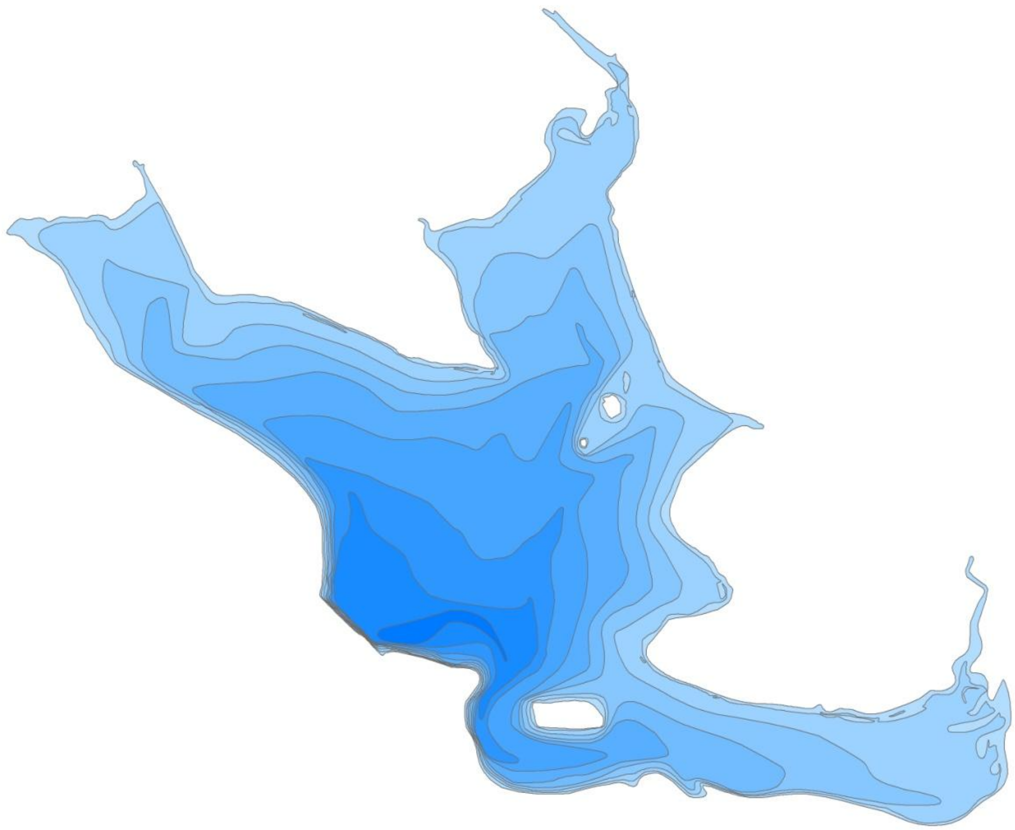
HYDROGRAPHIC SURVEY of MOUNTAIN LAKE



Final Report

November, 2013

Prepared by:

State of Oklahoma OWRB Water Resources Board the water agency

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INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Mountain Lake beginning in June of 2013. The purpose of this survey was to collect hydrographic data of the lake and convert this information into an elevation-area-capacity table. This project was funded by the City of Ardmore.

LAKE BACKGROUND

Mountain Lake is located on the Hickory Creek Tributary in Carter County (**Figure 1**). The dam was completed in 1923 and is located approximately sixteen miles north-northwest of the city of Ardmore, OK. Its primary purpose is recreation.

