Bathymetric Survey of Select Dissolved Oxygen Impaired Reservoirs

FY 2018

PROJECT #3 FY18/19 §106 I-006400-17
TABLE A-1 LAKES

Q-TRAK #18-205

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Final Report
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INTRODUCTION

Project

The Oklahoma Water Resources Board (OWRB) was contracted by the Oklahoma Department of Environmental Quality (ODEQ) to conduct hydrographic surveys on three Oklahoma reservoirs listed on the state's 303(d) list as impaired for dissolved oxygen. These reservoirs include Brushy Creek Lake, Greenleaf Lake, and Shell Lake. The purpose of this project is to produce current elevation-area-capacity tables, to allow for volumetric determination of dissolved oxygen for beneficial use assessment.

Reservoirs

Brushy Creek Reservoir

Brushy Creek Reservoir (Sallisaw Creek Site 29) is located on Brushy Creek, a tributary of the Arkansas River. It is located in Sequoyah County, approximately six miles northwest of the City of Sallisaw **Figure 1**. The dam (NID ID: OK01232) was completed in 1964, and the reservoir is owned by the City of Sallisaw. The dam is located at Latitude 35° 32' 06.3" Longitude 094° 49' 39.9" in Sec. 12-T12N-R23E. Brushy Creek's designated beneficial uses include Agriculture, Aesthetics, Fish and Wildlife Propagation, Recreation, and Public and Private Water Supply. Brushy Creek is also designated as a Sensitive Water Supply (OAC, 785:45, Appendix A).

Greenleaf Lake

Greenleaf Lake is located on Greenleaf Creek, a tributary of the Arkansas River. It is located in Muskogee County, approximately fourteen miles southeast of the City of Muskogee **Figure 2**. The dam (NID ID: OK20996) was completed in 1935, and the reservoir is owned by the United States Department of the Army who leases the reservoir to the State of Oklahoma. The dam is located at Latitude 35° 37' 00.9" Longitude 095° 10' 03.5" in Sec. 10-T13N-R20E. Greenleaf's designated beneficial uses include Fish and Wildlife Propagation, Recreation, and Public and Private Water Supply. Greenleaf Lake is also designated as a Sensitive Water Supply (OAC, 785:45, Appendix A).

Shell Lake

Shell Lake (Shell Creek Lake) is located on Shell Creek, a tributary of the Arkansas River. It is located in Osage County, approximately five miles northwest of the City of Sand Springs **Figure 3**. The dam (NID ID: OK11015) was completed in 1922, and the reservoir is owned by the City of Sand Springs. The dam is located at Latitude 36° 10' 50.9" Longitude 096° 10' 51.7" in Sec. 10-T13N-R20E. Shell's designated beneficial uses include Fish and Wildlife Propagation, Recreation, and Public and Private Water Supply. Shell Lake is also designated as a Sensitive Water Supply (OAC, 785:45, Appendix A).

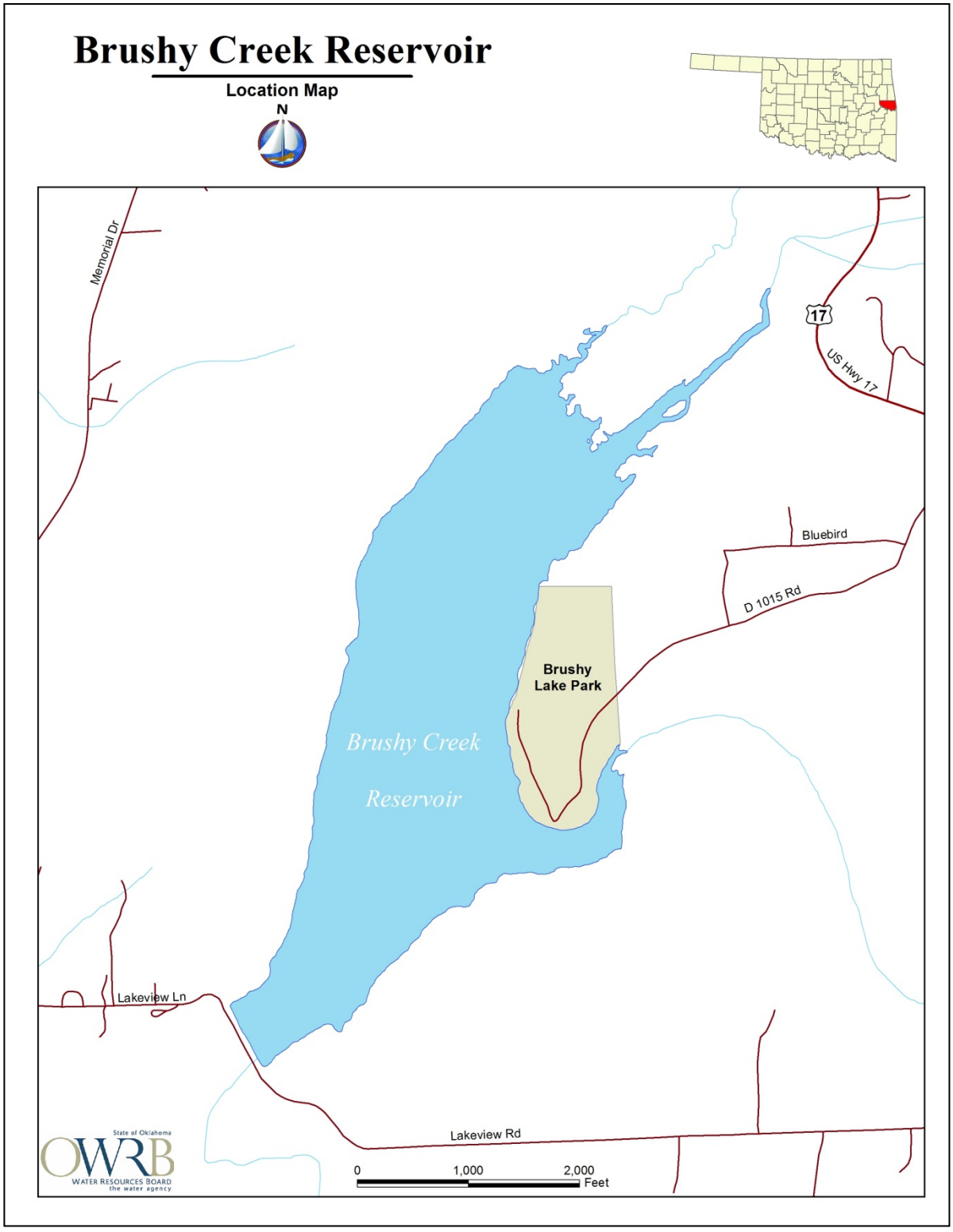


Figure 1: Location map for Brushy Creek Lake.

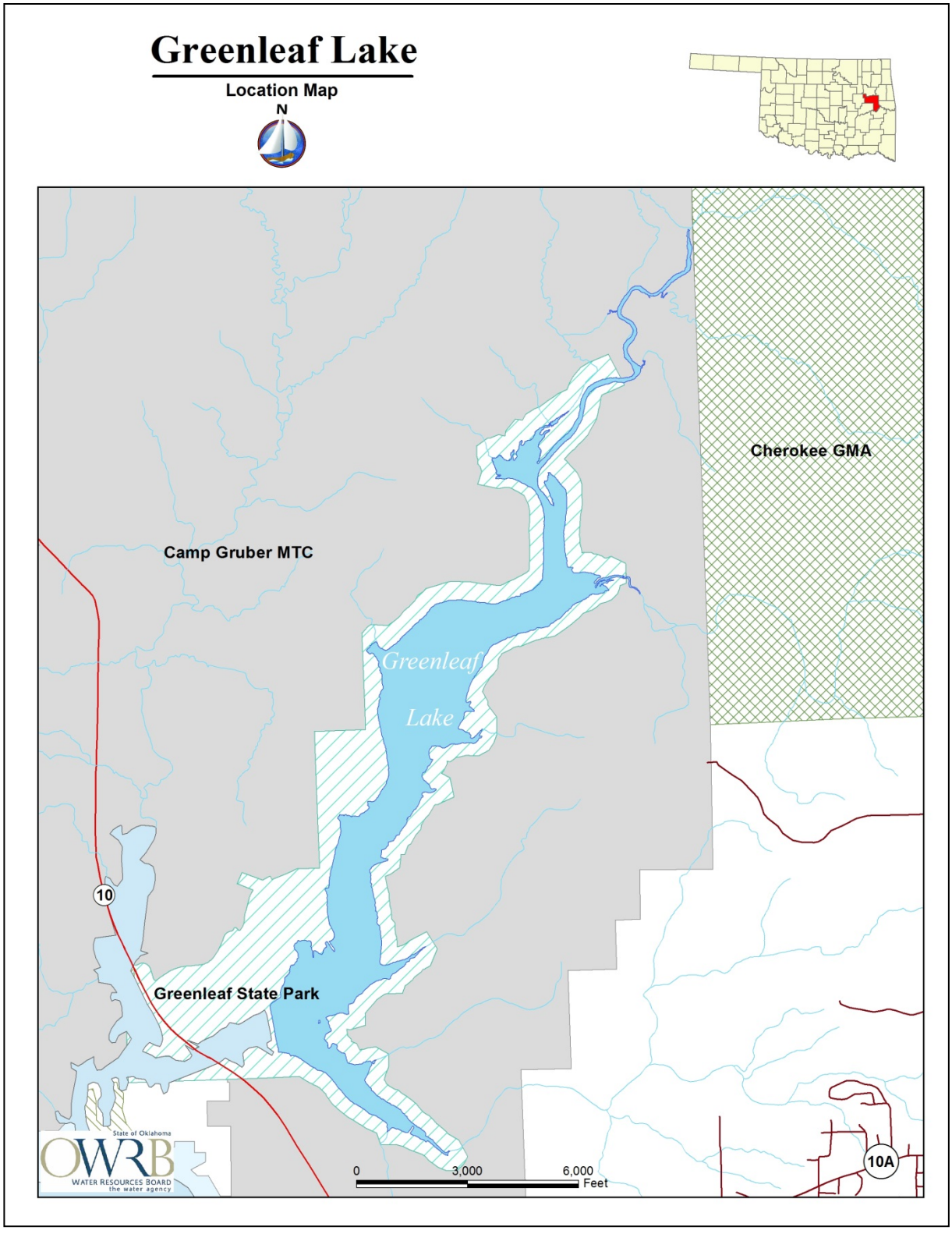


Figure 2: Location map of Greenleaf Lake

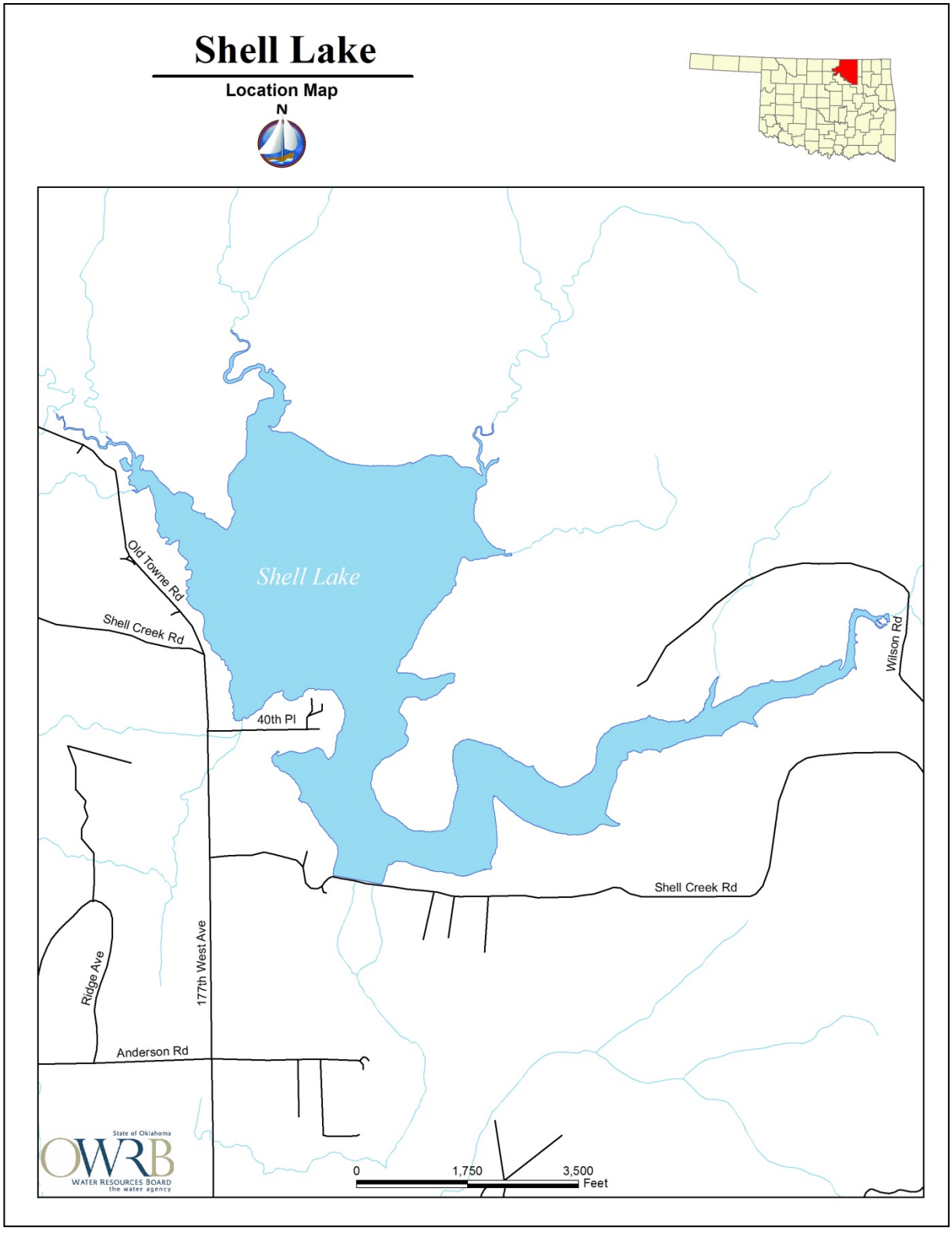


Figure 3: Location map of Shell Lake

HYDROGRAPHIC SURVEYING PROCEDURES

The process of surveying a reservoir uses a combination of Geographic Positioning Systems (GPS) and acoustic depth sounding technologies incorporated into a hydrographic survey vessel. As the survey vessel travels across the lake's surface, the echosounder gathers multiple depth readings every second. Depth readings are stored on the survey vessel's on-board computer along with positional data generated from the vessel's GPS receiver. The collected data files are downloaded daily from the computer and edited upon returning to the office. During editing, data "noise" is removed or corrected and depth readings are converted to elevation readings based on the water level elevation recorded on the day the survey was performed. The edited data sets are then thinned to manageable sizes using Hypack's "Sounding Selection-Sort Program" using a 1 sort radius. Using ArcGIS, accurate estimates of area-capacity can then be determined for the lake by building a three-dimensional model of the reservoir from the sorted data set. The process of completing a hydrographic survey includes four steps: pre-survey planning, field survey, data processing, and model construction.

Pre-Survey Planning

Boundary File

Brushy Creek Lake

The shoreline boundary for Brushy Creek Lake was derived from 2-meter DEM LiDAR data[1] downloaded from OKMaps at https://okmaps.org/OGI/search.aspx. The LiDAR raster file TIFF was clipped and contours were generated. The NRCS Contour Tool v10x, which utilizes the ArcGIS Spatial Analyst extension, was used to generate contours from the LiDAR file. A lake boundary line shapefile was created from the 634.0 ft contour line; this elevation was most representative of Brushy Creek Lake at or near normal pool elevation. This boundary file was verified using both orthophotos and measured elevation readings.

Greenleaf Lake

Contour lines created from available LiDAR data were developed for Greenleaf Lake, but after evaluation of these lines it was determined that they were not accurate enough to be used for boundary creation. This determination was based upon visual inspection when overlaid upon an aerial photo and compared with shore point elevations taken at the lake's boat ramp. These contours were **not used** due to these errors.

The most accurate method for creating a shapefile of the normal pool elevation (510.01 ft, NAVD88) would be by manually digitizing the visible shoreline shown on a March 11, 2012 Google Earth aerial image. The lake shoreline shown in this aerial imagery appeared to best correlate with normal pool elevation. This was determined by utilizing the shore points taken at the boat ramp, as well as identifying in the imagery a small amount of water discharging around the lake's spillway. The shoreline was first digitized using Google Earth Pro. It was then exported as a KMZ file, which was then converted to an ESRI shapefile layer.

[1] Sequoyah County, OK, NRCS_2M_DEM_Bare_Earth_2de85b45-b4f7-4e9a-9ad2-3f823ec7d59_selection_EPSG_32124_2_meters

Verification and adjustment for accuracy was accomplished by comparison of this boundary with a January 17, 2018 Google Earth aerial image as well as National Agriculture Imagery Program (NAIP) orthophotos flown in 2010, 2013 and 2015.

