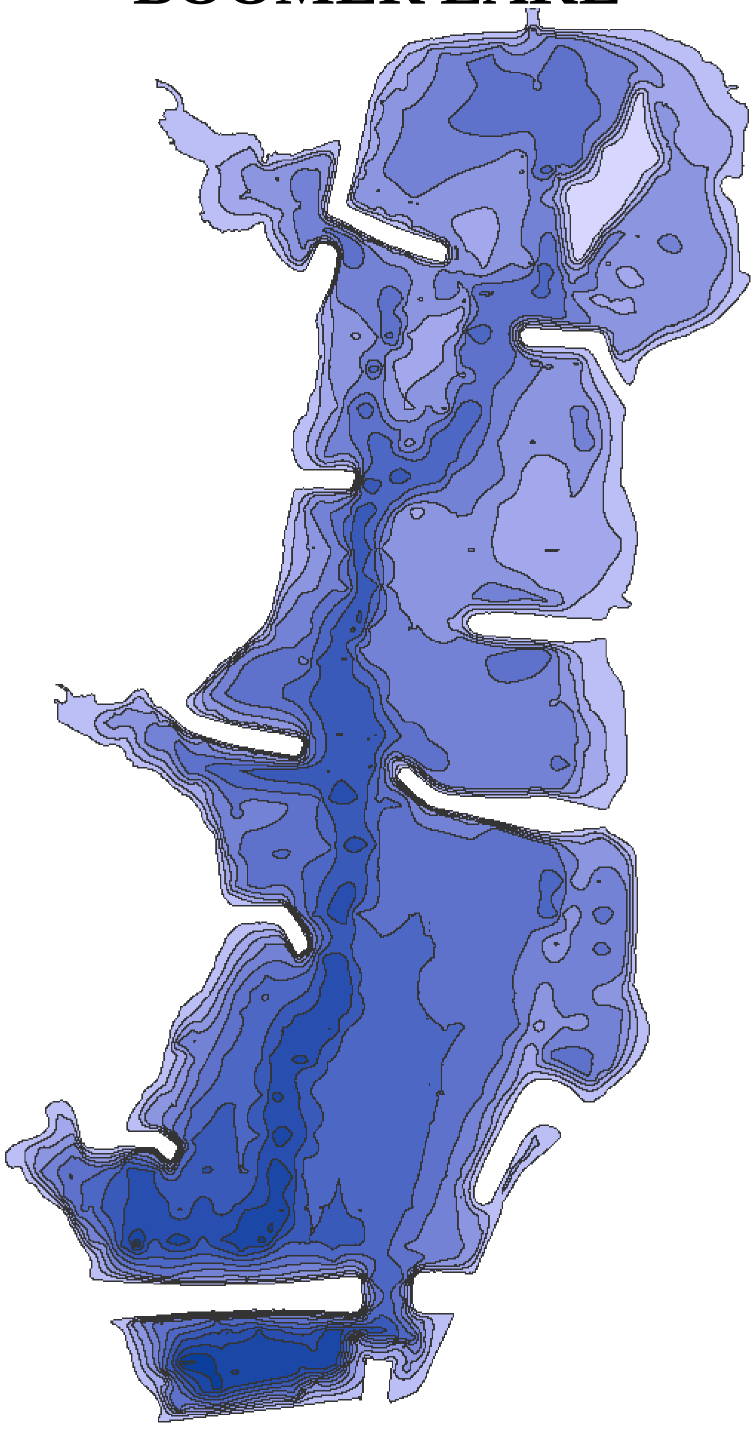
HYDROGRAPHIC SURVEY OF BOOMER LAKE



Final Report
September 28, 2015

Prepared by:

State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

BOOMER LAKE
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Boomer Lake beginning on August 5, 2015. The purpose of this survey was to produce a current elevation-area-capacity table for Boomer Lake to allow a volumetric determination of dissolved oxygen beneficial use assessment.

Boomer Lake is located on a tributary of Boomer Creek in Payne County (**Figure 1**). The dam was completed in 1932. Owned by the City of Stillwater, the reservoir's original purposes were cooling water and recreation. The dam is located in Sec. 11-T19N-R2E.

