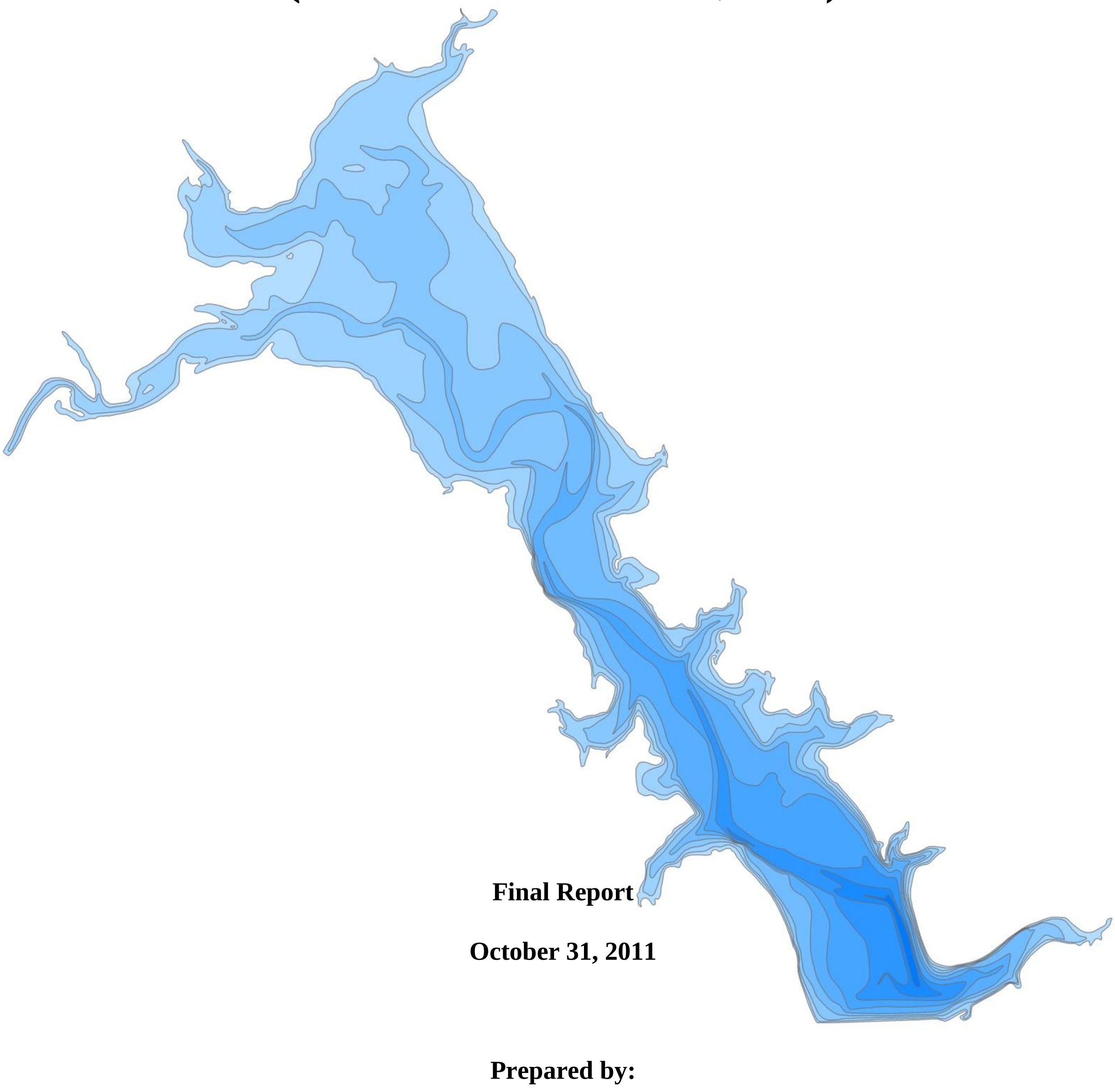
HYDROGRAPHIC SURVEY of LAKE HUDSON (OSAGE COUNTY, OK)



Final Report

October 31, 2011

Prepared by:

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OWRB
WATER RESOURCES BOARD
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INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Lake Hudson in August 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 Hudson is located on Butler Creek Tributary in Osage County (**Figure 1**). The dam was completed in 1949 and is located approximately six miles northwest of the city of Bartlesville, 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 Lake Hudson.