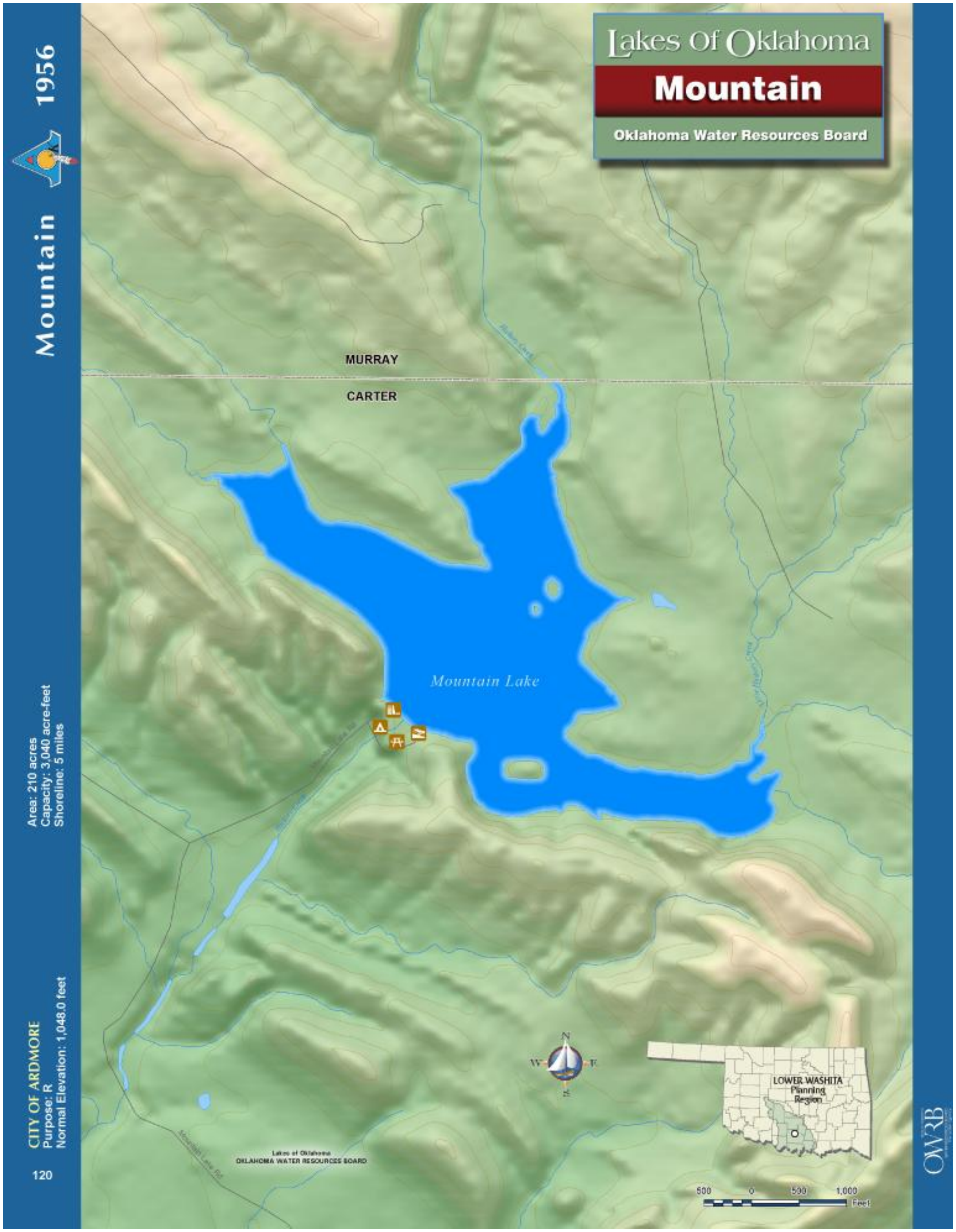


Figure 1: Location map for Mountain Lake.

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 average depths are converted to elevation readings based on the daily-recorded lake level elevation on the day the survey was performed. Accurate estimates of area-capacity can then be determined for the lake by building a 3-D model of the reservoir from the corrected data. The process of completing a hydrographic survey includes four steps: pre-survey planning, field survey, data processing, and GIS application.

Pre-survey Planning

Boundary File

The boundary file for Mountain Lake was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Carter County, Oklahoma. The screen scale was set to 1:1,500. A line was to represent the shoreline as closely as possible. Due to the photography being a summer photo, it was difficult to determine the actual shoreline when there are trees and other vegetation hanging over the lake. The 2008 and 2010 DOQQs of the lakes were used as back ground reference. The reservoir boundaries were digitized in NAD 1983 State Plane Coordinates (Oklahoma South-3502).

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 State Plane NAD 83 Zone OK-3502 Oklahoma South 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 300 ft increments and ran perpendicular to the original stream channels and tributaries. Approximately 17 virtual transects were created for Mountain Lake.

Field Survey

Lake Elevation Acquisition

The lake elevation for Mountain Lake was obtained by collecting positional data over a period of approximately 280 minutes with a survey-grade Global Positioning System (GPS) receiver. The receiver was placed over the water's surface. A measurement was taken from the antenna to the surface of the water. The collected data and antenna height was then uploaded to the On-line Positioning Users Service (OPUS) website. The National Geodetic Survey (NGS) operates OPUS as a means to provide GPS users easier access to the National Spatial Reference System (NSRS). OPUS allows users to submit their GPS data files to NGS, where the data is processed to determine a position using NGS computers and software. Calculated coordinates are averaged from three independent single-baseline solutions computed by double-differenced, carrier-phase measurements between the collected data file and 3 surrounding Continuously Operating Reference Stations (CORS). Under ideal conditions, OPUS can easily resolve most positions to within centimeter accuracy. A report containing the newly calculated positional data was electronically returned via email. This report contained the elevation of the surface of the water corrected for the antenna height.

