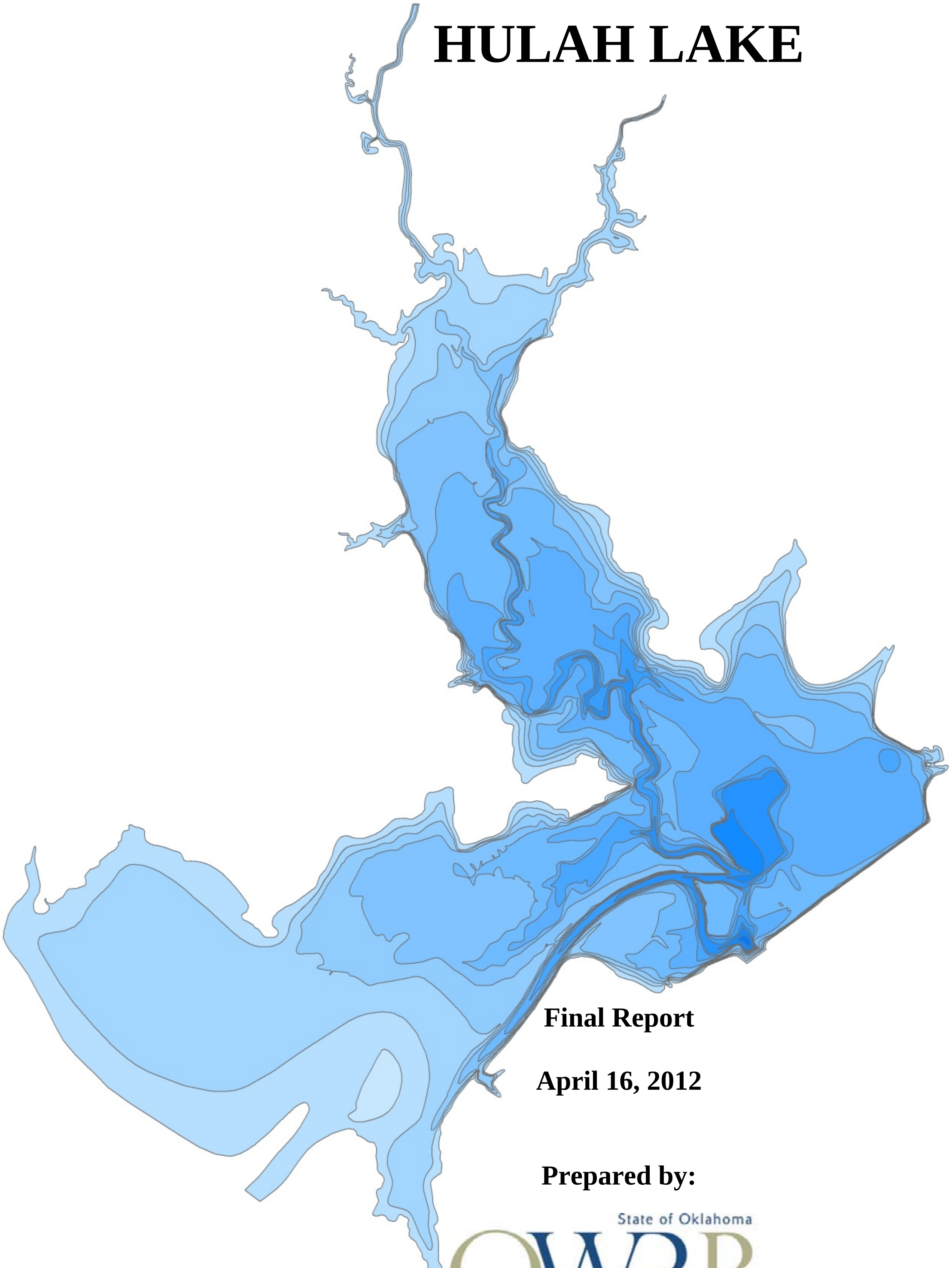
HYDROGRAPHIC SURVEY of HULAH LAKE



Final Report

April 16, 2012

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 Hulah Lake in November of 2010. The purpose of this survey was to produce a new elevation-area-capacity table and bathymetric map for Hulah Lake.

LAKE BACKGROUND

Hulah Dam is in the Arkansas River basin and is located on the Caney River (**Figure 1**) in Osage County about 2 miles west of the town of Hulah and about 15 miles northwest of Bartlesville. Construction by the U.S. Army Corps of Engineers began in May of 1946 and was completed in February 1951. Its original purposes were water supply and flood control.

The dam is rolled impervious earthfill structure with a total length of 5,200 feet and a maximum height of 94 feet above the streambed. The gate-controlled spillway has a total width of 472 feet and consists of ten 40 x 25 foot tainter gates. The spillway capacity is 266,200 cfs at maximum pool elevation.

The original design specifications called for the conservation pool elevation to be set at 731.0 feet. In 1957 the conservation pool elevation was raised to 733.0 feet.

