VOLUMETRIC SURVEY OF FORT PHANTOM HILL RESERVOIR

Prepared for:

THE CITY OF ABILENE

Prepared by:

The Texas Water Development Board

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INTRODUCTION

Staff of the Hydrologic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Fort Phantom Hill Reservoir in November, 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

Fort Phantom Hill Reservoir is owned by the City if Abilene. The reservoir is located on Big Elm Creek in Jones County, about 12.5 miles northeast of Abilene, Texas. Records indicate dam construction was started in June, 1937. Hawley, Freese and Nichols designed the dam and Cage Brothers and J. C. Ruby were the general contractors. The dam was completed in October, 1938. The earthfill embankment is approximately 3,740 feet with a maximum height of 84 feet. The spillway is natural ground with an 800-foot long concrete ogee crest at elevation 1635.9 feet above mean sea level (msl). The outlet works consist of a concrete tower with a 4 ft. by 7 ft. conduit. Engineering drawings show there are five gated openings in the tower with a low-flow outlet at elevation 1582.4 ft. above msl. Records show the conservation pool elevation to be 1635.9 feet above mean sea level. Storage capacity at this elevation is 74,300 acre-feet with a surface area of 4,246 acres. Drainage area for this facility is approximately 478 square miles. Water is pumped from the Clear Fork Brazos River to the lake to supplement runoff. Water usage is designated as follows: 20,690 acre-feet per annum for municipal use; and 10,000 acre-feet per annum for industrial use.

Water Rights Permit 1249 was issued August 9, 1937 to the City of Abilene by the Board of Water Engineers to construct a dam, to impound and not exceed 73,960 acre-feet of water and to divert but not exceed 30,690 acre-feet of water per annum for municipal purposes. An amendment to Permit 1249, dated October 15, 1969, allowed the City of Abilene to use 10,000 of the 30,960 acre-feet of water allocated for municipal purposes for industrial purposes. The Certificate of Adjudication 12-4161 was issued April 1, 1986 to the City of Abilene. It basically grants the same water rights as the amended permit described above.

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 continously 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 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 Fort Phantom Hill Reservoir. 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 Fort Phantom Hill Reservoir 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 was 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 readings were spaced quite a distance apart.

Another costly operation 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 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 used a United States Geological Survey(USGS) first-order benchmark as a control point for survey. The station used is officially named "KNOB" and was established in 1961. This station was secure and close enough to the reservoir to use as the control station for the survey. Since the NAVSTAR satellites use the World Geodetic System (WGS '84) spherical datum, coordinates for "KNOB" in this datum were used. (WGS '84 is essentially identical to the North American Datum of 1983 (NAD '83)). The coordinates for "KNOB" are published as North latitude 32° 36' 35.23344", West longitude 99° 39' 14.53098", with an ellipsoid height of 493.93 feet. The approximate NGVD '29 elevation is 588.31 feet. These coordinates were then entered into the shore station receiver located over "KNOB" to fix its location and allow calculation and broadcasting of corrections through the radio and modem to the roving receiver located on the boat.

The reservoir's surface area was determined by digitizing the lake boundary from the HAMBY USGS 7.5 minute quadrangle topographic map that was updated in 1987 from 1984 aerial photographs. AutoCad software was used to digitize the reservoir's 1,635.9 contour based on the North American Datum of 1927 (NAD '27) used for the map. 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 the NAD '83 datum that is compatible with the positional information received from the satellites. The surface area of the reservoir's 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 because the satellite positional data is received in this datum. NAD '27 is also a flat projection, but has a slightly different point of origin, and distinctly different state plane false northing and false easting coordinates. The differences help to distinguish point coordinates 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 4,213 acres, or within 1 percent of the recorded 4,246 acres. A current aerial topo of the upper four feet of the lake would provide better definition of 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 100 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 manually collected wherever the boat could maneuver. The manually collected data points were entered into the data set utilizing the DGPS horizontal position and manual polings of the depth. Additional random data were collected lengthwise in the reservoir after the pre-planned survey grid was completed. Figure 2 shows the actual location of the data collection sites. The figure represents some areas where data were not collected because the areas were inaccessible due to shallow water or obstructions. The data set included approximately 28,613 data points.

TWDB staff verified the horizontal accuracy of the DGPS used in the Fort Phantom Hill Reservoir 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.

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 better satellite geometry and thus 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 7 or less. An internal alarm 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 20 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 depending 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; 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. During post-processing, all points with a zero depth were deleted.

Each of the resulting data points collected consisted of a latitude, longitude and depth reading. The depths were transformed to elevations with a simple awk Unix command based on the water surface elevation recorded each day, rounded to the nearest tenth of a foot since the depth sounder reads in tenths of a foot. The water surface ranged from 1627.4 to 1627.5 feet during the field survey. 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 and the boundary file 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. 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. 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, 1,083 additional data points were estimated for these locations to allow for interpolation and contouring of the entire lake surface. 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 model size did not change after the additional data points were added, but the storage volume changed by about 2,500 acre/ft. Most of this volume change occurred due to the increased definition of the upper nine feet of the reservoir by the added points that were estimated due to the lake level being nine feet below the conservation pool capacity at the time of the survey.

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. 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 and typical cross-sections are presented in Figure 5.

DATA

Fort Phantom Hill Reservoir inundates approximately six river miles of the Big Elm Creek. The deepest portions of the lake are found along the old streambed channel. The DTM shows a fairly well-defined deep canyon that is periodically bounded by a flat floodplain on one side or the other of the lake. A distinct slope to the canyon floor can be distinguished from the headwaters of the reservoir to the dam.

