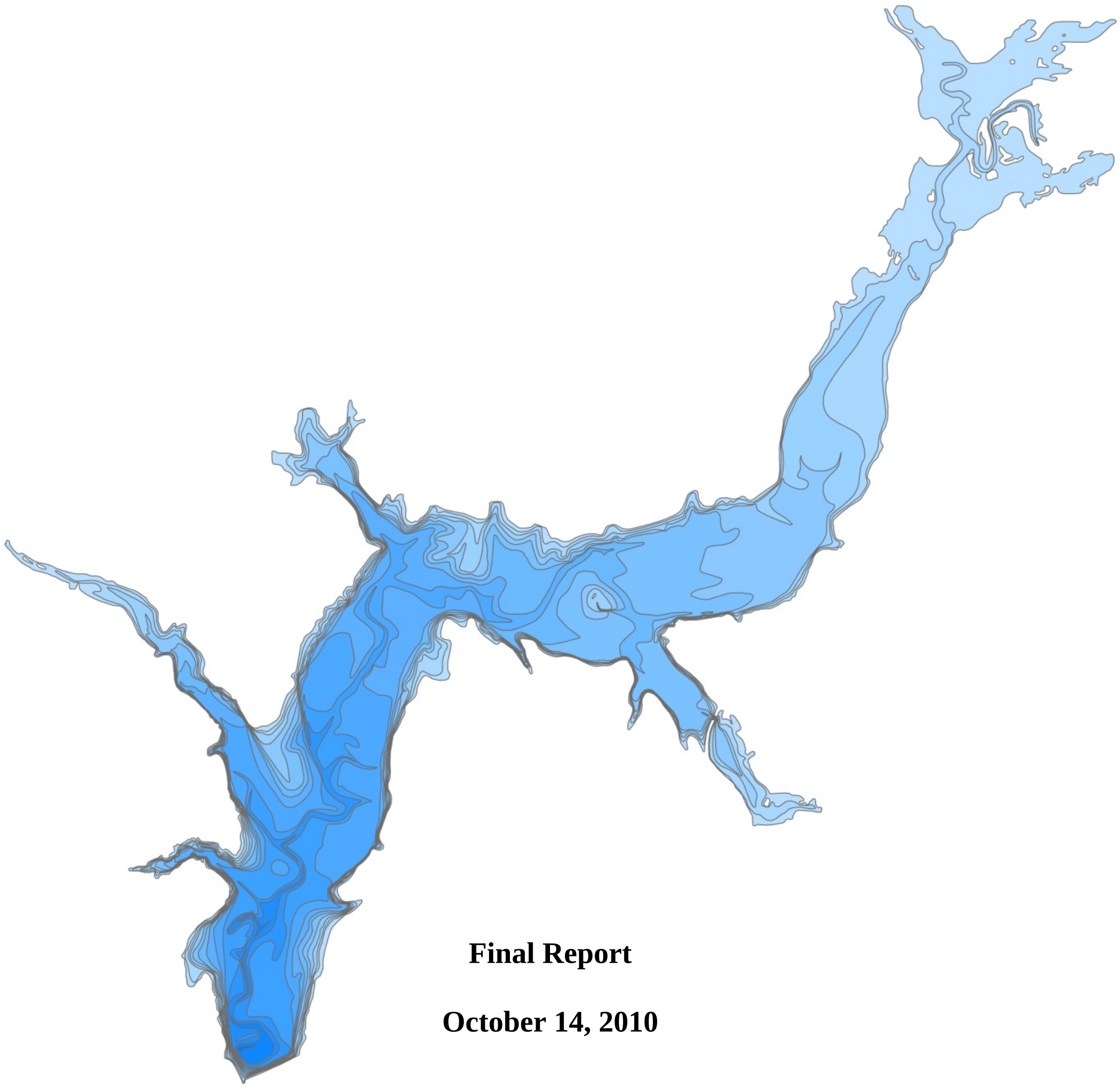
HYDROGRAPHIC SURVEY of CLAREMORE LAKE



Final Report

October 14, 2010

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INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Claremore Lake in April 2010. 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

Claremore Lake is located in Rogers County about 1 mile east of Claremore, Oklahoma. (**Figure 1**). It was constructed in 1930 and modified in 1967. Its original purpose was water supply, and is also used for 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.

