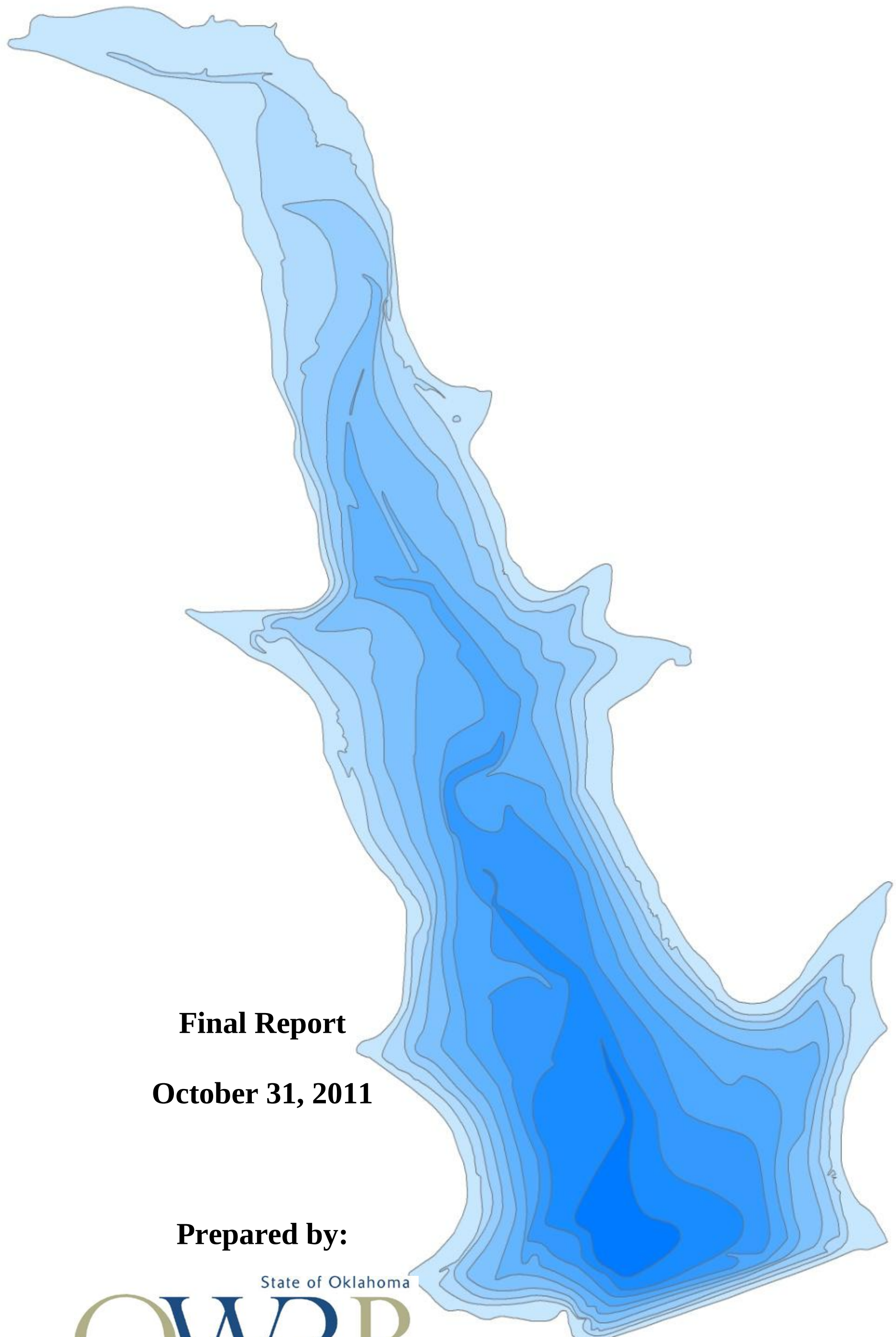
HYDROGRAPHIC SURVEY of LAKE PAWHUSKA



Final Report

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Prepared by:

State of Oklahoma
OWRB
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LAKE PAWHUSKA
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Lake Pawhuska beginning in May 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

Lake Pawhuska is located on the Clear Creek Tributary in Osage County (**Figure 1**). The dam was completed in 1936 and is located approximately three miles west and two miles south of the city of Pawhuska, OK. Its purposes are water supply, and recreation.

