VOLUMETRIC SURVEY
OF
E. V. SPENCE RESERVOIR

Prepared for:

Colorado River Municipal Water District

Prepared by
Texas Water Development Board

October 27, 2000

Texas Water Development Board

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Published and Distributed
by the
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

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INTRODUCTION

Staff of the Surface Water Section of the Texas Water Development Board (TWDB) conducted a volumetric survey of E. V. Spence Reservoir during the periods of June 8, 15- 17 and June 28 – July 1, 1999. The purpose of the survey was to determine the current volume of the reservoir at 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 can be determined. Survey results are presented in the following pages in both graphical and tabular form. Elevations presented in this report are in feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29). The conservation pool elevation for E. V. Spence Reservoir is 1,898.0 feet. Original design information (TWDB, 1973) showed the surface area at this elevation to be 14,950 acres and the storage volume to be 488,760 acre-feet.

RESERVOIR HISTORY AND GENERAL INFORMATION

Historical information on E. V. Spence Reservoir was obtained from the Texas Water Development Board (1971) and the United States Geological Survey (1977). The Colorado River Municipal Water District, hereafter referred to as CRMWD, owns the water rights to E. V. Spence Reservoir. CRMWD also owns, operates and maintains associated Robert Lee Dam. The reservoir is located on the Colorado River (Colorado River Basin) in Coke County, two miles west of Robert Lee, Texas (Figure 1). The upstream drainage basin covers approximately 2,695 square miles. At conservation pool elevation, the reservoir has approximately 68 miles of shoreline and is 16 miles long. The widest point of the reservoir is approximately 2.8 miles and is located about 3.8 miles upstream of the dam.

Water Rights Permit No. 2179 (Application No. 2162A) was issued to CRMWD on September 1, 1965. The permit authorized the construction of a dam to impound 488,760 acre-feet of water at conservation pool elevation 1,898.0 feet. Permission was granted to use 40,000 acre-feet of water annually for municipal purposes, 8,000 acre-feet of water for mining and 2,000 acre-feet of water for industrial use. The Texas Water Commission issued Certificate of Adjudication No. 14-1008 on August 19, 1977. The certificate basically reconfirms the authority given by Permit No. 2179. It authorizes CRMWD to maintain an existing dam and reservoir on the Colorado River known as Robert Lee Dam and E. V. Spence Reservoir and to impound not to exceed 488,760 acre-feet of water.

Construction for E. V. Spence Reservoir and Robert Lee Dam started December 15, 1966. Deliberate impoundment began one year later and the project was completed November 21, 1969. The design engineer for the project was Freese, Nichols and Endress and the general contractor was Clement Bros. Company, Hickory, N.C. The estimated cost of the dam was $9,315,000.00.

Robert Lee Dam and appurtenant structures consist of an earthfill embankment approximately 21,500 feet in length, with a maximum height of 140 feet and a crest elevation of 1,928.0 feet. A service road occupies the 21-foot wide crest.

The service spillway consists of a concrete drop inlet "morning glory" type structure. The crest elevation of the 59-foot diameter opening is 1,878 feet. Control for the service spillway consists of twelve lift gates, each approximately 14.5 feet wide by 22 feet tall, that rest on the spillway crest. The top of the gates is at elevation 1,900.0 feet. All discharges flow through a 28-foot diameter conduit and exit downstream of the dam. The outlet works consist of a five-foot diameter concrete pipe with an invert elevation of 1,790.0 feet. The control for the outlet is one 5-foot gated pipe and two 2-foot gated pipes to the service spillway. The emergency spillway is an excavated channel cut through natural ground. This spillway is 3,200 feet in length with a crest elevation of 1,908.0 feet.

Original design information (TWDB, 1971) estimated the surface area at conservation pool elevation 1,898.0 feet to be 14,950 acres and the storage volume to be 448,760 acre-feet of water. This report compares the 1999 survey results to those of the original design.

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 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. In shallow areas and where navigational hazards (stumps) were present, a 17-foot aluminum shallow-draft flat bottom MonArk craft equipped with a 15-horsepower Evinrude outboard motor was used. The portable data collection equipment on-board the boat included a Knudsen 320 B/P Echosounder (depth sounder), a Trimble Navigation, Inc. 4000SE GPS receiver, an OmniSTAR receiver, and a 486 laptop computer.

The GPS equipment, survey vessel, and depth sounder in combination provide an efficient hydrographic survey system. During the data collection phase, the depth sounder takes approximately ten bottom readings 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, 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 reservoir elevation recorded on the day the survey was performed. Accurate estimates of the reservoir 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 reservoir volumes, some of which are discussed in Appendix F.

PRE-SURVEY PROCEDURES

The waters edge boundary at lower elevations and the reservoir's boundary at conservation pool elevation were digitized using Arc/View software. The water's edge boundary file was created from a recently produced digital orthophoto quadrangle (DOQ) image for EDITH NW, Texas. (The DOQ was 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 this DOQ was originally in UTM Zone 14, and was subsequently converted to NAD '83. The photographs used in producing the DOQ were taken on February 5, 1996. The average lake elevation at the time the photographs were taken, obtained from the U.S. Army Corps of Engineers, was 1864.7 feet. The reservoir boundary at conservation pool elevation was obtained from four USGS topographic maps: Green Mountain (1962), Edith (1962), Millican (1962), and Silver (1987). The boundary obtained from these maps was converted from state-plane NAD'27 to NAD'83. This boundary was used to determine the outer lake boundary for subsequent use in calculating the lake's area and volume.

The survey layout was designed by placing survey track lines at 500-foot intervals within the digitized water's edge boundary using HyPack software. The survey design required the use of approximately 170 survey lines along the length of the reservoir.

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 reservoir bottom, and then raised to the surface. During this lowering and raising procedure, local speed-of-sound measurements were collected and used to compute the average speed by the velocity profiler. This average speed of sound was entered into the ITI449 depth sounder, which then provided the depth of the reservoir bottom. The depth was then checked manually with a measuring tape to ensure that the depth sounder was properly calibrated and operating correctly.

On the shallow draft boat the depth sounder was calibrated using the bar check feature in the Knudsen software program. This was accomplished by positioning the transducer over a known (measured) depth. The speed of sound was then adjusted (either higher or lower) until the displayed depths matched the known depth. The depth was then checked manually with a stadia (survey) rod to ensure that the depth sounder was properly calibrated and operating correctly.

While collecting data at E. V. Spence Reservoir, the speed of sound in the water column varied from 4,927 to 4,932 feet per second. Based on the measured speed of sound for various depths and the average speed of sound calculated for the entire water column, the depth sounder is accurate to within ±0.2 feet. An additional estimated error of ±0.3 feet arises from variation in boat inclination. These two factors combine to give an overall accuracy of ±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 reservoir'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

Due to low water levels, data collection for E. V. Spence Reservoir was divided into two surveys. TWDB collected survey data over the inundated or wet portion of the reservoir, while S&K Engineering of San Angelo, Texas collected land-based data over the portion of the reservoir between the water's edge (approximately elevation 1845 feet) to just above the emergency spillway elevation (approximately 1910 feet). TWDB staff collected data at E. V. Spence Reservoir during the period of June 8, 15-17, and June 28 – July 1, 1999, and S&K Engineering staff collected data from May to

September, 1999. Data provided by S&K Engineering were in NAVD'88, and were converted to NGVD '29 by TWDB prior to combining both data sets for later analysis.

Conditions during the TWDB data-collection phase consisted of high temperatures and mild winds. During the second week of data collection, heavy rains fell over the reservoir's watershed, raising the water level approximately three feet. Data collection was suspended until the reservoir’s water level again became stable.

The survey crew was able to collect data for approximately 130 of the 170 pre-plotted survey transects in the reservoir. Random data was collected along the shoreline and in those areas that were too restricted to drive the pre-plotted lines. A smaller boat with portable GPS and depth sounder equipment was used in the areas of the main reservoir that could not be maneuvered by the larger boat. This boat was also used to collect data upstream of CRMWD’s intake structure. Over 211,000 data points were collected in the approximately 100 boat-miles traveled. These points, shown in Figure 2, were stored digitally on the boat's computer in 235 data files. Data were not collected in areas with significant obstructions unless these areas represented a large amount of water.

