Illinois EPA Clean Lakes Program

Phase 1 Diagnostic/Feasibility Study of Lake Vermilion, Vermilion County, IL

(Final Draft Submittal – 2/2/04)

Illinois State Water Survey (1895)

(A Division of the Illinois Dept. of Natural Resources)

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with assistance from:

Consumers Illinois Water Company
Illinois Environmental Protection Agency

Phase I: Diagnostic Study of Lake Vermilion, Vermilion County, Illinois

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Prepared for
The Consumers Illinois Water Company
and Illinois Environmental Protection Agency

CONTENTS

Page

Page

FIGURES

Page

TABLES

Page

PART 1: DIAGNOSTIC STUDY OF LAKE VERMILION

INTRODUCTION

The Consumers Illinois Water Company (CIWC) applied for and received a grant to conduct a diagnostic-feasibility study on Lake Vermilion commencing in May 2000.

The diagnostic study was designed to delineate the existing lake conditions, to examine the causes of degradation, if any, and to identify and quantify the sources of nutrients and any other pollutants flowing into the lake. On the basis of the findings of the diagnostic study, water quality goals will be established for the lake. Alternative management techniques will then be evaluated in relation to the established goals.

The materials presented in this report consist of a review of existing information on the history of the lake, population and economic conditions, the basic physical setting of the lake, ecological characteristics of the lake and watershed, and existing watershed management programs. A baseline or current monitoring program was initiated for a one-year period to collect data on the existing water quality and physical characteristics of the watershed and lake. These baseline data were compared to the available historical record for these conditions to provide an evaluation of the apparent trends in these conditions. The baseline data were also used to evaluate the trophic state of the lake and limitations that these conditions may place on effective utilization of the lake.

The project was funded (60 percent) by the Illinois Environmental Protection Agency (Illinois EPA) through the Illinois Clean Lakes Program under Conservation 2000 with cost sharing by the CIWC. The Illinois EPA was responsible for grant administration and program management. The diagnostic phase of this project was contracted from the CIWC to the Watershed Science Section of the Illinois State Water Survey (ISWS). The feasibility phase of the study was conducted by Cochran & Wilken, Inc. of Springfield, Illinois (C&W) as consultants.

Lake Identification and Location

Lake Vermilion (Figure 1) is a 900-acre public access lake located in Vermilion County, one mile northwest of Danville, Illinois. The location of the dam is 40° 9' 24" north latitude and 87° 39'8" west longitude in Section 31, T.20N., R.11W., second Principle Meridian, Vermilion County, Illinois. The dam impounds the North Fork of the Vermilion River, a tributary of the Vermilion River in the Wabash River Basin. The watershed is a portion of Hydrologic Unit 05120109 as defined by the U.S. Geological Survey (U.S. Geological Survey, 1974).

Lake identification and other pertinent geographic information regarding Lake Vermilion are listed in Table 1.

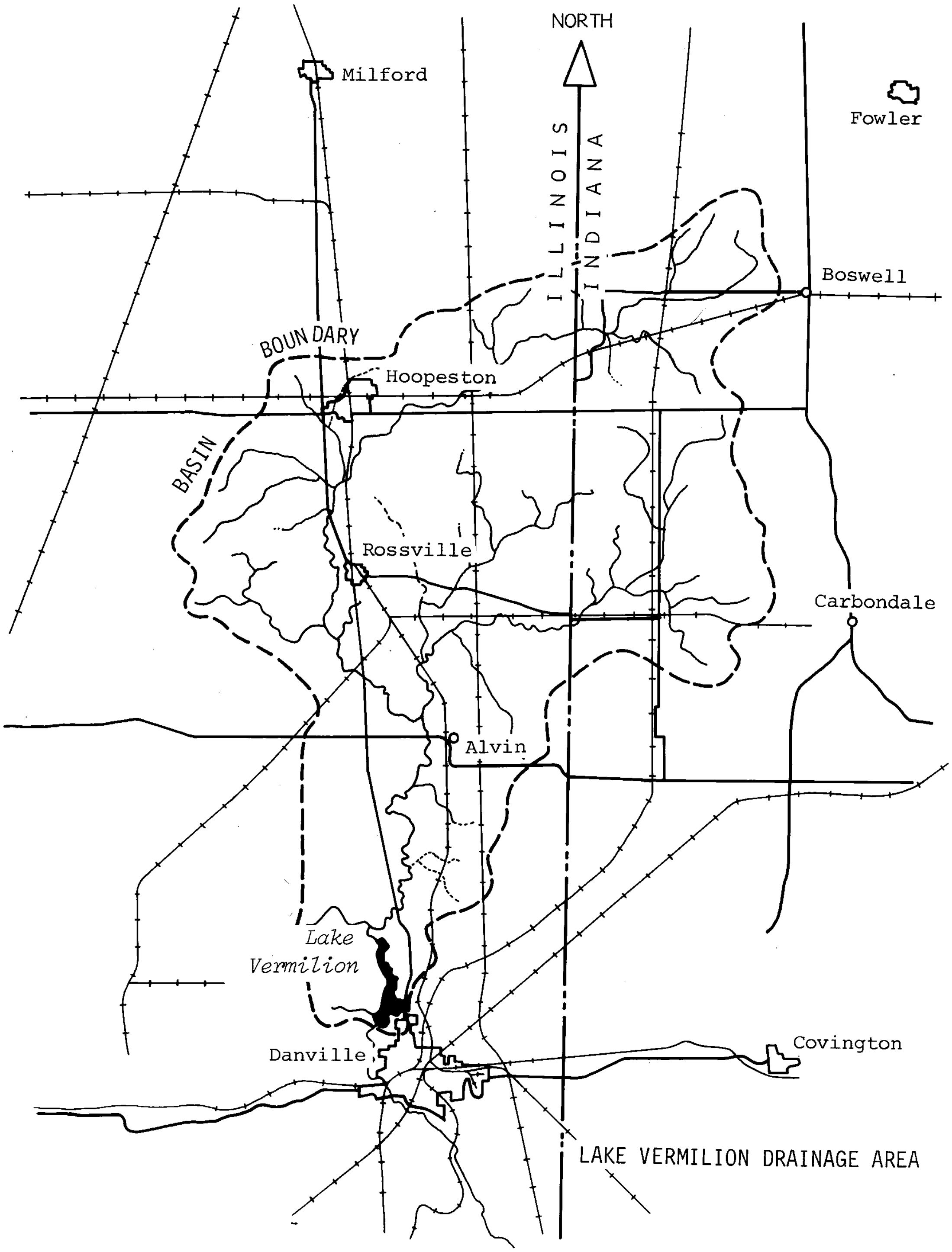


Figure 1. Location and watershed delineation for Lake Vermilion

Table 1. Lake Identification and Location

Lake name:	Lake Vermilion
IEPA/STORET lake code:	RBD
State:	Illinois
County:	Vermilion
Ownership:	Consumers Illinois Water Company
Nearest municipalities:	Danville, Champaign
Latitude:	40° 09’ 24” N
Longitude:	87° 39’ 08” E
USEPA region:	V
USEPA major basin name and code:	Ohio River Basin, 05
USEPA minor basin name and code	Wabash River Basin, 12
Major tributary:	North Fork Vermilion River
Outflowing stream:	North Fork Vermilion River
Receiving water body:	Wabash River and Ohio River via Vermilion River
Water quality standards:	General standards promulgated by the Illinois Pollution Control Board and applicable to water designated for aquatic life and whole body contact recreation: Title 35, Section C, Chapter 1, Part 302, Subpart B

Notes: IEPA - Illinois Environmental Protection Agency
USEPA - U.S. Environmental Protection Agency
STORET - storage and retrieval

Acknowledgments

This investigation was jointly sponsored by the Consumers Illinois Water Company and the Illinois EPA, as an Illinois Clean Lakes Program Phase I study.

Special thanks to David Cronk (Production Manager of the Danville Water Plant) of the CIWC. He was very courteous and shared his information and knowledge about the lake and the watershed, which made data collection easier. Without his full cooperation, this task could not have been accomplished in a timely and orderly fashion. The authors owe a debt of gratitude to Robert Bauer, David Cronk, and Donald Osborn of CIWC and Phyllis Borland of Illinois EPA personnel collected water and sediment samples.

The Illinois EPA Lakes Unit (Surface Water Section, Division of Water Pollution Control), under the direction of Amy Walkenbach was responsible for overall administration, coordination of this project, and in charge of field operations. Teri Holland reviewed the final draft of the report. Steve Kolsto and Jeff Mitzelfelt provided all data and information about publicly owned lakes within a 50-mile radius of Lake Vermilion. Chemical analyses were performed by the Illinois EPA staff. Paul Brewer and Joe Koronkoski of Champaign Regional Office of Illinois EPA provided discharge monitoring reports for three wastewater treatment plants in the watershed.

Thomas Benjamin (District Conservationist), Paul Sermersheim (Conservation Technician) of the U.S. Natural Resources Conservation Service (Vermilion County) provided information on watershed management of the Lake Vermilion watershed. Dr. Gary C. Lin of Bradley University performed the Mann-Whitney rank sum tests to evaluate any difference between the historical and current data. Dr. Edward Mehnert of the Illinois State Geological Survey prepared the geological and groundwater hydrology descriptions of the Lake Vermilion watershed. Michel Garthaus (District Fisheries Manager) of the Illinois Department of Natural Resources (Gibson City, IL) provided fisheries and other biological resources information. Steve Havera and Jeff Levengood of Illinois Natural History Survey provided waterfowl information.

A shoreline erosion survey and macrophytes survey were conducted by the Illinois EPA personnel. Peter Berrini of Cochran & Wilken, Inc. assisted in a review of the survey maps for these. The analysis of phytoplankton was performed under the direction of Professor Lawrence O'Flaherty of Western Illinois University, Macomb, IL.

Gen-Ming Zheng assisted in data entry. Long Duong and John Beardsley assisted in preparing the illustrations. Kevin Rennels assisted with the sample collection at the North Fork tributary site and the spillway. Linda Hascall prepared the graphics. Mei-ling Lin assisted in typing the report. Eva Kingston edited the final report. The efforts and assistance of all who worked on this project are gratefully acknowledged and appreciated.

The views expressed in this report are those of the author and do not necessarily reflect the views of the Illinois State Water Survey.

STUDY AREA

Lake Vermilion

The first public water supply system for Danville was placed in service by the Danville Water Company in 1883. This system was constructed under a franchise granted by the Danville City Council. The source of water for this system was the available flow from the North Fork of the Vermilion River. The original waterworks are described in Water Survey file notes as "a single brick building, divided into a boiler and an engine room." There are no indications of any water purification facilities.

With this initial supply system, the water taken directly from the river was unreliable in terms of quantity and quality. Water supply was limited during periods of low stream flow, and at other times water quality was affected by high turbidity. By 1902 several improvements to the system had been made: in-stream storage was increased by a small channel dam, a small excavated settling pond was added, turbidity was reduced with the installation of a rapid sand filtration plant, and the pumping capacity was increased. In 1912, the treatment plant was expanded to include a laboratory and hypochlorite treatment of the water.

Efforts to augment the surface water supply with a ground-water system periodically have been initiated since at least 1913. At that time, six wells were bored to a depth of 90 feet. According to Water Survey file reports, "these wells flowed and furnished a very large yield."

However, the high iron content and mineralization of the well water made it less desirable than the surface water supply.

The earliest impounding dam, the old dam located north of the Jaycee's boat ramp, was constructed in 1914 to augment flow to the pre-existing channel dam adjacent to the treatment plant. The present dam and spillway were constructed in 1925, with an initial storage capacity of 8,514 acre-feet (ac-ft) or 2,784 million gallons. The initial construction and filling of the new reservoir submerged the 1914 dam structure to just below the surface of the new water level. The gates of the 1925 spillway structure were modified in 1991 to accommodate an increase in the operating pool elevation.

A water shortage in 1976 prompted a search for additional sources of raw water. This search effort led a Water Survey report *Water Supply Alternatives for the City of Danville, Illinois* (Singh, 1978). Options considered in this study were raising the lake level, lake dredging, water transfers from the Vermilion or Wabash Rivers, and ground-water development either locally, in the Wabash River valley, or regionally, in northern Vermilion County.

Additional water shortages in 1988 and 1989 revived interest in the storage alternative presented in the 1978 study. In October 1991, an increase in the operating spillway level for Lake Vermilion was approved. The pool level was increased from 576 feet National Geodetic Vertical Datum (NGVD) to 582.2 feet NGVD, using extensions that had been added to the original spillway gates. The available storage in the reservoir was increased by approximately 4,600 ac-ft or 1,500 million gallons.

Several exploratory wells have been drilled both locally and in northern Vermilion County. At least one well near the lake was drilled, logged, and tested. In northern Vermilion County, several exploratory wells were drilled, but there have been no reported efforts to develop or run pumping tests on these wells.

The 878-acre impoundment is a public water supply lake owned by the Consumers Illinois Water Company. Currently, it has a maximum depth of 21.8 feet, a mean depth of 9.1 feet, a shoreline length of 14.3 miles, and an average hydraulic retention time of 0.042 years (15 days). From the upper end of the lake to the dam, Lake Vermilion is approximately 3.5 miles long.

The current water storage capacity is 7,971 acre-feet at the normal pool elevation (Bogner and Hessler, 1999). Average annual lake evaporation rates are 10.5 inches per year at Urbana, Illinois (Roberts and Stall, 1967).

Originally operated as the Danville Water Company beginning in 1883, it became the Inter-State Water Company in 1913. The company was purchased by Consumers Water Company in 1986 and became Consumers Illinois Water Company in 1995. Philadelphia Suburban Water Corporation purchased Consumers Water Company in 1999. Consumers Illinois Water Company is a wholly owned subsidiary of Philadelphia Suburban Corporation.

Watershed

The North Fork of the Vermilion River (Lake Vermilion) watershed consists of the approximately 298-square-mile (190,720 acres) area drained by the North Fork Vermilion River above the dam site (Figure 1). The river originates in Benton County, Indiana and flows south to Danville, Illinois where it is impounded to create Lake Vermilion. The river continues downstream and joins the Middle Fork and Salt Fork Rivers south of Danville, to become the Vermilion River. Water in the Vermilion River flows into the Wabash, Ohio, and Mississippi Rivers, and eventually into the Gulf of Mexico.

In Illinois, the watershed covers all or portions of T20N, R11W and R12W; T21N, R11W and R12W; T22N, R10W-R12W; T23N, R10W-12W; and of T24N, R10W-12W (Illinois maps, USGS, 1984).

Average annual precipitation in the area is 39.00 inches as measured at Danville (1925 to 2002), and the average runoff (1928 to 2001) is approximately 11.0 inches (Vermilion River at Danville).

The watershed mainly covers areas in Vermilion County and a small area in Iroquois County, Illinois. Approximately one-third of the watershed is in Benton and Warren Counties, Indiana. The highest point in the watershed is at an elevation of 820 feet NGVD. Approximately, 15,000 people live in the watershed. These residents get their water from wells in the watershed or from Lake Vermilion.

Climatologic Conditions of the Study Area

The following climatologic summary for Danville, Illinois, is based on a period of record of more than 100 years (1897-2001). Data taken from the Midwestern Regional Climate Center website (http://mrcc.sws.uiuc.edu/).

Danville has a temperate continental climate dominated by maritime tropical air from the Gulf of Mexico from about May through October; maritime polar air from the Pacific Ocean dominates the climatology in spring, fall, and winter with short-duration incursions of continental polar air from Canada in winter. Mid-winter high temperatures are typically between 0 and 5^{o}Celsius (^{o}C); summer highs are usually in the 25^{o}C range, with lows about 10^{o}C lower. Spring and fall are a mix of winter- and summer-like days, with rather large day-to-day temperature fluctuations common. The greatest day-to-day changes in temperature occur in late fall, winter, and early spring.

Winters are usually punctuated with two to eight cold, dry arctic outbreaks, in which daily lows drop into the -20^{o}C range. These outbreaks generally persist for three to five days, and are often preceded by a winter storm that can reach severe proportions consisting of snowfalls of 6 inches (15 centimeters or cm) or more with strong winds or freezing precipitation.

Summers are humid with dew points between 15^{o}C and 20^{o}C and afternoon relative humidity in the 60 percent range. Usually about 25 days per year have temperatures greater than 30^{o}C; temperatures greater than 35^{o}C are infrequent.

Average (1971-2000) precipitation for Danville is just under 41 inches (104 cm), including about 19 inches (48 cm) of snow. There is considerable variability from year to year. About 120 days per year have measurable precipitation, of which about 40 days are associated with thunder and about 10 days have freezing precipitation. On average, precipitation is most frequent and greatest in magnitude during the warmer half of the year. Thunderstorms are common in the afternoon and evening, primarily during spring and summer.

Sixty percent of the mean annual precipitation falls from April–September. The frost-free growing season averages about 169 days, beginning about April 25 and ending about October 11.

The highest temperature of record is 44.5^{o}C (112^{o}F on July 14, 1936); the lowest temperature of record is -32^{o}C (-26^{o}F January 17, 1982). The wettest year of record is 1990, with 54.24 inches (138 cm); the driest year was 1901, with only 18.86 inches (47.9 cm). During the 105 years of record (1897-2002) there were:

- 5 years with more than 50 inches (125 cm) of precipitation
- 18 years with more than 45 inches (115 cm) of precipitation
- 25 years with less than 35 inches (90 cm) of precipitation, and
- 10 years with less than 30 inches (75 cm) of precipitation
- 17 years of incomplete record

Table 2 provides the daily precipitation record for the Danville station during the monitoring year May 1, 2000 to April 30, 2001. Also included in Table 2 are the monthly precipitation normal values for the period 1971 to 2000.

Geological and Soil Characteristics of the Drainage Basin

Drainage Area

The drainage area for Lake Vermilion is shown in Figure 1. The watershed area is 298 square miles (Table 1).

Geology, Soils, and Topography

The following description is based on information taken from Illinois State Geological Survey (ISGS) publications and maps and from Indiana Geological Survey maps and was summarized by Dr. Edward Mehnart of the ISGS. The geologic conditions in the Indiana portion of the watershed are presumed to be similar to those for the Illinois geology.

Most of the available information is mapped over a broad scale. These maps are meant to represent the broad patterns in the geologic deposits and not capture all of the details found in the geologic deposits. Thus, it is possible that some local conditions may vary from the published data and maps.

Geologic Conditions

The glacial drift covering the Illinois portion of this watershed varies from less than 25 to greater than 400 feet in thickness. Drift is a term to describe the glacial, alluvial, and other nonlithified deposits that are deposited on top of the bedrock. The drift is greater than 200 feet over most of the 17 Illinois townships that are included in the watershed. In general, the drift thickness increases toward the northern end of this watershed because of the presence of the Mahomet bedrock valley.

The surficial deposits found in the uplands to a depth of 50 feet are mapped predominantly as greater than 20 to 50 feet of silty and clayey diamictons of the Wedron Formation, possibly underlain by less than 20 feet of silty and clayey diamictons of the Glasford Formation. Various combinations of alluvium and outwash over diamictons are found in the lowlands.

For the Lake Vermilion area, geologic cross-sections show that the distribution of sand and gravel aquifers is thickest in the Banner Formation. More importantly, these cross-sections show the presence of sand and gravel directly beneath the lake. A pumping test of a well on the west side of the lake showed a hydraulic connection between the lake and the Banner sand and gravel (Larson et al., 1997).

For Indiana, similar geologic materials would be expected-- silty and clayey diamictons in the upland areas and alluvium and/or outwash over diamictons in the lowlands. A map of surficial materials in the Indiana portion of this watershed (Wayne et al., 1966) shows Wisconsinan age materials. In addition, this map shows some features not found in Illinois,

Table 2. Precipitation Record for Danville Area, 2000-2001

Date	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*April*
1	0.31	0	0	0.74	0	0	0.11	T	M	0	0	0
2	0.13	0	0	0	0	0	0	0	0	T	0	0.12
3	0.02	0	0.08	0	0	0	0	0	0	T	0	0.15
4	0	0.06	0.16	0	0.26	0.28	0	0	0	0	0	0
5	0.01	0.45	M	0.19	0	1.09	0	0	0	0.01	0	0
6	0	0	0	0	0	0	0.34	T	0	0.07	0	0
7	0.08	0	0	0.01	0	0	0.21	T	0	0	0	0
8	0	0	0	0.07	0	0	0	0	0	T	0	0.04
9	1.27	0	0	0	0	0	1.66	0	0	0.96	0	0.84
10	0.15	0.77	T	0	0.63	0	0.03	0	0	T	0.07	T
11	0	0.16	0.07	0	0	0	0	1.08	0	0	0.01	0
12	0	0.02	0	0	1.43	0	0	0.06	M	0	0	0
13	0.42	0.35	0	T	0	0	0.45	0.32	0	0.01	0.02	0.24
14	0	1.68	0	0	0.06	0.03	0	0.02	0.02	0.22	0.79	0.03
15	0	T	0	0	0	0.26	0	0	0.02	T	0.08	0
16	T	0.06	0	0	0	0.02	0	0.26	0	T	0	0
17	0.08	0.12	0	0	0	0.08	0	0.08	0	0	0	0
18	0.45	0.11	0	0.30	0	0	0	0.10	0	0	0	0.08
19	0.35	0	0.20	0	0	0	0	0.04	0.01	0	0	0.06
20	T	0.17	0	0	0.06	0	0	T	T	0	0	0
21	0	1.30	0	0	0.07	0	0	0.06	0	0	0	0.12
22	0.07	0	0	0.12	0.24	0	0	0	0	0.02	0	0
23	0.05	0	0	0.03	0	0.01	0	0	0	0	0	0
24	0	1.82	0	0.34	0.46	0	0	0	M	0.74	0	0
25	0	0.05	0	0	1.21	0	0.68	0	0	0.87	0	0
26	0.17	0.02	0	0	0.01	0	0.06	0.02	0.29	0	0	0
27	1.36	0.02	0	0	0	0	0	0	0.02	0	0.01	0
28	0.47	0	T	0.15	0	0	0.02	0	0.08	0	0	0
29	0	T	0	0	0	0	0	0.13	0.27	0	0.06	0.22
30	0	0	0.12	0	0	0	0	0.06	0.13	0	0.11	0
31	0	0	0	0		0		0.01	0		0	
Total	5.08	7.16	0.63	1.95	4.43	1.77	3.45	2.35	0.84	2.90	1.15	1.90
Normals (1971 to 2000												
	4.47	4.70	4.39	3.94	3.03	3.04	3.53	2.79	2.05	1.99	3.17	3.86

Notes: M – missing data; T – trace; Blank spaces – not applicable
Project year annual: 32.61
Normal (1971 to 2000): 40.96

Source: Downloaded from the Midwest Climate Center database by Sandy Jones, Illinois State Water Survey, 2002 kames and eskers, which can contain thick deposits of sand and gravel. Deposits of muck, peat and marl are mapped at sporadic locations in the Indiana portion of the watershed. Muck, peat and marl are deposited in lacustrine environments and generally do not yield a great deal of water.

The uppermost bedrock is mapped as the Pennsylvanian age, Carbondale and Spoon Formations, Mississippian age Middle Valmeyeran and Kinderhookian Formations, and Upper Devonian (Willman and others, 1967). In general, the bedrock gets older as you go north in this watershed. The Mahomet bedrock valley eroded into the bedrock surface, exposing the older rocks (Mississippian and Devonian). The Carbondale Formation contains limestones, sandstones (channel and sheet facies), gray and fissile black shales, and coals. This formation contains the principal economic coals of Illinois, the Danville Coal (No. 7), the Herrin Coal (No. 6), the Springfield-Harrisburg (No. 5), and the Colchester (No. 2). The Spoon Formation is similar to the Carbondale Formation, but has less limestone and coal (Willman et al., 1975). The Mississippian age Middle Valmeyeran consists predominantly of limestones, siltstones, and sandstones. The Valmeyeran includes the Borden Siltstone, which may be the dominant unit in Vermilion County. The Mississippian age Kinderhookian Series is dominantly shale, but has a thin, extensive limestone near its top. The Upper Devonian Series consists largely of black and gray shales (Willman et al., 1975).

Hydrogeologic Conditions

The hydrogeologic conditions for the Illinois portion of this watershed were described by Selkregg and Kempton (1958). The probability of the occurrence of sand and gravel aquifers is generally rated as fair to good or good to excellent. In areas mapped as fair to good, sand and gravel aquifers in the drift are considered to have variable hydraulic conductivity and to be scattered and discontinuous. The areas mapped as good to excellent define the location of the Mahomet aquifer, which coincides with the Mahomet bedrock valley described earlier. The bedrock is not considered a significant source of water. Small groundwater supplies are obtained from sandstone, limestone and fractured shales.

Based on the available information, it appears that the shallow geologic materials (less than 50 feet) in the area near the lake have variable hydraulic conductivity. Shallow sand and gravel would be expected to be found most consistently in the areas that include the Cahokia alluvium or the Henry Formation.

In this watershed, surface water and groundwater appear to interact in a number of ways. Surface water interacts with the groundwater within the alluvial sand and gravel deposits in the lowlands of the watershed. During normal and low river stages, groundwater is likely to discharge from the alluvial sands into the river. During high river stages, water from the river is likely to flow into the alluvial sands. Another interaction between surface water and groundwater is likely to occur where the Vermilion River has eroded through the sand and gravel deposits in the drift. These sand and gravel deposits may discharge water directly to the river or its tributaries or be connected with the alluvial deposits described above. Finally, limited available data show a hydraulic connection between Lake Vermilion and the sands and gravels of the Banner Formation.

The soils of the Lake Vermilion watershed are predominantly Drummer clay loam, Elliot silt loam, Blount silt loam, and Ashkum clay loam soil types. Slopes range from nearly level or depressional for the Drummer and Ashkum soils to undulating or rolling for the Blount and Elliot soils. All of these soil types have poor subsurface drainage in their natural condition.

The upland soils in the watershed are dark, prairie soils formed in glacial till deposits. Valley wall soils, formed under forest conditions, are lighter in color. Each of these soil types is generally underlain by a poorly drained subsoil that causes them to be highly susceptible to erosion (Wascher et al., 1938; USDA-SCS, 1982). Tile drains accomplish most agricultural drainage for the more level soils in the watershed. Direct surface drainage is effective when the surface is sloped.

Hydrologic Description of Lake Vermilion

Hydrologic System

The hydrologic system of Lake Vermilion is composed of the following major units:

- the lake pool,

- surface drainage from the North Fork of the Vermilion River, smaller tributaries to the lake, and direct runoff to the lake,
- the local ground-water system,
- direct precipitation on the lake,
- evaporation from the lake surface, and
- discharge through the spillway,

Surface Inflow and Outflow Conditions

For any surface, runoff will be initiated only when precipitation volume has first wetted all surfaces and filled all depressions (puddles). After these initial losses have been exceeded, the precipitation rate must be greater than the infiltration rate for surface runoff to occur. For impervious surfaces (paved surfaces, building roofs), infiltration potential is very low. Runoff begins when initial losses have been met. For pervious surfaces (bare or vegetated soil and wooded areas), runoff occurs only for storm events that exceed infiltration rate.

Much of the drainage from the upland portions of the watershed is influenced by subsurface tile drainage systems. Most precipitation that falls in the watershed area seeps into the ground and is collected by the buried tiles. These tiles then serve as conduits to surface drainage channels. This process reduces the rate of runoff for the watershed and potential peak flows in the stream system.

As runoff enters the lake, the water level rises and the volume of water stored in the pool increases. Excess water is released through the spillway gate openings. Management of releases through the spillway gates minimizes the impacts of storm flows on the lake levels. During periods of low streamflow, releases through the spillway are constantly maintained to provide water at the water plant intakes located 2.5 stream miles downstream of the spillway.

Lake levels will generally follow a trend of steady decline through the summer months, when evaporation rates and spillway releases for water supply exceed inflow rates; stabilize during the fall and winter as the weather cools; and, hopefully, rise in the spring in response to high precipitation and saturated soil conditions. Most years, a surplus of water is passed through the spillway during the spring rise.

The balance of inflows and outflows from the lake will be discussed in more detail later.

Public Access to the Lake Area

There is a well-developed transportation network throughout the watershed. The major north-south highway is Illinois Route 1 whish bisects the watershed (including the city of Danville). East-west routes include Interstate Highway 74, US Routes 150 and 136 (Illinois Route 1), Illinois Route 9, Illinois Route 49, and Illinois Route 119. There are also several railroads that traverse the watershed. The railroads include the Louisville & Nashville Railroad, the Chicago & Eastern Illinois Railroad, the Chicago, Milwaukee, St. Paul & Pacific Railroad, and the Norfolk & Western Railroad.

Lake Vermilion is accessible from Interstate Highway 74, US Route 136 (Illinois Route 1) through the city of Danville. Lake Vermilion is located immediately at the northwest edge of Danville and much of the east shore of the lake is residential frontage. In addition, there are approximately 2,000 feet of residential frontage located on the west shore of the lake north of the boat ramp. West Newell Road is at the north end of the lake. Denmark Road (Dallas Bowman Memorial Bridge) runs generally west and south of the lake (Figure 2).

Approximately 40 percent of the 14.3 miles shoreline are residential and developed with numerous permanent homes and cottages along the lake shore. Woodland makes up 40 percent of the shoreline on the west side of the lake. Wetland and recreation/developed each have approximately 10 percent of the shoreline use. Most undeveloped shoreline is accessible for bank fishing.

There are two public parks along the west shore of Lake Vermilion. One park is at GAO Grotto located at the northwestern corner of the lower lake basin near the Dallas Bowman Memorial Bridge; and the other park is at the Jaycee's Boat Ramp (Jaycee's park). There are parking spaces for 10 vehicles at GAO Grotto; and parking 50 vehicles and 30 boat trailers at the Jaycee's Park. There is one public boat dock at each park. There is another public dock located about 3,000 feet north of the Denmark Road Bridge on the west shore of the lake. The Danville Park District maintains the boat dock/launch. The distance from downtown Danville to the access point is approximately 2 miles. There is no public transportation to the lake site.

No fee is charged for the use of the park and the lake for fishing. There is a $50 annual registration fee for all boats used on the lake. Bank fishing is available at many open areas

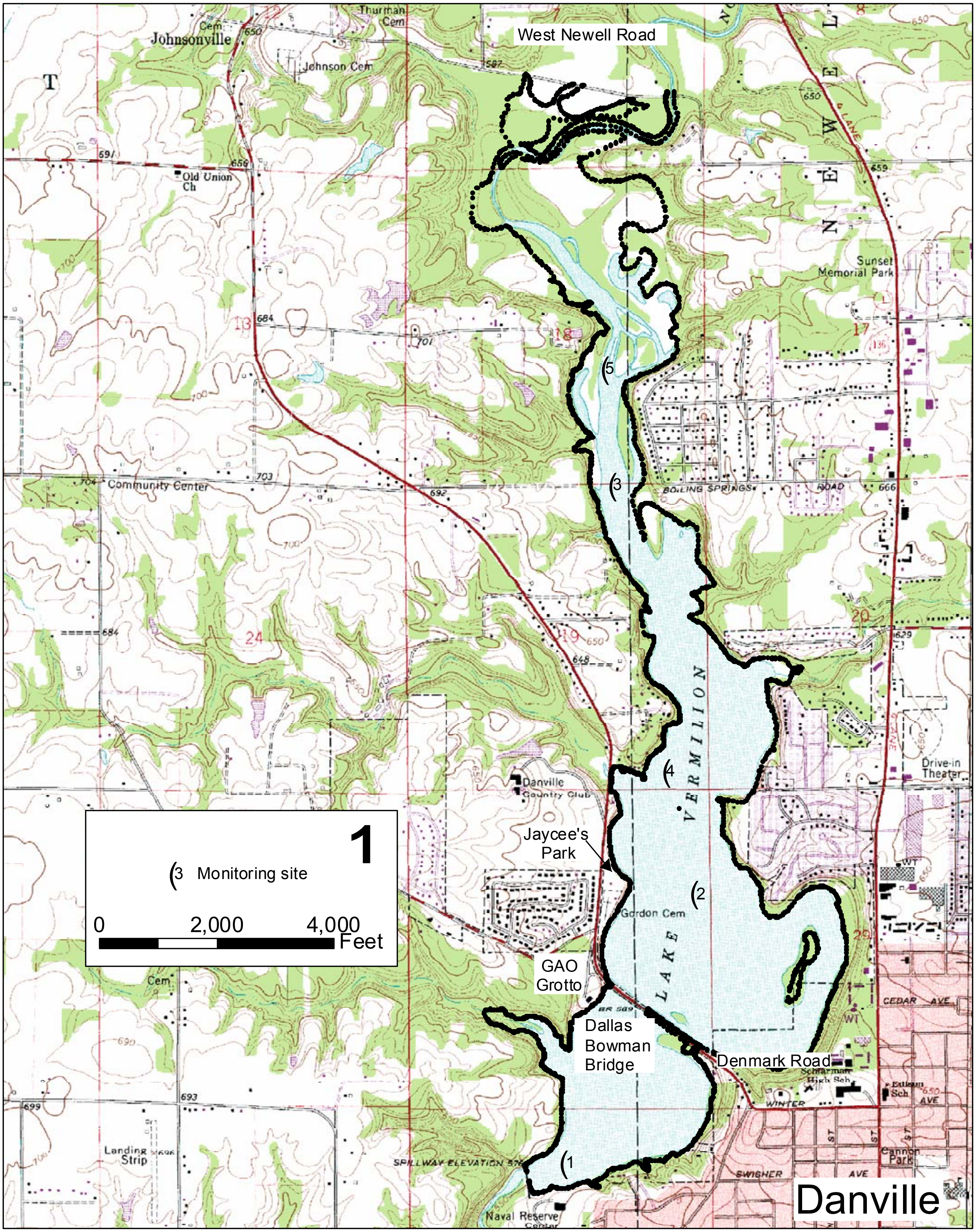


Figure 2. General location map for facilities at Lake Vermilion

(shoreline resident areas). There are no general limits on motor size or boat speed for the lake. The use of the lake is year round. Swimming is permitted at the GAO Grotto beach.

There is no camping facility, no shelter, and no boat renting. There is a concession stand, two public picnic areas, and rest-room facilities. Facilities at the boat ramp are handicapped accessible. Waterfowl hunting and observation are allowed. There is no hiking trail in the wooded areas.

Size and Economic Structure of Potential User Population

Potential User Population

Lake Vermilion's user population is a combination of the city of Danville and other residents in the area. As a recreational resource, Lake Vermilion is used primarily by persons with property adjacent to the lake or residents in Danville and the surrounding area. There is no attendance record so it is difficult to determine points of origin for visitors. As estimated by the Vermilion County Park District, the attendance is approximately 50,000 visitors annually. The lake probably receives its greatest use from Danville (population 33,900). In the watershed, potential user populations live in the towns of Hoopeston (21 miles north, population 5,965), Rossville (16 miles north, population 1,083), Alvin (11 miles north, population 316), and Bismark (7 miles north, population 542) are most likely to use the lake. Other area towns include Rantoul (30 miles northwest, population 12,857) and Georgetown (13 miles south, population 3,628). The total population of these six communities is 24,091 (Illinois Highway Map, 2001-2002).

A majority of the users travel from within a 50 miles (80 kilometers) radius of Lake Vermilion, with the metropolitan areas of Champaign-Urbana (35 miles east) and Terre Haute, Indiana (50 miles southeast) contributing the most non-city users. Major population centers (cities/towns) within a 50-mile (80-km) radius of Lake Vermilion are listed in Table 3. The data are based on the Illinois Highway Map 2001-2002 (Illinois Department of Transportation, 2001). The demographic and economic information for counties that lie within a 50 miles radius of Lake Vermilion are given in Table 4 (University of Illinois, 1999, Rand McNally Co., 2001). The total population of the 8 counties listed in Table 4 is 838,700.

Referring to Tables 3 and 4a, the population of Vermilion County on January 1, 2000 was 84,300. The largest city in Vermilion County is Danville (population 33,900) whose total population comprised 40.2 percent of the county's total population.

