VOLUMETRIC SURVEY OF LAKE TAWAKONI

Prepared for:

SABINE RIVER AUTHORITY

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Lake Tawakoni during the period March 6 - April 8, 1997. 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 noted otherwise. The conservation pool elevation for Lake Tawakoni is 437.5 feet. At this elevation, the original estimate for the surface area of the lake in 1960 was 36,700 acres and the estimated volume was 936,200 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Tawakoni and associated Iron Bridge Dam are owned and operated by the Sabine River Authority. The lake is located on the Sabine River, approximately ten miles northeast of Wills Point, TX and inundates parts of Hunt, Rains and Van Zandt Counties (see Figure 1.). Records indicate the drainage area is approximately 756 square miles. At the conservation pool elevation, the lake has approximately 203 miles of shoreline and is 16.7 miles long. The widest point of the reservoir (located 5.3 miles upstream of the dam) is approximately 4.1 miles.

The water rights to Lake Tawakoni were issued by the State Board of Water Engineers to the Sabine River Authority under Permit No. 1792 on November 14, 1955. This permit was amended several times over the next 33 years. Certificate of Adjudication # 05-4670 was issued by the Texas Water Commission on May 2, 1988. The certificate authorizes the Sabine River Authority the right to maintain an existing dam on the Sabine River and impound therein, not to exceed 927,440 acre-feet of water. The owner was authorized to divert and use not to exceed 238,100 acre-feet of water annually for municipal purposes. The certificate also stated the Sabine River Authority of Texas and the City of Dallas were authorized to operate Lake Tawakoni and Lake Fork Reservoir on a joint use basis. Details of the Joint Use Basis are described further in the "Special Conditions" of the Certificate of Adjudication.

Texas Water Development Board records indicate the construction for Iron Bridge Dam began in January of 1958 and was completed in December of 1960. Deliberate impoundment started in October of 1960 and the water level reached the conservation pool elevation on February 11, 1965. The engineer was Forrest and Cotton, Inc. and the general contractor was a joint venture between Moorman, Dewitt and Singleton and Whittle Contracting Company. The project's cost was $17,000,000.

The dam and appurtenant structures consist of an earthfill embankment and concrete spillway, 29,560 feet in length, with a maximum height of 85 feet or a crest elevation of 454.0 feet. The uncontrolled concrete ogee type spillway divides the dam's earthen embankment, is 480.0 feet in length, and has a crest elevation of 437.5 feet. Outlet works consist of two 20 inch cast iron pipes, controlled by motor-operated valves with an invert elevation of 416.5 feet, and two 4- by 6- foot sluice gates with an invert elevation of 378.0 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 $\pm$ 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 pool boundary (elevation 437.5) from USGS quad sheets. The name of the quad sheets are as follows: LONE OAK SOUTH, TX (Provisional 1980), IRON BRIDGE DAM, TX (Provisional 1980), ABLES SPRINGS, TX (Provisional 1979), WEST TAWAKONI, TX (Provisional 1980), and POETRY, TX (Provisional 1980). 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 433 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 Tawakoni 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 Tawakoni, the speed of sound in the water column varied daily between 4662 and 4821 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 Lake Tawakoni during the period March 6, 1997 through April 8, 1997. Approximately 325,209 data points were collected over the 736 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 585 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. More intensive data were also collected around the various different water supply intakes located around the lake. 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 between the dam and the Tawakoni (Two Mile) Causeway was clear of navigational hazards such as standing timber, submerged trees, and stumps. These hazards were encountered upstream of the causeway in both the Caddo and Pawnee Inlets. Sediment deposits were also observed in the upper reaches of these two inlets as well as Kitsee Inlet. Aquatic vegetation was predominant in the upper reaches of the inlets and coves. The crew was able to collect data in the aquatic vegetation but at a slower pace. No data was collected at various times during the survey due to high winds and rough waters.

Data collection in the headwaters was discontinued when the 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 437.94 to 438.87 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.

The TIN module computed poor area and volume values above elevation 435.0. This was caused by the lack of data, and the criteria of the software in relation to interpolation procedures. 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 437.5 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 154 additional points were required for interpolation and contouring of the entire lake surface at elevation 437.5 feet. Volumes and areas were then calculated from this modified TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 435.0 feet, the surface area and volume values for the lake were mathematically estimated up to elevation 437.5 feet. This was done by first distributing uniformly across each contour interval, the surface areas digitized from USGS topographic maps. 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 437.5 lake elevation was assigned the color of yellow. Different color shades were assigned to the different depths in between. 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 1997 TWDB survey indicate Lake Tawakoni encompasses 37,879 surface acres and contains a volume of 888,140 acre-feet at the conservation pool elevation of 437.5 feet. The shoreline at this elevation was calculated to be 203.0 miles. The deepest point of the lake, elevation 372.3, was located approximately 1,000 feet upstream from the southeastern point of the dam. The dead storage volume, or the amount of water below the lowest outlet in the dam, was calculated to be 14 acre-feet based on the low flow outlet invert elevation of 378.0 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, is therefore, 888,130 acre-feet.

SUMMARY

Lake Tawakoni was formed in 1960. Initial storage calculations estimated the volume at the conservation pool elevation of 437.5 feet to be 936,200 acre-feet with a surface area of 36,700 acres.

During the period of March 6, 1997 through April 8, 1997, a hydrographic survey of Lake Tawakoni was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1997 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 Tawakoni than previous survey methods. Results indicate that the lake's capacity at the conservation pool elevation of 437.5 feet was 888,140 acre-feet and the area was 37,879 acres.

The estimated reduction in storage capacity at the conservation pool elevation of 437.5 feet since 1960 was 48,060 acre-ft or 1,299 acre-ft per year. The average annual deposition rate of sediment in the conservation pool of the reservoir can be estimated at 1.72 acre-ft per square mile of drainage area.