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 Hudson 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 25 virtual transects were created for Lake Hudson.

Field Survey

Lake Elevation Acquisition

The lake elevation for Lake Hudson was obtained by collecting positional data over a period of approximately 170minutes 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 Hudson occurred in August of 2011. The water level elevation for Lake Hudson was 757.9 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 57 cross-sections points at Lake Hudson were used to compute error estimates. A mean difference (arithmetic mean) of 0.08ft and a standard deviation of 0.925 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 ± 1.82 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 0.08 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 Hudson 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: Lake Hudson** 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 Lake Hudson encompasses 268 acres and contains a cumulative capacity of 2,776 ac-ft at the normal pool elevation (757.0 ft NAVD88). The average depth for Lake Hudson was 10.36 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Lake Hudson at the normal pool elevation. Based on the design specifications, Lake Hudson had an area of 259 acres and cumulative volume of 4,000 acre-feet of water at conservation pool elevation (757 ft NAVD88). The surface area of the lake has had an increase of 9 acres or approximately 3%. The 2011 survey shows that Lake Hudson has had an apparent decrease in capacity of 30.6% or approximately 1,224 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 Lake Hudson at normal pool (757 ft NAVD88).

Feature	Survey Year	
	1949 Design Specifications	2011
Area (acres)	259	268
Cumulative Volume (acre-feet)	4,000	2,776
Mean depth (ft)	15.44	10.36
Maximum Depth (ft)	--	38.27

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 Hudson Capacity/Area by 0.1-ft Increments.

