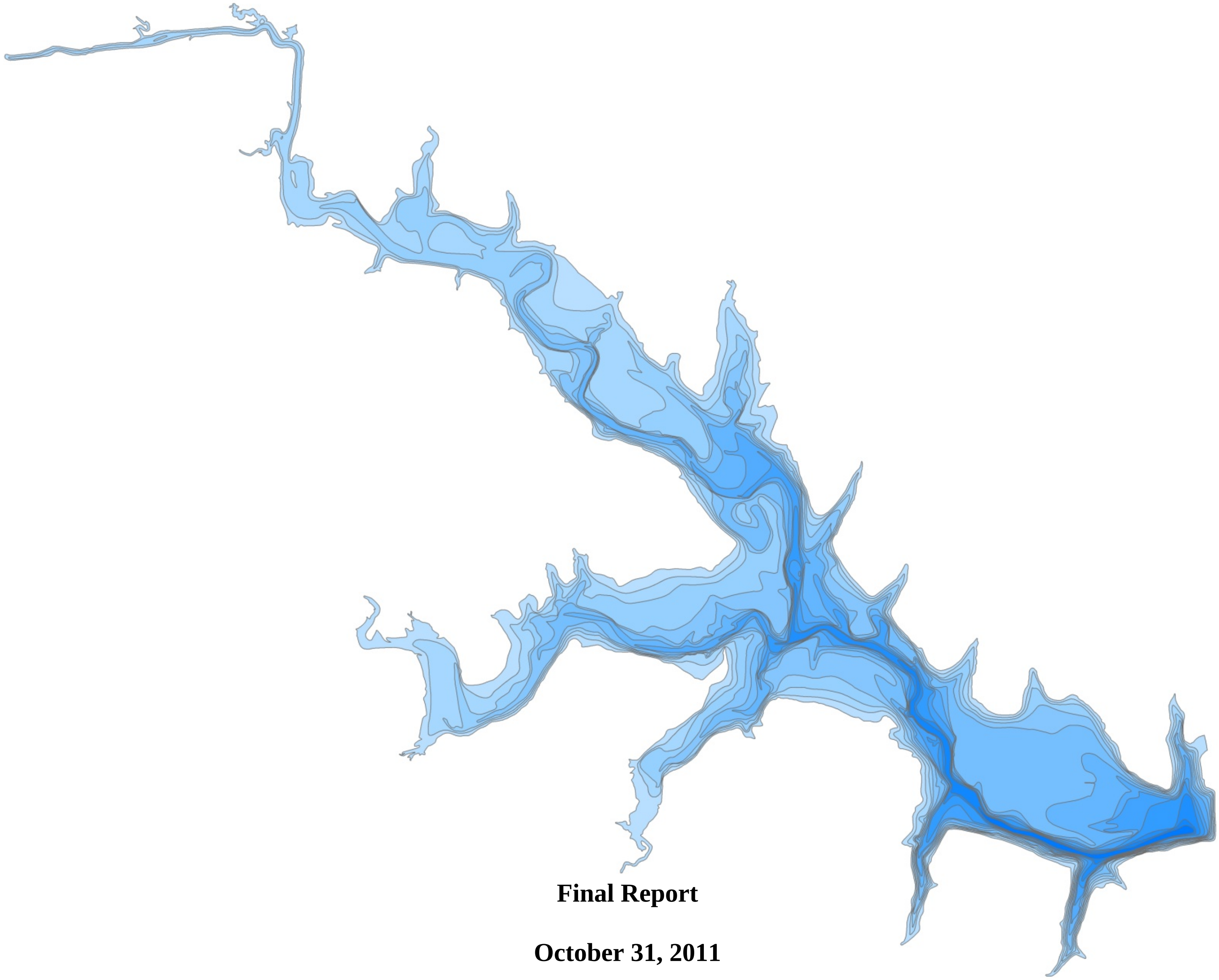
HYDROGRAPHIC SURVEY of BLUESTEM LAKE



Final Report

October 31, 2011

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 Bluestem Lake in August and September of 2011. 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 OWRB's Dam Safety Program.

LAKE BACKGROUND

Bluestem Lake is located on Middle Bird Creek in Osage County (**Figure 1**). The dam was completed in 1958 and is located approximately three miles west and two miles north of the city of Pawhuska, OK. Its purposes are water supply, and recreation. The dam on this reservoir is classified as a high hazard dam. The "high hazard" classification means that dam failure, if it occurred, may cause loss of life, serious damage to homes, industrial or commercial buildings, important public utilities, main highways or railroads. This classification does not mean that it is likely to fail.

