VOLUMETRIC SURVEY OF HUBBARD CREEK RESERVOIR

Prepared for:

WEST CENTRAL TEXAS MUNICIPAL WATER DISTRICT

Prepared by:

The Texas Water Development Board

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Texas Water Development Board

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Hubbard Creek Reservoir during the period February 3 - 21, 1997. The purpose of the survey was to determine the capacity of the lake up to the top of the conservation pool. From this information, future surveys will be able to determine the location and rates of sediment deposition in the conservation pool 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. The conservation pool elevation for Hubbard Creek Reservoir is 1,183.0 feet. At this elevation, the original estimate for the surface area of the lake in 1962 was 15,250 acres and the estimated volume was 317,800 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Hubbard Creek Reservoir and the dam facility are owned by the West Central Texas Municipal Water District. The reservoir is located on Hubbard Creek in Stephens County, approximately six miles northwest of Breckenridge, Texas (see Figure 1). Records indicate the drainage area is approximately 1,107 square miles. At the conservation pool elevation, the lake is approximately ten miles long. The widest point of the reservoir (located two and one-half miles upstream of the dam) is approximately four miles.

The State Board of Water Engineers issued Permit No. 1890 to the West Central Texas Municipal Water District on August 9, 1957 for Hubbard Creek Reservoir and subsequently amended the permit on June 23, 1959. The amended permit authorized the owner to construct a dam on Hubbard Creek and to impound, not to exceed, 320,000 acre-feet of water. The permit allowed the owner to divert 44,800 acre-feet of water annually for municipal use, 5,600 acre-feet of water annually for mining and the same amount, 5,600 acre-feet annually for industrial use. On September 18, 1972, Permit No. 1890A was again amended to change the allocation to 1,200 acre-feet of water annually for industrial purposes, and 10,000 acre-feet of water annually for mining purposes. The water rights to Hubbard Creek Reservoir were adjudicated under Certificate of Adjudication No. 12-4213, issued by the Texas Water Commission on April 1, 1986. The conditions and terms of the certificate stated that the owner, West Central Texas Municipal Water District, maintain an existing dam and reservoir (known as Hubbard Creek Lake) and to impound, not to exceed, 317,750 acre-feet of water. The uses for the impounded water as stated in the certificate are as follows:

A. Owner is authorized to divert and use not to exceed 44,800 acre-feet of water per annum for municipal purposes.

B. Owner is authorized to divert and use not to exceed 1,200 acre-feet of water per annum for industrial purposes.

C. Owner is authorized to divert and use not to exceed 2,000 acre-feet of water per annum for irrigational purposes.

D. Owner is authorized to divert and use not to exceed 6,000 acre-feet of water per annum for mining purposes.

E. Owner is authorized to divert and use not to exceed 2,000 acre-feet of water per annum for domestic and livestock purposes.

Due to clerical errors, the original certificate of adjudication was amended on March 6, 1991. The most recent amended Certificate (No. 12 - 4213B) reflects that all conditions and terms of the original certificate regarding the impoundment and uses remained the same. It was in the "Special Conditions" section that the following changes were made to the amended certificate: SPECIAL CONDITION B. of Certificate 12-4213, as amended is hereby deleted.

A. The authorization to use 2,000 acre-feet of water per annum for irrigation purposes shall automatically revert back to mining purposes after December 31, 2000.

B. The authorization to use 2,000 acre-feet of water per annum for domestic and livestock purposes shall automatically revert back to mining purposes after December 31, 2000.

According to the Texas Water Development Board's Report 126, dam construction started March 1, 1961 and was completed November 26, 1962. Deliberate impoundment began December 18, 1962. The engineer for the project was Freese, Nichols and Endress. The general contractor was Wm. A. Smith Construction Company. The total cost of the project was $7,697,089.

The dam and appurtenant structures consist of an earthfill embankment 15,150 feet in length (including levees) with a maximum height of 112 feet or elevation 1,208.0 feet. The service spillway is a circular concrete drop inlet structure that is gate controlled. The crest elevation of the drop inlet is 1,176.5 feet and the top of the gates is at elevation is 1,185.0 feet. All water that enters the drop inlet is discharged through the embankment and exits downstream via a 22 feet diameter conduit. The low-flow outlet consist of a 48-inch diameter valve-controlled pipe with an invert elevation of 1,136.0 feet. The emergency spillway is a excavated broad-crested weir located near the left end of the dam. The 2,000 feet long weir is at elevation 1,194.0 feet. Also, incorporated in the emergency spillway is a 4,000 feet long fuse plug with a crest elevation of 1,197.0 feet.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the theory behind Global Positioning System (GPS) technology and its accuracy. Equipment and methodology used to conduct the subject survey and previous hydrographic surveys are also addressed.

GPS Information

The following is a brief and simple description of Global Positioning System (GPS) technology. GPS is a relatively 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 1960's by the United States Air Force and the defense establishment. After program funding in the early 1970's, 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 was reached on April 27, 1995 when the NAVSTAR (NAVigation System with Time And Ranging) satellite constellation was composed of 24 Block II satellites. Initial operational capability, a full constellation of 24 satellites, in a combination of Block I (prototype) and Block II satellites, was achieved December 8, 1993. 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." In the early stages of this program, 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.

The need for setting up a stationary shore receiver for current surveys has been eliminated with the development of fee-based reference position networks. These networks use a small network of GPS receivers to create differential corrections for a large network of transmitting stations, Wide Area Differential GPS (WADGPS). The TWDB receives this service from ACCQPOINT, a WADGPS correction network over a FM radio broadcast. A small radio receiver purchased from ACCQPOINT, collects positional correction information from the closest broadcast station and provides the data to the GPS receiver on board the hydrographic surveying boat to allow the position to be differentially corrected.

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, an ACCQPOINT FM receiver, and an on-board 486 computer. 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 GPS equipment, survey vessel, and depth sounder 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 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 ± 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 pool boundary (elevation 1,183.0) from USGS quad sheets. The name of the quad sheets are as follows: BRECKENRIDGE, TX (Photo-revised 1981), EDWARDS BRANCH, TX (Photo-revised 1981), EOLIAN, TX (Photo-revised 1987), and BUCK MOUNTAIN, TX (Photo-revised 1982. 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 NADCON 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 186 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 PROCEDURES

The following procedures were followed during the hydrographic survey of Hubbard Creek Reservoir performed by the TWDB. Information regarding equipment calibration and operation, the field survey, and data processing is presented.

Equipment Calibration and Operation

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 Hubbard Creek Reservoir, the speed of sound in the water column varied daily between 4717 and 4749 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 $\pm$0.2 feet, plus an estimated error of $\pm$0.3 feet due to the plane of the boat for a total accuracy of $\pm$0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some are positive readings and some are negative readings. Further information on these calculations is presented in Appendix A.

During the survey, the onboard GPS receiver was set to a horizontal mask of 10° and a PDOP (Position Dilution of Precision) limit of 7 to maximize the accuracy of horizontal positions. 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. The lake's initialization file used by the Hypack data collection program was setup to convert the collected DGPS positions on-the-fly to state plane coordinates. Both sets of coordinates were then stored in the survey data file.

Field Survey

Data was collected on Hubbard Creek Reservoir during the period February 3 -21, 1997. Temperatures during the survey ranged from the 30's to the 70's and at times, high winds caused data collection to be suspended due to rough waters. Approximately 183,452 data points were collected over the 455 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 326 data files. Data were not collected in areas of shallow water (depths less than 3.0 feet) or with significant obstructions unless these areas represented a large amount of water. Some random data lines were also collected, perpendicular to the survey layout, by the field crew during the survey. Figure 2 shows the actual location of all data collection points.

TWDB staff observed the lake bottom to be fairly uniform with a gentle slope from the shoreline to the center of the lake. The bathemetry of the lake reflected similar characteristics of the terrain or topography surrounding the lake. Several creek channels could be distinguished on the depth sounder's analog charts. The majority of the lake was clear of navigational hazards such as standing timber, submerged trees, and stumps. These hazards as well as sediment deposits (sand bars) were observed in the upper reaches of Hubbard and Big Sandy Creeks in the vicinity and upstream of the Highway 180 bridge.

