VOLUMETRIC SURVEY
OF
LAKE GRANBURY

Prepared for:

THE BRAZOS RIVER AUTHORITY

Prepared by:

The Texas Water Development Board

March 10, 2003

Texas Water Development Board

This report was prepared by the Hydrographic Survey group:

Scot Sullivan, P.E.
Duane Thomas
Randall Burns

For more information, please call (512) 445-1471

Published and Distributed
by the
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LAKE GRANBURY
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

Staff of the Hydrologic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Lake Granbury in October, 1993. 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.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Granbury and associated De Cordova Bend Dam are owned by the Brazos River Authority (BRA). De Cordova Bend Dam is located on the Brazos River approximately eight miles southeast of Granbury, Texas in Hood County. Lake Granbury inundates approximately 33 miles of the original Brazos river bed. Ambursen Engineering Corp. of Houston, Texas designed the dam and the H. B. Zachry Company was the Contractor. Construction began on December 12, 1966 and deliberate impoundment commenced September 15, 1969. The earth-rolled embankment is 2,200 feet in length with a maximum height of 84 feet at elevation 706.5 feet above mean sea level (msl) . The service spillway is a gate-controlled ogee crest There are 16 tainter gates each 36 feet (L) by 35 feet (H) have a crest elevation of 658.0 feet above msl. Outlet works consist of two 84" by 96" openings, motor-controlled by sluice gates with invert elevations at 652.0 and 640.0 feet above msl.

Water Rights Permit No. 2111, issued July 24, 1964, authorized the Brazos River Authority (BRA) to construct and maintain a dam and reservoir (Lake Granbury) on the Brazos River, to impound and not exceed 155,000 acre-feet of water. BRA was permitted to divert and use not to exceed 10,000 acre-feet of water per annum for municipal purposes, 70,000 acre-feet per annum for industrial purposes, 20,000 acre-feet per annum for irrigation and 350,000 per annum for hydroelectric power generation. Several amendments were made to Permit 2111 in the following years. On September 28,1966 the authorization to divert 350,000 acre-feet of water per annum for hydroelectric power generation was deleted and on September 13, 1979 the impounded waters of Lake Granbury was approved for recreational purposes. A change in water use resulted in another amendment to the Permit that was approved on November 25, 1980. It allowed the permittee to use 500 acre-feet of the 20,000 acre-feet of water designated for irrigation to be used for mining purposes.

The Certificate of Adjudication, No. 12-5156, was issued to the Brazos River Authority on December 14, 1987. It basically grants the BRA the right to impound and use the waters of Lake Granbury as previously described along with several "Special Conditions" concerning the "Systems Operations Order". The priority rights of Lake Granbury also fall under the order of Certificate of Adjudication 5167 for the purpose of system operation as authorized by Commission Order of July 23, 1964, as amended and as modified, by the Commission's final determination of all claims of water rights in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin maintained by the Brazos River Authority, the Fort Bend County W.C.I.D. No. One and the Galveston County Water Authority on June 26,1985.

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 monitor the broadcasts from the satellites over time 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. Additional satellite readings would also produce a possible location on a sphere surrounding that satellite with a radius of the distance measured. The observation of two satellites from an unknown point 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 first utilized on February 22, 1978, when the initial satellite was launched. The NAVSTAR (NAVigation System with Time And Ranging) satellite constellation will consist of 24 satellites when fully implemented. At the time of the survey, 23 satellites of the constellation were fully functional. The United States Department of Defense (DOD) is 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 (1 to 3 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" and was used during the survey of Lake Granbury. 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 3 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 hydrographic survey of Lake Granbury 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 Depth Sounder and 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 is supported by a dot matrix printer and a B-size plotter. Power is 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 strung 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 hooked itself 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 strung across the body of water, so surveying instruments were utilized to determine the path of the boat. A monument was set for each end point 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 across the body of water. 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 reading 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 sounding. 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 hard to detect after the fact. 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 again 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.

Survey Methods

The Hydrographic Survey crew set a benchmark in October, 1993 that would serve as a control point for the shore station site. A brass cap marked TWDB #008 was embedded in concrete near the main office at the Brazos River Authority's SWATS facility. This location was chosen because of the proximity to the reservoir, and the security of the area.

A static survey using the two Trimble 4000SE GPS receivers was performed to obtain coordinates for the TWDB benchmark. One GPS receiver was positioned over a USGS first-order monument named HENSEN, located approximately eight miles northeast of De Cordova Dam. HENSEN was established in 1946. TWDB acknowledges the Brazos River Authority's Datum for Lake Granbury is 1.113 feet lower in elevation than the USGS datum. Satellite data were gathered from this station for approximately an hour and a half, with up to seven satellites visible to the receiver. During the same time period, data were gathered from the second receiver positioned over TWDB #008.

Once data collection ended, the data were retrieved from the two receivers using Trimble Trimvec software, and processed to determine coordinates for the shore station benchmark. The NAVSTAR satellites use the World Geodetic System (WGS '84) spherical datum. WGS '84 is essentially identical to the North American Datum of 1983 (NAD '83). The WGS' 84 coordinates for TWDB #008 were determined to be North latitude 32° 25' 03.45515", West longitude 97° 39' 54.31045", and ellipsoid height of 685.75 feet. The approximate NGVD '29 elevation is 779.0 feet. Those coordinates were then entered into the shore station receiver located over TWDB #008 to fix its location and allow calculation and broadcasting of corrections through the radio and modem to the roving receiver located on the boat.

Due to the size and geographical shape of the reservoir, and the surrounding terrain, two additional shore station sites were required to maintain contact with the roving receiver on the boat.. The same procedure discussed previously was used to establish the second and third shore station sites. The second shore station site (1/2 iron rod) was set on the grounds of the Granbury Country Club. TWDB #008 was used as the known point to establish the coordinates for the second shore station site. The WGS'84 coordinates for the Granbury Country Club shore station site were determined to be North Latitude 32° 26' 35.42336", West Longitude 97° 45' 54.16602" and ellipsoid height of 653.99 feet. The approximate NGVD '29 elevation is 747.7 feet. The third shore station site ("+" chiseled in a flat rock) is located on the property of Mr. Ronald Bush of Granbury, Texas. The second shore station site was used as the known point to establish the coordinates for this site. The coordinates for the Bush's property shore station site were determined to be North Latitude 32° 29' 39.25122", West Longitude 097° 50' 51.86681" and ellipsoid height of 777.41 feet. The approximate NGVD '29 elevation is 871.63 feet. Information regarding a more detailed location description for these sites are available upon request.