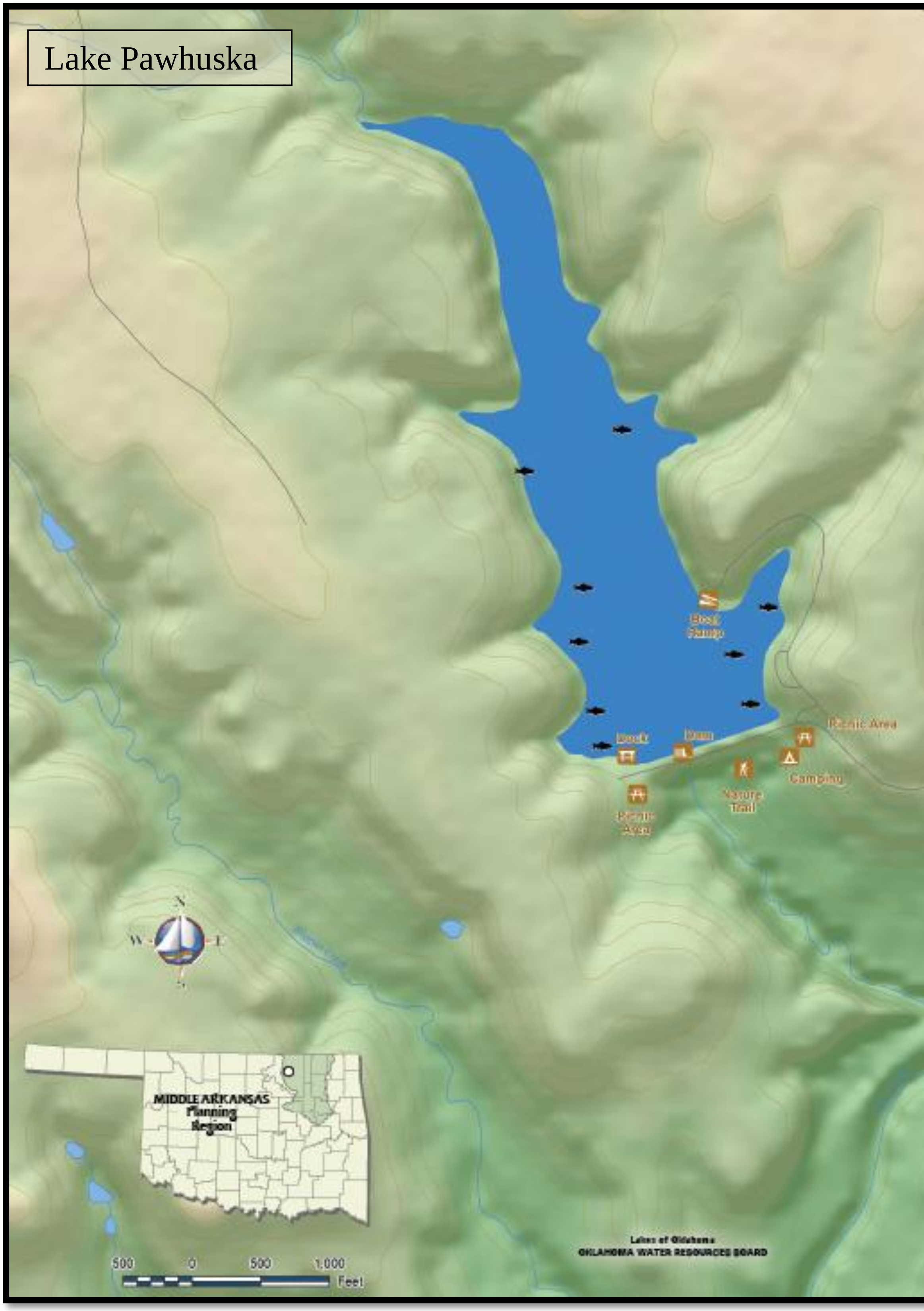


Figure 1: Location map for Lake Pawhuska.