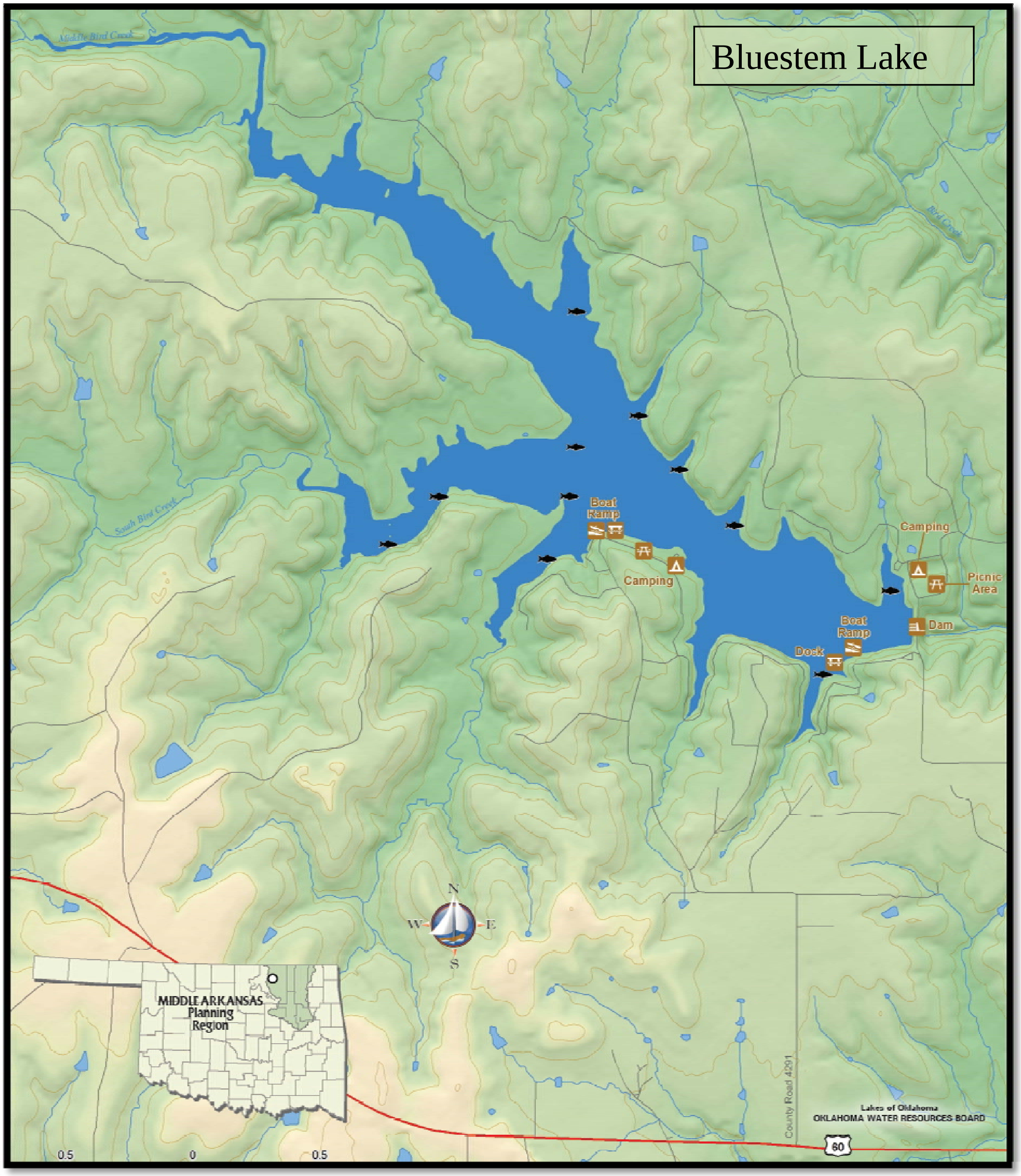


Figure 1: Location map for Bluestem Lake.

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 Bluestem Lake was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Osage 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 North-3501).

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-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 300 ft increments and ran perpendicular to the original stream channels and tributaries. Approximately 73 virtual transects were created for Bluestem Lake.

