VOLUMETRIC SURVEY OF LAKE KICKAPOO

Prepared for:
City of Wichita Falls

In cooperation with the
United States Army Corps of Engineers

Prepared by
Texas Water Development Board

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Texas Water Development Board

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LAKE KICKAPOO
VOLUMETRIC SURVEY REPORT

INTRODUCTION

Staff of the Surface Water Section of the Texas Water Development Board (TWDB) conducted a volumetric survey of Lake Kickapoo during the period April 9-18, 2001. The primary purpose of this survey was to determine the current volume of the lake at conservation pool elevation. Results from this survey will serve as a basis for comparison to future surveys to allow the location and rates of sediment deposition to be determined. Survey results are presented in the following pages in both graphical and tabular form.

The vertical datum used during this survey is that used by the United States Geological Survey (USGS) for the reservoir elevation gauge at Lake Kickapoo (07314000 LAKE KICKAPOO NEAR ARCHER CITY, TX.). The datum for this gauge is reported as mean sea level (msl) (USGS, 1999). Thus, elevations are reported here, according to the same datum, in feet above mean sea level (msl). Volume and area calculations in this report are referenced to water levels provided by the USGS gauge.

In the original design, the surface area was 6,200 acres at conservation pool elevation (1,045.0 feet); the total storage volume was estimated to be 106,000 acre-feet of water (U.S. Geological Survey 2001). This report will compare the 2001 survey results with the original design information.

LAKE HISTORY AND GENERAL INFORMATION

Historical information on Lake Kickapoo was obtained from the Texas Water Development Board (TWDB 1974), and United States Geological Survey (USGS 2001). The Lake Kickapoo project was originally designed to provide water for municipal purposes.

The City of Wichita Falls (hereinafter referred to as the City) owns the water rights to Lake Kickapoo. The City also owns and maintains the dam and appurtenant structures. All releases from the reservoir and other water-related operations are under the control of the City.

Permit No. 1363 (Application No. 1456) dated September 16, 1944, authorized the construction of a dam on the North Fork Little Wichita River, to impound water and to divert 40,000 ac-ft of water per annum for municipal purposes.

The current authorization for the water rights to Lake Kickapoo is based on Certificate of Adjudication # 02-5144 issued by the Texas Natural Resource Conservation Commission on August 7, 1987. The certificate authorizes the City to maintain an existing dam and reservoir on the North Fork Little Wichita River (Lake Kickapoo) and impound therein not to exceed 105,000 acre-feet (ac-ft) of water.

The owner is authorized to divert and use not to exceed 40,000 ac-ft of water per annum for municipal purposes of which amount, not more than 1,120 ac-ft of water per annum may be diverted from the Red River Basin to the Brazos River Basin for use by the City of Olney. The owner was also authorized to use the impounded water of Lake Kickapoo for recreational purposes.

Copies of the Permits and Certificate of Adjudication (original and amended) may be obtained from the Texas Natural Resource Conservation Commission's Central Records in Austin, Texas.

Lake Kickapoo is located on the North Fork Little Wichita River (Red River Basin) in Archer County, 10 miles northwest of Archer City, Texas (Figure 1). Records indicate the drainage area is approximately 275 square miles (USGS 2001). At conservation pool elevation (1,045.0 feet), the reservoir has approximately 62 miles of shoreline.

Construction for the Lake Kickapoo project started in January 1945 and was completed in December of the same year. Deliberate impoundment of water began in February 1946. F. M. Rugeley and A. J. Gates were the design engineers and the general contractor was Miles Construction Co. The estimated cost of the project was $3,500,000.

Engineering designs (TWDB, 1974) show Lake Kickapoo Dam and appurtenant structures to consist of a rolled-earthfill embankment, approximately 8,200 feet in length (including spillway) with a maximum height of 62 feet and a crest elevation that varies from 1059.2 feet to 1062.0 feet.

The spillway is an uncontrolled reinforced concrete ogee-type structure. It is located at the right (south) end of the embankment. The elevation of the spillway crest is 1,045 feet and is considered the conservation pool elevation.

The outlet works consist of a concrete control tower and two 4-feet by 5-feet concrete conduits. Releases are controlled by sluice gates. The invert elevation of the openings is 1,000.92 feet. One of the conduits is used for water supply and the other is for stream flow control.

SURVEYING EQUIPMENT

The equipment used to perform the volumetric survey consists of a 20-foot aluminum shallow-draft flat bottom SeaArk craft with cabin and is equipped with one 115-horsepower Evinrude outboard motor. 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 PC. (Reference to brand names throughout this report does not imply endorsement by TWDB).

The GPS equipment, survey vessel, and depth sounder in combination provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder takes approximately ten readings of the lake bottom each second. The depth readings are stored on the survey vessel's on-board computer along with the corrected positional data generated by the boat's GPS receiver. The data files collected are downloaded from the computer and brought to the office for editing after the survey is completed. During editing, poor-quality data is removed or corrected, multiple data points are averaged to get one data point per second, and average depths are converted to elevation readings based on the lake elevation recorded on the day the survey was performed. Accurate estimates of the lake volume can be quickly determined by building a 3-D model of the reservoir from the collected data.

PRE-SURVEY PROCEDURES

The reservoir's boundary was digitized using Environmental Systems Research Institute's (ESRI) Arcview from USGS quad sheets. The names of the quad sheets are as follows: LAKE KICKAPOO, TEX. (1965), DUNDEE, TEX. (1963), and DUNDEE SE, TEX (Photorevised 1981). The graphic boundary file created was then transformed into the proper datum, from NAD '27 datum to NAD '83, using Environmental Systems Research Institute's (ESRI) Arc/Info project command with the NADCOM parameters.

The survey layout was designed by placing survey track lines at 500-foot intervals within the digitized lake boundary using Coastal Oceanographics' HYPACK software. The survey design required the use of approximately 152 survey lines along the length of the lake and perpendicular to the original creek channels.

SURVEY PROCEDURES

Equipment Calibration and Operation

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 surveying Lake Kickapoo, the speed of sound in the water column ranged from 4,740 feet per second to 4,749 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 from variation in boat inclination. These two factors combine to give an overall accuracy of $\pm$0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some readings are positive and some are negative. Further information on these calculations is presented in Appendix G.

During the survey, the horizontal mask setting on the on-board GPS receiver was set to 10°, and the PDOP (Position Dilution of Precision) limit was set to 7 to maximize the accuracy of the horizontal positioning. An internal alarm sounds if 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 to state-plane coordinates on the fly.

Field Survey

TWDB staff collected data at Lake Kickapoo for five days during the period of April 9-18, 2001. The lake-level elevations varied from 1044.09 feet (Apr. 18) to 1044.16 (Apr. 16). Weather conditions became a factor during the survey. At times the crew experienced temperatures in the 80's with little or no wind and the surface water conditions were calm. Occasionally threatening weather moved into the area resulting in strong winds accompanied with thunderstorms. The survey crew postponed data collection twice due to the weather.

The survey crew began at the dam and started collecting data on pre-plotted range lines (transects) that were spaced 500 feet apart and designed to be perpendicular to the channel for the best cross-section results. A data point that consisted of latitude, longitude and depth was collected each second. Data were collected on 132 of the 152 pre-plotted survey range lines. The survey crew would collect irregular transects when navigational hazards such as trees and stumps or shallow depths kept the crew from driving on the pre-plotted lines. Approximately 74,368 data points were collected over the 133 miles traveled during the survey. These points, shown in Figure 2, were stored digitally on the boat's computer in 222 data files.

The topography surrounding Lake Kickapoo was typical of the West Texas Prairies and Lakes Region. Observed were wide flood plains along creeks, streams and rivers that meander through relatively flat land. On the north shore of Lake Kickapoo, the relief was much more apparent with the elevated slopes to a plateau.

The catchment basin of Lake Kickapoo is located on the North Fork Wichita River and lies in a west to east direction with Lake Kickapoo Dam located at the east end of the reservoir. There are several small tributaries that drain into the main basin from the foothills on the north side. Major contributing creeks that flow into the lake from the south side are Briar and Kickapoo Creeks.

Residential development was noted on the south side of the lake near the dam and spillway. Developed property was also observed on the hilly shoreline on the north side of the lake. The remainder of the land surrounding the lake was left undisturbed and mostly used for ranching. The fact that a limited amount of development was present or the lack of fishing piers and boat ramps on Lake Kickapoo made it easier for the survey crew to collect data along the shoreline.

Native plants and ground cover was observed around the majority of the lake. The survey crew noted areas of shoreline erosion with exposed red sandy and clay soil. Also noted were outcrops of boulder-size limestone rock. Lake Kickapoo is located in the Nocona Formation in the Wichita Group of the Permian Age (Bureau of Economic Geology, 1987).

As data were collected along the pre-plotted transects, the survey crew noticed that the lake bottom was generally flat. At times there was evidence of the original creek channels (thalweg) when the survey crew crossed over Kickapoo and Briar Creeks and the North Fork Wichita River.

The majority of the lake was clear of navigational hazards such as trees, rocks and debris. It was only in the upper reaches of the lake and in the channels of the creeks and river that the crew encountered such hazards.

Data Processing

The collected data was downloaded from diskettes onto TWDB's computer network. Tape backups were made for future reference. 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 each 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 April 2001 survey, the water surface varied from elevation 1044.09 to 1044.16 feet msl according to elevation data provided by USGS elevation gauge (007314000 LAKE KICKAPOO NEAR ARCHER CITY, TX.). 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 which was used with the GIS software to develop a model of the lake's bottom surface.

The resulting data file was downloaded to a Sun Ultra 10 workstation running the UNIX operating system. Environmental System Research Institute's (ESRI) Arc/Info GIS software was used to convert the data to a MASS points file. The MASS points and the boundary file were then used to create a Digital Terrain Model (DTM) of the lake'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 lake area and volume can be determined from the triangulated irregular network created using this method of interpolation. Volumes and area were calculated from the TIN for the entire reservoir at one-tenth of a foot interval from minimum elevation to conservation pool level. From elevation 1,001.6 feet to 1,045.0 feet, the surface areas and volumes of the lake were computed using the Arc/Info software. The computed reservoir volume table is presented in Appendix A and the area table is presented in Appendix B. Graphs for the volume and area tables can be found in Appendix C and D respectively.

Other products developed from the model include a shaded elevation range 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 elevation contour map of the bottom surface at two-foot intervals is presented in Figure 5. Finally, 13 cross-sections, shown on the map in Figure 5, are presented in the plots in Appendix E with the corresponding coordinates shown in Appendix F.

RESULTS

Results from the 2001 TWDB survey indicate Lake Kickapoo encompasses 6,028 surface acres and contains a total volume of 85,825 ac-ft at the conservation pool elevation of 1,045.0 feet msl (gauge datum). Dead pool storage, the volume below the invert elevation of the low-flow outlet pipe at 1,000.92 feet msl, is 0 ac-ft feet. Thus, the conservation storage (total volume - dead storage) for Lake Kickapoo is 85,825 acre-feet. The shoreline at conservation pool elevation was calculated to be approximately 62 miles. The deepest point that was measured during the survey was at elevation 1001.57 feet msl and corresponding to a depth of 43.43 feet, was located approximately 700 feet upstream from Lake Kickapoo Dam.