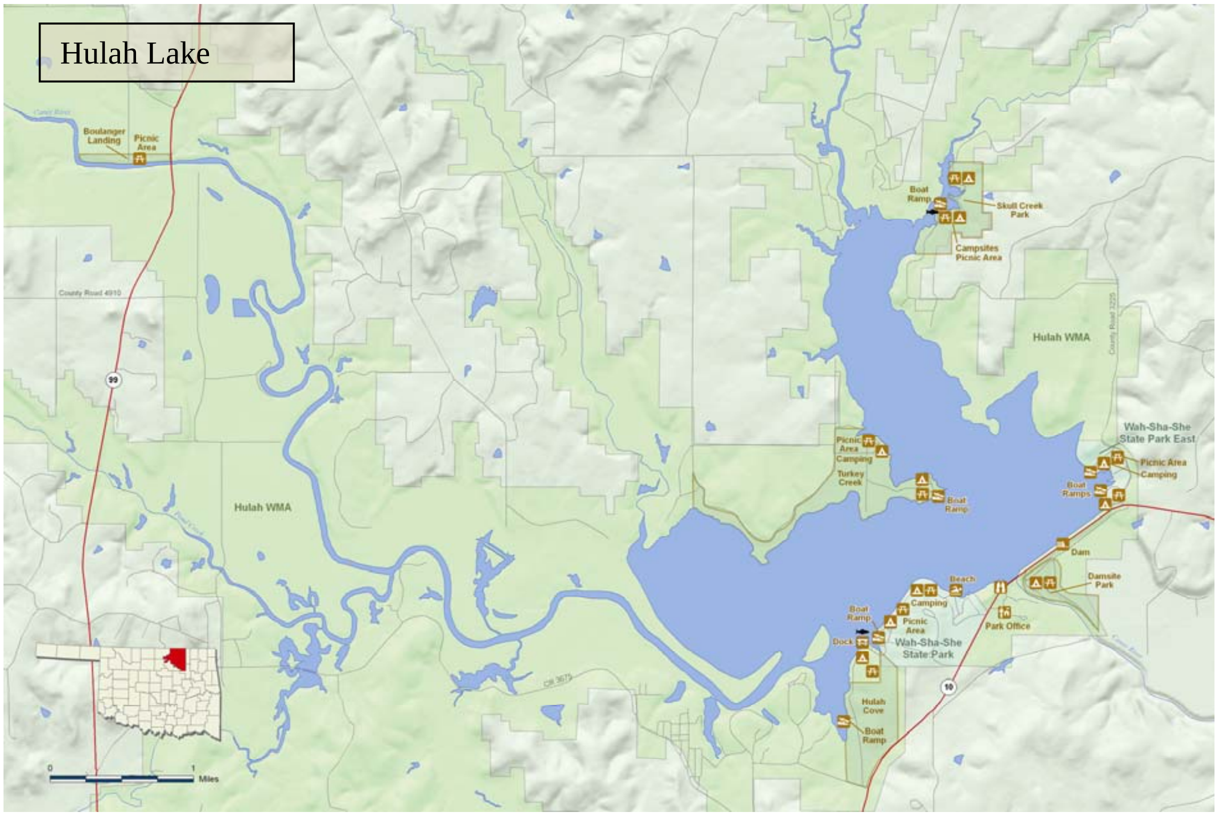


Figure 1: Location map for Hulah Lake.

HYDROGRAPHIC SURVEYING PROCEDURES

The process of surveying a reservoir uses a combination of Geographic Positioning System (GPS) and acoustic depth sounding technologies that are incorporated into a hydrographic survey vessel. As the survey vessel travels across the lake's surface, the echosounder gathers multiple depth readings every second. The depth readings are stored on the survey vessel's on-board computer along with the positional data generated from the vessel's GPS receiver. The collected data files are downloaded daily from the computer and brought to the office for editing. During editing, data "noise" is removed or corrected, and average depths are converted to elevation readings based on the daily-recorded lake level elevation on the day the survey was performed. Accurate estimates of area-capacity can then be determined for the lake by building a 3-D model of the reservoir from the corrected data. The process of completing a hydrographic survey includes four steps: pre-survey planning, field survey, data processing, and GIS application.

Pre-survey Planning

Boundary File

The boundary file for Hulah Lake was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Osage County, Oklahoma. The screen scale was set to 1:1,500. A line was to represent the shoreline as closely as possible. Due to the photography being a summer photo, it was difficult to determine the actual shoreline when there are trees and other vegetation hanging over the lake. The 2008 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.

Field Survey

Lake Elevation Acquisition

The lake elevation for Hulah Lake was obtained from a lake gauge maintained by the U.S. Army Corps of Engineers.

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 Hulah Lake occurred in November of 2010. The water level elevation for Hulah Lake was 732.4 ft Geodetic Vertical Datum (NGVD). 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. It should be noted that a fairly large portion of the western arm of the lake was of a depth of less than 3ft and as a result could not be mapped.

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 295 cross-sections points at Hulah Lake were used to compute error estimates. A mean difference of -0.013 ft and a standard deviation of 0.23 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 ± 0.45 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 -0.013 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 0.4 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. The average elevation of the lake during the survey was 732.4 ft (NGVD).