Data collection in the headwaters was discontinued when the boat could no longer make transects across the lake due to shallow water, islands, and extensive vegetation. Deep water could still be found in the river channel. The collected data were stored in individual data files for each pre-plotted range line or random data collection event. 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. Tape backups were made 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 1182.66 to 1183.5 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 and converted to a MASS points file. The MASS points and the boundary file were then 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.

If data points were collected outside the boundary file, the boundary was modified to include the data points. The boundary file in areas of significant sedimentation was also down-sized as deemed necessary based on the data points and the observations of the field crew. The resulting boundary shape was used to develop each of the map presentations of the lake in this report.

There were still some areas where volume and area values could not be calculated by interpolation because of a lack of information along the 1,183.0 contour line 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. Approximately 248 additional points were required for interpolation and contouring of the entire lake surface at elevation 1,183.0 feet. Volumes and areas were then calculated from this modified TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 1,178.0 feet, the surface area and volume values for the lake were mathematically estimated up to elevation 1183.0 feet because of the errors generated by the software in relation to interpolation procedures along the border. This was done by first distributing uniformly across each contour interval, the difference in surface area from the last TIN value, elevation 1,178.0 and the area of the modified boundary at elevation 1,183.0. Volumes for each 0.1 interval were calculated by adding to the existing volume, 0.1 of the existing area, and 0.5 of the difference between the existing area and the area value for the volume being calculated. 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 these maps, the TIN was converted to a lattice using the TINLATTICE command and then to a polygon coverage using the LATTICEPOLY command. Using the POLYSHADE command, colors were assigned to the range of elevations represented by the polygons that varied from navy to yellow. The lower elevation was assigned the color of navy, and the 1,183.0 lake elevation was assigned the color of yellow. Different color shades were assigned to the different depths in between. Figure 3 presents the resulting color shaded representation of the lake. Figure 4 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.

Linear filtration algorithms were then applied to the DTM to produce smooth cartographic contours versus using the sharp engineered contours. The resulting contour map of the bottom surface at five-foot intervals is presented in Figure 5. Various cross-sectional plots from the TIN model that are identified on the contour map are presented in Appendix E.

RESULTS

Results from the 1996 TWDB survey indicate Hubbard Creek Reservoir encompasses 14,922 surface acres and contains a volume of 324,983 acre-feet at the conservation pool elevation of 1,183.0 feet. The shoreline at this elevation was calculated to be 120.0 miles. The deepest point of the lake, elevation 1,111.53, was located approximately 980 feet upstream (due west) from the middle of the dam. The dead storage volume, or the amount of water below the lowest outlet in the dam, was calculated to be 6,916 acre-feet based on the low flow outlet invert elevation of 1,136.0 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, is, 318,070 acre-feet.

SUMMARY

Hubbard Creek Reservoir was formed in 1962. Initial storage calculations estimated the volume at the conservation pool elevation of 1,183.0 feet to be 317,750 acre-feet with a surface area of 15,250 acres.

During the period of February 3 - 21, 1997, a hydrographic survey of Hubbard Creek Reservoir was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1996 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 Hubbard Creek Reservoir than previous survey methods. Results indicate that the lake's capacity at the conservation pool elevation of 1,183.0 feet was 324,983 acre-feet and the area was 14,922 acres. This volume calculated is 7,233 acre-feet higher than the original estimated volume of the reservoir. Therefore, no estimates of sedimentation in the reservoir can be made at this time.

It is difficult to compare the original design information and the TWDB survey performed because little is known about the original design information, the amount of data collected, and the method used to process the collected data. However, the TWDB considers the 1997 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.

CALCULATION OF DEPTH SOUNDER ACCURACY

This methodology was extracted from the Innerspace Technology, Inc. Operation Manual for the Model 443 Velocity Profiler.

For the following examples, $t = (D - d)/V$

where: t_D = travel time of the sound pulse, in seconds (at depth = D)
D = depth, in feet
d = draft = 1.2 feet
V = speed of sound, in feet per second

To calculate the error of a measurement based on differences in the actual versus average speed of sound, the same equation is used, in this format:

$$D = [t(V)]+d$$

For the water column from 2 to 30 feet: V = 4832 fps

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR VOLUME TABLE

May 22 1997

HUBBARD CREEK RESERVOIR FEBRUARY 1997 SURVEY

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

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,112										
1,113			1	1	1	1	1	1	1	1
1,114	1	1	2	2	3	4	6	7	8	9
1,115	11	13	14	16	18	20	22	24	26	29
1,116	31	34	37	39	42	45	49	52	55	59
1,117	62	66	70	74	78	82	86	91	96	100
1,118	105	110	115	121	126	132	137	143	149	156
1,119	162	169	175	182	189	197	204	212	219	227
1,120	235	244	252	261	270	279	289	298	308	318
1,121	328	338	349	360	371	382	393	404	416	428
1,122	440	452	465	478	491	504	517	530	544	558
1,123	572	586	601	616	630	645	661	676	692	708
1,124	724	740	757	774	791	808	826	844	862	880
1,125	899	918	937	957	977	997	1017	1038	1058	1079
1,126	1101	1122	1144	1167	1189	1212	1235	1258	1282	1306
1,127	1330	1355	1380	1405	1431	1457	1483	1510	1537	1565
1,128	1593	1622	1651	1680	1711	1741	1773	1805	1837	1871
1,129	1905	1939	1974	2010	2046	2084	2122	2160	2200	2240
1,130	2280	2322	2364	2407	2451	2496	2541	2588	2635	2683
1,131	2733	2783	2834	2886	2940	2994	3050	3108	3166	3226
1,132	3288	3351	3416	3482	3549	3618	3688	3759	3832	3906
1,133	3981	4058	4136	4215	4296	4378	4462	4547	4635	4723
1,134	4814	4906	4999	5093	5189	5287	5385	5486	5588	5691
1,135	5796	5902	6009	6118	6227	6338	6451	6565	6680	6797
1,136	6916	7036	7157	7280	7404	7529	7656	7785	7915	8047
1,137	8181	8317	8454	8593	8733	8875	9017	9161	9307	9454
1,138	9602	9752	9903	10056	10211	10367	10525	10685	10847	11010
1,139	11175	11342	11510	11680	11852	12025	12200	12377	12555	12735
1,140	12917	13100	13284	13471	13658	13847	14038	14230	14423	14618
1,141	14815	15013	15213	15415	15617	15821	16027	16234	16442	16652
1,142	16863	17075	17288	17503	17720	17937	18156	18376	18598	18821
1,143	19045	19271	19497	19725	19954	20184	20416	20648	20882	21117
1,144	21354	21591	21830	22070	22311	22554	22797	23043	23289	23537
1,145	23786	24036	24288	24542	24796	25052	25310	25569	25830	26092
1,146	26355	26621	26888	27156	27426	27698	27972	28247	28525	28804
1,147	29085	29369	29654	29941	30231	30522	30816	31111	31410	31710
1,148	32012	32317	32623	32932	33243	33556	33871	34188	34508	34830
1,149	35154	35480	35809	36140	36473	36808	37146	37486	37830	38175
1,150	38522	38872	39224	39579	39935	40294	40655	41019	41385	41753
1,151	42123	42496	42871	43249	43629	44011	44396	44782	45171	45562
1,152	45955	46350	46747	47146	47547	47950	48355	48763	49173	49584
1,153	49999	50415	50833	51255	51678	52103	52531	52961	53394	53829
1,154	54267	54707	55150	55597	56045	56495	56949	57404	57863	58324
1,155	58787	59252	59720	60192	60665	61141	61619	62100	62584	63070
1,156	63558	64048	64541	65037	65535	66036	66539	67045	67554	68066
1,157	68580	69097	69618	70141	70667	71196	71727	72262	72800	73341
1,158	73885	74431	74981	75535	76091	76650	77212	77777	78347	78919
1,159	79494	80072	80654	81240	81828	82420	83015	83613	84216	84821
1,160	85429	86041	86657	87276	87899	88525	89154	89786	90423	91063

