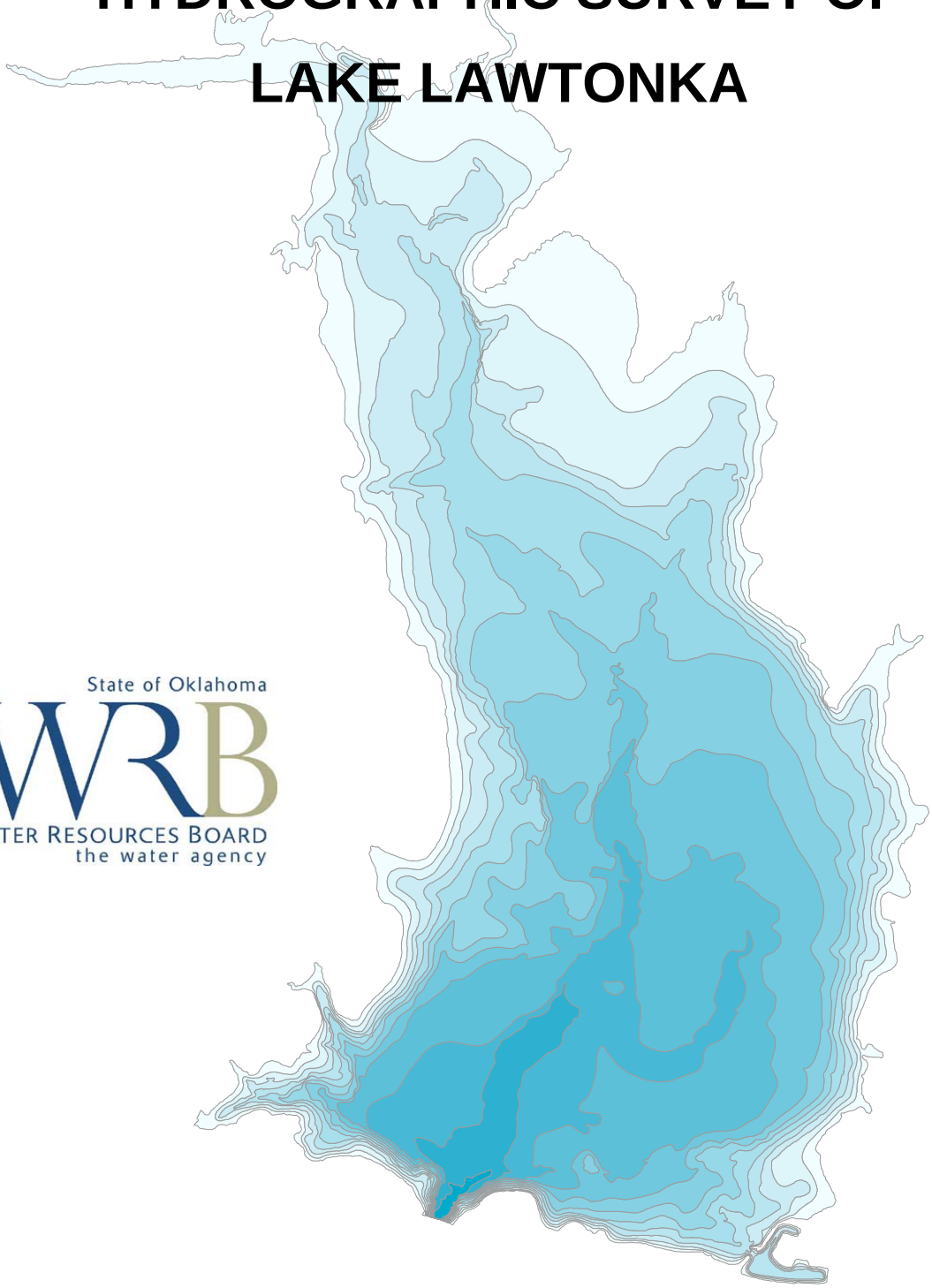
HYDROGRAPHIC SURVEY OF LAKE LAWTONKA



State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

Prepared by:
Oklahoma Water Resources Board

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LAKE LAWTONKA HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Lake Lawtonka in October and November of 2005. The purpose of the study was to collect hydrographic data of Lake Lawtonka and convert this information into an area-elevation-volume table at the conservation pool elevation. The information produced will serve as a base in determining a reliable yield for Lake Lawtonka.

Lake Lawtonka is located in Comanche County on Medicine Creek, a tributary of the East Cache Creek, approximately 9 miles north of the City of Lawton, Oklahoma. A general location map of Lake Lawtonka is shown on the following page (**Figure 1**). Lake Lawtonka is a multipurpose waterbody with the designated beneficial uses of public and private water supply, warm water aquatic community, and primary body contact recreation. These beneficial uses are promulgated through Oklahoma's Water Quality Standards and limit how much of specific contaminants can be in the water and the water still support these designated uses. Lake Lawtonka has the additional limitation of a Sensitive Water Supply. Due to this additional limitation, no new loads or increased loads from existing point sources shall be allowed unless those new or increased loads can be shown to maintain or improve existing water quality. The City of Lawton owns and operates the lake as its primary water supply.

LAKE HISTORY AND PERTINENT INFORMATION

Background

Lake Lawtonka is the primary water source for the City of Lawton. The original dam structure was completed in 1907 along with a pipeline to provide water to the City of Lawton. In 1909, the original dam structure was raised from 5 feet (ft) to 16 ft (OWRB-USACE, 1978). In 1910, the structure was raised to 50 ft with a storage capacity of 13,810 acre-feet (ac-ft) and a surface area of 1,100 acres (ac) (OWRB-USACE, 1978). In 1918, the structure was raised to elevation 1,325 ft with a storage capacity of 26,390 ac-ft and an area of 1,408 ac (OWRB-USACE, 1978). The US Army Corps of Engineers (USACE) prepared construction plans in 1939 to raise the top of the dam elevation of 1,335.0 ft with a storage capacity of 42,500 ac-ft and an area of 1,800 ac (OWRB-USACE, 1978). In 1954, the last modification to the dam occurred. Eight steel spillway gates were added at this time, raising Lake Lawtonka to its present-day elevation of 1,345.55 ft (City of Lawton 2004). Additional references can be found in the U.S. Bureau of Reclamation, Cache Creek Drainage Basin Oklahoma, Rainfall-Runoff Model Using HEC-1 (1995) and Lawton Metropolitan Area Planning Commission, Comprehensive Long Range Water Plan for Lawton Metropolitan Area (1969).

Figure 1: Location map for Lake Lawtonka.

The dam is considered a high hazard structure because of the probability of extensive flooding damage downstream in the event of a catastrophic dam failure (City of Lawton, 2004).

Lake Lawtonka is located in the Central Great Plains ecoregion, which features mixed grass prairie. The lake provides many attractive areas for water-oriented activities such as camping, picnicking, swimming, fishing, and boating. Facilities including surfaced roads, parking areas, boat ramps, camping and picnicking units, and sanitation are operated and maintained by the City of Lawton.

A majority of the land cover in the drainage basin of Lake Lawtonka is grasslands and deciduous forest, with some evergreen forest, small grains, row crops, and pasture/hay. There is some low intensity residential and commercial/industrial areas located within the watershed. The City of Meers is located upstream of Lake Lawtonka

A portion of the Lake Lawtonka watershed is located within the Wichita Mountains National Wildlife Refuge boundary. The tribal lands located within the watershed are Kiowa, Comanche, Apache, and Fort Sill Apache tribal jurisdiction statistical area (TJSA) and the Kiowa, Comanche, Apache tribal trust land for which no reservation exists.

Water Rights

The OWRB currently adjudicates the water rights for Lake Lawtonka and its tributaries. A vested right based on beneficial use from 1907 and application 1941-08 which was filed on 08/18/1941 to appropriate 12,000 acre-feet/year (ac-ft/yr) from Lake Lawtonka on Medicine Creek; recognized in Final Order Establishing Vested Surface Water Rights for Steam System 1-13 was (approved 06/09/1964 by OWRB); for municipal use by the City of Lawton.

