VOLUMETRIC SURVEY OF LAKE ARROWHEAD

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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INTRODUCTION

Staff of the Surface Water Section of the Texas Water Development Board (TWDB) conducted a volumetric survey of Lake Arrowhead during the period of June 5 through June 21, 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 Arrowhead (07314800 LAKE ARROWHEAD NEAR HENRIETTA, TX.). The datum for this gauge is reported as .40 feet below mean sea level (msl) (USGS, 2000). For the purposes of this report, adjustments have been made such that all elevation numbers are referenced to msl.

According to the original design information, the surface area was 16,200 acres at conservation pool elevation (926.0 feet); the total storage volume was estimated to be 262,100 acre-feet of water (TWDB Report 126 Part I, 1974). This report will compare the 2001 survey results with the original design information developed in 1966.

LAKE HISTORY AND GENERAL INFORMATION

Historical information on Lake Arrowhead was obtained from the TWDB (1974), and USGS (2000). Lake Arrowhead is located on Little Wichita River (Red River Basin) in Clay County, 13 miles southeast of Wichita Falls, Texas (Figure 1). At conservation pool elevation the reservoir extends approximately 13 miles upstream on Little Wichita River. Records indicate the drainage area is approximately 832 square miles of which 275 square miles is above Lake Kickapoo (USGS 2000). At conservation pool elevation (926.0 feet), the reservoir has approximately 136 miles of shoreline. Lake Arrowhead and Dam were designed for conservation water supply and recreational use.

The City of Wichita Falls (City) owns the water rights to Lake Arrowhead. 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.

The Texas Water Rights Commission granted Water Rights Permit No. 2015 (Application No. 3234) to the City of Wichita Falls on June 1, 1962. The permit allowed the City "to construct a dam and reservoir on Little Wichita River in Clay County and impound therein not to exceed 228,000 acre-feet of water. The City was authorized to divert from the proposed reservoir 45,000 acre-feet of water per annum for municipal use. The right to use the impounded waters for recreation use was also granted.

The City's current authorization is based on Certificate of Adjudication # 02-5150 issued by the Texas Water Commission on August 7, 1987. The certificate authorizes the City of Wichita Falls to maintain an existing dam and reservoir on Little Wichita River (Lake Arrowhead) and impound therein not to exceed 228,000 acre-feet (ac-ft) of water.

The owner of the certificate is authorized to divert and use not to exceed 45,000 ac-ft of water per annum for municipal purposes. The owner is also authorized to use the impounded water in the reservoir 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.

Construction for the Lake Arrowhead Project started in May 1965 and was completed in December 1966. Deliberate impoundment of water began in October 1966. Homer A. Hunter of Dallas and J. A. Wolverton of Austin were the design engineers and the general contractor was H. E. Cummins and Sons. The estimated cost of the project was $12,500,0,00.

Engineering designs (TWDB, 1974) show Lake Arrowhead Dam and appurtenant structures to consist of a rolled-earthfill embankment, approximately 15,900 feet in length (including spillway) with a maximum height of 62 feet and a crest elevation of 944.0 feet.

The spillway is an uncontrolled reinforced concrete ogee-type structure with a concrete chute. It is located at the West end of the embankment. The length of the spillway crest is approximately 1,580 feet; has a crest elevation of 926.0 feet and is also considered the conservation pool elevation.

The outlet works consist of a concrete cylindrical tower with two inlets at invert elevation 908.0 feet and 874.0 feet. Two slide gates each 5-feet in diameter control these openings. A third 5-foot diameter slide gate controls flow to a 60-inch diameter steel pipe installed inside the 8-foot diameter conduit for municipal water supply.

SURVEYING EQUIPMENT

The equipment used to perform the volumetric survey consists of a 23-foot aluminum tri-hull SeaArk craft with cabin, equipped with twin 90-Horsepower Honda outboard motors. (Reference to brand names throughout this report does not imply

endorsement by TWDB). Installed within the enclosed cabin are a Coastal Oceanographics' Helmsman Display (for navigation), an Innerspace Technology Model 449 Depth Sounder and Model 443 Velocity Profiler, Trimble Navigation, Inc. Ag132 GPS receiver, an OmniSTAR receiver, and an on-board personal 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 20-foot aluminum shallow-draft flat bottom SeaArk craft with cabin and equipped with one 115-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. Ag132 GPS receiver, an OmniSTAR receiver, and a Pentium 500 MHz laptop PC.

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 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 digital orthophoto quadrangle images (DOQ's). The DOQ's were produced by VARGIS of Texas LLC for the TEXAS Orthoimagery Program (TOP). The DOQ products produced for the Department of Information

Resources and the GIS Planning Council under the Texas Orthoimagery Program reside in the public domain. More information can be obtained on the Internet at http://www.tnris.state.tx.us/DigitalData/doqs.htm. The map boundary was created from the JOLLY, SCOTLAND, DEER CREEK and SLOOP CREEK, TEXAS DOQs and Digital Raster Graphics (DRG's) which are digital versions of 7.5-minute topographical maps. The lake elevation at the time the DOQs were photographed was 923.46 feet (January 23, 1995). The 926-foot contour was digitized from the DRG's to get the conservation pool elevation boundary.

The DOQ and DRG graphic boundary files were transformed from UTM Zone 14 datum to NAD '83, using Environmental Systems Research Institute's (ESRI) Arc/Info PROJECT command with the NADCOM (standard conversion method within the United States) 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 327 survey lines along the length of the lake and perpendicular to the original creek channels.

SURVEY PROCEDURES

Equipment Calibration and Operation

At the beginning of each day of the survey, the depth sounder was calibrated with the Innerspace 443 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 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.

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 surveying Lake Arrowhead, the speed of sound in the water column ranged from 4,746 feet per second to 4,850 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 horizontal mask setting on the on-board GPS receiver was set to 10 degrees 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 Arrowhead for approximately 10 days during the period of June 5 through June 21, 2001. The lake-level elevations varied from 922.23 feet (June 5) to 921.77 (June 21). Weather conditions during the survey consisted of temperatures in the upper 90's and low 100's. Winds were generally calm in the protected areas while strong winds were experienced in the open catchment basin. There were no weather-related delays during the survey.

Due to the water-level elevation dropping continually, the survey crew started data collection in the upper reaches of the reservoir. This strategy would allow the crew to collect data in areas that may have become too shallow to gain access by the end of the survey. While collecting data in these upper reaches, the survey crew noted an extended deltaic formation along both sides of the original channel of the Little Wichita River. Data was collected in the channel as the Little Wichita River meandered and emptied into the lake basin. Large sandbars (sediment deposits) with reeds and salt cedar (*Tamarix ramosissima*) made it difficult for the crew to continue collecting data along the pre-plotted lines that cross the original river channel. The shallow draft boat with the portable equipment was also used in the coves that were formed by the off channel creeks (Little Post Oak, East Little Post Oak and Deer Creek) on the east side of the lake. The survey crew collected data in these coves to a point navigational obstructions such as stumps, shallow depths and fences restricted the boat from advancing any further.

Once data was collected around the perimeter of the lake with the shallow draft boat, the survey crew then utilized the larger boat to collect data in the main basin. The survey crew started at the dam and collected 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 300 of the 327 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 139,910 data points were collected over the 292 miles traveled during the survey. These points, shown in Figure 2, were stored digitally on the boat's computer in 426 data files.

Little Wichita River originates in Archer County and flows in a southwest to northeast direction (Clay County). The topography surrounding Lake Arrowhead was generally flat with some relief near the flood plain of the Little Wichita River and off-channel tributaries. Along the shoreline of the reservoir, the survey crew observed red sandy soils mixed with clay. This is probably a contributing factor for the red tinted water of Lake Arrowhead. Land use around the lake was mostly rangeland used for grazing cattle. There were some residential developments on both sides of the lake near the dam. Lake Arrowhead State Park is located on the west side of the lake near the dam. The facility was well maintained and the survey crew used the boat ramps to gain access to the lake. A well-known landmark of Lake Arrowhead is the standing derricks towering over plugged oil and gas wells in the main basin of the lake.

Data Processing

The collected data was downloaded from diskettes onto TWDB's network disk drives. 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 June survey, the water surface varied from elevation 922.23 to 921.77 feet msl according to elevation data provided by USGS elevation gauge (07314800 LAKE ARROWHEAD NEAR HENRIETTA, 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 Dell Precision 410 workstation running the Microsoft's Windows NT 4.0 with service pack 6.0, Environmental System Research Institute's (ESRI) ArcGIS 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 923.43-foot boundary digitized from the DOQ's was added to assist with interpolating the volumes in the upper elevations of the lake. 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 of each triangular surface plane by determining the elevation along the leg of each 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 880-ft to 926-ft, the surface areas and volumes of the lake were computed using the ArcGIS 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.

