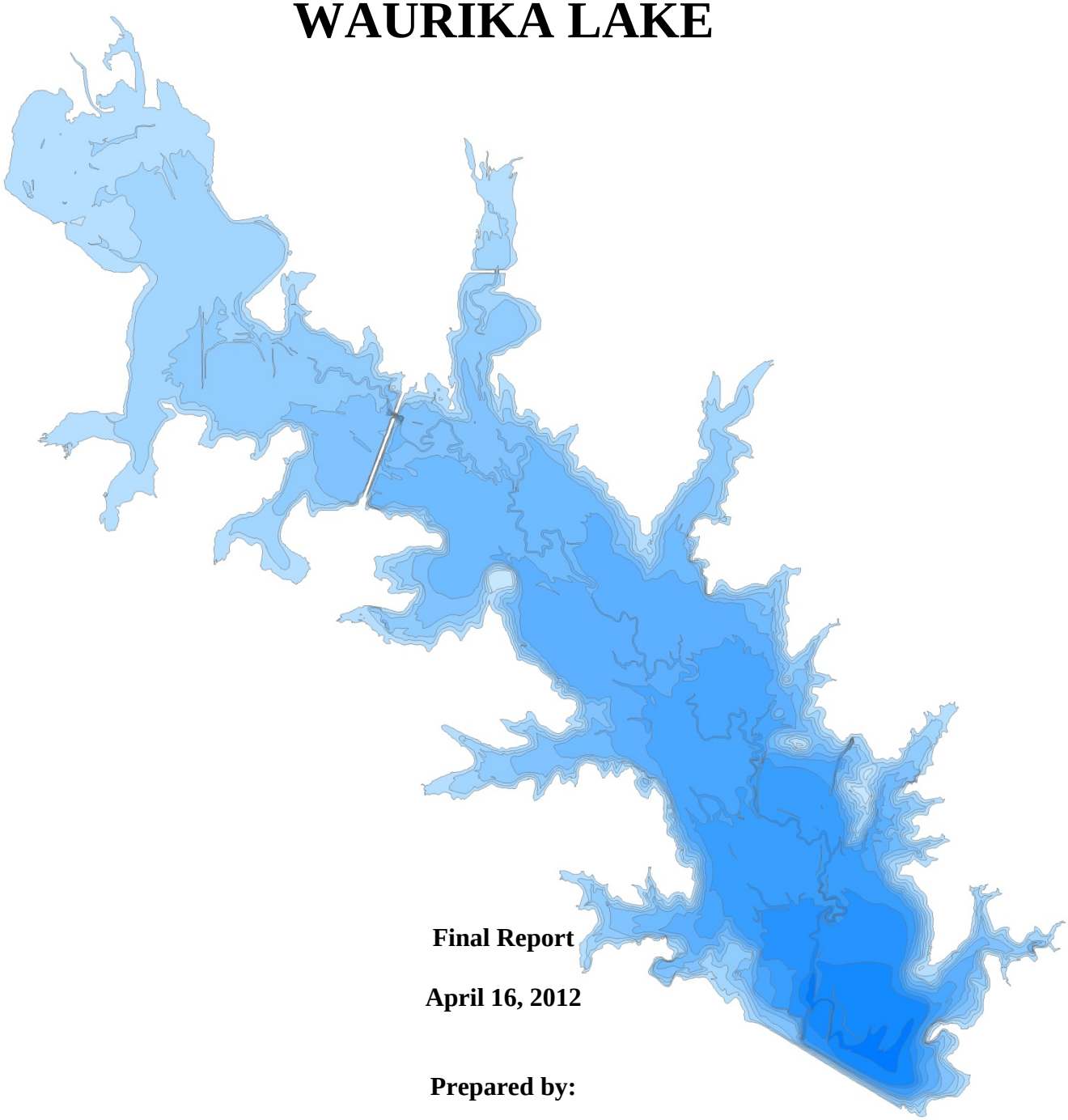
HYDROGRAPHIC SURVEY of WAURIKA LAKE



Final Report

April 16, 2012

Prepared by:

State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

TABLE OF CONTENTS

TABLE OF CONTENTS 2
TABLE OF FIGURES 3
TABLE OF TABLES 3
INTRODUCTION 4
LAKE BACKGROUND 4
HYDROGRAPHIC SURVEYING PROCEDURES 6
Pre-survey Planning 6
Boundary File 6
Set-up 6
Field Survey 6
Lake Elevation Acquisition 6
Method 6
Technology 7
Survey 7
Quality Control/Quality Assurance 7
Data Processing 9
GIS Application 9
RESULTS 10
SUMMARY and COMPARISON 10
REFERENCES 12
APPENDIX A: Area-Capacity Data 13
APPENDIX B: Waurika Lake Maps 19

TABLE OF FIGURES

Figure 1: Location map for Waurika Lake..... 5
Figure A. 1. Area-Capacity Curve for Waurika Lake..... 17
Figure B. 1: Waurika Lake Bathymetric Map with 5-foot Contour Intervals..... 20
Figure B. 2: Waurika Lake Shaded Relief Bathymetric Map. 21
Figure B. 3: Waurika Lake Collected Data Points. 22

TABLE OF TABLES

Table 1: Area and Volume Comparisons of Waurika Lake. 11
Table A 1: Waurika Lake Capacity/Area by 0.1-ft Increments. 14
Table A 2: Waurika Lake Capacity/Area by 0.1-ft Increments (cont). 15
Table A 3: Waurika Lake Capacity/Area by 0.1-ft Increments (cont). 16

WAURIKA LAKE
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Waurika Lake in September and October of 2010. The purpose of this survey was to produce a new elevation-area-capacity table and bathymetric map for Waurika Lake.

LAKE and DAM BACKGROUND

Waurika Dam is in the Red River Basin and is located on Beaver Creek (**Figure 1**) in Jefferson County about 6 miles northwest of the town of Waurika. Constructed by the U.S. Army Corps of Engineers, the project was started in July 1971 and was placed in operation on August 1, 1977. The reservoir was completed in 1977. Its original purposes were water supply, fish and wildlife propagation, irrigation, recreation, water quality, and flood control.