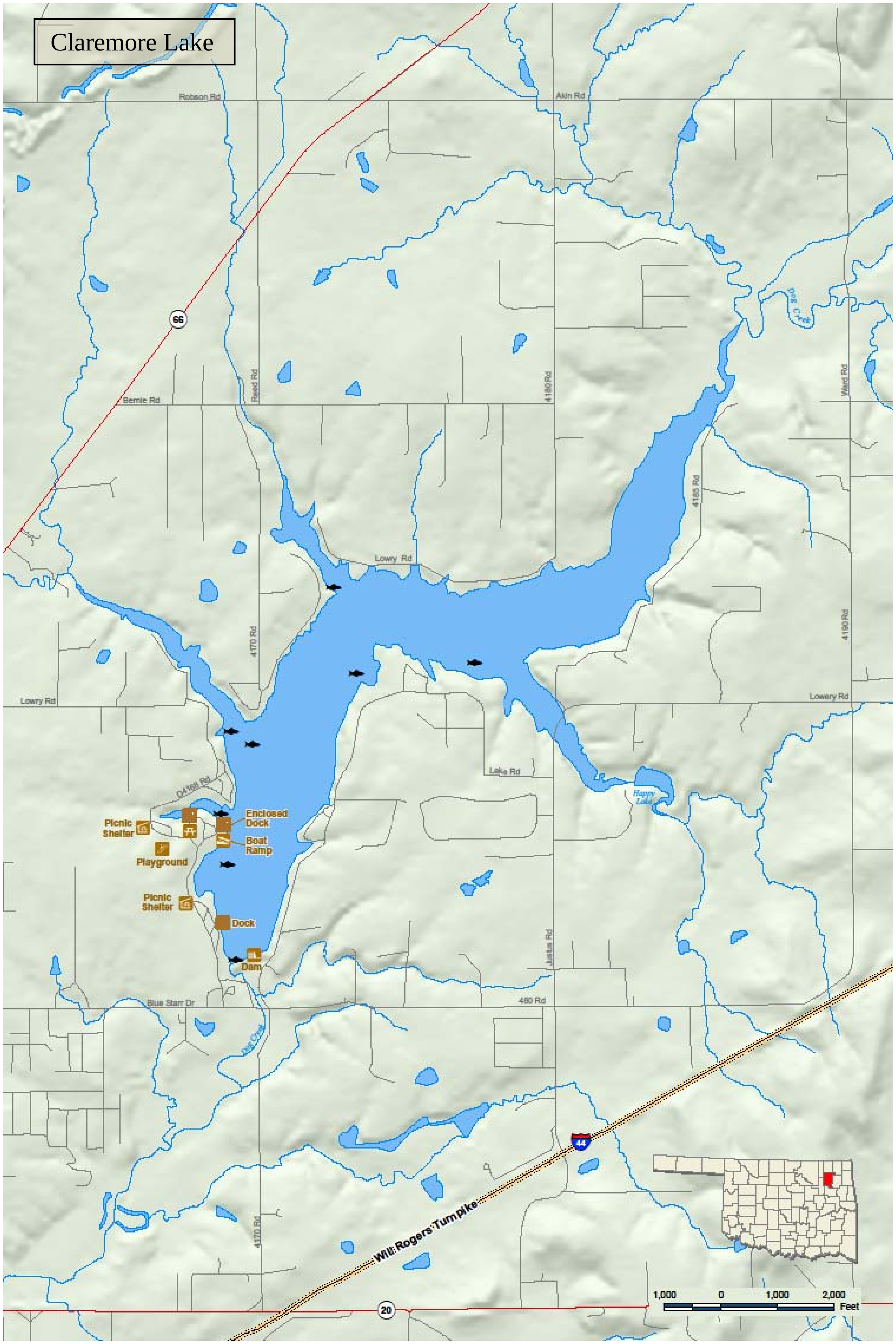


Figure 1: Location map for Claremore Lake.

