Lake De Pue	NA	NA	1983	592.0
Lake Park	NA	NA	late 1970s	22.3
Lake of the Woods	1948	85	NA	NA
Crystal Lake	1900	NA	1985	54.5

Note: NA = not available

projects. Most of these lakes are subject to chronic sedimentation problems and will need or already need further treatment. In some lakes, such as Lake Park and Crystal Lake, the dredging program was a part of an overall program to treat the sedimentation problem as well as the problems resulting from sedimentation. The locations of these 12 lakes and of Lakes Springfield and Decatur are shown in figure 7.

Water Supply Lakes

Spring Lake - McDonough County

Spring Lake serves as the water supply source for the city of Macomb. The dredging program conducted on this lake in 1951 was probably the first major dredging operation for a water supply lake in Illinois. The lake was built in 1927 with a capacity of 200 million gallons. A sedimentation survey conducted by the Soil Conservation Service in 1947 found that the capacity had been reduced to 105 million gallons, a 48% decrease in 20 years. In 1951, to restore water capacity to the reservoir, the city contracted to have 270,000 cubic yards (55 million gallons) of sediment removed from the lake at a cost of 29.8 cents per cubic yard. This dredging was conducted hydraulically, with the removed material pumped over the spillway directly to the outflowing creek.

The city was considering a contract to remove an additional 230,000 cubic yards (46 million gallons) of sediment, but this plan was dropped after the Department of Public Health determined that further direct discharge of dredge materials to the creek was not recommended.

Lake Carlinville - Macoupin County

Lake Carlinville is the water supply source for the city of Carlinville. The dredging program at Lake Carlinville continued for four years from 1968 to 1972. The lake was constructed in 1938 with a capacity of 560 million gallons. A 1959 sedimentation survey conducted by the Water Survey showed that the capacity had been reduced to 430 million gallons, a 23% decrease in 20 years.

In 1968, the city purchased a dredge, constructed a sediment storage basin, and initiated a dredging operation. This operation was continued for four summers but was discontinued in the fall of 1972 due to rising costs and labor difficulties.

During this dredging project, 22 million gallons of capacity was restored. A total of 108,000 cubic yards of sediment was removed at an average cost of $1.80 per cubic yard.

Paris West Lake - Edgar County

West Lake was built in 1905 to provide water and recreational opportunities for the residents of Paris. In 1915, West Lake was supplemented by East Lake. In 1959, Lake No. 3

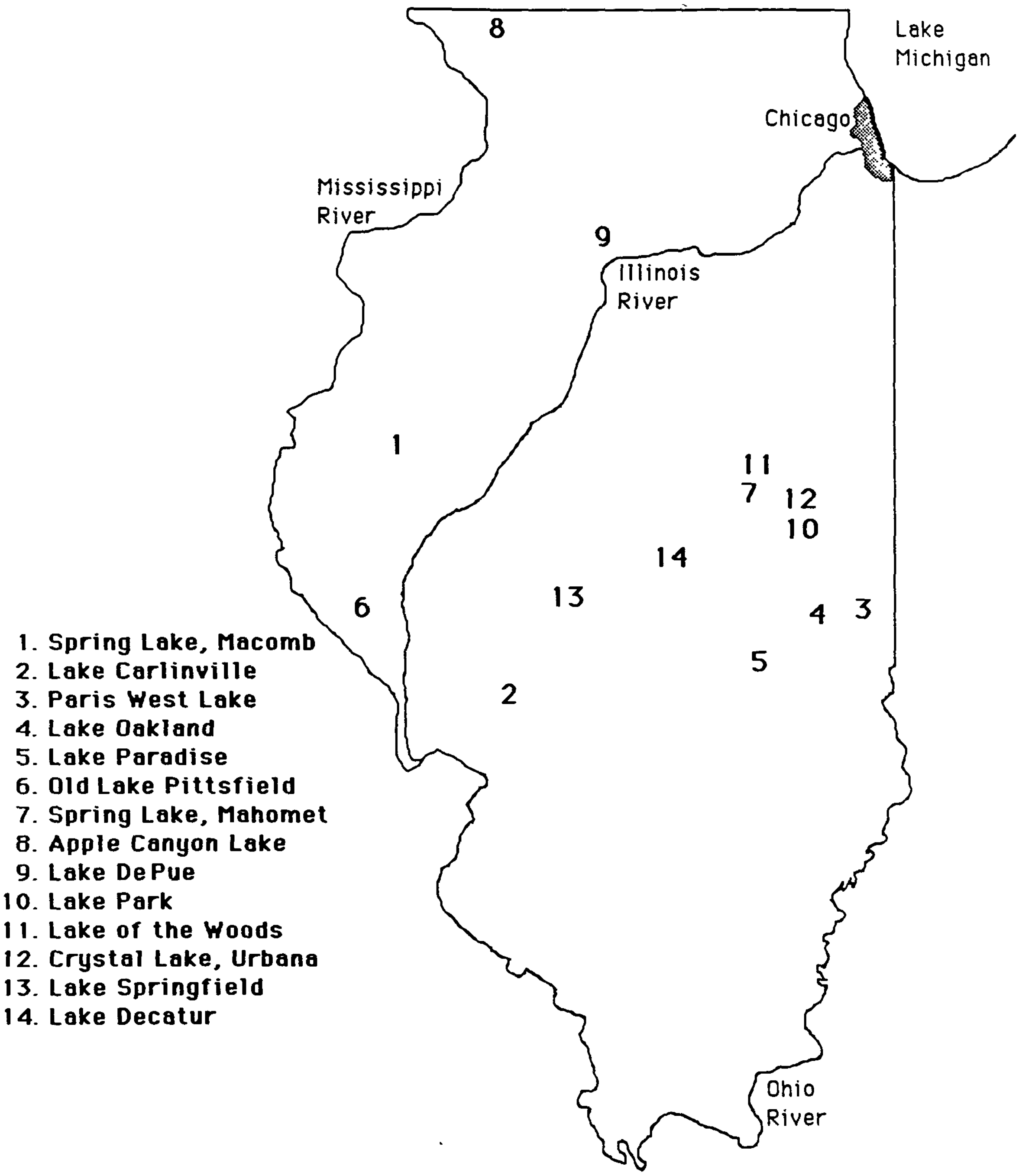

Figure 7. Locations of lake dredging sites in Illinois

was added. Since these lakes were built in a downstream series, West Lake protected both East Lake and Lake No. 3 from major sedimentation problems. West Lake itself, however, suffered severe sedimentation problems.

When it was built in 1905, West Lake had a capacity of 175 million gallons. By 1932, 13 feet of sediment had accumulated near the dam, and the upper third of the lake was completely full of sediment. By 1970, the lake could be used by boats only in the vicinity of the dam.

In the early 1970s, the city approached state officials concerning the initiation of a dredging program, and dredging began in 1972. The Illinois Department of Transportation, Division of Waterways, conducted the dredging as a research program and provided a dredge, slurry pipe, and personnel through 1974. During this time 284,000 cubic yards of sediment were removed from the lake, increasing its capacity by 57 million gallons.

In 1975, the city purchased the dredge from the state and continued the program on its own. Monitoring of this program, which continued through about 1981, was poor, and no estimates have been made of the volume of sediment removed. Dredging was discontinued in 1981.

Lake Oakland - Coles County

Lake Oakland is a 26-acre water supply lake that serves the city of Oakland. When it was built in 1937, its storage capacity was 38 million gallons. By 1955, the lake had lost 8 million gallons or 21% of its storage capacity to sediment deposition. By 1972, the lake capacity was less than 24 million gallons, which represented only 63% of the original capacity.

In 1972, the city initiated a dredging program, which was continued for a total of four years. During this time, the lake was restored to its original capacity through the removal of 95,000 cubic yards of sediment. The unit cost of this operation was approximately $0.76 per cubic yard over the four-year period.

Lake Paradise - Coles County

Lake Paradise and Lake Mattoon are the source of public water supply for the city of Mattoon. Lake Paradise was built in 1907. In later years, the spillway elevation was raised twice and a new dam was constructed, which increased the original capacity to 665 million gallons. A 1979 sedimentation survey showed that the capacity of the lake had been reduced to 458 million gallons, a 31.1% decrease.

In 1980, the Department of Agricultural Engineering at the University of Illinois used Lake Paradise for a pilot study of the potential benefits of using lake sediment as a soil additive.

For this purpose, 2,300 cubic yards of sediment were removed from the lake and applied to field plots, which were then monitored for crop production. The general finding of the study was that application of dredged sediments would be beneficial under certain conditions.

Lake Springfield - Sangamon County

Lake Springfield serves as the water supply and a major recreational development for the city of Springfield. When constructed in 1934, the lake had a storage capacity of 19,500 million gallons. A series of four sedimentation surveys were conducted on the lake to monitor sedimentation rates and patterns. The most recent survey in 1984 showed that the volume of the lake had been reduced to 17,000 million gallons, a decrease of 13% over 50 years.

To partially restore the volume loss in the lake as well as to increase the trap efficiency of the upper portion of the lake, the city initiated a dredging program in the upper end of the lake in June 1987. This dredging program will remove 2.7 million cubic yards of sediment. The program is expected to cost $10 million over a five-year period.

Lake Decatur - Macon County

Lake Decatur is the principal water supply lake for the city of Decatur. The lake was built in 1922 and was enlarged in 1956 by an increase in the spillway elevation. The lake covers an area of 3,072 acres (4.8 square miles) and had a capacity of 18,800 acre-feet (6.13 billion gallons) in 1983, at the time of the last sedimentation survey. The 1983 lake volume represented a volume loss of nearly one-third of the original volume. Extensive sedimentation has reduced water supply storage and recreational uses in the upper portions of the lake. As of 1983, the lake's average depth had decreased from 9 feet to 6 feet.

The city of Decatur is currently planning a pilot dredging program to assess the costs and benefits of dredging to restore recreational boat access to areas impaired by sediment accumulation. Current plans call for dredging 75,000 cubic yards of sediment from the upper portion of the lake.

Recreational Lakes

Old Lake Pittsfield - Pike County

The old lake at Pittsfield was built in 1924 and was the principal water supply source for the city until construction of the new lake in 1961. The original lake is now privately owned.

In 1951, it was noted that sometime in the past, the upper end of the lake had been excavated. However, no data could be located on the actual volume of sediment that was removed from the lake.

Spring Lake - Champaign County

Spring Lake is a small recreational lake near Mahomet. This lake was built in 1956 and reportedly suffered a storage loss of 3.4% per year as a result of being a small lake with a large watershed.

In 1976, the lot owners association purchased a dredge and operated it for five summers to remove sediment. No data are available about the volume of the sediment that was removed.

Apple Canyon Lake - Jo Daviess County

This large (440-acre) residential/recreational lake was built in 1969. Sedimentation has decreased water depths and increased aquatic weed growth. In 1978, a dredging program was initiated to restore lake depth in selected areas. A total of 48,000 cubic yards of sediment was dredged in 1978 and 1979.

Lake De Pue - Bureau County

Lake De Pue is a backwater lake along the Illinois River near De Pue. Although once heavily used for recreational purposes including nationally prominent speedboat races, the lake could barely be used by 1976 because of sedimentation.

The lake was dredged by the Illinois Department of Conservation in 1983 to promote the reestablishment of recreational benefits. A portion of the lake was dredged to provide at least 6 feet of depth. Approximately 592,000 cubic yards of sediment was removed. Field inspection by Department of Conservation personnel indicates that the dredged area has refilled with sediment.

Lake Park - Champaign County

This is a small residential lake south of Champaign. The dredging program removed 22,300 cubic yards of sediment in the late 1970s.

Lake of the Woods - Champaign County

Lake of the Woods is owned by the Champaign County Forest Preserve District and serves as a major park/recreational facility. The upper ends of the two main arms of the lake are privately owned.

