Abstract

Lakes and reservoirs are the water-supply source for many communities. As such, water-resource managers that oversee these water supplies require monitoring of the quantity and quality of the resource. Monitoring information can be used to assess the basic conditions within the reservoir and to establish a reliable estimate of storage capacity. In May 2013, a global navigation satellite system receiver and fathometer were used to collect bathymetric data, and an autonomous underwater vehicle was used to collect water-quality and bathymetric data at Table Rock Reservoir in Greenville County, South Carolina. These bathymetric data were used to create a bathymetric contour map and stage-area and stage-volume relation tables for the reservoir. Additionally, statistical summaries of the water-quality data were used to provide a general description of water-quality conditions in the reservoir.

Introduction

Greenville Water provides drinking water to more than 450,000 residents in the upstate region of South Carolina (Greenville Water, 2011). The water authority obtains its drinking water from three surface-water sources: Table Rock Reservoir, North Saluda (also known as Poinsett) Reservoir, and Lake Keowee (fig. 1). Accurate storage capacity and water-quality data are vital for management and planning of the drinking-water supply. Therefore, detailed surveys of bathymetry and water quality for the Table Rock Reservoir were conducted to determine the stage (water-level)-volume relations and water-quality condition of the reservoir. The U.S. Geological Survey (USGS), in cooperation with Greenville Water, conducted bathymetric, water-quality, and imaging surveys of Table Rock Reservoir. The resulting datasets were used to produce a digital bathymetric map of the reservoir and to describe the basic water-quality conditions within the reservoir at the time of data collection.

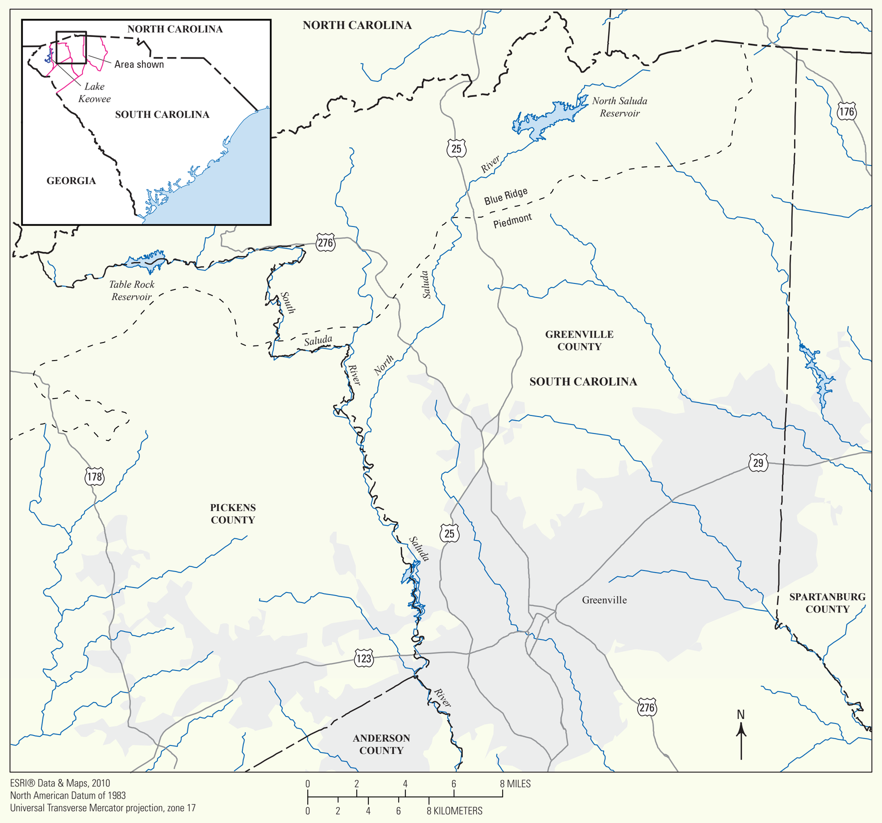

Figure 1. Location of Table Rock and North Saluda Reservoirs and Lake Keowee, Greenville County, South Carolina.

Purpose and Scope

The purpose of this report is to provide bathymetric, stage-volume, and water-quality data that can be used by water-resource managers to effectively plan and manage the resources available from the reservoir. Bathymetric, side-scan sonar, and water-quality data were collected at Table Rock Reservoir from May 14 to June 12, 2013. The bathymetric data were used to determine stage-volume relations, which can be used to assist water authorities in water-use planning. These relations are especially important during periods of high water usage or drought. Side-scan sonar data of the lake bed also were collected and used to verify and aid in the development of the bathymetric map. In addition, water temperature, pH, specific conductance, and dissolved-oxygen concentrations data were collected to provide a synoptic description of water-quality conditions in the reservoir.