RESULTS

Results from the 2001 TWDB survey indicate Lake Arrowhead encompasses 14,969 surface acres and contains a total volume of 235,997 acre-feet at the conservation pool elevation of 926.0 feet msl (gauge datum). Dead pool storage, the volume below the invert elevation of the low-flow outlet pipe at 874.0 feet msl, is 0 acre-feet. The shoreline at conservation pool elevation was calculated to be approximately 136 miles. The deepest point that was measured during the survey was at elevation 880.3-feet msl and corresponding to a depth of 45.7-feet, was located approximately 1450 feet upstream from Lake Arrowhead Dam.

SUMMARY AND COMPARISONS

Lake Arrowhead was completed in December 1966. Storage calculations in 1966 (TWDB 1974) reported the volume at conservation pool elevation 926.0 feet msl to be 262,100 acre-feet with a surface area of 16,200 acres. The current survey measured 14,969 surface acres, or a difference of 1,231 surface acres.

Results indicate that the lake's volume at the conservation pool elevation of 926.0 feet msl is 235,997 acre-feet. The total design volume of the reservoir was 262,100 acre-feet, thus it appears that 26,103 acre-feet of volume have been lost to siltation.

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 storage volume.

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

Year	1969 (Original Design)	2001 (TWDB Survey)
Area (acres)	16,200	14,969
Volume (acre-feet)	262,100	235,997

REFERENCES

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

2. 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 Arrowhead

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD — JUNE 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
881				0	1	1	1	2	2	2
882	3	3	4	5	6	6	7	8	9	11
883	12	13	15	16	18	20	22	24	26	28
884	30	33	35	38	41	44	47	50	54	57
885	61	65	69	74	80	86	94	103	114	127
886	141	156	174	194	216	240	266	294	323	354
887	386	420	454	490	528	566	605	645	686	728
888	771	815	860	906	953	1001	1049	1099	1151	1203
889	1256	1311	1368	1425	1484	1545	1607	1671	1737	1806
890	1876	1949	2025	2103	2183	2265	2350	2437	2525	2616
891	2708	2802	2898	2995	3094	3195	3297	3401	3507	3615
892	3724	3835	3948	4063	4179	4298	4418	4540	4664	4791
893	4919	5050	5183	5317	5454	5593	5735	5879	6025	6173
894	6323	6475	6629	6785	6944	7103	7265	7428	7593	7760
895	7929	8099	8270	8443	8618	8795	8973	9153	9334	9518
896	9702	9888	10077	10266	10458	10651	10845	11042	11240	11441
897	11645	11852	12064	12281	12502	12728	12959	13195	13436	13680
898	13929	14183	14440	14702	14967	15236	15508	15784	16064	16346
899	16632	16921	17215	17513	17815	18121	18430	18742	19057	19376
900	19697	20022	20351	20683	21017	21355	21696	22040	22386	22735
901	23088	23443	23802	24163	24527	24893	25261	25633	26006	26382
902	26760	27141	27525	27911	28300	28692	29087	29484	29885	30288
903	30694	31103	31514	31929	32346	32766	33189	33615	34043	34476
904	34911	35351	35795	36243	36696	37154	37616	38082	38552	39027
905	39505	39987	40473	40963	41457	41954	42455	42960	43468	43980
906	44494	45013	45535	46060	46590	47123	47659	48200	48745	49293
907	49845	50400	50959	51521	52087	52656	53228	53804	54382	54964
908	55549	56137	56727	57321	57919	58519	59123	59729	60339	60952
909	61569	62188	62811	63437	64067	64698	65333	65972	66613	67259
910	67907	68558	69213	69871	70533	71197	71864	72535	73209	73886
911	74566	75250	75937	76628	77322	78020	78721	79427	80136	80850
912	81569	82292	83020	83752	84488	85229	85974	86724	87478	88237
913	89001	89769	90542	91320	92103	92891	93685	94485	95290	96102
914	96920	97745	98578	99420	100271	101130	101996	102869	103749	104637
915	105530	106429	107334	108245	109162	110084	111011	111945	112885	113831
916	114783	115741	116706	117677	118654	119636	120625	121619	122619	123625
917	124635	125652	126674	127701	128735	129773	130817	131867	132921	133982
918	135047	136117	137193	138274	139360	140451	141547	142649	143755	144866
919	145982	147103	148231	149362	150499	151641	152788	153941	155098	156260
920	157426	158597	159772	160950	162133	163319	164508	165701	166897	168098
921	169301	170508	171719	172933	174151	175372	176597	177826	179058	180294
922	181534	182777	184025	185276	186531	187789	189052	190318	191588	192863
923	194141	195423	196710	197999	199294	200615	201976	203342	204712	206088
924	207467	208851	210240	211633	213032	214434	215841	217253	218668	220089
925	221514	222942	224376	225814	227256	228702	230153	231608	233067	234530
926	235997									