Dredging at this lake was conducted on the privately owned upper ends of the lake, and no data on dredged volume are available.

Crystal Lake - Champaign County

Crystal Lake is owned by the Urbana Park District and serves as the centerpiece of that city's largest recreational park. The lake was built in the early 1900s by the closing and rerouting of a section of stream channel. The lake has been severely impacted by urban sediment and nutrient loads.

Dredging was conducted in 1985, and 54,500 cubic yards of sediment were removed. The dredging increased the maximum depth from 4 feet to 10.5 feet and the average depth from 2.5 feet to 6.5 feet.

DREDGING PROCEDURES AND IMPACTS

Dredging has been used in streams, rivers, lakes, wetlands, oceans, and estuaries. The techniques employed, types of equipment used, and effects of dredging are quite varied, and descriptions of all of these processes could result in many volumes of reports. This section concentrates on the processes and impacts of dredging in relatively small lakes. This limitation is used to exclude the specific complex processes unique to the Great Lakes and estuarine systems.

Dredging is the process of excavating bottom materials from a water body, and dredges are specialized earth-moving machines that remove these bottom materials. Most dredging is performed to facilitate navigation by increasing water depths in waterways.

Approximately 400 to 450 million cubic yards (MCY) of sediment are dredged annually in the United States (Hatch, 1987). Most of the dredging (300 MCY) is performed by the U.S. Corps of Engineers as part of their maintenance and development duties on the national waterway system. The remainder of the material is dredged by other federal, state, and local agencies and by the private sector. Approximately half of the dredging is performed in marine coastal areas. The remainder is in the inland waterways, primarily the Mississippi River System and the Great Lakes (Hatch, 1987).

The annual volume of dredged materials in the United States is volumetrically equivalent to more than 90 billion gallons or 279,000 acre-feet, which is approximately equal to the entire volume of Lake Carlyle, the largest man-made lake in the state of Illinois.

Dredging Procedures

Most dredges in use today can be classified into two categories: mechanical and hydraulic. Both types of dredges are employed in lake dredging. Mechanical dredges typically remove dredged material by means of a dipper, drag-line bucket, or clam shell. Hydraulic dredges typically remove dredged material by using suction in combination with a cutterhead or horizontal auger. Hydraulic dredges are the type most commonly used. These dredges consist of a centrifugal pump installed on a hull with a suction pipe lowered on a ladder to the bed material (figure 8). The end of the suction pipe is usually fitted with a cutterhead or auger to break up the bed material and convey it to the suction pipe inlet. Suction dredges without augers or cutterheads are typically used in very loose and granular material where the sediment tends to flow on its own without being mechanically broken up.

Hydraulic dredges transport dredged material to the disposal site by using the pressure generated by the suction pump. Typically, dredged material is conveyed through a flexible floating pipeline that runs from the dredge to the disposal site, eliminating the need for additional handling of the material. Booster pumps are used on the disposal pipeline when the pumping distance exceeds the capabilities of the dredge pump. Typically, smaller dredges can pump dredged material about one-half mile, and larger types can pump up to two miles.

Hydraulic dredges tend to have an operational advantage over mechanical dredges because they can dispose of the dredged material with a single handling. Mechanical dredges are typically used in combination with hopper barges or some other means of transporting the material to the disposal site and tend to have more handling phases in operations where off-site disposal is used.

In the typical operation of a hydraulic dredge, the bottom material is loosened by a cutterhead, and a mechanical bucket wheel, auger, or other means is used to separate the material to be dredged from the bottom materials. The material loosened by the cutterhead is funneled to a suction pipe intake located at the cutterhead and then passed through a centrifuge pump and into the disposal pipeline. The disposal pipeline conveys the dredged material to the disposal site where the solids are separated from the water and sediment slurry, and the clarified waters are allowed to return to the water body.

Physical Impacts

The removal of bottom materials from a lake during dredging has many physical impacts, including elevated turbidity, changes in water quality, transport of resuspended materials, morphological changes to the lakebed, and effects on biota. The disposal of the dredged material also has a number of effects, which include morphological changes to the disposal site, solid-liquid separation of the dredge slurry, and impact of the return water.

The most visible impact of dredging is the increased levels of turbidity during and following the dredging operation. Increased levels of turbidity can interfere with the normal photosynthetic process, leading to detrimental effects on the lake biota. Dredging activities can be scheduled so as to avoid detrimental effects on lake aquatic habitats.

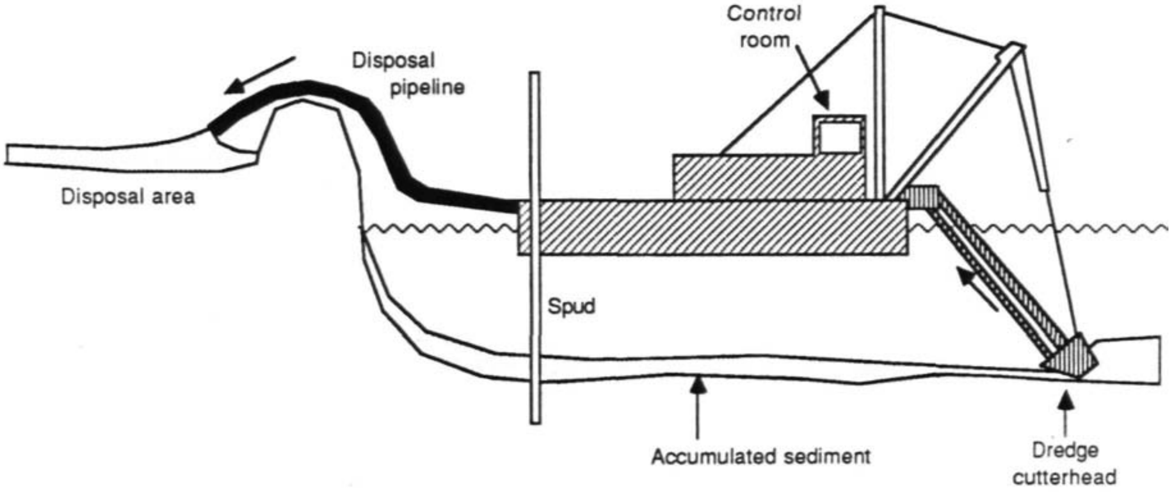

Figure 8. Components of a hydraulic dredge

Open-water dredging can initiate dissolved oxygen sag due to biochemical oxygen demand of the sediment, which may or may not have a long-term impact. If lake circulation is strong, some transport and movement of fine sediment to other parts of the lake can take place. This transport process can obviously move and redistribute the trace metals and organics that are present on lakebed sediments.

An obvious effect of dredging is the changes it produces in the topography of the lakebed. Dredging removes bottom materials and alters the shape of the bed. This removal can have impacts on lakeshore stability if the toe of the shore slope is removed. Changes in lakebed topography can affect in-lake flow patterns, development of stratification, vertical water quality gradients, future sedimentation rates and patterns, and fish and wildlife habitat.

Exposure and release of polluted sediments can result from dredging. Layers of contaminated sediment in the lakebed can be uncovered by dredging operations, and the contaminants can then be made available to the water overlying the sediment. In addition, where the sediments are substantial contributors of nutrients to the lake water, resuspension resulting from dredging can exacerbate existing water quality problems. In situations where the sediment is rich in nutrients and toxic contaminants, damage can be mitigated by employing specialized dredging techniques that reduce resuspension. Asbestos-contaminated sediments were recently dredged by using dredges specifically designed to minimize resuspension of the material and contamination of downstream water supplies (Jones and McGuire, 1987).

In 1970 the World Dredging Association held a conference in Singapore on various dredging projects around the world (World Dredging Conference, 1971), at which various speakers discussed techniques and effects of dredging.

In a study sponsored by the U.S. Environmental Protection Agency (Nawrocki, 1974), it was observed that techniques are available to separate highly concentrated sediment slurries, such as occur in dredging, and also to qualitatively and quantitatively estimate the impacts of dredging on water quality. Site-specific data from the monitoring of pre- and post-dredging operations are essential in the evaluation of the physical impacts of dredging.

In 1976, the American Society of Civil Engineers sponsored a conference on "Dredging and Its Environmental Effects" (ASCE, 1976). Speakers such as Cable and Pearson (1976), Chen et al. (1976), Smith et al. (1976), North and Clark (1976), Sustar et al. (1976), Barnard (1976), and Mayer (1976) discussed various aspects of dredging and its impact on the dredging environment including riverine, lacustrine, and marine areas. The economic value of dredged materials of small Illinois lakes was also discussed by Roberts (1976).

The American Society of Civil Engineers held a conference in 1984 on various aspects of dredged material disposal on the environment. Even though most of the research and case studies reported at this conference dealt with open water disposal or disposal within a marine environment, some of the studies were conducted on small lakes. At this conference, Kennedy and Cooke (1984) discussed the water quality aspects of reservoirs during dredging, Copp and Browne (1984) discussed costs of urban lake dredging, Shenman (1984) reported on reductions in turbidity levels during dredging, and Walsh and Carrantza (1984) presented a comparative evaluation of seven lake dredging projects.

It is apparent that a wealth of information on physical impacts of dredging is available. However, most of the data and research results generally pertain to marine or open-water environments where dredging has been practiced for a long time. Dredging for the removal of sediment from lakes such as Lake Springfield has not been evaluated in detail.

All biological processes within an aquatic environment are affected by physical processes that can be induced by either human intervention or natural phenomena. Understanding of the environmental and physical processes associated with sediment removal thus becomes an important factor for protection of the aquatic environment.

FIELD DATA COLLECTION AND ANALYSIS

Overall Objectives

The purpose of the data collection and sampling carried out for this project was to obtain water and sediment samples from Lake Springfield that would provide information on the baseline in-lake conditions prior to the initiation of dredging. Lake Springfield is known to have measurable levels of organochlorine pesticides in its lakebed sediment (IEPA, 1978; Kelly and Hite, 1981). Sampling performed as part of this project was intended to assess the current levels of these pesticides in the lakebed sediment. Sampling was also performed for analysis of metals in the sediment. The data will be compared with data on the concentrations in the sediment after dredging has been performed.

Site Selection

Figure 9 is a map of Lake Springfield showing the locations of the water and sediment sampling sites. The inset map in figure 9 shows the planned dredging sites. Sampling sites were selected to represent a variety of locations in the lake, including the planned dredge areas. Water samples were obtained from sites ranging from the upper areas of the Sugar Creek arm to the deeper downstream areas near the dam (table 2), in order to assess the total suspended sediment and chemical contaminent concentration gradient in the lake water from the upper to the lower ends of the lake. Concentration gradients of suspended materials in lake water have been observed in most lakes and are due primarily to the settling of particles carried by inflowing streams as the water moves through the lake.

