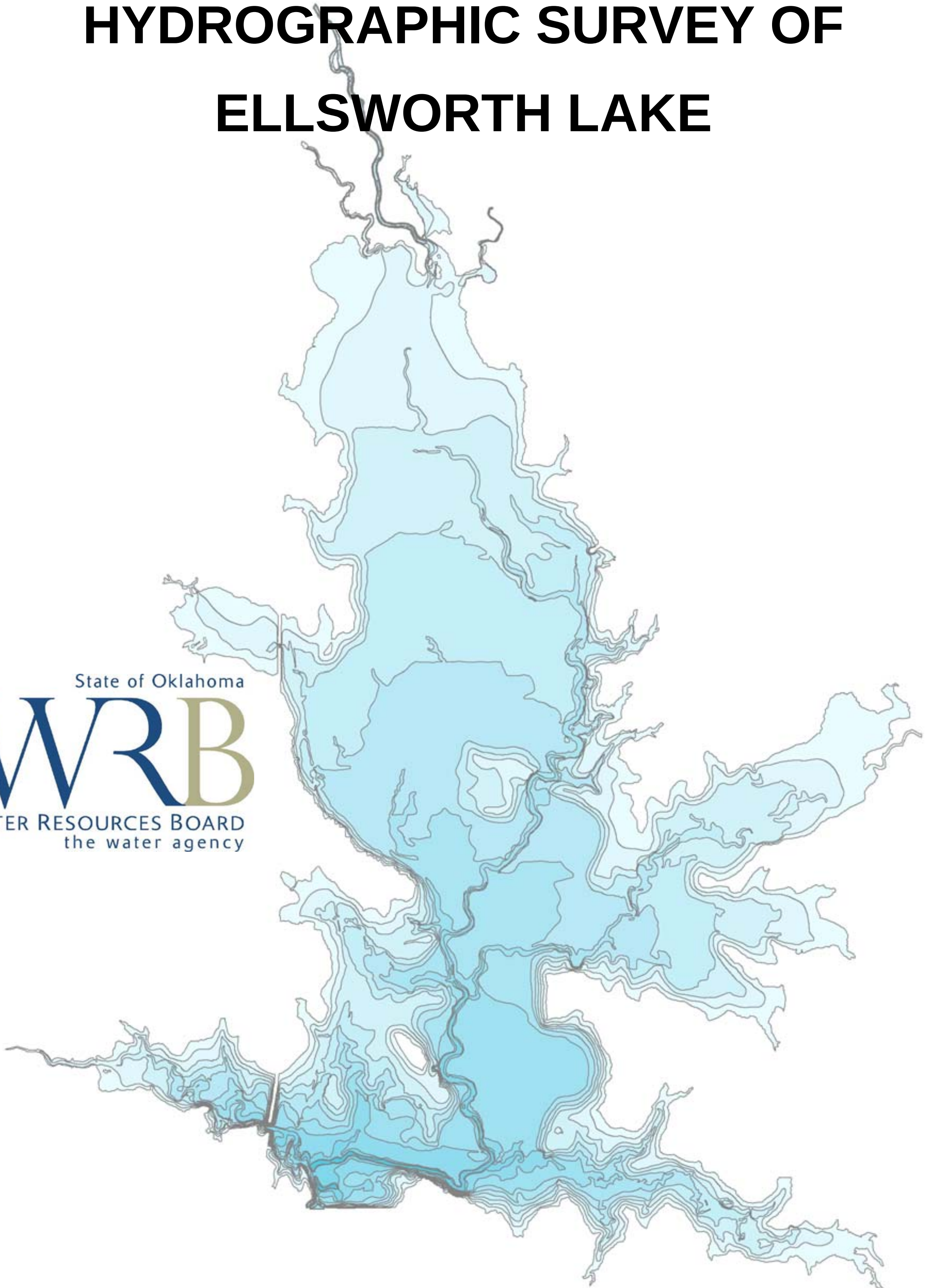
HYDROGRAPHIC SURVEY OF ELLSWORTH LAKE



Prepared by:
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LAKE ELLSWORTH HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Lake Ellsworth in the summer of 2005. The purpose of the study was to collect hydrographic data of Lake Ellsworth 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.

Lake Ellsworth is located on East Cache Creek, a tributary of the Red River, approximately 11 miles northeast of the City of Lawton, Oklahoma in Comanche County. A general location map of Lake Ellsworth is shown on the following page (**Figure 1**). Lake Ellsworth 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 Ellsworth 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 secondary water supply.

LAKE HISTORY AND PERTINENT INFORMATION

Background

Lake Lawtonka provided the majority of the municipal water to the City of Lawton until 1961. When the city grew in the early 1950's it was apparent that an additional source of water was needed.

On August 20, 1956 the City of Lawton secured approval of the electorate for construction of what was then called East Cache Creek Reservoir, now known as Lake Ellsworth (City of Lawton, 1982). A local consultant, Wyatt B. Hendrick, completed the design of the lake and a local contractor, Freeman Construction Company, completed the construction. Construction started in 1959 and was completed in 1962. A 42-inch high-pressure water line approximately eight miles from Lake Ellsworth to Lake Lawtonka was installed to allow the City of Lawton to treat Ellsworth raw water at the Lawtonka treatment facility (LMAPC, 1969). Additional references can be found in the U.S. Bureau of Reclamation, Cache Creek Drainage Basin Oklahoma, Rainfall-Runoff Model Using HEC-1 (1995).

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).

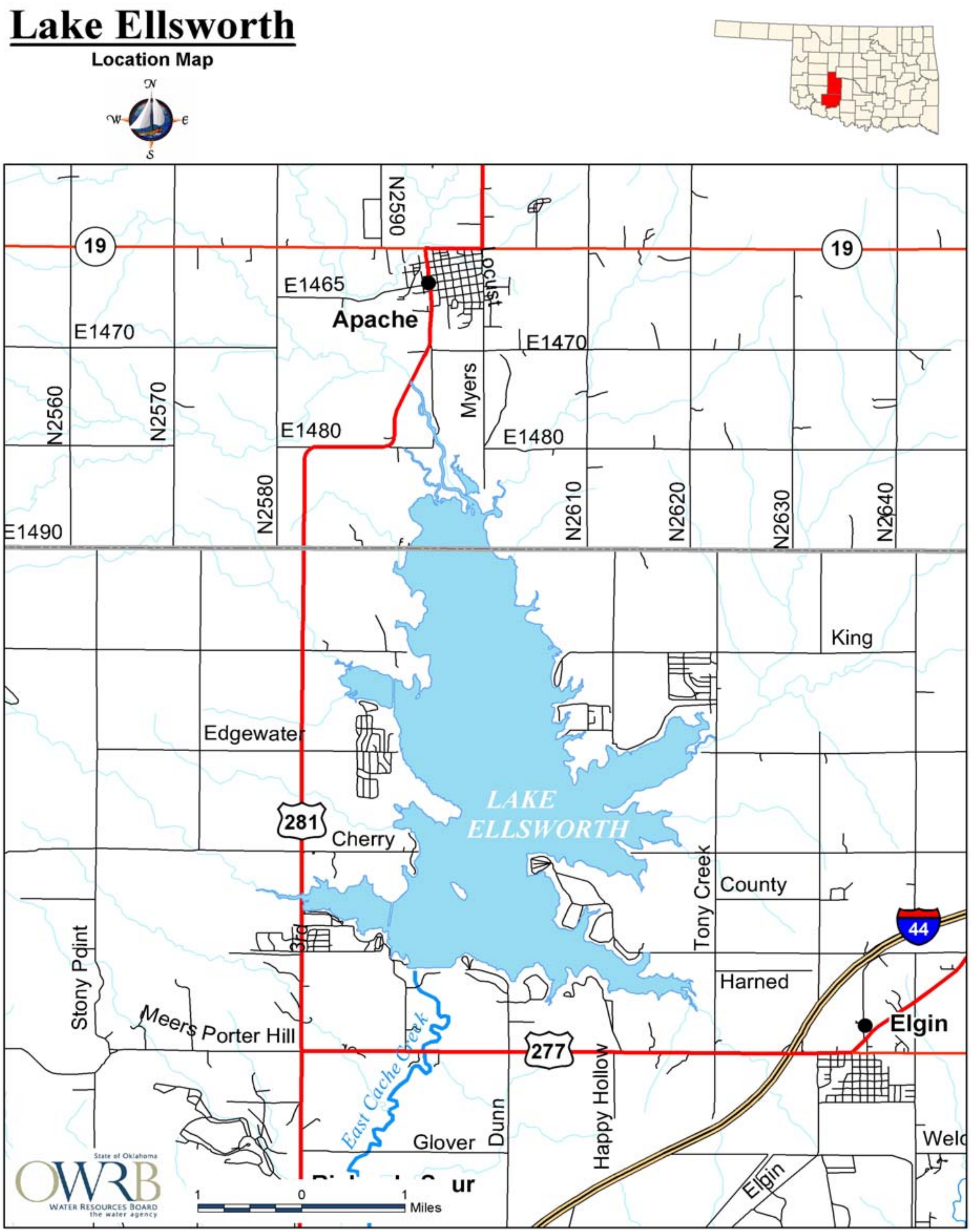

Figure 1: Location map for Lake Ellsworth.