HUBBARD CREEK RESERVOIR FEBRUARY 1997 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,161	91706	92353	93003	93658	94316	94977	95643	96312	96985	97660
1,162	98339	99022	99707	100397	101089	101784	102483	103184	103890	104597
1,163	105308	106022	106739	107460	108183	108909	109639	110372	111109	111848
1,164	112590	113336	114085	114839	115594	116354	117116	117882	118653	119426
1,165	120203	120983	121768	122557	123349	124144	124944	125747	126556	127367
1,166	128181	129000	129822	130649	131479	132312	133149	133990	134836	135684
1,167	136536	137392	138252	139117	139986	140859	141737	142620	143508	144399
1,168	145295	146196	147100	148011	148924	149842	150762	151687	152616	153547
1,169	154483	155422	156364	157312	158262	159216	160174	161135	162102	163071
1,170	164044	165021	166003	166989	167979	168973	169971	170974	171982	172993
1,171	174008	175027	176049	177077	178108	179142	180181	181223	182271	183321
1,172	184376	185434	186496	187564	188634	189709	190787	191869	192957	194047
1,173	195141	196239	197342	198449	199559	200674	201792	202914	204041	205171
1,174	206304	207442	208583	209730	210879	212032	213189	214351	215517	216687
1,175	217861	219039	220221	221410	222602	223799	225001	226207	227419	228634
1,176	229854	231079	232308	233544	234783	236026	237275	238527	239786	241048
1,177	242313	243583	244857	246137	247418	248704	249994	251287	252586	253887
1,178	255193	256502	257815	259132	260454	261779	263107	264438	265774	267114
1,179	268457	269804	271155	272510	273870	275233	276599	277969	279344	280723
1,180	282106	283491	284880	286272	287669	289066	290467	291870	293277	294688
1,181	296100	297515	298933	300354	301780	303206	304636	306069	307504	308945
1,182	310386	311831	313279	314730	316185	317642	319101	320564	322030	323500
1,183	324983									

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR AREA TABLE

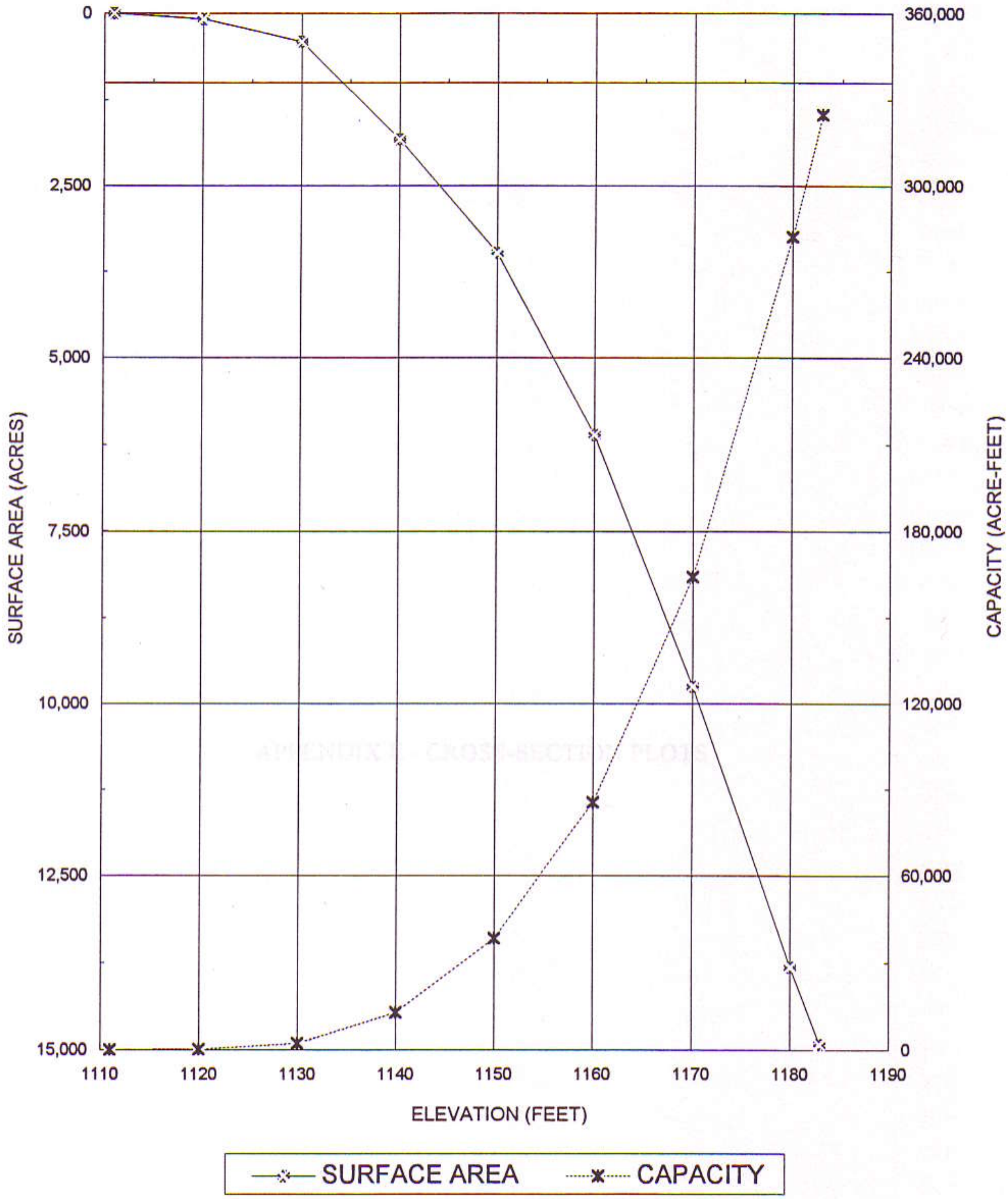
May 22 1997

HUBBARD CREEK RESERVOIR   FEBRUARY 1997 SURVEY

AREA IN ACRES   ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,112										
1,113	1	1	1	1	1	1	1	1	1	1
1,114	2	3	4	8	10	11	12	13	14	14
1,115	15	16	17	18	19	20	21	22	23	24
1,116	25	26	27	29	30	31	32	33	34	35
1,117	37	38	39	40	42	43	44	45	47	48
1,118	49	51	52	54	55	57	58	60	62	63
1,119	65	66	68	70	72	73	75	77	79	81
1,120	83	84	87	89	90	92	94	96	98	100
1,121	102	105	107	108	110	112	114	116	118	120
1,122	122	124	126	128	130	132	134	136	138	140
1,123	142	144	146	148	150	152	154	156	158	160
1,124	162	165	167	169	172	175	177	180	183	186
1,125	189	192	194	197	199	202	204	207	210	212
1,126	215	218	221	223	226	229	232	235	238	241
1,127	245	248	251	254	258	262	266	270	274	279
1,128	284	289	294	300	305	311	317	323	329	335
1,129	342	348	355	361	368	376	383	390	397	404
1,130	412	419	427	435	443	451	460	469	478	487
1,131	496	507	517	529	541	553	566	580	594	608
1,132	624	639	653	667	680	694	707	719	733	746
1,133	759	773	786	800	815	831	847	863	881	897
1,134	912	925	938	952	966	980	996	1011	1026	1040
1,135	1054	1067	1079	1091	1104	1118	1132	1146	1162	1178
1,136	1193	1207	1220	1234	1248	1263	1278	1295	1311	1330
1,137	1348	1365	1381	1395	1408	1421	1434	1448	1461	1475
1,138	1490	1505	1521	1538	1554	1571	1589	1608	1626	1643
1,139	1659	1676	1692	1709	1725	1741	1759	1775	1792	1808
1,140	1823	1839	1854	1869	1883	1898	1912	1927	1943	1959
1,141	1975	1991	2006	2021	2035	2048	2062	2075	2089	2103
1,142	2116	2129	2143	2156	2169	2183	2196	2210	2223	2235
1,143	2248	2260	2272	2284	2296	2308	2320	2332	2344	2357
1,144	2369	2382	2394	2407	2419	2431	2444	2457	2471	2484
1,145	2498	2512	2525	2539	2554	2568	2583	2599	2614	2630
1,146	2646	2661	2677	2693	2710	2728	2746	2764	2783	2803
1,147	2823	2843	2863	2884	2904	2925	2947	2969	2991	3013
1,148	3035	3055	3076	3097	3118	3140	3162	3185	3208	3231
1,149	3253	3274	3296	3318	3342	3367	3392	3417	3441	3464
1,150	3487	3510	3533	3556	3577	3600	3623	3647	3670	3694
1,151	3717	3740	3764	3788	3812	3834	3856	3877	3898	3918
1,152	3939	3960	3980	4001	4021	4042	4064	4086	4108	4130
1,153	4153	4175	4197	4220	4243	4266	4290	4314	4339	4365
1,154	4393	4419	4445	4470	4495	4520	4545	4570	4595	4620
1,155	4645	4670	4696	4721	4748	4773	4797	4821	4845	4869
1,156	4893	4918	4944	4969	4995	5021	5047	5073	5101	5131
1,157	5160	5188	5217	5245	5274	5303	5332	5363	5393	5423
1,158	5454	5484	5515	5545	5576	5607	5639	5672	5705	5738
1,159	5771	5802	5836	5869	5902	5934	5967	6002	6036	6070
1,160	6104	6138	6173	6208	6242	6276	6310	6344	6380	6415