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

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

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 Jul 2 1997

RESERVOIR VOLUME TABLE

LAKE TAWAKONI APRIL 1997 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
372										
373									1	1
374	1	1	1	1	1	1	2	2	2	2
375	2	3	3	3	3	4	4	4	5	5
376	5	5	6	6	7	7	7	8	8	9
377	9	9	10	10	11	11	12	13	13	14
378	14	15	16	16	17	18	18	19	20	21
379	21	22	23	24	25	26	27	28	29	30
380	31	32	33	34	35	37	38	39	40	42
381	43	45	46	48	49	51	53	55	56	58
382	61	63	65	68	71	74	77	81	85	89
383	94	99	105	112	120	130	141	153	166	181
384	197	214	234	255	278	303	331	362	397	434
385	476	521	571	625	683	743	807	874	945	1019
386	1097	1178	1263	1351	1443	1538	1636	1739	1846	1958
387	2075	2197	2323	2454	2590	2731	2876	3026	3180	3339
388	3503	3673	3848	4028	4216	4410	4611	4819	5034	5256
389	5486	5724	5968	6219	6476	6739	7007	7281	7561	7847
390	8138	8435	8738	9046	9360	9679	10004	10335	10672	11015
391	11364	11719	12080	12446	12818	13196	13579	13969	14363	14764
392	15170	15582	16000	16423	16852	17286	17726	18171	18621	19077
393	19539	20008	20484	20969	21460	21957	22462	22973	23490	24014
394	24545	25082	25625	26174	26729	27289	27855	28426	29003	29586
395	30174	30768	31368	31974	32584	33201	33822	34448	35080	35717
396	36360	37008	37661	38319	38982	39650	40322	41001	41685	42376
397	43073	43774	44480	45191	45907	46628	47354	48085	48821	49562
398	50310	51063	51822	52587	53359	54138	54924	55716	56514	57320
399	58133	58952	59777	60609	61446	62291	63142	64002	64869	65744
400	66627	67517	68414	69318	70230	71149	72074	73006	73944	74888
401	75839	76797	77763	78735	79715	80702	81697	82699	83707	84723
402	85746	86775	87812	88856	89909	90970	92038	93114	94197	95288
403	96387	97494	98608	99728	100856	101989	103128	104273	105422	106576
404	107736	108901	110070	111245	112425	113609	114799	115993	117193	118398
405	119608	120823	122043	123267	124496	125731	126971	128216	129466	130722
406	131983	133250	134522	135799	137083	138371	139666	140966	142272	143583
407	144901	146224	147552	148887	150228	151574	152925	154282	155644	157012
408	158385	159764	161149	162539	163936	165339	166746	168159	169577	171001
409	172430	173866	175307	176753	178205	179662	181127	182598	184075	185559
410	187050	188547	190051	191562	193079	194604	196136	197675	199222	200776
411	202338	203908	205487	207073	208667	210269	211880	213500	215127	216763
412	218407	220060	221720	223389	225066	226751	228444	230144	231851	233567
413	235291	237023	238763	240509	242264	244026	245795	247571	249355	251147
414	252947	254754	256569	258391	260221	262058	263903	265756	267616	269484
415	271359	273241	275131	277028	278933	280845	282764	284689	286621	288561
416	290508	292461	294422	296389	298364	300347	302336	304333	306335	308344
417	310359	312380	314408	316441	318481	320527	322579	324639	326704	328776
418	330855	332941	335033	337131	339235	341345	343462	345584	347711	349845
419	351985	354131	356282	358438	360599	362767	364940	367119	369303	371494
420	373691	375894	378103	380318	382540	384768	387002	389243	391490	393744

LAKE TAWAKONI APRIL 1997 SURVEY

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
421	396006	398274	400549	402831	405119	407415	409718	412028	414345	416670
422	419003	421342	423689	426043	428405	430774	433151	435536	437927	440326
423	442733	445147	447570	450001	452440	454888	457344	459807	462277	464756
424	467244	469739	472243	474755	477275	479805	482344	484892	487448	490013
425	492587	495170	497762	500362	502971	505588	508215	510850	513494	516148
426	518811	521482	524162	526849	529544	532248	534960	537680	540406	543142
427	545886	548637	551395	554160	556934	559715	562504	565302	568106	570920
428	573743	576573	579413	582261	585119	587985	590861	593745	596638	599540
429	602452	605374	608305	611245	614199	617164	620140	623129	626128	629140
430	632162	635196	638239	641292	644356	647429	650512	653605	656706	659817
431	662937	666066	669203	672349	675504	678668	681842	685025	688218	691421
432	694633	697856	701089	704331	707583	710846	714118	717399	720689	723990
433	727299	730618	733947	737284	740631	743989	747357	750735	754123	757521
434	760930	764348	767777	771215	774664	778123	781592	785072	788560	792060
435	795619	799189	802770	806361	809964	813578	817202	820837	824483	828141
436	831809	835487	839177	842878	846590	850312	854045	857790	861545	865311
437	869088	872876	876675	880484	884305	888137				

