VOLUMETRIC SURVEY OF BARDWELL LAKE

Prepared for:

U. S. Army Corps of Engineers, Fort Worth District

In Cooperation with

Trinity River Authority

Prepared by:

Texas Water Development Board

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Texas Water Development Board

This report was prepared by the Hydrographic Survey group:

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

For more information, please call (512) 463-7847

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey of Bardwell Lake on February 23 and 24, 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 are reported in feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29) unless that is otherwise noted. The conservation pool elevation for Bardwell Lake is 421.0 feet. The design information estimates the original surface area at this elevation to be 3,570 acres and the total storage volume to be 54,877 acre-feet of water.

LAKE HISTORY AND GENERAL INFORMATION

Information in this section was obtained from Texas Water Development Board Reports 48 and 126 (TWDB, 1967; TWDB 1974), the U.S. Army Corps of Engineers survey of 1972 (USACE, 1976), and from results of the current, 1999, volumetric survey. The Trinity River Authority owns the water rights for the conservation pool to Bardwell Lake. Bardwell Dam and the surrounding shoreline to elevation 444.0 feet of Bardwell Lake are owned by the United States Government and maintained by the U. S. Army Corps of Engineers, Fort Worth District. The lake is located on Waxahachie Creek in Ellis County approximately five miles south of Ennis, Texas (see Figure 1). Records indicate the drainage area is approximately 178 square miles. At the conservation pool elevation, the lake has approximately 25 miles of shoreline and is 5 miles long. The widest point of the reservoir is approximately 1.3 miles (located about 0.6 miles upstream of the dam).

Federal authorization was granted for the Bardwell Lake facility under the Flood Control Act of March 31, 1960. The Texas Water Commission granted Permit No. 2068 (Application No. 2250) to the Trinity River Authority of Texas on March 18, 1963. The District was granted authorization to impound 54,900 acre-feet of water in the conservation pool of Bardwell Lake. Annual use was limited to 9,600 acre-feet of water for municipal purposes. The Texas Water Commission issued certificate of Adjudication No. 08-5021 on May 5, 1987 to the Trinity River Authority. The certificate adjudicated the same water rights as stated in Permit No. 2068. Trinity River Authority was authorized to impound 54,900 acre-feet of water in Bardwell Lake below elevation 421.0 feet. The District was authorized to divert and use not to exceed 9,600 acre-feet of water per annum from Bardwell Lake for municipal purposes. The owner was also authorized to use the impounded waters of Bardwell Lake for recreational purposes.

Construction for the Bardwell Lake project began on August 28, 1963. Deliberate impoundment of water began November 20, 1965 and the project was officially completed March 27, 1966. The U. S. Army Corps of Engineers designed the project and M & S Construction Company was the general contractor. The estimated project cost was $11,500.00.

Bardwell Dam and appurtenant structures consist of an earthfill and concrete embankment 15,050 feet in length with a maximum height of 82 feet and a crest width of 20 feet at elevation 460.0 feet. The service spillway is an uncontrolled broadcrested weir located at the right (west) end of the embankment. The crest of the spillway is 350 feet in length at elevation 439.0 feet. The outlet works consists of a concrete tower with two 5 x 10 feet sluice gates that pass water through a gate controlled 10 feet diameter conduit. The invert elevation of the conduit is 391.0 feet.

Bardwell Lake was resurveyed in 1972 to determine the extent of sedimentation. The 1962 original design information stated Bardwell Lake had 3,570 surface acres and a volume of 54,877 acre-feet of water at conservation pool elevation (below elevation 421.0 feet). The 1972 resurvey found Bardwell Lake to have 3,558 surface acres and a volume of 52,291 acre-feet of water at conservation pool elevation.

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 uninterruptible power supply. Reference to brand names does not imply endorsement by the TWDB.

The GPS equipment, survey vessel, and depth sounder combine together to provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder 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 data files are downloaded daily 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 and surface area can be quickly determined by creating a 3-D digital 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 boundary was digitized using ArcView software. The boundary file was created from recently produced digital orthophoto quadrangles (DOQ) images for Cryer Creek, Texas and Ennis West, Texas. (The DOQ's were produced for the TEXAS Orthoimagery Program (TOP). DOQ products produced for the Department of Information Resources and the GIS Planning Council under the Texas Orthoimagery Program reside in the public domain and can be obtained on the Internet at http://www.tnris.state.tx.us/DigitalData/doqs.htm.) The boundary created with these DOQ's was originally in UTM Zone 14, and was subsequently converted to the NAD '83. The photographs used in the producing the DOQ's were taken February 8, 1995. The average lake elevation at the time the photographs were taken, obtained from the U.S. Army Corps of Engineers, was 421.11 feet. This boundary was used in determining the outer lake boundary for subsequent use in calculating the lake's area and volume.

The survey layout was designed with Coastal Oceangraphics, Inc. Hypack software by placing survey track lines at 500-foot intervals across the lake. The survey design for this lake required approximately 96 survey lines to be placed along the length of the lake. The survey layout files were copied onto diskettes for use during the field survey.

SURVEY PROCEDURES

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 Bardwell Lake, the speed of sound in the water column varied from 4,767 to 4,773 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. 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 the measured horizontal position. 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 Bardwell Lake on February 23 and 24, 1999. Weather conditions were favorable during the data collection phase of the survey. Approximately 45,836 data points were collected over the 56 miles traveled. These points were stored digitally on the boat's computer in 79 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 observed many similar features of the lakes bathemetry and the surrounding topography of the lake. The terrain around the lake was generally flat with some minor relief. The reservoir was mainly located in the flood plain of Waxahachie Creek. The flow was in a northwest to southeast direction with Mustang Creek feeding into the lake on the north side. In the main body of the lake, the creek channels were easily distinguishable on the depth sounder chart as the boat traveled perpendicular to the channel. The survey crew noted bank erosion along the north shore between the dam and Love Park. Silt bars extended on an average of 100 feet from the shoreline where bank erosion was occurring.

Data collection started at the dam and proceeded upstream. The field crew did not encounter any navigational hazards such as submerged trees, stumps or shallow depths until the boat was upstream of Waxahachie Creek Park. Data collection in the headwaters was discontinued when the boat could no longer maneuver due to shallow water and extensive vegetation. Extra data were collected around the outlet works at the dam and the two intake structures, one on the north shore near Love Park (City of Ennis) and one on the south shore just upstream of the Highway 34 bridge (City of Waxahachie). 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 remained constant at elevation 421.15 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 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 (triangular irregular network) software module. The module generates a TIN from the data points and the boundary file using a method known as Delauney's criteria for triangulation. In this method, 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. 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 intervals. From elevation 383.1 to elevation 421.0, the surface areas and volumes of the lake were mathematically estimated using Arc/Info software. The computed water surface area (total area - area of islands) of the lake at elevation 421.0 was 3,138 surface acres. This area is 432 surface acres less than originally reported in 1966 and 421 surface acres less than reported in the 1972 survey. 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, cross-sections from the original survey and the 1972 resurvey (USACE, 1976), shown on the map in Figure 5, are compared to cross-sections obtained from the current survey in the plots in Appendix D.

RESULTS

Results from the 1999 TWDB survey indicate Bardwell Lake encompasses 3,138 surface acres (total area - area of islands) and contains a total volume of 46,472 acre-feet at the conservation pool elevation of 421.0 feet. The shoreline at this elevation was calculated to be approximately 25 miles. The deepest point of the lake, elevation 383.17 feet or 37.83 feet of depth, was located approximately 1,100 feet upstream from Bardwell Dam in an old streambed. The dead storage volume, or the amount of water below the lowest outlet invert elevation in the dam (at 391.0 feet), was calculated to be 350 acre-feet, therefore the conservation storage volume is 46,122 acre-feet of water.

SUMMARY

Construction of Bardwell Lake was completed in 1966. Initial storage calculations estimated the volume at the conservation pool elevation of 421.0 feet to be 54,877 acre-feet with a surface area of 3,570 acres. The lake volume below the dead-pool elevation of 391.0 feet was reported as 391 acre-feet. Conservation pool volume (volume at conservation pool elevation - volume below dead pool elevation) was 53,553 acre-feet.

During February 23 and 24, 1999, staff from the Texas Water Development Board's Hydrographic Survey Program completed a hydrographic survey of Bardwell Lake. 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 total volume at conservation pool elevation is 46,472 acre-feet, and the corresponding area is 3,138 acres.

Comparing the findings from the original (1962) survey and the current survey, the estimated reduction in volume at the conservation pool elevation of 421.0 feet is 8,405 acre-feet (-15%) or 255 acre-feet/year (since 1966). The average annual deposition rate of sediment in the reservoir can be estimated at 1.4 acre-feet/square mile of drainage area. This compares to sedimentation rates based on the original survey and the 1972 resurvey of 431 acre-feet/year and 2.4 acre-feet/square mile. Some differences among results may arise from differences in surveying procedures and technology. Based on the amount of data collected and the improved methods and technology used in the current survey, the current data set is considered to be an improvement over previous survey procedures. It is recommended 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 I. Report 126. October 1974.

U. S. Army Corps of Engineers. 1976. Report on Sedimentation, Bardwell Lake, Waxahachie Creek, Texas, Trinity River Basin, Texas. Resurvey of November 1972.

