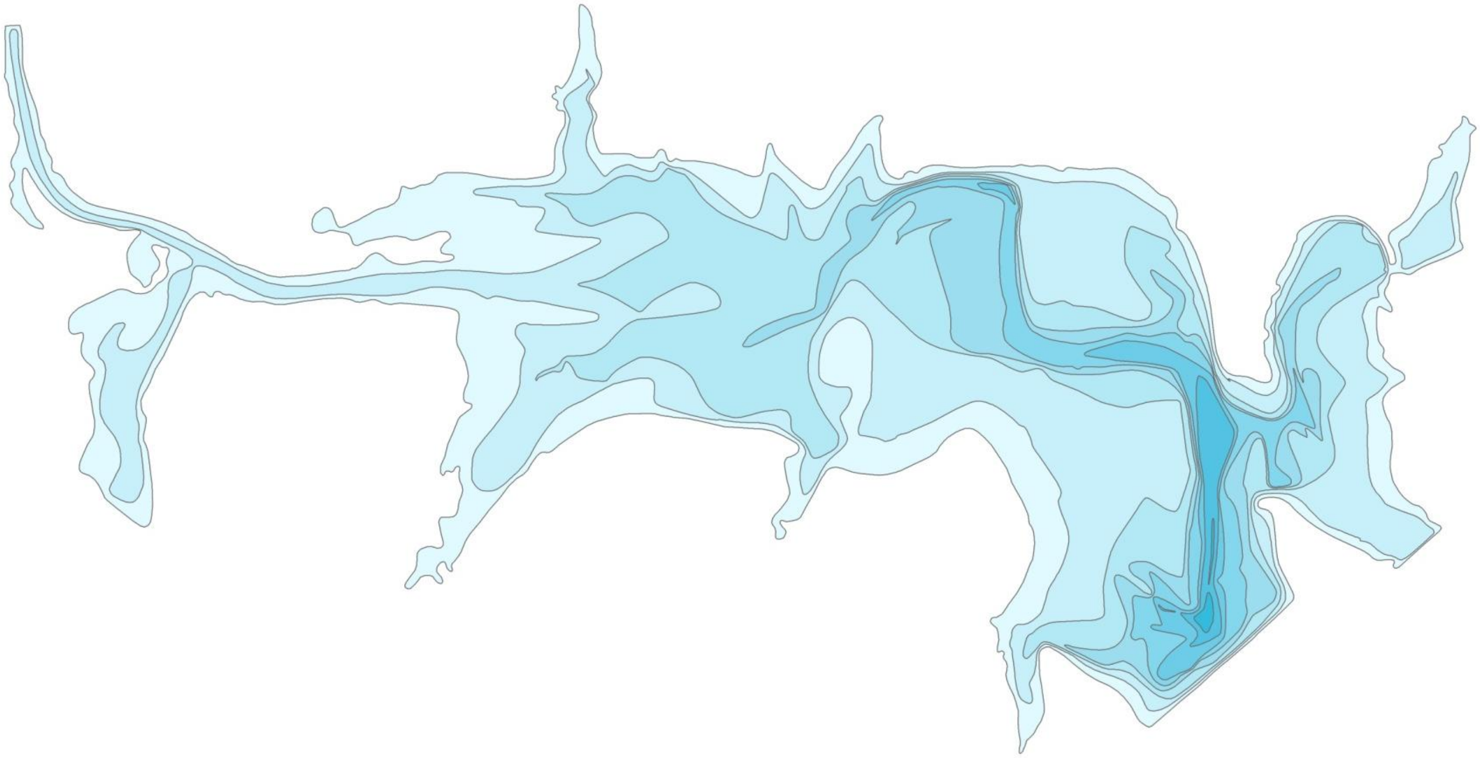
HYDROGRAPHIC SURVEY of SAHOMA LAKE



Final Report

October 31, 2011

Prepared by:

State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

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SAHOMA LAKE
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Sahoma Lake in July 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

Sahoma Lake is located on Rock Creek in Creek County (
Figure 1). The dam was completed in 1947and is located approximately one mile west and two miles north of the city of Sapulpa, 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.

