Bathymetric Map and Surface Area and Capacity Table for Beaver Lake near Rogers, Arkansas, 2018

By
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Introduction

Beaver Lake was constructed in 1966 on the White River in the northwest corner of Arkansas (fig. 1) for flood control, hydroelectric power, public water supply, and recreation. The surface area of Beaver Lake is about 27,900 acres (table 1) and approximately 449 miles of shoreline are at the conservation pool level (1,120 feet [ft] above the North American Vertical Datum of 1988; U.S. Army Corps of Engineers, 2019). Sedimentation in reservoirs can result in reduced water storage capacity and a reduction in usable aquatic habitat. Therefore, accurate and up-to-date estimates of reservoir water capacity are important for managing pool levels, power generation, recreation, and downstream aquatic habitat. Many of the lakes operated by the U.S. Army Corps of Engineers are periodically surveyed to monitor bathymetric changes that affect water capacity. In October 2018, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, completed one such survey of Beaver Lake using a multibeam echosounder (MBES). The echosounder data were combined with light detection and ranging (lidar) data to prepare a bathymetric map and a surface area and capacity table.

Methods

A bathymetric survey of Beaver Lake was completed between October 2 and 28, 2018, using methods similar to those described by Richards and others (2019). The average water-surface elevation of Beaver Lake during the survey was 1,117.5 ft. A bathymetric surface and a surface area and capacity table were created from a combination of the bathymetric survey data with the lidar topographic data.

Bathymetric Data Collection

Bathymetric data (water depths and positions) (fig. 2) were collected using a high-resolution multibeam mapping system (MBMS). The data were collected concurrently by two boats surveying different sections of Beaver Lake. The various components of the MBMS used for this study are described in more detail in reports on the Missouri and Mississippi Rivers in Missouri (not shown; Huizinga, 2010, 2017; Huizinga and others, 2010) and Sugar Creek water supply lake near Moberly, Missouri (not shown; Richards and others, 2019). The survey methods used to obtain the data for Beaver Lake were similar to these studies, as were the methods used to ensure data quality.

An MBMS is an integration of several individual components—the MBES, an inertial navigation system (INS), and a data-collection and data-processing computer. The MBES systems that were used were the NORBIT iWBMSh and the NORBIT iWBMSc, both operated at a frequency of 400 kilohertz (NORBIT, 2017). The iWMBSh and the iWMBSc are similar in operation to the MBES systems used in other previous studies in Missouri (Huizinga, 2010, 2017; Huizinga and others, 2010; Richards and others, 2019). Both of these MBES systems have a curved receiver array that enables bathymetric data to be collected throughout a swath range of 210 degrees. Optimum data generally are collected in a swath of less than 160 degrees (80 degrees on each side of nadir, or straight down below the MBES); nevertheless, the swath can be electronically rotated to either left or right of nadir, enabling data to be captured along sloping banks up to a depth just below the water surface. The INS—Applanix OceanMaster for the iWBMSh (Applanix Corporation, 2017) and NovAtel MarineSPAN with OEM-STIM300 for the iWBMSc (NovAtel, 2016)—provides position in three-dimensional space and measures the heave, pitch, roll, and heading of the vessel (and, thereby, the MBES) to accurately position the data received by the MBES. Survey data were collected using HYPACK/HYSWEEP software (HYPACK, Inc., 2019).

Real-time navigation during the survey used a real-time kinematic differential global positioning system solution. The navigation information from the iWBMSh was postprocessed using the POSPac Mobile Mapping Suite (MMS) software (Applanix Corporation, 2009). Postprocessing of the iWBMSc navigation information was accomplished with the Waypoint Inertial Explorer software (NovAtel, 2018). POSPac MMS and Waypoint Inertial Explorer provide tools to identify and compensate for sensor and environmental errors. These programs compute an optimally blended navigation solution from the global navigation satellite systems (GNSS) and inertial-measurement unit raw data from the INS. The location solution was further enhanced by collecting static GNSS data with a GNSS base receiver set up over a temporary reference mark near Beaver Lake, the coordinates for which were determined using techniques detailed in Rydlund and Densmore (2012), corresponding to a Level I survey. The blended navigation solution (called a "smoothed best estimate of trajectory" or "SBET" file) generated by postprocessing the daily navigation data was applied to the corresponding daily survey data.

