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IOWA WASTE REDUCTION CENTER, UNIVERSITY OF NORTHERN IOWA
and the
LAKE DELHI ASSOCIATION

Bathymetric Mapping, Sediment Quality, and Water Quality of Lake Delhi, Iowa, 2001–02

Water-Resources Investigations Report 03–4085

U.S. Department of the Interior
U.S. Geological Survey

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By DOUGLAS J. SCHNOEBELEN, JASON C. MCVAY, KYMM K. BARNES, and KENT D. BECHER

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Iowa City, Iowa
2003

U.S. Department of the Interior

Gale A. Norton, Secretary

U.S. Geological Survey

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
P.O. Box 1230
400 South Clinton
Iowa City, IA 52244–1230

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225–0286

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CONVERSION FACTORS, ABBREVIATIONS, DATUMS, AND DEFINITIONS

Multiply	By	To obtain
acre	4,047	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
liter (L)	0.2642	gallon (gal)
meter (m)	3.281	foot (ft)
microgram per gram (μg/g)	1.0000×10^{-6}	ounce per ounce (oz/oz)
microgram per kilogram (μg/kg)	1.000×10^{-3}	ounce per ounce (oz/oz)
microgram per liter (μg/L)	1.0	part per billion (ppb)
micron (μ)	3.937×10^{-5}	inch (in.)
mile (mi)	1.609	kilometer (km)
milligram (mg)	0.0000353	ounce (oz)
milligram per kilogram (mg/kg)	1.0×10^{-6}	ounce per ounce (oz/oz)
milligram per liter (mg/L)	1.0	part per million (ppm)
millimeter (mm)	0.03937	inch (in.)
pound (lb)	453.6	gram (g)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per square mile (lb/mi^2)	0.1751	kilogram per square kilometer (kg/km^2)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature can be converted to degree Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\,(°F - 32)$$
$$°F = 9/5\,(°C) + 32.$$

Vertical datum: Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 29). Elevation as used in this report, refers to distance above or below NGVD of 29. NGVD of 29 can be converted to the North America Vertical Datum of 1988 (NAVD of 88) by using the National Geodetic Survey conversion utility available at URL **http://www.ngs.noaa.gov/TOOLS/vertcon.html**

Horizontal datum: Horizontal datum information is referenced to the North American Datum of 1983 (NAD of 83).

Water year: In this report, "water year" is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 1998, is called the "1998 water year."

Bathymetric Mapping, Sediment Quality, and Water Quality of Lake Delhi, Iowa, 2001–02

By Douglas J. Schnoebelen, Jason C. McVay, Kymm K. Barnes, *and* Kent D. Becher

Abstract

Lake Delhi was formed in 1929 when the Interstate Power Company dammed the Maquoketa River near Delhi, Iowa, for generation of hydroelectric power. The resulting 450-acre lake became a popular area in eastern Iowa for boating, swimming, and fishing. Hydroelectric power generation ended in 1973, and lakeside residents purchased the dam to maintain the recreational opportunities of the lake. Increasing concerns about sediment deposition and water quality by lakeside residents led to a 2-year study that included a bathymetric survey, an assessment of sediment quality, and an assessment of water quality of Lake Delhi.

A bathymetric map of Lake Delhi was constructed using more than 300,000 data points from echo sounding results and GIS (geographic information system) software. Results of bathymetric mapping showed that the upstream reach through most of the upstream-middle reach of Lake Delhi (approximately 3 miles) from about 0.25 mile upstream from the Greenslades coring site through Clair View Acres were particularly affected by sedimentation, with water depths ranging from less than 1 foot to a few areas that were as much as 10 feet deep. Numerous areas in the upstream-most 1-mile of the lake (about 0.25 mile upstream from the Greenslades coring site to just downstream from The Cedars coring site) had depths of only 1 to 2 feet and were nearly impassable by boats. The middle reach of Lake Delhi (an approximately 2.5-mile segment) from about one-half mile upstream from the Linden Acres coring site to just downstream from the Hartwick Dredge coring site was less affected by sedimentation with water depths from less than 1 to 16 feet. The deepest section (26 feet) of the lake was near the dam.

Eleven trace metals and phosphorus were analyzed in 20 samples from seven lake-bottom sediment cores. The median and average trace-element concentrations from the sediment cores were less than the U.S. Environmental Protection Agency threshold-effects-level and probable-effects-level guidelines for toxic biological effects. Water-quality samples from eight sites (Maquoketa River, three lake sites, and four tributaries) were collected for five sampling periods (June 2001–July 2002). Water-quality samples were analyzed for physical properties (specific conductance, pH, temperature, turbidity, dissolved oxygen, and alkalinity), nutrients (nitrate, ammonia, and phosphorus), bacteria (total coliform and *E. coli),* and suspended sediment. Selected water samples were analyzed for major ions, trace elements, and pesticides.

Water-quality sampling results indicate areas affected by elevated nutrient and bacteria concentrations in the lake and tributary streams. The tributary streams had the highest median nitrate concentrations (12.1 milligrams per liter) when compared to median nitrate concentrations in the lake (8.7 milligrams per liter) or the Maquoketa River (10.5 milligrams per liter). The maximum nitrate concentrations detected for Maquoketa River, lake, and tributary sites were 13.5, 13.5, and 18.6 milligrams per liter, respectively. Nitrate concentrations in the late summer decreased from

the upstream (7.8 milligrams per liter) to the downstream (5.0 milligrams per liter) one-third of Lake Delhi and most likely were the result of uptake of nitrate by algae and aquatic biota in the lake. Median concentrations of total coliform and *E. coli* bacteria for the lake sites were 450 and 17 colonies per 100 milliliters of sample, respectively. The U.S. Environmental Protection Agency criteria for full body contact (swimming or bathing) are 200 colonies per 100 milliliters for fecal bacteria and 126 colonies per 100 milliliters for *E. coli* bacteria. The highest bacteria concentrations in the lake occurred after a rain and were 25,000 colonies per 100 milliliters total coliform and 1,900 colonies per 100 milliliters *E. coli*.

INTRODUCTION

Lake Delhi (Federally recognized as Hartwick Lake) was formed in 1929 when the Interstate Power Company dammed the Maquoketa River to build a hydroelectrical generating plant. The local name "Lake Delhi" was adopted in recognition of the nearby town of Delhi, Iowa. The resulting 450-acre lake became a popular area in eastern Iowa for boating, swimming, and fishing. Hydroelectric power generation ended in 1973, and lakeside residents formed the Lake Delhi Association. The Lake Delhi Association purchased the dam to maintain the recreational opportunities of Lake Delhi.

Since 1973, the increased population around Lake Delhi, the increased recreational use, and possible contaminant inputs (point and nonpoint sources) are of concern to lake users. In particular, inputs of nutrients (nitrate, ammonia, and phosphorus), sediment, and bacteria can negatively affect water quality and recreational users of Lake Delhi. An assessment of the bathymetry (depth to lake bottom), sediment quality, and water quality of Lake Delhi are the main areas of concern that have been identified by the Lake Delhi Association board and lakeside residents. Documenting baseline concentrations of nutrients, sediment, and bacteria is a first step in understanding the effects of contaminants on Lake Delhi now and for monitoring changes in the future.

Several studies in eastern Iowa have identified nutrients as a major contaminant of concern in impairing water quality (Goolsby and Battaglin, 1993; Hallberg and others, 1996; Schnoebelen and others, 1999; Kalkhoff and others, 2000; Becher and others, 2001). In addition, the increased concentrations of nitrogen and phosphorus from Iowa streams are discharged to the Mississippi River and have been linked to the occurrence of hypoxia (low-oxygen zone) in the Gulf of Mexico (Turner and Rabalais, 1994; Goolsby and others, 1999). Even though these previous studies in eastern Iowa have not focused directly on Lake Delhi, results from these studies may be applicable to the lake. Nitrogen and phosphorus are compounds that can occur naturally in ambient stream and lake water but generally at low concentrations (less than 5 mg/L for nitrogen and less than 1 mg/L for phosphorus). High concentrations of nitrogen (5–25 mg/L) and phosphorus (greater than 1 mg/L) in streams and lakes can be the result of increased discharges from wastewater plants, leaking septic tanks, fertilizer runoff, livestock production, and soil erosion. Each of these potential sources is present in the Lake Delhi watershed or upstream from Lake Delhi. The city of Manchester (population 5,308; State Library of Iowa, 2000) wastewater plant is approximately 6 mi upstream from Lake Delhi, all lakeside residents use septic tanks, and there are numerous farms and livestock in the watershed. Riparian zones along the tributaries are often small (less than 200 ft wide) in the Lake Delhi watershed, and in many places agricultural land adjoins streams. High concentrations of nitrogen and phosphorus in streams and lakes can contribute to increased aquatic plant growth and eutrophication which degrade recreational use.

Lakeside residents typically identify sediment (or sediment deposition) as a constituent of most concern to recreational use. Sediment often is mentioned by residents because it is readily visible in the water column. The Iowa Department of Natural Resources lists sediment as the number one contaminant in rivers and lakes of Iowa (Iowa Department of Natural Resources, 1994). Long-time lakeside residents report areas of the lake that are no longer navigable by boats because the water is too shallow. The Lake Delhi Association has discussed dredging and installation of sediment traps in the upstream part of the lake. Establishing baseline conditions of the bathymetry of Lake Delhi are important if future dredging does occur. If dredging does occur, the availability of historical baseline conditions would allow future bathymetric mapping to determine the amount of sediment deposition that has occurred by comparing new bathymetric maps to previous bathymetric maps.

Sediment quality is another area of concern before dredge work could begin. Trace metals, such as chromium and lead, often accumulate in lake-bottom sediments, and knowing the concentration of these metals in the lake-bottom sediments is important before dredging begins. Work on assisting farmers in implementing soil erosion control practices in the watershed has begun by the Lake Delhi Recreation Association, the Maquoketa River Water Quality Team, the Iowa Waste Reduction Center of the University of Northern Iowa, the Natural Resources Conservation Service (NRCS), and the Delaware County Soil and Water Conservation District (SWCD).

Increasing bacteria levels are of concern to those using Lake Delhi. In recent years elevated "indicator bacteria" levels in several Iowa streams and lakes have resulted in the closing of some beaches (Iowa Department of Natural Resources, 2003). Because of the difficulties analyzing for and detecting many disease-causing organisms, "indicator bacteria"—fecal coliform, total coliform, and *E. coli* bacteria—are used as the primary means of identifying fecal contamination. Pathogens causing many diseases live in the intestines of warmblooded animals and are passed along in feces. An increase in the concentrations of indicator bacteria above U.S. Environmental Protection Agency (USEPA) criteria in lake water may indicate the presence of pathogens. Water-borne pathogens can cause ear or skin infections and gastrointestinal illnesses. Data from water samples analyzed for indicator bacteria (total coliform and *E. coli*) are important information for residents that swim or water ski in Lake Delhi.

To address the concerns of water managers and users of Lake Delhi, the U.S. Geological Survey (USGS), in cooperation with the Iowa Waste Reduction Center, University of Northern Iowa, and the Lake Delhi Association conducted a study of the bathymetry, sediment quality, and water quality of Lake Delhi from 2001 through 2002.

Purpose and Scope

The purpose of this report is to describe results of a study to map the depth of Lake Delhi and to assess sediment quality and selected water-quality constituents of Lake Delhi. Figure 1 shows the location of Lake Delhi and lake-bottom core and water-quality sampling sites. The sediment-quality information from the cores provide a better understanding of selected trace-metal constituents in the lake-bottom sediments, and the water-column samples provide information on nutrients and bacteria with selected information on major ions, trace elements, and pesticides.

The bathymetric map can be used to identify possible dredging locations and to establish baseline lake-bottom conditions both before and after dredging. Selected trace-element concentrations from lake-bottom cores collected in September 2001 were analyzed to assess the quality of lake-bottom sediments. Water-quality samples were collected during June 2001 through July 2002 from the Maquoketa River, Lake Delhi, and four small tributaries to assess concentrations of nutrients, bacteria, and suspended sediment in the water column. Water-quality samples were collected in June 2001 from the Maquoketa River and the downstream reach of Lake Delhi (site 080 near the dam) and analyzed for pesticides. Water-quality samples were collected in June and September 2001 from the Maquoketa River, lake, and tributary sites and analyzed for major ions and trace metals.

A detailed examination of each of the sources of contaminants to Lake Delhi is beyond the scope of this report. The study results described in this report are not exhaustive but rather a first assessment of Lake Delhi.

Acknowledgments

The authors would like to thank the Iowa Waste Reduction Center, University of Northern Iowa, for assistance with project planning and coordination with lakeside residents, and facilitating access to the lake for water-quality sampling and mapping. In particular, Sue Behrns, Lake Delhi Association, helped with many activities. Mike Russell, a homeowner on the lake, volunteered to assist with the sediment coring. The USGS office in Lawrence, Kansas, provided the core boat and the assistance of Patrick Finnegan for the collection of the lake-bottom cores. Much appreciation goes to USGS Iowa employees—Jim Cerveny, Doug Goodrich, Mike Linhart, Jon Nania, and Nick VanderZwan—for their dedicated data-collection efforts throughout the study.

Special recognition and appreciation goes to Gray Krizanich with the USGS National Mapping Discipline (NMD) in Rolla, Missouri, who processed much of the collected data for the bathymetric map. In addition, Dan Christiansen with the USGS in Iowa assisted with finalizing the maps before publication.