The earthfill dam, including the spillway, is about 16,600 feet in length and rises approximately 106 feet above the streambed. It has a top width of 32 feet. The 300 feet wide uncontrolled spillway is located 1.5 miles west of the original river channel.

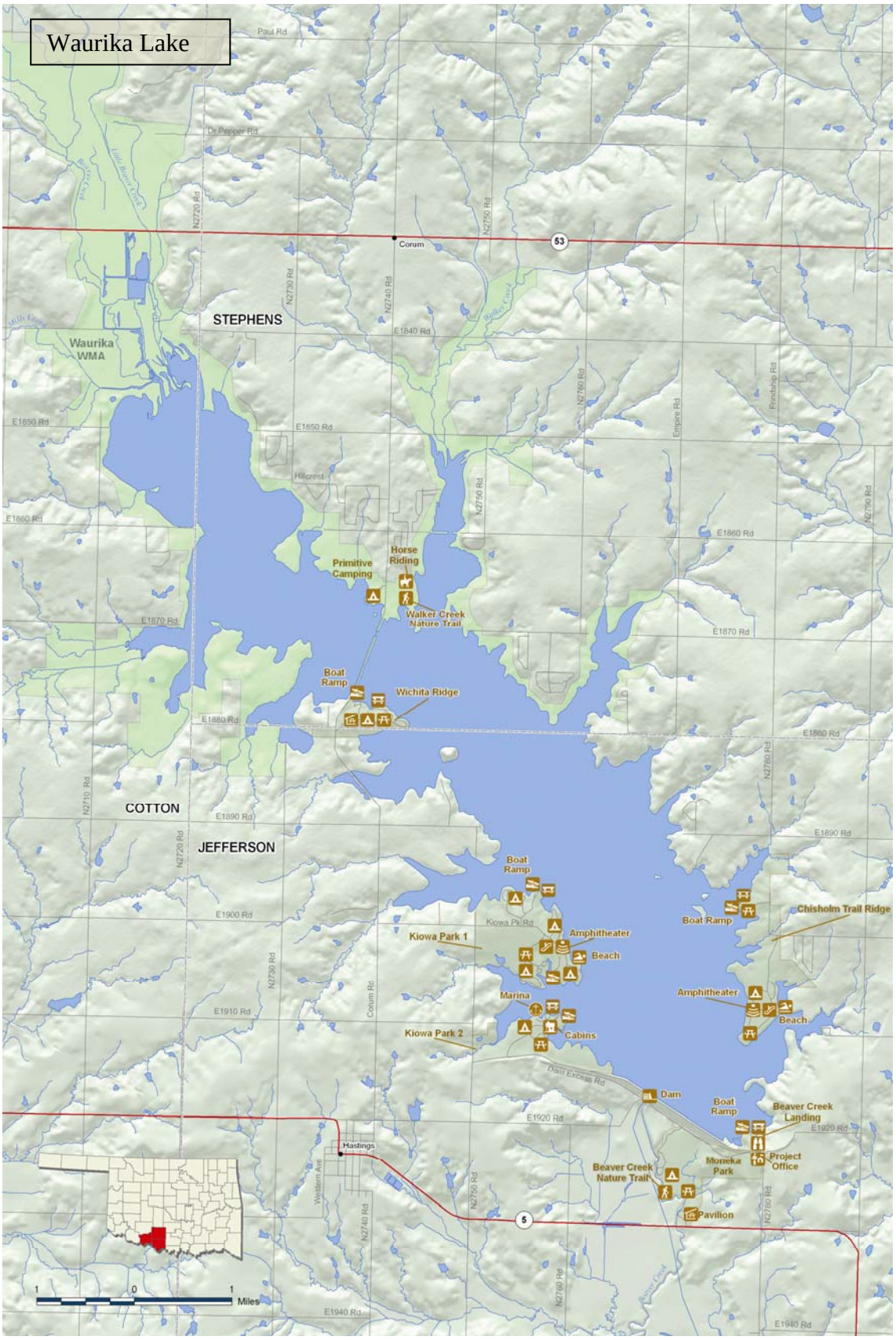


Figure 1: Location map for Waurika Lake.

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 Waurika Lake was on-screen digitized from the 2008 color digital orthoimagery quarter quadrangle (DOQQ) mosaic of Jefferson 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 2010, 2006 and 2003 DOQQs of the lake were used as back ground reference. The reservoir boundaries were digitized in NAD 1983 State Plane Coordinates (Oklahoma South-3502).

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-3502 Oklahoma South with distance units and depth as US Survey Feet. The survey transects were spaced according to the accuracy required for the project. The survey transects within the digitized reservoir boundary were at 300 ft increments and ran perpendicular to the original stream channels and tributaries.

Field Survey

Lake Elevation Acquisition

The lake elevation for Waurika 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 Waurika Lake occurred in September and October of 2010. The water level elevation for Waurika Lake ranged from 950.8ft to 951.4ft 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, 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 368 cross-sections points at Waurika Lake were used to compute error estimates. A mean difference of 0.067 ft and a standard deviation of 0.20 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 ± 0.40 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 0.067 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 951.1ft (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 Waurika Lake are located on the DVD entitled *Waurika 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 South Coordinate System referenced to the North American Datum 1983. Horizontal and vertical units are in feet. The edited data points in XYZ text file format were converted into ArcMap point coverage format. The point coverage contains the X and Y horizontal coordinates and the elevation and depth values associated with each collected point.

Volumetric and area calculations were derived using a Triangulated Irregular Network (TIN) surface model. The TIN model was created in ArcMap, using the collected survey data points, 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 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 lake are shown with 5-ft contour intervals in **APPENDIX B: Waurika Lake** 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 *Waurika HYPACK/GIS Metadata.*

RESULTS

Results from the 2010 OWRB survey indicate that Waurika Lake encompasses 10,114 acres and contains a cumulative capacity of 187,463 ac-ft at the normal pool elevation (951.4 ft NGVD). The average depth for Waurika Lake was 18.5 ft.