Fort Phantom Hill Reservoir was estimated by this survey to encompass 4,213 acres and to contain a volume of 70,036 acre-feet at the normal pool elevation of 1,635.9 feet. The reservoir volume table is presented in Appendix B and the area table in Appendix C. The one-tenth foot intervals are based on actual calculations from the model. An elevation-area-volume graph is presented in Appendix D. It is important to note that the surface elevation of the lake was nine feet below the normal pool elevation during the survey, and volumes for this area were estimated. At a minimum, the top two additional feet were also estimated since the boat cannot negotiate in shallow water. This estimation was 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 corresponded 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 5.3 percent lower than the previous record information for the lake. The low flow outlet is at elevation 1582.4 feet above msl, resulting in dead storage of 6 acre-feet. Therefore the conservation storage for the reservoir is calculated to be 70,030 acre-feet.

SUMMARY

The hydrographic survey performed on Fort Phantom Hill Reservoir in November, 1993 was performed when the reservoir was over 9 feet below the conservation storage capacity elevation. The survey was performed at this level because the information collected would update the storage values for the historical normal operating levels of the reservoir. The lowest elevation encountered during the survey was 1,553 feet, or 83 feet of depth from the conservation pool capacity elevation. This depth occurred around mid-lake, in a small deep hole. This depression could be something like an old inundated gravel mine. The maximum depth near the dam was around 50 feet or elevation 1,586. The original streambed elevation was estimated to be 1,565 feet in the old channel, with a top of bank elevation of 1,581 feet. The conservation storage capacity after the survey was calculated to be 70,030 acre-feet. The estimated reduction in conservation storage capacity is 4,270 acre-feet, or 5.3 percent less than that recorded in the permit. 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. A better estimate of the total conservation storage capacity of the reservoir would be obtained if this future survey could be performed when the reservoir was completely full.

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):

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

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

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

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

RESERVOIR VOLUME TABLE

Feb 23 1994

FORT PHANTOM HILL RESERVOIR NOVEMBER 1993 SURVEY

VOLUME IN ACRE-FEET — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,564					1	1	1	1	1	1
1,565	1	1	1	1	1	1	1	1	1	1
1,566	1	1	1	1	1	1	1	1	1	1
1,567	1	1	1	1	1	1	1	1	1	1
1,568	1	1	1	1	1	1	1	1	1	1
1,569	1	1	1	1	1	1	1	1	1	1
1,570	1	1	1	1	1	1	1	1	1	1
1,571	2	2	2	2	2	2	2	2	2	2
1,572	2	2	2	2	2	2	2	2	2	2
1,573	2	2	2	2	2	2	2	2	2	2
1,574	2	2	2	2	2	2	2	2	2	3
1,575	3	3	3	3	3	3	3	3	3	3
1,576	3	3	3	3	3	3	3	3	3	3
1,577	3	3	3	3	3	3	3	3	4	4
1,578	4	4	4	4	4	4	4	4	4	4
1,579	4	4	4	4	4	4	4	4	4	4
1,580	4	4	5	5	5	5	5	5	5	5
1,581	5	5	5	5	5	5	5	5	5	5
1,582	5	5	5	6	6	6	6	6	6	6
1,583	6	6	6	6	6	6	6	6	6	6
1,584	6	7	7	7	7	7	7	7	7	7
1,585	7	7	7	7	7	8	8	8	8	8
1,586	8	8	9	9	9	9	9	10	10	10
1,587	10	11	11	11	12	12	12	13	13	14
1,588	15	15	16	17	18	20	21	22	24	26
1,589	28	30	32	34	37	39	42	44	47	50
1,590	53	56	59	63	66	70	74	78	82	86
1,591	91	96	101	107	112	119	125	132	139	146
1,592	154	162	170	179	188	197	206	216	226	236
1,593	247	257	269	280	291	303	315	328	341	354
1,594	367	380	394	408	423	438	453	468	484	500
1,595	516	533	550	567	585	603	621	640	659	678
1,596	698	718	738	758	779	800	822	843	865	888
1,597	911	934	957	981	1005	1029	1054	1080	1105	1131
1,598	1158	1184	1211	1239	1267	1295	1323	1352	1382	1411
1,599	1442	1472	1503	1535	1567	1599	1632	1665	1699	1733
1,600	1768	1803	1839	1876	1912	1950	1987	2026	2065	2104
1,601	2144	2185	2225	2267	2309	2352	2395	2438	2483	2528
1,602	2573	2620	2666	2714	2762	2810	2859	2909	2960	3010
1,603	3062	3114	3167	3220	3274	3329	3385	3441	3498	3556
1,604	3615	3675	3735	3797	3859	3923	3987	4052	4119	4185
1,605	4253	4322	4391	4462	4533	4606	4679	4753	4829	4906
1,606	4983	5062	5142	5222	5304	5387	5471	5556	5642	5729
1,607	5817	5907	5997	6089	6181	6275	6369	6465	6562	6660
1,608	6759	6859	6959	7061	7163	7267	7371	7475	7581	7687
1,609	7794	7902	8011	8121	8232	8343	8455	8569	8683	8798
1,610	8914	9030	9148	9266	9386	9506	9626	9748	9871	9994
1,611	10118	10243	10369	10496	10624	10752	10882	11012	11144	11275