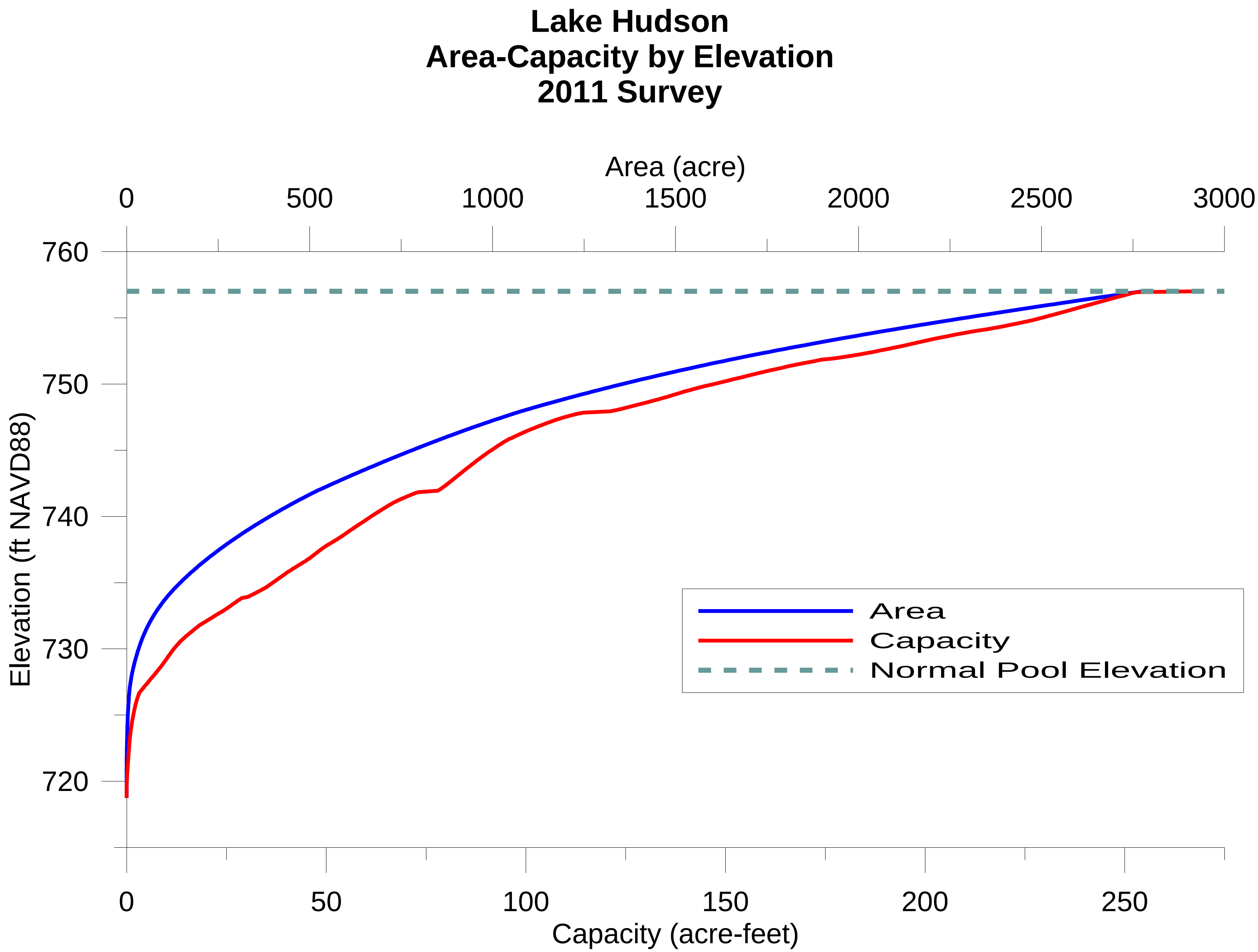
LAKE HUDSON AREA-CAPACITY TABLE
OKLAHOMA WATER RESOURCES BOARD
2011 Survey
Capacity in acre-feet by tenth foot elevation increments
Area in acres by tenth foot elevation increments

