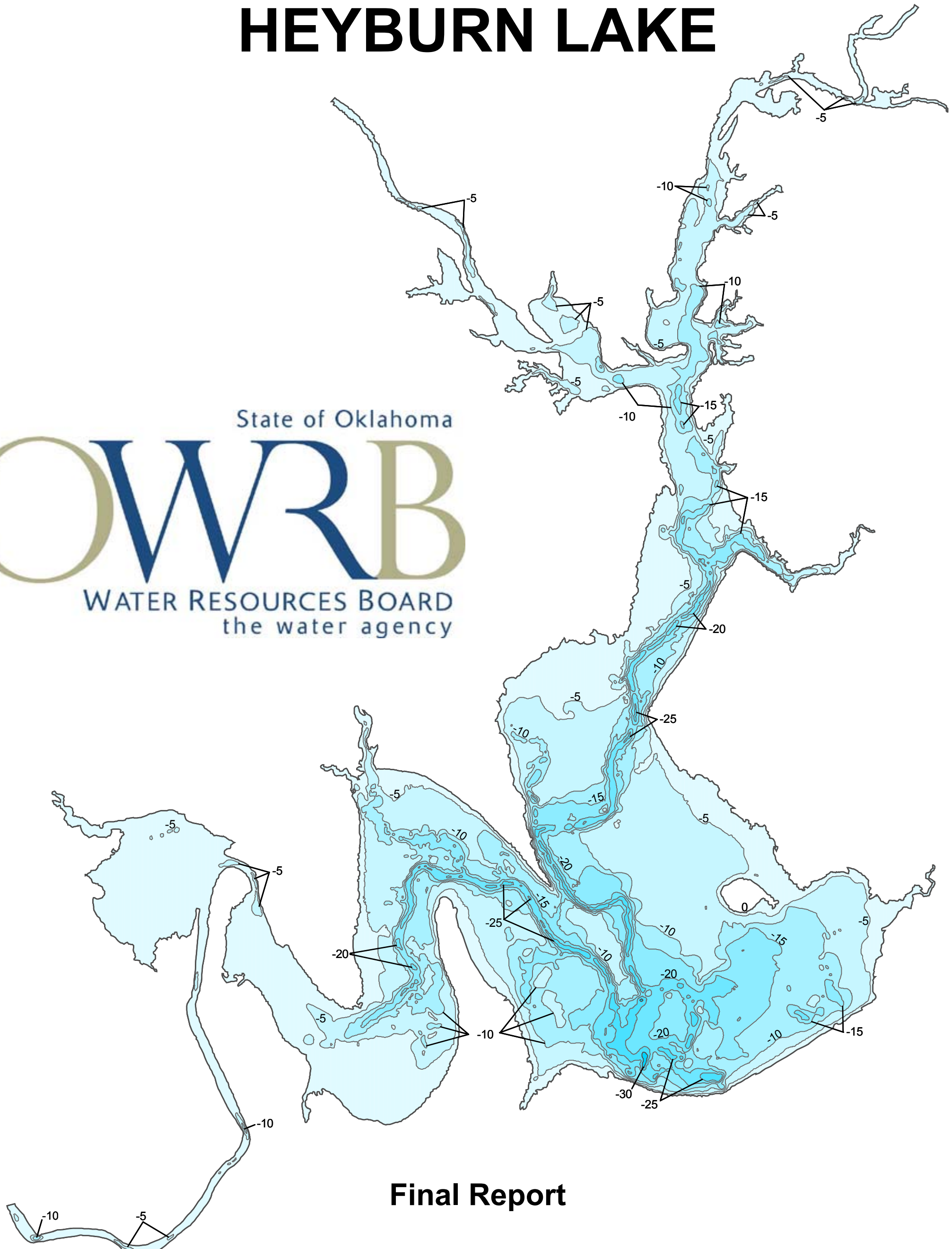
HYDROGRAPHIC SURVEY OF HEYBURN LAKE



State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

Final Report

Prepared for:
U.S. Army Corps of Engineers, Tulsa District

Prepared by:
Oklahoma Water Resources Board

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HEYBURN LAKE HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Heyburn Lake in May and June of 2004. The purpose of the study was to collect hydrographic data of Heyburn Lake and convert this information into an area-elevation-volume table at the conservation pool elevation. The information produced will serve as a base to establish the location and rate of sedimentation in the conservation pool for future surveys. The United States Army Corps of Engineers (USACE) reservoir elevation gauge at Heyburn Dam is reported in National Geodetic Vertical Datum 29 (NGVD 29). All vertical elevations referenced are reported as NGVD 29.

Heyburn Lake is located on Polecat Creek, a tributary of the Arkansas River in Creek County, approximately eleven miles southwest of Sapulpa, Oklahoma. A general location map of Heyburn Lake is shown on the following page as **Figure 1**. The facility is multi-purpose with the major uses of flood control, water supply, fish and wildlife management and recreation. The U.S. Government owns the dam and appurtenant structures and the operation of the facility is the responsibility of the USACE, Tulsa District.

LAKE HISTORY AND PERTINENT INFORMATION

Background

Heyburn Lake was authorized for construction by the Flood Control Act approved July 24, 1946: Public Law No. 526, 79th Congress 2nd Session, H.R. 6597. Dam, spillway, and outlet works construction were started in March of 1948 and completed in October 1950. Embankment closure was started in March 1950 and completed in June 1950. Impoundment in the conservation pool began in September 1950 and ended in March 1951 (USACE, 1947).

Tributaries of Heyburn Lake include Tiger Creek, Turkey Creek, Browns Creek, Mosquito Creek, and Polecat Creek. Polecat Creek, the major tributary to Heyburn Lake, flows in a winding valley with alternating wide and narrow reaches. The channel of the stream is crooked, narrow and traverses the valley floor from side to side. Heyburn Lake is located in the Osage Plains of the Central Oklahoma/Texas Plains ecoregion, which features semi-rugged, wooded hilly upland areas and gently sloping grasslands in the valley.

Approximately 70 percent of the rural lands above Heyburn Lake are devoted to agricultural purposes with the majority being used for grazing. There is a minimal amount of oil and gas production above Heyburn dam. The Oklahoma Department of

Wildlife and Conservation (ODWC) has license to 5,265 acres (ac) of USACE land surrounding Heyburn Lake and manages it for wildlife. A 3,500-ac waterfowl refuge with marshes has also been developed to enhance the area for waterfowl.

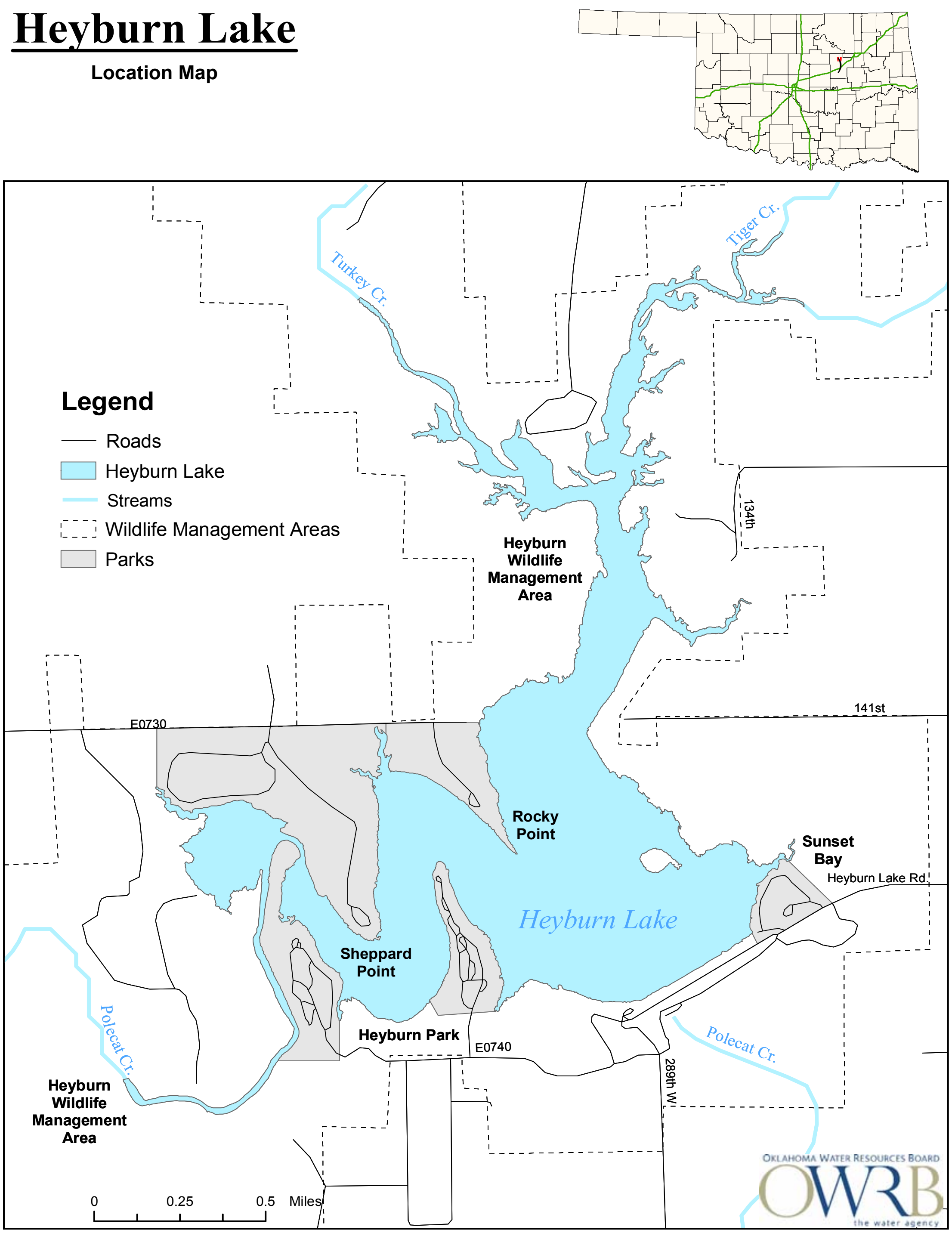

Figure 1: Location map for Heyburn Lake.

