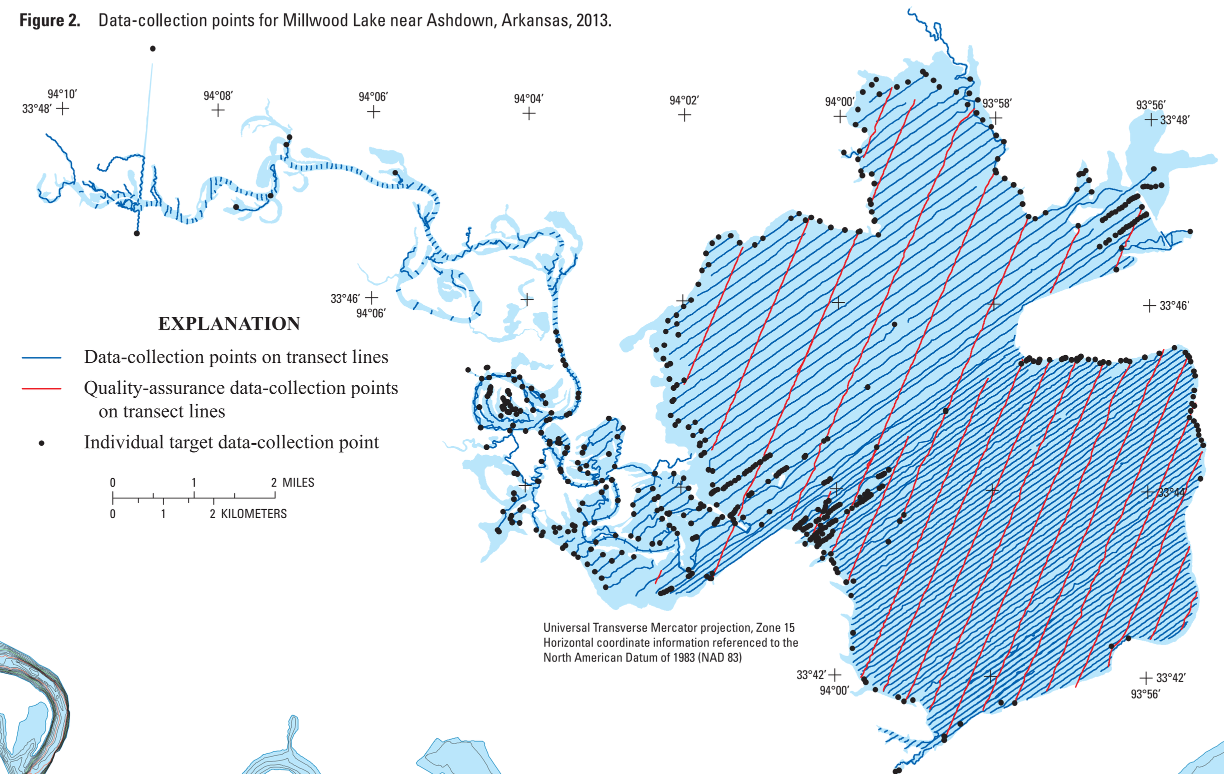
Figure 2. Data-collection points for Millwood Lake near Ashdown, Arkansas, 2013.