Elevation (ft NAVD 88)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
718	Area	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0008
	Capacity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
719	Area	0.0031	0.0064	0.0096	0.0131	0.0187	0.0253	0.0344	0.0416	0.0501	0.0603
	Capacity	0.0002	0.0007	0.0015	0.0026	0.0042	0.0064	0.0095	0.0133	0.0178	0.0233
720	Area	0.0720	0.0858	0.1014	0.1181	0.1361	0.1554	0.1757	0.1973	0.2202	0.2436
	Capacity	0.0299	0.0378	0.0472	0.0581	0.0708	0.0854	0.1019	0.1206	0.1415	0.1646
721	Area	0.2666	0.2877	0.3109	0.3338	0.3563	0.3779	0.3998	0.4223	0.4452	0.4687
	Capacity	0.1902	0.2179	0.2478	0.2801	0.3146	0.3513	0.3902	0.4313	0.4747	0.5204
722	Area	0.4926	0.5168	0.5416	0.5670	0.5931	0.6198	0.6472	0.6751	0.7037	0.7328
	Capacity	0.5684	0.6189	0.6718	0.7273	0.7853	0.8459	0.9093	0.9754	1.0443	1.1161
723	Area	0.7625	0.7929	0.8245	0.8577	0.8943	0.9331	0.9737	1.0154	1.0582	1.1020
	Capacity	1.1909	1.2687	1.3495	1.4337	1.5213	1.6127	1.7080	1.8074	1.9111	2.0191
724	Area	1.1469	1.1929	1.2403	1.2893	1.3423	1.4093	1.4738	1.5360	1.5976	1.6602
	Capacity	2.1316	2.2486	2.3702	2.4967	2.6283	2.7657	2.9098	3.0603	3.2170	3.3799
725	Area	1.7237	1.7868	1.8494	1.9140	1.9815	2.0514	2.1246	2.2031	2.2861	2.3732
	Capacity	3.5492	3.7247	3.9065	4.0947	4.2894	4.4912	4.6999	4.9162	5.1408	5.3737
726	Area	2.4706	2.5690	2.6671	2.7713	2.8834	3.0099	3.1579	3.3364	3.5846	3.8943
	Capacity	5.6158	5.8679	6.1296	6.4016	6.6842	6.9789	7.2870	7.6114	7.9564	8.3309
727	Area	4.1551	4.4082	4.6963	5.0038	5.2618	5.5203	5.7964	6.0752	6.3554	6.6398
	Capacity	8.7340	9.1619	9.6167	10.102	10.616	11.155	11.721	12.314	12.936	13.586
728	Area	6.9221	7.2039	7.4770	7.7475	8.0126	8.2755	8.5358	8.7923	9.0452	9.2906
	Capacity	14.264	14.971	15.705	16.466	17.254	18.069	18.910	19.776	20.668	21.585
729	Area	9.5269	9.7625	9.9956	10.228	10.464	10.703	10.944	11.187	11.435	11.688
	Capacity	22.526	23.491	24.479	25.490	26.525	27.583	28.666	29.772	30.904	32.060
730	Area	11.946	12.214	12.503	12.788	13.081	13.391	13.730	14.087	14.466	14.844
	Capacity	33.242	34.449	35.685	36.950	38.243	39.567	40.923	42.314	43.742	45.207
731	Area	15.222	15.627	16.045	16.457	16.854	17.250	17.653	18.074	18.538	19.130
	Capacity	46.711	48.253	49.837	51.463	53.128	54.834	56.579	58.365	60.196	62.078
732	Area	19.673	20.203	20.746	21.276	21.807	22.342	22.883	23.444	23.994	24.526
	Capacity	64.020	66.013	68.060	70.163	72.317	74.525	76.786	79.102	81.475	83.901
733	Area	25.038	25.521	26.000	26.467	26.929	27.393	27.866	28.347	28.865	30.513
	Capacity	86.381	88.909	91.485	94.109	96.779	99.496	102.26	105.07	107.93	110.88
734	Area	31.139	31.780	32.430	33.080	33.710	34.326	34.888	35.388	35.870	36.346
	Capacity	113.96	117.11	120.32	123.59	126.93	130.34	133.80	137.31	140.88	144.49
735	Area	36.817	37.283	37.747	38.210	38.676	39.148	39.624	40.094	40.566	41.089
	Capacity	148.15	151.85	155.60	159.40	163.25	167.14	171.08	175.06	179.10	183.18
736	Area	41.613	42.142	42.695	43.239	43.768	44.317	44.829	45.329	45.814	46.262
	Capacity	187.32	191.50	195.74	200.04	204.39	208.80	213.26	217.76	222.32	226.93
737	Area	46.690	47.111	47.544	47.977	48.408	48.855	49.322	49.795	50.274	50.903
	Capacity	231.58	236.27	241.00	245.78	250.60	255.46	260.37	265.33	270.33	275.39
738	Area	51.439	51.976	52.514	53.051	53.582	54.080	54.555	55.022	55.495	55.986
	Capacity	280.51	285.68	290.90	296.18	301.51	306.90	312.33	317.81	323.34	328.91