This investigation of bathymetry and water-quality conditions in drinking-water reservoirs in South Carolina supports two of the six USGS strategic science directions (U.S. Geological Survey, 2007). The first strategy, Understanding Ecosystems and Predicting Ecosystem Change, is designed to study and monitor ecosystem change as well as interpret the findings and predictions for policymakers (U.S. Geological Survey, 2007). The second strategy is the Water Census of the United States, which informs the public and decision makers with, among other things, the status and changes of water resources and forecasting possible outcomes for water availability, water quality, and ecosystems caused by changing environments (U.S. Geological Survey, 2007).

Description of the Study Area

The Table Rock Reservoir is located in the foothills of the Blue Ridge Mountains in Greenville County, South Carolina (fig. 1) and was created in 1930 by the impoundment of the South Saluda River. Both the reservoir and the surrounding watershed are owned by Greenville Water, making it a well-protected source of drinking water. The watershed area, measured using a 10-meter (m) digital elevation model (DEM) (Gesch and others, 2002; Gesch, 2007) with a geographic information system (GIS), is 9,737 acres (15.2 square miles (mi^2)). Table Rock Reservoir reaches full pool at an elevation of 1,250 feet (ft) relative to the National Geodetic Vertical Datum of 1929 (NGVD 29) (K.C. Price, Greenville Water, written commun., 2013). The surface area of the reservoir at full pool is 476 acres and includes 8.6 miles of shoreline.

Methods

The YSI Ecomapper™ autonomous underwater vehicle (AUV) was used, where possible, to collect bathymetric and water-quality data in the reservoir. The AUV can cost-effectively collect dense data by surveying large areas with minimal time compared to traditional manned boat surveys. Using the AUV, spatially dense Doppler Velocity Log (DVL) data were collected in the open-water and unobstructed areas of the reservoir. On the basis of initial site reconnaissance and using the AUV's VectorMap planning software, a data-collection plan was established using selectable settings such as depth, speed, location, and sonar resolution. Georeferenced aerial imagery of the water body was loaded into VectorMap as background data for programming the surveys and establishing numbered waypoints, which are points placed by the user to indicate the route for the AUV to travel. For optimal efficiency of data collection and accuracy of the datasets, a transect spacing of approximately 100 ft or 1 percent of the longitudinal length of the lake was used (Wilson and Richards, 2006). The AUV uses a Wide Area Augmentation System (WAAS) capable global positioning system (GPS) to navigate on the water surface and a DVL instrument for underwater navigation, which includes vertical beams for altitude and depth measurement. As a failsafe, the AUV can use an internal compass in the event that a problem occurs with the DVL. Vertical accuracy of the DVL at depths of 0 to 200 ft is ±0.4 ft (YSI, Incorporated, 2011).

In shallow areas (generally less than 3 ft), areas containing debris, or any area otherwise difficult for the AUV to maneuver, the bathymetric data were collected with digital echo sounding equipment attached to a manned boat. The data were collected by interfacing a 220-channel global navigation satellite system (GNSS) receiver and data logger to a dual-frequency fathometer and used methods described in Nagle and others (2009). Horizontal accuracy of both GPS types is typically less than 3 ft. The echo sounding equipment also was used as a quality-control check on selected AUV transects. The time measurement accuracy of echo sounding equipment typically is rated by manufacturers at ±0.1 ft plus 0.1 to 0.5 percent of the depth (U.S. Army Corps of Engineers, 2002). To assess potential outliers and erroneous depth data, all data were post-processed and imported into a three-dimensional program called ArcScene. Data that were determined to be erroneous were removed from further processing and analysis. Using a GIS, the data then were used to create a triangulated irregular network (TIN), which digitally represents a surface (Environmental Systems Research Institute, 2013). Using methods described by Johnson and others (2008), the TIN was used to produce contour maps at 10-ft intervals and stage-volume relations. All GIS processing was accomplished by using Environmental Systems Research Institute (Esri) GIS software, including ArcScene, ArcMap, and 3-D Analyst extension (Environmental Systems Research Institute, 2013).

