Contract Report 564

Frank Holten State Park Lakes:
Phase III, Post-Restoration Monitoring

by Raman K. Raman and William C. Bogner
Offices of Water Quality Management and Hydraulics & River Mechanics

Prepared for the
Illinois Environmental Protection Agency

December 1994

Illinois State Water Survey
Chemistry and Hydrology Divisions
Champaign, Illinois

A Division of the Illinois Department of Energy and Natural Resources

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EXECUTIVE SUMMARY

Whispering Willow Lake and Grand Marais Lake, collectively called Frank Holten State Park Lakes, lie within the Frank Holten State Park located in northwest St. Clair County in Illinois (figure 1). Whispering Willow Lake consists of two distinct water bodies, designated as Lake 1 and Lake 2 in this investigation, and Grand Marais Lake is designated as Lake 3. These designations are shown schematically in figure 2. The park and lakes are surrounded by East St. Louis urban development and are easily accessible from Interstates 255, 70, 64, and 55. These lakes, the remnants of a Mississippi River meander cutoff oxbow lakes, have a combined surface area of about 179 acres.

The Department of Conservation (IDOC) manages these publicly-owned lakes and the surrounding park for outdoor recreational activities, such as fishing, boating, picnicking, and hiking.

Prior to the commencement of restoration of the lakes and the parkgrounds in 1977, the area was visibly blighted by trash, junk, and grounds that were in need of mowing. The crime rate on the parkgrounds was also high for an Illinois state park. The three lakes were choked with sediment and rooted aquatic vegetation. Harding Ditch, the major tributary to the lake system, entered directly into Lake 3, depositing an estimated 50,000 cubic yards of sediment annually. It was reported in 1975 that Lake 3 was only about half the size that it was 15 to 20 years earlier.

To protect against future degradation of the lakes, IDOC undertook several measures with federal and state funding to reduce the external sources of lake degradation and maintain better lake water quality. The first measure was to divert Harding Ditch, the major source of nutrient and sediment loading, away from the lakes. The second measure included construction of a ditch between Lakes 2 and 3 to carry outflows from Lakes 1 and 2, and construction of a concrete inverted siphon across Interstate 255 and the Harding Ditch before entering Lake 3. The third measure included dredging all three lakes beginning in September 1981 and ending in July 1985. In all, a total of about 880,000 cubic yards of sediment were dredged and deposited in on-site dredged spoils disposal cells. The final step in the restoration program consisted of the removal of rough fish in the lakes, followed by restocking with game fish. Prior to this fish eradication program, fishing by trammel nets was permitted for ten days, and the fish taken were sold at the site.

The Clean Lakes Program of the U.S. Environmental Protection Agency (USEPA) provided $927,000 in March 1977 to partially cover the cost of the Harding Ditch diversion, construction of the inverted syphon, and dredging of Lakes 1 and 2. This was later supplemented with an additional award of $143,731 for total support of $1,070,731. The IDOC and the Illinois Department of Transportation (IDOT) together spent more than $5 million for dredging and park improvements.

The primary objective of the current investigation was to assess and delineate the long-term effectiveness of past restoration techniques for the lakes by comparing current and pre-restoration conditions of the lakes in the State Park, and to suggest methods to increase the effectiveness of the restoration techniques.

Based on the limnological data gathered for the lakes from 1988 to 1992 and user surveys, the following observations, conclusions, and recommendations can be made.

Observations and Conclusions

The overall impact on the park of the change in park management, the implementation of the USEPA-assisted Clean Lakes Program, and the completed lake restoration work has been very significant. Frank Holten State Park is now safe to visit and displays a landscape and lakes that are aesthetically attractive and conducive to outdoor recreational activities.

A user survey carried out during the summer of 1991 revealed that the park facilities are now safe and highly considered as a recreational resource. Gone are the criminals and the landscape strewn with garbage and discarded refrigerators and choked with uncut grass. Gone also are the weed-filled, shallow lakes overrun by rough fish.

A creel survey conducted in the lakes from March 15 to November 15, 1991, reveals that the fish and fishing opportunities are of very poor quality. The respondents, specifically anglers, rated the fishing opportunity at 2.7 on a scale of 1-10.

The poor quality of fisheries in the lakes can partly be attributed to the total absence of any aquatic macrophyte beds. Even the undredged areas of Lakes 1 and 2 are devoid of rooted vegetation. The lakebeds are devoid of any aquatic habitat structures and resemble an aquatic desert. The reasons for this total absence of aquatic vegetation are not known with certainty. One major reason could be the steep bank slopes of 3:1 used in dredging the lakes, which resulted in a relatively narrow littoral zone. An attempt was made to assess the physical characteristic such as bed material composition, in-situ shear strength, fetch, etc., in order to gain an insight about the total lack of vegetation in the lakes but the data gathered were inconclusive.

The diversion of Harding Ditch around Lake 3 has eliminated the influx of sediment and nutrient loads into Lake 3 during dry weather and moderate rainfall events. However, during heavy rainfall/runoff periods there is still interconnection between Harding Ditch and the outlet end of Lake 3.

Sedimentation conditions in the lakes appear to have been stabilized by the diversion of Harding Ditch. By bypassing Ditch flows around the lakes instead of passing it through them, sediment inputs to the lakes have been reduced to 2 percent of pre-restoration estimates.

Hydrologic conditions in the lakes following restoration continue to depend on Harding Ditch in order to maintain stable lake levels. Water levels in Lake 3 were maintained throughout the phase III monitoring period by the connection between the lake and the Ditch. Abrupt changes in Lake 3 water levels were always a result of storm flows in the Ditch or the clearing of beaver dams from the Ditch.

In Lakes 1 and 2, water levels were stable during winter periods when Lake 3 water backed up through the interconnecting channel. Water levels tended to decline steadily during the summer and fall seasons when Lake 3 levels dropped below the controlling elevation in the interconnecting channel.

The dredging increased water depths in all affected portions of the lakes. Water depths of 8 feet now exist from bank to bank in most of the dredged areas of the lakes. An area of the southwest basin of Lake 3 was dredged to a 4-foot depth. These depth conditions should remain stable for an extended period due to the very effective diversion of Harding Ditch flows around and past the lakes. The southwest basin of Lake 3 is likely to be more heavily impacted by sedimentation due to continued backup of Harding Ditch stormflow water.

The oxygen conditions in the lakes are very similar to conditions at lakes in other parts of the state. Lake 2, the deepest of the three lakes, exhibits typical summer stratification. The two shallow lakes (Lakes 1 and 3) exhibit temperature gradients during summer months. The oxygen conditions at depths below 8 to 10 feet from the surface are less than 5 mg/L during summer months, a level considered necessary to support desirable fish species.

All the lakes are highly eutrophic, exhibiting high nutrient concentrations, low Secchi disc visibility, low oxygen levels during summer months, high chlorophyll *a* concentrations, etc. Dredging did not significantly enhance the physical, chemical, and biological water quality characteristics in the lakes, but the lake volume in each lake has increased, and excessive aquatic weed growth has been brought under control.

There was no statistical difference between the data observed during the restoration and post-restoration periods for the following parameters: surface dissolved oxygen, total and dissolved phosphate-P, total suspended solids, and chlorophyll *a.* Significantly higher levels of nitrate were measured in Lake 3 compared to the other two lakes during the restoration and post-restoration periods. Total ammonia-N concentrations for the post-restoration period in all three lakes were lower compared to the observations made during the restoration period. Observed total alkalinity in Lakes 1, 2, and 3 was statistically similar for both monitoring periods, although Lake 3 had significantly higher observed total alkalinity than Lakes 1 and 2.

Recommendations

- Since the dissolved oxygen conditions in the lakes deteriorate during the summer months, thus limiting the extent of fish habitat, anoxic conditions in the deeper waters of the Lake 2 should be alleviated.
- A detailed investigation should be carried out to identify and alleviate the causes of a total lack of submerged vegetation in the lakes, which severely restricts the habitat for fish and fish food organisms. This may be the primary reason for the poor quality

of fisheries in the lakes as revealed by creel census. Installing artifical fish cribs, brush, and other fish habitat structures at strategic locations could be considered to improve fisheries. Techniques for restoring aquatic vegetation found successful by Roseboom *et al.* (1989) in Peoria Lake, with the attendant improvement in sport fisheries, could also be tried.

- Bottom sediments in and around the storm drain bay area of Lake 1 should be removed to help alleviate the anoxic conditions. Because this area is shallower than 4 feet, a horizontal flow mechanical mixing and aeration device should be considered as an alternative. This would enhance the oxic conditions in the water and the sediments, and thus mitigate the pervasive foul smell.
- The stagnant conditions in the storm drainpipe culverts in Lake 1 should be controlled by improving the hydraulic circulation patterns in the culverts using a strategically placed circulating pump.
- The logjam in Harding Ditch that causes its flow to back up into Lake 3, creating inundation problems, should be removed, and the ditch should be maintained for maximum conveyance.
- Construction of the Harding Ditch levee across the outlet from Lake 3 should be completed to provide full protection of the lake system from pollution by storm water. Construction of new outlet works for the lake system should be considered to limit backflow of water from the Ditch and at the same time allow outflows from Lake 3. The storm event impact of the Ditch on the lakes would be reduced, but water required to maintain the summer lake level should still be able to enter the lake. Water level should be controlled in Harding Ditch to back up water through Lake 3 to Lakes 1 and 2 to maintain all three lakes at a common level. This may necessitate clearing of the "siphon" and lowering the bed of the interconnecting channel between Lakes 2 and 3.

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INTRODUCTION

A long-term post-restoration monitoring project at Frank Holten State Park (FHSP) Lakes in St. Clair County, Illinois, from 1988 to 1992 was undertaken by the Illinois Environmental Protection Agency (IEPA) in cooperation with the Illinois State Water Survey Division - Department of Energy and Natural Resources (ISWS-ENR) and the Illinois Department of Conservation (IDOC). This monitoring study, comprising *in-situ* observations, and water and sediment samples collection for physical, chemical, and biological assessments, was designed to build upon an extensive database of monthly samples collected from one site in each of three lakes by the Illinois Natural History Survey (INHS) during the lakes' restoration period (1977-1983). Post-restoration data for the three lakes are available for the period October 1983 to June 1984 (collected by INHS) and for the period from April to October 1988 (collected by IEPA). Details of all these monitoring schemes will be dealt with subsequently.

The primary objective of the current (phase III) post-restoration monitoring program was to assess and delineate the long-term effectiveness of the restoration techniques employed in the past at the FHSP Lakes by comparing current lake conditions with their pre-restoration conditions in the state park, and suggest how to increase the efficiency and effectiveness of the restoration techniques employed.

The post-restoration monitoring study was funded by the U.S. Environmental Protection Agency (USEPA) through the IEPA, with non-federal cost-sharing provided by IDOC, IEPA, and ENR, all under the provisions of Section 314 of Public Law 95-217 of the Clean Water Act. The federal share of this study amounted to $134,216, and the state agencies contributed collectively $57,521, for a total of $181,737.

Frank Holten State Park, located in northwest St. Clair County, Illinois, within sight of the St. Louis Gateway Arch, is an urban park almost entirely surrounded by East

St. Louis (figure 1). The 1,125-acre park was established in 1964 and named Grand Marais. Harding Ditch flows through the park. Its name was changed to Frank Holten State Park on May 1, 1967, in honor of the late distinguished legislator from East St. Louis. The park contains three small lakes with an estimated combined area of 179 acres, having a combined shoreline of 7.2 miles. These lakes are the remains of what was once a natural oxbow lake of the Mississippi River. The present lake configuration (figure 2) is the result of hydrologic modifications to the oxbow lakes in the 1930s. Lake 1, the northernmost lake, has a surface area of 59 acres; Lake 2 has an areal extent of 42 acres; and Lake 3, the southernmost lake, covers about 78 acres. Lakes 1 and 2 together are commonly known as Whispering Willow Lake, and Lake 3 is known as Grand Marais Lake. Harding Ditch was the major source of sediment and nutrient input to Lake 3 before the lake restoration scheme was carried out.

These publicly-owned lakes and the surrounding park are managed by the IDOC for outdoor recreational activities, which include bank and small boat fishing, picnicking, hiking, and group activities such as basketball, baseball, etc. This state park is one of the largest day-use facilities in the surrounding area. The park can accommodate up to 2,000 people per day, has adequate parking for about 700 vehicles, and provides picnic shelters, barbecue pits, sanitation facilities, and drinking fountains. It features an 18-hole golf course and also offers a combined football-soccer field, a cross-country track, basketball and tennis courts, and a baseball diamond. Figure 1 shows the location map of the park, and other relevant general information is included in table 1.

Acknowledgments

This final report represents the cooperative efforts of many individuals representing local, state and federal organizations.

IDOC site personnel, Curtis Gathing and Bruce Wren, provided outstanding assistance in local project coordination and data collection. Their assistance was essential to the successful completion of both the phase II implementation project as well as this phase III post-restoration monitoring effort. Local activities were also supported by Sandra Andres, Southwestern Illinois Metropolitan and Regional Planning Commission

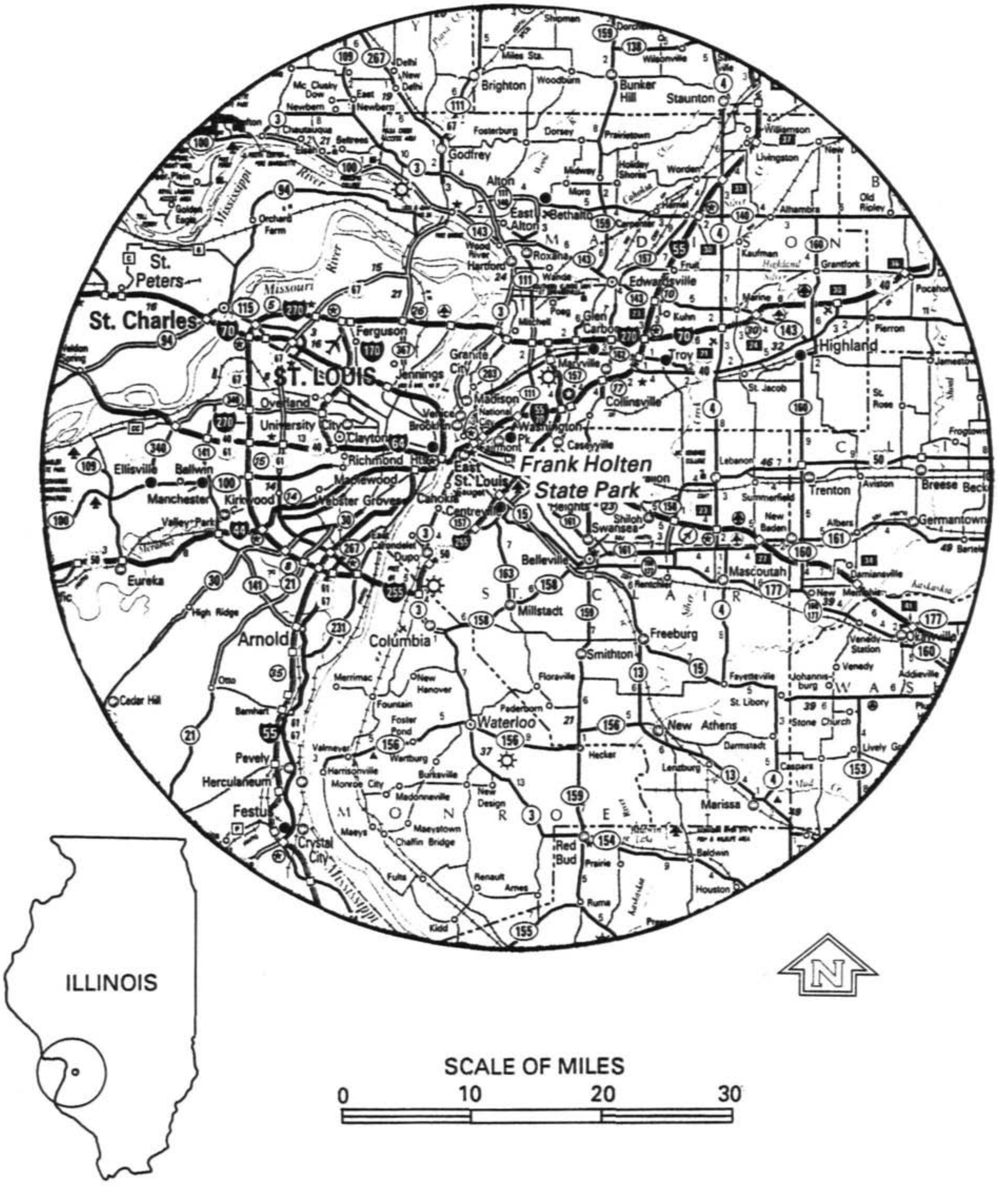


Figure 1. Location map of Frank Holten State Park Lakes

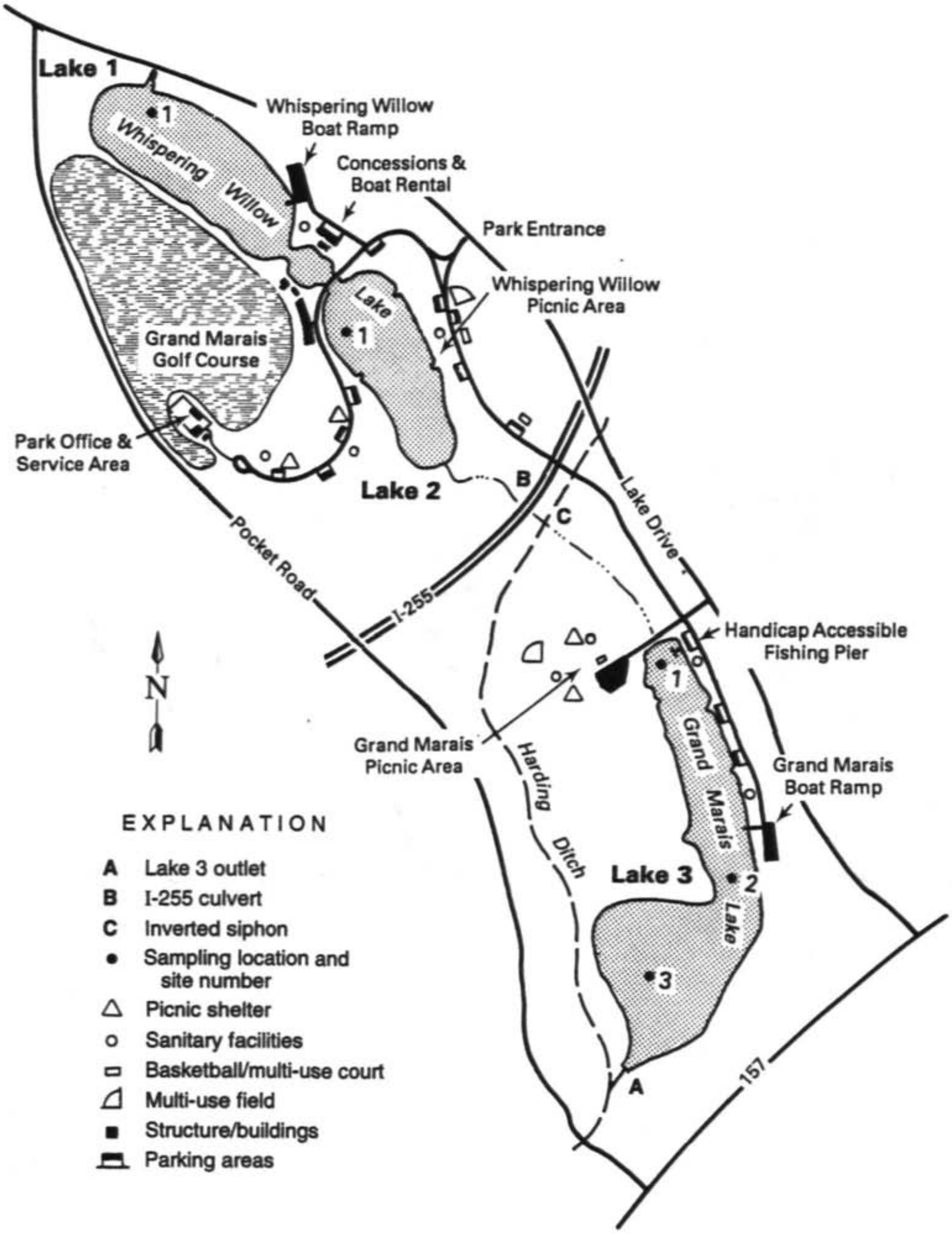


Figure 2. Public access points and facilities, Frank Holten State Park Lakes

Table 1. General Information Pertaining to Frank Holten State Park Lakes

Lake name:	*Whispering Willow Lake, Lake #1 *Whispering Willow Lake, Lake #2 *Grand Marais Lake, Lake #3
County:	St. Clair, T2N, R9E, Sections: Lake #1: 21 & 28 Lake #2: 28 Lake #3: 27 & 34
Latitude:	Lake #1: 38-36-01 Lake #2: 38-35-39 Lake #3: 38-35-12
Longitude:	Lake #1: 90-06-07 Lake #2: 90-05-45 Lake #3: 90-05-10
USEPA region:	V
IEPA major basin name and code:	Upper Mississippi Basin, 07
IEPA minor basin name and code:	Mississippi South Central 18
Major tributary:	Harding Ditch
Receiving water body:	Harding Ditch
Water quality standards	General use standards promulgated by the Illinois Pollution Control Board and applicable to waters designated for aquatic life.

Note:

* These lakes are also collectively called Frank Holten State Park Lakes. Lakes 1 and 2 are distinct portions of Whispering Willow Lake, separated by a bridge.

(SIMRPC), who coordinated and participated in collecting Volunteer Lake Monitoring Program (VLMP) data.

Brian Mahan (District Wildlife Manager), Thomas Seals (District Forester), and Scott Ballard (Natural Heritage Biologist), all of IDOC, provided valuable information about the project area's flora, fauna, and other natural resources. Their timely assistance is gratefully acknowledged.

The IEPA Lake and Watershed Unit (Planning Section, Division of Water Pollution Control), under the direction of Gregg Good and past direction of Donna Sefton, was responsible for overall state administration and coordination of this project. Jeff Mitzelfelt and Beverly Albarracin conducted various data entry, management, and interpretation activities necessary to insure the integrity of the monitoring program results. Amy Burns coordinated data collected under the VLMP and VLMP-Water Quality programs.

IEPA's Marion Regional field office staff, under the direction of Bob Hite, conducted lake and tributary monitoring activities over the three-year monitoring period. Staff involved in collection activities included Chris Bickers, Joan Levesque, and Jim Bivens. Analyses of various water and sediment samples collected were carried out by the Agency under the direction of John Hurley of the Springfield Laboratory and Roy Frazier of the Champaign Laboratory.

This project was funded in part with financial assistance provided by the USEPA under the Clean Lakes Program Grant #S005125-01. Tom Davenport and Don Roberts, USEPA Region V in Chicago, were responsible for federal administration of the phase III project. The authors are profoundly grateful to Gregg Good (Supervisor, IEPA Lake and Watershed Unit) for his untiring efforts in coordinating the endeavors of various individuals connected with this project and forwarding the results. He also developed the user survey questionnaire, analyzed the data, and provided a summary of the results. Jeff Mitzelfelt provided excellent technical support in carrying out the project during its various phases. He also compiled all the raw data into a manageable tabular form.

Several State Water Survey personnel participated in the successful completion of the field work for which the Survey was responsible, and in completing this report.

Thomas Hill, Rick Twait, and Davis Beuscher assisted in the macrophyte surveys. Hill identified and enumerated benthos, and evaluated the data. Beuscher identified and enumerated algae and zooplankton in the lake samples. Shundar Lin evaluated the algae and zooplankton data, and prepared the literature review segment of the report. Wayne Wendland provided meteorological data for the project area. Original project design and data collection for the hydrologic budget and lake bathymetry portions of the project were initiated by William P. Fitzpatrick, now with the Wisconsin Department of Natural Resources. Data collection was completed with the assistance of James Slowikowski, Richard Allgire, and John Burton. Linda Hascall prepared the illustrations. Linda Dexter and Kathleen Brown prepared the draft and the final reports. Eva Kingston edited the report. All of their efforts and assistance are gratefully acknowledged and appreciated.

STUDY AREA

Whispering Willow Lake (Lakes 1 and 2) and Grand Marais Lake (Lake 3), as shown in figure 2, lie within the Frank Holten State Park located in northwest St. Clair County, Illinois. The park and lakes are practically surrounded by East St. Louis urban development and are easily accessible from several interstate highways (I-2S5, 70, 64, and 55). As indicated earlier, the lakes are the remnants of Mississippi River oxbow lakes. The Mississippi River traverses about 5 miles west of the lakes. Lakes 1, 2, and 3 currently have surface areas of 59, 42, and 78 acres, respectively. Other pertinent morphometric details are included in table 2.

The direct drainage area of the lakes, totaling 3,296 acres, originates from bottomland areas in the floodplain of the Mississippi River. The drainage area of Harding Ditch, 20,459 acres, is a significant indirect source of water for the lakes. This drainage area is a mix of bottomland and bluff slope drainage. Much of the area drained by either of these sources is urban in character (Eicken, 1990).

Site History

The area of Frank Holten State Park originally was part of Lake Pittsburg, a backwater lake formed by an oxbow of the Mississippi River (figure 3 a). This large lake was drained in the early 1900s with the three park lakes forming small remnants of the larger lake. By 1940 (figure 3b), the lakes and the surrounding areas had been developed into a municipal park. Other changes apparent in 1940 were due to the channelization of Harding Ditch, which was formed by the diversion of Schoenberger Creek and Little Canteen Creek from the Cahokia Creek drainage basin. Harding Ditch was routed directly through Lake 3 and backed into the lower end of Lake 2 with major consequences for both lakes.

During the period from 1940 to 1980, water from Harding Ditch flowed directly into Lake 3. Water from the Ditch backed into Lake 2 during storm event runoff periods, and the full flow of the Ditch was carried through Lake 3 to the lakes' outlet in the southwest corner of Lake 3. During this time, much of the sediment carried by Harding

Table 2. Morphometric Details of Frank Holten State Park Lakes

	Lake 1	*Lake 2*	*Lake 3*
Surface area, acres (ha)	59.1 (23.9)	42.0 (17.0)	77.8(31.5)
Volume, acre-feet (10^6m^3)	472.8 (0.58)	340.0 (0.42)	508.6 (0.63)
Maximum depth, feet (m)	18.2 (5.5)	24.9 (7.6)	9.0 (2.7)
Mean depth, feet (m)	8.0 (2.4)	8.1 (2.5)	6.5 (2.0)
Length of shoreline, miles (km)	2.2 (3.5)	1.5 (2.4)	3.5 (5.6)

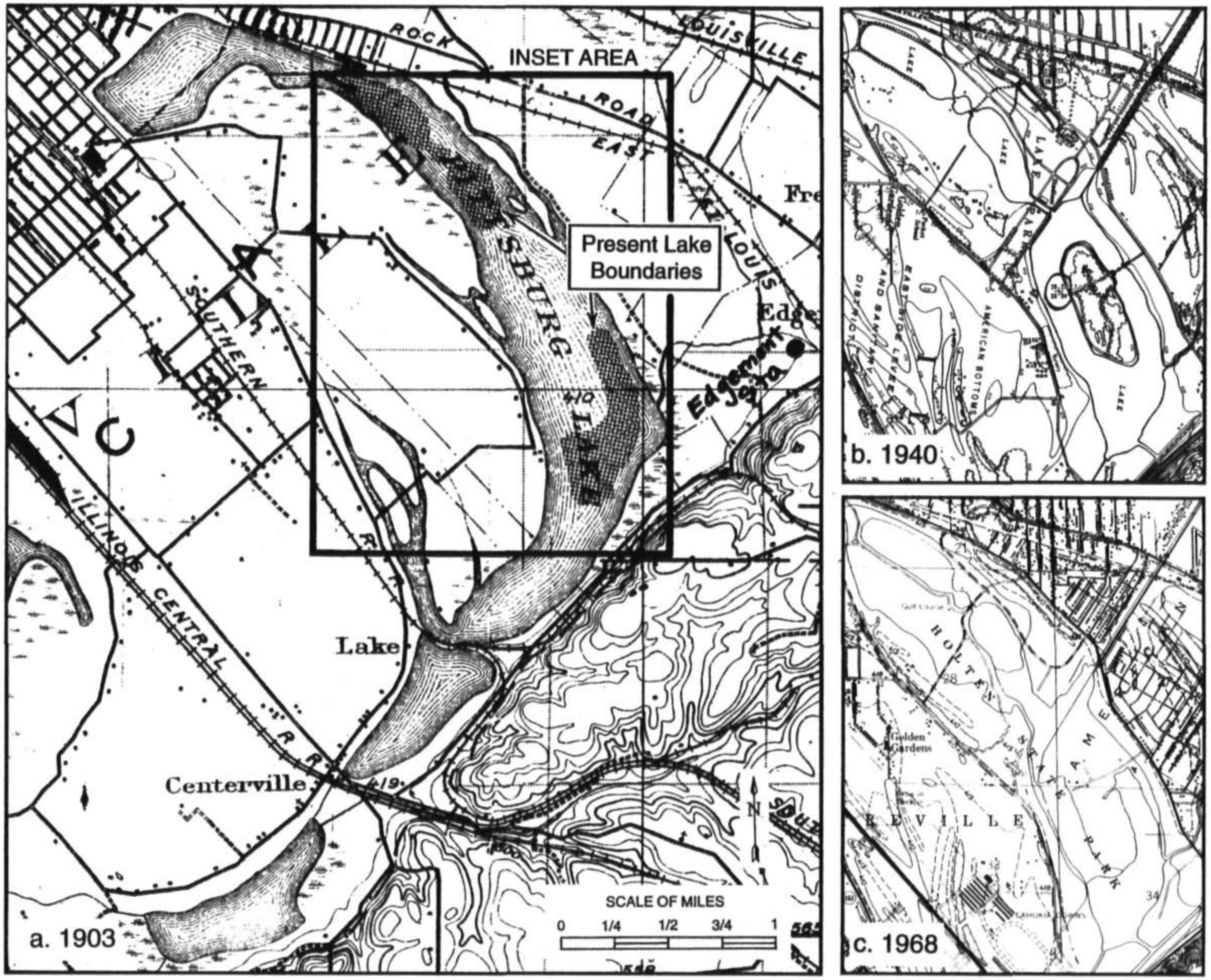


Figure 3. Maps showing the chronology of hydrologic changes in the area of Frank Holten State Park a) 1903, b) 1940, and c) 1968

Ditch was captured and held by the reduced flow environment of the lakes. The most striking impact of these inflows was the rapid loss of water depth and surface area due to sedimentation. Other impacts to the lakes included a variety of water quality problems associated with the sediments, urban storm water runoff, and bacteriological contamination.

The problems were first documented through fisheries investigations by the IDOC. These investigations were terminated in 1971 due to the "unmanageable nature of the lakes in their present condition." The effects of sedimentation on the lakes can be seen in figure 3 c. By the early 1980s, over half of the surface area of Lake 3 and smaller portions of Lake 2 had been filled by sediments.

These changes in the lake system are summarized in figure 4, which shows Lake Pittsburg's large water surface area and wetlands, associated with the lake, were reduced significantly by 1940 due to local drainage improvements. Also in 1940, drainage patterns were altered by the installation of the three culverts into Lake 1 and diversion of two creeks into a constructed Harding Ditch.

In 1968, Lakes 2 and 3 had been reduced in size due to the influx of sediment from Harding Ditch. The surface area of Lake 2 had been reduced by about 30 percent and the area of Lake 3 by about 50 percent. Since the "normal" flow direction in the lake system was north to south (Lake 1 to Lake 2 to Harding Ditch to Lake 3), Lake 1 and the northern end of Lake 2 do not appear to have been as significantly impacted physically.

Under the feasibility study conducted for the IDOC by Henry, Meisenheimer, & Gende, Inc., consulting engineers, the following solutions were devised:

- Dredging to remove existing contaminated sediments,
- Isolation of the lakes from Harding Ditch to reduce future contaminated inflows, and
- Relocation of Harding Ditch to reduce sediment loading to Lake 3.