The Colorado River flows in a northwest to southeast direction with Robert Lee Dam being located at the southeast end of the reservoir basin. TWDB staff observed the land surrounding the reservoir to be generally flat with some rolling hills. There were outcrops of major relief with steep walls and valleys observed in the reaches of Wildcat, Paint, and Salt Creeks. There was minimal residential development around the perimeter of the reservoir. CRMWD established and maintains four parks surrounding the reservoir.

While performing the survey the field crew noted on the depth sounder chart that the bathymetry or contour of the reservoir bottom was irregular in the main basin of the reservoir. Deeper measurements were recorded in the southern portion of the main reservoir between the dam and the confluence of Wildcat Creek. There was a defined channel (thalweg) of the Colorado River in the main basin of the reservoir. Only limited areas of shoreline erosion were seen along the perimeter of the reservoir. A major flat area was observed in the main basin between Wildcat Creek and Paint Creek on the south portion of the reservoir basin. As noted on the analog chart the old river channel had meandered to the north bank of the reservoir in this area. The river channel meanders from bank to bank throughout the main basin of the reservoir. The crew was able to run parallel cross-sections in the main reservoir to just upstream of CRMWD's intake structure. The crew also collected extra data around the structure.

Navigational hazards such as submerged vegetation were encountered upstream of Rough Creek. These hazards interfered with the propeller and restricted data collection. The reservoir in this area had more riverine characteristics with closer or narrower cut and fill shorelines.

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 survey data was 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 reservoir elevation at the time of data collection was also applied to each file during the EDIT routine. During the survey, the water surface varied from elevation 1,845.27 to 1,848.53 feet according to elevation data provided by CRMWD. After all corrections were applied 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 reservoir'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) 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 surface areas, presented in Appendices A and B, respectively, were calculated from the TIN using Arc/Info software. Results are shown in one-tenth of a foot interval from elevation 1792.3 to elevation 1910.0. 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 five-foot intervals is presented in Figure 5. Finally, cross-sections obtained from the current survey are presented in Appendix D.

RESULTS

Results from the 1999 TWDB survey indicate E. V. Spence Reservoir encompasses 14,640 surface acres and contains a total volume of 512,272 acre-feet at the conservation pool elevation of 1898.0 feet. The shoreline at this elevation was calculated to be approximately 68 miles. The deepest point of the reservoir, at elevation 1792.3 feet and corresponding to a depth of 105.7 feet, was located near the north shore approximately 3035 feet west of the dam in the old riverbed.

SUMMARY AND COMPARISONS

E. V. Spence Reservoir was initially impounded in 1968. Storage calculations based on 1962 data reported the volume at conservation pool elevation 1,898.0 feet to be 488,760 acre-feet with a surface area of 14,950 acres.

During June 8, 15-17, 28-30, and July 1, 1999, staff from the Texas Water Development Board's Surface Water Section completed a water-based volumetric survey of E. V. Spence Reservoir. From May to September 1998, S&K Engineering of San Angelo, Texas collected land-based survey data from the water's edge to the emergency spillway elevation. Both resulting data sets were combined and analyzed by TWDB staff to generate volume and area data for E.V. Spence Reservoir. The 1999 surveys 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 reservoir's volume at the conservation pool elevation of 1,898.0 feet is 517,272 acre-feet, with a corresponding area of 14,640 acres.

Comparing the findings from the original (1962) survey and the current survey, the estimated reduction in area at conservation pool elevation is 310 surface acres, although at elevations below approximately 1890 feet, there is an increase in area. The reservoir volume at conservation pool elevation found in the current survey is larger than in the original survey by 28,512 acre-feet (+5.8%). The volume increase, compared to data from the original survey (TWDB, 1971), occurs through the entire range of elevations. 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 reservoir's storage volume.

REFERENCES

Texas Water Development Board. 1971. Engineering data on dams and reservoirs in Texas. Part III. Report 126.

United States Geological Survey. 1997. Water Resources Data Texas. Volume 3.

Appendix A

Lake E.V. Spence

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD July 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
1792				0	0	0	0	0	0	0
1793	0	0	0	0	0	0	0	0	0	0
1794	0	0	0	0	0	0	0	0	0	0
1795	0	0	0	0	0	0	0	0	0	0
1796	0	0	0	1	1	1	1	1	2	2
1797	2	2	3	3	4	4	5	5	6	6
1798	7	8	8	9	10	11	12	13	14	15
1799	16	17	18	20	21	23	24	26	28	30
1800	31	33	35	38	40	42	44	47	49	52
1801	55	57	60	63	66	69	72	75	79	82
1802	86	89	93	96	100	104	108	112	117	121
1803	125	130	135	139	144	149	155	160	166	171
1804	177	183	189	196	202	209	216	224	231	239
1805	246	254	263	271	280	289	298	307	317	327
1806	337	347	357	368	379	390	402	413	425	437
1807	450	462	475	488	502	515	529	543	558	573
1808	588	603	619	635	651	668	685	702	720	738
1809	757	775	794	814	834	854	875	896	917	940
1810	962	985	1009	1033	1058	1083	1109	1135	1162	1189
1811	1217	1245	1274	1304	1334	1364	1396	1428	1460	1493
1812	1527	1561	1596	1632	1668	1704	1741	1779	1818	1856
1813	1896	1936	1976	2017	2059	2101	2144	2187	2230	2275
1814	2319	2365	2411	2457	2504	2552	2601	2650	2700	2750
1815	2801	2853	2906	2959	3013	3068	3123	3179	3235	3292
1816	3350	3409	3468	3528	3589	3650	3712	3775	3838	3902
1817	3966	4031	4097	4164	4231	4299	4367	4436	4506	4576
1818	4647	4719	4791	4864	4938	5012	5088	5163	5240	5318
1819	5396	5475	5555	5635	5717	5799	5882	5965	6050	6135
1820	6221	6308	6396	6484	6574	6664	6755	6846	6939	7032
1821	7126	7220	7316	7412	7508	7606	7704	7803	7902	8003
1822	8104	8206	8308	8412	8516	8621	8727	8834	8942	9050
1823	9160	9270	9381	9492	9605	9718	9832	9947	10062	10179
1824	10296	10414	10532	10652	10772	10893	11015	11137	11261	11385
1825	11510	11636	11763	11890	12018	12147	12277	12408	12539	12671
1826	12804	12938	13072	13208	13344	13482	13620	13758	13898	14039
1827	14181	14323	14466	14611	14756	14902	15049	15197	15346	15495
1828	15646	15797	15950	16104	16258	16414	16570	16728	16887	17046
1829	17206	17368	17530	17693	17857	18021	18187	18353	18521	18689
1830	18858	19028	19200	19372	19545	19720	19895	20072	20250	20429
1831	20609	20789	20971	21155	21339	21524	21711	21898	22087	22277
1832	22467	22659	22852	23046	23241	23436	23633	23831	24030	24230
1833	24430	24633	24836	25040	25246	25452	25660	25869	26079	26291
1834	26503	26717	26932	27148	27366	27585	27805	28027	28250	28475
1835	28701	28928	29156	29386	29618	29850	30084	30320	30557	30795
1836	31034	31275	31517	31760	32004	32250	32497	32745	32995	33245
1837	33497	33751	34006	34262	34520	34779	35039	35301	35565	35829
1838	36095	36362	36631	36901	37172	37445	37720	37995	38273	38552
1839	38832	39114	39397	39683	39969	40258	40548	40839	41133	41427
1840	41722	42019	42317	42616	42916	43218	43521	43824	44130	44436
1841	44744	45053	45363	45674	45987	46300	46615	46931	47249	47568
1842	47888	48210	48533	48857	49183	49510	49839	50169	50500	50833
1843	51167	51502	51839	52177	52517	52858	53200	53545	53891	54238
1844	54587	54937	55290	55644	56000	56357	56717	57078	57441	57806
1845	58173	58544	58920	59297	59676	60055	60436	60818	61201	61586
1846	61971	62357	62744	63133	63522	63912	64303	64695	65088	65482
1847	65877	66272	66669	67067	67465	67864	68265	68666	69069	69473
1848	69878	70285	70696	71110	71530	71953	72379	72807	73237	73669
1849	74101	74535	74970	75407	75845	76283	76723	77164	77607	78051
1850	78495	78941	79387	79836	80285	80735	81186	81638	82092	82546

Appendix A (continued)

