VOLUMETRIC SURVEY
OF
LAKE ATHENS

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Athens Municipal Water Authority

Prepared by:

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Lake Athens on January 20 & 21, 1998. A small boat and recording fathometer collected additional data on February 25, 1998 in areas inaccessible to the program's survey vessel. 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 that is noted otherwise. The conservation pool elevation for Lake Athens is 440 feet. The original design information estimates the surface area at this elevation to be 1,520 acres and the storage volume to be 32,790 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

The Athens Municipal Water Authority owns Lake Athens and Lake Athens Dam. The lake is located on Flat Creek in Henderson County, about eight miles east of Athens, Texas (see Figure 1). Records indicate the drainage area is approximately 21.6 square miles. At the conservation pool elevation, the lake has approximately 23.2 miles of shoreline and is 3.9 miles long. The widest point of the reservoir is approximately 2.2 miles (located 1.1 miles upstream of the dam).

Water Rights Permit No. 1915, dated September 26, 1958, was issued to the Athens Municipal Water Authority. This permit authorized the construction of a dam and reservoir to impound 32,840 acre-feet of water. It also granted the owner the right to divert and use annually 8,500 acre-feet of water for municipal purposes. The Texas Water Commission issued Certificate of Adjudication No. 06-3256 on February 7, 1985. The certificate basically reinforces the authorization for the Athens

Municipal Water Authority to impound 32,840 acre-feet of water and to divert and use not to exceed 8,500 acre-feet of water per year for municipal purposes.

Records indicate the construction for Lake Athens and Lake Athens Dam started September 25, 1961 and deliberate impoundment began November 1, 1962. The project was officially completed in May of 1963. The design engineer for the facility was Wisenbaker, Fix, and Associates. The general contractor was Elm Fork Construction Co. The estimated cost of the dam $361,000.

Lake Athens Dam and appurtenant structures consist of an earth-fill embankment, 3,000 feet in length, with a maximum height of 67 feet and a crest elevation of 453.0 feet. The service spillway is an uncontrolled rectangular drop inlet. The crest elevation for the six-feet by six-feet opening is 440.0 feet. The emergency spillway, located at the left (north) abutment of the dam, is an earth trench cut through the natural ground. The crest is 300 feet in length at elevation 446.0 feet. The outlet works is an 18-inch diameter concrete pipe with an invert elevation of 396.5 feet and is controlled by a slide valve.

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 $\pm$ 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 440-foot contour. The boundary file was created from the 7.5-minute USGS quadrangle maps, LEAGUEVILLE, TX. (provisional edition 1984), and ATHENS, TX (provisional edition 1984). 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 57 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 Athens 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 Athens, the speed of sound in the water column was determined to be 4,769 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 Athens on January 20-21 and February 25, 1998. Approximately 271,327 data points were collected over the 39 miles traveled along the 53 survey lines run (pre-planned, random, and parallel). These points were stored digitally on the boat's computer in 58 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. In addition, on February 25, fourteen lines of data were collected upstream of the FM 2495 bridge using a small boat outfitted with a recording depth sounder. Figure 2 shows the actual location of all data collection points.

TWDB staff observed the land surrounding the lake to be generally flat and no development was noted on either bank around the dam. Numerous sub-divisions were located around the rest of the lake. On the depth sounder, numerous distinct river channels were noted throughout the lake as the survey vessel traveled across the lake. From the survey vessel, the crew could see that the water was fairly clear with minimal underwater vegetation and that the lake was mostly free of any navigational hazards such as standing trees or stumps. Data collection was therefore quite easy. There were several islands near the dam and a more intensive effort was made to collect data around each of these islands by the TWDB survey team. Extensive data were also collected around the water intakes located at Impala Point. Data collection was halted when the TWDB vessel could not go under the bridges at FM 317 and FM 2495. Staff returned on February 25 and collected data above the FM 2495 bridge using a small boat outfitted with a recording depth sounder. No data was deemed necessary to be collected above the FM 317 bridge because the lake had pretty much ended at this point.

All of the collected data were stored in individual data files for each pre-plotted range line or random 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. 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 440.43 and 440.58 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. In addition, the fourteen lines collected using the recording depth sounder only, were digitized and converted to data points by incrementing each cross-section in 1 foot increments along both the X, Y and Z axes. This procedure was accomplished by running an Arc/Info script file developed by TWDB staff. The fourteen lines converted into 10,602 data points.

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 2,766 additional points were required for interpolation and contouring of the entire lake surface at elevation 440.0. Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 436.0 to elevation 440.0, 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 the lake at elevation 440.0 was 1,799 surface acres. The computed area was 279 surface acres more than originally 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 440.0 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 Athens encompasses 1,799 surface acres and contains a volume of 29,475 acre-feet at the conservation pool elevation of 440.0 feet. The shoreline at this elevation was calculated to be 23.2 miles. The deepest point of the lake, elevation 391.88 or 48.12 feet of depth was located approximately 915 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 40 acre-feet based on the low flow outlet invert elevation of 396.5 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, is therefore 29,440 acre-feet.

SUMMARY

Lake Athens was formed in 1962. Initial storage calculations estimated the volume at the conservation pool elevation of 440.0 feet to be 32,790 acre-feet with a surface area of 1,520 acres.

During the period of January 20 – 21 and February 25, 1998, a hydrographic survey of Lake Athens 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 Athens than previous survey methods. Results indicate that the lake's capacity at the conservation pool elevation of 440.0 feet was 29,475 acre-feet and the area was 1,799 acres.

The estimated reduction in storage capacity at the conservation pool elevation of 440.0 feet since 1962 is 3,315 acre-feet or 92.08 acre-feet per year. The average annual deposition rate of sediment in the conservation pool of the reservoir can be estimated at 4.263 acre-feet per square mile of drainage area. *(Please note that this is just a mathematical estimate based on the difference between the original survey and the current survey. In reality, the calculated value is unreasonable and should not be used. An error in the original volume is more likely the reason there is such a large difference in storage over the 36 years of operation.)*

