VOLUMETRIC SURVEY OF STILLHOUSE HOLLOW LAKE

Prepared for:

BRAZOS RIVER AUTHORITY

Prepared by:

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Stillhouse Hollow Lake in May, 1995. The purpose of the survey was to determine the capacity of the lake at the normal 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 1958, the U. S. Army Corps of Engineers calculated the initial surface area of Stillhouse Hollow Lake at the normal pool elevation of 622.0 feet to be 6,430 acres with a corresponding initial capacity of 235,700 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Stillhouse Hollow Lake is located on the Lampasas River in Bell County, five miles southwest of downtown Belton, 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). Inflows to lake the originate over a 1,313 square mile drainage area. The lake itself at the top of the conservation pool, elevation 622.0 feet, is approximately 12 miles long and approximately 2 miles wide at its widest point near the dam. Water rights of the lake are allocated to the Brazos River Authority.

Water Rights Permit 2109 was issued to the Brazos River Authority (BRA) July 24, 1964 by the Texas Water Commission. It authorized the BRA to impound 235,700 acre-feet of water in Stillhouse Hollow Lake. Impoundment of these waters would be limited to that portion of the lake below elevation 622.00 feet. BRA was authorized to divert and use not to exceed; 74,000 acre-feet of water per annum for municipal purposes, 74,000 acre-feet of water per annum for industrial purposes and 74,000 acre-feet of water per annum for irrigational purposes. Permit 2109 was amended September 13, 1979 to use the impounded waters for non-consumptive recreation purposes. A second amendment, Permit 2109B dated November 25, 1980, allocated 300 acre-feet of water (of the 74,000 acre-feet for irrigation purposes) to be used for mining purposes. Certificate of Adjudication 5161 was issued to the BRA December 14, 1987. It basically reinforces all provisions of impoundments and uses of water rights to the BRA as previously mentioned in Permit 2109B. 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 Stillhouse Hollow Lake and other reservoirs owned and operated by the Brazos River Authority.

Construction of the existing dam commenced on June 11, 1962. Deliberate impoundment of water began February 19, 1968 and the facility was completed May 10th of the same year. The project was designed by the COE and the general contractor was Tecon Corporation of Dallas, Tx. The estimated project cost was $20,100,000.

Stillhouse Hollow Dam is an earthfill structure with a length of 7,850 feet rising 200 feet above the natural streambed to an elevation of 698.0 feet. Adjacent to the dam and along the south bank is a 5,850 feet long dike that separates the dam from the 1,650 feet long uncontrolled spillway. The uncontrolled spillway is a broad-crested weir at elevation 666.0 feet with a discharge capacity of 673,500 cubic feet per second (cfs) at the maximum design flood stage of 693.2 feet. The outlet works are composed of a 12-

foot-diameter concrete conduit with an invert elevation of 515.0 feet. Discharges are controlled by two 5-foot 8-inch wide by 12 foot high hydraulically operated slide 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

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.

As the boat traveled across the lake surface, the depth sounder gathered approximately ten readings of the lake bottom each second. The depth readings were averaged over the one-second interval and stored with the positional data to an on-board computer. After the survey, the average depths were corrected to elevation using the daily lake elevation. The set of data points logged during the survey were used to calculate the lake volume. Accurate estimates of the lake volume can be quickly determined using these methods to produce an affordable survey. 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 normal pool boundary from three USGS quad sheets. The names of the quad sheets are as follows: Nolanville, TX 1958 (Photo-revised 1974); Killeen, TX 1958 (Photo-revised 1974); and Youngsport, TX 1958 (Photo-revised 1979). 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 150 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 CONTROL SETUP

The first task of the Hydrographic Survey field staff after arriving at Stillhouse Hollow 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 United States Geological Survey first-order monument named BELTON 1943 located on the campus of Mary Hardin Baylor in Belton, Tx.. The coordinates for the monument are published as Latitude 31° 04' 04.19687"N and Longitude 97° 27' 53.89148"W.

On April 12, 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 an existing U. S. Army Corps of Engineers' surveyor's cap identification number 0+00 set flush to the ground in concrete and located near the end of a levee between the dam and emergency spillway. The static survey was performed from the BELTON 1943 monument to the control point using two Trimble 4000SE GPS receivers. The GPS receivers were set up on tripods 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 0+00 were determined to be North latitude 31° 00' 54.01441" and West longitude 97° 32' 21.70293".

Using the newly determined coordinates, a shore station was set up at 0+00 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 Stillhouse Hollow 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 Stillhouse Hollow 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 Stillhouse Hollow Lake, the speed of sound in the water column varied daily between 4860 and 4873 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 Stillhouse Hollow Lake during the period of May 2-11,

1995. Approximately 57,540 data points were collected over the 104 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 179 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.

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 622.25 to 622.90 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 Systems 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 normal pool elevation of the lake. This was calculated as 6,429 acres for Stillhouse Hollow 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 normal 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 Stillhouse Hollow 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 normal 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

Stillhouse Hollow Lake facility (including all shoreline property) is owned by the Federal Government, and maintained by the U. S. Army Corps of Engineers. Stillhouse Hollow Lake is basically an on-channel reservoir located on the Lampasas River with a few contributing creeks. 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. While collecting data during the May 1995 survey, TWDB staff observed fairly steep relief of limestone outcrops along the perimeter of the lake in the vicinity of the dam. As the crew worked in the upper reaches, steep slopes on one bank were apparent while a flat, silt-laden floodplain comprised the shoreline of the other side. Both standing and submerged trees occupied some of the coves in the upper reaches making it difficult to maneuver the boat. Staff also noted that throughout the reservoir, the water clarity allowed objects to be viewed easily to depths of 12 feet. During data collection, the old streambed of the Lampasas River was easily detected on the analog charts of the depth sounder as the boat moved along the pre-plotted lines. The survey crew also made note that large trees and other debris were still located on the upstream slope of the dam marking the high water elevation reached during the December, 1990 flood.

Results from the 1995 survey indicate Stillhouse Hollow Lake now encompasses around 6,429 surface acres and contains a volume of 226,063 acre-feet at the normal pool elevation of 622.00 feet. The shoreline at this elevation was calculated to be 51.34 miles. The lowest elevation encountered was around elevation 502 feet, or 118 feet of depth and was found near the dam.