The reservoir's surface area was determined by digitizing the lake boundary from 1961 USGS quad sheets that were updated in 1979 from 1976 aerial photographs. AutoCad software was used to digitize an estimate of the 693.0 contour based on the North American Datum of 1927

(NAD '27) used for these maps. The graphic boundary was then transformed from NAD '27 to NAD '83 using Environmental Systems Research Institutes's (ESRI) Arc/Info project command with the NADCOM parameters, to get the boundary into a more recent datum compatible with the positions received from the satellites. The area of the boundary shape was the same in both datum. NAD '83, a flat projected representation of the curved earth surface, was chosen to calculate areas and volumes. NAD '27 is also a flat projection, but the two datum have a slightly different point of origin, and distinctly different state plane false northing and false easting coordinate to be able to distinguish coordinate points between the two datum.

The resulting shape was modified slightly to insure that all data points gathered were within the boundary. The acreage at the normal pool elevation was thereby estimated to be 8,310 acres, or within 4.5 percent of the recorded 8,700 acres. An aerial topo of the upper four feet of the lake or an aerial photograph 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 survey layout was pre-planned, using approximately 300 survey lines at a spacing of 500 feet. Innerspace Technology Inc. software was utilized for navigation and to integrate and store positional data along with depths. In areas where vegetation or obstructions prevented the boat from traveling the planned line, random data were collected wherever the boat could maneuver. Additional random data were collected lengthwise in the reservoir. Data points were entered into the data set utilizing the DGPS horizontal position and manually poling the depth in shallow areas where the depth was less than the minimum recordable depth of the depth sounder, which is about 3.5 feet. Figure 2 shows the actual location of the data collection sites. Data were not collected in areas that were inaccessible due to shallow water or obstructions. The data set included approximately 38,730 data points.

TWDB staff verified the horizontal accuracy of the DGPS used in the Lake Granbury survey to be within the specified accuracy of three meters. 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 set to receive and process the corrections. 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. For DGPS operation 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 better satellite geometry and thus better horizontal positions. The DGPS positions were within acceptable limits of horizontal accuracy with a PDOP (Position Dilution of Precision) of seven (7) or less. The GPS receivers have an internal alarm that sounds if the PDOP rises above the maximum entered by the user, to advise the field crew that the horizontal position has degraded to an unacceptable level.

The depth sounder measures depth by measuring the time between the transmission of the sound pulse and the reception of its echo. The depth sounder was calibrated with the Innerspace Velocity Profiler typically once per day, unless the maximum depth varied by more than twenty feet. The velocity profiler calculates an average speed of sound through the water column of interest (typically set at a range of two feet below the surface to about ten feet above the maximum encountered depth), and the draft value or distance from the transducer to the surface. The velocity profiler probe is placed in the water to wet the transducers, then raised to the water surface where the depth is zeroed. The probe is then lowered on a cable to just below the maximum depth set for the water column, and then raised to the surface. The unit reads out an average speed of sound for the water column and the draft measurement, which are then entered into the depth sounder. The speed of sound can vary based on temperature, turbidity, density, or other factors. 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, Page 13. Manual poling of depths within shallow areas agreed with the depth obtained by the depth sounder typically within ± 0.3 feet, and since the boat is moving much slower, the plane of the boat has much less effect.

Analog charts were printed for each survey line as the data were collected. The gate mark, which is a known distance above the actual depth that was recorded in the data file, was also printed on the chart. Each analog chart was analyzed, and where the gate mark indicated that the recorded depth was other than the bottom profile, depths in the corresponding data files were modified accordingly. The depth sounder was set to record bad depth readings as 0, and all points with a zero depth were deleted.

Each data point consisted of a latitude, longitude and depth. The depths were transformed to elevations with a simple Unix command based on the water surface elevation each day, rounded to the nearest tenth of a foot since the depth sounder reads in tenths of a foot, and ranged from 692.5 to 693.1 feet (BRA datum). The latitude, longitude data set was converted to decimal degrees and loaded into Arc/Info along with the NAD '83 boundary file using the CREATETIN command. The data points along with the boundary were used to create a Digital Terrain Model (DTM) of the reservoir's bottom surface using the Arc\Info TIN module. 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. This method preserves all data points for use in determining the solution. The set 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. Areas that were too shallow for data collection or obstructed by vegetation were estimated by the Arc/Info's TIN product using this method of interpolation. There were some areas where interpolation could not occur because of a lack of information along the boundary of the reservoir. "Flat triangles" were drawn at these locations. ArcInfo does not use flat triangle areas in the volume or contouring features of the model. Therefore, additional data points were estimated for these locations to allow for interpolation and contouring of the entire lake surface. The differences between the estimated volume from these two processes and the actual volume are believed to be very minor because these areas do not contain significant amounts of water. The model size changed by about 20 surface acres after the additional data points were added, and the storage volume changed by about 259 acre/ft. From this three-dimensional triangular plane surface representation, the TIN product calculated the surface area and volume of the entire reservoir at one-tenth of a foot intervals.

The three-dimensional triangular surface was then shaded 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 intensities of these colors were assigned to the different depths in between. Figure 3 consists of the resulting depth shaded representation of the lake, broken into two figures for enhanced clarity. Figure 4 presents a two-dimensional version of the same map, using bands of color for selected contour 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 following smoothing options were chosen for this model: Douglas-Peucker option with a 1/1000 tolerance level to eliminate any duplicate points, and Round Corners with a maximum delta of 1/1000 of the model's maximum linear size, in an attempt to smooth some of the angularity of the contours. Contours of the bottom surface at two foot intervals are presented in Figure 5. The lake has been broken into 4 sections for easier viewing purposes.