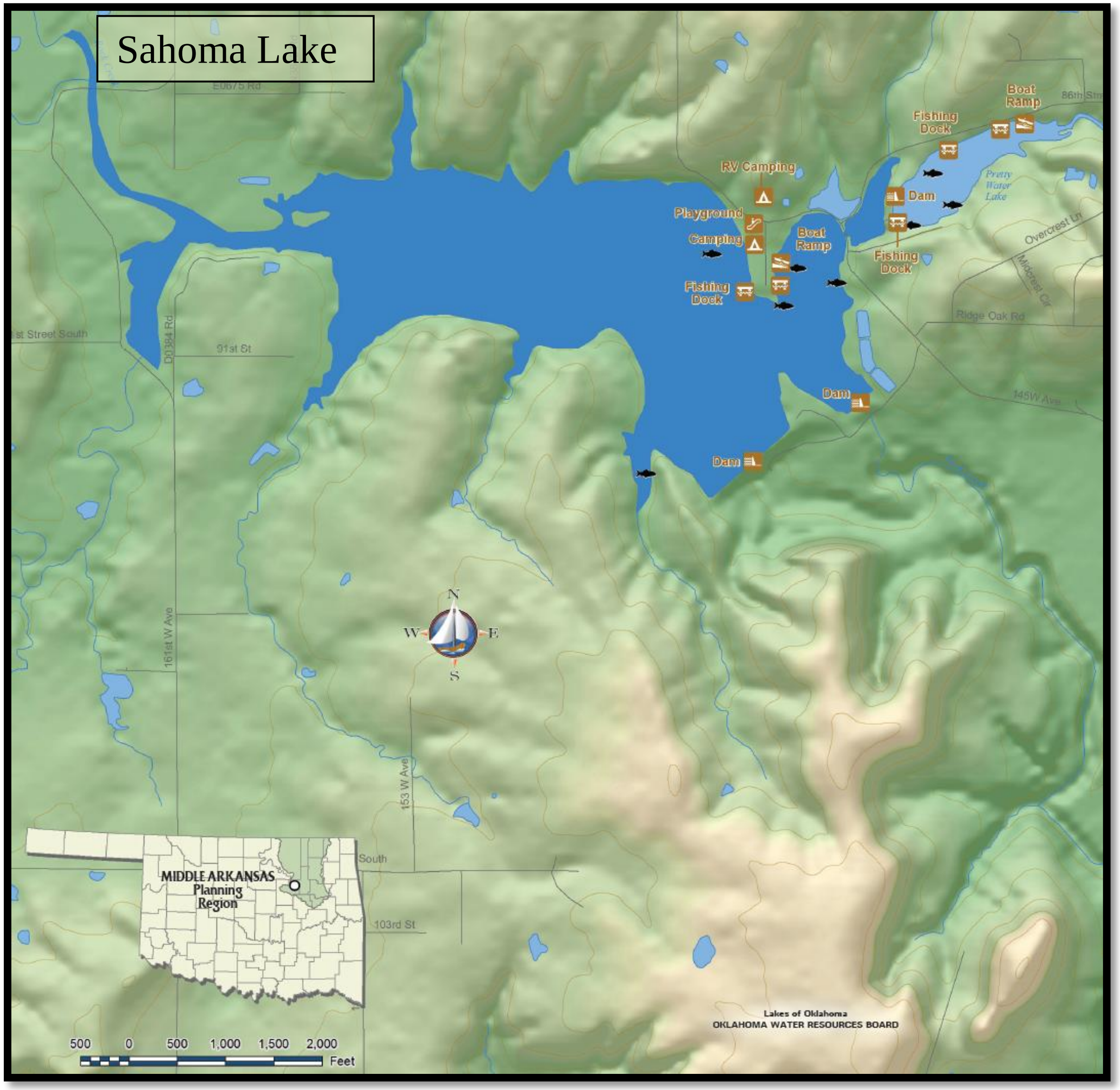


Figure 1: Location map for Sahoma Lake.