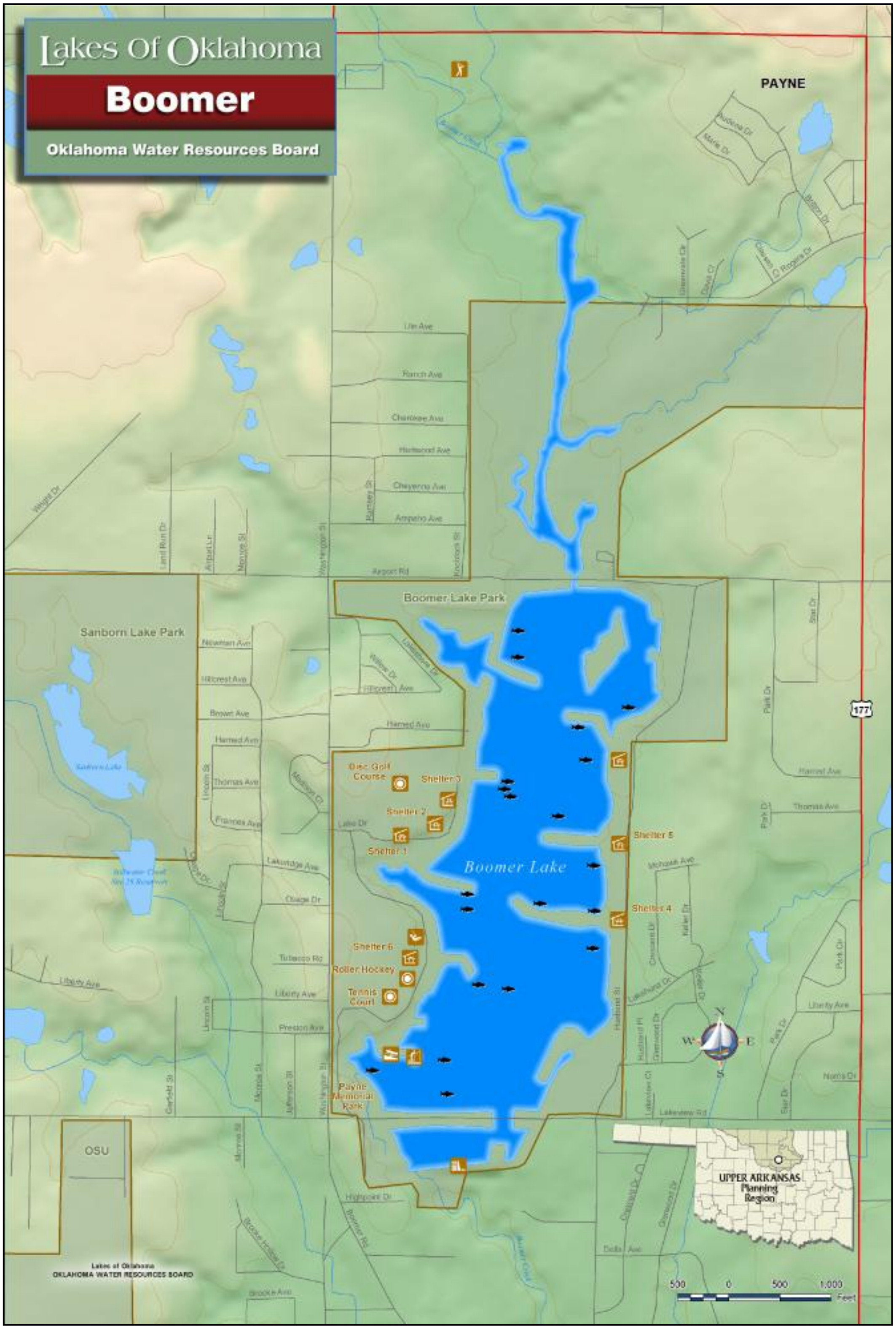


Figure 1: Location map for Boomer Lake taken from Lakes of Oklahoma Water Atlas, Second Edition (2012).

HYDROGRAPHIC SURVEYING PROCEDURES

The process of surveying a reservoir uses a combination of Geographic Positioning System (GPS) and acoustic depth sounding technologies that are incorporated into a hydrographic survey vessel. As the survey vessel travels across the lake's surface, the echosounder gathers multiple depth readings every second. The depth readings are stored on the survey vessel's on-board computer along with the positional data generated from the vessel's GPS receiver. The collected data files are downloaded daily from the computer and brought to the office for editing. During editing, data "noise" is removed or corrected, and depth readings are converted to elevation readings based on the daily-recorded lake level elevation on the day the survey was performed. The edited data sets are then thinned to manageable sizes using Hypack's "Sounding Selection-Sort Program" using a 1 ft sort radius. Using ArcGIS, accurate estimates of area-capacity can then be determined for the lake by building a 3-D model of the reservoir from the sorted data set. The process of completing a hydrographic survey includes four steps: pre-survey planning, field survey, data processing, and model construction.

Pre-Survey Planning

Boundary File

The boundary for Boomer Lake was derived using 2-meter lidar data. A lidar raster file (TIFF format) for the Stillwater North USGS 1:24,000 quadrangle was downloaded from the Natural Resources Conservation Service (NRCS) Geospatial Data Gateway website (https://gdg.sc.egov.usda.gov/). An NRCS tool developed for the ArcGIS Spatial Analyst extension was used to generate contours from the lidar file. A lake boundary line shapefile was created from the 910.0-ft contour, which is representative of normal pool elevation for Boomer Lake. This line shapefile was edited in ArcGIS software using the 2013 USDA-FSA National Agriculture Imagery Program (NAIP) orthophoto mosaic for Payne County, Oklahoma, as a reference to ensure complete shoreline coverage. The boundary was digitized in the NAD 1983 Oklahoma North State Plane coordinate system.

Set-up

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 ellipsoid World Geodetic System of 1984 (WGS-84) in State Plane North American Datum of 1983 (NAD-83) Zone OK-3501 Oklahoma North. The distance and depth units used were US Survey Feet. The vertical datum was set to the North American Vertical Datum of 1988 (NAVD88). The survey transects were spaced according to the accuracy required for the project. The survey transects within the digitized reservoir boundary for Boomer were set at 125ft increments and ran perpendicular to the original stream channels and tributaries. There were 27 virtual transects created for Boomer Lake. An additional 9 track lines set perpendicular to the transect lines were added for cross check statistics.

Field Survey

Lake Elevation Acquisition

The lake elevation for Boomer Lake was obtained by collecting positional data over a period of 138 minutes. Data collection was done using a Trimble Zephyr Geodetic Antenna connected to Trimble 5700 receiver, and controlled using Trimble TSCe survey controller. This data was then uploaded to the On-line Positioning Users Service-Rapid Static (OPUS-RS) website. The National Geodetic Survey (NGS) operates the OPUS as a means to provide GPS users' easier access to the National Spatial Reference System (NSRS). OPUS-RS allows users to submit their GPS data files to NGS, where the data is processed to determine a position using NGS computers and software. Each data file that is submitted is processed with respect to at least three Continuously Operating Reference Stations (CORS). All collection and processing of elevation data followed methods covered in full detail in the OWRB Standard Operating Procedures (SOP) for lake elevation measurement found in the approved project Quality Assurance Project Plan (QAPP) (OWRB, 2015).

Method

The procedures followed by the OWRB during the hydrographic survey adhere to U.S. Army Corps of Engineers (USACE) standards EM 1110-2-1003 (USACE, 2013) as stated in the approved project QAPP (OWRB, 2015). The quality assurance and quality control (QA/QC) procedures for equipment calibration and operation, field survey, data processing, and accuracy standards are presented in the following sections and covered in more detail in the approved project QAPP (OWRB, 2015).