DATA

Extra time was required to collect the field data of Lake Granbury due to trees and sand bars in the upper reaches of the lake. Submerged branches posed a significant hazard to navigation for the 33 mile long lake. The deepest part of the 25 year old lake was found near the dam and in the old channel bed of the Brazos River.

Lake Granbury was estimated by this survey to encompass 8,310 acres and to contain a volume of 136,823 acre-feet at the normal pool elevation of 693.0 feet. The reservoir volume table is presented in Appendix B, Page 3 and the area table in Appendix C, Page 4. The one-tenth foot intervals are based on actual calculations from the model. An elevation-area-volume graph is presented in Appendix D, Page 1. The surface elevation of the lake was near or above the normal pool elevation during the survey. The survey crew experienced high flows during data collection in the upper reaches of the lake. Since the boat cannot negotiate in shallow water, at a minimum the upper two feet are based on a straight-line interpolation from the last data points collected to the normal pool elevation lake boundary as digitized. The positional data collected in the field corresponds well with the boundary obtained from the photo-revised USGS map. The Board does not represent the boundary, as depicted in this report, to be a detailed actual boundary. It is an approximation of the actual boundary used to compute the volume and area within the upper elevations.

The storage volume calculated by this survey is approximately 11% percent less than the previous record information for the lake. The low flow outlet is at elevation 640.0 feet, resulting in a dead storage volume of 1,140 acre-feet. Therefore, the conservation storage for the reservoir is calculated to be 135,683 acre-feet.

SUMMARY

A hydrographic survey was performed by the Texas Water Development Board in October, 1993 on Lake Granbury. The lowest elevation encountered during this survey was elev. 626 feet, or a maximum depth of 67 feet. The conservation storage was calculated to be 135,683 acre-feet. The estimated reduction in storage capacity is 15,617 acre-feet, or 10 percent less capacity than the original capacity. It is assumed that the reduction in estimated storage is due to both a combination of sedimentation, and improved data and calculation methods. Repeating this survey with the same calculation methodology in five to ten years or after major flood events should remove any noticeable error due to improved calculation techniques and will help isolate the storage loss due to sedimentation.

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

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

TEXAS WATER DEVELOPMENT BOARD Jan 20 1994

RESERVOIR VOLUME TABLE

LAKE GRANBURY OCTOBER 1993 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
626										
627										1
628	1	1	1	1	1	2	2	2	3	3
629	3	4	4	5	6	6	7	8	9	10
630	12	14	16	18	20	23	26	29	32	35
631	39	43	47	51	55	59	63	68	72	77
632	82	87	92	97	102	107	113	119	125	131
633	138	144	151	159	166	174	181	189	197	206
634	214	223	232	241	251	260	270	280	290	300
635	310	321	332	343	354	365	377	389	401	413
636	425	438	451	464	477	491	505	519	533	547
637	562	577	593	609	625	641	657	674	692	709
638	727	745	763	782	801	820	840	860	880	900
639	920	941	962	984	1005	1027	1049	1071	1094	1117
640	1140	1163	1187	1211	1235	1260	1285	1310	1336	1362
641	1388	1414	1441	1468	1495	1523	1551	1579	1607	1636
642	1665	1694	1723	1753	1783	1813	1844	1874	1905	1936
643	1968	2000	2032	2064	2096	2129	2162	2195	2229	2263
644	2296	2342	2365	2410	2433	2479	2502	2548	2571	2617
645	2663	2686	2732	2778	2801	2847	2893	2938	2961	3007
646	3053	3099	3145	3191	3214	3260	3306	3352	3398	3444
647	3489	3535	3604	3650	3696	3742	3788	3834	3903	3949
648	3994	4040	4109	4155	4201	4270	4316	4362	4431	4477
649	4545	4591	4660	4706	4775	4821	4890	4936	5005	5073
650	5119	5188	5257	5303	5372	5441	5510	5556	5624	5693
651	5762	5831	5900	5969	6038	6107	6175	6244	6313	6382
652	6451	6520	6612	6680	6749	6818	6910	6979	7048	7140
653	7208	7300	7369	7461	7530	7622	7691	7782	7851	7943
654	8035	8104	8196	8287	8379	8471	8540	8632	8724	8815
655	8907	8999	9091	9183	9275	9366	9481	9573	9665	9757
656	9848	9963	10055	10147	10262	10354	10468	10560	10675	10767
657	10882	10973	11088	11203	11318	11410	11524	11639	11754	11869
658	11983	12098	12190	12305	12443	12557	12672	12787	12902	13017
659	13131	13269	13384	13499	13636	13751	13866	14004	14118	14256
660	14371	14509	14646	14761	14899	15037	15152	15289	15427	15565
661	15702	15840	15978	16116	16253	16391	16529	16667	16804	16942
662	17103	17241	17378	17516	17677	17815	17975	18113	18274	18411
663	18572	18710	18871	19031	19192	19330	19490	19651	19812	19972
664	20133	20294	20455	20615	20776	20937	21097	21258	21442	21602
665	21763	21924	22107	22268	22452	22612	22796	22957	23186	23416
666	23416	23646	23875	24105	24105	24334	24564	24793	25023	25023
667	25253	25482	25712	25941	26171	26171	26400	26630	26860	27089
668	27319	27319	27548	27778	28007	28237	28466	28696	28926	28926
669	29155	29385	29614	29844	30073	30303	30533	30762	30992	31221
670	31451	31680	31910	32140	32140	32369	32599	32828	33058	33287
671	33517	33747	33976	34206	34435	34665	34894	35124	35583	35813
672	36042	36272	36501	36731	36961	37190	37420	37649	37879	38108
673	38338	38797	39027	39256	39486	39715	39945	40174	40634	40863
674	41093	41322	41552	41781	42241	42470	42700	42929	43388	43618