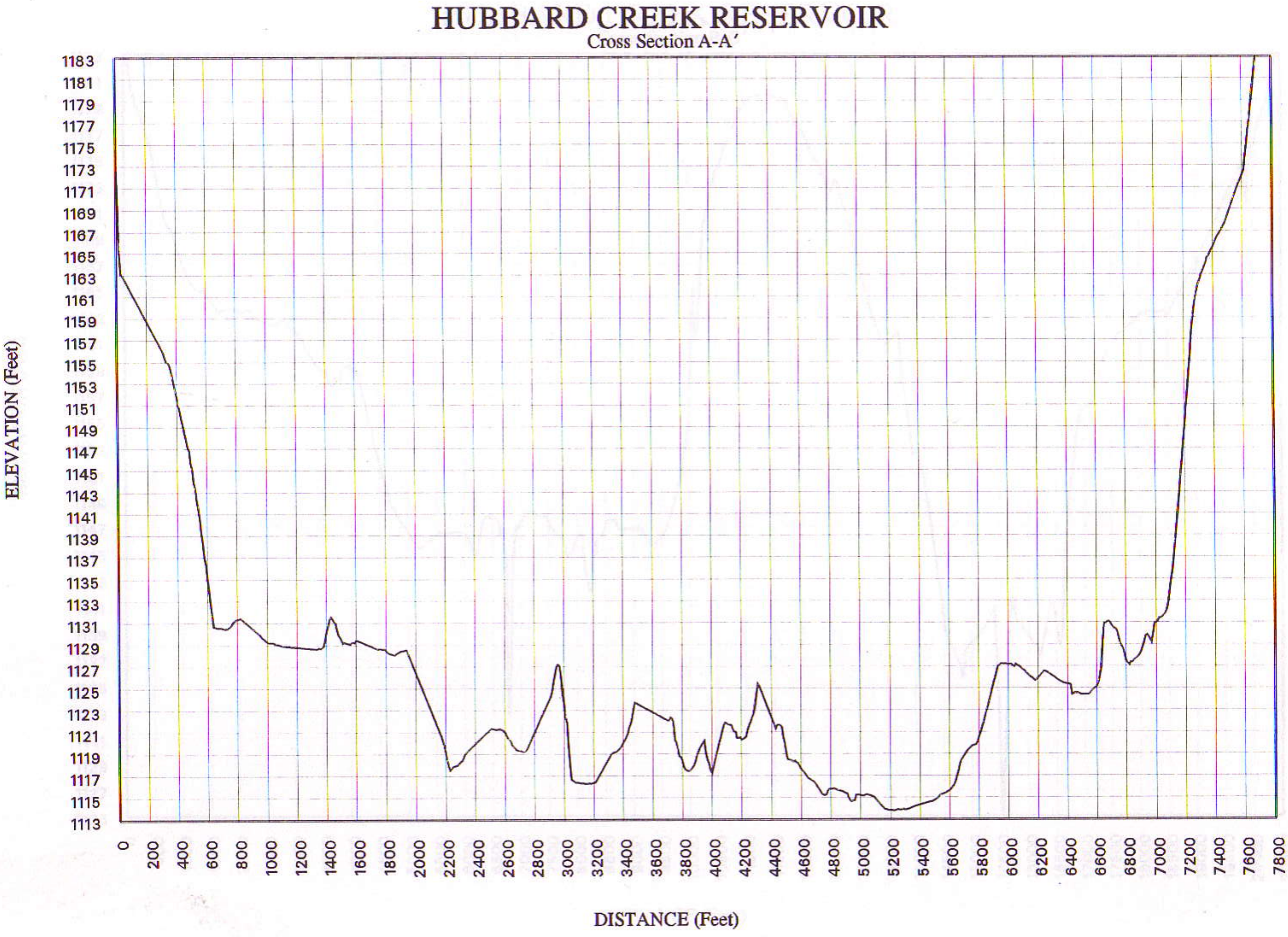
APPENDIX D - AREA-ELEVATION-CAPACITY GRAPH



