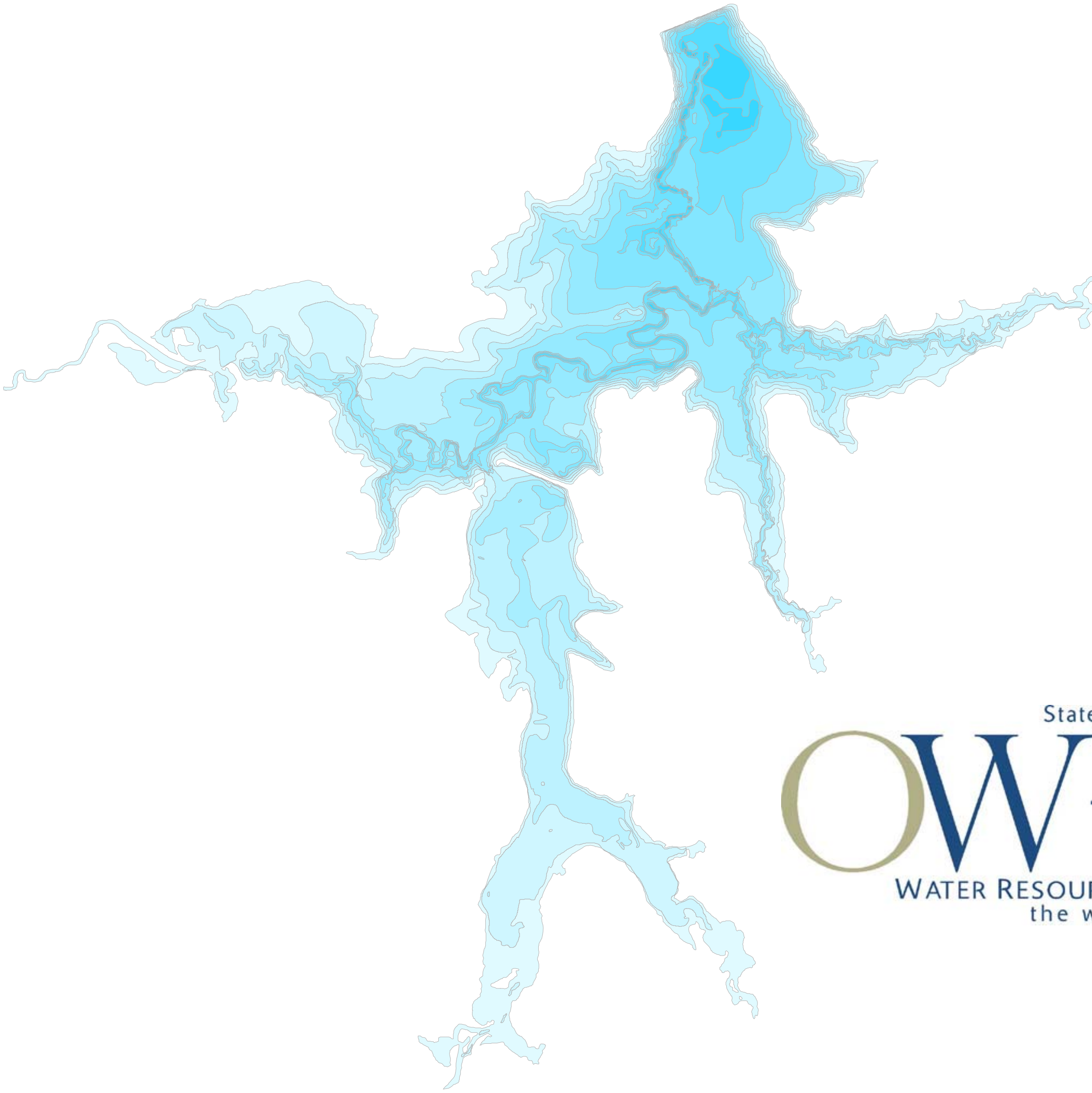
HYDROGRAPHIC SURVEY OF OKEMAH LAKE



Prepared by:
Oklahoma Water Resources Board

December 15, 2006

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

OKEMAH LAKE HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Okemah Lake. The purpose of the study was to collect hydrographic data of Okemah Lake 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 Okemah Lake. All vertical elevations referenced are reported as National Geodetic Vertical Datum (NGVD) 29.

Okemah Lake is located on Buckeye Creek, a tributary of the Deep Fork River in Okfuskee County, approximately 7 miles north of the City of Okemah, Oklahoma. A general location map of Okemah Lake is shown on the following page as **Figure 1**.

Okemah Lake 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. Okemah Lake 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 Okemah owns and operates the lake as its primary water supply.

LAKE HISTORY AND PERTINENT INFORMATION

Background

In September 1934, a bond issue was voted on for the purpose of a lake for a supplemental water supply. The lake was constructed in 1937 and was located on Buckeye Creek, a tributary to Deep Fork River. The surface area of this lake was 35 acres (ac), and a capacity of 350 acre-feet (ac-ft), and drainage area of 12 square miles. (OWRB, 1937)

A new dam and outlet structure for Okemah Lake was constructed on Buckeye Creek in 1962, downstream of the original lake that was constructed in 1937. The second dam for Okemah Lake expanded the lake to a surface area of 738 ac with a cumulative capacity of 13,100 ac-ft (M-J, 1978).