LAKE GRANBURY OCTOBER 1993 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
675	43848	44077	44536	44766	44995	45225	45684	45914	46143	46602
676	46832	47062	47521	47750	47980	48439	48669	48898	49357	49587
677	50046	50275	50505	50964	51194	51653	51882	52342	52571	53030
678	53260	53719	53949	54408	54637	55096	55326	55785	56015	56474
679	56933	57163	57622	57851	58310	58770	58999	59458	59917	60147
680	60606	61065	61524	61754	62213	62672	62902	63361	63820	64279
681	64738	64968	65427	65886	66345	66804	67034	67493	67952	68411
682	68871	69330	69789	70248	70707	71166	71625	72084	72314	72773
683	73232	73691	74151	74839	75298	75758	76217	76676	77135	77594
684	78053	78512	78972	79660	80119	80579	81038	81497	82185	82645
685	83104	83563	84252	84711	85170	85859	86318	87006	87466	87925
686	88613	89073	89761	90220	90909	91368	92057	92746	93205	93893
687	94353	95041	95730	96189	96878	97567	98026	98714	99403	100092
688	100781	101240	101928	102617	103306	103994	104454	105142	105831	106520
689	107208	107897	108586	109275	109963	110652	111341	112029	112718	113407
690	114096	114784	115473	116391	117080	117769	118457	119146	119835	120753
691	121442	122130	122819	123508	124426	125115	125803	126722	127410	128099
692	129017	129706	130624	131313	132002	132920	133609	134527	135216	136134
693	136823									

TEXAS WATER DEVELOPMENT BOARD

RESERVOIR AREA TABLE

Jan 20 1994

LAKE GRANBURY OCTOBER 1993 SURVEY

AREA IN ACRES

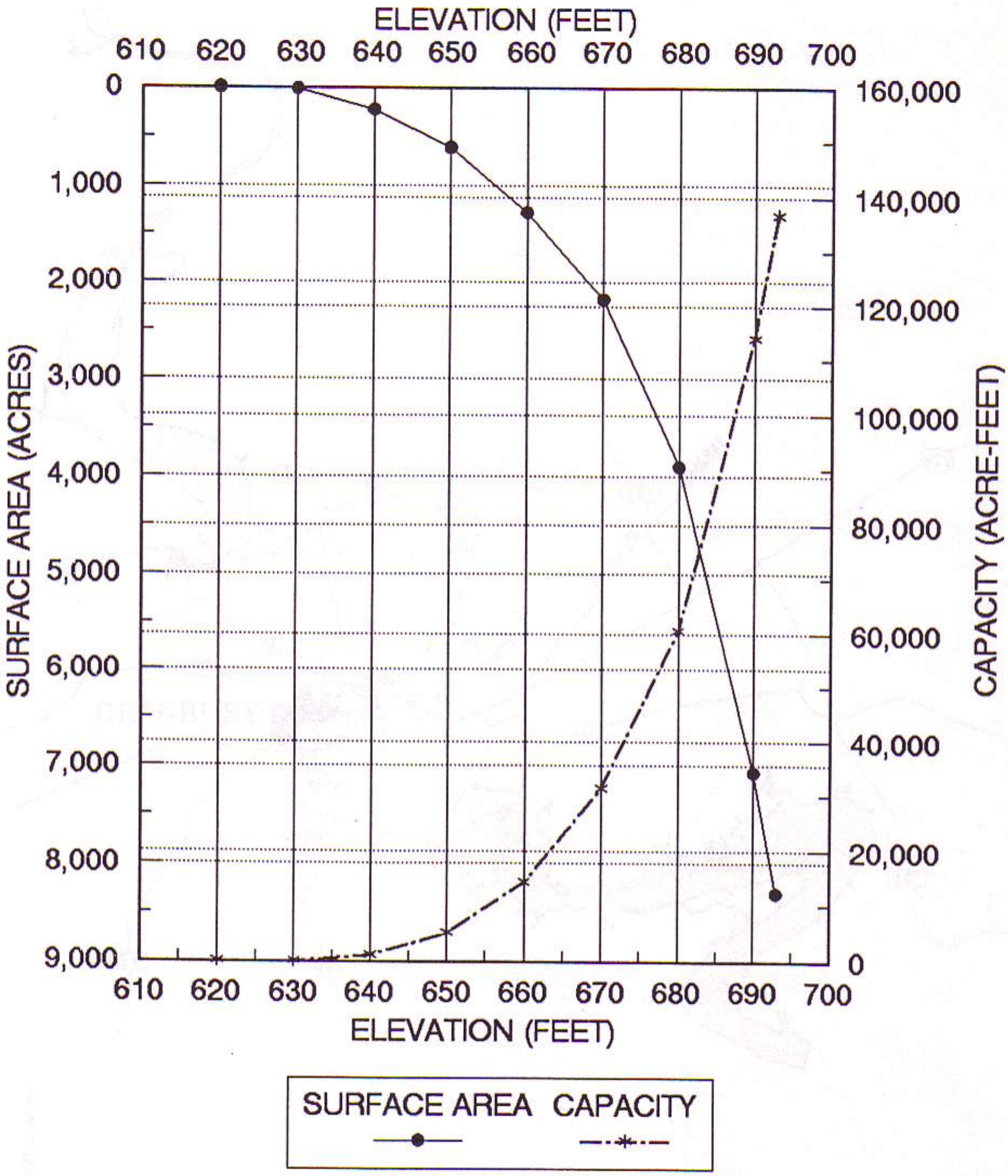
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
626										
627						1	1	1	1	1
628	1	1	2	2	2	3	3	3	4	4
629	5	5	6	6	7	8	9	10	11	14
630	16	18	20	23	25	27	30	32	34	36
631	37	38	40	41	42	43	44	45	46	47
632	48	49	50	52	53	55	57	59	62	64
633	67	69	71	73	75	77	79	81	83	85
634	87	89	91	93	94	96	98	100	101	103
635	105	107	109	111	113	115	116	119	121	123
636	126	128	130	132	134	136	139	142	144	147
637	150	153	156	158	161	165	168	171	174	177
638	179	182	185	188	191	194	196	199	202	204
639	207	209	212	214	217	219	222	224	227	230
640	233	235	239	242	245	248	251	255	257	260
641	263	266	269	272	274	277	280	282	285	288
642	290	293	295	298	300	303	306	308	311	313
643	316	318	321	323	326	329	331	334	337	340
644	343	346	349	352	355	358	361	365	368	371
645	375	379	383	387	391	396	400	405	410	415
646	420	425	430	436	441	446	452	457	462	468
647	473	478	483	487	492	497	501	506	510	515
648	520	524	529	533	538	543	547	552	556	561
649	565	570	575	580	584	589	594	598	603	608
650	612	617	622	627	632	637	643	648	654	659
651	665	670	676	681	687	693	698	704	710	716
652	722	728	735	741	748	754	761	767	774	780
653	786	793	799	806	812	819	825	831	837	843
654	849	856	862	868	875	881	888	894	901	908
655	915	922	928	935	942	948	955	962	969	975
656	982	989	996	1003	1011	1018	1026	1034	1041	1049
657	1058	1066	1074	1082	1089	1097	1104	1111	1118	1125
658	1132	1139	1146	1153	1160	1167	1174	1181	1188	1195
659	1202	1209	1217	1224	1232	1239	1247	1255	1262	1270
660	1278	1286	1294	1302	1310	1318	1326	1333	1341	1349
661	1356	1364	1372	1379	1387	1395	1403	1411	1418	1426
662	1434	1443	1451	1459	1467	1475	1484	1492	1500	1509
663	1517	1525	1533	1542	1550	1558	1566	1574	1582	1591
664	1599	1607	1615	1623	1632	1640	1648	1657	1665	1674
665	1683	1691	1700	1709	1718	1728	1737	1746	1755	1764
666	1774	1783	1792	1801	1810	1820	1829	1839	1849	1858
667	1868	1878	1888	1897	1907	1916	1926	1936	1946	1956
668	1966	1976	1986	1996	2006	2016	2026	2036	2046	2057
669	2067	2077	2088	2099	2109	2120	2131	2142	2154	2165
670	2176	2188	2199	2211	2222	2234	2246	2258	2270	2281
671	2293	2296	2319	2319	2342	2342	2365	2388	2388	2410
672	2410	2433	2433	2456	2456	2479	2502	2502	2525	2548
673	2548	2571	2594	2594	2617	2640	2640	2663	2686	2686
674	2709	2732	2755	2755	2778	2801	2801	2824	2847	2870