Appendix B

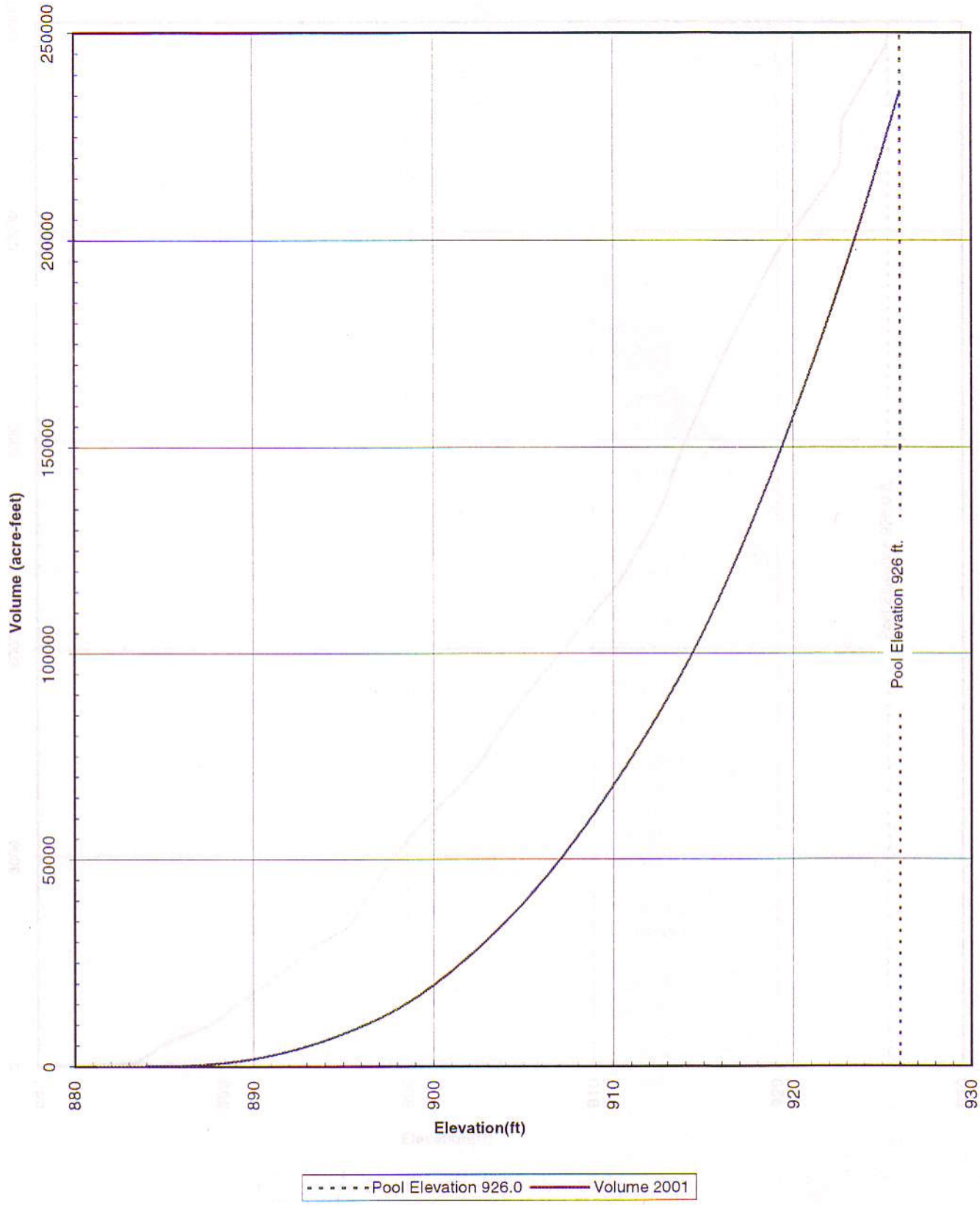
Lake Arrowhead

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — June 2001 SURVEY

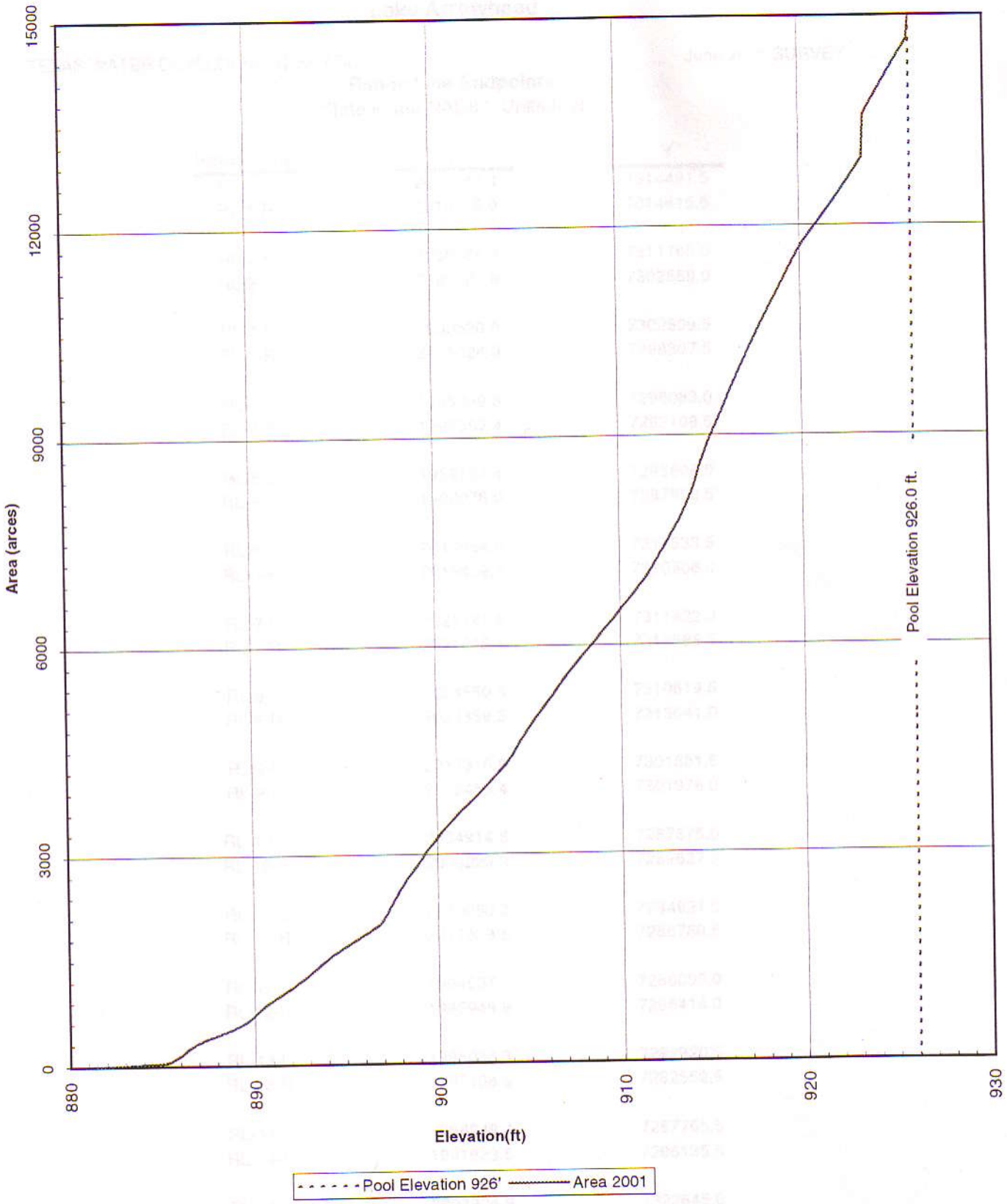
AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
881				2	2	3	3	4	4	5
882	5	6	7	7	8	9	10	11	11	12
883	13	14	15	16	17	18	19	20	22	23
884	24	25	26	28	29	31	32	34	35	37
885	39	41	46	52	60	70	84	100	117	133
886	148	164	185	211	233	251	269	287	301	315
887	329	341	353	366	377	387	396	405	415	424
888	435	445	455	464	474	484	495	505	517	529
889	542	556	570	583	598	613	631	651	672	694
890	719	743	766	789	813	837	858	876	896	915
891	932	949	965	981	998	1015	1032	1049	1066	1084
892	1102	1120	1139	1157	1176	1194	1213	1232	1253	1275
893	1296	1316	1336	1358	1380	1404	1428	1450	1470	1490
894	1511	1532	1552	1571	1590	1608	1625	1642	1659	1676
895	1692	1708	1724	1740	1756	1773	1790	1807	1823	1839
896	1855	1871	1889	1905	1922	1938	1956	1974	1995	2021
897	2054	2098	2141	2190	2240	2285	2333	2382	2426	2469
898	2511	2553	2596	2635	2672	2708	2742	2775	2808	2841
899	2877	2914	2960	3002	3039	3073	3105	3137	3167	3200
900	3234	3269	3301	3333	3364	3395	3422	3449	3477	3508
901	3540	3571	3597	3624	3650	3675	3700	3723	3747	3771
902	3796	3823	3849	3875	3903	3933	3963	3991	4019	4046
903	4074	4102	4130	4157	4186	4215	4243	4273	4304	4339
904	4375	4417	4461	4507	4554	4599	4640	4681	4722	4763
905	4803	4841	4880	4919	4955	4991	5028	5063	5099	5134
906	5168	5201	5236	5274	5312	5350	5387	5427	5466	5502
907	5536	5571	5605	5640	5673	5706	5738	5771	5803	5833
908	5862	5892	5924	5956	5989	6020	6050	6082	6115	6148
909	6180	6213	6245	6275	6306	6336	6367	6399	6433	6467
910	6499	6533	6565	6596	6627	6660	6692	6722	6752	6787
911	6822	6856	6889	6924	6960	6995	7032	7074	7118	7165
912	7211	7255	7298	7340	7383	7429	7474	7521	7567	7615
913	7662	7707	7752	7799	7854	7911	7970	8026	8085	8148
914	8217	8289	8372	8467	8551	8626	8697	8766	8837	8901
915	8963	9022	9081	9138	9194	9250	9307	9366	9429	9490
916	9552	9617	9679	9738	9796	9855	9913	9970	10027	10082
917	10137	10192	10249	10304	10358	10412	10467	10522	10576	10628
918	10680	10731	10782	10834	10886	10937	10987	11037	11086	11137
919	11189	11242	11293	11343	11394	11446	11497	11549	11596	11642
920	11686	11728	11767	11804	11842	11878	11913	11947	11982	12017
921	12053	12088	12124	12160	12196	12232	12268	12305	12342	12379
922	12416	12454	12492	12530	12568	12606	12645	12684	12723	12762
923	12802	12842	12882	12922	12963	13585	13633	13680	13727	13773
924	13820	13866	13912	13957	14003	14048	14093	14137	14182	14226
925	14270	14313	14356	14399	14442	14485	14527	14569	14611	14652
926	14969									



Lake Arrowhead
June 2001
Prepared by: TWDB

Appendix C Elevation vs. Volume



Lake Arrowhead
June 2001
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Appendix D Elevation vs. Area

Appendix E

Lake Arrowhead

TEXAS WATER DEVELOPMENT BOARD June 2001 SURVEY

Range Line Endpoints

State Plane NAD83 Units-feet

Range Line	X	Y
RL-1-L	2011383.4	7314491.5
RL-1-R	2019415.9	7314415.5
RL-2-L	2005064.4	7311765.0
RL-2-R	2020381.8	7302559.0
RL-3-L	2000530.0	7302509.5
RL-3-R	2005024.0	7298307.5
RL-4-L	1995089.8	7296083.0
RL-4-R	1998559.4	7292108.5
RL-5-L	1989594.4	7295608.0
RL-5-R	1992076.0	7287950.5
RL-6-L	2019964.0	7317533.5
RL-6-R	2019459.3	7320506.0
RL-7-L	2021121.8	7311422.0
RL-7-R	2021018.1	7313598.5
RL-8-L	2024550.5	7310619.5
RL-8-R	2024359.3	7313041.0
RL-9-L	2017318.8	7301681.5
RL-9-R	2019455.4	7301978.0
RL-10-L	2004914.6	7287875.0
RL-10-R	2006229.3	7289627.5
RL-11-L	2010080.3	7284921.0
RL-11-R	2011639.6	7286780.5
RL-12-L	1994537.0	7286095.0
RL-12-R	1995948.9	7286414.0
RL-13-L	1995036.3	7282920.5
RL-13-R	1997138.5	7282552.5
RL-14-L	1988248.4	7287765.5
RL-14-R	1991633.5	7286135.5
RL-15-L	2003904.8	7322645.0
RL-15-R	2016703.4	7322564.5
RL-16-L	2001954.5	7320408.0
RL-16-R	2004401.1	7318540.5

