VOLUMETRIC SURVEY
OF
GRANGER 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 Granger Lake during the period October 5-10, 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 Survey topographic maps dated 1963-64, the U. S. Army Corps of Engineers calculated the initial surface area of Granger Lake at the conservation pool elevation of 504.0 feet to be 4,400 acres with a corresponding initial capacity of 65,510 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Granger Lake is located on the San Gabriel River in Williamson County, about 7.1 miles east of Granger, 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 at the confluence of the San Gabriel River and Willis Creek. The Federal Government has restricted 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 730 square mile drainage area. At the conservation capacity pool elevation of 504.0 feet, the lake is approximately 4.5 miles long and 2.5 miles wide at its widest point near the dam.

Certificate of Adjudication #12-5163 was issued by the Texas Water Commission December 14, 1987 to the Brazos River Authority to impound 65,500 acre-feet of water in an existing reservoir on the San Gabriel River. The BRA was authorized a priority right to divert and use not to exceed 19,840 acre-feet of water per annum for municipal, industrial, irrigation, 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 Granger Lake not to exceed 30,000 acre-feet of water for municipal purposes; 5,500 acre-feet of water for irrigation purposes; 29,800 acre-feet of water for industrial purposes and 200 acre-feet of water for mining purposes. Any diversions and use of water from Granger Lake in excess of 19,840 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. The BRA was also authorized to use the water impounded in Granger Lake for non-consumptive recreation purposes. Certificate of Adjudication #12-5167 (issued December 14, 1987) states the BRA is authorized to divert and use not to 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 Granger Lake and other reservoirs owned and operated by the BRA.

Construction of the dam commenced on October 24, 1972. Deliberate impoundment of water began January 21, 1980 and the facility was completed July 22nd of the same year. The project was designed by the COE and the general contractor was J.D. Abrams. The estimated project cost was $62,000,000.

Granger Dam is a rolled earthfill structure with a length of 16,320 feet rising 115 feet above the natural streambed to an elevation of 555.0 feet. Located near the right end of the dam, the uncontrolled spillway is a 950.0 foot long ogee weir at elevation

528.0 feet with a discharge capacity of 318,600 cubic feet per second (cfs) at the maximum design flood stage of 549.3 feet. The outlet works are composed of a 18-foot-diameter concrete conduit with an invert elevation of 457.0 feet. Discharges into the conduit are controlled by two 8-foot wide by 18-foot high hydraulically operated slide gates. The low flow outlet, consisting of three 3-foot wide by 4-foot high slide gates with invert elevations of 486.0, 494.0, and 502.0 feet, also discharges into the conduit.

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 was determined prior to the survey by digitizing with AutoCad software the lake's normal pool boundary from two USGS quad sheets. The names of the quad sheets are as follows: Granger Lake, TX 1963 (Photo-revised 1988); and Granger, TX 1964 (Photo-revised 1988). 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 157 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 Granger 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 an U. S. Geological Survey first-order monument named "PETTIBONE" located approximately six miles west of Cameron, TX. The coordinates for the monument are published as Latitude 30° 50' 58.81060"N and Longitude 97° 04' 48.40617"W.

On September 21, 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 consisted of an unmarked USGS surveyor's cap set flush to the ground in concrete, located in a fenced area near the U S Army Corps of Engineer's lake headquarters. The GPS receivers were set up over this point and the U.S. Geological Survey first-order monument. Satellite data were gathered simultaneously at both points for approximately one hour, with up to six satellites visible.

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 30° 42' 58.24638" and West longitude 97° 19' 14.69335".

Using the newly determined coordinates, a shore station was set up at the control point to provide DGPS control during the survey. The coordinates from the static survey were entered into the GPS receiver 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 Granger 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 Granger 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 Granger Lake, the speed of sound in the water column varied daily between 4879 and 4891 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 Granger Lake during the period of October 5-10, 1995. Approximately 43,375 data points were collected over the 72.16 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 97 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, TWDB staff noted quite a bit of sediment in the reaches of Willis and Sore Finger Creeks. As the crew traveled the upper reaches of the San Gabriel River arm of Granger Lake, stumps and submerged trees were prevalent as the lake narrowed to more of a river channel characteristic. Throughout the main area of the lake, the bottom was fairly uniform and the old river and creek channels were hard to detect.