Economic Characteristics

The recent per capita income of the 50-mile surrounding communities (Table 3) is available only for large cities (Data from the 2000 Census are not available yet). The 1997 per capita income for Danville was $15,101. Tables 4a and 4b show population and economic data for counties within 50 miles (80 km) of Lake Vermilion and list sources of employment. The per capita income for the 8 counties listed in Table 4a averages $20,770 with a range from $19,163

Table 3. Demographic and Economic Data for Towns/Cities Surrounding Lake Vermilion

Town/city	*Population* Total, 2001	*Population* Under 18 years, %	*Population* Over 65 years, %	*Number of households*	*Person per household*	*1997 Per capita income, $*
Arcola	2,652	25.5	17.4	1,009	2.54	11,780
Catlin	2,087	29.2	10.8	801	2.71	13,010
Champaign	67,518	18.4	8.2	24,173	2.30	21,962
Danville	33,904	26.4	17.5	13,791	2.40	15,101
Fisher	1,647	28.2	12.1	576	2.65	13,489
Georgetown	3,628	28.7	15.7	1,447	2.54	9,568
Gibson City	3,373	23.6	22.8	1,431	2.30	12,569
Gilman	1,793	23.8	23.5	728	2.39	10,644
Hoopeston	5,965	27.3	17.2	2,332	2.49	11,205
Lake of the Wood	3,026	31.8	4.9	1,002	2.74	12,405
Mahomet	4,877	32.1	8.0	1,098	2.83	14,503
Milford	1,369	24.9	19.5	628	2.41	10,432
Monticello	5,138	23.5	17.8	1,816	2.44	15,531
Oakwood	1,502	27.5	10.8	585	2.62	11,327
Onarga	1,438	28.3	17.6	474	2.68	9,941
Paris	9,077	24.7	21.2	3,752	2.33	10,835
Paxton	4,525	26.5	17.9	1,682	2.48	11,193
Philo	1,314	28.8	12.5	375	2.74	15,215
Rantoul	12,857	29.0	5.8	5,461	2.75	11,360
Rossville	1,083	25.6	20.1	450	2.36	10,875
St. Joseph	2,912	27.8	11.8	776	2.63	13,861
Sheldon	1,232	25.5	18.3	430	2.50	10,950
Sidney	1,062	26.2	13.0	383	2.54	13,213
Thomasboro	1,233	25.4	11.5	500	2.50	12,854
Tilton	2,976	22.9	15.9	1,131	2.41	10,794
Tolono	2,700	28.0	9.8	1,005	2.59	11,588
Tuscola	4,448	25.0	15.5	1,708	2.43	12,685
Urbana	36,395	16.1	9.0	13,210	2.20	21,962
Villa Grove	2,553	28.9	12.9	1,022	2.68	10,971
Watseka	5,670	24.9	21.6	2,169	2.38	11,000
Westville	3,175	21.7	21.1	1,463	2.32	11,485

Source: University of Illinois, 1999; Rand McNally Company, 2001, llinois Highway Map 2001-2002.

Table 4a. Population and Economic Data for Counties near Lake Vermilion

County	Area (square miles)	Population (01/01/00)	Wholesale (thousands $)	Manufacturing: Number of establishments	Manufacturing: Units	Manufacturing: Number of employees	Manufacturing: Value added (thousands, $)	Total number of Establishments 1996	Total number of Employees 1997	Per capita Income, $ 1997
Champaign	997	170,300	2,033,468	173	940	11,000	1,333,600	256	115,921	$21,962
Coles	508	52,000	370,765	56	429	5,600	609,900	74	33,589	$20,218
Douglas	417	19,900	211,349	59	64	1,500	91,400	47	11,255	$20,885
Edgar	624	19,200	135,159	28	28	1,000	51,700	45	8,816	$19,163
Ford	486	14,000	387,588	21	21	1,000	70,000	43	7,348	$22,667
Iroquois	1,116	31,200	276,291	41	68	1,800	96,700	42	14,693	$20,355
Piatt	440	167,000	249,449	16	20	500	27,800	41	6,119	$23,325
Vermilion	486	84,300	548,525	117	560	8,300	797,200	130	42,872	$19,566

Sources: Rand McNally Company, 2001
University of Illinois, 1999
Gaqain et al., 2001

Table 4b. General Employment Categories for Counties near Lake Vermilion

County/County seat	*Major employment categories*
Champaign/Urbana	Education; governments; services (business, education, health, hotels, social); retail trade; finance, insurance, and real estate; manufacturing (food and kindred products, textile and fiber products, primary metal industries, electrical equipment, and components); transportation and public utilities; construction; trucking; wholesale and retail trade; construction; agriculture.
Coles/Charleston	Manufacturing (non-durable goods, electrical equipment and components); governments; services (business, education, health, social); retail trade; real estate; construction; agriculture.
Douglas/Tuscola	Manufacturing (lumber); retail trade; services (automotive, food, finance, health); governments; finance, insurance, and real estate; construction; agriculture.
Edgar/Paris	General and professional services; manufacturing (food robber and plastics); retail trade; governments; agriculture.
Ford/Paxton	Professional and related services; wholesale and retail trade; manufacturing (textile and fiber products, primary metal industries, electrical equipment, and components); mining; trucking; governments; agriculture.
Iroquois/Watseka	Services (business, health, personal, social); retail trade; retail trade; governments; financial; agriculture.
Piatt/Monticello	Services (business, engineering, financial, hotels and motels, health,); retail trade; governments; finance; manufacturing (paper and allied products, printing and publishing, chemical and allied products, primary metal industries); transportation and public utilities; wholesale trade; agriculture.
Vermilion/Danville	Services (business, education, engineering, hotels and motels, health)); retail trade; manufacturing (automobile parts, chemical and allied products, fabricated metal products, electronic equipment); governments; finance, insurance, and real estate; wholesale trade; transportation and public utilities (tracking and communication); agriculture

Sources: Rand McNally Company, 2001
University of Illinois, 1999
Gaqain et al., 2001

in Edgar County to $23,325 in Piatt County. The 1997 per capita income for Vermilion County was $19,566.

Vermilion County had an average labor force of 38,550 in 1999. The 1999 per capita income for Vermilion County was $20,436 as compared to $ 29,853 for the state of Illinois. The 1999 unemployment rate for Vermilion County was 6.0 percent as compared to the state average of 4.3 percent for Illinois. Approximately 97 percent of the labor force is in non-farm employment (University of Illinois, 1999, Rand McNally Co., 2001).

Agriculture and agribusiness are the major enterprises in Vermilion County. The major crops grown in the watershed are corn and soybeans. For Vermilion County, the average farm size is 493 acres; the total value of farm income in 1997 was 140 million dollars. Sales from crops constituted 95.7 percent of total farm sales; and livestock and poultry farm sales constituted 4.3 percent of total sales. The average yields under high levels of management for present conditions are corn 147 bushels, soybeans 42 bushels, and wheat 70 bushels per acre (T. Benjamin, USDA, personal communication, 2002).

A few light industrial plants, an underground coal mine, and several producing oil fields also contribute to the economy. The plants for the production and processing of canning crops (canneries) are located in Hoopeston and one formerly operated in Rossville. The furthest downstream portion of the watershed has several rural non-farm residential sub-divisions. The major transportation facilities in Vermilion County include railroads, Interstate Highway74, U.S. Routes 136 and 150, and Illinois Routes 1, 9, 49, and 119. The transportation facilities (including railroads discussed later) provide adequate market outlets for the agricultural production of the watershed.

Historical Lake Uses

Public Water Supply (Water Treatment Plants)

The Consumers Illinois Water Company's treatment facility was completed in early 1992. This state-of-the-art plant was designed to produce up to 14 million gallons per day (mgd) of treated water. The plant improvements, completed in 2000, provided additional treatment for nitrate removal, chloramine disinfection, and improved performance in raw water screening, powdered activated carbon feed, filtration, and plant controls.

The public water supply system for the Danville area is operated by the Consumers Illinois Water Company. Lake Vermilion impounds the North Fork Vermilion River. There is no intake structure in the lake. Water from Lake Vermilion is released at the spillway to supply a small holding basin at 2.5 river miles downstream and adjacent to the water treatment plant. The raw water intake is equipped with eight stainless steel screens feeding into two pump stations adjacent to the North Fork River containing a total of four submersible, flood-proof raw water pumps with capacities ranging from 2 to 9 mgd each.

There are four Eimco Reactor Clarifiers used for softening and solids removal. Each unit is rated at 7 mgd. Ferric chloride is added for coagulation; and lime is dosed for water softening purposes. After the clarifiers, the water flows into a recarbonation basin where carbon dioxide is injected to lower the pH. The 69 feet (ft) × 20 ft × 21.5 ft concrete basin is used for pH adjustment. Hydrofluosilic acid is added at the outflow to enhance dental health.

The clarified and softened water from the recarbonation basin enters six dual-media filters (anthracite coal and filter sand) with a capacity of 2.8 mgd each. Phosphate is dosed to remove and prevent lime build-up on the filter media. The filters are used for the final polishing of the water. Air and water are used for filter backwash.

Water from the filter flows into a cleanwell (wetwell) with 1.25 million gallons total capacity. Chlorine and aqueous ammonia are added for disinfection purpose. Two halves, fully baffled are used for maximum detention time.

There are four ion exchange units (10-foot diameter by 10-foot high ion exchange pressure vessels) for nitrate removal. Each unit is rated at 4.4 mgd. It is used as a "split-stream" treatment to reduce nitrate levels to below maximum allowable levels in finished water delivered to customers. Sodium hydroxide (for pH control), sodium chloride (for nitrate removal), and sodium thiosulfate (for dechlorination) are dosed in the ion exchange system.

The finished water then is pumped to a storage tank by four vertical turbine pumps (high service pumps). The total pumping capacity ranges from 2 to 9 mgd. They can pump purified water to an elevation of 285 feet above the treatment plant.

Full process and quality control are based on laboratory results of water chemistry. The treatment plant features an Illinois Department of Public Health certified bacteriological laboratory.

Distributed programmable logic controller and personal computers control the processes with advanced graphics, data logging, and reporting capabilities.

Recreational Uses

Since the completion of Lake Vermilion, the lake and park areas have been popular for recreation purposes for the population from the area surrounding Danville. Recreational activities included boating (include high power boating and sail boating), swimming, sport fishing, water skiing, duck hunting, wildlife observations, picnicking, and aesthetic enjoyment. Estimated user populations are 80,000 people annually (Danville Park District, 2001).

The recreational facilities around the lake area include a boat ramp, one concession stand, a swimming beach at the GAO Grotto, rest rooms, and two picnic areas. There is no shelter, campground, hiking or horse trail, and no bicycle trail.

The Oldsmobile Balloon Classic was held until 2000 but was suspended in 2001 due to lack of funding. Hot air balloons were launched over the lake and there was usually a contest. Approximate dates for this event are the second week in April.

The lake maintenance budgets were obtained from the Vermilion County Park District. Revenues received in fiscal year 2000-2001 were a total of $37,500. The lake incomes included $35,000 from boat licenses and $2,500 from the concession store. The annual expenditure for Lake Vermilion in 2000-2001 was $17,500. The annual expenditures were mainly for salaries of park employees. Other expenditures were for maintenance and operation supplies, and utilities. Annual revenues exceeded expenses of $20,000 in 2000-2001. There are plans for future capital improvements, such as a boardwalk tower, restrooms, and a concrete walkway.

Residential Uses

CIWC owns all shoreline around the lake. There have been home sites developed on adjacent properties. There are approximately 70 houses built adjacent to the lake (50 along the east side and 20 along the west side).

Population Segments Adversely Affected by Lake Degradation

Degradation of Lake Vermilion has been a gradual process. The degradation problems are common to most lakes in central Illinois; siltation, pesticide introduction due to agricultural and residential practices within the watershed, residential development along a large portion of the shoreline, and the presence of non-game fish.

Siltation is caused by the sheet and rill erosion and ephemeral gully erosion from the watershed. Siltation in the lake has an effect on lake volume, and reduced water depth impacts shoreline aesthetics and boat access. According to Bogner and Hessler (1999), sedimentation has reduced the potential capacity of Lake Vermilion from 13,209 ac-ft (4,304 million gallons) in 1925 to 7,971 ac-ft (2,597 million gallons) in 1998. The 1998 basin capacity was 60.3 percent of the 1925 potential basin capacity. For water supply purposes, these volumes convert to capacities of 4,304 million gallons in 1925 and 2,597 million gallons in 1998. The potential capacity of the lake in 1963 was 9,810 ac-ft (3,196 million gallons), and in 1976 it was 9,157 ac-ft (2,984 million gallons).

The sedimentation rates for Lake Vermilion and its watershed for the periods 1925-1963, 1963-1976, 1976-1998, and 1925-1998 indicate a steady decline in net sediment yield. Annual sedimentation rates for three separate periods, 1925-1963, 1963-1976, and 1976-1998 were 89.5, 50.2, and 53.9 ac-ft, respectively. The long-term average annual sediment yield from 1925-1998 was 71.8 ac-ft. These delivery rates show the need for continuing efforts to control watershed erosion, thereby reducing reservoir sedimentation rates.

Capacity loss rates as a result of lake sedimentation (0.54 percent per year) and watershed sediment yield rates (0.40 tons per acre) of the lake and its watershed are about average for Illinois impoundment lakes (Bogner and Hessler, 1999).

Lake Vermilion is used as a public drinking water source for Danville and several area communities, boat fishing, and bank fishing. The water quality and quantity are of utmost concern for the Consumers Illinois Water Company and its customers. Degradation of water quality of the lake water will increase the future cost of drinking water treatment, which may be passed on to water customers. In the past, the increased treatment costs have not been directly passed to the customers. Water rates were increased once after the new water treatment plant was constructed to improve the finished water quality (1998). A deteriorating fishery could affect the group of up to 16,700 people, who fish to supplement family food supplies (Ken Konsis, Vermilion County Park District, personal communication, 2001).

Residential developments along the lake shoreline can contribute to deterioration of the lake. Potential impacts range from problems due to septic systems to vegetation removal resulting in less and unbalanced macrophytes growth. In consequence of vegetation removal, many non-game fish, such as common carp, yellow bass, freshwater drum, and gizzard shed may be present in higher densities. The solution of these problems is complicated and expensive or impossible to correct. Rotenone, a chemical used for the control of undesirable fish, cannot be used be used in Lake Vermilion because it serves as a primary source for public water supply (M. Mounce, IDNR, personal communication).

Comparison of Lake Uses to Other Lakes in the Region

Within 50 miles (80 km) of Lake Vermilion, there are 17 lakes listed in files of the Illinois EPA. These lakes and information about size, maximum depth, existence of boat ramps, and lake use are listed in Table 5. Among these lakes, six lakes have surface areas greater than 100 acres. Lake Vermilion (878 acres) is the largest and the most significant water resource of the area.

Uses for most of these lakes and their surrounding areas as listed in Table 5 include recreation, boating, fishing, swimming, public water supply, and picnicking. Four lakes including Lake Vermilion are used as sources for public water supplies. Lake Vermilion with its park areas (approximately 500 acres) provides excellent recreation facilities.

Point Source Discharges

Municipal wastewater treatment plants or industrial treatment facility effluents are point source discharges released at concentrated outfalls into a body of water. Point source discharges fall under the U. S. EPA's National Pollutant Discharge Elimination System (NPDES) permit program. There are three NPDES permitted facilities (two municipal and one school sources) discharging into the Lake Vermilion watershed (Paul A. Brewer and Joe Koronkoski, IEPA, personal communication, 2001).

One permitted discharge is the effluent of the city of Hoopeston Wastewater Treatment Plant. The NPDES number is IL0024830. The treatment facilities include bar screens, grit chambers, two Imhoff tanks, two oxidation ditches, and four sand filters (travel bridge rapid sand filters). The recent discharge monitoring report (April 2000 - May 2001) with NPDES permitted limits is shown in Table 6. The Table indicates that the maximum discharge rate of the plant during the study period was 2.363 mgd. The average monthly flow ranges from 0.620 to 1.652 mgd with an annual average of 0.956 mgd. The values of pH were between 7.2 and 7.9 which is within the acceptable NPDES permit range of 6 and 9. The monthly average carbonaceous biochemical oxygen demand (CBOD) loading rates ranged from 11 pounds per day (lb/d) in

September 2000 to 56 lb/d in April 2001. Maximum loading rate was 265 lb/d in April 2001.

Average monthly CBOD concentrations were between 1 (February 2001) and 6 mg/L (April

Table 5. Illinois Public Lakes within a 50-Mile Radius of Lake Vermilion

Lake code	*Lake name*	*County*	*Surface area, acres*	*Maximum depth, feet*	*Average depth, feet*	*Boat ramp*	*Lake use/ facilities*
REU	Champaign Sportsmens	Champaign	3	5	3.7		
RBU	Crystal	Champaign	7				
RBO	Homer	Champaign	83.0	19.0	7.4	2	BR,C,CN,P,PK
REG	Lake of The Woods	Champaign	23.2	28.0	9.7	1	BR,C,H,P,PK
REZE	Spring	Champaign	35	17	6		
RBP	Oakland	Coles	23.4	9	5.5	1	WS/P
RBK	Walnut Point	Douglas	58.7	31.0	11.5	1	C,P,PK,WH
RBL	Paris Twin East	Edgar	162.8	26.5	10.2	1	WS/ P
RBX	Paris Twin West	Edgar	56.7	8.5	3.3	1	BR,P,S
RFA	Iroquois	Iroquois	125.0	36.0	12.8	1	C,P,PK
RFE	Bayles	Iroquois	125.0	22.0	9.2		
RBR	Clear	Vermilion	7.0	53.0	16.5	1	C,P,PK
RBS	Georgetown	Vermilion	46.1	12	4.1	1	WS,P
RBM	Long	Vermilion	56.6	39.0	12.1	1	C,CN,PK
RBN	Mingo	Vermilion	170.0	41.0	11.5	1	P,S
RBD	Vermilion	Vermilion	878.0	21.8	9.1	2	WS/BR,C,P,S
RBY	Willow Creek	Vermilion	7.0	16.0	12	1	BR,P

Notes: * All lakes are used for fishing/boating, WS = water supply, BR = boat rental, C = camping area, CN = concession, F = fishing/boating, H = hiking, P = picnic area, PK = park, S = swimming/beach, WH = waterfowl hunting, and. Blank spaces = no data

Source: J. Mitzelfelt and Steve Kolsto, Illinois EPA, personal communication, 2001, Sefton and Little, 1984

Table 6. Summary of Discharge Monitoring Report for City of Hoopeston, 2000-2001

Date	*Flow, mgd*		*pH*		*Carbonaceous BOD, lb/day*		*Carbonaceous BOD, mg/L*		*Total suspended solids, lb/day*		*Total suspended solids, mg/L*		*Ammonia, mg/L*	
	Avg.	*Max.*	*Avg*	*Max.*	*Avg*	*Max.*	*Avg.*	*Max.*	*Avg*	*Max.*	*Avg*	*Max.*	*Avg*	*Max.*
2000														
May	1.097	1.82	7.6	7.8	20	31	2	4	24	70	3	8	0.19	0.33
June	0.843	1.61	7.2	7.6	27	58	4	11	18	36	2	5	0.38	0.62
July	0.906	1.747	7.3	7.8	25	46	3	5	15	34	2	4	0.22	0.3
August	0.62	1.491	7.3	7.6	14	36	2	5	13	33	2	5	0.24	0.48
September	0.67	1.428	7.3	7.6	11	15	2	3	11	21	2	4	0.23	0.38
October	0.692	1.753	7.2	7.9	12	23	2	4	17	36	3	7	0.18	0.42
November	0.884	1.869	7.6	7.8	18	79	2	5	24	55	4	6	0.21	0.47
December	0.945	2.292	7.4	7.6	12	19	2	3	20	41	2	5	0.20	0.36
2001														
January	0.973	2.114	7.4	7.7	25	97	2	6	33	153	3	9	0.18	0.23
February	1.652	2.102	7.2	7.5	19	41	1	3	33	90	2	5	0.11	0.21
March	1.163	2.363	7.4	7.6	19	59	2	8	13	45	1	6	0.16	0.64
April	1.03	2.12	7.2	7.7	56	265	6	15	51	380	4	22	0.20	0.90
Yearly ave.	0.956	1.892			22	64	3	6	23	83	3	7	0.21	0.45
Yearly max.	1.652	2.363	7.6	7.9	56	265	6	15	51	380	4	22	0.38	0.90
Yearly min.	0.62	1.428	7.2	7.5	11	15	1	3	11	21	1	4	0.11	0.21
NPDES limit	Report	Report	6	9	220	440	10	20	264	528	12	24	1.5* 2.1**	7.3* 5.8**

Notes: BOD – biochemical oxygen demand, mgd – million gallons per day, Ave. –average, Max. –maximum, Min. – minimum,
* April through October, ** November through March

Source: Illinois EPA, Champaign Regional Office

2001). The average and maximum of both CBOD loading rates and concentrations were within the NPDES permitted limits.

Table 6 also shows total suspended solids (TSS) loading rates as well as concentrations and ammonia nitrogen (NH_3-N) concentrations monitored. Monthly average TSS loading rates ranged from a low of 11 lb/d in September 2000 to a high of 51 lb/d in April 2001 with a daily maximum of 380 lb/d in September. These values did not exceed the limits of 264 lb/d for a monthly average and 528 lb/d for the daily maximum loading rate. Average monthly TSS concentrations were between 1 and 4 mg/L with a maximum concentration of 22 mg/L found in April 2001. These TSS concentrations also did not exceed the NPDES limits. The average monthly ammonia concentrations in the Hoopeston effluents ranged from 0.11 in February 2001 to 0.38 mg/L in June 2000 with a maximum concentration of 0.90 mg/L. These NH_3-N concentrations were below the NPDES limits. The effluent standards for NH_3-N are 1.50 mg/L for monthly average and 7.30 mg/L for maximum concentration during April through October; and are 2.1 mg/L for monthly average and 5.8 mg/L for maximum concentration during November through March.

The discharge monitoring report for the village of Rossville wastewater treatment system during May 2000 through April 2001 is presented in Table 7. The NPDES number is ILG580064. The treatment facility uses two lagoon systems as primary and secondary treatments. The effluent is then polished by two intermittent sand filters. Table 7 shows that the average monthly flow rates range from 0.115 mgd in September 2000 to 0.28 mgd in December 2000 with a maximum flow of 0.397 mgd in January 2001. The range of monthly pH values was from 6.8 to 7.5 and was in the permitted range of 6-9. CBOD and TSS were determined only once a month. The CBOD loading rates ranged from 1.2 lb/d in October 2000 to 34 lb/d in January 2001 with an average of 13.2 lb/d. The regulatory maximum limit is 150 lb/d. The concentrations of CBOD were 1.3 and 23.5 mg/L with a mean of 11.5 mg/L. These values were under the maximum concentration limit of 40 mg/L. The ranges of TSS loading rates and concentrations were respectively 6.3-30 lb/d and 8-28 mg/L which were less than the limits of 169 lb/d and 45 mg/L. The averages of TSS loading rates and concentrations were 17 lb/d and 16 mg/L, respectively.

Bismarck-Henning School uses a septic tank system and four tertiary sand filters to treat the school wastewater. The recent discharge monitoring report (one sample per month required) is presented in Table 8. It can be seen from the Table that the effluent flows ranged from 0.0040 mgd only in April 2001 to 0.0045 in other months during the study period. For the period from May 2000 through April 2001, the effluent pH levels were 7.4-7.9 these were in the permitted range of 6-9. Biochemical oxygen demand (BOD) loading rates ranged form 0.04 to 0.30 lb/d with a mean of 0.16 lb/d. The concentrations of BOD were 1-8 mg/L with a mean of 4.3 mg/L. The observed BOD loading rates and concentrations were less than the limits of 2.34 lb/d and 10 mg/L, respectively. TSS loading rates were 0.08-0.30 lb/d with a mean of 0.14 lb/d; and TSS concentrations were 2-8 mg/L with a mean of 4 mg/L. TSS values did not exceed 2.8 lb/d and 12 mg/L effluent standards. The NH_3-N concentrations in the plant effluent were between 0.2 and 6.61 mg/L (January 2001). The sample taken in January 2001 exceeded the 4.00 mg/L limit.

Table 7. Summary of Discharge Monitoring Report for Village of Rossville, 2000-2001

Date	*Flow, mgd*		*pH*		*Carbonaceous BOD, pounds/day*		*Carbonaceous BOD, mg/L*		*Total suspended solids, pounds/day*		*Total suspended solids, mg/L*	
	Avg.	*Max.*	*Avg.*	*Max.*	*Avg.*	*Max.*	*Avg.*	*Max.*	*Avg.*	*Max.*	*Avg.*	*Max.*
2000												
May	0.132	0.168	7.2	7.2	5.9	5.9	7.5	7.5	6.3	6.3	8	8
June	0.145	0.257	7	7	2.8	2.8	3	3	13.1	13.1	14	14
July	0.131	0.203	7.4	7.4	10.3	10.3	8	8	25.7	25.7	20	20
August	0.131	0.171	7.3	7.3	8	8	7	7	19	19	17	17
September	0.115	0.175	6.8	7.2	6.4	6.4	6.8	6.8	14.9	14.9	16	16
October	0.125	0.214	7.3	7.3	1.2	1.2	1.3	1.3	7.7	7.7	8	8
November	0.17	0.339	7.4	7.4	6.6	6.6	6.8	6.8	11.7	11.7	12	12
December	0.28	0.33	7.2	7.2	24	24	19.5	19.5	30	30	24	24
2001												
January	0.241	0.397	7.5	7.5	34	34	16	16	17	17	8	8
February	0.235	0.394	7.4	7.4	30	30	23.5	23.5	13	13	10	10
March	0.163	0.266	6.9	6.9	21.5	21.5	23	23	26.2	26.2	28	28
April	0.142	0.2	7.2	7.2	12.5	12.5	15	15	20	20	24	24
Yearly ave.	0.168	0.260			13.6	13.6	11.5	11.5	17.1	17.1	16	16
Yearly max.	0.28	0.397	7.5	7.5	34.0	34.0	23.5	23.5	30.0	30.0	28	28
Yearly min.	0.115	0.168	6.8	6.9	1.2	1.2	1.3	1.3	6.3	6.3	8	8
NPDES limit	Report	Report	6	9	94	150	25	40	139	169	37	45

Notes: BOD – biochemical oxygen demand, mgd – million gallons per day, Ave. –average, Max. –maximum, Min. – minimum,
* April through October, ** November through March

Source: Illinois EPA, Champaign Regional Office

Table 8. Summary of Discharge Monitoring Report for Bismarck-Henning School, 2000-2001

Date	*Average flow, mgd*	*Minimum pH*	*Average BOD*		Total suspended solids		*Ammonia nitrogen, mg/L*
			pounds/day	*mg/L*	*pounds/day*	*mg/L*	
2000							
May	0.0045	7.7	0.14	3.7	0.11	3	0.2
June	0						
July	0						
August	0						
September	0.0045	7.8	0.04	1	0.3	8	1
October	0.0045	7.4	0.3	8	0.23	6	0.2
November	0.0045	7.7	0.23	6	0.08	2	4
December	0.0045	7.9	0.08	2	0.08	2	0.3
2001							
January	0.0045	7.7	0.26	7	0.15	4	6.61
February	0.0045	7.8	0.15	4	0.12	3	1.5
March	0.0045	7.8	0.15	4	0.12	3	1
April	0.004	7.5	0.1	3	0.1	3	0.2
Yearly average.	0.0033	7.7	0.16	4.3	0.14	3.8	1.7
Yearly maximum	0.0045	7.9	0.3	8	0.3	8	6.61
Yearly minimum	0	7.4	0.04	1	0.08	2	0.2
NPDES limit	Report	6	2.34	10	2.8	12	1.5* 4**

Notes: BOD – biochemical oxygen demand, mgd – million gallons per day,
* April through October, ** November through March

Source: Illinois EPA, Champaign Regional Office

There are 70 some houses located around the lake shoreline. Approximately 40 percent of the houses discharge to the Danville wastewater treatment plant. The others (approximately 40 to 50 per David Cronk, CIWC) use septic tanks to treat their wastewater. The influence of septic tanks effluents on the lake was not determined and is outside the scope of this study.

Land Use and Nonpoint Pollution Loadings

Watershed Land Use

Land use in a given area is contingent on many factors, including geology, topography, soil types and characteristics, geographic location, population, and ownership. In Illinois, the predominant land use is agriculture with approximately 70 percent of the acreage in the state in cropland and pasture. Major crops include corn, soybeans, wheat, and hay.

A breakdown of land use as a percentage of total acreage in the Lake Vermilion watershed is listed in Table 9. It includes cropland, pastureland and hayland, woodland, water, roads and railroad, urban development and water by acreage and percent of watershed. The primary land use in the watershed is row crop production (88.0 percent); an additional 3.0 percent is in pasture or hay production. Forest, wetland, wildlife, and recreational areas make up 5.1 percent. Roads and urban development occupy 2.0 percent.

There are 150 farms in the Lake Vermilion watershed with an average farm size of 65 acres. Land ownership is mostly private; lakes, parks, and forest preserves are publicly owned.

There are two minority farmers. The major type of farming is cash grain. Approximately 70 percent of the farming consist of corn and soybean rotation; the others are canning products. (T. Benjamin, Vermilion County Soil and Water Conservation District (SWCD), Danville, Illinois, personal communication, 2001).

The soils of the watershed are well suited to agricultural production and are generally intensively cropped. Major crops grown are corn and soybeans with some wheat and vegetable crops used for canning, primarily sweet corn, squash, pumpkins, lima beans, and kidney beans. Many fields require artificial drainage (tiles, surface and open ditches) to attain maximum productivity, while others require protection from erosion for sustained productivity.

Similar to other watersheds in Illinois, subsurface drainage systems are commonly used on cropland in the Lake Vermilion watershed. Subsurface drainage using clay tile or polyvinyl chloride pipes (so-called field tiles) can lower the water table enough to aerate the root zone and improve plant growth. Of the 167,833 acres of cropland in the watershed, approximately 16,800 acres (10 percent) have a whole-field subsurface drainage system. As is true with other watersheds in Illinois, field tiles have been identified as potential conduits from agricultural land, to ditches, and then to lakes for some nutrients and pesticides in water. Approximately 80 percent of the watershed land is adequately protected from erosion, which includes 78.2 percent of the cropland area and 97.4 percent of the remaining land use areas (Table 9).

Table 9. Land Use and Unprotected Acreage in the Lake Vermilion Watershed

Type	*Land use*		*Unprotected area*	
	Acres	*Percent of watershed*	*Acres*	*Percent of watershed*
Agricultural				
Cropland	167,833	88.0	36,650	19.2
Pasture and hayland	5,721	3.0	300	0.15
Farmstead/others	1,907	1.0		
Feedlots	75	0.04		
Forest/wildlife	9,728	5.1	300	0.15
Roads/urban development	3,813	2.0		
Water	1,643	0.86		
Total	190,720	100	37,250	19.5

Notes: Blank spaces – not applicable

Source: Tom Benjamin, Vermilion County SWCD, personal communication, 2002

Table 10. Total Erosion Rate and Sediment Yield from Cropland in the Lake Vermilion Watershed

Source, cropland	Area, *acres*	Erosion rate, *tons/acre/year*	Total erosion rate, *tons/year*	Sediment yield, *tons/year*
Highly erodible land	1,500	14.0	21,000	8,400
Potentially highly erodible land	30,000	6.0	180,000	37,800
Other sloping cropland	20,000	4.5	90,000	18,900
Other cropland	50,850	2.5	127,125	26,696
(Sub-total erodible cropland)	(102,350)			
Non-erodible cropland	65,483	0.0		
Total	167,833		418,125	91,796

Note: Blank space – not applicable

Source: Tom Benjamin, Vermilion County Soil and Water Conservation District, personal communication, 2002

Nonpoint Pollution Sources

The primary sources of nonpoint pollution for the watershed are agricultural chemicals and fertilizers from tile drainage and eroded soils. There are no livestock operations in the watershed. A large urban area drains directly to the lake.

Watershed Soil Loss. Table 9 also shows that 19.2 percent (36,650 acres) of land in the watershed is not adequately protected from erosion; most are in cropland. As shown in Table 10, an estimated 1,500 acres of highly erodible soil is used for crop production in the Lake Vermilion watershed. Most of these highly erodible soils are in hayland, pasture, and woodland uses. According to the District Conservationist (T. Benjamin, Vermilion County SWCD, personal communication, 2002), the highly erodible soils in cropland are eroding at an average of 14 tons per acre per year (t/a/y). There are approximately 30,000 acres of potentially highly erodible soils in the watershed where sheet and rill erosion generate approximately 6.0 t/a/y. Another 20,000 acres of cropland erodes at an average of 4.5 t/a/y. The remaining 50,850 acres of cropland erodes at an estimated 2.5 t/a/y. The total erosion rate in the watershed is 418,125 tons per year.

Table 10 also presents the estimated soil erosion rates from different sources from croplands. Assuming a sediment delivery rate of 70 percent off-field movement and 30 percent watershed transport efficiency, the yield factor would be 0.21 for most agricultural except highly erodible land. The sediment yield factor used for highly erodible land is 0.40. For example, for the 20,000-acre category of "Other sloping cropland", the sediment yield is 18,900 (20,000 x 4.5

x 0.70 x 0.30) tons of eroded soils into Lake Vermilion annually. The total sediment yield from cropland in the Lake Vermilion watershed is estimated as about 91,800 tons per year. This estimate was greater than the lake sediment survey result of 76,300 tons/year.

Nutrient Loadings. Nutrient loadings from nonpoint pollution sources within the watershed consist of nitrogen and phosphorus, which result primarily from runoff related to agricultural activities (crop production). Other sources include pasture and hayland, woodland, residential and other development, and atmospheric deposition.

A report by the Macoupin County SWCD (1995) indicated little contribution of plant nutrients from atmospheric deposition. Analytical results from the National Atmospheric Deposition Program (NADP) managed by the Water Survey indicate that atmospheric nitrogen deposition (wet and dry forms) in the watershed may be significant. Nitrogen deposition, like all other sources of nitrogen in the watershed, is subject to plant uptake as well as complex interactions within the soil chemistry system and the atmosphere.

Estimated total nitrogen (the sum of nitrite, nitrate, and total Kjeldahl nitrogen) and total phosphorus loads emanating from nonpoint sources for the entire watershed are shown in Table 11. The annual export rates per unit area for nitrogen and phosphorus were estimated from values provided by the Champaign County SWCD. An estimated 1,480,000 pounds (740 tons) of nitrogen and 86,000 pounds (43 tons) of phosphorus are added to the lake annually from the watershed, of which 99 percent of both nitrogen and phosphorus were contributed by agricultural activities.

Table 11. Estimated Nonpoint Nutrient Loading Rates

		Total nitrogen		*Total phosphorus*	
Land use	*Acres*	*Export rate, Lb/a/y**	*Loading rate, lb/y*	*Export rate, Lb/a/y**	*Loading rate, lb/y*
Cropland and feedlots	167,833	8.6	1,440,000	0.50	83,900
Pasture and hayland	5,721	3.2	18,000	0.25	1,430
Woodland	9,728	1.3	13,000	0.10	970
Resident and farmstead	1,982	1.2	2,400	0.10	200
Roads and developments	3,813	0	0	0	0
Water	1643	0	0	0	0
Total	190,720		1,480,000		86,000

Note: lb/a/y - pounds per acre per year
Blank space – not applicable

Sources: Tom Benjamin, Vermilion County Soil and Water Conservation District, personal communication, 2002
* Champaign County Soil and Water Conservation District

Past and Current Watershed Protection/Restoration Activities

North Fork River Drainage Project

In 1988 an agreement was reached between the Vermilion County SWCD, Vermilion County, and the Division of Water Resources of Illinois Department of Transportation(now the Office of Water Resources in the DNR), to develop and implement the North Fork River Drainage Project.

The agreement involved the 39 miles of the North Fork River and its two tributaries, Jordan Creek and Miller Branch, which added an additional 26 miles of waterway. Total drainage in the North Fork Special Service Area (NFSSA) in Vermilion County is approximately 117,000 acres.

The primary objectives of the Project are to:

1. Improve agricultural drainage,
2. Provide improved outlets of agricultural tile on urban storm water outlets,
3. Reduce flooding
4. Stabilize eroding stream banks,
5. Stabilize stream flows,
6. Reduce erosion and sedimentation, and
7. Keep the waterway free of dumped refuse, dead animals, and toxic wastes.

The NFSSA Committee is the governing body of the North Fork Vermilion River Drainage Project. The Committee consists of a nine-member Board, appointed by the Vermilion County Board, with a 3-year term. The field and administrative work for NFSSA is the responsibility of the Executive Director, Park Allison.

Revenue for the NFSSA is acquired through special taxation on land that drains into the North Fork River and its tributaries; not to exceed $60,000 annually. Maximum rate is 0.108/$100 valuation in rural areas and 0.065/$100 valuation urban. Current rate (December 2000) is $0.0698, $0.0498, and $0.0391 per $100 valuation for rural, urban, and Rossville, respectively. The NFSSA budget for 2001 was $55,000 (P. Allison, personal communication, 2001).

In the fiscal year 1996-1997, in order to implement a nutrient and/or pest management program to decrease the risk of contamination to water resources, 30 farms were selected to implement an Integrated Crop Management (ICM) plan. Vermilion County SWCD provided technical and financial assistance to users to implement conservation practices in the watershed. By 1998, the project completed 20 acres of buffer strips, 3,000 acres of no-till, 35 acres of water ways, 8,000 feet of terraces, 8 grade stabilization structures, 8 WASCOB's, 25 acres of tree planting, 15 acres of wildlife habitat, and 25 acres of timber stand improvement.

