Prepared in cooperation with the Grand River Dam Authority

Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

Background, Neosho River (left) and Spring River (right) at Twin Bridges State Park, Oklahoma.

Inset, Spring River (left foreground) converges with the Neosho River (right foreground and background) downstream from Twin Bridges State Park, Oklahoma.
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Conversion Factors

<table>
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<th>U.S. customary units to International System of Units</th>
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<tr>
<td>Multiply</td>
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</tr>
<tr>
<td>Length</td>
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<td>foot (ft)</td>
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<td>mile (mi)</td>
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<td>Area</td>
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<tr>
<td>square mile (mi²)</td>
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<tr>
<td>Flow rate</td>
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<td>foot per second (ft/s)</td>
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<td>cubic foot per second (ft³/s)</td>
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<tr>
<td>Hydraulic gradient</td>
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<td>foot per mile (ft/mi)</td>
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</table>

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

ADCP acoustic Doppler current profiler
DEM digital elevation model
dGPS differently corrected Global Positioning System
FERC Federal Energy Regulatory Commission
GIS geographic information system
GNSS global navigation satellite system
GPS Global Positioning System
GRDA Grand River Dam Authority
OPUS National Geodetic Survey Online Positioning User Service
RMSE root-mean-square error
RTK real-time kinematic
SEES single-beam echo sounder

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Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

By Shelby L. Hunter, Chad E. Ashworth, and S. Jerrold Smith

Abstract

In February 2017, the Grand River Dam Authority filed to relicense the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission. The predominant feature of the Pensacola Hydroelectric Project is Pensacola Dam, which impounds Grand Lake O’ the Cherokees (locally called Grand Lake) in northeastern Oklahoma. Identification of information gaps and assessment of project effects on stakeholders are central aspects of the Federal Energy Regulatory Commission relicensing process. Some upstream stakeholders have expressed concerns about the dynamics of sedimentation and flood flows in the transition zone between major rivers and Grand Lake O’ the Cherokees. To relicense the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission, the hydraulic models for these rivers require high-resolution bathymetric data along the river channels. In support of the Federal Energy Regulatory Commission relicensing process, the U.S. Geological Survey, in cooperation with the GRDA, performed bathymetric surveys of (1) the Neosho River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, (2) the Spring River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, and (3) the Elk River from Noel, Missouri, to the Oklahoma State Highway 10 bridge near Grove, Oklahoma. The Neosho River and Spring River bathymetric surveys were performed from October 26 to December 14, 2016; the Elk River bathymetric survey was performed from February 27 to March 21, 2017. Only areas inundated during those periods were surveyed.

The bathymetric surveys covered a total distance of about 76 river miles and a total area of about 5 square miles. Greater than 1.4 million bathymetric-survey data points were used in the computation and interpolation of bathymetric-survey digital elevation models and derived contours at 1-foot (ft) intervals. The minimum bathymetric-survey elevation of the Neosho River was 709.18 ft above North American Vertical Datum of 1988, which corresponds to a maximum depth of 34.22 ft. The minimum bathymetric-survey elevation of the Elk River was 715.18 ft above North American Vertical Datum of 1988, which corresponds to a maximum depth of 27.78 ft.

Introduction

In February 2017, the Grand River Dam Authority (GRDA) filed to relicense the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission (FERC). The predominant feature of the Pensacola Hydroelectric Project (FERC license number 1494) is Pensacola Dam, which impounds Grand Lake O’ the Cherokees (locally called Grand Lake) in northeastern Oklahoma (fig. 1A,B). Identification of information gaps and assessment of project effects on stakeholders are central aspects of the FERC relicensing process (Federal Energy Regulatory Commission, 2012). Some of the upstream stakeholders have expressed concerns about the dynamics of sedimentation and flood flows in the transition zone between major rivers and Grand Lake O’ the Cherokees. The Neosho River, Spring River, and Elk River are the largest tributaries to the lake (fig. 1A,B), and the Neosho River in the vicinity of Miami, Okla., in particular, has been the focus of numerous hydraulic modeling studies (Grand River Dam Authority, 2017). Updates to hydraulic models for these rivers require high-resolution topographic and bathymetric data along the river channels and adjacent flood plains. A high-resolution lidar topographic survey of the river flood plains (U.S. Geological Survey, 2016a) was completed in 2009, but that survey included no bathymetric data for lakes and streams because traditional lidar methods do not penetrate water. Complementary bathymetric surveys were needed to fill a major data gap and produce more accurate and defensible hydraulic models of river and lake interactions in the transition zone. In support of the FERC relicensing process, the U.S. Geological Survey, in cooperation with the GRDA, performed bathymetric surveys of the Neosho River, Spring River, and Elk River in 2016–17 and released the bathymetric-survey data in 2017 (Smith and others, 2017). The bathymetric-survey data may later serve as a baseline to which temporal changes in channel capacity can be compared.