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

<u>Boundary File</u>

The boundary file for Sahoma Lake was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Creek 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).

<u>Set-up</u>

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 20 virtual transects were created for Sahoma Lake.

Field Survey

<u>Lake Elevation Acquisition</u>

The lake elevation for Sahoma Lake was obtained by collecting positional data over a period of approximately 148 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 Sahoma Lake occurred in July of 2011. The water level elevation for Sahoma Lake was 715.76 ft Geodetic Vertical Datum (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, 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 104 cross-sections points at Sahoma Lake were used to compute error estimates. A mean difference (arithmetic mean) of 0.069ft and a standard deviation of 0.251 ft were computed from intersections. The following formulas were used to determine the depth accuracy at the 95% confidence level.

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

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 ± 0.51 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 0.069 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 Sahoma 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: Sahoma 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 at on the DVD entitled *FEMA 2011 Disk 2 HYPACK/GIS Metadata.*

RESULTS

Results from the 2011 OWRB survey indicate that Sahoma Lake encompasses 277 acres and contains a cumulative capacity of 2,543 ac-ft at the normal pool elevation (716 ft NAVD88). The average depth for Sahoma Lake was 9.15 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Sahoma Lake at the normal pool elevation. Based on the design specifications, Sahoma Lake had an area of 344 acres and cumulative volume of 4,850 acre-feet of water at conservation pool elevation (716 ft NAVD88). The surface area of the lake has had a decrease of 67 acres or approximately 19.5%. The 2011 survey shows that Sahoma Lake has had an apparent decrease in capacity of 47.6% or approximately 2,307 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 significant loss in capacity. Loss of this magnitude is typically not seen in Oklahoma reservoirs. 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 Sahoma Lake at normal pool (716 ft NAVD88).

Feature	Survey Year	
	1947 Design Specifications	2011
Area (acres)	344	277
Cumulative Volume (acre-feet)	4,850	2,543
Mean depth (ft)	14.10	9.15
Maximum Depth (ft)	--	35.66

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: Sahoma Lake Capacity/Area by 0.1-ft Increments.