The Lake Vermilion Water Quality Coalition

The Lake Vermilion Water Quality Coalition (Coalition) was organized to promote high quality of drinking water by reducing nitrate and sediment loading in the North Fork of the Vermilion River and in Lake Vermilion. The other goal is to improve working relationship with producers in the North Fork River watershed. The Coalition stresses the ideal that everyone lives on the watershed, and everyone is responsible for cleaner water. Ninety percent of farm owners and operators in the watershed are aware of financial and technical assistance available for improving water quality.

During the period of March 1, 1999 to February 28, 2002, work conducted by the Coalition included reducing nitrate and sediment loadings, habitat restoration, and information and education. Nutrient management plans were developed and implemented on 45,000 acres by 2002.

In order to meet or exceed state and federal erosion control guidelines, the use and installation of Best Management Practices have been increased. Ninety-eight percent of the land in the watershed is eroding at less than the tolerable amount and meets the standards of the "T by 2000" program in 2001.

For habitat restoration, funding from NRCS and Illinois DNR were utilized to improve the quality and therefore the function of habitat by restoring native grass areas and improving forest stands, thereby improving water quality.

The Coalition conducted educational programs for community members of all ages. Educational programs include such topics as economic, legal, and environmental impacts of Best Management Practices, health hazards, and basic watershed concepts. An ongoing education program will be provided to citizens throughout the watershed, which will enhance adoption of practices improving water quality. Educational programs increase public awareness of soil, water, and natural resources within the watershed for preservation and protection.

North Fork Vermilion River Habitat Enhancement Project

The Illinois Department of Natural Resources is initiating a pilot habitat enhancement program to serve as an example of ecosystem management. This program is built upon a foundation of voluntary participation and the availability of incentives for program participants. The target area for this project is located in the North Fork River watershed within the Vermilion River basin in Vermilion County, Illinois. The approximately 135,000 acre area is part of the Resource Rich Areas identified through the IDNR's Critical Trends Assessment Project (CTAP). Four focus areas within this watershed have been identified. These focus areas were chosen based on existing vegetation conditions, ownership patterns, and the potential to address natural resource concerns and meet specific natural resource goals.

The purpose of this pilot project is twofold:

1. To protect, increase, and enhance the amount of wildland habitat in four categories (grasslands, forests, wetlands, and vegetation along stream corridors) and

2. To develop an ecological planning process that could be used at any level of landscape planning to target specific natural resource issues.

Through the analysis of current and historical resource conditions, existing management practices and land use, the IDNR has developed future vegetation goals and program objectives. Technical and financial resources of the agency will be utilized to achieve program goals and objectives. The goals of this project are to:

1. Reduce habitat fragmentation,
2. Improve and protect water quality by reducing sedimentation and nitrates,
3. Maintain/improve stability of stream systems, and
4. Create core areas for forest and grassland dependent species.

The objectives of the project are to:

1. Establish permanent easements within focus areas.
2. Protect existing habitat,
3. Create a minimum of 500 acres blocks of contiguous forest,
4. Create a minimum of 80 acre blocks of contiguous grass, and
5. Establish grass or tree cover within a 300 foot zone along both sides of streams.

For the future implementation, the IDNR working with the Vermilion County SWCD will provide funding and technical assistance to landowners/operators willing to participate in the project. Financial incentives will be provided to create permanent easements and to assist landowners in establishing conservation practices that will meet the goals and objectives of this project. Future monitoring and assessments will provide IDNR and other conservation organizations valuable information on the development and implementation of programs that have positive influences on the State's flora and fauna.

BASELINE LIMNOLOGICAL DATA

In order to evaluate the lake water quality, both historical and current limnological data were gathered. A sampling program was developed to collect data from the lake and its main tributary for 13 consecutive months, May 2000 – April 2001. These data are referred to as the current baseline data. In situ monitoring and water and sediment sample collections were carried out. In addition, monitoring for macrophytes, a bathymetric survey, lakeshore erosion evaluation, and flow determinations were carried out as required. The historical data were obtained from the Illinois EPA (STORET), other agencies, and publications.

Morphometric Data

The pertinent morphometric details for Lake Vermilion listed below were obtained from a 1999 survey conducted by ISWS. Calculations were based on a spillway elevation of 582.2 feet NGVD.

Item	*English units*	*System International units*
Surface area	878 acres	355 hectares
Watershed area	190,720 acres	77,184 hectares
Maximum depth	21.8 feet	6.6 meters
Average depth	9.1 feet	2.8 meters
Shoreline length	14.3 miles	26.5 km

Normal pool elevation	582.2 feet	177.5 m
Storage capacity	7,971 ac-ft	9,832,000 cubic meters
Retention time	0.042 years	or 15.3 days

Materials and Methods

Field Measurements

In order to assess the current conditions of the lake, physical, chemical, and biological characteristics were monitored from May 8, 2000 through April 19, 2001. The lake was monitored twice a month from April to October and monthly from November to March. No samples were collected in December 2000 and February 2001 due to ice cover. During these sampling trips, the lake water samples were collected at three sites noted as sites 1 (lower lake, deepest water depth), 2 (mid lake), and 5 (upper lake, shallow water) in Figure 2. Sites 1 and 2 correspond to sites that have been sampled previously. Site 5 was located for this study to serve as the sampling site for the upstream end of the lake. Previously, samples had been collected at site 3 and site 4 (Figure 2). Site 3 was located in the upper reaches of the lake at the pre-1992 pool level. Site 4 was located upstream of the fill from the 1914 dam. A total of 15 sampling trips were made for Stations 1S (surface), 2S, 5S, and 1B (bottom).

In addition, tributary water samples were collected during or after storm events at the North Fork River at Bismark (RBD-02) and from the spillway outflow below the dam (RBD-01).

Thirty-seven samples were taken at the Bismark site (inflow) and 13 samples at the spillway site (outflow).

For the regular lake water quality analyses, grab water samples were taken at 0.3 meter (1 foot) below the surface as a surface sample and 0.6 m (2 feet) above the lake bottom for Station 1 as near bottom samples. However, for metals and organic analyses, grab water samples were taken at the mid-depth of Station 1, which is considered to be more representative for the water column. Only surface samples were taken for Stations 2 and 5 during the study period. Lake sediment samples also were collected once at Stations 1, 2, and 5 during this study period (Figure 2). Historical data were collected at Station 3 instead of Station 5.

CIWC employees and Illinois EPA personnel collected water and sediment samples for the baseline and historic database. All water and sediment chemistry analyses were completed by IEPA laboratories.

For most sampling runs, in situ observations for temperature, dissolved oxygen (DO), and Secchi disc readings were made at the sampling sites on the lake. A DO meter with a 50-foot cable and probe was calibrated at the site using the saturated air chamber standardization procedure. Temperature and DO measurements were obtained in the water column at 0.3-m (1 foot) or 0.6-m (2 feet) intervals from the surface.

Secchi disc visibility is a measure of a lake's water transparency, or its ability to allow sunlight penetration. Secchi disc transparencies were measured using an 8-inch diameter Secchi disc, which was lowered until it disappeared from view, and the depth was noted. The disc was lowered further, then slowly raised until it reappeared. This depth also was noted, and the average of the two depths was recorded.

Water Chemistry

Grab samples for water chemistry analyses were collected near the surface (1 foot below), near the bottom (2 feet above the lake bottom if the water depth was greater than 10 feet), and at mid-depth for Station 1 in two 500-milliliter (mL) plastic containers. Water samples for nutrient analyses were collected in 125-mL plastic bottles with and without filtration (0.45-micrometer or µm, membrane filter) that contained reagent-grade sulfuric acid as a preservative. These samples were kept on ice until transferred to the laboratory for analyses. Samples for metals (unfiltered) were collected in 500-mL plastic bottles containing reagent-grade nitric acid as a preservative. Samples for organic analyses were collected in 1-gallon dark amber bottles filled to the brim without any headspace. The methods and procedures involved in the analytical determinations followed Illinois EPA methods.

Chlorophyll

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 0.6 m (2 feet) above the bottom of the lake, and raised at a constant rate to the surface. This sampling approximates the limits of light penetration in the water column. For chlorophyll analysis, a measured amount of sample was filtered through a Whatman GF/C filter (4.7-cm, glass microfiber filter) using a laboratory vacuum system. The chlorophyll filters then were folded into quadrants and wrapped in aluminum foil. The filtrate volume was measured using a graduated cylinder. Filters were kept frozen in the laboratory until analyzed. Chlorophyll concentrations were analyzed by the Illinois EPA.

Macrophytes

A macrophyte survey was conducted on September 6, 2000, by Illinois EPA field staff. The entire perimeter of the lake was surveyed by moving a boat along the shoreline and macrophyte communities. Visible macrophyte areas were sketched onto the lake map with indication of the size and density of each macrophyte zone. Macrophytes were identified by common name as accurately as possible. If growth of an unidentified species was present, a specimen was collected to identify at the field office. The survey enabled the delineation of the areal extent and abundance of macrophytes in the lake.

While surveying the lake perimeter, the amount of each type of major shoreline development/land use also was noted. Land-use categories included, but were not limited to, woodland, pasture, residential, shrub/brush, golf course, picnic/camping, grass bordered crop, wetland, highway/dam, and industries.

Sediment

Surficial sediment samples were collected using an epoxy-coated Ekman dredge. Portions of each sample were placed in a 250-mL plastic bottle for metal and nutrient analyses and in a specially prepared 200-mL glass bottle for trace organics analyses according to the Illinois EPA guidelines (1987).

Data Analyses

Historical water quality data has been obtained from the Illinois EPA's Ambient Lake Monitoring Program (ALMP) and Volunteer Lake Monitoring Program (VLMP). The ALMP of Lake Vermilion began in 1977 (1 sample) and continued in 1979 (2 samples), 1983 (1 sample), and 1997 (5 samples). All data prior to the 2000-2001 study period shall be considered historical data.

Current water quality monitoring commenced on May 8, 2000 and continued through April 19, 2001. During the one-year sampling period, water and sediment quality samples were collected in order to establish a baseline for current conditions in Lake Vermilion.

For both the historical and baseline datasets, the water samples were collected either by Illinois EPA personnel or by the Consumers Illinois Water Company. All samples were collected using water sample collection protocols established by the Illinois EPA. Sampling frequencies for the current study were either monthly or bi-weekly. Historical samples were collected at irregular intervals from April through October for 6 years (Appendix A).

The analytical results of historical samples and baseline water samples (current study) from five sampling stations in Lake Vermilion are listed in Appendices A and B, respectively. Water quality data provided include turbidity, Secchi disc transparency, conductivity, pH, total and phenolphthalein alkalinity, total and volatile suspended solids, nitrogen (ammonia, nitrate-nitrite, and total Kjeldahl), and total and dissolved phosphorus. Sampling dates and site depths also are given. During the current study, five samples were collected from mid-depth at Station 1 for metal, organics, and other water quality analyses. The results for several water quality characteristics are listed in Appendix B but are not discussed in the text.

For the data in Appendices A and B, a "k" indicates that the actual value is not known, but is known to be less than the value shown. The value shown is the reporting limit (i.e. practical quantitative limit). For the purpose of evaluating the parameters examined, to determine whether a water quality standard has been violated, the detection limit values were substituted for calculations in the statistical analyses. It should be noted that the statistical results (means) should be higher than the results using the actual values.

The observed data for each station are divided into two groups: historical and baseline (current study) data. The mean values of historical and baseline water quality data for each station are summarized in Table 12. Because of the different sampling frequency and different number of samples, the statistical analysis of the difference of means for the historical and baseline study was not performed by the Student "t" test. However, "rank-sum" tests were performed for the difference in distributions between the historical and baseline datasets. The Mann-Whitney rank-sum tests were performed by Professor Gary C. Lin, of Bradley University, Peoria, Illinois. The rank sum test is a nonparametric statistic that compares distributions without specifying the form of the distributions. The results of the statistical analyses for Stations 1S, 1B and 2S are presented in Table 13 and are discussed in the following sections.

In-Lake Water Quality

Physical Characteristics

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

The temperature of a deep lake in the temperate zone is about 4°C during early spring. As air temperatures rise, the upper layers of water warm up and are mixed with the lower layers by wind action. Spring turnover is a complete mixing of a lake when the water temperature is uniform from top to bottom. By late spring, differences in thermal resistance cause the mixing to cease, and the lake approaches the thermal stratification of the summer season. Almost as important as water temperature variations is the physical phenomenon of increasing density with decreasing temperature. These two interrelated forces are capable of creating strata of water of vastly different characteristics within the lake.

Table 12. Mean Values of Water Quality Characteristics for Current Study and Historical Data

	Station 1 surface		*Station 1 Bottom*		Station 2 surface		*Station 5 surface*	
	Hist.	*Current*	*Hist.*	*Current*	*Hist.*	*Current*	*Hist.*	*Current*
Turbidity, NTU	12.4	75.8	14.6	73.6	14.0	14.2	19.5	30.4
Secchi transparency, in	17.7	22			15.5	17	10	14
Conductivity, μmho/cm	520	486	531	491	511	522	550	550
Alkalinity, mg/L as $CaCO_3$								
Total	176	177	191	181	170	179	200	234
Phenolphthalein	3	1	3	0	3	1	4	1
Total suspended solids, mg/L	17	15	23	22	35	17	57	24
Volatile suspended solids, mg/L	5	5	5	5	9	5	9	6
Ammonia nitrogen, mg/L	0.14	0.10	0.21	0.15	0.12	0.06	0.13	0.03
Total kjeldahl nitrogen, mg/L	0.87	1.04	0.79	1.23	1.08	0.99	1.08	0.90
Nitrate/nitrite nitrogen, mg/L	5.28	5.38	5.53	5.16	5.12	5.21	3.92	7.27
Total phosphorus, mg/L	0.077	0.060	0.082	0.062	0.115	0.054	0.163	0.068
Dissolved phosphorus, mg/L	0.035	0.027	0.034	0.027	0.031	0.024	0.044	0.041
Chlorophyll, μg/L	50.70	31.39			36.17	37.85	24.38	25.40
Total depth, feet	17.3	20	19	20	10.5	10.5	4.1	5.8

Notes: Hist. – historical, NTU – nephelometric turbidity unit, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate, Blank space – not applicable or no data

Table 13. Analyses of Rank-Sum Tests at a 95 Percent Confidence Level for Distributions of the Current Study versus Historical Data

Parameter	*Station 1 Surface*	*Station 1 Bottom*	*Station 2 Surface*
Turbidity, NTU	=	=	=
Secchi transparency, inches	=	=	=
Total Alkalinity, mg/L as $CaCO_3$	=	=	=
Suspended solids, mg/L			
Total	=	=	=
Volatile	=	=	=
Nitrogen, mg/L			
Ammonia	=	=	↓
Total Kjeldahl	↑	↑	=
Nitrate/nitrite	=	=	=
Phosphorus, mg/L			
Total	=	=	=
Dissolved	=	=	=
Chlorophyll *a*	↓		=

Notes: ↑ - indicates the current distribution is greater than historical distribution
↓ - indicates the current distribution is less than historical distribution
= indicates no significant difference between the two distributions
NTU - nephelometric turbidity unit
Blank space – not applicable

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

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

Declining air temperatures and the formation of ice cover during the winter produce a slightly inverse thermal stratification. The water column is essentially uniform in temperature at about 3-4°C, but slightly colder temperatures of 0-2°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 again becomes uniform in temperature, and spring circulation occurs (spring turnover).

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 for aquatic plants. In a eutrophic lake, the hypolimnion becomes anaerobic, or devoid of oxygen, because of the increased concentration of highly oxidizable material, isolation from atmospheric oxygen, and limited photosynthetic conditions due to limited light penetration. Conditions of low DO are favorable for chemical reduction and more nutrients and minerals such as manganese and sulfur 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 portions of the nutrients that were trapped during the stagnation period become oxidated and precipitate. Therefore, a continuous supply of plant nutrients from the drainage basin is not necessary for sustained aquatic plant production. After an initial stimulus, the recycling of nutrients within a lake might be sufficient to sustain highly productive conditions for several years.

DO is necessary for respiration by aquatic life. Thus adequate DO concentrations are necessary to maintain healthy conditions in the lake. Sources of oxygen include inflows (such as tributaries), precipitation; exchange with the atmosphere; and photosynthetic activities by phytoplankton and other aquatic plants. DO can be reduced or consumed by outflow (such as spillway overflow and withdrawal from the lake), respiration of fish and other aquatic organisms, decomposition of dead plants and animals, and by sediment oxygen demand.

The temperature and dissolved oxygen concentration data for Lake Vermilion at Station 1 are shown, respectively, in Figures 3 and 4. Temperature and DO conditions for the lower basin of the lake did not stabilize during the summer. In consequence, it was not possible to plot iso-lines for any of the lake stations. Lake Vermilion had a maximum water depth of about 21 feet at Station 1 (mostly 19-20 feet) during the study year. Most water depths during the one-year study at Station 2 were in the range of 10 to 11 feet; and 5-6 feet at Station 5 (Appendices B1 and B2).

For each sampling date, water temperatures were nearly uniform from surface to bottom at all three sampling Stations (Figure 3, Appendix C). The maximum temperature difference at Station 1 from surface to bottom was 3.0°C on May 29, 2001 (21.0 -18.0°C) and on October 24, 2000 (18.0 – 15.0°C). There was no significant thermal stratification observed at Station 1. In Mid-western lakes, with water depths greater than 10 feet, the lakes typically exhibit thermal stratification during summer months. The lack of thermal stratification in Lake Vermilion might be due to short retention time in the lake (15 days) combined with regular rainfall during the monitoring period. Another factor may be the constant flow of water through the spillway at the 6 to 10 foot depth, which may disrupt the formation of a thermocline except during prolonged low flow periods. There is no destratifier installed in the lake.

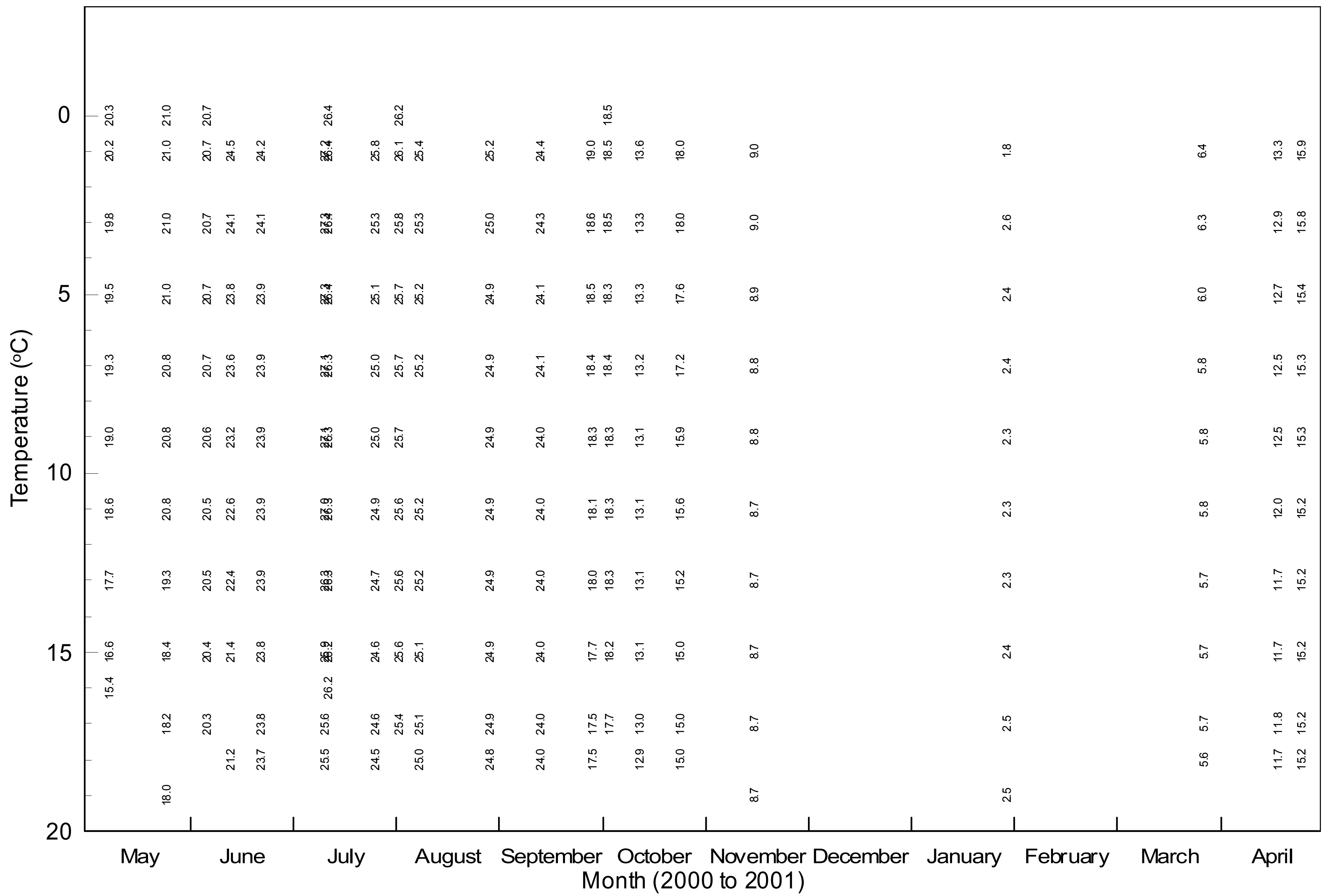


Figure 3. Isothermal plot for Lake Vermilion station 1

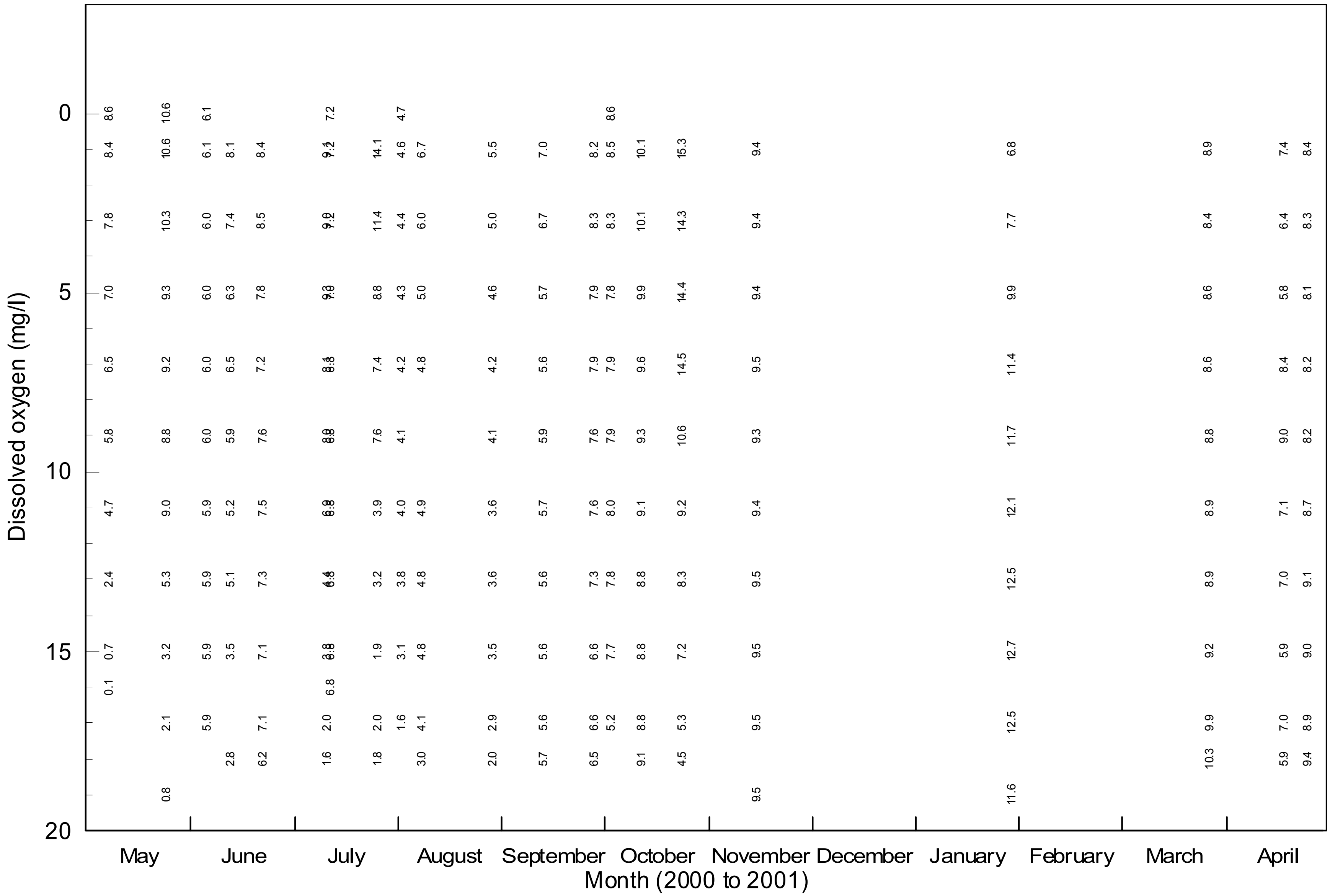


Figure 4. Isodissolved oxygen plot for Lake Vermilion station 1

An examination of the isodissolved oxygen profiles at Station 1 (Figure 4), shows that the DO levels began to decrease in the bottom waters in late May 2000. Moderate DO stratification was observed on May 25, July 11, July 26, August 28, and 29, and October 24, 2000 (Appendices C). However, on October 24, 2000, DO concentrations were very high (14 mg/L) in the top 10 feet and less than 5.0 mg/L only near the bottom below 18 feet. By comparison with precipitation records from Table 2, the formation of moderate DO stratifications generally occurred after several days of dry weather (without rainfall).

Generally water temperature and DO levels at Stations 2 and 5 were uniform in the water column (Appendix C). Maximum temperature gradient observed at Station 2 was 2.8°C on October 24, 2000. Moderate DO stratification at Station 2 occurred on July 27 and October 24, 2000, but with low DO of 5.4 mg/L (Appendix C). These were due to super-saturation (DO concentration exceeds calculated saturation values) in the top 3-5 feet. Oxygen depletion occurred at depths below 10-12 feet from the surface. However, most DO levels in the water column at Station 2 were above 5.0 mg/L, (Appendix C).

Station 5, which is relatively shallow (5-6 feet), exhibited minimal temperature gradient and very good oxygen conditions, except September 13, 2000. DO at the surface ranged from 4.8 mg/L on September 13, 2000 to 16.8 mg/L on October 24, 2000 (Appendix C).

Percent DO saturation values were determined from the observed DO and temperature records. Saturation DO values were computed using the formula (Committee on Sanitary Engineering Research, 1960):

$$DO = 14.652 - 0.410022T + 0.0079910T^2 - 0.000077774T^3$$

where

DO = the saturation dissolved oxygen, mg/L

T = water temperature, °C

The computed DO percent saturation values in Lake Vermilion at Stations 1, 2, and 5 also are included in Appendix C. The highest percent saturation values observed during the current study at Stations 1, 2, and 5 were, respectively, 175, 181, and 182. These highest values occurred on July 26, 2000 and October 24, 2000. Super-saturation of DO at Stations 2 and 5 also occurred on July 11, July 12, August 8, September 28, October 3, October 12, 2000 and January 29, 2001. In May 2000, DO saturation was less than 10 percent for the readings nearest the lake bottom. All other readings were near 20 percent or higher.

Turbidity. Turbidity is an expression of the property of water that causes light to be scattered and absorbed. As measured by a turbidimeter; it is expressed as nephelometric turbidity units (NTU). Turbidity in water is caused by colloidal and suspended matter, such as silt, clay, finely divided inorganic and organic materials, soluble colored organic compounds, plankton, and by other microorganisms. Generally, turbidity in lake waters is influenced by sediment in runoff from a lake's watershed or shoreline erosion, algae in the water column, resuspension of lake bottom sediments by wind wave action, bottom-feeding fish, power boats, etc. Elevated turbidity values make the appearance of a lake less pleasing aesthetically.

For the historical records (1977-1997, warm weather samples) used in this study, the ranges of turbidity at Stations 1S (S, surface), 2S, 3S, and 1B (B, bottom) were, respectively, 5.2-20.0, 3.6-32.0, 8.0-37.0, and 7.4-24.0 NTU. The maximum turbidity for all Stations was observed on different dates. The means and standard deviations of turbidity at these Stations were, respectively, 12.4 ± 6.0, 14.0 ± 9.2, 19.5 ± 9.7, and 14.6 ± 6.2 NTU (Appendices A1-A4). It should be noted that the mean turbidity at each station is not the same as the annual average value.

Turbidity was determined for one or two current water samples. The average turbidity for Stations 1S, 2S, 5S, and 1B were 11.5, 14.2, 30.4, and 40.5 NTU, respectively (Appendix B1-B4). A high turbidity (76.8 NTU) was found at Station 1B on October 3, 2000. This might be due to sampling or laboratory error.

Secchi Disc Transparency. Secchi disc visibility is another measure of the lake's water transparency, which estimates the depth of light penetration into a body of water (its ability to allow sunlight penetration). Even though the Secchi disc transparency is not an actual quantitative indication of light transmission, it provides an index for comparing similar bodies of water or the same body of water at different times. Because changes in water color and turbidity in deep lakes are generally caused by aquatic flora and fauna, transparency is related to these entities. The euphotic zone or region of a lake in which enough sunlight penetrates to allow photosynthetic production of oxygen by algae and aquatic plants is estimated as two to three times the Secchi disc depth (USEPA, 1980).

Suspended algae, microscopic aquatic animals, suspended matter (silt, clay, and organic matter), and water color are factors that interfere with light penetration into the water column and reduce Secchi disc transparency. Combined with other field observations, Secchi disc readings may furnish information on suitable habitat for fish and other aquatic life, the lake's water quality and aesthetics, the state of the lake's nutrient enrichment, and problems and potential solutions for the lake's water quality and recreational use impairment.

Mean values of Secchi disc transparency at Stations 1, 2, and 5 were 20.6, 17.1, and 17.6 inches, respectively (Appendices B1-B3). The ranges were, respectively, 8-42, 8-42, and 8-60 inches. The lowest transparency was observed on June 6, 2000 at stations 1 and 2 (Appendices B1- B3). Station 1 had the higher average Secchi disc transparency. Lowest Secchi disc transparency generally occurred at Station 5 due to shallower water depths. However, the winter period transparency at Station 5 was the highest for any station during the monitoring year.

The overall historical mean transparency for Stations 1, 2, and 3 were, respectively, 17.7, 15.5, and 10 inches (Appendices A1-A3). The ranges for these three Stations were 10-24, 6-26, and 6-16 inches, respectively (Appendices A1-A3). The summer season distribution of transparency for historical data at each Station 1S and 2S was found to be similar to that for the current study (Table 13).

The Illinois EPA's Lake Assessment Criteria (IEPA, 1978) state that Secchi depth values less than 18 inches indicate substantial lake-use impairment, and that depths between 18 and 48 inches indicate moderate lake-use impairment. The Illinois Department of Public Health has adopted the minimum Secchi transparency for bathing beaches of 48 inches, which was set by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers (1975). Nevertheless, a lake that does not meet the transparency criteria does not necessarily constitute a public health hazard, if it is not used for swimming. On the basis of these criteria, during this study, Stations 2 and 3 were classified as substantial use-impairment; Station 1 was considered as moderate use impairment.

Chemical Characteristics

pH. The pH value, or hydrogen ion concentration, is a measurement of the acidity or alkaline characteristics in water. It is measured on a scale of 0-14. A pH of 7.0 is exactly neutral and ideal for water conditions. Values below 7.0 indicate acidic water, and values above 7.0 indicate basic (or alkaline) water. The pH values are influenced by the concentration of carbonate in the water. One species of carbonate, carbonic acid, which forms as a result of dissolved carbon dioxide, usually controls pH to a great extent. Carbonic acid also is consumed by the photosynthetic activity of algae and other aquatic plants after the free carbon dioxide in water has been used up. A rise in pH can occur due to photosynthetic uptake of carbonic acid, causing water to become more basic. Decomposition and respiration of biota tend to reduce pH and increase bicarbonates.

The pH directly affects the amount of unionized ammonia in water. An increase in pH values above 7.0 combined with high water temperatures will result in higher levels of unionized ammonia which can stress or be deadly (pH>10) to fish. Shifts in pH levels can be attributed to a number of external processes such as agricultural practices and atmospheric sources as well as internal processes.

In general, pH values above 8.0 in surface waters are considered to be produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition (Mackenthun, 1969). Although rainwater in Illinois is acidic (pH about 4.4), most of the lakes can offset this acidic input by an abundance of natural buffering compounds in the lake water and the watershed. Most Illinois lakes have a pH between 6.5 and 9.0. The Illinois Pollution Control Board or IPCB (IEPA, 2002) general-use water quality standard for pH also ranges from 6.5-9.0, except for natural causes.

During the current study, the ranges of pH values for Stations 1S, 2S, 5S, and 1B were 7.5-8.2, 7.8-8.3, 7.8-8.3, and 7.5-8.0 (Appendices B1-B4).

In Appendices A1-A4 (historical data), the pH values ranged from 7.5-8.5, 7.4-8.6, 7.3-8.6, respectively, for the three surface water sites (1S, 2S, 3S) and from 6.5-8.7 in the bottom waters of Station 1. High pH values of the surface waters occurred on October 22, 1997 at all stations. The pH values for historical and current studies at all stations fell within the range of Illinois standards, 6.5-9.0.

Alkalinity. The alkalinity of water is its capacity to accept protons. It is generally imparted from the bicarbonate, carbonate, and hydroxide components in the water. The source 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.

Alkalinity is a measure of the water's acid-neutralizing capacity. It is expressed in terms of an equivalent amount of calcium carbonate ($CaCO_3$). Total alkalinity is defined as the amount of acid required to bring water to a pH of 4.5, and phenolphthalein alkalinity is measured by the amount of acid needed to bring water to a pH of 8.3 (APHA et al., 1998).

Lakes with low alkalinity are, or have the potential to be, susceptible to acid rain damage. However, Midwest lakes usually have a high alkalinity and thus are well buffered from the impacts of acid rain. Natural waters generally have a total alkalinity between 20 and 200 mg/L (APHA et al., 1998).

Total Alkalinity. During this study, the range of total alkalinity for the lake waters at Stations 1S, 2S, 5S, and 1B were 140-200, 170-185, 220-250, and 140-200, respectively; their means were, respectively, 177, 179, 234, and 181 mg/L as $CaCO_3$ (Appendices B1-B4). Total alkalinity at Stations 1S, 2S, and 1B are similar.

Historical data on total alkalinity at Stations 1S, 2S, 3S, and 1B, ranged from 154-210, 110-210, 125-280, and 164-230 mg/L as $CaCO_3$, and the means for these Stations were 176, 170, 200, and 191 mg/L as $CaCO_3$, respectively (Appendices A1-A4, Table12). Total alkalinity (historical data) at Stations 1S and 2S were similar in values.

As shown in Table 13, the distribution of lake water total alkalinity in the current study was not significantly different from the past.

Phenolphthalein Alkalinity. Phenolphthalein alkalinity conditions (pH over 8.3) were found in the lake waters only during warm weather periods. The current phenolphthalein alkalinity concentrations never exceeded 5 mg/L as $CaCO_3$ (Appendices B). Historical data show peak phenolphthalein alkalinity at Stations 1S, 2S, 3S, and 1B were respectively 10, 16, 10, and 10 mg/L as $CaCO_3$ (Appendices A1 and A4).

Conductivity. Specific conductance provides a measure of the water's capacity to convey electric current and represents a measure of the dissolved mineral quality (salinity) of water. This property is related to the total concentration of ionized substances in water and the temperature at which the measurement is made. An electrical conductivity meter is used to determine salt content in water and the value is recorded in micromhos per centimeter (μmho/cm). 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 soils in the drainage basin is the major determining factor in the chemical constituents in the waters. The higher the conductivity reading, the higher the concentration of dissolved minerals in the lake water. Practical applications of conductivity measurements include determination of the purity of distilled or de-ionized water, quick determination of the variations in dissolved mineral concentrations in water samples, and estimation of dissolved ionic matter in water samples.

High soil salinity interferes with plant water uptake resulting in reduced plant growth and germination. In excessive amounts (>1,000 micromhos per centimeter, µmho/cm), salts running off into nearby water can become toxic to freshwater plants and fish. Animal wastes as well as some agricultural products may have a high salt content and can be a problem when over-applied to the land.