Water Rights

The OWRB currently adjudicates the water rights for Heyburn Lake, assigning an available water supply yield of 1,904 acre-feet/year (ac-ft/yr) (USACE, 1993). Currently, the Creek County Rural Water District (RWD) No. 1 has contracted with the USACE for use of the water stored in the conservation pool between elevations 755.4-761.5 ft. The Creek County RWD No. 1 not only supplies water to their 2,187 customers, but also to Creek County RWD No. 2 and Consolidated RWD No. 3. The Creek County RWD No. 1 holds two water rights issued by the OWRB. The first water right, #1963-383 was issued on 6/9/1964 for 300 ac-ft/yr. The second, #1964-789, was issued on 11/10/1964 originally issued for 1,900 ac-ft/yr but was reduced in 1987 to 1,785 ac-ft/yr.

The Town of Kiefer was issued water right #1955-567 based on reported beneficial use beginning in 1950. The water right authorized the use of 39 ac-ft/yr of water from Polecat Creek. The Town of Kiefer held a contract with the USACE, Tulsa District for 1000 ac-ft of storage from the lake until February of 1970. At that time, the USACE Tulsa District stated that the contract for storage had expired since the Town of Kiefer had not paid their storage payment for several years. The town had previously asked the USACE for storage releases from the lake and picked up the water downstream on Polecat Creek. The Town of Kiefer no longer pumps water from Polecat Creek, but now purchases all of their water from Creek County Rural Water District No. 2.

The Sapulpa Rural Water Company applied for a water right from the Lake in 1984. Application #1984-018 was for 15,000 ac-ft but was never issued because there was no water available from water supply storage at the time the application was filed. The application was voluntarily withdrawn on 10/28/2002. In 1968, the City of Bristow was issued a permit (#1968-298) for 1,500 ac-ft/yr from the lake. The permit has been inactivated.

Outlet Works

Heyburn dam is a rolled earthfill structure. **Table 1** on the following page lists some of the relevant details of the dam and outlet works. The earthen embankment has an impervious core with rock-protected upstream slopes and native grass downstream slopes for erosion control. The embankment has a crest length of 2,920 ft and a crest width of 20 ft. The top of the dam is at elevation 807.0 ft, resulting in a maximum height above streambed of about 89 ft and an average height above the valley floor of about 67 ft.

The earthen emergency spillway is an uncontrolled chute type located in a saddle approximately 1000 ft west of the right abutment of the dam. The structure has a crest elevation of 784.0 ft and a bottom width of 200 ft.

Table 1: Heyburn Dam and Heyburn Pertinent Data.

Owner of Heyburn Dam and Facilities
United State of America

Operator of Heyburn Dam and Facilities
U.S. Army Corps of Engineers, Tulsa District

Engineer
U.S. Army Corps of Engineers (Design)

Location
On Polecat Creek, a tributary of the Arkansas River in Creek County, approximately eleven miles southwest of Sapulpa, Oklahoma.

Drainage Area
127 square miles (Above Heyburn dam site)

Dam

Type	Earthfill
Length	2,920 ft
Elevation	807.0 ft
Maximum Height	89.0 ft

Spillway

Type	Earthen
Length	200 ft
Crest Elevation	784.0 ft
Control	uncontrolled chute

Outlet Works

Type	morning glory drop inlet
Inlet invert elevation	761.5 ft
Size	8-ft 3-in diameter
Control	uncontrolled
Type	3 Low flow outlets
Entrance invert elevation	740.0 ft
Size	three- 36-in diameter
Control	Gated, manually operated pivot (butterfly) valves
Type	1 Water supply outlet
Entrance invert elevation	741.5 ft
Size	24-in diameter
Control	Gated, double disk, outside stem and yoke type

The primary spillway consists of an eight-foot three-inch diameter uncontrolled modified morning glory drop inlet and stilling basin located at the right abutment of the dam. The crest elevation of the drop inlets is at 761.5 ft. The purpose of the concrete morning glory structure includes maintaining the conservation pool elevation and floodwater release. Also included are three manually controlled 36-inch diameter low-flow pipes at elevation 740.0 ft that discharge directly into the flood control conduit and function for low flow releases, emergency drawdowns, and downstream water supply. A 24-inch diameter water supply pipe is located at elevation 741.5 ft.

Lake Design Specifications

The original design for Heyburn Lake at conservation and sedimentation reserve pool 761.5 ft indicated a surface area of 1,070 ac and a capacity of 10,200 ac-ft of water with a drainage area of 127 square miles (USACE, 1950). The top of the flood control pool at elevation 784.0 ft indicated a surface area of 3,700 acres and a total storage of 59,700 ac-ft of water (USACE, 1950).

Based on the 1978 sedimentation survey, Heyburn Lake had an area of 880 ac and a capacity of 7,105 ac-ft of water at 761.5 ft conservation pool elevation. Conservation storage, between elevations 755.4-761.5 ft indicated a capacity of 4,140 ac-ft, which includes 2,000 ac-ft for water supply and 1,800 ac-ft for sediment reserve. The top of the inactive pool at elevation 755.4 ft had an area of 520 ac and a capacity of 2,965 ac-ft of water. The top of the flood pool at elevation 784.0 ft indicated a surface area of 3,740 ac and a capacity of 55,395 ac-ft of water (USACE, 1996).

HYDROGRAPHIC SURVEYING PROCEDURES

Surveying Technology

The Hydro-survey vessel was an 18-ft aluminum Silverstreak hull with cabin, powered by a single 115-Horsepower Mercury outboard motor. Equipment used to conduct the survey included: a ruggedized notebook computer; Ocean Data Equipment Corporation (ODEC) Bathy 1500 Echo Sounder; Trimble Navigation, Inc. Pro XR GPS receiver with differential global positioning system (DGPS) correction; and a Odom Hydrographics, Inc, DIGIBAR-Pro Profiling Sound Velocimeter. A 12V battery and inverter provided the power supply to the equipment.

The echo sounder, GPS, and survey vessel were incorporated to provide an efficient hydrographic surveying system. The hydrographic survey consisted of four successive procedures. These include setup, field surveying, post-processing of the collected data, and GIS application. As the boat travels across the lake surface on pre-plotted transect lines, the echo sounder gathers approximately eight readings per second from the lake bottom. The depth readings are stored on the survey vessel's on-board computer along with the positional data generated from the boat's GPS receiver. The daily data files collected are downloaded from the computer and brought to the office for editing after the survey is completed. During editing, data “noise” is removed or corrected, and average depths are converted to elevation readings based on the daily-recorded lake level elevation on the day the survey was performed. Accurate estimates of area-capacity can be determined for the lake by building a 3-D triangulated irregular network (TIN) model of the reservoir from the collected data. The application of this new technology allows for accurate determinations of lake volume.

Pre-survey Technology

Boundary File

The Heyburn Lake boundary file was created by on-screen digitizing from digital ortho quarter-quadrangles (DOQQs), which are rectified aerial photography. Two sources of DOQQs were used. The 2003 Natural Resources Conservation Service (NRCS) color DOQQs and the 1995 United States Geological Survey (USGS) black and white DOQQs. Both sources have two quarter-quads that cover the extent of the lake (35096-H31 and 35069-H31). The 35096-H31 quarter-quad covers most of the main body of the lake. The photo dates were compared to the USACE lake level web site to determine the lake elevation on that date (USACE, 2004). The lake level on the photo date ranged between 761.42-761.44 ft. The normal pool elevation of Heyburn Lake is 761.50 ft. **Table 2** shows the data and lake elevation when each quarter-quad was taken.

Table 2: Digital Ortho Quarter-Quadrangles Used for Creating Lake Boundary File.

2003 DOQQs #	Date	Elevation (ft)
35096-H31	20030711	761.43
35096-H32	20030711	761.43
1995 DOQQs #	Date	Elevation (ft)
35096-H31	19950319	762.34
35096-H32	19950221	761.75

The 2003 DOQQs were used for the majority of the digitizing because the lake level was closest to the normal pool elevation of 761.5 ft. The limitation with the 2003 DOQQs is that the photos were taken in the summer during leaf-on conditions. This can make it difficult to determine the exact location of the shoreline where there are overhanging trees and vegetation. The advantage of the color photos is that water can easily be separated from other features. The 1995 DOQQs were used when additional shoreline verification was needed.

The digitized boundary of Heyburn Lake was produced from the two digital orthophoto quarter quadrangles at a scale of 1:1,500. The reservoir boundary was digitized in Universal Transverse Mercator (UTM) Zone 14 projection, and then reprojected to State Plane Coordinates (Oklahoma North). This conversion from UTM to State Plane is necessary for map units to be transformed from meters to feet. A digital elevation model (DEM) was used to determine the location of the 761.5 ft elevation.