Lake Ellsworth is located in the Central Great Plains ecoregion, which consists of a 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 Ellsworth is devoted to agricultural purposes with the majority being used for grasslands, small grains, row crops, and pasture/hay. There is some low intensity residential and commercial/industrial area located within the watershed. The City of Apache is located upstream of Lake Ellsworth.

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, and Fort Sill Apache tribal trust land for which no reservation exists.

Water Rights

The OWRB currently adjudicates the water rights for Lake Ellsworth and its tributaries. A vested right based on application #1955-1468 was filed on 09/22/1955 to appropriate 33,000 acre-feet/year (ac-ft/yr) from Lake Ellsworth on East Cache Creek. It was recognized in Final Order Establishing Vested Surface Water Rights for Steam System 1-13 (approved 06/09/1964 by OWRB) and was amended on 05/13/1986 to total 9,866 ac-ft/yr for municipal use by the City of Lawton.

Water right permit #1985-23 was issued on 05/13/1986 to the City of Lawton for 13,634 ac-ft/yr for municipal use. The schedule of use is shown below in **Table 1**.

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

Year	Amount (ac-ft)	Percentage (%)
2015	1,863	14
2025	2,841	21
2035	3,577	26
2045	4,942	36
2055	8,867	65
2065	13,634	100

Water right permit #1986-047 was issued on 03/16/1987 to the Oklahoma Department of Wildlife Conservation for 250 ac-ft/yr on East Cache Creek for recreation (fish and wildlife) use.

Outlet Works

Ellsworth Lake dam is a combination earth fill and concrete structure. **Table 2** lists some of the relevant details of the dam and outlet works. Each embankment consists of a central impervious core founded on rock, upstream and downstream pervious fill zones, upstream riprap, and a three ft thick downstream horizontal drainage blanket (OWRB/USACE, 1978). The structure is 3,900 feet (ft) long with a top width of 30 ft and the top of the dam is at elevation 1,250 ft National Geodetic Vertical Datum 29 (NGVD), resulting in a maximum height above streambed of approximately 96 ft.

Originally, the dam consisted of a gravity spillway with a top elevation of 1,225 ft NGVD. Piers and other concrete appurtenances were also constructed to facilitate addition at a later date of roller gates (City of Lawton, 1982). From March to July 1969, contractor W.D. Ford and Son, placed 15- 10 ft high X 20 ft wide steel roller control gates on the previously constructed dam. The spillway is flanked by counter-forted retaining walls extending downstream, and by intake structures for water supply and outlet works extending upstream (OWRB/USACE, 1978). The concrete structure has a width of 363 ft and a crest elevation of 1,235 ft NGVD.

Table 2: Ellsworth Dam and Lake Ellsworth Pertinent Data.

Owner of Ellsworth Dam and Facilities	
City of Lawton	
Operator of Ellsworth Dam and Facilities	
City of Lawton	
Engineer	
Wyatt B. Hendrick (Design)	
Location	
On East Cache Creek, a tributary of the Red River in Comanche County, approximately eleven miles northeast of Lawton, Oklahoma.	
Drainage Area	
251 square miles (Above Ellsworth dam site) or 34% of the total basin area of East Cache Creek (MWE, 1987)	
Embankment	
Location	On East Cache Creek just below its junction with Chandler Creek and Tony Creek
Type	Earth fill and concrete
Length	3,900 ft
Top Width	30 ft
Elevation	1,250 ft NGVD
Maximum Height	96 ft

Elevation of streambed	1,154 ft ± NGVD
Spillway	
Location	Right abutment
Type	Concrete, Gated Ogee
Length	363 ft
Crest Elevation	1,225 ft NGVD
Gates	Steel roller, 15- 10 feet high X 20 ft wide
Top of Gates Elevation	1,235 ft NGVD
Outlet Works	
Type	2-5 ft diameter gated conduits located in the spillway
Invert Elevation	1,185 ft NGVD
Water Line	42 inch diversion pipe to Lawtonka treatment facility

The outlet works consist of a gated intake structure and two-five ft diameter outlet pipes with invert elevations of 1,185 ft NGVD. The outlet pipes discharge into the stilling basin. The water supply intake tower supplies three 10,000 gallon-per-minute centrifugal pumps located in the pump house on the west side of the retaining wall at the downstream toe of the right embankment (OWRB/USACE, 1978).

Lake Design Specifications

Lake Ellsworth was formed by obstructing the flow of East Cache Creek just below its junction with Chandler Creek and Tony Creek. The dam was completed in 1962 with a maximum pool elevation of 1,225 ft NGVD and a storage capacity of 35,224 acre-feet (ac-ft), exclusive of a reserve of 12,300 ac-ft for sedimentation during a 50-yr period (LMAPC, 1969).

In October 1968, the City of Lawton awarded a contract to affix 10 ft high steel floodgates to appurtenances already in place on top of the concrete spillway, providing a maximum pool elevation of 1,235 ft NGVD upon completion of the project. The storage capacity (excluding reserve for sedimentation) was projected to be 82,855 ac-ft (LMAPC, 1969).

The “normal” water surface elevation at the Lake Ellsworth will be maintained year-round at elevation 1,232.5 ft NGVD (2.5 ft below the maximum pool storage elevation of 1,235 ft NGVD with gates closed) (City of Lawton, 2004). The change in operation is to provide downstream flood protection during a storm event.

In 1969 when the steel roller control gates were installed the original reference marks were destroyed. The last time the U.S. Geological Survey (USGS) ran levels at Lake Ellsworth they came off a global positioning system (GPS) reference point established by the City of Lawton. The gage datum elevation was + 0.47 ft using the elevation of the City of Lawton's reference point, based on NAVD of 1988 (USGS personal communication, December 15, 2005). The gage 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) 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 Ellsworth was produced from the one-meter 1995 black and white USGS digital ortho quarter quads (DOQQs) 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). Data used for digitization are summarized in **Table 3**. The photo dates for the black and white DOQQs were 19950205 and 19950219. On these days the lake levels were 1,233.65 ft and 1,233.66 ft NAVD. Although there is a 1.15 ft difference in elevation between "normal" pool elevation 1,232.5 ft and the level in the DOQQs, this was the best available data at the time. The 2003 United States Department of Agriculture-Farm Service Agency-Aerial Photography

Field Office (USDA-FSA-APFO) color DOQQs photo dates were 20030615 and lake level elevation was 1,226.06 ft NAVD. These photos were used as additional reference.

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

DOQQs	Date	Elevation (NAVD, ft)
USDA-FSA-APFO - Comanche and Caddo County, OK	20030615	1,226.06
USGS - Elgin NW and Elgin SW	19950205	1,233.65
USGS - Richards Spur SE and Richards Spur NE	19950219	1,233.66

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 172 virtual transects were created for the Ellsworth 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/s) 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 4,836.02 ft/sec to 4,931.26 ft/sec during the Lake Ellsworth 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 144 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 -0.09 ft and a standard deviation of 0.69 ft were computed from a number of 144 data points. Using the following formulas, a 95% depth accuracy of ±0.21 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).