Conductivity in Lake Vermilion during the current study ranged from 451 µmho/cm at Station 2S on October 3, 2000, to 655 µmho/cm at Station 3S on June 6, 2000 (Appendices B1-B4). The mean conductivity values for lake waters at stations 1S, 2S, 5S, and 1B were, respectively, 486, 522, 550, and 491 µmho/cm. These values are higher than typical of Illinois lake waters (Lin et al., 1996, 1999). The Illinois General Use Water Quality Standards for total dissolved solids is 1,000 mg/L (IEPA, 2002), which is approximately equivalent to a conductivity of 1,700 µmho/cm. The observed conductivity values did not exceed this criterion.

An examination of the historical conductivity data (Appendices A1-A4) for Lake Vermilion shows that conductivity varies by over 125 units within an annual period. In 1997, the conductivity ranged from 437 to 565 µmho/cm. Mean conductivity values for the historical data at stations 1S, 2S, 3S, and 1B were 520, 511, 550, and 531 µmho/cm, respectively.

The conductivity data for the 2000 summer season also show a wide range of values, from 456 to 544 µmho/cm. The rank-sum comparison of the current and historical data for conductivity for Station 1S, 1B, and 2S, indicates no significant change with time (Table 13).

Total Suspended Solids. Total suspended solids (TSS) are the portions of total solids retained by a filter ≤ 2.0 µm nominal pore size. Total solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at 103-105°C. Total solids include TSS and total dissolved solids, the portion that passes through the filter (APHA et al., 1998). Nonvolatile suspended solids (NVSS) are the inorganic portion of TSS. Volatile suspended solids (VSS) are the organic portion of TSS. NVSS and VSS are determined by heating TSS at 500°C, the material remaining after heating is the NVSS and the material lost during heating is the VSS.

Total suspended solids represent the amount of all inorganic and organic materials suspended in the water column. Typical NVSS originate from the weathering and erosion of rocks and soils in a lake's watershed and from resuspension of lake sediments. VSS are derived from a variety of biological origins, but in a lacustrine environment they mainly are composed of algae and resuspended plant and animal material from the lake bottom.

Generally, the higher the TSS concentration, the lower the Secchi disc reading. A high TSS concentration results in decreased water transparency. High TSS can reduce photosynthetic activities below a given depth in the lake and subsequently decrease the amount of oxygen produced by algae and increase the potential to develop anoxic conditions. Anaerobic water may limit fish habitat and potentially cause taste and odor problems by releasing noxious substances such as hydrogen sulfide, ammonia, iron, and manganese from the lake bottom sediments. A high concentration of TSS also may cause aesthetic problems in the lake.

The amount of suspended solids found in impounded waters is smaller compared with the amount found in streams because solids tend to settle to the bottom in lakes. However, in shallow lakes, this aspect is greatly modified by wind and wave actions and by the type and intensity of uses to which these lakes are subjected.

Referring to Appendices A1-A4 for the historical data, the mean TSS values at stations 1S, 2S, 3S, and 1B were, respectively, 17, 35, 57, and 23 mg/L. In comparison, the historical TSS values for station 3S were higher than historical values for other three stations. TSS concentrations decrease as the water flows through the lake. The range of the historical TSS values for all stations was between 8 mg/L (at Station 1S on June 28, 1979) and 97 mg/L (at Station 3S on July 2, 1977).

As shown in Appendices B1-B4, during this study, the highest TSS concentration (64 mg/L) occurred on June 22, 2000 at station 5S, because a storm (1.3 inches of rainfall) occurred on June 21, 2000 (Table 2). The mean TSS at stations 1S, 2S, 5S, and 1B were 15, 17, 24, and 22 mg/L, respectively (Table 12). Their ranges were, respectively, 2-35, 2-44, 4-64, and 2-46 mg/L. As expected, higher TSS values were found in the surface waters at Station 5. TSS distribution for the current study for Stations 1S, 1B, and 2S was not different from that for the historical data (Table 13).

On the basis of the Illinois Lake Assessment Criteria (IEPA, 1978), water with TSS > 25 mg/L is classified as having a high lake-use impairment; TSS between 15 and 25 mg/L indicates moderate-use impairment; TSS < 15 mg/L is considered to have minimal impairment. In this study, the number of samples that exceeded TSS levels of 25 mg/L was 14, 7, 42, and 33 percent of samples at Stations 1S, 2S, 5S, and 1B, respectively. At the same stations, the percent of samples having TSS values between 15 and 25 mg/L were 33, 60, 33, and 47 percent, respectively. On the basis of TSS, waters at Station 1S can be classified as minimal impairment (more than 50 percent of the samples were below 15 mg/L TSS); at Stations 2S, 5S, and 1B might be considered as at least moderately impaired(more than 50 percent of the samples had 15 mg/TSS or higher).

Volatile Suspended Solids. Volatile suspended solids (VSS) are the portions of TSS lost to ignition at 500 $\pm$ 50°C. The VSS represent the organic portion of TSS, such as phytoplankton, zooplankton, other biological organisms, and other suspended organic detritus. Resuspended sediments and other plant and animal matter resuspended from the lake bottom by bottom-feeding fish, wind action, or human activities can be major contributors of VSS and TSS.

The VSS levels in the surface and bottom samples at all four stations ranged from 1 (at Station 5S on March 28, 2001) to 12 mg/L (at Station 2S on May 8, 2000) during the current study. Mean concentrations of VSS were 5, 5, 6, and 5 mg/L at Station 1S, 2S, 5S, and 1B, respectively (Appendices B1-B4).

Appendices A1-A4 show that the historical mean VSS at Stations 1S, 2S, 3S, and 1B were, respectively, 5, 9, 9, and 5 mg/L. Comparing the VSS data, there were no statistical differences in VSS between the historical and Current data for any station (historical versus current data, Table 13).

Nitrogen. Nitrogen is generally found in surface waters in the form of ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and organic nitrogen. Organic nitrogen is determined by subtracting NH_3 nitrogen from the total Kjeldahl nitrogen (TKN) measurements. Organic nitrogen content can indicate the relative abundance of organic matter (algae and other vegetative matter) in water, but it has not been shown to be directly used as a growth nutrient by planktonic algae (Vollenweider, 1968). Total nitrogen is the sum of nitrite, nitrate, and TKN. Nitrogen is an essential nutrient for plant and animal growth, if found in excess it can cause algal blooms in surface waters and create public health problems. The IPCB has stipulated (IEPA, 2002) that nitrate not exceed 10 mg/L nitrate as Nor 1 mg/L nitrite as N for public water-supply and food-processing waters.

Nitrogen is one of the principal elemental constituents of amino acids, peptides, 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.

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 receive discharge from aerobic treatment processes. Nitrates also occur in percolating ground waters. Ammonia-nitrogen, a constituent of the complex nitrogen cycle, results from the decomposition of nitrogenous organic matter. It also can result from municipal and industrial waste discharges to streams and lakes.

The concerns about nitrogen as a contaminant in water bodies are threefold. 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 in excess of 0.3 mg/L as N is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1952). The third concern is the toxicity of unionized ammonia. The IEPA (1999) stipulates that ammonia as N and nitrate plus nitrite as N should not exceed 1.5 and 10.0 mg/L, respectively.

Vollenweider (1968) reports that, in laboratory tests, the two inorganic forms of ammonia and nitrate are, as a general rule, 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 plankton. With higher initial concentrations of ammonium salts, yields were noted to be lower than with equivalent concentrations of nitrates (Vollenweider, 1968). This was attributed to the toxic effects of ammonium salts. The use of nitrogenous organic compounds by algae has been studied by several investigators (Hutchinson, 1957). However, Vollenweider (1968) cautions that the direct use of organic nitrogen by plankton has not been established definitely, citing that not 1 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. Vollenweider (1968) has stated that, in view of the fact 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.

Ammonia-Nitrogen. As shown in Appendices A and B, the minimum ammonia-nitrogen (NH_3-N) concentration was less than 0.01 mg/L for all stations, especially during the current study. A k indicates that the actual value is not known, but known to be less than the value shown. The value shown is the reporting limit (i.e. practical quantitative limit.). The detectable level (0.01 for 0.01k) is used for the statistical analysis purposes. This also is the case for nitrate plus nitrite nitrogen.

An examination of observed data during this study in Appendices B1-B4 suggests that many (31-77 %) samples have NH_3 -N levels less than the detectable limit of 0.01 mg/L. The maximum NH_3-N levels observed, during this study, for Stations 1S, 2S, 5S, and 1B were 0.55, 0.24, 0.14, and 0.64 mg/L, respectively. At the same stations, the mean ammonia concentrations were low, respectively, 0.10, 0.06, 0.03, and 0.15 mg/L (Appendix B).

The Illinois General Use Water Quality Standards (IEPA, 2002) of NH_3-N vary according to water temperature and pH values, with the allowable concentration of NH_3-N decreasing as temperature and pH rise. High water temperatures and pH increase the toxicity of NH_3-N for fish and other aquatic organisms. The allowable concentration of NH_3-N for lake waters varied from 0.68-4.1 mg/L, depending on the available observations of temperature and pH values. The observed data in Lake Vermilion showed that the NH_3-N values are well within the lower limit of the standards.

For historical data, the mean NH_3-N concentrations for Stations 1S, 2S, 3S, and 1B were 0.14, 0.12, 0.13, and 0.21 mg/L, respectively (Appendices A1-A4). In comparison, the distribution of NH_3-N values for Stations 1S and 1B in the current study were no different from that of the historical data. In contrast, NH_3-N values for Station 2S in the current study were significantly less than the historical values (Table 13).

Total Kjeldahl Nitrogen. During this study, the ranges of TKN values at Station 1S, 2S, 5S, and 1B were 0.40-1.68, 0.06-1.51, 0.55-1.39, and 0.75-3.00 mg/L, respectively (Appendices B1-B4). Results in Appendices B1-B4 also show that mean TKN levels and standard deviations at these stations were 1.04 ± 0.33, 0.99 ± 0.36, 0.90 ± 0.26, and 1.23 ± 0.57 mg/L, respectively. All laboratory analyses for TKN in May 2000 or later were not subjected to established quality control criteria and should not be used to make management decisions.

For historical data, TKN ranged from 0.69-1.00, 0.67-2.50, 0.64-2.10, and 0.64-0.97 mg/L at Stations 1S, 2S, 3S, and 1B, respectively (Appendices A1-A4). Mean TKN concentrations and standard deviations for Stations 1S, 2S, 3S, and 1B were, respectively, 0.87 ± 0.11, 1.08 ± 0.67, 1.08 ± 0.51, and 0.79 ± 0.11 mg/L (Table 12, Appendices A1-A4). TKN values distribution at Stations 1S and 1B in this study were higher than that in historical study and no difference at Station 2S (Table 13).

The data for NH_3-N and TKN indicates that total Kjeldahl nitrogen in the water column was predominantly of organic origin (TKN minus NH_3-N). Organic nitrogen constituted approximately 88-97 percent of the total Kjeldahl nitrogen determined for the three surface water samples.

Nitrate/Nitrite-Nitrogen. Wide ranges of NO_3/NO_2-N concentrations were observed at each sampling station both during historical and current studies. During this study, the ranges of NO_3/NO_2 values for Stations 1S, 2S, 5S, and 1B were respectively 025-12.00, 0.17-14.00, 0.04-14.00, and 0.13-22.00 mg/L (Appendix B). The highest NO_3/NO_2-N concentration (14 mg/L) was found at Stations 2S and 5S on June 6, 2000. Mean NO_3/NO_2-N and standard deviations values for the 4 stations were 5.38 ± 4.38, 5.21 ± 4.61, 7.27 ± 4.72, and 5.16 ± 4.17 mg/L, respectively (Appendix B).

As can be seen in Appendices A1-A4, the historical ranges of NO_3/NO_2-N concentrations for Stations 1S, 2S, 3S, and 1B were from 0.12-12.30, 0.01-11.2, 0.01k-11.3, and 0.12-12.00 mg/L, respectively. The mean NO_3/NO_2-N concentrations were respectively 5.28 ± 3.91, 5.12 ± 3.63, 3.92 ± 3.66, and 5.53 ± 4.09 mg/L. The NO_3/NO_2-N values distribution at Stations 1S, 1B, and 2S in this study was no difference from that in historical study (Table 13).

Comparison of the data for nitrate/nitrite-nitrogen (NO_3/NO_2-N) and TKN levels shows that total nitrogen in the water column was predominantly of inorganic origin (NO_3/NO_2-N was higher). This high nitrate levels in the North Fork Vermilion River and in Lake Vermilion are of particular concern to the North Fork Special Service Area.

Phosphorus. The term total phosphorus (TP) represents all forms of phosphorus in water, both in particulate and dissolved forms, including three chemical types: reactive, acid-hydrolyzed, and organic. Dissolved phosphorus (DP) is the soluble form of TP (filterable through a 0.45-µm filter).

Phosphorus as phosphate may occur in surface water or ground water 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, as is true of nitrogen, it passes through cycles of decomposition and photosynthesis.

Phosphorus is one of the essential nutrients to the plant growth process. In many natural systems, phosphorus being singled out as probably the most limiting nutrient and the one most easily controlled by removal techniques. Because of this, it has received much attention in the study of eutrophication issues. Various facets of phosphorus chemistry and biology have been extensively studied in the natural environment.

In any ecosystem, the two aspects of interest for phosphorus dynamics are phosphorus concentration and phosphorus flux (concentration times flow rate) as functions of time and distance. The concentration alone indicates the possible limitation that this nutrient can place on vegetative growth in the water. Phosphorus flux is a measure of the amount of phosphorus being transported in flowing water.

Unlike nitrate-nitrogen, phosphorus applied to the land as a 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 adsorbed to soil particles. However, 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. Other sources of DP in the lake water may include the decomposition of aquatic plants and animals. Dissolved phosphorus is readily available for algae and macrophyte growth. However, the DP concentration can vary widely over short periods of time as plants take up and release this nutrient. Therefore, TP in lake water is the more commonly used indicator of a lake's nutrient status.

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.

To prevent biological nuisance, the Illinois Pollution Control Board (IEPA, 2002, Title 35, page 10) stipulates the phosphorus rule. It states that "Phosphorus as P shall not exceed a concentration of 0.05 mg/L in any lake or lake with a surface area of 20 acres (8.1 ha) or more or in any stream at the point where it enters any lake or lake. "

Total Phosphorus. During this study period, the ranges of TP values observed were 0.024-0.134, 0.029-0.098, 0.029-0.163, and 0.038-0.135 mg/L for Stations 1S, 2S, 5S, and 1B, respectively (Appendices B1-B4). The maximum TP values for Stations 1S, 5S, and 1B were found on June 6, 2000; Station 2 on April 19,2001 (but also high on 6/6/2000). At these four stations, the mean TP concentrations and standard deviations were 0.060 ± 0.035, 0.054 ± 0.023, 0.68 ± 0.037, and 0.062 ± 0.030 mg/L, respectively (Appendices B1-B4).

In this study, 43 percent (6/14), 40 percent (6/15), 62 percent (8/13), and 60 percent (9/15) of samples collected from Stations 1S, 2S, 5S, and 1B, respectively, exceeded the 0.05 mg/L TP standard.

Appendices A1-A4 show that the range of historical TP concentrations in Lake Vermilion were between 0.033 (at Station 1B on April 21, 1997) and 0.304 mg/L (at Station 3S on June 9, 1997). The means and standard deviations of TP for stations and standard deviations for Stations 1S, 2S, 3S, and 1B were, respectively, 0.077 ± 0.030, 0.115 ± 0.087, 0.163± 0.097, and 0.082 ± 0.032 mg/L. Historical TP values at Stations 1S, 2S, and 1B were lower than that at Station 3S. The current TP values distribution at Station 1S, 1B, and 2S were not significantly different from those for the historical data (Table 13).

Dissolved Phosphorus. During the study period, only four to six samples were analyzed for DP. Concentrations of DP for Stations 1S, 2S, 5S, and 1S, respectively, ranged from 0.005-0.088, 0.008-0.071, 0.001-0.067, and 0.005-0.088 mg/L; with means of 0.027, 0.054, 0.041, and 0.027 mg/L (Appendices B1-B4).

For the historical data in Appendices A1-A4, maximum DP concentrations in lake water samples at Stations 1S, 2S, 3S, and 1B were 0.101, 0.110, 0.155, and 0.065mg/L, respectively. The minimum DP for all four stations was less than the 0.001 mg/L minimum reporting level. The mean DP concentrations for these stations were, respectively, 0.035, 0.031, 0.44, and 0.021 mg/L.

Table 13 suggests that there is no significant difference in DP distributions between the historical and current data.

Limiting Nutrient. The ratio of total nitrogen to total phosphorus in the epilimnion can often be used to determine the limiting algal nutrient. Since the nitrogen to phosphorus atomic weight ratio in algal cell tissue is typically 15:1, a ratio of 15:1 indicates that both nutrients are equal in limiting algal growth. It is assumed that when the TN to TP ratio is between 10:1 and 20:1 both nutrients are in sufficient supply to sustain algal growth. If the ratio is 20:1 or greater, it is a strong indication that phosphorus is the limiting nutrient. A ratio of 10:1 or less is fairly certain that nitrogen is limiting (USEPA, 1980).

When using a mass ratio (mg/L) in algal cell tissue, the TN:TP ratio is typically 7.2:1. When the mass ratio is greater than 7.2 to 1, phosphorus is the limiting nutrient. When the ratio is less than 7.2:1, nitrogen is the limiting factor. However, Horne (1994) used the TN:TP ratio of 10:1 to determine the limiting nutrient. For this report, the mass ratio of TN (mg/L): TP (mg/L) was calculated for each sample.

During this study period, the TN/TP (mass) ratios for Stations 1S, 2S, 5S, and 1B ranged from 21.9-356.3, 12.2-365.5, 33.6-370.3, and 16.4-378.9, respectively. The maximum TN:TP ratio for these stations was observed on July 12, 2000, March 28, 2001, July 12, 2000, and on July 12, 2000, respectively. All samples collected during this study have TN:TP ratios greater than 7.2:1. The mean TN:TP ratios for Stations 1S, 2S, 3S, and 1B were respectively 119:1, 122:1, 140:1, and 118:1. These ratios indicate that phosphorus was typically the limiting nutrient during the current monitoring year. Therefore, it is concluded that Lake Vermilion is a phosphorus-limited lake. On the basis of historical data, the same conclusion (phosphorus-limited) was found

Chlorophyll. All green plants contain chlorophyll *a*, which constitutes approximately 1 to 2 percent of the dry weight of planktonic algae (APHA et al., 1998). Other pigments that occur in phytoplankton include chlorophyll *b* and *c*, xanthophylls, phycobilius, and carotenes. The important chlorophyll degradation products in water are the chlorophyllids, pheophorbids, and pheophytins. The concentration of photosynthetic pigments is used extensively to estimate phytoplanktonic biomass. The presence or absence of the various photosynthetic pigments is used, among other features, to identify the major algal groups present in the water.

Chlorophyll *a* is a primary photosynthetic pigment in all oxygen-evolving photosynthetic organisms. Extraction and quantification of chlorophyll *a* can be used to estimate biomass or the standing crop of planktonic algae present in a body of water. Other algae pigments, particularly chlorophyll *b* and *c*, can give information on the extent of algal diversity and productivity. Chlorophyll *b* is most common in the green species and serves as an auxiliary pigment for photosynthesis. Chlorophyll *c* is commonly in diatom species and also serves as an auxiliary pigment for photosynthesis. Blue-green algae (Cyanophyta) contain only chlorophyll *a*, and lack chlorophyll *b* and *c*. High concentrations of only chlorophyll *a* in a particular sample may indicate that blue-green algae are dominant.

Both the green algae (Chlorophyta) and the euglenoids (Euglenophyta) contain chlorophyll *a* and *b*. High concentrations of both chlorophyll *a* and *b* suggest green algal species are dominating. Chlorophyll *a* and *c* are present in the diatoms, yellow-green and yellow-brown (Chrysophyta), as well as dinoflagellates (Pyrrhophyta). High levels of both Chlorophyll *a* and c may indicate that diatoms are dominating. These accessory pigments can be used to identify the types of algae present in a lake.

Pheophytin *a* results from the breakdown of chlorophyll *a*, and a large amount indicates a stressed algal population or a recent algal die-off. Pheophytin has an absorption peak in the same spectral region as chlorophyll *a*. Corrected chlorophyll a values refer to a modified laboratory method necessary to make a correction when pheophytin concentration becomes significantly high.

Because direct microscopic examination of water samples was used to identify and enumerate the type and concentrations of algae present in the water samples, the indirect method of making such assessments was not used in this investigation.

Since chlorophyll a pigment is present in green algae, blue-green algae, and also in diatoms, chlorophyll *a* is often used to indicate the degree of eutrophication in a lake. In Illinois, concentrations of chlorophyll *a* exceeding 20 µg/L indicate that a lake may be exhibiting eutrophic conditions (Illinois EPA, 2000).

The observed, mean, and range of values for chlorophyll *a* and other pigments are given in Tables 14-15 for historical survey and the current study (Stations 1, 2, and 3 or 5), respectively. The mean concentrations of chlorophyll *a* (corrected) in the lake (Stations 1-3) during the current study were, respectively, 31.39, 37.86, and 25.4 μg/L (Table 15). The ranges

Table 14a. Historical Chlorophyll Concentrations in Lake Vermilion, Station 1

Sample *date*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
06/28/79	170.00	154.00	24.00	12.00	20.00
09/05/79	28.00	27.00	4.00	3.00	1.00
05/18/83	1.95	2.11	0.24	1.17	0.00
06/09/97	2.83	4.45	0.40	0.00	0.00
Count	4	4	4	4	4
Maximum	170.00	154.00	24.00	12.00	20.00
Minimum	1.95	2.11	0.24	0.00	0.00
Average	50.70	46.89	7.16	4.04	5.25
S.D.	80.45	72.28	11.36	5.45	9.84

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter
A k indicates that the actual value is known to be less than value given

Table 14b. Historical Chlorophyll Concentrations in Lake Vermilion, Station 2

Sample *date*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
07/14/97	20.84	21.35	4.73	0.00	0.13
08/12/97	51.49	55.89	9.53	1.24	5.24
Count	2	2	2	2	2
Maximum	51.49	55.89	9.53	1.24	5.24
Minimum	20.84	21.35	4.73	0.00	0.13
Average	36.17	38.62	7.13	0.62	2.69
S.D.	21.67	24.42	3.39	0.88	3.61

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter
A k indicates that the actual value is known to be less than value given

Table 14c. Historical Chlorophyll Concentrations in Lake Vermilion, Station 3

Sample *date*	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
04/21/97	16.53	14.64	0.65	0.00	0.00
10/22/97	32.24	38.00	3.86	1.52	7.96
Count	2	2	2	2	2
Maximum	32.24	38.00	3.86	1.52	7.96
Minimum	16.53	14.64	0.65	0.00	0.00
Average	24.38	26.32	2.26	0.76	3.98
S.D.	11.11	16.52	2.27	1.07	5.63

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter
A k indicates that the actual value is known to be less than value given

Table 15a. Current Chlorophyll Concentrations in Lake Vermilion, Station 1

Sample date	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
05/08/00	38.7	43.4	6.14	5.00	6.14
06/06/00	10.7	15.6	3.95	2.91	8.01
07/12/00	20.0	37.8	27.7	45.4	32.3
07/26/00	58.7	77.6	35.8	56.7	32.8
08/02/00	32.0	40.4	4.75	5.61	12.6
09/13/00	51.8	50.9	6.54	8.18	0.00
09/28/00	77.2	74.5	8.53	11.2	0.00
10/03/00	42.4	50.4	11.2	21.8	12.2
10/24/00	32.0	32.5	0.47	9.32	0.00
11/15/00	6.79	10.1	4.12	17.1	5.84
01/29/01	24.0	30.3	15.3	24.0	11.1
03/28/01	11.8	12.0	0.00	2.35	0.00
04/19/01	7.92	6.49	1.43	0.55	0.00
04/26/01	25.4	28.0	4.51	7.93	3.14
Count	14	14	14	14	14
Maximum	77.2	77.6	35.8	56.7	32.8
Minimum	6.79	6.49	0	0.55	0
Average	31.39	36.43	9.32	15.58	8.87
S.D.	20.80	22.12	10.47	16.73	11.08

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter.

Table 15b. Current Chlorophyll Concentrations in Lake Vermilion, Station 2

Sample date	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
05/08/00	40.0	48.1	11.3	8.56	12.3
06/06/00	21.4	18.0	2.87	2.58	0.00
07/12/00	45.4	62.9	35.8	94.2	32.2
07/26/00	61.4	84.0	53.4	72.5	41.4
08/02/00	42.3	50.2	5.54	8.14	11.3
09/13/00	87.9	108.0	68.2	128.0	38.9
09/28/00	19.3	39.7	25.4	43.3	36.2
10/03/00	69.5	73.5	28.0	33.1	6.45
10/24/00	41.2	49.7	3.79	14.9	12.1
11/15/00	20.0	28.1	12.2	20.5	0.00
01/29/01	19.4	19.8	1.10	2.75	0.00
03/28/01	11.9	12.8	3.95	9.86	1.32
04/19/01	24.4	23.2	2.00	5.85	0.00
04/26/01	25.8	25.7	1.07	5.16	0.00
Count	14	14	14	14	14
Maximum	87.9	108	68.2	128	41.4
Minimum	11.9	12.8	1.07	2.58	0
Average	33.85	45.98	18.19	32.10	13.73
S.D.	22.24	28.05	21.37	39.24	16.18

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter.

Table 15c. Current Chlorophyll Concentrations in Lake Vermilion, Station 5

Sample date	*Chlorophyll a corrected (µg/L)*	*Chlorophyll a uncorrected (µg/L)*	*Chlorophyll b (µg/L)*	*Chlorophyll c (µg/L)*	Pheophytin a *(µg/L)*
05/08/00					
06/06/00	16.0	12.6	11.8	14.9	0.00
07/12/00	13.4	18.0	14.6	19.2	9.08
07/26/00	21.4	76.4	71.9	115	100
08/02/00	35.5	45.5	12.1	7.30	15.8
09/13/00	22.0	25.4	8.62	11.6	5.50
09/28/00	28.6	32.3	7.15	18.6	5.58
10/03/00	52.2	55.5	4.29	8.48	2.94
10/24/00	69.2	74.0	0.00	14.0	3.79
11/15/00	15.8	17.2	2.98	11.3	1.93
01/29/01	1.57	4.03	1.55	3.49	4.20
03/28/01	0.94	1.41	0.95	2.92	0.90
04/19/01	20.0	20.7	0.86	3.81	0.06
04/26/01	33.6	35.1	18.6	29.7	3.44
Count	13	13	13	13	13
Maximum	69.2	76.4	71.9	115	100
Minimum	0.94	1.41	0.00	2.92	0.00
Average	25.40	32.16	11.95	20.02	11.79
S.D.	19.07	24.43	18.96	29.51	26.84

Notes: S.D. – standard deviation, *µg/L* – micrograms per liter.

of chlorophyll *a* were from 6.79-77.2, 11.9-87.9, and 0.94-69.2 μg/L, respectively. Chlorophyll values for Station 5 during the current study were lower than that for Stations 1 and 2 (Tables 15a-15c). However, at Station 1, mean chlorophyll *a* value was decreased compared with the summer mean of 1997 and 1998 (Tables 12 and 14).

Chlorophyll *a* concentration at each Station has a peak in summer and fall and reaches its annual maximum in September or October. During this study, the maximum values of chlorophyll *a* (corrected) for Stations 1, 2, and 5 were on September 28, 2000, September 13, 2000, and October 24, 2000, respectively.

Historical maximum values of chlorophyll *a* (corrected) for Stations 1, 2, and 3 were 170.00 (June 28, 1979), 51.49 (August 14, 1997), and 32.24 μg/L (June 6, 1995), respectively. In the past, only, two or four samples were collected for chlorophyll analyses. Comparison of the distributions of chlorophyll *a* concentrations between the historical and current study showed that there were decreased concentrations at Station 1 and there was no change at Station 2 (Table 13).

An examination of the data in Tables 14a-14c suggests that chlorophyll *b* and *c* and pheophytin *a* concentrations in Lake Vermilion were also variable. These indicate that algal species in the lake are diversified.

Metals. Four water samples were taken from the mid-depth at Station 1 on May 8, July 12, August 2, and October 3, 2000 for metals analyses. Results of 20 metals (with other chemical parameters) and are presented in Table 16. Table 16 indicates that nine elements (in most or all samples) were found to be less than the reporting limit. They were beryllium, cadmium, chromium, cobalt, copper, nickel, silver, vanadium, and zinc.

The IPCB (IEPA, 2002) stipulated chemical constituent concentrations for secondary contact and indigenous aquatic life standards as follows: barium, 5 mg/L; boron, 1.0 mg/L; chromium, 0.011 mg/L; manganese, 1.0 mg/L; silver, 1.1 mg/L, and zinc, 1.0 mg/L. Metals concentrations of Lake Vermilion were well below these standards.

Organics. Four water samples were taken from the mid-depth at Station 1 on June 6, July 12, August 2, and October 3, 2000 for organics analyses. Results of 35 organics analyses are shown in Table 17. The table suggests that concentrations of 30 out of 35 parameters tested were below reporting limit in all samples. Atrazine (0.33-10.0 μg/L) dicamba (4.9 μg/L), metribuzin (0.12 μg/L), metolachlor (0.25-3.1 μg/L) and diethylhexyphth (0.79-0.90 μg/L) were detected in one to four samples. The Illinois EPA has set limits for atrazine (<3.0 μg/L of MCL) and diethylhexyphth (<6.0 μg/L of MCL). Only the June 6, 2000 sample (10.0 μg/L) exceeded the atrazine limit.

Table 16. Metals Concentrations in Lake Vermilion at Station 1, Mid-Depth

Parameters	*05/08/00*	*07/12/00*	*08/02/00*	*10/03/00*
Calcium, mg/L	46	56	48	44
Magnesium, mg/L	31	26	28	29
Potassium, mg/L	1.9	1.6	2.3	2.1
Sodium, mg/L	15	5.3	6.1	8.6
Aluminum, µg/L	130	140	120	200
Barium, µg/L	37	39	37	39
Beryllium, µg/L	1 k	1 k	1 k	1 k
Boron, µg/L	61	45	51	61
Cadmium, µg/L	3 k	3 k	3 k	3 k
Chromium, µg/L	5 k	5 k	5 k	5 k
Cobalt, µg/L	10 k	10 k	10 k	10 k
Copper, µg/L	10 k	10 k	10 k	10k
Iron, µg/L	220	210	160	280
Manganese, µg/L	77	34	38	52
Nickel, µg/L	25 k	25 k	25 k	25 k
Silver, µg/L	3 k	3 k	3 k	3 k
Strontium, µg/L	120	89	95	100
Vanadium, µg/L	5 k	6.0	5 k	5 k
Zinc, µg/L	100 k	100 k	100 k	100 k
Hardness, mg/L as $CaCO_3$	244 C	245 C	233 C	229 C
Sample depth, feet	11	9	9	9
Total water depth, feet	18	18	19	19

Notes: Samples were taken at the mid-depth
Blank spaces indicate no data
C indicates that value is calculated
A k indicates that the actual value is known to be less than value given

Table 17. Organic Concentrations in Lake Vermilion at Station 1, Mid-Depth

Parameters	*06/06/00*	*07/12/00*	*08/02/00*	*10/03/00*
2,4-D, µg/L	7.0k	1.0k	1.0k	1.0k
Pentachlorophenol (PCP), µg/L	0.1k	0.1k	0.1k	0.1k
Silvex, µg/L	5.0k	5.0k	5.0k	5.0k
Dalapon, µg/L	20k	20k	20k	20k
Dicamba, µg/L	4.9	0.25k	0.25k	0.25k
Dinoseb, µg/L	0.7k	0.7k	0.7k	0.7k
Picloram, µg/L	50k	50k	50k	50k
Acifluorfen, µg/L	0.5k	0.5k	0.5k	0.5k
Hexaclcyclopentdiene, µg/L	5.0k	5.0k	5.0k	5.0k
Propachlor, µg/L	0.5k	0.5k	0.5k	0.5k
Trifluralin (Treflan), µg/L	0.05k	0.05k	0.05k	0.05k
Hexachlorobenzene, µg/L	0.1k	0.1k	0.1k	0.1k
Simazine, µg/L	0.4k	0.4k	0.4k	0.4k
Atrazine, µg/L	10	0.74	0.51	0.33
Lindane, µg/L	0.02k	0.02k	0.02k	0.02k
Metribuzin, µg/L	0.12	0.1k	0.1k	0.1k
Alachlor, µg/L	0.2k	0.2k	0.2k	0.2k
Heptachlor, µg/L	0.04k	0.04k	0.04k	0.04k
Metolachlor, µg/L	3.10	0.37	0.25	0.25k
Cyanazine, µg/L	0.5k	0.5k	0.5k	0.5k
Dacthal, µg/L	0.5k	0.5k	0.5k	0.5k
Aldrin, µg/L	0.05k	0.05k	0.05k	0.05k
Heptachlor epoxide, µg/L	0.02k	0.02k	0.02k	0.02k
Chlordane, µg/L	0.2k	0.2k	0.2k	0.2k
Butachlor, µg/L	0.5k	0.5k	0.5k	0.5k
Total DDT, µg/L	1.0k	1.0k	1.0k	1.0k
Dieldrin, µg/L	0.05k	0.05k	0.05k	0.05k
Endrin, µg/L	0.2k	0.2k	0.2k	0.2k
Diethylhexyladipate, µg/L	40k	40k	40k	40k
Methoxychlor, µg/L	4.0k	4.0k	4.0k	4.0k
Diethylhexylphth, µg/L	0.90	0.60k	0.60k	0.60k
Benzo (A) pyrene, µg/L	0.02k	0.02k	0.02k	0.02k
Acetochlor, µg/L	1.0k	1.0k	1.0k	1.0k
Toxaphene, µg/L	1.0k	1.0k	1.0k	1.0k
Total PCB, µg/L	0.4k	0.4k	0.4k	0.4k

Note: Blank spaces indicate no data
Samples were taken at mid-depth
A k indicates that the actual value is known to be less than value given

Biological Characteristics

Macrophytes. Macrophytes are commonly called aquatic plants (or weeds). The macrophytes consist principally of aquatic vascular flowering plants, including aquatic mosses, liverworts, ferns, and larger macroalgae (APHA et al., 1998). Macrophytes may include submerged, emerged, and floating plants and filamentous algae. In most lakes and ponds, aquatic vegetation is found that may beneficially and/or adversely impact the natural ecosystem. Reasonable amounts of aquatic vegetation improve water clarity by preventing shoreline erosion, stabilizing sediment, storing nutrients, and providing habitats and hiding places for many small fish (fingerlings, bluegill, sunfish, etc.). Aquatic plants also provide food, shade, and oxygen for aquatic organisms; block water movement (wind wave); and use nutrients in the water, reducing the excessive growth of phytoplankton.

However, excessive growth of aquatic vegetation in the lake can cause problems such as interference with recreational activities (fishing, boating, skiing, etc.); adverse affects on aquatic life (overpopulation of small fish and benthic invertebrates); fish kills; taste and odor in water due to decomposition of dense weed beds; blocking water movement and retarding heat transfer, creating vertical temperature gradients; and destroying aesthetic value to the extent of decreasing the economic values of properties surrounding a lake. Under these circumstances, aquatic plants often are referred to as weeds.

During the current study, the macrophyte survey was conducted on September 7, 2000, by the Illinois EPA. The following seven species of macrophytes were observed: waterwillow

(*Jastica americana*), cattails (*Typha sp*.), arrowhead (*Sagittaria sp*.), curlyleaf pondweed (*Potamogeton crispus*), sago pondweed (*Potamogetonpectinatus*), water lily (*Nymphae sp*.) and coontail (*Ceratophyllum demersum*).

Arrowhead was the dominant macrophyte (87.92 percent) followed by cattail with 7.81 percent, waterwillow (3.71 percent), water lily (0.33 percent), coontail (0.185 percent), sago pondweed (0.03 percent), and curlyleaf pondweed (0.02 percent). Most macrophytes observed were located on the northeastern side of Lake Vermilion.

Supplemental observations of the aquatic macrophyte conditions in the lake were made on September 17, 2002 by Cochran & Wilken, Inc. and the Illinois State Water Survey. The 2000 survey results and supplemental observations are plotted in Figure 5. The supplemental observations were made to better document conditions in the shallow upper end of the lake which was inundated by raising the spillway in 1992. The previously listed macrophytes were observed along with scattered areas of spatterdock, large leaf pondweed and creeping water primrose. The typical species found to be occurring along shorelines included arrowhead, water willow, cattails and creeping water primrose. Whereas, the species found in open to semi-protected shallow water included spatterdock, water lily, large leaf pondweed, sago pondweed, curly leaf pondweed, and coontail.