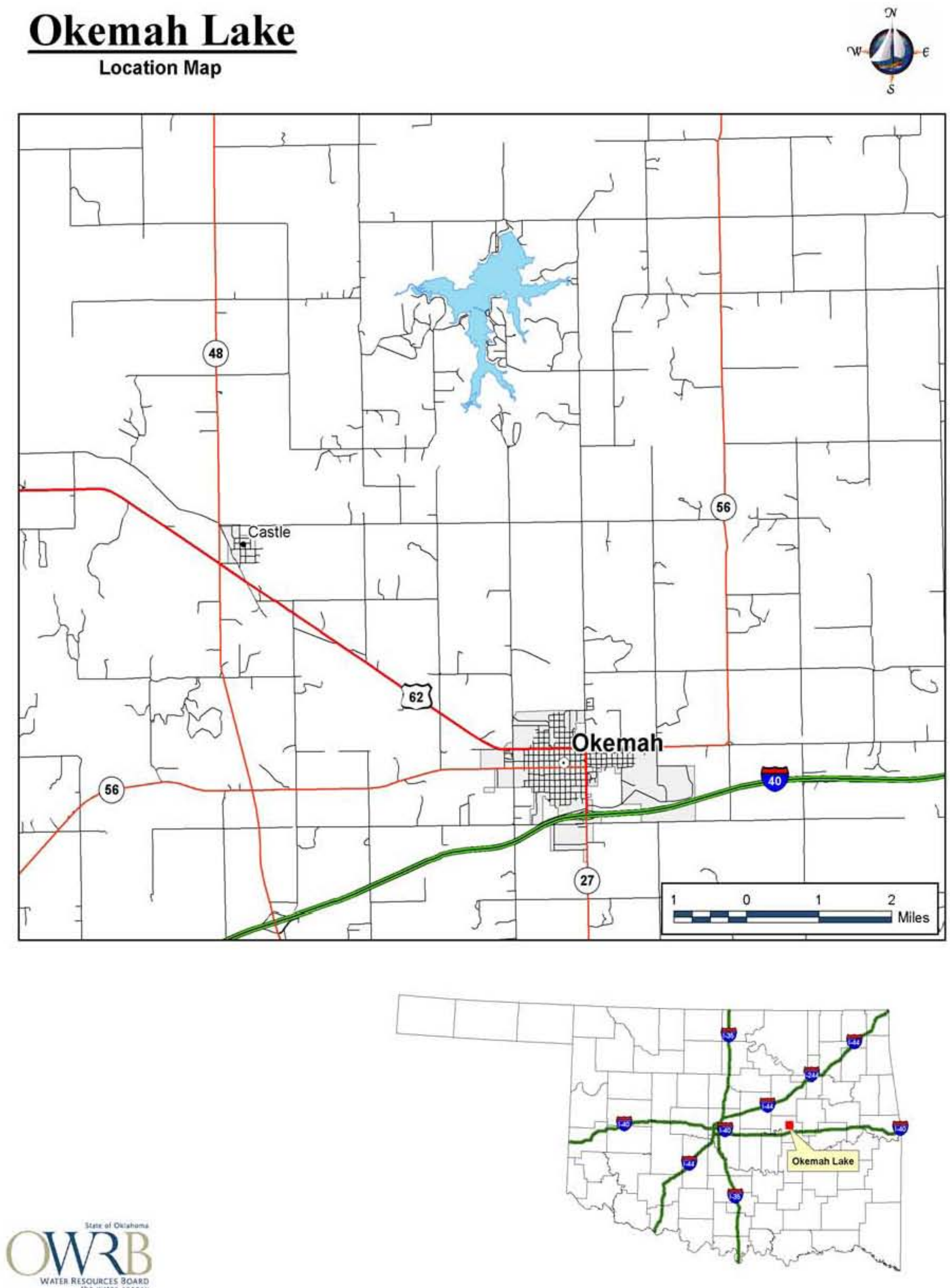


Figure 1: Location map for Okemah Lake.

Okemah 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. 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, sanitation, and potable water are operated and maintained by the City of Okemah.

Buckeye Creek, the major tributary to Okemah Lake, flows in an open and flat valley, which carves steep and narrow areas along the valley walls. A majority of the land cover in the drainage basin of Okemah Lake are deciduous forest, grasslands, pasture/hay with some row crops and low intensity residential area.

The tribal lands located within the watershed are the Creek tribal jurisdiction statistical area (TJSA) and the Thlopthlocco Tribal Town of the Creek Nation of Oklahoma; no reservation exists for this trust land.

Water Rights

The OWRB currently adjudicates the water rights for Okemah Lake, assigning an available water yield of 1,301 acre-feet/year (ac-ft/yr) to the City of Okemah. The City of Okemah not only supplies water to their 7,500 customers, but also to Okfuskee County RWD No. 2 (which sells to Seminole RWD # 3 and supplements Hughes RWD # 1) and Okfuskee County RWD No. 3. The City of Okemah holds two permits issued by the OWRB. The first water rights permit, #1967-519, was issued on 7/11/1964 for 478 ac-ft/yr located on the old lake built in 1934, which is now incorporated into the current Okemah Lake. The second, #1984-39, was issued on 10/09/1984 for use of 871 ac-ft/yr for municipal use, 5 ac-ft for industrial use, and 425 ac-ft for rural water districts in the area served by the City of Okemah.

Outlet Works

Okemah dam is an earth fill structure. **Table 1** 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 main embankment is 1,200 feet (ft) long with a crest width of 18 ft and the top of the dam is at elevation 798.5 ft, resulting in a maximum height above streambed of about 60 ft (Douglas E McCleary P.E. 2004).

The earthen spillway is an uncontrolled trapezoidal channel. The structure has a width of 350 ft and a crest elevation of 787 ft and is located in the immediate right abutment area. The emergency spillway channel discharges into Buckeye Creek, a tributary of the Deep Fork River. A remote left abutment saddle dike with a height of 8 ft and a length of 850 ft with a crest width of 22 ft at an approximate elevation of 786 ft was added in 1973 (M-J, 1978).

Table 1: Okemah Dam and Okemah Pertinent Data.

Owner of Okemah Dam and Facilities

City of Okemah

Operator of Okemah Dam and Facilities

City of Okemah

Engineer

Phelps – Spitz and Associates (Design)

Location

On Buckeye Creek, a tributary of the Deep Fork River in Okfuskee County, approximately five miles north of Okemah, Oklahoma.

Drainage Area

20.44 square miles (Above Okemah dam site)

Embankment

Location	Buckeye Creek,
Type	Earthen
Length	1,200 ft, main dam; dike 850 ft
Elevation	798.5 ft
Maximum Height	60.0 ft
Elevation of streambed	735 ft

Spillway

Location	Right Abutment
Type	Uncontrolled earthen trapezoidal channel
Net overflow length	350 ft
Crest Elevation	787 ft

Outlet Works

Type	Concrete rectangular intake tower
Top tower elevation	784 ft
Size	12 ft X16 ft
Control	Uncontrolled
Type	Outer drop inlet
Elevation	779 ft
Number and Size of inlets	4 – 4 ft X 4.9 ft
Control	Uncontrolled
Type	Weir (positive inner control)
Entrance invert elevation	781.5 ft
Outlet invert elevation	733 ft

Number and Size of inlets	4 – 4 ft X 4.9 ft vertical shaft
Control	concrete baffles
Type	1 Water supply outlet
Size	36 inch diameter pipe
Invert elevation	733 ft
Number and Size of outlets	1-1250 ft x 36 inches
Control	Slide gate

The outlet works consists of a rectangular tower approximately 12 X 16 ft with the top of the tower at elevation 784 ft. Crest elevation of the outer uncontrolled drop inlets is at elevation 779 ft, however, positive inner control is provided by four 4 X 4.9 ft concrete baffles at elevation 781.5 ft. The only outlet is a 36 inch concrete pipe conduit, which is supplied from the uncontrolled overflow or a low flow valve slide gate. In 2002, the OWRB inspected the conduit of the Okemah Lake Dam with a remote operated video camera. The conduit was found to be asphalt lined corrugated metal pipe. Numerous holes were found and portions of the pipe were rusted and deteriorating. The City of Okemah inserted a 32 inch high density polyethylene (HDP) pipe inside the existing 36 inch pipe (OWRB files, 2003). A 10 inch water supply pipe is also included but rarely used (M-J, 1978).