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 503.96 to 504.03 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 capacity elevation of the lake. This was calculated as 4,009 acres for Granger 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 Granger 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

Results from the 1995 survey indicate Granger Lake now encompasses around 4,009 surface acres and contains a volume of 54,280 acre-feet at the conservation pool elevation of 504.00 feet. The shoreline at this elevation was calculated to be 28.19 miles. The lowest elevation encountered was around elevation 463.19 feet, or 40.81 feet of depth and was found near the dam.

The storage volume calculated by the 1995 survey is approximately 17.1 percent less than the previous record information for the lake. The lowest gated outlet invert elevation is at elevation 457.0 feet. The outlet is lower than the lowest point found in the lake and it is questionable whether the outlet still works. There is no storage volume in the lake at this elevation. Therefore, the conservation storage capacity for the lake is 54,280 acre-feet.

SUMMARY

Granger Dam and Granger Lake were authorized by the Federal Flood Control

Act approved September 3, 1954 and the Public Works Appropriation Act of 1958. Construction commenced October 24, 1972. Deliberate impoundment began January 21, 1980. Initial storage calculations estimated the volume of the lake at the conservation pool elevation of 504.0 to be 65,510 acre-feet with surface area of 4,400 acres.

During the period October 5-10, 1995, a hydrographic survey of Granger 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 Granger Lake than previous survey methods. Results from the survey indicate that the lake's capacity at the conservation pool elevation of 504.0 feet was 54,280 acre-feet. The estimated reduction in storage capacity, if compared to the original volume in 1980 was 11,230 acre-feet, or 17.1 percent. This equates to an estimated loss of 748.67 acre-feet per year during the 15 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 1.0256 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 the raw data used in calculating the original storage information is no longer available. 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 Granger 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

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

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

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

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

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

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

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

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

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

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

Nov 27 1995

GRANGER LAKE OCTOBER 1995 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
463										
464							1	1	1	2
465	2	2	3	4	4	5	6	6	7	8
466	9	10	12	14	16	19	22	25	28	32
467	36	41	45	50	55	60	66	72	78	84
468	90	97	104	111	118	126	133	141	149	157
469	166	175	184	193	203	213	224	234	245	256
470	267	279	290	303	315	327	340	353	367	381
471	395	409	424	438	454	469	485	501	518	535
472	552	569	587	605	624	642	661	681	701	721
473	742	763	784	806	828	851	874	897	921	945
474	969	994	1019	1045	1070	1097	1123	1150	1178	1206
475	1234	1262	1292	1321	1351	1382	1413	1444	1477	1509
476	1543	1577	1611	1646	1682	1719	1756	1794	1832	1872
477	1912	1953	1995	2038	2081	2126	2171	2217	2263	2311
478	2359	2408	2458	2509	2562	2616	2671	2727	2785	2844
479	2904	2965	3028	3092	3156	3222	3289	3356	3425	3494
480	3565	3636	3709	3782	3856	3932	4008	4085	4163	4241
481	4321	4402	4483	4566	4649	4732	4817	4902	4987	5074
482	5161	5248	5337	5426	5516	5607	5698	5791	5884	5978
483	6073	6169	6266	6364	6462	6562	6662	6763	6865	6967
484	7071	7176	7281	7388	7496	7605	7715	7826	7938	8051
485	8166	8281	8398	8515	8634	8754	8875	8997	9120	9244
486	9370	9496	9624	9753	9883	10015	10147	10281	10415	10551
487	10688	10826	10965	11106	11247	11390	11533	11678	11824	11971
488	12119	12268	12418	12569	12722	12875	13030	13186	13343	13501
489	13660	13821	13982	14145	14309	14474	14641	14808	14977	15147
490	15318	15490	15664	15839	16016	16193	16372	16552	16734	16916
491	17100	17285	17471	17658	17847	18037	18228	18421	18614	18809
492	19006	19203	19403	19604	19806	20010	20215	20421	20629	20838
493	21049	21261	21475	21690	21906	22124	22344	22565	22788	23012
494	23238	23466	23695	23926	24158	24392	24627	24864	25103	25343
495	25585	25829	26074	26321	26570	26820	27073	27327	27583	27840
496	28100	28361	28625	28890	29156	29424	29694	29966	30239	30514
497	30790	31068	31347	31628	31911	32195	32480	32767	33056	33346
498	33638	33931	34226	34523	34821	35121	35422	35725	36029	36336
499	36643	36953	37264	37577	37892	38208	38525	38845	39165	39488
500	39812	40138	40465	40794	41124	41457	41792	42130	42470	42814
501	43159	43507	43856	44207	44560	44914	45270	45628	45986	46347
502	46709	47073	47438	47805	48174	48544	48915	49288	49663	50039
503	50417	50797	51178	51560	51944	52329	52717	53105	53495	53887
504	54280									