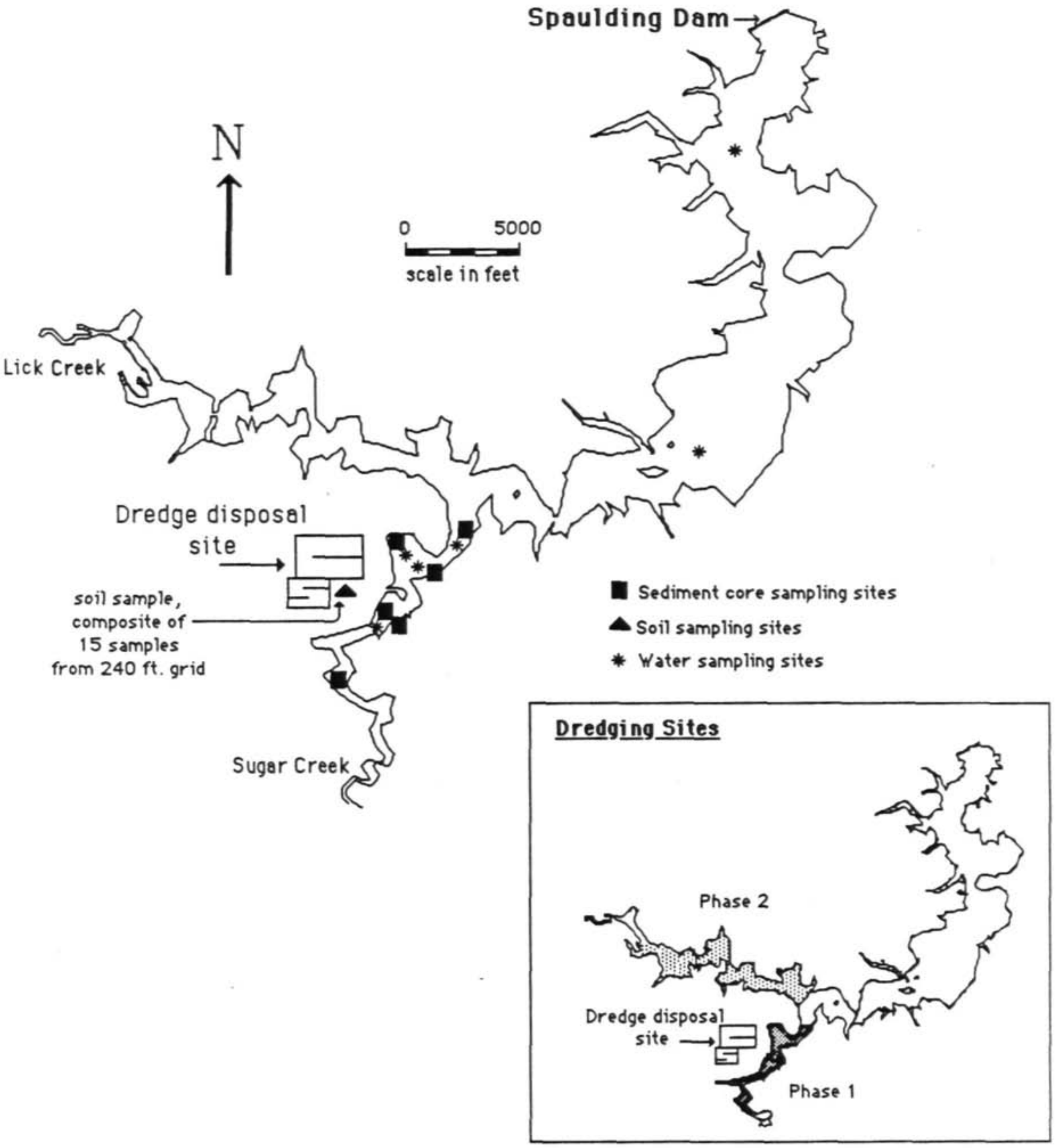

Figure 9. Project sampling sites on Lake Springfield and planned dredge areas

Table 2. Water and Sediment Sampling Sites on Lake Springfield

Distance from dam (feet)	Lake cross section	Distance on cross section from reference point (feet)	Reference point	Water samples	Sediment samples
48,500	R64-R65	262;269*	R65		X
44,600	R60-R61	150	R61	X	X
		200		X	X
40,600	R58-R59	248	R58		X
		300		X	
		1500		X	
		1557			X
38,600	R56-R57	150	R56	X	
		435			X
23,400	R20-R21	750	R20	X	
7,700	R8-R9	1000	R9	X	

* Metals samples from core at 262 feet and organics samples from core at 269 feet

Sampling sites in the lake were located and positioned by means of surveying monuments placed around the lakeshore during previous lake sedimentation studies conducted by the Water Survey (Fitzpatrick et al., 1985). This procedure of locating sampling points relative to surveying monuments can be of great value in helping to relocate the sampling points for later sampling.

Sediment samples were obtained only from the Sugar Creek arm of the lake. These sampling sites, shown in figure 9, were selected to represent the present pre-dredge conditions of the lakebed sediment. Individual sites for sediment core sampling in the Sugar Creek arm were selected on the basis of the extensive records of sediment accumulation obtained from the Water Survey's lake sedimentation surveys (Fitzpatrick et al., 1985). A total of six sites were selected for sediment coring (table 2). These sites represent a variety of variables including distances from the inflowing tributary, depth of sediment accumulation over time, and locations with respect to the main channel and sheltered bay areas.

A composite soil sample was obtained from the dredge material disposal area for particle size, metals, and organic chemistry analysis so that this soil could be compared with the lakebed sediment samples.

Sampling for Sediment Concentration and Physical Characteristics

Objectives

This component of the project had the overall objectives of providing information on the physical properties of the lakebed sediments and of identifying the locations and depths of samples obtained for metal and organic chemical analyses. The specific objectives of this component of the project were:

- Identify the time interval represented by the core samples obtained for chemical analyses.
- Quantify the distribution of suspended sediment in the lake water to assess the present levels of suspended sediment in the lake during pre-dredging conditions.
- Determine the particle size distribution and density of lakebed sediment to assess the association of any measured contaminants with various particle sizes.
- Assess the expected degree of resuspension of any measured contaminants in the lakebed sediment on the basis of the location of contaminated layers and their physical properties.

- Assess the depositional area of any measured contaminants that will be resuspended by dredging activities on the basis of the locations of contaminated layers and their physical properties.

Suspended Sediment Concentration Sampling

The waters of Lake Springfield were sampled for total sediment concentration on May 12, 1987. The locations of the water sampling sites are shown in figure 9. The purpose of this sampling was to determine the areal distribution of suspended sediment concentrations throughout the length of the lake.

Water samples were obtained by using an instrument recently developed at the Water Survey, which incorporates a peristaltic pump connected to a U.S. Geological Survey (USGS) US-DH 59 integrating sampler. This sampler was developed in order to obtain, from specific intervals in the water column, the large quantities of water necessary for trace chemical analysis. Samples were collected in standard 500 ml glass bottles used for this type of sampling. Sample analysis was performed at the Inter-Survey Geotechnical Laboratory. The laboratory analytical procedure was to filter the sample through a Whatman 934AH borosilicate glass filter, weigh the dried sample retained on the filter, and then divide the filtered weight by the net sample weight.

Core Sampling for Density and Particle Size Analysis

Cores of the lakebed sediment were obtained by using a thin-wall stainless steel sampler 2 inches in diameter and 3 feet long. The core sampler is typical of the kind used in lake sedimentation surveys at the Water Survey. The sampler was designed to obtain a core with a minimum of compaction and disturbance that could bias the analyses of density and particle size distribution. In water depths greater than 5 feet, sediment cores were obtained by driving the instrument into the lakebed by means of the sampler's operating lines. In shallower depths, the instrument was driven into the lakebed by hand. The core samples were extruded onto an examination and measuring board for visual inspection. Visual observations of organic material content, root zones, gas pockets, compaction, and changes in color and texture were performed. The core sample was then subsampled for density and particle size distribution analyses. On the average, two density and particle size samples were cut from each core to assess changes with depth.

The maximum core length obtained with this instrument is approximately 2.5 feet. However, a worn seal in the sampler precluded sampling beyond 2.0 feet. Greater core lengths could have been obtained, but the sample disturbance of the sediment core would have been unacceptable for the types of laboratory analysis to be performed. Table 3 lists the samples collected for this project.

Sampling for Organic Contaminants

Background

Organic contaminants found in lake water and sediments come from many sources. Thousands of new chemical compounds are synthesized each year in chemical laboratories. Many of these compounds eventually reach the marketplace in the form of various products for domestic, commercial, industrial, and agricultural uses. These chemicals ultimately find their way into the environment, and their toxic or hazardous properties may cause problems. Lake and reservoir sediments become sinks for these contaminants when the chemicals that are sorbed to particulates are carried in runoff water to the rivers and streams that feed the lakes. Alternatively, atmospheric deposition may be an important pathway by which some compounds, such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons, reach lake sediments.

Modern agricultural practices in use since the early 1950s rely heavily on the use of herbicides and insecticides to maintain or increase crop yields. During 1971-1972, about 34 million pounds of active ingredients of pesticides were applied to more than 14 million acres of Illinois farmland (Metcalf and Sanborn, 1975). In 1982, farm acreage receiving pesticides had increased to more than 26 million acres, and pesticide applications totaled more than 72 million pounds of active ingredients (Pike and Colwell, 1983). By 1985, the amounts of pesticides used by Illinois farmers had dropped to about 67 million pounds (Pike, 1986). Part of the downward trend in the number of pounds of active ingredients may be due to the use of new insecticides that are effective at lower rates of application, but the continuing decline in the farm economy may also have played an important role.

Unfortunately, many of the pesticides that were heavily used in the past were discovered to have devastating ecological effects only after millions of pounds of the chemicals had already been introduced into the environment. The problems surrounding past use of organochlorine insecticides such as DDT, aldrin, heptachlor, and others are now well known (Steffy et al., 1984; MacMonegle et al., 1984; Havera and Duzan, 1986). Past usage of organochlorine pesticides in Illinois, especially the cyclodiene insecticides aldrin, heptachlor, and chlordane, has been very high. In the 20-year period after their introduction in 1954, it is estimated that more than 82 million pounds of aldrin and heptachlor were applied to Illinois farm soils (Metcalf and Sanborn, 1975). Wiersma et al. (1972) estimated that more than 60 million pounds of aldrin alone was applied to Illinois farmland between 1954 and 1972. As a result of the massive use of this chemical, soils in Illinois had the highest average levels of aldrin (0.13 ppm) and dieldrin, the

Table 3. Lake Springfield Dredging Project Sample Identification

Sample ID*	Analysis	Distance from dam (feet)	Lake cross section	Distance from reference point (feet)	Reference point	Material sampled	Sample depth top (feet)	Sample depth bottom** (feet)	Estimated depositional time period
1	metals	48,500	R64-R65	269	R65	sediment	0.0	1.8	1940s-present
7	metals	44,600	R60-R61	150	R61	sediment	0.0	1.0	1960s-present
8	metals	44,600	R60-R61	200	R61	sediment	0.0	1.4	1960s-present
4	metals	40,600	R58-R59	248	R58	sediment	0.0	1.5	1970s-present
5	metals	40,600	R58-R59	1557	R58	sediment	0.0	1.0	1970s-present
6	metals	40,600	R58-R59	1557	R58	sediment	1.0	1.6	1940s-1970s
3	metals	38,600	R56-R57	435	R56	sediment	0.0	1.2	1960s-present
9	metals	38,600	R56-R57	midpt.		bulk sediment		surface	recent
2	metals		disposal site			soil	0.0		
6a, 6b	metals	44,600	R60-R61	midpt.		water	1.5		
4a, 4b	metals	40,600	R58-R59	300	R58	water	3.3		
5a, 5b	metals	40,600	R58-R59	1500	R58	water	3.3		
3a, 3b	metals	38,600	R56-R57	150	R57	water	4.6		
7a, 7b	metals	23,400	R20-R21	750	R20	water	11.5		
7c, 7d	metals	23,400	R20-R21	750	R20	water	4.9		
8a, 8b	metals	7,700	R08-R09	1000	R9	water	13.1		
8c, 8d	metals	7,700	R08-R09	1000	R9	water	3.3		
	organics	48,500	R64-R65	262	R65	sediment	0.0	1.6	1940s-present
	organics	44,600	R60-R61	150	R61	sediment	0.0	1.0	1960s-present
	organics	44,600	R60-R61	200	R61	sediment	0.0	1.4	1960s-present
	organics	40,600	R58-R59	248	R58	sediment	0.0	1.5	1970s-present
	organics	40,600	R58-R59	1557	R58	sediment	0.0	1.0	1970s-present
	organics	40,600	R58-R59	1557	R58	sediment	1.0	1.6	1940s-1970s
	organics	38,600	R56-R57	435	R56	sediment	0.0	1.2	1960s-present