The main water intake structure is located on the south side of the lake used for the City of Okemah water supply.

Lake Design Specifications

Published in the Dam Safety Inspection Report, Okemah Lake had a cumulative area of 738 ac and a cumulative capacity of 13,100 ac-ft at the top of conservation pool elevation 781.5 ft (McCleary, 2004).

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 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 eight readings per second along 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 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 Okemah Lake was produced from the 1995 black and white US Geological Survey (USGS) digital ortho quarter quads (DOQQs) of Okfuskee County, Oklahoma at a scale of 1:1,500. The reservoir boundary was digitized in NAD 1983 State Plane Coordinates (Oklahoma North-3501). The 2003 United States Department of Agriculture-Farm Service Agency-Aerial Photography Field Office (USDA-FSA-APFO) color DOQQ of Okfuskee County was also used for reference. The normal pool elevation for Okemah Lake is 781.5 feet. There were no historical recordings of Okemah lake levels. Therefore it was not possible to determine lake elevations for the two sets of DOQQs. Based on information gathered in the field and from the USGS Digital Raster Graphs (DRG), the lake level on black and white 1995 DOQQs appears to be close to the normal pool elevation of 781.5 feet.

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

2003 DOQQs #	Date	Elevation (ft)
USGS – 1995 Mason SW Quarter-Quad	19950221	Undetermined
USGS – 1995 Mason SE Quarter-Quad	19950310	Undetermined
USDA-FSA-APFO Okfuskee County, Oklahoma	2003	Undetermined

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 with 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 200 ft increments and ran perpendicular to the original stream channels and tributaries. Approximately 127 virtual transects were created for the Okemah 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.

This 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, and an averaged speed of sound was produced from the final readings. The averaged speed of sound 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 average speed of sound in the water column ranged from 4,911.72 ft/sec to 4,918.34 ft/sec during the Okemah Lake 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 158 cross-sections were used for statistical analyses 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 -0.19 ft and a standard deviation of 1.71 ft were computed from a number of 158 data points. Using the following formulas, a 95% depth accuracy of $\pm$0.45 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). These error estimates likely represent the outer limits of the survey error. This would be due to the bias included by the data set: the majority of cross-sections occurred within creek channels, where the sharpest changes in depth and likely the greatest possibility of error exist. Were there a higher percentage of data collected from cross-sections away from the creek channels the error estimate would likely be less than reported.

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 -0.20 to +0.70 ft.

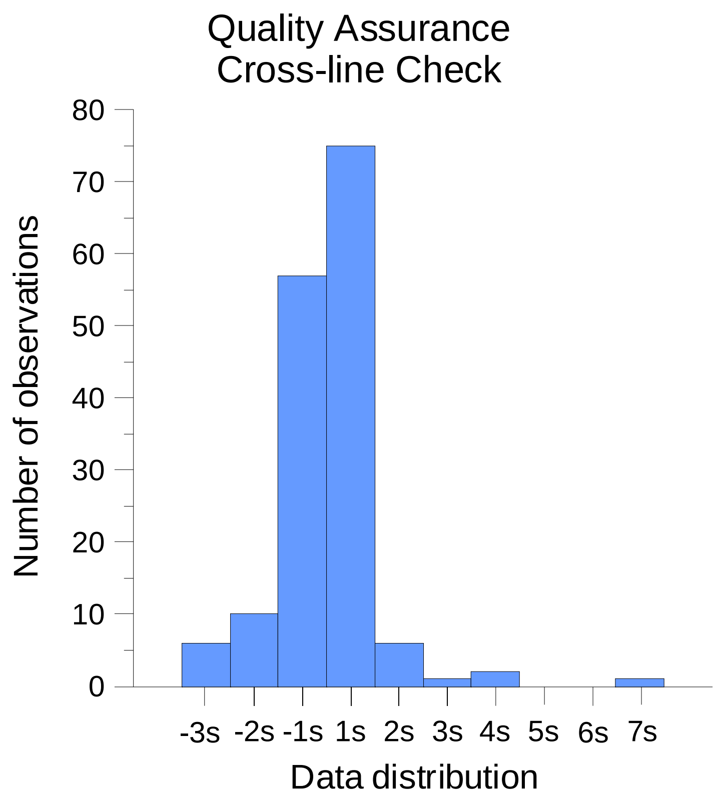


Figure 2: Histogram of relative depth distribution, in standard deviations, at cross-line intersections.

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 are 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 6. The position interval was set to 1 second and the Signal to Noise Ratio (SNR) mask was set to 4. The United States Coast Guard (USCG) reference station used in the Okemah 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 1.60 seconds was produced and adjustments were applied to the raw data in the EDIT program.

Field Survey

Data collection for Okemah Lake occurred September 23, 27, 28, 29, 2004 and September 1, 2005. The water level elevation during the data collection process for September 2004 was 1.4 ft below the outlet structure at approximately elevation 780.1 ft. In September 2005, the water level elevation was at conservation pool elevation 781.5 ft.

Data collection began at the dam area, moved to the large cove areas, and was completed in the Buckeye cove area. Data were collected on parallel transect lines on 200 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 were surveyed for the main body, and Buckeye Creek areas. Approximately 44 channel and contour track lines were created for Okemah Lake. The addition of this method allowed for the best delineation of the creek channels and lake contours. If data were collected on 200 ft increment transects alone, this critical detail would be missing. Data was collected in Buckeye and unnamed creek arms until the boat could no longer navigate in the shallow waters.

The crew was able to collect data on 113 of the 127 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 561,467 data points were collected while traversing a total of 86 US nautical miles. The data points were stored on the boat's computer in 275 data files.

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 allowed 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 were interpolated to be congruent with adjacent accurate points or deleted completely.

Offset correction values of 3.2 ft. starboard, 6.6 ft. forward, and -1.1 ft. vertical were applied to all raw data along with a latency correction factor of 1.60 seconds. The speed of sound readings, are documented in **Appendix A** from the Profiling Sound Velocimeter.

Using HYPACK, TIDES program, a tide correction file was 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 was subtracted from the elevation reading to convert the depth in feet to an elevation.

After editing the data for errors and correcting the spatial attributes (offsets and tide corrections), a data reduction scheme was needed. To accomplish this the data was 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 Okemah Lake is located at the end of the document on the CD entitled *Okemah 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 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 34,467 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 Okemah Lake is located at the end of the document on the CD entitled *Okemah HYPACK/GIS Metadata.*

RESULTS

Results from the 2004 OWRB survey indicate Okemah Lake encompasses 678 ac and contains a cumulative capacity of 10,392 ac-ft at the conservation pool elevation 781.5 ft. The shoreline calculated from the digitized reservoir boundary was 18.8 miles. The average depth for Okemah Lake was 15.1 ft with a maximum depth of 46.3 ft.