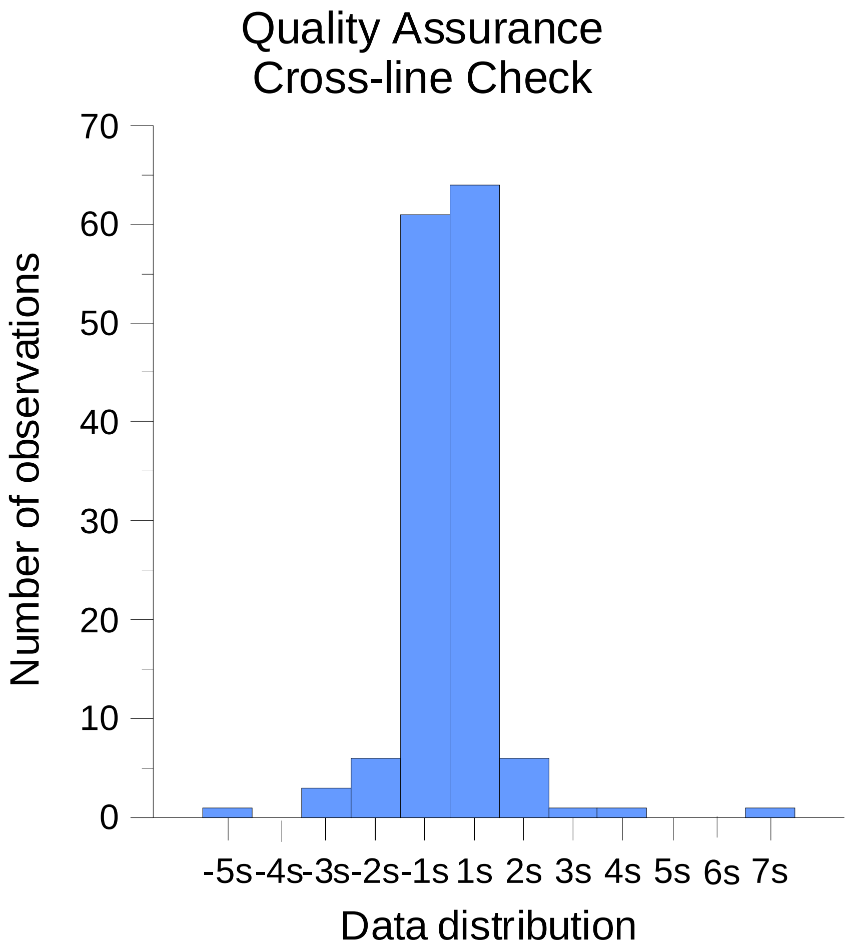

Figure 2: Histogram of relative depth distribution, in standard deviations, at cross-line intersections.

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 0.04 to +0.46 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 Configurator 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 -.10 seconds was produced and adjustments were applied to the raw data in the EDIT program.

Field Survey

Data collection for Lake Ellsworth occurred June 6, 8, 14, 15, 16, 20, 21, 22, 23, and 24; and August 17 and 23, 2005. The water level elevation during the data collection process for June was approximately 2.8 ft below "normal" pool elevation 1,232.5 ft (USGS, 2005). In August 2005, the water level elevation was approximately 4.5 ft below the "normal" pool elevation 1,232.5 ft NAVD. (USGS, 2005).

Data collection began at the dam area, proceeded to the cove east of the dam, and ended in the Tony and Chandler Creek cove areas. 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. Data was collected in the upper end of Lake Ellsworth until the boat could no longer navigate in the shallow, heavily vegetated waters. In order to survey East Cache Creek above Lake Ellsworth, the boat was taken to a boat ramp located on the East Cache Creek. The survey extended up to where US Highway 281 crosses East Cache Creek. Approximately 1,000 ft was impassable from the upper end of Lake Ellsworth to where East Cache Creek drains into the lake, documented in **Appendix C.**

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, East Cache Creek, Tony Creek, and Chandler Creek areas. Approximately, 52 channel and contour track lines were created for Lake Ellsworth. 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.

The crew was able to collect data on 156 of the 172 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 1,672,950 data points were collected while traversing a total of 271 US nautical miles. The data points were stored on the boat's computer in 468 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 -0.10 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 Ellsworth Lake is located at the end of the document on the CD entitled *Ellsworth 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 115,406 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 Ellsworth Lake is located at the end of the document on the CD entitled *Ellsworth HYPACK/GIS Metadata.*

RESULTS

Results from the 2005 OWRB survey indicate Lake Ellsworth encompasses 5,113 acres and contains a cumulative capacity of 81,554 ac-ft at “normal” pool elevation 1,232.5 ft NAVD. The shoreline calculated from the digitized reservoir boundary was 53.5 miles. The average depth for Ellsworth Lake was 15.8 ft with a maximum depth of 54.2 ft.

SUMMARY AND COMPARISONS

Ellsworth Dam was completed in 1962. Lake Ellsworth had a cumulative volume of 47,524 ac-ft of water at the then maximum pool elevation to 1,225 ft NGVD (LMACP, 1969). After the addition of the 15-10X20 ft steel gates, the maximum pool elevation was raised to 1,235 ft NGVD, and the storage capacity (excluding reserve for sedimentation) was projected to be 82,855 ac-ft (LMAPC, 1969).

The “normal” water surface elevation at the Lake Ellsworth will be maintained year-round at elevation 1,232.5 ft NGVD (2.5 ft below the maximum pool storage elevation of 1,235 ft NGVD with gates closed) (City of Lawton, 2004). The change in operation is to provide downstream flood protection during a storm event. After the survey was completed, discussion with the USGS indicated that the local datum of the gage was based on NAVD of 1988, which is 0.47 ft above NGVD, (USGS personal communication, December 15, 2005).

OWRB performed a hydrographic survey of Lake Ellsworth in June and August. For the production of the DEM of Lake Ellsworth's bathymetry, a DGPS, echo sounder, and GIS were utilized. The OWRB survey delineated 5,113 acres and a cumulative capacity of 81,554 ac-ft at "normal" pool elevation 1,232.5 ft NAVD 88 (**Table 4**).

Table 4: Reservoir Data from OWRB 2005 Survey.

Feature	Elevation (NAVD 88)	Area (acres)	Capacity (ac-ft)
Normal Pool	1,232.5	5,113	81,554
Sediment Storage	1,210	1,291	9,016

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 81,554 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 June 6 through 21, 2005.

Depth	6/6/05	6/8/05	6/14/05	6/15/05	6/16/05	6/21/05
1				4930.77	4928.15	
2		4909.78	4923.56	4927.49	4927.82	4942.91
3		4909.45	4922.90	4926.84	4927.49	4939.63
4	4901.57	4908.79	4922.24	4926.84	4927.49	4935.37
5	4901.25	4908.14	4921.26	4926.18	4927.17	4933.40
6	4900.92	4908.79	4920.93	4926.18	4926.84	4932.09
7	4900.59	4908.14	4920.60	4925.52	4926.51	4931.43
8	4900.59	4908.14	4920.28	4924.87	4926.18	4930.45
9	4900.59	4907.81	4919.95	4923.88	4925.85	4929.79
10	4900.59	4907.81	4919.62	4922.57	4925.52	4929.13
11	4900.59	4907.48	4919.29	4920.28	4924.87	4928.15
12	4900.59	4907.48	4918.96	4918.96	4924.21	4927.17
13	4900.26	4907.48	4918.96	4918.31	4923.56	4926.84
14	4900.26	4907.48	4918.96	4917.65	4923.56	4926.18
15	4900.26	4907.15	4918.64	4916.99	4923.56	4925.85
16	4900.26	4906.82	4918.31	4916.34	4923.56	4925.20
17	4900.26	4906.50	4918.31	4915.68	4923.56	4924.87
18	4900.26	4906.50	4917.65	4915.35	4923.23	4924.87
19	4900.26	4906.17	4916.99	4914.70	4923.23	4921.59
20	4900.26	4905.84	4916.67	4914.37	4920.28	4920.93
21	4900.26	4905.18	4915.35	4914.37	4919.62	4920.60
22	4899.93	4904.53	4914.37	4913.71	4917.98	4920.60
23	4899.93	4903.87	4913.39	4913.39	4916.99	
24	4899.93	4903.22	4912.07	4912.40	4916.01	
25	4899.61	4902.89	4911.42	4911.75	4915.68	
26	4899.61	4902.23	4911.09	4911.09	4915.03	
27	4898.29	4901.57	4910.43	4910.76	4914.70	
28	4897.64	4900.92	4909.12	4910.76	4914.37	
29	4897.31	4899.93	4908.79	4909.12	4914.37	
30	4896.33	4898.95	4907.81	4908.46		
31	4896.00	4897.64	4906.50	4908.14		
32	4895.67	4895.67	4905.51	4907.81		
33	4895.01	4893.70	4904.86	4907.15		
34	4895.01	4892.39	4903.54	4906.82		
35	4894.69	4891.40	4901.57	4906.50		
36	4893.37	4890.42	4897.64	4906.17		
37	4891.73	4889.11	4897.97	4905.51		
38	4890.09	4886.48	4895.34	4904.86		
39		4884.19	4895.67			
40		4880.58	4890.09			
41		4877.30	4888.78			
42		4875.66	4887.47			
43		4871.72	4885.83			
44		4869.75	4883.86			
45		4868.77	4882.87			
46		4864.50	4883.53			
47		4862.86				
48		4851.71				

Table A. 2: Sound Velocity Profile Data for June 22 through August 23, 2005.