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

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

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
RESERVOIR VOLUME TABLE

Jun 3 1998

Lake Athens February 1998 Survey

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
392										
393										
394	1	1	1	1	2	2	3	3	4	5
395	6	7	8	9	11	13	15	17	19	22
396	24	27	30	33	36	40	43	47	50	54
397	58	62	66	70	74	78	83	87	91	96
398	101	106	110	115	121	126	131	137	143	148
399	154	160	167	173	180	186	193	200	207	214
400	221	229	236	244	252	260	268	276	285	293
401	302	311	319	328	338	347	356	366	376	386
402	396	406	417	428	439	450	462	475	488	502
403	516	531	546	561	577	594	611	628	645	663
404	681	699	718	737	757	777	797	817	838	859
405	881	902	925	947	970	994	1017	1041	1065	1089
406	1114	1139	1164	1189	1214	1240	1266	1292	1319	1345
407	1372	1400	1427	1455	1483	1511	1540	1569	1598	1627
408	1657	1687	1718	1748	1779	1811	1842	1874	1906	1939
409	1971	2004	2038	2071	2105	2139	2173	2208	2243	2278
410	2313	2349	2385	2421	2457	2494	2531	2568	2605	2643
411	2681	2719	2758	2797	2836	2875	2914	2954	2994	3035
412	3076	3117	3158	3200	3242	3284	3327	3370	3414	3458
413	3502	3547	3592	3637	3683	3729	3775	3822	3869	3916
414	3964	4012	4060	4109	4158	4207	4257	4306	4356	4407
415	4457	4508	4560	4611	4663	4716	4768	4821	4874	4928
416	4981	5036	5090	5145	5200	5256	5311	5367	5424	5481
417	5538	5595	5653	5711	5769	5828	5887	5947	6007	6067
418	6127	6188	6249	6311	6373	6435	6498	6561	6625	6688
419	6753	6817	6882	6947	7012	7078	7144	7211	7277	7344
420	7412	7479	7547	7616	7684	7753	7823	7892	7962	8033
421	8103	8174	8246	8317	8389	8462	8535	8608	8681	8755
422	8829	8903	8978	9054	9129	9205	9281	9358	9435	9512
423	9590	9668	9746	9825	9904	9983	10063	10143	10223	10303
424	10384	10465	10547	10629	10711	10793	10876	10959	11042	11126
425	11210	11294	11379	11464	11549	11635	11721	11807	11894	11981
426	12068	12155	12243	12332	12420	12509	12599	12688	12778	12869
427	12959	13051	13142	13234	13326	13419	13512	13605	13699	13793
428	13888	13983	14078	14174	14270	14367	14464	14561	14659	14757
429	14856	14955	15054	15154	15254	15355	15456	15558	15660	15762
430	15865	15968	16072	16176	16280	16385	16491	16597	16703	16810
431	16917	17025	17133	17241	17350	17460	17570	17680	17791	17902
432	18014	18126	18239	18352	18466	18580	18695	18810	18926	19042
433	19159	19276	19394	19512	19631	19750	19870	19990	20111	20233
434	20355	20478	20602	20727	20852	20978	21104	21231	21359	21487
435	21616	21746	21876	22007	22139	22271	22404	22538	22673	22808
436	22949	23091	23234	23378	23524	23670	23818	23966	24116	24267
437	24418	24571	24725	24880	25036	25194	25352	25511	25672	25833
438	25996	26160	26324	26490	26657	26825	26994	27164	27336	27508
439	27682	27856	28032	28208	28386	28565	28745	28926	29108	29291
440	29475									

