VOLUMETRIC SURVEY OF LAKE CHEROKEE

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Lake Cherokee on October 29, 30 and 31, 1996. The purpose of the survey was to determine the capacity of the lake at the conservation pool elevation and to compare the results to any previous sediment surveys. From this information, future surveys will be able to determine the location and rates of sediment deposition over time. Survey results are presented in the following pages in both graphical and tabular form. All elevations presented in this report will be reported in feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29) unless noted otherwise. The conservation pool elevation for Lake Cherokee is 280.0 feet. At this elevation, the original estimate for the surface area of the lake in 1948 was 3,987 acres and the estimated volume was 49,295 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Cherokee and the Cherokee Dam facility are owned by the Cherokee Water Company. The lake is located on Cherokee Bayou, a tributary of the Sabine River, in Gregg and Rusk Counties, approximately 12 miles southeast of Longview, Texas (see Figure 1). Records indicate the watershed for Lake Cherokee is approximately 167 square miles. The shoreline at the conservation pool elevation is approximately 41.7 miles long. The lake is approximately seven and one-half miles long from the dam to the headwaters. The widest area of the lake (located 3/4 of a mile upstream of the dam) is approximately one mile.

Permit No. 1396 dated November 27, 1946, issued by the State Board of Water Engineers to Mr. Clyde Hill, trustee, for the Cherokee Water Company, authorized the

diversion of 62,400 acre-feet of water per year for municipal and recreational purposes. The uses of the water were extended to include industrial and manufacturing uses under Permit 1427 dated December 11, 1947. Records indicate that Mr. Clyde Hill, trustee for the Cherokee Water Company, transferred all rights and obligations by deed to the Cherokee Water Company on July 24, 1948. On December 10, 1986, the Texas Water Commission issued a Certificate of Adjudication (No. 05-4642) to the Cherokee Water Company. The certificate authorized the owner to maintain an existing reservoir known as Lake Cherokee and impound not to exceed 62,400 acre-feet of water. Authorization to divert and use not to exceed 62,400 acre-feet of water per year for municipal, industrial and recreational purposes was also granted.

The Cherokee Water Company began acquiring land for the lake along Cherokee Bayou in 1946. Construction of the dam facility began in April 1948 and was completed in November of the same year. Deliberate impoundment of water began in October 1948. The dam consists of an earthen-rolled embankment approximately 3,050 feet in length. The maximum height of the embankment is 45 feet above the natural stream bed at elevation 295.0 feet. The service spillway is an uncontrolled concrete weir and chute located at the north (left) end of the embankment. The weir is 828 feet in length with a crest elevation at 280.0 feet. The emergency spillway, located approximately 200 feet south (right) of the dam embankment, is natural earth. The graded cut is approximately 600 feet in length with an original crest elevation of 287.7 feet. Records indicate the emergency spillway was lowered to an unknown elevation and eight sluice gates were installed as a temporary control for the lake level during repairs to the service spillway after a 1957 flood. After the repairs were made to the service spillway, concrete filled sandbags were placed upstream of the sluice gates. There is no indication that the sluice gates are presently operable. A low-flow outlet, consisting of an 18 inch diameter pipe (invert elevation 260.0 feet), is controlled by a gate valve at a tower located upstream of the embankment.

The Soil Conservation Service (SCS) performed a sedimentation survey of Lake Cherokee in April 1960. The survey consisted of 34 range lines, of which approximately 1,025 data points were collected. The volumes were determined from the collected data by using the

range contour formula described by Eakin and Brown in U.S.D.A. Technical Bulletin No. 524, "Silting of Reservoirs." The new capacity at elevation 280.0 was calculated to be 46,705 acre-feet and the surface area at this elevation was calculated as 3,987 acres.

The Texas Water Development Board performed a reconnaissance survey of Lake Cherokee in February 1986. The TWDB survey re-ran the same range lines as the 1960 SCS survey. Data was collected by driving at a constant speed across the lake, and tracing the bottom profile on a thermal, paper chart recording depth sounder. The collected data was processed by the same formulas as the SCS survey. The new capacity at elevation 280.0 was calculated to be 45,186 acre-feet and an area of 3,367 acres.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the theory behind Global Positioning System (GPS) technology and its accuracy. Equipment and methodology used to conduct the subject survey and previous hydrographic surveys are also addressed.