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

LAKE HUDSON 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
739	Area	56.476	56.967	57.463	57.965	58.467	58.971	59.472	59.967	60.460	60.956
	Capacity	334.54	340.21	345.93	351.70	357.52	363.40	369.32	375.29	381.32	387.39
740	Area	61.459	61.972	62.485	63.017	63.546	64.072	64.604	65.143	65.684	66.244
	Capacity	393.51	399.68	405.90	412.18	418.51	424.89	431.32	437.81	444.36	450.95
741	Area	66.848	67.515	68.214	68.933	69.685	70.467	71.274	72.115	73.005	77.977
	Capacity	457.61	464.33	471.11	477.97	484.90	491.91	499.00	506.17	513.43	520.90
742	Area	78.484	78.966	79.433	79.882	80.313	80.734	81.149	81.561	81.968	82.377
	Capacity	528.72	536.60	544.51	552.48	560.49	568.55	576.64	584.78	592.96	601.18
743	Area	82.795	83.206	83.617	84.028	84.440	84.855	85.274	85.699	86.127	86.554
	Capacity	609.44	617.74	626.08	634.46	642.89	651.36	659.86	668.41	677.00	685.64
744	Area	86.983	87.415	87.851	88.291	88.735	89.185	89.643	90.111	90.585	91.067
	Capacity	694.32	703.04	711.80	720.61	729.46	738.36	747.30	756.29	765.33	774.41
745	Area	91.555	92.053	92.559	93.059	93.564	94.074	94.603	95.166	95.738	96.567
	Capacity	783.55	792.72	801.95	811.24	820.57	829.96	839.39	848.88	858.43	868.04
746	Area	97.242	97.929	98.650	99.392	100.16	100.95	101.78	102.63	103.46	104.31
	Capacity	877.73	887.49	897.32	907.22	917.20	927.26	937.39	947.61	957.92	968.31
747	Area	105.18	106.08	107.00	107.97	109.01	110.16	111.39	112.74	114.40	121.26
	Capacity	978.79	989.35	1000.0	1010.8	1021.6	1032.6	1043.6	1054.8	1066.2	1077.9
748	Area	122.76	124.10	125.44	126.76	128.05	129.34	130.61	131.87	133.11	134.32
	Capacity	1090.1	1102.4	1114.9	1127.5	1140.3	1153.2	1166.2	1179.3	1192.5	1205.9
749	Area	135.48	136.58	137.65	138.70	139.80	141.03	142.25	143.46	144.79	146.25
	Capacity	1219.4	1233.0	1246.7	1260.5	1274.5	1288.5	1302.7	1317.0	1331.4	1345.9
750	Area	147.66	149.04	150.39	151.76	153.11	154.44	155.76	157.11	158.49	159.90
	Capacity	1360.6	1375.5	1390.4	1405.5	1420.8	1436.2	1451.7	1467.3	1483.1	1499.0
751	Area	161.34	162.82	164.31	165.73	167.30	169.03	170.75	172.39	174.02	177.21
	Capacity	1515.1	1531.3	1547.7	1564.2	1580.8	1597.6	1614.6	1631.8	1649.1	1666.6
752	Area	179.52	181.71	183.69	185.51	187.23	188.88	190.53	192.19	193.76	195.26
	Capacity	1684.5	1702.5	1720.8	1739.3	1757.9	1776.7	1795.7	1814.8	1834.1	1853.6
753	Area	196.73	198.21	199.70	201.21	202.76	204.40	206.05	207.69	209.48	211.40
	Capacity	1873.2	1892.9	1912.8	1932.9	1953.1	1973.5	1994.0	2014.7	2035.5	2056.6
754	Area	213.36	215.51	217.45	219.26	220.95	222.52	224.14	225.72	227.15	228.43
	Capacity	2077.8	2099.3	2120.9	2142.7	2164.8	2186.9	2209.3	2231.8	2254.4	2277.2
755	Area	229.71	230.96	232.19	233.40	234.63	235.84	237.02	238.19	239.38	240.57
	Capacity	2300.1	2323.1	2346.3	2369.6	2393.0	2416.5	2440.2	2463.9	2487.8	2511.8
756	Area	241.76	242.97	244.17	245.39	246.61	247.84	249.08	250.32	251.57	252.82
	Capacity	2535.9	2560.2	2584.5	2609.0	2633.6	2658.4	2683.2	2708.2	2733.3	2758.5
757	Area	268.28									
	Capacity	2776.2									