RESERVOIR VOLUME TABLE

FORT PHANTOM HILL RESERVOIR NOVEMBER 1993 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,612	11408	11542	11676	11811	11947	12083	12220	12358	12497	12637
1,613	12777	12918	13060	13203	13347	13491	13636	13781	13928	14075
1,614	14222	14371	14520	14670	14821	14972	15124	15277	15430	15584
1,615	15739	15895	16051	16209	16367	16526	16686	16847	17008	17171
1,616	17334	17498	17663	17828	17994	18162	18330	18498	18668	18839
1,617	19010	19182	19355	19528	19703	19878	20054	20231	20409	20587
1,618	20767	20947	21128	21310	21492	21676	21860	22045	22231	22418
1,619	22605	22794	22983	23173	23363	23555	23747	23940	24134	24329
1,620	24525	24721	24918	25116	25315	25515	25715	25917	26119	26323
1,621	26527	26732	26938	27145	27353	27562	27771	27982	28194	28406
1,622	28619	28834	29049	29265	29482	29700	29919	30139	30361	30583
1,623	30806	31030	31255	31482	31710	31940	32171	32403	32637	32873
1,624	33110	33347	33586	33826	34067	34309	34551	34795	35040	35286
1,625	35533	35782	36031	36281	36533	36786	37042	37300	37560	37821
1,626	38085	38351	38619	38888	39158	39429	39701	39973	40248	40523
1,627	40799	41077	41356	41636	41917	42198	42481	42765	43049	43335
1,628	43621	43909	44198	44488	44778	45070	45362	45656	45951	46246
1,629	46542	46840	47138	47438	47738	48039	48341	48645	48949	49255
1,630	49561	49869	50178	50488	50799	51111	51424	51738	52053	52369
1,631	52686	53005	53325	53646	53968	54292	54616	54942	55269	55598
1,632	55927	56259	56592	56927	57263	57601	57940	58280	58623	58967
1,633	59312	59661	60012	60364	60717	61072	61428	61786	62145	62505
1,634	62867	63230	63595	63962	64330	64699	65070	65442	65816	66192
1,635	66569	66947	67328	67710	68093	68479	68865	69254	69644	70036

TEXAS WATER DEVELOPMENT BOARD Feb 23 1994

RESERVOIR AREA TABLE

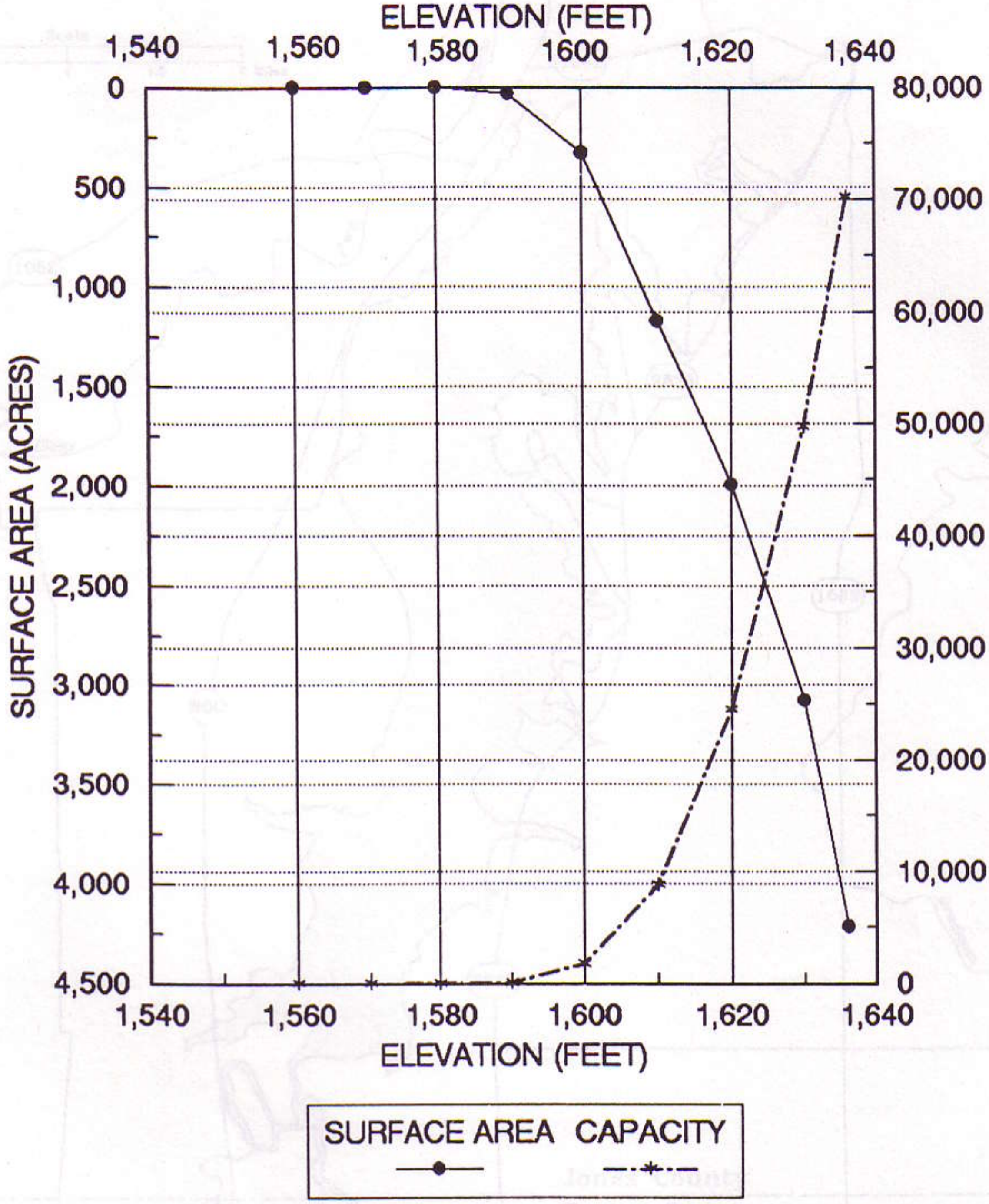
FORT PHANTOM HILL RESERVOIR NOVEMBER 1993 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,564										
1,565										
1,566										
1,567										
1,568										
1,569										
1,570										
1,571										
1,572										
1,573										
1,574										
1,575										
1,576										
1,577										
1,578										
1,579										
1,580										
1,581								1	1	1
1,582	1	1	1	1	1	1	1	1	1	1
1,583	1	1	1	1	1	1	1	1	1	1
1,584	1	1	1	1	1	1	1	1	1	1
1,585	1	1	1	1	1	1	1	1	1	2
1,586	2	2	2	2	2	2	2	2	2	2
1,587	3	3	3	3	4	4	4	5	5	6
1,588	7	8	10	11	12	13	14	16	17	19
1,589	20	21	22	23	24	25	26	27	28	29
1,590	31	32	33	34	36	37	40	41	43	45
1,591	48	50	53	56	60	63	66	69	72	75
1,592	78	81	84	87	90	93	96	99	101	104
1,593	107	109	112	115	117	120	123	125	128	131
1,594	134	137	140	143	146	149	152	155	159	162
1,595	166	169	172	175	178	181	185	188	191	194
1,596	197	200	204	207	210	213	216	219	222	225
1,597	229	232	236	239	243	248	251	255	258	262
1,598	265	269	273	276	280	284	288	292	296	300
1,599	304	308	312	317	321	326	331	335	341	346
1,600	351	356	361	365	370	376	381	386	392	397
1,601	402	407	412	417	423	429	434	441	447	453
1,602	459	465	471	477	483	489	494	500	507	512
1,603	518	524	531	537	545	552	560	567	575	584
1,604	593	602	611	621	630	639	648	656	665	673
1,605	682	691	700	709	719	729	738	750	761	772
1,606	782	792	802	812	822	833	845	856	868	879
1,607	889	899	908	919	930	942	953	963	974	985
1,608	994	1004	1012	1020	1027	1036	1044	1052	1059	1067
1,609	1075	1084	1093	1102	1110	1119	1129	1138	1146	1154
1,610	1163	1171	1180	1188	1196	1204	1212	1220	1229	1238
1,611	1247	1256	1264	1273	1282	1291	1300	1308	1316	1323