TEXAS WATER DEVELOPMENT BOARD

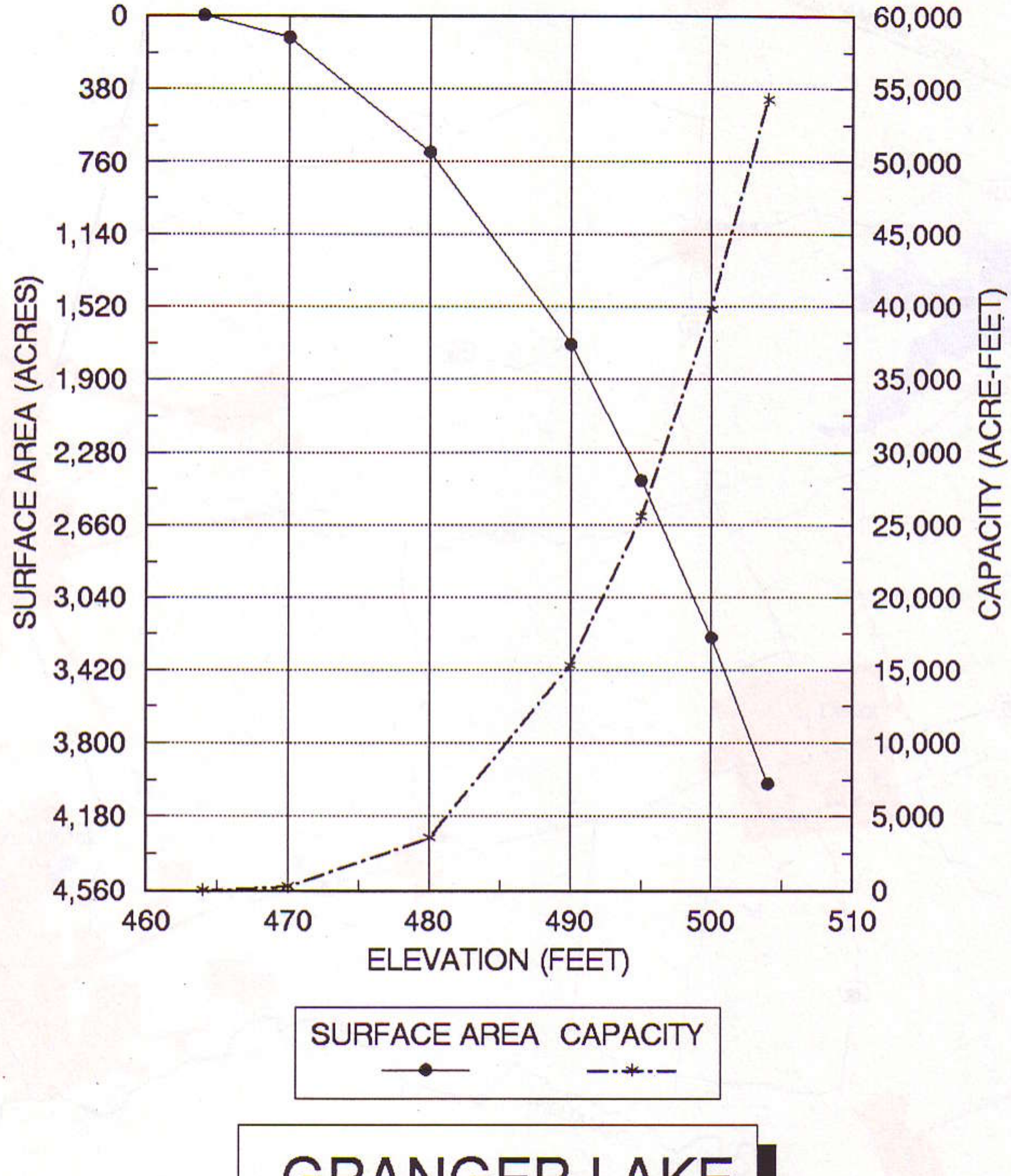
RESERVOIR AREA TABLE

Nov 27 1995

GRANGER LAKE OCTOBER 1995 SURVEY

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
463										
464				1	1	2	2	3	3	4
465	5	5	6	6	6	7	7	8	9	9
466	11	14	17	21	25	29	31	34	36	39
467	42	45	48	50	52	55	57	59	61	63
468	65	67	69	71	73	75	77	80	82	84
469	87	90	93	96	99	102	104	106	109	111
470	114	117	119	122	125	127	130	133	136	139
471	142	144	147	151	154	157	160	164	167	170
472	173	176	179	183	186	189	193	197	201	205
473	209	213	216	220	224	228	231	235	238	242
474	246	249	253	257	261	265	268	272	276	280
475	284	289	293	298	303	308	314	320	325	330
476	336	342	348	355	361	368	375	383	391	399
477	407	415	423	431	439	447	455	462	471	479
478	488	497	506	517	531	544	557	571	584	596
479	608	620	631	641	652	662	671	681	691	700
480	710	719	729	738	748	757	766	775	784	792
481	801	811	819	827	834	840	847	853	860	866
482	873	880	888	896	904	912	921	929	938	946
483	955	964	972	981	989	997	1006	1014	1023	1032
484	1042	1052	1062	1072	1083	1094	1106	1117	1128	1138