Field Survey

Lake Elevation Acquisition

The lake elevation for Bluestem Lake was obtained by collecting positional data over a period of approximately 286 minutes (over multiple days) 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 Bluestem Lake occurred on two separate days, one in August and one in September of 2011. The water level elevation for Bluestem Lake for the day of collection in August was 873.7 ft Geodetic Vertical Datum (NAVD 88) and on the day of collection in September was 872.9 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 151 cross-sections points at Bluestem Lake were used to compute error estimates. A mean difference (arithmetic mean) of 0.042 ft and a standard deviation of 0.392 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 ± 0.77 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 0.042 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. 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 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 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 Bluestem Lake are located on the DVD entitled *FEMA 2011 Disk 2 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 9.3.1, 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 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: Bluestem 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 at on the DVD entitled *FEMA 2011 Disk 2 HYPACK/GIS Metadata.*

RESULTS

Results from the 2011 OWRB survey indicate that Bluestem Lake encompasses 865 acres and contains a cumulative capacity of 14,436 ac-ft at the normal pool elevation (877 ft NAVD 88). The average depth for Bluestem Lake was 16.69 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Bluestem Lake at the normal pool elevation. Based on the design specifications, Bluestem Lake had an area of 890 acres and cumulative volume of 17,000 acre-feet of water at conservation pool elevation (877 ft NAVD 88). The surface area of the lake has had a decrease of 25 acres or approximately 2.8%. The 2011 survey shows that Bluestem Lake has had an apparent decrease in capacity of 15% or approximately 2,564 acre-feet. Caution should be used when directly comparing between the design specifications and the 2011 survey conducted by the OWRB because different methods were used to collect the data and extrapolate capacity and area figures. This could account for the apparent loss in capacity. It is the recommendation of the OWRB that another survey using the same method used in the 2011 survey be conducted in 10-15 years. By using the 2011 survey figures as a baseline, a future survey would allow an accurate sedimentation rate to be obtained.

Table 1: Area and Volume Comparisons of Bluestem Lake at normal pool (877 ft NAVD 88).

Feature	Survey Year	
	1958 Design Specifications	2011
Area (acres)	890	865
Cumulative Volume (acre-feet)	17,000	14,436
Mean depth (ft)	19.1	16.69
Maximum Depth (ft)	--	57.41

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). 1978. Phase 1 Inspection Report; National Dam Safety Program.

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

APPENDIX A: Area-Capacity Data

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

BLUESTEM 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
819	Area							0.0000	0.0015	0.0063	0.0159
	Capacity							0.0000	0.0000	0.0004	0.0015
820	Area	0.0282	0.0428	0.0593	0.0787	0.1018	0.1284	0.1567	0.1864	0.2188	0.2549
	Capacity	0.0037	0.0072	0.0123	0.0192	0.0282	0.0397	0.0539	0.0711	0.0913	0.1150
821	Area	0.2971	0.3524	0.4164	0.4939	0.5890	0.7012	0.8298	0.9728	1.1295	1.2991
	Capacity	0.1425	0.1749	0.2132	0.2586	0.3126	0.3770	0.4534	0.5435	0.6484	0.7698
822	Area	1.4829	5.6272	5.6851	5.7432	5.8017	5.8606	5.9198	5.9795	6.0401	6.1024
	Capacity	0.9088	1.4280	1.9935	2.5649	3.1424	3.7255	4.3148	4.9097	5.5106	6.1180
823	Area	6.1660	6.2390	6.3246	6.4021	6.4759	6.5510	6.6290	6.7147	6.8026	6.8916
	Capacity	6.7314	7.3517	7.9798	8.6162	9.2604	9.9117	10.571	11.238	11.914	12.599
824	Area	6.9814	7.0733	7.1689	7.2651	7.3687	7.4934	7.6146	7.7347	7.8565	7.9812
	Capacity	13.292	13.996	14.708	15.429	16.161	16.904	17.660	18.427	19.207	19.999
825	Area	8.1085	8.2386	8.3712	8.5057	8.6431	8.7830	8.9260	9.0761	9.2449	9.4266
	Capacity	20.803	21.621	22.451	23.295	24.153	25.024	25.910	26.810	27.726	28.660
826	Area	9.6161	9.8135	10.023	10.246	10.481	10.724	10.980	11.246	11.526	11.843
	Capacity	29.612	30.584	31.575	32.588	33.625	34.685	35.771	36.882	38.020	39.189
827	Area	12.246	14.305	14.437	14.569	14.701	14.834	14.968	15.103	15.239	15.377
	Capacity	40.392	41.797	43.234	44.685	46.149	47.625	49.116	50.620	52.136	53.668
828	Area	15.516	15.656	15.798	15.940	16.084	16.232	16.388	16.547	16.710	16.874
	Capacity	55.212	56.772	58.344	59.931	61.533	63.149	64.781	66.427	68.090	69.770
829	Area	17.040	17.209	17.380	17.556	17.742	17.935	18.134	18.341	18.549	18.760
	Capacity	71.465	73.178	74.908	76.654	78.420	80.204	82.008	83.831	85.676	87.542
830	Area	18.977	19.201	19.439	19.692	19.953	20.219	20.489	20.764	21.046	21.338
	Capacity	89.429	91.338	93.270	95.226	97.209	99.218	101.25	103.32	105.41	107.53
831	Area	21.644	21.967	22.303	22.644	22.990	23.344	23.708	24.078	24.470	24.902
	Capacity	109.68	111.86	114.07	116.32	118.60	120.92	123.27	125.66	128.09	130.56
832	Area	25.443	27.725	28.059	28.392	28.729	29.071	29.416	29.768	30.123	30.478
	Capacity	133.07	135.81	138.60	141.42	144.28	147.17	150.09	153.05	156.05	159.08
833	Area	30.833	31.191	31.557	31.928	32.293	32.663	33.043	33.421	33.805	34.194
	Capacity	162.14	165.25	168.38	171.56	174.77	178.02	181.30	184.63	187.99	191.39
834	Area	34.586	34.979	35.377	35.779	36.184	36.592	37.002	37.414	37.841	38.317
	Capacity	194.83	198.31	201.83	205.38	208.98	212.62	216.30	220.02	223.78	227.59
835	Area	38.818	39.329	39.838	40.310	40.757	41.203	41.649	42.085	42.528	42.980
	Capacity	231.45	235.36	239.32	243.33	247.38	251.48	255.62	259.81	264.04	268.32
836	Area	43.438	43.908	44.381	44.862	45.359	45.874	46.413	46.970	47.553	48.157
	Capacity	272.64	277.01	281.42	285.88	290.39	294.96	299.57	304.24	308.97	313.75
837	Area	48.796	51.594	52.125	52.643	53.126	53.594	54.054	54.510	54.964	55.419
	Capacity	318.60	323.71	328.90	334.14	339.43	344.76	350.15	355.58	361.05	366.57
838	Area	55.875	56.329	56.785	57.240	57.699	58.160	58.620	59.082	59.547	60.012
	Capacity	372.14	377.75	383.40	389.10	394.85	400.65	406.49	412.37	418.30	424.28
839	Area	60.475	60.946	61.411	61.876	62.341	62.805	63.272	63.742	64.215	64.692
	Capacity	430.31	436.38	442.50	448.66	454.88	461.13	467.44	473.79	480.19	486.64