Shell Lake

Appropriate LiDAR data was not available for the Shell Lake location. It was decided that the most accurate method for creating a shapefile of the normal pool elevation (725.38 ft, NAVD88) would be by heads-up digitizing the visible shoreline shown on a May 20, 2017 Google Earth aerial image. The lake shoreline shown in this aerial imagery appeared to best correlate with the normal pool elevation. This was determined by utilizing the shore points taken at the boat ramp, as well as identifying in the imagery water discharging over the lake's spillway. The shoreline was first digitized using Google Earth Pro. It was then exported as a Kmz file which was then converted to an ESRI shapefile layer. Verification and adjustment for accuracy was accomplished by comparison of this boundary with April 2, 2016 and March 9, 2017 ESRI basemap aerial images as well as NAIP orthophotos flown in 2010, 2013, and 2015.

Hypack Set-up

Hypack software from Xylem, Inc. was used to assign geodetic parameters, import background files, and create virtual track lines (transect and crosscheck) (Hypack, 2017). The geodetic parameters assigned were ellipsoid World Geodetic System of 1984 (WGS-84) in State Plane North American Datum of 1983 (NAD-83) Zone OK-3501 Oklahoma North or OK-3502 Oklahoma South, depending on location of the reservoir in regards to Highway Interstate 40 (I40). The distance and depth units used were US Survey Feet. The vertical datum was set to the North American Vertical Datum of 1988 (NAVD88), and any measurements in the National Geodetic Vertical Datum of 1929 (NGVD29) were converted. Vertical datum conversions were done using the National Geodetic Survey (NGS) VERTCON tool at http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html.

Table 1: Summary of track line coverage for all lakes surveyed.

Track Line Coverage				
Lake	Line Spacing	Transect Lines	Stream Lines	Additional QC Lines
Brushy Creek Lake	100 ft	77	2	8
Greenleaf Lake	100 ft	226	3	8
Shell Lake	100 ft	226	5	10

Survey transects were spaced according to the size and shape of each individual lake **Table 1** in order to maintain a high level of accuracy and coverage. The survey transects within the digitized reservoir boundary ran perpendicular to the original stream channels and tributaries. Stream lines were placed along the center of channels in areas deemed too small for transect coverage, as well as perpendicular to transect lines down the center of any major lake arms. These stream lines were used for data collection in difficult to navigate areas as well as for quality control (QC) purposes. Additional track lines set perpendicular to the transect lines were added to be used for QC cross check statistics if needed.

Field Survey

Lake Elevation Acquisition

The lake elevations for Brushy Creek Lake, Greenleaf Lake, and Shell Lake were obtained by collecting positional data over a period of time. Data collection was done using a Trimble Zephyr Geodetic Antenna connected to Trimble 5700 receiver controlled using Trimble TSC1 survey controller (Trimble, 2008). This data was then uploaded to the On-line Positioning Users Service (OPUS) website (https://www.ngs.noaa.gov/OPUS). The National Geodetic Survey (NGS) operates the OPUS as a means to provide GPS users with 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. Each data file that is submitted is processed with respect to at least three Continuously Operating Reference Stations (CORS). All collection and processing of elevation data followed methods covered in full detail in the OWRB Standard Operating Procedures (SOP) for lake elevation measurement found in the approved project Quality Assurance Project Plan (QAPP) (OWRB, 2018).

Method

The procedures followed by the OWRB during the hydrographic survey adhere to U.S. Army Corps of Engineers (USACE) standards EM 1110-2-1003 (USACE, 2013) as stated in the approved project QAPP (OWRB, 2018). The quality assurance and quality control (QA/QC) procedures for equipment calibration and operation, field survey, data processing, and accuracy standards are presented in the following sections and covered in more detail in the approved project QAPP (OWRB, 2018).

Technology

The Hydro-survey vessel is a 16-ft aluminum hull boat, powered by a single 40-horsepower outboard motor. Equipment used to conduct the survey included: a rugged notebook computer running Hypack's 2017 survey data collection software (Hypack, 2017), Knudsen 1614 Echo Sounder (Knudsen, 2010), with a depth resolution of 0.1 ft, Hemisphere R131 receiver with differential global positioning system (DGPS) correction (Hemisphere, 2013), an Odom Hydrographics Inc. DIGIBAR-Pro Profiling Sound Velocimeter (Odom, 2001), and an EXO2 Sonde (YSI, 2017). All field equipment was used in accordance with their corresponding manuals.

Survey

A two-man survey crew was used throughout the duration of the project. 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. In areas of the lake that were too narrow for pre-planned transect lines; stream lines were followed both straight and with a zigzag pattern to collect data. These areas included small tributaries as well as the upstream section of the reservoir. Similar to the shoreline data collection procedure, upstream data was collected until depths were too shallow for the boat to navigate and/or an obstruction prevented travel past a certain point. All lake surveys followed the aforementioned procedure for survey data collection. Survey dates and water level elevations can be found in **Table 2**.

Table 2: Summary of water elevations measured or recorded for all survey dates.

Survey Dates and Water Elevations		
Lake	Date	Water Elevations (NAVD88)
Brushy Creek Lake	11/29/2017	631.86 ft
Greenleaf Lake	12/05/2017	509.21 ft
	12/06/2017	509.20 ft
	03/13/2018	510.18 ft
Shell Lake	03/28/2018	721.64 ft
	03/29/2018	721.72 ft
	04/24/2018	721.27 ft
	05/24/2018	720.20 ft

Quality Assurance/Quality Control

Sound Velocity

The hydrographic surveys followed the quality control procedures presented in the approved QAPP (OWRB, 2018) and summarized in **Table 3**. While on board the Hydro-survey vessel, the Knudsen 1614 Echo Sounder was calibrated using both a DIGIBAR-Pro Profiling Sound Velocimeter and a bar-check setup. The sound velocimeter measures the speed of sound (SOS) at incremental depths throughout the water column. The factors that influence the SOS—depth, temperature, and salinity—are all taken into account. Deploying the unit involved lowering the probe 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 at one ft increments on both the deployment and retrieval phases. The data was then reviewed for any discrepancies, which were subsequently edited out of the sample. Sound velocity profiles calibrated collected raw depth readings during the editing process.

At Shell Lake sound velocity profiles were calculated using Conductivity-Temperature-Depth (CTD) measurements. CTD measurements were collected at one ft increments throughout the water column using the EXO2 Sonde. SOS at every depth was calculated using the CTD measurements in **Equation 1** (USACE, 2013). The calculated sound velocity profiles calibrated collected raw depth readings for Shell Lake during the editing process.

Equation 1: Sound Velocity Calculation Using CTD Measurements

$$V = 1448.96 + 4.591\,T - 5.304 \times 10^{-2}\,T2 + 2.374 \times 10^{-4}\,T3 + 1.340\,(S-35) + 1.630 \times 10^{-2}\,D + 1.675 \times 10^{-7}\,D2 - 1.025 \times 10^{-2}\,T\,(S - 35) - 7.139 \times 10^{-13}\,T \times D3 \text{ (meters/sec)}$$

where:

T = temperature in degrees Celsius
S = salinity in parts per thousand (ppt)
D = depth in meters

On the final survey day at Shell Lake both measured and calculated sound velocity profiles were collected. These profiles were compared during the editing process to determine consistency between methods. Differences were relatively negligible showing method interchangeability. All calculated sound velocity profiles for Shell Lake can be found in **Figure F- 1** located in **APPENDIX F**.

Bar-Check

The bar-check procedure adheres to USACE methods (USACE, 2013). The bar-check setup used consists of a steel plate lowered using chains measured and marked in five ft increments. The bar-check setup is lowered initially to a depth of five ft from the surface of the water. Taking the five ft depth and subtracting the unmodified depth from the echosounder provides the static draft or depth of the transducer in reference to the water's surface. This offset was measured and recorded by the Knudsen echosounder using its Bar-Check Mode where the SOS at five ft depth is also entered. The bar-check setup is then lowered to 25 ft to check for variations. Data is collected at both 25 ft and 5 ft depths and processed with the correlating sound velocity profile to validate the calibration. Bar-check echograms can be found in **Figure 4** for each individual lake surveys. **Table E- 1** containing Static draft, average SOS, as well as SOS set in the echosounder for all survey dates can be found in **APPENDIX E.**

Table 3: Summary of Relevant Minimum Performance Standards (MPS) and Quality Assurance (QA) Practices for the Hydrographic Survey (USACE, 2002&2013).

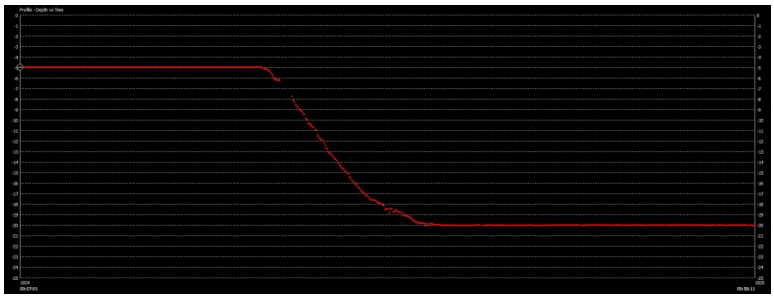
Minimum Performance Standards and Quality Assurance Practices for the Hydrographic Survey		
Repeatability (Bias)	0.3 ft	0.5 ft
Standard Deviation (± ft at 95%)	± 0.8 ft	
Resultant Elevation/Depth Accuracy (95%)(15>d<40 ft)	± 2.0 ft	
Horizontal Positioning System Accuracy (95%)	5 m (16 ft)	
Minimum Survey Coverage Density	Not to Exceed 500 ft (150 m)	
Quality Control and Assurance Criteria	--	
➢ Bar-check	1/project	
➢ Sound Velocity QC calibration	2/day	
➢ Squat Test	1/year	
➢ Position calibration QC check	1/project	
From the **2002** version of EM 1110-2-1003	From the **2013** version of EM 1110-2-1003	

Cross-Line Check

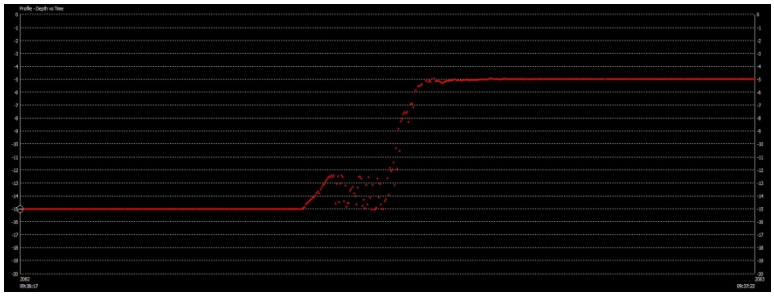
Depth observations contain both random errors (σ Random Error) and systematic biases (σ Bias). Biases are often referred to as systematic or external errors and may contain observational oversight. A constant error in tide or stage would be an example of a bias. Biases are reduced as much a possible by using the quality control measures previously discussed. Random errors are those errors present in the measurement system that cannot be easily minimized by additional calibration. Examples include echo sounder resolution, water sound velocity variations, tide/staff gage reading resolution, etc. The precision of the

observations is a measure of the closeness of a set of measurements--or their internal agreement. Accuracy relates to the closeness of measurements to their true or actual value.

a)



b)



c)

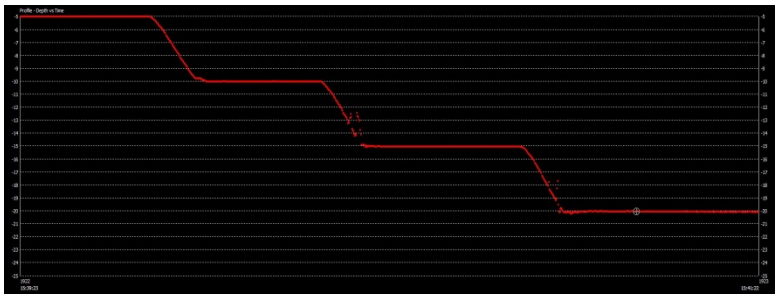


Figure 4: Digital Echogram of Bar-checks for All Lakes Surveyed a) Brushy Creek Lake 11/29/17 b) Greenleaf Lake 12/06/17 c) Shell Lake 03/28/18

Accuracy and precision were assessed utilizing a cross-line check method referenced in the approved QAPP (OWRB, 2018). The cross-line check was performed by collecting depth readings along survey track lines perpendicular to, and intersecting the survey transect lines. Hypack's Cross Check Statistics program was used to assess vertical accuracy and confidence measures of the recorded depths at the points where the lines intersected. This program tabulates and statistically analyzed the depth differences between overlapping points of single beam data. The program provides a report calculating the standard deviation and mean difference. **Table E- 2** containing the results of the cross-line checks; include the number of QC intersections, arithmetic mean (Bias), and the standard deviation (Random Error) for all reservoirs which can be found in **APPENDIX E.**

Depth Accuracy Calculation

Mean difference and the standard deviation can be used to calculate the Root Mean Square (RMS) error employing **Equation 2**. The RMS error estimate is used to compare relative accuracies of estimates that differ substantially in bias and precision (USACE, 2002). According to the recommended standards in the approved QAPP; the RMS at the 95% confidence level should not exceed a tolerance of ± 2.0 ft for reservoir surveys (OWRB, 2018). This simply means that on average, 19 of every 20 observed depths will fall within the specified accuracy tolerance.

Equation 2: Depth/Elevation Accuracy Calculation

$$RMS = \sqrt{\sigma^2{}_{Random\,error} + \sigma^2{}_{Bias}}$$

where:

Random error = standard deviation
Bias = mean difference
RMS = Root Mean Square error (68% confidence level)

and:

$$RMS\,(95\%)\ depth\ accuracy = 1.96 \times RMS(68\%)$$

All reservoirs resulted in an RMS of < ±2.0 ft with a 95% confidence level meeting the QAPP's MPS for reservoir surveys. The calculated 95% RMS for all reservoirs can be found in **Table 4**.

Table 4: Calculated Depth Accuracies for All Lakes Surveyed.

Calculated Depth Accuracy	
Lake	RMS at 95% Confidence
Brushy Creek Lake	±0.39 ft
Greenleaf Lake	±0.49 ft
Brushy Lake	±0.65 ft

GPS

The GPS system is an advanced high performance geographic data-acquisition tool that uses differential GPS (DGPS) to provide sub-meter positional accuracy on a second-by-second basis. Potential errors are reduced with DGPS because additional data from a reference GPS receiver at a known position are used to correct positions obtained during the survey. Prior to the survey, the settings on the Hemisphere R131 were checked to ensure correct configuration of the GPS receiver. These settings are discussed in more detail in the OWRB SOP for hydrographic surveying found in the approved project QAPP (OWRB, 2018).

Latency Test

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. Position latency in seconds was produced and adjustments were applied to the raw data using

Hypack's Single Beam Editor Program, during data processing. **Table E- 1** contains all latency offsets for all survey dates and can be found in **APPENDIX E.**

Data Processing

After uploading the collected data to an OWRB desktop, each raw data file was reviewed using the Single Beam Editor program within Hypack. The Single Beam Editor program allows the user to assign equipment 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. Data editing is covered in more detail in the approved project QAPP (OWRB, 2018).

The DGPS latency offset was applied. The Echosounder was corrected for the static vertical draft. These offsets were applied to all raw data sets. The SOS corrections were applied during editing of raw data using the sound velocity correction files created with the sound velocity tool.

An elevation correction file was produced using the Hypack's Manual Tides program to account for the variance in lake elevation at the time of data collection. The corrected depths were subtracted from the elevation reading to convert their depth in feet to an elevation within the Single Beam Editor program.

After editing the data for errors and correcting the spatial attributes (offsets and tide corrections), a data reduction scheme was utilized due to the large quantity of collected data. To accomplish this, the corrected data was sorted spatially at a 1 ft interval using the Sounding Selection program in Hypack. The resultant data was saved and exported out as a xyz.txt file containing X and Y horizontal coordinates as well as the Z elevations for all data points. The Hypack raw and corrected data files for all reservoirs are stored and available upon request.

GIS Application and Model Construction

Geographic Information Systems (GIS) software was used to process the edited XYZ data collected from the survey. The GIS software used was ArcGIS Desktop, version 10.2, from Environmental Systems Research Institute (ESRI). All of the GIS datasets created are in Oklahoma State Plane Coordinate System (North or South) 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 a point feature class in an ArcGIS file geodatabase. The point feature class contains the horizontal coordinates and the elevation and depth values associated with each collected point.