Purpose and Scope

This report describes the methods and results of bathymetric surveys of (1) the Neosho River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, (2) the Spring River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, and (3) the Elk River from Noel, Mo., to the Oklahoma State Highway 10 bridge near Grove, Okla. (fig. 1A,B). The Neosho River and Spring River bathymetric surveys were performed from October 26 to December 14, 2016; the Elk River bathymetric survey was performed from February 27 to March 21, 2017. Only areas inundated during those periods were surveyed.

Description of the Study Area

The Neosho River drains 6,136 square miles (mi²) of land area, and the Spring River drains 2,590 mi² of land area upstream from the U.S. Highway 60 bridges at Twin Bridges State Park (U.S. Geological Survey, 2016b). The Spring River joins the Neosho River about 0.3 mile downstream from the U.S. Highway 60 bridge at Twin Bridges State Park (appendix 1–1). The Elk River drains 1,025 mi² of land area upstream from the Oklahoma State Highway 10 bridge near Grove, Okla. (fig. 1B). The Neosho River, Spring River, and Elk River study areas each included a streamgage that has recorded streamflow from 1939 to present (2017). Streamflow at the Neosho River streamgage near Commerce (07185000, fig. 1A) averaged 3,802 cubic feet per second (ft³/s) and peaked at 267,000 ft³/s during the period of record (table 1). Streamflow at the Spring River streamgage near Quapaw (07188000, fig. 1A) averaged 2,231 ft³/s and peaked at 230,000 ft³/s during the period of record (table 1). Streamflow at the Elk River streamgage near Tiff City, Mo. (07189000, fig. 1B) averaged 824 ft³/s and peaked at 137,000 ft³/s during the period of record (table 1).
Figure 1. Map showing bathymetric-survey areas for A, the Neosho River and Spring River, and B, the Elk River, northeastern Oklahoma and southwestern Missouri, 2016–17.
Figure 1. Map showing bathymetric-survey areas for A, the Neosho River and Spring River, and B, the Elk River, northeastern Oklahoma and southwestern Missouri, 2016–17.—Continued
Bathymetric-Survey Methods

This section describes bathymetric-survey methods used on the Neosho River, Spring River, and Elk River. Data collection, data processing, and quality assurance are described.

Data Collection

Raw bathymetric-survey data (water-depth and position measurements) were collected using methods of Wilson and Richards (2006) and Mueller and others (2013). Two types of equipment were used to collect water-depth measurements. A Hydrographic Systems Echoscope CV100 single-beam echo sounder (SBES) with a dual frequency 200-kilohertz transducer (Odum Hydrographic Systems, Inc., 2008) was used in areas where the flat-bottom boat carrying the SBES was able to operate. These data were organized using the commercial hydrographic software HYPACK (HYPACK, Inc., 2016). The blanking depth, or minimum data collection period was about 0.3 ft measured at Grand Lake O’ the Cherokees at Langley (07190000) (fig. 1).

Two Teledyne RD Instruments RiverRays acoustic Doppler current profilers (ADCP; Teledyne RD Instruments, 2016) were towed behind the flat-bottom boat by kayaks in shallow areas that were inaccessible by flat-bottom boat. These data were collected using the hydrographic software WinRiver II (Teledyne RD Instruments, 2016). The blanking depth for the ADCPs was about 0.6 ft (table 2). During the bathymetric survey, position was measured by a differentially corrected Global Positioning System (DGPS) mounted directly above the SBES or ADCP. The stated positional accuracy of the DGPS data at a 95-percent confidence level was 1.97 ft (Hemisphere GNSS, Inc., 2013). The hydrographic software used the time provided by the DGPS to synchronize data from the echo sounder or ADCP and eliminate system latency.

