VOLUMETRIC SURVEY
OF
LAKE CONROE

Prepared for:

SAN JACINTO RIVER AUTHORITY

Prepared by:

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This report was prepared by the Hydrographic Survey group:

Scot Sullivan, P.E.
Duane Thomas
Steve Segura
Steve Hutton
Wayne Elliott
Marc Robichaud
For more information, please call (512) 936-0848

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Lake Conroe during the period of March 4 through April 3, 1996. The purpose of the survey was to determine the capacity of the lake at the conservation pool elevation and to establish baseline information for future surveys. From this information, future surveys will be able to determine sediment deposition locations and rates over time. Survey results are presented in the following pages in both graphical and tabular form. All elevations presented in this report will be reported in feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29) unless noted otherwise. According to previous records, the initial surface area of Lake Conroe at the conservation pool elevation of 201.0 feet was 20,985 acres with a corresponding initial capacity of 430,260 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Conroe is located on the West Fork of the San Jacinto River in Walker and Montgomery Counties, approximately seven miles northwest of Conroe, Tx. The water rights to Lake Conroe are owned by the San Jacinto River Authority and the City of Houston. The lake and dam facility are maintained by the San Jacinto River Authority. Inflows to the lake originate over a 445 square mile drainage area. At the conservation capacity pool elevation, the lake is approximately 19 miles long and five miles wide at its widest point and has approximately 150 miles of shoreline.

Construction of Lake Conroe began in February, 1970 and was completed in January,

1973. Freese, Nichols and Endress Engineering Inc. designed the project and H. B. Zachery Company was the general contractor. The project cost an estimated $30,000,000. Conroe Dam is an earthfill embankment, 11,300 feet in length including the levees. The crest elevation of the dam is 212.0 feet and has a height of 82 feet above the old riverbed. A controlled spillway is located near the center of the embankment. The spillway is a concrete ogee crest, 200 feet in length with a crest elevation of 173.0 feet. Control for the spillway consists of five tainter gates, 40 feet by 30 feet with the top elevation of 202.5 feet. Low flow releases are made through a separate multi-gated inlet tower. Two of the gates are four feet by six feet, the third gate is five feet by five feet. The invert for the lowest outlet in the control tower is 144.5. Discharges are through a 10 foot diameter concrete conduit through the dam.

Permit Number 1962 was issued June 9, 1960 to the San Jacinto River Authority authorizing the impoundment of 380,400 acre-feet of water. The annual allotted diversions were 66,000 acre-feet for municipal use, 28,500 for industrial use and 5,500 acre-feet for mining use. On August 31, 1965 the permit was amended to allow the relocation of the dam and to increase the impoundment capacity to 430,260 acre-feet. Certificate of Adjudication Number 10-4963 was issued by the Texas Water Commission on February 25, 1987. The Certificate gave the San Jacinto River Authority and the City of Houston diversion rights and uses as stated in the amended permit including the right to use the impounded waters of Lake Conroe for non-consumptive recreational purposes.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the equipment and methodology used to conduct this hydrographic survey. Some of the theory behind Global Positioning System (GPS) technology and its accuracy are also addressed.

GPS Information

The following is a brief and simple description of Global Positioning System (GPS) technology. GPS is a new technology that uses a network of satellites, maintained in precise orbits around the earth, to determine locations on the surface of the earth. GPS receivers continuously monitor the broadcasts from the satellites to determine the position of the receiver. With only one satellite being monitored, the point in question could be located anywhere on a sphere surrounding the satellite with a radius of the distance measured. The observation of two satellites decreases the possible location to a finite number of points on a circle where the two spheres intersect. With a third satellite observation, the unknown location is reduced to two points where all three spheres intersect. One of these points is obviously in error because its location is in space, and it is ignored. Although three satellite measurements can fairly accurately locate a point on the earth, the minimum number of satellites required to determine a three dimensional position within the required accuracy is four. The fourth measurement compensates for any time discrepancies between the clock on board the satellites and the clock within the GPS receiver.

GPS technology was developed in the 1960s by the United States Air Force and the defense establishment. After program funding in the early 1970s, the initial satellite was launched on February 22, 1978. A four year delay in the launching program occurred after the Challenger space shuttle disaster. In 1989, the launch schedule was resumed. Full operational capability will be reached when the NAVSTAR (NAVigation System with Time And Ranging) satellite constellation is composed of 24 Block II satellites. At the time of the survey, the system had achieved initial operational capability. A full constellation of 24 satellites, in a combination of Block I (prototype) and Block II satellites, was fully functional. The NAVSTAR satellites provide data based on the World Geodetic System (WGS '84) spherical datum. WGS '84 is essentially identical to NAD '83.

The United States Department of Defense (DOD) is currently responsible for implementing and maintaining the satellite constellation. In an attempt to discourage the use of these survey units as a guidance tool by hostile forces, the DOD has implemented means of false signal projection called Selective Availability (S/A). Positions determined by a single receiver

when S/A is active result in errors to the actual position of up to 100 meters. These errors can be reduced to centimeters by performing a static survey with two GPS receivers, one of which is set over a point with known coordinates. The errors induced by S/A are time-constant. By monitoring the movements of the satellites over time (one to three hours), the errors can be minimized during post processing of the collected data and the unknown position computed accurately.

Differential GPS (DGPS) can determine positions of moving objects in real-time or "on-the-fly." 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 using 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 dfferentially 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 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 depthsounder combine together to provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder gathers approximately ten readings of the lake bottom each second. The depth readings are stored on the survey vessel's on-board computer along with the corrected positional data generated by the boat's GPS receiver. The daily data files collected are downloaded from the computer and brought to the office for editing after the survey is completed. During editing, bad data is removed or corrected, multiple data points are averaged to get one data point per second, and average depths are converted to elevation readings based on the daily recorded lake elevation on the day the survey was performed. Accurate estimates of the lake volume can be quickly determined by building a 3-D model of the reservoir from the collected data. The level of accuracy is equivalent to or better than previous methods used to determine lake volumes, some of which are discussed below.

Previous Survey Procedures

Originally, reservoir surveys were conducted with a rope stretched across the reservoir along pre-determined range lines. A small boat would manually pole the depth at selected intervals along the rope. Over time, aircraft cable replaced the rope and electronic depth sounders replaced the pole. The boat was hooked to the cable, and depths were again recorded at selected intervals. This method, used mainly by the Soil Conservation Service, worked well

for small reservoirs.

Larger bodies of water required more involved means to accomplish the survey, mainly due to increased size. Cables could not be stretched across the body of water, so surveying instruments were utilized to determine the path of the boat. Monumentation was set for the end points of each line so the same lines could be used on subsequent surveys. Prior to a survey, each end point had to be located (and sometimes reestablished) in the field and vegetation cleared so that line of sight could be maintained. One surveyor monitored the path of the boat and issued commands via radio to insure that it remained on line while a second surveyor determined depth measurement locations by turning angles. Since it took a major effort to determine each of the points along the line, the depth readings were spaced quite a distance apart. Another major cost was the land surveying required prior to the reservoir survey to locate the range line monuments and clear vegetation.

Electronic positioning systems were the next improvement. If triangulation could determine the boat location by electronic means, then the boat could take continuous depth soundings. A set of microwave transmitters positioned around the lake at known coordinates would allow the boat to receive data and calculate its position. Line of site was required, and the configuration of the transmitters had to be such that the boat remained within the angles of 30 and 150 degrees in respect to the shore stations. The maximum range of most of these systems was about 20 miles. Each shore station had to be accurately located by survey, and the location monumented for future use. Any errors in the land surveying resulted in significant errors that were difficult to detect. Large reservoirs required multiple shore stations and a crew to move the shore stations to the next location as the survey progressed. Land surveying was still a major cost.

Another method used mainly prior to construction utilized aerial photography to generate elevation contours which could then be used to calculate the volume of the reservoir. Fairly accurate results could be obtained, although the vertical accuracy of the aerial topography was generally one-half of the contour interval or $\pm$ five feet for a ten-foot contour interval. This

method could be quite costly and was only applicable in areas that were not inundated.

PRE-SURVEY PROCEDURES

The reservoir's surface area was determined prior to the survey by digitizing with AutoCad software the lake's conservation pool boundary from USGS quad sheets. The name of the quad sheets are as follows: COWL SPUR, TX. 1958 (Photorevised 1976), SHEPARD HILL, TX. 1958 (Photorevised 1976), KEENAN, TX. 1962 (Photorevised 1976), SAN JACINTO, TX. 1959 (Photorevised 1976), MONTGOMERY, TX. 1959 (Photorevised 1976) and MOORE GROVE, TX. 1959 (Photorevised 1976). The graphic boundary file created was then transformed into the proper datum, from NAD '27 datum to NAD '83, using Environmental Systems Research Institutes's (ESRI) Arc/Info project command with the NADCOM parameters. The area of the lake boundary was checked to verify that the area was the same in both datums.