Method

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.

Technology

The Hydro-survey vessel is 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; Innerspace 456Xpe Echo Sounder, with a depth resolution of 0.1 ft; Trimble Navigation, Inc. Pro XR GPS receiver with differential global positioning system (DGPS) correction; and an Odom Hydrographics, Inc, DIGIBAR-Pro Profiling Sound Velocimeter. The software used was HYPACK.

Survey

A two-man survey crew was used during the project. Data collection for Mountain Lake occurred in November of 2012. The water level elevation for Mountain Lake was 818.2 ft Geodetic Vertical Datum (NAVD 88). 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, two to three feet deep. Areas with depths less than this were avoided.

Quality Control/Quality Assurance

While on board the Hydro-survey vessel, a sound velocity profile was collected each day using a DIGIBAR-Pro Profiling Sound Velocimeter, by Odom Hydrographics. The sound velocimeter measures the speed of sound at incremental depths throughout the water column. The factors that influence the speed of sound—depth, temperature, and salinity—are all taken into account. Deploying the unit involved lowering the probe, which measures the speed of sound, 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 to the raw depth readings.

A quality assurance cross-line check was performed on intersecting transect lines and channel track lines to assess the estimated accuracy of the survey measurements. The overall accuracy of an observed bottom elevation or depth reading is dependent on random and systematic errors that are present in the measurement process. Depth measurements contain both random errors and systematic bias. Biases are often referred to as systematic errors and are often due to observational errors. Examples of bias include a bar check calibration error, tidal errors, or incorrect squat corrections. Bias, however, does not affect the repeatability, or precision, of results. The precision of depth readings is affected by random errors. These are errors present in the measurement system that cannot be easily reduced by further calibration. Examples of random error include uneven bottom topography, bottom vegetation, positioning error, extreme listing of survey vessel, and speed of sound variation in the water column. An assessment of the accuracy of an individual depth or bottom elevation must fully consider all the error components contained in the observations that were used to determine that measurement. Therefore, the ultimate accuracy must be estimated (thus the use of the term "estimated accuracy") using statistical estimating measures (USACE, 2002).

The depth accuracy estimate is determined by comparing depth readings taken at the intersection of two lines and computing the difference. This is done on multiple intersections. The mean difference of all intersection points is used to calculate the mean difference (MD). The mean difference represents the bias present in the survey. The standard deviation (SD), representing the random error in the survey, is also calculated. The mean difference and the standard deviation are then used to calculate 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). According the USACE standards, the RMS at the 95% confidence level should not exceed a tolerance of ± 2.0 ft for this type of survey. This simply means that on average, 19 of every 20 observed depths will fall within the specified accuracy tolerance.

HYPACK Cross Statistics program was used to assess vertical accuracy and confidence measures of acoustically recorded depths. The program computes the sounding difference between intersecting lines of single beam data. The program provides a report that shows the standard deviation and mean difference. A total of 54 cross-sections points at Mountain Lake were used to compute error estimates. A mean difference (arithmetic mean) of 0.128 ft and a standard deviation of 0.391 ft were computed from intersections. The following formulas were used to determine the depth accuracy at the 95% confidence level.

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

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 ± 0.81 ft with a 95% confidence level is less than the USACE's minimum performance standard of ± 2.0 ft for this type of survey. A mean difference, or bias, of 0.128

ft is well below the USACE's standard maximum allowable bias of ± 0.5 ft for this type of survey.

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. 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 0.2 seconds was produced and adjustments were applied to the raw data in the EDIT program.

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 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 depth information. Raw data files are checked for gross inaccuracies that occur during data collection.

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 0.1 seconds. The speed of sound corrections were applied during editing of raw data.