The bathymetric-survey data that were recorded with the SBES were collected along primary transects aligned perpendicular to the riverbanks and separated by about 100 ft. The SBES primary-transect interval decreased to about 25 ft on the upstream side of road and railroad crossings (bridges) and one low-water dam to obtain higher-resolution bathymetric-survey data for those areas of possible localized sediment deposition. The SBES control transects were aligned parallel to the riverbanks so they would cross the primary transects. Other bathymetric-survey data were collected with two ADCPs simultaneously; one was arbitrarily designated the primary transect, and the other was designated the control transect. The ADCPs were towed by kayaks in a sinusoidal pattern, working diagonally bank to bank at about 100 ft. The ADCP primary-transect interval decreased to about 25 ft on the upstream side of road and railroad crossings (bridges).

About 650 water-surface elevations were measured (approximately every 500 ft) along streambanks using a real-time kinematic (RTK) GPS Rover. The RTK GPS Rover averaged elevation points for 3 minutes at a 1-second interval (Rydlund and Denimore, 2012) and received corrections through a virtual real-time station (VRS) network (Missouri Department of Transportation, 2017). Water-surface elevations were measured at shorter intervals in river reaches with rapid elevation drops (rifles). Water-surface elevations varied by several tenths of a foot greater or less than 743.4 ft above NAVD 1988 because of local pooling from bridges or debris, wind effects, and small GPS survey error. Grand Lake O’ the Cherokees remained near a normal pool elevation throughout the bathymetric-survey period (U.S. Geological Survey, 2017), and the maximum daily change in lake stage during the data-collection period was about 0.3 ft measured at Grand Lake O’ the Cherokees at Langley (07190000) (fig. 1, A, B; table 2; U.S. Geological Survey, 2017).

Nine reference marks were used as elevation control points during the bathymetric surveys (table 3). Each reference mark elevation was established by using a 4-hour static global navigation satellite system (GNSS) occupation (Rydlund and Densmore, 2012), which was processed by using the National Geodetic Survey Online Positioning User Service (OPUS; National Geodetic Survey, 2016). The vertical uncertainty of each reference mark elevation was less than or equal to 0.112 ft as calculated by OPUS (table 3). Throughout the bathymetric surveys, 74 RTK GPS elevations were measured at reference marks. These marks were measured at the beginning and end of each day surveyed. The difference between those RTK GPS observations and the reference mark elevation ranged from -0.341 to 0.295 ft (table 3).

Data Processing

Bathymetric-survey and water-surface elevation data were compiled in a geographic information system (GIS) using Esri ArcGIS 10.3.1 software. The GIS processing methods of Wilson and Richards (2006) were modified to adapt those methods (intended for reservoirs) to rivers. A reservoir water-surface elevation is relatively constant, but a river water-surface elevation generally decreases in a downstream direction; bathymetric-survey depths were converted to elevations by subtracting the depths from the nearest water-surface elevation measurement. The water-surface elevations changed comparatively quickly across some riffle reaches. When the difference between consecutive water-surface elevation measurements was greater than about 0.5 ft, additional water-surface elevations were interpolated in the riffle reach. These interpolated water-surface elevations also were used to convert bathymetric-survey depths to elevations.

Preliminary bathymetric-survey data were delineated from gaps (representing wide streams and lakes) in lidar-derived land-surface elevation data collected in 2009 (U.S. Geological Survey, 2016a). The preliminary bathymetric-survey areas were modified in some areas to account for changes to streambanks that have occurred since 2009 (the date of the lidar survey). Generally, the bathymetric-survey areas were enlarged, mostly common on the outside of meander bends, to encompass all bathymetric-survey transects. Some parts of the bathymetric-survey areas contained no bathymetric-survey transects. The largest unsurveyed areas were marked as “Area not surveyed” in the appendices. These unsurveyed areas either were too shallow to navigate or were occupied by debris or exposed sediment deposits.