Due to funding limitations, dredging was to be limited to Lakes 1 and 2. However, dredging of Lake 3 was accomplished by IDOT as mitigation locating I-255 through the park. Harding Ditch was channelized through the park and around the lakes. An "inverted siphon" was installed under the Ditch to provide a hydraulic connection between Lakes 2 and 3. With this configuration, the "normal" drainage pattern is now

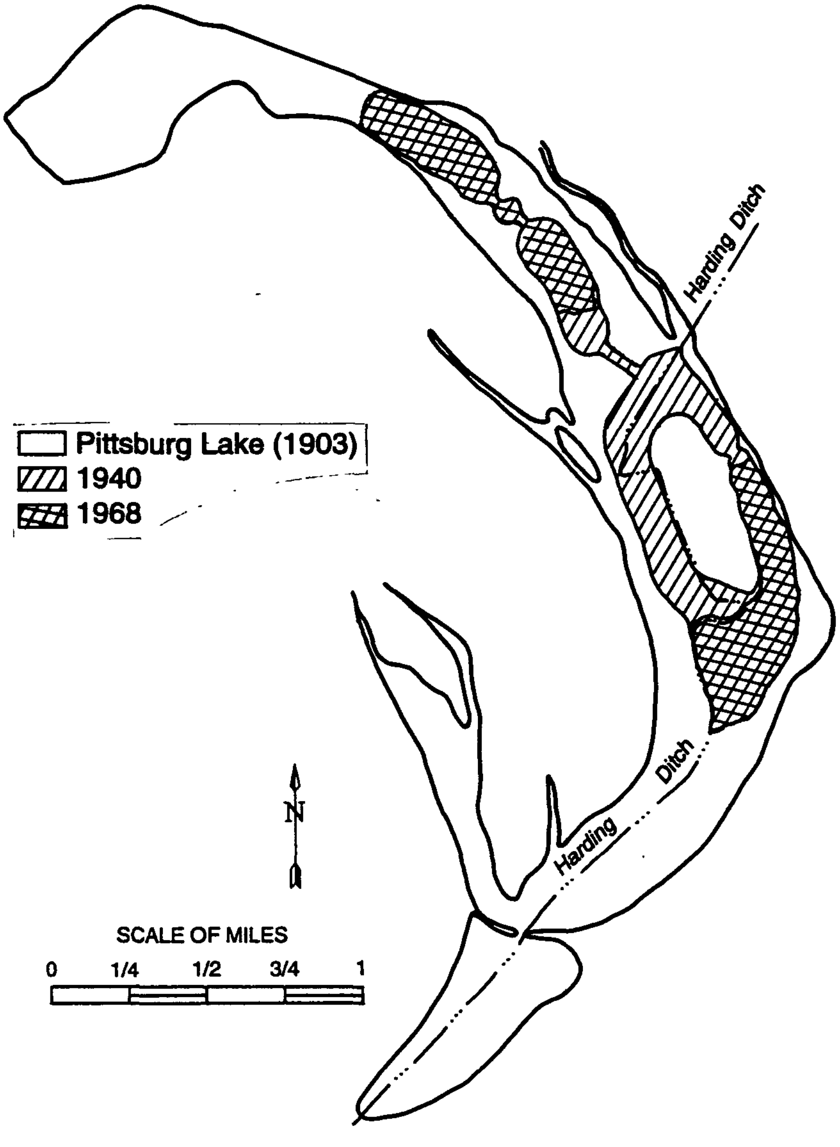


Figure 4. Overlay of Lake areas from map sources in figure 3

from Lake 1 to Lake 2 to Lake 3 to Harding Ditch, and the only connection between the Lakes and the Ditch is at the outlet from Lake 3. Because there is no water level control at this outlet, water continues to flow freely from the Ditch to Lake 3 when the Ditch water level is rising and from Lake 3 to the Ditch when the Ditch water level is falling.

Topography

Two distinctive topographic features dominate the FHSP Lakes watershed: the flat alluvial plain of the American Bottoms and the steep serrated bluff region rising 150 to 200 feet above the Bottoms. An alluvial fan at the base of the bluffs forms a short transition zone between the bottoms and the bluffs (SIMRPC, 1983). Steep slopes and narrow valleys characterize the upland portion of the watershed, which is deeply dissected by a series of westward flowing streams. Sixty percent of the bluff area has slopes varying in steepness from 8 percent to more than 40 percent. The overall relief in the American Bottoms portion of the watershed is 15 feet (ibid. plate 2).

Geological and Soil Characteristics of the Drainage Basin (SIMRPC, 1983)

The bluff section of the watershed area consists of bedrock material, which is mantled by a covering of till and loess, both of glacial origin. In the American Bottoms, the valley fill of unconsolidated alluvial and glacial terrain material is underlain by Mississippian and Pennsylvanian rock comprised of limestone and dolomite with some sandstone and shale. The average depth of fill is about 120 to 150 feet. The underlying bedrock material is of low permeability with the major aquifer present in the highly permeable valley fill.

The American Bottoms portion of the study area is covered by alluvial deposits that include the Henry Formation of Wisconsinan age and the Cahokia Alluvium of Wisconsinan and Holocene ages.

The Henry Formation consists of sand-and-gravel deposits, from the Wisconsinan glaciers found underlying the Cahokia Alluvium. The Henry, with its permeable sands and gravels, is the major aquifer for high-yielding wells on the Bottoms.

The Cahokia Alluvium, the dominant material exposed at the surface in the American Bottoms, consists of silts, clays, and interbedded sand lenses. The broad alluvial deposits in the Bottoms consist of particles transported down the Mississippi Valley and deposited during periods of flooding, while the alluvial fans and upland tributary portions of the Cahokia unit are mostly silt deposited by tributary streams of the eastern upland area.

The dominant surface deposit in the upland portion of the study area is Wisconsinan loess, which includes three geologic formations: Roxana Silt, Robein Silt, and Peoria Loess. The Roxana and the Peoria are composed of silts of varying mineral composition, while the Robein Silt consists of peat and organic-rich and deoxidized silts deposited in water. Thickness of the loess deposits varies, with the greatest thickness occurring along the bluff close to the source area. A maximum of 91 feet has been observed in a measured loess section on the bluff near the southwest section of the study area. From that point, it thins to less than 10 feet in southeastern St. Clair County.

The four major soils associations in the watershed, Fayette, Landes-Riley, Wakeland-Bonnie, and Darwin, are closely related to the physiographic features of upland loess and bottomland alluvium.

Fayette is the major soils association in the uplands, and these soils are characterized as gently sloping to very steep, well-drained soils that formed in loess under forest in the uplands. Fayette soils are found on narrow ridges, hilltops, and steep valley slopes. Typically the surface layer is dark grayish-brown silt loam, but it is brown on eroded slopes where the silty clay loam subsoil is exposed. The soil's organic matter is low, and available water capacity is high.

The minor soils in this association, which are present in the watershed, include the Worthen, Wakeland, Sylvan, and Bold series. Worthen soils are found on colluvium footslopes. Somewhat poorly drained Wakeland soils are found in small creeks and drainageways. The very steep Sylvan and Bold series are found in areas on side slopes of bluffs above the major streams. These soils are intermingled. Thickness of the subsoil varies, and the underlying material is calcareous silt loam.

The Landes-Riley, Wakeland-Bonnie, and Darwin associations are the three major soils associations in the alluvial areas of the American Bottoms. Landes-Riley soils are nearly level to sloping, well-drained to somewhat poorly drained soils that formed in loamy and sandy alluvium under forest and grasses on bottomlands. This association consists of an undulating bottomland made up of sandy ridges, fans, and swales. Landes soils are found on rounded, long, narrow ridges, and are nearly level to sloping and well drained. The surface layer is a fine sandy loam, and the subsoil is a loamy fine sand. Riley soils are found in concave areas between ridges of Landes soils. They are nearly level and somewhat poorly drained. The surface layer is silty clay loam, and the subsoil is loam.

The minor soils in this association, which are present in the watershed, are the Worthen and Littleton series. Moderately well-drained Worthen soils are in gently sloping to moderately sloping higher areas on alluvial fans. Somewhat poorly drained Littleton soils are found in lower, very gently sloping areas. Natural fertility for soils in this association is high. Available water capacity is moderate on sandy soils, but very high on Worthern and Littleton soils.

Wakeland-Bonnie soils are nearly level, somewhat poorly drained and poorly drained soils that formed in silty alluvial sediment under forest on bottomlands. This association consists of a nearly level floodplain that has low-gradient meandering streams. Wakeland soils are adjacent to streambanks and small tributary streams. They are somewhat poorly drained. The surface layer is silt loam, and the underlying material is mottled silt loam. Bonnie soils and minor soils in this association are not present in the watershed.

The Darwin association consists of nearly level, poorly drained soils that formed in clayey alluvial sediment under forest and grasses on bottomlands. This association consists of large sloughs, old river channel cuts, spills, and trapped shallow-ponded areas. Darwin soils are found in slack-water sloughs, in ponded areas, and on channel bottoms. They are poorly drained. The surface layer is black, silty clay, and the subsoil is gray, silty clay.

The minor soils in this association are in the Parkville, Dupo, and Beaucoup series. Somewhat poorly drained Parkville soils are found on the upper ends of sloughs that finger into sandy ridges. Dupo soils are found in areas that have light-colored silty overwash over black silty clay. Beaucoup soils are in low-lying, slack-water areas where the surface layer is very dark gray, silty clay loam. Natural fertility and available water capacity for soils in this association are high.

The specific details of soil associations and slopes information for the Frank Holten State Park and surrounding areas can be found in the U.S. Department of Agriculture, Soil Conservation Service's publication *Soil Survey of St. Clair County, Illinois,* Sheets 10, 11, 18, and 19 (1978).

Climate and Precipitation

Illinois experiences a continental climate due to its location midway between the Continental Divide and the Atlantic Ocean, and also north of the Gulf of Mexico. Three air masses dominate Illinois during the year. It receives the coldest, driest air, most commonly experienced in the winter, from Canada. The warmest, most humid air mass, found in the summer, originates over the Gulf of Mexico. While losing its moisture through precipitation on the windward side of the Rocky Mountains, the third air mass develops over the Pacific Ocean and brings Illinois mild, dry air. Any one of these air masses can be found over Illinois in any season, creating the variable weather the state experiences (Eicken, 1990).

Based on the climate data gathered at the Belleville, IL, weather station by the ISWS, the long-term mean annual precipitation for this area is 37 inches. Table 3 provides long-term mean monthly precipitation and temperature for Belleville. The table also provides information of total monthly precipitation and mean daily temperatures for each month of the calendar year for the period 1988 to 1992, the period covering the current investigation. Precipitation was much above average in 1990; near normal in 1988, 1989, and 1991; and much below average in 1992.

The mean annual snowfall for the area is 11.0 inches. The mean monthly snowfall for this area is 0.6, 0.8, 2.1, 4.1, 2.6, and 0.8 inches, respectively, for the months November through April.

Table 3. Precipitation (inches) and Temperature (°C) Data for Frank Holten State Park Area

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
Long-term mean monthly precipitation	1.86	2.20	3.56	3.43	4.04	3.72	3.45	3.37	3.29	2.80	3.48	3.16	38.36
Total monthly precipitation													
1988	3.11	2.42	4.01	1.40	1.82	1.54	6.05	2.51	1.83	2.30	5.70	2.20	34.89
1989	2.47	1.54	5.05	2.39	4.82	4.70	2.92	1.70	4.59	2.50	1.93	0.84	35.45
1990	1.62	4.16	2.67	4.21	11.75	3.08	1.06	1.68	1.21	3.76	3.78	7.11	46.09
1991	1.64	0.78	3.49	4.07	3.35	1.16	5.07	6.47	4.87	5.49	2.63	1.63	40.65
1992	1.20	1.14	3.13	3.49	1.05	2.18	3.76	2.79	2.70	0.97	4.56	2.72	29.69
Long-term mean daily temperature	29.9	34.3	45.4	56.2	65.0	73.6	77.4	75.0	68.5	57.5	46.1	34.4	
Mean daily temperature													
1988	29.9	32.9	45.8	56.6	66.3	74.2	78.3	78.9	69.1	52.2	46.1	37.6	
1989	40.9	29.6	45.0	55.1	61.6	71.1	75.8	74.1	64.9	57.5	46.1	22.3	
1990	41.6	43.0	49.5	53.7	62.4	74.4	77.5	74.3	71.0	55.2	50.3	33.5	
1991	27.6	39.8	49.0	59.5	70.3	75.5	76.8	75.0	68.1	59.2	41.5	40.2	
1992	37.5	44.1	48.9	58.3	64.2	71.7	78.2	71.4	68.6	57.2	44.5	35.2	

Source: Dr. Wayne Wendland, Illinois State Water Survey

Public Access to Lake Area

The major population centers reasonably close to the lake area are: Alorton, Belleville, Caseyville, Centerville, East St. Louis, Fairview Heights, Washington Park (all in Illinois), and St. Louis, MO. There is no public transportation available for use to and from the lakes and the state park; however, the park has excellent, easy access from I-55, 255, 70, and 64, in addition to several state highways such as 13, 15, 157, and 163. A map of the lakes, identifying public access points and facilities, is shown in figure 2.

A public road encircles the lakes (Lake Drive and Pocket Road), providing ready and easy access for bank fishing, nature study, use of playground facilities, picnicking, walking and jogging, and various other outdoor activities. Strategic lookout points with adequate parking facilities exist on the eastern side of the lakes. A noteworthy feature of this park is its special facilities that provide wheelchair access to fishing. Another unique feature is the state-owned golf course, which is open year-round, weather and ground conditions permitting. Pertinent information on public access points is provided in table 4.

Potential User Population

The park facilities attract visitors from the surrounding areas and predominantly from the neighboring East St. Louis, which is economically disadvantaged. The park attendance topped 400,000 visitors in 1991. The lakes and park facilities are heavily used by area residents. Table 5 gives information on a number of Illinois and Missouri counties that are relatively close to the state park. Data regarding county populations, major population centers in the counties, and pertinent economic characteristics are provided. Specifically, population (in thousands) of Alorton, Belleville, Caseyville, Centerville, East St. Louis, and Fairview Heights, communities within reasonable commuting distance from the FHSP Lakes, is 3.0, 42.8, 4.4, 7.5, 40.9, and 13.0, respectively.

Lakes within a 50-Mile Radius

There are 18 public lakes, reservoirs, and other water bodies in Illinois with surface areas of more than 20 acres within a 50-mile radius of the lakes under study. The region is also richly endowed with lotic surface water resources, such as the Mississippi,

Table 4. Public Access Points in Frank Holten State Park Lakes

Location	*Type*	*Land area, acres*	*Lake frontage, feet*	*Facility and capacities*
Lake 1	Boat ramp	1.10	340	Launching ramp for inland fishing boats (10 feet wide), and parking for 32 vehicles with trailers
Concession Stand	Dock for joy rides	0.30	150	Concession stand, house boat for hire, parking for 25 vehicles
Lake 3 (North end)	Fishing pier with handicapped access	0.20	170	Dock designed for handicapped access, playground, cookout facilities, parking for 15 vehicles
Grand Marais Boat Ramp	Boat ramp	0.80	250	10-foot wide ramp, parking for 18 vehicles with trailers
Ancillary Access Points				
Lake 2 (north middle third)	Lookout	0.14	150	Lookout, bank fishing, parking for 15 vehicles
Lake 2 (south middle third)	Lookout	0.17	170	Lookout, bank fishing, parking for 15 vehicles
Lake 3 (north)	Lookout	0.06	110	Lookout, bank fishing, parking for 10 vehicles
Lake 3 (south)	Lookout	0.06	110	Lookout, bank fishing, parking for 10 vehicles

Note: Entire eastern side of the lakes is easily accessible on foot for bank fishing (see figure 2).

Table 5. Population and Economic Data for Areas near Frank Holten State Park Lakes (population figures are in thousands)

County and population income	*Major cities within county and their population*	**Employment sources and number of people employed*	*General employment categories*	*Per capita*
Illinois				
St. Clair, 262.9	Belleville, 42.8 Fairview Heights, 13.0 East St. Louis, 40.9 Cahokia Village, 17.6 Centerville, 7.5 O'Fallon, 13.7 Scott AFB, 7.2	a: 175 b: 7.8 c: $404,000 d: 120.7	agricultural services; mining; manufacturing; construction; chemicals and allied products; fabricated metal products; industrial machinery and equipment; electronic equipment; wholesale and retail trades; personal and business services; health, legal, and social services	$12,238
Washington, 15.0	Nashville, 3.2	a: 11 b: 0.1 c: $3,000 d: 7.1	construction; manufacturing; wholesale and retail trades: finance, insurance, and real estate; health services	$11,706
Clinton, 33.9	Breese, 3.6 Centralia, 2.8 Carlyle, 3.5 Trenton, 2.5	a: 39 b: 0.8 c: $18,300 d: 16.2	mining; construction; manufacturing; wholesale and retail trades; health, education, engineering, and management services	$11,599
Bond, 15.0	Greenville, 4.8	a: 17 b: 0.6 c: $30,300 d: 7.0	construction; manufacturing; wholesale and retail trades: finance, insurance, and real estate; health and educational services	$11,708
Madison, 249.2	Alton, 32.9 Collinsville, 20.1 Edwardsville, 14.3 Glen Carbon, 7.6 Granite City, 32.9 Highland, 5.9 Wood River, 11.5	a: 204 b: 21.5 c: $1,019,600 d: 122.1	agricultural services; construction; manufacturing; printing and publishing; stone, clay, and glass products; fabricated metal products; industrial machinery and equipment; transportation and public utilities; wholesale and retail trades; finance, insurance, and real estate; health services; hotels, motels, and personal services	$11,982

Table 5. (Continued)

County and population income	Major cities within county and their population	Employment sources and number of people employed	General employment categories	Per capita
Randolph, 30.7	Chester, 8.2 Coulterville, 1.0 Redbud, 2.9 Sparta, 4.9	a: 33 b: 3.4 c: $136,600 d: 14.7	agriculture; forestry; fishing; coal mining; manufacturing; construction; wholesale and retail trades: finance, insurance, and real estate; health services	$11,261
Perry, 21.4	DuQuoin, 6.7 Pinckneyville, 3.4	a: 30 b: 1.2 c: $49,300 d: 9.5	coal mining; construction; manufacturing; transportation and public utilities; wholesale and retail trades; finance, insurance, and real estate; health services	$13,603
Monroe, 22.1	Waterloo, 5.1	a: 14 b: 0.1 c: $3,000 d: 11.4	construction; manufacturing; wholesale and retail trades; health and legal services	$12,365
Missouri				
Lincoln, 28.9	Troy, 3.8	a: 23 b: 0.6 c: $10,100 d: 14.1	agricultural services; mining; construction; manufacturing; wholesale and retail services	$10,825
Warren, 19.5	Warrenton, 3.6	a: 24 b: 1.3 c: $30,600 d: 9.7	construction, manufacturing; wholesale and retail services; health services	$11,758
St. Charles, 212.9	St. Charles, 212.9	a: 140 b: 6.1 c: $212,300 d: 117.3	construction; manufacturing; printing and publishing; fabricated metal products; industrial machinery and equipment; transportation and public utilities; wholesale and retail trades; finance, insurance, and real estate; health and educational services	$16,513

Table 5. (Concluded)

County and population ***income***	*Major cities within county and their population*	*Employment sources and number of people employed*	*General employment categories*	*Per capita*
St. Louis, 993.5	St. Louis, 396.7 Clayton, 13.9 Florissant, 51.2	a: 1,340 b: 101.9 c: $5,876,900 d: 533.2	construction; printing and publishing, chemical and allied products; rubber and plastic products; manufacturing; fabricated metal products; industrial machinery and equipment; refrigeration and service machinery; instruments and related products; aircraft and parts manufacturing; medical instruments and supplies; transportation and public utilities; wholesale and retail trades: finance, insurance, and real estate; personal and business services; health education, legal, social, engineering, and management services	$17,955
Franklin, 80.6	Union, 5.9 Washington, 10.7	a: 142 b: 6.8 c: $219,400 d: 40	construction; manufacturing; industrial machinery and equipment; wholesale and retail trades; finance, insurance, and real estate; health, engineering, and management services	$10,669
Jefferson, 171.4	Hilsboro, 1.6 Arnold, 19.1	a: 107 b: 4.4 c: $173,100 d: 88.3	mining; construction; fabricated metal products; industrial machinery and equipment; transportation and public utilities; wholesale and retail trades; health, legal, social, engineering, and management services.	$12,378

***Note:** a = number of manufacturing establishments, b = number of employees in manufacturing, c = value-added total in thousands of dollars, and d = total number gainfully employed.

Source: 1990 Census, U.S. Department of Commerce; and *Rand McNally Commercial Atlas and Marketing Guide* (1992), County Business Pattern; and CDB-89-15, U.S. Department of Commerce.

Missouri, and Illinois Rivers. No attempt was made to identify the lakes in the state of Missouri and St. Louis County, MO, which is adjacent to the FHSP Lakes, is a highly industrialized and densely populated area with no lakes or reservoirs.

Table 6 lists the 18 lakes in Illinois and provides information on such factors as surface area, maximum and mean depths, public access, and recreational facilities. Three of the lakes listed are significantly larger than the FHSP Lakes. Baldwin Lake in Randolph County provides industrial cooling water, nearly a dozen lakes serve as potable water supplies, and the recreational facilities range from fishing to picnicking, camping, etc. All the lakes have public access, and only six do not have boat launching ramps.

Land Uses

The predominant land uses of Harding Ditch watershed are forest (31.5%), urban, (29.9%), and row crops (26.2%). Other land uses are pasture (7.7%), quarry (0.3%), water supply (1.2%), and barren land (3.2%). Schoenberger Creek and Little Canteen Creek are the two major tributaries to the Harding Ditch, which has a total watershed area at FHSP of 23,755 acres (SIMRPC, 1983). There is no point source waste discharge (treated or otherwise) either directly or indirectly into the lakes system.

Biological Resources

The state park probably serves as a foraging area for the great blue heron *(Ardea herodias),* great egret *(Casmerodius albus),* little blue heron *(Egretta caerulea),* snowy egret *(Egretta thula),* and black-crowned night heron *(Nycticorax nycticorax).* With the exception of the great blue heron, all these birds are currently listed as State-endangered.

The following game species probably occur at FHSP: red fox *(Vulpes vulpes),* gray fox *(Urocyon cinereoargenteus),* white-tailed deer *(Odocoileus virginianus),* mink *(Mustela vison),* coyote *(Canis latrans),* muskrat *(Ondatra zibethicus),* beaver *(Castor candensis),* fox squirrel *(Sciurus niger),* gray squirrel *(Sciurus carolinensis),* eastern cottontail rabbit *(Sylvilagus floridanus),* Canada goose *(Brante canadensis),* wood duck *(Aix sponsa),* green-winged teal *(Anas crecca),* mallard *(Anas platyrhynchas),* blue-winged teal *(Anas discors),* northern shoveler *(Anas clypeatd),* greater scaup *(Aythya*

Table 6. Public Access Lakes in Illinois within a 50-Mile Radius of Frank Holten State Park Lakes

Name of Lake	*Area (acres)*	*Shoreline (miles)*	*Depth (feet)*		*Watershed area (acres)*	*Launching ramps*	*Recreational facilities, other uses*
			Maximum	*Mean*			
Bond County							
Greenville New City Lake	775.0	31.4	24.5	13.0	22080	2	F, WS
Greenville Old City Lake	25.1	1.5	18.0	7.4	320	0	F, P, S, PK, BR, WS
Madison County							
Horseshoe Lake	2107.0	11.2	6.0	3.5	17772	1	F, P, PK
Silver Lake	550.0	12.0	22.0	8.0	30400	1	F, WS
Monroe County							
Waterloo City Reservoir	29.0	1.0	42.0	-	600	0	F, P
Perry County							
Pinckneyville Lake	165.0	7.2	28.0	12.0	1600	1	F, WS, S, C, P
DuQuoin City Reservoir	210.0	12.0	30.0	10.0	2400	1	F, P, C, BR, WS
Wesslyn Lake (Pyramid)	24.2	3.3	44.0	27.0	-	1	F, PK, P
Boulder (3 South-Pyramid)	22.5	-	40.0	18.0	4	0	F, PK
Randolph County							
Coulterville City Reservoir	32.1	2.3	30.0	13.0	600	0	F, P, WS
Sparta Old Reservoir	25.0	1.2	16.0	7.7	720	1	F, WS
Sparta New Reservoir	27.0	1.3	12.0	5.1	125	1	F, WS
Baldwin Lake	2018.0	-	50.0	7.0	2808	1	F, CL
Randolph County Lake	65.0	3.4	35.0	19.0	2000	1	F, BR, C, P
St. Clair County							
Lenzburg Lake	24.0	0.5	66.0	20.0	40	0	F
Washington County							
Ashley Reservoir	20.0	0.8	27.0	12.0	1200	0	F, WS
Nashville City Reservoir	36.0	1.8	16.0	8.0	908	1	F, P, BR, WS
Washington County Lake	248.0	12.3	25.0	10.2	6800	2	F, C, P, BR, WS

Note: F = fishing; C = camping; BR = boat rental; P = picnic area; PK = park; S = beach; CL = cooling water; and WS = water supply.

marila), lesser scaup *(Aythya affinis),* ring-necked pheasant *(Phasianus colchicus),* northern bobwhite quail *(Colinus virginianus),* and mourning dove *(Zenaida macroura).*

Wildlife species inhabiting the area are typical of oak-hickory plant communities and associated habitats in southwestern Illinois. Mammals known to occur in the area include mink, beaver, and muskrat in and along the rivers and their tributaries; striped skunk, groundhog, cottontail rabbit, coyote, and red fox in the more open areas; gray fox, opossum, chipmunk, flying squirrel, fox squirrel, and gray squirrel in the forested portions; and various species of bats and small mammals, raccoon, and white-tailed deer in all the habitats (Ballard, 1992).

During various times of the year, numerous bird species can be found in the area. Baltimore oriole, summer and scarlet tanagers, chickadee, and several species of vireos, warblers, native sparrows, and woodpeckers have been observed in the wooded habitats. The edges of woods, thickets, brushy areas, and fields are home to indigo bunting, white-eyed vireo, woodcock, yellow-breasted chat, mockingbird, brown thrasher, bobwhite quail, mourning dove, cardinal, and several species of native sparrows.

Raptor species observed in the area include red-tailed hawk, Cooper's hawk, American kestrel, osprey, barred owl, screech owl, and great horned owl. Various waterfowl species, such as wood duck, mallard, green-winged teal, pintail, gadwall, blue-winged teal, giant Canada goose, great blue heron, various rails, egrets and herons, numerous shorebirds like the killdeer and spotted sandpiper, and snipe, make use of the rivers and other wetland habitats. Fairly new to the area, but now commonly seen and spreading into additional areas is the wild turkey. The loggerhead shrike, a State of Illinois-threatened species, is also commonly seen along thickets and fencerows (Mahan, 1992).

Reptiles and amphibians in the area include species such as chorus frog, bullfrog, snapping turtle, spring peeper, Fowler's toad, American toad, cricket frog, water snake, and pond slider. Black rat snake, garter snake, eastern box turtle, five-lined skink, broad-headed skink, and fence lizard also occur in the drier sites of the area. Copperheads and eastern timber rattlesnakes have also been documented in the area.

A few federally endangered or threatened species may possibly inhabit the area. In the winter, American bald eagles have been documented flying over the area during their forays along the nearby Mississippi River. The Indiana bat may also occur in the area. The Mississippi kite, a State of Illinois-endangered species, has also been seen in the area by local bird watchers. In addition, the brown creeper and red-shouldered hawk may pass through as migrants or are winter residents.

The naturally occurring woody vegetation on drained sites FHSP includes hackberry, box elder, American elm, sycamore, and shingle oak. Sites that are somewhat poorly drained have green ash, silver maple, black willow, and pin oak. Buttonbush occurs on a limited basis. (Seals, 1992).

Conditions before Completion of Restoration

The park, situated in one of the poorest areas in the state, was visibly blighted with trash and junk, uncut grass grew in its lawns, its three lakes were choked with sediment and macrophytes, and the crime rate on the parkgrounds was high for an Illinois state park. As a result of all these factors, there was a lower percentage of park visitors than at other Illinois state parks (Roberts *et al.,* 1988).

Prior to the restoration work, sediment accumulation had divided Lake 3 into two separate lakes. The northern portion, covering 39 acres, had an average depth of 2-3 feet; the southern portion was even shallower, fluctuating widely in areal extent as a result of small changes in water depth. This southern section of Lake 3, the most heavily degraded portion of all the lakes, was the discharge point for Harding Ditch. The respective average and maximum depths for each of the lakes were: Lake 1: 5-6 feet, 18 feet; Lake 2: 4-5 feet, 27 feet; and Lake 3: 2-3 feet, 4 feet (ibid.).

Harding Ditch, the major tributary to Lake 3, was estimated to have deposited 50,000 cubic yards of sediment annually. It was reported that Lake 3 was only about half the size that it was 15 to 20 years earlier (Henry, Meisenheimer, & Gende, Inc., 1975). Harding Ditch drains old alluvial regions consisting of reworked loess and sandy alluvium on bottomlands over 37 square miles of watershed with a maximum relief of 150 to 200 feet and slopes up to 40 percent at its eastern edge. Urban development on these slopes substantially increased the stormwater and sediment delivery rates to its tributaries (ibid.). During storm events, rapidly moving ditch waters carried heavy sediment loads for deposit in the southern portion of Lake 3, which acted as a sediment basin. The resulting delta steadily decreased the hydrologic retention capacity of Lake 3, which gradually increased the area flooded in the park after storm events.

Harding Ditch entered FHSP from the north, passed between Lakes 2 and 3, and then ran parallel to the western side of Lake 3 before entering nearer its southern end (ibid., exhibit #4). The overflows from Lakes 1 and 2 drained into Harding Ditch. The other surface sources to the lakes came from several small urban storm drains that entered the lakes directly.

A control structure at the southern end of Lake 3 functioned as the outflow point for the lakes under normal conditions. Flow patterns in the lakes were generally from Lake 1 to Lake 2 to Lake 3.

There are several anecdotal references to the aesthetic conditions of the lakes in the published documents. Henry, Meisenheimer, & Gende, Inc. (1975) reported extensive willow and American lotus covering the southern portion of Lake 1. Extensive macrophyte beds in the lakes and dense concentrations of algae in the water column and matted at the surface were known to exist (Roads *et al.,* 1975). However, a 1959 IDOC internal annual report for Grand Marais Lakes indicates that "very little aquatic vegetation exists in these three lakes. It is probable that vegetation is controlled by the large populations of rough fish" (Marbutt, personal communication, 1992). Physical, chemical, and bacteriological data exist for the lakes during the pre-restoration period, and these will be analyzed along with the results and discussions for the current study.

Lake Restoration and Improvement Projects

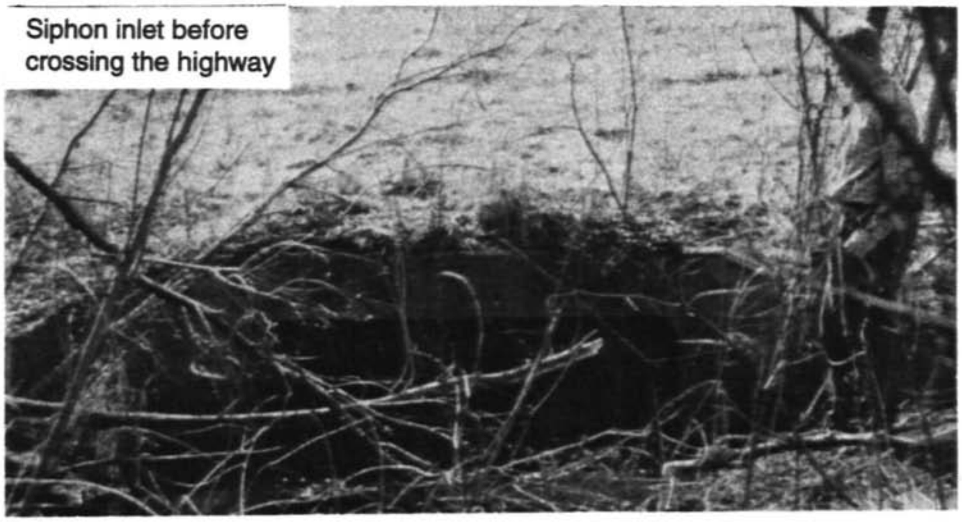
To protect against further degradation as well as to restore the lakes, IDOC included two key measures to mitigate the external source of lake degradation and thus maintain better lake water quality and postpone the need for lake dredging. The first of these measures was the diversion of Harding Ditch away from the lakes. This was accomplished by moving the location of Harding Ditch beginning at the north end of Lake

3, such that dry weather flows and all but major storm event flows passed around the southern edge of Lake 3 and away from the other lakes.