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 Hulah Lake are located on the DVD entitled *Hulah 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 9.3.1.3500, 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, the lake boundary inputs for normal pool elevations, and Light Detection and Ranging (LIDAR) data points supplied by the US Army Corp of Engineers for flood pool elevations. The TIN consists of connected data points that form a network of triangles representing the bottom surface of the lake and flood pool. 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 2-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 2-ft depth ranges across the lake. The bathymetric maps of the lakes are shown with 2-ft contour intervals in **APPENDIX B: Hulah 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 is located at on the DVD entitled *Hulah HYPACK/GIS Metadata.*

RESULTS

Results from the 2010 OWRB survey indicate that Hulah Lake encompasses 2,635 acres and contains a cumulative capacity of 15,968 ac-ft at the normal pool elevation (733 ft NGVD). The average depth for Hulah Lake was 6.1 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of multiple survey results of Hulah Lake at the normal pool elevation. Based on the design specifications, Hulah Lake had an area of 3,200 acres and cumulative volume of 30,000 acre-feet of water at normal pool elevation of 731.0 in 1949. In 1957 the normal pool elevation was raised to 733.0 feet. In 2002, the Texas Water Development Board (TWDB) conducted a survey of Hulah Lake. This survey included waters of the Caney River and Pond Creek. The 2010 OWRB survey included only lacustrine waters and therefore did not proceed into these riverine areas. In order to compare the 2002 and 2010 surveys and understand capacity loss, data from the 2002 survey in the riverine areas was removed. This lacustrine portion of the 2002 survey was calculated to have an area of 2,635 acres and a volume of 19,076 acre-feet. From 2002 to 2010, Hulah Lake lost 3,100 acre-feet or about 16.2 % of its volume. It is the recommendation of the OWRB that another survey using the same method used in the 2010 survey be conducted in 10-15 years.

Table 1: Area and Volume Comparisons of Hulah Lake at normal pool (733 ft NGVD).

Feature	Survey Year				
	USACE Original Design[1]	USACE 1958[2]	USACE 1973	TWDB 2002	OWRB 2010[3]
Area (acres)	3,200	3,590	3,570	3,120	2,635
Cumulative Volume (acre-feet)	30,000	34,670	31,160	22,565	15,968
Mean depth (ft)	7.3	9.7	8.7	7.2	6.1
Maximum Depth (ft)	--				20.2

Notes:

1. Original Design conservation pool was 731.0 ft.
2. Conservation pool was raised from 731.0 to 733.0 ft in 1957
3. Included only lacustrine area of lake. 2002 survey included riverine portion of Caney R. and Pond Cr. Caution should be used when comparing area and volume figures.

REFERENCES

Oklahoma Water Resources Board (OWRB). 1990. Oklahoma Water Atlas.

Texas Water Development Board (TWDB). 2003. Volumetric Survey of Hulah Reservoir.

U.S. Army Corps of Engineers (USACE). 2002. Engineering and Design - Hydrographic Surveying, Publication EM 1110-2-1003, 3rd version.