Setup

HYPACK software from Hypack Inc. was used to assign geodetic parameters, import background files, and create virtual track lines (transects). The geodetic parameters assigned were State Plane NAD 83 Zone OK-3501 Oklahoma North and distance units and depth as US Survey Foot. The color DOQQs were imported into the project as .tiff images. The survey transects were spaced according to the accuracy required for the project. The survey transects within the digitized reservoir boundary were at 300-ft increments and ran perpendicular to the original stream channels and tributaries. Approximately 142 virtual transects were created for the Heyburn project not including channel track lines, which were created after the initial surveying of the lake transects. Closely spaced virtual transects resulted in the collection of a large number of data points.

Surveying Methods

The procedures followed by the OWRB during the hydrographic survey adhere to USACE standards (USACE, 2002). The procedures for equipment calibration and operation, field survey, and data processing are presented in the following sections.

Equipment Calibration and Operation

At the beginning of the survey, a position verification of the GPS was performed using monument GH1053 (X, Y coordinate 2534812.18, 382945.1), NAD 83. The unit was positioned directly on the monument while collecting X, Y coordinates. When the points are averaged, they were within 0.38 ft of the monument. The X, Y coordinates and map of the GPS monument are shown in **Appendix A**.

While on board the Hydro-survey vessel, the ODEC Bathy 1500 Echo Sounder was calibrated using A DIGIBAR-Pro Profiling Sound Velocimeter, by Odom Hydrographics. The unit measures the variation in the speed of sound at different depths throughout the water column. The factors that influence the speed of sound: depth, temperature, and salinity, are all taken into account.

Two methods were utilized in the surveying process. The first method performed on May 25 and 26, 4004 involved lowering the probe in the water to the calibration depth mark to allow for acclimation and calibration of the depth sensor. The unit was then raised to as close to the water's surface as possible, gradually lowered at a controlled speed to a depth just above the lake bottom, and finally was raised again to the surface. The unit collected sound velocity measurements in ft/sec at a one-ft interval on both the deployment and retrieval phases. The data was then reviewed for any erroneous readings; if any occurred they were edited out of the sample. This data was used in the EDIT process to correct the soundings for the variations of the speed of sound with depth. A known speed of sound was entered into the echo sounder. The sound velocity corrections were applied to the raw data in the HYPACK EDIT program. Based on the sound velocity profile data and the designated speed of sound entered into the echo sounder, HYPACK will perform the depth adjustments to the raw data.

The second method was used for the June 29, 2004 data. The second method involved lowering the probe in the water to the calibration depth mark to allow for acclimation and calibration of the depth sensor. The unit was then raised to as close to the water's surface as possible, gradually lowered at a controlled speed to a depth just above the lake bottom, and finally was raised again to the surface. The unit collected sound velocity measurements in ft/sec at a one-ft interval on both the deployment and retrieval phases. The data was then reviewed for any erroneous readings, if any occurred they were edited out of the sample, an averaged speed-of-sound was produced from the final readings. The averaged speed of sound, 4894 ft/sec, was entered into the Bathy 1500 echo sounder. The depth was then checked manually with a weighted measuring tape to ensure that the echo sounder was properly calibrated and operating correctly.

The data from the two methods were be used for comparison purposes. HYPACK, CROSS STATISTICS program will be used to determine the difference in depth readings at intersecting points. This information determined the best method for applying sound velocity corrections to raw data.

The speed of sound in the water column ranged from 4,874 ft/sec to 4924 ft/sec during the Heyburn Lake survey. The sound velocity profiles for each date are shown in **Appendix B**. The formula $\Delta d = 0.5\ \Delta v * t$, t=0.03 seconds, where Δd = change in depth and Δv = change in sound velocity, was used to determine the accuracy of the echo sounder to ±0.75 ft. An estimated error of +0.25 ft was calculated for squat. Squat is defined as the change in vessel trim as it moves through the water. Squat corrections are considered positive due to the transducer depressing into the water at acceleration. When combined, the two factors give a range of -0.5 ft to +1.0 ft for any depth reading.

The GPS system is an advanced high performance geographic data-acquisition tool that uses DGPS to provide sub-meter positional accuracy on a second-by-second basis. Potential errors are reduced with differential GPS because additional data from a reference GPS receiver at a known position is used to correct positions obtained during the survey. Before the survey, Trimble's Pathfinder Controller software was used to configure the GPS receiver. To maximize the accuracy of the horizontal positioning, the horizontal mask setting was set to 15 degrees and the Position Dilution of Precision (PDOP) limit was set to six. The position interval was set to one second and the Signal to Noise Ratio (SNR) mask to four. The United States Coast Guard (USCG) reference station used in the Heyburn survey is located near Sallisaw, Oklahoma. The reference beacon system transmitted corrected signals in real time, so no post-processing corrections of position data were needed. The collected DGPS positions were converted to state-plane coordinate system using the HYPACK program.

A latency test was performed to determine the fixed delay time between the GPS and single beam echo sounder. The timing delay was determined by running reciprocal survey lines over a channel bank. The raw data files were downloaded into HYPACK, LATENCY TEST program. The program varies the time delay to determine the "best fit" setting. A position latency of 0.10 seconds was produced and adjustments were applied to the raw data in the EDIT program.

Field Survey

Data collection for Heyburn Lake occurred on March 25 and 26 and June 29, 2004. The water level elevations during the data collection process varied from 762.17 ft on May 25, 2004 to 761.92 ft on June 29, 2004 (USACE, 2004). Lake levels on sampled dates are shown in **Table 3** below.

Table 3: Summary of lake level elevation during data collection.

Date	Elevation (ft) 0800 hours	Elevation (ft) 1200 hours	Elevation (ft) 1400 hours	Elevation (ft) 1600 hours	Averaged (ft)
05/25/04	762.17	762.15	762.15	762.13	762.15
05/26/04	762.09	762.05	762.03	762.02	762.05
06/29/04	761.95	761.94	761.93	761.92	761.94

Data collection began in the Turkey Creek arm, then the Polecat Creek arm, and finally in the main body of the reservoir. Data was collected on parallel transect lines on 300 ft intervals that ran perpendicular to the streambed and cove areas. Shoreline data was collected two or three ft (or as close as the boat allows) offshore where applicable. Areas with depths less than the minimum depth limit of the boat were avoided. Once the entire lake had been surveyed, Hypack software was used to view the collected data and determine the location of the twalweg for each creek. Channel track lines for Polecat Creek and Turkey Creek channels were then created and surveyed. The addition of this method allowed for the best delineation of the creek channels. If data were collected on 300-ft increment transects alone, this critical detail would be missing.

Approximately three quarters of the lake from the Heyburn dam to just beyond both the Turkey and Polecat Creek coves were clear of navigational hazards. However, shallow sand bars were observed in both the Turkey and Polecat Creek arms of the lake. A sandbar obstruction west of Sheppard's Point in the Polecat Creek area of the lake was observed. Because the lake was above the conservation pool elevation during the survey period, the boat was capable of navigating past this obstruction. A large amount of the aquatic plant *Justicia americana*, commonly known as water willow, was observed along the shoreline in many areas of the lake.

The crew was able to collect data on 137 of the 142 pre-plotted transect lines. For both the pre-plotted transects and channel track lines approximately 325,421 data points were collected while traversing a total of 72 miles. The data points were stored on the boat's computer in 208 data files. The X, Y location information for the sedimentation range lines were not provided in time to create transect lines before the surveying started. A map showing historical sediment range lines in reference to collected data points is provided in **Appendix D** (USACE 1994). Due to narrow channels in the backwater areas of Polecat and Turkey creek, data lines were recorded in a zigzag pattern. This method is a way to record data when maneuverability is low. Data was collected in the Turkey creek arm until a logjam was encountered. Data was collected in the upper reaches of Polecat creek arm until signal loss to the GPS was encountered due to interference from large Sycamore trees overhanging the water.

Data Processing

The collected data was downloaded from the field computer onto the OWRB computer network and data burned to a CD as a permanent record. After downloading the data, each raw data file was reviewed for accuracy and completeness using the EDIT program within HYPACK. The EDIT program allows the user to assign transducer offsets, latency corrections, tide corrections, display the raw data profile, and review/edit all raw X, Y, and Z information. Collected data points that have inaccurate or absent depth or positional information are integrated with adjacent accurate points or deleted completely.

Offset correction values of 3.2 ft. starboard, 6.6 ft. forward, and 0.5 and 0.8 ft. vertical were applied to all raw data along with a latency correction factor of 0.10 sec. The speed of sound readings, documented in **Appendix B** from the Profiling Sound Velocimeter, were entered into the HYPACK, SOUND VELOCITY program. The data were used to apply sound velocity corrections to the 05/25-26/04 raw data within the EDIT program. No sound velocity corrections were required for the 06/29/04 raw data because the average speed of sound was entered into the echo sounder in the survey process. The two files were applied to the raw depth (Z) reading to produce a corrected depth.

Fluctuations in lake levels during the data collection process varied from 762.17 ft on May 25, 2004 to 761.92 ft on June 29, 2004 according to the USACE gauge data. Using HYPACK, TIDES program a tide correction file is produced to account for the variance in lake elevation at the time in which data was collected. Within the EDIT program, the corrected depth mentioned earlier is subtracted from the elevation reading to convert the depth in ft to an elevation.

After editing the data for errors and applying the sound velocity, offset, and tide corrections, the data were sorted on a ten-ft radius using the Sounding Selection program in HYPACK. The resultant data was saved and exported out as an xyz.txt file.

Geographic Information System (GIS) software was used to process the edited XYZ data collected from the survey. The GIS software used was ArcGIS Desktop and ArcInfo Workstation, version 8.3, from Environmental System Research Institute (ESRI). All of the GIS datasets created are in Oklahoma State Plane North Coordinate System referenced to the North American Datum 1983. Horizontal and vertical units are in feet.

