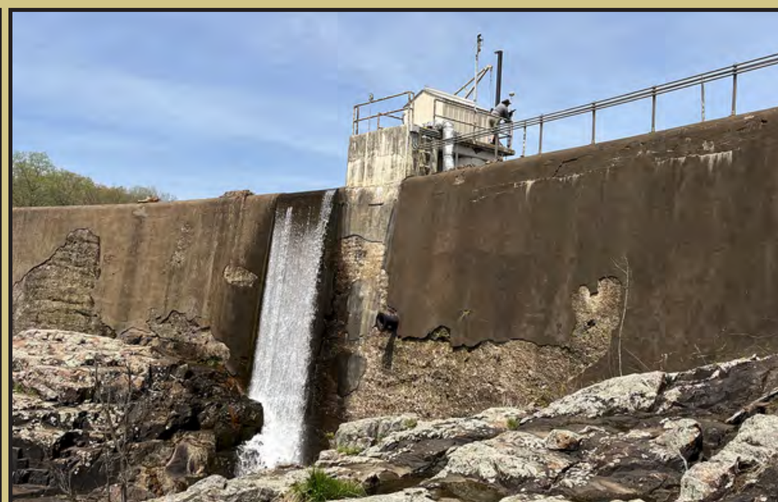
Prepared in cooperation with the Missouri Department of Natural Resources

Bathymetric Contour Maps, Surface Area and Capacity Tables, and Bathymetric Change Maps for Selected Water-Supply Lakes in Missouri, 2022–23



Scientific Investigations Report 2024–5114

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

A

B

C

D

Cover. *A*, Photograph showing the dam and picturesque intake tower of Unity Lake Number 1 on May 17, 2023. *B*, Photograph showing information about the reference mark at Shepherd Mountain Lake dam being collected with Global Positioning System equipment on April 19, 2023. *C*, Photograph showing Global Positioning System equipment and multibeam surveying boat prepared for a day of surveying at Fellows Lake on April 13, 2022. *D*, Photograph showing an acoustic Doppler current profiler collecting single beam data, taken at Fellows Lake on April 14, 2022. All photographs taken by Richard Huizinga, U.S. Geological Survey.

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By Benjamin C. Rivers, Richard J. Huizinga, and Garett J. Waite

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U.S. Department of the Interior
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Conversion Factor

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,046.86	square meter (m^2)
	Volume	
acre-foot (acre-ft)	1,233.48	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flux rate	
acre-foot per year (acre-ft/yr)	1,233.48	cubic meter per year (m^3/yr)
foot per year (ft/yr)	0.3048	meter per year (m/yr)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), using the geoid model GEOID18.

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

Supplemental Information

Frequency is given in kilohertz (kHz).

Data were collected, processed, and output in the International System of Units, and converted to U.S. customary units for presentation in the maps at the request and for the convenience of the cooperator.

Abbreviations

[Some abbreviations are used only once, but are used and included here at the convenience of cooperator and end users, who often are more familiar with the abbreviation than the definition]

ADCP	acoustic Doppler current profiler
CUBE	Combined Uncertainty and Bathymetry Estimator
DGPS	Differential Global Positioning System
GCD	Geomorphic Change Detection
GIS	geographic information system
GNSS	Global Navigation Satellite System
IMU	inertial measurement unit
INS	inertial navigation system
lidar	light detection and ranging
MBES	multibeam echosounder
MBMS	multibeam mapping system
MMS	Mobile Mapping Suite
MoDNR	Missouri Department of Natural Resources
NAVD 88	North American Vertical Datum of 1988
NED	National Elevation Dataset
RTK	real-time kinematic
SBET	smoothed best estimate of trajectory
sonar	sound navigation and ranging
TIN	triangulated irregular network
USGS	U.S. Geological Survey

Bathymetric Contour Maps, Surface Area and Capacity Tables, and Bathymetric Change Maps for Selected Water-Supply Lakes in Missouri, 2022–23

By Benjamin C. Rivers, Richard J. Huizinga, and Garett J. Waite

Abstract

Bathymetric data were collected at 13 water-supply lakes around the periphery of Missouri by the U.S. Geological Survey in cooperation with the Missouri Department of Natural Resources and various local agencies, as part of a multiyear effort to establish or update the surface area and capacity tables for the surveyed lakes. Surveys were carried out during the months of April and May in 2022 and 2023. All but two of the lakes had been surveyed previously by the U.S. Geological Survey, and the recent surveys were compared to the earlier surveys to document the changes in the bathymetric surface and capacity of the lake.

Bathymetric data were collected using a high-resolution multibeam mapping system mounted on a boat. Supplemental depth data at three of the lakes were collected in shallow areas with an acoustic Doppler current profiler on a remote-controlled boat. Data points from the various sources were exported at a gridded data resolution appropriate to each lake, either 0.82 foot, 1.64 feet, or 3.28 feet. Data outside the multibeam survey extent and greater than the surveyed water-surface elevation were obtained from data collected using aerial light detection and ranging (lidar) point cloud data. A linear enforcement technique was used to add points to the dataset in areas of sparse data (the upper ends of coves where the water was shallow or aquatic vegetation precluded data acquisition) based on surrounding multibeam and upland data values. The various point datasets were used to produce a three-dimensional triangulated irregular network surface of the lake-bottom elevations for each lake. A surface area and capacity table was produced from the three-dimensional surface for each lake showing surface area and capacity at specified lake water-surface elevations. Various quality-assurance tests were conducted to ensure quality data were collected with the multibeam, including beam angle checks and patch tests. Additional quality-assurance tests were conducted on the gridded bathymetric data from the survey, the bathymetric surface created from the gridded data, and the contours created from the bathymetric survey.

A bathymetric change map was generated from the elevation difference between the previous survey and the 2022 or 2023 bathymetric survey data points. After reconciling any vertical datum disagreement between the previous survey data and the 2022 or 2023 survey datum, coincident points between the surveys were identified, and a bathymetric change map was generated using the coincident point data.

The mean elevation change between repeat surveys was positive, indicating sedimentation, at most of the lakes. Relative to previous surveys, the change in capacity at the primary spillway elevation ranged from a 5.5-percent decrease at Adrian Reservoir to a 9.2-percent increase at Cameron Reservoir Number 1. The mean bathymetric change ranged from –0.94 foot at Cameron Reservoir Number 1 to 1.05 feet at McDaniel Lake. The sedimentation rate was determined from the mean bathymetric change times the area of the bathymetric change raster and divided by the duration between the surveys. The sedimentation rate generally ranged from –0.44 to 1.34 acre-feet per year at Cameron Reservoir Number 3 and Unionville Reservoir (Mahoney Lake), respectively; however, Fellows Lake and McDaniel Lake had substantially larger sedimentation rates of 11.8 and 11.5 acre-feet per year, respectively. The time-averaged mean bathymetric change ranged from –0.107 foot per year at Cameron Reservoir Number 1 to 0.050 foot per year at McDaniel Lake. Despite these substantial sedimentation rates, improved data collection along the steep sides of Fellows and McDaniel Lakes may have revealed areas of additional storage around the periphery of those lakes between the transects in the previous surveys.

Introduction

Managers of water-supply lakes need an accurate estimate of the lake capacity to ensure that enough water is available for consistent recreation pool levels, downstream aquatic habitat preservation, flood abatement, water supply, and power generation. Lake capacity is particularly important for managers of water-supply lakes during periods of drought, population growth, or exceptionally high water use in the area supplied by the lake. Typically, surveys are conducted to map the bathymetric (underwater) surface of the lake from which the capacity, or volume, of the lake is determined at specified elevations in a capacity table. Sedimentation, primarily from runoff into the lake, will cause a loss of storage capacity with time. Therefore, repeat surveys are beneficial to update the map of the bathymetric surface and the capacity table. Repeat surveys also can be used to quantify the bathymetric change and estimate sediment accumulation rates so that managers can better regulate and utilize the water supply.

In cooperation with several Federal, State, and local agencies, the U.S. Geological Survey (USGS) completed bathymetric surveys of several water-supply lakes in Missouri in the early 2000s (Richards, 2013) to determine the capacity of the lakes. All but one of these surveys were completed using a boat-mounted survey-grade singlebeam echosounder and Differential Global Positioning System (DGPS) equipment. Beginning in 2008, the USGS began using a multibeam echosounder (MBES) and a multibeam mapping system (MBMS) to survey river and lake bathymetry (for example, Huizinga and others, 2010; Clearwater Lake in Richards, 2013; Richards and others, 2019; Huizinga, 2022). Multibeam mapping systems collect bathymetric data at much higher resolution and density than singlebeam echosounders. In September 2018, the USGS, in cooperation with Missouri Department of Natural Resources (MoDNR) and the City of Moberly, Missouri, used an MBMS to survey Sugar Creek Lake to prepare an updated bathymetric map and a surface area and capacity table (Richards and Huizinga, 2019; Richards and others, 2019). The 2018 survey also was compared with the previous singlebeam survey in 2003 (Richards, 2013) to document the changes in the bathymetric surface of the lake and to compare MBMS and singlebeam survey data.

In 2019, the USGS, in cooperation with MoDNR and in collaboration with various local agencies, began a 5-year project to resurvey many of the water-supply lakes from the previous study (Richards, 2013), as well as to survey several lakes that had not been previously surveyed. From July 2019 to June 2020, 12 lakes in northwestern Missouri were surveyed (Huizinga and others, 2022); in June and July 2020, 10 additional lakes in north-central and west-central Missouri were surveyed (Huizinga and others, 2023); and from March through May 2021, 12 additional lakes in northeastern Missouri were surveyed to prepare new or updated bathymetric maps and surface area and capacity tables for those lakes (Rivers and others, 2023a). The data for the previous lake surveys were presented in Huizinga and others (2021), Huizinga and Rivers (2023), and Rivers and others (2023b).

In April and May 2022, seven additional lakes were surveyed near Cameron, Springfield, and Unionville, Mo. (fig. 1; table 1), and in April and May 2023, six additional lakes were also surveyed near Vandalia, Ironton, Adrian, and Unity Village, Mo. (fig. 1; table 1) to prepare updated bathymetric maps and surface area and capacity tables for these lakes. Previous surveys were conducted at all lakes except those near Unity Village (Richards, 2013; Huizinga, 2014). These earlier findings were compared with the 2022 or 2023 survey to track changes in the lake's bathymetric surface and create a bathymetric change map.

Purpose and Scope

The purpose of this report is to document the results of bathymetric surveys using an MBMS completed at water-supply lakes near Cameron, Springfield, and Unionville, Mo., during the spring of 2022, and near Vandalia, Ironton, Adrian, and Unity Village, Mo., during the spring of 2023. Equipment and methods used to process and ensure quality of the data are described. Bathymetric surface contours from each lake survey are presented, as well as the surface area and capacity table of the surveyed lake. Maps showing various quality-assurance metrics also are presented. Lakes previously surveyed, as documented in Richards (2013) and Huizinga (2014), were compared to the most recent MBMS survey data and results are presented on additional maps.

Description of Study Area

The study area for this report encompasses 13 water-supply system lakes near Cameron, Springfield, Unionville, Vandalia, Ironton, Adrian, and Unity Village, Mo. The locations of the 13 lakes in Missouri investigated in this report at the State scale are shown in figure 1, and the locations of each lake at the local scale are shown in figures 2–8. Lake numbers are a continuation of the numbering system established in Huizinga and others (2022).

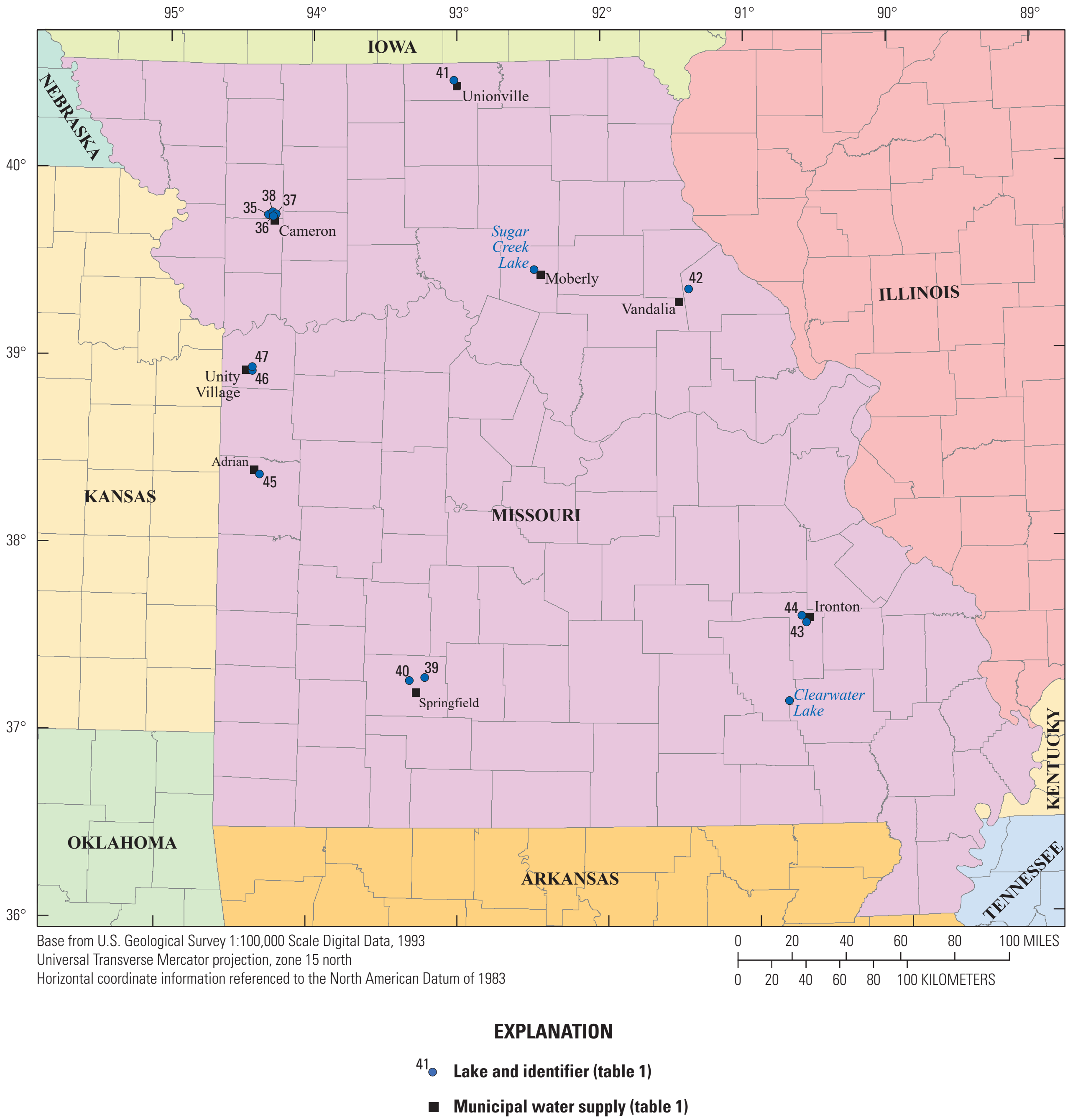


Figure 1. Location of water-supply lakes in Missouri surveyed in 2022 and 2023.

Table 1. Water-supply lakes in Missouri surveyed in 2022 and 2023.

[Dates are shown as month/day/year. All elevations are referenced to the North American Vertical Datum of 1988. NA, not applicable]

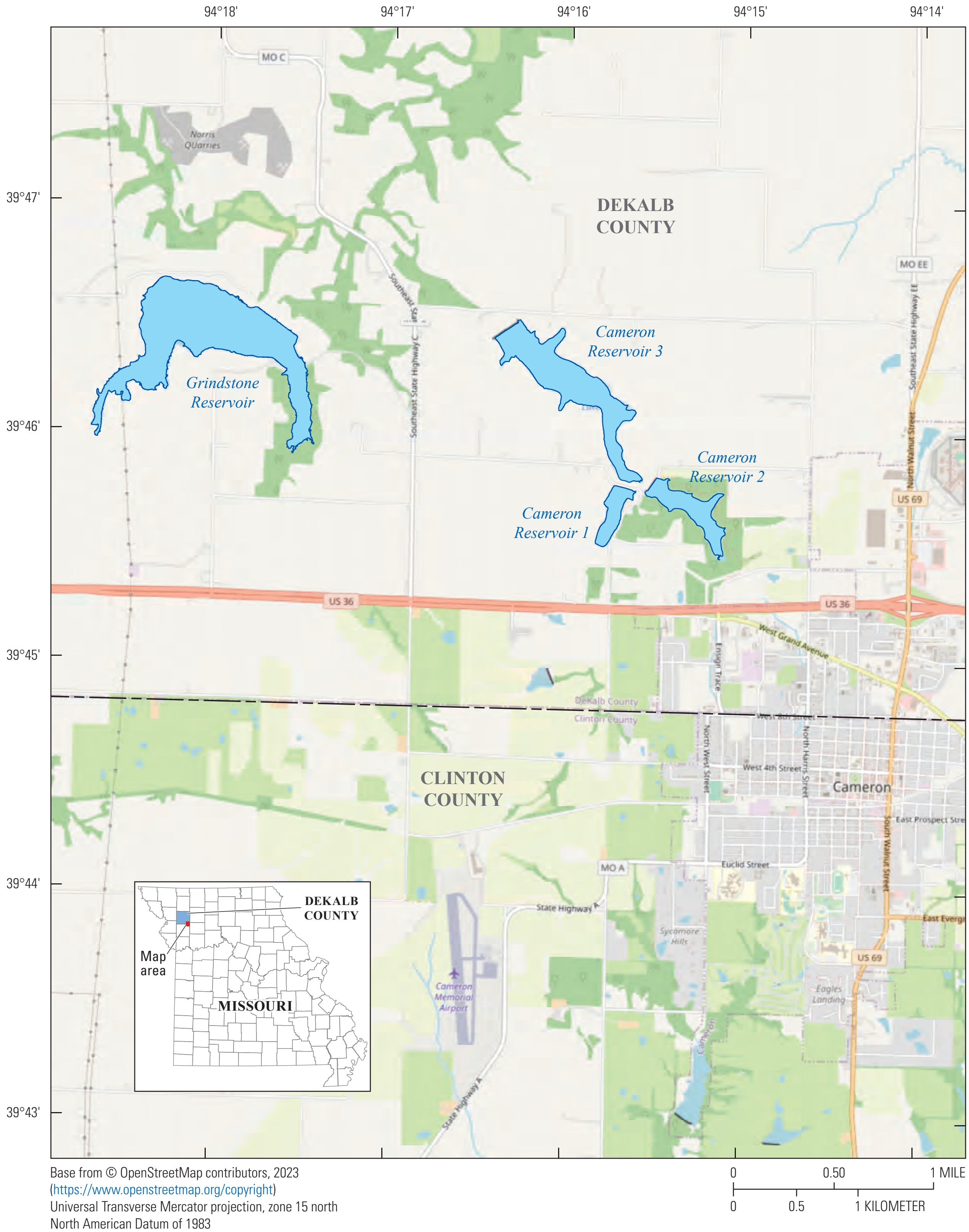
Lake name	Lake number[a] (fig. 1)	County	Municipal water supply	Survey date(s)	Previous survey date(s)	Mean water-surface elevation at time of survey, in feet	Primary spillway/inlet elevation, in feet	Emergency/overflow spillway elevation[b], in feet	Plate number
Grindstone Reservoir	35	DeKalb	Cameron	04/06/2022	07/02/2013	899.89	899.89	915.06	1
Cameron Reservoir Number 1	36	DeKalb	Cameron	04/05/2022	07/02/2013	938.20	938.20[c]	938.20[c]	2
Cameron Reservoir Number 2	37	DeKalb	Cameron	04/07/2022	07/01/2013	943.86	943.86[c]	943.86[c]	3
Cameron Reservoir Number 3	38	DeKalb	Cameron	04/07/2022	07/01/2013	911.07	911.07[c]	911.07[c]	4
Fellows Lake	39	Greene	Springfield	04/12/2022–04/13/2022	04/23/2001	1,261.00	1,264.44[c]	1,264.44[c]	5
McDaniel Lake	40	Greene	Springfield	04/18/2022–04/19/2022	05/30/2001	1,125.38	1,125.10[c]	1,125.10[c]	6
Unionville Reservoir (Mahoney Lake)	41	Putnam	Unionville	05/03/2022	04/06/2004	977.28	976.68[c]	976.68[c]	7
Vandalia Reservoir	42	Pike	Vandalia	04/18/2023	02/23/2005–02/24/2005	666.92	666.98[c]	666.98[c]	8
Shepherd Mountain Lake	43	Iron	Ironton	04/19/2023	07/09/2007–07/10/2007	977.25	977.26[c]	977.26[c]	9
Snow Hollow Lake	44	Iron	Ironton	04/19/2023	07/10/2007	1,285.53	1,285.53[c]	1,285.53[c]	10
Adrian Reservoir[d]	45	Bates	Adrian	05/16/2023	06/05/2003–06/06/2003	845.68	846.26[c]	846.26[c]	11
Unity Lake Number 1	46	Jackson	Unity Village	05/17/2023	NA	913.86	913.86[c]	913.86[c]	12
Unity Lake Number 2	47	Jackson	Unity Village	05/17/2023	NA	870.50	870.50[c]	870.50[c]	13

[a]Lake numbers are a continuation of the numbering started in Huizinga and others (2022).

[b]Emergency/overflow spillway elevation is the elevation at which uncontrolled overflow occurs as opposed to flow into an inlet drop structure. If the primary and emergency/overflow spillway elevations are the same, the lake did not have a drop inlet structure or did not have a clear indication of an inlet lip.

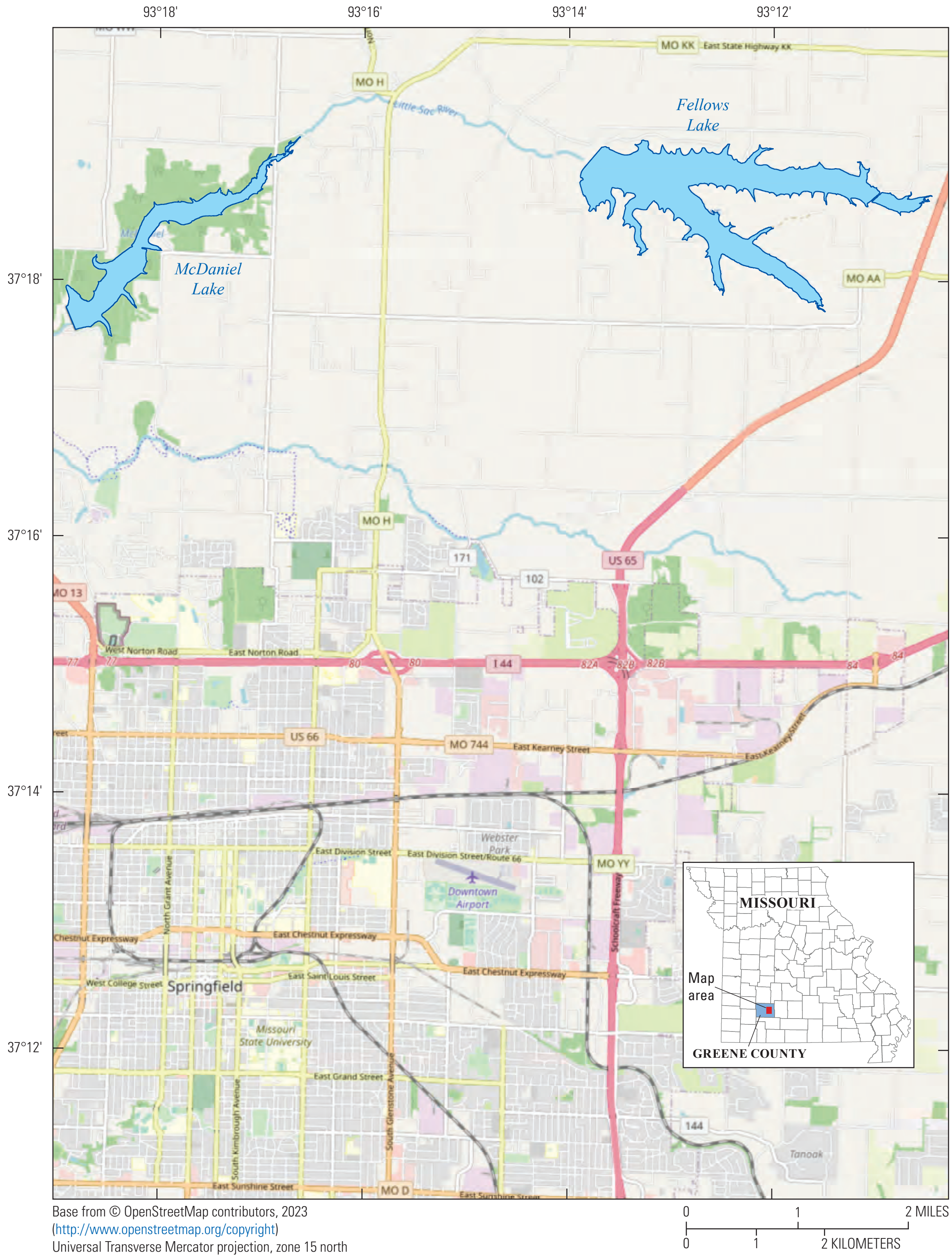
[c]The primary spillway is an uncontrolled overflow spillway at this site.

[d]Encompasses a system of two impoundments that are hydraulically connected, so they were analyzed together. The upper impoundment exists as a sediment catchment and was surveyed, but the area and capacity are not included in the results; nevertheless, contours are included for the upper impoundment. Mean water-surface elevation of the upper impoundment at the time of survey was 848.68 feet, and the emergency spillway elevation is 852.6 feet.



Base from © OpenStreetMap contributors, 2023
(https://www.openstreetmap.org/copyright)
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

Figure 2. Location of Grindstone Reservoir (lake 35), Cameron Reservoir Number 1 (lake 36), Cameron Reservoir Number 2 (lake 37), and Cameron Reservoir Number 3 (lake 38) near Cameron, Missouri.



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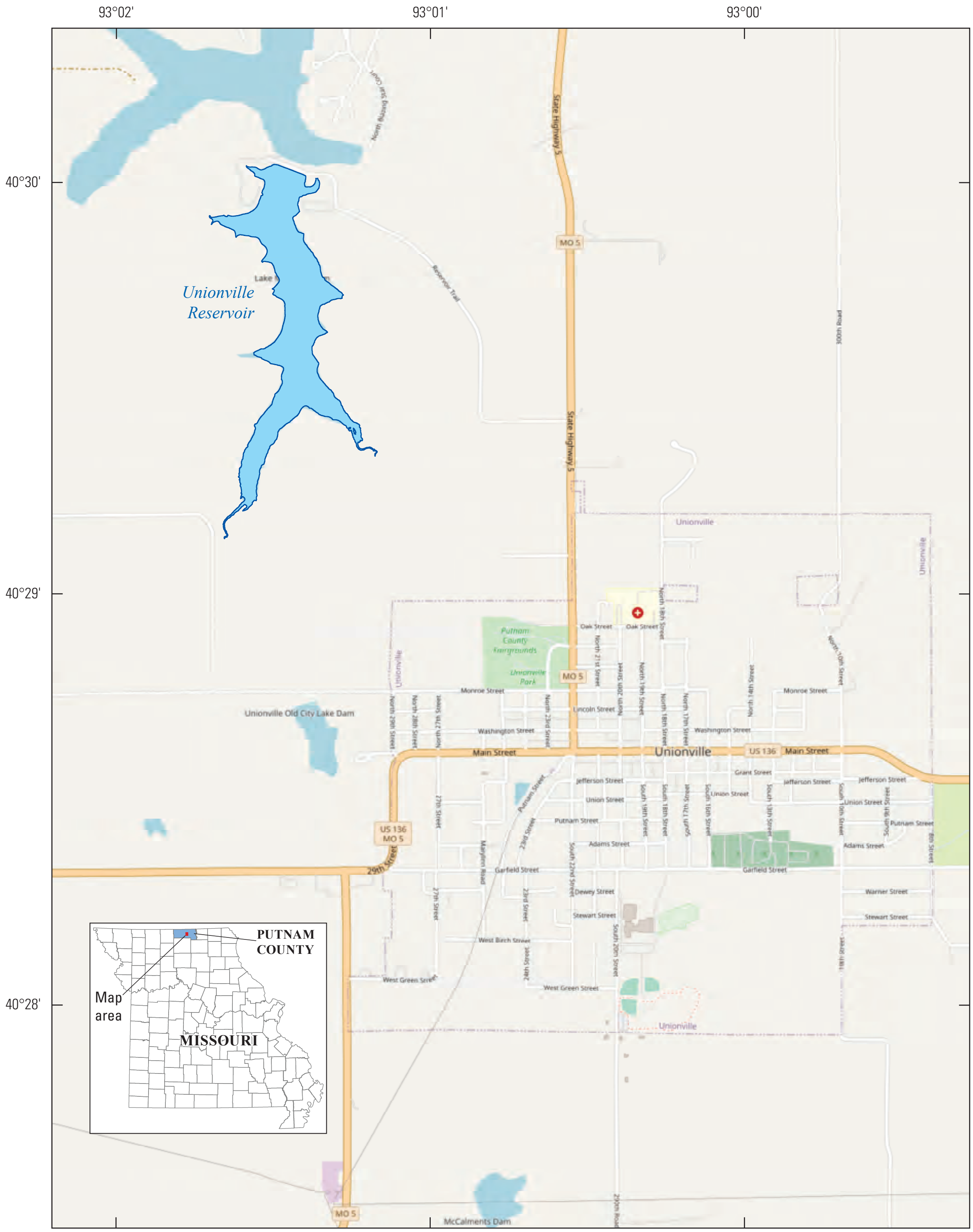
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

Figure 3. Location of Fellows Lake (lake 39) and McDaniel Lake (lake 40) near Springfield, Missouri.