A correction file was produced using the HYPACK TIDES program to account for the variance in lake elevation at the time of data collection. Within the EDIT program, the corrected depths were 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 due to the large quantity of collected data.. To accomplish this, the corrected data was resampled spatially at a 5 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 Mountain Lake are located on the DVD entitled *Mountain Lake 2012 Disk 1 HYPACK/GIS Metadata.*

GIS Application

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 ArcMap, version 10.1, 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 ArcMap 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 Triangulated Irregular Network (TIN) surface model. The TIN model was created in ArcMap, 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. 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 ArcMap Topo to Raster Tool and had a spatial resolution of five feet. 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 ArcMap 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 coverage and attributed to show 5-ft depth ranges across the lake. The bathymetric maps of the lakes are shown with 5-ft contour intervals in **APPENDIX B: Mountain 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 both lakes is located on the DVD entitled *Mountain Lake 2012 Disk 1 HYPACK/GIS Metadata.*

RESULTS

Results from the 2012 OWRB survey indicate that Mountain Lake encompasses 215 acres and contains a cumulative capacity of 3620 ac-ft at the normal pool elevation (1045.7 ft NAVD 88). The average depth for Mountain Lake was 16.69 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Mountain Lake at the normal pool elevation. Due to the age of the dam, original design specifications for Mountain Lake could not be found. It is the recommendation of the OWRB that another survey using the same method used in the 2012 survey be conducted in 10-15 years. By using the 2012 survey figures as a baseline, a future survey would allow an accurate sedimentation rate to be obtained.

Table 1: Area and Volume Comparisons of Mountain Lake at normal pool (1045.7 ft NAVD 88).

Feature	Survey Year	
	1923 Design Specifications	2012
Area (acres)	--	215
Cumulative Volume (acre-feet)	--	3620
Mean depth (ft)	--	16.69
Maximum Depth (ft)	--	43.38

REFERENCES

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

Oklahoma Water Resources Board (OWRB). 2010. Lakes of Oklahoma.

APPENDIX A: Area-Capacity Data

Table A.1 Mountain Lake Capacity/Area by 0.1-ft Increments.

MOUNTAIN LAKE AREA-CAPACITY TABLE
OKLAHOMA WATER RESOURCES BOARD
2013 Survey
Capacity in acre-feet by tenth foot elevation increments
Area in acres by tenth foot elevation increments

Elevation (ft NAVD 88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1003	Area							0	0	3E-04	9E-04
	Capacity							0	9E-04	0.004	0.008
1004	Area	0.002	0.004	0.007	0.012	0.019	0.03	0.045	0.064	0.09	0.123
	Capacity	0.014	0.023	0.037	0.06	0.089	0.127	0.172	0.226	0.292	0.367
1005	Area	0.164	0.214	0.274	0.345	0.427	0.52	0.624	0.746	0.928	1.119
	Capacity	0.453	0.549	0.654	0.762	0.873	0.985	1.102	1.779	1.865	1.952
1006	Area	1.319	1.527	1.745	1.972	2.208	2.454	2.709	2.975	3.251	3.538
	Capacity	2.042	2.132	2.225	2.315	2.408	2.505	2.604	2.706	2.816	2.939
1007	Area	3.84	4.157	4.491	4.844	5.215	5.607	6.021	6.46	6.924	7.413
	Capacity	3.092	3.253	3.43	3.615	3.814	4.027	4.259	4.513	4.769	5.02
1008	Area	7.928	8.467	9.028	9.613	10.22	10.85	11.51	12.19	12.89	13.62
	Capacity	5.27	5.5	5.728	5.96	6.195	6.435	6.673	6.913	7.154	7.405
1009	Area	14.37	15.15	15.95	16.78	17.64	18.52	19.42	20.35	21.3	22.28
	Capacity	7.664	7.913	8.165	8.414	8.659	8.907	9.154	9.4	9.646	9.898
1010	Area	23.28	24.31	25.36	26.44	27.55	28.68	29.85	31.07	32.36	33.68
	Capacity	10.15	10.41	10.67	10.93	11.21	11.5	11.86	12.81	13.06	13.3
1011	Area	35.02	36.39	37.78	39.19	40.62	42.09	43.57	45.08	46.61	48.17
	Capacity	13.54	13.78	14.01	14.25	14.48	14.72	14.96	15.2	15.45	15.7
1012	Area	49.75	51.36	52.99	54.65	56.33	58.04	59.77	61.54	63.33	65.14
	Capacity	15.94	16.19	16.45	16.7	16.95	17.22	17.49	17.76	18.03	18.31
1013	Area	66.99	68.86	70.77	72.7	74.66	76.65	78.68	80.73	82.82	84.94
	Capacity	18.59	18.88	19.17	19.47	19.77	20.08	20.39	20.7	21.02	21.34
1014	Area	87.09	89.27	91.48	93.73	96	98.32	100.7	103	105.4	107.9
	Capacity	21.65	21.97	22.3	22.62	22.94	23.27	23.6	23.92	24.25	24.59
1015	Area	110.4	112.9	115.4	118	120.6	123.3	126	128.7	131.5	134.4
	Capacity	24.94	25.28	25.63	25.98	26.35	26.71	27.1	28.24	28.66	29.07
1016	Area	137.4	140.3	143.3	146.4	149.5	152.7	155.8	159.1	162.4	165.7
	Capacity	29.48	29.91	30.36	30.8	31.25	31.69	32.15	32.61	33.09	33.57
1017	Area	169.1	172.5	176	179.5	183.1	186.7	190.4	194.2	198	201.8
	Capacity	34.06	34.54	35.03	35.55	36.06	36.57	37.11	37.66	38.21	38.76
1018	Area	205.7	209.7	213.7	217.7	221.9	226	230.2	234.5	238.8	243.2
	Capacity	39.3	39.85	40.39	40.91	41.43	41.94	42.47	43	43.52	44.04
1019	Area	247.7	252.1	256.7	261.3	265.9	270.6	275.4	280.2	285.1	290
	Capacity	44.58	45.11	45.64	46.19	46.75	47.31	47.87	48.43	48.98	49.53
1020	Area	295	300	305.1	310.2	315.4	320.7	326	331.4	336.9	342.4
	Capacity	50.07	50.61	51.17	51.72	52.27	52.85	53.43	54.54	55.06	55.55
1021	Area	348	353.6	359.3	365	370.8	376.6	382.4	388.3	394.3	400.3
	Capacity	56.02	56.47	56.92	57.39	57.86	58.34	58.81	59.27	59.72	60.18
1022	Area	406.3	412.4	418.5	424.7	430.9	437.2	443.5	449.9	456.3	462.8
	Capacity	60.63	61.09	61.55	62.02	62.48	62.96	63.47	63.98	64.48	64.97
1023	Area	469.3	475.9	482.5	489.2	495.9	502.7	509.5	516.3	523.2	530.2
	Capacity	65.46	65.95	66.41	66.88	67.35	67.82	68.28	68.75	69.21	69.66