FORT PHANTOM HILL RESERVOIR NOVEMBER 1993 SURVEY

	AREA IN ACRES					ELEVATION INCREMENT IS ONE TENTH FOOT				
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,612	1331	1339	1346	1353	1360	1368	1376	1384	1392	1401
1,613	1409	1417	1425	1432	1438	1445	1452	1459	1467	1474
1,614	1480	1488	1495	1502	1510	1517	1524	1531	1538	1545
1,615	1553	1561	1569	1577	1587	1596	1604	1612	1620	1628
1,616	1636	1643	1651	1659	1667	1676	1684	1693	1701	1709
1,617	1717	1724	1732	1740	1748	1756	1764	1773	1782	1790
1,618	1798	1806	1814	1822	1831	1839	1847	1855	1863	1872
1,619	1879	1888	1895	1903	1911	1919	1927	1935	1943	1951
1,620	1959	1967	1976	1984	1993	2002	2011	2020	2029	2038
1,621	2047	2056	2065	2074	2084	2093	2101	2110	2120	2129
1,622	2139	2148	2158	2167	2176	2186	2196	2206	2216	2226
1,623	2237	2248	2260	2274	2288	2302	2316	2334	2352	2362
1,624	2372	2382	2393	2403	2413	2424	2434	2444	2455	2466
1,625	2477	2487	2498	2509	2522	2546	2567	2587	2607	2626
1,626	2664	2673	2683	2693	2703	2713	2724	2734	2745	2756
1,627	2777	2786	2795	2804	2813	2822	2832	2841	2850	2859
1,628	2874	2883	2893	2902	2911	2921	2930	2940	2950	2959
1,629	2969	2979	2989	2999	3008	3018	3028	3038	3048	3058
1,630	3074	3084	3095	3105	3115	3125	3136	3146	3156	3167
1,631	3181	3193	3204	3216	3228	3241	3253	3265	3278	3291
1,632	3310	3324	3339	3354	3369	3384	3399	3415	3431	3447
1,633	3485	3499	3512	3526	3540	3554	3568	3583	3597	3612
1,634	3626	3641	3656	3671	3686	3701	3717	3732	3748	3763
1,635	3779	3795	3811	3827	3844	3860	3877	3893	3910	4213