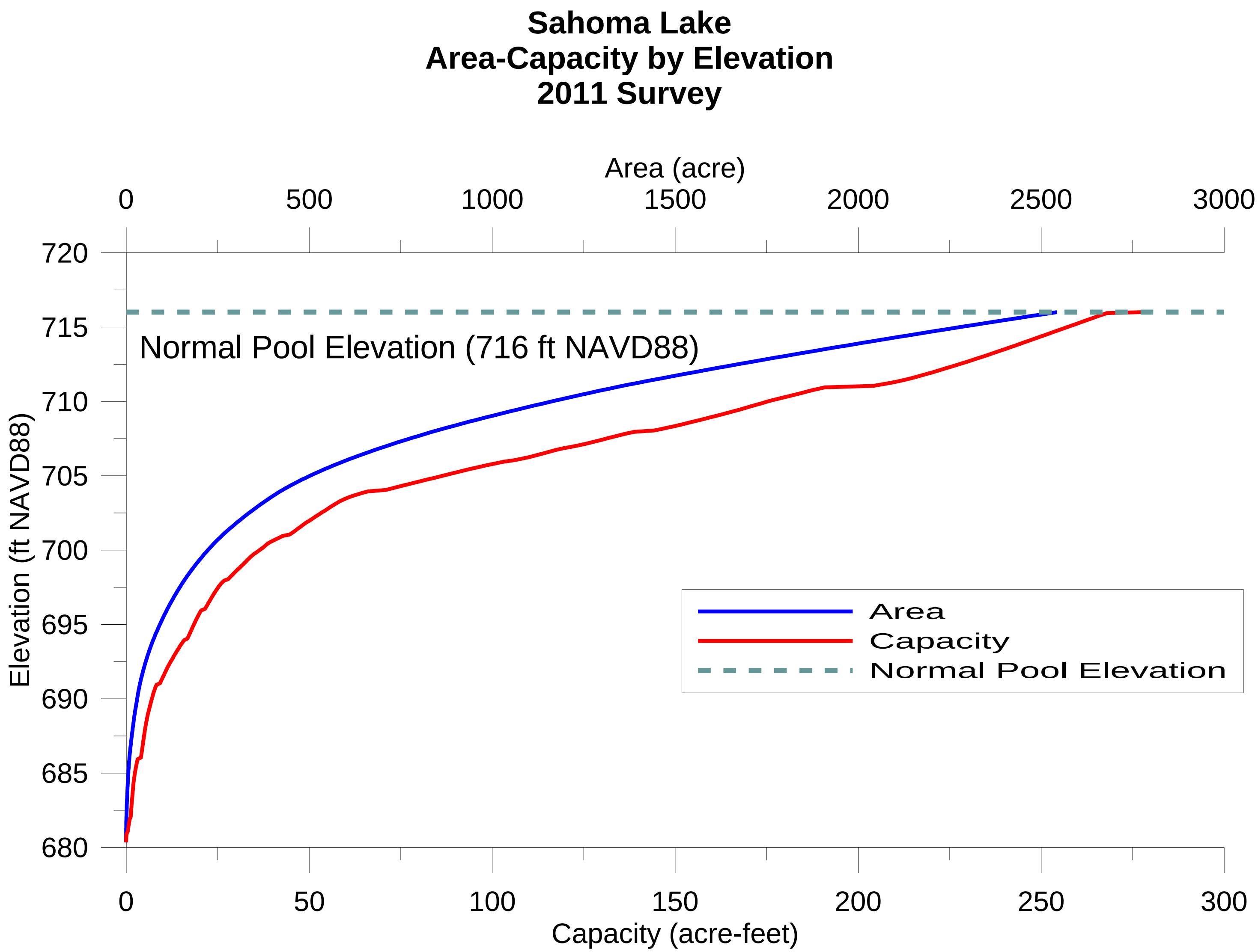
SAHOMA LAKE AREA-CAPACITY TABLE
OKLAHOMA WATER RESOURCES BOARD
2011 Survey
Capacity in acre-feet by tenth foot elevation increments
Area in acres by tenth foot elevation increments