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR AREA TABLE

Jun 3 1998

Lake Athens February 1998 Survey

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
392										
393								1	1	1
394	2	2	3	3	4	4	5	6	7	9
395	11	12	14	16	17	19	21	22	24	25
396	27	28	30	32	33	34	35	36	37	38
397	39	39	40	41	42	43	44	44	45	46
398	47	48	50	51	52	54	55	56	58	59
399	60	62	63	64	65	67	68	69	71	73
400	74	75	77	78	79	81	82	83	84	85
401	87	88	89	91	92	94	95	97	99	101
402	103	105	107	111	114	118	123	128	134	139
403	145	149	154	158	162	166	169	172	176	179
404	183	186	190	193	196	199	202	206	210	214
405	217	221	225	228	231	234	237	239	242	244
406	247	249	251	253	256	258	261	263	266	269
407	271	274	277	279	282	285	287	290	293	296
408	299	302	305	308	311	314	317	320	323	326
409	328	331	334	336	339	342	344	347	350	352
410	355	358	360	363	365	368	371	373	376	378
411	381	384	386	389	392	394	397	400	403	406
412	409	412	416	419	423	426	430	433	437	441
413	444	448	452	456	459	463	466	469	472	475
414	478	481	484	487	490	493	496	499	502	505
415	508	511	514	518	521	524	527	530	534	537
416	540	543	547	550	553	556	559	563	566	569
417	572	576	579	582	586	590	593	597	600	604
418	607	610	614	618	622	626	629	633	636	639
419	643	646	649	653	656	659	662	666	669	672
420	675	679	682	685	688	692	695	698	702	705
421	708	712	715	718	722	725	729	732	736	740
422	743	747	750	754	757	761	764	768	771	775
423	778	781	785	788	792	795	798	801	804	807
424	810	814	817	820	823	826	829	832	835	838
425	841	845	848	851	854	858	861	864	867	871
426	874	878	881	885	888	892	895	899	902	906
427	910	913	917	921	924	928	932	936	940	944
428	948	952	956	960	964	968	972	976	980	984
429	988	992	997	1001	1005	1009	1014	1018	1022	1026
430	1031	1035	1039	1043	1048	1052	1056	1060	1065	1069
431	1076	1080	1084	1088	1092	1097	1101	1105	1110	1115
432	1120	1125	1130	1135	1140	1145	1149	1154	1159	1164
433	1170	1175	1180	1185	1191	1196	1201	1207	1214	1221
434	1230	1236	1242	1248	1254	1261	1267	1273	1280	1286
435	1294	1301	1307	1314	1321	1328	1335	1342	1349	1356
436	1367	1378	1388	1399	1410	1421	1432	1442	1453	1464
437	1475	1486	1496	1507	1518	1529	1540	1550	1561	1572
438	1583	1594	1605	1615	1626	1637	1648	1659	1669	1680
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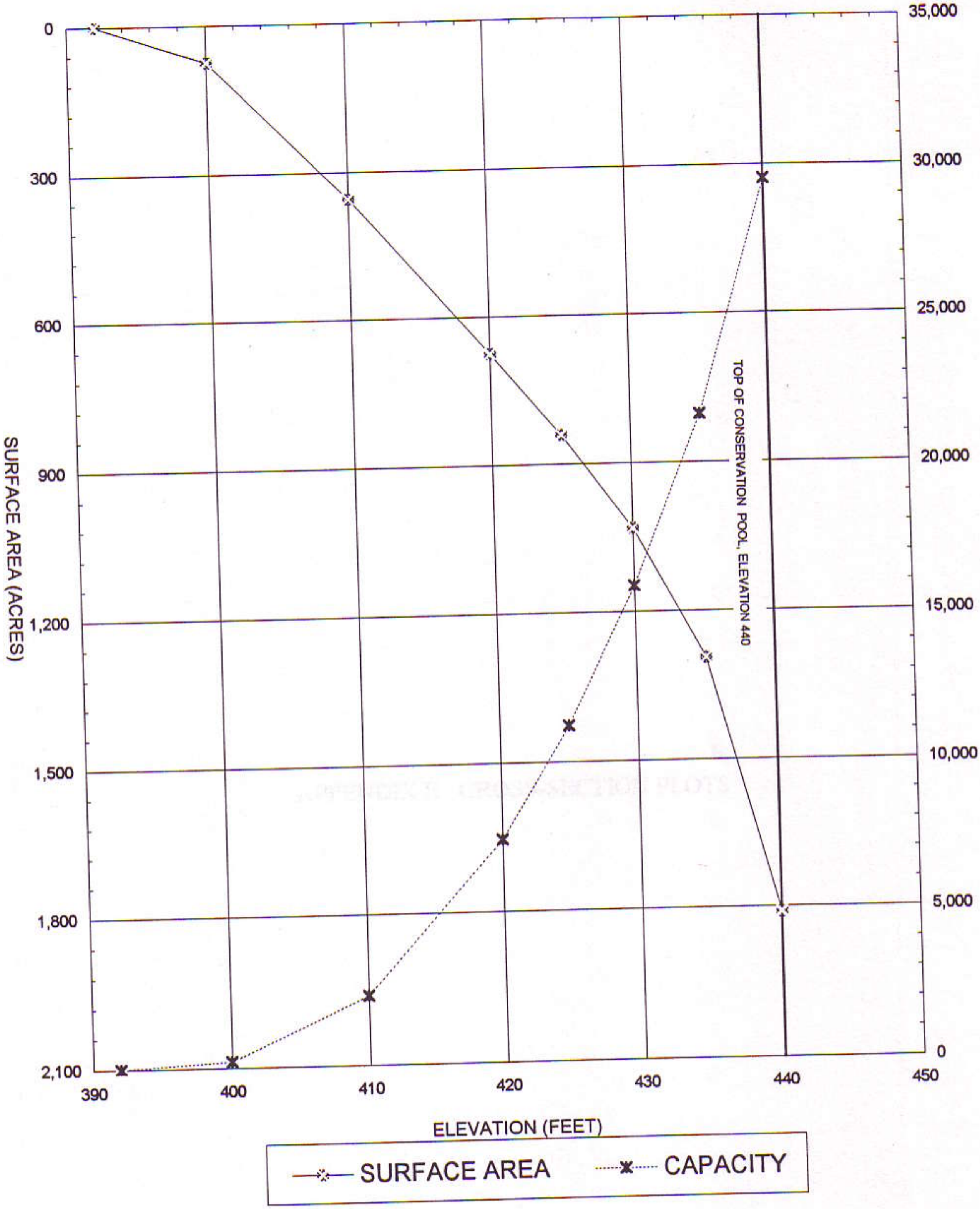
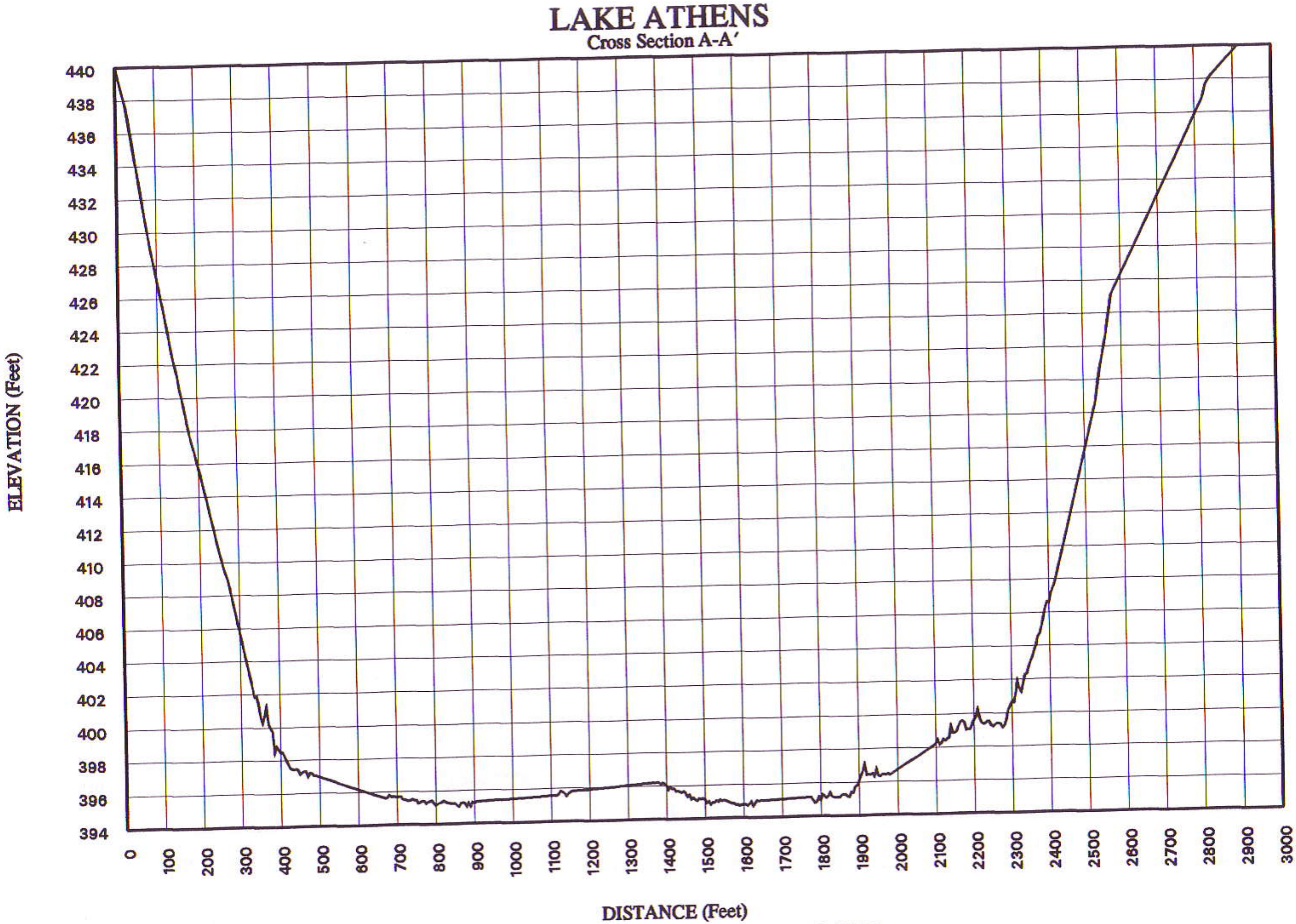
440	1799									