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



APPENDIX B: Lake Hudson Maps

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

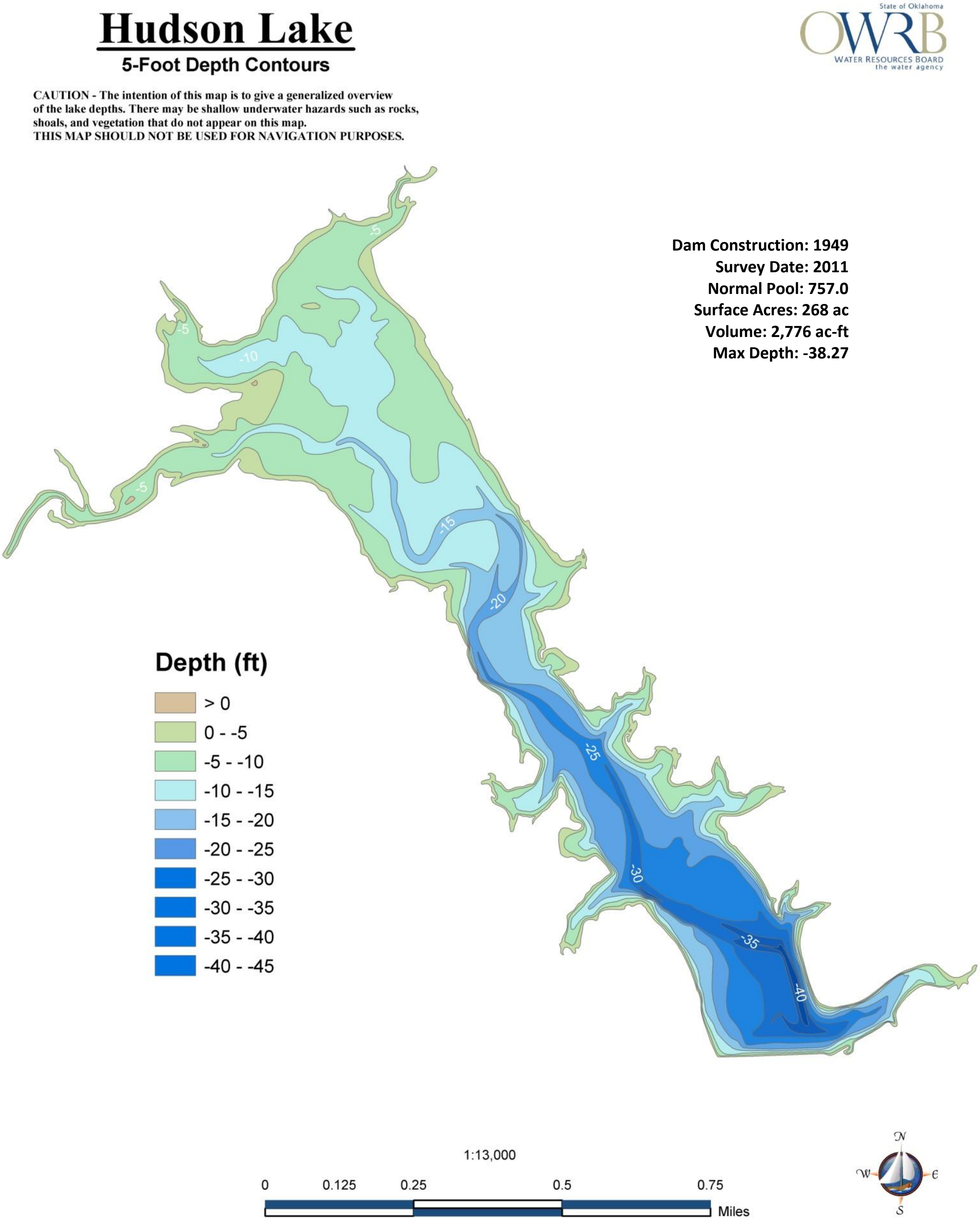


Figure B. 2: Lake Hudson Shaded Relief Bathymetric Map.