The survey layout was designed by placing survey track lines at 500 foot intervals across the lake. The survey design for this lake required approximately 455 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 represent 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 Lake Conroe performed by the TWDB. Information regarding equipment calibration and operation, the field survey, and data processing is presented.

Equipment Calibration and Operation

During the survey, the 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.

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 Lake Conroe, the speed of sound in the water column varied daily between 4780 and 4889 feet per second. Based on the measured speed of sound for various depths, and the average speed of sound calculated for the entire water column, the depth sounder is accurate to within ±0.2 feet, plus an estimated error of ±0.3 feet due to the plane of the boat for a total accuracy of ±0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some are plus readings and some are minus readings. Further information on these calculations is presented in Appendix A.

Field Survey

Data was collected on Lake Conroe during the period of March 4 through April 3, 1996. Approximately 233,751 data points were collected over the 348 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 495 data files. Data were not collected in areas of shallow water (depths

less than 3.0 ft.) or with significant obstructions unless these areas represented a large amount of water. Random data points were collected, when determined necessary by the field crew. Figure 2 shows the actual location of the data collection points.

While collecting data, TWDB staff observed the lake bottom to be fairly uniform upstream of the dam in the main reservoir area yet the old creek and river channels could still be distingushed on the analog charts. Lake Conroe was fairly clear of navigational hazards such as stumps in the main body of the lake. The crew did encounter large areas of stumps and shallows in the upper reaches of Caney Creek and certain areas upstream of the bridges of County Roads 1097 and 1375. A large part of the down time during the data collection was due to the inclimate weather, especially high winds.

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 200.70 to 200.93 feet. After all changes had been made to the raw data file, the edited file was saved with a different extension. After all the files were edited, the edited files were combined into a single data file, representative of the lake, to be used with the GIS software to develop a model of the lake's bottom surface.

The resulting DOS data file was imported into the UNIX operating system used to run Environmental System Research Institutes's (ESRI) Arc/Info GIS software. The latitude and longitude coordinates of each point were then converted to decimal degrees by a UNIX awk command. The awk command manipulates the data file format into a MASS points format for use by the GIS software. The graphic boundary file previously digitized was also imported.

The boundary and MASS points files were graphically edited using the Arc/Edit module. The MASS points file was converted into a point coverage and plotted along with the boundary file. If data points were collected outside the boundary file, the boundary was modified to include the data points. Also, the boundary near the edges of the lake in areas of significant sedimentation was down-sized to reflect the observations of the field crew. The resulting boundary shape was considered to be the acreage at the conservation pool elevation of the lake. This was calculated as 20,118 acres for Lake Conroe. The Board does not represent the boundary, as depicted in this report, to be a detailed actual boundary. Instead, it is a graphical approximation of the actual boundary used solely to compute the volume and area of the lake. The boundary does not represent the true land versus water boundary of the lake. An aerial topographic map of the upper four feet of the lake or an aerial photo taken when the lake is at the conservation pool elevation would more closely define the present boundary. However, the minimal increase in accuracy does not appear to offset the cost of those services at this time.

The edited MASS points and modified boundary file were used to create a Digital Terrain Model (DTM) of the reservoir's bottom surface using Arc/Info's TIN module. The module builds an irregular triangulated network from the data points and the boundary file. This software uses a method known as Delauney's criteria for triangulation. A triangle is formed between three non-uniformly spaced points, including all points along the boundary. If there is another point within the triangle, additional triangles are created until all points lie on the vertex of a triangle. All of the data points are preserved for use in determining the solution of the model by using this method. The generated network of three-dimensional triangular planes represents the actual bottom surface. Once the triangulated irregular network (TIN) is formed, the software then calculates elevations along the triangle surface plane by solving the equations for elevation along each leg of the triangle. Information for the entire reservoir area can be determined from the triangulated irregular network created using this method of interpolation.

There were some areas where values could not be calculated by interpolation because of a lack of information along the boundary of the reservoir. "Flat triangles" were drawn at these locations. Arc/Info does not use flat triangle areas in the volume or contouring features of the model. Approximately 3,936 additional points were required for interpolation and contouring of the entire lake surface. The TIN product calculated the surface area and volume of the entire reservoir at one-tenth of a foot intervals from the three-dimensional triangular plane surface representation. The computed reservoir volume table is presented in Appendix B and the area table in Appendix C. An elevation-area-volume graph is presented in Appendix D.

Other presentations developed from the model include a shaded relief map and a shaded depth range map. To develop the shaded relief map, the three-dimensional triangular surface was modified by a GRIDSHADE command. Colors were assigned to different elevation values of the grid. Using the command COLORRAMP, a set of colors that varied from navy to yellow was created. The lower elevation was assigned the color of navy, and the lake conservation pool elevation was assigned the color of yellow. Different color shades were assigned to the different depths in between. Figure 4 presents the resulting depth shaded representation of the lake. Figure 5 presents a similar version of the same map, using bands of color for selected depth intervals. The color increases in intensity from the shallow contour bands to the deep water bands.

The DTM was then smoothed and linear smoothing algorithms were applied to the smoothed model to produce smoother contours. The resulting contour map of the bottom surface at ten-foot intervals is presented in Figure 6.

RESULTS

Results from the 1996 survey indicate Lake Conroe now encompasses 20,118 surface acres and contains a volume of 416,228 acre-feet at the conservation pool elevation of 201.0 feet. The shoreline at this elevation was calculated to be 156 miles. The lowest elevation encountered was around elevation 122 feet, or 79 feet of depth and was found near the west end of the dam.

The storage volume calculated by the 1996 survey is approximately 3.26 percent less than the previous record information for the lake. The lowest gated outlet invert elevation is at elevation 144.5 feet. The dead storage at this elevation corresponds to 40 acre-ft. Therefore, the conservation storage capacity for the lake is 416,188 acre-feet.

SUMMARY

Lake Conroe was authorized to be constructed under Permit Number 1962 issued in November of 1962. Construction of the dam commenced in February of 1970 and deliberate impoundment of water began in January of 1973. Initial storage calculations estimated the volume of the lake at the conservation pool elevation of 201.0 feet to be 430,260 acre-feet with surface area of 20,985 acres.

During the period of March 4 and April 3, 1996, a hydrographic survey of Lake Conroe 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 Lake Conroe than previous survey methods. Results from the survey indicate that the lake's capacity at the conservation pool elevation of 201.0 feet was 416,228 acre-feet. The estimated reduction in storage capacity, if compared to the original volume was 14,032 acre-feet, or 3.26 percent. This equates to an estimated loss of 610 acre-feet per year during the 23 years between the TWDB's survey and the initial date impoundment began. The

annual deposition rate of sediment in the conservation pool can be estimated at 1.37 acre-ft per square mile of drainage area.

It is difficult to compare the original design information and the survey performed by the TWDB because little is know about the procedures and data used in calculating the original storage information. However, the TWDB considers the 1996 survey to be a significant improvement over previous survey procedures and recommends that the same methodology be used in five to ten years or after major flood events to monitor changes to the lake's storage capacity. The second survey will remove any noticeable errors between the original design data and the 1996 survey and will facilitate accurate calculations of sedimentation rates and storage losses presently occurring in Lake Conroe.

CALCULATION OF DEPTH SOUNDER ACCURACY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