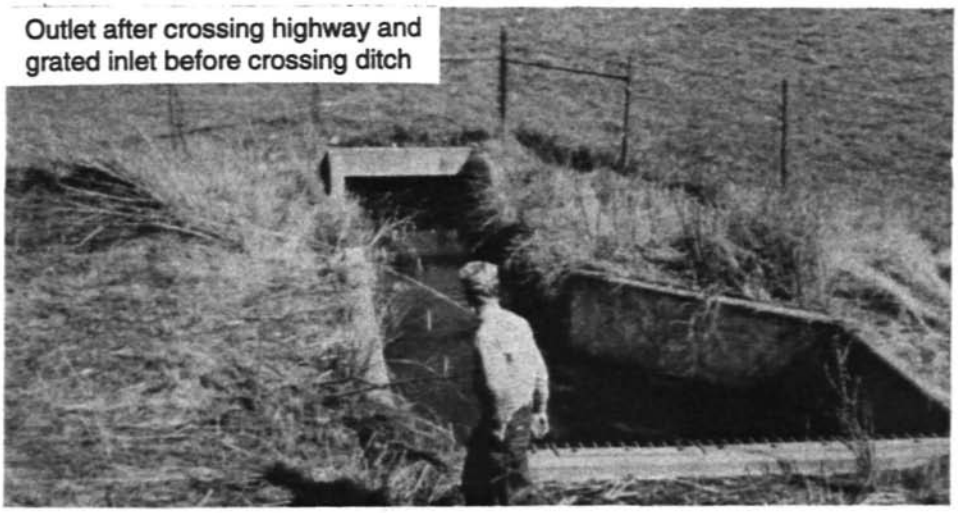
During very large storm events, the Ditch could overflow into the lake system through the Lake 3 control structure, identified as A in figure 2. This, under normal conditions, continues to act as the outflow for the lakes system. A proposed dike, intended to separate Lake 3 from the Harding Ditch floodplain and located just downstream from the southern end of Lake 3, was never built. Construction of that dike would have caused flooding downstream of Lake 3, unless a series of pumps or other water regulation measures were simultaneously established in the watershed. Funds for the installation of these water control measures were never appropriated.

The second measure included the construction of a ditch between Lake 2 and Lake 3 to carry excess water from Lake 1 and Lake 2 (water surface elevation: 405 feet) to Lake 3 (water surface elevation: 404 feet) and the construction of a concrete inverted siphon to pass under Harding Ditch. The siphon was designed and constructed to carry overflows from Lake 1 and Lake 2 under Harding Ditch and into Lake 3, thus maintaining the hydraulic isolation between Harding Ditch and the northern part of Lake 3. The location of the inverted siphon is marked as C in figure 2. Views of its entrance and exit points are shown in figure 5. A 4-foot by 6-foot concrete box culvert marked as B in figure 2 carries flow under I-255. There is a short open transition section between this culvert and the siphon. The relocation of Harding Ditch and the construction of the inverted siphon were begun in June 1977 and completed in October 1980.

After these two protection measures were completed, dredging of Lakes 1 and 2 was begun in September 1981 and completed in September 1983. Because of fiscal constraints, 25 percent of the northern end of the lake bottom of Lake 1 and about 15 percent of the southern end of Lake 2 were not dredged. Approximately 3 feet of sediment were removed from these two lakes with a total dredged volume of 262,388 cubic yards. A flat bottom configuration (at 397 feet elevation) selected and implemented for the dredged area, produced a water depth of at least 8 feet for most of the areas in these two lakes. The small four-acre lake between Lakes 1 and 2 was also dredged to the same flat bottom elevation.



Siphon inlet before crossing the highway



Outlet after crossing highway and grated inlet before crossing ditch

Outlet after crossing Harding Ditch

Figure 5a. Views of inverted siphon crossing Interstate 255 and Harding Ditch

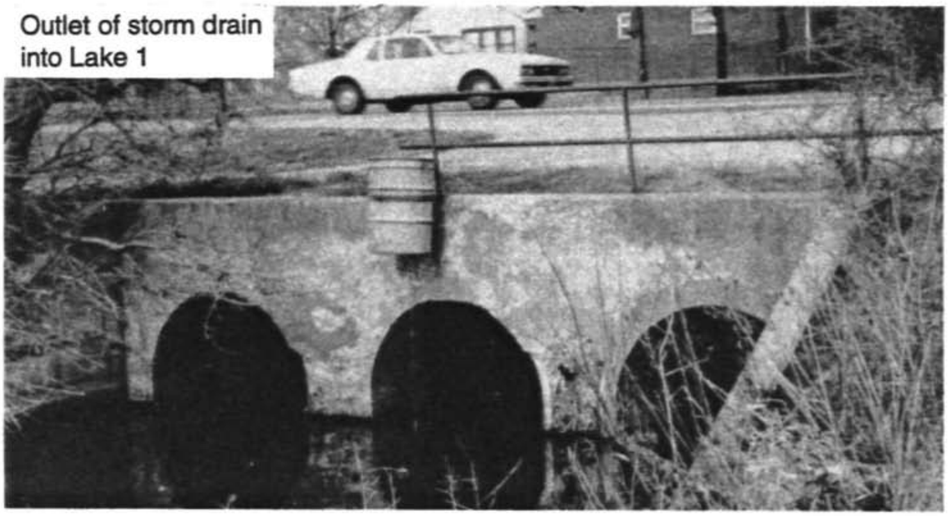


Figure 5b. Views of drainage area and storm drain into Lake 1

A different dredging plan was used for Lake 3, the most adversely impacted lake in the park. The work was begun in June 1983 and completed in July 1985. The northern portion of the lake and a central cut in the southern portion of the lake were dredged to an elevation of 396 feet, which provided a water depth of 8 feet in this area. The remainder of the southern portion was dredged only to an elevation of 400 feet. In all, a total of 618,667 cubic yards of sediment were removed from this lake.

The dredged spoils were disposed of in a specifically designed and constructed three-cell diked disposal site on the western side of Lake 3 for Lakes 1 and 2. The IDOT borrow pit, originally used as the source of fill material for a park overpass crossing I-255 was used for Lake 3. The engineering details for the relocation of Harding Ditch, inverted siphon, dredging, and the disposal sites can be found in Henry, Meisenheimer & Gende, Inc. (1975).

The final step in the restoration of the lakes consisted of the removal of rough fish followed by restocking with game fish. Prior to this fish eradication, fishing by trammel nets was permitted for ten days, and the fish taken were sold at the site. The lake was then treated with a copper-based herbicide to reduce the algae present. A week later, rotenone was applied at a concentration of 5 to 6 parts per million (ppm). Cleanup of the dead fish required a massive effort by site staff and IDOC fisheries personnel over several days. Approximately 54,000 pounds of 22 species of fish were removed. The largest number removed, 606,205 gizzard shad, had a total estimated weight of 24,250 pounds. In contrast, largemouth bass were very rare; only 291 fish were collected with a total estimated weight of 291 pounds.

To establish a desirable sport fish population in the lakes, the following species were stocked during October 1983: 97,000 (1-inch) bluegill, 9,700 (3-8-inch) channel catfish, and 5,500 (3-5-inch) largemouth bass. The following June, 9,700 additional 2-inch largemouth bass were stocked. After allowing this stocking program to develop, 5,865 (10-11-inch) rainbow trout were stocked in fall 1985 for put-and-take fishing opportunities.

Another significant factor that contributed to the restoration of the park area was the appointment of Curtis Gathing as the new site superintendent in late 1978 by IDOC.

He immediately instituted several physical, management, and procedural changes in the park, all of which enhanced the security and aesthetics of the area. He deployed necessary resources to remove all the trash from the park, rearranged and regulated the traffic flow through the park, tightened the security, and enforced safety rules and regulations with assistance from local law enforcement agencies. He spared no efforts to beautify the park, which became a safe and aesthetically pleasing area within a reasonable period after the new superintendent assumed his responsibilities.

HYDROLOGIC, SEDIMENTATION, AND BATHYMETRIC ASSESSMENT

Hydrologic System

The hydrologic system at FHSP operates as five separate but interactive units. These units are:

- Lakes 1 and 2 and their peripheral drainage,
- Lake 3 and its peripheral drainage,
- Harding Ditch,
- the Drainage District culverts into Lakes 1 and 2, and
- the ground-water system.

The interaction of these units is driven by relative water-level elevations in the system. The low gradients of the drainage system in the area of the park complicate things. With the possible exception of the culvert interface with Lake 1, each system can flow in either direction at the interface points. The operation of each of these interfaces will be described in this section.

The interface between Harding Ditch and Lake 3 at the outlet from Lake 3 (point A in figure 6) generally operates when surges of water from Harding Ditch enter Lake 3 during storm runoff periods. During these runoff events, the major portion of the flow in Harding Ditch is diverted through the lower end of Lake 3, across Pocket Road, and back into the main Ditch channel (figure 6). This diversion carries the Ditch flow around beaver dams and debris blockages that perennially occur in the Ditch channel. These storm runoff flows also raise the level of Lake 3 to a point of equilibrium with the creek level. Once this point of equilibrium is reached, the Ditch level declines and water stored temporarily in Lake 3 is returned to the Ditch. During static flow periods, little or no water is exchanged between the two bodies of water since minor water level variations driven by wind or evapotranspiration are the only sources of hydrologic exchange.

The "inverted siphon" installed between Lakes 2 and 3 is not the hydraulic control between these two systems. The control point is approximately 500 feet north of the I-255 culvert opening (figure 6, point B) and is at a level of 2.31 feet on staff gage 1 and 2.18 feet on staff gage 3. Beaver dams in the connecting channel often increased this control level. The siphon and the small channel size together restrict flow between the

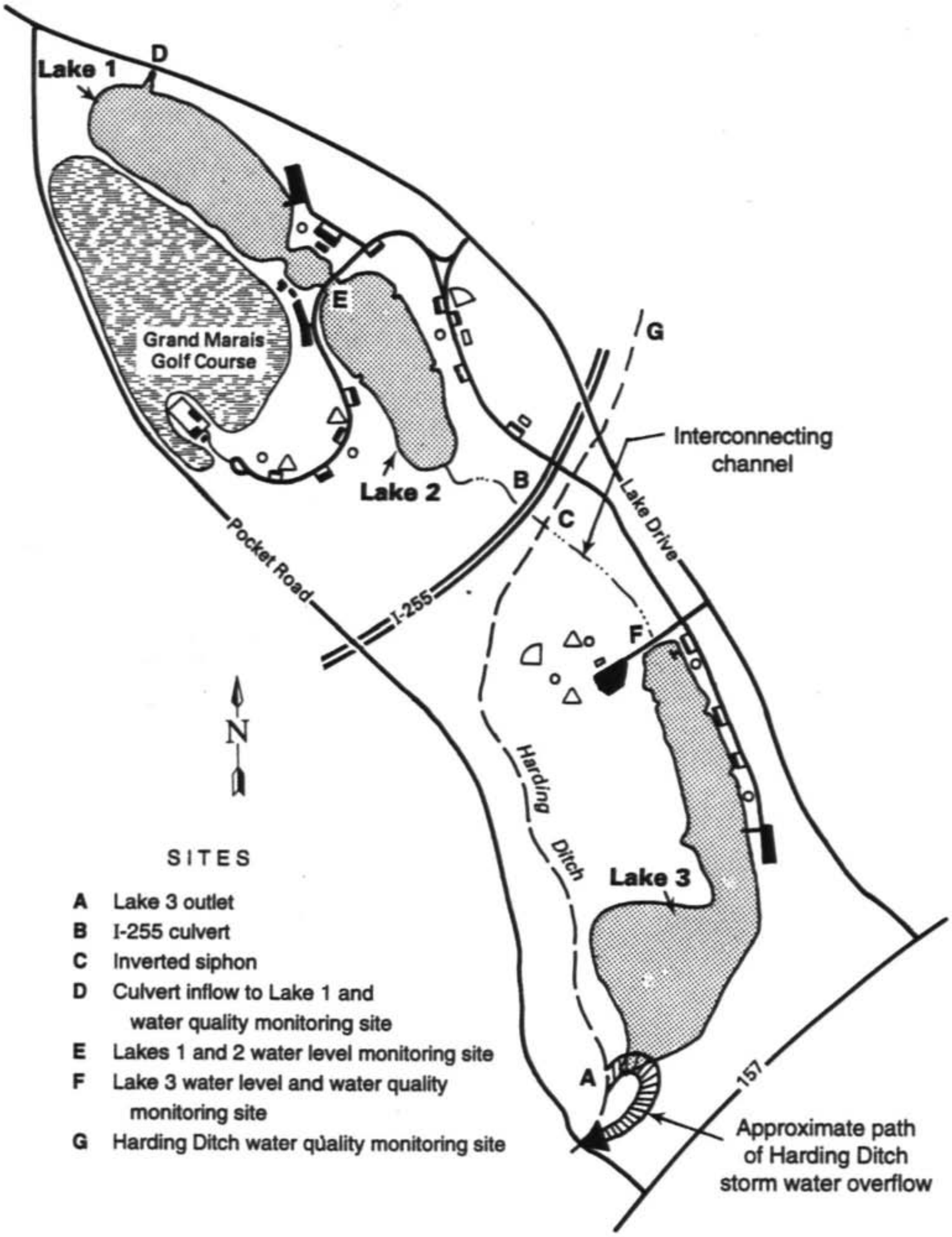


Figure 6. Location map for hydrologic and sediment transport monitoring of Frank Holten State Park Lakes

two lakes to the point that during the three years of this study, the interflow between Lakes 2 and 3 can be described as insignificant. When interflow does occur, however, its direction varies according to water-level differences between the two lakes. When Lake 3 rises rapidly due to backflow from Harding Ditch, water can flow "backwards" from Lake 3 to Lake 2. The siphon as constructed consists of parallel 36-inch and 96-inch culverts to carry water from Lake 2 and under Harding Ditch to Lake 3.

The three drainage district culverts (figure 6, point D) have a total drainage area of 942 acres and enter Lake 1 near its northeast corner. These culverts originate 500 feet north of this point on the west side of Downing High School. Prior to entering the culverts, the drainage area appears to be all storm drainage. There is a possibility for cross connection to sanitary sewers in the culverts' subgrade reach. This potential is most strongly suggested by the strong septic odor that is prevalent at the outlet during summer months, but this odor might also be from the combination of low discharges and the length of the subgrade reach.

Ground-water interaction with the other elements of the system is the most poorly defined of the five primary units, and the available phase HI funding would not support a detailed groundwater assessment. The alluvial deposits in the Mississippi floodplain and the oxbow origin of the lakes suggest easy interaction between the water table and the lake.

Hydrologic Budget

Data Collection

Water levels in the lakes were monitored at two points over a 28-month period (July 25, 1990 to December 16, 1992). Site 1 (figure 6, point E) was located on the bridge crossing between Lakes 1 and 2. This stage record is representative of water levels in both Lakes 1 and 2. Water levels for Lake 3 were monitored at the Lake 3 end of the interconnecting channel (figure 6, point F) between Lakes 2 and 3.

Both sites were monitored by a 5-pounds per square inch (psi) Druck pressure transducer connected to an Omnidata Data Pod II electronic data logger. Each data logger was programmed to measure water levels at hourly intervals and then record the levels once every 12 hours. The data logger also monitored for a specific water-level change at each hourly reading and recorded a date and time listing for major water-level rise or fall.

Plots of these water-level records are shown in figures 7-10 for Water Year 1990, 1991, 1992, and 1993, respectively.

Other Data Sources

In addition to data collected specifically for this project, some additional data sources were used.

SWS Well #2. Water levels in this well are monitored by the Water Survey's long-term ground-water monitoring program. The well is located approximately 1 mile northeast of Lake 3. The available record for this project is limited to the period following September 1991 due to periodic maintenance of the well.

Precipitation Data. Precipitation data were used from National Weather Service climatological stations at Cahokia and Belleville. Long-term average evaporation rates for St. Louis (Roberts and Stall, 1967) were used to estimate evaporation from the three lakes.

Data Analysis

The hydrologic budget of the FHSP Lakes or any other lake system takes the general form of an equation:

$$\text{Storage change} = \text{Inflows} - \text{Outflows}$$

In general, inflows to the lakes include direct precipitation, watershed runoff, ground-water inflow, and pumped input. Outflows include surface evaporation, discharge at the lake outlet, ground-water recharge, and withdrawals. For the FHSP Lakes, pumped inputs and withdrawals are not a factor.

These factors were evaluated by change in storage, surface runoff, precipitation, ground-water inflow, surface outflows, evaporation rates, and ground-water infiltration.

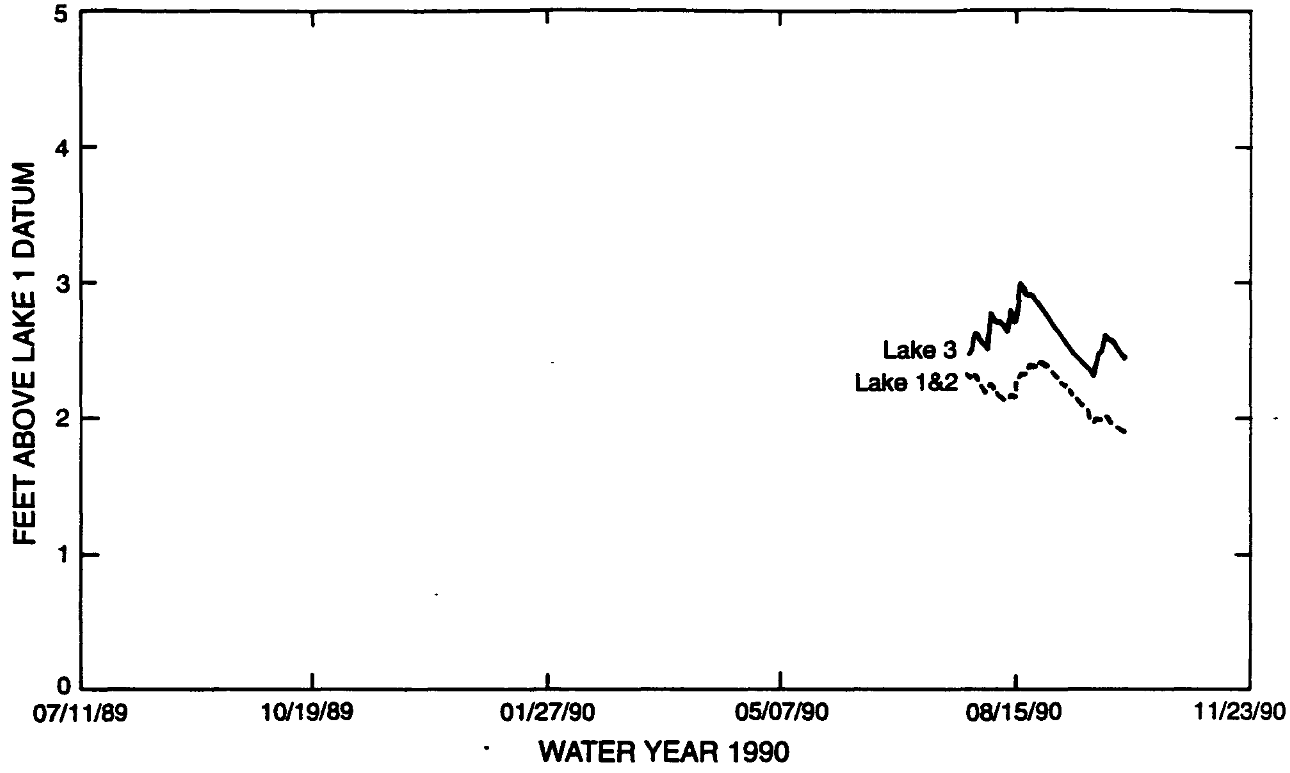


Figure 7. Stages for Frank Holten State Park Lakes for Water Year 1990

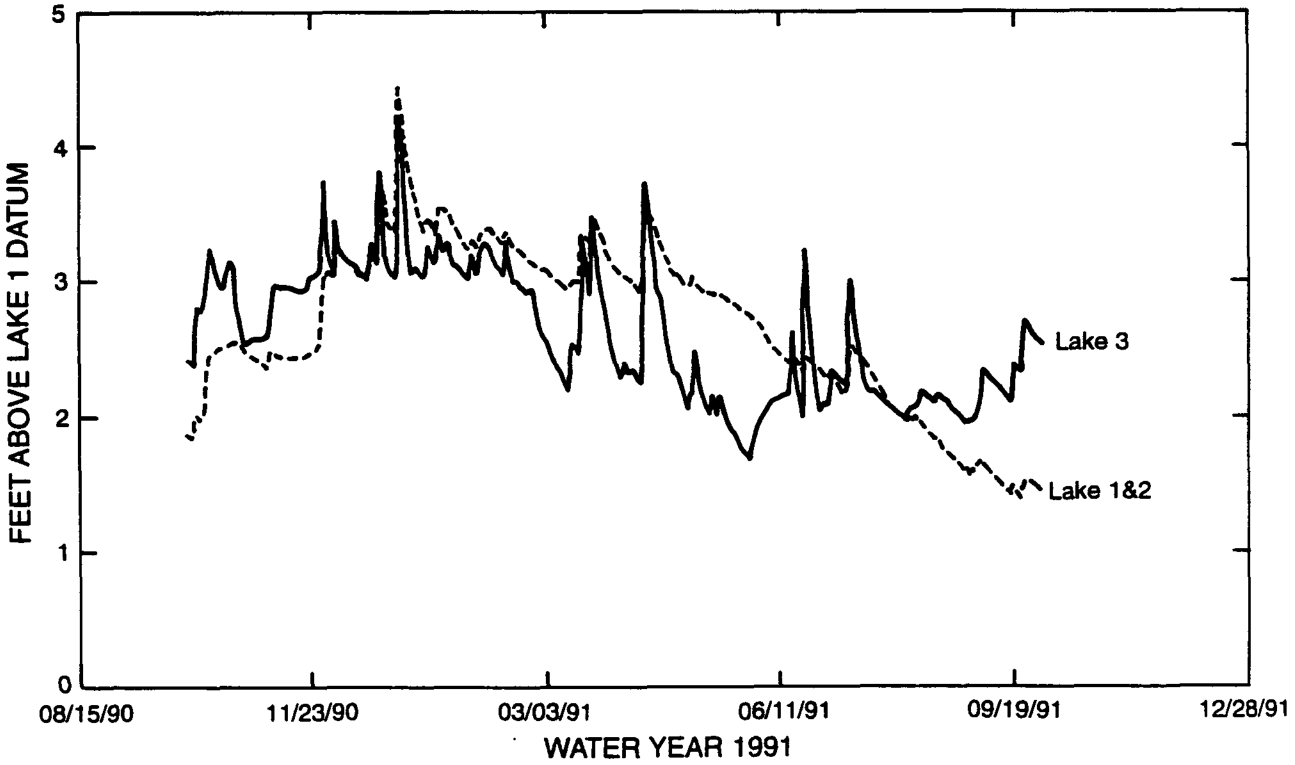


Figure 8. Stages for Frank Holten State Park Lakes for Water Year 1991

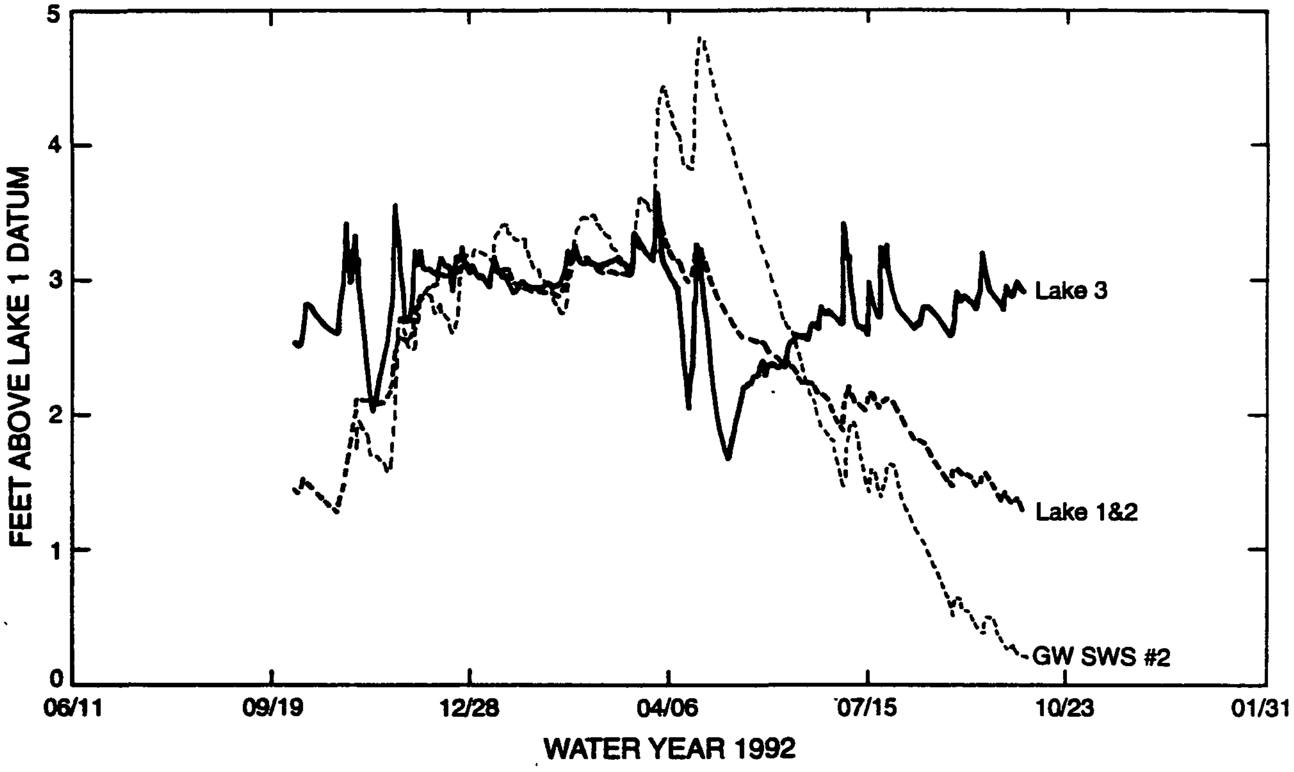


Figure 9. Stages for Frank Holten State Park Lakes for Water Year 1992 with groundwater levels for SWS Well No. 2

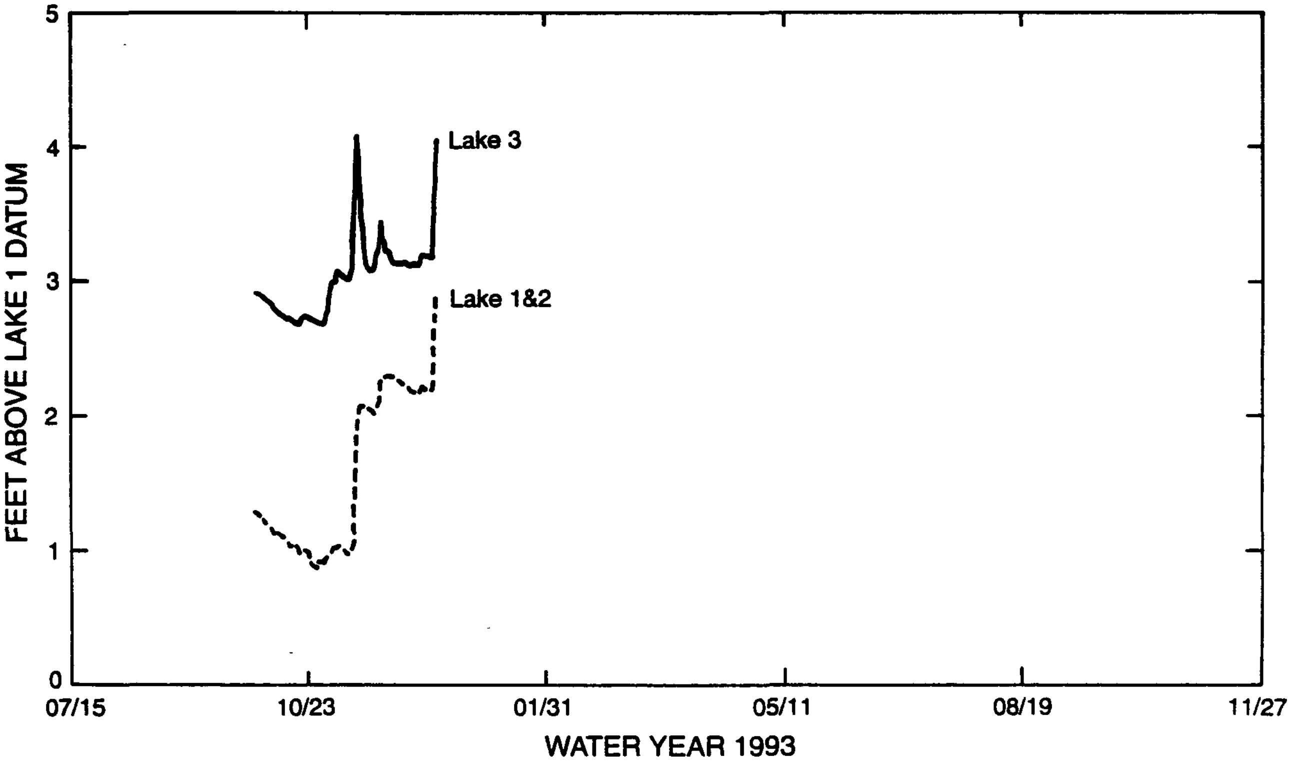


Figure 10. Stages for Frank Holten State Park Lakes for Water Year 1993

Change in Storage. Changes in lake stages over time as recorded at the water level recording sites were multiplied by lake surface area to determine inflow or outflow volume. These storage changes were evaluated on at least a half day interval based on the frequency of the water-level record.

Surface Runoff, Watershed runoff rates were not directly measured during this study. Instead, an indirect measure of net inflow and net outflow was made using change in storage in the lakes over time. Records were sorted by rate of change in storage to differentiate between rapid changes (most likely associated with surface inflow or outflow) and slower rates of change (more likely associated with long-term inputs and outputs, such as evaporation, small precipitation events, or ground-water interaction). Table 7 summarizes the results of this record sorting for Lakes 1 and 2 and table 8 summarizes the results for Lake 3. All volumes are given in acre-feet.

Precipitation. Direct precipitation input to the lakes was estimated using two local weather stations at Cahokia and Belleville, Illinois. Tables 7 and 8 also give monthly direct precipitation volume to the lakes. Annual precipitation for Water Year 1991 (45 to 49 inches) was higher than the average annual precipitation (36.8 inches), and annual precipitation for Water Year 1992 was about average (31 to 39 inches).

Ground-water Inflow. Ground-water inflow to the lake could not be directly measured. Instead, ground-water effects are included in a grouping of unaccountable inputs and outputs.

Surface Outflows. Outflows from the lakes were determined similar to surface runoff. Rates of storage reduction above a certain level were indicative of surface runoff rather than slower processes such as evaporation and ground-water infiltration. Surface outflows are also given in tables 7 and 8.

Evaporation Rates. Evaporation rates are given as the average monthly lake evaporation rates given by Roberts and Stall (1967).

Ground-water Infiltration. Like ground-water inflows, water losses to the ground-water system could not be directly determined by this study. They are also included under the heading of unaccountable inputs and outputs.

