Bathymetric Surveys of Morse and Geist Reservoirs in Central Indiana Made with Acoustic Doppler Current Profiler and Global Positioning System Technology, 1996

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft^2)	0.09290	square meter
foot per second (ft/sec)	0.3048	meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
acre-feet (acre-ft)	1,233.5	cubic meter
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter

Acre-foot: In this report, an acre-foot is the volume of water occupied by a depth of 1 foot over an area of 1 acre, which equals 43,560 cubic feet or approximately 326,000 gallons.

Knot: In this report, "knot" refers to nautical miles per hour, which equals about 1.15 statute miles per hour.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

The following abbreviations are used in this report:

Abbreviation	Description
ADCP	Acoustic Doppler current profiler
GIS	Geographic information system
GPS	Global positioning system
SA	Selective Availability
UTM	Universal Transverse Mercator
kHz	Kilohertz
m	meter
cm	centimeter
cm/sec	centimeter per second
km	kilometer
Bgal	Billion gallons
Mgal	Million gallons

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By John T. Wilson, Scott E. Morlock, *and* Nancy T. Baker

Abstract

Acoustic Doppler current profiler, global positioning system, and geographic information system technology were used to map the bathymetry of Morse and Geist Reservoirs, two artificial lakes used for public water supply in central Indiana. The project was a pilot study to evaluate the use of the technologies for bathymetric surveys. Bathymetric surveys were last conducted in 1978 on Morse Reservoir and in 1980 on Geist Reservoir; those surveys were done with conventional methods using networks of fathometer transects. The 1996 bathymetric surveys produced updated estimates of reservoir volumes that will serve as base-line data for future estimates of storage capacity and sedimentation rates.

An acoustic Doppler current profiler and global positioning system receiver were used to collect water-depth and position data from April 1996 through October 1996. All water-depth and position data were imported to a geographic information system to create a data base. The geographic information system then was used to generate water-depth contour maps and to compute the volumes for each reservoir.

The computed volume of Morse Reservoir was 22,820 acre-feet (7.44 billion gallons), with a surface area of 1,484 acres. The computed volume of Geist Reservoir was 19,280 acre-feet (6.29 billion gallons), with a surface area of 1,848 acres. The computed 1996 reservoir volumes are less than the design volumes and indicate that sedimentation has occurred in both reservoirs. Cross sections were constructed from the computer-generated surfaces for 1996 and compared to the fathometer profiles from the 1978 and 1980 surveys; analysis of these cross sections also indicates that some sedimentation has occurred in both reservoirs.

The acoustic Doppler current profiler, global positioning system, and geographic information system technologies described in this report produced bathymetric maps and volume estimates more efficiently and with comparable or greater resolution than conventional bathymetry methods.

INTRODUCTION

Morse and Geist Reservoirs in central Indiana are used primarily for public water supply and secondarily for recreation. The Indianapolis Water Company (IWC), which owns the reservoirs, and the Indiana Department of Natural Resources (IDNR) recognized the potential for sedimentation to affect the capacity of the two reservoirs and the need for data to assess the status of sedimentation in them and their current capacity.

The IDNR is mandated by the 1983 Water Resource Management Act to assess water-resource availability, water use, and conflicts involving limited water supply or competing uses (Indiana Department of Natural Resources, 1994).

IDNR has been assessing water availability on a regional scale by major drainage basin. Information on the current capacities of Morse and Geist Reservoirs will be important to the assessment of water availability in the White River Basin.

In 1996, the U.S. Geological Survey (USGS), in cooperation with the IDNR Division of Water, began bathymetric surveys of Morse and Geist Reservoirs. A pilot study was incorporated into the survey to evaluate the use of acoustic Doppler current profiler (ADCP) and global positioning system (GPS) technology. Bathymetric surveys were last conducted on Morse Reservoir in 1978 and on Geist Reservoir in 1980; those surveys were made with conventional methods using networks of fathometer transects.

Conventional methods of collecting bathymetry data usually involve measuring water depths along a set of cross sections with a sounding device or a fathometer. With the recent development and availability of new technologies such as the ADCP and GPS, the scope and quality of bathymetric surveys can be increased while the time to produce bathymetry maps and reservoir volumes is decreased. Also, the use of a geographic information system (GIS) to develop a data base, make maps, and compute reservoir volumes will increase the efficiency of bathymetry work. The use of a GIS also facilitates storage and retrieval of the data for future reference.

An awkward and time-consuming requirement of conventional bathymetric surveys is the need to accurately track the survey-boat position. This is usually done by stringing tag lines across the body of water or by surveying the boat position from shore. The ADCP used for this project's bathymetric surveys was mounted in the survey boat and provided depth and position data throughout the reservoirs in water depths ranging from 2 to more than 40 ft. With the use of GPS, boat positions were converted into "real-world" coordinates for making contour maps with a GIS.

Purpose and Scope

The purpose of this report is to describe and evaluate the use of ADCP and GPS technology for bathymetric surveys and to estimate the reduction in storage capacity in the reservoirs because of sedimentation. Methods of data collection and data processing, as well as the use of a geographic information system (GIS) to compute reservoir volumes and generate water-depth contour maps (hereafter referred to as "contour maps"), are described. Reservoir volumes computed from the bathymetry measured in 1996 are used to estimate the reduction in storage capacity caused by sedimentation. The 1996 volumes are compared to the original design volumes and bathymetric surveys from 1978 (Morse) and 1980 (Geist) to estimate the volume of sediment deposited in the reservoirs.

The bathymetric surveys described in this report will serve as base-line data for future estimates of storage capacity and sedimentation rates in Morse and Geist Reservoirs. The bathymetric data will be stored in a GIS data base that will allow for comparisons with bathymetric data collected in the future. The methods and results from using ADCP, GPS, and GIS technology described in this report demonstrate that bathymetric maps can be produced and reservoir volumes can be estimated faster and with greater resolution than with conventional bathymetry methods.

Physical Setting

Morse and Geist Reservoirs are large artificial lakes in central Indiana (fig. 1) that began operation in March 1956 and March 1943, respectively (Thomas Bruns, Indianapolis Water Company, written commun., 1996). The Indianapolis Water Company operates these reservoirs for public water supply. Recreation is a secondary use. The land use in the drainage basins above both reservoirs is primarily agricultural.

Morse Reservoir

Morse Reservoir is in north-central Hamilton County, 3.2 mi northwest of Noblesville and approximately 22 mi north-northeast of Indianapolis, and is formed by the impoundment of Cicero Creek. The reservoir has a design storage capacity of 25,380 acre-ft (8.27 Bgal) at normal pool elevation; a surface area of approximately 1,500 acres; and approximately 32.5 mi of shoreline (Thomas Bruns, Indianapolis Water Company, written commun., 1996).

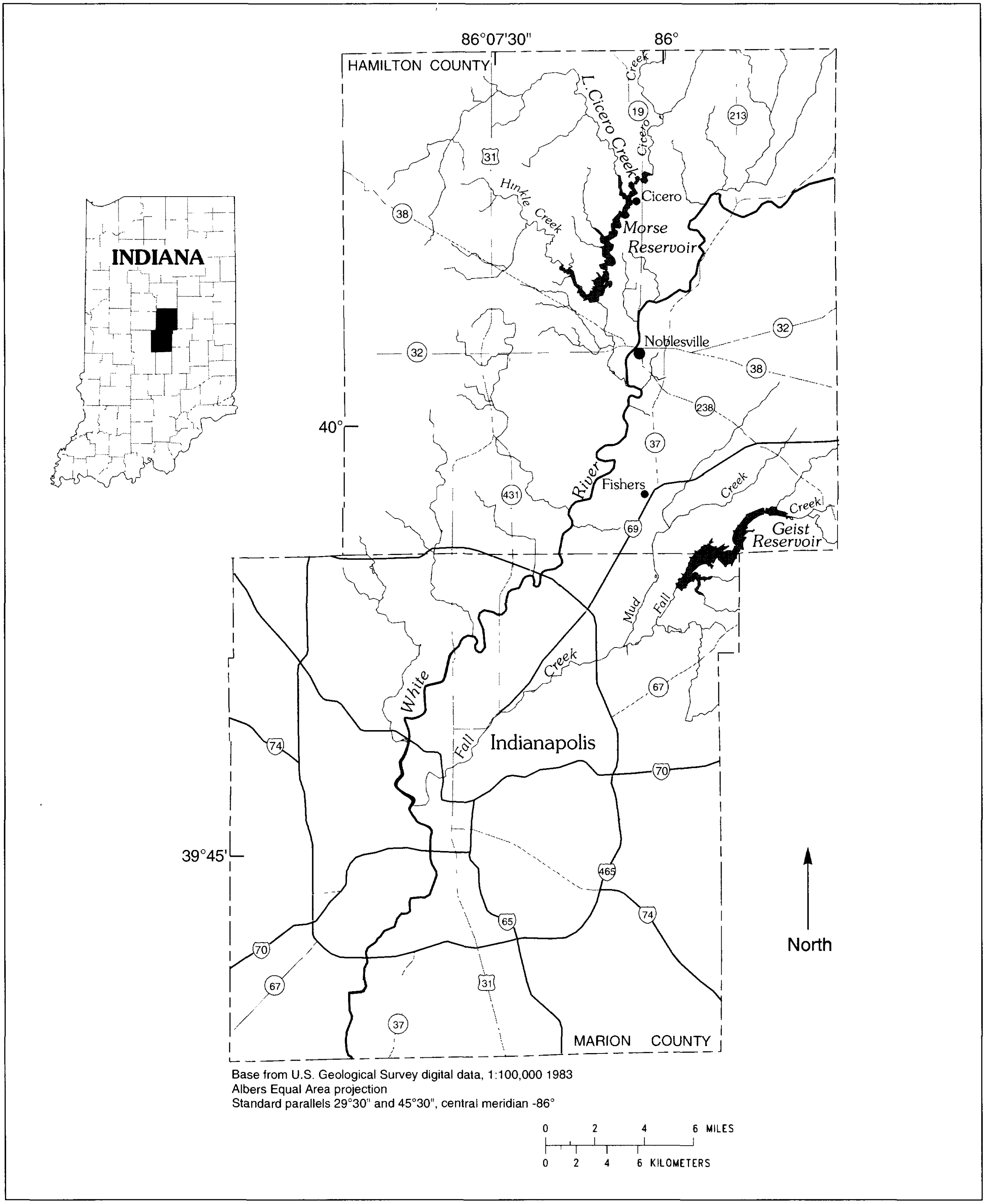


Figure 1. Location of Morse and Geist Reservoirs in Hamilton and Marion Counties, Indiana.

Normal pool elevation is 810 ft above sea level. The reservoir is approximately 6.5 mi long and varies in width from several hundred feet to more than 2,000 ft. Cicero Creek has a drainage area of 214 mi^2 at Morse dam (Hoggatt, 1975).

Geist Reservoir

Geist Reservoir is in northeastern Marion County and southeastern Hamilton County, approximately 14 mi northeast of Indianapolis, and is formed by the impoundment of Fall Creek. The reservoir has a design storage capacity of 21,180 acre-ft (6.9 Bgal) at normal pool elevation; a surface area of approximately 1,900 acres; and approximately 35 mi of shoreline (Thomas Bruns, Indianapolis Water Company, written commun., 1996). Normal pool elevation is 785 ft above sea level. The reservoir is approximately 6.5 mi long and varies in width from approximately 1,000 to 4,000 ft. Fall Creek has a drainage area of 215 mi^2 at Geist dam (Hoggatt, 1975).

Acknowledgments

The authors thank the staffs of Geist and Morse Marinas of the Marina Limited Partnership who were extremely helpful with solving mechanical problems, providing launch facilities, and providing a place to moor the USGS research vessel. The authors also thank Thomas Bruns of the Indianapolis Water Company for providing background information on the reservoirs and for providing information from previous bathymetric surveys of Morse and Geist Reservoirs.

METHODS OF INVESTIGATION

The bathymetry of the reservoirs was mapped by use of a boat-mounted ADCP and a mobile hand-held GPS receiver; detailed descriptions of each method are located in the "Acoustic Doppler Current Profiler" and the "Global Positioning System" sections of this report. The ADCP was used to measure depth and position as the boat moved around the reservoirs. Position was recorded as Northing and Easting, in feet, relative to the point where the ADCP began recording bathymetric data. Depth also was recorded in units of feet. Control points were established at various locations along a transect, usually at the tip of a boat dock, at an anchored buoy, or with a marker buoy. (For purposes of this report, a "transect" refers to the path of the ADCP as it collected bathymetric data.) A hand-held GPS receiver was used to determine the latitude and longitude of the control points.

ARC/INFO GIS software from Environmental Systems Research Institute (ESRI) of Redlands, Calif., was used to transform the values of Northing and Easting into Universal Transverse Mercator (UTM) coordinates. Northing and Easting for every depth point along the transect was transformed into UTM coordinates based on the coordinates of the control points, creating digital data sets in ARC/INFO called point "coverages" for each transect. A coverage is ARC/INFO's primary method for storing point, line, and area features. Coverages contain spatial (location) and attribute (descriptive) data. Coverages are typically a single set of geographic features, such as points (Environmental Systems Research Institute, Inc., 1994). The ARC/INFO point coverages were used for making contour maps and estimating reservoir volumes.

Because of the reservoirs' size, a large number of transects were required for the collection of adequate data to represent accurately the bathymetry of the reservoirs and to provide adequate data coverage for computer contouring. Data were collected from April 1996 through October 1996; data were collected for about 15 days on Morse Reservoir and about 19 days on Geist Reservoir. Data were collected so that a plot of the transects in the main body and larger bays of the reservoir would approximate a grid (fig. 2). The pattern of transects varied in smaller bays because the maneuverability of the boat was limited. Transects were collected close to and roughly parallel to the shoreline, except where water was too shallow for the ADCP to operate. Transects were collected in a zigzag or "S-turn" pattern along the length of the reservoir section being mapped, often with the same GPS control points as the transects along the shoreline.

Transects also were collected along the length of the reservoir, farther from shore but roughly parallel to the shoreline or perpendicular to the transects collected in the S-turn pattern (fig. 2). Use of common GPS control points was helpful because the amount of time necessary to collect GPS readings was reduced, transects could be related to each other, and potentially inaccurate GPS points could be identified when the transects were converted into ARC/INFO coverages.

In large areas with shallow water, depth soundings were made manually with a standard surveying rod. (The ADCP has a shallow depth limitation of approximately 2 feet if the lake bottom is free of aquatic vegetation, rocks, and logs.) The GPS receiver was used to record a latitude and longitude for each of the soundings. These point depths were used to augment the ADCP bathymetry and improve the computer interpolations in shallow areas between the shoreline and deeper water.

The values of depth are adjusted to normal pool elevation. Lake levels were recorded during each day of data collection by measuring the distance from reference marks to the water surface. Reference marks were established at two bridge crossings on each reservoir.

ARC/INFO coverages of the shorelines of both reservoirs were established by digitizing aerial photographs with a scale of either 1:1,200 or 1:2,400. Aerial photographs at these scales provided the detail necessary to show where the boat transects followed the shoreline. The aerial photographs were rectified and scaled by recording, with the GPS receiver, the latitude and longitude of at least four discrete points on each photograph. Approximately 25 photographs were required for each reservoir for complete coverage of the shoreline. The most recent photographs available at the time of the study were taken in March and April 1994. The 1994 aerial photographs identified changes to the shoreline from previous lake maps. Lake-level records indicate both reservoirs were close to normal pool elevation for most of March and April 1994.

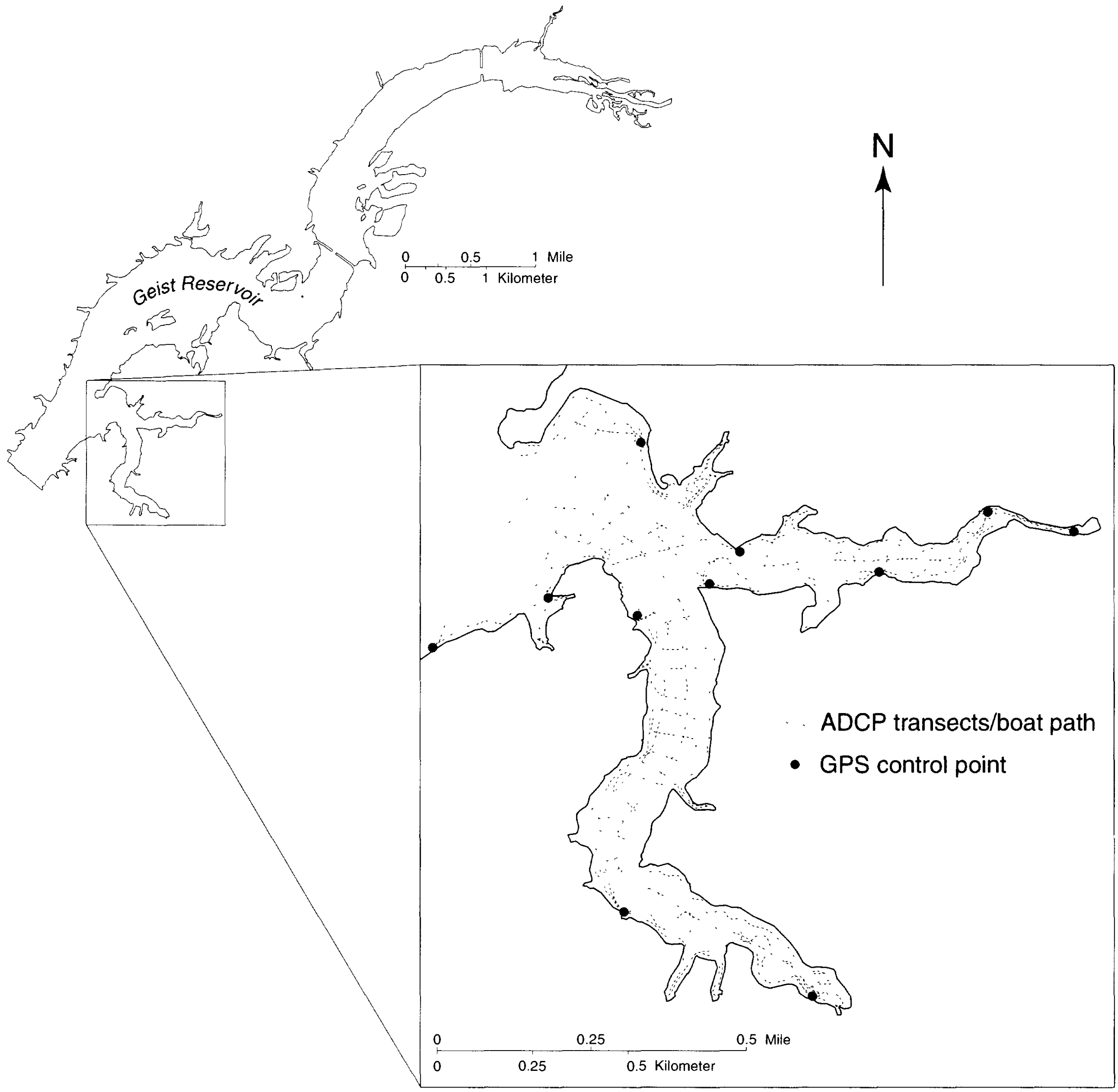
Acoustic Doppler Current Profiler

In 1992, RD Instruments introduced a broadband acoustic Doppler current profiler (ADCP) that uses acoustic pulses (called "pings") to measure water velocities and depths. The manufacturer's specifications for these instruments indicate the instruments would have sufficient resolution and precision to permit their use in making river-discharge measurements in water as shallow as 4 ft. The USGS Indiana District Office has been using an ADCP routinely since 1993 to measure discharge in rivers. Morlock (1996) evaluated ADCP measurements of river discharge and concluded that the ADCP produced results comparable to conventional methods of measuring discharge. Because the ADCP measured boat position as well as water depth, it became apparent that the ADCP could be used for applications other than measuring discharge, such as bathymetry. Recent upgrades in the ADCP firmware have reduced the shallow-water limit to less than 2 ft. The following sections on "Operation Principles" and "Operation Limitations" are based on Morlock (1996).

