

### Abstract

The U.S. Geological Survey (USGS) created bathymetric-contour and water-velocity vector maps for portions of Lake Herrington within 600 feet of the face of Dix Dam near Burgin, Kentucky. The mapping was in support of a study of noninvasive acoustic technology for assessing structural integrity of dams, both as a routine inspection tool or as an emergency tool during hydrologic events, such as high water or flooding. In April 2010, scientists from the USGS used a boat-mounted transducer and echo sounder to obtain bathymetric data to characterize lakebed relief and sediment distribution under a closed-intake condition. Also in April 2010, an acoustic Doppler current profiler was employed to measure water velocity and flow direction in the lake to locate velocities moving toward the dam face and, possibly, dam leakage.

The bathymetric survey showed the present condition of fill in the reservoir since the dam was completed, as well as provided an outline of the lake floor. The velocity survey indicated no discernible flow pattern or direction within the study area; only one transect had shown a difference from the others that was noticeable. The noninvasive acoustic bathymetric and velocity surveys used during the case study showed promise in locating potential dam or intake maintenance areas. Additional case studies throughout the Nation are needed to more clearly define whether the methods for noninvasive bathymetric and velocity surveys for dam safety will be successful in a variety of settings.

### Introduction

Throughout history, impoundments have been built for purposes of water supply, power generation, storage of waste materials, and recreation. As is the case with all retaining objects, dams or dikes that form impoundments are subject to forces from the contents inside, which can lead to erosion of the materials, seepage, and eventual destruction. One such instance of destruction happened in 2008, a failure of the northwest side of a dike used to contain fly ash at the TVA Kingston Fossil Fuel Plant, Roane County, Tennessee. The release extended approximately 300 acres outside of the fly ash storage areas of the plant into the main Emory River channel (U.S. Environmental Protection Agency, 2010). Although dam and dike failures cannot always be foreseen, inspections of impoundments can provide snapshots of current conditions and identify potential problems. Periodic inspections of dams, reservoirs, and appurtenant structures typically involve use of divers for visual underwater inspections and drilling crews to sample cores of dam and dike materials in areas of concern (Interagency Committee on Dam Safety, 2004).

There is a need to collect accurate georeferenced bathymetric and velocity data of impoundments throughout the Nation through use of noninvasive techniques in order to supplement traditional inspection methods and provide dam and reservoir managers with adequate tools to make decisions. Noninvasive techniques using acoustic instrumentation allow for minimal disturbance and improved safety conditions within a study area. The capabilities of acoustic technology can supply background data for future construction as well as focused data needed for routine inspection or emergency repair work.

On April 6 and 8, 2010, the U.S. Geological Survey (USGS), in cooperation with Kentucky Utilities Company (KU), conducted noninvasive bathymetric and velocity surveys as a case study at Herrington Lake at Dix Dam near Burgin, Kentucky. The goal of the data collection was to evaluate acoustic technology in an impoundment environment near the dam and intake and to start developing a methodology for using bathymetry and velocity surveys as components of an overall engineering strategy for assessing dam safety. This work supports the USGS mission "to provide the Nation with reliable, impartial information to describe and understand the Earth. This information is used to minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; enhance and protect the quality of life; and contribute to wise economic and physical development." Given this mission, USGS researchers have collected accurate bathymetry data at many sites throughout the country to provide partner organizations with useful information and assist them in managing their facilities. Specifically, this research falls in line with the USGS science strategies "A Water Census of the United States" and "A National Hazards, Risk, and Resilience Assessment Program" (U.S. Geological Survey, 2008).

### Purpose and Scope

This report details the case study at Herrington Lake at Dix Dam on April 6 and 8, 2010. Three goals were targeted for the study:

1. Acquire accurate georeferenced bathymetry and velocity surveys at a case study site.
2. Collect data at a constant low level with no discharge of water.
3. Produce findings that demonstrate whether acoustic technology may be utilized as a tool for impoundment safety.