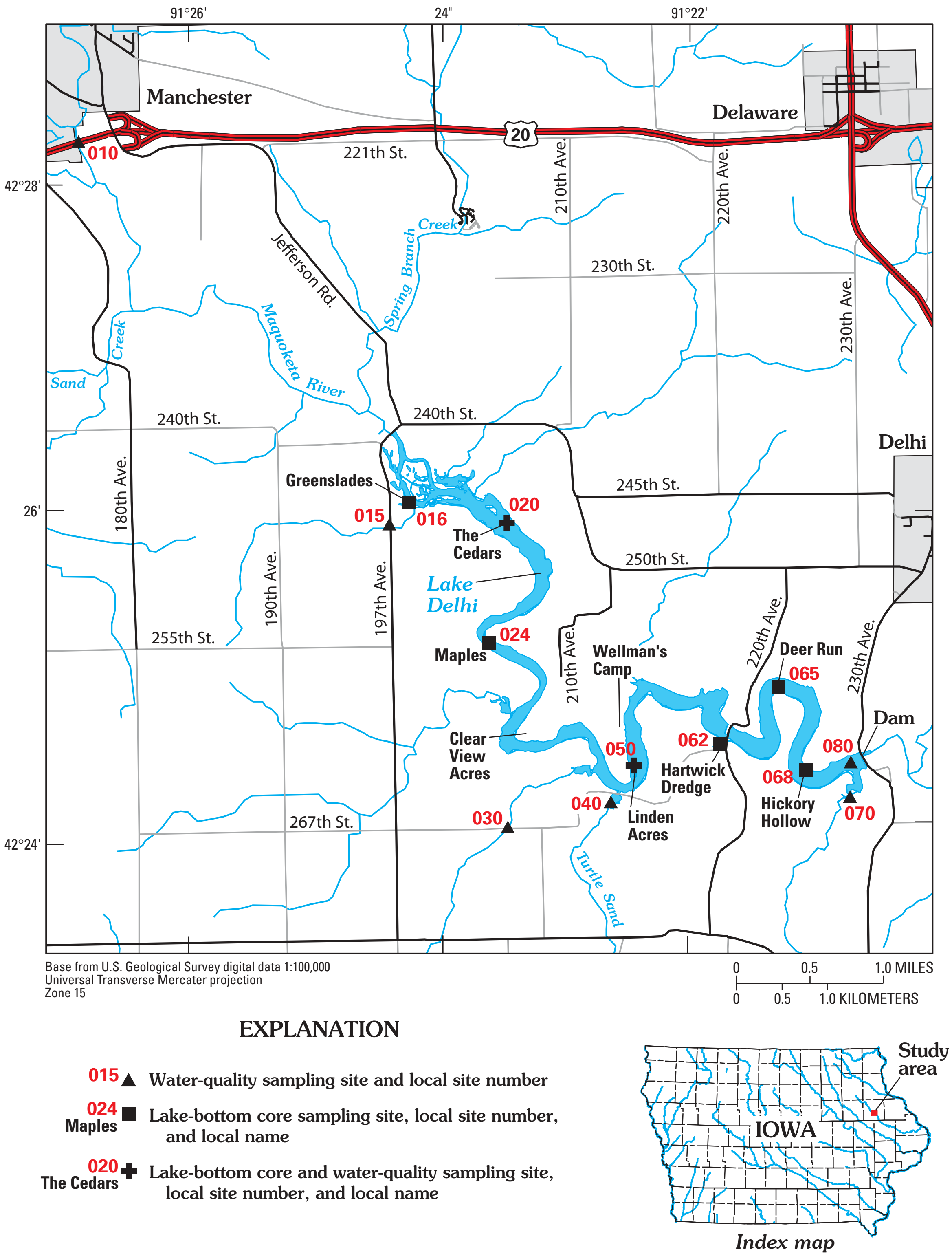


Figure 1. Location of Lake Delhi study area and sampling sites in eastern Iowa.

METHODS OF STUDY

The bathymetric mapping incorporated a combination of global positioning system (GPS) technology and echo sounding to determine the lake-bottom surface. Seven lake bottom cores were collected at seven sites (016, 020, 024, 050, 062, 065, and 068) for trace element analysis (fig. 1). Water-quality samples were collected five times at eight sites from June 2001 through July 2002 (fig.1)—one site on the Maquoketa River (site 010, upstream from Lake Delhi), three sites in Lake Delhi (sites 020, 050, and 080), and four tributary sites (sites 015, 030, 040, and 070). All sites in the report are identified by a local (three digit) site number (figs. 1–5) that corresponds to a standard (eight digit) USGS surface-water station number (tables 5–13).

Bathymetric Mapping

Bathymetric mapping was accomplished by use of GPS equipment, echo depth-sounding equipment, and *HypackMax* computer software. The *HypackMax* software is used to interpret and combine the depth-sounding data with the GPS data. Initial measurements determined the elevation of the surface of the lake referenced to National Geodetic Vertical Datum (NGVD) of 1929 using a triangulation process by establishing reference points using GPS and rover-receiving (mobile) units. Lake-surface elevations were collected each day compared to known reference points—a downstream location at the dam and an upstream location at the northwest corner of the lake. The downstream lake reference point is located on a steel piece of angle iron on the right bank upstream side of the dam. The upstream lake reference point (at the northwest corner of the lake) is located on the top of a section of conduit at the end of the private boat ramp located just off 197th Avenue (near coring site 016). The reference points were established using the *ASH-TECH* GPS system. These elevations were referenced to known benchmarks at two separate locations in Delaware County. The accuracy of these reference points is ± 0.03 ft.

The bathymetry and elevation data were collected from July 17–20, 2001, and July 24–25, 2001. There was a slight elevation drop between the upstream and downstream end of the lake-surface elevation, which was approximately 0.50 ft. The *HypackMax* software compensated for this slope difference in all calculations. The lake-surface elevation accuracy was ± 0.20 ft. The lake-surface elevation during data collection varied from 896.52 to 895.93 ft at the downstream location (the dam) and from 895.31 to 896.06 ft at the upstream location (off 197th Avenue). These fluctuations in lake surface-elevation do not affect the accuracy of the bottom elevation due to the time tagging (from the elevation and time recorded at the reference points) that the *HypackMax* software calculates. This process subtracts the depth from assigned elevation from the time-tagged values. When the lake-surface elevation changes, so do the depths; however, the bottom elevation remains constant even though the surface elevation of the lake may change.

Equipment used in the data collection included a boat, an echo sounder, a GPS system, and a laptop computer. A 14-ft flat-bottom boat was used for most of the data collection, and a canoe was used in the shallower water where the 14-ft boat was unable to navigate. Depths were measured by a *Bathy 500 MF* echo sounder (Ocean Data Equipment Corporation, Providence, Rhode Island). The echo sounder emitted pulses of sound that reflected off the lake bottom and were received by a transducer. Traveltimes were calculated taking into account the water temperature and speed of sound to determine the depth of water. The echo sounder transmitted at a frequency of 200 kilohertz. This is an ideal system for the Lake Delhi study due to the smooth and generally hard bottom of this lake. The only limitation was that this echo sounder would not measure depths less than 3.30 ft. When the depths were less than 3.30 ft, the depths were determined by hand using a USGS wading rod marked in 0.10-ft increments. The accuracy of these measurements was 0.05 ft. Position was determined by marking GPS points as depth readings were collected. The manual determination of shallow depths was labor intensive, but resulted in detailed measurements in many areas the echo sounder was unable to measure. Quality-control checks were performed on the echo sounder each day to make sure it was calibrated correctly.

A bar check on the echo sounder was performed at the start of each day following established protocols (U.S. Army Corps of Engineers, 1994, chapter 9). The bar check involved lowering a 2-ft-diameter flat piece of 3/8-in. thick aluminum plate suspended directly below the echo sounder. The plate was lowered to the maximum survey depth, and the speed of sound was adjusted to match the true depth. The plate was lowered and raised until the full range of the survey was correct. A check was performed on the offset value, which is related to the draft (depth at which the bottom of the echo sounder is below the lake surface). Each offset was stable and did not vary by more than 0.30 ft.

The GPS system used on the boat was connected to the echo sounder through the laptop computer. The GPS system measured a time-tagged latitude and longitude location—that was differentially corrected to improve the accuracy—for data received from the echo sounder. The GPS allowed for accuracies of about 3.28 ft (approximately 1 m) in the horizontal direction.

The *HypackMax* software was used for survey planning, survey execution, data storage, and editing. The *HypackMax* software interpreted and coordinated all the GPS and depth data received from the GPS and echo sounder units. Every individual depth had a unique latitude and longitude associated with it that was recorded by the *HypackMax* software. The software also was used to generate a preliminary bathymetric map of the lake bottom. The field crews were able to view the depths collected in real time on the monitor of the laptop computer. Real-time data monitoring allowed evaluation of any abnormal data spikes or depths. Depths of the lake were measured along approximately 300 uniformly spaced cross sections over the entire 7.5-mi length of the lake. Depths were measured at more than 300,000 points.

Bathymetry data were obtained by subtracting the depths at each location from the reference surface elevation of the lake, and data were exported to a flat-file or ASCII (American Standard Code for Information Interchange) format. This file contained latitude, longitude, and depth to the lake bottom for the data points. The latitude and longitude locations had the following projection parameters: Universal Transverse Mercator, zone 15, datum WGS84. Using a geographic information system (GIS) software package, ArcInfo, a point coverage representing discrete point locations of bathymetry was created. This point coverage then was used to generate a three-dimensional surface representing depth to the lake bottom. This surface then was contoured. The contours were reviewed, and the surface was adjusted to correct for interpretive errors and the process repeated as needed.

Sediment Sampling and Analysis

Lake-bottom sediments were cored at seven sites on Lake Delhi (fig. 1). Informal, “local names” near the seven coring sites included Greenslades (station 05417175, site 016), The Cedars (station 05417200, site 020), Maples (station 05417230, site 024), Linden Acres (station 05417320, site 050), Hartwick Dredge (station 05417390, site 062), Deer Run (station 05417440, site 065), and Hickory Hollow (station 05417460, site 068). The seven sites were located in areas where previous work (Mohn Surveying, Lansing, Iowa, written commun., October 1, 1999) and the Lake Delhi Association had indicated future dredging might be necessary. A latitude and longitude position was determined at each site using a handheld GPS receiver. Water depths were less than 5 ft deep in the areas selected for coring. The liner used in the corer was cellulose acetate butylate transport tubing with an inside diameter of 2.62 in.

Initially, a Benthos gravity corer mounted on a pontoon boat was used, but the shallow water did not allow the Benthos corer to gather enough momentum to fully penetrate the bottom sediment. Instead, all cores were collected by driving the core liner into the bottom sediment by hand. The core liner was driven until refusal or until pre-lake bottom material was encountered (bedrock or glacial till).

Cores ranged from approximately 2 to 5 ft in length and were transported to the USGS sediment laboratory in Iowa City, Iowa. Cores were numbered in a downstream order and identified by an eight-digit USGS station number, local name, and local site number. For example, the upstream-most lake core was from station 05417175, Lake Delhi at Greenslades, local site 016. Core numbers and station numbers increased in downstream order.

In the laboratory, each core liner was split lengthwise to expose the sediment for sampling and description. A total of 20 sediment samples from the seven cores were analyzed for selected trace-metal and phosphorus constituents. Each core was measured in tenths of feet from the bottom of the core (0.0 ft) to the top of the core (nearest the sediment/water interface). Two to four sediment samples were selected from each core starting at the base of the core (0.0 ft) and moving upwards. Sediment samples for analysis were typically collected every foot or where there was a change in the sediment type within the core. The presence of pre-lake bottom material was determined by a change in particle-size composition of the sediment indicating the presence of glacial till. The till had a brown color and a compacted texture.

Sediment samples (from the seven cores) selected for analysis were labeled (station number, date, time, and depth interval) and were shipped by overnight express on ice to the USGS National Water-Quality Laboratory in Denver, Colorado, for chemical analyses. Table 1 lists the sediment constituents analyzed, Chemical Abstract Registry (CAS) number, USGS National Water Information System (NWIS) database code, and minimum reporting level (MRL). The MRL is determined by the laboratory as the lowest concentration at which a constituent can be accurately be measured.

Water-Quality Sampling and Analysis

Water-quality samples were collected at eight sites (fig. 1)—one site on the Maquoketa River upstream from the lake (station 05416900, site 010), three sites on Lake Delhi (station 05417200, site 020; station 05417320, site 050; and station 05417480, site 080), and four tributary sites (station 05417170, site 015; station 05417275, site 030; station 05417300, site 040; and station 05417470, site 070). Each of the eight sites were sampled five times—June 2001, September 2001, March 2002, June 2002, and July 2002—and analyzed for physical properties, nutrients, bacteria, and suspended sediment. A few samples were collected to provide a limited assessment of major ions, trace metals, and pesticides in the water column. A one-time sampling for major ions and trace metals in the water column was done at all eight sites in September 2001. Two samples were collected for pesticides—one (June 2001) at the Maquoketa River site (station 05416900, site 010) and one at the upstream Lake Delhi site (station 05417480, site 080). All water samples were collected using USGS protocols (Shelton, 1994; U.S. Geological Survey, 1998). Water samples for analysis of nutrients, major ions, and trace metals were filtered onsite through a 0.45-µ capsule filter. Water samples for analysis of pesticides were filtered onsite through a 0.70-µ glass-fiber filter.

Table 1. Sediment constituents, Chemical Abstract Registry (CAS) number, National Water Information System (NWIS) database code, minimum reporting level (MRL), and reporting units

[µg/g, micrograms per gram; mg/kg, milligrams per kilogram]

Sediment constituent	CAS number	NWIS code	MRL	Reporting units
Aluminum	7429–90–5	01108	2.8	µg/g
Cadmium	7440–66–6	01028	.1	µg/g
Chromium	7440–47–3	01029	.4	µg/g
Cobalt	7440–48–4	01038	.1	µg/g
Copper	7440–50–8	01043	2.0	µg/g
Iron	7439–89–6	01170	2.1	µg/g
Lead	7439–92–1	01052	.1	µg/g
Manganese	7439–96–5	01053	.3	µg/g
Mercury	7439–97–6	71921	.01	µg/g
Nickel	7440–02–0	01068	.1	µg/g
Phosphorus	7723–14–0	00668	40	mg/kg
Zinc	7440–66–6	01093	3.1	µg/g

Physical properties (specific conductance, pH, temperature, turbidity, dissolved oxygen, and alkalinity) were recorded at each site. Samples for bacteria analysis (total coliform and *E. coli*) were collected by membrane filtration and incubation at the USGS laboratory Iowa City, Iowa, following standard methods (U.S. Geological Survey, 1998). All water samples (with the exception of samples for bacteria) were shipped overnight on ice to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, for analysis. Water samples were analyzed at the NWQL for dissolved nutrient species that included dissolved ammonia as nitrogen, dissolved ammonia plus organic nitrogen, dissolved nitrate plus nitrite nitrogen, dissolved nitrite nitrogen, dissolved phosphorus, and dissolved orthophosphorus. Dissolved orthophosphorus is the phosphorus species most available for aquatic plant growth and was analyzed in all samples. Total phosphorus is typically sorbed on sediment and was only analyzed in a few water samples. Nitrate as used in this report included the nitrite species as this form of the nitrogen species is typically a small concentration (less than 0.1 mg/L). Suspended-sediment concentrations were analyzed at the USGS sediment laboratory in Iowa City.