Appendix A

Bardwell Lake

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
383		0	0	0	0	0	0	0	0	1
384	1	2	3	4	5	6	8	9	10	12
385	13	15	17	19	20	22	24	26	28	30
386	32	34	36	38	40	43	45	47	50	52
387	54	57	59	62	65	67	70	73	77	81
388	85	89	94	98	103	109	114	120	126	133
389	140	147	155	163	171	180	189	198	208	218
390	228	239	250	261	273	285	298	311	324	337
391	350	364	378	392	406	421	435	450	465	481
392	497	513	529	546	563	581	599	618	638	659
393	682	706	732	758	786	815	846	877	909	942
394	976	1012	1048	1085	1123	1162	1202	1243	1285	1328
395	1372	1417	1463	1509	1557	1605	1654	1704	1755	1807
396	1860	1913	1968	2024	2080	2138	2197	2257	2318	2380
397	2442	2506	2570	2636	2703	2770	2839	2909	2981	3053
398	3127	3201	3276	3351	3428	3505	3583	3662	3742	3823
399	3904	3987	4071	4156	4242	4328	4416	4504	4593	4684
400	4775	4867	4960	5055	5150	5247	5345	5444	5544	5646
401	5749	5853	5958	6065	6172	6280	6389	6499	6610	6721
402	6833	6946	7059	7173	7287	7403	7518	7635	7752	7870
403	7989	8109	8229	8350	8472	8594	8717	8841	8966	9092
404	9218	9346	9474	9604	9734	9865	9997	10129	10263	10398
405	10534	10671	10809	10948	11088	11228	11370	11512	11656	11800
406	11946	12093	12241	12391	12541	12692	12844	12997	13151	13305
407	13461	13617	13775	13933	14093	14254	14416	14578	14742	14906
408	15072	15238	15405	15573	15742	15911	16082	16253	16426	16600
409	16775	16950	17127	17304	17483	17663	17844	18026	18209	18394
410	18580	18767	18955	19144	19334	19525	19718	19911	20106	20301
411	20498	20696	20896	21096	21298	21500	21704	21909	22115	22323
412	22532	22742	22954	23166	23380	23595	23812	24030	24249	24469
413	24691	24915	25139	25365	25593	25822	26053	26285	26518	26753
414	26990	27228	27467	27707	27948	28191	28435	28680	28926	29174
415	29422	29671	29922	30173	30425	30679	30933	31189	31446	31704
416	31963	32224	32487	32751	33017	33284	33552	33822	34092	34364
417	34637	34912	35187	35464	35742	36021	36301	36583	36866	37151
418	37437	37725	38015	38307	38599	38892	39185	39480	39775	40071
419	40367	40665	40963	41262	41562	41862	42164	42466	42769	43073
420	43378	43684	43990	44297	44605	44914	45224	45535	45846	46159
421	46472									