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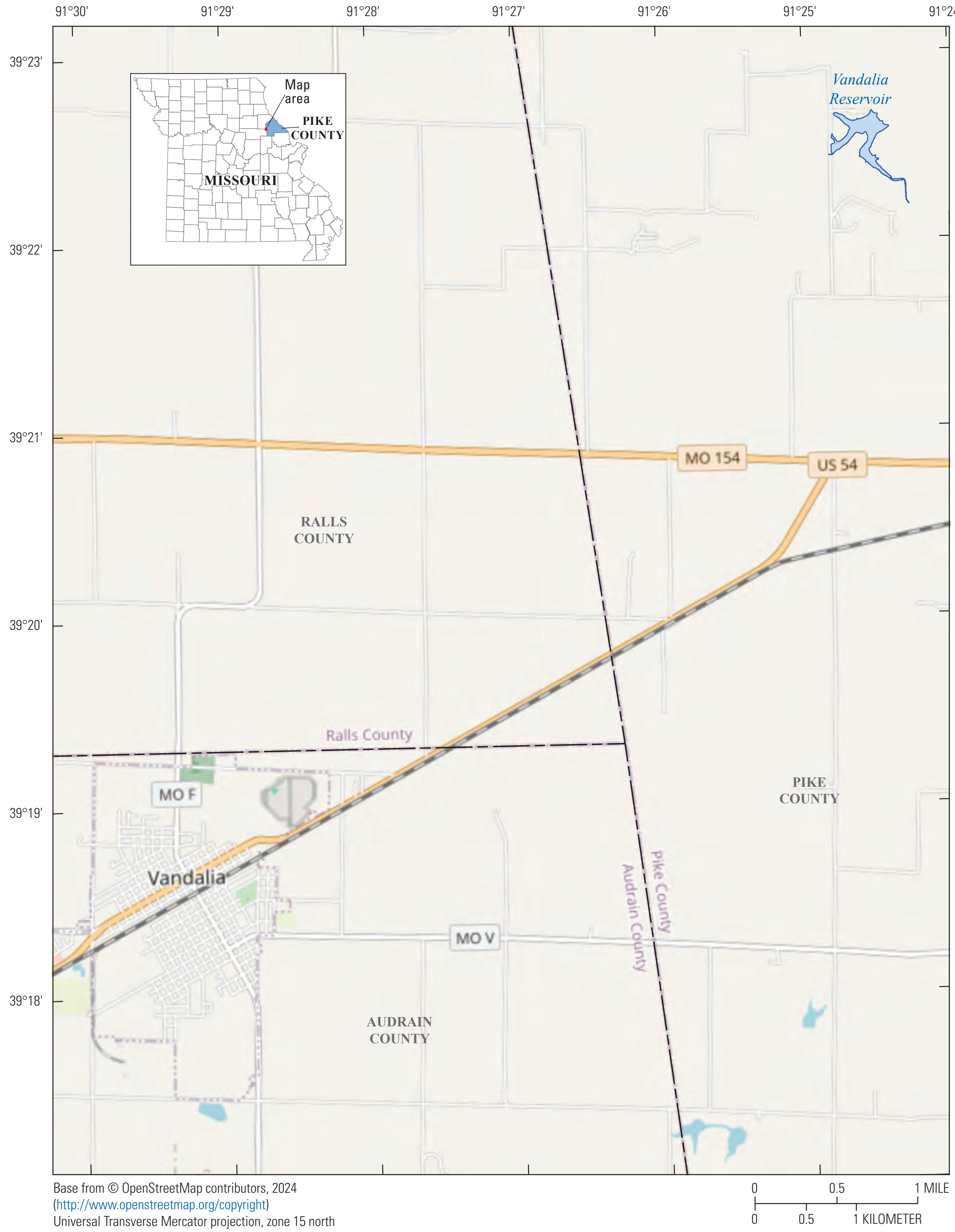
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

Figure 4. Location of Unionville Reservoir (Mahoney Lake; lake 41) near Unionville, Missouri.



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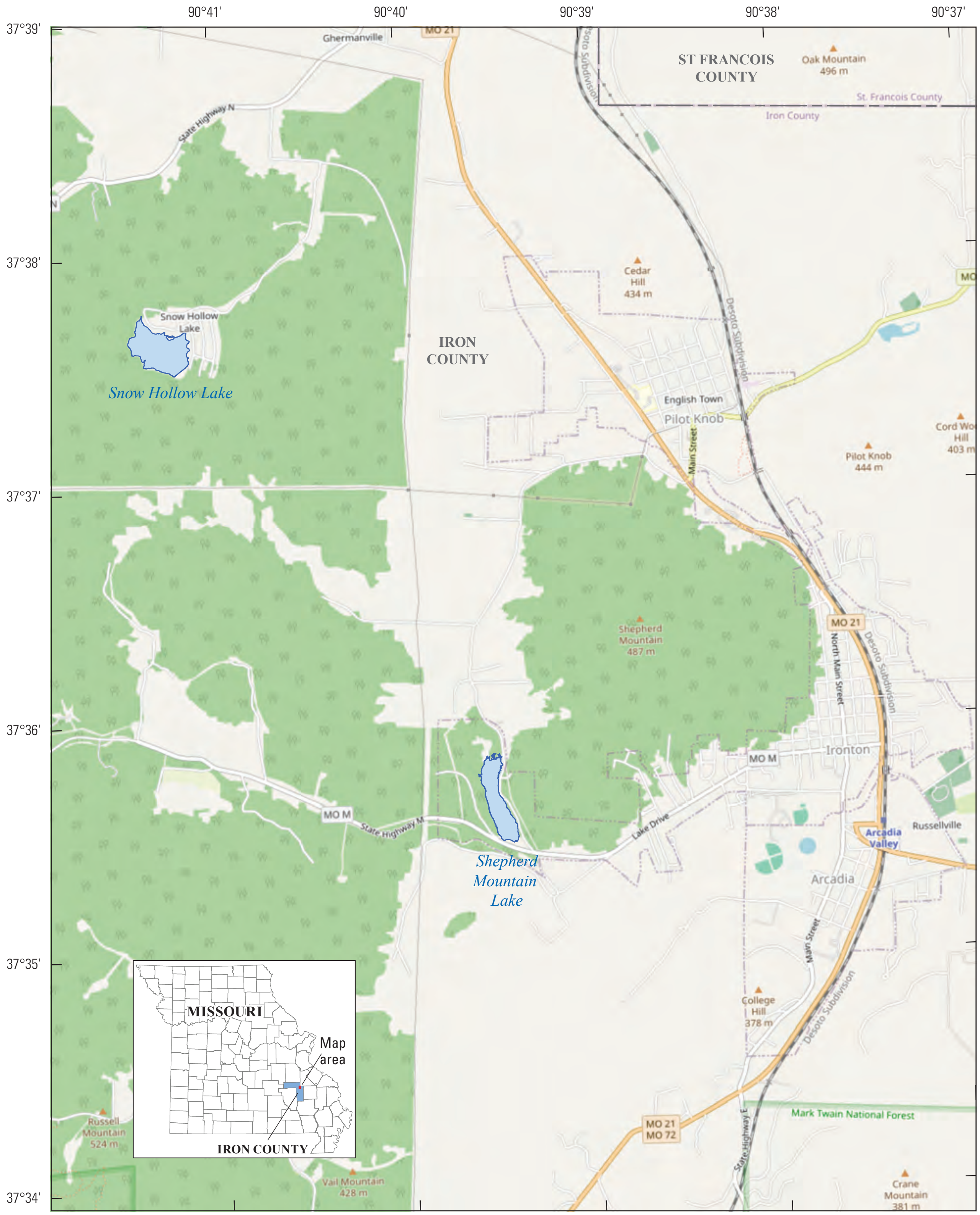
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

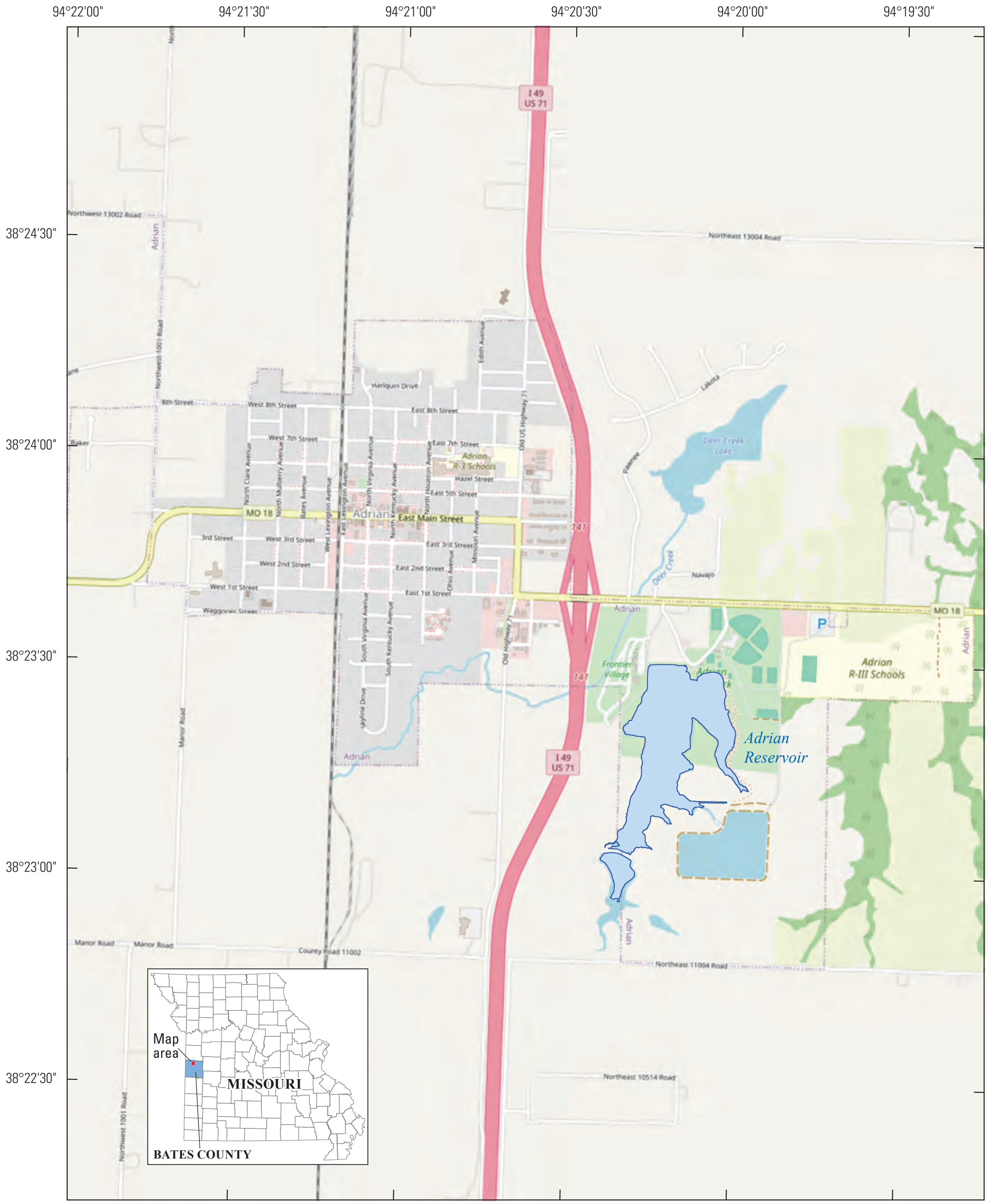
Figure 5. Location of Vandalia Reservoir (lake 42) near Vandalia, Missouri.



Base from © OpenStreetMap contributors, 2024
(http://www.openstreetmap.org/copyright)
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

0 0.5 1 MILE
0 0.5 1 KILOMETER

Figure 6. Location of Shepherd Mountain Lake (lake 43) and Snow Hollow Lake (lake 44) near Ironton, Missouri.



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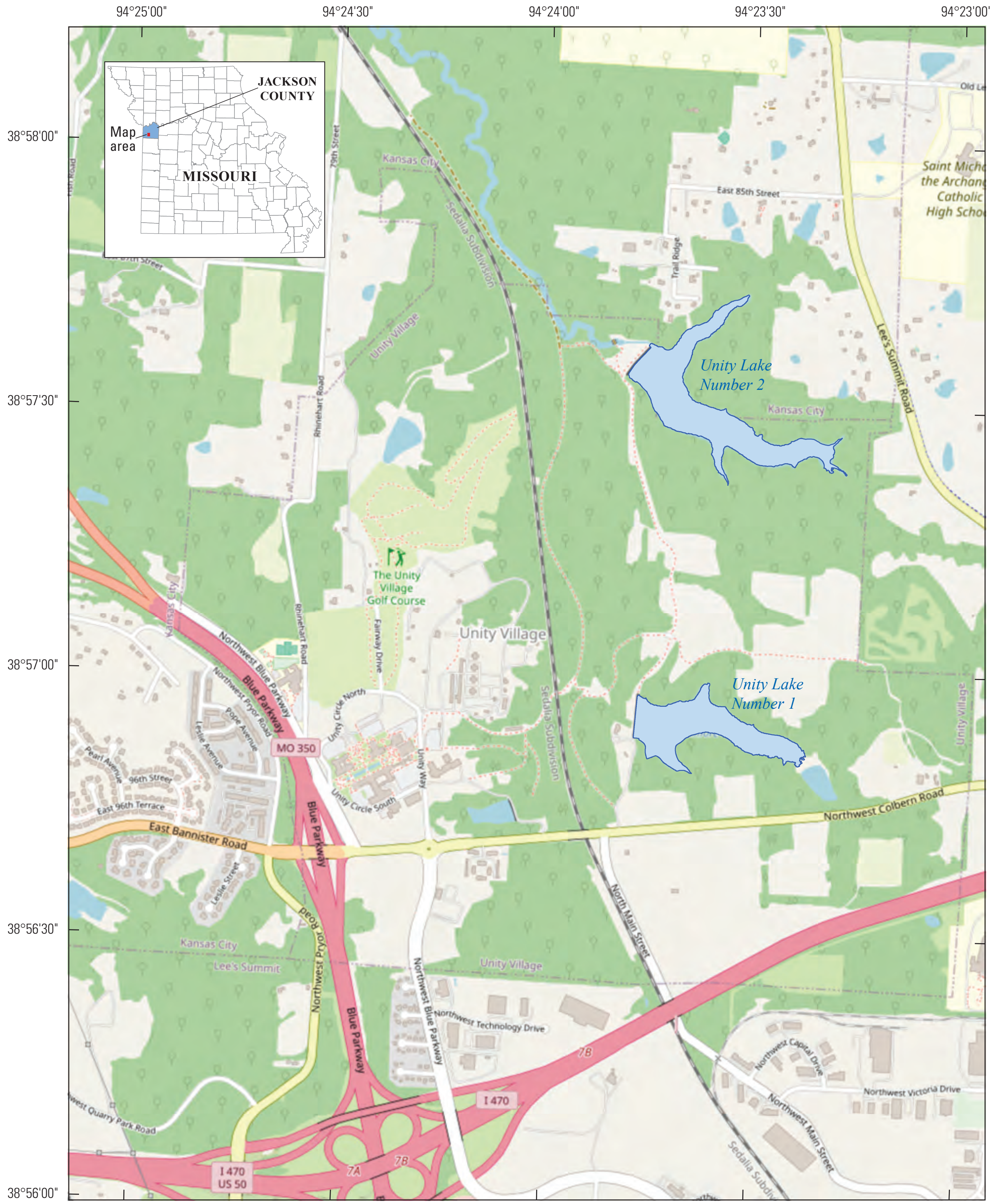
Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

0 0.1 0.2 0.3 0.4 0.5 MILE
0 0.1 0.2 0.3 0.4 0.5 KILOMETER

Figure 7. Location of Adrian Reservoir (Lower and Upper; lake 45) near Adrian, Missouri.



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Universal Transverse Mercator projection, zone 15 north
North American Datum of 1983

Figure 8. Location of Unity Lake Number 1 (lake 46) and Unity Lake Number 2 (lake 47) near Unity Village, Missouri.

Methods

Bathymetric surveys for the lakes in Missouri included in this report were conducted from April 5 to May 3, 2022, and April 18 to May 17, 2023 (table 1), using similar methods to the survey at Clearwater Lake near Piedmont, Mo., in 2017 (USGS station 07062000; Richards and Huizinga, 2018; fig. 1) and Sugar Creek Lake near Moberly, Mo., in 2018 (Richards and others, 2019; fig. 1), and are a continuation of the surveys at 34 water-supply lakes in Missouri completed in 2019 through 2021 (Huizinga and others, 2022, 2023; Rivers and others, 2023a). The mean water-surface elevation of each lake during the 2022 and 2023 surveys detailed in this report is shown in table 1. A bathymetric surface and a bathymetric contour map were created from the survey data for each lake. For lakes at which a previous survey had been completed (Richards, 2013; Huizinga, 2014), a bathymetric change map was created from the survey data.

Bathymetric Data Collection

Bathymetric data (water depths and positions) were collected using an MBMS mounted on a boat (fig. 9). Similar to 2021, two different boats were used for the multibeam surveying in 2022 and 2023: a 24-foot (ft) flat-bottom cabin boat with a custom built MBMS mount pole (fig. 9*B*), and a smaller 16-ft flat-bottom jon boat with a Norbit carbon fiber PORTUS mounting pole (fig. 9*C*), which could be more easily launched and retrieved from the bank of a lake. Supplemental depth data were collected in shallow areas with an acoustic Doppler current profiler (ADCP) on a remote-controlled boat either operated remotely or towed by a motorized boat. The various components of the MBMS, survey methods, and quality-assurance methods used for this study are described in more detail in reports about studies on the Missouri and Mississippi Rivers in Missouri (for example, Huizinga 2010, 2022; Huizinga and others, 2010). The study at Sugar Creek Lake near Moberly, Mo. (Richards and others, 2019) also used similar survey and quality-assurance methods. A brief description of the equipment and methods follows.

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 INS 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. The MBES was the Norbit iWBMSh, which was operated at a frequency of 400 kilohertz (kHz; fig. 9*A*). The iWBMSh has a curved receiver array, which enables bathymetric data to be collected throughout a swath range of 210 degrees. Optimum data usually 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 side of nadir, enabling data along sloping banks to be captured up to a depth just below the water surface.

As with the 2019 through 2021 surveys (Huizinga and others, 2022, 2023; Rivers and others, 2023a), the bathymetric survey data were collected using the following generalized methods:

- Positioning was provided by Global Navigation Satellite System (GNSS) using real-time kinematic (RTK) corrections from the Missouri Department of Transportation real-time network whenever possible.
- Data from a static GNSS base receiver set up over a temporary reference mark near each survey launch area were used to enhance the postprocessed navigation solution; coordinates of each reference mark are included in the USGS data releases for these lakes (Rivers and others, 2023b; Rivers and Huizinga, 2024).
- All navigation information was postprocessed using POS-Pac Mobile Mapping Suite (MMS) software (Applanix Corporation, 2021) to mitigate any degraded positional accuracy of the vessel during the survey.
- The blended navigation solution (called a “smoothed best estimate of trajectory” or “SBET” file) generated by postprocessing the navigation data was applied to the respective data collection in the survey.
- Most data in the main body of each lake were collected with the swath range limited to 140 degrees, 70 degrees on each side of nadir, along lines oriented longitudinally in the main lake area and spaced to create about 10- to 25-percent overlap of the adjacent survey swaths.
- The swath range was widened to 160 degrees and electronically tilted to port or starboard as needed to enhance acquisition of bathymetric data in the shallow areas near the banks, in coves, and in the upper reaches of the lake arms. 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 (usually, the point at which forward progress was blocked by vegetation, or water depth below the MBES decreased to less than about 3 ft), pivoting the boat 180 degrees, and egressing the cove along the ingress line.
- Sound velocity data were collected at the MBES head with a sound velocity probe (fig. 9*A*) throughout the survey, and sound velocity profiles were routinely measured with an AML Oceanographic Base X2 sound velocity probe at various locations throughout each survey day to mitigate potential sound velocity variations with time, location, and depth.

Figure 9. The multibeam echosounder. *A*, Viewed from the side. *B*, Mounted on the port side of the U.S. Geological Survey 24-foot cabin boat. *C*, Deployed on the port side of the 16-foot jon boat.

Preparation for and collection of each bathymetric survey was done in HYPACK/HYSWEEP data acquisition software. After completing the surveys, the acquired depth data were processed further to apply sound velocity profiles and to remove data spikes and other spurious points in the MBES swath trace, often caused by fish, submerged woody debris, or other vegetation. The data were georeferenced using the navigation and position solution data from the SBET file from POS-Pac MMS and preliminarily visualized in HYPACK/HYSWEEP as a triangulated irregular network (TIN) surface or a point cloud for editing. The georeferenced data were filtered and projected to a three-dimensional grid using the Combined Uncertainty and Bathymetry Estimator (CUBE) method (Calder and Mayer, 2003), as implemented in the MBMax processing package of the HYPACK/HYSWEEP software (HYPACK, Inc., 2020). The gridded CUBE bathymetry data were output to a comma-delimited file that was reduced to a data resolution appropriate to the size of the lake, with the aim of no more than about 5 million gridded points per lake to ensure the dataset was a computationally manageable size (table 2).

At Grindstone Reservoir (lake number 35; fig. 1; table 2), Fellows Lake (lake number 39; fig. 1; table 2), and Adrian Reservoir (lake number 45; fig. 1; table 2), a SonTek RiverSurveyor M9 ADCP mounted on a remote-controlled boat was used to collect bathymetric data in shallow, vegetation-free areas that were inaccessible to the MBMS boats. Data from the so-called “bottom-track” mean of the four acoustic beams of the ADCP were combined with position information provided by a DGPS receiver on the top of the boat to provide the equivalent of singlebeam echosounder data in these otherwise inaccessible areas.

Bathymetric Surface and Contour Map Creation

Data points from the MBMS, as well as any supplemental ADCP points, were exported at the gridded data resolution shown in table 2 from the raw data collected in the 2022 and 2023 surveys (Rivers and Huizinga, 2023, 2024). The vertical datum for the surveys was the North American Vertical Datum of 1988 (NAVD 88) using the geoid model GEOID18. The horizontal datum was the North American Datum of 1983. Esri ArcGIS (geographic information system [GIS] software) 10.8.1 (Build 14362) was used to filter the bathymetric data points so that the points would be no closer than the mapping minimum point spacing shown in table 2.

Data outside the MBES survey extent and greater than the surveyed water-surface elevation for all the lakes were obtained from data collected using aerial light detection and ranging (lidar) point cloud data (U.S. Geological Survey, 2023). The survey date associated with the downloaded lidar tiles can be found in table 2 under the “Upland survey data year” column. Only points classified as “ground” were used from the lidar point cloud data. These upland data points were resampled to a linear distance that matched the mapping minimum point spacing of the bathymetric data using GIS software (when needed for the larger lakes) and used to define the upland areas of the lake.

Using the linear enforcement techniques described in Wilson and Richards (2006), points were added to the dataset based on surrounding MBES and upland data values. These data were added to anchor the surface in areas of sparse data in the upper ends of coves where the water was too shallow for the MBES equipment or aquatic vegetation precluded data acquisition with the MBES or ADCP. Topography from a previous survey and recent (Google Earth, 2010–20) aerial imagery at water levels lower than surveyed in 2022 or 2023 often were used to guide the linear enforcement in these areas.

The point datasets were used to produce a three-dimensional TIN surface of the lake-bottom elevations for each lake. A surface area and capacity table was produced from the three-dimensional TIN surface showing surface area and capacity at specified lake water-surface elevations. Each lake surface was contoured at a 2-ft interval using Esri ArcGIS 10.8.1 software (Build 14362), and the contours were cartographically smoothed and edited to create a bathymetric contour map for each lake (plates 1–13; available for download at https://doi.org/10.3133/sir20245114.) using the techniques of Wilson and Richards (2006). A 5-ft contour interval was used at Fellows Lake (lake 39, plate 5) because of the range in depth of that lake.

Bathymetric Change Map Creation

A previous bathymetric survey is available for all the lakes surveyed in 2022 and 2023 except the two lakes near Unity Village (Unity Lake Number 1 and 2). A bathymetric change map was generated from the difference between the previous survey and the 2022 or 2023 bathymetric survey points where they were coincident. Accurate surface area and capacity determined from bathymetric surveys are independent of the vertical datum used to reference the bathymetric data; however, accurate comparisons between capacities at specific elevations or between bathymetric surfaces from different surveys require that any disagreement between the vertical datums is reconciled. To maximize comparability between surveys, a vertical adjustment was applied to the earlier survey to convert the elevations to the vertical datum of the recent surveys (NAVD 88 using geoid model GEOID18). Recent surveys assume minimal error compared to previous ones owing to advancements in GNSS technology, despite the inherent challenges of modeling and quantifying systematic and random errors in all surveys. The vertical adjustment was generally based on at least one reference location per lake with an elevation that is assumed to have not changed over time, such as a recoverable reference mark or spillway crest (refer to reference mark locations on plates 1–13). The elevation of the reference location was acquired with RTK GNSS technology following methods described by Rydlund and Densmore (2012). The magnitude and direction of the vertical

Table 2. Summary of gridded and selected bathymetric data points from surveys at water-supply lakes in Missouri in 2022 and 2023.

[--, no data]

Lake name	Lake number (fig. 1)	Gridded data resolution, in feet	Number of gridded points in multibeam bathymetric dataset	Number of supplemental points from sources other than multibeam	Mapping point minimum point spacing, in feet	Number of mapping points selected from the gridded bathymetric dataset used to make the bathymetric surface	Number of mapping quality-assurance points randomly selected from gridded bathymetric dataset	Upland survey data year
Grindstone Reservoir	35	1.64	1,988,950	2,164	3.28	380,200	67,128	2011
Cameron Reservoir Number 1	36	0.82	730,117	--	1.64	138,142	24,930	2011
Cameron Reservoir Number 2	37	0.82	1,491,373	--	1.64	285,073	50,125	2011
Cameron Reservoir Number 3	38	0.82	4,801,799	--	1.64	922,812	160,938	2011
Fellows Lake	39	3.28	2,880,910	2,697	6.56	530,198	97,678	2011
McDaniel Lake	40	1.64	3,911,002	--	3.28	736,895	132,715	2011
Unionville Reservoir (Mahoney Lake)	41	0.82	3,332,961	--	1.64	657,832	111,844	2011
Vandalia Reservoir	42	0.82	1,638,859	--	1.64	309,258	55,403	2023
Shepherd Mountain Lake	43	0.82	1,185,504	--	1.64	224,175	39,908	2017
Snow Hollow Lake	44	0.82	1,255,208	--	1.64	255,445	41,623	2017
Adrian Reservoir	45	0.82	2,247,852	831	1.64	431,098	75,431	2021
Unity Lake Number 1	46	0.82	981,026	--	1.64	184,173	32,077	2006
Unity Lake Number 2	47	0.82	1,449,108	--	1.64	269,620	48,214	2006

adjustment were then determined from the difference between the reference mark elevation in 2022 or 2023 and the elevation of a point in the earlier survey at (or near) the reference mark location. By assuming the vertical adjustment is spatially constant, vertical change as it is related to natural geomorphic processes can be observed when the earlier, vertically adjusted survey is compared with the more recent survey. Because of the advances in GNSS surveying techniques and accuracy since the previous surveys, it was assumed that the 2022 or 2023 elevation was the more accurate value. The vertical offsets between the surveys are listed in table 3.

A vertical shift was applied to the previous survey data for all the lakes (table 3) to ensure a match to the 2022 or 2023 survey. After applying the vertical shift at the lakes, coincident points between the surveys were identified for all lakes (other than those near Cameron, lakes 35–38). A 2022 or 2023 survey map point was considered “coincident” when it was within a given horizontal distance from a previous survey data point (the “coincident bathymetry point search radius” in table 3), and a bathymetric change TIN was generated using the difference in elevation of the coincident point datasets, which was computed using the following equation:

$$Difference = elevation_{YYYY} - elevation_{previous}. \quad (1)$$

where

$Difference$ is the difference in elevation of a coincident point pair (the bathymetric change),

$elevation_{YYYY}$ is the elevation of the point in the 2022 or 2023 survey, and

$elevation_{previous}$ is the elevation of the point in the previous survey.

The bathymetric change TIN at lakes 39–45 was converted to a raster surface with a spacing that matched the mapping minimum point spacing of the 2022 or 2023 surveys (“Mapping point minimum point spacing” in table 2) for use in further analysis and creation of the change map. The bathymetric change map was limited to the intersection of the previous survey and the 2022 or 2023 MBMS survey extents so that only bathymetric data that were in the area common to both surveys were compared. Minor positional offsets between points within the “Coincident bathymetry point search radius” listed in table 3 located in high-slope areas (observed in the contour maps as areas where the contours are closely spaced in plates 1–13) can bias the observed vertical difference; furthermore, high-slope areas typically are not well represented in rasterization, which could lead to potentially erroneous bathymetric change results. Therefore, areas that corresponded to a terrain slope greater than about 25 degrees, as represented in the 2022 or 2023 bathymetric surface, were excluded from the bathymetric change map.

The previous surveys at Grindstone Reservoir and Cameron Reservoirs 1–3 (lakes 35–38) were completed with an MBMS in 2013 (Huizinga, 2014), so the bathymetric change maps were created using the Geomorphic Change Detection (GCD; version 7) add-in tool for ArcGIS

Table 3. Summary of adjustments to previous survey elevation to match 2022 or 2023 surveys at water-supply lakes in Missouri.

Lake name	Lake number (fig. 1)	Elevation adjustment to previous survey,[a] in feet	Coincident bathymetry point search radius,[b] in feet
Grindstone Reservoir	35	−0.040	0.0[c]
Cameron Reservoir Number 1	36	0.097	0.0[c]
Cameron Reservoir Number 2	37	0.097	0.0[c]
Cameron Reservoir Number 3	38	0.097	0.0[c]
Fellows Lake	39	0.561	1.64
McDaniel Lake	40	−0.068	0.82
Unionville Reservoir (Mahoney Lake)	41	−0.110	0.56
Vandalia Reservoir	42	0.807	0.33
Shepherd Mountain Lake	43	0.001	0.49
Snow Hollow Lake	44	0.016	0.49
Adrian Reservoir	45	0.184	0.49

[a]Contour information and surface area and capacity tables for previous surveys in Richards (2013) need to be adjusted by the elevation adjustment value to be comparable to the 2022 or 2023 data.

[b]The search radius was used to select points from the 2022 or 2023 gridded data to match to previous survey data points to determine the elevation difference from the previous survey.

[c]The previous survey at this lake used a multibeam mapping system, and the 2022 bathymetric surface could be compared to the bathymetric surface from the previous survey for the entire area where the surfaces were coincident.

(Esri ArcGIS 10.8.1, Build 14362) available through the Riverscapes Consortium (2022). GCD computes elevation difference and volumetric change in storage between two gridded raster surfaces derived from repeat topographic or bathymetric surveys. The GCD program provides a suite of tools to associate the uncertainties for points in the various surveys (using the uncertainty values associated with each point) and propagates those uncertainties through the difference map. The GCD program also provides a way to segregate the best estimates of change using threshold masks. For lakes 39–45, the difference in elevation between the surveys was determined using equation 1, but with a threshold mask to remove computed differences that might be a result of data uncertainty.

Bathymetric Data Collection Quality Assurance

The principal quality-assurance measures 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 adjacent and overlapping swaths for agreement. In addition to the real-time quality-assurance assessments during the survey, beam angle checks and a suite of patch tests were done at various times throughout the surveys to ensure quality data were acquired from the MBMS. These tests generally were completed in the deepest part of a given lake, near the dam, or over a submerged feature such as the old channel or a submerged roadway.

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 by comparing results from two full-swath check lines over a reference surface (created from multiple passes over an area using only the high-quality beams near nadir; U.S. Army Corps of Engineers, 2013). Outer beam accuracy may change with time because of inaccurate sound velocities, physical configuration changes or damage, and water depth. A beam angle check was done at Fellows Lake (fig. 1) near Springfield on April 13, 2022, as part of the 2022 survey season, and at Unity Lake Number 2 (fig. 1) near Unity Village on May 17, 2023, as part of the 2023 survey season. The results for these beam angle checks were within the recommended performance standards used by the U.S. Army Corps of Engineers for hydrographic surveys for all the representative angles below 75 degrees (U.S. Army Corps of Engineers, 2013; tables 4 and 5), permitting the use of the full 150 degrees of the sonar swath with confidence. Points acquired outside of the central 100–110 degrees of the sonar swath generally had overlap with adjacent swaths, which increases the quality of the survey in the overlapped areas because of duplication.

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 (fig. 10), and 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, 2022). 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 (Huizinga, 2022). The offsets determined in the patch test are applied when processing the data collected during a survey. Patch tests were completed at various times in various lakes during the surveying projects during the 2022 and 2023 survey seasons (table 6), and angular offsets were updated in the data collection and post-processing software as appropriate.

