VOLUMETRIC SURVEY
OF
LAKE HALBERT

Prepared for:

CITY OF CORSICANA

Prepared by:

The Texas Water Development Board

March 10, 2003

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 Halbert during the period of February 10, 11 and 22, 1999. The purpose of the survey was to determine the volume 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 Halbert is 368.0 feet. Past design information from TWDB (1974) estimated the surface area at this elevation to be 650 acres and the storage volume to be 7,420 acre-feet of water.

LAKE HISTORY AND GENERAL INFORMATION

Historical information on Lake Halbert was obtained from Texas Water Development Board reports (TWDB 1967; TWDB 1974). The City of Corsicana owns the water rights to Lake Halbert and operates and maintains associated Halbert Dam. The lake is located on Little Elm Creek (Trinity River basin) in Navarro County, four miles southeast of Corsicana, Texas (see Figure 1). Records indicate the drainage area is approximately 12 square miles with supplemental pumping from Chambers Creek. At the conservation pool elevation, the lake has approximately 11.2 miles of shoreline and is 2.23 miles long. The widest point of the reservoir is approximately 0.74 miles (located 0.5 miles upstream of the dam).

Water Rights Permit No. 803 (Application No. 841) was issued to City of Corsicana on July 1, 1925 and authorized the construction of a dam to impound and use 7,653 acre-feet of water for municipal purposes. On April 14, 1950 Permit No. 1534 (Application No. 1644) allowed the owner to raise the spillway one foot and allowed diversion of 3,650 acre-feet of water annually from Chambers Creek. The Texas Water Commission issued Certificate of Adjudication No. 08-5030 on May 5, 1987. The certificate authorizes the City of Corsicana to maintain an existing dam and reservoir on Little Elm Creek (Lake Halbert) and to impound not to exceed 7,357 acre-feet of water. The owner was authorized to divert and use not to exceed 4,003 acre-feet of water per year from Lake Halbert for municipal purposes. Under the Special Conditions section of the Certificate, the owner is authorized to store water diverted from Richland Creek Reservoir (Richland Chambers Reservoir) in Lake Halbert for subsequent diversion and use to the extent authorized.

Records indicate the construction for Lake Halbert and Halbert Dam started in 1920 and was completed in 1921. Deliberate impoundment began that same year. The design engineer for the facility was J. W. Harrison.

Halbert Dam and appurtenant structures consist of a rolled-earthfill embankment 2,780 feet in length, with a maximum height of 49 feet and a crest elevation of 375.0 feet. The service spillway is an uncontrolled concrete chute located to the left (west) of the embankment. The crest of the spillway is 175 feet in length at elevation 368.0 feet. Records indicate a 24-inch diameter conduit that passes through the dam is valve controlled for releases to the water treatment plant and for downstream releases.

The estimated volume of Lake Halbert in 1921 at conservation pool elevation 367.0 feet was 8,010 acre-feet, and the surface area 593 acres. In 1949 the U. S. Soil Conservation Service performed a sediment survey. Results indicated the siltation had reduced the lake volume by 1,355 acre-feet of water, corresponding to an average loss of 48.4 acre-feet per year between 1921 and 1949. In 1950 the service spillway was raised one foot to elevation 368.0 feet. The surface area of the lake was then estimated to be 650 acres and the volume to be 7,420 acre-feet.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The equipment used in the performance of the hydrographic survey consists 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 provides electrical power through an in-line undisturbed power supply. Reference to brand names does not imply endorsement by the TWDB.

The GPS equipment, survey vessel, and depth sounder combine together to provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder 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 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 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 with AutoCad software the lake's pool boundary (elevation 368.0 feet). The boundary file was created from the 7.5-minute USGS quadrangle map, Corsicana, TX. (1965), Photo-revised 1978. 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 37 survey lines to be placed along the length of the lake.

SURVEY PROCEDURES

The following procedures were followed during the hydrographic survey of Lake Halbert 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 that measures the local speed of sound. The average speed of sound in the water column extending below the boat-mounted transducers (at the boat's draft of 1.2 ft) to the lake bottom was determined by averaging local speed-of-sound measurements collected by the velocity profiler 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 time the unit measured the local speed of sound. The average of the measurements was next computed and displayed by the unit. The displayed value of the 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. 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. An additional estimated error of $\pm$0.3 feet arises due to the 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 minimized 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 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 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 at Lake Halbert on February 10, 11 and 22, 1999. During data collection, the crew had excellent weather with moderate temperatures and mild winds. Approximately 8,475 data points were collected over the 12.7 miles traveled. These points were stored digitally on the boat's computer in over 22 data files. Data were not collected in areas with significant obstructions unless these areas represented a large amount of water. Figure 2 shows the actual location of all data collection points. The first two days of data collection were in the upper reaches of Lake Halbert where a smaller boat was used to gain access upstream of the railroad trestle and State Highway 287 bridge on Elm Creek. The small boat was also used to collect data upstream of a retention dam located on the north arm of the lake. The larger survey vessel was used in the main body of the lake.

Elm Creek flows in a southwest to northeast direction with Halbert Dam being at the northeast end of the lake basin. TWDB staff observed the land surrounding the lake to be generally flat to rolling hills. There was no residential or commercial development around the perimeter of the lake. The City of Corsicana owns the surrounding land around Lake Halbert. A city park along with a fishing pier and boat ramp facilities is located along the northwest shoreline of the lake.

While performing the survey on the lake, the field crew noted on the depth sounder chart that the bathymetry or contour of the lake bottom reflected the characteristics of the terrain surrounding the lake. A gradual slope was noticed as the boat traveled from the shoreline to the center of the lake. There was no defined channel or thalweg of Elm Creek in the main body of the lake. Between Halbert Dam and the railroad trestle, the crew noted extensive shoreline erosion on the east bank.

As the field crew collected data in the upper reaches of Elm Creek, navigational hazards such as submerged trees and stumps became apparent. In addition, sediment deposits and standing vegetation were observed. The crew was able to collect data in these areas, but at a much slower pace. Data collection in the headwaters was limited when the boat could no longer cross the lake 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. 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 remained at conservation pool elevation of 368.0 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, to be used with the GIS software to develop a model of the lake's bottom surface.

The resulting data file was downloaded to a Sun Sparc 20 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) network 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.

If data points were collected outside the digitized boundary, 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. These areas were determined to be insignificant for this project, therefore no additional points were needed to allow for interpolation and contouring of the entire lake surface at elevation 368.0. Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot intervals. From elevation 343.2 to elevation 368.0, the surface areas and volumes of the lake were computed using Arc/Info software. The computed area of the lake at elevation 368.0 was 603 surface acres. The computed area was 47 surface acres less than originally calculated in 1950 (Texas Water Development Board, 1967). 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 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 368.0 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.