Operation Principles

The main external components of an ADCP are a transducer assembly and a pressure case (fig. 3). The transducer assembly consists of four transducers that operate at a fixed, ultrasonic frequency, typically 300 to 1200 kilohertz (kHz). The transducers are horizontally spaced 90 degrees apart on the transducer assembly; all transducers have the same fixed angle from the vertical, referred to as a "beam angle," that is typically 20 or 30 degrees. The transducer assembly may have a convex or concave configuration. The pressure case is attached to the transducer assembly and contains most of the instrument electronics. The ADCP used for the bathymetric surveys of Morse and Geist Reservoirs operates at a frequency of 600 kHz and has a transducer beam angle of 20 degrees.

When an ADCP is deployed from a moving boat, it is connected by cable to a power source and to a portable laptop computer. The computer is used to program the instrument, to monitor its operation, and to collect and store the data.



Base from U.S. Geological Survey digital data,1:100,000 1983
Albers Equal Area projection
standard parallels 29°30' and 45°30' central meridian -86°

Figure 2. Example of the pattern of boat paths used to collect bathymetry data with the acoustic Doppler current profiler (ADCP) and a global positioning system (GPS) on Geist Reservoir, central Indiana.

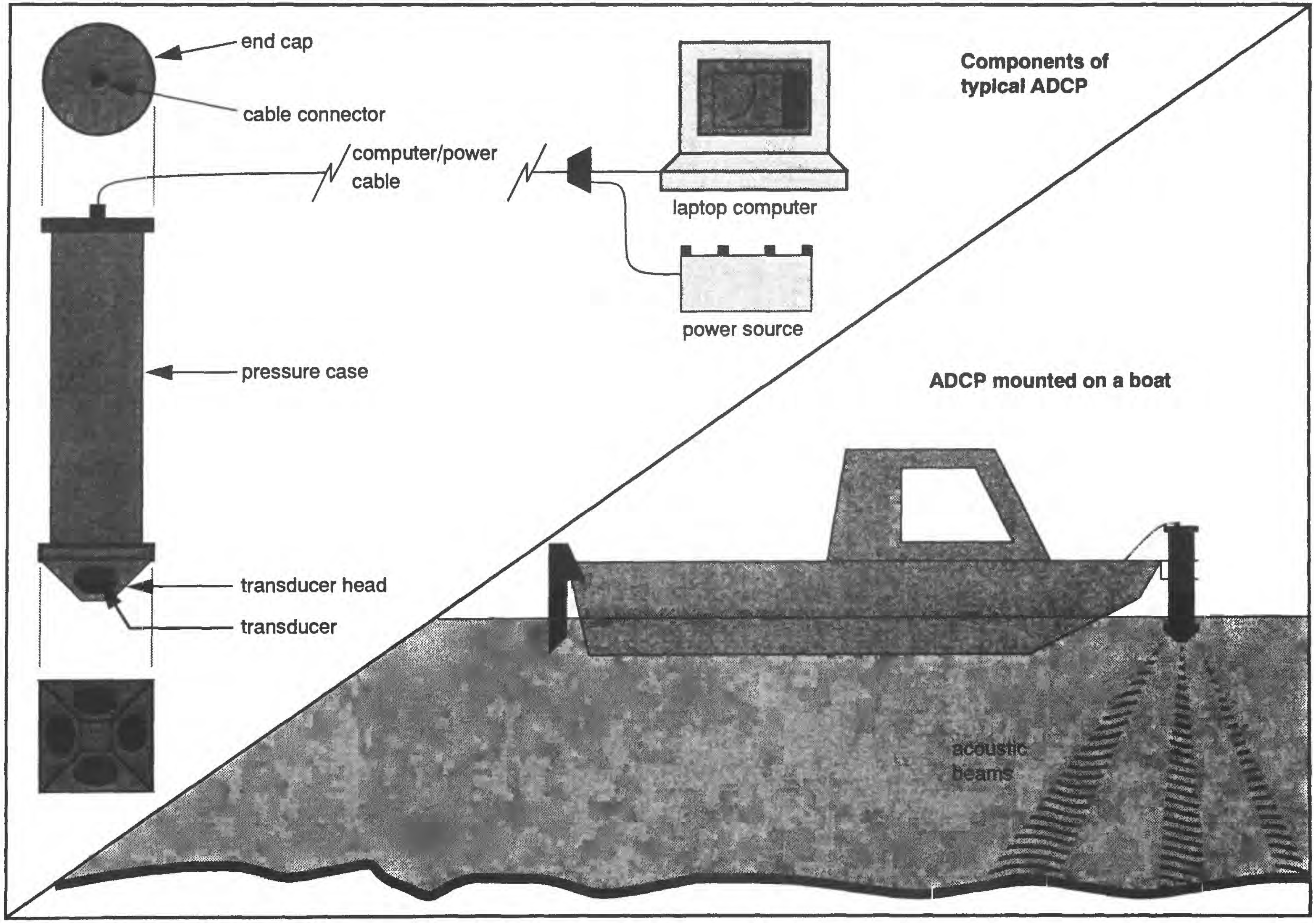


Figure 3. Sketch showing the components of a typical acoustic Doppler current profiler (ADCP) and sketch of an ADCP mounted on a boat.

The ADCP is capable of measuring velocity magnitude and direction in the water column. In bathymetric surveys of lakes, the depth and boat position, not the velocity of the water, are important (refer to Morlock, 1996, p. 9, for an explanation of how the ADCP measures the velocity of water).

The ADCP computes boat speed and direction using "bottom tracking" (RD Instruments, 1989). Measurement of the Doppler shift of acoustic pulses reflected from the bottom determines the boat speed, and the ADCP on-board compass determines the direction the boat is moving. The position of the boat is recorded as Northing and Easting, referenced from where the ADCP begins collecting data. The bottom-track echoes also are used to compute the depth of water.

As the boat moves along a transect, the ADCP transmits acoustic pulses from its four transducers into the water column. The groups of pulses include water-profiling pulses (if programmed) and bottom-tracking pulses. The ratio of water-profiling pulses (or water pings) to bottom-tracking pulses (or bottom pings) can be set by the operator. This group of water pings and bottom pings is called an "ensemble." For bathymetry data, each ensemble includes an ensemble number, a transect position in Northing and Easting, and four water depths—one for each transducer. The four water depths, also referred to as "beam depths," are averaged for the average water depth of each ensemble. Because the transducers have a fixed beam angle of 20 degrees pointing in four different directions, the average water depth is representative of an area below the ADCP rather than of a discrete point. This area scanned below the ADCP will increase as water depth increases.

Operation Limitations

ADCP's are subject to operation limitations that directly affect their application to bathymetry. One of these limitations is the inability of an ADCP to collect data in shallow water, which is also a limitation of conventional fathometers (depth finders). The inability of an ADCP to collect data in shallow water is the result of three factors: transducer draft, blanking distance, and lag. "Transducer draft" refers to the depth that the transducers are submerged underwater; the transducers must be fully submerged during operation. The transducer draft is measured and programmed into the ADCP as a depth-correction constant. "Blanking distance" refers to a zone directly below the transducers in which echoes cannot be received by the transducers because of their physical properties. "Lag" is the distance between successive parts of the pings transmitted by an ADCP. The sum of the transducer draft, blanking distance, and lag reduce the shallow-water limit of operation. If the ADCP exceeds its shallow-water limit, it will stop recording water depth and bottom tracking; if the ADCP loses bottom tracking, it will not record new boat positions. With recent upgrades in technology, however, the ADCP has been operated successfully in water as shallow as 2 ft.

Aquatic vegetation and irregularities in the lake or channel bottom can affect the ADCP's bottom-tracking capabilities. The ADCP is especially sensitive to these factors in shallow water (3 ft or less). The ADCP continuously pings from all four transducers; however, it only needs reflected signals at three transducers to maintain bottom tracking. Bottom tracking will be lost if more than one transducer does not receive its reflected signal. Irregularities in the bottom, such as chunks of rock, stumps, logs, or submerged bridge abutments, can prevent reflected signals from reaching the transducers. Lost bottom tracking can be detected by viewing the computer monitor while data are being collected. If bottom tracking is lost, the boat position will not be updated until bottom tracking is restored (at which point the Northing and Easting are updated from the last good ensemble). Lost bottom tracking is not a serious problem if the boat is not moving; if the boat is moving when bottom tracking is lost, however, position errors can be propagated through the rest of the transect. In such cases the transect should be terminated.

Other operation limitations can affect the quality of the bathymetry data. Boat speed and ADCP ping rate significantly can affect the precision of the resulting ensemble positions. The ping rate is related to ADCP program parameters (including the number of pings per ensemble and the time between pings) and the speed of the computer used to collect the data. The ratio of boat speed to ADCP ping rate controls the amount of sampling error in the boat-position data. If the boat speed is high and the ping rate is low, errors can become significant.

Pitching and rolling of an ADCP, such as when waves are present, also may affect measurement error. ADCP's have a pitch and roll sensor that can be activated during data collection to compensate for pitch and roll. The lakes were relatively calm for most of this study's bathymetry work, especially in bays; therefore, pitch and roll compensation of the ADCP was not quantified.

Accuracy of Acoustic Doppler Current Profiler Methods

When configured for the bathymetry work described in this report, the ADCP measures water depth with an accuracy of ±10 centimeters (cm) or 0.33 ft; the accuracy of the bottom tracking is ±9 cm/sec (0.3 ft/sec) (RD Instruments, written commun., 1995).

For quality-control purposes, water depths were measured manually with a surveying rod at some of the GPS control points for comparison with water depths measured with the ADCP. Figure 4 shows a plot of the average water depth from the ADCP compared to the water depth from the surveying rod and a plot of the difference between the two depths versus the water depth from the surveying rod. The mean difference between the two depths was +0.03 ft. This indicates the ADCP was unbiased in its measurement of water depth because the overestimated values balance out the underestimated values, and the average difference is close to zero. The standard deviation of the differences between the two methods was 0.29 ft, which is close to the ADCP manufacturer's estimated depth accuracy.

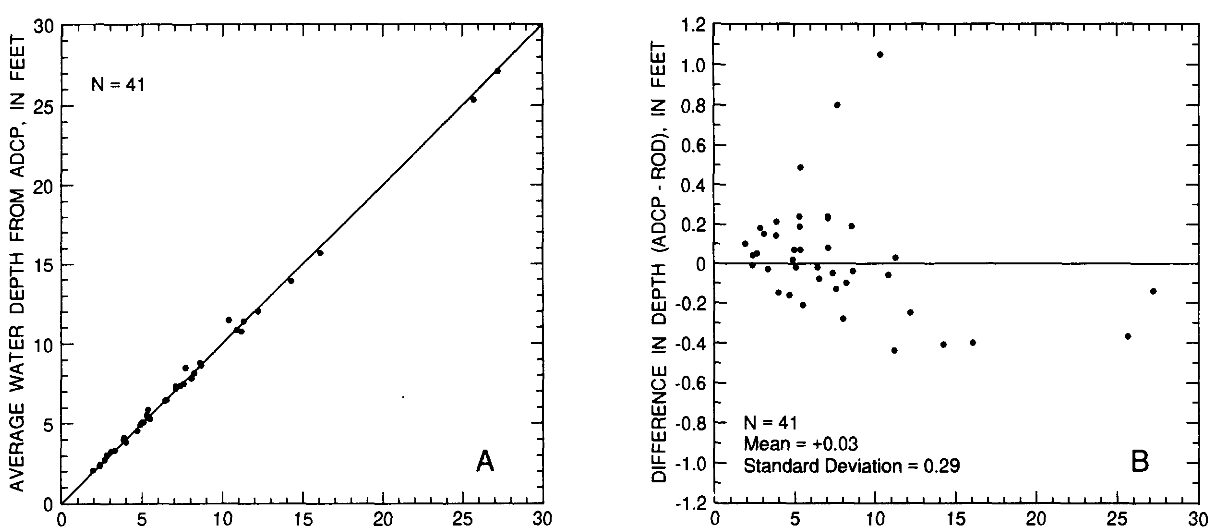


Figure 4. Comparison of (A) average water depth from the acoustic Doppler current profiler (ADCP) with water depth from a survey rod on Geist and Morse Reservoirs, central Indiana, and (B) a comparison of the difference in water depths between the two methods (ADCP-survey rod) and the water depth from a survey rod.

Figure 4B shows that all but seven of the differences between the two methods are within ±0.3 ft of the measured depth. Some of the larger differences shown in figure 4B can be explained by the steep slopes where these depths were measured. The steep slopes reduce the possibility that the average depth of the ADCP's four beams would match the surveying rod's point depth.

Global Positioning System

The GPS equipment required for a bathymetric survey includes a mobile GPS receiver and a stationary (base-station) GPS receiver. If real-time coordinate data are needed, the mobile GPS receiver and the stationary receiver should be equipped with two-way communication devices; GPS coordinates then can be "differentially corrected" (described in the following section) as the data are collected.

The GPS mobile receiver and base-station receiver provide "real-world" coordinates for the water-depth data recorded with the ADCP. Both receivers are needed to obtain the level of accuracy, 6.6–16.4 ft or 2–5 meters (m), required to complete the surveys. Much of the following section, "Operation Principles," is based on Baker and Morlock (1996).

Operation Principles

The GPS receiver calculates its position on Earth by determining the distance from the receiver to 3 or more of the 25 GPS satellites orbiting the Earth. The position obtained by a stand-alone GPS receiver is determined by "satellite trilateration." Satellite trilateration is the process of calculating the intersection of three or more spheres, the centers of which are the positions of the observable GPS satellites (Trimble Navigation, 1994). Accuracy can be affected by the Department of Defense, which has the ability to degrade GPS accuracy at any time with Selective Availability (SA); the resulting absolute positional accuracy on the ground can be anywhere between 25 and 100 m (Cloyd and others, 1995). To improve accuracy for the bathymetric surveys of Morse and Geist Reservoirs, the mobile GPS receiver was programmed to not record positions unless it was receiving signals from at least four satellites. Four satellites narrow the position to a single point and cancel out time errors caused by SA.

The application of differential techniques provides the solution for obtaining higher GPS accuracy. Differential techniques use two receivers—a stationary base-station receiver at a known location and a mobile receiver in close proximity, within 500 kilometers (km), to the base station. Both receivers operate simultaneously. Two receivers are used because each is influenced almost equally by SA positional errors and by atmosphere error. If the stationary receiver is at a known location, it is possible to correct the positional data collected by the mobile receiver by applying the amount of difference between the known location and the calculated location of the base-station receiver to the data collected by the mobile receiver.

Data can be corrected differentially at the time they are collected or after they are collected. If the data are differentially corrected as they are collected, real-time communication between the base station and the mobile receiver is required. The differential corrections for this study were applied after the data were collected because real-time data were not required for the bathymetric surveys.

Data collected for the lake surveys were differentially corrected with base-station files from the USGS Indiana District Office first-order base-station receiver. "First-order" means that the location of the station is known with an accuracy of 1:100,000, or 3.9 in. (10 cm) over 6.2 mi (10 km). The station is centrally located and provides sufficiently accurate base-station data for most GPS data-collection efforts in Indiana.

GPS data were collected for at least three control points along each ADCP transect, for each point depth measured with the surveying rod, and for each control point used to rectify and scale the aerial photographs. At least 120 position locations were collected for most points. After the points were differentially corrected, they were plotted and analyzed for "multipath errors." Multipath errors occur when the GPS receives satellite signals reflected by an object (a tree or a cliff) before the signal reaches the receiver. After multipath errors were eliminated, the remaining points were averaged and a single longitude and latitude coordinate was obtained for each control point or data point.

Operation Limitations

The operation limitations of the GPS are Selective Availability (SA), multipath errors, and lost signals. As mentioned previously, SA is controlled by the Department of Defense. Multipath errors can be reduced if the user selects sites in relatively open areas and collects at least 120 position locations per site. Multipath errors become obvious when the position locations are plotted; they then can be deleted before the position locations are averaged to compute a final position for each site. Lost signals are caused by obstacles between the mobile GPS receiver and the satellites (tree canopy, buildings, hills, highway embankments, bridges). Obstacles to satellite reception are a particular problem in narrow arms of a reservoir surrounded by tree-covered hills or buildings. Lost signals also can occur during certain times of day when not enough satellites are available for the GPS receiver to read a position.

Operation limitations made it impractical to collect continuous GPS positions while running the ADCP transects. Using a few control points along each transect allows for the collection of GPS data at any time, as long as the control points are fixed (such as a boat dock or an anchored buoy).

Accuracy of Global Positioning System Methods

As mentioned previously, GPS control points often were used for more than one ADCP transect; this allowed an opportunity to check the reliability of the GPS positions. Redundant positions were recorded at several GPS control points that were revisited. Table 1 shows a comparison of 10 sets of redundant GPS positions. The average difference between the redundant pairs of GPS points was 3.1 ft (0.94 m). Table 1 also shows a comparison between two different GPS receivers used during the study to see if they produced different results; points 070113A were collected simultaneously with two GPS receivers located next to each other. The difference between the two positions was only 1.1 ft (0.33 m), which is reasonable considering the GPS receivers are about 6 in. long and 3 in. wide.

The analysis summarized in table 1 shows that the mobile GPS receiver with post-processed differential correction produces consistent results; however, the analysis does not address the accuracy of the method to define a position in "real-world" coordinates. GPS positions were recorded at known control points to determine the accuracy of defining a position in "real-world" coordinates. Table 2 shows a comparison of six GPS readings collected at known IMAGIS[1] control monuments in northwestern Marion County and northeastern Hendricks County. Coordinates for these control monuments were provided by the Marion County Surveyor's Office. The average difference between the measured and known positions (latitude and longitude) was 9.29 ft (2.83 m) with a standard deviation of 4.98 ft (1.52 m). The average difference in latitude was 12.6 ft (3.84 m), and the average difference in longitude was 5.98 ft (1.82 m). These differences are consistent with the accuracy of the method (2–5 m) advertised by the manufacturer of the equipment used (Trimble Navigation, 1994).

BATHYMETRIC SURVEYS

The final data sets from the 1996 bathymetric surveys include ARC/INFO coverages for the shorelines, ADCP water-depth data, and shallow-water-depth data. Maps of Morse and Geist Reservoirs (figs. 5 and 6) show the distribution of the ADCP and shallow-water-depth data. These data were used to generate contour maps and to compute volumes for Morse and Geist Reservoirs.

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[1]Indianapolis Mapping and Geographic Infrastructure System—a consortium of private companies, public corporations, city/county government units, and the Indiana University-Purdue University at Indianapolis. IMAGIS serves as a geographically indexed data repository used for logistics, infrastructure development, and marketing planning (Richard Smith, Indianapolis Mapping and Geographic Infrastructure System, written commun., 1996).

Table 1. Comparison of redundant global positioning system (GPS) positions for evaluating the reproducibility of the GPS methods used to map Morse and Geist Reservoirs in central Indiana

GPS points	Longitude (degrees)	Longitude difference (degrees)	Longitude[1] difference (feet)	Latitude (degrees)	Latitude difference (degrees)	Latitude[2] difference (feet)
050915A[3]	85.909472			39.952189		
050923C	85.909455	0.000017	4.74	39.952192	0.000003	1.09
051315A	85.940452			39.931367		
052120A	85.940445	.000007	1.95	39.931382	.000015	5.45
052118A	85.953015			39.925192		
052218A	85.952999	.000016	4.47	39.925196	.000004	1.45
052118A	85.953015			39.925192		
060416K	85.952994	.000021	5.86	39.925173	.000019	6.90
052219E	85.976217			39.910703		
060417C	85.976226	.000009	2.51	39.910696	.000007	2.54
052219F	85.982006			39.905745		
060417A	85.982003	.000003	.84	39.905735	.000010	3.63
052220F	85.954941			39.930354		
053021F	85.954923	.000018	5.02	39.930337	.000017	6.18
070113A[4]	86.265496			39.875613		
070113A[4]	86.265492	.000004	1.12	39.875616	.000003	1.09
070914A	86.053925			40.076438		
071021A	86.053934	.000009	2.51	40.076445	.000007	2.54
071115A	86.040212			40.090654		
071221B	86.040218	.000006	1.67	40.090655	.000001	.36
AVERAGE			**3.07**			**3.12**
STANDARD DEVIATION			**1.80**			**2.32**

[1]Assumes that 1 second of longitude (.000278 degrees) is equal to 77.6 feet.