= 50.1'   (+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 Jul 12 1996

RESERVOIR VOLUME TABLE

LAKE CONROE APRIL 1996 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
135								1	1	1
136	1	1	1	1	1	1	1	1	1	1
137	1	1	1	1	1	1	1	1	2	2
138	2	2	2	2	2	2	2	2	3	3
139	3	3	3	3	3	4	4	4	4	4
140	5	5	5	5	6	6	6	6	7	7
141	7	8	8	9	9	9	10	10	11	11
142	12	13	13	14	14	15	16	17	18	18
143	19	20	21	22	23	25	26	27	28	30
144	31	33	35	36	38	40	42	44	47	49
145	51	54	57	60	63	66	70	74	78	82
146	86	91	96	101	107	113	119	125	132	139
147	147	155	163	172	181	190	200	211	222	234
148	247	260	274	289	305	321	339	357	377	397
149	419	442	466	490	517	544	572	602	632	664
150	697	731	766	803	840	879	919	960	1003	1047
151	1092	1139	1187	1236	1287	1339	1393	1448	1505	1563
152	1623	1685	1748	1814	1880	1949	2019	2090	2164	2239
153	2315	2394	2474	2556	2640	2726	2813	2902	2992	3084
154	3177	3271	3367	3465	3563	3664	3765	3868	3972	4078
155	4185	4294	4405	4518	4632	4748	4866	4987	5110	5235
156	5362	5492	5624	5759	5897	6037	6180	6326	6474	6624
157	6776	6930	7086	7244	7404	7567	7731	7898	8066	8237
158	8410	8585	8762	8941	9123	9307	9494	9684	9877	10074
159	10273	10474	10679	10886	11095	11307	11521	11738	11958	12180
160	12404	12631	12860	13091	13325	13560	13798	14038	14280	14524
161	14770	15018	15268	15521	15776	16033	16292	16554	16819	17086
162	17357	17629	17905	18183	18465	18749	19036	19326	19619	19915
163	20214	20516	20822	21130	21443	21758	22077	22399	22724	23053
164	23384	23718	24055	24394	24737	25082	25431	25782	26136	26493
165	26853	27216	27582	27952	28325	28701	29080	29463	29850	30240
166	30633	31030	31430	31834	32240	32650	33064	33481	33901	34324
167	34750	35178	35610	36044	36481	36920	37363	37808	38255	38706
168	39160	39616	40076	40539	41004	41473	41945	42420	42898	43380
169	43865	44354	44847	45344	45845	46351	46860	47374	47892	48414
170	48939	49468	50000	50536	51075	51617	52163	52712	53265	53821
171	54380	54943	55510	56080	56653	57230	57810	58393	58980	59570
172	60164	60760	61360	61962	62568	63177	63790	64405	65024	65646
173	66272	66900	67532	68167	68806	69449	70095	70744	71398	72055
174	72715	73380	74048	74720	75396	76076	76760	77448	78141	78838
175	79541	80249	80962	81680	82404	83135	83872	84616	85366	86123
176	86885	87653	88426	89205	89988	90776	91569	92366	93168	93974
177	94784	95599	96418	97241	98069	98901	99737	100578	101423	102273
178	103127	103986	104850	105719	106592	107471	108354	109243	110136	111034
179	111936	112843	113753	114668	115587	116510	117436	118367	119301	120240
180	121182	122128	123078	124032	124990	125953	126920	127890	128866	129845
181	130829	131818	132811	133808	134809	135815	136824	137838	138855	139877
182	140902	141931	142963	143999	145039	146082	147129	148179	149232	150289
183	151350	152414	153481	154552	155626	156704	157786	158870	159959	161051

RESERVOIR VOLUME TABLE

LAKE CONROE APRIL 1996 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
184	162147	163247	164351	165460	166572	167688	168808	169932	171060	172192
185	173328	174468	175611	176759	177910	179066	180227	181391	182560	183733
186	184911	186093	187278	188468	189663	190862	192065	193272	194483	195699
187	196920	198144	199373	200607	201845	203088	204335	205588	206845	208106
188	209372	210642	211917	213195	214478	215765	217055	218349	219648	220950
189	222256	223567	224881	226199	227521	228847	230178	231512	232850	234193
190	235540	236891	238246	239605	240969	242338	243710	245087	246469	247854
191	249245	250640	252039	253444	254853	256268	257687	259112	260542	261977
192	263418	264864	266315	267772	269233	270700	272173	273650	275133	276620
193	278113	279612	281115	282624	284139	285659	287184	288715	290251	291793
194	293341	294894	296452	298016	299586	301161	302742	304329	305923	307521
195	309126	310736	312352	313973	315601	317234	318873	320517	322168	323824
196	325487	327156	328830	330510	332195	333887	335583	337285	338992	340704
197	342423	344148	345880	347620	349367	351122	352884	354654	356429	358211
198	359998	361791	363588	365390	367197	369008	370824	372644	374469	376298
199	378131	379970	381813	383662	385515	387373	389237	391105	392978	394856
200	396740	398653	400572	402500	404434	406377	408331	410293	412263	414242
201	416228									

TEXAS WATER DEVELOPMENT BOARD Jul 12 1996

RESERVOIR AREA TABLE

LAKE CONROE APRIL 1996 SURVEY

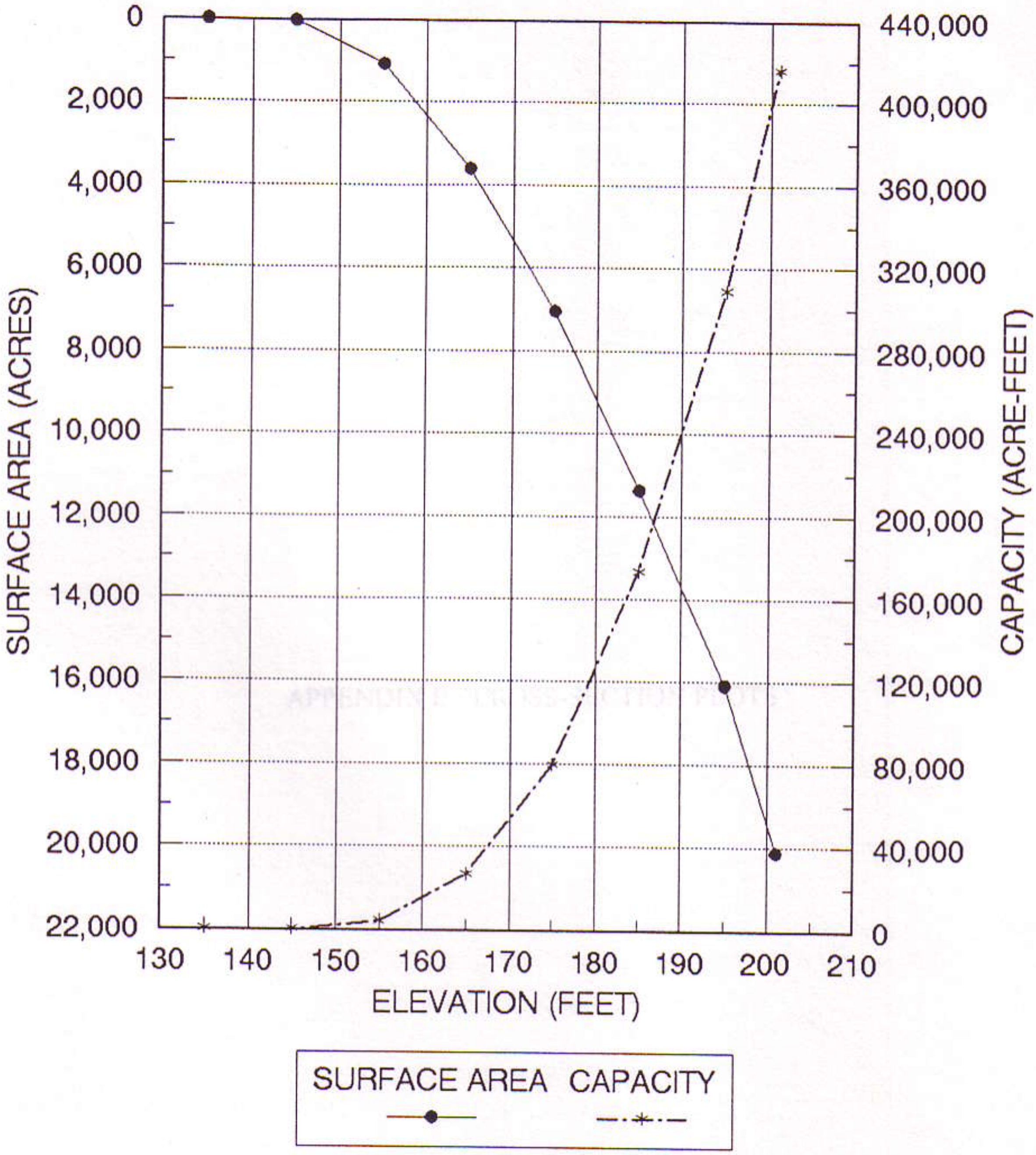
AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
135										
136										1
137	1	1	1	1	1	1	1	1	1	1
138	1	1	1	1	1	1	1	1	1	1
139	1	1	2	2	2	2	2	2	2	2
140	2	2	2	3	3	3	3	3	3	3
141	4	4	4	4	4	4	5	5	5	5
142	6	6	6	7	7	7	8	8	9	9
143	9	10	10	11	11	12	13	13	14	15
144	15	16	17	18	19	20	21	22	23	24
145	26	27	29	30	32	34	37	39	41	43
146	46	48	51	54	57	60	63	66	70	73
147	77	81	85	89	93	98	104	109	116	122
148	129	137	145	153	162	171	180	190	200	211
149	221	233	244	256	267	278	289	301	312	323
150	335	346	359	371	382	394	406	418	431	445
151	459	473	486	501	515	530	545	560	576	593
152	609	626	644	660	676	692	708	724	741	758
153	776	794	813	830	847	863	879	895	910	924
154	938	952	966	981	995	1009	1023	1036	1050	1065
155	1081	1098	1116	1134	1153	1173	1193	1215	1240	1264
156	1287	1310	1335	1362	1392	1417	1442	1468	1490	1510
157	1530	1551	1571	1592	1613	1634	1655	1676	1696	1716
158	1739	1761	1784	1806	1829	1854	1884	1916	1948	1978
159	2004	2030	2056	2081	2107	2133	2158	2183	2207	2232
160	2256	2279	2301	2323	2345	2366	2387	2408	2430	2451
161	2471	2492	2514	2537	2560	2584	2608	2634	2660	2687
162	2715	2743	2770	2798	2827	2856	2885	2914	2944	2975
163	3007	3039	3071	3106	3139	3172	3204	3237	3268	3298
164	3326	3354	3382	3411	3440	3468	3497	3525	3555	3585
165	3616	3647	3680	3712	3744	3777	3812	3848	3883	3917
166	3951	3985	4019	4052	4085	4118	4151	4184	4215	4244
167	4273	4301	4329	4355	4382	4409	4436	4464	4493	4522
168	4552	4581	4611	4642	4672	4703	4734	4766	4799	4833
169	4870	4909	4949	4992	5034	5078	5120	5158	5197	5234
170	5270	5306	5341	5375	5408	5441	5475	5509	5542	5576
171	5610	5647	5684	5718	5751	5785	5818	5852	5885	5917
172	5948	5980	6011	6043	6075	6107	6140	6172	6204	6237
173	6270	6302	6336	6370	6406	6442	6478	6515	6552	6589
174	6626	6663	6700	6739	6779	6820	6862	6906	6952	7001
175	7051	7103	7158	7213	7272	7338	7404	7470	7535	7595
176	7652	7707	7758	7809	7857	7904	7950	7995	8038	8081
177	8125	8170	8214	8256	8298	8341	8385	8429	8474	8520
178	8567	8613	8661	8712	8762	8811	8859	8908	8956	9000
179	9043	9085	9127	9168	9208	9248	9287	9325	9365	9403
180	9441	9481	9521	9562	9602	9644	9688	9731	9774	9818
181	9862	9906	9949	9992	10035	10076	10117	10156	10195	10233
182	10270	10307	10343	10379	10414	10448	10482	10518	10553	10589
183	10624	10658	10692	10725	10760	10795	10830	10866	10904	10941

