science for a changing world

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

Prepared in cooperation with the City of Tuscaloosa

Scientific Investigations Map 3176

Abstract

The U.S. Geological Survey, in cooperation with the City of Tuscaloosa, conducted a bathymetric survey of Carroll Creek, on May 12–13, 2010. Carroll Creek is one of the major tributaries to Lake Tuscaloosa and contributes about 6 percent of the surface drainage area.

A 3.5-mile reach of Carroll Creek was surveyed to prepare a current bathymetric map, determine storage capacities at specified water-surface elevations, and compare current conditions to historical cross sections. Bathymetric data were collected using a high-resolution interferometric mapping system consisting of a phase-differencing bathymetric sonar, navigation and motion-sensing system, and a data acquisition computer. To assess the accuracy of the interferometric mapping system and document depths in shallow areas of the study reach, an electronic total station was used to survey 22 cross sections spaced 50 feet apart. The data were combined and processed and a Triangulated Irregular Network (TIN) and contour map were generated. Cross sections were extracted from the TIN and compared with historical cross sections.

Between 2004 and 2010, the area (cross section 1) at the confluence of Carroll Creek and the main run of Lake Tuscaloosa showed little to no change in capacity area. Another area (cross section 2) showed a maximum change in elevation of 4 feet and an average change of 3 feet. At the water-surface elevation of 224 feet (National Geodetic Vertical Datum of 1929), the cross-sectional area has changed by 260 square feet for a total loss of 28 percent of cross-sectional storage area. The loss of area may be attributed to sedimentation in Carroll Creek and (or) the difference in accuracy between the two surveys.

Introduction

Lake Tuscaloosa, constructed in 1969 on North River in Tuscaloosa County, Alabama, serves as the water supply for Tuscaloosa, Northport, and other communities in Tuscaloosa County (fig. 1). The lake is also used for recreational activities in western Alabama. Protection and monitoring of this water supply has been a concern for many years. Bathymetric mapping can provide useful information to address a variety of issues on Lake Tuscaloosa and its tributaries.

Since the 1970s, several data-collection efforts have been undertaken to determine bathymetric changes in Lake Tuscaloosa. The bathymetric surveys were collected in 1973 (Hubbard, 1975), 1982 (Cole, 1985), 1986 (Slack and Pritchett, 1988), 2000 (Stricklin, 2001), and 2004 (Charley Foster and Associates, Inc., 2004). For the 1982 bathymetric survey (Cole, 1985), 17 cross sections were established in seven principal tributaries to Lake Tuscaloosa, including North River, Dry Creek, Turkey Creek, Binion Creek, Tierce Creek, Carroll Creek, and Brush Creek (fig. 1). Of the 17 cross sections established three are located on Carroll Creek. Results revealed that sediment depositions ranged from 2 to 20 feet in 14 of 17 cross sections (Cole, 1985). These cross sections were resurveyed in 1986 (Slack and Pritchett, 1988) and in May 2000 (Stricklin, 2001) to determine whether any additional sedimentation or scour occurred. Results from the 2000 survey indicated that the maximum amount of sediment deposition occurred in the upper end of Carroll Creek (Stricklin, 2001). The most recent survey, by Charley Foster and Associates, Inc., was conducted in 2004. Two cross sections on Carroll Creek were surveyed in a different location from the original surveys and are not directly comparable to the older cross sections. Since the completion of the 2004 survey, portions of Carroll Creek have been dredged.

The U.S. Geological Survey (USGS), in cooperation with the City of Tuscaloosa, is currently (2010) in the third year of a 4-year project to perform intensive suspended-sediment studies for seven tributaries. Sediment samples were collected for Carroll Creek, Turkey Creek, and North River during the first year of data collection. Sedimentation in Carroll Creek is a focus of the public because of land-use changes in the subwatershed and the high sediment loads experienced during storm events.