Depth	6-22-05 Chandler Cove	6-22-05 Upper End	6/23/05	6/24/05	8/17/05	8/23/05
1	4944.88	4935.37			4927.82	4937.99
2	4944.23	4934.38	4927.82		4926.51	4937.01
3	4943.57	4932.41	4927.49	4925.00	4925.20	4936.35
4	4941.27	4927.49	4927.17	4924.90	4925.20	4936.35
5	4937.99	4922.90	4926.51	4924.90	4925.20	4936.02
6	4937.66	4917.65	4925.85	4924.80	4924.87	4936.02
7	4934.38	4910.43	4925.20	4924.70	4924.87	4936.02
8	4932.09	4904.20	4924.54	4924.70	4924.87	4936.02
9	4929.13	4898.95	4923.88	4924.51	4924.87	4936.02
10	4928.15	4893.04	4923.56	4924.41	4924.87	4936.02
11	4927.17	4891.40	4923.23	4924.21	4924.87	4936.02
12	4926.51	4879.59	4922.90	4924.11	4924.87	4936.02
13	4926.18	4880.58	4922.24	4923.88	4924.87	4935.70
14	4924.54		4921.92	4923.79	4924.87	4935.70
15	4924.21		4921.59	4923.39	4924.87	4935.37
16	4923.56		4921.59	4922.90	4924.87	4935.04
17	4922.90		4920.93	4922.31	4924.54	4935.04
18	4922.57		4920.28	4921.59	4924.54	4935.04
19	4921.92		4919.62	4921.10	4924.54	4934.71
20	4920.93		4918.96	4920.60	4924.21	4934.71
21	4918.64		4918.31	4920.21	4924.21	4934.38
22	4916.99		4917.65	4919.82	4924.21	4934.06
23	4916.01		4916.34	4919.49	4924.21	4933.40
24	4915.35		4915.03	4919.09	4924.21	4932.09
25	4914.70		4914.70	4918.50	4923.88	4930.45
26	4914.37		4914.37	4918.01	4923.88	4929.79
27	4913.71		4913.71	4917.29	4923.88	4929.13
28	4913.06		4913.39	4916.50	4923.56	4928.48
29	4912.40		4912.40	4915.58	4923.56	4928.15
30	4911.75		4912.07	4914.60	4923.23	4928.15
31	4911.42		4911.42	4913.62	4923.23	4927.82
32	4910.76		4910.43	4912.89	4923.23	4927.49
33	4910.10		4909.45	4912.20	4922.90	4927.17
34	4909.78		4907.81	4911.52	4922.90	4926.51
35	4909.45		4906.50	4910.30	4922.90	4926.51
36	4909.12		4905.51	4908.79	4922.57	4925.85
37	4909.45		4904.86	4907.19	4922.24	4925.52
38	4909.12		4904.20	4905.41	4922.24	4925.52
39			4902.56	4903.81	4921.92	4925.20
40			4900.59	4901.21	4921.59	4924.87
41			4897.97	4898.20	4920.60	4923.88
42			4893.70	4893.41	4919.62	4922.57
43			4887.47	4888.39	4918.31	4919.95
44			4881.56	4883.20	4918.96	4921.26
45			4877.62	4880.81		
46			4875.00	4877.20		
47			4871.06	4872.11		
48			4872.70	4872.60		

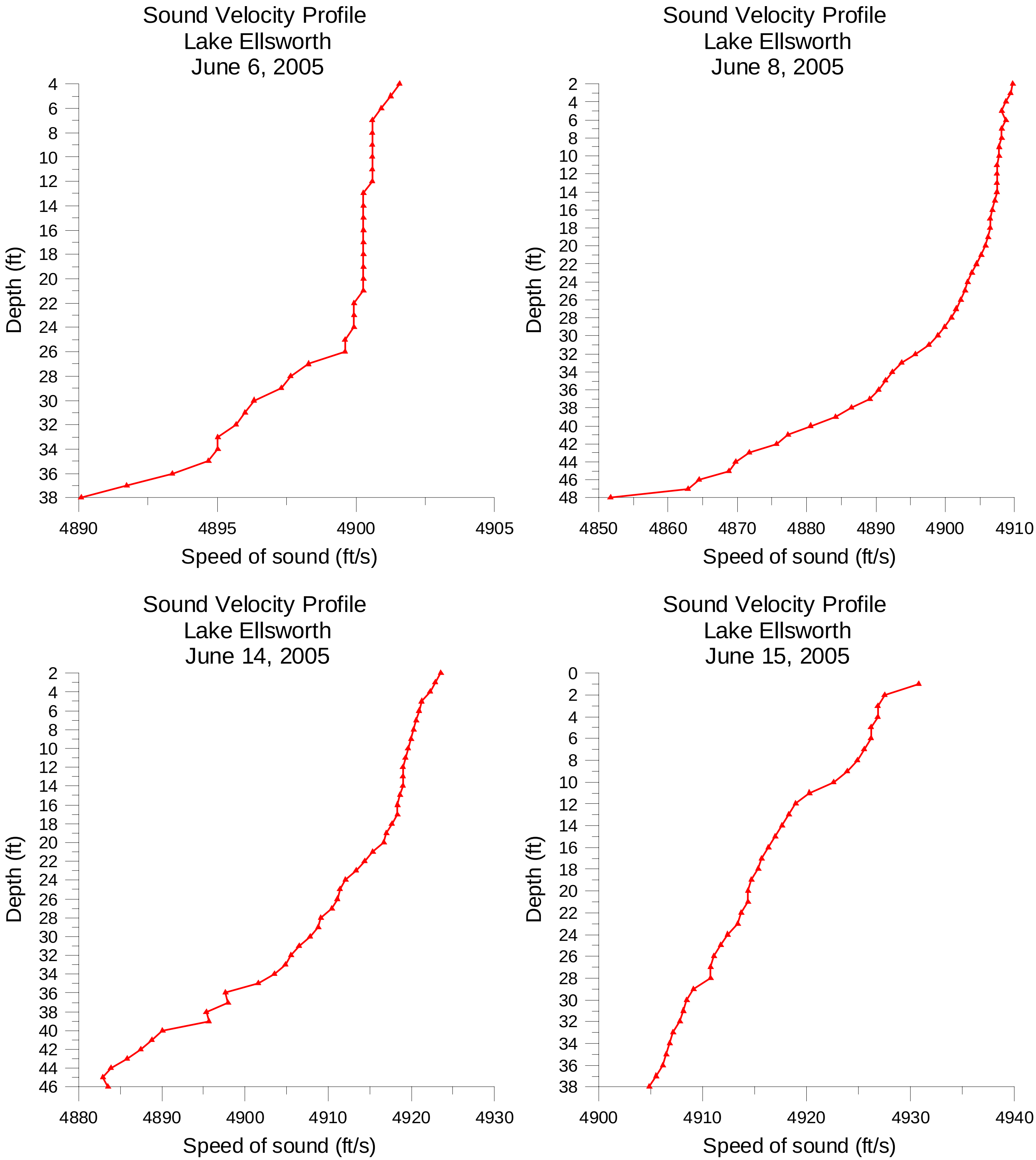

Figure A. 1: Sound Velocity Profiles for June 6, 8, 14, and 15, 2005.