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 Lake Pawhuska 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 17 virtual transects were created for Lake Pawhuska.

Field Survey

Lake Elevation Acquisition

The lake elevation for Lake Pawhuska was obtained by collecting positional data over a period of approximately 114 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 Lake Pawhuska occurred in May of 2011. The water level elevation for Lake Pawhuska was 889.4 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 83 cross-sections points at Lake Pawhuska were used to compute error estimates. A mean difference (arithmetic mean) of 0.164 ft and a standard deviation of 0.358 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 ± 0.77 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 0.164 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 Lake Pawhuska 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 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: Lake Pawhuska** 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 Lake Pawhuska encompasses 103 acres and contains a cumulative capacity of 1,806 ac-ft at the normal pool elevation (889 ft NAVD 88). The average depth for Lake Pawhuska was 17.53 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Lake Pawhuska at the normal pool elevation. Based on the design specifications, Lake Pawhuska had an area of 100 acres and cumulative volume of 3,600 acre-feet of water at conservation pool elevation (889 ft NAVD 88). The surface area of the lake has had an increase of 3 acres or approximately 3%. The 2011 survey shows that Lake Pawhuska has had an apparent decrease in capacity of 49.8% or approximately 1,794 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, 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 Lake Pawhuska at normal pool (889 ft NAVD 88).

Feature	Survey Year	
	1936 Design Specifications	2011
Area (acres)	100	103
Cumulative Volume (acre-feet)	3,600	1,806
Mean depth (ft)	36	17.53
Maximum Depth (ft)	--	44.22

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

LAKE PAWHUSKA 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
844	Area								0.0000	0.0007	0.0029
	Capacity								0.0000	0.0000	0.0002
845	Area	0.006	0.013	0.021	0.027	0.035	0.045	0.055	0.003	0.000	0.085
	Capacity	0.001	0.002	0.003	0.006	0.009	0.013	0.018	0.024	0.031	0.039
846	Area	0.098	0.112	0.127	0.144	0.163	0.183	0.206	0.231	0.262	0.325
	Capacity	0.048	0.058	0.070	0.084	0.099	0.116	0.136	0.158	0.182	0.211
847	Area	0.451	0.552	0.639	0.708	0.770	0.831	0.894	0.955	1.016	1.078
	Capacity	0.250	0.300	0.360	0.427	0.501	0.581	0.667	0.760	0.858	0.963