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 Claremore Lake was on-screen digitized from the 2006 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Rogers 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 2003 DOQQs of the lakes were used as background 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 40 virtual transects were created for the Claremore Lake.

Field Survey

Lake Elevation Acquisition

The lake elevation for Claremore Lake was obtained by collecting positional data over a period of approximately 150 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; Syqwest Bathy 1500 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 Claremore Lake occurred in April of 2010. The water level elevation for Claremore Lake was 610.6 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.

Quality Control/Quality Assurance

While on board the Hydro-survey vessel, the Syqwest Bathy 1500 Echo Sounder was calibrated 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. The average speed of sound in the water column was 4814.30 ft/sec during the Claremore Lake survey.

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 77 cross-sections points at Claremore Lake were used to compute error estimates. A mean difference of 0.05 ft and a standard deviation of 0.48ft 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 ± 0.49 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 0.05 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 610.6 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 Claremore Lake are located on the DVD entitled *FEMA 2010 HYPACK/GIS Metadata Disk 2.*

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 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: Claremore 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 2010 HYPACK/GIS Metadata Disk 2.*

RESULTS

Results from the 2010 OWRB survey indicate that Claremore Lake encompasses 621 acres and contains a cumulative capacity of 5,188 ac-ft at the normal pool elevation (610 ft NGVD). The average depth for Claremore Lake was 8.3 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Claremore Lake at the normal pool elevation. Based on the design specifications, Claremore Lake had an area of 740 acres and cumulative volume of 7,900 acre-feet of water at normal pool elevation (610 ft NGVD). The surface area of the lake has had a decrease of 128 acres or approximately 17%. The 2010 survey shows that Claremore Lake has had a decrease in capacity of 34% or approximately 2,712 acre-feet. Caution should be used when directly comparing between the design specifications and the 2010 survey conducted by the OWRB because different methods were used to collect the data and extrapolate capacity and area figures. 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. By using the 2010 survey figures as a baseline, a future survey would allow an accurate sedimentation rate to be obtained.

Table 1: Area and Volume Comparisons of Claremore Lake at normal pool (610 ft NGVD).

Feature	Survey Year	
	1930/1967 Design Specifications	2010
Area (acres)	740	621
Cumulative Volume (acre-feet)	7,900	5,188
Mean depth (ft)	10.7	9.5
Maximum Depth (ft)	--	24.25

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). 1970. Oklahoma Water Atlas.

Oklahoma Water Resources Board (OWRB). 1979. Phase 1 Inspection Report; National Dam Safety Program.