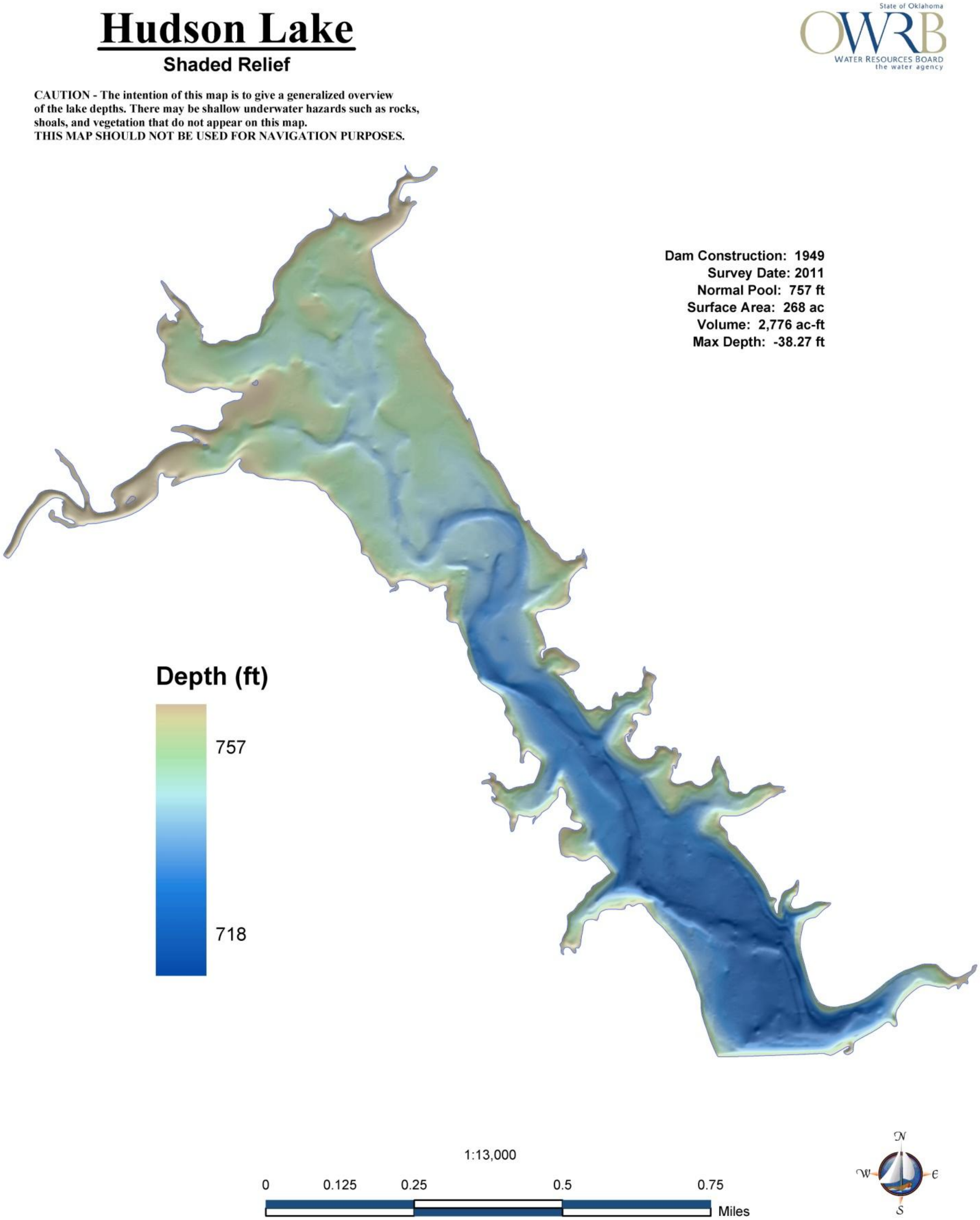


Figure B. 3: Lake Hudson Collected Data Points.