FORT PHANTOM HILL RESERVOIR

November 1993 Survey

Prepared by : TWDB February 1994

FORT PHANTOM HILL RESERVOIR

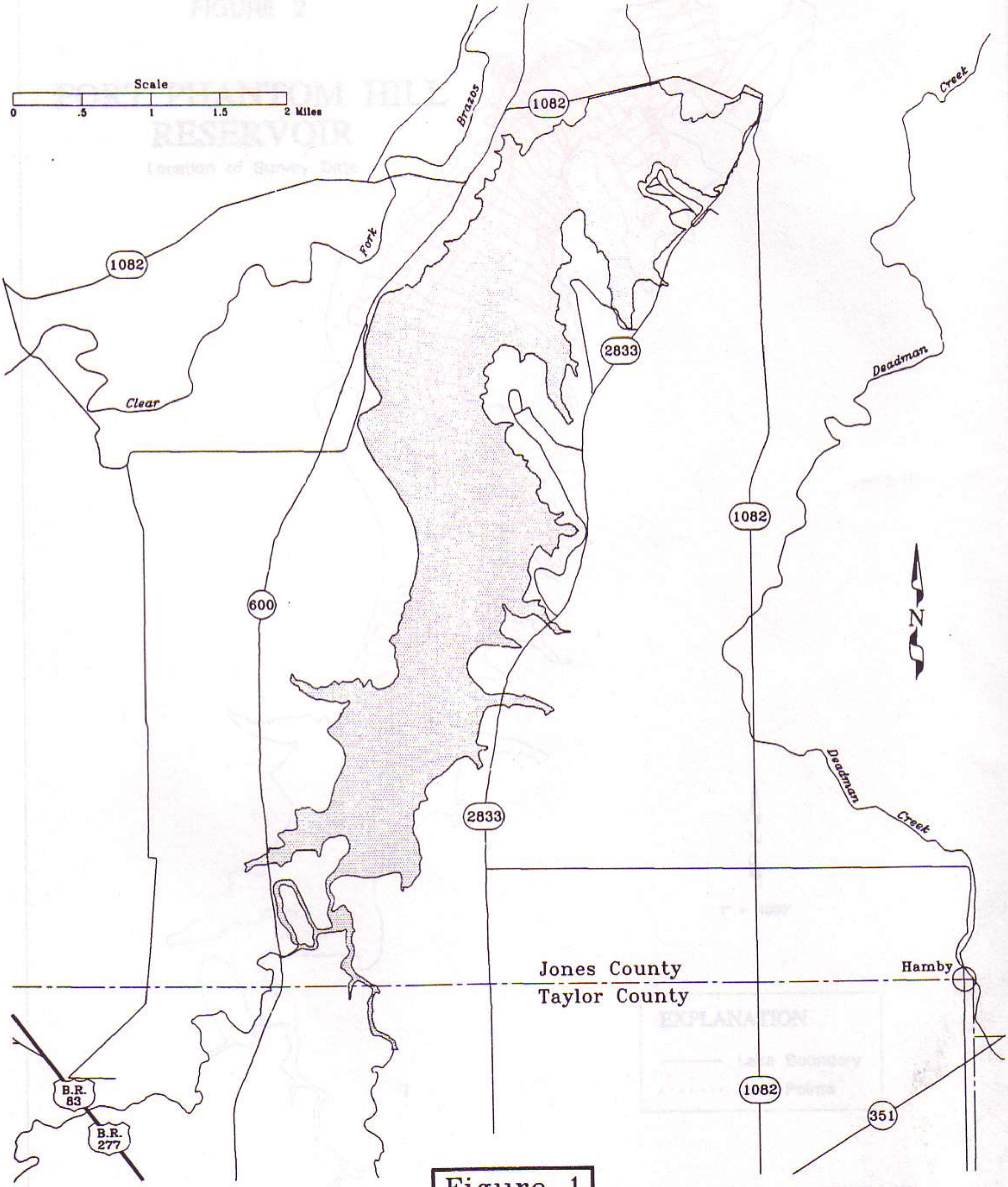


Figure 1

Location Map

FIGURE 2

FORT PHANTOM HILL RESERVOIR

