

VOLUMETRIC SURVEY OF AQUILLA LAKE

Prepared for:

BRAZOS RIVER AUTHORITY



Prepared by:

The Texas Water Development Board

March 10, 2003

Texas Water Development Board

TABLE OF CONTENTS

INTRODUCTION	1
HISTORY AND GENERAL INFORMATION OF THE RESERVOIR	1
HYDROGRAPHIC SURVEYING TECHNOLOGY	3
GPS Information.....	3
Equipment and Methodology	4
Previous Survey Procedures.....	5
PRE-SURVEY PROCEDURES	7
SURVEY CONTROL SETUP	7
SURVEY PROCEDURES	8
Equipment Calibration and Operation.....	9
Field Survey.....	10
Data Processing.....	11
RESULTS.....	13
SUMMARY.....	13

APPENDICES

APPENDIX A - DEPTH SOUNDER ACCURACY
APPENDIX B - RESERVOIR VOLUME TABLE
APPENDIX C - RESERVOIR AREA TABLE
APPENDIX D - AREA-ELEVATION-CAPACITY GRAPH

LIST OF FIGURES

FIGURE 1 - LOCATION MAP
FIGURE 2 - LOCATION OF SURVEY DATA
FIGURE 3 - LOCATION OF SURVEY CONTROL POINT
FIGURE 4 - SHADED RELIEF
FIGURE 5 - DEPTH CONTOURS
FIGURE 6 - 2-D CONTOUR MAP

AQUILLA LAKE HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Aquilla Lake during the period October 12-18, 1995. The purpose of the survey was to determine the capacity of the lake at the conservation pool elevation and to establish baseline information for future surveys. From this information, future surveys will be able to determine sediment deposition locations and rates 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. Based on U. S. Geological topographic maps dated 1957, the U. S. Army Corps of Engineers calculated the initial surface area of Aquilla Lake at the conservation pool elevation of 537.5 feet to be 3,280 acres with a corresponding initial capacity of 52,400 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Aquilla Lake is located on Aquilla Creek in Hill County, about seven miles southeast of Hillsboro, TX. The lake and dam facility are owned by the United States Government, and maintained and operated by the U. S. Army Corps of Engineers, Fort Worth District (COE). The lake was designed as a multi-purpose reservoir for flood control and water supply. The lake is basically an on-channel reservoir located on Aquilla Creek, downstream of the confluence of Hackberry Creek. The Federal Government has restricted any kind of private development at the facility, leaving the lake free of retaining walls, private dock facilities, or other structures. Inflows to the lake originate over a 255 square mile drainage area. The lake, at the conservation capacity pool elevation of 537.5 feet, is approximately 5.0 miles long and approximately 1.27 miles wide at its widest point near the dam.

Certificate of Adjudication #12-5158 was issued by the Texas Water Commission December 14, 1987 to the Brazos River Authority (BRA) to impound 52,400 acre-feet of water at elevation 537.5 in an existing reservoir on Aquilla Creek. The BRA was authorized a priority right to divert and use not to exceed 13,896 acre-feet of water per annum for municipal, industrial and mining purposes. For the purposes of the system operation, the BRA was authorized to exceed the priority right and annually divert and use from Aquilla Lake not to exceed 17,000 acre-feet for municipal purposes; 18,200 acre-feet for industrial purposes and 200 acre-feet for mining purposes. Any diversions and use of water from Aquilla Lake in excess of 13,896 acre-feet of water in one calendar year would be charged against the sum of the amounts designated as priority rights in other reservoirs included in the System Operation Order. BRA was also authorized to use the water impounded in Aquilla Lake for non-consumptive recreation purposes. Certificate of Adjudication #5167 (issued December 14, 1987) states the BRA is authorized to divert and use not exceed, 30,000 acre-feet of water for municipal purposes and 170,000 acre-feet of water for industrial purposes, to be used in the San Jacinto-Brazos Coastal Basin. These waters are to be released from Aquilla Lake and other reservoirs owned and operated by the Brazos River Authority.

Construction of the dam commenced in July 1977 and was completed in January 1983. Deliberate impoundment of water began April 29, 1983 and the facility was completed May 16, 1983. The project was designed by the COE and the general contractor was Clearwater Construction. The estimated project cost was \$46,100,000.

Aquilla Dam is an earthfill structure with a length of 11,890 feet rising 104.5 feet above the natural streambed to an elevation of 582.5 feet. Located near the left abutment, the uncontrolled spillway is a 1,200 foot long ogee weir at elevation 564.5 feet with a discharge capacity of 126,800 cubic feet per second (cfs) at the maximum design flood stage of 577.5 feet. The outlet works are composed of a 10-foot-diameter concrete conduit with an invert elevation of 503.0 feet. Discharges into the conduit are controlled by two 4.5-foot wide by 10-foot high hydraulically operated sluice gates.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the equipment and methodology used to conduct this hydrographic survey. Some of the theory behind Global Positioning System (GPS) technology and its accuracy 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 1960s by the United States Air Force and the defense establishment. After program funding in the early 1970s, 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 will be reached when the NAVSTAR (NAVigation System with Time And Ranging) satellite constellation is composed of 24 Block II satellites. At the time of the survey, the system had achieved initial operational capability. A full constellation of 24 satellites, in a combination of Block I (prototype) and Block II satellites, was fully functional. 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." 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.

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, a Motorola Radius radio with an Advanced Electronic Applications, Inc. packet modem, and an on-board computer. The computer was supported by a dot matrix printer and a B-size plotter. 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 shore station included a second Trimble 4000SE GPS receiver, Motorola Radius radio and Advanced Electronic Applications, Inc. packet modem, and an omni-directional antenna mounted on a modular aluminum tower to a total height of 40 feet. The combination of this equipment provided a data link with a reported range of 25 miles over level to rolling terrain that does not require that line-of-sight be maintained with the survey vessel in most conditions, thereby reducing the time required to conduct the survey.