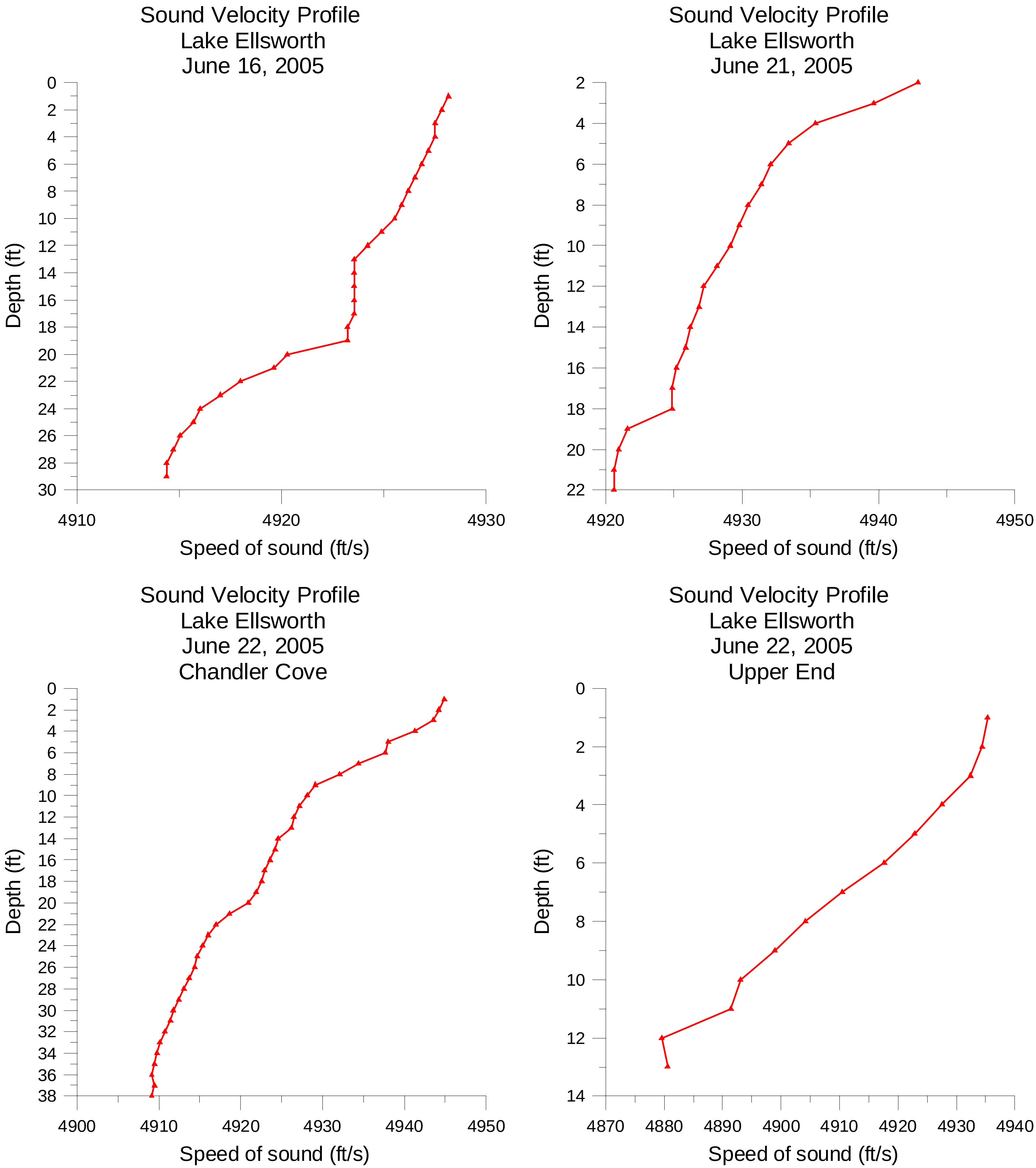

Figure A. 2: Sound Velocity Profiles for June 16, 21, and 22, 2005.

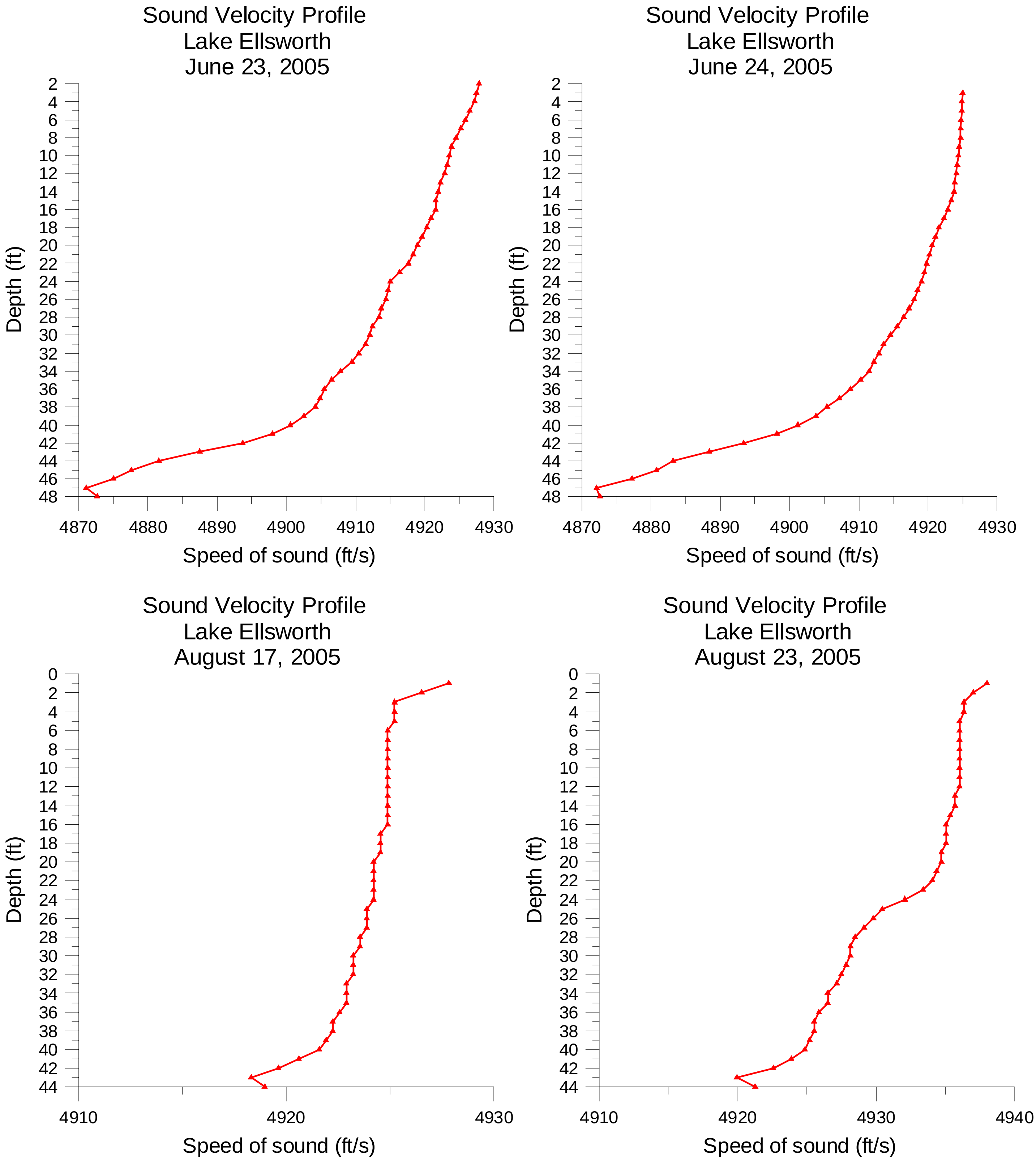

Figure A. 3: Sound Velocity Profiles for June 23 and 24, August 17 and 23, 2005.

Appendix B: Area-Capacity Data

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

LAKE ELLSWORTH 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
1178								0.064	0.1163	0.192
1179	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.9
1180	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6
1181	1.8	1.9	2.1	2.3	2.5	2.8	3.1	3.3	3.6	3.9
1182	4.1	4.4	4.7	5.1	5.5	6.1	7.4	7.5	7.6	7.8
1183	7.9	8.1	8.2	8.4	8.5	8.7	8.8	9.0	9.1	9.3
1184	9.4	9.5	9.7	9.8	10.0	10.1	10.3	10.4	10.6	10.7
1185	10.9	11.1	11.2	11.4	11.6	11.8	12.0	12.2	12.5	13
1186	13	13	14	14	14	14	15	15	15	16
1187	16	16	17	17	18	18	20	20	21	21
1188	21	22	22	23	23	24	24	25	25	26
1189	26	27	27	28	28	29	30	31	32	32
1190	33	34	35	35	36	37	38	39	40	41
1191	42	43	44	45	46	47	48	49	50	52
1192	53	54	56	57	59	61	64	66	68	70
1193	71	73	75	77	79	81	83	85	87	89
1194	91	93	95	97	99	101	104	106	108	111
1195	113	115	118	120	123	125	128	130	133	135
1196	138	140	142	145	147	150	152	155	158	160
1197	163	166	169	172	176	181	190	194	198	203
1198	207	213	218	223	228	232	237	242	247	251
1199	256	261	266	272	279	286	293	301	309	316
1200	324	334	348	363	377	389	398	408	418	427
1201	437	446	456	465	474	481	488	495	502	508
1202	515	521	527	533	538	544	552	557	563	569
1203	574	580	587	594	600	607	613	620	626	632
1204	639	645	651	657	664	671	678	685	692	698
1205	706	713	721	728	735	742	749	756	764	772
1206	780	790	799	809	818	829	839	850	862	873
1207	884	896	910	923	937	953	983	1002	1020	1037
1208	1054	1070	1086	1100	1115	1127	1139	1152	1163	1173
1209	1183	1193	1202	1212	1222	1232	1243	1255	1267	1279
1210	1291	1303	1314	1325	1336	1349	1361	1374	1389	1403
1211	1418	1433	1449	1466	1487	1508	1530	1552	1574	1597
1212	1619	1641	1660	1680	1699	1718	1748	1766	1787	1808
1213	1826	1843	1859	1874	1891	1909	1928	1947	1966	1985
1214	2005	2023	2042	2061	2079	2097	2115	2132	2151	2170