A bathymetric-survey digital elevation model (DEM) at 4-ft resolutions for the Neosho River and Spring River and at a 2-ft resolution for the Elk River and contours at 1-ft intervals were derived in the GIS using the “Topo To Raster” (ESRI, Inc., 2016a) and “Contour” (ESRI, Inc., 2016b) tools. Data inputs to the “Topo to Raster” tool included (1) bathymetric-survey (SBES and ADCP) elevations, (2) GPS water-surface elevations, (3) selected Oklahoma Water Resources Board (2009, 2016) bathymetric-survey elevations in shallow areas (mostly downstream from the U.S. Highway 46 bridge), and (4) contours generated from lidar-derived land-surface elevation data (U.S. Geological Survey, 2016a) within 0.8 ft of the bathymetric-survey area. Additional control was needed in many areas where the preliminary “Topo to Raster” and “Contour” tool outputs were incorrectly interpolated. Guiding contours were manually digitized in those areas, and the tools were run again with the guiding contours as an additional input. In shallow areas not covered by bathymetric-survey data, the GIS tools were allowed to assume a steady gradient between the bathymetric-survey data and the nearest lidar-derived land-surface elevation data (outside the bathymetric-survey area). The bathymetric-survey DEM and contours in unsurveyed areas were mostly interpolated from the Oklahoma Water Resources Board (2009, 2016). A depth image at 10-ft resolution also was derived from the bathymetric-survey data using the “Topo To Raster” (ESRI, Inc., 2016a) tool; this depth image was used for maps presented in appendixes 2–4 of this report to aid in visualization of the bathymetric surface. Bathymetric-survey data, interpolated bathymetric-survey DEMs, and bathymetric-survey areas were published on 2017 (Smith and others, 2017) using the Oklahoma State Plane North coordinate system.

Quality Assurance

Accuracy of the bathymetric surface and derived contours is a function of the survey data accuracy, survey data density (transect interval and data-collection frequency), and the processing steps that occur during creation of the bathymetric surface and contours (Wilson and Richards, 2006). Survey data accuracy is also dependent on factors such as vessel draft, platform stability, vessel velocity, and the presence of snags or debris. According to the manufacturer’s specifications, the survey-grade echo sounder used in this study had a resolution of better than...
Table 2. Summary statistics and quality-assurance statistics for bathymetric survey data for the Neosho River, Spring River, and Elk River, northeastern Oklahoma and southwestern Missouri, 2016–17.

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</thead>
<tbody>
<tr>
<td>Neosho River</td>
<td>10–26–2016 to 12–14–2016</td>
<td>Oklahoma border</td>
<td>U.S. Highway 60</td>
<td>6,136</td>
<td>1.58</td>
<td>SBES</td>
<td>34.16</td>
<td>17.38</td>
<td>344,833</td>
<td>742.65</td>
<td>709.18</td>
<td>1.10</td>
<td>34.22</td>
<td>1.93</td>
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<td></td>
<td></td>
<td></td>
<td>Bridge near Twin</td>
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<td>ADCP</td>
<td>16.78</td>
<td>126,199</td>
<td>759.03</td>
<td>734.94</td>
<td>0.68</td>
<td>10.36</td>
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<td>Bridges State Park, Okla.</td>
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<td>SBES</td>
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<td>742.29</td>
<td>714.18</td>
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<td>ADCP</td>
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<td>730.34</td>
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<td>Elk River</td>
<td>02–27–2017 to 03–21–2017</td>
<td>Noel, Missouri</td>
<td>Oklahoma State</td>
<td>1,025</td>
<td>1.96</td>
<td>SBES</td>
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<td>434,081</td>
<td>742.30</td>
<td>715.62</td>
<td>1.10</td>
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<td></td>
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<td></td>
<td>Highway 10 bridge</td>
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<td>ADCP</td>
<td>14.90</td>
<td>176,452</td>
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<td>0.60</td>
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</tbody>
</table>