Lake E.V. Spence

RESERVOIR VOLUME TABLE

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
1851	83002	83459	83916	84376	84836	85297	85759	86222	86687	87153
1852	87619	88087	88556	89027	89498	89970	90444	90918	91395	91872
1853	92350	92830	93310	93793	94276	94760	95246	95733	96222	96711
1854	97202	97694	98187	98683	99179	99677	100177	100678	101181	101685
1855	102191	102699	103208	103720	104233	104747	105264	105782	106304	106826
1856	107351	107878	108407	108939	109472	110007	110545	111085	111627	112171
1857	112718	113267	113817	114371	114925	115482	116040	116600	117162	117726
1858	118291	118859	119428	120000	120573	121149	121727	122306	122888	123472
1859	124057	124644	125232	125824	126416	127010	127606	128204	128804	129406
1860	130009	130616	131225	131837	132450	133064	133681	134299	134920	135542
1861	136166	136792	137420	138050	138682	139316	139952	140590	141232	141874
1862	142519	143167	143816	144468	145122	145777	146435	147095	147758	148422
1863	149089	149758	150430	151104	151780	152458	153139	153822	154509	155197
1864	155888	156583	157280	157981	158684	159389	160097	160806	161519	162233
1865	162949	163667	164386	165108	165831	166556	167283	168011	168741	169473
1866	170206	170941	171677	172416	173155	173897	174639	175384	176130	176878
1867	177627	178377	179129	179883	180638	181394	182151	182910	183671	184433
1868	185196	185961	186727	187496	188265	189035	189807	190582	191359	192137
1869	192918	193701	194489	195280	196075	196874	197678	198486	199299	200115
1870	200935	201759	202586	203418	204253	205091	205932	206776	207625	208474
1871	209326	210180	211036	211895	212756	213618	214483	215350	216220	217092
1872	217965	218841	219719	220600	221483	222368	223255	224145	225037	225931
1873	226826	227724	228623	229526	230429	231335	232242	233152	234064	234978
1874	235893	236810	237730	238652	239575	240501	241428	242358	243290	244224
1875	245159	246097	247036	247979	248922	249868	250815	251765	252717	253671
1876	254626	255584	256544	257506	258470	259436	260404	261374	262347	263320
1877	264296	265274	266254	267236	268220	269206	270194	271184	272177	273172
1878	274168	275166	276167	277170	278174	279181	280189	281200	282213	283228
1879	284244	285262	286283	287306	288330	289357	290385	291416	292450	293484
1880	294521	295560	296601	297646	298692	299739	300789	301841	302896	303951
1881	305009	306069	307131	308197	309263	310332	311403	312476	313552	314629
1882	315709	316790	317874	318961	320050	321140	322233	323328	324426	325526
1883	326627	327731	328837	329947	331057	332170	333285	334402	335522	336644
1884	337768	338894	340023	341155	342288	343423	344561	345701	346845	347990
1885	349137	350287	351439	352594	353751	354910	356071	357235	358402	359569
1886	360739	361911	363086	364263	365442	366623	367805	368990	370179	371368
1887	372559	373752	374948	376147	377346	378548	379752	380958	382167	383377
1888	384589	385803	387019	388239	389459	390682	391906	393132	394362	395592
1889	396825	398059	399295	400535	401776	403019	404263	405510	406760	408011
1890	409264	410519	411776	413037	414298	415562	416827	418095	419367	420639
1891	421913	423190	424468	425751	427034	428320	429607	430897	432191	433485
1892	434781	436080	437381	438686	439992	441300	442611	443924	445241	446559
1893	447879	449202	450527	451856	453186	454518	455853	457190	458532	459874
1894	461219	462566	463916	465269	466624	467982	469342	470704	472071	473439
1895	474809	476182	477557	478937	480318	481702	483088	484478	485871	487266
1896	488663	490064	491467	492875	494284	495696	497111	498529	499951	501375
1897	502803	504233	505667	507107	508548	509993	511441	512893	514351	515810
1898	517272	518737	520206	521679	523154	524632	526114	527600	529093	530593
1899	532102	533625	535165	536725	538303	539894	541494	543101	544714	546330
1900	547948	549570	551196	552826	554458	556093	557730	559370	561014	562660
1901	564308	565958	567612	569270	570928	572589	574253	575919	577590	579261
1902	580935	582612	584291	585974	587658	589345	591034	592726	594422	596119
1903	597818	599520	601225	602933	604643	606355	608069	609786	611507	613229
1904	614954	616680	618410	620144	621878	623615	625354	627096	628842	630589
1905	632338	634090	635844	637603	639362	641123	642887	644654	646425	648196
1906	649970	651746	653525	655308	657092	658878	660667	662458	664253	666049
1907	667848	669648	671451	673259	675067	676878	678691	680506	682326	684146
1908	685969	687794	689621	691453	693285	695120	696957	698796	700640	702485
1909	704331	706180	708032	709888	711744	713603	715464	717328	719196	721064
1910	722936									

Appendix B

Lake E.V. Spence

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD July 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
1792				0	0	0	0	0	0	0
1793	0	0	0	0	0	0	0	0	0	0
1794	0	0	0	0	0	0	0	0	0	0
1795	0	0	0	0	0	0	0	0	0	0
1796	1	1	1	1	1	2	2	2	3	3
1797	3	3	4	4	4	5	5	6	6	6
1798	7	7	8	8	8	9	9	10	10	11
1799	12	12	13	14	15	16	16	17	18	19
1800	19	20	21	22	22	23	24	25	26	26
1801	27	28	29	29	30	31	32	32	33	34
1802	35	36	37	38	39	40	41	42	43	44
1803	45	46	47	49	50	51	53	55	56	58
1804	59	61	63	65	67	69	71	73	75	77
1805	79	81	83	86	88	90	92	95	97	99
1806	101	104	106	108	111	113	115	118	120	123
1807	125	127	130	132	135	138	140	143	146	149
1808	152	155	159	162	166	169	172	176	179	182
1809	186	189	193	197	201	205	209	214	218	223
1810	228	233	239	244	249	255	260	265	271	276
1811	281	287	292	298	304	310	316	322	328	334
1812	340	346	352	358	363	369	374	380	386	391
1813	397	402	408	413	418	424	429	434	440	445
1814	450	456	462	469	475	481	488	494	501	508
1815	516	523	530	536	542	549	555	562	569	575
1816	582	589	596	603	610	617	623	629	636	642
1817	648	655	661	668	674	681	687	694	700	707
1818	714	720	727	734	741	748	756	763	771	779
1819	787	794	802	809	817	825	832	840	848	856
1820	865	874	882	890	898	906	913	921	928	935
1821	942	949	956	963	970	978	985	993	1000	1008
1822	1015	1023	1031	1039	1047	1056	1064	1072	1081	1089
1823	1097	1105	1113	1121	1129	1136	1144	1151	1159	1167
1824	1175	1183	1190	1198	1207	1215	1223	1231	1239	1246
1825	1254	1262	1270	1278	1286	1293	1301	1309	1318	1326
1826	1334	1342	1351	1359	1368	1376	1385	1393	1402	1411
1827	1420	1429	1438	1447	1456	1465	1474	1483	1492	1502
1828	1511	1521	1531	1541	1551	1561	1571	1581	1590	1599
1829	1608	1617	1625	1634	1643	1652	1660	1669	1678	1687
1830	1697	1707	1717	1728	1739	1751	1762	1773	1783	1793
1831	1804	1815	1826	1838	1849	1860	1870	1880	1891	1902
1832	1913	1923	1933	1943	1953	1963	1973	1983	1993	2004
1833	2015	2026	2038	2049	2061	2072	2084	2096	2108	2120
1834	2132	2144	2156	2170	2183	2197	2211	2225	2238	2252
1835	2265	2278	2292	2306	2320	2334	2348	2361	2374	2388
1836	2400	2413	2426	2438	2450	2462	2475	2488	2501	2515
1837	2528	2542	2556	2570	2585	2599	2612	2625	2638	2651
1838	2666	2680	2694	2708	2723	2737	2751	2765	2779	2795
1839	2811	2827	2843	2860	2878	2894	2908	2922	2936	2948
1840	2961	2973	2985	2998	3010	3022	3034	3046	3058	3070
1841	3082	3094	3107	3119	3132	3144	3157	3169	3182	3195
1842	3209	3223	3237	3251	3265	3280	3294	3307	3320	3333
1843	3346	3360	3374	3388	3404	3419	3435	3450	3466	3482
1844	3498	3515	3532	3549	3567	3585	3602	3621	3640	3662
1845	3690	3751	3765	3778	3790	3802	3814	3826	3837	3847
1846	3858	3868	3878	3887	3897	3906	3916	3925	3934	3943
1847	3952	3962	3971	3980	3990	3999	4009	4020	4032	4044
1848	4061	4089	4126	4183	4218	4246	4270	4290	4306	4320
1849	4333	4346	4359	4371	4383	4395	4406	4417	4429	4440
1850	4451	4462	4474	4485	4496	4507	4518	4529	4540	4551