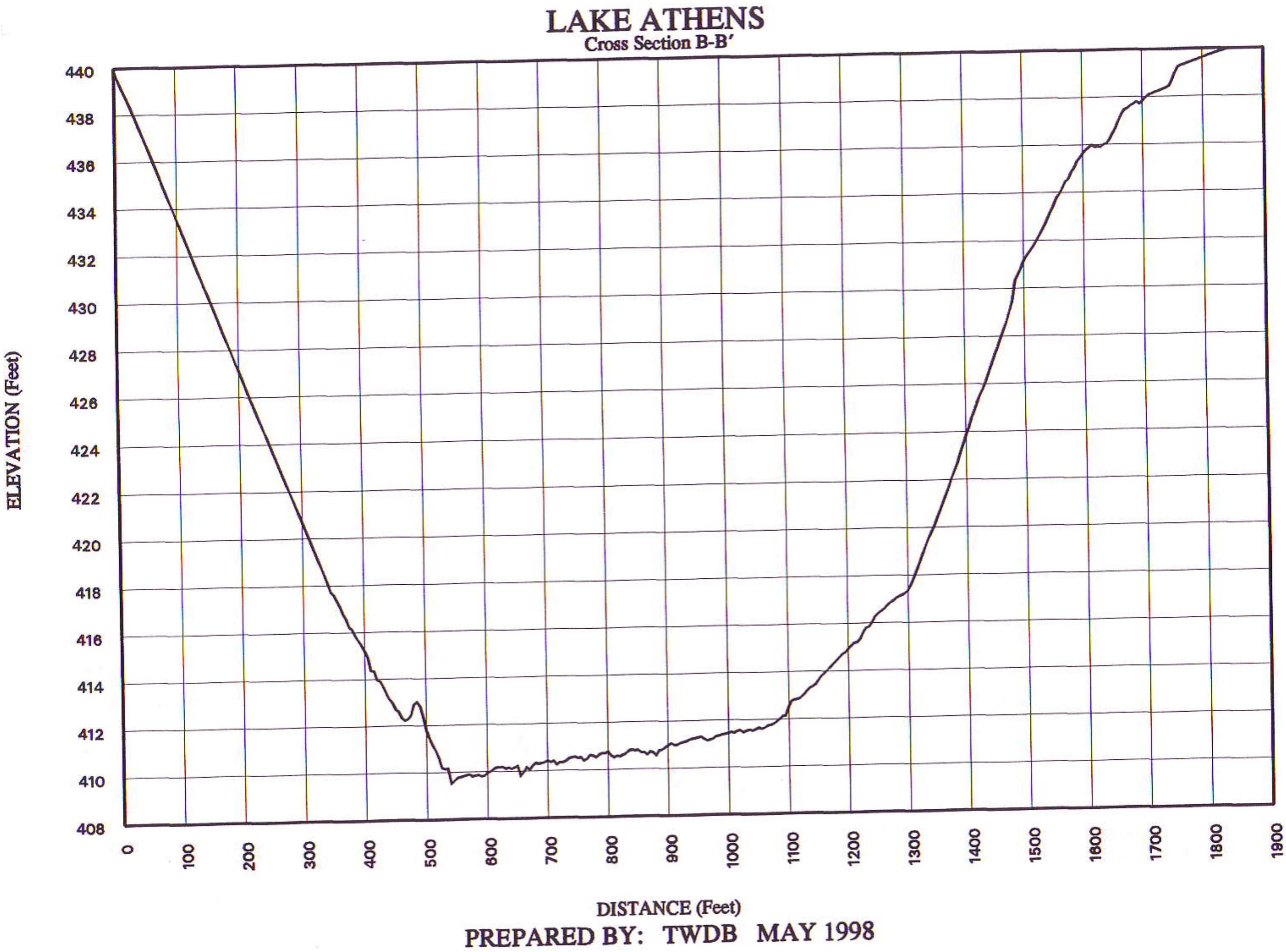
LAKE ATHENS

February 1998 Survey

Prepared by: TWDB June 1998

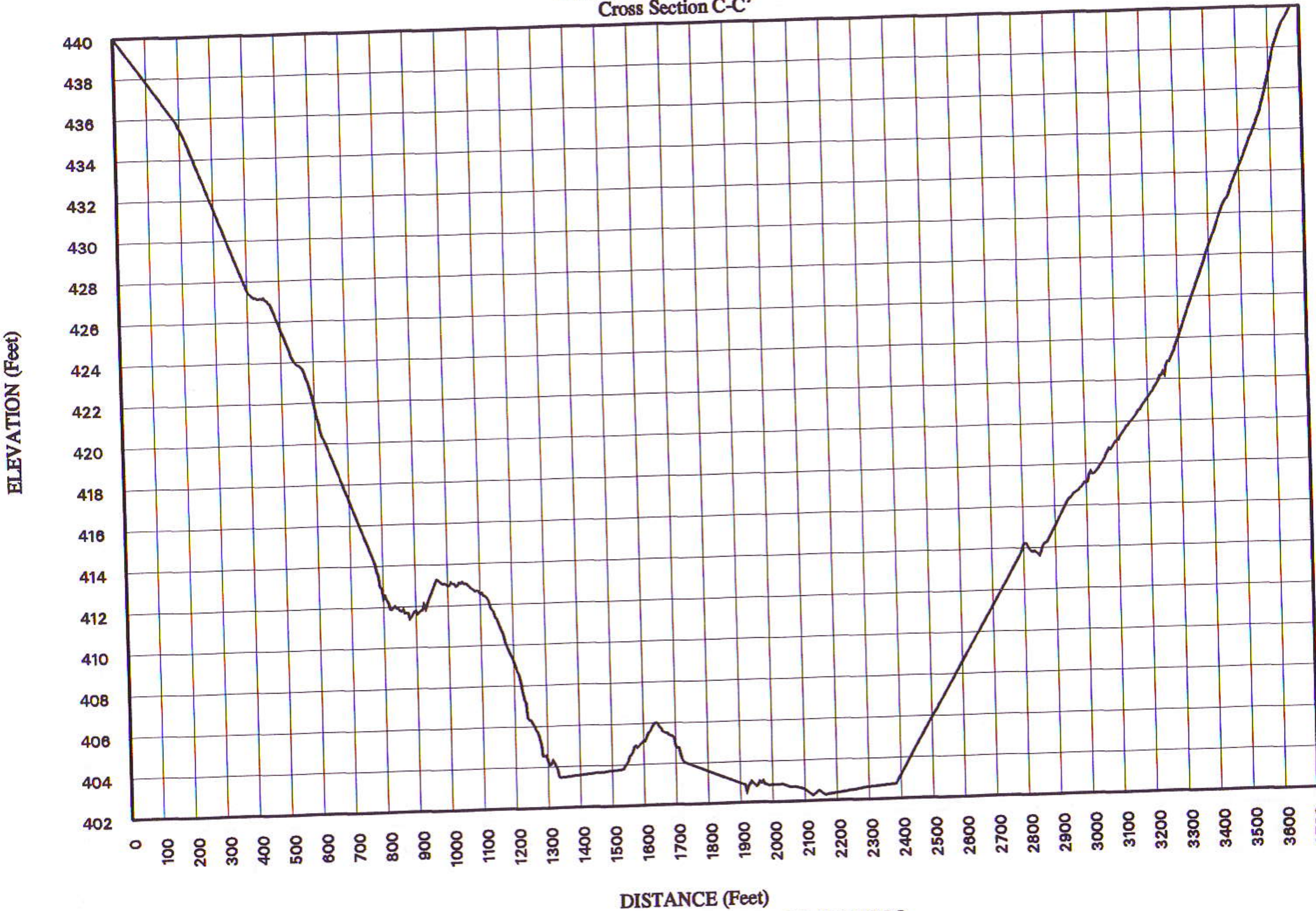


PREPARED BY: TWDB MAY 1998


LAKE ATHENS
Cross Section B-B'
ELEVATION (Feet)
440
438
436
434
432
430
428
426
424
422
420
418
416
414
412
410
408
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
DISTANCE (Feet)
PREPARED BY: TWDB MAY 1998