LAKE CONROE APRIL 1996 SURVEY

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

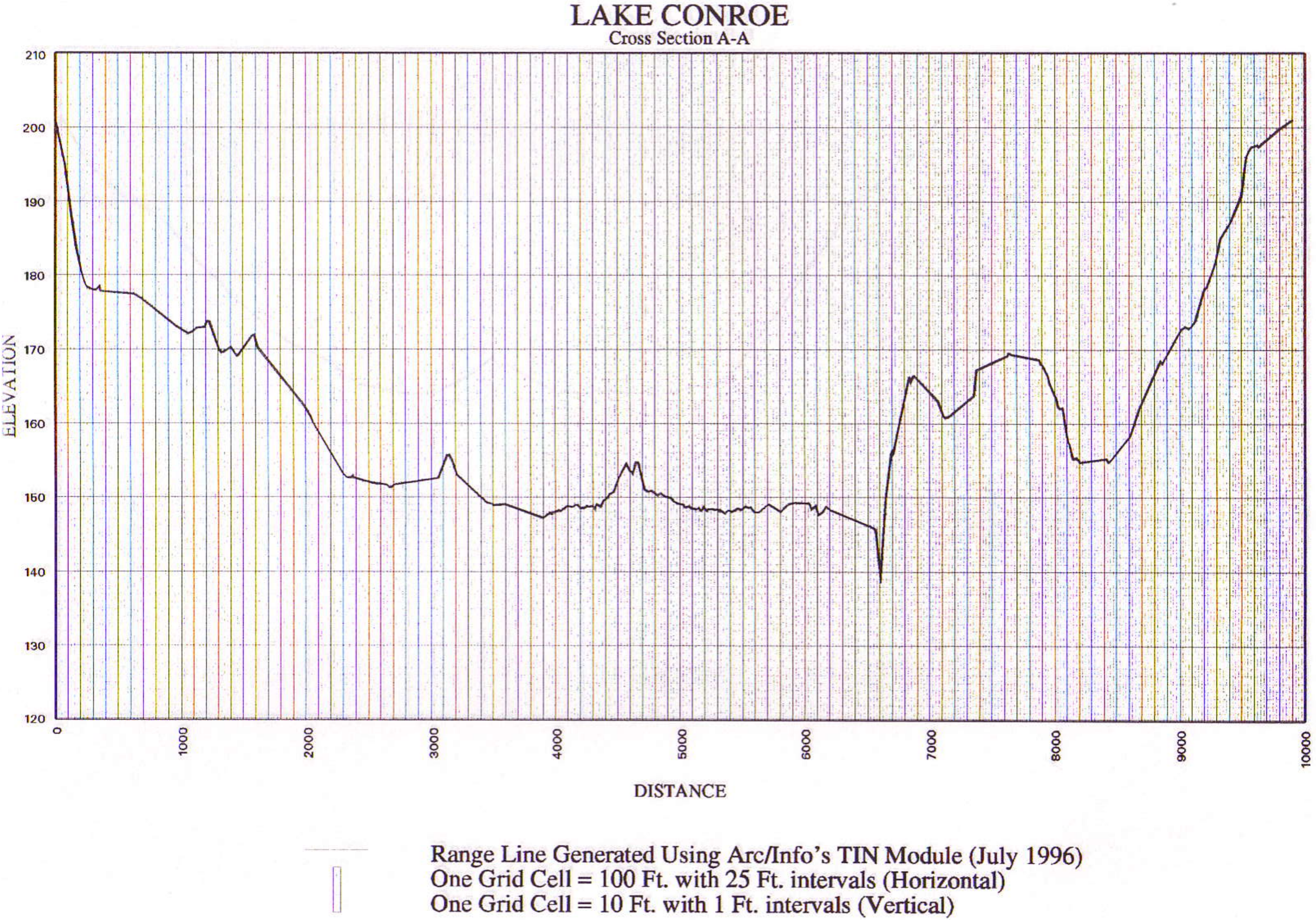
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
184	10980	11023	11063	11102	11140	11181	11221	11261	11300	11339
185	11377	11416	11455	11497	11539	11581	11625	11668	11710	11753
186	11796	11837	11879	11922	11966	12008	12051	12094	12137	12182
187	12226	12269	12314	12358	12404	12451	12499	12546	12592	12638
188	12682	12724	12765	12806	12845	12885	12925	12964	13003	13042
189	13082	13122	13162	13202	13242	13282	13322	13363	13404	13447
190	13489	13532	13574	13618	13661	13705	13748	13792	13836	13881
191	13926	13972	14020	14069	14120	14171	14222	14273	14325	14379
192	14433	14487	14539	14592	14644	14696	14748	14800	14852	14904
193	14956	15009	15063	15118	15172	15226	15281	15337	15393	15447
194	15501	15557	15613	15669	15725	15782	15841	15902	15960	16017
195	16074	16130	16186	16244	16301	16359	16418	16476	16536	16595
196	16655	16714	16772	16828	16884	16938	16992	17045	17099	17153
197	17221	17285	17363	17436	17508	17582	17659	17728	17788	17843
198	17901	17952	17998	18043	18089	18134	18179	18224	18269	18314
199	18361	18410	18459	18508	18558	18608	18658	18708	18758	18809
200	19087	19161	19235	19310	19386	19501	19581	19662	19743	19825
201	20118									