[2]Assumes that 1 second of latitude (.000278 degrees) is equal to 101 feet.

[3]Global positioning system points are labeled as month, day, hour, point. For example, 050915A is the first point collected after 15:00 hours Greenwich Mean Time on May 9, 1996.

[4]These two points were collected simultaneously with two different receivers placed side by side.

Table 2. Comparison of measured global positioning system (GPS) positions with known control points for evaluating the accuracy of the GPS methods used to map Morse and Geist Reservoirs in central Indiana

[°, degrees; ′, minutes; ″, seconds]

GPS point	GPS latitude/longitude	IMAGIS[1] control monument	IMAGIS latitude/longitude[2]	GPS-IMAGIS difference (seconds)	GPS-IMAGIS difference[3] (feet)
100414A[4]	39° 51′ 05.25382″	22	39° 51′ 05.33178″	-0.07796″	7.87
	86° 17′ 51.18841″		86° 17′ 51.12467″	0.06374″	4.95
100416B	39° 54′ 34.14567″	11	39° 54′ 34.30390″	-0.15823″	16.0
	86° 20′ 41.53233″		86° 20′ 41.45635″	0.07598″	5.90
100417A	39° 51′ 15.07208″	21	39° 51′ 15.27621″	-0.20413″	20.6
	86° 11′ 53.72758″		86° 11′ 53.65621″	0.07137″	5.54
100418A	39° 53′ 04.01030″	14	39° 53′ 04.11678″	-0.10648″	10.8
	86° 12′ 37.91960″		86° 12′ 37.84732″	0.07228″	5.61
100418B	39° 55′ 21.09169″	9	39° 55′ 21.22668″	-0.13499″	13.6
	86° 13′ 41.16376″		86° 13′ 41.08756″	0.07620″	5.91
100419A	39° 54′ 36.99899″	10 RESET	39° 54′ 37.06586″	-0.06687″	6.75
	86° 16′ 13.42553″		86° 16′ 13.52802″	-0.10249″	7.95
AVERAGE					**9.29**
STANDARD DEVIATION					**4.98**

[1]IMAGIS, Indianapolis Mapping and Geographic Infrastructure System—a consortium of private companies, public corporations, city/county government units, and the Indiana University-Purdue University at Indianapolis. IMAGIS serves as a geographically indexed data repository used for logistics, infrastructure development, and marketing planning (Richard Smith, Indianapolis Mapping and Geographic Infrastructure System, written commun., 1996).

[2]Marion County Surveyor's Office, written commun., 1996.

[3]Assumes that 1″ of latitude (.000278°) is equal to 101 feet, and 1″ of longitude (.000278°) is equal to 77.6 feet.

[4]Global positioning system points are labeled as month, day, hour, point. For example, 100414A is the first point collected after 14:00 hours Greenwich Mean Time on October 4, 1996.

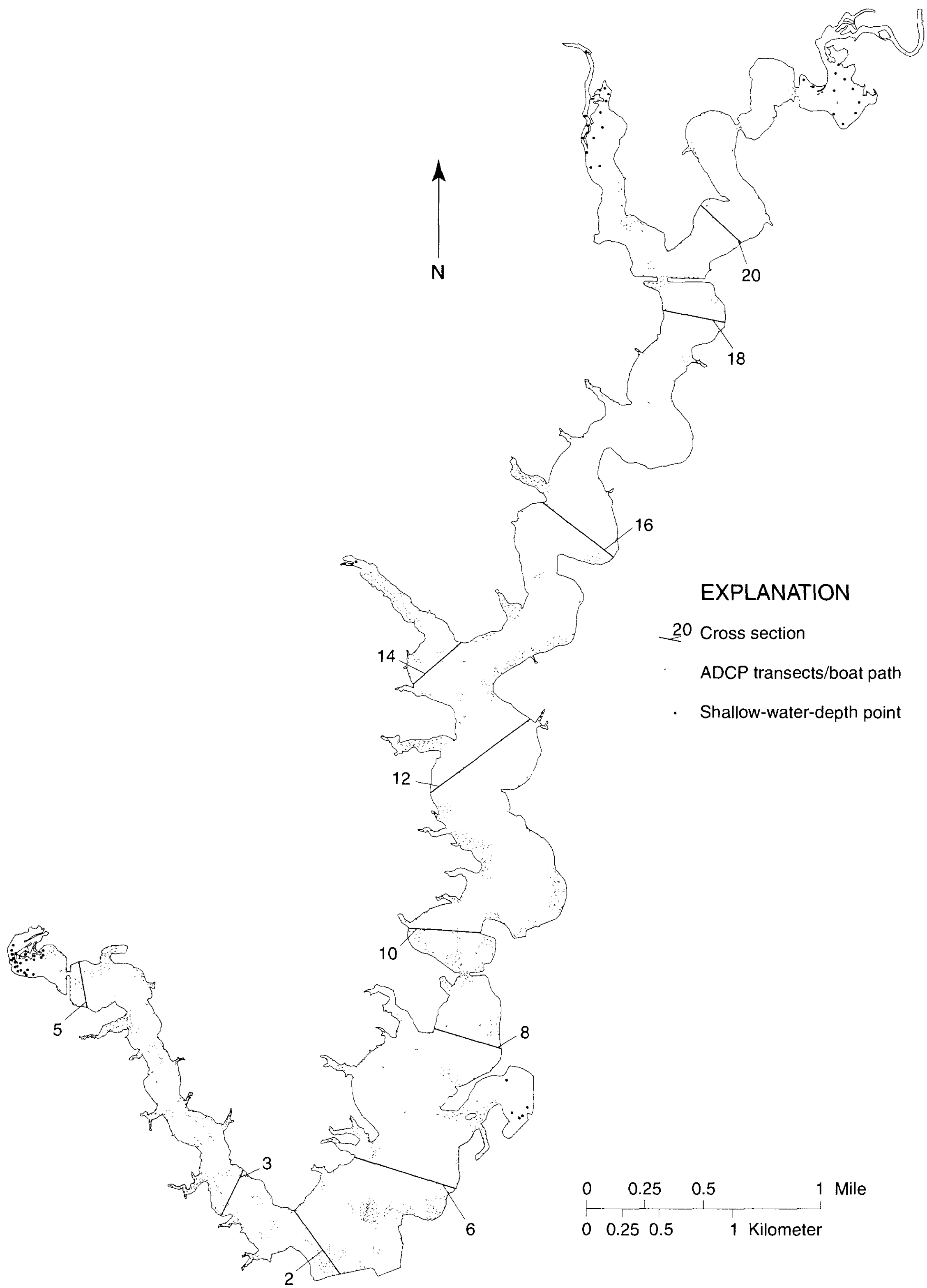

Figure 5. Location of acoustic Doppler current profiler (ADCP) transects, shallow-water-depth points, and cross sections for Morse Reservoir, central Indiana.

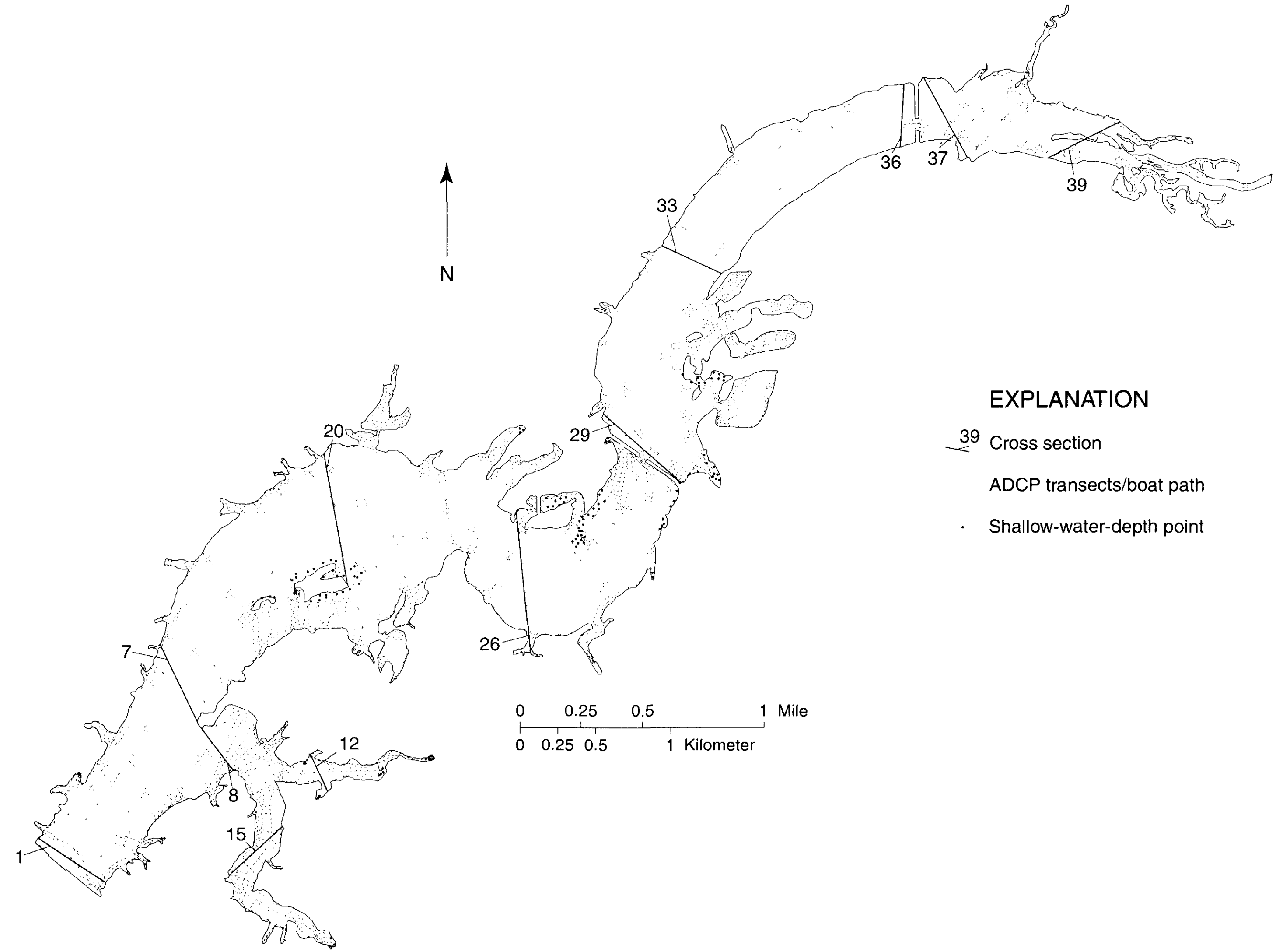

Figure 6. Location of acoustic Doppler current profiler (ADCP) transects, shallow-water-depth points, and cross sections for Geist Reservoir, central Indiana.

The volumes computed for the 1996 bathymetry were compared to the volumes from the previous bathymetric surveys to estimate the loss in reservoir storage capacity because of sedimentation. The following sections describe the contour mapping, estimation of reservoir volumes, and the estimation of sedimentation.

Contour Mapping

Contour maps were generated for Morse and Geist Reservoirs by use of ARC/INFO. ADCP water-depth and location data and GPS coordinates were processed and converted to ARC/INFO coverages. Coverages for the shorelines, ADCP water-depth data, and the shallow-water-depth data were used to generate the maps.

Contour Map Generation

The first step in creating contour maps was to transfer all data collected with the ADCP and GPS receivers to the ARC/INFO data base. The ADCP manufacturer's data-processing software was used to produce text files of all data sets collected with the ADCP. One text file was created for each ADCP transect. The data from the GPS receivers were processed with software provided by the GPS manufacturer. Text strings containing latitude and longitude were produced for all control points. The ADCP and GPS text files were used to generate ARC/INFO coverages. All coverages were converted into a map projection for making contour maps. The Universal Transverse Mercator (UTM) projection was selected because it is commonly used for the scale of maps to be created.

Data in the ARC/INFO water-depth coverages were edited to identify and delete points with one or more invalid ADCP beam depth (for this discussion, the term "point" refers to a single ADCP ensemble and position; each point has four ADCP beam depths). After invalid data points were removed from the coverages, average depths were computed from the four ADCP beam depths and corrected for normal pool elevation.

All water-depth data were quality checked by an inspection of the average ADCP beam depths at intersecting transects. The beam depths of each transect were checked at intersections to ensure they did not differ by more than a few tenths of a foot (small variations were allowable because slight variations in locations of the four beams would likely produce variations in the average depths). The ADCP transects also were checked to ensure they passed through the GPS control points and did not cross the reservoir shoreline.

The water-depth data were edited in areas where depths of intersecting transects did not match. In areas where the transects crossed the shoreline, either the transect data or the shoreline data were edited. Most edits involved adjusting the position of the transect or shoreline slightly. If errors in position seemed excessive, all or parts of the transect were deleted. Position errors in water-depth data were attributed to errors in the bottom-tracking caused by inaccuracies of the on-board compass of the ADCP; the analysis of the accuracy of the GPS methods indicated that positions on average could be determined within 10 ft. Some of the initial depth data collected from Morse and Geist Reservoirs had significant position errors caused by excessive boat speed (5 knots maximum) coupled with a slow ADCP ping rate. Data were re-collected where needed with a faster ADCP ping rate and with a slower boat speed (3 knots maximum). After data editing, all transects were appended within ARC/INFO to create master depth coverages that included all ADCP depth data for each reservoir. The master depth coverages also included the point depths collected by manual soundings in shallow areas.

The coverages of shorelines and water-depth data were used to generate contour maps and to compute reservoir volumes. Two different ARC/INFO software methods of surface generation for contouring—TIN and Topogrid—were used and evaluated.

The acronym TIN stands for Triangulated Irregular Network (Environmental Systems Research Institute, Inc., 1991) and is defined as:

> . . . a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x, y coordinates and z values. The TIN model stores the topological relationship between triangles and their adjacent neighbors; i.e., which points define each triangle and which triangles are adjacent to each other.

For the water-depth coverages, the x, y coordinates are UTM coordinates and the z values are water depth in feet. The TIN model subdivides the bathymetric data of the reservoir into thousands of triangles. Each of these triangles or TIN's has a surface area and an average depth. The ARC/INFO command "TINcontour" generates contours using the TIN surface. Refer to the ARC/INO documentation for a detailed discussion of TIN and TINcontour (Environmental Systems Research Institute, Inc., 1991).

ESRI states that Topogrid generates a "hydrologically correct" grid of elevation (Environmental Systems Research Institute, Inc., 1994). In the case of a reservoir, for example, the submerged stream channel might be defined by a limited number of data points. Topogrid could generate a smooth, continuous stream-channel surface from the points (the shape and continuity of the surface is dictated by factors such as data density and location). The ARC/INFO command "Latticegrid" was used to generate water-depth contours from the Topogrid surfaces.

Contour map surfaces generated from the TIN and Topogrid methods were evaluated by a comparison of the contours with selected point depths. Inaccuracies in the Topogrid-generated contours resulted in selection of the TIN-generated contours for the contour maps. Limitations in the use of TIN and Topogrid for this project are discussed in the "Contour Mapping Limitations" section.

The TIN-generated contours were examined and required manual edits in some areas. Most edits consisted of manually smoothing contour lines and connecting isolated closures in contour lines, for example, to follow a known submerged channel or roadbed. The Topogrid surface produced smoother contour lines than the TIN surface and was used as a guide to smooth the TIN-generated contour lines. Older contour maps of the reservoirs also were used to identify areas on the TIN-generated map that could be edited, especially along the submerged stream channels. Completing the edits to the TIN-generated contours produced the final contour maps for Morse and Geist Reservoirs (figs. 7 and 8).

Contour Mapping Limitations

It would not have been practical to develop hand-drawn contour maps for Geist and Morse Reservoirs because more than 120,000 data points were used to produce each map. ARC/INFO was capable of generating contours from the data, but the process had limitations. One obvious limitation was that the computer-generated contours were not as aesthetically pleasing as hand-drawn contours. This problem can be minimal if data are collected in a grid pattern dense enough to identify all features, including linear features such as stream channels. Many of the 120,000 data points used for contouring each reservoir were packed tightly along transects, resulting in many duplicate data points. Ideally, data would be distributed in a uniform grid for computer contouring; however, it may be impractical and inefficient to collect data in this manner on large reservoirs.

Most of the limitations in producing contour maps with methods described in this report were related to data collection. In some areas, the data coverage was not adequate to properly define topographic features, especially stream channels. Inadequate data resulted in missing contours; contours in the wrong positions; or contours that defined isolated "islands" when they should have defined continuous, linear features such as submerged stream channels. In some areas, depths were collected near the shoreline then collected at a considerable distance from the shore (figs. 5 and 6). This had the effect of "pulling" some depth contours away from their true position and out towards the next closest data point, causing the contour lines to define protrusions into the reservoir that were not real.

Some limitations are associated with TIN and Topogrid, but these limitations apply specifically to this project. Changes in software configurations and data-collection techniques could change or eliminate the limitations discussed below.

The locations and shapes of contours generated from the TIN surfaces were accurate where depth data were sufficient. TINcontour produces straight and angular contour lines, which are not as aesthetically pleasing as hand-drawn contour lines. Because contour lines are generally smooth, the angularity of TIN contours appeared unrealistic in some areas and needed to be smoothed manually.

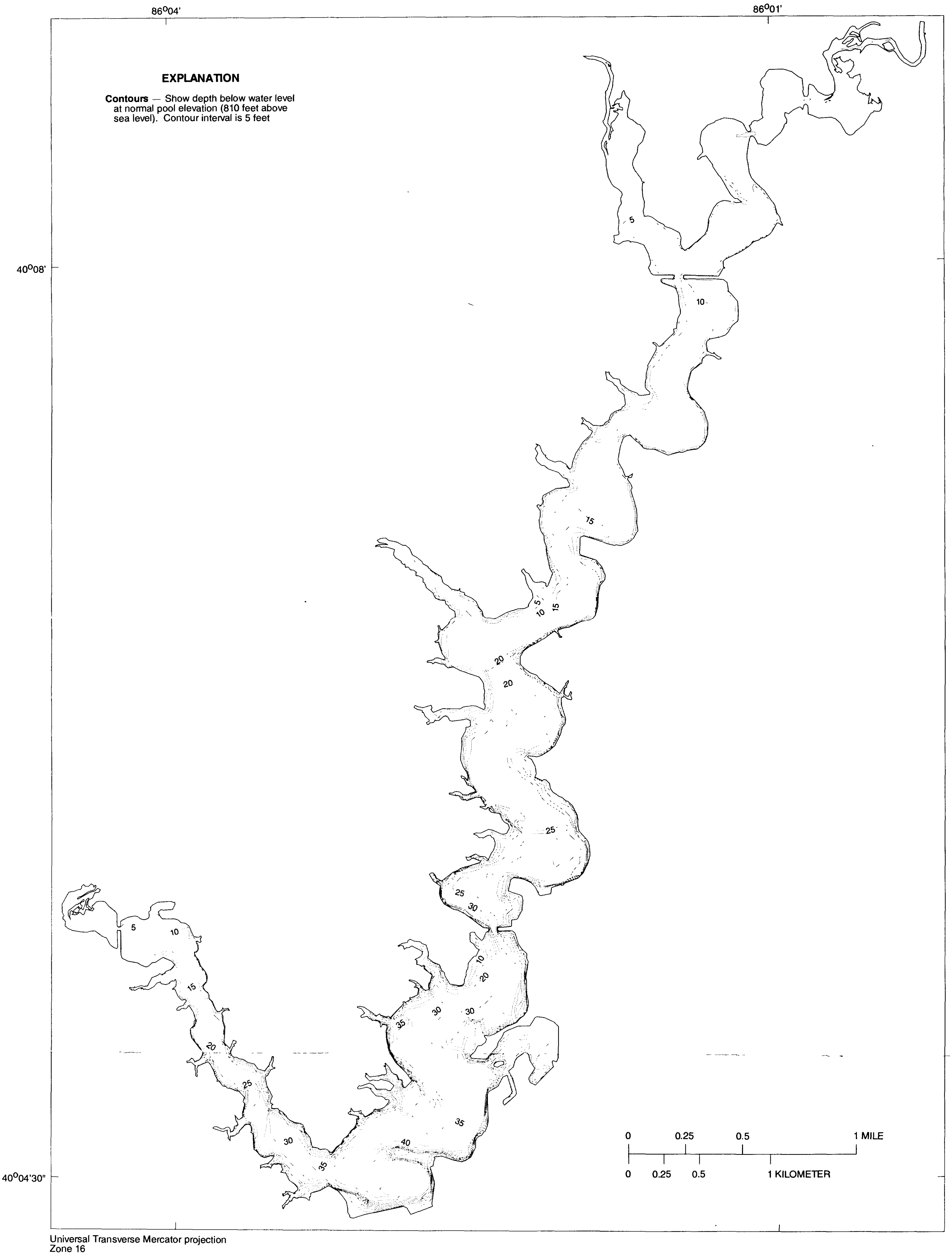

Figure 7. Water-depth contours of Morse Reservoir, central Indiana.