With the Norbit iWBMSh, the INS and MBES are considered to be tightly coupled because the inertial measurement unit (IMU) of the INS is mounted on the same mounting bracket (fig. 9*A*); therefore, there was no measured timing offset and no measured angular offset for pitch (table 6). The yaw is a measure of the alignment of the GNSS receivers relative to the IMU of the INS on the echosounder head, and the measured offset for yaw ranged from 0 to −2.5 for all the tests (table 6). These values generally are consistent with latency, pitch, and yaw test results for this equipment configuration used in other surveys (Richards and others, 2019; Huizinga, 2022). The variable angular offset for yaw observed in the 2022 and 2023 surveys is likely to be the result of a combination of a loose connection on the T-pole on which the GNSS receivers were mounted (figs. 9*B* and 9*C*) and an incorrectly applied magnetic variation or grid convergence parameter in the post-processing of the survey data. The measured angular offset for roll was a constant −0.10 (table 6), which is consistent with results for this equipment configuration in other recent surveys (Rivers and others, 2023a). It was noted in the earliest work with the MBMS in Missouri (Huizinga, 2010) that a sensitivity analysis of the four offsets implied that the ultimate position of surveyed points in three-dimensional space was least sensitive to the angular offset for yaw, whereas it was most sensitive to the angular offset for roll. Processing all the data for the lakes detailed in this report with an angular offset for roll of –0.10 degree, no angular offset for pitch, and an angular offset for yaw as determined by incremental patch testing, generally yielded good results with no noticeable artifacts caused by incorrect offsets.

Table 4. Results of a beam angle check at Fellows Lake near Springfield, Missouri, on April 13, 2022.

[<, less than; --, no data]

Beam angle limit, in degrees	Maximum outlier, in feet	Mean difference, in feet	Standard deviation, in feet	95-percent confidence, in feet
		Beam angle check results		
0	0.26	0.00	0.07	0.13
5	0.23	0.00	0.07	0.10
10	0.26	0.00	0.07	0.13
15	0.33	0.00	0.07	0.13
20	0.36	0.00	0.07	0.16
25	0.33	0.00	0.10	0.20
30	0.36	0.00	0.10	0.20
35	0.46	0.03	0.10	0.16
40	0.46	0.03	0.10	0.16
45	0.43	0.10	0.07	0.16
50	0.36	0.07	0.07	0.16
55	0.39	0.07	0.10	0.20
60	0.49	0.03	0.16	0.30
65	0.79	0.03	0.20	0.39
70	0.82	0.13	0.20	0.39
75	0.66	0.07	0.20	0.36
		Performance standards[a]		
Threshold	1.00	<0.20	--	<0.80
Result	Met	Met	--	Met

[a]Performance standard check values are from U.S. Army Corps of Engineers (2013, table 3-1) for soft sand/silt bottoms.

Table 5. Results of a beam angle check at Unity Lake Number 2 near Unity Village, Missouri, on May 17, 2023.

[<, less than; --, no data]

Beam angle limit, in degrees	Maximum outlier, in feet	Mean difference, in feet	Standard deviation, in feet	95-percent confidence, in feet
Beam angle check results				
0	0.36	0.03	0.07	0.13
5	0.43	0.03	0.07	0.13
10	0.36	0.07	0.07	0.13
15	0.39	0.07	0.07	0.13
20	0.43	0.03	0.07	0.16
25	0.33	0.03	0.10	0.16
30	0.46	0.00	0.10	0.20
35	0.59	0.00	0.10	0.20
40	0.52	0.03	0.10	0.20
45	0.59	0.07	0.10	0.20
50	0.75	0.07	0.10	0.20
55	0.59	0.03	0.13	0.26
60	0.69	0.00	0.16	0.30
65	0.92	0.03	0.13	0.26
70	0.46	−0.03	0.13	0.26
75	0.92	0.03	0.13	0.23
Performance standards[a]				
Threshold	1.00	<0.20	--	<0.80
Result	Met	Met	--	Met

[a]Performance standard check values are from U.S. Army Corps of Engineers (2013, table 3-1) for soft sand/silt bottoms.

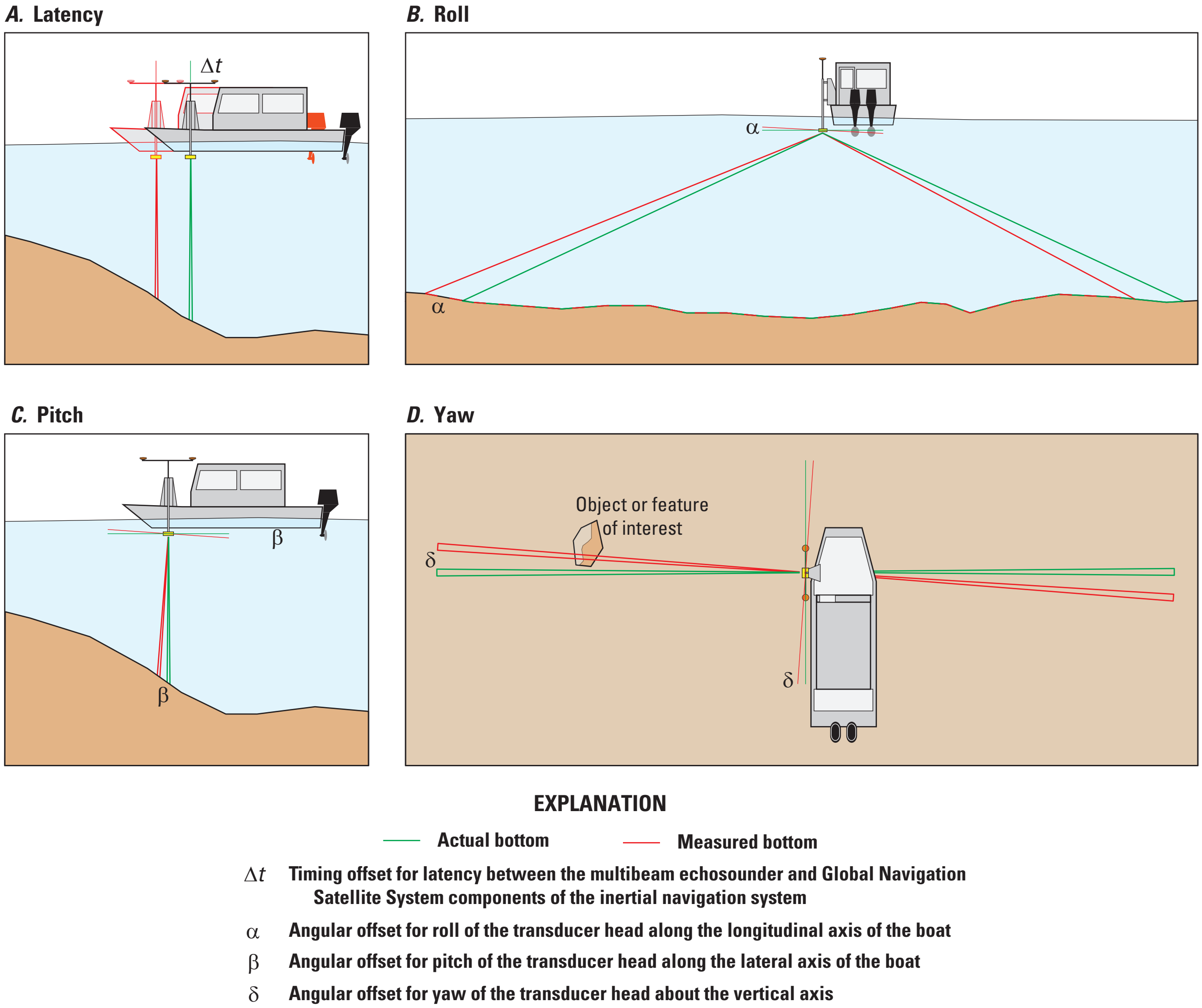


Figure 10. Generalized effects on data from a multibeam echosounder. *A*, Timing offset for latency. *B*, Angular offset for roll. *C*, Angular offset for pitch. *D*, Angular offset for yaw. Figure from Huizinga (2022).

Table 6. Patch test results at select locations in Missouri from April 13, 2022, to May 17, 2023.

[Dates are shown as month/day/year]

Date of test	Timing offset, in seconds	Angular offset for roll, in degrees	Angular offset for pitch, in degrees	Angular offset for yaw, in degrees	Location
04/13/2022	0	−0.10	0	0	Fellows Lake near Springfield, Missouri
04/19/2022	0	−0.10	0	−2.00[a]	McDaniel Lake near Springfield, Missouri
05/17/2023	0	−0.10	0	−2.50[a]	Unity Lake Number 1 near Unity Village, Missouri

[a]Multibeam echosounder mounted to PORTUS pole on jon boat (fig. 9*C*).

Uncertainty Estimation

Similar to the previous studies of bathymetry in Missouri (Huizinga, 2010, 2022; Richards and others, 2019), bathymetry and uncertainty in the multibeam survey was estimated for each survey-grid cell in the surveyed area using the CUBE method (Calder and Mayer, 2003) as implemented in the MBMax processing package of the HYPACK/HYSWEEP software (HYPACK, Inc., 2020). The CUBE uncertainty is a measure of the variability of the individual points in the cell used to determine the CUBE-derived elevation for the cell. Statistics of gridded uncertainty for each of the surveyed lakes are shown in table 7, and the spatial distribution of uncertainty observed in each lake is shown in figures 11–23. The CUBE uncertainty data were output and combined with the three-dimensional bathymetric data and are included with metadata in the USGS data releases associated with this study (Rivers and Huizinga, 2023, 2024). Data from the ADCP do not have an associated CUBE uncertainty.

Most of the uncertainly values (more than 88 percent) were less than 0.25 ft, which is within the specifications for a “Special Order” survey, the most-stringent survey standard of the International Hydrographic Organization (International Hydrographic Organization, 2022; table 7). The largest mean uncertainty value for the surveys was 0.23 ft, the largest median uncertainty value was 0.20 ft, and the largest overall uncertainty in these surveys was 4.99 ft (table 7). All three of these largest values were observed at Unity Lake Number 2 (lake 47) near Unity Village and likely are affected by the substantial local relief caused by large submerged blocks around the perimeter, as well as the narrow and deep nature of that lake (fig. 23), because the gridded uncertainty as determined by the CUBE method is affected by large variations in raw elevation values in a single grid cell. Large uncertainties also were observed at Snow Hollow Lake (lake 44) near Ironton and likely result from substantial submerged vegetation around the perimeter of that lake (fig. 20). The uncertainty 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 a lake (figs. 11–23).

Additional uncertainty at Cameron Reservoir Number 3 (lake 38), Unionville Reservoir (Mahoney Lake; lake 41), Shepherd Mountain Lake (lake 43), and Snow Hollow Lake (lake 44) can be linked to strong winds during data collection at those lakes. These strong winds cause the surface of the lake to become uneven with waves, thus introducing higher than typical pitch and roll. McDaniel Lake (lake 40; fig. 16) and the two Unity Village lakes (Unity Lake Number 1 and Number 2, lakes 46 and 47; figs. 22 and 23, respectively) also had steep terrain with deep valleys or other abrupt topography changes, which affect gridded uncertainties.

Table 7. Uncertainty results for gridded bathymetric data from surveys at water-supply lakes surveyed in Missouri in 2022 and 2023.

Lake name	Lake number (fig. 1)	Maximum value of uncertainty, in feet	Mean value of uncertainty, in feet	Median value of uncertainty, in feet	Standard deviation of uncertainty, in feet	Percentage of bathymetric points with uncertainty value less than a given threshold			
						1.00 foot	0.50 foot	0.25 foot	0.10 foot
Grindstone Reservoir	35	2.76	0.07	0.03	0.10	99.83	98.91	95.89	89.99
Cameron Reservoir Number 1	36	3.64	0.11	0.07	0.12	99.78	98.03	90.88	81.33
Cameron Reservoir Number 2	37	2.89	0.15	0.13	0.12	99.70	98.06	91.34	41.81
Cameron Reservoir Number 3	38	4.99	0.16	0.13	0.16	99.40	97.32	90.74	35.39
Fellows Lake	39	4.89	0.10	0.10	0.08	99.93	99.47	97.65	70.70
McDaniel Lake	40	4.99	0.06	0.07	0.07	99.94	99.68	98.43	92.63
Unionville Reservoir (Mahoney Lake)	41	4.95	0.16	0.13	0.15	99.36	97.28	91.62	32.81
Vandalia Reservoir	42	4.99	0.14	0.10	0.15	99.50	97.85	92.10	55.64
Shepherd Mountain Lake	43	4.99	0.12	0.10	0.13	99.59	97.87	92.91	64.31
Snow Hollow Lake	44	4.99	0.17	0.13	0.16	99.48	97.84	88.54	30.73
Adrian Reservoir	45	4.95	0.11	0.07	0.12	99.71	98.02	93.76	81.81
Unity Lake Number 1	46	4.40	0.15	0.13	0.17	99.15	96.88	91.09	47.63
Unity Lake Number 2	47	4.99	0.23	0.20	0.25	98.82	96.32	66.45	25.57

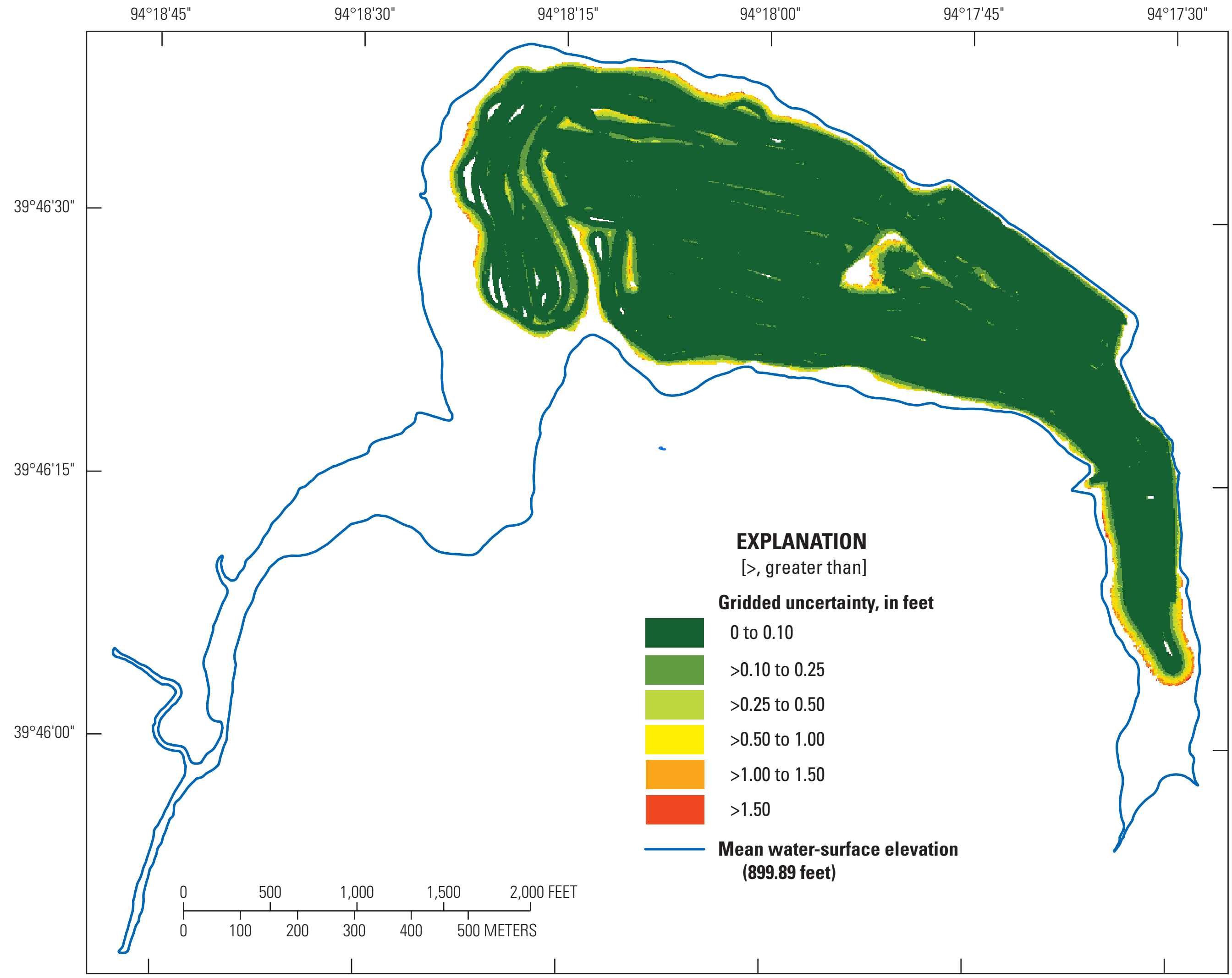


Figure 11. Gridded uncertainty of the bathymetric surface of Grindstone Reservoir (lake 35) near Cameron, Missouri, 2022.

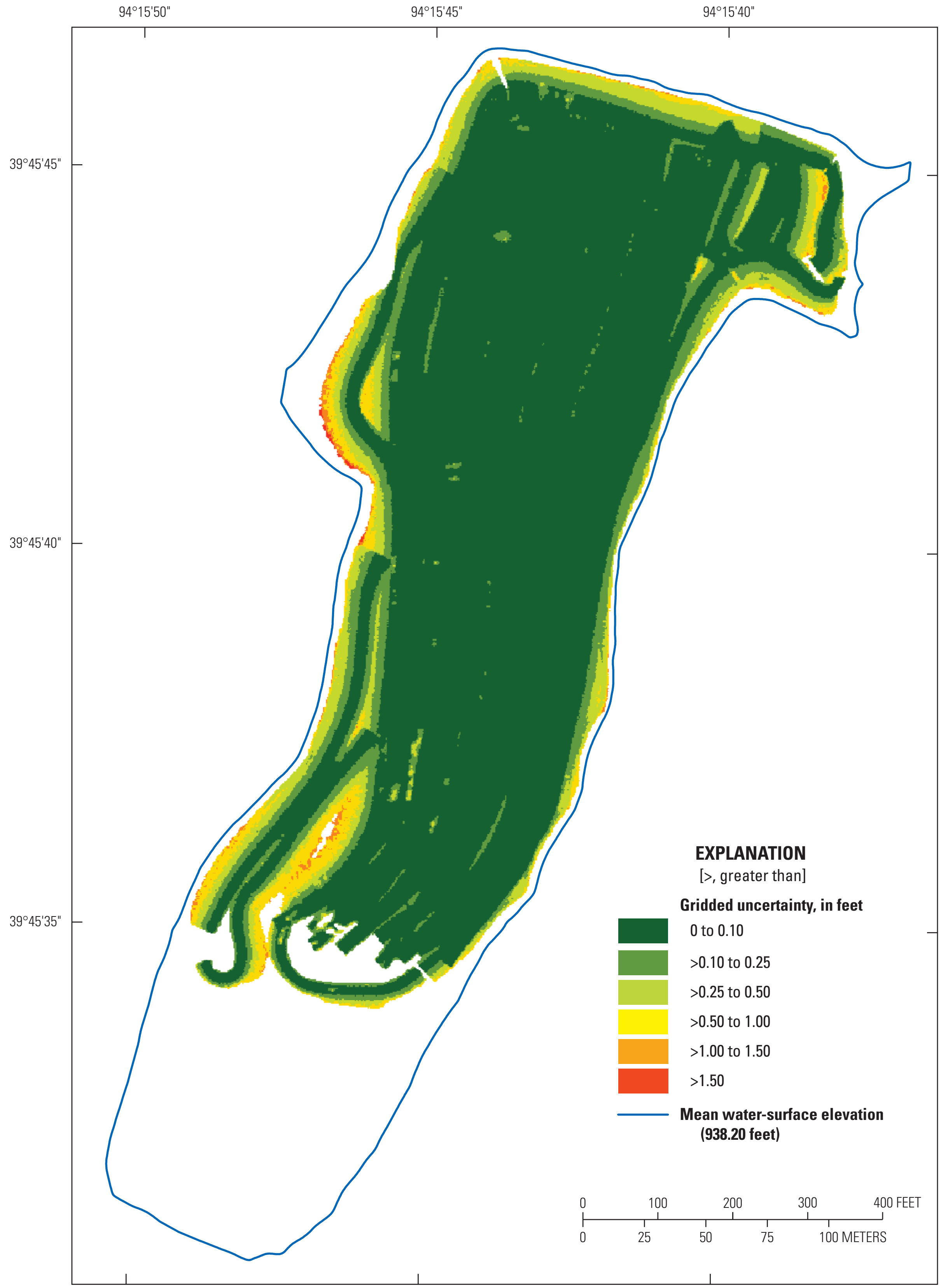


Figure 12. Gridded uncertainty of the bathymetric surface of Cameron Reservoir Number 1 (lake 36) near Cameron, Missouri, 2022.

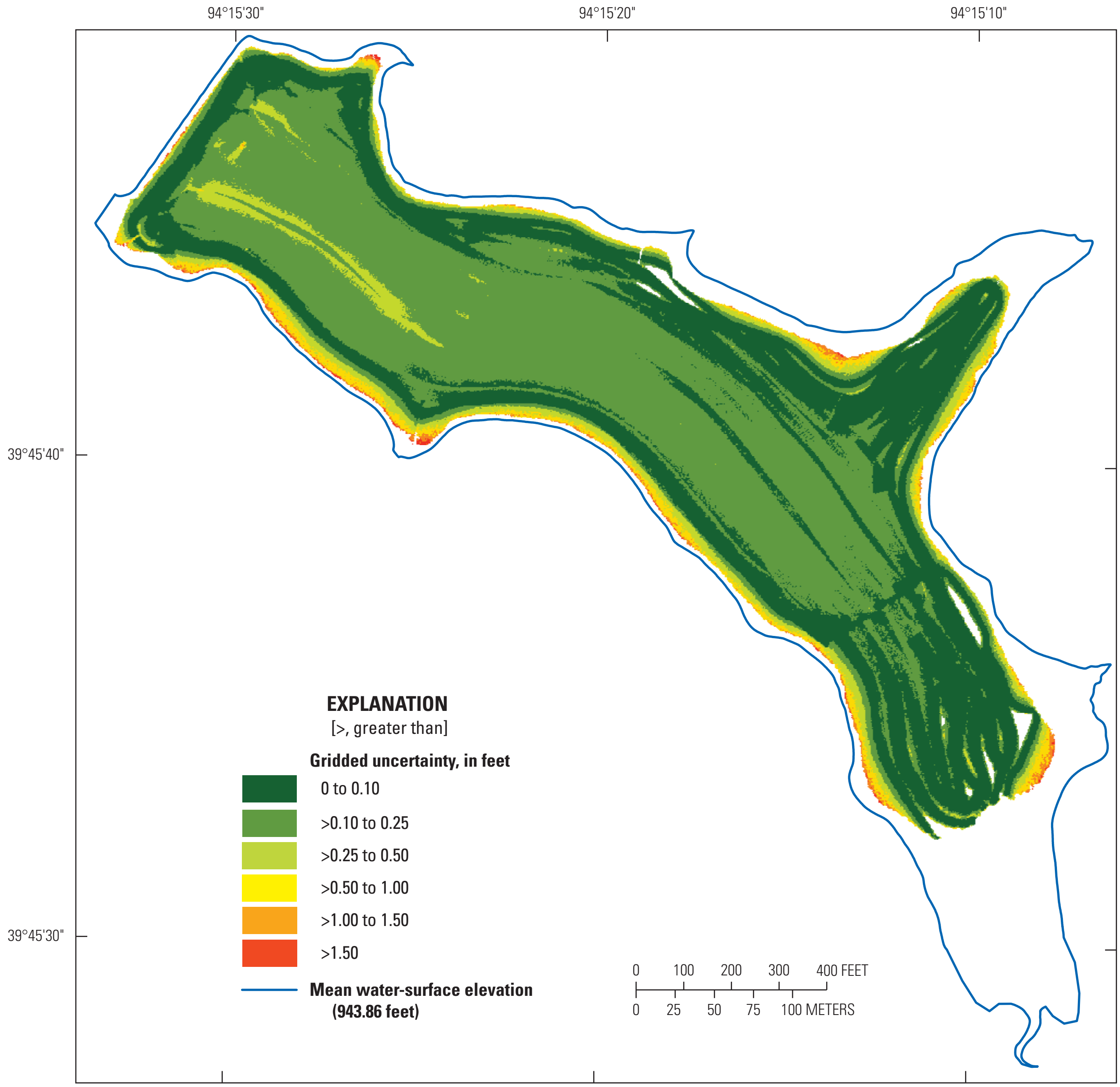


Figure 13. Gridded uncertainty of the bathymetric surface of Cameron Reservoir Number 2 (lake 37) near Cameron, Missouri, 2022.

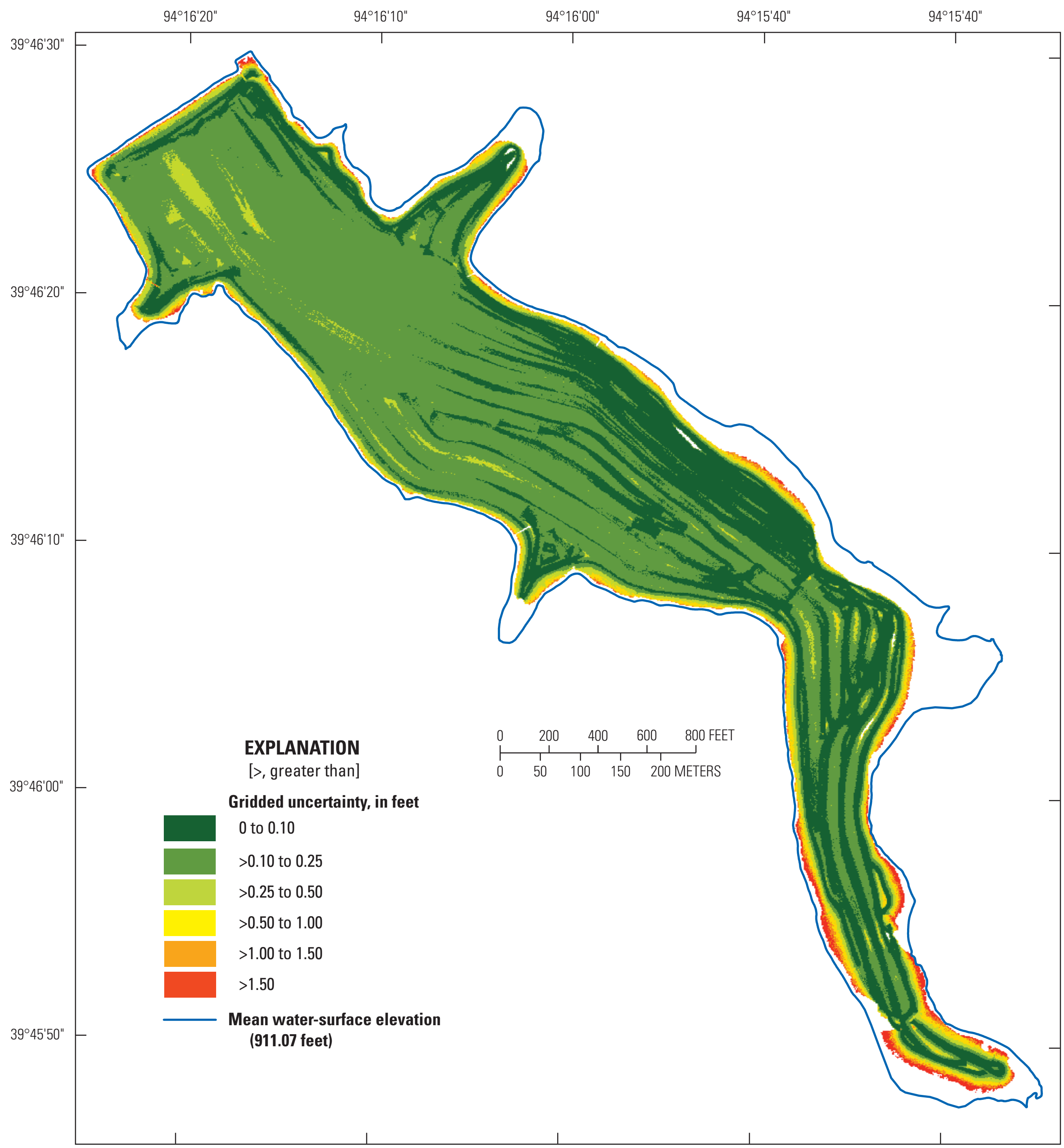


Figure 14. Gridded uncertainty of the bathymetric surface of Cameron Reservoir Number 3 (lake 38) near Cameron, Missouri, 2022.

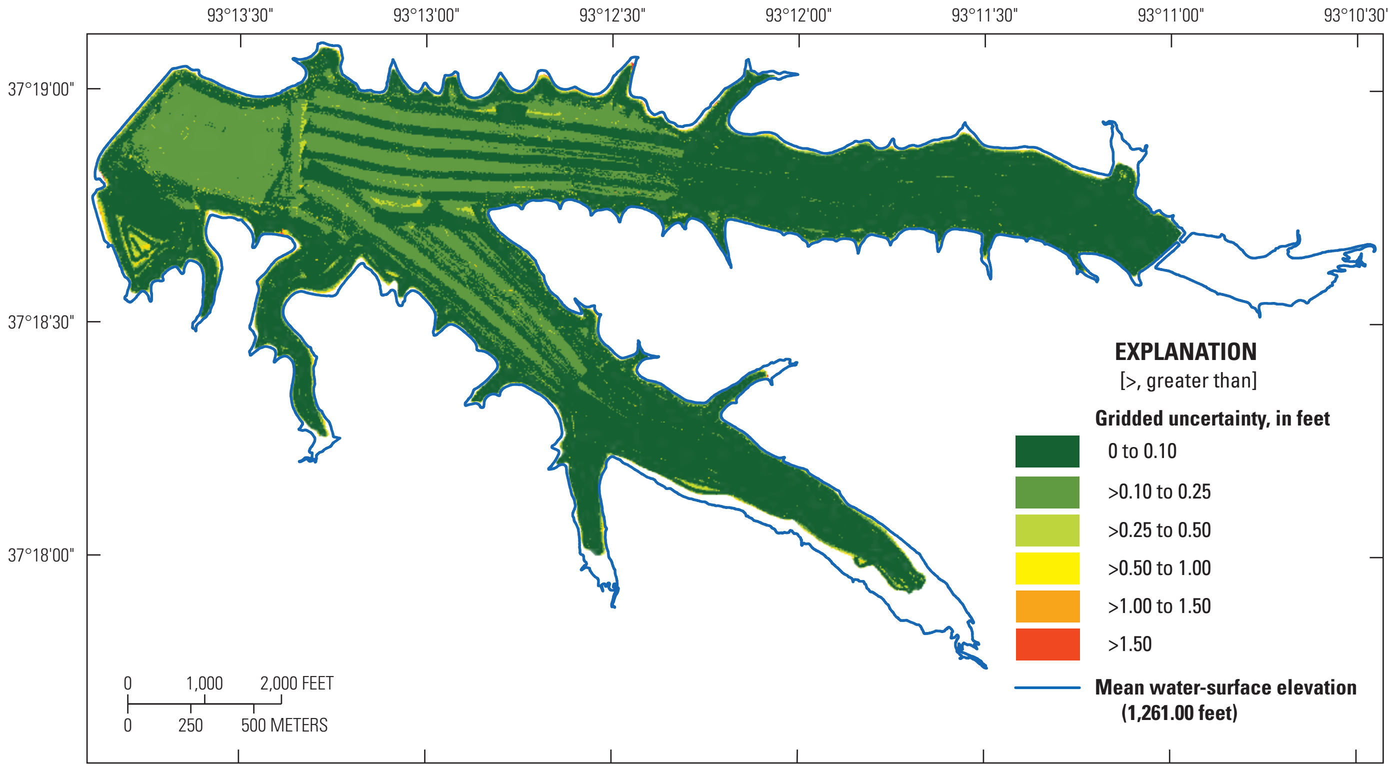


Figure 15. Gridded uncertainty of the bathymetric surface of Fellows Lake (lake 39) near Springfield, Missouri, 2022.