* Metal samples identified by alphanumeric code, other samples identified by cross section and distance

** Sample depth bottom applies only to core samples

Note: midpt. = midpoint of the lake cross section

Table 3. Continued

Sample ID*	Analysis	Distance from dam (feet)	Lake cross section	Distance from reference point (feet)	Reference point	Material sampled	Sample depth top (feet)	Sample depth bottom** (feet)	Estimated depositional time period
	organics		disposal site			soil	0.0		
	organics	44,600	R60-R61	midpt.		water	1.6		
	organics	40,600	R58-R59	300	R58	water	3.3		
	organics	40,600	R58-R59	1500	R58	water	3.3		
	organics	38,600	R56-R57	150	R57	water	4.6		
	organics	23,400	R20-R21	750	R20	water	11.5		
	organics	23,400	R20-R21	750	R20	water	4.9		
	organics	7,700	R08-R09	1000	R9	water	13.1		
	organics	7,700	R08-R09	1000	R9	water	3.3		
	P.S.	44,600	R60-R61	150	R61	sediment	0.0	0.2	
	P.S.	44,600	R60-R61	150	R61	sediment	0.6	0.7	
	P.S.	44,600	R60-R61	150	R61	sediment	1.5	1.6	
	P.S.	44,600	R60-R61	200	R61	sediment	0.0	0.2	
	P.S.	44,600	R60-R61	200	R61	sediment	1.2	1.3	
	P.S.	40,600	R58-R59	248	R58	sediment	0.5	0.6	
	P.S.	40,600	R58-R59	248	R58	sediment	1.5	1.6	
	P.S.	40,600	R58-R59	1557	R58	sediment	0.2	0.3	
	P.S.	40,600	R58-R59	1557	R58	sediment	1.0	1.1	
	P.S.	40,600	R58-R59	1557	R58	sediment	1.6	1.7	
	P.S.	38,600	R56-R57	435	R56	sediment	0.4	0.5	
	P.S.	38,600	R56-R57	435	R56	sediment	1.0	1.1	
	P.S.		disposal site			soil	0.0		
	TSS	44,600	R60-R61	midpt.		water	1.6		

* Metal samples identified by alphanumeric code, other samples identified by cross sect and distance

** Sample depth bottom applies only to core samples

Note: P.S. = particle size sample
TSS = total suspended solids
midpt. = midpoint of the lake cross section

Table 3. Concluded

Sample ID*	Analysis	Distance from dam (feet)	Lake cross section	Distance from reference Doint (feet)	Reference point	Material sampled	Sample; depth top (feet)	bottom** (feet)	Estimated depositional time period
	TSS	40,600	R58-R59	300	R58	water	3.3		
	TSS	40,600	R58-R59	1500	R58	water	3.3		
	TSS	38,600	R56-R57	150	R57	water	4.6		
	TSS	23,400	R20-R21	750	R20	water	4.9		
	TSS	23,400	R20-R21	750	R20	water	11.5		
	TSS	7,700	R08-R09	1000	R9	water	3.3		
	TSS	7,700	R08-R09	1000	R9	water	13.1		
	density	44,600	R60-R61	150	R61	sediment	0.3	0.6	
	density	44,600	R60-R61	150	R61	sediment	1.2	1.5	
	density	44,600	R60-R61	200	R61	sediment	0.2	0.5	
	density	44,600	R60-R61	200	R61	sediment	0.7	1.0	
	density	40,600	R58-R59	248	R58	sediment	0.2	0.5	
	density	40,600	R58-R59	248	R58	sediment	1.2	1.5	
	density	40,600	R58-R59	1557	R58	sediment	0.3	0.6	
	density	40,600	R58-R59	1557	R58	sediment	1.1	1.4	
	density	38,600	R56-R57	435	R56	sediment	0.1	0.4	
	density	38,600	R56-R57	435	R56	sediment	0.5	0.8	

* Metal samples identified by alphanumeric code, other samples identified by cross section and distance

** Sample depth bottom applies only to core samples

Note: TSS = total suspended solids

epoxidation product of aldrin (0.11 ppm), in the nation (Wiersma et al., 1972). The last appreciable use of aldrin was in 1977; heptachlor was discontinued after 1978 (Steffy et al., 1984).

Following the discontinuance of the use of chlorinated pesticides, many new families of pesticides were developed that were supposed to be more target-specific, more efficient, and more quickly degraded than previous pesticides. Some of the popular herbicides and insecticides in Illinois over the past five to ten years (Pike, 1986) are:

acetanilides: alachlor (Lasso) and metolachlor (Dual)
benzothiadiazoles: bentazon (Basagran)
dinitroanilines: trifluralin (Treflan)
thiocarbamates: butylate (Sutan)
triazines: atrazine (Atrazine), cyanazine (Bladex), metribuzin (Sencor-Lexone), and simazine (Princep)
organophosphate insecticides: terbufos (Counter), chloropyrifos (Lorsban/Dursban), and fonofos (Dyfonate)

Although these compounds are less persistent than the previous generation of pesticides, they are still persistent enough to be transported to many places (e.g., see Libra et al., 1986).

Contamination of Illinois surface waters and sediments with pesticides occurs primarily from agricultural runoff. A 1977 survey of Lakes Vermilion, Taylorville, Shelbyville, Carlyle, and Springfield (IEPA, 1978) found that lake and streambed sediments from all five lakes were contaminated with dieldrin and heptachlor epoxide, and those from all but Lake Vermilion were contaminated with chlordane. The mean concentrations of dieldrin, heptachlor epoxide, and chlordane for the five lakes were 14.1, 4.5, and 21.7 µg/kg, respectively. The concentrations of these pesticides in Lake Springfield sediments averaged 23.9 µg/kg dieldrin, 5.3 µg/kg heptachlor epoxide, and 24.1 µg/kg chlordane. The lake sediments were also analyzed for the pesticides atrazine, trifluralin, phorate, and Counter. Atrazine, phorate, and Counter did not exceed the detection limit in any sample. Trifluralin did exceed the 5 µg/kg detection limit in Lake Shelbyville (18 ppb), in four samples from Lake Taylorville (mean 13.2 ppb), and in 11 samples from Lake Springfield (mean 11.9 ppb).

In a 1979 survey of 63 lakes conducted by the Illinois Environmental Protection Agency (Kelly and Hite, 1981) for the organochlorine pesticides dieldrin, DDT, and heptachlor, dieldrin was detected in more sediment samples (58%) than any other pesticide. Heptachlor epoxide, the epoxidation product of heptachlor, was detected in 25% of the samples. The highest pesticide levels were found in lakes with large watersheds under intensive row crop cultivation. The Lake Springfield sediment sample analyses measured 20 µg/kg of dieldrin. Unfortunately, no similar study has been conducted to monitor the contamination of Illinois surface waters from pesticides that have taken the place of the organochlorines.

Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are also ubiquitous contaminants of aquatic sediments (Eisenreich, 1981). A PCB is any one of 209 compounds produced by chlorination of the biphenyl compound, which has ten positions available for chlorine atoms. PCBs were sold in the United States from 1929 to 1975, usually under the Aroclor trademark. PCBs were used as coolants and dielectric fluids in transformers and capacitors, as heat transfer fluids, and as coatings to reduce the flammability of wood products. Later they were incorporated into paints, inks, dust-control agents, carbonless paper, and pesticides. It is estimated that, by 1978, landfills contained 140×10^6 kg of PCB and that an additional 8.25×10^7 kg were still in the environment in forms available for transport, transformation, and accumulation (Alford-Stevens, 1986).

The occurrence of PAH in the environment has been well documented (National Academy of Sciences, 1972; Laflamme and Hites, 1978; Wakeham et al., 1980). PAHs are generated by the incomplete combustion of any material containing carbon and hydrogen. While some PAHs are of natural origin, most are the result of anthropogenic activities such as the combustion of gasoline (Pedersen et al., 1980), diesel fuel (Schuetzle et al., 1981) and coal (Lee et al., 1977). Inputs to aquatic sediments come primarily from urban stormwater runoff (Whipple and Hunter, 1979), municipal/industrial effluents (Eganhouse and Kaplan, 1982), and atmospheric deposition (Andren and Strand, 1981).

Collection and Analysis of Water Samples

Water samples for organic contaminant analysis were collected from six locations (figure 9 and table 3) on May 12, 1987. Samples were analyzed for dieldrin, atrazine, PCBs, heptachlor epoxide, chlordane, terbufos, alachlor, trifluralin, metolachlor, simazine, and PAH. At sampling locations with water depths less than 5 feet, water samples were taken at mid-depth. At deeper sites, samples were taken at approximately 3·feet above the bottom and 3 feet below the surface. The water was obtained with a peristaltic pump fitted with polyethylene tubing ahead of and behind the silicone tubing used in the pump head. Samples were collected in 1-liter amber glass bottles with teflon-lined caps. The bottles were cleaned with detergent, thoroughly rinsed with distilled water, and then heated in an oven to 400° for four hours before use. The samples were kept in an ice chest until their arrival at the lab, where they were transferred to a refrigerator and stored at 4°C until analysis.

The analytical procedures used were adapted from the U.S. Environmental Protection Agency (USEPA) (1982, 1987b). Briefly, the samples were extracted by using separatory funnel techniques. A 1-liter aliquot of water was placed in a 2-liter separatory funnel. The pH was adjusted to between 5 and 9, and a surrogate spiking solution was added to the sample. The sample was extracted by adding 60 ml of hexane and shaking the funnel for two minutes. The water and solvent layers were then allowed to separate for a period of 10 minutes before the solvents and water were drained and captured in separate vessels. The water was returned to the separatory funnel, and the process was repeated two more times. The solvent extracts were combined after each procedure. Upon completion of the extraction process, all remaining water was removed from the combined solvents by passing them through a drying column containing about 10 cm of anhydrous granular sodium sulfate. The solvents were collected in a Kuderna-Danish concentrator and placed on a hot water bath (90°C) so that the concentrator was partially immersed in the hot water. The solvent was then allowed to evaporate to a volume of approximately 10 ml. If sulfur crystals were present, an additional sulfur removal and extraction step was required. If sulfur was not present, the concentrator tube was placed under a gentle stream of clean, dry nitrogen, and evaporation was continued until the volume reached 0.5 ml. The extract was then transferred to an alumina cleanup column to remove organic compounds that were not of interest but that would interfere with the analysis. The alumina cleanup procedure involved passing the extract through a column of activity III neutral alumina. The extract was eluded with 10 ml of hexane. The extract volume was reduced to 0.5 ml under a dry nitrogen stream before transfer to a 1.0 ml volumetric flask and adjustment of the final volume to 1.0 ml. Gas chromatographic and gas chromatography/mass spectrometric analysis was performed on the extract.

Gas chromatographic and gas chromatography/mass spectrometric analysis of sediment extracts was performed on a Hewlett Packard 5890 GC/MS (gas chromatograph/mass spectrometer) with flame ionization detector, or a Hewlett Packard 5890 gas chromatograph/mass spectrometer with a 5970B mass selective detector (MSD). SPB 608 (Supelco) or DB-5 (J & W Scientific) bonded-phase fused-silica capillary columns (30m x 0.25mm interior diameter) were used for the analyses. The temperature program was as follows: 100°C for 4 minutes; then an increase to 290°C at the rate of 8°C per minute; then held at 290°C for 5 minutes. The injector temperature was 200°C, and MSD capillary direct interface was maintained at 280°C. The carrier gas was high-purity helium. Injection was in the on-column mode.

Collection and Analysis of Sediment Samples

Sediment samples were obtained from six locations in the Sugar Creek arm (figure 9 and table 2) on June 12,1987. A soil sample from near the dredge disposal site was obtained on the May 12 trip. Sediment samples were collected with a stainless steel coring device and were extruded directly into 1-liter large-mouth glass bottles with foil-lined caps. The bottles were washed and muffled as described above for water samples. The sediment samples were stored at the laboratory at 4°C until extraction.