Appendix B

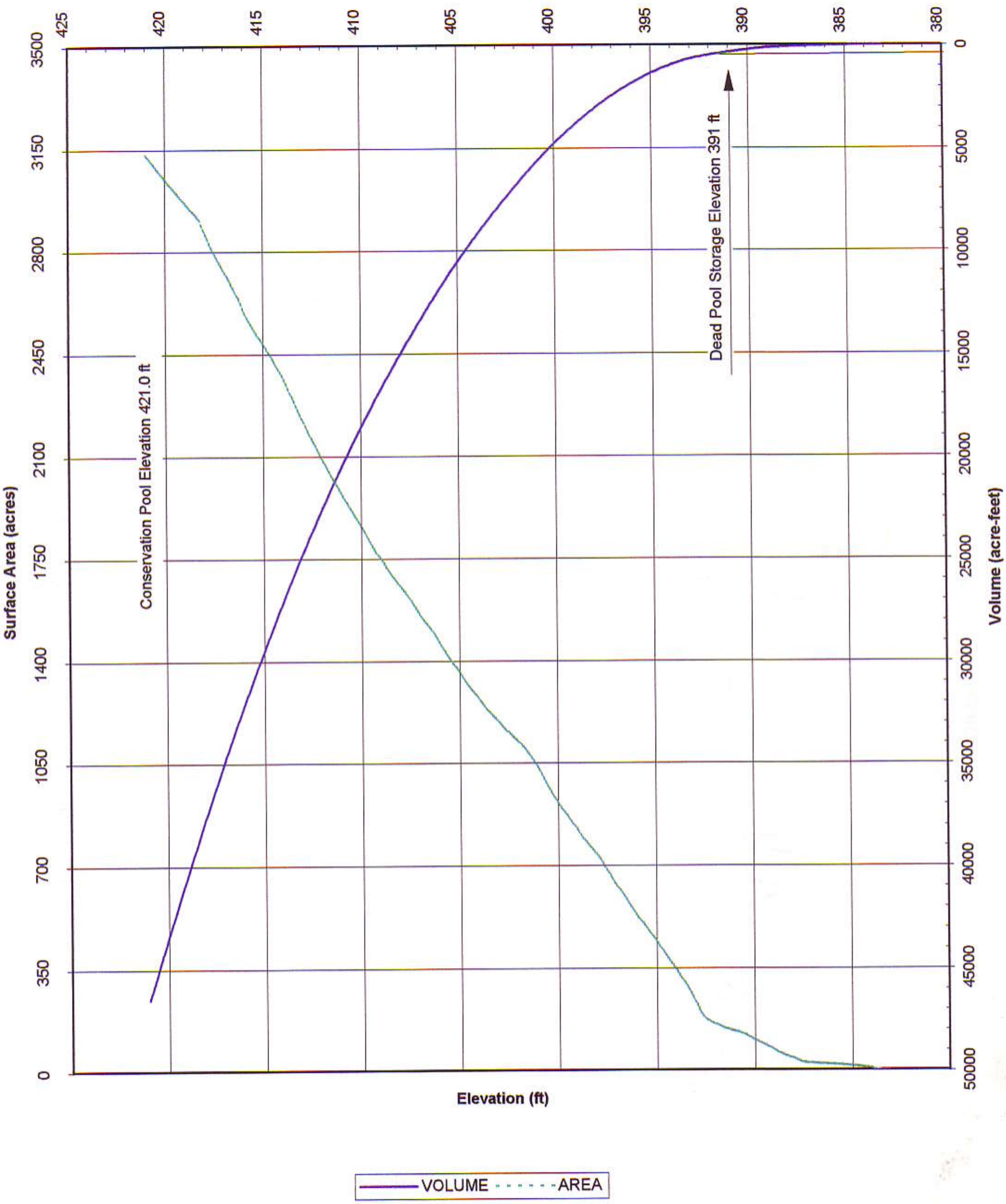
Bardwell Lake

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — FEBRUARY 1999 SURVEY

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

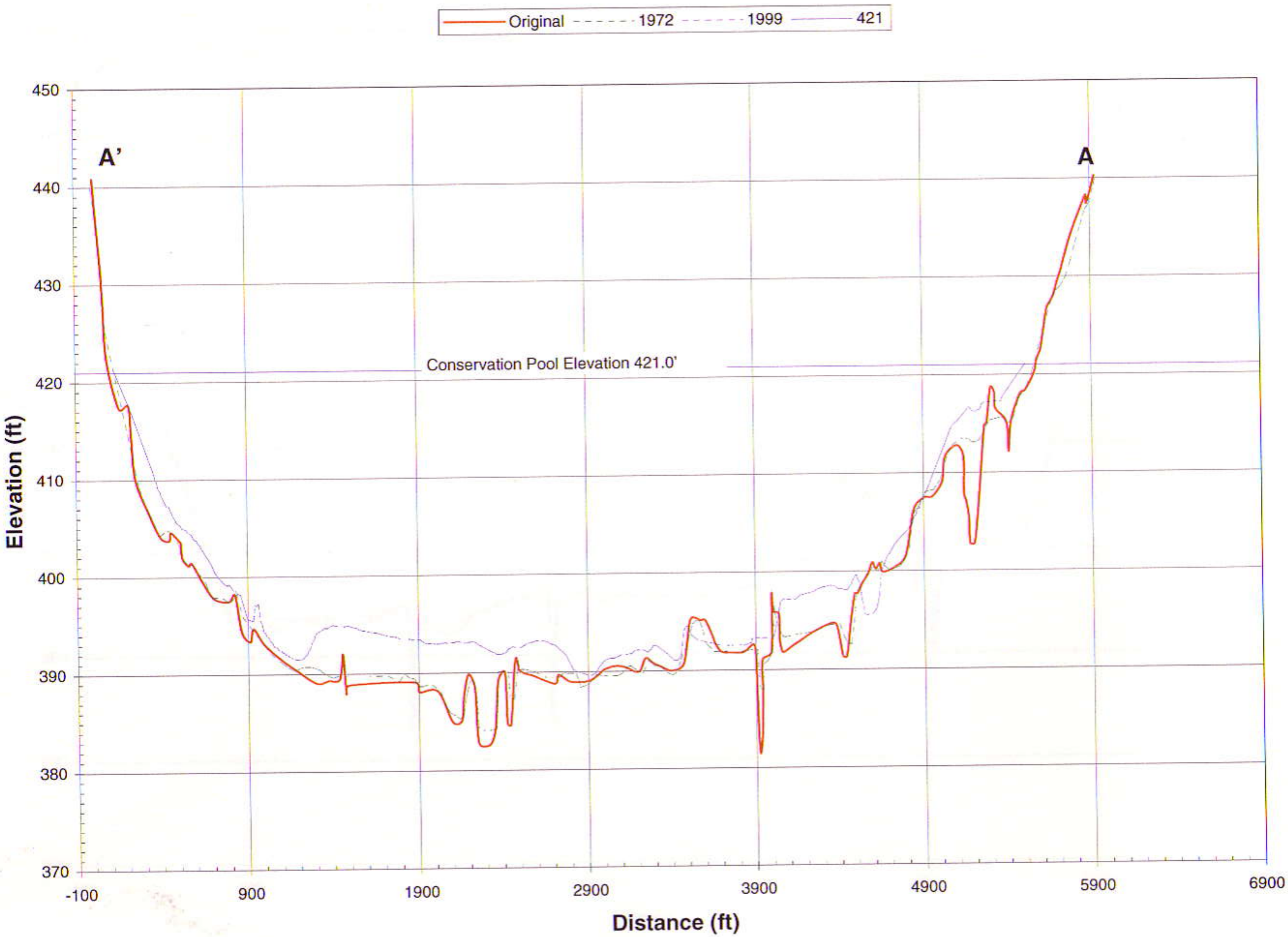
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
383		0	0	0	0	0	1	1	3	5
384	7	9	9	10	11	12	13	14	15	16
385	16	17	17	17	18	18	19	19	20	20
386	20	21	21	22	22	23	23	23	24	24
387	25	25	26	26	27	28	30	33	36	40
388	42	44	47	49	51	54	57	60	63	68
389	72	76	79	82	85	88	92	95	98	102
390	105	109	112	116	121	124	127	129	132	133
391	135	137	139	141	143	145	148	151	154	157
392	160	163	166	169	173	178	185	193	206	220
393	235	248	262	274	286	297	306	316	326	337
394	348	358	367	376	386	395	405	414	424	434
395	445	454	462	470	480	489	497	505	513	521
396	531	542	552	562	572	583	594	604	613	622
397	631	640	650	662	674	684	695	708	719	728
398	738	746	753	761	768	777	785	793	803	814
399	824	834	843	852	862	871	879	888	897	907
400	917	928	938	950	962	973	984	996	1010	1024
401	1037	1047	1057	1067	1077	1086	1095	1103	1110	1117
402	1123	1130	1136	1142	1148	1155	1162	1169	1176	1184
403	1192	1200	1207	1213	1220	1227	1236	1245	1253	1262
404	1271	1280	1289	1297	1305	1314	1322	1332	1344	1355
405	1365	1375	1384	1392	1401	1411	1420	1431	1441	1452
406	1463	1476	1487	1498	1508	1516	1524	1532	1541	1550
407	1560	1570	1581	1592	1602	1613	1623	1632	1640	1649
408	1658	1666	1675	1683	1692	1701	1710	1721	1732	1743
409	1752	1762	1771	1780	1791	1803	1815	1829	1842	1853
410	1864	1875	1885	1896	1907	1918	1929	1940	1951	1963
411	1974	1986	1998	2010	2022	2032	2044	2057	2070	2083
412	2095	2108	2121	2133	2145	2159	2171	2185	2199	2214
413	2227	2240	2254	2268	2283	2299	2313	2327	2343	2358
414	2372	2385	2397	2409	2420	2433	2445	2457	2467	2478
415	2488	2498	2508	2518	2529	2540	2551	2562	2574	2587
416	2602	2620	2635	2649	2662	2675	2688	2702	2714	2726
417	2738	2749	2761	2773	2785	2797	2810	2825	2840	2855
418	2871	2889	2909	2917	2924	2932	2940	2947	2955	2963
419	2971	2979	2986	2994	3002	3011	3019	3027	3035	3043
420	3052	3060	3068	3077	3085	3094	3103	3111	3120	3129
421	3138									