Linear filtration algorithms were then applied to the DTM smooth cartographic contours. The resulting contour map of the bottom surface at two-foot intervals is presented in Figure 5.

RESULTS

Results from the 1999 TWDB survey indicate Lake Halbert encompasses 603 surface acres and contains a total volume of 6,033 acre-feet at the conservation pool elevation of 368.0 feet. The shoreline at this elevation was calculated to be 11.2 miles. The deepest point of the lake, elevation 343.2 feet and corresponding to a depth of 24.8 feet, was located approximately 170 feet upstream from the center of Lake Halbert Dam.

SUMMARY

Lake Halbert was initially impounded in 1921. Storage calculations in 1950 estimated the volume at conservation pool elevation 368.0 feet to be 7,420 acre-feet with a surface area of 650 acres.

During the period February 10, 11 and 22, 1999, a hydrographic survey of Lake Halbert was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1999 survey used technological advances such as differential global positioning and geographical information system technology to model the reservoir's bathymetry. These advances allowed a survey to be performed quickly and to collect significantly more bathymetric data on Lake Halbert than previous survey methods. Results indicate that the lake's volume at the conservation pool elevation of 368.0 feet is 6,033 acre-feet with an area of 603 acres.

The estimated reduction in storage volume at the conservation pool elevation of 368.0 feet since 1950 is 1,387 acre-feet, or roughly 28.3 acre-feet per year, significantly less than the estimated loss rate between 1921 and 1949 of 48.4 acre-feet per year (TWDB, 1967). The average annual deposition rate of sediment in the conservation pool of the reservoir can be estimated at 2.36 acre-feet per square mile of drainage area. *(Please note that this is just a mathematical estimate based on differences between past and current surveys.)*

It is difficult to compare the original design area and volume for Lake Halbert to that determined by the current TWDB survey because little is known about the original design method, the amount of data collected, and the method used to process the collected data. However, TWDB considers the 1999 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 volume.

REFERENCES

Texas Water Development Board. 1967. Dams and reservoirs in Texas, historical and descriptive information, Report 48, June 1967.

Texas Water Development Board. 1974. Engineering data on dams and reservoirs in Texas. Part II. Report 126. October 1974.

Appendix A

Lake Halbert

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD — FEBRUARY 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
343			0	0	0	0	0	0	0	0
344	0	0	0	0	0	0	0	0	0	1
345	1	1	1	1	1	1	1	2	2	2
346	2	2	2	3	3	3	3	4	4	4
347	5	5	5	6	6	7	7	8	9	11
348	12	14	16	18	21	23	26	29	32	36
349	40	44	49	54	59	64	70	76	82	88
350	95	102	110	118	126	135	144	154	164	174
351	185	197	208	220	232	245	258	271	284	298
352	312	326	341	356	371	386	402	418	434	450
353	466	483	500	518	536	554	572	590	609	627
354	647	666	685	705	725	746	766	787	808	829
355	851	873	895	917	939	962	985	1008	1032	1055
356	1079	1103	1127	1152	1177	1202	1227	1252	1278	1304
357	1330	1356	1383	1409	1436	1463	1491	1518	1546	1575
358	1603	1632	1661	1690	1720	1750	1780	1811	1842	1873
359	1904	1936	1969	2001	2034	2068	2101	2135	2169	2203
360	2238	2273	2308	2343	2379	2415	2451	2488	2525	2562
361	2600	2638	2676	2715	2755	2794	2834	2875	2916	2957
362	2999	3041	3083	3126	3170	3214	3258	3302	3347	3392
363	3437	3483	3529	3575	3622	3669	3716	3763	3811	3859
364	3907	3956	4004	4053	4103	4152	4202	4252	4302	4353
365	4404	4455	4506	4557	4609	4661	4713	4765	4818	4871
366	4924	4977	5030	5084	5138	5192	5247	5301	5356	5411
367	5467	5522	5578	5634	5690	5747	5804	5861	5918	5975
368	6033									