Table 2 lists the nutrient and bacteria constituents analyzed for in the water column, the Chemical Abstract Registry (CAS) number, USGS National Water Information System (NWIS) database code, and minimum reporting level (MRL). Tables 3 lists the major ions, trace elements, and pesticides analyzed for in the water column, the Chemical Abstract Registry (CAS) number, USGS National Water Information System (NWIS) database code, and the laboratory reporting level (LRL). The LRL is used instead of the

Table 2. Nutrient and bacteria constituents analyzed in water samples, Chemical Abstract Registry (CAS) number, National Water Information System (NWIS) database code, minimum reporting level (MRL), and reporting units

[mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters of sample; --, no data]

Water-quality constituent	CAS number	NWIS code	MRL	Reporting units
Nutrients				
Nitrogen, ammonia, dissolved as N	7664–41–7	00608	0.041	mg/L
Nitrogen, ammonia + organic, dissolved as N	17778–88–0	00623	.10	mg/L
Nitrogen, nitrate + nitrite, dissolved as N	--	00631	.047	mg/L
Nitrogen, nitrite, dissolved as N	14797–65–0	00613	.008	mg/L
Phosphorus, dissolved as P	7723–14–0	00666	.0044	mg/L
Phosphorus, ortho, dissolved as P	14265–44–2	00671	.018	mg/L
Bacteria				
Total coliform	--	31501	--	colonies/100 mL
E. coli	--	31633	--	colonies/100 mL

MRL for specifying quantifiable limits for the majority of constituents listed in table 3 (unless footnoted). The LRL is defined more rigorously by statistics than the MRL and is replacing the MRL at the USGS NWQL (Oblinger-Childress and others, 1999).

BATHYMETRY, SEDIMENT QUALITY, AND WATER QUALITY

Bathymetry

The results of the bathymetric mapping show a number of areas with shallow water (less than 4 ft deep). In general, Lake Delhi can be divided into four reaches that show increasingly deeper water in a downstream direction toward the dam area. Figures 2 through 5 illustrate the bathymetry for the upstream (A), upstream-middle (B), middle (C), and downstream (D) lake reaches. The upstream reach through most of the upstream-middle reach of Lake Delhi (approximately 3 mi) from about 0.25 mi upstream from the Greenslades coring site through Clair View Acres includes the shallowest areas of the lake, with water depths ranging from less than 1 ft to a few areas as much as 10 ft deep (figs. 2 and 3). In particular, the upstream-most 1 mi of Lake Delhi (from about 0.25 mi upstream from the Greenslades coring site to 0.25 mi downstream from The Cedars coring site is particularly shallow (on average 1 to 2 ft) with some areas only accessible by canoe (fig. 2). The middle reach of Lake Delhi (approximately 2.5 mi, fig. 4) is less affected by sediment accumulation, with water depths from less than 1 to 16 ft, but near the Linden Acres coring site and Wellman's Camp there are shallow areas that average 2 to 8 ft. The downstream reach of Lake Delhi (approximately 1.75 mi, fig. 5) has depths from less than 1 to 26 ft deep. The deepest section measured on the lake was 26 ft just upstream from the dam.

Figures 2 through 5 show indications of the original Maquoketa River channel in Lake Delhi. The deepest part of the lake seems to follow the original river channel. Typically, the shallow parts of the lake were along the inside bank curves of the lake (inner area of the bank curve when looking in a downstream direction). Perhaps the flow through the lake could be following the old river channel where water velocities would be slower on the inner bank side of a curve. The slower velocities allow sediment to "drop out" of suspension and accumulate near the inner bank side. The bathymetric maps also show the possible sediment accumulation near the mouths of three tributaries that discharge into Lake Delhi. The mouths of the three tributaries—an unnamed tributary (fig. 3), Turtle Creek (fig. 4), and an unnamed tributary northwest of Turtle Creek (fig. 4)—all have shallow (less than 1 to 4 ft) water where the tributaries merge with Lake Delhi. The sediment from Turtle Creek appears to be accumulating just downstream from a small island near site 050 (fig. 4). Possibly, the island acts as an obstacle further slowing water velocities and allowing sediment to accumulate. The water level between the island and the west bank is currently too shallow to boat through; however, long-time lakeside residents have reported that 20 years ago a boat could pass through on the west side of the island.

Table 3. Major ions, trace elements, and pesticides analyzed in water samples, Chemical Abstract Registry (CAS) number, National Water Information System (NWIS) database code, laboratory reporting level (LRL), and reporting units

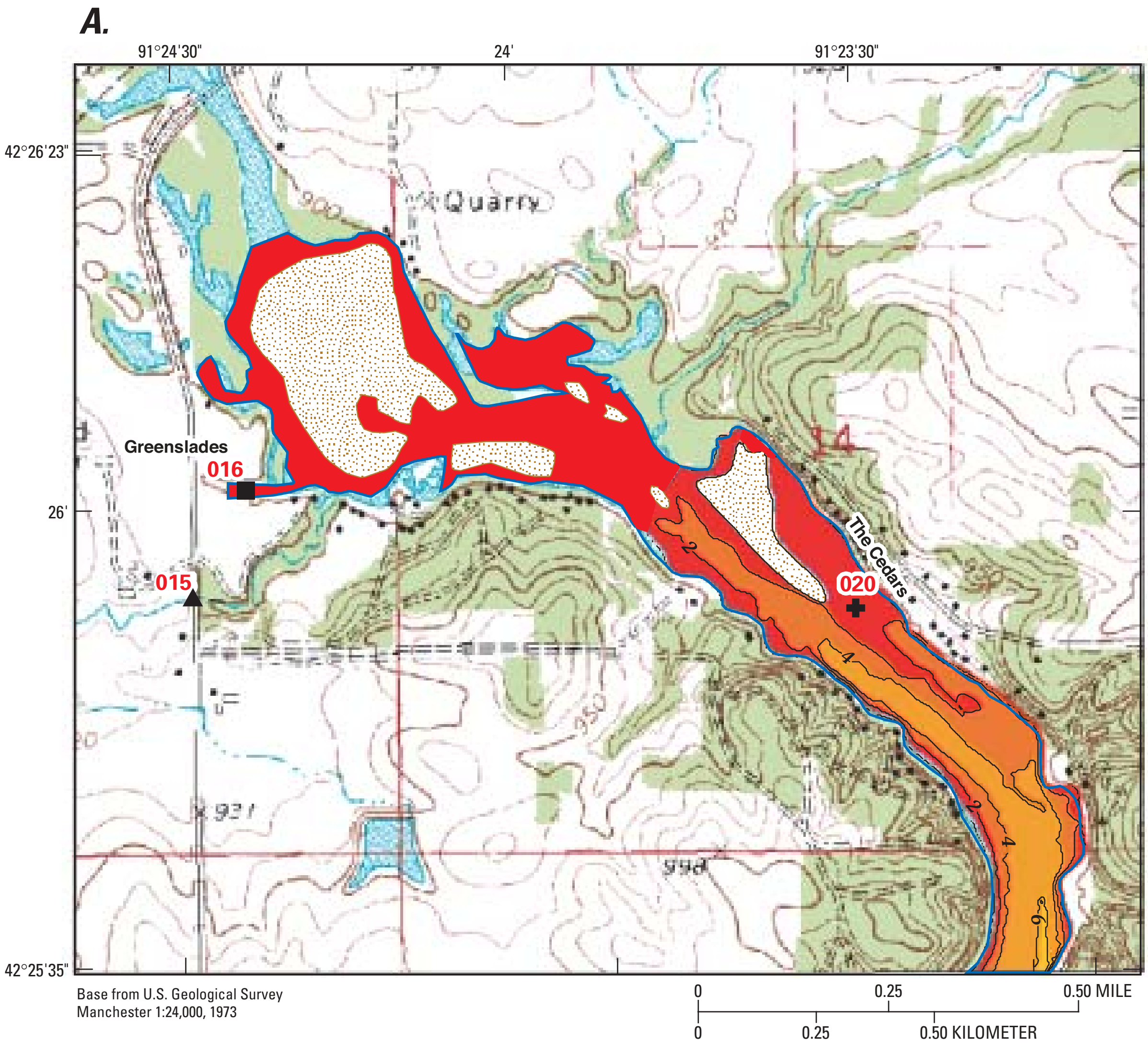
[µg/L, micrograms per liter; mg/L milligrams per liter; --, no data]

Water-quality constituent	CAS number	NWIS code	LRL	Reporting units
		Major ions		
Calcium	7440–70–2	00915	0.012	mg/L
Chloride	16887–00–6	00940	.20	mg/L
Fluoride	16984–48–8	00950	[1].17	mg/L
Magnesium	7439–95–4	00925	.008	mg/L
Potassium	7440–09–7	00935	.11	mg/L
Silica	7631–86–9	00955	.13	mg/L
Sodium	7440–23–5	00930	.09	mg/L
Sulfate	14808–79–8	00945	.18	mg/L
		Trace elements		
Barium	7440–39–3	01005	.9	µg/L
Beryllium	7440–41–7	01010	.5	µg/L
Cadmium	7440–43–9	01025	8	µg/L
Chromium	7440–47–3	01030	10	µg/L
Cobalt	7440–48–4	01035	8	µg/L
Copper	7440–50–8	01040	5.8	µg/L
Iron	7439–89–6	01046	10	µg/L
Lead	7439–92–1	01049	.08	µg/L
Lithium	7439–93–2	01130	3.9	µg/L
Manganese	7439–96–5	01056	1.6	µg/L
Molybdenum	7439–98–7	01060	30	µg/L
Nickel	7440–02–0	01065	29	µg/L
Silver	7440–22-4	01075	9	µg/L
Strontium	7440–24–6	01080	.6	µg/L
Vanadium	7440–62–2	01085	8	µg/L
Zinc	7440–66–6	01090	24	µg/L
		Pesticides		
2,6-Diethylaniline	579–66–8	82660	.006	µg/L
Acetochlor	34256–82–1	49260	.006	µg/L
Alachlor	15972–60–8	46342	.0045	µg/L
Atrazine	1912–24–9	39632	.007	µg/L
Azinphos-methyl	86–50–0	82686	.05	µg/L
Benfluralin	1861–40–1	82673	.010	µg/L
Butylate	2008–41–5	04028	.002	µg/L
Carbaryl	63–25–2	82680	.041	µg/L
Carbofuran	1563–66–2	82674	.020	µg/L
Chlorpyrifos	2921–88–2	38933	.005	µg/L
cis-Permethrin	54774–45–7	82687	.006	µg/L
Cyanazine	21725–46–2	04041	.018	µg/L
Dacthal	1861–32–1	82682	.0030	µg/L

Table 3. Major ions, trace elements, and pesticides analyzed in water samples, Chemical Abstract Registry (CAS) number, National Water Information System (NWIS) database code, laboratory reporting level (LRL), and reporting units—Continued

Water-quality constituent	CAS number	NWIS code	LRL	Reporting units
Pesticides—Continued				
Deethylatrazine	6190–65–4	04040	0.006	µg/L
Diazinon	333–41–5	39572	.005	µg/L
Dieldrin	60–57–1	39381	.0048	µg/L
Disulfoton	298–04–4	82677	.021	µg/L
EPTC	759–94–4	82668	.0020	µg/L
Ethalfluralin	55283–68–6	82663	.009	µg/L
Ethoprophos	13194–48–4	82672	.005	µg/L
Fonofos	944–22–9	04095	.0027	µg/L
Lindane	58–89–9	39341	.0040	µg/L
Linuron	330–55–2	82666	.035	µg/L
Malathion	121–75–5	39532	.027	µg/L
Metolachlor	51218–45–2	39415	.013	µg/L
Metribuzin	21087–64–9	82630	.006	µg/L
Molinate	2212–67–1	82671	.0016	µg/L
Napropamide	15299–99–7	82684	.007	µg/L
p,p'-DDE	72–55–9	34653	.0025	µg/L
Parathion	56–38–2	39542	.010	µg/L
Parathion-methyl	298–00–0	82667	.006	µg/L
Pebulate	1114–71–2	82669	.0041	µg/L
Pendimethalin	40487–42–1	82683	.022	µg/L
Phorate	298–02–2	82664	.011	µg/L
Prometon	1610–18–0	04037	.015	µg/L
Propachlor	1918–16–7	04024	.010	µg/L
Propanil	709–98–8	82679	.011	µg/L
Propargite	2312–35–8	82685	.023	µg/L
Simazine	122–34–9	04035	.005	µg/L
Tebuthiuron	34014–18–1	82670	.016	µg/L
Terbacil	5902–51–2	82665	.034	µg/L
Terbufos	13071–79–9	82675	.017	µg/L
Thiobencarb	28249–77–6	82681	.0048	µg/L
Triallate	2303–17–5	82678	.0023	µg/L
Trifluralin	1582–09–8	82661	.009	µg/L

[1]Minimum reporting level (MRL).