Water right permit # 1985-59 was issued on 05/13/1986 to the City of Lawton for a total of 11,500 ac-ft/yr (6,300 ac-ft/yr for industrial and 5,200 ac-ft/yr for municipal use). The schedule of use is provided in **Table 1**.

Table 1: City of Lawton schedule of municipal use of Lake Lawtonka water.

Year	Amount (ac-ft)	Percentage (%)
1995	5,896	51
2005	7,766	68
2015	8,500	74
2025	9,500	83
2035	10,500	91
2045	11,500	100

Outlet Works

Lake Lawtonka's dam is a combination masonry and concrete structure approximately 600 ft in length with a maximum height of 90 ft (OWRB-USACE, 1978). The original masonry structure was encased in concrete due to an increased demand of water. The encasing brought the top of the dam to its present height of 1,355 ft. Concrete piers supporting 10 ft high by 20 ft wide steel gates on the weir crest were the last modifications made to the structure (OWRB-USACE, 1978). **Table 2** lists some of the relevant details of the dam and outlet works. Dam specification elevations are referenced as National Geodetic Vertical Datum (NGVD) 29.

The dam consists of a 200 ft ogee weir spillway section surmounted by 8-10 ft high by 20 ft long steel gates. The right and left non-overflow sections, 158 ft long and 254 ft long respectfully, were placed against the rock faces of the steep abutments (OWRB-USACE, 1978).

On the upstream side of the left non-overflow section, an intake structure controls flows through two 30-inch water supply lines. A 24-inch line exists through the ogee section near the left wall.

Table 2: Lawtonka Dam and Lawtonka Pertinent Data.

Owner of Lawtonka Dam and Facilities	
City of Lawton	
Operator of Lawtonka Dam and Facilities	
City of Lawton	
Engineer	
Design	Concrete dam in present form-Little Rock District USACE with exception of crest gates and piers
Construction	Works Progress Administration under USACE direction
Location	
On Medicine Creek, a tributary of the East Cache Creek in Comanche County, approximately 11 miles northeast of Lawton, Oklahoma.	
Drainage Area	
92 square miles (Above Lawtonka dam site)	
Embankment	
Location	On Medicine Creek
Type	Masonry and Concrete
Crest Length	612 ft
Top Width	10 ft

Elevation	1,355 ft NGVD
Maximum Height	90 ft
Elevation of streambed	1,265 ft ±
Spillway	
Location	Center
Type	Concrete ogee weir
Length of weir	200 ft gross, 160 ft net
Crest Elevation	1,335 ft NGVD
Gates	8-10 ft high X 20 ft wide vertical lift steel gates
Top of Gates Elevation	1,345 ft NGVD
Outlet Works	
Type	2- 30 inch diameter cast iron pipe
Location	Through left non-overflow
Type	1-24 inch diameter pipe
Location	Through weir

Lake Design Specifications

Obstructing the flow of Medicine Creek just above the town of Medicine Park formed Lake Lawtonka. After the final modification in 1954, Lake Lawtonka had a storage capacity of 63,000 (ac-ft) and a surface area of 2,375 ac at pool elevation 1,345.55 ft (City of Lawton, 2004).

The current gate operation policy provides for the incremental raising of the spillway gates to release rising waters during storm events and to maintain a “normal” water surface elevation of 1,343.35 ft (City of Lawton, 2004). The change in operation is to provide downstream flood protection during a storm event. The gage for Lake Lawtonka currently reads in NAVD 88, and all data for this survey is referenced to NAVD 88.

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. Real time kinematic (RTK) global positioning system (GPS) consisting of a 4800 base and a 4700 rover with

differential GPS (DGPS) correction; and an 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 integrated 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 ten readings per second along the lake bottom. The depth readings are stored on the survey vessel's on-board computer along with the positional and elevation 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, sound velocity corrections are applied, offsets are applied, and depths are converted to elevation readings. Accurate estimates of area-capacity are 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 digitized boundary of Lake Lawtonka was produced from the one-meter 1995 black and white U.S. Geological Survey (USGS) digital ortho quarter quads (DOQQ) of Comanche County, Oklahoma at a scale of 1:1,500. The reservoir boundary was digitized in NAD 1983 State Plane Coordinates (Oklahoma South-3502). The normal pool elevation for Lake Lawtonka is 1,343.35 ft NAVD (City of Lawton, 2004). Information for the DOQQs is shown in **Table 3**. The photo dates for the black and white DOQQs were 19950219. The closest known lake water level elevations to this date were 1,342.70 ft on 19950217 and 1,342.68 ft on 19950220. Although the lake level in the 1995 DOQQs is 0.66 ft below "normal" pool elevation 1,343.35 ft, it was the best available resource at the time. The 2003 United States Department of Agriculture-Farm Service Agency-Aerial Photography Field Office (USDA-FSA-APFO) color digital ortho county mosaic for Comanche County, Oklahoma was used as reference data. The photos were collected on 20030615. The closest recorded lake water level elevation for this date was 1,341.87 ft or 1.48 ft below "normal" pool elevation 1,343.35 ft on 20030612.

Table 3: Digital Ortho Quarter-Quadrangles Used for Creating Lake Boundary File.

DOQQs	Date	Elevation (ft NAVD)
USGS - Fort Sill NW (34098-F42)	19950219	~1,342.68
USGS - Meers SE (30098-G54)	19950219	~1,342.68
USGS - Mount Scott NE (34098-F51)	19950219	~1,342.68
USGS - Richards Spur SW (34098-G43)	19950219	~1,342.68
USDA-FSA-APFO - Comanche County, OK	20030615	~1,341.87

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-3502 Oklahoma South and distance units and depth as US Survey Feet. 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 57 virtual transects were created for the Lawtonka project not including channel track lines, which were created after the initial surveying of the lake transects.

Surveying Methods

The procedures followed by the OWRB during the hydrographic survey adhere to U.S. Army Corps of Engineers (USACE) standards (USACE, 2002). The quality control and quality assurance procedures for equipment calibration and operation, field survey, data processing, and accuracy standards are presented in the following sections.

Equipment Calibration and Operation

While on board the Hydro-survey vessel, the ODEC Bathy 1500 Echo Sounder with a depth resolution of 0.1 ft 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.

The 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 feet/seconds (ft/sec) at 1 ft increments on both the deployment and retrieval phases. The data was then reviewed for any erroneous readings, which were then 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 average speed of sound in the water column ranged from 4,825.74 ft/sec to 4,877.14 ft/sec during the Lake Lawtonka survey. The sound velocity profiles for each date are shown in **Appendix A**.

A quality assurance cross-line check was undertaken on intersecting (cross-section) lake transect lines and channel track lines to verify compliance with the resultant depth accuracy (95%) of ±2.0 ft. HYPACK Cross Statistics program was used to assess vertical accuracy and confidence measures of acoustically recorded depths. The program reads the cross-section profile data and longitudinal profile data, computes the intersection, and interpolates a depth from each input file (USACE, 2002). For each cross-section the output file will list the horizontal intersection, the interpolated depths, absolute difference in depth reading, mean difference, and standard deviation. A total of 208 cross-sections were used for statistical analysis to compute error estimates.

The maximum allowable bias for general surveys and studies is ± 0.5 ft. Biases are often referred to as systematic or external errors and may contain observational errors (USACE, 2002). Examples of bias include a bar check calibration error, tidal errors, or erroneous squat corrections. Random errors are the errors that are present in the measurement system that cannot be easily minimized by further calibration. Examples of random error include uneven bottom topography, bottom vegetation, positioning error, and speed of sound variation in the water column. The depth accuracy estimate is determined from actual depth comparisons taken over the same terrain and computing the mean difference (MD) which are considered bias errors and the standard deviation (SD) which are considered random errors between single-beam cross-line check comparisons. The two estimates are then combined to compute the Root Mean Square (RMS) error. The RMS error estimate is used to compare relative accuracies of estimates that differ substantially in bias and precision (USACE, 2002).