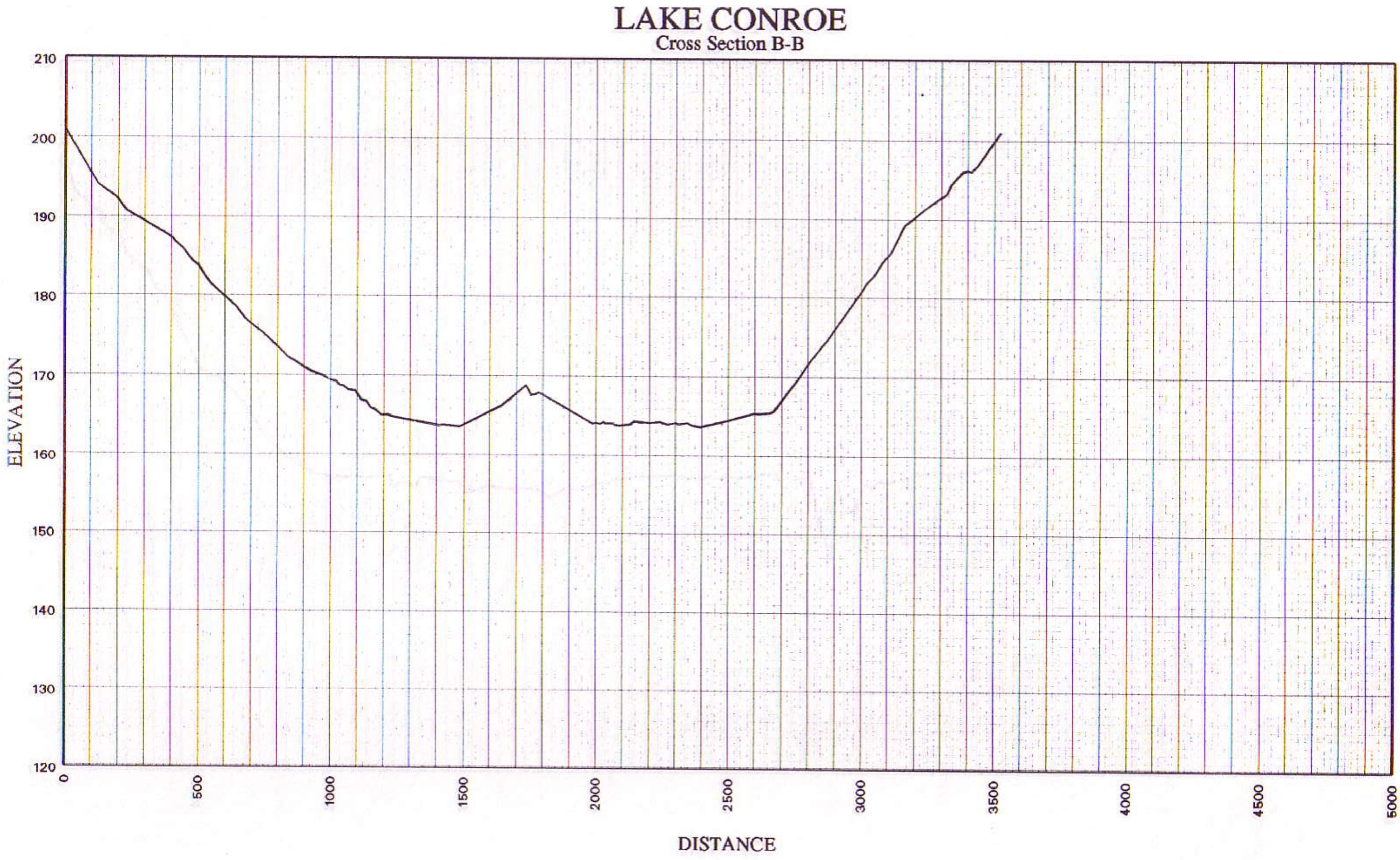


LAKE CONROE

April 1996 SURVEY

Prepared by: TWDB July 1996

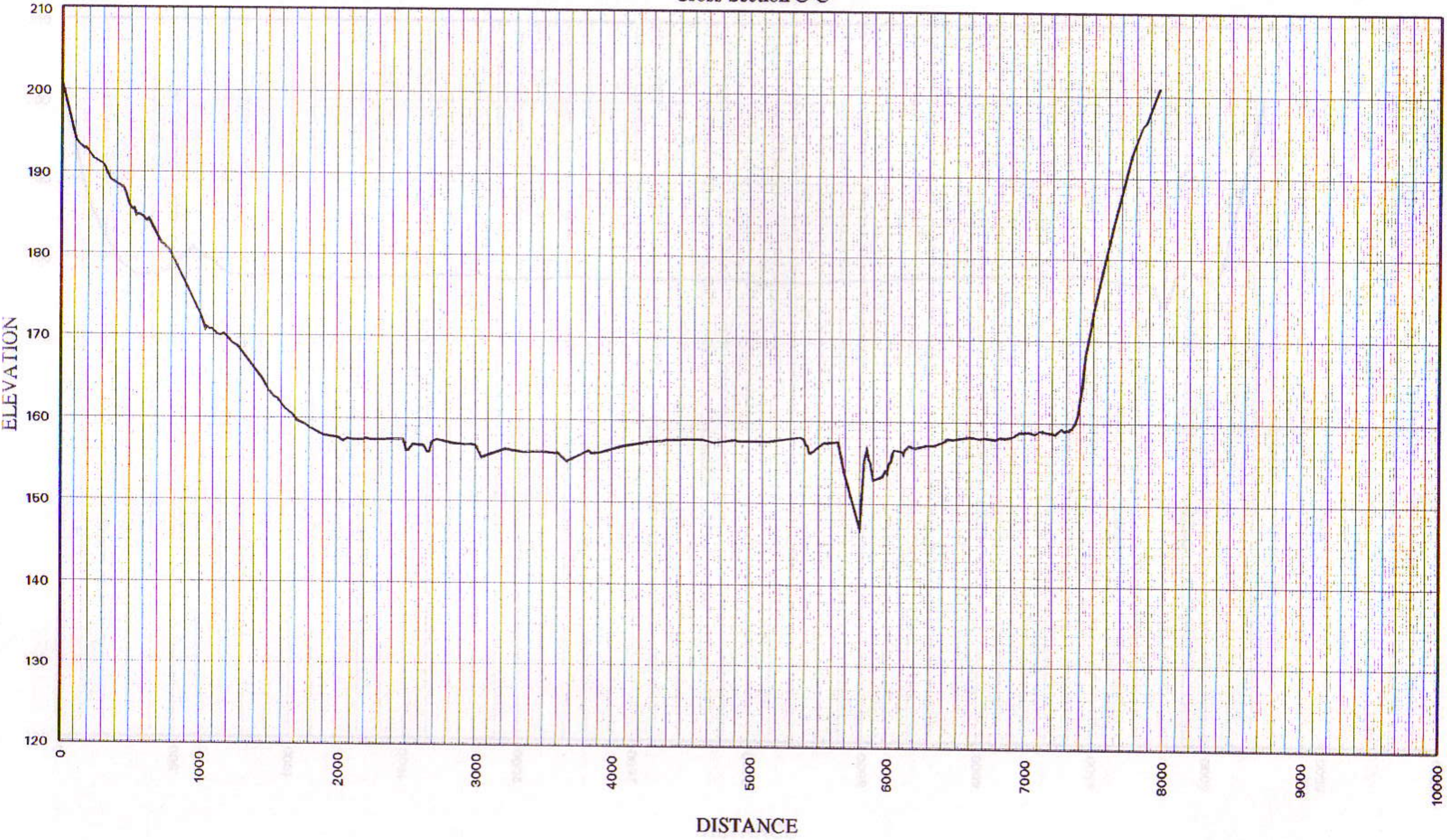

LAKE CONROE
Cross Section A-A
ELEVATION
210
200
190
180
170
160
150
140
130
120
DISTANCE
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Range Line Generated Using Arc/Info's TIN Module (July 1996)
One Grid Cell = 100 Ft. with 25 Ft. intervals (Horizontal)
One Grid Cell = 10 Ft. with 1 Ft. intervals (Vertical)



Range Line Generated Using Arc/Info's TIN Module (July 1996)
One Grid Cell = 100 Ft. with 25 Ft. intervals (Horizontal)
One Grid Cell = 10 Ft. with 1 Ft. intervals (Vertical)