LAKE ATHENS

Cross Section C-C′



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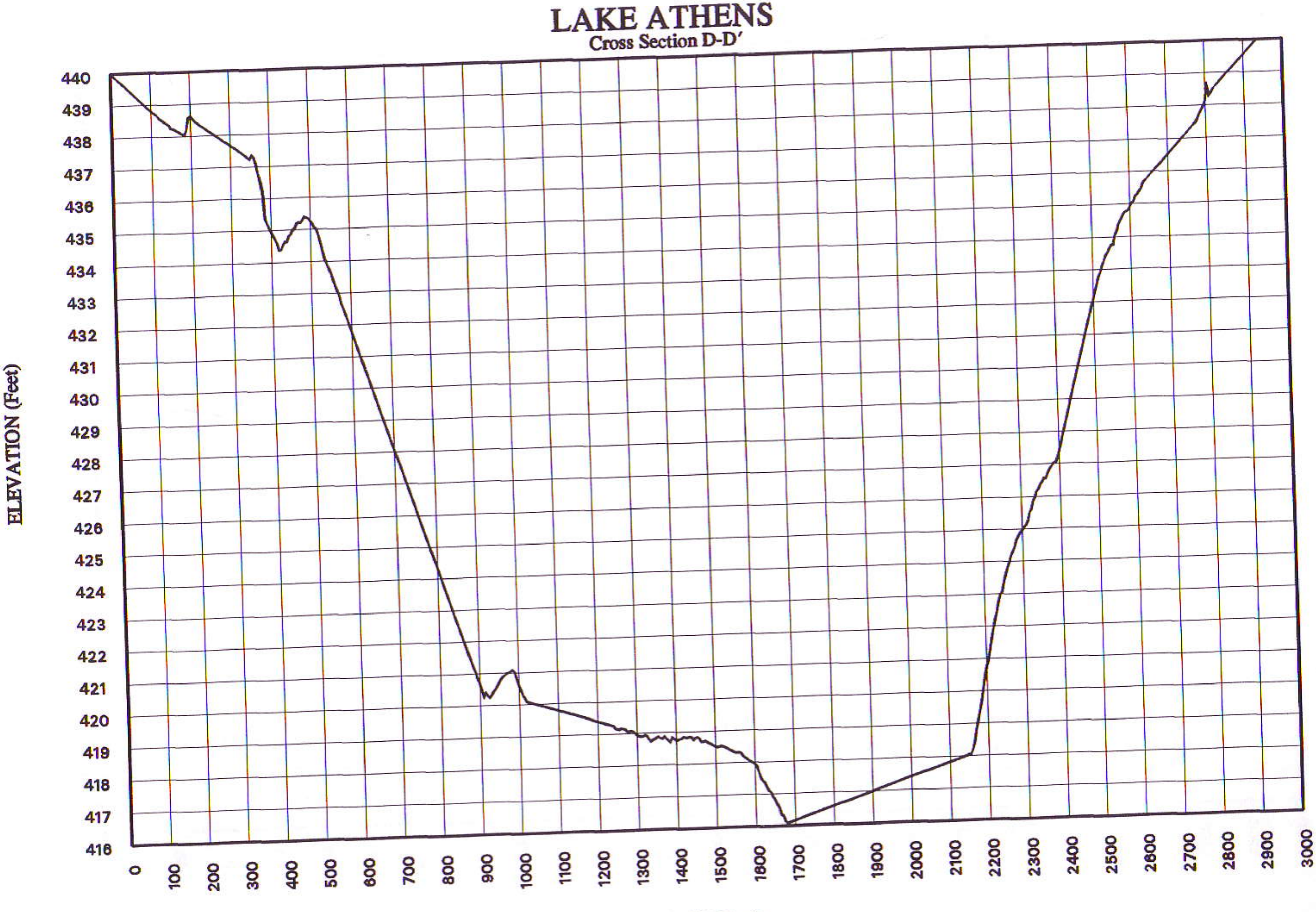

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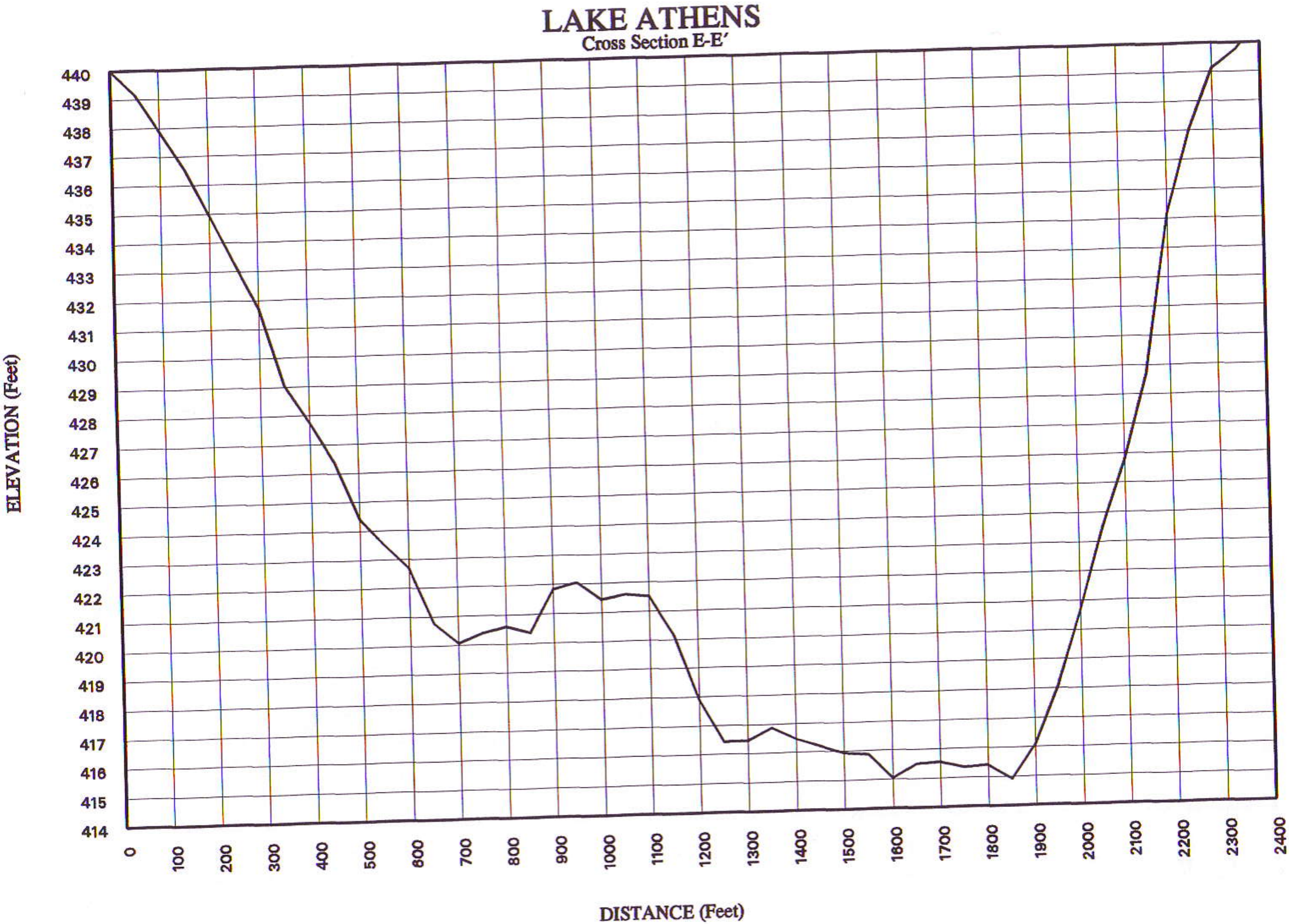

