VOLUMETRIC SURVEY
OF
LAKE AUSTIN

Prepared for:

City of Austin

In conjunction with
Lower Colorado River Authority

Prepared by:
Texas Water Development Board

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Texas Water Development Board

Craig D. Pedersen, Executive Administrator

This report was prepared by staff of the Surface Water Section:

Barney Austin, Ph.D.
Ruben S. Solis, Ph.D., P.E . *
Duane Thomas*
Randall Burns
Marc Sansom

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* Now with Lower Colorado River Authority

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INTRODUCTION

Staff of the Surface Water Section of the Texas Water Development Board (TWDB) conducted a volumetric survey of Lake Austin during the period of March 3-5, 1999. The purpose of the survey was to determine the current volume of the lake at the conservation pool elevation. This survey will establish a basis for comparison to future surveys from which the location and rates of sediment deposition in the conservation pool over time can be determined. Survey results are presented in the following pages in both graphical and tabular form. All elevations presented in this report are in feet above mean sea level that are based on the National Geodetic Vertical Datum of 1929 (NGVD '29). Lake Austin and associated Tom Miller Dam are located on the Colorado River between Lake Travis and Town Lake. The lake is located within the city limits and west of downtown Austin, Texas. Records indicate the top of Lake Austin's conservation pool is elevation 492.8 feet. Design information (1939) for the existing dam and lake shows the surface area at elevation 492.8 feet to be 1,830 acres and the storage volume to be 21,000 acre-feet (Texas Water Development Board, 1971).

LAKE HISTORY AND GENERAL INFORMATION

More than a century of recorded documentation can be found on Lake Austin (formerly Lake McDonald) and associated Tom Miller Dam (formerly Austin Dam)(References 1-11). A brief discussion of the original Austin Dam, the re-built Austin Dam, and the present day Tom Miller Dam is based on these sources.

The City of Austin acquired water rights prior to 1890 to use the waters of the Colorado River for municipal use and for electric power generation (Texas Water Development Board, 1966).

In 1889 John McDonald won the Austin's mayoral race based on a platform to build Austin Dam. By October of the same year funds were appropriated, designs for the new dam were approved, and bids for construction were taken. The contract was awarded on October 15, 1890 and construction began on November 5, 1890 on then, "the world's largest masonry dam across a major river". In that same year (1890) Thomas U. Taylor (later the first Dean of Engineering at the University of Texas) established 16 cross sections upstream of Austin Dam to measure sedimentation (Taylor, 1910).

On May 2, 1893 the main structure of the dam was completed and deliberate impoundment began. Flow spilled over the spillway crest for the first time on May 16, 1893 as work continued on the electric generating powerhouse. The crest of the original spillway was 1,100 feet in length at elevation 490± feet, 60 feet above the dam's toe. Taylor performed the first baseline survey of the lake at Austin in 1893 and calculated a surface area of 2,000 acres and a total volume of 49,300 acre-feet of water. Records indicate the U. S Geological Survey also began documenting the new lake's sedimentation rate at that time.

In January 1900, Taylor surveyed the lake and calculated the volume to be 25,741 acre-feet. Later, on April 7, 1900 a major flood crested at eleven feet above the spillway structure. At 11:20 a.m. two sections (both approximately 250 in length) of the spillway slid 60 feet downstream releasing the floodwaters that destroyed the electric generating powerhouse and resulting in eight fatalities. Nine people drowned in Austin and another 38 lives were loss as the floodwaters continued downstream to the Gulf of Mexico (Wilson, 1999).

Results of investigations into the failure of the original dam by Taylor (1910) and Dr. Daniel W. Mead (1917) were published in the following years. The failure was attributed to an inferior foundation consisting of a weak limestone and hydrostatic pressure of the foundation. Other contributing factors were the loss of passive resistance along the toe of the dam and the unaccounted lateral pressure of silt and water against the upstream face of the dam (Meade, 1917).

In 1908 the idea of reconstructing the Austin Dam was entertained by City of Austin officials. The feasibility of rebuilding the dam at the original site or an alternative site was to be studied by professional consultants nationwide. After a subsurface investigation, this panel of consultants known as the "Board of Engineers" recommended that the second dam be built at an alternative site because of the undesirable foundation conditions and the potential for seepage at the original dam site (King and Huber, 1994). The controversial decision was made to rebuild the dam at the original site. The City of Austin joined into an agreement to franchise the reconstruction project with City Water Company, a private electric-power development company. The agreement allowed City Water Company to make any design changes as long as there was no reduction in the height of the dam or the stability of the structure. Many design changes were made prior to and during the construction of the rebuilt dam.

On July 29, 1911 a contract was awarded to William D. Johnson and the reconstruction of the dam began. The new design included a hollow core structure to replace the breached section of the spillway. The rebuilt dam would consist of 54 crest gates that would automatically open when the lake level reached elevation 495.0 feet. The construction project was continually delayed by severe flooding in 1913 and 1914.

In September of 1913 the lake filled to an elevation of 481± feet, fifty-one feet above the dam's toe. This elevation was the crest of the hollow core section that was rebuilt after the 1900 flood. Twenty-eight of the fifty-four crest gates operated at this elevation. Taylor performed a survey in 1913 and calculated the volume of the lake to be 32,025 acre-feet of water.

While the second dam was still under construction, the City of Austin filed for water rights with the State Board of Water Engineers. Certified Filing No. 330 dated June 30, 1914 renewed prior rights stated to have been in effect prior to 1890. The water rights were for the purpose of supplying water, lights, and power to Austin and State Institutions. It also appropriated and stored the flows and underflows of storm and rainwater from the Colorado River for generating electricity, for domestic use, and for general municipal and State purposes. Deliberate impoundment of the second lake at Austin began in December of 1914.

In April of 1915, a flood caused floating debris to be trapped among the crest gate piers. Four crest gates were destroyed but were immediately replaced. Taylor was able to perform another survey within the month and calculated the lake's volume to be 32,000 acre-feet of water. In

September of the same year another flood caused floating debris be jammed into the piers, taking out most of the 54 crest gates. Construction had not yet been completed at the time of the September flood, and therefore the City had not accepted the project. Construction was halted and the City Water Company went into bankruptcy. In 1918, Mr. Guy A. Collett, who held the note for the incomplete project, secured permission from Federal authorities to sell lake water to rice farmers downstream, thus draining the lake (Taylor, 1924).

Taylor surveyed the lake at Austin again in 1922 and 1924. The lake's volume in 1924 was found to be 2,901 acre-feet, or only 9% of the volume measured in 1913. Almost 91% of the lake’s volume was reduced by sedimentation in those eleven years. No improvements were made to the second Austin Dam for nearly 21 years.

In 1934 the charter for the Lower Colorado River Authority (LCRA) was created by the Texas Legislature. The purpose of the conservation/reclamation district was flood control, generation of electricity, water supply, and conservation.

The current flood of record passed over the Austin Dam in September of 1935. The floodwaters crested at elevation 506.2 feet. This was 16.2 feet above the crest of the original dam. Again floating debris took out most of the remaining piers of the second dam. There was considerable damage to the crest slab of the hollow portion of the dam.

In 1937 the City of Austin executed a lease agreement with LCRA. The 30-year lease agreement allowed LCRA to design, build, operate and maintain the dam and hydroelectric powerhouse. The agreement allowed the City of Austin to buy hydroelectric power from LCRA. The LCRA and Moran, Proctor, Freeman and Mueser Consulting Engineers of New York were the design engineers (Stone and Webster Engineering Corporation, 1989). Foundation and stability analyses were conducted, and structural stress tests were performed. The site of the original dam was used for the present day structure. The design engineers felt comfortable with the integrity of the dam site based on all the foundation work that was to be performed.

Construction started on the present day Tom Miller Dam on July 5, 1938. LCRA served as both the design engineers and construction contractors for the project (Texas Department of Water Resources, 1979). The work entailed foundation grouting and underpinning. Some portions of the original dam (1890) were incorporated into the present dam. The old masonry overflow spillway section received a new face with reinforced steel and concrete. It was also raised 2.8 feet to an elevation of 492.8 feet. This elevation is the top of the current day operating range for Lake Austin. The width of the uncontrolled ogee crest is 458 feet. The hollow dam section was rebuilt containing nine feet wide piers spaced 60 feet apart. These piers were anchored into the limestone foundation and extended above the deck slab. Besides reinforcing the hollow section of the dam, the nine piers are used as anchor piers for the fifty-one feet wide tainter gates. The net length for all nine tainter gates is 459 feet. Five of the nine gates are 51 feet wide by 12 feet tall. These gates rest on an ogee crest at elevation of 480.8 feet. The other four gates are 51 feet wide by 18 feet tall. The total length of the dam is 1,590 feet. There are no outlet works for Tom Miller Dam. Releases are through the penstock for the turbines located in the powerhouse. The invert elevation for the penstock is 462.0 feet.

Two other appurtenant structures located at Lake Austin are the intake structures for the Ulrich Water Treatment Plant (located near Tom Miller Dam) and the Davis Water Treatment Plant (located near Mount Bonnell). The lowest operating lake level elevation for the Ulrich intake structure is approximately 466.0 feet, and the Davis intake is approximately 475.0 feet.

Construction on the present day Tom Miller Dam was completed in 1939, and deliberate impoundment began immediately thereafter. The same year, LCRA performed a survey of Lake Austin and found the surface area of Lake Austin (at elevation 492.8 feet) to be 1,830 acres, and the total volume of Lake Austin to be 21,000 acre-feet.

On March 31,1940 the hydroelectric power plant at Tom Miller Dam came on line. The dam was dedicated on April 6, 1940. The estimated cost for the project was $3,479,309.

A significant external factor that influenced Tom Miller Dam and Lake Austin was the completion of Mansfield Dam, located approximately 20.5 miles upstream from Tom Miller Dam, in 1942. Lake Austin today is the sixth lake in a chain of seven lakes known as the Highland Lakes.

With the completion of Mansfield Dam, flood flows and normal operating releases through Lake Austin and Tom Miller Dam are much more controlled.

Certificate of Adjudication No. 14-5471 was issued June 28, 1989 by the Texas Water Commission to the City of Austin (Texas Water Commission, 1989). The certificate authorizes the City of Austin to maintain an existing dam (Tom Miller Dam) and reservoir (Lake Austin) on the Colorado River and impounds not to exceed 21,000 acre-feet of water. The owner of the certificate was authorized to divert and use not to exceed 250,000 acre-feet of water per year from Lake Austin for municipal use. The City of Austin can also use 150 acre-feet per annum for irrigation and can also use the impounded waters of Lake Austin for recreation purposes. The City of Austin is authorized to divert and use water through Tom Miller Dam for generating hydroelectric power only under special conditions. The conditions for generating hydroelectric power, inner basin transfers, priority rights and other topics are described in detail in the certificate.

Lake Austin is normally a constant level riverine lake and is operated as a "pass through" reservoir. The operating level of the lake can vary between elevation 491.8 feet and 492.8 feet. Releases at Tom Miller Dam are coordinated with upstream releases that are controlled by LCRA. The dam and lake were not designed to provide flood storage above the conservation pool elevation. The widest point of the lake is approximately 0.2 miles and is located about 1.2 miles upstream of the dam. The approximate length of the lake is 20.5 miles. The total drainage basin for Lake Austin is 38,846 square miles, and of that part 11,403 square miles is probably noncontributing (USGS, 1998).

VOLUMETRIC SURVEYING TECHNOLOGY

The equipment used in the performance of the volumetric survey consists of a 23-foot aluminum tri-hull SeaArk craft with cabin, equipped with twin 90-Horsepower Johnson outboard motors. (Reference to brand names throughout this report does not imply endorsement by TWDB). 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 PC, a Trimble Navigation, Inc. 4000SE GPS receiver, and an OmniSTAR receiver. The OmniSTAR reciever is a subscribed service that furnishes a differential correction associated with the GPS receiver. See Appendix G for more details on GPS. A water-cooled generator provides electrical power through an in-line uninterruptible power supply.

The GPS equipment, survey vessel, and depth sounder in combination provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder takes 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 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, poor-quality 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 lake elevation recorded 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 in Appendix F.

PRE-SURVEY PROCEDURES

The reservoir's surface area was determined prior to the survey by digitizing the lake's pool boundary (elevation 492.8) with AutoCad software. The boundary file was created from three USGS 7.5-minute quadrangle maps: Austin West, TX (1988), Bee Cave, TX (1986) and Mansfield Dam, TX (1986). A typographical error noting a pool elevation of 483 feet exists on the Austin West, TX quadrangle map. The correct elevation as confirmed by LCRA, and the elevation assumed during digitization, is 492.8 feet. The survey layout was designed by placing survey track lines at 500-foot intervals within the digitized lake boundary using HYPACK software. The survey design required the use of approximately 257 survey lines placed along the length of the lake.

SURVEY PROCEDURES

The following procedures were followed during the volumetric survey of Lake Austin 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, an instrument used to measure the variation in the speed of sound at different depths in the water column. The average speed of sound through the entire water column below the boat was determined by averaging local speed-of-sound measurements collected through the water column. The velocity profiler probe was first placed in the water to moisten and acclimate the probe. The probe was next raised to the water surface where the depth was zeroed. The probe was then gradually lowered on a cable to a depth just above the lake bottom, and then raised to the surface. During this lowering and raising procedure, local speed-of-sound measurements were collected, from which the average speed was computed by the velocity profiler. This average speed of sound was entered into the ITI449 depth sounder, which then provided the depth of the lake bottom. The depth 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 Austin, the speed of sound in the water column varied from 4,834 to 4,855 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 for the "average" depth of the lake. An additional estimated error of $\pm$0.3 feet arises from variation in boat inclination. These two factors combine to give an overall accuracy of $\pm$0.5 feet for any instantaneous reading. These errors tend to be insignificant over the entire survey, since some readings are positive and some are negative. Further information on these calculations is presented in Appendix F.

