VOLUMETRIC SURVEY
OF
LAKE PAT CLEBURNE

Prepared for:

City of Cleburne

Prepared by:

The Texas Water Development Board

March 10, 2003

Texas Water Development Board

This report was prepared by the Hydrographic Survey group:

Scot Sullivan, P.E.
Duane Thomas
Wayne Elliott
Priscilla Hays
Marc Sansom
For more information, please call (512) 936-0848

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

TABLE OF CONTENTS

INTRODUCTION 1

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR 1

HYDROGRAPHIC SURVEYING TECHNOLOGY 3
- GPS Information 3
- Equipment and Methodology 5
- Previous Survey Procedures 6

PRE-SURVEY PROCEDURES 7

SURVEY PROCEDURES 8
- Equipment Calibration and Operation 8
- Field Survey 9
- Data Processing 10

RESULTS 12

SUMMARY 12

APPENDICES

APPENDIX A - DEPTH SOUNDER ACCURACY
APPENDIX B - LAKE PAT CLEBURNE VOLUME TABLE
APPENDIX C - LAKE PAT CLEBURNE AREA TABLE
APPENDIX D - LAKE PAT CLEBURNE AREA-ELEVATION-CAPACITY GRAPH
APPENDIX E - CROSS-SECTION PLOTS

LIST OF FIGURES

FIGURE 1 - LOCATION MAP
FIGURE 2 - LOCATION OF SURVEY DATA
FIGURE 3 - SHADED RELIEF
FIGURE 4 - DEPTH CONTOURS
FIGURE 5 - 2-D CONTOUR MAP

LAKE PAT CLEBURNE
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Lake Pat Cleburne during the period of January 19 – 20, 1998. The purpose of the survey was to determine the capacity of the lake at the conservation pool elevation. 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 the elevation is noted otherwise. The conservation pool elevation for Lake Pat Cleburne is 733.5 feet. The 1958 design information/field survey estimates the original surface area at this elevation to be 1,545 acres and the storage volume to be 25,560 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Pat Cleburne and Cleburne Dam are owned and operated by the City of Cleburne. The lake is located on Nolan Creek in Johnson County, approximately four miles south of Cleburne, Texas (see Figure 1). Records indicate the drainage area for the lake is 100 square miles. At the conservation pool elevation, the lake has approximately 15.325 miles of shoreline and is just over three and one-half miles long. The widest point of the lake is approximately one and one-half miles (located four-tenths of a mile upstream of the dam).

Water rights Permit No. 2027, dated October 1, 1962, was issued to the City of Cleburne. This permit authorized the construction of a dam and reservoir to impound 25,600 acre-feet of water. It also granted the City of Cleburne the right to divert and use annually 6,000 acre-feet of water for municipal purposes. The Texas Water Commission issued Certificate of Adjudication No. 12-4106 on February 28, 1986. The certificate basically reinforces the authorization for the City of Cleburne to impound 25,600 acre-feet of water and to divert and use not to exceed 5,760 acre-feet of water per year for municipal purposes. The certificate also authorizes the owner to use 240 acre-feet of water annually for irrigation purposes.

Records indicate the construction for Lake Pat Cleburne and Dam started August 9, 1963 and deliberate impoundment began August 4, 1964 when the construction was completed. The design engineer was Hunter Associates and the general contractor was Moorman and Singleton. The estimated cost of the dam was $1,316,600.

Cleburne Dam and appurtenant structures consist of a rolled-earth embankment, 4,900 feet in length, with a maximum height of 76 feet and a crest elevation of 753.0 feet. The service spillway is an uncontrolled concrete weir and chute located at the left (east) end of the embankment. The concrete weir is 150 feet in length at elevation 733.5 feet. The emergency spillway, located at the right (west) end of the embankment, is an earth trench cut through the natural ground. The crest is 500 feet in length at elevation 744.0 feet. The outlet works consist of a vertical-octagon shaped shaft located upstream of the dam near the original streambed. A walkway from the embankment to the outlet structure serves for access to the controls of the outlet works. There are two 36-inch diameter sluice gates with control valves located in the outlet works tower. One opening has an invert elevation of 722.0 feet and the other opening's invert elevation is 690.0 feet. The releases from these outlets flow through a 30-inch steel pipe (encased in a 36-inch diameter concrete pipe). Near the downstream toe of the embankment, two 30-inch pipes branch from the outlet conduit. One pipe, with a valve control, discharges water downstream into the natural streambed. The other 30-inch diameter pipe supplies water to the filtration and treatment plant located at the east abutment of the dam.

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.

The United States Air Force and the defense establishment developed GPS technology in the 1960's. 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 the 1983 North American Datum (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) is an advance mode of satellite surveying in which positions of moving objects can be determine in real-time or "on-the-fly." This technological breakthrough was the backbone of the development of the TWDB's Hydrographic Survey Program. In the early stages of the 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 another 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. This type of operation can obtain a horizontal positional accuracy of within one meter. In addition, the large positional errors experienced by a single receiver when S/A is active are negated. Since a greater accuracy is needed in the vertical direction, the depth sounder supplies vertical data during a survey. The lake surface during the survey serves as the vertical datum for the readings from the depth sounder.

The need for setting up a stationary shore receiver for current surveys has been eliminated by registration with a fee-based satellite reference position network (OmniSTAR). This service works in a differential mode basically the same way as the shore station, except on a worldwide basis. For a given area in the world, a network of several monitoring sites (with known positions) collect GPS signals from the NAVSTAR network. GPS corrections are computed at each of these sites to correct the GPS signal received to the known coordinates of the site. The corrections from each of the sites within the network are automatically sent via a leased line to a "Network Control Center" where the data corrections are checked and repackaged for up-link to a "Geostationary" L-band satellite. The "real-time" corrections for the entire given area in the world are then broadcast by the satellite to users of the system in the area covered by the satellite. The OmniSTAR receiver translates the information and supplies it to the on-board Trimble receiver for correction of the boat's GPS positions. The accuracy of this system in a real-time mode is normally one meter or less.

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 OmniSTAR receiver, and an on-board 486 computer. A water-cooled generator through an in-line uninterruptible power supply provided electric power. 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 with 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 remained a major cost with this method.