LAKE GRANBURY OCTOBER 1993 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
675	2870	2893	2916	2938	2938	2961	2984	2984	3007	3030
676	3053	3076	3076	3099	3122	3145	3145	3168	3191	3214
677	3237	3260	3260	3283	3306	3329	3352	3375	3398	3421
678	3444	3466	3489	3512	3535	3558	3581	3604	3627	3650
679	3673	3696	3719	3742	3765	3788	3811	3834	3857	3880
680	3903	3926	3926	3949	3972	3994	4017	4040	4063	4086
681	4109	4132	4155	4178	4201	4224	4247	4270	4293	4316
682	4339	4362	4385	4431	4454	4477	4500	4523	4545	4568
683	4591	4614	4660	4683	4706	4729	4752	4798	4821	4844
684	4890	4936	4959	5005	5028	5073	5119	5142	5188	5211
685	5257	5280	5303	5349	5395	5418	5464	5510	5556	5601
686	5647	5670	5716	5762	5808	5854	5900	5946	5992	6038
687	6061	6107	6129	6175	6198	6244	6267	6290	6336	6359
688	6405	6428	6451	6497	6520	6566	6612	6635	6680	6703
689	6749	6795	6818	6841	6887	6910	6956	6979	7002	7025
690	7071	7094	7140	7163	7185	7231	7254	7300	7323	7369
691	7415	7438	7484	7507	7553	7576	7622	7645	7668	7714
692	7736	7782	7828	7851	7897	7943	7966	8012	8058	8104
693	8310									