Water-quality data were collected simultaneously with the bathymetric data by using a bulkhead-mounted multiparameter sonde that is part of the AUV. The water-quality data were used to assess the spatial variability of water temperature, pH, specific conductance, and dissolved-oxygen concentrations. During the period of study, water-quality conditions in the reservoir were relatively uniform with minimal variability; therefore, no maps of the water-quality conditions were produced. Statistical summaries of the water-quality data are provided for the reservoir. In addition, near-surface and near-bottom measurements of water-quality conditions were made periodically and assessed to determine if changes in water quality occurred vertically in the water column. These water-quality data were collected using a hand-held multiparameter sonde from a manned boat. All water-quality sensors were calibrated prior to and after the deployment according to procedures outlined by YSI and the USGS National Field Manual (YSI, Incorporated, 2011; Wilde, variously dated; respectively).

Bathymetry and Storage Volumes

The maximum depth recorded in Table Rock Reservoir was 123 ft (fig. 2). On the basis of side-scan sonar data, there are many areas in the reservoir in which the relic stream channel is clearly visible. Also, no obvious areas of sediment buildup were detected. The reservoir is considered to be at full pool when the surface elevation reaches 1,250 ft. Using the 3-D Analyst extension within ArcMap, the volume of the reservoir at full pool was determined to be 1,180 x 10^6 cubic feet (ft^3) (table 1; fig. 3). During the data-collection period, the highest recorded surface elevation was 1,250.2 ft.

Table 1. Stage-area and stage-volume relations for selected elevations at Table Rock Reservoir, Greenville County, South Carolina, May 2013.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Elevation (feet, NGVD 29)	Surface area (acres)	Volume (cubic feet x 10^6)
1,250.2	478	1,184
[a]1,250	476	1,180
1,248	468	1,138
1,246	460	1,098
1,244	451	1,058
1,242	443	1,019
1,240	432	981
1,238	423	944
1,236	415	907
1,234	407	872

[a]Full-pool elevation.

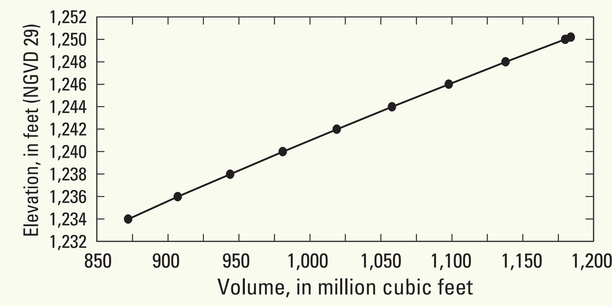

Figure 3. Stage-volume curve at Table Rock Reservoir, Greenville County, South Carolina, May 2013.

Water-Quality Conditions

Spatial variability of water-quality conditions were assessed in Table Rock Reservoir for May 14–15, 2013. Subsequent data were collected on June 12, 2013, in order to add more depth data in targeted areas of the reservoir. As mentioned previously, water-quality conditions were relatively uniform and demonstrated minimal spatial variability.

During the 2-day, data-collection period in May, water-quality data were collected near the surface at depths of 2 to 6 ft. The water temperature ranged from 17.3 to 21.1 degrees Celsius (°C) (table 2), and pH ranged from 5.4 to 6.3. Specific conductance ranged from 13 to 14 microsiemens per centimeter (µS/cm) at 25 degrees Celsius, and dissolved-oxygen concentrations ranged from 9.4 to 9.7 milligrams per liter (mg/L).

In order to determine vertical changes in the water column, a hand-held multiparameter sonde was used periodically to collect near-surface and near-bottom water-quality data. In Table Rock Reservoir, near-surface and near-bottom measurements of water temperature (17.8 and 8.2 °C, respectively) demonstrated a temperature change with depth, indicating some degree of thermal stratification (table 3). A different pattern, however, was identified for pH, specific conductance, and dissolved-oxygen concentrations in the reservoir, which had fairly constant measurements at both near-surface and near-bottom depths (table 3).

Table 2. Statistical summary of water-quality conditions at Table Rock Reservoir, Greenville County, South Carolina, May 14–15, 2013.

[Water-quality data were collected at a depth of 2 to 6 feet]

Water-quality constituent	Unit	Minimum	Maximum	Mean	Median
Table Rock Reservoir					
Water temperature	Degrees Celsius	17.3	21.1	18.1	18.0
pH	Standard units	5.4	6.3	5.8	5.8
Specific conductance	Microsiemens per centimeter at 25 degrees Celsius	13	14	14	14
Dissolved-oxygen concentration	Milligrams per liter	9.4	9.7	9.5	9.5

Table 3. Near-surface and near-bottom water-quality data collected at Table Rock Reservoir, Greenville County, South Carolina, May 14–15, 2013.

