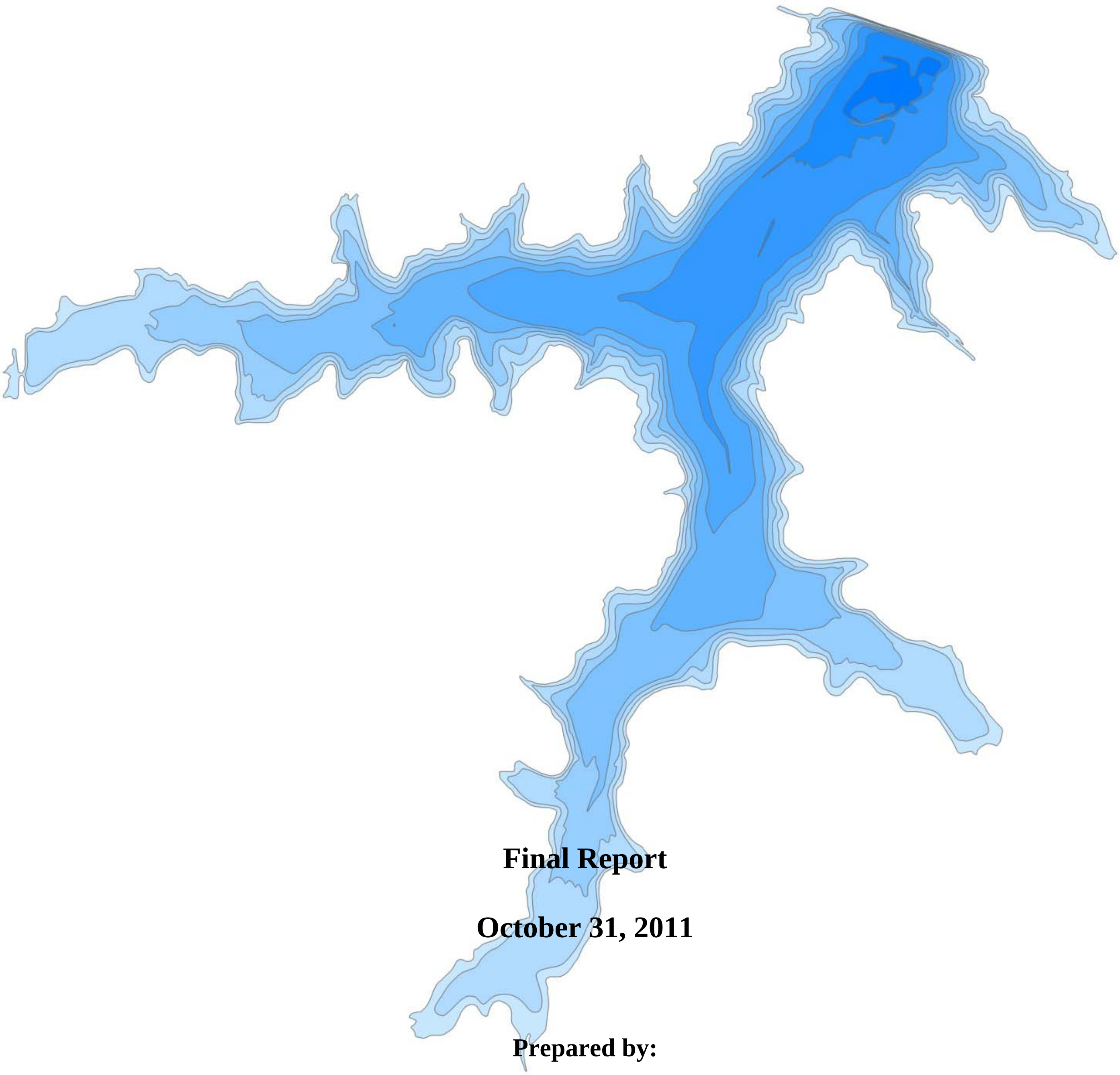
HYDROGRAPHIC SURVEY of SHAWNEE TWIN LAKE NO. 1



Final Report

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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 Shawnee Twin Lake No. 1 beginning 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

Shawnee Twin Lake No. 1 is located on South Deer Creek in Pottawatomie County (**Figure 1**). The dam was completed in 1936, with adjustments to the spillway made in 1961, and is located within the city limits of Shawnee, OK; approximately eight miles west of the Shawnee business district. Its purposes are water supply, and recreation.