SUMMARY and COMPARISON

Table 1 is a comparison of area and volume changes of Waurika Lake at the normal pool elevation. Based on the design specifications, Waurika Lake had an area of 10,100 acres and cumulative volume of 203,100 acre-feet of water at normal pool elevation (951.4 ft NGVD). The surface area of the lake has had a nominal increase of 14 acres or approximately 0.1%. The 2010 survey shows that Waurika Lake has a decrease in capacity of 7.7% or approximately 15,637 acre-feet since construction. Since the 1991 re-survey, the lake has lost 2,693 or 1.3% of its original volume. 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 Waurika Lake at normal pool (951.4 ft NGVD).

Feature	Survey Year		
	1971 Design Specifications	1991	2010
Area (acres)	10,100	10,101	10,114
Cumulative Volume (acre-feet)	203,100	190,156	187,463
Mean Depth (ft)	19.4	18.8	18.5
Maximum Depth (ft)	62.4	--	52.1
Volume Loss Since Previous Survey (acre-feet)	--	12,944	2,693
Sedimentation Rate (acre-feet/yr)	--	431.5	141.7

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

WAURIKA 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
899	Area				0.0	0.0	0.1	0.2	0.4	0.8	1.2
	Capacity				0.0	0.0	0.0	0.0	0.0	0.1	0.2
900	Area	1.8	2.4	3.1	3.9	5.0	6.2	7.8	9.6	11.7	14.3
	Capacity	0.4	0.6	0.9	1.2	1.6	2.2	2.9	3.8	4.8	6.1
901	Area	17.8	22.1	27.8	35.7	64.9	69.7	74.2	78.3	82.1	85.8
	Capacity	7.7	9.7	12.2	15.4	20.3	27.0	34.2	41.8	49.9	58.3
902	Area	89.3	92.9	96.3	99.9	103.6	107.5	112.0	119.0	127.0	135.1
	Capacity	67.0	76.1	85.6	95.4	105.6	116.1	127.1	138.6	150.9	164.0
903	Area	142.9	150.1	157.2	164.0	171.5	180.3	189.5	197.5	205.3	212.4
	Capacity	177.9	192.6	207.9	224.0	240.8	258.3	276.9	296.2	316.4	337.3
904	Area	219.5	226.5	233.3	240.4	248.0	255.0	261.4	267.4	273.2	278.8
	Capacity	358.8	381.2	404.2	427.8	452.3	477.4	503.2	529.7	556.7	584.3
905	Area	284.3	289.9	296.0	302.7	309.2	315.1	320.7	326.0	330.9	335.7
	Capacity	612.5	641.2	670.5	700.4	731.0	762.2	794.1	826.4	859.2	892.6
906	Area	340.3	344.8	349.4	354.1	372.0	374.6	377.1	379.6	382.1	384.6
	Capacity	926.4	960.6	995.3	1,030.5	1,066.7	1,104.1	1,141.7	1,179.5	1,217.6	1,255.9
907	Area	387.2	390.0	393.1	396.4	400.0	403.7	407.7	411.6	415.4	419.1
	Capacity	1,294.5	1,333.4	1,372.5	1,412.0	1,451.8	1,492.0	1,532.6	1,573.6	1,614.9	1,656.7
908	Area	422.9	426.6	430.3	434.2	438.8	444.0	449.3	454.9	461.1	468.0
	Capacity	1,698.8	1,741.2	1,784.1	1,827.3	1,871.0	1,915.1	1,959.8	2,005.0	2,050.8	2,097.2
909	Area	476.1	485.2	495.9	507.3	527.5	536.4	544.6	553.2	563.1	573.8
	Capacity	2,144.4	2,192.5	2,241.5	2,291.7	2,343.4	2,396.6	2,450.7	2,505.6	2,561.4	2,618.2
910	Area	586.0	598.0	610.2	620.4	631.1	641.4	650.8	660.6	671.1	681.3
	Capacity	2,676.2	2,735.4	2,795.8	2,857.4	2,920.0	2,983.6	3,048.2	3,113.8	3,180.4	3,248.0
911	Area	691.5	701.4	709.9	718.6	740.1	750.8	760.9	771.2	781.8	794.7
	Capacity	3,316.6	3,386.3	3,456.9	3,528.3	3,601.1	3,675.7	3,751.3	3,827.9	3,905.6	3,984.4
912	Area	807.0	817.5	828.3	839.2	849.8	860.1	870.9	883.3	896.2	909.4
	Capacity	4,064.5	4,145.7	4,228.0	4,311.4	4,395.9	4,481.4	4,567.9	4,655.6	4,744.7	4,834.9
913	Area	923.2	937.7	952.3	967.5	995.7	1,012.9	1,029.9	1,047.8	1,067.3	1,084.6
	Capacity	4,926.5	5,019.6	5,114.1	5,210.1	5,308.2	5,408.6	5,510.8	5,614.6	5,720.4	5,828.1
914	Area	1,099.7	1,113.5	1,127.1	1,140.9	1,154.5	1,168.5	1,182.9	1,199.5	1,217.1	1,231.3
	Capacity	5,937.3	6,048.0	6,160.0	6,273.5	6,388.2	6,504.3	6,622.0	6,741.0	6,861.9	6,984.4
915	Area	1,243.0	1,254.6	1,266.4	1,278.7	1,293.1	1,312.3	1,333.2	1,351.7	1,368.2	1,382.7
	Capacity	7,108.1	7,233.0	7,359.1	7,486.4	7,614.9	7,745.1	7,877.5	8,011.7	8,147.8	8,285.4
916	Area	1,396.8	1,410.0	1,423.4	1,437.9	1,478.4	1,492.4	1,504.8	1,515.5	1,525.8	1,534.9
	Capacity	8,424.3	8,564.8	8,706.4	8,849.5	8,995.1	9,143.6	9,293.6	9,444.6	9,596.7	9,749.8
917	Area	1,543.7	1,552.7	1,562.4	1,573.8	1,609.5	1,628.0	1,643.1	1,657.4	1,672.2	1,687.6
	Capacity	9,903.7	10,058.6	10,214.3	10,371.2	10,530.0	10,692.0	10,855.6	11,020.6	11,187.2	11,355.2
918	Area	1,702.4	1,717.2	1,731.9	1,746.7	1,760.1	1,772.5	1,784.0	1,795.1	1,806.2	1,817.7
	Capacity	11,524.7	11,695.7	11,868.2	12,042.2	12,217.5	12,394.2	12,572.1	12,751.0	12,931.2	13,112.3
919	Area	1,830.3	1,843.8	1,858.6	1,876.5	1,921.1	1,939.0	1,953.8	1,967.3	1,980.9	1,995.0
	Capacity	13,294.7	13,478.5	13,663.6	13,850.4	14,040.1	14,233.1	14,427.8	14,623.9	14,821.4	15,020.2