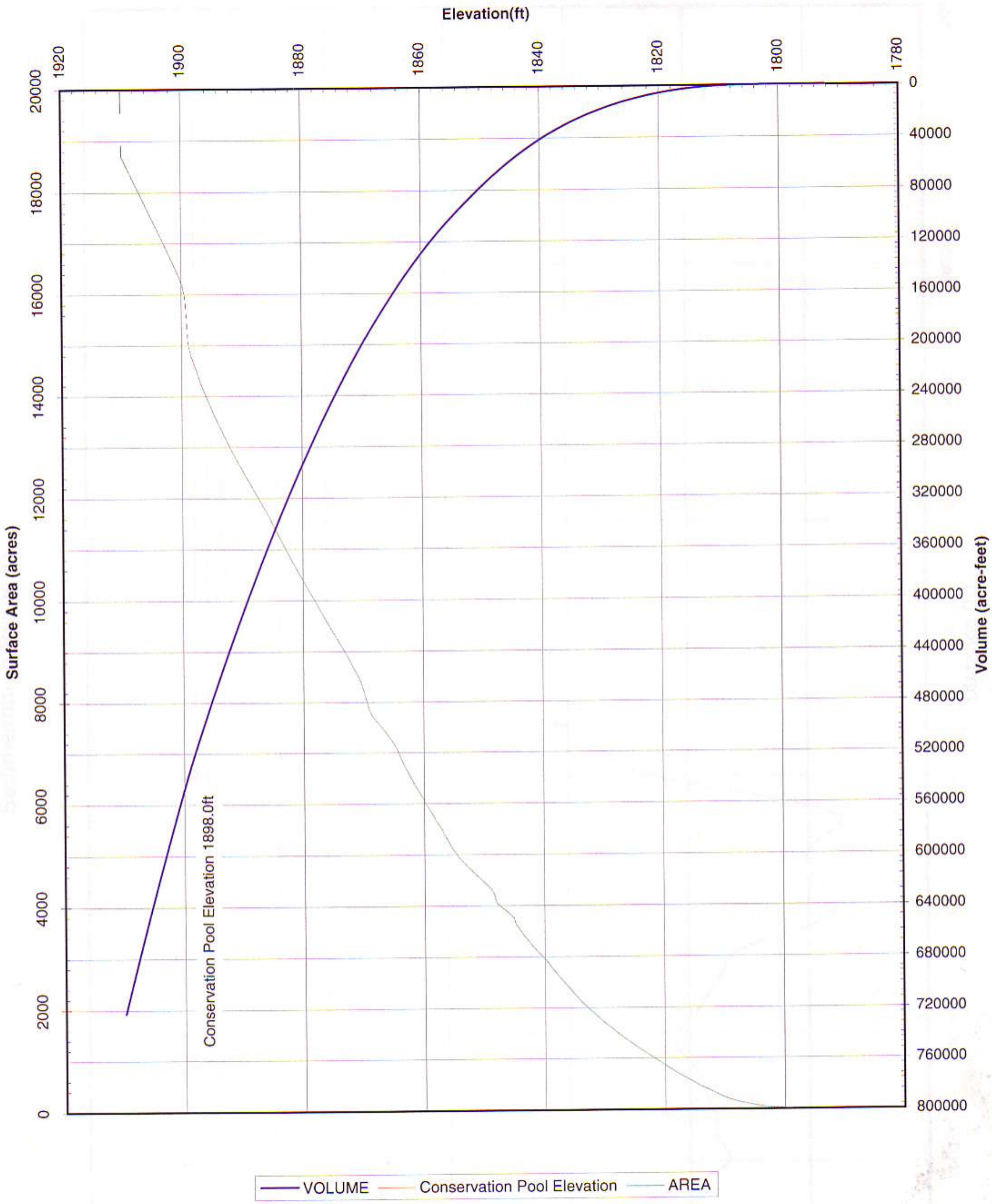
Appendix B (continued)