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1215	2188	2206	2224	2241	2258	2274	2291	2307	2324	2341
1216	2358	2375	2390	2405	2421	2436	2451	2467	2482	2497
1217	2513	2529	2545	2562	2579	2599	2629	2648	2666	2683
1218	2700	2716	2732	2749	2767	2784	2802	2819	2838	2857
1219	2878	2898	2918	2939	2959	2978	2997	3018	3036	3053
1220	3068	3083	3099	3115	3131	3147	3163	3180	3196	3212
1221	3229	3244	3260	3275	3291	3306	3322	3337	3353	3369
1222	3386	3403	3419	3435	3452	3468	3501	3518	3534	3550
1223	3565	3581	3597	3612	3628	3644	3660	3677	3692	3708
1224	3724	3739	3755	3771	3787	3803	3818	3834	3850	3865
1225	3882	3898	3915	3932	3949	3964	3980	3994	4008	4021
1226	4033	4046	4058	4070	4082	4094	4105	4117	4128	4140
1227	4151	4162	4173	4184	4195	4205	4286	4298	4309	4321
1228	4333	4345	4357	4369	4381	4393	4405	4417	4430	4442
1229	4454	4466	4479	4491	4503	4516	4528	4541	4553	4566
1230	4578	4591	4603	4616	4629	4642	4654	4667	4680	4693
1231	4706	4719	4732	4745	4758	4771	4784	4797	4810	4823
1232	4837	4850	4863	4877	4890	4903	5113			

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

LAKE ELLSWORTH 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**
1178				0	0.0013	0.0045	0.0088	0.0144	0.0235	0.0388
1179	0.062	0.0926	0.1316	0.18	0.23	0.30	0.37	0.44	0.53	0.62
1180	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9
1181	2.0	2.2	2.4	2.6	2.9	3.2	3.4	3.8	4.1	4.5
1182	4.9	5.3	5.8	6.3	6.8	7.4	8.1	8.8	9.6	10.4
1183	11.1	11.9	12.7	13.6	14.4	15.3	16.2	17.0	18.0	18.9
1184	20	21	22	23	24	25	26	27	28	29
1185	30	31	32	33	34	36	37	38	39	41
1186	42	43	44	46	47	49	50	52	53	55
1187	56	58	59	61	63	65	67	69	71	73
1188	75	77	79	82	84	86	89	91	93	96
1189	99	101	104	107	109	112	115	118	121	125
1190	128	131	135	138	142	145	149	153	157	161
1191	165	169	174	178	183	187	192	197	202	207
1192	212	217	223	229	234	240	247	253	260	267
1193	274	281	289	296	304	312	320	329	337	346
1194	355	364	374	383	393	403	413	424	434	445

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1195	457	468	480	492	504	516	529	542	555	568
1196	582	596	610	624	639	654	669	684	700	716
1197	732	748	765	782	800	817	836	855	875	895
1198	915	936	958	980	1002	1025	1049	1073	1097	1122
1199	1148	1173	1200	1227	1254	1282	1311	1341	1372	1403
1200	1435	1468	1502	1537	1574	1613	1652	1692	1734	1776
1201	1819	1863	1908	1955	2002	2049	2098	2147	2197	2247
1202	2298	2350	2403	2456	2509	2563	2618	2674	2730	2786
1203	2843	2901	2960	3019	3078	3139	3200	3261	3324	3387
1204	3450	3514	3579	3645	3711	3777	3845	3913	3982	4051
1205	4121	4192	4264	4337	4410	4484	4558	4634	4710	4786
1206	4864	4942	5022	5102	5184	5266	5349	5434	5519	5606
1207	5694	5783	5873	5965	6058	6153	6250	6349	6450	6553
1208	6657	6764	6872	6981	7092	7204	7317	7432	7547	7664
1209	7782	7901	8021	8141	8263	8386	8510	8635	8761	8888
1210	9016	9146	9277	9409	9542	9676	9812	9949	10087	10226
1211	10367	10510	10654	10800	10948	11097	11249	11404	11560	11718
1212	11879	12042	12207	12374	12543	12714	12888	13064	13241	13421
1213	13603	13786	13971	14158	14346	14536	14728	14922	15118	15315
1214	15515	15716	15919	16125	16332	16540	16751	16963	17178	17394
1215	17611	17831	18053	18276	18501	18728	18956	19186	19418	19651
1216	19886	20122	20361	20601	20842	21085	21329	21575	21823	22072
1217	22322	22574	22828	23084	23341	23599	23861	24125	24391	24658
1218	24928	25198	25471	25745	26021	26298	26578	26859	27142	27426
1219	27713	28002	28293	28586	28881	29178	29476	29778	30080	30385
1220	30691	30998	31308	31618	31930	32244	32560	32877	33196	33516
1221	33838	34162	34488	34814	35143	35472	35804	36137	36472	36808
1222	37145	37485	37826	38169	38513	38859	39208	39559	39912	40266
1223	40622	40979	41338	41699	42061	42424	42790	43157	43525	43895
1224	44267	44640	45015	45391	45769	46149	46530	46913	47297	47683
1225	48070	48459	48850	49242	49636	50032	50429	50828	51228	51630
1226	52032	52436	52842	53248	53656	54065	54474	54886	55298	55712
1227	56126	56542	56959	57377	57796	58216	58642	59072	59502	59934
1228	60366	60800	61236	61672	62109	62548	62988	63430	63872	64315
1229	64760	65206	65654	66102	66552	67003	67455	67909	68364	68819
1230	69277	69735	70195	70656	71118	71582	72047	72513	72980	73449
1231	73919	74390	74863	75337	75812	76288	76766	77246	77726	78207
1232	78690	79175	79661	80148	80636	81126	81224			