485	1149	1160	1171	1181	1192	1203	1214	1225	1237	1249
486	1261	1273	1286	1297	1307	1318	1329	1340	1352	1364
487	1375	1387	1398	1409	1420	1431	1441	1452	1463	1474
488	1485	1496	1507	1519	1530	1542	1553	1565	1576	1587
489	1599	1611	1622	1634	1646	1657	1669	1681	1693	1706
490	1718	1732	1744	1758	1770	1783	1795	1807	1819	1831
491	1843	1855	1868	1880	1893	1905	1918	1931	1943	1957
492	1971	1986	2001	2015	2030	2044	2058	2072	2086	2100
493	2114	2128	2142	2157	2173	2189	2205	2220	2235	2251
494	2267	2284	2300	2316	2331	2347	2362	2378	2394	2411
495	2428	2445	2462	2478	2496	2514	2532	2550	2568	2586
496	2605	2624	2641	2658	2674	2691	2708	2724	2739	2755
497	2770	2786	2801	2816	2832	2847	2863	2879	2895	2911
498	2926	2942	2957	2973	2989	3005	3021	3037	3054	3070
499	3087	3104	3121	3136	3153	3169	3185	3200	3216	3232
500	3249	3265	3281	3298	3316	3336	3364	3388	3419	3448
501	3466	3485	3502	3518	3534	3550	3566	3582	3598	3614
502	3630	3645	3661	3677	3692	3708	3724	3739	3755	3770
503	3786	3801	3817	3832	3848	3863	3879	3894	3909	3925
504	4009									