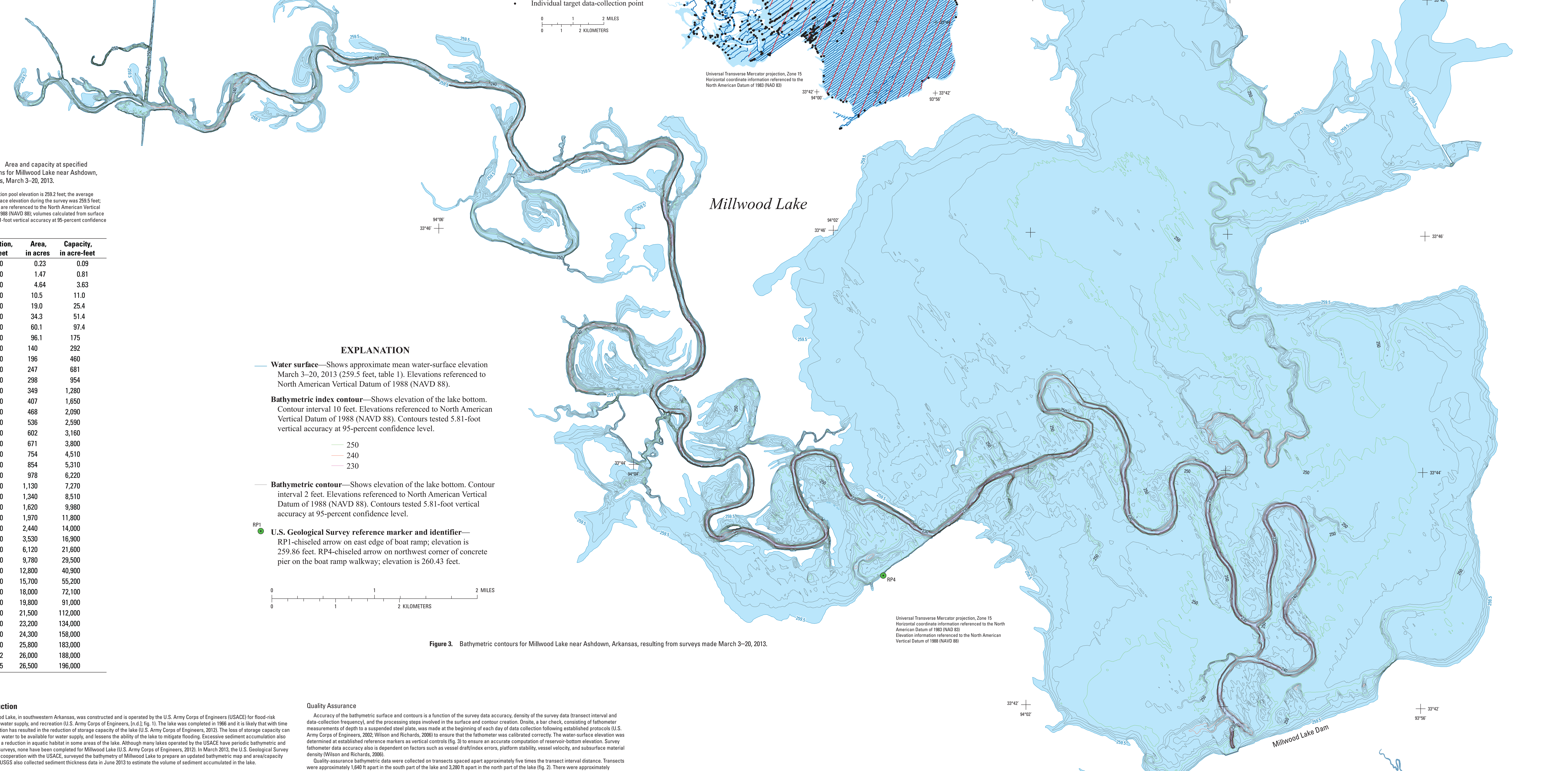


Figure 3. Bathymetric contours for Millwood Lake near Ashdown, Arkansas, resulting from surveys made March 3–20, 2013.

Table 1. Area and capacity at specified elevations for Millwood Lake near Ashdown, Arkansas, March 3–20, 2013.