The GPS equipment, survey vessel, and depthsounder 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 together 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 \pm 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 at the conservation pool elevation was determined prior to the survey from 1:100,000 scale 1990 Census TIGER line files. This data was checked against the approximate reservoir area determined by free-drawing the lake boundary on the 1:24,000 USGS topographic map, PEORIA, TX 1957 (photo-inspected 1976). 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 172 survey lines to be placed along the length of the lake. Survey setup files were created using Coastal Oceanographics, 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 CONTROL SETUP

The first task of the Hydrographic Survey field staff after arriving at Aquilla Lake was to establish a horizontal reference control point. Figure 3 shows the location of the control point established. This location was chosen due to the close proximity to the reservoir and the security of the area.

Prior to the field survey, TWDB staff had researched locations of known first-order benchmarks and requested Brazos River Authority employees to physically locate the associated monuments. Of the monuments found, the one chosen to provide horizontal control for the survey

was a U. S. Geological Survey first-order monument named "PECAN" located approximately four miles east of Hillsboro, TX. The coordinates for the monument are published as Latitude 32° 00' 34.992"N and Longitude 97° 04' 26.597"W.

On September 20, 1995, TWDB staff performed a static survey to determine the WGS'84 coordinates of the lake survey control point. The control point used for the shore station was installed by TWDB staff and consists of an unmarked USGS surveyor's cap set flush to the ground in concrete and located in a fenced area that surrounds the raw water intake pumps for the Aquilla Water Supply District. The GPS receivers were set up over each point and satellite data were gathered for approximately one hour, with up to six satellites visible at the same time to the receivers.

Once data collection ended, the data were retrieved and processed from both receivers, using Trimble Trimvec software, to determine the coordinates for the control point. The WGS' 84 coordinates for the control point were determined to be North latitude 31° 54' 55.41025" and West longitude 97° 11' 27.70921".

Using the newly determined coordinates, a shore station was set up to provide DGPS control during the survey. The coordinates from the static survey were entered into the GPS receiver located over the control point to fix its location. Data received during the survey could then be corrected and broadcast to the GPS receiver on the moving boat during the survey.

SURVEY PROCEDURES

The following procedures were followed during the hydrographic survey of Aquilla Lake 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 GPS receivers were operated in the following DGPS modes. The reference station receiver was set to a horizontal mask of 0° , to acquire information on the rising satellites. A horizontal mask of 10° was used on the roving receiver for the purpose of calculating better horizontal positions. A PDOP (Position Dilution of Precision) limit of 7 was set for both receivers. The DGPS positions are known to be within acceptable limits of horizontal accuracy when the PDOP is seven (7) or less. 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.

Prior to the survey, TWDB staff verified the horizontal accuracy of the DGPS used during the Aquilla Lake survey to be within the specified accuracy of three meters by the following procedure. The shore station was set up over a known United States Geological Service (USGS) first order monument and placed in differential mode. The second receiver, directly connected to the boat with its interface computer, was placed over another known USGS first order monument and data was collected for 60 minutes in the same manner as during a survey. Based on the differentially-corrected coordinates obtained and the published coordinates for both monuments, the resulting positions fell within a three-meter radius of the actual known monument position.

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 Aquilla Lake, the speed of sound in the water column varied daily between 4872 and 4890 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 plus readings and some are minus readings. Further information on these calculations is presented in Appendix A.

Field Survey

Data was collected on Aquilla Lake during the period of October 12-18, 1995. Approximately 49,749 data points were collected over the 53.6 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 111 data files. Data were not collected in areas of shallow water (depths less than 3.0 ft.) or with significant obstructions unless these areas represented a large amount of water. Random data points were collected, when determined necessary by the field crew, by manually poling the depth and entering the depth value into the data file. As each point was entered, the DGPS horizontal position was stored automatically with each return keystroke on the computer. The boat was moving slowly during this period so positions stored were within the stated accuracy of ± 3 meters to the point poled. Figure 2 shows the actual location of the data collection points.

While collecting data, the field crew noted that a sand bar was located across the confluence of Aquilla and Hackberry Creeks. Standing timber and stumps were common in the upper reaches of both creeks. Throughout the main area of the lake, the lake bottom was fairly uniform on the depthsounder charts, with the exception of the old creek channels still being visible.

The collected data were stored in individual data files for each pre-plotted range line or random data collection events. 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.

The diskettes were then stored in a secured, safe location 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 537.25 to 537.38 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 3,266 acres for Aquilla Lake. 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. These areas were determined to be insignificant on Aquilla Lake. Therefore no 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 4 presents the resulting depth shaded representation of the lake. Figure 5 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 ten-foot intervals is presented in Figure 6.

RESULTS

Results from the 1995 survey indicate Aquilla Lake now encompasses 3266 surface acres and contains a volume of 45,962 acre-feet at the conservation pool elevation of 537.5 feet. The shoreline at this elevation was calculated to be 38.73 miles. The lowest elevation encountered was around elevation 490.8 feet, or 46.7 feet of depth and was found near the dam.

The storage volume calculated by the 1995 survey is approximately 12.3 percent less than the previous record information for the lake. The lowest gated outlet invert elevation is at elevation 503.0 feet. The storage volume in the lake at this elevation is 291 acre-feet. Therefore, the conservation storage capacity for the lake is 45,670 acre-feet.

SUMMARY

Aquilla Lake was authorized by the Federal Flood Control Act approved September 3, 1954 and the Public Works Appropriation Act of 1958. Construction commenced August 3, 1976. Deliberate impoundment began April 29, 1983. Initial storage calculations estimated the volume of the lake at the conservation pool elevation of 537.5 to be 52,400 acre-feet with surface area of 3,280 acres.

During the period October 12-18, 1995, a hydrographic survey of Aquilla Lake was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1995 survey used technological advances such as differential global positioning system and

geographical information system technology to build a model of the reservoir's bathymetry. These advances allowed a survey to be performed quickly and to collect significantly more data of the bathymetry of Aquilla Lake than previous survey methods. Results from the survey indicate that the lake's capacity at the conservation pool elevation of 537.5 feet was 45,962 acre-feet. The estimated reduction in storage capacity, if compared to the original volume in 1983 was 6,438 acre-feet, or 12.29 percent. This equates to an estimated loss of 536.5 acre-feet per year during the 12 years between the TWDB's survey and the initial date impoundment began. The annual deposition rate of sediment in the conservation pool can be estimated at 2.1 acre-ft per square mile of drainage area.