The storage volume calculated by the 1995 survey is approximately 4.1 percent less than the previous record information for the lake. The lowest gated outlet invert elevation is at elevation 515.0 feet. The dead storage volume at this elevation corresponds to 30 acre-ft. The conservation storage capacity of the lake will not be modified to reflect this storage volume. Therefore, the conservation storage capacity for the lake is 226,060 acre-feet.

SUMMARY

Stillhouse Hollow Dam and Lake were authorized by the Federal Flood Control Act approved September 3, 1954 and the Public Works Appropriation Act of 1958. Construction commenced June 11, 1962. From September 2, 1966 to February 19, 1968, the lake was operated as a detention basin only. Deliberate impoundment began February 19, 1968. Initial storage calculations estimated the volume of the lake at the conservation pool elevation of 622.0 to be 235,700 acre-feet with surface area of 6,430 acres.

In May 1995, a hydrographic survey of Stillhouse Hollow 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 bathemetry. These advances allowed a survey to be performed quickly and to collect significantly more data of the bathemetry of Stillhouse Hollow Lake than previous survey methods. Results from the survey indicate that the lake's capacity at the normal pool elevation of 622.0 feet was 226,063 acre-feet. The estimated reduction in storage capacity, if compared to the original volume in 1968 was 9,637 acre-feet, or 4.1 percent. This equates to an estimated loss of 357 acre-feet per year during the 27 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 0.272 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 know 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 Stillhouse Hollow Lake.

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):

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

TEXAS WATER DEVELOPMENT BOARD

RESERVOIR VOLUME TABLE

Jul 20 1995

STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

VOLUME IN ACRE-FEET

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
502										
503										
504										
505				1	1	1	1	1	1	1
506	1	1	1	1	1	1	1	1	2	2
507	2	2	2	2	2	2	2	2	3	3
508	3	3	3	3	3	4	4	4	4	4
509	4	4	5	5	5	5	5	6	6	6
510	6	7	7	7	7	8	8	8	8	9
511	9	9	10	10	10	10	11	11	12	12
512	12	13	13	13	14	14	15	15	16	16
513	17	17	18	18	19	19	20	20	21	22
514	22	23	24	24	25	26	26	27	28	29
515	30	30	31	32	33	34	35	37	38	39
516	41	42	44	46	47	49	51	53	55	58
517	60	63	65	68	71	74	77	80	83	86
518	90	93	97	101	104	108	112	116	121	125
519	129	134	139	143	148	153	159	164	169	175
520	180	186	192	198	204	211	217	224	231	239
521	246	254	262	271	279	288	297	307	317	327
522	337	347	358	369	380	391	403	415	427	439
523	452	465	478	491	504	518	532	546	561	575
524	590	605	621	636	652	668	684	700	717	734
525	751	768	786	803	821	839	857	875	894	912
526	931	950	969	988	1008	1028	1047	1067	1088	1108
527	1128	1149	1170	1191	1212	1233	1255	1277	1298	1321
528	1343	1365	1388	1411	1434	1457	1481	1504	1528	1552
529	1577	1601	1626	1651	1676	1701	1727	1752	1778	1804
530	1830	1857	1884	1911	1938	1965	1992	2020	2048	2076
531	2105	2133	2162	2191	2220	2249	2278	2308	2338	2368
532	2398	2429	2459	2490	2521	2552	2583	2615	2646	2678
533	2710	2743	2775	2808	2841	2874	2907	2940	2974	3008
534	3041	3075	3110	3144	3178	3213	3248	3283	3318	3353
535	3389	3424	3460	3496	3532	3568	3604	3641	3677	3714
536	3751	3787	3825	3862	3899	3937	3974	4012	4050	4088
537	4126	4164	4203	4242	4280	4319	4358	4397	4437	4476
538	4516	4556	4595	4636	4676	4716	4757	4797	4838	4879
539	4921	4962	5004	5045	5087	5130	5172	5215	5257	5301
540	5344	5388	5431	5476	5520	5565	5610	5655	5701	5746
541	5793	5839	5886	5933	5980	6028	6076	6125	6173	6223
542	6272	6322	6372	6423	6474	6525	6577	6629	6681	6734
543	6787	6841	6895	6949	7004	7059	7115	7171	7227	7284
544	7341	7399	7457	7515	7574	7633	7692	7752	7812	7873
545	7934	7995	8056	8118	8180	8243	8306	8369	8432	8496
546	8560	8624	8688	8753	8818	8883	8949	9015	9081	9147
547	9214	9281	9348	9416	9483	9551	9620	9688	9757	9827
548	9896	9966	10036	10106	10177	10248	10320	10391	10464	10536
549	10609	10682	10756	10830	10904	10979	11054	11130	11206	11282
550	11359	11435	11513	11590	11668	11747	11826	11905	11984	12064

STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
551	12144	12224	12305	12386	12468	12550	12632	12715	12798	12882
552	12966	13050	13135	13220	13306	13392	13478	13565	13653	13740
553	13828	13917	14006	14096	14186	14276	14367	14458	14550	14642
554	14735	14828	14922	15016	15110	15205	15301	15397	15493	15590
555	15688	15785	15884	15982	16082	16181	16281	16382	16483	16584
556	16686	16788	16891	16994	17098	17202	17306	17411	17516	17622
557	17728	17835	17942	18049	18157	18266	18375	18484	18594	18704
558	18815	18926	19037	19149	19262	19375	19488	19602	19717	19831
559	19946	20062	20178	20294	20411	20528	20646	20764	20882	21001
560	21121	21241	21361	21482	21603	21725	21847	21969	22092	22216
561	22340	22464	22589	22714	22840	22966	23093	23220	23348	23476
562	23604	23734	23863	23993	24124	24255	24387	24519	24652	24785
563	24919	25053	25188	25323	25460	25596	25733	25871	26009	26148
564	26287	26427	26568	26709	26851	26993	27136	27279	27423	27568
565	27713	27859	28005	28152	28299	28447	28596	28746	28896	29046
566	29197	29349	29501	29654	29807	29961	30116	30271	30426	30583
567	30739	30896	31054	31213	31371	31531	31691	31851	32012	32174
568	32336	32499	32662	32826	32990	33155	33321	33487	33653	33821
569	33988	34156	34325	34494	34664	34834	35004	35176	35347	35519
570	35692	35865	36038	36213	36387	36562	36738	36914	37090	37267
571	37445	37623	37802	37981	38161	38341	38522	38703	38885	39067
572	39250	39433	39617	39802	39987	40172	40358	40545	40732	40920
573	41108	41297	41486	41676	41867	42058	42249	42441	42633	42826
574	43020	43214	43408	43603	43799	43995	44191	44388	44586	44784
575	44983	45182	45382	45582	45783	45984	46186	46389	46592	46796
576	47000	47205	47411	47617	47824	48031	48239	48448	48657	48867
577	49077	49288	49500	49712	49925	50138	50352	50567	50782	50998
578	51214	51431	51649	51868	52087	52307	52528	52749	52971	53194
579	53417	53641	53866	54091	54317	54544	54772	55000	55228	55458
580	55688	55919	56150	56382	56615	56848	57081	57316	57551	57786
581	58023	58259	58497	58735	58974	59213	59453	59694	59935	60177
582	60419	60663	60906	61151	61396	61642	61888	62135	62383	62631
583	62880	63130	63381	63632	63884	64136	64389	64643	64898	65153
584	65409	65666	65923	66181	66440	66699	66959	67220	67481	67743
585	68006	68269	68533	68798	69063	69329	69596	69863	70131	70400
586	70669	70938	71209	71480	71752	72025	72298	72572	72847	73123
587	73399	73676	73954	74232	74512	74792	75072	75354	75636	75919
588	76202	76487	76772	77058	77344	77631	77919	78207	78496	78786
589	79077	79368	79660	79953	80247	80541	80836	81132	81428	81725
590	82023	82321	82621	82920	83221	83522	83824	84127	84431	84735
591	85040	85346	85652	85959	86267	86576	86885	87195	87506	87818
592	88131	88444	88758	89073	89389	89706	90023	90342	90661	90981
593	91302	91623	91945	92269	92593	92917	93243	93569	93896	94225
594	94553	94883	95213	95544	95876	96208	96541	96875	97210	97545
595	97881	98218	98556	98894	99234	99574	99914	100256	100598	100941
596	101285	101630	101975	102322	102669	103016	103365	103714	104065	104416
597	104767	105119	105473	105827	106181	106537	106893	107250	107608	107967
598	108326	108686	109048	109410	109772	110136	110500	110866	111232	111599
599	111967	112336	112705	113076	113447	113819	114192	114566	114941	115317
600	115694	116072	116450	116830	117210	117592	117974	118358	118742	119127

STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

	VOLUME IN ACRE-FEET				ELEVATION INCREMENT IS ONE TENTH FOOT					
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
601	119514	119901	120289	120678	121068	121460	121852	122245	122640	123036
602	123432	123830	124229	124629	125030	125432	125835	126239	126644	127051
603	127458	127866	128276	128687	129098	129511	129925	130340	130757	131174
604	131593	132012	132433	132855	133278	133702	134127	134554	134981	135410
605	135839	136270	136702	137135	137569	138004	138440	138877	139315	139755
606	140195	140637	141080	141523	141968	142414	142861	143310	143759	144210
607	144662	145114	145568	146023	146480	146937	147395	147855	148316	148778
608	149241	149705	150171	150637	151105	151574	152043	152515	152987	153460
609	153935	154410	154888	155366	155845	156325	156807	157290	157774	158259
610	158745	159233	159722	160212	160703	161195	161689	162184	162680	163177
611	163675	164175	164676	165178	165682	166186	166692	167199	167708	168218
612	168728	169240	169754	170269	170785	171302	171820	172339	172860	173382
613	173904	174428	174953	175479	176007	176535	177064	177595	178127	178660
614	179194	179730	180267	180804	181343	181883	182425	182967	183511	184056
615	184602	185150	185699	186248	186800	187352	187906	188461	189017	189575
616	190134	190694	191255	191817	192381	192946	193512	194079	194647	195217
617	195788	196360	196934	197508	198084	198661	199239	199819	200400	200983
618	201567	202152	202739	203327	203917	204508	205101	205695	206290	206887
619	207485	208085	208686	209288	209893	210499	211106	211714	212324	212935
620	213548	214161	214777	215393	216011	216630	217250	217871	218494	219118
621	219743	220369	220997	221626	222256	222887	223520	224154	224789	225425
622	226063									

TEXAS WATER DEVELOPMENT BOARD Jul 20 1995

RESERVOIR AREA TABLE

STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
502										
503										
504										
505						1	1	1	1	1
506	1	1	1	1	1	1	1	1	1	1
507	1	1	1	1	1	1	1	1	1	1
508	1	1	1	1	1	1	2	2	2	2
509	2	2	2	2	2	2	2	2	2	2
510	2	2	2	2	3	3	3	3	3	3
511	3	3	3	3	3	3	3	4	4	4
512	4	4	4	4	4	4	4	5	5	5
513	5	5	5	5	5	6	6	6	6	6
514	6	6	7	7	7	7	7	8	8	8
515	9	9	9	10	10	11	12	12	13	14
516	15	16	16	17	18	19	20	22	23	24
517	25	25	26	27	28	30	31	32	33	34
518	35	36	37	38	39	40	41	42	43	44
519	45	46	47	48	50	51	52	53	54	56
520	57	59	60	61	63	65	67	69	72	74
521	77	80	83	85	88	91	94	96	98	101
522	103	105	108	110	113	115	117	120	122	124
523	127	129	131	134	136	138	141	143	145	148
524	150	152	154	156	159	161	163	165	167	169
525	171	173	175	177	178	180	182	184	185	187
526	189	190	192	194	196	197	199	201	203	204
527	206	208	209	211	213	214	216	218	220	222
528	224	226	228	230	232	234	236	238	240	242
529	244	246	248	250	252	254	256	258	260	262
530	264	266	268	270	272	274	276	278	280	282
531	284	286	288	290	292	294	296	297	299	301
532	303	305	307	308	310	312	314	316	318	320
533	322	324	326	328	329	331	333	334	336	338
534	339	341	342	344	346	347	349	350	352	353
535	355	356	358	359	361	362	363	365	366	367
536	369	370	372	373	374	376	377	378	380	381
537	383	384	385	387	388	390	391	392	394	395
538	397	398	400	402	403	405	406	408	410	411
539	413	415	417	419	421	423	425	428	430	432
540	435	437	440	443	446	448	451	454	457	460
541	463	466	469	473	476	479	482	486	489	493
542	497	500	504	508	511	515	519	523	527	530
543	534	538	542	546	550	554	558	562	566	570
544	574	578	582	585	589	593	596	600	604	607
545	610	614	617	620	623	626	629	632	635	638
546	640	643	646	649	652	654	657	660	663	665
547	668	671	674	676	679	682	685	688	690	693
548	696	700	703	706	709	713	716	720	724	727
549	731	735	738	742	746	750	753	757	761	764
550	768	771	775	778	782	785	789	792	796	799

