VOLUMETRIC SURVEY OF LAKE GRAHAM

Prepared for:

City of Graham

Prepared by:

The Texas Water Development Board

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Lake Graham during the period of April 14 – 15, 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 Graham is 1075.0 feet. The 1945 design information/field survey estimates the original surface area at this elevation to be 2,550 acres and the storage volume to be 53,680 acre-feet of water.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Graham is unique in that it is basically two lakes connected by a canal. Eddleman Dam was built on Flint Creek in 1928 and created Lake Eddleman. In 1958, Graham Dam was built on Salt Creek and formed Lake Graham. The two lakes were connected via canal sometime after June of 1959 and are considered to be one lake, known as Lake Graham.

The lake is located two miles northwest of Graham, TX. on Flint and Salt Creeks, tributaries to the Brazos River (see Figure 1) in Young County. Records indicate the drainage area is approximately 221 square miles. At the conservation pool elevation, the lake has approximately 38 miles of shoreline and is 5.3 miles long. The widest point of the reservoir is approximately 1.5 miles (located about 0.16 miles upstream of the dam).

The project is owned and operated by the City of Graham. The water rights date back to two permits. Permit No. 1061 (Application No. 1136) issued by the State Board of Water Engineers on May 1, 1928 authorized the City to construct a dam on Flint Creek to impound 6,500 acre-feet of water and use annually 5,000 acre-feet of water for municipal purposes. Permit No. 1747 (Application 1871) dated May 10, 1955 authorized the City to construct a dam on Salt Creek and to impound 39,000 acre-feet of water. The City of Graham was allowed an annual diversion of 15,000 acre-feet of water (7,000 acre-feet for municipal use and 8,000 acre-feet for industrial use). Due to the water requirements increasing beyond the water supply available from both lakes, plans were made to raise the dam on Lake Eddleman to the same height as Lake Graham. Permit No. 1747A (Application No. 2064) dated February 27, 1958 authorized the City of Graham to raise the height of Eddleman Dam, thus increasing the storage capacity of the original Lake Eddleman and to combine the two lakes into one lake known today as Lake Graham. The Texas Water Commission issued Certificate of Adjudication No. 12-3458 on February 20, 1985 to the City of Graham. The owner was authorized to maintain an existing dam on Flint Creek (Lake Eddleman) and impound therein not to exceed 13,386 acre-feet of water. The owner was also authorized to maintain an existing dam on Salt Creek (Lake Graham) and impound therein not to exceed 39,000 acre-feet of water. The City of Graham was authorized to annually divert and use not to exceed 11,000 acre-feet of water for municipal purposes, 8,400 acre-feet of water for industrial purposes and 500 acre-feet of water for mining purposes.

Records indicate the construction for the original Eddleman Dam started in 1928 and was completed in 1929. Deliberate impoundment of water began that same year. Freese and Nichols were the design engineers and Womack-Henning Construction Company was the general contractor. The cost of the original dam was estimated at $237,100.

The construction for Graham Dam started on September 17, 1956 and was completed in July of 1958. During this construction phase, work began in 1957 and ended in 1958 to the raise the height of Eddleman Dam. Deliberate impoundment of water began April 28, 1958. Freese and Nichols were the design engineers and Weldon C. Jourdan was the general contractor for both projects. The estimated cost for both projects was $486,490. The canal that connects the two lakes was dredged sometime in the later half of 1959.

The original Eddleman Dam consist of an earthfill embankment 1,400 feet in length with a maximum height of 35 feet and a crest width of 20 feet at a crest elevation of 1,075.0 feet. The 1958 dam enlargement lengthened the embankment to 4,495 feet and raised it to a maximum height of 57 feet with a crest elevation of 1,093.3 feet.

Graham Dam is a rolled-earth structure 3,700 feet in length, with a maximum height of 82 feet and a crest elevation of 1,093.3 feet. The emergency spillway (located to the west of Graham Dam is uncontrolled and cut in natural ground. The crest width is 1,050 feet at elevation 1,075.0 feet. The outlet works structure consists of a concrete tower rising up through the dam about 30 feet from the crest and about 700 feet from the left end. There are two control valves, each 20-inches in diameter that release water downstream through a 24-inch diameter conduit from a submerged 18-inch pipe extending out into the lake. The inlet elevation for the submerged pipe is 1,051.3 feet. A low-flow flapper valve at elevation 1,031.3 feet is available for small releases when the inlet pipe is above water.

Texas Utilities operates an electricity generating plant that pumps water for circulation and cooling purposes from the Graham Dam side of the lake and returns the water to the Eddleman Dam side.

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 1 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 provides electrical 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 1075.0). The boundary file was created from the following 7.5 minute USGS quadrangle maps: NEWCASTLE, TX (photo-revised 1981), SOUTH BEND, TX (photo-revised 1981), and LAKE EDDLEMAN, TX (photo-revised 1981). 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 (standard conversion method within the United States) 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 89 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 Graham 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 Graham, the speed of sound in the water column varied from 4850 to 4856 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 ± 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 Graham during the period of April 14 - 15, 1998. Weather conditions were excellent with moderately cool temperatures and mild winds. Approximately 32,203 data points were collected over the 94 miles traveled along the 96 survey lines run (pre-planned, random, and parallel). These points were stored digitally on the boat's computer in 102 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. Figure 2 shows the actual location of all data collection points.

TWDB staff visually observed that the terrain around the lake was generally rolling hills with residential development concentrated mostly along the West Bank of Salt Creek**.** Minimal amounts of navigational hazards such as standing trees, brush, submerged trees and stumps were noted till reaching an island about four miles upstream of the dam on the Salt Creek side. From this point, upstream to the Highway 380 bridges, navigation became more hazardous with numerous areas of standing trees, brush, submerged trees and stumps. The boat was able to pass through a 12-foot opening in the old Highway 380 bridge and then pass under the new Highway 380 bridge. Sediment deposits and aquatic vegetation were observed one-half a mile prior to the bridges and upstream in the headwaters of Salt Creek. In the Flint Creek arm, navigational hazards were minimal upstream to the Highway 380 bridge and the old Highway 380 bridge. There was an outlet tower located on the East End of Eddleman Dam containing the intake pumps for the City of Graham. The survey crew collected extensive data around this structure. The old Highway 380 bridge blocked the survey vessel from traveling further upstream. The crew did note numerous areas of sediment and aquatic vegetation around the bridges.

Data collection in the headwaters was discontinued when the boat could no longer maneuver due to shallow water and extensive vegetation. 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 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 held steady at 1074.5 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 2,286 additional points were manually added to allow for interpolation and contouring of the entire lake surface at elevation 1075.0. Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 1071.0 to elevation 1075.0, the surface areas and volumes of the lake were mathematically estimated. This was done by first 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 1075.0 was 2,444 surface acres. The computed area was 106 surface acres less than originally calculated in 1945. 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 1075.0 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 Graham encompasses 2,444 surface acres and contains a volume of 45,302 acre-feet at the conservation pool elevation of 1075.0 feet. The shoreline at this elevation was calculated to be 38 miles. The deepest point of the lake, elevation 1025.9 or 49.1 feet of depth, was located approximately 1,824 feet northwest from the center of Graham Dam. The dead storage volume, or the amount of water below the lowest outlet in the dam, was calculated to be 42 acre-feet based on the low flow outlet invert elevation of 1031.3 feet. The conservation storage capacity, or the amount of water between the spillway and the lowest outlet, is therefore calculated to be 45,260 acre-feet.

SUMMARY

Lake Graham was formed in 1950. Initial storage calculations estimated the volume at the conservation pool elevation of 1075.0 feet to be 53,680 acre-feet with a surface area of 2,550 acres.

During the period of April 14 - 15, 1998, a hydrographic survey of Lake Graham 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 Graham than previous survey methods. Results indicate that the lake's capacity at the conservation pool elevation of 1075.0 feet was 45,302 acre-feet and the area was 2,444 acres.