EXPLANATION

Depth, in feet below water surface

- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 14
- 14 – 16
- 16 – 18
- 18 – 20
- 20 – 22
- 22 – 24
- 24 – 26

Lake boundary

Water body

Island

—2— **Line of equal depth to lake-bottom sediment**—Interval is 2 feet. Datum is lake surface (896.0 feet above NGVD of 29)

—950— **Topographic contour**—Shows elevation of land surface. Contour interval 10 feet. Datum is NGVD of 29

015 ▲ **Water-quality sampling site and local site number**

016 ■ **Lake-bottom core sampling site and local site number**

020 ✚ **Lake-bottom core and water-quality sampling site and local site number**

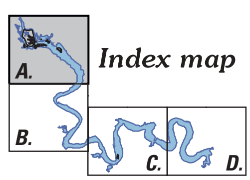
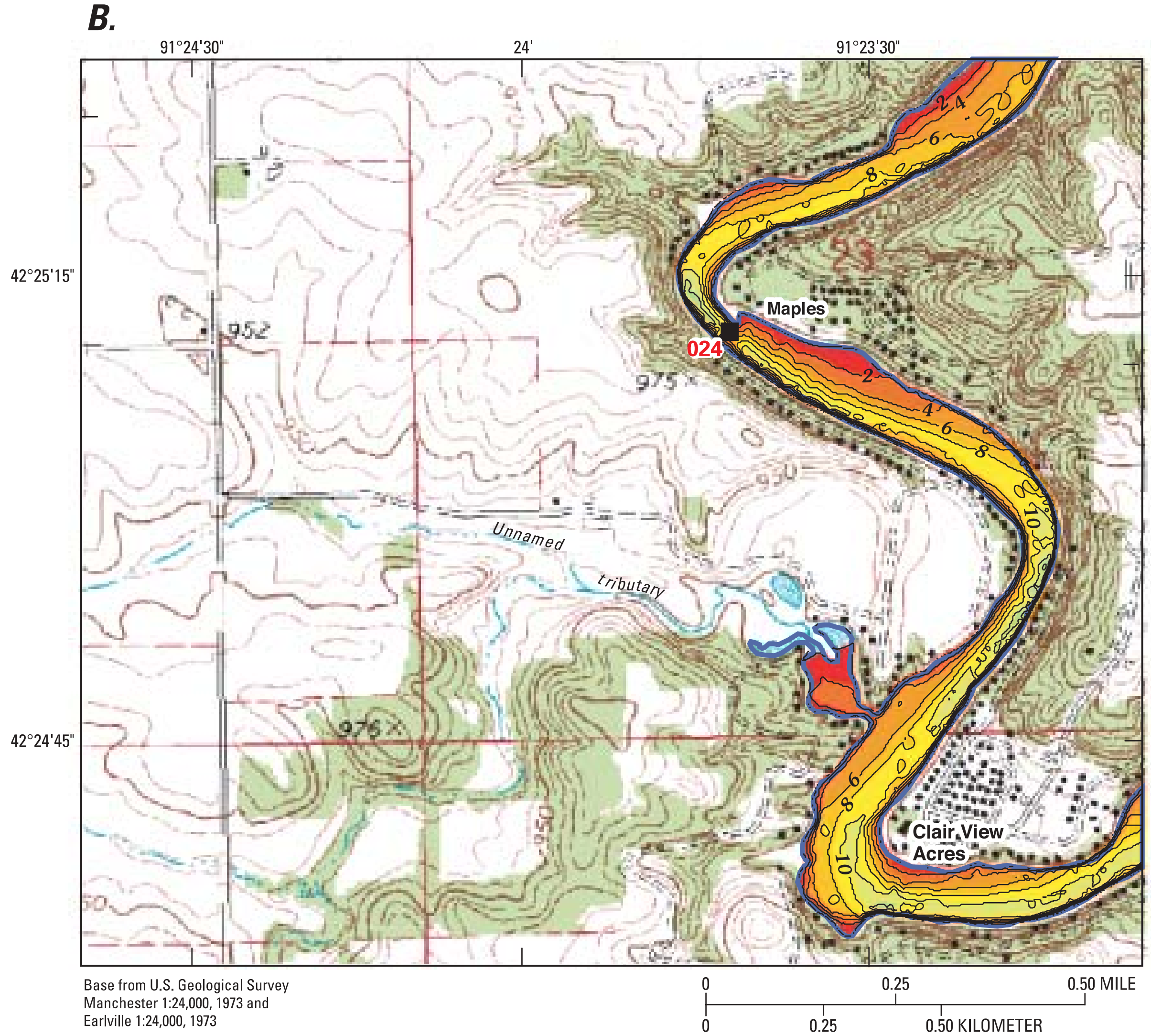


Figure 2. Bathymetry for upstream reach of Lake Delhi.



EXPLANATION

Depth, in feet below water surface

- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 14
- 14 – 16
- 16 – 18
- 18 – 20
- 20 – 22
- 22 – 24
- 24 – 26

Lake boundary

Water body

Island

—*2*— **Line of equal depth to lake-bottom sediment—**Interval is 2 feet. Datum is lake surface (896.0 feet above NGVD of 29)

—*950*— **Topographic contour—**Shows elevation of land surface. Contour interval 10 feet. Datum is NGVD of 29

024 ■ **Lake-bottom core sampling site and local site number**

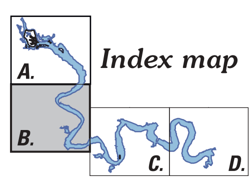
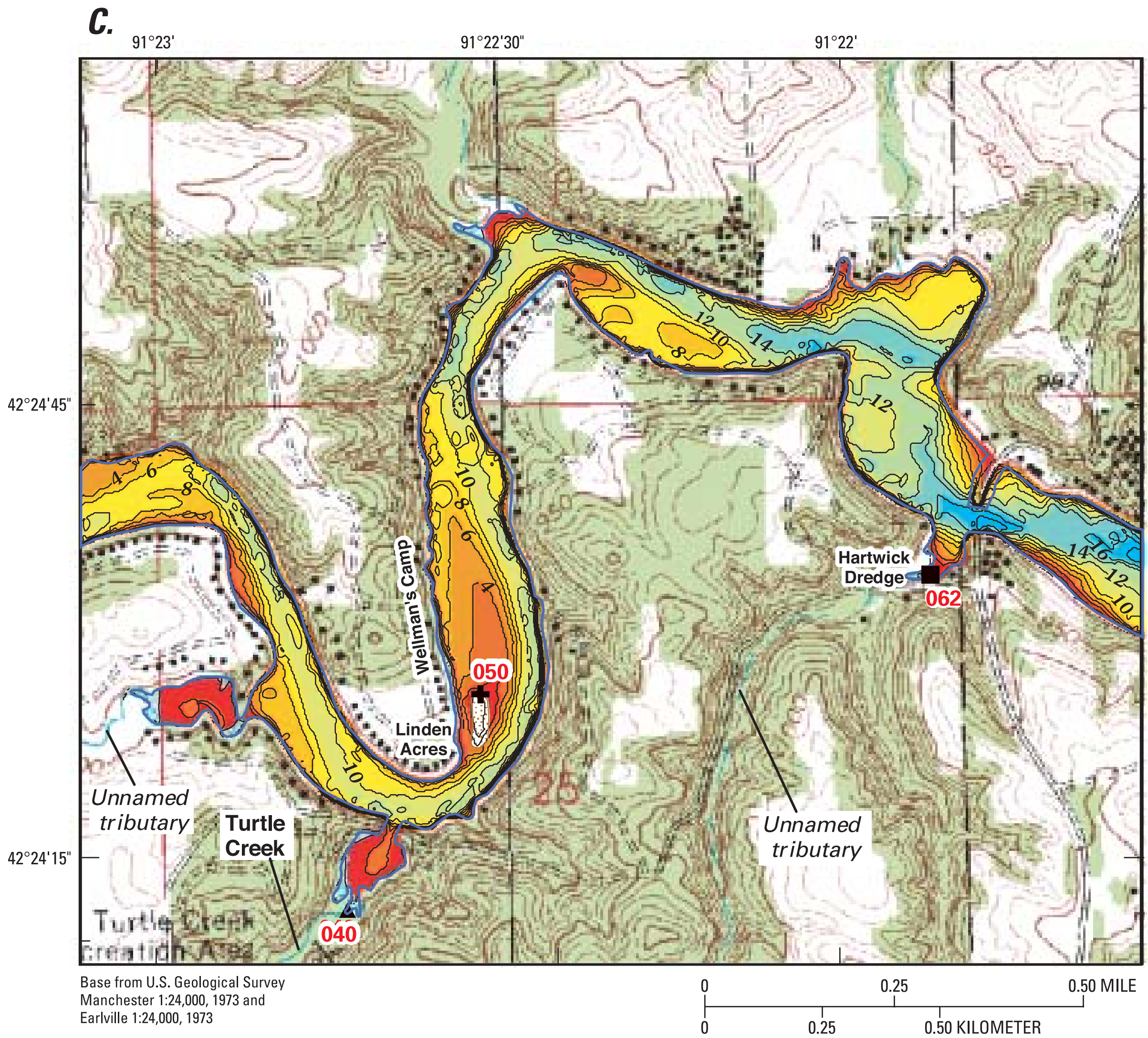


Figure 3. Bathymetry for upstream-middle reach of Lake Delhi.



EXPLANATION

Depth, in feet below water surface

- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 14
- 14 – 16
- 16 – 18
- 18 – 20
- 20 – 22
- 22 – 24
- 24 – 26

- Lake boundary
- Water body
- Island

—*2*— **Line of equal depth to lake-bottom sediment**—Interval is 2 feet. Datum is lake surface (896.0 feet above NGVD of 29)

—*950*— **Topographic contour**—Shows elevation of land surface. Contour interval 10 feet. Datum is NGVD of 29

040▲ **Water-quality sampling site and local site number**

062■ **Lake-bottom core sampling site and local site number**

050✚ **Lake-bottom core and water-quality sampling site and local site number**

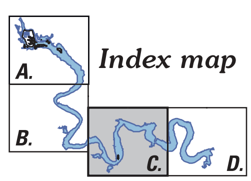


Figure 4. Bathymetry for middle reach of Lake Delhi.

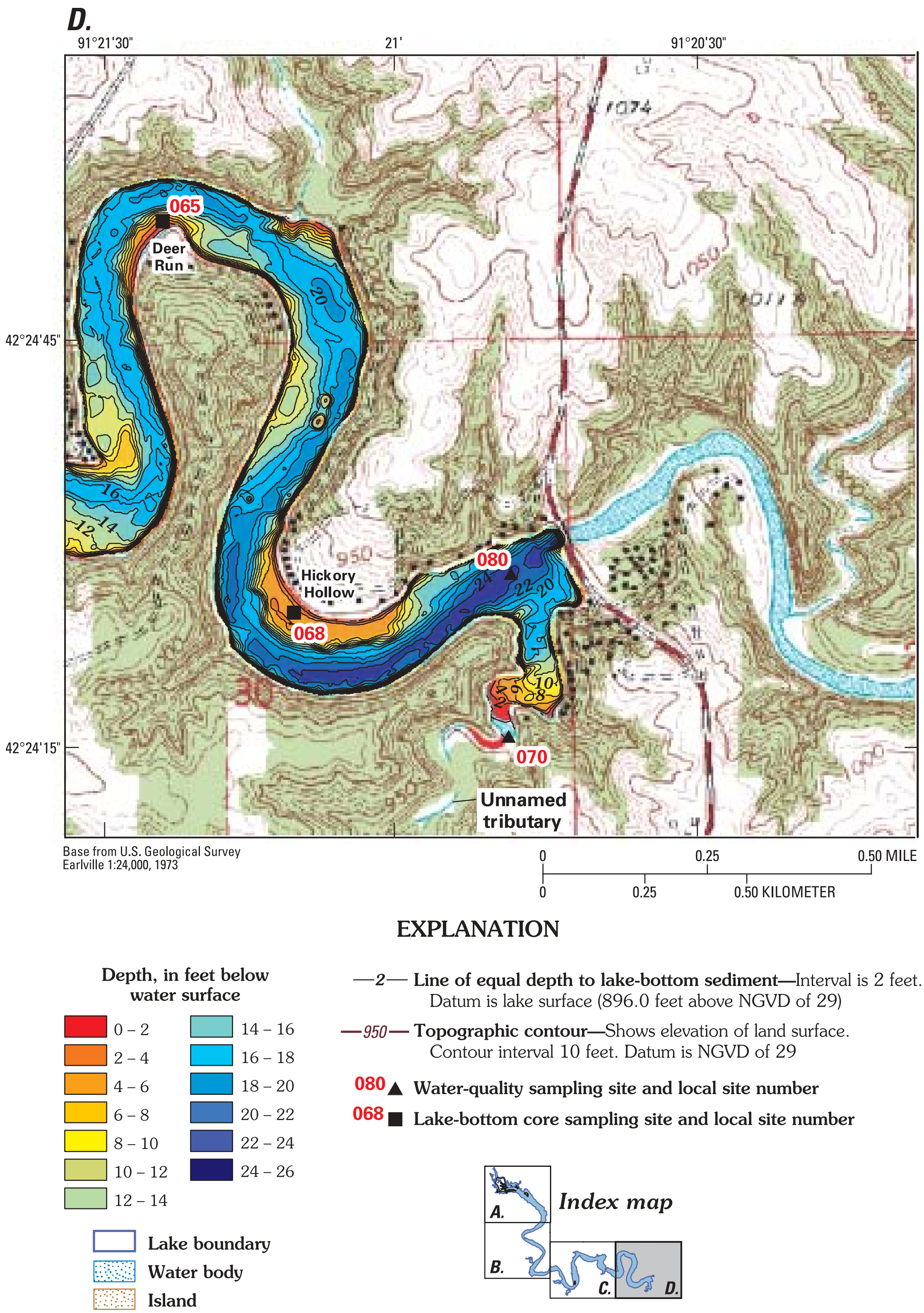


Figure 5. Bathymetry for downstream reach of Lake Delhi.