Appendix B

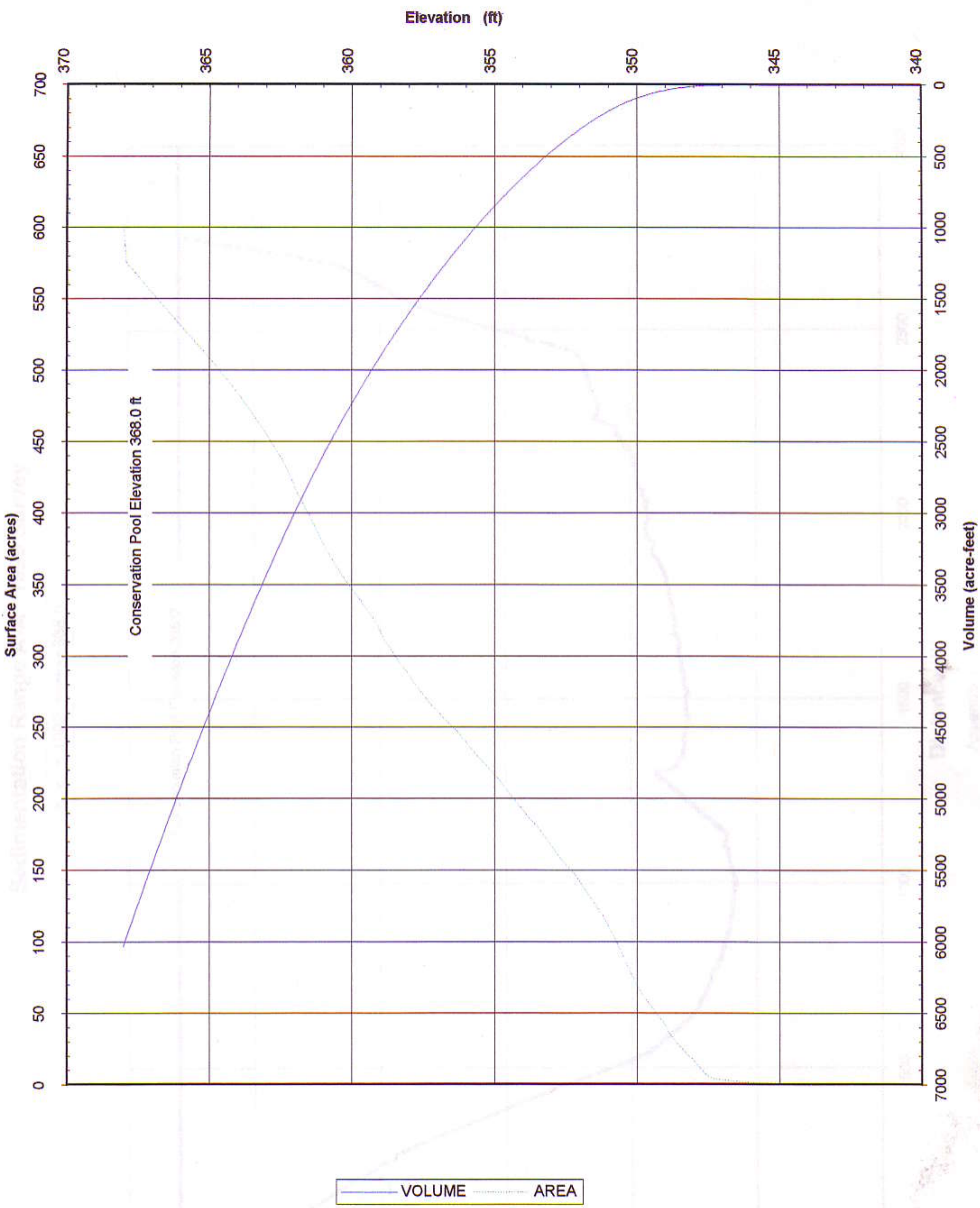
Lake Halbert

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — FEBRUARY 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
343			0	0	0	0	0	0	0	0
344	0	0	0	1	1	1	1	1	1	1
345	1	1	1	1	1	1	1	1	2	2
346	2	2	2	2	2	2	3	3	3	3
347	4	4	4	5	5	6	8	10	13	15
348	17	19	21	23	25	27	29	32	34	37
349	41	44	47	50	53	55	58	60	63	66
350	71	74	78	81	86	90	95	99	103	107
351	111	115	118	121	124	127	130	133	136	139
352	142	145	147	150	152	154	157	159	161	164
353	167	170	173	176	178	181	183	185	187	189
354	192	194	197	199	202	204	207	210	212	215
355	217	219	221	223	226	228	230	232	235	237
356	239	242	245	247	249	251	253	255	257	259
357	261	264	266	268	270	273	276	278	281	284
358	287	290	292	295	298	301	304	307	310	314
359	318	321	325	328	331	334	337	339	342	345
360	347	350	353	356	359	362	365	368	371	375
361	379	383	387	391	395	399	403	407	410	414
362	419	423	428	432	436	439	443	446	449	452
363	455	458	461	464	467	470	473	476	478	481
364	484	486	489	492	494	497	499	502	504	506
365	509	511	513	516	518	520	522	525	527	529
366	531	534	536	538	541	543	545	548	550	552
367	555	557	559	561	564	566	568	571	573	576
368	603									