APPENDIX A: Area-Capacity Data

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

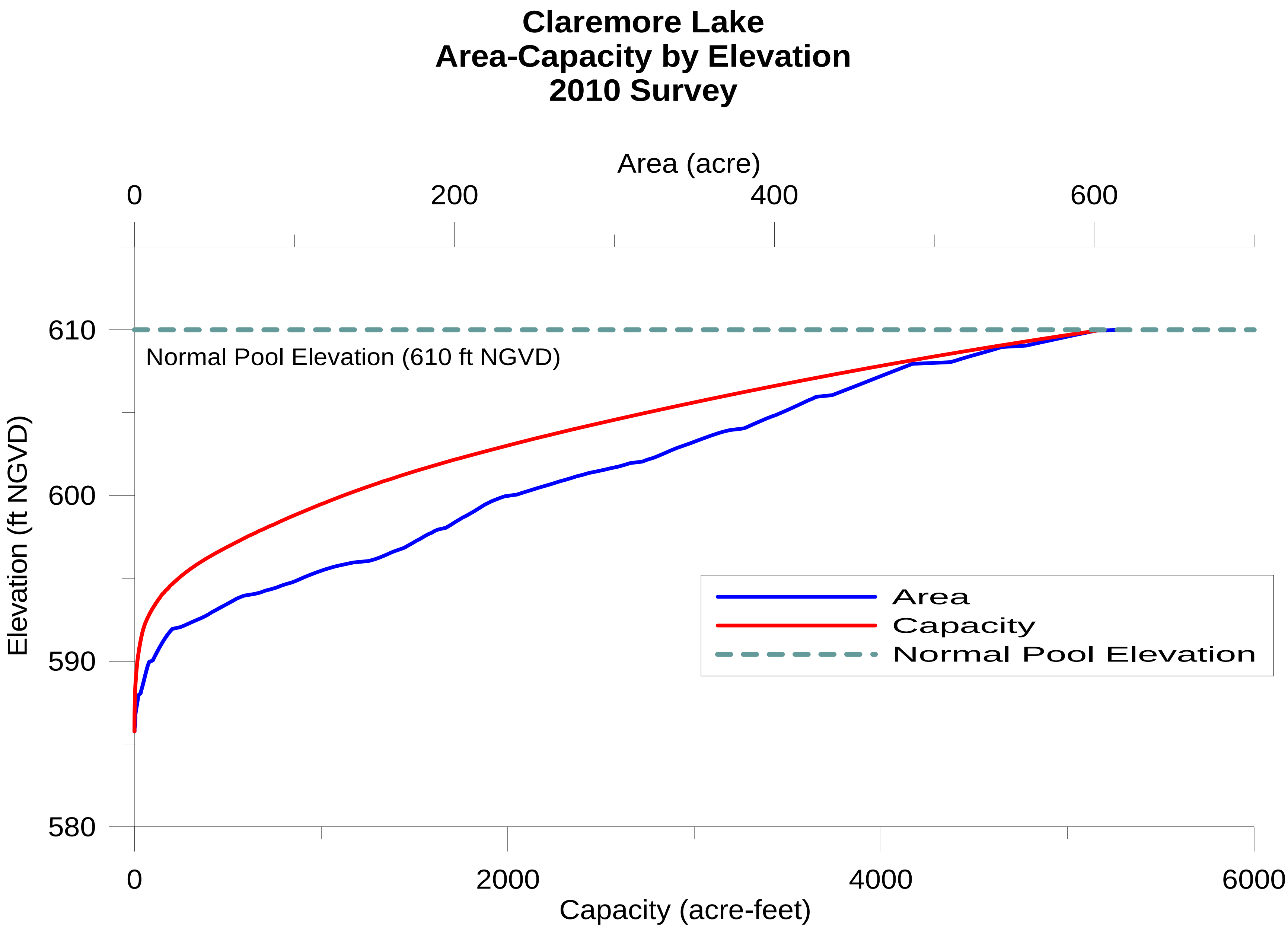
CLAREMORE LAKE AREA-CAPACITY TABLE
OKLAHOMA WATER RESOURCES BOARD
2010 Survey
Capacity in acre-feet by tenth foot elevation increments
Area in acres by tenth foot elevation increments