More recently, aerial photography has been used prior to construction, to generate elevation contours from which 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 733.5). The boundary file was created from the 7.5 minute USGS quadrangle map, CLEBURNE WEST, TX., 1961 (Photo-revised, 1978). The graphic boundary file created was then transformed into the proper datum, from NAD '27 datum to NAD '83, using Environmental Systems Research Institute'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 34 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 Lake Pat Cleburne 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 Lake Pat Cleburne, the speed of sound in the water column remained constant at 4,742 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 positive 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 were collected at Lake Pat Cleburne during the period of January 19 - 20, 1998. Weather conditions were excellent with moderately cool temperatures and mild winds. Approximately 176,302 data points were collected over the 45 miles traveled along the 47 survey lines run (pre-planned, random, and parallel). These points were stored digitally on the boat's computer in 44 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. Random data lines were also collected parallel to the original streambed in the main body of the lake. Figure 2 shows the actual location of all data collection points.

TWDB staff observed the land surrounding the lake to be generally flat. The east bank was fairly developed with numerous residences and a golf course. Several fishermen were scattered along the east bank and many golfers were enjoying the break from the cold weather. In contrast, the West

Bank was void of any development or activity. Within the lake, there were two islands just south of the highway 67 bridge and one just north of the bridge. The TWDB vessel could not get to the East Side of the island north of the bridge due to shallow water.

While performing the survey on the lake, TWDB staff noted some interesting characteristics. On the depth sounder, a gentle bottom slope was noted from the shoreline to the center of the old streambed. From the survey vessel, the crew could see that the water was fairly clear with minimal underwater vegetation and that the lake surface was void of any navigational hazards such as standing trees or stumps. There was an inundated house near the West Bank directly across from the public boat ramp. Sediment deposits were also observed in the area just south of the highway 67 bridge. The crew was able to collect data in this area, but at a much slower pace. The end of the survey occurred when the survey crew reached a point in the Nolan River where the river was consistently too narrow to turn the vessel.

All of the collected data were stored in individual data files for each pre-plotted range line or random data collection event. Each of these files is tagged with a unique file tag, representative of the lake being surveyed. At the end of each day, the data files were copied to diskettes, for future processing in the office.

Data Processing

The collected data were downloaded 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 varied between 733.85 and 733.87 feet. After all changes had been made to the raw data file, the edited file was saved with a different extension. The edited files were combined into a single X,Y,Z 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 data file was imported into the UNIX operating system used to run Environmental System Research Institute'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 software 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 downsized 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 some areas where volume and area values could not be calculated by interpolation because of a lack of information within 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 23 additional points were required for interpolation and contouring of the entire lake surface at elevation 733.5. Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 731.0 to elevation 733.5, the surface areas and volumes of the lake were mathematically estimated. This was done first by distributing uniformly across each elevation increment; the surface areas digitized from USGS topographic maps. Volumes were then calculated in a 0.1 foot step method by adding to the existing volume, 0.1 of the existing area, and 0.5 of the difference between the existing area the area for the value being calculated. The computed area of lake at elevation 733.5 was

1,558 surface acres. The computed area was 13 surface acres more than originally calculated in 1958. 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 733.5 lake elevation was assigned the color of yellow. Different color shades were assigned to the intermediate depths. Figure 3 presents the resulting depth 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 smooth cartographic contours versus using the sharp-engineered contours. The resulting contour map of the bottom surface at two-foot intervals is presented in Figure 5.

RESULTS

Results from the 1998 TWDB survey indicate Lake Pat Cleburne encompasses 1,558 surface acres and contains a volume of 25,730 acre-feet at the conservation pool elevation of 733.5 feet. The shoreline at this elevation was calculated to be 15.325 miles. The deepest point of the lake, elevation 690.0 or 33.5 feet of depth was located approximately 1,505 feet north from the center of the dam. The dead storage volume, or the amount of water below the lowest outlet in the dam, was calculated to be 0.0 acre-feet based on the low flow outlet invert elevation of 690.0 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, is therefore also, 25,730 acre-feet.

SUMMARY

Lake Pat Cleburne was formed in 1964. Initial storage calculations estimated the volume at the conservation pool elevation of 733.5 feet to be 25,560 acre-feet with a surface area of 1,545 acres.

During the period of January 19 - 20, 1998, a hydrographic survey of Lake Pat Cleburne was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1998 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 Pat Cleburne than previous survey methods. Results indicate that the lake's capacity at the conservation pool elevation of 733.5 feet was 25,730 acre-feet and the area was 1,558 acres.

The 1998 calculated volume for Lake Pat Cleburne at the conservation pool elevation of 733.5 feet is 170 acre-feet more than the reported original volume of the lake. Therefore, no estimated sedimentation rate can be determined from this survey.

It is difficult to compare the original design information and the TWDB performed survey because little is know about the original design method, the amount of data collected, and the method used to process the collected data. However, the TWDB considers the 1998 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):