Elevation (ft NAVD 88)		0.04	0.14	0.24	0.34	0.44	0.54	0.64	0.74	0.84	0.94
680	Area				0.0000	0.0027	0.0183	0.0420	0.0719	0.1070	0.1541
	Capacity				0.0000	0.0001	0.0011	0.0040	0.0097	0.0186	0.0315
681	Area	0.4287	0.4949	0.5550	0.6150	0.6753	0.7367	0.8015	0.8683	0.9402	1.0229
	Capacity	0.0589	0.1051	0.1576	0.2162	0.2807	0.3512	0.4282	0.5116	0.6020	0.7001
682	Area	1.2482	1.2735	1.2995	1.3267	1.3549	1.3842	1.4147	1.4463	1.4790	1.5127
	Capacity	0.8130	0.9392	1.0678	1.1992	1.3332	1.4701	1.6101	1.7532	1.8995	2.0490
683	Area	1.5476	1.5836	1.6201	1.6559	1.6912	1.7262	1.7612	1.7963	1.8318	1.8675
	Capacity	2.2020	2.3587	2.5188	2.6827	2.8501	3.0209	3.1954	3.3732	3.5547	3.7397
684	Area	1.9035	1.9400	1.9781	2.0219	2.0703	2.1224	2.1790	2.2375	2.2980	2.3602
	Capacity	3.9282	4.1205	4.3163	4.5164	4.7209	4.9305	5.1457	5.3665	5.5933	5.8262
685	Area	2.4252	2.4940	2.5676	2.6452	2.7248	2.8058	2.8880	2.9714	3.0640	3.1921
	Capacity	6.0654	6.3115	6.5645	6.8252	7.0937	7.3702	7.6550	7.9479	8.2497	8.5620
686	Area	4.0483	4.1111	4.1689	4.2262	4.2830	4.3402	4.3976	4.4550	4.5126	4.5708
	Capacity	8.9182	9.3264	9.7404	10.160	10.586	11.017	11.454	11.897	12.345	12.799
687	Area	4.6293	4.6878	4.7466	4.8057	4.8651	4.9250	4.9854	5.0461	5.1073	5.1687
	Capacity	13.259	13.725	14.197	14.675	15.158	15.648	16.144	16.645	17.153	17.667
688	Area	5.2311	5.2965	5.3660	5.4399	5.5165	5.5956	5.6766	5.7595	5.8450	5.9349
	Capacity	18.187	18.713	19.246	19.787	20.335	20.890	21.454	22.026	22.606	23.195
689	Area	6.0294	6.1296	6.2305	6.3318	6.4353	6.5438	6.6538	6.7614	6.8691	6.9787
	Capacity	23.793	24.401	25.019	25.648	26.286	26.935	27.595	28.266	28.948	29.640
690	Area	7.0887	7.1981	7.3090	7.4273	7.5531	7.6871	7.8293	7.9787	8.1348	8.3016
	Capacity	30.343	31.058	31.783	32.520	33.269	34.031	34.807	35.598	36.404	37.225
691	Area	9.2846	9.4571	9.6394	9.8283	10.025	10.227	10.425	10.616	10.804	10.994
	Capacity	38.096	39.034	39.989	40.962	41.955	42.967	44.000	45.052	46.124	47.214
692	Area	11.195	11.402	11.622	11.846	12.070	12.299	12.533	12.768	13.008	13.248
	Capacity	48.323	49.454	50.605	51.779	52.974	54.193	55.435	56.700	57.989	59.302
693	Area	13.489	13.730	13.978	14.229	14.475	14.723	14.989	15.270	15.562	15.867
	Capacity	60.638	62.000	63.385	64.796	66.231	67.691	69.177	70.690	72.232	73.803
694	Area	16.750	16.943	17.130	17.313	17.496	17.681	17.865	18.050	18.235	18.421
	Capacity	75.430	77.115	78.819	80.542	82.282	84.041	85.819	87.614	89.430	91.262
695	Area	18.609	18.802	18.999	19.200	19.404	19.612	19.824	20.040	20.262	20.494
	Capacity	93.113	94.985	96.875	98.785	100.72	102.67	104.64	106.63	108.65	110.69
696	Area	21.564	21.797	22.028	22.260	22.492	22.734	22.979	23.221	23.463	23.707
	Capacity	112.78	114.95	117.14	119.36	121.59	123.85	126.14	128.45	130.79	133.14
697	Area	23.954	24.208	24.475	24.745	25.021	25.307	25.614	25.942	26.319	26.766
	Capacity	135.53	137.94	140.37	142.83	145.32	147.84	150.38	152.96	155.57	158.23
698	Area	27.879	28.275	28.668	29.068	29.465	29.866	30.272	30.700	31.145	31.572
	Capacity	160.95	163.76	166.61	169.50	172.42	175.39	178.40	181.45	184.54	187.68
699	Area	31.996	32.396	32.794	33.200	33.614	34.037	34.492	34.997	35.604	36.187
	Capacity	190.86	194.08	197.34	200.64	203.98	207.36	210.79	214.26	217.79	221.38
700	Area	36.742	37.264	37.760	38.248	38.766	39.417	40.254	41.103	41.898	42.652
	Capacity	225.03	228.73	232.48	236.29	240.13	244.04	248.03	252.09	256.24	260.47