LAKE TAWAKONI APRIL 1997 SURVEY

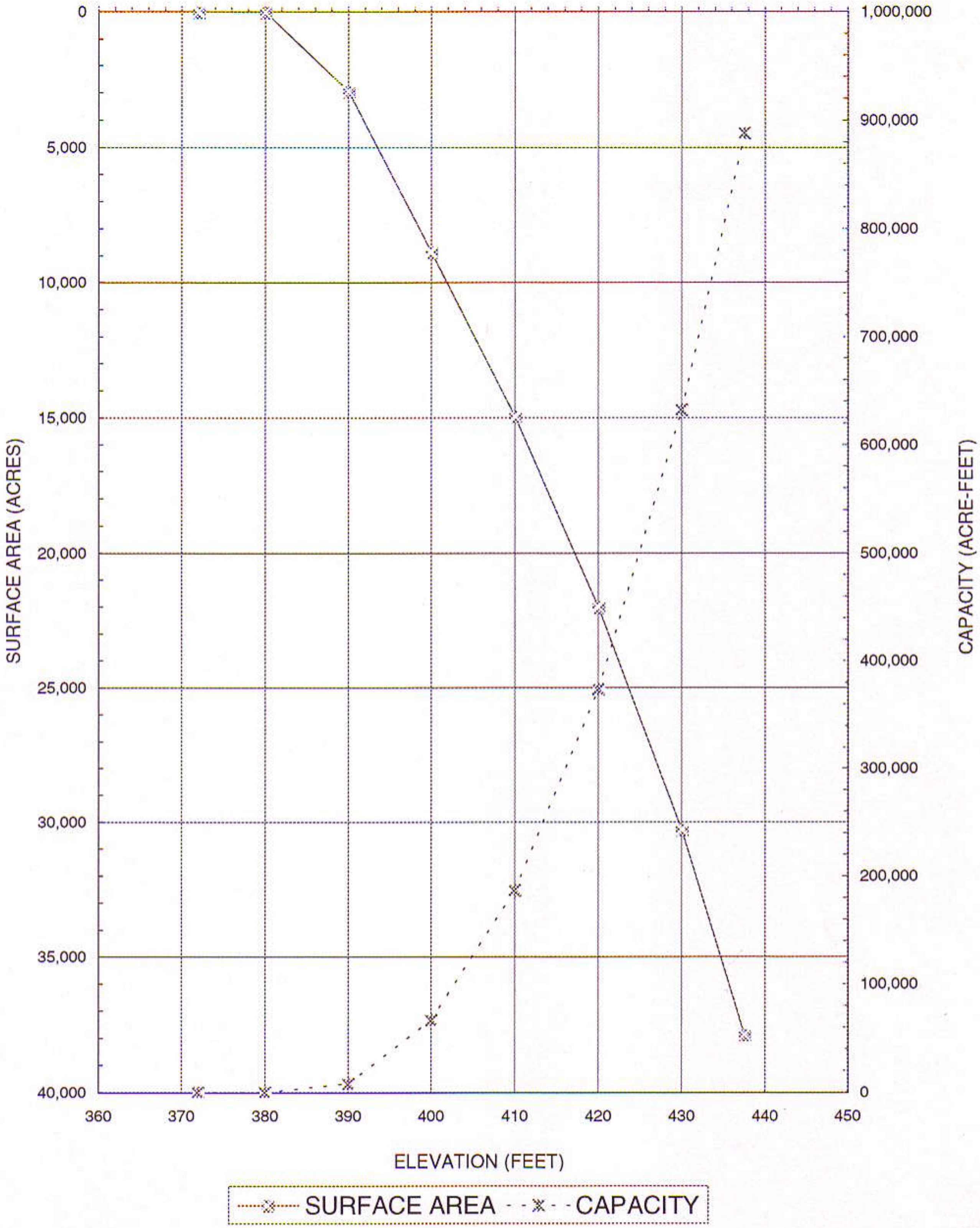
AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
372										
373				1	1	1	1	1	1	1
374	1	1	1	2	2	2	2	2	2	2
375	2	2	2	2	3	3	3	3	3	3
376	3	3	3	4	4	4	4	4	4	4
377	4	5	5	5	5	5	5	6	6	6
378	6	6	7	7	7	7	7	8	8	8
379	8	8	9	9	9	9	10	10	10	11
380	11	11	11	12	12	12	13	13	13	14
381	14	15	15	16	16	17	18	19	19	21
382	22	23	25	27	30	32	35	38	42	45
383	50	56	64	74	89	102	114	127	140	154
384	169	185	202	220	242	268	296	326	358	396
385	434	478	519	557	591	623	653	687	725	762
386	797	832	865	897	931	968	1006	1051	1096	1142
387	1191	1241	1290	1338	1383	1429	1474	1518	1565	1615
388	1669	1722	1778	1841	1910	1977	2042	2114	2188	2260
389	2336	2412	2477	2539	2597	2655	2713	2771	2829	2883
390	2941	3000	3055	3109	3165	3220	3278	3338	3401	3463
391	3522	3579	3634	3691	3747	3805	3866	3923	3977	4031
392	4089	4150	4205	4261	4316	4370	4422	4475	4530	4589
393	4654	4727	4805	4878	4943	5011	5077	5141	5206	5273
394	5338	5404	5465	5520	5576	5628	5684	5740	5799	5853
395	5911	5970	6029	6082	6135	6187	6238	6291	6346	6401
396	6453	6504	6555	6605	6654	6703	6753	6814	6880	6939
397	6987	7035	7084	7135	7186	7235	7285	7334	7387	7443
398	7502	7562	7623	7687	7754	7821	7887	7954	8025	8094
399	8159	8221	8282	8345	8410	8478	8553	8636	8714	8789
400	8862	8935	9008	9080	9151	9220	9288	9351	9413	9476
401	9542	9617	9690	9763	9835	9908	9982	10053	10123	10191
402	10261	10331	10407	10485	10564	10645	10721	10797	10874	10950
403	11025	11102	11174	11244	11305	11363	11417	11468	11519	11570
404	11621	11671	11722	11773	11821	11869	11921	11971	12023	12075
405	12125	12172	12221	12269	12320	12371	12423	12477	12531	12585
406	12640	12696	12750	12804	12859	12916	12973	13030	13087	13144
407	13199	13258	13319	13378	13433	13487	13542	13595	13648	13702
408	13758	13819	13880	13941	13996	14049	14102	14156	14209	14265
409	14324	14381	14436	14490	14547	14609	14676	14743	14809	14874
410	14940	15005	15074	15140	15209	15282	15357	15432	15507	15581
411	15658	15742	15823	15901	15982	16066	16150	16235	16317	16401
412	16483	16565	16649	16733	16810	16885	16960	17038	17118	17199
413	17279	17357	17433	17509	17581	17653	17727	17803	17881	17958
414	18034	18109	18185	18261	18336	18412	18487	18567	18641	18711
415	18784	18862	18938	19012	19083	19152	19221	19289	19360	19431
416	19500	19570	19640	19713	19787	19859	19929	19997	20059	20120
417	20181	20240	20302	20367	20431	20493	20558	20622	20690	20756
418	20823	20887	20951	21013	21074	21132	21190	21249	21310	21369
419	21427	21481	21535	21590	21645	21700	21757	21817	21879	21939
420	22000	22062	22124	22186	22247	22308	22372	22439	22507	22579