The procedures used to extract the sediment samples were adapted from USEPA (1987) methods. Briefly, the procedure involved extraction of organic contaminants with 100 ml of a 1:1 mixture of hexane and acetone. The extraction was accomplished by using a 500 watt ultrasonic disrupter (Tekmar model TSD P-500) with a 3/4-inch horn. The extraction process was repeated three times, with the solvents collected by filtration after each turn. The combined solvent extracts were then transferred to a Kudema-Danish concentrator on a hot water bath, and solvent volume was reduced to about 10 ml. The extracts then underwent cleanup, with disposable 3-ml octadecyl (C_{18}) solid-phase extraction columns (J.T. Baker Chemical Co.) used to separate interfering compounds from the materials of interest. Following the clean-up step, the extract was concentrated to 0.5 ml by use of a Kuderna-Danish concentrator and dry nitrogen blow-down. Finally, the extract volume was reduced to 0.5 ml, transferred to a 1.0 ml volumetric flask and brought up to volume. The extract was readied for gas chromatographic and gas chromatography/mass spectrometric analysis as above.

Sampling for Metals

Background

Numerous reconnaissance and some research studies have been made of metals and toxic substances in aquatic sediments. Relevant case studies outside of Illinois are discussed first, followed by previous Illinois studies.

Selected Case Studies. Perhac (1972) found that Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn were most concentrated in fine-sized fractions of suspended sediments in two Tennessee streams. Since amounts of total suspended solids (TSS) were very low in these forested watersheds, despite 1,000-fold and greater concentrations of metals in TSS relative to water, most quantities of metals were transported in dissolved form. However, it was concluded that for streams with appreciable TSS, most metals would be transported in association with TSS.

Analysis of sediments from Narragansett Bay, Rhode Island, showed that essentially all Pb and Cu entering the bay were associated with sediments (Santachi et al., 1984). The content of a broad range of metals was found to be correlated with the clay-sized fraction of sediments in the Menomonee River watershed in Wisconsin (Dong et al., 1984). Metals in offshore sediments of Lake Erie were distributed bimodally between the 63 to 250 micron size (principally with large organic particles) and the <4 micron size. Metals close to shore were associated primarily with the clay-sized fraction (Murdock, 1984).

Sanchez and Lee (1978) studied Cu in the sediments of Lake Monona, Wisconsin, where copper sulfate had been used to control algae. They found that the sediments acted as a sink for Cu from accumulation of copper sulfide. Jackson (1979) studied the transport of mercury (Hg) through two connected lakes in Canada and found that Hg accumulated in association with organic matter in the lake sediments, with the greatest accumulation in the upstream lake. Wilber and Hunter (1979a and b) found that more than 50% of metals in sediments of the Saddle River, New Jersey, were associated with reducible iron oxides, being especially concentrated in the smaller silt- and clay-sized fractions.

Matson et al. (1969) have shown that Cd, Pb, and Cu do not exist in free ionic form in waters of the Great Lakes but rather as organic complexes. Evidence has been mounting over the last one or two decades that atmospheric deposition is an important, and perhaps the dominant, pathway by which heavy metals reach the Great Lakes (Winchester and Nifong, 1971; Gatz, 1975a; Eisenreich, 1980, 1982; Schmidt and Andren, 1983). Atmospheric deposition of metals to remote lakes in the mountains of northern New England and the Adirondack Mountains of New York has resulted in concentrations of metals in lake sediments of 100 ppm or more (Norton, 1986), values comparable to those for highly polluted sediments in northern Illinois (Van Luik, 1984; Cahill and Steele, 1986). These exceptionally and surprisingly high concentrations are apparently due to low rates of sedimentation and thereby relatively low dilution of atmospherically derived metals in lake sediments. A large amount of the metals in non-point urban runoff apparently come from large, locally derived aerosols (Gatz, 1975b; Wilber and Hunter, 1979a and b).

Most studies of sediments simply measure the total concentration of metals. Such studies do not consider the partitioning of potentially toxic elements among various reactive components of sediment, their potential to become bioavailable, and impacts on water chemistry under different environmental conditions. A review of the literature clearly shows that greater than 50% of total transition metals (e.g., Cu, Pd, Cd) are present in non-bioavailable mineral form that requires total sample destruction- to free the metals (Tessier et al., 1979). Useful information on the environmental chemistry of metals can be obtained by correlation analysis of total metal content with sediment physical and chemical properties. As with sequential extraction procedures, such information is used to evaluate transport, persistence, and environmental availability. For example, toxic substances associated with reducible metal oxides (Fe, Mn) are expected to become remobilized when these metals are solubilized under reducing conditions. Toxics associated with clays will accumulate in zones with sluggish flow, and so on.

Reviews of the metals/sediment interaction literature (Hem, 1977; Johannson, 1977; Jackson et al., 1978; Krug, 1978; Kiekens and Cottenie, 1983; Rapin and Foerstner, 1983) and toxic organics/sediment interaction literature (Helling et al., 1971; Weber, 1977; Khan, 1978; Brownawell and Farrington, 1985; Saltzmann and Yaron, 1986) show that the interactions of most toxic organic substances with sediments remarkably parallel those of metals.

Most transition metals and toxic organic substances have very limited solubilities in water and have great affinity for earth materials. Earth materials have three principal classes of chemically reactive components: minerals; hydrolysis products of Fe, Al, and Mn (sesquioxides); and organic matter. The latter two components, along with clay minerals and secondary sulfides and carbonates (which concentrate in fine-grained silty and clayey sediments), are especially reactive with toxic materials. This common behavior of metals and toxic organics does not appear to be recognized. Sequential extractions, used so far only for metals, will probably.be exceedingly useful in studying toxic organic/sediment interactions.

Previous Illinois Studies. Total metal contents have been analyzed for a number of Illinois lakes and streams. In highly polluted northern urban areas, the total concentrations of transition metals commonly are over 1,000 ppm. Lakes and streams in central and southern Illinois, while polluted, have lesser concentrations, totaling 100 to 200 ppm (IEPA, 1978; Cahill and Steele, 1986). Data for individual metals for specific lakes and groups of lakes are contained in tables 4 and 5.

Lake sediments of Lake Springfield and the central and southern Illinois lakes have been found to have from two to four times the metal content of the sediments in the tributaries that feed these lakes (table 4). These elevated concentrations of metals in lakebed materials are consistent with our hypothesis of the importance of sediment component analysis, as lakebed materials are finer-textured and higher in iron than streambed materials (table 6).

For eighteen backwater lakes on the Illinois River, metals were found to be most highly correlated with organic carbon, and secondly with Fe (table 7).

In summary, data for Illinois and elsewhere indicate that the sequential extraction approach of identifying metals/sediment component interactions is vital to the understanding of the effects of dredging and the biogeochemistry of metals.

The wealth of physical data that the Illinois State Water Survey has for Lake Springfield and other major lakes in the state, combined with the approach used in this study, would be invaluable to reconstructing the past water chemistry of Illinois lakes, as sediments act as integrators of water chemistry at the time of their deposition. For example, Cahill and Steele (1986) related the timing of elevated metals deposition in Lake Decatur sediments to the demise of certain benthic fauna in the lake.

Table 4. Average Total Values for Selected Metals in Sediment
from Five Illinois Lakes (Carlyle, Shelbyville, Vermilion,
Taylorville, and Springfield) and Their Watersheds*

	Cu (mg/1)	Cr (mg/1)	Pb (mg/1)	Hg (mg/1)	Zn (mg/1)	Fe (mg/1)
Average of all five lakes						
Streambed	14.2	8.7	13.8	0.06	44.9	10,562
Lakebed	23.8	24.1	24.3	0.11	87.7	20,030
Lake Springfield						
Streambed	12.5	9.2	16.9	0.07	51.0	13,280
Lakebed	34.1	36.7	26.9	0.13	98.5	20,435

* Data from IEPA (1978)

Table 5. Values for Selected Metals (in mg/1) in Sediment
from Some Illinois Lakes

	Cd (mg/1)	Cr (mg/1)	Cu (mg/1)	Hg (mg/1)	Ni (mg/1)	Pb (mg/1)	Zn (mg/1)
Illinois River*	0.8	127	67	0.35	47	77	483
Lake Michigan	0.9	46	22	0.11	24	40	97
Lake Paradise	<0.8	87	24	-	49	<5	94

*Eighteen impoundments on the Illinois River. Data from Cahill and Steele (1986).

Table 6. Average Size Distribution of Sediment from Five Illinois Lakes (Carlyle, Shelbyville, Vermilion, Taylorville, and Springfield) and their Watersheds, 1977*

	Clay (% dry weight)	Silt (% dry weieht)	Sand (% dry weight)
Average of all five lakes			
Streambed	12.3	32.8	54.9
Lakebed	39.3	47.5	13.2
Lake Springfield			
Streambed	16.5	46.7	36.8
Lakebed	38.8	50.7	10.5

* Data from IEPA (1978)

Note: Clay, silt, and sand are 0-2, 2-50,50-2,000 micron particle size classes, respectively.

Corrected particle size data for Lake Springfield. Except for stream clay data, all other data originally published were incorrect.

Table 7. Correlations between Selected Sediment Components and Metals in Illinois River Sediments*

Element or component	Clay	Carbon	Fe
Sand	0.10	0.17	N.D.
Silt	-0.99	0.19	N.D.
Clay		-0.21	0.29
Organic Carbon	-0.21		-0.38
Fe	0.29	-0.38	
Cd	-0.94	0.47	N.D.
Cr	0.35	0.74	N.D.
Cu	0.40	0.80	0.34
Hg	-0.09	0.69	N.D.
Ni	-0.44	0.71	N.D.
Pb	-0.89	0.70	0.29
Zn	-0.25	0.43	0.25

*For eighteen impoundments on the Illinois River. Data from Cahill and Steele (1986).

Collection and Analysis of Samples

Except for the type of container used, water and sediment from Lake Springfield (figure 9 and table 3) were sampled and handled prior to metal analysis in the same way as the samples collected for organic chemistry analysis. For metals, new 500-ml high density polypropylene bottles soaked in acid (HC1, 10% V/v) and thoroughly rinsed with deionized water were used. Water samples were filtered through deionized water rinsed in 0.45 micron metricil filters, and were analyzed for specific conductance and total dissolved solids. A number of cations were determined by inductively coupled argon plasma (ICP), and standard deviations were developed from five replicate analyses for each of the following parameters: Ag, Al, B, Ba, Be, Ca, Cd, Cr, Cu, Fe, K, Mg, Mo, Na, Ni, P, Pb, Sb, Se, Sr, Tl, V, and Zn. Filters from samples 6a and 8a (table 3) were saved for elemental analysis by neutron activation. Unfiltered water samples were digested in hot (70°C) concentrated pH 2.0 $HN0_3$ for one week (USEPA, 1983) and were analyzed for total constituents by ICP.

Sediments were processed by a sequential extraction procedure used by Tessier et al. (1979) and subsequently modified by Meguellati et al. (1983), Rapin and Foerstner (1983), Krug and Isaacson (1984), and Grabarek and Krug (1987).

RESULTS

Physical Properties of Lakebed Sediments

The time interval represented by sediment core samples obtained for physical and chemical analyses was determined by reference to the sedimentation survey data for the lake. Figure 10 is a cross-sectional topographic profile of Lake Springfield's bed elevation over time. These data were assembled from the sedimentation surveys of the lake performed in 1948, 1977, and 1984. The locations of core samples obtained for metal and organic chemistry analyses are also shown in figure 10. These locations were determined by infra-red electronic distance meter positioning of the sampling boat relative to surveying monuments on the lakeshore. The core for organic chemistry analysis was obtained on the cross section line 262 feet from the surveying monument R65 (figure 10). The core length was 1.6 feet and therefore penetrated to an elevation in the sediment below the lakebed surface measured in 1948. The core sample was estimated to include sediment deposited over the period ranging from the 1940s to 1987. A more precise determination of the time interval of the core sample could be performed by analyzing the rate of compaction over time in the sediments at this location in the lake. However, the very low levels of contamination observed in the chemical analyses indicated that this level of precision was not needed.