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

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

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

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

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

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

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

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

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

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

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

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR VOLUME TABLE

Apr 2 1998

Lake Pat Cleburne   January 1998 Survey

VOLUME IN ACRE-FEET   ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
690										
691					1	1	1	2	2	2
692	3	3	4	5	6	7	8	9	11	12
693	14	15	17	19	21	24	26	28	31	34
694	36	39	42	45	49	52	55	59	63	66
695	70	75	79	83	88	92	97	102	107	113
696	118	124	130	136	142	149	155	162	169	177
697	184	192	199	207	216	224	232	241	249	258
698	267	277	286	296	305	315	326	336	347	357
699	369	380	391	403	415	427	439	451	464	477
700	490	503	516	530	544	558	572	587	601	616
701	631	647	663	679	695	712	729	746	763	781
702	798	816	835	853	872	891	910	930	950	970
703	991	1011	1033	1054	1076	1098	1120	1143	1166	1190
704	1213	1237	1261	1286	1311	1336	1361	1387	1413	1439
705	1466	1493	1520	1548	1576	1604	1632	1661	1690	1719
706	1749	1779	1809	1839	1870	1901	1932	1963	1995	2027
707	2059	2091	2124	2156	2189	2223	2256	2290	2324	2358
708	2392	2427	2462	2497	2533	2569	2605	2641	2678	2715
709	2753	2790	2829	2867	2906	2945	2984	3024	3064	3104
710	3145	3186	3228	3270	3312	3355	3398	3441	3485	3529
711	3574	3619	3665	3711	3757	3804	3852	3899	3947	3996
712	4045	4094	4144	4194	4244	4295	4346	4398	4450	4503
713	4555	4609	4662	4717	4771	4826	4882	4938	4994	5051
714	5108	5166	5224	5282	5341	5401	5460	5521	5581	5642
715	5704	5766	5828	5891	5954	6017	6082	6146	6211	6277
716	6343	6409	6476	6544	6612	6680	6749	6818	6888	6958
717	7028	7099	7170	7242	7314	7386	7459	7533	7607	7681
718	7756	7832	7907	7984	8061	8138	8216	8294	8372	8451
719	8531	8611	8691	8772	8854	8936	9018	9101	9184	9268
720	9352	9437	9522	9608	9694	9781	9868	9956	10045	10133
721	10223	10312	10403	10493	10584	10676	10768	10861	10954	11048
722	11142	11237	11332	11428	11524	11621	11718	11816	11914	12012
723	12112	12211	12311	12412	12513	12614	12716	12819	12922	13026
724	13130	13234	13340	13445	13552	13658	13766	13874	13982	14091
725	14201	14311	14422	14533	14645	14757	14870	14984	15098	15213
726	15328	15444	15560	15677	15795	15913	16032	16151	16271	16392
727	16513	16635	16757	16880	17004	17129	17254	17380	17506	17633
728	17761	17890	18019	18149	18280	18411	18543	18676	18809	18943
729	19078	19213	19349	19485	19623	19761	19899	20039	20179	20319
730	20460	20602	20744	20887	21031	21175	21319	21464	21609	21756
731	21905	22054	22203	22352	22502	22652	22803	22954	23105	23256
732	23408	23561	23713	23866	24020	24173	24327	24482	24637	24792
733	24947	25103	25259	25416	25572	25730				