During the survey, the onboard GPS receiver was set to a horizontal mask of 10° and a PDOP (Position Dilution of Precision) limit of seven to maximize the accuracy of horizontal positions. An internal alarm sounds if the PDOP rises above seven to advise the field crew that the estimate of the horizontal position has degraded to an unacceptable level. The lake's initialization file used by the HYPACK data collection program was set up 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 on Lake Austin on March 3 - 5, 1999. During data collection, the crew had excellent weather with moderate temperatures and mild winds. Approximately 31,120 data points were collected over the approximately 64 miles traveled. These points were stored digitally on the boat's computer in 269 data files. Data were not collected in areas with significant obstructions. Figure 2 shows the actual location of all data collection points.

Data collection for Lake Austin began at Tom Miller Dam and continued upstream to near Mansfield Dam. The 252 cross sectional lines were collected in 500 feet increments running perpendicular to the original river channel. The survey crew was able to collect data in two off-channel tributaries, Bee Creek and Bull Creek, upstream to the point the creeks became too narrow or shallow for the boat to maneuver.

Lake Austin inundates the flood channel of the Colorado River. The approximately 20.5 mile long riverine lake meanders through the Balcones Escarpment (Hill Country) in a northwest to southeast direction. The average width of the lake at Tom Miller Dam is 1,200 feet and narrows to approximately 400 feet at the tailwaters of Mansfield Dam. The physical topography along the perimeter of the lake consists of deep valleys and steep-sided walls.

The land use along the shorelines of Lake Austin from Tom Miller Dam to Commons Ford Metropolitan Park is mostly residential development. Bulkheads protect most of the lake's shoreline in the developed area. Lake front property upstream of Commons Ford to Mansfield Dam is mostly undeveloped rural land with some pockets of residential development. Some shoreline erosion was noticed in this area during the survey.

As the 500-foot-spacing transects were collected, the recording analog chart for the depth sounder showed distinct patterns in different parts of the lake. The river bathymetry from Tom Miller Dam to approximately Bull Creek was a sharp "V" shape. From Bull Creek to Panther Park, the contour of the bottom of the lake was more "U"-shaped. In the upper reaches of Lake Austin the cross-section of the channel was generally flat. As the riverbed curved the survey crew noted the depths to be shallow on the fill side bank and a deeper bottom with a steep sidewall on the cut bank.

Very often the old channel or thalweg would be defined on the analog chart as the transects were collected. See Appendix D for cross-sections.

It should also be noted that the data collection was performed without encountering Eurasian Milfoil Myriophyllum spicatum that at times is a dominant feature. At the time of the survey the current (09/00) infestation of Hydrilla verticullata was thought to have covered only 23 acres. Fortunately, the lake-level was lowered approximately 10 feet to kill the weed just months before the survey was performed.

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 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 pool elevation varied from 492.08 to 492.23 feet according to elevation data provided by LCRA. 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, to be used with the GIS software to develop a model of the lake bottom elevation.

The resulting data file was downloaded to a Sun Ultra 10 workstation running the UNIX operating system. Environmental System Research Institute’s (ESRI) Arc/Info GIS software was used to convert the data 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 generates a triangulated irregular network (TIN) from the data points and the boundary file using 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 used in this method. The generated network of three-dimensional triangular planes represents the actual bottom surface. With this representation of the bottom, the software then calculates elevations along the triangle surface plane by determining the elevation along each leg of the triangle. The reservoir area and volume can be determined from the triangulated irregular network created using this method of interpolation.

Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot interval from minimum elevation to conservation pool level. From elevation 440.4 feet to 492.8 feet, the surface areas and volumes the lake were computed using Arc/Info software. The computed reservoir volume table is presented in Appendix A and the area table in Appendix B. An elevation-area-volume graph is presented in Appendix C.

Other products developed from the model include a shaded relief map (Figure 3) and a shaded depth range map (Figure 4). 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. Linear filtration algorithms were applied to the DTM to produce smooth cartographic contours. The resulting contour map of the bottom surface at two-foot intervals is presented in Figure 5. Finally, the location of cross-sections in Appendix D was approximated from those established in 1890 and reported by Taylor (1924). No comparisons between historical and the present survey were made due to uncertainty in water levels and exact endpoint positions.

RESULTS

Results from the 1999 TWDB survey indicate Lake Austin encompasses 1,599 surface acres and contains a total volume of 21,804 acre-feet at the conservation pool elevation of 492.8 feet. The shoreline at this elevation was calculated to be 57.6 miles. The deepest point physically measured during the survey was 52.4 feet (elevation 440.4 feet), and was located approximately 720 feet upstream of Tom Miller Dam.

SUMMARY AND COMPARISONS

The existing Tom Miller Dam was completed and Lake Austin was impounded in 1939, although Austin Dam was constructed and what was then Lake McDonald was impounded at this site as early as 1893. A summary of the many volumetric surveys conducted on Lake Austin and Lake McDonald is presented in Table 1 below.

Date	Elevation (feet, NGVD29)	Volume (acre-feet)	1999 Volume at Same Elevation (acre-feet)
1893	490.0	49,300	17,676
1900 (Feb)	490.0	25,741	17,676
1900 (Apr) Dam breaks			
1913	481.0	32,025	7,626
1915	481.0	32,000	7,626
1922	481.0	5,362	7,626
1924	481.0	2,901	7,626
1935 Dam breaks			
1939	492.8	21,000	21,804
1942 Mansfield Dam completed			

Table 1. Volume comparisons for surveys conducted since 1893 on Lake Austin and Lake McDonald.

During March 3, 4, and 5, 1999, staff from the Texas Water Development Board's Surface Water Section completed a volumetric survey of Lake Austin. The 1999 survey took advantage of technological advances such as differential global positioning system and geographical information system technology to create a digital model of the reservoir's bathymetry. With these advances, the survey was completed more quickly and significantly more bathymetric data were collected than in previous surveys. Results indicate that the lake's volume at the conservation pool elevation of 492.8 feet is 21,804 acre-feet, with a corresponding surface area of 1,599 acres.

Comparing the findings from the 1939 survey to the current survey, the estimated increase in volume at conservation pool elevation 492.8 feet is 725 acre-feet (+3.5%). This change is insignificant in comparison to changes observed between earlier surveys, and is also insignificant when compared to differences found between earlier surveys and the 1999 survey at comparable elevations. Between 1893 and 1900, there was a loss in volume of roughly 3,400 acre-feet/year, and between 1913 and 1924, the loss rate was roughly 2,600 acre-feet/year. Lake Austin appears to have reached an equilibrium with respect to sedimentation, likely due to the construction between 1938 and 1951 of the complex of dams comprising the Highland Lakes. Although some differences among results may arise from differences in surveying procedures and technology, there is no question that the present sediment loading on Town Lake is a small fraction of the loading experienced in the past. It is recommended that a similar survey be carried out in five to ten years or after major flood events to monitor changes to the lake's storage volume and to more clearly establish the current sedimentation rates.

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Appendix A

Lake Austin

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD

May 1999 SURVEY

VOLUME IN ACRE-FEET

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
440					0	0	0	0	0	0
441	0	0	0	0	0	0	0	0	0	0
442	0	0	1	1	1	1	1	1	1	1
443	2	2	2	2	2	2	3	3	3	3
444	3	4	4	4	5	5	5	6	6	6
445	7	7	7	8	8	9	9	9	10	10
446	11	11	12	12	13	14	14	15	15	16
447	17	17	18	19	19	20	21	21	22	23
448	24	25	25	26	27	28	29	30	31	32
449	33	34	35	36	37	38	39	40	41	42
450	43	45	46	47	48	49	51	52	53	55
451	56	57	59	60	62	63	65	66	68	69
452	71	73	74	76	78	79	81	83	85	87
453	88	90	92	94	96	98	100	102	104	107
454	109	111	113	115	118	120	122	125	127	130
455	132	135	137	140	143	145	148	151	154	157
456	160	163	166	169	172	175	178	181	184	188
457	191	195	198	202	205	209	212	216	220	224
458	228	231	235	239	244	248	252	256	261	265
459	269	274	279	283	288	293	298	303	308	313
460	318	324	329	335	340	346	352	358	364	370
461	377	383	390	397	403	410	417	425	432	439
462	447	455	462	470	478	486	495	503	512	520
463	529	538	547	556	566	576	585	595	606	616
464	627	638	649	660	671	683	695	707	719	732
465	745	758	771	784	798	812	826	841	855	870
466	885	900	916	932	948	964	981	998	1015	1032
467	1050	1068	1087	1105	1125	1144	1164	1184	1204	1224
468	1245	1267	1288	1310	1333	1355	1378	1401	1425	1449
469	1474	1498	1524	1549	1575	1602	1628	1656	1683	1711
470	1740	1769	1798	1827	1858	1888	1919	1950	1982	2014
471	2046	2079	2112	2146	2180	2214	2249	2285	2320	2356
472	2393	2430	2467	2505	2543	2582	2621	2660	2700	2741
473	2782	2823	2864	2906	2949	2992	3035	3079	3123	3168
474	3213	3259	3305	3351	3398	3445	3493	3541	3590	3639
475	3689	3739	3789	3840	3892	3944	3996	4049	4102	4156
476	4211	4265	4321	4376	4433	4489	4547	4605	4663	4722
477	4781	4841	4901	4962	5023	5085	5148	5211	5275	5339
478	5403	5469	5534	5601	5668	5735	5803	5872	5941	6011
479	6081	6152	6224	6296	6370	6443	6517	6592	6668	6744
480	6821	6899	6977	7056	7135	7215	7296	7378	7460	7543
481	7626	7711	7795	7881	7967	8054	8142	8230	8319	8409
482	8499	8591	8682	8775	8868	8962	9056	9151	9247	9343
483	9440	9537	9635	9734	9833	9933	10033	10134	10235	10337
484	10440	10543	10647	10751	10856	10962	11068	11175	11282	11390
485	11499	11608	11718	11829	11940	12052	12164	12278	12391	12506
486	12621	12736	12852	12969	13087	13205	13323	13442	13562	13682
487	13803	13925	14047	14169	14292	14416	14540	14665	14790	14916
488	15043	15170	15298	15427	15556	15686	15816	15948	16079	16212
489	16345	16478	16613	16747	16883	17019	17155	17293	17430	17568
490	17707	17847	17986	18127	18268	18409	18551	18694	18837	18980
491	19125	19269	19414	19560	19706	19853	20000	20148	20296	20444
492	20594	20743	20893	21044	21195	21347	21499	21651	21804	

