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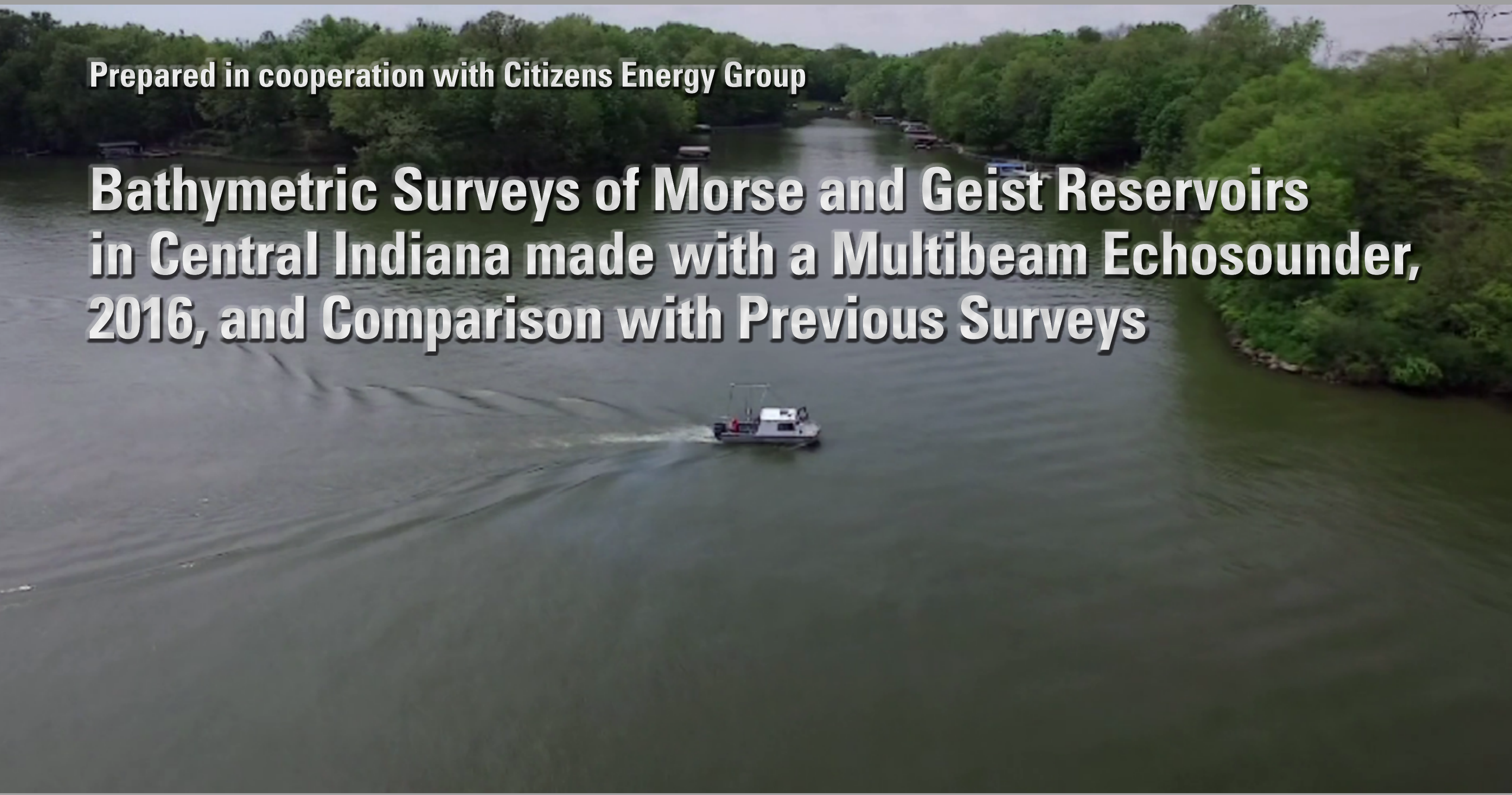

Prepared in cooperation with Citizens Energy Group

Bathymetric Surveys of Morse and Geist Reservoirs in Central Indiana made with a Multibeam Echosounder, 2016, and Comparison with Previous Surveys

Scientific Investigations Report 2020–5067

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

Front cover, top. Survey on Morse Reservoir, May 2016 (photograph by Mike Berry).
Front cover, bottom. Multibeam echosounder setup on the side of the survey boat, April 7, 2016 (photograph by Zachary Martin).
Back cover. Water flowing over the Geist Reservoir spillway, April 28, 2016 (photograph by Justin Boldt).

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By Justin A. Boldt and Zachary W. Martin

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U.S. Department of the Interior
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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2020

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
billion gallons (Bgal)	3,785,000	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Velocity	
foot per second (ft/s)	0.3048	meter per second (m/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) and [or] the National Geodetic Vertical Datum of 1929 (NGVD 29). All the new data collected in this study is referenced to NAVD 88, but most existing data and the data from previous surveys is referenced to NGVD 29. Datum shifts were calculated using the National Geodetic Survey VERTCON 2.0 model.

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

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

ADCP	acoustic Doppler current profiler
DEM	digital elevation model
GIS	geographic information system
GNSS	Global Navigation Satellite System
INS	inertial navigation system
kHz	kilohertz
MBES	multibeam echosounder
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
RTK	real-time kinematic (a type of differential correction for navigation with GNSS)
SBET	smoothed best estimate of trajectory (a postprocessed navigation solution)
TIN	triangulated irregular network
USGS	U.S. Geological Survey

Bathymetric Surveys of Morse and Geist Reservoirs in Central Indiana made with a Multibeam Echosounder, 2016, and Comparison with Previous Surveys

By Justin A. Boldt and Zachary W. Martin

Abstract

The U.S. Geological Survey, in cooperation with Citizens Energy Group, conducted a bathymetric survey of Morse and Geist Reservoirs in central Indiana in April and May of 2016 with a multibeam echosounder. Both reservoirs serve as water supply, flood control, and recreational resources for the city of Indianapolis and the surrounding communities.

Morse and Geist Reservoirs were surveyed to create updated bathymetric maps, determine storage capacities (volume) at specified water-surface elevations, and compare current conditions to historical surveys. Bathymetric data were collected using a high-resolution multibeam echosounder, and supplemental data were collected in coves and other shallow areas using an acoustic Doppler current profiler. The data were processed and combined using HYPACK and ArcMap software to develop a triangulated irregular network, a 5-foot gridded bathymetric dataset, a reservoir capacity table, and a bathymetric contour map for each reservoir.

The computed volume of Morse Reservoir was 23,136 acre-feet (7.54 billion gallons) with a surface area of 1,439 acres (62.7 million square feet). The computed volume of Geist Reservoir was 21,146 acre-feet (6.89 billion gallons) with a surface area of 1,853 acres (80.7 million square feet).

Between 1996 and 2016, lake bottom elevations have increased by a mean of 0.32 feet in Morse Reservoir and 0.27 feet in Geist Reservoir. The data indicate higher sedimentation rates in the upper parts of each reservoir as compared to near the dam and higher sedimentation rates in Morse Reservoir (0.5 inch per year) than in Geist Reservoir (0.2 inch per year). The differences between the current and historical surveys may be due to sedimentation, differences in accuracy between previous surveys, or a combination of both.

Introduction

Morse Reservoir near Noblesville, Indiana, and Geist Reservoir near Fishers, Ind., are both located in central Indiana north of Indianapolis (fig. 1) and serve as water supply, flood control, and recreational resources to the city of Indianapolis and the surrounding communities. The last full reservoir survey on both reservoirs was done in 1996 by the U.S. Geological Survey (USGS; Wilson and others, 1997). Important issues relating to the reservoirs throughout the years have been the effect of low water levels during droughts and navigation or access problems due to sedimentation. Sedimentation decreases the storage capacity (volume) of the reservoir which affects water availability and creates hazardous conditions for boats in shallow areas. Property owners have also modified the shoreline in both reservoirs throughout the years. Additionally, since the 1996 survey, a large area of Geist Reservoir was mined for gravel and new coves have been added to Geist Reservoir, both of which would increase the storage capacity. There have also been several areas in each reservoir that have been dredged.

Recent advancements in sonar technology and survey methods are superior to conventional methods used in previous studies. The USGS, in cooperation with Citizens Energy Group, conducted a bathymetric survey of Morse and Geist Reservoirs in April and May of 2016 to produce updated bathymetric maps and storage capacities and to compare current conditions to historical surveys.

The results of the bathymetric survey of Morse and Geist Reservoirs can be used to document temporal change in reservoir bottom elevation and storage capacity. This study contributes to the strategic science directions established by the USGS in 2007 (U.S. Geological Survey, 2007)

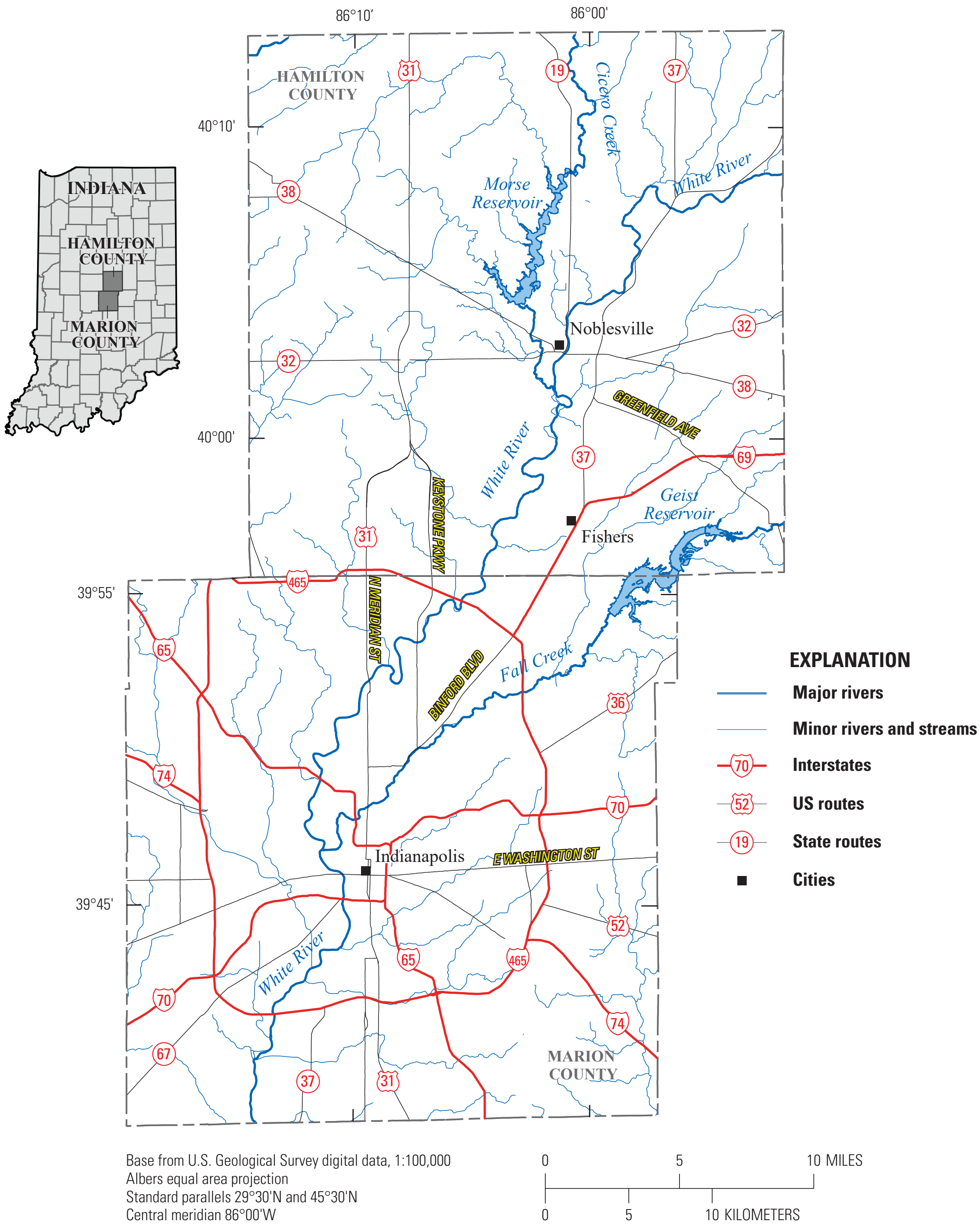


Figure 1. The location of Morse Reservoir near Noblesville, Indiana, in Hamilton County and Geist Reservoir near Fishers, Indiana, in Hamilton County and Marion County.

by providing data that are essential to a water census and informing about the status of freshwater resources and how they are changing. Additionally, the storage capacities calculated in this study will be reported real-time on the internet along with water-level information via a new USGS streamgage at each reservoir.

The purpose of this report is to present the results of the 2016 bathymetric surveys of Morse and Geist Reservoirs. This report also presents a comparison between the 2016 bathymetric surveys with previous surveys.

Description of the Study Area

Morse Reservoir is located in Hamilton County, Ind., near the city of Noblesville (fig. 1). The reservoir was created by the impoundment of Cicero Creek with an earthfill dam and was completed in 1956. It had a design storage capacity of 25,380 acre-feet (acre-ft; 8.27 billion gallons [Bgal]) at normal pool elevation, a surface area of approximately 1,500 acres, and approximately 32.5 miles (mi) of shoreline (Wilson and others, 1997). Cicero Creek flows through the reservoir, but other inlets include Little Cicero Creek, Bear Slide Creek, and Hinkle Creek (shown but not all labeled in fig. 2). Cicero Creek flows from the reservoir at the southern end and empties into the White River about 4.9 mi downstream. The drainage area encompasses 214 square miles (U.S. Geological Survey, 2019a; fig. 2), and the mean annual discharge into the reservoir based on data from 2006 through 2016 at USGS streamgage 03349510 Cicero Creek at Arcadia, IN, is 164 cubic feet per second (U.S. Geological Survey, 2019b). Historically, 810 feet (ft; National Geodetic Vertical Datum of 1929 [NGVD 29]) has been considered the full pool elevation. Current water levels may be obtained on the internet from two different sources. The first existing source is the National Weather Service Advanced Hydrologic Prediction Service at https://water.weather.gov/ahps2/hydrograph.php?wfo=ind&gage=nmsi3. Current observations from the past 10 days are plotted, and there are data from historic crests, recent crests, and low water records. The record high water level was 813.44 ft (NGVD 29) on April 19, 2013, and the record low water level was 800.26 ft (NGVD 29) on November 19, 1999 (National Weather Service, 2020a). Numerous top 10 crests occurred in 2013, 2015, 2017, and 2018 (National Weather Service, 2020a). The second source of current water levels is from the USGS National Water Information System at https://waterdata.usgs.gov/usa/nwis/uv?03350400 (U.S. Geological Survey, 2020a) for gage 03350400. This is a new USGS gage that was installed in December 2019 (fig. 3*A*) and reports real-time reservoir elevation (North American Vertical Datum of 1988 [NAVD 88]) and reservoir storage capacity values based on the results of this study.

Geist Reservoir is located in Marion and Hamilton Counties, Ind., near the city of Fishers. The reservoir was created by the impoundment of Fall Creek with an earthfill dam and was completed in 1943. It had a design storage capacity of 21,180 acre-ft (6.90 Bgal) at normal pool elevation, a surface area of approximately 1,900 acres, and approximately 35 mi of shoreline (Wilson and others, 1997). Fall Creek flows through the reservoir, but other inlets include Thorpe Creek, Flatfork Creek, Thor Run, Mount Zion Branch, Bee Camp Creek, Bills Branch, North Fork Dry Branch, and Dry Branch (shown but not all labeled in fig. 2). Fall Creek flows from the reservoir at the southwestern end and empties into the White River about 17.7 mi downstream. The drainage area encompasses 219 square miles (U.S. Geological Survey, 2019a; fig. 2), and the mean annual discharge into the reservoir based on data from 2006 through 2016 at USGS streamgage 03351500 Fall Creek near Fortville, IN, is 241 cubic feet per second (U.S. Geological Survey, 2019c). Historically, 785 ft (NGVD 29) has been considered the normal (or full to top) pool elevation. Current water levels may be obtained on the internet from two different sources. The first existing source is the National Weather Service Advanced Hydrologic Prediction Service at https://water.weather.gov/ahps2/hydrograph.php?wfo=ind&gage=olni3. Current observations from the past 10 days are plotted, and there are data from historic crests, recent crests, and low water records. The record high water level was 788.02 ft (NGVD 29) on May 18, 1943, and the record low water level was 778.36 ft (NGVD 29) on November 3, 1988 (National Weather Service, 2020b). Numerous top ten crests occurred in 2013, 2015, 2017, and 2018 (National Weather Service, 2020b). The second source of current water levels is from the USGS National Water Information System at https://waterdata.usgs.gov/usa/nwis/uv?03351700 (U.S. Geological Survey, 2020b) for gage 03351700. This is a new USGS gage that was installed in February 2020 (fig. 3*B*) and reports real-time reservoir elevation (NAVD 88) and reservoir storage capacity values based on the results of this study.

The area of study has a humid subtropical climate. Mean annual precipitation, based on data for the 1981–2010 period at the National Weather Service Forecast Office in Indianapolis, Ind., is 42.4 inches (National Weather Service, 2020c). The area of study is in the Central Till Plain physiographic region in Indiana (Gray, 2000), which is mostly flat and has rich soils as a result of past retreating glaciers.

Most of the land use, as defined by the National Land Cover Database 2016 (Multi-Resolution Land Characteristics Consortium, 2020), contiguous to the study areas (the reservoirs) can be classified as developed (residential). The land use in the drainage basins upstream from both reservoirs is primarily cultivated crops and hay/pasture (agricultural; figs. 4–5). Table 1 shows the land use classification for the Morse Reservoir and Geist Reservoir basins in 2001 and 2016 (Multi-Resolution Land Characteristics Consortium, 2020) and the changes during that time period. The Morse Reservoir basin developed land use class increased by 0.3 percent in those 15 years. In the Geist Reservoir basin, the developed land use class increased by 3.0 percent during the same time period. As of 2016, the Geist Reservoir basin is about twice as developed as the Morse Reservoir basin

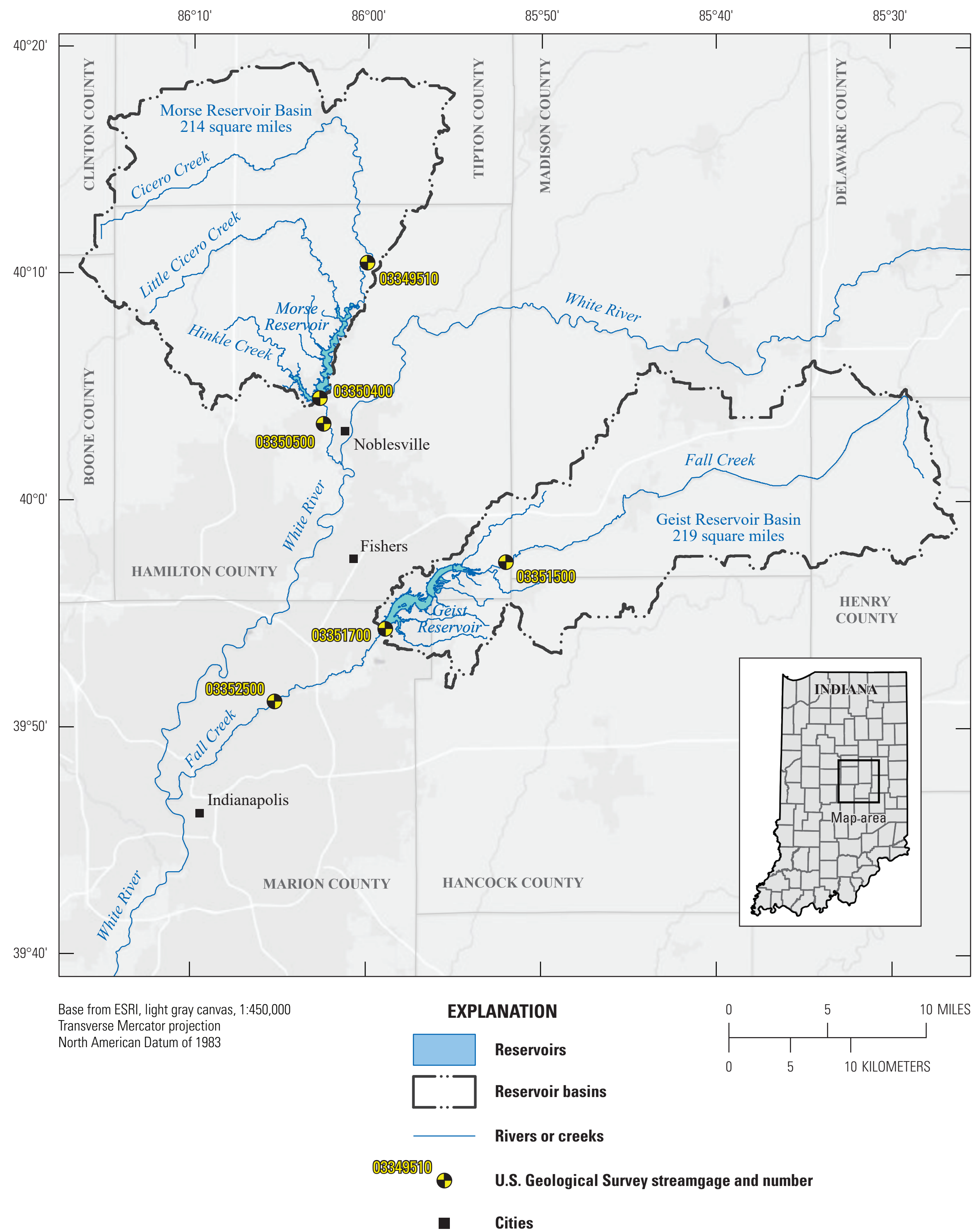


Figure 2. Drainage basins of Morse Reservoir and Geist Reservoir and location of U.S. Geological Survey streamgages.