Technology

The Hydro-survey vessel is an 18-ft aluminum hull with cabin, powered by a single 115-horsepower outboard motor. Equipment used to conduct the survey included: a notebook computer running Hypack’s 2014 survey data collection software; Innerspace 456 Echo Sounder, with a depth resolution of 0.1 ft; Hemisphere R131 receiver with differential global positioning system (DGPS) correction; and an Odom Hydrographics, Inc, DIGIBAR-Pro Profiling Sound Velocimeter.

Survey

A two-man survey crew was used during the project. Data collection for Boomer Lake occurred on August 5, 2015. The water level elevation for Boomer Lake was measured at 910.73 ft (NAVD88). Data collection began at the dam and moved upstream. The survey crew followed the parallel transects created during the pre-survey planning while collecting depth soundings and positional data. Data was also collected along a path parallel to the shoreline at a distance that was determined by the depth of the water and the draft of the boat – generally a depth of 3 to 5 ft. In areas of the lake that were too narrow for pre-planned transect lines, a zigzag pattern was used to collect data. These areas included small tributaries as well as the upstream section of the reservoir. Similar to the shoreline data collection procedure, upstream data was collected until depths were too shallow for the boat to navigate.

Quality Assurance/Quality Control

The Boomer Lake hydrographic survey followed the quality control procedures presented in the approved QAPP (OWRB, 2015) and summarized in **Table 1**. While on board the Hydro-survey vessel, the Innerspace 456 Echo Sounder was calibrated using both a DIGIBAR-Pro

Profiling Sound Velocimeter and a bar check setup. The sound velocimeter measures the speed of sound (SOS) at incremental depths throughout the water column. The factors that influence the SOS—depth, temperature, and salinity—are all taken into account. Deploying the unit involved lowering the probe, which measures the SOS, into the water to the calibration depth mark to allow for acclimation and calibration of the depth sensor. The unit was then gradually lowered at a controlled speed to a depth just above the lake bottom, and then was raised 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. The sound velocity corrections were then applied to the raw depth readings during the editing process using Hypack's Sound Velocity tool. The mean SOS in the water column was 4943 ft/sec during the Boomer Lake survey. A bar check was performed using the mean SOS and bar check setup to calibrate the echosounder. The bar check procedure adheres to USACE methods (USACE, 2013). **Figure 2** is the final Boomer Lake echogram showing the bar check setup progressing in 5ft intervals from setting the draft to a maximum depth of 15 ft. The bar check yielded a final SOS setting of 4923 ft/sec and a static draft depth offset of 1.2 ft. Both settings were entered into the echo-sounder prior to survey sampling.

Table 1: Summary of Relevant Minimum Performance Standards and Quality Assurance Practices (QA) for the Hydrographic Survey (USACE, 2002&2013).

Minimum Performance Standards and Quality Assurance Practices for the Hydrographic Survey	
Repeatability (Bias)	**0.3 ft**
Standard Deviation (± ft at 95%)	**± 0.8 ft**
Horizontal Positioning System Accuracy (95%)	**5 m (16 ft)**
Minimum Survey Coverage Density	**Not to Exceed 500 ft (150 m)**
Quality Control and Assurance Criteria	--
➢ Bar Check	**1/project**
➢ Sound Velocity QC calibration	**2/day**
➢ Squat Test	**1/year**
➢ Position calibration QC check	**1/project**
From the **2002** version of EM 1110-2-1003	From the **2013** version of EM 1110-2-1003

Depth observations contain both random errors (σ RANDOM ERROR) and systematic biases (σ BIAS). Biases are often referred to as systematic or external errors and may contain observational blunders. A constant error in tide or stage would be an example of a bias. Biases are reduced as much a possible by using the quality control measures previously discussed. Random errors are those errors present in the measurement system that cannot be easily minimized by further calibration. Examples include echo sounder resolution, water sound velocity variations, tide/staff gage reading resolution, etc. The precision of the observations is a measure of the closeness of a set of measurements--or their internal agreement. Accuracy relates to the closeness of measurements to their true or actual value

Accuracy and precision were assessed utilizing a cross-line check method referenced in the approved QAPP (OWRB, 2015). The cross-line check was performed by collecting depth readings along survey track lines perpendicular to, and intersecting the survey transect lines. Hypack's Cross Check Statistics program was used to assess vertical accuracy and confidence measures of the recorded depths at the points where the lines intersected. This program tabulated and statistically analyzed the depth differences between intersecting points of single beam data. The program provides a report calculating the standard deviation and mean difference. A total of 83 cross-sections points at Boomer Lake were used by the cross check statistics program. A mean difference (Bias) of 0.003 ft and a standard deviation (Random Error) of 0.146 ft were computed from intersecting points. Both values meet and exceed the minimum performance standards (MPS) for USACE Reservoir Surveys found in **Table 1**.

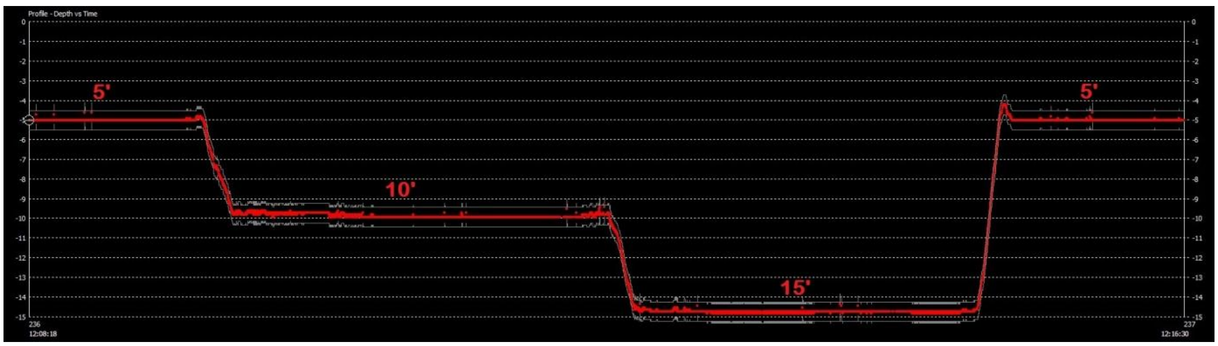


Figure 2: Digital Echogram of Boomer Lake barcheck.