Volumetric and area calculations were derived from a Triangulated Irregular Network (TIN) surface model. A TIN consists of connected data points that form a network of triangles representing the bottom surface of the lake. The TIN model was created with ArcGIS using the collected survey data points; 2, 5, or 10 ft contours derived from a raster file interpolated from the collected survey data points; and inputs representing the lake boundary at normal pool elevation. Lake area and cumulative volume was calculated by slicing the TIN horizontally into planes 0.1 ft thick. The area and cumulative volume of each slice are shown in **APPENDIX A: Area-Capacity Data.**

Contours, depth ranges, and the shaded relief maps were derived from a constructed digital elevation model grid. This grid was created using the ArcGIS Topo to Raster Tool and had a spatial resolution of 1 ft Contours were created at a 2, 5, or 10 ft interval using the ArcGIS contour tool. Contour lines were edited to allow for polygon topology improving accuracy and general smoothness of the lines. The contour lines were edited visually paying close attention to the channel area, while also ensuring the lines matched the original data set. The contours were then converted to a polygon feature class and attributed to show 2, 5, or 10 ft depth ranges across the lake.

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 all reservoirs are stored and available upon request along with all GIS Data.

RESULTS

Brushy Creek Lake
Results from the November 2017 OWRB survey indicate that Brushy Creek Lake encompasses 227.92 surface acres and contains a cumulative capacity of 3534.08 acre-ft at the normal pool elevation of 633.86 ft (NAVD88). The mean depth for Brushy Creek Lake is 15.51 ft, while the deepest point measured was 37.70 ft. Lake Maps can be found in **APPENDIX B: Brushy Creek Lake Maps**.

Greenleaf Lake
Results from the December 2017 OWRB survey indicate that Greenleaf Lake encompasses 718.52 surface acres and contains a cumulative capacity of 10384.38 acre-ft at the normal pool elevation of 510.01 ft (NAVD88). The average depth for Greenleaf Lake is 14.45 ft, while the deepest point measured was 44.64 ft. Lake Maps can be found in **APPENDIX C: Greenleaf Lake Maps**.

Shell Lake
Results from the March 2018 OWRB survey indicate that Shell Lake encompasses 560.19 surface acres and contains a cumulative capacity of 8234.22 acre-ft at the normal pool elevation of 725.38 ft (NAVD88). The average depth for Shell Lake is 14.70 ft, while the deepest point measured was 47.36 ft. Lake Maps can be found in **APPENDIX D: Shell Lake Maps**.

SUMMARY and COMPARISON

Table 5 displays areas and volumes calculated at normal pool elevations for both design specifications and the current surveys. Percent change was then calculated for area, capacity, and average depth. Caution should be used when directly comparing between the design specifications and the current surveys conducted by the OWRB as different methods were used to collect the data and extrapolate capacity and area. In order to make the most accurate comparison across surveys, it is the recommendation of the OWRB that additional/future surveys utilizing the same methods used in the current surveys be conducted in 10 years. By

using the current survey figures as a baseline, similarly performed future surveys would allow for accurate mean sedimentation rates to be determined. All current calculated changes are only estimations and can be verified using the additional surveys mentioned above.

Table 5: Areas and Volumes calculated at normal pool elevations during design specifications and current survey periods for all lakes (OWRB, 1990). *Areas at conservation elevation not available

Feature	Survey Year		Change (%)
	Design Specifications	Current Survey	
Brushy Creek Lake – November 2017			
Area (acres)	*	227.92	N/A
Capacity (acre-ft)	3513	3534.08	0.60
Mean depth (ft)	N/A	15.51	N/A
Greenleaf Lake – December 2017			
Area (acres)	*	718.52	N/A
Capacity (acre-ft)	14720	10384.38	29.45
Mean depth (ft)	N/A	14.45	N/A
Shell Lake – March 2018			
Area (acres)	573	560.19	2.24
Capacity (acre-ft)	9500	8234.22	13.24
Mean depth (ft)	16.58	14.70	11.34

Brushy Creek Lake

The change in surface area of Brushy Creek Lake could not be calculated due to the lack of an area estimation at normal conservation elevation in the design specifications. The November 2017 survey shows that Brushy Creek Lake had an apparent increase in capacity of 21.08 acre-ft or 0.60%. Changes in average depth for the reservoir could not be calculated due to the lack of design specification area estimates. Brushy Creek Lake calculations were done using design specifications in a lake planning document (Mickle – Daniel Associates, 1963). Estimation of the average annual capacity loss was not done due to the increase in capacity; this increase in capacity may be attributed to updated survey methods.

Greenleaf Lake

The change in surface area of Greenleaf Lake could not be calculated due to the lack of an area estimation at normal conservation elevation in the design specifications. The December 2017 survey shows that Greenleaf Lake had an apparent decrease in capacity of 4335.62 acre-ft or 29.45%. Changes in average depth for the reservoir could not be calculated due to the lack of design specification area estimates. Greenleaf Lake calculations were done using design specifications from the Oklahoma Water Atlas (OWRB, 1990). The estimated average annual loss in capacity is 55.58 acre-ft or 0.38% over the 78-year life of the reservoir.

Shell Lake

The surface area of Shell Lake has decreased 12.81 acres or 2.24%. The March 2018 survey shows that Shell Lake had a decrease in capacity of 1265.78 acre-ft or 13.32%. Average depth

for the reservoir has decreased 1.88 ft or 11.9%. Shell Lake calculations were done using design specifications from the Oklahoma Water Atlas (OWRB, 1990). The estimated average annual loss in capacity is 13.19 acre-ft or 0.14% over the 96-year life of the reservoir.

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APPENDIX A: Area-Capacity Data

Table A- 1: Brushy Creek Lake Area by 0.1 ft Increments.

Brushy Creek Area Table Area in Acres by 0.1 ft Elevation Increments November 2017 Survey Oklahoma Water Resources Board										
Elevation in Feet	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
595										0.00
596	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
597	0.03	0.05	0.07	0.09	0.12	0.15	0.18	0.21	0.24	0.27
598	0.30	0.33	0.36	0.39	0.42	0.45	0.49	0.52	0.57	0.63
599	0.70	0.79	0.89	1.01	1.15	1.31	1.46	1.62	1.80	2.00
600	2.25	2.56	2.94	3.40	3.96	4.58	5.22	5.87	6.53	7.19
601	7.83	8.45	9.12	9.74	10.36	10.96	11.52	12.06	12.61	13.17
602	13.72	14.28	14.81	15.31	15.81	16.29	16.74	17.15	17.54	17.88
603	18.20	18.52	18.85	19.15	19.47	19.80	20.13	20.45	20.79	21.11
604	21.44	21.75	22.05	22.34	22.64	22.95	23.25	23.57	23.90	24.27
605	24.65	25.04	25.44	25.83	26.24	26.63	27.03	27.43	27.83	28.23
606	28.64	29.06	29.47	29.89	30.30	30.70	31.09	31.46	31.81	32.12
607	32.40	32.68	32.97	33.25	33.53	33.82	34.13	34.45	34.81	35.23
608	35.70	36.24	36.80	37.35	37.89	38.42	38.90	39.38	39.94	40.50
609	41.10	41.72	42.36	43.01	43.65	44.26	44.88	45.48	46.10	46.78
610	47.51	48.26	49.00	49.70	50.39	51.04	51.65	52.26	52.87	53.48
611	54.11	54.78	55.45	56.12	56.78	57.47	58.22	58.91	59.58	60.25
612	60.88	61.50	62.13	62.79	63.49	64.21	64.92	65.57	66.18	66.80
613	67.37	67.94	68.49	69.04	69.58	70.16	70.76	71.39	72.06	72.76
614	73.48	74.21	74.97	75.76	76.58	77.41	78.30	79.20	80.10	80.96
615	81.86	82.75	83.56	84.36	85.19	86.07	87.00	87.98	88.87	89.75
616	90.59	91.42	92.18	92.96	93.77	94.58	95.42	96.27	97.14	98.05
617	99.02	99.99	100.96	101.90	102.82	103.75	104.64	105.52	106.46	107.40
618	108.36	109.22	110.08	110.96	111.81	112.67	113.50	114.30	115.13	115.88
619	116.61	117.33	118.03	118.68	119.27	119.88	120.49	121.07	121.64	122.21
620	122.78	123.36	123.96	124.57	125.19	125.83	126.54	127.32	128.08	128.83
621	129.58	130.39	131.24	132.14	133.08	134.01	134.89	135.71	136.55	137.39
622	138.21	139.03	139.86	140.67	141.53	142.40	143.33	144.25	145.12	145.97
623	146.89	147.71	148.48	149.22	150.00	150.77	151.54	152.27	152.99	153.72
624	154.46	155.20	155.95	156.73	157.50	158.24	158.97	159.71	160.42	161.11
625	161.88	162.65	163.36	164.05	164.78	165.52	166.24	166.97	167.70	168.48
626	169.23	169.99	170.72	171.45	172.18	172.90	173.65	174.41	175.18	175.98
627	176.77	177.53	178.31	179.09	179.88	180.75	181.57	182.31	183.03	183.73
628	184.41	185.08	185.77	186.45	187.15	187.90	188.66	189.44	190.28	191.17
629	192.18	194.15	194.93	195.59	196.22	196.85	197.83	198.48	199.11	199.73
630	200.36	201.47	202.16	202.74	203.30	203.84	204.47	204.98	205.48	205.98
631	206.49	207.38	207.91	208.45	209.00	209.55	210.44	211.02	211.62	212.22
632	212.83	213.75	214.37	214.99	215.61	216.23	217.02	217.65	218.30	218.95
633	219.61	220.69	221.38	222.08	222.79	223.49	224.64	225.60	226.57	227.92

Table A- 2: Brushy Creek Lake Capacity by 0.1 ft Increments.

Brushy Creek Capacity Table Volume in Acre-Feet by 0.1 ft Elevation Increments November 2017 Survey Oklahoma Water Resources Board										
Elevation in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
595										0.00
596	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
597	0.01	0.01	0.02	0.02	0.03	0.05	0.06	0.08	0.11	0.13
598	0.16	0.19	0.23	0.26	0.30	0.35	0.39	0.45	0.50	0.56
599	0.63	0.70	0.78	0.88	0.99	1.11	1.25	1.40	1.57	1.76
600	1.97	2.21	2.49	2.80	3.17	3.60	4.09	4.64	5.26	5.95
601	6.70	7.51	8.39	9.34	10.34	11.41	12.53	13.71	14.94	16.23
602	17.58	18.98	20.43	21.94	23.50	25.10	26.75	28.45	30.18	31.95
603	33.76	35.59	37.46	39.36	41.29	43.26	45.25	47.28	49.35	51.44
604	53.57	55.73	57.92	60.14	62.39	64.66	66.97	69.32	71.69	74.10
605	76.54	79.03	81.55	84.12	86.72	89.36	92.05	94.77	97.53	100.34
606	103.18	106.06	108.99	111.96	114.97	118.02	121.11	124.24	127.40	130.59
607	133.82	137.08	140.36	143.67	147.01	150.38	153.77	157.20	160.66	164.17
608	167.71	171.31	174.96	178.67	182.43	186.24	190.11	194.02	197.99	202.01
609	206.09	210.23	214.44	218.71	223.04	227.44	231.89	236.41	240.99	245.63
610	250.35	255.13	260.00	264.93	269.94	275.01	280.15	285.34	290.60	295.92
611	301.29	306.74	312.25	317.83	323.47	329.19	334.97	340.83	346.75	352.74
612	358.80	364.92	371.10	377.35	383.66	390.04	396.50	403.03	409.62	416.26
613	422.97	429.74	436.56	443.44	450.37	457.35	464.40	471.51	478.68	485.92
614	493.23	500.62	508.08	515.61	523.23	530.93	538.71	546.59	554.55	562.61
615	570.75	578.98	587.29	595.69	604.17	612.73	621.38	630.13	638.97	647.91
616	656.92	666.02	675.20	684.46	693.80	703.21	712.71	722.30	731.97	741.73
617	751.58	761.53	771.58	781.72	791.96	802.29	812.71	823.21	833.81	844.51
618	855.30	866.17	877.14	888.19	899.33	910.56	921.86	933.25	944.73	956.28
619	967.90	979.60	991.37	1003.20	1015.10	1027.06	1039.07	1051.15	1063.29	1075.48
620	1087.73	1100.04	1112.40	1124.83	1137.32	1149.87	1162.49	1175.18	1187.95	1200.80
621	1213.72	1226.71	1239.80	1252.96	1266.23	1279.58	1293.03	1306.56	1320.17	1333.87
622	1347.65	1361.51	1375.45	1389.48	1403.59	1417.79	1432.07	1446.45	1460.92	1475.48
623	1490.12	1504.85	1519.66	1534.55	1549.51	1564.54	1579.66	1594.85	1610.11	1625.45
624	1640.86	1656.34	1671.90	1687.53	1703.24	1719.03	1734.89	1750.83	1766.83	1782.91
625	1799.06	1815.28	1831.58	1847.96	1864.40	1880.91	1897.50	1914.16	1930.89	1947.70
626	1964.59	1981.55	1998.59	2015.69	2032.87	2050.13	2067.46	2084.86	2102.34	2119.90
627	2137.53	2155.25	2173.04	2190.91	2208.86	2226.89	2245.01	2263.20	2281.47	2299.81
628	2318.21	2336.69	2355.23	2373.84	2392.52	2411.27	2430.10	2449.01	2467.99	2487.06
629	2506.23	2525.55	2545.01	2564.54	2584.13	2603.78	2623.52	2643.33	2663.21	2683.15
630	2703.16	2723.25	2743.43	2763.68	2783.98	2804.34	2824.76	2845.23	2865.75	2886.32
631	2906.95	2927.64	2948.41	2969.23	2990.10	3011.03	3032.03	3053.10	3074.23	3095.43
632	3116.68	3138.01	3159.42	3180.88	3202.41	3224.01	3245.67	3267.40	3289.20	3311.06
633	3332.99	3355.01	3377.11	3399.29	3421.53	3443.84	3466.25	3488.76	3511.37	3534.08

Table A- 3: Greenleaf Lake Area by 0.1 ft Increments.

Greenleaf Area Table Area in Acres by 0.1 ft Elevation Increments December 2017 Survey Oklahoma Water Resources Board										
Elevation in Feet	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
466	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.08	0.12	0.18
467	0.27	0.39	0.54	0.69	0.85	0.97	1.09	1.20	1.30	1.41
468	1.53	1.63	1.73	1.83	1.92	2.03	2.18	2.35	2.57	2.78
469	3.02	3.26	3.52	3.78	4.07	4.42	4.79	5.11	5.42	5.74
470	6.12	6.49	6.84	7.19	7.51	7.83	8.14	8.45	8.77	9.13
471	9.44	9.74	10.02	10.29	10.55	10.81	11.06	11.31	11.56	11.81
472	12.05	12.28	12.50	12.73	12.95	13.18	13.41	13.64	13.87	14.11
473	14.34	14.57	14.80	15.03	15.27	15.50	15.73	15.97	16.23	16.51
474	16.79	17.06	17.36	17.70	18.05	18.38	18.74	19.10	19.46	19.83
475	20.18	20.57	20.95	21.33	21.70	22.07	22.44	22.81	23.18	23.55
476	23.93	24.33	24.72	25.14	25.60	26.06	26.58	27.10	27.61	28.10
477	28.61	29.13	29.66	30.17	30.69	31.21	31.77	32.34	32.92	33.51
478	34.12	34.75	35.42	36.11	36.83	37.57	38.37	39.23	40.11	40.99
479	41.92	42.89	43.86	44.86	45.82	46.78	47.75	48.72	49.68	50.61
480	51.58	52.57	53.65	54.69	55.70	56.67	57.62	58.63	59.66	60.71
481	61.83	62.96	64.07	65.19	66.32	67.45	68.56	69.64	70.68	71.69
482	72.67	73.63	74.62	75.64	76.67	77.76	78.89	80.04	81.20	82.42
483	83.64	84.93	86.28	87.67	89.16	90.58	91.86	93.14	94.55	95.99
484	97.41	98.77	100.17	101.54	102.83	104.12	105.41	106.71	108.01	109.35
485	110.70	112.05	113.43	114.90	116.44	118.01	119.60	121.23	122.87	124.52
486	126.20	127.92	129.64	131.39	133.18	135.04	136.86	138.47	140.02	141.57
487	143.16	144.77	146.40	148.00	149.54	151.06	152.59	154.12	155.69	157.31
488	158.98	160.73	162.59	164.59	166.51	168.45	170.45	172.44	174.39	176.30
489	178.28	180.37	182.49	184.65	186.83	188.93	191.05	193.26	195.43	197.76
490	200.25	202.67	205.15	207.42	209.65	212.02	214.30	216.59	218.87	221.20
491	223.58	226.00	228.55	231.30	233.96	236.56	239.31	242.19	245.19	248.19
492	251.26	254.52	257.79	261.04	264.39	267.71	270.82	273.89	277.09	280.36
493	283.85	287.10	290.16	293.18	296.15	298.92	301.53	303.89	306.10	308.47
494	310.64	312.62	314.66	316.69	318.75	320.85	323.09	325.30	327.50	329.75
495	332.21	334.73	337.43	339.94	342.17	344.37	346.89	349.51	352.17	354.78
496	357.10	359.39	361.78	364.19	366.67	369.37	372.01	374.41	376.82	379.14
497	381.40	383.68	385.96	388.13	390.35	392.69	395.06	397.57	400.05	402.55
498	405.27	408.29	411.15	413.84	416.39	418.72	421.05	423.26	425.45	427.64
499	429.90	432.15	434.39	436.71	439.13	441.58	444.01	446.40	448.77	451.13
500	453.46	455.80	458.11	460.40	462.74	465.12	467.62	470.22	472.80	475.37
501	477.93	480.42	482.86	485.30	487.71	490.14	492.51	494.81	497.08	499.35
502	501.62	503.92	506.22	508.61	511.00	513.46	515.97	518.73	521.52	524.13
503	526.54	528.95	531.40	533.63	535.86	538.06	540.17	542.27	544.47	546.80
504	549.28	551.85	554.32	556.58	558.77	561.11	563.38	565.65	567.97	570.26
505	572.60	575.04	577.52	580.05	582.59	585.24	588.02	590.74	593.43	596.17
506	598.94	601.80	604.67	607.52	610.36	613.21	616.06	618.92	622.00	624.90
507	627.63	630.26	632.79	635.25	637.64	640.09	642.49	645.00	647.49	649.94
508	652.20	654.46	656.70	658.93	661.17	663.40	665.63	667.85	670.08	672.30
509	674.52	676.74	678.96	681.18	683.39	685.60	687.82	690.03	692.24	694.44
510	718.52									

Table A- 4: Greenleaf Lake Capacity by 0.1 ft Increments.