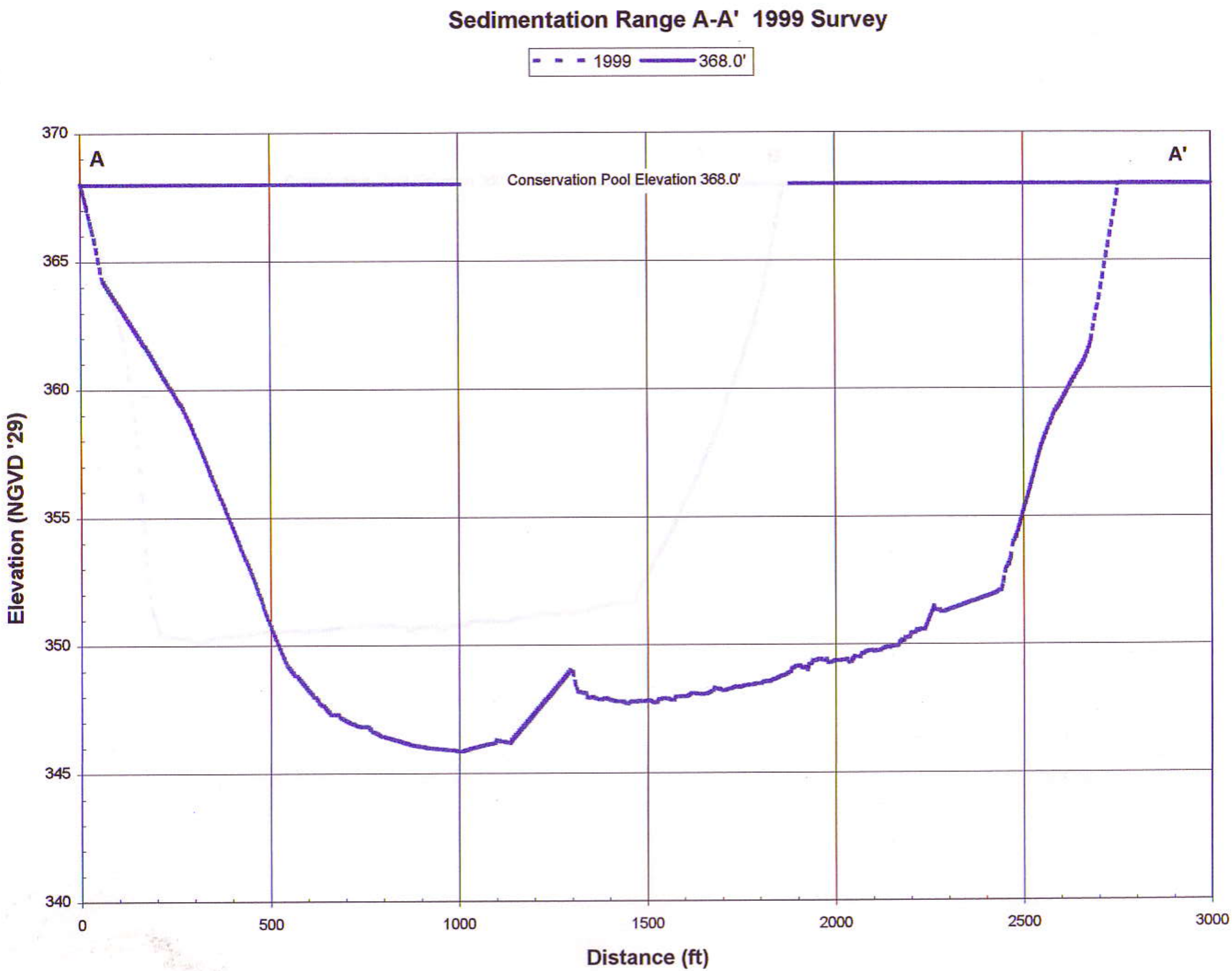


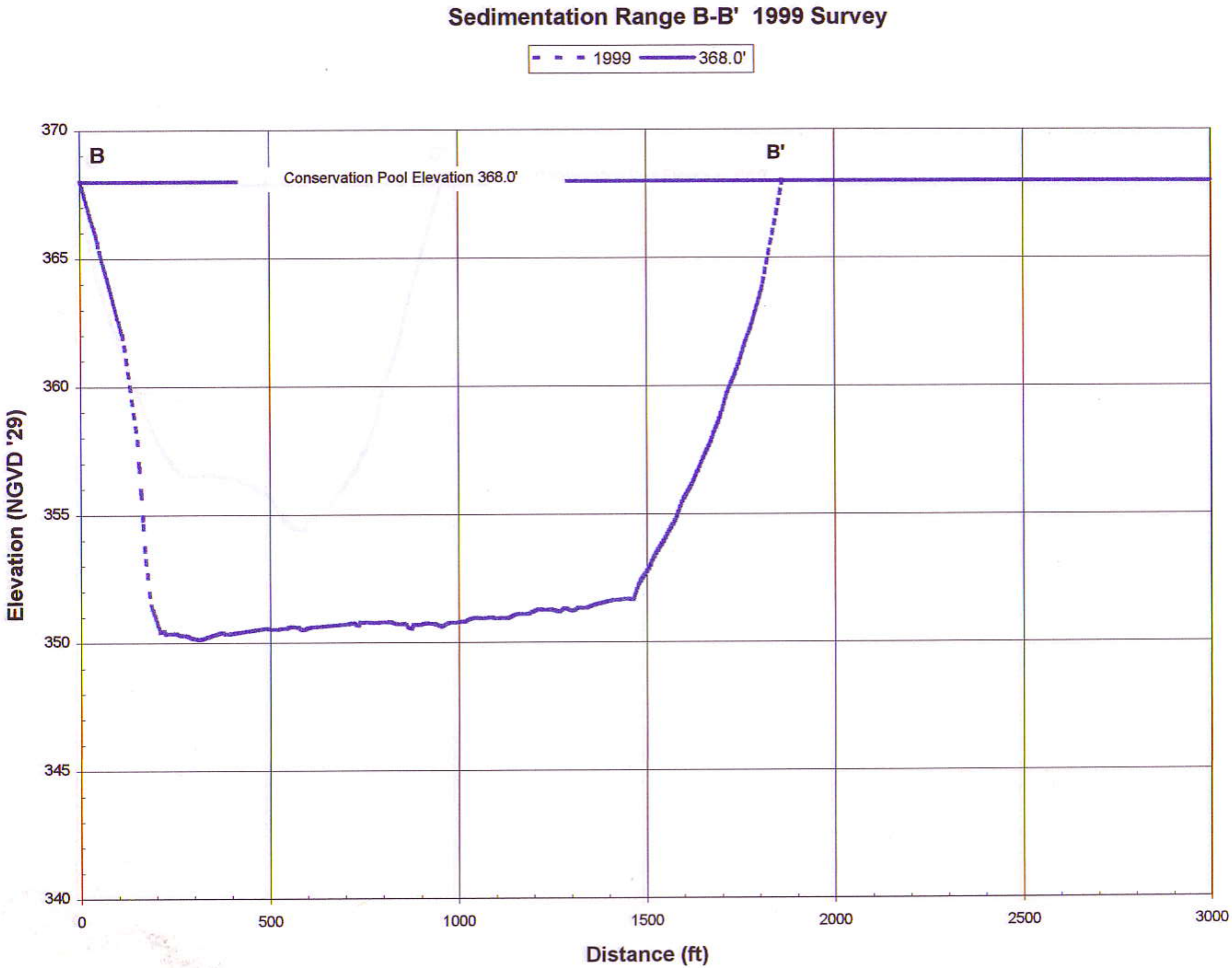
Lake Halbert

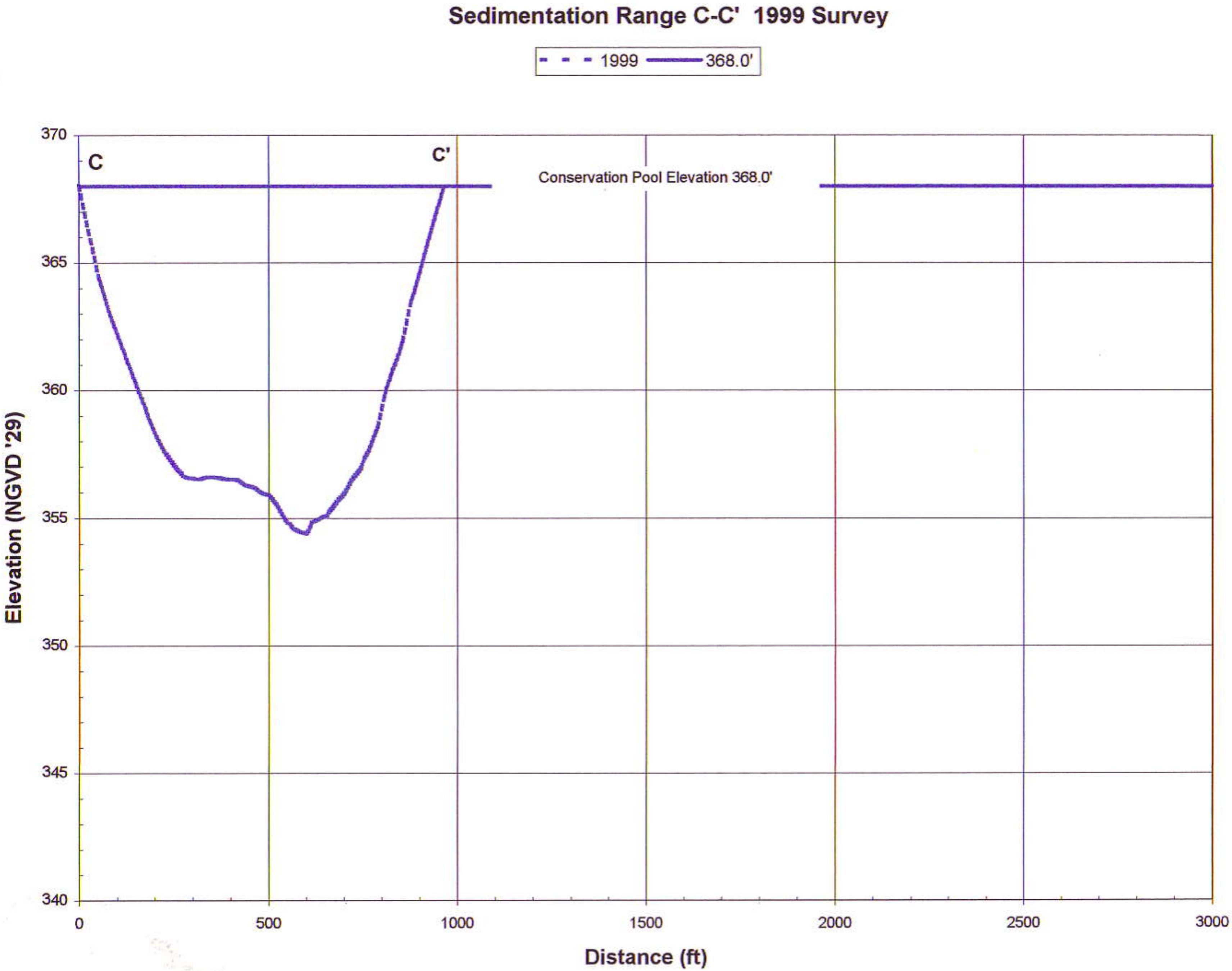
February 1999

Prepared by: TWDB July 1999

Appendix C


Sedimentation Range A-A' 1999 Survey
1999
368.0'
A
A'
Conservation Pool Elevation 368.0'
370
365
360
355
350
345
340
Elevation (NGVD '29)
0
500
1000
1500
2000
2500
3000
Distance (ft)


Sedimentation Range B-B' 1999 Survey