0.1 ft for depths less than 600 ft and an accuracy of ±0.1 percent (Odom Hydrographic Systems, Inc., 2008). A hand-held sound velocity meter (Odom Hydrographic Systems, Inc., 2001) was used to measure the speed of sound through the water column, and bar checks were performed daily to calibrate the SBES (U.S. Army Corps of Engineers, 2013) to two known depths (from 3 ft to 27 ft) in the water column. These depths were chosen to span the expected range of most water-depth measurements. Vessel speeds were kept at less than 5 feet per second to ensure adequate point spacing (U.S. Army Corps of Engineers, 2013).
Table 3. Reference mark locations and surveyed elevations, northeastern Oklahoma and southwestern Missouri, 2016–17.

<table>
<thead>
<tr>
<th>Reference mark name</th>
<th>Description</th>
<th>Latitude (decimal degrees)</th>
<th>Longitude (decimal degrees)</th>
<th>x coordinate, in feet (Oklahoma State Plane North coordinate system)</th>
<th>y coordinate, in feet (Oklahoma State Plane North coordinate system)</th>
<th>Elevation (z coordinate) (feet)</th>
<th>OPUS vertical uncertainty (National Geodetic Survey, 2016)</th>
<th>RTK GPS elevation (feet)</th>
<th>Difference between reference mark elevation and RTK GPS elevation (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM-M</td>
<td>Concrete anchor bolt at boat ramp near low-water dam in Miami, Oklahoma</td>
<td>36.863683</td>
<td>-94.880224</td>
<td>2881060.27</td>
<td>693105.46</td>
<td>755.059</td>
<td>± 0.033</td>
<td>754.731</td>
<td>755.147</td>
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<tr>
<td>RM-T</td>
<td>Concrete anchor bolt at boat ramp near U.S. Highway 60 bridge in Twin Bridges State Park, Oklahoma</td>
<td>36.798319</td>
<td>-94.754926</td>
<td>2918492.54</td>
<td>670521.60</td>
<td>748.553</td>
<td>± 0.023</td>
<td>748.430</td>
<td>748.634</td>
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<td>RM-C</td>
<td>Concrete anchor bolt at boat ramp near S 590 Road (Connors) bridge near Fairland, Oklahoma</td>
<td>36.799278</td>
<td>-94.818872</td>
<td>2899767.86</td>
<td>670251.11</td>
<td>752.316</td>
<td>± 0.105</td>
<td>751.999</td>
<td>752.611</td>
</tr>
<tr>
<td>RM-CK</td>
<td>Concrete anchor bolt at boat ramp in Chetopa, Kansas</td>
<td>37.035929</td>
<td>-95.080003</td>
<td>2820755.35</td>
<td>753976.19</td>
<td>787.480</td>
<td>± 0.013</td>
<td>787.360</td>
<td>787.445</td>
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<tr>
<td>RM-BS</td>
<td>Concrete anchor bolt at boat ramp in Baxter Springs, Kansas</td>
<td>37.020826</td>
<td>-94.721530</td>
<td>2925530.42</td>
<td>751819.46</td>
<td>790.732</td>
<td>± 0.049</td>
<td>790.491</td>
<td>790.598</td>
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<tr>
<td>RM-Q</td>
<td>Concrete anchor bolt at boat ramp near E 57 Road bridge near Quapaw, Oklahoma</td>
<td>36.934169</td>
<td>-94.744659</td>
<td>2919838.90</td>
<td>720005.25</td>
<td>773.373</td>
<td>± 0.059</td>
<td>773.171</td>
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<tr>
<td>RM-10</td>
<td>Concrete anchor bolt at left upstream sidewalk of Oklahoma State Highway 10 bridge near Miami, Oklahoma</td>
<td>36.871323</td>
<td>-94.764159</td>
<td>2914904.90</td>
<td>696997.05</td>
<td>796.060</td>
<td>± 0.026</td>
<td>795.943</td>
<td>795.975</td>
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<tr>
<td>RM-G</td>
<td>Concrete anchor bolt at boat ramp at Oklahoma State Highway 43 bridge near Grove, Oklahoma</td>
<td>36.652419</td>
<td>-94.707825</td>
<td>2934077.06</td>
<td>617897.06</td>
<td>754.295</td>
<td>± 0.069</td>
<td>753.954</td>
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<td>RM-43</td>
<td>Concrete anchor bolt at boat ramp at Missouri State Highway 43 bridge near Tiff City, Missouri</td>
<td>36.631191</td>
<td>-94.587569</td>
<td>2896604.91</td>
<td>611391.17</td>
<td>769.485</td>
<td>± 0.112</td>
<td>769.411</td>
<td>769.552</td>
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Average: ± 0.054
Bathymetric-Survey Results