Most of the bathymetric survey data within Beaver Lake were collected with the swath range limited to 140 degrees (70 degrees on each side of nadir). However, along the banks and in the shallow areas at the upstream ends of the lake arms, the swath range was widened to 160 degrees to cover a wider swath of the bottom. The receiver array also was electronically tilted to port or starboard as needed to enhance acquisition of bathymetric data in the shallow areas near the shoreline, in coves, and in the upper reaches of the lake arms. The electronically tilted swath was generally about 120 degrees wide, extending from about 10 degrees above horizontal on the landward side of the survey vessel to about 20 degrees past nadir below the vessel.

The bathymetric data were collected along longitudinal transect lines in the main lake area. The transect lines were spaced to create about 10- to 25-percent overlap of the survey swaths to ensure complete coverage of the lake bottom and minimize sonic shadows. Data along the shoreline were collected by navigating the boat parallel to the shore while overlapping the data collected in the main body of the lake. Cove data were collected by navigating into a cove along the approximate centerline of the cove as far as practical (generally the point at which forward progress was blocked by vegetation or water depth decreased to less than about 3 ft), pivoting the boat 180 degrees, and egressing the cove along the ingress line.

The speed of sound in water needs to be known to accurately determine the depths acquired by a MBES. In a lake, the speed of sound in the water commonly varies in space and time. To mitigate variations in sound speed near the water surface, sound velocity data are collected at the MBES head continuously throughout the survey; however, the speed of sound also can vary over the water column because of water temperature variations with depth. Therefore, sound velocity profiles were measured with a sound velocity probe at various locations throughout each survey day and were applied during postprocessing in the HYPACK/HYSWEEP software.

Preparation for the bathymetric survey, data collection during the survey, and postprocessing were done in HYPACK/HYSWEEP software (HYPACK, Inc., 2019). During postprocessing, the data were georeferenced using the navigation and position solution data in the SBET file and visualized in HYPACK/HYSWEEP as a triangulated irregular network (TIN) surface or a point cloud. The acquired depth data were processed further to apply sound velocity profiles, to apply patch test corrections, and to remove data spikes and other spurious points, often caused by fish and submerged woody debris. The georeferenced point data were then filtered and reduced to a 3.28-ft data resolution and exported to a comma-delimited text file.

Bathymetric Surface and Contour Map Creation

About 107,000,000 data points, spaced 3.28-ft horizontally, were exported from the raw data collected during the 2018 survey (Ellis and others, 2019). For the survey, the vertical datum was the North American Vertical Datum of 1988 using the geoid model GEOID12b and the horizontal datum was the North American Datum of 1983. Geographic information system (GIS) software was used to filter the 3.28-ft spaced bathymetric data points so that the points would be spaced no closer than about 16.4 ft apart. The data reduction retained about 3,580,000 surveyed data points from the 2018 MBES survey.

Data outside the MBES survey extent (fig. 2) and between 1,052 and 1,284 ft in elevation were obtained from the National Elevation Dataset (NED). The NED data were derived from lidar data collected in 2015 and 2016 and were gridded to a 3.28-ft spacing (https://viewer.nationalmap.gov/basic/). These data define the upland areas of Beaver Lake. Approximately 1,510,000 lidar data points were used.

In addition to the MBES and lidar data, additional data in bathymetric surface analyses were developed using the linear enforcement techniques described in Wilson and Richards (2006). About 51,100 points were created based on surrounding MBES and lidar data values to anchor the bathymetric surface in areas of sparse data in the upper ends of coves where the water was too shallow for the MBES equipment.

The MBES, lidar, and linearly enforced cove point datasets (a total of about 5,140,000 points) were used to produce a three-dimensional TIN surface (also referred to as a "bathymetric surface") of the lake-bottom elevations. A surface area and capacity table at specified lake water-surface elevations was produced from the three-dimensional TIN surface (table 1). The surface was contoured at a 20-ft interval using GIS software, and the contours were cartographically smoothed and edited to create a bathymetric contour map (fig. 2) using the techniques of Wilson and Richards (2006).