LAKE CONROE

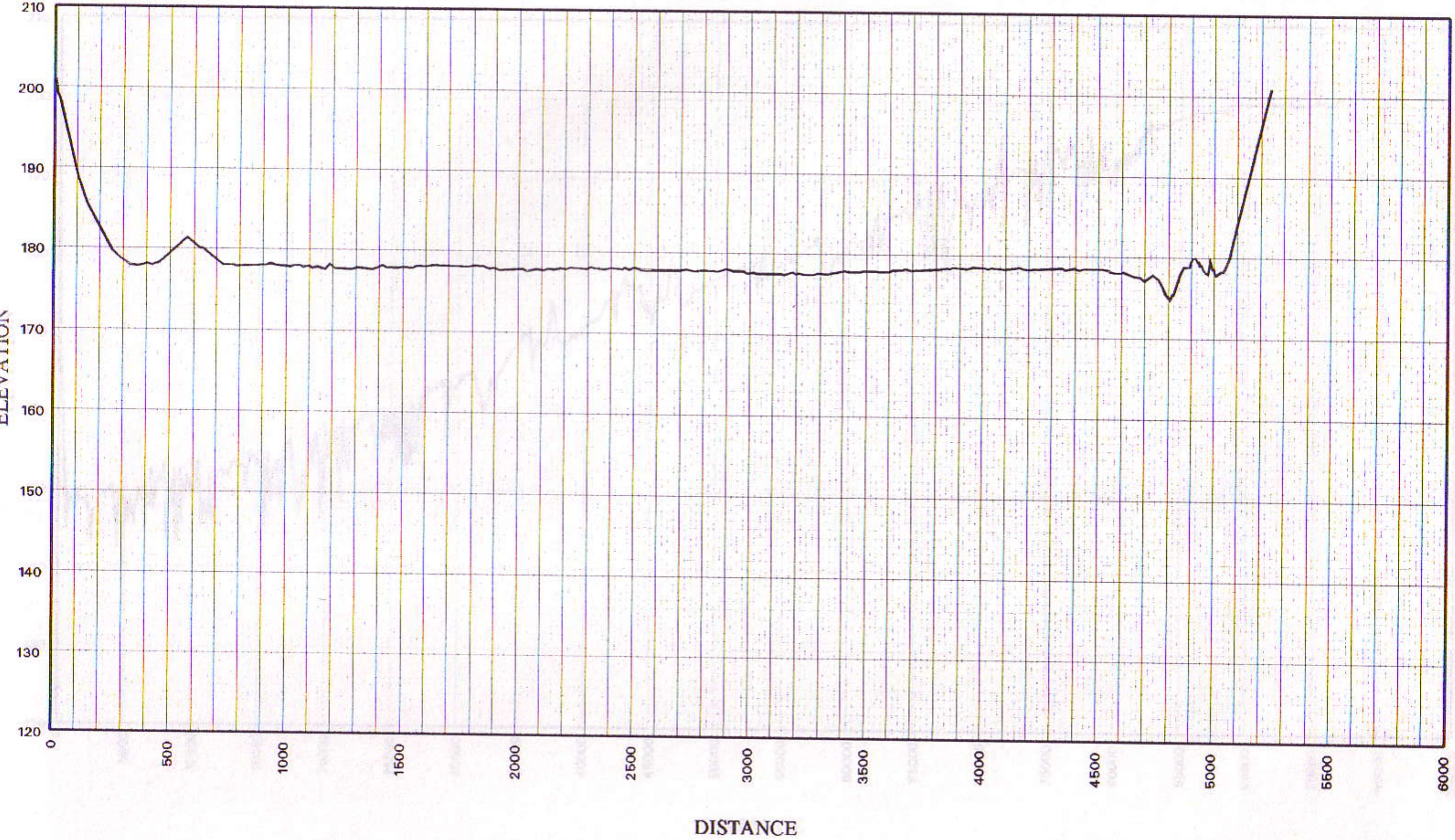
Cross Section C-C



Range Line Generated Using Arc/Info's TIN Module (July 1996)
One Grid Cell = 100 Ft. with 25 Ft. intervals (Horizontal)
One Grid Cell = 10 Ft. with 1 Ft. intervals (Vertical)

LAKE CONROE

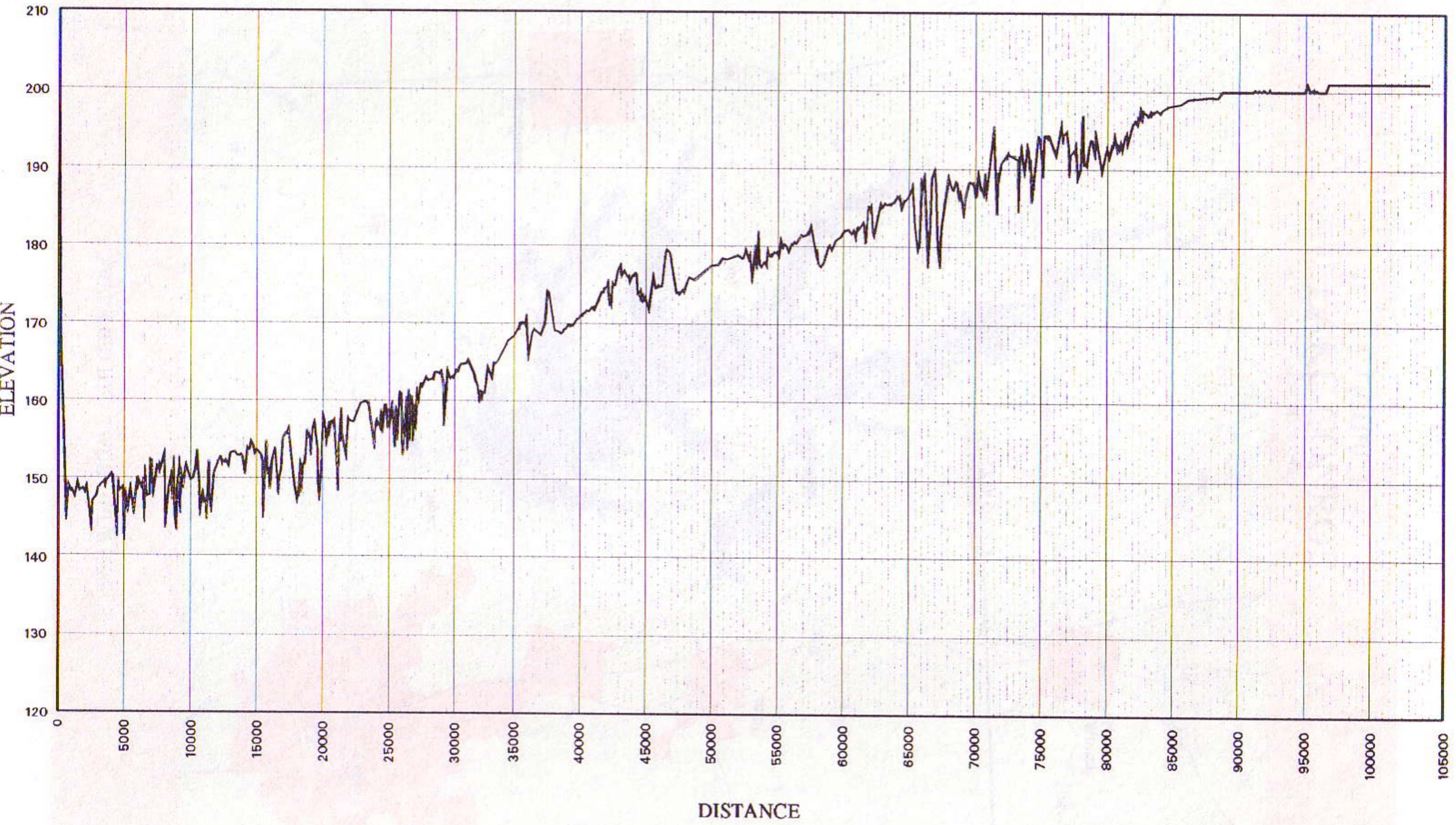
Cross Section D-D



Range Line Generated Using Arc/Info's TIN Module (July 1996)
One Grid Cell = 100 Ft. with 25 Ft. intervals (Horizontal)
One Grid Cell = 10 Ft. with 1 Ft. intervals (Vertical)

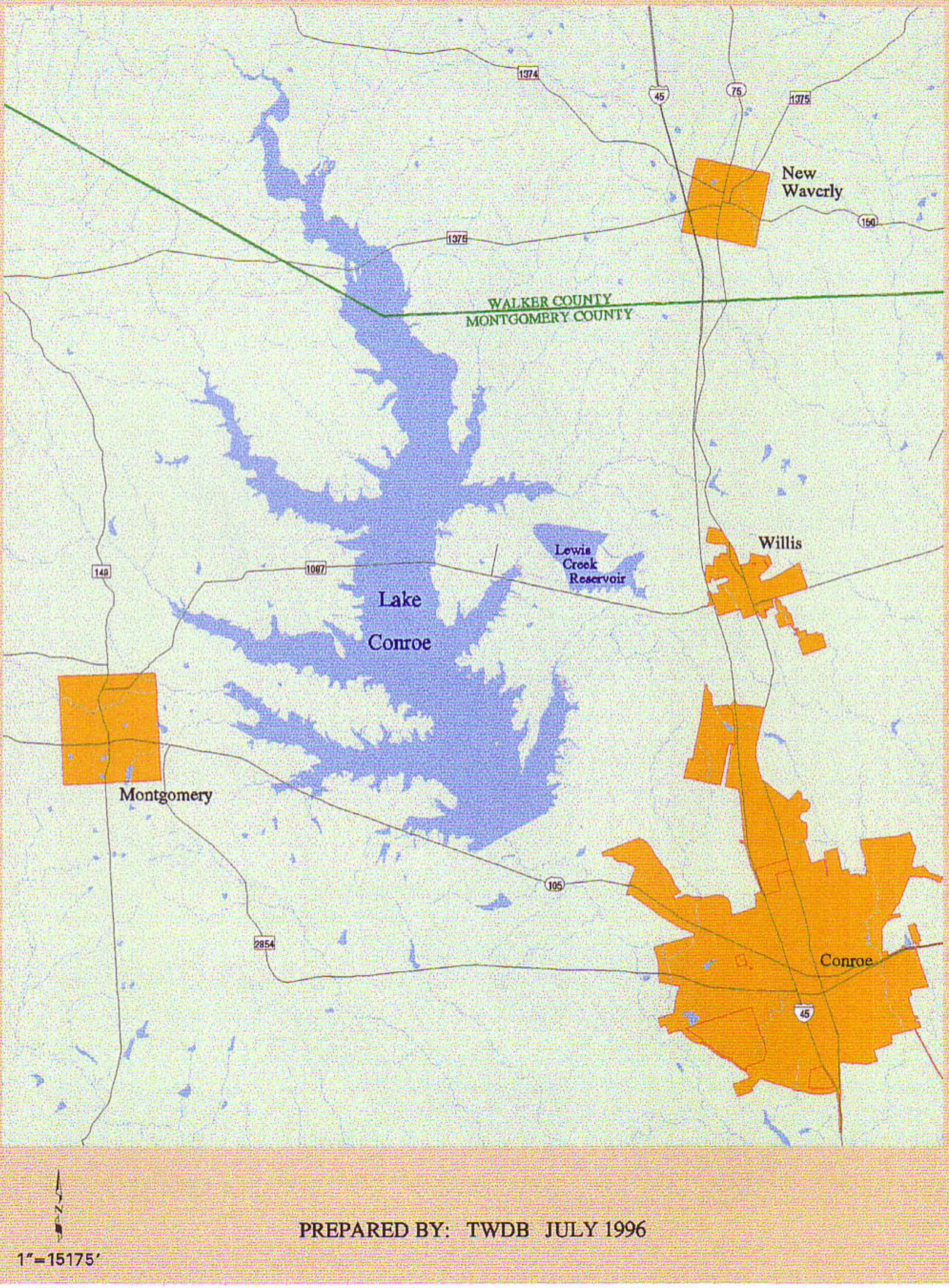
LAKE CONROE

Cross Section E-E



Range Line Generated Using Arc/Info's TIN Module (July 1996)
One Grid Cell = 5000 Ft. with 500 Ft. intervals (Horizontal)
One Grid Cell = 10 Ft. with 1 Ft. intervals (Vertical)