APPENDIX A: Area-Capacity Data

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

HULAH LAKE AREA-CAPACITY TABLE OKLAHOMA WATER RESOURCES BOARD 2010 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
712	Area									0.0	0.1
	Capacity									0.0	0.0
713	Area	0.6	0.6	0.7	0.8	0.8	0.9	1.1	1.3	2.3	3.9
	Capacity	0.0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.1
714	Area	6.0	7.7	8.6	9.5	10.3	11.1	11.9	12.7	13.5	14.3
	Capacity	1.6	2.3	3.1	4.0	5.0	6.1	7.2	8.5	9.8	11.2
715	Area	17.0	18.7	20.7	22.6	24.6	26.5	28.1	29.6	31.0	32.4
	Capacity	12.7	14.5	16.4	18.6	21.0	23.5	26.3	29.1	32.2	35.3
716	Area	33.9	35.6	37.4	39.5	42.1	44.9	48.2	51.6	55.2	59.2
	Capacity	38.7	42.1	45.8	49.6	53.7	58.1	62.7	67.7	73.0	78.7
717	Area	71.0	72.4	73.7	75.0	76.3	77.7	79.3	80.9	82.5	84.1
	Capacity	85.1	92.2	99.5	107.0	114.5	122.2	130.1	138.1	146.3	154.6
718	Area	85.7	87.5	89.3	91.3	93.3	95.3	97.6	100.0	102.6	105.4
	Capacity	163.1	171.7	180.6	189.6	198.8	208.3	217.9	227.8	237.9	248.3
719	Area	113.5	115.9	118.3	120.8	123.5	126.3	129.2	132.2	135.4	138.6
	Capacity	259.1	270.6	282.3	294.3	306.5	319.0	331.7	344.8	358.2	371.9
720	Area	141.9	145.4	149.3	154.1	159.1	164.3	169.2	174.3	180.0	186.5
	Capacity	385.9	400.3	415.0	430.2	445.8	462.0	478.7	495.9	513.6	531.9
721	Area	200.7	210.1	219.6	229.1	238.6	248.9	260.8	273.0	284.6	299.5
	Capacity	551.0	571.6	593.1	615.5	638.9	663.3	688.7	715.4	743.3	772.5
722	Area	325.8	362.3	387.6	410.6	434.9	460.2	487.5	513.7	540.2	567.6
	Capacity	803.7	838.2	875.7	915.6	957.9	1,002.6	1,050.0	1,100.0	1,152.8	1,208.1
723	Area	615.5	645.4	666.9	685.3	702.8	721.2	738.7	755.1	771.1	787.4
	Capacity	1,266.8	1,329.9	1,395.6	1,463.3	1,532.7	1,603.9	1,676.9	1,751.6	1,828.0	1,905.9