SUMMARY AND COMPARISONS

Lake Kickapoo Dam was completed in December 1945 and deliberate impoundment began in February 1946. Original design information in 1945 (TWDB, 1974) reported the volume at conservation pool elevation 1,045 feet msl to be 1006,000 ac-ft with a surface area of 6,200 acres.

During April 9-18, 2001, TWDB staff completed a volumetric survey of Lake Kickapoo. The 2001 survey utilized a differential global positioning system, depth sounder and geographical information system technology to create a digital model of the lake's bathymetry.

At conservation pool elevation, the current survey measured 6,028 surface acres, or a difference of 172 surface acres.

The 2001 survey results indicate that the lake's volume at the conservation pool elevation of 1045.0 feet msl is 85,825 ac-ft. The dead pool below elevation 1,000.92 feet was found to be 0 ac-ft, and thus the conservation storage found in this survey is 85,825 acre-feet. The total design volume of the reservoir was 106,000 ac-ft.

Comparisons between the original design information and the 2001 data collection set is difficult and some apparent changes might simply be due to methodological differences. It is recommended that the similar survey be performed in five to ten years or after major flood events to monitor changes to the lake's capacity.

Table 1. Area and volume comparisons at elevation 403.0 feet msl.

Year	1945 (Original Design)	2001 (TWDB Survey)
Area (acres)	6,200	6,028
Volume (acre-feet)	106,000	85,825

REFERENCES

1.Bureau of Economic Geology, The University of Texas at Austin. 1987. Geologic Atlas of Texas Wichita Falls – Lawton Sheet

2. Texas Water Development Board. 1966. Dams and Lakes in Texas, Historical and Descriptive Information. Report 48.

3. Texas Water Development Board. 1974. Engineering Data on Dams and Lakes in Texas. Part I. Report 126.

4. United States Geological Survey. 2001. "Water Resources Data – Texas. Water Year 2000". Volume 1. Arkansas River Basin, Red River Basin, Sabine River Basin, Neches River Basin and Intervening Coastal Basins. Water-Data Report TX-00-1.

Appendix A

Lake Kickapoo

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD — APRIL 2001 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
1001						0	0	0	0	0
1002	0	0	0	0	0	0	0	0	0	0
1003	0	0	0	0	0	0	0	0	1	1
1004	1	1	1	1	1	1	1	2	2	2
1005	2	2	3	3	3	3	3	4	4	4
1006	5	5	6	6	6	7	8	8	9	10
1007	11	11	12	13	15	16	17	18	20	22
1008	24	26	28	31	34	38	43	47	53	58
1009	65	71	79	86	95	104	113	123	134	145
1010	157	169	182	196	210	224	239	255	271	288
1011	305	323	342	362	382	403	425	448	472	496
1012	522	549	576	605	634	665	697	729	763	798
1013	833	870	908	946	986	1027	1069	1113	1157	1202
1014	1248	1294	1342	1390	1440	1490	1541	1593	1646	1699
1015	1754	1809	1866	1923	1981	2040	2100	2162	2224	2287
1016	2351	2416	2482	2548	2616	2684	2753	2824	2895	2967
1017	3040	3114	3190	3267	3344	3423	3503	3584	3666	3750
1018	3834	3920	4006	4094	4182	4272	4363	4454	4547	4641
1019	4736	4832	4929	5027	5126	5227	5329	5432	5536	5642
1020	5749	5858	5967	6078	6190	6303	6417	6533	6649	6767
1021	6886	7006	7127	7249	7372	7496	7622	7749	7877	8006
1022	8136	8268	8402	8537	8673	8811	8950	9091	9233	9377
1023	9522	9668	9816	9965	10115	10266	10419	10573	10728	10884
1024	11041	11200	11360	11522	11685	11849	12015	12182	12351	12522
1025	12694	12867	13042	13219	13397	13576	13756	13938	14122	14307
1026	14494	14682	14871	15063	15255	15449	15644	15841	16039	16238
1027	16439	16641	16845	17051	17259	17468	17679	17891	18106	18321
1028	18539	18758	18979	19202	19426	19652	19879	20108	20338	20570
1029	20803	21038	21274	21511	21750	21990	22231	22474	22719	22965
1030	23213	23463	23714	23967	24221	24478	24736	24996	25258	25521
1031	25787	26055	26325	26599	26875	27153	27434	27717	28003	28290
1032	28579	28870	29163	29459	29755	30054	30354	30656	30960	31266
1033	31574	31884	32196	32512	32829	33148	33470	33793	34120	34447
1034	34777	35109	35444	35781	36119	36460	36804	37150	37500	37852
1035	38206	38563	38923	39287	39652	40020	40391	40764	41141	41519
1036	41900	42283	42668	43056	43446	43839	44234	44632	45032	45435
1037	45841	46249	46660	47075	47492	47911	48334	48759	49187	49617
1038	50049	50483	50920	51359	51800	52244	52689	53137	53587	54040
1039	54494	54951	55410	55872	56336	56803	57272	57743	58217	58694
1040	59172	59653	60137	60623	61111	61602	62095	62590	63088	63588
1041	64090	64595	65102	65613	66125	66640	67157	67677	68200	68725
1042	69251	69780	70310	70843	71377	71913	72451	72990	73532	74074
1043	74618	75164	75711	76260	76810	77362	77915	78470	79027	79585
1044	80145	80705	81268	81833	82398	82965	83534	84104	84677	85250
1045	85825									