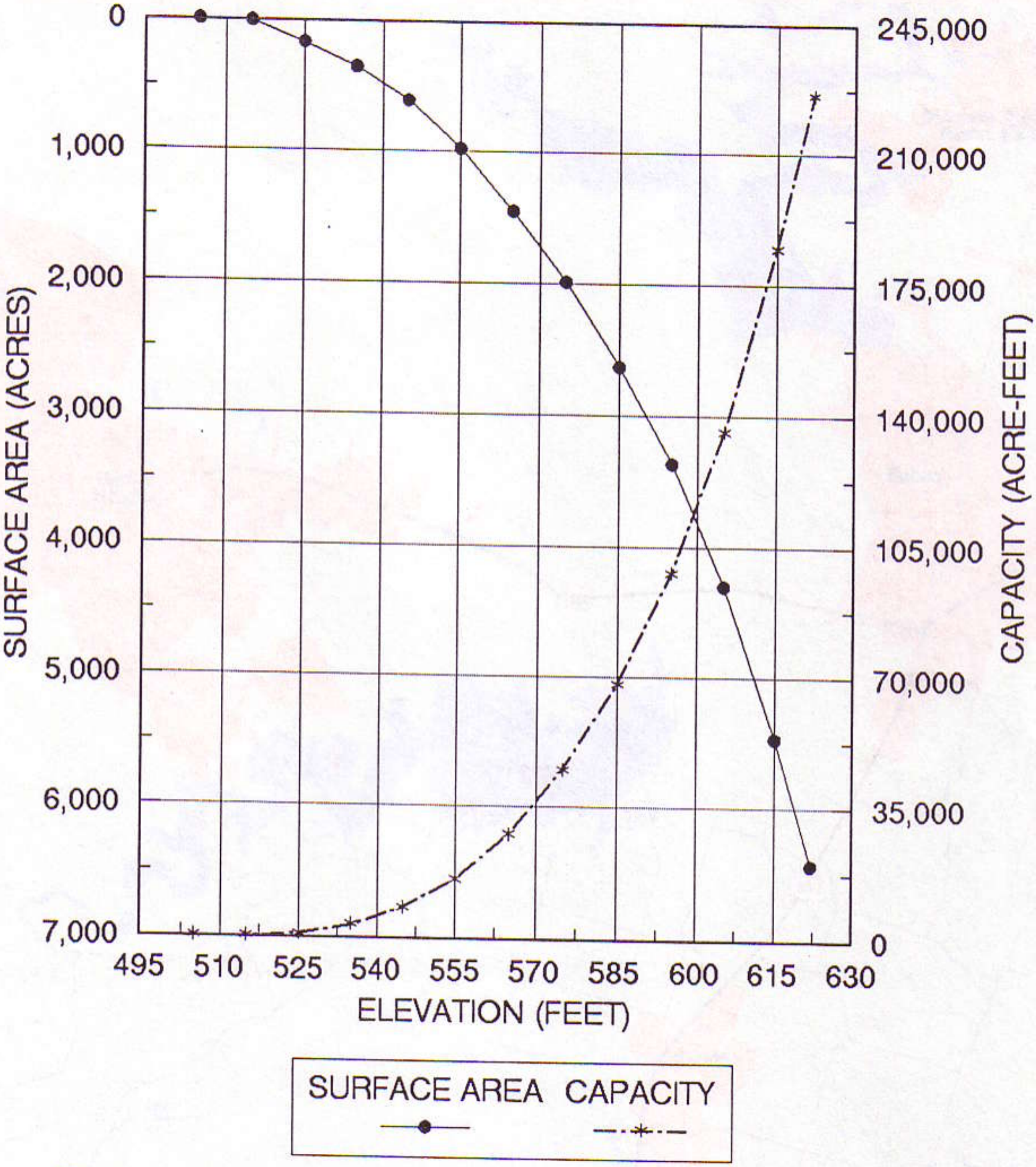
STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