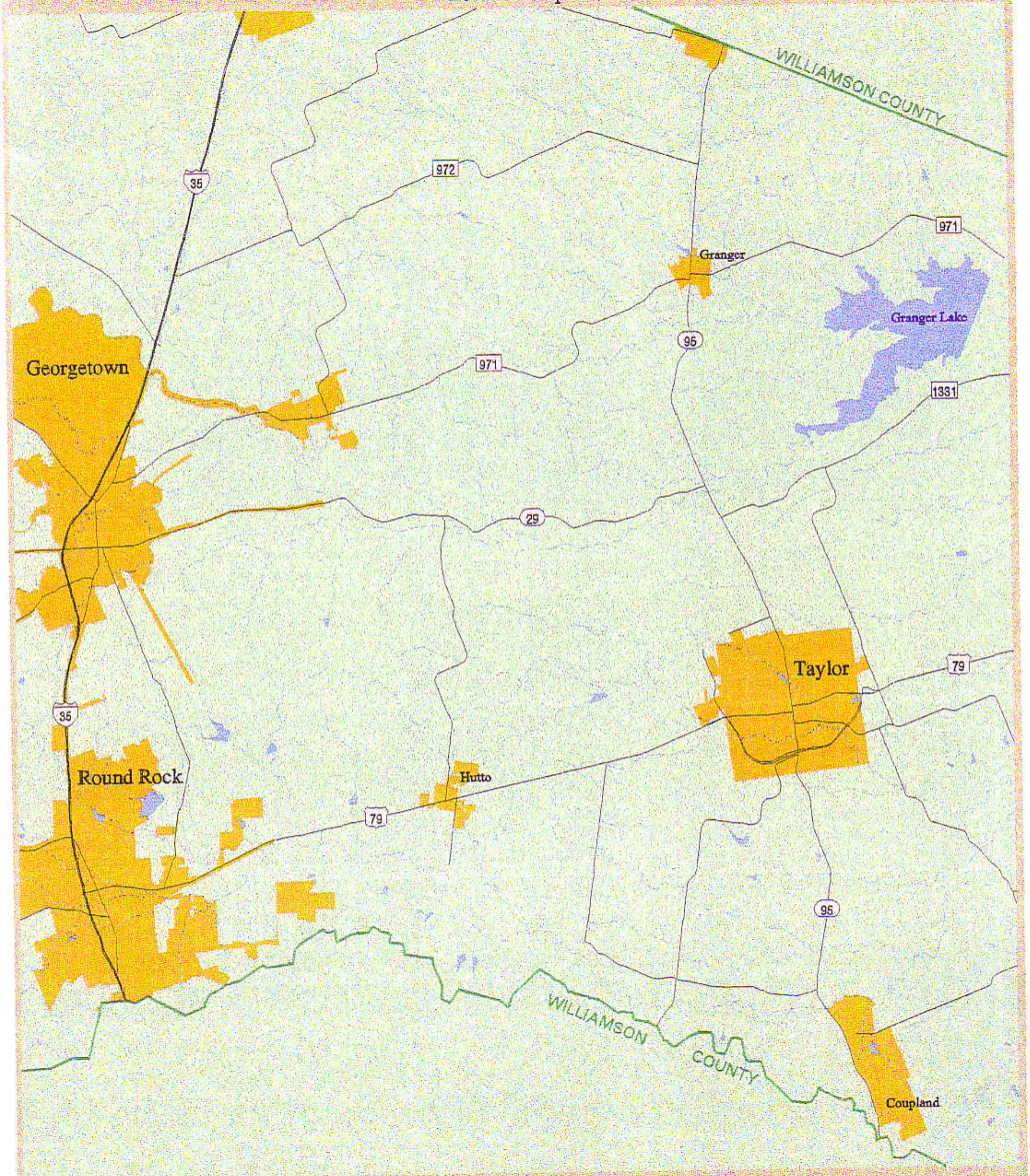


GRANGER LAKE

October 1995 SURVEY

Prepared by: TWDB December 1995

FIGURE 1
GRANGER LAKE
Location Map