848	Area	1.143	1.209	1.274	1.341	1.410	1.486	1.575	1.681	1.813	1.966
	Capacity	1.074	1.191	1.316	1.446	1.584	1.729	1.882	2.044	2.219	2.408
849	Area	2.379	2.446	2.514	2.585	2.660	2.738	2.819	2.901	2.983	3.064
	Capacity	2.634	2.876	3.124	3.379	3.641	3.911	4.189	4.475	4.769	5.071
850	Area	3.150	3.247	3.353	3.455	3.582	3.764	3.986	4.173	4.398	4.620
	Capacity	5.382	5.702	6.032	6.372	6.723	7.091	7.481	7.888	8.317	8.768
851	Area	5.142	5.330	5.488	5.641	5.790	5.937	6.075	6.208	6.341	6.471
	Capacity	9.264	9.788	10.329	10.885	11.457	12.043	12.644	13.258	13.886	14.526
852	Area	6.601	6.733	6.866	6.999	7.134	7.269	7.406	7.544	7.685	7.835
	Capacity	15.180	15.847	16.527	17.220	17.927	18.647	19.381	20.129	20.890	21.666
853	Area	7.998	8.187	8.374	8.559	8.744	8.931	9.119	9.309	9.508	9.711
	Capacity	22.458	23.267	24.095	24.942	25.807	26.691	27.594	28.515	29.456	30.417
854	Area	9.995	10.226	10.443	10.652	10.857	11.065	11.276	11.486	11.701	11.927
	Capacity	31.404	32.415	33.449	34.504	35.579	36.675	37.792	38.931	40.090	41.272
855	Area	12.163	12.329	12.493	12.657	12.824	12.994	13.164	13.334	13.506	13.676
	Capacity	42.478	43.702	44.944	46.201	47.475	48.767	50.075	51.400	52.742	54.101
856	Area	13.848	14.024	14.201	14.383	14.568	14.758	14.949	15.141	15.335	15.535
	Capacity	55.478	56.871	58.283	59.712	61.160	62.626	64.112	65.617	67.140	68.684
857	Area	15.738	15.942	16.152	16.369	16.594	16.824	17.052	17.281	17.506	17.735
	Capacity	70.248	71.832	73.437	75.063	76.711	78.383	80.076	81.794	83.533	85.295
858	Area	17.967	18.208	18.456	18.701	18.947	19.194	19.443	19.689	19.931	20.170
	Capacity	87.081	88.889	90.723	92.581	94.463	96.371	98.303	100.26	102.24	104.25
859	Area	20.868	21.118	21.362	21.597	21.826	22.040	22.254	22.466	22.672	22.880
	Capacity	106.31	108.41	110.54	112.68	114.86	117.05	119.26	121.50	123.76	126.04
860	Area	23.088	23.296	23.504	23.715	23.929	24.151	24.376	24.603	24.833	25.080
	Capacity	128.34	130.65	133.00	135.36	137.74	140.14	142.57	145.02	147.49	149.99
861	Area	25.663	25.836	26.005	26.172	26.338	26.502	26.658	26.813	26.969	27.123
	Capacity	152.54	155.11	157.70	160.31	162.94	165.58	168.24	170.91	173.60	176.31
862	Area	27.276	27.430	27.584	27.742	27.895	28.045	28.195	28.345	28.495	28.645
	Capacity	179.03	181.76	184.52	187.28	190.06	192.86	195.67	198.50	201.34	204.20
863	Area	28.797	28.949	29.102	29.255	29.410	29.575	29.746	29.925	30.110	30.312
	Capacity	207.07	209.96	212.86	215.78	218.72	221.67	224.63	227.62	230.62	233.64
864	Area	30.578	30.780	30.983	31.185	31.390	31.597	31.804	32.015	32.230	32.450
	Capacity	236.69	239.75	242.84	245.95	249.08	252.23	255.40	258.59	261.81	265.04