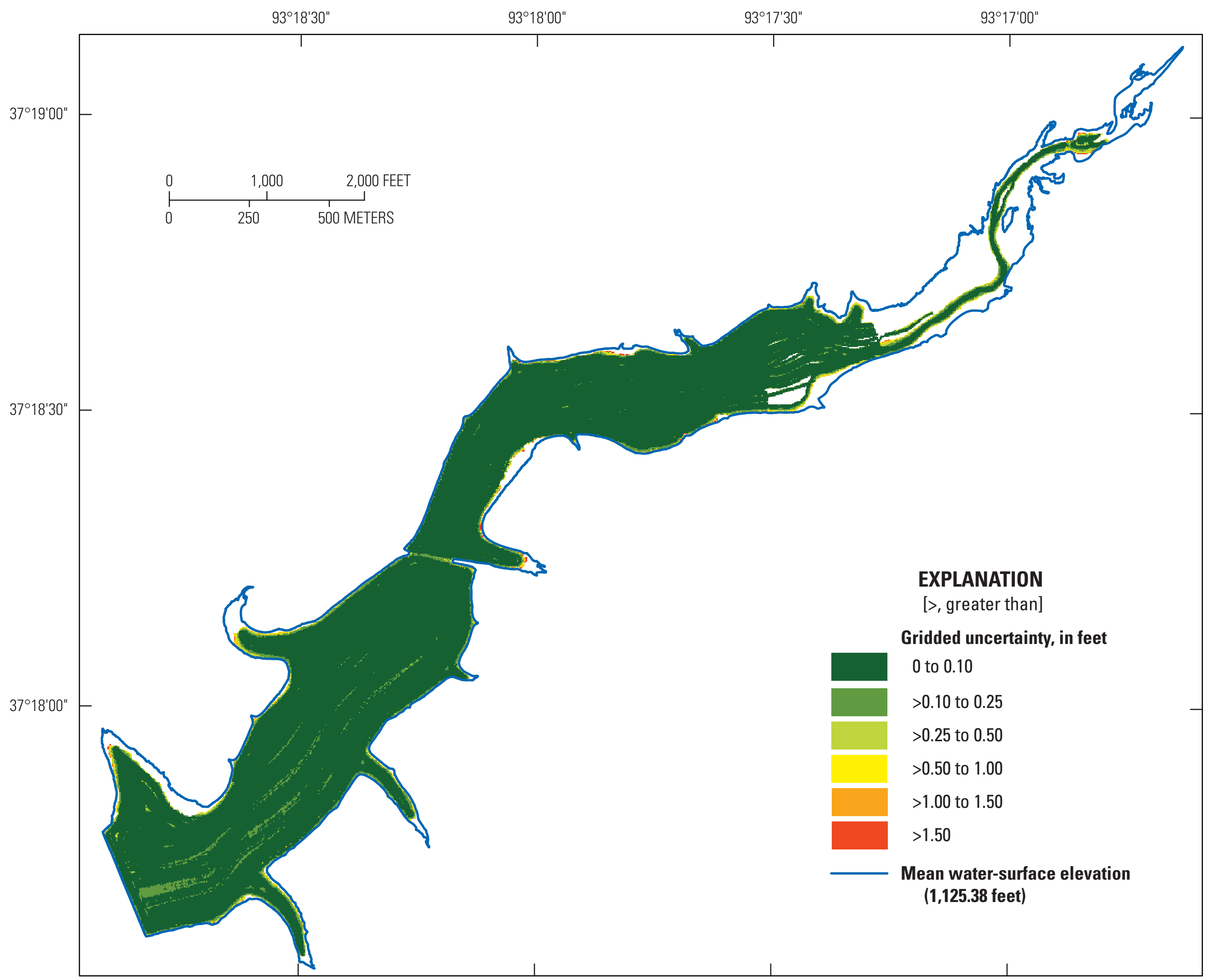


Figure 16. Gridded uncertainty of the bathymetric surface of McDaniel Lake (lake 40) near Springfield, Missouri, 2022.

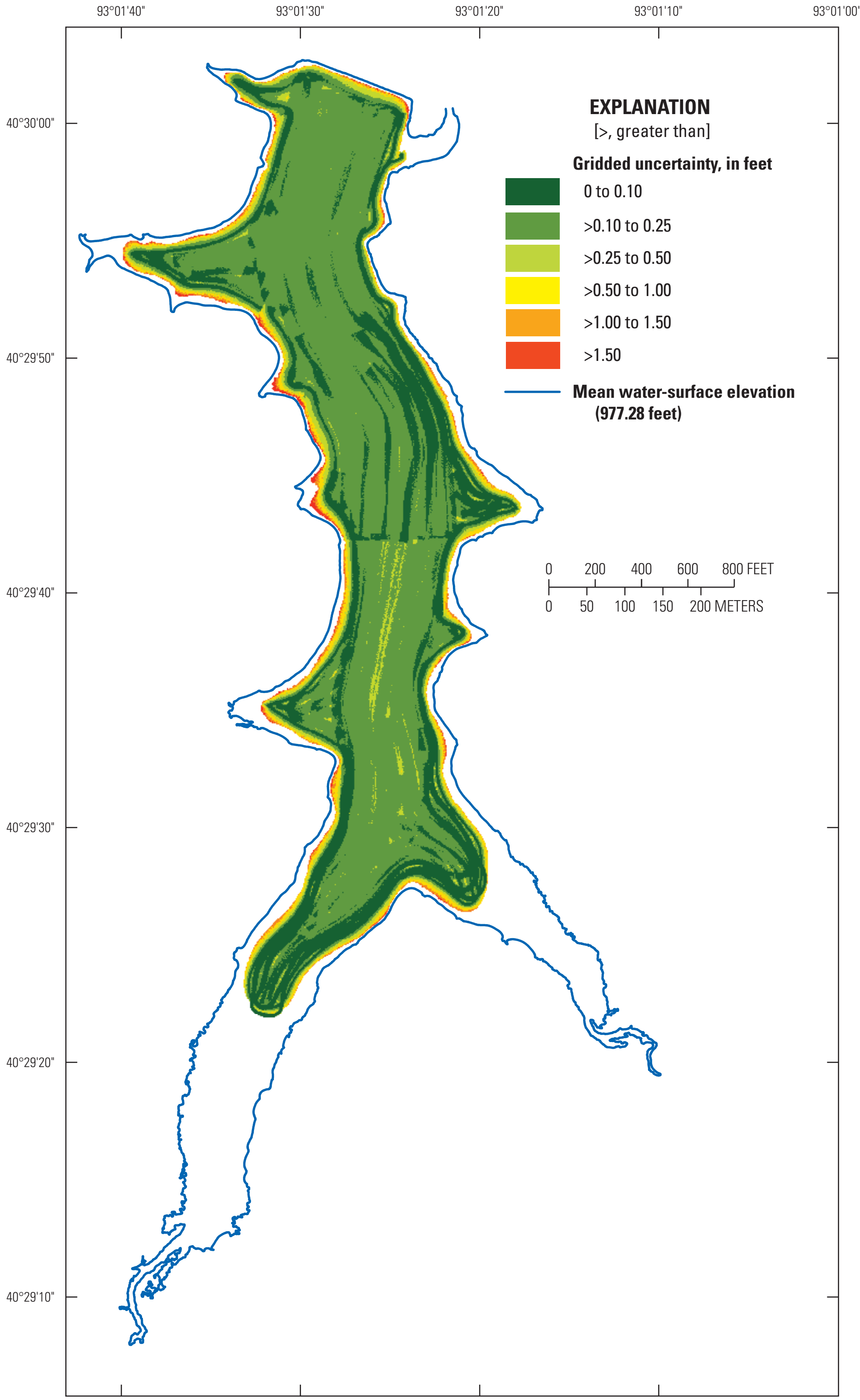


Figure 17. Gridded uncertainty of the bathymetric surface of Unionville Reservoir (Mahoney Lake; lake 41) near Unionville, Missouri, 2022.

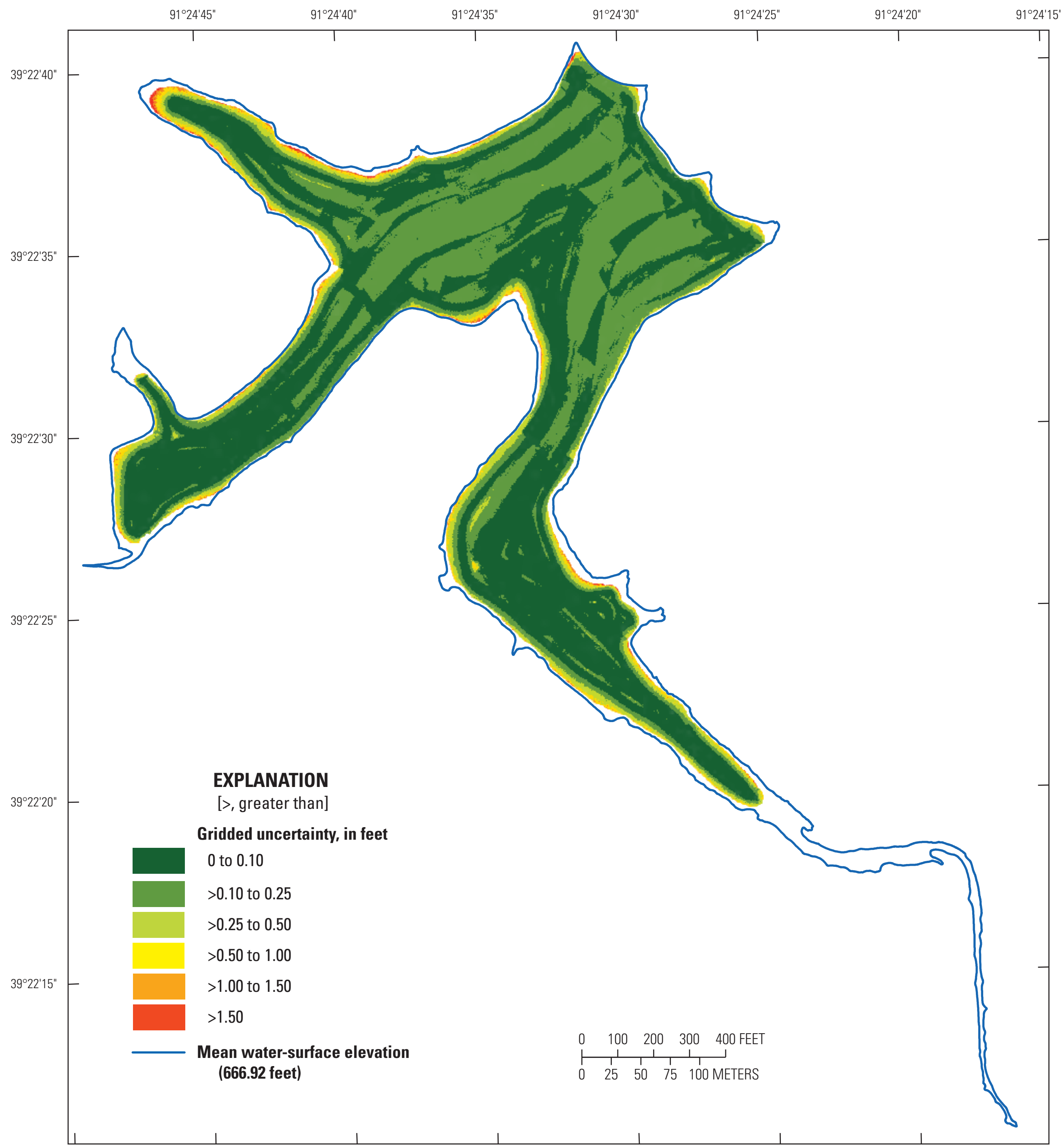


Figure 18. Gridded uncertainty of the bathymetric surface of Vandalia Reservoir (lake 42) near Vandalia, Missouri, 2023.

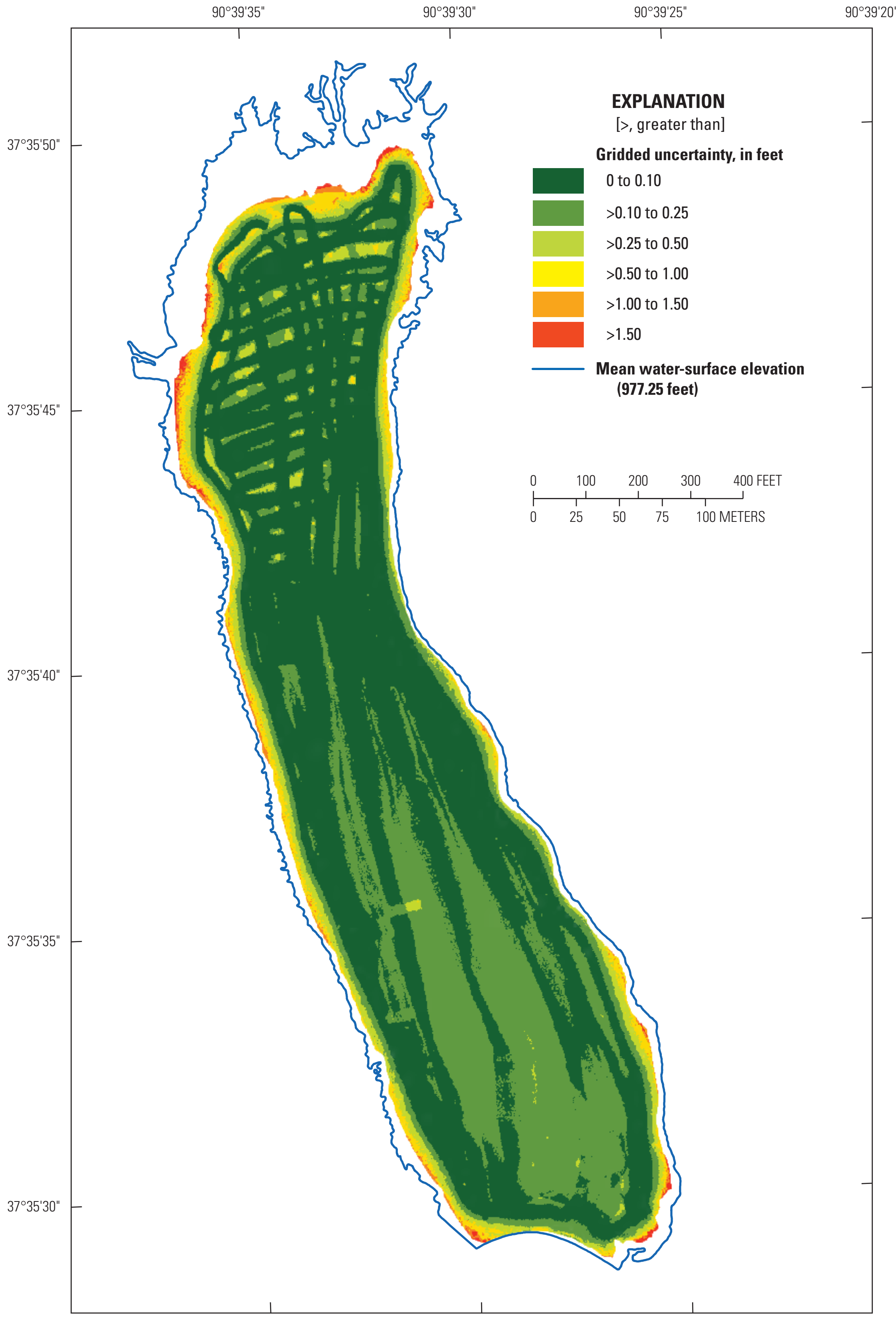


Figure 19. Gridded uncertainty of the bathymetric surface of Shepherd Mountain Lake (lake 43) near Ironton, Missouri, 2023.

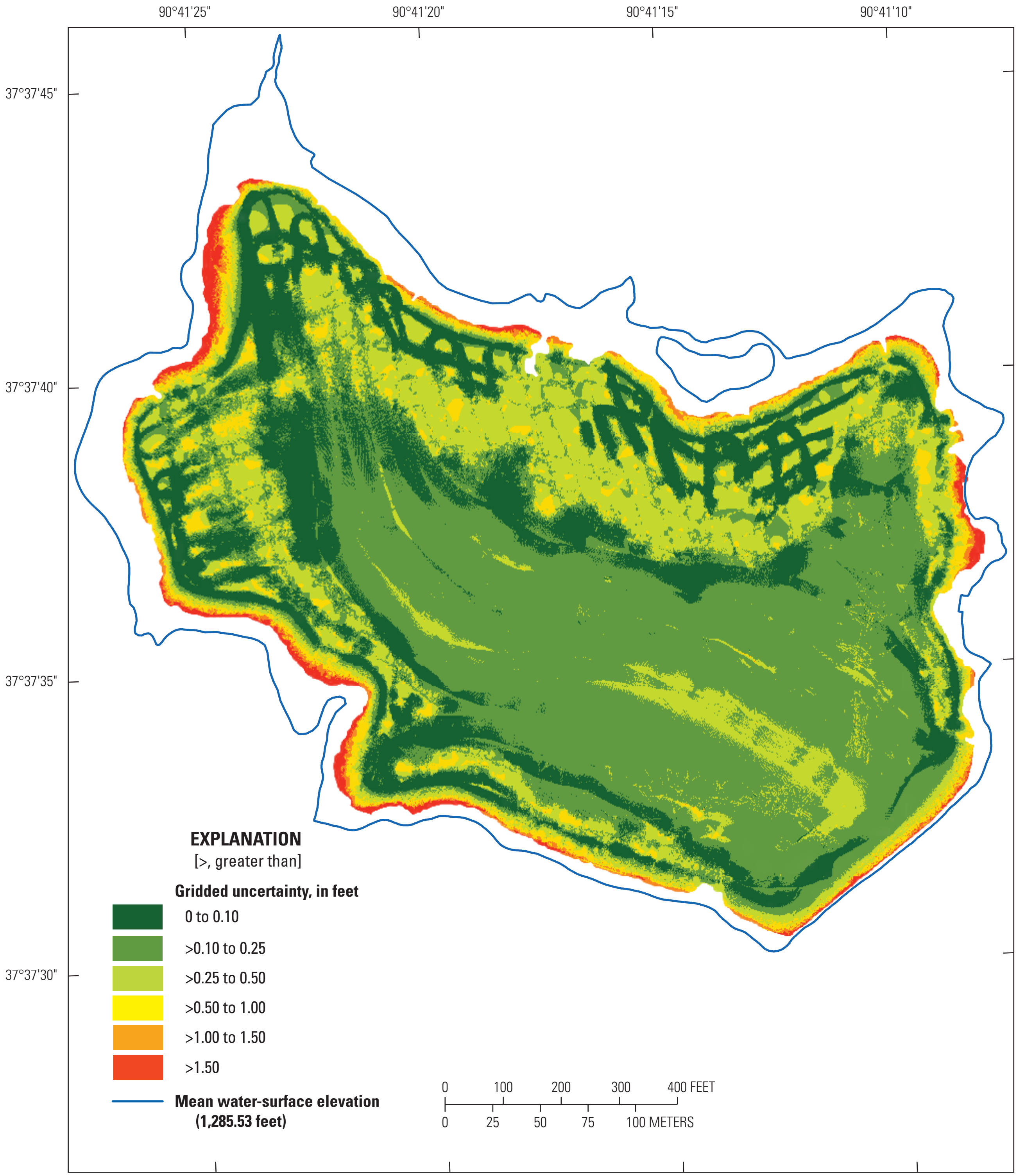


Figure 20. Gridded uncertainty of the bathymetric surface of Snow Hollow Lake (lake 44) near Ironton, Missouri, 2023.

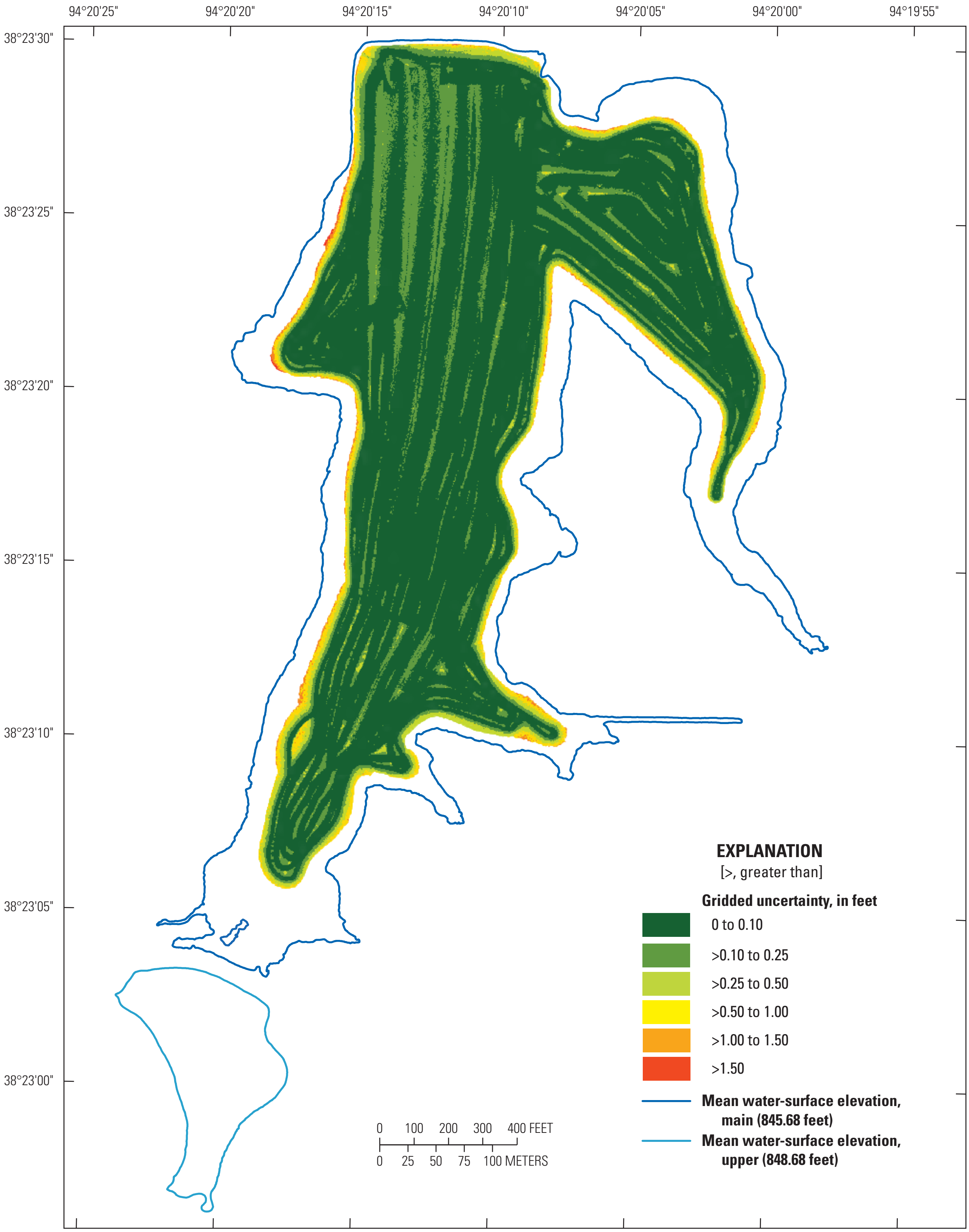


Figure 21. Gridded uncertainty of the bathymetric surface of Adrian Reservoir (lake 45) near Adrian, Missouri, 2023.

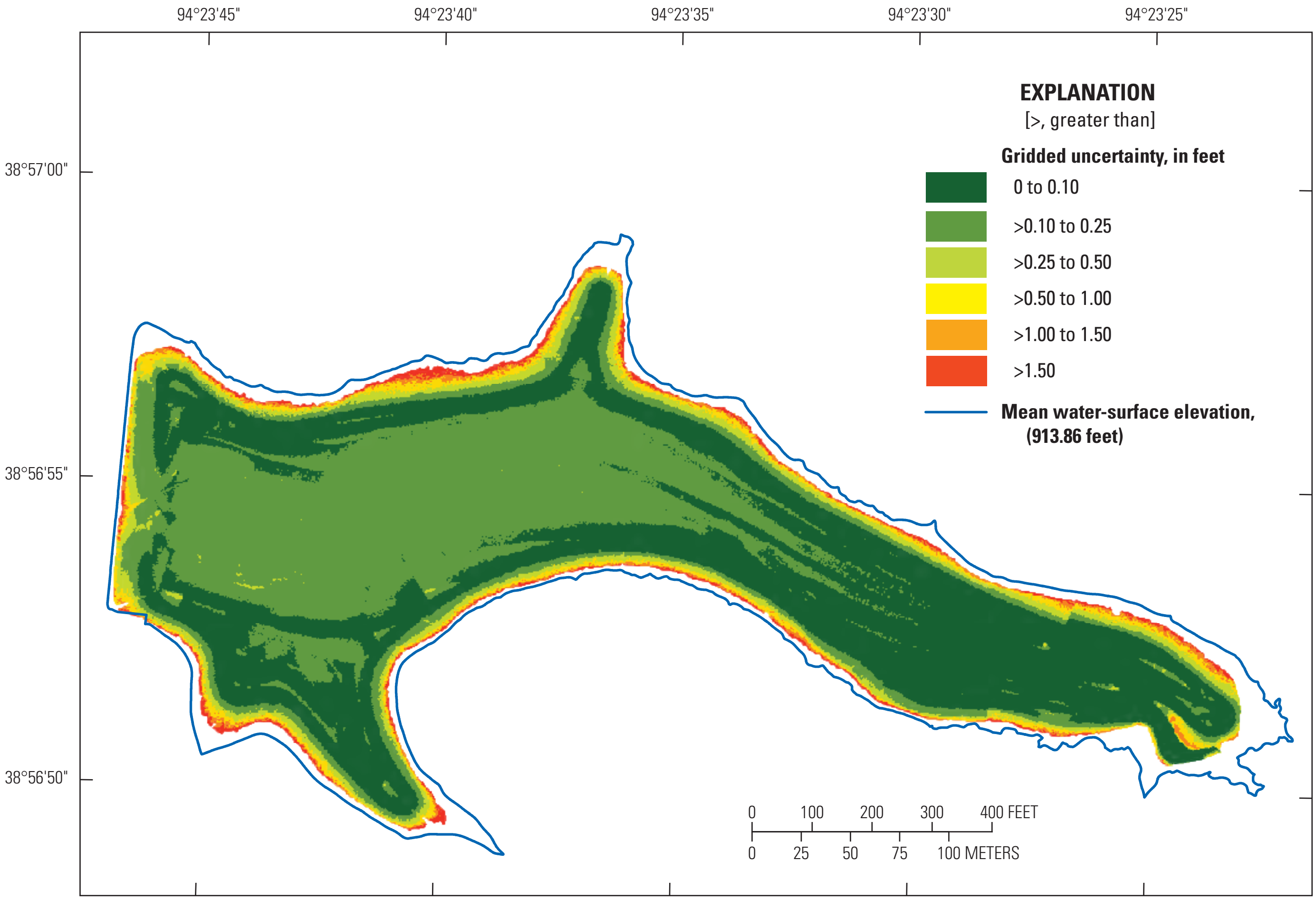


Figure 22. Gridded uncertainty of the bathymetric surface of Unity Lake Number 1 (lake 46) near Unity Village, Missouri, 2023.

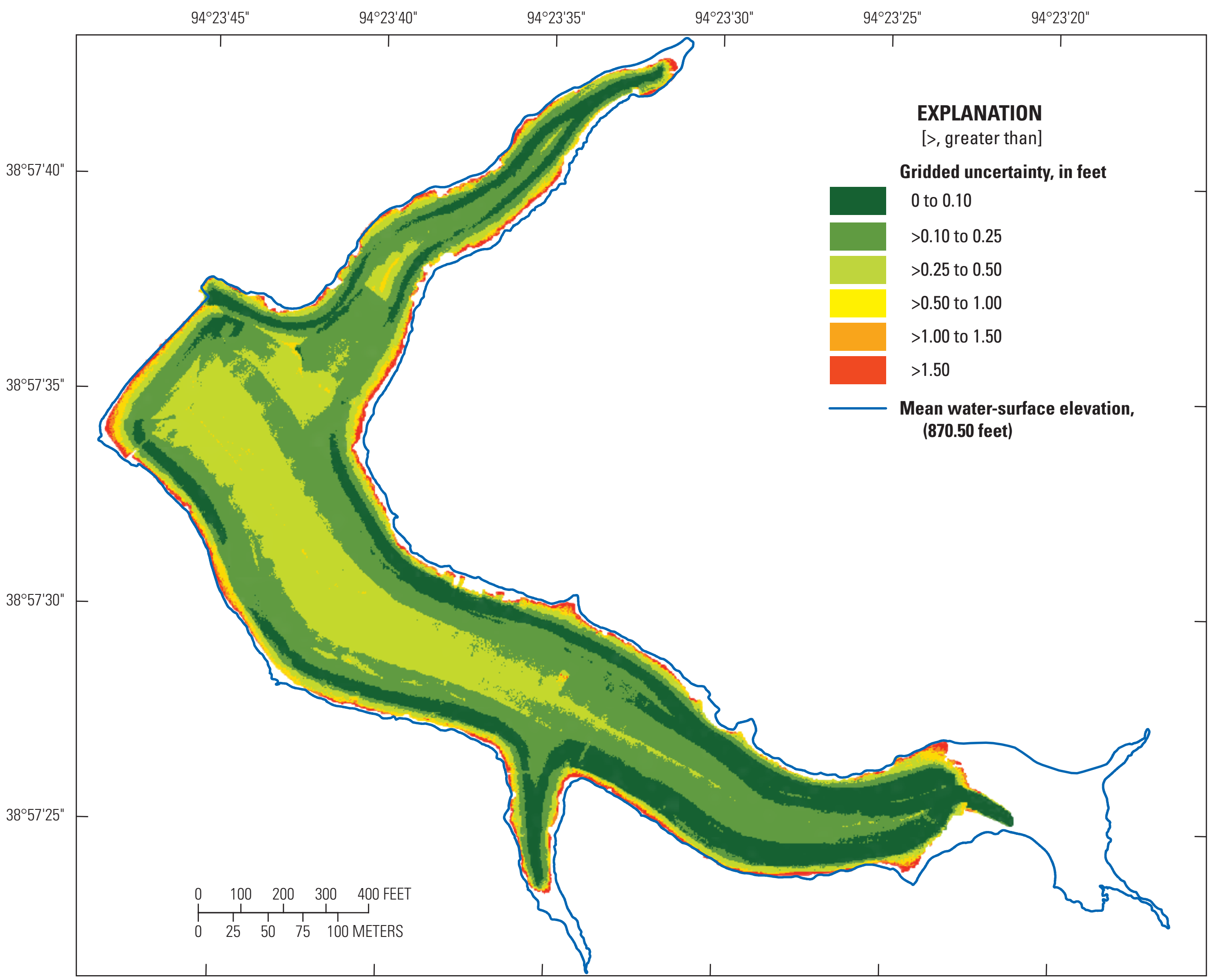


Figure 23. Gridded uncertainty of the bathymetric surface of Unity Lake Number 2 (lake 47) near Unity Village, Missouri, 2023.