[Conservation pool elevation is 259.2 feet; the average water-surface elevation during the survey was 259.5 feet; elevations are referenced to the North American Vertical Datum of 1988 (NAVD 88); volumes calculated from surface testing 2.21-foot vertical accuracy at 95-percent confidence level]

Elevation, in feet	Area, in acres	Capacity, in acre-feet
223.0	0.23	0.09
224.0	1.47	0.81
225.0	4.64	3.63
226.0	10.5	11.0
227.0	19.0	25.4
228.0	34.3	51.4
229.0	60.1	97.4
230.0	96.1	175
231.0	140	292
232.0	196	460
233.0	247	681
234.0	298	954
235.0	349	1,280
236.0	407	1,650
237.0	468	2,090
238.0	536	2,590
239.0	602	3,160
240.0	671	3,800
241.0	754	4,510
242.0	854	5,310
243.0	978	6,220
244.0	1,130	7,270
245.0	1,340	8,510
246.0	1,620	9,980
247.0	1,970	11,800
248.0	2,440	14,000
249.0	3,530	16,900
250.0	6,120	21,600
251.0	9,780	29,500
252.0	12,800	40,900
253.0	15,700	55,200
254.0	18,000	72,100
255.0	19,800	91,000
256.0	21,500	112,000
257.0	23,200	134,000
258.0	24,300	158,000
259.0	25,800	183,000
259.2	26,000	188,000
259.5	26,500	196,000

Introduction

Millwood Lake, in southwestern Arkansas, was constructed and is operated by the U.S. Army Corps of Engineers (USACE) for flood-risk reduction, water supply, and recreation (U.S. Army Corps of Engineers, [n.d.]; fig. 1). The lake was completed in 1966 and it is likely that with time sedimentation has resulted in the reduction of storage capacity of the lake (U.S. Army Corps of Engineers, 2012). The loss of storage capacity can cause less water to be available for water supply, and lessens the ability of the lake to mitigate flooding. Excessive sediment accumulation also can cause a reduction in aquatic habitat in some areas of the lake. Although many lakes operated by the USACE have periodic bathymetric and sediment surveys, none have been completed for Millwood Lake (U.S. Army Corps of Engineers, 2012). In March 2013, the U.S. Geological Survey (USGS), in cooperation with the USACE, surveyed the bathymetry of Millwood Lake to prepare an updated bathymetric map and area/capacity table. The USGS also collected sediment thickness data in June 2013 to estimate the volume of sediment accumulated in the lake.

Study Area

Millwood Lake is located on the Little River about 7 miles northeast of Ashdown, in southwestern Arkansas (fig. 1). The Millwood Lake Dam was constructed approximately 5 river miles downstream from the confluence of the Little River that flows into the lake from the west and the Saline River that flows into the lake from the north (fig. 1) and approximately 16 miles upstream from the confluence of the Little River and the Red River (not shown on map). The basin area upstream from the dam is approximately 4,144 square miles and consists of approximately 68 percent forest, 14 percent pasture, 9 percent herbaceous cover, and 9 percent is a combination of urban land use, water, and cropland (Arkansas Natural Resources Commission, [n.d.]). The surficial geology of the basin consists of the dominantly clastic sedimentary rock of the Tokio Formation, Woodbine Formation, and the Trinity Group overlain by alluvium and terrace deposits near the lake, and Stanley Shale in the northern part of the basin (Haley, 1993).

Using techniques and technology available at the time of construction in 1966, it was estimated that the Millwood Lake Dam flooded approximately 29,000 acres at the conservation pool elevation of 259.2 feet (ft) relative to the National Geodetic Vertical Datum of 1929 (NGVD 29). The capacity was computed at the time to be 172,000 acre-feet (acre-ft) at the conservation pool elevation (U.S. Army Corps of Engineers, 2013). The lake had approximately 20,000 acres of timber (about 70 percent of the lake area) when impounded in 1966. Much of the timber has broken off at the conservation pool elevation, leaving many stumps and break-offs scattered throughout the lake. There are narrow boat lanes that are free from timber, allowing navigation through the timbered areas of the lake, and the area near the dam largely is free from submerged timber.