The tributary streams typically have small streamflows (less than 1.0 ft^3/s); however; the tributary streams can carry large volumes of sediment during storm runoff. For example, during storm runoff (September 2001) Turtle Creek transported more than four times the sediment load compared to nonrunoff (July 2002) conditions. Sediment loads and yields for the Maquoketa River and tributary streams are discussed in more detail in the "Water Quality" section of this report, and results are tabulated in table 8 of that section.

Sediment Quality

The USEPA has established sediment-quality guidelines in the form of "level-of-concern concentrations" for several trace metals (U.S. Environmental Protection Agency, 1997). These level-of-concern concentrations were derived from biological effects correlations made on the basis of paired onsite and laboratory data to relate incidence of adverse biological effects to dry-weight sediment concentrations. Two such level-of-concern concentrations defined by the USEPA are the threshold effects level (TEL) and the probable effects level (PEL). The TEL is the smaller of the two levels of concern and is defined as the concentration below which toxic biological effects rarely occur. At concentrations above the PEL, toxic effects typically occur. In the range of concentrations between the TEL and PEL, adverse effects occasionally occur. Both the TEL and PEL are guidelines to be used as screening tools for possible contaminant effects and are not regulatory criteria. The USEPA (1997) has made this statement because, although biological effects correlation identifies level-of-concern concentrations associated with adverse organism response, the procedure does not demonstrate that a particular contaminant is solely responsible. In particular, chromium concentrations were of interest at Lake Delhi because lakeside residents had mentioned that a tanning factory once operated upstream of Lake Delhi in Manchester, Iowa. Chromium and its salts are typically used in the tanning industry. Chromium in large quantities can cause health problems in humans (Agency for Toxic Substances and Disease Registry, 2002). It is unknown if the tanning factory ever used or discharged chromium to the Maquoketa River.

The median and average trace-element concentrations in the lake-bottom sediment samples did not exceed the TEL or PEL guidelines as set by the USEPA (table 4). Only one sample from site 016 (Greenslades) contained concentrations that slightly exceeded the TEL guidelines for copper and nickel (table 4). The potential source of the nickel and copper concentrations is unknown. However, nickel and copper are two common metals that naturally occur in soils and commonly are used in the production of metal alloys. Nickel often is used in stainless-steel production, and copper is often used in bronze or brass

Table 4. Statistical summary of selected trace metal and phosphorus concentrations in bottom-sediment samples from Lake Delhi, eastern Iowa, September 2001, and comparison to sediment-quality guidelines

[µg/g, micrograms per gram; mg/kg, milligrams per kilogram; TEL, threshold effects level; PEL, probable effects level]

Constituent	Concentrations in bottom-sediment samples (µg/g, except for phosphorus which is mg/kg)				[1]Sediment guidelines (µg/g)	
	Minimum	Maximum	Median	Average	TEL	PEL
Aluminum	1,500	19,000	4,900	6,950	--	--
Cadmium	<.03	.4	.20	.18	0.68	4.21
Chromium	2.6	22	6.50	9.30	52.3	160
Cobalt	.9	9.2	4.40	4.28	--	--
Copper	<2	20	7.0	7.1	18.7	108
Iron	2,200	25,000	8,900	10,440	--	--
Lead	1	20	6.85	8.16	30.2	112
Manganese	22	510	255	240	--	--
Mercury	<.01	.11	.02	.29	.13	.696
Nickel	1.9	23	10.4	9.7	15.9	42.8
Phosphorus	1,300	190	495	540	--	--
Zinc	5	80	30	32.4	124	271

[1]Sediment-quality guidelines from U.S. Environmental Protection Agency (1997).

production. Chromium, a constituent of some concern because of the former tanning factory, did not have concentrations above the TEL or PEL (table 4).

Water Quality

Nutrients, bacteria, and suspended sediment were the main constituents of concern in Lake Delhi. Nutrients in the tributary streams and Lake Delhi include several species of nitrogen (ammonia, ammonia plus organic, nitrite plus nitrate, and nitrite) and phosphorus (orthophosphate and total phosphorus) that are dissolved in the water or attached to suspended sediment. Nutrients concentrations at specific sites are affected by numerous environmental and human factors such as climate, instream processing (algal growth, biotic uptake, and denitrification in bed material), soil transport, proximity to sources, land use, and magnitude of rainfall and storm runoff. Concentrations of total coliform and *E. coli* bacteria in the water column may originate from municipal sewage, agricultural wastes, and septic tanks. Bacteria concentrations can vary substantially in type and number depending on proximity to source, concentration of source material, soil type, rainfall, and runoff. Suspended sediment in the lake and the tributaries originates from upland erosion and erosion within the tributaries and lake. Storms can transport large loads of suspended sediment.

Results from the water-quality sampling in the lake and the tributaries show areas that are affected by nutrients, bacteria, and sediment. Table 5 summarizes the water-quality results for nutrients and bacteria collected from the Marquoketa River sampling site upstream from Lake Delhi (site 010), the lake sites (upstream lake site 020, middle lake site 050, and downstream lake site 080), and the tributary sites (030, 040, 060, 070). Sixty-eight percent of the samples collected (17 of 25 samples, table 10 in the “Supplemental Data” section at the end of this report) had nitrate concentrations (nitrite plus nitrate as nitrogen) greater than the 10-mg/L MCL (Maximum Contaminant Level) established by the USEPA (1986) for drinking water. The maximum nitrate concentration recorded was 18.6 mg/L (site 015, unnamed tributary) during the June 2002 sampling (table 10). The *E. coli* concentrations (that indicate the presence of feces from warmblooded animals) were particularly high (greater than 1,000 colonies per 100 mL) after storm runoff (September 2001) in the watershed (table 10). Supplemental data tables 9–13 at the end of this report list all the sediment-quality and water-quality data collected for the report.

The median nutrient concentrations were typically higher in the tributary samples than in the river and lake samples (table 5). Median concentrations of nitrate in samples from the river and tributary sites ranged from 10.5 to 12.1 mg/L, respectively, as compared to a median nitrate concentration of 8.7 mg/L in samples from the Lake Delhi sites. Other studies in eastern Iowa have shown that runoff from livestock waste and fertilizers may rapidly enter tributary streams during storms and increase nutrient and bacteria concentrations in the stream (Schnoebelen and others, 1999; Kalhoff and others, 2000; Becher and others, 2001). Livestock (in or near the tributary streams) and fertilizer runoff may be contributing to increased inputs of nutrients and bacteria in the tributary streams compared to those in the lake. Typically, a decrease in nitrate concentrations in Lake Delhi was observed in samples from the upstream lake site (010) to the downstream lake site (080) during each of the sample periods (reading across the columns of table 6). This decrease in nitrate concentrations from upstream to downstream in the lake was most likely the result of uptake of nitrate by algae and aquatic biota in the lake. The one exception to this pattern were the samples collected from Lake Delhi during March 2002 when all sites had similar nitrate concentrations (table 6). In this case, the March sample collection occurred just after “ice-out” of the lake, and most likely there was little (if any) processing of nitrate by algae. The lack of uptake by algae or other aquatic biota probably resulted in similar nitrate concentrations throughout the lake at this time.

Seasonal variations of nitrate concentrations in Lake Delhi also were found (reading down the columns of table 6), with large nitrate concentration occurring in the samples collected during spring and late spring (May/June) and with small concentrations in samples collected during the summer and late summer (July and September). In eastern Iowa, large nitrate concentrations typically occur in the spring owing to applications of fertilizers followed by spring rain that transports nitrate to streams and lakes (Schnoebelen and others, 1999; Kalkhoff and others; 2000; Becher and others, 2001). However, as the growing season continues, nitrate concentrations decrease as runoff becomes smaller (less rain) and the agricultural crops use the fertilizer. In addition, aquatic

Table 5. Statistical summary of nutrient and bacteria concentrations in water samples from Maquoketa River, Lake Delhi, and tributary sites, eastern Iowa, June 2001 through June 2002, and comparison to water-quality guidelines

[Constituent concentrations in milligrams per liter unless otherwise noted. USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Level; E, estimated value; mg/L, milligrams per liter; colonies/100 mL, colonies per 100 milliliters of sample; --, no data; <, less than]

Constituent	Concentration				EPA MCL or guideline
	Minimum	Maximum	Median	Average	
Maquoketa River [station 05416900 (site 010) upstream of Lake Delhi]					
Nitrogen, ammonia, dissolved as nitrogen	E0.032	0.065	0.050	0.049	[1]Temperture and pH dependent
Nitrogen, ammonia + organic, dissolved as nitrogen	.22	.49	.39	.37	--
Nitrogen, nitrite + nitrate, dissolved as nitrogen	8.28	13.5	10.5	10.7	[2]10 mg/L
Nitrogen, nitrite, dissolved as nitrogen	.027	.065	.049	.049	[2]1 mg/L
Phosphorus, dissolved as phosphorus	.050	.158	.071	.088	[3]0.1 mg/L
Phosphorus, ortho, dissolved as phosphorus	.500	.146	.460	.660	--
Total coliform (colonies/100 mL)	1,300	21,000	1,600	5,750	[4]200 colonies/100 mL (fecal)
E. coli (colonies/100 mL)	100	3,100	310	452	[4]126 colonies/100 mL
Lake sites [stations 05417200 (site 020), 05417320 (site 050), and 05417480 (site 080)]					
Nitrogen, ammonia, dissolved as nitrogen	<.040	.198	.040	.065	[1]Temperture and pH dependent
Nitrogen, ammonia + organic, dissolved as nitrogen	.21	.71	.46	.45	--
Nitrogen, nitrite + nitrate, dissolved as nitrogen	.500	13.5	8.7	9.66	[2]10 mg/L
Nitrogen, nitrite, dissolved as nitrogen	.031	.110	.061	.062	[2]1 mg/L
Phosphorus, dissolved as phosphorus	.033	.213	.072	.079	[3]0.1 mg/L
Phosphorus, ortho, dissolved as phosphorus	.010	.199	.047	.058	--
Total coliform (colonies/100 mL)	17	25,000	450	3,510	[4]200 colonies/100 mL (fecal)
E. coli (colonies/100 mL)	0	1,900	17	350	[4]126 colonies/100 mL
Tributary sites [stations 05417170 (site 015), 05417275 (site 030), 05417300 (site 040), and 05417470 (site 070)]					
Nitrogen, ammonia, dissolved as nitrogen	.029	.751	.046	.122	[1]Temperture and pH dependent
Nitrogen, ammonia + organic, dissolved as nitrogen	.23	2.1	.58	.79	--
Nitrogen, nitrite + nitrate, dissolved as nitrogen	1.30	18.6	12.1	10.7	[2]10 mg/L
Nitrogen, nitrite, dissolved as nitrogen	.020	.158	.041	.074	[2]1 mg/L
Phosphorus, dissolved as phosphorus	.032	.658	.098	.203	[3].1 mg/L
Phosphorus, ortho, dissolved as phosphorus	<.020	.396	.065	.168	--
Total coliform (colonies/100 mL)	1	140,000	8,200	26,100	[4]200 colonies/100 mL (fecal)
E. coli (colonies/100 mL)	1	29,000	1,600	6,560	[4]126 colonies/100 mL

[1]U.S. Environmental Protection Agency (1999).
[2]U.S. Environmental Protection Agency (1996).
[3]U.S. Environmental Protection Agency (1986).
[4]Iowa Department of Natural Resources (2003), bacteria standards are for body contact. Also, U.S. Environmental Protection Agency (1998).

Table 6. Nitrate concentrations in water samples from upstream, middle, and downstream portions of Lake Delhi, eastern Iowa sites, by season, June 2001 through July 2002

Season (sampling date)	Nitrate concentrations, in milligrams per liter of nitrogen		
	Upstream (station 05417200, site 020)	Middle (station 05417320, site 050)	Downstream (station 05417480, site 080)
Early spring (March 2002)	8.65	8.61	8.76
Spring (May/June 2002)	13.5	13.1	8.49
Late spring (June 2001)	12.7	12.2	12.0
Summer (July 2002)	7.30	6.53	6.32
Late summer (September 2001)	7.80	5.11	5.00

plants process much of the nitrate that moves to streams and lakes in Iowa during the summer and early fall (Becher and others, 2001). Algae blooms in Iowa during the late summer (September) confirm the large amount of aquatic plant growth and instream processing of nitrate during this time.

Total coliform bacteria concentrations were more variable in samples from the lake (table 7) when compared to nitrate concentrations (table 6). In general, bacteria concentrations decreased in samples from the upstream to downstream lake sites (reading across the columns, table 7). This decrease most likely was related to the decrease in sediment particles settling out because bacteria often are attached to sediment particles. However, exceptions to this occur during runoff. During the September 2001 sample collection, rainfall caused runoff at the downstream lake site, and the bacteria concentrations quickly increased at this site. Typically, large bacteria concentrations were related to runoff, and no seasonal patterns were noted. The one exception to this was the March 2002 sample collection that occurred during ice-out when the weather was still cold and no runoff was entering the lake. The combination of no runoff and colder temperatures resulted in the lowest bacteria concentrations measured for this report.

Sediment was a constituent of concern. Suspended-sediment concentrations and instantaneous loads and yields were calculated for the Maquoketa River and the four tributary water-quality sampling sites (table 8). An instantaneous load is the concentration of the suspended sediment multiplied by the streamflow (discharge) at the time of sediment collection. The load number helps identify how much sediment a stream is transporting. The sediment yield for a drainage area is the instantaneous load divided by the drainage area. The sediment yield for a drainage area is particularly important because the sediment yield allows a comparison that can identify the relative contribution of sediment by an area.