Bathymetric Data Collection Quality Assurance

The principal quality-assurance measures for the MBMS were assessed in real time during the survey. The MBMS operator continuously assessed the quality of the data collected during the survey by making observations of across-track swaths (such as convex, concave, or skewed bed returns in flat, smooth bottoms), noting data-quality flags and alarms from the MBES and the INS, and inspecting comparisons between adjacent overlapping swaths. In addition to the real-time quality-assurance assessments during the survey, beam-angle checks and a suite of patch tests were done during the survey to ensure that quality data were acquired from the MBMS.

Beam-Angle Check

A beam-angle check is used to determine the accuracy of the depth readings obtained by the outer beams (greater than 25 degrees from nadir) of the MBES (U.S. Army Corps of Engineers, 2013). The accuracy of the outer beams may change with time because of inaccurate sound velocities, physical configuration changes, and water depth. A beam-angle check for each MBES was done during the survey, and the results were within the recommended performance standards used by the U.S. Army Corps of Engineers for hydrographic surveys for all the representative angles below 70 degrees (U.S. Army Corps of Engineers, 2013). Therefore, the central 140 degrees of the echosounder swath can be used with confidence.

Patch Tests

Patch tests are a series of dynamic calibration tests that are used to check for subtle variations in the orientation and timing of the MBES with respect to the INS and real-world coordinates. The patch tests are used to determine timing offsets caused by latency between the MBES and the INS and angular offsets to roll, pitch, and yaw caused by the alignment of the transducer head (Huizinga, 2017). These offsets have been observed to be essentially constant for a given survey, barring an event that causes the mount to change such as striking a floating or submerged object (see Huizinga, 2017). The offsets determined in the patch test are applied when processing the data collected during a survey. Patch tests were completed at Beaver Lake, and angular offsets were updated in the data collection software as appropriate. This study did not have a measured timing offset, which is consistent with latency test results for survey boats and for similar equipment configurations used in other surveys (Huizinga, 2010, 2017; Huizinga and others, 2010).

Uncertainty Estimation

Similar to the previous studies of bathymetry in Missouri (Huizinga, 2010, 2017), uncertainty in the survey was estimated by computing the total propagated uncertainty (TPU) for each 3.28-ft survey-grid cell in the surveyed area using the Combined Uncertainty and Bathymetry Estimator (CUBE) method (Calder and Mayer, 2003). The CUBE method allows all random system component uncertainties and resolution effects to be combined and propagated through the data processing steps, which provides a robust estimate of the spatial distribution of possible uncertainty within the survey area (Czuba and others, 2011). Thus, when all relevant error sources are considered, the TPU of a point is a measure of the accuracy to be expected for such point (Czuba and others, 2011).

Most of the TPU values (more than 95 percent) were less than 0.7 ft, which is within the specifications for a "Special Order" survey, the most-stringent survey standard of the International Hydrographic Organization (International Hydrographic Organization, 2008). The median TPU value of the data was about 0.16 ft. The largest TPU in this survey was about 20.0 ft; however, TPU values of this magnitude typically are near high-relief features—near vertical surfaces such as bridge abutments or submerged cliffs that may exist on some parts of Beaver Lake (figs. 2 and 3). The TPU values were larger near moderate-relief features (steep banks and submerged channels and ridges; figs. 2 and 3). The TPU values also were sometimes larger in the outermost beam extents of the MBES swath in the overlap with an adjacent swath, particularly when the swath was tilted for the survey lines along the banks or widened in the upper extent of the lake (fig. 3).