HUBBARD CREEK RESERVOIR

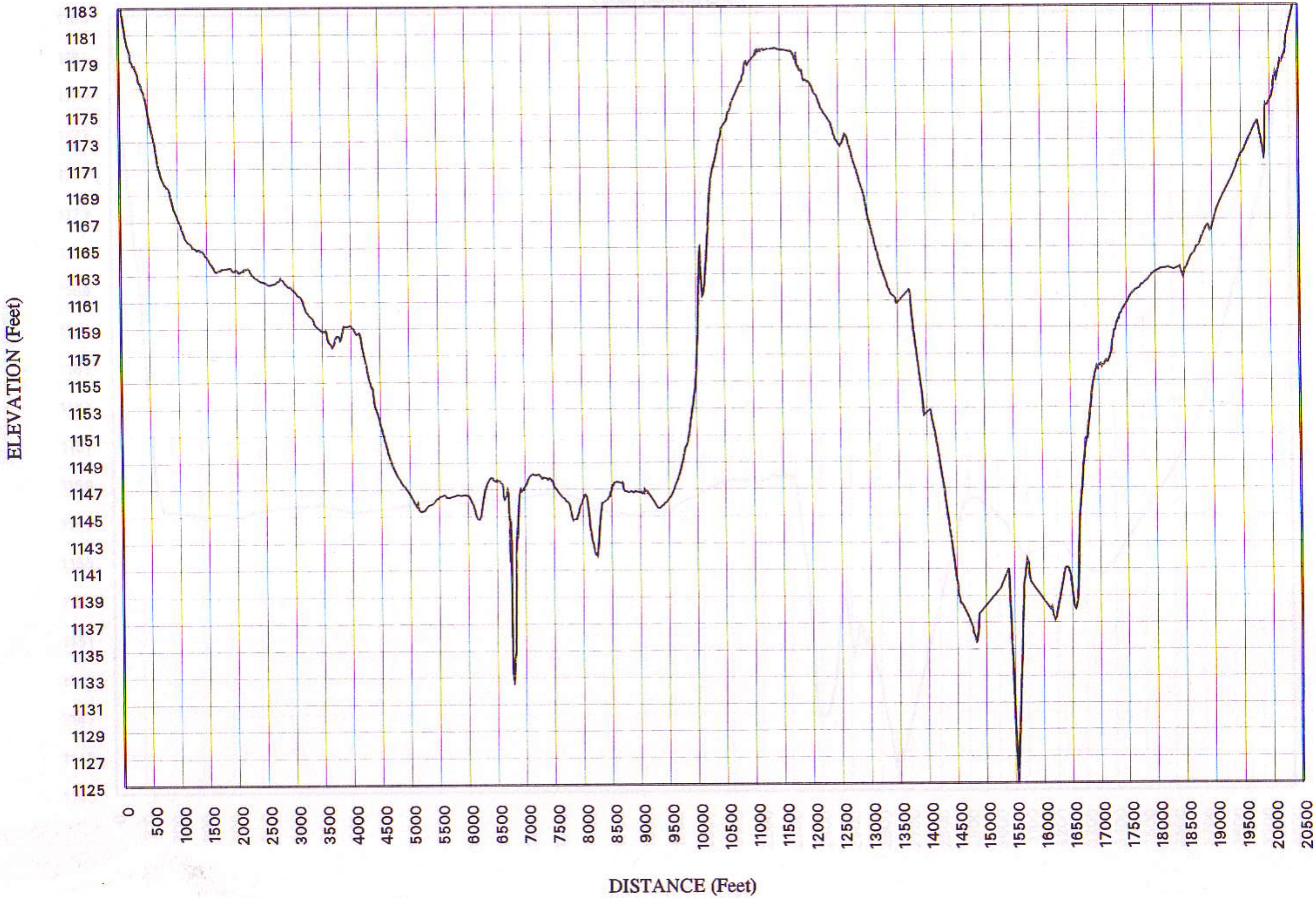
February 1997 Survey

Prepared by: TWDB May 1997



PREPARED BY: TWDB MAY 1997

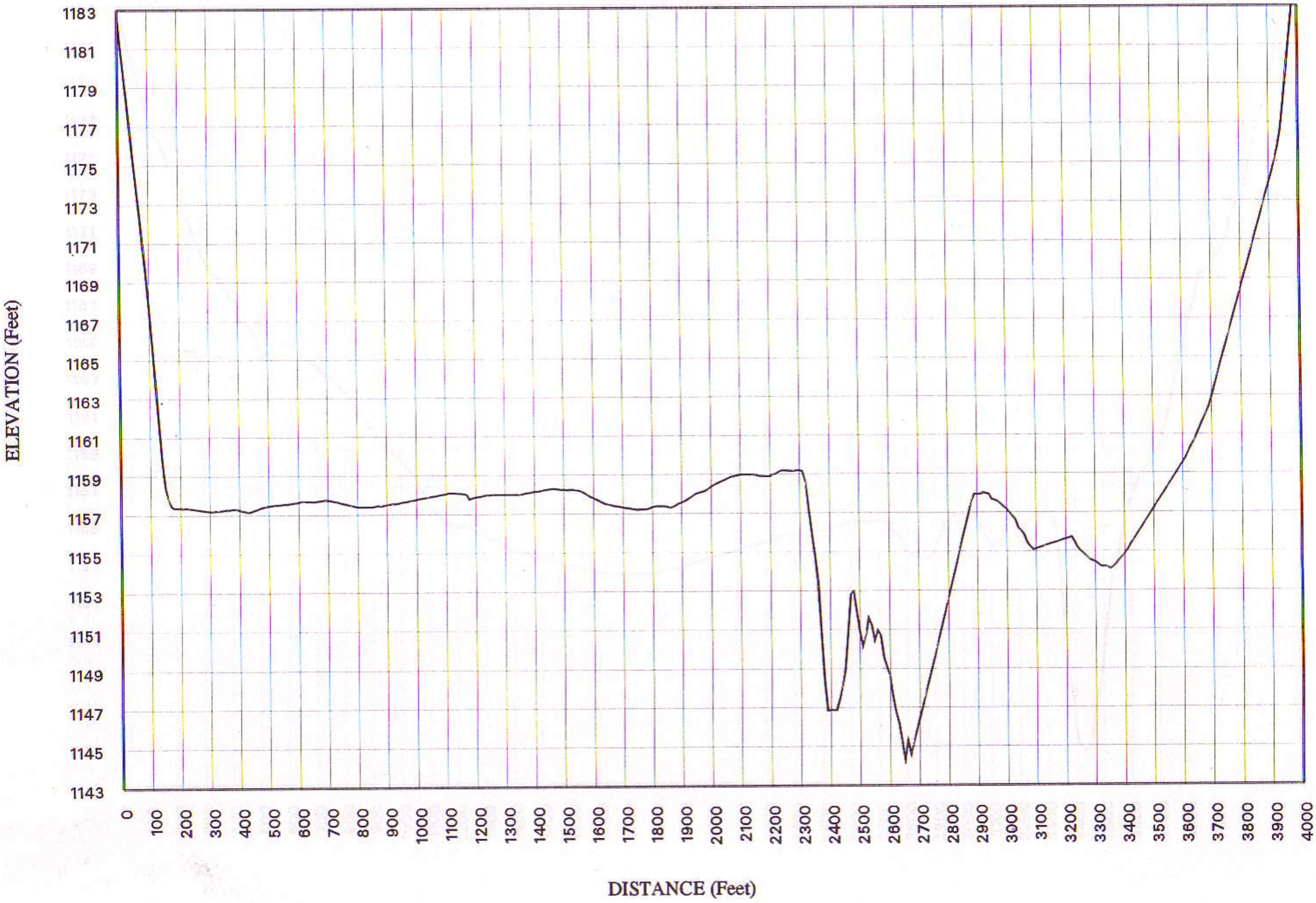
HUBBARD CREEK RESERVOIR
Cross Section B-B'