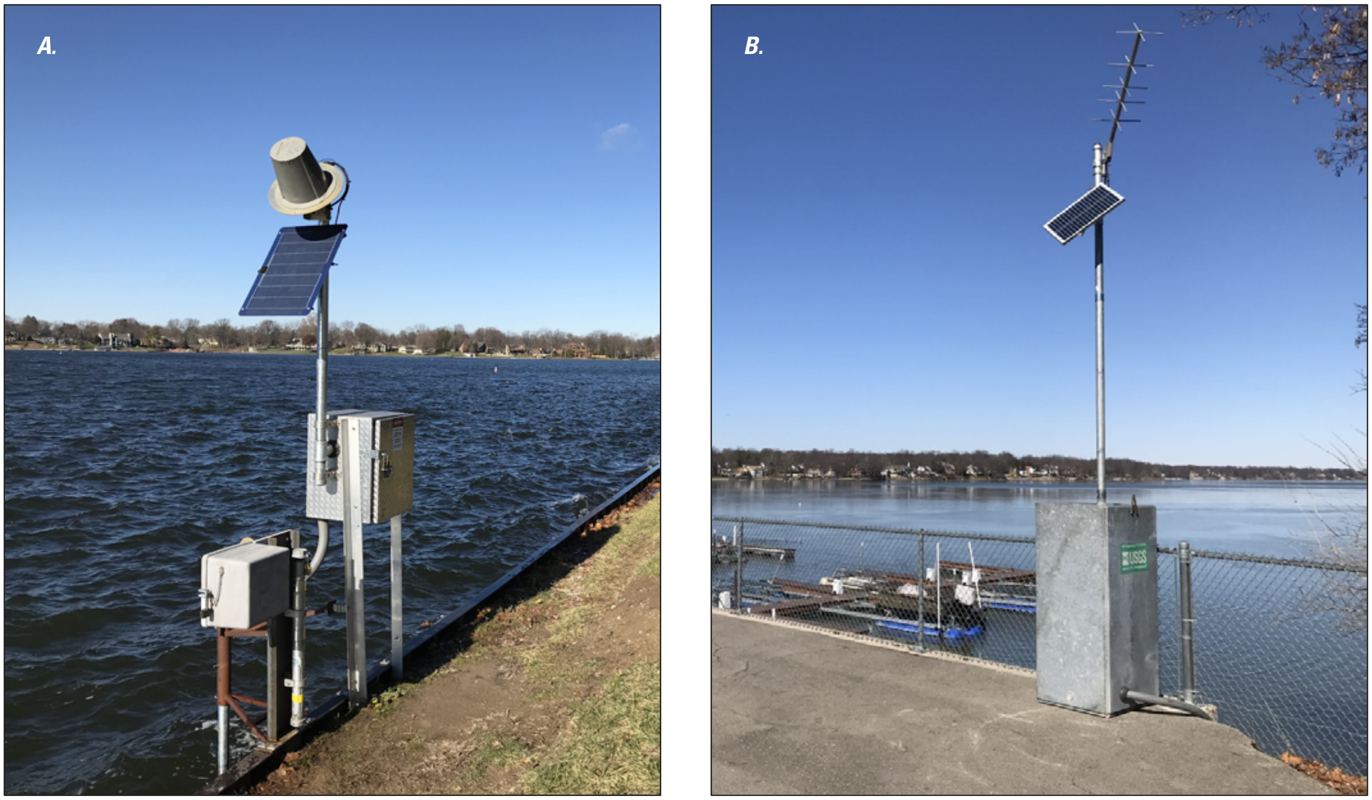


Figure 3. *A,* U.S. Geological Survey (USGS) gage number 03350400 Morse Reservoir at Noblesville, Indiana (photo credit: Benjamin Sperl [USGS], December 4, 2019) and, *B*, USGS gage number 03351700 Geist Reservoir at Indianapolis, Indiana (photo credit: Benjamin Sperl [USGS], February 21, 2020).

(18.3 percent versus 8.7 percent, respectively). On the contrary, the Morse Reservoir basin is 14.9 percent more agricultural than the Geist Reservoir basin (84.6 percent versus 69.7 percent, respectively).

Previous Surveys

Bathymetric surveys were last conducted on Morse and Geist Reservoirs in 1996 (hereafter referred to as the 1996 survey) and were documented in a report by Wilson and others (1997). Those surveys were made with an acoustic Doppler current profiler (ADCP). ADCPs are commonly used for measuring streamflow (Mueller and others, 2013), but they have also been used to measure bathymetry (Ruby, 2012; Wernly and others, 2016). The ADCP used in the 1996 survey operated at a frequency of 600 kilohertz (kHz) and had a transducer beam angle of 20 degrees. Prior to the 1996 survey, a survey using networks of fathometer transects was conducted on Morse Reservoir in 1978 and on Geist Reservoir in 1980. At the basic level, both pieces of equipment (fathometer and ADCP) are sounding devices that measure the water depth. A fathometer uses a single beam to measure the depth, whereas the ADCP used in the 1996 survey utilized four beams to measure the depths (although the data were averaged into a single depth during postprocessing). A major technological advancement in the 1996 survey was the use of Global Positioning System technology to track the boat position during the survey. This allowed for more accurate position data, faster data collection, and the ability to cover more of the reservoirs. The use of a geographic information system (GIS) in postprocessing the data in the 1996 survey also increased the efficiency of bathymetry work. A paragraph from the 1996 survey report is worth restating here:

> "The bathymetric surveys described in this report [Wilson and others, 1997, pg. 2] will serve as baseline 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 [Global Positioning System], 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 [fathometer] bathymetry methods."

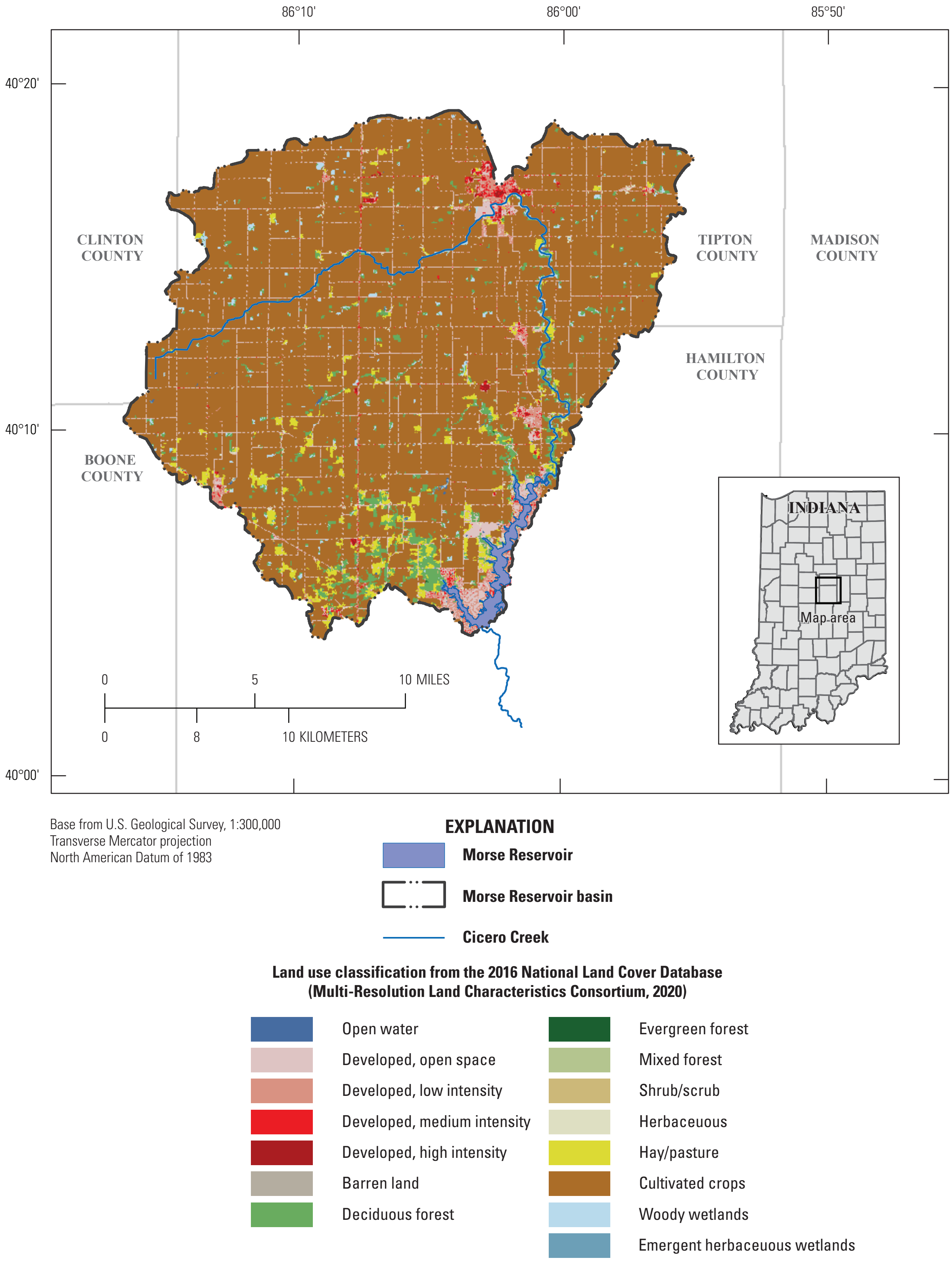


Figure 4. Land use classification in the Morse Reservoir basin.

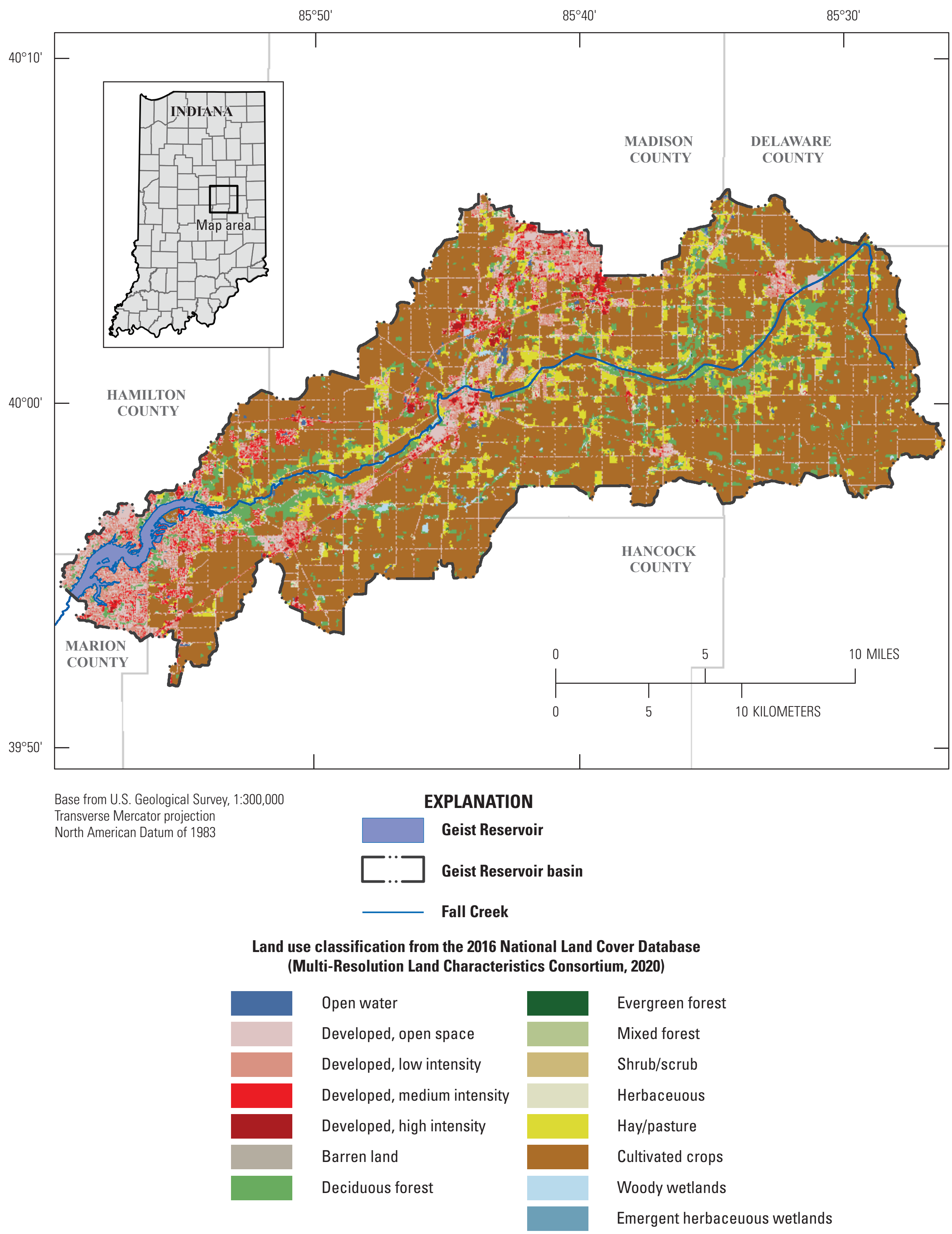


Figure 5. Land use classification in the Geist Reservoir basin.

Table 1. Land use classification in the Morse Reservoir and Geist Reservoir basins in 2001 and 2016.

[NLCD, National Land Cover Database (Multi-Resolution Land Characteristics Consortium, 2020); %, percent; —, no change (or < 0.1%)]

NLCD land cover class	NLCD 2001 percent of basin		NLCD 2016 percent of basin		Percent change from 2001 to 2016	
	Morse	Geist	Morse	Geist	Morse	Geist
Open water	1.1%	1.6%	1.1%	1.6%	—	—
Developed, open space	5.1%	7.4%	5.1%	8.3%	—	0.8%
Developed, low intensity	2.5%	5.9%	2.6%	6.9%	0.1%	1.0%
Developed, medium intensity	0.6%	1.5%	0.7%	2.5%	0.1%	0.9%
Developed, high intensity	0.2%	0.4%	0.2%	0.7%	0.1%	0.2%
Developed (all types)	8.4%	15.3%	8.7%	18.3%	0.3%	3.0%
Barren land	< 0.1%	< 0.1%	< 0.1%	< 0.1%	—	—
Deciduous forest	3.7%	8.1%	3.7%	7.9%	—	-0.2%
Evergreen forest	< 0.1%	< 0.1%	< 0.1%	< 0.1%	—	—
Mixed forest	< 0.1%	0.2%	< 0.1%	0.2%	—	—
Forest (all types)	3.7%	8.3%	3.7%	8.1%	—	-0.2%
Shrub/scrub	< 0.1%	< 0.1%	< 0.1%	< 0.1%	—	—
Herbaceuous	0.7%	1.2%	0.7%	1.1%	—	-0.1%
Hay/pasture	3.2%	8.2%	2.9%	7.5%	-0.2%	-0.6%
Cultivated crops	81.7%	64.3%	81.7%	62.2%	—	-2.0%
Woody wetlands	1.0%	0.8%	1.1%	0.8%	—	—
Emergent herbaceuous wetlands	0.1%	0.2%	0.1%	0.2%	—	—

The same statement could be said about the current study; however, the primary piece of equipment is now a multibeam echosounder (MBES) which collects data from as many as 512 beams in a swath array which covers a width of about 3–4 times the depth. Thus, the data collected can now cover nearly the entire area rather than a series of discrete transects. ADCPs and single-beam echosounders are still used to supplement multibeam surveys, particularly in shallow areas. In general, the MBES used in this survey can collect more data (individual depth measurements) in a few minutes (although it would all be in a limited area) than the data of the entire 1996 survey. The time spent navigating throughout the survey area is comparable for both survey methods, but the MBES can collect orders of magnitude more data. Most importantly, the coverage has transitioned from partial to nearly full coverage. As a result, map resolution and computed storage capacity are vastly improved compared to previous surveys, but there are challenges in comparing to past survey data and interpreting the results.

Methods and Data Collection

The bathymetry of Morse and Geist Reservoirs was surveyed using a high-resolution MBES mounted on a manned boat (fig. 6*A*). The MBES used in this study was a 400-kHz NORBIT iWBMSc Wideband Multibeam Sonar (fig. 6B). The MBES collects a wide swath of high-resolution bathymetric data by recording the intensity of sound reflected off the lake bottom (acoustic backscatter). The MBES was operated at a frequency of 400 kHz with an 80 kHz bandwidth, and data were typically collected at a 160-degree swath with various amounts of overlap between swaths. During the nearest shoreline passes, the MBES swath was electronically tilted toward the shoreline to better capture data points up the banks. The water-surface elevation at the time of data collection ranged from approximately 810.25–810.37 ft (NGVD 29) for Morse Reservoir and from approximately 785.23–785.38 ft (NGVD 29) for Geist Reservoir (Andrew White, National Weather Service, written comm., February 2020). Additional data were collected in shallow areas using an ADCP mounted in a trimaran and tethered to a small manned boat. For additional information about bathymetric surveys of rivers and lakes using a MBES mapping system, see Huizinga and Heimann (2018). Similar studies involving MBES and reservoir maps and storage capacity calculations include Lee and Kimbrow (2011), Kohn (2012), Lee (2013), Huizinga (2014), Kohn and others (2017), Nystrom (2018), Richards and Huizinga (2018), and Marineau and others (2020).

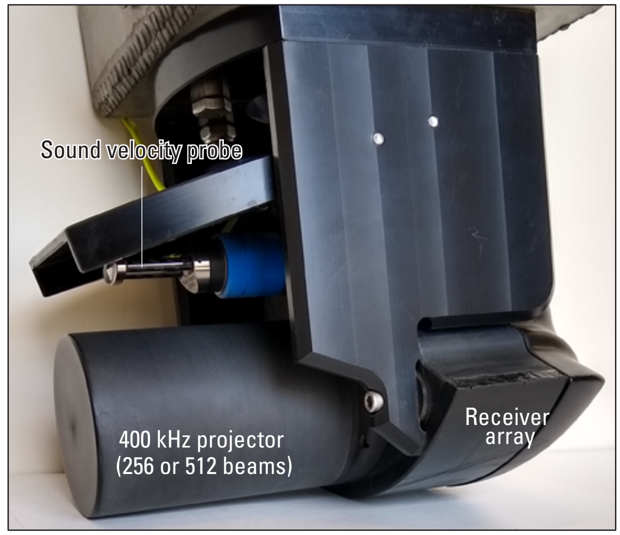


Figure 6. *A,* the multibeam echosounder setup on the side of the survey boat (photo credit: Zachary Martin [U.S. Geological Survey], April 7, 2016) and *B,* the NORBIT iWBMSc multibeam echosounder (photo credit: Justin Boldt [U.S. Geological Survey], April 8, 2020).

Multibeam Echosounder Methods

The bathymetric data collected by the MBES are accurately represented in three-dimensional space by use of a navigation and motion-sensing system. Positioning for the MBES is produced by a Global Navigation Satellite System (GNSS) coupled with an inertial measurement unit, collectively referred to as the inertial navigation system (INS). The INS can measure the pitch, roll, and heading of the boat, accurate within 0.02 degree (pitch/roll) and 0.03 degree (heading). A cellular network link with a Virtual Reference Station network, InCORS (Indiana Continuously Operating Reference Stations), established and maintained by the Indiana Department of Transportation (2020), was used to provide the real-time kinematic (RTK) differential corrections to the positioning software during the survey. The INS data from the survey was postprocessed using Inertial Explorer software (NovAtel Inc., 2014) to generate a blended navigation solution (standard best-estimate of travel [SBET] file). The postprocessed navigation data (SBET file) was applied to the MBES data. The MBES data were collected and processed using HYPACK/HYSWEEP data acquisition software (HYPACK, Inc., 2019). In addition to the SBET file, the Inertial Explorer software generates a file describing the accuracy of the postprocessed solution. The horizontal accuracy of the postprocessed file has a root mean square error of 0.03 to 0.06 ft (1 to 2 centimeters). The root mean square error of the vertical accuracy ranged from 0.03 to 0.06 ft (1 to 2 centimeters). Stated accuracies are based on peak-to-peak errors, and most of the points have higher accuracies and lower associated errors.

The errors associated with the collection of bathymetric data can be classified as systematic or random. Systematic errors are those that can be measured or modeled through calibration (Byrnes and others, 2002). Random errors are a result of the measuring device's limitations and an inability to perfectly model the systematic errors. Errors associated with the SBET file would be applicable to the positional accuracy of the bathymetric data. The bathymetric point accuracy is represented by an error ellipsoid of which one of the vertical components is the depth measurement error. Because the reservoir bottom is not visible, random errors associated with the limitations of the MBES are more difficult to quantify. To minimize these errors, additional field data and quality assurance assessments, including patch tests, sound velocity casts, and a performance test, were collected or performed before, during, or after the survey and used in postprocessing to accurately adjust the MBES. Sound velocity casts were collected throughout the survey area to account for vertical variations of the speed of sound in the water column, and patch tests were performed to check for variations in the orientation of the sonar head (Norbit, 2015). The angular offsets of the transducer head were measured for their respective axis—longitudinal axis (roll test), lateral axis (pitch test), and rotation about vertical axis (yaw test). All angular offsets (roll, pitch, and yaw) were accounted for in the HYPACK/HYSWEEP software.