Bathymetric Surface and Contour Quality Assurance

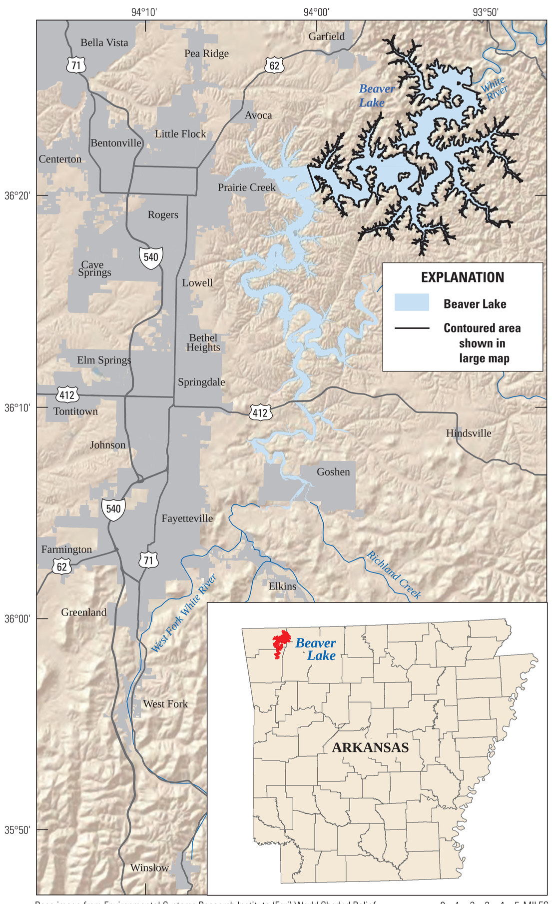
Accuracy of the bathymetric surface and contours is a function of the survey data accuracy, density of the survey data, and the processing steps involved in the surface and contour creation. The process of data reduction to obtain the 3.28-ft gridded dataset from the raw survey data likely degraded the accuracy of the 3.28-ft gridded dataset relative to the raw data. To collect a dataset that could be used to estimate the accuracy of the 3.28-ft gridded dataset, nine areas of Beaver Lake were surveyed twice (fig. 2). The nine areas had a combined total of about 14,000,000 raw survey points (Ellis and others, 2019). Raw points that were within a horizontal distance of 0.33 ft of a 3.28-ft gridded point were selected as quality-assurance data points, and the elevation values of these points were compared to the 3.28-ft gridded points. Approximately 255,000 selected raw points were compared to 3.28-ft gridded points, and the data tested at a vertical accuracy of 0.71 ft at a 95-percent confidence level; the median absolute vertical error was about 0.20 ft (Ellis and others, 2019).

The vertical accuracy and median absolute vertical error also were calculated for the bathymetric surface, which was used to calculate the surface area and capacity values in table 1 and to generate the bathymetric contour map (fig. 2). The quality-assurance dataset used to evaluate the bathymetric surface included about 567,000 data points selected at random from the about 94,000,000 3.28-ft data points (Ellis and others, 2019). Points that were used to create the bathymetric surface were not included as quality-assurance points. The three-dimensional bathymetric surface was tested against the quality-assurance dataset to determine the vertical accuracy of the surface using methods described in Wilson and Richards (2006). The surface tested at a vertical accuracy of 1.63 ft at the 95-percent confidence level; the median absolute vertical error was 0.073 ft. A map of the vertical accuracy of the bathymetric surface is shown in figure 4.

The process of smoothing and cartographic editing of the bathymetric contours to produce an aesthetic map degrades the positional and vertical accuracy of the contours; however, the contours are used primarily for visualization of the surface in an illustration, so some accuracy degradation is expected. The bathymetric contours (fig. 2) were tested with the same quality-assurance dataset used to evaluate the bathymetric surface (Ellis and others, 2019). A point was considered a contour elevation evaluation point if the point was within a horizontal distance of 1 ft of a given contour line. Of the about 567,000 quality-assurance points, approximately 8,280 points were selected as evaluation points for the contour lines, and the contour vertical accuracy was computed to be 4.78 ft at the 95-percent confidence level; the median absolute vertical error was about 0.28 ft.

Bathymetry and Surface Area and Capacity

The bathymetric surface TIN was used to produce a bathymetric contour map (fig. 2). The meandering form of the submerged White River channel is clearly visible throughout Beaver Lake (fig. 2). Submerged channels of several tributaries also were evident in some areas. A surface area and capacity table (table 1) was computed from the bathymetric surface TIN. At the conservation pool elevation of 1,120 ft, the surface area of the lake was about 27,900 acres and the capacity was about 1,640,000 acre-feet (table 1). At the flood pool elevation of 1,130 ft, the surface area of the lake was about 31,500 acres and the capacity was about 1,940,000 acre-feet (table 1).



Base image from Environmental Systems Research Institute (Esri) World Shaded Relief, Esri Roads (2010), Esri City Boundaries (2010); Rivers from USGS National Atlas, 2005
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Universal Transverse Mercator projection, zone 15 North

Figure 1. Location of Beaver Lake near Rogers, Arkansas.