A mean difference of .45 ft and a standard deviation of 1.03 ft were computed from a number of 208 data points. Using the following formulas, a 95% depth accuracy of ±0.89 ft was calculated.

$$SE = SD / \sqrt{n}$$

$$RMS = \sqrt{MD^{2} + SE^{2}}$$

$$RMS\ (95\%)\ depth\ accuracy = 1.96 \times RMS$$

where:

SE = standard error
SD = standard deviation
n = number of data points
RMS = root mean square error

MD = mean difference

The data plotted in **Figure 2** illustrates that the measurements have high precision, high repeatability, and high absolute accuracy. It must be noted that high precision or repeatability does not necessarily indicate high accuracy. Tightly scattered data may be highly accurate, whereas highly repeatable data could have large undetected biases (USACE, 2002).

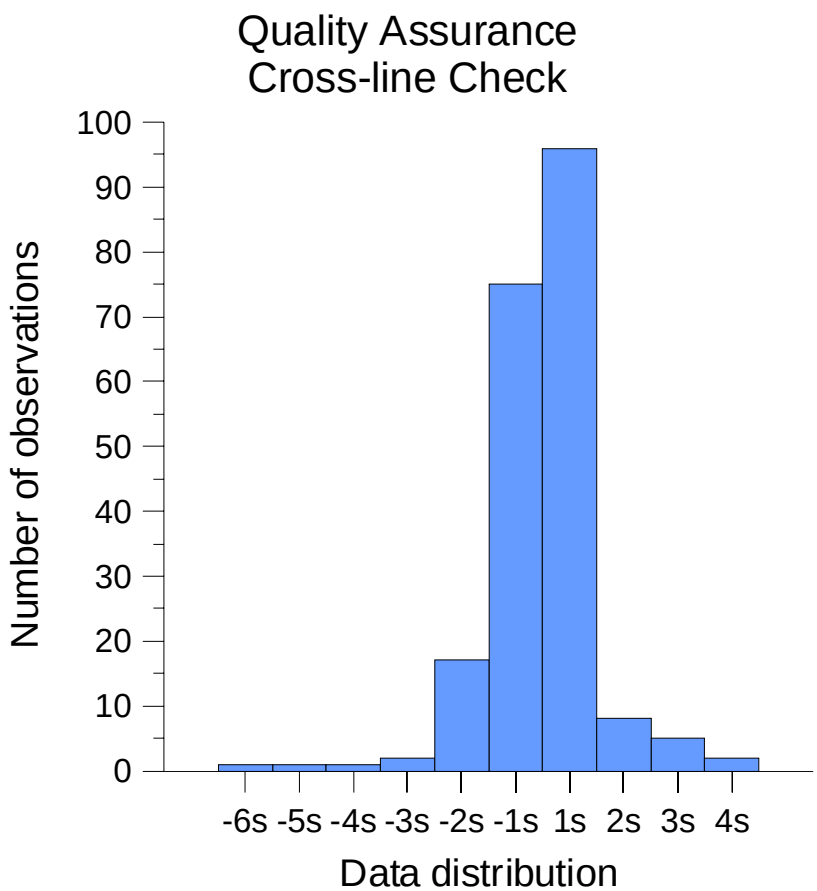

Figure 2: Histogram of relative depth distribution, in standard deviations, at cross-line intersections.

In addition to depth accuracy estimate, error was also estimated 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. The estimated error for squat was +0.25 ft. When combined, the two factors give a total estimated error range of -0.64 to +1.14 ft.

The GPS system is an advanced high performance geographic data-acquisition tool that uses DGPS to provide sub-centimeter positional accuracy on a second-by-second basis. Potential errors are reduced with DGPS RTK system due to the initial integer ambiguity between satellites and receiver being resolved. Before the survey, Trimble's

GPS Configuration 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 6. The position interval was set to 2 seconds because a 1 pulse per second box (PPS) was not available and the Signal to Noise Ratio (SNR) mask was set to 4. 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 -1.40 seconds was produced and adjustments were applied to the raw data in the EDIT program.

Field Survey

Data collection for Lake Lawtonka occurred October 12,13,17,18, November 11, 2005. The water level elevation during the data collection process for October was approximately 4.3 ft below "normal" pool elevation 1,343.35 ft NAVD (USGS, 2005). In November 2005, the water level elevation was 5.1 ft below "normal" pool elevation 1,343.35 ft (USGS, 2005).

Data collection began at the dam and moved up lake. Data were collected on parallel transect lines on 300 ft intervals that ran perpendicular to the streambed and cove areas. Where applicable shoreline data was collected in the two to three ft water depth (or as close as the boat draft allows). Areas with depths less than the minimum depth limit of the boat were avoided.

Once the entire lake had been surveyed, Hypack and ArcGIS software were used to view the collected data and approximate the location of contours for the lake and the thalweg for each creek. Channel and contour track lines were then created by on screen digitizing and surveyed for the main body and Medicine Creek. Approximately, 13 channel and contour track lines were created for Lake Lawtonka. The addition of this method allowed for the best delineation of the creek channels and lake contours. If data were collected on 300 ft increment transects alone, this critical detail would be missing. Data was collected in the upper end of Lake Lawtonka until the boat could no longer navigate in the shallow vegetated waters. Data was collected up to Robinson Landing, documented in **Appendix C.**

The crew was able to collect data on 55 of the 57 pre-plotted transect lines. Data was collected on all of the channel and contour track lines created. For both the pre-plotted transects and channel track lines approximately 716,186 data points were collected while traversing a total of 124 US nautical miles. The data points were stored on the boat's computer in 209 data files.

Data Processing

The collected data was downloaded from the field computer onto the OWRB computer network and also 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, GPS offsets, and latency 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 interpolated to be congruent with adjacent accurate points or deleted completely.

Offset correction values of 8.3 ft for height of the GPS and a -1.1 ft vertical for the transducer were applied to all raw data along with a latency correction factor of 1.40 seconds. The speed of sound readings, are documented in **Appendix A** from the Profiling Sound Velocimeter.

Within the EDIT program, the corrected depth mentioned earlier that is recorded by the echo sounder is subtracted from the elevation reading recorded by the GPS to convert the depth in feet to an elevation.

After editing the data for errors and correcting the spatial attributes (offsets), a data reduction scheme is needed. To accomplish this the data is resampled spatially at a 10 ft interval using the Sounding Selection program in HYPACK. The resultant data was saved and exported out as a xyz.txt file. The HYPACK data file for Lake Lawtonka is located at the end of the document on the CD entitled *Lawtonka HYPACK/GIS Metadata.*

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 South 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 53,476 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 B**.

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 5-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 5-ft depth ranges across the lake. The bathymetric map of the lake is shown with 5-ft contour intervals in **Appendix C**.

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 GIS metadata file for Lake Lawtonka is located at the end of the document on the CD entitled *Lawtonka HYPACK/GIS Metadata.*

RESULTS

Results from the 2005 OWRB survey indicate Lake Lawtonka encompasses 2,325 ac and contains a cumulative capacity of 55,171 ac-ft at "normal" pool elevation 1,343.35 ft. The shoreline calculated from the digitized reservoir boundary was 19.2 miles. The average depth for Lake Lawtonka was 23.6 ft with a maximum depth of 58.4 ft.

SUMMARY AND COMPARISONS

The original dam structure was completed in 1907. After the final modification in 1954, Lake Lawtonka had a storage capacity of 63,000 ac-ft and a surface area of 2,375 ac at pool elevation 1,345.55 ft (City of Lawton, 2004). However, "normal" water surface elevation is 1,343.35 ft to provide for downstream flood protection during a storm event (City of Lawton, 2004).