1999
368.0'
B
B'
Conservation Pool Elevation 368.0'
Elevation (NGVD '29)
370
365
360
355
350
345
340
0
500
1000
1500
2000
2500
3000
Distance (ft)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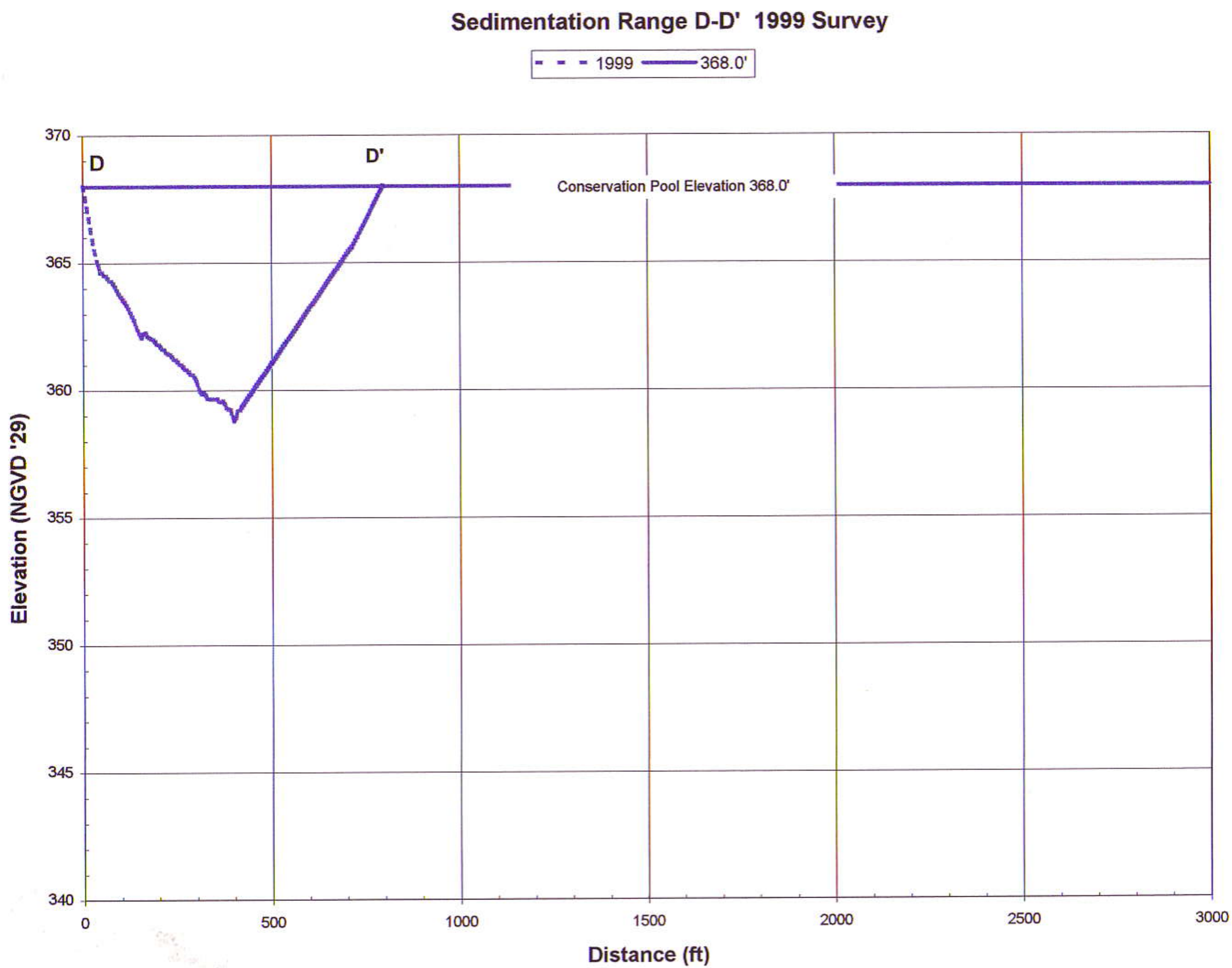
1999
368.0'
C
C'
Conservation Pool Elevation 368.0'
Elevation (NGVD '29)
370
365
360
355
350
345
340
0
500
1000
1500
2000
2500
3000
Distance (ft)