Water-quality constituent	Unit	Near-surface measurement	Near-bottom measurement
Table Rock Reservoir			
Water temperature	Degrees Celsius	17.8	8.2
pH	Standard units	6.7	6.6
Specific conductance	Microsiemens per centimeter at 25 degrees Celsius	14	15
Dissolved-oxygen concentration	Milligrams per liter	9.5	9.4

Acknowledgments

The authors would like to recognize the contributions of Greenville Water for providing boats and staff to assist in data collection.

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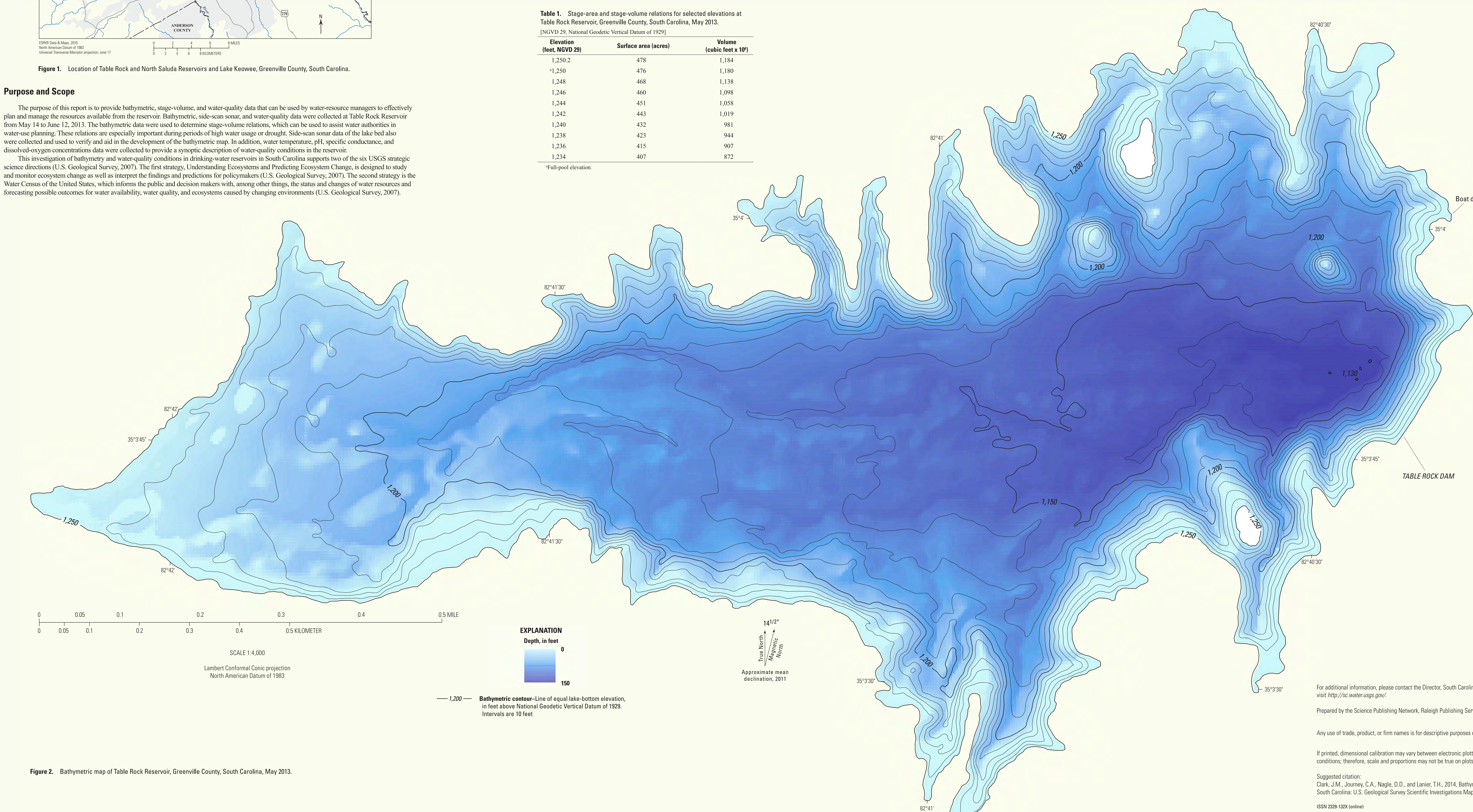

Figure 2. Bathymetric map of Table Rock Reservoir, Greenville County, South Carolina, May 2013.

For additional information, please contact the Director, South Carolina Water Science Center, email: dc_sc@usgs.gov, or visit *http://sc.water.usgs.gov/*.