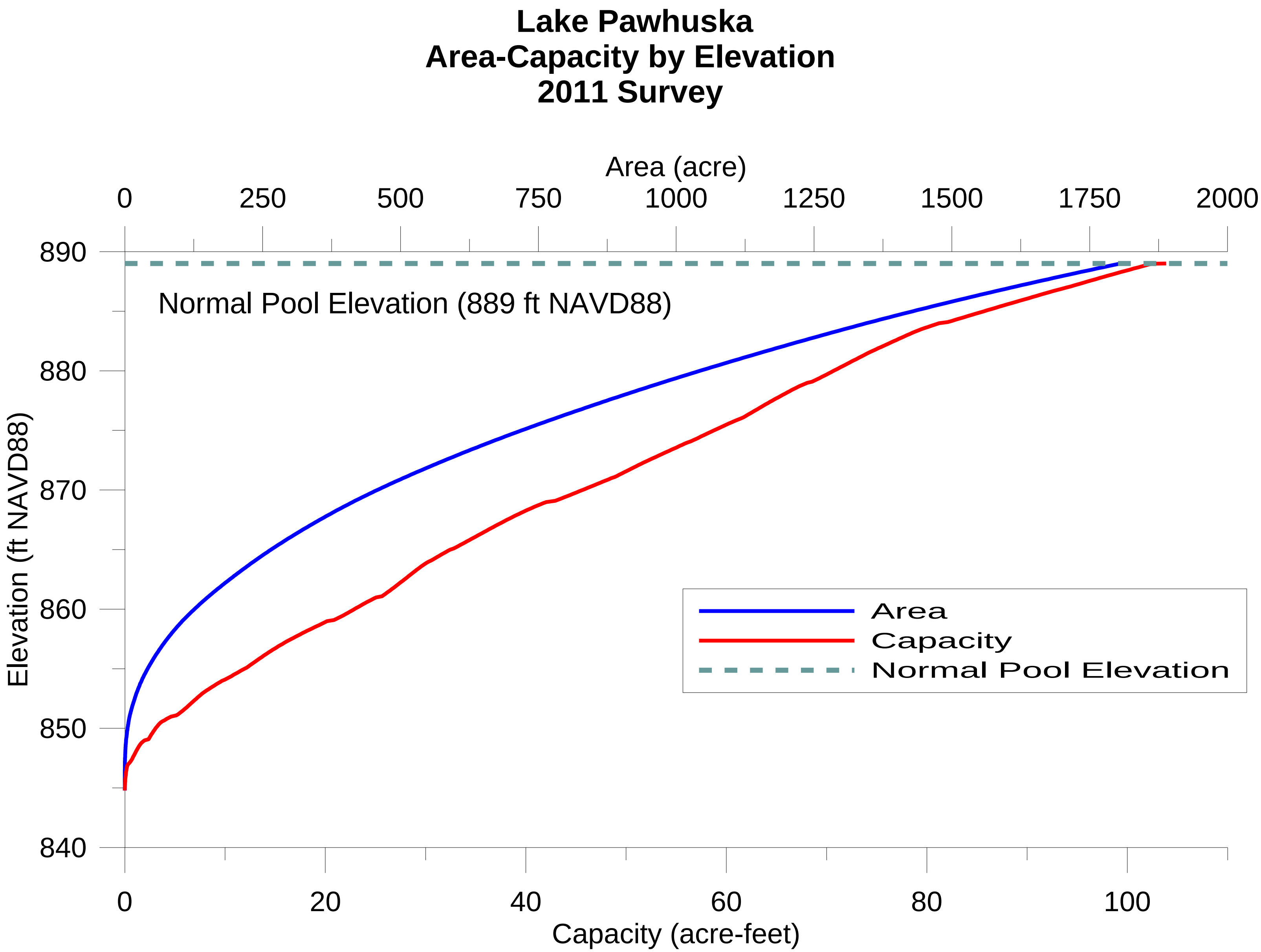
Table A. 2: Lake Pawhuska Capacity/Area by 0.1-ft Increments (cont).