Bathymetric and GNSS Surveys of Morse and Geist Reservoirs

The MBES system was used to collect data on April 5–7, April 25–28, and May 9–10, 2016, for Geist Reservoir and May 11–12 and May 16–18, 2016, for Morse Reservoir. HYPACK/HYSWEEP software was used for real-time display of navigation and data collection. In general, the data were collected in longitudinal transects with overlapping coverage from one swath to the next. Additional data were collected on Morse Reservoir in the coves and other shallow areas using a

600 kHz ADCP on June 14, 2016, June 17, 2016, and November 3, 2017. Additional data were collected on Geist Reservoir in the coves and other shallow areas using a 600-kHz ADCP on June 21, 2016, and September 26, 2018; using a 200-kHz single-beam echosounder on December 21, 2017, and May 23, 2018 (courtesy of DLZ); and using a 1200-kHz ADCP on May 30, 2019. The ADCP and single-beam echosounder were each coupled with an RTK–GNSS. Elevations were derived by subtracting the depths from the water surface elevation at the time of the survey. The data were processed and combined using HYPACK/HYSWEEP (HYPACK, Inc., 2019) and ArcMap (Environmental Systems Research Institute, 2019) software. The processing included the use of filters and manual editing to remove data spikes and erroneous points. A triangular irregular network (TIN) was created and the final bathymetric dataset was exported on a 5-ft regular grid. The cell center was used as the horizontal position (X- and Y-coordinates), and the elevation (Z-coordinate) was the mean of all the individual soundings within each 5-ft cell. The final bathymetric datasets produced from this study are available for download through a data release at https://doi.org/10.5066/P9A2ITC6 (Boldt and Martin, 2020).

The elevation of the crest of the spillway at each reservoir was measured with a Trimble R8 RTK–GNSS system (table 2). The elevations reported by this system, like the other bathymetric data collected in this study, are referenced to NAVD 88. However, historical data, like the normal pool levels for each reservoir, are referenced to the NGVD 29. VERTCON (National Geodetic Survey, 2019) can be used to convert between the two datums to an accuracy of about 0.06 ft (Mulcare, 2004). Applying the VERTCON 2.0 model for each reservoir at a location near the dam, the vertical datum shift was −0.417 ft for Morse Reservoir and −0.440 ft for Geist Reservoir (for example, NGVD 29 elevation in feet minus 0.440 ft equals NAVD 88 elevation in feet). For documentation of the VERTCON 2.0 model, see Milbert (1999). As shown in table 2, what has historically been considered the full pool is not quite the actual elevation of the spillway crest but rather has been rounded for convenience. All elevations from the current survey are referenced to the current datum (NAVD 88), so caution should always be used when comparing to other data sources. The record high water levels for both reservoirs are approximately 3.5 ft above the spillway crest.

Bathymetric Survey Results for Morse and Geist Reservoirs

The bathymetric survey results consist of elevation maps, depth contours, and storage capacity tables.

Elevation Maps and Depth Contours

The processed MBES data that were exported from HYPACK on a 5-ft regular grid were used to create bathymetric maps and contours with ArcMap GIS software. The 5-ft grid also matches the resolution of the existing land surface digital elevation model (DEM), which was downloaded from the Indiana Spatial Data Portal (Indiana Spatial Data Portal, 2019) in order to combine and create a seamless surface. In figures 7–8, the color contour represents the reservoir bottom elevation from lower elevations (in blue) to higher elevations (in red). Based on the bathymetric maps, the deepest point in Morse Reservoir is 42.5 ft deep, located near the dam in a remnant of the old river channel. The deepest point in Geist Reservoir is 37.6 ft deep, where gravel was dredged in the area upstream from Fall Creek Road. Both depths are referenced to the full pool level (when the water level is at the spillway crest). The 5-ft contour lines are also referenced to the spillway crest.

Table 2. Reservoir spillway crest elevations, historically referenced full levels, and record high water levels.

[ft, feet; NAVD 88, North American Vertical Datum of 1988]

Surveyed (2016) spillway crest	Morse Reservoir	Geist Reservoir
Elevation (NAVD 88)	809.44 ft	784.03 ft
Historically referenced full level (water level at the spillway crest)		
Elevation (NAVD 88)	809.58 ft[1]	784.56 ft[2]
Difference	–0.14 ft	–0.53 ft
Record high water level		
Date	April 19, 2013	May 18, 1943
Elevation (NAVD 88)	813.02 ft	787.58 ft
Height above spillway	3.58 ft	3.55 ft

[1]810 ft NGVD 29

[2]785 ft NGVD 29

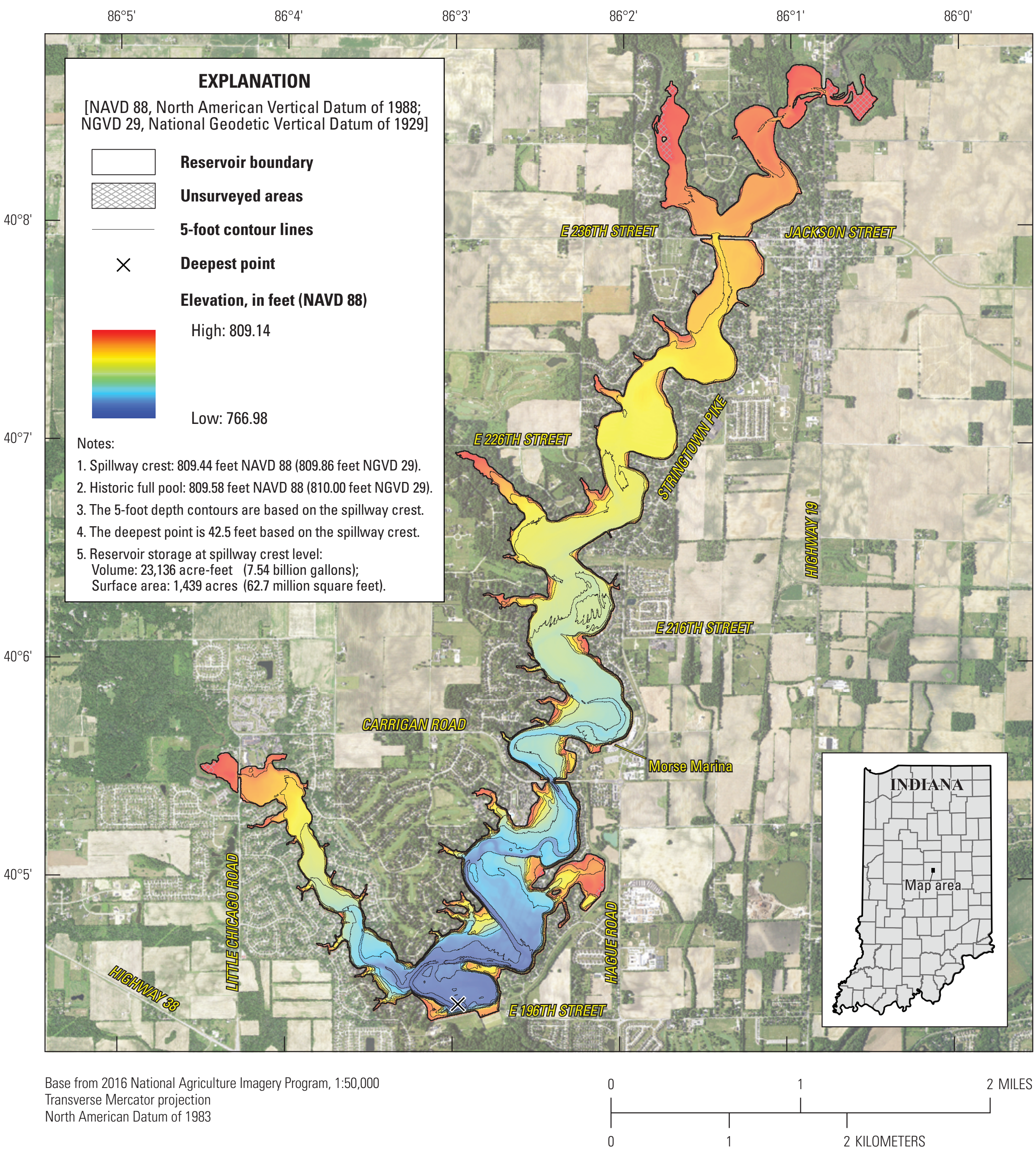
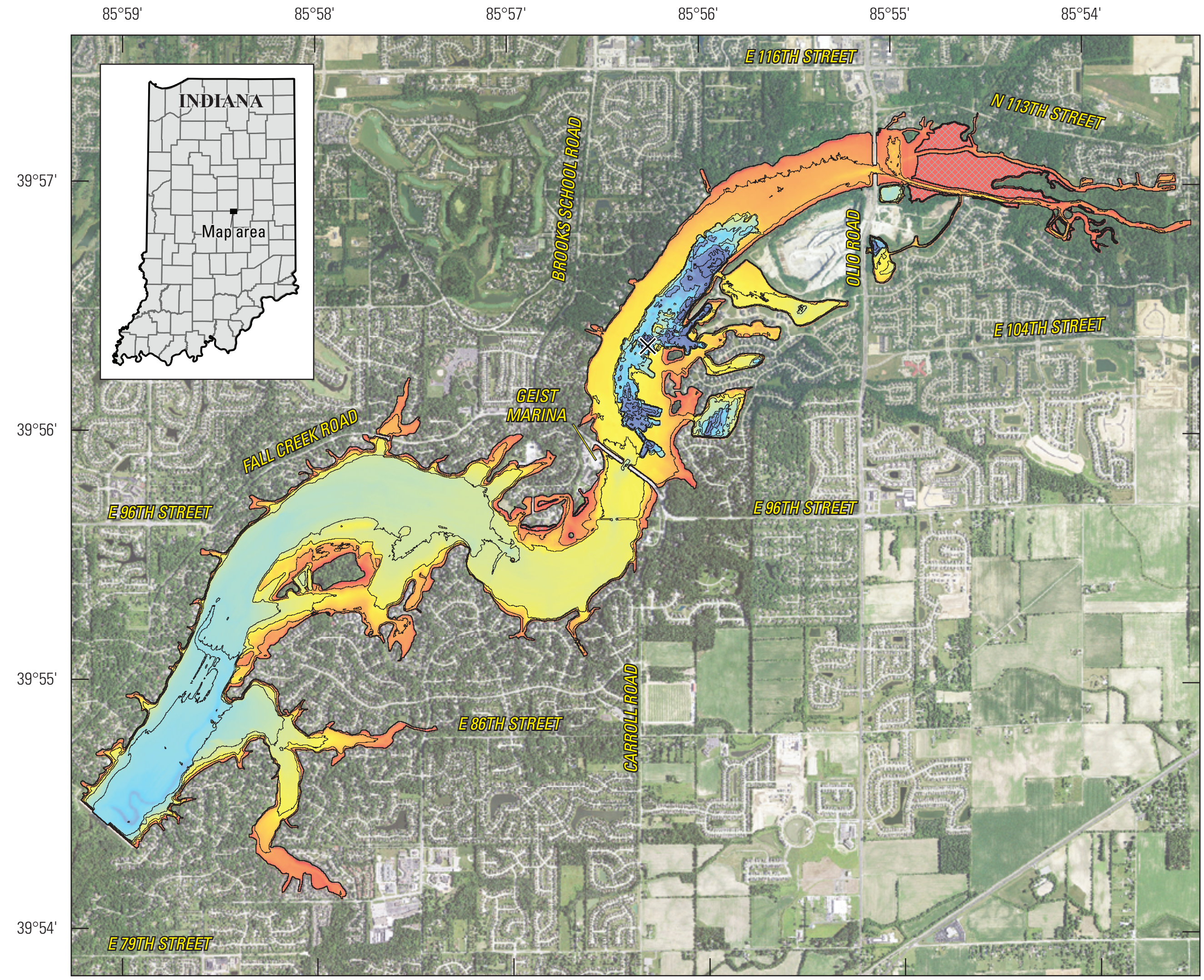
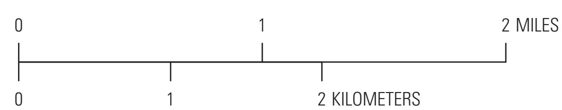


Figure 7. Bathymetric map and water-depth contours of Morse Reservoir near Noblesville, Indiana, 2016.



Base from 2016 National Agriculture Imagery Program, 1:50,000
Transverse Mercator projection
North American Datum of 1983



EXPLANATION

[NAVD 88, North American Vertical Datum of 1988; NGVD 29, National Geodetic Vertical Datum of 1929]

Reservoir boundary

Unsurveyed areas

5-foot contour lines

Deepest point

Elevation, in feet (NAVD 88)

High: 784.06

Low: 746.43

Notes:

1. Spillway crest: 784.03 feet NAVD 88 (784.47 feet NGVD 29).
2. Historic full pool: 784.56 feet NAVD 88 (785.00 feet NGVD 29)
3. The 5-foot depth contours are based on the spillway crest.
4. The deepest point is 37.6 feet based on the spillway crest.
5. Reservoir storage at spillway crest level:
   Volume: 21,146 acre-feet (6.89 billion gallons);
   Surface area: 1,853 acres (80.7 million square feet).

Figure 8. Bathymetric map and water-depth contours of Geist Reservoir near Fishers, Indiana, 2016.

Storage Capacities

The processed bathymetric data were combined with the existing land surface DEM to provide a three-dimensional model of the reservoir. The three-dimensional model was used to calculate reservoir storage capacities using HYPACK software. This software produces volume data by performing computations between two specified surfaces (for example, a lakebed and a water-surface elevation). A TIN model of the bathymetric surface was then created in HYPACK. The TIN model was used as the lower bounding surface for the computation of storage capacity, and specified water-surface elevations (in 1-ft increments) were input as upper surface boundaries. Volumes were then computed at various water-surface elevations (tables 3–4). The relation of water-surface elevation to storage capacity is rated to an elevation of 813 ft (NAVD 88) for Morse Reservoir and 788 ft (NAVD 88) for Geist Reservoir, which is about 3.5 ft and 4.0 ft above the crest of the spillway at Morse Reservoir and Geist Reservoir, respectively. The full capacity of Morse Reservoir (at the spillway crest elevation of 809.44 ft NAVD 88) is a volume of 23,136 acre-ft (7.54 Bgal) and a surface area of 1,439 acres (62.7 million square feet). The full capacity of Geist Reservoir (at the spillway crest elevation of 784.03 ft NAVD 88) is a volume of 21,146 acre-ft (6.89 Bgal) and a surface area of 1,853 acres (80.7 million square feet).

Comparison with Previous Surveys

There are four different ways to compare the current bathymetry from this study with previous surveys: by volume, point-to-point, surface-to-surface, and cross-section-to-cross-section. As mentioned before, the sonar technology and survey methods used in the current study (2016) are superior to the sonar technology and survey methods used in previous surveys because the MBES provides nearly complete coverage for

Table 3. Reservoir surface area and volume for Morse Reservoir at specified water-surface elevations.

[Bolded values are for the Morse Reservoir spillway crest: 809.44 feet (NAVD 88); ft, feet; NAVD 88, North American Vertical Datum of 1988]

Elevation (ft, NAVD 88)	Area (acres)	Volume (acre-feet)	Elevation (ft, NAVD 88)	Area (acres)	Volume (acre-feet)
767.00	0	0	791.00	564	5,155
768.00	0.70	0.15	792.00	591	5,733
769.00	5.22	2.33	793.00	629	6,341
770.00	12.3	11.6	794.00	679	6,996
771.00	17.6	25.9	795.00	718	7,696
772.00	29.8	49.4	796.00	769	8,434
773.00	48.0	87.7	797.00	824	9,237
774.00	72.2	148	798.00	866	10,080
775.00	94.6	231	799.00	919	10,977
776.00	122	340	800.00	959	11,916
777.00	142	471	801.00	1,015	12,905
778.00	172	628	802.00	1,049	13,937
779.00	202	815	803.00	1,093	15,007
780.00	223	1,028	804.00	1,160	16,134
781.00	246	1,261	805.00	1,202	17,316
782.00	272	1,522	806.00	1,253	18,541
783.00	292	1,803	807.00	1,293	19,816
784.00	316	2,107	808.00	1,347	21,134
785.00	347	2,437	809.00	1,421	22,506
786.00	381	2,801	**809.44**	**1,439**	**23,136**
787.00	416	3,199	810.00	1,453	23,946
788.00	446	3,630	811.00	1,490	25,418
789.00	487	4,096	812.00	1,517	26,923
790.00	533	4,604	813.00	1,537	28,449

Table 4. Reservoir surface area and volume for Geist Reservoir at specified water-surface elevations.

[Bolded values are for the Geist Reservoir spillway crest: 784.03 feet (NAVD 88); ft, feet; NAVD 88, North American Vertical Datum of 1988]

Elevation (ft, NAVD 88)	Area (acres)	Volume (acre-feet)
746.00	0	0
747.00	0.07	0.01
748.00	0.41	0.24
749.00	0.89	0.86
750.00	1.60	2.13
751.00	2.55	4.14
752.00	4.25	7.40
753.00	7.89	13.4
754.00	12.1	23.3
755.00	17.5	38.0
756.00	24.3	58.9
757.00	30.9	86.5
758.00	38.9	121
759.00	47.6	164
760.00	59.6	217
761.00	77.7	286
762.00	107	376
763.00	159	509
764.00	223	698
765.00	302	962
766.00	374	1,303
767.00	439	1,708
768.00	531	2,195
769.00	623	2,769
770.00	689	3,427
771.00	752	4,145
772.00	865	4,956
773.00	923	5,851
774.00	993	6,806
775.00	1,097	7,850
776.00	1,182	8,994
777.00	1,243	10,207
778.00	1,317	11,484
779.00	1,430	12,854
780.00	1,530	14,334
781.00	1,616	15,909
782.00	1,678	17,557
783.00	1,805	19,262
784.00	1,852	21,091
784.03	**1,853**	**21,146**
785.00	1,892	22,963
786.00	1,959	24,888
787.00	2,006	26,872
788.00	2,067	28,920

each reservoir. Figures 9–10 show the difference in coverage between the 1996 survey and the 2016 survey for Morse and Geist Reservoirs. After gridding the 2016 multibeam surveys for both reservoirs, each contain more than 2 million points compared to 100–200 thousand points for the 1996 surveys, which is an order of magnitude more. The coverage from the 2016 multibeam survey is also more uniform with much smaller gaps between data points. For example, the closest that the 1996 survey got to the Geist Reservoir dam was about 300 ft, whereas the multibeam survey was able to collect data right up to the dam face.

Volume Comparison

The 1996 survey report by Wilson and others (1997) contains information about historical reservoir volumes and are shown in tables 5–6 for Morse Reservoir and Geist Reservoir, respectively. The design volumes were estimated using a cross-section area method to interpolate the volumes between cross sections. Because the interpolated area is largely unmeasured, the uncertainty is increased. Quantifying the uncertainties is challenging and beyond the scope of this report, but qualitatively, the older the survey, the greater the uncertainty. Although it appears that the volume increased slightly between the 1978/1980 survey and the 1996 survey and again between the 1996 survey and the 2016 survey, it is likely due to improved surveying techniques, which allow for more of the reservoir to be measured. Because the reservoir bottom tends to have a concave shape, a lack of data will tend to be biased low. (This is an observational comment. A thorough analysis is beyond the scope of this report.) This is due to how data are interpolated between measured points. Unmeasured areas between points are estimated by connecting points with a line. The actual depths in the unmeasured areas could be greater than, equal to, or less than what was estimated, but the overall effect of linear interpolation in these reservoirs (which are old river valleys) is that there will be more unmeasured areas with depths that are less than what was estimated. This is particularly true when interpolating along the shoreline and in areas that are much deeper than the surrounding area (for example, old river channel, dredged areas). Thus, the current values represent the most accurate volumes to date, but a sedimentation rate should not be calculated from the volume comparisons due to the uncertainty of the previous values.

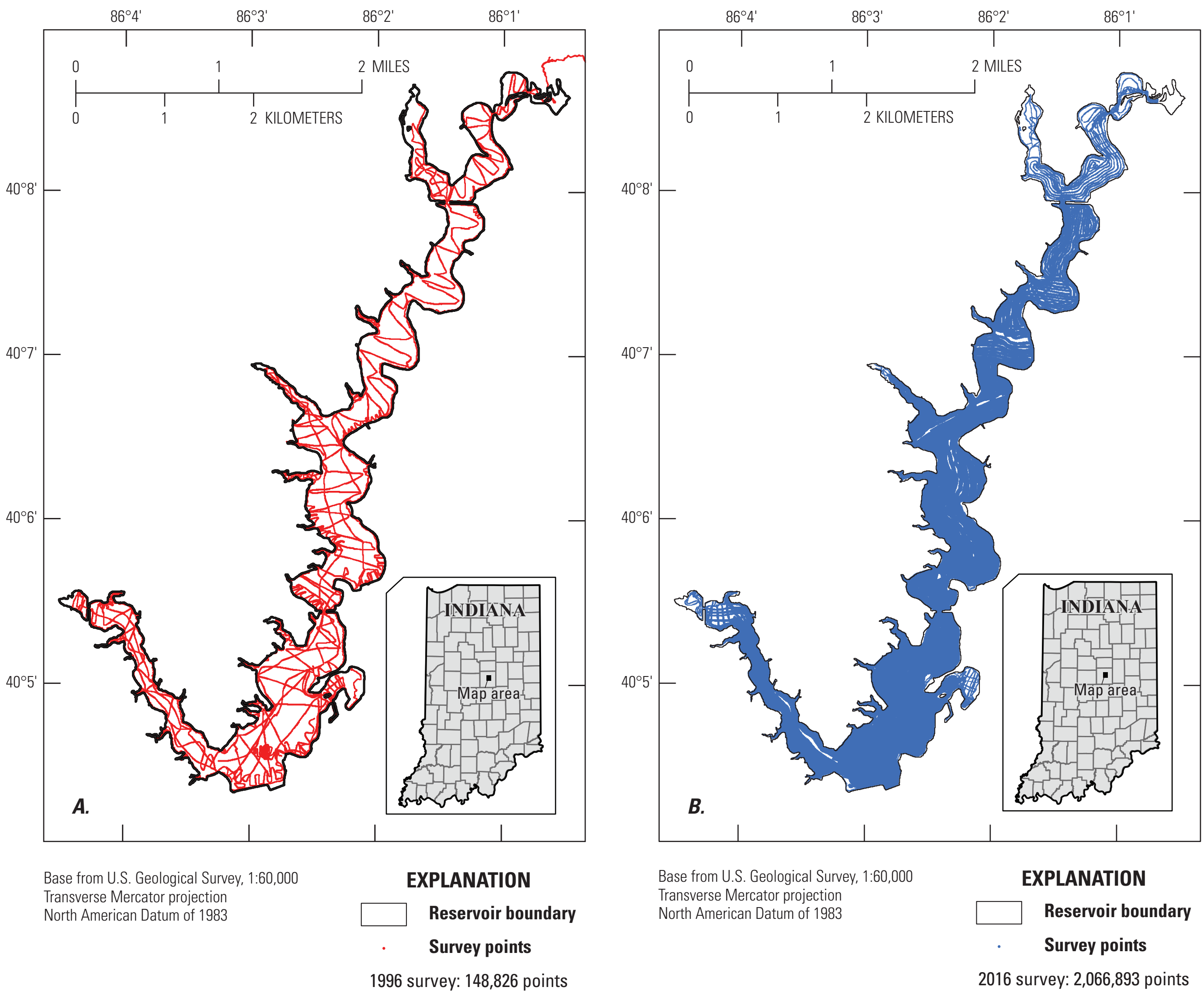


Figure 9. Comparison of *A,* 1996 and *B,* 2016 survey coverage for Morse Reservoir.