The estimated reduction in storage capacity at the conservation pool elevation of 1075.0 feet since 1952 was 8,378 acre-feet or 232.72 acre-feet per year. The average annual deposition rate of sediment in the conservation pool of the reservoir can be estimated at 1.053 acre-feet per square mile of drainage area. *(Please note that this is just a mathematical estimate based on the difference between the original design and the current survey. Limited knowledge on actual sedimentation can be determined from one field 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' (+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 16 1998

Lake Graham April 1998 Survey

VOLUME IN ACRE-FEET ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,027										
1,028	1	1	1	2	2	2	3	3	4	4
1,029	5	6	6	7	8	9	10	11	12	13
1,030	14	15	17	18	20	22	24	26	28	30
1,031	33	36	39	42	45	48	52	56	60	65
1,032	70	75	80	85	91	96	102	108	115	121
1,033	128	135	142	149	156	164	171	179	187	195
1,034	204	212	221	230	238	248	257	266	276	286
1,035	296	306	316	327	338	349	360	371	383	395
1,036	407	420	432	445	458	471	485	498	512	527
1,037	541	556	571	586	601	617	633	650	666	683
1,038	700	718	735	754	772	791	810	829	849	868
1,039	888	909	930	951	972	994	1016	1038	1061	1084
1,040	1108	1132	1157	1181	1207	1232	1258	1285	1312	1339
1,041	1366	1394	1423	1452	1481	1511	1541	1572	1603	1635
1,042	1667	1700	1733	1766	1800	1835	1869	1905	1940	1977
1,043	2013	2050	2088	2126	2164	2203	2243	2283	2323	2364
1,044	2405	2447	2490	2533	2576	2620	2665	2709	2755	2801
1,045	2847	2894	2941	2989	3038	3086	3136	3186	3236	3288
1,046	3339	3391	3444	3498	3552	3606	3662	3718	3775	3833
1,047	3891	3950	4010	4071	4132	4194	4257	4320	4383	4447
1,048	4512	4577	4643	4709	4776	4843	4911	4980	5049	5119
1,049	5189	5260	5331	5402	5475	5547	5620	5694	5768	5843
1,050	5918	5994	6070	6147	6225	6303	6382	6461	6541	6622
1,051	6703	6785	6868	6952	7036	7120	7206	7291	7378	7465
1,052	7553	7642	7731	7821	7911	8002	8094	8186	8279	8372
1,053	8467	8561	8657	8753	8850	8947	9045	9144	9244	9344
1,054	9445	9547	9649	9752	9856	9961	10066	10172	10278	10386
1,055	10493	10602	10711	10821	10931	11042	11154	11267	11380	11494
1,056	11608	11723	11839	11955	12072	12190	12308	12427	12547	12667
1,057	12787	12909	13031	13154	13277	13401	13526	13651	13777	13903
1,058	14030	14158	14286	14415	14544	14674	14805	14936	15068	15200
1,059	15333	15466	15600	15735	15870	16005	16141	16278	16415	16553
1,060	16691	16830	16969	17109	17250	17391	17533	17675	17818	17961
1,061	18106	18250	18395	18541	18688	18835	18982	19130	19279	19428
1,062	19578	19729	19880	20032	20184	20337	20491	20645	20800	20955
1,063	21111	21268	21425	21584	21743	21902	22063	22224	22385	22548
1,064	22711	22875	23039	23205	23371	23537	23705	23873	24042	24211
1,065	24381	24551	24723	24895	25067	25241	25414	25589	25764	25940
1,066	26117	26294	26472	26651	26831	27011	27192	27374	27557	27740
1,067	27924	28109	28295	28481	28668	28856	29045	29234	29425	29616
1,068	29807	30000	30194	30388	30583	30779	30976	31173	31372	31571
1,069	31771	31971	32173	32375	32579	32783	32987	33193	33400	33607
1,070	33815	34025	34235	34447	34659	34872	35086	35301	35516	35732
1,071	35952	36172	36393	36615	36837	37061	37284	37509	37734	37960
1,072	38187	38414	38642	38870	39100	39330	39560	39792	40024	40257
1,073	40490	40724	40959	41194	41431	41667	41905	42143	42382	42622
1,074	42862	43103	43345	43587	43830	44074	44318	44563	44809	45055
1,075	45302									