Appendix E (continued)

Lake Arrowhead

TEXAS WATER DEVELOPMENT BOARD June 2001 SURVEY

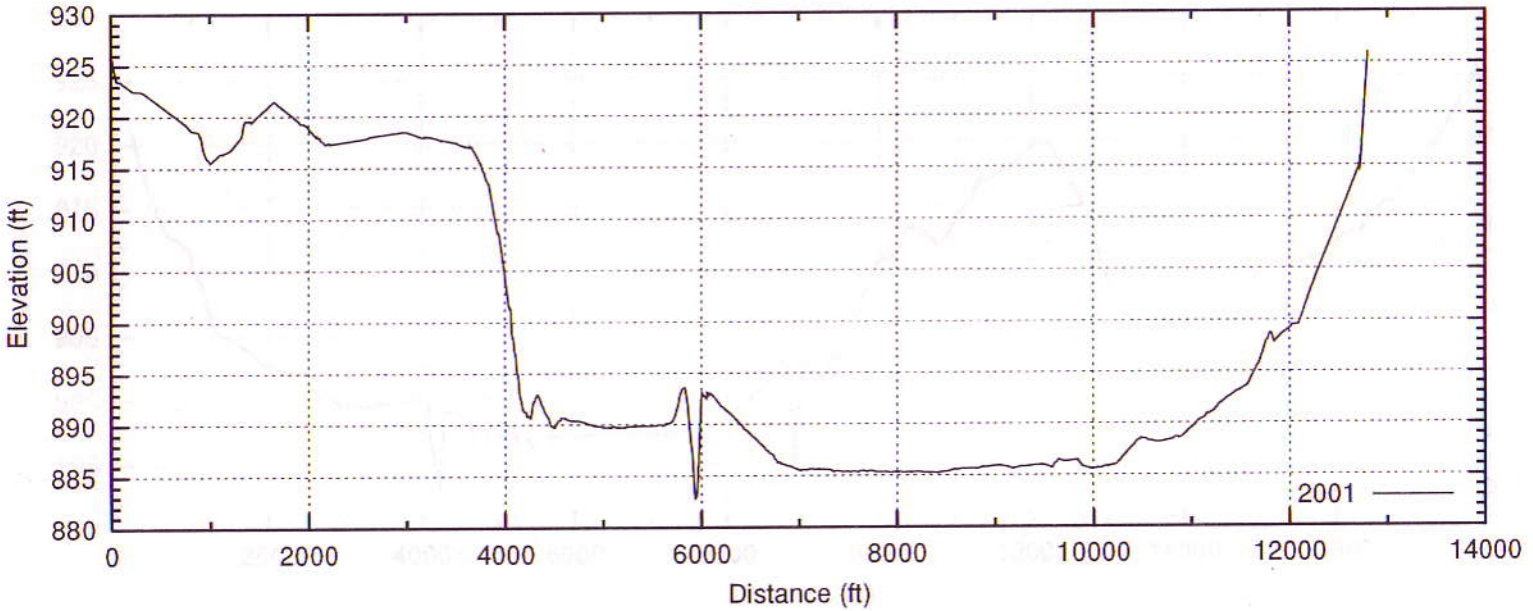
Range Line Endpoints

State Plane NAD83 Units-feet

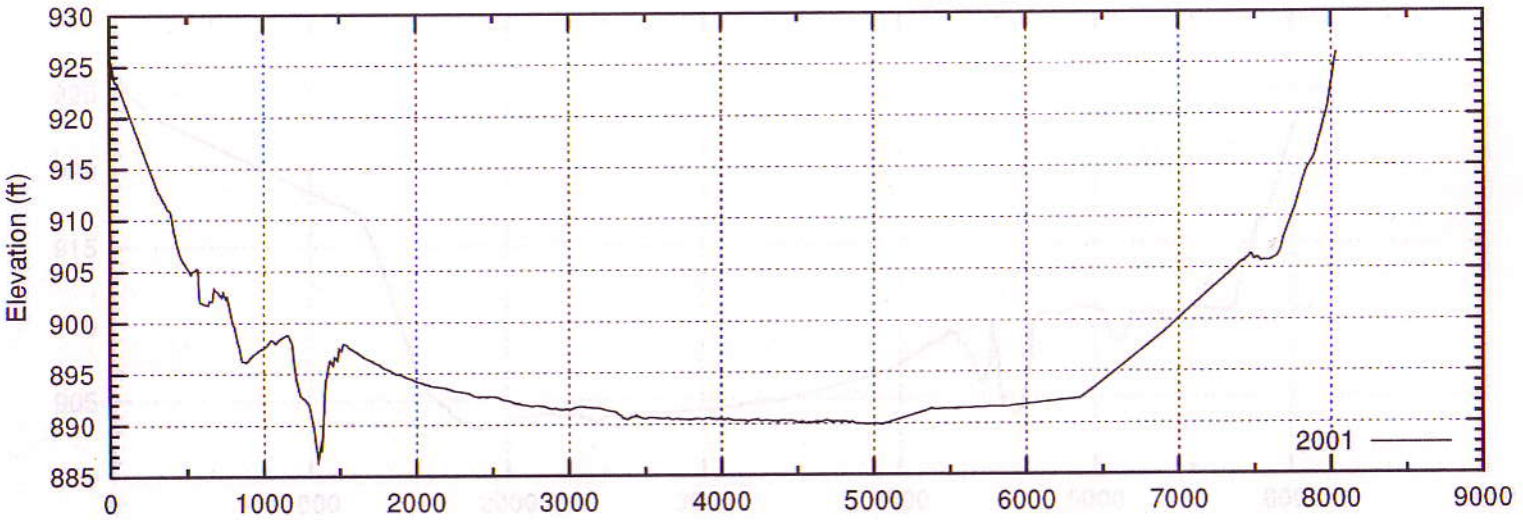
Range Line	X	Y
RL-17-L	2001890.4	7293606.0
RL-17-R	2005077.5	7293915.5
RL-18-L	1986000.5	7296542.5
RL-18-R	1984624.1	7290876.0