The mean difference and the standard deviation can then be used to calculate the Root Mean Square (RMS) error employing the following calculation. The RMS error estimate is used to compare relative accuracies of estimates that differ substantially in bias and precision (USACE, 2002). According the USACE recommended standards; the RMS at the 95% confidence level should not exceed a tolerance of ± 0.8 ft for reservoir surveys (Hydrography). This simply means that on average, 19 of every 20 observed depths will fall within the specified accuracy tolerance.

$$RMS = \sqrt{\sigma^2{}_{Random error} + \sigma^2{}_{Bias}}$$

where:

Random error = standard deviation
Bias = mean difference
RMS = Root Mean Square error (68% confidence level)

and:

$$RMS\ (95\%)\ depth\ accuracy = 1.96 \times RMS(68\%)$$

An RMS of ±0.286 ft with a 95% confidence level is less than the USACE's minimum performance standard of ± 0.8 ft for reservoir surveys. A mean difference, or bias, of 0.003 ft is well below the USACE's standard maximum allowable bias of 0.3 ft. The standard deviation of ±0.146 at 95% confidence level meets the USACE MPS of ±0.8 ft. (USACE, 2013)

The GPS system is an advanced high performance geographic data-acquisition tool that uses differential GPS (DGPS) to provide sub-meter positional accuracy on a second-by-second basis. Potential errors are reduced with DGPS because additional data from a reference GPS receiver at a known position are used to correct positions obtained during the survey. Before the survey, the settings on the Hemisphere R131 were checked to configure the GPS receiver. To maximize the accuracy of the horizontal positioning, the horizontal mask setting was set to 6 degrees and the MaxDGPSAge was set to 300. The GGA and VTG were both set to 1 Hz. The RTCM option was enabled with all other options disabled. The United States Coast Guard reference station used in the survey is located near Sallisaw, Oklahoma.

A latency test was performed to determine the fixed delay time between the GPS and single beam echo sounder. The timing delay was determined by running reciprocal survey lines over a channel bank. The raw data files were downloaded into Hypack - LATENCY TEST program. The program varies the time delay to determine the "best fit" setting. A position latency of 0.4 seconds was produced and adjustments were applied to the raw data, Hypack's Single Beam Editor Program, during data processing.

Data Processing

The collected data was transferred from the field computer onto an OWRB desktop computer. After downloading the data, each raw data file was reviewed using the Single Beam Editor program within Hypack. The Single Beam Editor program allowed the user to assign transducer offsets, latency corrections, tide corrections, display the raw data profile, and review/edit all raw depth information. Raw data files are checked for gross inaccuracies that occur during data collection. Data editing is covered in more detail in the approved project QAPP (OWRB, 2015).

Offset correction values of 3.2 ft. starboard, 6.6 ft. forward, and -1.3 ft vertical were applied to all raw data along with a latency correction factor of 0.4 seconds. The SOS corrections were applied during editing of raw data using the sound velocity corrections created using the sound velocity tool.

A correction file was produced using the Hypack's Manual Tides program to account for the variance in lake elevation at the time of data collection. Within the Single Beam Editor program, the corrected depths were subtracted from the elevation reading to convert the depth in feet to an elevation. The measured elevation of the lake during the survey was 910.72ft (NAVD88).

After editing the data for errors and correcting the spatial attributes (offsets and tide corrections), a data reduction scheme was needed due to the large quantity of collected data. To accomplish this, the corrected data was sorted spatially at a 1 ft interval using the Sounding Selection program in Hypack. The resultant data was saved and exported out as a xyz.txt file. The Hypack raw and corrected data files for Boomer Lake will be stored and made available upon request.

GIS Application

Geographic Information Systems (GIS) software was used to process the edited XYZ data collected from the survey. The GIS software used was ArcGIS Desktop, version 10.1, from Environmental Systems 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 a point feature class in an ArcGIS file geodatabase. The point feature class 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 Triangulated Irregular Network (TIN) surface model. The TIN model was created with ArcGIS using the collected survey data points; 2-foot contours derived from a raster file interpolated from the collected survey data points; and inputs representing the lake boundary at normal pool elevation. The TIN consists of connected data points that form a network of triangles representing the bottom surface of the lake. The lake volume was calculated by slicing the TIN horizontally into planes 0.1 ft thick. The cumulative volume and area of each slice are shown in **APPENDIX A: Area-Capacity Data.**

Contours, depth ranges, and the shaded relief map were derived from a constructed digital elevation model grid. This grid was created using the ArcGIS Topo to Raster Tool and had a spatial resolution of 1 ft. The contours were created at a 2 ft interval using the ArcGIS contour tool.

The contour lines were edited to allow for polygon topology and to improve accuracy and general smoothness of the lines. The contours were then converted to a polygon feature class and attributed to show 2-ft depth ranges across the lake. The bathymetric maps of the lakes are shown with 2-ft contour intervals in **APPENDIX B: Boomer Lake Maps**.

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 Boomer Lake is located on the DVD entitled Boomer *Hypack/GIS Metadata.*

RESULTS

Results from the 2015 OWRB survey indicate that Boomer Lake encompasses 212.9 acres and contains a cumulative capacity of 1,484.3 ac-ft at the normal pool elevation of 910 ft (NAVD88). The mean depth for Boomer Lake was 7.0 ft.

SUMMARY and COMPARISON

Table 1 displays area and volume calculations of Boomer Lake at the normal pool elevation for 1932 and 2015. Based on the design specifications, Boomer Lake had an area of 260 acres and cumulative volume of 3200 ac-ft of water at normal pool elevation (910 ft NAVD88). The surface area of the lake has had a decrease of 47 acres or approximately 18%. The 2015 survey shows that Boomer Lake has an apparent decrease in capacity of 54% or approximately 1,716 acre-feet. Caution should be used when directly comparing between the design specifications and the 2015 survey conducted by the OWRB because different methods were used to collect the data and extrapolate capacity and area. It is the recommendation of the OWRB that another survey using the same method used in the 2015 survey be conducted in 10-15 years. By using the 2015 survey figures as a baseline, a future survey would allow an accurate mean sedimentation rate to be obtained.