TEXAS WATER DEVELOPMENT BOARD

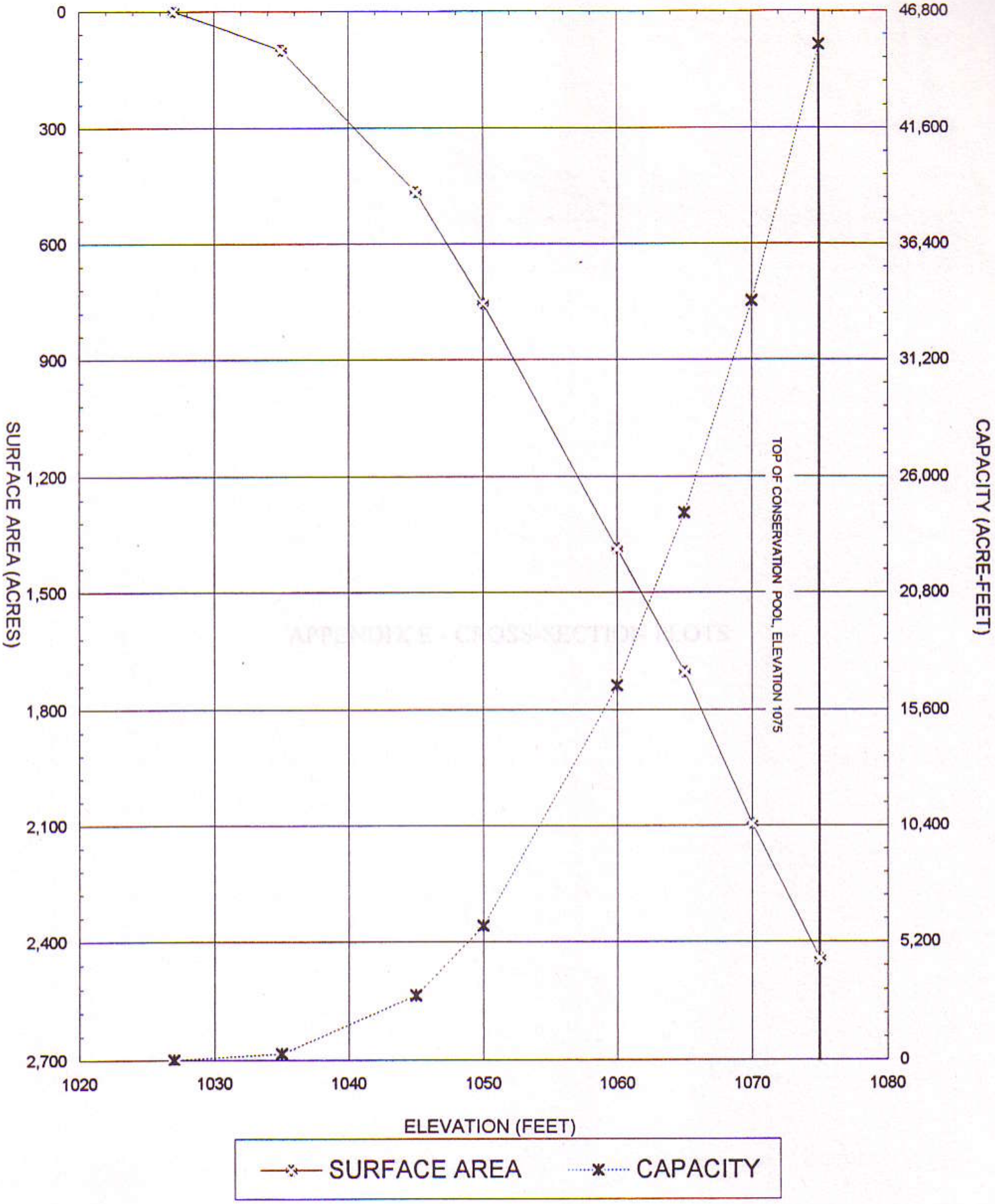
Jun 16 1998

RESERVOIR AREA TABLE

Lake Graham April 1998 Survey

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

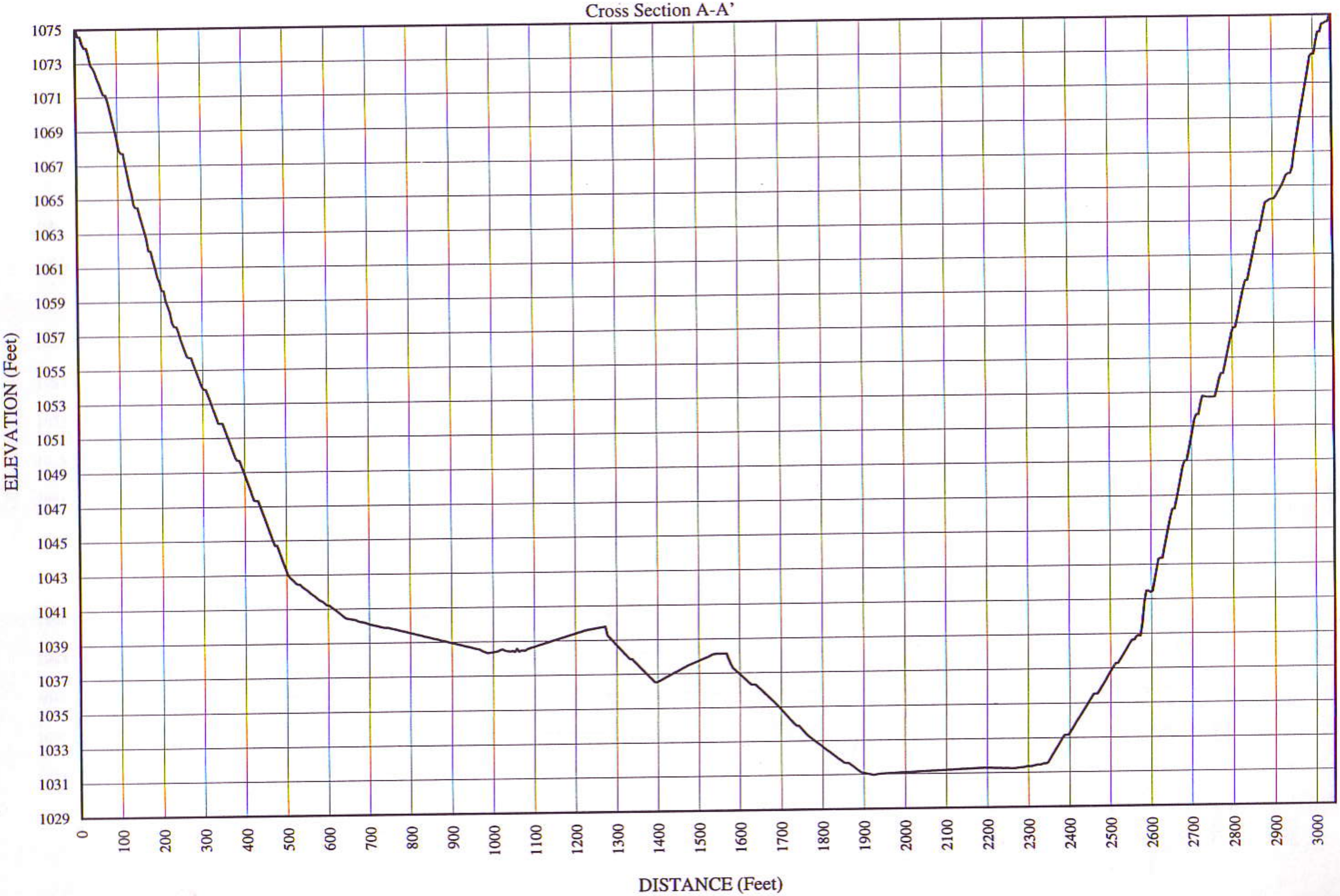
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1,027							1	1	1	2
1,028	2	3	3	3	4	4	5	5	6	6
1,029	7	7	7	8	8	9	9	10	11	11
1,030	13	14	15	16	17	19	20	21	23	25
1,031	26	28	29	31	34	37	39	41	44	47
1,032	49	50	53	55	57	58	60	62	64	66
1,033	67	69	71	73	74	76	77	79	81	82
1,034	84	85	87	89	90	92	94	95	97	99
1,035	101	103	105	107	109	112	114	116	118	120
1,036	123	125	127	129	131	134	136	138	141	143
1,037	146	148	151	154	156	159	162	164	167	170
1,038	173	176	180	183	186	189	191	194	197	200
1,039	203	206	209	212	215	219	222	226	230	235
1,040	239	243	247	251	254	258	262	266	270	274
1,041	278	282	287	292	296	301	305	310	314	319
1,042	324	328	333	338	342	346	351	355	359	364
1,043	368	373	377	382	387	392	397	402	407	412
1,044	417	422	427	432	437	442	447	452	457	461
1,045	466	471	476	481	486	491	497	503	509	514
1,046	520	525	531	537	544	551	558	566	574	581
1,047	589	596	603	610	616	622	627	632	638	643
1,048	649	654	660	666	672	678	684	689	694	699
1,049	704	709	714	719	724	729	734	739	744	750
1,050	755	760	766	772	778	784	790	797	805	811
1,051	817	824	830	837	844	850	857	863	869	876
1,052	882	888	894	901	907	913	920	926	932	939
1,053	945	951	957	964	971	979	986	993	1000	1006
1,054	1013	1020	1027	1034	1041	1048	1055	1062	1069	1075
1,055	1082	1088	1095	1102	1108	1115	1121	1128	1134	1141
1,056	1147	1154	1160	1167	1173	1179	1186	1192	1199	1205
1,057	1211	1218	1224	1230	1236	1243	1249	1255	1261	1267
1,058	1273	1279	1285	1291	1298	1304	1309	1315	1320	1325
1,059	1331	1336	1342	1347	1352	1358	1363	1369	1374	1380
1,060	1386	1391	1397	1403	1409	1415	1420	1426	1432	1438
1,061	1444	1450	1456	1461	1467	1473	1478	1484	1490	1496
1,062	1503	1509	1515	1521	1527	1533	1539	1544	1550	1556
1,063	1565	1572	1579	1586	1593	1600	1607	1614	1621	1628
1,064	1636	1642	1649	1656	1663	1670	1677	1684	1690	1697
1,065	1703	1709	1716	1722	1729	1736	1742	1749	1756	1763
1,066	1770	1778	1785	1792	1800	1807	1815	1823	1830	1838
1,067	1845	1853	1860	1867	1875	1883	1891	1898	1906	1914
1,068	1924	1931	1939	1947	1955	1963	1971	1979	1987	1995
1,069	2003	2011	2020	2028	2036	2044	2052	2061	2069	2077
1,070	2095	2103	2111	2119	2127	2135	2142	2149	2156	2163
1,071	2170	2177	2184	2190	2197	2204	2211	2218	2225	2232
1,072	2238	2245	2252	2259	2266	2273	2279	2286	2293	2300
1,073	2307	2314	2321	2327	2334	2341	2348	2355	2362	2369
1,074	2375	2382	2389	2396	2403	2410	2416	2423	2430	2437
1,075	2444									



LAKE GRAHAM
April 1998 Survey
Prepared by: TWDB June 1998

LAKE GRAHAM

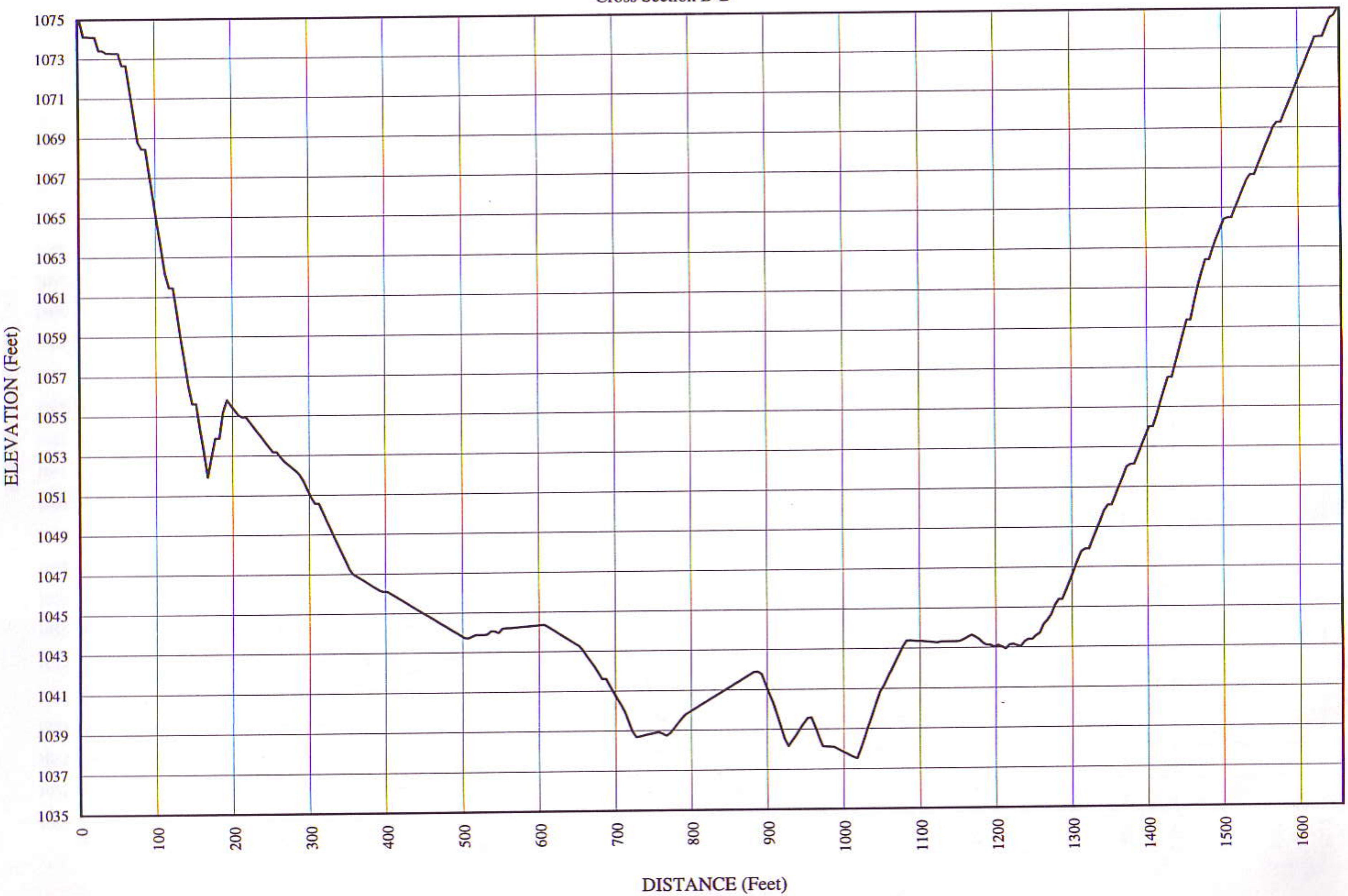
Cross Section A-A'



PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

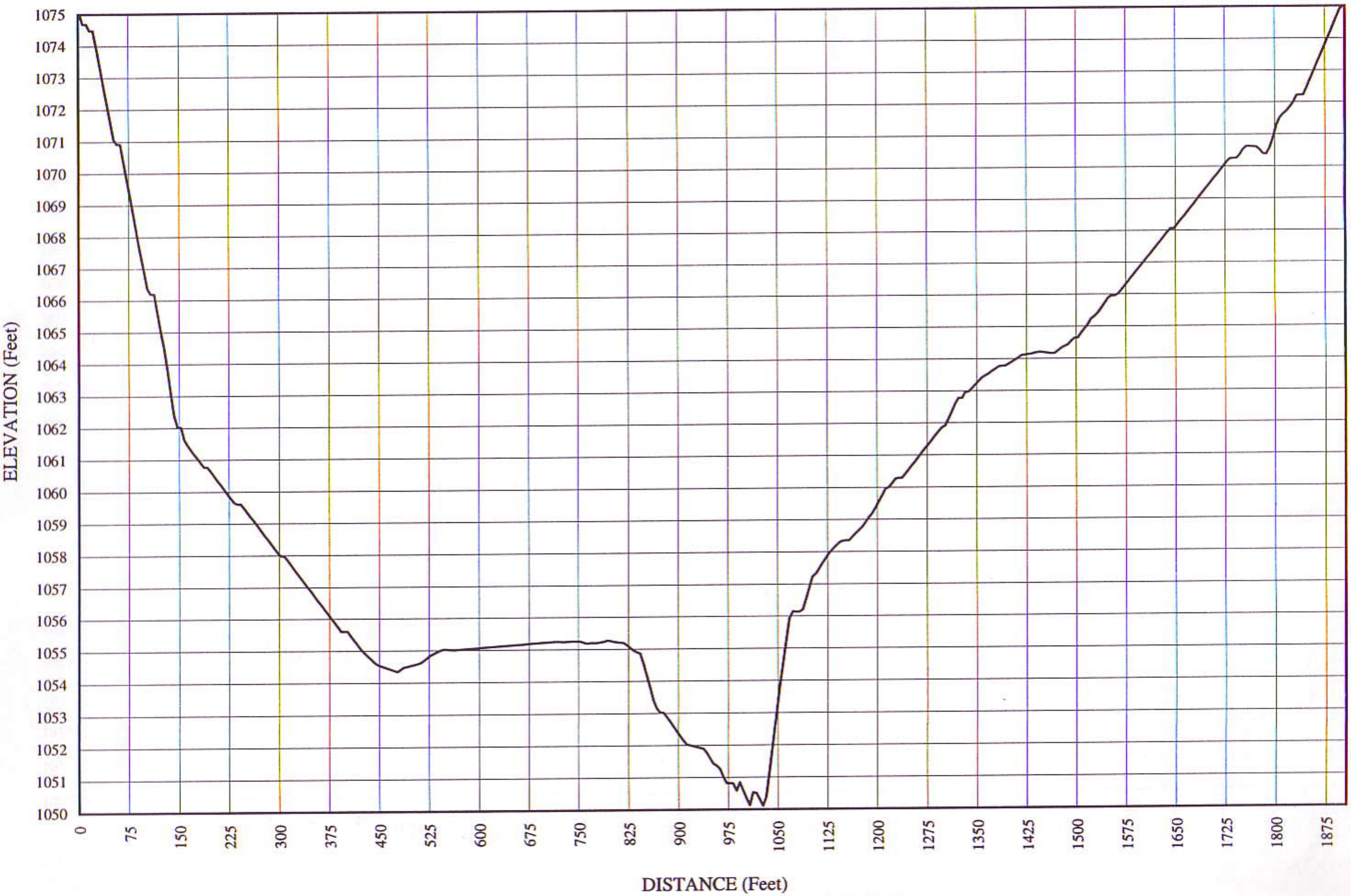
Cross Section B-B'



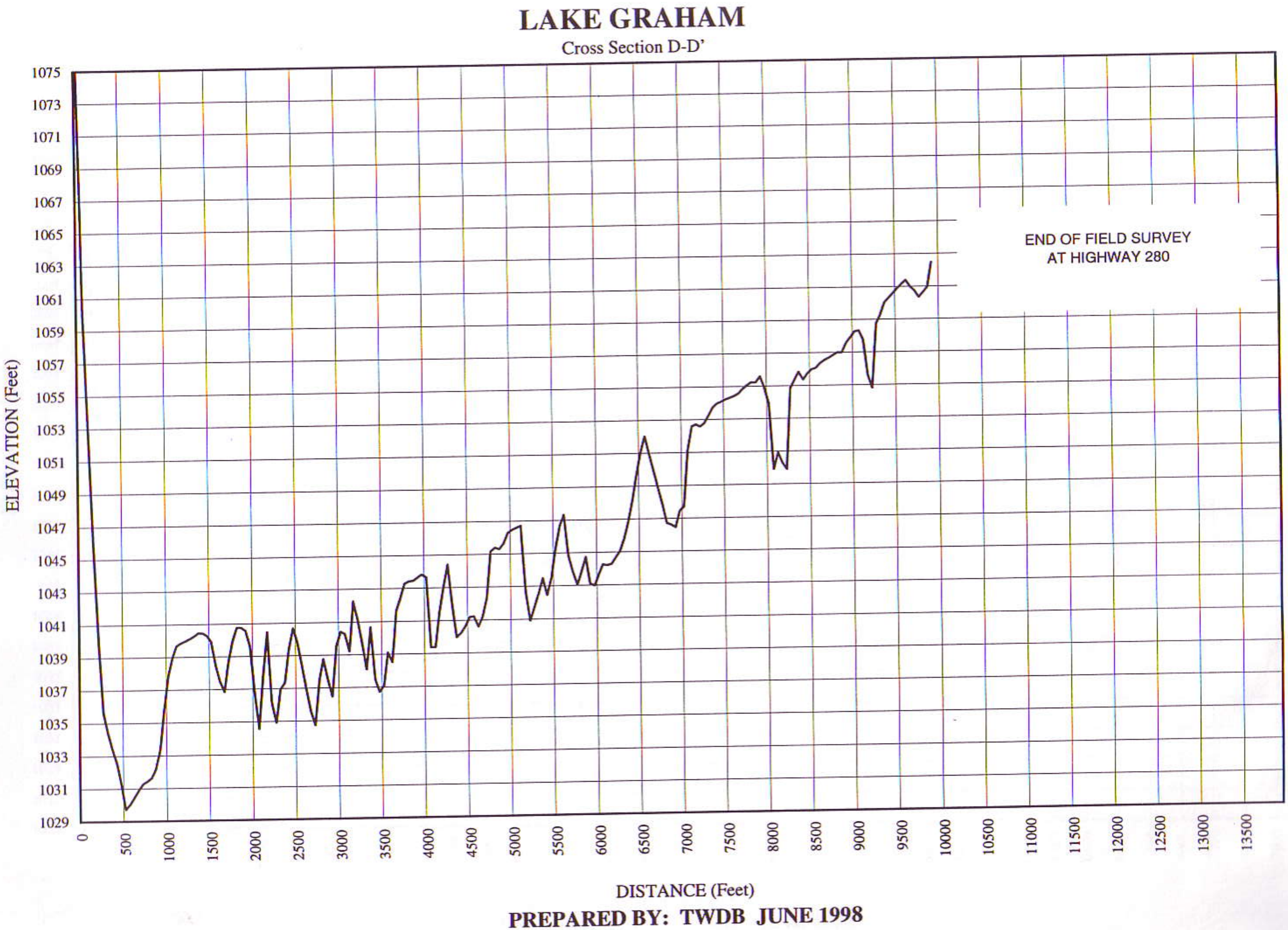
PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

Cross Section C-C'