Greenleaf Capacity Table Volume in Acre-Feet by 0.1 ft Elevation Increments December 2017 Survey Oklahoma Water Resources Board										
Elevation in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
466	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
467	0.04	0.06	0.09	0.14	0.20	0.28	0.37	0.47	0.58	0.71
468	0.84	0.99	1.15	1.32	1.50	1.68	1.88	2.09	2.32	2.56
469	2.83	3.12	3.44	3.77	4.14	4.53	4.96	5.42	5.91	6.44
470	6.99	7.59	8.22	8.88	9.59	10.32	11.09	11.89	12.72	13.58
471	14.47	15.40	16.36	17.35	18.36	19.41	20.47	21.57	22.69	23.83
472	25.00	26.19	27.41	28.65	29.91	31.19	32.50	33.83	35.18	36.56
473	37.96	39.38	40.82	42.29	43.78	45.30	46.84	48.40	49.98	51.59
474	53.23	54.90	56.59	58.31	60.06	61.85	63.67	65.53	67.42	69.35
475	71.31	73.31	75.35	77.42	79.54	81.69	83.88	86.10	88.37	90.67
476	93.00	95.38	97.79	100.24	102.73	105.27	107.85	110.48	113.17	115.90
477	118.69	121.53	124.41	127.35	130.34	133.39	136.48	139.63	142.83	146.10
478	149.42	152.80	156.24	159.75	163.33	166.97	170.69	174.49	178.37	182.34
479	186.39	190.54	194.77	199.11	203.55	208.08	212.71	217.44	222.26	227.18
480	232.20	237.31	242.52	247.83	253.24	258.76	264.38	270.10	275.91	281.82
481	287.84	293.97	300.21	306.56	313.02	319.60	326.29	333.09	340.00	347.01
482	354.13	361.35	368.67	376.08	383.59	391.21	398.93	406.76	414.71	422.77
483	430.95	439.25	447.68	456.24	464.94	473.78	482.77	491.89	501.14	510.52
484	520.05	529.72	539.53	549.48	559.56	569.78	580.13	590.61	601.21	611.95
485	622.82	633.82	644.96	656.23	667.64	679.21	690.93	702.81	714.86	727.06
486	739.43	751.97	764.67	777.55	790.60	803.83	817.24	830.84	844.61	858.53
487	872.61	886.85	901.24	915.80	930.52	945.40	960.43	975.61	990.95	1006.44
488	1022.09	1037.90	1053.88	1070.05	1086.41	1102.97	1119.71	1136.66	1153.80	1171.14
489	1188.68	1206.41	1224.34	1242.48	1260.84	1279.41	1298.20	1317.20	1336.41	1355.85
490	1375.50	1395.41	1415.55	1435.95	1456.57	1477.43	1498.51	1519.83	1541.37	1563.14
491	1585.15	1607.39	1629.86	1652.59	1675.58	1698.84	1722.37	1746.16	1770.24	1794.61
492	1819.27	1844.25	1869.53	1895.15	1921.09	1947.36	1973.97	2000.90	2028.13	2055.68
493	2083.55	2111.76	2140.31	2169.18	2198.34	2227.81	2257.57	2287.59	2317.87	2348.37
494	2379.09	2410.05	2441.21	2472.58	2504.15	2535.92	2567.90	2600.09	2632.51	2665.15
495	2698.01	2731.11	2764.45	2798.06	2831.93	2866.04	2900.36	2934.92	2969.75	3004.83
496	3040.18	3075.77	3111.60	3147.65	3183.95	3220.49	3257.30	3294.37	3331.69	3369.25
497	3407.05	3445.08	3483.33	3521.81	3560.52	3599.44	3638.59	3677.98	3717.61	3757.49
498	3797.62	3838.01	3878.68	3919.66	3960.91	4002.42	4044.18	4086.17	4128.38	4170.82
499	4213.47	4256.35	4299.45	4342.78	4386.33	4430.13	4474.16	4518.44	4562.96	4607.72
500	4652.71	4697.94	4743.41	4789.10	4835.03	4881.19	4927.58	4974.21	5021.11	5068.26
501	5115.67	5163.33	5211.25	5259.42	5307.82	5356.47	5405.37	5454.50	5503.87	5553.46
502	5603.28	5653.33	5703.61	5754.11	5804.85	5855.83	5907.06	5958.53	6010.26	6062.27
503	6114.56	6167.09	6219.87	6272.89	6326.14	6379.61	6433.31	6487.22	6541.34	6595.68
504	6650.24	6705.05	6760.10	6815.41	6870.96	6926.73	6982.72	7038.95	7095.40	7152.08
505	7208.99	7266.13	7323.51	7381.14	7439.02	7497.15	7555.54	7614.20	7673.14	7732.35
506	7791.83	7851.58	7911.62	7971.94	8032.55	8093.45	8154.63	8216.09	8277.84	8339.89
507	8402.23	8464.86	8527.75	8590.91	8654.31	8717.96	8781.84	8845.97	8910.34	8974.97
508	9039.84	9104.95	9170.28	9235.84	9301.62	9367.63	9433.85	9500.31	9566.98	9633.88
509	9700.99	9768.34	9835.90	9903.68	9971.69	10039.92	10108.37	10177.04	10245.93	10315.05
510	10384.38									

Table A- 5: Shell Lake Area by 0.1 ft Increments.

Shell Area Table Area in Acres by 0.1 ft Elevation Increments March 2018 Survey Oklahoma Water Resources Board										
Elevation in Feet	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
677									0.00	0.00
678	0.00	0.00	0.00	0.02	0.05	0.14	0.27	0.42	0.62	0.87
679	1.12	1.39	1.64	1.90	2.18	2.47	2.76	3.07	3.40	3.73
680	4.10	4.52	4.97	5.47	5.93	6.40	6.87	7.34	7.78	8.21
681	8.64	9.06	9.48	9.90	10.30	10.72	11.14	11.54	11.93	12.35
682	12.76	13.19	13.63	14.07	14.49	14.89	15.27	15.63	15.99	16.33
683	16.67	16.99	17.31	17.63	17.95	18.28	18.63	18.95	19.27	19.61
684	19.98	20.35	20.71	21.08	21.44	21.82	22.21	22.57	22.92	23.27
685	23.65	24.05	24.45	24.86	25.27	25.68	26.11	26.55	26.99	27.40
686	27.79	28.17	28.55	28.90	29.23	29.55	29.88	30.22	30.55	30.87
687	31.18	31.48	31.79	32.10	32.41	32.71	33.01	33.30	33.58	33.87
688	34.15	34.41	34.68	34.95	35.21	35.47	35.73	36.00	36.26	36.52
689	36.78	37.05	37.33	37.60	37.87	38.14	38.41	38.70	38.99	39.28
690	39.58	39.89	40.21	40.53	40.86	41.19	41.52	41.86	42.20	42.56
691	42.92	43.27	43.62	43.98	44.35	44.72	45.09	45.45	45.81	46.18
692	46.57	46.97	47.37	47.75	48.13	48.51	48.88	49.26	49.64	49.98
693	50.31	50.63	50.95	51.26	51.58	51.88	52.18	52.47	52.76	53.05
694	53.34	53.64	53.93	54.23	54.54	54.86	55.18	55.52	55.86	56.20
695	56.54	56.89	57.27	57.66	58.08	58.50	58.93	59.39	59.87	60.31
696	60.75	61.18	61.63	62.07	62.51	62.98	63.48	63.99	64.54	65.05
697	65.54	66.02	66.51	66.98	67.46	67.93	68.40	68.87	69.35	69.82
698	70.31	70.81	71.31	71.82	72.35	72.86	73.38	73.92	74.46	75.01
699	75.56	76.11	76.65	77.19	77.73	78.27	78.80	79.34	79.89	80.45
700	81.01	81.57	82.13	82.69	83.26	83.86	84.48	85.10	85.71	86.34
701	86.99	87.67	88.36	89.10	89.87	90.67	91.48	92.27	93.08	93.92
702	94.82	95.78	96.84	98.02	99.34	100.66	101.94	103.16	104.33	105.50
703	106.67	107.83	109.03	110.23	111.43	112.61	113.83	115.05	116.25	117.46
704	118.66	119.88	121.15	122.44	123.75	125.11	126.51	127.91	129.31	130.68
705	132.06	133.47	134.98	136.63	138.38	140.24	142.15	143.87	145.59	147.29
706	149.03	150.86	152.75	154.62	156.55	158.55	160.88	163.20	165.47	167.62
707	169.79	172.02	174.24	176.39	178.50	180.61	182.72	184.79	186.87	188.97
708	191.19	193.42	195.60	197.77	199.91	202.10	204.31	206.49	208.64	210.75
709	212.90	214.95	216.99	219.02	220.97	222.90	224.83	226.80	228.85	230.91
710	233.03	235.16	237.27	239.33	241.36	243.32	245.29	247.27	249.25	251.23
711	253.20	255.12	257.00	258.87	260.76	262.65	264.52	266.44	268.38	270.36
712	272.36	274.32	276.34	278.34	280.41	282.52	284.58	286.68	288.87	290.95
713	293.01	295.15	297.31	299.50	301.70	303.98	306.29	308.63	310.99	313.34
714	315.70	318.11	320.52	322.93	325.28	327.57	329.79	332.04	334.34	336.66
715	339.02	341.41	343.77	346.12	348.50	350.93	353.36	355.77	358.18	360.57
716	362.96	365.35	367.82	370.37	372.86	375.26	377.58	379.85	382.14	384.52
717	387.11	389.85	392.39	394.83	397.33	399.87	402.43	405.02	407.37	409.53
718	411.37	413.23	415.07	417.10	419.29	421.12	422.83	424.56	426.25	427.93
719	429.59	431.25	432.91	434.56	436.21	437.91	439.63	441.33	443.06	444.75
720	446.41	448.03	449.63	451.23	452.83	454.42	456.02	457.63	459.23	460.83
721	462.44	464.04	465.65	467.26	468.87	470.48	472.10	473.71	475.33	476.95
722	478.57	480.19	481.81	483.44	485.06	486.69	488.32	489.94	491.58	493.21
723	494.84	496.48	498.11	499.75	501.39	503.03	504.67	506.32	507.96	509.61
724	511.26	512.91	514.56	516.21	517.87	519.52	521.18	522.83	524.49	526.16
725	527.82	529.48	531.15	532.81	560.19					

Table A- 6: Shell Lake Capacity by 0.1 ft Increments.

Shell Capacity Table Volume in Acre-Feet by 0.1 ft Elevation Increments March 2018 Survey Oklahoma Water Resources Board										
Elevation in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
677									0.00	0.00
678	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.12
679	0.19	0.29	0.42	0.57	0.75	0.95	1.18	1.44	1.74	2.06
680	2.42	2.81	3.24	3.71	4.23	4.80	5.42	6.08	6.79	7.55
681	8.35	9.19	10.08	11.00	11.97	12.98	14.03	15.13	16.26	17.43
682	18.65	19.90	21.20	22.54	23.93	25.36	26.82	28.33	29.88	31.46
683	33.07	34.72	36.41	38.12	39.87	41.65	43.46	45.31	47.19	49.10
684	51.04	53.02	55.04	57.09	59.18	61.30	63.47	65.67	67.91	70.18
685	72.49	74.84	77.22	79.65	82.11	84.62	87.17	89.76	92.39	95.07
686	97.79	100.55	103.35	106.18	109.05	111.96	114.90	117.87	120.87	123.91
687	126.98	130.09	133.22	136.38	139.58	142.80	146.06	149.35	152.66	156.00
688	159.38	162.78	166.21	169.66	173.14	176.65	180.18	183.74	187.33	190.94
689	194.58	198.25	201.94	205.66	209.41	213.18	216.98	220.81	224.66	228.55
690	232.46	236.40	240.38	244.38	248.42	252.49	256.59	260.73	264.89	269.10
691	273.34	277.61	281.92	286.26	290.64	295.06	299.51	304.00	308.53	313.09
692	317.69	322.33	327.01	331.73	336.48	341.27	346.11	350.98	355.88	360.83
693	365.81	370.82	375.87	380.95	386.06	391.20	396.38	401.58	406.81	412.07
694	417.36	422.68	428.03	433.41	438.82	444.26	449.73	455.23	460.76	466.33
695	471.94	477.57	483.24	488.95	494.70	500.48	506.31	512.18	518.10	524.06
696	530.07	536.13	542.22	548.36	554.55	560.78	567.05	573.37	579.75	586.17
697	592.65	599.18	605.76	612.39	619.06	625.78	632.55	639.37	646.23	653.14
698	660.10	667.11	674.17	681.27	688.43	695.64	702.90	710.21	717.57	724.99
699	732.47	739.99	747.58	755.22	762.91	770.65	778.45	786.31	794.22	802.18
700	810.19	818.27	826.40	834.58	842.82	851.12	859.47	867.89	876.37	884.91
701	893.51	902.18	910.91	919.71	928.58	937.53	946.56	955.67	964.86	974.12
702	983.47	992.91	1002.44	1012.07	1021.81	1031.68	1041.68	1051.81	1062.06	1072.44
703	1082.93	1093.54	1104.26	1115.11	1126.07	1137.15	1148.35	1159.68	1171.12	1182.69
704	1194.37	1206.18	1218.10	1230.16	1242.34	1254.64	1267.09	1279.67	1292.39	1305.25
705	1318.25	1331.39	1344.66	1358.08	1371.66	1385.41	1399.34	1413.47	1427.77	1442.24
706	1456.88	1471.70	1486.69	1501.87	1517.24	1532.80	1548.55	1564.52	1580.73	1597.16
707	1613.82	1630.69	1647.78	1665.09	1682.62	1700.37	1718.32	1736.49	1754.86	1773.45
708	1792.24	1811.25	1830.48	1849.93	1869.60	1889.48	1909.58	1929.90	1950.44	1971.20
709	1992.17	2013.35	2034.75	2056.34	2078.14	2100.14	2122.34	2144.72	2167.31	2190.09
710	2213.08	2236.27	2259.68	2283.30	2307.13	2331.17	2355.40	2379.83	2404.46	2429.28
711	2454.31	2479.53	2504.95	2530.55	2556.35	2582.33	2608.50	2634.86	2661.40	2688.14
712	2715.08	2742.22	2769.55	2797.08	2824.82	2852.75	2880.90	2909.26	2937.82	2966.60
713	2995.59	3024.79	3054.19	3083.82	3113.66	3143.72	3174.00	3204.51	3235.26	3266.24
714	3297.46	3328.91	3360.60	3392.53	3424.70	3457.11	3489.76	3522.63	3555.72	3589.04
715	3622.59	3656.37	3690.39	3724.65	3759.14	3793.87	3828.84	3864.06	3899.52	3935.21
716	3971.15	4007.33	4043.74	4080.40	4117.31	4154.47	4191.88	4229.52	4267.39	4305.49
717	4343.82	4382.40	4421.25	4460.36	4499.72	4539.33	4579.19	4619.31	4659.68	4700.30
718	4741.15	4782.20	4823.43	4864.84	4906.45	4948.27	4990.29	5032.49	5074.86	5117.40
719	5160.11	5202.98	5246.03	5289.24	5332.61	5376.15	5419.85	5463.73	5507.78	5552.00
720	5596.39	5640.95	5685.67	5730.55	5775.59	5820.80	5866.16	5911.68	5957.36	6003.21
721	6049.21	6095.37	6141.70	6188.18	6234.83	6281.63	6328.60	6375.73	6423.02	6470.47
722	6518.09	6565.86	6613.80	6661.90	6710.16	6758.59	6807.18	6855.93	6904.84	6953.92
723	7003.15	7052.56	7102.12	7151.85	7201.75	7251.80	7302.02	7352.41	7402.96	7453.67
724	7504.55	7555.60	7606.80	7658.18	7709.72	7761.42	7813.29	7865.32	7917.52	7969.89
725	8022.42	8075.12	8127.99	8181.02	8234.22					