724	Area	802.8	818.3	834.6	850.6	865.6	880.9	896.3	912.9	930.8	949.1
	Capacity	1,985.5	2,066.5	2,149.1	2,233.5	2,319.3	2,406.6	2,495.5	2,585.9	2,678.1	2,772.1
725	Area	978.9	996.7	1,012.0	1,027.3	1,043.5	1,061.1	1,081.2	1,101.2	1,121.2	1,141.9
	Capacity	2,868.3	2,967.1	3,067.5	3,169.5	3,273.0	3,378.3	3,485.4	3,594.5	3,705.6	3,818.8
726	Area	1,159.2	1,174.4	1,188.1	1,202.1	1,216.4	1,232.4	1,247.6	1,263.2	1,279.1	1,293.6
	Capacity	3,933.9	4,050.6	4,168.7	4,288.2	4,409.2	4,531.7	4,655.6	4,781.2	4,908.3	5,037.0
727	Area	1,311.6	1,324.7	1,335.9	1,347.7	1,360.4	1,374.0	1,386.2	1,396.8	1,407.0	1,416.6
	Capacity	5,167.2	5,299.0	5,432.1	5,566.3	5,701.7	5,838.4	5,976.4	6,115.6	6,255.8	6,397.0
728	Area	1,426.2	1,436.1	1,446.4	1,457.3	1,468.4	1,478.4	1,487.8	1,498.3	1,508.7	1,519.3
	Capacity	6,539.2	6,682.3	6,826.4	6,971.7	7,117.9	7,265.4	7,413.7	7,562.9	7,713.4	7,864.8
729	Area	1,533.7	1,546.7	1,559.3	1,570.5	1,581.5	1,591.9	1,602.5	1,613.6	1,624.8	1,636.0
	Capacity	8,017.4	8,171.4	8,326.7	8,483.3	8,640.9	8,799.6	8,959.3	9,120.1	9,282.1	9,445.1
730	Area	1,647.4	1,659.0	1,670.8	1,683.0	1,695.2	1,707.7	1,720.2	1,733.0	1,745.9	1,758.9
	Capacity	9,609.4	9,774.7	9,941.2	10,108.9	10,277.8	10,448.0	10,619.4	10,792.1	10,966.1	11,141.3
731	Area	2,134.6	2,154.7	2,174.9	2,195.4	2,216.0	2,236.7	2,257.7	2,278.8	2,300.1	2,321.6
	Capacity	11,325.2	11,539.6	11,756.1	11,974.7	12,195.2	12,418.0	12,642.7	12,869.5	13,098.5	13,329.6
732	Area	2,343.3	2,365.1	2,387.2	2,409.4	2,431.7	2,454.3	2,477.0	2,499.9	2,523.0	2,546.3
	Capacity	13,563.0	13,798.4	14,036.0	14,275.9	14,517.9	14,762.3	15,008.9	15,257.7	15,509.0	15,762.4

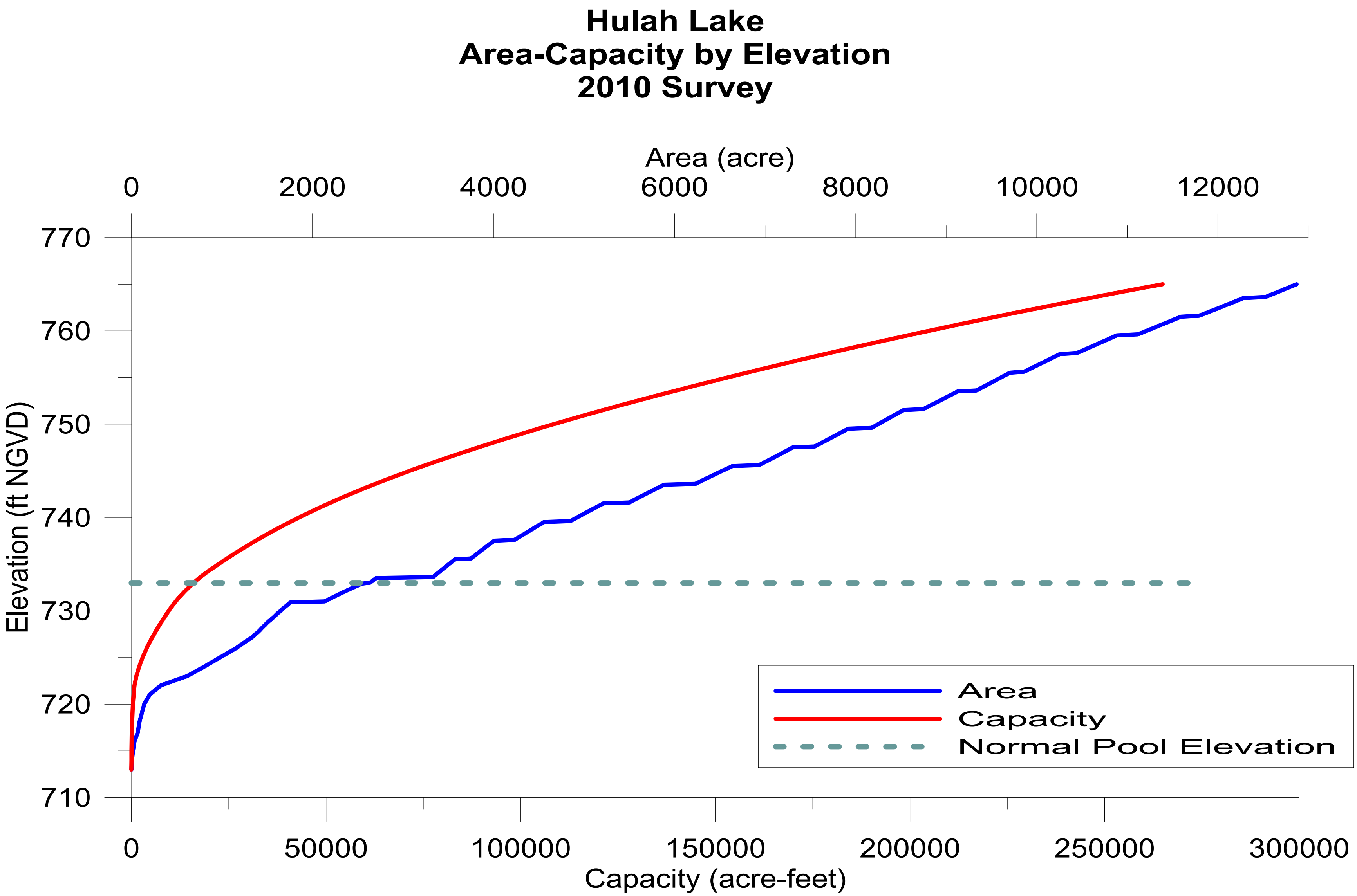
Table A. 2: Hulah Lake Capacity/Area by 0.1-ft Increments (cont).