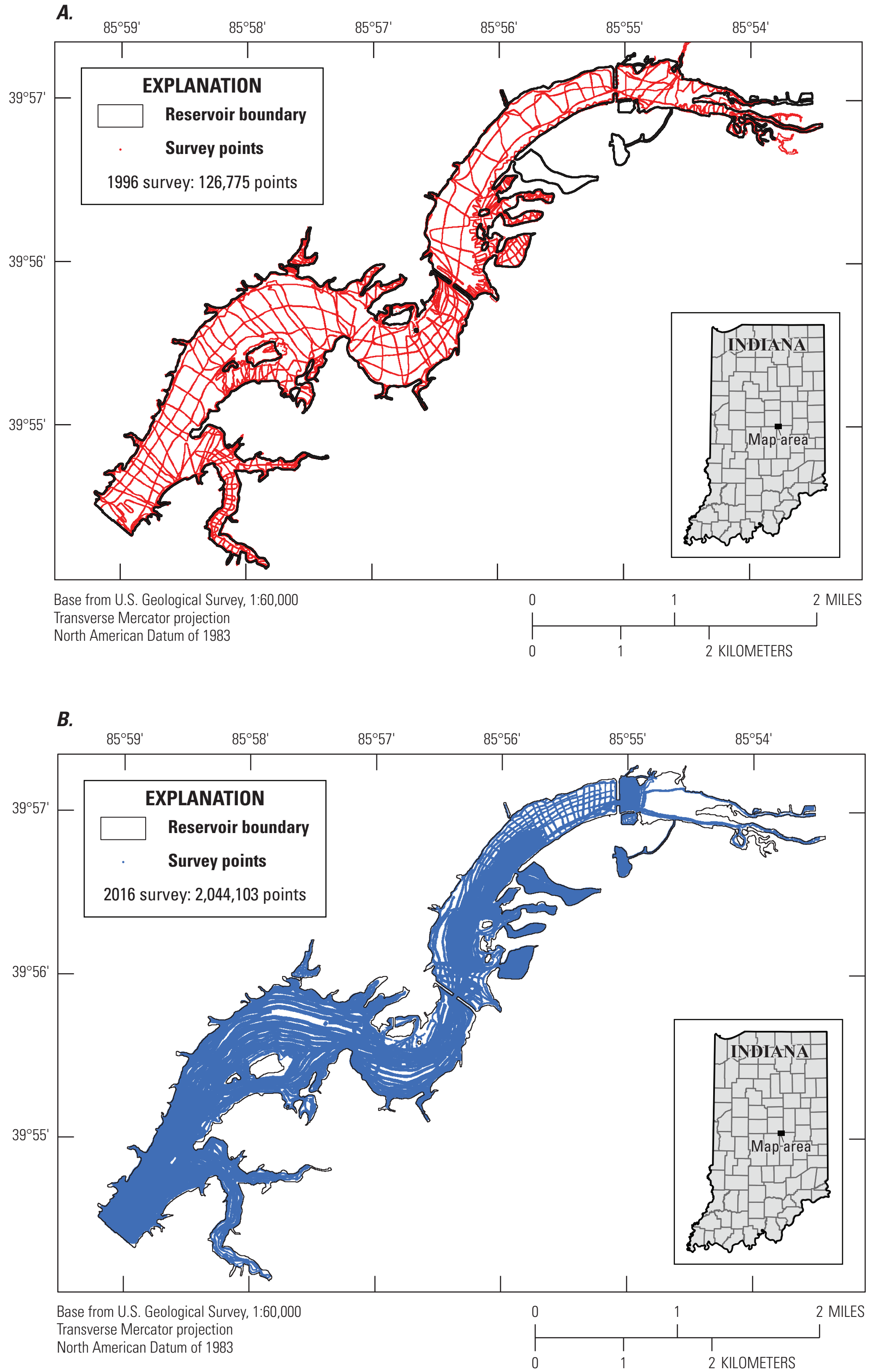


Figure 10. Comparison of *A*, 1996 and *B*, 2016 survey coverage for Geist Reservoir.

The current volume of Morse Reservoir is a decrease of 8.8 percent from the design volume, and the current volume of Geist Reservoir is a decrease of 0.2 percent from the design volume. If only total volume is considered, the data seem to indicate a sharp drop in volume between the reservoir completion and the fathometer surveys and then relatively stable volumes since then. The exception is that the Geist Reservoir volume increased between 1996 and 2016; however, this is due to man-made changes. Since the 1996 survey, a large area of Geist Reservoir was mined for gravel and three new coves were added to Geist Reservoir, each increasing the volume of the reservoir. The area that was mined for gravel is by far the largest pool that would trap water in the event of a dramatic drawdown of the reservoir water level (in other words, the water in that dredged area would not be able to naturally flow toward the dam during drawdown). The volume of water contained in that dredged area (up to the 773 ft NAVD 88 contour) is 1,490 acre-ft, which is about 7.0 percent of the total reservoir volume. By subtracting the volume of these areas (the gravel dredged area and the three new coves since 1996), we can better match the 1996 shoreline and nondredged conditions and the result is a volume of 19,031 acre-ft. Using this volume is much more representative of natural changes (sedimentation) and is a decrease of 10.1 percent from the design volume, which is consistent with the decrease in Morse Reservoir. Geist Reservoir has been in operation 13 years longer than Morse Reservoir (1943 versus 1956), so that may explain the decrease in total volume in Geist compared to Morse.

Point-to-Point Comparison

The 1996 survey data consists of point data throughout the reservoir (fig. 9a and fig. 10a). These points were overlaid on the 2016 survey raster dataset, which is a 5-ft-by-5-ft grid with numerous individual depth measurements averaged for each grid cell, and that grid value was extracted for each point. The result is a one-to-one comparison at each survey point. A difference value was computed for each point defined as the 2016 elevation minus the 1996 elevation. Thus, positive values indicate deposition and negative values indicate scour. The goal was to get an estimate of sedimentation in the reservoir, so a subset of points was used which excludes points near the shorelines and in areas with known man-made modifications (for example, dredging).

For Morse Reservoir, there were a total of 146,175 points available for a point-to-point comparison analysis; however, the subset that was used contained 53,583 points. The mean difference was 0.32 ft with a standard deviation of 0.62 ft (table 7). In other words, the mean bed elevation change in Morse Reservoir from 1996 to 2016 was an increase (sedimentation) of 0.32 ft.

For Geist Reservoir, there were a total of 118,282 points available for this analysis; however, the subset that was used contained 35,220 points. The mean difference was 0.27 ft with a standard deviation of 0.53 ft (table 7). In other words, the mean bed elevation change in Geist Reservoir from 1996 to 2016 was an increase (sedimentation) of 0.27 ft.

For both Morse and Geist Reservoirs, this does not mean that the entire reservoir has only changed by 0.32 ft (for Morse) and 0.27 ft (for Geist). In fact, the standard deviation values indicate that some areas of the reservoir have had no change or gotten slightly deeper and other parts of the

Table 5. Reservoir volume throughout time for Morse Reservoir.

[ADCP, acoustic Doppler current profiler]

Year	Survey Type	Volume (acre-feet)
1956	Design volume	25,380
1978	Fathometer	22,100
1996	ADCP	22,810
2016	Multibeam	23,136

Table 6. Reservoir volume throughout time for Geist Reservoir.

[ADCP, acoustic Doppler current profiler]

Year	Survey Type	Volume (acre-feet)
1943	Design volume	21,180
1980	Fathometer	18,720
1996	ADCP	18,630
2016	Multibeam	21,146[1]

[1]The reservoir volume is 19,031 acre-feet when excluding the dredged gravel area and the three new coves added since 1996.

Table 7. Point comparison statistics from the difference between the 1996 survey and the 2016 survey for Morse and Geist Reservoirs.

Statistic	Morse Reservoir	Geist Reservoir
Number of samples (total)	146,175	118,282
Number of samples (subset)	53,583	35,220
Minimum, in feet	-4.91	-6.84
Q1 (first quartile), in feet	-0.02	0.01
Mean, in feet	0.32	0.27
Median, in feet	0.36	0.27
Q3 (third quartile), in feet	0.71	0.52
Maximum, in feet	6.45	5.35
Standard deviation, in feet	0.62	0.53
IQR (interquartile range), in feet	0.73	0.51
Number of outliers	177	509
Skewness	-0.28	0.16
Kurtosis	7.24	18.8

reservoir have had close to 1 ft of sedimentation in the last 20 years. The next section describes elevation changes spatially in different parts of the reservoirs.

Surface-to-Surface Comparison

A TIN surface model was created from the 1996 survey data and exported to a 5-ft regular grid so that the difference between each raster surface could be calculated. A grid was generated showing the difference between the two datasets. This gave a general overview of the scour and deposition that has occurred during the 20-year period from 1996 to 2016. The raster differencing process was done in ArcMap, and the result is a raster of the same extent (figs. 11–12). The raster values are the elevation change from the 1996 survey to the 2016 survey (20 years), with positive values (brown colormap) showing an increase in elevation and negative values (blue colormap) showing a decrease in elevation during that time period. A value of ±0.50 ft was arbitrarily chosen as the cutoff for the positive and negative change colormaps to highlight the extreme changes. In other words, the green color represents areas where the change is too small to have much meaning, and where there is uncertainty as to whether it is real change or due to interpolation or other sources of error. An increase in elevation can be caused by sedimentation or fill, and a decrease in elevation can be caused by scour or dredging. This could be attributed to sediment inflows, difference in accuracy of the two surveys, or a combination of both. Because the 1996 coverage is not near the same level as the 2016 survey, the 1996 raster has significant interpolation between points so the change in elevation can also be caused by the changes in sonar technology and survey methods. At first glance, Morse Reservoir (fig. 11) appears to have more brown colors (indicating deposition, fill, and [or] sedimentation) throughout the main body of the reservoir as compared to Geist Reservoir (fig. 12). The gravel dredged area of Geist Reservoir is obvious in fig. 12 (dark blue colors). The blue colors near the shoreline elevation in both reservoirs are due to interpolation limitations in the 1996 data (fig. 13). The TIN model connects the shoreline with the closest depth points, which for the 1996 survey may be 25–50 ft from the shore and thus creates a trapezoidal shape which almost certainly underestimates the depth along the nearshore areas (fig. 13, red line). In the 2016 survey, the MBES was able to survey all the way to the shoreline (fig. 13, black line), which confirmed that the interpolation of the 1996 data along the nearshore areas underestimated the depth.

Another way to look at the surface-to-surface comparison is to divide each reservoir up into zones (figs. 14–15) and then subsample the difference raster in an area with high density of 1996 survey data. This allows an estimate of sedimentation rates in the different parts of each reservoir. The creation of zones in each reservoir was somewhat arbitrary but tended to correspond to bridges or other natural constriction points. The total number of zones was kept to less than 10. The hypothesis is that the upper reaches in both reservoirs are filling in faster than the lower reaches near the dams. The reason for the subsampling was to avoid including areas where there was interpolation to the shoreline elevation or other areas of known man-made changes so that the mean difference computed from the subsampled area would be representative of the typical sedimentation in each zone. The creation of the subsampled areas was also somewhat arbitrary but was a single polygon typically near the middle of each zone and containing a majority of the 1996 survey data points. The results of this analysis are reported in tables 8–9 and support the hypothesis of the upper reaches filling faster. In the upper reaches of Morse Reservoir (zone 1 and zone 9), the sedimentation rates are approximately 0.5 inch per year, and near the dam (zone 6 and zone 7), the sedimentation rates are approximately 0–0.1 inch per year (table 8). In the upper reaches of Geist Reservoir (zone 1), the sedimentation rate is approximately 0.2 inch per year, and near the dam (zone 7), the sedimentation rate is nearly zero (table 9). Another finding is that the sedimentation rate for Morse Reservoir is about double the sedimentation rate for Geist Reservoir. This supports the previous observation that the Morse difference raster (fig. 11) had more brown colors (deposition, fill, and [or] sedimentation) than the Geist difference raster (fig. 12). The higher sedimentation rate in Morse Reservoir may also tie back to the land use in the basins. Morse Reservoir has 14.9 percent more agricultural land in its basin than Geist Reservoir, so the incoming sediment load may be higher. The surface-to-surface comparison in conjunction with the zones (or any other area) can also be used to estimate bulk quantities of sediment change in localized areas of each reservoir. This can be done by computing the volume change (using the difference raster) within a localized area or zone. For example, there has been about 56 acre-ft of sedimentation above E 236th Street (Jackson Street) in Morse Reservoir (zone 1) from 1996 to 2016.

Cross-Section Comparison

The final way to compare the updated bathymetry from this study with previous surveys is by looking at cross sections. The supplemental data provided in Wilson and others (1997) are cross section plots of the 1978/1980 fathometer profiles and cross sections generated from the TIN computed for the 1996 survey. The data from these plots were obtained and converted to the NAVD 88 datum. The cross-section lines used in the previous surveys (fig. 16 for Morse Reservoir and fig. 28 for Geist Reservoir) were used with the 3D Analyst toolbox in ArcMap to extract cross-section data from the 2016 bathymetry raster, which were then plotted with the data from the previous two surveys (figs. 17–27 for Morse Reservoir and figs. 29–40 for Geist Reservoir). The cross sections shown represent a sample of the original cross-section lines from the fathometer surveys and were selected to show elevation changes throughout the reservoir from the dam to the headwaters. Because the positioning methods and how the elevation

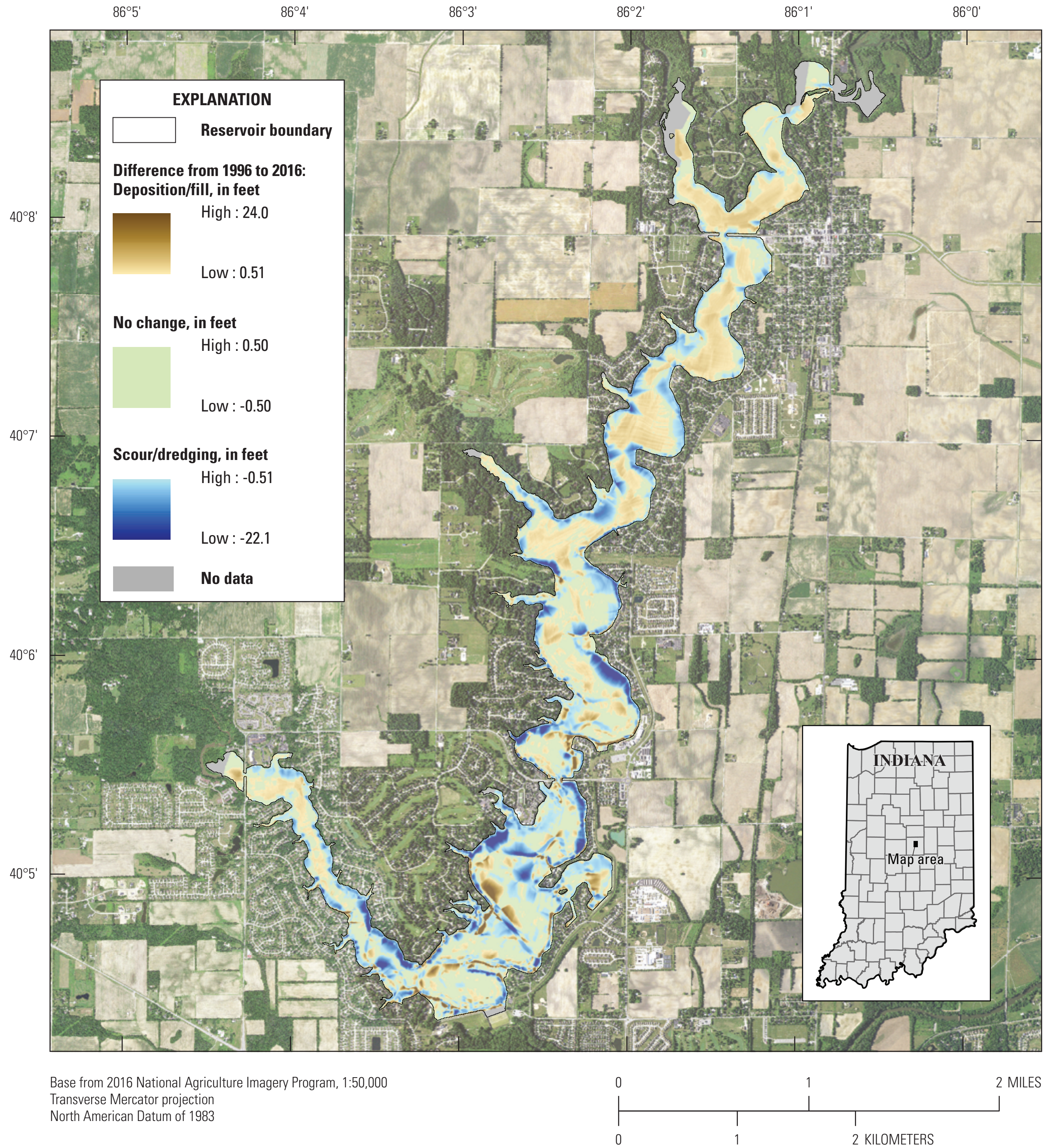


Figure 11. Raster difference between 1996 and 2016 surveys for Morse Reservoir.

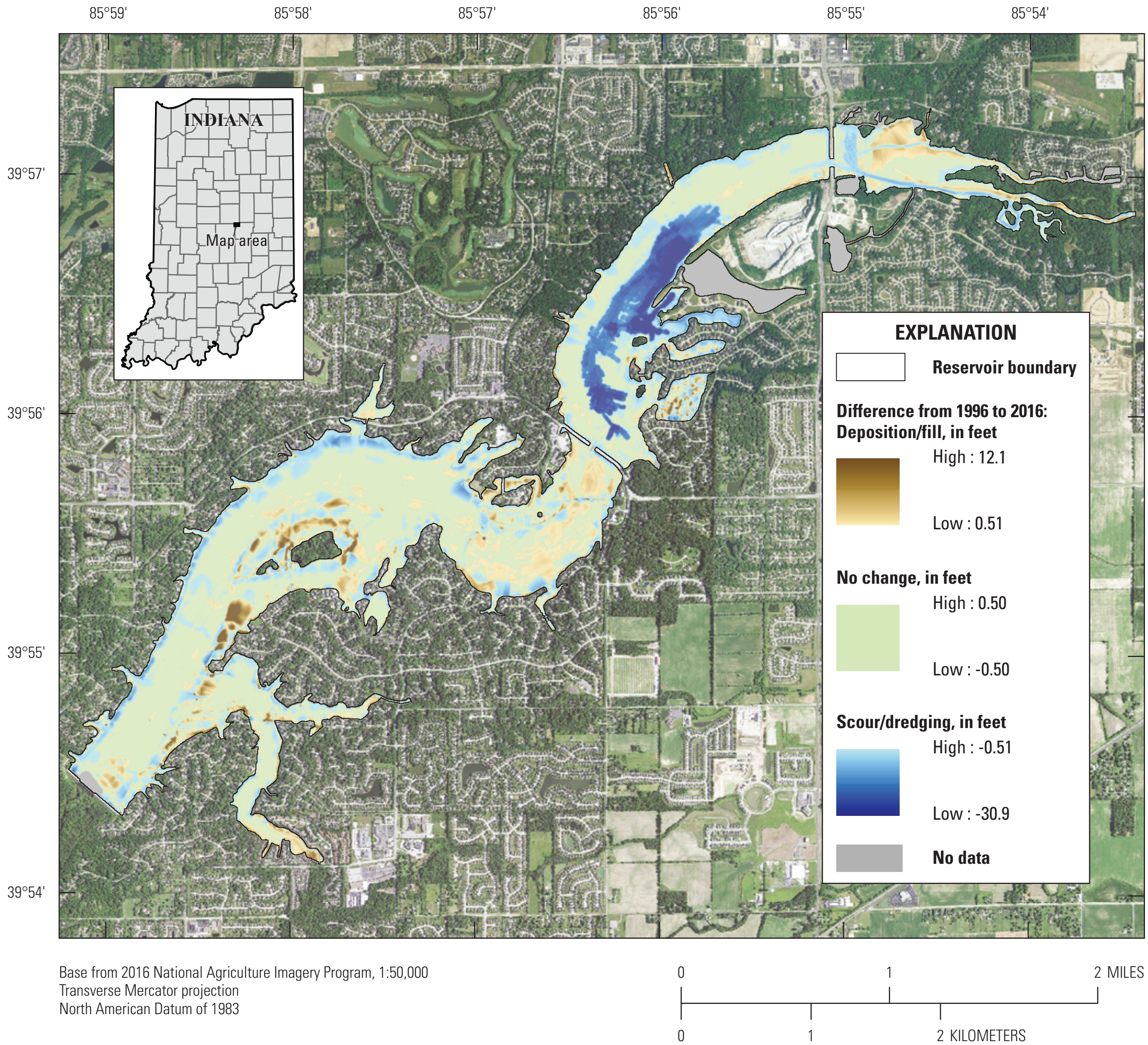


Figure 12. Raster difference between 1996 and 2016 surveys for Geist Reservoir.