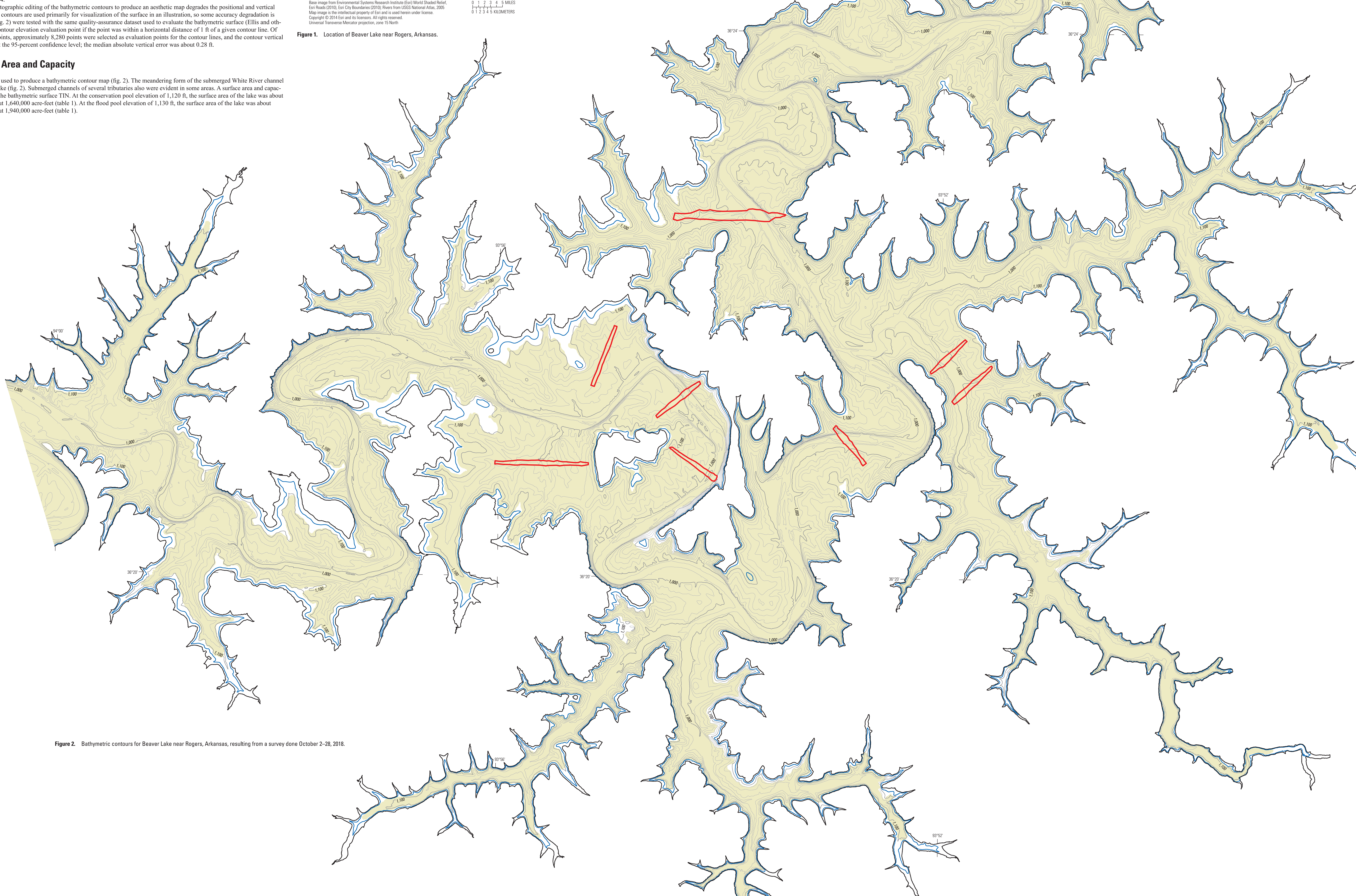

Figure 2. Bathymetric contours for Beaver Lake near Rogers, Arkansas, resulting from a survey done October 2–28, 2018.