LAKE TAWAKONI APRIL 1997 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

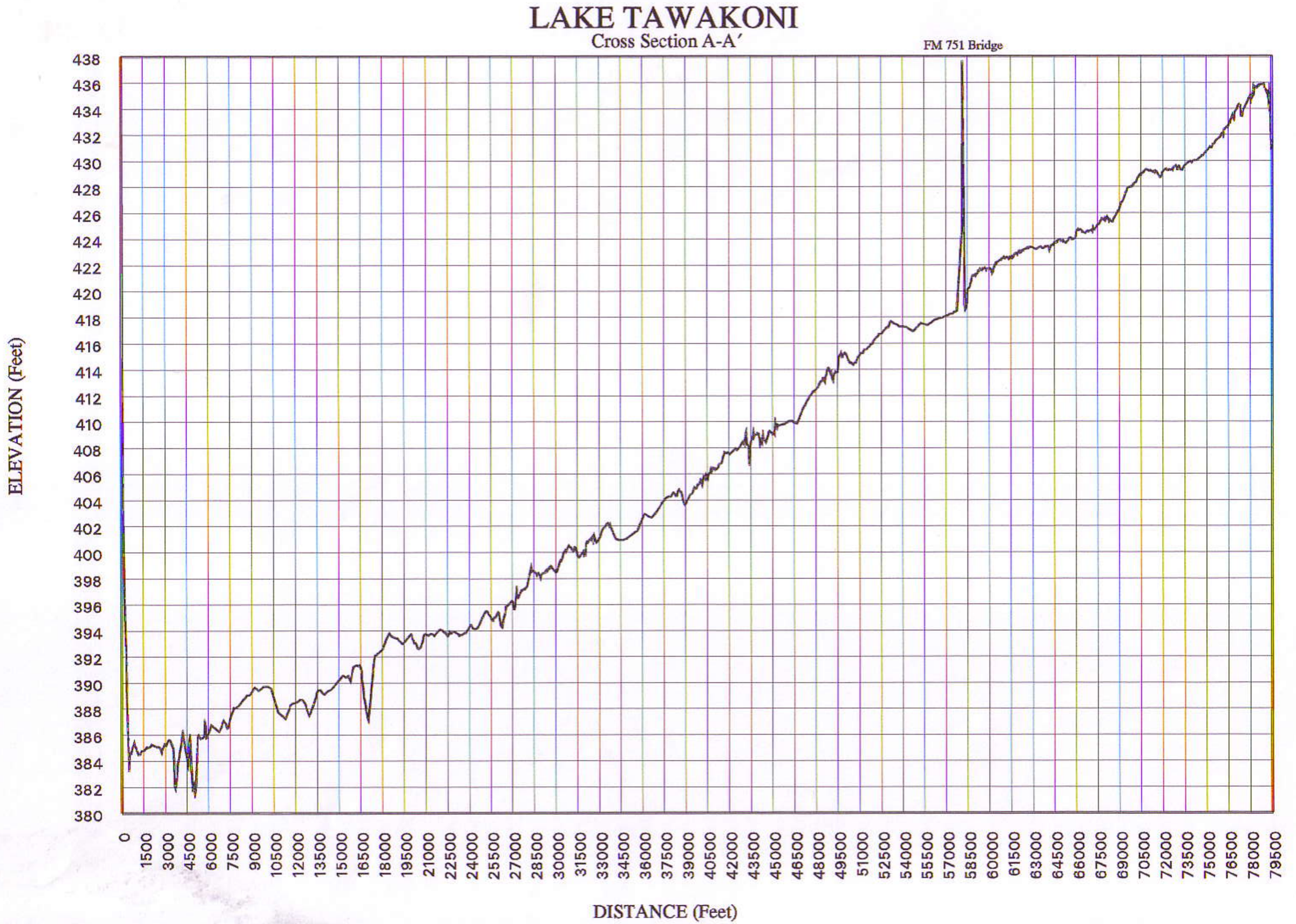
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
421	22650	22719	22784	22850	22919	22990	23064	23141	23215	23287
422	23358	23429	23504	23582	23656	23732	23807	23880	23953	24027
423	24104	24185	24269	24353	24439	24517	24593	24668	24747	24829
424	24913	24998	25080	25162	25247	25339	25432	25523	25609	25697
425	25785	25872	25960	26046	26133	26220	26307	26398	26492	26581
426	26669	26753	26837	26916	26997	27078	27156	27234	27316	27395
427	27472	27545	27620	27694	27772	27852	27931	28012	28095	28179
428	28265	28351	28440	28530	28620	28707	28797	28888	28980	29071
429	29164	29259	29360	29471	29590	29707	29822	29941	30060	30171
430	30280	30382	30484	30586	30683	30780	30877	30973	31066	31156
431	31242	31328	31416	31506	31597	31688	31784	31881	31978	32076
432	32176	32276	32376	32474	32573	32671	32768	32861	32953	33046
433	33140	33236	33331	33427	33526	33627	33728	33832	33933	34033
434	34132	34232	34336	34438	34540	34641	34742	34843	34944	35045
435	35154	35263	35372	35481	35590	35699	35808	35917	36026	36135
436	36244	36353	36462	36571	36680	36789	36898	37007	37116	37225
437	37334	37443	37552	37661	37770	37879				