OWRB performed a hydrographic survey of Lake Lawtonka in October and November. For the production of the DEM of Lake Lawtonka's bathymetry, a DGPS, echo sounder, and GIS were utilized. The OWRB survey delineated 2,325 ac and a cumulative capacity of 55,171 ac-ft at "normal" pool elevation 1,343.35 ft NAVD (**Table 4**).

Table 4: Reservoir Data from OWRB 2005 Survey.

Feature	Elevation (NAVD)	Area (acres)	Capacity (ac-ft)
Top of Conservation Pool	1343.35	2,325	55,171

The OWRB considers the 2005 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 original

design and the OWRB hydrographic survey, the new capacity calculation of 55,171 ac-ft will serve as a more accurate number for future comparisons.

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Appendix A: Sound Velocity Profiles

Table A. 1: Sound Velocity Profile Data for October 12, 13, 17, 18, and November 10, 2005.

Depth (ft)	10/12/05	10/13/05	10/17/05	10/18/05	11/10/05
1	4876.31		4879.59	4874.34	4836.94
2	4875.98	4875.98	4879.59	4874.34	4836.61
3	4875.66	4875.98	4879.27	4874.02	4836.61
4	4875.33	4875.98	4879.27	4874.02	4836.29
5	4875.33	4875.66	4878.94	4874.02	4835.63
6	4875.33	4875.98	4878.61	4874.02	4833.99
7	4875.33	4875.98	4878.28	4873.69	4830.71
8	4875.33	4875.98	4878.28	4873.69	4826.77
9	4875.33	4875.98	4877.95	4873.69	4824.80
10	4875.33	4875.98	4877.95	4873.69	4824.80
11	4875	4875.98	4877.62	4873.69	4824.48
12	4875	4875.98	4877.30	4873.36	4824.48
13	4875	4875.98	4877.30	4873.36	4824.48
14	4875	4875.66	4877.30	4873.36	4824.48
15	4875	4875.33	4877.30	4873.36	4824.48
16	4875	4873.36	4876.97	4873.36	4824.48
17	4874.67		4876.64	4873.36	4824.48
18	4874.67		4876.64	4873.36	4824.48
19	4874.67		4876.64	4873.36	4824.48
20	4874.34	4873.36	4876.64	4873.36	4824.48
21	4874.34	4873.03	4876.31	4873.36	4824.48
22	4874.02	4873.03	4876.31	4873.36	4824.15
23	4874.02	4873.03	4876.31	4873.36	4824.48
24	4874.02	4873.03	4875.98	4873.36	4824.48
25	4873.69	4872.70	4875.98	4873.36	4824.48
26	4873.69	4872.70	4875.98	4873.36	4824.48
27	4873.69	4872.70	4875.66	4873.36	4824.48
28	4873.69	4872.70	4875.33	4873.36	4824.48
29	4873.69	4872.70	4875.33	4873.36	4824.15
30	4873.36	4872.70	4875	4873.03	4824.15
31	4873.36	4872.70	4875	4872.38	4824.15
32	4873.36	4872.70		4872.38	4824.15
33	4873.36	4872.70		4872.05	4824.15
34	4873.36	4872.70		4872.05	4824.15
35	4873.36	4872.70		4871.72	4824.15
36	4873.36	4872.70		4871.72	4824.15
37	4873.36	4872.70		4871.72	4824.15
38	4873.03	4872.38		4871.72	4824.15
39	4873.03	4872.38		4871.72	4824.15
40	4873.03	4872.38		4871.72	4824.15
41	4873.36	4872.38		4871.72	4824.15
42	4873.36	4872.38		4871.72	4824.15
43	4873.36	4872.05		4871.72	4824.15
44	4873.36	4872.05		4871.72	4824.15
45	4873.36	4872.05		4871.72	4824.15
46	4873.36	4872.05		4871.72	4823.82
47	4873.36	4872.05		4871.72	4823.82
48	4873.36	4872.05		4871.72	4823.49

49	4873.36	4872.05		4871.72	4823.16
50	4873.36	4872.05		4871.72	4822.51
51	4873.36	4872.05		4871.72	4822.18
52	4873.36	4872.05		4871.72	
53	4873.03	4872.05		4871.72	
54	4873.03				

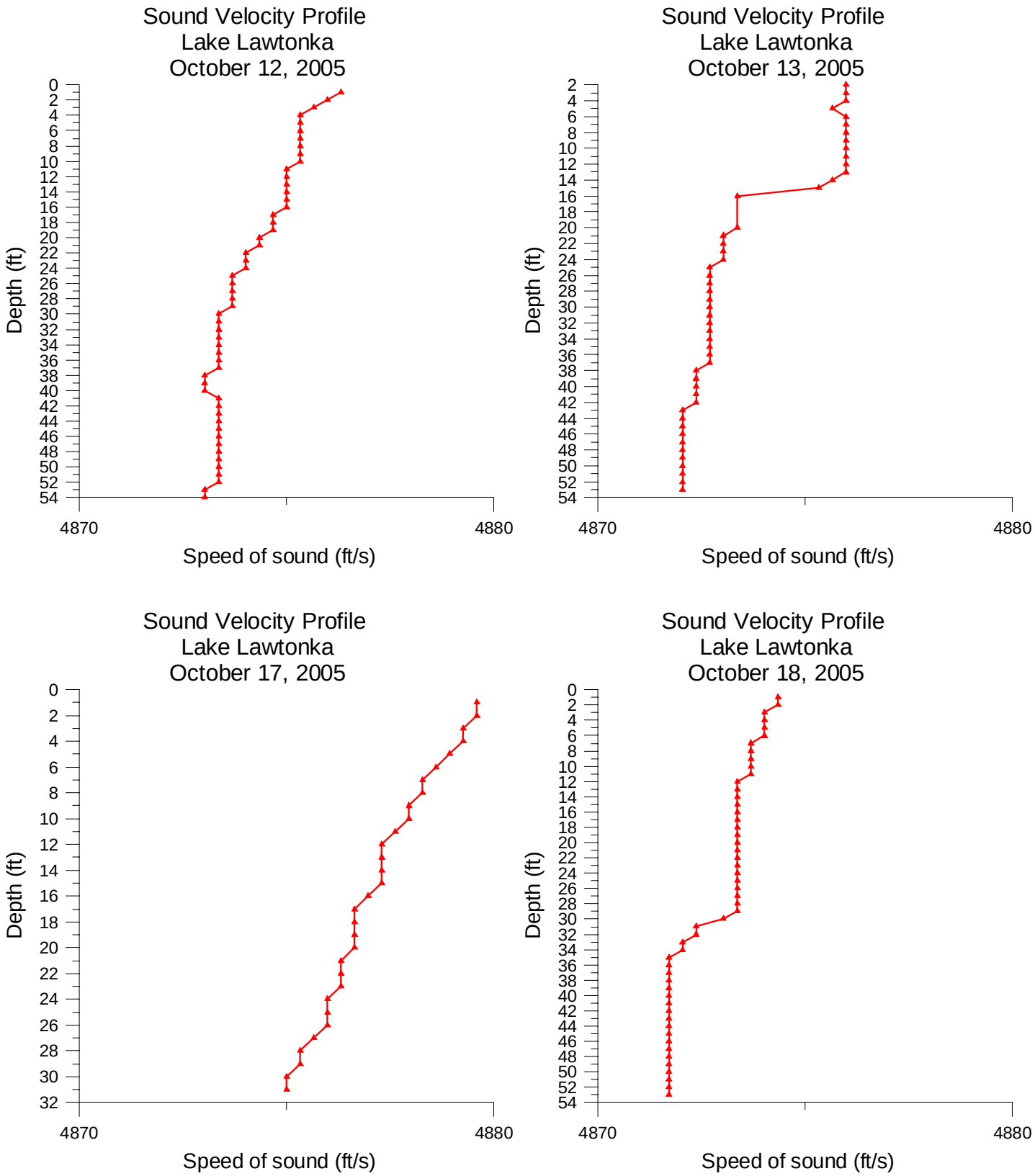

Figure A. 1: Sound Velocity Profiles for October 12, 13, 17, and 18, 2005.