Table A.2: Mountain Lake Capacity/Area by 0.1-ft Increments (cont).

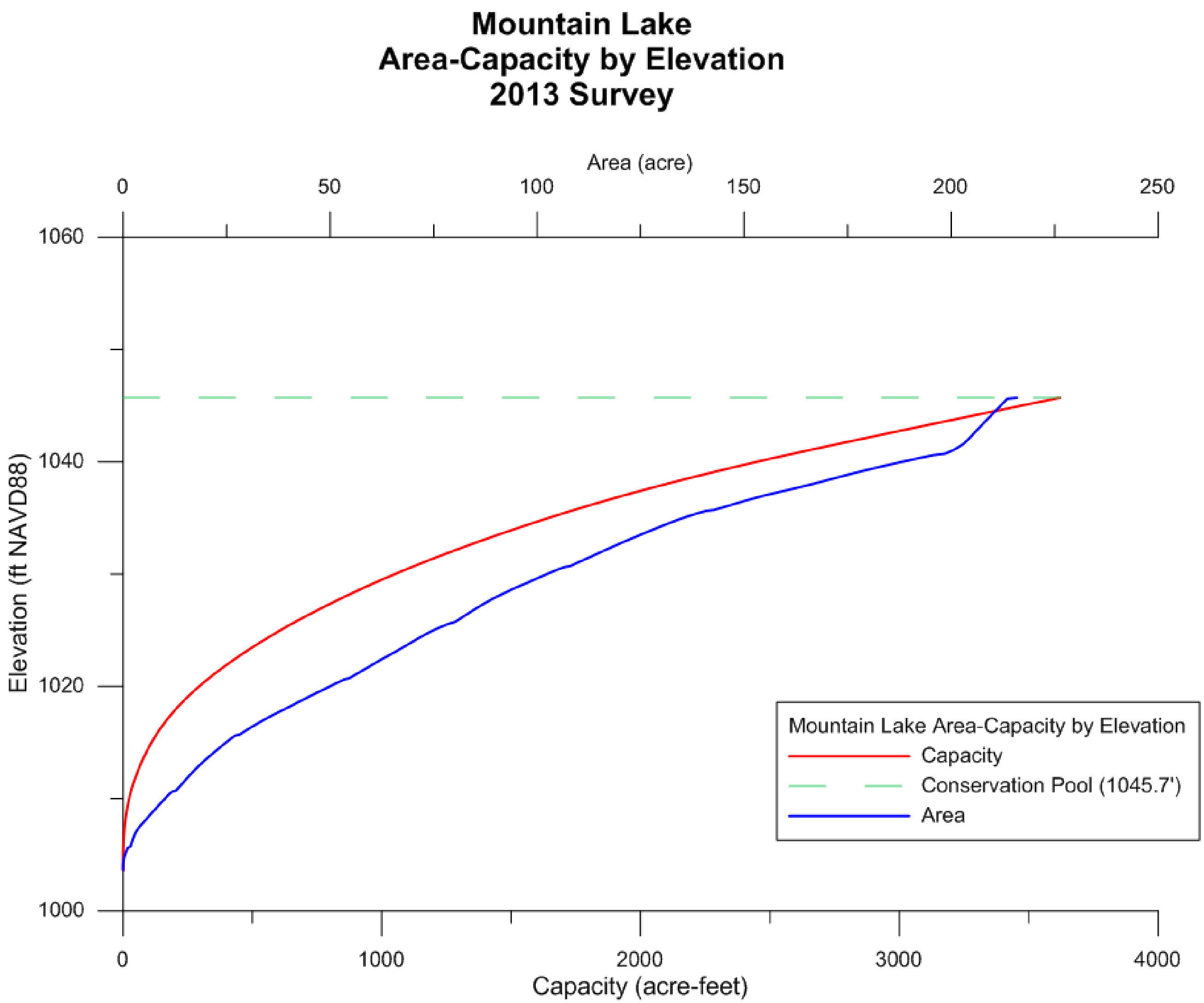
MOUNTAIN LAKE AREA-CAPACITY TABLE
OKLAHOMA WATER RESOURCES BOARD
2013 Survey
Capacity in acre-feet by tenth foot elevation increments
Area in acres by tenth foot elevation increments