Methods

A bathymetric survey was conducted during March 2013 and was followed up with a sediment thickness probing survey in June 2013 at Millwood Lake. The general method of bathymetric data collection was using fathometer measurements of water depth, and the general method of sediment data collection was direct measurement of sediment thickness at dispersed points throughout the lake.

Bathymetry

Bathymetric data (water depths and positions) were collected from March 3 to March 20, 2013 (fig. 2), using methods described in Wilson and Richards (2006). Position data were collected using a boat-mounted differential global positioning system (DGPS). Water depths were collected using a survey-grade 200-kilohertz single-beam fathometer emitting sound pulses that were reflected off the lake bottom and received by a transducer. In some areas of the lake, water depths were measured manually (target data-collection points; fig. 2) using a rod graduated in tenths of a foot, because the water depth was below the minimum operating depth of the fathometer, which is approximately 2.5 ft. Water-surface edge points were collected using the DGPS coordinate data with zero depth.

Reference water-surface elevations were measured from at least one of two reference points (RP1 and RP4 on fig. 3) at least twice daily, and a mean water-surface elevation for the day was computed from these measurements. The reference points were established with a survey-grade Global Navigation Satellite Systems (GNSS) using methods documented in Rydlund and Densmore (2012) and Wilson and Richards (2006). Horizontal and vertical coordinates of the reference points were established using real-time and static GNSS methods that were localized to confident geodetic control. The water-surface elevation ranged from 259.37 ft to 259.66 ft during the survey period, and the computed mean water-surface elevation of the lake was 259.50 ft during the survey period. The reference points were not used to establish or verify horizontal position of the bathymetric survey points.

The bathymetric survey was designed to collect data along transects roughly oriented northwest to southeast and at an interval that would provide sufficient data to produce a bathymetric surface (fig. 2). Water-depth data were collected with the fathometer along the transect lines spaced approximately 328 ft apart in the southeast part of the main body of the lake, and approximately 656 ft apart in the northwest part of the main body of the lake (fig. 2). Transect lines were spaced approximately 328 ft apart (fig. 2) in the Little River arm of the lake (fig. 1). The transects were farther apart in the north part of the lake because it was shallower, had less bathymetric relief, and had more near-surface obstructions to navigation. Approximately 3,340,000 data points along the approximately 490 miles of surveyed transect lines were collected in the survey. The mean spacing of data points along a transect line was 1.3 ft. The position data for the fathometer data were used as collected from the DGPS with a stated positional accuracy of less than 3.28 ft (Trimble Navigation Limited, 1999). The vertical datum for the survey was the North American Vertical Datum of 1988 (NAVD 88) and the horizontal datum was the North American Datum of 1983 (NAD 83).

Water-depth data were converted to lake-bottom elevations by subtracting the depth at each location from the reference water-surface elevation of the lake for the day the point was collected. Geographic information system (GIS) software was used to resample the bathymetric data points so that the points would be no closer than approximately 2 ft apart. The data reduction retained approximately 788,000 data points. These bathymetric data points were used to produce a three-dimensional surface of the lake-bottom elevations using the techniques described in Wilson and Richards (2006). The boundary of the lake at the time of the survey was estimated from aerial imagery (Google Earth, site accessed May 2013), surveyed edge point data, and USGS digital elevation data (*http://ned.usgs.gov/*). An area and capacity table was produced from the three-dimensional surface (table 1) showing surface area and capacity at specified elevations. The surface was contoured at a 2-ft interval using GIS software and the contours were cartographically edited to create a bathymetric map using the techniques of Wilson and Richards (2006; fig. 3).

Sediment Thickness Measurement

Before being impounded, the Little River was a sinuous, low-gradient river with a deep, well defined channel and numerous oxbow lakes and marshes adjacent to the main channel as shown on 1949 aerial photography (data on file at U.S. Geological Survey, Rolla, Missouri). Because the area was a riverine environment before being impounded, sediment potentially accumulated in the channel and, in times of high flow, on overbank areas. Determination of the depth of sediment that is only the result of deposition after the lake was created is very difficult and cannot be determined using the methods described in this report. Nevertheless, all sediment thicknesses measured during this study were assumed to be the result of sediment deposition in the lake.