KU impounded the Dix River behind Dix Dam to create Herrington Lake in the 1920s, mainly for hydropower generation. Dix Dam is approximately 2 miles upstream of the confluence of the Dix River with the Kentucky River (fig. 1). Dix Dam is a rock-filled dam with one water intake. The intake is approximately 300 feet (ft) southwest of the dam face and approximately 700 ft southeast of the spillway. The dam and intake pipes are regularly inspected as part of dam safety procedures. Regular inspections of the impoundment are conducted to ensure the structure is safe. A typical dam-safety inspection at Dix Dam would consist of a diver team looking below the water surface to inspect the dam and intake structures to identify areas of concern. A drilling team would then be used to explore the areas of concern. Voids or holes, if identified, would be investigated and repaired.

During the case study, the area of concern was approximately 800 ft wide and 600 ft long, perpendicular to the dam face. The water intake was closed during the case study, and overflow gates were not in use because the lake level was lower than the gates. The elevation of the lake level was 720.5 ft, and the weather was calm with no precipitation.

Read-me files and the extensive data files from the bathymetry and velocity can be downloaded from <http://pubs.usgs.gov/sim/3198/>.

### Acknowledgments

The USGS thanks Kentucky Utilities Company for granting access to their property for the survey. The author also thanks Shawn LeMaster, Ed Puckett, and Ellen Barringer from the Louisville USGS office for their work in collecting, filtering, and processing the data.

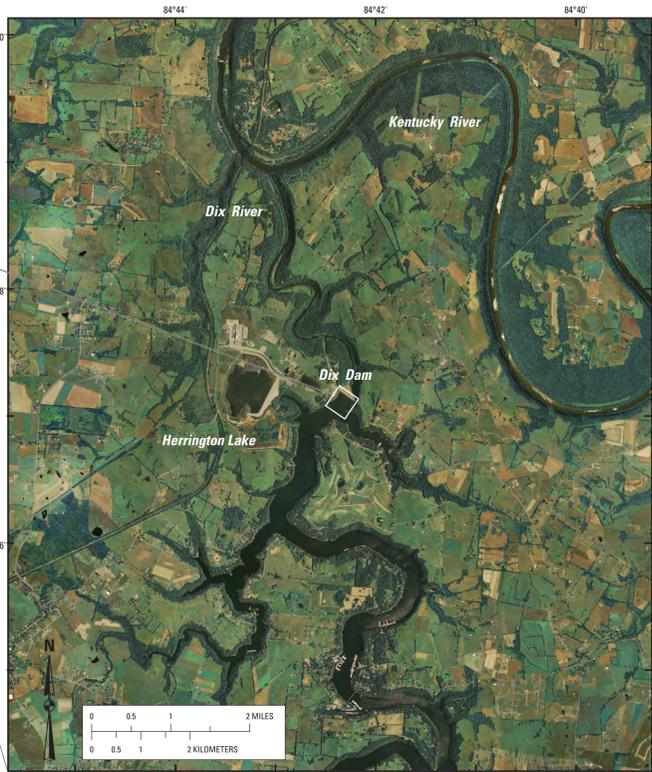


Image produced by PhotoScience Inc. for Kentucky Division of Geographic Information, 2008. Lambert Conformal Conic Projection NAD83

Figure 1. Location of the study area at Herrington Lake near Burgin, Ky.

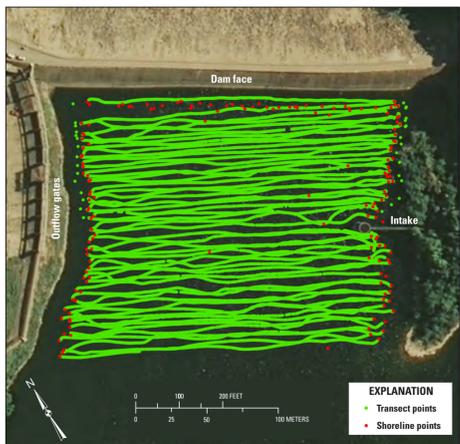
### Methods

USGS bathymetry surveys usually employ a hydroacoustic apparatus called an echo sounder. An echo sounder uses the frequency of sound to measure the distance from surface to bottom in a water body. USGS velocity surveys employ an acoustic Doppler current profiler (ADCP). ADCPs use Christian Doppler's principle (published in 1842) that relates the change in frequency of a source to the relative velocities of the source and the observer. Use of an ADCP to measure velocities allows for unsteady, bidirectional flows to be more easily recognized than is possible with earlier types of current-measurement systems (Mueller and Wagner, 2009).