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

SAHOMA 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)		0.04	0.14	0.24	0.34	0.44	0.54	0.64	0.74	0.84	0.94
701	Area	44.731	45.324	45.875	46.418	46.962	47.509	48.060	48.622	49.213	49.842
	Capacity	264.83	269.33	273.89	278.51	283.18	287.90	292.68	297.52	302.41	307.36
702	Area	50.486	51.110	51.725	52.342	52.966	53.600	54.250	54.881	55.506	56.134
	Capacity	312.38	317.46	322.60	327.81	333.07	338.40	343.79	349.25	354.77	360.35
703	Area	56.774	57.439	58.140	58.905	59.808	60.818	61.949	63.194	64.548	66.092
	Capacity	366.00	371.71	377.49	383.34	389.28	395.31	401.45	407.70	414.09	420.62
704	Area	70.940	72.539	74.118	75.722	77.354	79.028	80.690	82.335	83.976	85.636
	Capacity	427.44	434.62	441.95	449.45	457.10	464.92	472.91	481.06	489.38	497.86
705	Area	87.262	88.874	90.529	92.202	93.864	95.622	97.439	99.283	101.19	103.16
	Capacity	506.50	515.31	524.28	533.42	542.72	552.20	561.86	571.69	581.72	591.93
706	Area	106.13	108.15	109.98	111.60	113.12	114.59	116.08	117.62	119.45	121.53
	Capacity	602.39	613.11	624.02	635.10	646.34	657.72	669.26	680.94	692.80	704.85
707	Area	123.61	125.54	127.22	128.81	130.39	131.96	133.50	135.08	136.81	138.84
	Capacity	717.11	729.57	742.21	755.02	767.98	781.10	794.38	807.80	821.40	835.18
708	Area	144.29	146.32	148.16	150.03	151.72	153.37	155.09	156.71	158.29	159.88
	Capacity	849.31	863.85	878.57	893.49	908.58	923.83	939.26	954.85	970.60	986.51
709	Area	161.44	163.04	164.59	166.12	167.58	168.99	170.40	171.83	173.23	174.61
	Capacity	1002.6	1018.8	1035.2	1051.7	1068.4	1085.2	1102.2	1119.3	1136.6	1154.0
710	Area	176.07	177.59	179.31	181.00	182.60	184.20	185.79	187.38	189.06	190.83
	Capacity	1171.5	1189.2	1207.0	1225.1	1243.2	1261.6	1280.1	1298.7	1317.6	1336.6
711	Area	204.20	206.55	208.74	210.89	212.67	214.27	215.81	217.29	218.75	220.16
	Capacity	1356.2	1376.7	1397.5	1418.5	1439.7	1461.0	1482.5	1504.2	1526.0	1548.0
712	Area	221.54	222.90	224.24	225.59	226.91	228.22	229.50	230.78	232.03	233.26
	Capacity	1570.0	1592.3	1614.6	1637.1	1659.7	1682.5	1705.4	1728.4	1751.6	1774.8
713	Area	234.48	235.68	236.88	238.05	239.23	240.50	241.66	242.81	243.95	245.10
	Capacity	1798.2	1821.7	1845.4	1869.1	1893.0	1917.0	1941.1	1965.3	1989.7	2014.1
714	Area	246.24	247.39	248.54	249.68	250.83	251.97	253.12	254.26	255.40	256.55
	Capacity	2038.7	2063.4	2088.2	2113.1	2138.1	2163.2	2188.5	2213.9	2239.4	2265.0
715	Area	257.69	258.84	259.98	261.12	262.26	263.41	264.55	265.69	266.83	267.97
	Capacity	2290.7	2316.5	2342.4	2368.5	2394.7	2421.0	2447.4	2473.9	2500.5	2527.3
716	Area	277.8									
	Capacity	2543.4	* Final values are for 716.00								