Until recently, the use of conventional surveying and sonar methods made conducting highly accurate bathymetric surveys of Lake Tuscaloosa and its tributaries time consuming. Recent advancements in technology are superior to conventional methods used in previous studies. The USGS, in a collaborative effort with the City of Tuscaloosa, conducted a bathymetric survey of Carroll Creek along a 3.5-mile reach on May 12–13, 2010, to show current bathymetric changes and storage capacities and to compare current conditions to historical cross sections.

The results of the bathymetric survey of Carroll Creek can be used to document temporal changes in streambed elevation and storage capacities. This study contributes to the strategic science directions established by the USGS in 2007 (U.S. Geological Survey, 2007) by providing data that will be used to help understand the ecosystem of Carroll Creek and by developing a component that is essential to a water census for the Lake Tuscaloosa water supply.

Description of the Study Area

Lake Tuscaloosa is located in north-central Tuscaloosa County, Alabama. The reservoir was created by the impoundment of North River approximately 1.5 miles upstream from its confluence with the Black Warrior River (fig. 1). The Lake Tuscaloosa watershed (Upper Black Warrior Subbasin hydrologic unit code (HUC) 0316011204) drains surface area from Fayette and Tuscaloosa Counties. Lake Tuscaloosa receives surface runoff from a drainage area that encompasses 423 square miles. Carroll Creek is one of six subwatersheds (Carroll Creek HUC 031601120405, Binion Creek HUC 031601120403, Headwaters North River HUC 031601120401, Upper North River HUC 031601120402, Middle North River HUC 031601120404, and Lower North River HUC 031601120406) that drain into Lake Tuscaloosa (fig. 1). Carroll Creek contributes about 6 percent of the surface drainage area.

The area of study has a subtropical climate characterized by warm, humid weather. According to long-term climatological records compiled by the National Oceanic and Atmospheric Administration (NOAA), the mean annual air temperature is 62.2 degrees Fahrenheit (°F). Generally, July is the hottest month with a mean temperature of 83.8 °F, and January is the coldest with a mean temperature of 52.5 °F (National Oceanic and Atmospheric Administration, 2002). Average annual precipitation, based on records for the 1971–2000 period at NOAA precipitation stations in Tuscaloosa and Fayette Counties, is about 56 inches (National Oceanic and Atmospheric Administration, 2002). Streamflow is generally highest during December through April and lowest during May through November. Average annual runoff at long-term USGS gaging stations in the watershed is about 22 inches or 1.6 cubic feet per second per square mile.

Methods and Data Collection

The bathymetry of Carroll Creek was surveyed using a high-resolution interferometric mapping system. An interferometric mapping system operates with an interferometer, also referred to as phase-differencing bathymetric sonar (PDBS), a navigation and motion-sensing system, and a data acquisition computer. The PDBS used in this study was the 468-kilohertz SEA SWATHplus Interferometric Sonar. The SEA SWATHplus collects a wide swath of high resolution bathymetric and sidescan data by recording the intensity of sound reflected off the lake bottom (acoustic backscatter). The SEA SWATHplus is ideal for collecting data in shallow areas, such as shorelines, and can survey swath widths of 10 to 15 times water depth up to 30 meters (98 feet; SEA, 2011). The SEA SWATHplus is an angle-measuring instrument and depth accuracy decreases with horizontal range. The accuracy of the system is better than 0.1 degree (SEA, 2011). The system was operated under the maximum range of 57 meters (187 feet) to provide maximum accuracy. The depths were converted to elevations using the Lake Tuscaloosa stream gage (USGS 02464800). The stream gage is located at the spillway of the dam and records water-surface elevations on a 1 hour interval. The water-surface elevation during the collection efforts was 223.6 feet relative to National Geodetic Vertical Datum of 1929 (NGVD 29).