Bardwell Lake
June 1999
Prepared by: TWDB June 1999

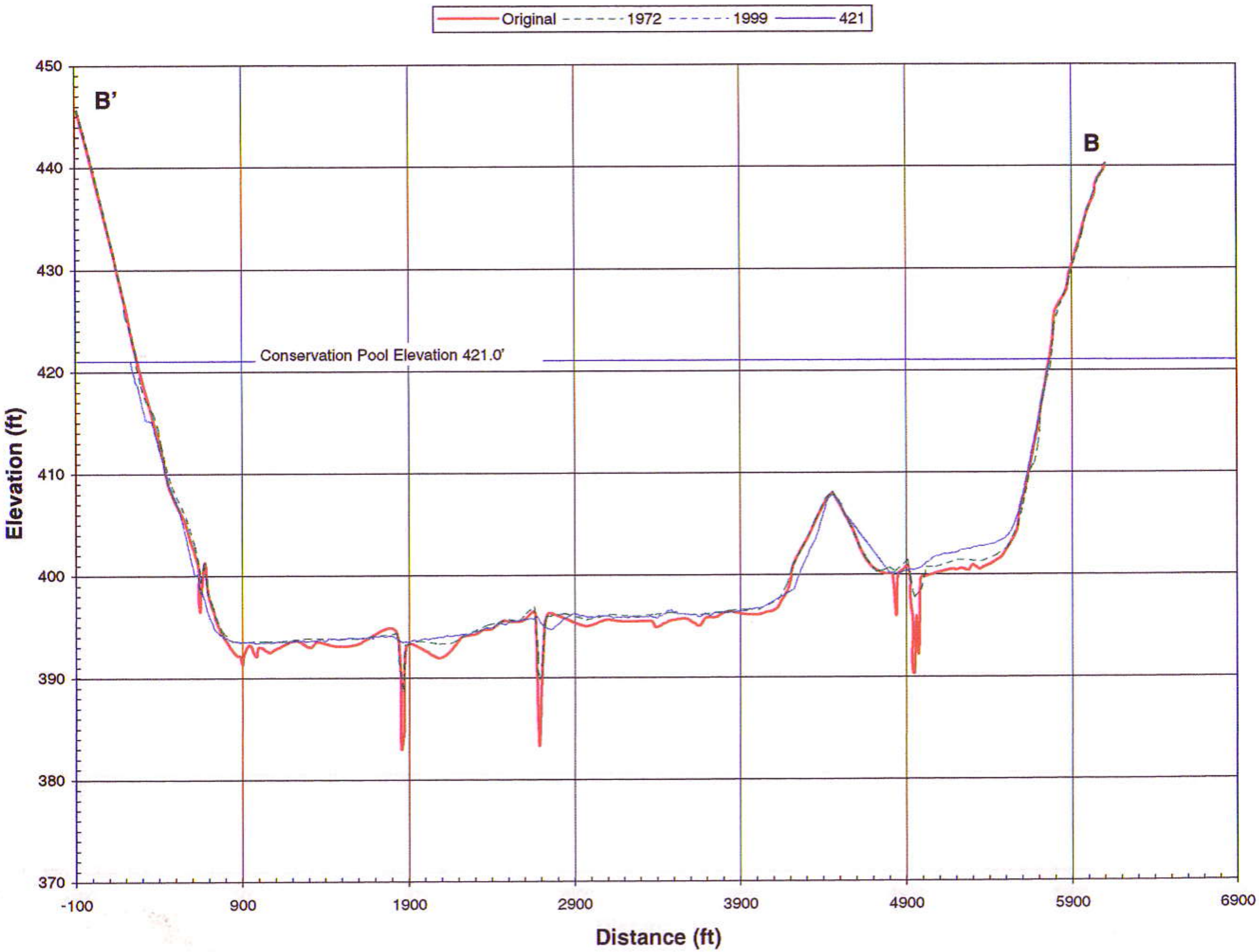
Appendix C

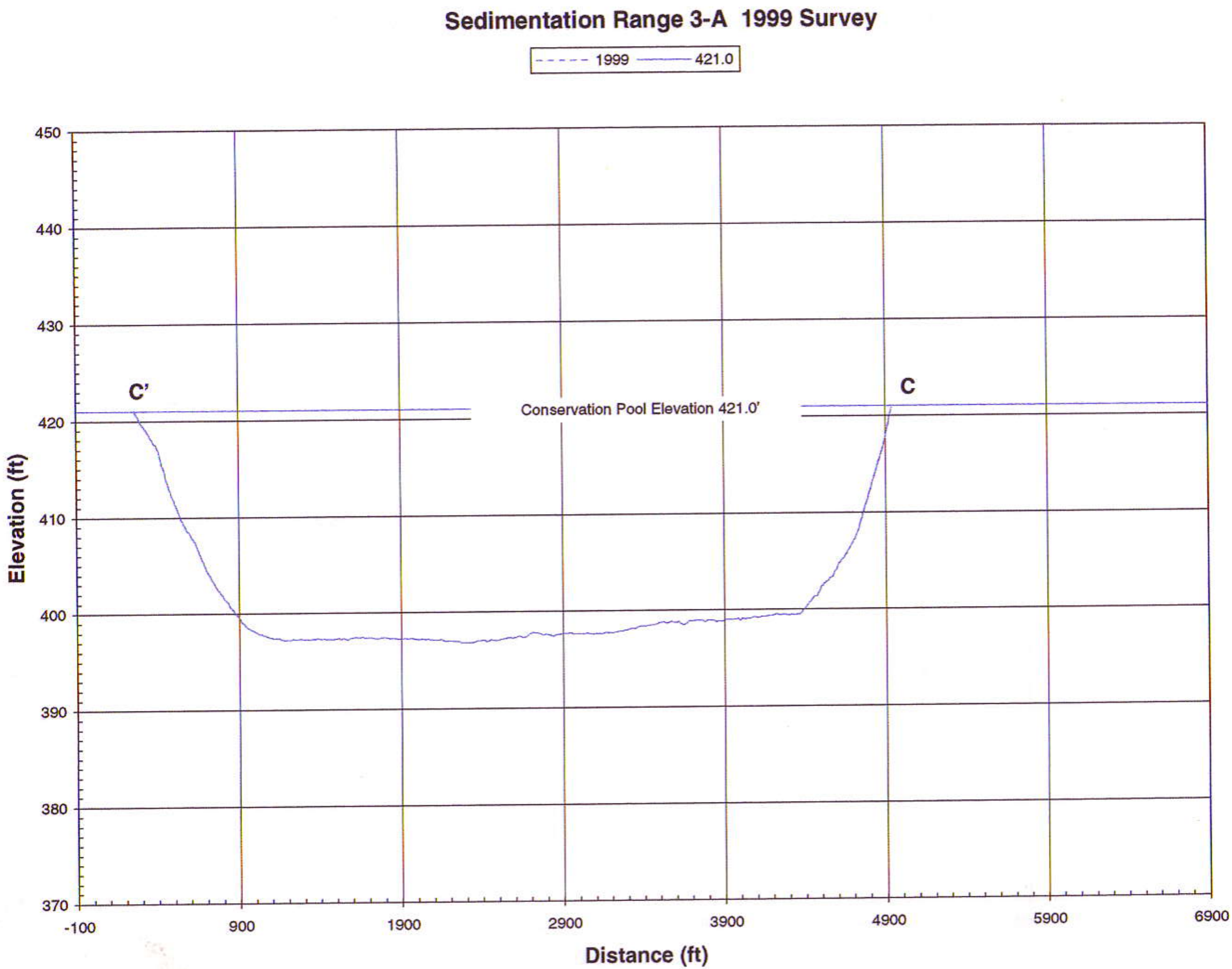
Sedimentation Range 1-A Original, 1972, and 1999 Surveys



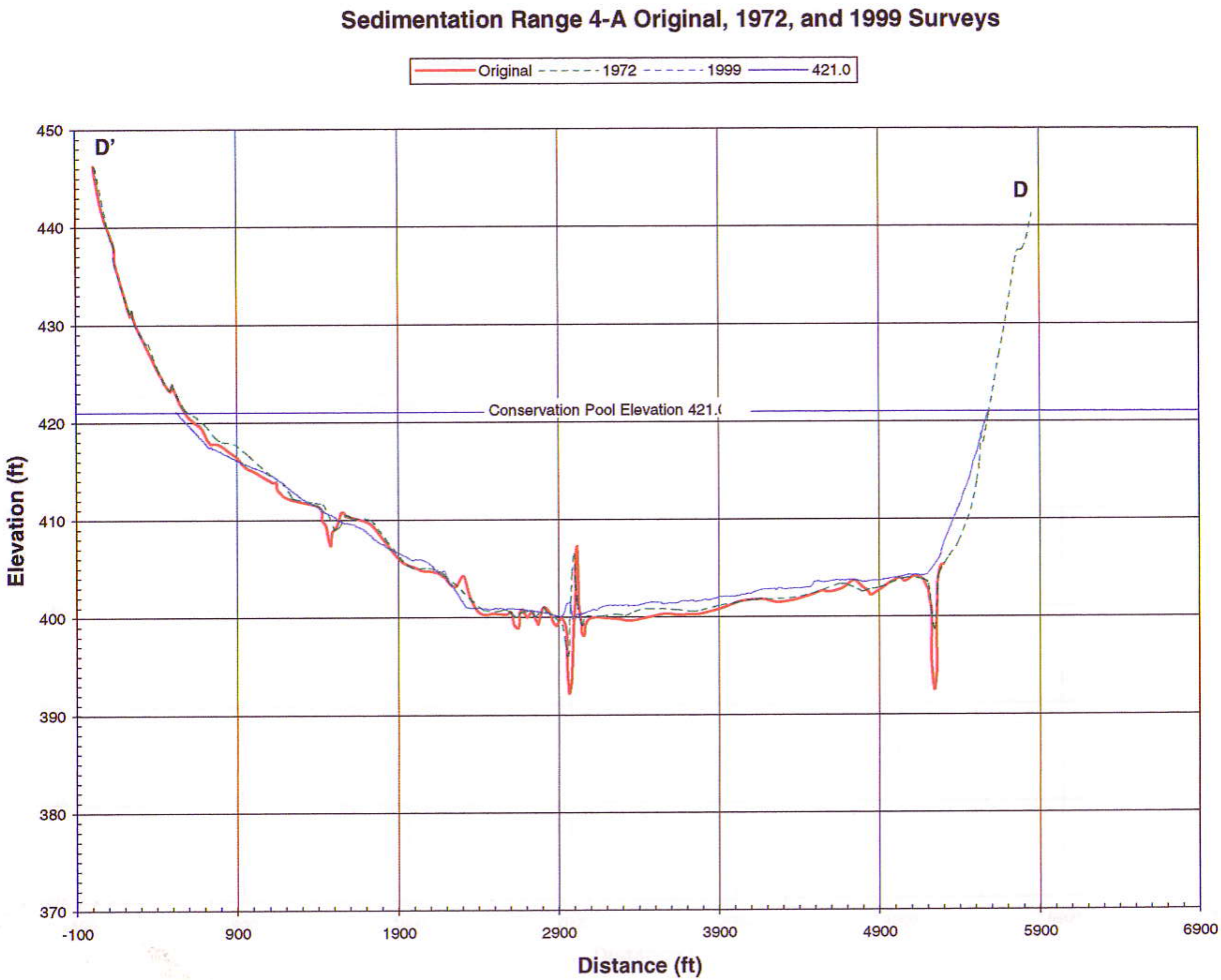
Appendix D

Sedimentation Range 2-A Original, 1972, and 1999 Surveys



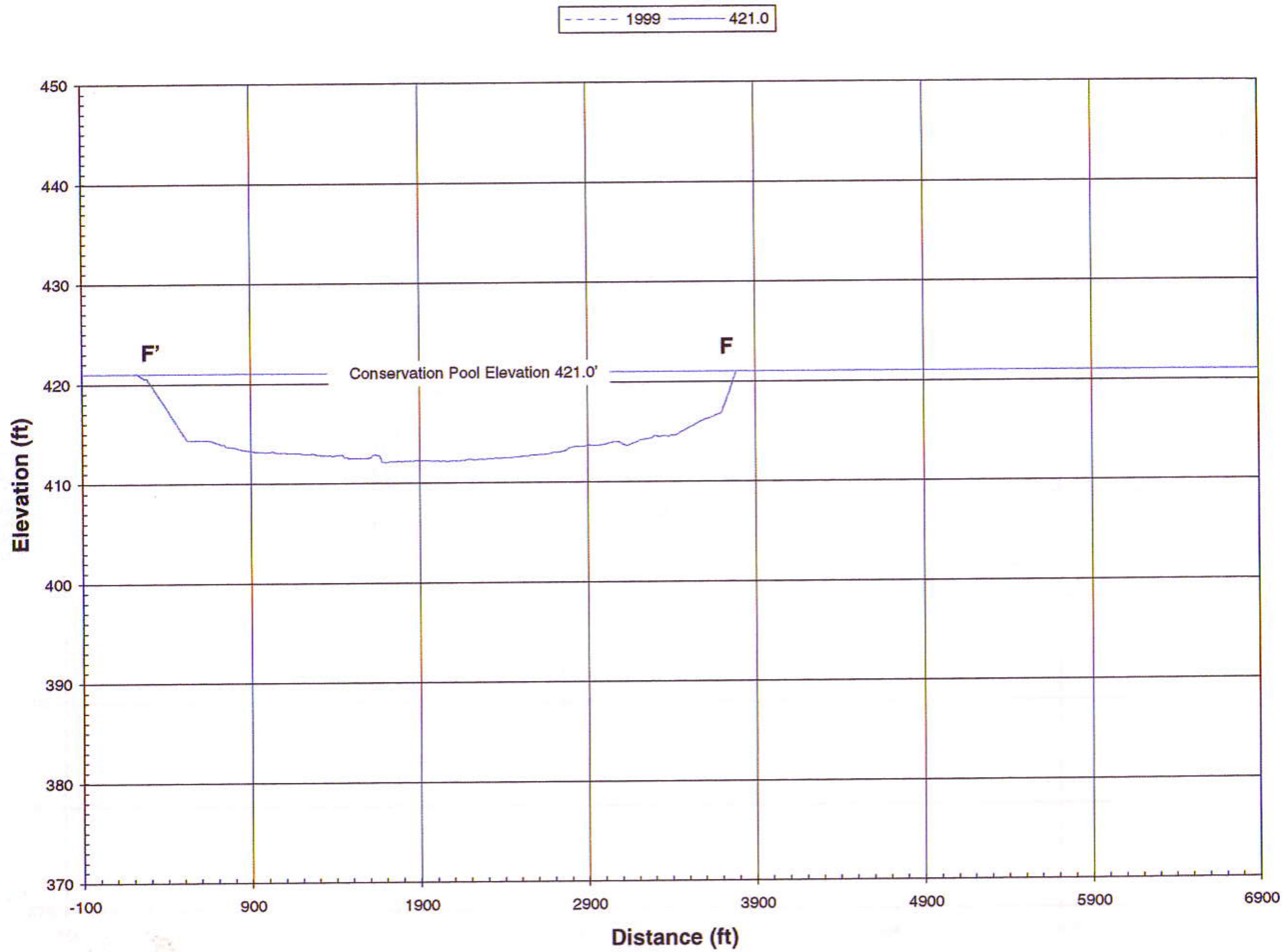

Sedimentation Range 3-A 1999 Survey
1999
421.0
C'
C
Conservation Pool Elevation 421.0'
Elevation (ft)
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
Distance (ft)