Bathymetric and velocity surveys were made on April 6 and 8, 2010, respectively, by way of a 19-ft boat with a 2-inch pipe mount that was used to affix the acoustic equipment. A boat with direct-mounted equipment allowed for the best means for data collection. An initial visit to the site on March 30, 2010, was made to determine conditions at the site, safety allowances, and case study area. The case study area consisted only of the location near the dam and intake. As mentioned previously, the study area was approximately 800 ft wide and approximately 600 ft long, perpendicular to the dam face (fig. 2). The intake was shut down and was not discharging during the time of the surveys. The level of the lake was drawn down to minimum level so the survey could be done. The lake elevation for both surveys stayed constant at 720.5 ft. The weather on April 6, 2010, was clear and calm, with an average temperature of 23.8 degrees Celsius (°C). On April 8, 2010, the weather was still calm but overcast, with an average temperature of 12.2°C.

The bathymetric survey was completed on April 6, 2010. The following equipment and software were used to collect the bathymetric data:

- A 210-kilohertz (kHz) Airmar™ transducer and a Navisound™ 210 Reson echo sounder were used. The Navisound™ 210 Reson echo sounder had a depth range from 0.6 to 600 meters (m) (Reson, Inc., 2005).
- A Trimble™ Differential Global Positioning System (DGPS) was used for horizontal positioning during the survey.



Base from U.S. Geological Survey digital data, 2009. Lambert Conformal Conic Projection NAD83

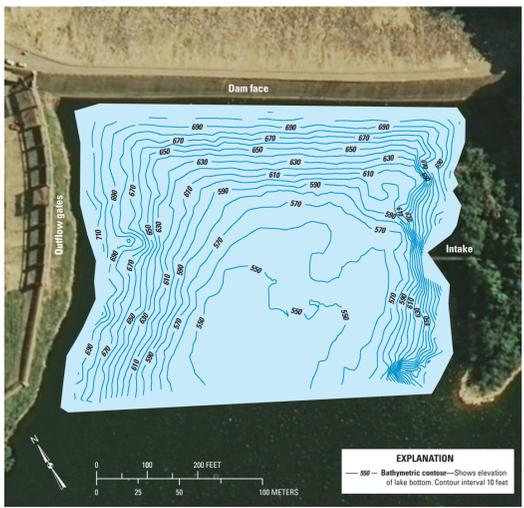
Figure 2. Bathymetric data-collection points for Herrington Lake near the dam, April 6, 2010.

- The HYPACK™ navigation software package installed on a laptop computer was used to integrate the lakebed depths along with the DGPS horizontal position data and to display the location of the boat on a georeferenced aerial photo of the lake for navigation.
- A laser rangefinder computed distance measurements and was used with a compass module, enabling determination of accurate azimuths and delineation of the shoreline.
- The velocity survey was completed on April 8, 2010. The following equipment and software were used to collect the velocity data:
  - A 600-kHz Teledyne RD Instruments Rio Grande™ ADCP with a 0.7- to 75-m profiling range (Teledyne RD Instruments, 2010) was used to measure velocities.
  - A Trimble™ DGPS system was used for horizontal positioning during the survey.
- The WinRiver II™ software package installed on a laptop computer was used to set configurations, collect data, and play back previous transects while integrating with a DGPS (Teledyne RD Instruments, 2006).
- A laser rangefinder computed distance measurements and was used with a compass module, enabling determination of accurate azimuths and delineation of the shoreline.

### Bathymetric Data Collection and Processing

Bathymetric data collection followed predetermined transect lines created in HYPACK™ (fig. 2) to ensure complete coverage of the lake study area. The area was photographed when the lake level was not gaged and was presumed higher than that on the day of the surveys; the water line in the figure 2 image therefore does not match with the survey water line. At the start of the bathymetric survey, the boat operator held the boat stationary on one side of the plan line near the shore. The echo sounder and DGPS were started, and depths and position data were simultaneously recorded within HYPACK™. The operator of the laser rangefinder measured and recorded the distance and azimuth reading to the shoreline edge of water, shouting "mark" for the equipment operator to mark the edge in HYPACK™. Subsequently, a distance and bearing were entered to define the shoreline point. The boat operator then proceeded across the lake, following the predetermined transect line to its opposite end. During the survey, the equipment operator took detailed notes to assist in data processing in the field and office. As the boat made its approach to the shoreline, the boat was stopped, held in position, and steadied to allow the operator of the laser rangefinder and equipment operator to mark the ending shoreline location. The recording was stopped, and the crew proceeded to the next transect to repeat the process (Hittle and Ruby, 2008).