Table 7. Hydrologic Analysis for Frank Holten Park Lakes 1 and 2

	Lake 1&2 Input Summary			*Lake 1&2 Outflow Summary*		
Year and month	*Net storage*	*Surface inflow*	*Direct precip.*	*Surface outflow*	*Evaporation volume*	*Unaccounted for inflow(+) or outflow(-)*
1990						
August	7.1	32.3	18.6	0.0	-41.0	-2.9
September	-42.6	0.0	10.9	0.0	-29.3	-24.1
October	52.6	60.0	38.6	0.0	-19.5	-26.5
November	66.7	66.7	31.6	0.0	-10.3	-21.3
December	119.8	190.7	67.8	-47.8	-5.8	-85.1
1991						
January	-100.6	33.3	15.6	-106.6	-5.8	-37.2
February	-18.2	15.2	6.5	-3.0	-8.5	-28.4
March	1.8	56.6	28.8	-40.5	-16.8	-26.3
April	-10.9	61.6	32.0	-61.3	-27.3	-15.9
May	-26.4	13.5	30.9	-23.0	-38.6	-9.2
June	-43.6	18.2	9.6	-7.4	-44.1	-19.8
July	-28.1	45.5	50.2	0.0	-49.2	-74.6
August	-42.2	21.2	36.1	0.0	-41.0	-58.6
September	-16.2	30.0	47.6	0.0	-29.3	-64.5
WY1991	-45	612	395	-290	-296	-467
Percentages	4	58	38	27	28	44
October	57.4	77.8	48.5	0.0	-19.5	-49.3
November	71.9	67.2	27.2	0.0	-10.3	-12.2
December	36.4	34.5	18.0	-6.5	-5.8	-3.7
1992						
January	-16.1	13.6	10.5	-13.1	-5.8	-21.3
February	17.2	19.2	13.5	-6.1	-8.5	-0.9
March	38.2	50.8	29.2	-0.2	-16.8	-24.8
April	-61.8	30.4	26.7	-51.5	-27.3	-40.1
May	-48.1	2.0	9.3	-0.2	-38.6	-20.7
June	-45.4	19.2	24.2	0.0	-44.1	-44.7
July	5.0	49.5	41.1	0.0	-49.2	-36.4
August	-41.4	18.2	21.4	0.0	-41.0	-40.0
September	-28.3	11.3	21.7	0.0	-29.3	-32.0
WY1992	-15	394	291	-78	-296	-326
Percentages	2	56	42	11	42	47
October	-33.3	8.1	8.5	0.0	-19.5	-30.4
November	133.3	144.4	38.4	0.0	-10.3	-39.2
December	62.6	75.8	22.9	0.0	-5.8	-30.2

Table 8. Hydrologic Analysis for Frank Holten Park Lake 3

Year and month	*Lake 3 Input Summary* Net storage	Surface inflow	Direct precip.	*Lake 3 Outflow Summary* Surface outflow	Evaporation volume	Unaccounted for inflow(+) or outflow(-)
1990						
August	7.0	52.9	14.4	-10.1	-31.6	-18.6
September	-17.0	21.8	8.4	0.0	-22.6	-24.6
October	13.9	83.9	29.7	-60.7	-15.0	-24.0
November	46.3	90.3	24.3	-45.5	-7.9	-14.9
December	38.5	197.6	52.2	-142.8	-4.5	-64.0
1991						
January	-50.5	38.9	12.0	-91.3	-4.5	-5.6
February	-33.6	34.2	5.0	-53.7	-6.5	-12.6
March	-17.0	139.5	22.2	-151.4	-13.0	-14.4
April	-42.8	127.9	24.6	-139.1	-21.0	-35.2
May	-5.5	66.7	23.8	-80.2	-29.8	14.0
June	13.2	145.5	7.4	-141.4	-34.0	35.7
July	-10.1	78.6	38.7	-71.1	-37.9	-18.4
August	41.2	20.0	27.8	-12.3	-31.6	37.2
September	87.3	77.1	36.6	-12.1	-22.6	8.3
WY1991	81	1100	304	-1001	-228	95
Percentages	5	73	20	67	15	6
October	40.7	120.8	37.3	-61.6	-15.0	-40.9
November	11.7	167.5	20.9	-156.6	-7.9	-12.3
December	-11.7	52.6	13.9	-48.3	-4.5	-25.5
1992						
January	-9.4	21.9	8.1	-18.0	-4.5	-16.9
February	11.7	28.2	10.4	-21.9	-6.5	1.7
March	28.2	66.5	22.5	-25.8	-13.0	-22.0
April	-120.4	93.8	20.6	-201.8	-21.0	-12.1
May	36.0	54.0	7.2	-20.5	-29.8	25.0
June	25.0	37.5	18.6	-7.0	-34.0	9.9
July	4.7	147.8	31.7	-133.7	-37.9	-3.1
August	10.2	35.2	16.5	-3.9	-31.6	-6.0
September	3.9	52.4	16.7	-26.7	-22.6	-15.9
WY1992	30	878	224	-726	-228	37
Percentages	3	77	20	64	20	3
October	-11.7	10.2	6.6	-2.4	-15.0	-11.1
November	28.2	134.5	14.8	-97.0	-7.9	-16.2
December	63.3	74.3	8.8	-11.0	-4.5	-4.3

In general, the inflows and outflows to the lakes can be treated in pairs as the surface flows (surface inflows and outflows), the climatologic system (precipitation and evaporation), and the ground-water system. In general, the surface flows approximately balance themselves for individual lake events. This basically holds true for Lake 3 but not for Lakes 1 and 2. In Lake 3, event inflows from Harding Ditch are roughly matched by return flows to the Ditch. For Lakes 1 and 2, surface outflows are limited and are usually in response to backflows from Lake 3. The majority of inflow to Lakes 1 and 2 from the direct watershed is needed to replenish evaporative and ground-water infiltration losses.

The relationship between individual climatologic factors in the water budget varies by season. In fall, winter, and spring, precipitation is the dominant factor, and there is a net increase in storage. For the summer period, however, evaporation is the predominant factor, and there is a net loss of water from the lakes. For Lakes 1 and 2, this relationship results in the summer drawdown of the lakes with a recovery of the water levels in early winter. For Lake 3, the open connection to Harding Ditch maintains steady water levels for nonstorm periods.

The relationship of ground-water levels follows the pattern set by precipitation and evaporation. As can be seen in the plot of 1992 lake and ground-water levels in figure 9, ground-water levels are depressed in the summer and fall seasons to a level well below the lake surface. During these periods, infiltration combines with the effect of evaporation to accentuate lake level drawdown. In the winter and spring periods, ground-water levels recover and may occasionally serve as inputs to the lakes. Again these effects are more pronounced in Lakes 1 and 2 where no replacement source of water is available. In Lake 3, Harding Ditch is a generally reliable source of replacement water for both ground-water infiltration and evaporation.

Unaccountable Flow Factors. The unaccountable inflows and outflows listed in tables 7 and 8 can be from a number of immeasurable sources. The value given is a residual of the water budget equation after all other determinate factors have been included. As such, this value is likely to be a sum of several factors including both inflows and outflows. In most cases, these factors may tend to negate each other. For example, the summer decline in lake level due to ground-water infiltration may be offset by an interlake transfer. These values would partially negate each other, and only the net effect would be noted.

For Lakes 1 and 2, the types of unaccountable flows are limited. Interlake transfers can be either inflows from Lake 3 or outflows to Lake 3. These flow rates, which are generally low due to the limited interconnecting channel capacity, can be significant over long periods of time. A one-directional flow of as little as 1 cubic foot per second (cfs) can result in a monthly inflow of more than 50 acre-feet. Ground-water inflow and outflow tend to vary on a seasonal basis. From the time of ground-water level recovery in late fall to the late spring decline, levels are at or above lake levels, and the ground water will be a net input to the lakes. During the summer decline, ground-water levels fall well below the lake levels, and there may be a considerable outflow from the lakes. The major part of the unaccountable flows from the lakes in summer may be attributable to ground-water infiltration.

For Lake 3, the unaccountable flows are more numerous. In addition to the interlake transfers and ground-water flows discussed for Lakes 1 and 2, there are replacement inflows from Harding Ditch to restore evaporation and infiltration losses. These replacement flows are not available to the upper lakes following their summer drop in level. The connection of Lake 3 to Harding Ditch is continuous, and these "slow" losses can be made up.

Hydrologic Evaluation. The hydrologic analyses for the FHSP Lakes in tables 7 and 8 highlight several distinct differences between the hydrologic conditions for Lakes 1 and 2 and those for Lake 3. Primary among these differences is the significance of available surface inflows to maintain lake levels. Surface inflow volume to Lake 3 is higher for both years of analysis due to the constant connection to Harding Ditch to make up evaporation and ground-water infiltration losses. Surface runoff volume to Lake 3 for both years is approximately double the surface inflow volume to Lakes 1 and 2.

Surface outflows from Lake 3 are also higher than outflows from Lakes 1 and 2 for similar reasons. During much of the summer season, water levels in Lakes 1 and 2 drop below the control point on the interconnecting channel. When this is the case, no surface outflows can exist from Lakes 1 and 2. This does not hold true for Lake 3 where inflow and outflow are always possible.

Direct precipitation and evaporation rates for the lakes vary only by the surface area of the water body. Thus, direct precipitation and evaporation rates for Lakes 1 and 2 are higher than those for Lake 3 only because they are 23 acres larger.

The unaccountable inflows and outflows from the lakes (tables 7 and 8 are somewhat deceptive because several of the unaccounted factors tend to directly cancel each other out. For example, lake levels in Lakes 1 and 2 drop at a fairly steady rate during the summer season. This drop is due to the combined effects of evaporation, which can be accounted for, and ground-water infiltration, which cannot be accounted for. For Lake 3, small inflows from Harding Ditch, which also cannot be directly measured, replace ground-water infiltration losses as they occur. Both ground-water infiltration and make-up inflow from Harding Ditch occur, however, these two unaccountable factors in the hydrologic balance cancel each other out since neither can be directly determined using available data sources.

As can be seen from the values given in tables 7 and 8, approximately 55 to 60 percent of the inflow to Lakes 1 and 2 originates as surface inflows compared to 75 percent of the inflows to Lake 3. Direct precipitation to the lakes is the source of 40 percent of the water input to Lakes 1 and 2 but only 20 percent of the input to Lake 3. Nearly 50 percent of the outflow volume, probably ground-water infiltration, from Lakes 1 and 2 cannot be accounted for in this analysis, while only about 10 percent of the outflow volume from Lake 3 is unaccounted for. Much of the unaccountable inflow and outflow from Lake 3 is immediately cancelled out by replacement flows, and unaccountable flows for Lake 3 are much higher than has been stated.

Sediment Inputs

Two ISCO model 2900 automatic pumped samplers were installed on the lake inlets on August 13, 1990. Site 1 (figure 6, point D) was located at the inlet from the storm drain into Lake 1. Site 3 was located on the Lake 3 end of the interconnecting channel (figure 6, point F) between Lakes 2 and 3. Site 3 was relocated in June 1992 to a point on Harding Ditch at the entrance to the park (figure 6, point G).

Samples were collected at 12-hour intervals until all sample bottles were filled (24 sample bottles or 12 days of sampling). Sampler servicing was scheduled for 10- to 14-day intervals.

Tables 9 and 10 present the results of the sediment budget analysis for Water Years 1991 and 1992, respectively. Monthly sediment discharges were determined by:

- Determining periodic water discharges from the hydrologic budget,
- Assigning a representative sediment concentration value for each time period based on field sample results,
- Calculating sediment load for each time period by multiplying the periodic water discharge by its corresponding sediment concentration, and
- Summing periodic sediment loads to determine monthly sediment loads.

Sediment concentrations for inflows to Lakes 1 and 2 were determined using sample concentrations from site 1 or values interpolated from two sample collections. Since only a limited record was available for sediment transport into Lake 3 from Harding Ditch, field data were analyzed to determine a relationship between sediment concentration and inflow rate. No evaluation was made for sediment transport in the interconnection channel.

The sediment discharges presented in tables 9 and 10 indicate the relatively small impact of the culvert flow directly into Lake 1 on the overall sedimentation rate of the lake system. These sediment inputs of less than 50 tons per year indicate a sedimentation loss of less than 0.01 percent per year to Lake 1.

Under the restoration plan, no remedial work was either planned or implemented on the culvert sediment inflows to Lake 1. Based on the sediment inputs determined in this study no remedial action is warranted to reduce sediment inputs. Some debris removal and limited dredging are warranted at the inflow point based on aesthetic considerations.

Sediment inflows to Lake 2 appear to have been effectively eliminated by the diversion of Harding Ditch. Prior to the restoration no significant direct sediment sources

Table 9. Sediment Inflows to the Frank Holten Park Lakes for Water Year 1991

Year and month	*Sediment input at culverts (tons)*	*Sediment input to Lake 3 (tons)*	*Water inflow*	
			at culverts (ac-ft)	*at Lake 3 (ac-ft)*
1990				
October	3.4	72.8	73.7	96.1
November	5.0	78.5	81.4	93.1
December	8.6	286.3	192.9	203.1
1991				
January	1.8	29.5	36.4	52.9
February	1.2	23.4	23.2	38.9
March	7.9	154.6	64.6	144.1
April	6.9	204.2	67.7	130.7
May	1.8	54.5	20.2	70.1
June	0.6	207.4	19.2	161.9
July	1.4	84.1	45.5	85.2
August	1.0	12.5	24.7	27.8
September	3.0	71.0	34.3	84.8
Totals	43	1279	684	1189

Table 10. Sediment Inflows to the Frank Holten Park Lakes for Water Year 1992

Year and month	*Sediment input at culverts (tons)*	*Sediment input to Lake 3 (tons)*	*Water inflow*	
			at culverts (ac-ft)	*at Lake 3 (ac-ft)*
1991				
October	6.6	116.1	91.8	125.1
November	7.8	136.0	90.1	172.5
December	2.2	38.4	58.5	56.9
1992				
January	0.3	22.7	26.3	34.4
February	0.8	33.8	38.4	42.2
March	1.6	56.9	66.7	75.1
April	2.6	100.7	32.3	95.8
May	0.9	32.0	12.1	67.2
June	1.1	26.6	29.3	50.1
July	7.1	177.5	63.3	149.5
August	0.7	31.7	22.2	45.6
September	1.0	50.7	24.2	58.0
Totals	33	823	555	972

to Lake 2 were observed during this study, and no sediment input measurements were made.

Sedimentation conditions for Lake 3 also show marked improvement over the pre-restoration conditions. The feasibility study for the restoration project noted a 1959 estimate by C. E. Thunman that "as much as 50,000 cubic yards of silt are carried into Lake No. 3 each year." Given a unit weight of 80 pounds per cubic foot, this would be equivalent to an annual sediment input of 54,000 tons. The measured inputs for the present study were 1,279 tons and 823 tons of sediment input annually for 1991 and 1992, respectively.

The relocation of Harding Ditch under the restoration program has reduced sediment inputs to Lake 3 to two percent of pre-restoration levels. In terms of volume loss, the diversion of Harding Ditch has resulted in a 1992 sedimentation rate of 0.16 percent per year compared to a rate of 6.1 percent per year if the diversion had not been implemented. Over the approximate ten-year period since the dredging of Lake 7, the lake volume has been reduced by 1.6 percent; without the diversion, more than 60 percent of the dredged volume would have refilled with sediment.

Sedimentation impacts to Lake 3 will be more apparent where the Harding Ditch stormwaters enter the lake in the southwesterly basin. The sediment input analysis included only those sediments carried into the lake by rising Harding Ditch levels. As noted in the general description of the hydrologic system, flows from Harding Ditch continue to pass through this area of Lake 3 well after the lake level begins to drop. This continued inflow due to blockages in the Ditch channel carries additional sediment input into the lake. The situation could be alleviated by maintaining a clear ditch channel and establishing an inflow and outflow control structure at the outlet of Lake 3.

Bathymetric Surveys

Bathymetric surveys of the three lakes were conducted to document existing water depths. Lakes 1 and 2 were surveyed during February 19 to 23, 1990. Cross-sectional transects of the lakes were measured by a Lowrence depth sounder. Transects were run perpendicular to a shoreline traverse line and at intervals of 330 feet.

The bathymetric survey of Lake 3 was made in March 1992. Control points for horizontal control were extended to Lake 3 from the survey base line for the Lakes 1 and 2 survey. Depths were measured by a Lowrance depth sounder, and horizontal position was determined using a Racal Survey Microfix microwave positioning system.

The maps generated from these surveys are presented in figures 11 and 12. The map for Lakes 1 and 2 shows 2-foot interval contours. Due to the extent of the dredging operation on Lake 3, the map for depth indicates dredge range and depth of cut. Table 11 lists the calculated lake volumes for given depths below reference marks. These reference marks can be determined on site by the listed reading from the project staff gages, which were left in place at the end of the project.

No post-dredging survey was conducted for the lake depths. Depths surveyed for the present study correspond closely to the nominal dredge depths and dredging limits as documented at the end of the restoration project. Periodic repetition of these surveys on a five- to ten-year interval would provide more quantitative substantiation of the effectiveness of the reduction in sediment inputs to the lakes.

Lakebed Sediments

Samples of the accumulated sediments from all three lakes were collected during the March 1992 survey of Lake 3. Samples were collected for laboratory analysis of unit weight. Sediments were also probed at this time to determine sediment thickness.

Sediment probings indicated that 1 to 2 feet of soft material exists in the dredged portions of the lakes. These materials are evenly distributed on the lakebeds and may include materials sloughed off during the dredging project. Sediment coring for sample collection indicated less sediment (0.5 to 1.0 foot). However, the sounding pole used for probing is more sensitive to the soft sediment surface than is the core sampler.

Thicker sediment accumulations (up to 10 feet) were noted in the deepest areas of Lakes 1 and 2 as well as the area of Lake 3 adjacent to Harding Ditch. The accumulations in these areas are presumed to be partly or wholly predredging sediments. There are no indications of any effort to dredge to these depths.

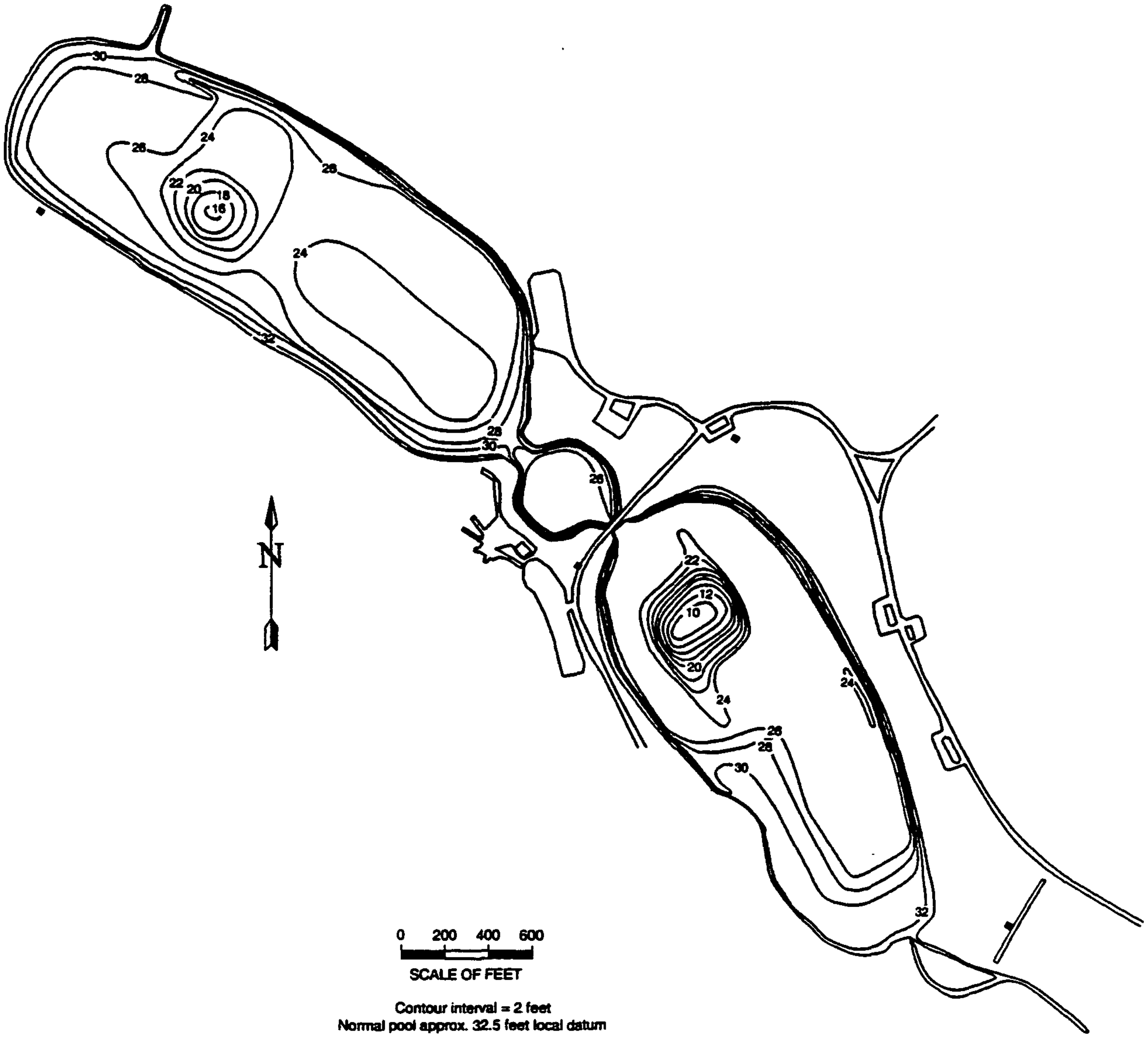


Figure 11. Bathymetry of Frank Holten State Park Lakes 1 and 2 (1990)

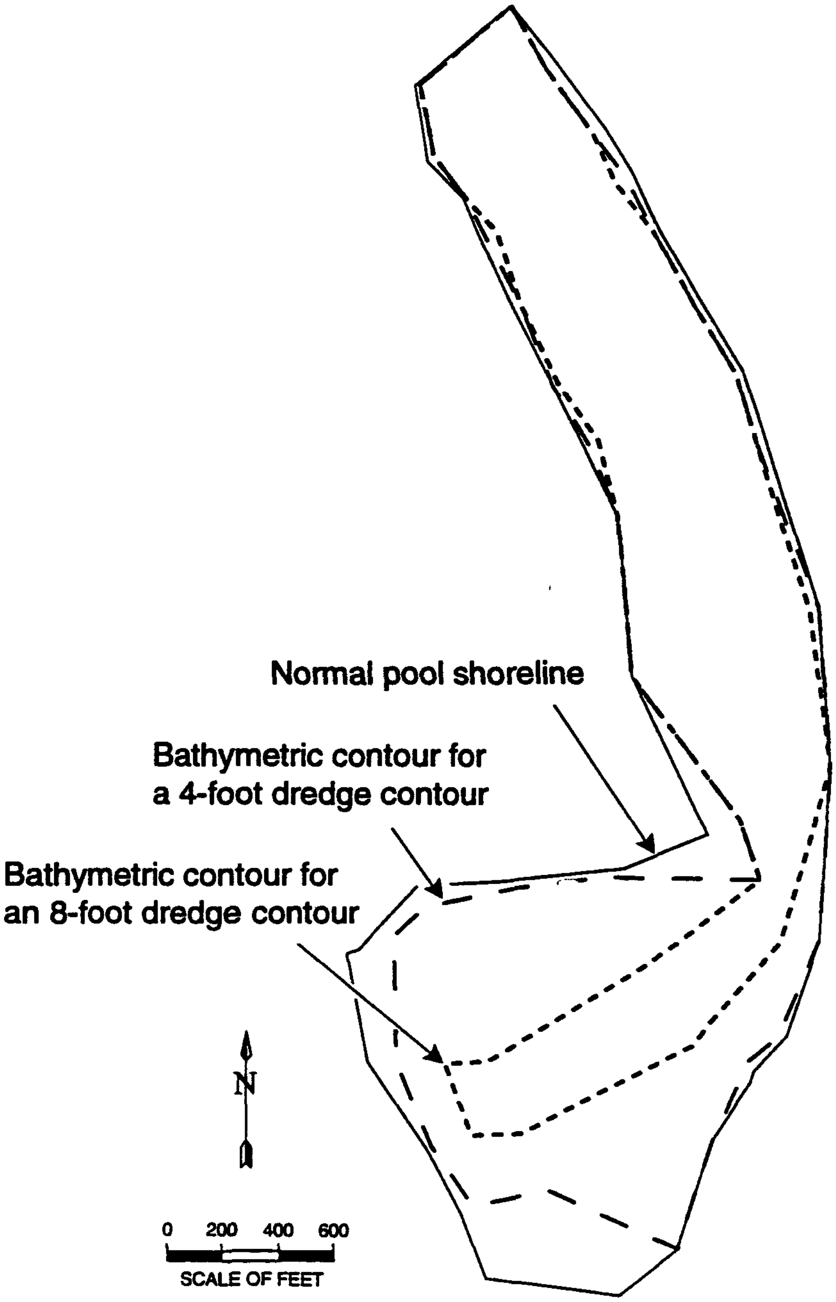


Figure 12. Bathymetry of Frank Holten State Park Lake 3 (1992)

Table 11. Stage-Volume-Area Analysis for Frank Holten Park Lakes

	Depth contour below 406 msl (2.4' staff gage)	*Contour area (acres)*	*Total volume (acre-ft)*
Lake 1			
	0	59.08	472.8
	2	56.51	357.2
	4	52.34	248.4
	6	47.38	148.7
	8	33.97	67.8
	10	14.09	21.1
	12	2.39	6.3
	14	1.36	2.6
	16	0.64	0.6
	18	0.07	0.0
	18.2	0	
Lake 2			
	0	42.03	339.9
	2	39.33	258.5
	4	33.85	185.4
	6	30.14	121.4
	8	27.31	64.0
	10	5.44	34.1
	12	3.9	24.8
	14	3.18	17.7
	16	2.48	12.0
	18	2.03	7.5
	20	1.53	4.0
	22	0.97	1.5
	24	0.45	0.1
	24.88	0	0.0
Lake 3			
	0.0	77.8	508.6
	2.0	67.9	353.0
	4.5	45.3	183.3
	6.5	43.6	92.7
	7.0	35.4	70.9
	9.0	35.4	92.7

Lake sediment unit weight values are listed in table 12. The low unit weights in most of Lakes 1 and 2 are indicative of highly organic sediments. The number of samples collected was limited due to the soft consistency of the sediments, which prevented collection of adequate sample volume at most sites.

Samples collected in Lake 3 were somewhat heavier but still show indications of high organic content. The three heavier samples were all collected in the southwest section of Lake 3 nearest Harding Ditch. Sample collection in the narrower section of Lake 3 was also limited by the loose consistency of the samples.

Table 12. Sediment Sample Unit Weights for Frank Holten State Park Lakes

Sample	***Unit Wt (lbs per cubic ft)***
FH1-1	27.22
FH1-2	45.52
FH1-3	25.97
FH1-4	15.87
FH1-5	23.99
FH2-1	37.90
FH2-2	54.78
FH2-3	17.42
FH2-4	25.67
FH3-1	44.74
FH3-2	21.12
FH3-4	54.68
FH3-7	49.86
FH3-9	67.62

LIMNOLOGICAL ASSESSMENT

Materials and Methods

To assess the post-restoration conditions of the lakes, certain physical, chemical, and biological characteristics were monitored from 1988 to 1992. Table 13 provides sampling dates and the types of sampling, which included water quality, chlorophyll, phyto- and zooplankton, benthos, macrophytes, and sediment organics and metals determinations. Sampling locations for the three lakes are shown in figure 2. Determinations for water quality, chlorophyll, phyto- and zooplankton, benthos, and sediment organics and metals were made for all the lakes at site 1. Only water quality and chlorophyll determinations were made at site 2 of Lake 3. For site 3, in addition to water quality and chlorphyll, sediment organics and metals determinations were also made.

All the sample collections, except for aquatic macrophytes, listed in table 13 were made by IEPA field personnel. Samples were collected according to IEPA field methods guide quality assurance/quality control (QA/QC) (1987) procedures and were transported to and analyzed by IEPA laboratories using approved methods shown in table 14 with the exception of identification and enumeration of algae samples that were performed by the ISWS. Macrophyte assessments were also made by ISWS staff. All the data were entered into the USEPA STORET database and checked for accuracy and internal consistency by IEPA personnel.

Data collected and analyzed in the field included dissolved oxygen (DO), temperature, pH, conductivity, Secchi transparency, water depth, and total and phenolphthalein alkalinities. Field observations were also recorded, which included weather information (wind speed and direction, wave height, cloud cover, and precipitation) and qualitative assessment of lake conditions (water color, amount of suspended solids and algae, aquatic macrophytes, water level, odor, and general lake use).

DO, temperature, pH, and conductivity were measured *in-situ* using a Hydrolab 4041 or Surveyor II with a 50-foot cable or, if necessary, using separate meters (table 14). DO and temperature measurements were taken at the water surface, at a depth of 1 foot, and at 2-foot intervals to 2 feet above the bottom of the water column. Conductivity and

Table 13. Sampling Dates for Frank Holten State Park Lakes and Types of Samples

Dates	*Water quality*	*Chlorophyll*	*Phyto- and zooplankton*	*Benthos*	*Macrophytes*	*Sediment organics and metals*
4/27/88	X	X				
6/7	X	X				X
7/12	X	X				
8/23	X	X				
9/21	X	X				
4/27/89	X	X				
5/18	X	X	X			
6/8	X	X	X			
6/16	X					
7/6	X					
7/13	X	X	X			
7/26	X					
8/3	X			X		
8/10	X					
8/17	X	X	X			
8/29	X					
9/8	X					
9/14	X	X	X			
9/27	X					
10/5	X	X	X			
10/10	X					
10/23	X					
10/31	X					
11/7	X	X	X	X		
12/5	X	X				
1/17/90	X	X				
2/14	X	X				
3/21	X	X		X		
4/23	X	X	X			
5/11	X					
5/16	X	X	X			
5/23	X					
5/24	X	X	X			
5/30	X					
6/6	X					
6/7	X	X	X			
6/12					X	
6/13					X	
6/30	X					
7/9	X	X	X	X		
7/16	X					
7/25					X	
7/26					X	
8/13	X	X	X			
9/17					X	
9/18					X	
9/19	X	X	X			

Table 13. (Concluded)

Dates	*Water quality*	*Chlorophyll*	*Phyto- and zooplankton*	*Benthos*	*Macrophytes*	*Sediment organics and metals*
10/9	X	X	X			
11/7	X	X	X			
12/11	X	X	X			
2/21/91	X	X	X			
3/19	X	X	X			
4/17	X	X	X	X		
5/14	X	X	X			
5/23					X	
6/13	X	X	X			
7/10	X					
7/11	X	X	X			
7/25					X	
8/22	X	X	X	X		
9/4	X					
9/18	X				X	
9/19					X	
9/20	X	X	X			
10/15	X		X			
10/22	X					
9/16/92					X	
9/17					X	

Table 14. Analytical Procedures

Parameter	*Method of analysis (reference)*	*Units of measure*	*Detection limits*	*General use standard*
Temperature (Temp)	*In situ* determination using Hydrolab 4041 or Hydrolab Surveyor II or Yellow Springs Instruments (YSI) model 57 dissolved oxygen meter	*°C*	0.1°	
Dissolved Oxygen (DO)	*In situ* determination using Hydrolab 4041 or 8000 or YSI model 57 dissolved oxygen meter	mg/L O_2	0.1 mg/L	≥ 5 mg/L
Transparency	Secchi disc	inches	1 inch	
Total suspended solids (TSS)	Filtration on glass fiber filter, determination of increase in weight upon drying at 103-105°C	mg/L TSS	1 mg/L	
Volatile suspended solids (VSS)	Loss in weight of TSS filter upon ignition at 550°C	mg/L VSS	1 mg/L	
Turbidity (Turb)	Nephelometric use of Hach model 2100A turbidimeter	NTU	0.1 NTU	
Conductivity (Cond)	YSI model 33 S-C-T conductivity meter or electrolytic conductivity measuring set, model MC-1 or Hydrolab 4041 or Surveyor II	µmho/cm	1 µmho/cm	
Alkalinity (Alk)	Titration of 10 mL sample 0.02 N H_2SO_4 to phenolphthalein and brom cresol green-methyl red end points	mg/L $CaCO_3$	1 mg/L	
pH	Sargent-Welch model PBL pH meter, calibrated in field or Hydrolab 4041 or Hydrolab Surveyor II	Units	0.1 units	6.5-9.0 range
Nitrate-Nitrite-N (NO_3+NO_2-N)	Cadmium reduction method on Technicon Auto-Analyzer	mg/L N	0.01 mg/L	

Table 14. (Concluded)

Parameter	*Method of analysis (reference)*	*Units of measure*	*Detection limits*	*General use standard*
Ammonia-N (NH_3-N)	Phenate method on Technicon Auto-Analyzer	mg/L N	0.01 mg/L	1.5 mg/L
Total kjeldahl-N (TKN)	Digestion at 370°C followed by determination of ammonia as above	mg/L N	0.1 mg/L	
Total phosphorus (TP)	Digestion to convert all phosphorus forms to orthophosphate followed by determination using ascorbic acid reduction method using Technicon Auto-Analyzer	mg/L P	0.001 mg/L	0.05 mg/L
Dissolved phosphorus (DP)	Field filtration followed by TP analysis as above	mg/L P	0.001 mg/L	
Chemical oxygen demand (COD)	Titrimetric, low-level method sample refiuxed with a sulfuric acid, potassium dichromatic, mercuric sulfate, and silver sulfate solution; treated with standard ferrous ammonium	mg/L	1 mg/L	
Chlorophyll (ChL)	Concentration by filtration, extraction with acetone, determination of optical density and calculation of concentration by standard formulae	µg/L	1 µg/L	

pH were measured at depths 1 foot below the surface and 2 feet above the bottom of Lakes 1, 2, and 3, except when they were thermally stratified at which time measurements were made only at a depth of 1 foot.

Secchi disc transparencies were measured using an 8-inch diameter Secchi disc, which was lowered until it disappeared from view, and the depth noted. The disc was lowered further and slowly raised until it reappeared. This depth was also noted, and the average of the two depths was recorded. Site depth was measured using a weighted line calibrated in feet.

Samples for water chemistry were collected using a 4.2-liter (L) plastic Kemmerer bottle. Near-surface (1 foot below surface) water samples were collected from all the sites in the three lakes, and near-bottom samples (2 feet above the bottom) were collected when the lakes were thermally stratified, most often only at Lakes 1 and 2. Total alkalinity and phenolphthalein alkalinity were measured in the field on these samples using Hach alkalinity kits. Sample bottles were filled and sent to the IEPA laboratory for additional analyses. Samples for dissolved phosphorus were filtered in the field through 0.45-micrometer (urn) pore size type MF-Millipore filters. All samples destined for the laboratory were stored on ice during transport and kept refrigerated until processed.

Vertically integrated samples for chlorophyll and phytoplankton were collected using a weighted bottle sampler with a half-gallon plastic bottle. The sampler was lowered at a constant rate to a depth twice the Secchi depth, or to near the lake bottom, and raised at a constant rate to the surface. Chlorophyll samples were transferred to a foil-wrapped quart sample bottle and filtered through microfiber filters. The chlorophyll filters were then wrapped in aluminum foil and the filtrate volume measured using a graduated cylinder. Filters were kept frozen in the laboratory until analyzed. For algal identification and enumeration, 380-milliliter (mL) water subsamples were taken, preserved with 20 mL of formalin at the time of collection, and stored at room temperature until they could be examined.