LAKE GRANBURY SURVEY

October 1993

Prepared by : TWDB January 1994

LAKE GRANBURY

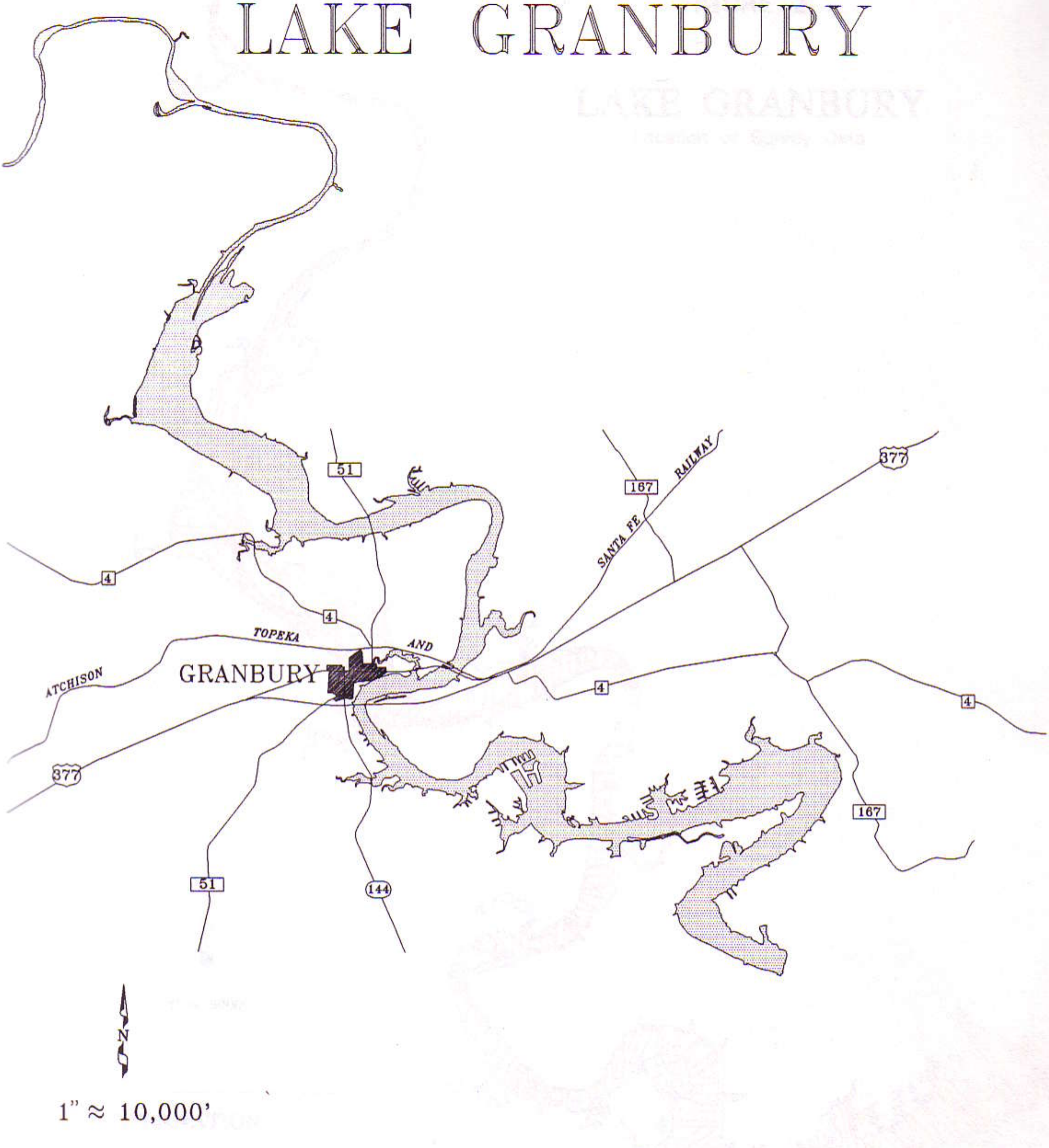
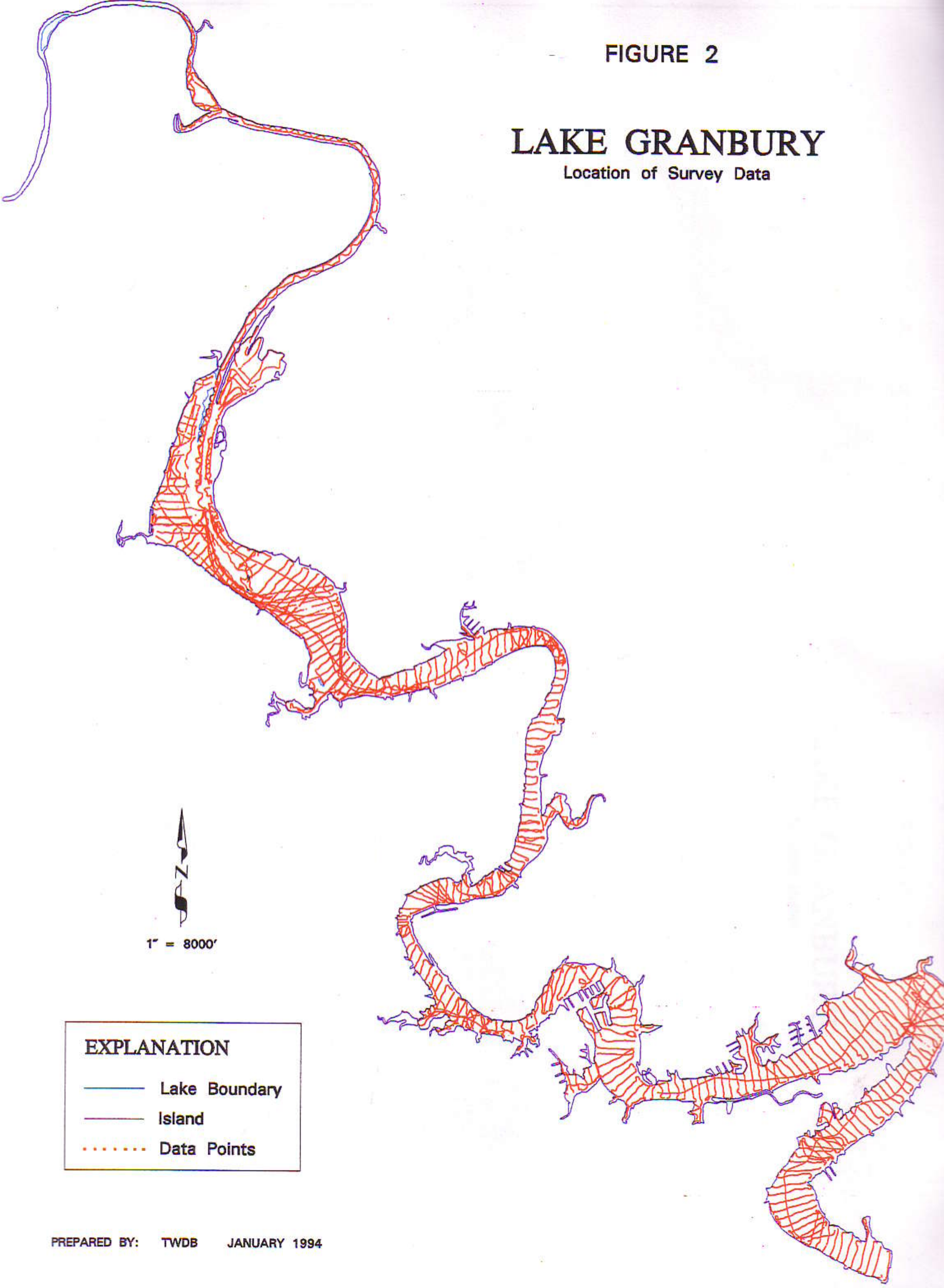