FIGURE 1
LAKE CONROE
Location Map

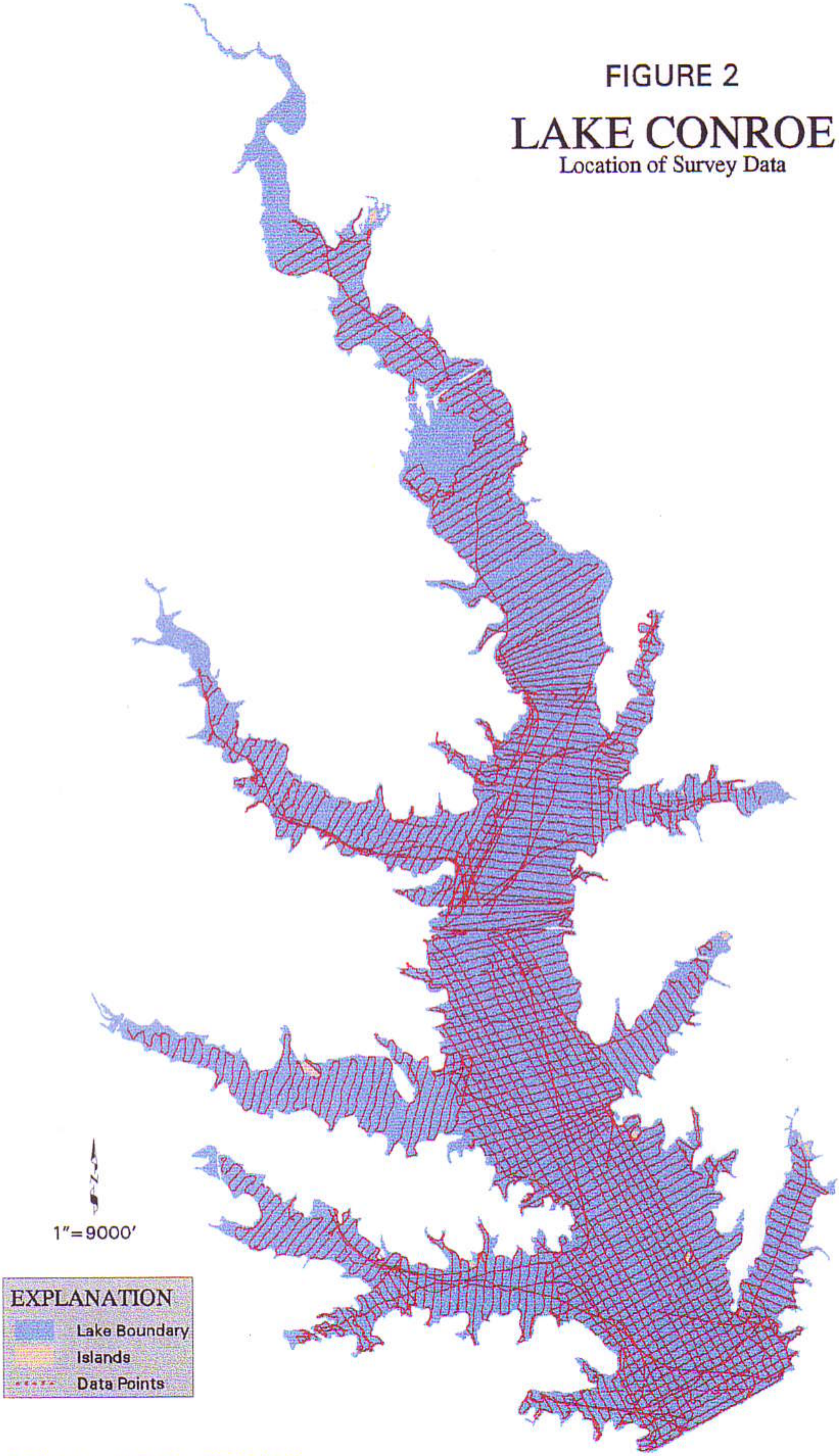


PREPARED BY: TWDB JULY 1996

FIGURE 2

LAKE CONROE

Location of Survey Data



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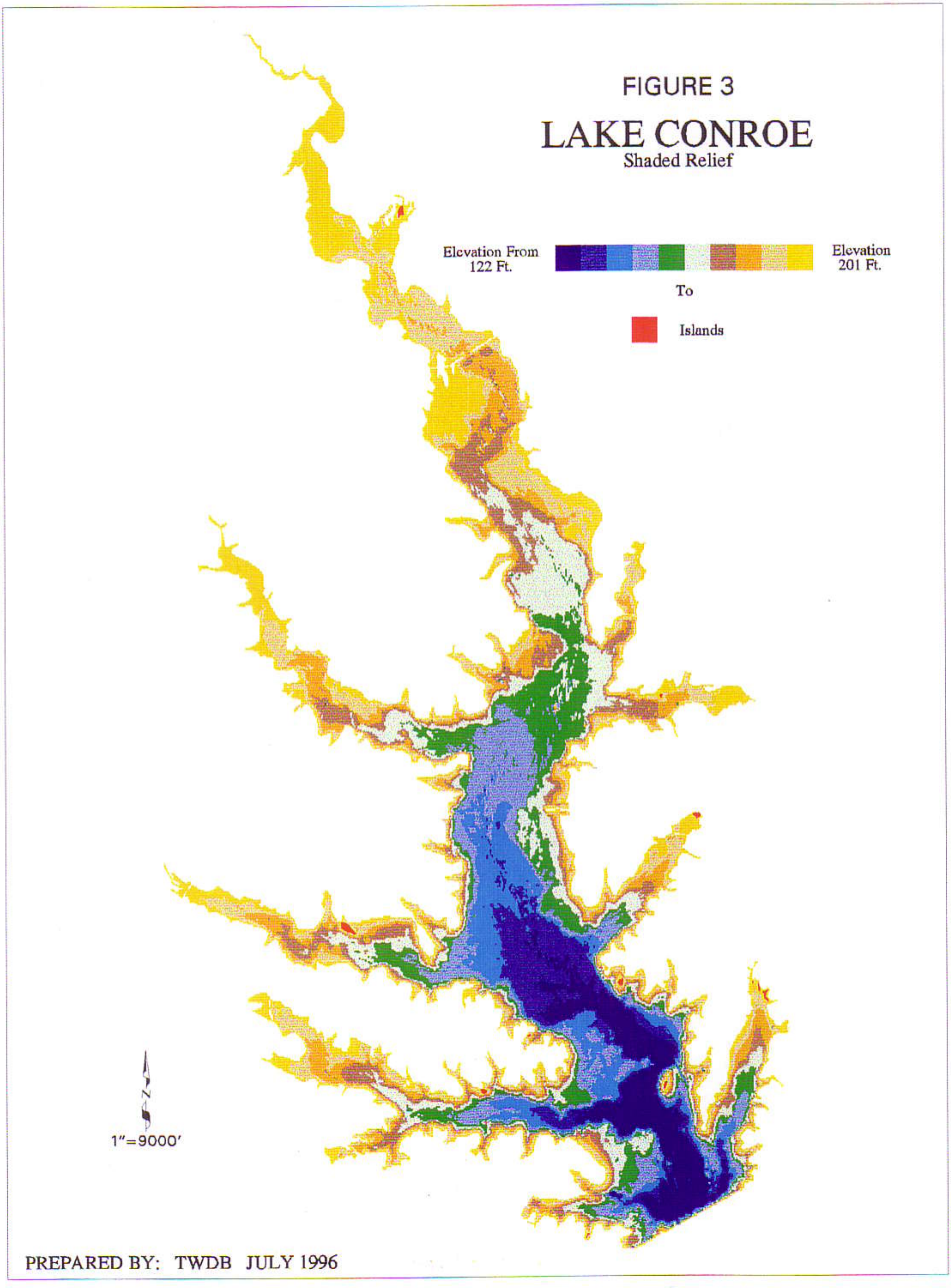
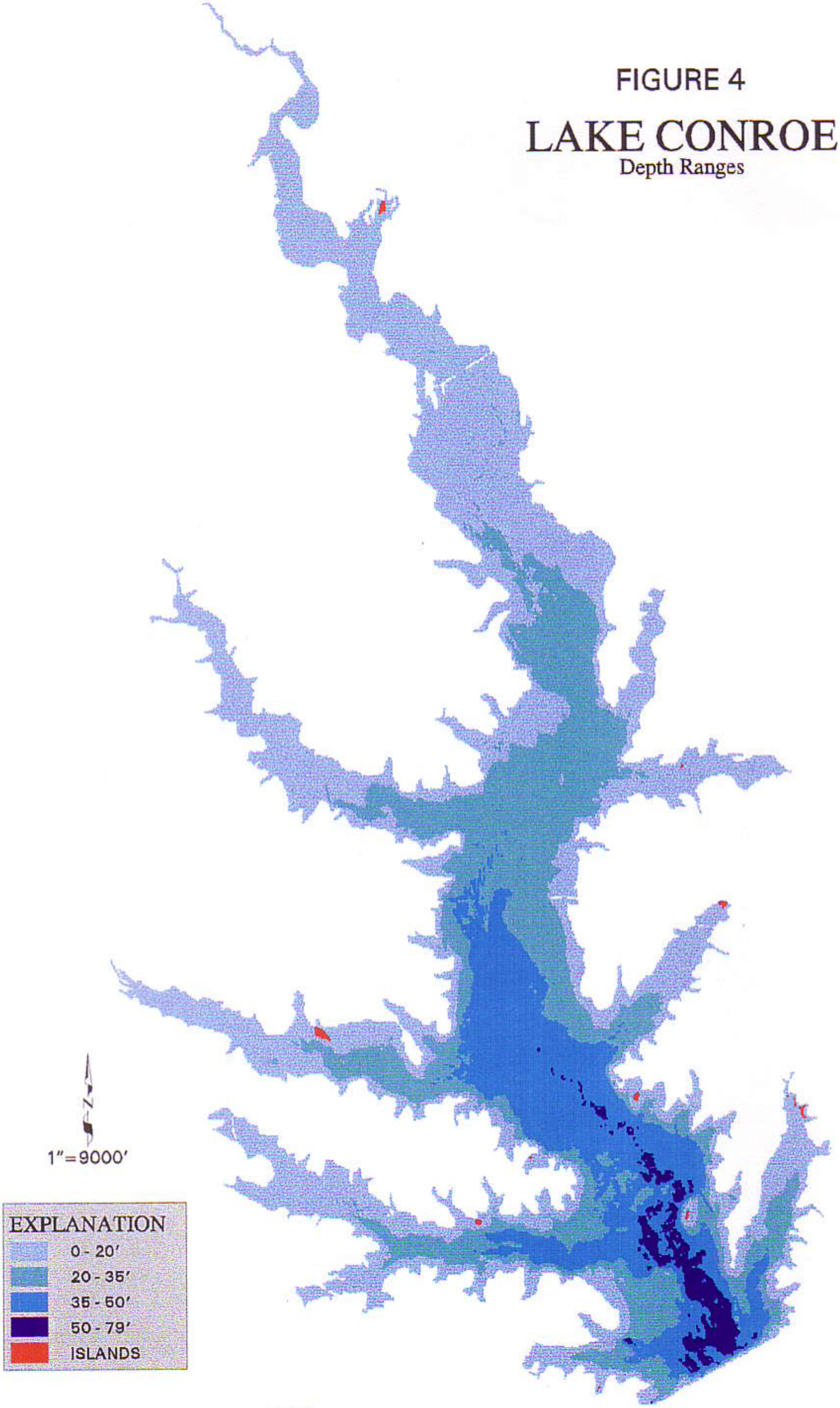