Appendix B

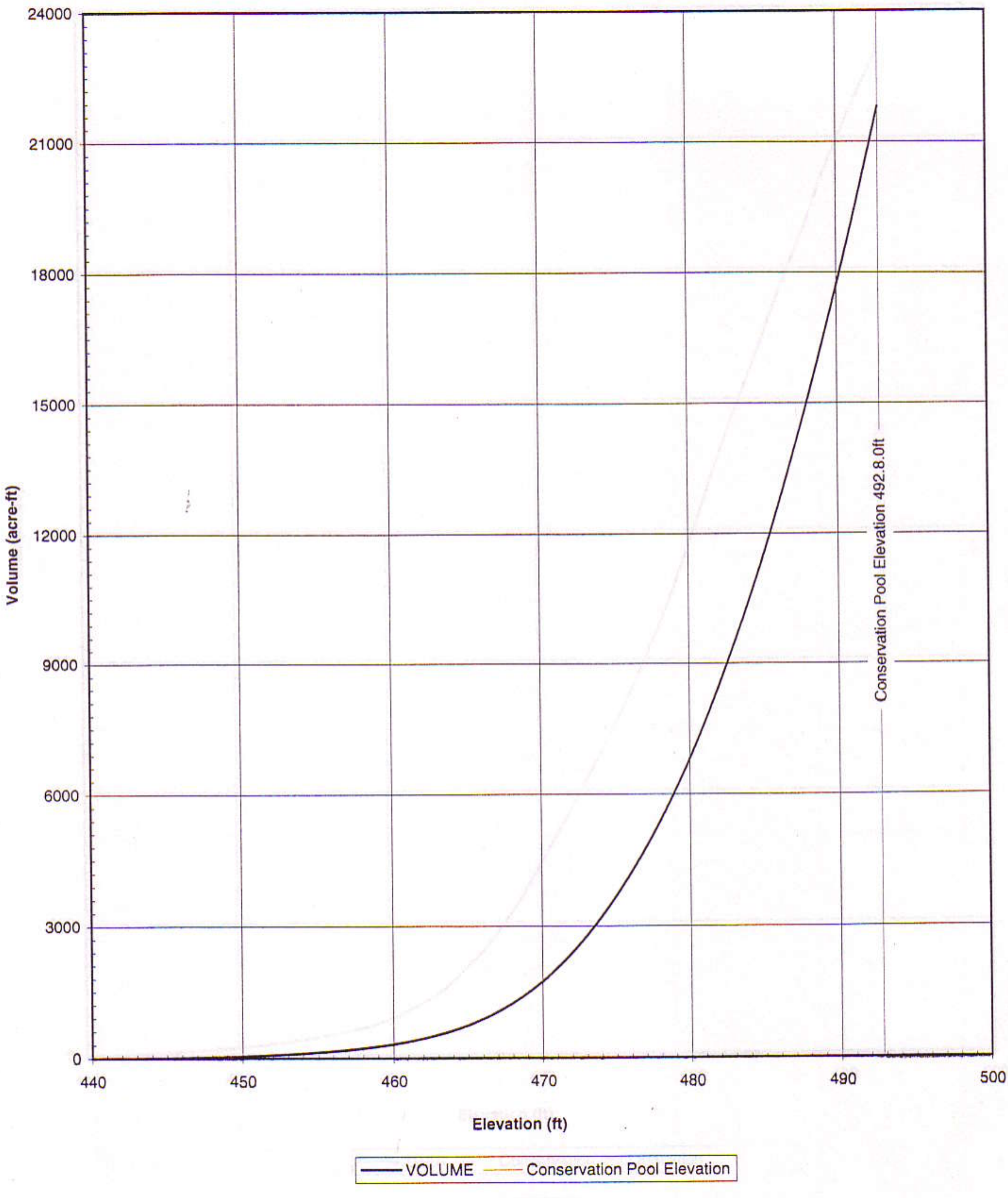
Lake Austin

RESERVOIR AREA TABLE

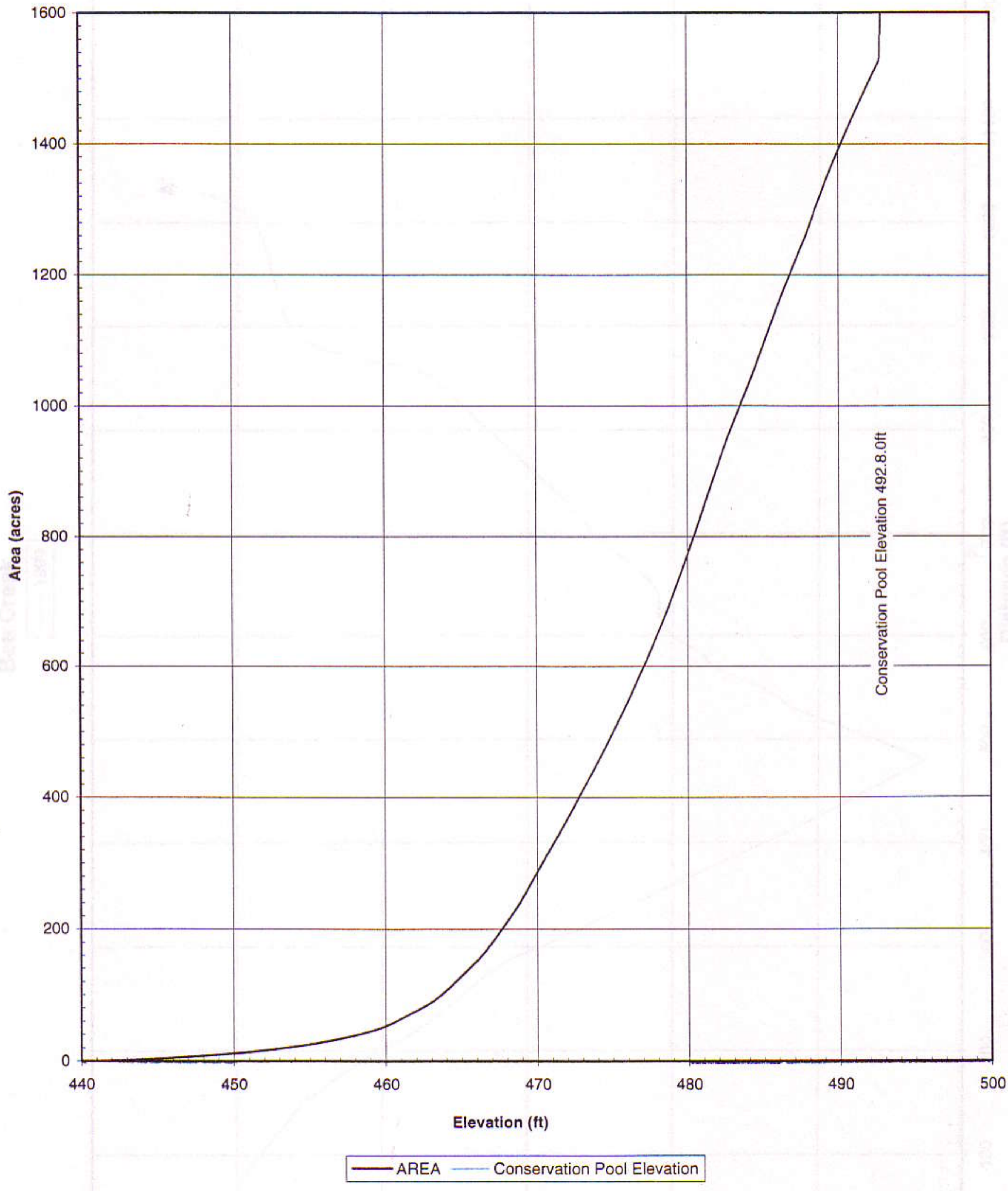
TEXAS WATER DEVELOPMENT BOARD — May 1999 SURVEY

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

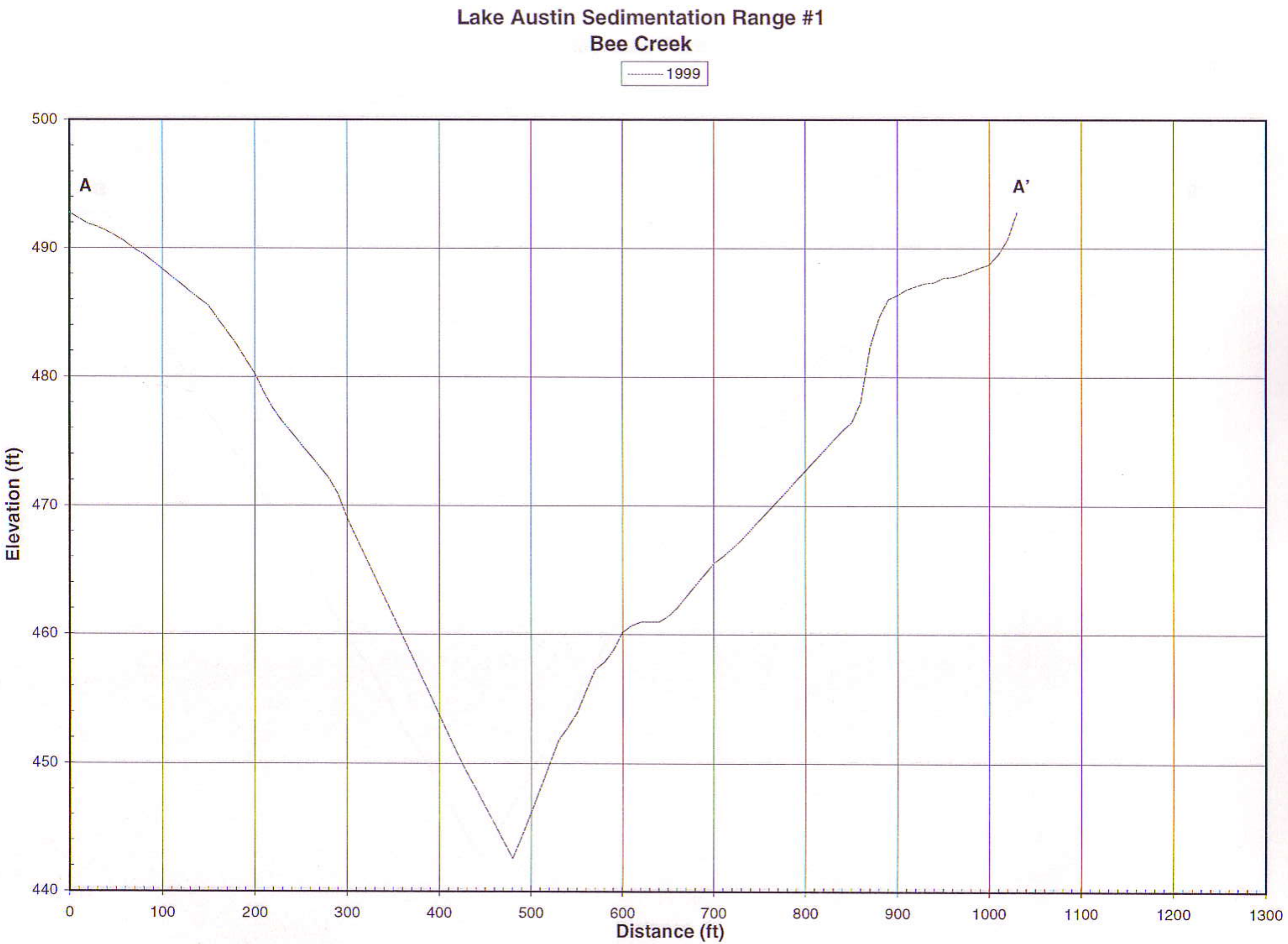
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
440					0	0	0	0	0	0
441	0	0	0	0	0	0	0	0	1	1
442	1	1	1	1	1	1	1	1	1	1
443	2	2	2	2	2	2	2	2	2	2
444	3	3	3	3	3	3	3	3	3	4
445	4	4	4	4	4	4	4	5	5	5
446	5	5	5	5	6	6	6	6	6	6
447	6	7	7	7	7	7	7	8	8	8
448	8	8	8	9	9	9	9	9	9	10
449	10	10	10	10	11	11	11	11	11	11
450	12	12	12	12	12	13	13	13	13	14
451	14	14	14	14	15	15	15	15	16	16
452	16	16	17	17	17	17	18	18	18	19
453	19	19	19	20	20	20	21	21	21	22
454	22	22	23	23	23	24	24	24	25	25
455	25	26	26	26	27	27	28	28	28	29
456	29	30	30	31	31	32	32	32	33	33
457	34	34	35	35	36	36	37	37	38	38
458	39	40	40	41	41	42	43	43	44	44
459	45	46	47	47	48	49	50	50	51	52
460	53	54	55	56	57	58	59	61	62	63
461	64	65	67	68	69	70	71	73	74	75
462	76	77	78	80	81	82	83	85	86	87
463	89	90	92	94	96	98	99	101	103	105
464	107	109	111	114	116	118	120	122	125	127
465	129	131	134	136	138	140	143	145	147	150
466	152	154	157	159	162	165	168	171	174	176
467	179	183	186	189	192	195	198	202	205	208
468	211	214	218	221	224	228	231	235	238	242
469	246	250	254	258	262	266	270	274	278	282
470	287	291	295	299	303	307	311	315	319	323
471	326	330	334	338	342	347	351	355	359	363
472	367	371	376	380	384	389	393	397	402	406
473	410	414	419	423	427	431	436	440	445	449
474	453	458	462	467	471	476	480	485	489	494
475	499	503	508	513	517	522	526	531	536	541
476	545	550	555	560	565	570	575	581	586	591
477	596	601	606	611	617	622	627	633	638	644
478	649	655	661	666	672	678	683	689	695	702
479	708	714	720	727	733	740	746	752	759	765
480	772	779	785	792	798	805	812	819	825	832
481	839	846	853	860	866	873	880	887	894	900
482	907	914	921	928	934	941	947	953	960	966
483	971	977	983	989	995	1000	1006	1012	1017	1023
484	1029	1035	1040	1046	1053	1059	1065	1071	1078	1084
485	1090	1096	1103	1109	1115	1122	1128	1134	1140	1147
486	1153	1159	1165	1171	1177	1183	1189	1194	1200	1206
487	1211	1217	1223	1228	1234	1240	1245	1251	1257	1263
488	1269	1275	1282	1289	1296	1302	1308	1314	1321	1327
489	1333	1340	1346	1352	1357	1363	1368	1374	1379	1385
490	1390	1396	1401	1407	1412	1417	1423	1428	1433	1438
491	1444	1449	1454	1459	1464	1469	1474	1479	1484	1489
492	1494	1499	1504	1509	1513	1518	1523	1528	1599	