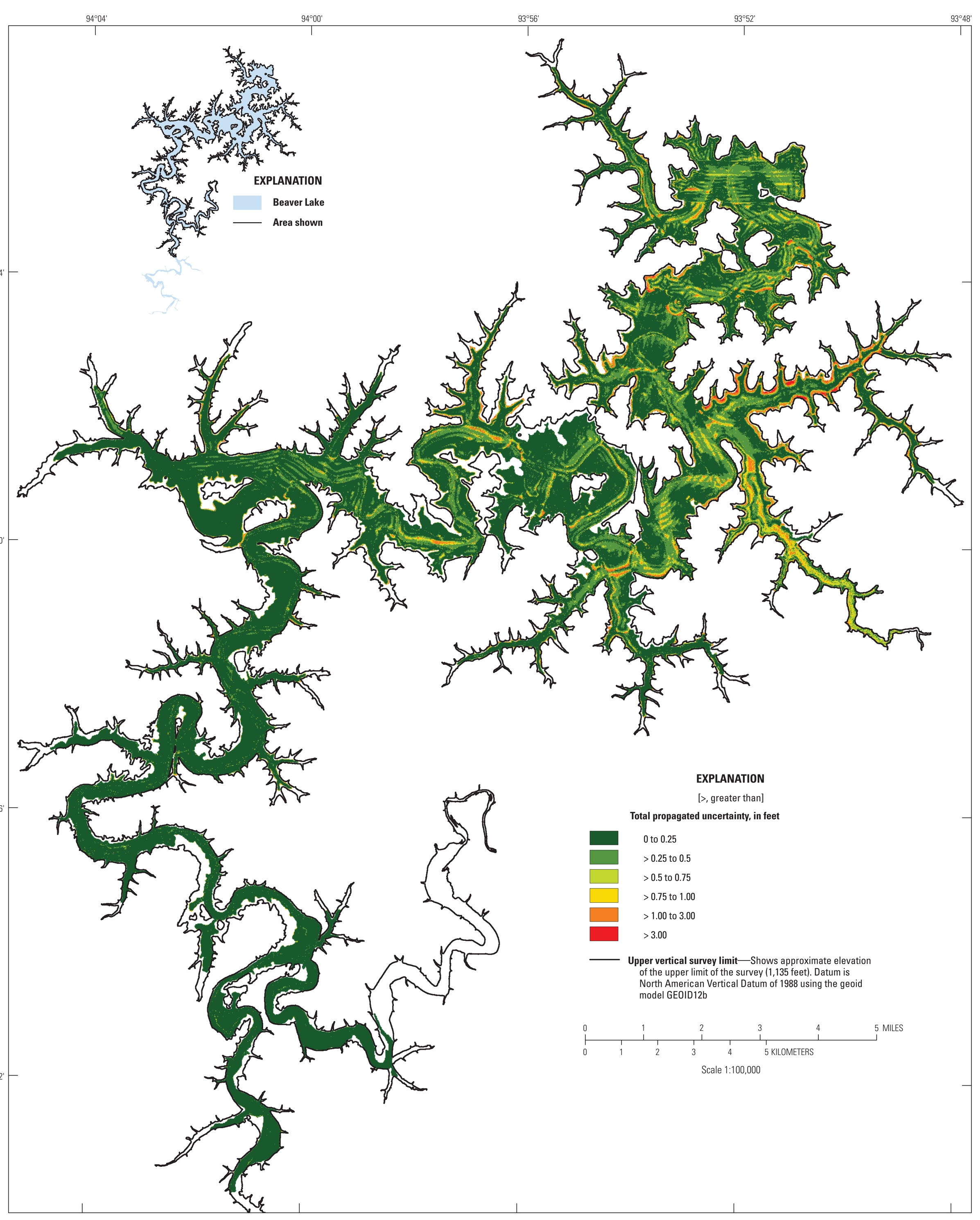

Figure 3. Total propagated uncertainty of bathymetric data from the survey of Beaver Lake near Rogers, Arkansas, 2018.

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Suggested citation:
Huizinga, R.J., Ellis, J.T., Sharpe, J.B., LeRoy, J.Z., and Richards, J.M., 2019, Bathymetric map and surface area and capacity table for Beaver Lake near Rogers, Arkansas, 2018: U.S. Geological Survey Scientific Investigations Map 3445, 2 sheets, https://doi.org/10.3133/sim3445.

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ISSN 2329-132X (online)
https://doi.org/10.3133/sim3445