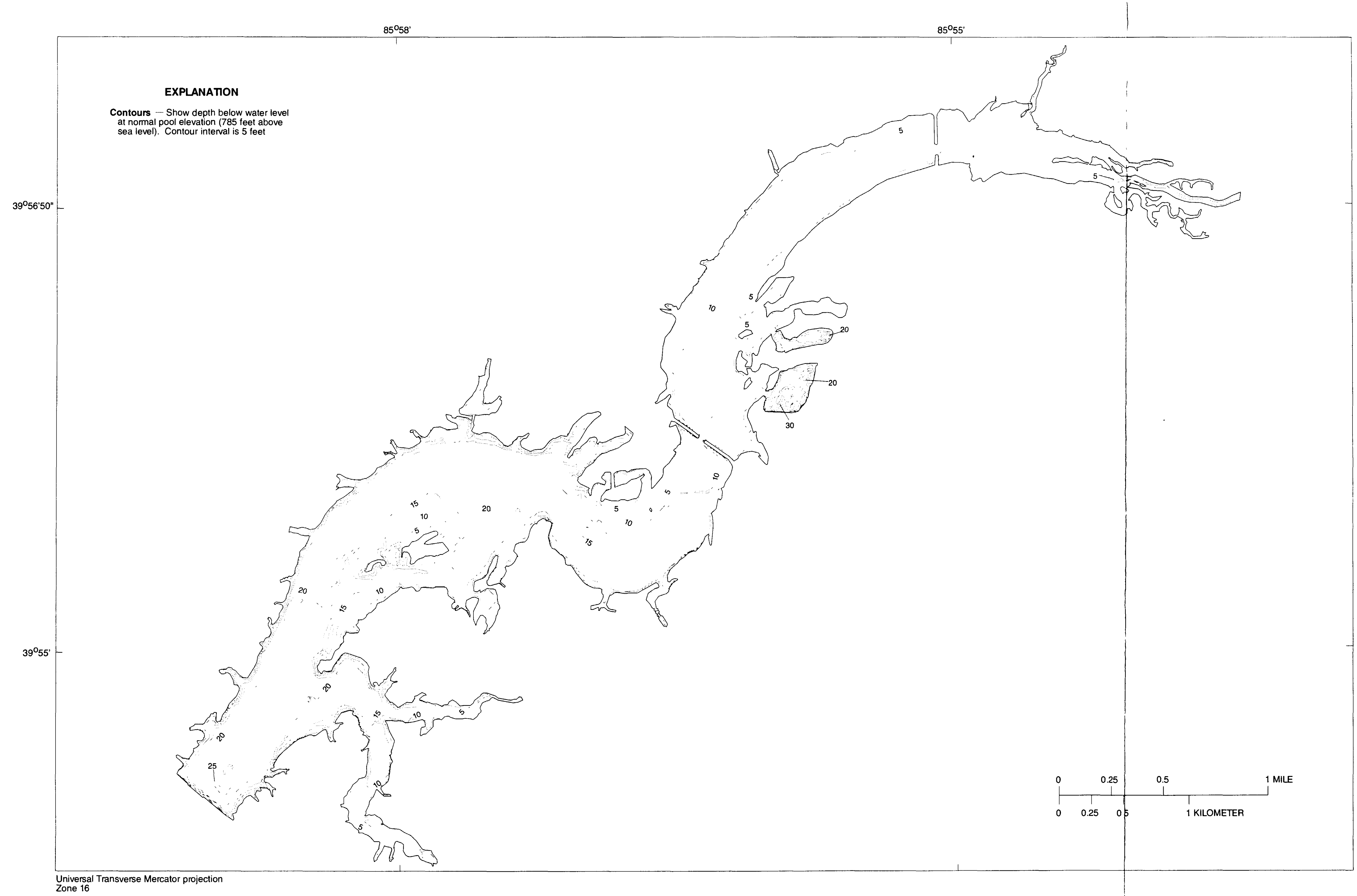

Figure 8. Water-depth contours of Geist Reservoir, central Indiana.

Part of the problem with contours protruding from shore was a function of the TINcontour procedure. The protrusion of contour lines into areas of deeper water was edited, and data points were added to the coverage to represent where the contour lines should be located. This editing was done before the volume calculations (discussed in the next section) were made to ensure that the volumes would not be underestimated.

In some areas, the Topogrid-generated contours appeared more representative of real topographic features than the TIN-generated contours. ESRI states that Topogrid is designed to produce "hydrologically correct" surfaces (Environmental Systems Research Institute, Inc., 1994). In many areas, Topogrid contour lines were not as accurate as desired, probably because Topogrid computes grid values by averaging only four data points. For example, shallow contours would extend into areas that were known to be deep. The inaccuracies may have been reduced or eliminated by reducing the grid size of the Topogrid surface.

It was beyond the scope of this project to analyze the many programs/algorithms available for computer contouring. It is possible that some other method would produce a more accurate computer-generated map with the available data and not require manual editing. With the manual editing, the TIN-generated contours (figs. 7 and 8) are accurate representations of the reservoir bathymetries but could be improved with additional data. The data coverages shown in figures 5 and 6 can be used to evaluate the contour maps—the denser the data coverage, the more accurate the contours.

Estimation of Reservoir Volumes

In addition to creating water-depth contours, the TIN-generated surface was used to compute volumes for both reservoirs. Each triangle generated by TIN has a surface area and an average depth, the product of which is volume. The sum of all of the TIN volumes is the volume of the reservoir. The final TIN-generated surface was computed after data points were added to represent the edited locations of contour lines, as explained in the previous section. This editing was done so that volumes would not be underestimated from shallow contour lines inaccurately extending into areas of deeper water.

Computations of volume by TIN may be influenced by the density of data because TIN sums volumes of areas of equal depth. Greater densities of data are likely to increase accuracy; for example, increasing the data collected in a channel area might result in more areas of greater average depth, thereby increasing the computed volume. This project did not attempt to quantify the effect on volume computations with varying data density.

Morse Reservoir

The volume of Morse Reservoir based on the 1996 bathymetry is 22,820 acre-ft (7.44 Bgal). The surface area of the reservoir (not including islands) was computed to be 1,484 acres, making the average depth of water 15.4 ft. In much of the north end of the reservoir and at the mouths of tributaries, the water is less than 5 ft deep; in many areas at the south end of the reservoir, water depths of 40 ft or more were measured in the submerged channel of Cicero Creek (fig. 7).

Geist Reservoir

The volume of Geist Reservoir based on the 1996 bathymetry is 19,280 acre-ft (6.29 Bgal). The surface area of the reservoir (not including islands) was computed to be 1,848 acres, making the average depth of water 10.4 ft. In much of the upper end of the reservoir and at the mouths of tributaries, the water is less than 5 ft deep; in a few areas at the lower end of the reservoir, water depths of 25 ft or more were measured in the submerged channel of Fall Creek (fig. 8). The 1996 volume and area include the addition of several bays and inlets that did not exist in 1980. The two largest of the new bays were apparently old sand and gravel quarries and had a combined area of about 38 acres and a combined volume of about 523 acre-ft (170.4 Mgal).

Estimation of Sedimentation

Reductions in reservoir storage capacity from the design volumes and since the previous bathymetric surveys can be attributed to sedimentation.

The lost storage capacity, or volume of sediment, was estimated by subtracting the 1996 reservoir volumes from the previous estimates of volumes. Before the differences could be estimated, however, the 1996 shorelines had to be adjusted to match the shorelines from the previous bathymetric surveys (Morse Reservoir in 1978 and Geist Reservoir in 1980). Contour maps provided by the IWC and old aerial photographs indicated the shorelines changed since the last surveys. The shoreline of Geist Reservoir has undergone the most change with the addition of two new bays that were apparently old sand and gravel quarries and the addition of some smaller bays for boat docking. The 1996 shorelines were adjusted by deleting features that did not exist at the time of the earlier surveys and by generally trying to match the 1996 shorelines to those represented on the maps provided by the IWC.

The comparison of 1996 reservoir volumes with previous volumes should be considered gross estimates because the volumes were computed with different methods. The 1996 volumes are computer generated (TIN), based on the bathymetry data that were collected throughout the reservoirs (figs. 5 and 6). Although the density of data varies, most areas of the reservoirs were covered. The 1978 volume for Morse Reservoir was based on a network of 25 cross sections (fathometer profiles), and the 1980 volume for Geist Reservoir was based on a network of 40 cross sections (fathometer profiles). Reservoir volumes were calculated by measuring the area of the cross sections and applying the areas to lengths of reservoir between the cross sections (Steve Grant, Indianapolis Water Company, personal commun., 1997). The design volumes probably were based on valley sections of the topographical surveys prior to construction of the reservoirs.

The computer-generated (TIN) volumes for the 1996 bathymetry are based on a more accurate method that uses data for the entire reservoir and not just data from along a few cross sections. The accuracy of the TIN may be affected by the density of the data coverage. Ideally, data should be collected in a grid pattern dense enough to allow the TIN to identify all of the bottom features. This may not be practical, however, on large reservoirs. Morse Reservoir has more relief and a more defined channel than Geist Reservoir. Therefore, the volume estimates for Morse Reservoir may be less accurate than those for Geist Reservoir.

Morse Reservoir

Bakken and Bruns (1991) reported an original (1956) design volume of 25,380 acre-ft (8.27 Bgal) for Morse Reservoir and a 1978 volume of 22,100 acre-ft (7.2 Bgal). This difference represents a 12.9-percent reduction in reservoir volume over 22 years. The 1996 volume with the 1978 shoreline was computed to be 22,810 acre-ft (7.44 Bgal), which is 3.2 percent larger than the volume computed for 1978. The area of the reservoir, adjusted to represent the 1978 shoreline, was 1,508 acres.

The difference in volume can be attributed to the different methods used to compute volume and not to an actual increase in volume. The volume of 22,810 acre-ft represents a 10.1-percent reduction from the design volume (since 1956); however, the design volume probably was estimated with the cross-section area method. The 1996 volumes, either with the 1978 shoreline (22,810 acre-ft) or the 1996 shoreline (22,820 acre-ft), are smaller than the design volume (25,380 acre-ft), which suggests sedimentation is reducing the storage capacity of Morse Reservoir. Because different methods were used to compute volume, the actual loss in storage capacity and the annual sedimentation rate cannot be estimated.

Figures 9 through 19 (Supplemental Data at back of report) are comparisons of the 1978 fathometer profiles from a sedimentation project to the cross sections generated from the TIN computed for the 1996 bathymetry. The locations of the cross sections are shown in figure 5; the numbers of the cross sections are the same as those used in the IWC sedimentation project. A representative sample of the 25 IWC cross sections was selected to show sedimentation and changes in the reservoir bottom. The depth of water in figures 9 through 19 is referenced to a normal pool elevation of 810 ft above sea level.

The cross sections are viewed in the downstream direction, with the horizontal station referenced to zero at the left end. Differences in the lengths of the cross sections and positions of bottom features could be caused by discrepancies in the shorelines used for the two studies and the technique used to measure the horizontal station along the fathometer profiles. The 1996 cross sections are computer generated from a TIN of the bathymetry. The depth of water was computed every meter (3.281 ft) along the sections, from the left edge of water to the right edge of water. The lengths of the 1996 cross sections are based on the shoreline coverages made from aerial photographs.

The cross sections were selected to show potential changes in the bottom of the reservoir, from the dam (fig. 9) to the headwaters where Cicero Creek flows into the reservoir (fig. 19). All of the cross sections indicate some sedimentation has occurred, but because of the limitations of the data—present and past—the sedimentation cannot be quantified accurately. The sedimentation appears less in the lower parts of the reservoir near the dam. In these areas, the sedimentation appears to have occured mainly in and near the submerged stream channel. Cross sections in the headwater areas show as much as 1 ft of sedimentation in some areas.

Some of the discrepancies between the 1996 cross sections and the 1978 fathometer profiles were caused by natural processes in the reservoir, such as sedimentation. Some discrepancies most likely were caused by areas of sparse data collection, particularly in and near the submerged stream channel. The accuracy of the water depths for the cross sections is based on the proximity of the cross section to bathymetry data. Intersections of the cross sections and the ADCP transects are shown on figures 9 through 19 (at back of report). Cross sections that parallel ADCP transects also will show a more accurate representation of the water depths than areas not near a transect (fig. 5). The proximity of a cross section to the bathymetry data should be considered when evaluating the cross sections for sedimentation.

Geist Reservoir

Bakken and Bruns (1991) reported an original (1943) design volume of 21,180 acre-ft (6.9 Bgal) for Geist Reservoir and a 1980 volume of 18,720 acre-ft (6.1 Bgal). The difference represents an 11.6-percent reduction in reservoir volume over 37 years. The 1996 volume, computed with the 1980 shoreline, was 18,630 acre-ft (6.08 Bgal) and represents a 0.4-percent reduction in reservoir volume since 1980 and a 12.0-percent reduction since 1943. The area of the reservoir, adjusted to represent the 1980 shoreline, was 1,756 acres.

The estimated reduction in reservoir volume of 0.4 percent from 1980 to 1996 is not consistent with the estimated reduction in volume of 11.6 percent for the 37 years prior to 1980. This inconsistency can be attributed to the different method used to estimate the 1996 volume than that used for the previous estimates by the IWC. Dredging also could contribute to this small difference. Some places appear to have been dredged to allow boat traffic around docks, but it is not known if dredging did occur and if the dredged sediments were removed from the reservoir.

Cross sections were generated for the 1996 bathymetry and compared to the 1980 data to show if sedimentation has occured in Geist Reservoir since 1980. Figures 20 through 31 (Supplemental Data at back of report) are comparisons of the 1980 fathometer profiles from a sedimentation project to the cross sections generated from the TIN computed for the 1996 bathymetry. The locations of the cross sections are shown in figure 6; the numbers of the cross sections are the same as those used by the 1980 IWC sedimentation project. A representative sample of the 40 IWC cross sections was selected to show sedimentation and changes in the reservoir bottom. The depth of water in figures 20 through 31 is referenced to a normal pool elevation of 785 ft above sea level.

The 1996 cross sections for Geist Reservoir were generated with the same method as those for Morse Reservoir. The cross sections were selected to show potential changes in the bottom of the reservoir, from the dam (fig. 20) to the headwaters where Fall Creek flows into the reservoir (fig. 31). As with Morse Reservoir, the accuracy of the cross sections is related to the proximity of the cross section to the bathymetry data. Figures 20 through 31 (at back of report) show where the cross sections intersect ADCP transects. Some of the cross sections also parallel ADCP transects for limited distances (fig. 6).

All of the cross sections indicate sedimentation, which suggests that the estimated reduction in volume of 0.4 percent from 1980 to 1996 underestimates the amount of sedimentation. Many of the cross sections show areas with at least 1 ft of sedimentation. If 1 ft of sediment were added to the entire bottom of the reservoir (1,848 acres), a reduction of 8.7 percent from the design volume of 21,180 acre-ft would result. Because of the limitations of the data—present and past—the sedimentation, however, cannot be quantified accurately.

Accurate estimates of the reduction in reservoir volume since 1980 and the annual sedimentation rate cannot be made because the 1980 and 1996 volumes were computed with different methods. Figures 20 through 31 (at back of report), however, suggest that 0.4 percent underestimates the reduction of volume in Geist Reservoir since 1980. The 1996 volumes, either with the 1980 shoreline (18,630 acre-ft) or the 1996 shoreline (19,280 acre-ft), are smaller than the design volume (21,180 acre-ft); this difference suggests sedimentation is reducing the storage capacity of Geist Reservoir.

SUMMARY AND CONCLUSIONS

Morse and Geist Reservoirs are large artificial lakes in central Indiana that are used primarily for public water supply. The bathymetry of the reservoirs was mapped from April 1996 through October 1996 by use of an acoustic Doppler current profiler (ADCP) and a global positioning system (GPS) mobile receiver. The ADCP was used to measure water depth and position from a boat, and the GPS receiver was used to collect positions in latitude and longitude at control points along the boat path to convert ADCP coordinates to "real-world" coordinates.

The ADCP and GPS data were post-processed and imported to a geographic information system (GIS). The water depth and position data were processed with the GIS to produce a data base, or coverage, for each reservoir. Coverages consisted of a shoreline and water depths with positions in a Universal Transverse Mercator projection. These coverages were used by the GIS to generate contour maps and to compute volumes for each reservoir. Because the computer-contouring methods had limitations, the final contour maps were edited manually to smooth and connect areas of closure that were determined to be continuous (for example, a submerged stream channel or roadbed).

Reservoir volumes were computed with the GIS by generating a surface for the 1996 bathymetry. The 1996 area and volume of Morse Reservoir were computed to be 1,484 acres and 22,820 acre-ft (7.44 Bgal), respectively. The 1996 area and volume of Geist Reservoir were computed to be 1,848 acres and 19,280 acre-ft (6.29 Bgal), respectively.

The reservoir volumes from 1996 were compared to previous reservoir volumes to estimate the reduction in storage capacity resulting from sedimentation. Previous reservoir volumes included the design volumes for each reservoir and volumes resulting from sedimentation projects on Morse Reservoir in 1978 and Geist Reservoir in 1980. Because different methods were used to compute volume, the actual loss in storage capacity and the annual sedimentation rate could not be estimated. The 1996 volumes were from a computer-generated surface based on data spread throughout the reservoirs. The volumes from the earlier sedimentation projects were estimated from a network of fathometer profiles on each reservoir. Design volumes probably were based on cross sections of the topographical surveys of the valleys prior to construction of the reservoirs. To verify sedimentation, cross sections were constructed from the computer-generated surfaces for 1996 and compared to the fathometer profiles from the 1978 and 1980 sedimentation projects. These cross sections indicate some sedimentation throughout both reservoirs.

One of the objectives of this report was to evaluate the use of ADCP and GPS technology for bathymetric surveys. Bathymetric mapping of large lakes with the technologies and methods described in this report is practical. More than 120,000 data points were collected on each reservoir. The ADCP and GPS technology eliminated the need to string tag lines across the lake or to determine the boat position from shore-based instruments, allowing more bathymetric data to be collected in less time and with less manpower than with conventional methods. One boat crew collected the data on each reservoir in less than 20 (non-consecutive) field days. The accuracy of the computer-generated contour maps and reservoir volumes, however, could be increased if additional data were collected to define local features in the bathymetry. Morse Reservoir has a more defined channel and more relief compared to Geist Reservoir and, therefore, should require more data to accurately map such features.

An understanding of the limitations of the technology used in this study can be helpful. The ADCP has a shallow-water limit of about 2 ft and, when operated in depths less than 3 ft, is affected by irregularities in the bottom such as vegetation, rocks, and logs. Also, the configuration of the ADCP and the speed of the boat can affect the data quality. GPS receivers will not work in locations where tree canopies, buildings, and road embankments block satellite signals.