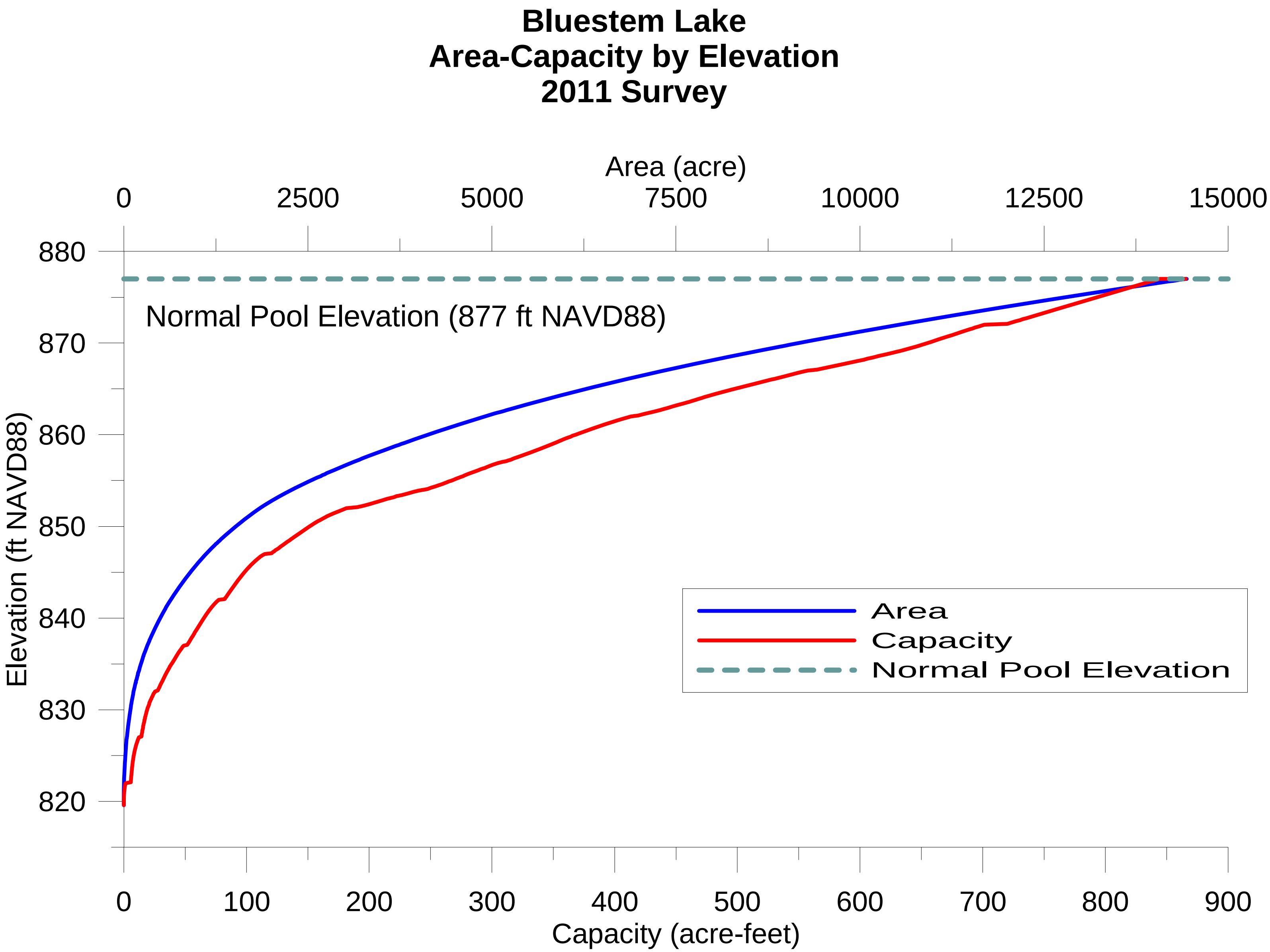
Table A. 2: Bluestem Lake Capacity/Area by 0.1-ft Increments (cont).