Elevation (ft NGVD)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
585	Area									0.0	0.0
	Capacity									0.0	0.0
586	Area	0.0	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7
	Capacity	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3
587	Area	0.8	0.9	1.1	1.3	1.5	1.6	1.8	1.9	2.1	2.2
	Capacity	0.4	0.5	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.8
588	Area	2.4	3.8	4.0	4.3	4.5	4.8	5.1	5.3	5.6	5.9
	Capacity	2.0	2.3	2.7	3.1	3.6	4.0	4.5	5.1	5.6	6.2
589	Area	6.1	6.4	6.6	6.9	7.2	7.5	7.7	8.0	8.4	8.7
	Capacity	6.8	7.4	8.1	8.7	9.4	10.2	10.9	11.7	12.5	13.4
590	Area	9.1	11.5	12.0	12.5	13.0	13.5	14.1	14.6	15.1	15.7
	Capacity	14.3	15.3	16.5	17.7	19.0	20.3	21.7	23.1	24.6	26.2
591	Area	16.3	16.9	17.5	18.2	18.9	19.6	20.3	21.1	21.9	22.7
	Capacity	27.8	29.4	31.1	32.9	34.8	36.7	38.7	40.8	42.9	45.1
592	Area	23.6	28.5	31.0	33.4	35.7	38.1	40.5	42.7	44.8	46.6
	Capacity	47.5	50.0	53.0	56.2	59.7	63.4	67.3	71.5	75.9	80.4
593	Area	48.4	50.2	52.0	53.9	55.9	57.8	59.7	61.6	63.5	65.7
	Capacity	85.2	90.1	95.2	100.5	106.0	111.7	117.6	123.6	129.9	136.3
594	Area	68.5	75.1	78.6	81.9	85.2	88.9	91.8	94.8	98.4	101.1
	Capacity	143.0	150.2	157.9	165.9	174.3	183.0	192.0	201.4	211.0	221.0
595	Area	103.5	105.9	108.3	110.9	113.6	116.4	119.5	122.9	127.0	131.8
	Capacity	231.2	241.7	252.4	263.4	274.6	286.1	297.9	310.0	322.5	335.5
596	Area	136.6	146.5	150.0	153.0	155.6	158.1	160.4	162.9	166.0	168.6
	Capacity	348.9	363.0	377.9	393.0	408.5	424.2	440.1	456.2	472.7	489.4
597	Area	170.5	172.3	174.2	176.1	178.0	179.8	181.6	183.5	185.6	187.7
	Capacity	506.4	523.5	540.9	558.4	576.1	594.0	612.0	630.3	648.8	667.4
598	Area	189.9	194.8	196.4	198.1	199.8	201.5	203.2	205.0	206.9	208.8
	Capacity	686.3	705.6	725.1	744.8	764.7	784.8	805.0	825.5	846.1	866.8
599	Area	210.6	212.4	214.1	215.8	217.4	219.2	221.1	223.3	225.8	228.5
	Capacity	887.8	909.0	930.3	951.8	973.4	995.3	1,017.3	1,039.5	1,062.0	1,084.7
600	Area	231.4	238.9	242.2	245.4	248.6	251.9	255.5	259.1	262.6	266.0
	Capacity	1,107.7	1,131.2	1,155.3	1,179.6	1,204.3	1,229.4	1,254.7	1,280.5	1,306.6	1,333.0
601	Area	269.3	272.8	276.5	280.2	284.3	288.7	293.5	298.2	302.5	306.6
	Capacity	1,359.8	1,386.9	1,414.3	1,442.2	1,470.4	1,499.1	1,528.2	1,557.8	1,587.8	1,618.3
602	Area	310.1	317.5	320.6	323.7	326.5	329.0	331.3	334.0	336.2	338.7
	Capacity	1,649.1	1,680.5	1,712.4	1,744.6	1,777.1	1,809.9	1,842.9	1,876.2	1,909.7	1,943.5
603	Area	341.5	344.5	347.6	350.4	353.0	355.8	358.6	361.5	364.5	368.0
	Capacity	1,977.5	2,011.8	2,046.4	2,081.3	2,116.5	2,151.9	2,187.6	2,223.7	2,260.0	2,296.6
604	Area	372.3	381.0	383.5	385.7	388.0	390.4	392.8	395.3	397.9	400.8
	Capacity	2,333.6	2,371.3	2,409.5	2,448.0	2,486.7	2,525.6	2,564.8	2,604.2	2,643.8	2,683.8
605	Area	403.3	405.7	408.0	410.2	412.6	414.8	417.1	419.3	421.6	423.9
	Capacity	2,724.0	2,764.5	2,805.2	2,846.1	2,887.2	2,928.6	2,970.2	3,012.0	3,054.1	3,096.3

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

CLAREMORE 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
606	Area	426.1	436.2	438.8	441.5	444.2	446.8	449.5	452.1	454.7	457.4
	Capacity	3,138.9	3,182.0	3,225.7	3,269.8	3,314.0	3,358.6	3,403.4	3,448.5	3,493.9	3,539.5
607	Area	460.0	462.6	465.3	467.9	470.5	473.2	475.8	478.5	481.1	483.7
	Capacity	3,585.3	3,631.5	3,677.9	3,724.5	3,771.5	3,818.7	3,866.1	3,913.9	3,961.8	4,010.1
608	Area	486.4	510.2	513.6	517.1	520.5	524.0	527.6	531.2	534.8	538.4
	Capacity	4,058.6	4,108.4	4,159.6	4,211.2	4,263.0	4,315.3	4,367.9	4,420.8	4,474.1	4,527.8
609	Area	542.1	557.5	562.3	567.1	571.9	576.8	581.6	586.5	591.4	596.3
	Capacity	4,581.8	4,636.8	4,692.8	4,749.3	4,806.2	4,863.7	4,921.6	4,980.0	5,038.9	5,098.3
610	Area	621.7									
	Capacity	5,188.3									