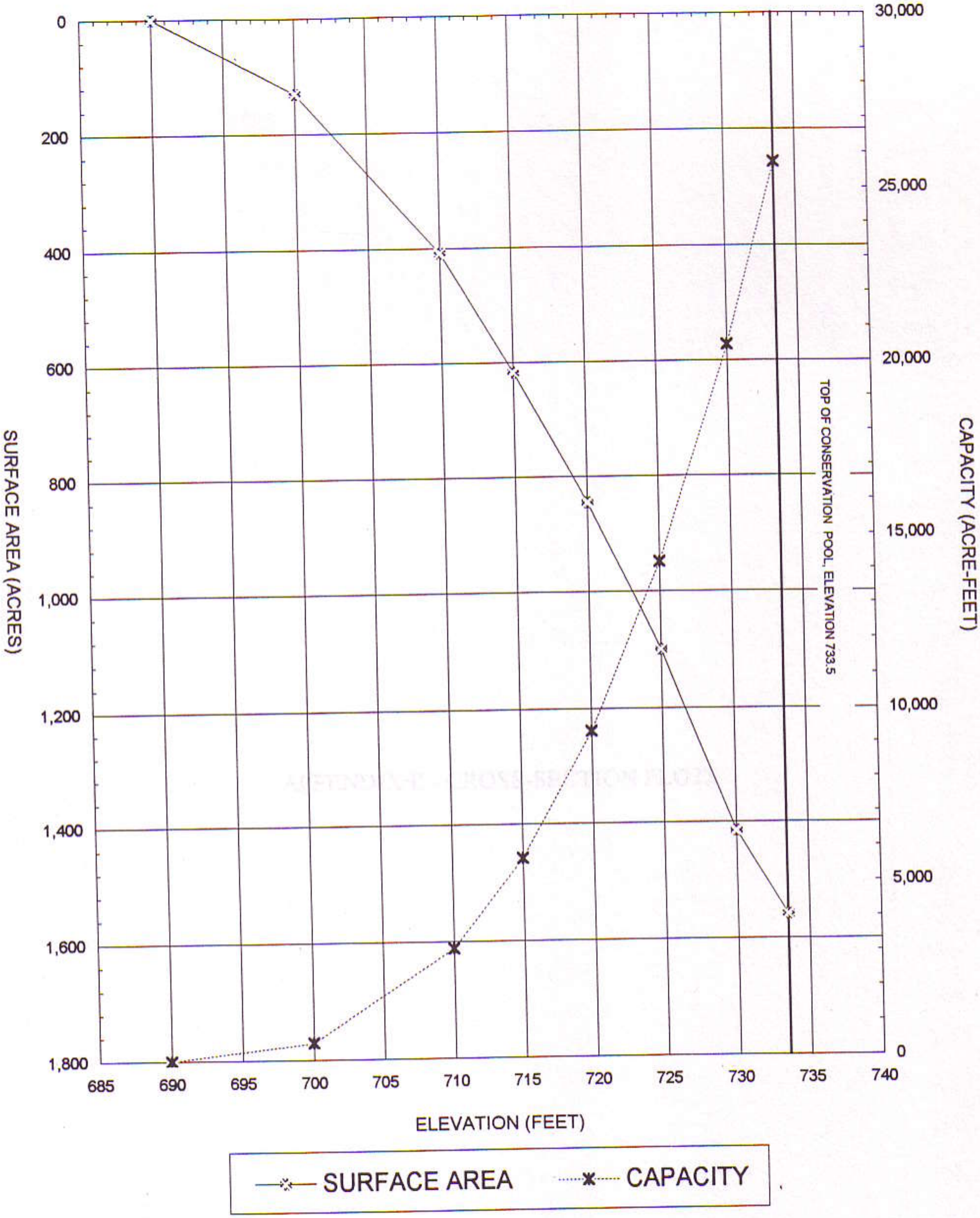
TEXAS WATER DEVELOPMENT BOARD
RESERVOIR AREA TABLE

Apr 2 1998

Lake Pat Cleburne   January 1998 Survey

AREA IN ACRES   ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
690										
691	1	1	1	2	2	3	3	4	4	5
692	5	6	8	9	10	11	12	13	14	16
693	17	18	20	21	22	23	24	25	26	27
694	28	29	30	32	33	34	35	36	38	39
695	40	42	43	45	46	48	49	51	53	55
696	56	58	60	62	64	66	68	70	72	74
697	75	77	79	80	82	83	85	86	88	90
698	92	93	95	97	99	101	103	105	107	109
699	111	113	115	117	120	122	123	125	127	129
700	131	133	135	137	140	142	144	146	148	151
701	153	156	159	163	165	168	170	172	174	177
702	179	181	184	186	189	192	195	198	201	204
703	207	210	213	217	220	223	226	229	232	235
704	238	241	244	246	250	253	256	259	262	265
705	268	271	274	277	279	283	286	289	292	294
706	297	300	303	305	308	310	312	315	317	320
707	322	324	327	329	331	334	336	338	341	343
708	346	349	352	354	357	360	363	366	369	373
709	376	379	383	386	389	393	396	399	403	406
710	409	413	416	421	425	429	433	437	441	445
711	450	454	458	463	467	471	475	479	483	487
712	491	495	499	503	507	510	514	518	522	526
713	531	535	540	544	548	552	557	561	566	570
714	575	579	583	587	592	596	600	604	608	613
715	617	621	625	630	634	639	644	648	653	658
716	663	668	672	677	681	686	690	694	698	702
717	706	710	714	719	723	728	733	738	742	747
718	752	756	761	766	770	775	779	784	789	793
719	798	802	807	811	816	821	826	830	835	840
720	845	850	856	861	866	871	876	881	886	890
721	895	900	904	909	914	919	924	929	935	940
722	945	950	955	960	965	970	975	979	984	989
723	993	998	1003	1008	1013	1018	1023	1028	1033	1039
724	1044	1049	1055	1060	1066	1071	1077	1082	1088	1093
725	1099	1104	1110	1115	1121	1127	1133	1139	1145	1151
726	1156	1162	1168	1174	1179	1185	1191	1197	1203	1209
727	1215	1221	1227	1234	1241	1248	1255	1263	1270	1277
728	1283	1290	1297	1303	1310	1316	1323	1329	1336	1342
729	1349	1356	1363	1370	1377	1383	1390	1396	1403	1409
730	1415	1421	1426	1431	1437	1442	1447	1452	1458	1464
731	1470	1473	1477	1481	1484	1488	1491	1495	1498	1502
732	1505	1509	1512	1516	1519	1523	1526	1530	1534	1537
733	1541	1544	1548	1551	1555	1558				

