HYDROGRAPHIC SURVEY OF LAKE HUDSON

State of Oklahoma
OWRB
WATER RESOURCES BOARD
the water agency

Final Report

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Oklahoma Water Resources Board

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LAKE HUDSON (MARKHAM FERRY RESERVOIR) HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) conducted a hydrographic survey of Lake Hudson (Markham Ferry Reservoir) from November to December of 2006 and March of 2007. The purpose of the study was to collect hydrographic data of Lake Hudson and convert this information into an area-elevation-volume table up to the conservation pool elevation. The information produced will serve as a base to establish the location and rate of sedimentation in the conservation pool for future surveys.

LAKE BACKGROUND

History

On August 18, 1941, the Flood Control Act authorized the construction of what was initially called the Markham Ferry Reservoir. In July of 1946, it was incorporated into the Arkansas River multi-purpose plan by the River and Harbor Act. The Lake's authorization was further modified in July 1954 by Public Law 476. This authorized the Grand River Dam Authority (GRDA) to construct Lake Hudson. Construction of Lake Hudson began in January of 1962 and was completed in 1964 (USACE, 1992). The lake is used for flood control and hydroelectric power and was authorized by the Flood Control Act approved August 18, 1941. The lake is a multi-purpose project for flood control, hydropower, and navigation.

Lake Information

Lake Hudson is located in Mayes County in the Arkansas River Basin on Grand (Neosho) River. The Robert S. Kerr Dam located on Lake Hudson is approximately 2 miles northwest of Locust Grove and 8 miles southeast of Pryor. A general location map of Lake Hudson is shown on the following page as **Figure 1**. Based on the original sediment surveys, Lake Hudson covers an area of 10,900 acres and has a capacity of 200,400 acre-feet at the top of the conservation pool elevation of 619 ft NGVD. The reservoir has a length of 29.6 miles and an estimated total of 200 miles of shoreline at the top of the conservation pool (USACE, 1992).

GRDA owns and is the regulating agency of Lake Hudson. The Tulsa District of the US Army Corps of Engineers (USACE), by authority of the Flood Control Act of 1944 (Public Law 78-534, 58 Stat. 890, 33 U.S.C. 709), is responsible for prescribing regulation for the use of the flood control storage in the lake between elevations 619 and 636 ft NGVD (USACE, 1992).

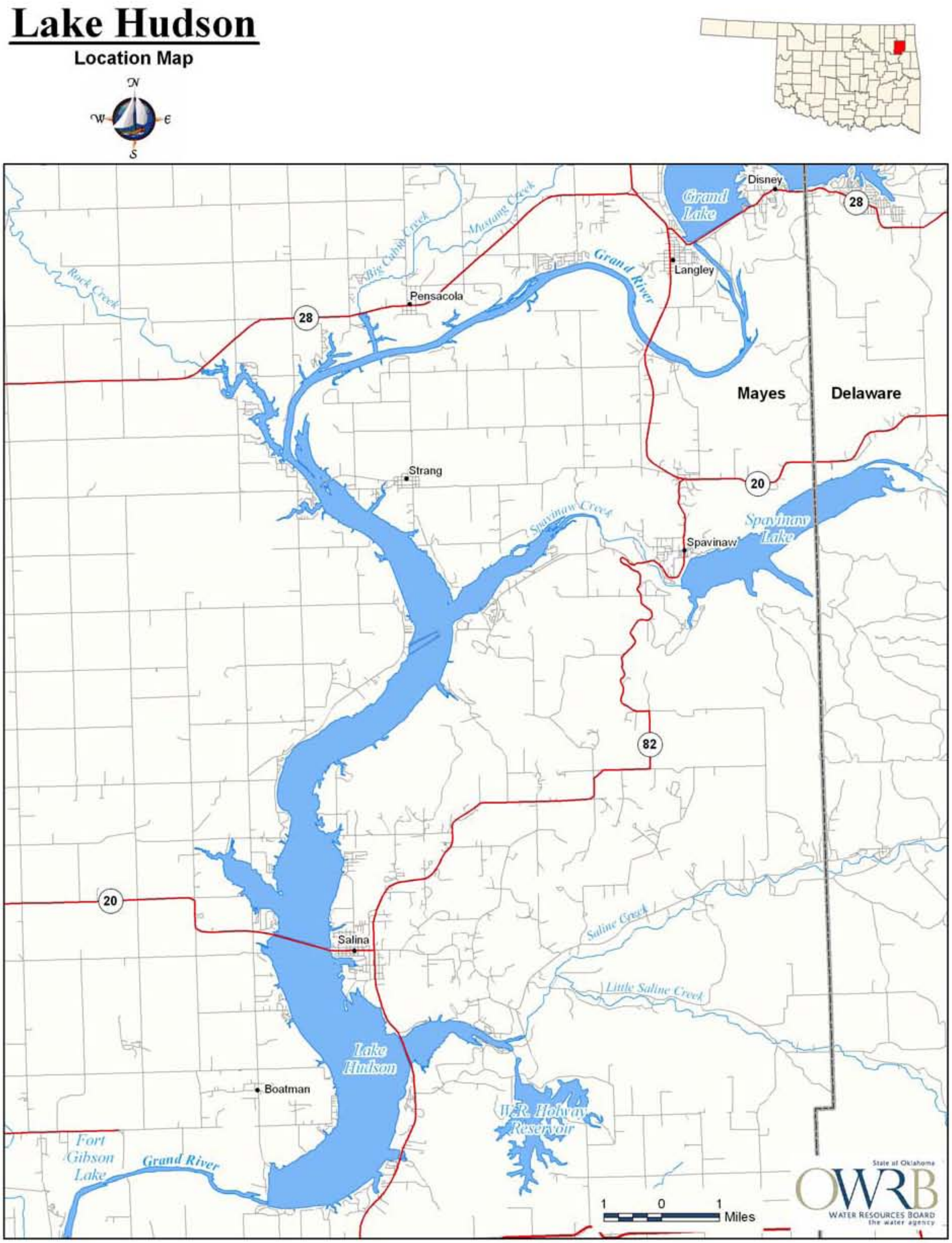

Figure 1: Location map for Lake Hudson.

HYDROGRAPHIC SURVEYING PROCEDURES

The process of surveying a reservoir uses a combination of Geographic Positioning System (GPS) and acoustic depth sounding technologies that are incorporated into a hydrographic survey vessel. As the survey vessel travels across the lake's surface, the echosounder gathers multiple depth readings every second. The depth readings are stored on the survey vessel's on-board computer along with the positional data generated from the vessel's GPS receiver. The collected data files are downloaded daily from the computer and brought to the office for editing after the survey is completed. 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

<u>Boundary File</u>

The digitized boundary of Lake Hudson was produced from the 1995 black and white US Geological Survey (USGS) digital ortho quarter quads (DOQQs) of Mayes County, Oklahoma at a scale of 1:1,500. The lake elevation at the time of the 1995 DOQQ was 619.17 ft NGVD. The reservoir boundary was digitized in NAD 1983 State Plane Coordinates (Oklahoma North-3501). The 2003 United States Department of Agriculture-Farm Service Agency-Aerial Photography Field Office (USDA-FSA-APFO) color DOQQ of Mayes County was also used for reference. The lake elevation at the time the 2003 DOQQ was taken was 619.9 ft NGVD.

<u>Set-up</u>

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 500 ft increments and ran perpendicular to the original stream channels and tributaries. Approximately 285 virtual transects were created for the Lake Hudson project not including channel track lines, which were created after the initial surveying of the lake transects.

Field Survey

<u>Method</u>

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.

<u>Technology</u>

The Hydro-survey vessel was 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. A 12V battery and inverter provided the power supply to the equipment. The software used was HYPACK.