Raw bathymetric data were processed within HYPACK™ to filter (1) problems related to the echo sounder processing a multiple-return acoustic signal in shallow water, which causes the measured depth to be twice the actual depth; (2) invalid GPS positions; and (3) redundant areas along the banks caused by overlap of data collection at the ends of various cross sections. Analog printouts of the bottom profiles were produced during data collection and used as a quality-assurance measure in bathymetric data processing, because multiple-return errors can be identified in the analog printouts. The data were first reviewed and filtered within HYPACK™ and then were compared to all supporting field notes and analog printouts. The processed bathymetric data (including edge-of-water points) were next exported from HYPACK™ into a text file that included geographic coordinates and a corresponding depth (Hittle and Ruby, 2008). The water depths were then subtracted from the water-surface elevation to establish an elevation for the lakebed. HYPACK™ was finally used to produce a study-area map with 10-ft bathymetric contour intervals (fig. 3). This was accomplished by converting the dataset into a matrix and then building a Triangular Irregular Network (TIN) model for the final map product.



Base from U.S. Geological Survey digital data, 2009. Lambert Conformal Conic Projection NAD83

Figure 3. Bathymetric contours of Herrington Lake near the dam, April 6, 2010.

### Velocity Data Collection and Processing

Advances in velocity-measurement technology allow three-dimensional velocities to be measured from a moving boat by using an ADCP (Oberg and Mueller, 1994; Mueller and Wagner, 2009), and all velocities in this study were measured with an ADCP. Three-dimensional velocities were measured from approximately 2 ft beneath the water surface to within 6 percent of the depth to the bottom. Depths ranged from 80 to 160 ft during the survey. The locations for velocity data collection were determined by the number of expansion joints on the face of the dam (fig. 4). The locations were chosen because of potential areas of concern on the dam face where the expansion joints aligned, and the velocity data collected would serve as a tool to locate velocities moving toward the dam face and, possibly, dam leakage. Velocity data were collected along transects that were perpendicular to the bathymetric transects. Each transect was started at the warning buoys, which were approximately 600 ft upstream from the dam. The first transect was initiated on the west side of the dam near the overflow gates, and following transect started in succession from the previous. The ADCP and DGPS were started simultaneously by use of the WinRiver II™ software (Teledyne RD Instruments, 2006) on the west side of the dam near the overflow gates, and the boat was then navigated directly toward the adjacent expansion joint. Field notes were kept to document any errors, anomalies, or issues experienced during each transect. Fourteen transects were collected during the velocity survey.

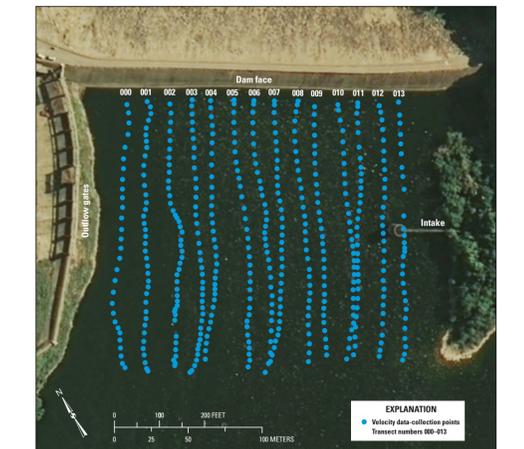
Each transect was processed with WinRiver II™ software, in accordance with established USGS techniques (Mueller and Wagner, 2009). Three-dimensional velocity data were exported from WinRiver II™ into a Geographic Information System (GIS) to create an example illustration of the mean vector velocities from the top 10 ft of the lake near the dam (fig. 5).