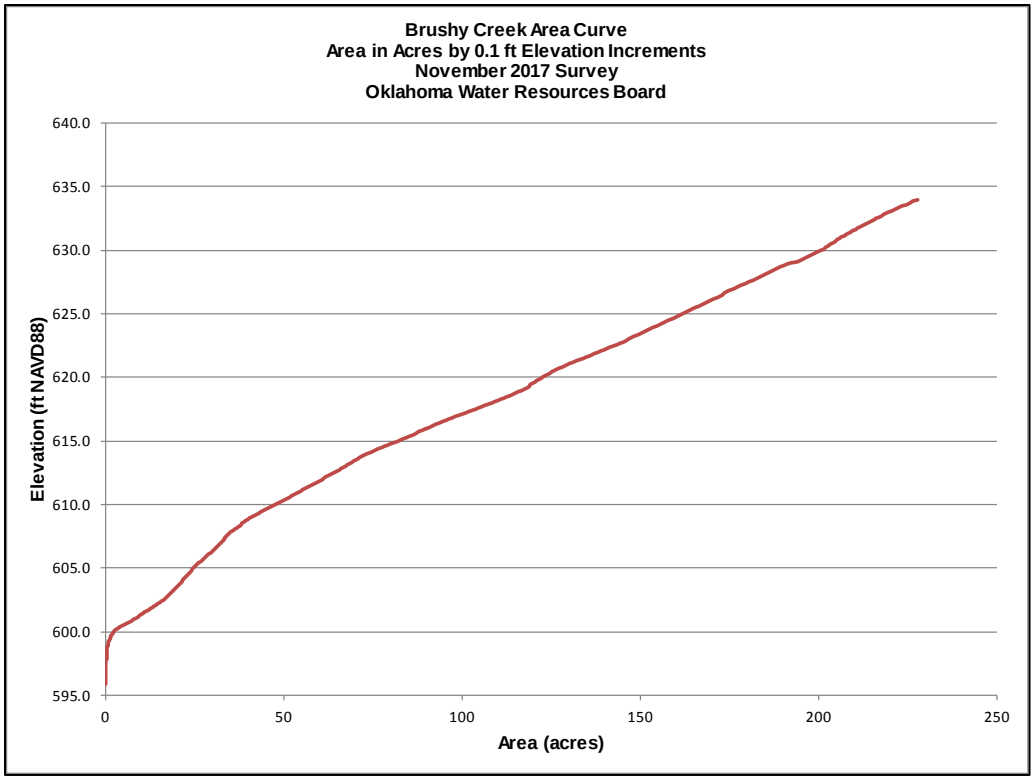

Figure A- 1: Area Curve for Brushy Creek Lake.

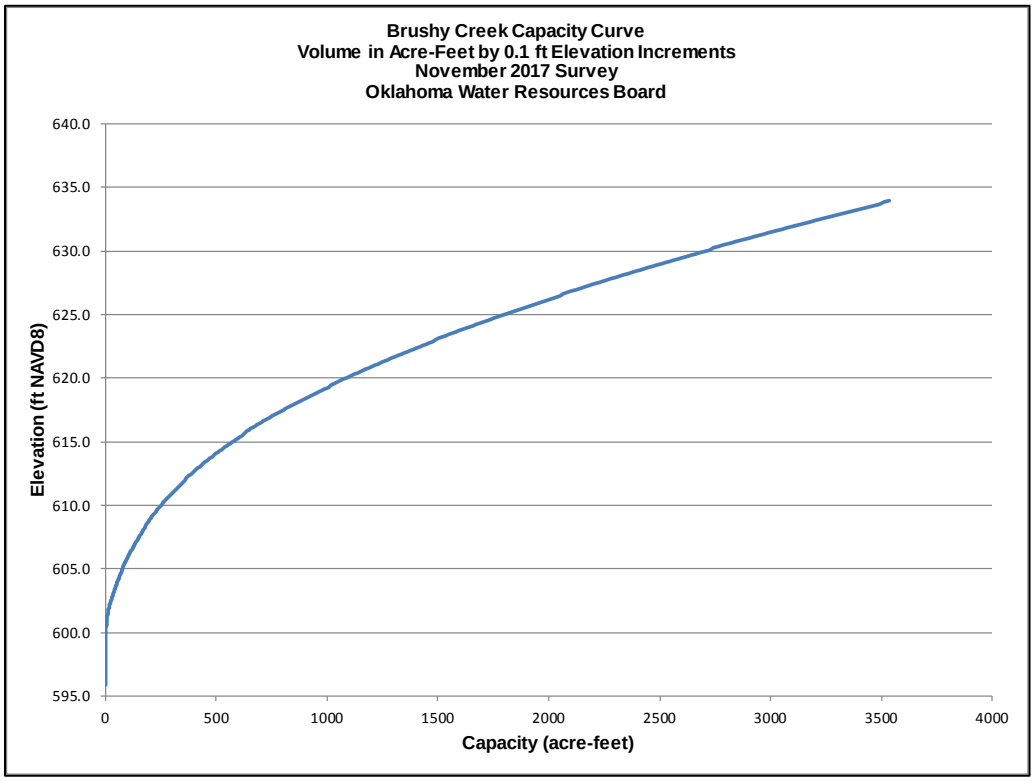

Figure A- 2: Cumulative Capacity Curve for Brushy Creek Lake.

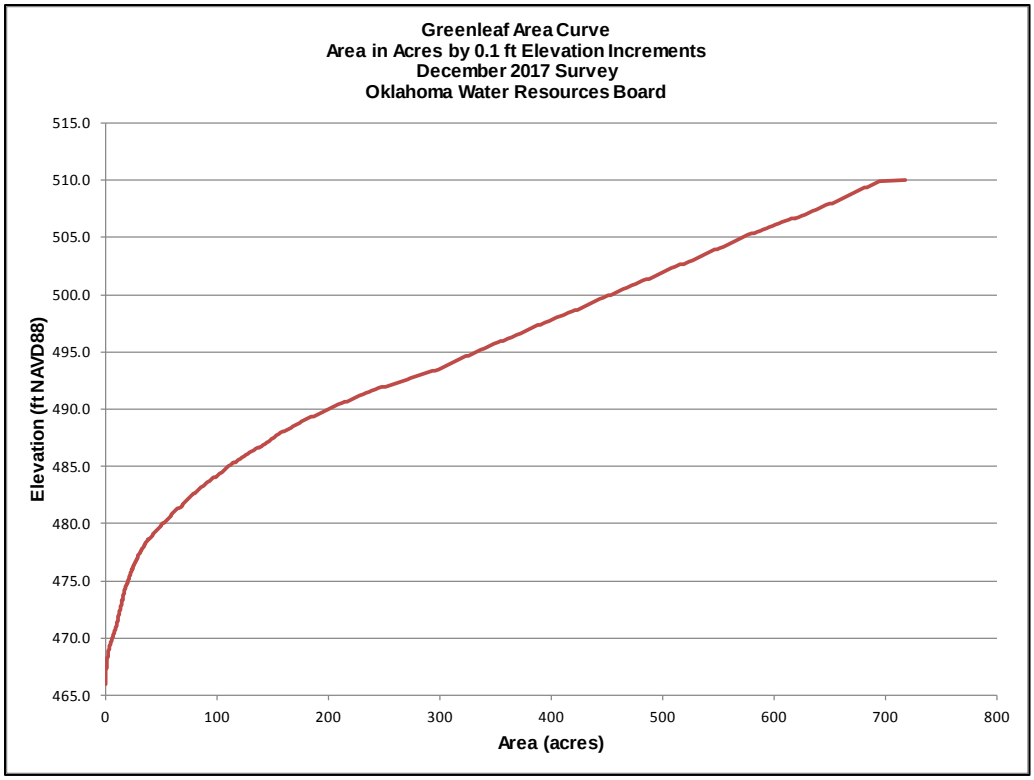

Figure A- 3: Area Curve for Greenleaf Lake.

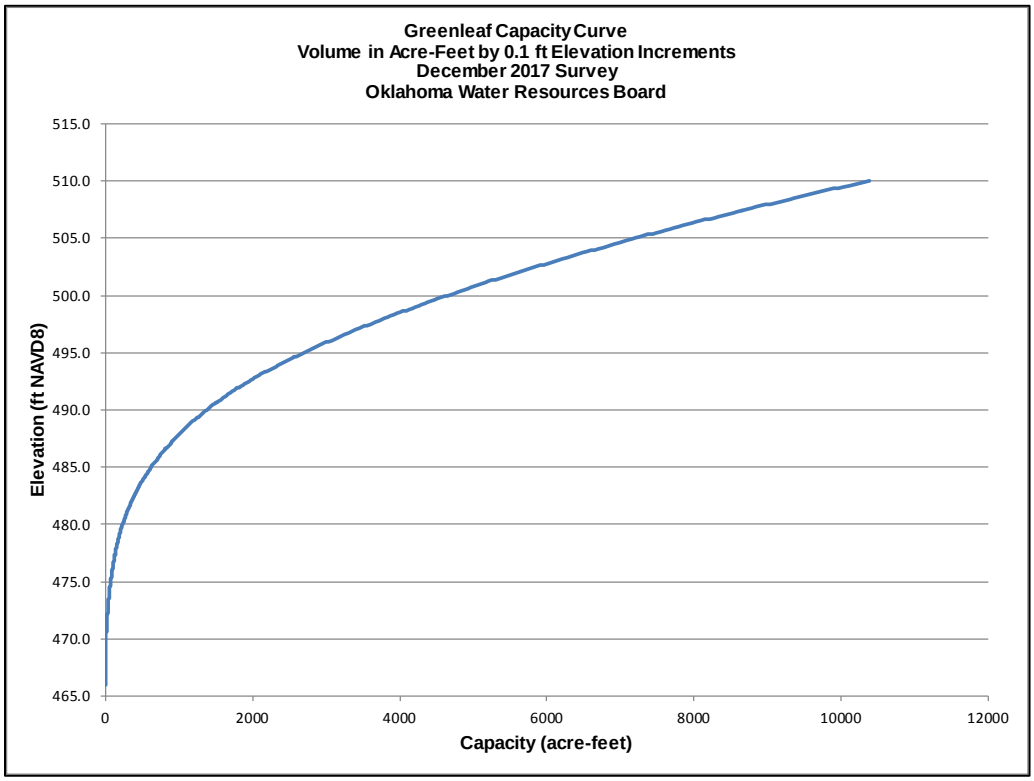

Figure A- 4: Cumulative Capacity Curve for Greenleaf Lake.

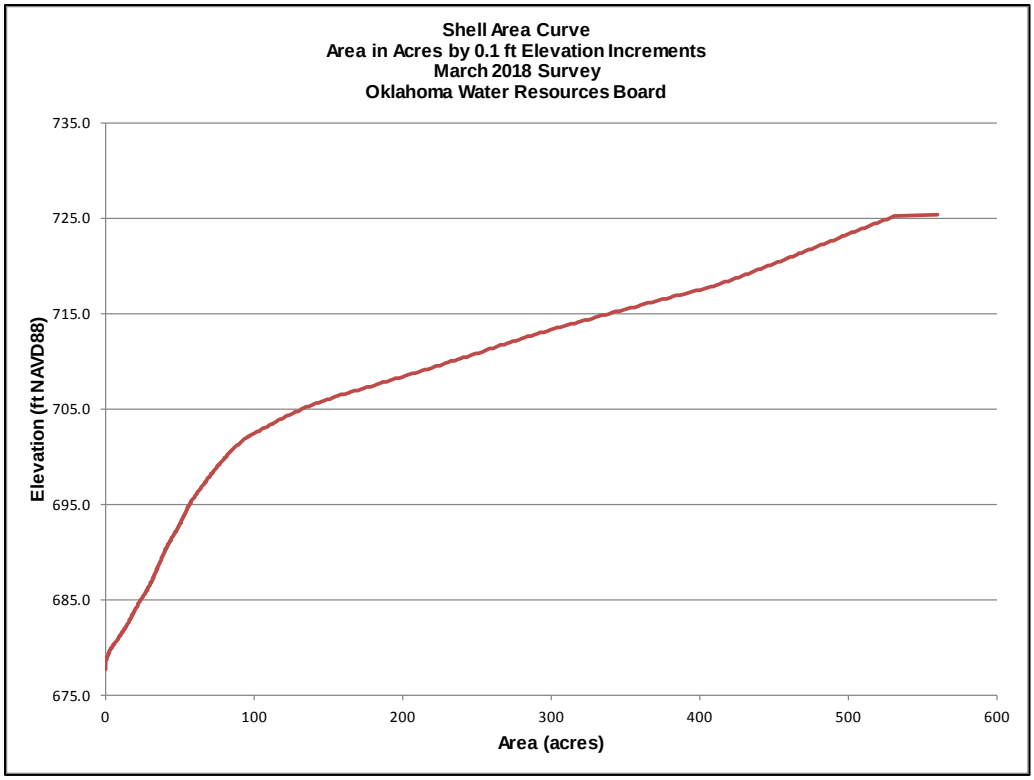

Figure A- 5: Area Curve for Shell Lake.

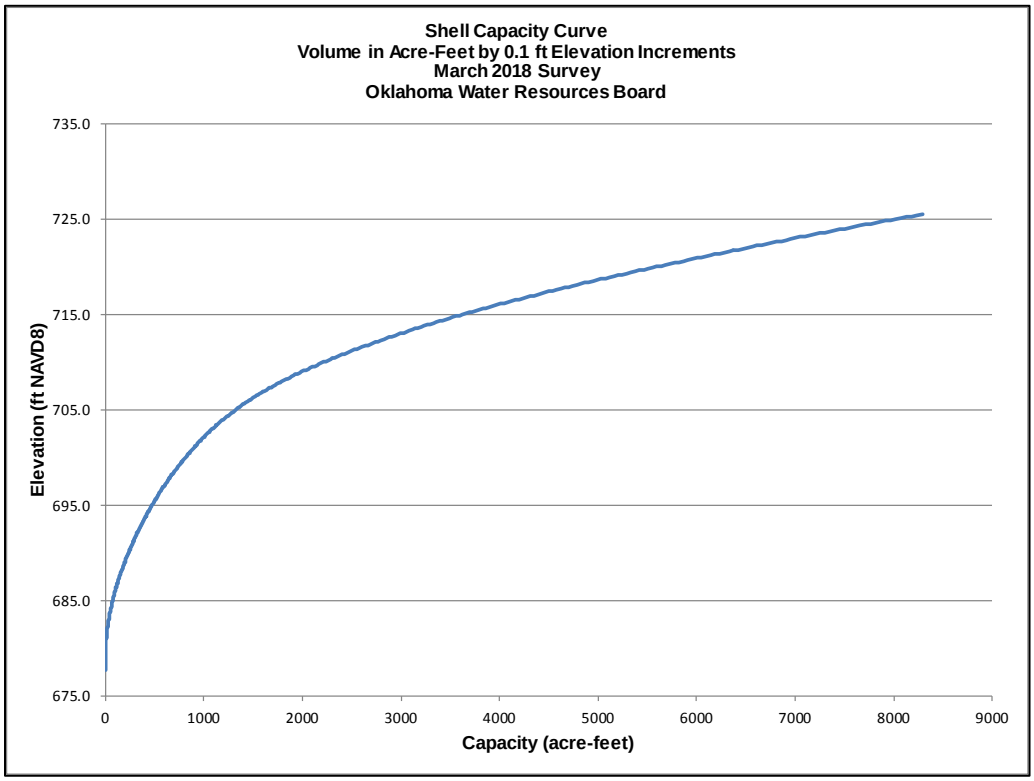

Figure A- 6: Cumulative Capacity Curve for Shell Lake.