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SUPPLEMENTAL DATA

CROSS SECTIONS OF MORSE RESERVOIR

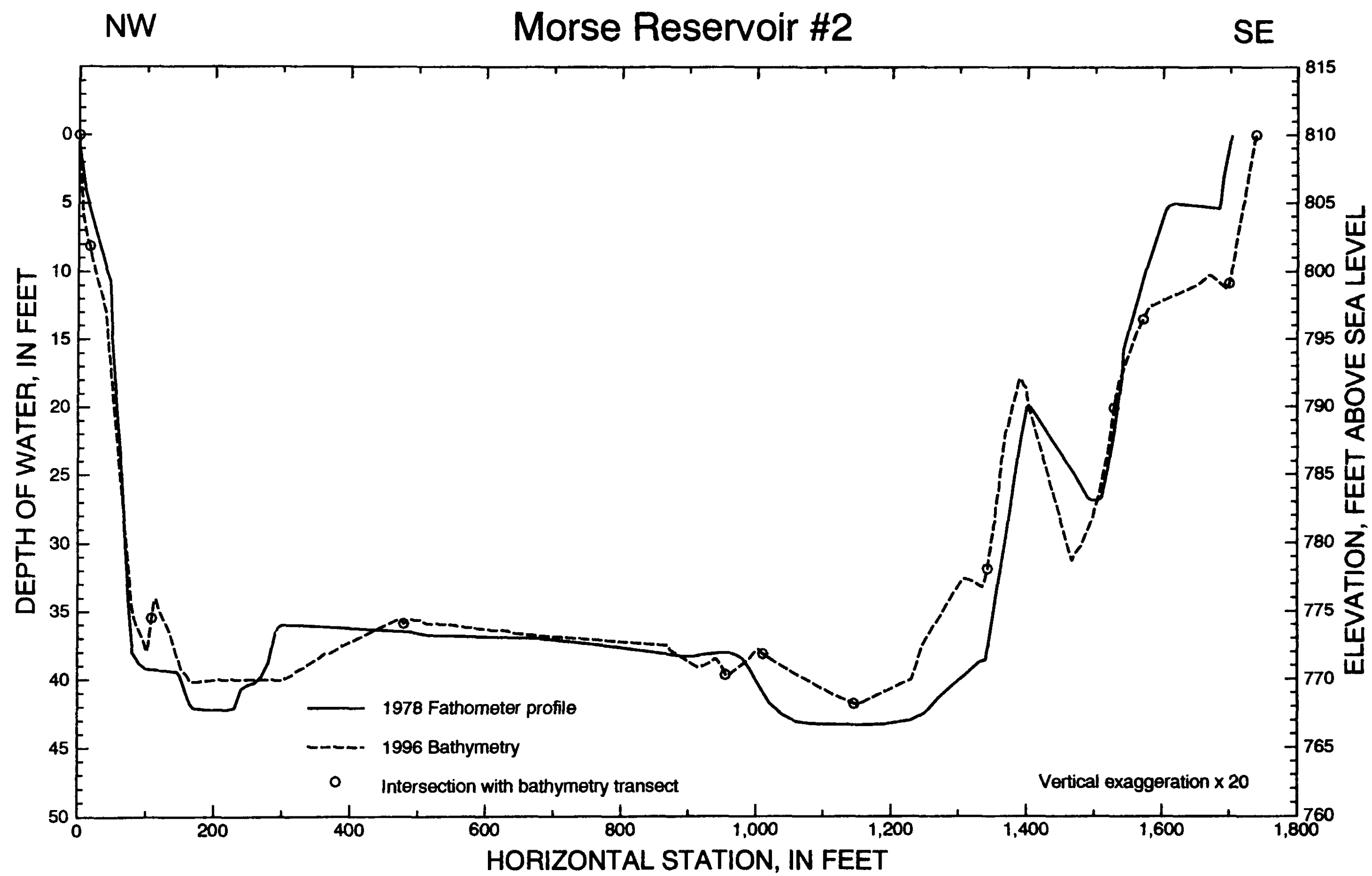

Figure 9. Cross section #2 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

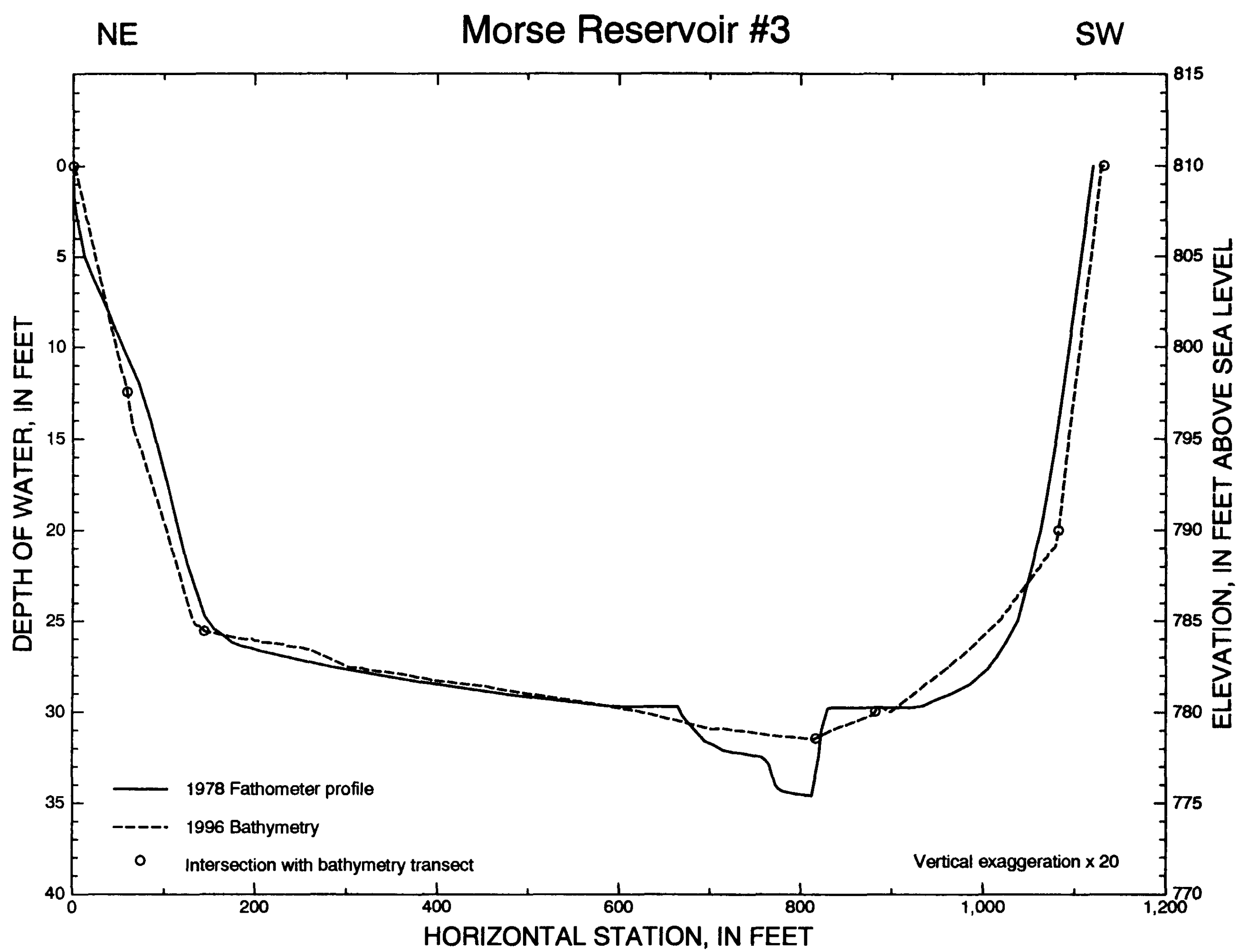

Figure 10. Cross section #3 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

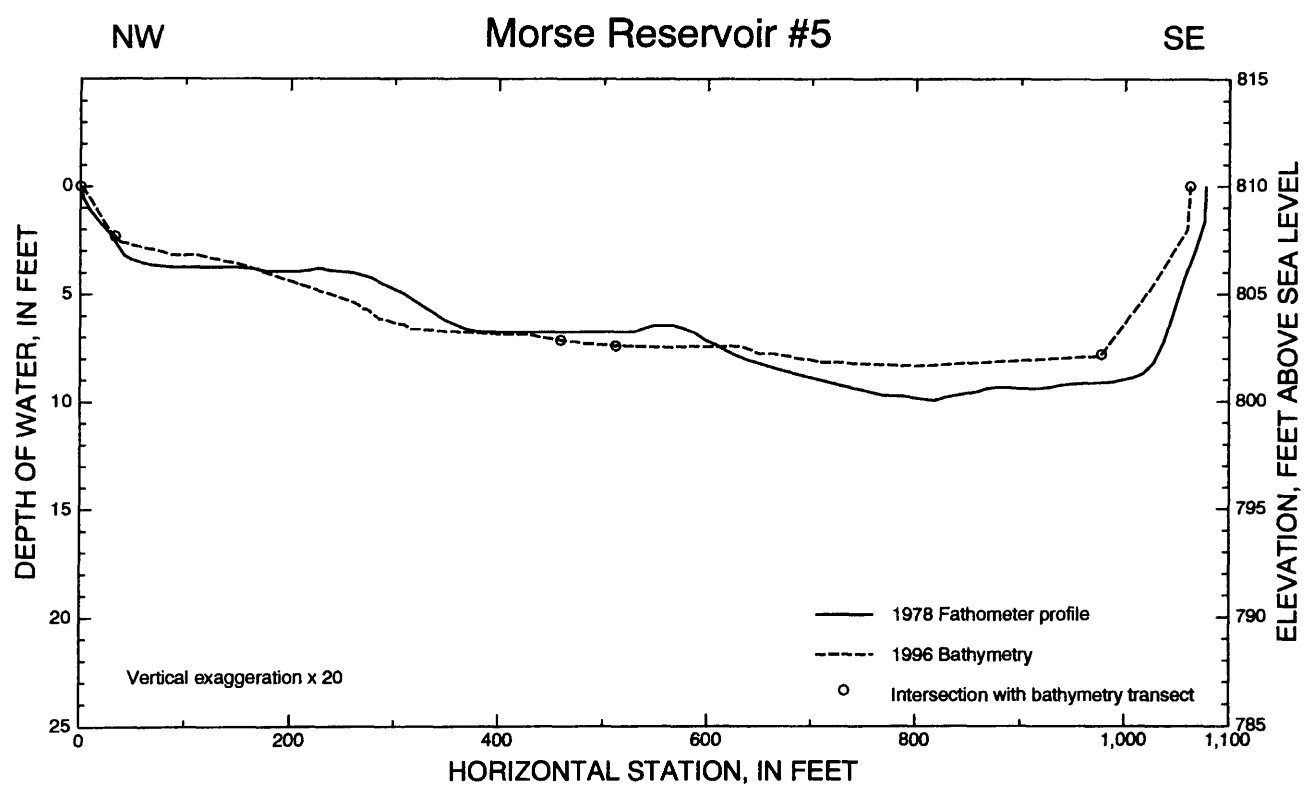

Figure 11. Cross section #5 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

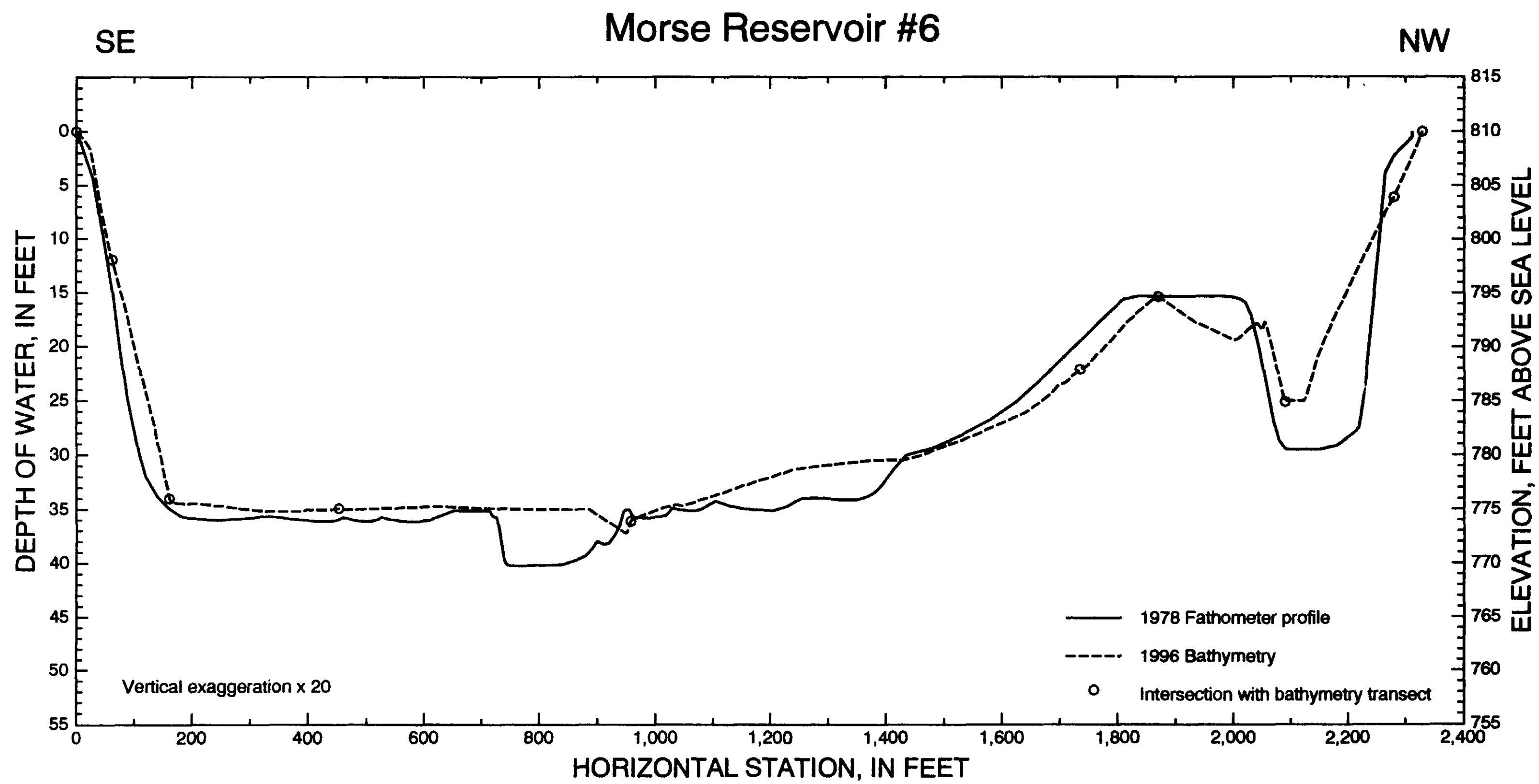

Figure 12. Cross section #6 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

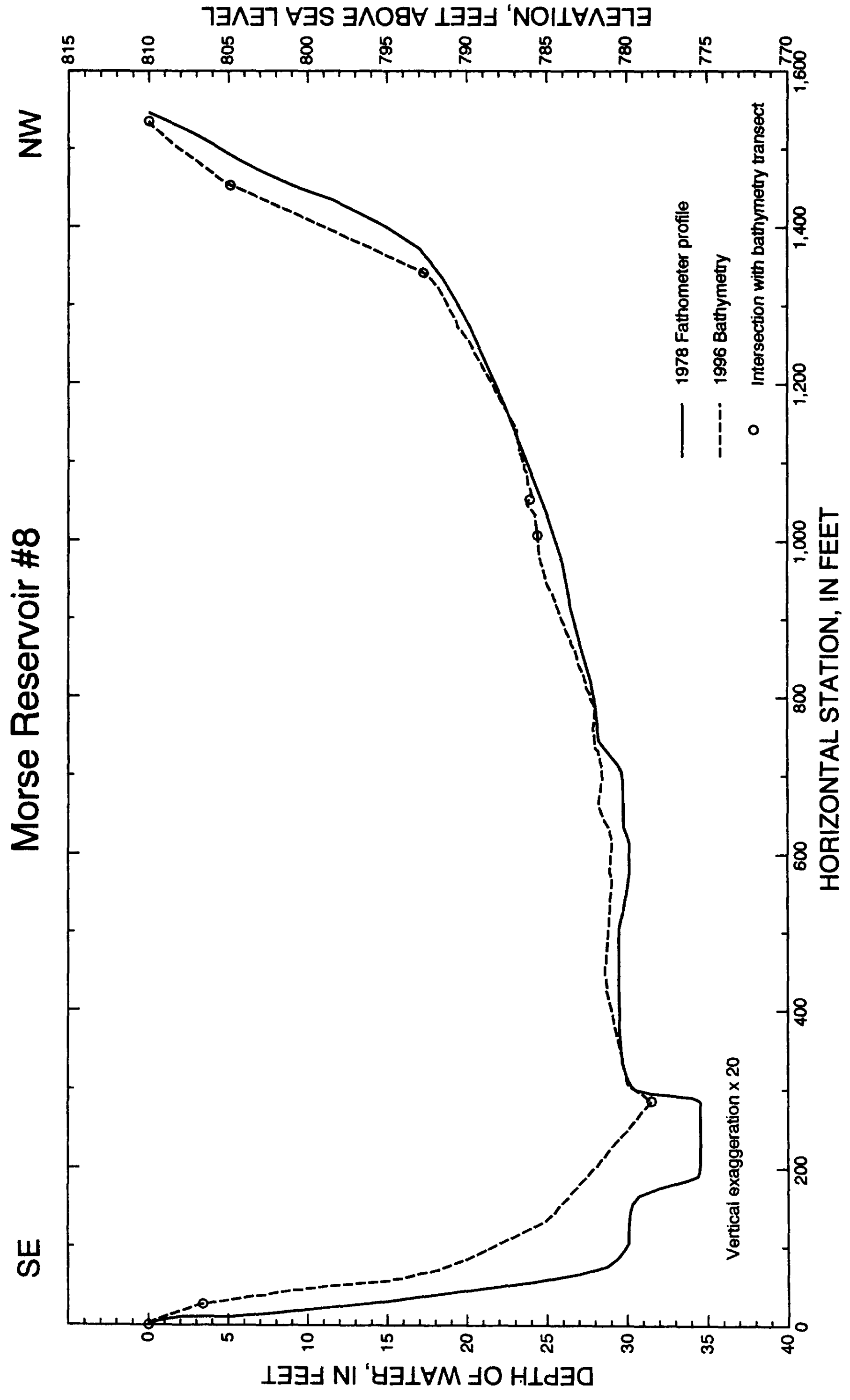

Figure 13. Cross section #8 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