LAKE TAWAKONI

April 1997 Survey

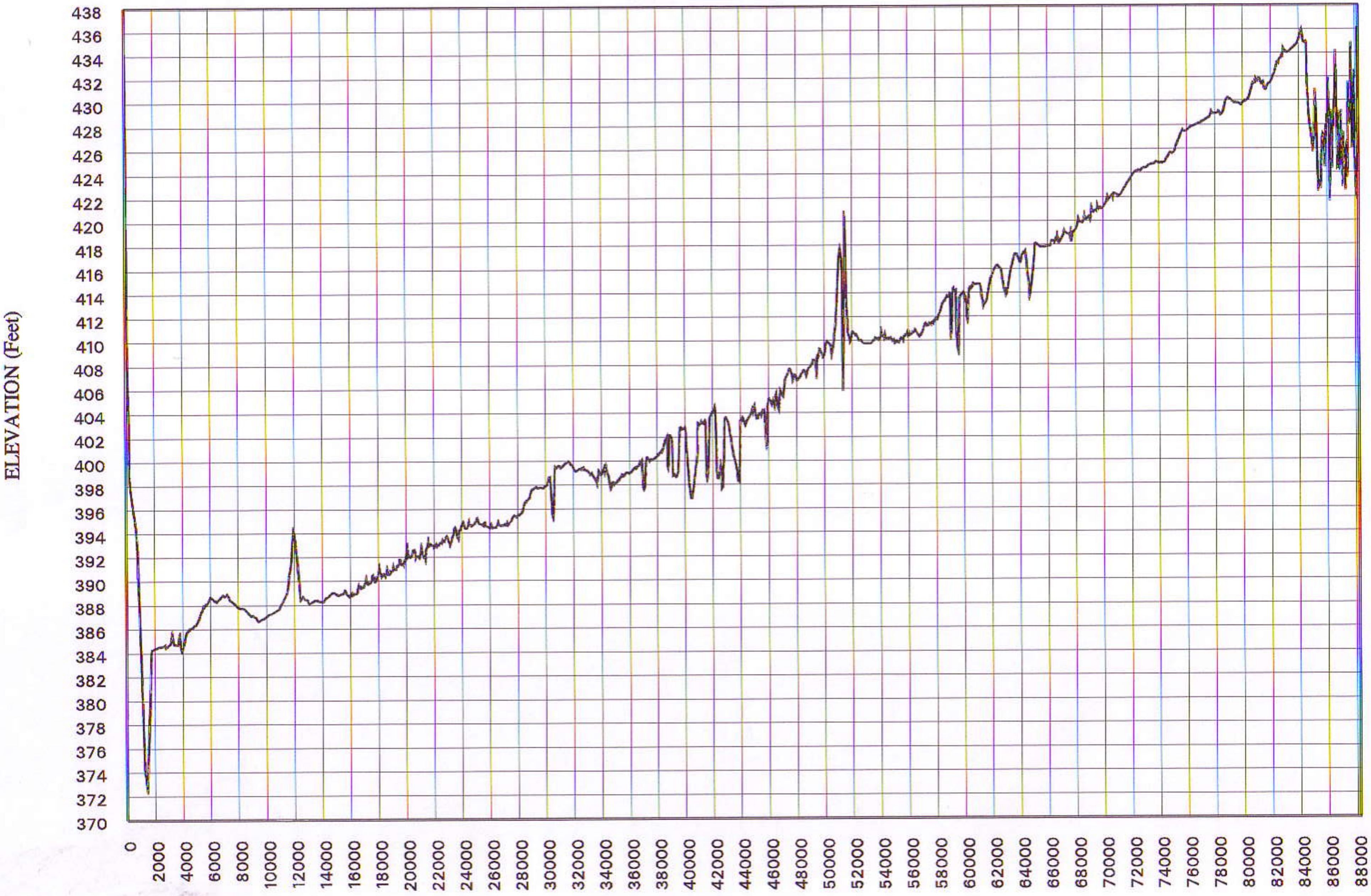
Prepared by: TWDB August 1997



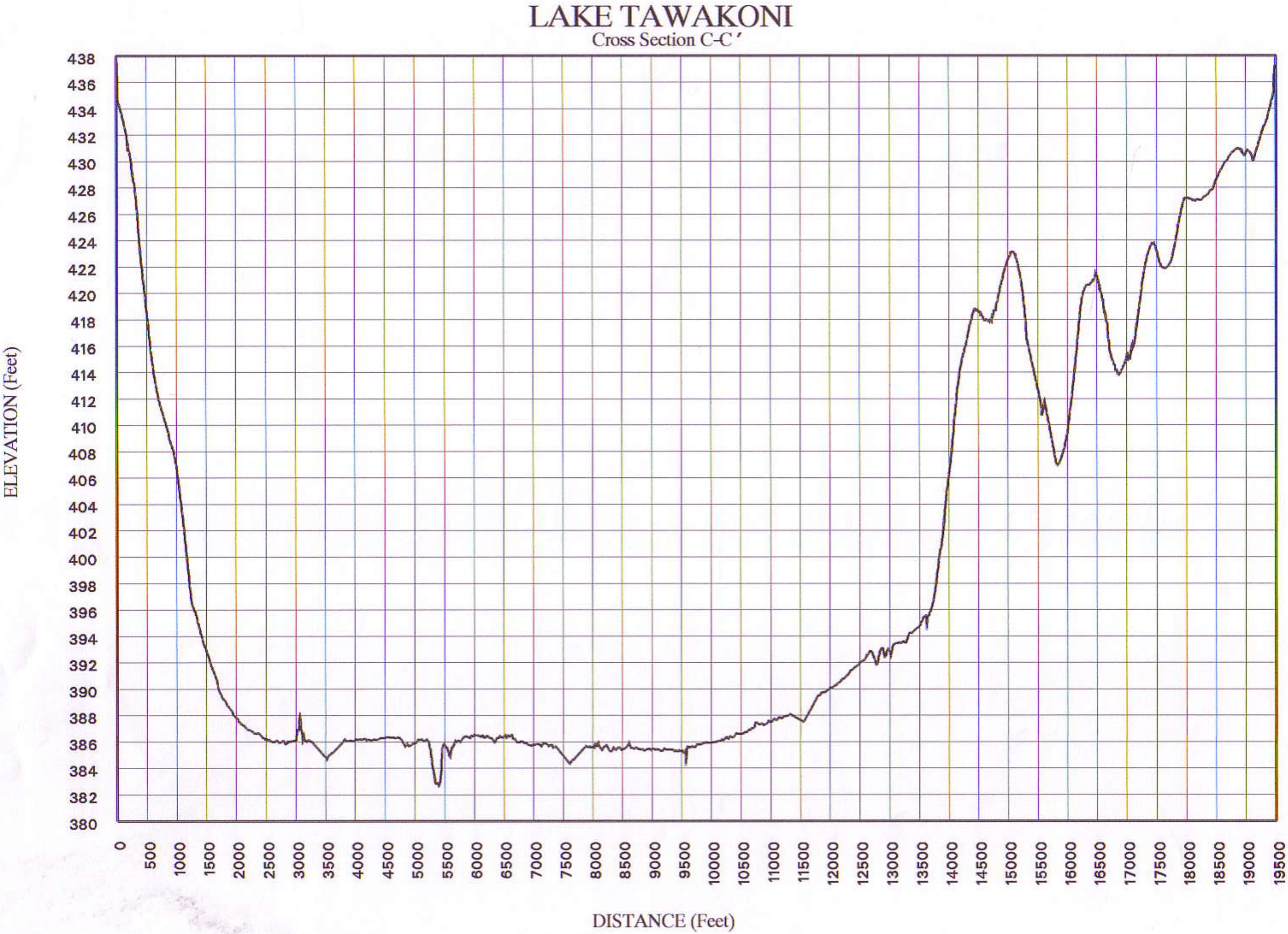
PREPARED BY: TWDB AUGUST 1997

LAKE TAWAKONI