APPENDIX B: Brushy Creek Lake Maps

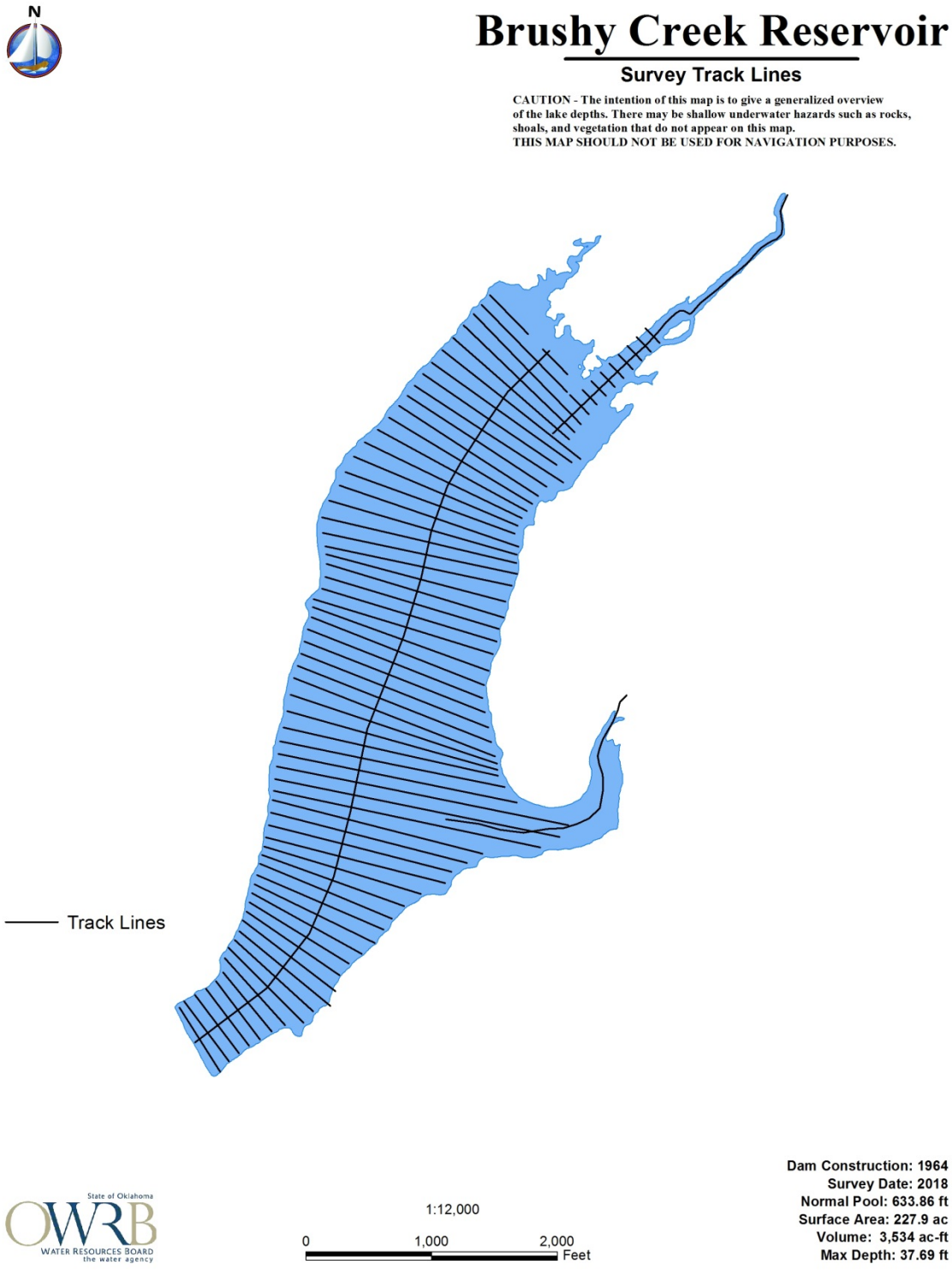

Figure B- 1: Brushy Creek Lake Survey Track Lines.

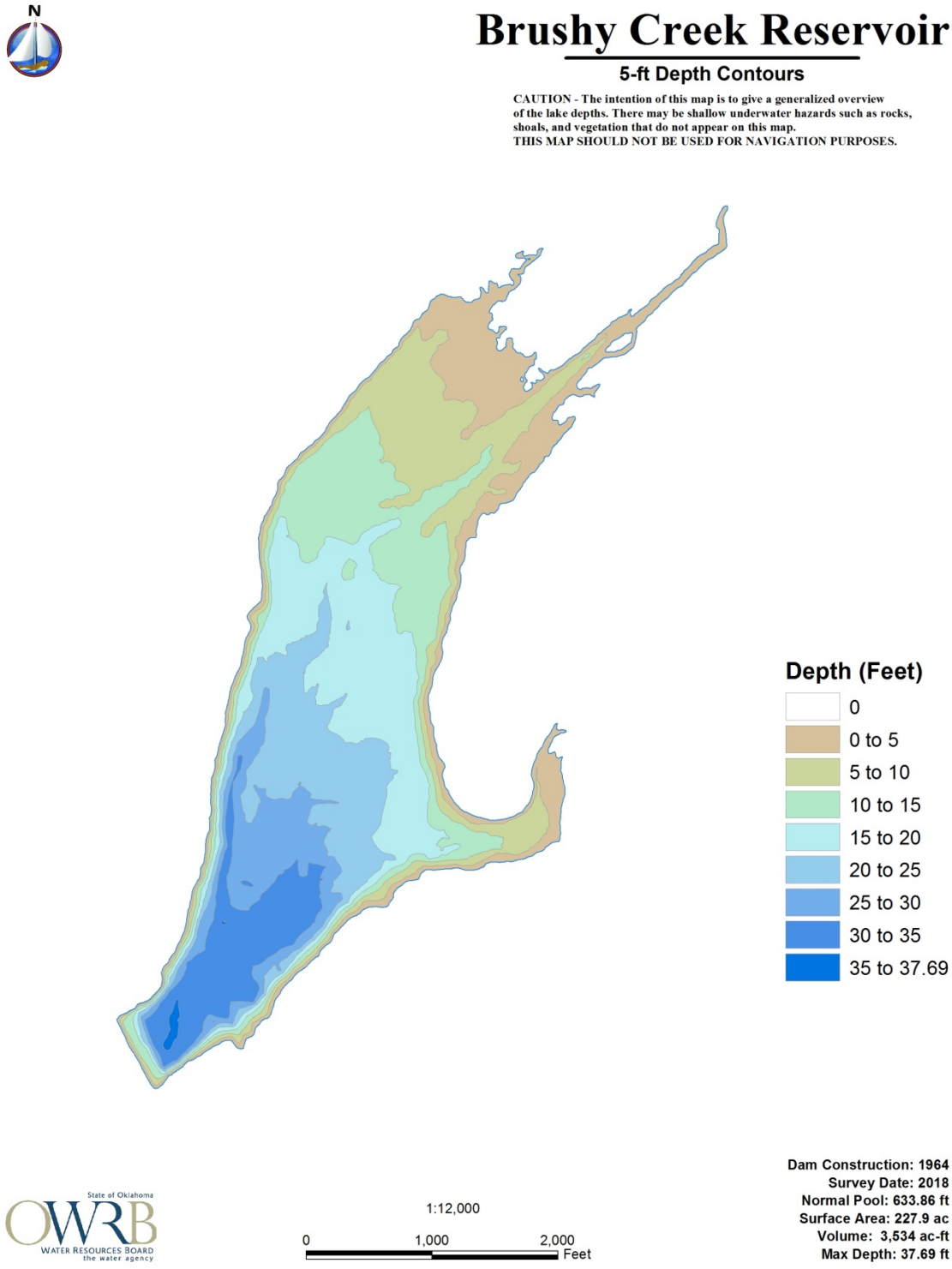

Figure B- 2: Brushy Creek Lake Contour Map with 5 ft Intervals.

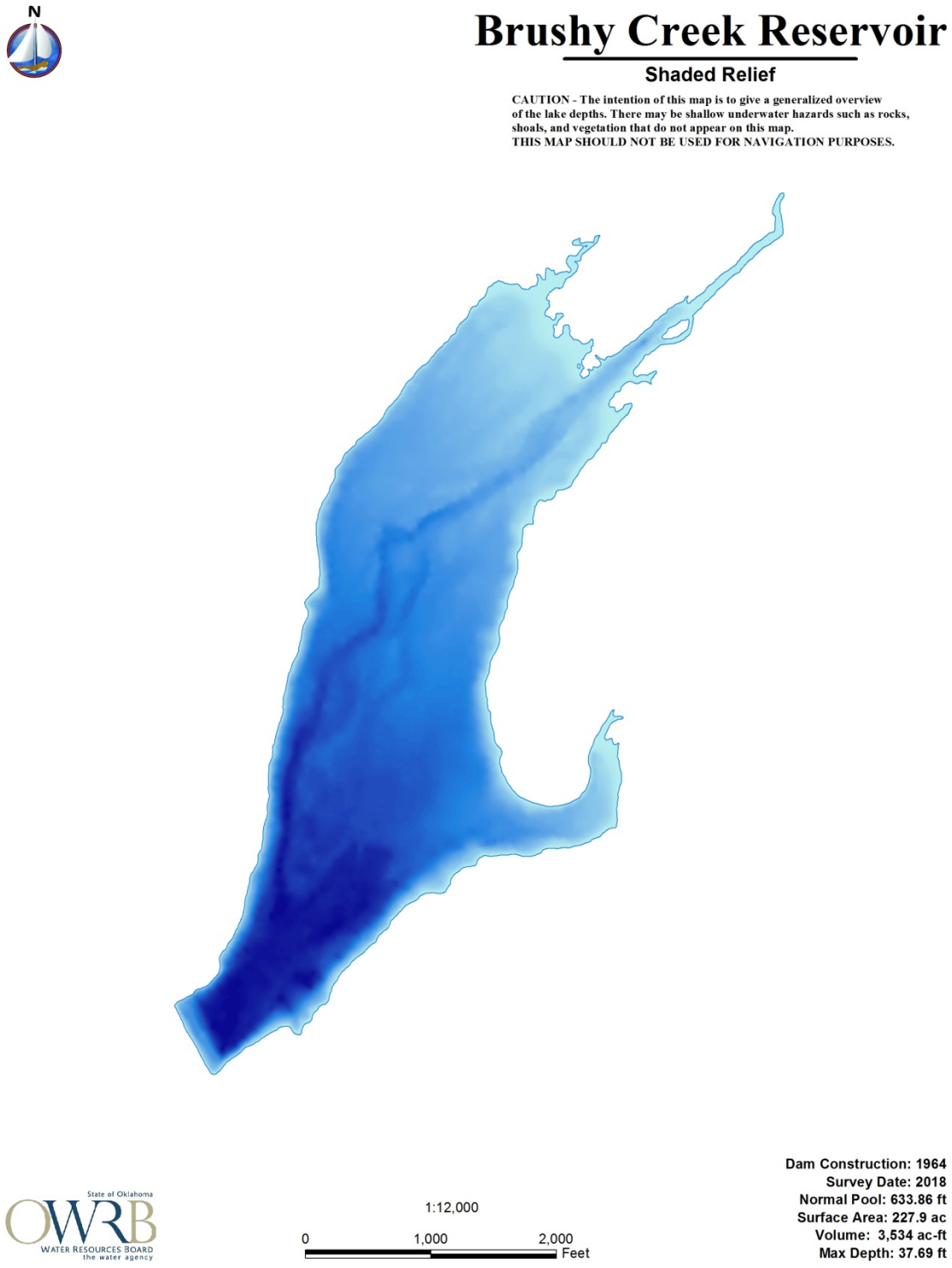

Figure B- 3: Brushy Creek Lake Shaded Relief Map.

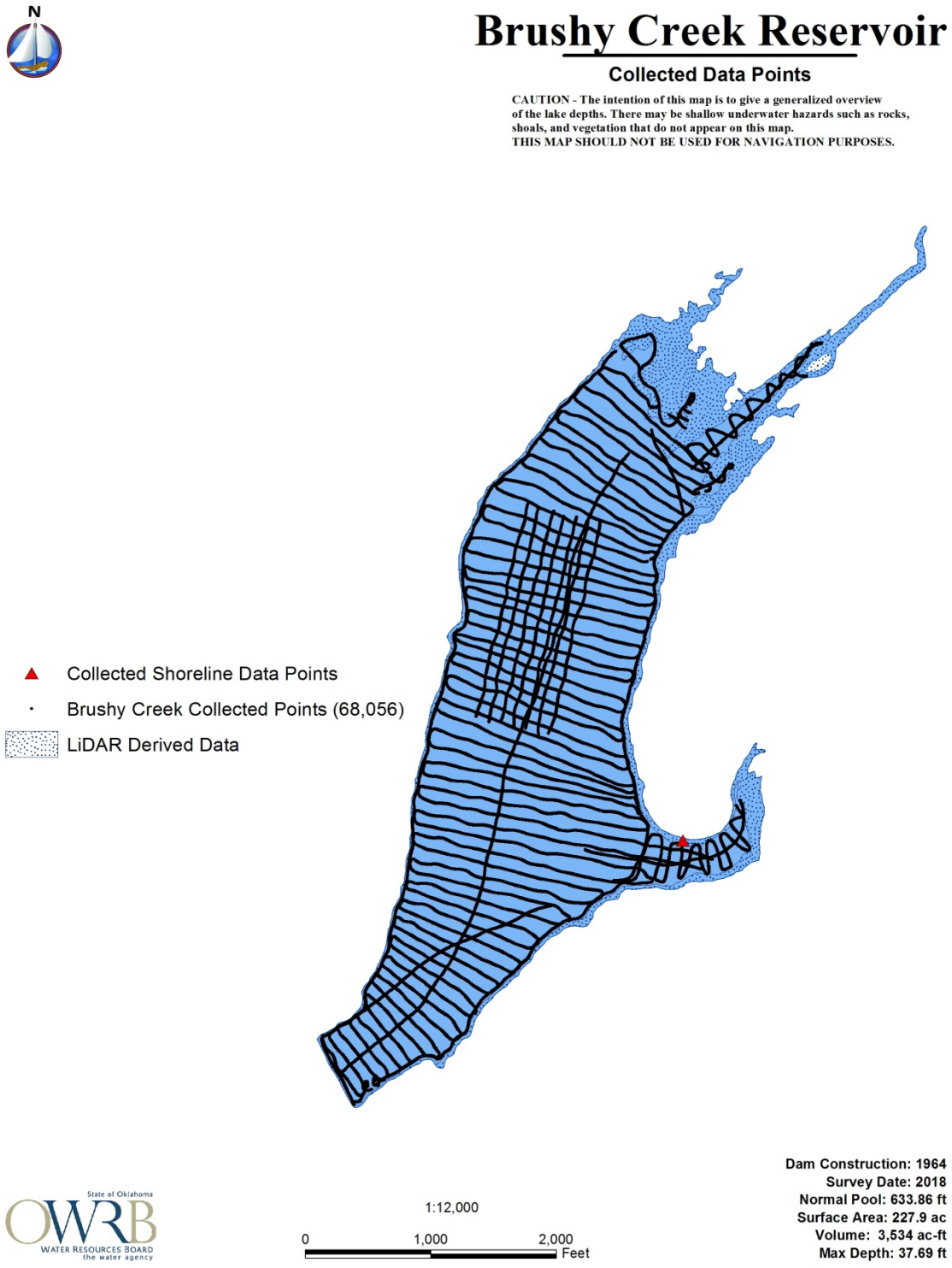

Figure B- 4: Brushy Creek Lake Collected Data Points Map.

APPENDIX C: Greenleaf Lake Maps

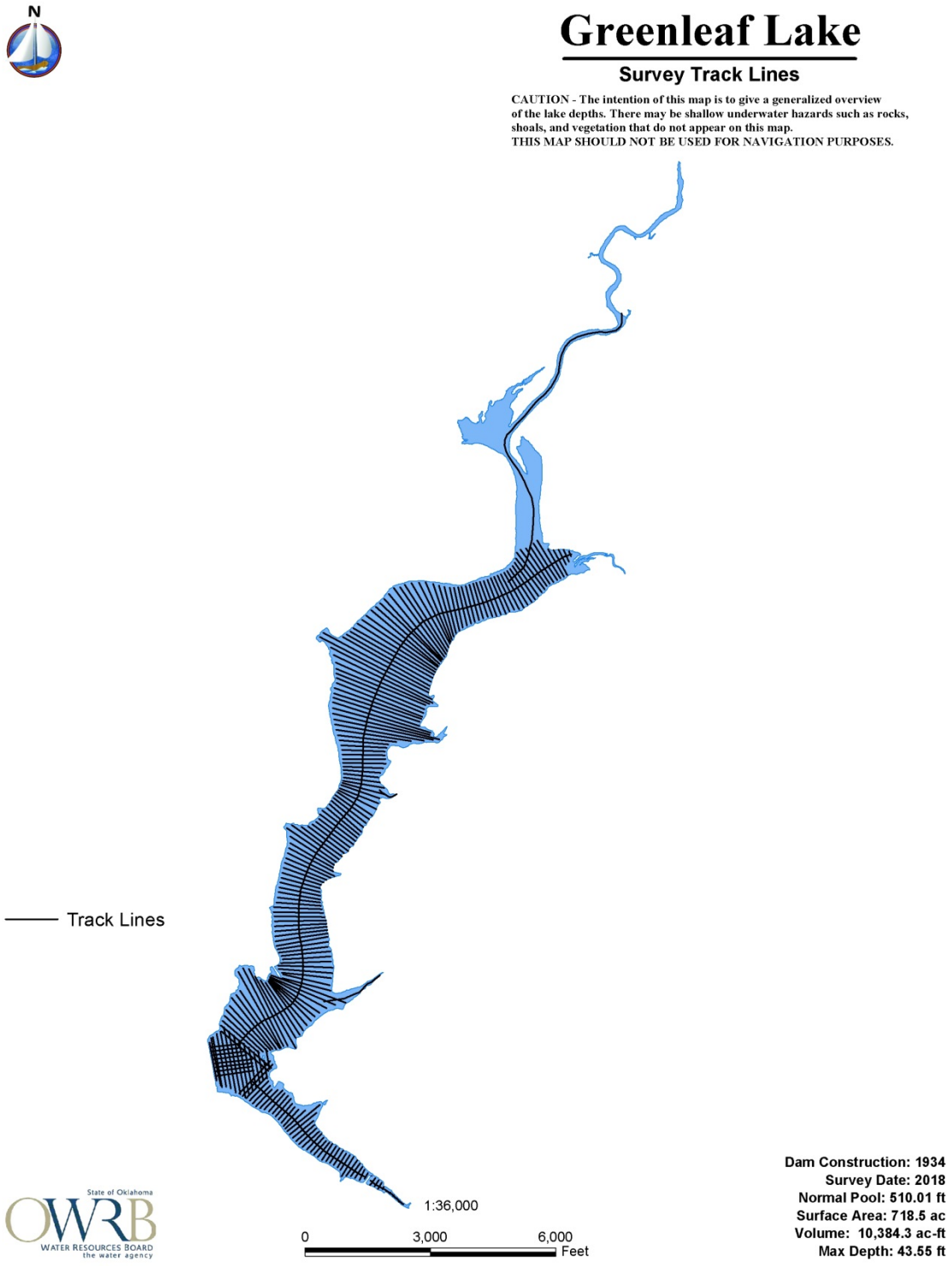

Figure C- 1: Greenleaf Lake Survey Track Lines Map.