HULAH LAKE AREA-CAPACITY TABLE OKLAHOMA WATER RESOURCES BOARD 2010 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
733	Area	2,635.5	2,648.8	2,662.3	2,676.0	2,689.8	2,703.9	3,330.6	3,343.1	3,355.6	3,368.2
	Capacity	15,968.0	16,283.9	16,549.4	16,816.4	17,084.7	17,354.5	17,644.0	17,977.6	18,312.7	18,648.9
734	Area	3,380.8	3,393.4	3,406.0	3,418.7	3,431.3	3,444.1	3,456.8	3,469.6	3,482.4	3,495.3
	Capacity	18,986.5	19,325.2	19,665.1	20,006.5	20,348.9	20,692.9	21,037.9	21,384.2	21,732.0	22,080.8
735	Area	3,508.2	3,521.1	3,534.0	3,547.1	3,560.1	3,573.2	3,753.6	3,766.1	3,778.7	3,791.5
	Capacity	22,431.2	22,782.6	23,135.3	23,489.5	23,844.9	24,201.7	24,564.6	24,940.6	25,318.0	25,696.5
736	Area	3,804.3	3,817.2	3,830.2	3,843.3	3,856.5	3,869.9	3,883.3	3,896.8	3,910.4	3,924.1
	Capacity	26,076.5	26,457.5	26,839.8	27,223.7	27,608.7	27,995.2	28,382.8	28,771.7	29,162.3	29,554.0
737	Area	3,937.9	3,951.8	3,965.8	3,979.9	3,994.1	4,008.4	4,235.4	4,252.0	4,268.7	4,285.3
	Capacity	29,947.3	30,341.7	30,737.6	31,135.0	31,533.7	31,934.0	32,341.9	32,766.2	33,192.5	33,620.1
738	Area	4,302.1	4,318.8	4,335.6	4,352.4	4,369.3	4,386.2	4,403.2	4,420.2	4,437.2	4,454.2
	Capacity	34,049.7	34,480.7	34,913.4	35,348.0	35,784.0	36,222.0	36,661.5	37,102.6	37,545.7	37,990.2
739	Area	4,471.4	4,488.5	4,505.7	4,522.9	4,540.1	4,557.4	4,847.7	4,866.8	4,885.8	4,904.9
	Capacity	38,436.7	38,884.6	39,334.3	39,786.0	40,239.1	40,694.2	41,158.9	41,644.6	42,132.4	42,621.9
740	Area	4,924.0	4,943.1	4,962.3	4,981.5	5,000.7	5,019.9	5,039.2	5,058.5	5,077.8	5,097.1
	Capacity	43,113.6	43,606.9	44,102.1	44,599.6	45,098.6	45,599.9	46,102.8	46,607.6	47,114.7	47,623.4
741	Area	5,116.5	5,135.9	5,155.4	5,174.8	5,194.3	5,213.8	5,499.5	5,519.3	5,539.1	5,559.0
	Capacity	48,134.3	48,646.9	49,161.4	49,678.2	50,196.6	50,717.3	51,247.5	51,798.4	52,351.6	52,906.5
742	Area	5,578.9	5,598.8	5,618.8	5,638.9	5,659.0	5,679.1	5,699.3	5,719.6	5,739.9	5,760.2
	Capacity	53,463.6	54,022.5	54,583.3	55,146.4	55,711.3	56,278.5	56,847.3	57,418.2	57,991.5	58,566.4
743	Area	5,780.6	5,801.0	5,821.5	5,842.1	5,862.7	5,883.3	6,232.0	6,252.5	6,273.2	6,293.9
	Capacity	59,143.8	59,722.8	60,303.8	60,887.3	61,472.5	62,060.1	62,659.2	63,283.4	63,910.0	64,538.3
744	Area	6,314.7	6,335.7	6,356.7	6,377.8	6,399.0	6,420.4	6,441.8	6,463.3	6,485.0	6,506.7
	Capacity	65,169.0	65,801.5	66,436.0	67,073.1	67,711.8	68,353.1	68,996.2	69,641.4	70,289.1	70,938.6
745	Area	6,528.5	6,550.5	6,572.5	6,594.6	6,616.9	6,639.2	6,931.5	6,951.8	6,972.0	6,992.1
	Capacity	71,590.7	72,244.6	72,900.7	73,559.3	74,219.8	74,883.0	75,556.0	76,250.1	76,946.7	77,644.8
746	Area	7,012.2	7,032.2	7,052.2	7,072.1	7,092.0	7,111.8	7,131.5	7,151.2	7,170.8	7,190.4
	Capacity	78,345.4	79,047.5	79,751.7	80,458.2	81,166.4	81,876.9	82,589.0	83,303.1	84,019.5	84,737.5
747	Area	7,209.9	7,229.4	7,248.8	7,268.2	7,287.5	7,306.7	7,548.5	7,567.9	7,587.3	7,606.6
	Capacity	85,457.9	86,179.8	86,903.6	87,629.8	88,357.5	89,087.6	89,825.8	90,581.6	91,339.7	92,099.3
748	Area	7,626.0	7,645.4	7,664.9	7,684.3	7,703.7	7,723.2	7,742.6	7,762.1	7,781.5	7,801.0
	Capacity	92,861.3	93,624.8	94,390.3	95,158.1	95,927.4	96,699.2	97,472.4	98,247.5	99,025.1	99,804.1
749	Area	7,820.5	7,840.0	7,859.5	7,879.0	7,898.5	7,918.1	8,177.7	8,196.0	8,214.4	8,232.7
	Capacity	100,585.6	101,368.6	102,153.4	102,940.8	103,729.6	104,520.8	105,320.7	106,139.3	106,960.2	107,782.5
750	Area	8,251.1	8,269.5	8,287.9	8,306.4	8,324.9	8,343.4	8,361.9	8,380.5	8,399.1	8,417.7
	Capacity	108,607.1	109,433.0	110,260.8	111,090.9	111,922.4	112,756.3	113,591.4	114,428.5	115,267.9	116,108.6
751	Area	8,436.3	8,454.9	8,473.6	8,492.3	8,511.1	8,529.8	8,745.9	8,766.3	8,786.6	8,806.9
	Capacity	116,951.7	117,796.2	118,642.5	119,491.3	120,341.3	121,193.8	122,053.5	122,929.1	123,807.2	124,686.7
752	Area	8,827.2	8,847.5	8,867.7	8,887.9	8,908.1	8,928.2	8,948.3	8,968.4	8,988.5	9,008.5
	Capacity	125,568.9	126,452.5	127,338.2	128,226.4	129,116.1	130,008.4	130,902.1	131,797.9	132,696.2	133,595.9
753	Area	9,028.6	9,048.5	9,068.5	9,088.4	9,108.3	9,128.2	9,333.3	9,353.1	9,372.9	9,392.7
	Capacity	134,498.2	135,402.0	136,307.7	137,216.0	138,125.8	139,038.1	139,957.3	140,891.6	141,828.3	142,766.5