The data collected by the PDBS are accurately represented in three-dimensional space by use of the navigation and motion-sensing system. The Applanix Position Orientation Solution for Marine Vessels (POS MV™) was used to measure the pitch, roll, and heading of the boat that are accurate within ±0.02 degree and heave within 5 percent of the heave amplitude, or 5 centimeters (0.4 inches), whichever is greater (Applanix Corporation, 2006). The POS MV™ has a Global Positioning System (GPS) subsystem that is comprised of two antennas and two survey grade receiver cards. The GPS subsystem computes position to 1 meter (3.28 feet) or better with standard differential corrections. The data were collected and processed using HYPACK®/HYSWEEP® data acquisition software (HYPACK, Inc., 2009).

Additional data were collected in the field and used for post processing. A sound velocity cast was taken at the beginning of data collection to account for variations of sound in the water column. Patch tests were also performed to check for variations in the orientation of the sonar head and timing of the PDBS with respect to the POS MV™ and real-world coordinates. The latency test measures the timing offset between the PDBS and GPS component of the POS MV™. The angular offsets of the transducer head were measured for their respective axis—longitudinal axis (roll test), lateral axis (pitch test), rotation about vertical axis (yaw test). All timing (latency) and angular offsets (roll, pitch, and yaw) were accounted for in the HYPACK®/HYSWEEP® software.

The interferometric mapping system was deployed on May 12–13, 2010. The data were collected in longitudinal transects to provide a complete swath of the 3.5-mile study reach. Additional data were also collected in the upper reach of the navigable portion of Carroll Creek (fig. 2). To properly document the storage capacity and streambed profile of this area, an electronic total station was used to survey 22 cross sections spaced 50 feet apart. The surveyed cross sections overlapped the data collected by the PDBS. The two datasets were compared for quality control and assurance. The cross sections were imported into HYPACK®/HYSWEEP® software and merged with the PDBS data. The resulting bathymetric dataset was processed using filters to remove data spikes or erroneous points.

Bathymetric Contours

Bathymetric contours were created using HYPACK® bathymetric software in conjunction with ArcGIS (Environmental Systems Research Institute, 2010) geographic information system (GIS) software. The original bathymetric sounding data were reduced in HYPACK® by overlaying a 2-foot grid and averaging all the data points that fall within each square. Subsetting the original sounding data with the 2-foot grid removes unnecessary spikes that may result from instrument error in the data-collection process. The subset data were then imported into ArcGIS, and a Triangulated Irregular Network (TIN) model of the bathymetric surface was numerically rendered. Elevation contours of the bathymetric surface were created from the TIN surface model in ArcGIS. Because contours generated from a TIN surface model are produced from triangles, their jagged edges do not fully represent the smooth curvatures of the true bathymetric surface of Carroll Creek (Wilson and Richards, 2006). Thus, the elevation contours generated by the software were subsequently edited and smoothed using the Polynomial Approximation with Exponential Kernel (PAEK) algorithm within ArcGIS. The PAEK algorithm removes vertices within a specified tolerance of each other along the contour lines based on a tolerance specified by the user. The tolerance is the length of a "moving" path used in calculating the new vertices (Environmental Systems Research Institute, 2010). The smoothed contours were compared with the original edited elevation data to ensure that the true topography of the lake bed was maintained. Contours are labeled at 10-foot elevation intervals (fig. 3).

Storage Capacities

Reservoir storage volumes for Carroll Creek were calculated using HYPACK® bathymetric software. This software produces volume data by performing computations between two specified surfaces (for example, a lake bed and a pool surface-elevation level). Erroneous soundings that resulted from instrument error in the original data collection were removed by using a 2-foot grid overlay and averaging all points that fall within each square. A TIN model of the bathymetric surface was then created in HYPACK® from the subset data. The TIN model was used as the lower bounding surface for computation of storage capacity, and specified water-surface elevations were input as upper surface boundaries. Volumes were then computed at various water-surface elevations (table 1).