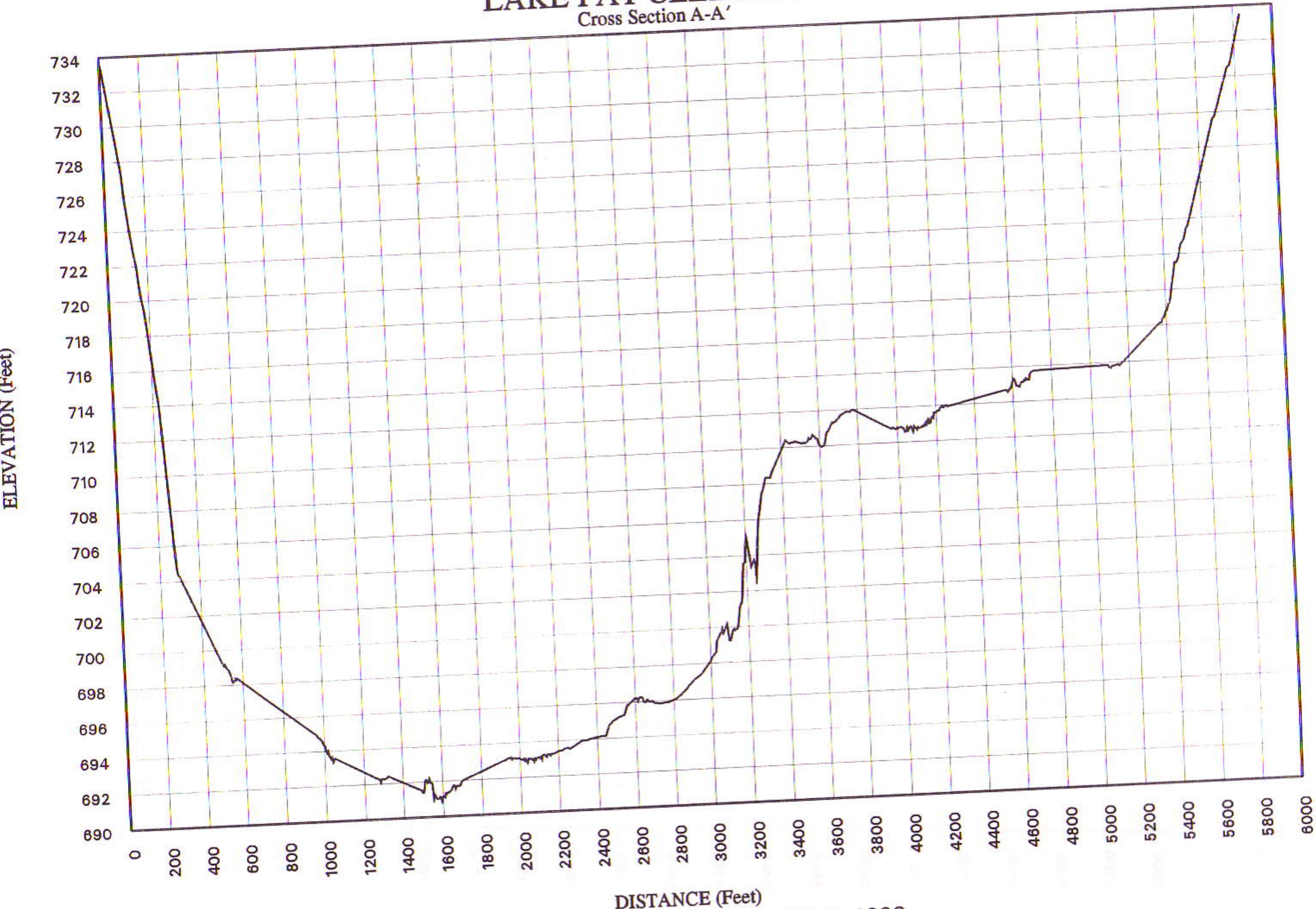


LAKE PAT CLEBURNE

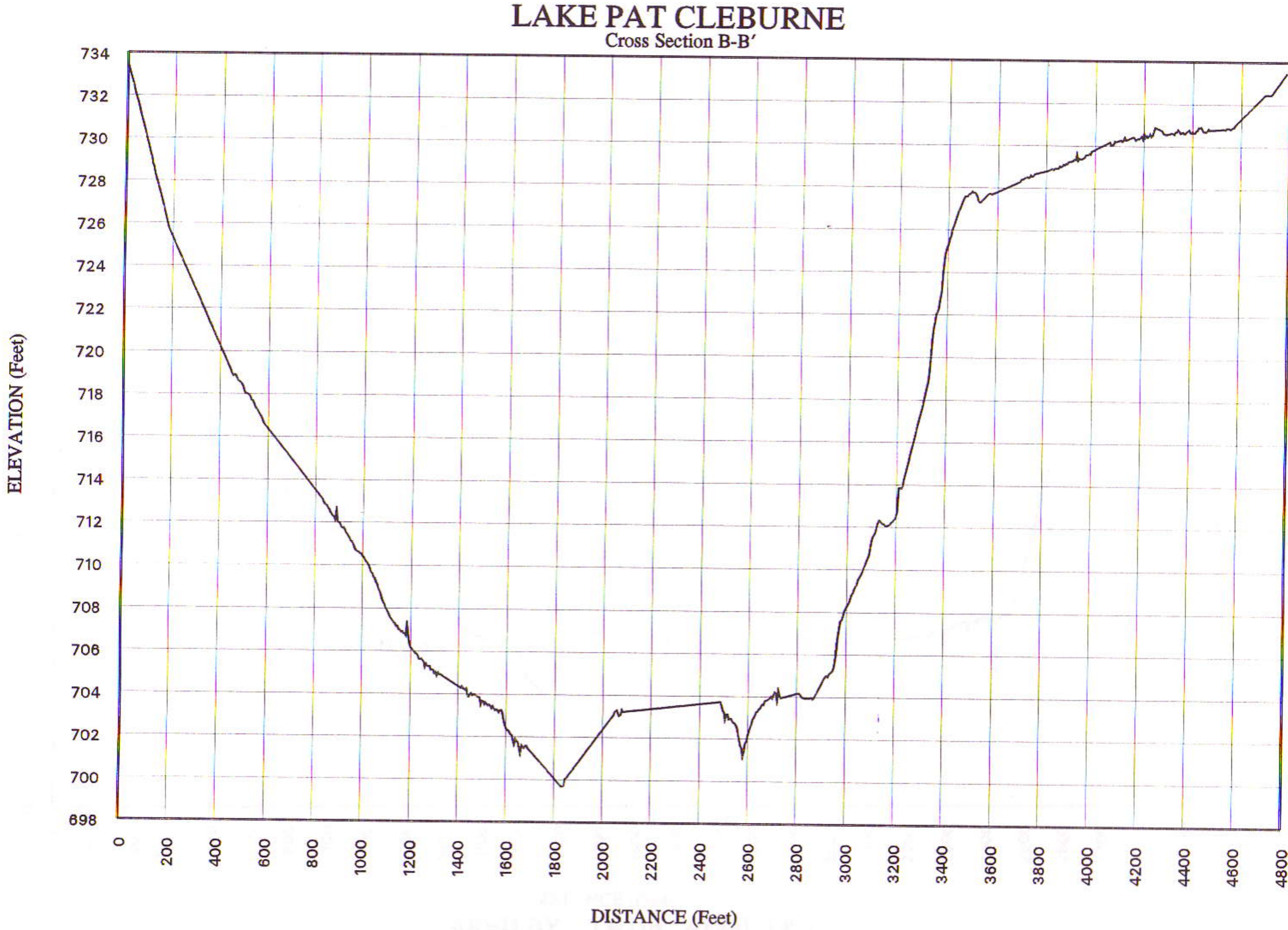
January 1998 Survey

Prepared by: TWDB April 1998

LAKE PAT CLEBURNE
Cross Section A-A′