Appendix D


Sedimentation Range 4-A Original, 1972, and 1999 Surveys
Original
1972
1999
421.0
D'
D
Conservation Pool Elevation 421.0
Elevation (ft)
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
Distance (ft)

Appendix D

Sedimentation Range 6-A 1999 Survey



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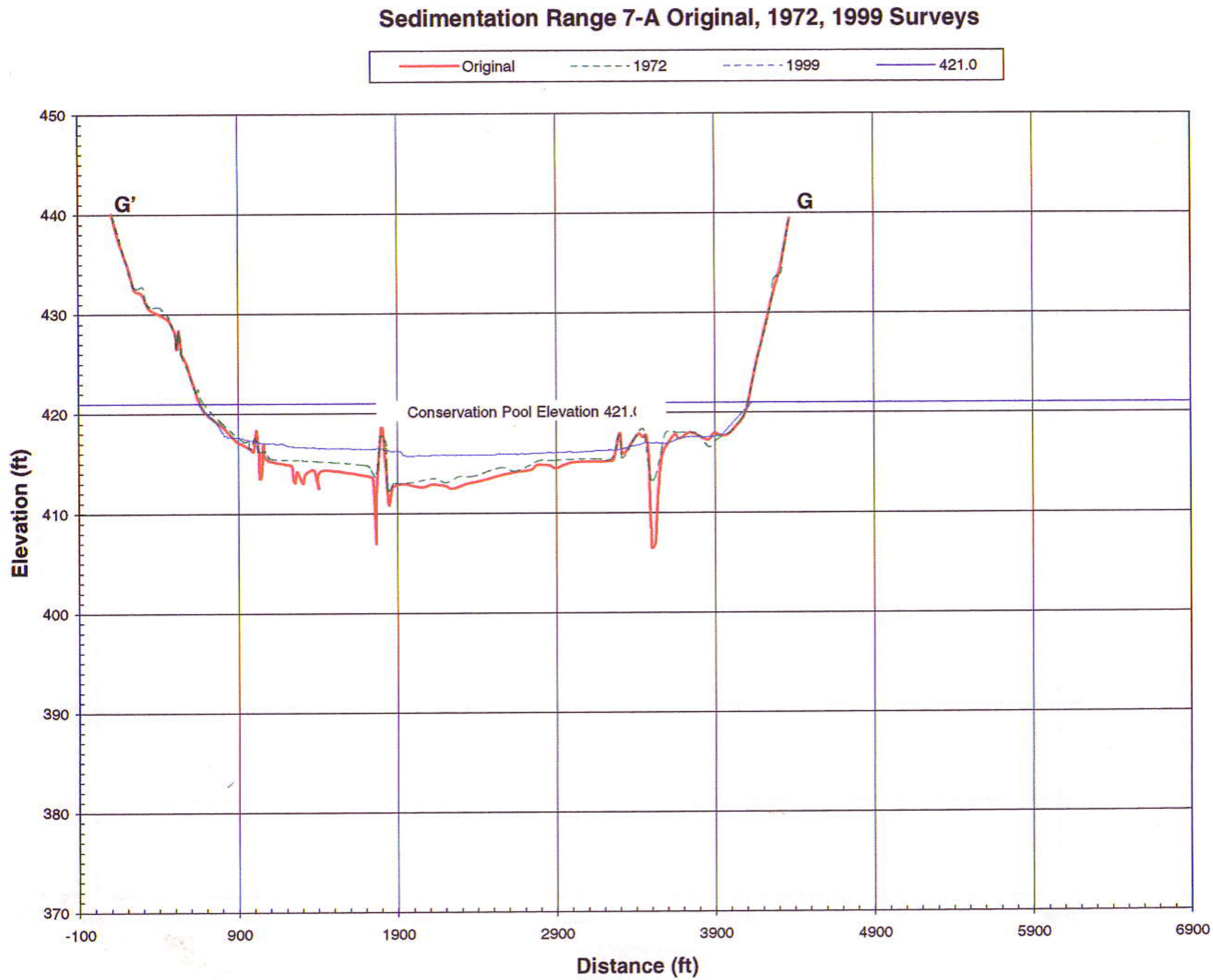
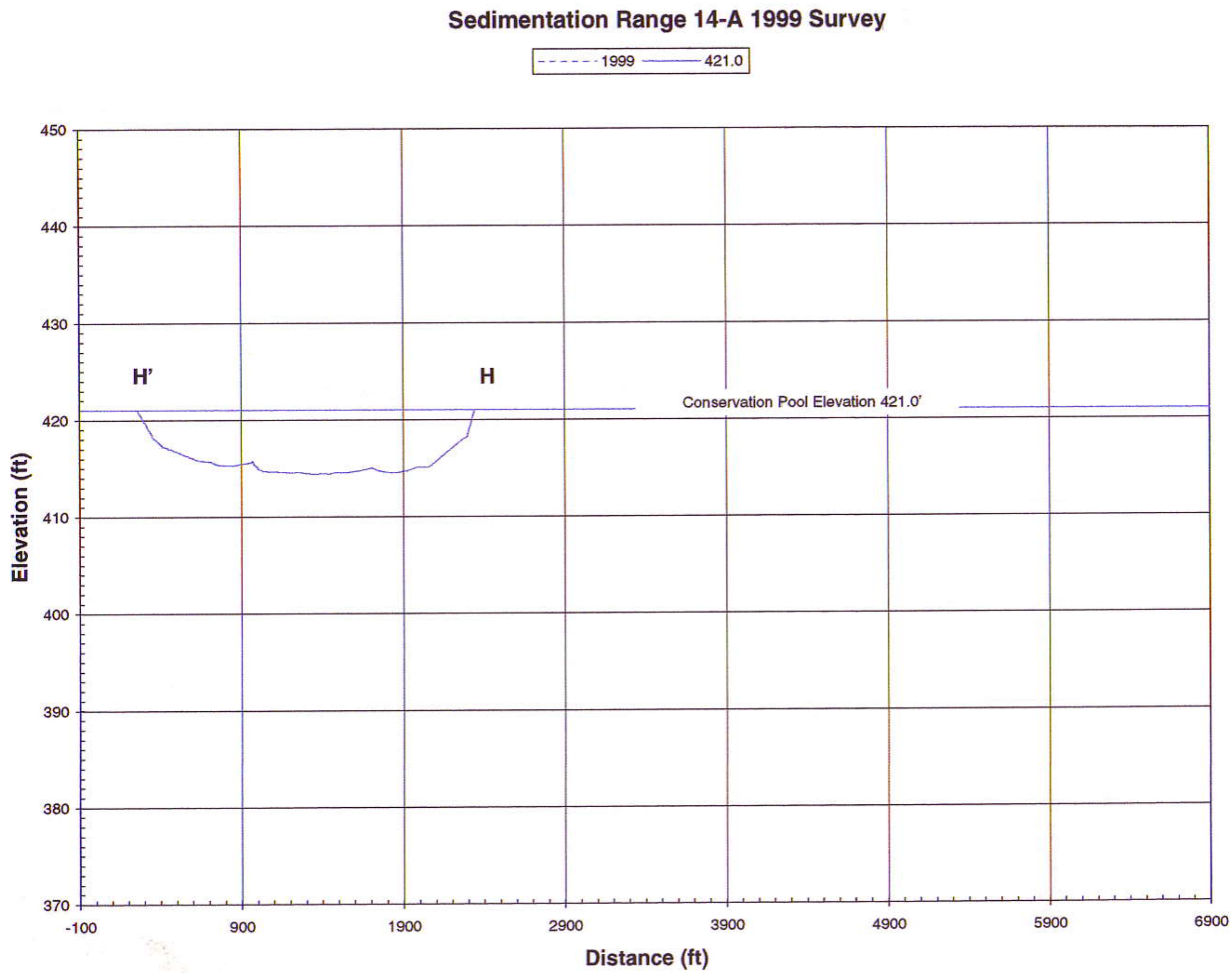