Quality Assurance for Bathymetric Surface, Contour Map, and Bathymetric Change

Accuracy of the bathymetric surface and contours in relation to the survey data is a function of the survey data accuracy, the density of the survey data, and the various processing steps involved in the surface and contour creation. The process of data reduction to obtain the gridded dataset (at a given grid resolution) from the raw survey data likely degraded the accuracy of the gridded dataset relative to the raw data. Consistent with all the water-supply lake bathymetry work in 2018–21, at least one area of each lake was resurveyed after the main survey, generally in a direction 45 to 90 degrees to the main survey, to collect a dataset (hereinafter referred to as a "cross-check line") that could be used to estimate the accuracy of the gridded dataset used to produce the bathymetric surface (table 8). Raw points in the cross-check lines that were within a horizontal distance of 0.16 ft from a gridded point were selected as cross-check quality-assurance data points, and the elevation values of these cross-check line points were compared to the gridded points. The horizontal distance was chosen to permit a reasonable number of comparison points between the gridded and cross-check data and was loosely based on the interpoint spacing of the raw cross-check line data. The nearest raw cross-check line points were compared to the gridded points, with the data testing at a vertical accuracy shown in table 8 at a 95-percent confidence level; the mean and median absolute vertical error of each survey also is shown in table 8. The mean error is included because it is shown to be a key metric of volumetric uncertainty (Anderson, 2019).

A mapping quality-assurance dataset was used to evaluate the bathymetric surface and included data points selected at random from the gridded data points at each lake. Points that were used to create the bathymetric surface were not included as bathymetric surface quality-assurance points. The three-dimensional bathymetric surface was tested against the surface quality-assurance dataset from a given lake to determine the vertical accuracy of the surface using methods described in Wilson and Richards (2006). The surface of each lake tested at a vertical accuracy is shown in table 9 at the 95-percent confidence level; the mean error and median absolute vertical error of each surface are also shown in table 9. The spatial distribution of the vertical accuracy for each lake is shown in figs. 24–36. The three-dimensional bathymetric surface of each lake was used as the source for the computation of the surface area and capacity values for the lake and the source for the development of the bathymetric contour map for each lake (plates 1 through 13).

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 for a given lake were tested with the dataset used to create the bathymetric surface. A map point was considered a contour elevation evaluation point if it was within a certain horizontal distance of a given contour line (the "Contour quality-assurance point search tolerance" in table 10). The contour quality-assurance point search tolerance was chosen such that most of the quality-assurance points could be reasonably considered to be a match to the contour, and generally was less than one-half of the minimum horizontal distance between closely spaced contours, and excluded points on the dam face at lakes with a vertical or near-vertical dam face (McDaniel Lake, Vandalia Reservoir, Shepherd Mountain Lake, and Unity Lake Number 1). The contours of each lake tested at a vertical accuracy are shown in table 10 at the 95-percent confidence level; the mean error and median absolute vertical error of the contours for each lake also are shown in table 10.

The quality-assurance statistics in tables 8–10 provide a measure of the effects of each processing step in the development of the final products for each lake. The results in table 8 summarize the effect of gridding the bathymetry data from the raw data, the results in table 9 summarize the effect of creating a TIN surface from the subsampled gridded data, and the results in table 10 summarize the combined effects of creating a TIN surface from the subsampled gridded data and creating contours from the TIN surface. However, the contours and area and capacity tables were created from the TIN surface; therefore, the bathymetric TIN surface quality-assurance results presented in table 9 are the best representation of the overall quality of the final products for these lakes.

Quality-assurance data were used to evaluate the bathymetric surface accuracy of Unionville Reservoir (Mahoney Lake; lake 41), Vandalia Reservoir (lake 42), Shepherd Mountain Lake (lake 43), and Snow Hollow Lake (lake 44) in the previous surveys at these lakes (Wilson and Richards, 2006). These same data were used as an independent dataset to estimate the accuracy of the bathymetric change raster in the comparisons with the current surveys for these four lakes. The differences between the elevations of the previous survey quality-assurance data points and the 2022 or 2023 bathymetric mapping points at coincident locations were compared. The bathymetric change surface of each lake tested at a vertical accuracy is shown in table 11 at the 95-percent confidence level; the mean error and median absolute vertical error of the change surface for each lake also are shown in table 11.

Table 8. Summary of cross-check line results used for quality assurance of gridded bathymetric data from surveys at water-supply lakes in Missouri in 2022 and 2023.

Lake name	Lake number (fig. 1)	Number of raw quality-assurance points in cross-check line dataset	Number of points in comparison dataset	Tested vertical accuracy at a 95-percent confidence level, in feet	Mean vertical error, in feet	Median absolute vertical error, in feet
Grindstone Reservoir	35	525,564	4,193	0.20	−0.01	0.07
Cameron Reservoir Number 1	36	393,004	7,906	0.12	0.01	0.03
Cameron Reservoir Number 2	37	459,839	14,204	0.14	0.02	0.07
Cameron Reservoir Number 3	38	1,109,386	30,685	0.17	0.00	0.07
Fellows Lake	39	3,864,611	18,959	0.53	0.15	0.16
McDaniel Lake	40	1,625,296	15,056	0.17	−0.03	0.07
Unionville Reservoir (Mahoney Lake)	41	1,123,911	28,182	0.16	−0.01	0.07
Vandalia Reservoir	42	341,334	19,068	0.11	0.02	0.03
Shepherd Mountain Lake	43	435,466	13,183	0.17	0.06	0.07
Snow Hollow Lake	44	655,619	24,804	0.37	−0.03	0.07
Adrian Reservoir	45	1,055,397	20,920	0.15	0.02	0.03
Unity Lake Number 1	46	761,881	29,134	0.25	0.04	0.07
Unity Lake Number 2	47	773,801	44,574	0.18	−0.02	0.07

Table 9. Summary of bathymetric surface quality-assurance results from surveys at water-supply lakes in Missouri in 2022 and 2023.

Lake name	Lake number (fig. 1)	Number of points in quality-assurance dataset (table 2)	Tested vertical accuracy at a 95-percent confidence level, in feet	Mean vertical error, in feet	Median absolute vertical error, in feet
Grindstone Reservoir	35	67,128	0.10	0.00	0.01
Cameron Reservoir Number 1	36	24,930	0.36	−0.02	0.00
Cameron Reservoir Number 2	37	50,125	0.22	0.00	0.00
Cameron Reservoir Number 3	38	160,938	0.09	0.00	0.00
Fellows Lake	39	97,678	0.50	−0.02	0.00
McDaniel Lake	40	132,715	0.21	0.00	0.00
Unionville Reservoir (Mahoney Lake)	41	111,844	0.07	0.00	0.02
Vandalia Reservoir	42	55,403	0.14	−0.01	0.02
Shepherd Mountain Lake	43	39,908	0.12	0.00	0.02
Snow Hollow Lake	44	41,623	0.20	0.00	0.02
Adrian Reservoir	45	75,341	0.07	0.00	0.01
Unity Lake Number 1	46	32,077	0.24	−0.01	0.02
Unity Lake Number 2	47	48,214	0.32	−0.01	0.02

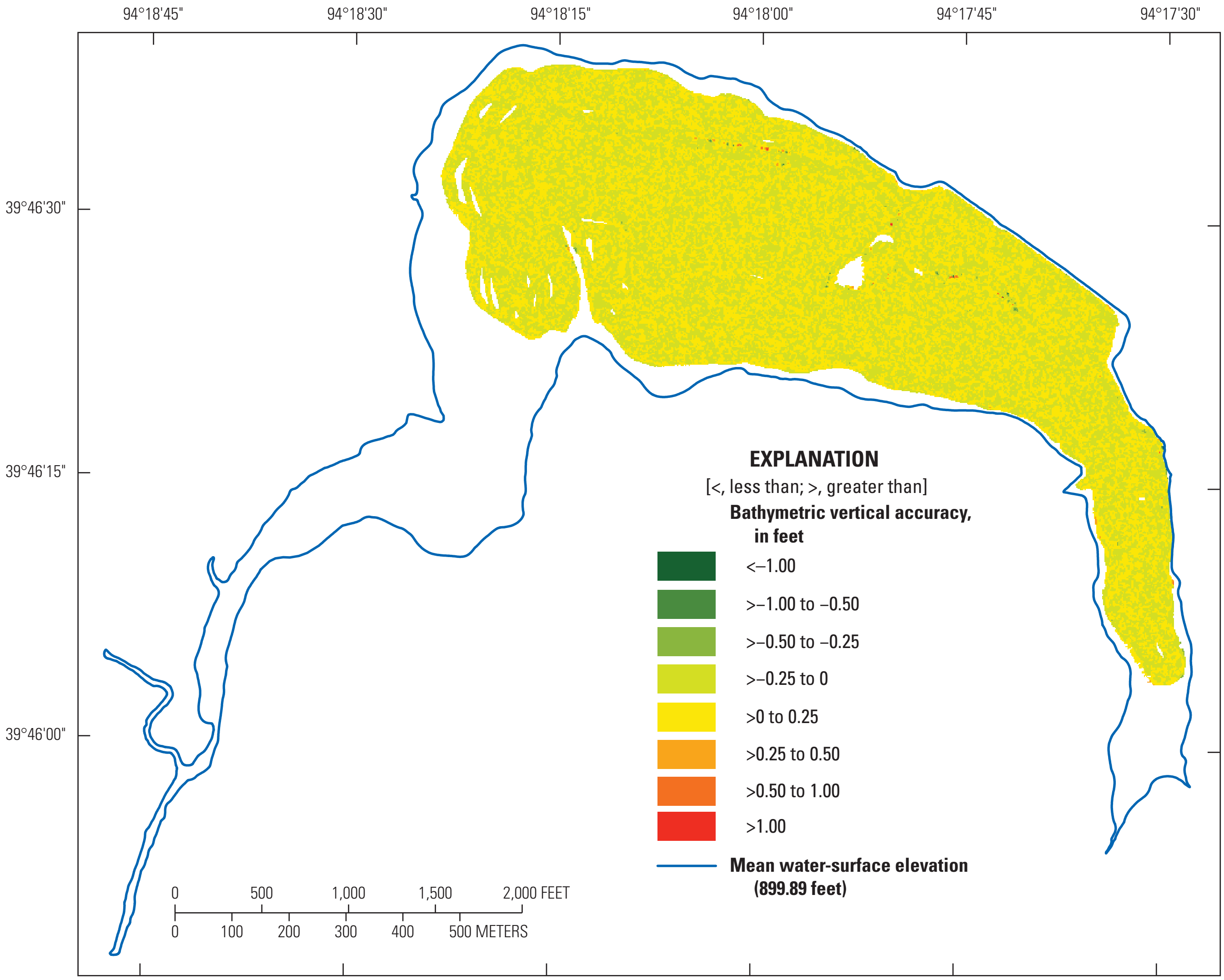


Figure 24. Vertical accuracy of the bathymetric surface of Grindstone Reservoir (lake 35) near Cameron, Missouri, 2022.

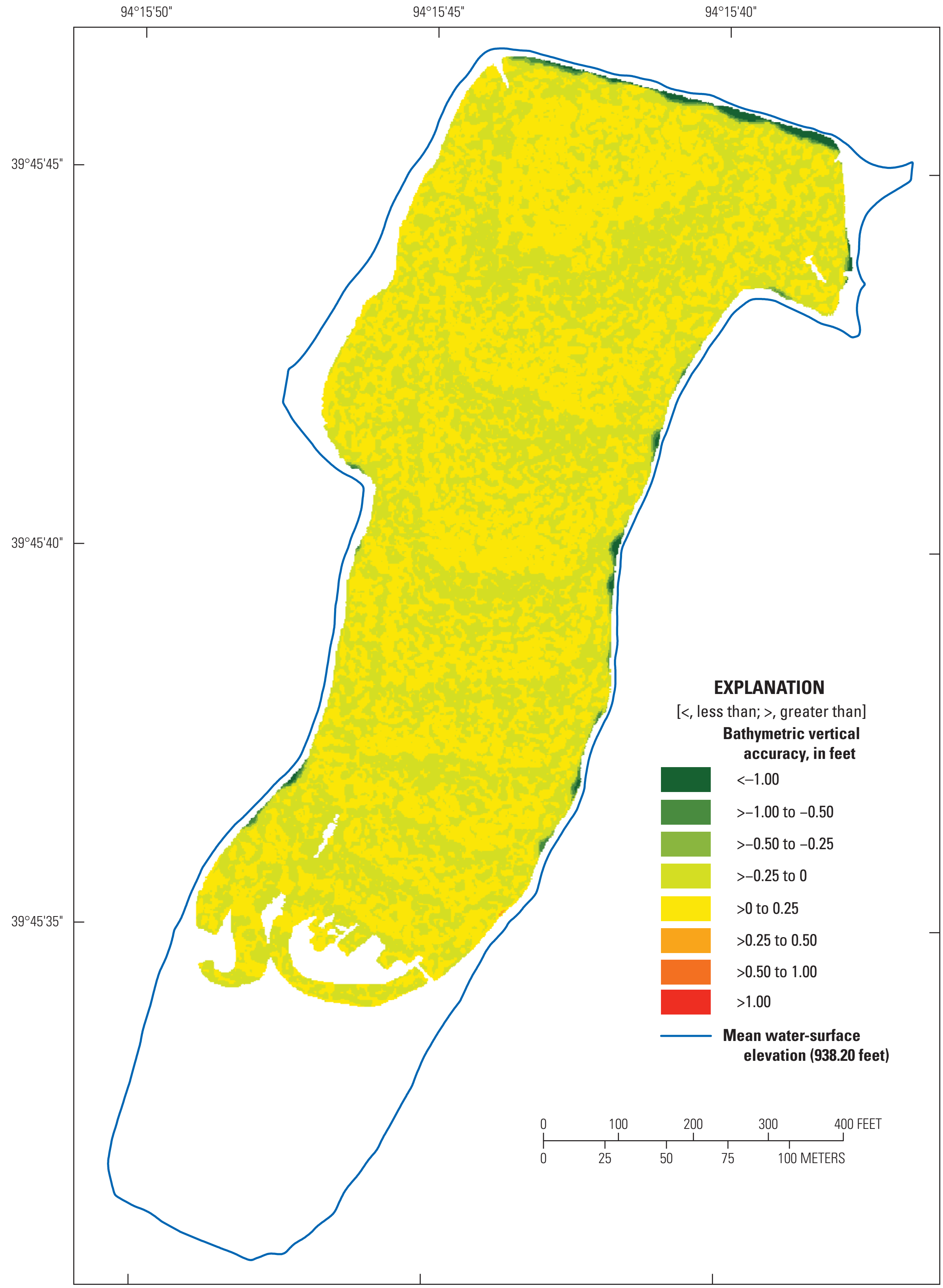


Figure 25. Vertical accuracy of the bathymetric surface of Cameron Reservoir Number 1 (lake 36) near Cameron, Missouri, 2022.

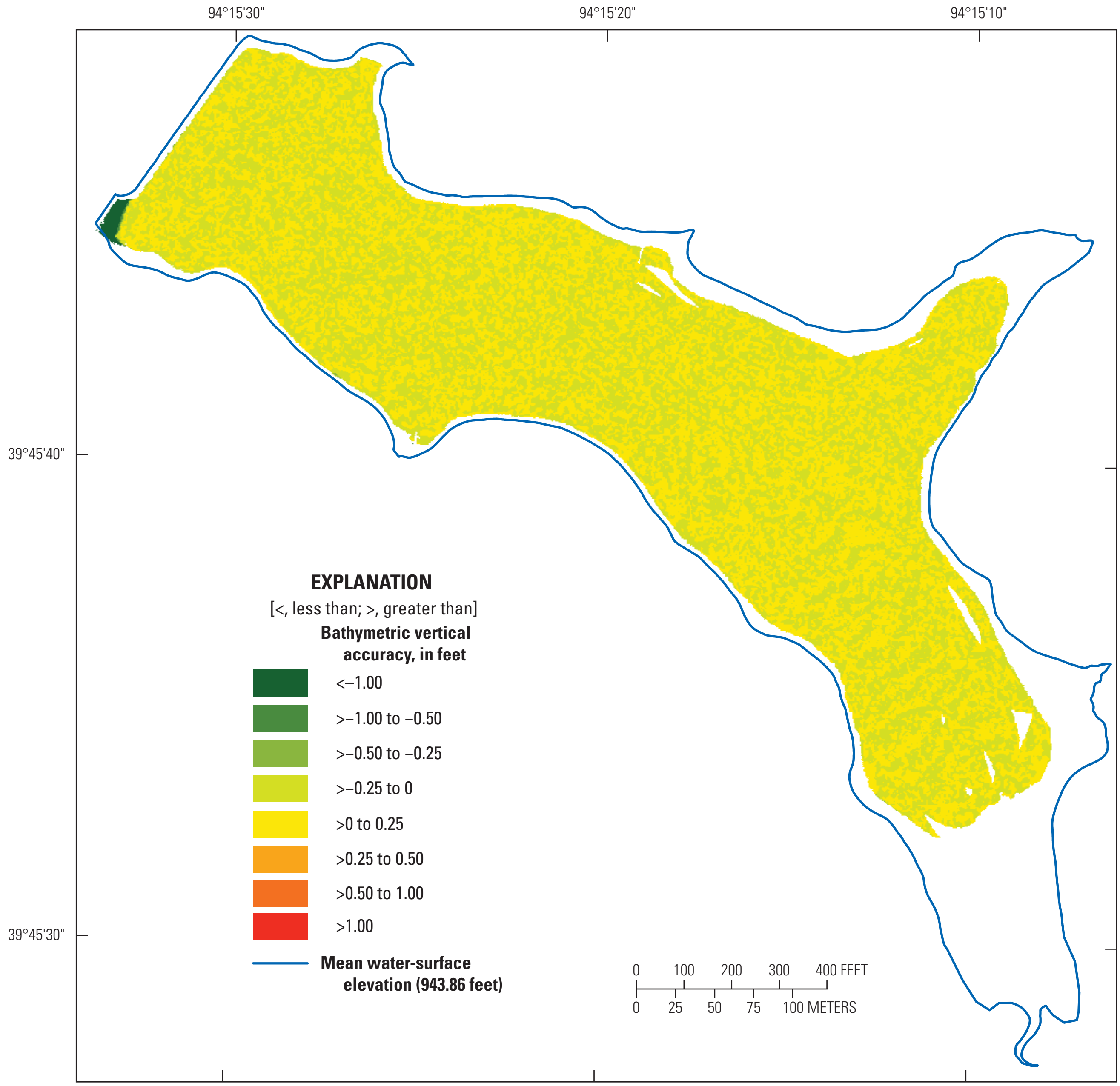


Figure 26. Vertical accuracy of the bathymetric surface of Cameron Reservoir Number 2 (lake 37) near Cameron, Missouri, 2022.

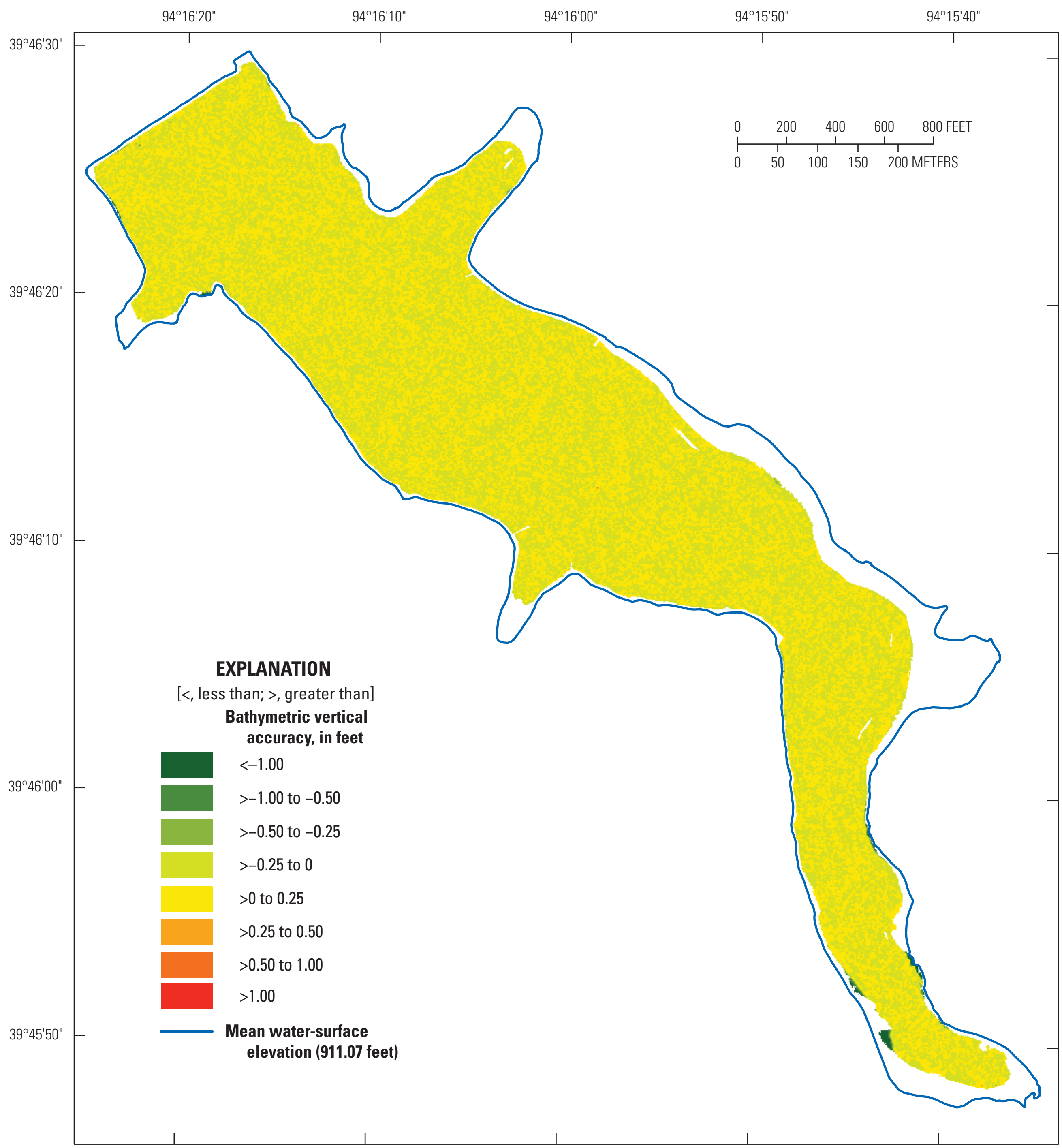


Figure 27. Vertical accuracy of the bathymetric surface of Cameron Reservoir Number 3 (lake 38) near Cameron, Missouri, 2022.

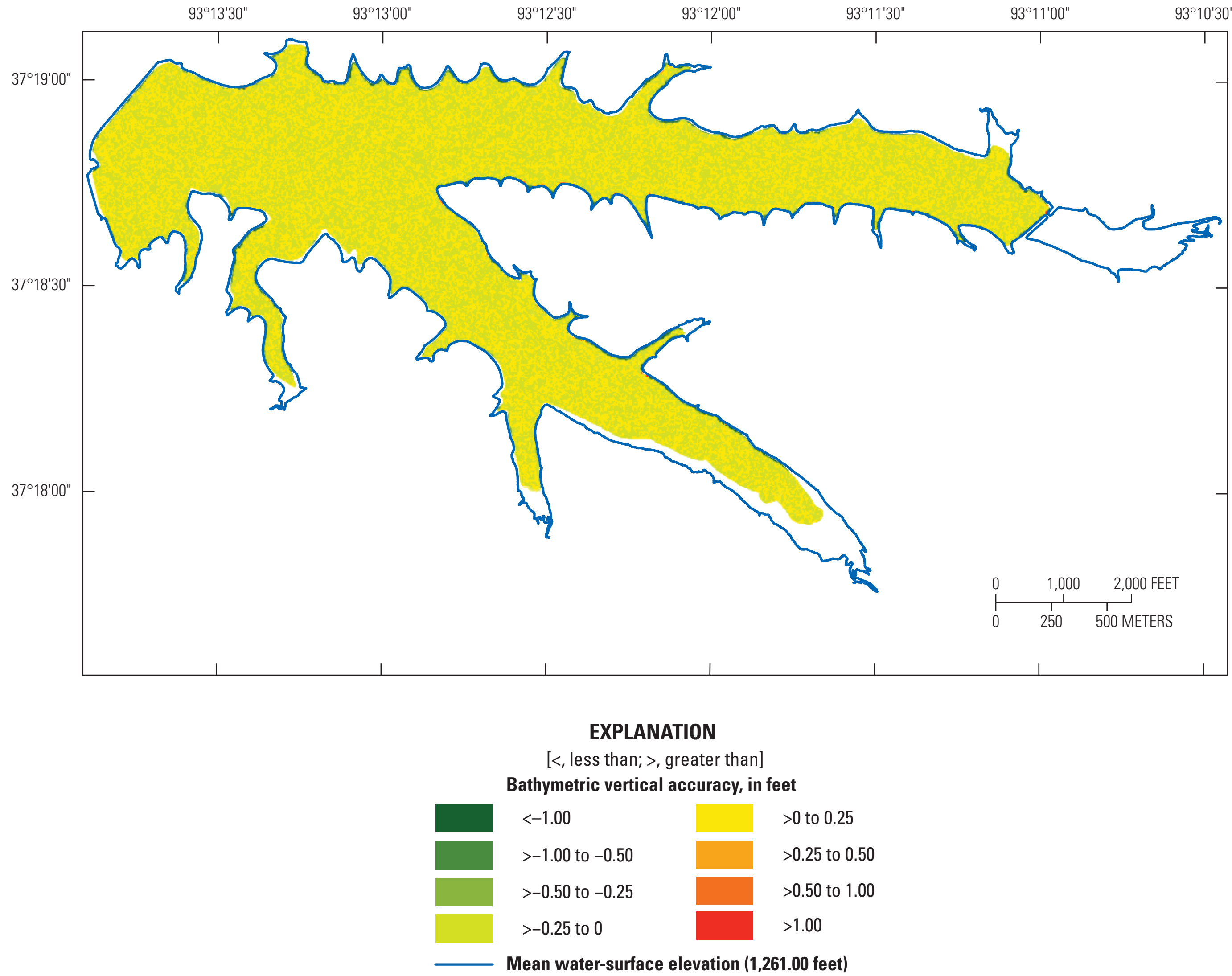


Figure 28. Vertical accuracy of the bathymetric surface of Fellows Lake (lake 39) near Springfield, Missouri, 2022.

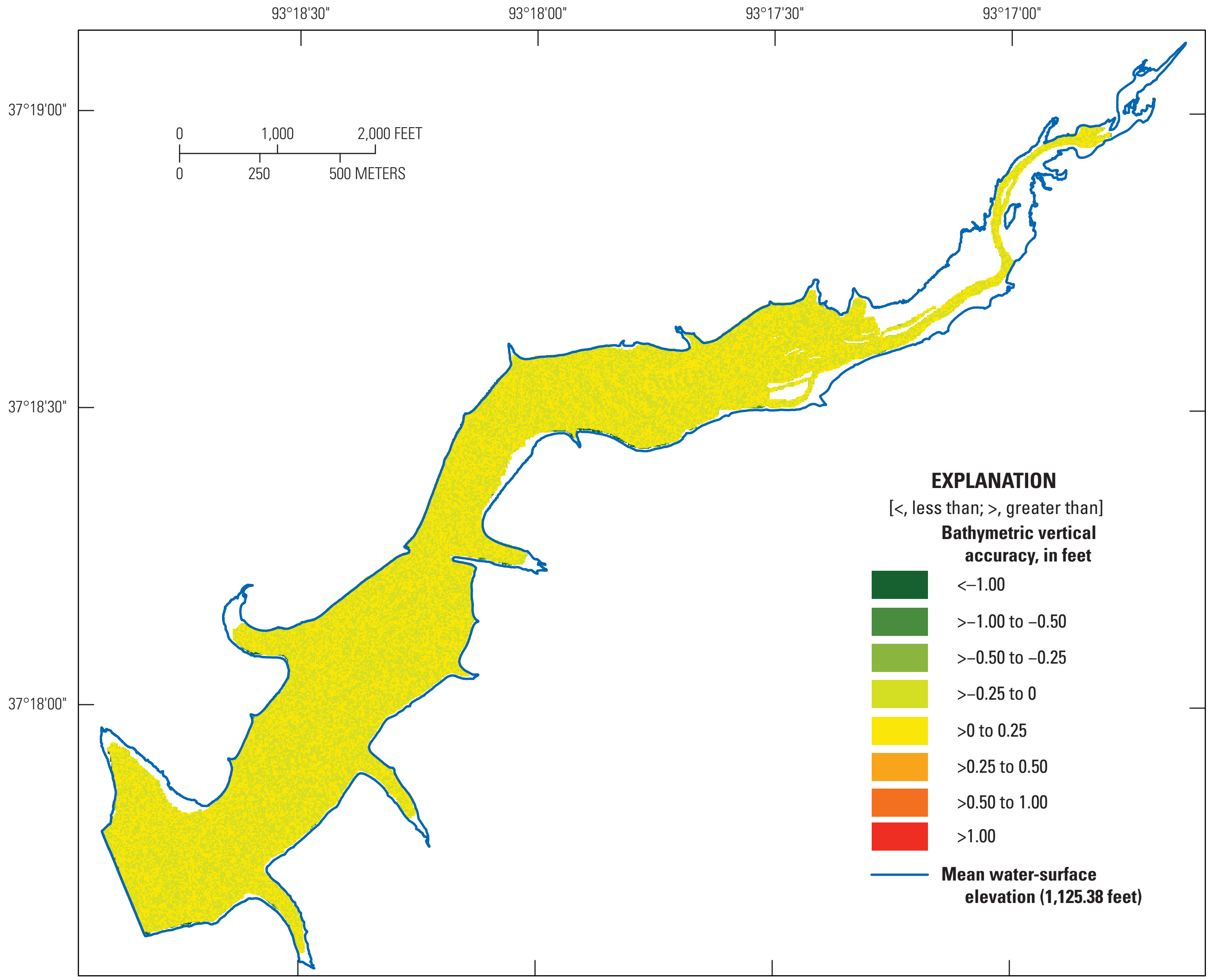


Figure 29. Vertical accuracy of the bathymetric surface of McDaniel Lake (lake 40) near Springfield, Missouri, 2022.