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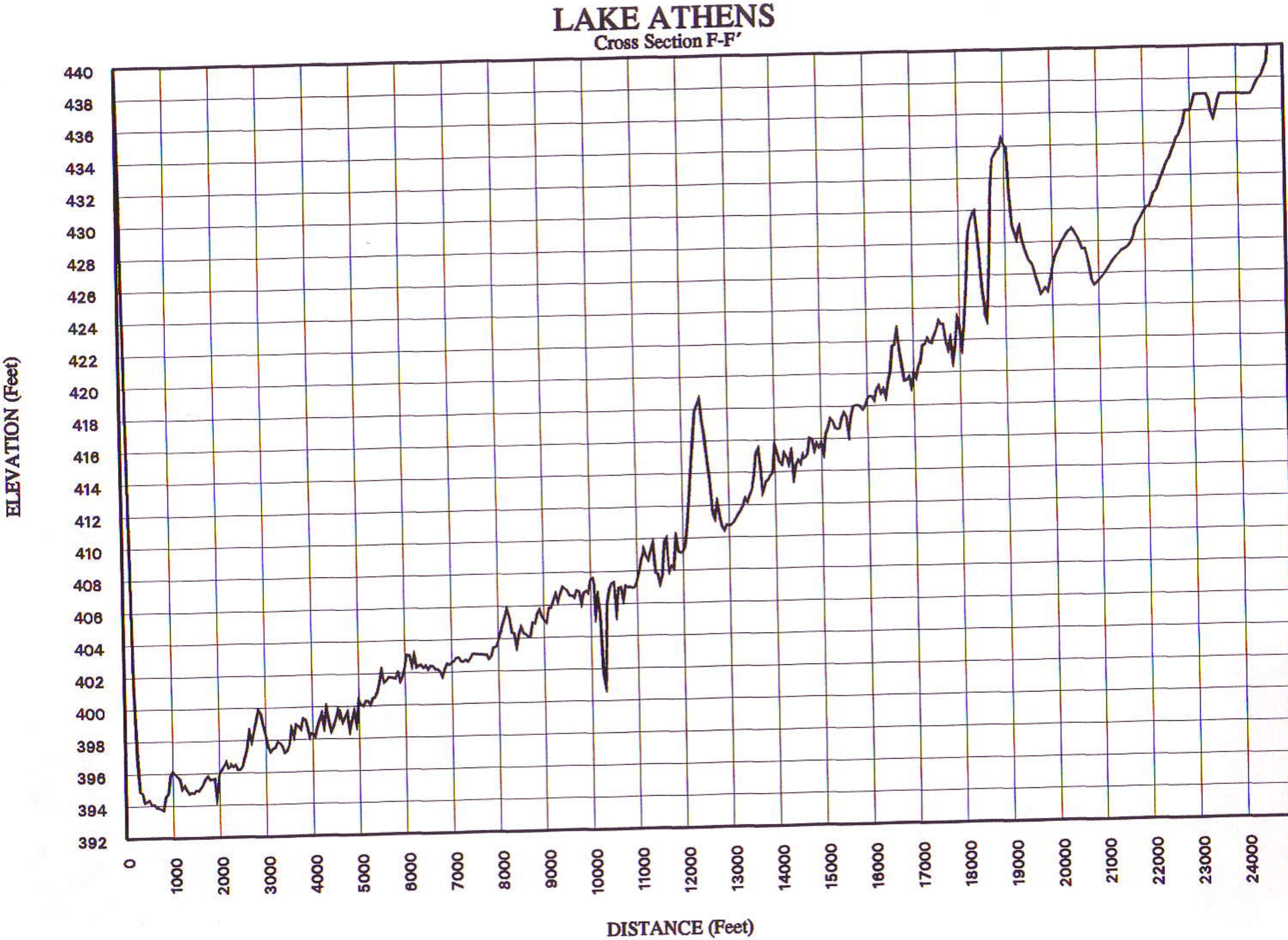

PREPARED BY: TWDB MAY 1998

FIGURE 1

LAKE ATHENS

Site Location Map

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N

1" = 6500'