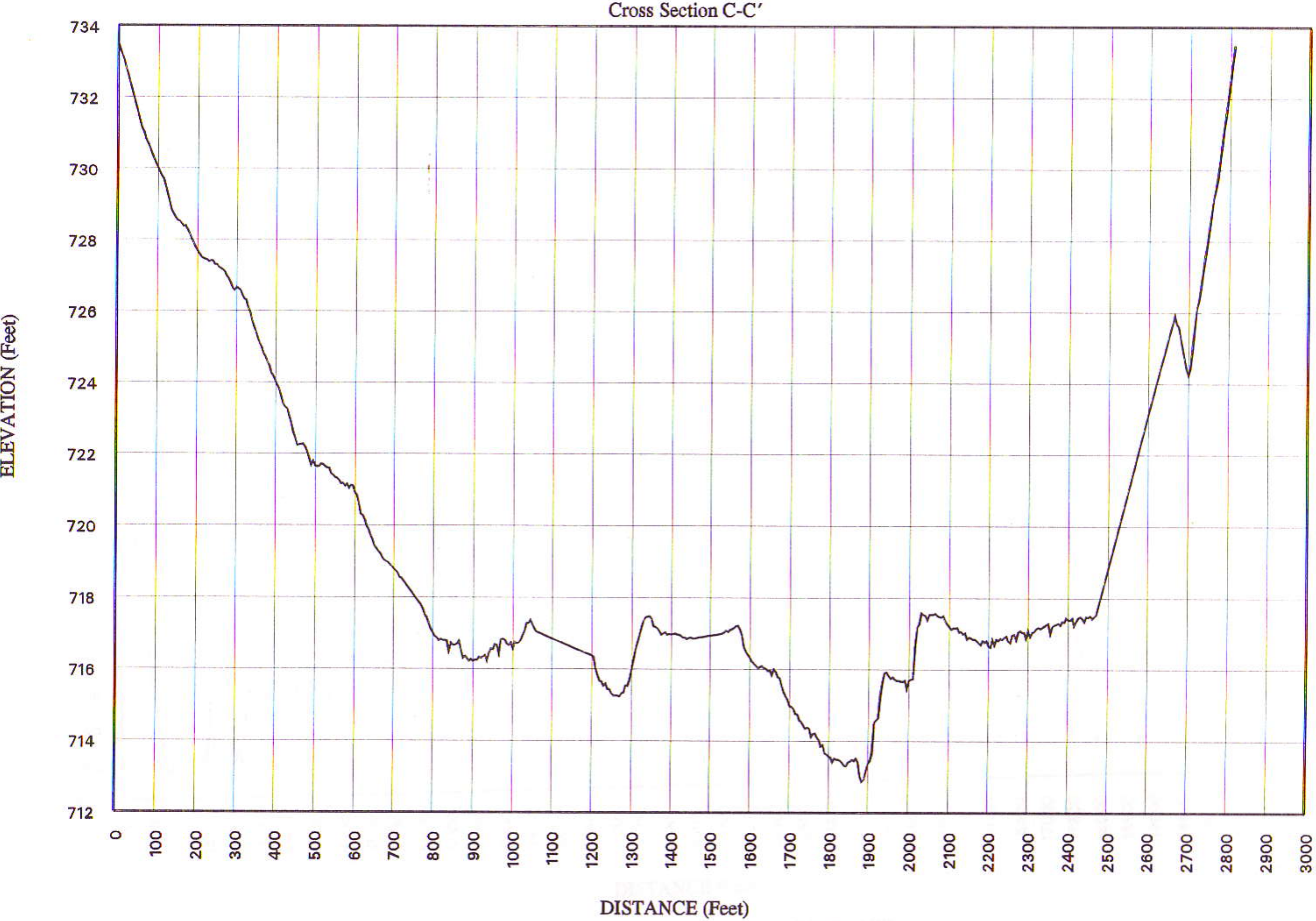


PREPARED BY: TWDB APRIL 1998



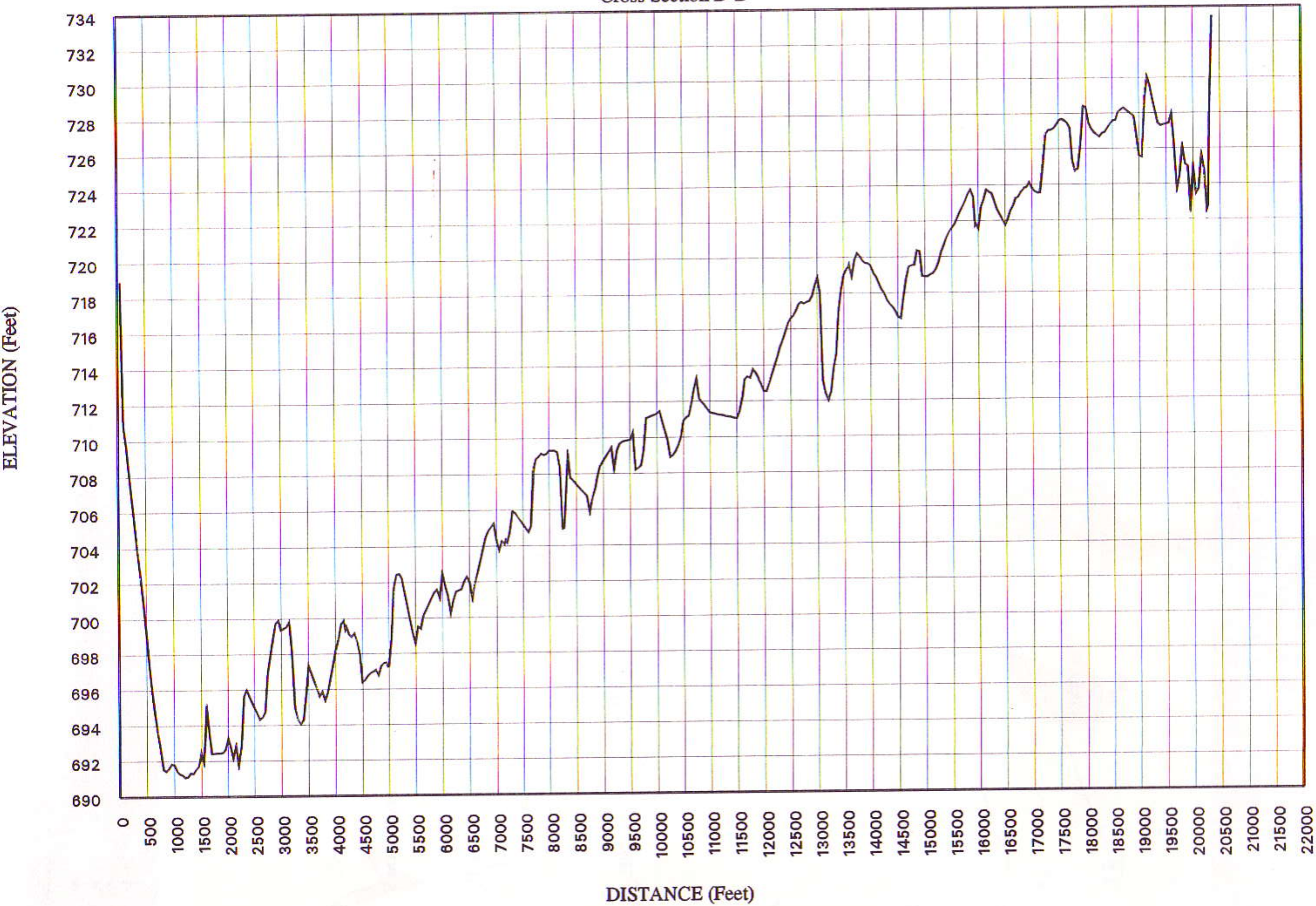
PREPARED BY: TWDB APRIL 1998

LAKE PAT CLEBURNE



PREPARED BY: TWDB APRIL 1998

Cross Section D-D'