Lake E.V. Spence

RESERVOIR AREA TABLE

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

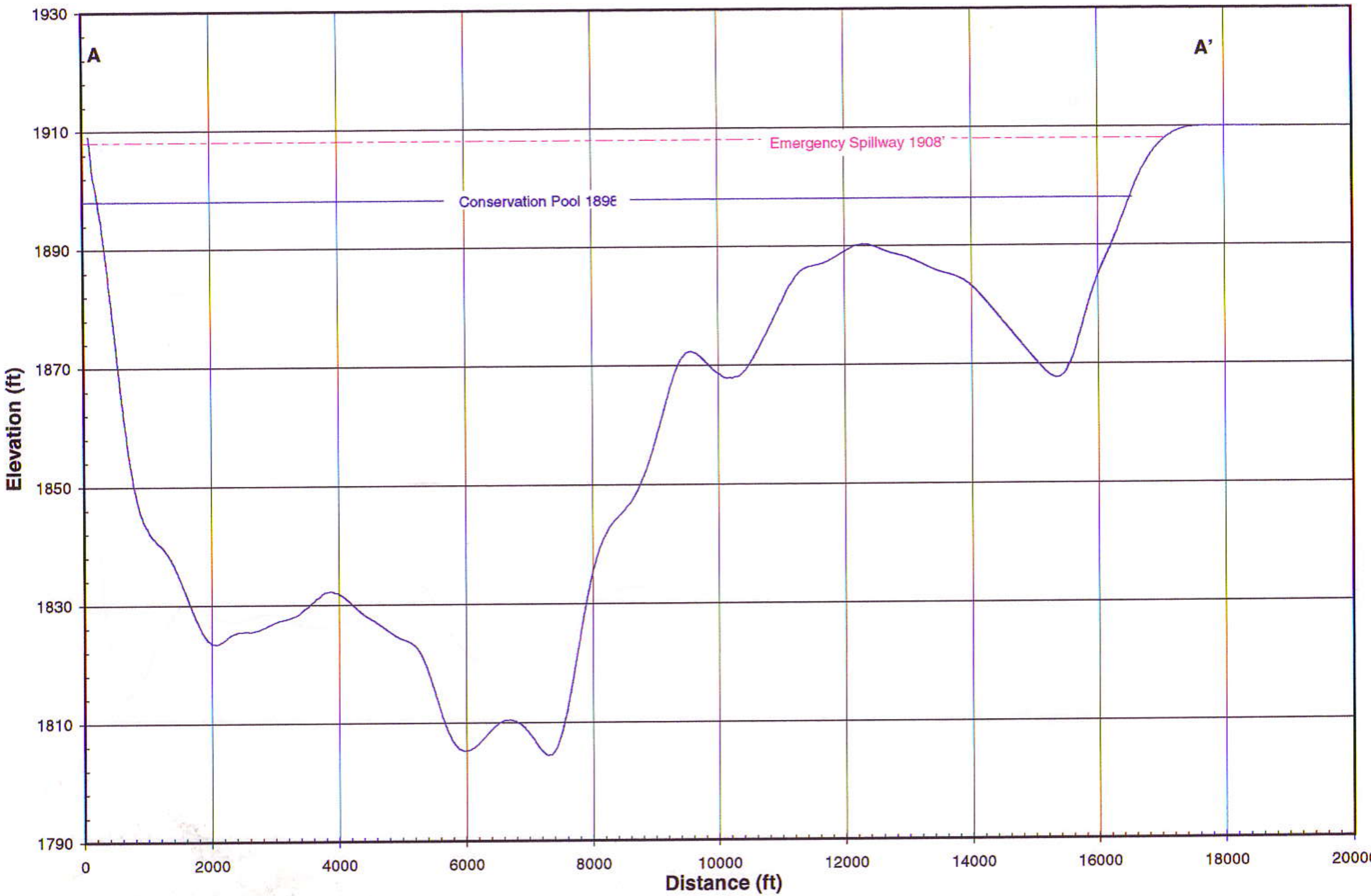
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1851	4562	4573	4584	4595	4607	4618	4628	4639	4651	4662
1852	4673	4685	4696	4707	4719	4730	4742	4754	4766	4778
1853	4790	4802	4814	4827	4839	4851	4864	4877	4889	4902
1854	4915	4928	4942	4957	4973	4989	5005	5020	5036	5052
1855	5069	5086	5103	5120	5138	5157	5177	5197	5218	5239
1856	5260	5281	5302	5323	5345	5366	5387	5409	5432	5455
1857	5478	5499	5519	5538	5556	5574	5592	5610	5628	5646
1858	5665	5683	5703	5727	5747	5767	5787	5806	5825	5844
1859	5862	5880	5898	5916	5934	5952	5970	5988	6007	6026
1860	6066	6084	6102	6120	6138	6156	6174	6194	6214	6233
1861	6252	6270	6288	6309	6329	6352	6374	6396	6418	6440
1862	6462	6484	6505	6526	6547	6569	6591	6612	6635	6657
1863	6680	6704	6727	6750	6774	6798	6821	6845	6870	6895
1864	6940	6966	6991	7016	7040	7064	7087	7110	7131	7151
1865	7170	7188	7206	7224	7241	7258	7275	7291	7308	7324
1866	7341	7357	7373	7389	7406	7421	7437	7453	7468	7483
1867	7498	7513	7527	7541	7556	7570	7584	7598	7613	7627
1868	7641	7656	7670	7685	7699	7716	7733	7753	7774	7796
1869	7824	7856	7892	7928	7971	8015	8059	8103	8145	8183
1870	8220	8257	8293	8330	8367	8400	8430	8460	8486	8510
1871	8531	8552	8573	8595	8617	8639	8660	8683	8705	8727
1872	8748	8770	8793	8816	8840	8864	8886	8908	8928	8948
1873	8968	8988	9007	9027	9047	9067	9087	9106	9126	9146
1874	9165	9185	9205	9225	9246	9267	9287	9307	9327	9347
1875	9367	9387	9407	9427	9447	9467	9487	9507	9528	9548
1876	9568	9588	9609	9629	9650	9670	9691	9711	9730	9750
1877	9770	9790	9810	9830	9851	9871	9892	9913	9934	9955
1878	9975	9996	10016	10036	10056	10076	10096	10116	10136	10156
1879	10176	10196	10216	10236	10256	10276	10297	10318	10340	10361
1880	10382	10403	10425	10447	10468	10489	10510	10530	10550	10571
1881	10592	10613	10634	10656	10678	10700	10721	10742	10764	10786
1882	10807	10829	10851	10874	10897	10919	10941	10963	10985	11007
1883	11030	11052	11074	11096	11118	11140	11162	11185	11207	11230
1884	11253	11277	11300	11323	11346	11370	11393	11416	11439	11463
1885	11486	11509	11534	11558	11581	11603	11625	11647	11669	11691
1886	11713	11735	11756	11778	11799	11820	11841	11862	11883	11904
1887	11925	11946	11967	11988	12009	12030	12052	12073	12093	12114
1888	12134	12154	12174	12195	12215	12235	12256	12276	12296	12317
1889	12337	12357	12378	12398	12419	12440	12460	12481	12501	12522
1890	12543	12564	12585	12606	12627	12648	12670	12692	12714	12735
1891	12757	12779	12801	12824	12846	12868	12890	12912	12935	12957
1892	12980	13003	13026	13050	13073	13097	13121	13145	13169	13193
1893	13217	13241	13265	13291	13315	13340	13364	13389	13413	13438
1894	13463	13488	13513	13539	13564	13590	13616	13641	13667	13694
1895	13720	13746	13773	13800	13827	13854	13881	13908	13936	13965
1896	13993	14022	14050	14079	14108	14137	14167	14197	14228	14260
1897	14291	14326	14365	14399	14433	14468	14506	14546	14578	14609
1898	14640	14671	14703	14735	14767	14802	14841	14892	14956	15040
1899	15156	15314	15499	15683	15860	15967	16041	16096	16138	16174
1900	16207	16240	16275	16306	16335	16363	16390	16417	16444	16471
1901	16497	16523	16550	16576	16602	16628	16654	16679	16705	16731
1902	16756	16782	16807	16833	16858	16883	16909	16934	16959	16984
1903	17010	17035	17060	17085	17110	17135	17160	17185	17210	17235
1904	17260	17285	17310	17335	17360	17384	17409	17434	17459	17484
1905	17509	17533	17558	17583	17607	17632	17657	17681	17706	17730
1906	17755	17780	17804	17829	17853	17878	17902	17927	17951	17975
1907	18000	18024	18048	18073	18097	18121	18145	18170	18194	18218
1908	18242	18266	18290	18315	18339	18363	18387	18411	18435	18459
1909	18483	18507	18531	18555	18580	18604	18628	18652	18677	18702
1910	19953									-