	AREA IN ACRES				ELEVATION INCREMENT IS ONE TENTH FOOT					
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
551	802	806	810	814	818	822	826	830	834	838
552	842	846	850	854	858	862	867	871	875	879
553	884	888	893	897	902	906	911	915	920	925
554	929	934	939	944	948	953	958	962	967	971
555	976	980	985	989	994	998	1003	1007	1012	1016
556	1020	1025	1029	1034	1038	1042	1047	1051	1055	1060
557	1064	1069	1073	1077	1082	1086	1091	1095	1100	1105
558	1109	1114	1118	1123	1127	1132	1136	1141	1145	1149
559	1153	1157	1161	1166	1170	1174	1179	1183	1187	1192
560	1196	1201	1206	1210	1215	1219	1224	1228	1233	1237
561	1241	1246	1250	1255	1260	1265	1269	1274	1279	1284
562	1289	1294	1299	1304	1309	1314	1319	1325	1330	1335
563	1341	1347	1352	1357	1363	1368	1374	1379	1385	1391
564	1397	1403	1409	1414	1420	1426	1431	1437	1442	1448
565	1454	1460	1466	1472	1478	1485	1491	1497	1503	1508
566	1514	1520	1525	1531	1537	1542	1548	1553	1559	1564
567	1570	1575	1581	1586	1591	1597	1602	1608	1613	1619
568	1624	1630	1636	1641	1647	1652	1658	1663	1668	1674
569	1679	1684	1689	1694	1699	1704	1709	1714	1718	1723
570	1728	1733	1738	1743	1748	1753	1758	1763	1768	1773
571	1779	1784	1789	1794	1800	1805	1810	1816	1821	1826
572	1831	1837	1842	1847	1852	1858	1863	1869	1874	1880
573	1886	1891	1896	1902	1907	1912	1917	1922	1927	1932
574	1937	1943	1948	1953	1958	1963	1968	1973	1979	1984
575	1989	1995	2000	2006	2011	2017	2023	2029	2035	2041
576	2047	2053	2059	2065	2071	2077	2083	2089	2095	2100
577	2106	2112	2118	2124	2131	2137	2143	2150	2156	2163
578	2169	2176	2182	2189	2195	2202	2209	2216	2223	2230
579	2237	2244	2251	2258	2264	2271	2278	2284	2291	2297
580	2304	2310	2316	2322	2329	2335	2341	2347	2353	2359
581	2365	2371	2378	2384	2390	2397	2403	2410	2416	2422
582	2429	2435	2441	2448	2454	2460	2467	2474	2480	2487
583	2494	2501	2509	2516	2522	2529	2536	2543	2550	2556
584	2563	2570	2576	2583	2590	2597	2604	2610	2617	2624
585	2631	2637	2643	2650	2656	2663	2669	2675	2682	2689
586	2695	2702	2709	2716	2723	2730	2737	2744	2752	2759
587	2766	2774	2781	2789	2796	2804	2811	2818	2826	2833
588	2840	2847	2854	2861	2867	2874	2881	2888	2895	2902
589	2909	2917	2925	2932	2939	2946	2953	2960	2967	2975
590	2982	2989	2996	3003	3010	3017	3024	3031	3039	3046
591	3053	3060	3068	3075	3083	3090	3098	3106	3114	3122
592	3130	3138	3146	3154	3162	3171	3179	3187	3196	3204
593	3211	3219	3227	3235	3244	3252	3260	3268	3276	3283
594	3291	3299	3306	3313	3321	3328	3336	3343	3350	3358
595	3366	3373	3381	3388	3396	3404	3411	3419	3428	3435
596	3443	3451	3458	3466	3474	3482	3490	3498	3505	3513
597	3520	3528	3536	3543	3551	3559	3567	3575	3583	3591
598	3599	3607	3615	3624	3632	3640	3649	3658	3666	3675
599	3683	3692	3700	3709	3718	3727	3736	3745	3754	3763
600	3772	3781	3791	3800	3810	3819	3829	3839	3848	3858

STILLHOUSE HOLLOW LAKE MAY 1995 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
601	3867	3877	3887	3897	3907	3917	3929	3940	3951	3962
602	3973	3984	3994	4005	4015	4026	4036	4047	4058	4068
603	4079	4090	4101	4111	4123	4134	4146	4157	4168	4180
604	4191	4201	4213	4224	4236	4247	4258	4269	4280	4291
605	4302	4313	4324	4335	4345	4356	4367	4378	4388	4399
606	4410	4421	4432	4444	4455	4466	4477	4489	4500	4511
607	4522	4534	4545	4557	4568	4580	4591	4603	4614	4625
608	4637	4648	4659	4671	4682	4693	4705	4716	4728	4740
609	4752	4764	4775	4787	4799	4811	4822	4834	4846	4858
610	4870	4882	4894	4906	4918	4930	4942	4954	4966	4979
611	4991	5003	5016	5028	5040	5053	5065	5078	5090	5103
612	5115	5128	5141	5153	5165	5177	5188	5199	5211	5222
613	5233	5244	5256	5267	5279	5290	5302	5313	5325	5337
614	5348	5360	5372	5383	5395	5408	5420	5432	5444	5456
615	5469	5481	5493	5506	5519	5532	5544	5557	5569	5581
616	5594	5606	5618	5630	5642	5654	5667	5679	5691	5703
617	5715	5728	5740	5752	5765	5778	5790	5804	5819	5832
618	5846	5859	5874	5890	5905	5919	5933	5947	5961	5975
619	5989	6004	6019	6035	6052	6065	6078	6092	6105	6118
620	6133	6145	6158	6170	6182	6195	6207	6220	6232	6245
621	6257	6270	6282	6295	6307	6320	6332	6345	6357	6370
622	6429									