GPS Information

The following is a brief and simple description of Global Positioning System (GPS) technology. GPS is a new technology that uses a network of satellites, maintained in precise orbits around the earth, to determine locations on the surface of the earth. GPS receivers continuously monitor the broadcasts from the satellites to determine the position of the receiver. With only one satellite being monitored, the point in question could be located anywhere on a sphere surrounding the satellite with a radius of the distance measured. The observation of two satellites decreases the possible location to a finite number of points on a circle where the two spheres intersect. With a third satellite observation, the unknown location is reduced to two points where all three spheres intersect. One of these points is obviously in error because its location is in space, and it is ignored. Although three satellite measurements can fairly

accurately locate a point on the earth, the minimum number of satellites required to determine a three dimensional position within the required accuracy is four. The fourth measurement compensates for any time discrepancies between the clock on board the satellites and the clock within the GPS receiver.

GPS technology was developed in the 1960's by the United States Air Force and the defense establishment. After program funding in the early 1970's, the initial satellite was launched on February 22, 1978. A four year delay in the launching program occurred after the Challenger space shuttle disaster. In 1989, the launch schedule was resumed. Full operational capability was reached on April 27, 1995 when the NAVSTAR (NAVigation System with Time And Ranging) satellite constellation was composed of 24 Block II satellites. Initial operational capability, a full constellation of 24 satellites, in a combination of Block I (prototype) and Block II satellites, was achieved December 8, 1993. The NAVSTAR satellites provide data based on the World Geodetic System (WGS '84) spherical datum. WGS '84 is essentially identical to NAD '83.

The United States Department of Defense (DOD) is currently responsible for implementing and maintaining the satellite constellation. In an attempt to discourage the use of these survey units as a guidance tool by hostile forces, the DOD has implemented means of false signal projection called Selective Availability (S/A). Positions determined by a single receiver when S/A is active result in errors to the actual position of up to 100 meters. These errors can be reduced to centimeters by performing a static survey with two GPS receivers, one of which is set over a point with known coordinates. The errors induced by S/A are time-constant. By monitoring the movements of the satellites over time (one to three hours), the errors can be minimized during post processing of the collected data and the unknown position computed accurately.

Differential GPS (DGPS) can determine positions of moving objects in real-time or "on-the-fly." In the early stages of this program, one GPS receiver was set up over a benchmark with known coordinates established by the hydrographic survey crew. This receiver remained

stationary during the survey and monitored the movements of the satellites overhead. Position corrections were determined and transmitted via a radio link once per second to a second GPS receiver located on the moving boat. The boat receiver used these corrections, or differences, in combination with the satellite information it received to determine its differential location. The large positional errors experienced by a single receiver when S/A is active are greatly reduced by utilizing DGPS. The reference receiver calculates satellite corrections based on its known fixed position, which results in positional accuracies within three meters for the moving receiver. DGPS was used to determine horizontal position only. Vertical information was supplied by the depth sounder.

The need for setting up a stationary shore receiver for current surveys has been eliminated with the development of fee-based reference position networks. These networks use a small network of GPS receivers to create differential corrections for a large network of transmitting stations, Wide Area Differential GPS (WADGPS). The TWDB receives this service from ACCQPOINT, a WADGPS correction network over a FM radio broadcast. A small radio receiver purchased from ACCQPOINT, collects positional correction information from the closest broadcast station and provides the data to the GPS receiver on board the hydrographic surveying boat to allow the position to be differentially corrected.

Equipment and Methodology

The equipment used in the performance of the hydrographic survey consisted of a 23-foot aluminum tri-hull SeaArk craft with cabin, equipped with twin 90-Horsepower Johnson outboard motors. Installed within the enclosed cabin are an Innerspace Helmsman Display (for navigation), an Innerspace Technology Model 449 Depth Sounder and Model 443 Velocity Profiler, a Trimble Navigation, Inc. 4000SE GPS receiver, an ACCQPOINT FM receiver, and an on-board 486 computer. Power was provided by a water-cooled generator through an in-line uninterruptible power supply. Reference to brand names does not imply endorsement by the TWDB.