Table 2: Area and Volume of Boomer Lake at normal pool (910 ft NAVD88) for 1932 Original Design and 2015 Survey (OWRB, 1979).

Feature	Survey Year	
	1932 Design Specifications	2015
Area (acres)	260	213
Cumulative Volume (acre-feet)	3200	1484
Mean depth (ft)	12.3	7.0
Maximum Depth (ft)	--	22.1

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

U.S. Army Corps of Engineers (2002): Engineering Design: Hydrographic Surveying(EM 1110-2-1003); Chapter 3. Table 3-1: *Minimum Performance Standards for Corps of Engineers Hydrographic Surveys (Mandatory)*; Project Classification – Other General Surveys & Studies.www1.frm.utn.edu.ar/laboratorio_hidraulica/Biblioteca_Virtual/Hydrographic%20Surveying/c-3.pdf

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APPENDIX A: Area-Capacity Data

Table A- 1: Boomer Lake Capacity by 0.1-ft Increments.

Boomer Lake Capacity Table
Volume in Acre-Feet by Tenth Ft Elevation Increments
2015 SURVEY
Oklahoma Water Resources Board

Elevation in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
887										0.00
888	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
889	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
890	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.05
891	0.06	0.07	0.08	0.09	0.11	0.13	0.14	0.16	0.19	0.21
892	0.24	0.28	0.33	0.40	0.48	0.59	0.71	0.85	0.99	1.15
893	1.32	1.50	1.70	1.92	2.15	2.39	2.65	2.93	3.23	3.55
894	3.90	4.29	4.69	5.11	5.56	6.03	6.52	7.03	7.57	8.14
895	8.74	9.37	10.04	10.75	11.50	12.29	13.12	13.99	14.91	15.88
896	16.90	18.01	19.17	20.39	21.66	22.99	24.38	25.81	27.30	28.85
897	30.45	32.11	33.83	35.62	37.47	39.39	41.38	43.44	45.58	47.82
898	50.16	52.68	55.32	58.10	61.01	64.03	67.15	70.39	73.75	77.22
899	80.80	84.46	88.22	92.09	96.06	100.14	104.32	108.60	113.01	117.54
900	122.21	127.10	132.15	137.36	142.75	148.32	154.07	159.98	166.08	172.37
901	178.82	185.43	192.21	199.16	206.27	213.54	220.97	228.56	236.32	244.24
902	252.33	260.65	269.12	277.75	286.54	295.52	304.70	314.07	323.67	333.50
903	343.54	353.77	364.19	374.77	385.53	396.45	407.57	418.86	430.34	442.02
904	453.90	466.10	478.50	491.11	503.91	516.91	530.12	543.52	557.14	570.96
905	584.99	599.20	613.60	628.19	642.95	657.90	673.04	688.37	703.88	719.57
906	735.45	751.59	767.88	784.32	800.90	817.64	834.52	851.55	868.74	886.07
907	903.53	921.12	938.83	956.67	974.63	992.71	1010.92	1029.24	1047.68	1066.24
908	1084.92	1103.72	1122.64	1141.68	1160.83	1180.10	1199.49	1219.00	1238.63	1258.38
909	1278.27	1298.27	1318.41	1338.68	1359.08	1379.61	1400.27	1421.08	1442.02	1463.09
910	1484.31									

Table A- 2: Boomer Lake Area by 0.1-ft Increments.

Boomer Lake Area Table
Area in Acres by Tenth Ft Elevation Increments
2015 SURVEY
Oklahoma Water Resources Board

Elevation in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
887										0.00
888	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
889	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
890	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09
891	0.10	0.11	0.13	0.14	0.16	0.17	0.19	0.21	0.23	0.26
892	0.30	0.47	0.59	0.75	0.94	1.16	1.30	1.41	1.50	1.63
893	1.78	1.93	2.07	2.21	2.36	2.52	2.70	2.89	3.12	3.37
894	3.63	3.93	4.14	4.35	4.56	4.78	5.02	5.27	5.54	5.84
895	6.17	6.52	6.89	7.27	7.67	8.09	8.53	8.98	9.45	9.95
896	10.50	11.35	11.89	12.45	13.03	13.57	14.09	14.63	15.17	15.73
897	16.29	16.89	17.53	18.19	18.86	19.55	20.26	21.02	21.86	22.87
898	24.18	25.78	27.10	28.51	29.70	30.70	31.73	33.09	34.21	35.21
899	36.20	37.14	38.12	39.18	40.26	41.31	42.33	43.42	44.64	46.00
900	47.60	49.69	51.31	53.03	54.82	56.62	58.32	60.14	61.94	63.70
901	65.36	66.97	68.64	70.32	71.91	73.50	75.09	76.71	78.38	80.06
902	81.80	83.95	85.48	87.08	88.87	90.76	92.73	94.83	97.19	99.34
903	101.39	103.26	105.02	106.71	108.40	110.14	112.04	113.87	115.78	117.74
904	119.81	123.02	125.05	127.05	129.03	131.03	133.03	135.10	137.20	139.25
905	141.22	143.08	144.91	146.75	148.57	150.43	152.33	154.20	156.01	157.84
906	159.72	162.15	163.67	165.14	166.60	168.06	169.54	171.10	172.65	173.98
907	175.24	176.49	177.73	178.98	180.23	181.47	182.66	183.82	184.98	186.16
908	187.39	188.63	189.77	190.93	192.10	193.29	194.49	195.71	196.94	198.18
909	199.45	200.72	202.02	203.32	204.65	205.99	207.34	208.71	210.09	211.49
910	212.90									