To determine sediment thickness accumulated during the past 47 years in the lake since 1966, physical measurements were made spatially at 132 locations throughout the lake using the sediment probe refusal method (Juracek, 2006; fig. 4). Water depth greater than about 25 ft prevented measurement of sediment thickness in some areas of the lake. In most cases, the point of refusal was marked by a red clay layer evident on the sediment probe. A spatially representative sample of measurements was made on a 2,640-ft grid (fig. 4) in the north part of the main body of the lake. Measurements were made on a 5,280-ft grid in the south part of the main body of the lake (fig. 4). It was assumed that the sediment thickness would be less in the south part of the main body of the lake because it was farthest from the sediment source areas. Thus, grid spacing was larger in that area. In the Little River arm of the lake (figs. 1, 4), several measurements were made where possible to provide an estimate of the sediment thickness for that part of the lake.

The sediment probe refusal method used a probe consisting of a length of ¾-inch threaded steel rod that was pushed by hand from a boat into the sediment to the point of refusal. The probe was removed and the depth of sediment penetration was measured from the sediment accumulated on the threaded rod. The process usually was repeated two additional times within approximately 15 feet of the initial measurement at most of the measurement sites to determine the magnitude of the variation in the measurements. The mean of all the measurements taken at each site was used as the sediment thickness value, and is shown on figure 4.

Based on the variance in sediment thickness, sediment-thickness data were grouped spatially and sediment-deposition zones were delineated in the lake (fig. 4). Inside each zone, the mean of the physically measured sediment-thickness values was used with the surface area of the region to determine an estimate of sediment volume for that zone.

Quality Assurance

Accuracy of the bathymetric surface and contours is a function of the survey data accuracy, density of the survey data (transect interval and data-collection frequency), and the processing steps involved in the surface and contour creation. Onsite, a bar check, consisting of fathometer measurements of depth to a suspended steel plate, was made at the beginning of each day of data collection following established protocols (U.S. Army Corps of Engineers, 2002; Wilson and Richards, 2006) to ensure that the fathometer was calibrated correctly. The water-surface elevation was determined at established reference markers as vertical controls (fig. 3) to ensure an accurate computation of reservoir-bottom elevation. Survey fathometer data accuracy also is dependent on factors such as vessel draft/index errors, platform stability, vessel velocity, and subsurface material density (Wilson and Richards, 2006).

Quality-assurance bathymetric data were collected on transects spaced apart approximately five times the transect interval distance. Transects were approximately 1,640 ft apart in the south part of the lake and 3,280 ft apart in the north part of the lake (fig. 2). There were approximately 454,000 data points collected along the 78 miles of quality-assurance transect lines. The quality-assurance bathymetric data were resampled to approximately 164,000 data points using the same GIS techniques that were used on the bathymetric survey data. The three-dimensional bathymetric surface was tested against the quality-assurance dataset to determine the accuracy of the surface using methods described in Wilson and Richards (2006). The surface tested 2.21 ft vertical accuracy at the 95-percent confidence level. The contours (fig. 3) also were tested with the quality-assurance dataset and a point was considered a contour elevation evaluation point if it was located within 3.28 ft of a given contour line. Of the approximately 164,000 quality-assurance points collected, 5,283 points were considered an evaluation point for the contour lines, and the contour vertical accuracy was computed to be 5.81 ft at the 95-percent confidence level.

A total of 359 sediment thickness measurements were made for this study at 132 locations. Measurements were repeated multiple times (usually three at any given location) to determine the variation in the measurement method. The standard deviation of the differences between the measured values and the mean of the measured values at each location was 0.67 ft.