The edited data points in XYZ text file format were converted into ArcInfo point coverage format. The point coverage contains the X and Y horizontal coordinates and the elevation and depth values associated with each collected point.

Volumetric and area calculations were derived using a TIN surface model. The TIN model was created in ArcInfo, using the collected survey data points and the lake boundary inputs. The TIN consists of connected data points that form a network of triangles representing the bottom surface of the lake. Approximately 29,613 data points were used to create the TIN model. The lake volume was calculated by slicing the TIN horizontally into planes 0.1 ft thick. The volume and area of each slice are shown in **Appendix C**.

Contours, depth ranges, and the shaded relief map were derived from a digital elevation model grid. This grid was created using the ArcInfo TOPOGRIDTOOL command and had a spatial resolution of 10 ft. A low pass 3x3 filter was run to lightly smooth the grid to improve contour generation. The contours were created at a five-ft interval using the ArcInfo LATTICECONTOUR command. Some contour lines required editing to allow for polygon topology and to improve general smoothness of the lines. The contours were then converted to a polygon coverage and attributed to show five-ft depth ranges across the lake. The bathymetric map of the lake is shown with five-ft contour intervals in **Appendix D**.

All geographic datasets derived from the survey contain Federal Geographic Data Committee (FGDC) compliant metadata documentation. The metadata describes the procedures and commands used to create the datasets. The metadata file for Heyburn Lake is located at the end of the document on the CD entitled *Heyburn GIS Metadata.*

RESULTS

Results from the 2004 OWRB survey indicates Heyburn Lake encompasses 660 ac and contains a volume of 5,350 ac-ft at the conservation pool elevation 761.5 ft. The shoreline calculated from the digitized reservoir boundary was 25 miles. The average depth for Heyburn Lake was 7.6 ft with a maximum depth of 31.8 ft. Four points of maximum depth were recorded, all within 37 ft of each other, located approximately 400 ft north then 890 ft west of the outlet structure **(Appendix B)**.

SUMMARY AND COMPARISONS

Heyburn Dam was completed in 1950 and impoundment in the conservation pool was started that same year. Original design records indicate that Heyburn Lake was a 1,070-ac lake and had a total volume of 10,200 ac-ft of water at conservation pool elevation 761.5 ft.

OWRB performed a hydrographic survey of Heyburn Lake on May 25 and 26 and June 29, 2004. For the production of the DEM of Heyburn Lake's bathymetry, a DGPS, echo sounder, and GIS were utilized. The OWRB survey delineated 660 surface ac and a total volume of 5,380 ac-ft at conservation pool elevation 761.5 ft. The inactive pool below elevation 755.4 ft had a capacity of 2,300 ac-ft, leaving approximately 3,080 ac-ft of water in the conservation storage (**Table 4**).

Table 4: Reservoir Data from OWRB 2004 Survey.

Feature	Elevation (NGVD)	Area (acres)	Capacity (ac-ft)
Conservation pool elevation (total storage)	761.5	660	5,350
Conservation pool	755.4-761.5		3,050
Inactive pool	755.4-729.8	362	2,300

USACE sedimentation data for the years 1947,1978, and 1984 was obtained and compared to the 2004 data set for the purpose of area-capacity evaluation. **Table 5** summarizes the combined data for the 761.5 ft conservation pool elevation.

Table 5: Area and Capacity Comparisons of Heyburn Lake at conservation pool elevation (761.5 ft).

FEATURE	SURVEY YEAR			
	1947	1978	1984	2004
Area (acres)	1,070	880	920	660
Cumulative Volume (acre-feet)	10,200	7,105	6,970	5,380
Maximum Depth (feet)	-	-	-	31.8
Mean Depth (feet)	-	-	-	7.6

The OWRB considers the 2004 survey to be a significant improvement over previous survey endeavors and recommends that the same methodology be used in five years or after major flood events to monitor changes to the lake's storage capacity. The survey and computation methods utilized in the OWRB survey differ from those employed in the historical surveys. When comparing area-capacity between the historical USACE original design and the OWRB hydrographic survey, the new volume calculation of 5,380 ac-ft will serve as a more accurate number for future comparisons.

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Appendix A: GPS Monuments

Table A. 1: Collected X, Y coordinates for GPS verification.

Identification #	Date	Time	X	Y
1	5/18/2004	16:54:04	2534806	382940.3
2	5/18/2004	16:53:39	2534807	382939.8
3	5/18/2004	16:53:50	2534808	382950.8
4	5/18/2004	16:53:14	2534809	382938.3
5	5/18/2004	16:53:31	2534812	382952.1
6	5/18/2004	16:53:46	2534817	382950.3
7	5/18/2004	16:53:22	2534819	382948.4
8	5/18/2004	16:53:57	2534820	382945.9

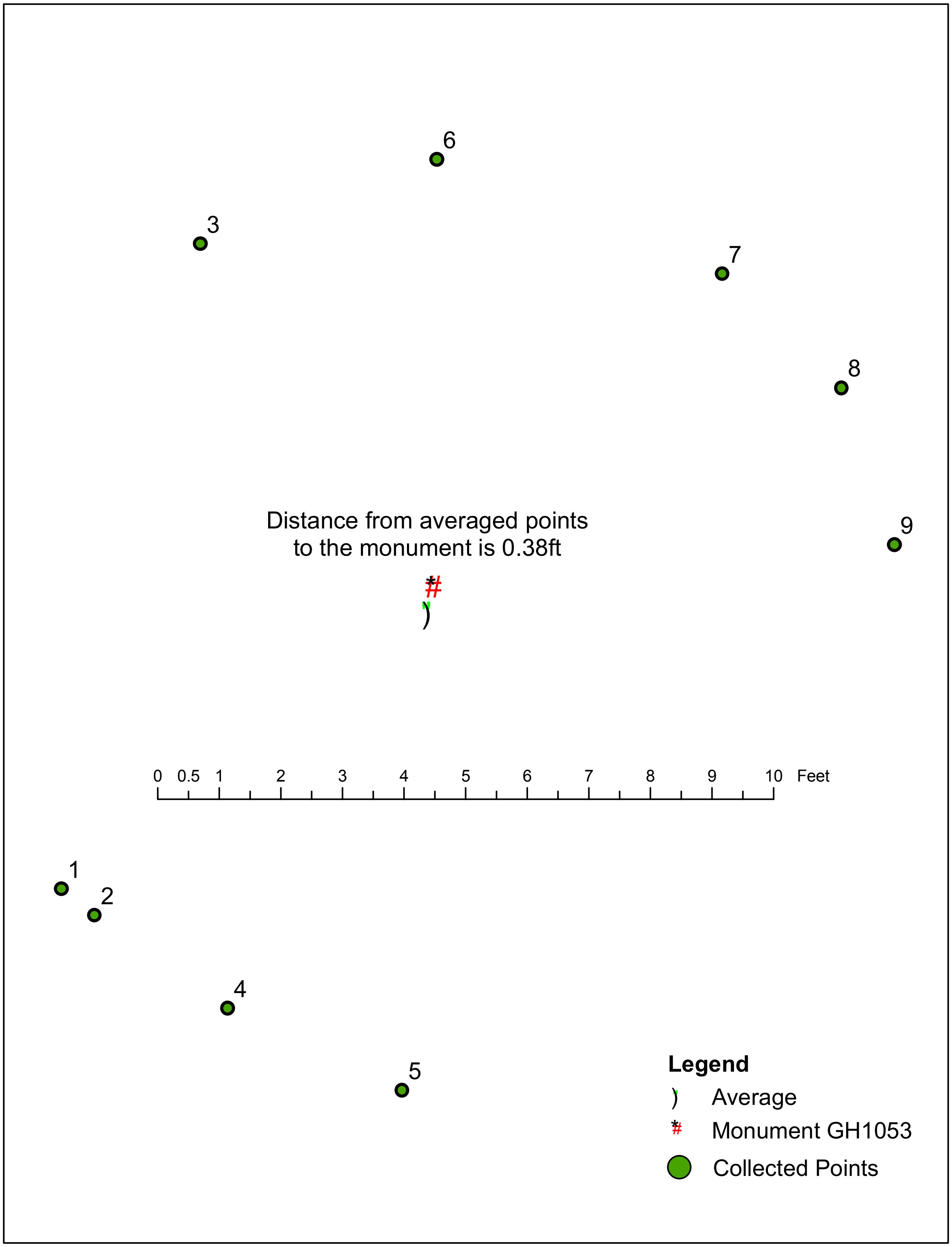


Figure A. 1: Collected data points in comparison to Monument GH1053 (X, Y coordinate 2534812.18, 382945.1), NAD 83.