STILLHOUSE HOLLOW LAKE

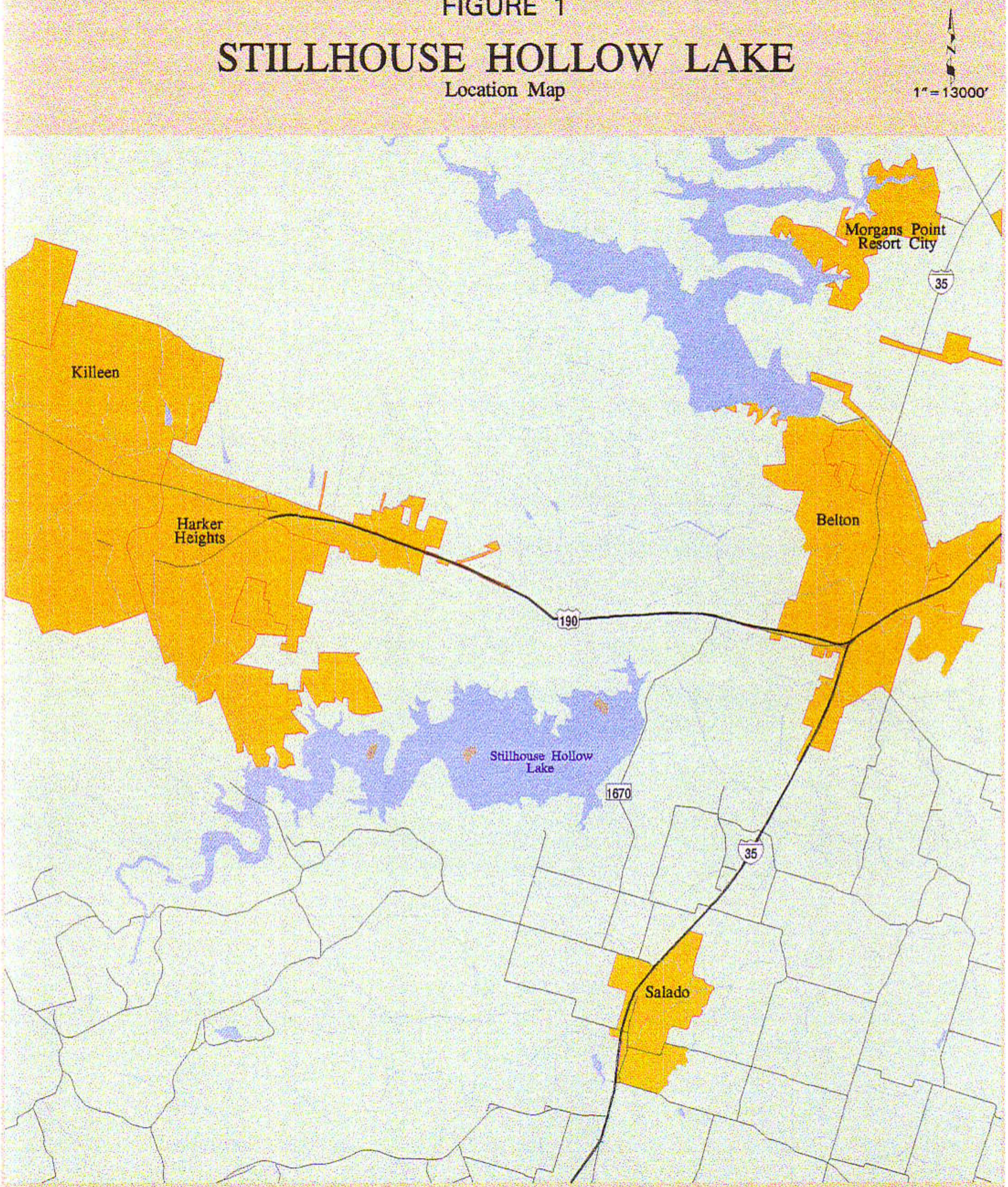
MAY 1995 SURVEY

Prepared by: TWDB July 1995

FIGURE 1

STILLHOUSE HOLLOW LAKE

Location Map

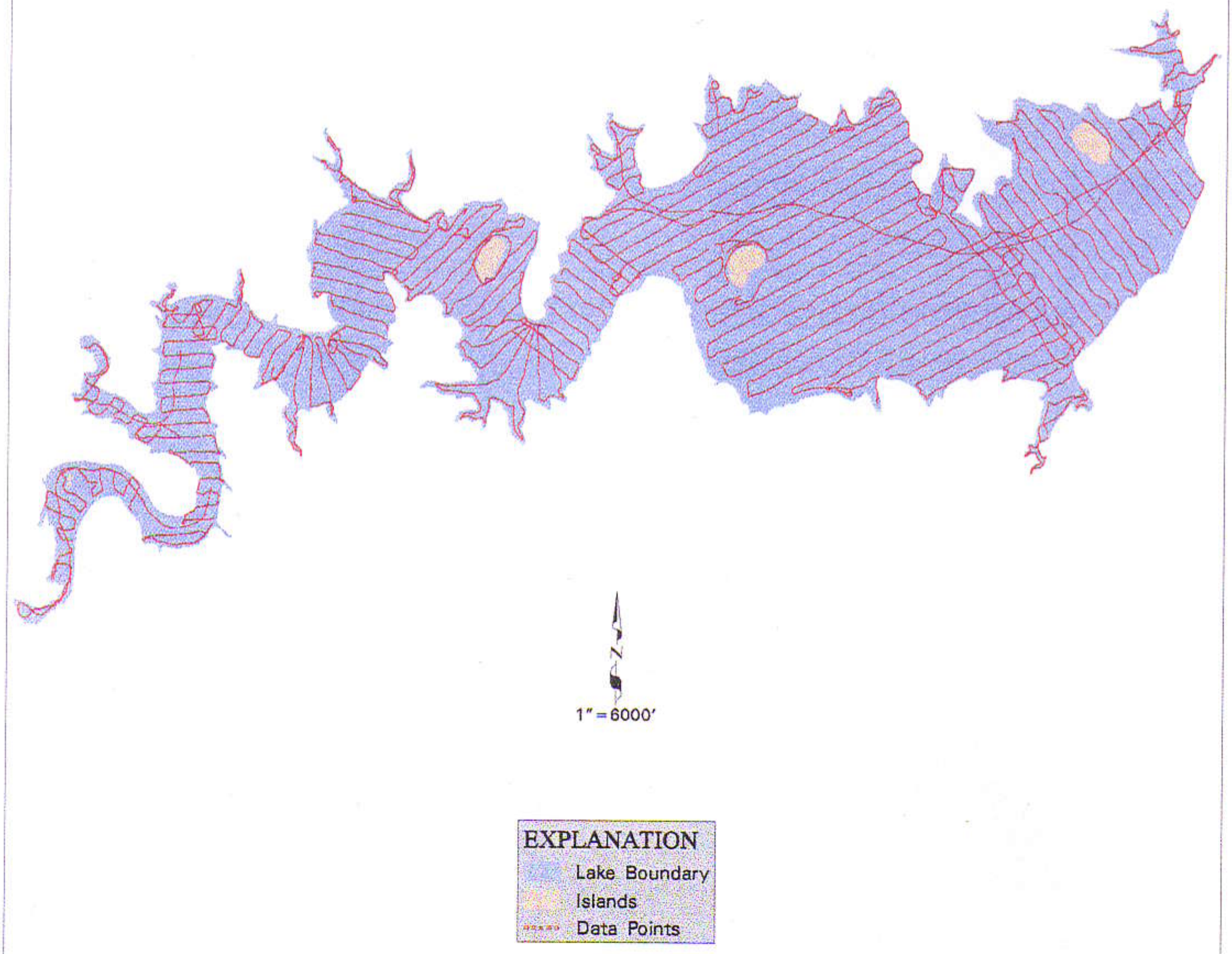


PREPARED BY: TWDB JULY 1995

FIGURE 2