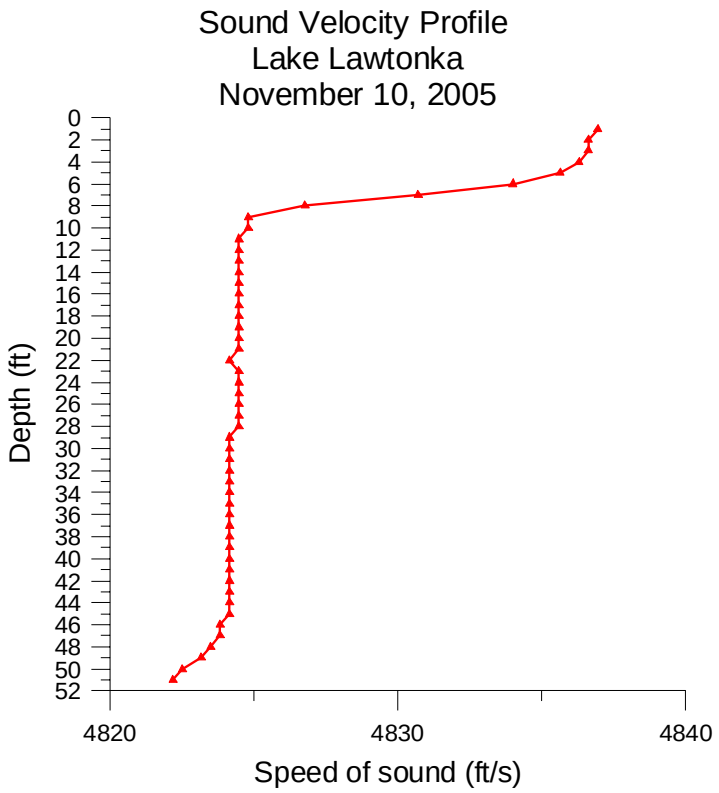

Figure A. 2: Sound Velocity Profiles for November 10, 2005.

Appendix B: Area-Capacity Data

Table B. 1: Lake Lawtonka Cumulative Area by 0.1-ft Increments.

LAKE LAWTONKA AREA TABLE										
Area in acres by tenth ft elevation increments										
2005 SURVEY										
OKLAHOMA WATER RESOURCES BOARD										
ELEVATION										
(ft NAVD)	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1285								0.0723	0.0933	0.113
1286	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4
1287	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.3
1288	1.6	1.9	1.9	2.2	2.6	3.1	3.3	3.5	3.7	3.9
1289	4.3	4.6	4.6	5.0	5.6	6.3	6.9	7.4	8.0	8.7
1290	9.9	10.5	10.5	11.0	11.6	12.2	12.9	13.6	14.5	15.3
1291	17.4	18.6	18.6	19.8	21.0	22.0	23.0	24.0	25.0	26.1
1292	28.5	29.8	29.8	31.1	32.4	33.6	34.8	36.0	37.2	38
1293	41	42	42	44	45	48	49	50	52	53
1294	55	56	56	58	59	60	62	63	65	66
1295	71	73	73	75	76	78	80	82	83	85
1296	90	93	93	95	98	101	104	108	111	114
1297	122	127	127	131	136	140	145	150	155	161
1298	172	178	178	183	189	198	204	210	216	222
1299	233	239	239	245	250	256	263	269	275	281
1300	294	301	301	307	315	322	329	338	346	353
1301	368	374	374	379	384	388	393	397	402	407
1302	416	420	420	423	427	431	435	440	444	448
1303	456	460	460	464	468	473	477	481	485	489
1304	496	500	500	504	507	511	514	518	522	527
1305	537	542	542	546	550	554	558	562	566	570
1306	578	582	582	587	591	595	599	603	607	612
1307	621	626	626	631	635	640	644	648	653	657
1308	666	671	671	676	681	688	693	698	704	709
1309	719	724	724	729	733	739	744	749	753	758
1310	768	772	772	777	782	786	791	796	801	806
1311	815	819	819	823	827	832	836	840	845	849
1312	858	862	862	866	871	876	880	884	888	892
1313	899	903	903	907	911	916	919	923	927	930
1314	937	941	941	944	947	951	954	958	961	965
1315	972	976	976	980	984	988	992	996	999	1003
1316	1010	1014	1014	1017	1021	1025	1030	1034	1039	1044
1317	1053	1058	1058	1063	1067	1072	1076	1081	1086	1091
1318	1101	1106	1106	1112	1117	1123	1128	1133	1138	1143
1319	1152	1157	1157	1162	1166	1171	1175	1179	1183	1187
1320	1196	1200	1200	1204	1208	1212	1215	1219	1223	1227
1321	1234	1238	1238	1242	1246	1250	1254	1258	1261	1265
1322	1272	1276	1276	1280	1283	1287	1290	1294	1297	1301

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1323	1307	1311	1311	1314	1318	1322	1325	1328	1331	1335
1324	1341	1344	1344	1347	1351	1354	1358	1361	1364	1368
1325	1374	1377	1377	1380	1383	1386	1389	1393	1396	1399
1326	1405	1409	1409	1412	1415	1418	1421	1424	1427	1430
1327	1436	1440	1440	1443	1446	1449	1452	1455	1459	1462
1328	1469	1472	1472	1476	1481	1486	1491	1496	1501	1505
1329	1515	1520	1520	1525	1530	1535	1540	1545	1550	1555
1330	1565	1569	1569	1574	1578	1583	1587	1591	1595	1599
1331	1607	1612	1612	1616	1620	1624	1628	1633	1637	1641
1332	1650	1654	1654	1658	1663	1667	1672	1678	1683	1687
1333	1697	1701	1701	1706	1712	1720	1726	1731	1736	1741
1334	1750	1754	1754	1758	1763	1767	1771	1776	1781	1785
1335	1795	1800	1800	1805	1810	1816	1822	1828	1834	1841
1336	1855	1861	1861	1867	1873	1878	1884	1890	1896	1902
1337	1914	1919	1919	1924	1930	1935	1940	1945	1950	1955
1338	1965	1970	1970	1975	1979	1984	1989	1994	1998	2003
1339	2013	2018	2018	2022	2027	2032	2037	2042	2047	2052
1340	2062	2068	2068	2073	2078	2083	2088	2094	2099	2104
1341	2115	2120	2120	2126	2131	2137	2142	2148	2154	2159
1342	2171	2176	2176	2182	2188	2194	2200	2205	2211	2217
1343	2229	2235	2235	2241	2324.80					

Table B. 2: Lake Lawtonka Cumulative Volume by 0.1-ft Increments.