Core samples (fig. 4) were collected periodically using a 60-inch Ogeechee corer with acrylic liner as a quality-assurance measure of overall sediment thickness sampling to support physical measurement of thickness using the refusal method. The core sampler was pushed into the bed sediments by hand using vertical extensions screwed onto the head of the Ogeechee corer. When the corer could not be pushed any deeper, the sampler was removed from the lake sediment and the acrylic liner was removed from the core tube. The liner was then capped on the bottom, sawed off a couple inches above the top of the core, drained, and capped at the top. Sediment height inside the core liner was recorded. Core samples were collected at 10 sites and core sample lengths compared favorably with the sediment thickness data of the refusal method measurement points (fig. 4). The process of coring the sediment caused the sediment to compact in the core barrel, so the core length was always less than the sediment thickness measured with the probe refusal method. The mean difference between the sediment probe thickness and the sediment core length for the 10 sites was 1.6 ft.

Bathymetry, Capacity, and Sediment Volume Estimate

In an effort to verify the original Millwood Lake capacity reported by the USACE, the pre-inundation topographic data from 1:24,000 scale USGS quadrangle maps of the area (data on file at U.S. Geological Survey, Rolla, Missouri) were digitized and a legacy bathymetric surface was created. The same methods of volume computation used for the current (2013) survey data were used on this legacy surface to compute an estimated original lake capacity of approximately 200,000 acre-ft at the conservation pool elevation of 259.2 ft. The methods that were used to determine the original bathymetry and capacity of the lake are unknown, but the capacity of 172,000 acre-ft computed by the USACE in 1966 does compare favorably, within 14 percent, to the capacity obtained using data from the pre-inundation topographic data.

A bathymetric surface was created from the current (2013) surveyed data (fig. 2) and an area/capacity table was computed from the surface (table 1). At the conservation pool elevation of 259.2 ft, the surface area of the lake is approximately 26,000 acres and the capacity is approximately 188,000 acre-ft (table 1). The lake bathymetric contours show that the Little River channel is still present and is still well defined (fig. 3). Many of the tributary stream channels are evident in the lake bathymetric map as well. In the north part of the lake, the bathymetric surface appears to be gently sloping to the south. The topographic expression of many of the small tributary channels that were mapped on the 1:24,000 scale topographic maps (data on file at the U.S. Geological Survey, Rolla, Missouri) has been muted. It is suspected that sediment deposition has partially or completely filled in some of the defined channels that were present on the 1:24,000 scale topographic maps, resulting in a less detailed (muted) topographic surface in the north part of the lake (fig. 3).

For the sediment volume estimate, the lake was divided into five zones of similar sediment thickness (fig. 4). Zone 1 (northwest part of the main lake body) had a mean thickness of 2.3 ft, zone 2 (northeast part of the main lake body) had a mean thickness of 3.0 ft, zone 3 (the west, south, and east part of the main lake body) had a mean thickness of 2.2 ft. Zone 4 (center of main lake body; mean thickness 5.7 ft) and zone 5 (west part of the lake; mean thickness 4.9 feet) had the greatest sediment thickness. Mean sediment thickness was the greatest in zone 4 possibly because of resuspension of sediment from other shallower parts of the lake and subsequent deposition in the deeper and probably calmer water in the center of the lake. In zone 5, sediment thickness also was greater than the thickness in some of the other parts of the lake and the increased thickness likely is because of its proximity to the inflow of the Little River, the primary source of sediment to the lake. It should be noted that the measured values were assumed to be the result of sediment deposition after the lake was impounded. It is possible that many, if not most, of the sediment measurements include some unknown measure of pre-impoundment sediment.

Sediment volume for each zone was computed by multiplying the mean sediment thickness by the area of the zone at the conservation pool elevation of 259.2 ft. The total sediment volume of the lake was computed by summing the volume in each zone, and was approximately 87,000 acre-ft. The mean sediment thickness, computed by dividing the total sediment volume by the surface area of the lake at the conservation pool elevation, was approximately 3.3 ft. On average, approximately 1,850 acre-ft or 0.07 vertical ft of sediment was deposited in the lake per year.