FIGURE 2

LAKE ATHENS

Location of Survey Data

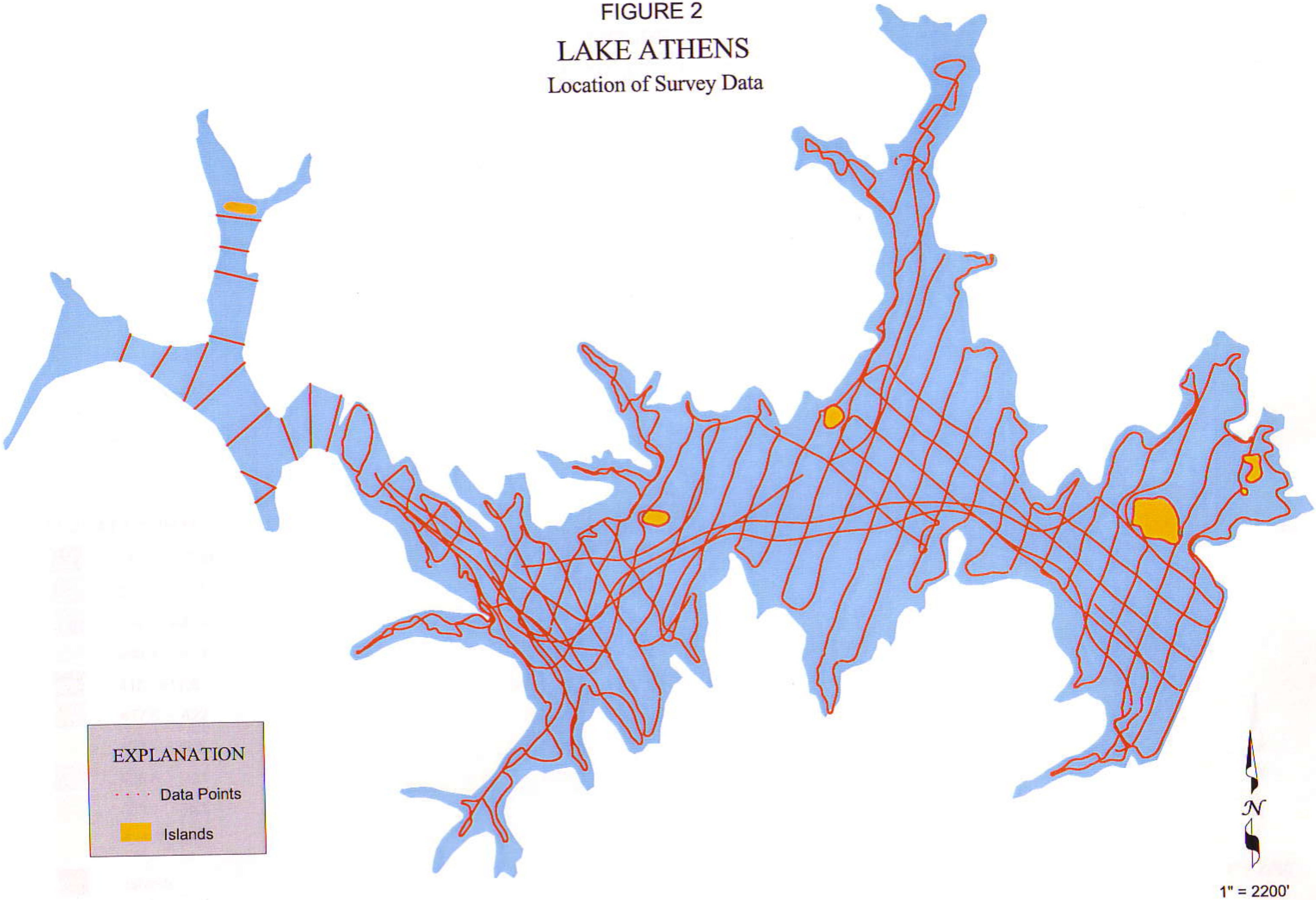

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FIGURE 3

LAKE ATHENS

Shaded Relief

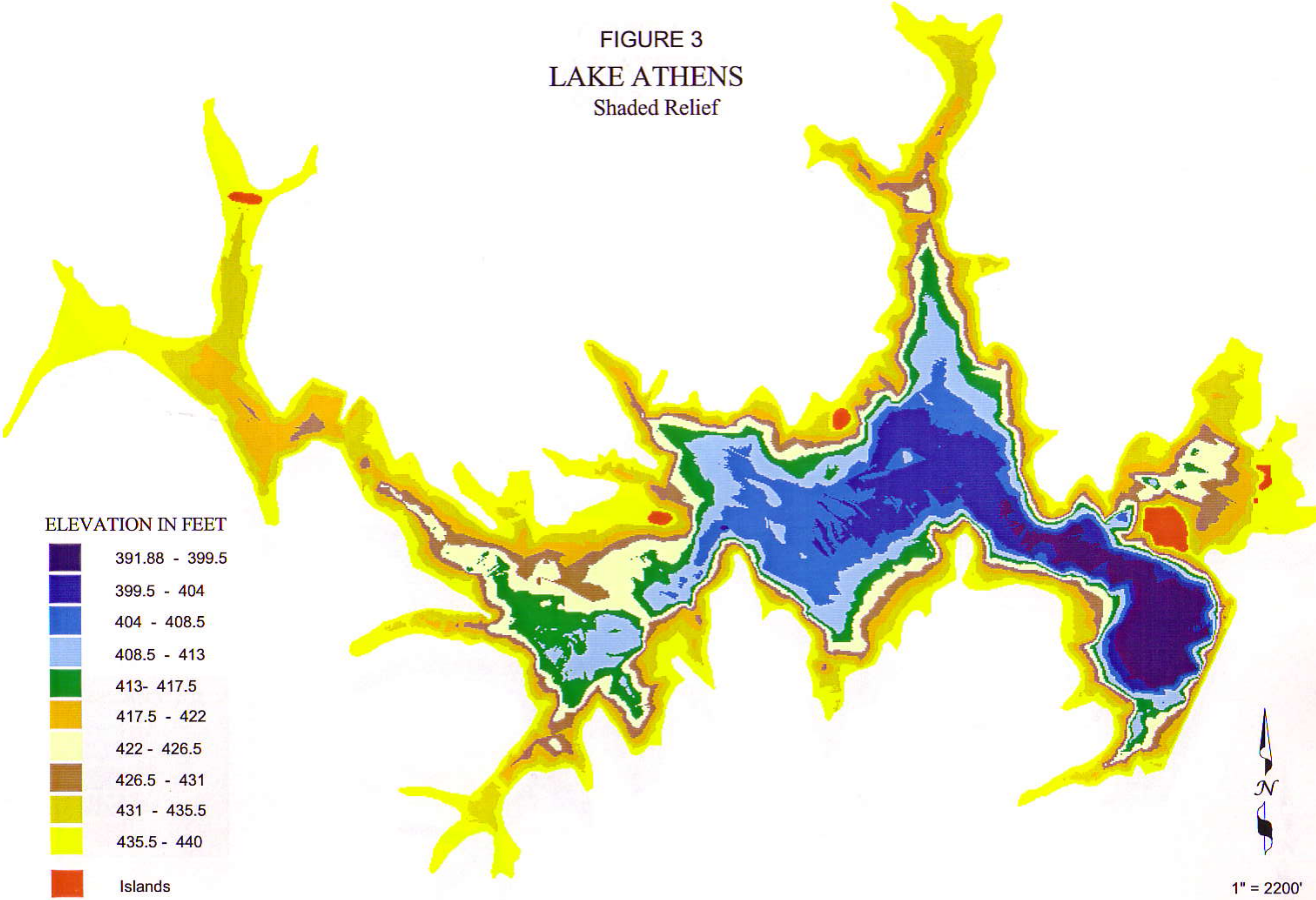

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