BLUESTEM 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
840	Area	65.170	65.658	66.153	66.646	67.137	67.632	68.135	68.670	69.225	69.786
	Capacity	493.13	499.67	506.26	512.90	519.60	526.33	533.12	539.96	546.86	553.81
841	Area	70.366	70.965	71.587	72.230	72.892	73.569	74.259	74.967	75.698	76.462
	Capacity	560.82	567.89	575.01	582.20	589.46	596.79	604.18	611.64	619.17	626.79
842	Area	77.352	82.223	82.759	83.273	83.781	84.287	84.794	85.314	85.850	86.390
	Capacity	634.47	642.63	650.88	659.18	667.53	675.94	684.39	692.90	701.46	710.07
843	Area	86.922	87.449	87.974	88.500	89.030	89.567	90.114	90.666	91.223	91.784
	Capacity	718.74	727.46	736.23	745.05	753.93	762.86	771.85	780.89	789.98	799.14
844	Area	92.348	92.918	93.496	94.079	94.665	95.254	95.846	96.442	97.042	97.649
	Capacity	808.34	817.61	826.93	836.31	845.75	855.24	864.80	874.42	884.09	893.83
845	Area	98.262	98.883	99.511	100.15	100.80	101.48	102.18	102.89	103.61	104.36
	Capacity	903.62	913.49	923.41	933.39	943.44	953.55	963.74	973.99	984.32	994.72
846	Area	105.12	105.90	106.71	107.54	108.40	109.29	110.19	111.18	112.28	113.50
	Capacity	1005.2	1015.7	1026.4	1037.1	1047.9	1058.8	1069.8	1080.8	1092.0	1103.3
847	Area	114.84	120.49	121.53	122.57	123.62	124.67	125.73	126.76	127.77	128.79
	Capacity	1114.7	1126.7	1138.8	1151.0	1163.3	1175.7	1188.2	1200.8	1213.6	1226.4
848	Area	129.82	130.86	131.90	132.95	134.01	135.08	136.16	137.24	138.30	139.37
	Capacity	1239.3	1252.4	1265.5	1278.7	1292.1	1305.6	1319.1	1332.8	1346.6	1360.5
849	Area	140.43	141.50	142.57	143.63	144.70	145.76	146.83	147.91	148.99	150.08
	Capacity	1374.4	1388.5	1402.7	1417.1	1431.5	1446.0	1460.6	1475.4	1490.2	1505.2
850	Area	151.20	152.34	153.49	154.67	155.87	157.17	158.52	159.86	161.22	162.58
	Capacity	1520.2	1535.4	1550.7	1566.1	1581.7	1597.3	1613.1	1629.0	1645.1	1661.3
851	Area	163.98	165.45	167.05	168.75	170.53	172.32	174.11	175.92	177.69	179.52
	Capacity	1677.6	1694.1	1710.7	1727.5	1744.5	1761.6	1778.9	1796.4	1814.1	1832.0
852	Area	181.43	190.18	193.52	196.49	199.30	201.87	204.39	206.82	209.28	211.90
	Capacity	1850.0	1868.8	1888.0	1907.5	1927.3	1947.3	1967.7	1988.2	2009.0	2030.1
853	Area	214.43	217.41	220.00	222.46	225.68	228.79	231.38	233.88	236.64	239.88
	Capacity	2051.4	2073.0	2094.9	2117.0	2139.4	2162.1	2185.1	2208.4	2231.9	2255.8
854	Area	244.63	247.76	250.04	252.26	254.47	256.65	258.74	260.77	262.79	264.86
	Capacity	2280.0	2304.6	2329.5	2354.6	2379.9	2405.5	2431.3	2457.3	2483.4	2509.8
855	Area	266.88	268.82	270.71	272.59	274.47	276.34	278.23	280.13	282.10	284.14
	Capacity	2536.4	2563.2	2590.2	2617.3	2644.7	2672.3	2700.0	2727.9	2756.0	2784.3
856	Area	286.18	288.21	290.21	292.22	294.22	296.22	298.21	300.23	302.30	304.46
	Capacity	2812.9	2841.6	2870.5	2899.6	2929.0	2958.5	2988.2	3018.1	3048.3	3078.6
857	Area	306.81	311.26	313.40	315.51	317.59	319.65	321.72	323.78	325.82	327.92
	Capacity	3109.2	3140.2	3171.4	3202.8	3234.5	3266.4	3298.5	3330.7	3363.2	3395.9
858	Area	330.05	332.13	334.15	336.11	338.02	339.90	341.78	343.65	345.49	347.33
	Capacity	3428.8	3461.9	3495.2	3528.8	3562.5	3596.4	3630.5	3664.7	3699.2	3733.9
859	Area	349.15	350.97	352.78	354.61	356.45	358.30	360.20	362.11	363.99	365.94
	Capacity	3768.7	3803.7	3838.9	3874.2	3909.8	3945.6	3981.5	4017.6	4053.9	4090.4
860	Area	367.92	369.90	371.90	374.02	376.16	378.28	380.47	382.61	384.82	387.03
	Capacity	4127.1	4164.0	4201.1	4238.4	4275.9	4313.6	4351.6	4389.8	4428.1	4466.7