Appendix 1 shows the extents of maps (presented in the other appendixes) showing the bathymetric survey results. The bathymetric surveys of the Neosho River (appendix 2), Spring River (appendix 3), and Elk River (appendix 4) covered a total distance of about 76 river miles and a total area of about 5 square miles. Greater than 1.4 million bathymetric-survey data points were used in the computation and interpolation of bathymetric-survey DEMs (at 4-ft resolutions for the Neosho River and Spring River and at a 2-ft resolution for the Elk River) and derived contours at 1-ft intervals (table 2). The minimum bathymetric-survey elevation of the Neosho River was 709.18 ft, which corresponds to a maximum water depth of 29.22 ft. The minimum bathymetric-survey elevation of the Elk River was 715.62 ft, which corresponds to a maximum water depth of 27.78 ft. Because of the spacing of the survey transects (100 ft), river-bottom features with a maximum dimension less than 100 ft generally could not be resolved by these bathymetric surveys.

An unusually deep pool (appendix 3–10) was found on the Spring River about halfway between the Oklahoma border and the E 57 county road bridge; the maximum depth of that pool was about 20 ft, or about 15 ft deeper than most pools in that reach. Large changes in bathymetric-survey depths (and elevations) occurred at the U.S. Highway 60 bridges on the Neosho River and Spring River near Twin Bridges State Park (appendix 2–1); bathymetric-survey depths were shallower on the upstream side of these bridges as compared to the downstream side. Similar changes in bathymetric-survey depths were observed at the Oklahoma State Highway 10 bridge on the Elk River (appendix 4–1). These changes could indicate accumulation of sediment on the upstream sides of the bridges, erosion (scour) of sediment or bedrock on the downstream sides of the bridges, or both. If similar bathymetric surveys are performed in the future, the bathymetric-survey data presented in this report could be used as a baseline for estimating rates of sediment accumulation and erosion over time.

Summary

In February 2017, the Grand River Dam Authority filed to relicense the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission. The predominant feature of the Pensacola Hydroelectric Project is Pensacola Dam, which impounds Grand Lake O’ the Cherokees (locally called Grand Lake) in northeastern Oklahoma. Identification of information gaps and assessment of project effects on stakeholders are central aspects of the Federal Energy Regulatory Commission relicensing process, and some upstream stakeholders have expressed concerns about the dynamics of sedimentation and flood flows in the transition zone between major rivers and Grand Lake O’ the Cherokees. To relicense the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission, the hydraulic models for these rivers require high-resolution bathymetric data along the river channels. In support of the Federal Energy Regulatory Commission relicensing process, the U.S. Geological Survey, in cooperation with the Grand River Dam Authority, performed bathymetric surveys of (1) the Neosho River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, (2) the Spring River from the Oklahoma border to the U.S. Highway 60 bridge at Twin Bridges State Park, and (3) the Elk River from Noel, Missouri, to the Oklahoma State Highway 10 bridge near Grove, Oklahoma. The Neosho River and Spring River bathymetric surveys were performed from October 26 to December 14, 2016; the Elk River bathymetric survey was performed from February 27 to March 21, 2017. Only areas inundated during those periods were surveyed.