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Bathymetric Maps and Water-Quality Profiles of Table Rock and North Saluda Reservoirs, Greenville County, South Carolina

By

Jimmy M. Clark, Celeste A. Journey, Douglas D. Nagle, and Timothy H. Lanier

2014

Abstract

Lakes and reservoirs are the water-supply source for many communities. As such, water-resource managers that oversee these water supplies require monitoring of the quantity and quality of the resource. Monitoring information can be used to assess the basic conditions within the reservoir and to establish a reliable estimate of storage capacity. In April and May 2013, a global navigation satellite system receiver and fathometer were used to collect bathymetric data, and an autonomous underwater vehicle was used to collect water-quality and bathymetric data at North Saluda Reservoir in Greenville County, South Carolina. These bathymetric data were used to create a bathymetric contour map and stage-area and stage-volume relation tables for the reservoir. Additionally, statistical summaries of the water-quality data were used to provide a general description of water-quality conditions in the reservoir.

Introduction

Greenville Water provides drinking water to more than 450,000 residents in the upstate region of South Carolina (Greenville Water, 2011). The water authority obtains its drinking water from three surface-water sources: Table Rock Reservoir, North Saluda (also known as Poinsett) Reservoir, and Lake Keowee (fig. 1). Accurate storage capacity and water-quality data are vital for management and planning of the drinking-water supply. Therefore, detailed surveys of bathymetry and water-quality for the North Saluda Reservoir were conducted to determine the stage (water-level)-volume relations and water-quality condition of the reservoir. The U.S. Geological Survey (USGS), in cooperation with Greenville Water, conducted bathymetric, water-quality, and imaging surveys of North Saluda Reservoir. The resulting datasets were used to produce a digital bathymetric map of the reservoir and to describe the basic water-quality conditions within the reservoir at the time of data collection.

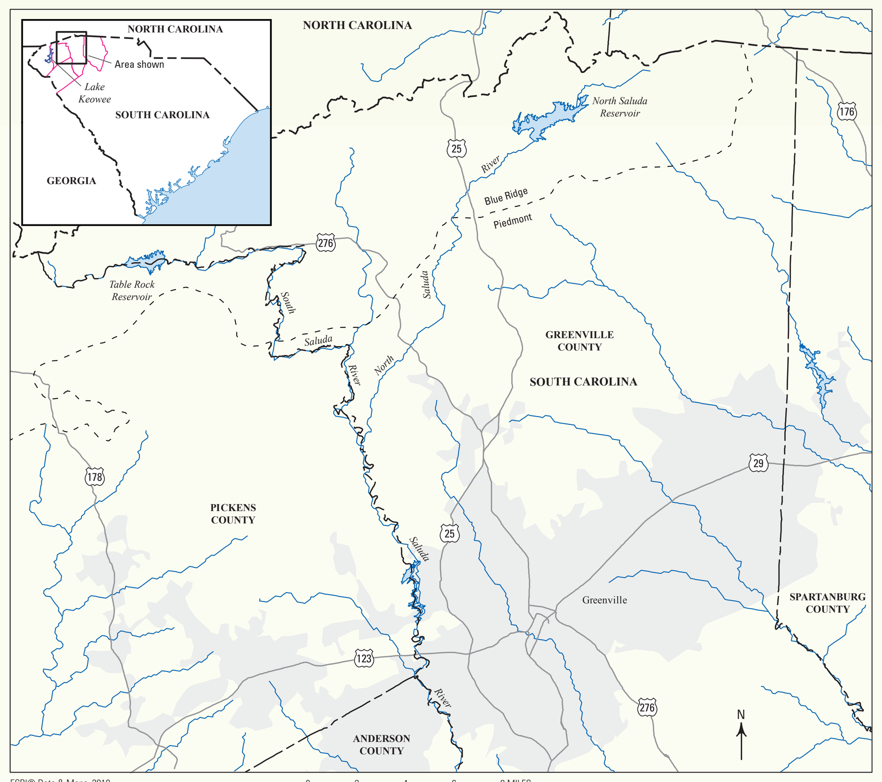

Figure 1. Location of Table Rock and North Saluda Reservoirs and Lake Keowee, Greenville County, South Carolina.

Purpose and Scope

The purpose of this report is to provide bathymetric, stage-volume, and water-quality data that can be used by water-resource managers to effectively plan and manage the resources available from the reservoir. Bathymetric, side-scan sonar, and water-quality data were collected at North Saluda Reservoir from April 15 to June 12, 2013. The bathymetric data were used to determine stage-volume relations, which can be used to assist water authorities in water-use planning. These relations are especially important during periods of high water usage or drought. Side-scan sonar data of the lake bed also were collected and used to verify and aid in the development of the bathymetric map. In addition, water temperature, pH, specific conductance, and dissolved-oxygen concentrations data were collected to provide a synoptic description of water-quality conditions in the reservoir.