Lake E.V. Spence
July 1999
Prepared by: TWDB

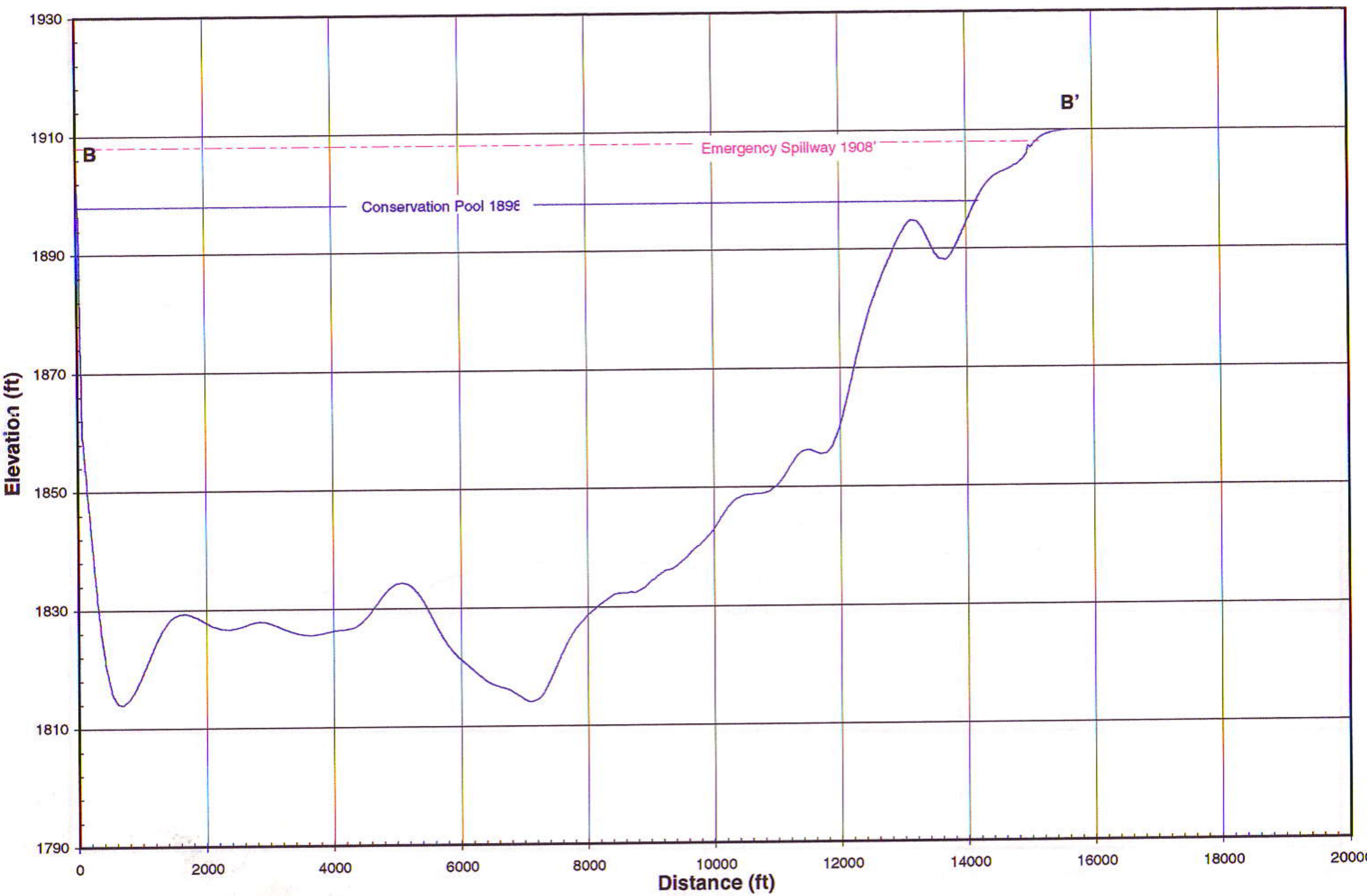
Appendix C

E. V. Spence Reservoir
Sedimentation Range #1



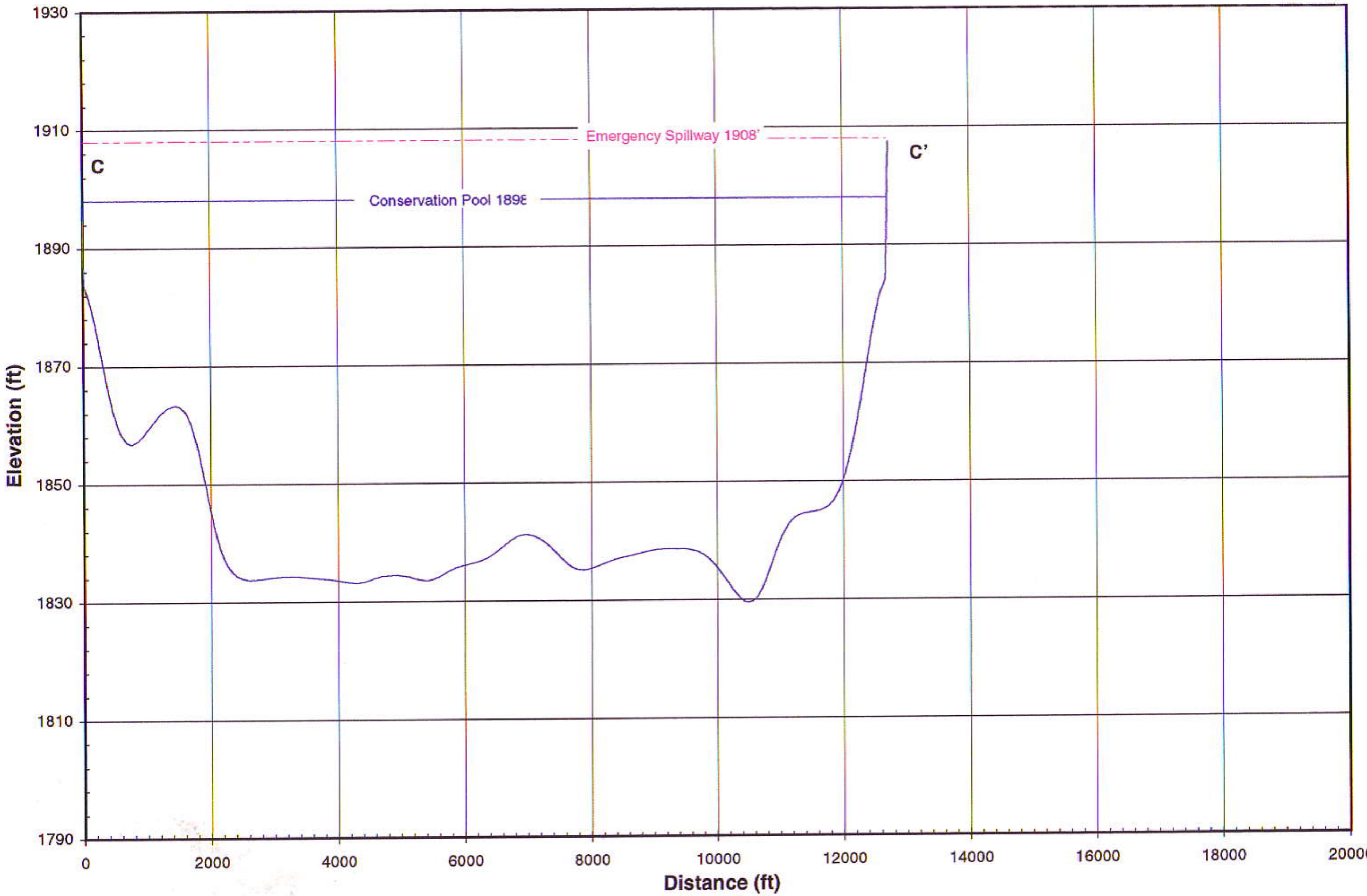
Appendix D

E.V. Spence Reservoir
Sedimentation Range #2



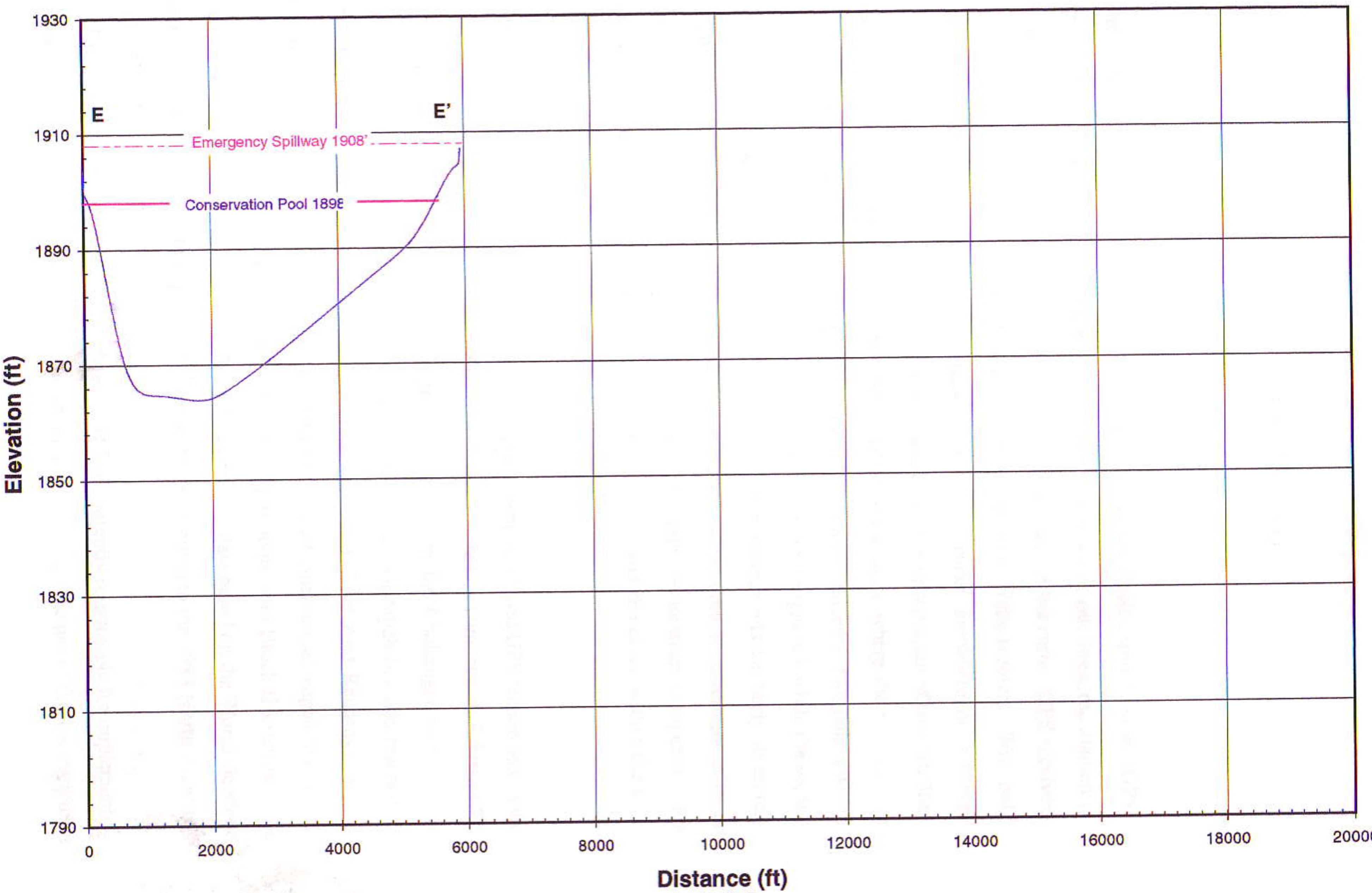
Appendix D

E.V. Spence Reservoir
Sedimentation Range #3



Appendix D

E.V. spence Reservoir
Sedimentation Range #5



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 reservoir surface during the survey serves as the vertical datum for the bathymetric readings from a depth sounder. The sounder determines the reservoir'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.