Elevation (ft NAVD 88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1024	Area	537.2	544.2	551.3	558.4	565.6	572.8	580.1	587.4	594.8	602.2
	Capacity	70.12	70.58	71.03	71.5	71.98	72.48	72.97	73.48	74.02	74.56
1025	Area	609.7	617.2	624.8	632.5	640.2	648	655.9	663.8	671.9	679.9
	Capacity	75.12	75.71	76.32	76.96	77.62	78.31	79.04	80.1	80.53	80.96
1026	Area	688.1	696.2	704.4	712.7	721	729.3	737.7	746.1	754.5	763
	Capacity	81.38	81.81	82.23	82.65	83.07	83.49	83.92	84.34	84.77	85.2
1027	Area	771.6	780.2	788.8	797.5	806.2	815	823.8	832.6	841.6	850.5
	Capacity	85.64	86.08	86.53	86.99	87.46	87.94	88.42	88.91	89.42	89.94
1028	Area	859.6	868.6	877.8	887	896.2	905.5	914.9	924.3	933.8	943.3
	Capacity	90.48	91.04	91.6	92.16	92.72	93.29	93.86	94.44	95.03	95.63
1029	Area	952.9	962.6	972.3	982.1	991.9	1002	1012	1022	1032	1042
	Capacity	96.31	96.94	97.57	98.19	98.8	99.4	100	100.6	101.2	101.8
1030	Area	1052	1063	1073	1083	1094	1104	1115	1126	1137	1147
	Capacity	102.5	103.1	103.8	104.4	105.1	105.8	106.6	108	108.6	109.2
1031	Area	1158	1169	1180	1192	1203	1214	1225	1237	1248	1260
	Capacity	109.8	110.4	111	111.6	112.2	112.8	113.4	114	114.6	115.2
1032	Area	1271	1283	1294	1306	1318	1330	1342	1354	1366	1378
	Capacity	115.8	116.4	117	117.6	118.2	118.8	119.4	120	120.6	121.2
1033	Area	1390	1402	1414	1427	1439	1452	1464	1477	1490	1502
	Capacity	121.9	122.5	123.2	123.8	124.5	125.1	125.7	126.4	127.1	127.7
1034	Area	1515	1528	1541	1554	1567	1580	1593	1607	1620	1633
	Capacity	128.4	129.1	129.7	130.4	131.1	131.8	132.5	133.2	133.9	134.7
1035	Area	1647	1661	1674	1688	1702	1716	1730	1744	1758	1773
	Capacity	135.4	136.2	137.1	137.9	138.8	139.7	140.7	142.7	143.7	144.6
1036	Area	1787	1802	1816	1831	1846	1861	1876	1891	1907	1922
	Capacity	145.6	146.5	147.4	148.3	149.2	150.1	151.1	152.1	153.1	154.1
1037	Area	1937	1953	1969	1984	2000	2016	2033	2049	2065	2082
	Capacity	155.1	156.3	157.4	158.6	159.8	160.9	162.1	163.2	164.3	165.4
1038	Area	2098	2115	2132	2149	2166	2183	2200	2217	2235	2252
	Capacity	166.5	167.5	168.6	169.6	170.6	171.7	172.7	173.7	174.7	175.8
1039	Area	2270	2288	2306	2323	2342	2360	2378	2396	2415	2434
	Capacity	176.8	177.9	179	180.1	181.3	182.4	183.6	184.7	185.9	187.2
1040	Area	2452	2471	2490	2510	2529	2548	2568	2587	2607	2627
	Capacity	188.4	189.6	190.9	192.1	193.3	194.6	196.1	198.4	199.1	199.7
1041	Area	2647	2667	2687	2708	2728	2748	2768	2789	2809	2829
	Capacity	200.3	200.9	201.3	201.8	202.2	202.6	203	203.4	203.6	203.9
1042	Area	2850	2870	2891	2911	2932	2952	2973	2993	3014	3035
	Capacity	204.2	204.4	204.7	204.9	205.2	205.5	205.7	206	206.2	206.5
1043	Area	3055	3076	3097	3117	3138	3159	3180	3201	3222	3242
	Capacity	206.7	207	207.3	207.5	207.8	208	208.3	208.6	208.8	209.1
1044	Area	3263	3284	3305	3326	3347	3368	3389	3411	3432	3453
	Capacity	209.3	209.6	209.9	210.1	210.4	210.7	210.9	211.2	211.5	211.7