Location of Survey Data

PREPARED BY: TWDB FEBRUARY 1994

FIGURE 3

FORT PHANTOM HILL RESERVOIR

Shaded Relief

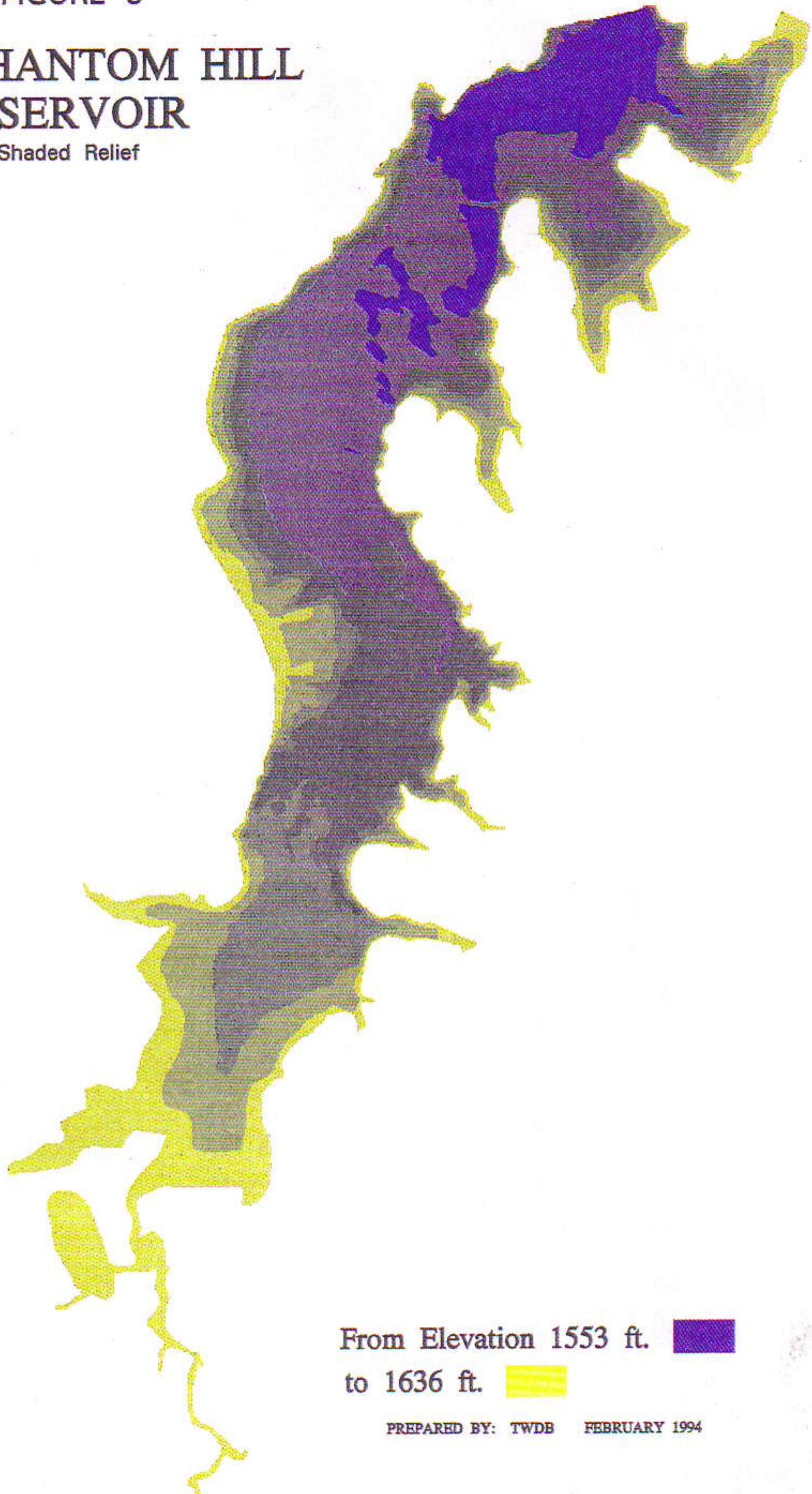
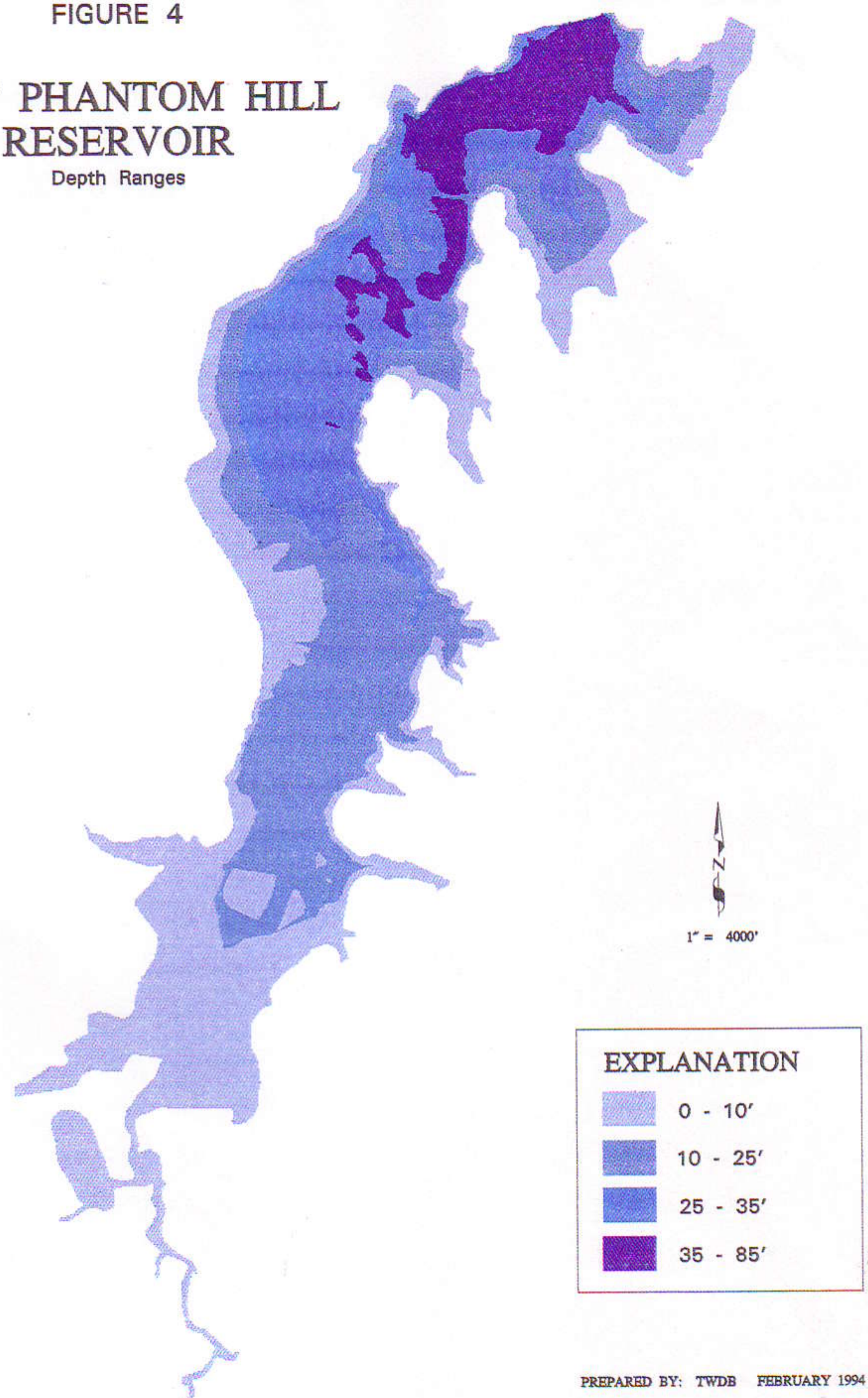