Survey

A two-man survey crew was used during the project. Data collection for Lake Hudson occurred on 11/06-08/2006, 11/13-14/2006, 11/27-29/2006, 12/05-06/2006, 12/13-14/2006, and 2/28-29/2007. The average water level elevation in November and December 2006 was approximately 618.4 ft NGVD. The average elevation in March 2007 was approximately 619 ft NGVD. Data collection began at the dam and moved north up the reservoir. 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. This was usually in a water depth of two to three feet. Areas with depths less than what could accommodate the boat 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 ranged from 4,711.7 ft/sec to 4,808.5 ft/sec during the Lake Hudson survey. The sound velocity profiles for each date of surveying are shown in **APPENDIX A: Sound Velocity Profile**.

A quality assurance cross-line check was undertaken 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 many random and systematic errors that are present in the measurement processes used to determine that depth readings. 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 from comparing depth readings between readings taken at an intersection of two lines and computing the difference. The mean difference of all intersection points 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 should not exceed a tolerance of ± 2.0 ft for this type of survey. This is done to verify compliance with the resultant depth accuracy of ± 2.0 ft at the 95% confidence level. 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 114 cross-sections points were used to compute error estimates. A mean difference of 0.0 ft and a standard deviation of 1.09 ft were computed from a number of 114 data points. Using the following formulas, a 95% depth accuracy of ± 2.1 ft was calculated.

$$RMS = \sqrt{SD^{2} + MD^{2}}$$

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

where:

MD	= mean difference
SD	= standard deviation
RMS	= root mean square error

An RMS of ± 2.1 ft with a 95% level is slightly higher than the USACE's minimum performance standard of ± 2.0 ft for this type of survey. A mean difference, or bias, of 0.0 ft is well below the USACE's standard maximum allowable bias of ± 0.5 ft for this type of survey. It must be remembered that minimizing constant bias errors is far more important than reducing deviations (USACE, 2002). The data plotted in **Figure 2** illustrates that the measurements have somewhat low precision but high accuracy (USACE, 2002).

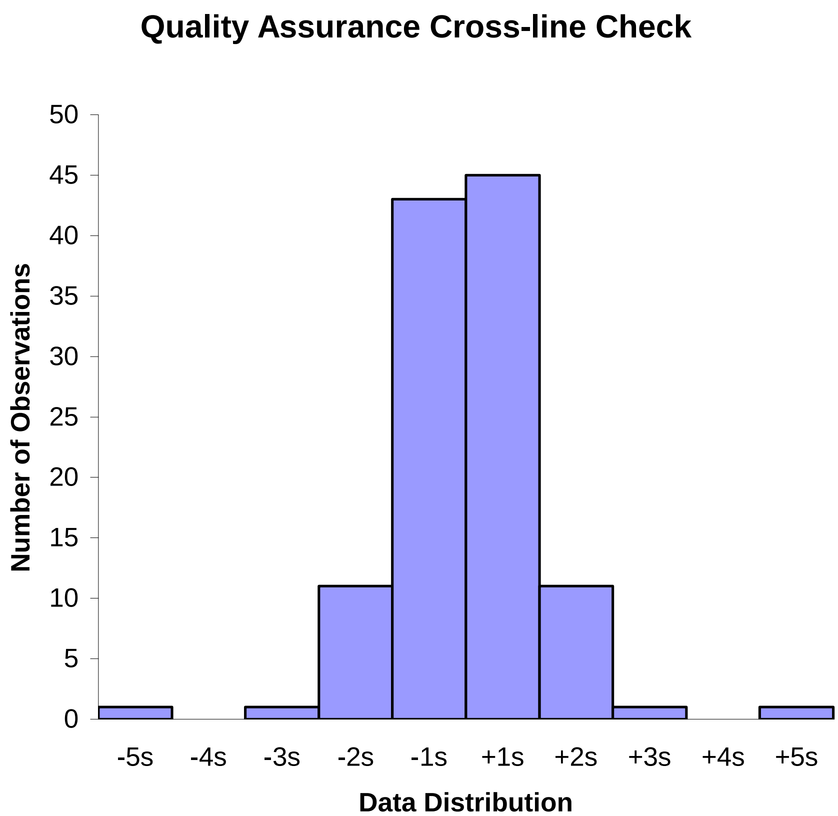

Figure 2: Histogram of relative depth distribution at cross check lines - in standard deviation.

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 Lake Hudson survey is located near Sallisaw, Oklahoma. The reference beacon system transmitted corrected signals in real time, so no post-processing corrections of position data were needed. The collected DGPS positions were converted to state-plane coordinate system using the HYPACK program.

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 0.1 seconds was produced and adjustments were applied to the raw data in the EDIT program.

Data Processing

The collected data was downloaded from the field computer onto the OWRB computer network and data burned to a CD as a permanent record. After downloading the data, each raw data file was reviewed for accuracy and completeness 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 X, Y, and Z information. Collected data points that have inaccurate or absent depth or positional information were interpolated to be congruent with adjacent accurate points or deleted completely.

Offset correction values of 3.2 ft. starboard, 6.6 ft. forward, and -1.1 ft. vertical were applied to all raw data along with a latency correction factor of 0.1 seconds. The speed of sound readings from the sound profiling velocimeter are documented in **APPENDIX A: Sound Velocity Profile**.

Using HYPACK, TIDES program, a tide correction file was produced to account for the variance in lake elevation at the time in which data was collected. Within the EDIT program, the corrected depths were subtracted from the elevation reading to convert the depth in feet to an elevation.

After editing the data for errors and correcting the spatial attributes (offsets and tide corrections), a data reduction scheme was needed. To accomplish this the data was resampled spatially at a 10 ft interval using the Sounding Selection program in HYPACK. The resultant data was saved and exported out as a xyz.txt file. The HYPACK data file for Lake Hudson is located at the end of the document on the CD entitled *Hudson 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 9.1, 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 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. Approximately 131,373 data points were used to create the TIN model. The lake volume was calculated by slicing the TIN horizontally into planes 0.1 ft thick. The volume and area of each slice are shown in **APPENDIX B: Area-Capacity Data**.

Contours, depth ranges, and the shaded relief map were derived from a 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 map of the lake is shown with 5-ft contour intervals in Appendix C.

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 Lake Hudson is located at the end of the document on the CD entitled *Hudson HYPACK/GIS Metadata.*

RESULTS

Results from the 2006-2007 OWRB survey indicate that Lake Hudson encompasses 11,029 acres and contains a cumulative capacity of 200,185 ac-ft at the conservation pool elevation (619 ft NGVD). The average depth for Lake Hudson was 18.2 ft with a maximum depth of 65 ft.

SUMMARY

Table 1 summarizes all surveys conducted of Lake Hudson at the conservation pool elevation. Based on the original sediment survey, Lake Hudson had an area of 10,900 acres and cumulative volume of 200,400 acre-feet of water at conservation pool elevation (USACE, 1992). The surface area of the lake has increased 1.5% or approximately 164 acres. Hudson Lake has had a less than a 0.1% decrease in capacity or a loss of approximately 178 acre-feet. However, caution should be used when directly comparing between the original survey and the 2006-2007 survey conducted by the OWRB. 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 2006-2007 survey be conducted in 15 years.

Table 1: Area and Volume Comparisons of Lake Hudson at Conservation Pool Elevation (619.0 ft).

Feature	Survey Year	
	Original Survey	2006-2007
Area (acres)	10,865	11,029
Cumulative Volume (acre-feet)	200,363	200,185
Mean depth (ft)	18.44	18.15

REFERENCES

U.S. Army Corps of Engineers (USACE). 1992. Water Control Manual – Markham Ferry Reservoir.

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

APPENDIX A: Sound Velocity Profile

Table A. 1: Sound Velocity Profile Data (ft/sec) for November 6 – 29, 2006.