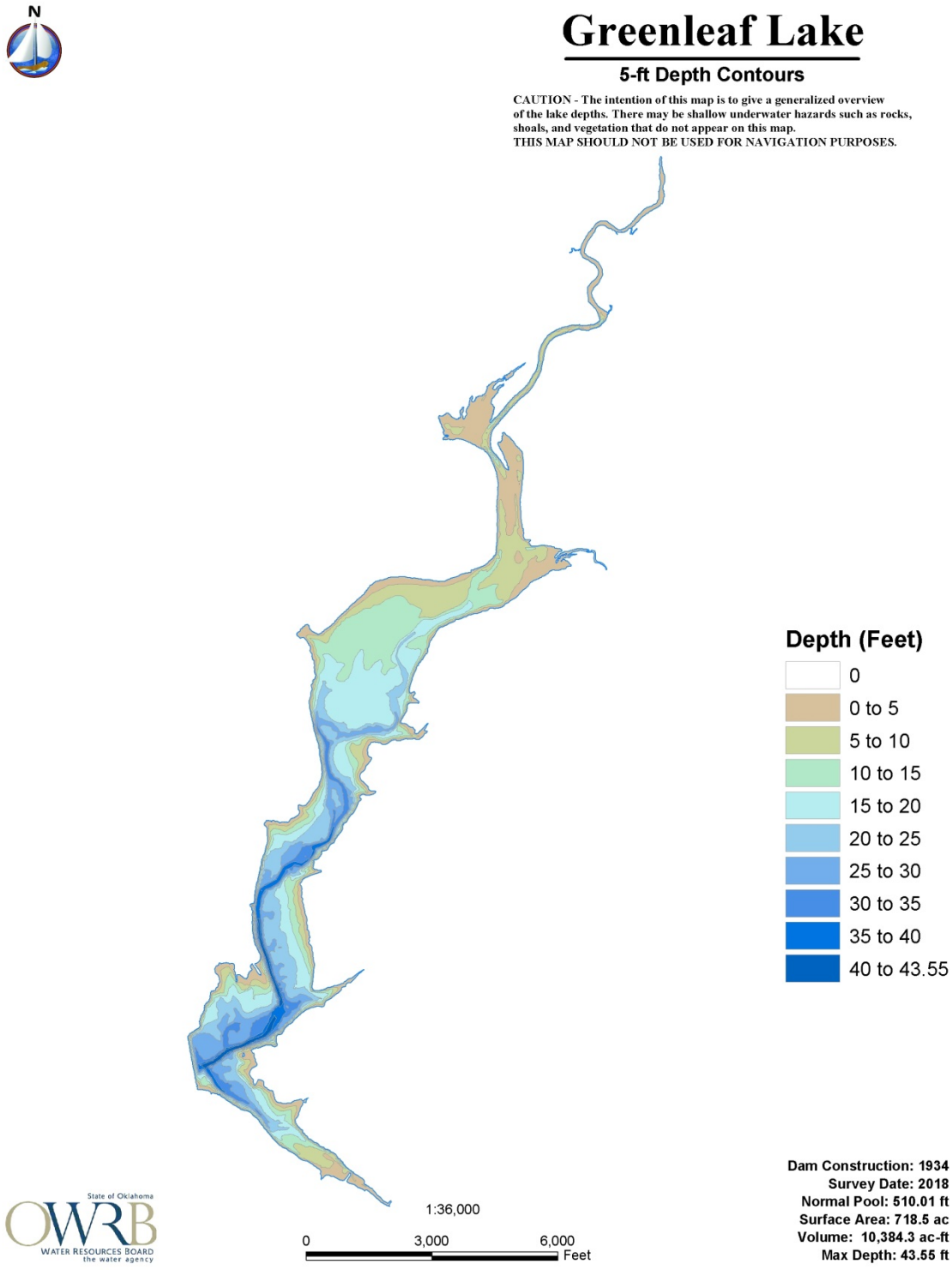

Figure C- 2: Greenleaf Lake Contour Map with 5 ft Intervals.

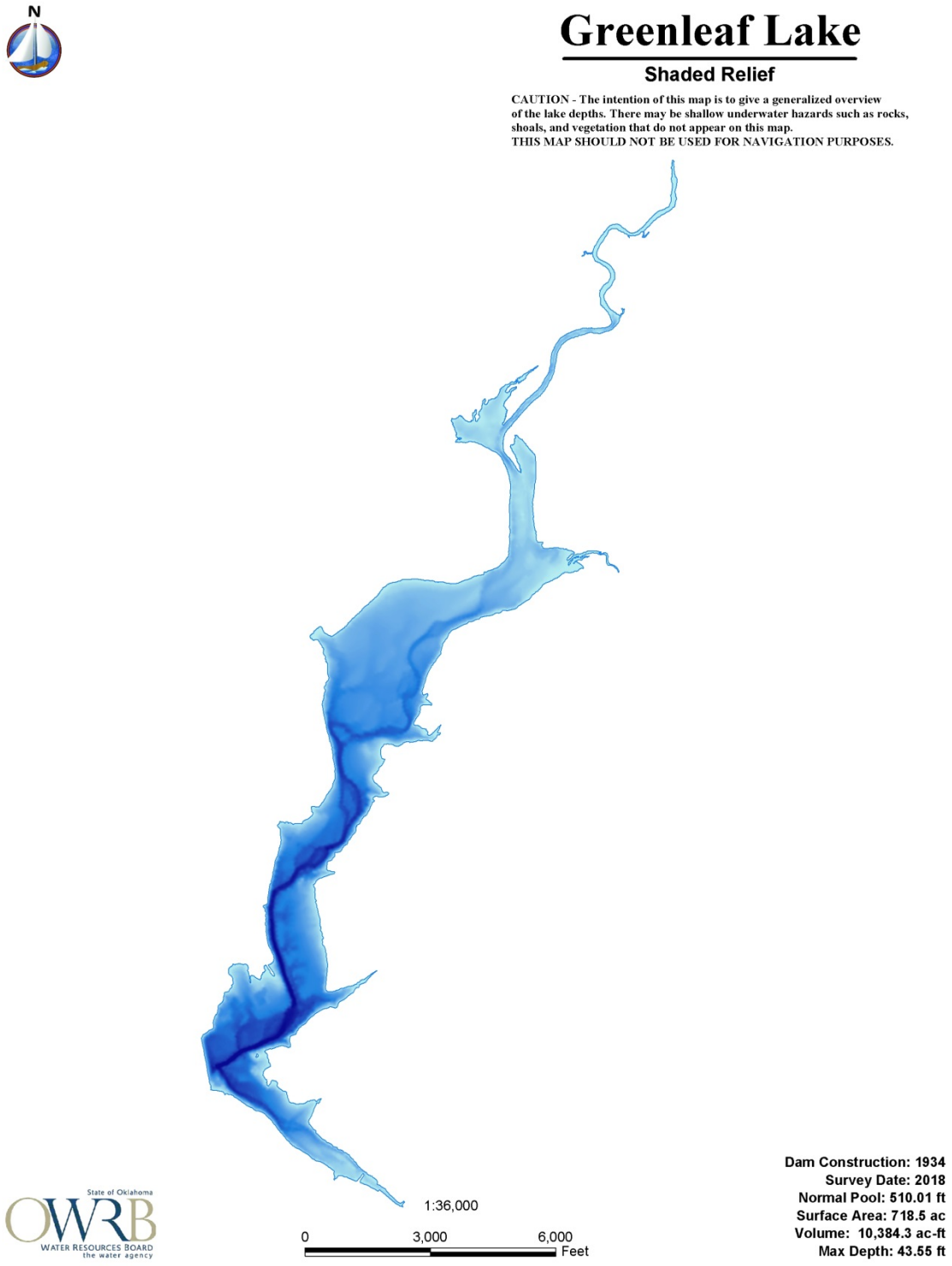

Figure C- 3: Greenleaf Lake Shaded Relief Map.

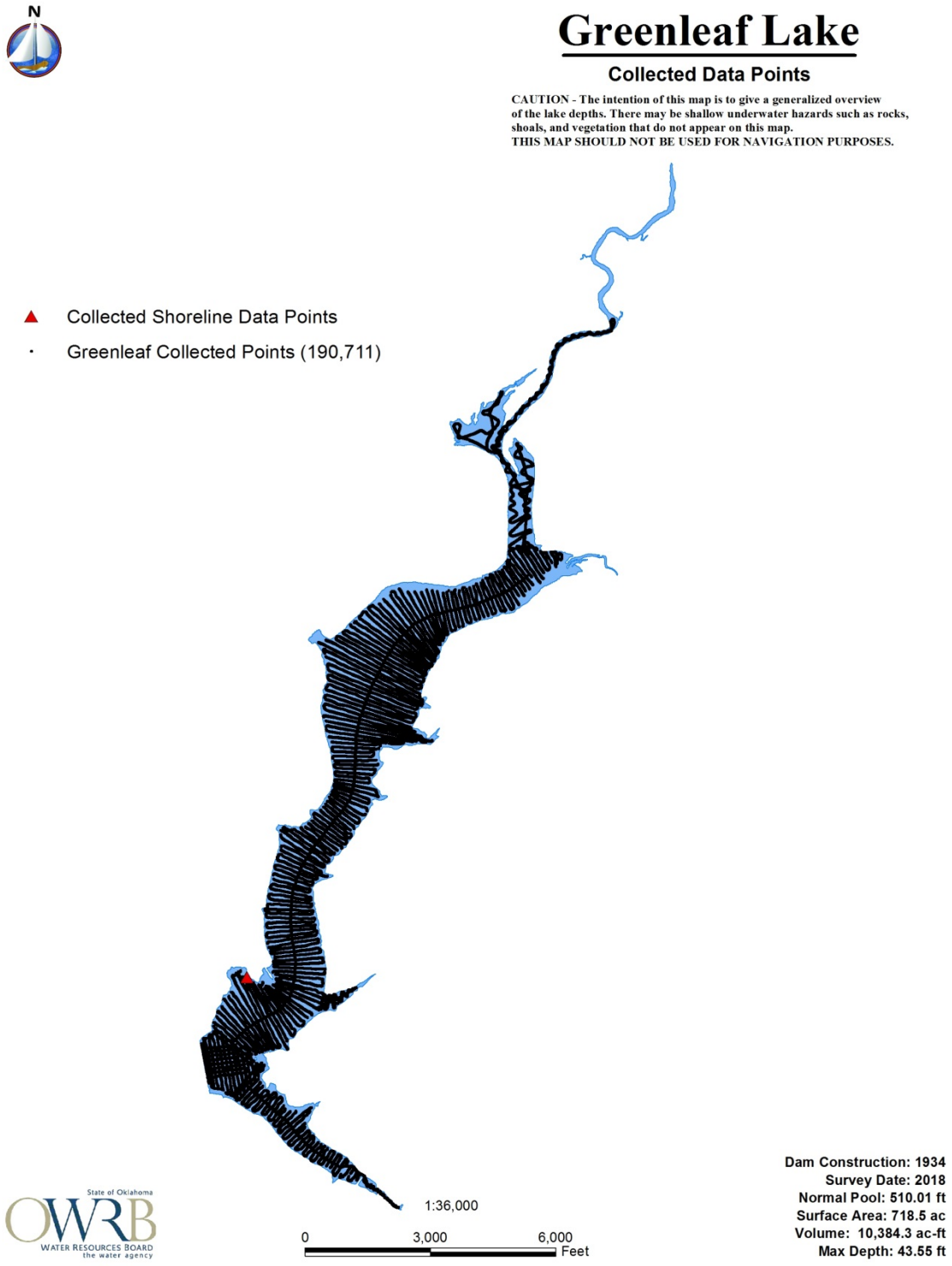

Figure C- 4: Greenleaf Lake Collected Data Points Map.

APPENDIX D: Shell Lake Maps

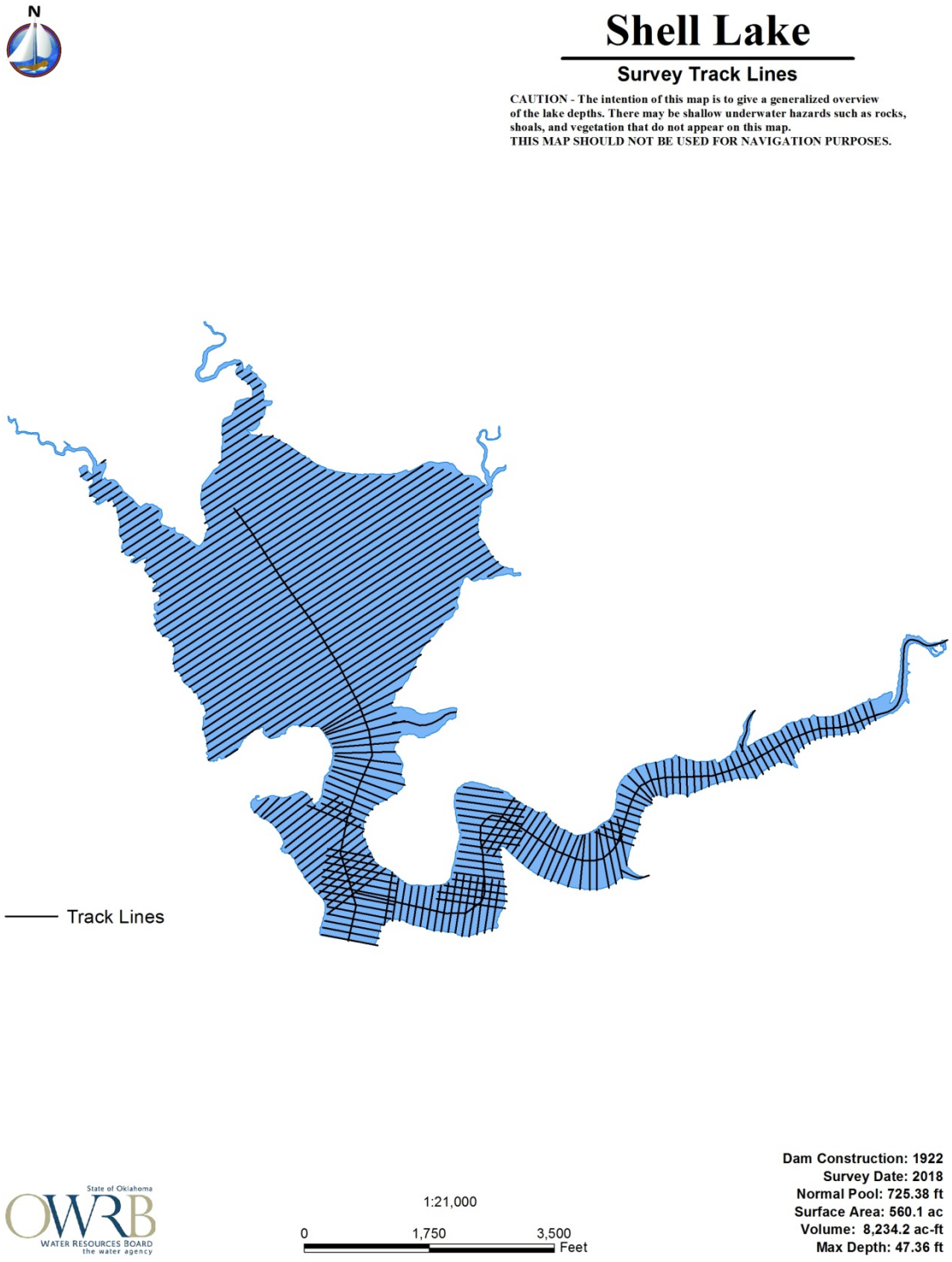

Figure D- 1: Shell Lake Survey Track Lines Map.