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

HULAH LAKE AREA-CAPACITY TABLE OKLAHOMA WATER RESOURCES BOARD 2010 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
754	Area	9,412.4	9,432.1	9,451.7	9,471.3	9,490.8	9,510.3	9,529.8	9,549.2	9,568.6	9,588.0
	Capacity	143,707.2	144,649.4	145,593.5	146,540.1	147,488.1	148,438.6	149,390.5	150,344.4	151,300.8	152,258.5
755	Area	9,607.3	9,626.5	9,645.8	9,665.0	9,684.1	9,703.2	9,859.0	9,880.2	9,901.4	9,922.5
	Capacity	153,218.7	154,180.3	155,143.8	156,109.9	157,077.2	158,047.1	159,022.3	160,009.2	160,998.8	161,989.8
756	Area	9,943.6	9,964.6	9,985.7	10,006.7	10,027.6	10,048.5	10,069.4	10,090.3	10,111.1	10,131.9
	Capacity	162,983.6	163,978.9	164,976.4	165,976.5	166,978.1	167,982.4	168,988.2	169,996.1	171,006.6	172,018.7
757	Area	10,152.6	10,173.3	10,194.0	10,214.7	10,235.3	10,255.8	10,441.1	10,464.7	10,488.2	10,511.7
	Capacity	173,033.4	174,049.6	175,067.9	176,088.8	177,111.2	178,136.3	179,167.7	180,212.9	181,261.0	182,310.9
758	Area	10,535.2	10,558.6	10,582.1	10,605.4	10,628.8	10,652.1	10,675.4	10,698.7	10,721.9	10,745.1
	Capacity	183,363.8	184,418.4	185,475.3	186,535.2	187,596.8	188,661.4	189,727.7	190,796.3	191,867.8	192,941.1
759	Area	10,768.3	10,791.4	10,814.5	10,837.6	10,860.7	10,883.7	11,113.3	11,138.9	11,164.5	11,190.0
	Capacity	194,017.3	195,095.2	196,175.3	197,258.5	198,343.3	199,431.1	200,526.6	201,639.1	202,754.9	203,872.5
760	Area	11,215.4	11,240.8	11,266.2	11,291.5	11,316.7	11,342.0	11,367.1	11,392.2	11,417.3	11,442.3
	Capacity	204,993.3	206,116.0	207,241.2	208,369.7	209,500.0	210,633.5	211,768.8	212,906.7	214,047.7	215,190.6
761	Area	11,467.2	11,492.1	11,517.0	11,541.8	11,566.5	11,591.3	11,791.9	11,818.5	11,845.0	11,871.4
	Capacity	216,336.6	217,484.5	218,634.8	219,788.3	220,943.6	222,102.1	223,267.6	224,448.0	225,631.7	226,817.4
762	Area	11,897.8	11,924.1	11,950.2	11,976.3	12,002.3	12,028.2	12,054.1	12,079.8	12,105.5	12,131.0
	Capacity	228,006.5	229,197.5	230,391.1	231,588.0	232,786.8	233,988.9	235,192.9	236,399.5	237,609.4	238,821.1
763	Area	12,156.5	12,181.9	12,207.2	12,232.4	12,257.5	12,282.6	12,524.0	12,549.5	12,574.9	12,600.3
	Capacity	240,036.0	241,252.8	242,472.2	243,694.8	244,919.1	246,146.7	247,382.6	248,636.1	249,893.0	251,151.6
764	Area	12,625.6	12,650.8	12,675.9	12,701.0	12,726.1	12,751.0	12,775.9	12,800.7	12,825.5	12,850.2
	Capacity	252,413.6	253,677.2	254,943.4	256,212.9	257,484.1	258,758.7	260,034.9	261,313.5	262,595.5	263,879.1
765	Area	12,869.9									
	Capacity	264,908.3									

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



APPENDIX B: Hulah Lake Maps

Figure B. 1: Hulah Lake Bathymetric Map with 2-foot Contour Intervals.