LAKE PAWHUSKA 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
865	Area	32.808	33.039	33.264	33.485	33.703	33.921	34.139	34.358	34.575	34.790
	Capacity	268.31	271.60	274.92	278.25	281.61	284.99	288.40	291.82	295.27	298.74
866	Area	35.006	35.223	35.444	35.663	35.881	36.098	36.315	36.532	36.752	36.975
	Capacity	302.23	305.74	309.28	312.83	316.41	320.01	323.63	327.27	330.94	334.62
867	Area	37.201	37.430	37.661	37.887	38.116	38.349	38.584	38.821	39.062	39.306
	Capacity	338.33	342.06	345.82	349.60	353.40	357.22	361.07	364.94	368.83	372.75
868	Area	39.554	39.811	40.071	40.335	40.602	40.872	41.149	41.436	41.730	42.043
	Capacity	376.70	380.67	384.66	388.68	392.73	396.80	400.90	405.04	409.19	413.38
869	Area	42.940	43.249	43.554	43.859	44.156	44.451	44.748	45.045	45.338	45.632
	Capacity	417.65	421.96	426.30	430.67	435.07	439.50	443.96	448.46	452.97	457.52
870	Area	45.927	46.222	46.513	46.801	47.089	47.379	47.668	47.956	48.244	48.534
	Capacity	462.10	466.71	471.35	476.01	480.71	485.43	490.19	494.97	499.78	504.62
871	Area	48.869	49.113	49.354	49.590	49.825	50.060	50.294	50.529	50.765	51.003
	Capacity	509.49	514.39	519.32	524.26	529.23	534.23	539.25	544.29	549.35	554.44
872	Area	51.244	51.488	51.735	51.988	52.241	52.495	52.751	53.008	53.266	53.525
	Capacity	559.56	564.69	569.86	575.04	580.25	585.49	590.75	596.05	601.36	606.70
873	Area	53.785	54.043	54.302	54.562	54.822	55.081	55.339	55.600	55.863	56.137
	Capacity	612.07	617.46	622.88	628.32	633.79	639.29	644.81	650.36	655.93	661.53
874	Area	56.476	56.741	56.995	57.243	57.489	57.737	57.986	58.237	58.491	58.746
	Capacity	667.16	672.82	678.51	684.22	689.96	695.72	701.51	707.32	713.16	719.02
875	Area	59.000	59.254	59.510	59.770	60.033	60.297	60.564	60.836	61.117	61.409
	Capacity	724.91	730.82	736.76	742.73	748.72	754.74	760.78	766.85	772.95	779.07
876	Area	61.703	61.907	62.111	62.316	62.520	62.723	62.925	63.127	63.329	63.530
	Capacity	785.24	791.42	797.62	803.84	810.08	816.35	822.63	828.93	835.26	841.60
877	Area	63.735	63.943	64.152	64.362	64.577	64.792	65.007	65.223	65.438	65.656
	Capacity	847.97	854.35	860.76	867.18	873.63	880.10	886.59	893.10	899.64	906.19
878	Area	65.879	66.102	66.324	66.547	66.773	67.009	67.257	67.514	67.781	68.081
	Capacity	912.77	919.37	925.99	932.64	939.30	945.99	952.71	959.45	966.21	973.00
879	Area	68.566	68.825	69.072	69.310	69.544	69.775	70.007	70.237	70.466	70.696
	Capacity	979.85	986.71	993.61	1000.5	1007.5	1014.4	1021.4	1028.4	1035.5	1042.5
880	Area	70.925	71.155	71.383	71.610	71.837	72.066	72.296	72.529	72.756	72.992
	Capacity	1049.6	1056.7	1063.9	1071.0	1078.2	1085.4	1092.6	1099.8	1107.1	1114.4
881	Area	73.227	73.455	73.683	73.910	74.144	74.389	74.640	74.901	75.158	75.416
	Capacity	1121.7	1129.0	1136.4	1143.8	1151.2	1158.6	1166.1	1173.5	1181.0	1188.6
882	Area	75.676	75.940	76.204	76.464	76.722	76.981	77.241	77.502	77.764	78.030
	Capacity	1196.1	1203.7	1211.3	1219.0	1226.6	1234.3	1242.0	1249.8	1257.5	1265.3
883	Area	78.300	78.576	78.856	79.144	79.458	79.796	80.145	80.506	80.859	81.223
	Capacity	1273.1	1281.0	1288.8	1296.7	1304.7	1312.6	1320.6	1328.7	1336.7	1344.8
884	Area	82.093	82.500	82.895	83.287	83.680	84.080	84.479	84.877	85.274	85.674
	Capacity	1353.0	1361.3	1369.5	1377.8	1386.2	1394.6	1403.0	1411.5	1420.0	1428.5
885	Area	86.076	86.469	86.863	87.267	87.677	88.091	88.501	88.913	89.322	89.731
	Capacity	1437.1	1445.7	1454.4	1463.1	1471.9	1480.7	1489.5	1498.4	1507.3	1516.2