Also, vertically integrated 10-L samples were collected from site 1 at each of the three lakes for zooplankton identification and enumeration. The samples were filtered through a Wisconsin net, and the collected zooplankton were placed in a 250-mL bottle with 10 mL of ethyl alcohol and 190 mL of deionized water. In the laboratory, each sample was filtered through a 0.45-µm filter. The organisms were resuspended in 10 mL of deionized water. One mL of sample was placed in Sedgwick Rafter Cell and examined using a differential contrast microscope at 100X magnification. Organisms in the five widths of the cell were counted and recorded.

For algal identification and enumeration, the sample was thoroughly mixed, and a 1-mL aliquot was pipetted into a Sedgwick Rafter Cell. A differential interference contrast microscope equipped with a 10X or 20X eyepiece, 20X or 100X objective, and a Whipple disc was used for identification and counting purposes. Five short strips were counted. The algae species were identified and were classified into five main groups: blue-greens, greens, diatoms, flagellates, and others. For enumeration, blue-green algae were counted by trichomes. Green algae were counted by individual cells except for *Actinastrum, Coelastrum,* and *Pediastrum,* which were recorded by each colony observed. Each cell packet of *Scenedesmus* was counted. Diatoms were counted as one organism regardless of their grouping connections. For flagellates, a colony of *Dinobryon* or a single cell of *Ceratium* was recorded as a unit.

Benthic samples for macroinvertebrate examination were collected using a petite ponar dredge. The samples were washed in a 30-mesh screen bucket, and the residue was preserved in glass jars containing 95 percent ethyl alcohol. In the laboratory, the samples were washed again, and the organisms were picked from the bottom detritus, identified, counted, and preserved in 70 percent ethyl alcohol.

Literature Review

The literature is replete with publications dealing with lake and reservoir restoration, as a result of the impetus provided by the Congressional mandate through the Clean Lakes Program of the Clean Water Act. Noteworthy among them are: Dunst *et al.* (1974), USEPA (1979), Cooke and Kennedy (1981), Peterson (1981), Welch (1981), Reckhow and Chapra (1983), Chapra and Reckhow (1983), Cooke *et al.* (1986), Refield *et al.* (1987), Refield *et al.* (1988), Moore and Thornton (1988), Olem and Flock (1990), and Wedepohl *et al.* (1990).

Recently, two publications on lake management were released by USEPA. Olem and Flock (1990) updated the *Lake and Reservoir Restoration Guidance Manual* first prepared in 1988. This second edition was written primarily to give lake managers practical information on how to protect, restore, and manage lakes and reservoirs. Another manual, *Monitoring Lake and Reservoir Restoration,* by Wedepohl *et al.* (1990) is the first in a series of technical supplements. This volume included information on design and implementation of a lake monitoring program during and after a lake restoration project.

Lake restoration processes are broadly classified into those limiting nutrient and sediment influx and in-lake treatment and control measures. The former include point source nutrient removal and control, nutrient diversion, and control of nonpoint sources of nutrients and sediment. The latter include such techniques as dredging, dilution and dispersion, nutrient inactivation/precipitation, artificial destratification and hypolimnetic aeration, harvesting of nuisance organisms, and biological control of nuisance organisms. Not all the restoration techniques can be successfully applied to all lakes; occasionally, potential negative impacts do occur.

This study, phase III post-restoration monitoring of FHSP Lakes, followed phase II, a program of flow diversion and sediment dredging for nutrient and sediment control and removal. Hence, this literature survey, dealt with only the case histories of lakes where diversion and dredging were the primary or major restoration techniques employed to protect, preserve, and enhance the water quality conditions and lake uses. The responses of these lakes to the management techniques used are summarized here to make the readers aware of the wide variations in results reported in the literature.

Diversion

Diversion of nutrient-rich inflow streams is one method of restoring lakes by reducing both nitrogen and phosphorus sources. The diversion of treated wastewater effluents or stormwaters from eutrophic lakes and reservoirs has resulted in different degrees of success in reversing the eutrophication process and improving water quality. The diversion of ten municipal wastewater treatment plant effluents from Lake

Washington, WA produced a significant improvement in lake water quality (Edmondson, 1968, 1969, 1970). A similar diversion program for Lake Sammamish, 4 miles east of Lake Washington, had little effect on trophic conditions (Emerry *et al.,* 1973). After nutrient diversion, by which approximately 40 percent of the total phosphorus (TP) and 22 percent of the nitrate-nitrogen input were diverted away from Isaaquah Creek, the lake's largest tributary, there had been no measurable amelioration in surface water nutrient concentrations, algal activity, light penetration, or hypolimnetic oxygen deficit. The primary reason attributed was that the amount of phosphorus (P) diverted did not result in the phosphorus input to the lake below the critical level.

Significant short-term water quality improvements were observed in White, Muskegon, and Mona Lakes near Muskegon, MI, for P, nitrogen (N), hypolimnetic DO, and chlorophyll *a* after the diversion of treated wastewater from discharging directly into these lakes. But the lakes did not experience any significant improvements in Secchi disc transparency (Freeman and Canale, 1979). Reduction in lake P concentrations were correlated with changes in nutrient loading. Similar correlations for N were inconclusive, but changes in ammonia and nitrate levels were explained in terms of the effect of diversion on various limnological processes.

Following diversion of one-third of the external P loading of Lake Sammamish, WA, Welch *et al.* (1980) reported that P concentration decreased from 33 micrograms/liter (µg/L) to 27 µg/L. Although Secchi disc and phytoplankton biomass did not change, blue-green algae decreased by SO percent. It was indicated that rapid community development of the shoreline might lead to an increase in P loading, which could equal one-half of P previously diverted in 1968. In contrast, in the case of dilution/flushing technique, low-nutrient dilution water added to Moses Lake in 1977-1978 produced significant improvements of lake water quality (e.g., chlorophyll *a* decreased 60 to 80 percent, TP decreased 50 to 60 percent, blue-green algae decreased from 96 percent in 1970 to 68 percent of the total phytoplankton in 1977-1978), and resulted in adequate control of productivity in portions of the lake (Welch and Patmont, 1980; Welch, 1981).

Lake Vesijarvi, Finland, was reported to have shown rapid improvement in bacteriological quality and water quality (Keto, 1982) after the diversion of municipal wastewater that had been discharged to the lake for 60 years. P level decreased 60 percent and N level decreased 30 percent. After several years, although the recovery process slowed, and blue-green algal blooms began to appear during summer months, subsequent changes have indicated a continuing improvement.

Garrison and Knauer (1983) evaluated a restoration project with storm sewer diversion, alum treatment, and artificial circulation in Mirror and Shadow Lakes, Waupaca, WI. Four years after lake restoration, there were no signs of the lakes reverting to the pre-restoration trophic state.

The reduction in nutrient loading by diversion to a subarctic lake in Sweden produced a 75 percent reduction in phytoplankton biomass (Holmgren, 1985). Mean seasonal TP levels decreased from 168 to 74 µg/L, and Secchi disc transparency increased from 1.3 to 2.1 m with a significant shift in algal species composition.

To reduce P cycling and the occurrence of nuisance blooms of *Oscillatoria agardhii,* both P loading reduction (from 3 to 1 g/m^2) and intensified flushing with low P waters were implemented for the restoration of Lake Velume, the Netherlands (Hasper, 1985). Results indicated a reduction in algal biomass and a 75 percent reduction in summer TP concentrations.

Welch *et al.* (1986) studied the decrease in the release of sediment P and oxygen deficit following wastewater diversion from Lake Sammamish, WA. The improvement in water quality has been the result of a decrease in the anaerobic sediment P release rate during summer and fall. The rate decreased from 5.8 ± 2.5 milligrams per square meter per day (mg/m^{2}d) before and after wastewater diversion (1964-1966 and 1971-1974) to an average of 2.5 ± 2.5 mg/m^{2}d in the early 1980s. A 50 percent decrease in hypolimnetic oxygen deficit rate has been associated with this decrease in the release rate. Total loading (including internal loading) decreased by 10 percent following the 1968 wastewater diversion, and by 36 percent since 1975 because of the decrease in sediment release and a slight decrease in external loading.

In 1971, sewage effluents were diverted from the watershed of Lake Mendota, WI (Lathrop, 1990). P levels and summer blue-green algal blooms in the lake did not decrease immediately following the effluent diversion because of high phosphorus loading from spring runoff from 1973 to 1976. However, beginning in the late 1970s, P levels began to decrease because of lower P loadings from many years of below-normal spring runoff As a result, summer algal blooms became less severe and water quality improved, particularly from 1986 to 1988.

The lower P levels in Lake Mendota also caused decreased P loadings to downstream lakes, which exhibited a decrease in P contents and algal blooms (ibid.). Although improved water clarity was not dramatic in shallower lakes, Waubesa and Kegosa continued to have algal growth. The long-term data indicated that all the Yahara lakes were much more responsive to changes in external P loadings than was thought during the 1970s before diversion. These results suggest the importance of control of agricultural and urban sources of nonpoint pollution to the lakes.

A multivariate analysis focused on the impact of municipal wastewater diversion (in early 1979) from Lake Tuusulanjarvi, Finland on the phytoplankton community (Varis, 1990). The concentration of total N appeared to have been strongly influenced by the wastewater diversion. The growth factors with strongest correlations in the canonical system were the dissolved inorganic N/dissolved inorganic P ratio and temperature.

Dredging

Dredging of sediments is increasingly being used as a method for restoring eutrophic lakes or reservoirs. Dredging has been shown to improve water quality, reduce internal P loadings, decrease aquatic macrophyte growth, and restore lost recreational amenities by physically deepening the lake, and removing oxygen demanding and nutrient-rich organic bottom materials. The number of dredging projects has increased in recent years.

The disadvantages of dredging are its cost, P release from sediment during dredging, reduction of benthic food supplies, potential environmental problems with disposal of dredged material, and noise (Edmondson, 1990).

Heavily polluted from 1930 to 1957, Lake Trummen, the Netherlands, was restored by suction dredging of the top layer of the bottom sediments (Gronberg, 1982). Nutrients and biomass levels decreased significantly and eutrophic species of phytoplankton disappeared as oligotrophic species returned to this once oligotrophic lake.

Dunst (1982) discussed a dredging program for 12 Wisconsin lakes, including the design methodology and information requirements to select a suitable project. Sediment disposal from 12 other dredging projects in Wisconsin was also discussed.

Dooris *et al.* (1982) strongly suggested that dredging of bottom sediments from Sawgrass Lake (Pinellas County, FL) was favored over drawdown as a lake restoration measure. They arrived at this conclusion based on laboratory tests after considering the problems of contamination in the lake sediment and the unfavorable sediment properties (arsenic, chlordane, polychlroinated biphenyls, high organic matter and water content, slow drying characteristics, etc.).

The Hyde Park Lake (Niagara Falls, NY) restoration project consisted of removing polluted lake water and the dredging of lakebottom muck and clay (Pettit *et al.,* 1982). The clay was used as a liner for existing secured landfills. Continuous fresh water was supplied by a nearby reservoir. Pre- and post-construction studies, along with several investigations undertaken during the construction period, verified the improvement of water and environmental quality during the construction phases. Construction of a siltation (settling) pond with a trash collector and an oil boom ensured the prevention of silt and trash from entering the lake via its tributary, Gill Creek. Also, stone riprap and new vegetation provided stabilization of the surrounding soil areas to help prevent erosion.

Approximately 1.6 million cubic yards of soft sediments were dredged from Lake Lansing, ML, from May 1978 through August 1983, and 221,000 cubic yards of sand were redistributed within the lake (Mikula, 1985). Surface area (182 hectares or ha, 450 acres) and maximum depth (11 m, 35 feet) remained the same after dredging, but the mean depth increased from 2.1 m (6.9 feet) to 2.7 m (9 feet). It is reported that the lake exhibited no apparent change in the extent of oxygen depletion due to dredging. There was no oxygen near the bottom shortly after the onset of stratification (May, June). Oxygen concentrations less than 1 mg/L extended upwards to the 4.0 m depth. Comparison of pre- and post-dredging data indicated an increase in transparency and substantial reductions in in-lake P and chlorophyll *a.* It was postulated that the increased volume of Lake Lansing would have had some effect on decreasing the lake TP concentrations due to "dilution." Changes in nitrite and nitrate and oxygen depletion were not evident. The lake improved in trophic status from a highly eutrophic condition to a mesotrophic condition. Heavy metals, especially arsenic and mercury, were not remobilized during dredging.

Benthic macroinvertebrate communities did not change in composition, but their individual numbers did increase after dredging. Composition of the fish community was poor before and after dredging. Phytoplankton growths displayed a seasonal diversity of types, which varied in patterns typical of mesotrophic and/or eutrophic lakes. Although zooplankton populations did not change in composition, their individual numbers did increase after dredging.

Prior to dredging in 1978, *Chara* and *Najas* were the dominant species in Lake Lansing (ibid.). Dominant species occurring after dredging (1983, 1984) were *Myriophyllum* sp. and *Chara.* Native milfoil (*M. exalbescens)* was much more abundant than Eurasian milfoil (*M. spicatum).* Similar to pre-dredging, plants grew to a depth of 3.0 to 3.5 m.

Reelfoot Lake (15,500 acres at normal pool level) is renowned for its abundance of fish and wildlife resources, and it is estimated to bring in a recreational revenue of about $4 million annually. Since the 1950s this Tennessee lake has been degrading as a sports fishing resource. Only large-scale dredging, drawdown, or both were considered to be effective in restoring this lake (Tennessee Wildlife Resources Agency, 1985). Because dredging was found to be prohibitively expensive ($53.7 million), drawdown was selected as the restoration alternative. It would occur from July to December when fishing activity was estimated to be at only 30 percent of its total activity. Fishing trips were expected to increase from 50,000 to 65,000 trips annually as a result of the lake restoration.

It is reported that upstream development increased the sediment load entering North Park Lake near Pittsburgh, PA. The buildup of sediment within the lake had reduced its surface area by approximately 5 acres. Between April 1984 and November 1986, an estimated 35,500 cubic yards of sediment were dredged at a cost of $69,450 (Pennsylvania Department of Environmental Resources, 1988). The water quality after dredging was not reported, but dredging resulted in increased lake surface area, fishing places, and boating areas. The appearance of the lake is also reported to have improved.

The dredging of Ramona Lake and its surrounding park in Berkeley, MO, provided a much-needed water-based recreational facility for residents and visitors. The project began with the removal of a portion of an earthen dam to release water from the lake, followed by dredging and storage of dredged material on site for dewatering (Bhasin, 1988). Later, additional sediment was removed to provide a healthy environment for aquatic life by increasing the lake depth, and finally, the earthen dam was restored.' Approximately 20,000 cubic yards of sediment were dredged. Other improvements included landscaping disturbed areas, retention walls of railroad ties, roads, beach improvements, and lighting. The total cost of dredging and the other improvements was approximately $400,000.

Diversion and Dredging

Stormwater diversion and dredging of Lake Sacajawea, WA, have dramatically decreased the lake's seasonal and yearly mean N levels (Gibbs & Olson, Inc., 1985). Ammonia and nitrate loadings were both reduced as a result of the diversion, while dredging has reduced ammonia release from the sediment during stratification. The lake's P content also decreased due to dredging. Biological productivity in the lake decreased because algal growth appeared to be N limited. Since 1981, Lake Sacajawea has experienced increasing Secchi disc transparency and decreasing chlorophyll *a*. Average summer chlorophyll *a* levels indicated a shift from a eutrophic lake to a mesotrophic lake following lake restoration. However, Secchi disc readings are still in the eutrophic ranges (<80 inches). Nevertheless, 87 percent of P was contributed by the ground water.

Stormwater diversion and inflow stream sedimentation ponds reduced the total suspended solids (TSS) load to Lake Fenwick, WA (URS Co., 1985). The average annual total N and TP in the lakewater were 0.489 and 0.043 mg/L, respectively. Watershed management reduced T P by 68 percent and TSS by 78 percent. Ninety percent of the TSS reduction was due to the stormwater runoff diversion, while the remaining 10 percent was due to retention in the ponds. Stormwater P load was reduced 30 to 70 percent, which is equivalent to an overall P reduction of 17 to 40 percent. Stormwater TSS loads were reduced by 60-80 percent, which is equivalent to an overall TSS reduction of 54 to 70 percent. However, in-lake nutrient concentrations have not changed significantly since 1979. The lake is still reported to be dominated by blue-green algae in the summer.

The multipart restoration program for Wapato Lake (30 acres), in Tacoma, WA, consisted of 1) gradual dilution of the recreation basin (south) of the lake with nutrient-poor municipal water during the summer months; 2) stormwater detention and treatment in the north basin and adjacent wetlands with a berm/overflow spillway between the two lake basins; 3) diversion of most stormwater around the lake; 4) limited dredging of storm sewer outfall areas; 5) a drastic drawdown of lake water to consolidate bottom sediments; and 6) an application of alum to the recreational basin in summer 1984 (Entranco Engineers, Inc., 1986). Stormwater diversion and wetlands treatment reduced P loading to the south basin by more than 90 percent and demonstrated a successful project. However, summer blue-green algal blooms continued to persist due to the unavailability of satisfactory dilution water and major changes in the lake's ecological characteristics.

A wide range of studies have been performed before possible restoration of Liberty Lake, in Spokane, WA (Kennedy Consulting Engineers, 1985). These studies pointed to high concentrations of phosphorus in certain inflows to the lake and within the lake sediments causing eutrophication. Sewering of the developed areas of the lake basin was first done to eliminate the large source of P. Additional project activities were diversion of flood flows around the marsh at the south end of the lake, alum treatment of the entire lake, dredging of the most enriched sediments from 50 acres, water quality monitoring during and after the in-lake works, and a study of stormwater runoff. The water clarity in Liberty Lake during the summer and fall of 1984 was better than it had been for almost ten years. The lake reverted to mesotrophic conditions after these restoration measures, based on four years of monitoring. Comparison of pre- and post-restoration nutrient budgets indicated that P loading was reduced 34 percent. Sewering was primarily responsible for this reduction. Even though the desired change in the phytoplankton communities (from primarily blue-green to primarily green algae) was not seen, indications are that long-term algal productivity and incidence of blue-green algal blooms had been significantly reduced.

The Norfolk Broadland, England, comprises about SO small, shallow eutrophic lakes. As an experiment in lake restoration, the Alderfen Broad was isolated by diversion of an inflow stream without removal of its recently deposited P-rich sediments (Moss *et al.,* 1986, 1990). In four years (1979-1982) after isolation of Alderfen Broad, the phytoplankton crop was greatly decreased; the lakewater cleared; and net release of phosphate-phosphorus (PO_4-P) from the sediment ceased. Because of reduced water-column turbulence caused by plants and the organic matter supplied to the sediment surface in their decay, the mechanism for release of PO4-P from the sediment was reactivated, which resulted in a large phytoplankton crop in spring 1984. As a consequence, the aquatic plant population declined. In 1985 there were both spring and summer phytoplankton growths.

In another experiment, sediments were dredged from Cockshoot Broad, and dams were placed against the nutrient-rich River Bure, but the Broad continued to be fed by a small stream draining an agricultural and fen catchment. A reduction in phytoplankton growth occurred soon after the isolation and dredging, and the water cleared. Part of the Broad was recolonized with a diverse species of aquatic plants.

Gorton Pond in Warwich, RI, is used for both primary and secondary contact recreation, propagation of fish, and other aquatic life and wildlife. It serves as a drainage sink for its surrounding watershed, and as such receives the surface runoff from 790 acres of urban area. There is a small enclave of homes without sewers, however (Keyes Associates, 1982). Stormwater and wastewater diversion, as well as dredging along the inlet and outlet areas, were recommended as part of the comprehensive lake restoration project.

Between 1978 and 1986 an estimated 276,000 m^3 (361,000 cubic yards) of sediment was removed from Nutting Lake at Billerica, MA, by hydraulic dredging (Baystate Environmental Consultants, 1987). The influence of domestic wastewater on the lake has been eliminated. However, the dredging was not as successful as anticipated. Considerable quantities of soft sediment remain in the lake. The only benefit observed was an increase in DO levels at the surface of the east basin and throughout the west basin of the lake. Reduction of macrophyte nuisance in selected areas has fostered increased lake use for swimming and boating.

Economic evaluations of restored lakes in Florida showed that gravity drawdown was the least expensive method, whereas sewage effluent diversion was 10,000 times more expensive in terms of hectares (Dierberg and Williams, 1989). Options for all lake restoration or enhancement measures can be ranked in the following order (least expensive to most expensive): gravity drawdown < grass carp introduction < mechanical drawdown < aeration < stormwater control (drawdown and dredging) < effluent diversion. Within a particular restoration category, the cost spanned approximately 1-1/2 orders of magnitude.

Lily Lake in Kenosha County, WI, with a surface area of 90 acres and a maximum depth of six feet, was dredged in 1978 and 1979 to eliminate dense weed growth, prevent fish kills, and in general enhance recreational usage (fishing, swimming, boating, and water skiing). The lake was deepened to a maximum depth of 22 feet and the storage volume increased from 432 acre-feet to 986 acre-feet (LLPRD, 1981). The lake was monitored from 1976 to 1981.

Since completion of the dredging project in Lily Lake, DO concentrations did not drop below 7 mg/L at any depth during winter, thus avoiding winter fish kills. Prior to dredging, the lake had low orthophosphorus levels, 4 µg/L. Little change was noted either during or after the dredging project. Likewise, chlorophyll *a* levels were low in the lake. However, the concentration increased from about 3 µg/L to an average value of 18.5 µg/L during dredging. Chlorophyll levels dropped back to 5 µg/L after dredging.

Macrophyte growth covered the entire lakebed prior to dredging. A diversity of plant species was present but *Potamogeton robbinsii* dominated. In 1980, the first year after dredging, the lake was found to be reinvaded by vegetation, however. Growth covered 75 percent of the lake bottom, with *Chora* and *Myriophyllum* as codominant species.

It is reported that the overall lake usage increased greatly at Lily Lake. Water skiing and sail boating became common, and beach usage rose by a factor of ten. Fish habitat also improved. Comments received on the project were positive, expressing pleasure with revitalized lake conditions and usability.

RESULTS AND DISCUSSION

Water Quality Characteristics: Phase III Monitoring (1988-1991)

Physical Characteristics

Temperature and Dissolved Oxygen. Lakes in the temperate zone generally undergo seasonal variations in temperature through the water column. These variations, with their accompanying phenomena, are perhaps the most influential controlling factors within the lakes.

The temperature of a deep lake in the temperate zone is about 4°C during early spring. As the air temperatures rise, the upper layers of water warm up, and wind action mixes them with the lower layers. By late spring, the differences in thermal resistance cause the mixing to cease, and the lake approaches the thermal stratification of the summer season. Shortly after the temperature variation in water comes the physical phenomenon of increasing density with decreasing temperature up to a certain point. These two interrelated forces are capable of creating strata of water of vastly differing characteristics within the lake.

During thermal stratification, the upper layer (epilimnion) is isolated from the lower layer of water (hypolimnion) by a temperature gradient (thermocline). Temperatures in the epilimnion and hypolimnion are essentially uniform. The thermocline will typically have a sharp temperature drop per unit depth from the upper to the lower margin. When the thermal stratification is established, the lake enters the summer stagnation period, so named because the hypolimnion becomes stagnant.

With cooler air temperatures during the fall season, the temperature of the epilimnion decreases until it is the same temperature as the upper margin of the thermocline. Successive cooling through the thermocline to the hypolimnion results in a uniform temperature through the water column. The lake then enters the fall circulation period (fell turnover) and is again subjected to a complete mixing by wind.

Declining air temperatures and the formation of an ice cover during the winter produce a slight inverse thermal stratification. The water column is essentially uniform in temperature at about 3 to 4°C, but slightly colder temperatures of 0 to 2°C prevail just below the ice. With the advent of spring and gradually rising air temperatures, the ice begins to disappear, and the temperature of the surface water rises. The lake temperature again becomes uniform, and the spring circulation occurs.

The most important phase of the thermal regime from the standpoint of eutrophication is the summer stagnation period. The hypolimnion, by virtue of its stagnation, traps sediment materials such as decaying plant and animal matter, thus decreasing the availability of nutrients during the critical growing season. In a eutrophic lake, the hypolimnion becomes anoxic or devoid of oxygen because of the increased content of highly oxidizable material and because of its isolation from the atmosphere. In the absence of oxygen, the conditions for chemical reduction become favorable, and more nutrients are released from the bottom sediments to the overlying waters.

However, during the fall circulation period, the lake water becomes mixed, and the nutrient-rich hypolimnetic waters are redistributed. The nutrients that remained trapped during the stagnation period become available during the following growing season. Therefore, a continual supply of plant nutrients from the drainage basin is not mandatory for sustained plant production. Fruh (1967) and Fillos and Swanson (1975) state that after an initial stimulus, the recycling of nutrients within a lake might be sufficient to sustain highly productive conditions for several years.

Isothermal plots for Lake 1 and Lake 2 in 1990 are shown in figures 13 and 14, respectively. Also, the vertical temperature profiles for these two lakes at selected dates in 1989 are shown in figures 15 and 16, respectively. The vertical temperature profiles for Lake 3, site 1 for 1989 and 1990 are shown in figure 17.

Figures 13 and 14 show that the summer stratification begins in early April and intensifies progressively during the summer months. Lake 2 is deeper than Lake 1 and exhibits a typical stratification pattern. However, the thermal gradient exhibited