Because residential development tends to reduce macrophyte growth near the shore, the lack of aquatic vegetation on other parts of the lake continues to be a problem in the lake. Significant attention should be given to developing an improved aquatic community in the lake.

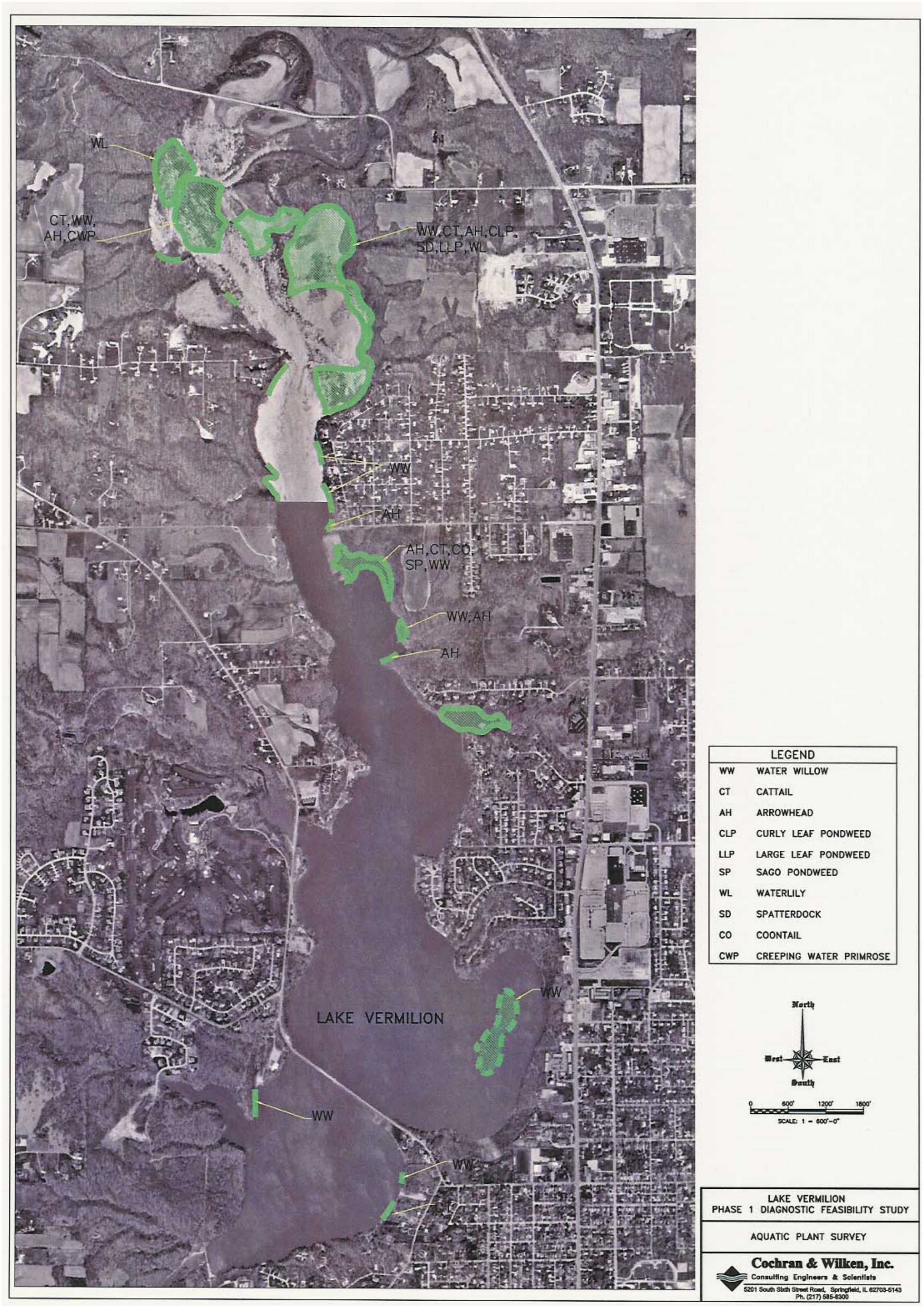


Figure 5. Macrophyte distribution in Lake Vermilion, September 17, 2002

Water Quality of Surface Inflows and Outflows

The inflows and spillway outflow water quality was also monitored. The inflow site, Station T2 (RBD-02), is located at a bridge near Bismark on the North Fork Vermilion River. The outflow site T1 (RBD-01) is located at the spillway. Water samples were taken at either or both stations during and after rainfall events. Thirteen and 37 samples were collected form Station T1 and T2 during this study, respectively. All of the samples collected were analyzed for turbidity, conductivity, pH, TSS, VSS, NH_3-N, TKN, NO_2/NO_3-N, and TP. The laboratory results for these samples are presented in Appendix D (D1-D2). The statistical summary for the parameters monitored also are included in these Appendices.

It can be seen from Appendix D2 for the tributary site, during or after storm events, high levels of turbidity, TSS, VSS, TKN, NO_2/NO_3-N, and TP were observed (5/27-6/1/00, 7/5/00, 7/11/00 and 2/5/01, 2/9/01, and 2/25-28/01). During storm periods, total alkalinity decreased.

A comparison of the water quality characteristics of the inflow (Appendix D1) and outflow (Appendix D2) was made. The changes in mean concentrations from Station T2 to Station T1 (spillway) for the parameters monitored were turbidity from 370 to 86 NTU, conductivity 611 to 528 μmho/cm, total alkalinity 178 to 113 mg/L as $CaCO_3$, TSS 137 (increased) to 161 mg/L, VSS 23 (increased) to 29 mg/L, NH_3-N 0.15 (increased) to 0.21 mg/L, TKN 1.22 (increased) to 1.88 mg/L, NO_2/NO_3-N 9.20 to 8.30 mg/L, and TP 0.244 (increased) to 0.429 mg/L.

Trophic State

Eutrophication is a normal process that affects every impounded body of water from its time of formation. As a lake ages, the degree of enrichment due to accumulated nutrient materials increases. In general, the lake traps a portion of the nutrients originating in the surrounding watershed. Precipitation, dry fallout, ground-water inflow, septic tank effluents, waterfowl, etc. are potential other contributing sources.

Lakes are generally classified by limnologists into one of three trophic states: oligotrophic, mesotrophic, or eutrophic. Oligotrophic lakes are known for their clean and cold waters and lack of aquatic plants or algae due to low nutrient levels. There are few oligotrophic lakes in the Midwest. At the other extreme, eutrophic lakes are characterized by high nutrient levels and are likely to be very productive in terms of plant growth and algal blooms. Eutrophic lakes can support large fish populations, but the fish tend to be rougher species that can better tolerate depleted levels of DO. Mesotrophic lakes are in an intermediate stage between oligotrophic and eutrophic. The majority of Midwestern lakes are eutrophic. A hypereutrophic lake is one that has undergone extreme eutrophication to the point of having developed undesirable aesthetic qualities (e.g., odors, algal mats, and fish kills) and water-use limitations (e.g., extremely dense growth of vegetation). The natural aging process causes all lakes to progress to the eutrophic condition over time, but this eutrophication process can be accelerated by certain land uses in the contributing watershed (e.g., agricultural activities, application of lawn fertilizers, and erosion from construction sites). Given enough time, a lake will grow shallower and eventually will fill in with trapped sediments and decayed organic matter, until it becomes a shallow marsh or emergent wetland.

A wide variety of indices of lake trophic conditions have been proposed. These indices have been based on Secchi disc transparency; nutrient concentrations; hypolimnetic oxygen depletion; and biological parameters, including chlorophyll *a*, species abundance, and diversity.

The USEPA (1980) suggests the use of four parameters as trophic indicators: Secchi disc transparency, chlorophyll *a*, surface water TP, and total organic carbon. In addition, the lake trophic state index (TSI) developed by Carlson (1977) on the basis of Secchi disc transparency, chlorophyll *a*, and surface water TP can be used to calculate a lake's trophic state. The TSI can be calculated from Secchi disc transparency (SD) in meters, chlorophyll *a* (CHL) in micrograms per liter (µg/L), and TP in micrograms per liter as follows:

on the basis of SD, $$TSI = 60 - 14.4 \ln (SD) \qquad (1)$$

on the basis of CHL, $$TSI = 9.81 \ln (CHL) + 30.6 \qquad (2)$$

on the basis of TP, $$TSI = 14.42 \ln (TP) + 4.15 \qquad (3)$$

The TSI is based on the amount of algal biomass in surface water, generally using a scale of 0 to 100. Each increment of ten in the TSI represents a theoretical doubling of biomass in the lake. Hudson et al. (1992) discussed the advantages and disadvantages of using the TSI. Water coloration or suspended solids other than algae often diminish the accuracy of Carlson’s index.

Applying TSI classification to lakes that are dominated by rooted aquatic plants may indicate less eutrophication than actually exists.

The values of TSI for Lake Vermilion were calculated for each Station using equations 1-3, based on Secchi disc transparency, TP, and chlorophyll *a* concentrations of both the historical and the current study data. The TSI results, range and average of TSI values, and trophic state are listed in Table 18. The trophic state of each station or of the lake average was categorized using mean TSI values and the information provided in Table 19.

The mean TSI values shown in Table 18 suggest that values calculated using the three parameters vary for each station and for each study period. Higher TSI's (>100) are found by the calculations CHL-TSI in historical data. TP-TSI and CHL-TSI (including current CHL-TSI) gave comparable values. When considering the results of the TSI calculations, one should keep in mind the assumptions on which the Carlson formulae are based: Secchi disc transparency is a function of phytoplankton biomass, phosphorus is the factor limiting algal growth, and TP concentration is directly correlated with algal biomass. These assumptions will not necessarily hold when suspended solids other than algal biomass are a major source of turbidity, short retention times prohibit a large algal standing crop from developing, or grazing by zooplankton affects algal populations.

As mentioned previously, Lake Vermilion is phosphorus limited, for algal growth, thus TP-TSI is included for the overall TSI calculations. The overall average TSI values for stations 1, 2, and 5 using three TSI's, during the current study, were 64.2, 65.7, and 65.6, respectively. Based on the TSI evaluations, all three stations are classified as eutrophic.

During the period 1977-1997, the overall average TSI values for Stations 1, 2, and 3 were, respectively, 79.2, 81.3, and 84.7 (Table 18). These historical values indicate that the lake waters could be classified as hypereutrophic or a lower quality condition than the current

Table 18. Statistical Summary of Trophic State Index (TSI) and Trophic State of Lake Vermilion

TSI/ Trophic state	*Station 1* *1977-1997*	*Station 1* *2000-2001*	*Station 2* *1977-1997*	*Station 2* *2000-2001*	Station 3 *1977-1997*	Station 5 *2000-2001*
SD-TSI						
Count	8	5	8	5	8	4
Maximum	79.7	83.0	87.1	83.0	87.1	78.7
Minimum	67.1	64.9	66.0	70.0	73.0	73.0
Mean	72.1	69.4	74.9	73.0	80.8	75.7
Trophic state	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Hyper-eutrophic	Hyper-eutrophic	Hyper-eutrophic
CHL-TSI						
Count	4	14	2	14	2	13
Maximum	147.8	73.2	137.0	74.5	132.4	72.2
Minimum	105.7	49.4	128.2	54.9	125.9	30.0
Mean	124.3	62.1	132.6	64.7	129.2	58.0
Trophic state	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic
TP-TSI						
Count	7	14	8	13	8	13
Maximum	71.9	74.8	85.4	69.8	86.6	77.6
Minimum	57.3	50.0	55.4	52.7	55.4	52.7
Mean	65.7	61.2	69.1	59.5	73.4	63.3
Trophic state	Eutrophic	Eutrophic	Eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic
Overall*						
Count	19	33	18	32	14	30
Mean	79.2	64.2	81.3	65.7	84.7	65.7
Trophic state	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic

Notes: CHL - chlorophyll *a*
SD - Secchi disc transparency
TP - total phosphorus
TSI - trophic state index

Table 19. Quantitative Definitions of Lake Trophic States

Trophic state	*Secchi disc transparency (in.)*	*(m)*	*Chlorophyll a (µg/L)*	*Total phosphorus, lake surface (µg/L)*	*Trophic State Index*
Oligotrophic	>145	>3.7	<2.5	<12	<40
Mesotrophic	>79-≤145	>2.0-≤3.7	≥2.5-<7.5	≥12-<25	≥40-<50
Eutrophic	>18-≤79	>0.5-≤2.0	≥7.5-<55	≥25-<100	≥50-<70
Hypereutrophic	≤18	≤0.5	≥55	≥100	≥70

Source: Illinois EPA, 2000

conditions. The current mean TSI for all stations in Lake Vermilion decreased from those of the historical data numerically. This improved condition may be a result of climatic and hydrologic conditions prevalent during the monitoring year or the altered condition of the lake since the spillway was increased.

Use-Support Analysis

Definition

An analysis of use support for Lake Vermilion was conducted using a methodology developed by the Illinois EPA (1998). The degree of support identified for each designated use indicates the ability of the lake to support a variety of high-quality recreational activities, such as boating, sport fishing, swimming, and aesthetic enjoyment; support healthy aquatic life and sport fish populations; and provide adequate, long-term quality and quantity of water for public or industrial water supply (if applicable). Determination of a lake's use support is based upon the state's water quality standards as described in the State of Illinois Administrative Code (IEPA, 2002). Each of four established use designation categories (including General Use, Public and Food Processing Water Supply, Lake Michigan, and Secondary Contact and Indigenous Aquatic Life) has a specific set of water quality standards.

For the lake uses assessed in this report, the General Use standards–primarily the 0.05 mg/L TP standard–were used. The TP standard was established for the protection of aquatic life as well as primary contact (e.g., swimming) and secondary contact (e.g., boating) recreation, agriculture, and industrial uses. In addition, lake-use support is based in part on the amount of sediment, macrophytes, and algae in the lake and how these might impair designated lake uses. The following is a summary of the various classifications of use impairment:

- Full = full support of designated uses, with minimal impairment.
- Full/threatened = full support of designated uses, with indications of declining water quality or evidence of existing use impairment.
- Partial = partial support of designated uses, with slight-to-moderate-impairment.
- Nonsupport = no support of designated uses, with severe impairment.

Lakes that fully support designated uses still may exhibit some impairment, or have slight-to-moderate amounts of sediment, macrophytes, or algae in a portion of the lake (e.g., headwaters or shoreline); however, most of the lake acreage shows minimal impairment of the aquatic community and uses. If a lake is rated as not fully supporting designated uses, it does not necessarily mean that the lake cannot be used for those purposes or that a health hazard exists. Rather, it indicates impairment in the ability of significant portions of the lake waters to support either a variety of quality recreational experiences or a balanced sport fishery. Because most lakes are multiple-use bodies of water, a lake can fully support one designated use (e.g., aquatic life) but exhibit impairment of another (e.g., swimming).

Lakes that partially support designated uses have a designated use that is slightly-to-moderately impaired in a portion of the lake (e.g., swimming impaired by excessive aquatic macrophytes or algae, or boating impaired by sediment accumulation). So-called nonsupport lakes have a designated use that is severely impaired in a substantial portion of the lake (e.g., a large portion of the lake has so much sediment that boat ramps are virtually inaccessible, boating is nearly impossible, and fisheries are degraded. But nonsupport does not necessarily mean that a lake cannot support any uses, that it is a public health hazard, or that use of the lake is prohibited.

For Lake Vermilion, the lake-use support and level of attainment were determined for aquatic life, recreation, swimming, drinking water supply, and overall lake use, using methodologies described by the Illinois EPA (2000).

The primary criterion in the aquatic-life-use assessment is an Aquatic Life Use Impairment Index (ALI); in the recreation use assessment, the primary criterion is a Recreation Use Impairment Index (RUI). Both indices combine ratings for TSI (Carlson, 1977) and degree of use impairment from sediment and aquatic macrophytes; each index is specifically designed for the assessed use. The ALI rating reflects the degree of attainment of the “fishable goal” of the Clean Water Act; the RUI rating reflects the degree to which pleasure boating, canoeing, and aesthetic enjoyment may be obtained at a lake.

The assessment of swimming use for primary-contact recreation was based on available data using two criteria: Secchi disc transparency depth data and Carlson's overall TSI. The swimming use rating reflects the degree of attainment of the “swimmable goal” of the Clean Water Act. A rating of “nonsupport” for swimming does not mean the lake cannot be used or that health hazards exist. It indicates that swimming may be less desirable than at those lakes assessed as fully or partially supporting swimming.

In addition to assessing individual uses (aquatic life, fish consumption, recreation, swimming uses, drinking water supply), the overall use support of the lake was assessed. The overall use-support methodology aggregates the use support attained for each of the lake uses assessed. Values assigned to each use-support attainment category were summed and averaged, then used to assign an overall lake-use attainment value for the lake.

Use-Support Analysis for Lake Vermilion

Support of designated uses in Lake Vermilion was determined based on Illinois' use-support assessment criteria using data from both Stations 1 and 2 (IEPA, 2000). The use-support analysis results for the lake were assessed as full support (based on a score of zero RUI points) for aquatic life, full support (zero points) for fish consumption, partial support (1 point) for recreation, partial support (1 point) for swimming, and partial support (1 point) for drinking water supply uses. For overall use, Lake Vermilion during 2000-2001 can be classified as having partial use support (0.60 points RUI rating).

Sediment Characteristics

Lake sediments can be potential pollution sources (for pollutants such as phosphorus and metals) affecting lake water quality. Metal and/or organic chemical toxicities can directly affect the presence of aquatic animals and plants on the lake bottom. Lake sediments, if and when dredged, should be carefully managed to prevent surface water and ground-water contamination.

Sediment monitoring is becoming increasingly important as a tool for detecting pollution loadings in lakes and streams because (Indiana Department of Environmental Management, 1992):

- Many potential toxicants are easier to assess in sediments as they accumulate at levels far greater than those normally found in the water column.
- Sediments are less mobile than water and can be used more reliably to infer sources of pollutants.
- Nutrients, heavy metals, and many organic compounds can become tightly bound to the fine particulate silts and clays of the sediment deposits where they remain until they are released to the overlying water and made available to the biological community through physical, chemical, or biological processes.
- Remedial pollution mitigation projects may include the removal of contaminated sediments as a necessary step.

Sediment Quality Standards

No regulatory agencies promulgate sediment quality standards, but sediment quality in Illinois generally is assessed by using data by Kelly and Hite (1981), who collected 273 individual sediment samples from 63 lakes across Illinois during the summer of 1979. On the basis of each parameter measured, they defined "elevated levels" as concentrations of one to two standard deviations greater than the mean value, and "highly elevated levels" as concentrations greater than two standard deviations from the mean. The Illinois EPA (J. Mitzelfelt, personal communication, 1996) revised classification of lake sediments as shown in Table 20. In this classification, lake sediment data are considered to be elevated based on a statistical comparison of levels found in a 20-year record and not on toxicity data. Therefore, elevated or highly elevated levels of parameters do not necessarily indicate a risk to human health or the aquatic biota.

Nutrients and Metals

Sediment samples were collected on July 12, 2000 at Stations 1, 2, and 5. Results of nutrients and metals concentrations are given in Table 21. An examination of data in Table 21 shows that mercury and silver concentrations were below the detectable levels. For all parameters measured, with the exception of total organic carbon, total solids, and silver, concentrations at stations 1 and 2 were higher than that at station 5. TKN concentrations were highest at station 2. All other measured parameters followed the trend station 1 > station 2 > station 5.

On the basis of the classification given in Table 20, nickel and potassium concentrations at Stations 1, 2, and 5 were highly elevated. At Station 1, chromium and iron also were highly elevated; and iron was also highly elevated at Station 2. Iron was elevated at Station 5. At the

Table 20. Classification of Lake Sediments (revised 1996)

Parameters	*Detection limit**	*Low*	*Normal*	*Elevated*	*Highly elevated*
Phosphorus	0.1	<394	394-<1115	1115-<2179	≥2179
Total Kjeldahl-N	1.0	<1300	1300-<5357	5357-<11,700	≥11,700
Arsenic	0.5	<4.1	4.1-<14	14-<95.5	≥95.5
Barium	1.0	<94	94-<271	271-<397	≥397
Cadmium	0.1	n/a	<5	5-<14	≥14
Chromium	10	<13	13-<27	27-<49	≥49
Copper	1.0	<16.7	16.7-<100	100-<590	≥590
Iron	10	<16,000	16,000-<37,000	37,000-<56,000	≥56,000
Lead	0.1	<14	14-<59	59-<339	≥339
Manganese	10	<500	500-<1700	1700-<5500	≥ 5500
Mercury	0.1	n/a	<0.15	0.15-<0.701	≥0.701
Nickel	1.0	<14.3	14.3-<31	31-43	≥43
Potassium	1.0	<410	410-<2100	2100-<2797	≥2797
Silver	0.1	n/a	<0.1	0.1-<1	≥1
Zinc	10	<59	59-<145	145-<1100	≥1100
PCB	10	n/a	<10	10-<89	≥89
Aldrin	1	n/a	<1	1-<1.2	≥1.2
Dieldrin	1	n/a	<3.4	3.4-<15	≥15
DDT	10	n/a	<10	10-180	≥180
Chlordane	5	n/a	<5	5-12	≥12
Endrin	1	n/a	<1	n/a	≥1
Methoxychlor	5	n/a	<5	n/a	≥5
Alph-BHC	1	n/a	<1	n/a	≥1
Gamma-BHC	1	n/a	<1	n/a	≥1
HCB	1	n/a	<1	n/a	≥1
Heptachlor	1	n/a	<1	n/a	≥1
Heptachlor epoxide	1	n/a	<1	1-<1.6	≥1.6

Notes: * Amounts of metals and inorganics expressed as mg/kg; organics expressed as μg/kg
BHC - benzene hexachloride
DDT - dichloro-diphenyl-trichloro-ethane
HCB - hexachlorobenzene
n/a - data not available
PCB - polychlorinated biphenyls

Source: J. Mitzelfelt, Illinois EPA, personal communication, 1996

Table 21. Sediment Quality of Lake Vermilion, July 12, 2000

Parameters	*Station 1*	*Station2*	*Station 5*
Phosphorus, mg/kg	1,070	817	802
Kjeldahl-nitrogen, mg/kg.	2,000	2,380	1,270
Total organic carbon, %	2.3	2.3	3.3
Total solids, % of wet sample	44.5	46.1	47.4
Volatile solids, % of wet sample	10.3	8.0	7.8
Arsenic, mg/kg	20	15	14
Barium, mg/kg	340	280	220
Cadmium, mg/kg	1.0	1.0	1.0
Chromium, mg/kg	55	46	36
Copper, mg/kg	61	53	42
Iron, mg/kg	72,000	57,000	46,000
Lead, mg/kg	52	44	36
Manganese, mg/kg	1,900	1,800	1,600
Mercury, mg/kg	0.10k	0.10k	0.10k
Nickel, mg/kg	64	54	43
Potassium, mg/kg	5,200	4,200	3,300
Silver, mg/kg	0.7k	0.7k	0.9
Zinc, mg/kg	240	200	160
Water depth, feet	18	11	6

Note: A k indicates that the actual value is known to be less than value given
Blank spaces indicate no data

three stations, arsenic and zinc were classified as elevated. At Stations 1 and 2, barium and manganese were elevated. Chromium was elevated at Stations 2 and 5.

At all three stations, phosphorus, cadmium, and lead were classified as normal levels. TKN was normal at stations 1 and 2, and low at station 5. For station 5, other parameters determined (barium, copper, lead, and manganese) were considered normal for Illinois lakes. The bottom sediments near Station 5 would require more evaluation of sediment metals quality if dredging is determined to be an option for the restoration phase.

Organic Compounds

Chlorinated hydrocarbon compounds consist of a group of pesticides that are no longer in use but are persistent in the environment. These compounds, such as chlordane, dieldrin, and dichloro-diphenyl trichloroethane (DDT) present a somewhat unique problem in aquatic systems because of their potential for bioaccumulation in fish from the food web. Organochlorine compounds are relatively insoluble in water but highly soluble in lipids, in which they are retained and accumulate. Minute and often undetectable concentrations of these compounds in water and sediment ultimately may pose a threat to aquatic life, then possibly to human health.

Table 22 presents the current observed sediment concentrations of tested organochlorine compounds. An examination of Table 22 indicates that almost all (25) parameters assessed at all three stations were below detection levels, with the except P,P'-DDD at stations 1 (1.1 mg/L) and 2 (1.4 mg/L). These levels are slightly higher than the detectable limit. P,P'-DDD is not included in the sediment classification list (Table 20).

Sediment quality results indicate that the lake sediment is non-hazardous and would not require disposal in a special hazardous facility if the sediment were to be dredged.

Shoreline Erosion Evaluation

A shoreline condition survey of the lake was conducted on September 17, 2002. The results of this survey are shown in Figure 6. The shoreline condition is summarized as follows:

		Affected length	Percent of Total
Condition	Defined as:	*Linear feet*	Shoreline Length
Severe	8-foot or more exposed bank	5,429	7.2
Moderate	3 to 8 feet of exposed bank	2,322	3.1
Slight	0 to 3 feet of exposed bank	4,344	5.8
Existing stabilization	Artificially armored by rock or shore wall	12,497	16.6
Total shoreline length		75,400	

Table 22. Organochlorine Compounds Tested for Sediments in Lake Vermilion, July 12, 2000

Organic compounds, μg/kg	*Station 1*	*Station 2*	*Station 5*
Total PCBs	10k	10k	10k
Hexachlorobenzene	1.0k	1.0k	1.0k
Trifluralin	10k	10k	10k
Alpha-BHC	1.0k	1.0k	1.0k
Gamma-BHC(lindane)	1.0k	1.0k	1.0k
Atrazine	50k	50k	50k
Heptachlor	1.0k	1.0k	1.0k
Aldrin	1.0k	1.0k	1.0k
Alachlor	10k	10k	10k
Metribuzin	10k	10k	10k
Metolachlor	25k	25k	25k
Heptachlor epoxide	1.0k	1.0k	1.0k
Pendimethalin	10k	10k	10k
Gamma-chlordane	2.0k	2.0k	2.0k
Alpha-chlordane	2.0k	2.0k	2.0k
Total α & γ chlordane	5.0k	5.0k	5.0k
Dieldrin	1.0k	1.0k	1.0k
Captan	10k	10k	10k
Cyanazine	25k	25k	25k
Endrin	1.0k	1.0k	1.0k
P,P'-DDE	1.1	1.4	1.0k
P,P'-DDD	1.0k	1.4	1.0k
P,P'-DDT	1.0k	1.0k	1.0k
Total DDT	10k	10k	10k
Methoxychlor	5k	5k	5k

Notes: A k indicates that the actual value is known to be less than value given
PCB - polychlorinated biphenyls
BHC - benzene haxachlorine
DDE - dichloro-diphenyl ethylene
DDD - dichloro-diphenyl dichloroethane
DDT - dichloro-diphenyl trichloroethane
Blank spaces - no data

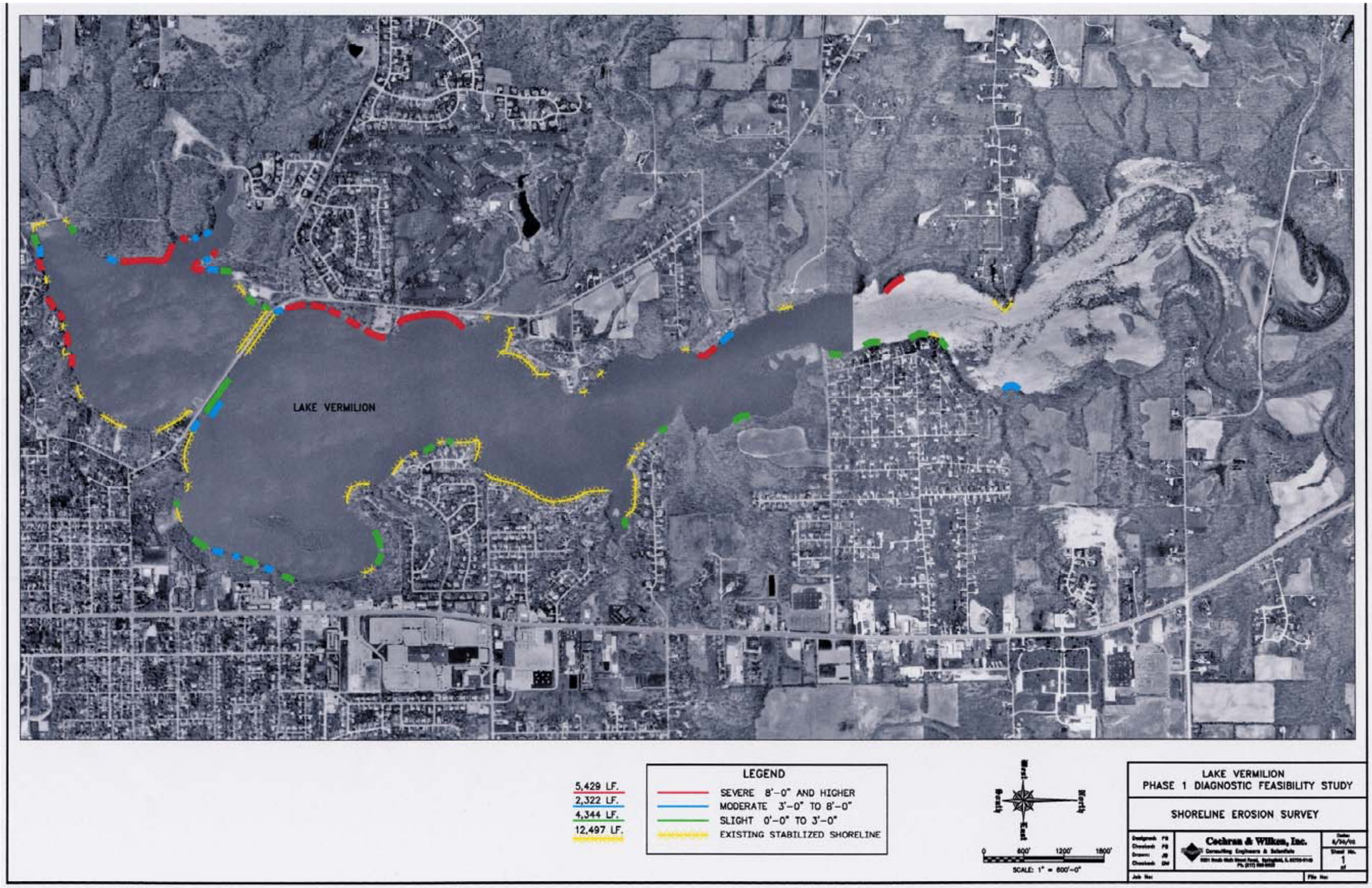


Figure 6. Bank erosion survey for Lake Vermilion, September 17, 2002

Lake Sedimentation Survey

Sedimentation of a reservoir is a natural process that can be either accelerated or slowed by human activities in the watershed. In general, sedimentation of a lake is presumed to be unintentionally accelerated as a secondary impact of other developments within the watershed. For example, construction and agricultural activities in a lake watershed generally are presumed to increase sediment delivery to the lake due to increased exposure of soil material to erosive forces.

Reductions of the sedimentation rate in a lake due to human impacts almost always are the result of programs intentionally designed to reduce soil and streambank erosion, and they are often the result of implementing lake remediation programs. These programs might include, but are not limited to, the implementation of watershed erosion control practices, streambank and lakeshore stabilization, stream energy dissipaters, and lake dredging.

Sedimentation of a reservoir is the final stage of a three-step sediment transport process. The three steps are watershed erosion by sheet, rill, gully, and/or streambank erosion; sediment transport in a defined stream system; and deposition of the sediment, in which stream energy is reduced such that the sediment can no longer be transported either in suspension or as bedload. Sediment deposition can occur throughout the stream system.

Lake sedimentation occurs when sediment-laden water in a stream enters the reduced flow velocity regime of a lake. As water velocity is reduced, suspended sediment is deposited in patterns related to the size and fall velocity of each particle. During this process, soil particles are partially sorted by size along the longitudinal axis of the lake. Larger and heavier sand and coarse silt particles are deposited in the upper end of the lake; finer silts and clay particles tend to be carried further into the lake.

Several empirical methods have been developed for estimating sedimentation rates in Illinois (ISWS, 1967; Upper Mississippi River Basin Commission, 1970; Singh and Durgunoglu, 1990). These methods use regionalized relationships between watershed size and lake sedimentation rates. As estimates, they serve well within limits. A more precise measure of the sedimentation rate is provided by conducting a sedimentation survey of the reservoir. The sedimentation survey provides detailed information on distribution patterns within the lake as well as defining temporal changes in overall sedimentation rates.

Sedimentation Survey Methods

The ISWS conducted sedimentation surveys of Lake Vermilion in 1963 (Neibel and Stall, 1964) and 1976 (Bogner and Gibb, 1977). The 1998 sedimentation survey of Lake Vermilion (Figure 7) repeated as closely as possible a series of survey lines established during the 1963 survey. In 1963, cross sections were laid out at 18 lines across the lake, surveyed, and monumented by installing 4-inch by 4-inch concrete posts to mark the transect ends. During the 1976 and 1998 surveys, these survey lines were resurveyed to define temporal changes in lakebed topography.

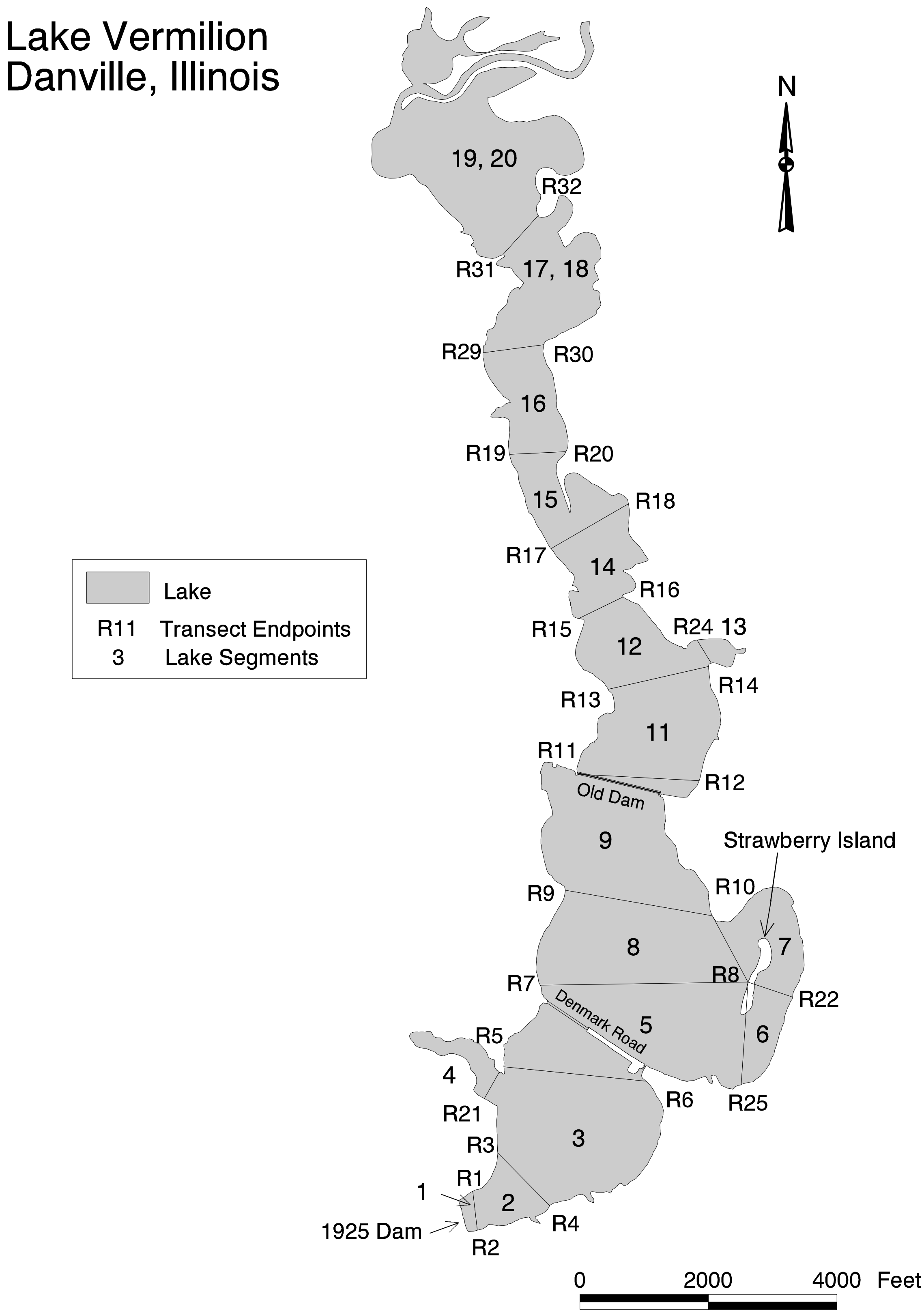


Figure 7. Survey plan for Lake Vermilion, 1998

For the 1963 and 1976 sedimentation surveys, horizontal distances along the cross-sectional transects were measured by stretching a marked polyethylene cable between corresponding range end monuments. Water depth (vertical control) was referenced to the water surface, and all depths were adjusted to the spillway crest elevation. Depth measurements were made using an aluminum sounding pole lowered to the top of the sediment surface to measure the existing water depth. The pole was then used to probe to the original bottom as determined by the initial point of resistance to the sediment probe.