Appendix B: Sound Velocity Profiles

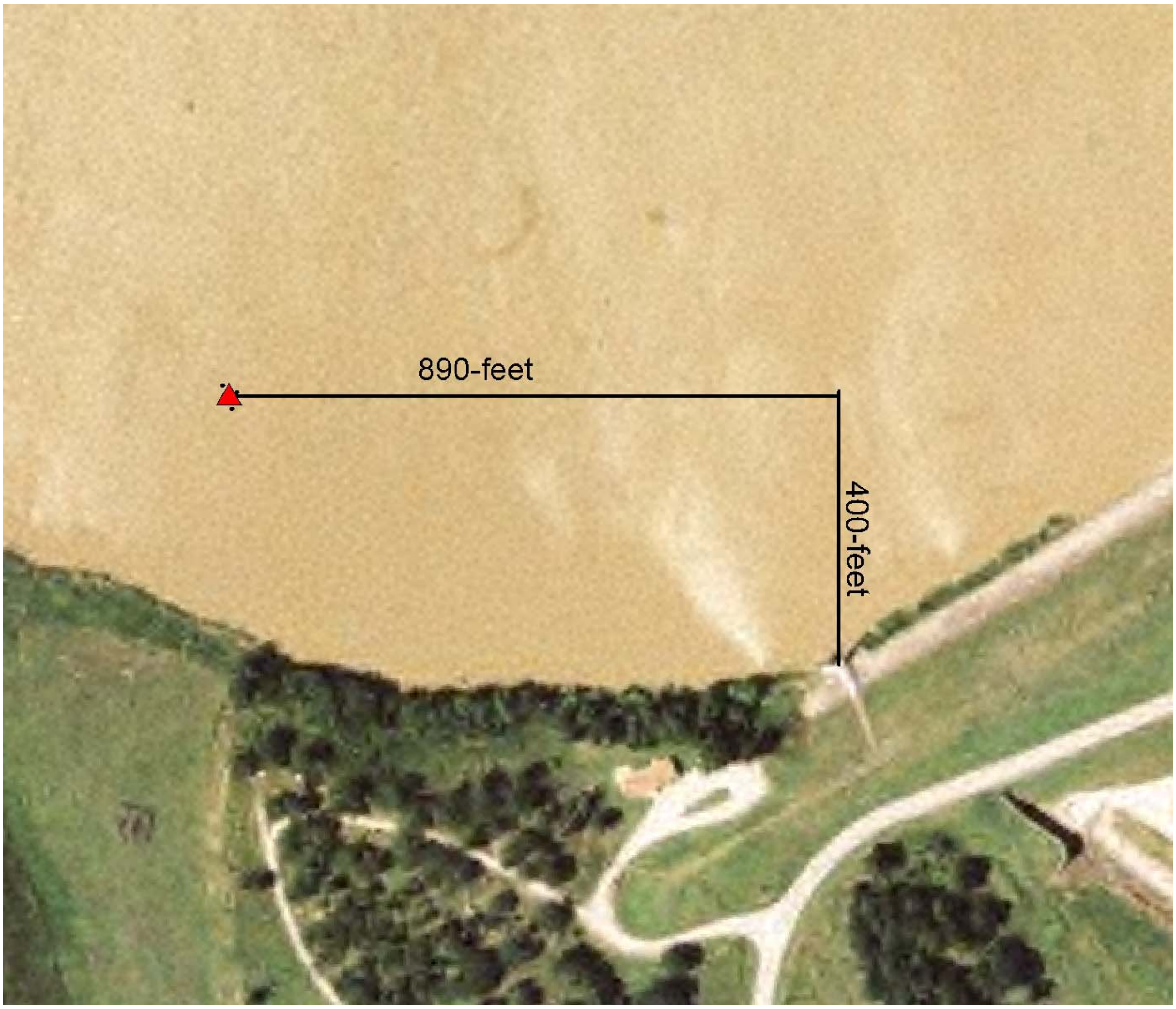


Figure B. 1: Location of Deepest Survey Point.

Table B. 1: Sound Velocity Profile Measurements (June 29, 2004).

Depth (ft)	Speed of Sound (ft/s)
1	4924.0
2	4923.6
3	4923.0
4	4921.1
5	4920.1
6	4915.3
7	4908.0
8	4901.6
9	4897.8
10	4895.8
11	4894.4
12	4892.8
13	4891.9
14	4890.9
15	4890.4
16	4889.8
17	4888.9
18	4888.5
19	4888.0
20	4887.5
21	4886.6
22	4886.0
23	4885.4
24	4884.7
25	4883.9
26	4883.0
27	4881.9
28	4879.5
29	4871.9
30	4848.0
32	4875.8
Averaged Speed of Sound 4894.0 ft/s	

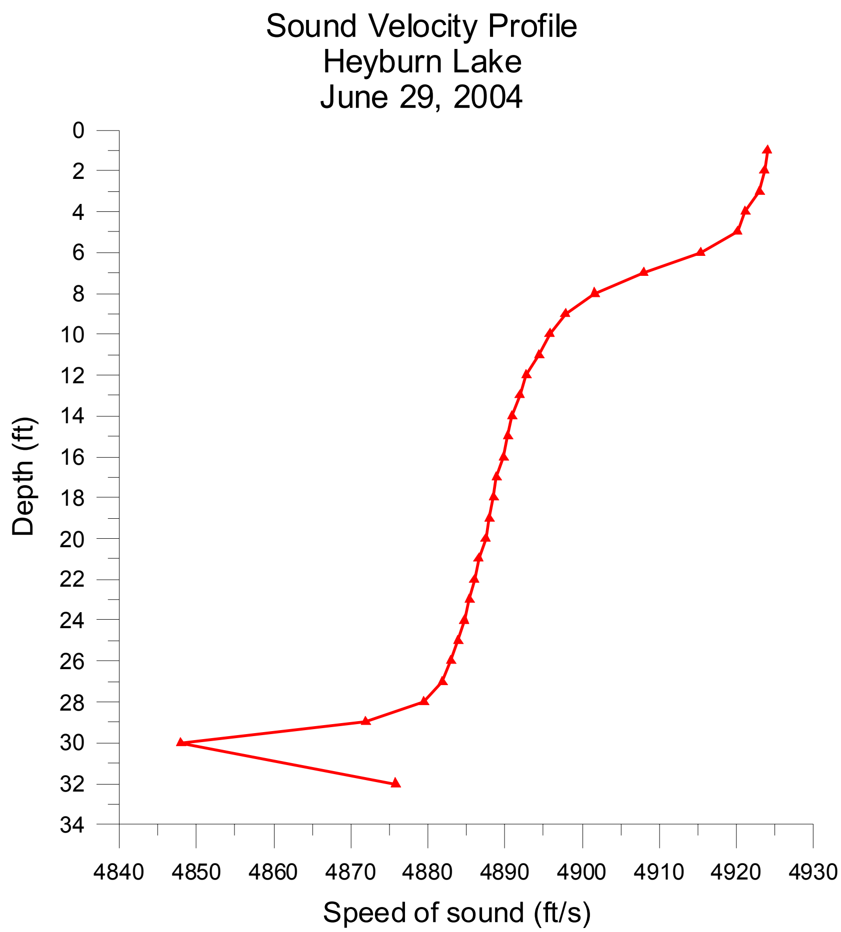


Figure B. 2: Sound Velocity Profile (June 29, 2004).

Table B. 2: Sound Velocity Profile Measurements (May 25, 2004).

Depth (ft)	Speed of Sound (ft/s)
1	4914.0
2	4913.6
3	4913.0
4	4913.0
5	4913.0
6	4913.0
7	4912.3
8	4912.3
9	4912.0
10	4911.4
11	4910.7
12	4910.7
13	4909.7
14	4909.1
15	4908.4
16	4907.4
17	4906.1
18	4904.5
19	4902.5
20	4899.6
21	4897.9
22	4894.6
23	4874.9

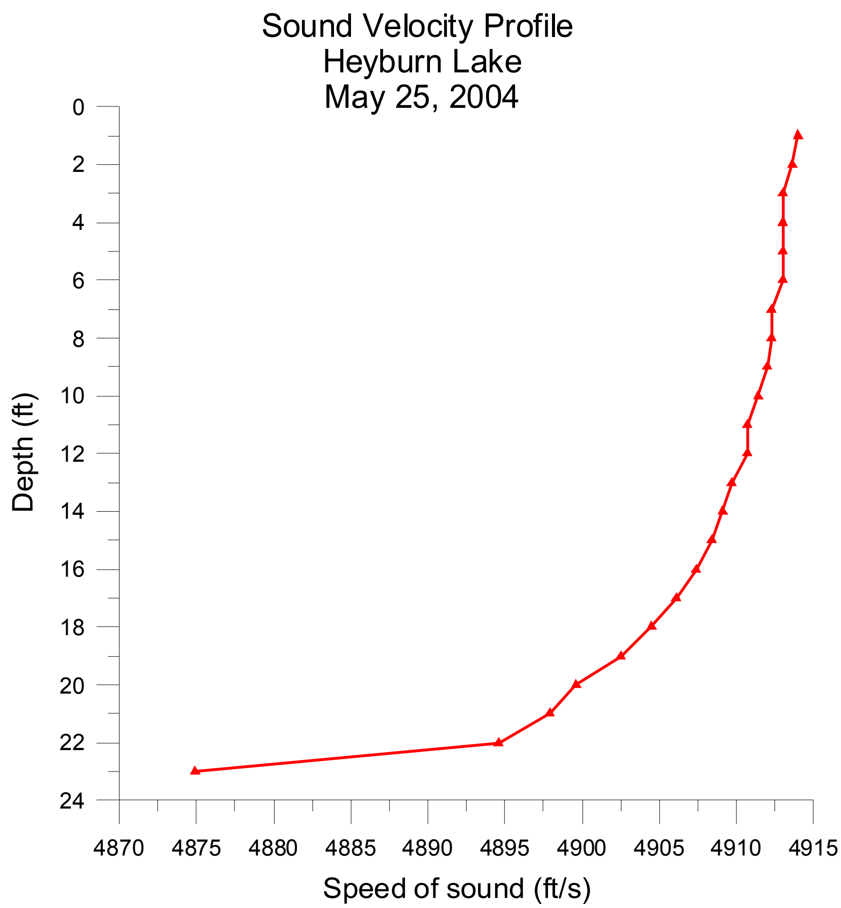


Figure B. 3: Sound Velocity Profile (May 25, 2004).

Table B. 3: Sound Velocity Profile Measurements (May 26, 2004).