SUMMARY AND COMPARISONS

Okemah Dam was constructed in 1962. Original design records indicate that Okemah Lake was a 738 ac lake and had a cumulative volume of 13,100 ac-ft of water at conservation pool elevation 781.5 ft (McCleary, 2004).

OWRB performed a hydrographic survey of Okemah Lake. For the production of the DEM of Okemah Lake's bathymetry, a DGPS, echo sounder, and GIS were utilized. The OWRB survey delineated 678 surface ac and a cumulative capacity of 10,392 ac-ft at conservation pool elevation 781.5 ft (**Table 3**).

Table 3: Reservoir Data from OWRB 2004-05 Survey.

Feature	Elevation (NGVD)	Area (acres)	Capacity (ac-ft)
Top of Conservation Pool	781.5	678	10,392
Municipal Storage			*10,000
Sediment Storage			*1,500

* Phelps-Spitz and Associates Inc. 1963

Area and capacity figures from original design was compared to the 2004-05 data set for the purpose of area-capacity evaluation. **Table 4** summarizes the combined data for the 781.5 ft conservation pool elevation.

Table 4: Area and Capacity Comparisons of Okemah Lake at Conservation Pool Elevation (781.5 ft).

Feature	Year	
	1978*	2004-05
Area (acres)	738	678
Cumulative Volume (acre-feet)	13,100	10,392

* M-J, 1978

The OWRB considers the 2004-05 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 10,392 ac-ft will serve as a more accurate number for future comparisons.

REFERENCES

Douglas E. McCleary P.E. 2004. Dam Safety Inspection Report, Okemah Lake Dam.

Mason-Johnston and Associates Inc. (M-J) 1978. Buckeye Creek, Phase I Inspection Report National Dame Safety Program, Okemah Lake- Dam and Spillway, Okfuskee County, OK, Inventory No. OK 02395.

Oklahoma Water Resources Board. 1937. Historical Record from 1937.

Phelps-Spitz and Associates Inc. 1963 General Plan of Reservoir, Project No. APW OKLA 13C Contract No. 3.

U.S. Army Corps of Engineers (USACE). 2002. Engineering and Design - Hydrographic Surveying, Publication EM 1110-2-1003, 3rd version.

Appendix A: Sound Velocity Profiles

Table A.1: Sound Velocity Profile Data for September 2004 and 2005.

Depth (ft)	9/23/04	9/27/04	9/28/04	9/29/04	9/1/05
1	4919.62	4914.50	4911.29	4911.29	
2	4918.96	4914.21	4911.61	4911.61	
3	4918.96	4914.21	4911.71	4911.71	4979.00
4	4918.64	4914.11	4911.81	4911.81	4958.01
5	4918.64	4914.01	4911.81	4911.81	4957.02
6	4918.31	4913.91	4911.91	4911.91	4956.04
7	4918.31	4913.91	4912.01	4912.01	4953.74
8	4918.31	4913.81	4912.01	4912.01	4951.44
9	4918.31	4913.91	4912.01	4912.01	4950.13
10	4918.31	4913.81	4912.01	4912.01	4948.49
11	4918.31	4913.81	4912.11	4912.11	4947.51
12	4918.31	4913.81	4912.11	4912.11	4946.85
13	4918.31	4913.71	4912.11	4912.11	4946.19
14	4918.31	4913.48	4912.01	4912.01	4945.87
15	4918.31	4913.39	4912.01	4912.01	4945.54
16	4918.31	4913.19	4912.01	4912.01	4945.21
17	4918.31	4913.09	4911.91	4911.91	4944.23
18	4918.31	4912.99	4911.81	4911.81	4941.27
19	4918.31	4912.80	4911.61	4911.61	4937.66
20	4918.31	4912.70	4911.38	4911.38	4934.71
21	4918.31	4912.60	4911.19	4911.19	4931.43
22	4918.31	4912.40	4910.70	4910.70	4927.82
23	4918.31	4912.20	4910.40	4910.40	4923.89
24	4918.31	4912.01			4917.65
25	4918.31	4911.81			4911.75
26	4918.31	4911.29			4904.86
27	4917.98	4911.09			4897.31
28	4917.65	4910.89			4887.47
29	4917.32	4910.79			4878.61
30	4916.01	4910.89			4871.72
31	4913.39				4867.12
32	4908.14				4863.51
33	4903.22				4860.89
34	4896.98				4858.92
35	4892.06				4856.96
36	4886.81				4854.66
37					4853.02
38					4851.05
39					4849.74