Figure 1: Location map for Shawnee Twin Lake No. 1.

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 Shawnee Twin Lake No. 1 was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Pottawatomie 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).

<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-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 73 virtual transects were created for Shawnee Twin Lake No. 1.

Field Survey

<u>Lake Elevation Acquisition</u>

The lake elevation for Shawnee Twin Lake No. 1 was obtained by collecting positional data over a period of approximately 31 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 Shawnee Twin Lake No. 1 occurred in July of 2011. The water level elevation for Shawnee Twin Lake No. 1 was 1071.2 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 70 cross-sections points at Shawnee Twin Lake No. 1 were used to compute error estimates. A mean difference (arithmetic mean) of 0.074 ft and a standard deviation of 0.297 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 ± 0.60 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

0.074ft 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 Shawnee Twin Lake No. 1 are located on the DVD entitled *FEMA 2011 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 9.3.1, 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: Shawnee Twin No. 1 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 1 HYPACK/GIS Metadata.*

RESULTS

Results from the 2011 OWRB survey indicate that Shawnee Twin Lake No. 1 encompasses 1,142 acres and contains a cumulative capacity of 19,031 ac-ft at the normal pool elevation (1073.5 ft NAVD88). The average depth for Shawnee Twin Lake No. 1 was 16.66 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Shawnee Twin Lake No. 1 at the normal pool elevation. Based on the design specifications, Shawnee Twin Lake No. 1 had an area of 1,275 acres and cumulative volume of 22,600 acre-feet of water at normal pool elevation (1073.5 ft NAVD88). The surface area of the lake has had a decrease of 133 acres or approximately 10%. The 2011 survey shows that Shawnee Twin Lake No. 1 has had an apparent decrease in capacity of 15.8% or approximately 3,569 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, which is unlikely to be 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 Shawnee Twin Lake No. 1 at normal pool (1073.5 ft NAVD88).

Feature	Survey Year	
	1936 Design Specifications	2011
Area (acres)	1,275	1,142
Cumulative Volume (acre-feet)	22,600	19,031
Mean depth (ft)	17.72	16.66
Maximum Depth (ft)	--	43.52

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: Shawnee Twin Lake No. 1 Capacity/Area by 0.1-ft Increments.