Appendix D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D
D'
Conservation Pool Elevation 368.0'
Elevation (NGVD '29)
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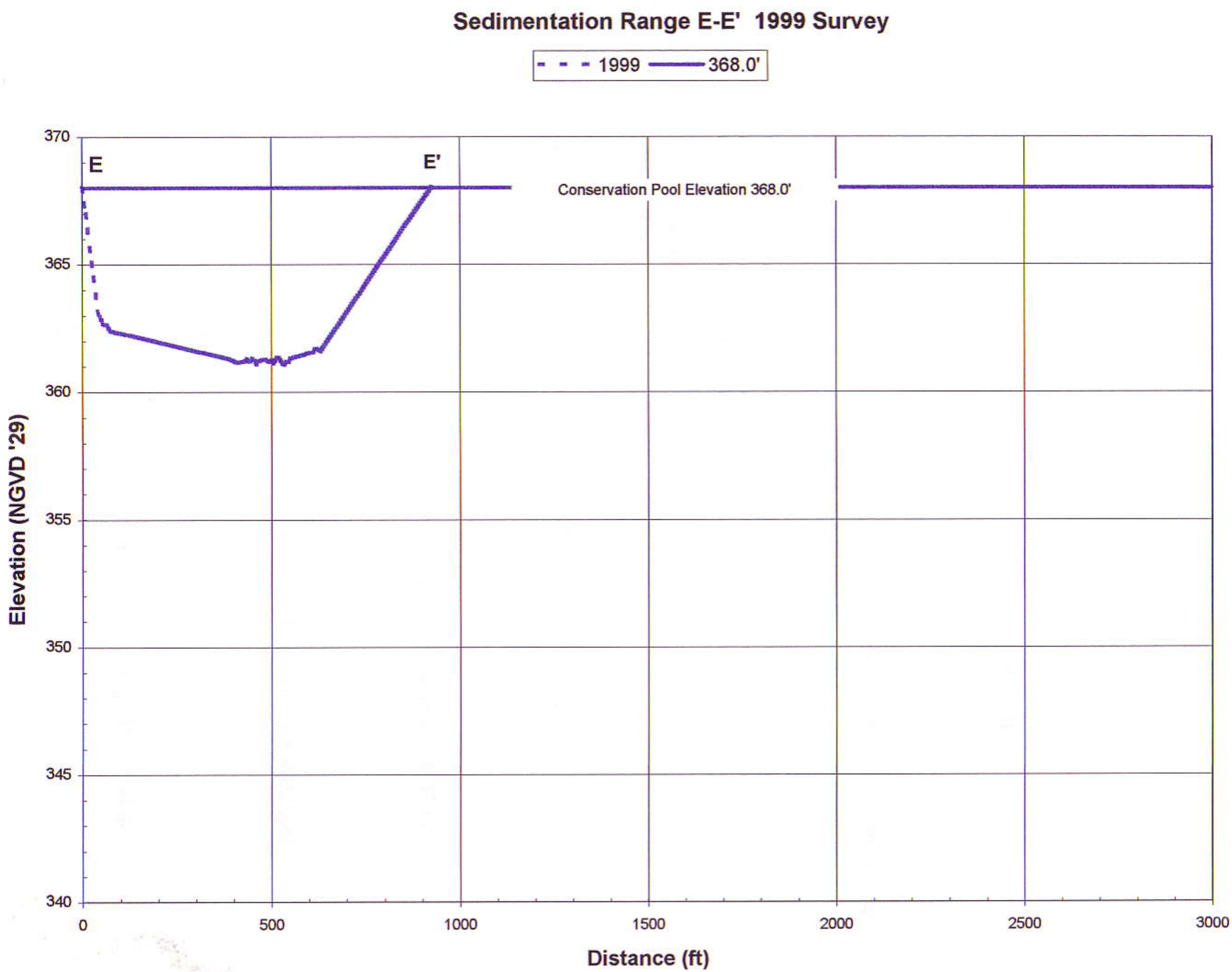
360
355
350
345
340
0
500
1000
1500
2000
2500
3000
Distance (ft)

Appendix D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368.0'
E
E'
Conservation Pool Elevation 368.0'
Elevation (NGVD '29)
370
365
360
355
350
345
340
0
500
1000
1500
2000
2500
3000
Distance (ft)

Appendix D

APPENDIX E - 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 F - 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 $\pm$ 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 HALBERT