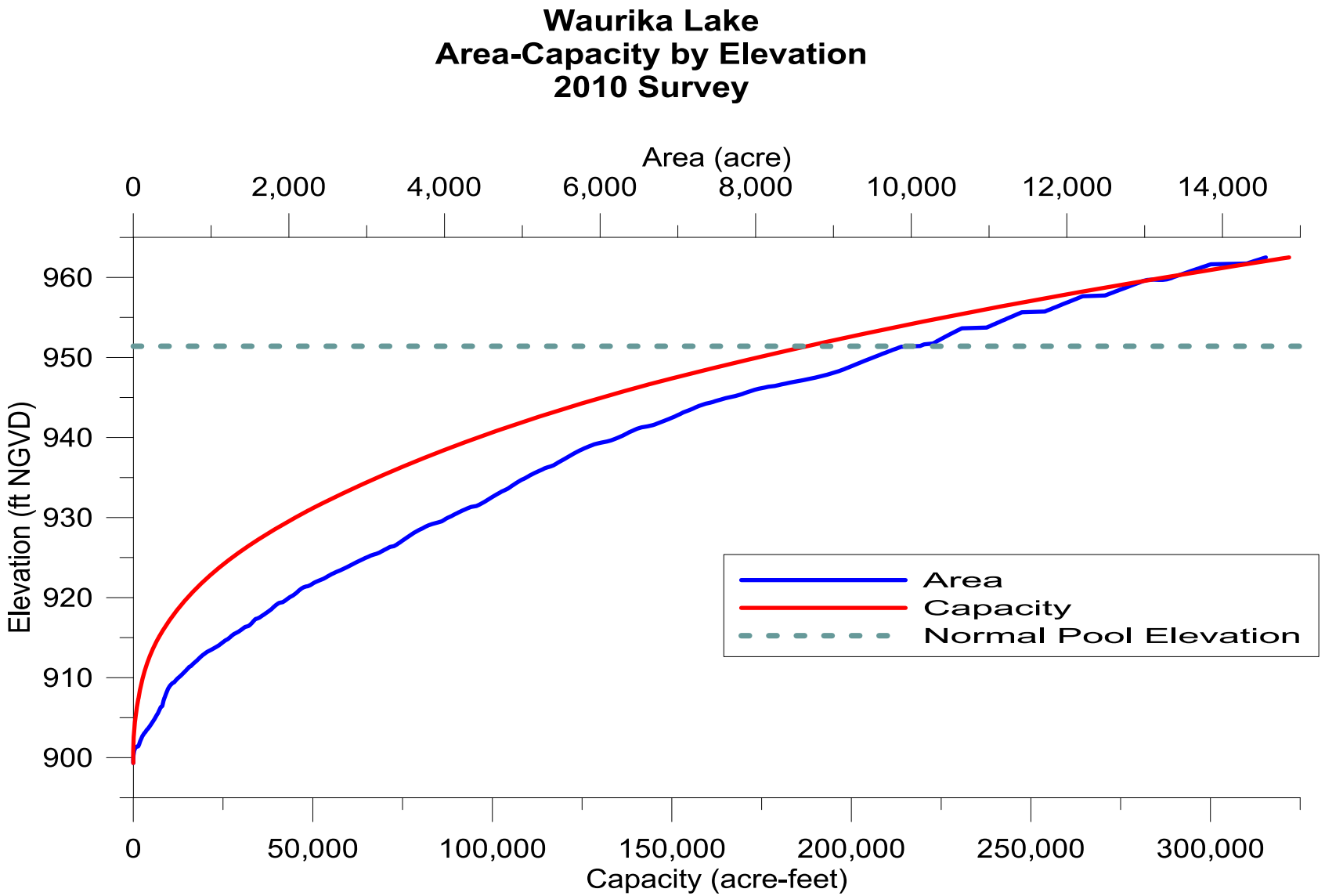
Table A 2: Waurika Lake Capacity/Area by 0.1-ft Increments (cont).