Depth (ft)	Speed of Sound (ft/s)
1	4909.4
2	4909.1
3	4909.1
4	4909.1
5	4909.1
6	4909.1
7	4908.4
8	4908.1
9	4908.1
10	4908.1
11	4907.8
12	4907.4
13	4907.4
14	4907.4
15	4907.1
16	4906.1
17	4905.8
18	4904.1
19	4901.5
20	4896.6
21	4892.7
22	4885.8
23	4879.5
24	4875.6
25	4874

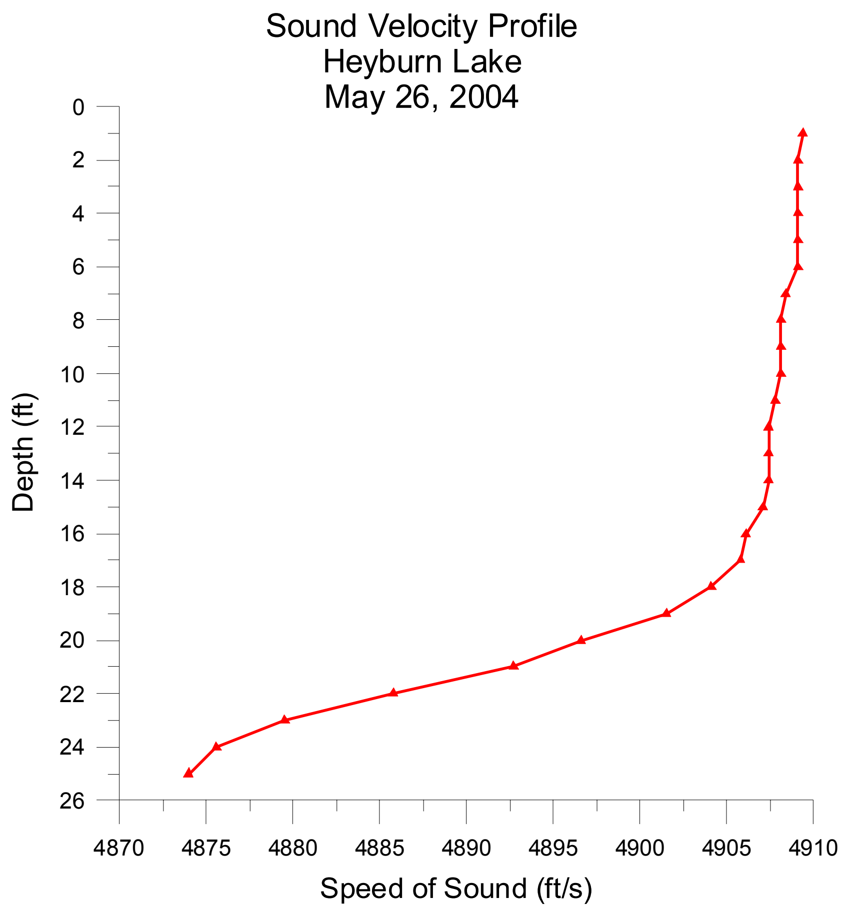


Figure B. 4: Sound Velocity Profile (May 26, 2004).

Appendix C: Area-Capacity Data

Table C. 1: Heyburn Lake Cumulative Area by 0.1-foot Increments.

HEYBURN LAKE AREA TABLE Area in acres by tenth foot elevation increments MAY 2004 SURVEY OKLAHOMA WATER RESOURCES BOARD										
ELEVATION										
(ft NGVD)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
729									0.01	0.01
730	0.02	0.02	0.04	0.05	0.07	0.07	0.08	0.08	0.09	0.09
731	0.1	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.18
732	0.19	0.21	0.24	0.28	0.32	0.36	0.4	0.43	0.46	0.49
733	0.53	0.56	0.6	0.65	0.7	0.75	0.81	0.88	0.94	1.01
734	1.09	1.17	1.26	1.35	1.45	1.56	1.68	1.82	1.98	2.19
735	2.44	2.7	3	3.3	3.58	3.88	4.2	4.53	4.86	5.19
736	5.51	5.81	6.1	6.4	6.71	7.05	7.39	7.73	8.09	8.46
737	8.83	9.22	9.62	10.03	10.45	10.87	11.3	11.76	12.24	12.72
738	13.24	13.75	14.26	14.8	15.35	15.89	16.41	16.93	17.47	18.01
739	18.54	19.06	19.56	20.07	20.58	21.1	21.63	22.15	22.69	23.22
740	23.76	24.32	24.9	25.51	26.19	26.94	27.75	28.6	29.49	30.39
741	31.22	32.04	32.87	33.72	34.61	35.51	36.48	37.46	38.45	39.48
742	40.54	41.64	42.83	44.1	45.39	46.75	48.16	49.52	50.78	52.03
743	53.29	54.61	56.02	57.4	58.77	60.08	61.39	62.63	63.85	65.04
744	66.19	67.35	68.56	69.79	70.96	72.17	73.42	74.69	75.97	77.26
745	78.58	79.93	81.31	82.7	84.13	85.59	87.14	88.82	90.64	92.36
746	94.06	95.73	97.39	99	100.65	102.33	104.04	105.79	107.6	109.46
747	111.41	113.56	115.83	118.25	120.77	123.25	125.59	127.84	130.09	132.23
748	134.43	136.72	138.79	140.89	143	145.14	147.28	149.32	151.35	153.35
749	155.32	157.29	159.25	161.2	163.16	165.11	167.16	169.26	171.44	173.64
750	175.84	178.06	180.25	182.39	184.53	186.69	188.9	191.2	193.46	195.74
751	197.99	200.24	202.58	205.01	207.47	209.9	212.39	215.08	217.77	220.61
752	223.6	226.72	229.67	232.55	235.49	238.6	242.19	245.73	248.78	251.81
753	255.01	258.57	262.18	265.95	269.94	274.07	278.26	282.66	287.42	292.39
754	297.83	303.11	307.98	312.89	317.62	322.14	326.58	331.24	335.88	340.36
755	344.7	349.04	353.35	357.64	362.1	366.52	370.91	375.21	379.6	384.31
756	389.14	393.63	397.9	402.06	406.13	410.1	414.08	418.01	421.88	425.29
757	428.46	431.6	434.71	437.87	441.17	444.74	448.72	452.77	456.63	460.19
758	463.9	467.7	471.62	475.62	479.68	483.93	488.25	492.84	497.57	502.49
759	507.51	512.76	518.34	524.21	530.22	536.31	542.34	548.4	554.51	560.78
760	567.17	573.09	577.93	582.57	587.2	591.81	596.43	601.08	605.75	610.44
761	615.14	619.87	624.62	629.39	634.18	660.08				

Table C. 2: Heyburn Lake Cumulative Volume by 0.1-foot Increments.

HEYBURN RESERVOIR CAPACITY TABLE Volume in acre-feet by tenth foot elevation increments MAY 2004 SURVEY OKLAHOMA WATER RESOURCES BOARD										
ELEVATION										
(ft NGVD)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
729									0	0
730	0	0.01	0.01	0.01	0.02	0.03	0.03	0.04	0.05	0.06
731	0.07	0.08	0.09	0.1	0.12	0.13	0.15	0.16	0.18	0.2
732	0.22	0.24	0.26	0.28	0.31	0.35	0.39	0.43	0.47	0.52
733	0.57	0.63	0.68	0.75	0.81	0.89	0.96	1.1	1.1	1.2
734	1.3	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.7
735	3.0	3.2	3.5	3.8	4.2	4.5	4.9	5.4	5.9	6.4
736	6.9	7.5	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1
737	14.0	14.9	15.8	16.8	17.8	18.9	20.0	21.2	22.4	23.6
738	24.9	26.3	27.7	29.1	30.6	32.2	33.8	35.5	37.2	39.0
739	40.8	42.7	44.6	46.6	48.6	50.7	52.8	55.0	57.3	59.6
740	61.9	64.3	66.8	69.3	71.9	74.5	77.3	80.1	83.0	86.0
741	89.1	92.2	95.5	98.8	102	106	109	113	117	121
742	125	129	133	137	142	146	151	156	161	166
743	172	177	182	188	194	200	206	212	218	225
744	231	238	245	252	259	266	273	281	288	296
745	304	312	320	328	336	345	353	362	371	380
746	390	399	409	419	429	439	449	460	470	481
747	492	503	515	527	539	551	563	576	589	602
748	615	629	643	657	671	685	700	715	730	745
749	760	776	792	808	824	840	857	874	891	908
750	926	943	961	979	998	1016	1035	1054	1073	1093
751	1112	1132	1153	1173	1194	1214	1235	1257	1279	1300
752	1323	1345	1368	1391	1415	1438	1462	1487	1511	1536
753	1562	1587	1613	1640	1667	1694	1721	1750	1778	1807
754	1837	1867	1897	1928	1960	1992	2024	2057	2090	2124
755	2158	2193	2228	2264	2300	2336	2373	2410	2448	2486
756	2525	2564	2604	2644	2684	2725	2766	2808	2850	2892
757	2935	2978	3021	3065	3109	3153	3198	3243	3288	3334
758	3380	3427	3474	3521	3569	3617	3666	3715	3765	3815
759	3865	3916	3968	4020	4073	4126	4180	4234	4289	4345
760	4402	4459	4516	4574	4633	4692	4751	4811	4871	4932
761	4993	5055	5117	5180	5243	5307.04				

Figure C. 1: Heyburn Lake Area-Elevation Curve.