Cross Section B-B′



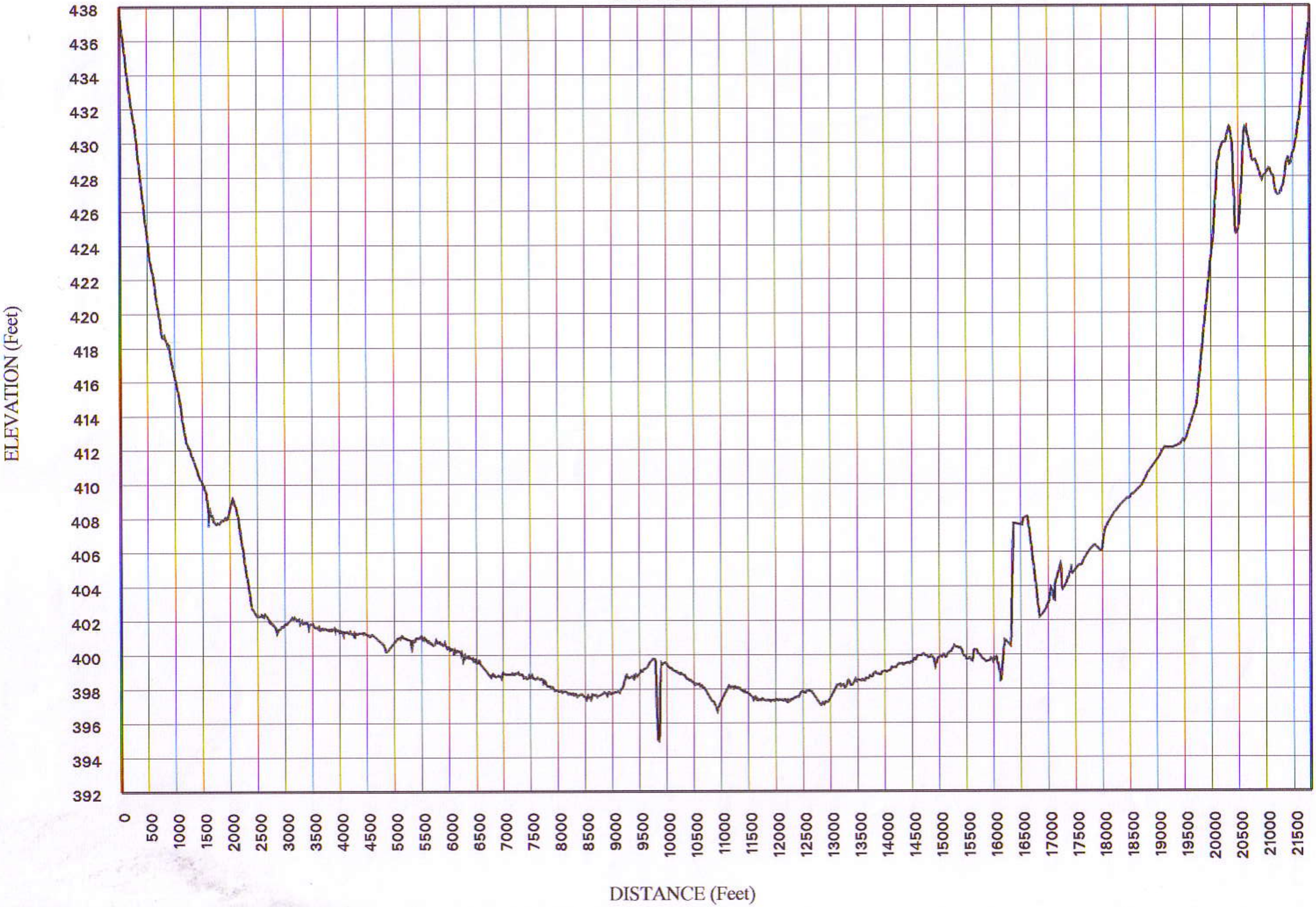
PREPARED BY: TWDB JULY 1997



PREPARED BY: TWDB JULY 1997

LAKE TAWAKONI

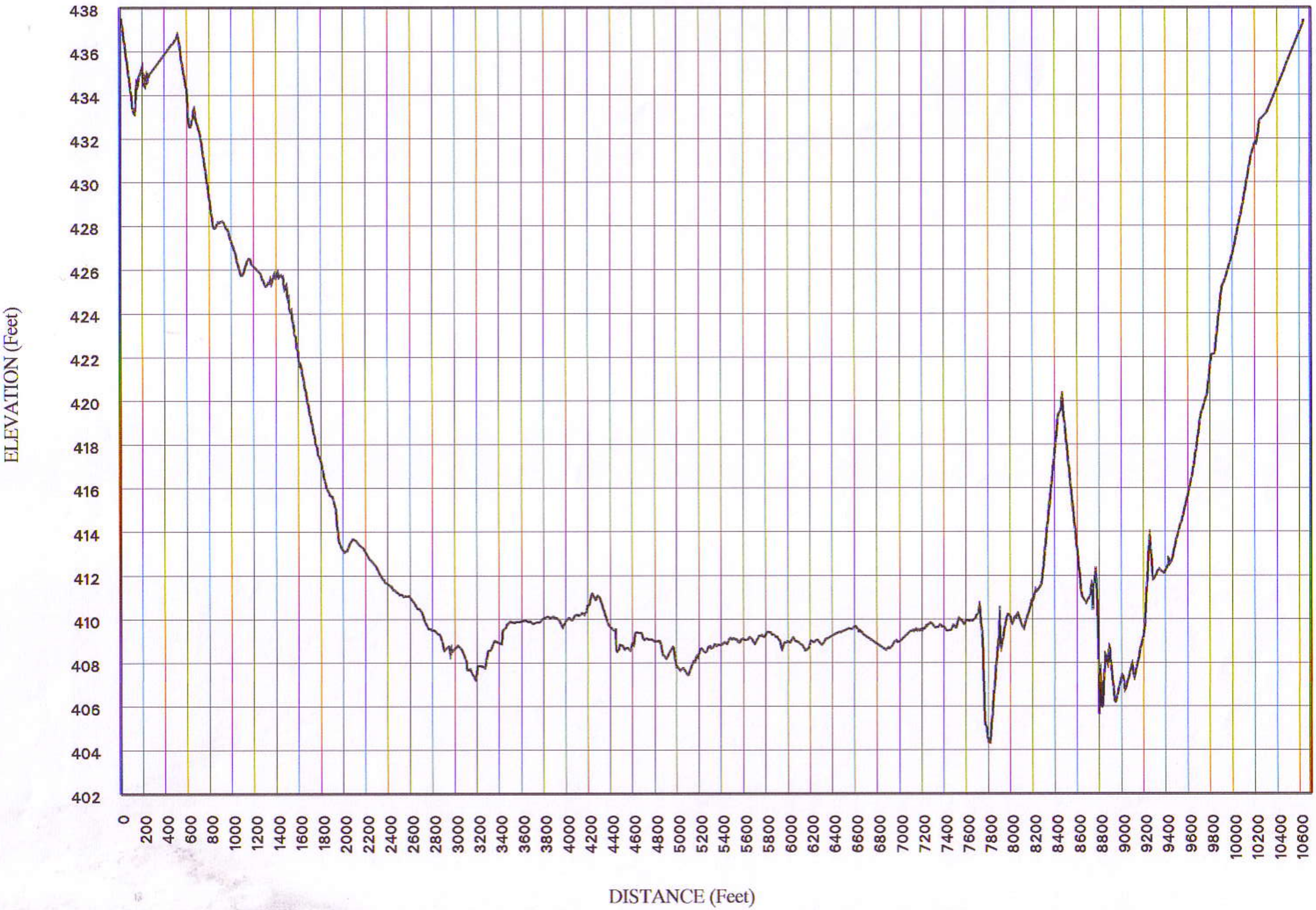
Cross Section D-D′