The 1998 survey was conducted using an Odom Hydrographic Systems MK II fathometer for depth measurement and a differentially corrected Geodetic Position Systems (GPS) for horizontal control across the transect. The GPS system units used were either a Trimble Pathfinder GPS or a Leica 9600 System. All navigation and data logging functions were controlled using Hypack, a hydrographic survey software. The GPS positions were differentially corrected using RTCM correction signals broadcast by the U.S. Coast Guard from St. Louis, Missouri, or Rock Island, Illinois.

The fathometer was calibrated daily prior to initiating measurements. Calibration checks at the end of most work days showed daily variations of 0.1-0.2 feet in a profile at one-foot depth intervals. For each main lake cross section, three to five physical measurements of the water depth and sediment thickness were made with an aluminum sounding pole.

Plots of all surveyed cross sections from 1963, 1976, and 1998 are presented in Appendix I of Bogner and Hessler, 1999. For comparison, the 1998 pole measurements also are plotted in

Appendix I (Bogner and Hessler, 1999) as point data. These water-depth measurements with the pole show a close correspondence with the 1998 depth sounder readings. Comparison of the original lake depth for the 1998 pole readings to the full cross-section data collected for the 1963 and 1976 surveys shows a good match in the deeper areas of the lake (R1-R2 through R9-R10). In shallower water areas, the sediments have become more consolidated and difficult to penetrate due to the occasional exposure events prior to 1991.

Lake Basin Volumes

Calculations of the lake capacities were made using the method described in *the National Engineering Handbook* of the U.S. Soil Conservation Service (USDA-SCS, 1968). This method requires the surface area of the lake segments, the cross-sectional area and widths of their bounding segments, and a shape factor to determine the original and present volume of each segment. These volumes are then summed to determine the total lake volume. The reference elevation used for the lake was the top of the spillway gates, 582.2 feet NGVD.

The volume calculation results of the three surveys are presented in Table 23. Given the 1991 change in lake elevation, the analysis of sedimentation rates required the use of a potential capacity for the pre-1991 lake volumes. For consistency, the volumes discussed in the remainder of this report are relative to the capacity of the valley basin below the reference spillway elevation of 582.2 feet NGVD. This potential capacity corresponds to the volume of lake storage that would have been achieved if the original 1925 lake had been constructed in the valley at the

Table 23. Reservoir Capacity and Capacity Loss Analysis

Period	*Capacity*	*Capacity loss for period*	*Cumulative capacity loss*	*Period annual capacity loss rate*	*Cumulative annual capacity loss rate*
a) Analysis in units of ac-ft					
1925	13,209				
1925-1963	9,810	3,399	3,399	89.5	89.5
1963-1976	9,157	653	4,052	50.2	79.5
1976-1998	7,971	1,186	5,238	53.9	71.8
b) Analysis in units of million gallons					
1925	4,304				
1925-1963	3,196	1,108	1,108	29.1	29.1
1963-1976	2,984	213	1,320	16.4	25.9
1976-1998	2,597	386	1,707	17.6	23.4

Note: Lake surface area is 878 acres for 1998.
Capacity shown is for the sedimentation survey conducted at the end of the period.

1991 spillway elevation. Prior to 1991, it was physically impossible to maintain the pool level at this elevation, so the capacity discussed is defined as the potential capacity.

Sedimentation has reduced the basin capacity from 13,209 ac-ft in 1925 to 7,971 ac-ft in 1998. The 1998 basin capacity was 60.3 percent of the 1925 potential basin capacity. For water supply purposes, these volumes convert to capacities of 4,304 million gallons in 1925 and 2,597 million gallons in 1998. The potential capacity of the lake in 1963 was 9,810 ac-ft (3,196 million gallons), and in 1976 it was 9,157 ac-ft (2,984 million gallons).

The 1998 water depths for the lake were used to generate the bathymetric map in Figure 8 and the volume distribution curve data in Figure 9. Figure 9 can be used to determine the capacity of the reservoir below a given stage elevation. For example, the water volume below the 4-foot depth contour (shown by the dashed line in Figure 9) is 4,543 ac-ft. With time and continued sedimentation, the relationships shown in Figure 9 will become obsolete. Alteration of the spillway elevation or the implementation of a dredging program would likewise alter these relationships.

During the 1998 survey, much of the area inundated because the 1991 spillway level increase was found to have a depth of 4 to 5 feet. Much of the inundated area had been part of the original lake. Earlier sedimentation surveys found that 165 acres of the original surface area of the lake had become terrestrial. Analyses of aerial photography verify that in 1936, 11 years after construction of the present dam and 23 years after construction of the old dam, the lake covered an area approximately equal to the present extent of the lake. By 1976, sediment had filled most of this 165-acre area and had formed exposed land above the then existing lake pool level.

Sedimentation Rates

Analysis of the sedimentation rates for Lake Vermilion was made in terms of delivery rates from the watershed and accumulation rates in the reservoir. The in-lake accumulation rate provides a means of extrapolating future lake conditions from past and present lake conditions in order to evaluate the integrity of the lake as a water supply source as well as a recreational resource. The watershed delivery rates are the link between soil erosion processes in the watershed, sediment transport processes, and water supply quantity impacts in the reservoir. These delivery rates measure the actual sediment yield from the watershed, including reduced sediment transport due to field and in-stream redeposition.

The sedimentation rates for Lake Vermilion and its watershed are given in Table 24 and Table 25 for the periods 1925-1963, 1963-1976, 1976-1998, and 1925-1998. These rates indicate a steady decline in net sediment yield from the watershed from 89.5 ac-ft from 1925-1963 to 53.9 ac-ft annually from 1976-1998. The long-term average annual sediment yield from 1925-1998 was 71.8 ac-ft. These delivery rates show the need for continuing efforts to control watershed erosion, thereby reducing reservoir sedimentation rates.

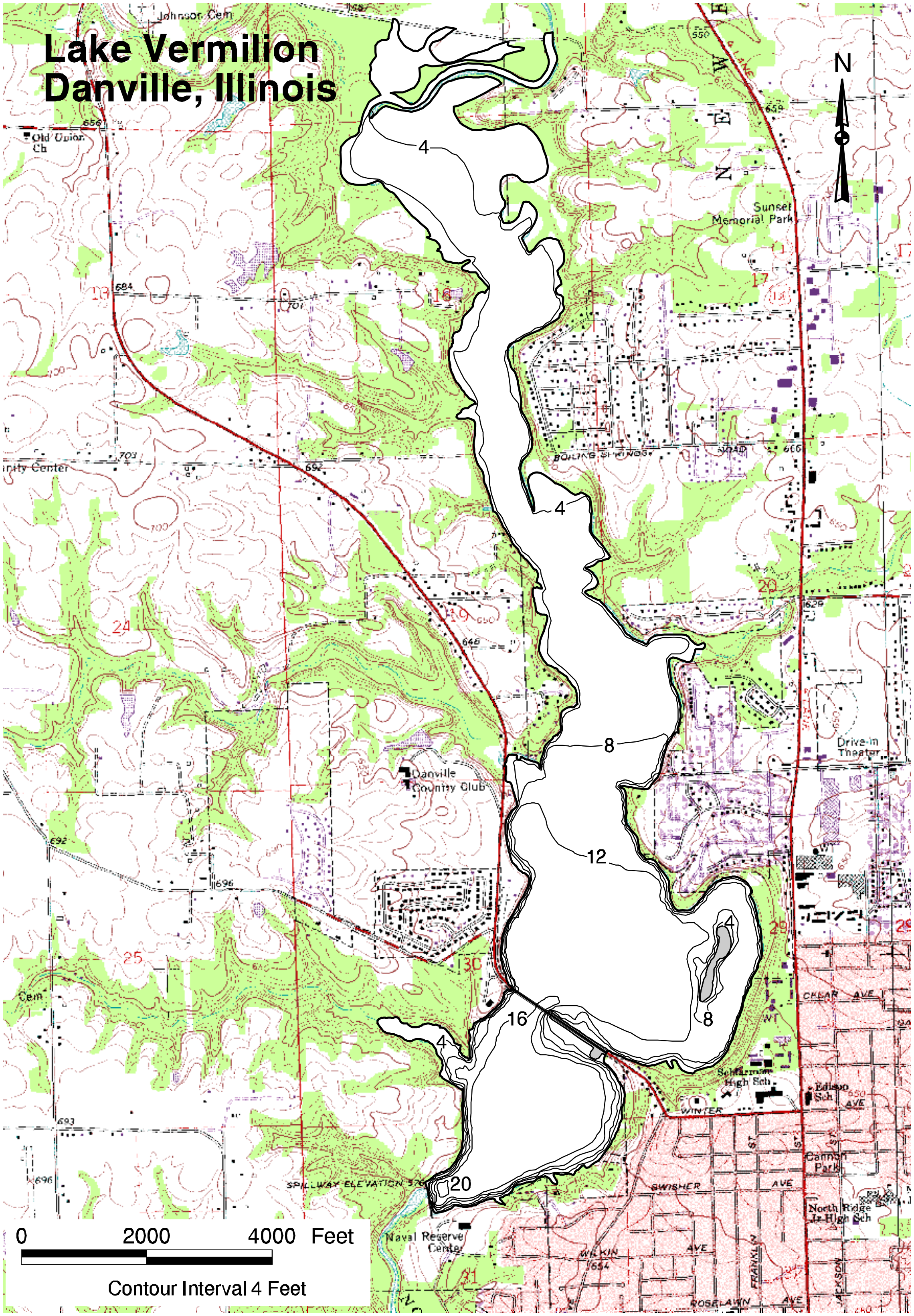


Figure 8. Bathymetric map of Lake Vermilion, 1998

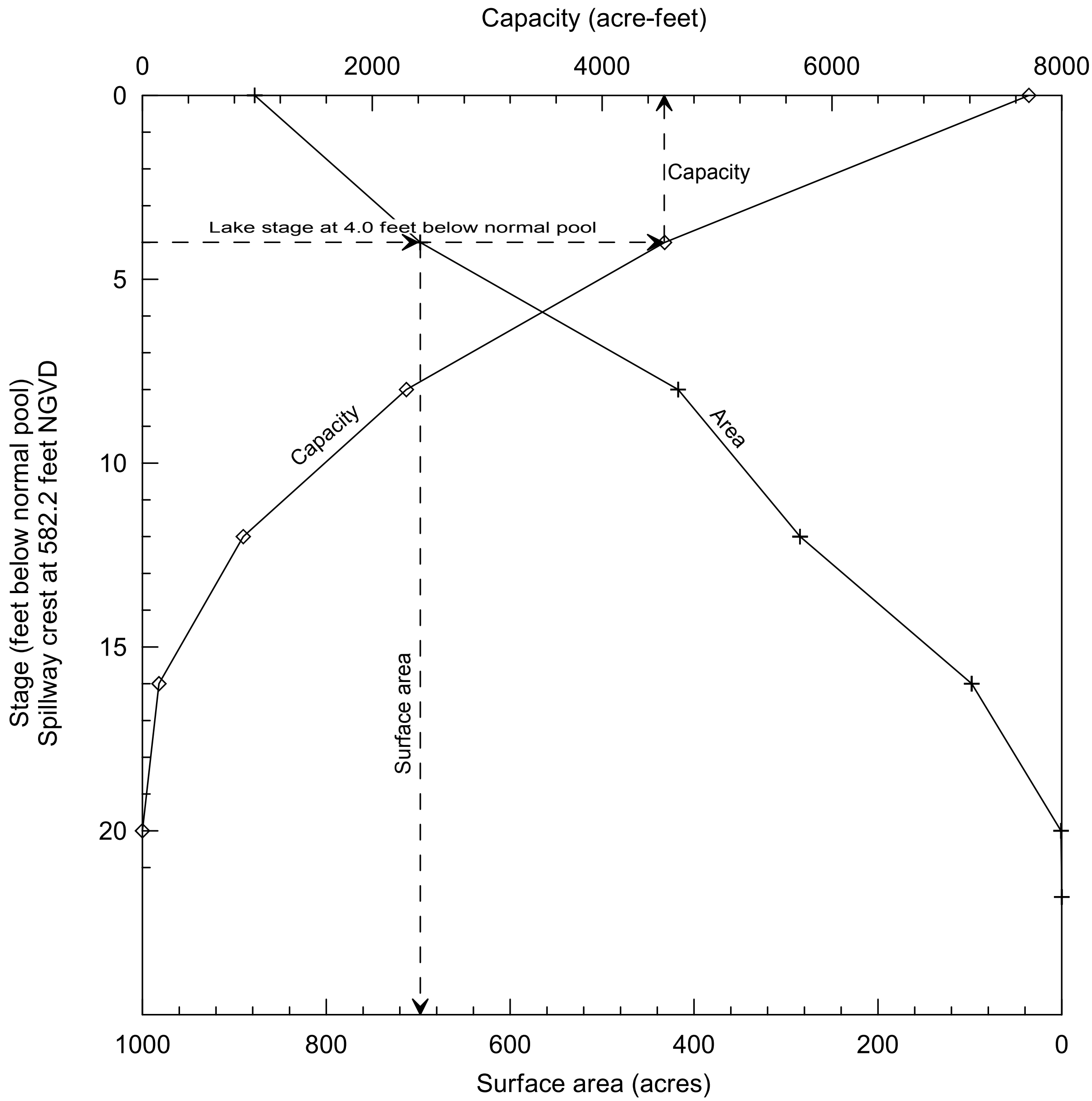


Figure 9. Stage vs. volume vs. area relationship for Lake Vermilion, 1998

Table 24. Computed Sediment Delivery Rates from the Watershed for Each Sedimentation Period

	Annual deposition rates			
Period	*acre-feet*	*acre-feet per square mile*	*cubic feet per acre*	*tons per acre*
1925-1963	89.5	0.30	20.4	0.52
1963-1976	50.2	0.17	11.5	0.28
1976-1998	53.9	0.18	12.3	0.28
1925-1998	71.8	0.24	16.4	0.40

Note: Total watershed area is 298 square miles.

Table 25. Capacity Loss Rates (percent) Relative to the Original Lake Capacity

Period	*Per period*	*Cumulative*	*Period annual loss*	*Cumulative annual loss*
1925-1963	25.7	25.7	0.68	
1963-1976	4.9	30.7	0.38	
1976-1998	9.0	39.7	0.41	0.54

Factors Impacting Lake Sedimentation Rates

Sedimentation rates in a lake can vary over time due to changes in either watershed or in-lake conditions. Changes in climatic and watershed conditions, such as altered precipitation patterns, land-use patterns, and streamflow variability, also affect the sediment delivery rates to the lake.

In-lake conditions that also impact sedimentation rates involve the variation of trap efficiency (due to reduced storage capacity) and sediment consolidation. Sedimentation conditions for Lake Vermilion are further complicated by the old dam that predated the present dam. This structure would have accumulated sediment in the upper end of Lake Vermilion prior to 1925. The annual rate of sedimentation of the lake prior to 1925 cannot be determined today.

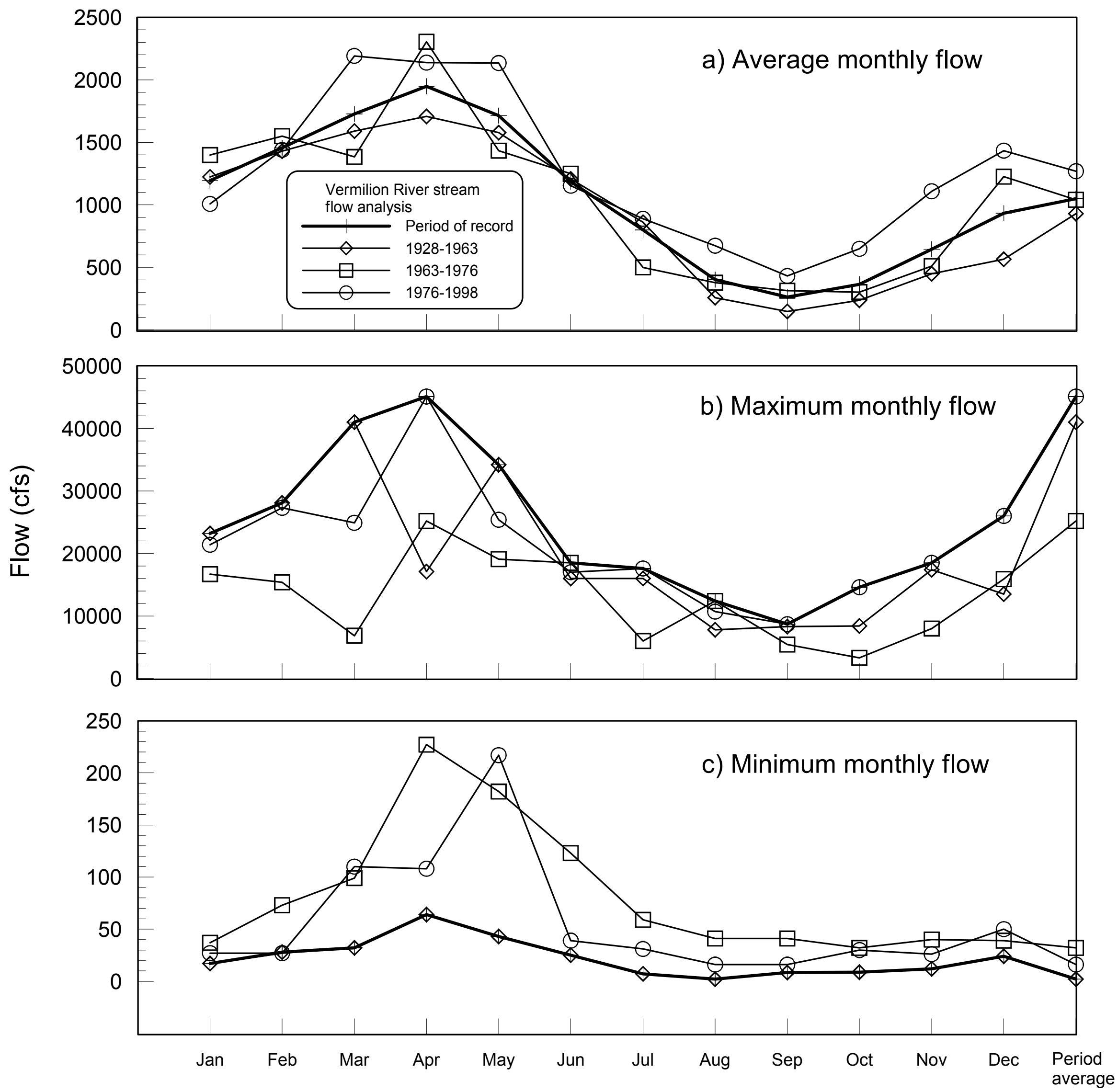
Due to the old lake's smaller size, it would have had a lower trap efficiency than the larger 1925 structure, and, therefore a lower accumulation rate.

As a rough estimate of the impact of the sedimentation of the old lake on the 1925-1963 sedimentation rates for Lake Vermilion, the 1963 sediment accumulation can be averaged over the 49 years from 1914 instead of the 38 years from 1925. The 49-year sedimentation rate is 69.4 ac-ft per year in contrast to the 89.5 ac-ft per year during the 38-year period. In reality, the sedimentation rate for the 1925-1963 period probably lies between these values.

Representative streamflow values for the Vermilion River at Danville from October 1928- September 1996 are shown in Figure 10. The most important of these plots for analysis of lake sedimentation are the maximum flows and the average flows. High sediment transport rates are closely related to peak water discharge periods (Demissie et al., 1983; Bhowmik et al., 1993).

The plots in Figure 10 indicate that average flows for most months have been higher during the most recent (1976-1998) sedimentation study period for Lake Vermilion. This observation is consistent with statistical analyses of streamflow records presented in IDNR (1999), which indicate that average streamflow since 1965 has been 20 percent higher than in previous years. This increase in flow was observed to coincide with an increase in annual precipitation. This suggests that sediment delivery to the lake should be somewhat higher during the latter two survey periods. Instead, the latter two survey periods show lower sedimentation relative to the 1925-1963 period. This suggests that other watershed conditions have been larger factors in determining Lake Vermilion sedimentation rates.

The trap efficiency (percentage portion of sediment captured by the reservoir) of the lake was determined using a predictive equation developed by Dendy (1974) based on the relationship between the annual capacity to inflow ratio and sediment-holding capacity. The trap efficiency of Lake Vermilion was 75 percent in 1925, meaning that 75 percent of all sediment entering the lake was trapped in the lake basin. In the following years, as sediment accumulation reduced the volume of the basin, the holding time for water entering the lake was reduced. This reduction in holding time meant that there was less time for sediment to drop out of suspension and the trap efficiency was reduced. By 1963 and 1976, the trap efficiency was reduced to 67



Note: Maximum and minimum lines and symbols for sub-periods are hidden when they are coincident with the period of record (heavier line) in the Figure.

Figure 10. Comparison of a) average monthly flow, b) maximum monthly flow, c) minimum monthly flow for the Vermilion River near Danville for the three sedimentation periods (1928-1963, 1963-1976, and 1976-1998) and the full record of the station

respectively. The 1991 increase in spillway elevation meant that the lake basin volume was again increased thereby increasing trap efficiency to 74 percent.

Gradual consolidation of lake sediments affects the calculated sedimentation rate of the lake by reducing the volume of accumulated sediments. Sediments accumulate on the bottom of the lake in a very loose, fluid mass. As these sediments are covered by continued sedimentation or are exposed by occasional lake drawdown, they are subject to compaction. This process reduces the volume of the sediments while increasing the weight per unit volume. Thus, the tonnage of the sediments accumulated during a period of time will not change, but the volume of the sediments may be reduced over time by up to 50 percent. This is also consistent with a reduced volumetric sedimentation rate over time. Consolidation of sediments would be most pronounced in the north end of Lake Vermilion. The exposure of sediment in the terrestrial deposits previously mentioned and the shallow water deposits that are subject to frequent exposure due to lake level drawdown would be consolidated on an annual basis.

Overall, sedimentation rates for Lake Vermilion were high for the initial period (1925-1963) with a possible range of 69 to 89 ac-ft per year. Sedimentation rates for subsequent periods (1963-1976 and 1976-1998) have been considerably lower with slight variations that may reflect variations in streamflow conditions.

Sediment Distribution

The distribution of sediment in the lake is shown in Table 26. This table lists the average sediment thickness and mass distribution for the lake and for each lake calculation segment as shown in Figure 7. Sediment thickness ranges from 2.3 to 9.3 feet. The most significant accumulation by either measure, depth or mass, is in the segments north of Denmark Road and north beyond the old dam.

Density analyses of the sediment samples (Appendix II, Bogner and Hessler, 1999) indicate that sediment north of the old dam has greater unit weight than sediment south of the old dam. In general, coarser sediments are expected to be deposited in the upstream portion of a lake where the entrainment velocity of the stream is reduced to the much slower velocities of a lake environment. These coarser sediments tend to be denser when settled and are subject to drying and higher compaction rates as a result of more frequent drawdown exposure in the shallow water environment. As the remaining sediment load of the stream is transported through the lake, increasingly finer particle sizes and decreasing unit weight are observed.

Sediment Particle Size Distribution

A total of 16 lakebed sediment samples were collected for particle size distribution analysis. The laboratory analyses for these samples are presented in Figure 11. The analyses shown in Figure 11a and 11b are particle size distribution plots for samples collected from the top surface of the accumulated sediments near the center of the designated cross section. These samples show extremely uniform characteristics south of the old dam area (Figure 11a). Surface sediment samples collected north of the old dam show a tendency to become slightly finer from upstream to downstream. This reduction in deposited sediment particle sizes is consistent with all other

Table 26. Sediment Distribution in Lake Vermilion

Segment from Figure 7	*Sediment accumulation (ac-ft)*	*Sediment weight (tons)*	*Sediment thickness (feet)*	*Sediment per segment acre (tons)*
1	19	13,769	7.1	5,296
2	137	110,387	7.9	6,344
3	560	464,383	5.6	4,648
4	66	54,647	6.1	5,060
5	692	609,088	6.2	5,497
6	125	120,385	2.6	2,498
8	671	648,726	8.1	7,844
9	876	770,804	9.2	8,071
11	598	836,437	9.3	13,069
12	267	368,044	6.7	9,224
13	22	29,223	4.9	6,641
14	154	207,648	4.8	6,469
15	195	267,294	6.3	8,622
16	233	320,873	6.8	9,382
17	283	381,766	4.9	6,548
19	341	420,928	2.3	2,879
Totals	5,238	5,624,404	6.0	6,406

Note: Several lake segments have been combined in this analysis. The segment number listed is the lower numbered segment.

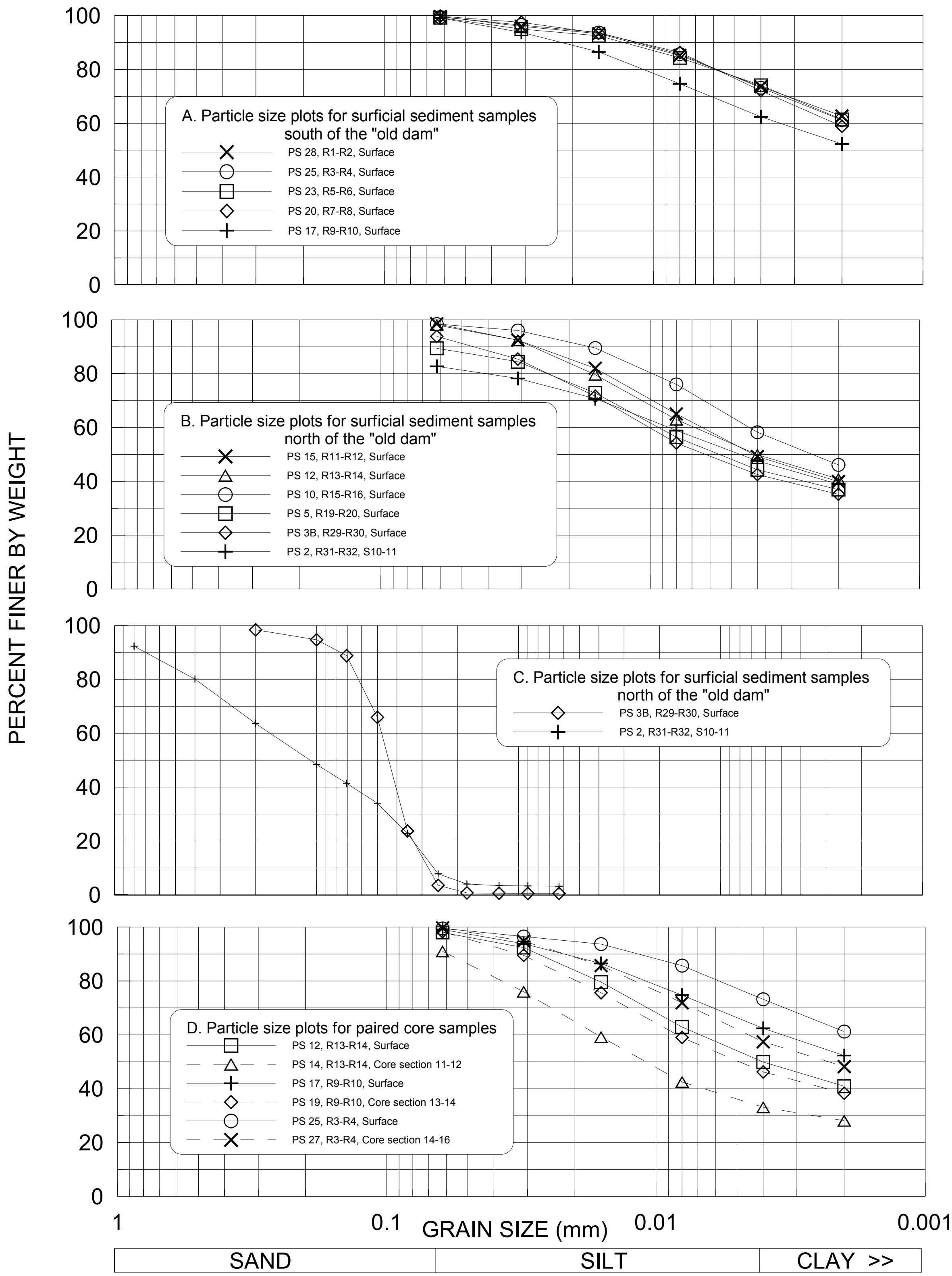


Figure 11. Particle size (ps) distributions for Lake Vermilion sediment samples

Illinois impoundment lakes for which particle size distribution data are available. This trend in particle-size distribution is a result of the natural sorting of suspended sediments in the lake environment. Coarser sediments are deposited as the inflowing stream water is first slowed upon entering the lake. As water moves through the lake, the suspended sediments become finer as the coarser-sized fractions fall out of suspension. At the dam, the suspended sediments are predominantly composed of colloidal and organic materials.

Field examination of two samples indicated sand size material (Figure 11c). Both samples were collected in the near-channel areas of the north end of the lake. All other samples were composed of clay and fine silt size sediment materials. This would be consistent with general observations concerning sediment distribution in Illinois lakes (Fitzpatrick et al., 1987; Bogner, 1986). These and other sources indicate that the occurrences of sand exceeding 10 percent are unusual for samples collected from lake sediments. In this case the sand was associated with the redevelopment of the stream channel since 1991.

Three sets of samples (Figure 11d) were collected to analyze vertical variations in particle size distribution. These samples show a temporal trend toward finer sediments in the surface layer at each sample site. This observation is counter to the usual trend in lake sediments. Surficial sediment, the most recently deposited sediment, tends to be coarser with time at a given point. This is due to the downlake shift in the initial depositional environment of the lake due to the loss of trap efficiency of the upper end of the lake. With time, the initial depositional zone in the lake will move further down the lake because of water volume loss to sedimentation. For Lake Vermilion, this tendency was interrupted by the 1991 spillway increase, which re-established upstream sediment storage capacity.

Hydrologic Budget

The hydrologic balance for Lake Vermilion, or any other lake system, takes the general form:

storage change = inflows - outflows

In general, inflows to the lake include direct precipitation, watershed runoff, ground-water inflow, and pumped input. Outflows include surface evaporation, discharge at the lake outlet, ground-water outflow, and withdrawals. Watershed runoff to the lake was gaged for the area upstream of the USGS station on the North Fork near Bismark. For this site, provisional discharge records were obtained from the USGS web site. Final data for this site will not be available in time for the completion of this study. The inflow for the portion of the watershed to the lake below the gage at Bismark was estimated using a watershed area ratio for the gaged watershed area.

For Lake Vermilion, pumped inputs is not a significant factor because there are no existing pumped inputs to the lake. Ground-water interaction both as inputs and outputs from the lake system has been noted in the geological discussion as potential factors. The groundwater interaction could not be adequately measured for this analysis but will be included in the discussion of undocumented factors. All other factors have been considered in developing an effective hydrologic budget for the lake.

Data necessary for evaluating various parameters to analyze the hydrologic fluxes for the lake were collected for a one-year period (May 2000-April 2001) during the diagnostic phase of the project. Table 27 presents monthly results of this monitoring. This analysis reflects the result of a one-year monitoring period and should not be construed to represent a long-term hydrologic or nutrient loading budget.

The following discussion of the lake level management system is based on personal observation of the system over a one-year period. It is presented only in the context of preparing a hydrologic budget and should not be construed as adequately describing the detailed operating protocols used by CIWC to manage the spillway and lake levels.

The lake level management system for Lake Vermilion is somewhat unique for Illinois water supply impoundments. Most water supply systems are designed to remove raw (untreated) water directly from an intake structure in the lake. Water releases downstream are generally limited to excess flow capacity when the lake storage requirement has been satisfied. At Lake Vermilion, there is a constant release of water at the spillway to maintain a flow to the treatment plant intakes 2.5 miles downstream. This release always includes some excess water that maintains some flow downstream of the treatment plant.

During storm flows, there is sufficient capacity at the spillway gates to pass almost any flow volume to maintain a stable lake level. The operation of the gates is coordinated by monitoring upstream flow rates and adjusting gate openings at any time interval necessary to maintain a stable lake level. For the one-year observation period, the operating system was very effective. In no case did the observed lake level exceed the projected pool level. Lake levels also never exceeded one foot below the projected pool level.

Since lake level variations were so small, storage factors were not major factors in the hydrologic analysis for either a monthly basis or the annual record. In most other years storage would be a significant factor in the analysis. As an example, in the Winter of 1999-2000 the lake level was down by over 4 feet.

Most elements of this analysis were evaluated on the basis of data collected during the monitoring period, including:

- Inflow to the lake for the area above the USGS gage was directly gaged (262 sq mi of the 298 sq mi drainage area).
- Inflow from the remaining non-lake area was estimated as a ratio of its area to the gaged area, (298-262-1.37)/262 or 13.2 percent.
- Direct precipitation on the lake surface was determined on the basis of the USWS precipitation record for Danville times the surface area of the lake, 1.37 sq mi or 878 acres
- Reservoir storage change was determined on the basis of direct monitoring of the lake level during the study. Data were collected by CIWC staff usually on a daily basis.

Table 27. Summary of Hydrologic Fluxes for Lake Vermilion, May 2000-April 2001

	Inflow						*Outflow*					
Date	*Discharge at Bismark** *ac-ft*	*Direct precipitation** *inches*	*Direct precipitation** *ac-ft*	*Total Measured inflow* *ac-ft*	*Ungaged portion* *ac-ft*	*Total inflow* *ac-ft*	*Discharge at spillway** *ac-ft*	*Evaporation rates* *inches*	*Evaporation rates* *ac-ft*	*Total outflow* *ac-ft*	*Storage* *ac-ft*	*Discrepancy* *ac-ft*
2000												
May	14,826	5.08	372	15,198	1,960	17,157	17,459	4.00	293	17,751	-9	-585
June	18,999	7.16	524	19,523	2,511	22,034	21,673	4.85	355	22,027	9	-2
July	10,712	0.63	46	10,758	1,416	12,174	11,183	5.50	402	11,585	158	430
August	2,658	1.95	143	2,800	351	3,151	2,566	4.71	345	2,911	-255	495
September	1,019	4.43	324	1,343	135	1,477	1,948	3.31	242	2,190	-325	-388
October	1,074	1.77	130	1,204	142	1,346	1,634	2.01	147	1,781	18	-453
November	3,339	3.45	252	3,592	441	4,033	3,916	0.82	60	3,976	492	-435
December	3,738	2.35	172	3,910	494	4,404	3,940	0.33	24	3,965	-351	791
2001												
January	12,085	0.84	61	12,146	1,597	13,743	9,018	0.31	23	9,041	35	4,667
February	54,629	2.90	212	54,841	7,220	62,062	66,499	0.61	45	66,544	184	-4,667
March	12,534	1.15	84	12,618	1,657	14,274	13,264	1.39	102	13,366	114	795
April	12,149	1.90	139	12,288	1,606	13,894	14,666	2.68	196	14,862	-79	-890
Annual	147,762	33.61	2,459	150,221	19,529	169,750	167,766	30.52	2,233	170,000	-9	-240

* -- Measured values

- Spillway discharge was also determined using records maintained by CIWC staff for water level and spillway gate openings.
- Evaporation was estimated using average monthly values for Urbana as determined by Roberts and Stall (1967).

These values were initially determined for time periods based on the frequency of measurement and were then combined into monthly values that could in turn be combined into annual values.

The summation of these analyses made for a monthly basis is presented in Table 27. Table 28 summarizes the hydrologic budget for the one-year monitoring period. The relative importance of each inflow and outflow component can be be seen in the measures of each value as a percentage of the total inflow volume. During this period, 1.5 percent of the inflow volume to the lake was direct precipitation on the lake surface, 87.0 percent was measured at the Bismark gaging station, and 11.5 percent was estimated runoff from the ungaged portion of the watershed. Outflow volume was 1.3 percent evaporation and 98.8 percent spillway discharge. The change in storage was less than 0.1 percent.