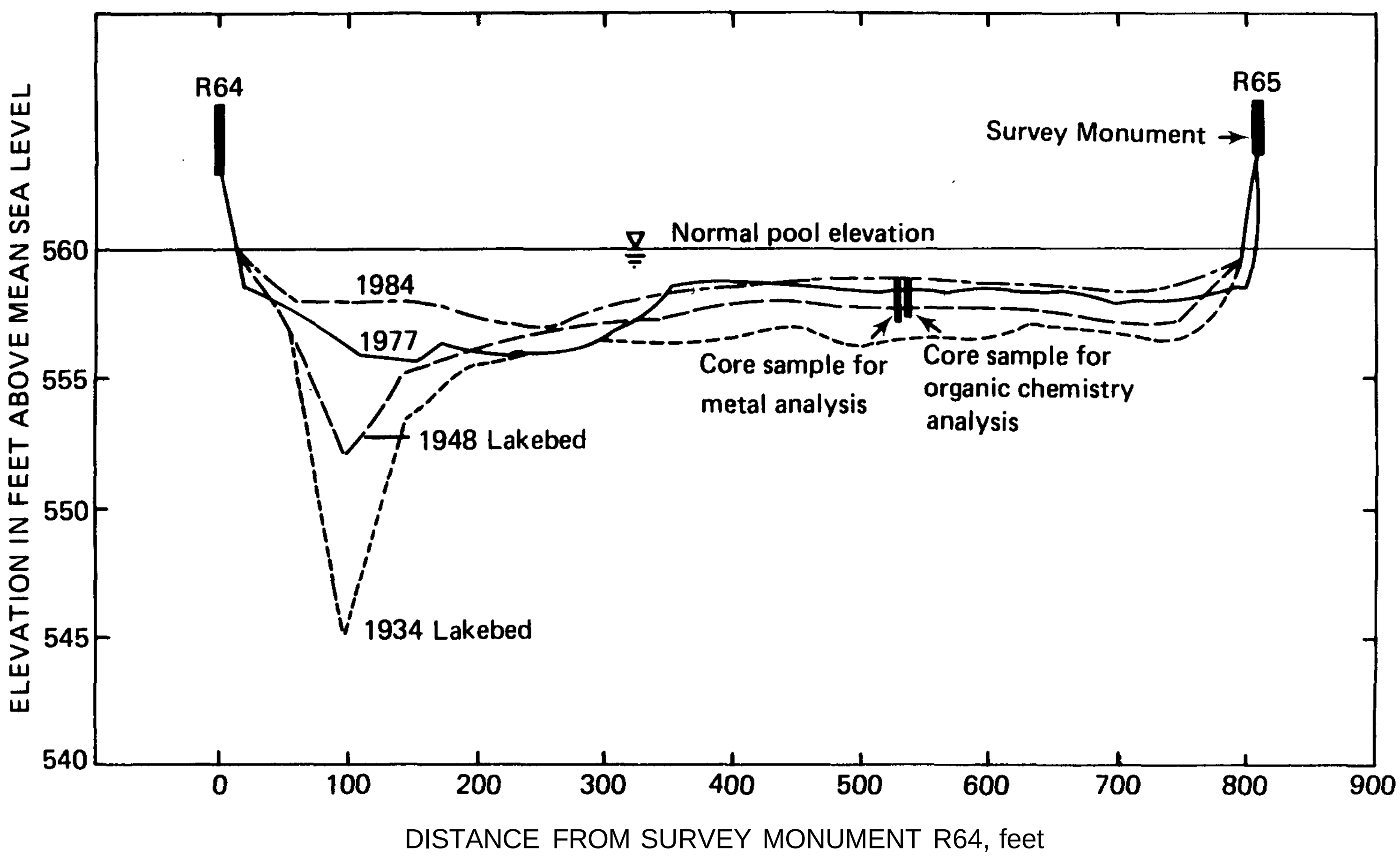

Figure 10. Cross-sectional topographic profile of Lake Springfield's bed elevation over time, showing core sample locations and sediment deposition patterns at cross section R64-R6S

The particle size of the lakebed sediments in the planned dredging areas was sampled to document the association of contaminants with various particle sizes. Many studies have shown that finer particles (silts and clay) have a greater association with contaminants than coarser particles (Perhac, 1972; Dong et al, 1984; Murdock, 1984; Jackson, 1979; IEPA, 1978). Sediments in Lake Springfield are known to be primarily silts and clays with a simple average, from 45 locations sampled in 1984, of 66% clay and 33% silt (Fitzpatrick et al., 1985). Finer sediments such as clays tend to remain in suspension in the water column much longer than coarser particles. Therefore if contaminated sediments are resuspended by dredging, these finer particles may be a source of contamination to the lake water and may also be redistributed areally within the lakebed sediments.

Table 8 presents the results of particle size analyses performed on core samples from Lake Springfield. Particles in sampled cores tend to be very fine, ranging from approximately 44% to over 69% clay. However, the chemical analyses showed very low levels of measured contamination in the sediment cores. Therefore although disturbance of the sediment by dredging activities could cause elevated turbidity levels, there is little indication that the sediment would release contaminants to the lake water.

Total suspended sediment in the lake water was measured on May 12, 1987, prior to the beginning of dredging activities in the lake. Figure 11 presents the results of total suspended sediment analyses of samples throughout the lake area from the upstream areas to the downstream areas of the lake near the dam. Total suspended sediment concentrations typically decrease in a downstream direction towards the dam because of the relatively low velocities of the lake water compared to the inflowing tributaries, which allow entrained sediment to settle out of suspension as the water moves through the lake (figure 11). These data provide background information on the gradient of suspended sediment concentrations under background conditions prior to dredging. They will be of value in assessing the effects of dredge-induced resuspension on lake water quality.

Organic Contaminants in Water and Lakebed Sediments

In previous studies of pesticide residues in Lake Springfield sediments (IEPA, 1978; Kelly and Hite, 1981), trace levels of dieldrin, heptachlor epoxide, and chlordane were detected. More recently, in September 1984, two surveys of Lake Springfield sediments were commissioned by the Springfield City Water, Light & Power Company (CWLP) to determine, among other things, levels of dieldrin, chlordane, PCBs, and several other organochlorine pesticides. These surveys, however, failed to detect any of the aforementioned pesticide residues.

The discrepancy between the CWLP results and those of previous studies illustrates one of the main problems typically encountered in studies of trace level pesticide residues in

Table 8. Particle Size Distribution of Lakebed Sediment Cores

Distance from dam (feet)	Lake cross section	Distance on cross section reference point (feet)	Reference point	Sample midpoint (feet)	Percent by weight Sand	Silt	Clay
44600	R60-R61	150	R61	0.10	0.72	53.10	46.18
44600	R60-R61	150	R61	0.65	0.78	52.27	46.95
44600	R60-R61	150	R61	1.55	0.30	49.71	49.99
44600	R60-R61	200	R61	0.10	1.31	48.34	50.35
44600	R60-R61	200	R61	1.25	0.38	55.63	43.99
40600	R58-R59	248	R58	0.55	0.07	30.36	69.57
40600	R58-R59	248	R58	1.55	0.10	32.72	67.18
40600	R58-R59	1557	R58	0.25	0.12	34.74	65.14
40600	R58-R59	1557	R58	1.05	0.16	30.82	69.02
40600	R58-R59	1557	R58	1.65	0.26	33.87	65.87
38600	R56-R57	435	R56	0.45	0.27	32.45	67.28
38600	R56-R57	435	R56	1.05	0.35	34.66	64.99

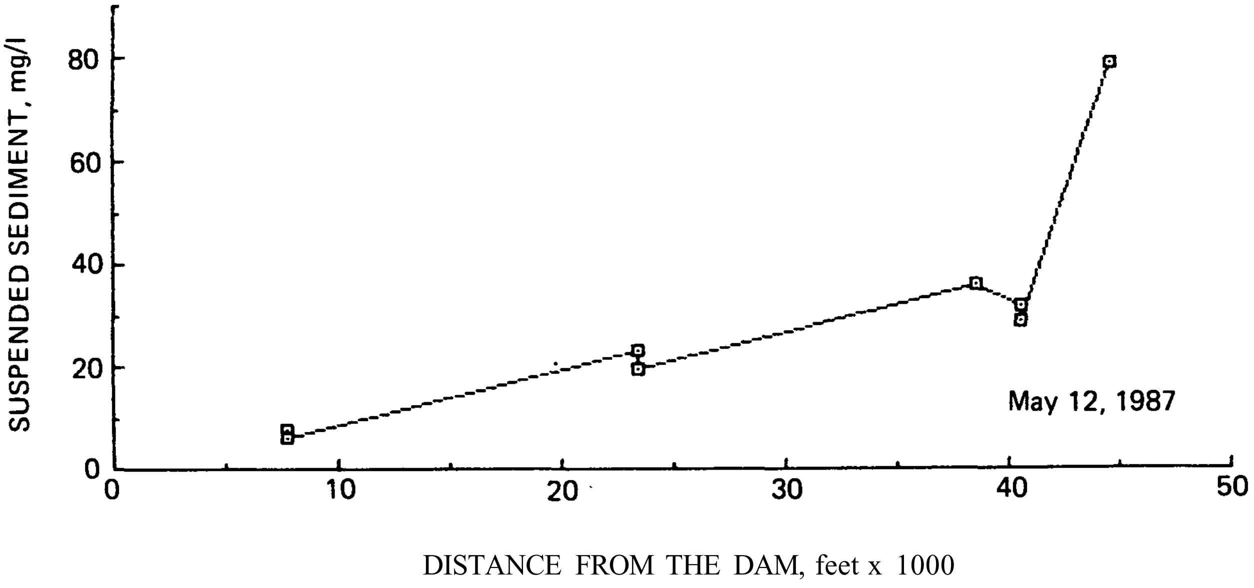

Figure 11. Suspended sediment concentration in Lake Springfield

sediments and water: the high degree of uncertainty of detection and quantification. The present study encountered similar problems. Due to unexpected problems with the preferred detector system, the electron-capture detector (NI-63 ECD), analyses were performed on the Hewlett Packard MSD gas chromatography system. The MSD is a mass spectrometer, and although it is a highly selective detector in the selected ion monitoring (SIM) mode, it is from 2 to 3 orders of magnitude less sensitive than the ECD for chlorinated compounds such as pesticide residues and PCBs.

Nevertheless, residues of the pesticide chlordane were detected in all sediment cores except the core from cross section R60-61 (table 3). It is also interesting to note that residues of heptachlor epoxide, but not of chlordane, were detected in the composite soil sample taken from the disposal site. No other pesticide residues or PCBs were detected in any of the water or sediment samples obtained for this study. Trace levels of polycyclic aromatic hydrocarbons (PAHs) were also detected in all sediment samples. The PAHs detected include naphthalene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, and chrysene.

The concentration levels of all pesticide residues and PAHs detected in the sediment and soil samples were too low to be reliably quantified. Concentrations for all contaminants detected were estimated to be in the range of 5 to 20 µg/kg (ppb). These values were derived by taking into account the sensitivity of the detector, the volume and percent moisture of sediment extracted, and the recovery efficiency of known pesticide standard spikes from sediment samples. The limit of detection for this study was approximately 3 µg/kg. The concentration level at which quantification would be statistically valid (ACS, 1983) was determined to be approximately 30 µg/kg.