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



APPENDIX B: Sahoma Lake Maps

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

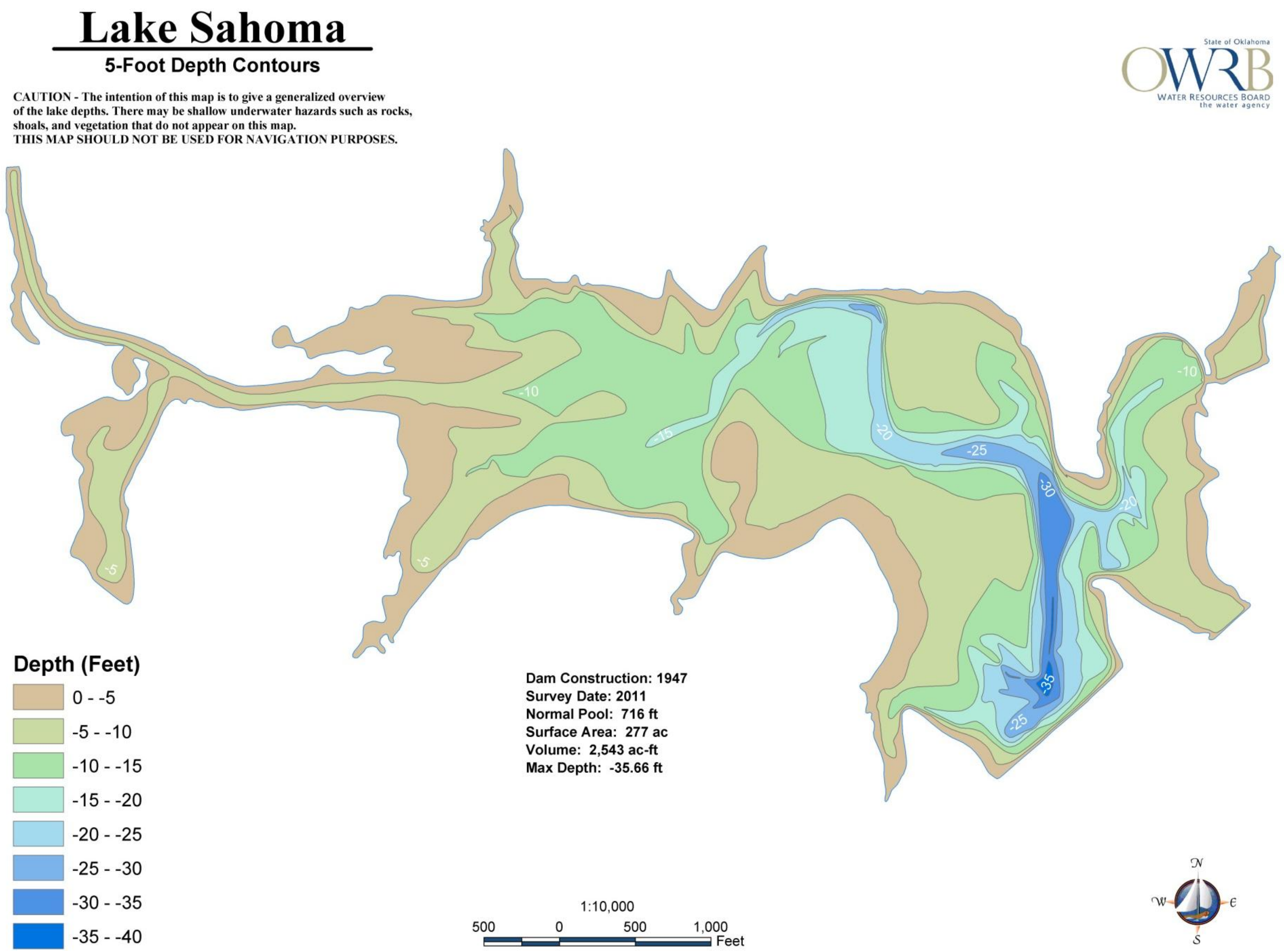


Figure B. 2: Sahoma Lake Shaded Relief Bathymetric Map.