SHAWNEE TWIN LAKE #1 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 NAVD88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1029	Area	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1030	Area	0.0001	0.0002	0.0005	0.0017	0.0122	0.0554	0.1221	0.1981	0.2814	0.3665
	Capacity	0.0000	0.0000	0.0000	0.0001	0.0007	0.0038	0.0126	0.0285	0.0525	0.0849
1031	Area	0.4507	0.5386	0.6349	0.7609	1.0235	1.2968	1.6403	2.0606	2.5407	3.0743
	Capacity	0.1258	0.1753	0.2338	0.3031	0.3913	0.5075	0.6543	0.8387	1.0684	1.3497
1032	Area	3.5635	4.0030	4.4544	4.9445	5.4507	6.0235	6.6618	7.2689	7.8780	8.4748
	Capacity	1.6820	2.0609	2.4834	2.9531	3.4724	4.0453	4.6803	5.3769	6.1342	6.9518
1033	Area	9.0635	9.6595	10.273	10.872	11.492	12.804	13.149	13.502	13.859	14.214
	Capacity	7.8286	8.7657	9.7621	10.819	11.937	13.180	14.479	15.812	17.179	18.583
1034	Area	14.560	14.904	15.254	15.606	15.922	16.225	16.522	16.814	17.103	17.394
	Capacity	20.022	21.496	23.004	24.547	26.124	27.731	29.370	31.037	32.732	34.457
1035	Area	17.682	17.972	18.271	18.586	18.920	19.278	19.645	19.986	20.288	20.604
	Capacity	36.211	37.995	39.807	41.650	43.524	45.434	47.382	49.364	51.378	53.422
1036	Area	20.925	21.255	21.592	21.995	22.351	22.703	23.122	23.553	23.946	24.341
	Capacity	55.498	57.610	59.752	61.932	64.149	66.402	68.695	71.029	73.403	75.817
1037	Area	24.788	25.456	26.302	27.009	27.812	29.619	30.612	31.601	32.639	33.773
	Capacity	78.273	80.786	83.375	86.040	88.780	91.672	94.687	97.797	101.0	104.3
1038	Area	35.080	36.594	38.417	40.345	42.792	47.383	49.777	52.333	55.124	58.067
	Capacity	107.8	111.4	115.1	119.0	123.2	127.8	132.6	137.7	143.1	148.8
1039	Area	60.540	62.623	64.651	66.591	68.477	70.327	72.246	74.232	76.232	78.331
	Capacity	154.7	160.9	167.2	173.8	180.5	187.5	194.6	201.9	209.5	217.2
1040	Area	80.448	82.647	84.920	87.320	89.851	95.325	97.841	100.3	102.8	105.2
	Capacity	225.13	233.30	241.67	250.28	259.14	268.48	278.15	288.05	298.21	308.61
1041	Area	107.57	110.14	112.77	115.52	118.42	124.59	127.84	130.74	133.36	135.87
	Capacity	319.25	330.14	341.28	352.70	364.39	376.59	389.23	402.16	415.36	428.82
1042	Area	138.36	140.98	143.77	146.56	149.22	151.76	154.19	156.63	159.08	161.53
	Capacity	442.53	456.51	470.75	485.26	500.05	515.10	530.42	545.95	561.74	577.77
1043	Area	163.99	166.53	169.14	171.69	174.51	179.60	182.44	185.04	187.48	190.07
	Capacity	594.04	610.59	627.37	644.41	661.71	679.47	697.60	715.97	734.59	753.47
1044	Area	192.52	194.89	197.26	199.72	202.24	204.84	207.19	209.50	211.78	213.90
	Capacity	772.60	791.99	811.59	831.44	851.54	871.89	892.52	913.35	934.41	955.70
1045	Area	215.90	217.88	219.81	221.79	223.72	225.70	227.71	229.84	232.06	234.23
	Capacity	977.18	998.90	1020.8	1042.9	1065.1	1087.6	1110.3	1133.2	1156.3	1179.6
1046	Area	236.38	238.70	240.98	243.27	245.69	248.12	250.44	252.74	255.06	257.47
	Capacity	1203.1	1226.9	1250.9	1275.1	1299.5	1324.2	1349.2	1374.3	1399.7	1425.3
1047	Area	259.86	262.10	264.33	266.58	268.99	271.49	274.07	276.74	279.47	282.21
	Capacity	1451.2	1477.3	1503.6	1530.2	1557.0	1584.0	1611.3	1638.8	1666.6	1694.7
1048	Area	284.93	287.68	290.48	293.57	296.90	300.97	303.05	305.16	307.33	309.53
	Capacity	1723.1	1751.7	1780.6	1809.8	1839.3	1869.3	1899.5	1929.9	1960.6	1991.4
1049	Area	311.70	314.13	316.48	318.87	321.15	323.48	325.83	328.20	330.55	332.91
	Capacity	2022.5	2053.8	2085.3	2117.1	2149.1	2181.3	2213.8	2246.5	2279.4	2312.6