Table A.3 : Mountain Lake Capacity/Area by 0.1-ft Increments (cont).

MOUNTAIN LAKE AREA-CAPACITY TABLE OKLAHOMA WATER RESOURCES BOARD 2011 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NAVD 88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1045	Area	3474	3495	3517	3538	3559	3580	3602	3621		
	Capacity	212	212.2	212.5	212.8	213	213.3	213.6	215.9		

Figure A. 1. Area-Capacity Curve for Mountain Lake



APPENDIX B: Mountain Lake Maps

Figure B. 1: Mountain Lake Bathymetric Map with 5-foot Contour Intervals.

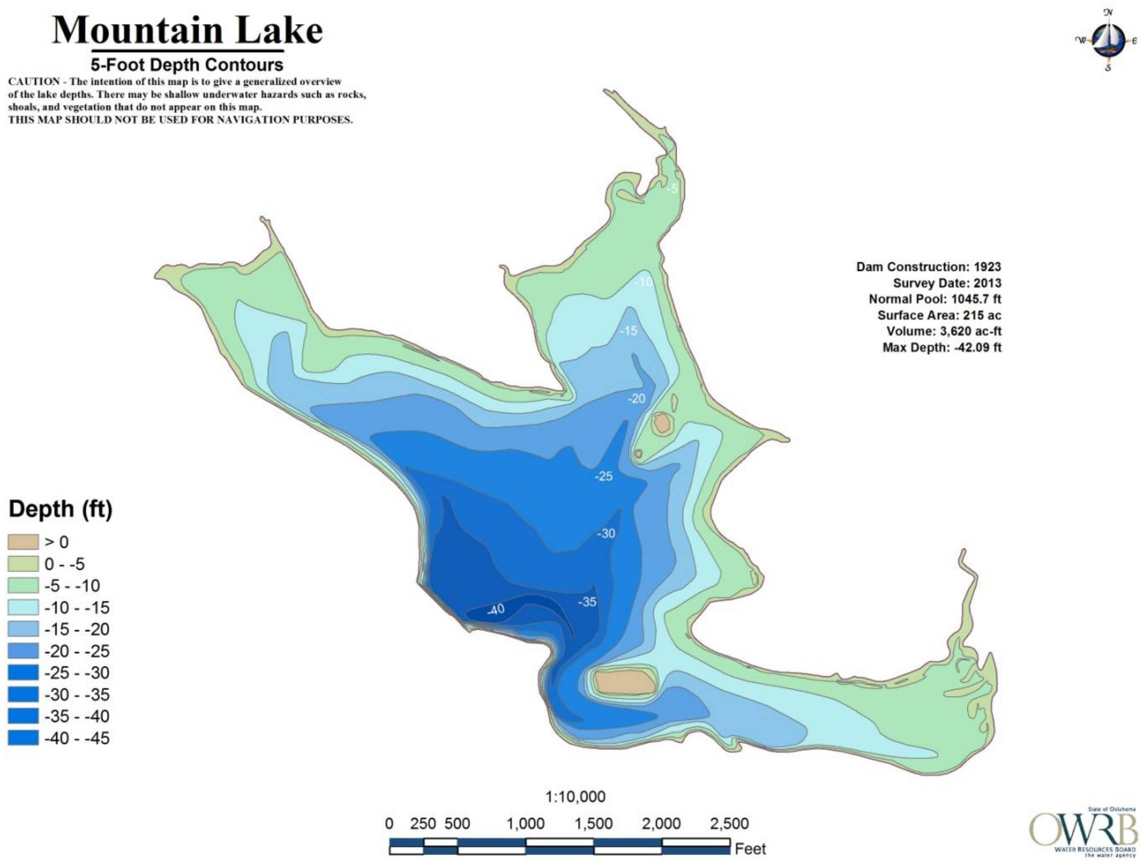


Figure B. 2: Mountain Lake Shaded Relief Bathymetric Map.

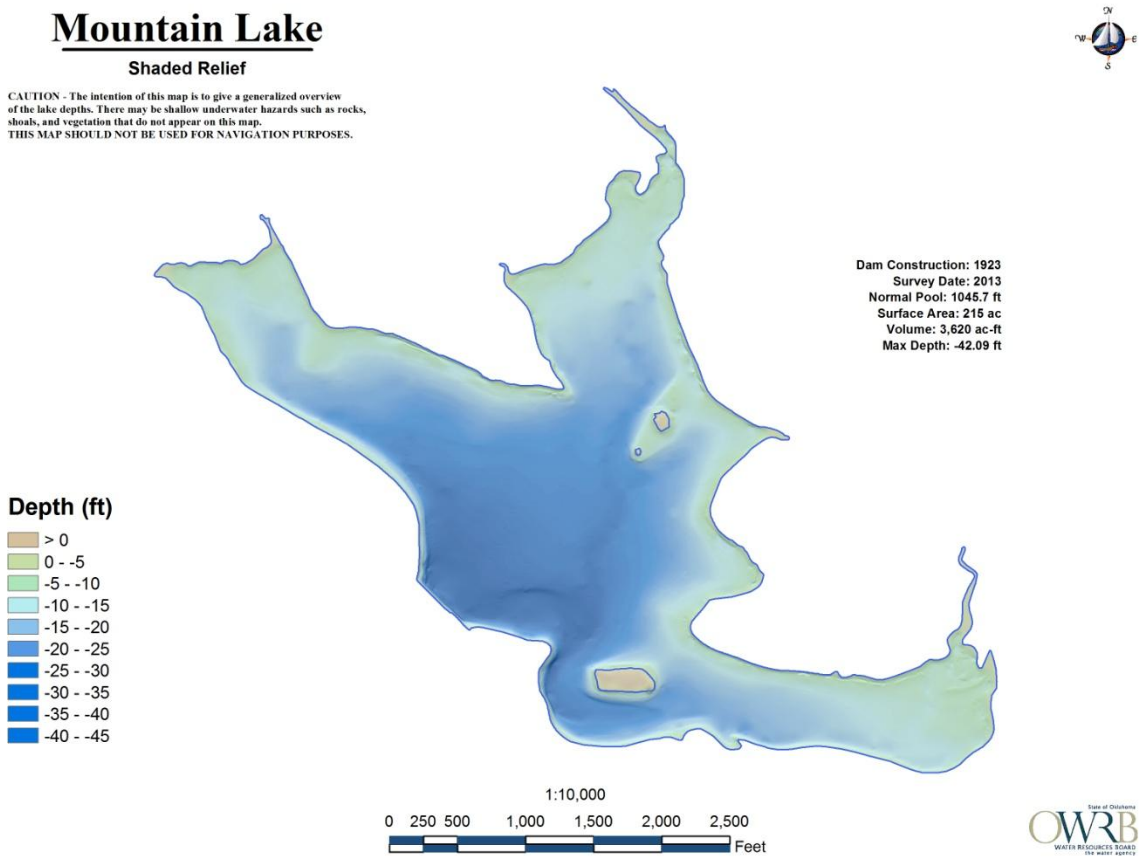


Figure B. 3: Mountain Lake Collected Data Points.