Appendix B

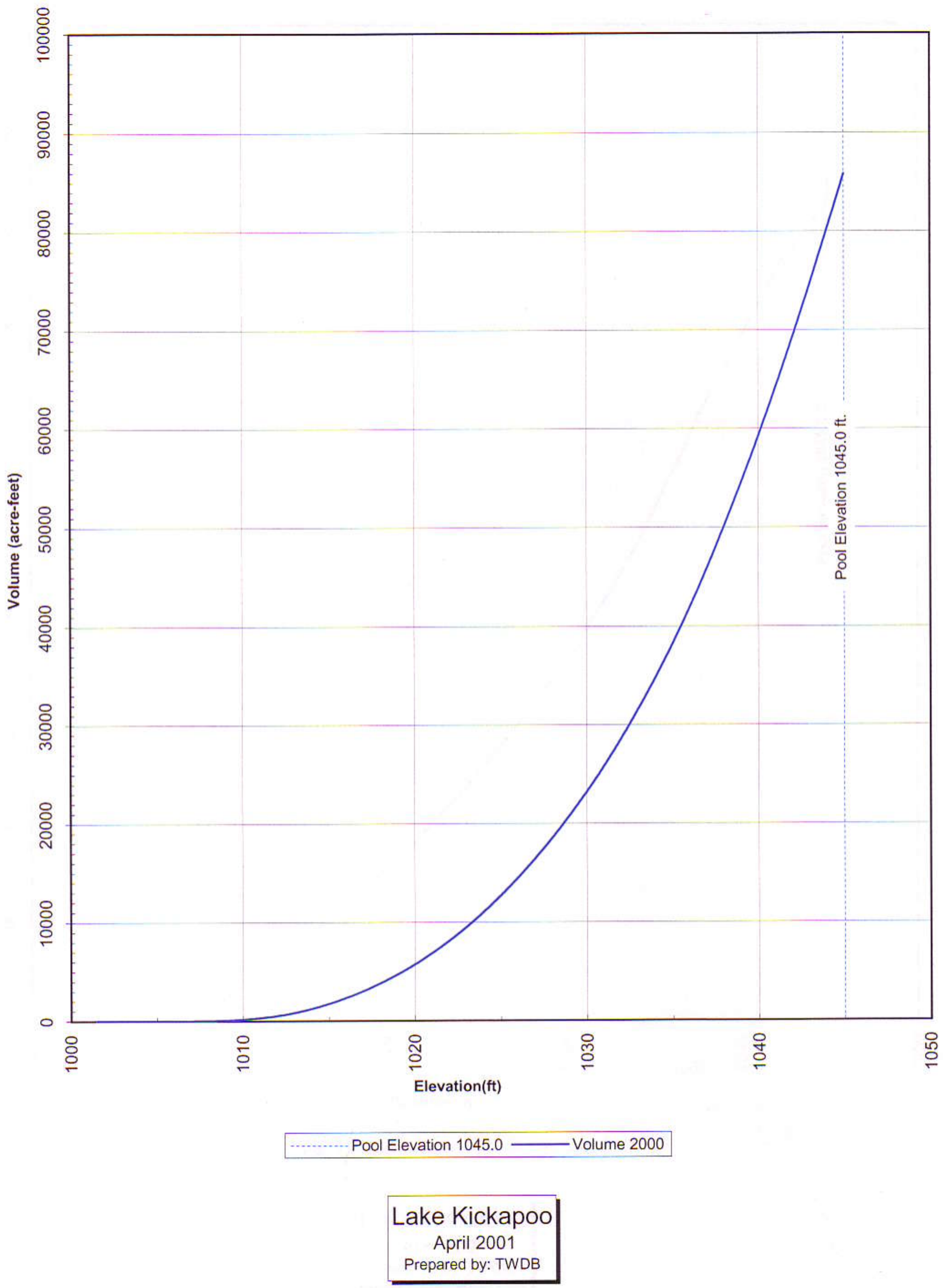
Lake Kickapoo

RESERVOIR AREA TABLE

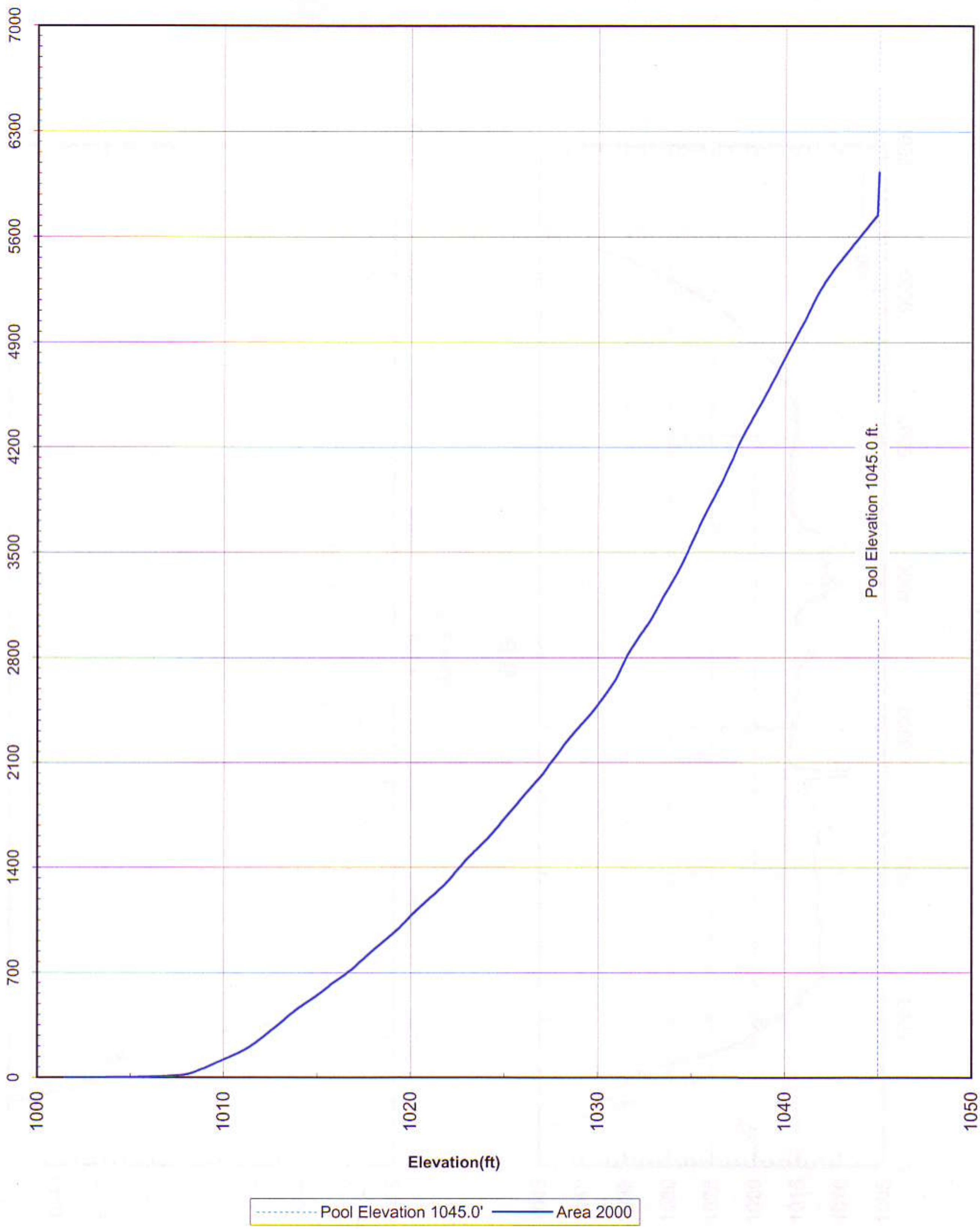
TEXAS WATER DEVELOPMENT BOARD — April 2001 SURVEY

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
1001						0	0	0	0	0
1002	0	0	0	0	0	0	0	0	0	0
1003	0	0	0	0	1	1	1	1	1	1
1004	1	1	1	1	1	1	1	2	2	2
1005	2	2	2	2	2	3	3	3	3	3
1006	4	4	4	5	5	6	6	7	7	8
1007	9	9	10	11	12	13	14	15	16	18
1008	20	23	27	31	36	40	45	51	55	60
1009	65	70	75	81	87	93	98	104	109	115
1010	120	126	131	137	142	148	153	159	165	171
1011	178	184	192	199	207	215	224	233	242	251
1012	261	271	281	291	302	311	321	331	341	351
1013	362	372	383	394	405	415	426	436	445	455
1014	463	472	481	490	498	507	515	523	532	540
1015	549	558	567	577	587	597	607	617	627	636
1016	645	653	662	671	679	688	698	707	716	727
1017	738	750	762	772	783	794	805	816	828	839
1018	849	860	870	881	892	902	912	923	933	944
1019	955	965	976	987	999	1012	1025	1038	1051	1065
1020	1078	1090	1102	1113	1125	1137	1148	1160	1171	1183
1021	1194	1205	1215	1226	1238	1250	1261	1273	1286	1298
1022	1312	1326	1342	1357	1372	1386	1400	1414	1429	1443
1023	1457	1470	1483	1495	1508	1520	1532	1544	1556	1569
1024	1582	1595	1608	1622	1637	1651	1666	1681	1697	1712
1025	1728	1743	1757	1771	1785	1799	1813	1829	1844	1859
1026	1874	1888	1903	1917	1931	1945	1960	1973	1987	2001
1027	2016	2031	2048	2067	2085	2102	2117	2133	2149	2166
1028	2184	2202	2219	2235	2251	2266	2281	2296	2310	2324
1029	2338	2352	2366	2380	2395	2408	2423	2437	2453	2470
1030	2487	2504	2520	2538	2555	2572	2590	2608	2627	2646
1031	2669	2693	2720	2748	2772	2798	2821	2844	2864	2883
1032	2901	2920	2940	2959	2976	2993	3011	3029	3049	3070
1033	3091	3113	3137	3161	3184	3206	3227	3248	3268	3289
1034	3310	3333	3355	3377	3400	3424	3451	3478	3505	3532
1035	3560	3588	3614	3642	3669	3696	3722	3747	3772	3796
1036	3819	3843	3866	3890	3915	3939	3964	3989	4017	4045
1037	4072	4098	4124	4154	4185	4214	4239	4264	4287	4310
1038	4333	4356	4379	4401	4424	4446	4468	4489	4512	4535
1039	4559	4582	4604	4629	4653	4677	4702	4727	4751	4776
1040	4800	4824	4847	4871	4895	4919	4942	4966	4989	5012
1041	5036	5060	5086	5112	5138	5163	5188	5212	5235	5256
1042	5277	5296	5315	5334	5352	5370	5387	5403	5418	5434
1043	5449	5465	5480	5495	5511	5526	5542	5557	5572	5588
1044	5603	5619	5634	5650	5665	5680	5696	5711	5727	5742
1045	6028									