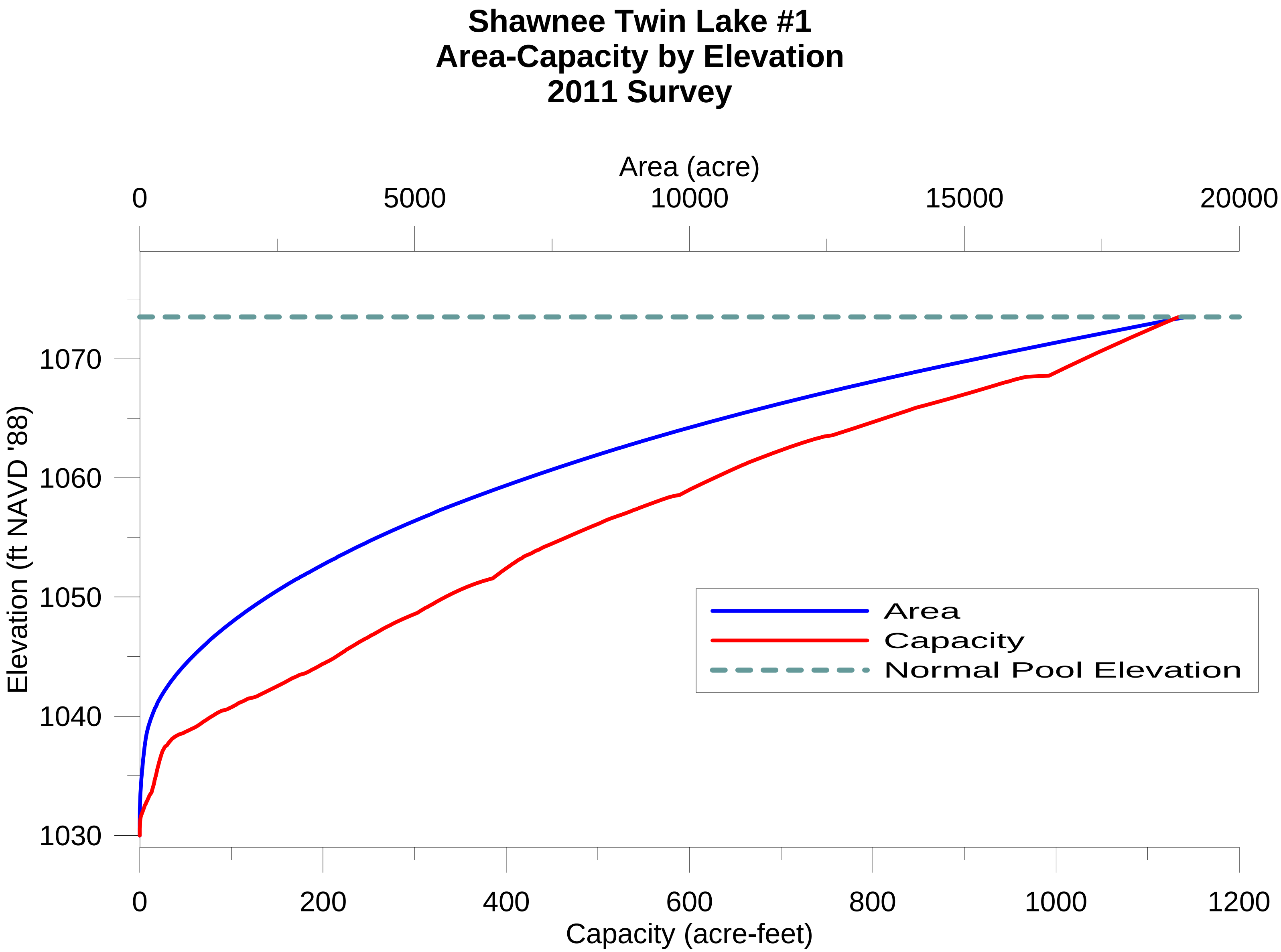
Table A. 2: Shawnee Twin Lake No. 1 Capacity/Area by 0.1-ft Increments (cont).