PREPARED BY: TWDB MAY 1997

HUBBARD CREEK RESERVOIR

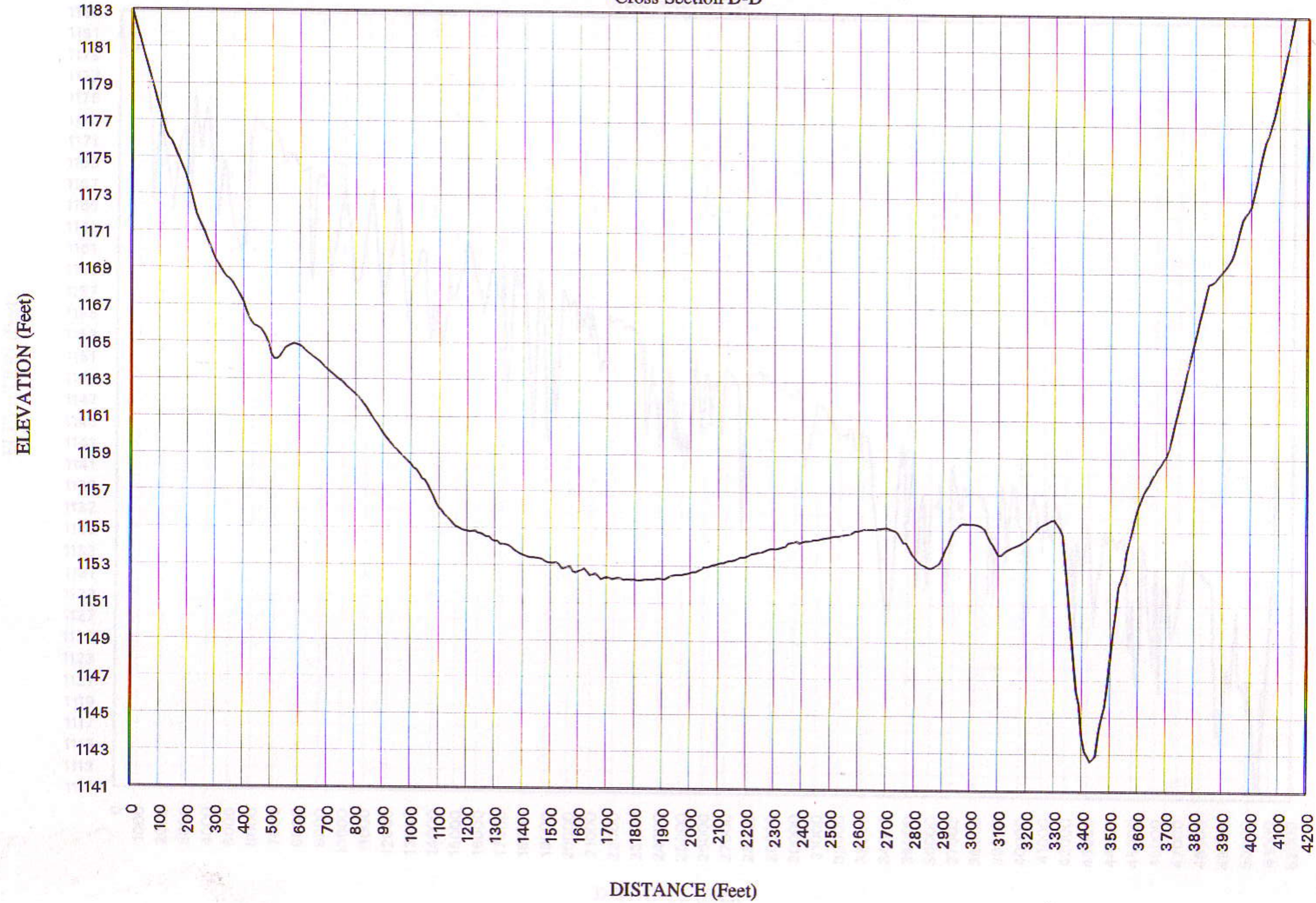
Cross Section C-C′



PREPARED BY: TWDB MAY 1997

HUBBARD CREEK RESERVOIR

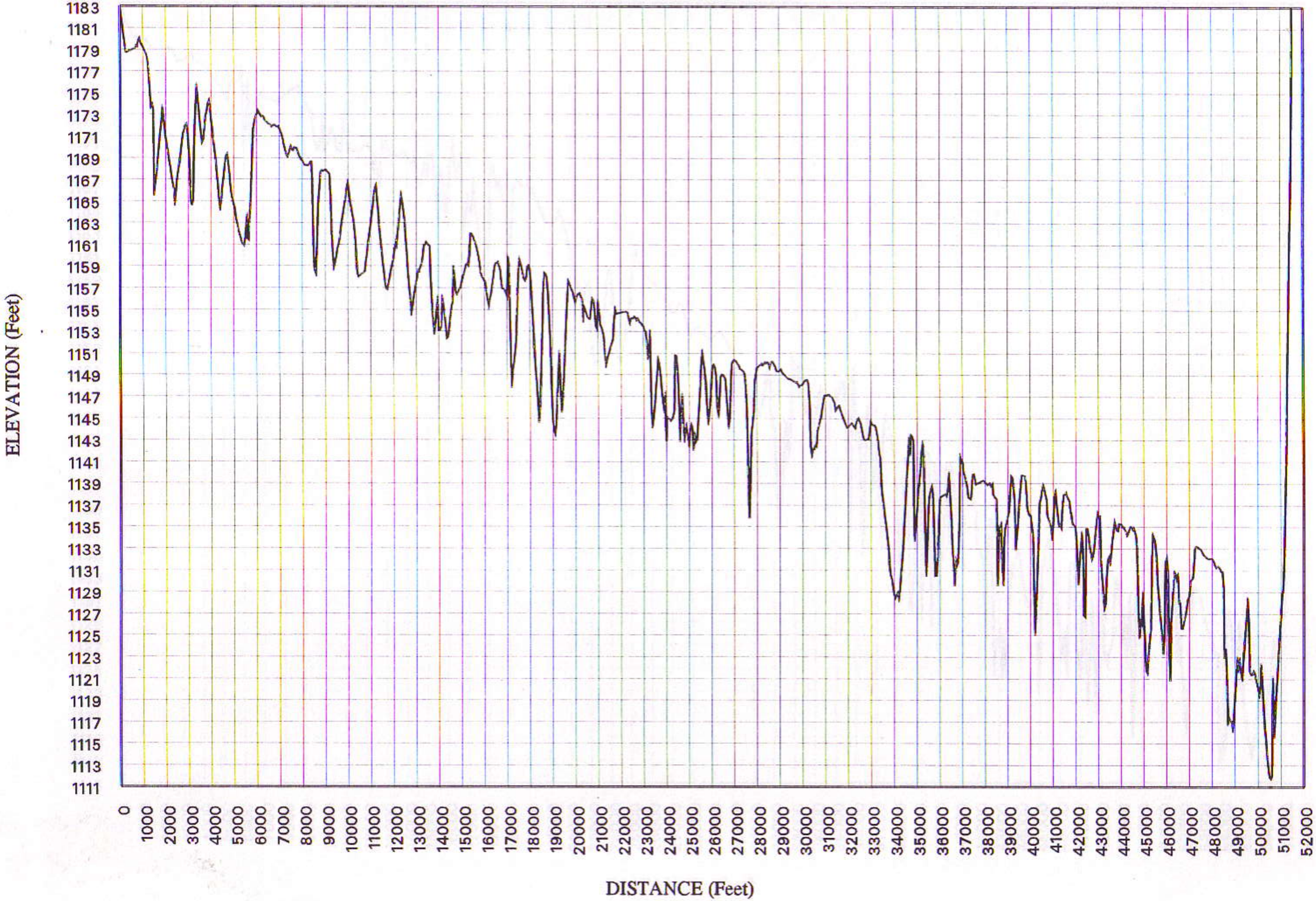
Cross Section D-D′



PREPARED BY: TWDB MAY 1997