The results from the suspended-sediment analyses indicated large loads of sediment being transported to Lake Delhi from the Maquoketa River. Sediment loads calculated for the Maquoketa River (station 05416900, site 010) during the five sampling periods had loads that ranged from 12,600 to 98,000 lb/d (table 8). Loads for the tributary streams were smaller and ranged from 0.1 to 5,300 lb/d (table 8). However, some of the tributary streams were shown to have high yields during rainfall and runoff. The unnamed tributary site 030 had the highest sediment yield (2,300 lb/mi^2) of any site during runoff in September 2001 (table 8). In general,

Table 7. Total coliform and *E. coli* bacteria concentrations in water samples from upstream, middle, and downstream portions of Lake Delhi, eastern Iowa, by season, June 2001 through July 2002

[--, no data; E, estimated; M, material verified but not quantified]

Season (sampling date)	Total coliform and *E. coli* concentrations, in colonies per 100 milliliters of sample		
	Upstream (station 05417200, site 020)	Middle (station 05417320, site 050)	Downstream (station 05417480, site 080)
Early spring (March 2002)	420 (30)	20 (0)	17 (0)
Spring (May/June 2002)	5,300 (1,100)	1,000 (380)	450 (280)
Late spring (June 2001)	4,300 (--)	530 (E0)	E40 (E2)
Summer (July 2002)	330 (170)	68 (4)	291 (0)
Late summer (September 2001)	E 25,000 (M1)	1,900 (1,000)	S13,000 (E1,900)

Table 8. Instantaneous discharge, suspended-sediment concentrations, loads, and yields by season for Maquoketa River and four tributary sites, eastern Iowa, June 2001 through July 2002

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; lb/d, pounds per day; lb/mi^2; pounds per square mile; mi^2, square miles]

Season (sample date)	Instantaneous discharge (ft^3/s)	Suspended-sediment concentration (mg/L)	Load (lb/d)	Yield (lb/mi^2)
Maquoketa River (station 05416900, site 010)—drainage area 275 mi^2				
Early spring (March 2002)	164	28	24,800	90
Spring (May/June 2002)	395	46	98,000	360
Late spring (June 2001)	240	41	53,100	190
Summer (July 2002)	[1]122	19	12,600	46
Late summer (September 2001)	356	34	65,300	240
Average	**255**	**34**	**50,800**	**180**
Unnamed tributary (station 05417170, site 015)—drainage area 2.09 mi^2				
Early spring (March 2002)	.64	1	3.5	1.7
Spring (May/June 2002)	2.3	6	74	35
Late spring (June 2001)	.34	10	18	8.8
Summer (July 2002)	.35	2.5	4.7	2.3
Late summer (September 2001)	.41	13	29	14
Average	**.81**	**6.5**	**26**	**12**
Unnamed tributary (station 05417275, site 030)—drainage area 2.29 mi^2				
Early spring (March 2002)	.79	26	110	48
Spring (May/June 2002)	1.8	28	270	120
Late spring (June 2001)	.70	10	38	17
Summer (July 2002)	.49	15	40	18
Late summer (September 2001)	3.5	280	5,300	2,300
Average	**1.46**	**72**	**1,200**	**500**
Turtle Creek (station 05417300, site 040)—drainage area 2.10 mi^2				
Early spring (March 2002)	.80	8	34	16
Spring (May/June 2002)	1.1	33	200	93
Late spring (June 2001)	.87	120	550	260
Summer (July 2002)	.88	26	120	58
Late summer (September 2001)	1.1	98	580	280
Average	**.95**	**57**	**300**	**140**
Unnamed tributary (station 05417470, site 070)—drainage area 1.51 mi^2				
Early spring (March 2002)	.16	17	15	9.7
Spring (May/June 2002)	.07	23	8.7	5.8
Late spring (June 2001)	.08	36	15	10
Summer (July 2002)	[2].001	21	.1	.1
Late summer (September 2001)	.82	48	210	140
Average	**.23**	**29**	**50**	**33**

[1]Flow from stream gage.
[2]Flow observed but was too small to measure, estimated value.

the watershed upstream from site 030 has little if any riparian zone near the stream. Typically, a larger riparian zone near a stream provides beneficial effects to water quality in the stream (Sorenson and others, 1999). The loads from the tributary sites may be small when compared to the input from the Maquoketa River, but on a yield basis, the tributaries can contribute substantial amounts of sediment during runoff (table 8).

Additional Water-Quality Data

Additional water-quality data include the analytical results of two pesticide samples and a one-time sampling of major ions and trace metals that are listed in tables 9–13 in the “Supplemental Data” section at the back of this report. The pesticides detected were acetochlor (0.024 and 0.179 µg/L), alachlor (0.007 µg/L), atrazine (0.613 and 1.48 µg /L), and metolachlor (0.142 and 0.448 µg /L). Other pesticides were not detected (table 12). Acetochlor, atrazine, and metolachlor are the three most commonly used pesticides in eastern Iowa and are typically the most frequently detected (Akers and others, 2000; Kalkhoff and others, 2000). In general, the results of the major-ion and trace-metal data also were typical of results collected from other streams in eastern Iowa for these constituents. Large concentrations of trace metals in the water column that might pose a human health concern were not detected.

SUMMARY AND CONCLUSIONS

Lake Delhi (Federally recognized as Hartwick Lake) was formed in 1929 when the Interstate Power Company dammed the Maquoketa River to build a hydroelectrical generating plant. The local name “Lake Delhi” was adopted in recognition of the nearby town of Delhi, Iowa. The resulting 450-acre lake became a popular area in eastern Iowa for boating, swimming, and fishing. Hydroelectric power generation ended in 1973, and lakeside residents formed the Lake Delhi Association. The Lake Delhi Association purchased the dam to maintain the recreational opportunities of Lake Delhi.

Since 1973, the increased population around Lake Delhi, the increased recreational use, and possible contaminant inputs (point and nonpoint sources) are of concern to lake users. In particular, inputs of nutrients (nitrate, ammonia, and phosphorus), bacteria, and sediment can negatively affect water quality and recreational use of Lake Delhi. Increasing concerns of sediment deposition and water quality by lakeside residents led to the study described in this report that included a bathymetric survey and an assessment of sediment quality and water quality of Lake Delhi. The USGS conducted the study from June of 2001 through July 2002.

A bathymetric map of Lake Delhi was constructed using over 300,000 data points from echo-sounding results and GIS software. Results of the bathymetric mapping showed that the upstream reach through most of the upstream-middle reach of Lake Delhi (approximately 3 mi) from about 0.25 mi upstream from the Greenslades coring site through Clair View Acres were the shallowest areas of the lake, with water depth ranging from less than 1 ft to a few areas that were as much as 10 ft deep. The upstream-most 1 mi of Lake Delhi (from about 0.25 mi upstream from the Greenslades coring site to 0.25 mi downstream from The Cedars coring site) was particularly shallow (on average 1 to 2 ft) with some areas only accessible by canoe. The middle reach of Lake Delhi (approximately 2.5 mi) was less affected by sediment accumulation with water depths ranging from less than 1 to 16 ft, but near the Linden Acres coring site and Wellman’s Camp the lake had shallow areas that averaged 2 to 8 ft deep. The deepest section measured in the lake was 26 ft just upstream from the dam. Tributary streams can contribute significant sediment loads during rainfall and runoff. Bathymetric mapping indicated that the deeper areas of the lake may follow the original Maquoketa River channel.

Eleven trace metals and phosphorus were analyzed in 20 samples collected from seven bottom-sediment cores. The median and average concentrations from the lake bottom sediments did not exceed the threshold-effects-level or probable-effects-level guidelines for toxic biological effects established by USEPA. Chromium, a constituent of some concern (because of possible use in a former tanning factory in Manchester upstream from Lake Delhi) did not occur in concentrations that exceeded the threshold-effects-level or probable-effects-level guidelines.

Water-quality samples were collected at eight sites—one site on the Maquoketa River upstream from the lake, three sites on Lake Delhi, and four tributary sites. Each of the eight sites were sampled five times—June 2001, September 2001, March 2002, June 2002, and July 2002—and analyzed for physical properties (specific conductance, pH, temperature, dissolved oxygen, turbidity, and alkalinity), nutrients, bacteria (total coliform and *E. coli*), and suspended sediment. Two sites were sampled for pesticides in June 2001. A one-time sampling for major ions and trace metals in the water column was done at all eight sites in September 2001. Trace metals in the water column were not found in concentrations exceeding USEPA guidelines. Two samples were collected for pesticide analysis during the June 2001 sampling. The pesticides detected were acetochlor (0.024 and 0.179 μg/L), alachlor (0.007 μg/L), atrazine (0.613 and 1.48 μg/L), and metolachlor (0.142 and 0.448 μg/L).

Results from the water-quality sampling of the lake and tributaries showed areas that have been affected by nutrients and bacteria. The tributary streams had the highest median nitrate concentrations (12.1 mg/L) when compared to median nitrate concentrations in the lake (8.7 mg/L) or the Maquoketa River (10.5 mg/L). The maximum nitrate concentrations occurred during the spring, with 13.5 mg/L in a sample from the Maquoketa River, 13.5 mg/L in a sample from upstream lake site, and 18.6 mg/L in a sample from a tributary site. Median nitrate concentrations during the late summer decreased in samples from upstream (7.8 mg/L) to the downstream (5.0 mg/L) reaches of Lake Delhi, indicating possible instream processing of nitrate by algae and other aquatic organisms.

Median concentrations of total and *E. coli* bacteria in samples from the lake sites were 450 and 17 colonies per 100 mL, respectively. The highest bacteria concentrations observed in lake samples were 25,000 total coliform per 100 mL (upstream lake site) and 1,900 *E. coli* per 100 mL (downstream lake site) after a rain and subsequent runoff (September 2001). Median total coliform and *E. coli* concentrations in samples from the tributary sites had the highest bacteria counts (of all sites) and were 8,200 and 1,600 colonies per 100 mL, respectively. In general, the tributary sites have small (less than 200 ft wide) riparian zones near the stream and agricultural land commonly adjoins the tributary streams. Runoff from livestock waste and fertilizers can enter tributary streams rapidly during storm runoff increasing nutrient and bacteria concentrations in the stream. Livestock in or near the tributary streams can contribute to increased inputs of nutrients and bacteria compared to those in the lake. Typically, a decrease in nitrate concentrations in Lake Delhi occurred in samples from the upstream lake site (010) to the downstream lake site (080) during each of the sample periods. The decrease in nitrate concentrations in samples from the upstream lake site to the downstream lake site was most likely the result of uptake of nitrate by algae and aquatic biota in the lake.

Seasonal variations of nitrate concentrations in samples from Lake Delhi also were found, with larger nitrate concentrations (8.49–13.5 mg/L) occurring in the late spring (May/June) and smaller concentrations (5.0–7.8 mg/L) in the middle to late summer (July and September). In Iowa larger nitrate concentrations typically occur in the spring due to applications of fertilizers followed by spring rain that mobilize large concentrations of nitrate to streams and lakes. However, as the growing season continues nitrate concentrations decrease as runoff becomes smaller (less rain) and as agricultural plants grow and use more of the fertilizer. In addition, aquatic plants process much of the nitrate that moves to streams and lakes in Iowa during the summer and early fall.

In general, bacteria concentrations decreased from the upstream to downstream lake sites. This reduction was most likely related to the decrease in sediment particles settling out as bacteria often are attached to sediment particles. However, exceptions to this observation occurred during rainfall and runoff conditions. For example, during the September 2001 sample collection, rain caused runoff at the downstream lake site (site 080) that quickly increased the bacteria concentrations at this site to 13,000 total coliform colonies per 100 mL and 1,900 *E. coli* colonies per 100 mL. Typically, the larger bacteria concentrations recorded during the study were related to runoff, and no seasonal patterns were noted.

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SUPPLEMENTAL DATA

Table 9. Phosphorus and trace-element concentrations in samples from sediment cores, Lake Delhi, eastern Iowa, September 18, 2001

[mg/kg, milligrams per kilogram; µg/g, micrograms per gram; P, phosphorus; CD, cadmium; CO, cobalt; CU, copper; FE, iron; PB, lead; HG, mercury; NI, nickel; ZN, zinc; <, less than; M, presence verified but not quantified]

Local site number (fig. 1)	Station number	Station name	Time of sample collection (24-hour)	Core sample interval (feet)	Moisture content dry weight (percent of total)	Phophorus, total in bottom material (mg/kg as P)	Aluminum, recoverable from bottom material (µg/g as Al)
016	05417175	Lake Delhi at Greenslades	1000	0.2–0.5	42	1,000	19,000
			1005	1.0–1.3	42	1,300	19,000
			1010	1.35–1.65	29	540	9, 400
			1015	2.0–2.3	17	210	1,500
020	05417200	Upstream Lake Delhi near The Cedars	1100	0.2–0.5	39	790	13,000
			1105	1.0–1.3	29	520	10,000
			1110	1.35–1.65	31	880	9,300
			1115	1.8–2.1	39	790	8,200
024	05417230	Lake Delhi at Maples	1200	0.2–0.5	17	750	2,500
			1205	1.3–1.6	29	550	7,800
			1210	1.95–2.25	21	420	3,700
050	05417320	Middle Lake Delhi near Linden Acres	1300	0.7–1.0	9	190	1,800
			1305	2.6–3.1	15	190	1,500
062	05417390	Hartwick Dredge at Lake Delhi	1400	0.2–0.5	16	510	4,600
			1405	1.0–1.3	25	470	5,100
			1410	1.7–2.0	24	230	5,900
			1415	2.7–3.0	36	480	4,700
065	05417440	Lake Delhi at Deer Run	1500	0.95–1.25	12	270	3,100
068	05417460	Lake Delhi at Hickory Hollow	1600	0.3–0.6	8	480	4,500
			1605	1.1–1.4	13	220	4,400

Table 9. Phosphorus and trace-element concentrations in samples from sediment cores, Lake Delhi, eastern Iowa, September 18, 2001—Continued