It is difficult to compare the original design information and the survey performed by the TWDB because little is known about the procedures and data used in calculating the original storage information. However, the TWDB considers the 1995 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. The second survey will remove any noticeable errors between the original design data and the 1995 survey and will facilitate accurate calculations of sedimentation rates and storage losses presently occurring in Aquilla Lake.

APPENDIX A - DEPTH SOUNDER ACCURACY

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

$$\begin{aligned} t_{30} &= (30-1.2)/4832 \\ &= 0.00596 \text{ sec.} \end{aligned}$$

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

$$\begin{aligned} t_{45} &= (45-1.2)/4808 \\ &= 0.00911 \text{ sec.} \end{aligned}$$

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

$$\begin{aligned} D_{20} &= [((20-1.2)/4832)(4808)]+1.2 \\ &= 19.9' \quad (-0.1') \end{aligned}$$

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

$$\begin{aligned} D_{30} &= [((30-1.2)/4832)(4808)]+1.2 \\ &= 29.9' \quad (-0.1') \end{aligned}$$

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

$$\begin{aligned} D_{50} &= [((50-1.2)/4799)(4808)]+1.2 \\ &= 50.1' \quad (+0.1') \end{aligned}$$

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

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

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

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

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

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

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

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

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

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

RESERVOIR VOLUME TABLE

SMALLER LANE OCTOBER 1958 SURVEY

ELEVATION FEET	VOLUME IN ACRES FEET				ELEVATION THICKNESS IN ONE TENTH FEET				
	1	2	3	4	5	6	7	8	9
95					1	1	1	1	1
96	1	1	1	1	2	2	2	2	2
97	2	2	2	2	3	3	3	3	3
98	3	3	3	3	4	4	4	4	4
99	4	4	4	4	5	5	5	5	5
100	5	5	5	5	6	6	6	6	6
101	6	6	6	6	7	7	7	7	7
102	7	7	7	7	8	8	8	8	8
103	8	8	8	8	9	9	9	9	9
104	9	9	9	9	10	10	10	10	10
105	10	10	10	10	11	11	11	11	11
106	11	11	11	11	12	12	12	12	12
107	12	12	12	12	13	13	13	13	13
108	13	13	13	13	14	14	14	14	14
109	14	14	14	14	15	15	15	15	15
110	15	15	15	15	16	16	16	16	16
111	16	16	16	16	17	17	17	17	17
112	17	17	17	17	18	18	18	18	18
113	18	18	18	18	19	19	19	19	19
114	19	19	19	19	20	20	20	20	20
115	20	20	20	20	21	21	21	21	21
116	21	21	21	21	22	22	22	22	22
117	22	22	22	22	23	23	23	23	23
118	23	23	23	23	24	24	24	24	24
119	24	24	24	24	25	25	25	25	25
120	25	25	25	25	26	26	26	26	26
121	26	26	26	26	27	27	27	27	27
122	27	27	27	27	28	28	28	28	28
123	28	28	28	28	29	29	29	29	29
124	29	29	29	29	30	30	30	30	30
125	30	30	30	30	31	31	31	31	31
126	31	31	31	31	32	32	32	32	32
127	32	32	32	32	33	33	33	33	33
128	33	33	33	33	34	34	34	34	34
129	34	34	34	34	35	35	35	35	35
130	35	35	35	35	36	36	36	36	36
131	36	36	36	36	37	37	37	37	37
132	37	37	37	37	38	38	38	38	38
133	38	38	38	38	39	39	39	39	39
134	39	39	39	39	40	40	40	40	40
135	40	40	40	40	41	41	41	41	41
136	41	41	41	41	42	42	42	42	42
137	42	42	42	42	43	43	43	43	43
138	43	43	43	43	44	44	44	44	44
139	44	44	44	44	45	45	45	45	45
140	45	45	45	45	46	46	46	46	46
141	46	46	46	46	47	47	47	47	47
142	47	47	47	47	48	48	48	48	48
143	48	48	48	48	49	49	49	49	49
144	49	49	49	49	50	50	50	50	50
145	50	50	50	50	51	51	51	51	51
146	51	51	51	51	52	52	52	52	52
147	52	52	52	52	53	53	53	53	53
148	53	53	53	53	54	54	54	54	54
149	54	54	54	54	55	55	55	55	55
150	55	55	55	55	56	56	56	56	56
151	56	56	56	56	57	57	57	57	57
152	57	57	57	57	58	58	58	58	58
153	58	58	58	58	59	59	59	59	59
154	59	59	59	59	60	60	60	60	60
155	60	60	60	60	61	61	61	61	61
156	61	61	61	61	62	62	62	62	62
157	62	62	62	62	63	63	63	63	63
158	63	63	63	63	64	64	64	64	64
159	64	64	64	64	65	65	65	65	65
160	65	65	65	65	66	66	66	66	66
161	66	66	66	66	67	67	67	67	67
162	67	67	67	67	68	68	68	68	68
163	68	68	68	68	69	69	69	69	69
164	69	69	69	69	70	70	70	70	70
165	70	70	70	70	71	71	71	71	71
166	71	71	71	71	72	72	72	72	72
167	72	72	72	72	73	73	73	73	73
168	73	73	73	73	74	74	74	74	74
169	74	74	74	74	75	75	75	75	75
170	75	75	75	75	76	76	76	76	76
171	76	76	76	76	77	77	77	77	77
172	77	77	77	77	78	78	78	78	78
173	78	78	78	78	79	79	79	79	79
174	79	79	79	79	80	80	80	80	80
175	80	80	80	80	81	81	81	81	81
176	81	81	81	81	82	82	82	82	82
177	82	82	82	82	83	83	83	83	83
178	83	83	83	83	84	84	84	84	84
179	84	84	84	84	85	85	85	85	85
180	85	85	85	85	86	86	86	86	86
181	86	86	86	86	87	87	87	87	87
182	87	87	87	87	88	88	88	88	88
183	88	88	88	88	89	89	89	89	89
184	89	89	89	89	90	90	90	90	90
185	90	90	90	90	91	91	91	91	91
186	91	91	91	91	92	92	92	92	92
187	92	92	92	92	93	93	93	93	93
188	93	93	93	93	94	94	94	94	94
189	94	94	94	94	95	95	95	95	95
190	95	95	95	95	96	96	96	96	96
191	96	96	96	96	97	97	97	97	97
192	97	97	97	97	98	98	98	98	98
193	98	98	98	98	99	99	99	99	99
194	99	99	99	99	100	100	100	100	100
195	100	100	100	100	101	101	101	101	101
196	101	101	101	101	102	102	102	102	102
197	102	102	102	102	103	103	103	103	103
198	103	103	103	103	104	104	104	104	104
199	104	104	104	104	105	105	105	105	105
200	105	105	105	105	106	106	106	106	106