Location Map

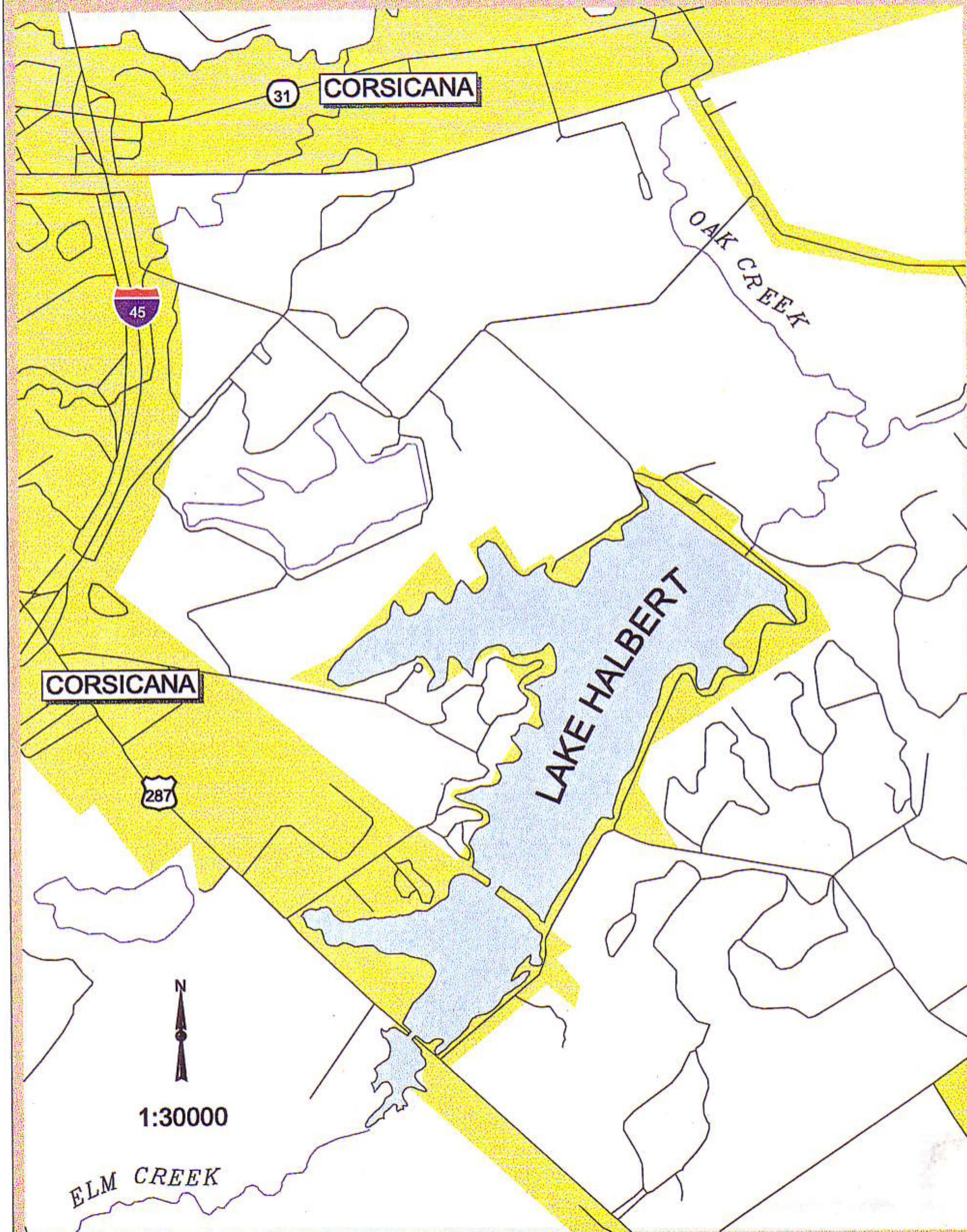

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Figure 2
Location of Survey Data