Depth	11/06/2006	11/07/2006	11/08/2006	11/13/2006	11/14/2006	11/27/2006	11/28/2006	11/29/2006
1	4802.8		4800.1	4795.5	4790.6	4784.1	4789.7	4794.7
2	4802.5	4802.7	4800.1	4795.5	4790.8	4784.0	4789.6	4794.7
3	4802.2	4801.6	4800.1	4795.5	4790.8	4783.7	4789.5	4794.7
4	4802.1	4801.4	4800.1	4795.5	4790.8	4783.3	4789.4	4794.6
5	4802.0	4801.1	4800.1	4795.1	4790.9	4783.0	4789.3	4794.6
6	4801.7	4801.0	4800.1	4794.8	4790.9	4782.5	4789.2	4794.6
7	4801.4	4800.9	4800.1	4794.8	4791.0	4782.1	4789.2	4794.6
8	4801.2	4800.8	4800.1	4794.8	4791.1	4782.0	4789.0	4794.6
9	4801.1	4800.8	4800.2	4794.5	4791.2	4782.0	4789.0	4794.6
10	4801.1	4800.7	4800.2	4794.5	4791.3	4781.8	4789.0	4794.6
11	4801.1	4800.7	4800.2	4794.5	4791.2	4781.7	4788.9	4794.6
12	4801.0	4800.7	4800.3	4794.5	4791.2	4781.7	4788.9	4794.6
13	4801.1	4800.7	4800.3	4794.5	4791.3	4781.7	4788.8	4794.5
14	4801.1	4800.7	4800.3	4794.5	4791.2	4781.6	4788.8	4794.4
15	4801.1	4800.7	4800.3	4794.5	4791.1	4781.5	4788.9	4794.3
16	4801.1	4800.7	4800.2	4794.5	4791.2	4781.5	4788.9	4794.3
17	4801.1	4800.7	4800.3	4794.5	4791.0	4781.6	4788.9	4794.3
18	4801.1	4800.7	4800.3	4794.5	4790.9	4781.6	4788.9	4794.2
19	4801.1	4800.7	4800.3	4794.5	4790.9	4781.6	4788.9	4794.1
20	4801.0	4800.6	4800.2	4794.8	4790.9	4781.6	4788.9	4794.0
21	4801.1	4800.7	4800.0	4794.8	4790.9	4781.6	4788.9	4793.9
22	4801.0	4800.6	4799.7	4794.8	4790.9	4781.6	4788.9	4793.8
23	4801.0	4800.5	4799.2	4794.8	4791.0	4781.6	4788.9	4793.8
24	4801.0	4800.3	4798.8	4794.8	4791.0	4781.6	4788.8	4793.7
25	4801.1	4800.1	4798.3	4794.8	4791.0	4781.6	4788.8	4793.7
26	4801.0	4799.9	4798.2	4794.8	4791.0	4781.6	4788.8	4793.8
27	4800.9	4799.6	4798.0	4794.8	4791.1	4781.6	4788.8	
28	4800.8	4799.3	4797.7	4794.8	4791.1	4781.6	4788.7	
29	4800.7	4799.0	4797.5	4794.8	4791.1	4781.6	4788.6	
30	4800.5	4798.9	4797.4	4794.8	4791.1	4781.6	4788.5	
31	4800.4	4798.8	4797.3	4794.8	4791.1	4781.6	4788.5	
32	4800.2	4798.7	4797.0	4794.8	4791.0	4781.5	4788.4	
33	4799.9	4798.6	4796.9	4794.8	4791.1	4781.5	4788.4	
34	4799.9	4798.6	4796.6	4794.8	4791.1	4781.5	4788.3	
35		4798.5	4796.1	4794.8	4791.1	4781.5	4788.2	
36		4798.4	4795.7	4794.8	4791.1		4788.2	
37		4798.4	4795.5	4794.8	4791.1		4788.3	
38		4798.3	4795.4	4794.8	4791.2		4788.2	
39		4798.3	4795.2	4794.8	4791.2			
40		4798.2	4794.8	4794.8	4791.2			
41		4798.1	4794.6	4794.8	4791.3			
42		4798.0	4794.5	4794.8	4791.2			
43		4798.0	4794.2	4794.8				
44		4797.9	4794.1	4794.8				
45		4797.7	4794.1	4794.8				
46		4797.4	4794.0	4794.8				
47		4797.1	4793.9	4794.5				
48		4796.7	4793.8	4794.5				
49		4796.3	4793.7	4794.5				
50		4796.0	4793.7	4794.5				
51		4795.9	4793.6	4794.5				
52		4795.8	4793.6	4794.5				
53		4795.7	4793.5					

Table A. 2: Sound Velocity Profile Data (ft/sec) for December 5, 2006 - March 29, 2007.