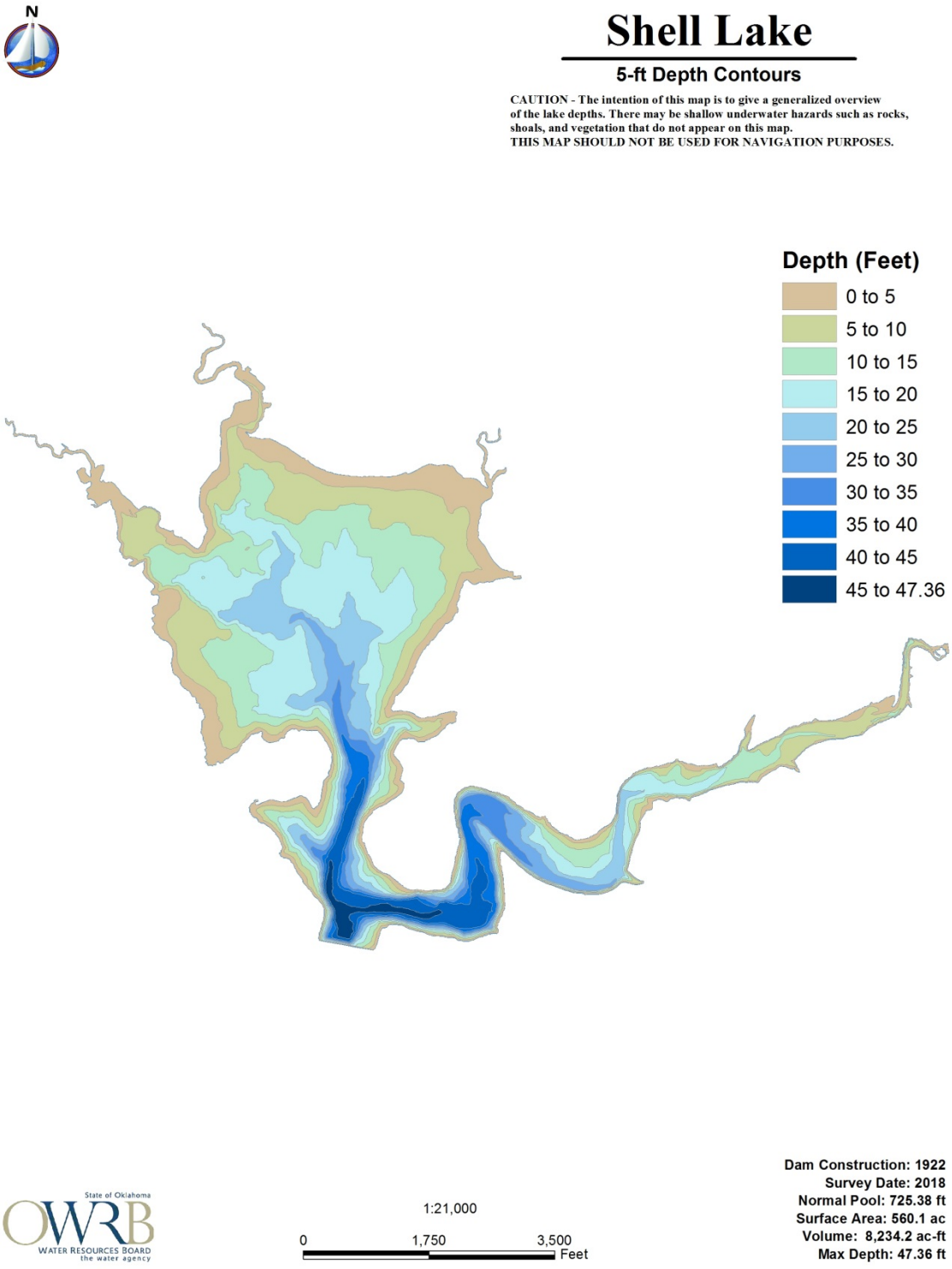

Figure D- 2: Shell Lake Contour Map with 5 ft Intervals.

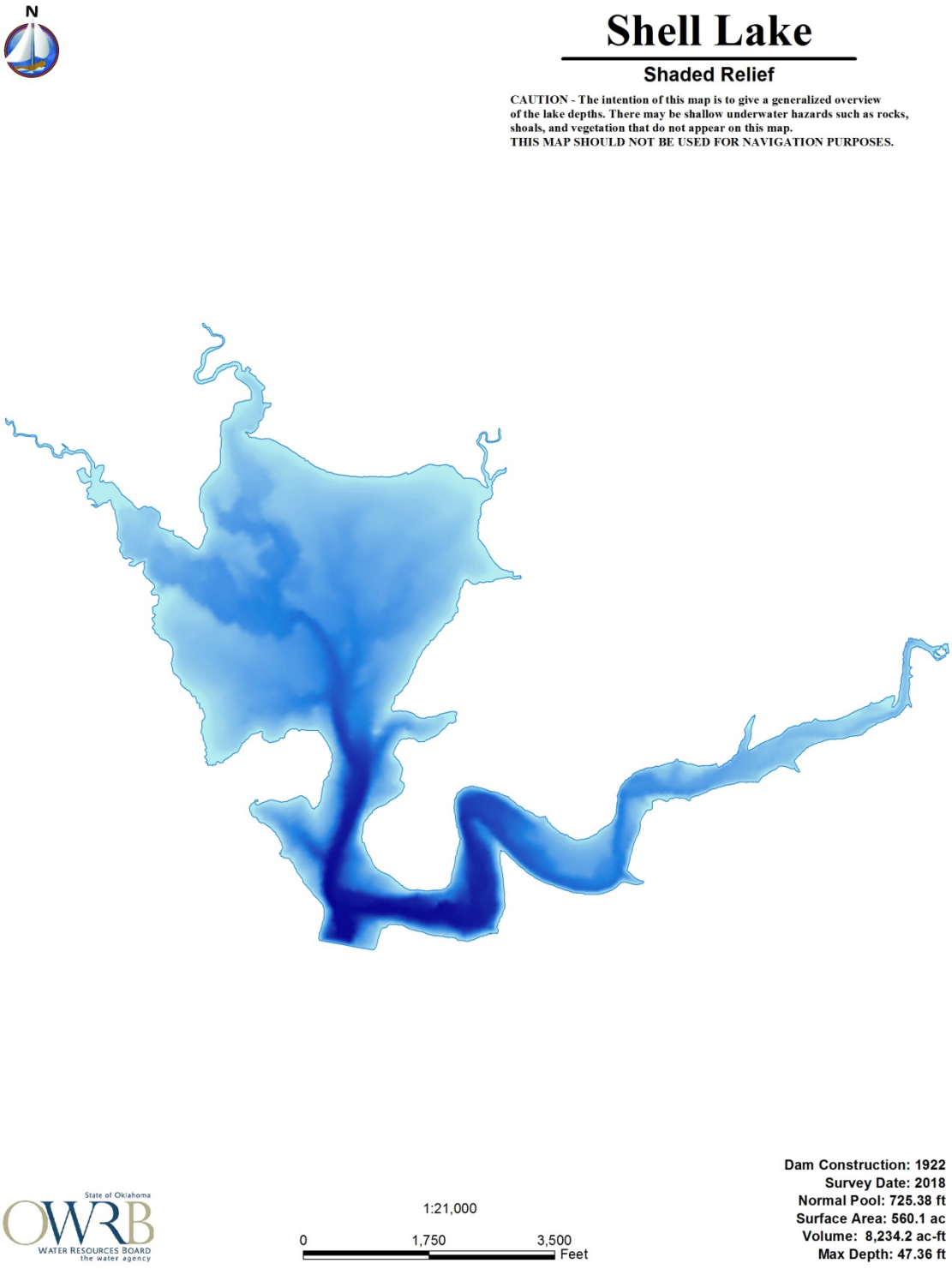

Figure D- 3: Shell Lake Shaded Relief Map.

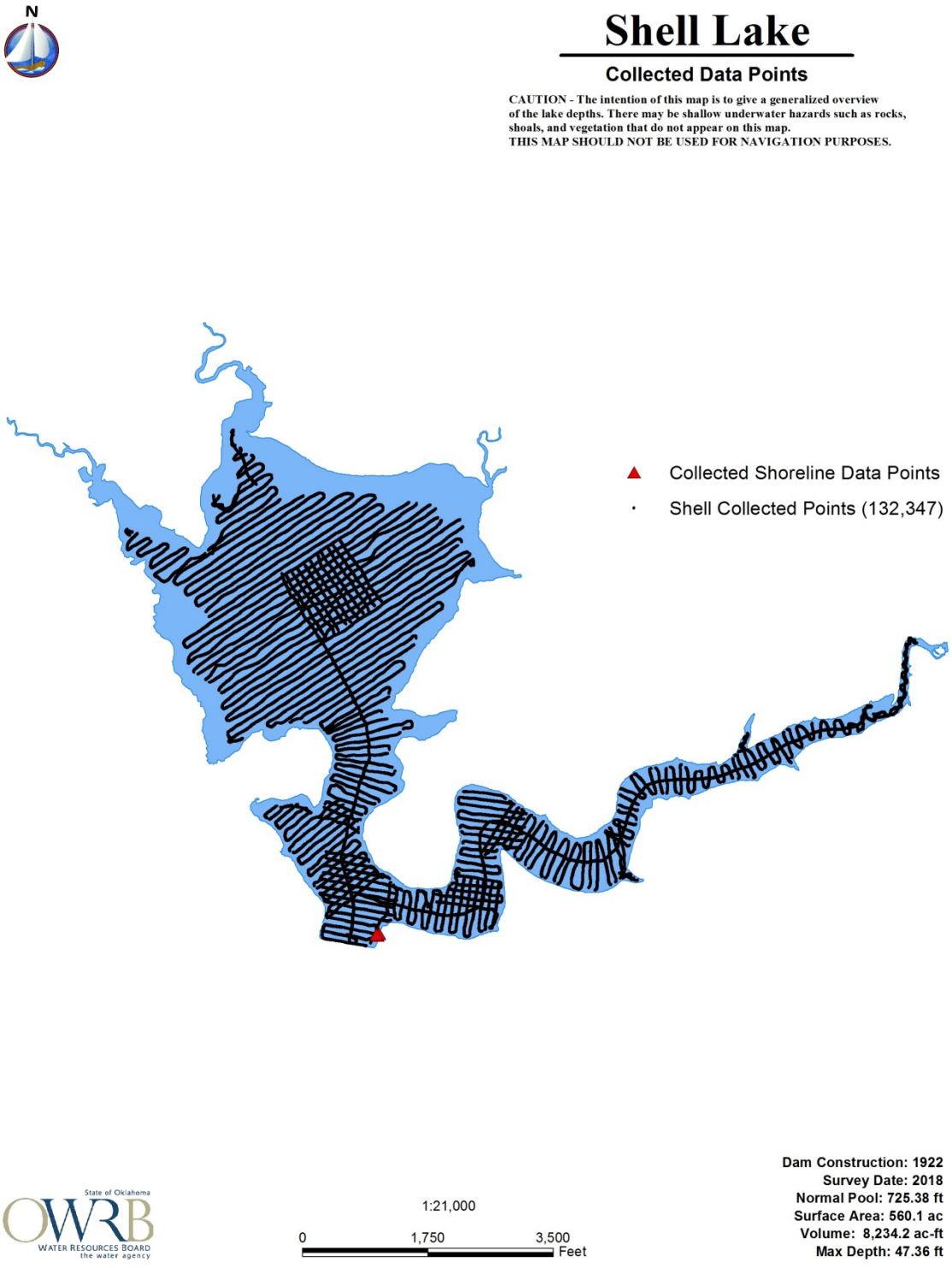

Figure D- 4: Shell Lake Collected Data Points Map.

APPENDIX E: Additional Survey Data Tables.

Table E- 1: Survey offsets used during the calibration and editing process.

Survey Offsets				
Lake	Brushy Creek Lake (11/29/17)	Greenleaf Lake (12/5/17)	Greenleaf Lake (12/6/17)	Greenleaf Lake (3/13/18)
Static Draft (ft)	0.7	0.6	0.6	0.6
Average SOS (m/s)	1455.74	1457.00	1454.13	1453.30
Echosounder SOS (m/s)	1456.64	1456.94	1454.20	1453.30
Latency Offset (sec)	0.25	0.25	0.25	.25
Lake	Shell Lake (3/28/18)	Shell Lake (3/29/18)	Shell Lake (4/24/18)	Shell Lake (5/24/18)
Static Draft (ft)	0.8	0.8	0.7	0.8
Average SOS (m/s)	1457.85	1459.43	1461.62	1475.41
Echosounder SOS (m/s)	1451.15	1451.15	1465.78	1499.01
Latency Offset (sec)	0.40	0.40	0.40	0.40

Table E- 2: Cross check statistic results showing accuracy of the survey data sets.

Cross Check Statistics			
Lake	Brushy Creek Lake	Greenleaf Lake	Shell Lake
# of Intersections	219	377	430
Arithmetic Mean (ft)	0.053	0.021	0.064
Standard Deviation (ft)	0.19	0.25	0.326

APPENDIX F: Shell Lake Sound Velocity Profiles.

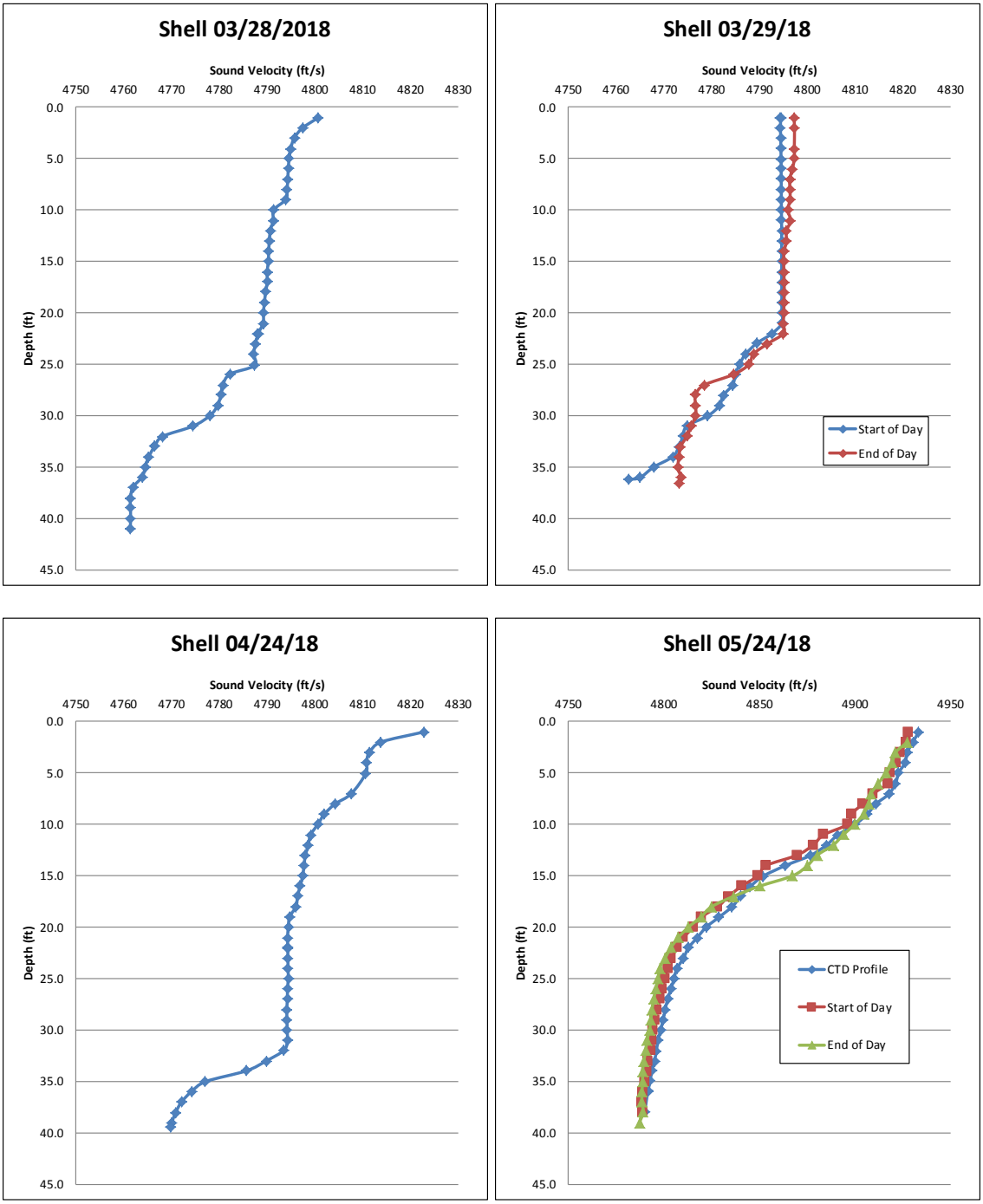

Figure F- 1: Shell Lake Sound Velocity Profiles (Calculated and Measured).