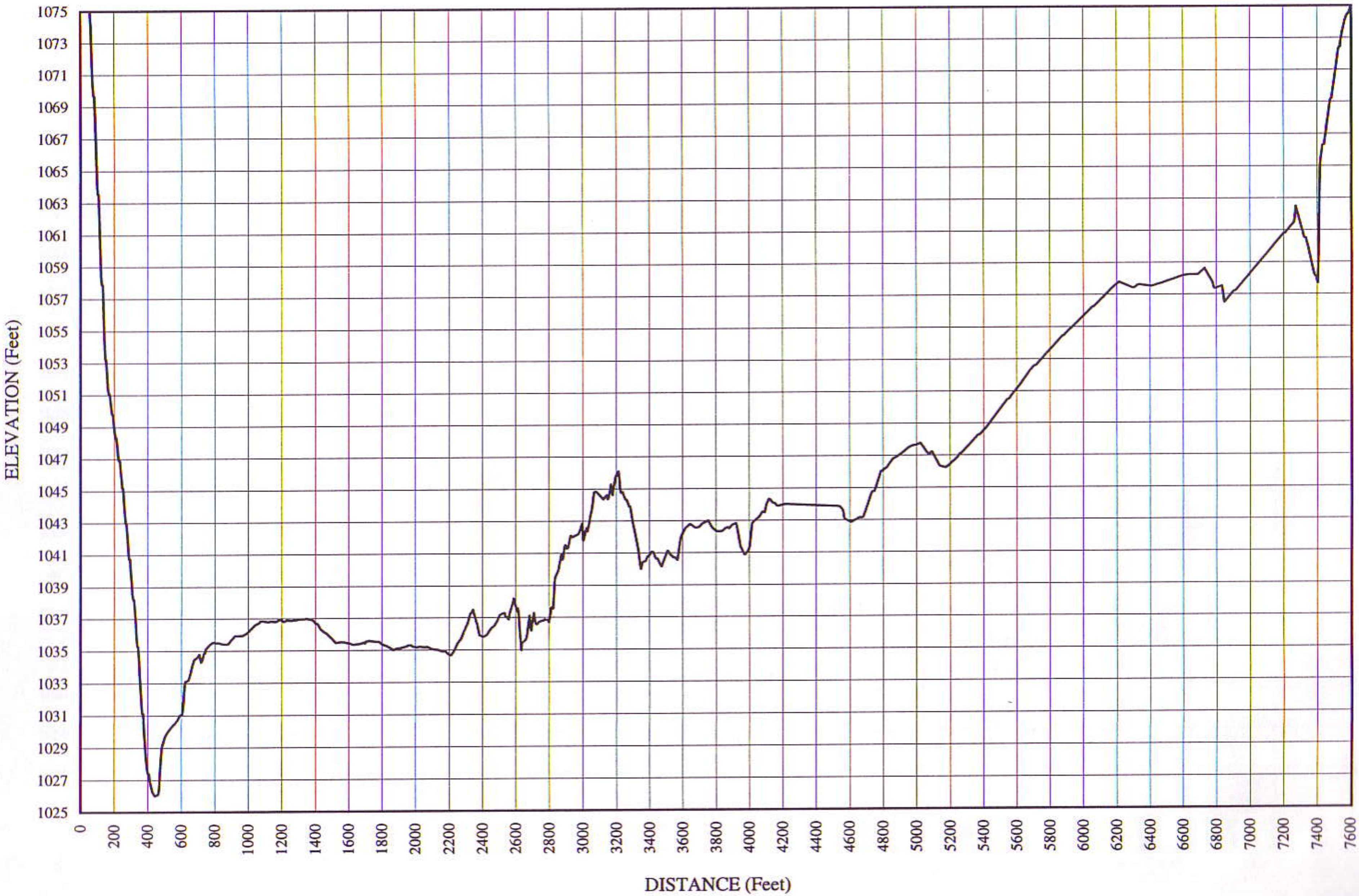
PREPARED BY: TWDB JUNE 1998



LAKE GRAHAM
Cross Section D-D'
ELEVATION (Feet)
1075
1073
1071
1069
1067
1065
1063
1061
1059
1057
1055
1053
1051
1049
1047
1045
1043
1041
1039
1037
1035
1033
1031
1029
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
END OF FIELD SURVEY
AT HIGHWAY 280
DISTANCE (Feet)
PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

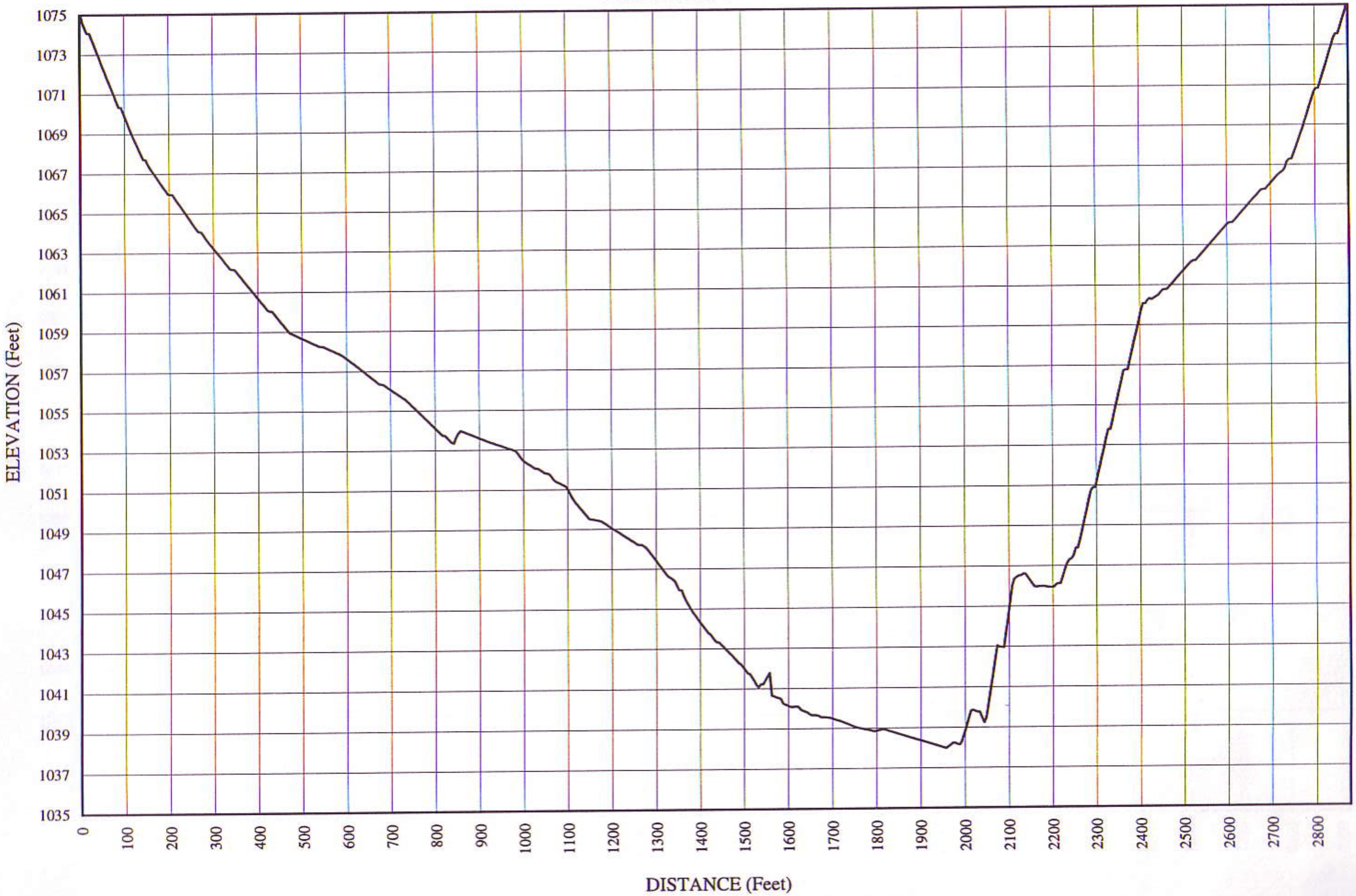
Cross Section E-E'



PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

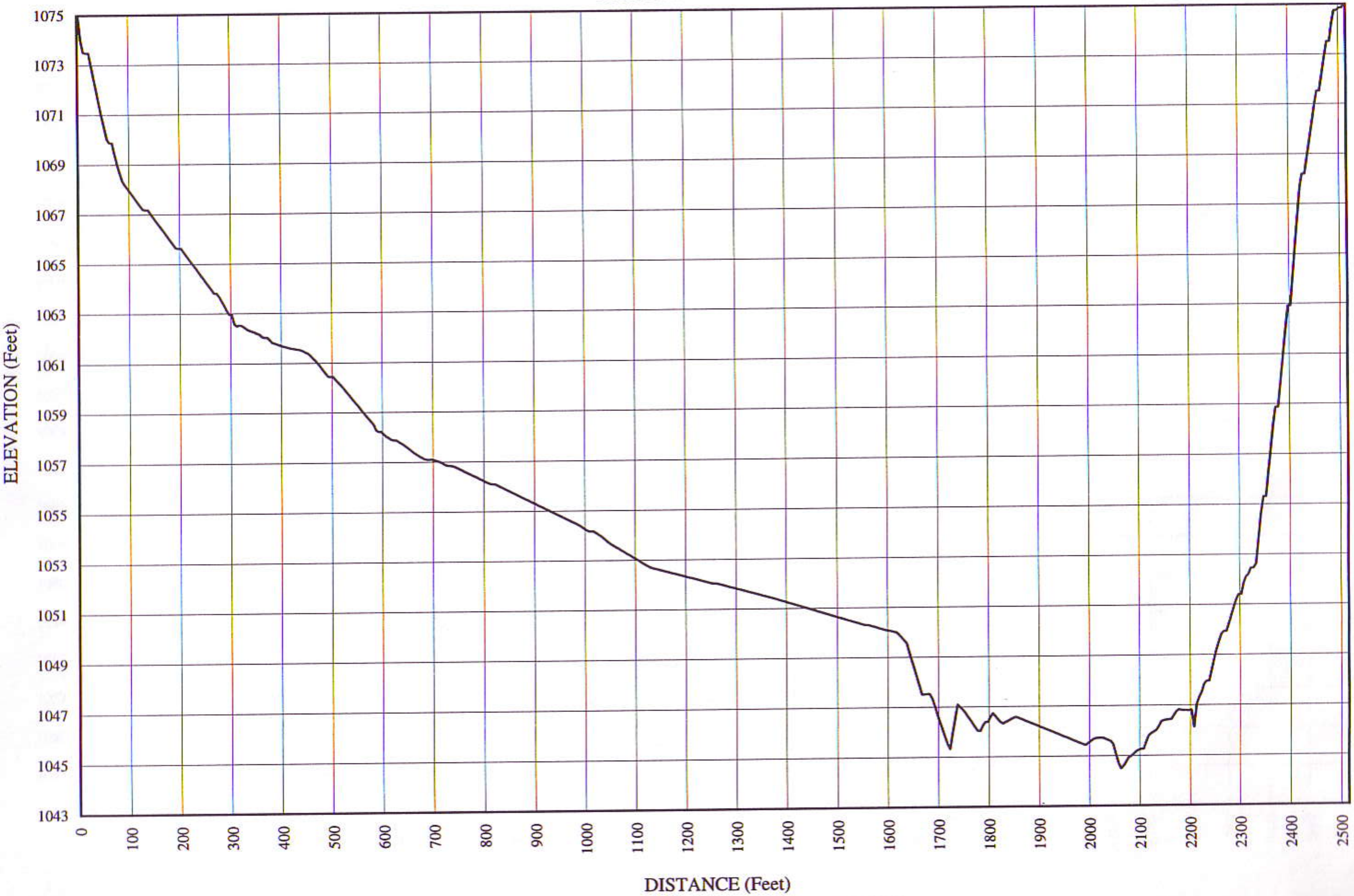
Cross Section F-F'



PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

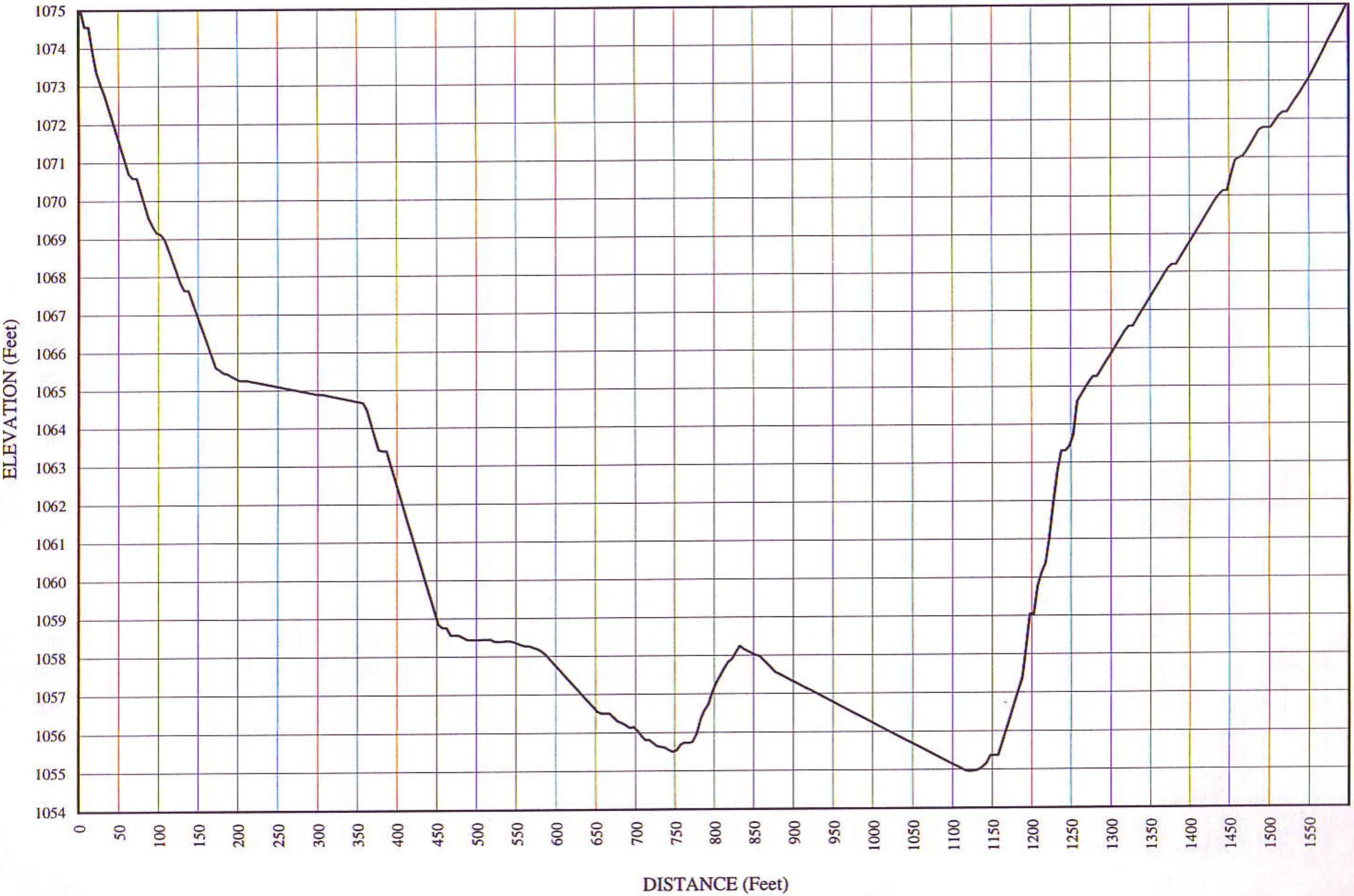
Cross Section G-G'



PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

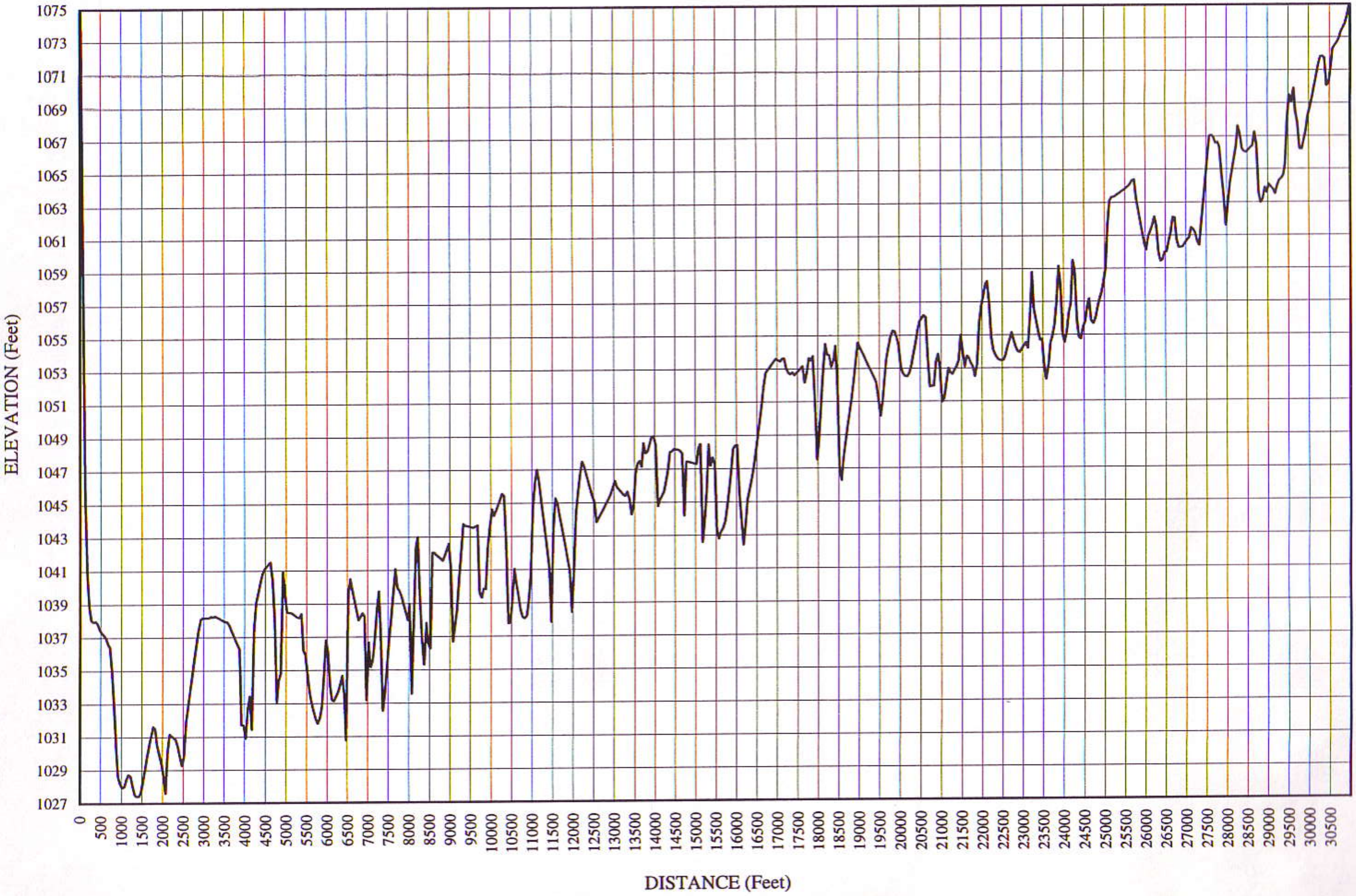
Cross Section H-H'