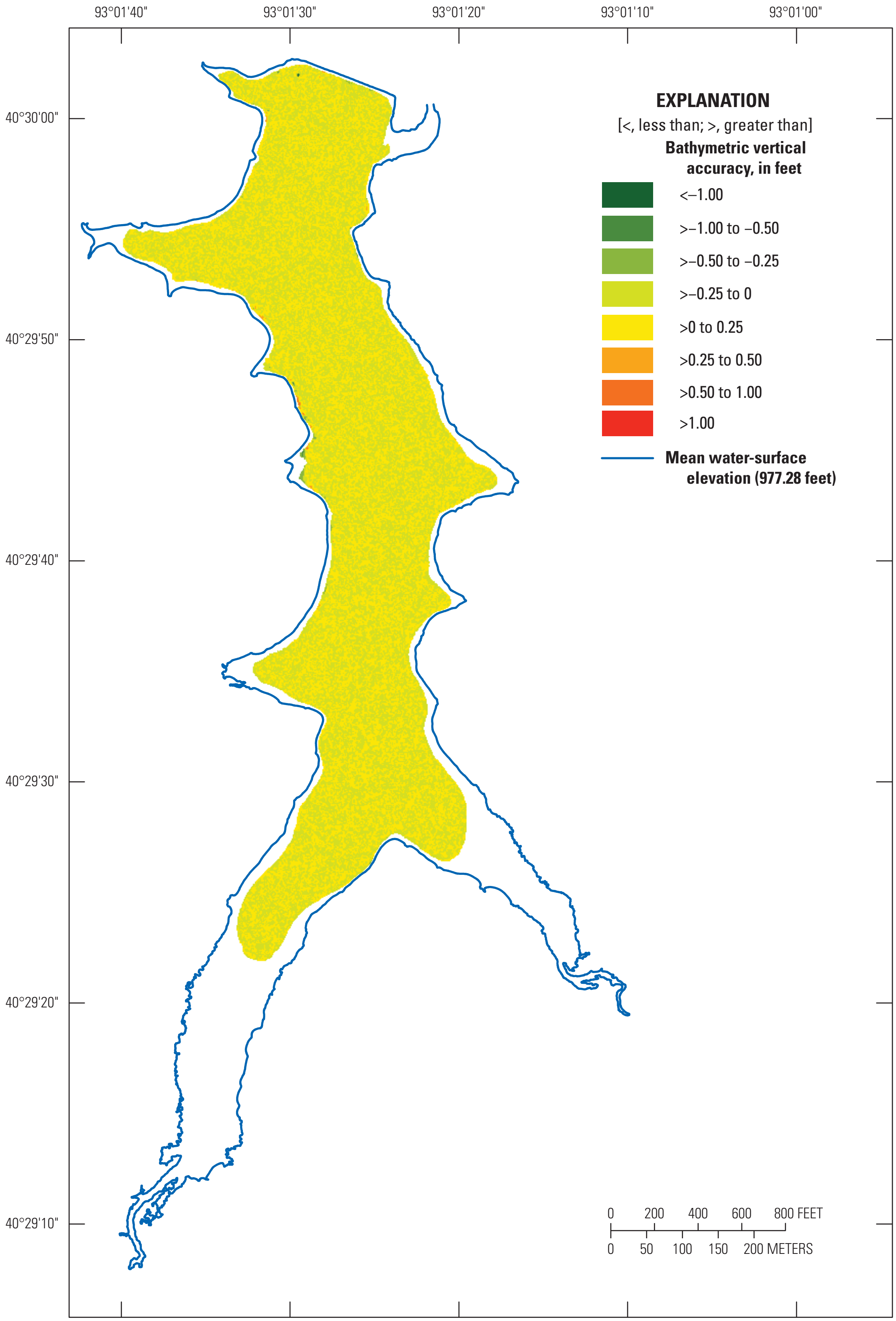


Figure 30. Vertical accuracy of the bathymetric surface of Unionville Reservoir (Mahoney Lake; lake 41) near Unionville, Missouri, 2022.

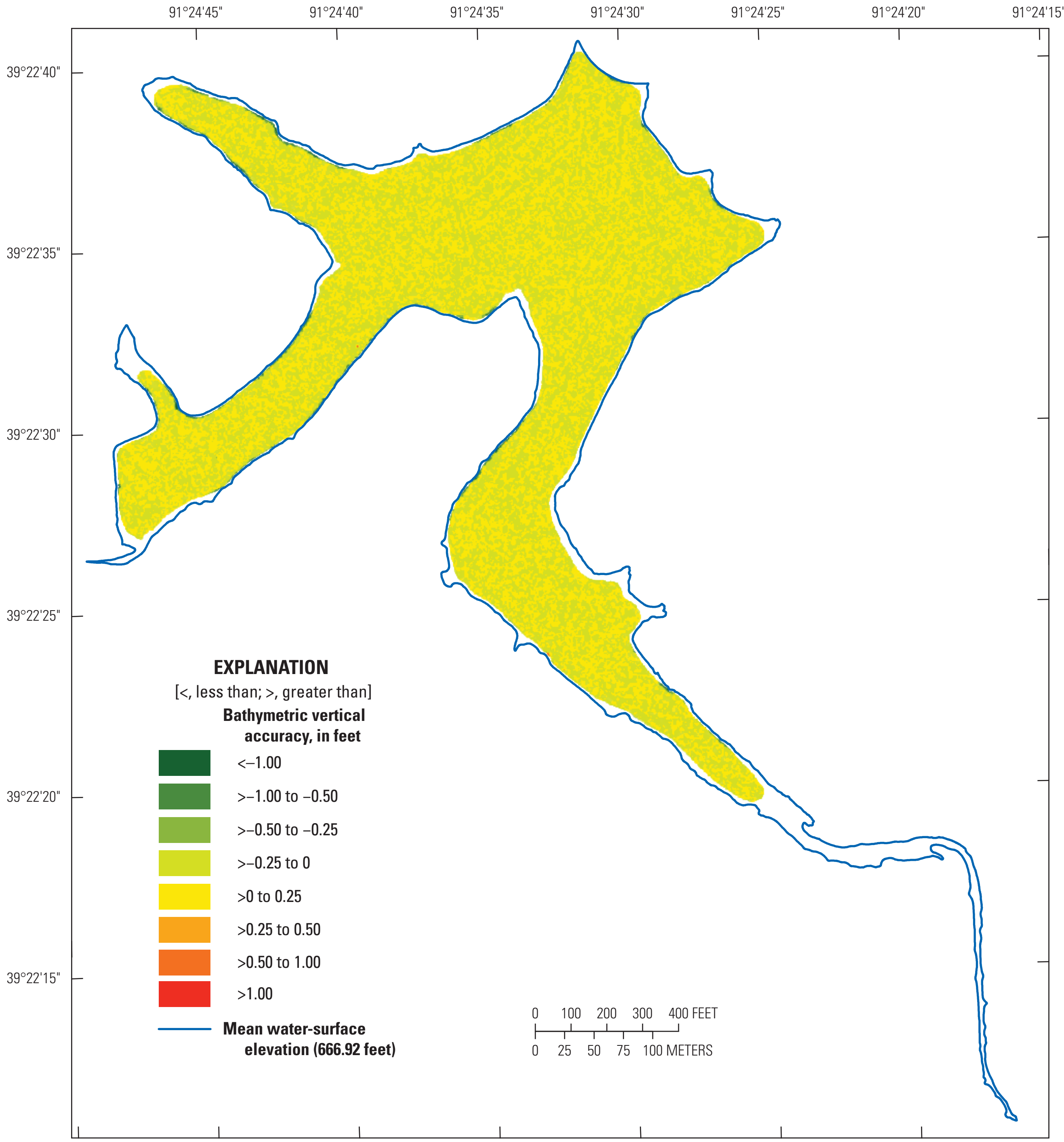


Figure 31. Vertical accuracy of the bathymetric surface of Vandalia Reservoir (lake 42) near Vandalia, Missouri, 2023.

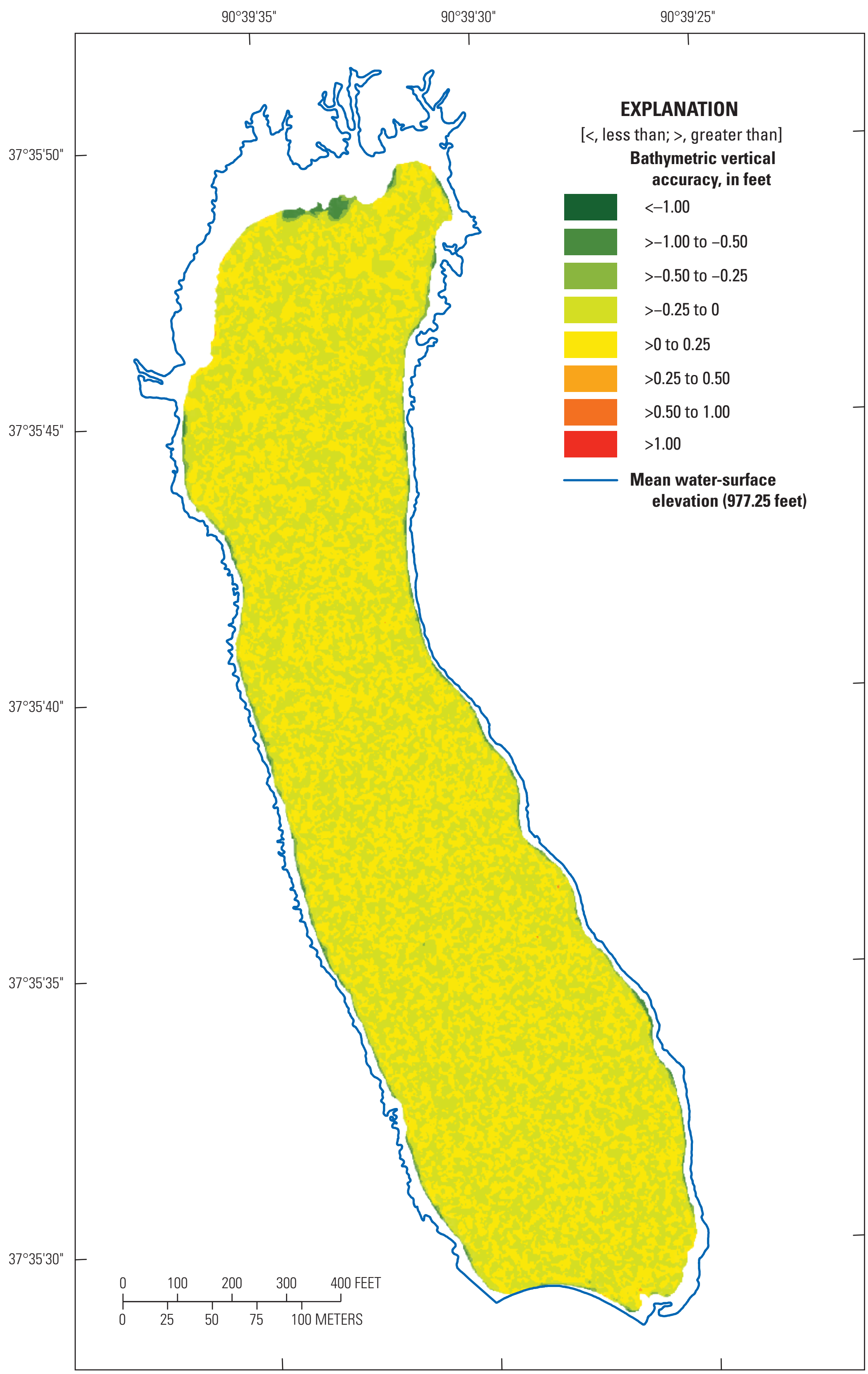


Figure 32. Vertical accuracy of the bathymetric surface of Shepherd Mountain Lake (lake 43) near Ironton, Missouri, 2023.

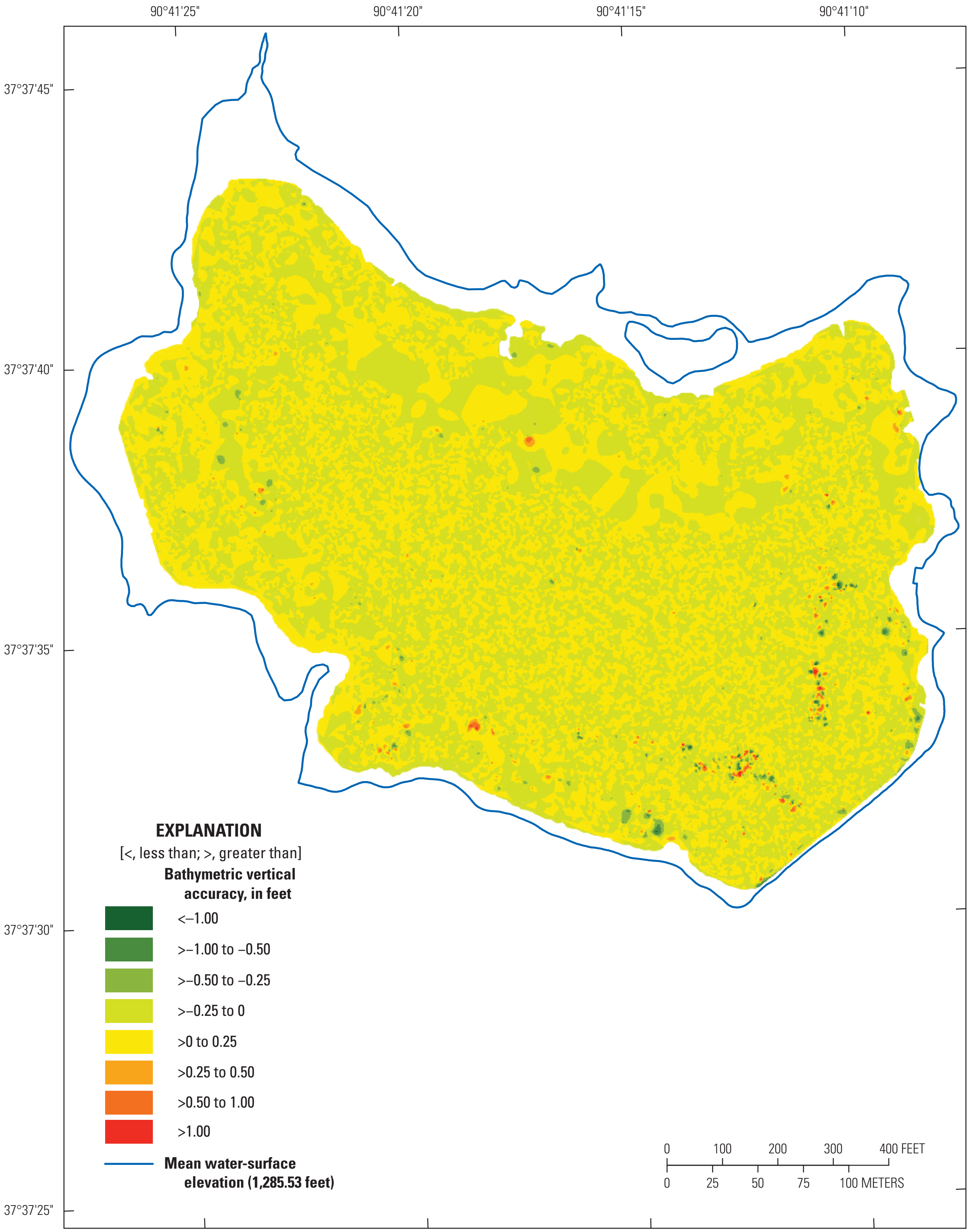


Figure 33. Vertical accuracy of the bathymetric surface of Snow Hollow Lake (lake 44) near Ironton, Missouri, 2023.

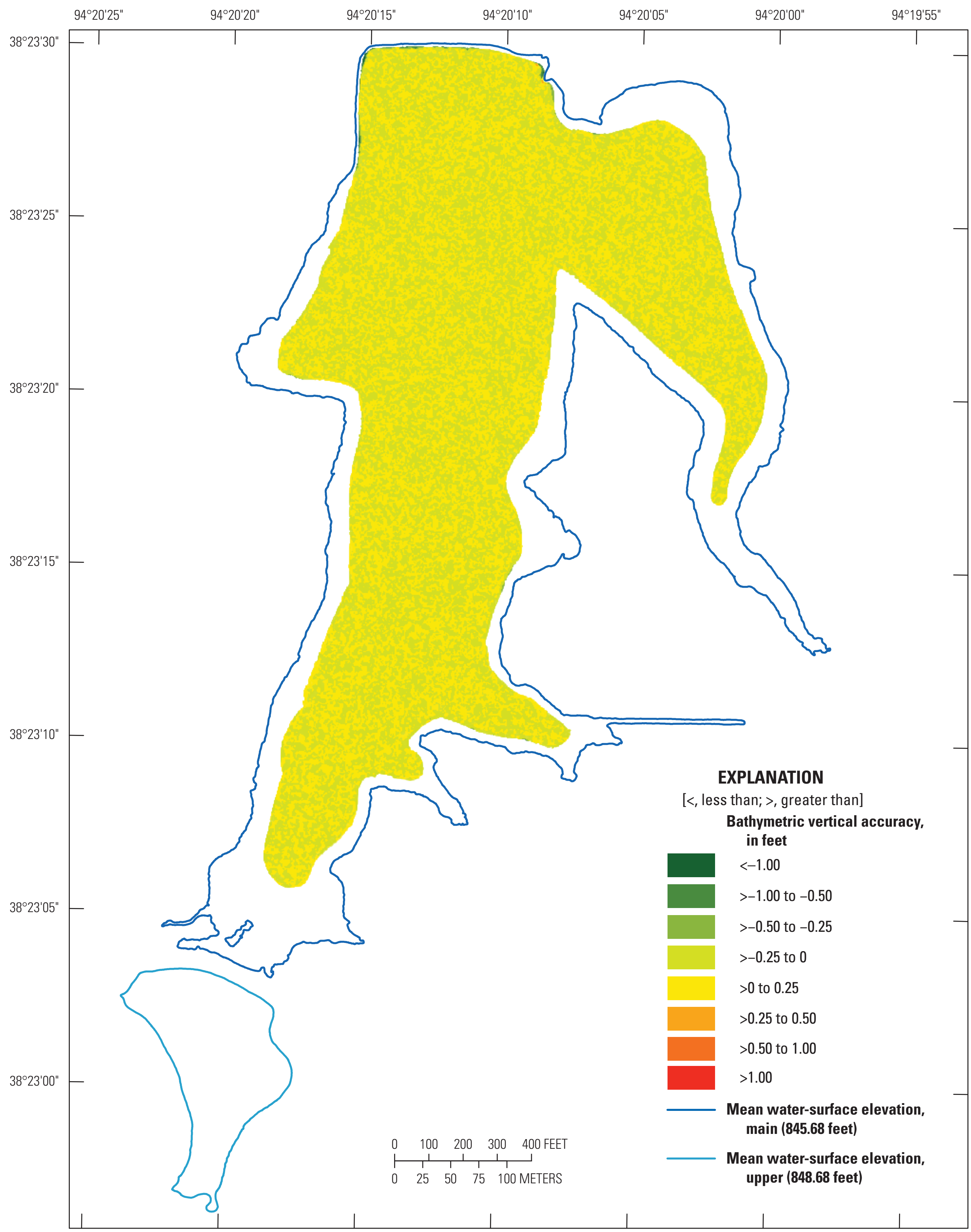


Figure 34. Vertical accuracy of the bathymetric surface of Adrian Reservoir (lake 45) near Adrian, Missouri, 2023.

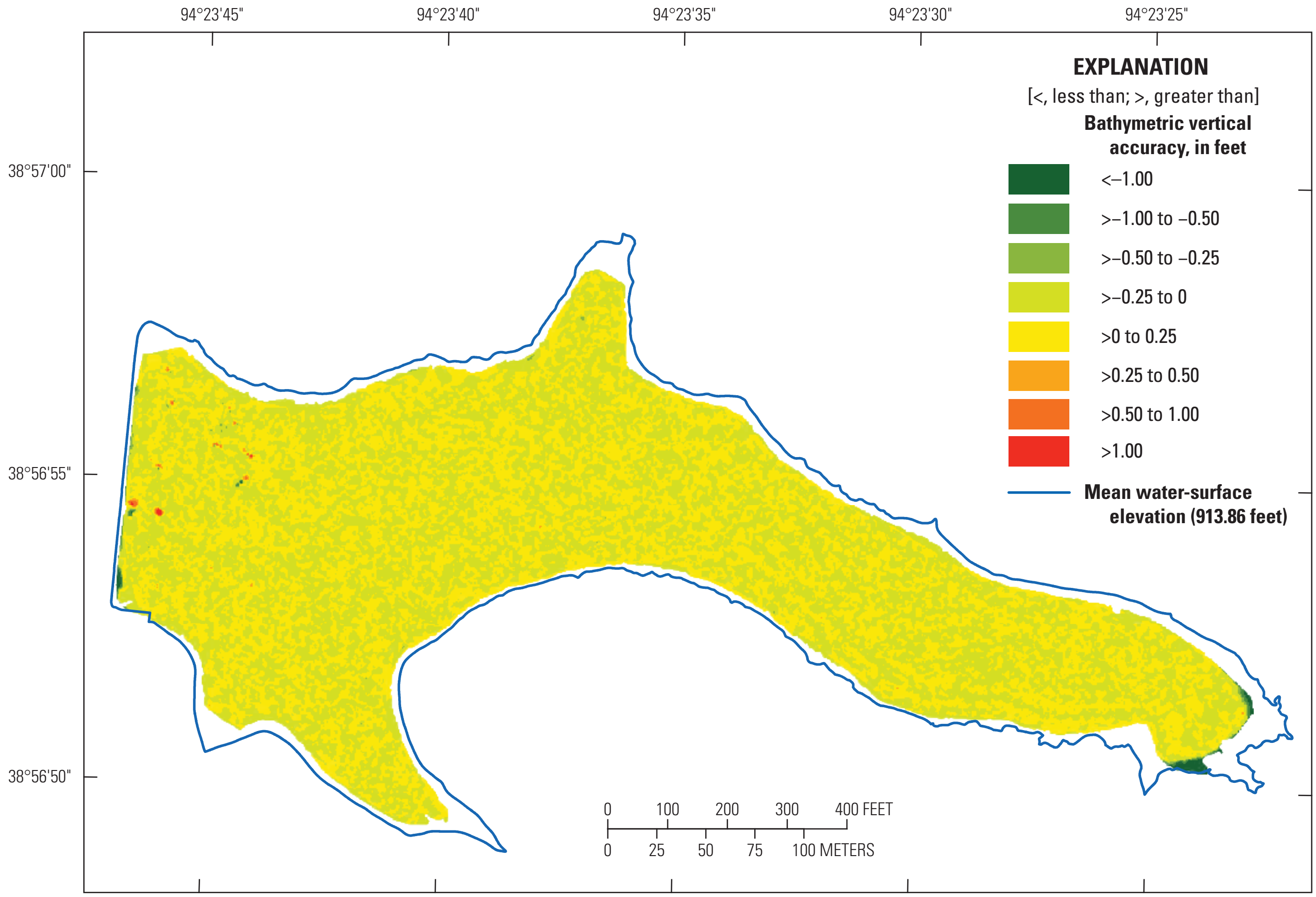


Figure 35. Vertical accuracy of the bathymetric surface of Unity Lake Number 1 (lake 46) near Unity Village, Missouri, 2023.

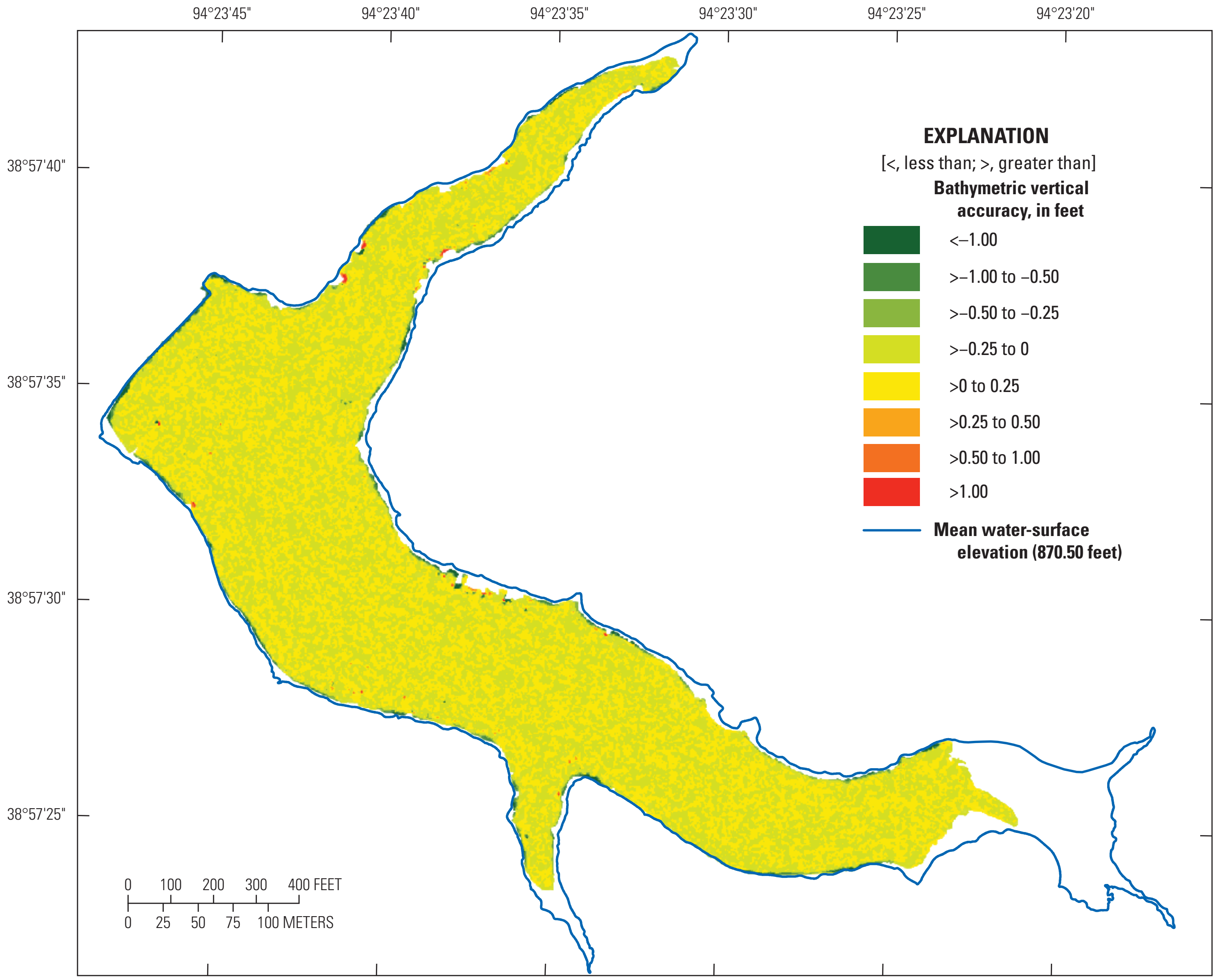


Figure 36. Vertical accuracy of the bathymetric surface of Unity Lake Number 2 (lake 47) near Unity Village, Missouri, 2023.

Table 10. Summary of bathymetric contour quality-assurance results from surveys at water-supply lakes in Missouri in 2022 and 2023.

Lake name	Lake number (fig. 1)	Number of points in quality-assurance dataset (table 2)	Contour quality-assurance point search tolerance, in feet	Number of points in contour-to-point comparison	Tested vertical accuracy at a 95-percent confidence level, in feet	Mean vertical error, in feet	Median absolute vertical error, in feet
Grindstone Reservoir	35	67,128	0.33	4,187	0.40	0.00	0.02
Cameron Reservoir Number 1	36	24,930	0.33	1,228	0.10	0.00	0.02
Cameron Reservoir Number 2	37	50,125	0.33	7,021	0.11	0.00	0.02
Cameron Reservoir Number 3	38	160,938	0.33	11,929	0.26	0.00	0.02
Fellows Lake	39	97,678	0.33	5,489	0.56	−0.01	0.06
McDaniel Lake	40	132,715	0.16	29,957	0.29	0.00	0.02
Unionville Reservoir (Mahoney Lake)	41	111,844	0.33	9,363	0.12	0.00	0.03
Vandalia Reservoir	42	55,403	0.16	5,186	0.13	−0.01	0.03
Shepherd Mountain Lake	43	39,908	0.16	2,313	0.13	0.00	0.01
Snow Hollow Lake	44	41,623	0.16	3,316	0.31	−0.01	0.03
Adrian Reservoir	45	75,341	0.33	3,292	0.08	0.00	0.02
Unity Lake Number 1	46	32,077	0.16	4,142	0.38	−0.01	0.03
Unity Lake Number 2	47	48,214	0.13	6,089	0.37	0.00	0.03

Table 11. Summary of bathymetric change surface quality-assurance results from selected surveys at water-supply lakes in Missouri in 2022 and 2023.

Lake name	Lake number (fig. 1)	Number of points in quality-assurance dataset from previous survey	Number of points in surface comparison	Tested vertical accuracy at a 95-percent confidence level, in feet	Mean vertical error, in feet	Median absolute vertical error, in feet
Unionville Reservoir (Mahoney Lake)	41	5,834	2,664	0.60	−0.06	0.16
Vandalia Reservoir	42	8,412	3,201	0.69	−0.06	0.15
Shepherd Mountain Lake	43	5,224	1,857	0.83	0.34	0.35
Snow Hollow Lake	44	7,755	2,196	0.94	−0.05	0.19

Bathymetry, Capacity, and Bathymetric Change

A bathymetric surface was created from the 2022 and 2023 surveyed data and used to produce a bathymetric contour map for each lake (plates 1–13). The bathymetric maps are similar to maps produced from the earlier surveys (Wilson and Richards, 2006; appendix of Richards, 2013; Huizinga, 2014). The bathymetric surfaces still show aspects of the topography that existed prior to lake impoundment, such as a defined river channel indicated by concentric V-shaped contours that formed when the area was dominated by fluvial processes (plates 1, 3–10, 12 and 13). However, many features have likely been affected by post-impoundment sedimentation and compaction of sediments, which tends to mute the sharp and distinct channel bank features evident in a nonsubmerged channel (for example, upper end of the lake in plates 3, 4, 7, and 9; and the entire lake in plates 2 and 11).

A surface area and capacity table was computed at a 2-ft interval for each lake (5-ft interval for Fellows Lake [lake 39]) from the bathymetric surface TIN, and is on the respective map plate for each lake (plates 1–13). The surface area and capacity values for each lake at the primary spillway or drop inlet elevation are summarized in table 12.

When a previous survey existed for a lake (Richards, 2013; Huizinga, 2014), the 2022 or 2023 bathymetric surface was compared to the previous surface to create a bathymetric change map (figs. 37–47) as described in the “Bathymetric Change Map Creation” section above. At the lakes near Cameron (Grindstone Reservoir and Cameron Reservoir Numbers 1–3 [lakes 35–38]), the GCD program was used to compute the difference between the surveys using a threshold mask of 80-percent confidence. Using this threshold mask, the effects of the larger uncertainties of the 2013 survey (mean uncertainty of about 0.50 ft [refer to table 4 in Huizinga, 2014]) could be partially removed from the comparison so that the bathymetric difference shown in figs. 37–40 more clearly shows actual bathymetric change between the surveys. Nevertheless, effects of larger gridded uncertainty in the 2013 surveys appear as isolated strips of apparent change (typically erosion, but also some deposition) in the middle of large, low-relief areas of the lakes in figures 37–40. Some of the erosion and deposition apparent along the edges of the lakes near Cameron may be the result of erosive wave action in these areas, insufficient removal of stray points from vegetation, or may simply be the result of minor positional offsets between the surveys.