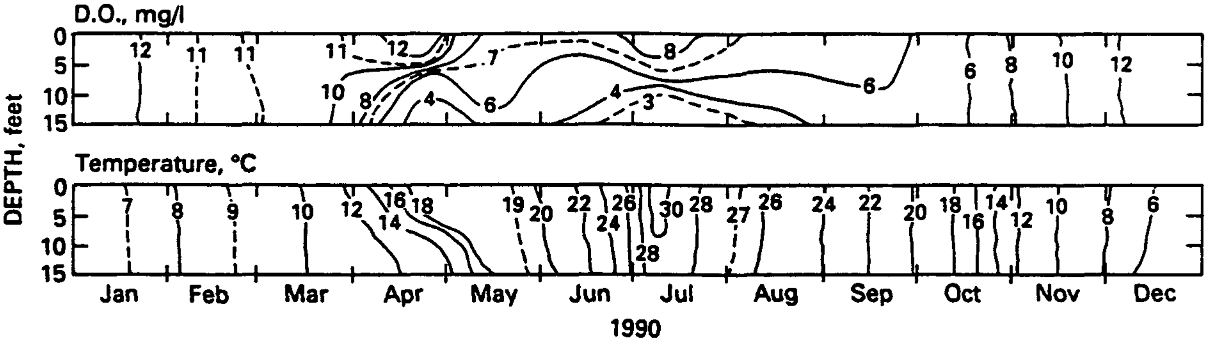


Figure 13. Isothermal and iso-dissolved oxygen plots for Lake 1

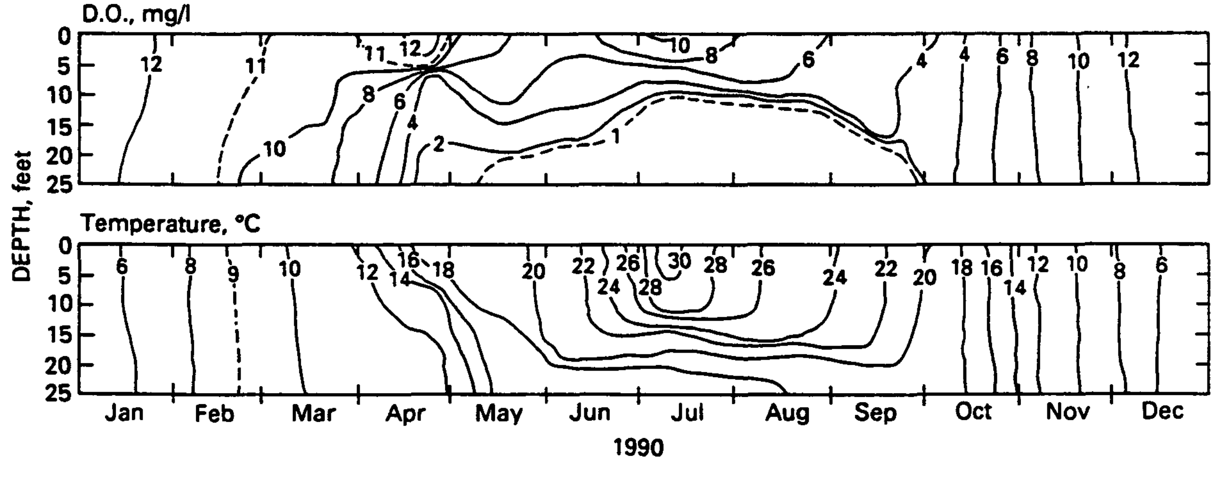


Figure 14. Isothermal and dissolved oxygen profiles for Lake 2

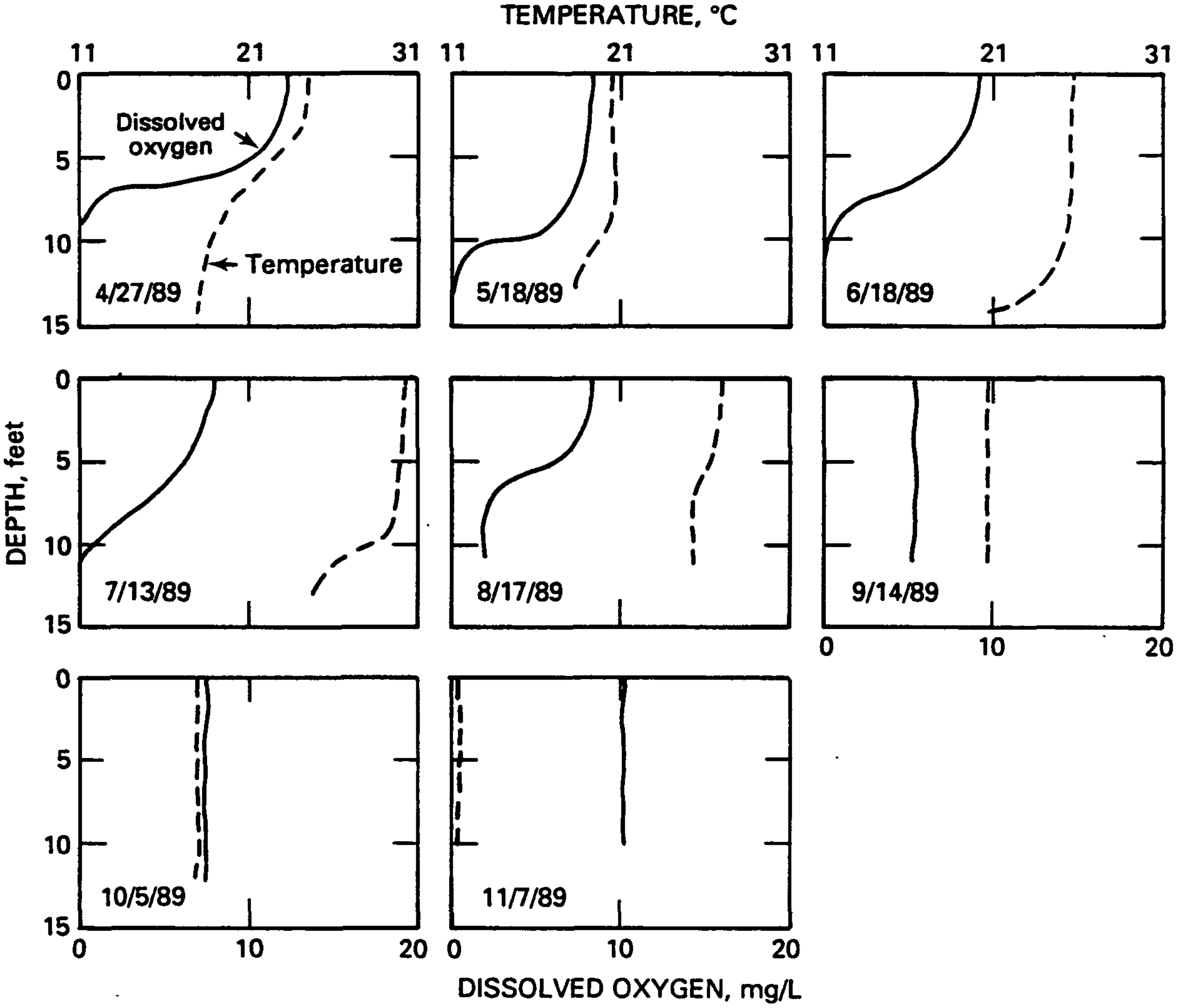


Figure 15. Temperature and dissolved oxygen profiles for Lake 1

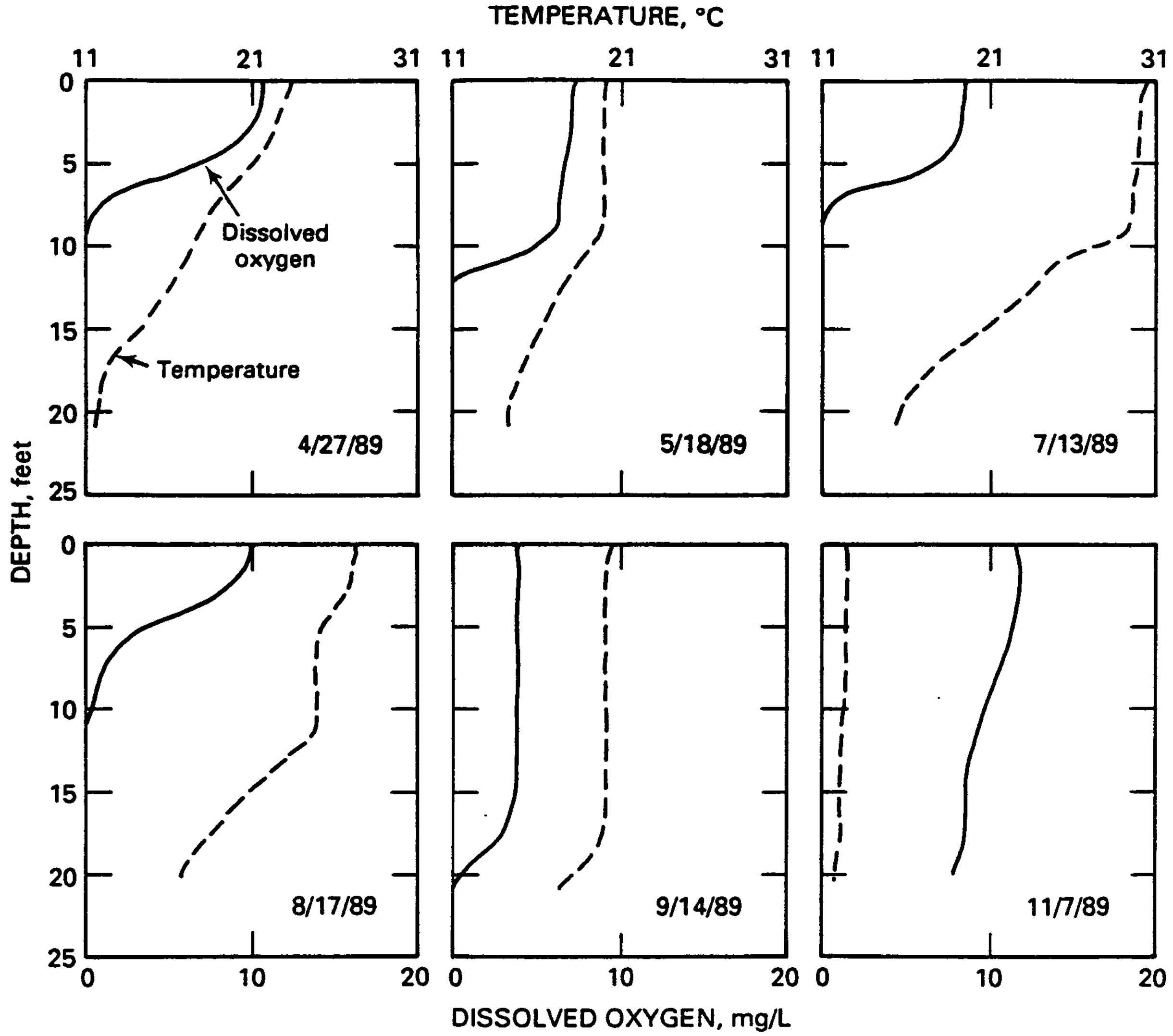


Figure 16. Temperature and dissolved oxygen profiles for Lake 2

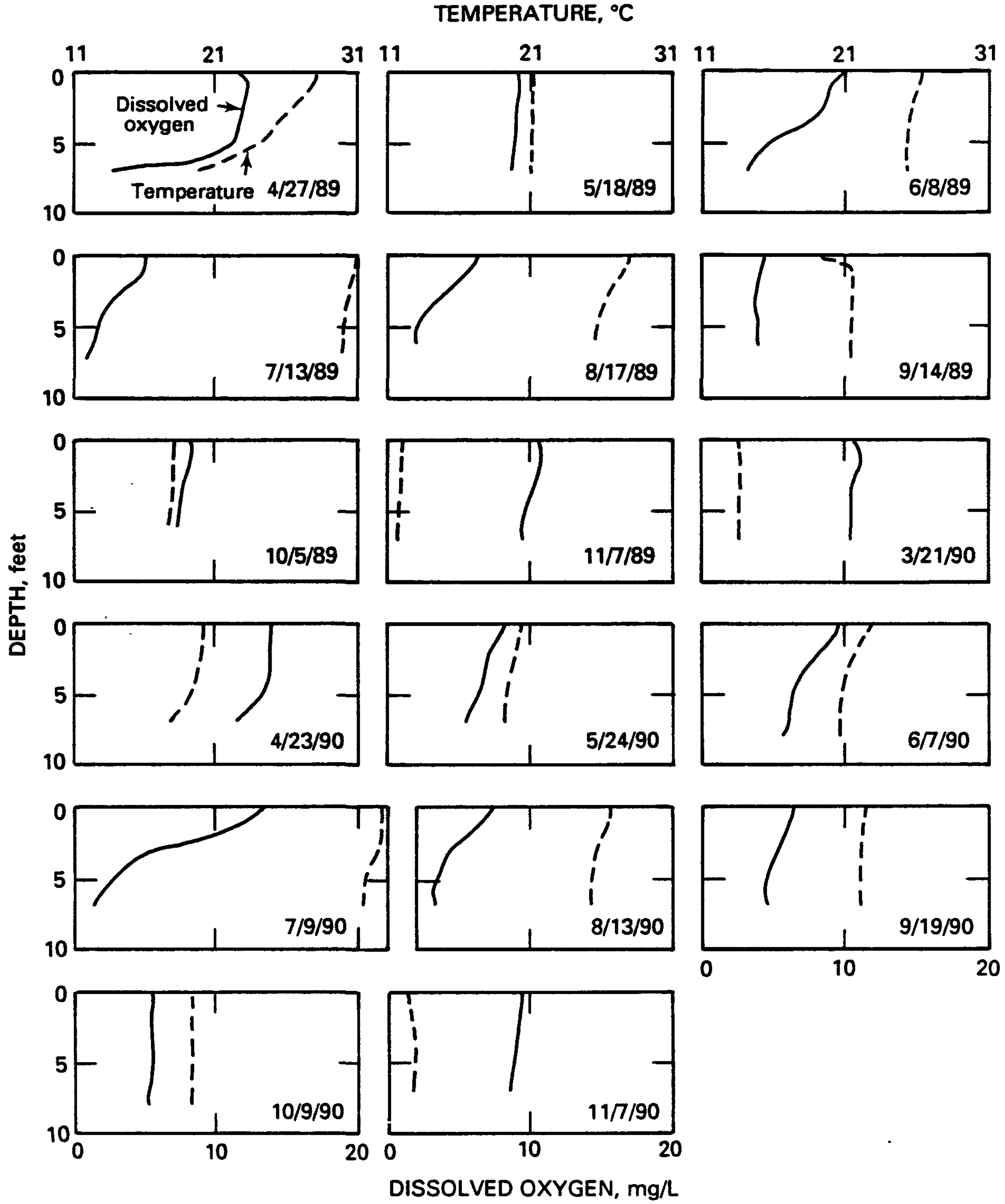


Figure 17. Temperature and dissolved oxygen profiles for Lake 3

throughout Lake 1 is as pronounced as that for Lake 2. In both these lakes, the maximum observed water temperature was about 31°C on July 14, 1990. The maximum temperature differentials experienced by Lakes 1 and 2 during 1989, 1.0°C and 13.2°C, respectively, occurred on the same date. Thereafter, the intensity of stratification began to decrease. Lake 3, shallowest of the three lakes, experienced much less thermal gradient, except for the observation on April 27, 1989, when the difference between surface and near-bottom water temperatures was 7.2°C. The reason for the anomalous observation is not readily apparent. Such a magnitude of temperature gradient was observed at no other time in Lake 3 during this investigation. Lake 2 was found to become isothermal by October 9, 1990, after fall turnover, whereas Lake 1 was isothermal by early September 1990.

The aforementioned general observations for the three lakes apply to data gathered in 1989 (figures 15-17) and other post-implementation monitoring years. All the data gathered for the FHSP Lakes - physical, chemical, and biological - have been entered into USEPA's STORET system and are readily accessible.

It is common knowledge that the impoundment of water alters its physical, chemical, and biological characteristics. The literature is replete with detailed reports on the effects of impoundments on various water quality parameters. The physical changes in the configuration of the water mass after impoundment reduce reaeration rates to a small fraction of those of free-flowing streams. Where the depth of impoundment is considerable, the thermal stratification acts as an effective barrier for the wind-induced mixing of the hypolimnetic zone. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanism.

During the period of summer stagnation and increasing water temperatures, the bacterial decomposition of the bottom organic sediments exerts a high rate of oxygen demand on the overlying waters. When this rate of demand exceeds the oxygen replenishment by molecular diffusion, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom. Hypolimnetic zones of artificial impoundments were also found to be anaerobic within a year of their formation (Kothandaraman and Evans, 1975).

The DO isopleths for Lakes 1 and 2 for 1990 are shown in figures 13 and 14, respectively. Selected vertical DO profiles for the three lakes are included in figures 15-17. The DO profiles for Lakes 1 and 2 pertain to 1989, whereas figure 17 shows the DO profiles for Lake 3 for both 1989 and 1990.

DO depletion was more severe in Lake 2 compared to Lake 1 and began to occur during the latter part of April. As the summer thermal stagnation intensified, the anoxic zone of hypolimnetic waters in Lake 2 progressively increased, reaching a maximum during early July. The extent of this anaerobic zone started diminishing thereafter, and the DO concentration became uniform in the water column in early October.

During the period of peak stratification, Lake 2 was totally anoxic at depths 9 feet from the surface and below. About 49 acre-feet or approximately 14 percent of the lake volume was anoxic, somewhat restricting habitat for desirable fish food organisms and fish. During summer months, adequate oxygen levels did not generally exist at depths below 6 feet from the surface.

Oxygen depletion in the shallow Lakes 1 and 3 was not as severe. No anoxic conditions were observed in Lake 1 during 1990; however, near-bottom anoxic conditions were observed there during 1989 (figure 15) and 1991. Significant oxygen depletion occurred in Lake 3 even though the water body experienced only weak thermal gradients during summer months (figure 17). Oxygen demand from lake bottom sediments during summer months appears to be substantial in all three lakes.

Table 15 shows the percent DO saturation levels at the surface of the FHSP Lakes. The highest and lowest percent saturation values observed for Lake 1 were 172.5 and 55.0; Lake 2, 201.2 and 41.1; and Lake 3, 185.8 and 45.8. For inexplicable reasons, the DO levels were supersaturated in all three lakes for the first eight months of calendar year 1991, with very few exceptions. Such supersaturated conditions did not prevail during 1990. The saturation levels in the lakes were generally higher throughout 1991 compared to 1990.

Secchi Disc Transparencies. Secchi disc visibility is a measure of the lake water transparency or its ability to allow light transmission. Even though the Secchi disc transparency is not an actual quantitative indication of light transmission, it serves as an

Table 15. Surface Percent Dissolved Oxygen (DO) Saturation Levels in Frank Holten State Park Lakes

Date	*Lake 1*	*Lake 2*	***Lake 3*** *Site 1*
4/27/88	*11A*	68.0	97.0
6/07	172.5	201.2	122.8
7/12	139.9	142.7	85.6
8/23	72.4	68.0	90.7
9/21	100.2	102.4	105.0
4/27/89	147.6	134.9	149.9
5/18	91.8	81.4	102.0
6/08	121.2	_	124.1
7/13	112.2	114.0	67.0
8/17	106.7	126.3	80.1
9/4	62.0	45.0	45.8
10/05	79.8	98.0	86.7
11/07	95.6	103.9	97.9
1/17/90	100.5	100.0	110.3
2/14	97.3	98.2	101.2
3/21	95.0	95.6	98.9
4/23	140.6	139.3	154.4
5/16	80.9	91.5	-
5/24	92.9	102.9	92.8
6/07	83.9	81.0	111.9
7/09	117.9	137.6	185.8
8/13	81.0	86.8	89.9
9/19	75.9	57.6	73.4
10/09	55.0	41.1	58.9
11/07	85.2	80.4	85.1
12/11	103.5	100.8	97.7
2/21/91	124.8	117.1	133.9
3/19	104.1	103.2	113.8
4/17	136.0	136.6	126.6
5/14	135.4	122.4	182.1
6/13	170.3	176.5	151.6
7/11	94.5	119.8	93.3
8/22	143.8	158.5	147.8
9/20	99.4	52.8	72.4
10/22	94.9	98.3	87.1
11/19	95.1	102.3	99.1

index and a means of comparing similar bodies of water or the same body of water at different times. Since changes in water color and turbidity in a deep lake are generally caused by aquatic flora and fauna, transparency is often related to this entity.

The mean and range of values observed for Secchi disc readings (in inches) for Lakes 1, 2, and 3 were, respectively, 16, 5-28; 16, 6-28; and 18, 7-30. Table 16 provides these values along with a summary of observations for other physical and chemical water quality parameters. The mean Secchi disc values for all the lakes were comparable, as were the minimum and the maximum values for these lakes. No clear trend among Secchi disc readings, turbidity, and suspended sediment values could be discerned. It is somewhat surprising that Secchi disc values were not higher in Lake 2, which has a maximum depth of about 25 feet, compared to the other two shallower lakes. Impounded water bodies with maximum depths of about 25 feet are known to have much higher mean and maximum Secchi disc transparencies (Kothandaraman and Evans, 1983a; 1983b).

Turbidity. High turbidity affects the aesthetic quality of the water. Its origins are generally considered to be municipal and industrial wastes; clastic materials derived from the drainage basin; soil erosion resulting from agricultural practices and urban and highway developments; lake sediments stirred by wind, waves, and high-speed boating activities in shallow lakes; and detrital remains of algae and aquatic and terrestrial plants and animals. However, in the case of the FHSP Lakes, some of these causative agents, such as industrial wastes and high-speed boating activities, are absent.

The mean and range of turbidity values for these lakes were similar except for one very high value (110 NTU) of the near-bottom sample from Lake 1 on May 6, 1990. The mean value for site 3 of Lake 3, the shallowest of all the sampling sites in the lake system, was higher than other sites. In nearby Horseshoe Lake in Madison County, IL, an oxbow lake with a mean depth of only 3 feet, the mean and range of turbidity values were reported as 40 and 22 to 66 NTU (Rehfeldt *et al.,* 1992). Clarity in the FHSP Lakes is much better than that for Horseshoe Lake. The mean and range of turbidity values in NTU for surface samples were 8.5, 0.3-39.0 for Lake 1; 7.1, 0.2-15.0 for Lake 2; 7.4, 0.5-17.0; 8.0, 1.2-19.0; and 11.9, 0.5-27.0 for sites 1, 2, and 3, respectively, of Lake 3.

Table 16. Water Quality Characteristics of Frank Holten State Park Lakes

	Lake 1				***Lake 2***			
	Surface		***Near-bottom***		***Surface***		***Near-bottom***	
Parameters	***Mean***	***Range***	***Mean***	***Range***	***Mean***	***Range***	***Mean***	***Range***
Secchi readings (inches)	16	5-28	_	-	16	6-28	-	-
Total suspended solids	24	8-76	31	8-214	22	6-62	22	8-47
Volatile suspended solids	14	1-29	14	4-32	13	2-32	12	2-24
Turbidity (NTU)	8.5	0.3-39.0	11.1	0.5-110.0	7.1	0.2-15.0	9.0	0.8-39.0
Nitrate/nitrite-N	0.06	0.01-0.10	0.06	0.01-0.10	0.07	0.01-0.34	0.05	0.01-0.10
Total ammonia-N	0.11	0.01-0.37	0.15	0.01-0.47	0.15	0.01-0.60	1.23	0.04-7.30
Total kjehdahl-N	1.9	0.7-3.3	1.9	0.8-3.0	1.7	0.4-2.7	2.6	0.8-8.1
Total phosphate-P	0.18	0.08-0.39	0.18	0.08-0.30	0.17	0.04-0.44	0.36	0.07-2.20
Dissolved phosphate-P	0.05	0.00-0.28	0.06	0.00-0.17	0.05	0.00-0.26	0.27	0.00-1.74
Conductivity (µmho/cm)	373	296-450	382	282-468	381	312-456	466	238-747
Total alkalinity	114	20-140	119	70-150	122	80-170	148	80-260
Phenolphthalein alkalinity	12	0-25	6	0-20	11	0-25	3	0-20
pH (units)	-	7.7-9.5	-	7.1-9.2	-	7.6-9.5	-	6.5-8.7
Chemical oxygen demand	37	24-49	36	25-47	36	26-48	33	23-44
Chlorophyll-*a*	91.3	33.5-158.8			90.9	42.2-161.8		
Chlorophyll-*a* (Corr)	91.4	32.3-173.6			91.1	38.3-155.4		
Chlorophyll-*b*	8.2	2.0-23.5			7.6	2.4-14.0		
Chlorophyll-*c*	5.0	0.9-13.5			4.8	0.1-21.5		
Phaeophytin	1.2	0.0-8.3			1.3	0.0-11.5		

	Lake 3, Surface					
	Site 1		*Site 2*		*Site 3*	
Parameters	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Secchi readings (inches)	18	7-30	17	6-28	13	5-25
Total suspended solids	22	5-50	22	4-52	30	4-61
Volatile suspended solids	8	2-26	8	3-23	9	2-19
Turbidity (NTU)	7.4	0.5-17.0	8.0	1.2-19.0	11.9	0.5-27.0
Nitrate/nitrite-N	0.20	0.01-5.30	0.07	0.01-0.22	0.09	0.01-0.38
Total ammonia-N	0.11	0.01-0.60	0.09	0.01-0.38	0.10	0.02-0.39
Total kjeldahl-N	1.2	0.10-2.40	1.1	0.30-2.40	1.1	0.10-2.10
Total phosphate-P	0.14	0.01-0.31	0.14	0.03-0.28	0.18	0.06-0.42
Dissolved phosphate-P	0.05	0.01-0.14	0.05	0.01-0.20	0.05	0.02-0.20
Conductivity (µmho/cm)	573	433-714	577	443-719	580	448-748
Total alkalinity	164	90-220	165	90-230	169	70-240
Phenolphthalein alkalinity	4	0-20	4	0-15	6	0-25
pH (units)	-	7.6-8.8	-	7.4-8.8	-	7.5-8.8
Chemical oxygen demand	27	19-42	26	18-37	28	20-48
Chlorophyll *a*	56.9	21.2-120.5	55.4	23.4-111.5	60.4	14.6-172.2
Chlorophyll *a* (Corr)	56.8	18.5-120.2	55.3	23.2-117.9	60.7	13.1-186.9
Chlorophyll *b*	8.7	1.1-38.4	8.9	0.8-45.3	11.1	1.3-58.3
Chlorphyll *c*	3.4	0.0-11.5	3.3	0.0-10.4	3.3	0.0-11.0
Phaeophytin	2.0	0.0-11.7	1.6	0.0-11.2	1.8	0.0-15.4

Note: All chlorophyll values are in µg/L; other values are in mg/L except where noted.

Chemical Characteristics

pH and Alkalinity. It is generally considered that pH values above 8.0 in natural waters are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition (Mackenthun, 1969). Photosynthesis by aquatic plants uses carbon dioxide removed from bicarbonates when no free carbon dioxide exists in the water medium. Decomposition and respiration tend to reduce pH and increase bicarbonates.

The alkalinity of a water or its capacity to accept protons is generally imparted by bicarbonate, carbonate, and hydroxide components. The species makeup of alkalinity is a function of pH and mineral composition. The carbonate equilibrium, in which carbonate and bicarbonate ions and carbonic acid are in equilibrium, is the chemical system present in natural waters. Determination of the phenolphthalein end point provides a measure of the carbonate species of the total alkalinity, which is generally taken to be twice the amount indicated by this end point. Phenolphthalein alkalinity is then the difference between the total alkalinity and carbonate alkalinity.

The pH and alkalinity values observed in the lakes are typical of Illinois lakes. The highest pH values of 9.5 were observed in the surface water samples from Lakes 1 and 2, indicating algal bloom conditions. Lake 3, generally turbid from resuspension of bottom sediments, exhibited a maximum pH value of 8.8. The near-bottom samples of Lake 2 had lower pH values than the near-bottom samples of Lake 1. Lake 2, being deeper than Lake 1, underwent a higher degree of anoxic conditions in the deeper strata, resulting in a higher degree of anaerobic decomposition of organic matter. As expected, this resulted in a lower range of pH values and a higher range of total alkalinity in Lake 2 than in Lake 1. The mean carbonate alkalinity for the surface samples of Lakes 1 and 2 was about 25 mg/L and that for Lake 3 was about 9 mg/L; however, the mean total alkalinity for Lake 3 was 165 mg/L, much higher than the mean values for the surface samples from Lakes 1 and 2. Generally, alkalinity of surface water in Lakes 1 and 2 decreased during summer months, presumably due to algal photosynthesis, and simultaneously increased in the bottom water samples.

Conductivity. Specific conductance provides a measure of a water's capacity to convey electric current and is used as an estimate of the dissolved mineral quality of water. This property is related to the total concentration of ionized substances in water and the temperature at which the measurement is made. While specific conductance is affected by factors such as the nature of dissolved substances, their relative concentrations, and the ionic strength of the water sample, the geochemistry of the drainage basin is the major factor determining the chemical constituents in the waters. Practical applications of conductivity measurements include purity of distilled or deionized water, variations in dissolved mineral concentrations in water samples, and estimation of dissolved ionic matter in water samples.

The conductivity values for Lake 3 were higher than the surface sample values for Lakes 1 and 2, a phenomenon similar to that observed for total alkalinity. This is primarily because of the direct impact of Harding Ditch on Lake 3. Also, the increasing trend of conductivity toward the lake bottom follows the same pattern as for alkalinity. The mean and range of conductivity values (in µmho/cm) for surface and near-bottom samples, respectively, were 373, 296-450 and 382, 282-468, for Lake 1; 381, 312-456 and 466, 238-747 for Lake 2; and 573, 433-714; 577, 443-719; and 580, 448-748 for Lake 3, sites 1, 2, and 3, respectively.

Phosphorus. Phosphorus as phosphate may occur in surface waters or ground waters as a result of leaching from minerals or ores, natural processes of degradation, or agricultural drainage. Phosphorus is an essential nutrient for plant and animal growth and, like nitrogen, it passes through cycles of decomposition and photosynthesis.

Because phosphorus is essential to the plant growth process, it has become the focus of attention in the entire eutrophication issue. With phosphorus being singled out as probably the most limiting nutrient and the one most easily controlled by removal techniques, various facets of phosphorus chemistry and biology have been extensively studied in the natural environment. To prevent biological nuisance, the Illinois Pollution Control Board (IPCB) (1990) stipulates that "Phosphorus as P shall not exceed 0.05 mg/L in any reservoir or lake with a surface area of 8.1 hectares (20 acres) or more or in any stream at the point where it enters any such reservoir or lake."

Unlike nitrate-nitrogen, phosphorus applied as fertilizer is held tightly to the soil. Most of the phosphorus carried into streams and lakes from runoff over cropland will be in the particulate form. On the other hand, the major portion of phosphate-phosphorus emitted from municipal sewer systems is in a dissolved form. This is also true of phosphorus generated from anaerobic degradation of organic matter in the lake bottom. Consequently, the form of phosphorus, namely particulate or dissolved, is indicative of its source to a certain extent.

From his experience with Wisconsin lakes, Sawyer (1952) concluded that aquatic blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus exceed 0.3 and 0.01 mg/L, respectively. These critical levels for nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature.

A summary of the observations for total and dissolved phosphate-phosphorus in the lakes is given in table 16. The mean dissolved phosphorus levels in all the lakes varied from 0.05 to 0.06 mg/L, and the mean total phosphorus varied from 0.14 to 0.18 mg/L for surface samples. Even the lowest observed total phosphorus values in the lakes were three to eight times higher than the critical values suggested by Sawyer (1952). The total and dissolved phosphorus mean values for Lake 2 bottom samples were 0.36 and 0.27 mg/L, respectively, indicating that a very high proportion of the total phosphorus is in the readily available dissolved form. These phosphorus values are much higher than those for the surface samples. Levels of dissolved oxygen play a key role in controlling the amount of phosphorus released from the sediments into the overlying water. Fillos and Swanson (1975) reported a 21-fold increase in phosphorus release from sediments during anoxic conditions as opposed to aerobic conditions. The total and dissolved phosphorus data for Lake 2 near-bottom water samples clearly show this internal regeneration of phosphorus during periods of stratification.

Nitrogen. Nitrogen in natural waters is generally found in the form of nitrate, organic nitrogen, and ammonia-nitrogen. Nitrates are the end product of the aerobic stabilization of organic nitrogen, and as such they occur in polluted waters that have undergone self-purification or aerobic treatment processes. Nitrates also occur in percolating ground waters. Ammonia-nitrogen, being a constituent of the complex nitrogen cycle, results from the decomposition of nitrogenous organic matter. Ammonia-nitrogen can also result from municipal and industrial waste discharges to streams and rivers, however.

The concerns about nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because the traditional water treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/L in public water supplies. Second, a concentration > 0.3 mg/L is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1952). The IPCB stipulates that ammonia-nitrogen and nitrate plus nitrite as nitrogen should not exceed 1.5 and 10.0 mg/L, respectively.

Nitrogen is one of the principal elemental constituents of amino acids, peptide, proteins, urea, and other organic matter. Various forms of nitrogen (for example, dissolved organic nitrogen and inorganic nitrogen such as ammonium, nitrate, nitrite, and elemental nitrogen) cannot be used to the same extent by different groups of aquatic plants and algae.

Vollenweider (1968) reports that in laboratory tests, as a general rule, the two inorganic forms of nitrogen, ammonia and nitrate, are used by planktonic algae to roughly the same extent. However, Wang *et al.* (1973) reported that during periods of maximum algal growth under laboratory conditions, ammonium-nitrogen was the source of nitrogen preferred by planktons. In the case of higher initial concentrations of ammonium salts, lower yields were noted than with equivalent concentrations of nitrates (Vollenweider, 1968). This was attributed to the toxic effects of ammonium salts. The use of nitrogenous organic compounds has been noted by several investigators, according to Hutchinson (1957). However, Vollenweider (1968) cautions that the direct use of organic nitrogen by planktons has not been definitely established, citing that none of 12 amino acids tested with green algae and diatoms was a source of nitrogen when bacteria-free cultures were used. But the amino acids were completely used up after a few days when the cultures were inoculated with a mixture of bacteria isolated from water. He has opined that in view of the fact that there are always bacterial fauna active in nature, the question of the use of organic nitrogen sources is of more interest to physiology than to ecology.

The mean and range of values for ammonia, nitrate/nitrite, and kjeldahl nitrogen in the lakes are included in table 16. The mean and range of values for ammonia-N (in mg/L) for surface and near-bottom samples were 0.11, 0.01-0.37 and 0.15, 0.01-0.47, respectively for Lake 1 and 0.01-0.60 and 1.23, 0.04-7.30 for Lake 2. Corresponding values for Lake 3 surface samples at sites 1, 2, and 3 were, respectively, 0.11, 0.01-0.60; 0.09, 0.01-0.38; and 0.10, 0.02-0.39.

The mean and range of values for nitrate/nitrite-N in mg/L for surface and near-bottom samples were 0.06, 0.01-0.10 and 0.06, 0.01-0.10, respectively, for Lake 1 and 0.07, 0.01-0.34 and 0.05, 0.01-0.10 for Lake 2. Corresponding values for Lake 3 surfece samples at sites 1, 2, and 3 were, respectively, 0.20, 0.01-5.30; 0.07, 0.01-0.22, and 0.09, 0.01-0.38.

The mean and range of values for kjeldahl-N in mg/L surface and near-bottom samples were 1.9, 0.7-3.3 and 1.9, 0.8-3.0, respectively, for Lake 1 and 1.7, 0.4-2.7 and 2.6, 0.8-8.1 for Lake 2. Corresponding values for Lake 3 surface samples at sites 1, 2, and 3 were, respectively, 1.2, 0.10-2.40; 1.1, 0.30-2.40; and 1.1, 0.10-2.10.

Mean inorganic nitrogen (total ammonia-nitrogen and nitrate-nitrogen) for the surface water samples was generally less than the suggested critical concentration (0.3 mg/L) for nitrogen. In Lake 2, the mean values for total ammonia nitrogen increased from 0.15 mg/L at the surface to 1.23 mg/L at the bottom. Kjeldahl-nitrogen mean values showed an increasing trend toward the bottom of the lake. These are clear indications of the significant anaerobic decomposition of the organic debris occurring on the lake bottom.

Total Suspended Solids and Volatile Suspended Solids. Generally, the amount of suspended solids found in impounded waters is small compared with the amount found in streams because solids tend to settle to the bottom of the lake. In shallower lakes, however, this aspect is greatly modified by wind and wave action and by the type and intensity of use to which these lakes are subjected. Also, bottom-feeding fish, particularly carp, are known to stir up bottom sediments and increase turbidity and sediment concentrations in the overlying waters. Volatile suspended solids (VSS) are measures of the organic fraction of the total suspended solids (TSS), and thus the difference between these entities is taken as the inorganic suspended particulate matter. There are no state water quality standards for the suspended sediments in the surface waters of Illinois.

Barring one very high TSS value for a Lake 1 bottom sample, the mean and range of values found for the three lakes (table 16) are typical of shallow lakes in Illinois. The mean and range of values observed in Horseshoe Lake, Madison County, were 49 and 25 to 70, respectively. Horseshoe Lake is much shallower than Lake 3. Generally, the organic fractions of the suspended sediments in the lake varied from 35 to 60 percent. For Horseshoe Lake, it was about 45 percent (Rehfeldt *et al.,* 1992).

Chlorophyll. Chlorophyll a is a primary photosynthetic pigment in all oxygen-evolving photosynthetic organisms. Extraction and quantification of chlorophyll *a* can be used to estimate the biomass or standing crop of planktonic algae present in a body of water. Other algal pigments have limited distribution and are considered accessory photosynthetic pigments; particularly chlorophyll *b* and *c* can give information on the type of algae present. Blue-green algae (Cyanophyta) contain only chlorophyll *a,* while both the green algae (Chlorophyta) and the euglenoids (Euglenophyta) contain chlorophyll *a* and *c.* Chlorophyll *a* and *c* are also present in the diatoms, yellow-green, and yellow-brown algae (Chrysophyta), as well as the dinoflagellates (Pyrrhophyta). Therefore these accessory pigments can be used to identify the types of algae present in a lake (IEPA, 1990).

To obtain living algal biomass, chlorophyll *a* values are corrected for phaeophytin *a,* which is produced when chlorophyll *a* breaks down. If a large amount of phaeophytin *a* is present, a stressed algal population or recent die-off is indicated (ibid.).

Chlorophyll values for the lakes are shown in table 16. The mean and range of chlorophyll *a* values in µg/L were 91.4 and 32.3-173.6 for Lake 1; 91.1, 38.3-155.4 for Lake 2; and 56.8, 18.5-120.2; 55.3, 23.2-117.9; and 60.7, 13.1-186.9, respectively, for sites 1, 2, and 3 of Lake 3. Algal biomass for Lakes 1 and 2 were comparable and much higher than for Lake 3. Based on chlorophyll *a* criteria for classifying the trophic state of lakes, all three lakes could be categorized as highly eutrophic. This aspect will be subsequently dealt with in more detail.

Biological Characteristics

Algae. Seasonal and spatial distributions of algal densities, expressed as the total counts per milliliter (cts/mL), for each of the three lakes are depicted in figure 18. As shown, algal densities of the 80 water samples collected during the three years ranged from a low of 225 cts/mL on September 19, 1990, to a high of 33,300 cts/mL on October 15, 1991, both in Lake 3. Except for one sample (May 16, 1992, from Lake 2), all the other 53 samples collected from Lakes 1 and 2 showed algal densities > 2000 cts/mL.

In an earlier study (Kothandaraman and Evans, 1983 a), algal densities in Johnson Sauk Trail Lake, IL, were between 270 cts/mL and 22,000 cts/mL during a period from May 1981 through September 1981. In Lake Le-Aqua-Na, IL, total algal counts ranged from 800' cts/mL to 25,000 cts/mL during spring through fall of the three years from 1984 through 1986 (IEPA, 1990). For a period from April 1990 through October 1990, total algal densities in Horseshoe Lake, IL, ranged from 180 cts/mL to 286,000 cts/mL (Rehfeldt *et al.,* 1992). Algal dynamics is a complex phenomenon, and the algal counts in a lake ecosystem fluctuate in a very wide range.