This investigation of bathymetry and water-quality conditions in drinking-water reservoirs in South Carolina supports two of the six USGS strategic science directions (U.S. Geological Survey, 2007). The first strategy, Understanding Ecosystems and Predicting Ecosystem Change, is designed to study and monitor ecosystem change as well as interpret the findings and predictions for policymakers (U.S. Geological Survey, 2007). The second strategy is the Water Census of the United States, which informs the public and decision makers with, among other things, the status and changes of water resources and forecasting possible outcomes for water availability, water quality, and ecosystems caused by changing environments (U.S. Geological Survey, 2007).

Description of the Study Area

The North Saluda Reservoir, which also is known as the Poinsett Reservoir, is located in the foothills of the Blue Ridge Mountains in Greenville County, South Carolina (fig. 1). The reservoir was created by the impoundment of the North Saluda River and was put into operation in 1961. Both the reservoir and the surrounding watershed are owned by Greenville Water, making it a well-protected source of drinking water. The watershed area, measured using a 10-meter (m) digital elevation model (DEM) (Gresch and others, 2002; Gesch, 2007) with a geographic information system (GIS), is 16,122 acres (25.2 square miles (mi^2)). North Saluda Reservoir reaches full pool at an elevation of 1,230 feet (ft) relative to the National Geodetic Vertical Datum of 1929 (NGVD 29) (K.C. Price, Greenville Water, written commun., 2013). The surface area of the reservoir at full pool is 1,049 acres and includes 17.9 miles of shoreline.

Methods

The YSI Ecomapper™ autonomous underwater vehicle (AUV) was used, where possible, to collect bathymetric and water-quality data in the reservoir. The AUV can cost-effectively collect dense data by surveying large areas with minimal time compared to traditional manned boat surveys. Using the AUV, spatially dense Doppler Velocity Log (DVL) data were collected in the open-water and unobstructed areas of the reservoir. On the basis of initial site reconnaissance and using the AUV's VectorMap planning software, a data-collection plan was established using selectable settings such as depth, speed, location, and sonar resolution. Georeferenced aerial imagery of the water body was loaded into VectorMap as background data for programming the surveys and establishing numbered waypoints, which are points placed by the user to indicate the route for the AUV to travel. For optimal efficiency of data collection and accuracy of the datasets, a transect spacing of approximately 100 ft or 1 percent of the longitudinal length of the lake was used (Wilson and Richards, 2006). The AUV uses a Wide Area Augmentation System (WAAS) capable global positioning system (GPS) to navigate on the water surface and a DVL instrument for underwater navigation, which includes vertical beams for altitude and depth measurement. As a failsafe, the AUV can use an internal compass in the event that a problem occurs with the DVL. Vertical accuracy of the DVL at depths of 0 to 200 ft is ±0.4 ft (YSI, Incorporated, 2011).

In shallow areas (generally less than 3 ft), areas containing debris, or any area otherwise difficult for the AUV to maneuver, the bathymetric data were collected with digital echo sounding equipment attached to a manned boat. The data were collected by interfacing a 220-channel global navigation satellite system (GNSS) receiver and data logger to a dual-frequency fathometer and used methods described in Nagle and others (2009). Horizontal accuracy of both GPS types is typically less than 3 ft. The echo sounding equipment also was used as a quality-control check on selected AUV transects. The time measurement accuracy of echo sounding equipment typically is rated by manufacturers at ±0.1 ft plus 0.1 to 0.5 percent of the depth (U.S. Army Corps of Engineers, 2002). To assess potential outliers and erroneous depth data, all data were post-processed and imported into a three-dimensional program called ArcScene. Data that were determined to be erroneous were removed from further processing and analysis. Using a GIS, the data then were used to create a triangulated irregular network (TIN), which digitally represents a surface (Environmental Systems Research Institute, 2013). Using methods described by Johnson and others (2008), the TIN was used to produce contour maps at 10-ft intervals and stage-volume relations. All GIS processing was accomplished by using Environmental Systems Research Institute (Esri) GIS software, including ArcScene, ArcMap, and 3-D Analyst extension (Environmental Systems Research Institute, 2013).