Cross sections were generated from the HYPACK® TIN model and compared to historical surveys. Two cross sections (fig. 3) were extracted in the same location as the cross sections surveyed in 2004 by Charley Foster and Associates, Inc. The area (cross section 1) at the confluence of Carroll Creek and the main run of Lake Tuscaloosa (fig. 3) showed little to no change in capacity area. The primary area of concern is located at the upstream-most portion of the study area (fig. 2). Cross section 2 (fig. 3) showed a maximum change in elevation of 4 feet and an average change of 3 feet. At the water-surface elevation of 224 feet (NGVD 29), the cross-sectional area has changed by 260 square feet for a total loss of 28 percent of cross-sectional storage area. The change in cross-sectional area is not reflective of the total change between 2004 and 2010 because parts of Carroll Creek were dredged between the two surveys. The loss of area may be attributed to sedimentation in Carroll Creek and (or) the difference in accuracy between the two surveys.

References Cited

Applanix Corporation, 2006, POS-MV™ V4 user guide, Rev. 0: Richmond Hill, Ontario, Canada, PUBS–MAN–000513, 369 p.

Charley Foster and Associates, Inc., 2004, Surveyor's report for Lake Tuscaloosa bathymetric survey: Tuscaloosa, Ala., 5 p.

Cole, E.F., 1985, Effects of coal mining on the water quality and sedimentation of Lake Tuscaloosa and selected tributaries, North River basin, Alabama: U.S. Geological Survey Water-Resources Investigations Report 84–4310, 53 p.

Environmental Systems Research Institute, 2010, ArcGIS–A complete integrated system, accessed February 2011 at *http://www.esri.com/software/arcgis/.*

Hubbard, E.F., 1975, Fathometer survey of Lake Tuscaloosa, Alabama: U.S. Geological Survey Open-File Report, 94 p.

HYPACK, Inc., 2009, HYPACK® Hydrographic survey software user's manual 1/09: Middletown, Conn., 1,394 p.

National Oceanic and Atmospheric Administration, 2002, Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971–2000: Asheville, N.C., National Climatic Data Center, Climatography of the United States No. 81, 26 p. (Available online at *http://nsstc.uah.edu/aosc/files/ALnorm.pdf.)*

SEA, 2011, SWATHplus, accessed January 12, 2011, at *http://www.sea.co.uk/Products/Survey/SWATHplus/SWATHplus_Specifications.aspx.*

Slack, L.J., and Pritchett, J.L., Jr., 1988, Sedimentation in Lake Tuscaloosa, Alabama, 1982-86: U.S. Geological Survey Water-Resources Investigations Report 87–4256, 24 p.

Stricklin, V.E., 2001, Sedimentation profiles in Lake Tuscaloosa, Alabama, 2000: U.S. Geological Survey Open-File Report 01–317, 19 p.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017: U.S. Geological Survey Circular 1309, 70 p.

Wilson, G.L., and Richards, J.M., 2006, Procedural documentation and accuracy assessment of bathymetric maps and area/capacity tables for small reservoirs: U.S. Geological Survey Scientific Investigations Report 2006–5208, 24 p. plus oversize figs.

Table 1. Reservoir storage volumes for Carroll Creek tributary to Lake Tuscaloosa at specified water-surface elevations in 2010.

[Normal water-surface elevation shaded in blue. Capacity at specified water-surface elevations were calculated from the bathymetric TIN model created in HYPACK and not from smoothed bathymetric contours. Elevation, as used in this report, refers to distance above the National Geodetic Vertical Datum of 1929 (NGVD 29)]

Water-surface elevation, in feet above NGVD 29	Storage capacity, in acre-feet
230	8,470
229	8,280
228	8,080
227	7,880
226	7,690
225	7,490
224	7,290
223	7,100
220	6,520
210	4,780
200	3,370
190	2,240
180	1,360
170	690
160	220
150	18