APPENDIX B - RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR VOLUME TABLE

Dec 27 1995

AQUILLA LAKE OCTOBER 1995 SURVEY

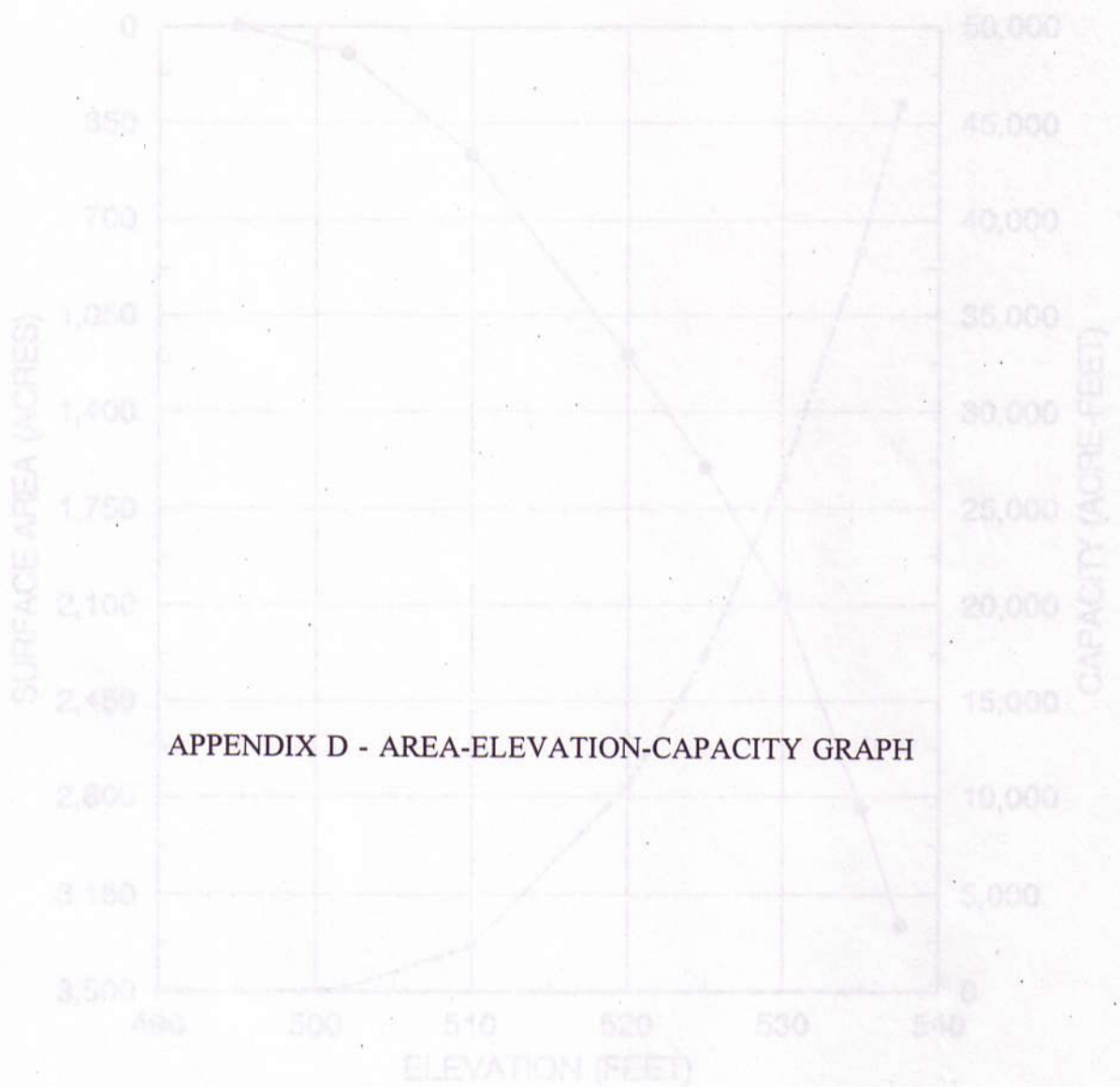
ELEV. FEET	VOLUME IN ACRE-FEET									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
495						1	1	1	1	1
496	1	1	1	1	1	2	2	2	2	2
497	3	3	3	3	4	4	5	5	5	6
498	7	7	8	8	9	10	11	12	13	15
499	16	18	20	22	25	27	30	32	35	39
500	42	46	50	54	58	63	68	73	78	84
501	90	97	104	111	118	126	134	143	152	161
502	171	181	191	202	213	225	237	250	263	277
503	291	305	320	335	351	367	383	400	417	435
504	453	471	490	509	528	548	568	588	609	631
505	652	674	697	720	743	767	791	816	841	867
506	893	919	946	973	1001	1029	1058	1087	1117	1147
507	1178	1209	1240	1272	1305	1338	1372	1406	1440	1475
508	1511	1547	1584	1621	1659	1698	1736	1776	1816	1856
509	1897	1939	1981	2024	2067	2110	2155	2200	2245	2291
510	2338	2385	2432	2481	2530	2579	2629	2679	2730	2782
511	2834	2887	2940	2993	3048	3103	3158	3214	3271	3329
512	3387	3446	3507	3567	3629	3692	3756	3820	3886	3952
513	4018	4086	4154	4223	4293	4364	4435	4507	4580	4653
514	4727	4801	4876	4951	5027	5104	5181	5259	5338	5417
515	5497	5577	5659	5740	5823	5906	5990	6075	6160	6247
516	6333	6421	6509	6598	6688	6778	6870	6962	7055	7149
517	7244	7340	7436	7533	7631	7730	7829	7930	8031	8134
518	8237	8341	8446	8552	8660	8768	8876	8986	9097	9208
519	9320	9433	9547	9661	9776	9892	10008	10125	10243	10362
520	10481	10601	10721	10842	10964	11086	11209	11333	11457	11582
521	11708	11834	11961	12089	12218	12347	12478	12609	12740	12873
522	13006	13140	13275	13410	13546	13683	13820	13958	14097	14236
523	14377	14518	14660	14802	14946	15090	15235	15382	15529	15677
524	15826	15977	16128	16281	16434	16589	16745	16901	17059	17218
525	17377	17538	17699	17862	18025	18189	18354	18520	18687	18855
526	19023	19193	19363	19535	19707	19880	20054	20230	20406	20583
527	20762	20941	21121	21303	21485	21668	21852	22038	22224	22411
528	22599	22788	22978	23169	23361	23554	23748	23943	24139	24336
529	24534	24733	24933	25134	25335	25538	25742	25947	26152	26359
530	26566	26775	26984	27194	27405	27617	27830	28044	28258	28474
531	28690	28908	29126	29346	29567	29789	30012	30236	30461	30687
532	30914	31142	31372	31603	31835	32069	32304	32540	32778	33018
533	33259	33503	33748	33995	34243	34492	34742	34994	35247	35501
534	35756	36013	36271	36531	36792	37055	37319	37586	37854	38124
535	38395	38680	38966	39253	39542	39831	40122	40415	40708	41004
536	41300	41597	41896	42197	42498	42801	43109	43419	43731	44044
537	44359	44676	44995	45316	45638	45962				