Figure 1
Location Map

FIGURE 2

LAKE GRANBURY

Location of Survey Data

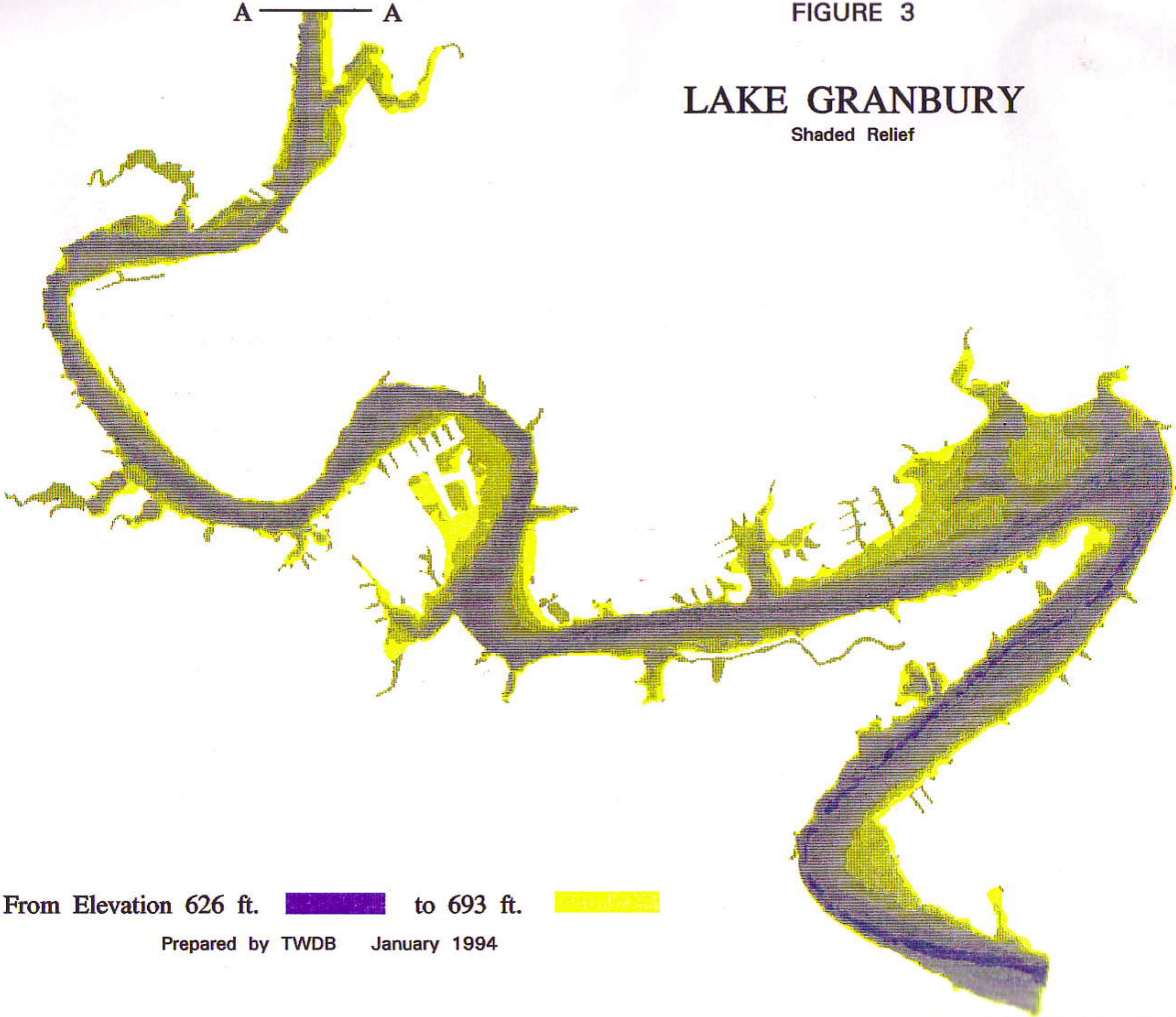


PREPARED BY: TWDB JANUARY 1994

FIGURE 3

LAKE GRANBURY

Shaded Relief



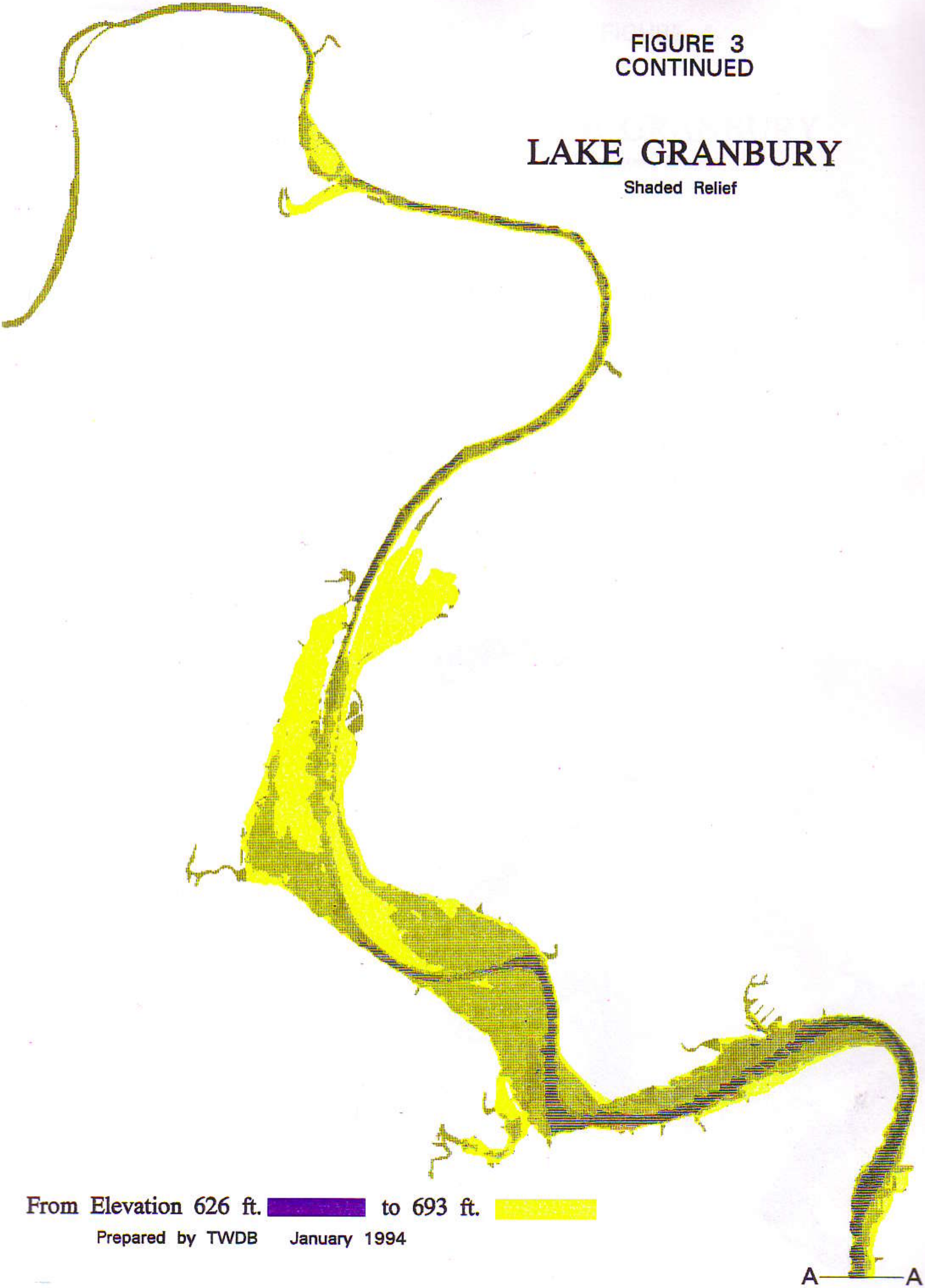
From Elevation 626 ft. to 693 ft.