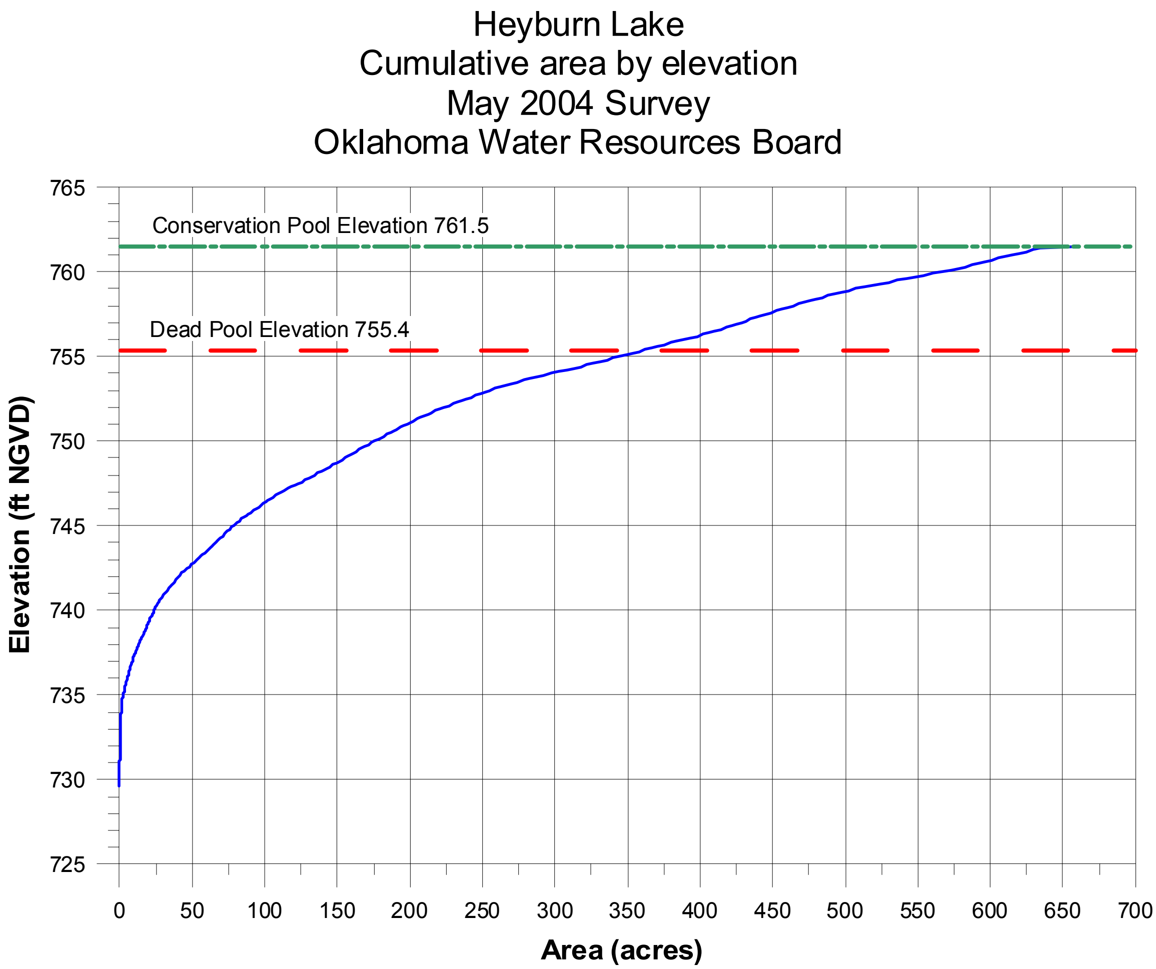
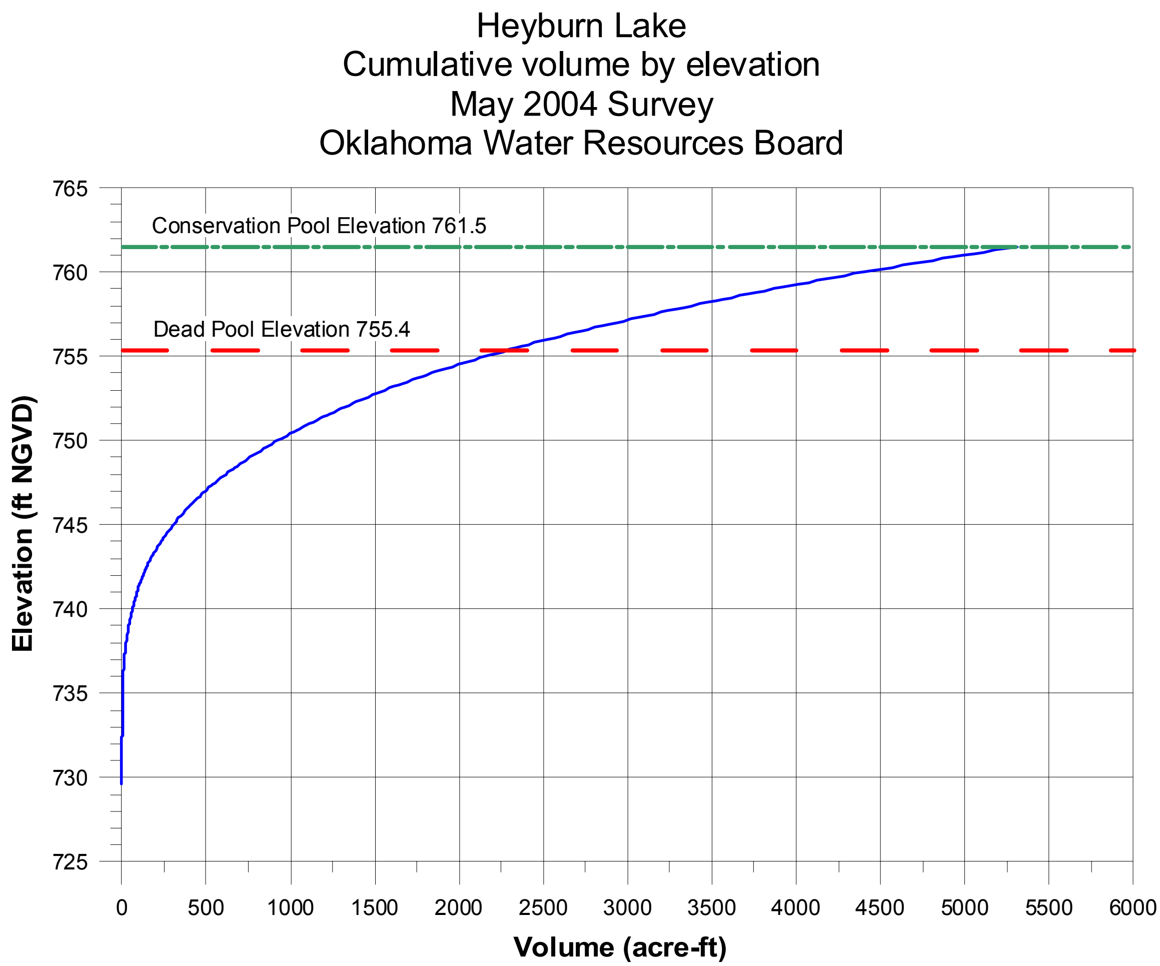


Figure C. 2: Heyburn Lake Volume-Elevation Curve.