WAURIKA 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
920	Area	2,010.0	2,027.4	2,046.1	2,063.6	2,078.2	2,089.9	2,101.5	2,112.9	2,124.1	2,135.6
	Capacity	15,220.4	15,422.3	15,626.0	15,831.6	16,038.7	16,247.1	16,456.8	16,667.5	16,879.4	17,092.4
921	Area	2,148.2	2,163.8	2,181.7	2,201.7	2,249.8	2,269.2	2,287.0	2,304.8	2,322.5	2,341.5
	Capacity	17,306.5	17,522.2	17,739.5	17,958.7	18,181.0	18,407.0	18,634.9	18,864.5	19,096.0	19,329.1
922	Area	2,364.1	2,390.8	2,418.2	2,441.1	2,460.9	2,478.7	2,496.1	2,513.5	2,531.3	2,551.0
	Capacity	19,564.3	19,802.2	20,042.7	20,285.8	20,530.9	20,777.9	21,026.7	21,277.2	21,529.6	21,783.6
923	Area	2,572.9	2,595.8	2,617.4	2,639.8	2,675.3	2,692.6	2,710.7	2,730.3	2,750.2	2,772.2
	Capacity	22,039.8	22,298.4	22,559.0	22,822.0	23,087.7	23,356.0	23,626.3	23,898.3	24,172.5	24,448.6
924	Area	2795.9	2816.9	2835.5	2854.6	2874.3	2894.4	2914.2	2935.0	2957.8	2981.4
	Capacity	24,727	25,008	25,290	25,575	25,861	26,150	26,440	26,733	27,028	27,325
925	Area	3004.5	3027.8	3051.4	3076.2	3120.4	3142.5	3164.0	3185.0	3205.1	3224.4
	Capacity	27,624	27,926	28,230	28,536	28,846	29,159	29,474	29,792	30,111	30,433
926	Area	3242.9	3262.2	3281.8	3303.8	3350.7	3371.4	3388.2	3403.8	3418.7	3433.2
	Capacity	30,756	31,082	31,409	31,738	32,071	32,407	32,745	33,085	33,426	33,768
927	Area	3447.3	3462.4	3478.6	3495.0	3509.9	3523.9	3537.3	3551.3	3566.6	3581.4
	Capacity	34,112	34,458	34,805	35,154	35,504	35,856	36,209	36,563	36,919	37,277
928	Area	3596.6	3614.3	3633.7	3654.9	3675.9	3695.7	3714.7	3732.9	3753.2	3774.2
	Capacity	37,636	37,996	38,359	38,723	39,090	39,458	39,829	40,202	40,576	40,952
929	Area	3797.9	3829.6	3860.2	3888.1	3943.3	3965.4	3983.7	4000.0	4,016	4,035
	Capacity	41,330.9	41,712.4	42,096.9	42,484.6	42,875.8	43,271.3	43,669.0	44,068.1	44,469.1	44,871.6
930	Area	4,057.0	4,079.7	4,100.4	4,120.0	4,139.6	4,160.0	4,180.9	4,202.1	4,223.7	4,246.7
	Capacity	45,276.2	45,683.2	46,092.2	46,503.5	46,916.4	47,331.3	47,748.6	48,167.7	48,589.2	49,012.7
931	Area	4,269.7	4,294.0	4,318.5	4,344.1	4,409.2	4,431.1	4,451.9	4,471.6	4,490.6	4,510.3
	Capacity	49,438.4	49,866.8	50,297.4	50,730.8	51,168.0	51,610.0	52,054.4	52,500.5	52,948.8	53,398.8
932	Area	4,529.3	4,546.6	4,562.2	4,577.4	4,593.0	4,608.5	4,625.6	4,643.3	4,661.4	4,679.6
	Capacity	53,850.8	54,304.8	54,760.2	55,217.4	55,675.9	56,135.9	56,597.8	57,061.2	57,526.7	57,993.6
933	Area	4,697.1	4,715.4	4,733.3	4,751.0	4,783.5	4,800.7	4,817.2	4,833.3	4,849.0	4,864.2
	Capacity	58,462.4	58,933.3	59,405.7	59,880.1	60,356.7	60,835.8	61,317.0	61,799.4	62,283.8	62,769.4
934	Area	4,879.3	4,894.9	4,910.7	4,926.6	4,943.2	4,959.7	4,976.7	4,996.7	5,019.9	5,040.0
	Capacity	63,256.5	63,745.5	64,235.7	64,727.8	65,221.2	65,716.3	66,213.4	66,711.9	67,213.0	67,716.0
935	Area	5,058.2	5,076.1	5,094.0	5,112.4	5,134.9	5,153.4	5,173.8	5,196.3	5,218.9	5,242.4
	Capacity	68,220.8	68,727.8	69,236.3	69,746.8	70,259.1	70,773.5	71,290.1	71,808.5	72,329.5	72,852.5
936	Area	5,266.2	5,289.6	5,313.2	5,337.8	5,384.2	5,402.9	5,420.6	5,437.9	5,455.1	5,472.0
	Capacity	73,377.9	73,906.0	74,436.0	74,968.8	75,504.7	76,044.1	76,585.5	77,128.4	77,673.3	78,219.6
937	Area	5,489.0	5,506.4	5,524.0	5,543.2	5,568.1	5,585.1	5,601.6	5,618.7	5,636.1	5,653.1
	Capacity	78,767.6	79,317.6	79,869.1	80,422.7	80,978.2	81,535.8	82,095.4	82,656.4	83,219.4	83,783.8
938	Area	5,670.2	5,688.3	5,707.1	5,727.6	5,749.7	5,773.2	5,796.4	5,820.9	5,845.7	5,870.2
	Capacity	84,349.9	84,918.1	85,487.8	86,059.8	86,633.6	87,209.7	87,788.5	88,369.2	88,952.9	89,538.6
939	Area	5,896.1	5,924.0	5,960.8	5,999.7	6,072.4	6,102.4	6,133.0	6,167.5	6,194.6	6,221.3
	Capacity	90,126.8	90,718.1	91,312.2	91,910.5	92,513.8	93,122.5	93,734.6	94,349.6	94,968.0	95,588.8
940	Area	6,245.8	6,268.7	6,291.3	6,312.5	6,332.0	6,351.6	6,371.8	6,393.7	6,416.6	6,439.7
	Capacity	96,212.1	96,838.1	97,466.1	98,096.6	98,728.8	99,362.9	99,999.4	100,637.6	101,278.4	101,921.2