As shown in figure 18, there were extreme fluctuations in algal densities in each lake. Highest algal density for each lake was observed in July for each year. Other algal density pulses occurred in April and October or November. In general, algal density decreased in May, August, and September compared to the previous months. By contrast, high algal counts in Johnson Sauk Trail Lake (Kothandaraman and Evans, 1983a) occurred in August and September 1981. The highest algal density observed in Lake Le-Aqua-Na was in the sample collected on November 14, 1984 (IEPA, 1990).

Figure 18 also indicates that the seasonal and spatial distribution of algal densities in Lakes 1 and 2 are very similar. Lake 3 had lower algal densities than Lakes 1 and 2, especially during the summer and fall of 1989 and 1990. However, in 1991 all three lakes had similar algal density distribution patterns.

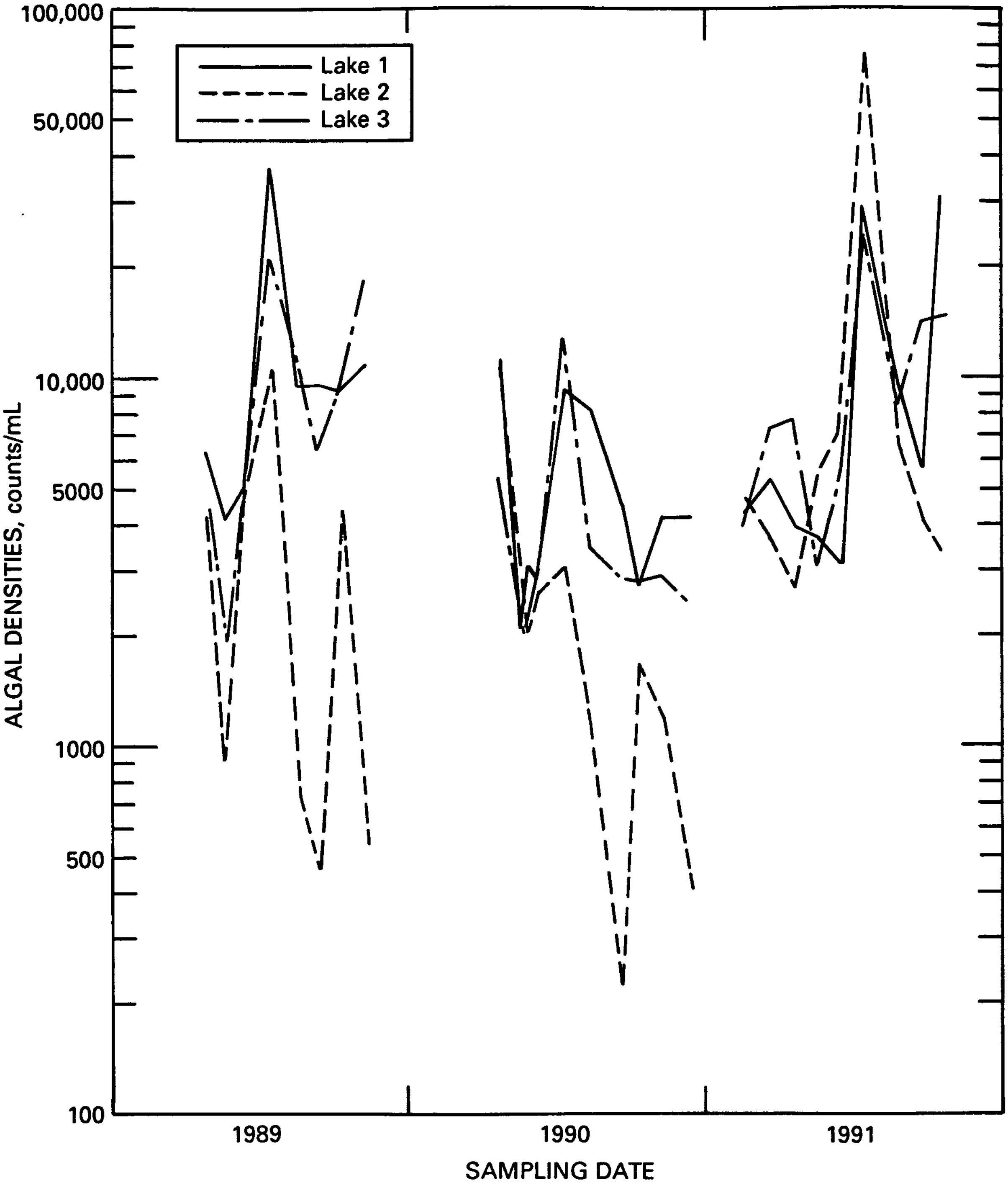


Figure 18. Total algal densities in Frank Holten State Park Lakes

Algal Species Richness. The number of algal species in the samples ranged from 6 (February 21 and March 19, 1991, in Lake 2, and May 14, 1991, in Lake 3) to 19 (July 11, 1991, in Lake 1).

In the 80 water samples examined, 65 algal species were found: 9 blue-greens (Cyanophytes), 19 greens (nonmotile Chlorophytes), 19 diatoms (Bacillariophytes), 15 flagellates (Euglenophytes, Volvocales of Chlorophytes), and 3 desmids. These 65 algae species and their occurrence in the three lakes for each year are listed in table 17. In this table, the occurrence is marked as "X" or "Y". An "X" indicates the occurrence of the organism in any given year of investigation. A "Y" indicates the organism was found in more than 50 percent of the samples in a given year.

Table 17 suggests that the occurrence of green algae and diatoms in each lake was quite frequent. The algae occurring most frequently in the three lakes were *Aphanizomenon flos-aquae, Coelastrum microporum, Crucigenia rectangularis, Oocystis borgei, Scenedesmus dimorphus, Melosira granulata, Euglena gracilis,* and *Trachelomonas crebea.* Most of these algae are indicators of eutrophic conditions. A polluted water blue-green algae, *Lyngbya diqueti,* also occurred frequently and dominated in Lakes 1 and 2 during summer and fall. *Actinastrum hantzschii* occurred frequently in the three lakes in 1989 and in Lakes 2 and 3 in 1991 only, but it was never a dominant species. *Coelastrum microporum* was frequently found in Lakes 1 and 2 in 1989 and 1990. *Euglena acus,* a taste and odor flagellate, was only present in Lake 3, more frequently in 1990. *Anabena spiroides, Pediastrum duplex, Cyclotella ocellata,* and *Phacus pleuronectes* also occurred in all three lakes during each year of the study.

An examination of the data shows that algal density peaks in July or during fall were due to high counts of blue-greens or green algae or a combination of both. The dominant algae were either *Anabaena spiroides, Cyanarcus homiformis, Lyngbya digneti, Oscillatoria chlorina, Chlorella ellipsoidea,* or *Chlorella* sp.

A study of nearby Horseshoe Lake, 5 miles north of FHSP Lakes (Rehfeldt *et al.,* 1992), reported that *Aphanizomenon flos-aquae, Crucigenia rectangularis,* and *Synedra delicatissima* were the most frequently observed algal species in the lake.

Table 17. Occurrence of Algae in Frank Holten State Park Lakes

	Lake 1			*Lake 2*			*Lake 3*		
Algal species	*1989*	*1990*	*1991*	*1989*	*1990*	*1991*	*1989*	*1990*	*1991*
Blue-green algae									
Agmenellum sp.	X			X			X		
Anabena spiroides	X	X	X	X	X	X	X	X	X
Anacystis thermalis	X	X	X	X	X	X	X	X	X
Aphanizomenon flos-aquae	X	Y	Y	X	X	X	X	X	X
Cyanarcus homiformis	X								
Lyngbya digneti	Y	X	X	X	X	X	X		
Oscillatoria angustissima			X			X			X
O. chlorina	X			X			X		
Oscillatoria sp.		X	X		X	X	X	X	X
Green algae									
Actinastrum hantzschii	Y	X	X	X	X	X	Y	X	X
Ankistrodesmus convolatus		X	X			X			X
A. spiralis	X		X	X	X	X			X
Chlocoarcina consociata		X		X				X	
Chlorella ellipsoidea				X					
Chlorella sp.	X		X			X			X
Chlorosorcina consociata			X			X			X
Coelastrum microporum	X	X	X	X	X	X	X	X	X
Crucigenia rectangularis	X	X	X	X	X	X	X	X	X
C. tetrapedia							X		
Micactinium pusillum				X					
Oocystis borgei	X	X	X	X	X	X	Y	X	X
Pediastrum duplex	X	X	X	X	X	X	X	X	X
P. simplex	X	X	X	X	X		X	X	X
P. tetras			X		X	X		X	X
Scenedesmus carinatus		X			X				
S. dimorphus	X	X	X	X	X	X	X	X	X
S. quadricauda		X		X					
Schroecleria sp.					X				
Diatoms									
Asterionella formosa				X			X		
Caloneis amphisbaena		X							
Cyclotella atomus	X			X			X		
C. meneghiniana	X	X	X	X	X	X			
C. ocellata	X	X	X	X	X	X	Y	X	X
Cymatooleura solea							X		
Fragilaria crotonensis	X								
Gomphoneis herculeana							X		
Gyrosigma marcum	X						X		
Melosira ambigua	X	X					X		
M. bindesana				X					
M. granulata	X	X	X	X	X	X	X	X	X
Navicula cryptocephala	X	X			X	X			
N. gastrium			X						
Stephanodiscus niagarae	X			X					

Table 17. (Concluded)

Algal species	*Lake 1* *1989*	 *1990*	 *1991*	*Lake 2* *1989*	 *1990*	 *1991*	*Lake 3* *1989*	 *1990*	 *1991*
Diatoms									
Surviella ovata					X				X
Synedra acus	X	X	X	X	X	X	X	X	
S. tabulata		X			X			X	
S. ulna		X			X				
Flagellates									
Carteria multifilis			X						X
Ceratium hirundinella		X	X	X	X		X	X	X
Chlamydomonas reinhardi					X		X		
Chrysococcus rufescens			X					X	
Dinobryon sertularia							X	X	X
Euglena acus							X	X	X
E. gracilis	X	X	X	X	X	X	X	X	X
E. oxyuris	X	X			X		X	X	X
E. viridis	X	X	X	X	X	X	X		
Glenadinium sp.			X						X
Peridinium cinctum							X		
Phacus pleuronectes	Y	X	Y	X	X	X	X	X	X
P. sp.								X	
Platydorina candatum		X		X		X		X	
Trachelomonas crebea	Y	X	X	X	X	X	X	X	X
Desmids									
Closterium sp.	X								X
Glenodinium borgei							X		
Glenodinium sp.		X			X		X	X	X

Notes: X = organism was found in a given year; and Y = organism was found in more than 50 percent of the samples in a given year.

Zooplankton Density. The term "plankton" refers to those microscopic aquatic forms having little or no resistance to currents and living free-floating and suspended in open or pelagic waters (American Public Health Association *et al.,* 1992). Plankton can be divided into planktonic plants or phytoplankton (microscopic algae), and planktonic animals, zooplankton. The zooplankton in fresh water comprise principally protozoans, rotifers, cladocerans, and copepods; a greater variety of organisms occur in marine waters. Since Wisconsin plankton net was used for collecting plankton samples, protozoans were not detected. In this report, protozoans are not included in zooplankton.

Total observed zooplankton densities ranged from 300 to 7500 cts/L, from 200 to 14,300 cts/L, and from 600 to 6,800 cts/L for Lakes 1, 2, and 3, respectively. The variation of zooplankton densities for each lake showed no trend with time.

In the three lakes investigated, 25 zooplankton species were found. These included 14 rotifera, 6 cladocera, 3 copepoda, and 2 other species. All three major groups of zooplankton were found during the three-year study period. However, *Acari* and *Cyclocypris forbezi* were observed in 1991 only at Lakes 1 and 3.

The dominant zooplanktons were found to be either rotifera or cladocera. The dominant species were *Chromagaster ovalis, Keratella cochlearis, K. stipitata, Bosmenia coregoni, Daphnia Iaevis,* and *Diaptomus minutus. Diaptomus minutus, Bosmenia coregoni,* and *Daphnia pulex,* species occuring most frequently, occurred more than 50 percent of the time.

Benthic Organisms. Benthic macroinvertebrates are animals within the aquatic system visible to the naked eye, and they can be retained by a U.S. Standard No. 30 mesh sieve. These common, easily collected organisms have limited mobility and are present throughout the growing season. An abundant and diverse community of macroinvertebrates is important as a reliable food source for fish. Macroinvertebrates are sensitive to changes in the aquatic environment, especially DO.

In terms of population density, samples from site 1 of Lake 2 had the lowest and highest populations, ranging from 28 individuals per square meter (July 13, 1989) to 11,481 (November 7, 1989). In terms of sample dry weight, the sample at the same location on July 13, 1989, was the lowest, with 0.019 g. Again, samples from this site showed the widest variation in population levels due to fluctuation in *Chaoborus* levels. Numerous factors influence the weight of a sample, such as population density, species composition, and growth stage. The sample with the highest dry weight, 3.921 g was found on March 21, 1990, at the sampling site in Lake 2 established during the period when the dredging restoration program was implemented (historic site).

The mean values of the samples collected at each station are presented in table 18. Lake 2, had the highest two stations in mean population and sample weight. Perhaps nutrient and phytoplankton abundance influenced the benthic productivity of this lake.

The mean benthic DO is inversely related to the depth of the station. The deepest station, site 1 of Lake 2, had the lowest mean DO levels and were usually < 1 ppm during the summer. The shallow stations (historical sites of Lakes 1 and 2, and site 1 of Lake 3) all had a mean benthic DO > 5 ppm.

The community composition of the sampling station means, shows that the shallower stations are mainly dominated by *Oligochaeta* and *Chironomidae,* while the deeper stations are dominated by *Chaoborus*.

Benthic macroinvertebrates, an important source of fish food organisms, are chiefly needed during the growing season. Low DO conditions make the benthos in the deeper areas of the lake unavailable during the critical warmer months. The productive volume of the lake, in terms of fish habitat and food, is therefore reduced.

Trophic State. Eutrophication is a natural process that affects every body of water from the time of its formation. As the lake ages, the degree of enrichment by nutrient materials increases. In general, the lake traps a portion of the nutrients originating in the surrounding drainage basin. In addition, precipitation, dry fallout, and ground-water inflow are the other contributing sources.

The literature has suggested a wide variety of indices of trophic conditions. Indices have been based on Secchi disc transparency, chlorophyll *a,* hypolimnetic oxygen depletion, nutrient concentrations, and biological parameters, including species abundance and diversity. The USEPA (1980) suggests in its *Glean Lakes Program Guidance Manual* (table 3.10-4) the use of four parameters as trophic indicators: Secchi disc

Table 18. Mean Benthic Macroinvertebrates Values in Frank Holten State Park Lakes (individuals per square meter)

	Stations				
	Lake No. 1		*Lake No. 2*		*Lake No. 3*
	Hist. Site	*Site I*	*Hist. Site*	*Site I*	*Site I*
Chironomus (bloodworm)	50	294	212	235	2
Chironomidae (non-*Chironomus*)	586	182	158	31	323
Chaoborus (phantom midge)	194	1,321	715	4,769	273
Ceratopogonidae (biting midge)	181	48	57	110	72
Oligochaeta (aquatic worm)	876	475	1,835	464	820
Total numbers	1,887	2,320	2,977	5,609	1,490
Total dry weight, grams	0.789	0.815	1.182	0.901	0.488
Dissolved oxygen, parts per million	8.0	3.9	7.8	2.8	5.7
Approximate depth, feet	6	18	6	25	7

(Samples were collected on 8/3/89, 11/7/89, 3/21/90, 7/9/90, 4/17/91, and 8/22/91) transparency, and concentrations of carbon, phosphorus, and chlorophyll *a.* Those criteria are reproduced in table 19.

In addition, the lake trophic state index (TSI) system developed by Carlson (1977) on the basis of Secchi disc transparencies, chlorophyll a, and total phosphate-P values can be used to evaluate a lake's trophic state. The index number can be calculated from Secchi disc transparency (SD) in meters, chlorophyll *a* (CHL) in micrograms per liter (µg/L), and total phosphorus (TP) in µg/L as follows:

$\mathrm{TSI\ (SD)} = 60 - 14.41\ \mathrm{In\ (SD)}$

$\mathrm{TSI\ (CHL)} = 9.81\ \mathrm{In\ (CHL)} + 30.6$

$\mathrm{TSI\ (TP)} = 14.42\ \mathrm{In\ (TP)} + 4.15$

The numerical index ranges from 0 to 100. Lakes with TSI values <40 are classified as oligotrophic (nutrient-poor or relatively unproductive, biologically speaking), and those with TSI values >S0 are classified as eutrophic (highly productive). Each major division (10, 20, 30, etc.) represents a probability of a doubling biomass.

Table 20 gives the mean and range of values of TSI for the lake stations, using the observed SD, TP, and CHL values. The mean TSI values for the lakes, based on all three parameters, are high and in the 70s except for Lake 3, which has a TSI mean based on chlorophyll *a* values of 69. Lake 3 exhibited the lowest chlorophyll *a* values of all three lakes. However, the TSI mean value was found to be almost 70. Based on the USEPA criteria and the TSI values for the lakes, it is concluded that they are currently hypereutrophic or highly nutrient enriched. This is not entirely surprising because most Illinois lakes and impoundments were found to be nutrient enriched and even exhibited symptoms of eutrophy right from their nascency (Kothandaraman and Evans, 1983a, 1983b) because of their organic, rich bottom soils. Internal regeneration of nutrients under anoxic conditions during the summer stratification period was determined to be adequate to cause algal blooms (ibid). Bodamer (1992) reported for Lake Springfield, IL, which underwent significant dredging in the upper reaches of the tributary arms of the lake, that dredging alone was not the solution to reducing nutrient levels in the water column.

Table 19. Quantitative Definitions of Lake Trophic State (USEPA, 1980)

	Oligotrophy	*Eutrophy*
Total phosphorus (winter), µg/L	≤10-15	≥ 20-30
Chlorphyll-*a* (summer), µg/L	<2-4	>6-10
Secchi disc depth (summer), m	≥ 3-5	≤1.5-2
Primary productivity		
Carbon (mg/m^2/yr)	30-100	300-3000
Carbon (ug/m^2/day)	7-25	75-700

Table 20. Carlson Trophic State Index Values for Lake Stations

	Lake 1		*Lake2*		*Lake 3. Site 1*	
Parameter	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Secchi disc	72	65-78	71	65-77	71	66-80
Total phosphate-P	78	67-90	76	67-92	74	65-87
Chlorophyll *a*	74	65-81	74	66-80	69	59-76

Macrophytes. As indicated in table 13, macrophyte surveys were conducted on seven different occasions during this investigation. During the first two trips, (June and July 1990) the lakebed was examined at 15 to 20 feet (more than twice the Secchi disc transparency) from the shoreline all around each lake by walking, searching for aquatic rooted vegetation. It became apparent that the lakes are totally devoid of any rooted submerged aquatic plants. This is true not only for the dredged portions of the lakes, but also for the two undredged areas, one each in Lake 1 and Lake 2. Even relatively shallow Lake 3 did not harbor any vegetation. This total absence of aquatic vegetation is quite puzzling. Transparencies in the lakes are low (average Secchi disc readings are ≤18 inches), which is one of the factors contributing to the lack of vegetation. A second factor could be the loose, fluffy lake bottom sediments (which is true for the southern portion of Lake 3, more so than for Lakes 1 and 2) from which macrophytes could easily get uprooted by wind and wave action. Also, grazing pressures from wildlife populations could easily decimate the standing crop as experienced in Peoria Lake (Roseboom *et al.,* 1989). As is well known, rooted aquatic vegetation is an essential component of a well-balanced ecosystem providing food and shelter for desirable sports fisheries. This aspect is all the more important and relevant, considering the fact that the lakes are heavily used for fishing. The remaining five macrophyte surveys were made from a boat by probing the lakebed with an oar at frequent intervals.

Sediment Characteristics. The significance of sediments in the aquatic ecosystem is not only physical in nature, but also chemical and biological. In addition to the direct loss of storage capacity resulting from sediment deposition, lake sediments play an important role in introducing substances such as phosphorus, nitrogen, adsorbed trace metals, and organic compounds to the overlying waters particularly under anoxic conditions during periods of thermal stratification. Also, the benthic organisms are known to bioaccumulate toxic substances from the aquatic medium and pass them up the food chain to potentially dangerous levels for birds, animals, and humans.

The results of analyses of sediment samples collected from the lakes on June 7, 1988, are given in table 21. Also, included for reference are the mean values for phosphorus, kjeldahl nitrogen, and a few of the heavy metals reported by Kelly and Hite

Table 21. Frank Holten State Park Lakes Sediment Characteristics

	Lake 1	*Lake 2*	*Lake 3*		*Mean Value for 63 Illinois Lakes**
Parameter	*Historical Site*	*Historical Site*	*Site 1*	*Site 2*	
Percent residue by weight	27.7	29.5	21.5	24.5	
Percent residue by volume	10.3	8.9	4.8	8.8	
Phosphorus	72	691	870	985	666
Kjeldahl nitrogen-N	3530	2740	1660	1730	5530
Cadmium	3.4	2.2	3.9	5.0	1.0
Copper	38	24	27	28	41
Lead	91	29	47	52	50
Mercury	0.37	0.04	0.05	0.06	0.09
Arsenic	9	6	8	12	11
Chromium	17	11	17	22	23
Iron	16000	15000	22000	28000	28631
Manganese	4400	630	11000	1000	1313
Zinc	180	83	108	120	111
PCB's	75.0	10.0	10.0	10.0	
Aldrin	1.0	1.0	1.0	1.0	
Dieldrin	1.6	1.0	1.0	1.5	
DDT Analogs	10.0	10.0	10.0	10.0	
O'P'-DDE	1.0	1.0	1.0	1.0	
P'P'-DDE	1.0	1.0	1.2	3.0	
O'P'-DDD	1.0	1.0	1.0	1.0	
P'P'-DDD	1.0	1.0	1.0	2.0	
O'P'-DDT	1.0	1.0	1.0	1.0	
P'P'-DDT	1.0	1.0	1.0	1.0	
Chlordane tech. & met.	5.2	5.0	5.0	7.9	
Chlordane C isomer	2.1	2.0	2.0	3.7	
Chlordane T isomer	3.1	2.0	2.0	4.2	
Endrin	1.0	1.0	1.0	1.0	
Methoxychlor	5.0	5.0	5.0	5.0	
Alpha-BHC	1.0	1.0	1.0	1.0	
Gamma-BHC	1.0	1.0	1.0	1.0	
HCB	1.0	1.0	1.0	1.0	
Heptachlor	1.0	1.0	1.0	1.0	
Heptachlor epoxide	1.0	1.0	1.0	1.0	

Note: Nutrients and metals are expressed as mg/kg of sample, and all the organics are expressed as µg/kg of sample.

* Kelly and Hite (1981).

(1981) for sediments collected from 63 Illinois lakes during summer 1979. Phosphorus concentrations in the FHSP Lakes are comparable to the values reported for other Illinois lakes, and kjeldahl-N values are much less than the mean value for other lakes. The cadmium level is three to five times higher in FHSP Lakes. The sampling site in Lake 1 exhibited much higher levels of lead, mercury, and zinc than the other two FHSP Lakes and the mean values for the 63 Illinois lakes. There has been no fish advisory in the recent past for the fish caught in these lakes. The IPCB has not set standards for sediment quality characteristics. The organic constituents reported in table 21 are in parts per billion. The polychlorinated biphenyls (PCBs) values measured for Lake 1 were 7-1/2 times higher than the values measured for the other lakes in the system. However, all other reported organic constituents for the three lakes were the same or comparable.

Comparisons of Water Quality Characteristics for the Restoration and Post-Restoration Periods

Limnological data on the pre-restoration conditions of the lakes are extremely sparse. Henry, Meisenheimer, & Gende, Inc. (1975) reported on the lake conditions based on one sample collected from each lake on October 27, 1975. They concluded that Lakes 1 and 2 were relatively clear, but Lake 3 was murky. Lakes 2 and 3 exhibited high concentrations of nitrates. Ammonia levels were below detection limits in Lakes 1 and 3 and 0.2 mg/L in Lake 2. They also reported very high counts of fecal coliform in Lake 1 (2400 cts/100 mL), probably due to sewage or contamination by waterfowl. These organisms were not detected in the other two lakes.

Table 22 shows the mean and range of values observed in the lakes during the restoration period (1977 to 1984) for certain water quality parameters, which were also monitored during the post-restoration monitoring period (1988 to 1991). Barring the very low pH value of 2.4 reported for Lake 3 by Brigham (1984), which is anomalous, all other mean and ranges of values shown in the table are typical of Illinois lakes. Brigham indicated in the report that the chlorophyll *a* values are expressed as mg/L. It is presumed these values are μg/L, which will be commensurate with the observations for other Illinois lakes.

Table 22. Surface Water Quality Characteristics Frank Holten State Park Lakes during Restoration Period (1977-1984)

Parameters	*Lake No. 1*		*Lake No. 2*		*Lake No. 3*	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*
Dissolved oxygen	9.0	3.4-18.6	8.8	3.8-18.4	8.2	1.0-18.0
pH, units		6.3-9.4		7.2-9.3		2.4-9.6
Total alkalinity	95	9-160	118	76-166	155	60-320
Dissolved phosphate-P	0.05	0.01-0.17	0.04	0.01-0.13	0.08	0.01-0.42
Total phosphate-P	0.17	0.04-0.35	0.13	0.03-0.23	0.26	0.04-0.71
Total ammonia-N	0.45	0.45-1.77	0.29	0.03-0.70	0.50	0.03-2.60
Nitrate-N	0.07	0.01-0.85	0.06	0.01-0.72	0.07	0.00-0.79
Particulate residue (180°C)	26	0-198	22	1-206	47	1-389
Chlorophyll *a*	84.5	0.1-329	35.7	0.6-259.0	94.0	0.2-429.0

Note: Values in mg/L unless otherwise indicated.
Source: Brigham (1984).

Table 23 shows the mean values of these parameters for both the restoration and post-restoration periods. The surface mean DO concentrations in all the lakes during these two periods are high and are comparable. Brigham (1984) reported that only 8 percent of all the surface DO observations for the lakes were ≤ 5 mg/L, and 20 percent more were ≤ 6 mg/L. The corresponding values for the current investigation are 5 and 6 percent based on 282 and 106 observations, respectively. Brigham (1984) opined in her report that "removal of 3 feet of accumulated sediment from each of the lakes, however, should improve DO concentrations by limiting the amount of potential oxygen-demanding material in the sediment." However, as discussed earlier, oxygen demand from the lake bottom sediments caused oxygen depletion in the bottom waters of the lake during the warm summer periods.

Total alkalinity was correspondingly higher in the lakes during the post-restoration period, dissolved phosphate-P was similar, TP was lower in Lake 3, total ammonia was significantly less, and nitrate was much higher and particulate residue (suspended sediments) much lower in Lake 3 during the post-restoration period. A statistical evaluation of the parameters common to both the periods follows.

Table 24 presents the frequency of occurrence of total and dissolved phosphate-P, ammonia-N, and nitrate-N for all three lakes during the restoration and post-restoration periods. For TP in Lake 1, 95 percent of the observed values were ≤ 0.3 mg/L, 75 percent were ≤0.2 mg/L, 50 percent were ≤ 0.15 mg/L, and 25 percent were ≤ 0.11 mg/L during the restoration period. The corresponding values for the post-restoration period in Lake 1 were 0.38, 0.22, 0.17, and 0.13 mg/L, respectively. In Lake 1, a higher range of concentrations of total and dissolved phosphorus were found for the top quartile of values during the post-restoration period. There was a significant reduction in ammonia-N values throughout the post-restoration period. For nitrate-N in Lake 1, the middle two quartile values were double or more during the post-restoration period than the values found for the restoration period.

Total and dissolved phosphorus levels were higher in Lake 2 during post-restoration monitoring. They were lower in Lake 3, however, due to the diversion of Harding Ditch, resulting in decreased sediment inflow into the lake. Ammonia-N levels in

Table 23. Mean Water Quality Characteristics of Frank Holten State Park Lakes for Restoration (1977-1984) and Post-Restoration (1988-1991) Periods

	Restoration Period			*Post-Restoration Period*		
Parameters	*Lake J*	*Lake2*	*Lake 3*	*Lake 1*	*Lake 2*	*Lake 3*
Dissolved oxygen	9.0^{a}	8.8^{a}	8.2^{a}	8.5^{a}	9.6^{a}	9.6^{a}
Total alkalinity	95^{a}	118^{a}	$155^{b,c}$	114^{a}	$122^{a,b}$	164^{c}
Dissolved phosphate-P	0.05^{a}	0.04^{a}	0.08^{a}	0.05^{a}	0.05^{a}	0.05^{a}
Total phosphate-P	0.17^{a}	0.13^{a}	0.26^{a}	0.18^{a}	0.17^{a}	0.14^{a}
Total ammonia-N	0.45^{a}	$0.29^{a,b}$	0.50^{a}	0.11^{b}	0.15^{b}	0.11^{b}
Nitrate-N	0.07^{a}	0.06^{a}	0.07^{a}	0.06^{a}	0.07^{a}	0.20
Particulate residue	26^{a}	22^{a}	47^{a}	24^{a}	22^{a}	22^{a}
Chlorophyll *a*	84.5^{a}	55.7^{a}	94.7^{a}	91.3^{a}	90.9^{a}	56.9^{a}

Notes: Chlorophyll *a* expressed as µg/L; and all other measurements are mg/L.

Mean values with similar superscripts are not significantly different by Duncan's multiple range tests at 0.0S significance level.

Table 24. Frequency of Occurrence of Certain Water Quality Parameters in Frank Holten State Park Lakes

	Lake 1							
	Total phosphorus		*Dissolved phosphorus*		*Ammonia-A*		*Nitrate-N*	
Percent ≤ indicated value	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
95	0.30	0.38	0.15	0.20	0.98	0.36	0.20	0.10
75	0.21	0.22	0.08	0.08	0.62	0.10	0.04	0.10
50	0.15	0.17	0.04	0.03	0.38	0.10	0.30	0.10
25	0.11	0.13	0.02	0.02	0.21	0.06	0.01	0.01

	Lake 2							
	Total phosphorus		*Dissolved phosphorus*		*Ammonia-A*		*Nitrate-N*	
Percent ≤ indicated value	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
95	0.20	0.42	0.08	0.24	0.60	0.54	0.14	0.18
75	0.16	0.22	0.04	0.06	0.38	0.16	0.05	0.10
50	0.12	0.15	0.03	0.03	0.29	0.10	0.03	0.10
25	0.08	0.11	0.02	0.02	0.15	0.09	0.01	0.01

	Lake 3							
	Total phosphorus		*Dissolved phosphorus*		*Ammonia-A*		*Nitrate-N*	
Percent ≤ indicated value	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
95	0.65	0.24	0.17	0.10	1.00	0.42	0.30	0.39
75	0.35	0.17	0.10	0.06	0.66	0.10	0.06	0.10
50	0.21	0.13	0.06	0.04	0.34	0.10	0.03	0.10
25	0.11	0.11	0.02	0.03	0.25	0.05	0.01	0.01

Notes: A = data for restoration period (1977-1984); B = data for post-restoration period (1988-1991); and all values are expressed as mg/L unless indicated otherwise.

each quartile were lower in Lakes 2 and 3 during the post-restoration monitoring period. However, the trend was reversed in the case of nitrate in both lakes.

Duncan's multiple range test (Walpole and Meyers, 198S) was used to delineate the differences in the mean values of the water quality characteristics in Lakes 1, 2, and 3, grouping the data for these lakes individually for the periods covering the restoration (1977 to 1984) and post-restoration (1988 to 1991). The tests were carried out at the 5 percent significance level, and the results are included in table 23.

The statistical tests indicate that for several of the water quality characteristics in the three lakes, no statistical difference was observed between the data during the restoration and the post-restoration periods. The surface DO, total and dissolved phosphate-P, particulate residue, and chlorophyll a all fall under this category. Total alkalinity in Lake 3 was much higher compared to the other two lakes for both types of data sets considered here. Total ammonia levels were higher in all lakes for the restoration period compared to the post-restoration period. Observed data formed two distinct sets of data with respect to ammonia-N. Significantly high nitrate levels were measured in Lake 3 during the post-restoration period compared to the other two lakes and the restoration period data for all three lakes. Mean values of nitrates in Lakes 1 and 2 for the post-restoration period and the values for all three lakes during the restoration period were statistically similar. Nitrate-N values for Lake 3 were significantly higher during the post-restoration period.

Creel Survey

A creel survey was conducted on FHSP Lakes from March 15 to November 15, 1991, by the INHS under Federal Aid Project F-69-R. The data for the creel survey are included in the appendix as tables A1 and A2. For the most part, the results of the creel survey were about what would be expected from an urban lake. But exceptions were found in angling pressure and boat fishing versus shore fishing. The total of 248 hours/acre (hrs/ac) fishing pressure measured is low compared to 666 hrs/ac at Beaver Dam and 850 hrs/ac at Siloam Springs. Further, shore fishing accounted for 80 percent of the fishing effort and boats accounted for only 20 percent. Normally, one would expect a

60-40 split the other way. The angler using FHSP Lakes traveled an average 4.6 miles to fish, and the overall rating of the lake by the anglers on a scale of 1 - 10 was 2.7, indicating much dissatisfaction with the fishing.