Appendix D: Heyburn Lake Bathymetric Maps

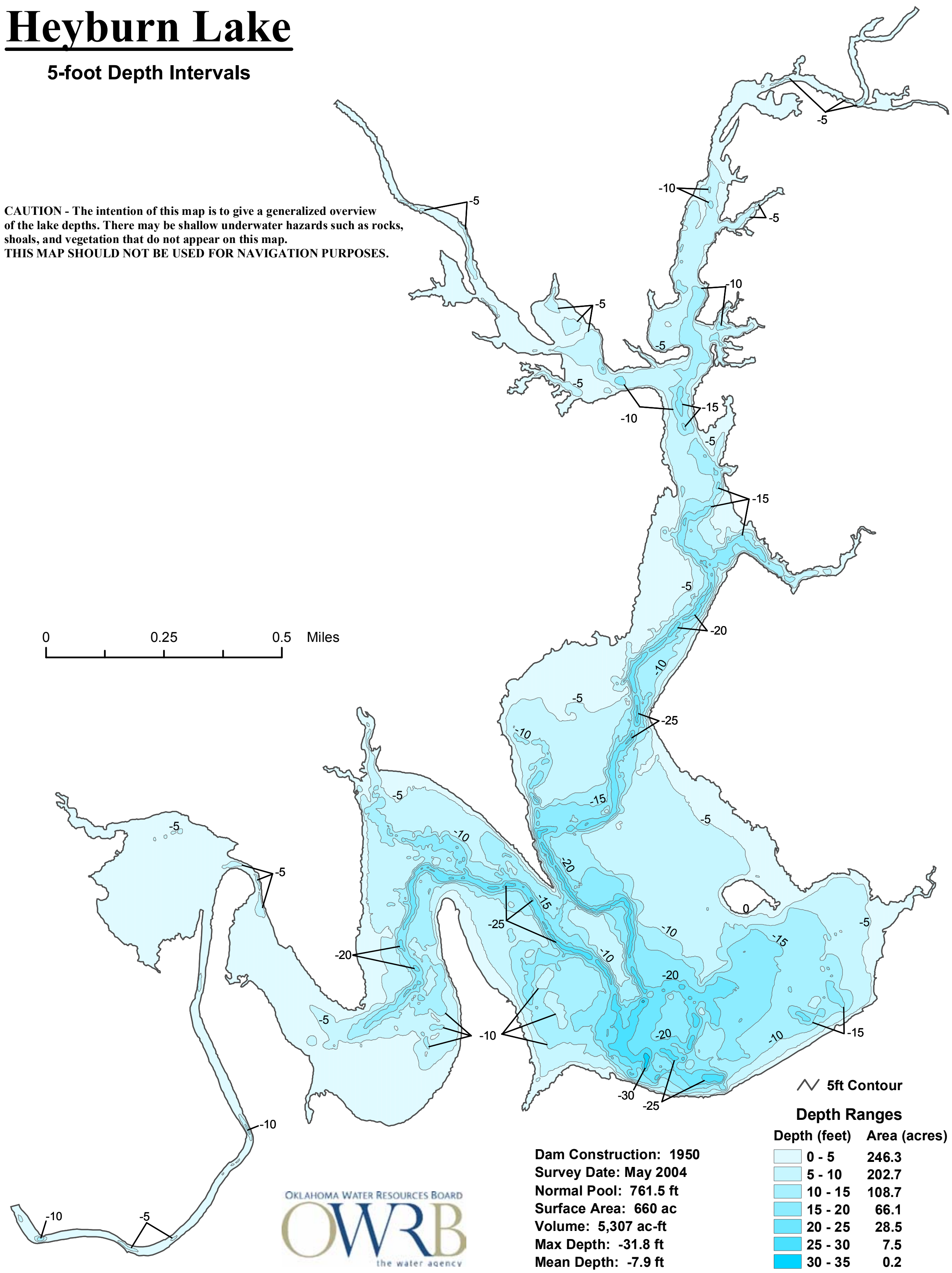


Figure D. 1: Heyburn Lake Bathymetric Map with 5-foot Contour Intervals.

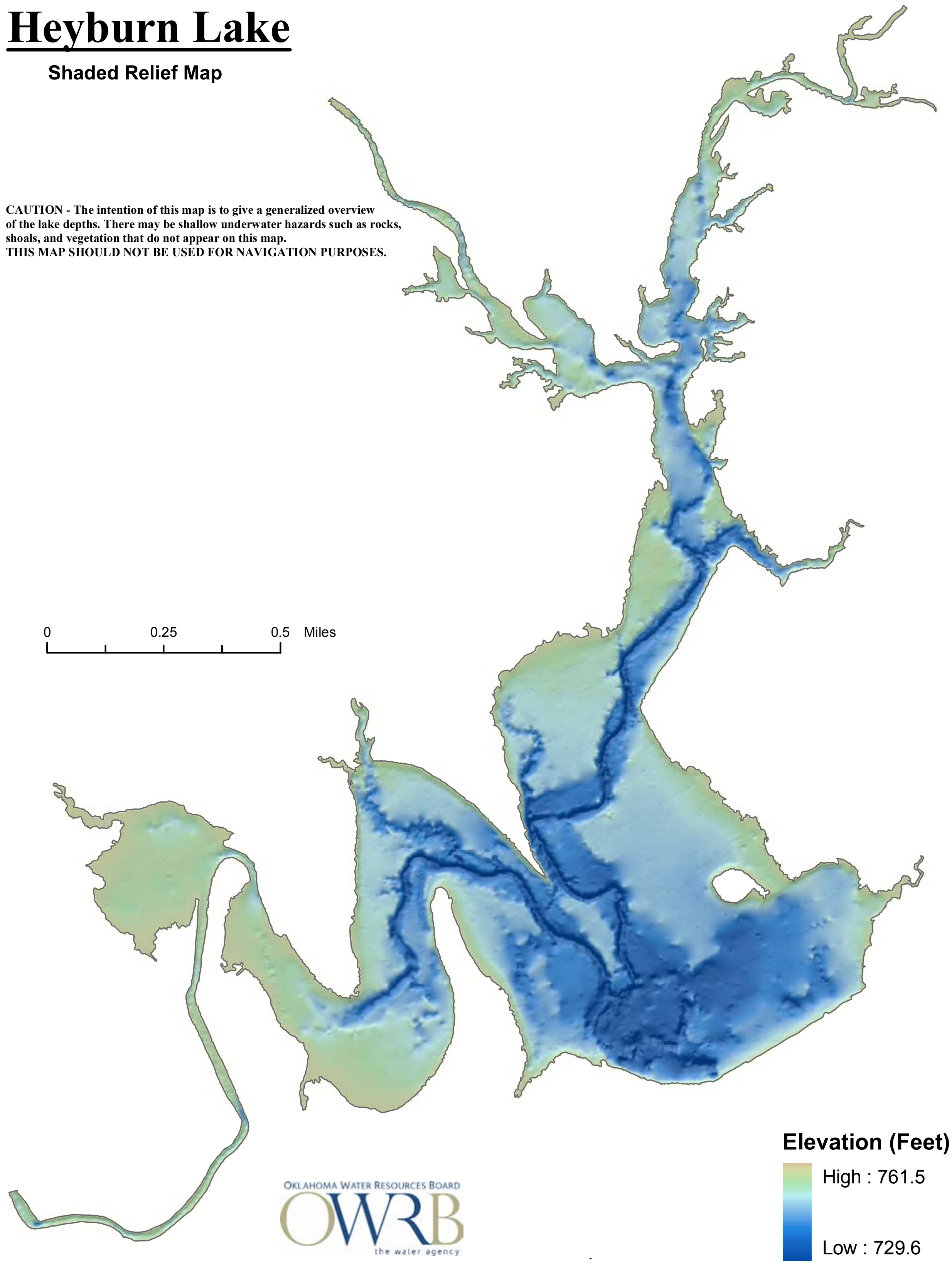


Figure D. 2: Heyburn Lake Shaded Relief Bathymetric Map.

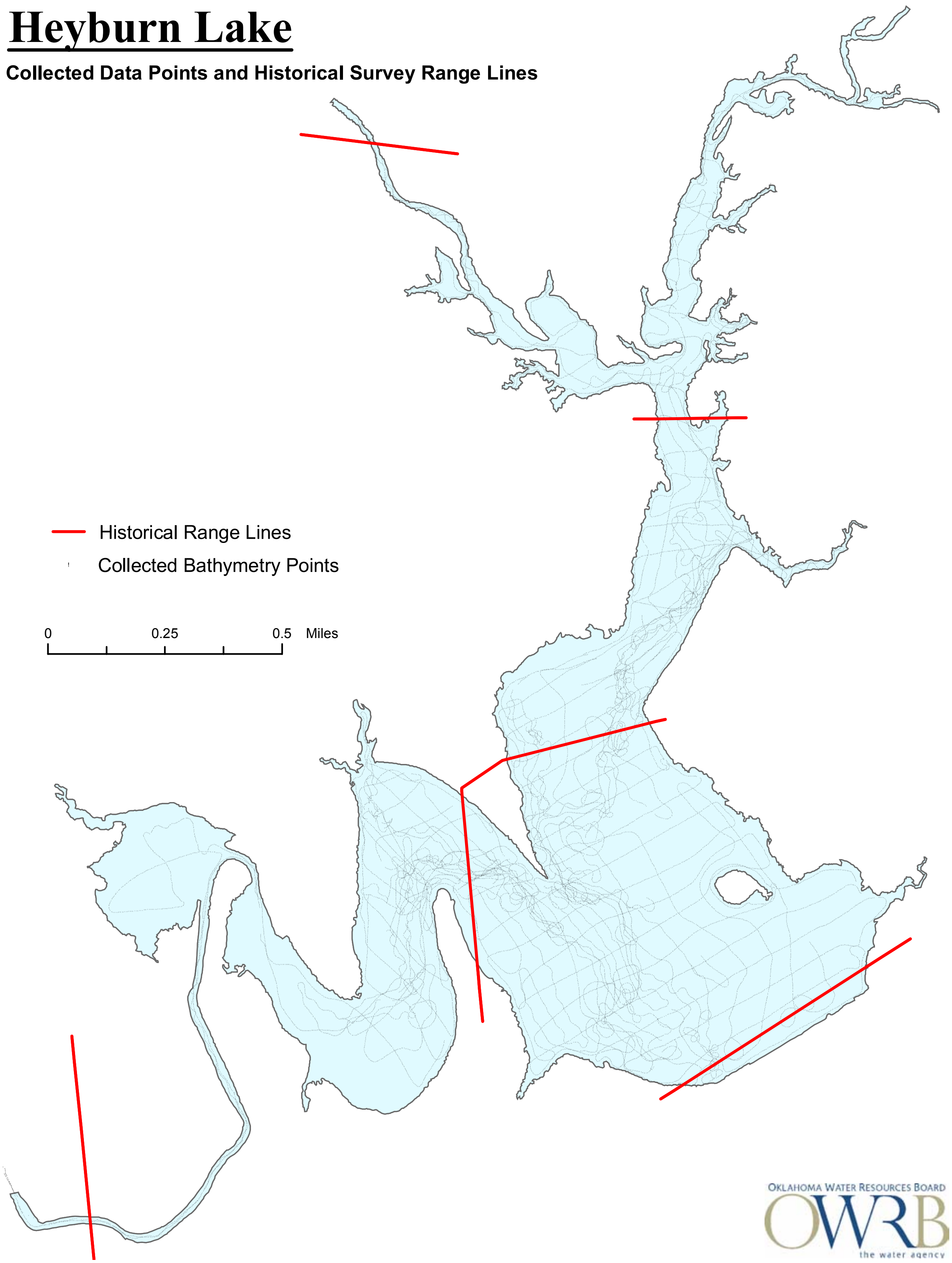


Figure D. 3: Collected Data Points and Historical Survey Range Lines.