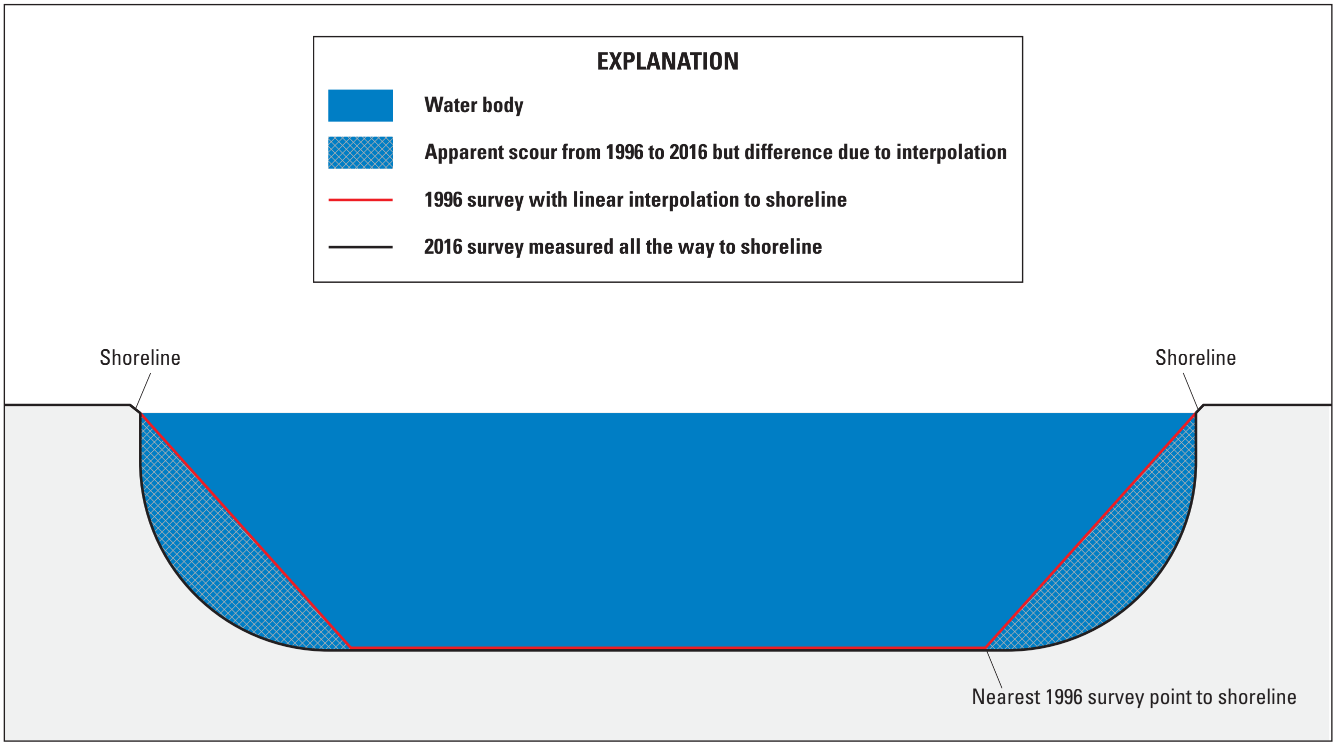


Figure 13. Schematic of 1996 survey and 2016 survey data collection near the shoreline.

data were extracted to each cross section varied between surveys, the elevation data plotted in each cross-section plot are from nearly the same location. The cross sections are oriented facing the downstream or down-reservoir direction (toward the dam), with the horizontal station referenced to zero at the left end. All of the cross sections indicate some sedimentation has occurred. In the cross sections near the dam, the sedimentation appears to be primarily in the old river channel and nearly zero elsewhere; whereas, in the cross sections near the headwaters, the sedimentation is more uniform across the width. The changes due to dredging in Geist Reservoir are obvious in those cross sections (for example, fig. 37, fig. 39, fig. 40). All of the cross-section plots have some comparison limitations due to the differences in data collection techniques so the sedimentation cannot be quantified accurately, but it appears consistent with the findings from the previous three comparison methods.

Discussion of Comparison Methods

This study looked at four different ways to compare the updated bathymetry with previous surveys: by volume, point-to-point, surface-to-surface, cross-section-to-cross-section. Each method has its own benefits and limitations but when used together gives the best picture of changes in each reservoir during a 20-year period from 1996 to 2016. The total volume is a value that is broad and simple and is useful to engineers and managers, but previous volume estimates likely have a high amount of uncertainty because the unmeasured areas were larger (the coverage was less as shown in figs. 9–10). The point-to-point comparison method is the most direct comparison of measured points, but there is uneven distribution from the 1996 survey and reporting a single mean value of the change does not represent localized changes in each reservoir. The surface-to-surface comparison method works well to show spatial changes and would be the best method if both surveys were of the same resolution but is limited by interpolation of the 1996 data. Dividing the reservoirs into zones and subsampling the difference data was useful to estimate sedimentation rates. The cross-section plots were able to show spatial changes along cross-section lines across the reservoirs from all three surveys to date and help show changes in different parts (from near the dam to near the headwaters) of each reservoir.

Summary

The U.S. Geological Survey, in cooperation with Citizens Energy Group, conducted a bathymetric survey of Morse and Geist Reservoirs in April and May of 2016 with a multibeam echosounder to create updated bathymetric maps, compute updated storage capacities, and compare current conditions to historical surveys. Storage capacities were estimated by combining high-resolution multibeam sonar bathymetry data

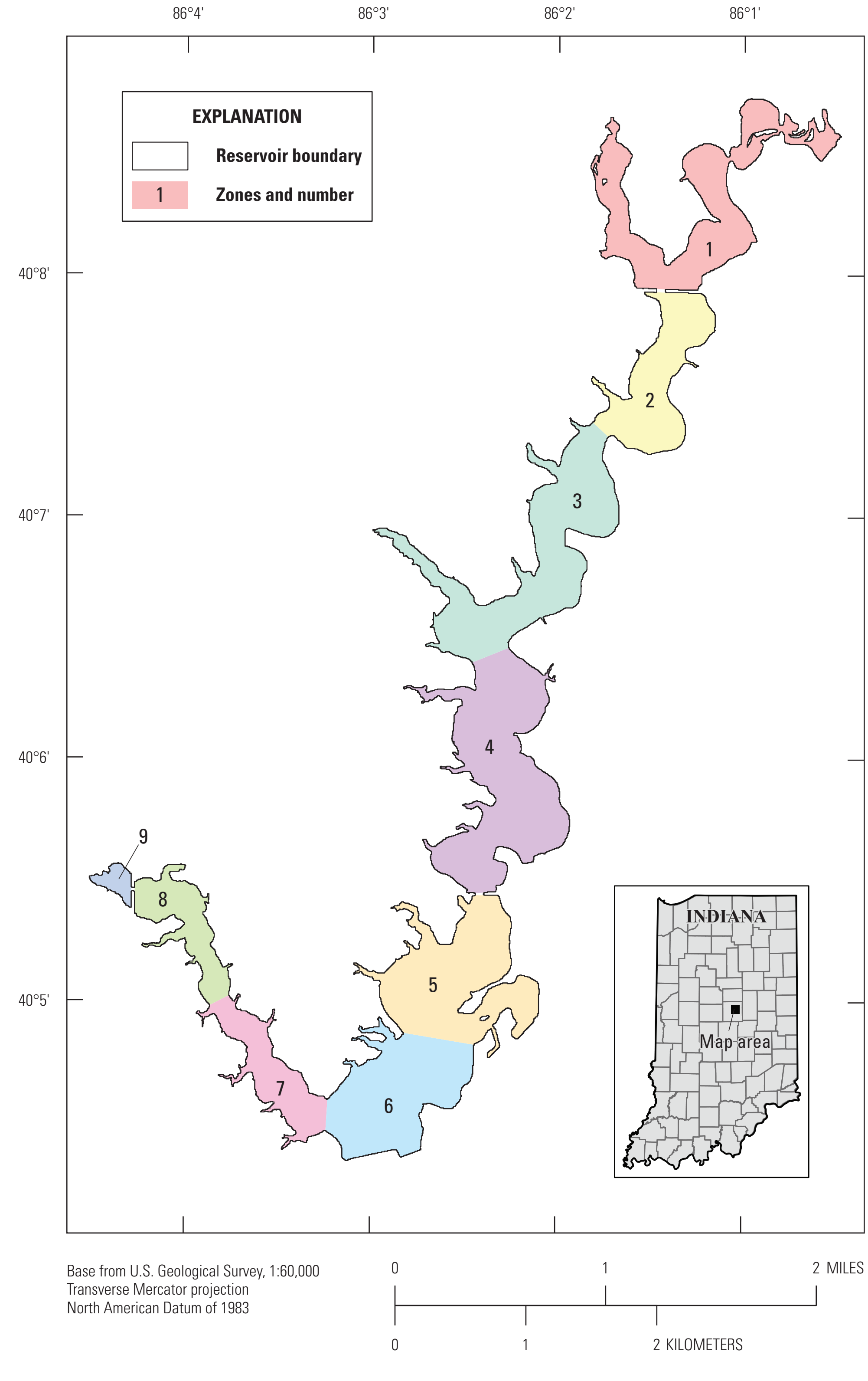


Figure 14. Zones in Morse Reservoir used for sedimentation rate analysis.

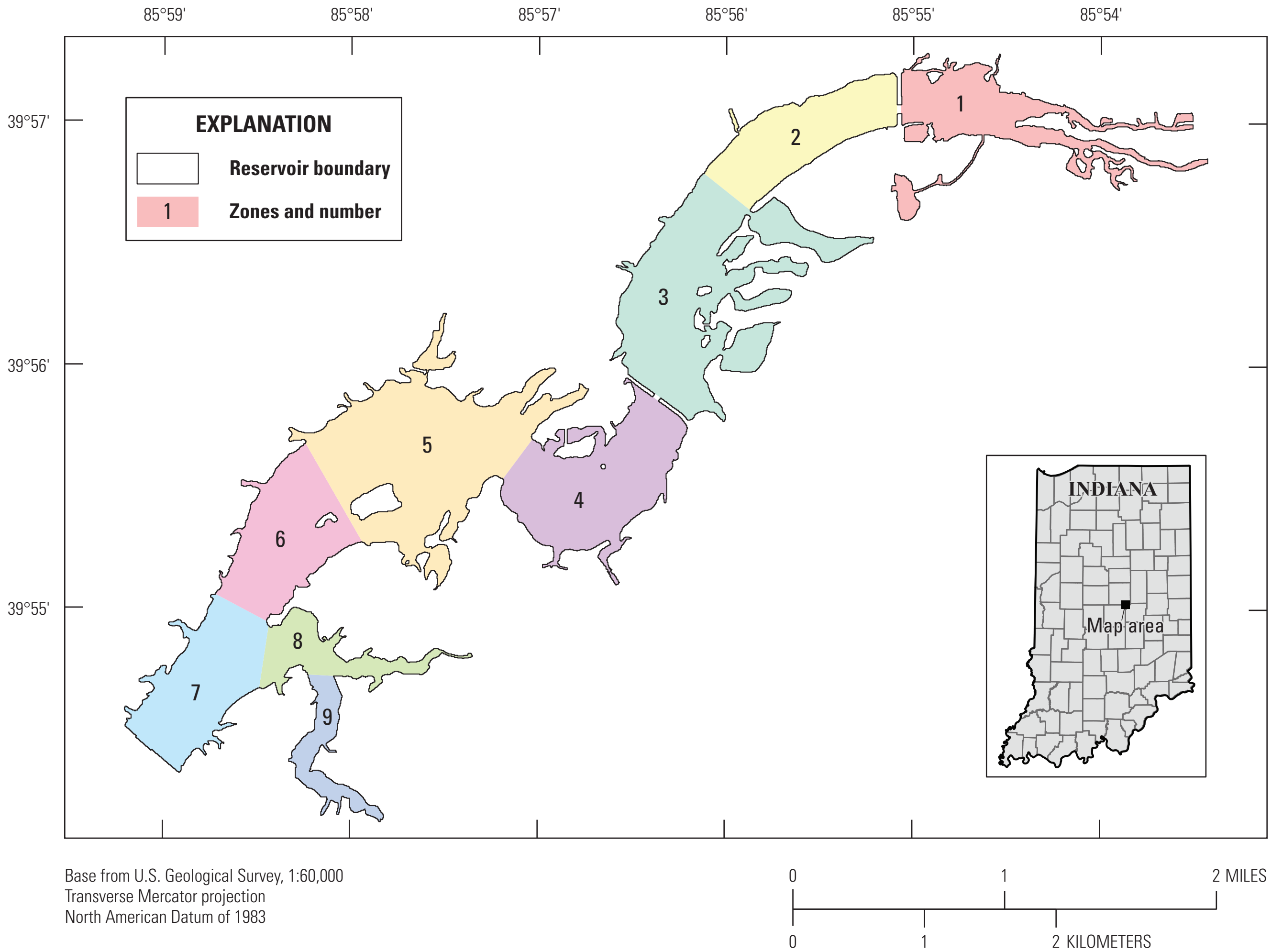


Figure 15. Zones in Geist Reservoir used for sedimentation rate analysis.

Table 8. Sedimentation rates by zone for Morse Reservoir.

Zone	Change from 1996 to 2016, in feet		Sedimentation rate, in inches per year
	Mean	Standard deviation	
1	0.83	0.39	0.5
2	0.72	0.43	0.4
3	0.61	0.59	0.4
4	0.27	0.70	0.2
5	-0.13	0.54	-0.1
6	0.09	0.42	0.1
7	0.03	0.46	0.0
8	0.64	0.25	0.4
9	0.79	0.72	0.5

Table 9. Sedimentation rates by zone for Geist Reservoir.

Zone	Change from 1996 to 2016, in feet		Sedimentation rate, in inches per year
	Mean	Standard deviation	
1	0.35	0.29	0.2
2	0.17	0.18	0.1
3	0.23	0.17	0.1
4	0.49	0.20	0.3
5	0.11	0.18	0.1
6	0.02	0.23	0.0
7	0.05	0.15	0.0
8	0.17	0.16	0.1
9	0.24	0.17	0.1

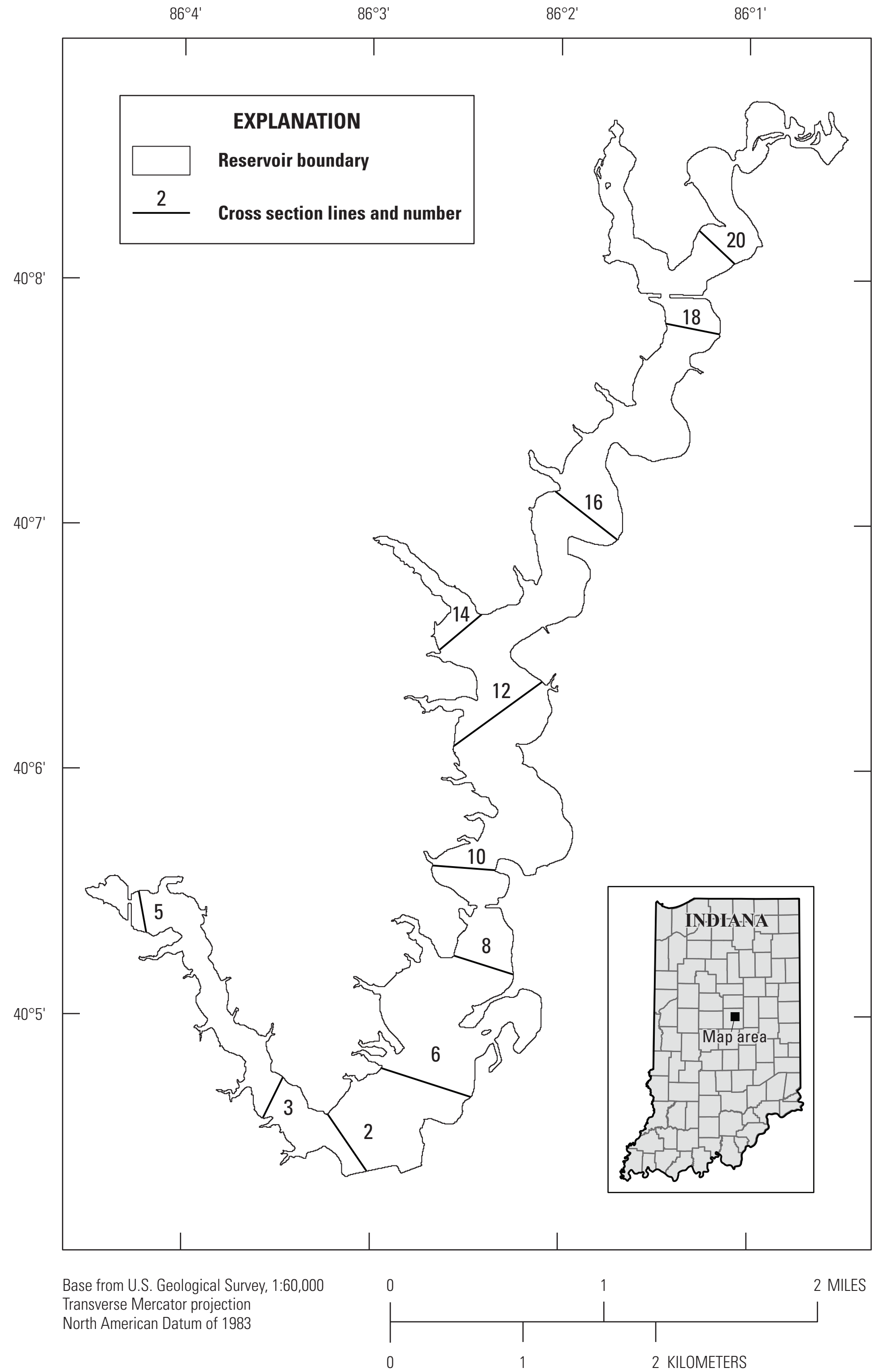


Figure 16. Locations of cross sections for Morse Reservoir.