PREPARED BY: TWDB JUNE 1998

LAKE GRAHAM

Cross Section I-I'



PREPARED BY: TWDB JUNE 1998

FIGURE 1

LAKE GRAHAM

Site Location Map

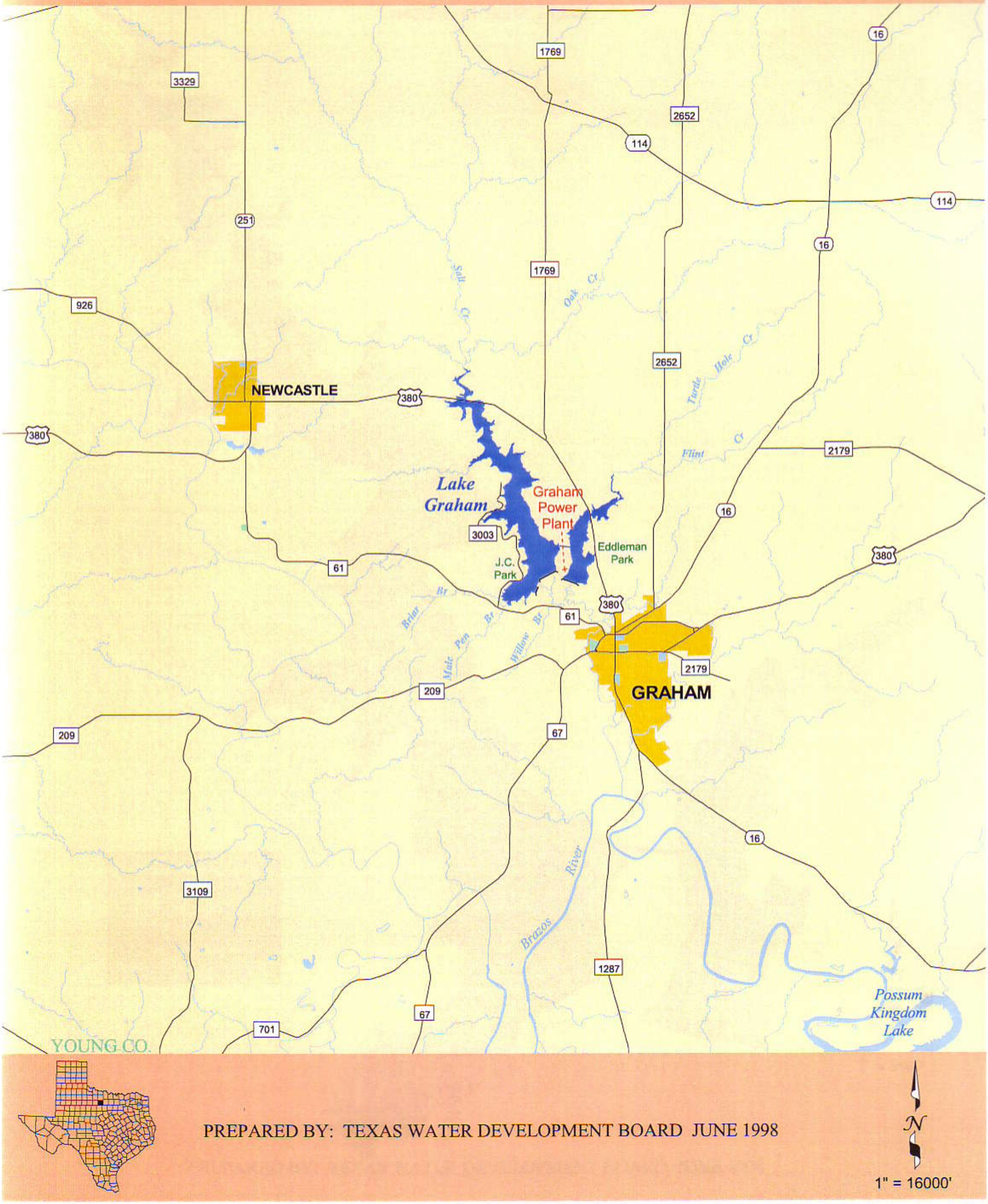


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FIGURE 2

LAKE GRAHAM

Location of Survey Data

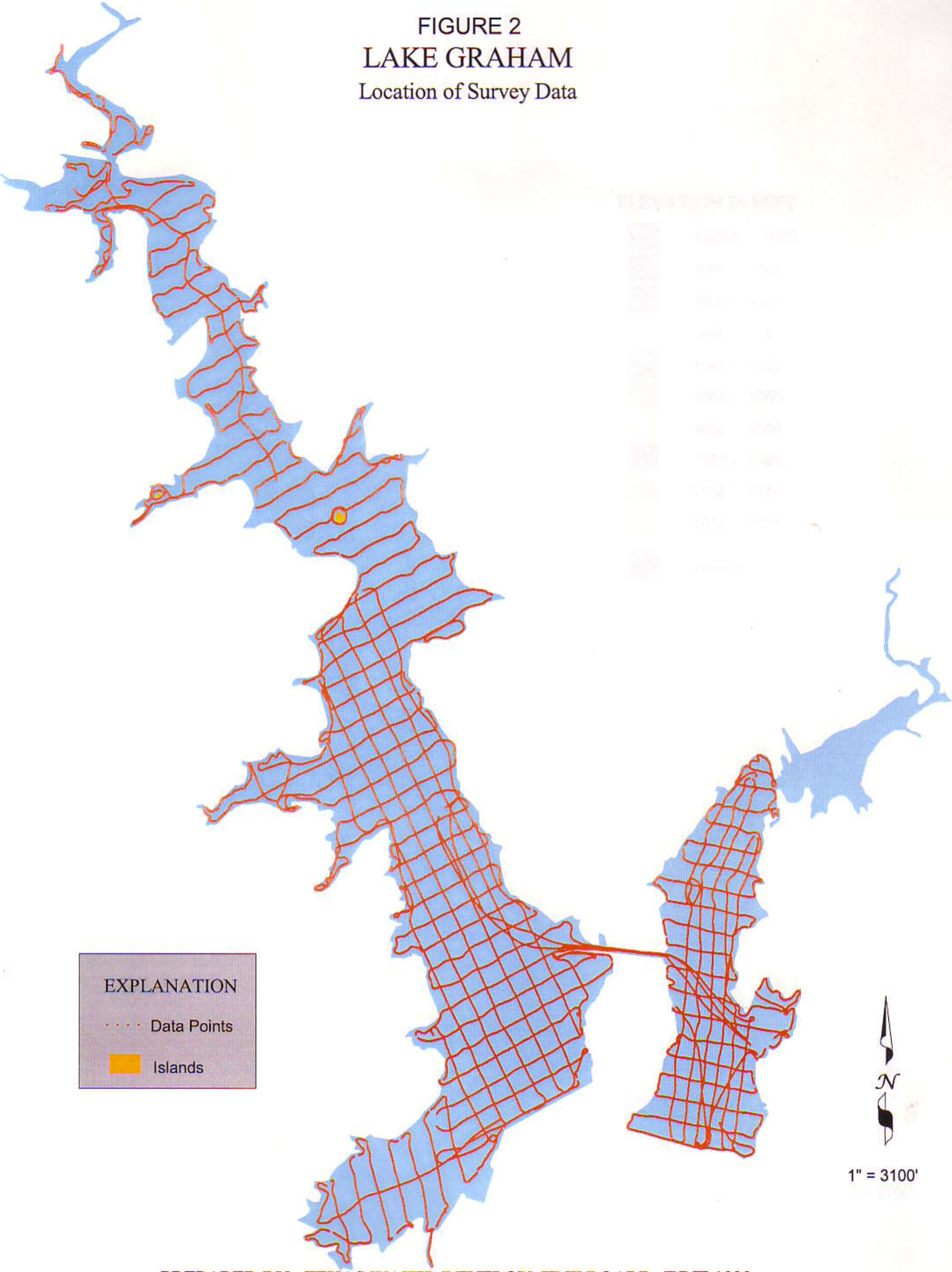