LAKE LAWTONKA CAPACITY TABLE										
Volume in acre-feet by tenth ft elevation increments										
2005 SURVEY										
OKLAHOMA WATER RESOURCES BOARD										
ELEVATION										
(ft NAVD)	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1285								0.0125	0.0208	0.0311
1286	0.058	0.0742	0.0742	0.09	0.11	0.14	0.16	0.19	0.22	0.26
1287	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0
1288	1.3	1.5	1.5	1.7	1.9	2.2	2.5	2.9	3.2	3.6
1289	4.4	4.9	4.9	5.4	5.9	6.5	7.1	7.9	8.6	9.5
1290	11.3	12.4	12.4	13.4	14.6	15.7	17.0	18.3	19.7	21.2
1291	24	26	26	28	30	32	35	37	39	42
1292	47	50	50	53	57	60	63	67	70	74
1293	82	86	86	91	95	100	105	110	115	120
1294	131	136	136	142	148	154	160	166	173	179
1295	193	200	200	207	215	223	231	239	247	255
1296	273	282	282	291	301	311	321	332	343	354
1297	378	390	390	403	416	430	445	459	475	490
1298	524	541	541	559	578	597	617	638	659	681

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1299	727	750	750	774	799	824	850	877	904	932
1300	989	1019	1019	1050	1081	1113	1145	1178	1213	1248
1301	1320	1357	1357	1394	1433	1471	1510	1550	1590	1630
1302	1713	1754	1754	1796	1839	1882	1925	1969	2013	2058
1303	2148	2194	2194	2240	2287	2334	2381	2429	2477	2526
1304	2625	2674	2674	2725	2775	2826	2877	2929	2981	3034
1305	3140	3194	3194	3248	3303	3358	3414	3470	3526	3583
1306	3698	3756	3756	3814	3873	3932	3992	4052	4113	4174
1307	4297	4359	4359	4422	4485	4549	4613	4678	4743	4809
1308	4941	5008	5008	5075	5143	5211	5281	5350	5420	5491
1309	5634	5706	5706	5778	5852	5925	5999	6074	6149	6225
1310	6377	6454	6454	6532	6610	6688	6767	6846	6926	7007
1311	7169	7250	7250	7333	7415	7498	7581	7665	7750	7834
1312	8005	8091	8091	8177	8264	8352	8439	8528	8616	8705
1313	8884	8975	8975	9065	9156	9247	9339	9431	9524	9617
1314	9803	9897	9897	9992	10086	10181	10276	10372	10468	10564
1315	10758	10855	10855	10953	11052	11150	11249	11349	11448	11549
1316	11750	11851	11851	11952	12055	12157	12260	12363	12466	12571
1317	12780	12886	12886	12992	13099	13205	13313	13421	13529	13638
1318	13857	13968	13968	14078	14190	14302	14415	14528	14641	14755
1319	14985	15100	15100	15216	15333	15450	15567	15685	15803	15921
1320	16160	16279	16279	16399	16520	16641	16762	16884	17006	17129
1321	17375	17499	17499	17623	17747	17872	17997	18123	18249	18375
1322	18629	18756	18756	18884	19012	19141	19269	19399	19528	19658
1323	19919	20050	20050	20181	20313	20445	20577	20710	20843	20976
1324	21244	21378	21378	21512	21648	21783	21918	22054	22190	22327
1325	22601	22739	22739	22877	23015	23154	23292	23431	23571	23711
1326	23991	24132	24132	24273	24414	24556	24698	24840	24983	25126
1327	25412	25556	25556	25700	25845	25990	26135	26280	26426	26572
1328	26865	27012	27012	27159	27307	27456	27605	27754	27904	28054
1329	28356	28508	28508	28660	28813	28966	29120	29274	29429	29584
1330	29896	30053	30053	30210	30368	30526	30684	30843	31003	31163
1331	31483	31644	31644	31805	31967	32130	32292	32455	32619	32783
1332	33112	33277	33277	33443	33609	33775	33942	34110	34278	34446
1333	34785	34955	34955	35125	35296	35468	35640	35813	35986	36160
1334	36509	36684	36684	36860	37036	37213	37390	37567	37745	37923
1335	38281	38461	38461	38641	38822	39003	39185	39368	39551	39735
1336	40104	40290	40290	40476	40664	40851	41039	41228	41417	41607
1337	41989	42181	42181	42373	42566	42759	42953	43147	43342	43537
1338	43929	44126	44126	44323	44521	44719	44918	45117	45317	45517
1339	45918	46120	46120	46322	46525	46727	46931	47135	47339	47545
1340	47956	48162	48162	48369	48577	48785	48994	49203	49412	49623
1341	50045	50256	50256	50469	50682	50895	51109	51324	51539	51755
1342	52188	52405	52405	52623	52842	53061	53280	53500	53721	53943
1343	54387	54611	54611	54834	55171.43					

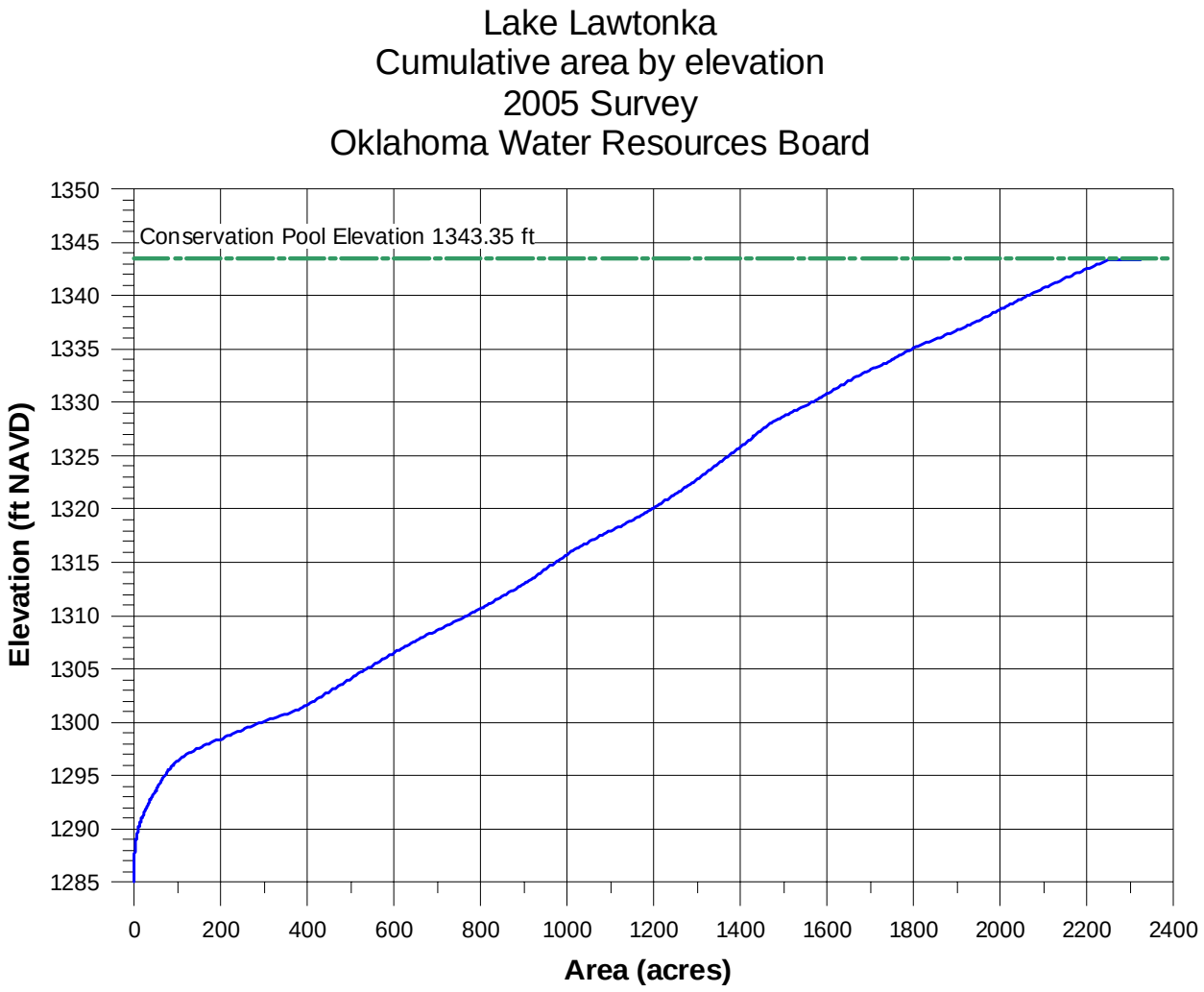

Figure B. 1: Lake Lawtonka Area-Elevation Curve.