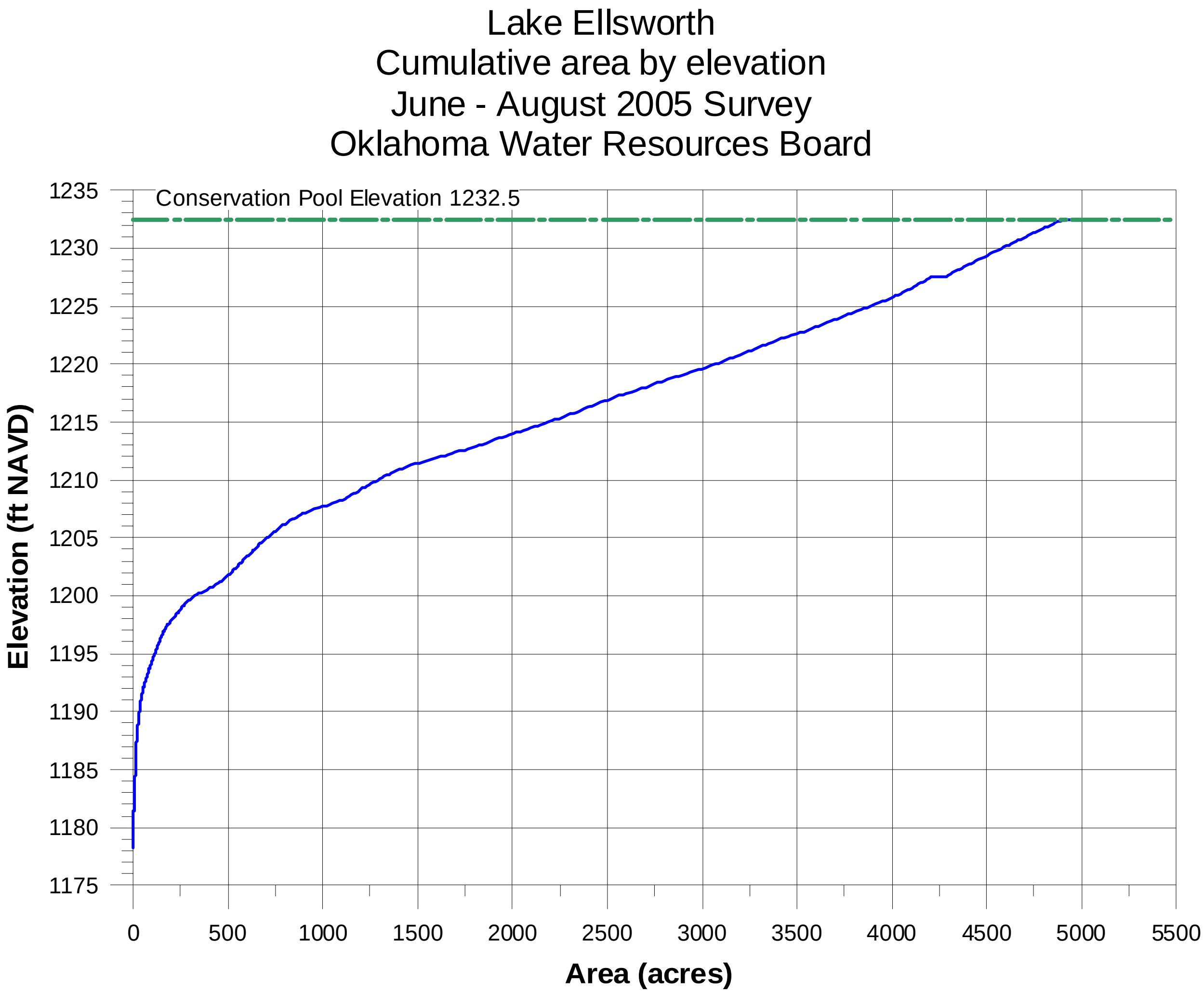

Figure B. 1: Ellsworth Lake Area-Elevation Curve.

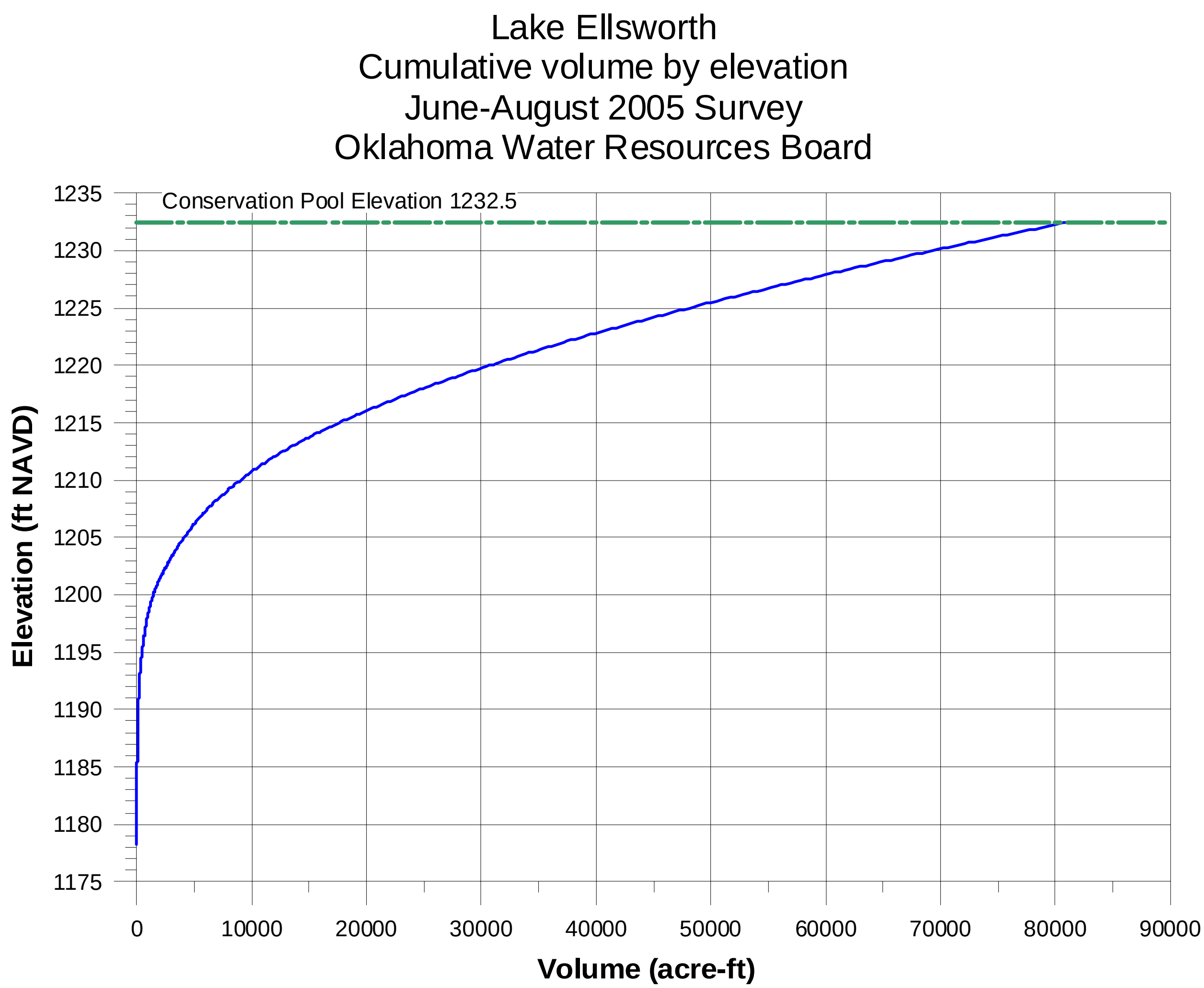

Figure B. 2: Ellsworth Lake Volume-Elevation Curve.

Appendix C: Ellsworth Lake Bathymetric Maps

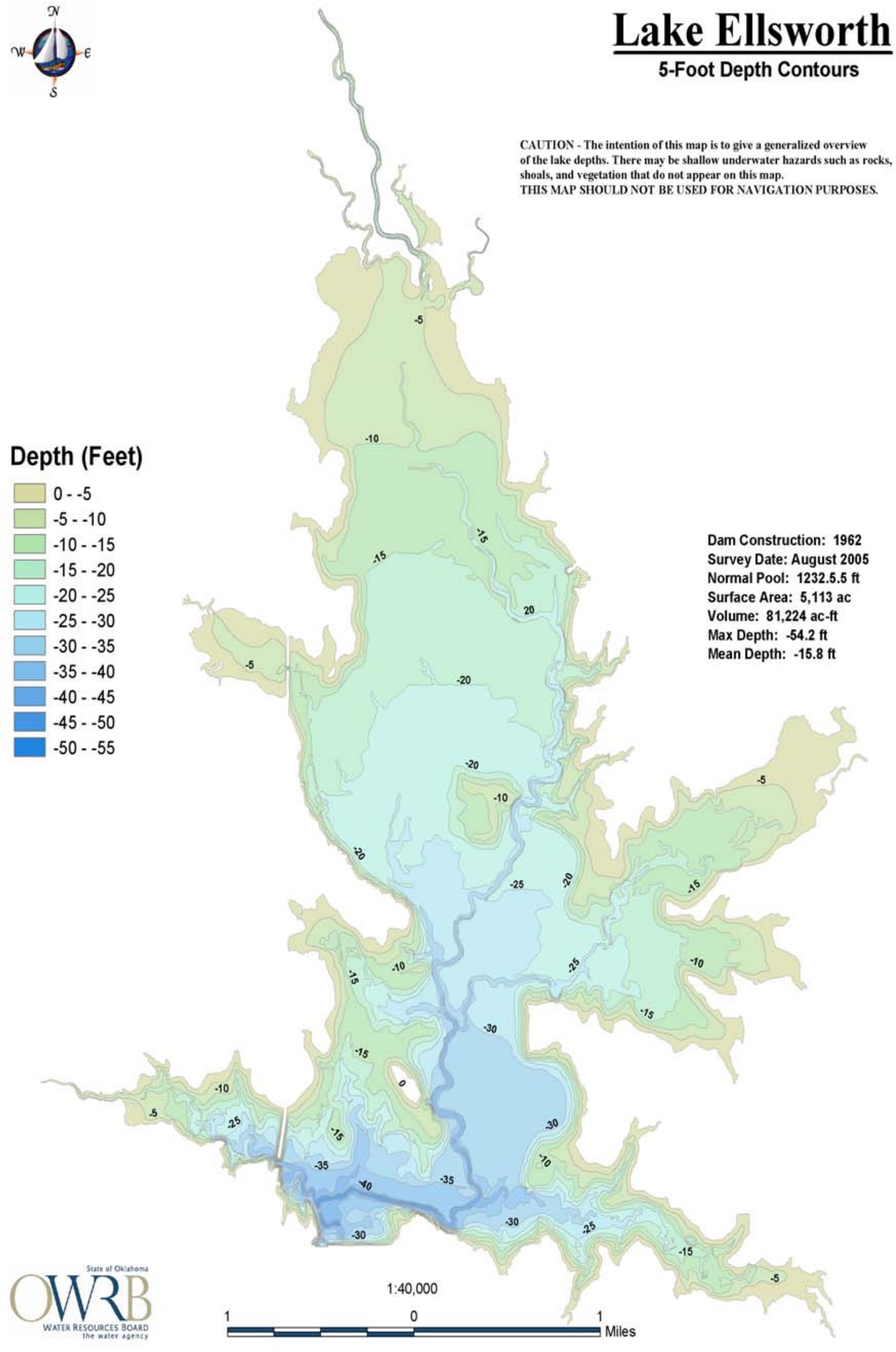

Figure C. 1: Ellsworth Lake Bathymetric Map with 5-ft Contour Intervals.