The discrepancy factor listed in the last column of Table 27 is resulted from minor discrepancies in the basic data set. These include such problems as discharge rating errors due to ice formation, precipitation and evaporation values, and the spillway discharge rating. The large discrepancies in January and February are due to the timing of a storm the affected the stream gage at Bismark on January 31 and the lake level on February 1. The annual discrepancy factor is less than 0.15 percent of the annual inflow/outflow volumes.

Sediment and Nutrient Fluxes

The sediment and nutrient fluxes for the lake were analyzed using the inflow and outflow volumes determined by the hydrologic analysis and the sediment and nutrient analyses from the one-year monitoring program. The laboratory results from the water samples collected during the field monitoring were compared to flow conditions. For the suspended sediment and the phosphorus load, sufficient data were collected and analyzed to define the variation of the constituent concentration with discharge rates and time by interpolating between data points. Analysis for total nitrogen concentrations appeared to be related more to seasonal factors rather than flow related factors. Nitrogen concentrations were determined by seasonal average values.

Determination of the suspended sediment and phosphorus inputs and suspended sediment, nitrogen, and phosphorus discharges from the lake was made using a series of interpolated concentration values between measured or inserted points in the time series. The interpolated concentrations were determined for each incremental discharge determined for the hydrologic analysis. The total nitrogen loading to the lake was determined using a seasonal average relationship as follows:

Total nitrogen

May 1, 2000 to July 15, 2000	13.0 mg/L
July 16, 2000 to August 15, 2000	7.5 mg/L

Table 28. Annual Summary of the Hydrologic Fluxes for Lake Vermilion, May 2000-April 2001

Source	*Inflow volume (acre-feet)*	*Outflow volume (acre-feet)*	*Inflow (percent)*	*Outflow (percent)*
Storage change	9			
Direct precipitation	2,459		1.5	
Surface inflow				
Gaged at Bismark	147,762		87.0	
Ungaged	19,529		11.5	
Spillway discharge		167,766		98.8
Evaporation		2,233		1.3
Totals	169,759	170,000		

Note: Percentages based on total inflow volume
Blank spaces – not applicable

August 16, 2000 to November 20, 2000	1.6 mg/L, and
November 21, 2000 to April 30, 2001	13 mg/L

Inserted points in the water quality data sets refer to the process of placing an unmeasured value for phosphorus and suspended sediment concentrations at the start of a storm event. This alters the application of the higher concentration values for these parameters to the storm discharges and not to the low flow period preceding the storm. For example, a low flow sediment concentration value may be collected a week before the start of a storm event. The next sediment concentration sample is collected during the storm event and reflects the higher sediment load due to the storm runoff. An inserted point at the initiation of the storm event extends the sediment concentration value of the preceding week to that point in the hydrograph improving the calculation of interpolated concentration values for that period.

For these water-based sites, concentration is in milligrams per liter. These concentrations were weighted by the incremental discharges corresponding to each concentration value to determine nutrient loading. The results of this analysis are summarized in Table 29 on a monthly basis and Table 30 for the May 2000 to April 2001 annual period.

For the one-year monitoring period, the sediment input from the watershed of 45,593 tons represented an annual yield of 0.24 tons per acre from the watershed. This input of sediment was offset by the discharge of 20,171 tons of sediment at the spillway. By subtraction of the outflow of sediment from the lake from the inflow to the lake, the sediment accumulation in the lake for the one year monitoring period was 25,422 tons. This is an accumulation of 0.133 tons for the year and is comparable to the annualized rate of 0.28 tons of sediment accumulation determined by the 1998 sedimentation survey and presented in Table 24.

No precipitation chemistry samples were collected for this study. Average precipitation chemistry results for a 1997-1998 study of Homer Lake in Champaign County were used to estimate direct precipitation chemistry inputs. These values were 13.9 mg/L of nitrogen and 1.6 mg/L of phosphorous (Lin and Bogner, .2000)

Total nitrogen load from the watershed was 2,580 tons, with an additional 47.4 tons of nitrogen from direct precipitation. This was offset by 1,837 tons of nitrogen discharged at the spillway. There were 791 tons of nitrogen (30.1 percent of the source nitrogen) deposited in the lake.

Total phosphorus input to the lake was 78.7 tons, of which 73.2 tons originated from watershed runoff and 5.46 tons came from precipitation. Spillway phosphorus discharge from the lake was 53.7 tons. There were 25 tons of phosphorus (31.7 percent of the source phosphorus) deposited in the lake.

One-hundred percent of sediment input to the lake and 98.2 and 93.1 percent, respectively, of the nitrogen and phosphorus input to the lake originate in the watershed. Just over 44 percent of the sediment input, 69.9 percent of the nitrogen input, and 68.3 percent of the phosphorus input to the lake leaves the lake in flow over the spillway.

Table 29. Monthly Summary of Sediment and Nutrient Fluxes for Lake Vermilion, May 2000 - April 2001

Nutrient inflow to the lake

Date	*At Bismark (gaged)*			*For ungaged area*			*For direct precipitation*		*Total inflow*		
	Sediment tons	*Nitrogen tons*	*Phosphorus tons*	*Sediment tons*	*Nitrogen tons*	*Phosphorus tons*	*Nitrogen tons*	*Phosphorus tons*	*Sediment tons*	*Nitrogen tons*	*Phosphorus tons*
2000											
April	107	57.9	0.66	14	7.7	0.09	3.6	0.41	121	69.2	1.16
May	6,255	270.7	7.18	827	35.8	0.95	7.0	0.81	7,082	313.5	8.93
June	3,236	324.8	4.43	428	42.9	0.59	9.9	1.14	3,664	377.7	6.15
July	1,829	181.1	2.02	242	23.9	0.27	0.9	0.10	2,071	206.0	2.39
August	56	21.2	0.43	7	2.8	0.06	2.7	0.31	63	26.7	0.79
September	18	2.1	0.21	2	0.3	0.03	6.1	0.70	20	8.5	0.94
October	6	2.4	0.18	1	0.3	0.02	2.4	0.28	7	5.2	0.48
November	21	19.7	0.41	3	2.6	0.05	4.8	0.55	23	27.1	1.01
December	56	68.3	0.51	7	9.0	0.07	3.2	0.37	63	80.5	0.95
2001											
January	5,240	213.5	7.87	693	28.2	1.04	1.2	0.13	5,933	242.9	9.04
February	23,108	871.8	39.17	3,054	115.2	5.18	4.0	0.46	26,162	991.0	44.80
March	339	245.1	1.61	45	32.4	0.21	1.6	0.18	384	279.1	2.01
Annual	40,271	2,278.8	64.67	5,322	301.2	8.55	47.4	5.46	45,593	2627.4	78.68

47.4 5.46

Table 29. Concluded

Date	*Discharge at spillway* Sediment *Tons*	Nitrogen *Tons*	Phosphorus *Tons*	*Deposition in Lake* Sediment *Tons*	Nitrogen *Tons*	Phosphorus *Tons*
2000						
April	57	14.9	0.19	65	54.3	0.97
May	1,687	151.3	2.02	5,395	162.2	6.92
June	1,247	350.6	2.81	2,417	27.1	3.34
July	454	176.8	0.99	1,617	29.1	1.40
August	18	21.2	0.10	45	5.4	0.69
September	43	6.4	0.13	-23	2.2	0.82
October	31	3.6	0.09	-24	1.6	0.40
November	73	9.8	0.32	-49	17.3	0.69
December	61	20.9	0.49	2	59.6	0.47
2001						
January	74	80.7	1.51	5,859	162.2	7.53
February	15,428	788.5	39.75	10,733	202.5	5.06
March	999	211.8	5.32	-615	67.3	-3.31
Annual	20,171	1,836.6	53.72	25,422	790.8	24.96

Table 30. Annual Summary of Sediment and Nutrient Fluxes for Lake Vermilion, May 2000 - April 2001

Source	**Sediment load** (tons)	(percent of total)	*Total nitrogen* (tons)	(percent of total)	*Total phosphorus* (tons)	(percent of total)
Annual sediment and nutrient inflows						
North Fork at Bismark	40,271	88.3	2,279	86.7	64.67	82.2
Ungaged area	5,322	11.7	301.2	11.5	8.55	10.9
Direct precipitation on the lake			47.4	1.8	5.46	6.9
Total	45,593		2,627		78.68	
Outflow at spillway	20,171	44.2	1,837	69.9	53.72	68.3
Deposition in lake	25,422	55.8	790.8	30.1	24.96	31.7

Note: Numbers in parentheses represent subtotals and are not included in the total.

Internal regeneration of phosphorus is a mechanism by which phosphorus held in the lake sediments becomes available for use in biological processes. The rate of release is dependant on the aerobic condition of the water-sediment interface. Highly anaerobic conditions are more conducive to the release of phosphorus from the sediments.

The USEPA recommends (USEPA, 1980) that internal regeneration of phosphorus can be estimated on the basis of a maximum range of values of 5 grams/meter^2/year (g/m^2/year) under aerobic conditions and 20 g/m^2/year under anaerobic conditions. The condition of the bottom waters at Lake Vermilion for the monitoring year was never severely anaerobic because thermal stratification never became established. Using the value of 5 g/m2/year, as much as 19.6 tons of phosphorus may have been regenerated from the sediments of Lake Vermilion during the monitoring year.

BIOLOGICAL RESOURCES AND ECOLOGICAL RELATIONSHIPS

Lake Vermilion and its surrounding woodland and a park provide habitat for fish, waterfowl, shorebirds, and other wildlife. The total area managed by the Vermilion Park District is approximately 1,400 acres, of which 878 acres is water surface. According to biologists, Lake Vermilion being a large lake is more attractive to wildlife. The abundance of natural community and species diversity is a significant attraction to many users of the area.

Two Illinois DNR's publications, "Vermilion River Area Assessment, Volume 3 – Living Resources (IDNR, 1999)" and "The Vermilion River Basin – An Inventory of the Region's Resources (IDNR, 2000) documented the natural resources in the Vermilion River Basin. These describe in detail the natural vegetative communities, birds, mammals, amphibians, and aquatic biota in the Vermilion River watershed. Common species as well as threatened and endangered species of plants and animals are listed.

Local Fauna

Fish

History. The construction of the lake was originally completed in 1925. Since 1940, the IDNR (formerly Illinois Department of Conservation) has conducted fish stocking in Lake Vermilion. Bass and bluegill were stocked in early 1940s. In addition, crappie, perch, and mixed fish have been stocked in later years. The records of the fish stocking with recent lake management activities are summarized in the cumulative history (first six pages) of Appendix F. Historically, fish stocked in the lake were bluegill, largemouth bass, white crappie, walleye, perch, bullhead, channel catfish, muskie, and mixed fish. The species of fish stocked in recent years were largemouth bass, muskie, and walleye.

A fish kill was recorded on June 30, 1964. There have been no recent fish kills reported. Fish flesh analyses were carried out by the Illinois EPA, recently (August 29, 1999) and during this study (August 21, 2000).

Appendix F also includes the recent (2002) Lake Management Primary Report prepared by the Illinois DNR. Reports include fishing regulations, fish stocking history, lake management plan progress, fish population survey, stocking success survey, creel surveys, and recommendations.

Fishing Rules. The Illinois DNR set the fishing rules as follow:

- Pole and line fishing only (per person), except that a sport fisherman may take carp and carpsuckers by pitchfork, gigs, bow and arrow, or bow and arrow devices north of Boiling Spring Road, but not within 300 feet around the wetland boardwalk.
- Two hooks or lures per pole.
- Trotline and jug fishing are allowed north of Boiling Spring Road.
- 15-inch minimum length on largemouth or smallmouth bass.
- 6 fish daily limit on largemouth or smallmouth bass.

- 9-inch minimum length on crappies.
- 25 fish daily limit on crappies.
- 48 inches length and one daily creel limit on muskie.
- All others - no limit

Population Survey. The IDNR has conducted three standard full fish population surveys at Lake Vermilion during recent years: in June 1996, June 1997, and May 2001. A level 1, long-term standardized fish population (community) survey was conducted on May 29, 2001. The lake was surveyed using an AC electrofishing boat for a total of 150 minutes on 3 pre-planned routes.

The species collected were enumerated, weighed, and measured in length. Species were then categorized into groups by length. Each length group was given a condition factor rating to estimate the overall health. The condition factor is a constant that relates height and width to length for estimation of the growth rates of fish. The statistical results of these three fish population surveys are presented in Appendix F. A total of 573 fish were collected during the 2001 survey. Longear sunfish, bluegill, largemouth bass, white crappie, gizzard shad, green sunfish, and yellow bass composed 21.5, 17.6, 16.5, 12.9, 10.3, 7.3, and 5.8 percent of fish population, respectively.

A general summary of the major fish species (largemouth bass, bluegill, and white crappie) collected from the 2001 survey follows. The Catch Per Hour (CPH) of electrofishing for largemouth bass was 41, which meets the objective of 40-60 per hour. The proportional stock density (PSD) is defined as number of quality size fish compared to whole catch fish population based upon bass 200 mm (8-inch) and longer. The PSD or percentage greater than 300 mm (12-inch) was 70 percent, which falls within the optimal range of 40-70 percent. The RSD-15 (relative stock density or percentage greater than 380mm (15-inch) was 33 percent which is above the optimal range of 10-30 percent. The body condition of the bass as expressed by relative weight was 95, which meets the 95-105 optimal range.

On October 3, 2001 a largemouth bass survey was conducted. The bass population was doing very well. The stocking program appears to be working very nicely in building up the largemouth bass population in Lake Vermilion.

The CPH for bluegill was 44, which is below the management objective of 100-250. Based on bluegill 80 mm (3") and longer, 54 percent were greater than 150 mm (6"). This is above the 20-40 percent optimal range. No bluegills were collected over 200 mm (8"). Body condition as expressed by relative weight was 102, which is within the optimal range of 95-105.

The CPH for white crappie was 29, which meets the objective of 25-50. Based upon crappie 130 mm (5") and longer, 7 percent were over 200 mm (8"). This value is below the optimal range of 40-60 percent. Of white crappie 130 mm and longer, one percent were longer than 250 mm. The optimal range for this size group is 10-20 percent. Body condition using relative weight was 87, well below the 95-105 optimal range. The crappie population is considered fair (average).

The walleye and muskie populations have a few fish left and offer a little hope to anglers for an additional species. The channel catfish population continues to be good. Channel catfish were removed from the contaminant list.

Recommendations are made to:

1. continue the largemouth bass stocking program,
2. maintain the current fishing regulations,
3. conduct a largemouth bass survey again in the fall, and
4. conduct fish community survey in May/June of 2003.

Fish Flesh Analyses. The primary concern in fish flesh analyses is the possibility of the bioaccumulation of toxic substances such as mercury, organochlorine, and other organochemicals in fish, which may prove detrimental to higher forms in the food chain including humans. In taking a preventive approach, the U.S. Food and Drug Administration (FDA) has adopted cancer-risk assessment guidelines as well as guidelines for other health effects (U.S. Food and Drug Administration, 1998). To protect the public from long-term health effects, states have used the FDA guidelines to establish threshold concentrations for organics and metals in fish tissues above which an advisory will be issued that the fish should not be consumed. The federal action levels are listed in Table 31.

Fish flesh samples were collected by the IDNR and analyzed by the Illinois EPA. Fish flesh analyses were performed for channel catfish fillets (without skin) on May 6, and August 29,

1999. During this study, fish flesh samples (fillets without skin) of carp and largemouth bass were analyzed on August 21, 2000; and samples of channel catfish were analyzed on November 2, 2000. The results of fish flesh analyses are given in Tables 31 and 32. Most of the organochlorine tests were below detection levels. Total chlordane, total DDT and analogs, dieldrin, total PCBs, and heptachlor epoxide concentrations were lower than the action levels.

Birds

The watershed is typical of primarily agricultural areas of east-central Illinois. Most non-agricultural habitats exist in narrow riparian areas where the terrain is too steep to plow, usually along the major steams and river systems. Bird species composition in the watershed is typical for agricultural portions of the state, breeding species have benefited from several large public land holdings. These areas contain a variety of grassland and wetland habitats, as well as restored prairies, riparian forest, upland forest, and open lake. Because a number of excellent birders operate in the area, far more is known about the birds here than in any other agricultural area. Approximately 270 bird species regularly visit the area. This represents approximately 90 percent of 300 species that regularly occur in the state (IDNR, 1999).

Out of these 300 species, 140 breed or formerly bred here (IDNR, 1999). Currently four state endangered species (northern harrier, upland sandpiper, short-eared owl, and Henslow's sparrow) and five state threatened species (pied-billed grebe, least bittern, red-shouldered hawk, brown creeper, and loggerhead shrike) breed here. In 2001 and 2002, several bald eagles nested in the upper lake area. While several species have disappeared from the area, including the

Table 31. Results of Fish Flesh Analyses from Lake Vermilion, 1999

Organics	*Channel catfish* 05/06/99	*Channel catfish* 08/29/99	*Federal action level*
Aldrin	0.01 k	0.01 k	
Total chlordane	0.06	0.05	0.3
Total DDT and analogs	0.07	0.07	5.0
Dieldrin	0.04	0.02	0.3
Endrin	0.01 k	0.01 k	
Total PCBs	0.1 k	0.1 k	2.0
Heptachlor	0.01 k	0.01 k	
Heptachlor epoxide	0.01 k	0.01 k	0.3
Toxaphene	1.0 k	1.0 k	
Methoxychlor	0.05 k	0.05 k	
Hexachlorobenzene	0.01 k	0.01 k	
Alpha-BHC	0.01 k	0.01 k	
Gamma-BHC	0.01 k	0.01 k	
Mirex	0.01 k	0.01 k	
Lipid content, percent	2.4	2.4	
Number of individual	4	4	
Sample weight, pounds	2.10	2.10	
Length, inches	19.5	22.2	

Notes: Unit – μg/g, unless specified, fillet samples
A k indicates that the actual value is known to be less than value given
BHC – benzene hexachloride
DDT – dichloro-diphenyl-trichloro-ethane
PCBs – polychlorinated biphenyls
Blank spaces – no data or not applicable

Table 32. Results of Fish Flesh Analyses from Lake Vermilion, 2000

Organics	*08/21/00* *Carp*		*Largemouth bass*		*11/02/00* *Channel catfish*	
Aldrin	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Total chlordane	0.04	0.02	0.02 k	0.02 k	0.04	0.04
Total DDT and analogs	0.05	0.03	0.01 k	0.02	0.06	0.04
Dieldrin	0.02	0.01	0.01 k	0.01 k	0.02	0.01
Endrin	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Total PCBs	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Heptachlor	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Heptachlor epoxide	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Toxaphene	1.0 k	1.0 k	1.0 k	1.0 k	1.0 k	1.0 k
Methoxychlor	0.05 k	0.05 k	0.05 k	0.05 k	0.05 k	0.05 k
Hexachlorobenzene	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Alpha-BHC	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Gamma-BHC	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Mirex	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k	0.01 k
Lipid content, percent	4.1	1.6	0.61	0.82	2.5	3.1
Number of individual	4	4	5	4	3	5
Sample weight, pounds	3.39	5.79	2.24	2.88	2.20	1.07
Length, inches	20.0	24.9	15.9	17.8	19.0	16.3

Notes: Unit – μg/g, unless specified, fillet samples
A k indicates that the actual value is known to be less than value given
BHC – benzene hexachloride
DDT – dichloro-diphenyl-trichloro-ethane
PCBs – polychlorinated biphenyls

passenger pigeon, Carolina parakeet, and greater prairie chicken, the wild turkey has been successfully reestablished, especially along the Middle Fork and Big and Little Vermilion River valleys where it nests in scrublands and prairies adjacent to forest (IDNR, 2000).

The habitat quality for birds is good but there is potential for improvement. For example, upland forests could be managed to maintain oak trees, and floodplain forests to maintain sycamores. A high priority in the basin should be to restore forested wetlands. Also, grasslands should be expanded to at least 100 acres and be burned or mowed on a three-year schedule to accommodate grassland birds. As the breeding habitat continues to improve, perhaps the sandhill crane, Swainson's hawk, and yellow-headed blackbird will return, not only as migrants, but once again to breed along the Vermilion River (IDNR, 2000).

Waterfowl. Canada geese (*Branta canadensis*) and ducks (mostly mallards, *Anas platyrhynchos*) migrate through Illinois in fall and spring. There are no quantitative data for bird populations in the study area. Waterfowl supported by the lake include migratory use by all species of common ducks, geese, and wading birds. Some shorebird use is noted in late summer on mud flats. Breeding bird use should include wood ducks, and green-backed herons.

Gwiazda (1996) reported that one gram of the feces of mallard ducks contains 8.5 mg P and 53.1 mg N. The mallard defecated 0.42 g of P and 2.62 g of N per day per individual in Poland. Manny et al. (1994) determined that the daily nutrient load to Wintergreen Lake, Michigan, by an average, migrant Canada goose was 24.86 g C (carbon), 1.57 g N, and 0.49 g P. They proposed annual P loading rate as follows:

$$\text{Annual P loading rate (in g/year)} = k \times UD$$

where $k = 0.49$ for geese

$= 0.22$ for dabbling duck

$= 0.19$ for diving duck

UD = effective use days

No waterfowl survey has been conducted by the Illinois DNR. However, according to Ken Konsis (Director of Vermilion County Conservation District, personal communication, 2000) there are approximately 100 resident ducks and 1,000 migrant geese around Lake Vermilion. The geese stay a few days to one week during the spring and fall migrations. It is not known whether resident population is dabbling or diving ducks.

Assuming k = 0.20 for 100 ducks with 50 percent use-day during a year, annual P loading rate by ducks is 3,650 g P/year (= 0.20 × 100 × 365 × 0.5) or 8.05 lb P/year. For 1,000 migrant geese, assuming the use-day is five each for spring and fall, annual P loading rate would be 4,900 g P/year (= 0.49 × 1,000 × 5 × 2) or 10.80 lb P/year. The total P loading rate by waterfowl is estimated of 8,550 g P/year or 18.85 lb P/year.

By proportion (using Manny et al nutrient ratios), annual N and C loading rates would be, respectively, 27,400 g N/year (= 8,550 × 1.57/0.49, or 60.4 lb N/year) and 434,000 g C/year (= 8,550 × 24.86/0.49, or 956 lb C/year).

For nitrogen and phosphorus, these values are 0.002 and 0.01 percent, respectively, of the annual nutrient input to the lake.

Mammals

Jack Williams wrote in the *History* of *Vermilion County,* "As late as 1857 there were a great many deer here. Wolves were as thick as rabbits as late as 1858. Of a flock of sheep which had gotten away from a man in the northern part of the township eighty were killed in one night by wolves." Wolves have been extirpated from the county and the state for quite some time, while the white tail deer has enjoyed a successful re-introduction (IDNR, 2000).

Forty-six species representing 78 percent of the state's 59 mammal species are known to be in the basin. Two species of these are listed as federally-endangered, the Indiana bat and the state-threatened river otter (IDNR, 1999). As part of the Illinois DNR's river otter re-introduction program, 30 otters were released in the basin between 1996 and 1997. The first released otter at Kennekuk County Park was witnessed by 2,000 interested spectators, many of whom had provided funding for the otters. Since then, otter sightings are reported in the Vermilion County Conservation District newsletter. In 1998 the newsletter reported that an adult with young was sighted in an area where otters had not been released, a promising sign for the otter's future in the Vermilion River basin (IDNR, 2000).

Mammal species known or likely to occur in the area are restricted to forested habitats. They are the hoary bat, eastern chipmunk, southern flying squirrel, woodland vole, gray fox, Virginia opossum, red bat, fox and gray squirrels, white-footed mouse, raccoon, and white-tailed deer (IDNR, 1999). Other bats, such as little brown bat, big brown bat, northern long-eared bat, eastern pipisstrelle, and evening bat forage in forested habitats and nest in trees or man-made structures such as buildings. The federally endangered Indiana bat has been found at two locations in the Vermilion River area. One of these is a maternity colony that roosts primarily between slabs of exfoliating bark on dead trees. Roost trees have been located in both upland

and floodplain forests; most of the trees are relatively large with a diameter at breast height of at least 30 cm (IDNR, 2000).

Mammal species restricted to prairie/grassland habitats are the least shrew, thirteen-lined and Franklin's ground squirrels, western harvest mouse, deer mouse, prairie and meadow voles, badger, southern shrew, northern short-tailed shrew, eastern cottontail, woodchuck, southern bog lemming, meadow jumping mouse, and red fox (IDNR, 1999).

Mammal species in the watershed requiring wetland or aquatic habitats are the beaver, muskrat, and river otter. Raccoons and opossums are most abundant in areas near water. Other species such as bats, southern shrew, northern short-tailed shrew, southern bog lemming, and meadow jumping mouse use emergent wetlands (IDNR, 1999).

Reptiles and Amphibians

Chester Loomis wrote, "Of reptiles, they have rattle-snakes, of two kinds, large and small; black snakes, copper heads, and the glass snake. The latter is a curiosity. Upon striking a slight blow with a small stick, it will generally break into several pieces." [The glass snake is actually a lizard with a break-away tail] (IDNR, 2000).

Twenty-three amphibian species and 27 reptile species occur in the Vermilion River watershed, representing 57 percent of the amphibian species and 45 percent of the reptiles that regularly occur in the state. The state-endangered silvery salamander (*Ambystoma platineum*) and the state- threatened four-toed salamander (*Hemidactylium scutatum*) are known to exist in the Vermilion River area. The status of the state-threatened Kirtland's snake (*Clonophis kirtlandii*) is uncertain, but the state-endangered eastern massasauga (*Sistrurus catenatus*) has been extirpated from the area due to the draining of prairie wetlands (IDNR, 1999). Jack Williams wrote, "There were lots badgers, rattlesnakes were everywhere. They were so plentiful that on a single farm a hundred were killed in one season. They were dangerous neighbors. They seem as adverse to civilization as any of the wild animals. As soon as the prairie grass was plowed or cultivated they disappeared. Scarcely any of them have been seen here since 1870" (IDNR, 2000).

The state-threatened four-toed salamander is associated with undisturbed forests containing seeps or bogs, although they may also be found near rocky, spring-fed creeks. Females congregate near woodland ponds in March and April for egg laying and brooding. The most common nest sites are in sphagnum mats, but grass hummocks, leaf litter, rotten logs and undercut stream banks are also used. The nests are situated so the larvae fall directly into the water when the eggs hatch. The main threat to this species is draining the breeding ponds or artificially stocking them with fish.

The Middle Fork Woods Nature Preserve, a remnant of the vast mesic forest that once occurred in the area, harbors the state's only native colony of the endangered silvery salamander. This salamander inhabits underground burrows and runways constructed by rodents and shrews in forested areas. During late winter adults come to the surface and migrate to woodland ponds and wetlands to reproduce during late winter: These ponds must be fishless and retain water until the aquatic larvae transform into terrestrial juveniles, usually in mid-June. What makes the silvery salamander unique is that it requires the presence of the smallmouth salamander to stimulate embryonic development. Silvery salamanders have no males. The population at the Middle Fork shares this bizarre characteristic with silvery salamanders in other of its range, but takes it one step further - it interbreeds with the smallmouth salamander.

River Biota

The Vermilion River and its tributaries support a large diversity of aquatic species: 97 species of fishes, 45 species of mussels, 16 species of large crustaceans, and 540 species of aquatic macroinvertebrates (IDNR, 1999).

Chester Loomis again writes, "Fish in great numbers are every where swimming in its waters. Some of them of 15 or 20 pounds weight" (IDNR, 2000). Today, the headwaters are dominated by creek chubs and orangethroat darters; the creeks by spotfin, sand and striped shiners, stonecats, and jonny darters; and the larger river habitats by bluntnose minnows, golden redhorses, longear sunfish, and spotted bass. Listed species from the area include the state-threatened river redhorse and the state- endangered bigeye chub, bigeye shiner, river chub, northern madtom, Iowa darter, eastern sand darter, and bluebreast darter (IDNR, 1999). The bluebreast darter is found in Illinois only within the Vermilion River area. Once near extirpation in Illinois, this species has made a dramatic comeback following recent improvements in water quality (IDNR, 2000).

The North Fork Vermilion River supports the greatest concentration of rare, threatened, or endangered mussels in Illinois and its protection is crucial to the continued survival of those species. A ten square mile area in Vermilion County supports as many freshwater mussel species as the entire Illinois River. Ten endangered mussel species are still thought to be present in the drainage - slippershell, clubshell, rabbitsfoot, wavy-rayed lampmussel, round hickorynut, kidneyshell, purple lilliput, rayed bean, rainbow, and little spectaclecase. Many of these are found nowhere else in Illinois. The clubshell, also listed as federally endangered, was thought to have been extirpated from the state, but in September 1998 a live clubshell was found in the North Fork Vermilion River. This is the only known population of clubshell in the state (IDNR, 2000).

Local Flora

The native vegetation of the Vermilion River area was mostly tall grass prairie. Forest, savannas, and wetlands were concentrated primarily on the slopes, ravines, and bottomlands. Beginning with the flowering of skunk cabbage in late February, to the final goldenrods of Indian Summer, the Vermilion River basin is a curious mix of plant species.

Twenty-eight percent of the state's flora (908 taxa) grow in the basin. Four state-threatened species (fibrous-rooted sedge, drooping sedge, Willdenow's sedge, and false hellebore) and two state-endangered plants (Wolf's bluegrass and queen of the prairie) are found here. Several populations of fibrous-rooted sedge and false hellebore are found in the Vermilion River area, whereas queen of the prairie is represented by 50 plants and drooping sedge by 20 plants, each in a single location (IDNR, 1999). The population of Wolf's bluegrass is found at the base of a seep that has been actively slumping. As a result, the population is not secure and it could soon be extirpated. Five species that occurred historically within the area have been extirpated for many years - heartleaved plantain, prairie dandelion, white lady's slipper, showy lady's slipper, and buffalo clover (IDNR, 2000).

Forest

Approximately 5.2 percent of Vermilion River watershed remains in forest cover currently. There are nine natural preserves in Vermilion County. Certain native species (black snakeroot and honewort) are often abundant in grazed forests. Other plants are honey locust, Missouri gooseberry, prickly ash, red haw, and Rubus spp. Exotic species are garlic mustard, Japanese barberry, multiflora rose and Osage orange.

The dominant canopy species in dry upland forests are white oak and black oak. Occasional species include Chinquapin oak, red cedar, shagbark hickory, mockernut hickory, pignut hickory, shingle oak, and white ash.

Common to occasional canopy species in floodplain forest include American elm, bitternut hickory, black walnut, box elder, cottonwood, green ash, hackberry, honey locust, mockernut hickory, pin oak, silver maple, and slippery elm. Subcanopy species include red haw and red mulberry. Shrubs and vines include common blackberry, elderberry, bristly catbrier, leatherflower, poison ivy, riverbank grape, and trumpet creeper.

Prairie

Approximately 8.5 percent of Vermilion River watershed is tallgrass prairie. Common grass in dry-mesic prairie include crested hair grass, Indian grass, little bluestem, panic grass, porcupine grass, and prairie dropseed. Common grass species in the mesic prairie include big bluestem, Indian grass, little bluestem, panic grass, porcupine grass, prairie dropseed, and prairie switch grass.

Common grass species in wet-mesic prairie include big bluestem, blue-joint grass, Indian grass, and prairie cord grass. Blue-joint grass and prairie cord grass also are characterized as wet prairie grass species. Big bluestem, Indian grass, little bluestem, poverty oak grass, and side oaks gramma are found in hill prairie areas (IDNR, 1999).

Prairies support not only the common species of prairie dock, coneflower, and big bluestem, but also the unusual species, such as Indian paintbrush and ladies' tresses orchids. Here species are present that are restricted to rich forest habitats - squirrel corn, Gleason's trillium, celandine poppy, and hepatica. Also present are species that are of extremely limited occurrence in Illinois - squaw root, fire pink, yellow lady's slipper and beech drops, a parasite of the equally restricted American beech (IDNR, 2000).

Savanna

Savannas are characterized by scattered, open-grow trees, with or without shrubs, and a continuous herbaceous groundcover typically dominated by graminoid species (grasses and sedges) and numerous forbs. Three savannas subclasses are recognized in Illinois: savanna (generally on fine-textured soils), sand savannas and barrens (prairie flora on shallow soils, within an otherwise forested landscape). The common species in dry-mesic savana include oak and white oak. The occasional species are black cherry, blue ash, chinquapin oak, sassafras, shagbark hickory, shingle oak, and white ash. A few rare plants occur in savanna habitats include buffalo clover, ear-leafed foxglove, and prairie trout-lily.

Species established in mesic savanna include American elm, basswood, blue ash, hackberry, honey locust, red oak, sassafras, shagbark hickory, slippery elm, sugar maple, white oak, and yellow poplar (IDNR, 1999).

Wetland

There are approximately 9,438 acres of wetland in the Vermilion River watershed. Wetland community classifications include mesic, wet-mesic, wet floodplain forest (about 64 percent of total), marsh (17.3 percent), swamp, shrub swamp, seep, calcareous seep, and spring.

Characteristics graminoid species in marsh include the grasses fowl manna grass, prairie cord grass, reed canary grass, Virginia wild rye, several species of sedges. Common forb and other monocot species include arrowleaf, blue flag, clearweed, common boneset, common cattail, common water horehound, field mint, fog fruit, groundnut, pale dock, swamp milkweed, sweet flag, water hemloak, and water smartweed. Black willow, green ash, and silver maple are common trees associated with marshes in the area.

Within the Vermilion River watershed, dominant canopy species are black ash, green ash, and silver maple. Occasional trees include American elm, cottonwood, Ohio buckeye, swamp white oak, and sycamore. The dominant shrub species is bottom bush. Occasional shrubs include bladdernut, hazelnut, Missouri gooseberry, prickery ash, and spicebush.

Common herbaceous species include beggar ticks, bitter cress, blue flag, blue skullcap, clearweed, common beggar ticks, common water plantain, dotted smartweed, duckweed, grasses, green stemmed Joe Pye weed, late goldenrod, panicled aster, sedges, sensitive fern, shining bedstraw, side-flowered aster, spotted touch-me-not, three seeded mercury, water parsnip, white avens, and yellow water crowfoot (IDNR, 1999)

Seeps are wetland communities characterized by a constant diffused flow of groundwater, typically from the lower portions of slopes of glacial moraines, ravines, and terraces. Three high quality seep communities are found in the Vermilion River area and all three are nature preserves. Howards Hollow Seep is a one-acre wetland in the 30-acre Forest Glen Forest Preserve. Forest Glen Seep is a seep community on a terrace above the Vermilion River in the northeast corner of Forest Glen Forest Preserve. The third seep community is found within Windfall Prairie natural Preserve.

Herbaceous species in seep and swamp areas include a diverse assortment of graminoid. Forb species including arrowleaf, blue lobelia, blue skullcap, bog clearweed, bulrush, common boneset, common cattail, cup plant, dotted smartweed, false nettle, fen thistle, goldenglow, honeset, late goldenrod, grasses (fowl manna grass, reed canary grass, rice cutgrass, stout wood reed, white grass), marsh fleabane, marsh marigold, panicled aster, sedges, side-flowered aster, skunk cabbage, spotted touch-me-not, swamp buttercup, swamp milkweed, sweet-scented bedstraw, water parsnip, and white avens. Woody plants include alternated leaved dogwood, American elm, black ash, gray dogwood, green ash, pale dogwood, poison ivy, riverbank grape, and Virginia creeper.

Common species of macrophytes include American bulrush (Scirppus americanus), beggar ticks, bog clearweed, clearweed, common boneset, common cattail, common horsetail, common mountain mint, Dudley's rush, grass-of-Parnassus, grasses (common red reed, rice cut grass), Jerusalem artichoke, nodding beggar ticks, pale dock, Riddel's goldenrod, rough-leaf goldenrod, sedges, scouring rush, side-flowered aster, spotted touch-me-not, white turtlehead, scouring rush, spotted Joe-Pye weed, swamp wood betony, and whorled loosestrife. Occasional shrubs include hert-leaved willow and sandbar willow (IDNR, 1999).