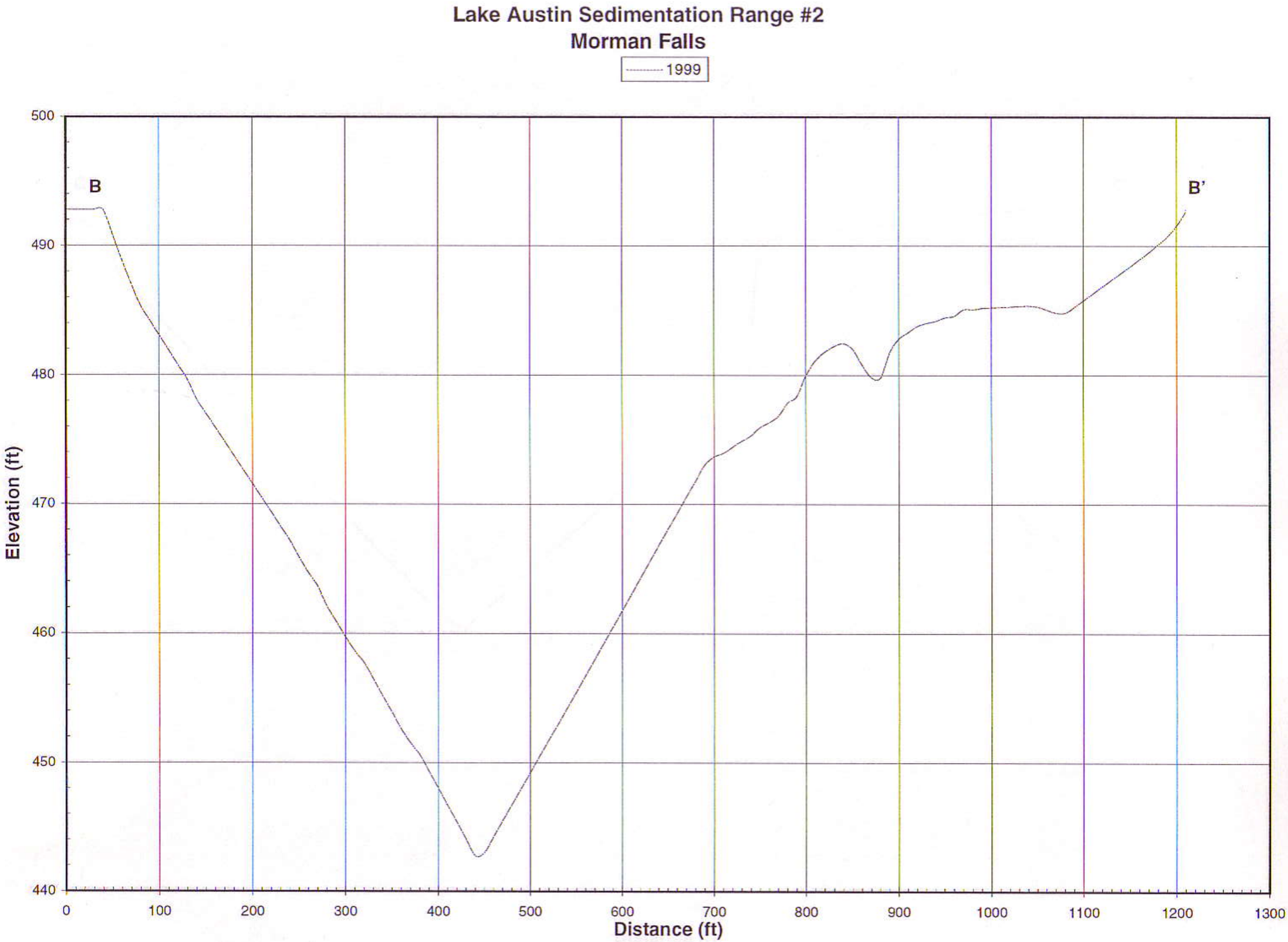
Lake Austin
March 1999



Lake Austin
March 1999

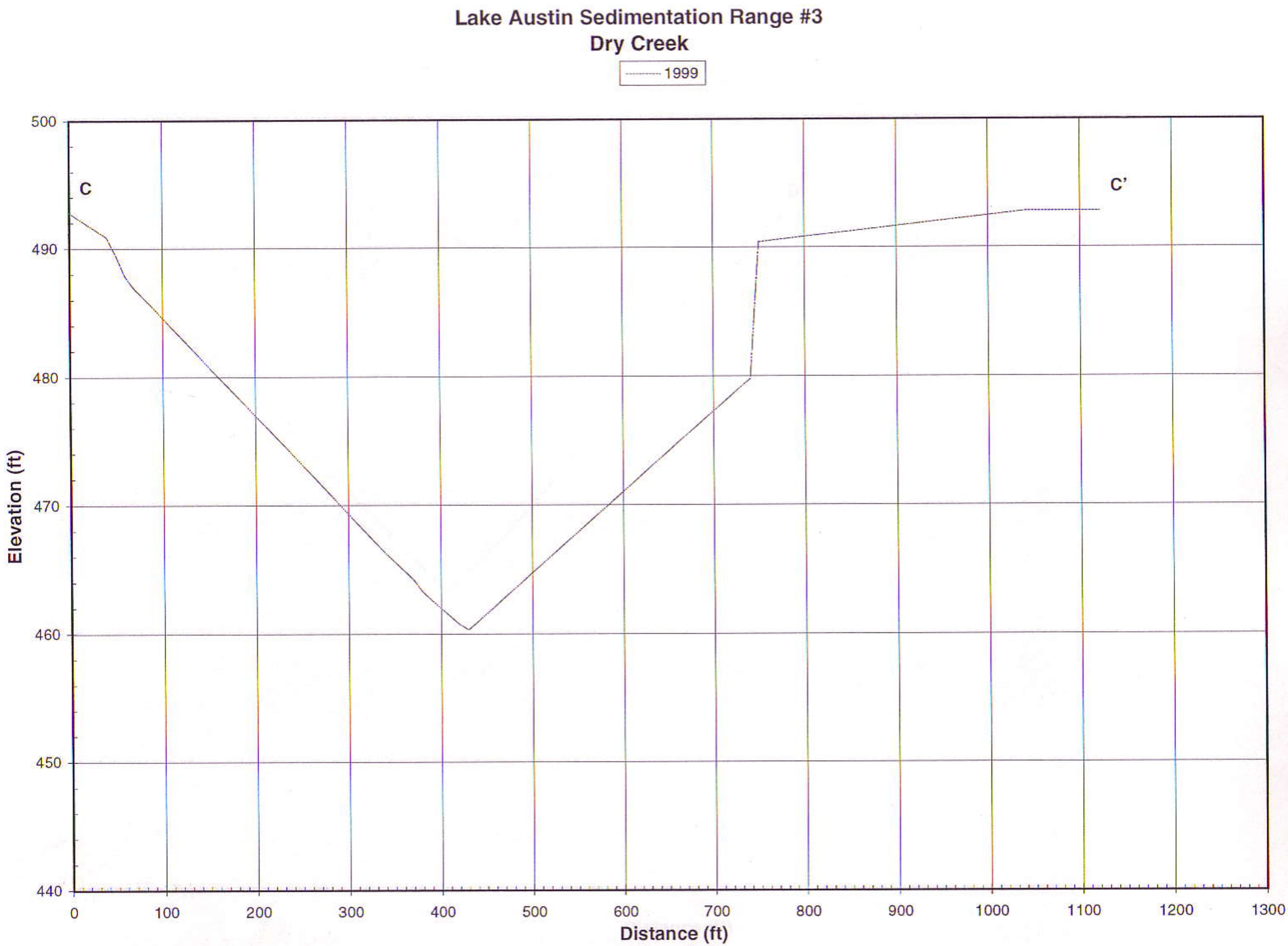


Lake Austin Sedimentation Range #1
Bee Creek
1999
A
A'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)

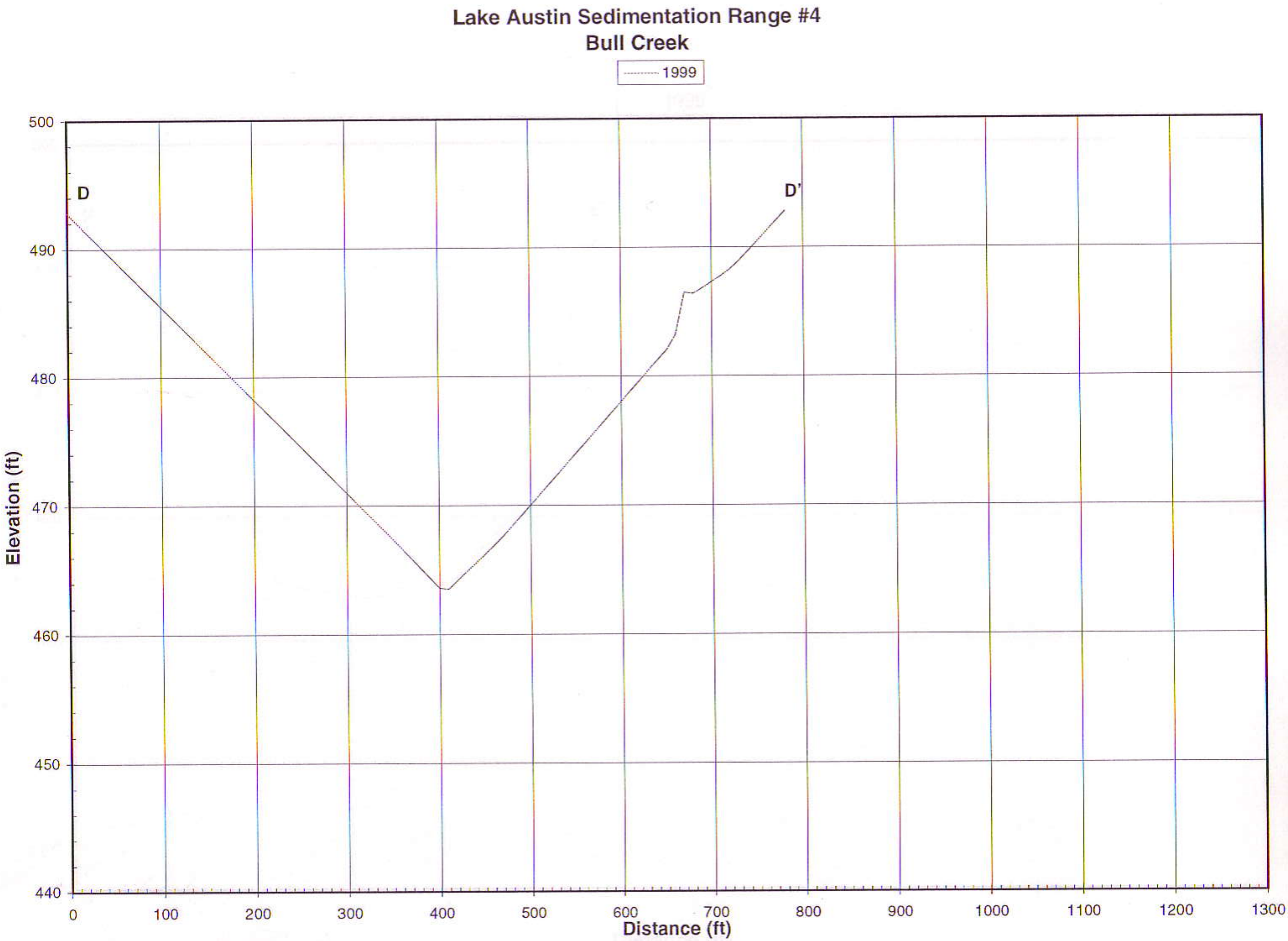


Lake Austin Sedimentation Range #2
Morman Falls
1999
B
B'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)