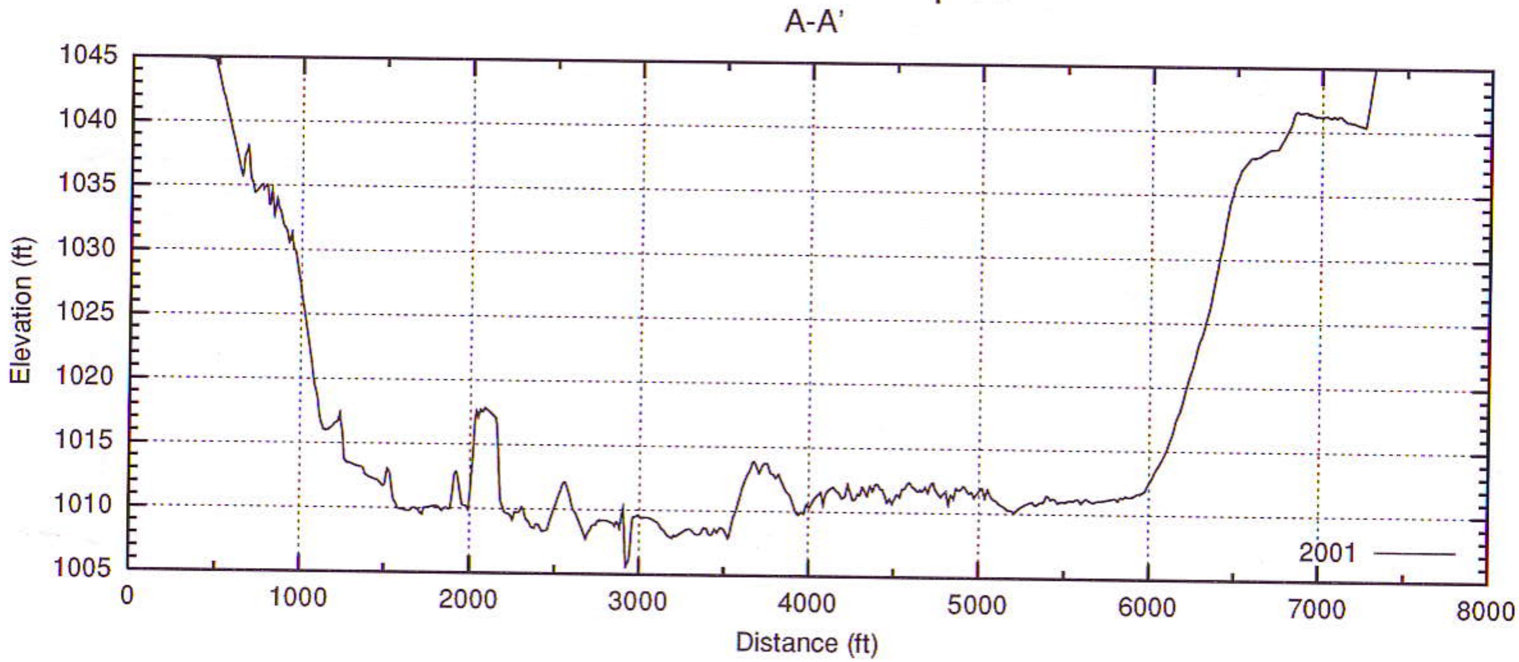
Appendix C Elevation vs. Volume

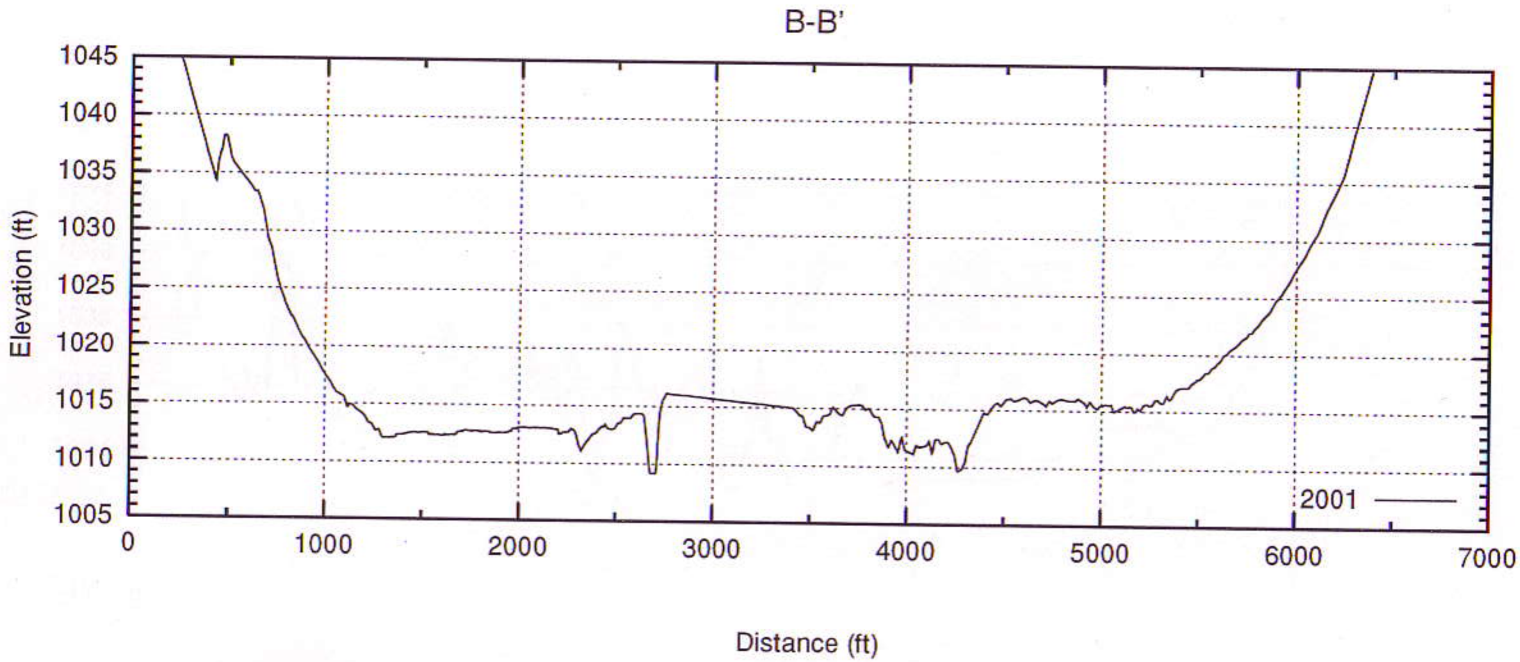


Lake Kickapoo
April 2001
Prepared by: TWDB

Appendix D Elevation vs. Area

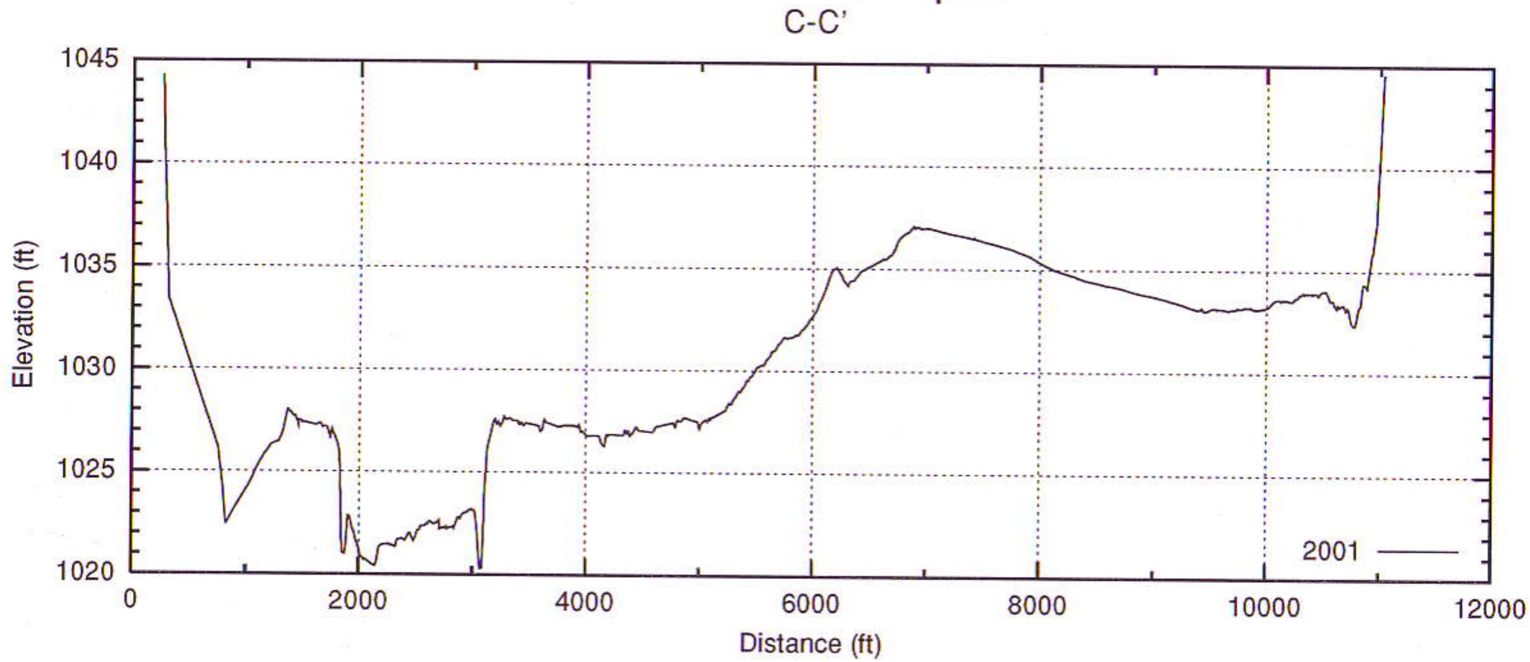
Lake Kickapoo

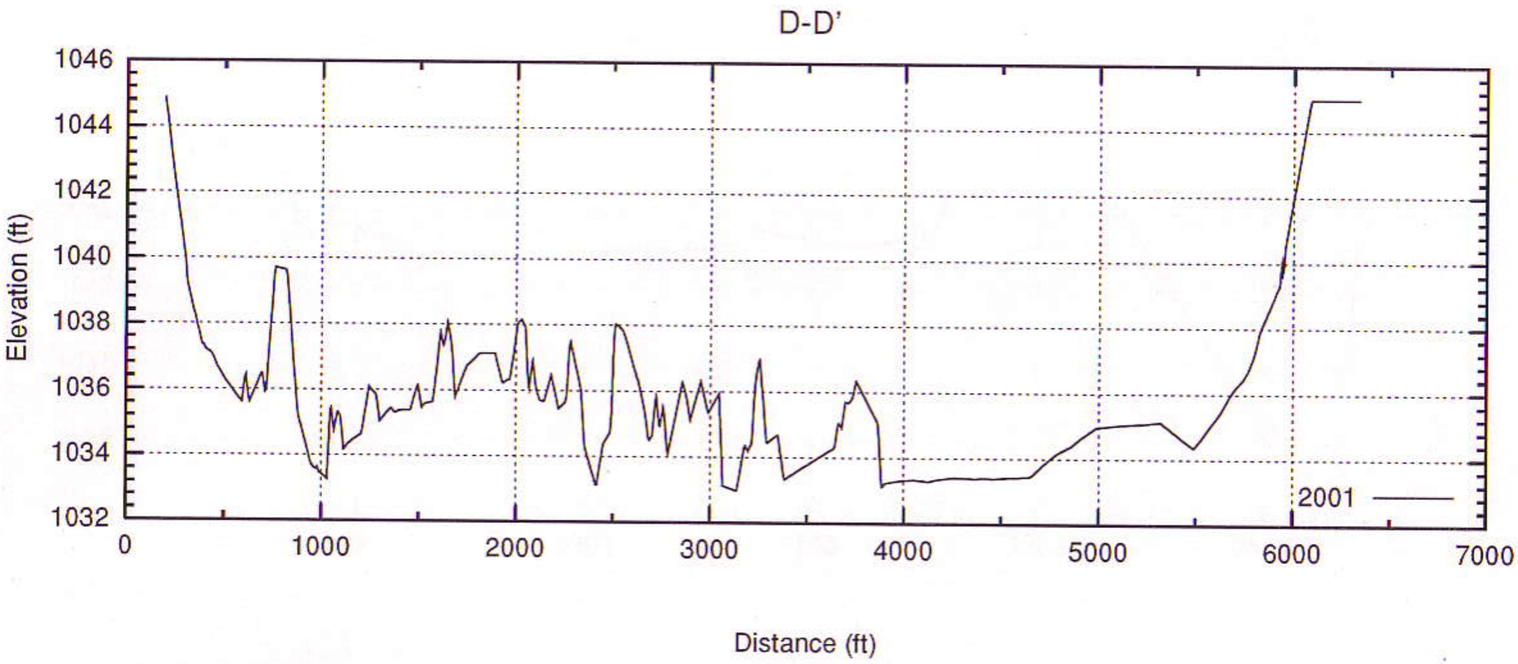