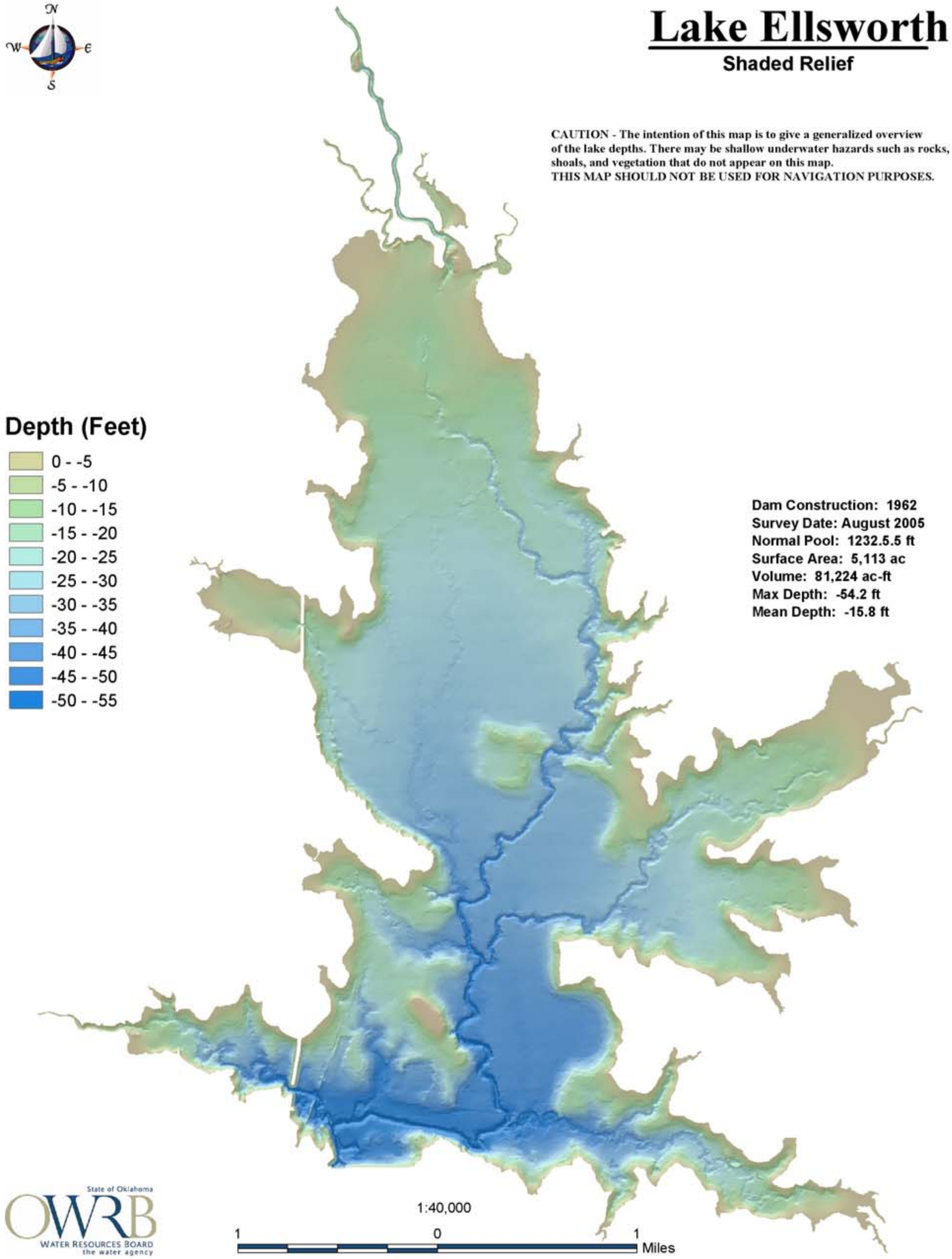

Figure C. 2: Ellsworth Lake Shaded Relief Bathymetric Map.

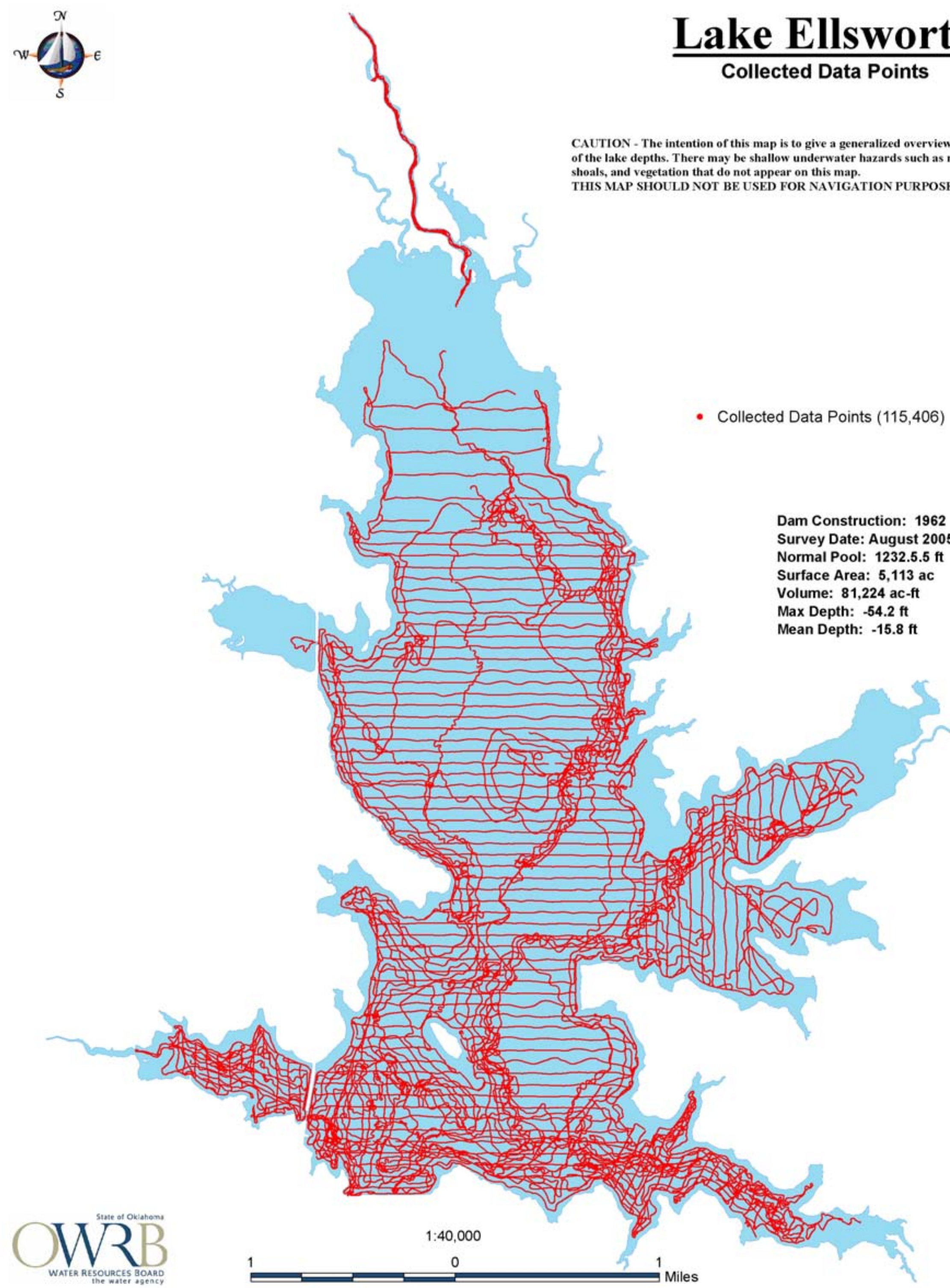

Figure C. 3: Collected Data Points.