STILLHOUSE HOLLOW RESERVOIR

Location of Survey Data

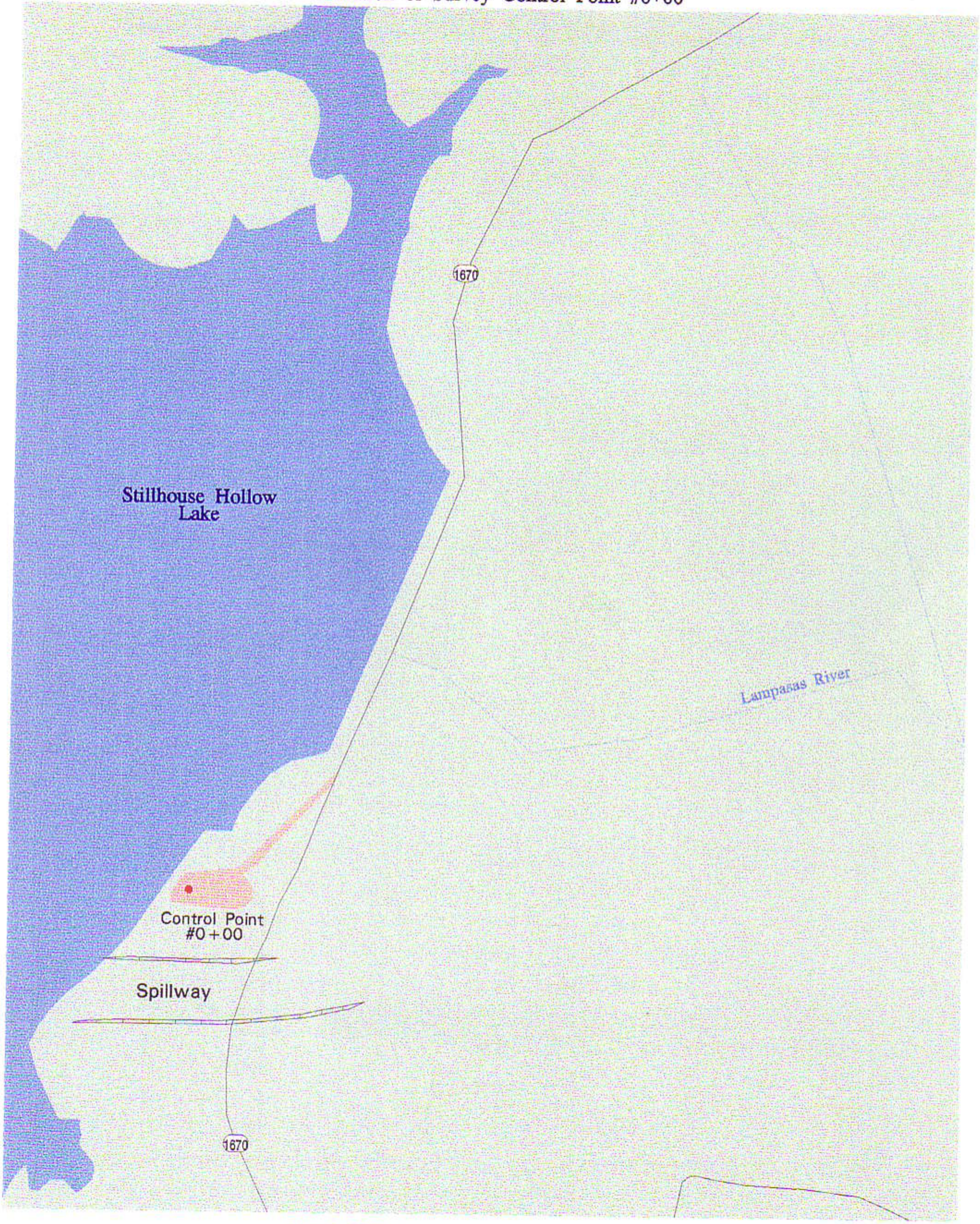


PREPARED BY: TWDB JULY 1995

FIGURE 3

STILLHOUSE HOLLOW LAKE

Location of Survey Control Point #0+00

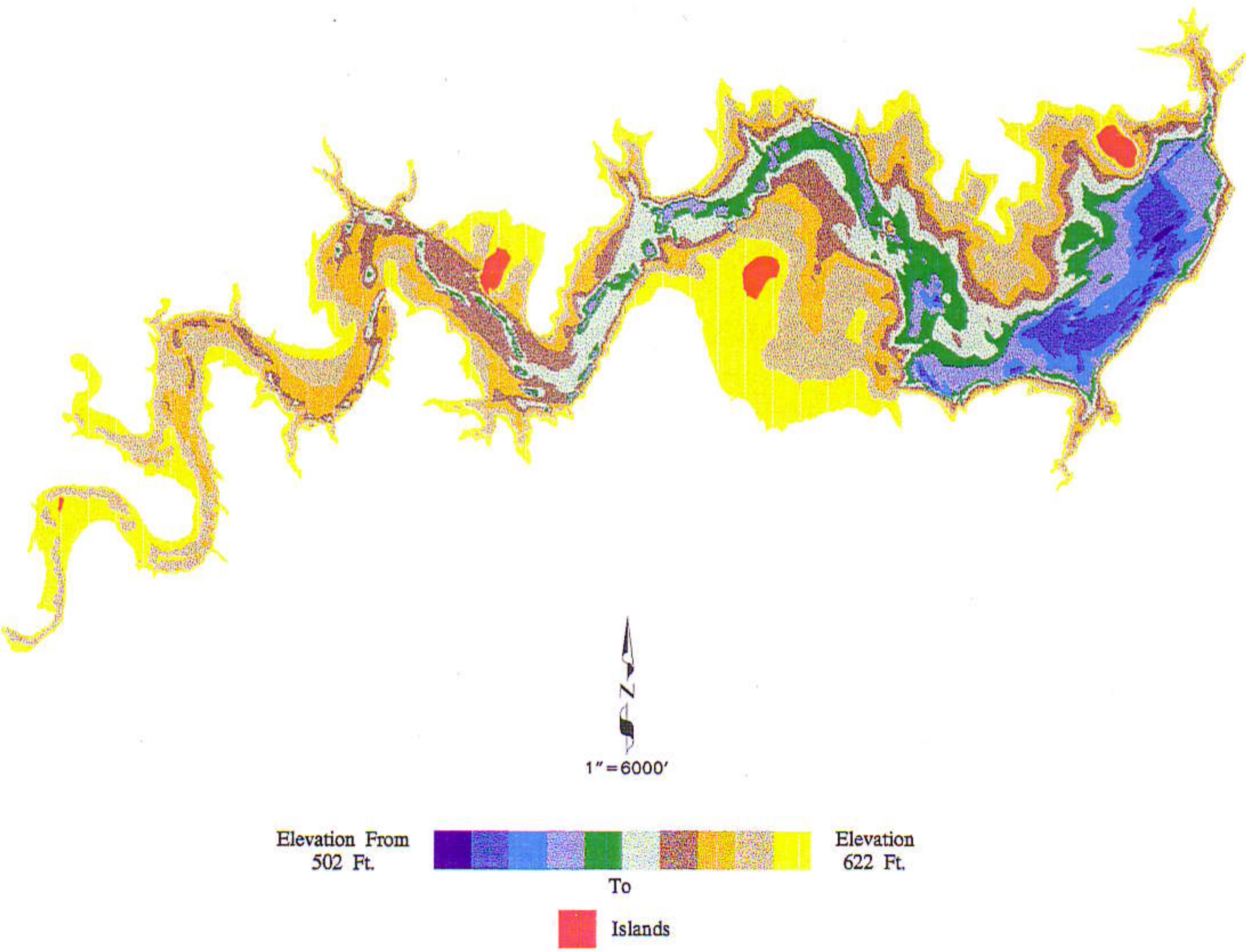