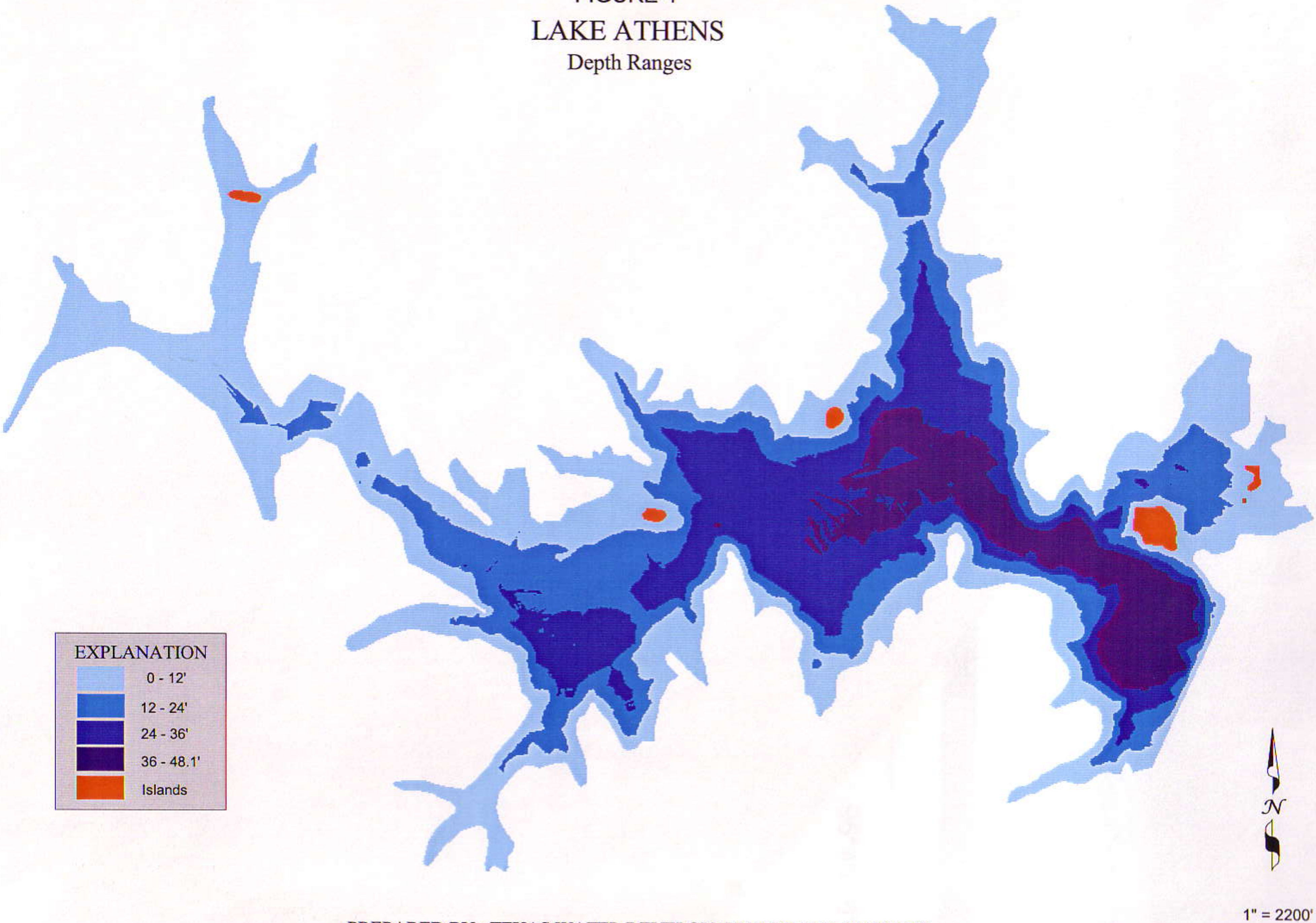
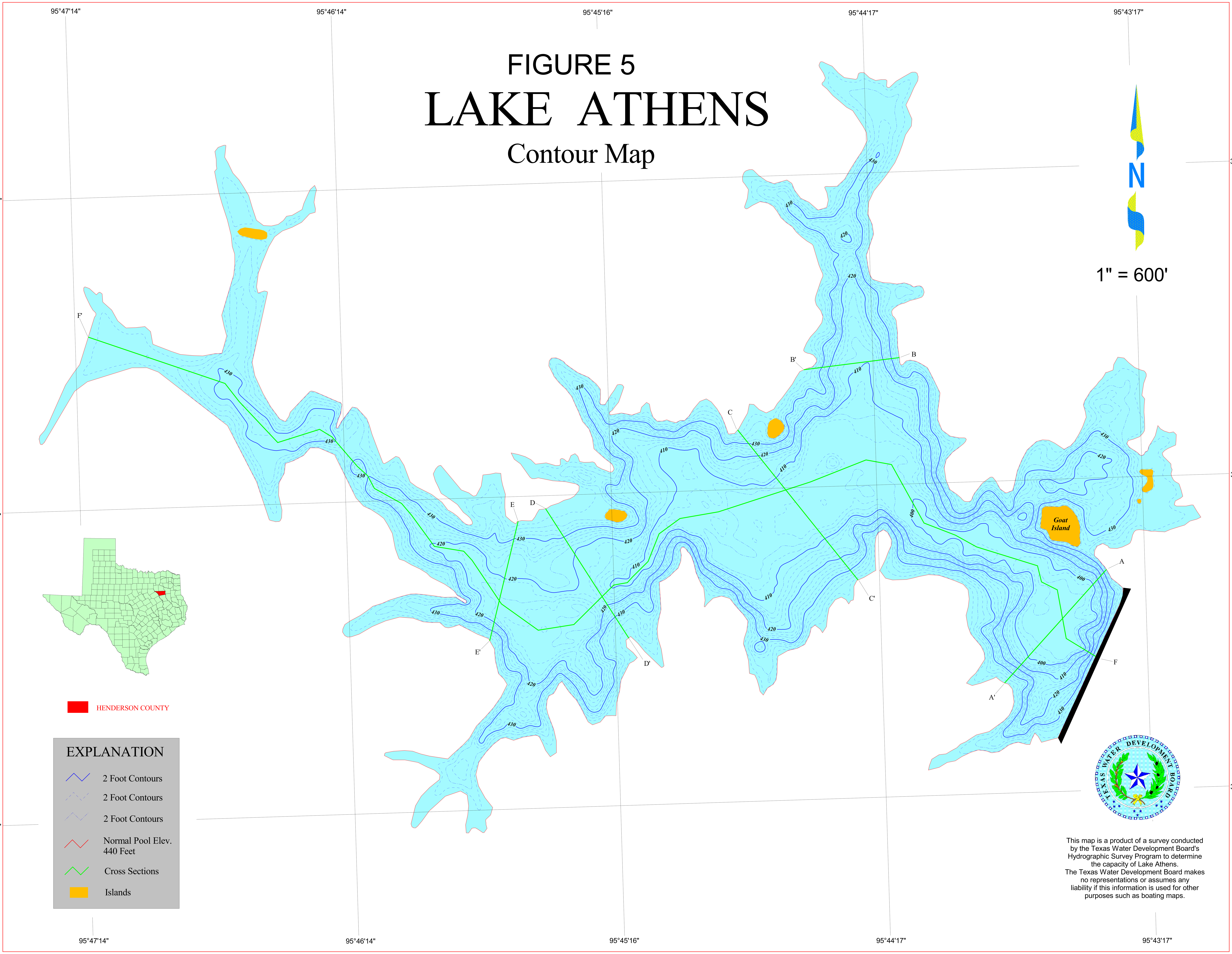
FIGURE 4

LAKE ATHENS

Depth Ranges



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD MAY 1998



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD MAY 1998