FIGURE 3
LAKE CONROE
Shaded Relief
Elevation From 122 Ft.
To
Elevation 201 Ft.
Islands
N
1"=9000'
PREPARED BY: TWDB JULY 1996

FIGURE 4

LAKE CONROE

Depth Ranges

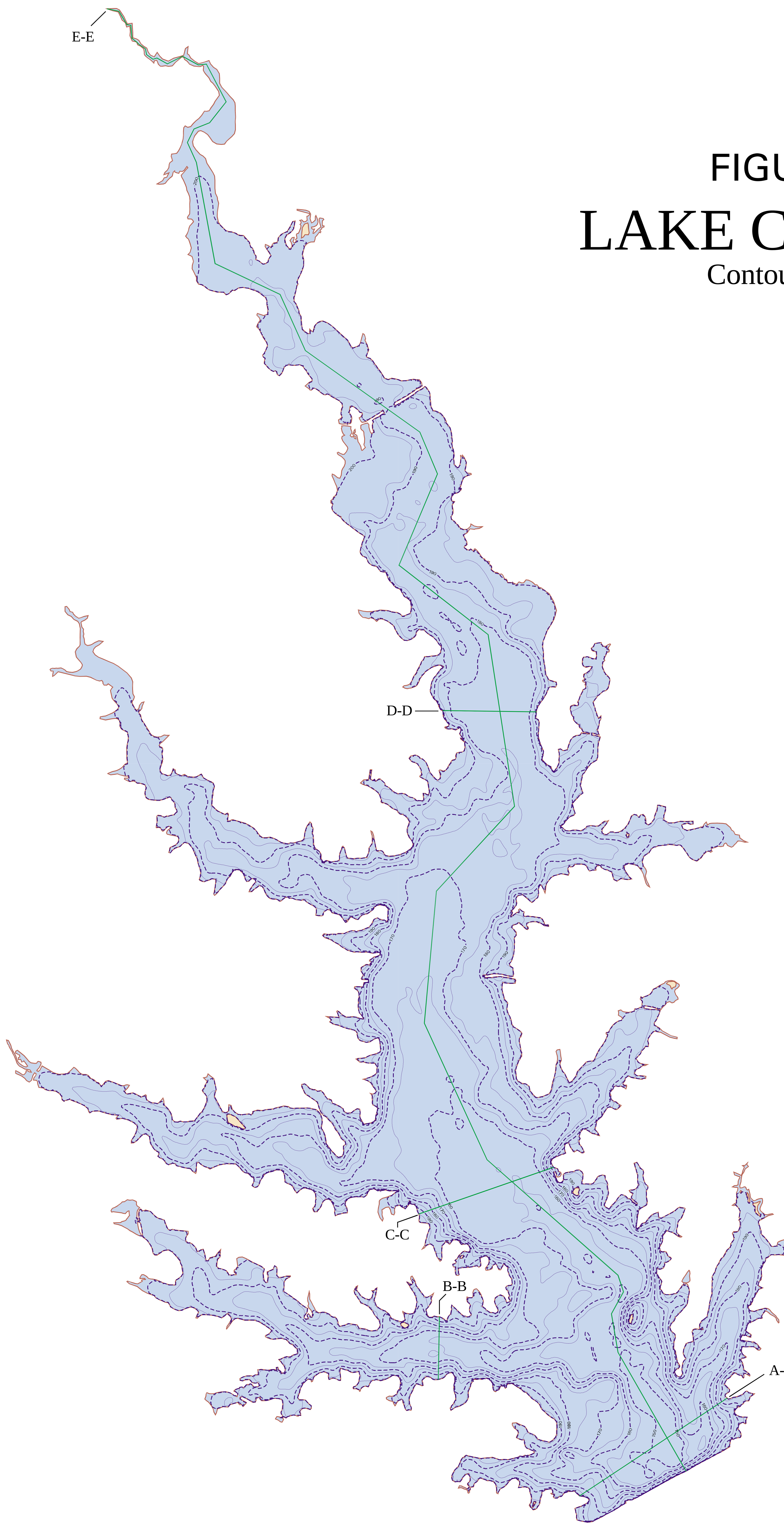


PREPARED BY: TWDB JULY 1996

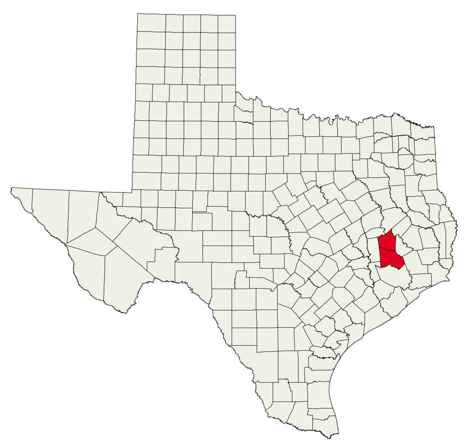
FIGURE 5

LAKE CONROE

Contour Map



1"=2750'



MONTGOMERY AND WALKER COUNTIES

EXPLANATION

- Islands
- 10 Ft. Contour Lines
- 5 Ft. Contour Lines
- Normal Pool Elevation 201 Ft.
- Cross Section Line

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Lake Conroe. The Texas Water Development Board makes no representations or assumes any liability if this information is used for other purposes such as boating maps.

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