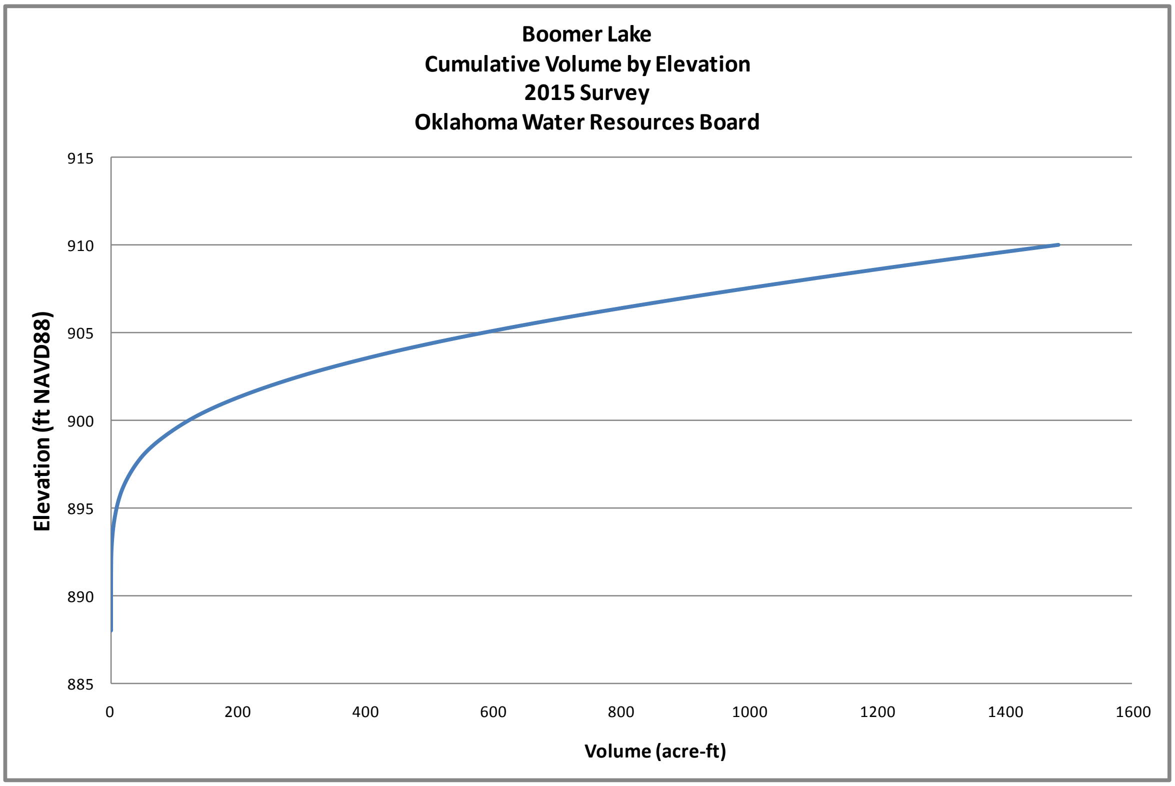

Figure A- 1: Cumulative Capacity Curve for Boomer Lake.

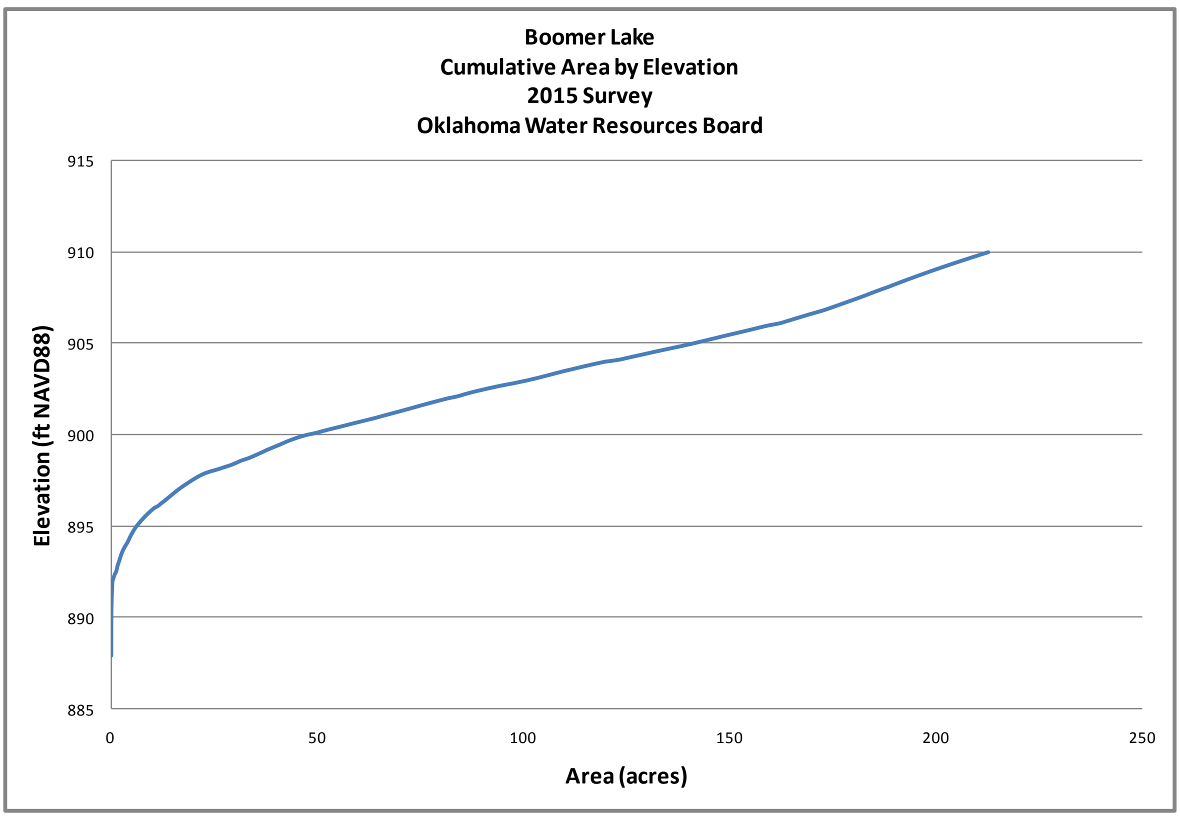

Figure A- 2: Cumulative Area Curve for Boomer Lake.