The previous survey capacity at the primary spillway or inlet elevation at each lake is listed in table 13. The capacity value shown for the previous survey has been corrected for any elevation discrepancy between the surveys listed in table 3. The new area and capacity table for each lake generally is similar to the previous survey.

The bathymetric change maps for the lakes with previous surveys (figs. 37–47) show erosional as well as depositional areas (table 14). Deposition generally appears to be uniform across a given lake area with some localized erosion near the edges of the lake. Notable exceptions include the deposition evident throughout the old river channel at Grindstone Reservoir near Cameron (lake 35; fig. 37), and the uppermost area of McDaniel Lake near Springfield (lake 40; fig. 42). Fellows Lake (lake 39; fig. 41) had more deposition in the north arm than in the south arm, and Vandalia Reservoir (lake 42; fig. 44) had more deposition in the east arm than in the west arm.

Relative to previous surveys, the change in capacity at the primary spillway elevation ranged from a 5.5-percent decrease at Adrian Reservoir to a 9.2-percent increase at Cameron Reservoir Number 1 (table 13). The mean bathymetric change ranged from –0.94 ft at Cameron Reservoir Number 1 to 1.05 ft at McDaniel Lake (table 14), with a corresponding yearly mean bathymetric change of –0.107 foot per year at Cameron Reservoir Number 1 and 0.050 foot per year at McDaniel Lake (table 14). A volumetric sedimentation rate was determined from the mean bathymetric change times the area of the bathymetric change raster, divided by the duration between the surveys (table 14). The sedimentation rate generally ranged from –0.44 to 1.34 acre-feet per year at Cameron Reservoir Number 3 and Unionville Reservoir (Mahoney Lake), respectively; however, Fellows Lake and McDaniel Lake had substantially larger sedimentation rates of 11.8 and 11.5 acre-feet per year, respectively, because of their substantially larger size and larger area of bathymetric change (table 14).

Several lakes in the 2021 surveys showed ridges of alternating deposition and erosion that may be the result of erroneous position or depth readings in prior surveys (refer to bathymetric change maps for Hazel Creek Lake and Forest Lake in Rivers and others, 2023a). Such ridges were not clearly evident in the 2022–23 surveys. Nonetheless, the bathymetric change maps at Fellows Lake (fig. 41) and to a lesser degree at McDaniel Lake (fig. 42) and Snow Hollow Lake (fig. 46) display artifacts that coincide with the singlebeam transect locations from the previous survey and may be the result of erroneous position or depth readings in the previous surveys. The effects of the lack of motion correction and imprecise positioning of the older singlebeam echosounder data are described in the 2019 lake survey report (Huizinga and others, 2022). As mentioned in the “Bathymetric Change Map Creation” section, masking the areas of high slope likely helps limit the areas where minor horizontal positional offsets between coincident points in the two surveys sometimes create erroneous bathymetric change results. Nevertheless, these positional artifacts may persist in other locations of the bathymetric change maps because of roll or pitch offsets. In particular, several transects from the previous survey of Fellows Lake are near the confluence of the two major arms that create an area of apparent deposition in the bathymetric change map in the middle of that lake (fig. 41).

Areas of apparent erosion in the shallows along the margins of the lakes often coincide with deposition in the deeper parts of the same lake (figs. 37, 41, 43, 46, 47). This phenomenon had been observed in the 2019 surveys (Huizinga and others, 2022) and was attributed to shallow water wave action, possibly affecting sediment deposition with fluctuating lake levels during low-water years. Another explanation posited in the 2020 lake survey report (Huizinga and others, 2023) was compaction of sediments deposited in high-water years but exposed to the air in low-water years. However, because the edge erosion phenomenon seems ubiquitous throughout the 2019 through 2023 surveys, it also may be an indication of some other systemic error in the singlebeam data collected in the previous survey, in addition to shallow water wave action or sediment compaction. Errors caused by motion-induced echosounder attitude changes and issues caused by the lack of a full sound velocity profile were fully discussed in the 2020 lake survey report (Huizinga and others, 2023).

It is unlikely that a motion-induced pitch angle or elevation change would fully account for the apparent erosion along the shoreline. Furthermore, motion-induced error likely does not account for the apparent alternation from deposition to erosion as the boat crossed a shallow point near a confluence or approached the bank while traveling at a more-constant speed in the previous survey (figs. 41, 44). As explained in the 2020 lake survey report (Huizinga and others, 2023), the appearance of erosion predominantly in the shallower areas of a lake often coincides with deposition in the deeper part of the same area of the lake, which may point to a variable-with-depth phenomenon such as a sound velocity profile issue or another depth-related issue. Ultimately, the cause for the apparent erosion in the shallows of the comparisons to previous singlebeam surveys to date (2019 through 2023) is unknown. Future resurveys using equipment that fully accounts for boat (and echosounder) position and movement would help to draw reasonable conclusions and to mitigate potential motion-induced artifacts. Furthermore, sound velocity profiles in various places throughout the lake are warranted to fully account for subtle variations that might affect echosounder depth readings.

Conversely, the apparent erosion in the shallows of the lakes near Cameron (lakes 35–38; figs. 37–40) likely is the result of the uncertainty in the outer beam areas in the previous multibeam surveys (Huizinga, 2014). The areas of erosion generally correspond to the periphery of the lakes where data were acquired with the outer beams in the previous survey (refer to figure 3 in Huizinga, 2014). Furthermore, the previous surveys were in July 2013 when aquatic vegetation was more substantial in these peripheral areas than in the 2022 surveys. Some of the apparent erosion may be residual erroneous data points from vegetation that were not adequately removed when processing those previous surveys.

Several of the lakes in the 2022–23 surveys exhibit apparent capacity gain (negative capacity loss in table 13) despite the sedimentation observed in those lakes (positive sedimentation rate in table 14). For Fellows Lake and McDaniel Lake near Springfield (lakes 39–40), improved data collection along the steep sides of the lake may have revealed

Table 12. Summary of surface area and capacity at the listed spillway or inlet elevation from surveys at water-supply lakes in Missouri in 2022 and 2023.

[All elevations are referenced to the North American Vertical Datum of 1988]

Lake name	Lake number (fig. 1)	Primary spillway/ inlet elevation, in feet	Surface area, in acres	Capacity, in acre-feet
Grindstone Reservoir	35	899.89	188	2,000
Cameron Reservoir Number 1	36	938.20	16.0	109
Cameron Reservoir Number 2	37	943.86	30.5	330
Cameron Reservoir Number 3	38	911.07	90.0	947
Fellows Lake	39	1,264.44	872	30,900
McDaniel Lake	40	1,125.10	293	4,110
Unionville Reservoir (Mahoney Lake)	41	976.68	73.1	611
Vandalia Reservoir	42	666.98	29.4	304
Shepherd Mountain Lake	43	977.26	24.1	190
Snow Hollow Lake	44	1,285.53	31.5	333
Adrian Reservoir	45	846.26	52.9	274
Unity Lake Number 1	46	913.86	17.9	211
Unity Lake Number 2	47	870.50	26.5	468

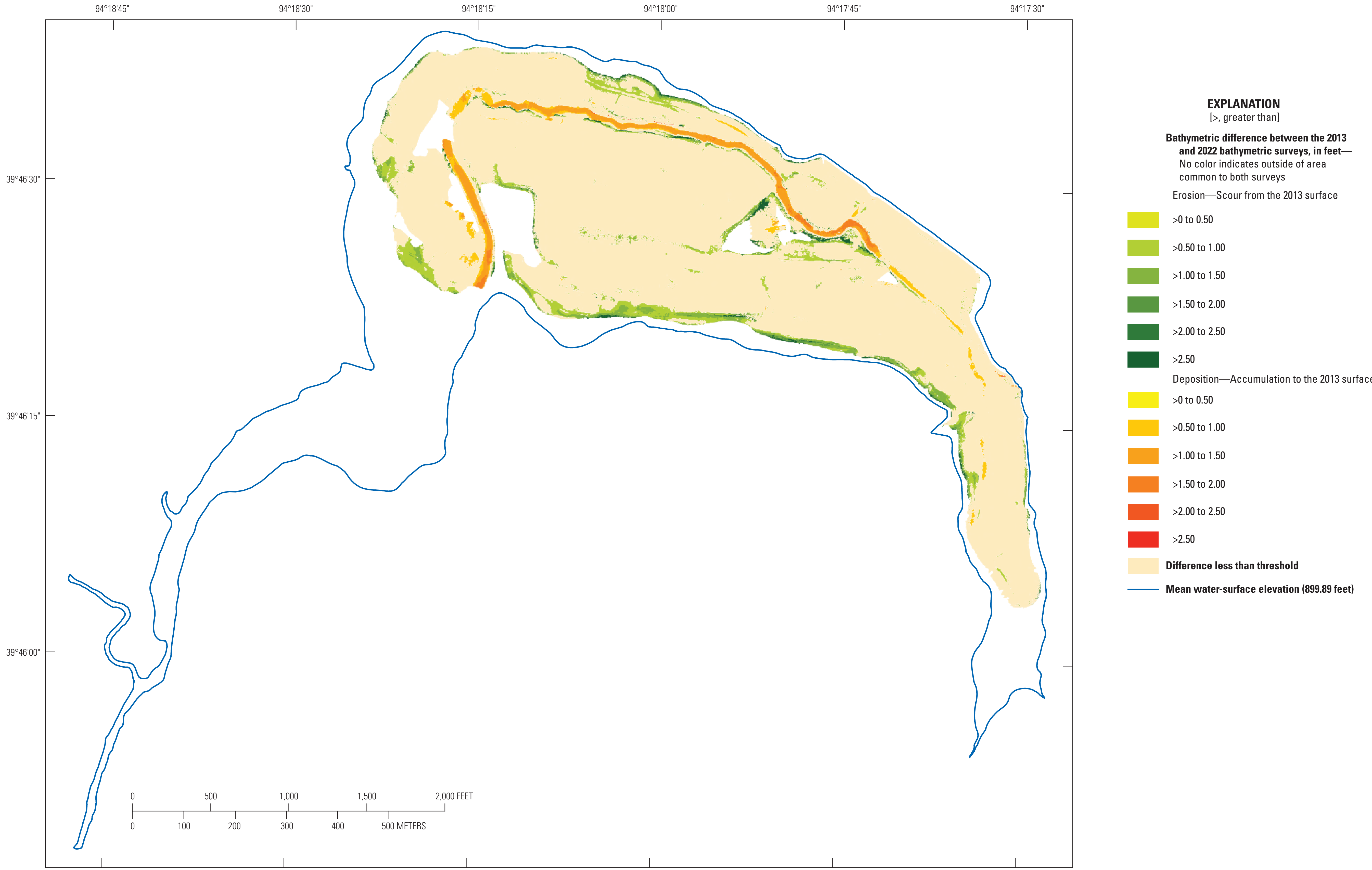


Figure 37. Bathymetric change between the 2013 survey and the 2022 survey of Grindstone Reservoir (lake 35) near Cameron, Missouri.

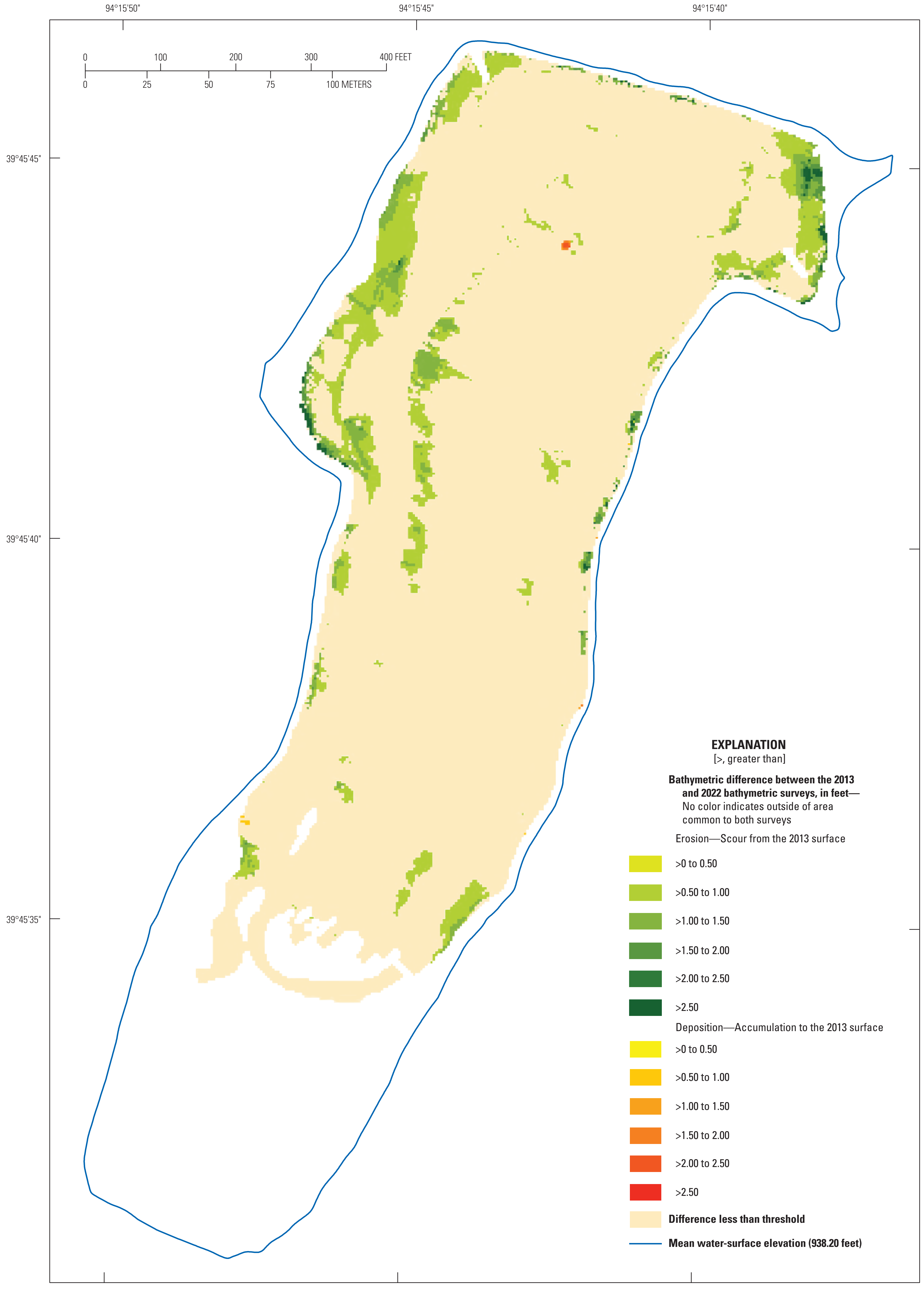


Figure 38. Bathymetric change between the 2013 survey and the 2022 survey of Cameron Reservoir Number 1 (lake 36) near Cameron, Missouri.

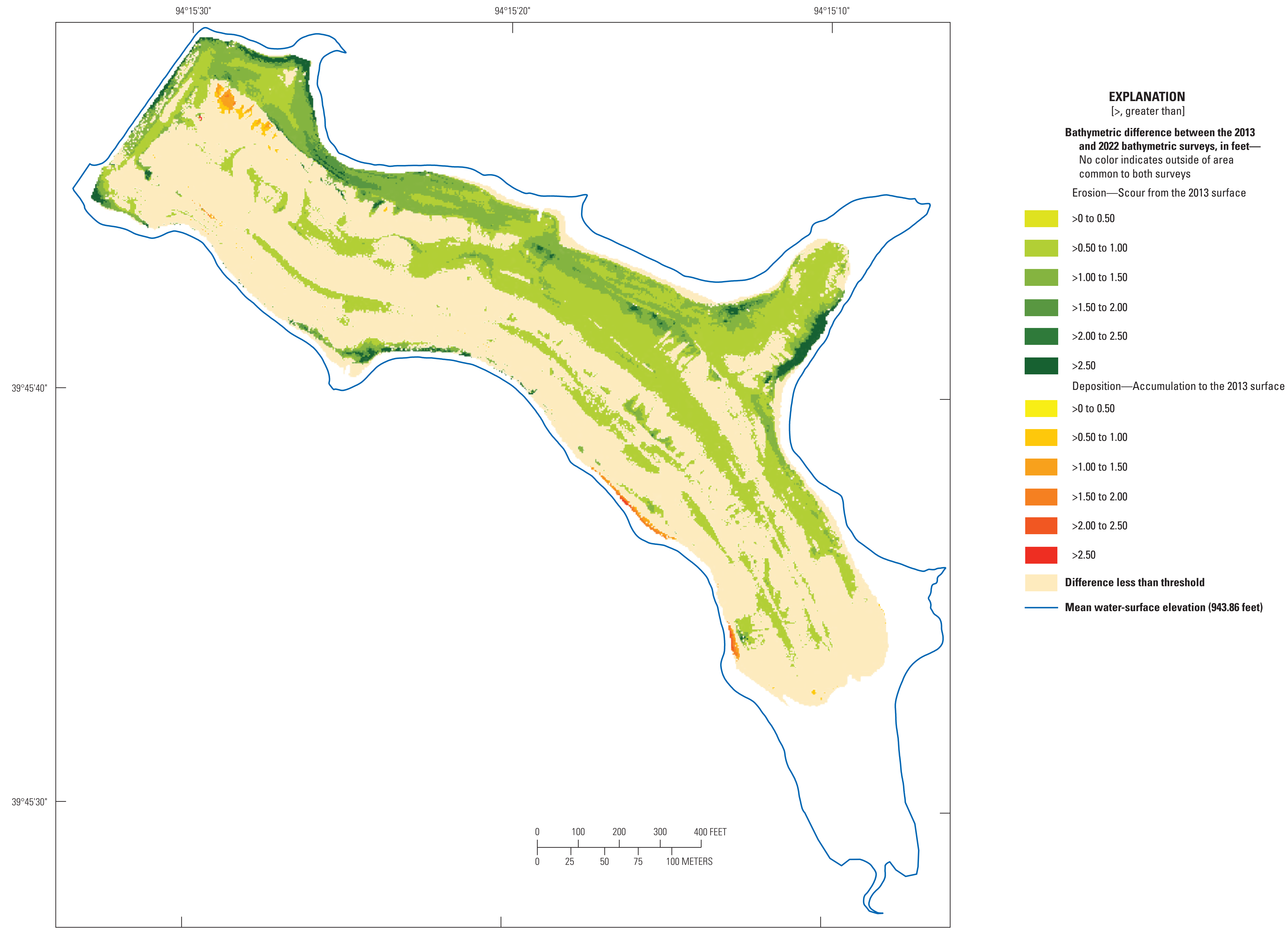
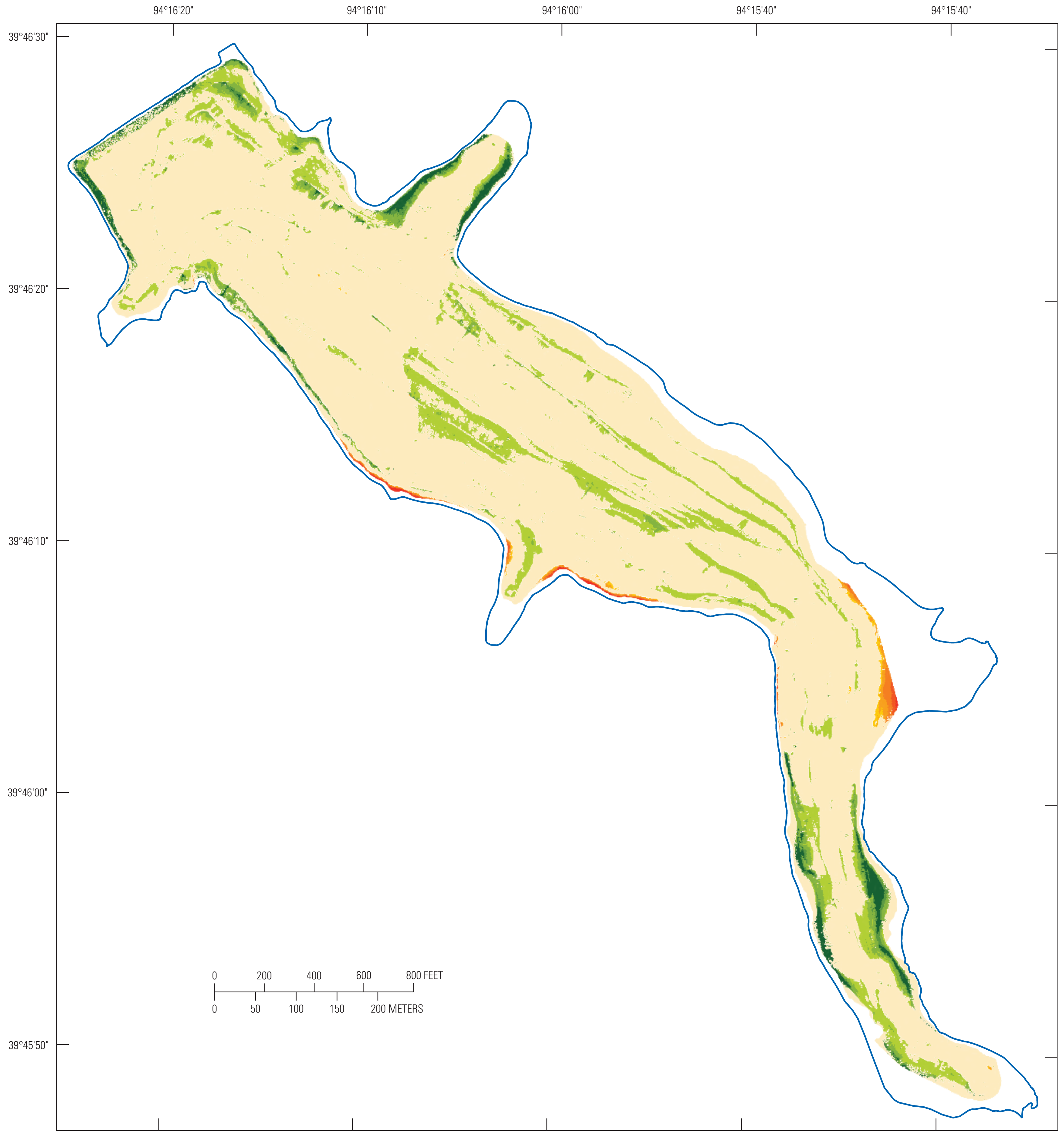


Figure 39. Bathymetric change between the 2013 survey and the 2022 survey of Cameron Reservoir Number 2 (lake 37) near Cameron, Missouri.



EXPLANATION

[>, greater than]

Bathymetric difference between the 2013 and 2022 bathymetric surveys, in feet—No color indicates outside of area common to both surveys

Erosion—Scour from the 2013 surface	Deposition—Accumulation to the 2013 surface
>0 to 0.50	>0 to 0.50
>0.50 to 1.00	>0.50 to 1.00
>1.00 to 1.50	>1.00 to 1.50
>1.50 to 2.00	>1.50 to 2.00
>2.00 to 2.50	>2.00 to 2.50
>2.50	>2.50

Difference less than threshold

Mean water-surface elevation (911.07 feet)

Figure 40. Bathymetric change between the 2013 survey and the 2022 survey of Cameron Reservoir Number 3 (lake 38) near Cameron, Missouri.

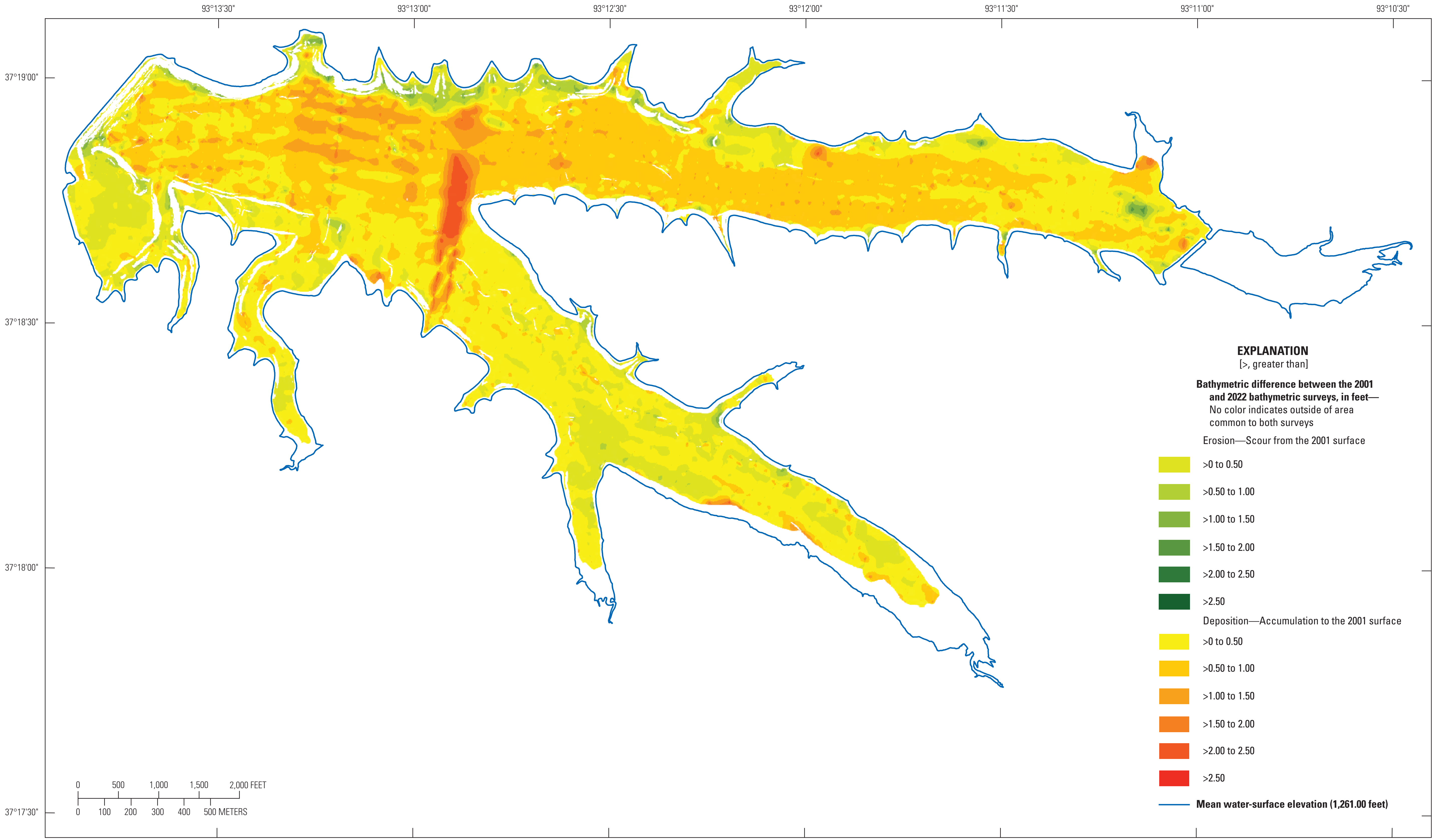


Figure 41. Bathymetric change between the 2001 survey and the 2022 survey of Fellows Lake (lake 39) near Springfield, Missouri.

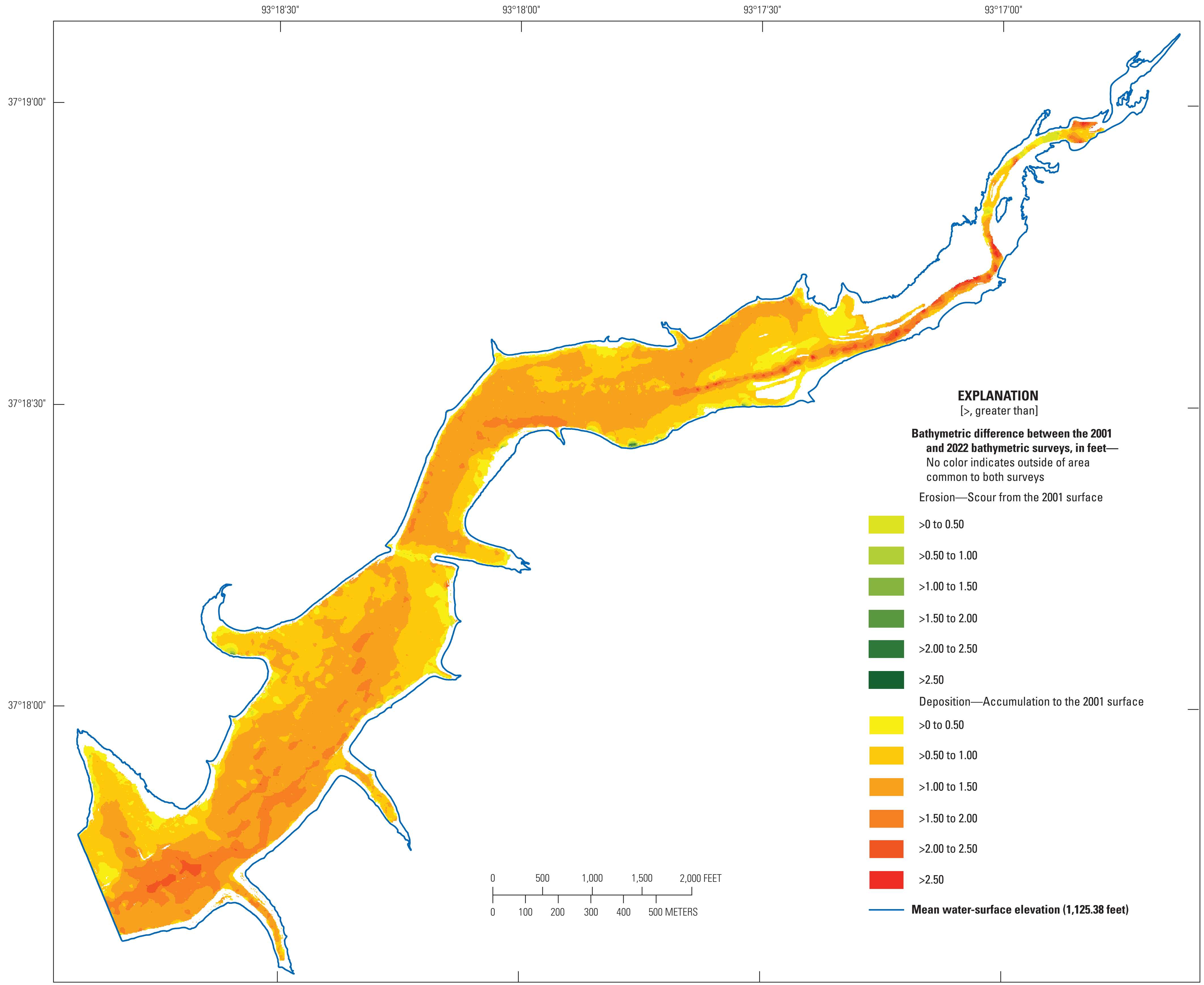


Figure 42. Bathymetric change between the 2001 survey and the 2022 survey of McDaniel Lake (lake 40) near Springfield, Missouri.