Although the exact original volume of the lake is unknown, it probably ranges between about 200,000 acre-ft (obtained from the pre-inundation legacy bathymetric surface) and 275,000 acre-ft (the total of the lake capacity at the conservation pool elevation and sediment volume for this survey). Given the estimated volume of sediment in the lake, the loss of capacity in Millwood Lake during the last 47 years ranges between about 32 and 44 percent, which is about 0.7 to 0.9 percent per year. Because of the possibility of pre-inundation sediment in the sediment thickness measurements, the volume and capacity loss estimates given here should be considered an upper limit for the lake.

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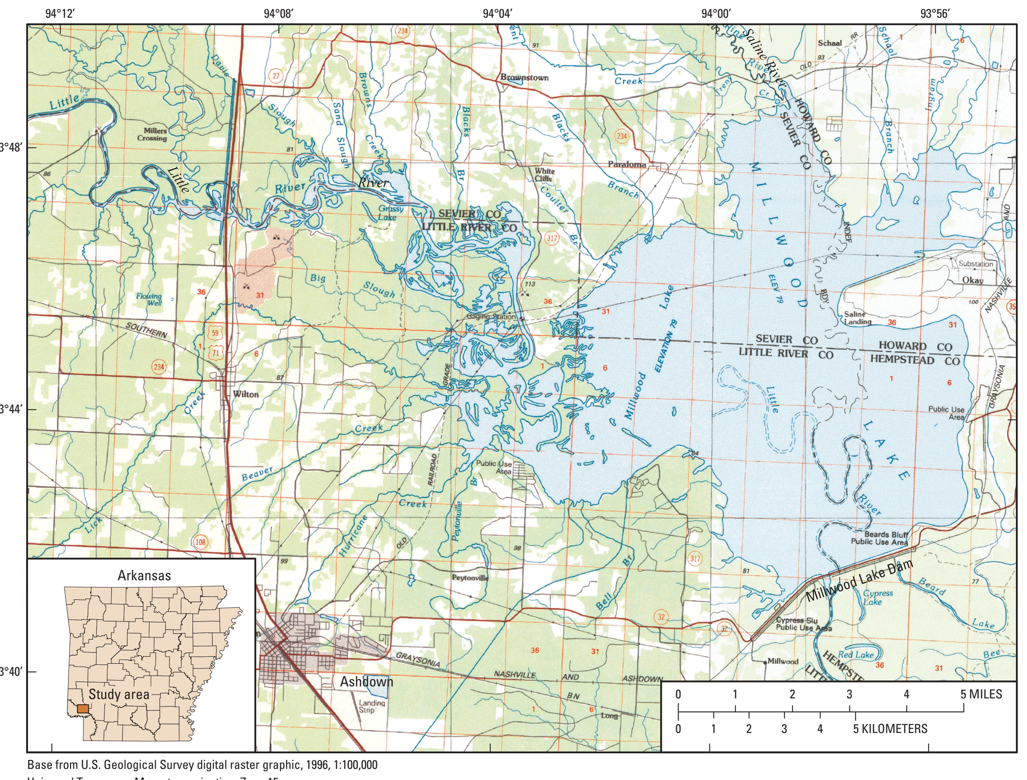

Base from U.S. Geological Survey digital raster graphic, 1996, 1:100,000
Universal Transverse Mercator projection, Zone 15

Figure 1. Location of Millwood Lake near Ashdown, Arkansas.