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

WAURIKA 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
941	Area	6,464.0	6,489.8	6,521.4	6,563.6	6,641.8	6,675.6	6,706.3	6,733.4	6,759.9	6,787.5
	Capacity	102,566.3	103,214.3	103,864.7	104,519.3	105,179.1	105,845.0	106,514.5	107,186.4	107,861.4	108,538.6
942	Area	6,813.1	6,839.2	6,865.7	6,891.7	6,916.6	6,940.9	6,964.2	6,986.2	7,007.8	7,029.7
	Capacity	109,218.6	109,901.5	110,586.7	111,274.9	111,965.3	112,658.1	113,353.7	114,051.1	114,751.2	115,453.0
943	Area	7,051.4	7,073.2	7,095.5	7,119.7	7,155.2	7,178.1	7,200.0	7,223.4	7,247.5	7,271.6
	Capacity	116,156.9	116,863.5	117,571.9	118,283.0	118,996.5	119,713.1	120,432.4	121,153.5	121,877.4	122,603.3
944	Area	7,296.9	7,327.3	7,370.6	7,411.7	7,448.2	7,481.2	7,515.3	7,550.3	7,588.2	7,627.5
	Capacity	123,331.6	124,063.0	124,797.8	125,537.3	126,280.2	127,026.6	127,776.8	128,530.0	129,287.2	130,047.9
945	Area	7,669.0	7,717.0	7,761.2	7,796.2	7,828.3	7,857.8	7,886.5	7,917.0	7,947.8	7,980.3
	Capacity	130,812.6	131,582.3	132,356.2	133,134.5	133,915.7	134,699.9	135,487.5	136,277.6	137,071.2	137,867.5
946	Area	8,020.4	8,064.8	8,113.1	8,162.9	8,246.9	8,289.9	8,335.4	8,385.1	8,436.1	8,485.5
	Capacity	138,667.4	139,472.0	140,280.8	141,095.0	141,915.2	142,742.0	143,573.6	144,409.5	145,251.0	146,097.0
947	Area	8,538.7	8,595.5	8,650.2	8,703.0	8,752.8	8,795.2	8,832.2	8,868.7	8,912.1	8,952.8
	Capacity	146,948.0	147,805.2	148,667.4	149,535.6	150,408.3	151,285.7	152,167.5	153,052.5	153,941.9	154,835.1
948	Area	8,991.7	9,023.3	9,053.3	9,082.3	9,110.3	9,137.4	9,163.7	9,190.0	9,215.5	9,240.6
	Capacity	155,732.3	156,633.5	157,537.2	158,444.5	159,354.0	160,266.3	161,181.8	162,099.4	163,020.2	163,942.9
949	Area	9,265.6	9,290.7	9,315.6	9,340.6	9,365.8	9,391.1	9,416.6	9,442.3	9,468.1	9,494.0
	Capacity	164,868.1	165,796.4	166,726.6	167,659.9	168,595.1	169,532.8	170,473.7	171,416.5	172,362.5	173,310.5
950	Area	9,520.1	9,546.4	9,572.8	9,599.3	9,626.0	9,652.9	9,679.9	9,707.1	9,734.4	9,761.9
	Capacity	174,261.1	175,214.9	176,170.8	177,129.9	178,091.0	179,054.9	180,022.0	180,991.2	181,963.8	182,938.5
951	Area	9,789.5	9,817.3	9,845.2	9,873.3	10,113.8	10,141.1	10,166.8	10,278.7	10,296.8	10,315.1
	Capacity	183,916.0	184,896.8	185,879.8	186,866.3	187,863.4	188,876.0	189,891.9	190,910.6	191,939.9	192,970.4
952	Area	10,333.6	10,352.2	10,371.0	10,389.9	10,409.0	10,428.2	10,447.6	10,467.1	10,486.8	10,506.7
	Capacity	194,002.7	195,037.5	196,073.6	197,112.1	198,152.0	199,193.7	200,238.0	201,283.6	202,331.8	203,381.4
953	Area	10,526.7	10,546.9	10,567.2	10,587.7	10,608.3	10,629.1	10,650.0	10,969.6	10,993.1	11,016.6
	Capacity	204,433.0	205,487.2	206,542.8	207,601.0	208,660.7	209,722.5	210,787.0	211,855.9	212,954.6	214,055.0
954	Area	11,040.1	11,063.6	11,087.2	11,110.8	11,134.4	11,158.0	11,181.6	11,205.3	11,229.0	11,252.7
	Capacity	215,157.7	216,263.4	217,370.9	218,481.3	219,593.4	220,707.9	221,825.5	222,944.7	224,067.0	225,191.0
955	Area	11,276.5	11,300.2	11,324.0	11,347.8	11,371.7	11,395.5	11,419.4	11,717.2	11,742.4	11,767.6
	Capacity	226,317.3	227,446.7	228,577.8	229,712.0	230,847.8	231,986.0	233,127.4	234,273.1	235,446.7	236,622.1
956	Area	11,792.9	11,818.3	11,843.6	11,869.0	11,894.4	11,919.8	11,945.3	11,970.8	11,996.4	12,021.9
	Capacity	237,800.0	238,981.1	240,164.1	241,350.3	242,538.4	243,729.0	244,922.8	246,118.5	247,317.4	248,518.2
957	Area	12,047.5	12,073.2	12,098.8	12,124.6	12,150.3	12,176.0	12,201.9	12,488.8	12,516.0	12,543.2
	Capacity	249,721.6	250,928.2	252,136.7	253,348.5	254,562.1	255,778.3	256,997.8	258,221.8	259,472.6	260,725.4
958	Area	12,570.5	12,597.7	12,625.0	12,652.3	12,679.6	12,706.9	12,734.2	12,761.5	12,788.9	12,816.2
	Capacity	261,981.0	263,240.0	264,501.0	265,765.6	267,032.0	268,301.2	269,573.9	270,848.5	272,126.7	273,406.8
959	Area	12,843.6	12,871.0	12,898.4	12,925.8	12,953.2	12,980.6	13,008.1	13,284.1	13,313.2	13,342.5
	Capacity	274,689.7	275,976.0	277,264.4	278,556.2	279,850.1	281,146.6	282,446.7	283,751.2	285,081.8	286,414.4
960	Area	13,371.8	13,401.2	13,430.7	13,460.2	13,489.9	13,519.6	13,549.5	13,579.4	13,609.4	13,639.4
	Capacity	287,750.0	289,089.3	290,430.7	291,776.0	293,123.3	294,473.7	295,827.8	297,184.1	298,544.2	299,906.5
961	Area	13,669.6	13,699.8	13,730.1	13,760.6	13,791.0	13,821.6	13,852.3	14,311.6	14,344.1	14,376.5
	Capacity	301,271.8	302,641.0	304,012.3	305,387.5	306,765.0	308,145.5	309,529.8	310,920.8	312,354.3	313,790.1
962	Area	14,408.9	14,441.3	14,473.7	14,506.0	14,538.3	14,557.7				
	Capacity	315,229.3	316,672.5	318,118.1	319,567.8	321,019.9	321,892.8				