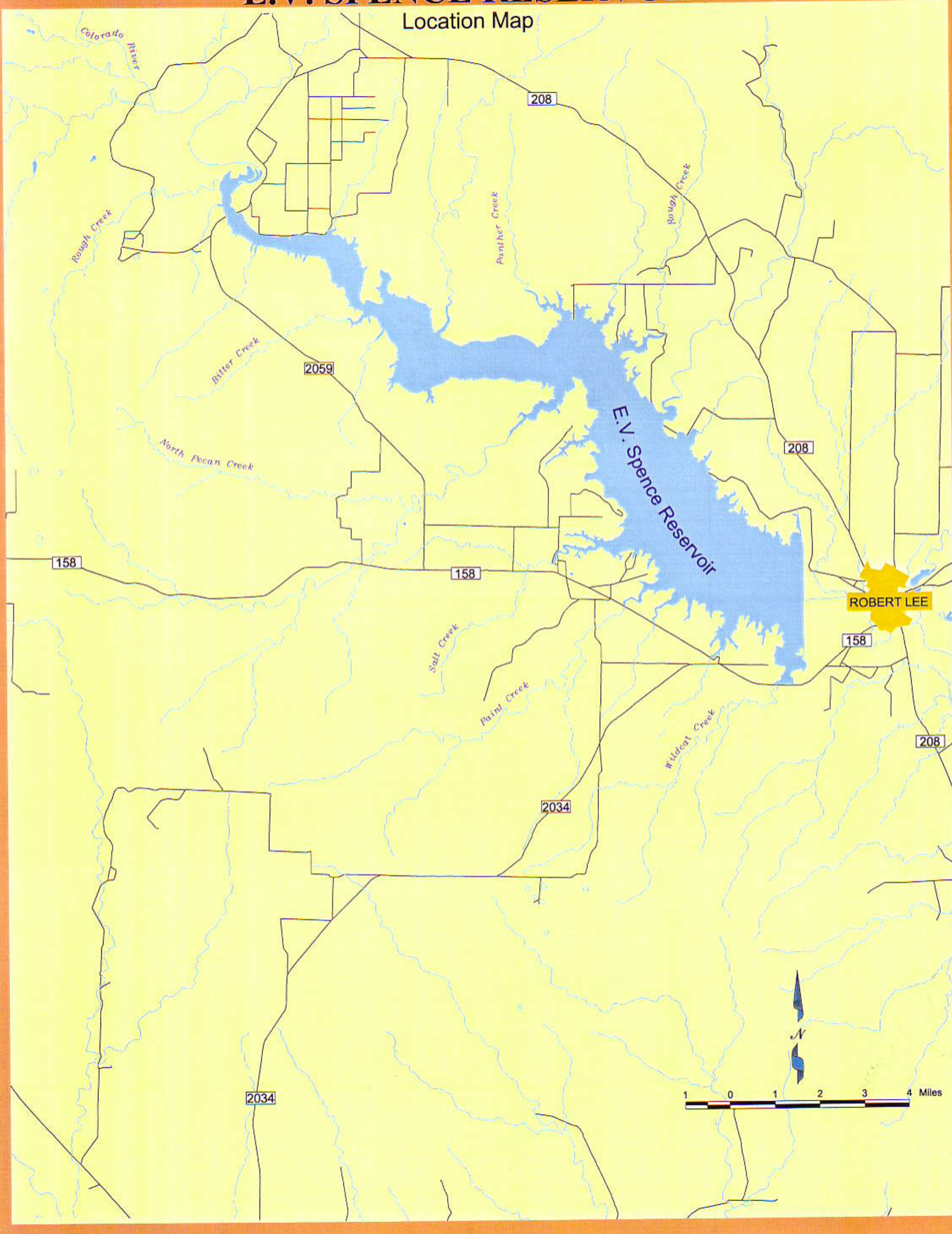
Electronic positioning systems were the next improvement. Continuous horizontal positioning by electronic means allowed for the continuous collection of depth soundings by boat. A set of microwave transmitters positioned around the reservoir at known coordinates allowed the boat to receive data and calculate 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