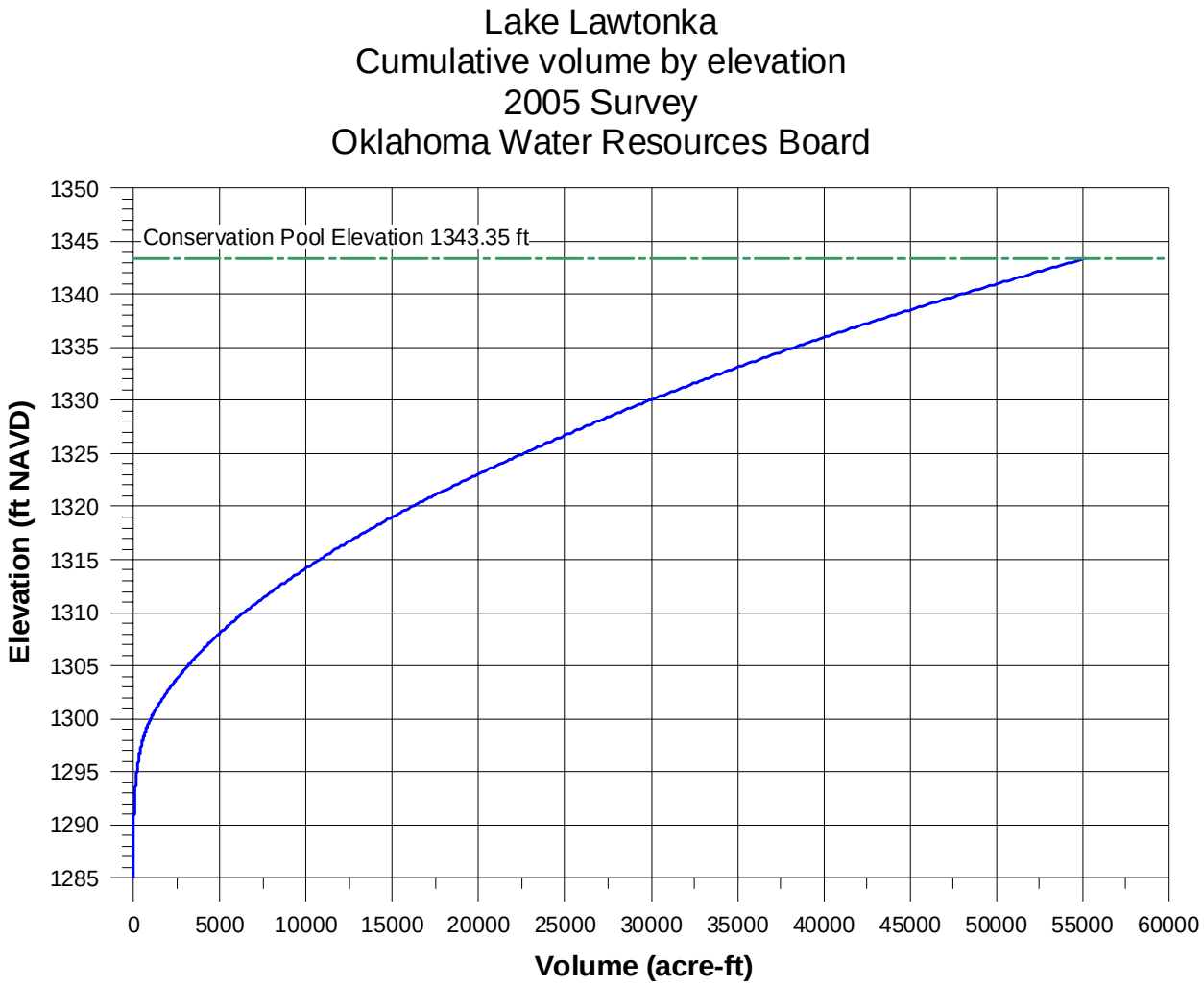

Figure B. 2: Lake Lawtonka Volume-Elevation Curve.

Appendix C: Lake Lawtonka Bathymetric Maps

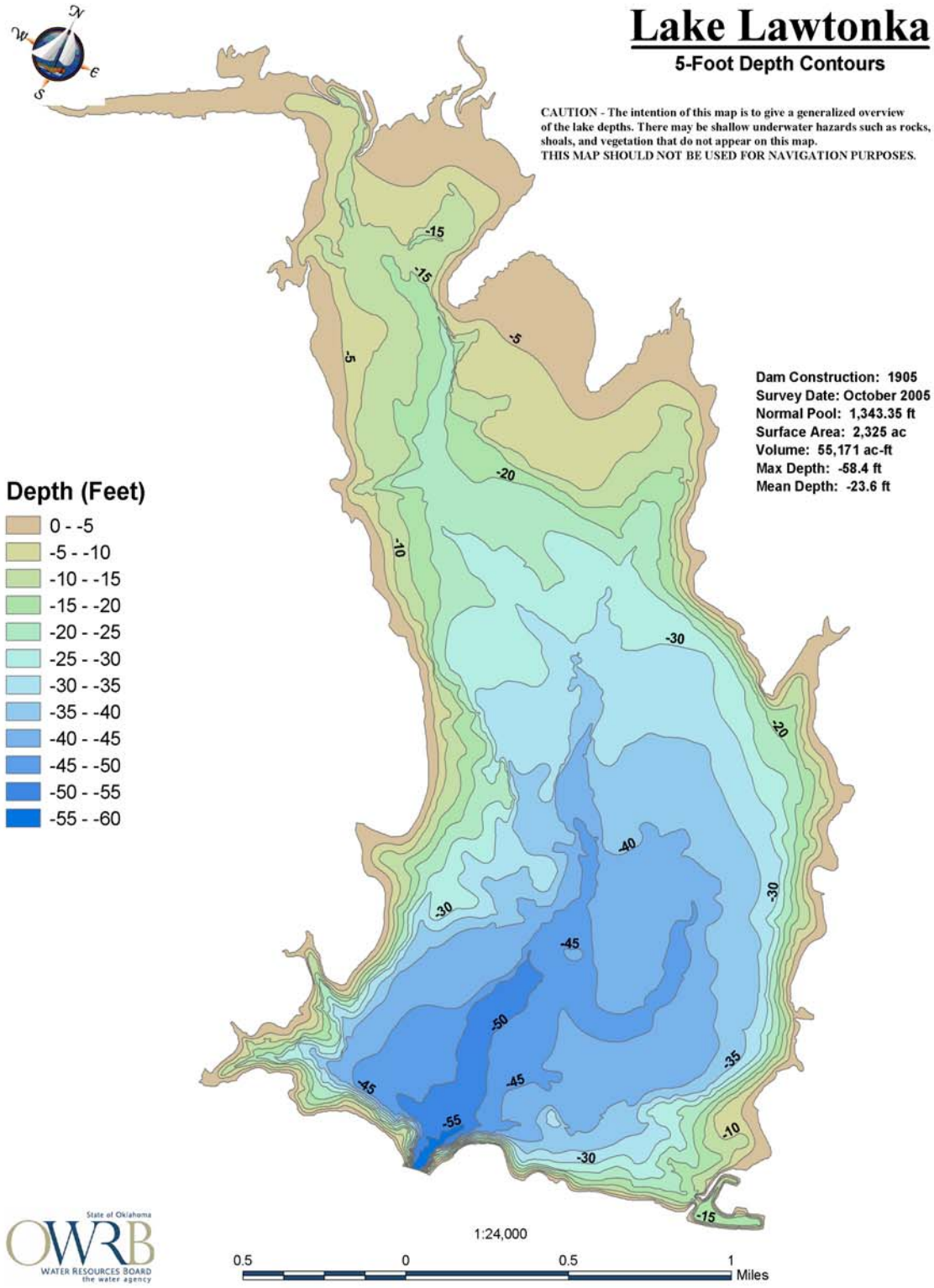

Figure C. 1: Lake Lawtonka Bathymetric Map with 5-foot Contour Intervals.