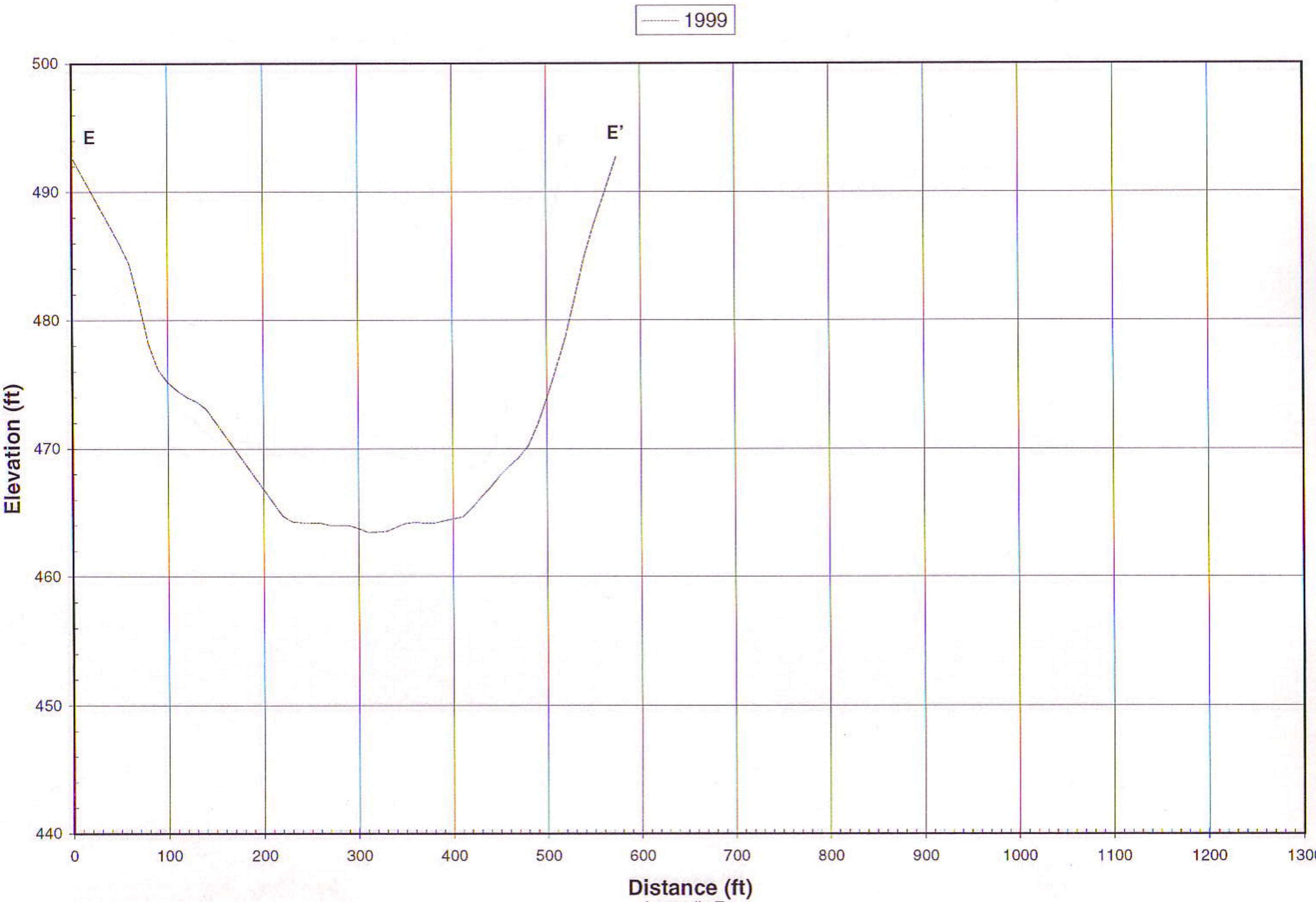
Appendix E

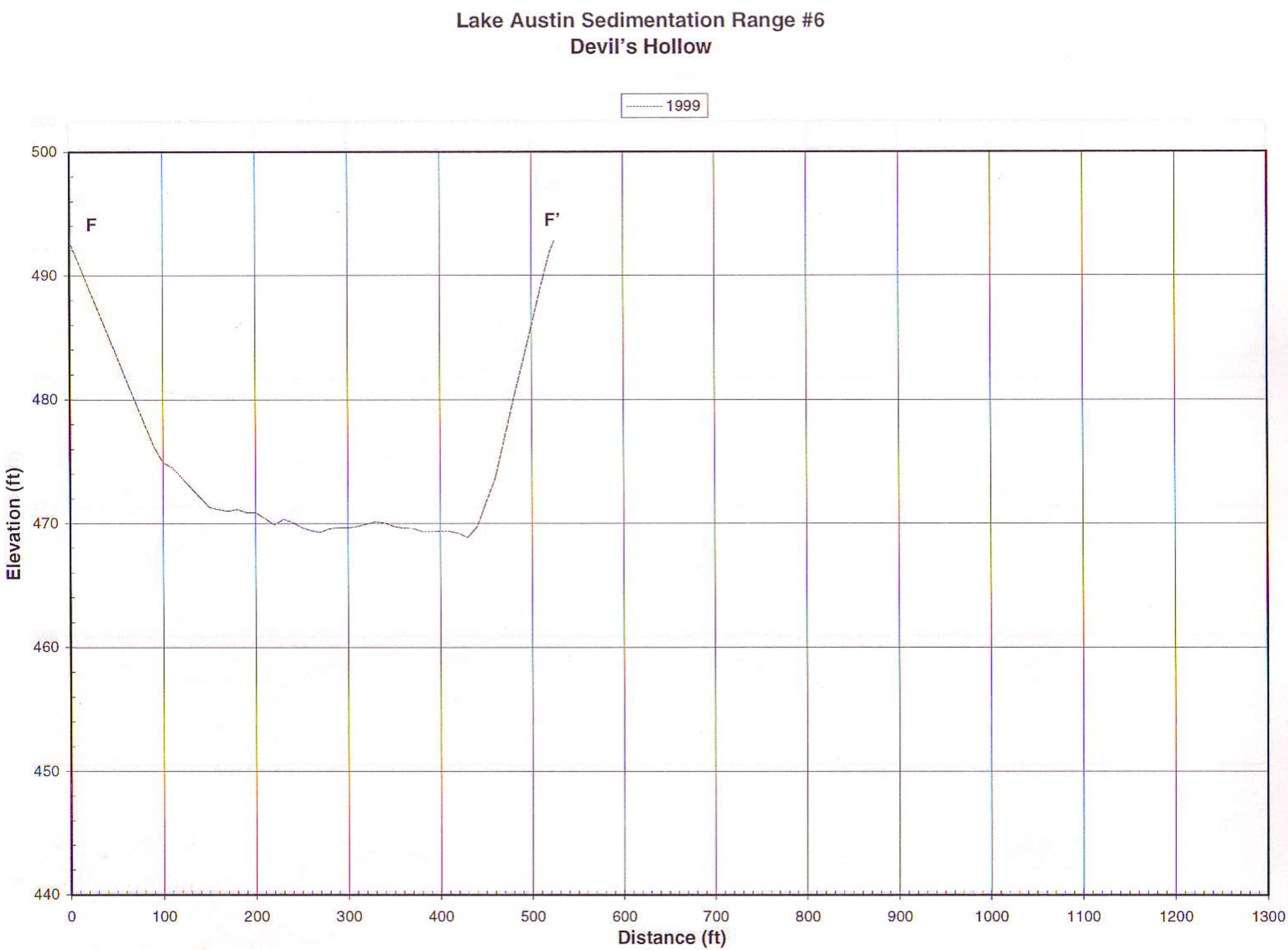

Lake Austin Sedimentation Range #3
Dry Creek
1999
C
C'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)

Appendix E


Lake Austin Sedimentation Range #4
Bull Creek
1999
D
D'
Elevation (ft)
Distance (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Appendix E

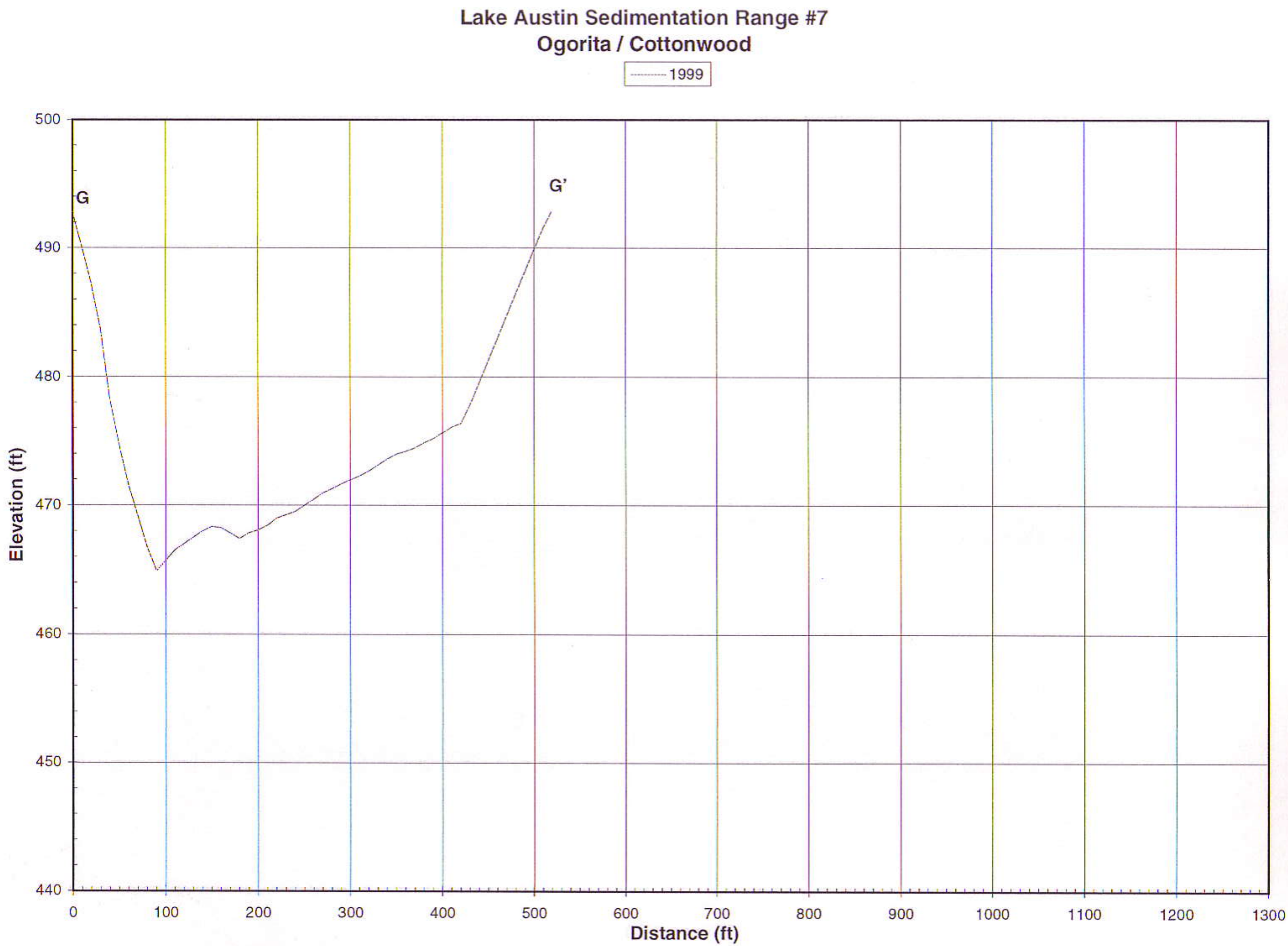
Lake Austin Sedimentation Range #5
Ennis Farm



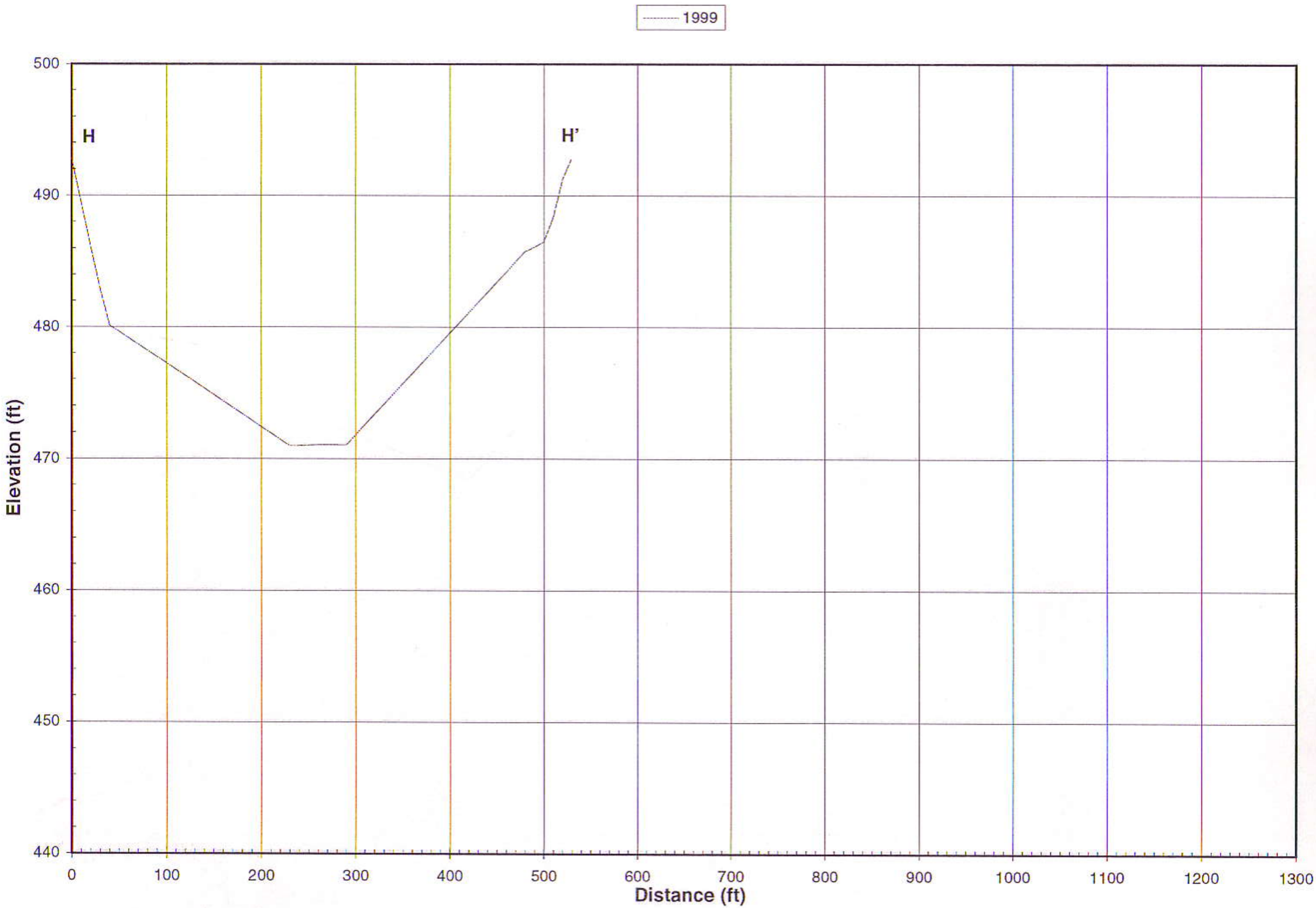


Lake Austin Sedimentation Range #6
Devil's Hollow
1999
F
F'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)