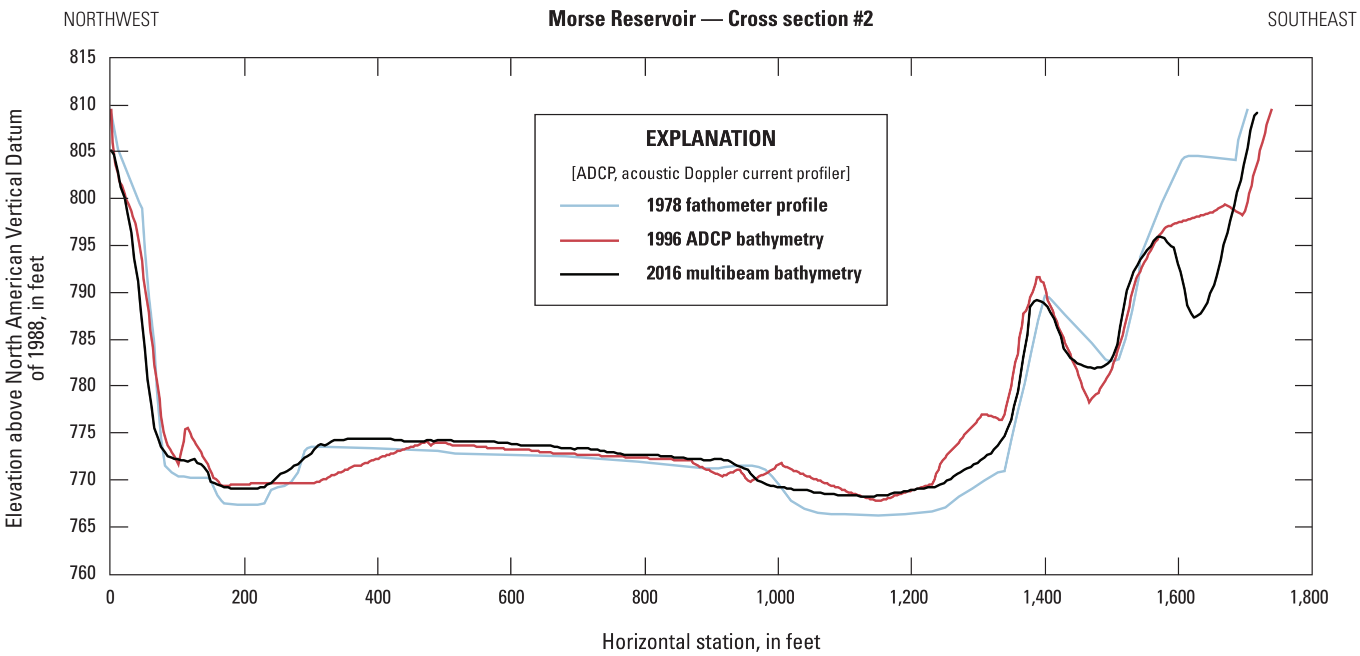


Figure 17. Cross section number 2 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

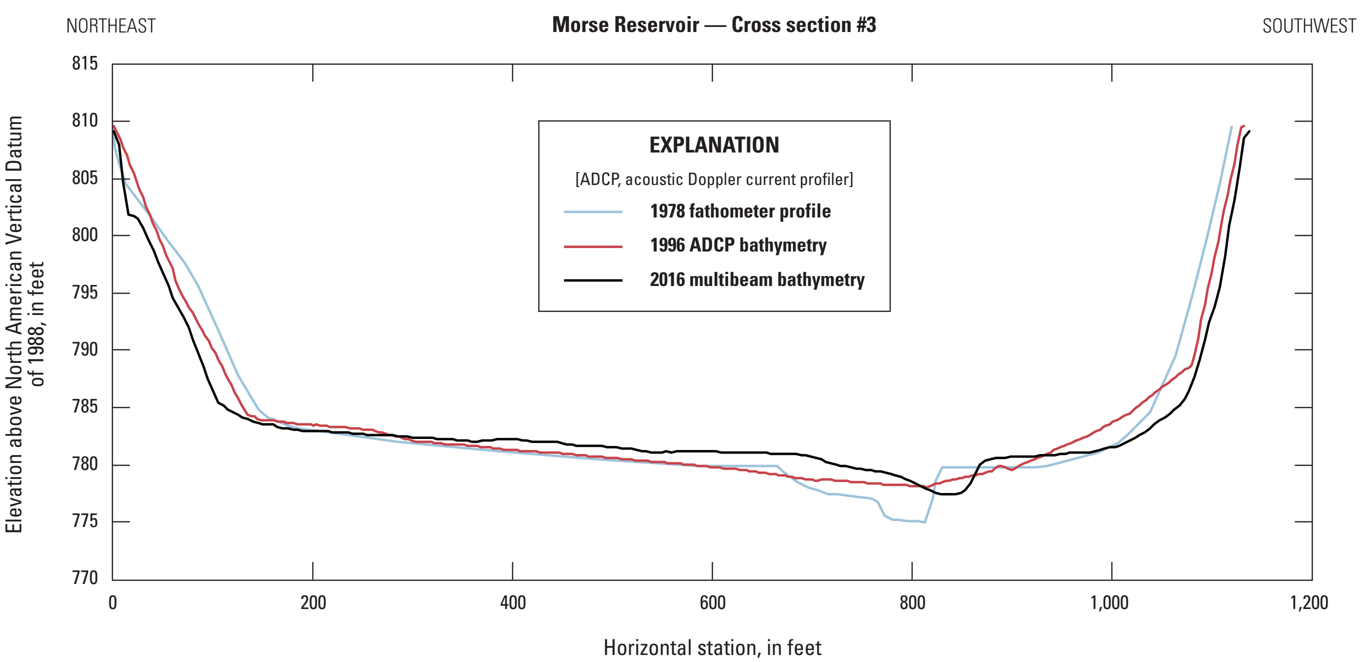


Figure 18. Cross section number 3 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

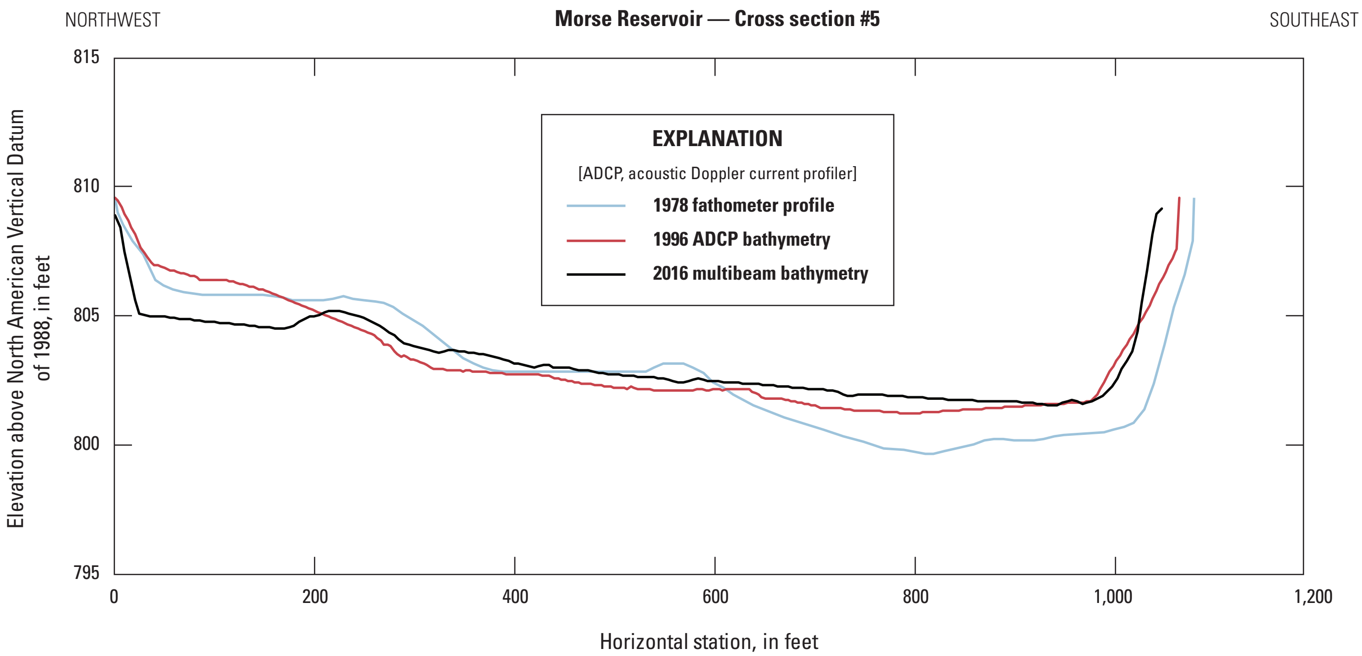


Figure 19. Cross section number 5 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

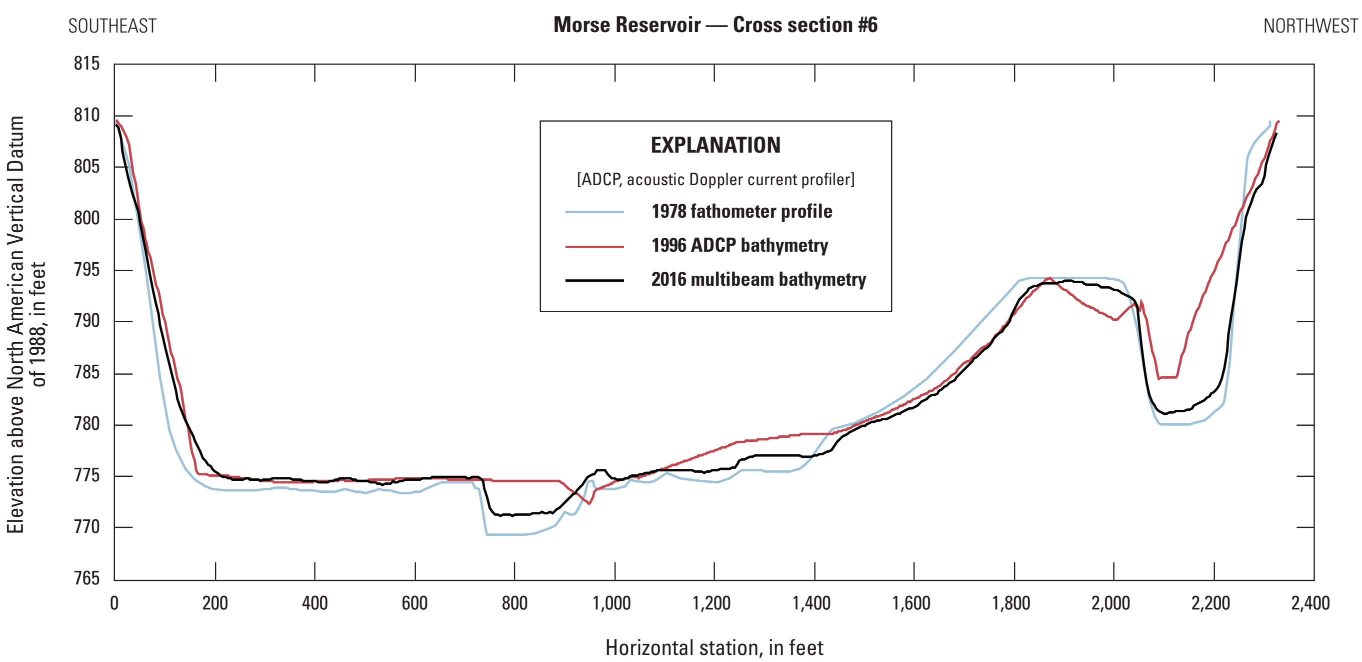


Figure 20. Cross section number 6 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

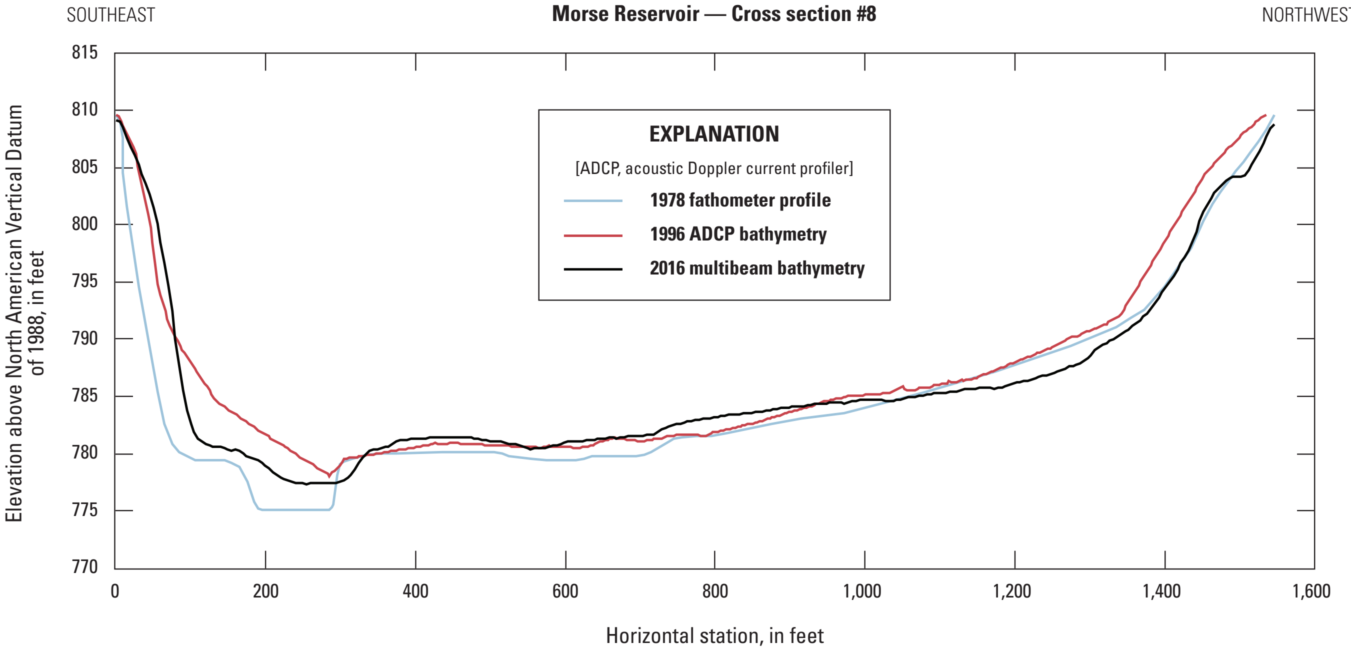


Figure 21. Cross section number 8 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

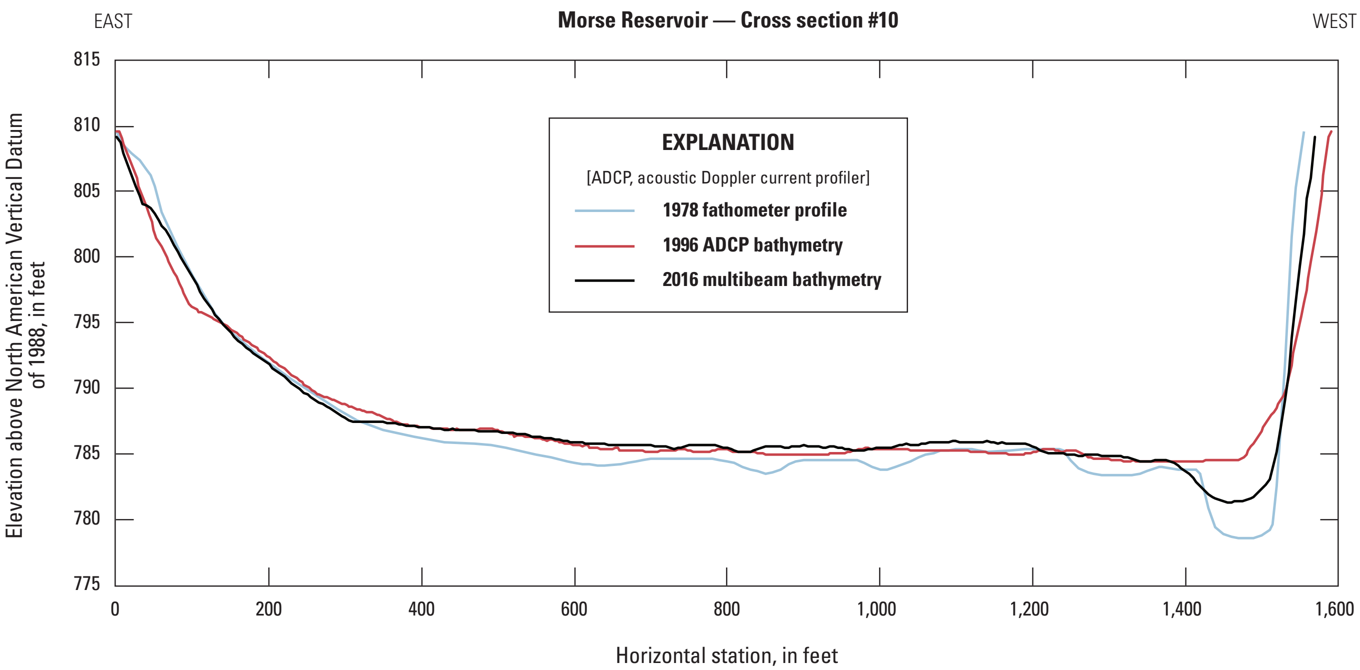


Figure 22. Cross section number 10 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

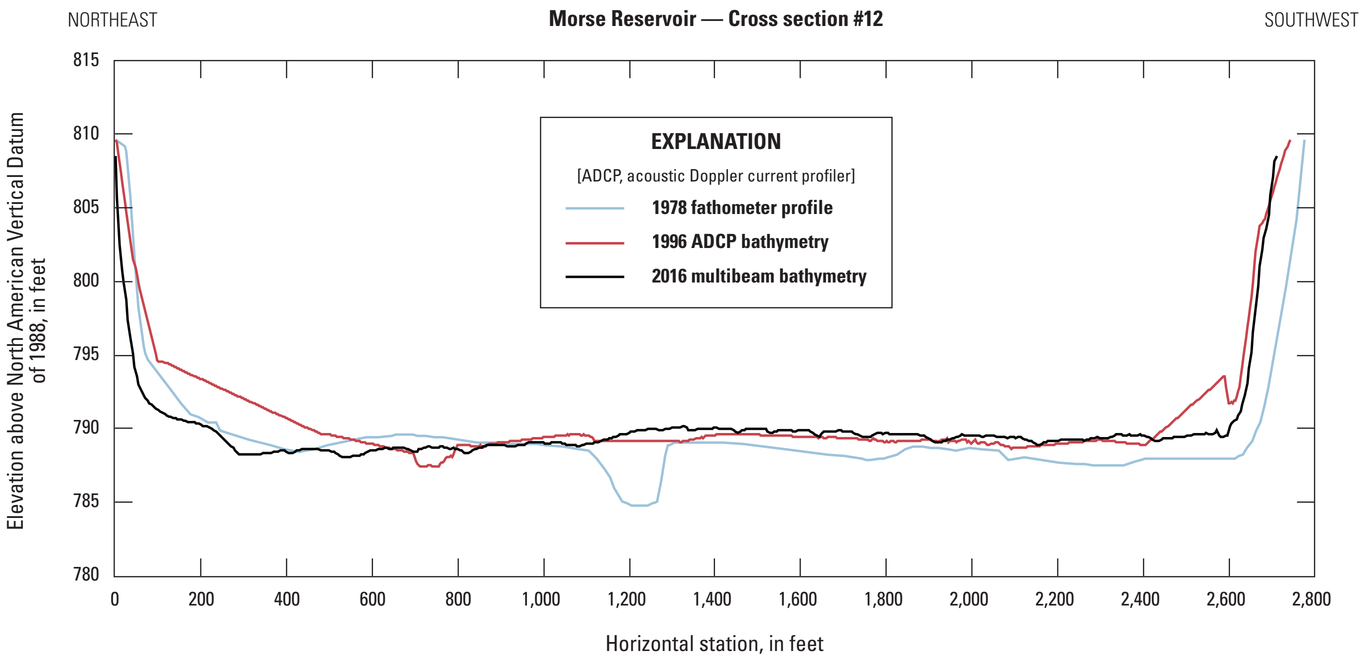


Figure 23. Cross section number 12 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

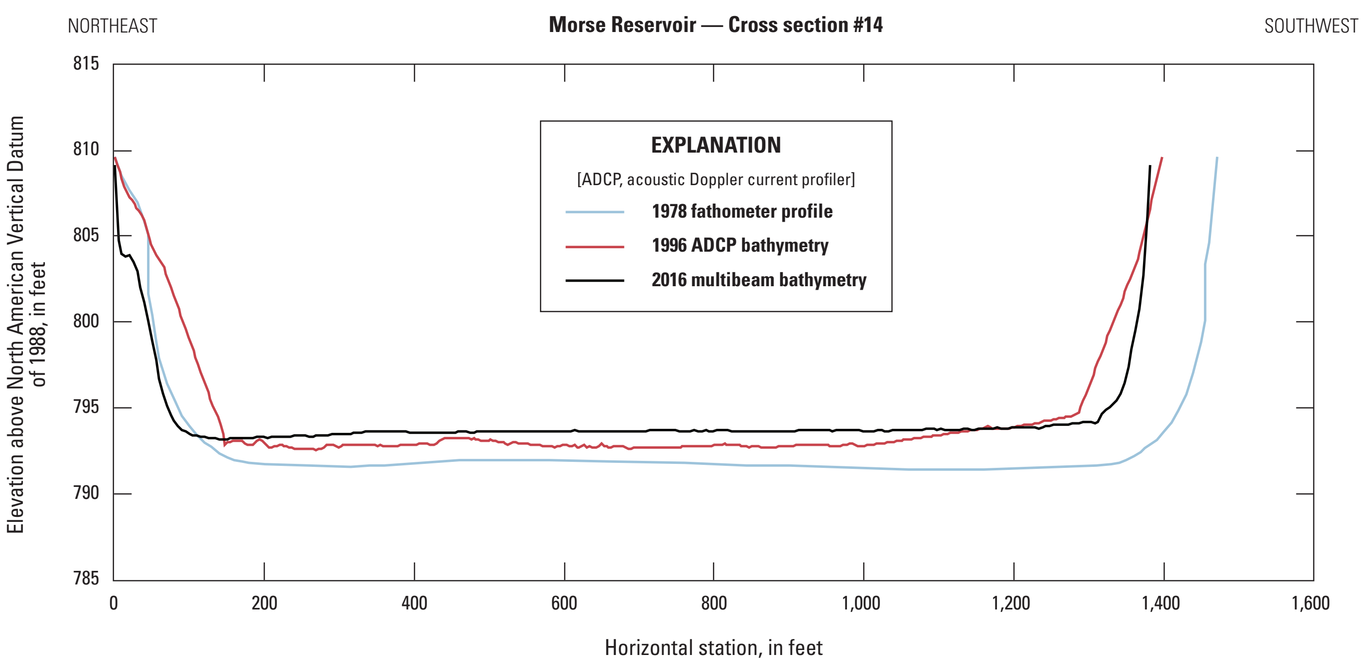


Figure 24. Cross section number 14 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

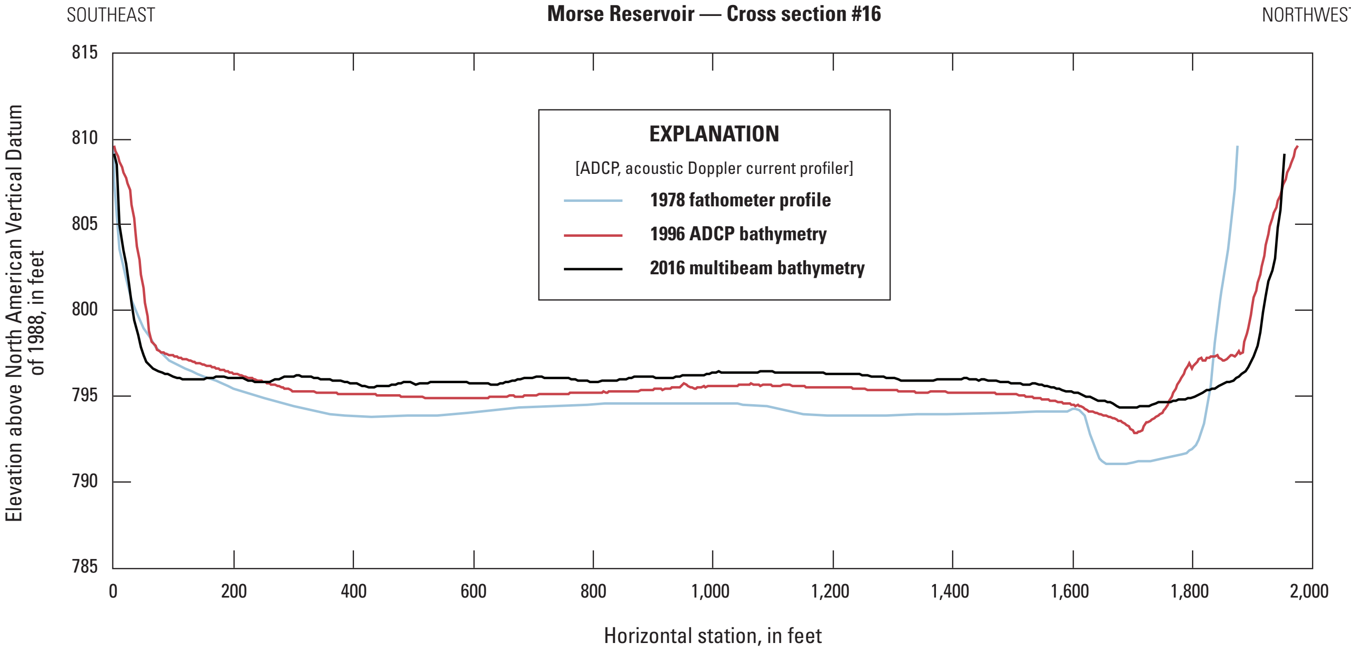


Figure 25. Cross section number 16 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