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



APPENDIX B: Waurika Lake Maps

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

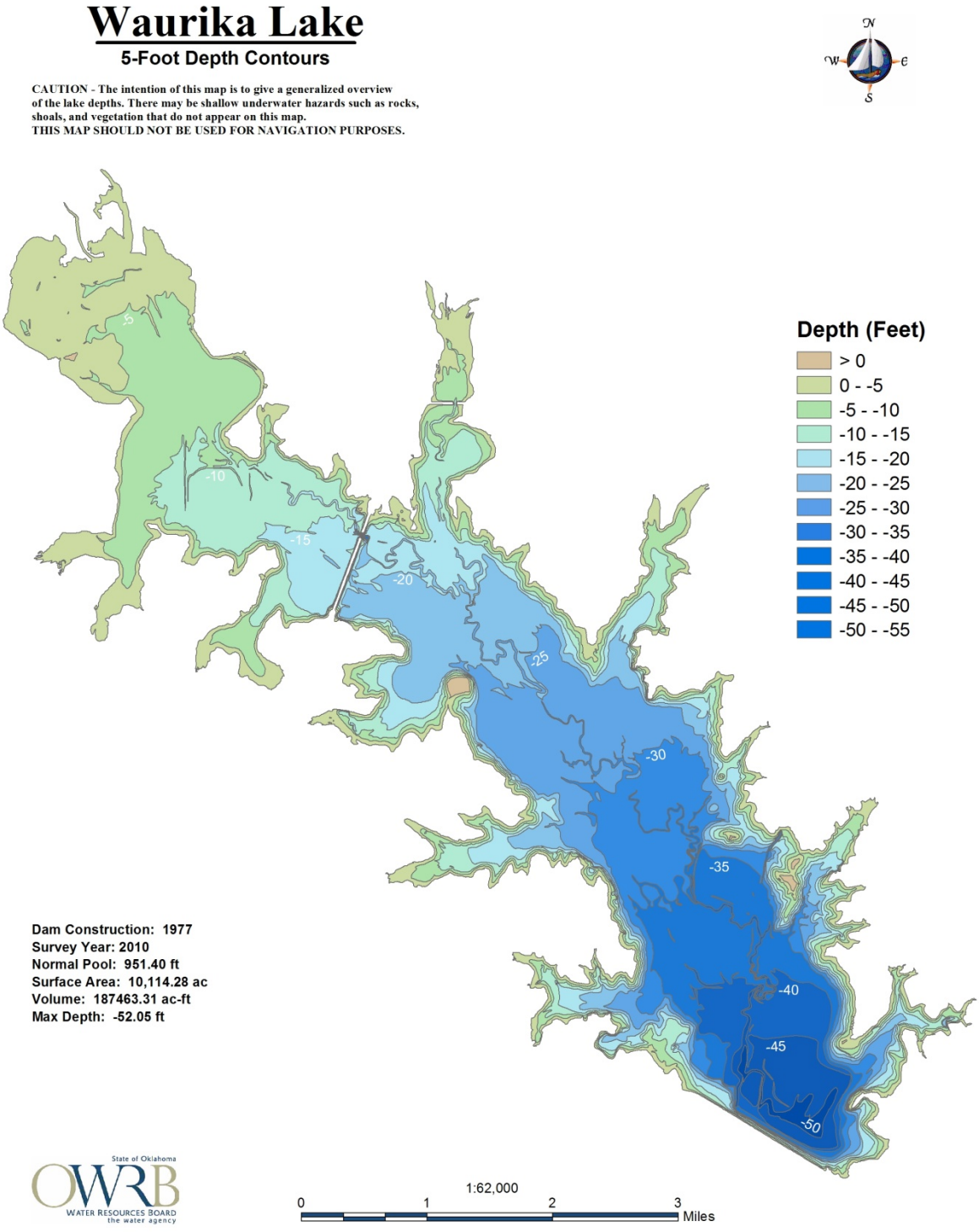


Figure B. 2: Waurika Lake Shaded Relief Bathymetric Map.