The bathymetric surveys covered a total distance of about 76 river miles and a total area of about 5 square miles. Greater than 1.4 million bathymetric-survey data points were used in the computation and interpolation of bathymetric-survey digital elevation models and derived contours at 1-foot (ft) intervals. The minimum bathymetric-survey elevation of the Neosho River was 709.18 ft, which corresponds to a maximum depth of 34.22 ft. The minimum bathymetric-survey elevation of the Spring River was 714.18 ft, which corresponds to a maximum depth of 29.22 ft. The minimum bathymetric-survey elevation of the Elk River was 715.62 ft, which corresponds to a maximum depth of 27.78 ft. An unusually deep pool was found on the Spring River about halfway between the Oklahoma border and the E 57 county road bridge; the maximum depth of that pool was about 20 ft, or about 15 ft deeper than most pools in that reach. Large changes in bathymetric-survey depths (and elevations) occurred at the U.S. Highway 60 bridges on the Neosho River and Spring River near Twin Bridges State Park; bathymetric-survey depths were shallower on the upstream side of these bridges as compared to the downstream side. Similar changes in bathymetric-survey depths were observed at the Oklahoma State Highway 10 bridge on the Elk River. These changes could indicate accumulation of sediment on the upstream sides of the bridges, erosion (scour) of sediment or bedrock on the downstream sides of the bridges, or both. If similar bathymetric surveys are performed in the future, the bathymetric-survey data presented in this report could be used as a baseline for estimating rates of sediment accumulation and erosion over time.

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References Cited


Appendix 1. Maps showing extents for maps in appendixes 2–4 that show bathymetric surveys of the Neosho River, Spring River, and Elk River, northeastern Oklahoma and southwestern Missouri, 2016–17.
Appendix 1–2.
Appendix 2. Maps showing bathymetric survey of the Neosho River, northeastern Oklahoma, 2016
Appendix 2–8.
Appendix 2–9.
Appendix 2–13.
28 Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

EXPLANATION

Area not surveyed
Approximate river centerline
Bathymetric survey transects
Bathymetric survey boundary

Bathymetric survey
contours, 1-ft interval,
with elevation in feet above NAVD 88

Terrestrial lidar contours,
5-ft interval, with elevation
in feet above NAVD 88

Intermediate
Index (10-ft interval)
Reference mark (RM)

Appendix 2-15.
Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

Base from U.S. Geological Survey digital data, 2016
Oklahoma State Plane North projection
North American Vertical Datum of 1988 (NAVD 88)
Topographic contours derived from lidar (U.S. Geological Survey, 2016a)
Microsoft product screen shot(s) reprinted with permission from Microsoft Corporation (2017)
Topographic contours not available in all areas

EXPLANATION

Data and maps are not intended for navigational use
Area not surveyed
Approximate river centerline
Bathymetric survey transects
Bathymetric survey boundary
Intermediate
Reference mark (RM)
Terrestrial lidar contours, 5-ft interval, with elevation in feet above NAVD 88
Terrestriallidarcontours, 5-ft interval, with elevation in feet above NAVD 88
Appendix 2–19.
Appendix 3. Maps showing bathymetric survey of the Spring River, northeastern Oklahoma, 2016
34 Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

Appendix 3–1.
Base from U.S. Geological Survey digital data, 2016
Oklahoma State Plane North projection
North American Vertical Datum of 1988 (NAVD 88)
Topographic contours derived from lidar (U.S. Geological Survey, 2016a)
Microsoft product screen shot(s) reprinted with permission from Microsoft Corporation (2017)
Topographic contours not available in all areas

Appendix 3–3.
40 Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016–17

Appendix 3–7.
Oklahoma State Plane North projection
North American Vertical Datum of 1988 (NAVD 88)
Topographic contours derived from base U.S. Geological Survey, 2016a
Microsoft product screen shot(s) reprinted with permission from Microsoft Corporation (2017)
Topographic contours not available in all areas

EXPLANATION
Area not surveyed
Approximate river centerline
Bathymetric survey transects
Bathymetric survey boundary

Bathymetric survey depth, in feet (ft)

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

Terrestrial lidar contours, 5-ft interval, with elevation in feet above NAVD 88

Reference mark (RM) and water-surface elevation (WSE) elevations (Smith and others, 2017)
Appendix 4. Maps showing bathymetric survey of the Elk River, northeastern Oklahoma and southwestern Missouri, 2017
Appendix 4–8.
Appendix 4–11.