Lake Arrowhead

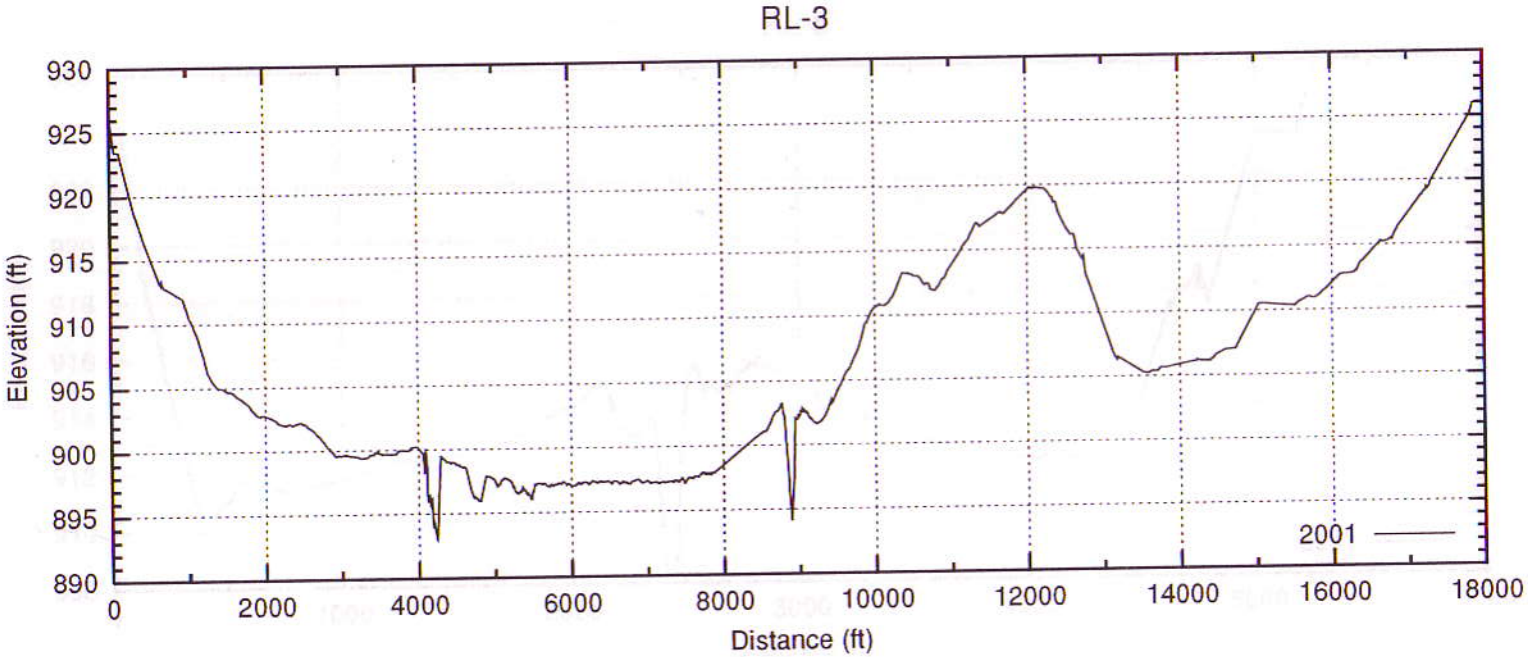
RL-1

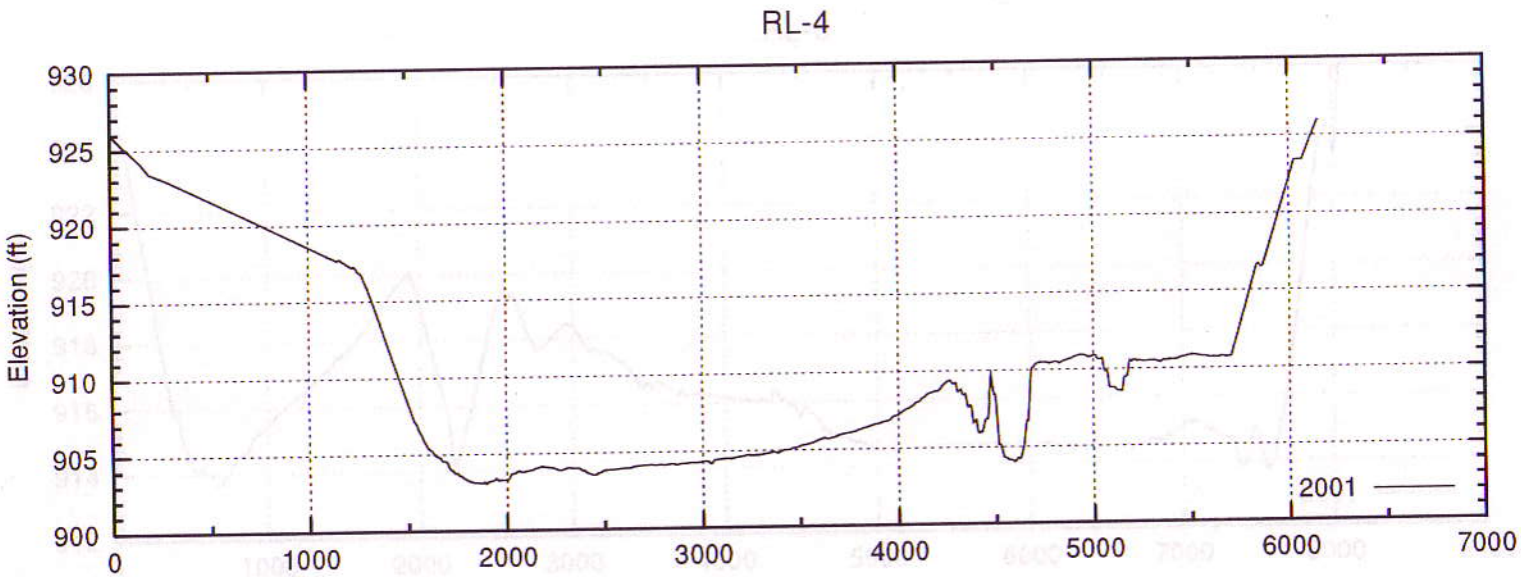


RL-2



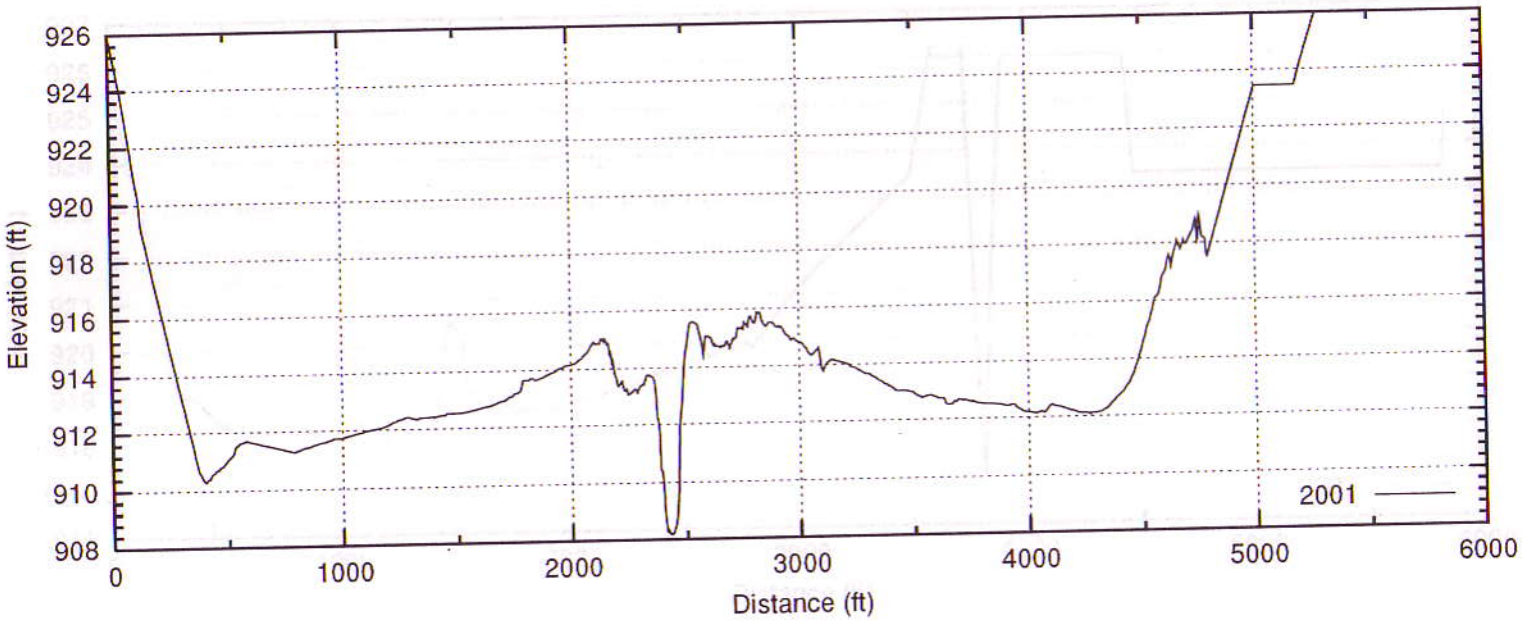
Lake Arrowhead