These results indicate that the sediments of Lake Springfield still harbor low but detectable amounts of chlorinated pesticides that have not been used on agricultural lands for more than 10 years. Because these compounds are highly hydrophobic and are strongly sorbed to sediment particles, there is little tendency for them to migrate into the overlying water column unless the sediments are disturbed. The dredging process currently in use on the tributaries of Lake Springfield, while designed to create minimal disturbance and resuspension of sediments, will nonetheless cause some relocation of these contaminants. The potential magnitude of the problem cannot be assessed without further study.

Metal Chemistry of Lakebed Sediments

The data in table 9 show that a positive correlation exists between total suspended solids (TSS), total dissolved solids (TDS), and conductivity. Thus any process that increases TSS will

Table 9. Selected Filtered Water Chemistry Data for Lake Springfield*

Sample ID**	Conductivity (us/cm)	TSS (mg/l)	TDS 180°C (mg/l)	Al Conc. (mg/l)	Al S.D. (mg/l)	Ba Conc. (mg/l)	Ba S.D. (mg/l)
Blank	--	--	6	<0.019	--	<0.002	--
3a	513	36.15	312	<0.019	--	0.068	0.0016
4a	503	31.94	302	0.024	0.0612	0.070	0.0007
5a	526	28.77	297	<0.019	--	0.069	0.0001
6a	571	79.40	345	<0.019	--	0.079	0.0004
7a	493	23.07	279	<0.019	--	0.066	0.0003
7c	467	19.64	286	<0.019	--	0.065	0.0006
8a	474	7.86	281	<0.019	--	0.062	0.0003
8c	474	6.40	295	<0.019		0.061	0.0002

Sample ID**	Ca Cone. (mg/l)	Ca S.D. (mg/l)	Cd Conc. (mg/l)	Cd S.D. (mg/l)	Cr Cone. (mg/l)	Cr S.D. (mg/l)	Cu Cone. (mg/l)	Cu S.D. (mg/l)
Blank	0.01	0.004	<0.006	--	<0.005	--	<0.002	--
3a	48.77	0.793	<0.006	--	<0.005	--	<0.002	--
4a	47.50	1.333	<0.006	--	<0.005	--	<0.002	--
5a	48.14	0.093	<0.006	--	<0.005	--	<0.002	--
6a	60.91	0.185	<0.006	--	<0.005	--	<0.002	--
7a	44.93	0.082	<0.006	--	<0.005	--	<0.002	--
7c	45.08	0.153	<0.006	--	<0.005	--	<0.002	--
8a	45.12	0.146	<0.006	--	<0.005	--	<0.002	--
8c	44.21	0.088	<0.006	--	<0.005	--	<0.002	--

*Lake sampled May 12,1987. Elemental analyses were performed on filtered (0.45 micron) samples. "Less than" values are reported for analyses less than the estimated method detection limits for that particular element.

"Refer to table 3 for sample locations

Cone. = concentration; S.D. = standard deviation

Table 9. Concluded

	Fe		K		Mg		Na	
Sample ID**	Cone. (mg/1)	S.D. (mg/1)	Cone. (mg/1)	S.D. (mg/1)	Cone. (mg/1)	S.D. (mg/1)	Cone. (ms/1)	S.D. (mg/1)
Blank	0.008	0.006	<0.9	--	<0.001	--	0.04	0.031
3a	<0.004	--	<0.9	--	30.41	0.658	10.54	0.275
4a	<0.004	--	<0.9	--	29.19	0.847	11.69	0.089
5a	<0.004	--	<0.9	--	29.62	0.033	11.70	0.026
6a	<0.004	--	<0.9	--	29.85	0.130	14.13	0.087
7a	<0.004	--	<0.9	--	27.82	0.133	11.07	0.147
7c	<0.004	--	<0.9	--	27.83	0.158	10.91	0.091
8a	<0.004	--	<0.9	--	27.99	0.123	11.14	0.061
8c	<0.004		<0.9		27.60	0.086	10.99	0.037

	Ni		Pb		Sr		Zn	
Sample ID**	Cone. (mg/1)	S.D. (mg/1)	Cone. (ms/1)	S.D. (mg/1)	Cone. (mg/1)	S.D. (mg/1)	Cone. (mg/1)	S.D. (mg/1)
Blank	<0.017	--						
3a	<0.017	--	<0.04	--	0.159	0.0047	<0.004	--
4a	<0.017	--	<0.04	--	0.170	0.0037	<0.004	--
5a	<0.017	--	<0.04	--	0.165	0.0003	<0.004	--
6a	<0.017	--	<0.04	--	0.194	0.003	<0.004	--
7a	<0.017	--	<0.04	--	0.151	0.0013	<0.004	--
7c	<0.017	--	<0.04	--	0.149	0.0009	<0.004	--
8a	<0.017	--	<0.04	--	0.148	0.0006	<0.004	--
8c	<0.017	--	<0.04	--	0.146	0.0003	<0.004	--

*Lake sampled May 12,1987. Elemental analyses were performed on filtered (0.45 micron) samples. Less than values are reported for analyses less than the estimated method detection limits for that particular element.

**Refer to table 3 for sample locations

Cone. = concentration; S.D. = standard deviation most likely increase the concentration of dissolved constituents as well. Concentrations of metals, however, were all found to be very low and below detection limit by inductively coupled argon plasma (ICP).

Table 10 compares the concentrations of some filterable mineral substances with concentrations of total suspended solids (TSS). Although concentrations of the most common mineral element, silicon (Si), were not measured, it is apparent that TSS are related to suspended mineral substances (table 10). The only transition metal of concern to health that was measurably related to TSS was chromium (Cr) (table 11). The USEPA (1987a) recommends that Cr not exceed 0.050 mg/1 in drinking water. The maximum concentration of Cr in the unfiltered water sample was 0.009 mg/1 (table 11).

A sequential extraction procedure was applied to Lake Springfield sediments to determine not only total but different forms of environmentally and biologically available metal fractions.

Duplicate 1 g dry weight sediment samples were equilibrated with 1 M (molar) barium acetate pH 7.0 solution to determine exchangeable metals. Exchangeable metals are retained relatively weakly by sediment and are therefore readily released to the environment.

All values for exchangeable metals were below their respective detection limits. Accordingly, data for exchangeable metals are not reported.

One set of the duplicate sediment samples was digested in warm hydrogen peroxide for four days to determine the amount of metals associated with oxidizable organic matter and/or reduced inorganic substances, such as sulfides. Metals released by this treatment would theoretically be equivalent to the maximum values released upon oxidation of sediments in aerobic environs (such as land disposal of lake sediment). . All values for metals released upon oxidation were below their respective detection limits. Accordingly, these values are not reported.

The other set of duplicate sediment samples was digested for four days in warm HNO3 with a pH of approximately 2.0 (USEPA, 1983). This treatment releases all potentially reactive metals to solution. Only metals present in large particles, such as mineral grains, were not released to solution. These values are reported in table 12.

Table 12 includes blank values for the acid digestion procedure as well as for the barium acetate treatment for exchangeable metals. The acid digestion and barium treatment results are shown in table 12 because the sediments retained some barium, and barium acetate is slightly contaminated with metals of interest. The acid digestion blank does not contain any barium salt. The barium acetate blank contains 137,340 mg Ba/1, easily thousands of times the barium retained and re-released by the sediments upon acid digestion. Accordingly, table 12 illustrates

Table 10. Total Suspended Solids (TSS), Some Measured Filterable Substances, and Sum of Some Measured Filterable Substances from Lake Springfield
(in mg/1)

Sample*	TSS	Sample	Filterable Ca	Ca as Ca CO_3	Filterable Al	Al as Al_2 O_3	Filterable Fe	Fe as Fe_2O_3	Sum of Ca + Al + Fe as Fe_2O_3 $CaCo_3$ + Al_2O_3
3a	36.15	3b	2.61	6.53	2.00	3.79	1.07	1.53	11.85
4a	31.94	4b	2.70	6.75	2.25	4.26	1.21	1.73	12.74
5a	28.77	5b	1.42	3.55	2.16	4.08	1.21	1.73	9.36
6a	79.40	6b	1.73	4.32	4.19	7.92	2.09	3.52	15.76
7a	23.07	7b	2.51	6.25	1.64	3.09	0.83	1.19	10.53
7c	19.64	7d	2.01	5.03	1.59	3.00	0.74	1.06	9.09
8a	7.86	8b	1.05	2.62	0.52	0.97	0.24	0.34	3.93
8c	6.40	8d	2.18	5.45	0.58	1.09	0.20	0.29	6.83

* See table 3 for sample locations

Note: Lake sampled May 12,1987. Filterable = dissolved minus total digested

Table 11. Selected Unfiltered Water Chemistry Data for Lake Springfield

	Al		Ba		Ca		Cd	
Sample ID*	Cone. (me/1)	S.D. (me/1)	Cone. (me/1)	S.D. me/1)	Cone. (me/1)	S.D. (me/1)	Cone. (mg/1)	S.D. (mg/l)
Blank 1	0.311	0.004	<0.002	0.000	0.719	0.009	<0.006	0.002
Blank 1	<0.019	0.003	<0.002	0.000	0.479	0.009	<0.006	0.001
3B	2.023	0.020	0.082	0.000	51.38	0.19	<0.006	0.001
4B	2.277	0.028	0.083	0.001	50.20	0.45	<0.006	0.002
5B	2.179	0.022	0.083	0.001	49.56	0.33	<0.006	0.001
6B	4.207	0.023	0.109	0.001	62.64	0.32	<0.006	0.002
7B	1.657	0.012	0.073	0.001	47.44	0.22	<0.006	0.002
7D	1.607	0.101	0.071	0.000	47.09	0.11	<0.006	0.002
8B	0.535	0.006	0.061	0.000	46.17	0.04	<0.006	0.003
8D	0.597	0.010	0.061	0.001	46.39	0.19	<0.006	0.002

	Ni		Pb		Zn		Cr	
Sample ID*	Cone. (mg/1)	S.D. (me/1)	Cone. (mg/1)	S.D. me/1)	Cone. (me/1)	S.D. (mg/1)	Cone. (mg/1)	S.D. (mg/l)
Blank 1	<0.017		<0.04	--	<0.004	--	<0.005	0.001
Blank 2	<0.017	--	<0.04	--	<0.004	--	<0.005	0.001
3B	<0.017	--	<0.04	--	<0.004	--	0.006	0.000
4B	<0.017	--	<0.04	--	<0.004	--	0.008	0.001
5B	<0.017	--	<0.04	--	<0.004	--	0.008	0.002
6B	<0.017	--	<0.04	--	<0.004	--	0.007	0.001
7B	<0.017	--	<0.04	--	<0.004	--	0.009	0.002
7D	<0.017	--	<0.04	--	<0.004	--	0.009	0.001
8B	<0.017	--	<0.04	--	<0.004	--	0.008	0.000
8D	<0.017	--	<0.04	--	<0.004	--	0.008	0.001

	Cu		Fe		K		Mg		Na	
Sample ID*	Cone. (mg/l)	S.D. (mg/l)	Cone. (me/1)	S.D. (me/1)	Cone. (me/1)	S.D. (me/1)	Cone. (mg/1)	S.D. (mg/1)	Cone (mg/1)	S.D. (mg/l)
Blank 1	<0.002	0.001	0.026	0.001	<0.9	0.3	0.73	0.01	1.52	0.02
Blank 2	<0.002	0.000	<0.004	0.001	1.9	0.3	0.41	0.01	1.35	0.01
3B	0.005	0.001	1.070	0.008	2.3	0.3	32.10	0.14	12.46	0.11
4B	0.002	0.001	1.209	0.017	2.6	0.5	30.78	0.31	12.94	0.19
5B	<0.002	0.001	1.214	0.005	2.6	0.3	30.22	0.23	12.54	0.12
6B	<0.002	0.000	2.092	0.008	2.9	0.1	30.88	0.16	16.33	0.10
7B	<0.002	0.001	0.829	0.008	3.3	0.2	29.06	0.14	12.15	0.06
7D	<0.002	0.000	0.740	0.003	3.6	0.3	28.84	0.10	12.43	0.05
8B	<0.002	0.001	0.235	0.002	2.6	0.2	28.43	0.11	11.74	0.24
8D	<0.002	0.001	0.205	0.001	3.0	0.3	28.70	0.15	12.19	0.09