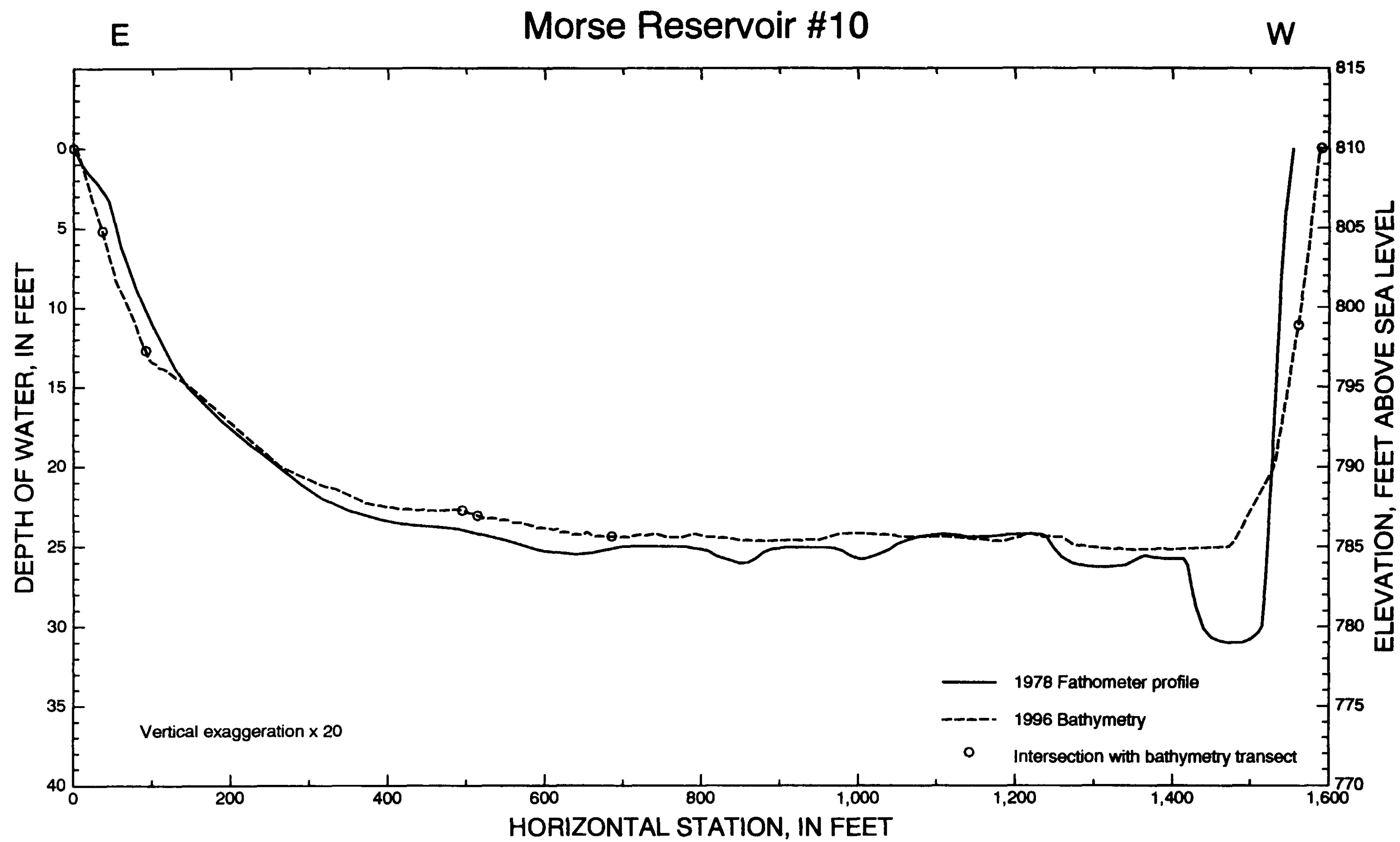

Figure 14. Cross section #10 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

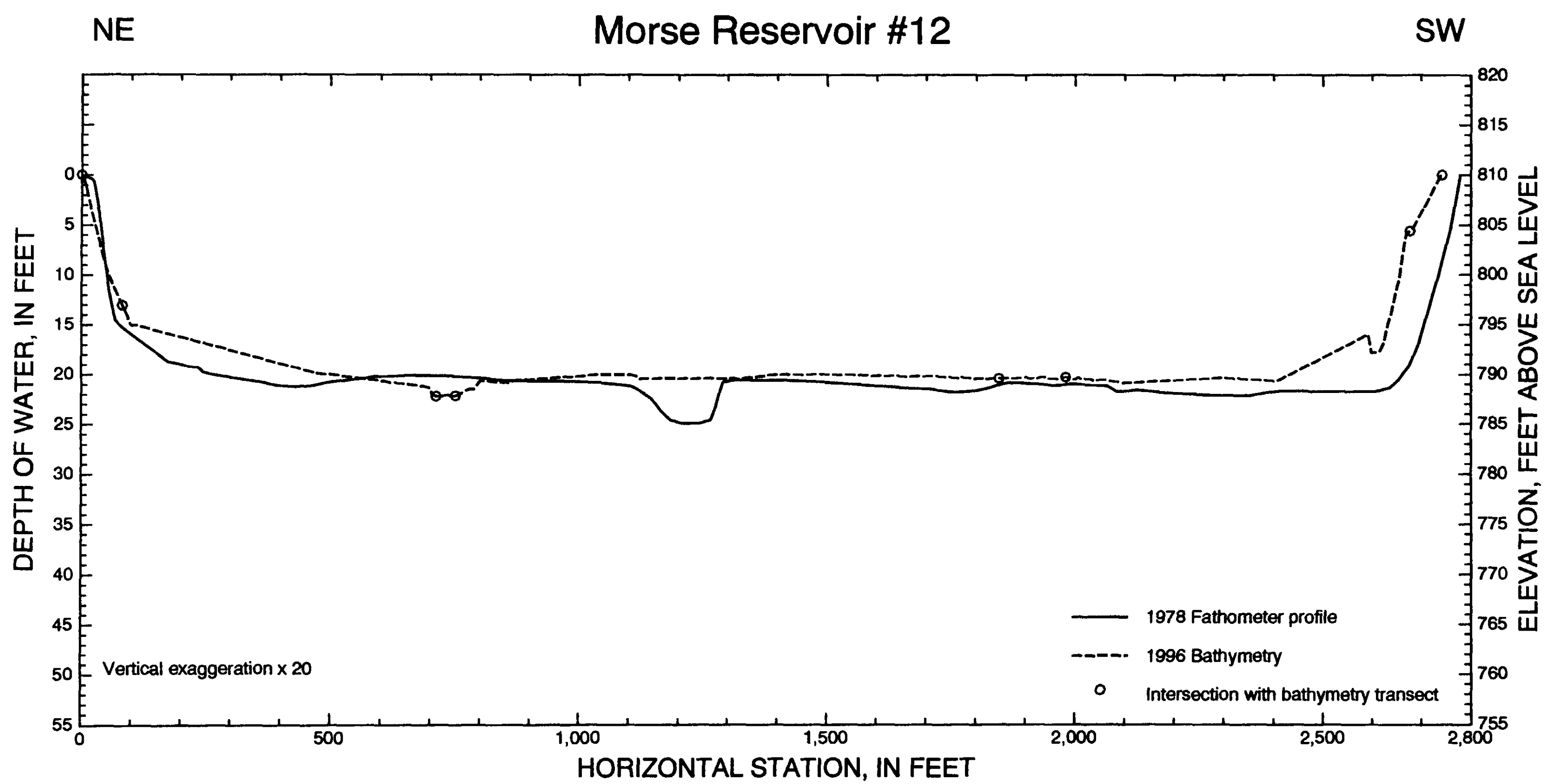

Figure 15. Cross section #12 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

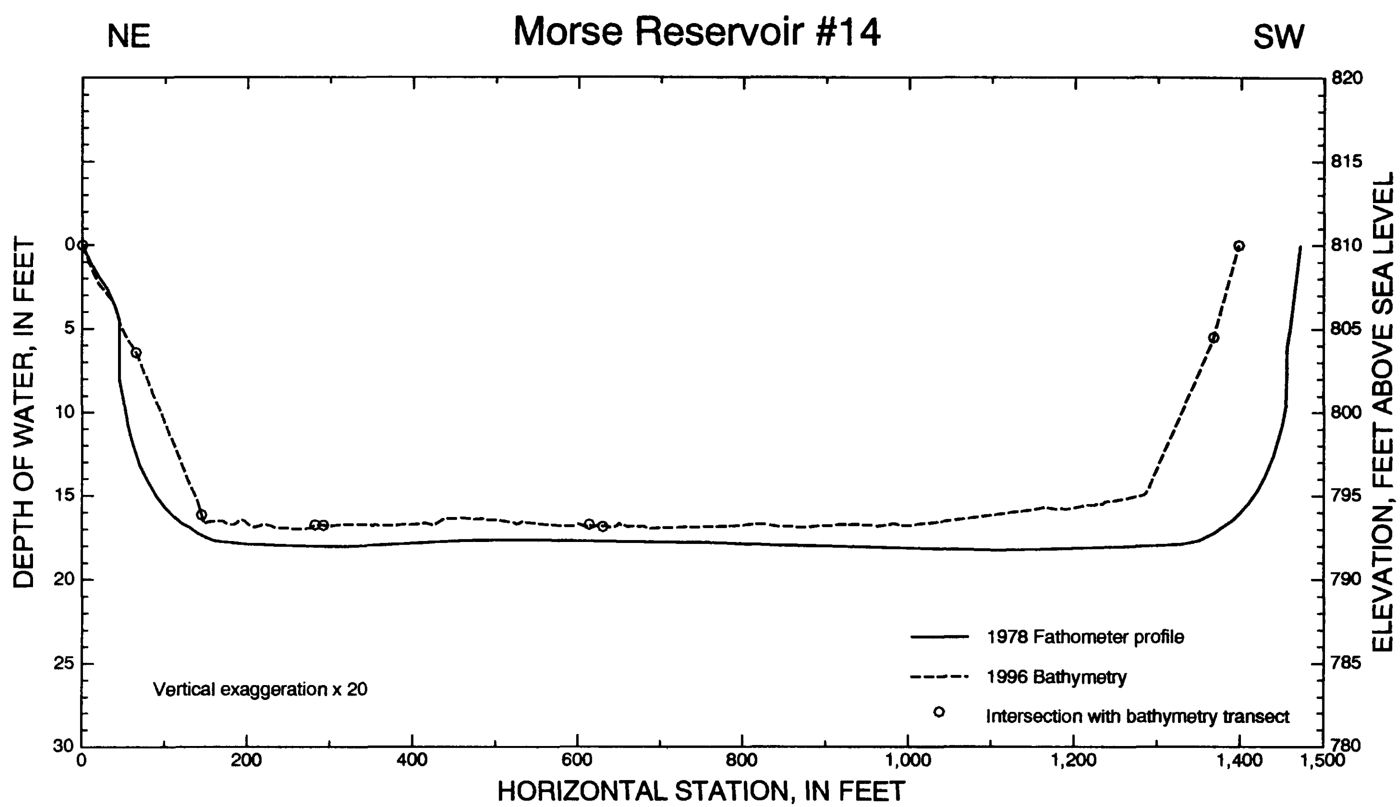

Figure 16. Cross section #14 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

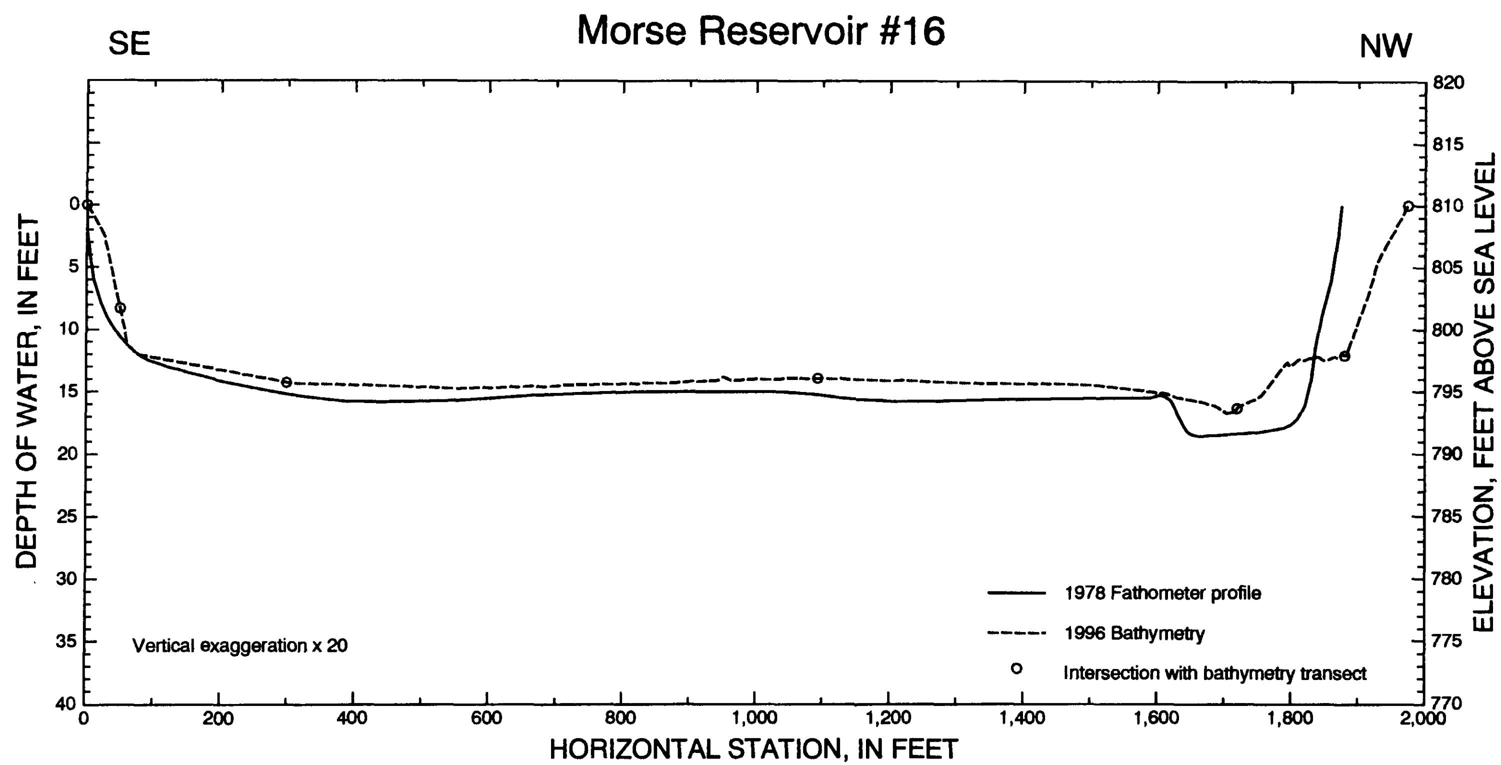

Figure 17. Cross section #16 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

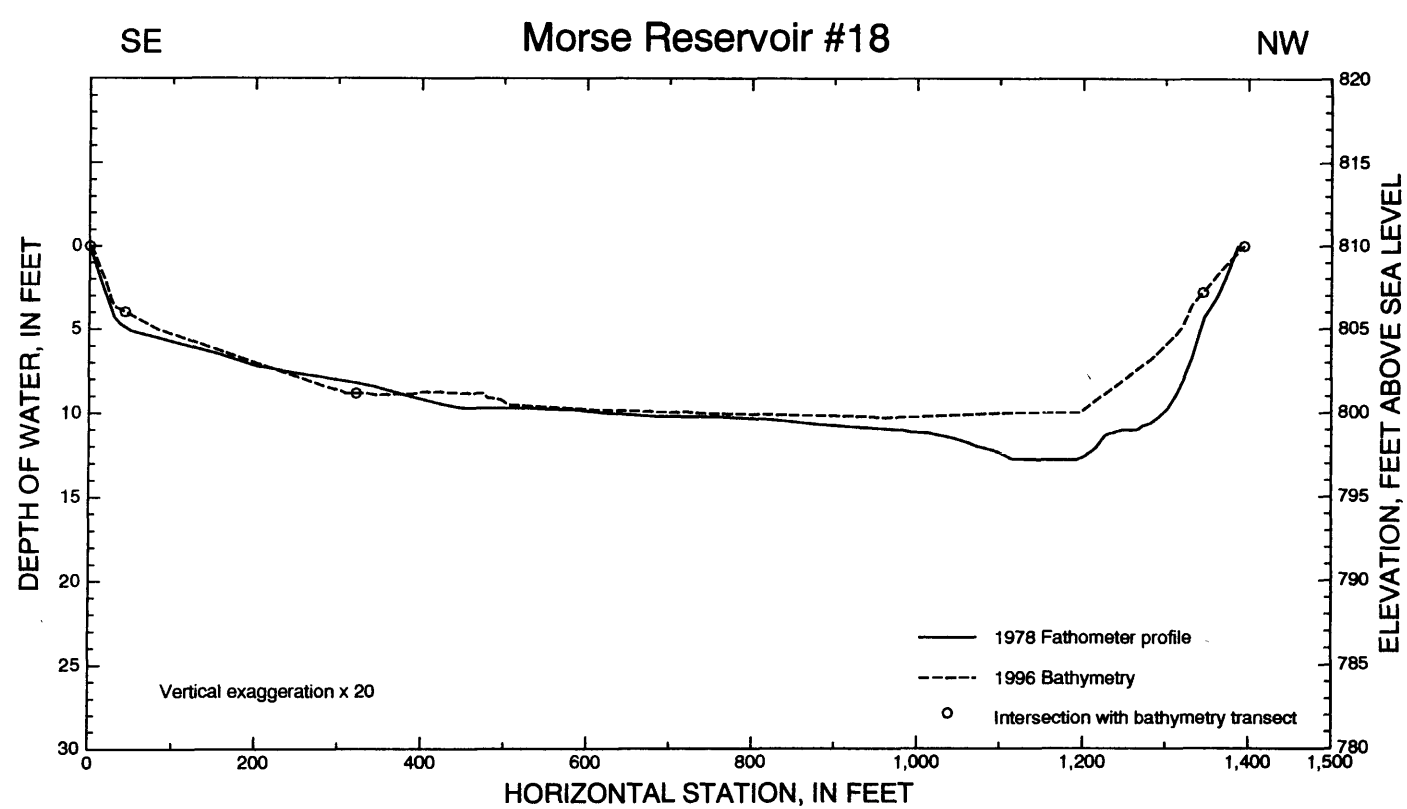

Figure 18. Cross section #18 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

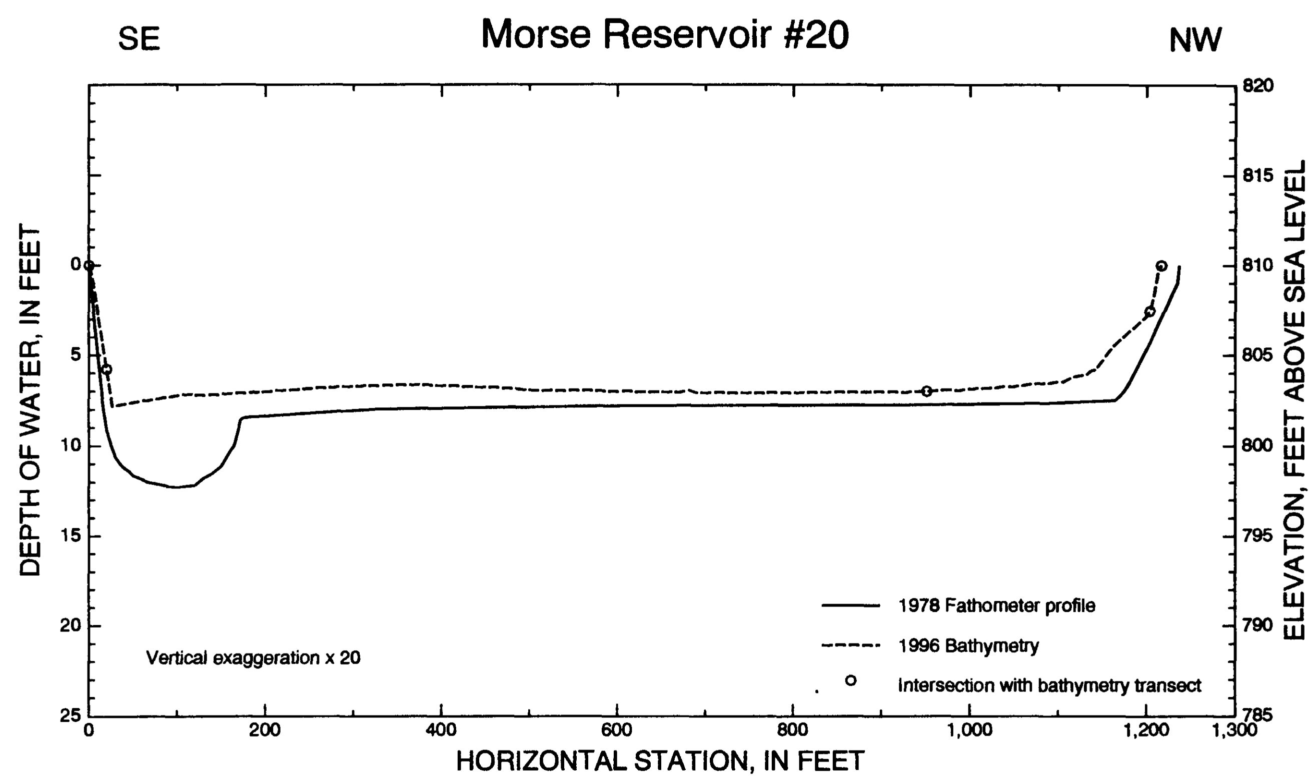

Figure 19. Cross section #20 of Morse Reservoir, central Indiana, from a 1978 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