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

BLUESTEM 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
861	Area	389.21	391.41	393.62	395.85	398.10	400.50	402.97	405.46	408.01	410.62
	Capacity	4505.5	4544.6	4583.8	4623.3	4663.0	4703.0	4743.1	4783.6	4824.2	4865.2
862	Area	413.48	419.25	422.22	425.17	428.23	431.19	434.14	437.02	439.80	442.51
	Capacity	4906.4	4948.1	4990.2	5032.6	5075.3	5118.2	5161.5	5205.1	5248.9	5293.1
863	Area	445.14	447.79	450.44	453.10	455.70	458.26	460.79	463.31	465.83	468.34
	Capacity	5337.4	5382.1	5427.0	5472.2	5517.6	5563.3	5609.3	5655.5	5702.0	5748.7
864	Area	470.82	473.30	475.79	478.33	480.88	483.47	486.01	488.60	491.48	494.68
	Capacity	5795.6	5842.9	5890.3	5938.0	5986.0	6034.2	6082.7	6131.4	6180.4	6229.8
865	Area	497.57	500.53	503.45	506.35	509.18	512.01	515.04	518.25	521.31	524.33
	Capacity	6279.4	6329.3	6379.5	6430.0	6480.8	6531.8	6583.2	6634.9	6686.8	6739.2
866	Area	527.46	530.59	533.40	536.23	539.11	541.97	544.85	547.76	550.76	553.99
	Capacity	6791.7	6844.7	6897.9	6951.3	7005.1	7059.2	7113.5	7168.2	7223.1	7278.3
867	Area	557.64	564.80	568.24	571.69	575.24	578.91	582.61	586.25	589.81	593.24
	Capacity	7333.9	7390.2	7446.9	7503.8	7561.2	7618.9	7677.0	7735.5	7794.3	7853.4
868	Area	596.56	599.95	603.16	606.28	609.27	612.30	615.42	618.52	621.82	625.15
	Capacity	7912.9	7972.8	8032.9	8093.4	8154.2	8215.3	8276.7	8338.4	8400.4	8462.8
869	Area	628.41	631.57	634.46	637.29	640.05	642.61	645.17	647.77	650.16	652.49
	Capacity	8525.5	8588.5	8651.8	8715.4	8779.3	8843.4	8907.8	8972.5	9037.3	9102.5
870	Area	654.78	657.09	659.41	661.74	664.05	666.34	668.61	671.10	673.37	675.64
	Capacity	9167.9	9233.5	9299.3	9365.4	9431.7	9498.2	9565.0	9632.0	9699.2	9766.7
871	Area	677.91	680.19	682.47	684.74	687.00	689.3	691.64	694.00	696.39	698.80
	Capacity	9834.3	9902.3	9970.4	10039	10107	10176	10245	10315	10384	10454
872	Area	701.24	720.16	722.66	725.16	727.67	730.18	732.68	735.19	737.7	740.21
	Capacity	10524	10596	10668	10740	10813	10886	10959	11032	11106	11180
873	Area	742.73	745.24	747.76	750.27	752.79	755.31	757.83	760.36	762.88	765.41
	Capacity	11254	11328	11403	11478	11553	11629	11704	11780	11856	11933
874	Area	767.93	770.46	772.99	775.52	778.05	780.59	783.12	785.66	788.2	790.74
	Capacity	12009	12086	12163	12241	12319	12397	12475	12553	12632	12711
875	Area	793.28	795.82	798.36	800.91	803.46	806.00	808.55	811.10	813.65	816.21
	Capacity	12790	12870	12949	13029	13109	13190	13271	13352	13433	13514
876	Area	818.76	821.32	823.88	826.43	829.00	831.56	834.12	836.68	839.25	841.82
	Capacity	13596	13678	13760	13843	13926	14009	14092	14176	14259	14344
877	Area	865.51									
	Capacity	14436									