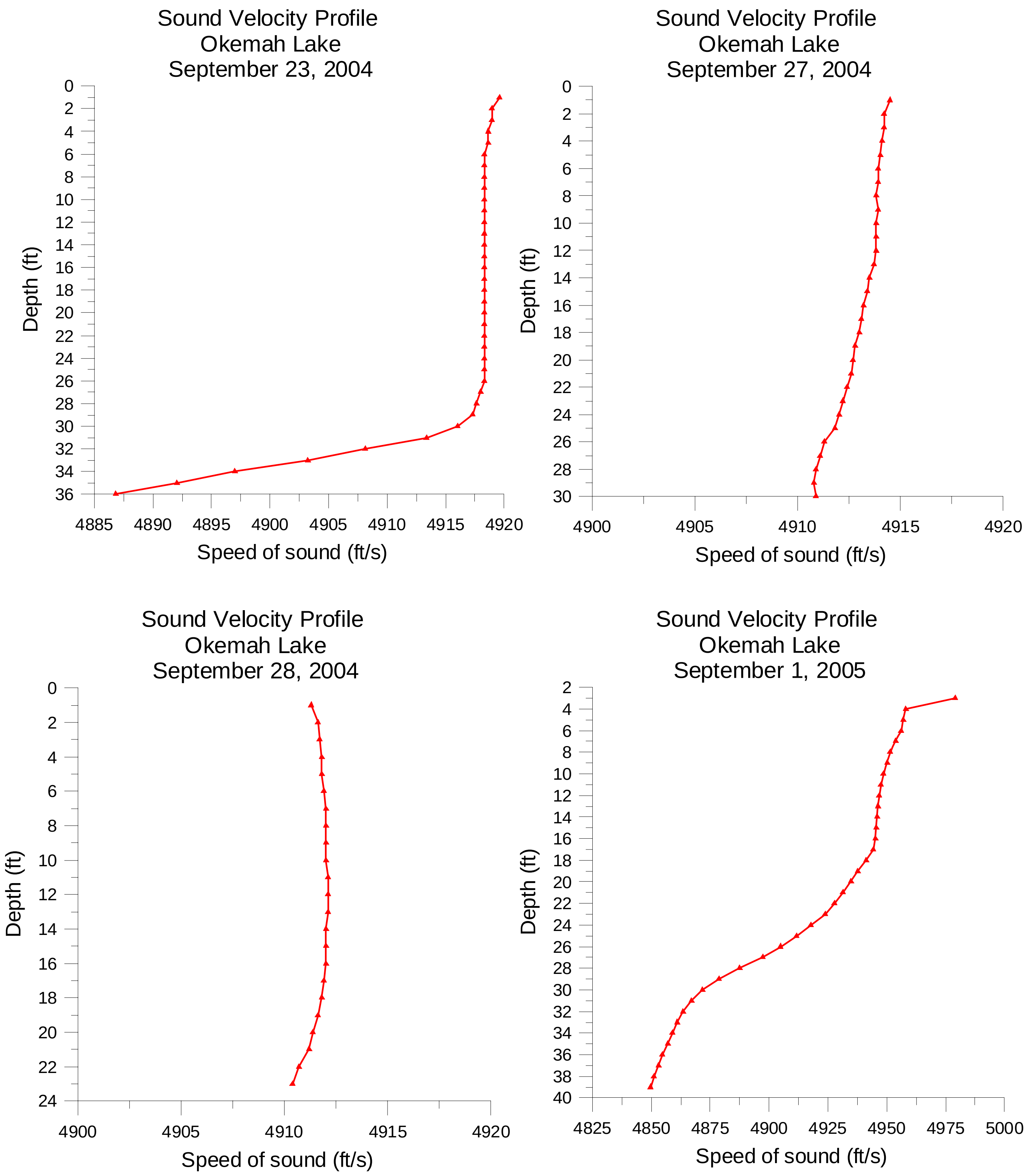


Figure A.1: Sound Velocity Profiles for September 23, 27, and 28, 2004 and September 1, 2005.

Appendix B: Area-Capacity Data

Table B.1: Okemah Lake Cumulative Area by 0.1-foot Increments.

OKEMAH LAKE AREA TABLE										
Area in acres by tenth foot elevation increments										
2005 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
735								0.0006	0.0014	0.004
736	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
737	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
738	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8
739	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.5	1.6	1.8
740	2.0	2.2	2.5	2.8	3.3	3.8	4.4	5.1	5.7	6.3
741	6.8	7.4	7.9	8.5	9.0	10.6	11.2	11.7	12.0	12.4
742	12.7	13.0	13.3	13.5	13.8	14.1	14.3	14.6	14.8	15
743	15	15	16	16	16	16	17	17	17	17
744	18	18	18	18	19	19	19	19	20	20
745	20	20	21	21	21	22	22	22	23	23
746	23	24	24	24	25	27	27	28	29	29
747	30	30	31	31	32	33	33	34	34	35
748	36	36	37	37	38	38	39	40	40	41
749	41	42	42	43	44	45	45	46	47	47
750	48	49	50	51	52	53	54	55	56	57
751	58	60	61	63	64	69	70	72	74	75
752	77	78	80	81	83	84	86	87	89	90
753	91	93	94	95	97	98	99	101	102	104
754	105	106	108	109	111	112	114	115	116	118
755	119	120	121	123	124	126	127	129	131	133
756	134	136	138	139	141	146	149	151	153	155
757	157	159	161	162	164	166	168	169	171	173
758	175	176	178	180	181	183	184	186	187	189
759	190	192	193	194	196	197	199	200	201	203
760	204	205	207	208	209	211	212	213	215	216
761	218	219	221	222	224	227	229	230	232	233
762	235	236	238	239	241	242	244	245	247	248
763	250	251	252	254	255	257	258	260	261	262
764	264	265	267	269	270	272	273	275	277	278
765	280	282	283	285	287	289	290	292	294	296
766	298	300	302	304	306	311	314	317	319	321
767	324	326	328	330	332	334	337	339	341	343
768	345	347	349	351	354	356	359	361	363	365
769	368	370	372	374	376	378	380	382	384	386
770	388	391	393	395	398	400	403	406	408	411
771	413	415	418	420	422	427	429	432	434	436

ELEVATION										
(ft NGVD)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
772	438	441	443	445	447	449	452	454	456	458
773	461	463	465	468	470	472	475	477	479	481
774	484	486	489	491	494	496	499	501	504	506
775	509	511	514	516	518	521	523	526	528	531
776	533	536	540	543	547	552	554	557	559	561
777	564	566	568	570	573	575	577	579	582	584
778	586	588	590	591	593	595	597	599	601	603
779	604	606	608	610	612	614	616	617	619	621
780	623	625	627	629	630	632	634	636	638	640
781	642	644	646	648	649	679				

Table B.2: Okemah Lake Cumulative Volume by 0.1-foot Increments.

OKEMAH LAKE CAPACITY TABLE Volume in acre-feet by tenth foot elevation increments 2005 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
735								0.0001	0.0002	0.0004
736	0.001	0.0017	0.0031	0.01	0.01	0.01	0.02	0.04	0.05	0.07
737	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
738	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9
739	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.1
740	2.3	2.5	2.7	3.0	3.3	3.7	4.1	4.5	5.1	5.7
741	6	7	8	9	10	10	12	13	14	15
742	16	18	19	20	22	23	24	26	27	29
743	30	32	33	35	37	38	40	42	43	45
744	47	48	50	52	54	56	58	60	62	64
745	66	68	70	72	74	76	78	80	83	85
746	87	90	92	94	97	99	102	105	108	111
747	114	117	120	123	126	129	132	136	139	143
748	146	150	153	157	161	165	169	173	177	181
749	185	189	193	197	202	206	211	215	220	224
750	229	234	239	244	249	254	260	265	271	276
751	282	288	294	300	307	313	320	327	334	342
752	349	357	365	373	381	390	398	407	416	425
753	434	443	452	462	471	481	491	501	511	522
754	532	543	553	564	575	586	597	609	620	632
755	644	656	668	680	693	705	718	731	744	757
756	770	784	797	811	825	839	854	869	884	900

ELEVATION (ft NGVD)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
757	915	931	947	963	979	996	1013	1030	1047	1064
758	1081	1099	1116	1134	1152	1170	1189	1207	1226	1245
759	1264	1283	1302	1321	1341	1361	1380	1400	1420	1441
760	1461	1481	1502	1523	1544	1565	1586	1607	1628	1650
761	1672	1693	1715	1738	1760	1782	1805	1828	1851	1874
762	1898	1921	1945	1969	1993	2017	2041	2066	2090	2115
763	2140	2165	2190	2216	2241	2267	2292	2318	2344	2370
764	2397	2423	2450	2477	2504	2531	2558	2585	2613	2641
765	2669	2697	2725	2753	2782	2811	2840	2869	2898	2928
766	2957	2987	3017	3048	3078	3109	3140	3172	3204	3236
767	3268	3300	3333	3366	3399	3432	3466	3500	3534	3568
768	3602	3637	3672	3707	3742	3777	3813	3849	3885	3922
769	3958	3995	4032	4070	4107	4145	4183	4221	4260	4298
770	4337	4376	4415	4454	4494	4534	4574	4615	4655	4696
771	4737	4779	4820	4862	4904	4947	4990	5033	5076	5119
772	5163	5207	5251	5296	5340	5385	5430	5476	5521	5567
773	5613	5659	5705	5752	5799	5846	5893	5941	5989	6037
774	6085	6134	6182	6231	6281	6330	6380	6430	6480	6531
775	6581	6632	6684	6735	6787	6839	6891	6943	6996	7049
776	7102	7156	7210	7264	7318	7373	7428	7484	7540	7596
777	7652	7708	7765	7822	7879	7937	7994	8052	8110	8168
778	8227	8286	8345	8404	8463	8522	8582	8642	8702	8762
779	8822	8883	8943	9004	9065	9127	9188	9250	9312	9374
780	9436	9498	9561	9624	9687	9750	9813	9877	9940	10004
781	10068	10133	10197	10262	10327	10392				