APPENDIX B: Boomer Lake Maps

Figure B- 1: Boomer Lake Survey Track Lines.

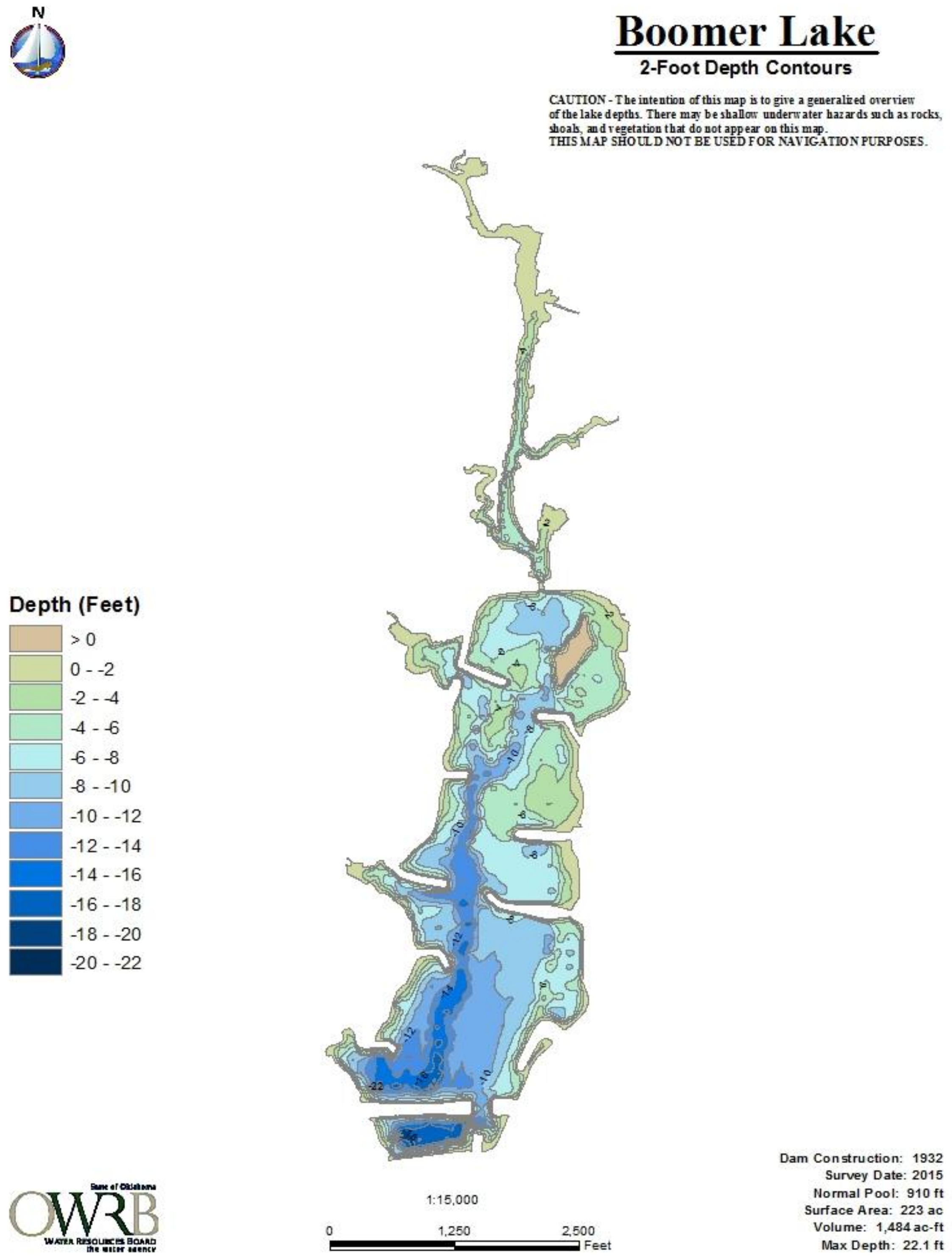

Figure B- 2: Boomer Lake Bathymetric Map with 2-ft Contour Intervals.