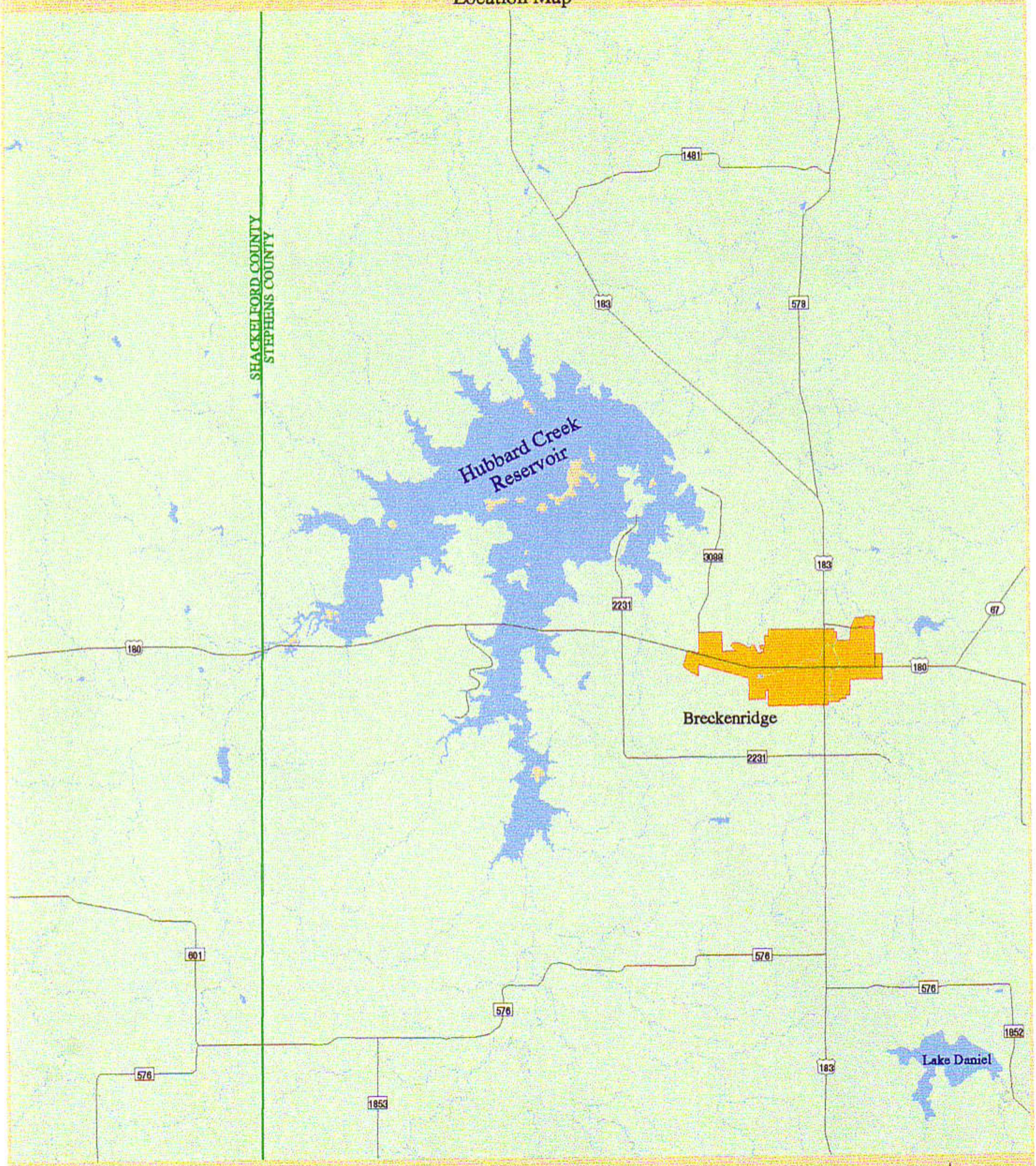
HUBBARD CREEK RESERVOIR

Cross Section E-E′



PREPARED BY: TWDB MAY 1997

FIGURE 1
HUBBARD CREEK RESERVOIR
Location Map



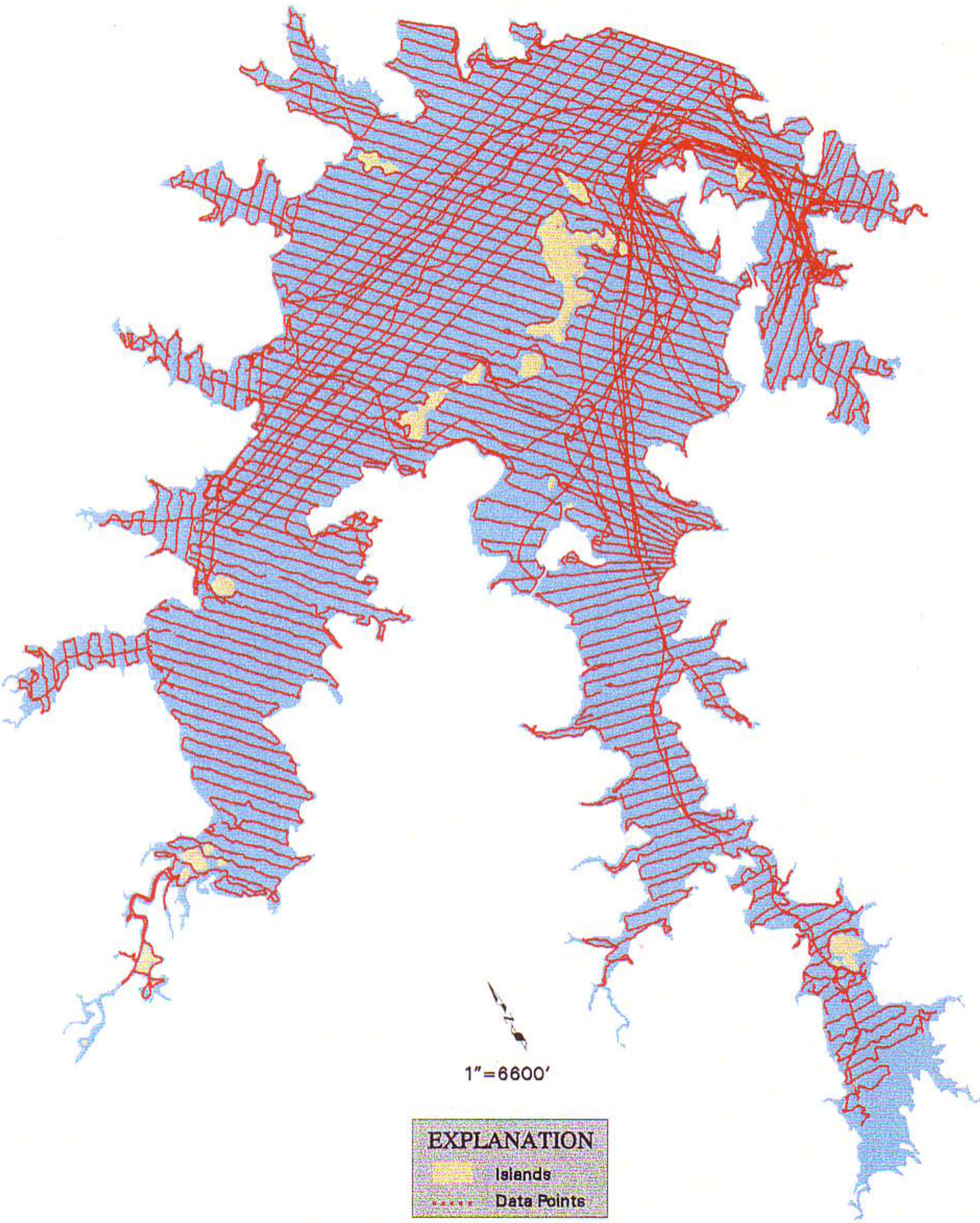
PREPARED BY: TWDB MAY 1997

1"=14850'