SUPPLEMENTAL DATA

CROSS SECTIONS OF GEIST RESERVOIR

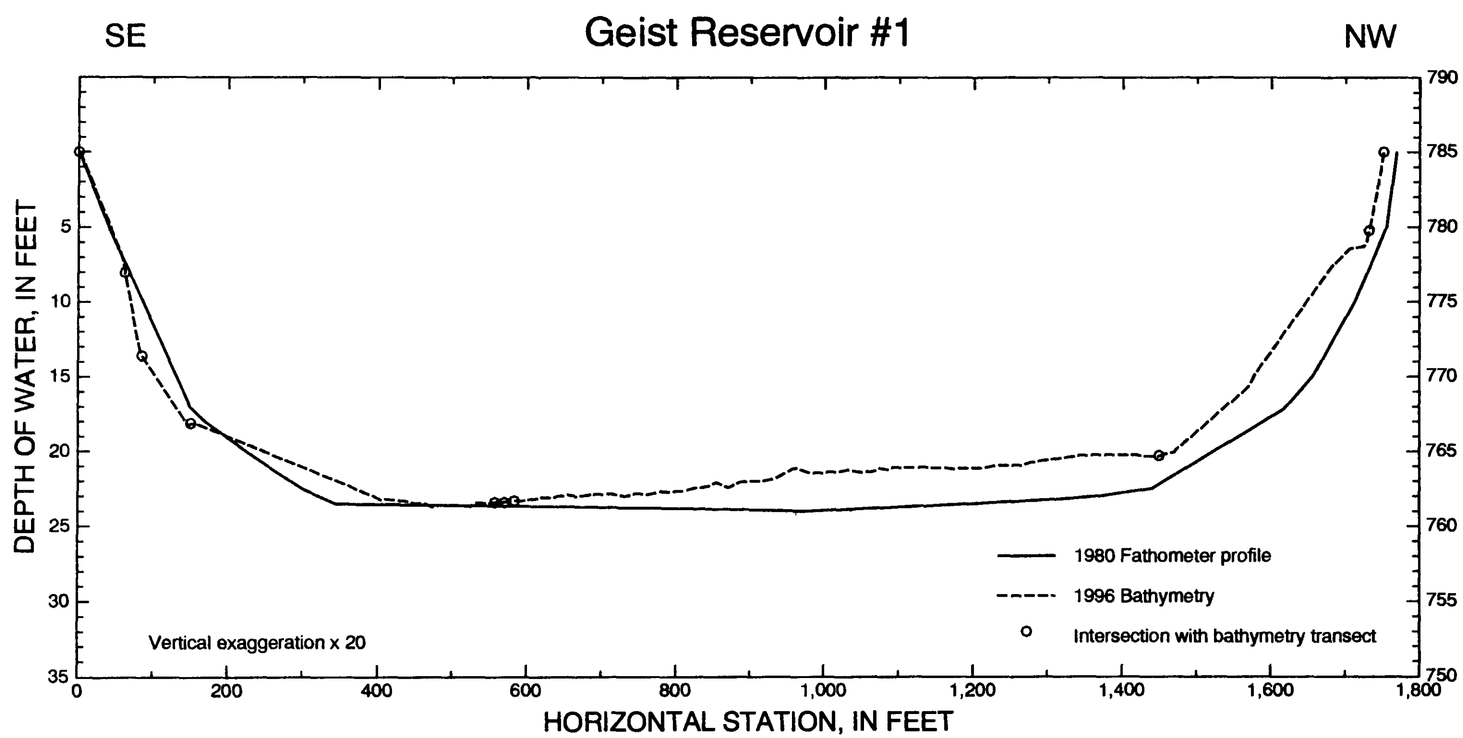

Figure 20. Cross section #1 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

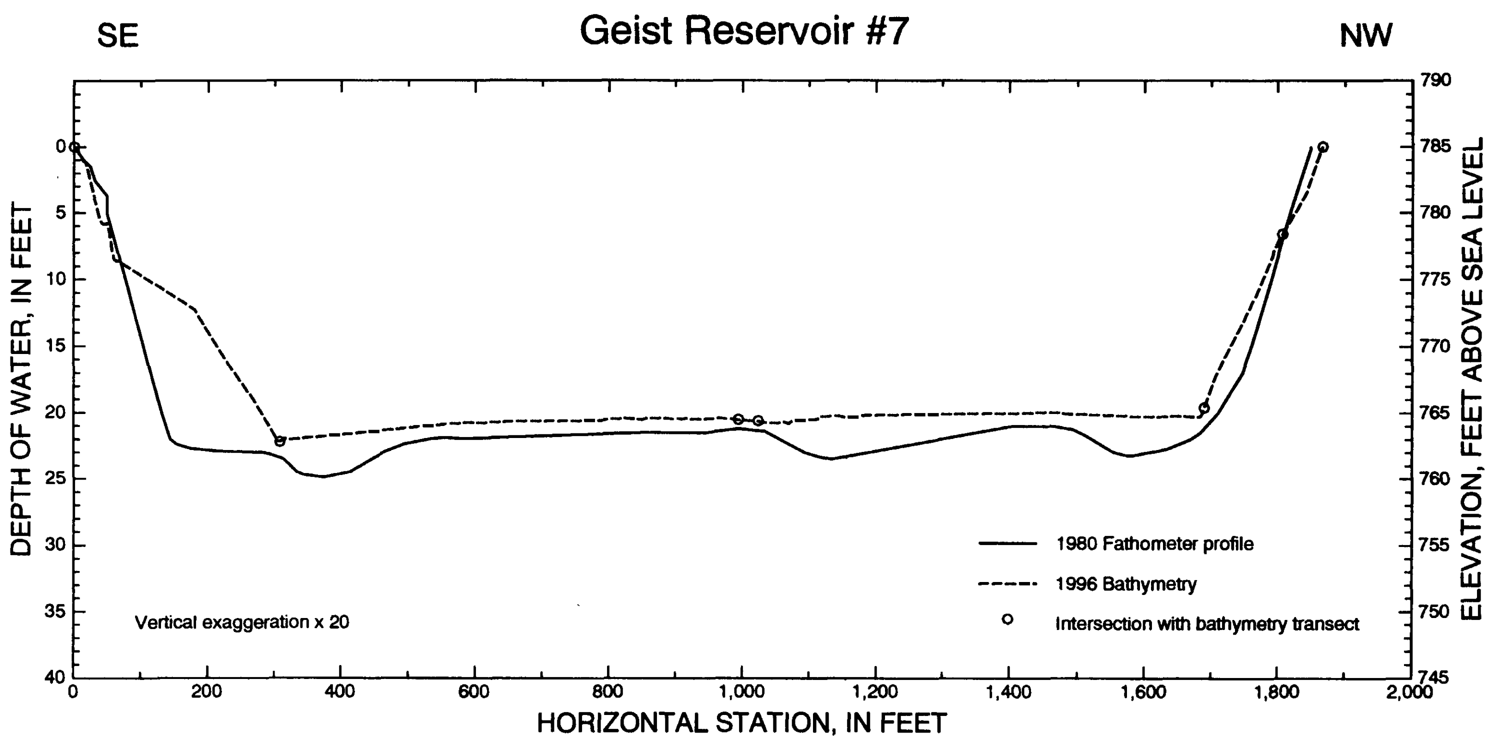

Figure 21. Cross section #7 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

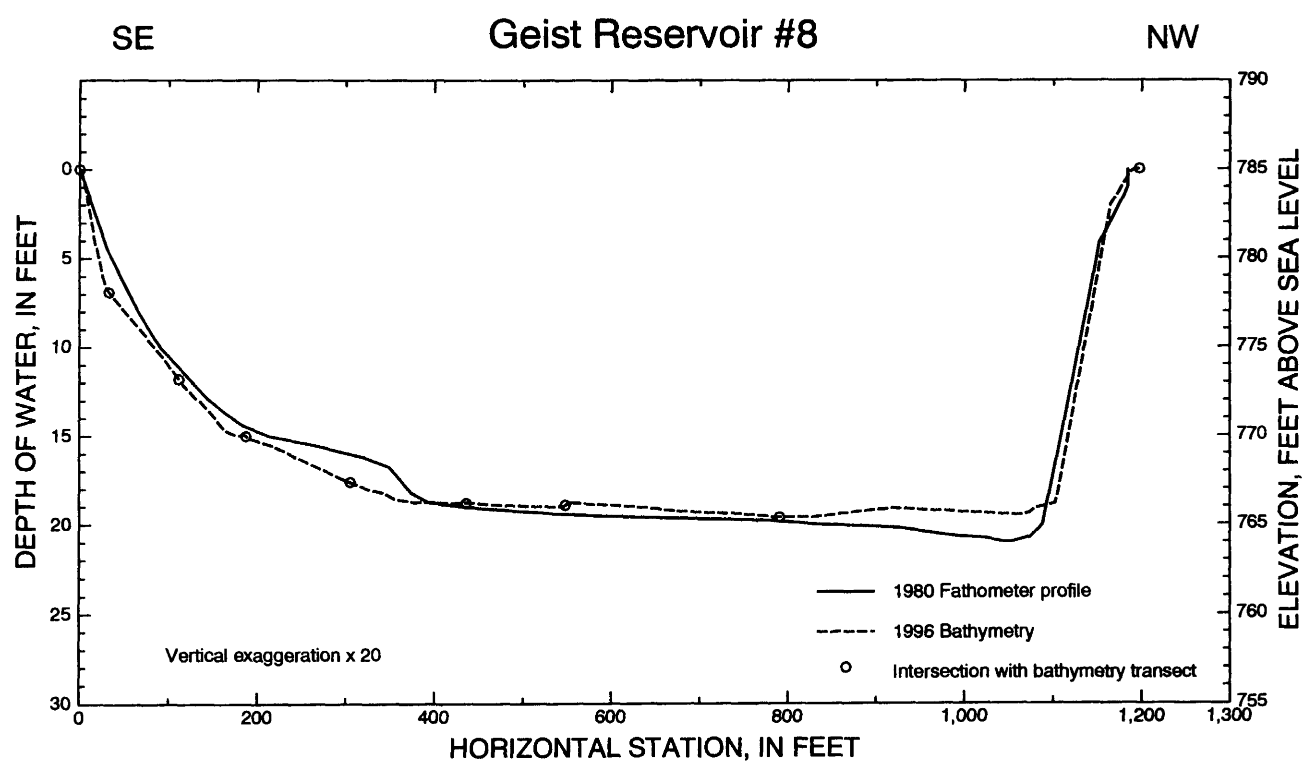

Figure 22. Cross section #8 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

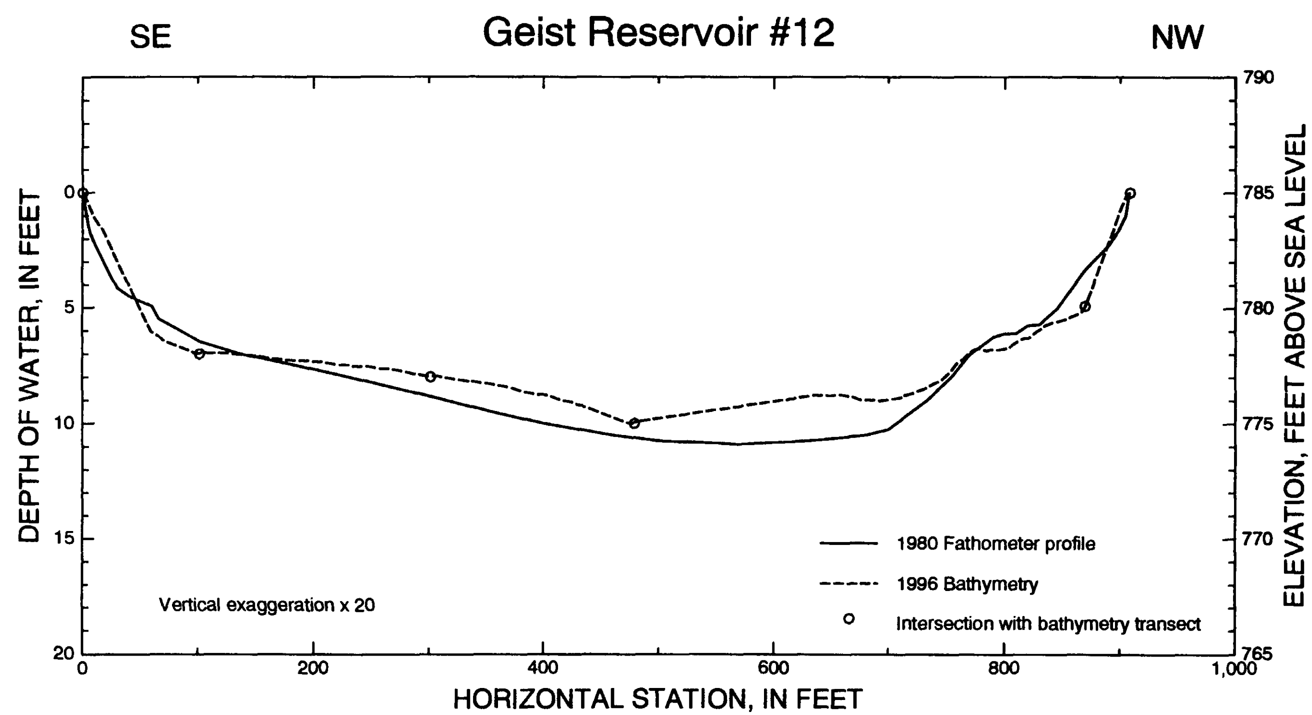

Figure 23. Cross section #12 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

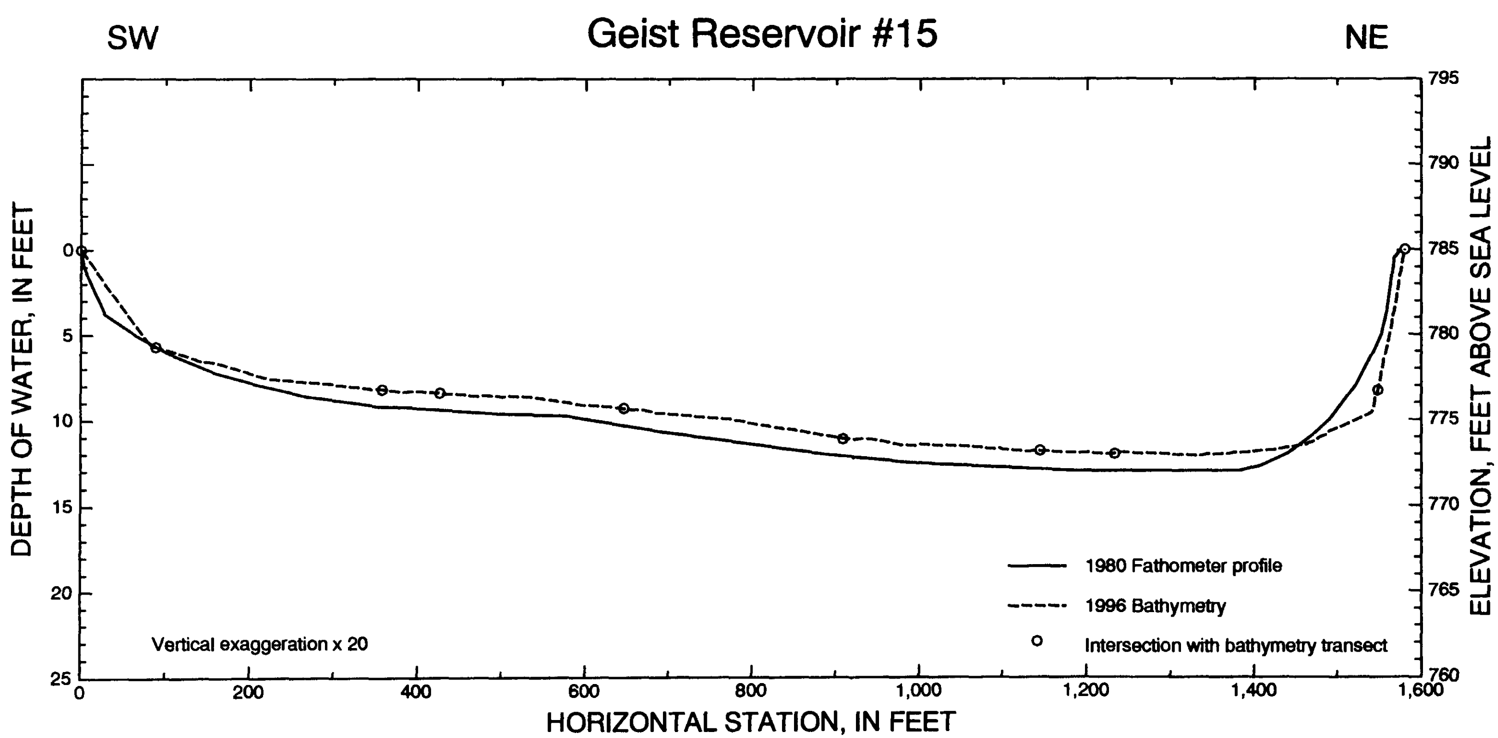

Figure 24. Cross section #15 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

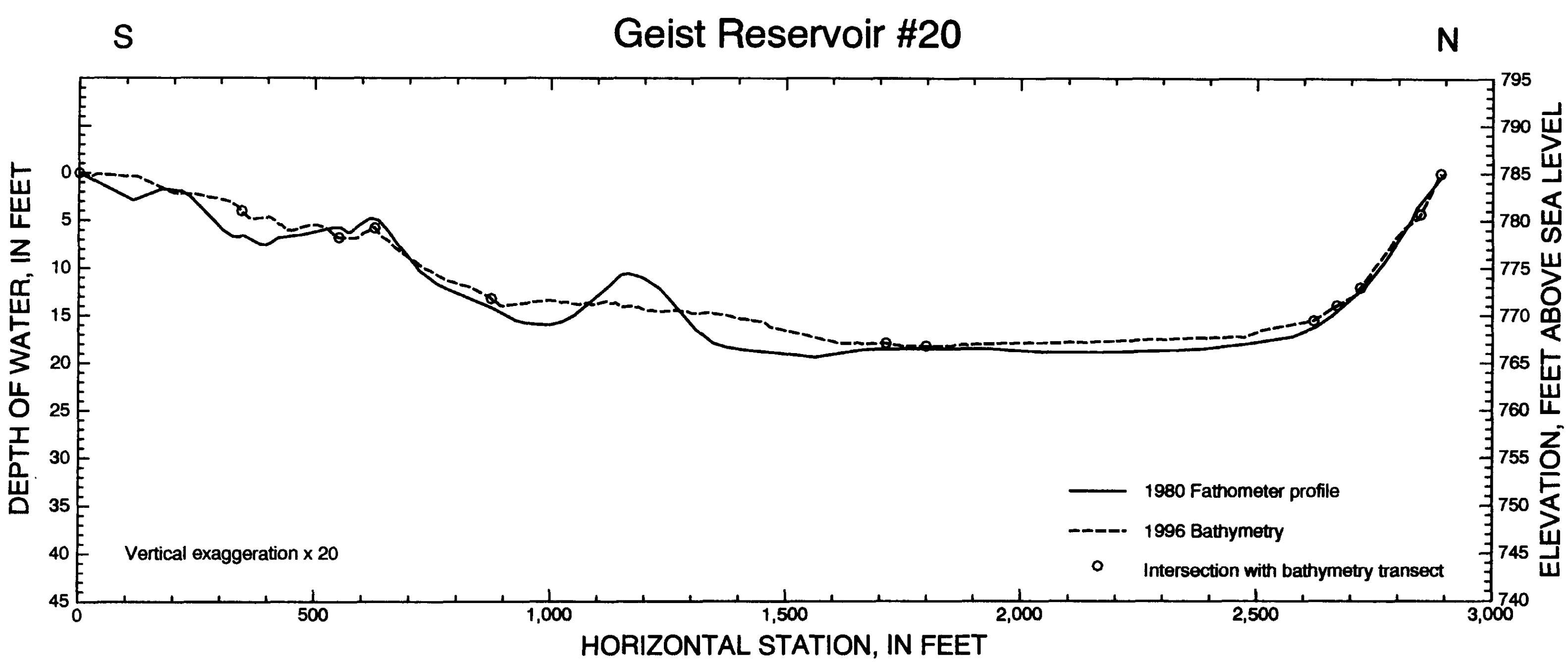

Figure 25. Cross section #20 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