Angler catch results are presented separately for fish caught (includes both fish harvested and those released) and for fish harvested. The results of the survey showed that anglers caught and/or harvested nine species of fish including black and white crappie, largemouth bass, channel catfish, bluegill, drum, rainbow trout, redear sunfish, and yellow bass. A miscellaneous category for fish caught in too low a quantity to be included in the summary statistics includes yellow and black bullhead, carp, bigmouth buffalo, bowfin, gizzard shad, green sunfish, and shortnose gar. In all cases, the catch statistics are below what would be expected or targeted for these lakes. As an example, largemouth bass, the main predator stocked in these lakes, were caught at only 4.8 pounds/ac, but one would expect the catch rate to be about 20 pounds/ac. Further, it appears that the anglers are keeping most of what they catch, as the difference between catch and harvest is not great. The average size of fish harvested was small. Yellow bass, for instance, were less than 0.1 pound on the average. It is difficult to envision anyone being able to catch a fish that small.

In summary, the catch results reflect the angler rating of the lake. Anglers were catching low numbers of fish that, for the most part, were smaller than expected or desired. This is probably due to lack of macrophytes, significant reduction in fish habitat during the summer stratification period, poor quality and quantity of benthos, overharvest, and/or possibly because most of the fishing was from the bank, limiting anglers to a relatively small proportion of the lake. The lack of a trout stocking program, which was discontinued after 1990, might also account for diminished fishing pressure.

Park Attendance and User Survey

Ever since lake restoration and the upgrade of the State Park facilities, park attendance has steadily increased. Table 25 shows the estimated number of visitors to the State Park from 1981 through 1991 based on the number of vehicles entering through the main entrance, counted using an automatic counter, and assuming an average of three

Table 25. Estimated Visitors Record for Frank Holten State Park

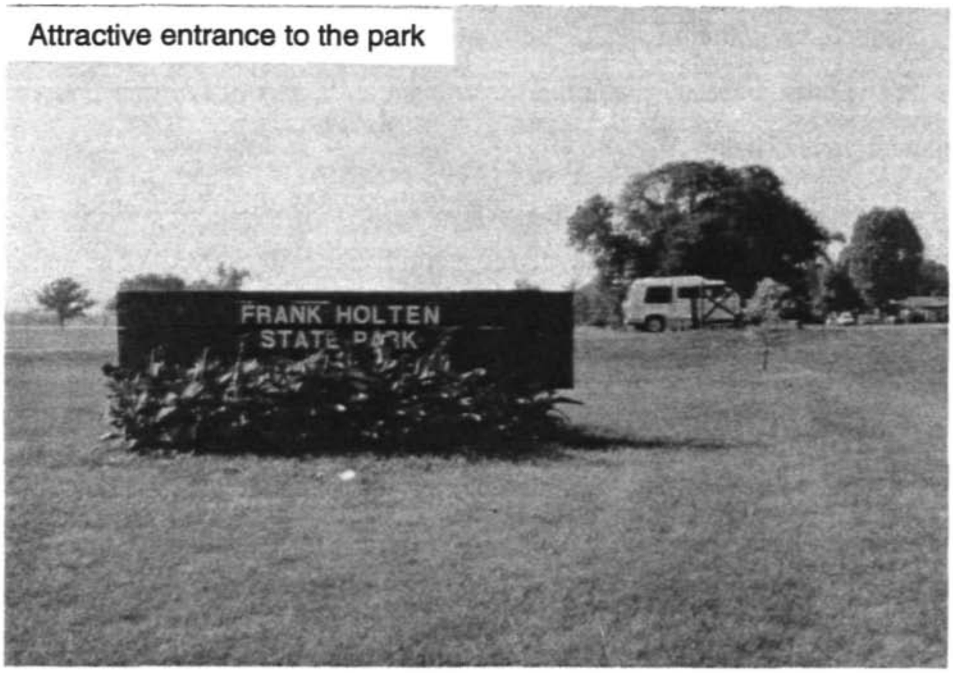
Month	*1981*	*1982*	*1984*	*1985*	*1989*	*1990*	*1991*	*Monthly average*
January	3,031	1,389	3,096	3,806	10,747	17,334	3,574	6,138
February	2,062	2,640	3,001	5,828	5,412	19,625	12,704	7,325
March	2,266	3,627	6,545	7,916	14,143	22,530	25,227	11,751
April	2,295	5,734	2,488	37,686	38,949	36,315	37,175	22,949
May	14,524	18,456	17,897	27,706	43,898	45,691	60,165	32,620
June	14,322	15,882	22,424	29,100	43,831	44,359	49,283	31,314
July	18,176	20,598	27,010	25,294	46,905	45,458	70,959	36,343
August	19,415	16,839	20,864	29,453	34,033	39,335	88,149	35,441
September	8,502	13,685	14,807	25,975	53,058	39,043	48,794	29,123
October	7,396	11,789	8,030	7,655	23,038	28,251	22,840	15,571
November	5,173	11,469	10,182	9,320	19,094	22,644	14,002	13,126
December	2,234	6,232	2,935	3,289	5,780	11,604	13,177	6,464
Totals	99,396	128,340	139,279	213,028	338,888	372,189	446,049	

persons per vehicle. The number of vehicles entering the park was estimated upwards to account for the vehicles entering through another entrance for Lake 3. As indicated earlier, the park provides excellent recreational facilities such as picnicking, hiking, jogging, baseball, basketball, fishing, and boating. Figure 19 shows views of the attractive entrance to the park, baseball diamond, basketball court, part of the golf course adjoining Lake 1, and a picnic shelter.

Park attendance increased significantly in 1985 after completion of the lake restoration project and the upgrade of the park facilities by 1984. The park shows a steadily increasing number of visitors since 1985. This is due in large measure to the excellent upkeep and management of the park facilities and control and elimination of once rampant crime, trash, and debris problems. The authors have seen men and women walking, jogging, and exercising during early morning and late evening hours. This would not have been the case prior to 1984. Table 25 indicates heavy use of the park facilities from April through September. The site superintendent indicated that several thousand people use the park's picnic facilities during holiday weekends such as Memorial Day, Fourth of July, and Labor Day.

To elicit information about the perceptions of park facility users, a questionnaire was prepared and distributed during the summer of 1991 from the on-site concession stand and by FHSP personnel. A copy of the questionnaire is presented as table 26. A summary of the results of the 17 responses received is given in table 27.

Of the 17 respondents, 12 were male and 5 were female. Most were in the 41-50 age group, and no one under 20 responded. The survey indicates that picnicking is the most common activity, followed by fishing. The park facilities are used heavily during weekends, and 40 percent of the respondents used the park throughout the week. Almost all of them had visited the park prior to the restoration program. The majority are very frequent users of the facility and rate it highly as a recreational resource. Water quality and fishing in the lakes are perceived as having improved. It was unanimous that the parkgrounds have improved a lot and are much safer to use. Nearly everyone had positive feelings about the facility and indicated that they used this valuable resource more frequently after the restoration and enhancement of the quality of the lakes and the park.

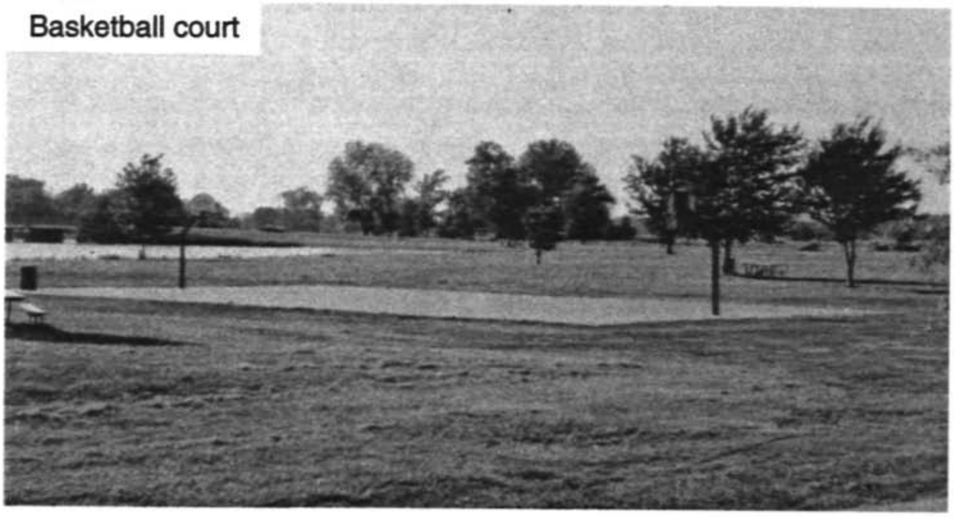


Attractive entrance to the park

Golf course adjoining Lake 1

Figure 19. Frank Holten State Park


Picnic shelter


Basketball court

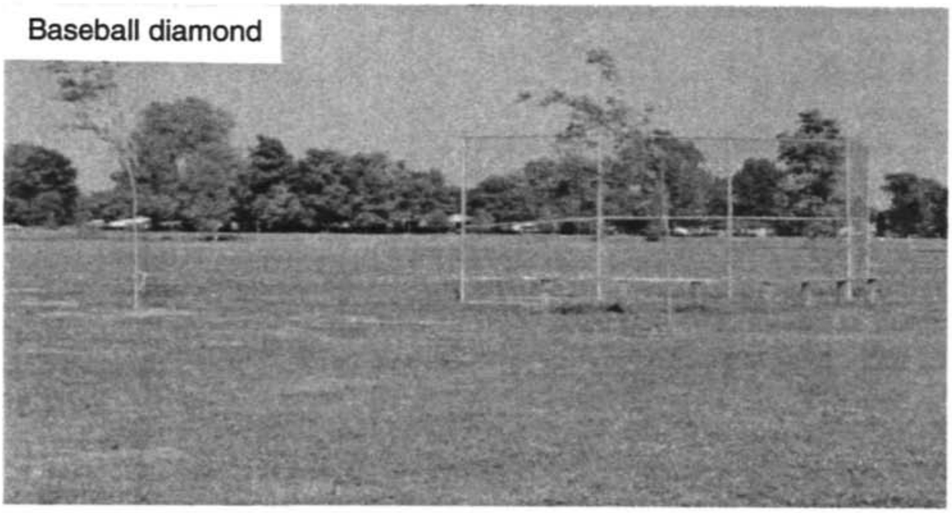

Baseball diamond

Figure 19. Concluded

Table 26. Frank Holten State Park User Survey

1. I am a: Male_____Female___

I am between the ages of:
<20 years old _____
20-30 years old _____
31-40 years old _____
41-50 years old _____
51-60 years old _____
60+ years old _____

2. I usually go to FHSP to go:

fishing ______
jogging/walking ______
picnicking ______
biking ______
other___________________
other___________________
bird watching ______
boating/canoeing ______
on a family outing ______
boy scouting ______

3. When I visit FHSP, it is usually:

during the week ______
on the weekend ______
any day during the week ______

4. The first time I ever visited FHSP was:

before 1975 ______
between 1976-1980 ______
between 1981-1985 ______
between 1986-1990 ______
after 1990 ______

5. I go to FHSP:

0-5 times per year ______
6-10 times per year ______
11-20 times per year ______
21-50 times per year ______
51+ times per year ______

because it's the only park around ______

because it's the best park around ______

6. On a scale of 1 to 10 (1 is the worst, 10 is the best), how would you rate FHSP as a recreation resource?

(circle one) 1 2 3 4 5 6 7 8 9 10

IF YOU HAVE BEEN VISITING FHSP SINCE BEFORE 1985, PLEASE ANSWER THE FOLLOWING QUESTIONS:

7. Has the quality of the water in the three FHSP lakes improved since 1985?

yes, a lot _____
yes, a little _____
no, not at all _____

8. Has the fishing improved since 1985?

yes, a lot _____
yes, a little _____
no, not at all _____

9. Has the quality of the park grounds improved since before 1985 (i.e., trash is picked up, grass is regularly mowed, restrooms are clean)?

yes, a lot _____
yes, a little _____
no, not at all _____

10. Is FHSP a safer place to recreate (i.e., fish, jog, walk, picnic) now than it was before 1985?

yes, a lot _____
yes, a little _____
no, not at all _____

11. Do you use the park and its facilities more now than you did before 1985?

yes, a lot _____
yes, a little _____
no, not at all _____

<u>If yes,</u> why do you use the park more? (check all that apply)

	Major Reason	Minor Reason
The fishing is better now than it was	_____	_____
The water is cleaner and more attractive	_____	_____
The park is a much safer place to go	_____	_____
There is more to do at the park	_____	_____
Other ______________________________	_____	_____
Other ______________________________	_____	_____

12. Please provide any comments you have regarding FHSP.

____

____

____

____

____

____

____

____

____

____

THANK YOU for answering this questionnaire. Please return your completed questionnaire to the concession stand, the park office, or by mailing it using the self-addressed, stamped envelope to:

Gregg Good
10S Mesa Road
Springfield, IL 62702

Table 27. Summary of User Survey Responses

Response Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		*Number of responses*	*Percent of responses to the question*
Question 1																				
a. male	1	1	1	1	1	1	1						1	1	1	1	1		12	70.6
b. female								1	1	1	1	1							5	29.4
																		total	17	100
age < 20																			0	0.0
21-30			1																1	5.9
31-40										1	1	1			1	1			5	29.4
41-50	1	1		1	1		1						1	1					7	41.2
51-60						1			1								1		3	17.6
60 +								1											1	5.9
																		total	17	100.0
Question 2																				
a. fish	1	1	1	1	1		1						1	1	1	1			10	58.8
b. jog/walk	1			1		1	1									1			5	29.4
c. picnic	1	1	1	1	1	1		1	1	1	1	1				1	1		13	76.5
d. bike	1	1					1									1			4	23.5
e. bird watch	1																		1	5.9
f. boat/canoe																			0	0.0
g. family outing								1									1		2	11.8
h. boy scouting																			0	0.0
i. other		1		1	1														3	17.6
Question 3																				
a. during the week																			0	0.0
b. on the weekend		1			1		1	1	1	1	1	1	1	1					10	58.8
c. any day	1		1	1		1									1	1	1		7	41.2
																		total	17	100.0
Question 4																				
a. before 1975	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1		16	94.1
b. 1976-1980																			0	0.0
c. 1981-1985																			0	0.0
d. 1986-1990			1																1	5.9
e. after 1991																			0	0.0
																		total	17	100.0
Question 5																				
a. 0-5 times								1	1	1									3	17.6
b. 6-10 times																			0	0.0
c. 11-20 times											1	1		1					3	17.6
d. 21-50 times		1					1						1	1					4	23.5
e. 51+ times	1		1	1	1	1										1	1		7	41.2
																		total	17	100.0
Question 6																				
a. FHSP Ranking (0-10)	9	10	10	10	10	10	8	10	5	7	7	9	10	10	10	8	10	total average	153 9	100.0

Table 27. Concluded

																			Number of responses	Percent of responses to the question
Question 7																				
Water quality improve?																				
a. lots	1	1	1	1	1	1	1	1			1	1	1	1	1		1		14	82.4
b. little																1			1	5.9
c. no																			0	0.0
																		total	15	88.2
Question 8																				
Fishing improve?																				
a. lots	1	1	1	1	1	1	1				1	1	1	1	1		1		13	76.5
b. little								1								1			2	11.8
c. no																			0	0.0
																		total	15	88.2
Question 9																				
Park grounds improve?																				
a. lots	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		17	100.0
b. little																			0	0.0
c. no																			0	0.0
																		total	17	100.0
Question 10																				
Safer to recreate?																				
a. lots	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		17	100.0
b. little																			0	0.0
c. no																			0	0.0
																		total	17	100.0
Question 11																				
Use park more?																				
a. lots	1	1	1	1	1	1	1		1			1	1	1	1	1	1		14	82.4
b. little								1		1	1								3	17.6
c. no																			0	0.0
																		total	17	100.0
If yes,																				
a. 10% more								1		1									2	11.8
b. 25% more											1								1	5.9
c. 50% more		1														1			2	11.8
d. 75% more				1	1		1					1					1		5	29.4
e. 100% more	1		1										1	1	1				5	29.4
																		total	15	88.2
If yes (1 major, 2 minor)																				
a. fishing is better	1		1	1	1	1	1	1					1		1	1			10	58.8
b. water is cleaner	1		1	1	1	1	1	1			2	1	1		1	1	1		13	76.5
c. park is safer	1	2	1	1	1	1	1	1		1	1		1	1	1	1	1		15	88.2
d. more to do	1	1	1	1	1	1	1	1			1		1	1	1	1	1		14	82.4
e. other						1				1									2	11.8
Question 12																				
other comments	1	1	1	1	1	1	1		1	1	1			1	1	1	1		14	82.4
(1 positive, 2 negative)													2						1	5.9
																		total	15	88.2

The overall impact on the park of the change in park management, the implementation of the USEPA-assisted Clean Lakes Program, and the lake restoration work done to mitigate routing of I-255 through the park has been very significant. Gone are the criminals and the landscape strewn with garbage and urban trash and choked with uncut grass. Gone also are the weed-filled, shallow lakes overrun by rough fish (Roberts *et al.,* 1988).

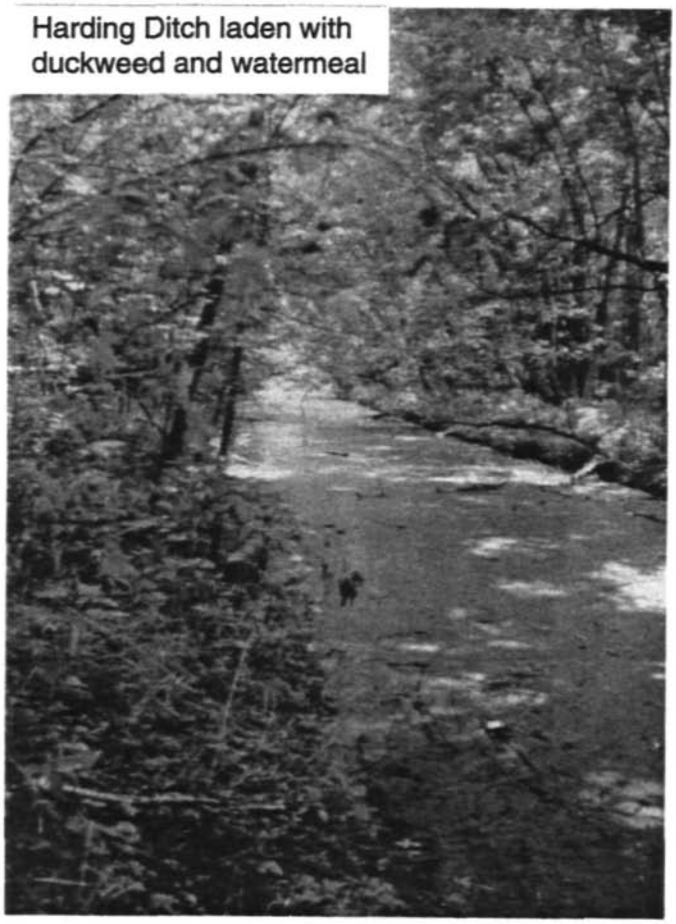
Frank Holten State Park is now safe to visit and displays a landscape and lakes that are aesthetically attractive. This setting regularly attracts large numbers of picnickers. The expanse of open water is extensive enough to invite the use of small recreational boats. Day visits to the park have increased significantly. For example, on Memorial Day 1979, approximately 1000 people visited the park; on Memorial Day 1991, that number increased to nearly 17,000. Use of the golf course has increased as well; women now use the course, and tournaments are regularly held there. Park officials have observed many more families visiting in recent years than during the late 1970s. Family reunions and church picnics occur regularly at the park, and groups now need to reserve park space one year in advance.

The early morning hours find walkers and joggers at FHSP, including groups of women who would not have driven, let alone walked, through the park in the late 1970s and early 1980s. Boy Scout troops use FHSP facilities each year to enhance their skills during organized scouting events. Area junior high schools also reserve the park each year for special events, and high schools hold cross-country meets there each fall (ibid.).

Fishing has also increased noticeably after IDOC completed dredging the FHSP Lakes. Anglers are numerous enough to support a bait shop, which opened in 1988. A boat rental concession also opened that same year. The extent of these positive changes at FHSP considerably exceeded the expectations of most of the professionals involved with the park and lake restoration project, when project planning began in the mid-1970s (ibid.).

Currently, the area near the inlet of the storm drain at Lake 1 is blighted with urban debris such as tires, cans, and shopping carts. It also reeks of a foul stench even during winter months. This storm drain serves a very low-density, light nonresidential land use for the Bistate Development Agency Station Garage and a school with a large paved playground. A stormwater detention basin serves the station garage before rainwater flows into the drainage system. Figure 5 shows views of the detention basin, the inlet to the underground storm drain for crossing the Lake Drive east of the lake, and the outlet of the drain discharging into the lake. These three pipe drains always have standing, stagnant water, which is invariably septic and emits a foul odor. The bay area into which the storm drain discharges has soft, black, septic bottom sediments resembling sewage sludge. Aesthetic conditions in and around the storm drain and bay area could be and should be improved by increasing the water circulation/movement patterns, and by eliminating anoxic conditions of the lake bottom sediments in and around this bay area. Park visitors use this area extensively for bank fishing.

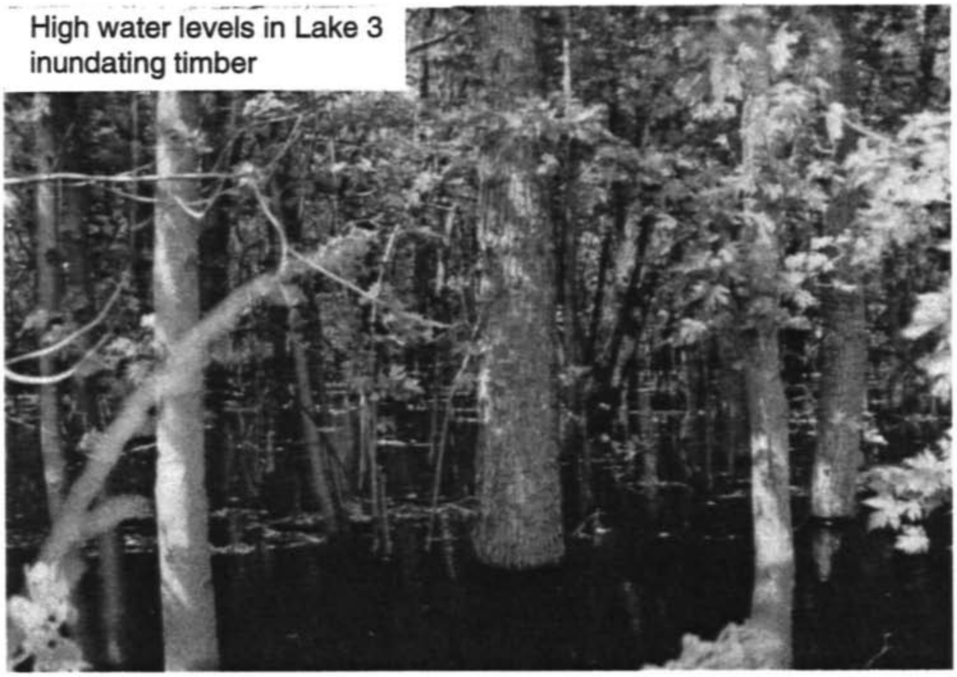
Figure 20 shows views of Harding Ditch and the dredged spoil disposal site. As indicated earlier, Harding Ditch was relocated along the western edge of Lake 3. However, the hydraulic conditions of the drainage system are such that heavy rainfall events, and flows from the Ditch back up into the lake through the outlet in the lake. This problem is further compounded by logjams in the Ditch both upstream and downstream of the lake's outlet. These logjams also cause uncontrollable backup of water into Lake 3, resulting in the inundation of timberland between Lake 3 and Lake 2. Since the completion of dredging operations in 1984, the disposal sites have been overgrown with volunteer native timber and vegetation.



Harding Ditch laden with duckweed and watermeal

Log jam in Harding Ditch

Figure 20. Harding Ditch and dredged spoil deposal site



High water levels in Lake 3 inundating timber

Dredged spoil disposal site with native bushes and trees

Figure 20. Concluded

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- The overall impact on the park of the change in park management, the implementation of the USEPA-assisted CLean Lakes Program, and the completed lake restoration work has been very significant. Frank Holten State Park is now safe to visit and displays a landscape and lakes that are aesthetically attractive.
- A general user survey carried out during the summer of 1991 revealed that the park facilities are considered safe and highly rated as a recreational resource. Gone are the vandals and criminal elements and the landscape strewn with garbage and urban trash and choked with uncut grass - and this occurred soon after the implementation of the restoration of the lakes and management of the parkgrounds in the late 1970s. Also gone are the weed-filled, shallow lakes overrun by rough fish.
- A creel survey conducted in the lakes from March 15 to November 15, 1991, reveals that the fish and fishing opportunities are of very poor quality. The respondents, specifically anglers, indicated that they rate the fishing opportunity at 2.7 on a scale of 1-10. The poor quality of fisheries in the lakes can partly be attributed to the total absence of any aquatic macrophyte beds in the lakes. Even the undredged areas of Lakes 1 and 2 are devoid of rooted vegetation. The lakebeds are devoid of any aquatic habitat structures and resemble an aquatic desert. Additionally, these lakes have not been restocked with game fish periodically in recent years.
- The oxygen conditions in the lake are very similar to conditions at lakes in other parts of the state. The surface DO concentrations in these lakes were not statistically different between the post-restoration and restoration periods. Lake 2, the deepest of the three lakes, exhibits typical summer stratification, and the two shallow lakes exhibit temperature gradients during summer months. The oxygen conditions at depths below 8 to 10 feet from the surface are also below standard during summer months.
- All the lakes continue to be highly eutrophic, exhibiting high nutrient concentrations, low Secchi disc visibility, high oxygen depletion during summer, high chlorophyll *a*

concentrations, etc. Dredging did not significantly enhance the physical, chemical, and biological water quality characteristics in the lakes, but the lake volume in each lake has increased and excessive weed growth has been brought under control.

- There was no statistical difference between the data observed during the restoration and post-restoration periods for the following parameters: surface dissolved oxygen, total and dissolved phosphate-P, total suspended solids, and chlorophyll *a.*
- Significantly high levels of nitrate were measured in Lake 3 compared to the other two lakes during the post-restoration and restoration periods.
- Bathymetric conditions in the lakes have been very stable since the completion of the dredging projects. Sedimentation has been very light, ranging from 0.5 to 1 foot. Some of this may have resulted from sloughing of bed material during the dredging period. The limited sediment inputs to the lakes further support the effectiveness of rerouting Harding Ditch in reducing sediment inputs to the lakes.
- Sediment inputs from the storm drains into Lakes 1 and 2 were minimal for the two full years of study (less than 50 tons each year). Based on the average to above average precipitation for the period, these numbers can be considered representative of "normal" conditions.
- The Harding Ditch sediment inputs of 1279 tons for Water Year 1991 and 823 tons for Water Year 1992 indicate that sediment input to Lake 3 is likely to be more variable. These sediment inputs represent in-lake sediment accumulation of 0.015 feet and 0.01 feet, respectively. Anticipating an annual loss near the higher of these values, sediment accumulation rates will be 0.015 feet per year or 1 foot every 67 years.
- Because of the concentration of sediment input from Harding Ditch, this accumulation should not be expected to be evenly distributed. Instead, it should be expected to concentrate near the Ditch connection. This process may already be indicated in the lake by a slight distortion of lake depth distribution as shown in figure 12.
- Hydrologic conditions for the two-year evaluation period indicate that in general, an inflow surplus exists for all of the lakes during the winter and spring. For these

seasons, evaporation rates are low and the ground-water table is high, resulting in stable and generally high lake levels.

- In the summer and fall, evaporation and ground-water infiltration rates are higher, and lake levels for Lakes 1 and 2 decline steadily except following heavy rainfall periods. Levels in Lake 3 appear to be maintained by the makeup flow provided by Harding Ditch. Clearing of Harding Ditch to maximize flow capacity would certainly lower Lake 3 water levels by 1.5 to 2 feet.
- Overall, the restoration program had a very positive, aesthetically pleasing, and beneficial impact on the surrounding urban area. The lakes and park system draw significantly more visitors to this recreational area compared to the pre-restoration period.

Recommendations

- Alleviate anoxic conditions in the deeper waters of the lakes. The dissolved oxygen conditions in the lake deteriorate during the summer months, thus limiting the extent of fish habitat.
- Carry out a detailed investigation to identify and alleviate the causes of a total lack of submerged vegetation in the lakes, which severely restricts the habitat for fish and fish food organisms. This may also be the primary reason for the poor quality of fisheries in the lakes as revealed by creel census.
- Install artificial fish cribs, brush, and other fish habitat structures at strategic locations to improve fisheries. Apply techniques for restoring aquatic vegetation found successful by Roseboom *et al.* (1989) in Peoria Lake.
- Remove bottom sediments in and around the storm drain bay area of Lake 1 to alleviate anoxic conditions. As an alternative, this area being shallower than 4 feet, a horizontal flow mechanical mixing and aeration device should be considered. This would enhance the oxic conditions in the water and the sediments, and thus mitigate the pervasive foul smell.

- Control stagnant conditions in the storm drainpipe culverts in Lake 1 by improving the hydraulic circulation patterns in the culverts using a strategically placed circulating pump.
- Remove the logjam in Harding Ditch, which causes flow to back up into Lake 3, causing inundation problems. Maintain the Ditch for maximum hydraulic flow.
- Complete construction of the Harding Ditch levee across outlet from Lake 3 to provide protection of lake system from pollution by stormwater. Consider construction of new outlet works for the lake system to limit backflow of water from the Ditch and at the same time allow outflows from Lake 3. Storm event impact of the ditch on the lakes would be reduced, but makeup water to maintain summer lake levels should still be able to enter the lake. Control water level in Harding Ditch to back up water through Lake 3 to Lakes 1 and 2 to maintain all three lakes at a common level. This may necessitate clearing of the "siphon" and lowering the bed of the interconnecting channel between Lakes 2 and 3.

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APPENDIX

Table A1. Fish Caught by Anglers at Frank Holten State Park Lakes from March 15 to November 15, 1992

Species	*Number/hour*	*Number caught*	*Number/acre*
Black crappie	.036	2391	15.14
Bluegill	.328	23568	149.17
Channel catfish	.064	2846	24.34
Drum	.001	102	.65
Largemouth bass	.032	1520	9.62
Rainbow trout	.013	1144	7.24
Redear sunfish	.004	194	1.23
White crappie	.151	6069	38.41
Yellow bass	.061	3683	23.31
Miscellaneous	.029	1642	10.39
Total	.719	44159	279.49

Species	*Pounds/hour*	*Pounds caught*	*Pounds/acre*	*Average weight (pounds)*
Black crappie	.005	348	2.202	.1455
Bluegill	.036	2476	15.668	.1050
Channel catfish	.043	1966	12.446	.5113
Drum	.001	99	.630	.9789
Largemouth bass	.014	764	4.832	.5022
Rainbow trout	.009	769	4.868	.6752
Redear sunfish	.001	39	.245	.1992
White crappie	.029	999	6.321	.1646
Yellow Bass	.002	146	.927	.0398
Miscellaneous	.025	1607	10.170	.9786
Total	.165	9213	58.309	.2086

Notes: Information provided above pertains to the total number and weight of fish caught.

Miscellaneous category: Fish caught in too low a quantity to be included in the summary - yellow and black bullhead, carp, gizzard, shad, etc.

Table A2. Fish Harvested at Frank Holten State Park Lakes from March 15 to November 15, 1992

Species	*Number/hour*	*Number harvested*	*Number/acre*
Black crappie	.009	828	5.24
Bluegill	.214	14706	93.08
Channel catfish	.047	2738	17.33
Drum	.000	86	.55
Largemouth bass	.003	222	1.41
Rainbow trout	.012	1041	6.59
Redeared sunfish	.004	133	.84
White crappie	.076	2663	16.86
Yellow bass	.011	619	3.92
Miscellaneous	.021	1269	8.04
Total	.397	24305	153.84

Species	*Pounds/hour*	*Pounds harvested*	*Pounds/acre*	*Average weight (pounds)*
Black crappie	.002	215	1.359	.2594
Bluegill	.032	2205	13.957	.1499
Channel catfish	.041	1856	11.749	.6779
Drum	.001	99	.628	1.1527
Largemouth bass	.005	322	2.039	1.4504
Rainbow trout	.009	720	4.556	.6912
Redeared sunfish	.000	36	.226	.2691
White crappie	.023	731	4.629	.2747
Yellow bass	.000	42	.263	.0670
Miscellaneous	.023	1507	9.538	1.1872
Total	.136	7733	48.944	.3182

Notes: Fish harvested represent the total number and weight of fish kept (total fish caught minus the fish released back).

Miscellaneous category: Fish caught in too low a quantity to be included in the summary - yellow and black bullhead, carp, gizzard, shad, etc.