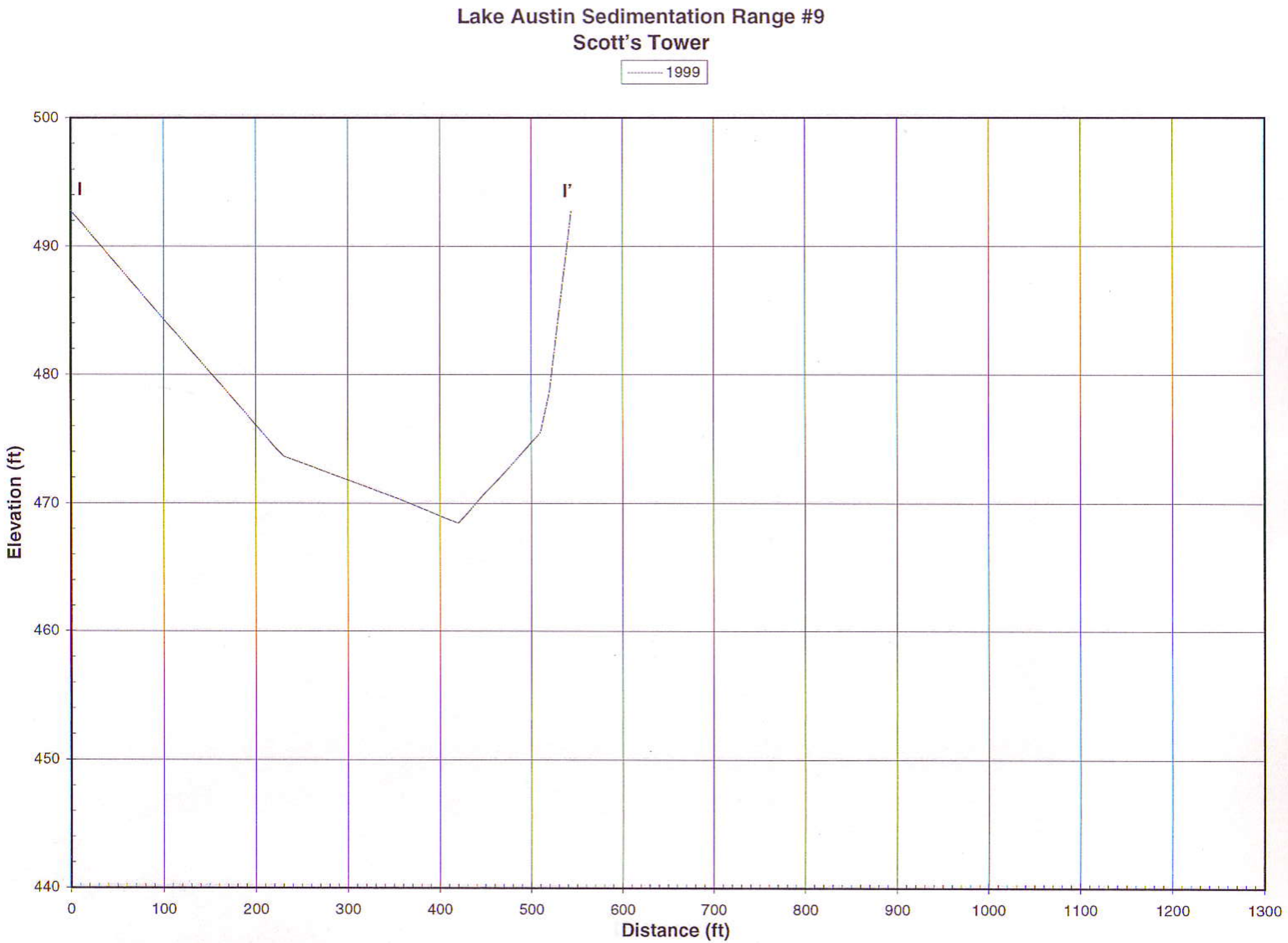
Appendix E

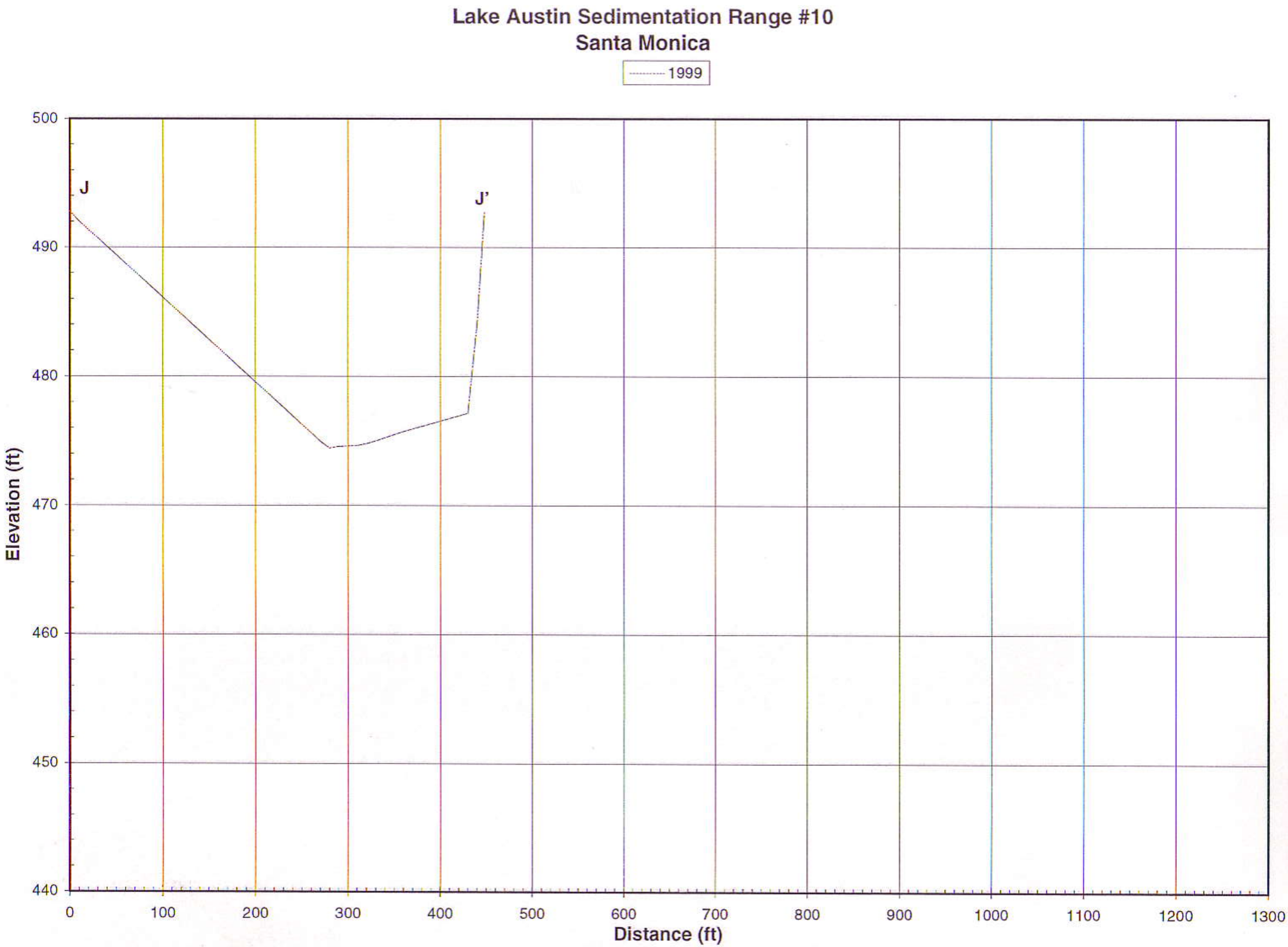

Lake Austin Sedimentation Range #7
Ogorita / Cottonwood
1999
G
G'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)
Appendix E

Lake Austin Sedimentation Range #8
McNeill's Lane



Appendix E

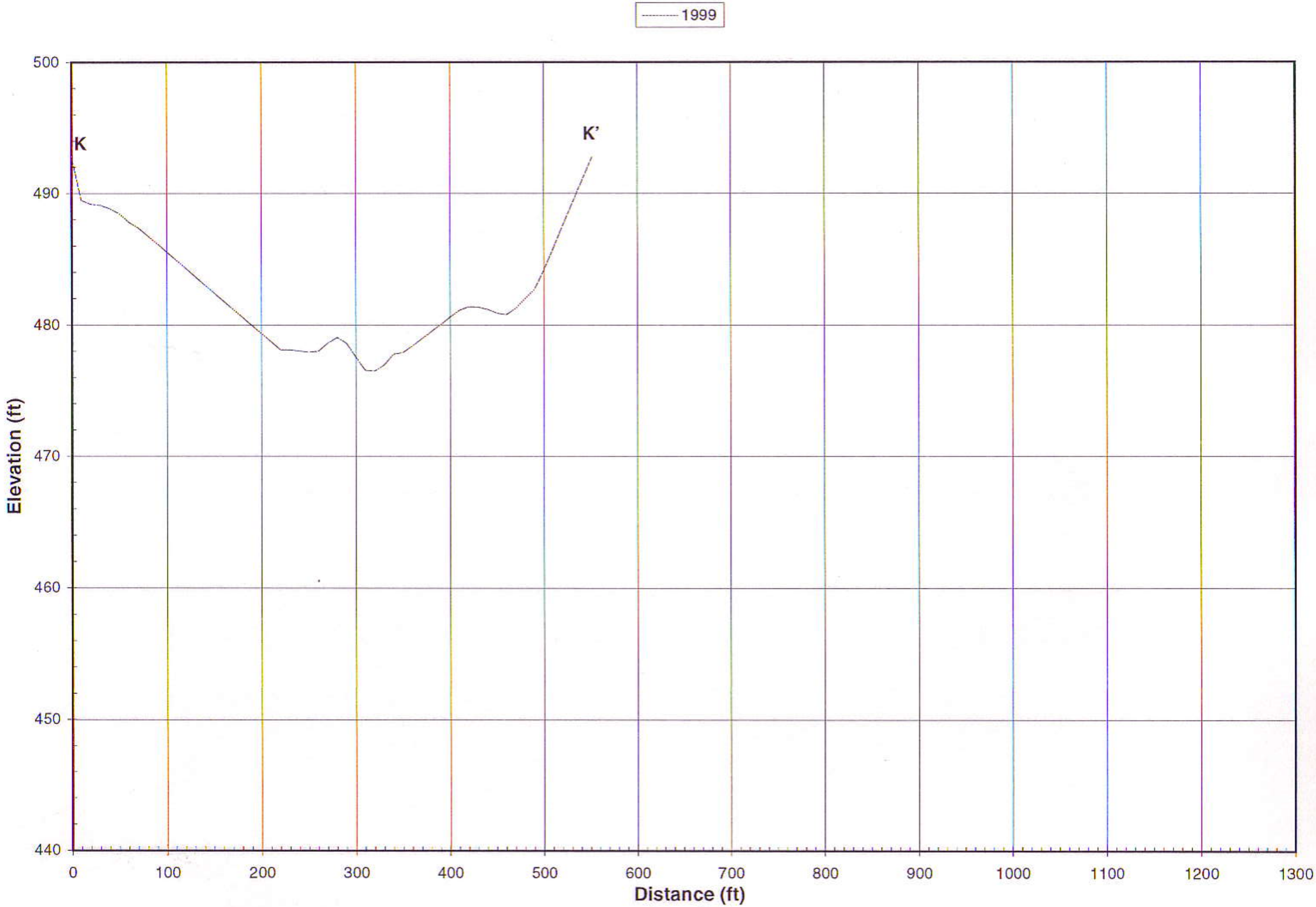

Lake Austin Sedimentation Range #9
Scott's Tower
1999
I
I'
Elevation (ft)
500
490
480
470
460
450
440
Distance (ft)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300



Lake Austin Sedimentation Range #10
Santa Monica
1999
J
J'
500
490
480
470
460
450
440
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)