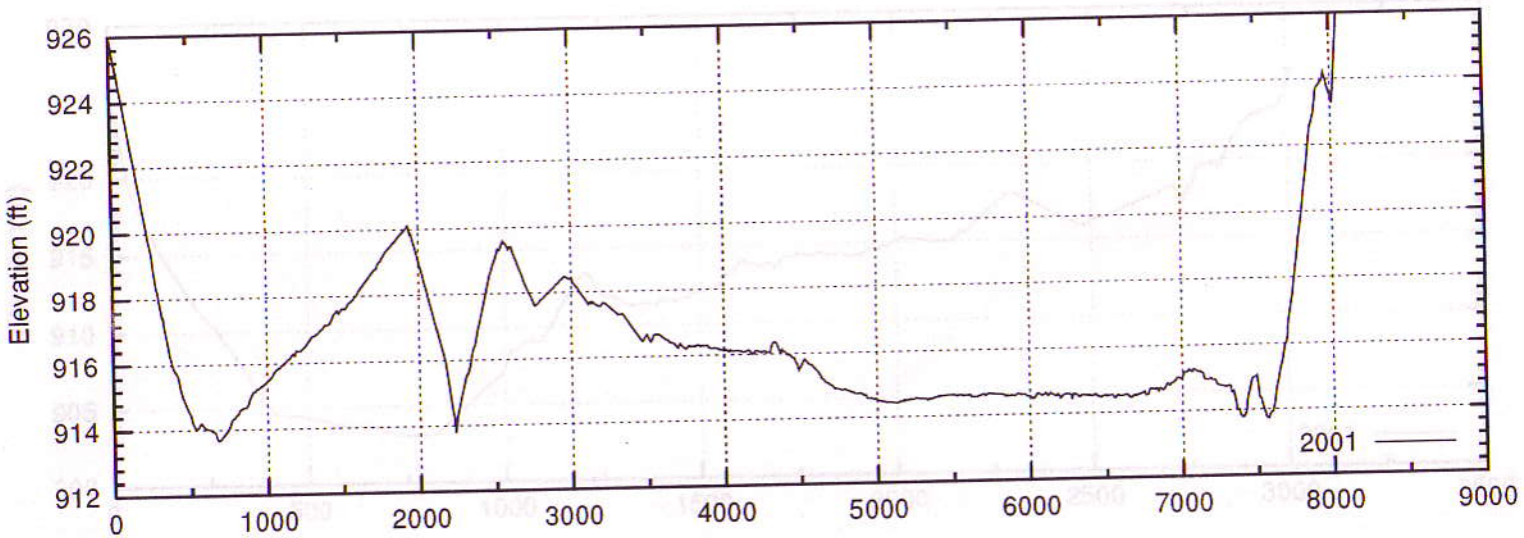


Lake Arrowhead

RL-5

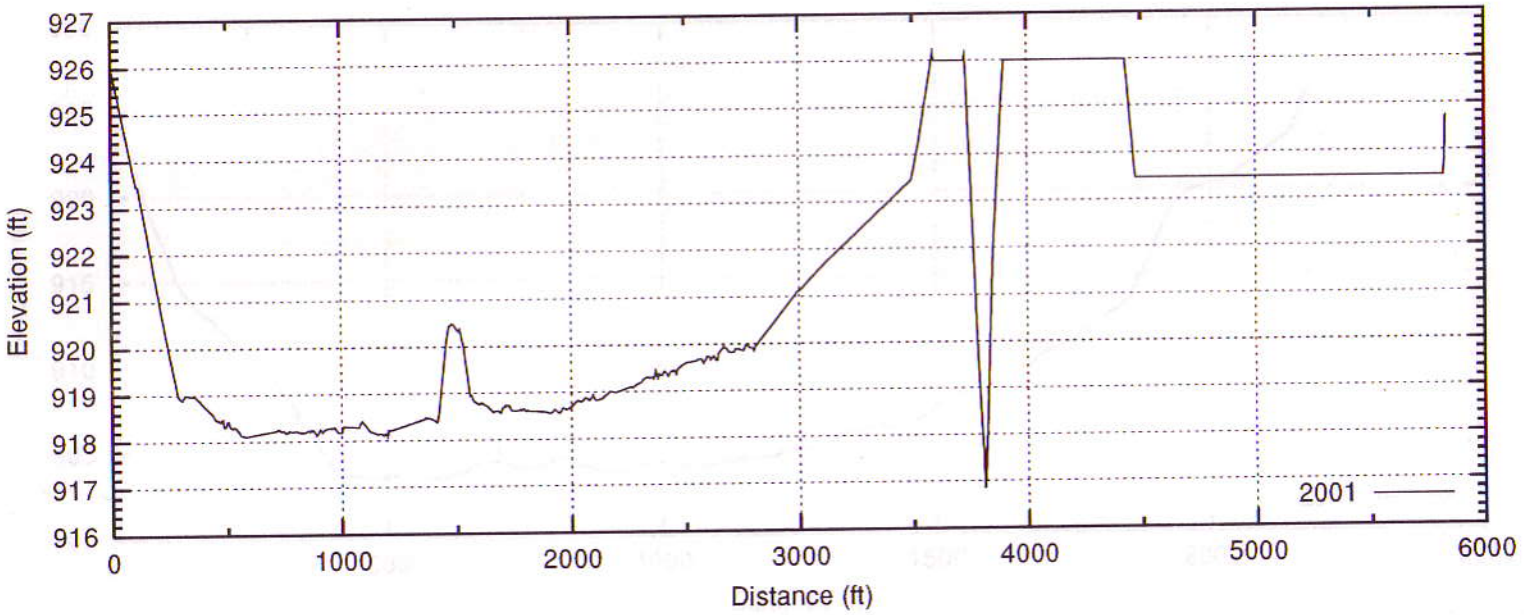


RL-6

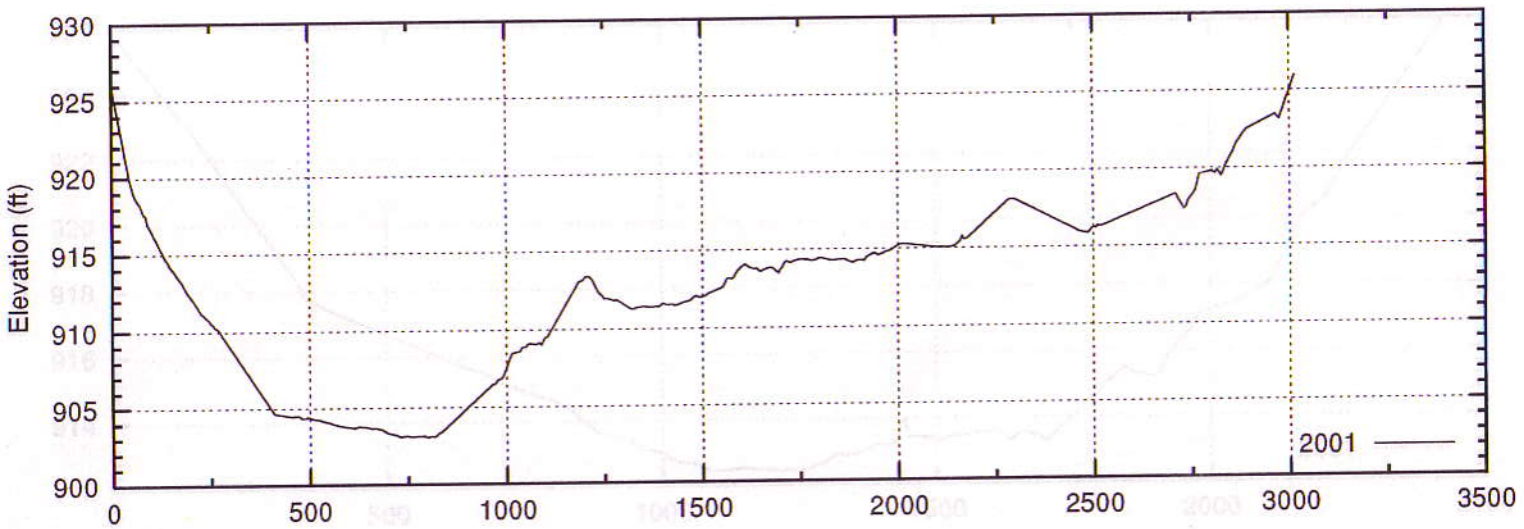


Lake Arrowhead

RL-7



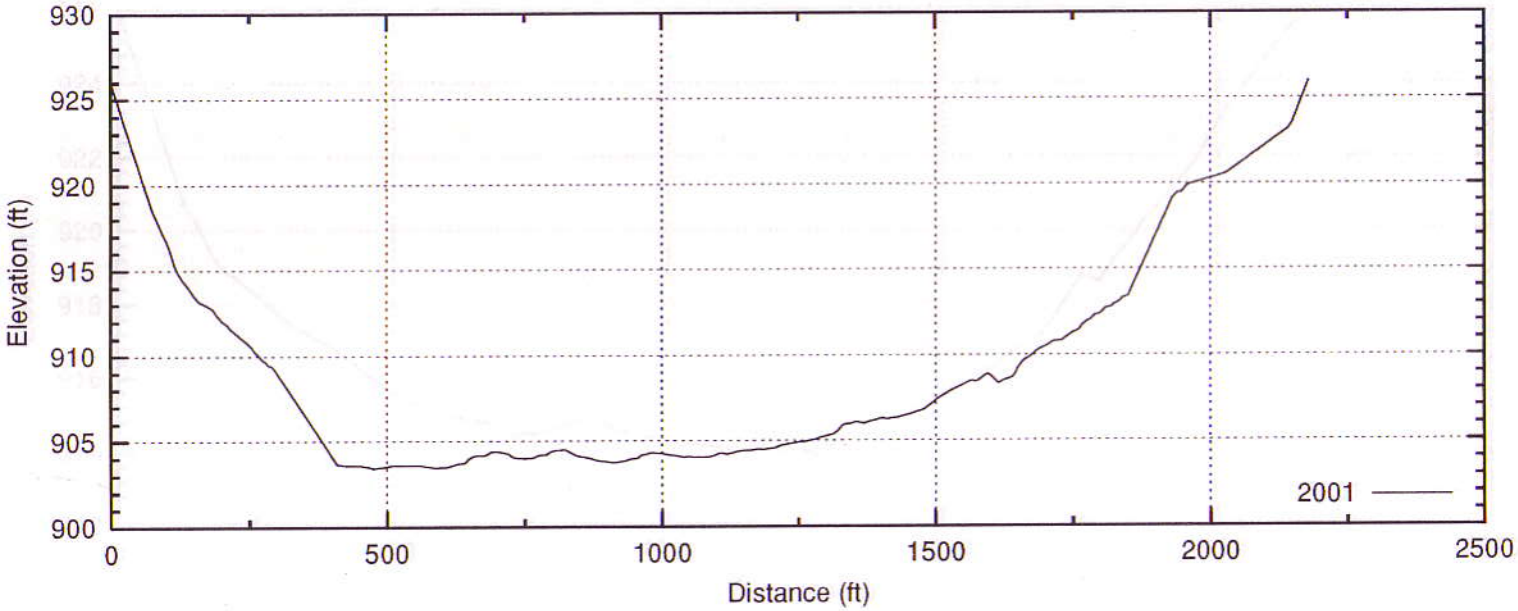