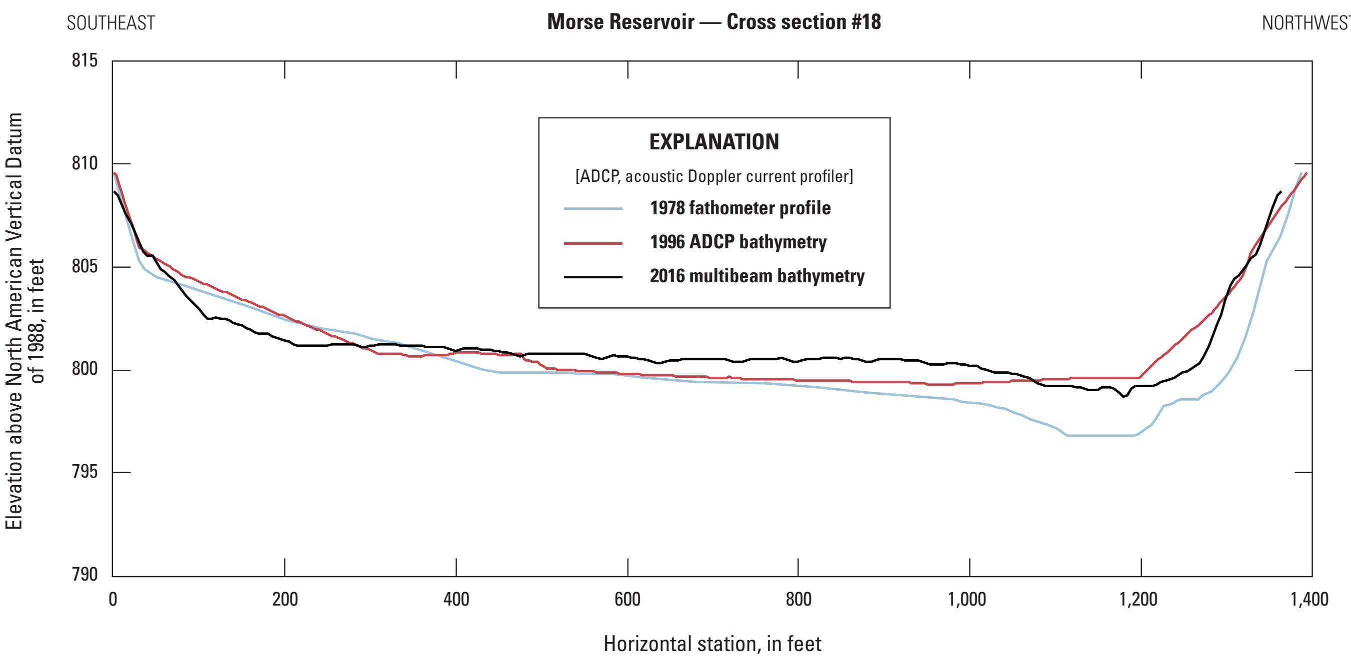


Figure 26. Cross section number 18 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

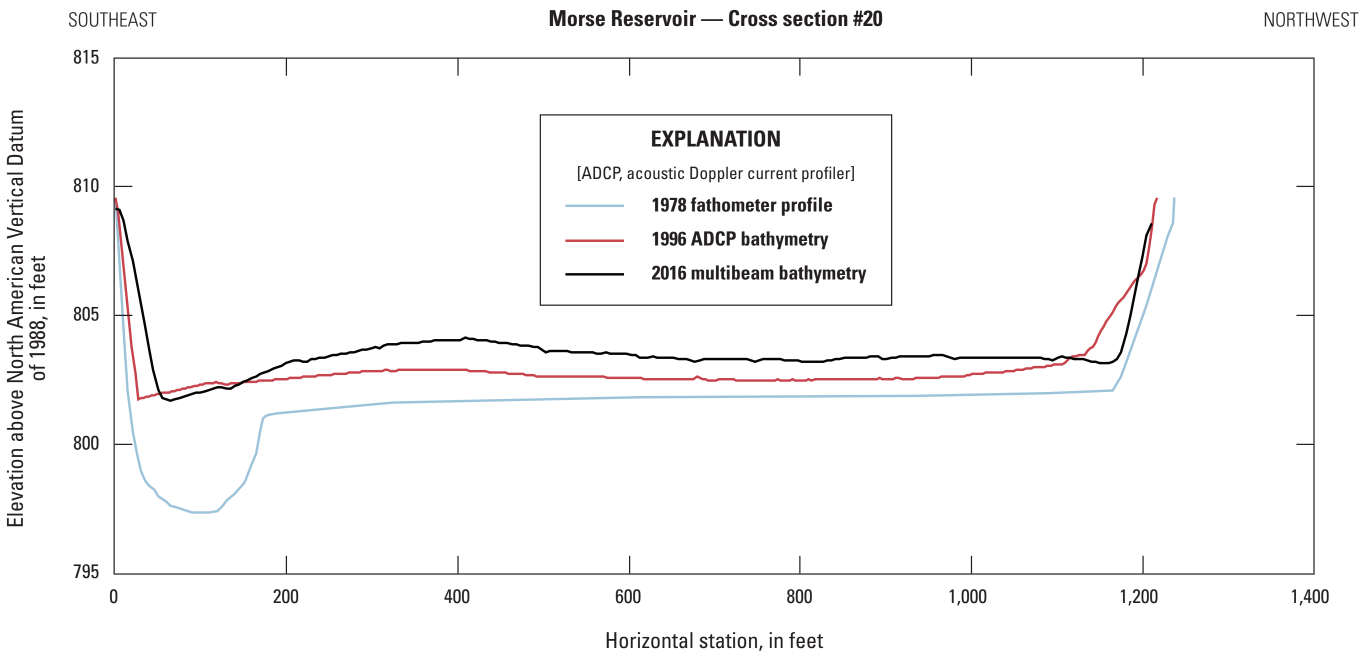


Figure 27. Cross section number 20 of Morse Reservoir from a 1978 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

merged with digital elevation model data. The updated data were compared to historical surveys to show bathymetric changes and storage capacity differences. The computed volume of Morse Reservoir was 23,136 acre-feet (7.54 billion gallons) with a surface area of 1,439 acres (62.7 million square feet). The computed volume of Geist Reservoir was 21,146 acre-feet (6.89 billion gallons) with a surface area of 1,853 acres (80.7 million square feet). The final bathymetric datasets produced from this study are available for download through a data release at https://doi.org/10.5066/P9A2ITC6.

Although differences in sonar technology and survey methods make comparisons between surveys challenging, the four comparison methods revealed an increase in sediment at the upper portion of each reservoir. The Geist Reservoir storage capacity has increased since 1996 as a result of man-made changes (for example, dredging and the addition of new coves). If the man-made changes are excluded, the storage capacity is nearly the same as in 1996. Likewise, the updated storage capacity of Morse Reservoir is nearly the same as the volume calculated from the 1996 survey. Improved survey methods can now measure areas in the reservoirs that were missed before, but this increase in volume is likely offset more or less by sedimentation in the upper portion of each reservoir which is why the volumes are similar to what was estimated from the 1996 survey. More sedimentation is evident in the main body of Morse Reservoir than in the main body of Geist Reservoir, and a subsample analysis indicates the sedimentation rate in Morse Reservoir is about twice the sedimentation rate in Geist Reservoir.

The sonar technology and survey methods have changed greatly since the last survey in 1996 and now allow for greater survey coverage. This multibeam survey is the first survey of the reservoir to be on the same resolution as the surrounding land surface. In the future (perhaps 5–10 years from this survey), a repeat multibeam bathymetric survey of each reservoir would allow for a detailed surface-to-surface comparison without concerns about interpolation effects. If a complete reservoir survey is not feasible, a partial survey focused in the upper reaches of each reservoir would still be beneficial and would reveal what sedimentation is occurring there.

This survey provides up-to-date values of storage capacity and can serve as a more accurate baseline for monitoring changes in lake bottom elevation, storage capacity, and sedimentation rates in Morse and Geist Reservoirs in the future. The results from this study can be used to inform reservoir managers, professionals, and the general public about information that is critical for operational and recreational uses. Given the sedimentation that is occurring in the upstream portion of each reservoir, diligent monitoring and reevaluation are important for the future.

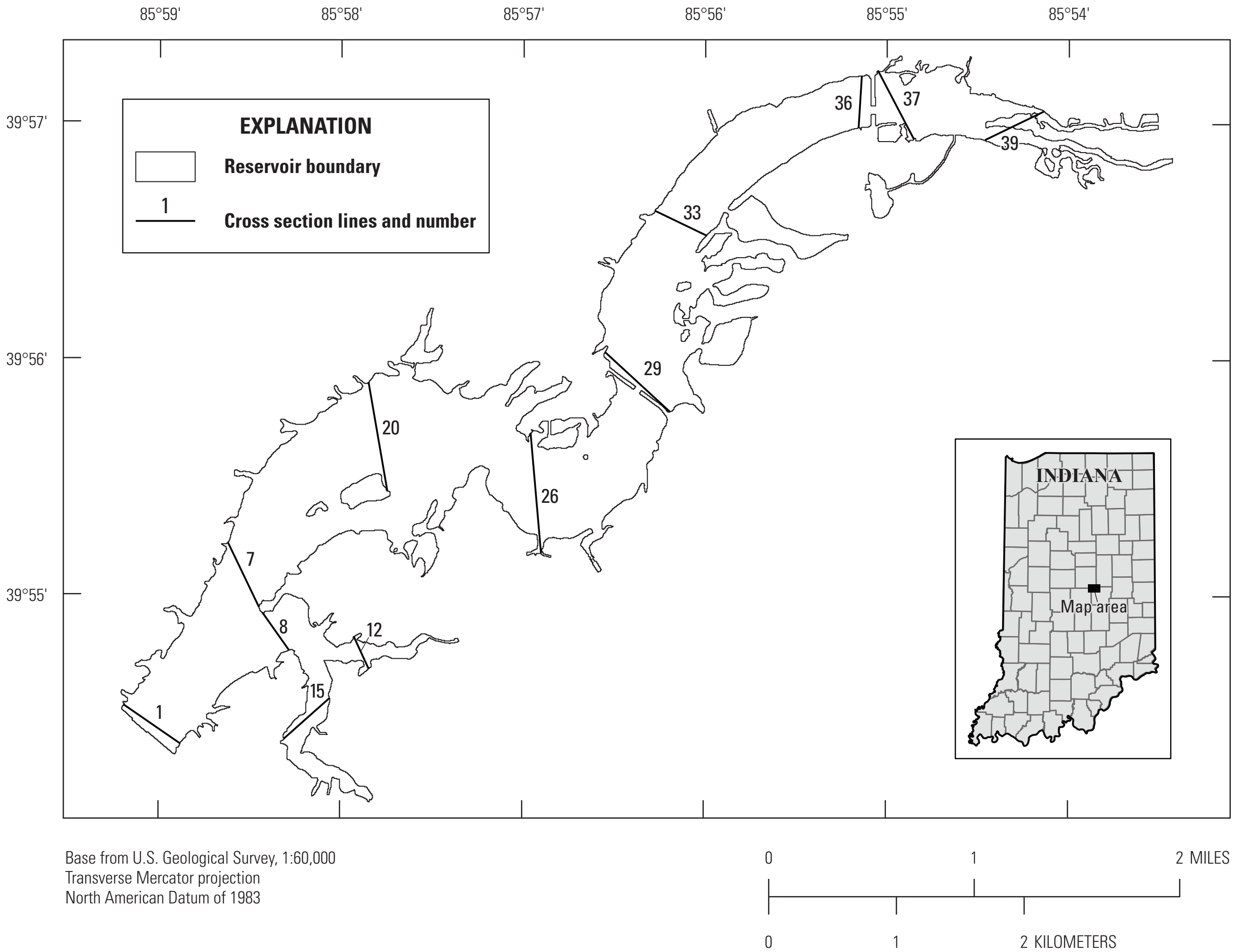


Figure 28. Locations of cross sections for Geist Reservoir.

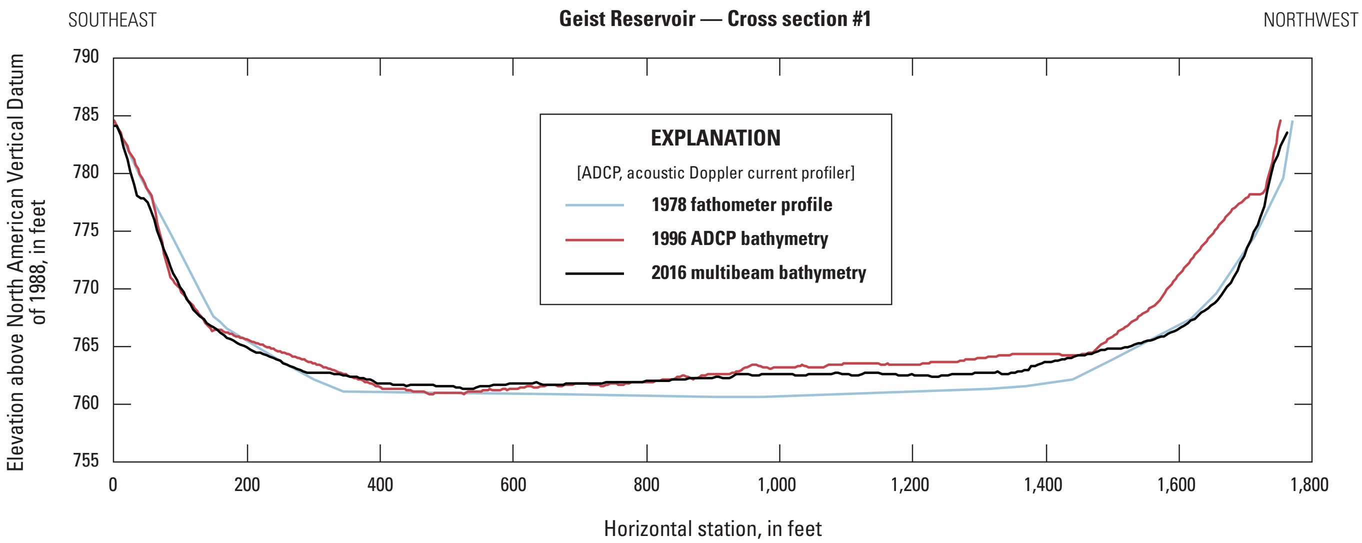


Figure 29. Cross section number 1 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

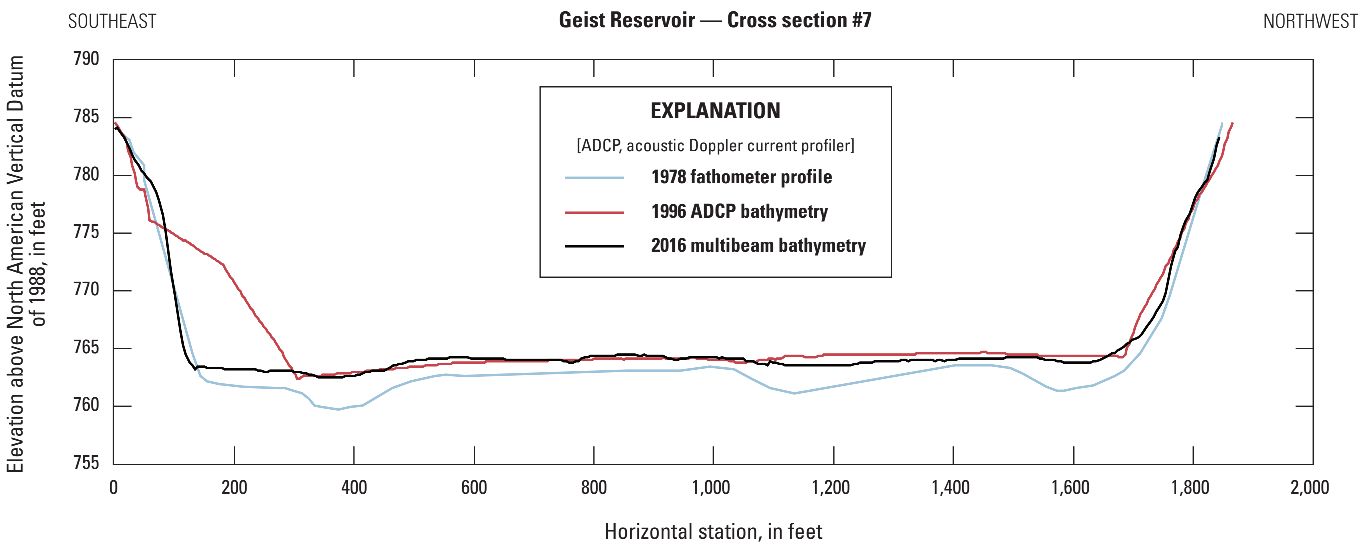


Figure 30. Cross section number 7 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

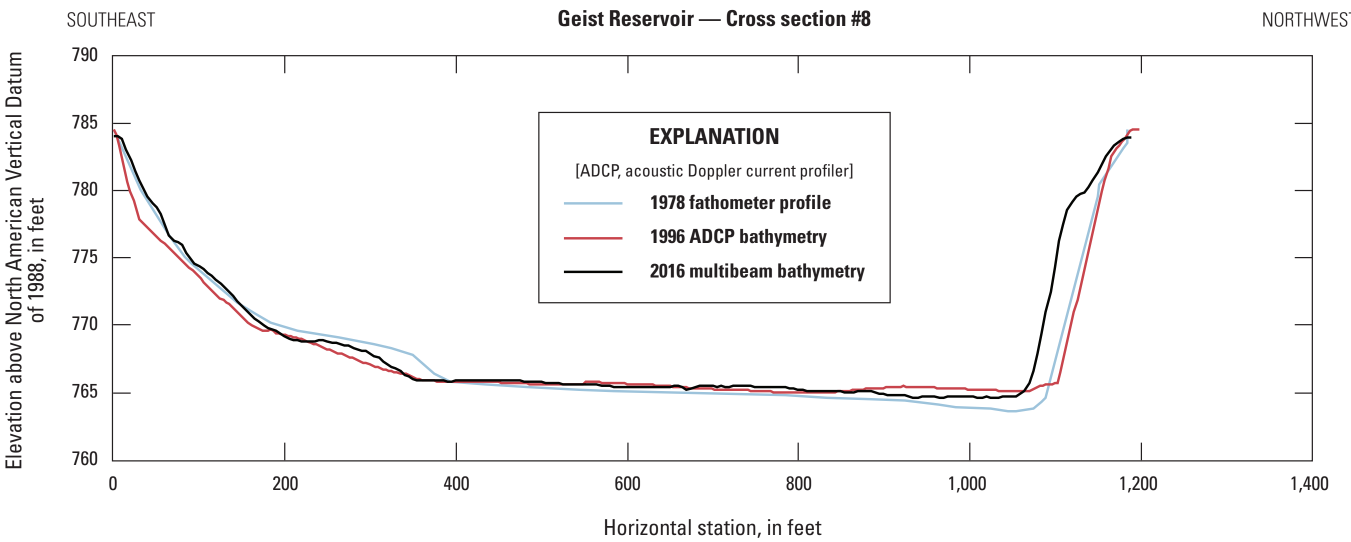


Figure 31. Cross section number 8 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