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR AREA TABLE

Dec 27 1995

AQUILLA LAKE OCTOBER 1995 SURVEY

ELEV. FEET	AREA IN ACRES									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
495						1	1	1	1	1
496	1	1	1	1	2	2	2	2	2	2
497	3	3	3	3	4	4	4	5	5	5
498	6	6	7	7	8	9	10	12	13	15
499	17	19	20	22	24	26	27	29	31	33
500	35	38	40	43	45	48	51	54	57	60
501	63	66	69	72	76	80	84	88	92	95
502	99	103	106	111	115	120	125	129	134	138
503	142	146	150	154	158	162	166	170	174	177
504	181	185	188	192	196	199	203	207	211	215
505	219	223	227	231	235	240	245	249	254	258
506	263	267	271	276	280	285	289	294	299	303
507	308	313	318	323	328	333	338	343	348	354
508	359	365	371	376	381	386	392	397	402	408
509	413	418	424	429	434	440	446	451	457	463
510	469	474	480	486	491	497	502	507	513	518
511	523	529	534	540	546	552	558	565	572	580
512	589	597	606	614	623	632	641	649	657	664
513	671	679	687	695	702	710	717	723	729	735
514	741	746	752	758	764	770	776	782	788	795
515	802	809	816	823	830	837	843	850	857	864
516	871	878	886	894	902	911	919	928	936	944
517	952	960	968	975	983	991	1000	1009	1018	1027
518	1037	1047	1057	1067	1076	1085	1093	1101	1109	1117
519	1125	1132	1139	1146	1154	1161	1168	1175	1182	1189
520	1195	1201	1208	1214	1220	1226	1233	1240	1247	1254
521	1261	1268	1275	1283	1290	1298	1306	1314	1321	1329
522	1336	1343	1350	1357	1363	1370	1377	1384	1391	1399
523	1406	1414	1422	1431	1440	1449	1458	1467	1476	1487
524	1498	1509	1520	1531	1542	1552	1562	1572	1582	1591
525	1600	1610	1619	1628	1637	1646	1655	1664	1673	1682
526	1691	1700	1709	1718	1728	1738	1748	1758	1768	1778
527	1789	1799	1809	1818	1828	1837	1847	1856	1866	1876
528	1886	1896	1906	1915	1925	1935	1945	1955	1965	1975
529	1984	1994	2004	2013	2023	2033	2042	2052	2061	2071
530	2080	2088	2097	2106	2114	2123	2132	2141	2150	2161
531	2171	2181	2192	2203	2213	2224	2234	2245	2256	2267
532	2279	2291	2303	2315	2329	2343	2357	2371	2386	2402
533	2433	2447	2460	2473	2485	2498	2510	2523	2536	2549
534	2562	2575	2589	2604	2620	2636	2653	2671	2689	2709
535	2840	2853	2866	2878	2891	2904	2917	2930	2943	2956
536	2970	2983	2996	3009	3023	3071	3089	3107	3125	3143
537	3161	3179	3197	3215	3233	3266				