RL-8



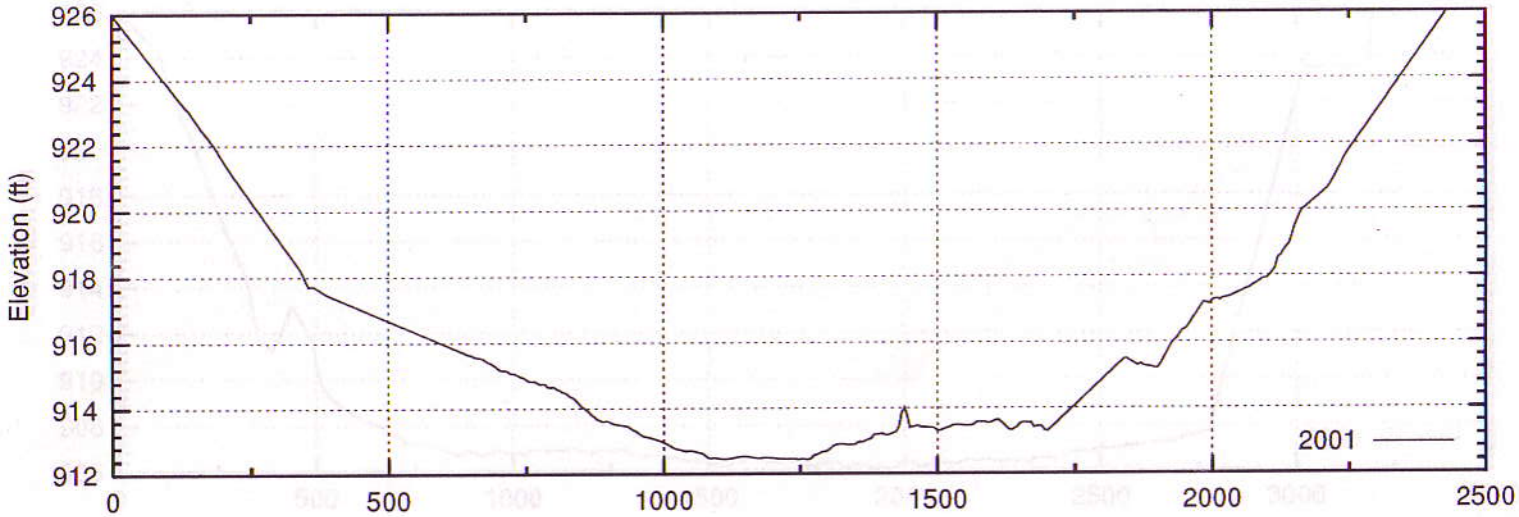
Appendix E

Lake Arrowhead

RL-9



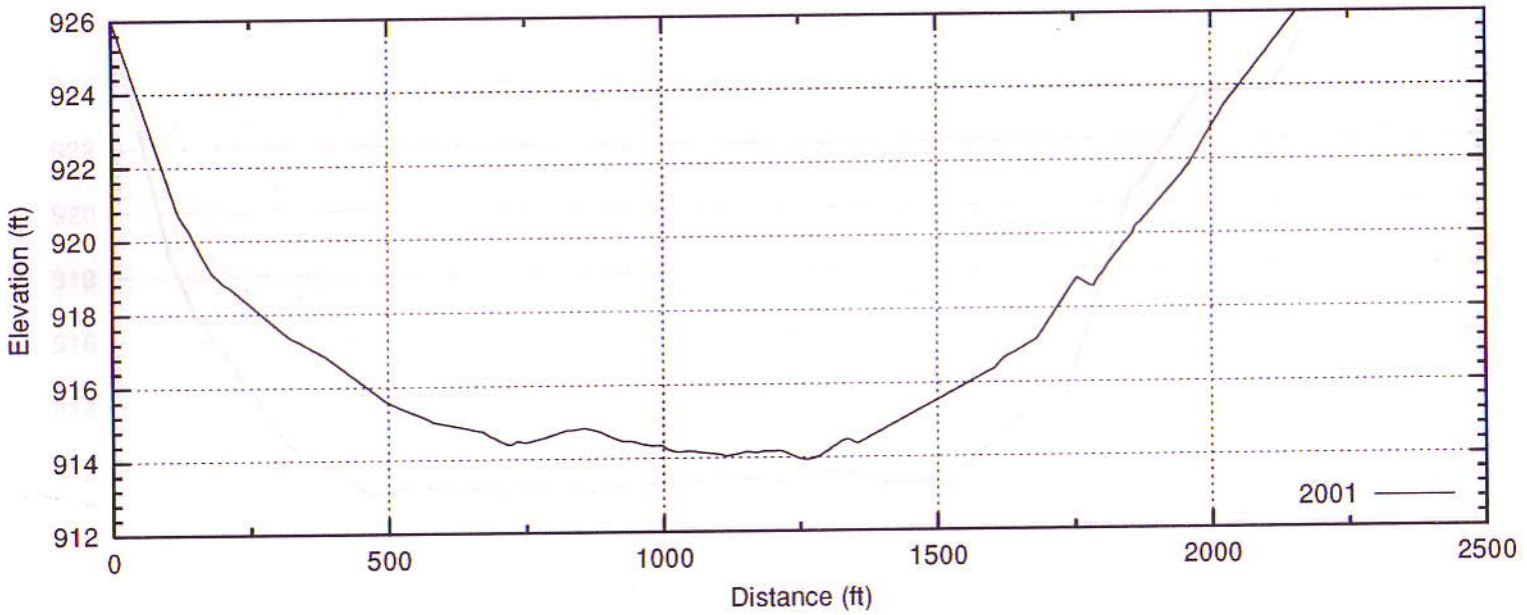
RL-10



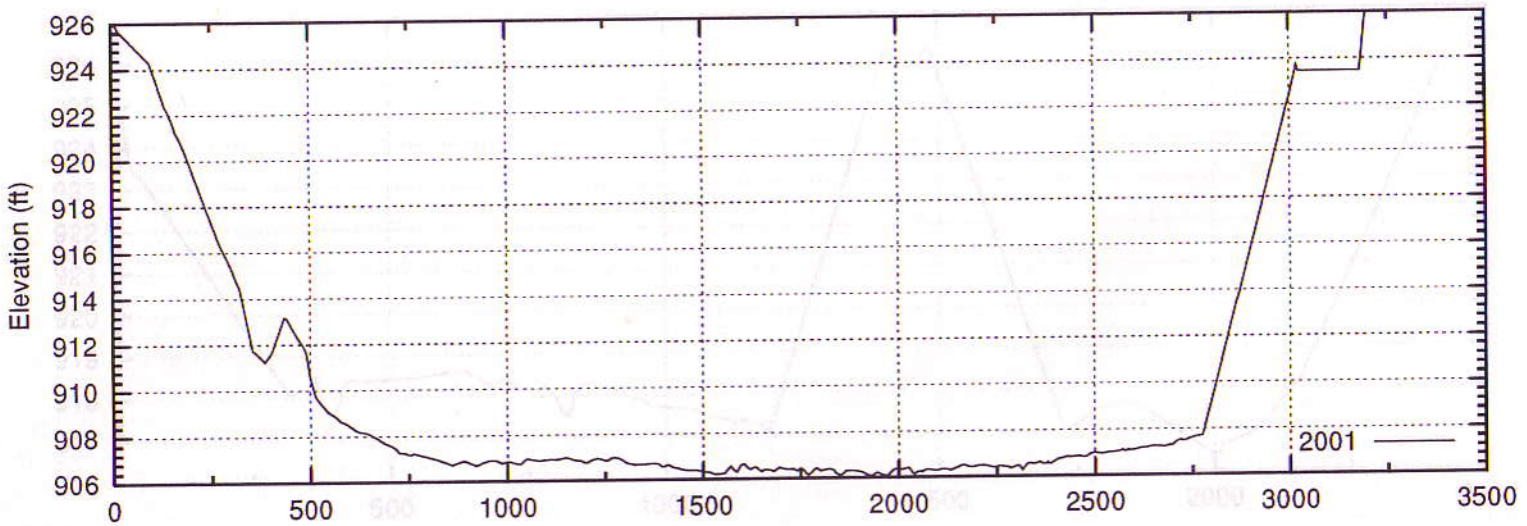
Appendix E