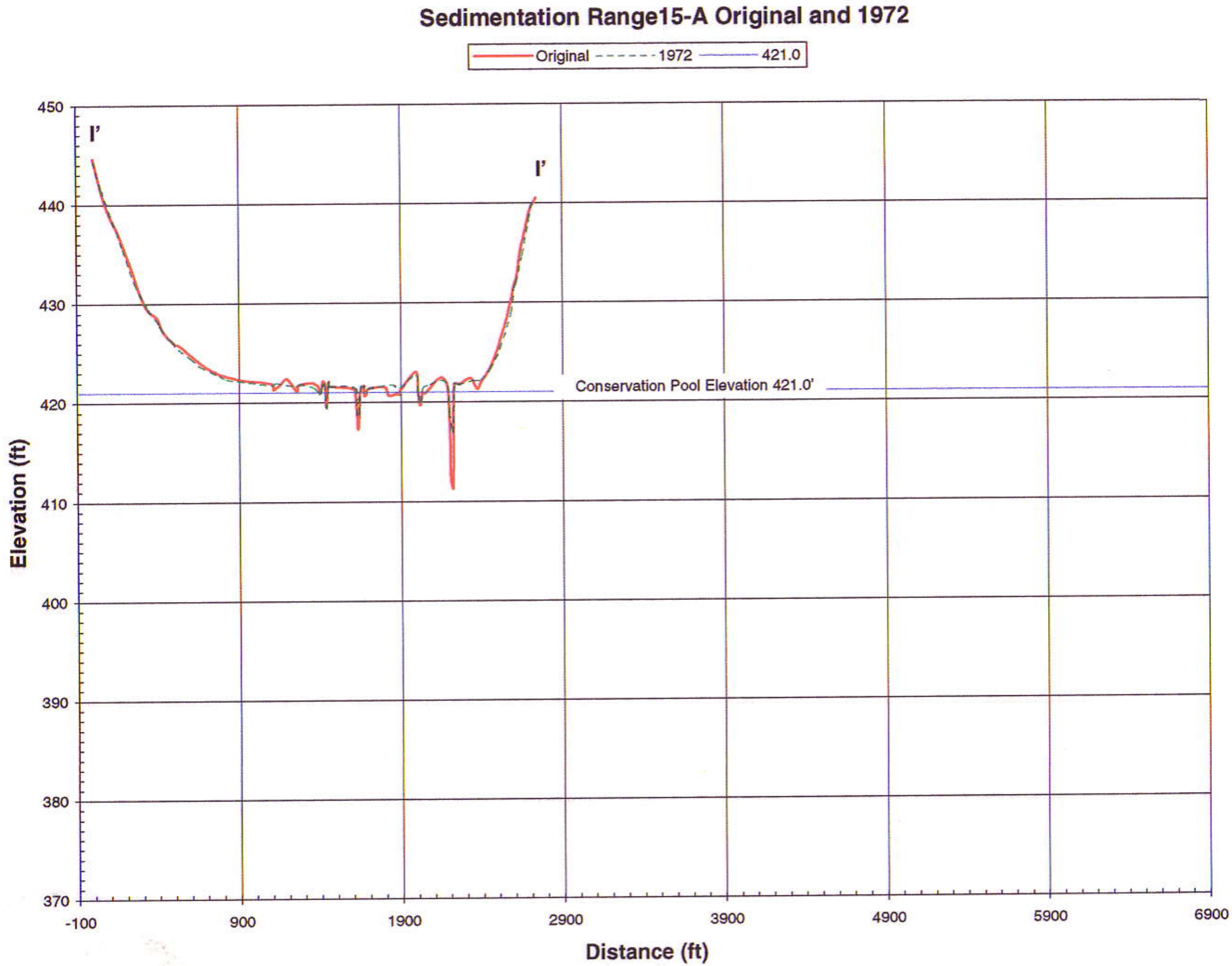
Sedimentation Range 7-A Original, 1972, 1999 Surveys
Original
1972
1999
421.0
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
G'
G
Conservation Pool Elevation 421.(
Elevation (ft)
Distance (ft)

Appendix D



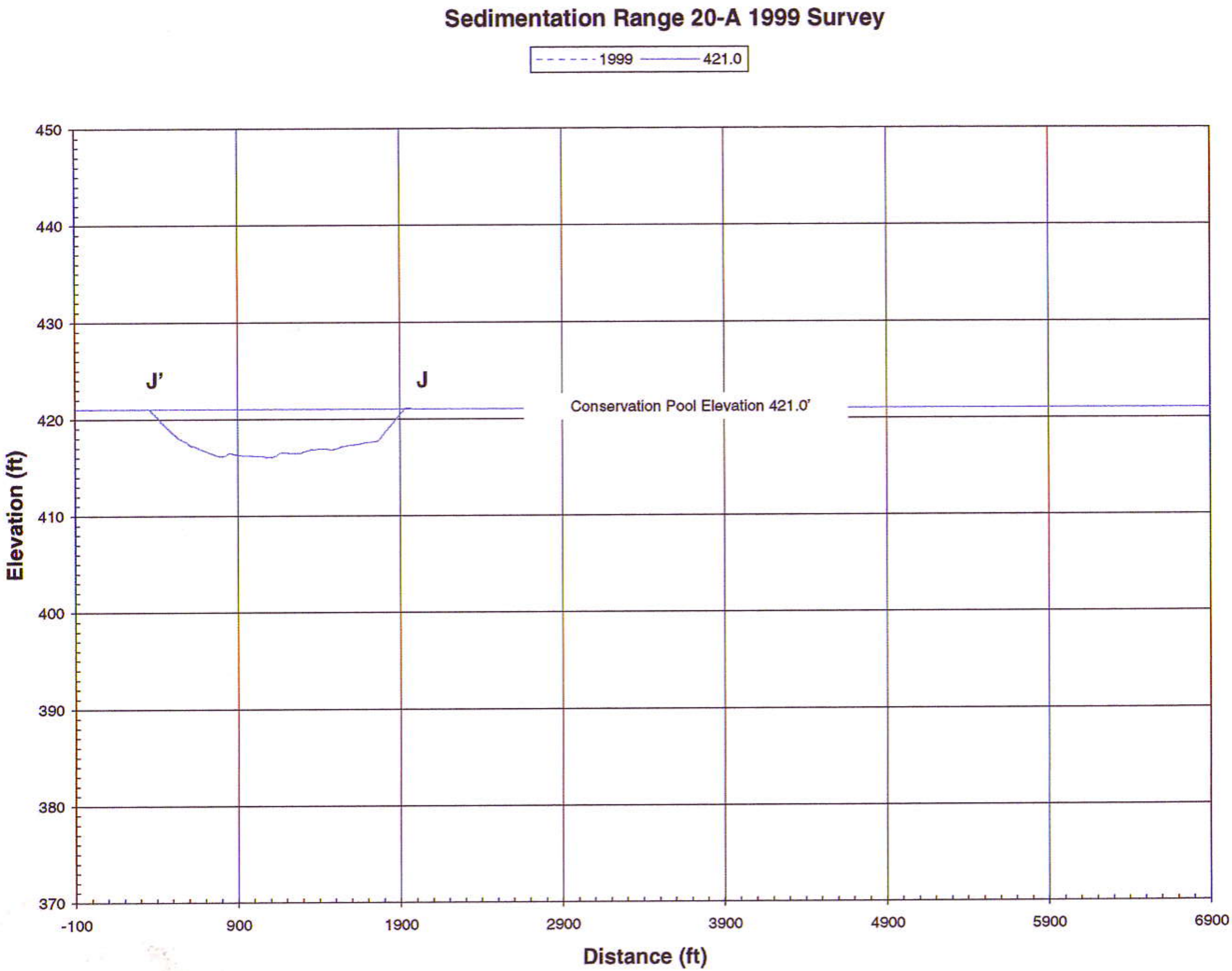
Sedimentation Range 14-A 1999 Survey
1999
421.0
H'
H
Conservation Pool Elevation 421.0'
Elevation (ft)
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
Distance (ft)