APPENDIX D - AREA-ELEVATION-CAPACITY GRAPH

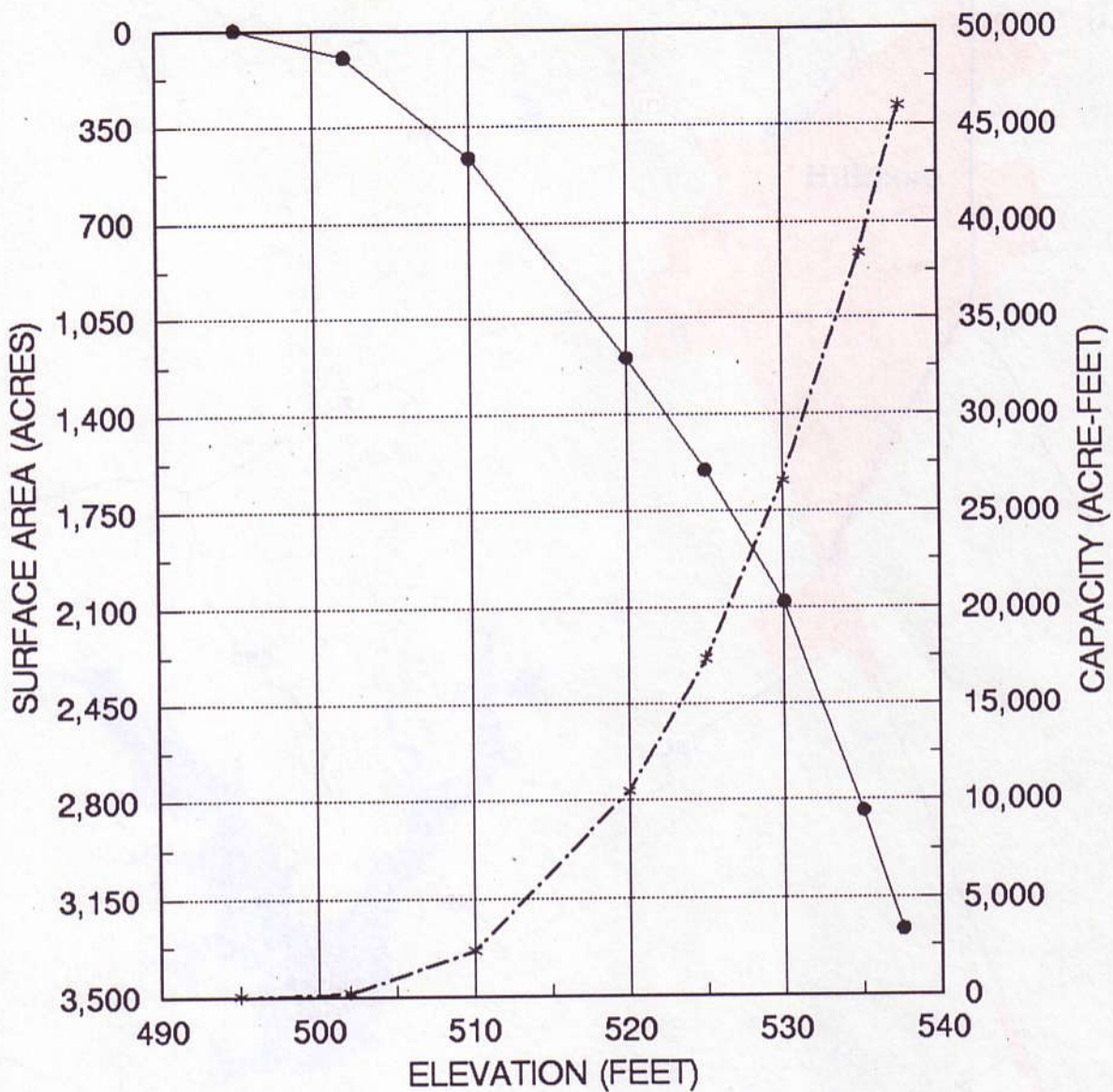
SURFACE AREA CAPACITY

AQUILLA LAKE

October 1995 SURVEY

Prepared by TWDB January 1996

FIGURE 1
AQUILLA LAKE
January 1996



SURFACE AREA CAPACITY
—●— -*-