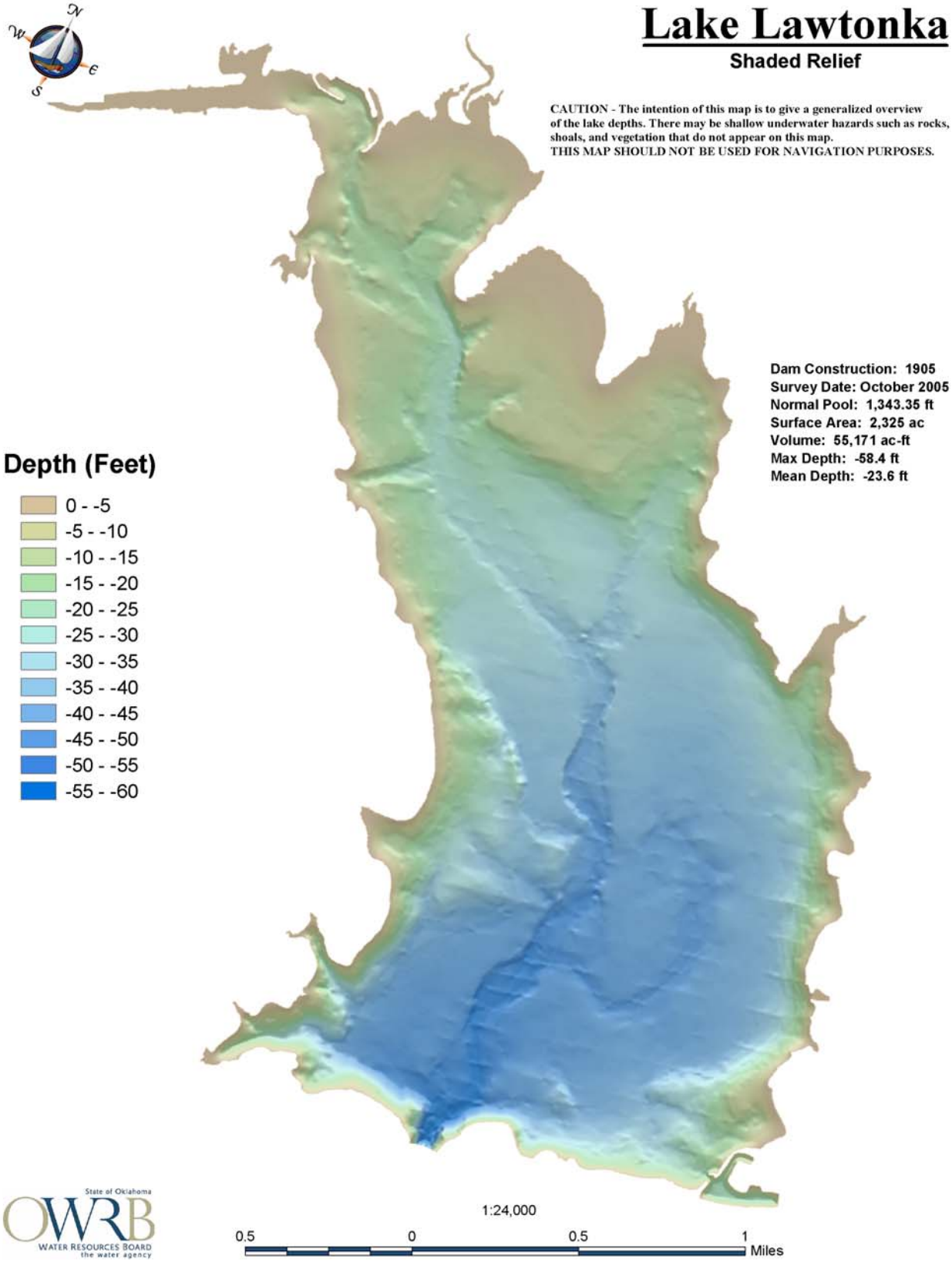

Figure C. 2: Lake Lawtonka Shaded Relief Bathymetric Map.

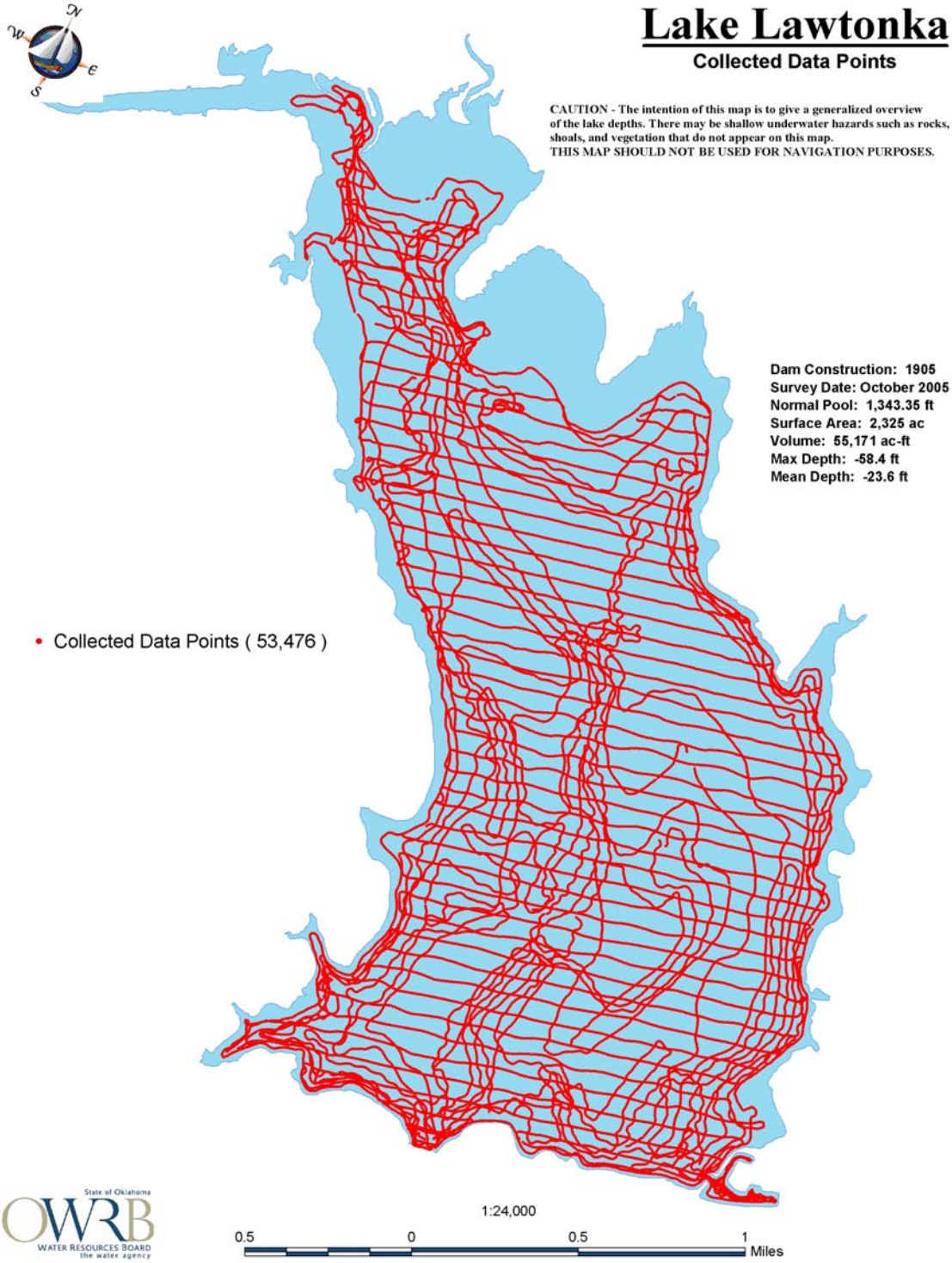

Figure C. 3: Collected Data Points.