Water-quality data were collected simultaneously with the bathymetric data by using a bulkhead-mounted multiparameter sonde that is part of the AUV. The water-quality data were used to assess the spatial variability of water temperature, pH, specific conductance, and dissolved-oxygen concentrations. During the period of study, water-quality conditions in the reservoir were relatively uniform with minimal variability; therefore, no maps of the water-quality conditions were produced. Statistical summaries of the water-quality data are provided for the reservoir. In addition, near-surface and near-bottom measurements of water-quality conditions were made periodically and assessed to determine if changes in water quality occurred vertically in the water column. These water-quality data were collected using a hand-held multiparameter sonde from a manned boat. All water-quality sensors were calibrated prior to and after the deployment according to procedures outlined by YSI and the USGS National Field Manual (YSI, Incorporated, 2011; Wilde, variously dated; respectively).

Bathymetry and Storage Volumes

The maximum depth recorded in North Saluda Reservoir was 149.5 ft (fig. 2). Side-scan sonar did not indicate any obvious sediment buildup and, similar to Table Rock Reservoir, the relic stream channel was distinct throughout the reservoir. North Saluda Reservoir is considered to be at full pool when the surface elevation reaches 1,230 ft. Reservoir volume at this level was determined to be $3,181 \times 10^6$ cubic feet (ft^3) (table 1; fig. 3). During the data-collection period, the highest recorded surface elevation was 1,230.3 ft.

Table 1. Stage-area and stage-volume relations for selected elevations at North Saluda Reservoir, Greenville County, South Carolina, April 2013.

[NGVD 29, National Geodetic Vertical Datum of 1929]

Elevation (feet, NGVD 29)	Surface area (acres)	Volume (cubic feet x 10^6)
1,230.3	1,052	3,195
[a]1,230	1,049	3,181
1,228	1,033	3,091
1,226	1,018	3,001
1,224	1,003	2,913
1,222	988	2,826
1,220	970	2,741
1,218	949	2,657
1,216	931	2,575
1,214	913	2,495

[a]Full-pool elevation.

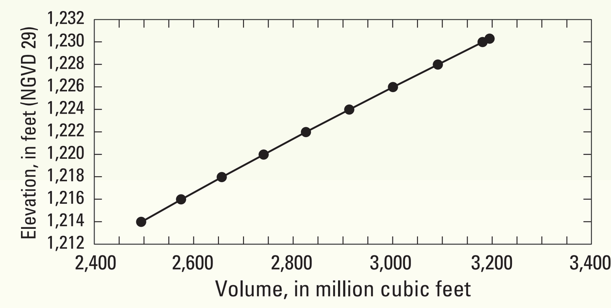

Figure 3. Stage-volume curve at North Saluda Reservoir, Greenville County, South Carolina, April 2013.

Table 2. Statistical summary of water-quality conditions at North Saluda Reservoir, Greenville County, South Carolina, April 15–18, 2013.

[Water-quality data were collected at a depth of 2 to 6 feet]

Water-quality constituent	Unit	Minimum	Maximum	Mean	Median
North Saluda Reservoir					
Water temperature	Degrees Celsius	14.2	18.1	15.0	14.9
pH	Standard units	5.6	6.8	6.3	6.3
Specific conductance	Microsiemens per centimeter at 25 degrees Celsius	23	24	23.8	24
Dissolved-oxygen concentration	Milligrams per liter	10.2	10.7	10.4	10.4

Table 3. Near-surface and near-bottom water-quality data collected at North Saluda Reservoir, Greenville County, South Carolina, April 15–18, 2013.

Water-quality constituent	Unit	Near-surface measurement	Near-bottom measurement
North Saluda Reservoir			
Water temperature	Degrees Celsius	16.6	8.3
pH	Standard units	6.9	6.8
Specific conductance	Microsiemens per centimeter at 25 degrees Celsius	23	24
Dissolved-oxygen concentration	Milligrams per liter	9.8	9.7