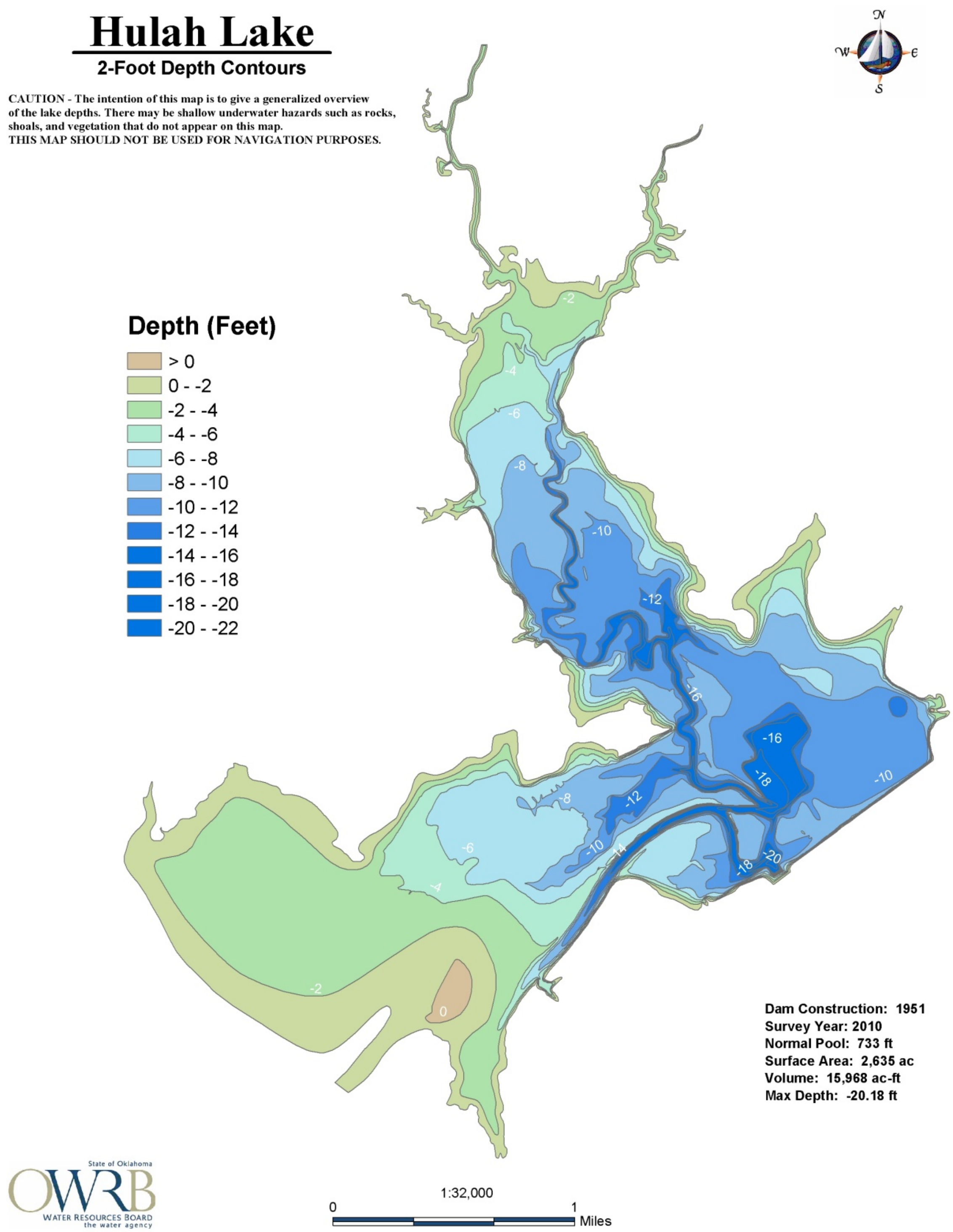


Figure B. 2: Hulah Lake Shaded Relief Bathymetric Map.

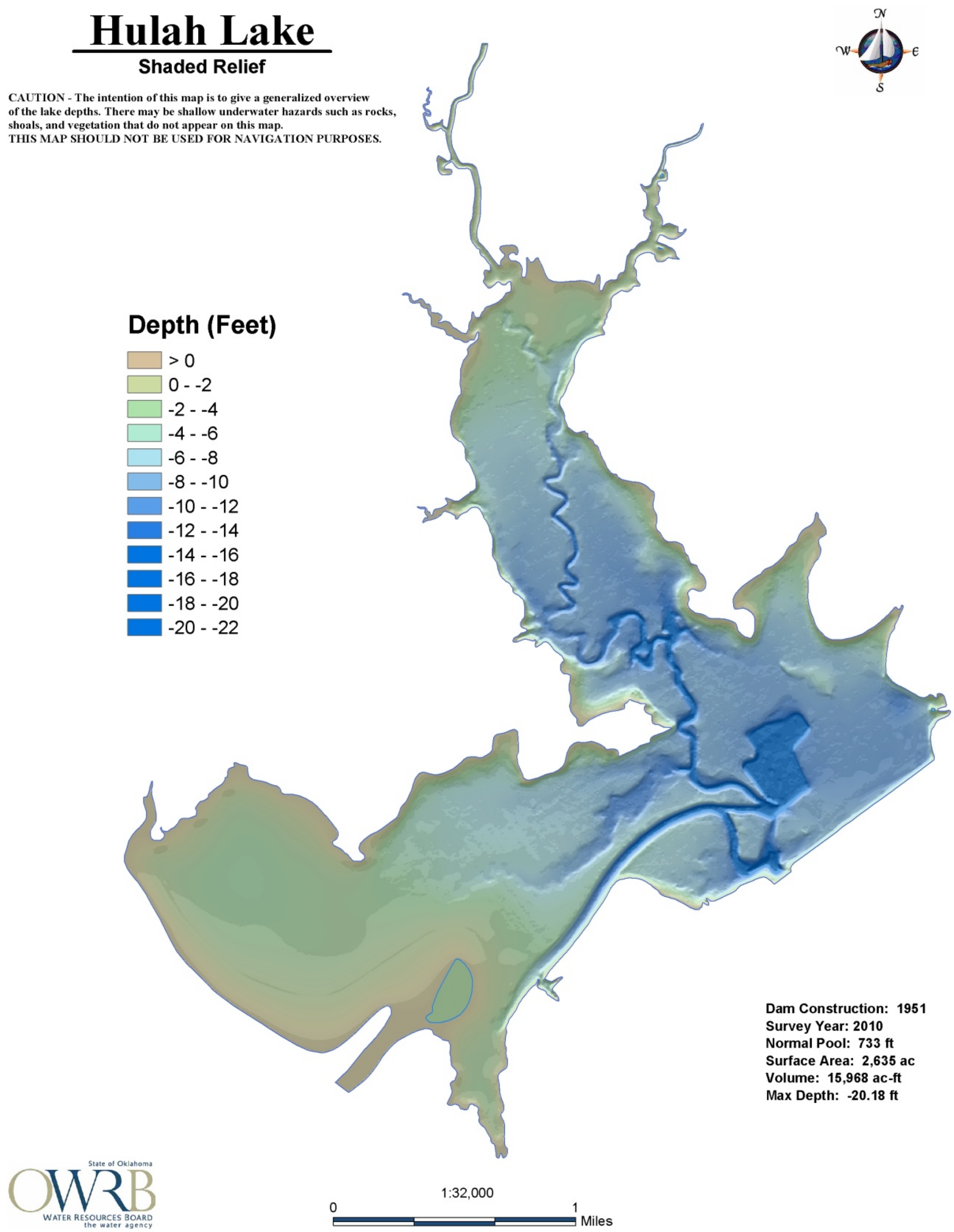


Figure B. 3: Hulah Lake Collected Data Points.