Local site number (fig. 1)	Station number	Cadmium, recoverable from bottom material (µg/g as Cd)	Chromium, recoverable from bottom material (µg/g as Cr)	Cobalt, recoverable from bottom material (µg/g as Co)	Copper, recoverable from bottom material (µg/g as Cu)	Iron, sediment, bed material (µg/g as Fe)	Lead, recoverable from bottom material (µg/g as Pb)	Manganese, recoverable from bottom material (µg/g as Mn)	Mercury, recoverable from bottom material (µg/g as Hg)	Nickel, recoverable from bottom material (µg/g as Ni)	Zinc, recoverable from bottom material (µg/g as Zn)
016	05417175	0.40	22	9.2	20	25,000	20	500	0.04	23	80
		.40	22	8.4	17	25,000	19	510	.06	21	80
		.20	12	5.2	10	14,000	12	290	.05	12	40
		<.03	3.5	1.4	<2.0	3,300	2.0	83	<.01	2.9	7.0
020	05417200	.40	17	7.1	13	18,000	17	450	.11	17	60
		.20	17	4.9	9.0	13,000	10	270	.06	12	40
		.30	13.6	5.7	10	15,000	16	280	.06	13	50
		.20	12	4.5	8.0	12,000	9.9	270	.03	11	40
024	05417230	M	4.3	1.6	<2.0	3,400	1.7	22	<.01	3.0	9.0
		.20	11	4.0	8.0	11,000	9.6	160	.03	9.9	40
		.10	5.6	2.0	3.0	5,500	4.0	79	.01	4.5	20
050	05417320	<.03	3.2	1.3	<2.0	2,800	1.3	33	<.01	2.3	7.0
		<.03	2.6	.9	<2.0	2,200	1.0	73	<.01	1.9	5.0
062	05417390	.10	6.5	4.6	7.0	8,900	5.7	500	.02	12	20
		.20	6.3	5.2	7.0	8,200	7.8	320	.02	11	30
		.20	7.9	5.5	9.0	8,900	7.6	270	.02	12	30
		.10	6.2	4.3	5.0	7,100	6.1	200	.02	8.8	30
065	05417440	.10	6.6	2.5	3.0	8,900	2.8	240	<.01	5.4	10
068	05417460	.10	5.9	3.5	3.0	9,900	4.0	140	.01	5.3	20
		.10	4.9	3.7	6.0	6,700	5.8	110	.01	5.7	30

Table 10. Nutrient and bacteria concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002

[mg/L, milligrams per liter; N, nitrogen; E, estimated value; <, less than; P, phosphorus; --, no data; colonies/100 mL, colonies per 100 milliliters of sample; S, most probable value; M, presence verified, not quantified; N, presumptive evidence of presence; V, contamination; mL, milliliters]

Local site number (fig. 1)	Station number	Station name	Sampling date (month/day/year)	Time of sample collection (24-hour)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, dissolved (mg/L as N)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)
010	05416900	Maquoketa River at Manchester, Iowa	6/27/2001	1755	E0.039	0.40	12.4	0.057
			9/20/2001	0810	.061	.49	8.28	.042
			3/19/2002	1545	E.032	.22	8.69	.027
			6/01/2002	0830	.065	.38	13.5	.065
			7/16/2002	1410	.045	.52	6.83	.045
015	05417170	Unnamed tributary near Bailey Ford	6/27/2001	0955	E.038	.43	13.9	.130
			9/20/2001	1230	E.040	.47	9.88	.151
			3/19/2002	1445	.084	.39	12.5	.045
			6/01/2002	0945	E.027	.26	18.6	.036
			7/17/2002	0810	.071	.38	10.9	.133
020	05417200	Upstream Lake Delhi near The Cedars	6/27/2001	0835	E.039	.55	12.7	.075
			9/20/2001	0935	.109	.59	7.80	.052
			3/19/2002	1245	E.023	.23	8.65	.036
			5/31/2002	1550	.077	.46	13.5	.073
			7/16/2002	1240	<.040	.25	7.30	.032
030	05417275	Unnamed tributary at County Highway 267 and 205 Avenue	6/27/2001	1215	E.031	.23	16.0	.154
			9/19/2001	1050	.165	.98	6.60	.032
			3/19/2002	1400	.174	.52	11.8	.023
			5/31/2002	1740	E.029	.26	15.1	.021
			7/17/2002	0905	<.040	.28	13.5	.032
040	05417300	Turtle Creek at Turtle Creek recreation area	6/27/2001	1435	.072	1.8	17.0	.115
			9/19/2001	1550	E.026	.80	11.3	.037
			3/19/2002	1115	E.033	.85	12.4	.020
			5/31/2002	1630	.047	.28	17.6	.036
			7/16/2002	0925	<.040	.25	13.8	0.041

Table 10. Nutrient and bacteria concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local site number (fig. 1)	Station number	Station name	Sampling date (month/day/year)	Time of sample collection (24-hour)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, dissolved (mg/L as N)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)
050	05417320	Middle Lake Delhi near Linden Acres	6/26/2001	1520	E0.040	0.71	12.2	0.091
			9/19/2001	1655	<.040	.25	5.11	.036
			3/19/2002	1155	<.040	.21	8.61	.042
			5/31/2002	1510	.161	.66	13.1	.110
			7/16/2002	1215	.140	.48	6.53	.046
070	05417470	Unnamed Creek at cove near dam, site 070	6/26/2001	1150	.045	.65	2.75	.093
			9/19/2001	1430	.236	1.5	1.30	.112
			3/20/2002	1045	.751	2.1	2.62	.280
			5/31/2002	1335	.147	1.2	1.54	.158
			7/16/2002	1030	<.04	.88	1.89	.016
080	05417480	Downstream Lake Delhi near dam	6/26/2001	1230	.046	.47	12.0	.069
			9/19/2001	1330	E.022	.39	5.00	.048
			3/20/2002	0940	<.040	.24	8.76	.031
			5/31/2002	1415	.198	.60	8.49	.076
			7/16/2002	1115	.123	.52	6.32	.058

Table 10. Nutrient and bacteria concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local number (fig. 1)	Station number	Sampling date (month/day/year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Phosphorus, total (mg/L as P)	Total coliform (colonies/100 mL)	*E. coli* (colonies/100 mL)
010	05416900	6/27/2001	0.081	0.029	0.111	1,300	310
		9/20/2001	.158	.146	--	S21,000	S3,100
		3/19/2002	E.050	.040	--	1,600	100
		6/01/2002	.061	.051	.134	4,000	1,100
		7/16/2002	.038	<.040	.100	830	150
015	05417170	6/27/2001	.059	E.011	.071	E16,000	E9,900
		9/20/2001	.297	.275	--	S120,000	22,000
		3/19/2002	E.040	.034	--	6,100	110
		6/01/2002	.032	.027	.046	4,300	130
		7/17/2002	.041	.026	.065	13,900	1,400
020	05417200	6/27/2001	.072	E.016	.107	4,300	--
		9/20/2001	.213	.199	--	E25,000	M1
		3/19/2002	E.033	.029	--	420	30
		5/31/2002	.072	.056	.164	5,300	1,100
		7/16/2002	.042	.029	.106	330	170
030	05417275	6/27/2001	.060	<.020	.066	5,300	140
		9/19/2001	.658	.62	--	V1	V1
		3/19/2002	E.054	.043	--	4,600	150
		5/31/2002	.052	.046	.105	8,600	540
		7/17/2002	.072	.063	.096	11,800	1,800
040	05417300	6/27/2001	.104	<.020	.417	E64,000	E29,000
		9/19/2001	.536	.51	--	S72,000	S18,000
		3/19/2002	.060	.048	--	1,800	700
		5/31/2002	.092	.081	.159	6,900	4,000
		7/16/2002	.102	.091	.158	7,800	7,000
050	05417320	6/26/2001	.071	E.011	.103	530	E0
		9/19/2001	.064	.057	--	--	--
		3/19/2002	E.034	.025	--	20	0
		5/31/2002	.106	.086	.197	1,000	380
		7/16/2002	.064	.044	.175	68	4
070	05417470	6/26/2001	.268	.187	.399	E2,400	E40
		9/19/2001	.434	.386	--	E140,000	N1
		3/20/2002	.237	.161	--	13,000	4,200
		5/31/2002	.267	.221	.375	19,000	12,000
		7/16/2002	.256	.213	.328	3,700	20,000

Table 10. Nutrient and bacteria concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local number (fig. 1)	Station number	Sampling date (month/day/year)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Phosphorus, total (mg/L as P)	Total coliform (colonies/100 mL)	*E. coli* (colonies/100 mL)
080	05417480	6/26/2001	0.048	E0.010	0.071	E40	E2
		9/19/2001	.079	.071	--	S13,000	E1,900
		3/20/2002	E.043	.037	--	17	0
		5/31/2002	.114	.093	.209	450	280
		7/16/2002	.054	.036	.090	291	0

Table 11. Instantaneous discharge, physical properties, and suspended-sediment concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; ^oC, Celsius degrees; NTU, nephelometric turbidity units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; HCO_3, bicarbonate; CO_3, carbonate; --, no data; E, estimated]

Local site number (fig. 1)	Station number	Station name	Sampling date (month/day/year)	Time of sample collection (24-hour)	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, air (^oC)	Temperature, water (^oC)
010	05416900	Maquoketa River at Manchester, Iowa	6/27/2001	1755	240	532	8.1	29	24.6
			9/20/2001	0810	356	502	7.7	14.5	15.6
			3/19/2002	1545	164	519	8.4	3.5	5.8
			6/01/2002	0830	395	507	8.0	25	17.8
			7/16/2002	1410	122	514	8.4	--	24.2
015	05417170	Unnamed tributary near Bailey Ford	6/27/2001	0955	.34	485	7.5	30	21.3
			9/20/2001	1230	.407	653	7.7	--	19.5
			3/19/2002	1445	.64	337	8.1	4.0	5.9
			6/01/2002	0945	2.3	497	7.7	17	16
			7/17/2002	0810	.35	550	7.4	--	18.5
020	05417200	Upstream Lake Delhi near The Cedars	6/27/2001	0835	--	530	7.9	25	22.3
			9/20/2001	0935	--	497	7.8	15	15.9
			3/19/2002	1245	--	517	8.3	3.5	5.8
			5/31/2002	1550	--	490	7.9	--	20.4
			7/16/2002	1240	--	513	8.3	--	25.6
030	05417275	Unnamed tributary at County Highway 267 and 205 Avenue	6/27/2001	1215	.70	512	7.6	30.5	19
			9/19/2001	1050	3.5	487	7.1	22	15.7
			3/19/2002	1400	.79	402	8.1	4.0	4.8
			5/31/2002	1740	1.8	455	7.6	--	14.9
			7/17/2002	0905	.49	547	7.8	--	15.6
040	05417300	Turtle Creek at Turtle Creek recreation area	6/27/2001	1435	.87	418	7.5	30	19.4
			9/19/2001	1550	1.10	536	7.4	25	16.3
			3/19/2002	1115	.80	557	7.8	4.0	5.0
			5/31/2002	1630	1.1	528	7.8	22	16.1
			7/16/2002	0925	.88	585	7.4	--	15.0

Table 11. Instantaneous discharge, physical properties, and suspended-sediment concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local site number (fig. 1)	Station number	Station name	Sampling date (month/day/year)	Time of sample collection (24-hour)	Discharge, instantaneous (ft^3/s)	Specific conductance (μS/cm)	pH, water whole, field (standard units)	Temperature, air (°C)	Temperature, water (°C)
050	05417320	Middle Lake Delhi near Linden Acres	6/26/2001	1520	--	499	8.1	30.5	24.4
			9/19/2001	1655	--	486	8.0	25	17.8
			3/19/2002	1155	--	494	8.3	3.5	4.0
			5/31/2002	1510	--	454	7.7	--	21.4
			7/16/2002	1215	--	497	8.0	--	26.1
070	05417470	Unnamed tributary at cove near dam	6/26/2001	1150	0.08	286	8.0	28	22
			9/19/2001	1430	.82	390	7.7	24	17.6
			3/20/2002	1045	.16	373	8.3	3.5	5.9
			5/31/2002	1335	.07	486	8.0	--	20.8
			7/16/2002	1030	E .001	462	8.1	--	21.2
080	05417480	Downstream Lake Delhi near dam	6/26/2001	1230	--	492	8.2	29	22.8
			9/19/2001	1330	--	426	7.8	--	18.5
			3/20/2002	0940	--	495	7.9	3.5	4.0
			5/31/2002	1415	--	400	7.9	23	22.1
			7/16/2002	1115	--	473	8.2	--	26.9

Table 11. Instantaneous discharge, physical properties, and suspended-sediment concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local site number (fig. 1)	Station number	Station name	Turbidity, laboratory (NTU)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Alkalinity, water, dissolved, total, field (mg/L as $CaCO_3$)	Bicarbonate, water, dissolved, field (mg/L as HCO_3)	Carbonate, water, dissolved, field (mg/L as $CaCO_3$)	Sediment, suspended (mg/L)
010	05416900	6/27/2001	13	8.2	101	--	--	--	41
		9/20/2001	20	9.3	97	177	214	0	34
		3/19/2002	3.9	12.5	100	178	215	0	28
		6/01/2002	130	9.8	103	145	175	0	46
		7/16/2002	8.8	9.2	110	203	244	2	19.1
015	05417170	6/27/2001	4.4	8.8	102	--	--	--	10
		9/20/2001	9.5	8.7	--	200	241	1	13
		3/19/2002	2.1	13.2	106	150	182	0	1.0
		6/01/2002	3.3	10.1	111	125	151	0	6.0
		7/17/2002	3.1	7.9	82	188	228	0	2.5
020	05417200	6/27/2001	21	7.3	86	--	--	--	44
		9/20/2001	14	8.2	86	180	217	1	--
		3/19/2002	2.9	12.5	100	179	216	0	5.0
		5/31/2002	30	8.8	98	144	174	0	45
		7/16/2002	9.9	10.8	134	192	229	3	32
030	05417275	6/27/2001	4.9	9.2	102	--	--	--	10
		9/19/2001	48	1.7	18	149	182	0	281
		3/19/2002	7.3	12.4	96	140	170	0	26
		5/31/2002	18	10.3	102	120	145	0	28
		7/17/2002	7.0	8.7	89	175	212	0	15.1
040	05417300	6/27/2001	62	7.8	87	--	--	--	117
		9/19/2001	22	--	--	186	226	0	98
		3/19/2002	5.0	12.5	98	184	223	0	8.0
		5/31/2002	14	9.7	98	149	180	0	33
		7/16/2002	14	9.0	89	208	252	0	25.7
050	05417320	6/26/2001	18	10.4	128	--	--	--	28