Appendix E

Lake Kickapoo

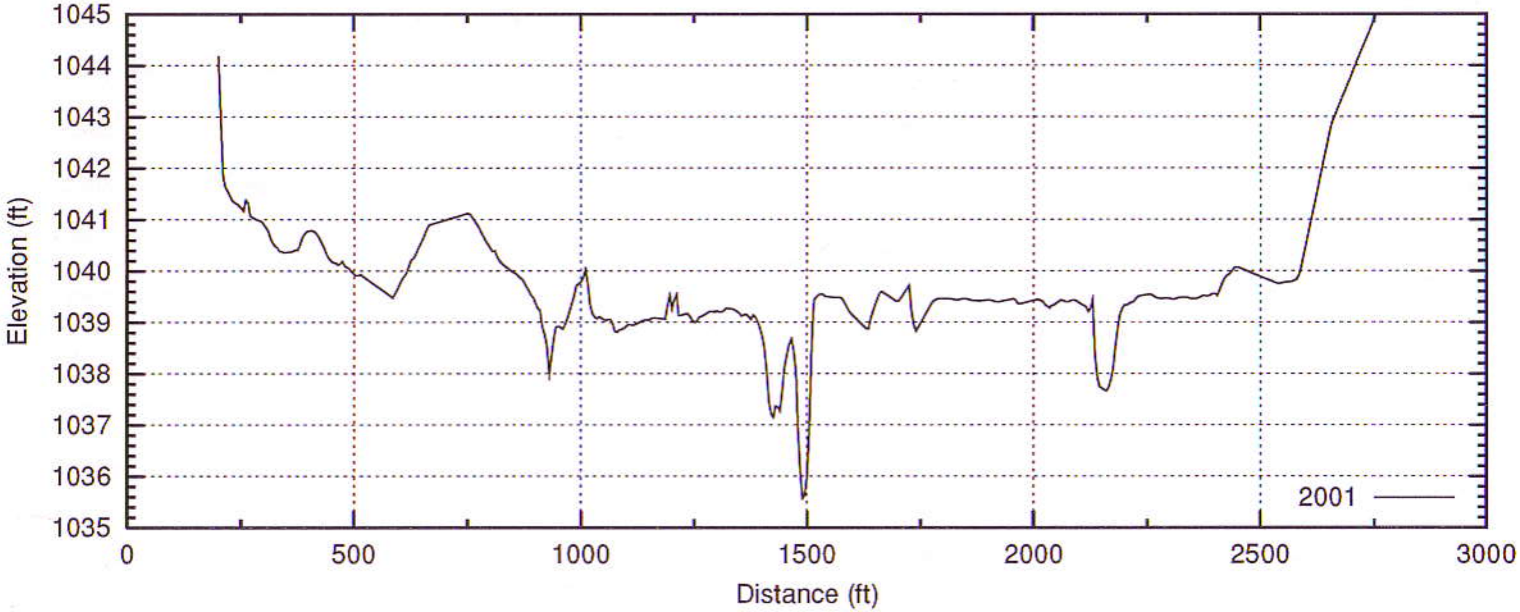




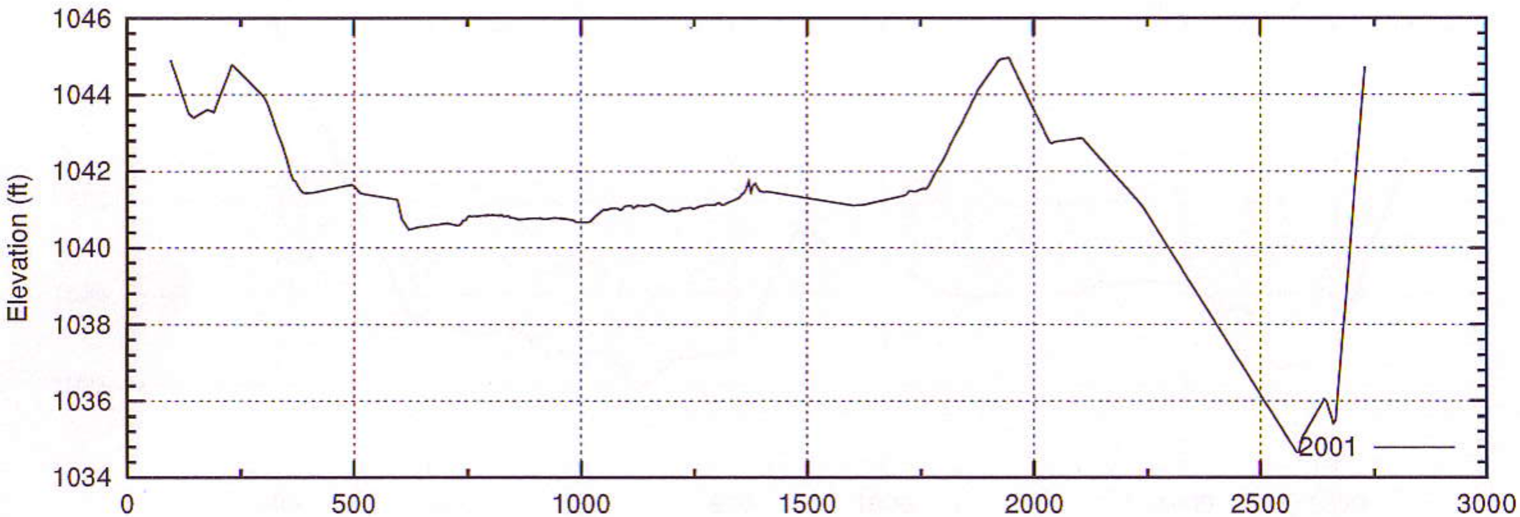
Appendix E

Lake Kickapoo

E-E'



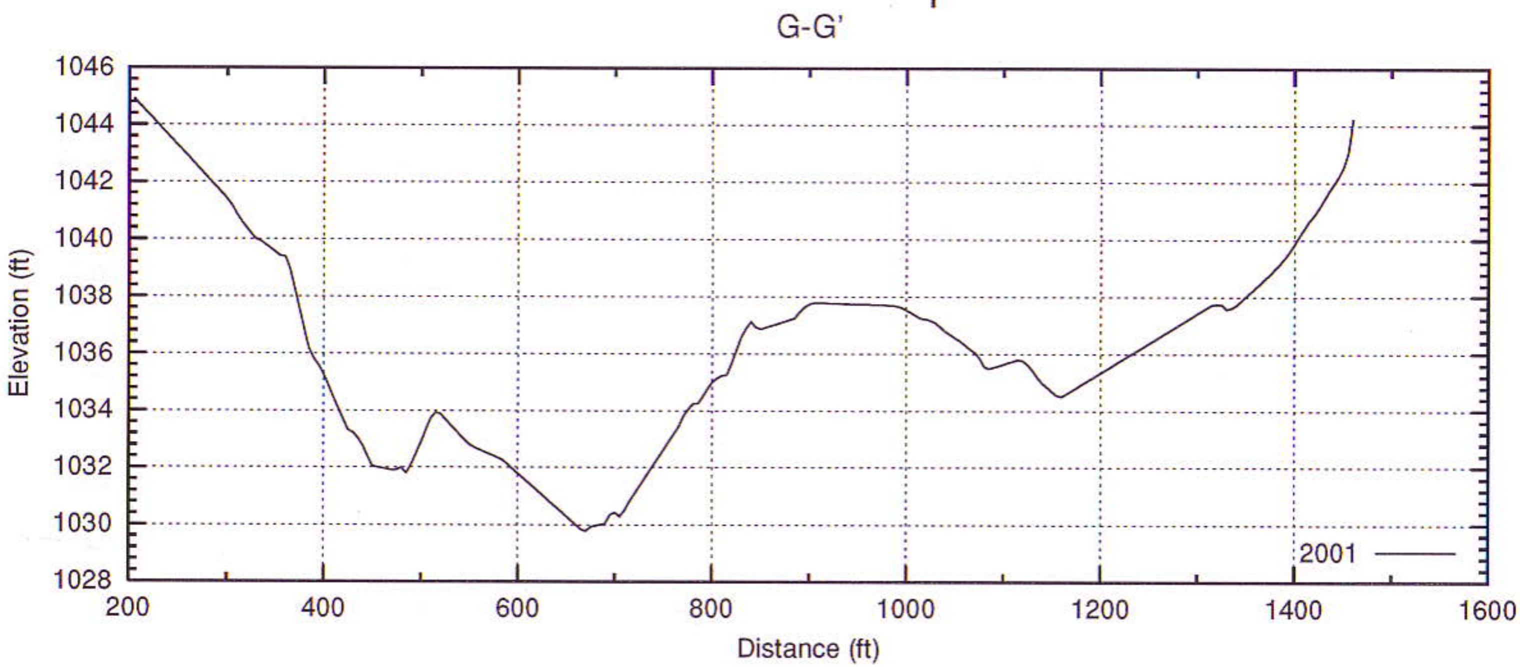
F-F'

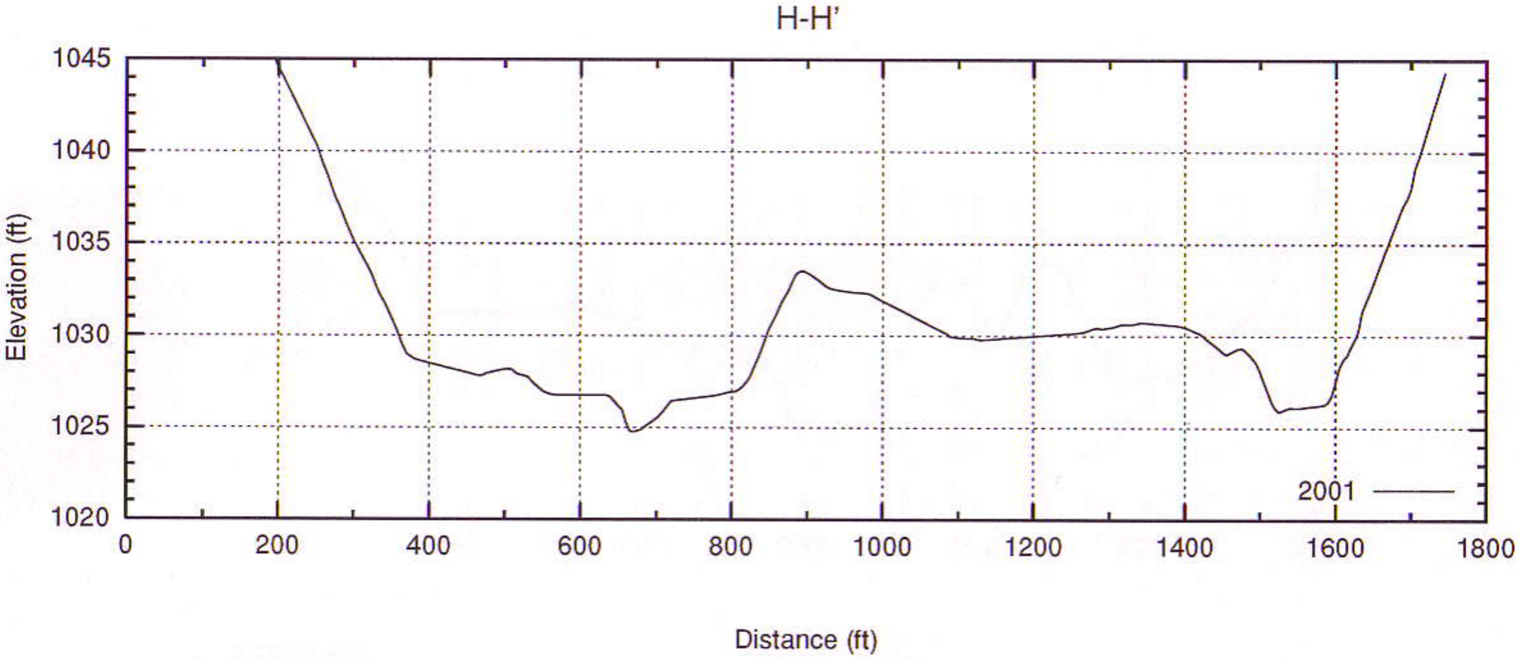


Distance (ft)