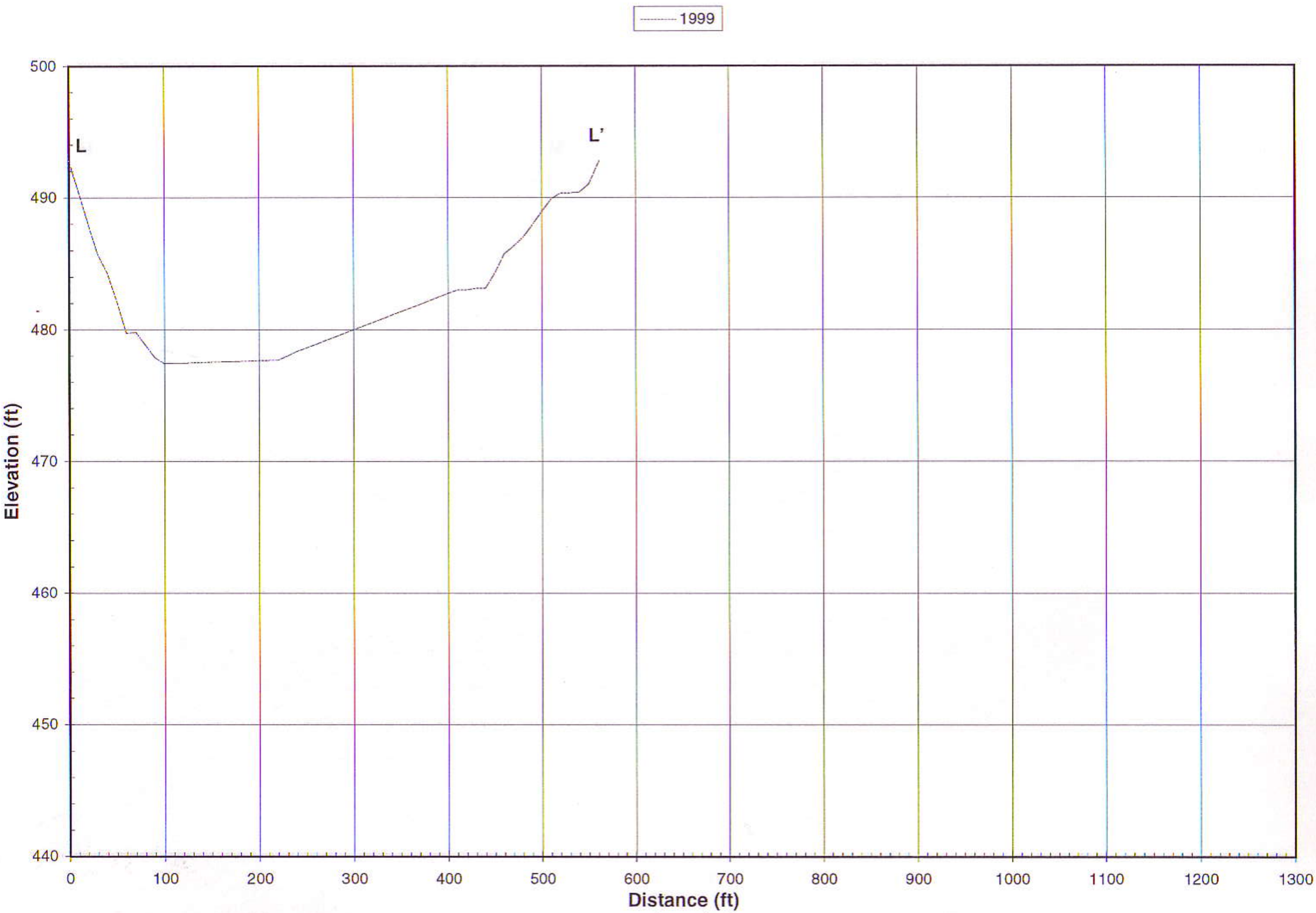
Appendix E

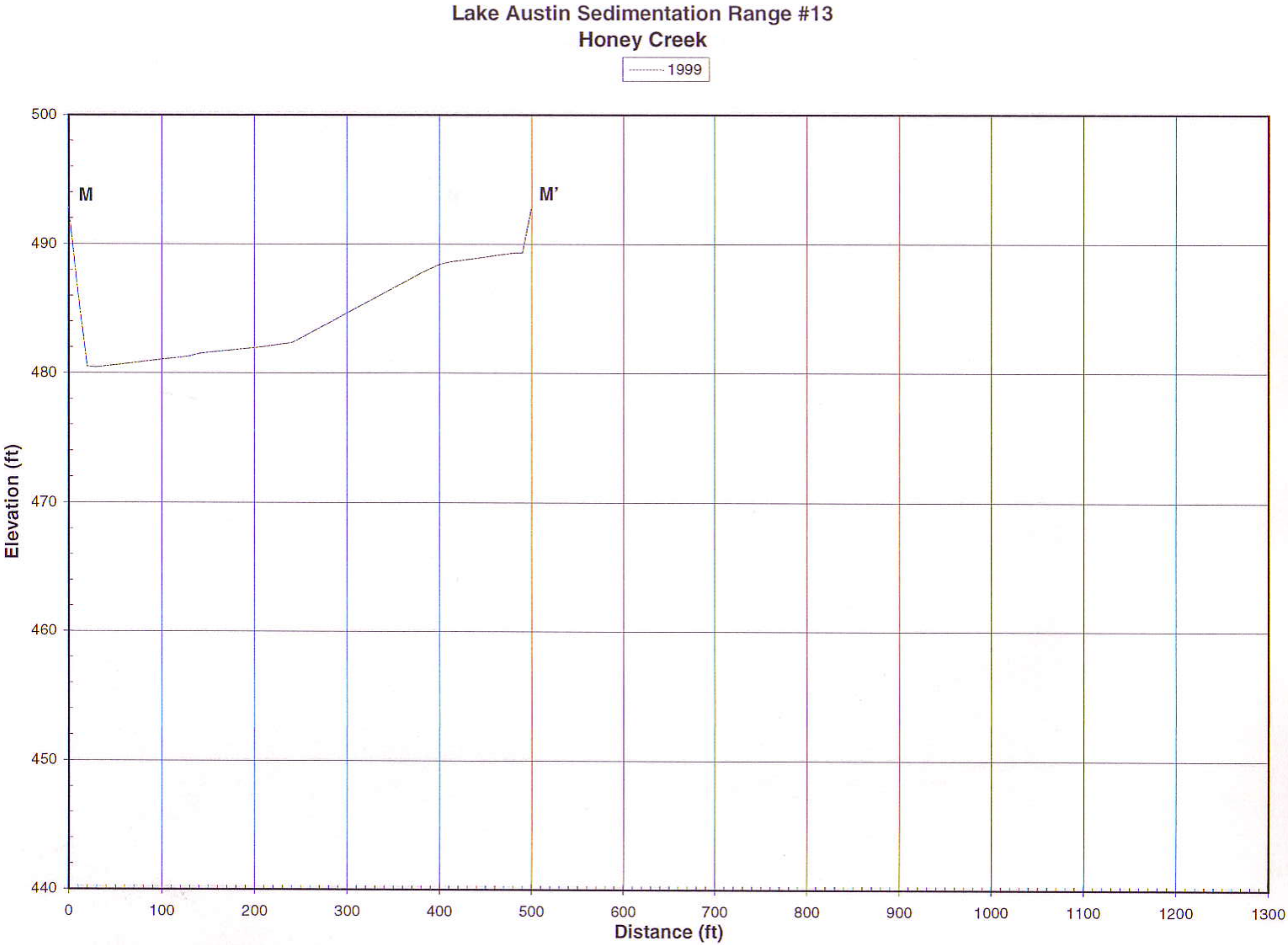
Lake Austin Sedimentation Range #11
Hughes



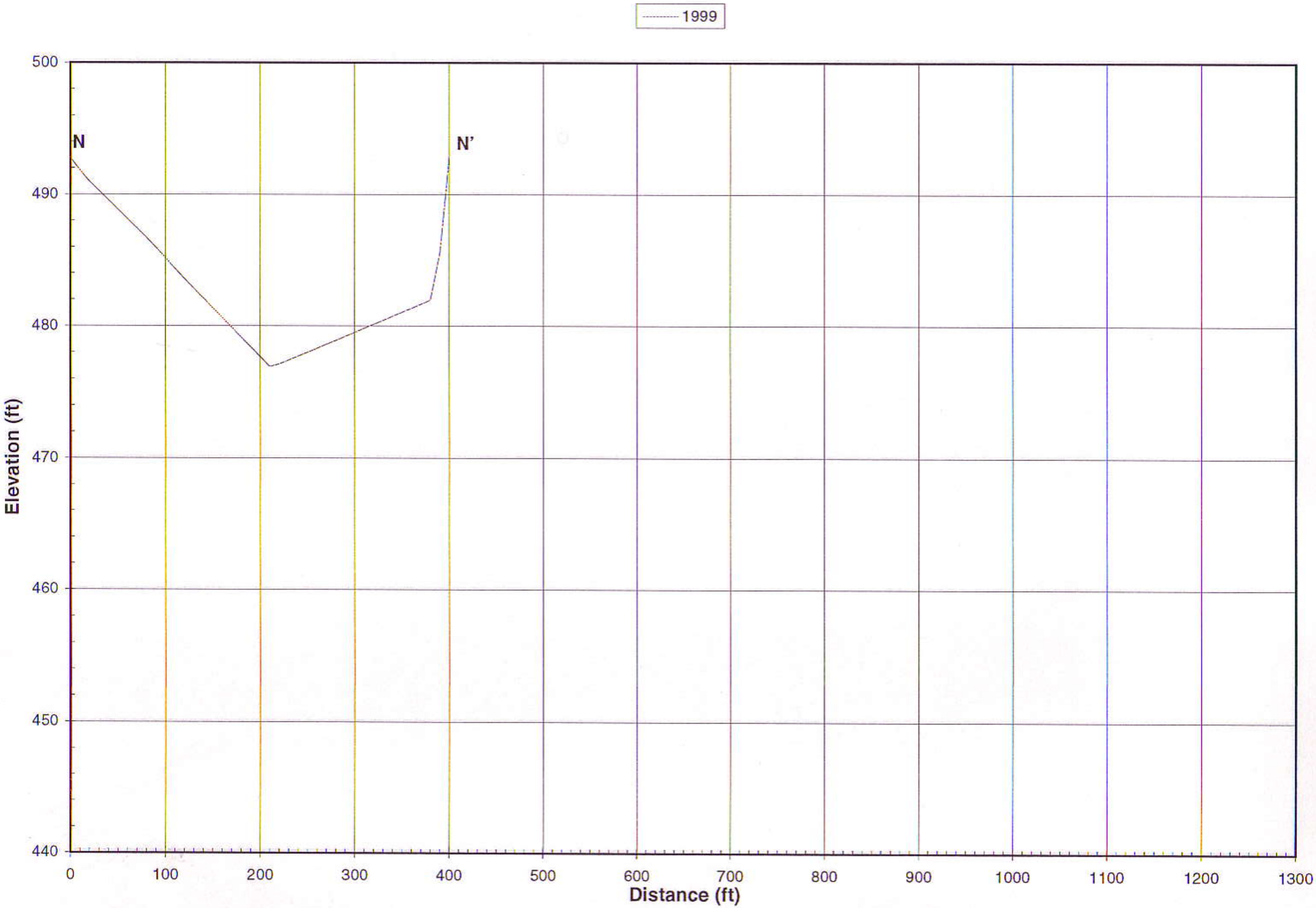
Appendix E

Lake Austin Sedimentation Range #12



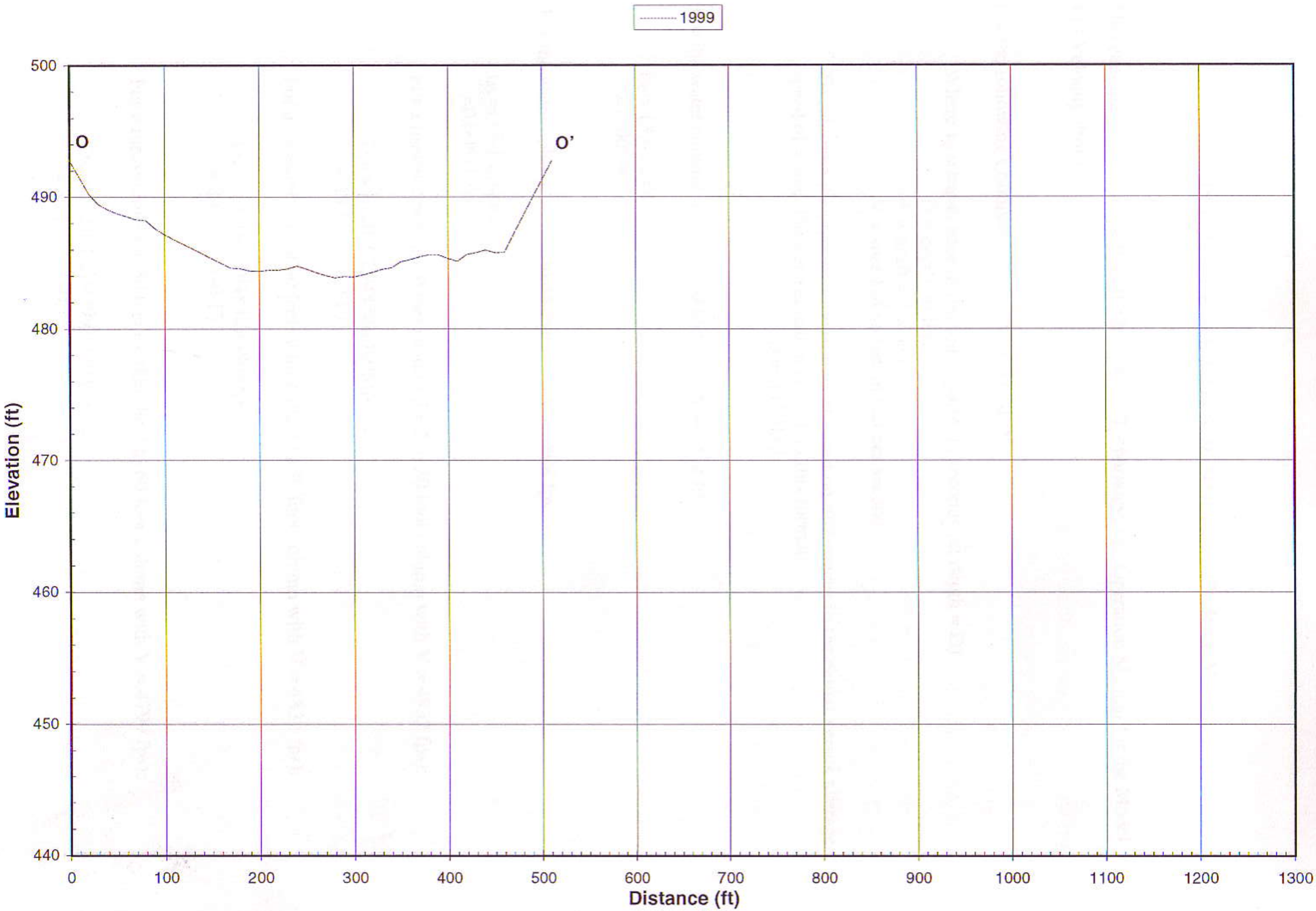

Lake Austin Sedimentation Range #13
Honey Creek
1999
M
M'
Elevation (ft)
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Distance (ft)
Appendix E

Lake Austin Sedimentation Range #14
Harrison's Branch



Appendix E

Lake Austin Sedimentation Range #15
Clifton



Appendix E

APPENDIX F - DEPTH SOUNDER ACCURACY

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

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

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')

APPENDIX G - GPS BACKGROUND

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 satellite broadcasts 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 located in space, and is ignored, while the second is the point of interest located on earth. 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, DOD 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, of which one 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 provide horizontal positional accuracy within one meter. In addition, the large positional errors experienced by a single receiver when S/A is active are negated. The lake surface during the survey serves as the vertical datum for the bathymetric readings from a depth sounder. The sounder determines the lake's depth below a given horizontal location at the surface.

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 on a worldwide basis in a differential mode basically the same way as the shore station. 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 correction corresponding to each site is automatically sent to a "Network Control Center" where they are checked and repackaged for up-link to a "Geostationary" L-band satellite. The "real-time" corrections are then broadcast by the satellite to users of the system in the area covered by that 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.

Previous Survey Procedures

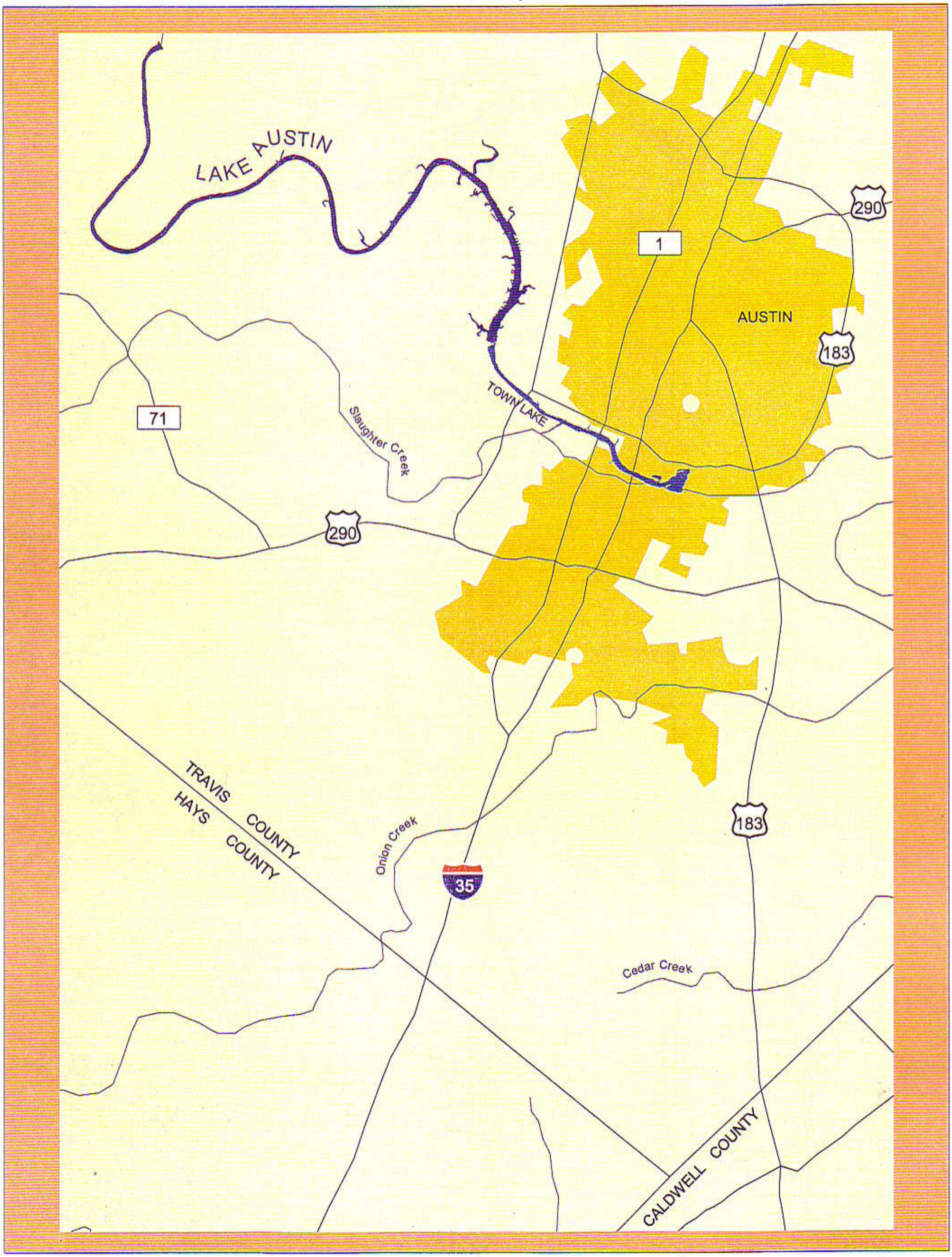
Originally, reservoir surveys were conducted by stretching a rope across the reservoir along pre-determined range lines and, from a small boat, poling the depth at selected intervals along the rope. Over time, aircraft cable replaced the rope and electronic depth sounders replaced the pole. The boat was hooked to the cable, and depths were 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. Monuments were set at 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 the horizontal location 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. Continuous horizontal positioning by electronic means allowed for the continuous collection of depth soundings by boat. A set of microwave transmitters positioned around the lake at known coordinates allowed 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 is generally one-half of the contour interval or ± five feet for a ten-foot contour interval. This method can be quite costly and is applicable only in areas that are not inundated.