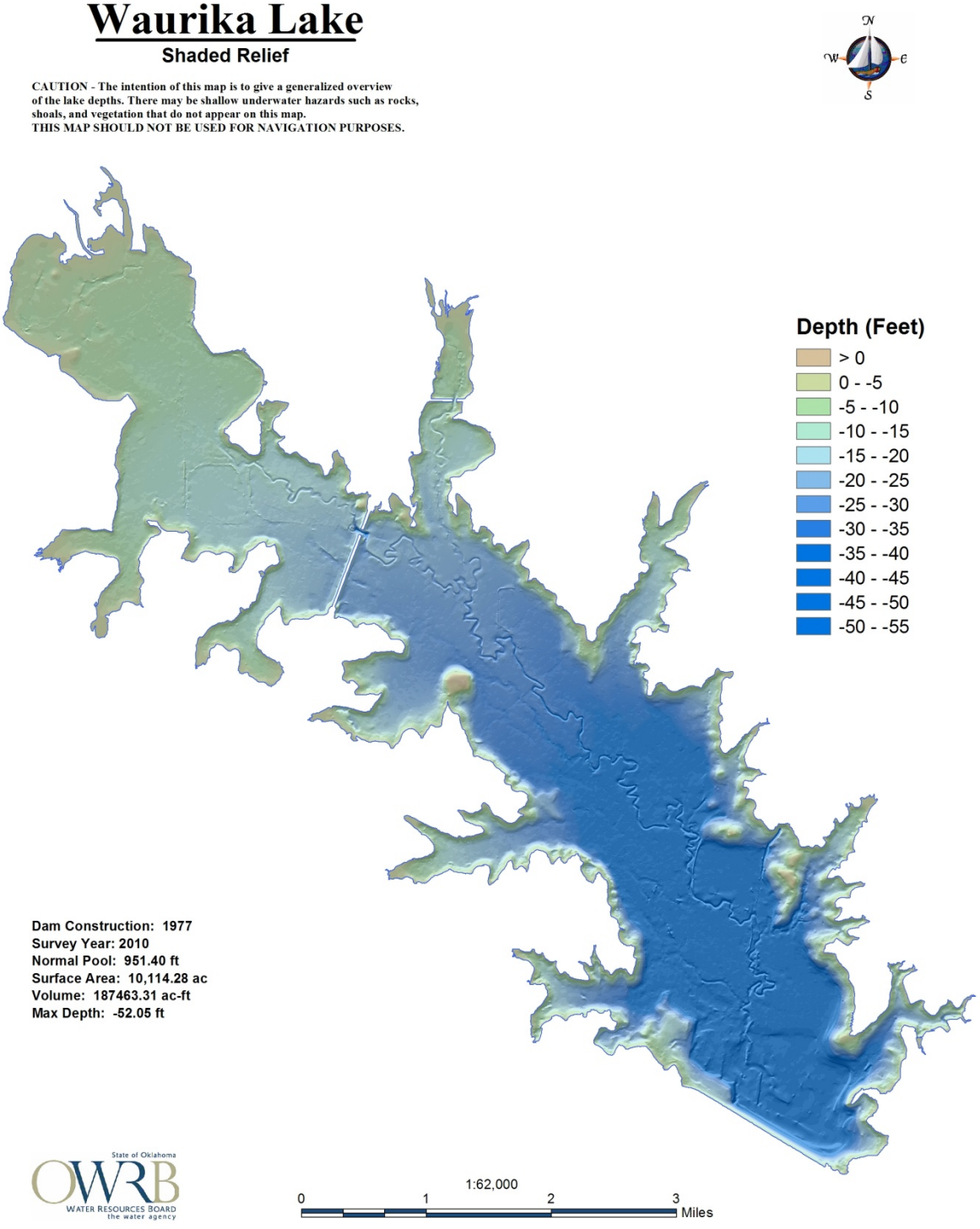
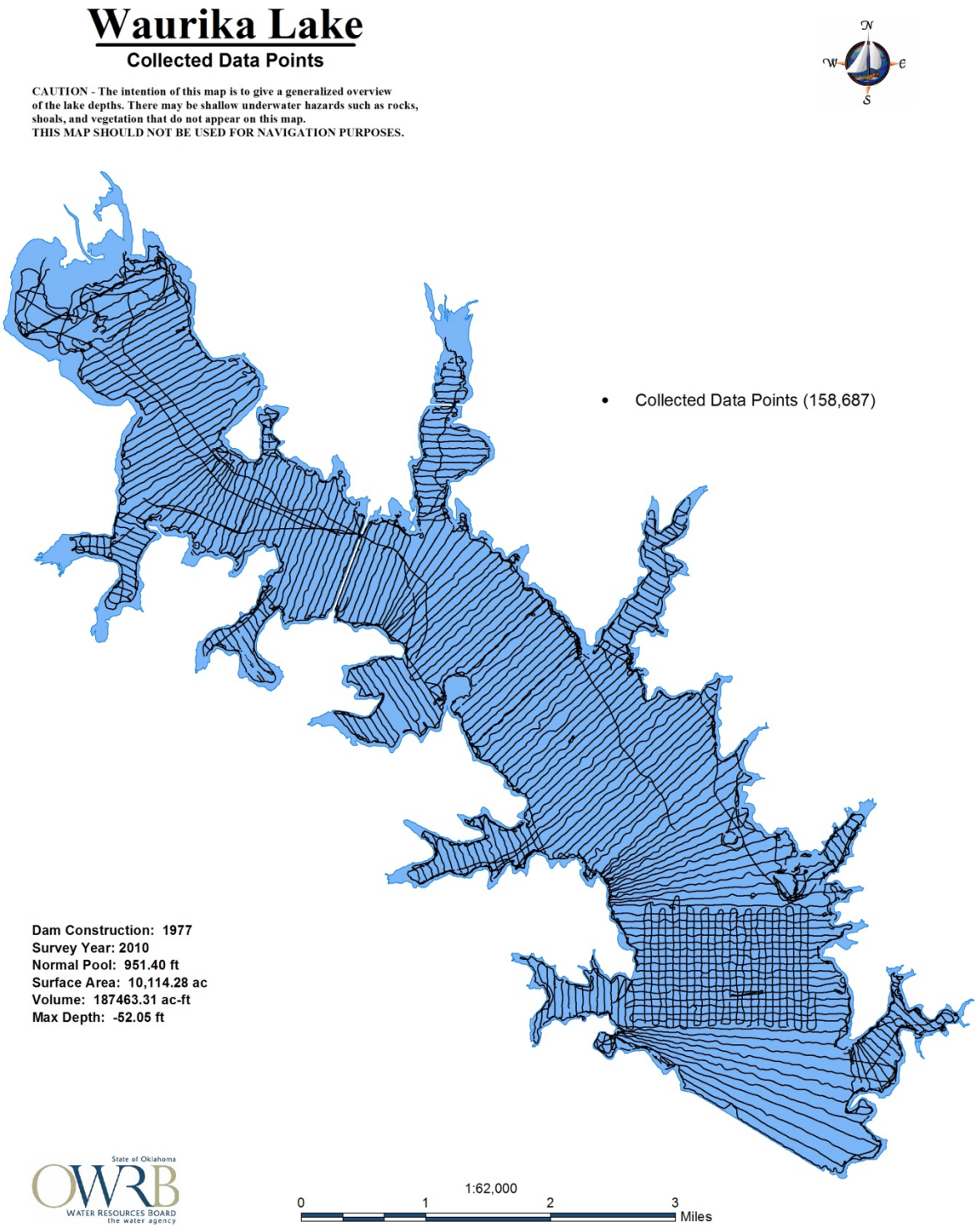



Figure B. 3: Waurika Lake Collected Data Points.