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



APPENDIX B: Bluestem Lake Maps

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

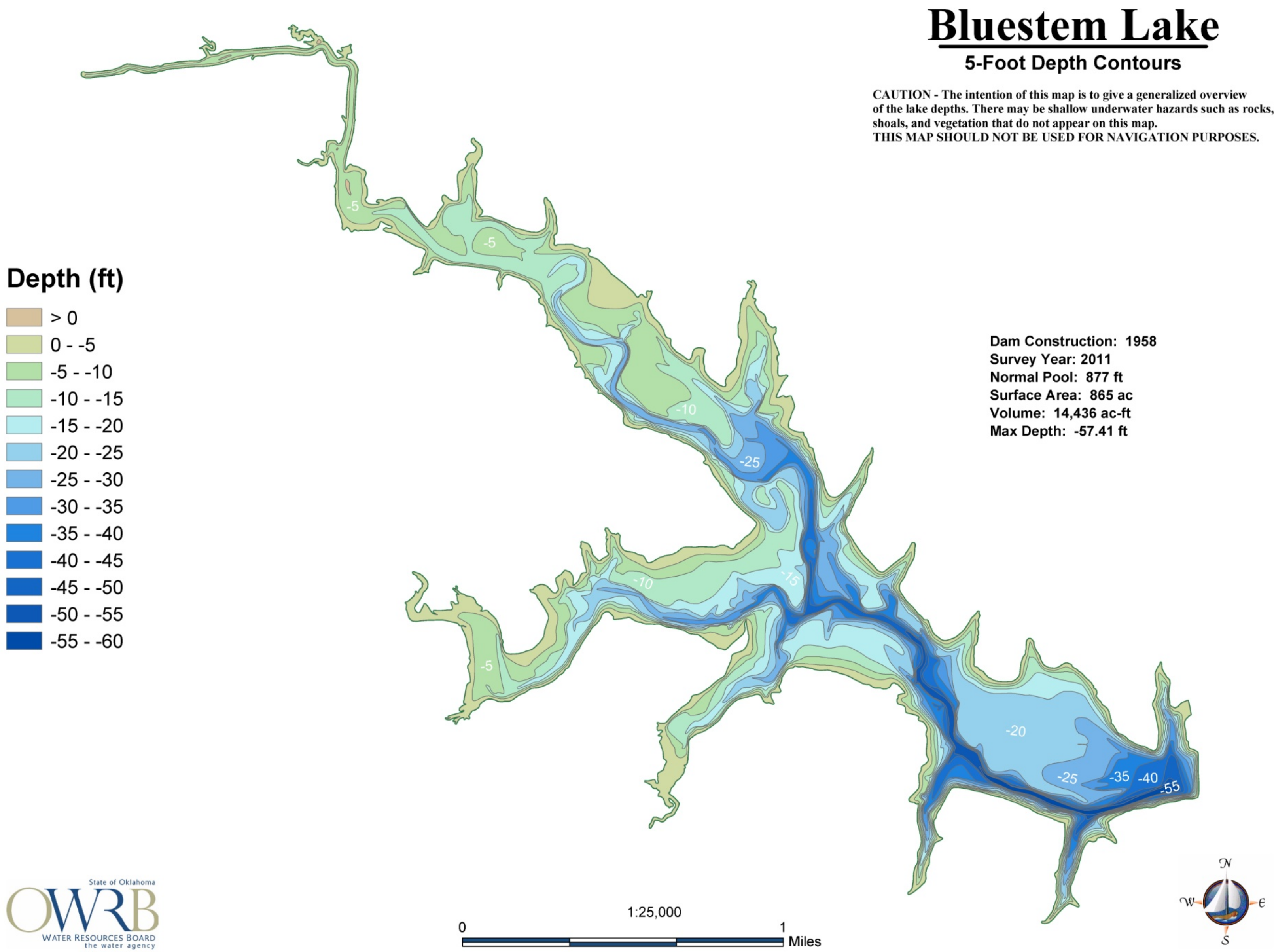


Figure B. 2: Bluestem Lake Shaded Relief Bathymetric Map.