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

LAKE PAWHUSKA 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
886	Area	90.143	90.544	90.957	91.362	91.768	92.182	92.607	93.042	93.482	93.948
	Capacity	1525.2	1534.3	1543.3	1552.5	1561.6	1570.8	1580.0	1589.3	1598.7	1608.0
887	Area	94.403	94.808	95.210	95.615	96.022	96.432	96.845	97.261	97.679	98.101
	Capacity	1617.5	1626.9	1636.4	1646.0	1655.5	1665.2	1674.8	1684.5	1694.3	1704.1
888	Area	98.525	98.952	99.382	99.814	100.25	100.69	101.13	101.57	102.02	102.47
	Capacity	1713.9	1723.8	1733.7	1743.7	1753.7	1763.7	1773.8	1783.9	1794.1	1804.3
889	Area	103.89									
	Capacity	1806.4									

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



APPENDIX B: Lake Pawhuska Maps

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

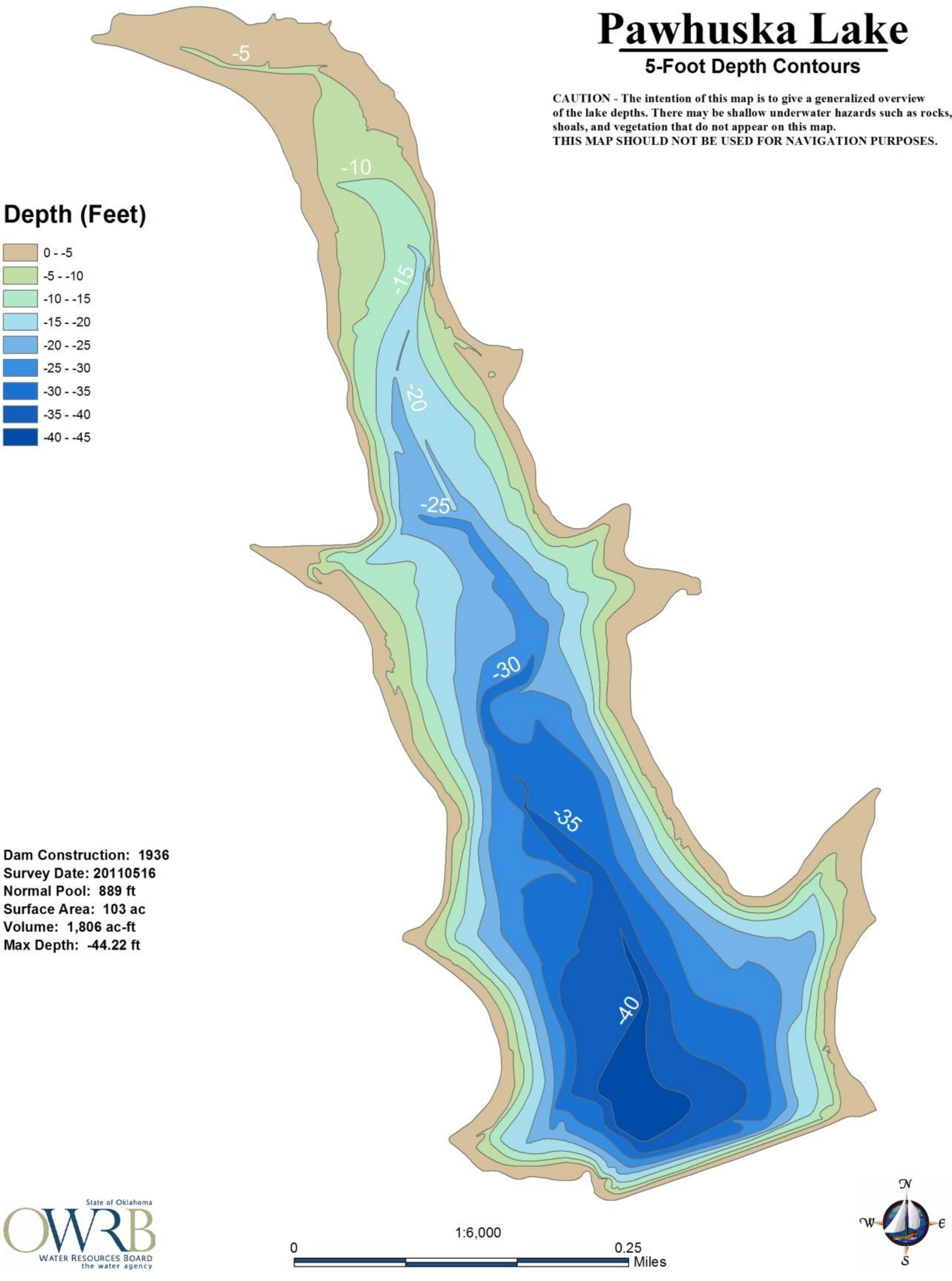


Figure B. 2: Lake Pawhuska Shaded Relief Bathymetric Map.