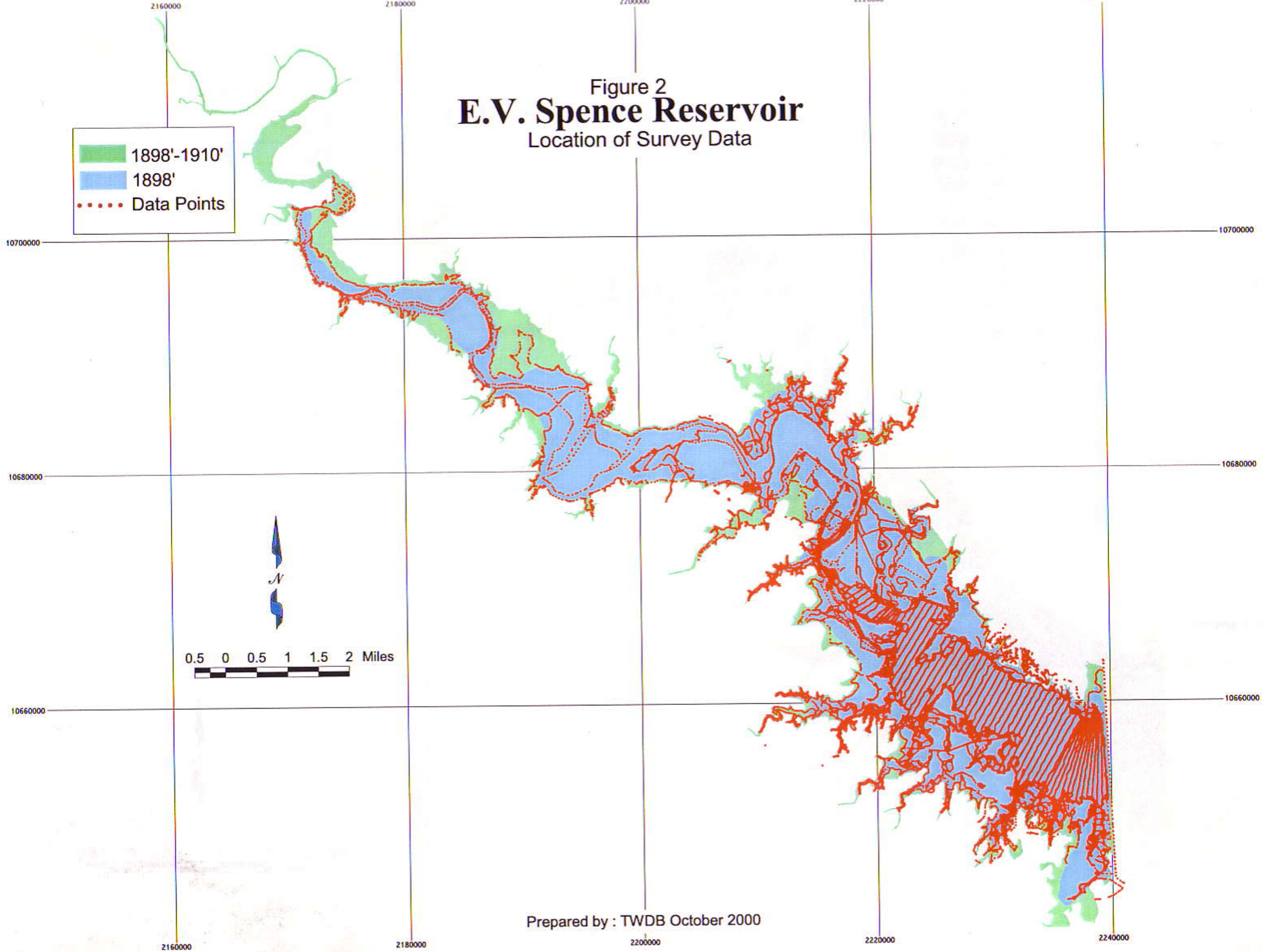
E.V. SPENCE RESERVOIR

Location Map



Prepared by : Texas Water Development Board October 2000

Figure 2
E.V. Spence Reservoir
Location of Survey Data



Prepared by : TWDB October 2000

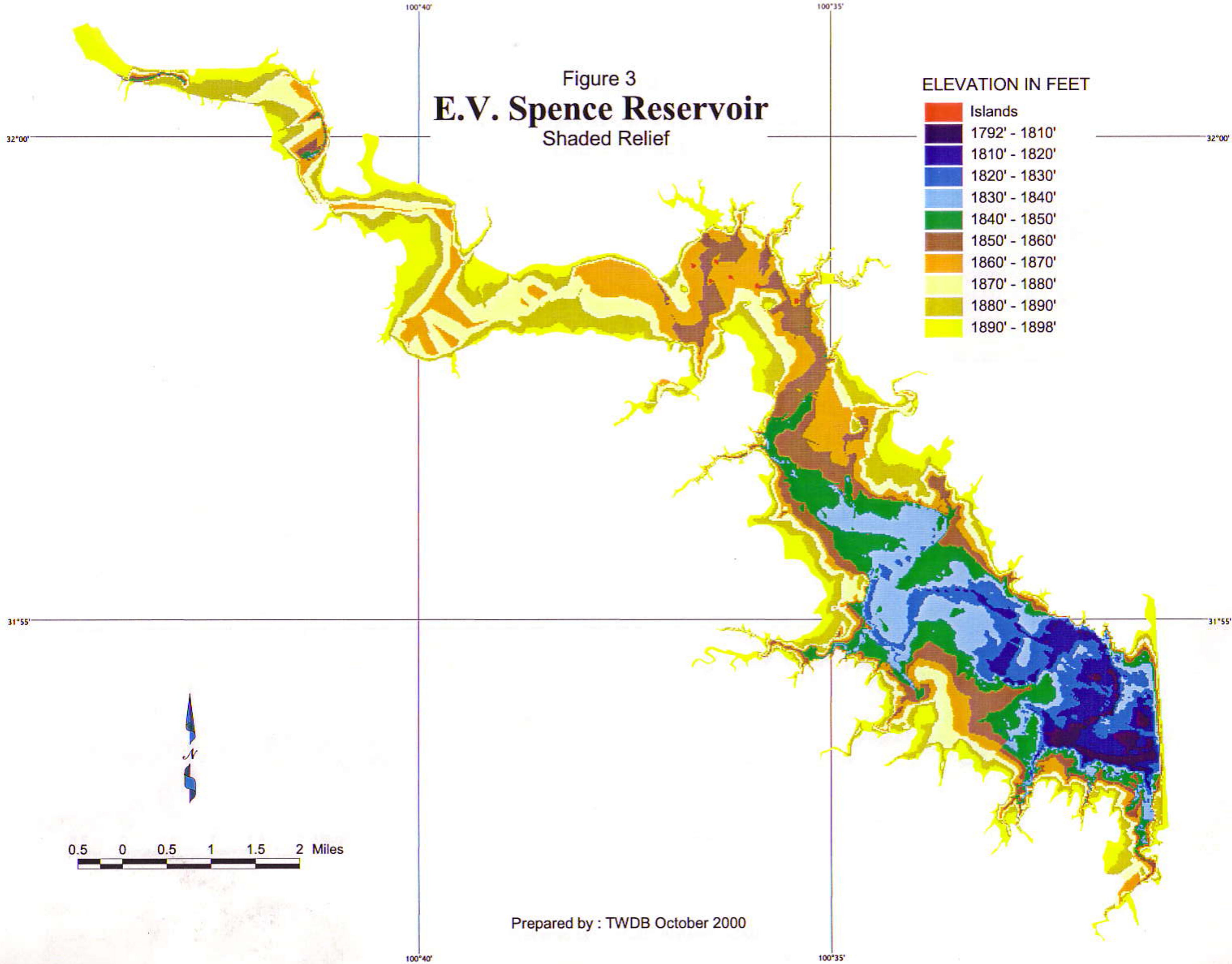


Figure 3
E.V. Spence Reservoir
Shaded Relief
ELEVATION IN FEET
Islands
1792' - 1810'
1810' - 1820'
1820' - 1830'
1830' - 1840'
1840' - 1850'
1850' - 1860'
1860' - 1870'
1870' - 1880'
1880' - 1890'
1890' - 1898'
100°40'
100°35'
32°00'
31°55'
N
0.5 0 0.5 1 1.5 2 Miles
Prepared by : TWDB October 2000

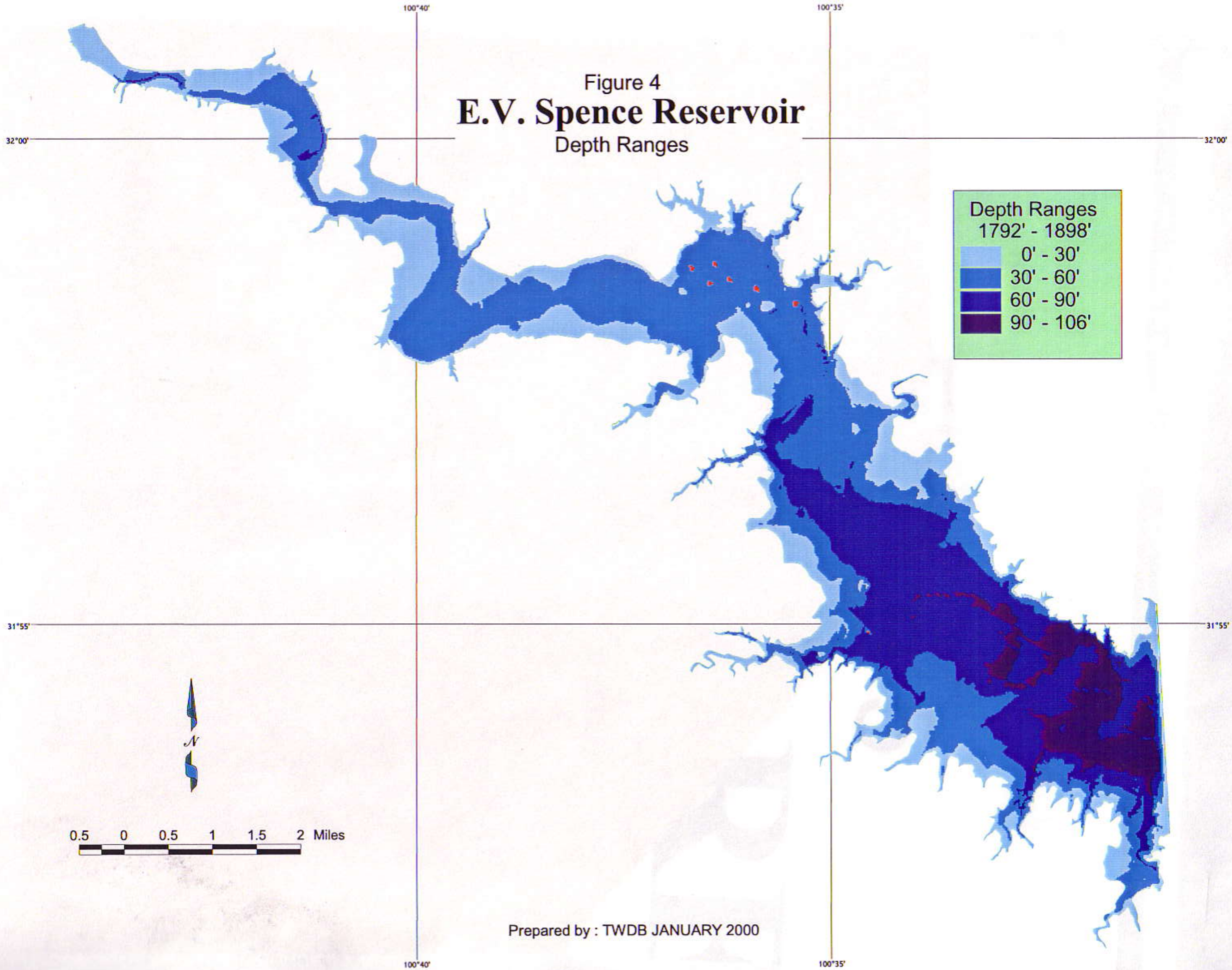


Figure 4
E.V. Spence Reservoir
Depth Ranges
Depth Ranges
1792' - 1898'
0' - 30'
30' - 60'
60' - 90'
90' - 106'
0.5 0 0.5 1 1.5 2 Miles
N
Prepared by : TWDB JANUARY 2000