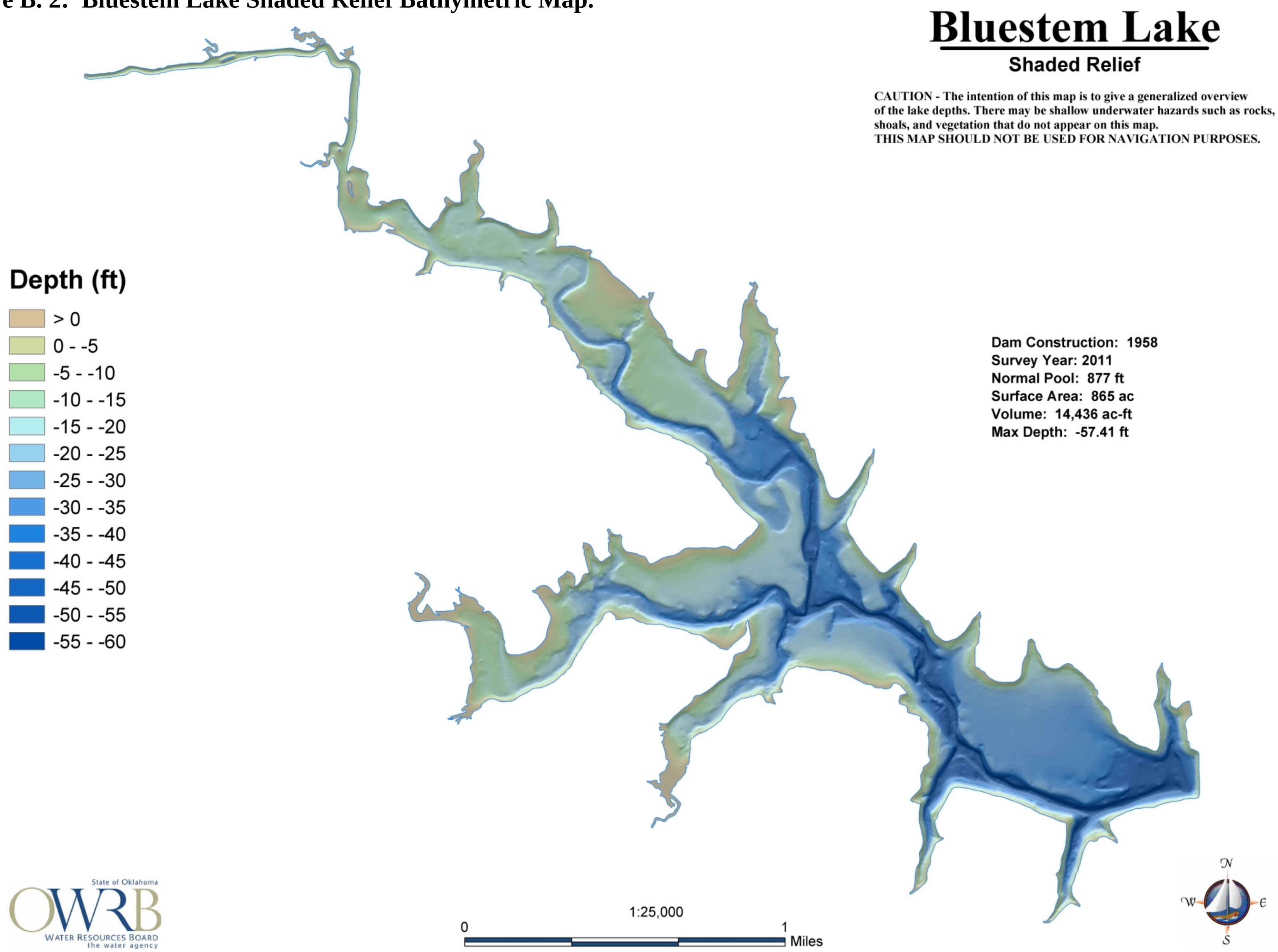


Figure B. 3: Bluestem Lake Collected Data Points.