PREPARED BY: TWDB JULY 1995

FIGURE 4

STILLHOUSE HOLLOW RESERVOIR

Shaded Relief

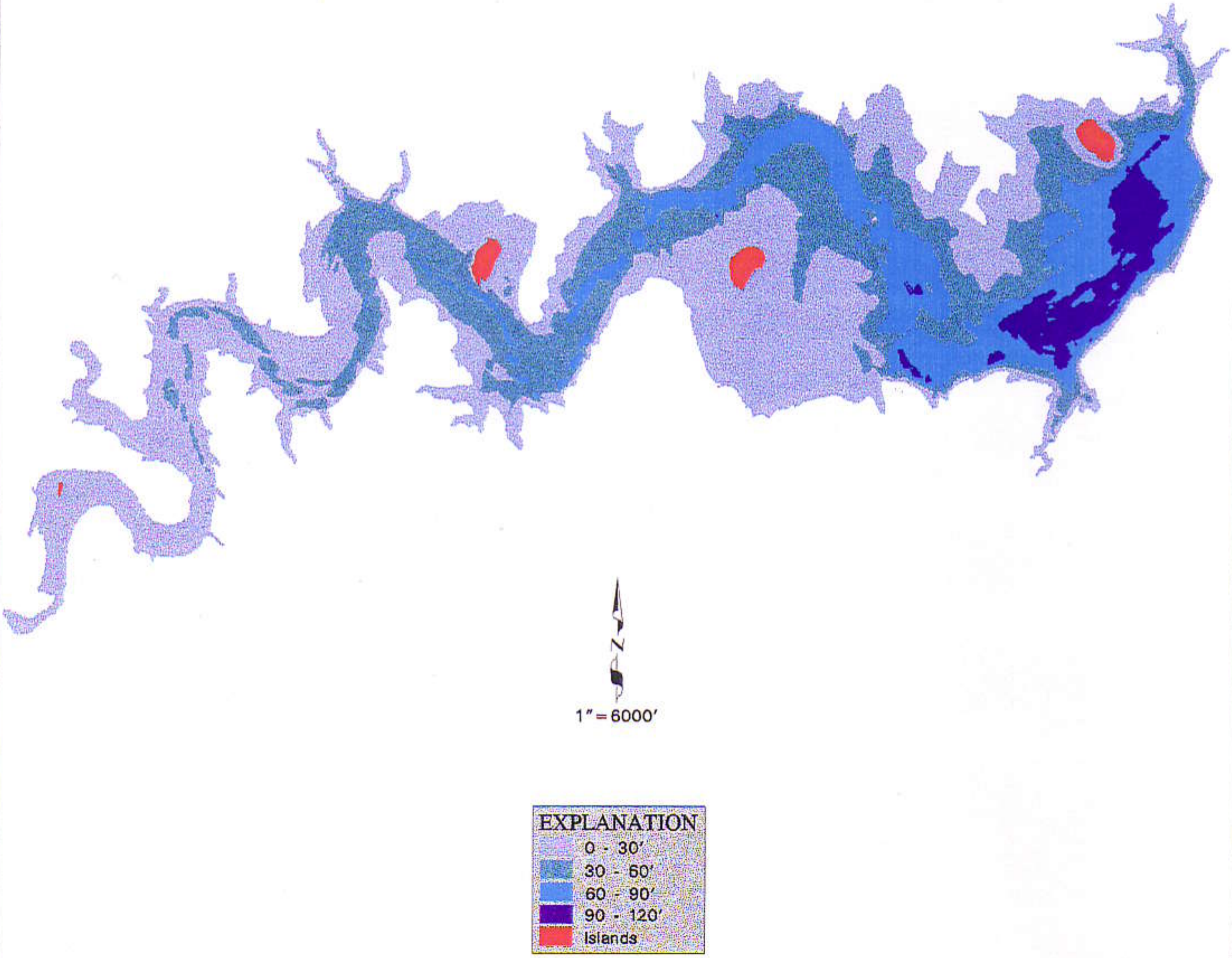


PREPARED BY: TWDB JULY 1995

FIGURE 5

STILLHOUSE HOLLOW RESERVOIR

Depth Ranges



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