FIGURE 1
LAKE AUSTIN
Location Map

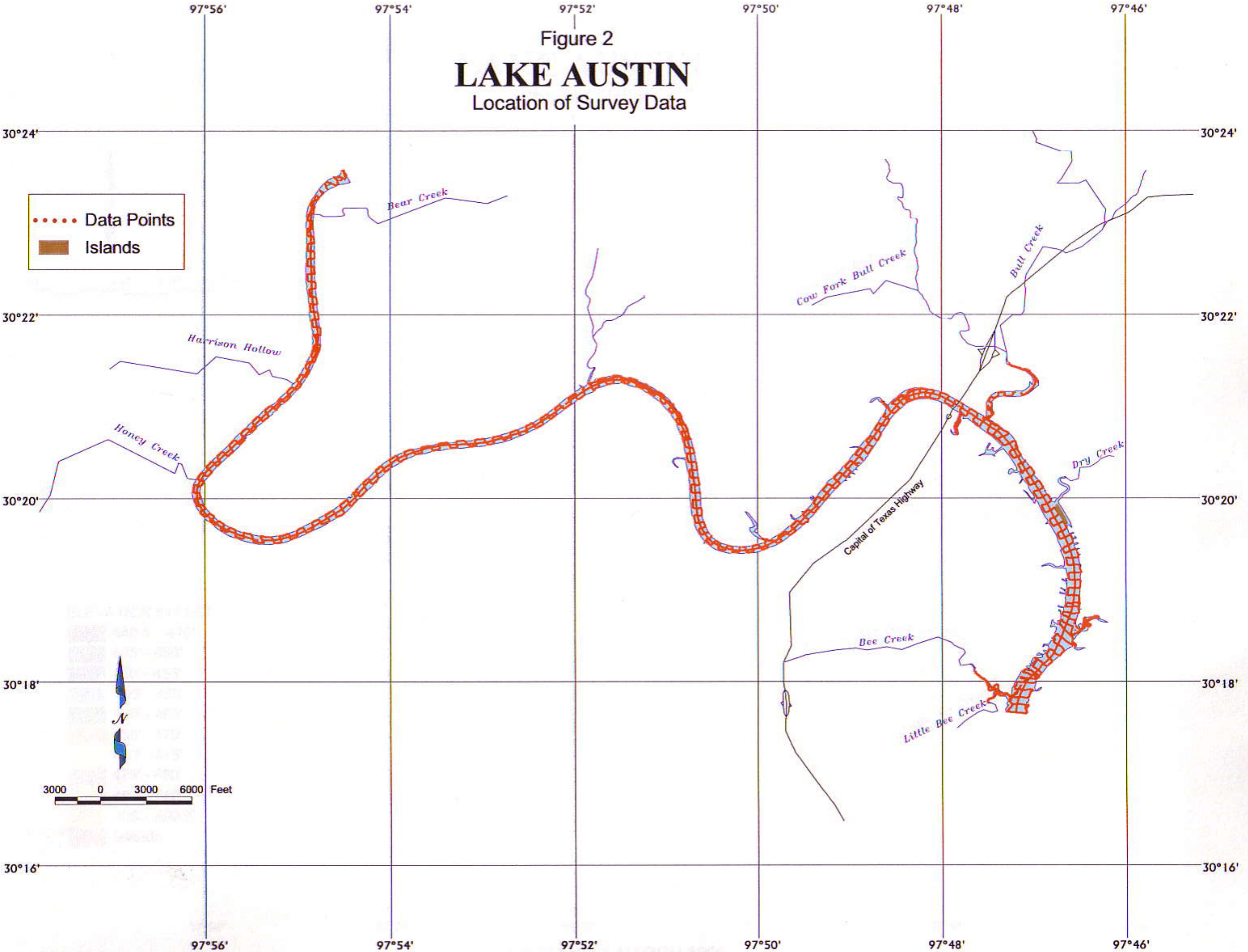


TWDB SURVEY MARCH 1999

Figure 2

LAKE AUSTIN

Location of Survey Data

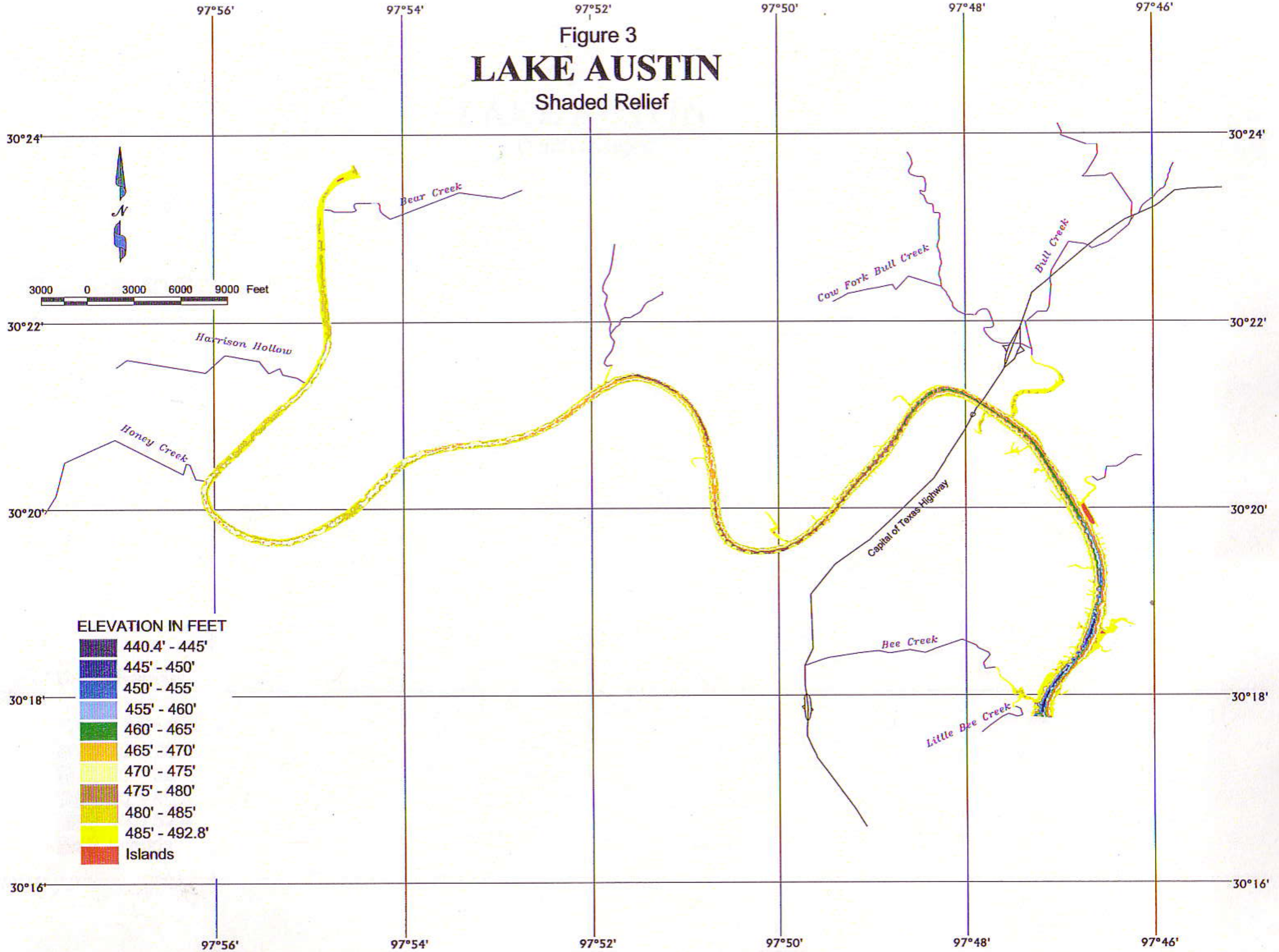


TWDB SURVEY MARCH 1999

Figure 3

LAKE AUSTIN

Shaded Relief



TWDB SURVEY MARCH 1999

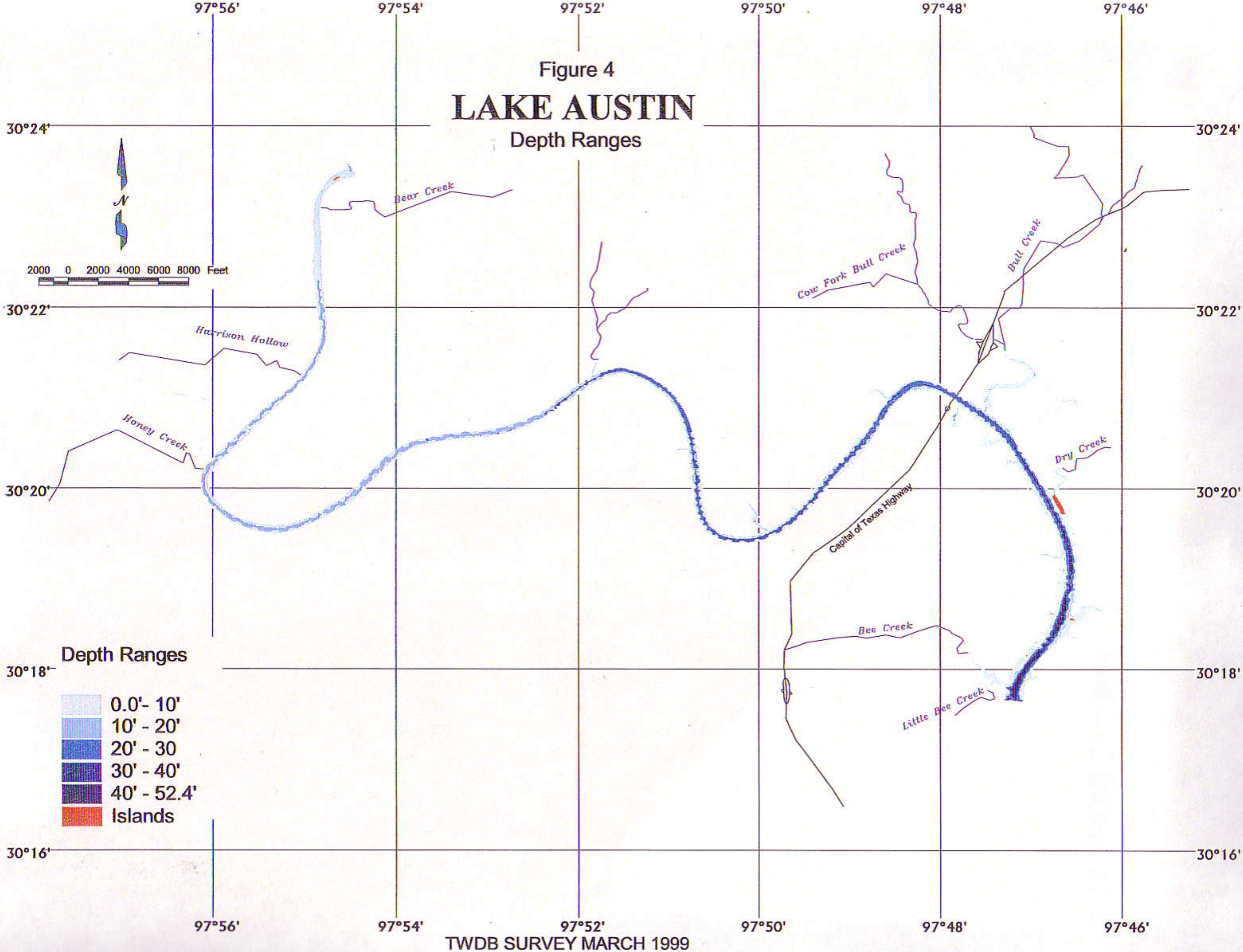


Figure 4
LAKE AUSTIN
Depth Ranges
97°56'
97°54'
97°52'
97°50'
97°48'
97°46'
30°24'
30°22'
30°20'
30°18'
30°16'
N
2000 0 2000 4000 6000 8000 Feet
Bear Creek
Harrison Hollow
Honey Creek
Cow Fork Bull Creek
Bull Creek
Dry Creek
Capital of Texas Highway
Bee Creek
Little Bee Creek
Depth Ranges
0.0'- 10'
10' - 20'
20' - 30
30' - 40'
40' - 52.4'
Islands
TWDB SURVEY MARCH 1999