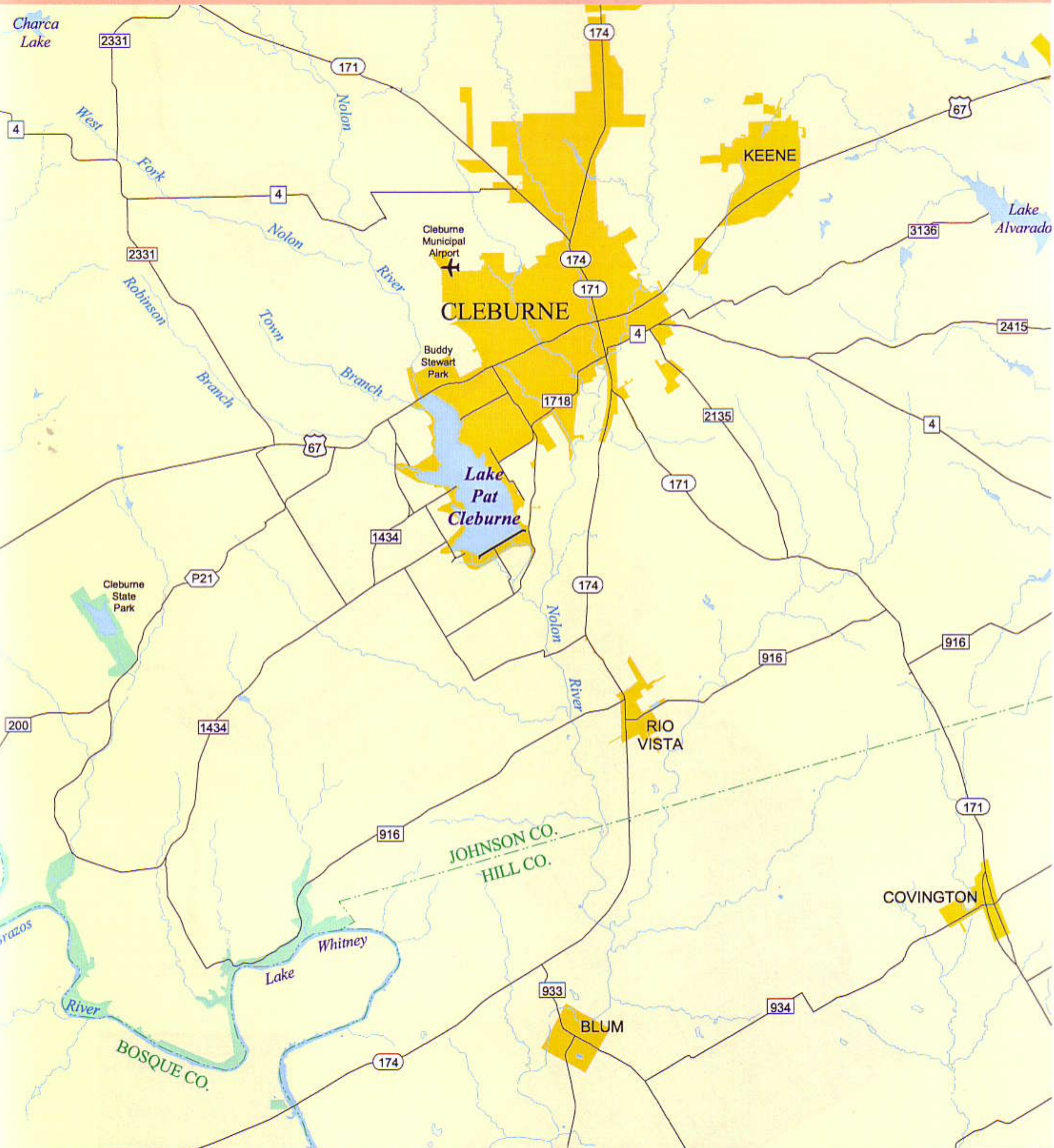


PREPARED BY: TWDB APRIL 1998

FIGURE 1

LAKE PAT CLEBURNE

Site Location Map



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD APRIL 1998

FIGURE 2

LAKE PAT CLEBURNE

Location of Survey Data