*See table 3 for sample locations

Table 12. Potentially Environmentally and Biologically Available (Acid-Extractable) Metals in Lake Springfield Sediments
(in mg/1)

Sample*	Al	Cd	Cr	Ca	Fe	Ni	Pb	Zn
1	6,800	1.4	13.7	43.8	15,200	16.8	43.6	80.5
2	6,400	1.5	13.8	43.7	18,700	17.4	41.4	82.4
3	9,500	1.5	18.8	56.3	15,500	18.8	62.6	88.5
4	9,700	2.2	21.4	53.5	15,400	17.5	68.6	92.1
5	8,300	1.8	17.2	52.5	15,400	16.9	52.3	90.8
6	9,000	1.5	19.5	52.1	14,800	17.4	58.3	92.4
7	9,100	1.5	18.8	51.1	17,900	16.2	51.9	101.9
8	7,900	1.2	17.3	41.9	13,900	16.3	51.6	92.2
9	7,400	1.3	16.5	46.2	14,800	16.6	50.9	96.8
Blank	<100	<0.8	<1.4	<1.7	<100	<1.8	<4.2	<2.7
Blank-Ba	<100	<4	41	<10	<2	<20	<15	10

*See table 3 for sample locations

Note: Blank = blank values for the acid digestion procedure; Blank-Ba = blank values for the barium acetate treatment that concentrations of acid-extractable metals are not expected to be measurably influenced by barium contamination.

Table 12 shows that concentrations of potentially environmentally and biologically available metals in Lake Springfield sediments are relatively low when compared to the total metal concentrations of some other lake sediments (table 5). Nevertheless, it appears that these lake sediments act as a sink for most measured metals and that these pollutants persist in the environment. The one exception appears to be cadmium. Cadmium forms relatively strong complexes with chloride and sulfate (plentiful anionic ligands in Lake Springfield and most Illinois waters) and reacts relatively weakly with the reactive components of sediments (Krug, 1978). Accordingly, cadmium simply appears to move with the water through the reservoir with little deposition in the lakebed sediments.

The total metal content of Lake Springfield sediments was determined by lithium borate fusion at 950°C, and the fused material was transferred to 1 molar $HN0_3$. These data are presented in table 13. The fusion method for determination of total metals theoretically underestimates total metal concentrations becuse the high temperature results in some vaporization of metals (Lamothe et al., 1986). Volatilization losses of metals are expected to be especially severe for metals whose boiling points are below 950°C ~ the temperature used to fuse the sample. The boiling points of Cd and Zn are 765 and 907°C, respectively. Table 13 shows that the total metals contents of Lake Springfield sediments are relatively low. Values from tables 12 and 13 can be compared to see what fraction of total metals are "available" or "non-available," taking into consideration the above-stated caveats.

The Illinois State Water Survey has recently acquired equipment that will enable fusion analyses to be performed without volatilization loss of metals. The new fusion method of analysis is under development.

Analysis of Lake Springfield sediments shows that they are about 50% water by weight. Thus release of sediment pore water upon decantation of lake sediment after land application will release this pore water back to Lake Springfield and local ground water.

Table 14 shows that the concentrations of all metals in pore-water samples are below detection limits except those for Cr. At elevated concentrations, chromium is an especially toxic metal (especially in its hexavalent state). Accordingly, the USEPA's (1987a) recommended limit in drinking water is only 0.050 mg/1.

These limited data show that Lake Springfield sediments have relatively low concentrations of total and environmentally and biologically available metals.

Table 13. Total Metal Content of Lake Springfield Sediments
(in mg/l)

Replicate sample*	Al	Cd	Cr	Ca	Fe	Ni	Pb	Zn
1a	59,000	<12	88	32	25,400	132	<144	52
1b	62,000	<12	63	<24	27,300	92	<144	54
2a	54,500	<12	82	32	25,500	<88	<144	68
2b	61,400	<12	72	<24	28,800	<88	<144	60
3a	72,100	<12	111	54	35,400	<88	<144	132
3b	79,600	12	88	<24	38,600	<88	<144	96
4a	70,800	<12	88	36	34,800	<88	<144	80
4b	74,800	<12	67	42	36,100	<88	<144	358
5a	70,200	<12	100	43	32,300	<88	<144	143
5b	69,000	<12	88	38	31,400	<88	<144	121
6a	73,800	<12	96	42	35,900	100	<144	87
6b	75,600	<12	64	44	36,100	<88	<144	140
7a	71,000	<12	96	42	33,800	<88	<144	96
7b	72,800	<12	62	38	34,600	<88	<144	138
8a	63,900	<12	100	52	28,500	<88	<144	64
8b	66,500	15	58	31	30,200	<88	<144	112
9a	68,000	<12	68	32	31,200	<88	<144	68
9b	62,900	<12	72	32	28,800	<88	<144	108
Blank a	<2,400	<12	<32	<24	<120	<88	<144	<2
Blank b	<560	<12	<32	<24	<208	<88	<144	<2

*See table 3 for sample locations

Table 14. Concentration of Metals in Lake Springfield Sediment Pore Waters
(in mg/1)

Sample*	Al	Cd	Cr	Ca	Fe	Ni	Pb	Zn
4a	<0.05	<0.008	0.039	<0.017	<0.1	<0.018	<0.042	<0.027
6a	<0.05	<0.008	0.053	<0.017	<0.1	<0.018	<0.042	<0.027
8c	<0.05	<0.008	0.046	<0.017	<0.1	<0.018	<0.042	<0.027
Blank	<0.05	<0.008	<0.014	<0.017	<0.1	<0.018	<0.0042	<0.027

*See table 3 for sample locations

SUMMARY

This report summarizes the results of a research project initiated under the sponsorship of the Department of Energy and Natural Resources (ENR) for the evaluation of lake dredging in Illinois with a special emphasis on pre-dredging conditions at Lake Springfield.

Many Illinois lakes have been facing acute sedimentation problems, and lake dredging may be one of the best alternatives for revitalizing Illinois lakes. At least 12 Illinois lakes are losing their capacities at the rate of 2% or more per year, indicating that in about 25 years from the date of construction, these lakes may lose 50% of their capacities. In most lakes, the upper portions have already silted to such an extent that they are close to becoming mudflats.

A summary of 12 lake dredging projects has been made and is included in this report.

A fairly comprehensive literature review indicated that a significant amount of information on physical effects of dredging on open flowing water (navigation waterways) and marine environments is available. However, information on the physical impacts of dredging of small- to medium-sized lakes is lacking. Some of the physical impacts such as increased turbidity, resuspension and movement of sediment, and alteration in biological habitats should be similar in riverine and lacustrine environments.

Field data on both water and deposited sediment were collected in May and June 1987. These data were collected before the actual dredging was begun. All the sampling was done with state-of-the-art instrumentation and equipment. Samples were subsectioned for the determination of physical and chemical characteristics, including sediment concentration, particle size distribution, trace metal characteristics, and organic components.

A detailed explanation of the procedures used in the organic component and trace metal analyses is included in the report. A review of the sources of the organic contaminants of the lakebed sediments indicated the diverse flow path to this sink, with the majority of the loads originating in the agricultural watershed and being transported to the lake with water and sediment. In 1982, more than 72 million pounds of pesticides were applied to Illinois farmland. By 1985, the number had dropped to about 67 million pounds. Massive application of pesticides in Illinois has resulted in higher than average concentrations of some organic compounds in Illinois soils.

An evaluation of existing data on lake sediments from many Illinois lakes shows that sediments in many lakes are contaminated with dieldrin, heptachlor, epoxide, and chlordane. Trifluralin was also found in some samples. In the IEPA's evaluation of 63 Illinois lakes in 1979, it was found that the organic contamination of lakebed sediments was greatest for lakes with large agricultural watersheds. The 1979 study was concentrated on organochlorine insecticides, and no similar studies have been conducted in recent years to determine the contamination of

Illinois surface waters and sediments from pesticides that have taken the place of organochlorines.

A detailed evaluation of the metal chemistry of lakebed sediments has shown that most of the metals are transported to the lake environment as suspended solids. A close affinity of the metals with fine sediments has been observed in almost all cases. Physical characteristics of deposited sediment in Illinois lakes indicate that these are almost 80 to 90% by weight in the clay and silt ranges. These fine sediments are acting as a sink for many of the metals introduced within the water, soil, and atmospheric environments.

Some of the existing data on metal concentrations in lakebed sediments from Lake Springfield and central and southern Illinois lakes show that the metal concentration of the sediments is two to four times higher than in the sediments in tributary streams that feed these lakes. In some of the highly polluted environments of northern Illinois, total concentrations of transition metals commonly sum up to over 1000 ppm. For many backwater lakes along the Illinois River, metals in sediments are strongly correlated with organic carbon.

The metal chemistry analysis of Lake Springfield's sediment indicated that a positive correlation exists between total suspended solids (TSS), total dissolved solids (TDS), and conductivity. Therefore an increase in TSS (because of an operation such as dredging) will most likely be associated with an increase in the concentration of dissolved constituents.

The organic chemistry analysis of Lake Springfield's sediment showed very low concentrations of the organochlorine pesticides chlordane and heptachlor epoxide, as well as of polycyclic aromatic hydrocarbons. Levels of these parameters were below reliable quantification limits but above detection limits. These parameters were estimated to be in the range of 5 to 20 µg/kg. No other pesticide residues or PCBs were detected in any of the water or sediment samples.

Samples of the lakebed materials from various locations in the Sugar Creek arm of the lake, representing materials deposited over the time periods of the 1940s to the present, were obtained for analyses of metal and organic contaminants. Chemical analyses for selected metal and organic chemical parameters showed very low levels of contamination. Therefore if these materials are resuspended by dredging activities, they are expected to pose no significant threat to lake water quality and uses.

Additional data on the gradient of suspended sediments in the lake water and the chemistry of these sediments should be obtained by further study to determine the effects of dredging activities on the lake water quality and lake uses. The present study obtained valuable data on background pre-dredging conditions related to lake water chemistry, sediment chemistry, and total suspended sediment concentrations in the lake water. This information can be used as background data for analyses of the effects of dredging on the lake, and additional research will benefit greatly from this work.

Recommendations

A continuation of the research from pre-dredging to post-dredging is essential in order to determine the physical and chemical impacts of dredging of lakes such as Lake Springfield. Many other cities and communities are contemplating dredging their water supply lakes, and lessons learned from the Lake Springfield project must be applied in order to revitalize the important lake resources of Illinois. The Lake Springfield project is thus a very important project not only for the city of Springfield but also for the natural resources agencies in Illinois. Moreover, the availability of scientific data and evaluations of those data make it much easier for individual communities to justify dredging programs and to properly execute dredging operations so as to cause minimal environmental impacts. In accordance with these premises, the following recommendations are made.

1. During the dredging operation at Lake Springfield, field data should be collected on water quality, resuspension and movement of sediment, sediment quality (both organics and metals), and redeposition of disturbed materials. Data should also be obtained to determine the quality of return water from the dredge disposal sites with respect to trace metals and organic chemistry.
2. Collections of physical and chemical data (for both sediments and lake water) should be continued for the duration of the dredging project.
3. The lake water quality should be monitored downstream from the dredging site.
4. All the data collected for the project should be analyzed and evaluated.
5. An evaluation should be made of the application of the lake dredging techniques at Lake Springfield to other lakes in Illinois.

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