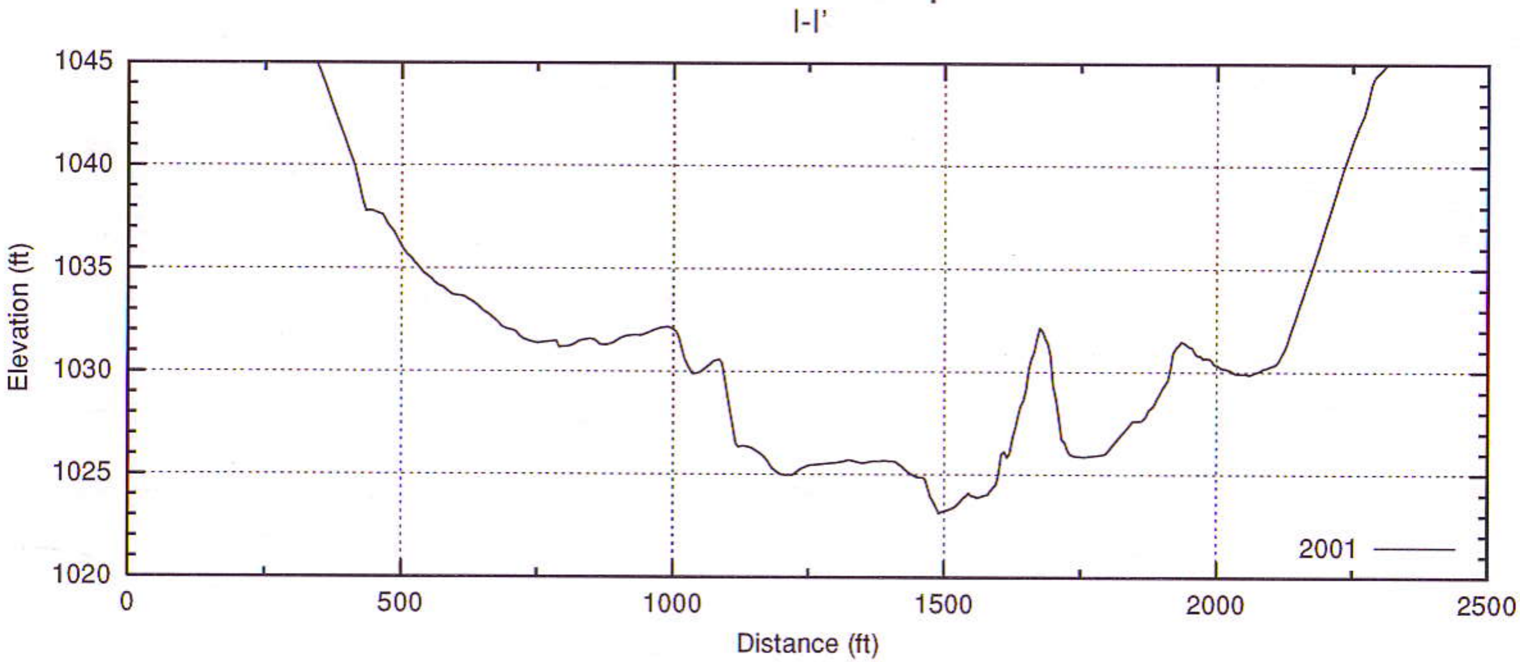
Appendix E

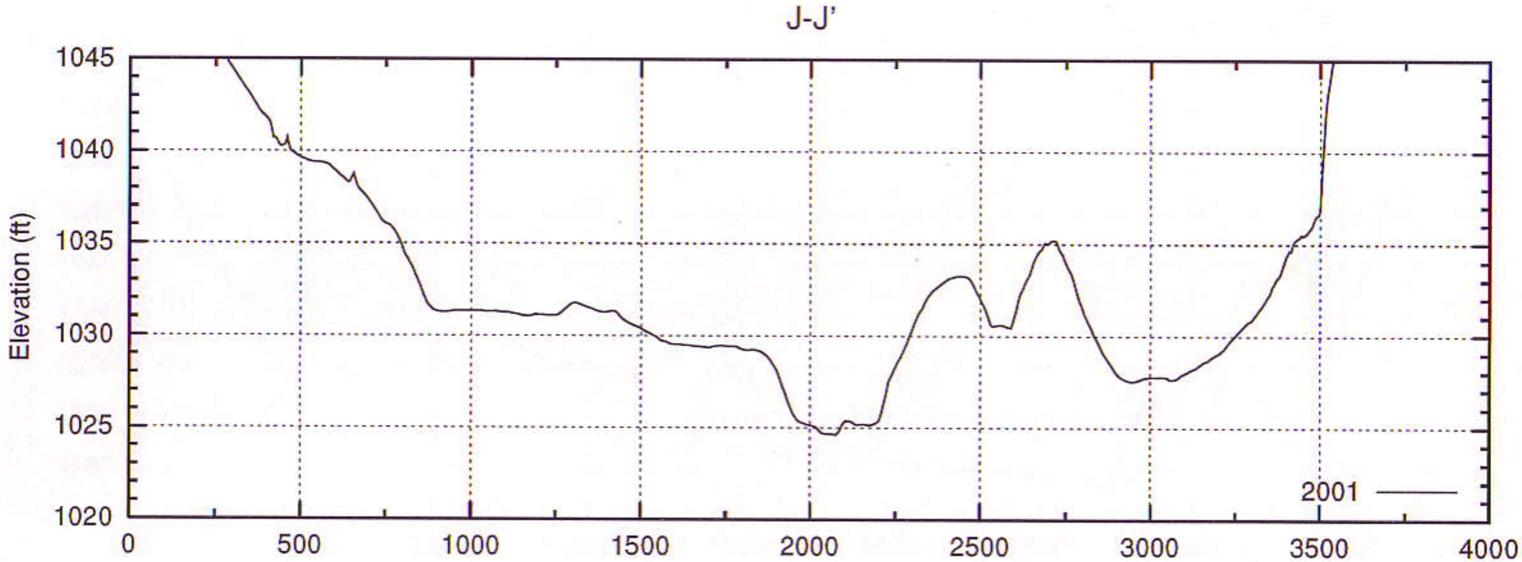
Lake Kickapoo





Lake Kickapoo



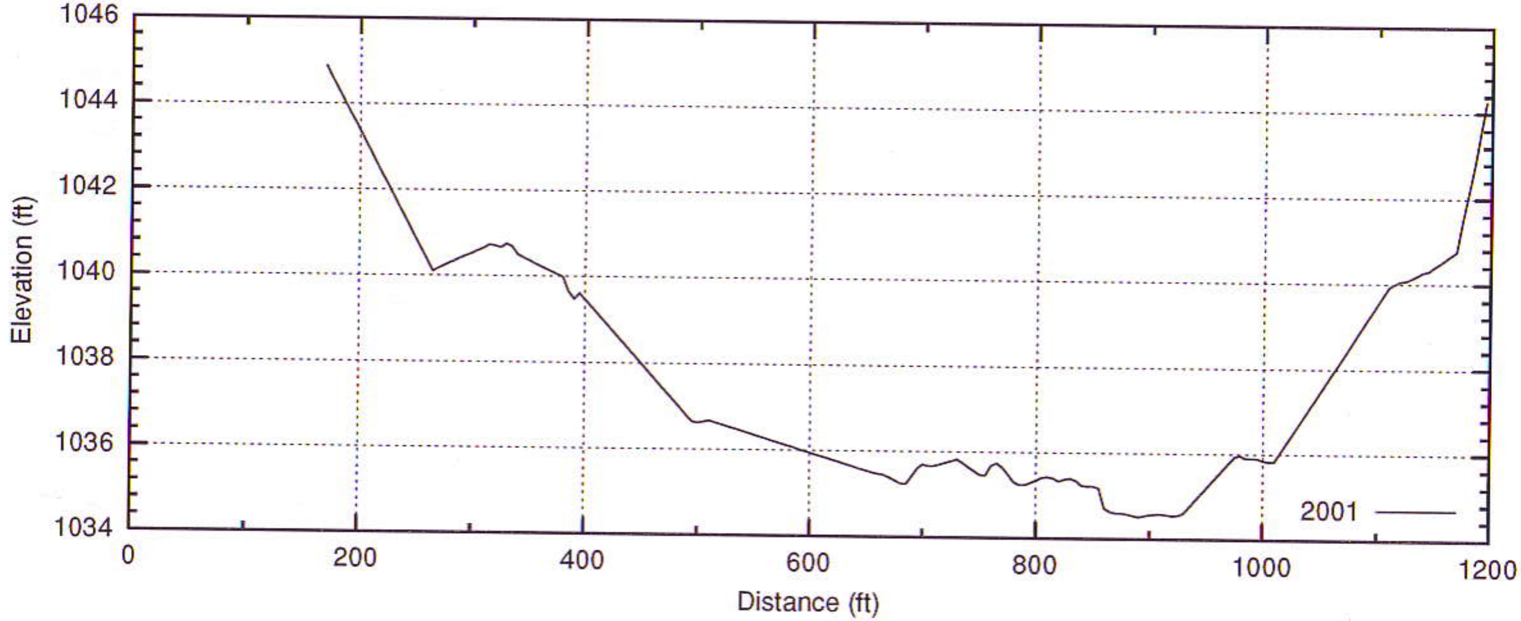


Distance (ft)

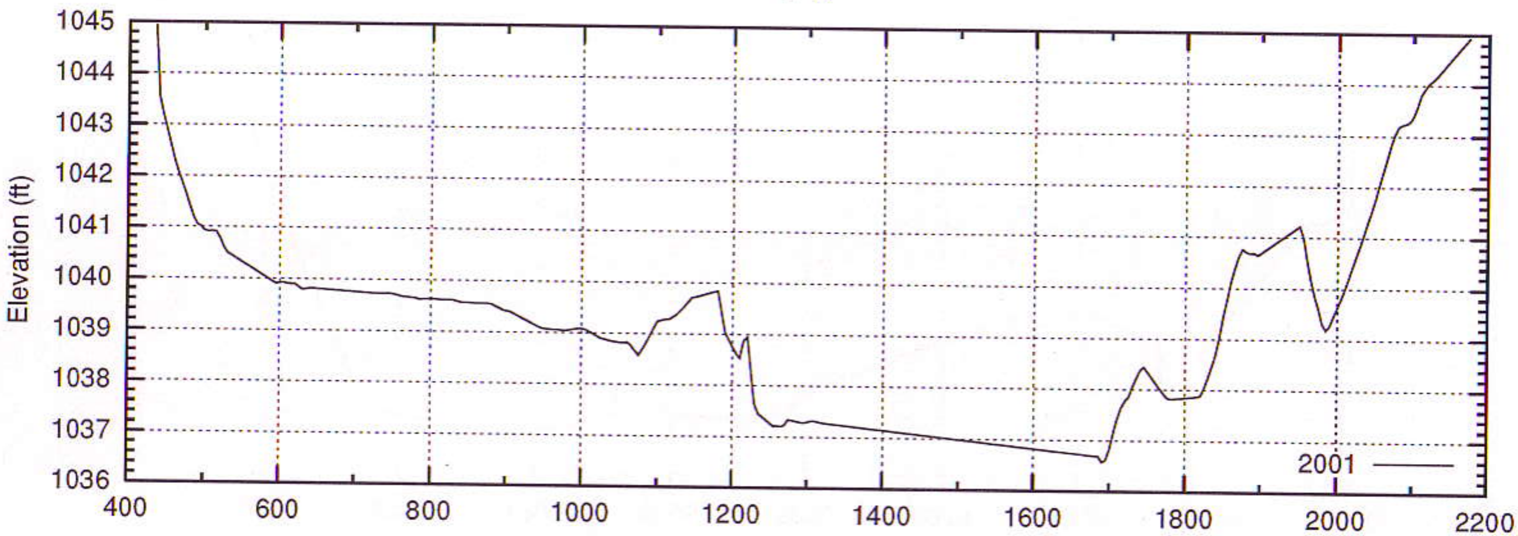
Appendix E

Lake Kickapoo

K-K'