Prepared by TWDB January 1994

FIGURE 3
CONTINUED

LAKE GRANBURY

Shaded Relief



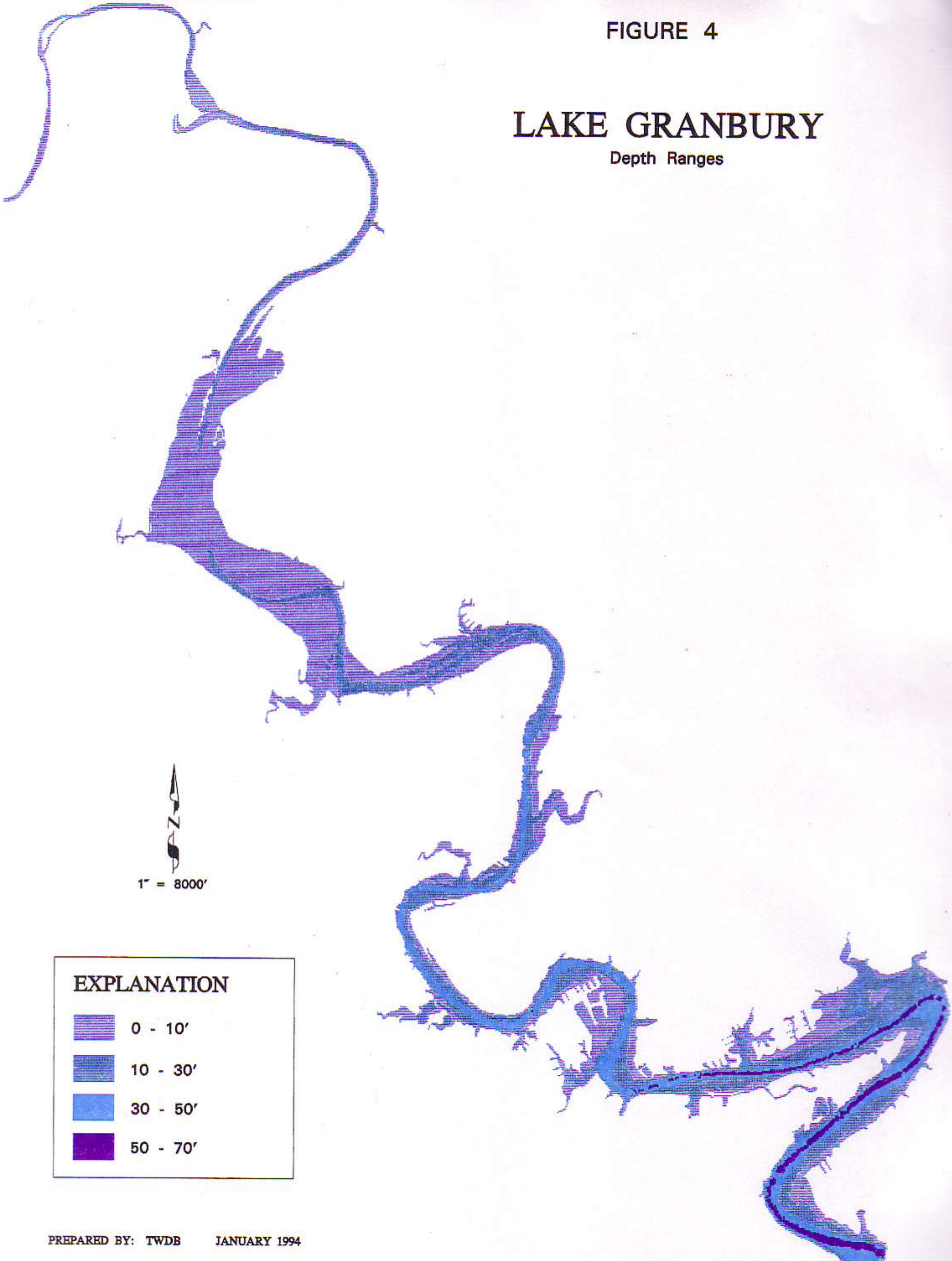
From Elevation 626 ft. to 693 ft.

Prepared by TWDB January 1994

FIGURE 4

LAKE GRANBURY

Depth Ranges



PREPARED BY: TWDB JANUARY 1994