Table 11. Instantaneous discharge, physical properties, and suspended-sediment concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through July 2002—Continued

Local site number (fig. 1)	Station number	Station name	Turbidity, laboratory (NTU)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Alkalinity, water, dissolved, total, field (mg/L as $CaCO_3$)	Bicarbonate, water, dissolved, field (mg/L as HCO_3)	Carbonate, water, dissolved, field (mg/L as $CaCO_3$)	Sediment, suspended (mg/L)
050	05417320	9/19/2001	14	9.2	101	194	236	0	21
		3/19/2002	6.0	13.4	105	171	207	0	14
		5/31/2002	34	8.1	92	136	164	0	26
		7/16/2002	25	8.4	103	183	219	0	28
070	05417470	6/26/2001	17	7.8	92	--	--	--	36
		9/19/2001	34	7.9	87	152	185	0	48
		3/20/2002	15	13.7	110	213	255	2	17
		5/31/2002	18	9.7	108	202	242	0	23
		7/16/2002	33	8.2	91	197	237	0	20.6
080	05417480	6/26/2001	7.9	10.6	127	--	--	--	45
		9/19/2001	13	7.2	79	178	216	0	38
		3/20/2002	4.9	15.7	120	165	199	0	5.0
		5/31/2002	33	8.3	96	130	157	0	10
		7/16/2002	11	9.0	112	130	158	0	2.5

Table 12. Pesticide concentrations in water samples collected at selected sites near or at Lake Delhi, eastern Iowa, June 2001

[µg/L, micrograms per liter; <, less than; E, estimated; U, analyzed for but not detected]

Pesticide compound (unit of measurement)	Maquoketa River at Manchester, Iowa (site 010, station 05416900, sampled June 27, 2001; fig. 1)	Lake Delhi near dam (site 080, station 05417480, sampled June 26, 2001; fig. 1)
2,6-Diethylaniline, dissolved (µg/L)	<0.002	<0.002
Acetochlor, dissolved (µg/L)	.024	.179
Alachlor, dissolved (µg/L)	.007	<.002
Atrazine, dissolved (µg/L)	.613	1.48
Azinphos-methyl, dissolved (µg/L)	<.050	<.050
Benfluralin, dissolved (µg/L)	<.010	<.010
Butylate, dissolved (µg/L)	<.002	<.002
Carbaryl, dissolved (µg/L)	<.041	<.041
Carbofuran, dissolved (µg/L)	E.007	E.072
Chlorpyrifos, dissolved (µg/L)	<.005	<.005
cis-Permethrin, dissolved (µg/L)	<.006	<.006
Cyanazine, dissolved (µg/L)	<.018	E.004
Dacthal, dissolved (µg/L)	<.003	<.003
Deethylatrazine, dissolved (µg/L)	E.081	E.109
Diazinon, dissolved (µg/L)	<.005	<.005
Dieldrin, dissolved (µg/L)	<.005	<.005
Disulfoton, dissolved (µg/L)	<.021	<0.21
EPTC, dissolved (µg/L)	<.002	<.002
Ethalfluralin, dissolved (µg/L)	<0.009	<0.009
Ethoprophos, dissolved (µg/L)	<.005	<.005
Fonofos, dissolved (µg/L)	<.003	<.003
Lindane, dissolved (µg/L)	<.004	<.004
Linuron, dissolved (µg/L)	<.035	<.035
Malathion, dissolved (µg/L)	<.027	<.027
Metolachlor, dissolved (µg/L)	.142	.448
Metribuzin, dissolved (µg/L)	<.006	<.006
Molinate, dissolved (µg/L)	<.002	<.002
Napropamide, dissolved (µg/L)	<.007	<.007
P,P'-DDE, dissolved (µg/L)	<.003	<.003
Parathion, dissolved (µg/L)	<.007	<.007
Parathion-methyl, dissolved (µg/L)	<.006	<.006
Pebulate, dissolved (µg/L)	<.002	<.002
Pendimethalin, dissolved (µg/L)	<.010	<.010
Phorate, dissolved (µg/L)	<.011	<.011
Prometon, dissolved (µg/L)	E.004	E.004

Table 12. Pesticide concentrations in water samples collected at selected sites near or at Lake Delhi, eastern Iowa, June 2001—Continued

Pesticide compound (unit of measurement)	Maquoketa River at Manchester, Iowa (site 010, station 05416900, sampled June 27, 2001; fig. 1)	Lake Delhi near dam (site 080, station 05417480, sampled June 26, 2001; fig. 1)
Propachlor, dissolved (µg/L)	<0.010	<0.010
Propanil, dissolved (µg/L)	<.011	<.011
Propargite, dissolved (µg/L)	<.023	<.023
Simazine, dissolved (µg/L)	E.004	E.007
Tebuthiuron, dissolved (µg/L)	E.004	<.016
Terbacil, dissolved (µg/L)	<.034	<.034
Terbufos, dissolved (µg/L)	<.017	<.017
Thiobencarb, dissolved (µg/L)	<.005	<.005
Triallate, dissolved (µg/L)	<.002	<.002
Trifluralin, dissolved (µg/L)	<.009	<.009

Table 13. Major-ion and trace-metal concentrations in water samples collected from Marquoketa River, tributary, and lake sites, Lake Delhi, eastern Iowa, June 2001 through March 2002

[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; Ca, calcium; Cl, chloride; F, fluoride; Mg, magnesium; K, potassium; SiO_2, silica; Na, sodium; SO_4, sulfate; µg/L, micrograms per liter; Ba, barium; Be, beryllium; Cd, cadmium; Cr, chromium; Co, cobalt; Cu, copper; Fe, iron, Pb, lead; Li, lithium; Mn, manganese; Mo, molybdenum; Ni, nickel, Ag, silver; Sr, strontium; V, vanadium; Zn, zinc; --, no data; M, presence verified but not quantified; <, less than; E, estimated value]

Local site number (fig. 1)	Station number	Station name	Sampling date (month/day/year)	Time of sample collection (24-hour)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)
010	05416900	Maquoketa River at Manchester, Iowa	6/27/2001	1755	260	74.4	18.1	0.2
			9/20/2001	810	250	70.6	--	--
			3/19/2002	1545	250	68.8	--	--
015	05417170	Unnamed tributary near Bailey Ford	6/27/2001	955	240	72.5	15.4	E.2
			9/20/2001	1230	270	83.3	--	--
			3/19/2002	1445	240	72.1	--	--
020	05417200	Upstream Lake Delhi near The Cedars	6/27/2001	835	250	70.5	17.9	E.2
			9/20/2001	935	240	68.0	--	--
			3/19/2002	1245	240	65.1	--	--
030	05417275	Unnamed Creek at County Highway 267 and 205 Avenue	6/27/2001	1215	250	65.5	18.9	.2
			9/19/2001	1050	210	58.8	--	--
			3/19/2002	1400	230	60.8	--	--
040	05417300	Turtle Creek at Turtle Creek recreation area	6/27/2001	1435	270	71.4	16	E.1
			9/19/2001	1550	260	70.8	--	--
			3/19/2002	1115	270	71.5	--	--
050	05417320	Middle Lake Delhi near Linden Acres	6/26/2001	1520	230	66.4	16.2	.2
			9/19/2001	1655	230	61.7	--	--
			3/19/2002	1155	240	66.0	--	--
070	05417470	Unnamed tributary at cove near dam	6/26/2001	1150	270	64.1	17.8	.2
			9/19/2001	1430	160	37.6	--	--
			3/20/2002	1045	250	60.6	--	--
080	05417480	Downstream Lake Delhi near dam	6/26/2001	1230	240	68.2	16.6	.2
			9/19/2001	1330	200	53.4	--	--
			3/20/2002	940	230	64.9	--	--

Table 13. Major-ion and trace-metal concentrations for water samples collected from river, tributary, and lake sites for Lake Delhi, eastern Iowa, September 2001 through March 2002—Continued

Local site number (fig. 1)	Station number	Sampling date (month/day/year)	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Silica, dissolved (mg/L as SiO_2)	Sodium, dissolved (mg/L as Na)	Sulfate, dissolved (mg/L as SO_4)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)
010	05416900	6/27/2001	18.8	1.77	11.0	8.7	25.7	--	--	--	--	--
		9/20/2001	17.3	--	11.7	7.7	--	80.5	<1.00	<8.00	<10.0	<13.0
		3/19/2002	18.6	--	7.6	11.7	--	67.9	E.720	<8.00	<10.0	<13.0
015	05417170	6/27/2001	14.0	1.60	10.8	5.1	20.2	--	--	--	--	--
		9/20/2001	15.7	--	11.8	7.5	--	76.7	<1.00	<8.00	<10.0	<13.0
		3/19/2002	13.4	--	7.9	6.4	--	73.3	E.850	<8.00	<10.0	<13.0
020	05417200	6/27/2001	17.9	1.59	10.2	7.8	25.1	--	--	--	--	--
		9/20/2001	17.2	--	11.3	8.2	--	77.5	<1.00	<8.00	<10.0	<13.0
		3/19/2002	17.7	--	6.6	8.5	--	63.8	1.15	<8.00	<10.0	<13.0
030	05417275	6/27/2001	20.1	1.27	13.4	7.3	21.9	--	--	--	--	--
		9/19/2001	16.3	--	14.7	10.6	--	125	<1.00	<8.00	<10.0	<13.0
		3/19/2002	17.7	--	10.5	8.2	--	111	E.760	<8.00	<10.0	<13.0
040	05417300	6/27/2001	22.1	4.19	12.8	6.6	23.1	--	--	--	--	--
		9/19/2001	19.7	--	14.6	8.1	--	100	<1.00	<8.00	<10.0	<13.0
		3/19/2002	22.8	--	8.6	6.3	--	85.8	1.25	<8.00	<10.0	<13.0
050	05417320	6/26/2001	16.3	1.82	10.3	6.2	21.2	--	--	--	--	--
		9/19/2001	18.0	--	10.6	7.4	--	73	<1.00	<8.00	<10.0	<13.0
		3/19/2002	17.8	--	6.8	8.8	--	63.9	E.730	<8.00	<10.0	<13.0
070	05417470	6/26/2001	26.0	4.58	8.1	8.2	14.4	--	--	--	--	--
		9/19/2001	15.5	--	7.8	7.2	--	67.2	<1.00	<8.00	<10.0	<13.0
		3/20/2002	24.5	--	5.3	8.2	--	70.3	1.21	<8.00	<10.0	<13.0
080	05417480	6/26/2001	16.4	1.87	10.2	6.8	21.4	--	--	--	--	--
		9/19/2001	16.8	--	8.8	6.9	--	69	<1.00	<8.00	<10.0	<13.0
		3/20/2002	17.5	--	7.3	7.4	--	64.4	E.810	<8.00	<10.0	<13.0

Table 13. Major-ion and trace-metal concentrations for water samples collected from river, tributary, and lake sites for Lake Delhi, eastern Iowa, September 2001 through March 2002—Continued

Local site number (fig. 1)	Station number	Sampling date (month/day/year)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
010	05416900	6/27/2001	--	<10	--	--	13.9	--	--	--	--	--	--
		9/20/2001	<5.0	M	<0.08	<4.0	7.8	<50.0	<50.0	<5.0	114	<8.0	<20
		3/19/2002	<6.0	20	.08	E2.4	26.1	<50.0	<30.0	<9.0	100	<8.0	<24
015	05417170	6/27/2001	--	<10	--	--	35.0	--	--	--	--	--	--
		9/20/2001	<5.0	40	E.06	E2.5	52.1	<50.0	<50.0	<5.0	149	<8.0	<20
		3/19/2002	<6.0	40	E.06	<4.0	29.4	<50.0	<30.0	<9.0	123	<8.0	<24
020	05417200	6/27/2001	--	<10	--	--	14.2	--	--	--	--	--	--
		9/20/2001	<5.0	M	<.08	<4.0	9.1	<50.0	<50.0	<5.0	107	<8.0	<20
		3/19/2002	<6.0	20	.1	<4.0	42.8	<50.0	<30.0	<9.0	94.2	<8.0	<24
030	05417275	6/27/2001	--	<10	--	--	26.4	--	--	--	--	--	--
		9/19/2001	E2.6	20	<.08	<4.0	94.5	<50.0	<50.0	<5.0	162	<8.0	<20
		3/19/2002	<6.0	<10	<.08	E2.1	27.0	<50.0	<30.0	<9.0	148	<8.0	<24
040	05417300	6/27/2001	--	<10	--	--	118	--	--	--	--	--	--
		9/19/2001	<5.0	30	.24	E2.1	73.5	<50.0	<50.0	<5.0	133	<8.0	<20
		3/19/2002	<6.0	10	E.05	E2.0	62.5	<50.0	<30.0	<9.0	117	<8.0	<24
050	05417320	6/26/2001	--	<10	--	--	12.5	--	--	--	--	--	--
		9/19/2001	<5.0	<10	<.08	<4.0	6.7	<50.0	<50.0	<5.0	95.5	<8.0	<20
		3/19/2002	<6.0	M	.08	<4.0	24.1	<50.0	<30.0	<9.0	97.5	<8.0	<24
070	05417470	6/26/2001	--	<10	--	--	10.2	--	--	--	--	--	--
		9/19/2001	<5.0	30	.22	<4.0	58.9	<50.0	<50.0	<5.0	108	<8.0	<20
		3/20/2002	<6.0	40	<.08	E3.4	31.1	<50.0	<30.0	<9.0	134	<8.0	<24
080	05417480	6/26/2001	--	<10	--	--	<3.0	--	--	--	--	--	--
		9/19/2001	<5.0	<10	.1	<4.0	<3.0	<50.0	<50.0	<5.0	85.6	<8.0	<20
		3/20/2002	<6.0	<10	<.08	<4.0	13.5	<50.0	<30.0	<9.0	95.7	<8.0	<24