AQUILLA LAKE
October 1995 SURVEY
Prepared by: TWDB January 1996

FIGURE 1
AQUILLA LAKE
Location Map

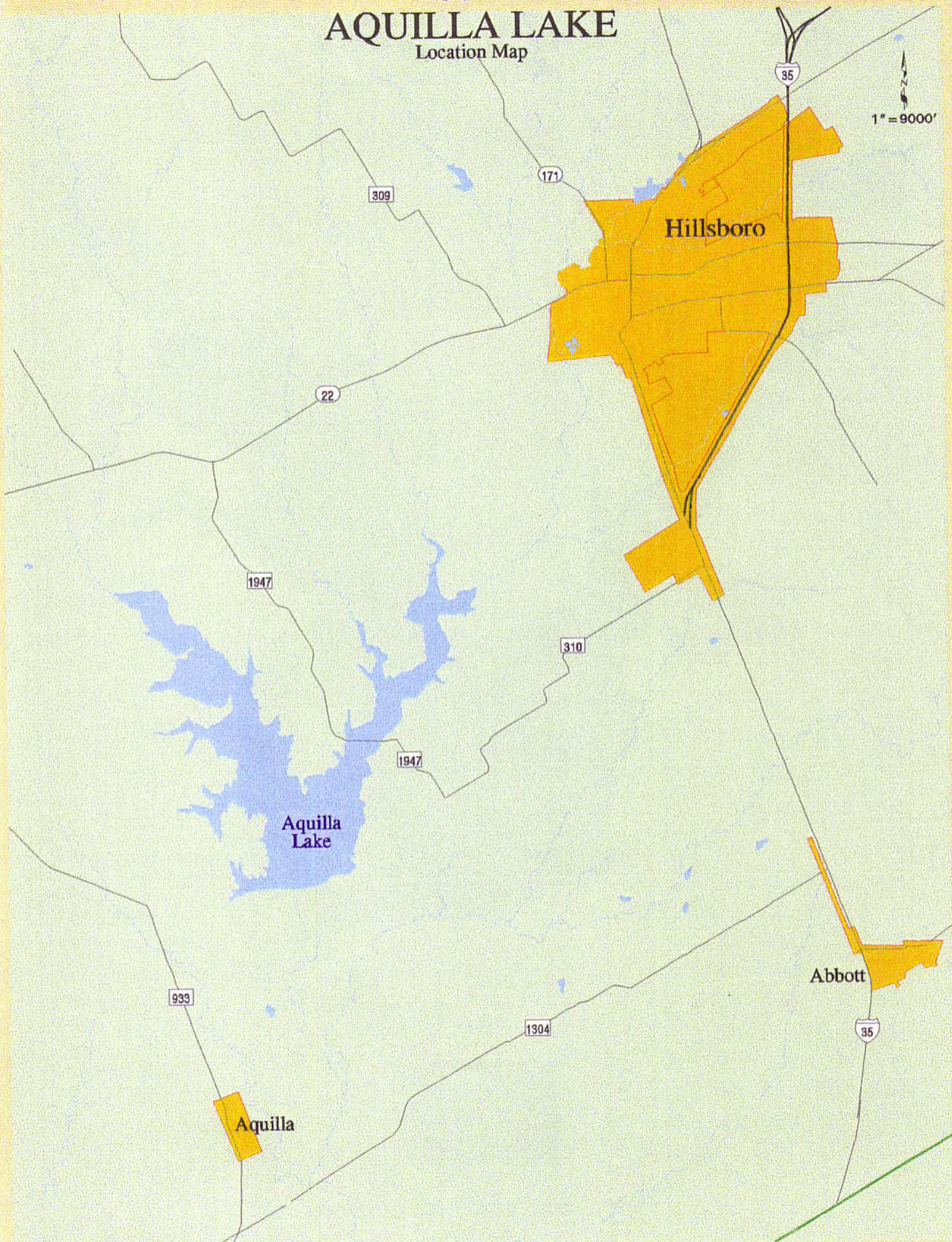
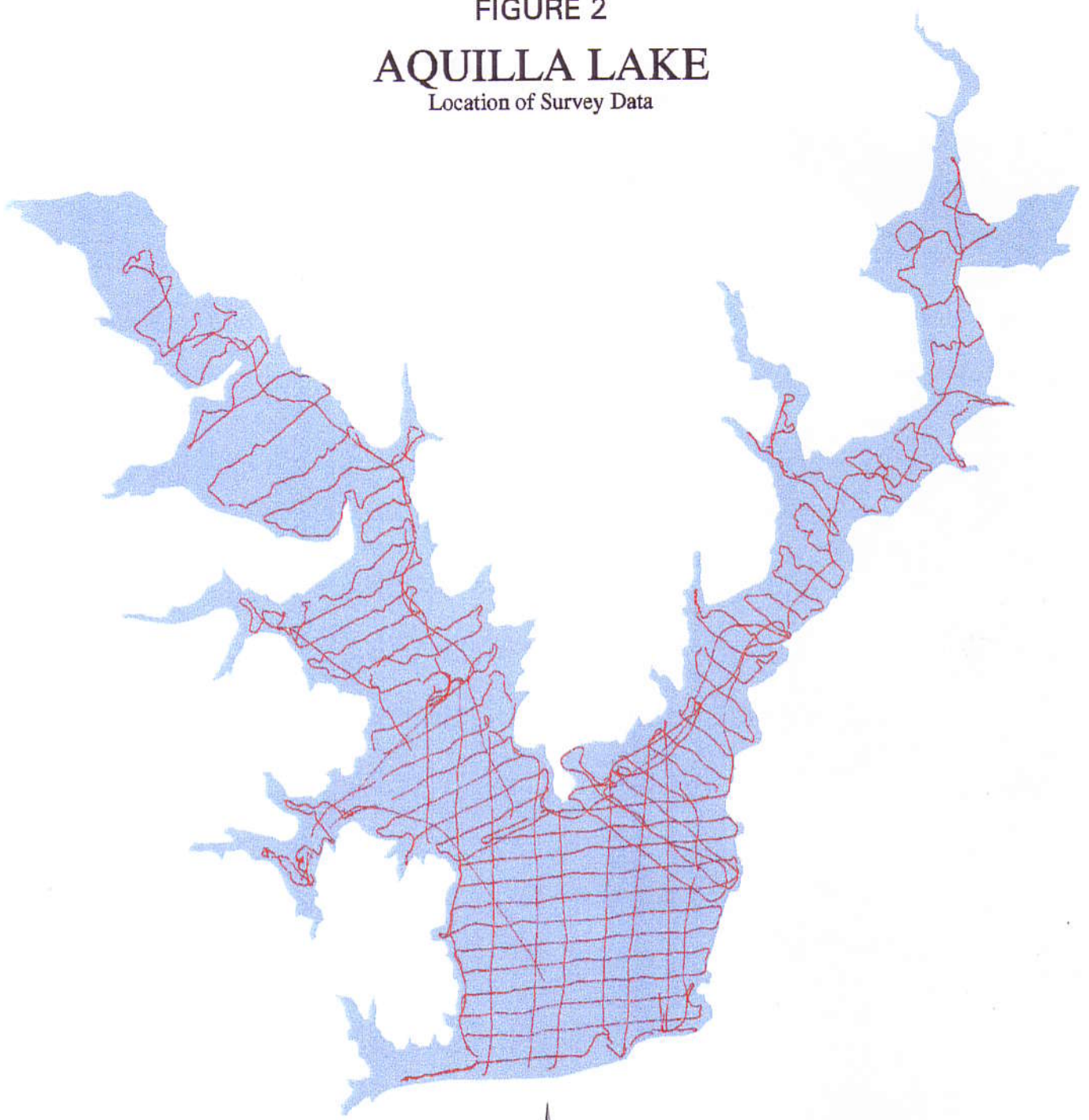




FIGURE 2
AQUILLA LAKE
Location of Survey Data



↑
N
↓
1" = 3500'