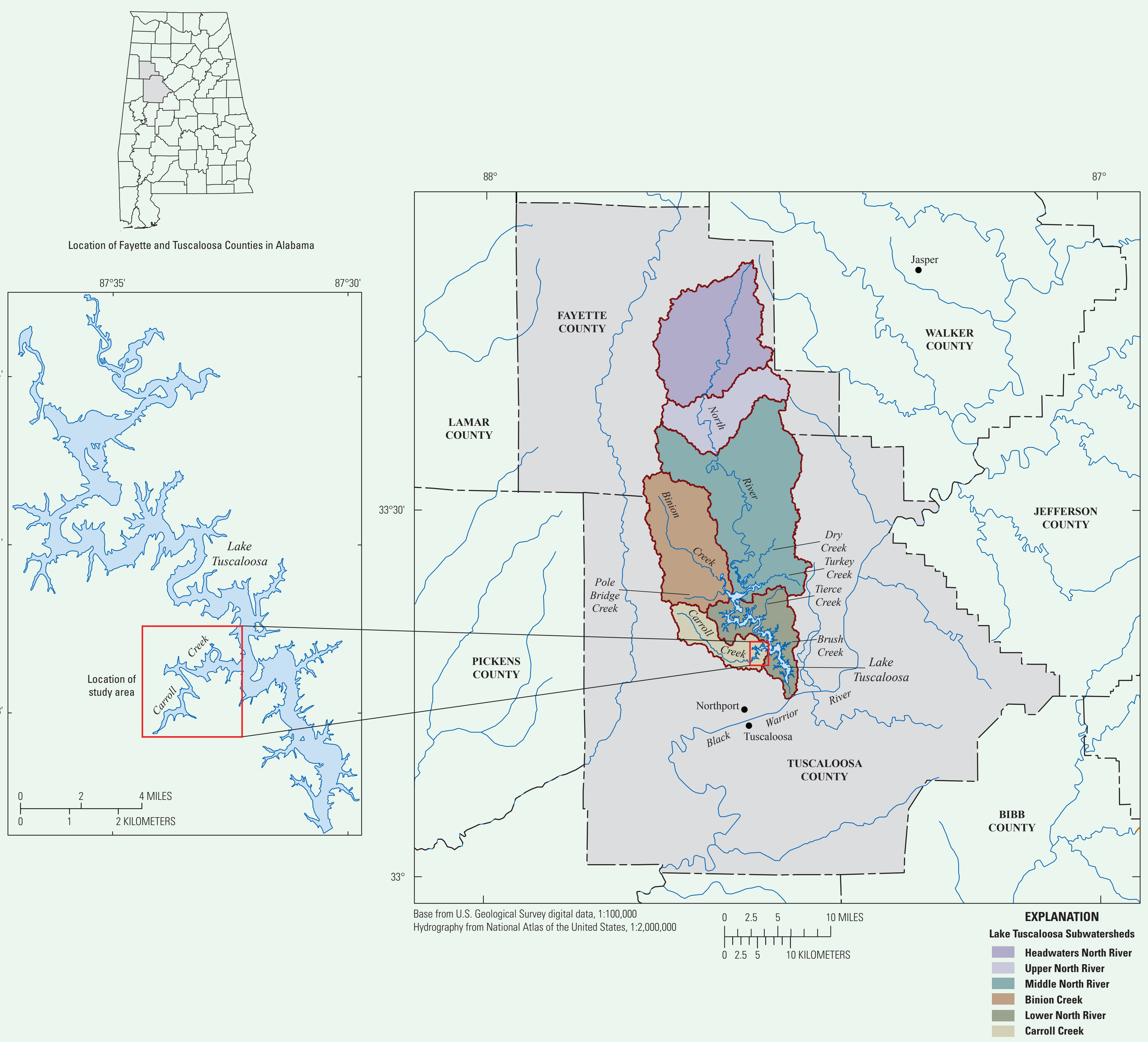

Figure 1. Location of Lake Tuscaloosa and Carroll Creek watersheds, and tributaries in Tuscaloosa County, Alabama.

Figure 2. Upstream limit of the Carroll Creek study area, March 2009 (photograph by Scott Sanderford, Lakes Division Manager, City of Tuscaloosa).