The GPS equipment, survey vessel, and depth sounder combine together to provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder gathers approximately ten readings of the lake bottom each second. The depth readings are stored on the survey vessel's on-board computer along with the corrected positional data generated by the boat's GPS receiver. The daily data files collected are downloaded from the computer and brought to the office for editing after the survey is completed. During editing, bad data is removed or corrected, multiple data points are averaged to get one data point per second, and average depths are converted to elevation readings based on the daily recorded lake elevation on the day the survey was performed. Accurate estimates of the lake volume can be quickly determined by building a 3-D model of the reservoir from the collected data. The level of accuracy is equivalent to or better than previous methods used to determine lake volumes, some of which are discussed below.

Previous Survey Procedures

Originally, reservoir surveys were conducted with a rope stretched across the reservoir along pre-determined range lines. A small boat would manually pole the depth at selected intervals along the rope. Over time, aircraft cable replaced the rope and electronic depth sounders replaced the pole. The boat was hooked to the cable, and depths were again recorded at selected intervals. This method, used mainly by the Soil Conservation Service, worked well for small reservoirs.

Larger bodies of water required more involved means to accomplish the survey, mainly due to increased size. Cables could not be stretched across the body of water, so surveying instruments were utilized to determine the path of the boat. Monumentation was set for the end points of each line so the same lines could be used on subsequent surveys. Prior to a survey, each end point had to be located (and sometimes reestablished) in the field and vegetation cleared so that line of sight could be maintained. One surveyor monitored the path of the boat and issued commands via radio to insure that it remained on line while a second surveyor determined depth measurement locations by turning angles. Since it took a major effort to determine each of the points along the line, the depth readings were spaced quite a distance apart. Another major cost was the land surveying required prior to the reservoir survey to locate the range line monuments and clear vegetation.

Electronic positioning systems were the next improvement. If triangulation could determine the boat location by electronic means, then the boat could take continuous depth soundings. A set of microwave transmitters positioned around the lake at known coordinates would allow the boat to receive data and calculate its position. Line of site was required, and the configuration of the transmitters had to be such that the boat remained within the angles of 30 and 150 degrees in respect to the shore stations. The maximum range of most of these systems was about 20 miles. Each shore station had to be accurately located by survey, and the location monumented for future use. Any errors in the land surveying resulted in significant errors that were difficult to detect. Large reservoirs required multiple shore stations and a crew to move the shore stations to the next location as the survey progressed. Land surveying was still a major cost.

Another method used mainly prior to construction utilized aerial photography to generate elevation contours which could then be used to calculate the volume of the reservoir. Fairly accurate results could be obtained, although the vertical accuracy of the aerial topography was generally one-half of the contour interval or ± five feet for a ten-foot contour interval. This method could be quite costly and was only applicable in areas that were not inundated.

PRE-SURVEY PROCEDURES

The reservoir's surface area was determined prior to the survey by digitizing with AutoCad software the lake's conservation pool boundary from USGS quad sheets. The name of the quad sheets are as follows: ELDERVILLE, TX. (Provisional 1983), LAKEPORT, TX. (Provisional 1983) and TATUM, TX. (Provisional 1983). The graphic boundary file created was then transformed into the proper datum, from NAD '27 datum to NAD '83, using Environmental

Systems Research Institutes's (ESRI) Arc/Info project command with the NADCOM parameters. The area of the lake boundary was checked to verify that the area was the same in both datums.

The survey layout was designed by placing survey track lines at 500 foot intervals across the lake. The survey design for this lake required approximately 127 survey lines to be placed along the length of the lake. Survey setup files were created using Coastal Oceangraphics, Inc. Hypack software for each group of track lines that represented a specific section of the lake. The setup files were copied onto diskettes for use during the field survey.

SURVEY PROCEDURES

The following procedures were followed during the hydrographic survey of Lake Cherokee performed by the TWDB. Information regarding equipment calibration and operation, the field survey, and data processing is presented.