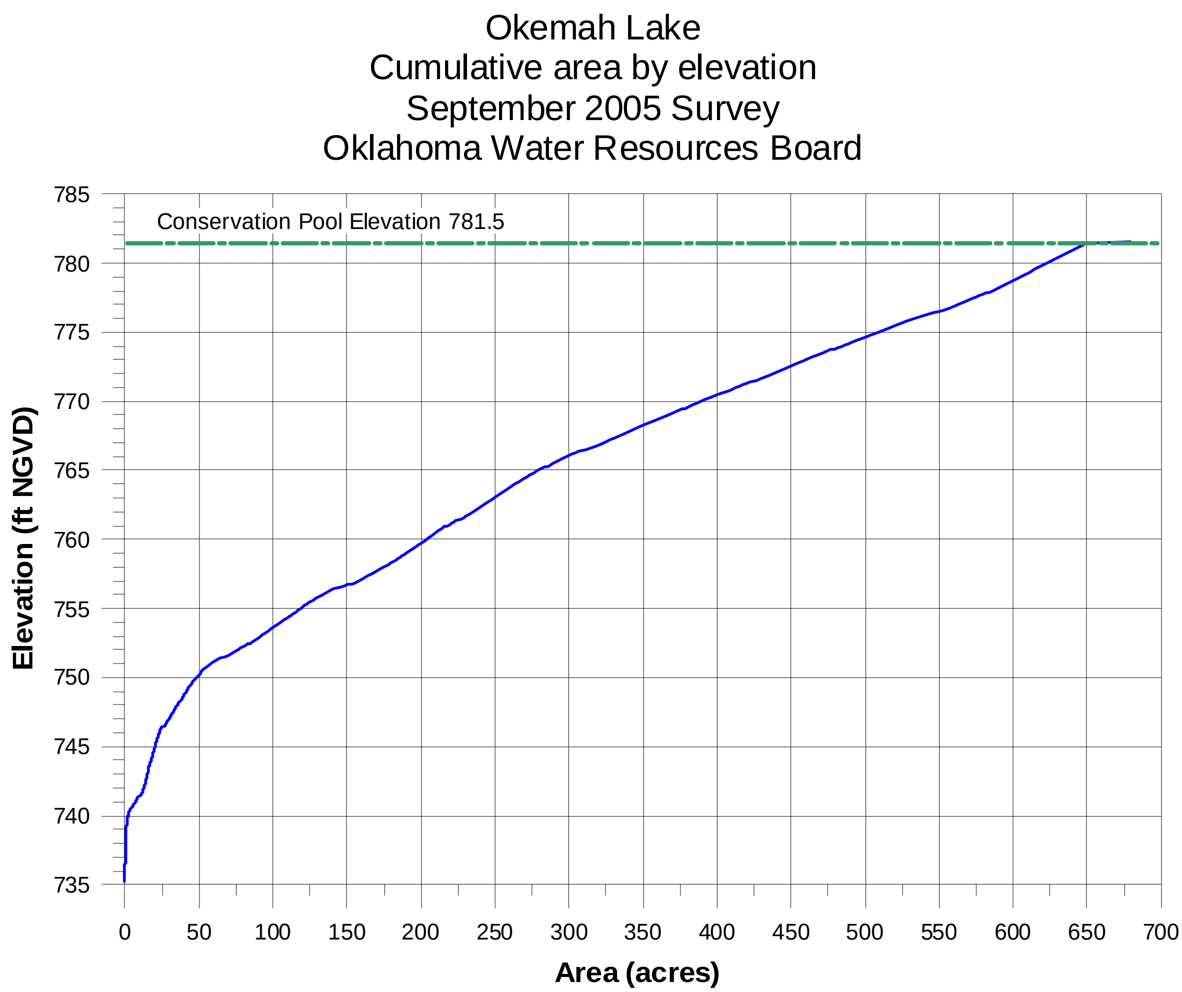


Figure B.1: Okemah Lake Area-Elevation Curve.