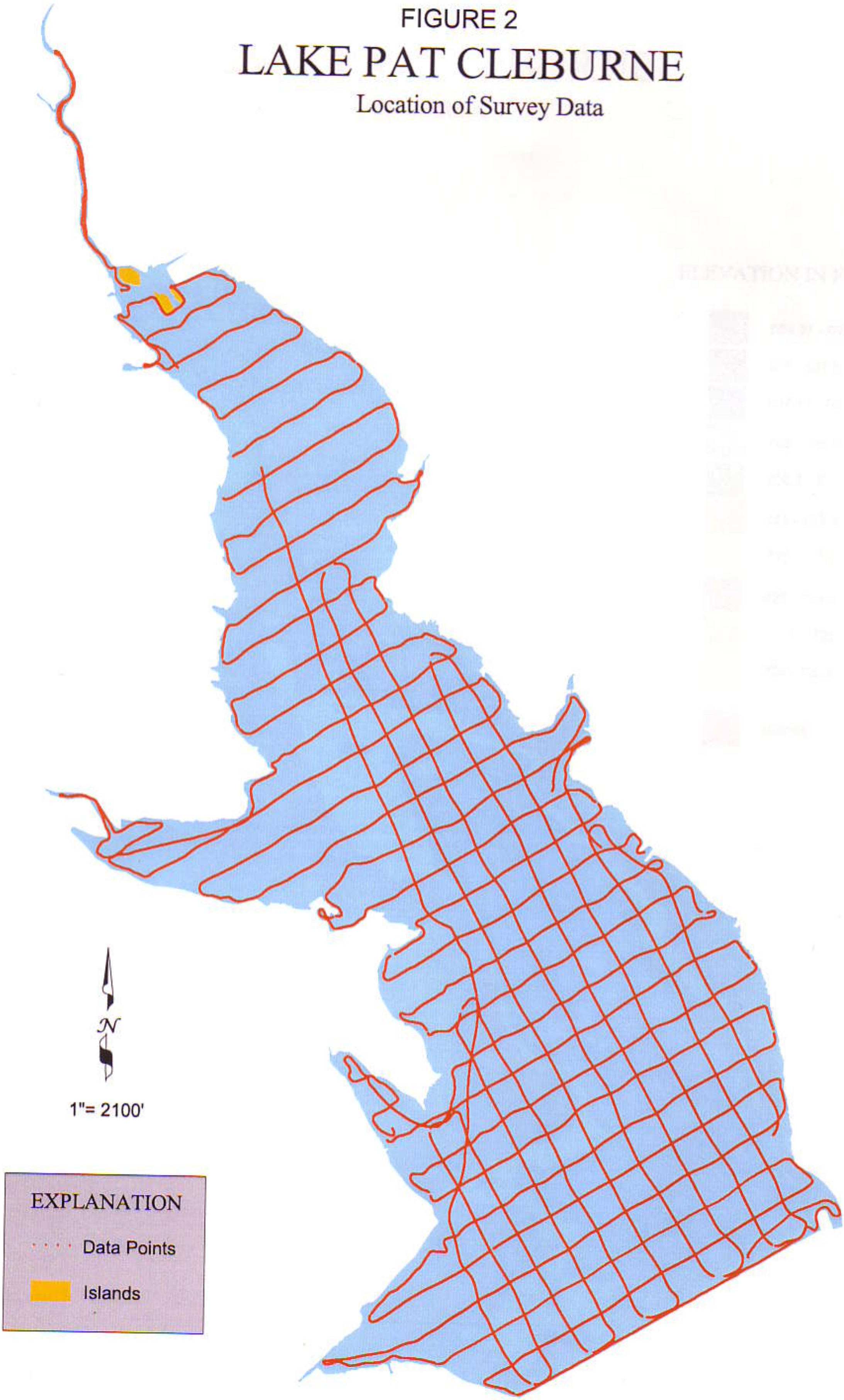
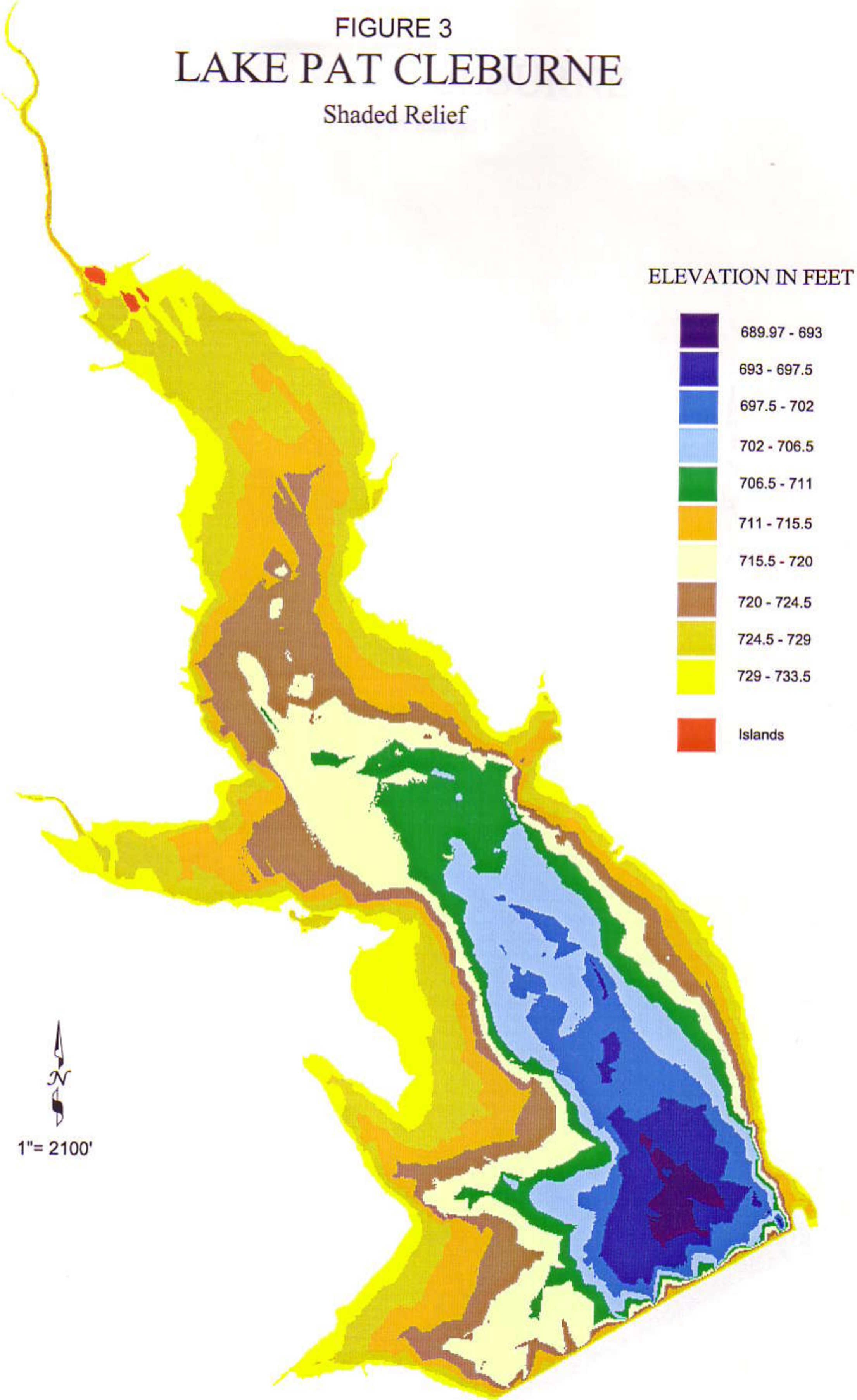


FIGURE 3

LAKE PAT CLEBURNE

Shaded Relief



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD APRIL 1998

FIGURE 4

LAKE PAT CLEBURNE

Depth Ranges