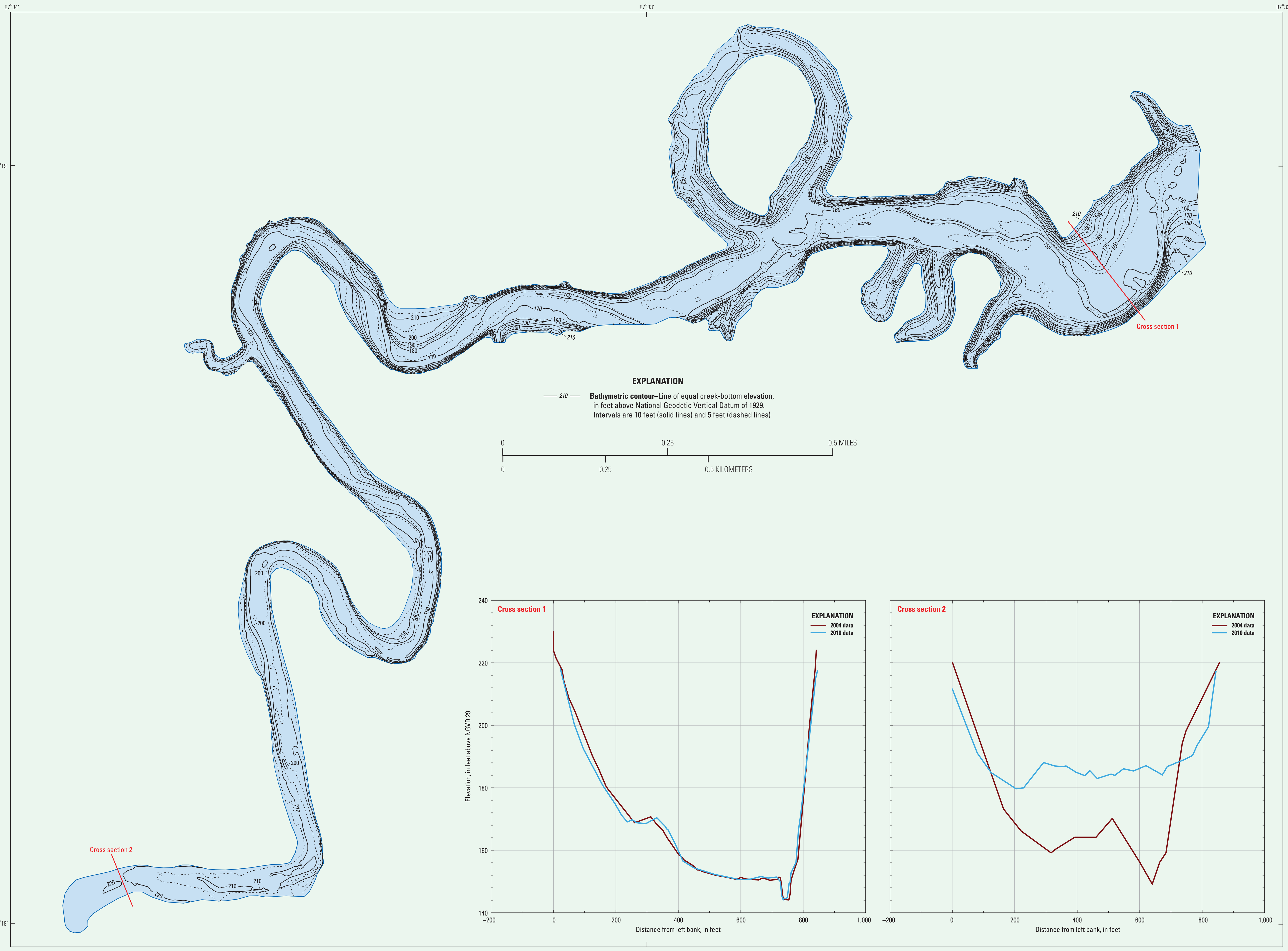

Figure 3. Bathymetry and cross sections of Carroll Creek tributary to Lake Tuscaloosa, May 2010.

Bathymetric Survey of Carroll Creek Tributary to Lake Tuscaloosa, Tuscaloosa County, Alabama, 2010

By
K.G. Lee and D.R. Kimbrow
2011