Appendix D

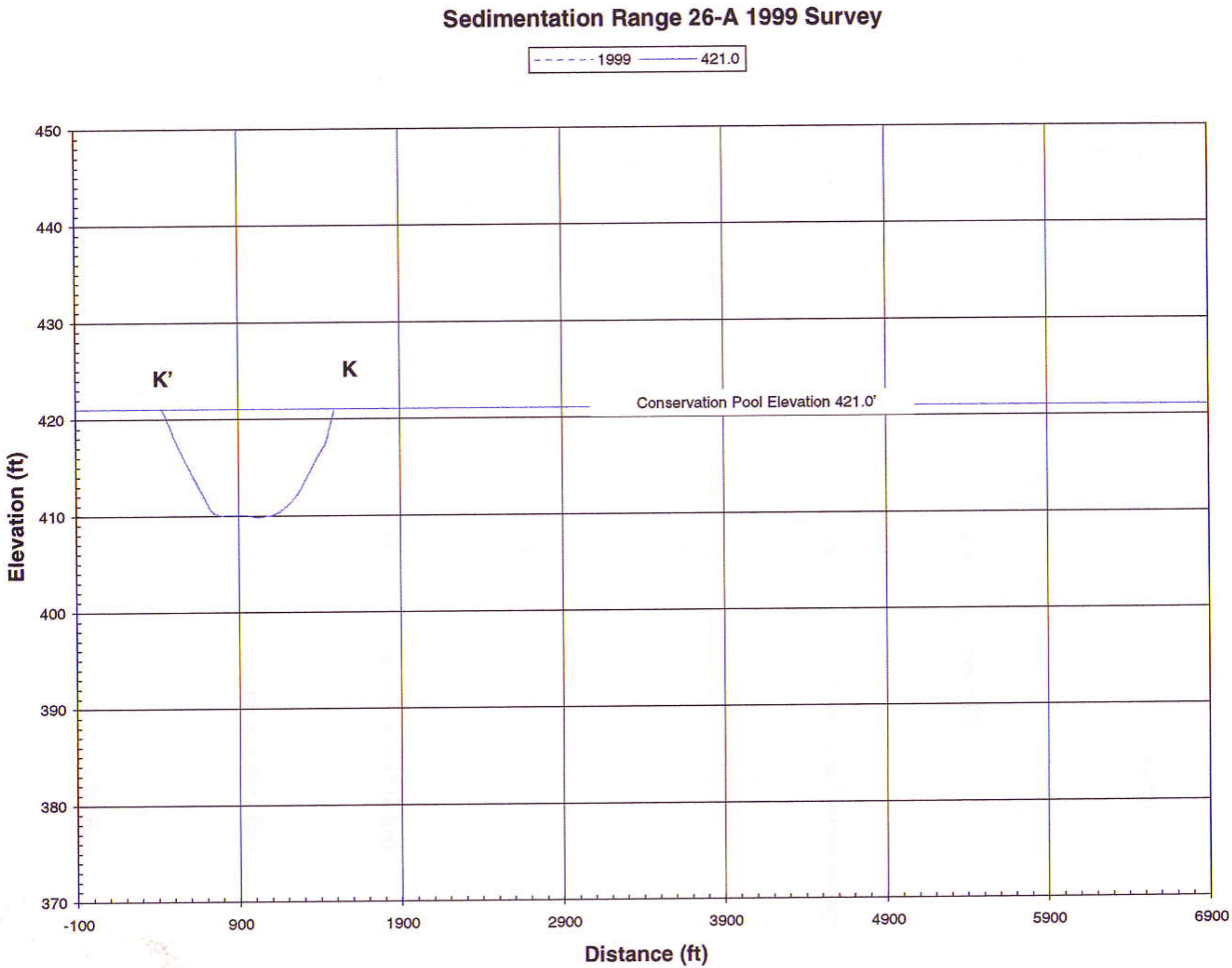


Sedimentation Range15-A Original and 1972
Original
1972
421.0
I'
I'
Conservation Pool Elevation 421.0'
Elevation (ft)
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
Distance (ft)

Appendix


Sedimentation Range 20-A 1999 Survey
1999
421.0
450
440
430
420
410
400
390
380
370
Elevation (ft)
J'
J
Conservation Pool Elevation 421.0'
-100
900
1900
2900
3900
4900
5900
6900
Distance (ft)

Appendix D



Sedimentation Range 26-A 1999 Survey
1999
421.0
K'
K
Conservation Pool Elevation 421.0'
Elevation (ft)
450
440
430
420
410
400
390
380
370
-100
900
1900
2900
3900
4900
5900
6900
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, 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 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

BARDWELL LAKE

Location Map

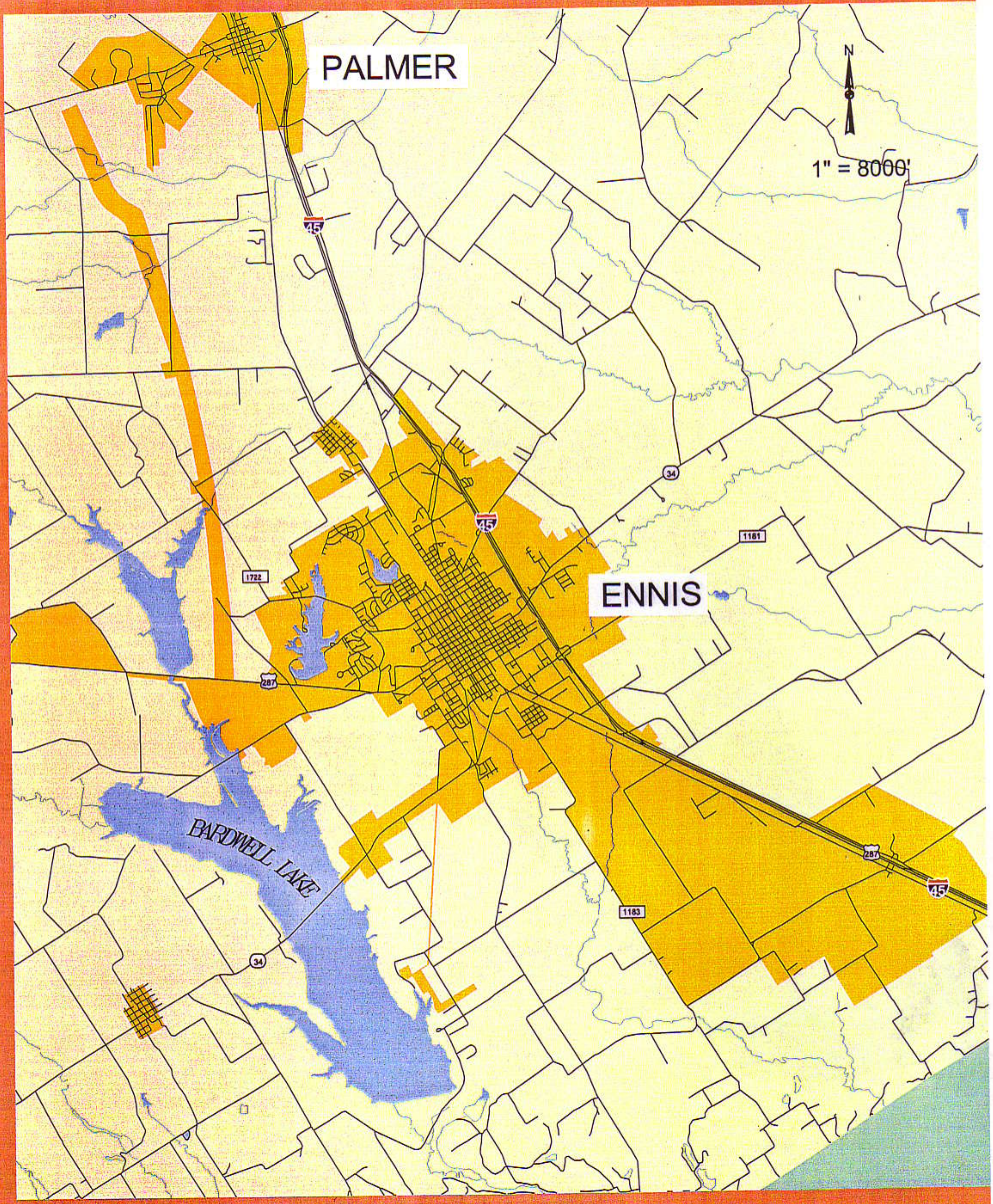


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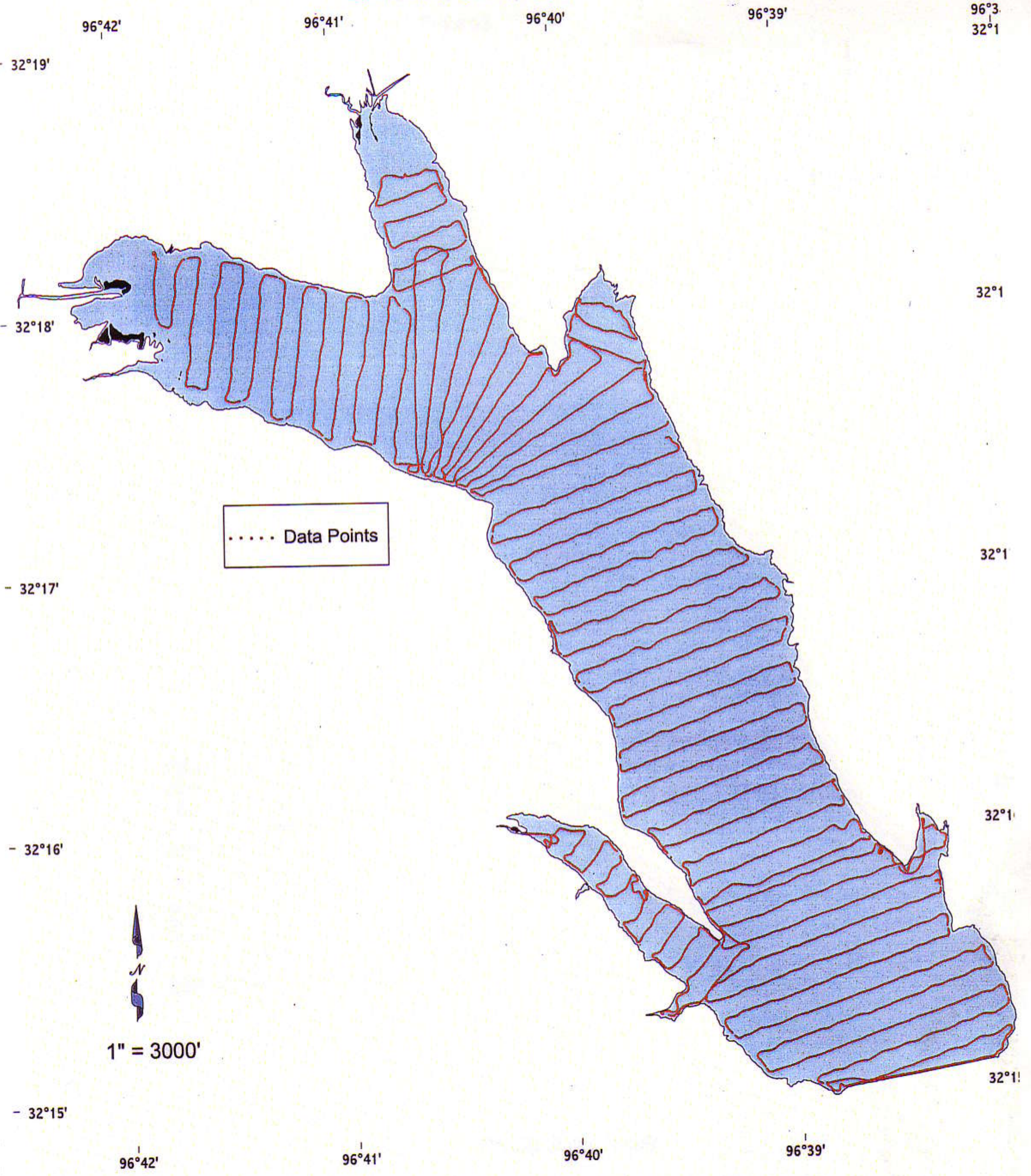
Figure2