Depth	12/05/2006	12/06/2006	12/12/2006	12/13/2006	12/14/2006	03/28/2007	03/29/2007
1	4723.1	4718.9	4715.0	4718.1		4781.0	
2	4722.9	4718.9	4713.9	4718.1		4777.9	4808.5
3	4722.4	4719.1	4713.3	4718.1	4720.2	4774.9	4808.0
4	4721.8	4719.3	4712.8	4718.1	4720.2	4772.3	4807.5
5	4721.8	4719.3	4712.5	4718.1	4720.2	4771.9	4807.4
6	4721.7	4719.4	4712.2	4718.2	4720.2	4771.3	4807.3
7	4721.6	4719.4	4712.2	4718.3	4720.3	4769.7	4806.9
8	4721.7	4719.5	4712.1	4718.4	4720.2	4766.3	4806.4
9	4721.6	4719.4	4712.1	4718.4	4720.3	4764.6	4805.8
10	4721.4	4719.4	4712.1	4718.5	4720.3	4763.9	4804.7
11	4721.2	4719.4	4712.1	4718.4	4720.4	4763.9	4802.2
12	4720.9	4719.4	4712.1	4718.4	4720.4	4763.9	4800.1
13	4720.9	4719.4	4712.1	4718.4	4720.4	4763.8	4797.6
14	4720.8	4719.4	4712.1	4718.4	4720.4	4763.8	4796.5
15	4720.8	4719.4	4712.1	4718.4	4720.5	4763.8	4795.5
16	4720.7	4719.4	4712.1	4718.4	4720.2	4763.7	4794.7
17	4720.7	4719.4	4712.0	4718.4		4763.4	4793.8
18	4720.6	4719.5	4712.0	4718.4		4762.9	4792.4
19	4720.5	4719.5	4711.9	4718.4		4762.6	4791.2
20	4720.6	4719.6	4712.0	4718.3		4761.5	4789.8
21	4720.6	4719.6	4711.9	4718.1		4761.0	4788.4
22	4720.5	4719.6	4711.9	4718.0		4760.9	4787.5
23	4720.5	4719.7	4711.8	4717.8		4760.8	4787.1
24	4720.5	4719.8	4711.8	4717.7		4760.7	4786.7
25	4720.5	4719.7	4711.8	4717.8		4760.7	4786.1
26	4720.5	4719.8	4711.7			4760.7	4785.3
27	4720.4	4719.7	4711.7			4760.7	4784.3
28	4720.3	4719.7	4711.7			4760.6	4782.6
29	4720.3	4719.7	4711.7			4760.6	4781.4
30	4720.3	4719.7	4711.8			4760.5	4780.4
31	4720.4	4719.7	4711.8			4760.5	4779.4
32	4720.4	4719.7	4711.8			4760.5	4779.2
33	4720.3	4719.7	4711.8			4760.5	4779.1
34	4720.3	4719.9	4711.8			4760.4	4779.0
35	4720.4	4719.9	4711.8			4760.4	4778.7
36	4720.4	4719.9	4711.9			4760.4	4778.1
37	4720.4	4720.0	4711.9			4760.4	4777.3
38	4720.4	4720.0	4711.9			4760.4	4776.5
39		4719.8	4711.9			4760.3	4776.1
40			4712.0			4760.3	4775.6
41			4711.9			4760.2	4775.1
42			4712.0				4774.7
43			4711.8				4774.3
44							4774.0
45							4773.8
46							4773.2
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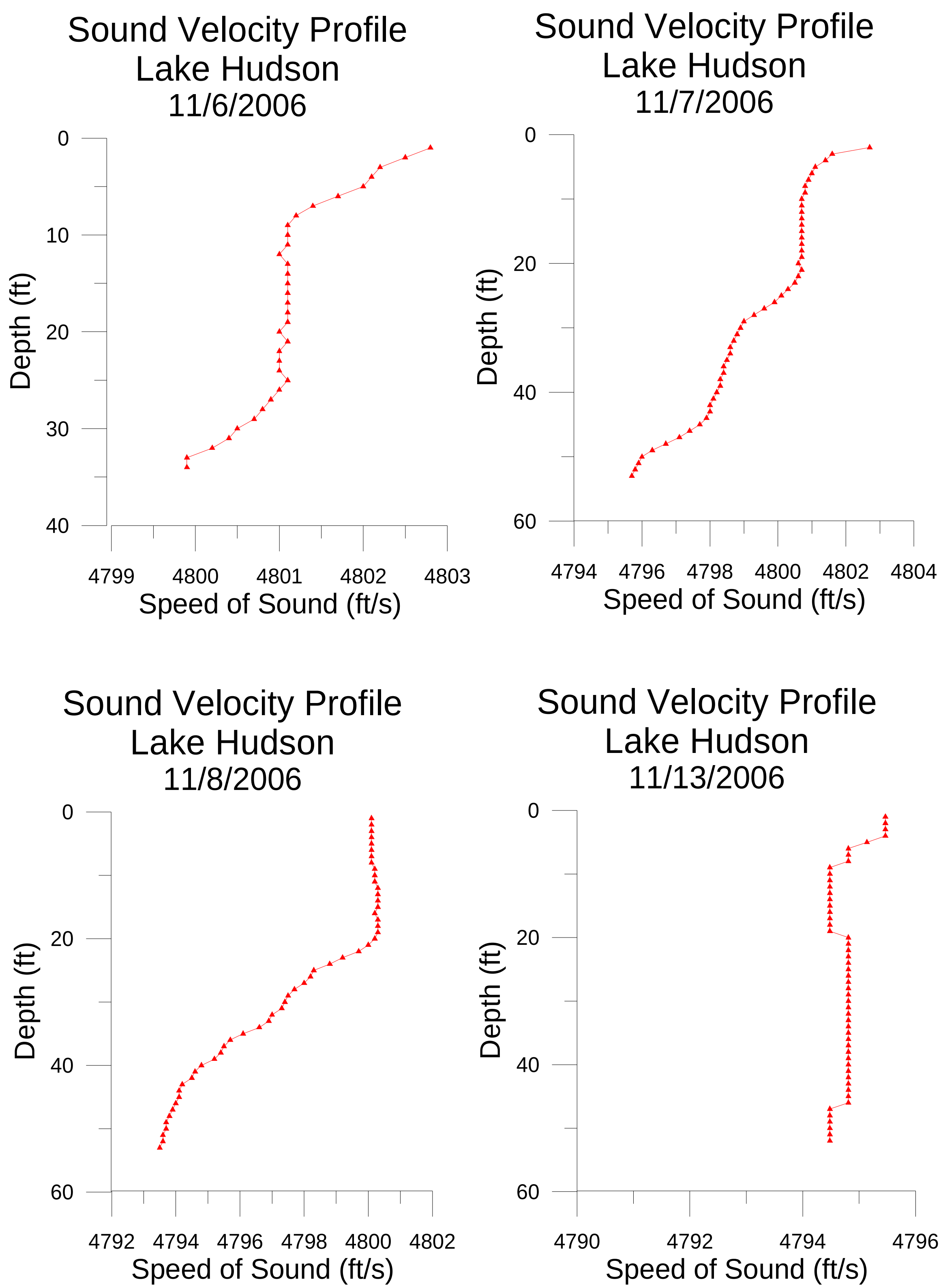


Figure A. 1: Sound Velocity Profiles for November 6, 7, 8, and 13, 2006.

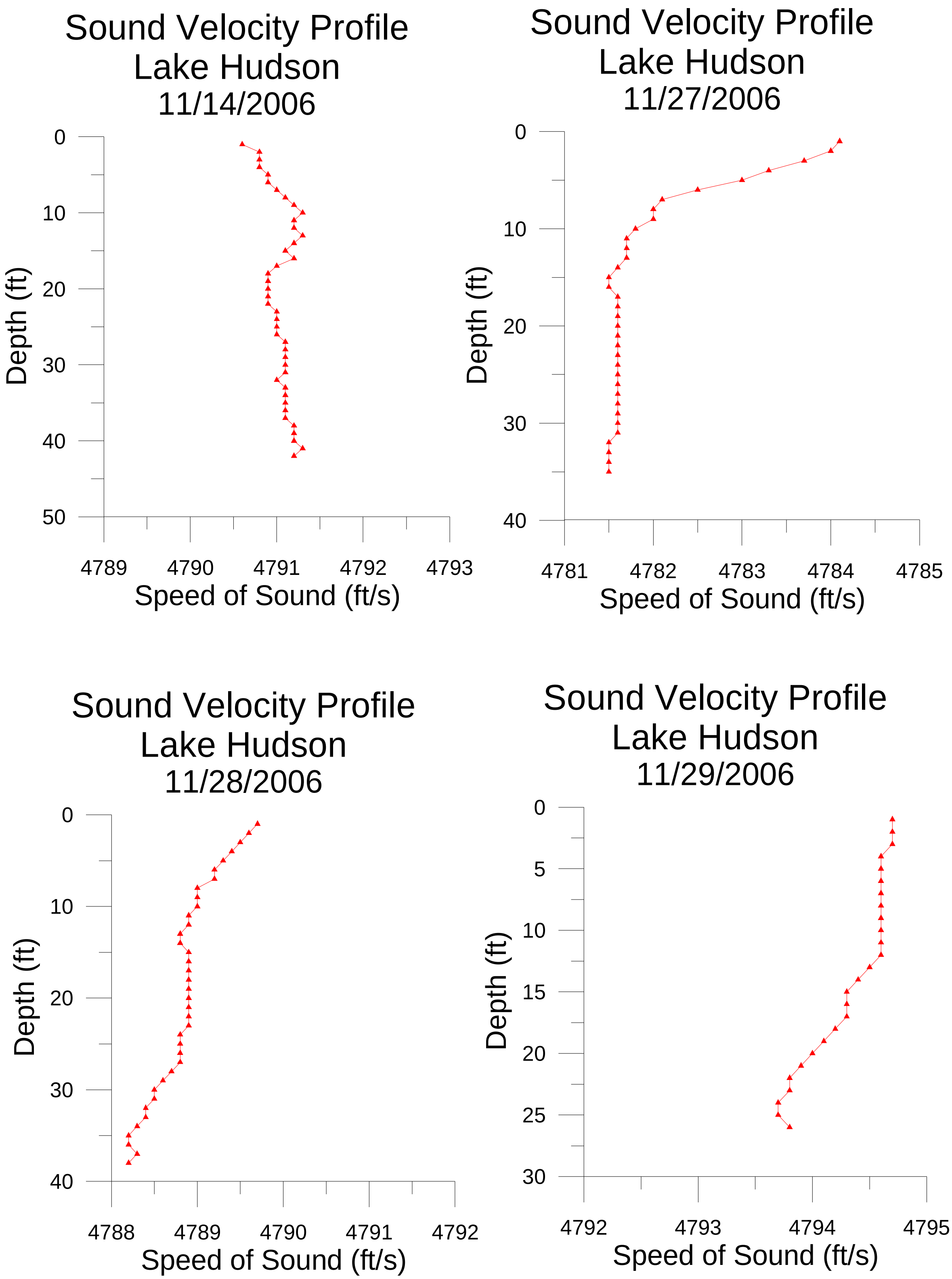


Figure A. 2: Sound Velocity Profiles for November 14, 27, 28, and 29, 2006.