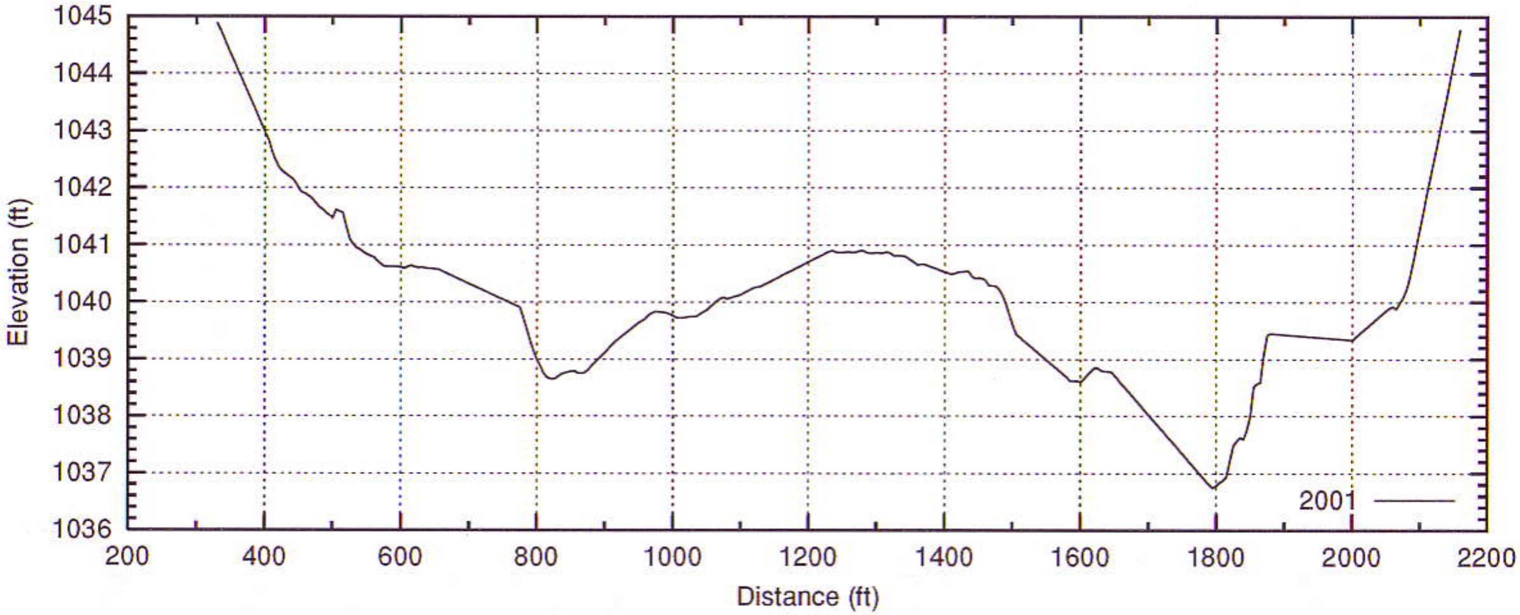
L-L'



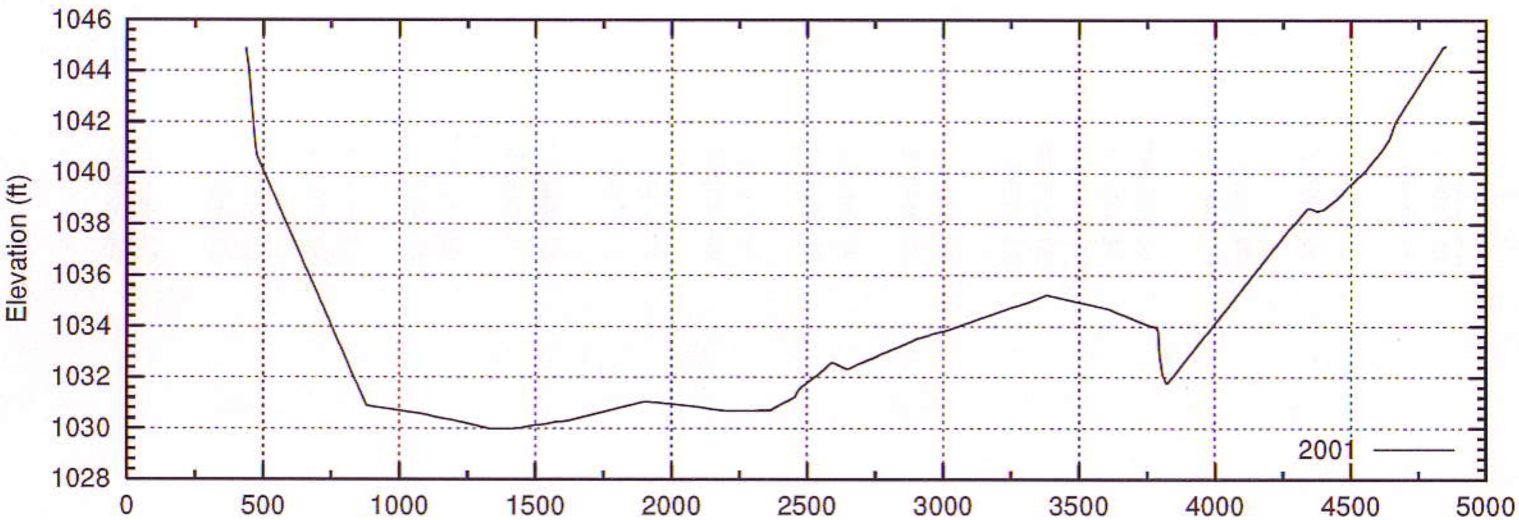
Distance (ft)

Lake Kickapoo

M-M'



N-N'



Distance (ft)

Appendix E

Appendix F
Lake Kickapoo

TEXAS WATER DEVELOPMENT BOARD APRIL 2001 SURVEY

Range Line Endpoints

State Plane NAD83 Units-feet

Range Line	X	Y
A	1880803.314	7289845.35
A'	1885507.105	7283749.23
B	1877153.169	7287324.12
B'	1880690.421	7281604.31
C	1868197.147	7284050.28
C'	1873879.331	7274304.02
D	1861461.318	7282244.02
D'	1862590.228	7275846.86
E	1857284.35	7279722.79
E'	1857886.435	7276599.47
F	1853709.467	7279609.90
F'	1854311.552	7276486.58
G	1878921.795	7288866.96
G'	1877604.735	7287399.38
H	1873954.59	7286270.47
H'	1871621.509	7285216.82
I	1870831.27	7286571.51
I'	1867670.324	7284577.10
J	1862552.597	7283485.82
J'	1861386.057	7282432.17
K	1859993.734	7276411.32
K'	1862627.857	7275696.34
L	1870981.794	7274115.87
L'	1872223.595	7271970.94
M	1877303.69	7274529.80
M'	1881518.288	7277690.75
N	1879561.51	7290409.81
N'	1878357.34	7289280.90

APPENDIX G - 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):

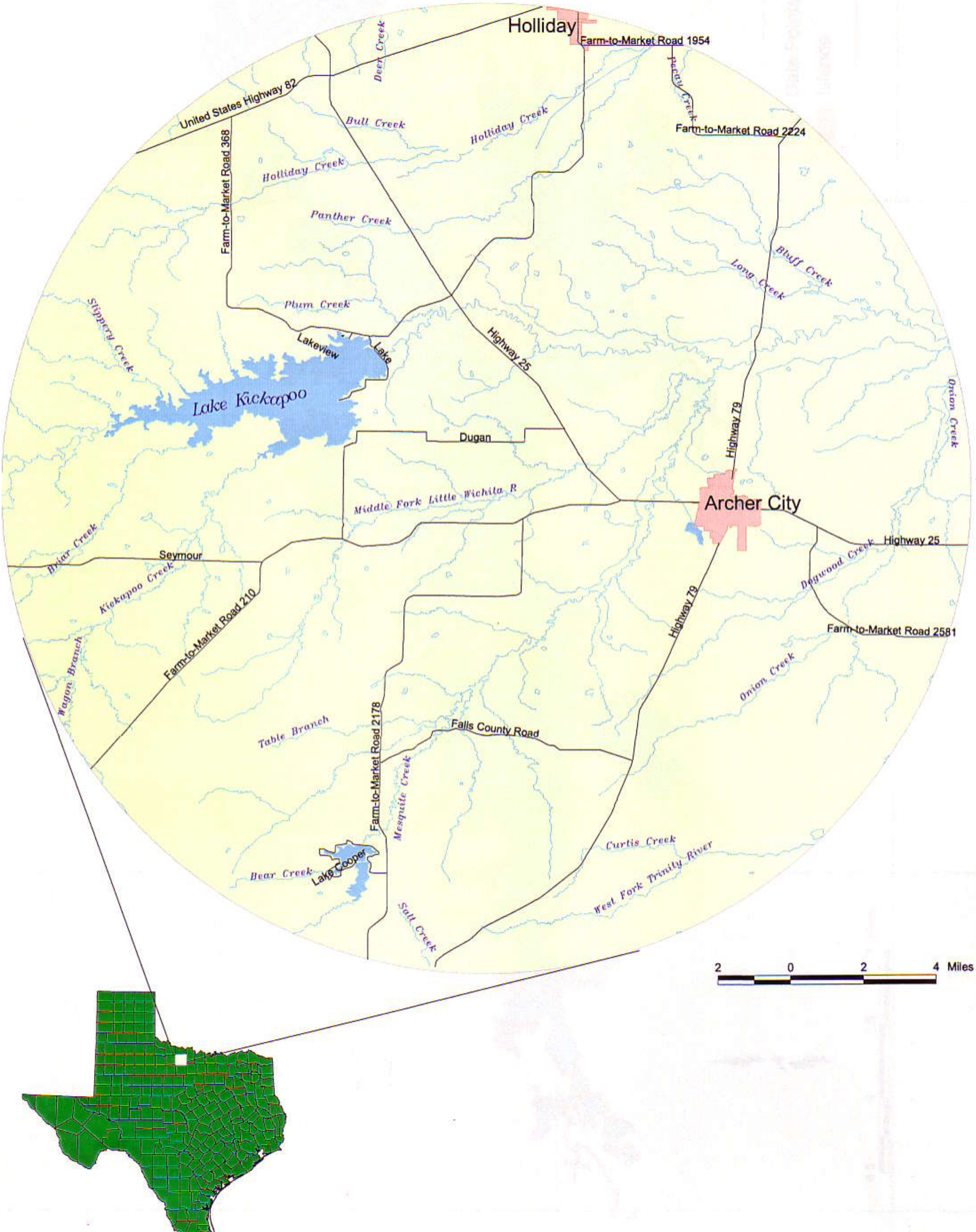
D_{80} = [((80-1.2)/4785)(4799)]+1.2

= 80.2’ (+0.2’)