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



APPENDIX B: Claremore Lake Maps

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

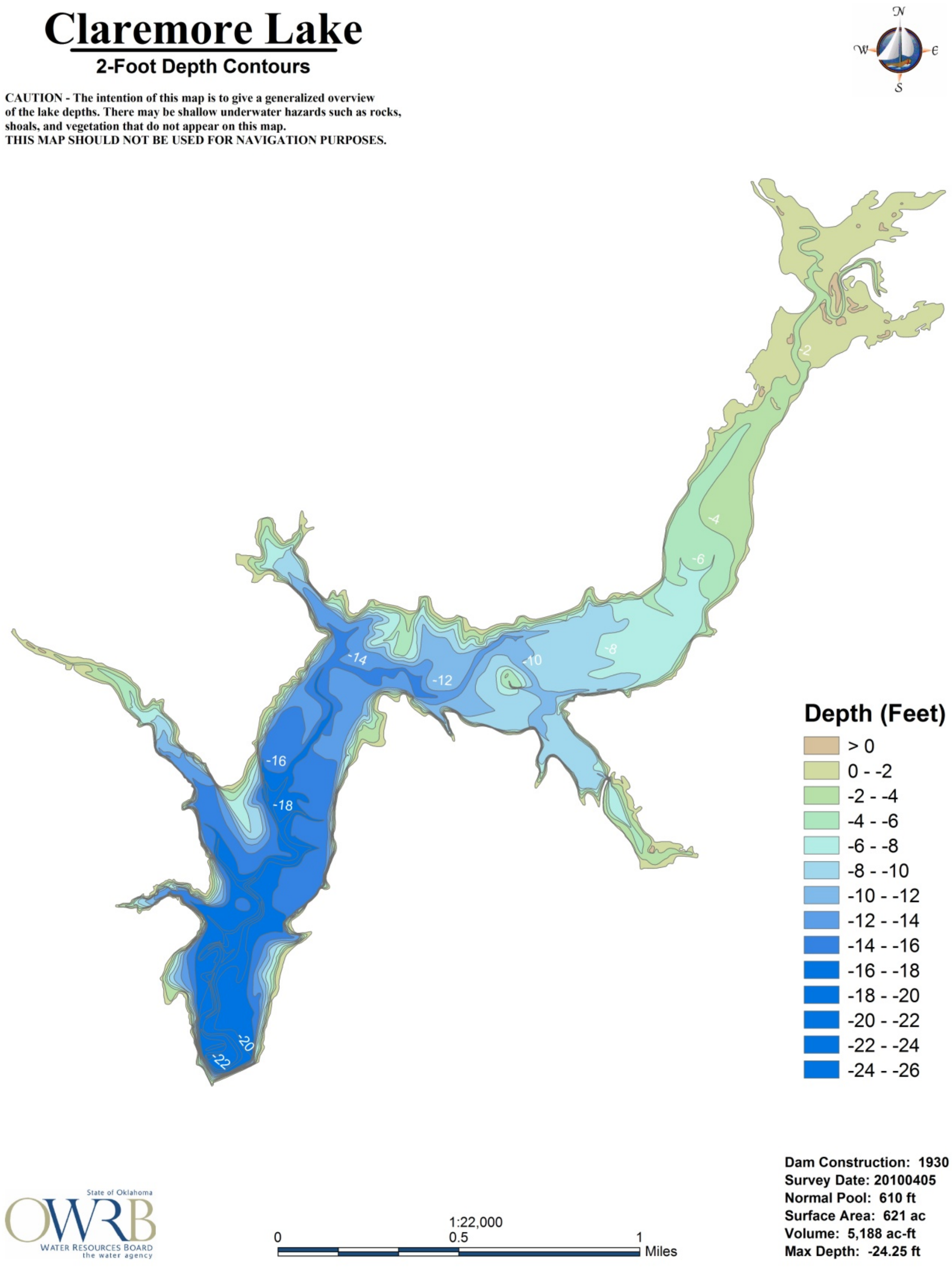


Figure B. 2: Claremore Lake Shaded Relief Bathymetric Map.