BARDWELL LAKE

Location of Survey Data



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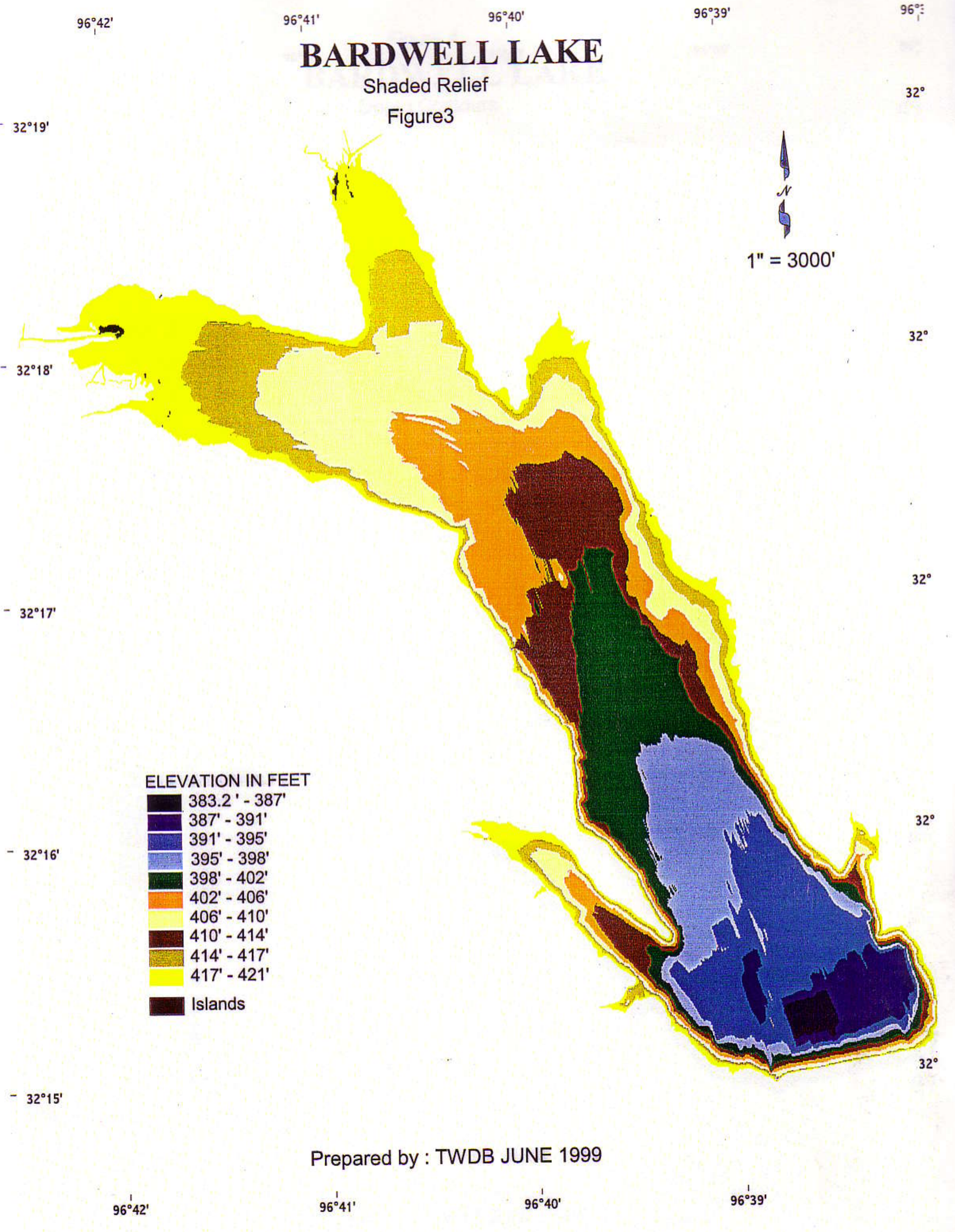
96°42'
96°41'
96°40'
96°39'
BARDWELL LAKE
Shaded Relief
Figure3
32°19'
32°18'
32°17'
32°16'
32°15'
N
1" = 3000'
ELEVATION IN FEET
383.2 ' - 387'
387' - 391'
391' - 395'
395' - 398'
398' - 402'
402' - 406'
406' - 410'
410' - 414'
414' - 417'
417' - 421'
Islands
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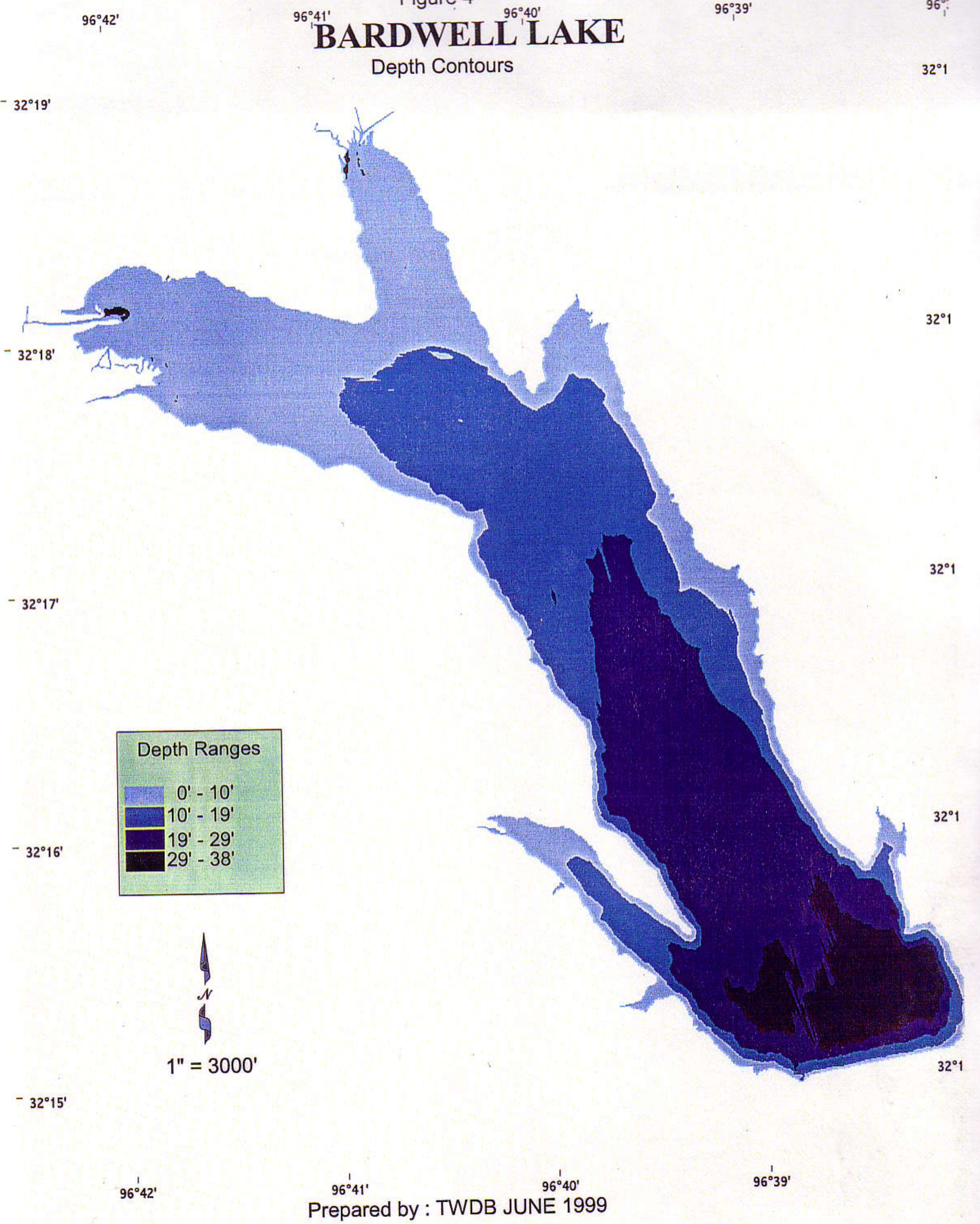
Figure 4

BARDWELL LAKE

Depth Contours



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