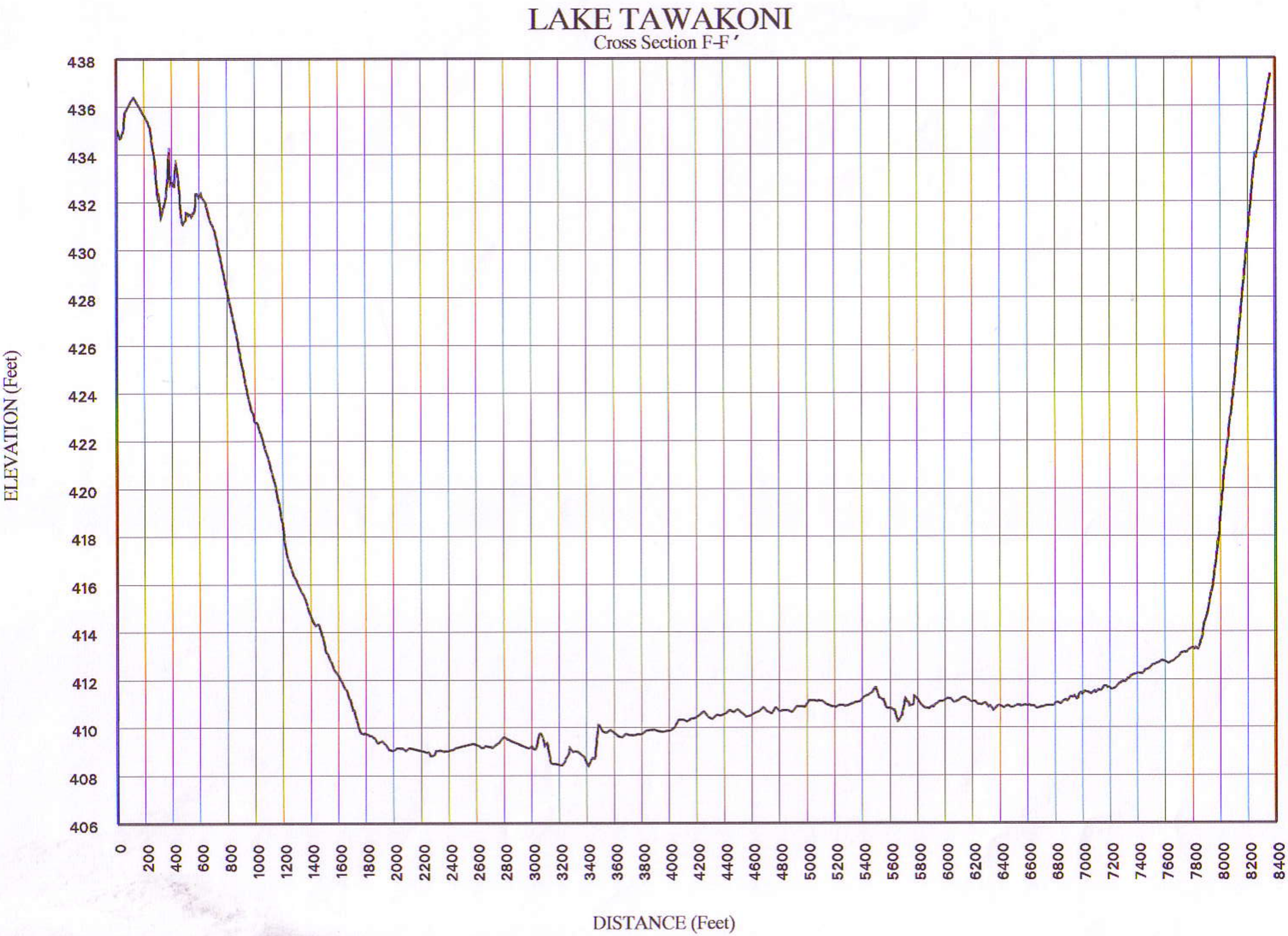
PREPARED BY: TWDB JULY 1997

LAKE TAWAKONI

Cross Section E-E′



PREPARED BY: TWDB JULY 1997

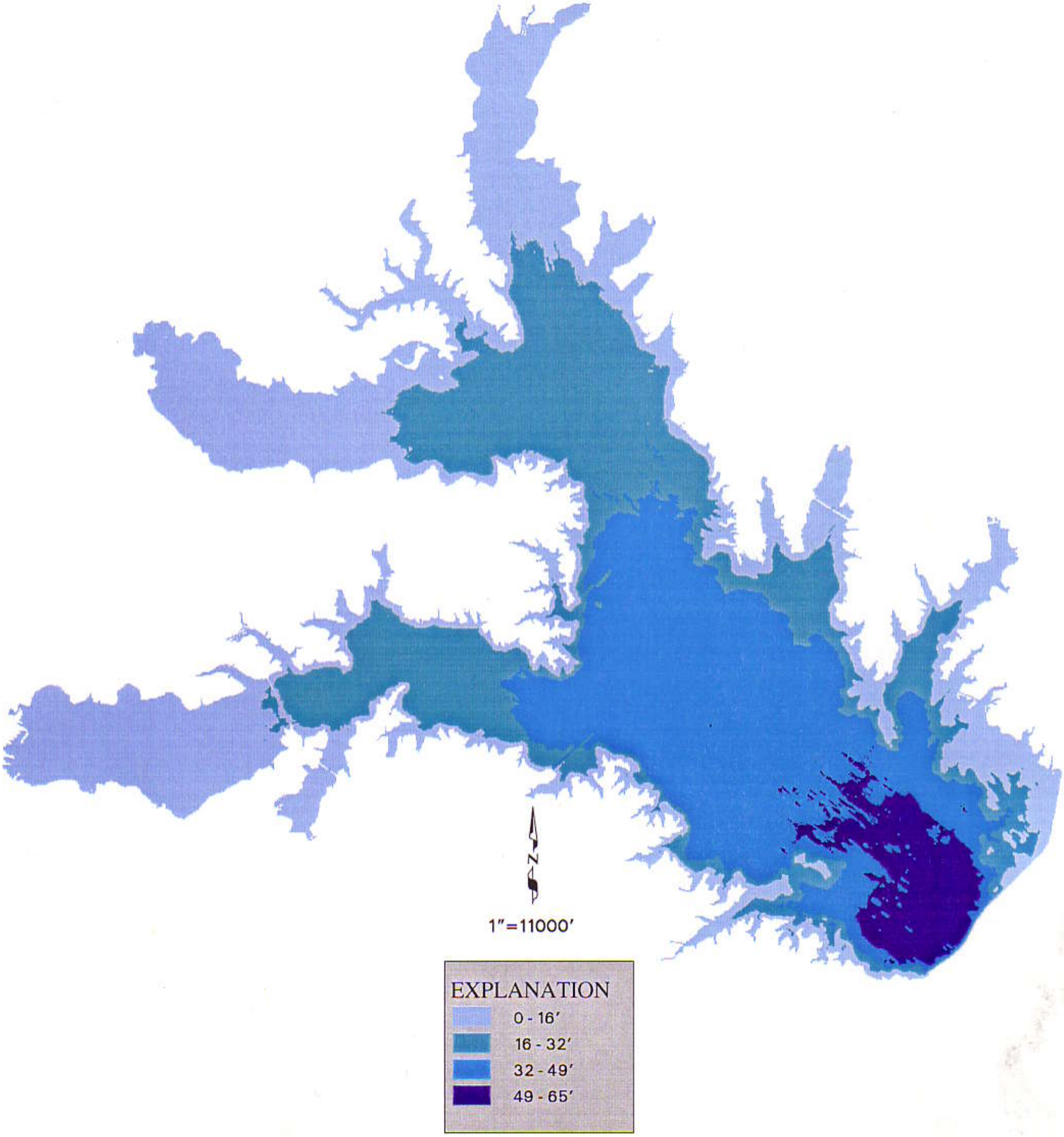


PREPARED BY: TWDB JULY 1997

FIGURE 4