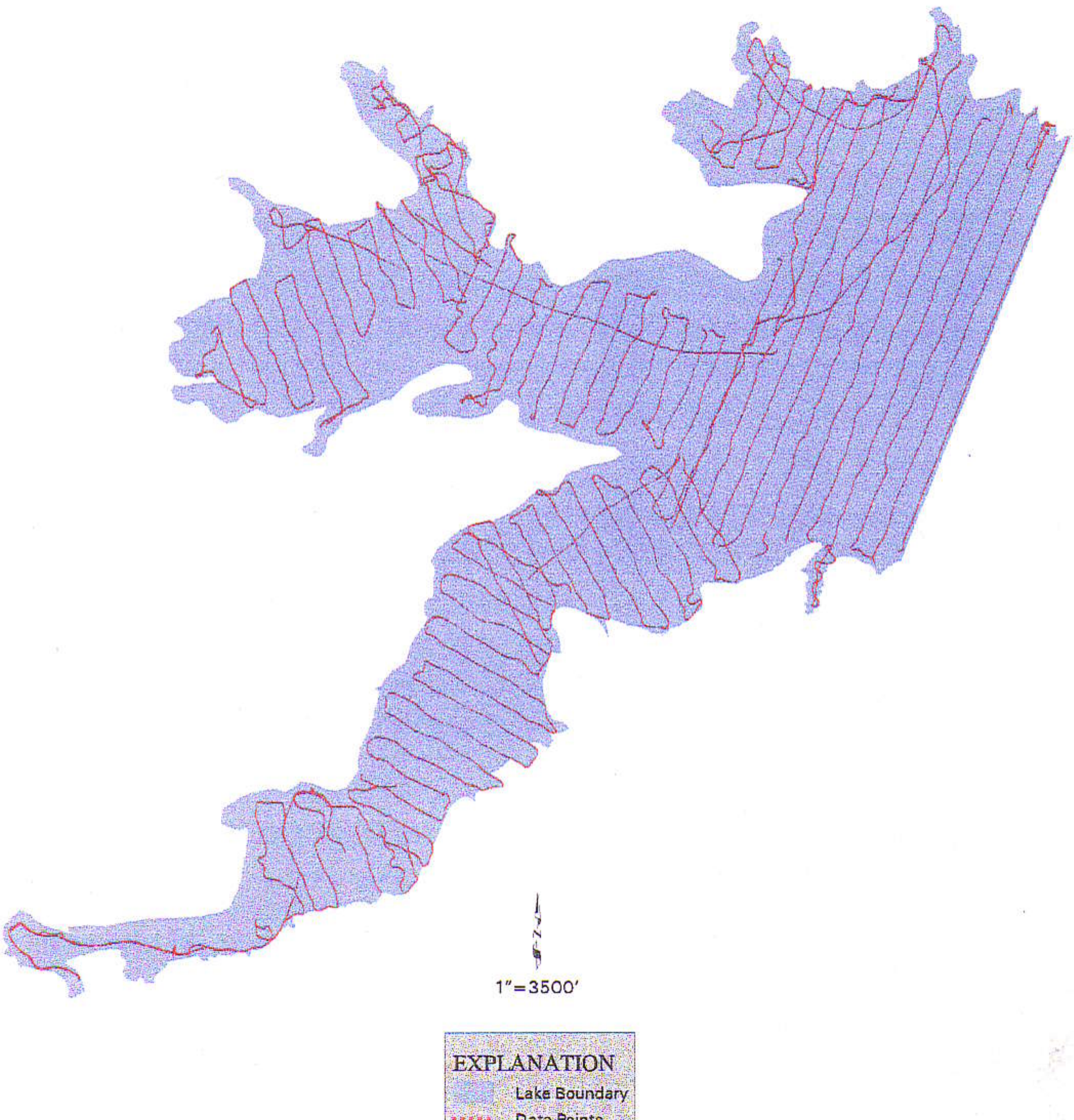


PREPARED BY: TWDB DECEMBER 1995

FIGURE 2

GRANGER LAKE

Location of Survey Data



PREPARED BY: TWDB December, 1995

FIGURE 3

Granger Lake