SHAWNEE TWIN LAKE #1 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 NAVD88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1050	Area	335.30	337.76	340.41	343.22	346.21	349.23	352.23	355.22	358.25	361.37
	Capacity	2346.0	2379.7	2413.6	2447.8	2482.3	2517.0	2552.1	2587.5	2623.2	2659.1
1051	Area	364.57	367.94	371.99	376.54	381.71	385.36	387.07	388.80	390.53	392.25
	Capacity	2695.4	2732.1	2769.1	2806.5	2844.4	2882.8	2921.5	2960.3	2999.2	3038.4
1052	Area	393.96	395.67	397.44	399.37	401.26	403.17	405.05	406.95	408.85	410.78
	Capacity	3077.7	3117.2	3156.9	3196.7	3236.7	3276.9	3317.4	3358.0	3398.8	3439.8
1053	Area	412.76	414.85	416.99	419.16	421.38	424.90	427.45	430.05	432.71	435.40
	Capacity	3480.9	3522.4	3563.9	3605.7	3647.8	3690.1	3732.8	3775.6	3818.8	3862.2
1054	Area	438.22	441.00	443.80	446.58	449.45	452.55	455.82	459.26	462.30	465.25
	Capacity	3905.8	3949.9	3994.1	4038.6	4083.4	4128.5	4174.0	4219.7	4265.8	4312.2
1055	Area	468.09	470.94	473.81	476.76	479.80	482.87	485.97	489.11	492.16	495.12
	Capacity	4358.8	4405.8	4453.1	4500.6	4548.4	4596.5	4645.0	4693.8	4742.8	4792.2
1056	Area	498.07	501.06	504.08	507.12	510.20	513.49	517.22	520.84	524.50	528.24
	Capacity	4841.9	4891.9	4942.1	4992.7	5043.5	5094.7	5146.3	5198.2	5250.5	5303.1
1057	Area	531.92	535.47	538.86	542.22	545.57	548.95	552.38	555.81	559.27	562.80
	Capacity	5356.1	5409.5	5463.2	5517.3	5571.7	5626.4	5681.5	5736.9	5792.7	5848.8
1058	Area	566.43	570.23	574.19	578.31	582.78	589.33	591.88	594.44	596.95	599.49
	Capacity	5905.2	5962.1	6019.3	6076.9	6135.0	6193.7	6252.8	6312.1	6371.7	6431.5
1059	Area	602.07	604.67	607.28	609.95	612.69	615.44	618.25	621.09	623.97	626.87
	Capacity	6491.6	6552.0	6612.6	6673.4	6734.6	6796.0	6857.7	6919.7	6981.9	7044.5
1060	Area	629.62	632.31	634.98	637.67	640.37	643.15	645.97	648.86	651.88	654.95
	Capacity	7107.3	7170.5	7233.8	7297.4	7361.3	7425.5	7490.0	7554.8	7619.8	7685.1
1061	Area	658.00	661.08	664.22	667.41	670.68	674.03	677.52	681.02	684.42	687.96
	Capacity	7750.8	7816.8	7883.1	7949.6	8016.5	8083.8	8151.4	8219.3	8287.6	8356.2
1062	Area	691.57	695.12	698.62	702.13	705.56	709.20	712.83	716.62	720.64	724.66
	Capacity	8425.2	8494.6	8564.3	8634.3	8704.7	8775.4	8846.6	8918.0	8989.9	9062.2
1063	Area	728.80	733.12	737.66	742.50	747.88	755.98	760.08	764.12	768.13	772.08
	Capacity	9134.8	9208.0	9281.5	9355.5	9430.0	9505.3	9581.2	9657.4	9734.0	9811.0
1064	Area	776.02	779.97	783.97	788.25	792.32	796.28	800.23	804.15	808.02	811.80
	Capacity	9888.4	9966.3	10045	10123	10202	10282	10361	10442	10522	10603
1065	Area	815.58	819.54	823.73	827.82	831.65	835.47	839.27	843.13	847.25	851.91
	Capacity	10685	10766	10849	10931	11014	11098	11181	11265	11350	11435
1066	Area	857.13	862.14	866.70	871.37	875.73	880.09	884.83	889.45	894.32	899.08
	Capacity	11520	11606	11693	11780	11867	11955	12043	12132	12221	12311
1067	Area	903.75	908.29	912.63	916.93	921.22	925.51	929.85	934.22	938.67	943.17
	Capacity	12401	12492	12583	12674	12766	12858	12951	13044	13138	13232
1068	Area	947.73	952.38	957.12	962.03	967.25	992.31	995.12	997.84	1000.5	1003.2
	Capacity	13327	13422	13517	13613	13710	13808	13908	14007	14107	14207
1069	Area	1006.0	1008.7	1011.4	1014.1	1016.9	1019.6	1022.4	1025.2	1027.9	1030.7
	Capacity	14308	14409	14510	14611	14713	14814	14917	15019	15122	15225
1070	Area	1033.5	1036.3	1039.1	1041.9	1044.7	1047.6	1050.4	1053.2	1056.1	1058.9
	Capacity	15328	15431	15535	15639	15743	15848	15953	16058	16164	16269

Table A. 3: Shawnee Twin Lake No. 1 Capacity/Area by 0.1-ft Increments (cont).