TAWAKONI LAKE

Depth Ranges

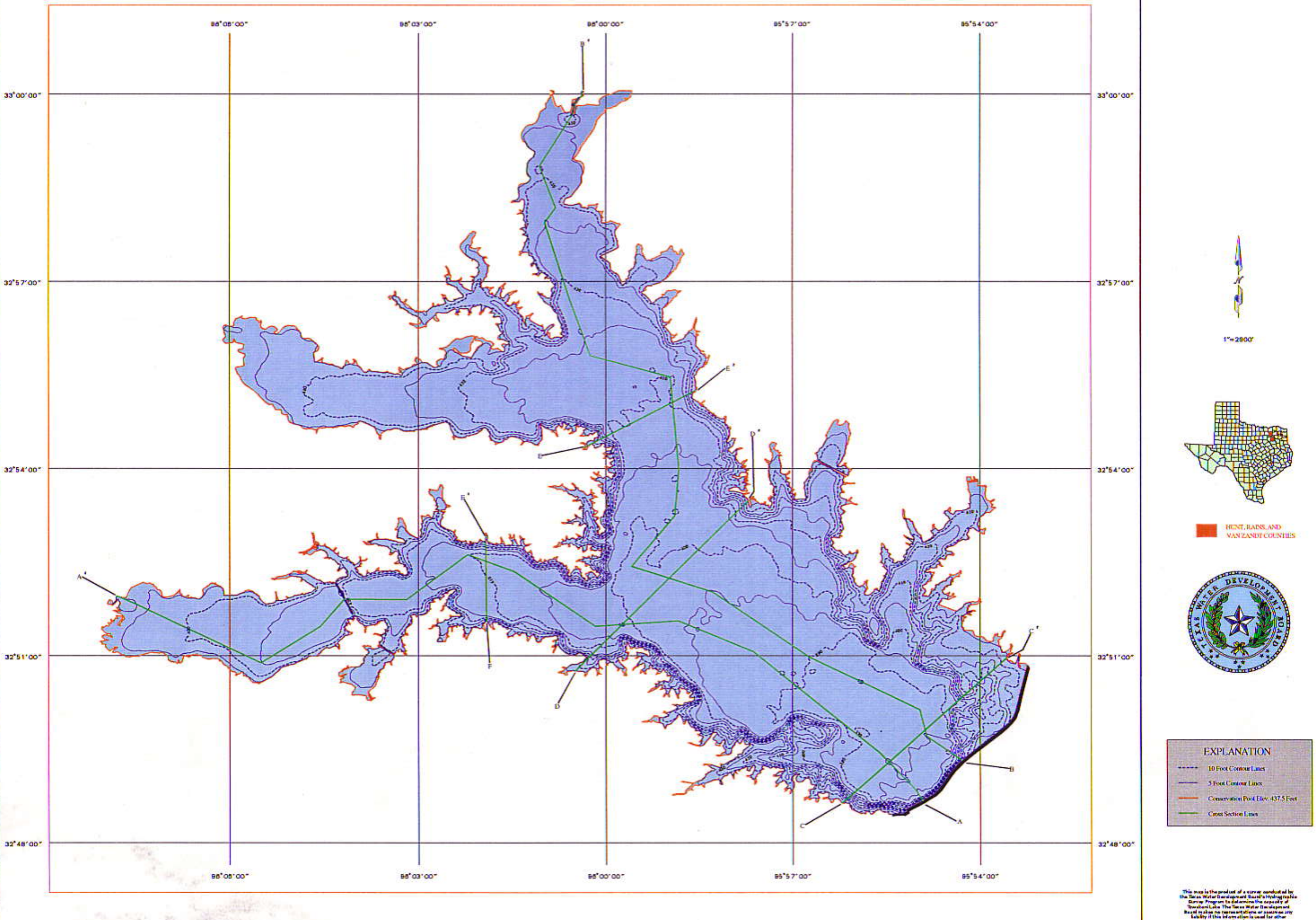


PREPARED BY: TWDB JULY 1997

FIGURE 5

LAKE TAWAKONI

Contour Map



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD JULY 1997