Location of Survey Control Point

PREPARED BY: TWDB DECEMBER 1995

FIGURE 4

GRANGER LAKE

Shaded Relief

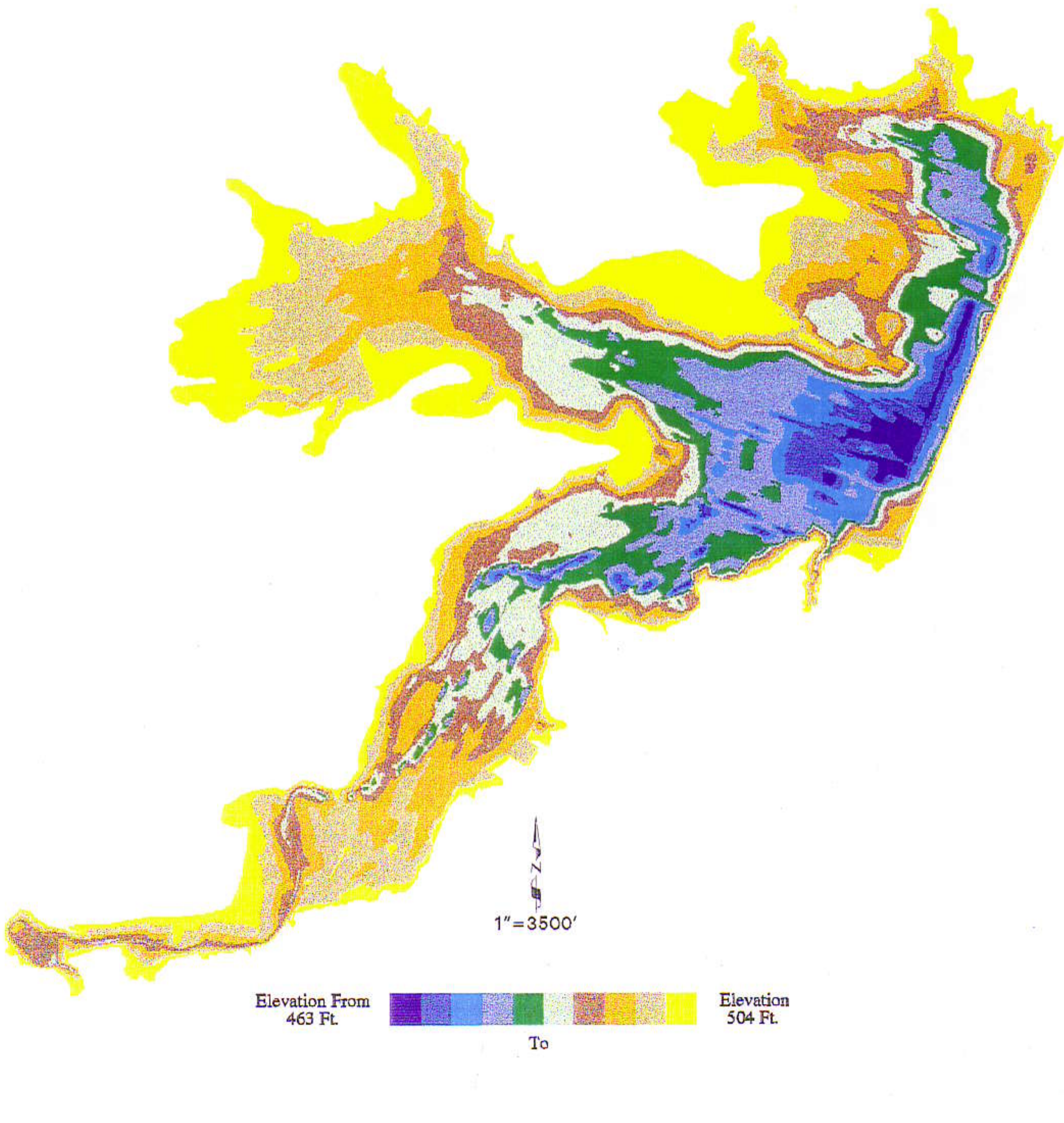