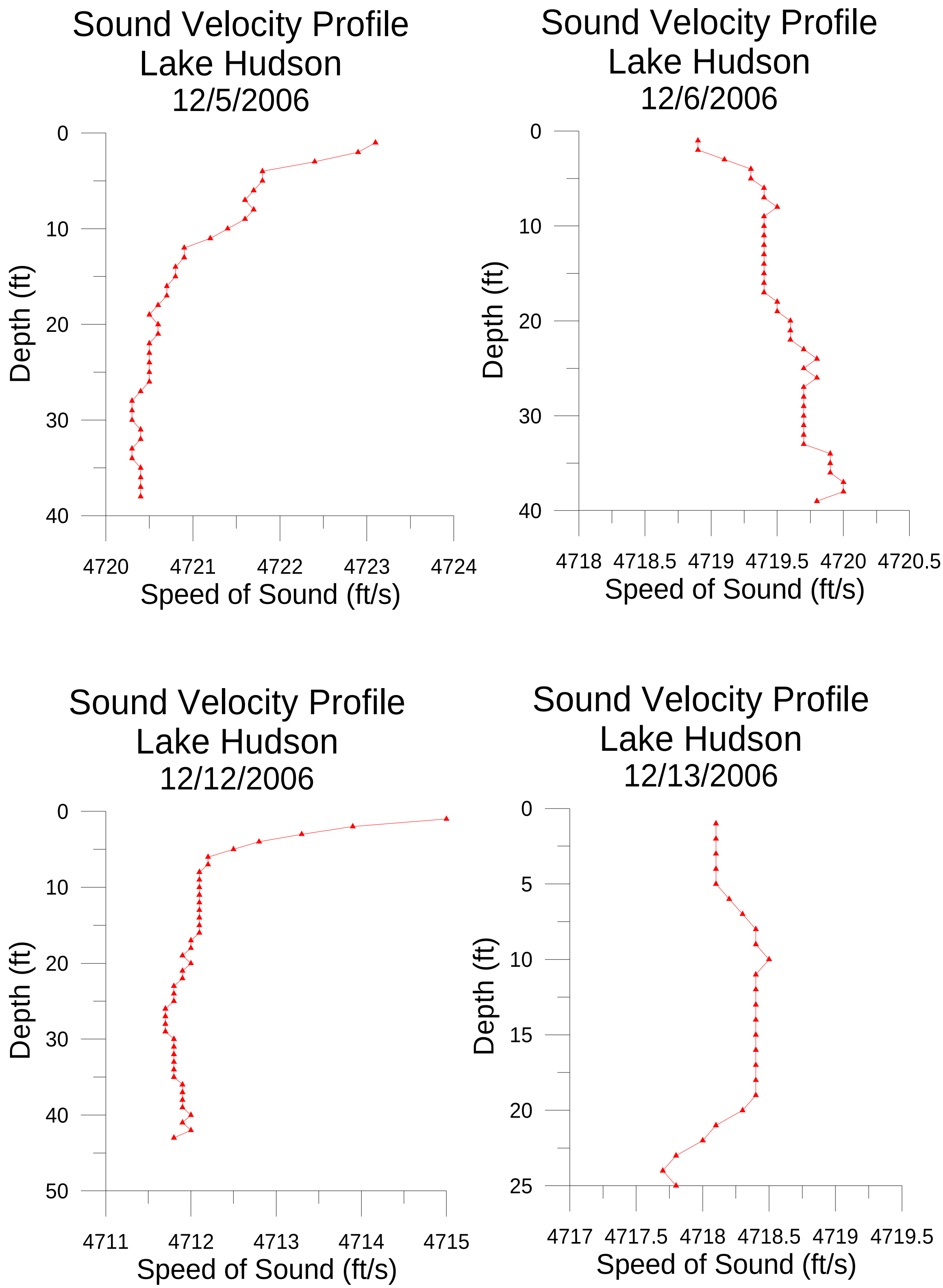


Figure A. 3: Sound Velocity Profiles for December 5, 6, 12, and 13, 2006.

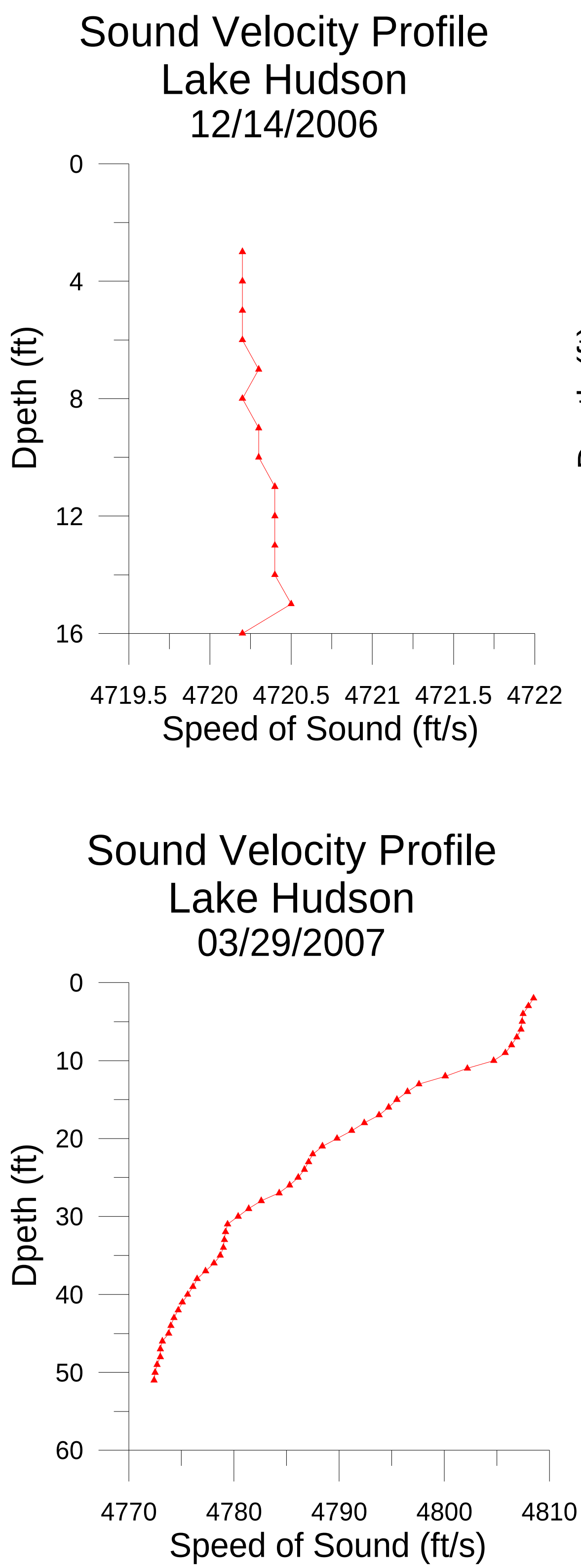


Figure A. 4: Sound Velocity Profiles for December 14, 2006 and March 28 and 29, 2007.

APPENDIX B: Area-Capacity Data

Table B. 1: Lake Hudson Capacity/Area by 0.1-ft Increments.