Equipment Calibration and Operation

During the survey, the onboard GPS receiver was set to a horizontal mask of 10° and a PDOP (Position Dilution of Precision) limit of 7 to maximize the accuracy of horizontal positions. An internal alarm sounds if the PDOP rises above seven to advise the field crew that the horizontal position has degraded to an unacceptable level.

At the beginning of each surveying day, the depth sounder was calibrated with the Innerspace Velocity Profiler. The Velocity Profiler calculates an average speed of sound through the water column of interest for a designated draft value of the boat (draft is the vertical distance that the boat penetrates the water surface). The draft of the boat was

previously determined to average 1.2 ft. The velocity profiler probe is placed in the water to moisten and acclimate the probe. The probe is then raised to the water surface where the depth is zeroed. The probe is lowered on a cable to just below the maximum depth set for the water column, and then raised to the surface. The unit displays an average speed of sound for a given water depth and draft, which is entered into the depth sounder. The depth value on the depth sounder was then checked manually with a measuring tape to ensure that the depth sounder was properly calibrated and operating correctly. During the survey of Lake Cherokee, the speed of sound in the water column varied daily between 4866 and 4870 feet per second. Based on the measured speed of sound for various depths, and the average speed of sound calculated for the entire water column, the depth sounder is accurate to within ±0.2 feet, plus an estimated error of ±0.3 feet due to the plane of the boat for a total accuracy of ±0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some are positive readings and some are negative readings. Further information on these calculations is presented in Appendix A.

Field Survey

Data was collected on Lake Cherokee during the period October 29, 30 and 31, 1996. Approximately 41,407 data points were collected over the 74 miles traveled along the pre-planned survey lines and the random data-collection lines. These points were stored digitally on the boat's computer in 113 data files. Data were not collected in areas of shallow water (depths less than 3.0 feet) or with significant obstructions unless these areas represented a large amount of water. Some random data lines were also collected, perpendicular to the survey layout, by the field crew during the survey. In addition, a small boat was outfitted with a paper recording depth sounder to collect 4 additional depth data cross-sections above the Hwy. 2011 (Silvery) bridge because no access was available for the standard survey vessel. These lines were field located, and the latitude/longitude information for the points created from the lines were added in the office. Approximately 7,915 data points were created from the 4 additional cross-sections. Figure 2 shows the actual location of all data collection points.

TWDB staff observed the lake bottom to be fairly uniform with a gentle slope from the shoreline to the center of the lake. The bathemetry of the lake reflected similar characteristics of the terrain or topography surrounding the lake. Several creek channels could be distinguished on the depth sounder's analog charts. The climatic conditions (the lack of strong winds) were quite favorable during the three days of data collection. Approximately one-half of the lake was clear of navigational hazards such as standing timber and submerged trees and stumps. Navigation in the other half of the lake was difficult and the pace of data collection slowed considerably. All of the pre-plotted range lines were run successfully, albeit the route did vary. Above Hwy. 2011, heavy underwater vegetation in combination with a very soft bottom, made it difficult to determine the lake bottom accurately. Data collection in the headwaters was discontinued when the vegetation became continuous throughout the water column and trees became predominant in the lake.

The collected data were stored in individual data files for each pre-plotted range line or random data collection event. These files were downloaded to diskettes at the end of each day for future processing.

Data Processing

The collected data were down-loaded from diskettes onto the TWDB's computer network. Tape backups were made for future reference as needed. To process the data, the EDIT routine in the Hypack Program was run on each raw data file. Data points such as depth spikes or data with missing depth or positional information were deleted from the file. The depth information collected every 0.1 seconds was averaged to get one reading for each second of data collection. A correction for the lake elevation at the time of data collection was also applied to each file during the EDIT routine. During the survey, the water surface ranged daily from 280.3 to 280.4 feet. After all changes had been made to the raw data file, the edited file was saved with a different extension. After all the files were edited, the edited files were combined into a single data file, representative of the lake, to be used with the GIS software to develop a model of the lake's bottom surface.