SHAWNEE TWIN LAKE #1 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 NAVD88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1071	Area	1061.8	1064.7	1067.6	1070.4	1073.3	1076.2	1079.1	1082.1	1085	1087.9
	Capacity	16375	16482	16588	16695	16803	16910	17018	17126	17234	17343
1072	Area	1090.8	1093.8	1096.7	1099.7	1102.7	1105.6	1108.6	1111.6	1114.6	1117.6
	Capacity	17452	17561	17671	17781	17891	18001	18112	18223	18334	18446
1073	Area	1120.6	1123.6	1126.7	1129.7	1132.7	1142.9				
	Capacity	18558	18670	18783	18895	19008	19031				

Figure A. 1. Area-Capacity Curve for Shawnee Twin Lake No. 1



APPENDIX B: Shawnee Twin Lake No. 1 Maps

Figure B. 1: Shawnee Twin Lake No. 1 Bathymetric Map with 5-foot Contour Intervals.

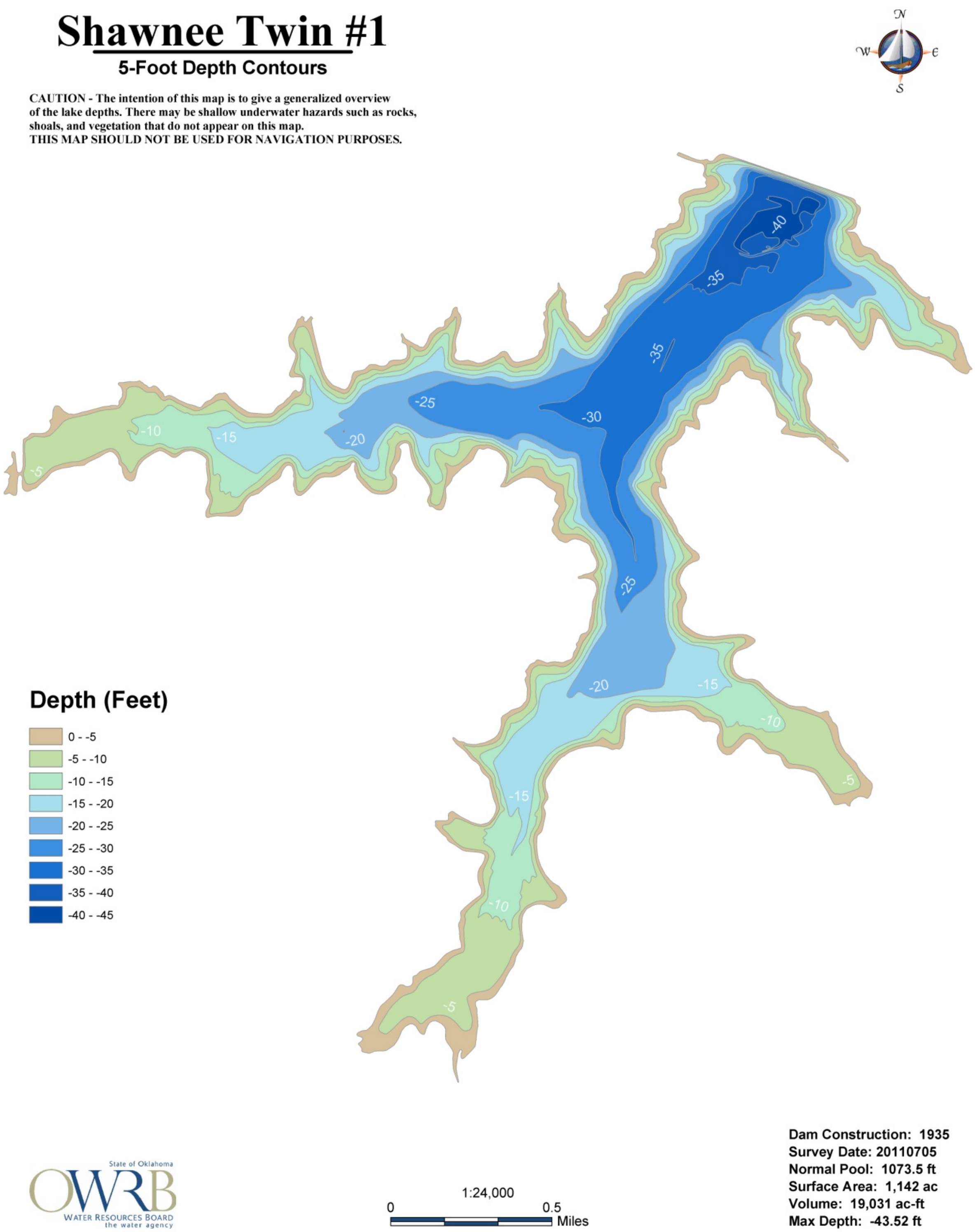


Figure B. 2: Shawnee Twin Lake No. 1 Shaded Relief Bathymetric Map.