LAKE HUDSON CAPACITY-AREA TABLE OKLAHOMA WATER RESOURCES BOARD 2006-2007 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		.04	.14	.24	.34	.44	.54	.64	.74	.84	.94
554	Area	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.004	0.006	0.008
	Capacity	0.000	0.001	0.002	0.004	0.007	0.009	0.012	0.014	0.017	0.020
555	Area	0.010	0.012	0.015	0.018	0.021	0.025	0.029	0.033	0.037	0.042
	Capacity	0.023	0.026	0.029	0.032	0.035	0.038	0.041	0.044	0.048	0.052
556	Area	0.048	0.054	0.060	0.067	0.074	0.082	0.090	0.099	0.108	0.119
	Capacity	0.056	0.060	0.065	0.070	0.075	0.081	0.087	0.093	0.099	0.105
557	Area	0.130	0.141	0.153	0.166	0.181	0.196	0.213	0.233	0.257	0.284
	Capacity	0.112	0.119	0.127	0.135	0.146	0.163	0.186	0.216	0.253	0.291
558	Area	0.32	0.35	0.39	0.43	0.48	0.53	0.59	0.65	0.71	0.78
	Capacity	0.33	0.37	0.41	0.45	0.49	0.54	0.58	0.62	0.67	0.71
559	Area	0.86	0.95	1.04	1.14	1.24	1.34	1.44	1.55	1.66	1.77
	Capacity	0.88	0.91	0.94	0.97	1.00	1.03	1.05	1.08	1.12	1.15
560	Area	1.89	2.01	2.13	2.26	2.39	2.52	2.66	2.80	2.96	3.13
	Capacity	1.18	1.22	1.25	1.29	1.32	1.36	1.40	1.48	1.62	1.85
561	Area	3.33	3.57	3.87	4.22	4.63	5.10	5.64	6.26	6.95	7.73
	Capacity	2.20	2.66	3.21	3.79	4.42	5.08	5.79	6.53	7.32	8.15
562	Area	8.6	9.5	10.6	11.7	13.0	14.4	15.9	17.6	19.4	21.5
	Capacity	9.0	9.9	11.0	12.1	13.3	14.6	16.0	17.6	19.3	21.2
563	Area	23.7	26.1	28.7	31.6	34.7	38.0	41.6	45.4	49.5	53.8
	Capacity	23.2	25.3	27.4	29.7	32.0	34.4	36.9	39.5	42.3	45.4
564	Area	59.3	66.1	73.0	80.0	87.0	94.1	101	108	116	123
	Capacity	67.4	68.3	69.3	70.1	70.6	71.2	71.7	72.3	72.8	73.4
565	Area	130	138	145	153	160	168	176	184	191	199
	Capacity	73.9	74.5	75.1	75.6	76.2	76.8	77.3	78.0	78.7	79.6
566	Area	207	215	224	232	240	249	258	267	276	285
	Capacity	80.7	81.8	83.0	84.2	85.4	86.6	87.9	89.2	90.5	91.8
567	Area	294	303	313	323	333	343	354	365	376	387
	Capacity	93.4	95.2	97.1	99.3	102	104	107	110	114	117
568	Area	399	412	424	437	451	465	479	494	509	525
	Capacity	121	125	128	132	137	141	145	150	154	159
569	Area	542	562	583	604	625	646	667	688	710	732
	Capacity	201	204	206	208	210	212	214	216	218	219
570	Area	754	776	799	821	844	867	890	914	937	961
	Capacity	221	223	225	227	229	231	233	235	237	239
571	Area	985	1009	1034	1058	1083	1108	1133	1159	1185	1211
	Capacity	241	243	245	247	250	252	254	256	258	261
572	Area	1237	1263	1290	1317	1344	1372	1399	1427	1456	1484
	Capacity	263	265	268	270	273	276	278	281	284	287
573	Area	1513	1542	1572	1601	1631	1662	1693	1724	1755	1787
	Capacity	290	293	296	299	303	306	309	313	316	320
574	Area	1820	1855	1890	1926	1961	1997	2033	2069	2105	2142
	Capacity	348	350	352	354	356	358	360	362	364	366

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

LAKE HUDSON CAPACITY-AREA TABLE OKLAHOMA WATER RESOURCES BOARD 2006-2007 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		.04	.14	.24	.34	.44	.54	.64	.74	.84	.94
575	Area	2178	2215	2252	2290	2328	2365	2404	2442	2481	2519
	Capacity	368	371	373	375	378	380	382	385	387	390
576	Area	2558	2598	2637	2677	2718	2758	2799	2840	2881	2923
	Capacity	392	395	397	400	403	406	409	412	416	419
577	Area	2965	3007	3050	3093	3137	3181	3225	3270	3315	3360
	Capacity	422	426	429	433	437	440	444	448	452	457
578	Area	3406	3452	3499	3546	3594	3643	3692	3742	3792	3843
	Capacity	461	466	471	476	482	488	494	501	508	516
579	Area	3898	3958	4018	4079	4140	4202	4264	4327	4390	4454
	Capacity	594	600	606	611	616	620	625	629	634	638
580	Area	4518	4583	4647	4713	4779	4845	4912	4979	5047	5115
	Capacity	643	647	652	656	660	665	669	674	678	683
581	Area	5183	5252	5321	5391	5462	5533	5604	5676	5748	5821
	Capacity	687	692	696	701	706	710	715	720	725	730
582	Area	5894	5968	6042	6117	6192	6268	6344	6421	6499	6577
	Capacity	735	740	745	750	756	761	767	773	779	785
583	Area	6656	6735	6815	6896	6978	7060	7143	7226	7311	7396
	Capacity	791	797	804	811	818	825	833	841	850	859
584	Area	7486	7582	7679	7777	7876	7976	8077	8178	8280	8383
	Capacity	954	966	975	984	993	1002	1010	1019	1027	1035
585	Area	8487	8592	8698	8804	8911	9019	9128	9238	9350	9462
	Capacity	1043	1051	1060	1068	1077	1086	1095	1105	1119	1130
586	Area	9576	9690	9806	9923	10041	10159	10279	10400	10523	10646
	Capacity	1141	1152	1162	1173	1183	1194	1204	1216	1229	1243
587	Area	10771	10898	11026	11156	11289	11424	11561	11699	11839	11980
	Capacity	1257	1273	1292	1313	1338	1360	1375	1390	1405	1420
588	Area	12123	12267	12413	12561	12710	12861	13015	13171	13331	13495
	Capacity	1435	1451	1467	1484	1502	1523	1548	1580	1618	1666
589	Area	13672	13864	14059	14256	14455	14657	14862	15068	15278	15489
	Capacity	1901	1935	1961	1984	2008	2031	2055	2079	2103	2128
590	Area	15703	15920	16139	16361	16586	16813	17043	17276	17511	17749
	Capacity	2152	2178	2206	2233	2260	2287	2313	2340	2365	2387
591	Area	17988	18230	18474	18720	18968	19218	19470	19724	19981	20240
	Capacity	2407	2428	2448	2469	2489	2511	2532	2554	2576	2600
592	Area	20501	20765	21031	21301	21573	21848	22125	22404	22686	22970
	Capacity	2625	2652	2679	2707	2735	2763	2784	2804	2826	2847
593	Area	23255	23543	23833	24125	24420	24716	25015	25317	25622	25930
	Capacity	2868	2888	2909	2931	2953	2977	3003	3032	3066	3104
594	Area	26248	26578	26910	27245	27582	27922	28264	28608	28954	29303
	Capacity	3280	3309	3336	3361	3384	3407	3429	3451	3473	3498
595	Area	29654	30008	30364	30724	31086	31451	31818	32188	32559	32932
	Capacity	3525	3551	3578	3609	3637	3661	3682	3701	3720	3739