FIGURE 4

FORT PHANTOM HILL RESERVOIR

Depth Ranges

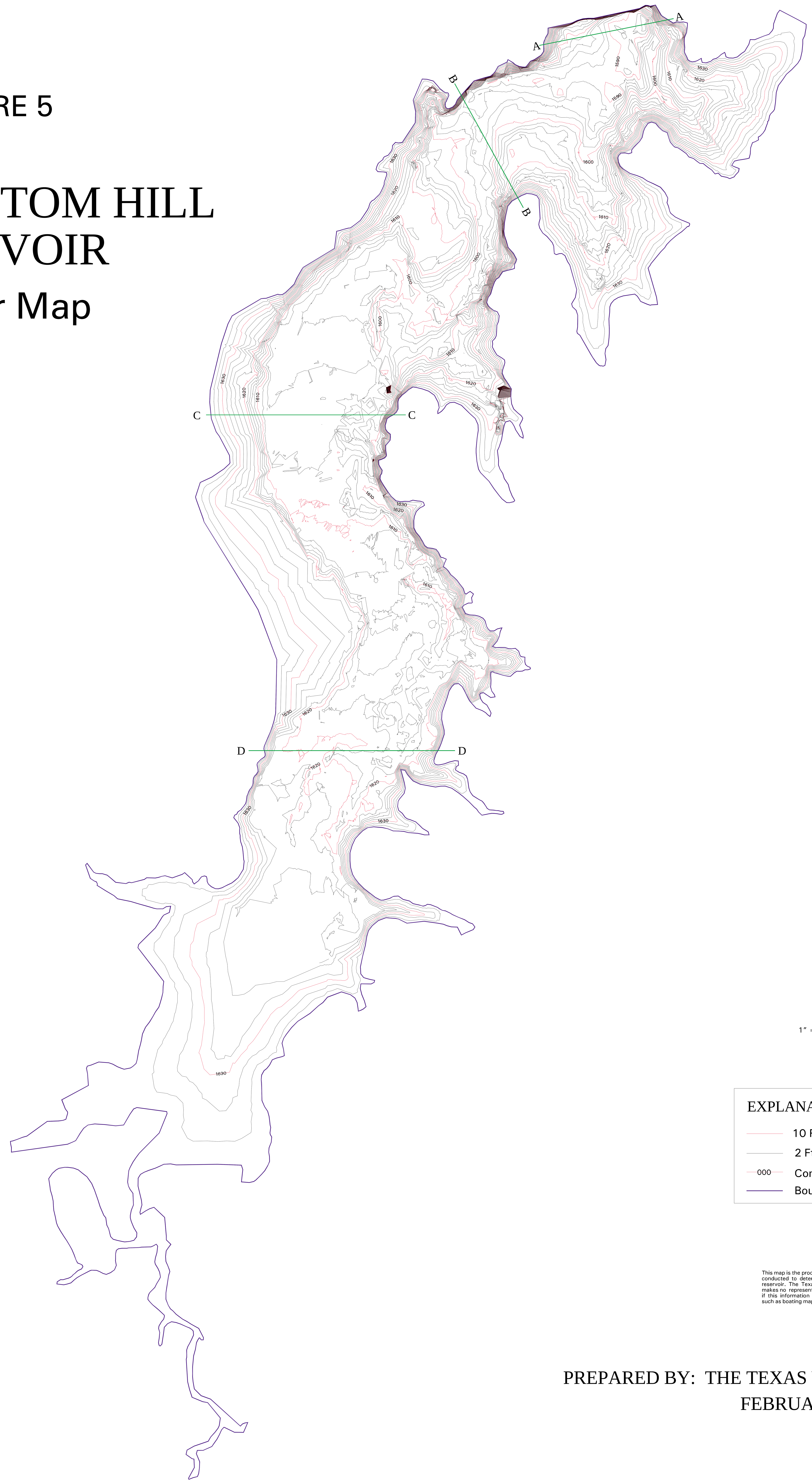


PREPARED BY: TWDB FEBRUARY 1994

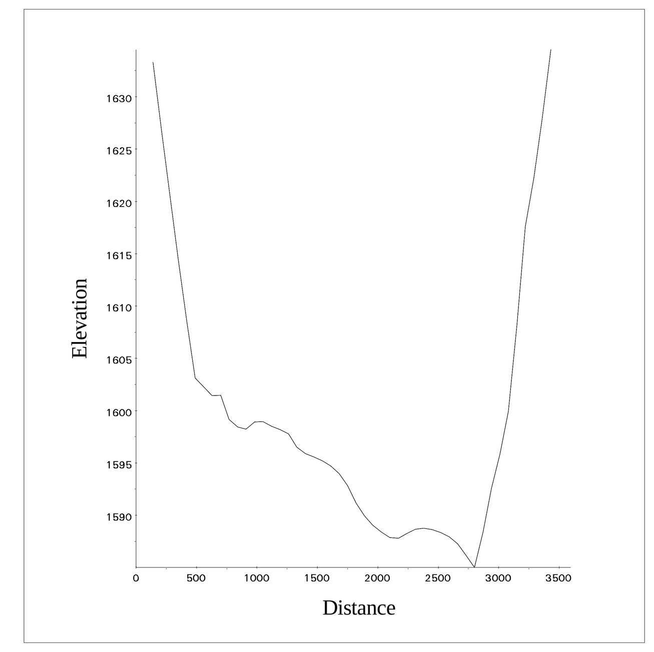
FIGURE 5

FORT PHANTOM HILL RESERVOIR

Contour Map



SECTION A-A



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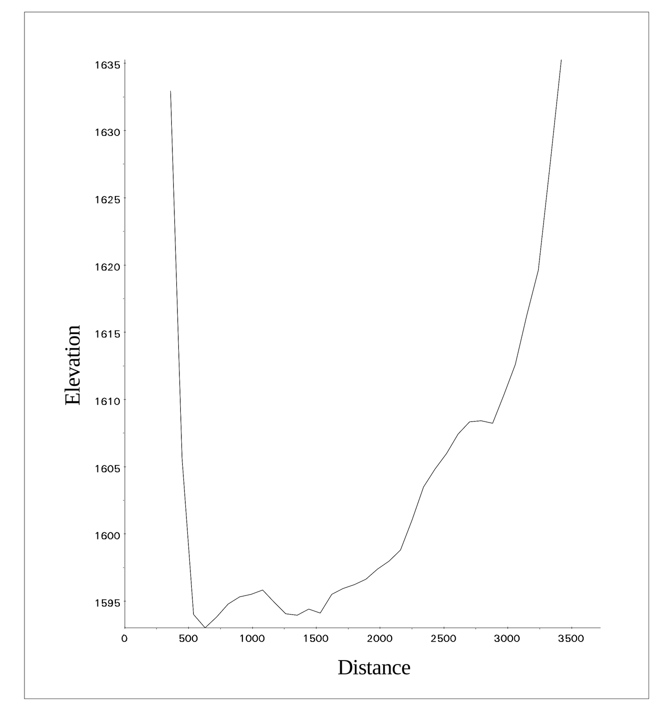
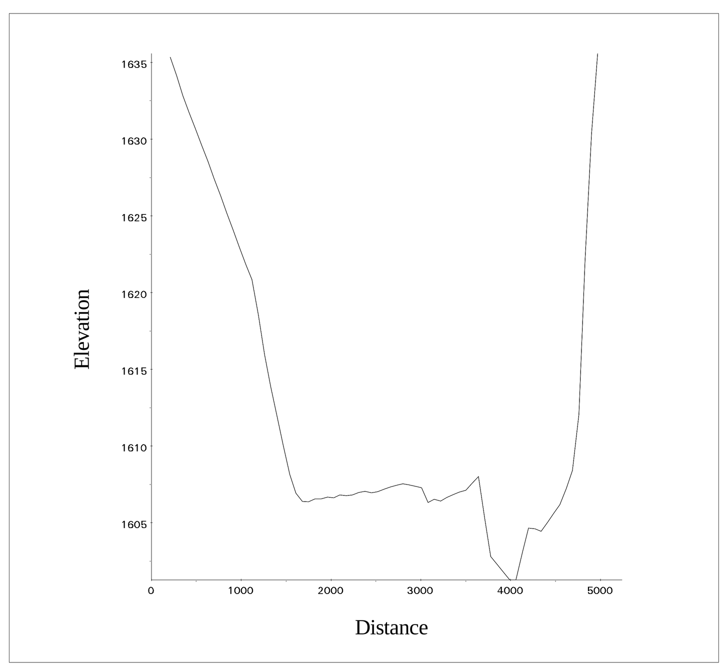
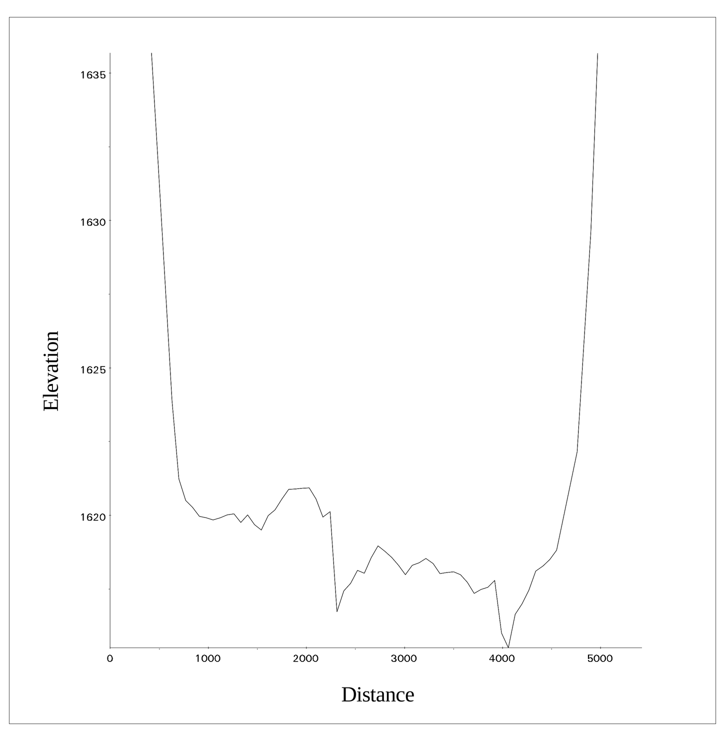
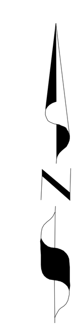


SECTION C-C



SECTION D-D





1" = 1000'

EXPLANATION

- 10 Ft. Contour Line
- 2 Ft. Contour Line
- 000 Contour Elevation
- Boundary

This map is the product of a hydrographic survey conducted to determine the capacity of the reservoir. The Texas Water Development Board makes no representations or assumes any liability if this information is used for other purposes such as boating maps.

PREPARED BY: THE TEXAS WATER DEVELOPMENT BOARD
FEBRUARY 1994