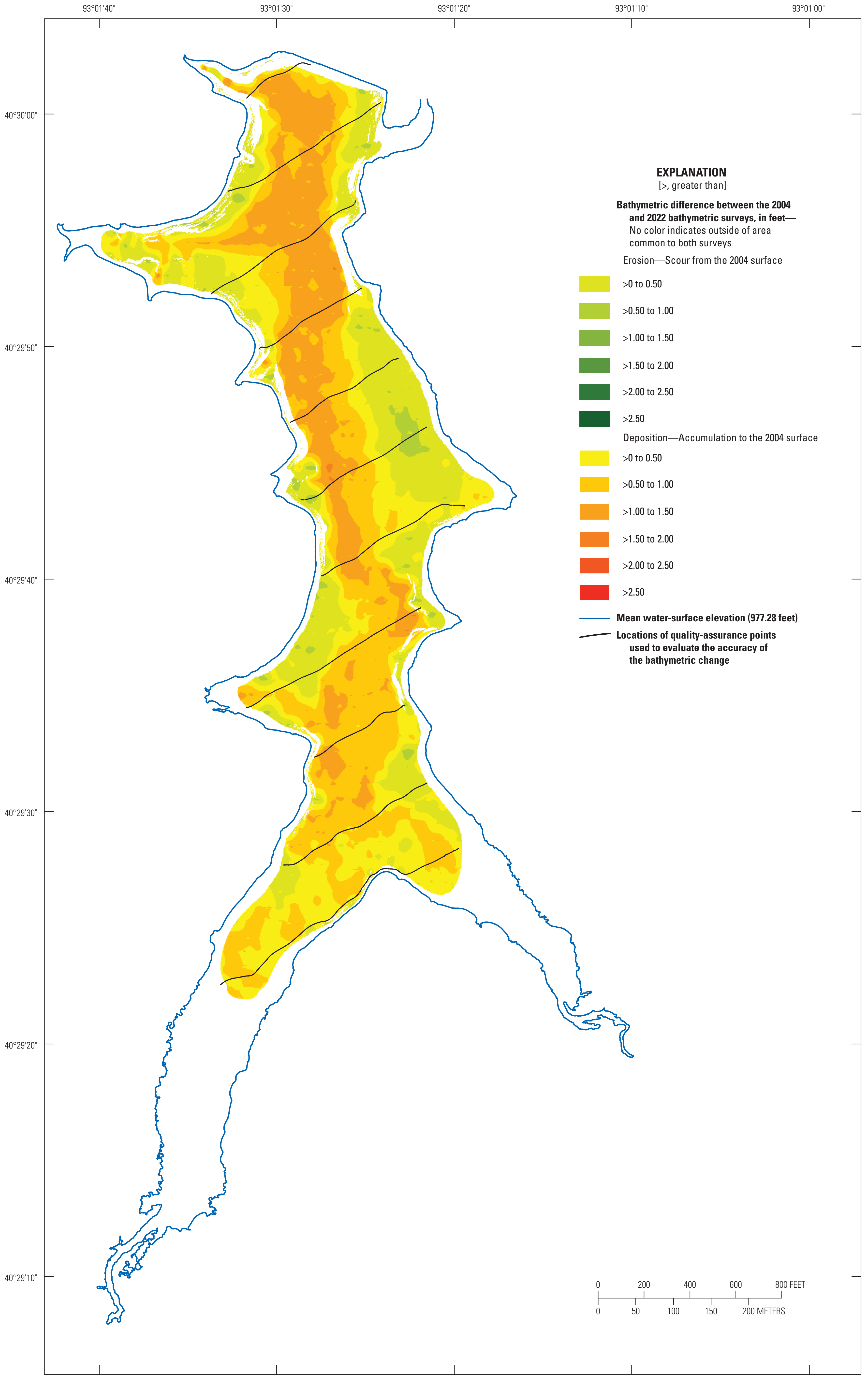


Figure 43. Bathymetric change between the 2004 survey and the 2022 survey of Unionville Reservoir (Mahoney Lake; lake 41) near Unionville, Missouri.

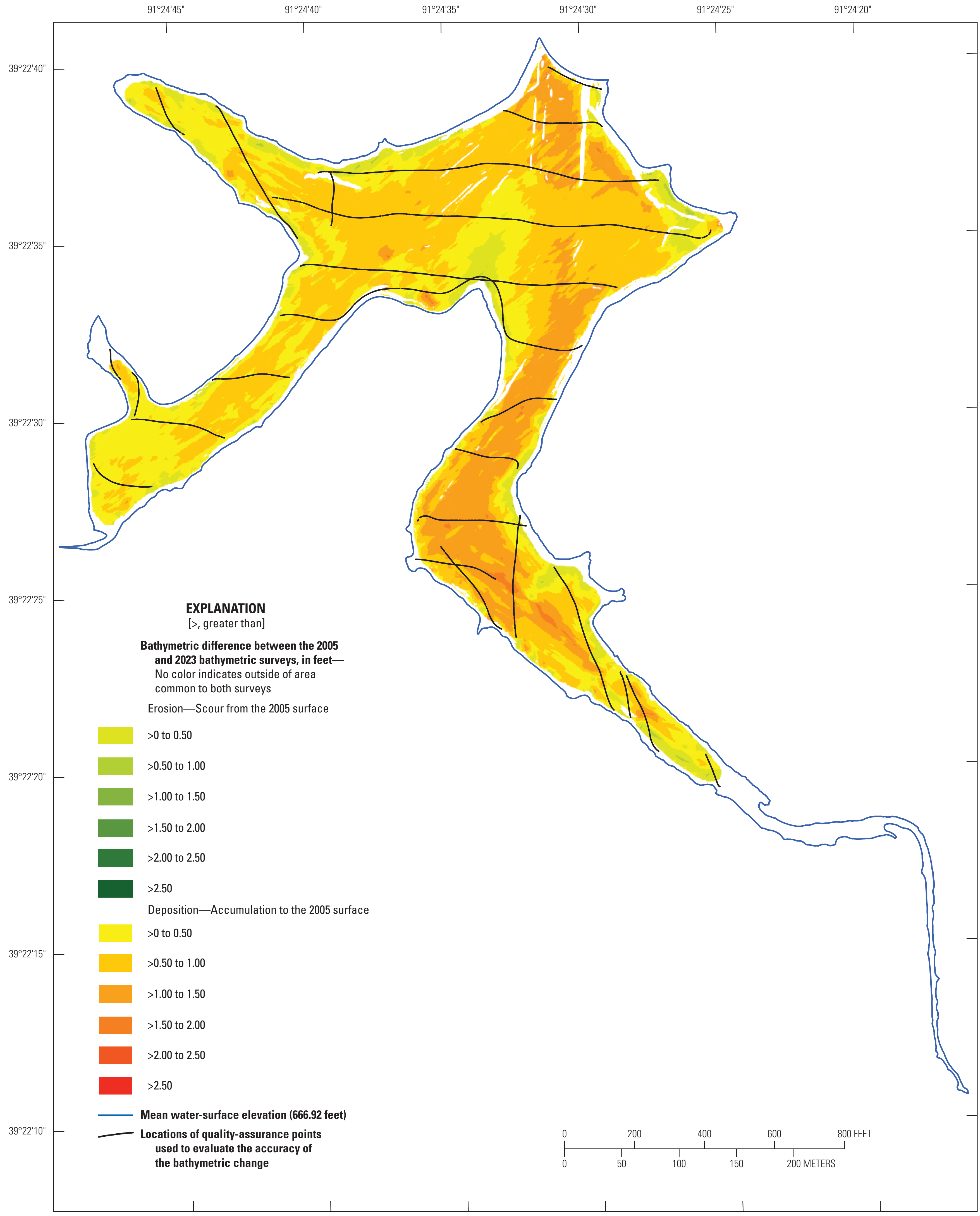


Figure 44. Bathymetric change between the 2005 survey and the 2023 survey of Vandalia Reservoir (lake 42) near Vandalia, Missouri.

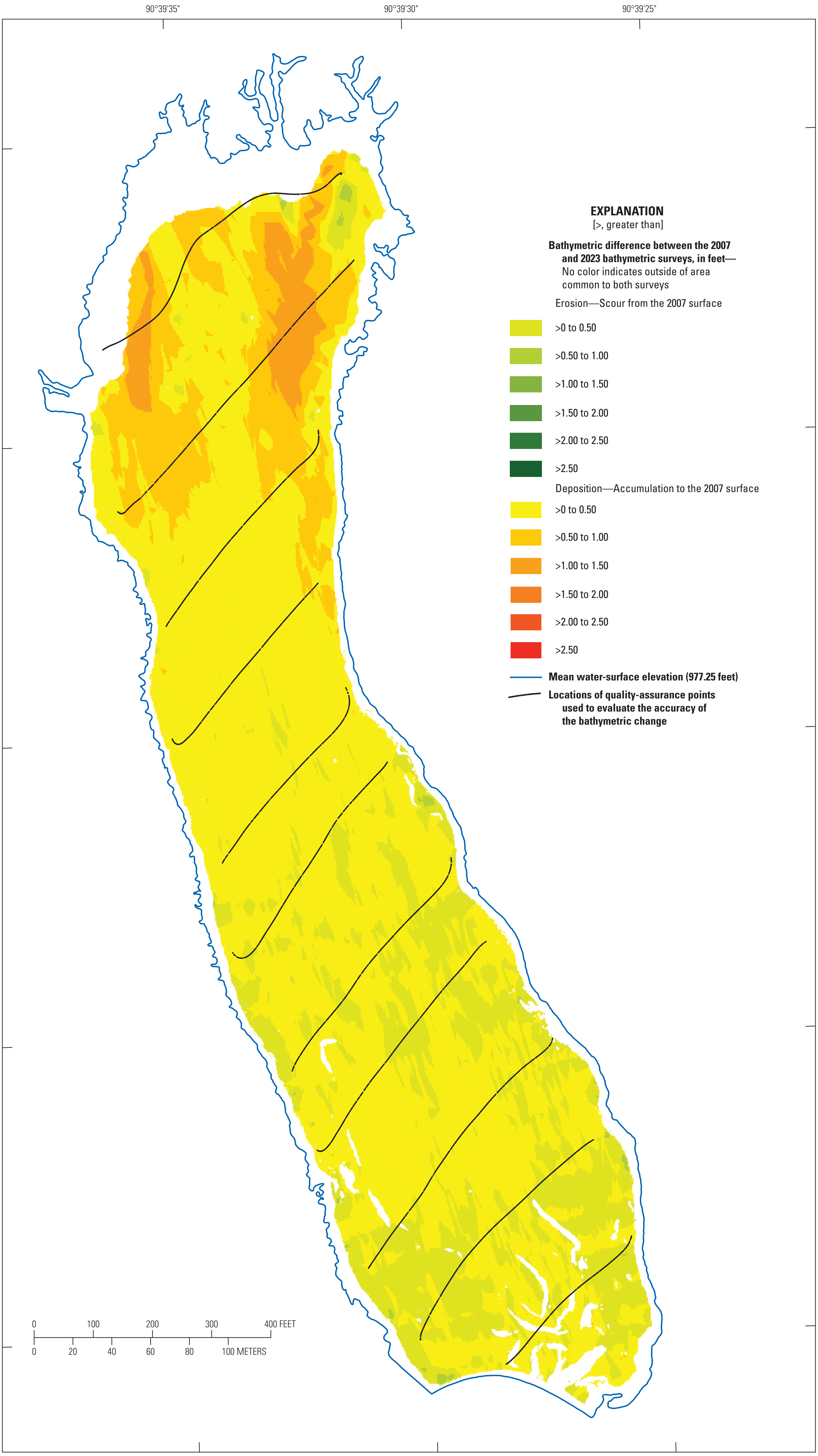


Figure 45. Bathymetric change between the 2007 survey and the 2023 survey of Shepherd Mountain Lake (lake 43) near Ironton, Missouri.

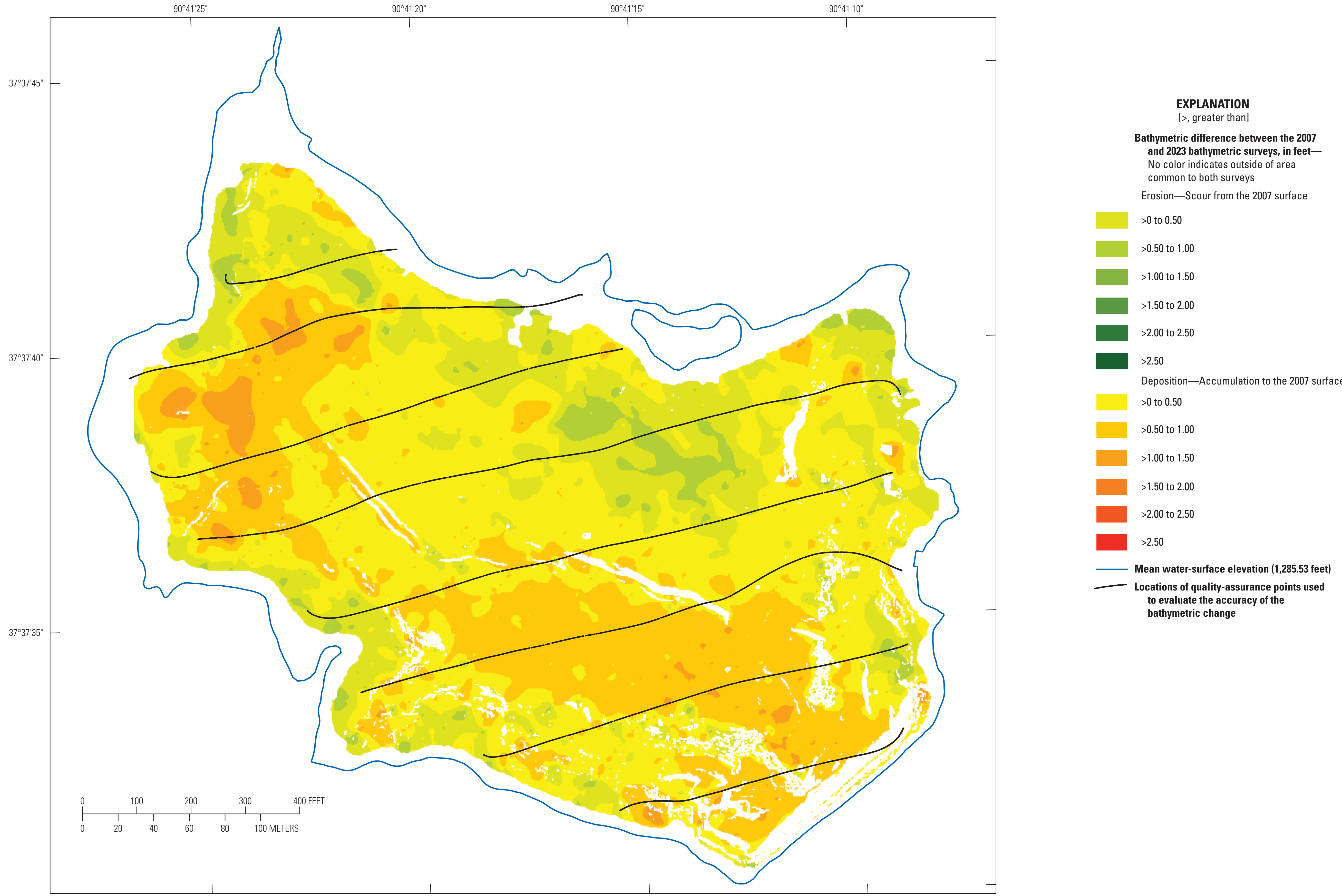


Figure 46. Bathymetric change between the 2007 survey and the 2023 survey of Snow Hollow Lake (lake 44) near Ironton, Missouri.

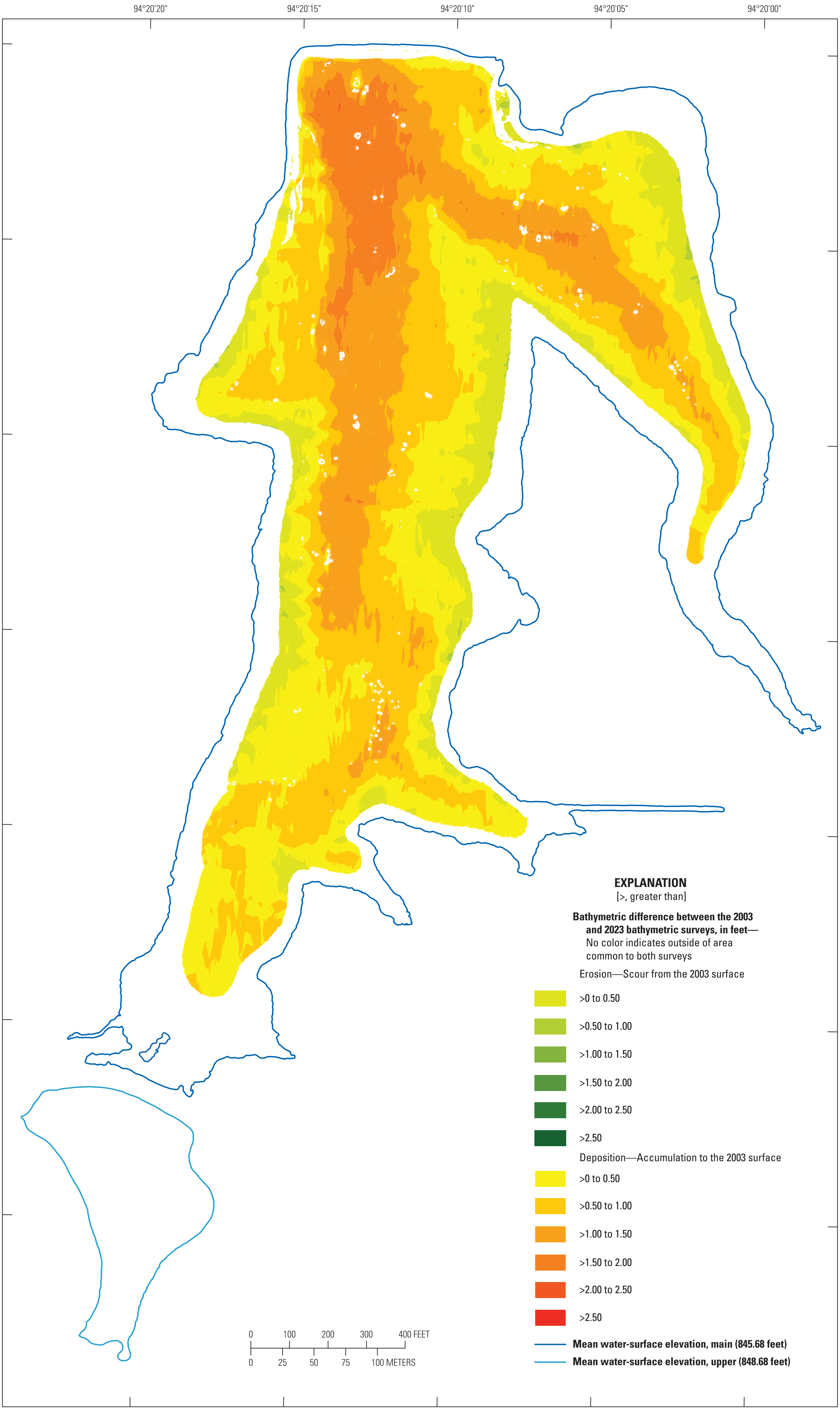


Figure 47. Bathymetric change between the 2003 survey and the 2023 survey of Adrian Reservoir (lake 45) near Adrian, Missouri.

Table 13. Summary of surface area and capacity changes at the listed primary spillway elevation from surveys at water-supply lakes in Missouri in 2022 and 2023 and previous surveys.

Lake name	Lake number (fig. 1)	Primary spillway/ intake elevation, in feet	Previous survey		Capacity in 2022/2023, in acre-feet	Capacity loss, in percent[b]
			Date(s)	Capacity,[a] in acre-feet		
Grindstone Reservoir	35	899.89	07/02/2013	1,960[c]	2,000	−2.0[c]
Cameron Reservoir Number 1	36	938.20	07/02/2013	99.8[c]	109	−9.2[c]
Cameron Reservoir Number 2	37	943.86	07/01/2013	301[c]	330	−8.8[c]
Cameron Reservoir Number 3	38	911.07	07/01/2013	896[c]	947	−5.4[c]
Fellows Lake	39	1,264.44	04/23/2001	30,800[d]	30,900	−0.3[d]
McDaniel Lake	40	1,125.10	05/30/2001	4,070[d]	4,110	−1.0[d]
Unionville Reservoir (Mahoney Lake)	41	976.68	04/06/2004	618	611	1.1
Vandalia Reservoir	42	666.98	02/23/2005-02/24/2005	317	304	4.1
Shepherd Mountain Lake	43	977.26	07/09/2007-07/10/2007	186	190	−2.2
Snow Hollow Lake	44	1,285.53	07/10/2007	321	333	−3.7
Adrian Reservoir	45	846.26	06/05/2003-06/06/2003	290	274	5.5

[a]The capacity values shown for previous surveys are from the area and capacity tables from Richards (2013) or Huizinga (2014), with elevations adjusted to account for datum discrepancies found between the previous and current surveys detailed in table 3.

[b]Negative values indicate an increase in capacity at the indicated elevation.

[c]The previous surveys at these lakes (Huizinga, 2014) only extended to the approximate surveyed water-surface elevation and to the primary spillway elevation. Therefore, the previous capacity likely is somewhat less than the full capacity at the time of the survey and contributes to the negative capacity loss (implied capacity gain).

[d]The 2022 survey at these lakes included more robust data collection along the perimeter of the lake than in the previous survey (Richards, 2013), which is masked by the slope mask in figures 41 and 42. Therefore, the previous capacity likely is somewhat less than the full capacity at the time of the survey and contributes to the negative capacity loss (implied capacity gain).

Table 14. Summary of gridded and selected bathymetric data points from surveys at water-supply lakes in Missouri in 2022 and 2023.

[--, no data]

Lake name	Lake number (fig. 1)	Maximum value of erosion, in feet	Maximum value of deposition, in feet	Mean bathymetric change, in feet	Time between surveys, in years	Yearly mean bathymetric change, in feet per year	Area of bathymetric change raster, in acres	Volume of deposition, in acre-feet	Volume of erosion, in acre-feet	Net volume of sediment, in acre-feet	Volumetric sedimentation rate, in acre-feet per year
Grindstone Reservoir	35	8.42	8.74	−0.36	8.8	−0.041	121.7	1.94	3.85	−1.91	−0.22
Cameron Reservoir Number 1	36	2.80	2.43	−0.94	8.8	−0.107	11.3	0.00	0.36	−0.36	−0.04
Cameron Reservoir Number 2	37	4.65	10.19	−0.93	8.8	−0.106	23.6	0.08	2.97	−2.89	−0.33
Cameron Reservoir Number 3	38	6.25	4.76	−0.86	8.8	−0.098	76.8	0.47	4.30	−3.83	−0.44
Fellows Lake	39	1.70	2.31	0.38	21.0	0.018	724	282	33.0	249	11.8
McDaniel Lake	40	3.12	3.15	1.05	20.9	0.050	248	241	0.53	240	11.5
Unionville Reservoir (Mahoney Lake)	41	0.81	1.66	0.46	18.1	0.025	56.0	27.5	3.19	24.4	1.34
Vandalia Reservoir	42	0.62	1.70	0.60	18.2	0.033	26.1	15.0	0.43	14.5	0.80
Shepherd Mountain Lake	43	0.88	1.32	0.21	15.8	0.013	19.8	4.40	0.38	4.02	0.25
Snow Hollow Lake	44	1.00	1.50	0.27	15.8	0.017	26.7	8.48	1.73	6.74	0.43
Adrian Reservoir	45	0.95	2.13	0.61	20.0	0.031	37.1	22.9	0.79	22.2	1.11

areas of additional storage around the periphery of those lakes between the transects in the previous surveys that are covered by the slope masks used in the bathymetric change maps (figs. 41, 42). The apparent capacity gain at the lakes near Cameron likely resulted from the previous capacities being for the surveyed water-surface elevation at those lakes (refer to footnote “c” in table 13), which was slightly lower than the spillway elevations at those lakes as well as the result of the apparent erosion from residual vegetation points not removed in the previous surveys, as discussed in the previous paragraph.

As in the previous lake survey reports (Huizinga and others, 2022, 2023; Rivers and others, 2023a), an implied sedimentation rate can be computed from the capacity changes at the primary spillway or intake shown in table 13. For example, at Unionville Reservoir (Mahoney Lake, lake 41), the loss of capacity at the primary spillway elevation is 7 acre-feet (computed as the difference between the “Previous survey capacity” and “Capacity in 2022/2023” at the spillway elevation, table 13) and dividing this value over the 18.1 years between the surveys (table 14) implies a sedimentation rate of about 0.39 acre-foot per year. This implied sedimentation rate at the spillway elevation is substantially different than the volumetric sedimentation rate computed from the bathymetric change raster of 1.34 acre-feet per year for this lake (table 14), and yet still implies substantial sedimentation during the interval. However, the implied sedimentation rate at the spillway elevation of Fellows Lake is about –4.76 acre-feet per year (computed from capacity values in table 13 and time between surveys in table 14), which implies a gain of capacity and a loss of sediment, whereas the volumetric sedimentation rate computed from the bathymetric change raster is a substantial 11.5 acre-feet per year (table 14), and the bathymetric change map indicates sediment deposition in most of the north arm of the lake (fig. 41). As originally discussed in the 2020 surveys (Huizinga and others, 2023), sediment tends to accumulate more quickly at the upper ends of a lake, where the sediment-laden streamflow initially encounters the slack water of the lake, and the heavier sediment settles out of suspension owing to the sudden decrease in water velocity. This dynamic is evident in the bathymetric change maps of McDaniel Lake (fig. 42) and Shepherd Mountain Lake (fig. 45). These upper ends of the lake often tend to be where multibeam data cannot be acquired owing to the resulting shallow water, and so the sedimentation rate computed from the bathymetric change raster (table 14) may not fully account for deposition or erosion in these areas. Ongoing efforts have been made to mitigate this limitation including the uses of a remote-controlled boat with ADCP for shallow water data collection and surveying during a time of year when vegetation is at a minimum. Nevertheless, determination of bathymetric change in areas without multibeam data was not attempted in this study, because comparing singlebeam data from different sources or surveys typically results in a comparison of interpolated data with interpolated data, which substantially increases the uncertainty. The implied sedimentation rates computed from the spillway capacity values in table 13 may not accurately estimate the overall loss of volume of a given lake throughout the full range of elevations because they only represent loss at the primary spillway or intake elevation. Therefore, the implied sedimentation rates computed from spillway capacity values in table 13 and the computed volumetric sedimentation rates presented in table 14 likely bracket the sedimentation rate of each lake.

Summary

In April and May 2022 and 2023, bathymetric data were collected at 13 water-supply lakes throughout Missouri by the U.S. Geological Survey in cooperation with the Missouri Department of Natural Resources and in collaboration with various local agencies. These surveys are the last in a 5-year series to establish or update the surface area and capacity tables for the surveyed lakes. All the lakes but the two near Unity Village had been surveyed by the U.S. Geological Survey before, and the recent surveys were compared to the earlier surveys to document the changes in the bathymetric surface and capacity of the lake and produce a bathymetric change map.

Bathymetric data were collected using a high-resolution multibeam mapping system (MBMS) mounted on a boat. Two different boats were used for the 2022 and 2023 surveys: a 24-foot flat-bottom cabin boat and a 16-foot jon boat, which could be more easily launched and retrieved from the bank of a lake. The bathymetric data were collected along transect lines oriented longitudinally in the main lake area, using about 10- to 25-percent overlap of the adjacent survey swaths. 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. Supplemental depth data were collected in shallow areas with an acoustic Doppler current profiler (ADCP) on a remote-controlled boat at five of the lakes.

Data points from the MBMS, as well as any supplemental ADCP points, were exported at a gridded data resolution appropriate to each lake, either 0.82, 1.64, or 3.28 feet. Geographic information system software was used to filter the gridded bathymetric data points to create a dataset that had a minimum point spacing that was about twice that (that is, lower resolution) of the gridded data resolution. Data outside the MBMS survey extent and greater than the surveyed water-surface elevation were obtained from data collected using aerial light detection and ranging (lidar) point cloud data. These upland data points were resampled to a linear distance that matched the map resolution of each lake using geographic information system software and used to define the upland areas of the lake. A linear enforcement technique was used to add points to the dataset in areas of sparse data (the upper ends of coves where the water was too shallow for the MBMS equipment or aquatic vegetation precluded data

acquisition with the MBMS or ADCP) based on surrounding MBMS and upland data values. The various point datasets (MBMS, ADCP, upland data, and linear enforcement) were used to produce a three-dimensional triangulated irregular network (TIN) surface of the lake-bottom elevations for each lake. A surface area and capacity table for each lake was produced from the three-dimensional TIN surface showing surface area and capacity at specified lake water-surface elevations.

If data from a previous bathymetric survey exists for a given lake, a bathymetric change map was generated from the difference between the previous survey and the 2022 or 2023 bathymetric survey data points where they were coincident. Comparing the results of the previous survey to the 2022 or 2023 survey required both datasets to be at a common elevation datum, so a point of coincident location and elevation from the previous survey was surveyed again in 2022 or 2023 (such as the reference mark from the previous survey or the spillway crest) using Global Navigation Satellite System techniques. If there was a difference between the 2022 or 2023 and the previous elevation, it was assumed that the 2022 or 2023 elevation was the more accurate value. After applying any vertical elevation changes to the previous survey data to ensure a match to the 2022 or 2023 survey datum and position, coincident points between the surveys were identified, and a bathymetric change TIN was generated using the difference in elevation between the coincident point data.

Various quality-assurance tests were conducted to ensure quality data were collected with the MBMS, including beam angle checks and patch tests. Additional quality-assurance tests were conducted on the various datasets from these surveys. The gridded bathymetric data from the MBMS survey were compared to raw data collected along at least one cross-check line at each lake to quantify the vertical accuracy of the gridded data at a 95-percent confidence level. A second quality-assurance dataset was used to evaluate the bathymetric surface and contours and included data points selected at random from the gridded data points at each lake. Points that were used to create the bathymetric surface were not included as bathymetric surface quality-assurance points. The bathymetric surface and contours were tested to quantify the vertical accuracy of each at a 95-percent confidence level.

A change in capacity was observed at all the lakes for which a previous survey existed, and the mean elevation change between the surveys was positive (implying sedimentation) at most of the lakes. Relative to previous surveys, the change in capacity at the primary spillway elevation ranged from a 5.5-percent decrease at Adrian Reservoir to a 9.2-percent increase at Cameron Reservoir Number 1. The mean bathymetric change ranged from –0.94 foot at Cameron Reservoir Number 1 to 1.05 feet at McDaniel Lake. The time-averaged mean bathymetric change ranged from –0.107 foot per year at Cameron Reservoir Number 1 to 0.050 foot per year at McDaniel Lake. The sedimentation rate generally ranged from –0.44 to 1.34 acre-feet per year at Cameron Reservoir Number 3 and Unionville Reservoir (Mahoney Lake), respectively; however, Fellows Lake and McDaniel Lake had substantially larger sedimentation rates of 11.8 and 11.5 acre-feet per year, respectively. Despite these substantial sedimentation rates, improved data collection along the steep sides of Fellows and McDaniel Lakes may have revealed areas of additional storage around the periphery of those lakes between the transects in the previous surveys that are covered by the slope masks used in the bathymetric change maps. Some changes observed in other bathymetric change maps are likely to result from the difference in data-collection equipment and techniques between the previous and present bathymetric surveys. Certain erosional features around the perimeter of certain lakes may be the result of wave action during low-water years or may indicate an unidentified but systemic error in the older singlebeam echosounder survey data.

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