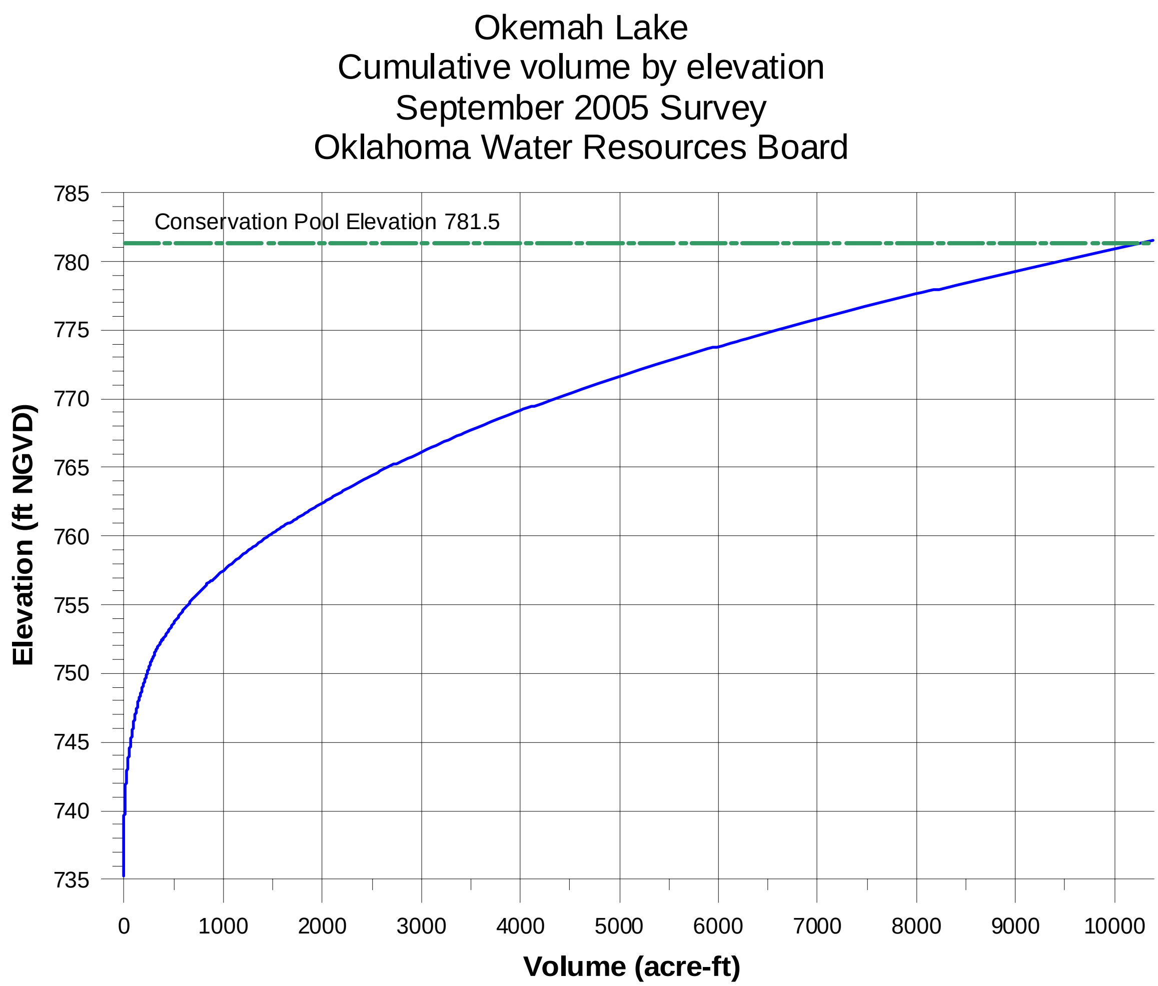


Figure B.2: Okemah Lake Volume-Elevation Curve.

Appendix C: Okemah Lake Bathymetric Maps

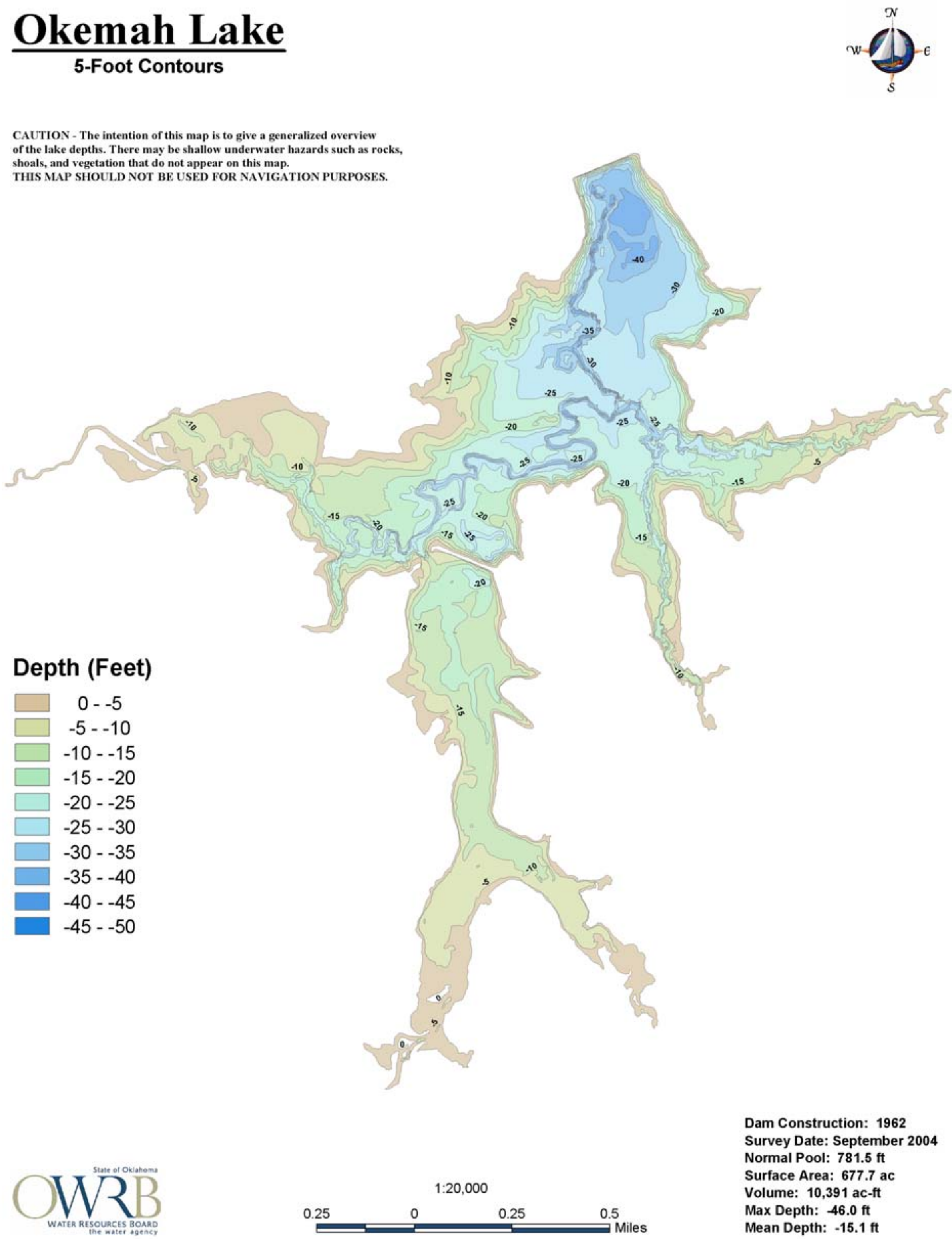


Figure C.1: Okemah Lake Bathymetric Map with 5-foot Contour Intervals.