FIGURE 2

HUBBARD CREEK RESERVOIR

Location of Survey Data

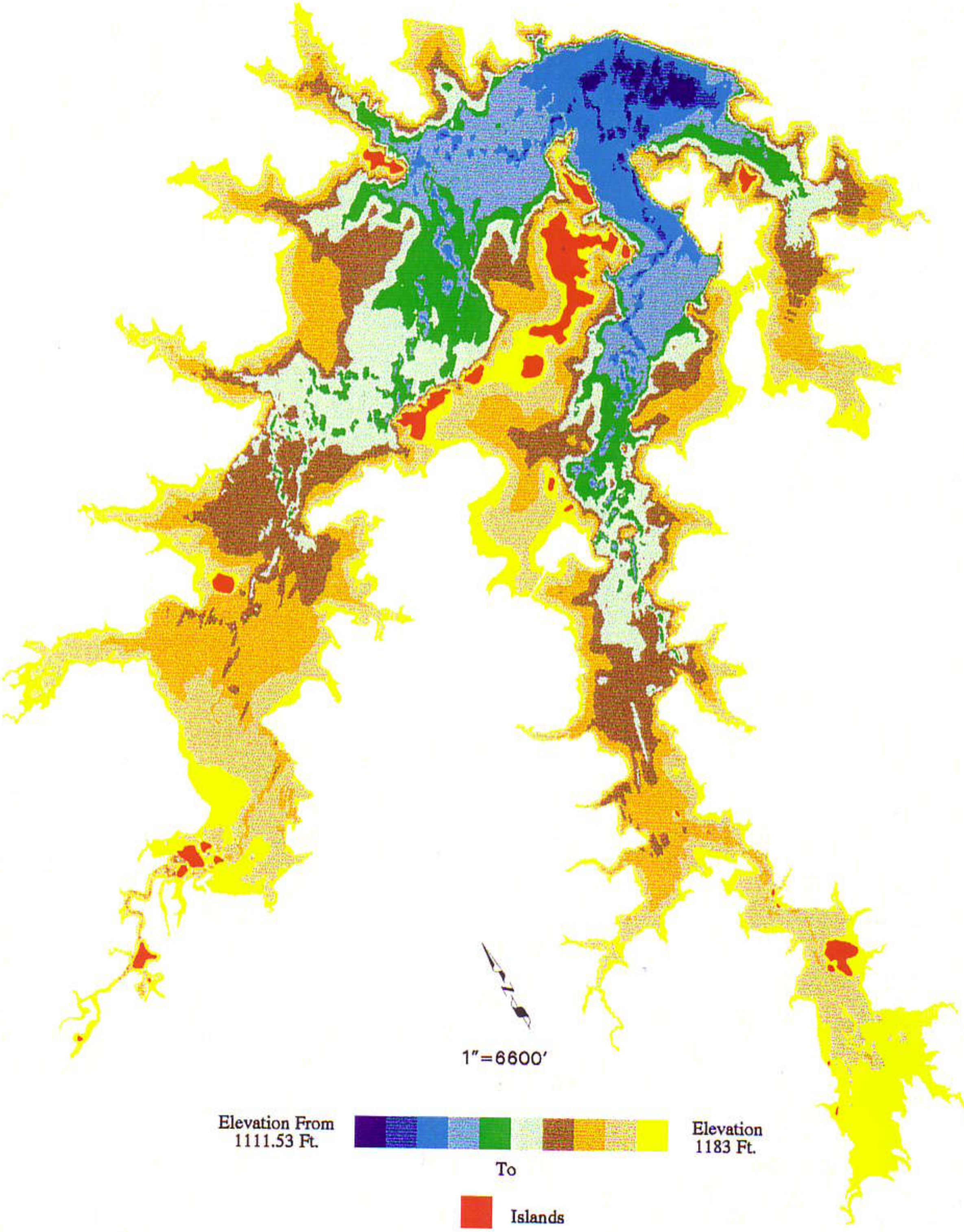


PREPARED BY: TWDB MAY 1997

FIGURE 3

HUBBARD CREEK RESERVOIR

Shaded Relief

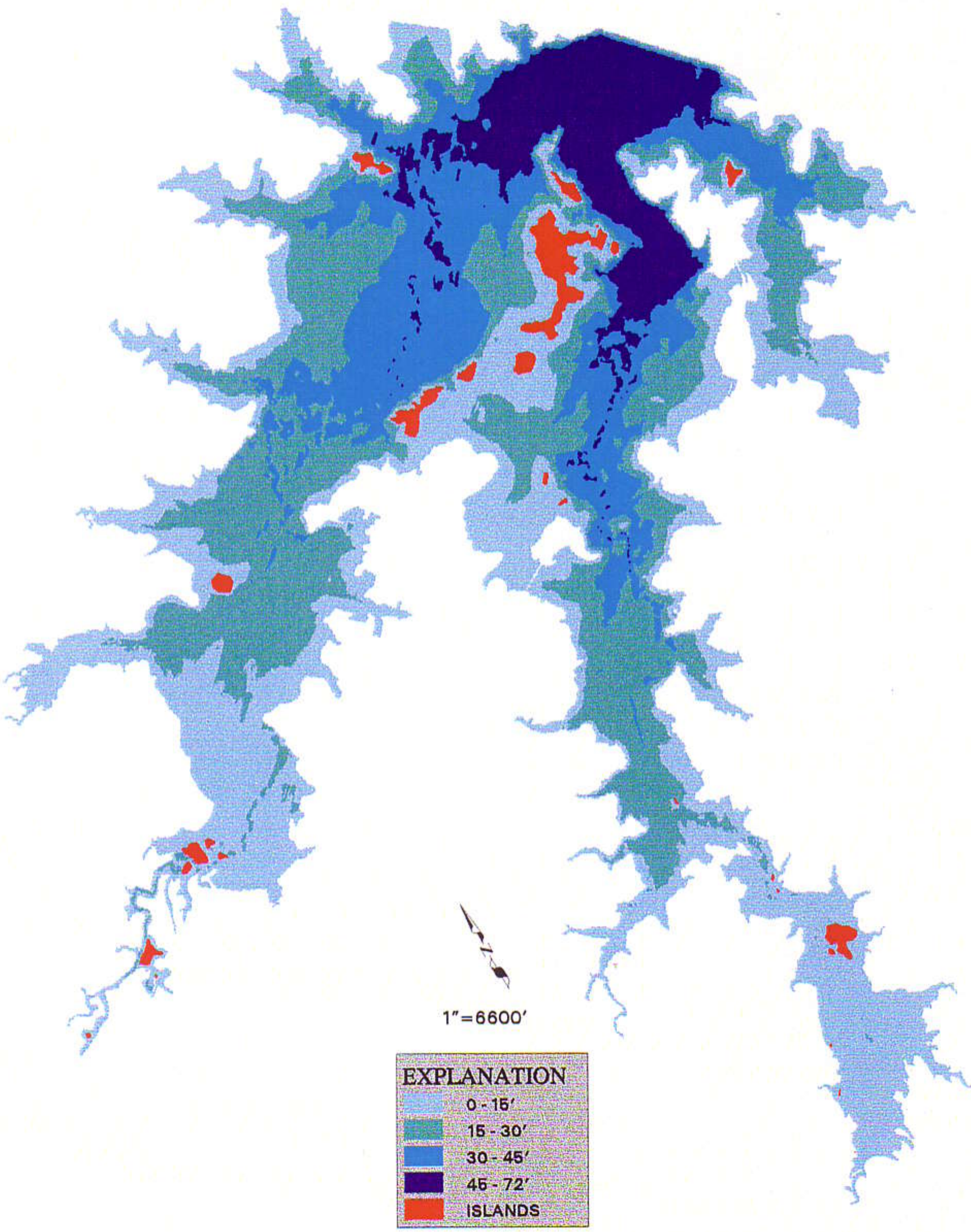


PREPARED BY: TWDB MAY 1997

FIGURE 4

HUBBARD CREEK RESERVOIR

Depth Ranges

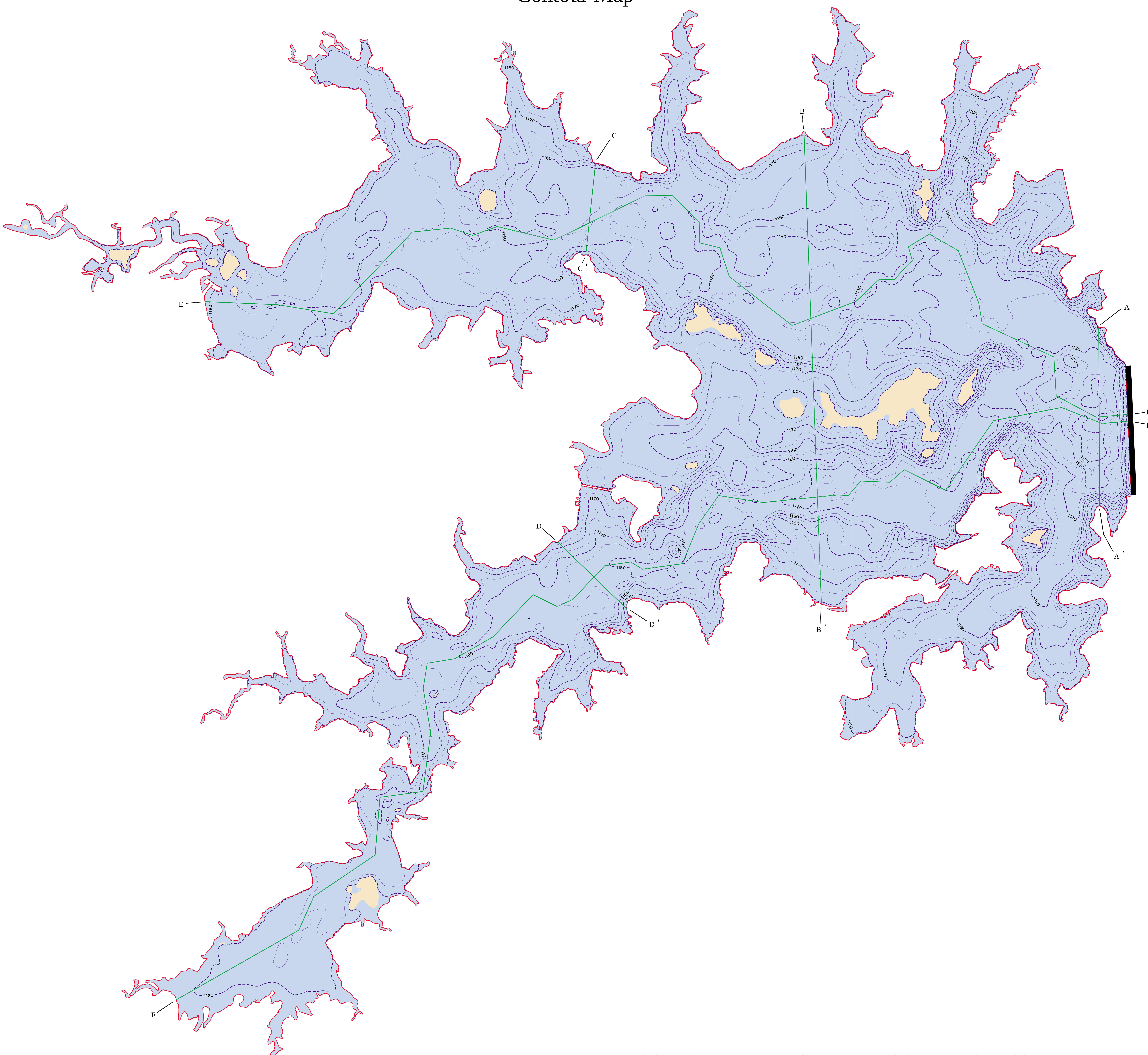


PREPARED BY: TWDB MAY 1997

FIGURE 5

HUBBARD CREEK RESERVOIR

Contour Map



1"=1600'

SHACKELFORD AND STEPHENS COUNTIES

EXPLANATION

- Islands
- 10 Foot Contour Lines
- 5 Foot Contour Lines
- Conservation Pool Elev. 1183 Feet
- Cross Section Lines

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Hubbard Creek 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: TEXAS WATER DEVELOPMENT BOARD MAY 1997