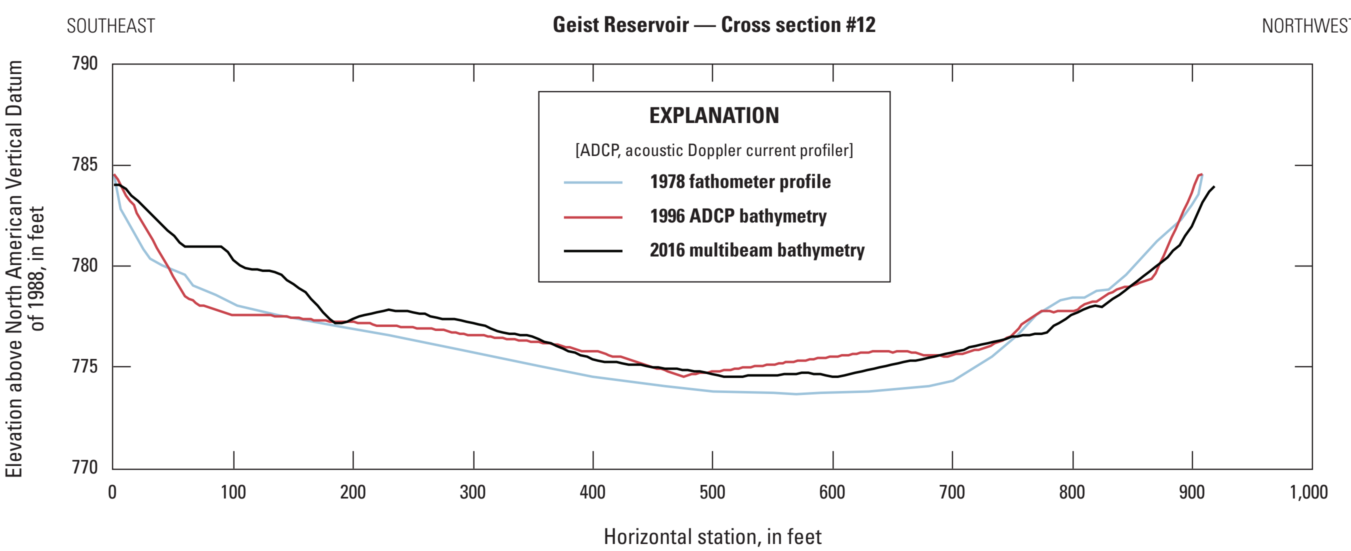


Figure 32. Cross section number 12 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

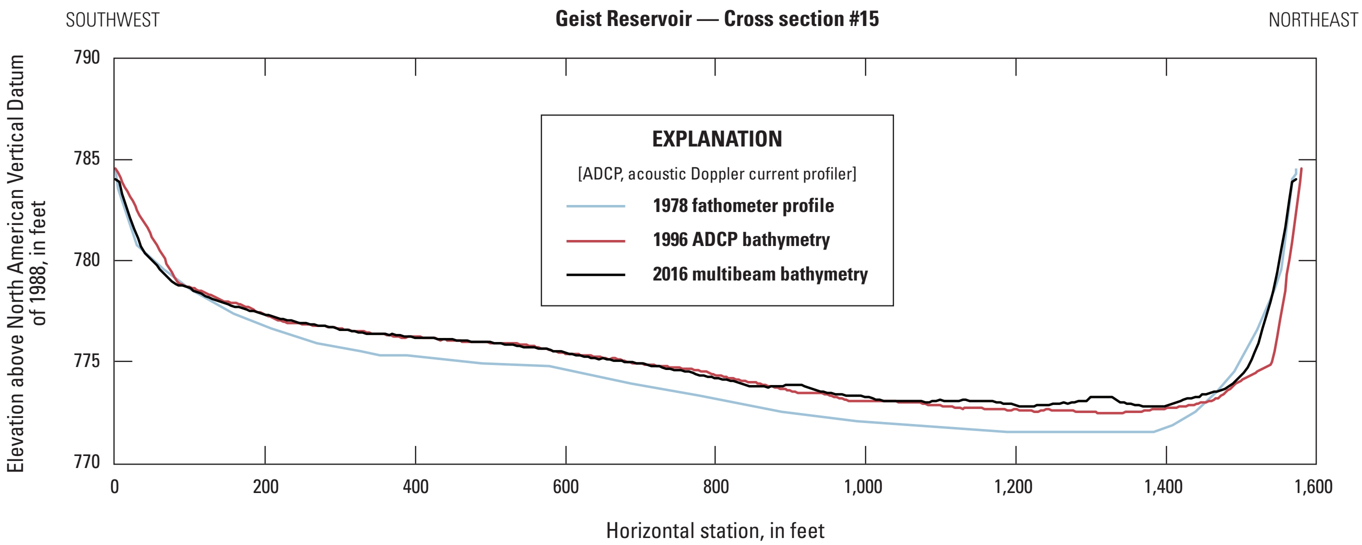


Figure 33. Cross section number 15 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

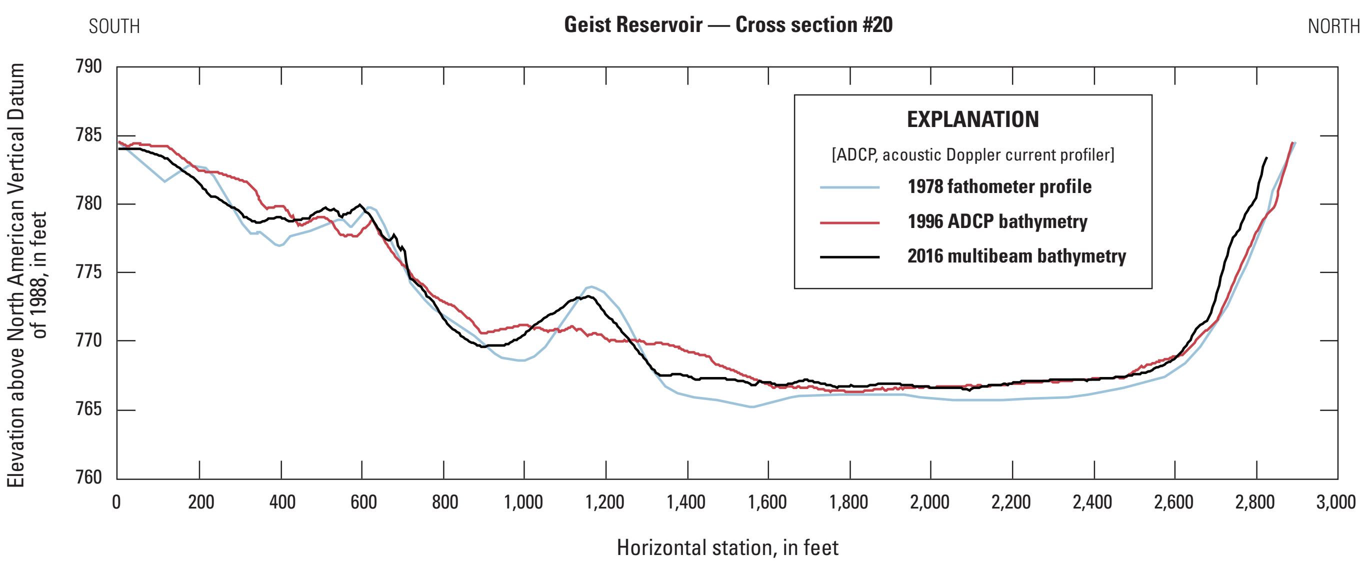


Figure 34. Cross section number 20 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

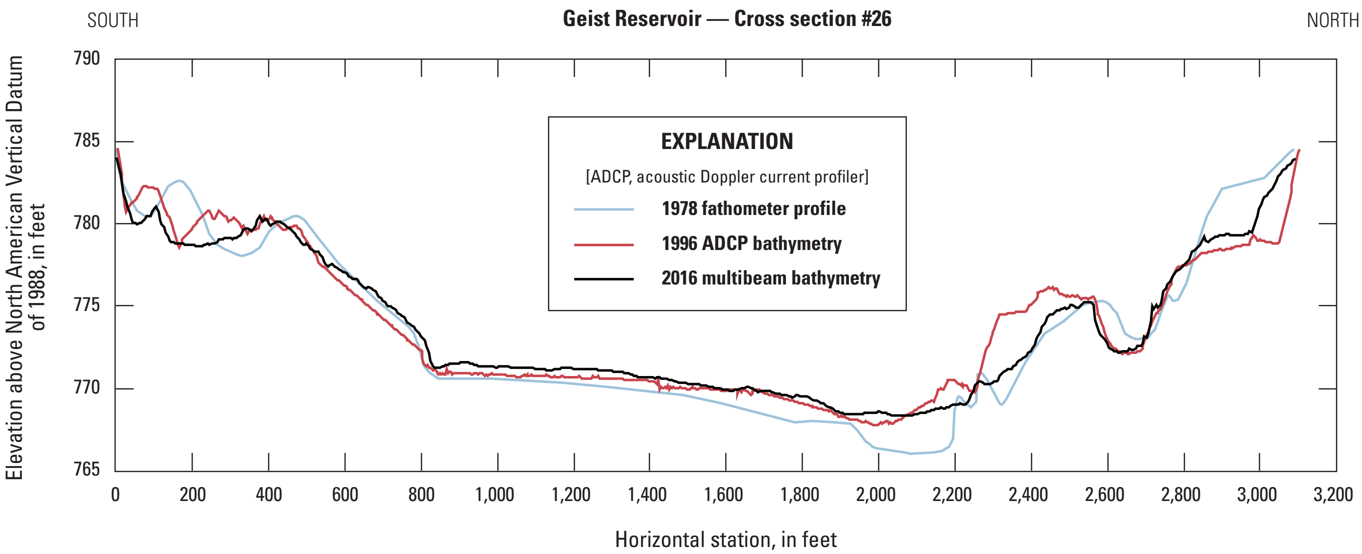


Figure 35. Cross section number 26 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

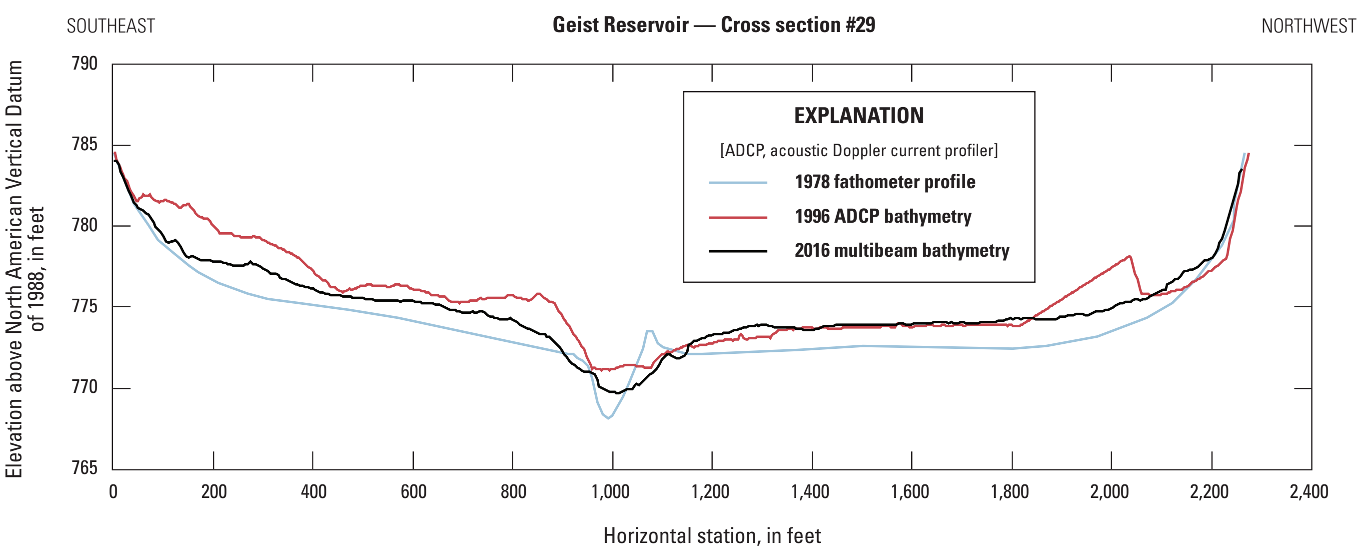


Figure 36. Cross section number 29 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

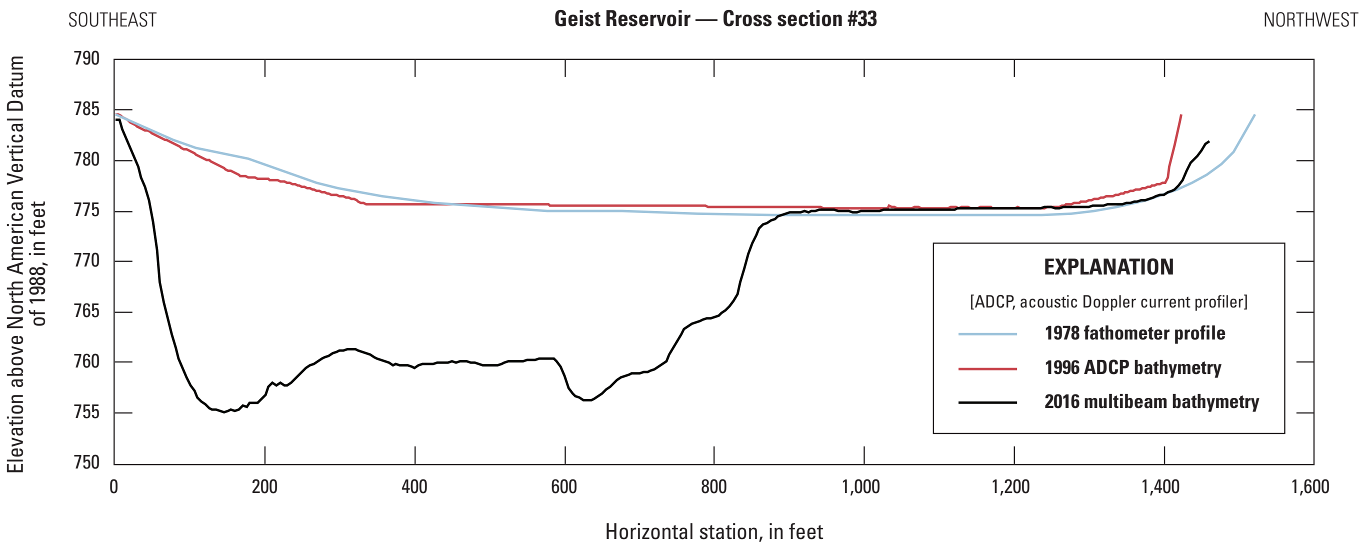


Figure 37. Cross section number 33 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

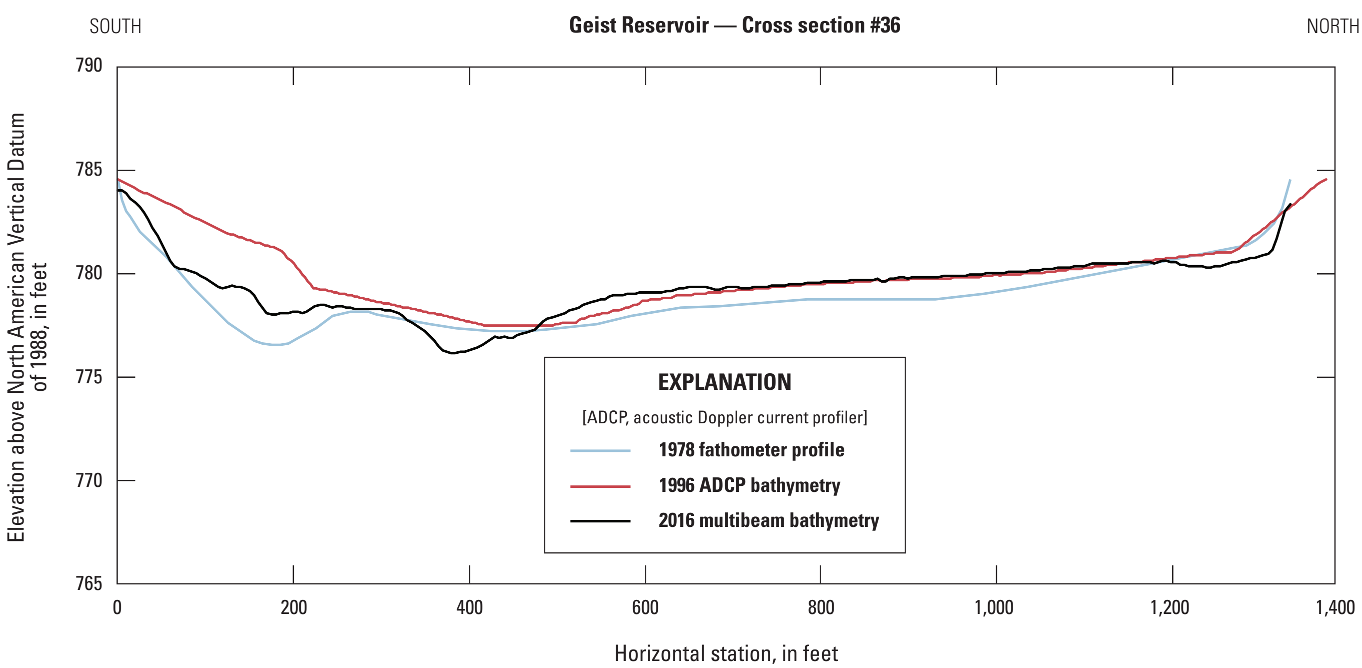


Figure 38. Cross section number 36 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

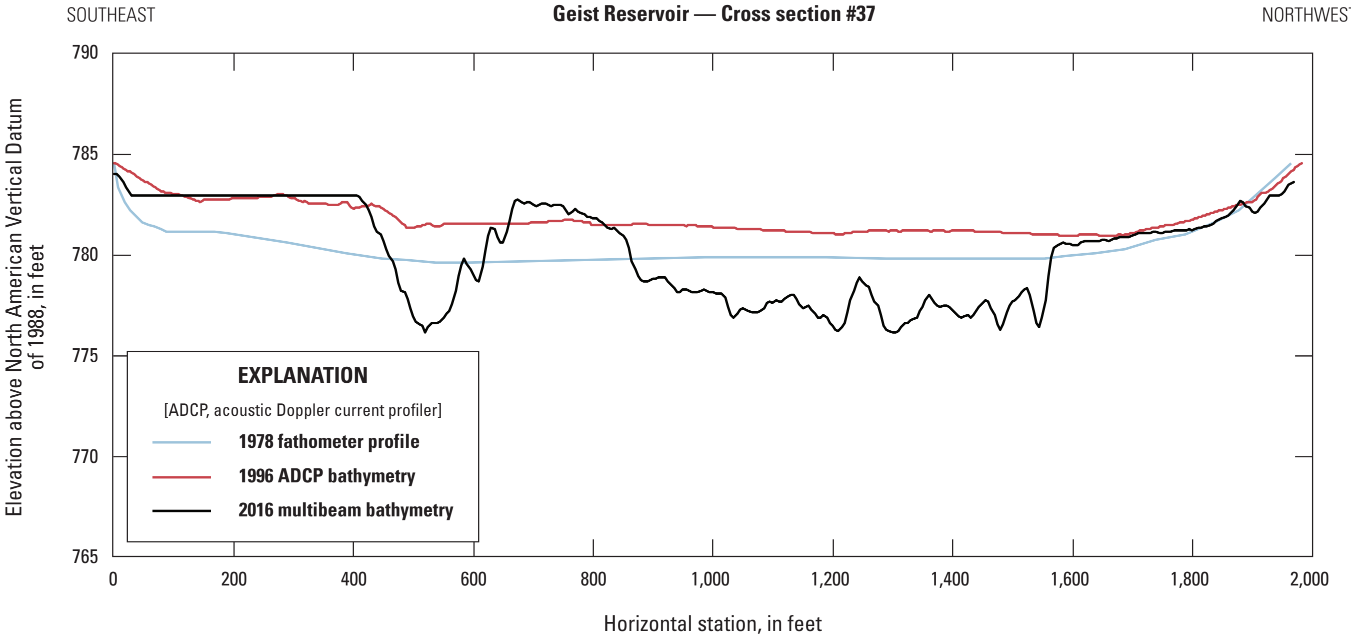


Figure 39. Cross section number 37 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

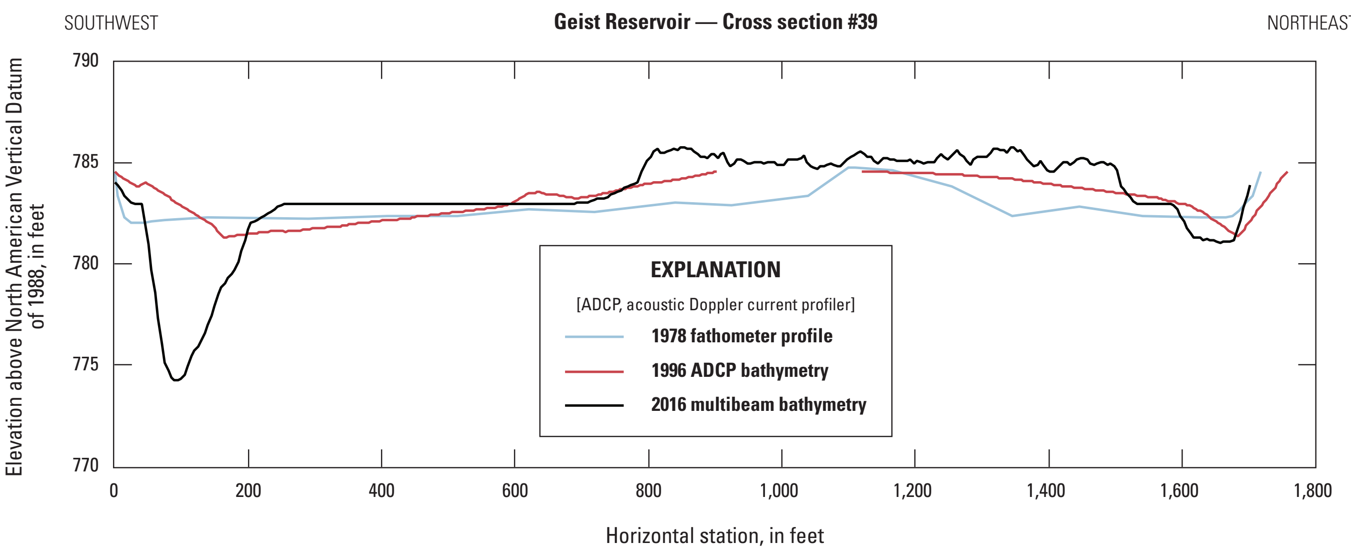


Figure 40. Cross section number 39 of Geist Reservoir from a 1980 fathometer profile, a 1996 acoustic Doppler current profiler (ADCP) bathymetry survey, and a 2016 multibeam survey.

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