### Bathymetric Survey Quality Assurance/Calibration

The bathymetric survey was quality assured by using the echo sounder and a bar-check method. The Navisound™ 210 Reson echo sounder has an accuracy of 0.03 ft at 210 kHz (Reson, Inc., 2005). A built-in bar-check utility enabled depth verification by using a correction for the speed of sound. The U.S. Army Corps of Engineers suggests performing the bar-check procedure to ensure the adequate calibration of an echo sounder (U.S. Army Corps of Engineers, 2002). Multidepth bar checks of the echo sounder were conducted by lowering a 2-ft by 4-ft plate to known depths between 5 and 30 ft at 5-ft increments. The echo sounder always reported within plus or minus 0.1 ft of the bar check. A bar check was also conducted at a depth of 100 ft by using a boat-mounted crane with a motorized crank equipped with a 100-pound sounding weight to lower the plate. A counter mounted within the boom unit that was incremented to tenths of feet measured the actual depth. The vertical accuracy of the echo sounder was conservatively estimated to be plus or minus 0.1 ft. The bar-check process was repeated four times throughout the day to ensure accurate data collection (Hittle and Ruby, 2008). The survey was completed on a calm day to minimize the effects of wave action on the accuracy of the depth data.

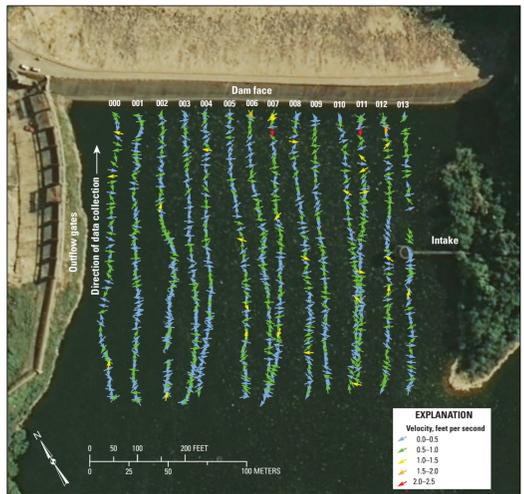
Lake-elevation stage readings were documented by using staff plates fastened to the west side of the dam intakes, which is the primary reference for Herrington Lake's elevation, at the beginning and end of each survey day to determine any changes in the lake-surface elevation. The elevation of the lake was constant during the bathymetric survey. The echo sounder recorded the depth data both digitally and by analog signal via a built-in thermal paper recorder that was used for comparison to the digital data during processing in the office.

The accuracy of the distance measurements from the transducer location to the shoreline point data was enhanced by equipment configurations and operator locations. The equipment on the boat was configured so that the transducer was mounted on the starboard side, and the DGPS was mounted directly above the transducer. Readings taken from the laser rangefinder from this position would correlate the lakeshore with the boat/transducer position. The equipment operator sat on the port side to offset the boat operator on the starboard side, reducing the roll of the boat during surveys (Hittle and Ruby, 2008).



Base from U.S. Geological Survey digital data, 2009. Lambert Conformal Conic Projection NAD83

Figure 4. Velocity data-collection points for Herrington Lake near the dam, April 8, 2010.



Base from U.S. Geological Survey digital data, 2009. Lambert Conformal Conic Projection NAD83

Figure 5. Velocity vectors near top with bathymetric contours of Herrington Lake near the dam, April 8, 2010.

### Velocity Survey Quality Assurance/Calibration

A series of pre-measurement field procedures are mandated by USGS to ensure the ADCP will perform accurately for the conditions present, and procedures were conducted in accordance with these documented USGS methods (Mueller and Wagner, 2009). The procedures were an instrument diagnostic check, water temperature measurement, and compass calibration. The ADCP equipment on the boat was configured such that the ADCP was mounted on the starboard side and the DGPS was mounted directly above it. As with the bathymetric survey, the equipment operator sat on the port side to offset the boat operator on the starboard side to reduce pitch and roll. The three pre-measurement field procedures (instrumentation diagnostics check, water temperature measurement, and compass calibration) were done in the middle of

the study area. The independent water temperature check was done by using a YSI 30 temperature meter that was checked during an yearly five-point temperature inspection (Wagner and others, 2006). The compass calibration resulted in an error of 1.2 degrees.