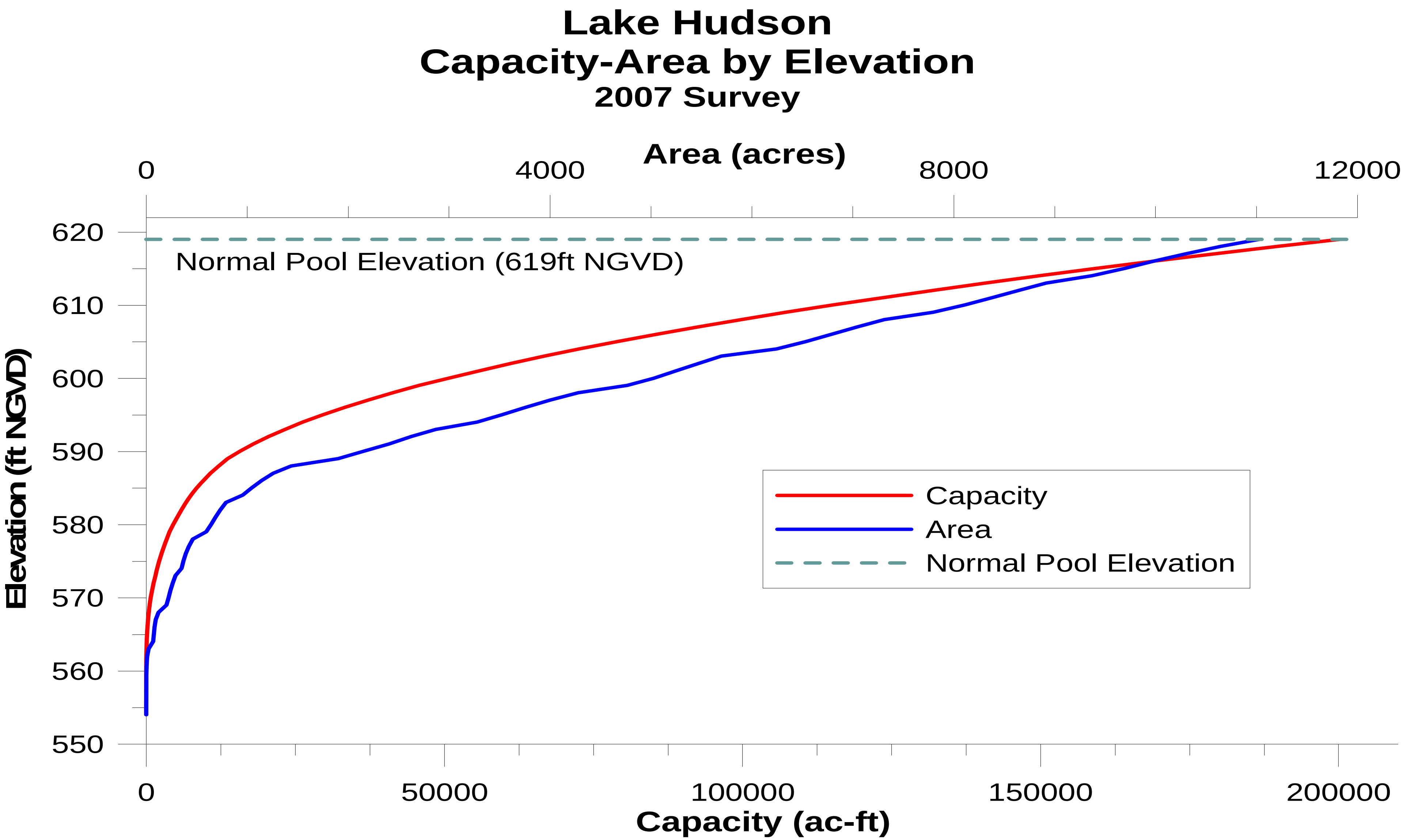
Table B. 3: Lake Hudson Capacity/Area by 0.1-ft Increments (cont).

LAKE HUDSON CAPACITY-AREA TABLE OKLAHOMA WATER RESOURCES BOARD 2006-2007 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		.04	.14	.24	.34	.44	.54	.64	.74	.84	.94
596	Area	33307	33684	34062	34443	34826	35211	35598	35988	36381	36776
	Capacity	3758	3777	3797	3816	3838	3862	3886	3911	3938	3967
597	Area	37174	37576	37981	38390	38801	39215	39632	40051	40473	40897
	Capacity	4000	4036	4070	4099	4126	4152	4178	4203	4228	4254
598	Area	41323	41753	42185	42620	43058	43498	43943	44391	44843	45299
	Capacity	4280	4306	4334	4363	4393	4425	4460	4498	4540	4586
599	Area	45765	46244	46725	47209	47696	48186	48678	49173	49670	50169
	Capacity	4764	4798	4828	4857	4884	4910	4934	4958	4981	5005
600	Area	50671	51175	51682	52191	52702	53215	53731	54248	54768	55289
	Capacity	5028	5052	5076	5099	5121	5143	5164	5185	5205	5225
601	Area	55813	56339	56866	57397	57929	58463	59000	59539	60081	60624
	Capacity	5246	5267	5289	5311	5333	5356	5379	5402	5426	5450
602	Area	61171	61719	62270	62823	63378	63936	64495	65057	65622	66188
	Capacity	5473	5496	5518	5541	5563	5585	5607	5629	5652	5675
603	Area	66756	67328	67902	68480	69060	69644	70232	70824	71421	72022
	Capacity	5699	5726	5756	5788	5822	5860	5900	5943	5987	6035
604	Area	72635	73261	73890	74523	75159	75797	76439	77083	77730	78379
	Capacity	6244	6277	6309	6340	6371	6399	6427	6455	6482	6509
605	Area	79032	79687	80344	81005	81667	82333	83001	83671	84344	85020
	Capacity	6535	6562	6588	6615	6641	6667	6691	6716	6740	6766
606	Area	85697	86378	87061	87747	88435	89125	89818	90513	91212	91912
	Capacity	6793	6818	6842	6866	6890	6915	6940	6965	6991	7017
607	Area	92615	93321	94029	94741	95454	96170	96889	97611	98335	99062
	Capacity	7044	7072	7097	7123	7148	7174	7201	7228	7255	7281
608	Area	99791	100524	101260	101998	102739	103483	104230	104980	105735	106492
	Capacity	7312	7340	7367	7395	7424	7454	7486	7520	7557	7597
609	Area	107260	108042	108828	109617	110410	111205	112005	112806	113611	114418
	Capacity	7797	7837	7874	7908	7941	7973	8003	8031	8058	8085
610	Area	115228	116041	116855	117674	118494	119316	120142	120970	121800	122633
	Capacity	8111	8137	8163	8190	8216	8240	8265	8289	8314	8349
611	Area	123470	124309	125151	125996	126843	127692	128545	129399	130257	131118
	Capacity	8377	8405	8432	8458	8483	8508	8534	8563	8590	8617
612	Area	131981	132847	133715	134586	135460	136336	137215	138097	138982	139869
	Capacity	8643	8670	8696	8722	8749	8777	8803	8830	8858	8887
613	Area	140759	141653	142549	143448	144351	145256	146165	147077	147994	148913
	Capacity	8917	8945	8975	9009	9040	9071	9105	9141	9177	9213
614	Area	149841	150781	151724	152671	153621	154574	155531	156491	157454	158419
	Capacity	9373	9415	9450	9483	9516	9548	9581	9611	9640	9670
615	Area	159388	160359	161333	162311	163291	164274	165260	166248	167240	168234
	Capacity	9699	9727	9756	9786	9814	9843	9872	9900	9929	9957
616	Area	169232	170232	171235	172242	173250	174261	175276	176293	177313	178335
	Capacity	9989	10016	10044	10072	10099	10127	10155	10182	10209	10237

Table B. 4: Lake Hudson Capacity/Area by 0.1-ft Increments (cont).