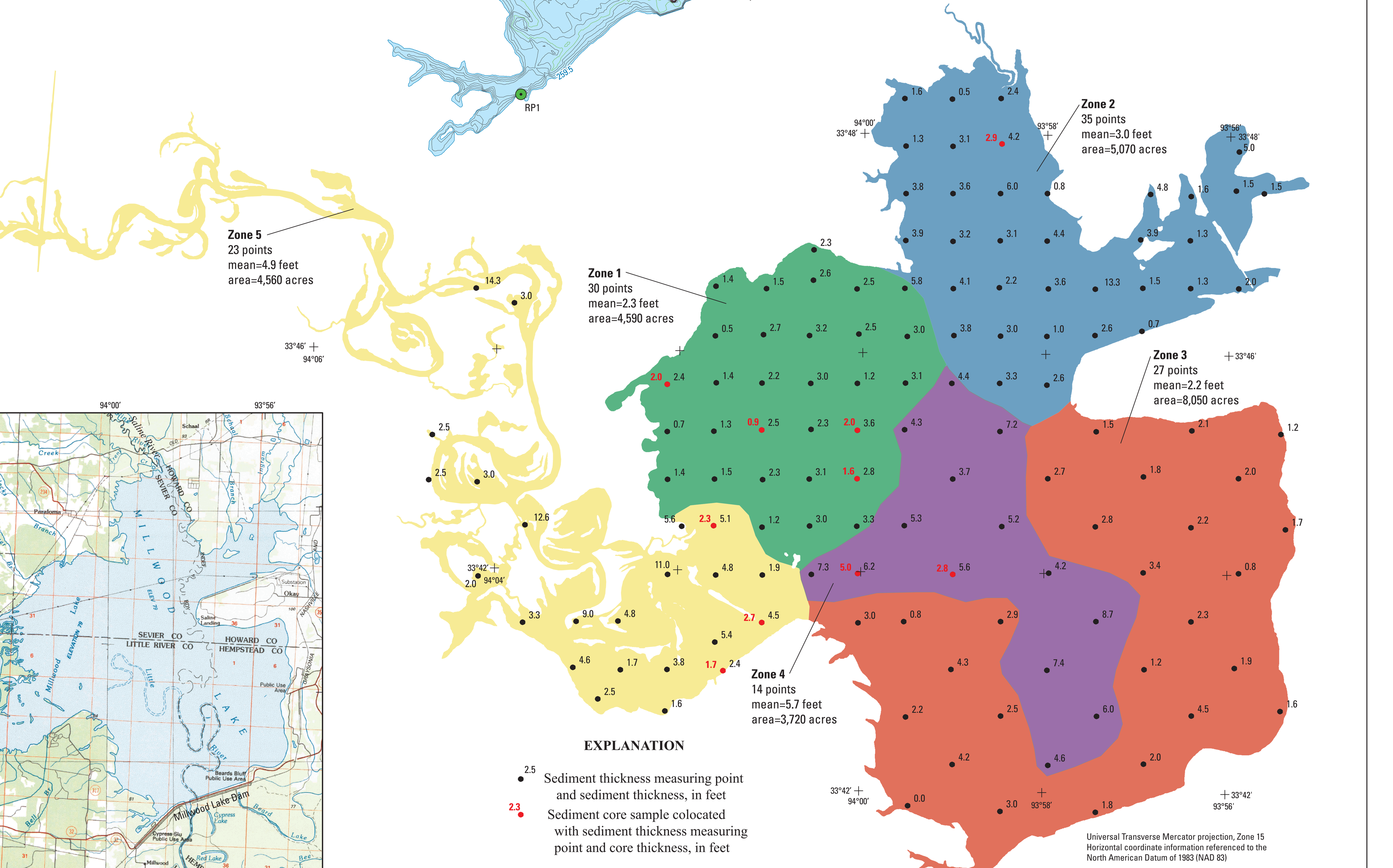

Figure 4. Sediment thickness zones and measurement locations in Millwood Lake near Ashdown, Arkansas, March 2013.

Bathymetric Map, Area/Capacity Table, and Sediment Volume Estimate for Millwood Lake near Ashdown, Arkansas, 2013

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2013

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