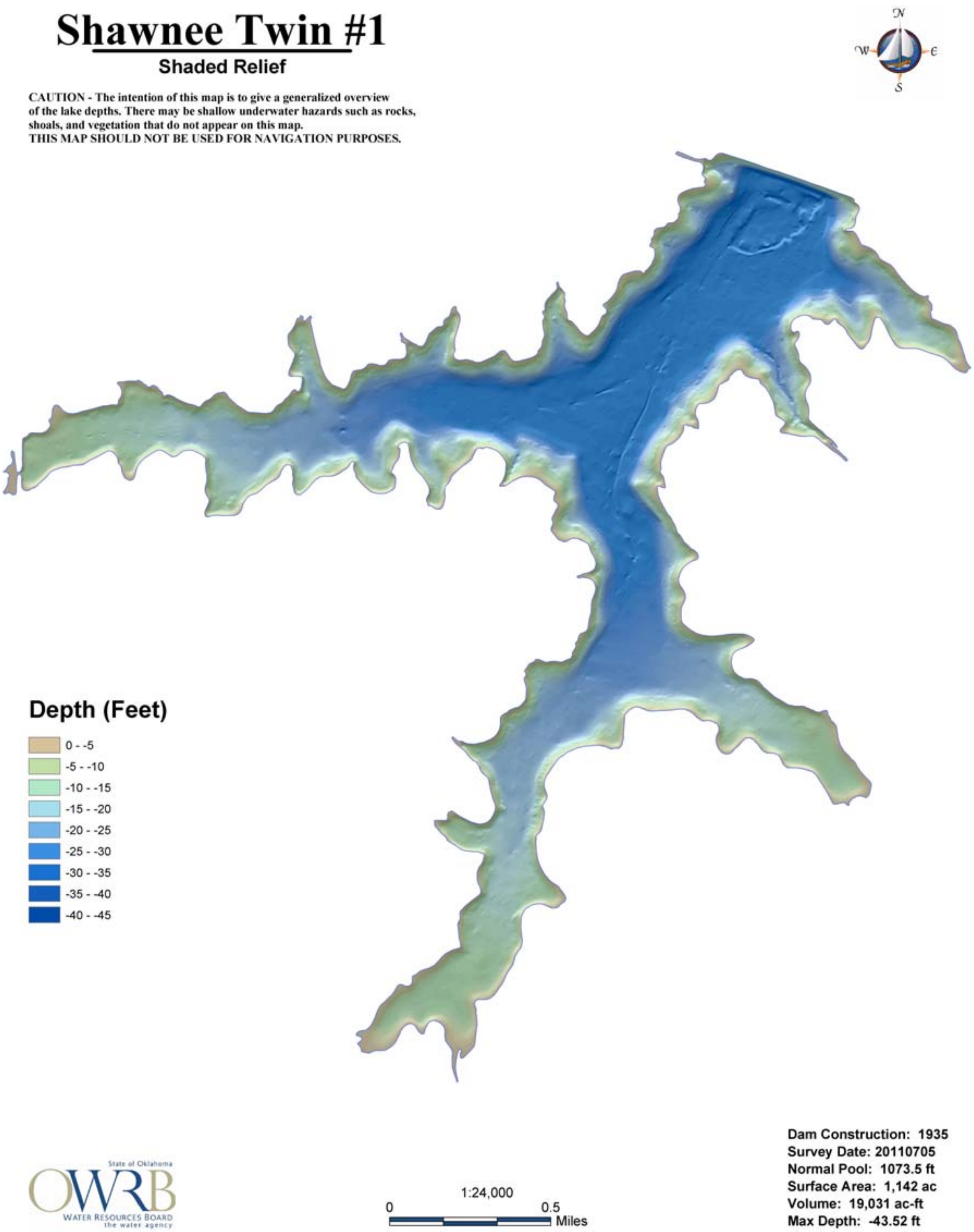


Figure B. 3: Shawnee Twin Lake No. 1 Collected Data Points.