### Survey Results

The noninvasive acoustic bathymetric and velocity surveys used in this case study show promise in locating potential dam or intake maintenance areas; however, additional case studies throughout the Nation are needed to more clearly define whether the methods for noninvasive bathymetric and velocity surveys for dam safety will be successful in a variety of settings. The bathymetric survey results from the case study can be used to help determine how much sediment has filled the reservoir since the dam was completed, as well as provide an outline of the lake floor. The velocity survey indicated that there is no discernible flow pattern or direction within the study area. For this particular case study, only transect 012 showed a slightly varied flow pattern from the other transects across the lake (not visible in figure 5 because the velocity vectors are averaged and the slightly varied flow pattern is obscured as a result). Further testing at the same study area at different conditions (higher levels in the lake, intake releasing at half open and also at full open) would help confirm differences at transect 012.

### References Cited

Hittle, C.D., and Ruby, A.T., III, 2008, Bathymetric surveys of Lake Arthur and Raccoon Lake, Pennsylvania, June 2007: U.S. Geological Survey Data Series 357, p. 3, 4, 9.

Interagency Committee on Dam Safety, 2004, Federal guidelines for dam safety: Accessed November 15, 2011, at <http://www.fema.gov/library/viewRecord.do?id=1578>.

Mueller, D.S., and Wagner, C.R., 2009, Measuring discharge with acoustic Doppler current profilers from a moving boat: U.S. Geological Survey Techniques and Methods 3A-22, 72 p., available at <http://pubs.water.usgs.gov/tm3a22>.

Oberg, K.A., and Mueller, D.S., 1994, Recent applications of acoustic Doppler current profilers, in Fundamentals and advancements in hydraulic measurements and experimentation, Buffalo, N.Y., 1994, Proceedings: Hydraulics Division/American Society of Civil Engineers (ASCE), p. 341-350.

Reson, Inc., 2005, Navisound 200/400 users guide: Navisound™ 100, 200 & 400 series operator's manual, version 4.01, 177 p.

Teledyne RD Instruments, 2006, WinRiver II quick start guide: San Diego, Calif., Teledyne RD Instruments, P/N 957-6230-00, 3 p.

Teledyne RD Instruments, 2010, Workhorse Rio Grande ADCP: Accessed Nov. 5, 2010, at <http://www.rdinstruments.com/rio.aspx>.

U.S. Army Corps of Engineers, 2002, Engineering and design—Hydrographic surveying: Washington, D.C., manual no. 1110 2-1003, 510 p.

U.S. Environmental Protection Agency, 2010, U.S. Environmental Protection Agency Action Memorandum (AM) fact sheet on selected Engineering Evaluation/Cost Analysis (EE/CA) Alternative Kingston Fossil Fuel Plant Release Site, Harriman, Roane County, Tennessee: 4 p., accessed Dec. 12, 2011, at [http://www.epa.gov/region4/kingston/FINAL\\_TVA\\_EECA\\_Fact\\_Sheet051810.pdf](http://www.epa.gov/region4/kingston/FINAL_TVA_EECA_Fact_Sheet051810.pdf).

U.S. Geological Survey, 2008, Facing tomorrow's challenges—An overview: U.S. Geological Survey Fact Sheet 2008-3008, 4 p.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3, 51 p. + 8 attachments; accessed September 30, 2011, at <http://pubs.water.usgs.gov/tm1d3>.

### Conversion Factors, Abbreviations, and Datum Information

Inch/Pound to SI		
Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

SI to Inch/Pound		
Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32

Vertical coordinate information is referenced to the Kentucky Utilities Datum, which can be converted to the National Geodetic Vertical Datum of 1929 and the National Geodetic Vertical Datum of 1988 as shown below.

To convert from	Subtract	To obtain
	Vertical datum	
Kentucky Utilities Datum	13.81	NGVD 29
Kentucky Utilities Datum	14.31	NAVD 88

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

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

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## Methods for Noninvasive Bathymetric and Velocity Surveys for Impoundment Safety—A Case Study of Herrington Lake at Dix Dam near Burgin, Kentucky

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