Figure 1

LAKE KICKAPOO

Location Map

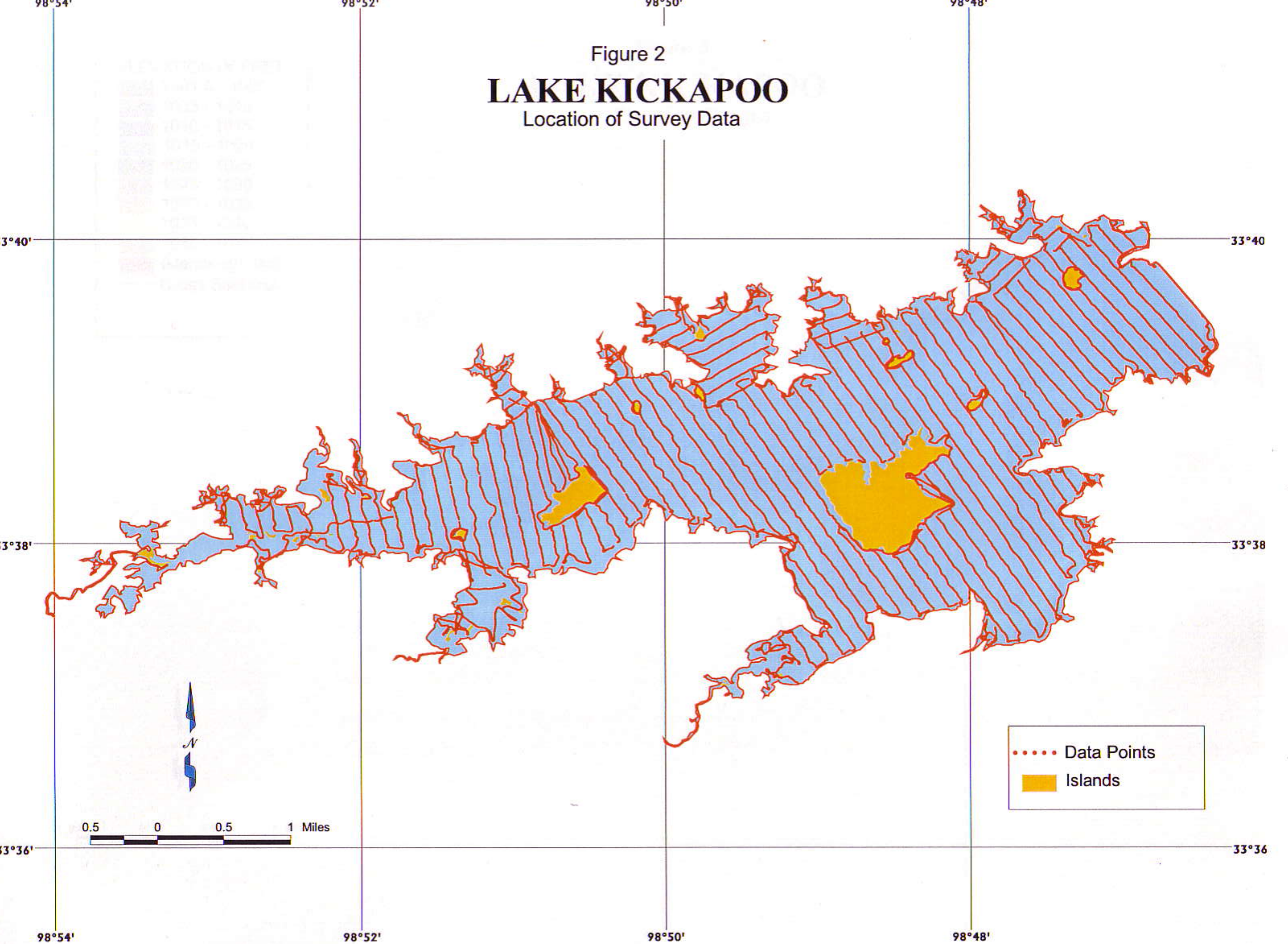


TWDB Survey April 2001

Figure 2

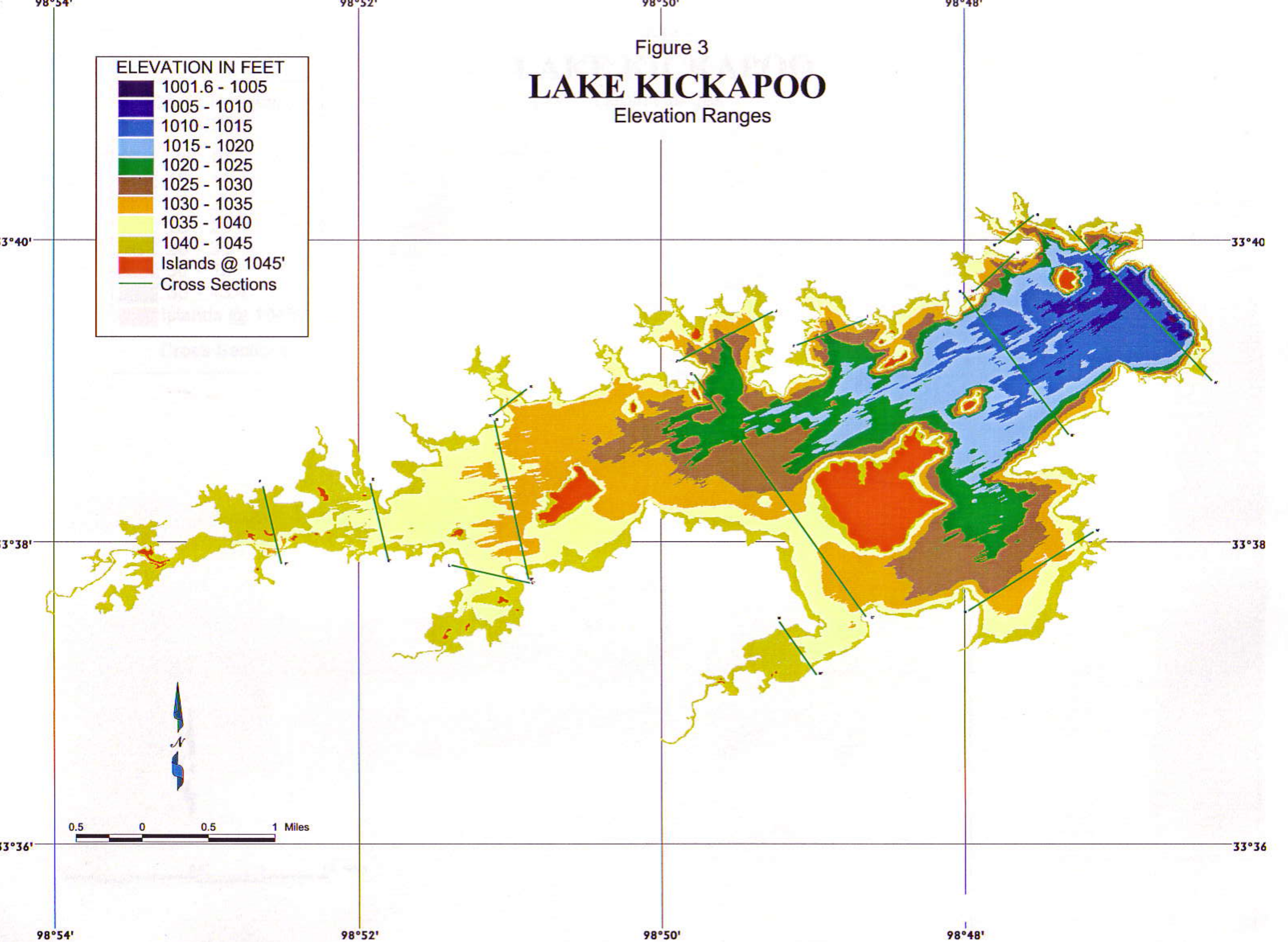
LAKE KICKAPOO

Location of Survey Data



TWDB Survey, April 2001

Figure 3
LAKE KICKAPOO
Elevation Ranges

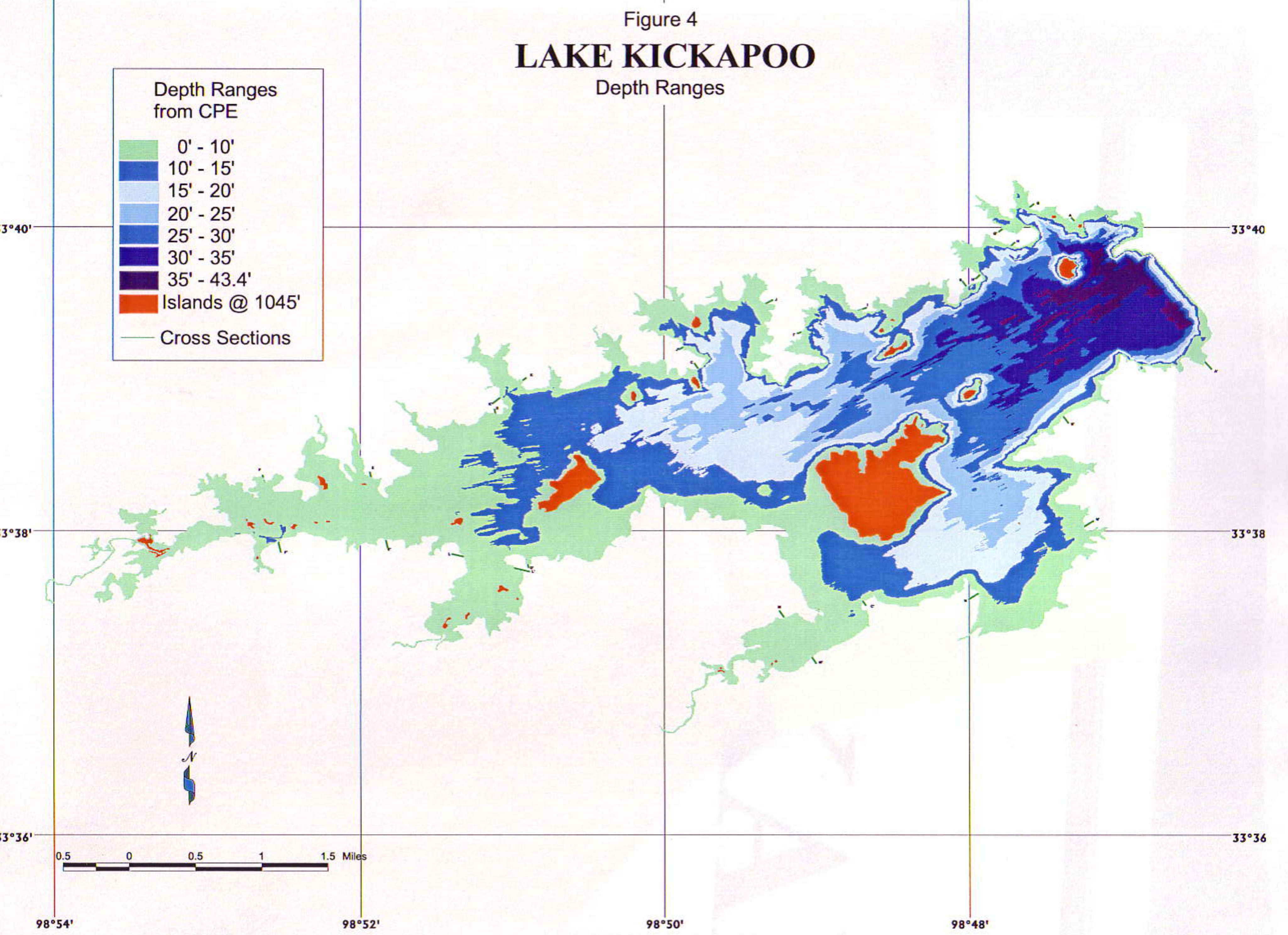


TWDB Survey April 2001

Figure 4

LAKE KICKAPOO

Depth Ranges



TWDB Survey April 2001