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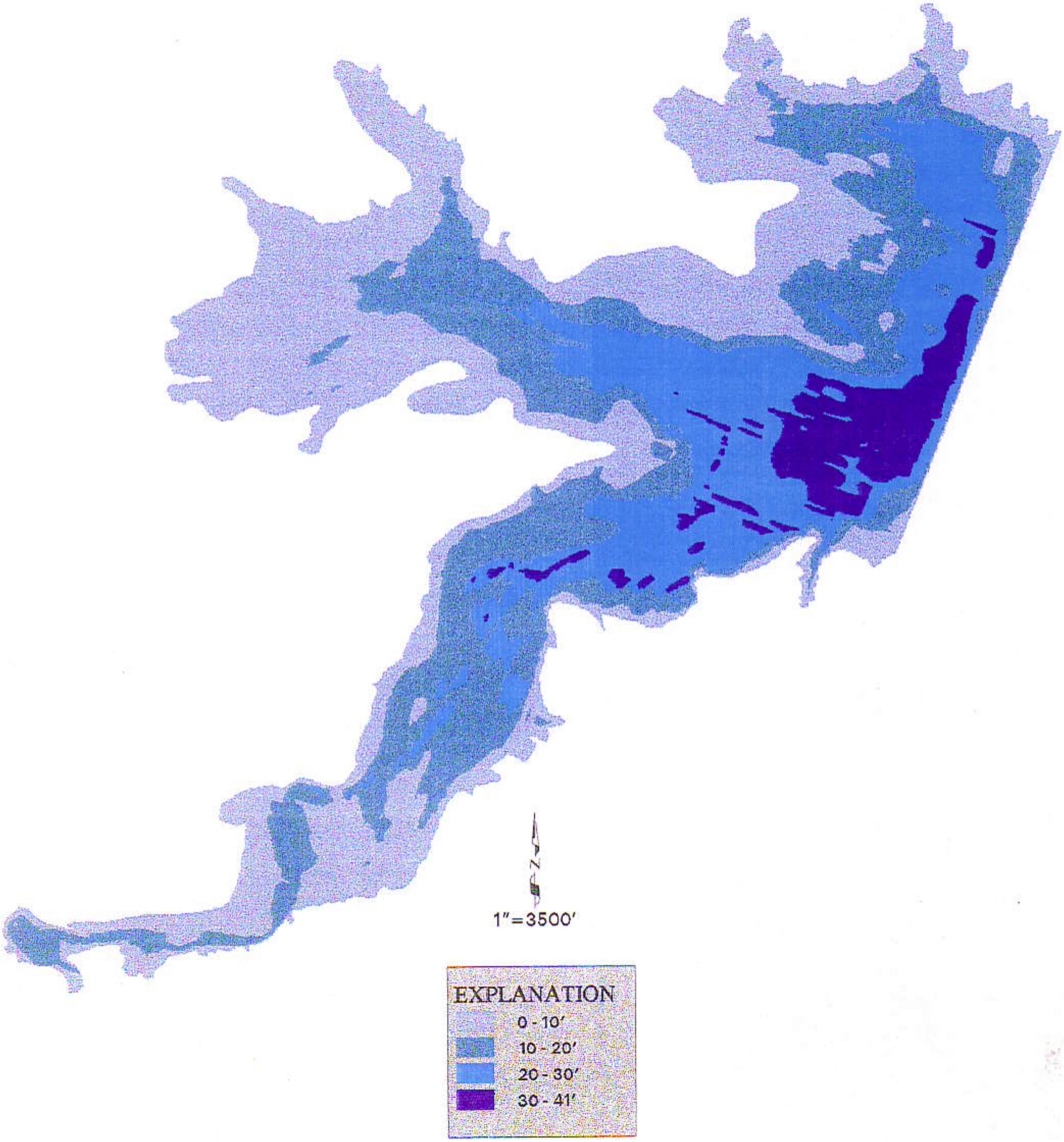
FIGURE 5

GRANGER LAKE

Depth Ranges



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