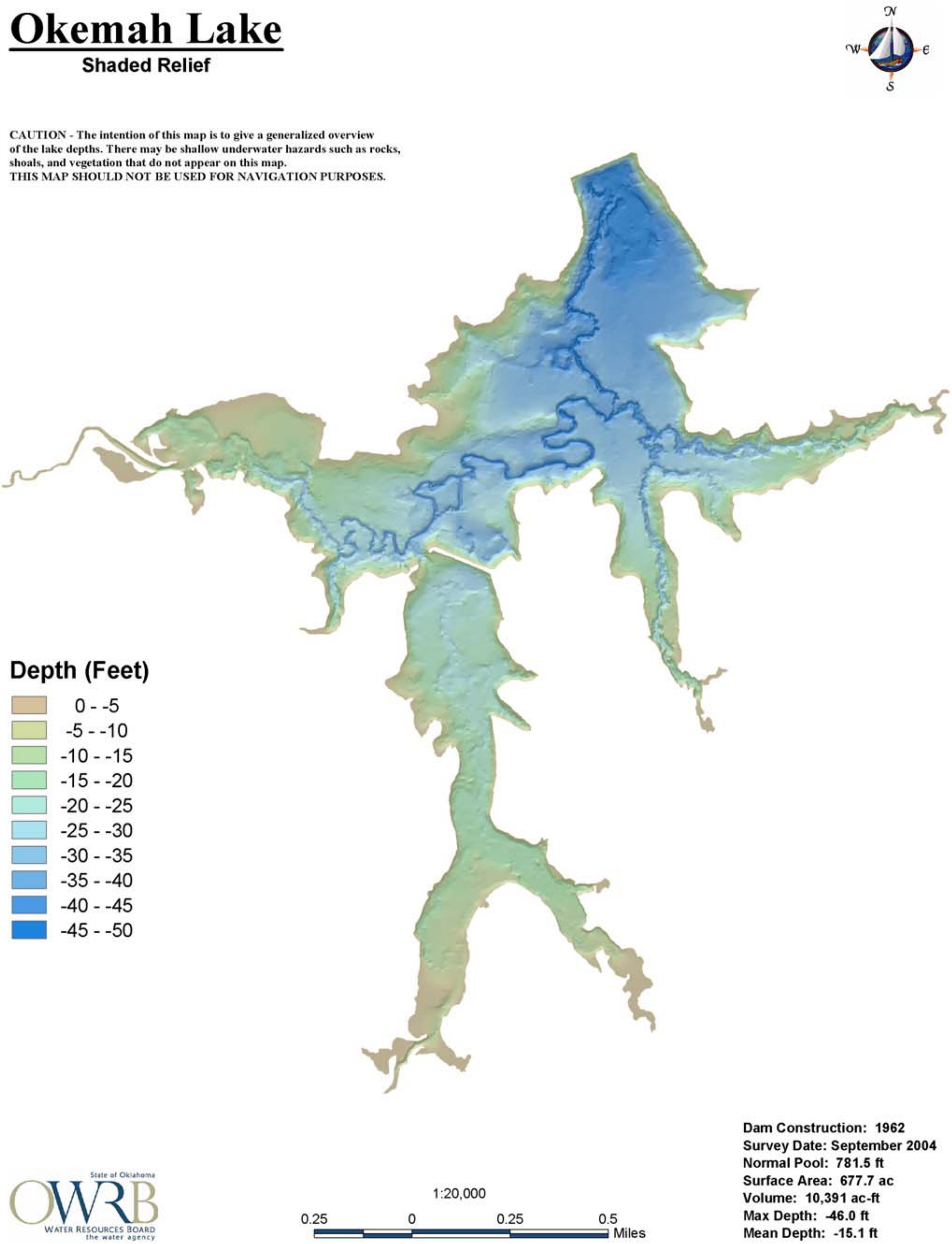


Figure C.2: Okemah Lake Shaded Relief Bathymetric Map.

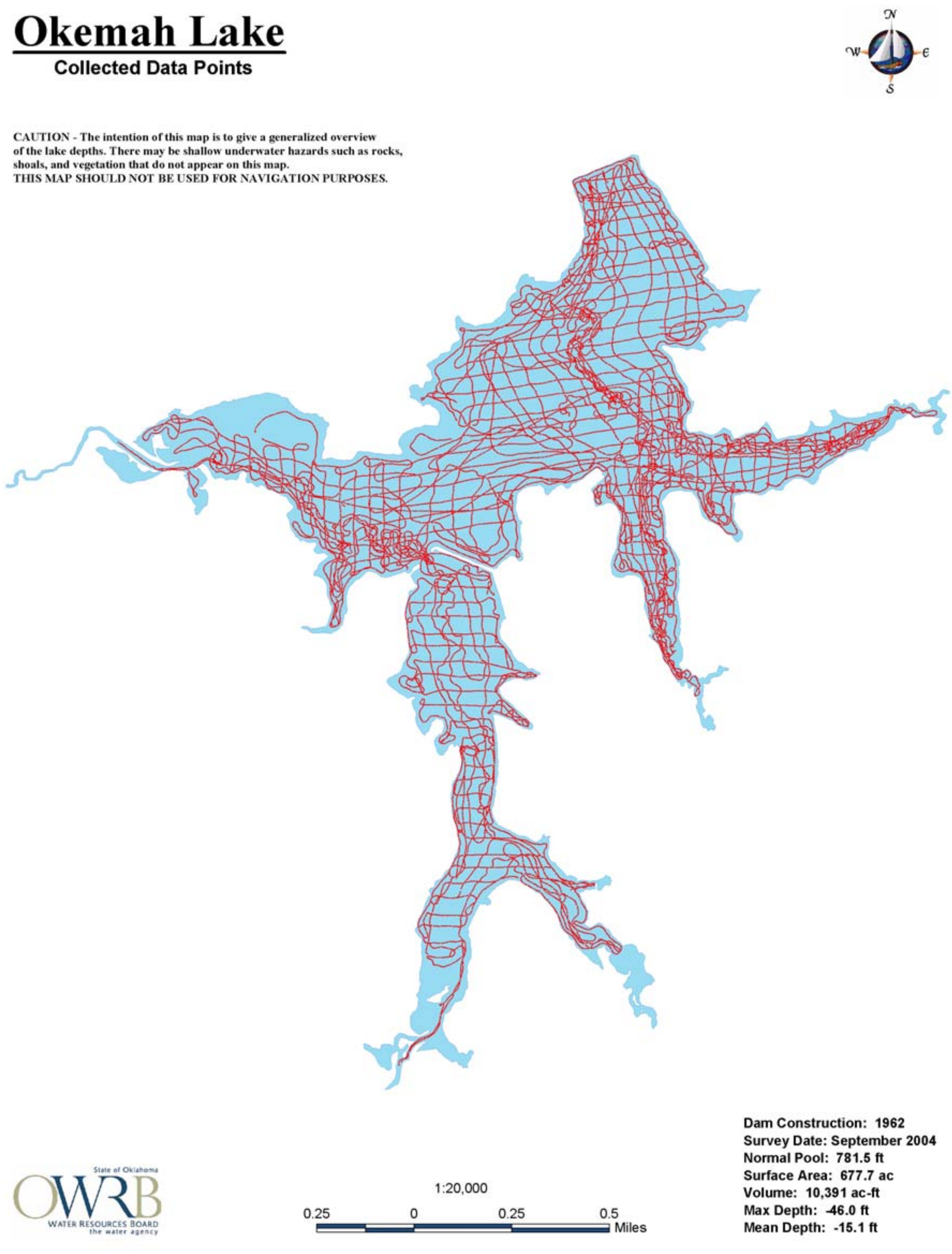


Figure C.3: Okemah Lake Survey Collected Data Points.