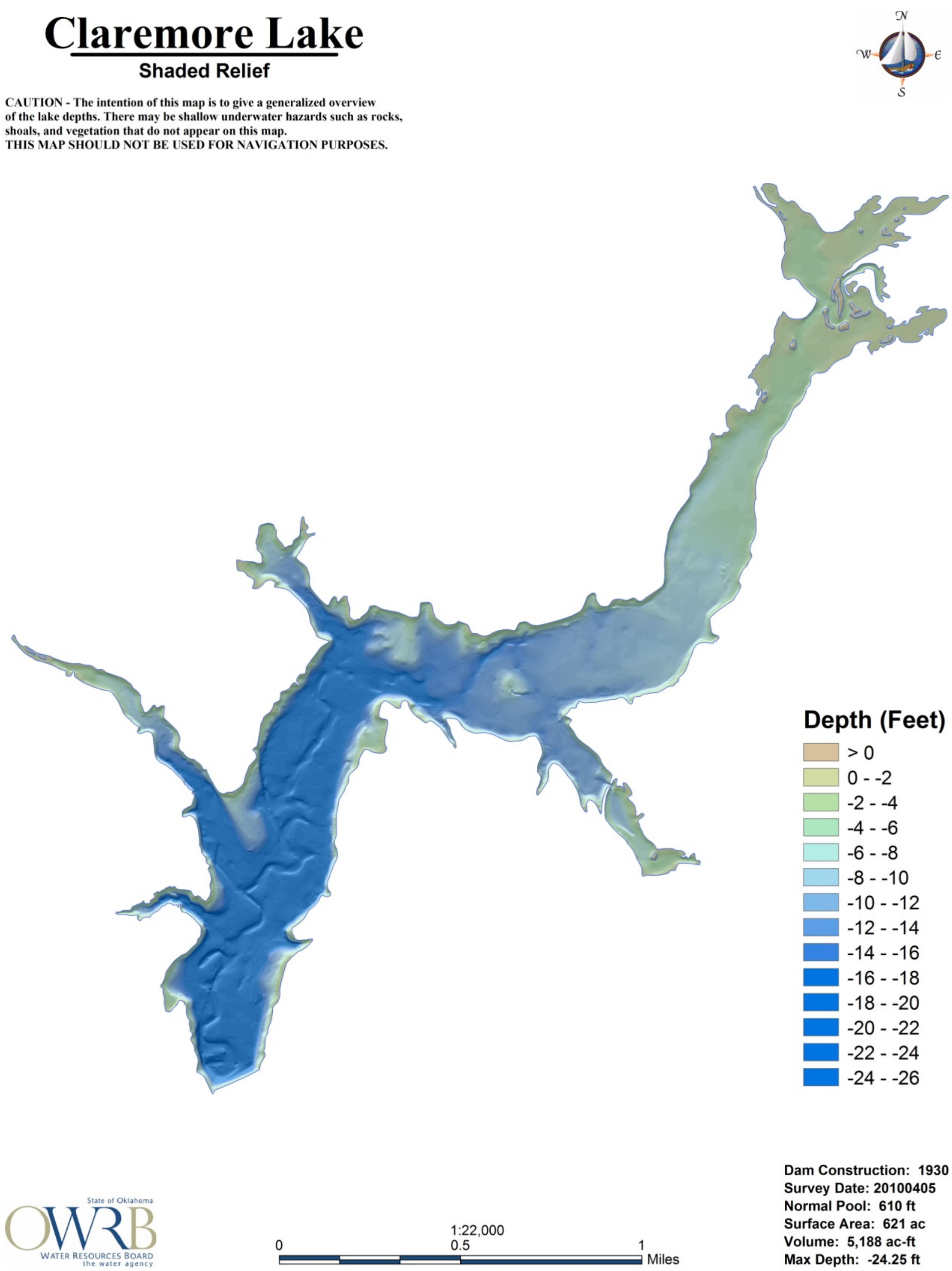


Figure B. 3: Claremore Lake Collected Data Points.