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Appendix A. Historical Water Quality Characteristics in Lake Vermilion

Appendix A1. Historical Water Quality Characteristics in Lake Vermilion Station 1 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
07/02/77	0		21.6	580	8.00	160		15	5	0.00		3.00			
06/28/79	1	5.5	22.0	630	7.55	210	0	8	3	0.06	0.80	5.10	0.050	0.020	
09/05/79	1	5.2	16.0	434	8.50	160	0	11	3	0.01	1.00	3.80	0.050	0.010k	14.0
05/18/83	1	15.0	10.0	507	7.60	170	0	19	8	0.10k	0.80	8.00	0.110	0.101	12.5
04/21/97	1	8.0	24.0	565	8.10	190	10	19	6	0.04	0.69	7.80	0.040	0.010	20.0
06/09/97	1	17.0	12.0	537	7.50	170	0	30	5	0.12	0.97	12.30	0.107	0.053	20.0
07/14/97															
08/12/97	1	16.0	18.0	437	7.80	154	0	20	4	0.50	0.88	2.10	0.084	0.026	19.0
10/22/97	1	20.0	18.0	472	8.50	196	10	17	5	0.27	0.94	0.12	0.096	0.026	18.0
Count		7	8	8	8	8	7	8	8	8	7	8	7	7	6
Maximum		20	24	630	8.5	210	10	30	8	0.50	1.00	12.30	0.110	0.101	20
Minimum		5.2	10	434	7.5	154	0	8	3	0.00	0.69	0.12	0.040	0.010	12.5
Average		12.4	17.7	520		176	3	17	5	0.14	0.87	5.28	0.077	0.035	17.3
S.D.		6.0	4.9	70		20	5	7	2	0.17	0.11	3.91	0.030	0.032	3.2

Notes: NTU – nephelometric turbidity unit, μmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix A2. Historical Water Quality Characteristics in Lake Vermilion Station 2 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
07/02/77	0		15.6	590	8.4	168		23	6	0.10		2.40	0.110		
06/28/79	1	32.0	10.0	595	8.0	110	0	68	27	0.03	2.50	4.20	0.280	0.020	
09/05/79	1	3.6	12.0	515	8.4	190	0	15	4	0.02	0.70	3.80	0.060	0.010k	7.0
05/18/83	1	16.0	10.0	550	7.6	195	0	59	9	0.10k	1.00	8.80	0.114	0.054	6.5
04/21/97	1	6.1	18.0	578	8.0	210	0	19	6	0.06	0.69	7.70	0.035	0.008	10.0
06/09/97	1	11.0	6.0	426	7.4	120	0	80	14	0.14	1.14	11.20	0.244	0.110	20.0
07/14/97	1	7.2	26.0	428	8.2	174	6	18	6	0.06	0.87	6.20	0.054	0.009	11.0
08/12/97	1	17.0	18.0	444	8.0	162	0	19	5	0.34	0.67	1.78	0.069	0.018	10.0
10/22/97	1	19.0	24.0	474	8.6	200	16	11	3	0.21	1.10	0.01k	0.073	0.018	9.0
Count		8	9	9	9	9	8	9	9	9	8	9	9	8	7
Maximum		32	26	595	8.6	210	16	80	27	0.34	2.5	11.2	0.280	0.110	20
Minimum		3.6	6	426	7.4	110	0	11	3	0.02	0.67	0.01	0.035	0.008	6.5
Average		14.0	15.5	511		170	3	35	9	0.12	1.08	5.12	0.115	0.031	10.5
S.D.		9.2	6.7	70		35	6	26	8	0.10	0.60	3.63	0.087	0.035	4.5

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix A3. Historical Water Quality Characteristics in Lake Vermilion Station 3 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
07/02/77	0		6.0	620	8.4	198		97	16	0.00		1.20	0.300		
06/28/79	1	37.0	6.0	610	7.8	220	10	66	16	0.02	2.10	3.70	0.240	0.020	
09/05/79	1	30.0	6.0	660	8.0	280	0	58	5	0.03	0.70	3.60	0.160	0.070	3.0
05/18/83	1	14.0	7.0	596	7.6	215	0	52	5	0.10k	0.80	1.30	0.098	0.028	2.5
04/21/97	1	8.0	16.0	585	8.0	210	0	14	5	0.13	0.64	7.40	0.035	0.007	5.0
06/09/97	1	22.0	6.0	402	7.3	125	0	86	12	0.13	1.60	11.30	0.304	0.155	5.0
07/14/97	1	15.0	14.0	521	8.0	182	8	36	6	0.09	0.87	5.70	0.083	0.018	5.0
08/12/97	1	13.0	10.0	460	7.9	168	0	78	14	0.45	0.84	1.11	0.142	0.032	5.0
10/22/97	1	17.0	16.0	496	8.6	200	10	23	6	0.21	1.10	0.01k	0.102	0.018	3.0
Count		8	9	9	9	9	8	9	9	9	8	9	9	8	7
Maximum		37	16	660	8.6	280	10	97	16	0.45	2.1	11.3	0.304	0.155	5
Minimum		8	6	402	7.3	125	0	14	5	0.00	0.64	0.01	0.035	0.007	2.5
Average		19.5	10	550		200	4	57	9	0.13	1.08	3.92	0.163	0.044	4.1
S.D.		9.7	4	85		42	5	28	5	0.14	0.51	3.66	0.097	0.049	1.2

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,

Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix A4. Historical Water Quality Characteristics in Lake Vermilion Station 1 Bottom

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
07/02/77															
06/28/79	14	20.0		630	7.31	230	0	20	4	0.24	0.90	4.50	0.080	0.040	
09/05/79	12	9.1		517	7.50	170	0	16	4	0.10	0.70	4.10	0.050	0.010k	
05/18/83	10	24.0		542	7.50	190	0	35	5	0.10k	0.80	8.40	0.123	0.065	
04/21/97	18	7.4		565	7.90	200	10	15	6	0.07	0.64	7.70	0.033	0.007	18.0
06/09/97	18	10.0		539	7.50	186	0	34	6	0.21	0.97	12.00	0.106	0.053	19.0
07/14/97															
08/12/97	17	14.0		451	7.40	164	0	28	5	0.54	0.75	1.92	0.101	0.035	20.0
10/22/97	16	18.0		474	8.30	200	10	16	3	0.23	0.77	0.12	0.082	0.025	20.0
Count		7		7	7	7	7	7	7	7	7	7	7	7	4
Maximum		24.0		630	8.3	230	10	35	6	0.54	0.97	12.00	0.123	0.065	20
Minimum		7.4		451	7.3	164	0	15	3	0.07	0.64	0.12	0.033	0.007	18
Average		14.6		531		191	3	23	5	0.21	0.79	5.53	0.082	0.034	19
S.D.		6.2		59		22	5	9	1	0.16	0.11	4.09	0.032	0.021	1

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,

Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix B. Current Water Quality Characteristics in Lake Vermilion

Appendix B1. Current Water Quality Characteristics in Lake Vermilion Station 1 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/08/2000	1	8.6	28	544	8.2	174	5	11	6	0.01k	0.49	2.4	0.037	0.017	18
05/25/2000	1		20					14	7	0.01k	1.18	2.7	0.039		21
06/06/2000	1		8	484	7.5	170	0	35	7	0.15	1.44	12	0.134	0.088	19
06/13/2000			14												
06/22/2000	1							14	4	0.01k		10		0.021	20
07/12/2000	1		24	485	7.9	200	0	11	5	0.15	1.12	9.3	0.029	0.005	18
07/26/2000	1							11	8	0.01	0.4	7.7	0.04		20
08/02/2000	1		28	463	8	140	0	2	2	0.01k	0.9	6.39	0.024	0.008	19
08/08/2000			26												
08/29/2000			16												
09/13/2000	1		18					15	8	0.01k	1.04	1.3	0.046		20
09/28/2000	1		16					22	4	0.01k	0.95	1.05	0.063		20
10/03/2000	1	14.3	24	456	8.05	200	0	16	5	0.01k	1.01	0.87	0.042	0.02	19
10/12/2000			12												
10/24/2000	1		22					11	6	0.01k	1	0.25	0.032		20
11/15/2000	1		18					15	4	0.34	0.93	0.43	0.062		21
01/29/2001	1		42					5	4	0.55	1.22	5.1	0.127		21
03/28/2001	1		14					16	3	0.07	1.26	9.2	0.081		20
04/19/2001	1		16					26	4	0.15	1.68	12	0.087		20
04/26/2000			24												
Count		2	18	5	5	5	5	15	15	7	14	15	14	6	15
Maximum		14.3	42	544	8.2	200	5	35	8	0.55	1.68	12	0.134	0.088	21
Minimum		8.6	8	456	7.5	140	0	2	2	0.01	0.4	0.25	0.024	0.005	18
Average		11.5	20.6	486.4	7.9	176.8	1.0	14.9	5.1	0.20	1.04	5.38	0.1	0.027	19.7
S.D.		4.0	7.8	34.6	0.3	24.9	2.2	8.0	1.8	0.18	0.33	4.38	0.0	0.031	1.0

Notes: NTU – nephelometric turbidity unit, μmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix B2. Current Water Quality Characteristics in Lake Vermilion Station 2 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/08/2000	1	13.2	18	554	8.2	185	0	20	12	0.06	0.06	0.44	0.041	0.016	11
05/25/2000	1		16					16	7	0.01k	1.14	3.3	0.037		11
06/06/2000	1		8	622	7.8	180	0	44	5	0.01k	1.13	14	0.095	0.071	5
06/13/2000			14												
06/22/2000	1							16	5	0.01k	0.7	9.9	0.029		11
07/12/2000	1		20	509	8.1	180	0	14	5	0.08	1.51	9.7	0.035	0.01	11
07/26/2000	1							15	9	0.01k	1.08	7.2	0.046		11
08/02/2000	1		20	473	8.2	170	0	2	2	0.01k	0.74	5.7	0.042	0.008	10
08/08/2000			16												
08/29/2000			16												
09/13/2000	1		12					22	7	0.01k	0.75	1.1	0.053		11
09/28/2000	1		14					19	4	0.01k	1.06	0.86	0.052		11
10/03/2000	1	15.1	18	451	8.32	180	5	18	6	0.01k	1.02	0.63	0.04	0.015	10
10/12/2000			18												
10/24/2000	1		18					13	6	0.01	1.23	0.17	0.03		11
11/15/2000	1		16					14	4	0.2	0.81	0.21	0.061		11
01/29/2001	1		42					6	3	0.19	0.9	5.5	0.084		11
03/28/2001	1		15					16	3	0.01k	1.41	9.5	0.072		11
04/19/2001	1		10					21	4	0.24	1.35	9.9	0.098		11
04/26/2000			16												
Count		2	18	5	5	5	5	15	15	6	15	15	15	5	15
Maximum		15.1	42	622	8.32	185	5	44	12	0.24	1.51	14	0.098	0.071	11
Minimum		13.2	8	451	7.8	170	0	2	2	0.01	0.06	0.17	0.029	0.008	5
Average		14.2	17.1	521.8	8.1	179.0	1.0	17.1	5.5	0.13	0.99	5.21	0.1	0.024	10.5
S.D.		1.3	7.0	68.3	0.2	5.5	2.2	9.1	2.6	0.09	0.36	4.61	0.0	0.026	1.6

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,

Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix B3. Current Water Quality Characteristics in Lake Vermilion Station 5 Surface

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as CaCO3)*	*Phenolph-thalein alkalinity (mg/Las CaCO3)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/08/2000															
05/25/2000	1		16					23	5	0.01k	0.89	9.5	0.041		6
06/06/2000	1		10	655	7.8	240	0	27	6	0.01k	0.76	14	0.097	0.067	6
06/13/2000			14												
06/22/2000	1							64	8	0.01k	0.97	12	0.163		5
07/12/2000	1		12	490	7.9	250	0	20	4	0.01k	0.96	11	0.085	0.063	6
07/26/2000	1							21	8	0.01k	1.02	6.6	0.035		6
08/02/2000	1		16	540	8.3	220	5	13	7	0.01k	0.64	4	0.033	0.01	6
08/08/2000			10												
08/29/2000			8												
09/13/2000	1		8												
09/28/2000	1		10					26	6	0.01k	1.39	0.41	0.067		6
10/03/2000	1	30.4	16	514	8.21	225	0	26	7	0.01k	1.32	0.29	0.055	0.022	5
10/12/2000			12												
10/24/2000	1		12					23	8	0.01k	1	0.04	0.046		6
11/15/2000	1		16							0.08	0.55	8.1	0.102		6
01/29/2001	1		54					4	2	0.01k	0.57	7.7	0.064		5
03/28/2001	1		60					7	1	0.06	0.84	9.9	0.029		6
04/19/2001	1		16					32	4	0.14	0.8	11	0.071		6
04/26/2000			10												
Count		1	17	4	4	4	4	12	12	3	13	13	13	4	13
Maximum		30.4	60	655	8.3	250	5	64	8	0.14	1.39	14	0.163	0.067	6
Minimum		30.4	8	490	7.8	220	0	4	1	0.06	0.55	0.04	0.029	0.01	5
Average		30.4	17.6	549.8	8.1	233.8	1.3	23.8	5.5	0.09	0.90	7.27	0.1	0.041	5.8
S.D.			15.1	73.1	0.2	13.8	2.5	15.1	2.4	0.04	0.26	4.72	0.0	0.029	0.4

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix B4. Current Water Quality Characteristics in Lake Vermilion Station 1 Bottom

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/08/00	16	4.2		566	7.5	200	0	20	10	0.24	0.89	2.1	0.045	0.014	18
05/25/00	19							19	3	0.64	1.32	2.8	0.073		21
06/06/00	17			482	7.5	165	0	46	7	0.04	1.59	12.0	0.135	0.088	19
06/22/00	18							38	7	0.01k	0.77	9.9	0.045		20
07/12/00	16			488	7.9	200	0	13	4	0.01	1.21	9.4	0.028	0.006	18
07/26/00	18							24	7	0.16	3.00	7.3	0.052		20
08/02/00	17			463	8	140	0	8	4	0.17	0.95	5.9	0.028	0.005	19
09/13/00	18							22	6	0.01k	0.75	1.4	0.049		20
09/28/00	18							27	5	0.01k	0.96	1.04	0.067		20
10/03/00	17	76.8		456	8.05	200	0	15	5	0.01k	0.97	0.88	0.041	0.021	19
10/24/00	18							34	6	0.26	1.36	0.38	0.054		20
11/15/00	18							15	5	0.23	0.77	0.13	0.055		21
01/29/01	19							2	2	0.23	0.89	5.0	0.066		21
03/28/01	18							18	4	0.08	1.59	9.3	0.084		20
04/19/01	18							28	4	0.17	1.45	9.8	0.112		20
Count		2		5	5	5	5	15	15	15	15	15	15	5	15
Maximum		76.8		566	8.05	200	0	46	10	0.64	3.00	12.00	0.135	0.088	21
Minimum		4.2		456	7.5	140	0	2	2	0.01	0.75	0.13	0.028	0.005	18
Average		40.5		491		181	0	22	5	0.15	1.23	5.16	0.062	0.027	20
S.D.		51.3		44		27	0	11	2	0.17	0.57	4.17	0.030	0.035	1

Notes: NTU – nephelometric turbidity unit, μmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given

Appendix B5. Current Water Quality Characteristics in Lake Vermilion Station 1 Mid-Depth

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/08/00	9	7.9		548	8	200	0	16	10	0.11	0.62	2.4	0.037		18
05/25/00															
06/06/00	8			481	7.5	170	0	40	5	0.11	1.74	12.0	0.135		19
06/22/00															
07/12/00	9			487	7.9	200	0	12	4	0.01k	1.38	9.4	0.024	0.004	18
07/26/00															
08/02/00	9			465	7.8	150	0	4	3	0.01k	0.88	6.3	0.026	0.005	19
09/13/00															
09/28/00															
10/03/00	9	16.2		456	8.02	160	0	16	5	0.01k	0.99	0.85	0.043	0.021	19
10/24/00															
11/15/00															
01/29/01															
03/28/01															
04/19/01															
Count		2		5	5	5	5	5	5	5	5	5	5	3	5
Maximum		16.2		548	8.02	200	0	40	10	0.11	1.74	12.00	0.135	0.021	19
Minimum		7.9		456	7.5	150	0	4	3	0.01	0.62	0.85	0.024	0.004	18
Average		12.1		487	8	176	0	18	5	0.05	1.12	6.19	0.053	0.010	18.6
S.D.		5.9		36	0	23		13	3	0.05	0.44	4.66	0.047	0.010	0.5

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix C. Temperature and Dissolved Oxygen Data

Appendix C. Temperature and Dissolved Oxygen Data

	Station 1				Station 2				Station 5			
Date	Depth, feet	Temp., °C	DO, mg/L	% sat.	Depth, feet	Temp., °C	DO, mg/L	% sat.	Depth, feet	Temp., °C	DO, mg/L	% sat.
05/25/00	0	21.0	10.6	119.9								
	1	21.0	10.6	119.9								
	3	21.0	10.3	116.5								
	5	21.0	9.3	105.2								
	7	20.8	9.2	103.6								
	9	20.8	8.8	99.1								
	11	20.8	9.0	101.4								
	13	19.3	5.3	57.9								
	15	18.4	3.2	34.3								
	17	18.2	2.1	22.4								
	19	18.0	0.8	8.5								
06/06/00	0	20.7	6.1	68.5	0	20.1	7.6	84.4	0	18.4	7.7	82.6
	1	20.7	6.1	68.5	1	20.1	7.8	86.6	1	18.4	7.6	81.5
	3	20.7	6.0	67.4	3	20.0	7.4	82.0	3	18.3	7.6	81.4
	5	20.7	6.0	67.4					4	18.2	7.5	80.1
	7	20.7	6.0	67.4								
	9	20.6	6.0	67.3								
	11	20.5	5.9	66.1								
	13	20.5	5.9	66.1								
	15	20.4	5.9	65.9								
	17	20.3	5.9	65.8								
06/22/00	1	24.2	8.4	101.2					1	21.7	6.9	79.1
	3	24.1	8.5	102.2					2	21.3	7.0	79.6
	5	23.9	7.8	93.4					3	20.7	7.0	78.7
	7	23.9	7.2	86.2								
	9	23.9	7.6	91.0								
	11	23.9	7.5	89.8								
	13	23.9	7.3	87.4								
	15	23.8	7.1	84.8								
	17	23.8	7.1	84.8								
	18	23.7	6.2	74.0								
07/11/00	1	27.2	9.1	116.1	1	27.1	9.2	117.0	1	26.5	8.0	100.6
	3	27.3	9.0	114.9	3	27.1	9.0	114.5	2	26.1	7.6	94.9
	5	27.3	9.3	118.6	5	27.1	8.9	113.2	3	25.2	7.0	86.0
	7	27.1	8.1	113.0	7	27.1	8.7	110.7	4	24.9	6.9	84.2
	9	27.1	8.0	111.8	9	27.0	8.7	110.5	5	24.7	6.7	81.5
	11	27.0	6.9	87.7								
	13	26.3	4.4	55.1								
	15	25.9	3.8	47.3								

Appendix C. Continued

	Station 1				*Station 2*				*Station 5*			
Date	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*
07/11/00	17	25.6	2.0	24.8								
	18	25.5	1.6	19.8								
07/12/00	0	26.4	7.2	90.5	0	26.7	8.7	109.8	0	25.2	7.0	86.0
	1	26.4	7.2	90.5	1	26.7	8.7	109.8	1	25.2	6.9	84.8
	3	26.4	7.2	90.5	3	26.5	8.6	108.2	3	23.2	5.9	69.3
	5	26.4	7.0	87.9	5	26.2	7.9	98.9	4	23.0	5.9	69.4
	7	26.3	6.8	85.2	7	25.9	8.1	100.7				
	9	26.3	6.8	85.2	9	25.2	7.5	92.1				
	11	26.3	6.8	85.2								
	13	26.3	6.8	85.2								
	15	26.2	6.8	85.1								
	16	26.2	6.8	85.1								
07/26/00	1	25.8	14.1	175.2	1	26.2	14.5	181.5	1	25.8	14.0	173.9
	3	25.3	11.4	140.2	3	25.8	14.8	183.9	2	25.9	14.5	180.3
	5	25.1	8.8	107.8	5	25.2	10.4	127.8	3	25.5	13.9	171.6
	7	25.0	7.4	90.5	7	25.0	7.6	92.9	4	24.8	12.5	152.3
	9	25.0	7.6	92.9	9	24.9	5.4	65.9				
	11	24.9	3.9	47.6								
	13	24.7	3.2	30.9								
	15	24.6	1.9	23.1								
	17	24.6	2.0	24.3								
	18	24.5	1.8	21.8								
08/02/00	0	26.2	4.7	58.8	0	26.4	5.2	65.3	0	27.0	5.6	71.1
	1	26.1	4.6	57.4	1	26.3	5.2	65.2	1	26.8	5.6	70.9
	3	25.8	4.4	54.6	3	26.3	5.2	65.2	3	25.6	4.5	55.7
	5	25.7	4.3	53.3	5	26.2	5.0	62.6	4	25.2	4.1	50.4
	7	25.7	4.2	52.0	7	26.1	4.8	59.9				
	9	25.7	4.1	50.0	8	26.0	4.7	58.6				
	11	25.6	4.0	49.5								
	13	25.6	3.8	47.0								
	15	25.6	3.1	38.4								
	17	25.4	1.6	19.7								
08/08/00	1	25.4	6.7	82.6	1	25.7	8.4	104.1	1	26.2	6.9	86.4
	3	25.3	6.0	73.8	3	25.7	8.4	104.1	2	25.9	8.0	99.5
	5	25.2	5.0	61.4	5	25.7	8.4	104.1	3	25.6	7.9	97.8
	7	25.2	4.8	59.0	7	25.7	8.3	102.9	4	25.4	7.7	94.9
	9				9	25.7	8.2	101.6				
	11	25.2	4.9	60.2								
	13	25.2	4.8	59.0								
	15	25.1	4.8	58.8								

Appendix C. Continued

	Station 1				Station 2				Station 5			
Date	Depth, feet	Temp., °C	DO, mg/L	% sat.	Depth, feet	Temp., °C	DO, mg/L	% sat.	Depth, feet	Temp., °C	DO, mg/L	% sat.
	17	25.1	4.1	50.2								
	18	25.0	3.0	36.7								
08/29/00	1	25.2	5.5	67.6	1	25.8	7.6	94.4	1	25.9	6.7	83.3
	3	25.0	5.0	61.1	3	25.6	7.6	94.1	2	25.6	6.0	74.3
	5	24.9	4.6	56.2	5	25.5	7.4	91.4	3	25.2	5.2	63.9
	7	24.9	4.2	51.3	7	25.4	7.0	86.3	4	24.8	3.5	42.6
	9	24.9	4.1	50.0	9	25.3	6.8	83.6	5	24.8	3.3	40.2
	11	24.9	3.6	44.0								
	13	24.9	3.6	44.0								
	15	24.9	3.5	42.7								
	17	24.9	2.9	35.4								
	18	24.8	2.0	24.4								
09/13/00	1	24.4	7.0	84.5	1	24.1	7.1	85.3	1	23.6	4.8	57.1
	3	24.3	6.7	80.8	3	24.0	6.6	79.2	2	23.4	4.5	53.4
	5	24.1	5.7	68.5	5	23.7	5.9	70.4	3	23.1	3.3	38.9
	7	24.1	5.6	67.3	7	23.6	5.7	67.9	4	22.9	2.7	31.6
	9	24.0	5.9	70.8	9	23.5	5.5	65.3	5	22.9	2.7	31.6
	11	24.0	5.7	68.4								
	13	24.0	5.6	67.2								
	15	24.0	5.6	67.2								
	17	24.0	5.6	67.2								
	18	24.0	5.7	68.4								
09/28/00	1	19.0	8.2	90.3	1	18.9	9.4	101.8	1	19.2	10.9	118.9
	3	18.6	8.3	89.3	3	18.0	8.3	88.3	2	17.6	9.6	101.3
	5	18.5	7.9	84.9	5	17.8	8.4	89.0	3	16.6	8.6	88.8
	7	18.4	7.9	84.8	7	17.4	8.0	84.0	4	16.5	8.0	82.4
	9	18.3	7.6	81.4	9	17.2	7.6	79.5	5	16.5	6.6	68.0
	11	18.1	7.6	81.0								
	13	18.0	7.3	77.7								
	15	17.7	6.6	69.8								
	17	17.5	6.6	69.5								
	18	17.5	6.5	68.4								
10/03/00	0	18.5	8.6	92.5	0	19.4	10.0	109.5	0	20.0	9.4	104.2
	1	18.5	8.5	91.4	1	19.4	9.9	108.8	1	20.0	9.3	103.1
	3	18.5	8.3	89.2	3	19.0	9.9	107.5	3	19.3	7.9	76.5
	5	18.3	7.8	83.5	5	18.7	9.3	100.3				
	7	18.4	7.9	84.8	7	18.7	9.2	99.2				
	9	18.3	7.9	84.6	8	18.7	9.2	99.2				
	11	18.3	8.0	85.7								
	13	18.3	7.8	83.5								

Appendix C. Continued

	Station 1				*Station 2*				*Station 5*			
Date	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*	*Depth, feet*	*Temp., °C*	*DO, mg/L*	*% sat.*
10/03/00	15	18.2	7.7	82.3								
	17	17.7	5.2	55.0								
10/12/00	1	13.6	10.1	97.5	1	13.7	13.7	164.6	1	12.1		
	3	13.3	10.1	96.8	3	13.5	13.0	125.2	2	12.0		
	5	13.3	9.9	94.9	5	13.2	12.6	120.6	3	11.9		
	7	13.2	9.6	91.9	7	13.1	13.0	120.0	4	11.9		
	9	13.1	9.3	88.7	9	13.0	12.2	116.2	5	11.2		
	11	13.1	9.1	86.8								
	13	13.1	8.8	84.0								
	15	13.1	8.8	84.0								
	17	13.0	8.8	83.8								
	18	12.9	9.1	86.5								
10/24/00	1	18.0	15.3	162.8	1	18.2	15.0	160.3	1	18.9	16.8	182.0
	3	18.0	14.3	152.1	3	16.5	10.4	107.1	2	18.6	16.1	173.3
	5	17.6	14.4	151.8	5	15.8	8.5	86.2	3	17.8	13.2	139.8
	7	17.2	14.5	151.7	7	15.6	7.3	73.7	4	16.8	8.3	86.0
	9	15.9	10.6	101.6	9	15.4	5.6	56.3	5	16.8	4.1	42.5
	11	15.6	9.2	92.9								
	13	15.2	8.3	80.0								
	15	15.0	7.2	69.8								
	17	15.0	5.3	49.9								
	18	15.0	4.5	44.9								
11/15/00	1	9.0	9.4	81.4	1	7.8	10.9	91.6	1	5.1	11.8	92.9
	3	9.0	9.4	81.4	3	7.8	10.9	91.6	2	5.1	11.9	93.3
	5	8.9	9.4	81.2	5	7.8	10.7	89.9	3	5.2	11.9	93.6
	7	8.8	9.5	81.8	7	7.7	10.8	90.5	4	5.2	11.9	93.6
	9	8.8	9.3	80.1	9	7.7	10.8	90.5	5	5.1	11.8	92.5
	11	8.7	9.4	80.8								
	13	8.7	9.5	81.6								
	15	8.7	9.5	81.6								
	17	8.7	9.5	81.6								
	19	8.7	9.5	81.6								
01/29/01	1	1.8	6.8	48.8	1	1.9	7.0	50.4	1	0.3	15.5	106.7
	3	2.6	7.7	56.5	3	1.9	10.9	78.4	2	0.3	15.0	103.8
	5	2.4	9.9	72.2	5	1.9	11.4	82.0	3	0.5	14.7	101.7
	7	2.4	11.4	83.2	7	1.9	10.9	78.4	4	0.6	14.6	101.3
	9	2.3	11.7	85.1	9	1.9	10.2	71.9	5	0.8	14.6	101.9
	11	2.3	12.1	88.0								
	13	2.3	12.5	90.9								
	15	2.4	12.7	92.6								

Appendix C. Concluded

Date	Station 1 Depth, feet	Station 1 Temp., °C	Station 1 DO, mg/L	Station 1 % sat.	Station 2 Depth, feet	Station 2 Temp., °C	Station 2 DO, mg/L	Station 2 % sat.	Station 5 Depth, feet	Station 5 Temp., °C	Station 5 DO, mg/L	Station 5 % sat.
01/29/01	17	2.5	12.5	91.4								
	19	2.5	11.6	85.8								
03/28/01	1	6.4	8.9	72.2								
	3	6.3	8.4	68.0								
	5	6.0	8.6	64.2								
	7	5.8	8.6	68.6								
	9	5.8	8.8	70.2								
	11	5.8	8.9	71.0								
	13	5.7	8.9	70.9								
	15	5.7	9.2	73.6								
	17	5.7	9.9	78.8								
	18	5.6	10.3	79.4								
04/19/01	1	13.3	7.4	70.9	1	13.1	4.1	39.1	1	11.0	9.7	88.2
	3	12.9	6.4	60.8	3	12.9	4.4	41.8	2	11.9	9.8	91.0
	5	12.7	5.8	54.9	5	12.8	4.0	37.9	3	10.9	9.6	87.0
	7	12.5	8.4	79.1	7	12.8	5.7	54.0	4	10.9	9.6	87.0
	9	12.5	9.0	84.7	9	12.8	6.2	58.8	5	10.9	9.6	87.0
	11	12.0	7.1	66.0								
	13	11.7	7.0	64.7								
	15	11.7	5.9	46.2								
	17	11.8	7.0	64.8								
	18	11.7	5.9	49.0								
04/26/01	1	15.9	8.4	85.4	1	16.4	9.7	99.7	1	16.1	9.0	91.9
	3	15.8	8.3	84.2	3	16.3	9.9	101.5	2	15.8	9.0	91.3
	5	15.4	8.1	81.4	5	16.3	10.0	103.1	3	15.7	8.9	90.1
	7	15.3	8.2	82.2	7	16.2	10.1	103.4	4	16.0	8.9	90.6
	9	15.3	8.2	82.2	9	16.2	10.1	103.4	5	15.5	8.9	89.7
	11	15.2	8.7	87.1								
	13	15.2	9.1	91.1								
	15	15.2	9.0	90.1								
	17	15.2	8.9	89.1								
	18	15.2	9.4	94.1								

Notes: Temp. – temperature, *°C* – degree Celcius, DO – dissolved oxygen, % sat. – percent saturation, blank spaces –no data

Appendix D. Water Quality Characteristics for the Inflow and Outflow of Lake Vermilion

Appendix D1. Water Quality Characteristics for Spillway (RBD-01) of Lake Vermilion, 2000-2001

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (µmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/27/00	1.0	22		610	8.0	170	1k	28	9	0.05	1.17	3.0	0.037		20
05/28/00	1.0	100		610	8.2	153	1k	142	38	0.06	1.71	5.3	0.092		20
05/29/00	1.0	90		600	8.2	137	1k	78	34	0.16	0.88	6.0	0.106		20
05/30/00	1.0	130		600	7.9	95.0	1k	86	42	0.21	1.58	11.0	0.208		20
06/01/00	1.0			480	7.7	106	1k	58	8	0.10		11.0	0.166		20
06/26/00	1.0			500	8.0	155		86	12	0.01k		15.0	0.166		
02/10/01	1.0			550	7.9	119		84	11	0.31	2.15	7.5	0.487		
02/26/01	1.0			340	7.8	17.4		597	80	0.09	3.16	6.6	0.867		18
02/27/01	1.0			400	8.1	26.0	1k	388	54	0.49	3.16	7.5	0.887		
02/28/01	1.0			490	7.9	58.1	1k	326	50	0.52	2.64	7.9	0.787		
				390	7.9	78.8	1k	150	23	0.39	2.40	8.1	0.669		
03/05/01	1.0			480	8.0	128	1k	48	7	0.27	1.10	9.2	0.371		
03/26/01	1.0			810	8.3	232	10	17	4	0.08	0.73	9.7	0.74		
Count		4		13	13	13		13	13	13	11	13	13		6
Maximum		130		810	8.3	232		597	80	0.52	3.16	15	0.887		20
Minimum		22		340	7.7	17.4		17	4	0.01	0.73	3	0.037		18
Average		86		528		113		161	29	0.21	1.88	8.3	0.429		20
S.D.		46		123		60		172	23	0.17	0.88	3.0	0.323		1

Notes: NTU – nephelometric turbidity unit, µmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,

Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation

Appendix D2. Water Quality Characteristics for Tributary (Inflow, RBD-02) of Lake Vermilion, 2000-2001

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
05/25/00	1							22	5	0.07		10.	0.141		3
05/27/00	1	900		610	7.7	20.2	1k	770	90	0.21	1.62	9	0.612		4
05/28/00	1	400		610	7.8	50.8	1k	340	76	0.13	1.57	13	0.484		6
05/29/00	1	120		600	7.9	111	1k	160	104	0.01 k	1.55	17	0.261		3
05/30/00	1	60		600	8.1	158	1k	120	58	0.01 k	1.06	18	0.160		3
06/01/00	1			600	8.3	185	1k	76	11	0.04		16	0.113		
06/07/00	1			660	8.1	211	1k	26	3	0.02	0.28	14	0.085		
06/19/00	1					217	1k	17	3	0.01k	0.28	13	0.085		
07/05/00	1							464	56	0.01k	1.42	9.9	0.268		
07/11/00	1			490	7.7	131	1k	208	32	0.01k	1.05	11	0.018		
07/24/00	1			780	8.3		1k	10	3	0.01k	0.60	7	0.073		
08/08/00	1			690	8.4	234	1	20	3	0.30	1.27	5.8	0.114		
08/23/00	1			630	8.3	217	1k	11	3	0.07	1.04	1.49	0.149		
09/12/00	1			730	8.5	225	1k	19	3	0.27	0.30	1.01	0.156		
10/02/00	1			780	8.4			4		0.03	0.60	1.29	0.167		
10/17/00	1			650	8.2	241	1k	3	1	0.01k	0.27	2.2	0.076		
10/30/00	1			660	8.3	274	1k	4	2	0.16	0.26	0.31	0.147		
11/06/00	1			710	7.7	276	1k	6	2	0.01k	0.10k	0.16	0.113		
11/20/00	1			820	8.3	256	1k	3	1	0.01 k		10	0.073		
12/04/00	1			820	8.3	248	1k	2	1	0.14	1.28	8.2	0.105		
12/14/00	1			880	8.1	236		6	2	0.05	1.09	10	0.074		
01/02/01	1			510	8.3	251		2	1	0.01 k	0.58	7.6	0.144		
02/05/01	1			580	8.6	209	6	19	4	0.44	0.78	10.2	0.299		
02/09/01	1			410	7.9	115		462	49	0.28	3.16	9.2	0.406		5
02/10/01	1			440	7.7	73.9		443	48	0.10	2.86	9.3	0.579		6
02/12/01	1			500	8.1			43	5	0.01k	1.85	12	0.170		
02/13/01	1			620	8.1			48	6	0.01k	1.04	12	0.131		
02/25/01	1			350	8.1	81.2	1k	816	108	0.39	5.26	5.2	1.400		8
02/26/01	1			420	7.5	23.4		442	58	0.26	2.91	8.2	0.985		7
02/27/01	1			480	8.2	93	1k	254	34	0.20	2.00	11	0.558		
02/28/01	1			450	8.1	149	1k	124	18	0.17	1.09	11	0.353		

Appendix D2. Concluded

Sample date	*Sample depth (feet)*	*Turbidity (NTU)*	*Secchi transpa-rency (in.)*	*Conduc-tivity (μmho/cm)*	*pH*	*Total alkalinity (mg/L as $CaCO_3$)*	*Phenolph-thalein alkalinity (mg/Las $CaCO_3$)*	*Total suspen-ded solids (mg/L)*	*Volatile suspen-ded solids (mg/L)*	*Ammonia-nitrogen (mg/L)*	*Total Kjeldahl nitrogen (mg/L)*	*Nitrate/ Nitrite-nitrogen (mg/L)*	*Total phos-phorus (mg/L)*	*Dissolved phos-phorus (mg/L)*	*Total depth (feet)*
03/01/01	1			450	8.0	167	1k	68	10	0.08	0.86	11	0.245		
03/05/01	1			500	8.2		1k	17	3	0.08	0.49	11	0.090		
03/19/01	1			690	8.3	199		14	2	0.01k	0.64	13	0.043		
03/26/01	1			700	8.4	207	12	2	1	0.01	0.28	11	0.037		
04/09/01	1			730	8.0	221	1k	10	2	0.05		9.2	0.046		
04/23/01	1			630	8.3	208		17	3	0.05	0.91	11	0.060		
Count		4		34	34	31	3	37	36	24	33	37	37		10
Maximum		900		880	8.6	276	12	816	108	0.44	5.26	18	1.4		8
Minimum		60		350	7.5	20.2	1	2	1	0.01	0.1	0.16	0.018		2
Average		370		611		178		137	23	0.15	1.22	9.20	0.244		5
S.D.		383		132		74		216	32	0.12	1.06	4.50	0.283		2

Notes: NTU – nephelometric turbidity unit, μmho/cm – micromhos per centimeter, mg/L – milligrams per liter, $CaCO_3$ – calcium carbonate,
Blank spaces – no data, a k indicates that the actual value is known to be less than value given, S.D. – standard deviation