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FIGURE 3

LAKE GRAHAM

Shaded Relief

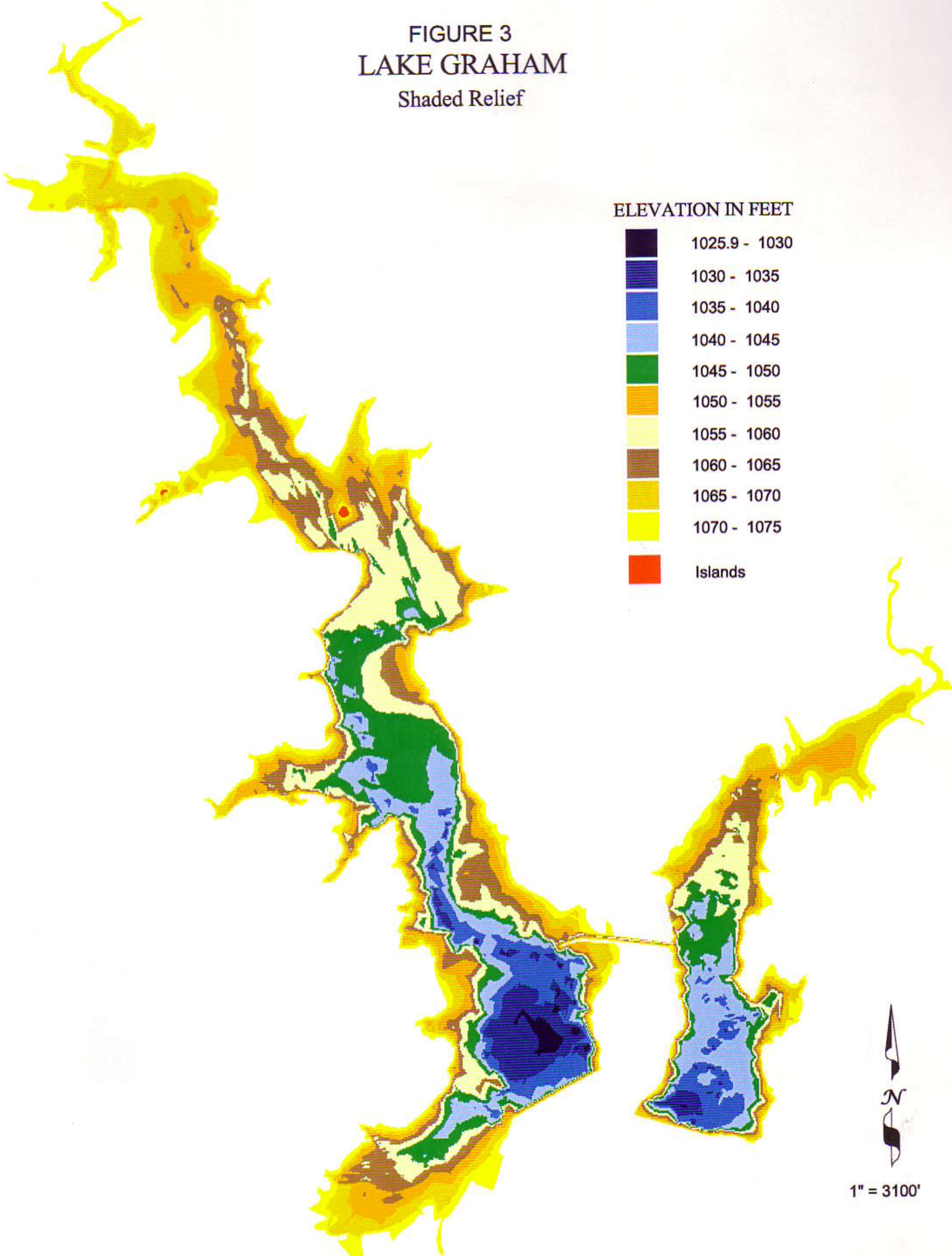

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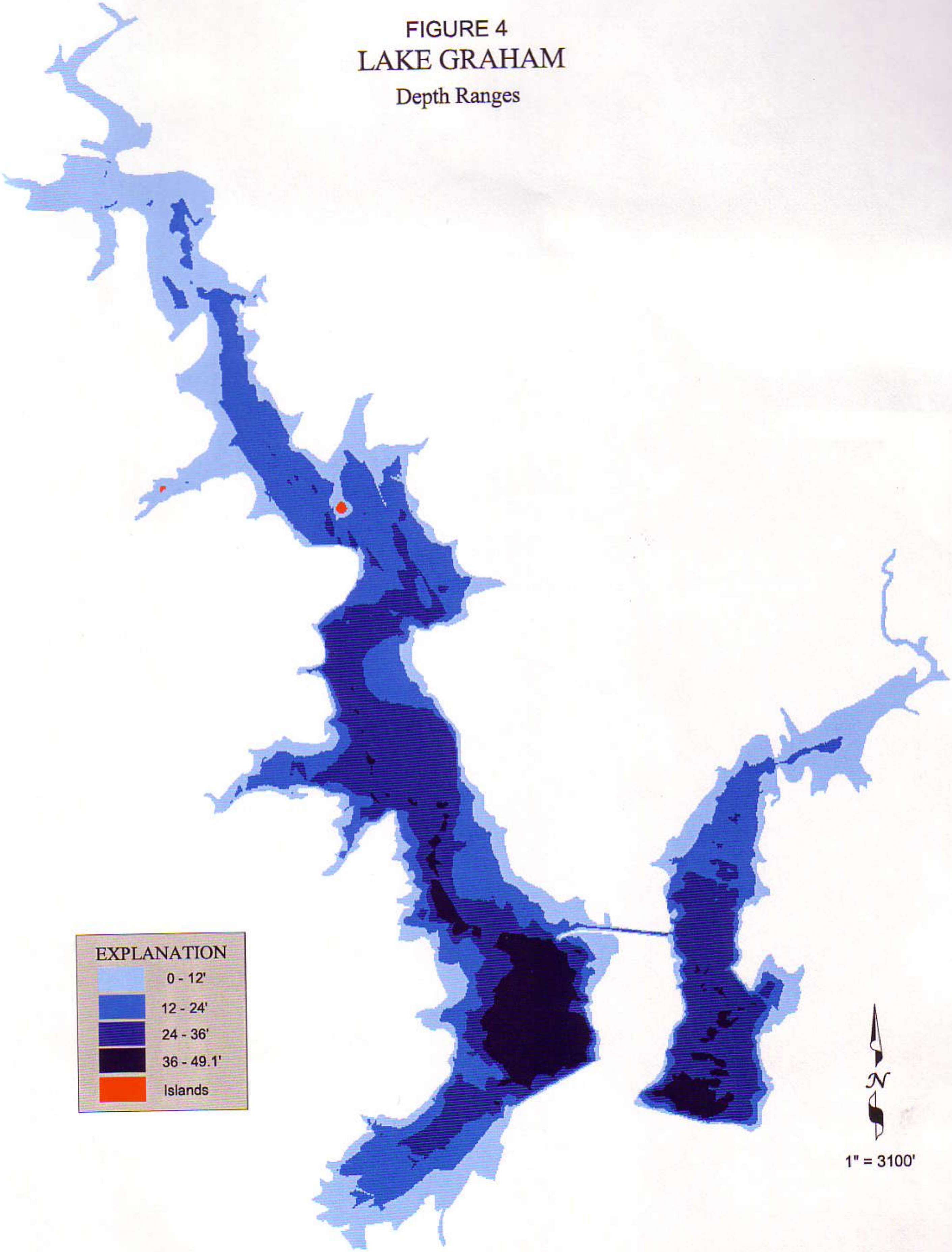
FIGURE 4
LAKE GRAHAM
Depth Ranges



PREPARED BY: TEXAS WATER DEVELOPMENT BOARD JUNE 1998