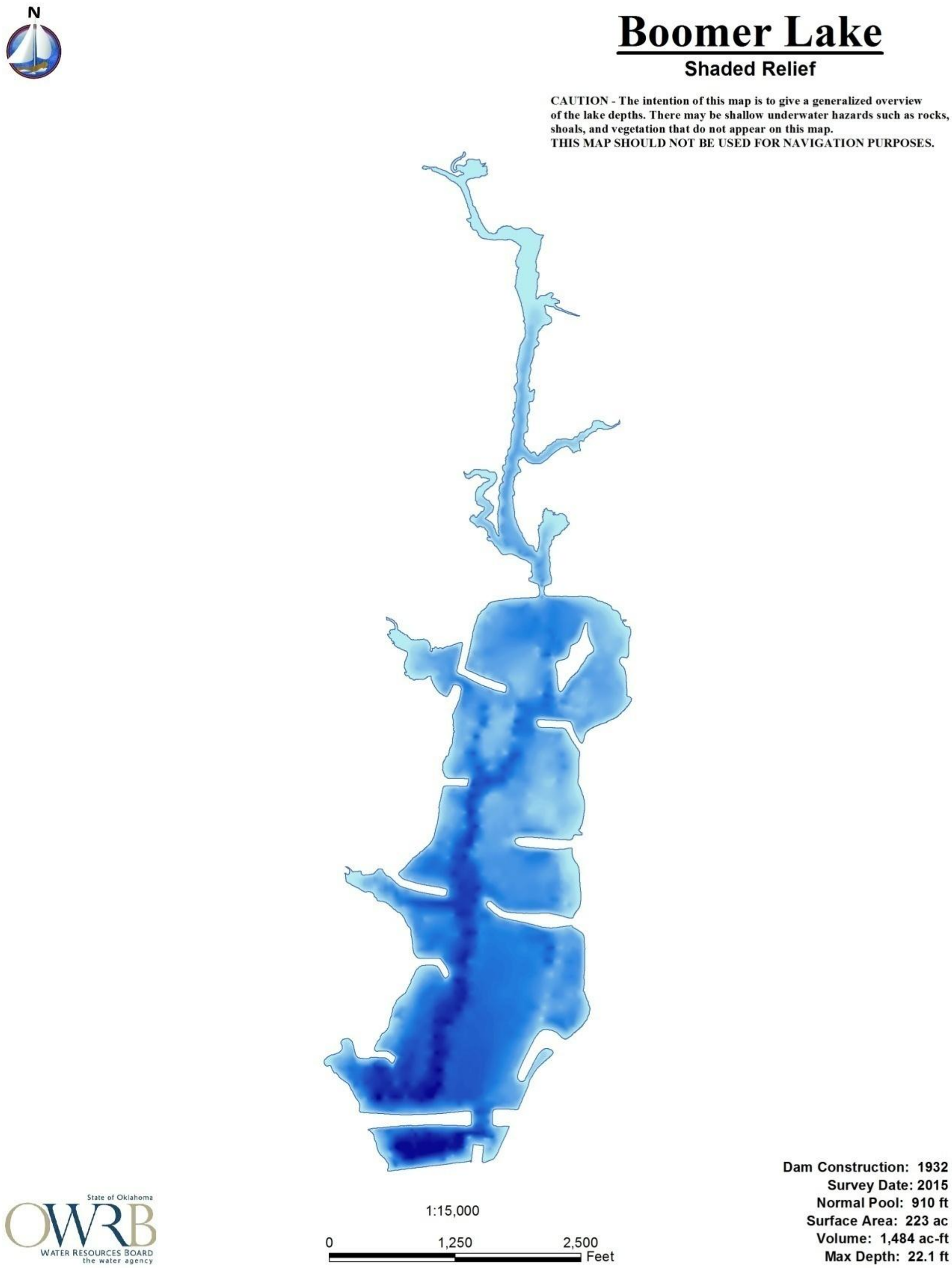

Figure B- 3: Boomer Lake Shaded Relief Bathymetric Map.

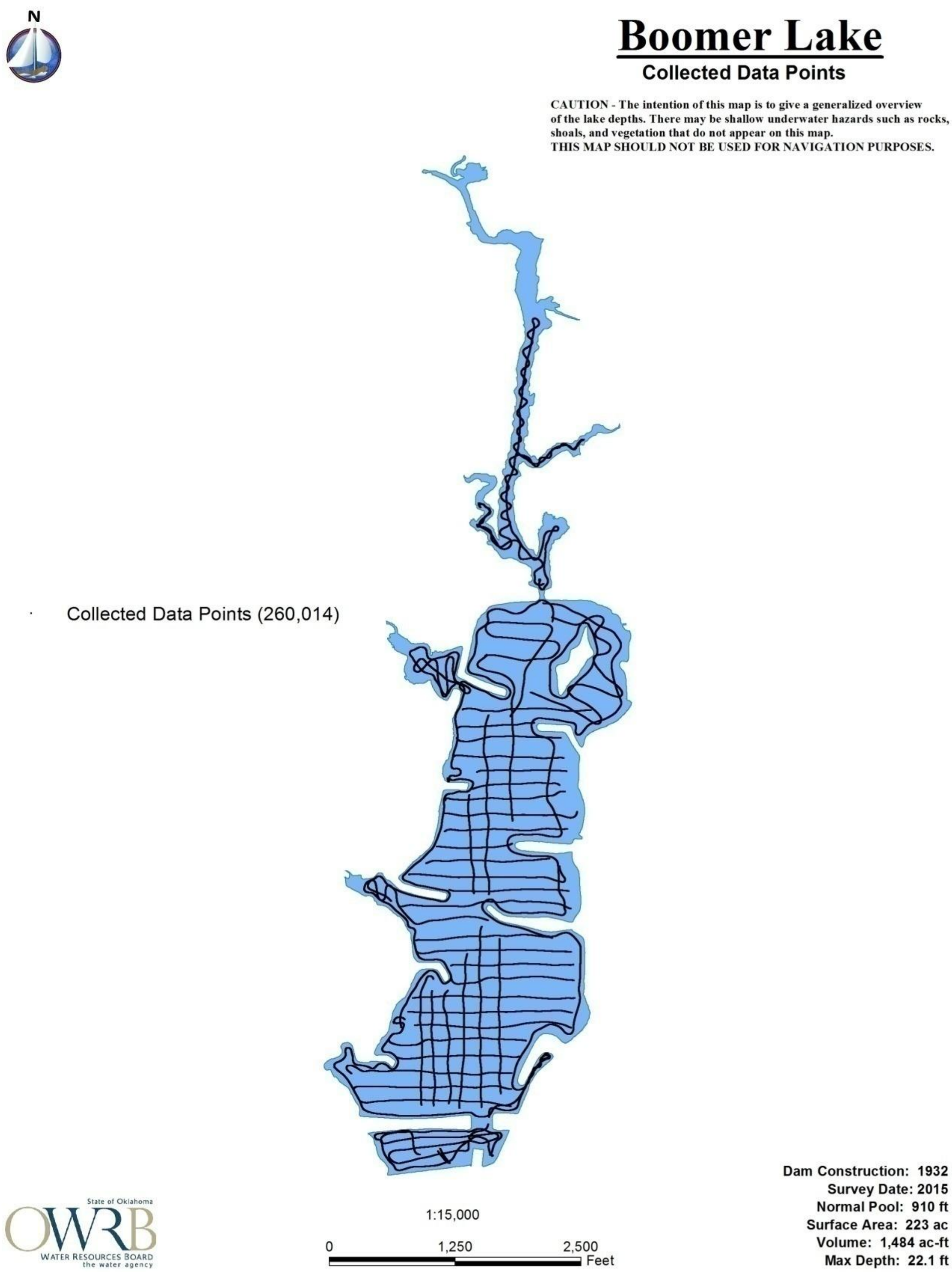

Figure B- 4: Boomer Lake Collected Data Points Map.