The resulting DOS data file was imported into the UNIX operating system used to run Environmental System Research Institutes's (ESRI) Arc/Info GIS software. The latitude and longitude coordinates of each point were then converted to decimal degrees by a UNIX awk command. The awk command manipulates the data file format into a MASS points format for use by the GIS software. The graphic boundary file previously digitized was also imported.

The boundary and MASS points files were graphically edited using the Arc/Edit module. The MASS points file was converted into a point coverage and plotted along with the boundary file. If data points were collected outside the boundary file, the boundary was modified to include the data points. Also, the boundary near the edges of the lake in areas of significant sedimentation was down-sized to reflect the observations of the field crew. The resulting boundary shape was considered to be the acreage at the conservation pool elevation of the lake. This was calculated as 3,083 acres for Lake Cherokee. The Board does not represent the boundary, as depicted in this report, to be a detailed actual boundary. Instead, it is a graphical approximation of the actual boundary used solely to compute the volume and area of the lake. The boundary does not represent the true land versus water boundary of the lake. An aerial topographic map of the upper four feet of the lake or an aerial photo taken when the lake is at the conservation pool elevation would more closely define the present boundary. However, the minimal increase in accuracy does not appear to offset the cost of those services at this time.

The edited MASS points and modified boundary file were used to create a Digital Terrain Model (DTM) of the reservoir's bottom surface using Arc/Info's TIN module. The module builds an irregular triangulated network from the data points and the boundary file. This software uses a method known as Delauney's criteria for triangulation. A triangle is formed between three non-uniformly spaced points, including all points along the boundary. If there is another point within the triangle, additional triangles are created until all points lie on the vertex of a triangle. All of the data points are preserved for use in determining the solution of the model by using this method. The generated network of three-dimensional triangular planes represents the actual bottom surface. Once the triangulated irregular network (TIN) is formed, the software then calculates elevations along the triangle surface plane by solving the equations for elevation along each leg of the triangle. Information for the entire reservoir area can be determined from the triangulated irregular network created using this method of interpolation.

There were some areas where values could not be calculated by interpolation because of a lack of information along the boundary of the reservoir. "Flat triangles" were drawn at these locations. Arc/Info does not use flat triangle areas in the volume or contouring features of the model. Approximately 270 additional points were required for interpolation and contouring of the entire lake surface. The TIN product calculated the surface area and volume of the entire reservoir at one-tenth of a foot intervals from the three-dimensional triangular plane surface representation. The computed reservoir volume table is presented in Appendix B and the area table in Appendix C. An elevation-area-volume graph is presented in Appendix D.

Other presentations developed from the model include a shaded relief map and a shaded depth range map. To develop the shaded relief map, the three-dimensional triangular surface was modified by a GRIDSHADE command. Colors were assigned to different elevation values of the grid. Using the command COLORRAMP, a set of colors that varied from navy to yellow was created. The lower elevation was assigned the color of navy, and the lake conservation pool elevation was assigned the color of yellow. Different color shades were assigned to the different depths in between. Figure 3 presents the resulting depth shaded representation of the lake. Figure 4 presents a similar version of the same map, using bands of color for selected depth intervals. The color increases in intensity from the shallow contour bands to the deep water bands.

The DTM was then smoothed and linear smoothing algorithms were applied to the smoothed model to produce smoother contours. The resulting contour map of the bottom surface at two-foot intervals is presented in Figure 5.

RESULTS

Results from the 1996 TWDB survey indicate Lake Cherokee encompasses 3,083 surface acres and contains a volume of 41,506 acre-feet at the conservation pool elevation of 280.0 feet. The shoreline at this elevation was calculated to be 39.6 miles. The lowest elevation encountered during the survey was 246.8 feet, or 33.2 feet of depth, and was found in the middle of the lake, within a mile of the dam. The dead storage volume, or the amount of water below the lowest outlet in the dam, was calculated to be 4,165 acre-feet based on the low flow outlet invert elevation of 260.0 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, was determined to be 37,340 acre-feet.

SUMMARY

Lake Cherokee was formed in 1948. Initial storage calculations estimated the volume at the conservation pool elevation of 280.0 feet to be 49,295 acre-feet with surface area of 3,987 acres.