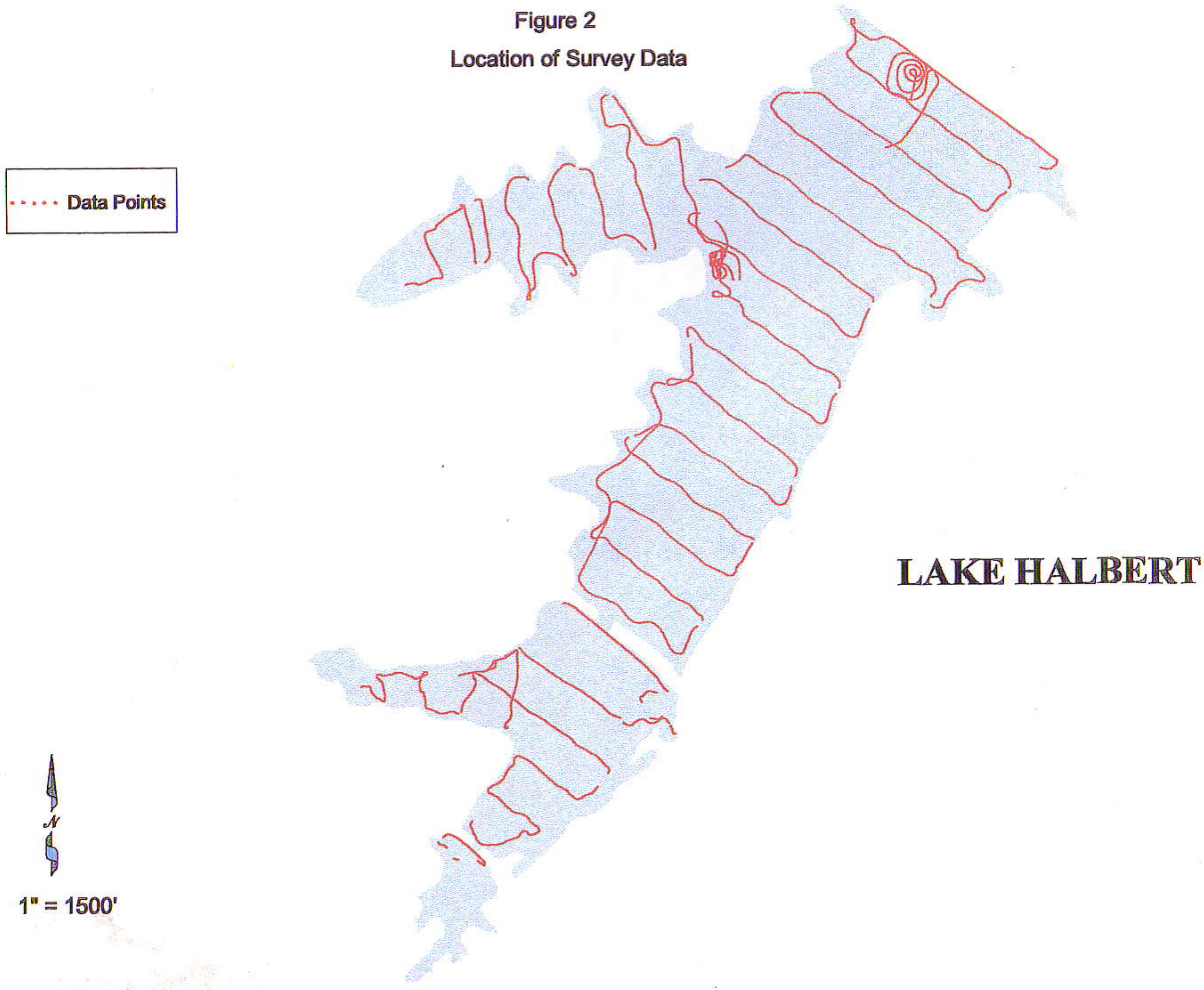

Figure 3
Shaded Relief

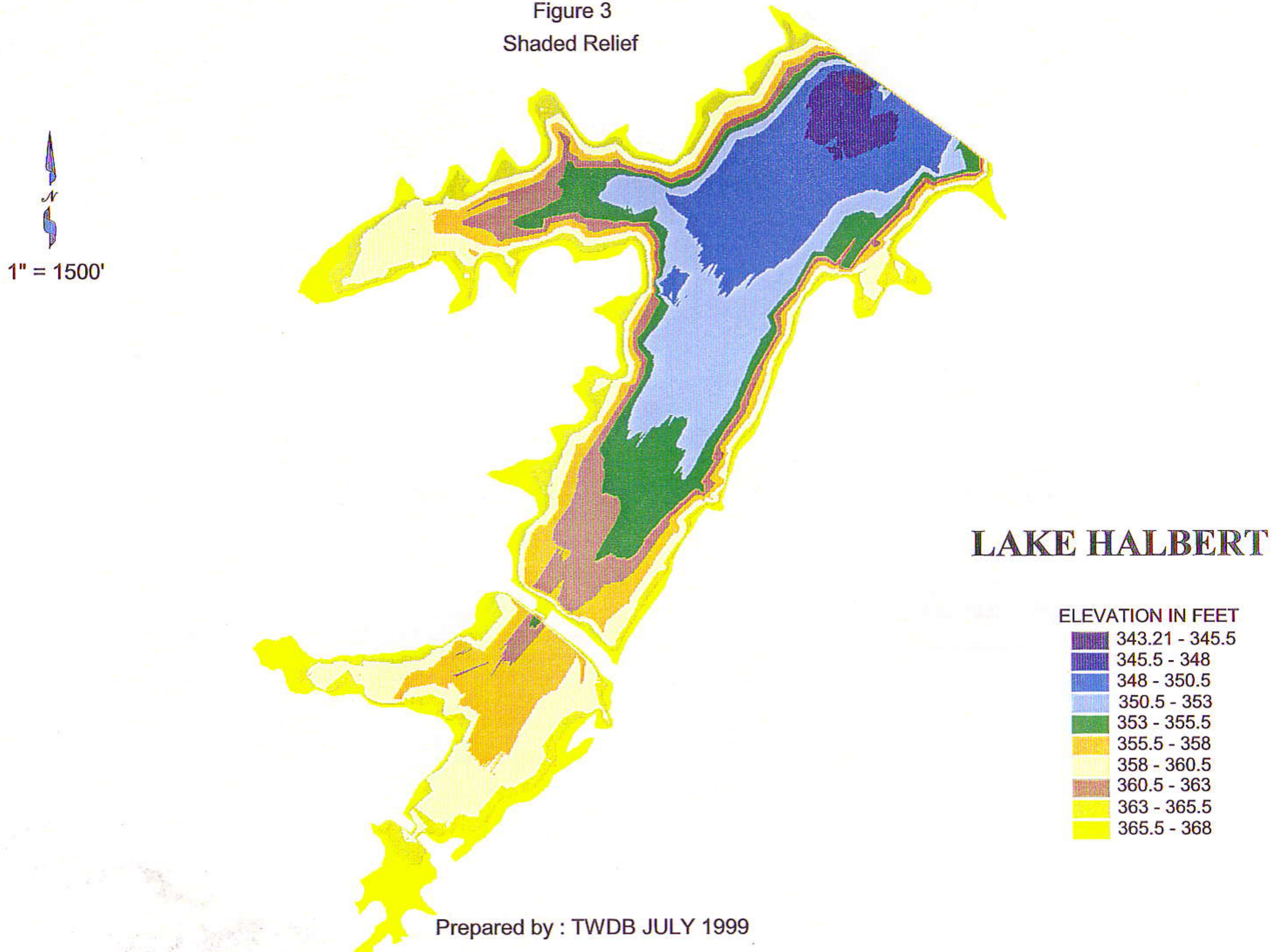

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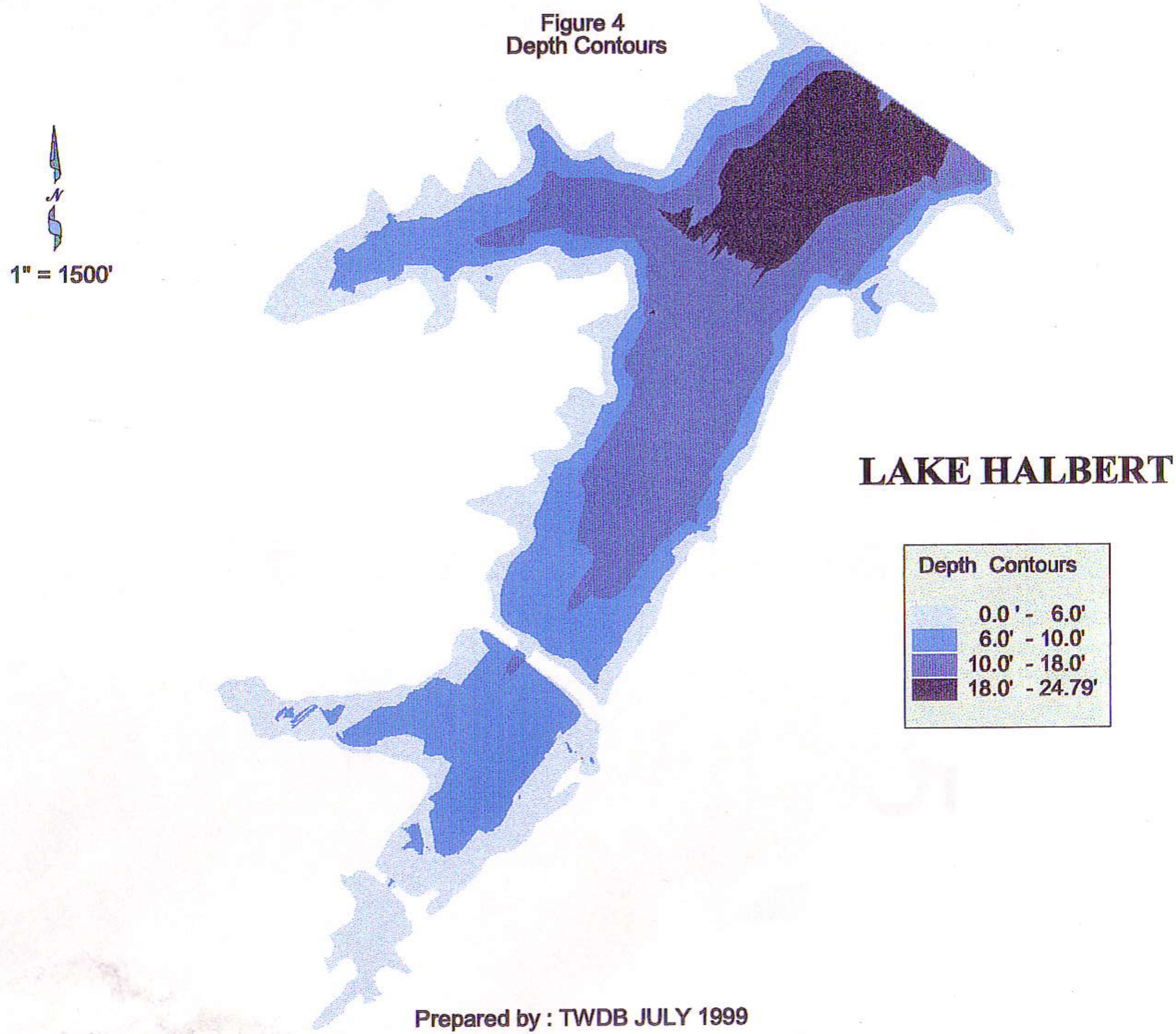
Figure 4
Depth Contours



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