LAKE HUDSON CAPACITY-AREA TABLE OKLAHOMA WATER RESOURCES BOARD 2006-2007 Survey Capacity in acre-feet by tenth foot elevation increments Area in acres by tenth foot elevation increments											
Elevation (ft NGVD)		**.04**	**.14**	**.24**	**.34**	**.44**	**.54**	**.64**	**.74**	**.84**	**.94**
617	Area	179361	180394	181428	182466	183505	184548	185594	186642	187693	188747
	Capacity	10304	10331	10358	10385	10412	10439	10467	10495	10523	10551
618	Area	189806	190872	191942	193015	194092	195172	196256	197342	198433	199527
	Capacity	10645	10679	10714	10748	10782	10817	10851	10886	10921	10956
619	Area	200185									
	Capacity	11029									

Figure B. 1. Capacity-Area Curve



APPENDIX C: Lake Hudson Bathymetric Maps

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

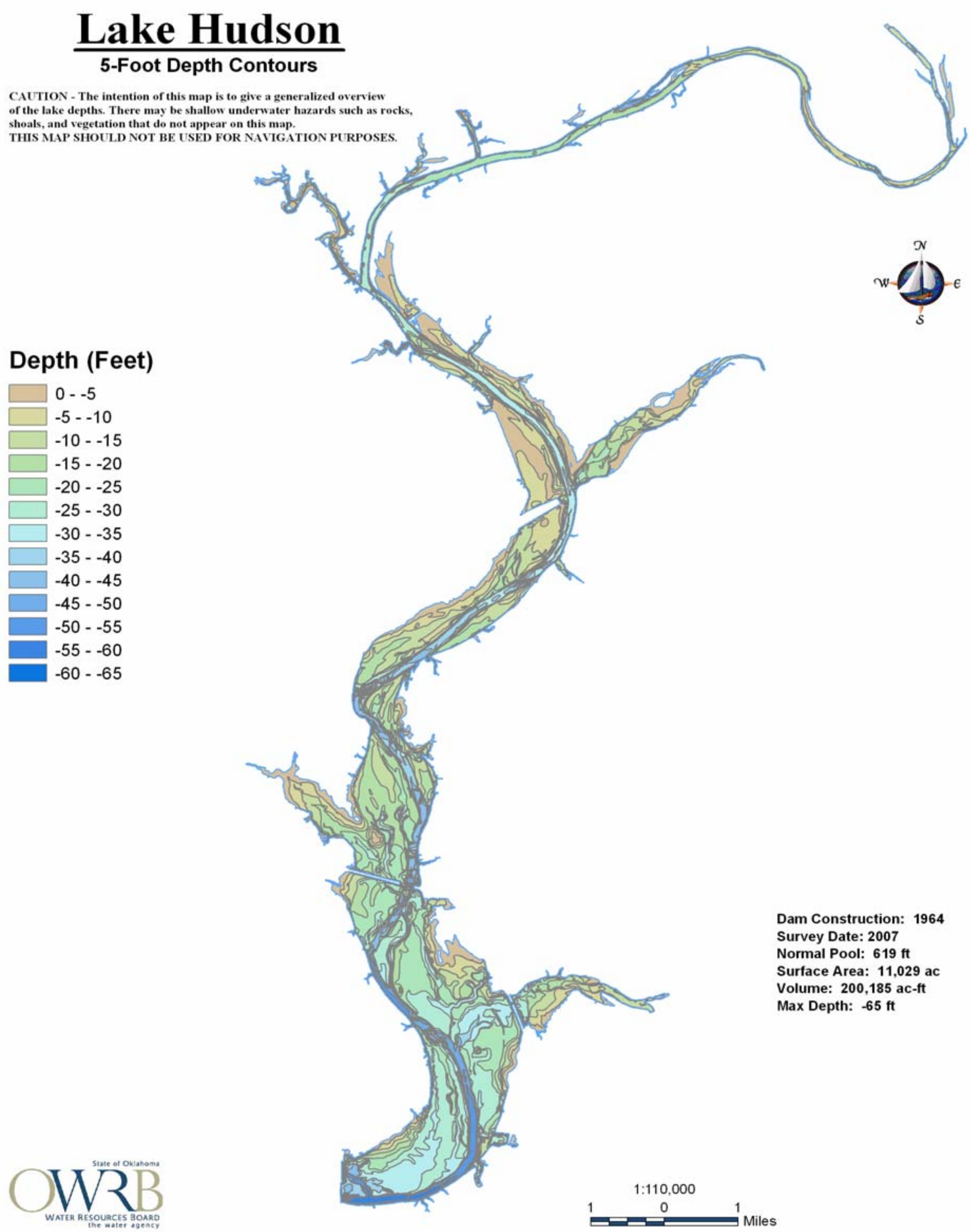


Figure C. 2: Lake Hudson Shaded Relief Bathymetric Map.

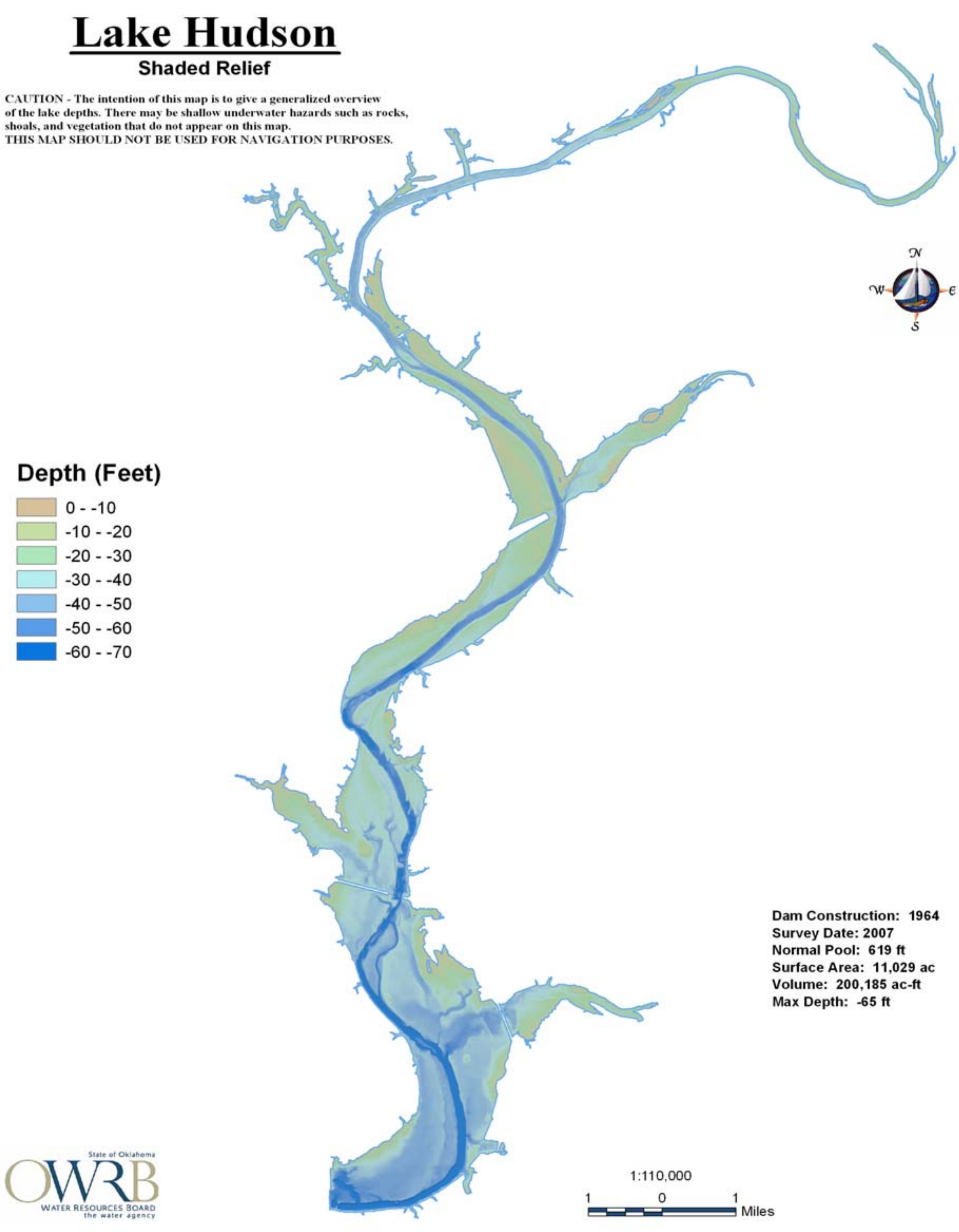


Figure C. 3: Lake Hudson Collected Data Points.