EXPLANATION	
	Lake Boundary
	Data Points

PREPARED BY: TWDB January, 1996

FIGURE 3
AQUILLA LAKE
Location of Survey Control Point

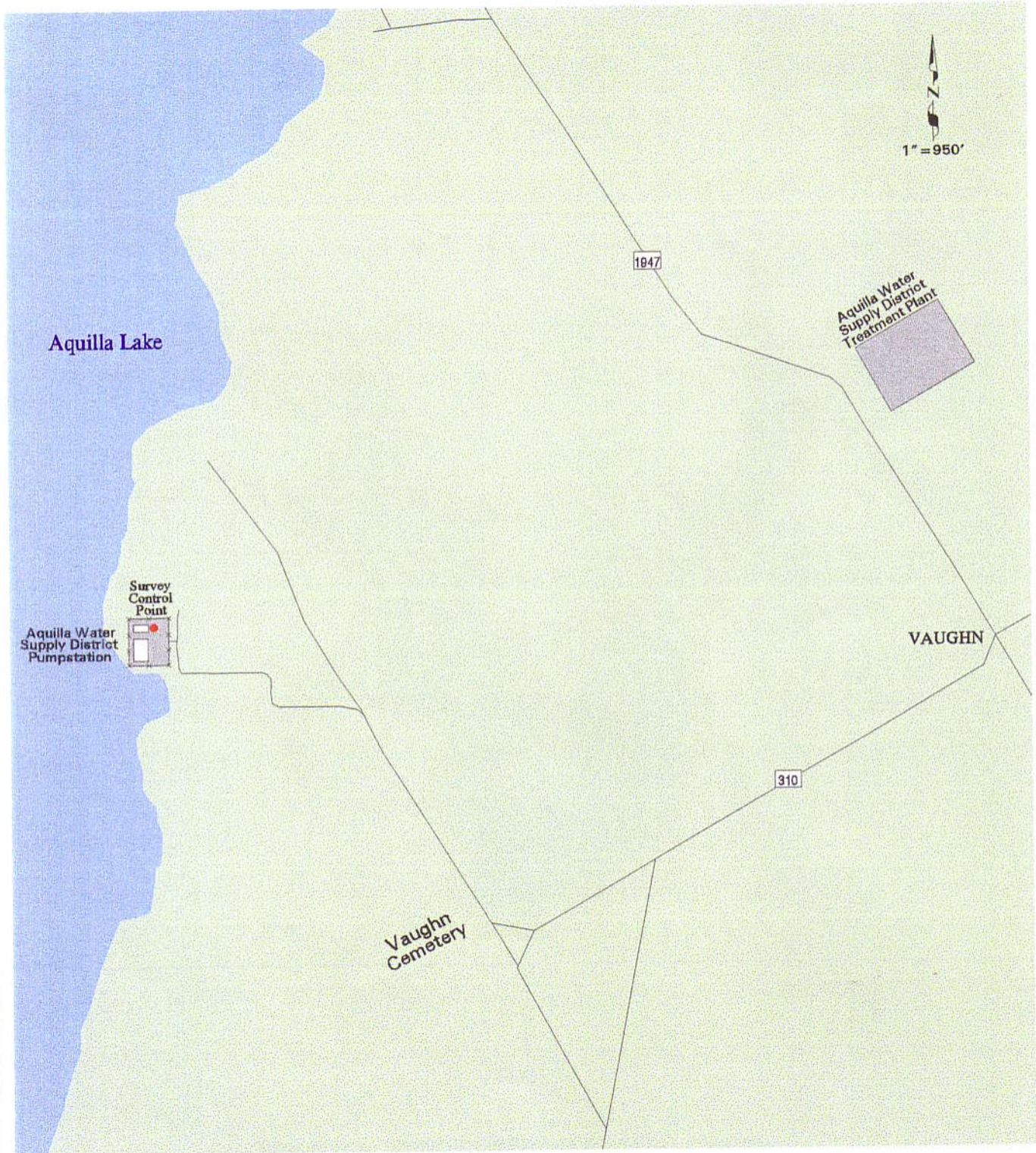


FIGURE 4
AQUILLA LAKE
Shaded Relief



1" = 3500'

Elevation From
490.8 Ft.

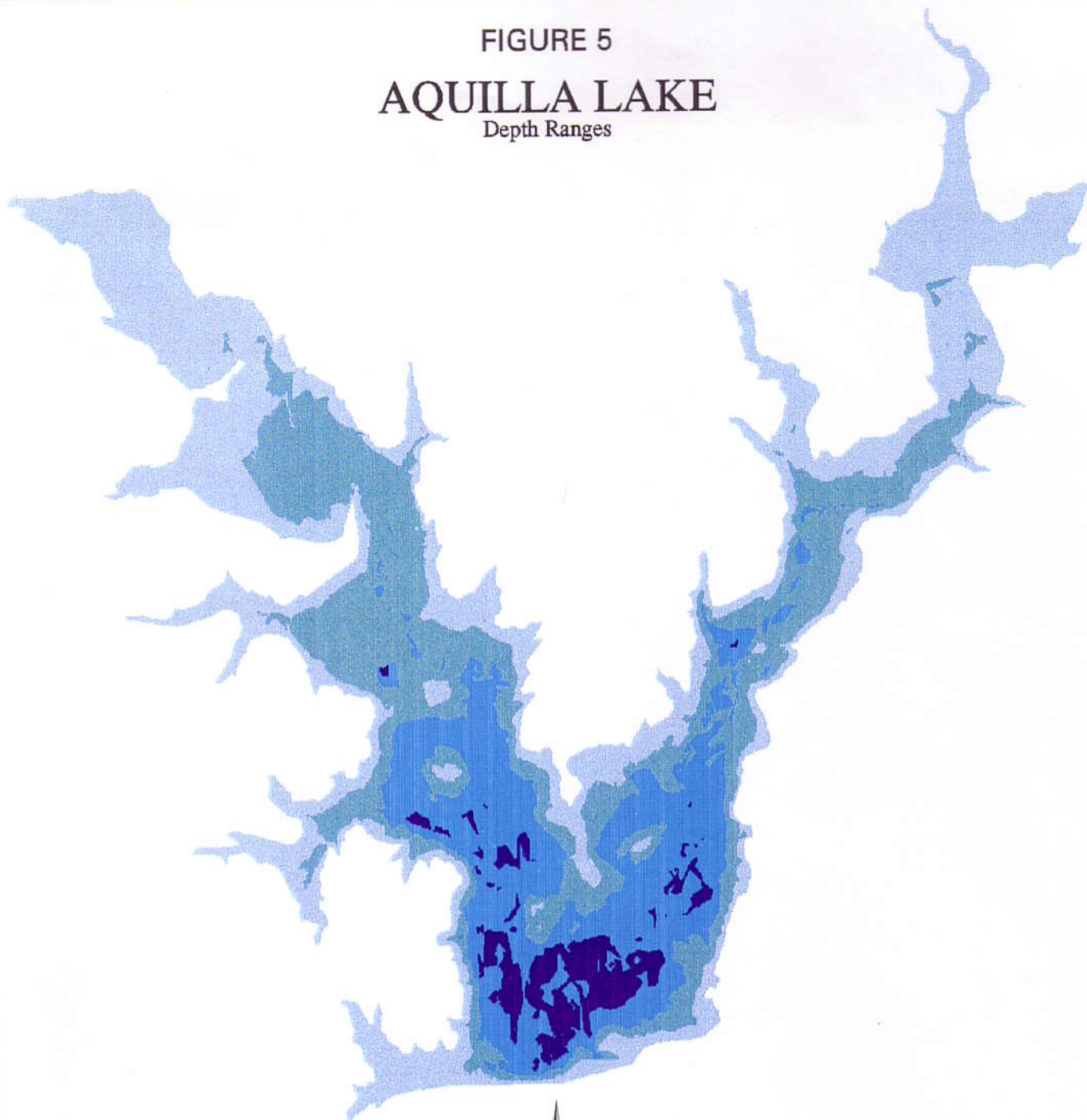


Elevation
537.5 Ft.

To

PREPARED BY: TWDB January, 1996

FIGURE 5
AQUILLA LAKE
Depth Ranges



1" = 3500'

EXPLANATION	
Light Blue	0 - 12'
Medium Blue	12 - 24'
Dark Blue	24 - 36'
Purple	36 - 47'