During the period of October 29, 30, and 31, 1996, a hydrographic survey of Lake Cherokee was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1996 survey used technological advances such as differential global positioning system and geographical information system technology to build a model of the reservoir's bathemetry. These advances allowed a survey to be performed quickly and to collect significantly more data of the bathemetry of Lake Cherokee than previous survey methods. Supplemental data was also collected above the Hwy. 2011 bridge with a paper chart recording depth sounder. Together, these two sets of data were combined to develop the model of the lake. Results indicate that the lake's capacity at the conservation pool elevation of 280.0 feet was 41,506 acre-feet and the area was 3,083 acres.

Previous surveys of Lake Cherokee were performed in 1960 and 1986. The estimated reduction in storage capacity between 1948 and 1960 was estimated at 2,590 acre-ft or 225 acre-ft per year. The estimated reduction in storage capacity between 1960 and 1986 was estimated

at 1,519 acre-ft or 59 acre-ft per year. The estimated reduction in storage capacity between 1986 and 1996 was 3,680 acre-ft or 342.3 acre-ft per year. The average reduction in storage capacity since 1948 was 7,789 acre-ft or 162 acre-ft per year. The average annual deposition rate of sediment in the reservoir can be estimated at 0.97 acre-ft per square mile of drainage area.

It is difficult to compare the original design information and the three surveys performed because of the different procedures, different data collection techniques, and the different ways the data was processed. However, the TWDB considers the 1996 survey to be a significant improvement over previous survey procedures and recommends that the same methodology be used in five to ten years or after major flood events to monitor changes to the lake's storage capacity.

CALCULATION OF DEPTH SOUNDER ACCURACY

This methodology was extracted from the Innerspace Technology, Inc. Operation Manual for the Model 443 Velocity Profiler.

For the following examples, $t = (D - d)/V$

where:

t_D = **travel time of the sound pulse, in seconds (at depth = D)**
D = **depth, in feet**
d = **draft = 1.2 feet**
V = **speed of sound, in feet per second**

To calculate the error of a measurement based on differences in the actual versus average speed of sound, the same equation is used, in this format:

$$D = [t(V)]+d$$

For the water column from 2 to 30 feet: $V = 4832$ **fps**

$t_{30} = (30-1.2)/4832$
$= 0.00596$ **sec.**

For the water column from 2 to 45 feet: $V = 4808$ **fps**

$t_{45} = (45-1.2)/4808$
$= 0.00911$ **sec.**

For a measurement at 20 feet (within the 2 to 30 foot column with V = 4832 fps):

$D_{20} = [((20-1.2)/4832)(4808)]+1.2$
$= 19.9'$ (-0.1')

For a measurement at 30 feet (within the 2 to 30 foot column with V = 4832 fps):

$D_{30} = [((30-1.2)/4832)(4808)]+1.2$
$= 29.9'$ (-0.1')

For a measurement at 50 feet (within the 2 to 60 foot column with V = 4799 fps):

$D_{50} = [((50-1.2)/4799)(4808)]+1.2$

= 50.1' (+0.1')

For the water column from 2 to 60 feet: V = 4799 fps Assumed V_{80} = 4785 fps

t_{60} =(60-1.2)/4799
=0.01225 sec.

For a measurement at 10 feet (within the 2 to 30 foot column with V = 4832 fps):

D_{10} = [((10-1.2)/4832)(4799)]+1.2
= 9.9' (-0.1')

For a measurement at 30 feet (within the 2 to 30 foot column with V = 4832 fps):

D_{30} = [((30-1.2)/4832)(4799)]+1.2
= 29.8' (-0.2')

For a measurement at 45 feet (within the 2 to 45 foot column with V = 4808 fps):

D_{45} = [((45-1.2)/4808)(4799)]+1.2
= 44.9' (-0.1')

For a measurement at 80 feet (outside the 2 to 60 foot column, assumed V = 4785 fps):

D_{80} = [((80-1.2)/4785)(4799)]+1.2
= 80.2' (+0.2')