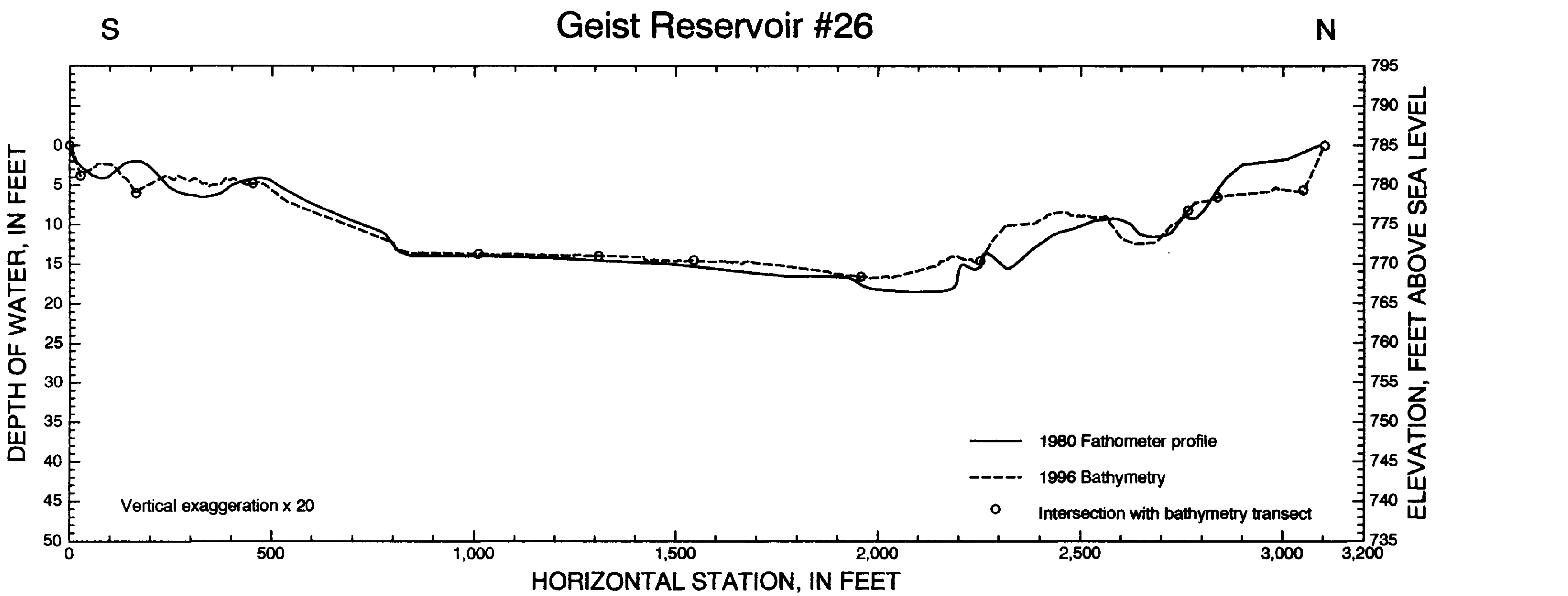

Figure 26. Cross section #26 of Morse Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

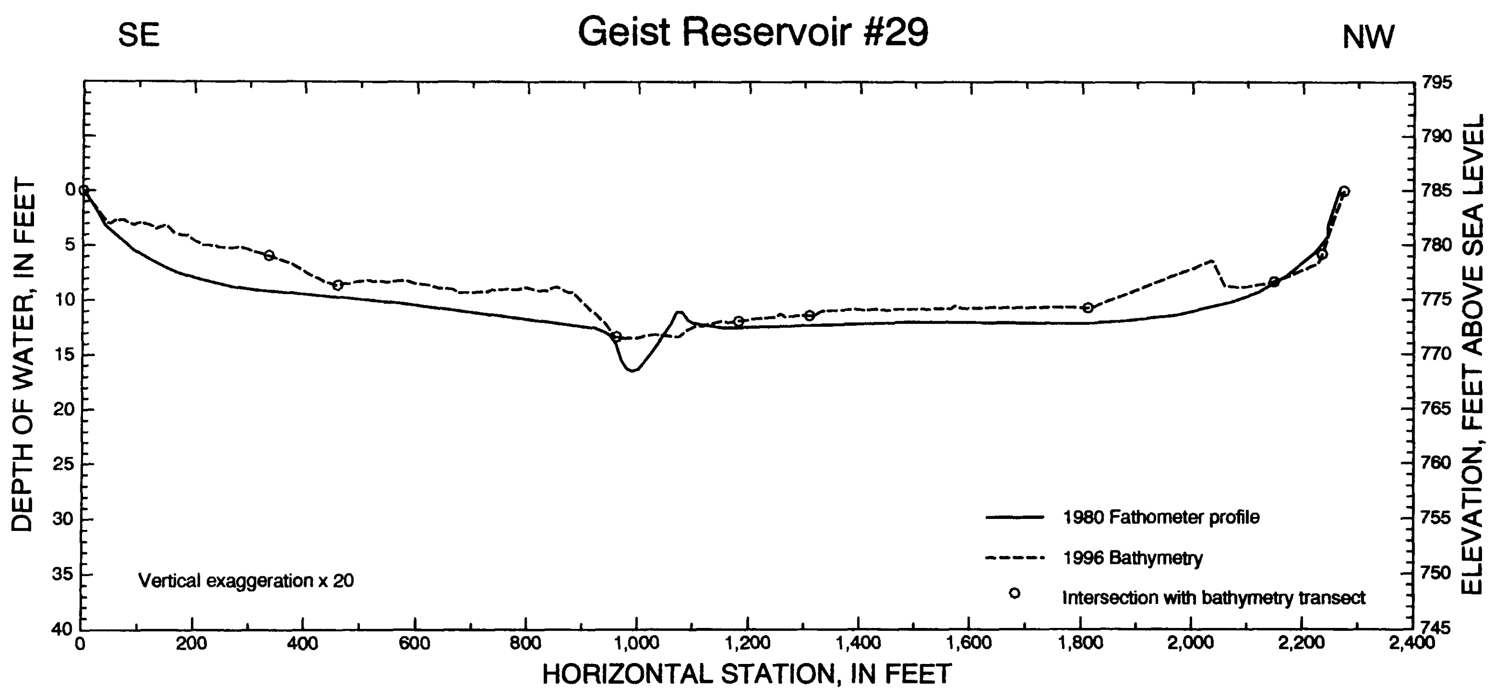

Figure 27. Cross section #29 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

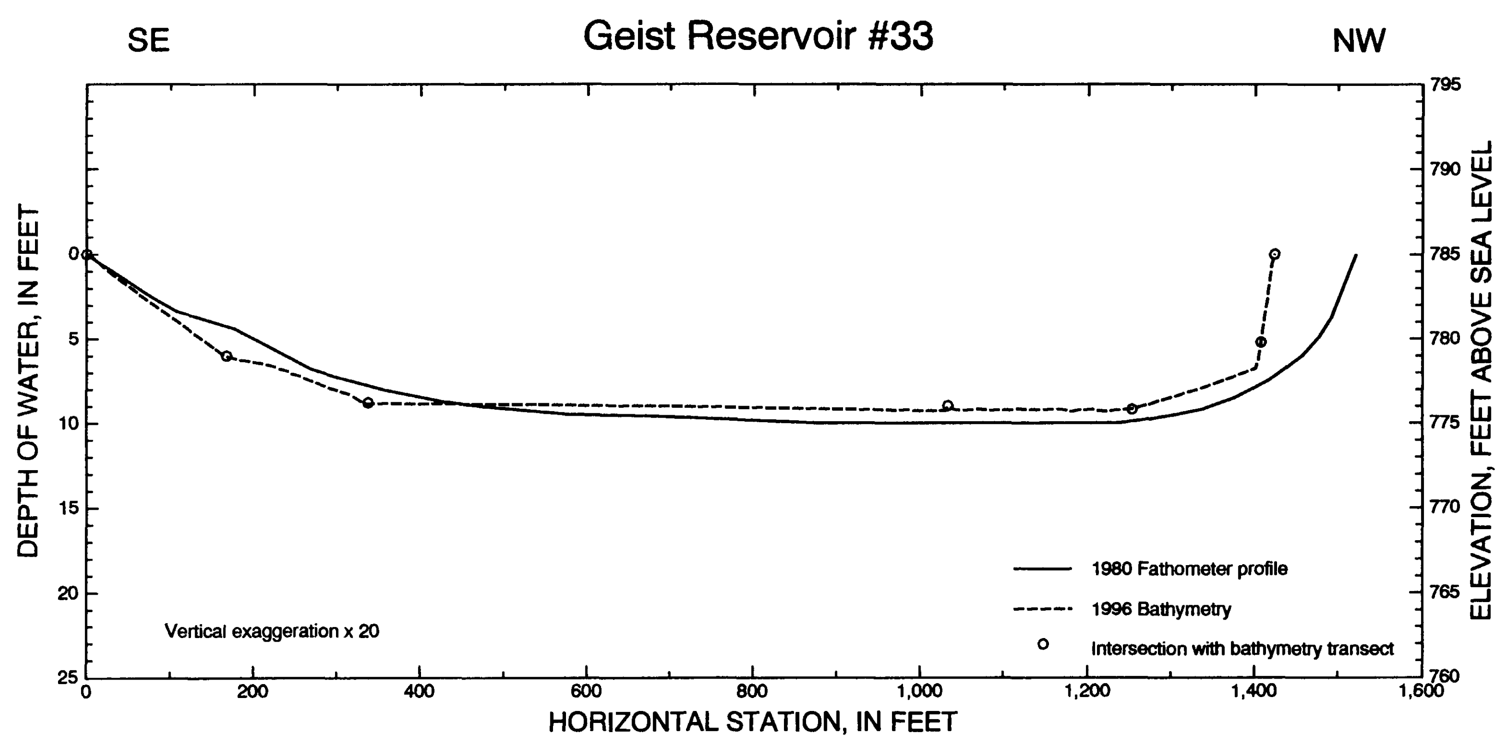

Figure 28. Cross section #33 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

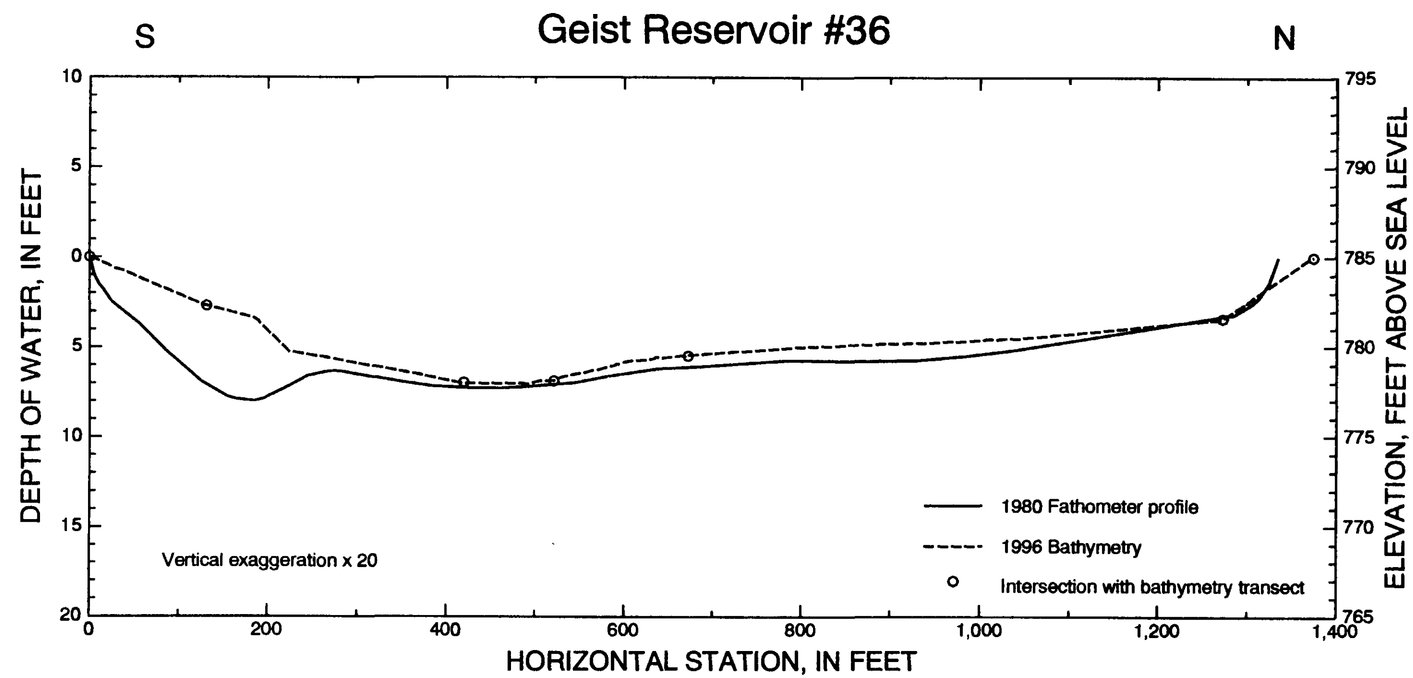

Figure 29. Cross section #36 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

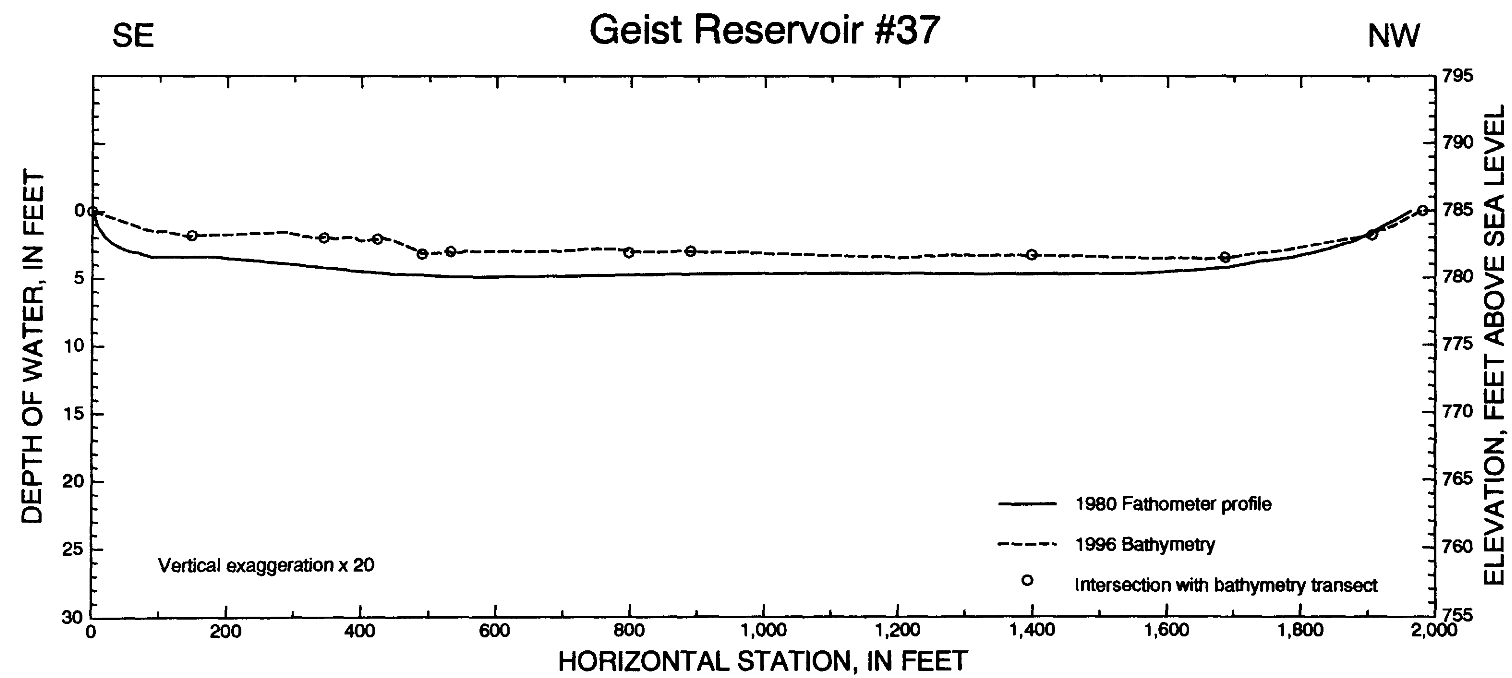

Figure 30. Cross section #37 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.

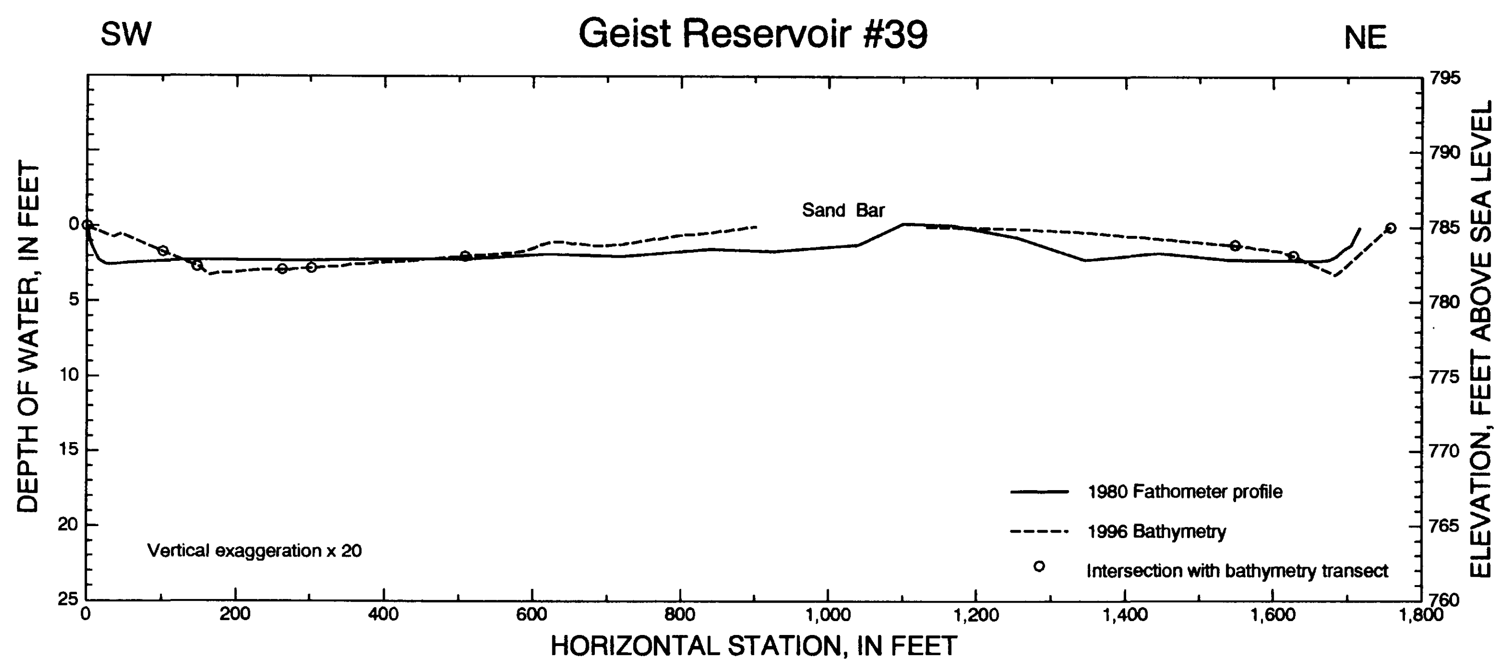

Figure 31. Cross section #39 of Geist Reservoir, central Indiana, from a 1980 fathometer profile (Indianapolis Water Company sedimentation project) and a cross section from the bathymetric surface computed from the 1996 survey.