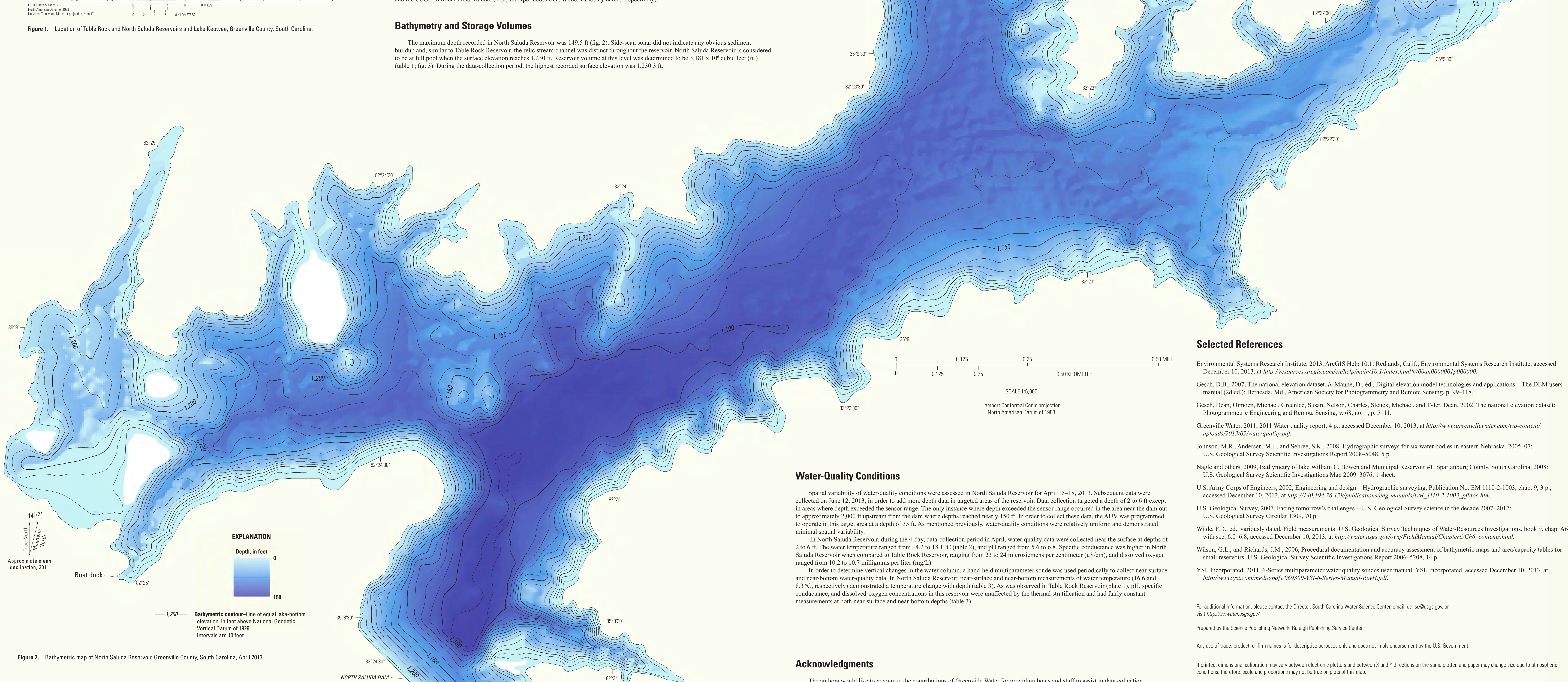

Figure 2. Bathymetric map of North Saluda Reservoir, Greenville County, South Carolina, April 2013.

Water-Quality Conditions

Spatial variability of water-quality conditions were assessed in North Saluda Reservoir for April 15–18, 2013. Subsequent data were collected on June 12, 2013, in order to add more depth data in targeted areas of the reservoir. Data collection targeted a depth of 2 to 6 ft except in areas where depth exceeded the sensor range. The only instance where depth exceeded the sensor range occurred in the area near the dam out to approximately 2,000 ft upstream from the dam where depths reached nearly 150 ft. In order to collect these data, the AUV was programmed to operate in this target area at a depth of 35 ft. As mentioned previously, water-quality conditions were relatively uniform and demonstrated minimal spatial variability.

In North Saluda Reservoir, during the 4-day, data-collection period in April, water-quality data were collected near the surface at depths of 2 to 6 ft. The water temperature ranged from 14.2 to 18.1 °C (table 2), and pH ranged from 5.6 to 6.8. Specific conductance was higher in North Saluda Reservoir when compared to Table Rock Reservoir, ranging from 23 to 24 microsiemens per centimeter (µS/cm), and dissolved oxygen ranged from 10.2 to 10.7 milligrams per liter (mg/L).

In order to determine vertical changes in the water column, a hand-held multiparameter sonde was used periodically to collect near-surface and near-bottom water-quality data. In North Saluda Reservoir, near-surface and near-bottom measurements of water temperature (16.6 and 8.3 °C, respectively) demonstrated a temperature change with depth (table 3). As was observed in Table Rock Reservoir (plate 1), pH, specific conductance, and dissolved-oxygen concentrations in this reservoir were unaffected by the thermal stratification and had fairly constant measurements at both near-surface and near-bottom depths (table 3).

Acknowledgments

The authors would like to recognize the contributions of Greenville Water for providing boats and staff to assist in data collection.

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2014