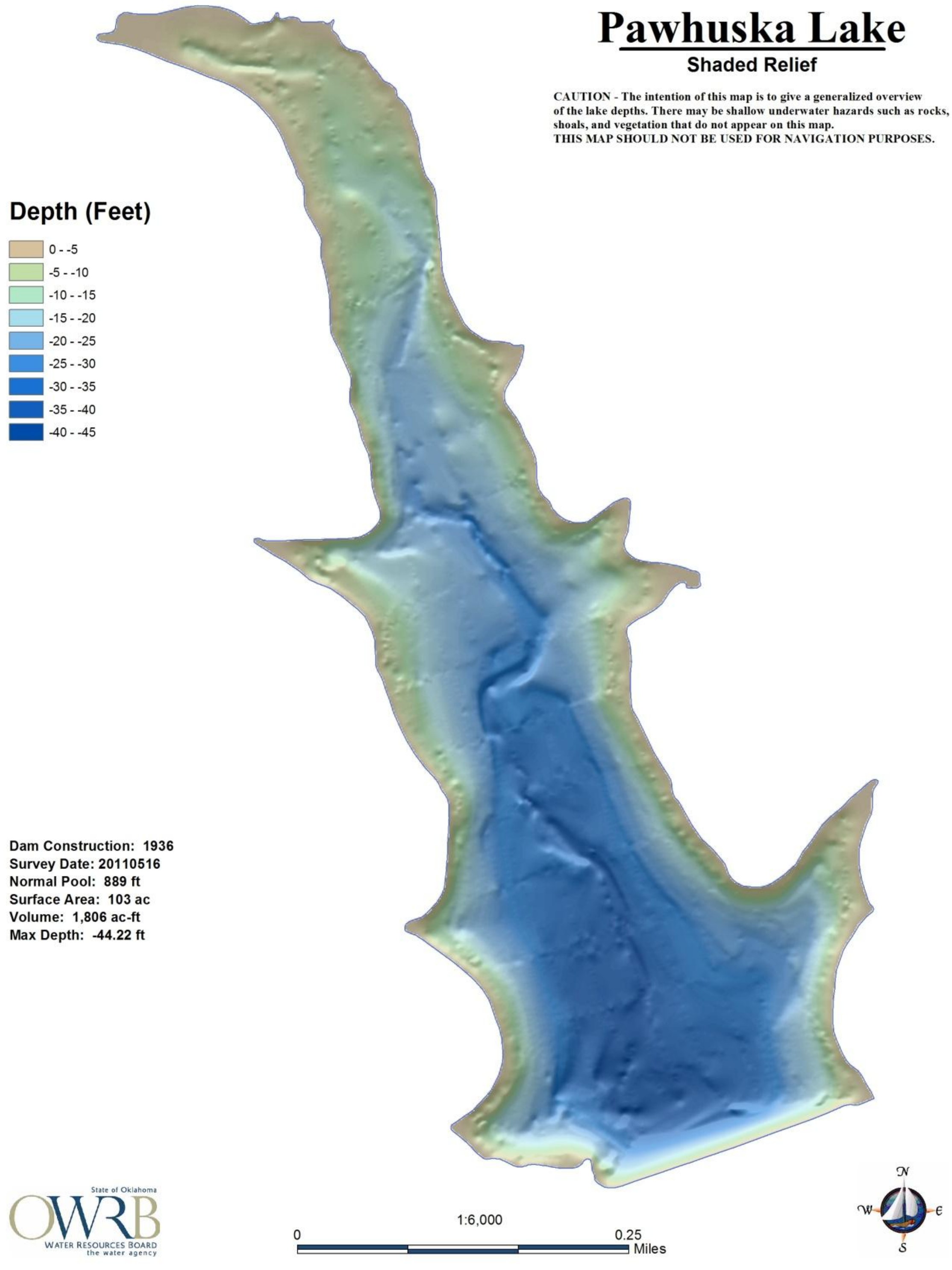


Figure B. 3: Lake Pawhuska Collected Data Points.