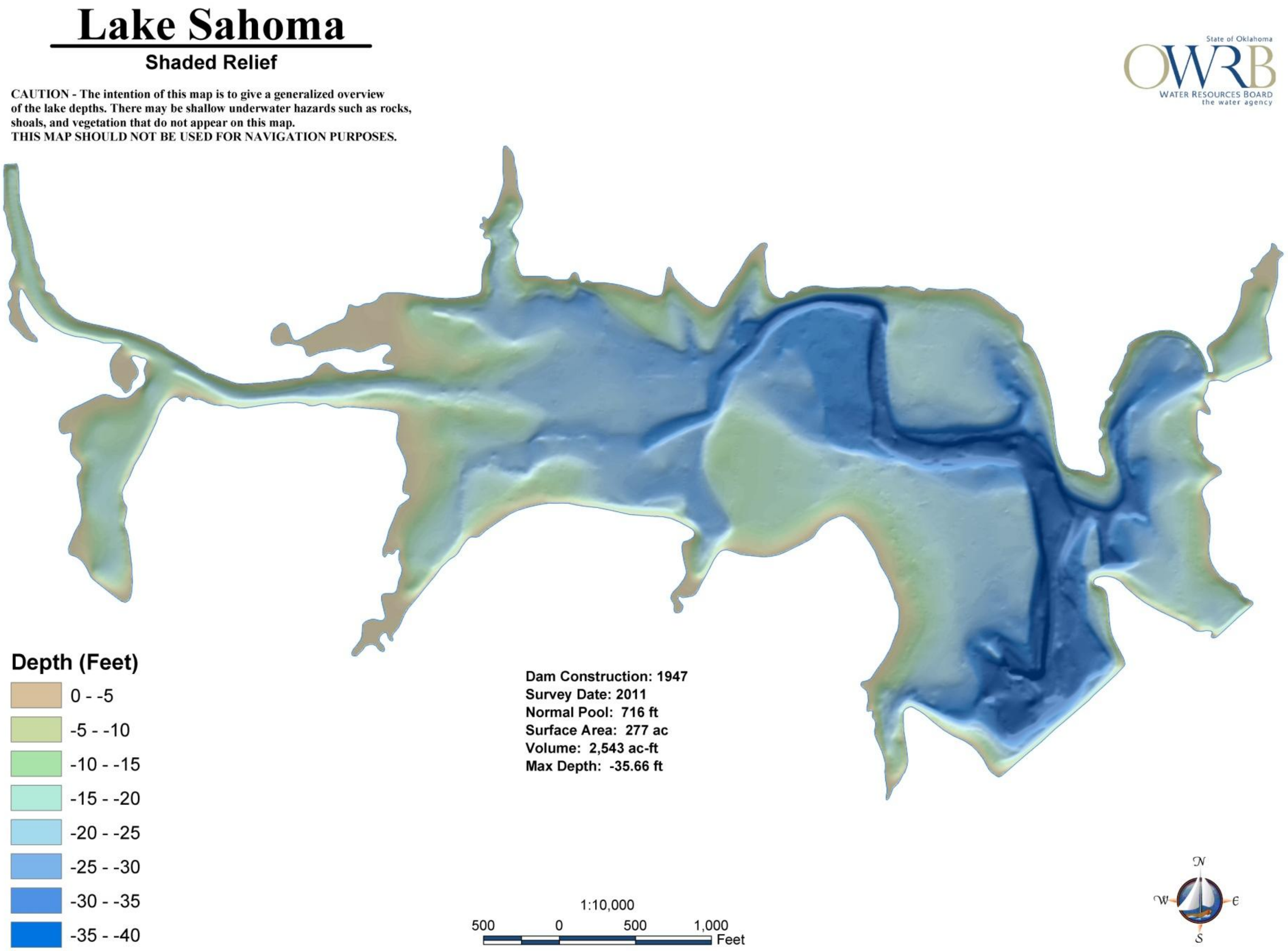


Figure B. 3: Sahoma Lake Collected Data Points.