Lake Arrowhead

RL-11

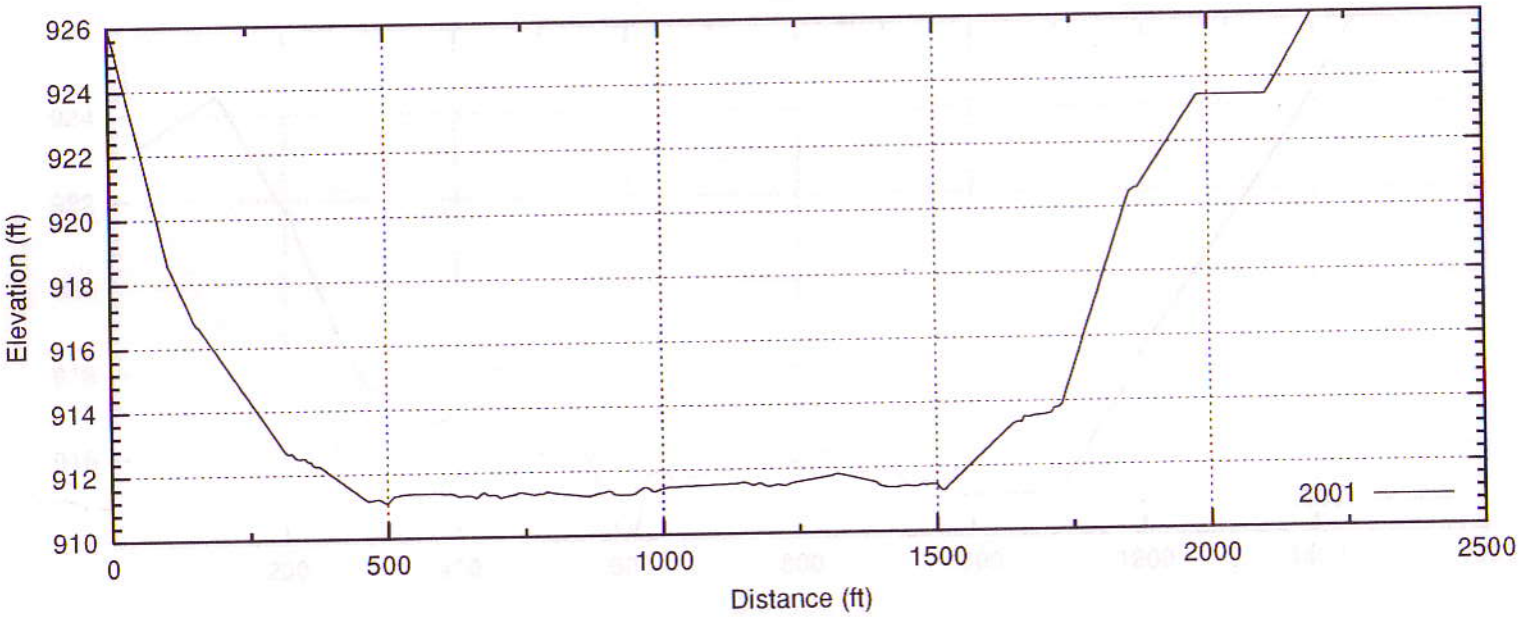


RL-12

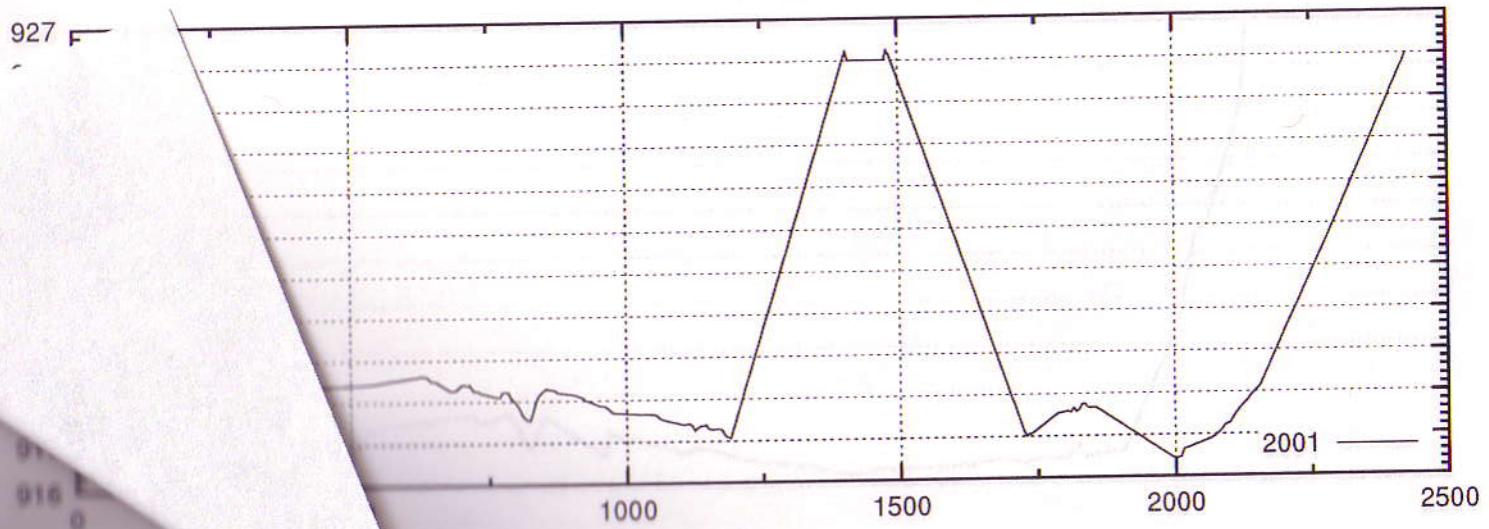


Lake Arrowhead

RL-13

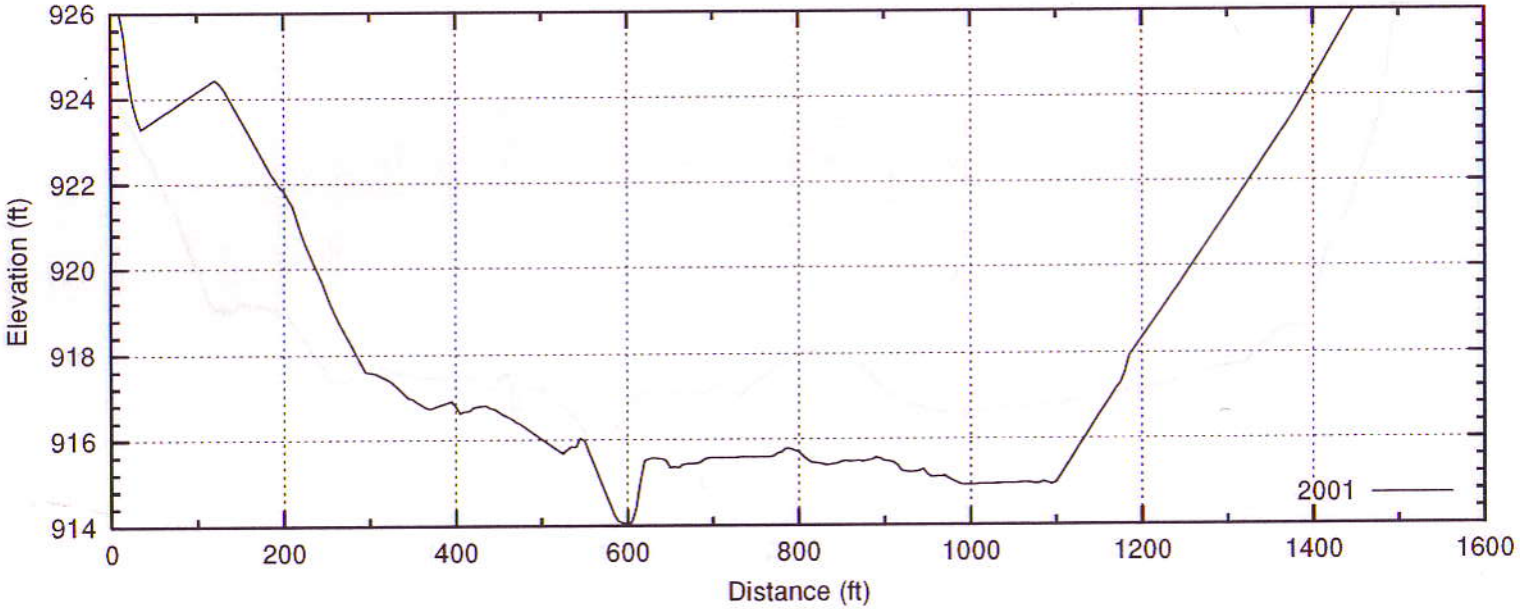


RL-14

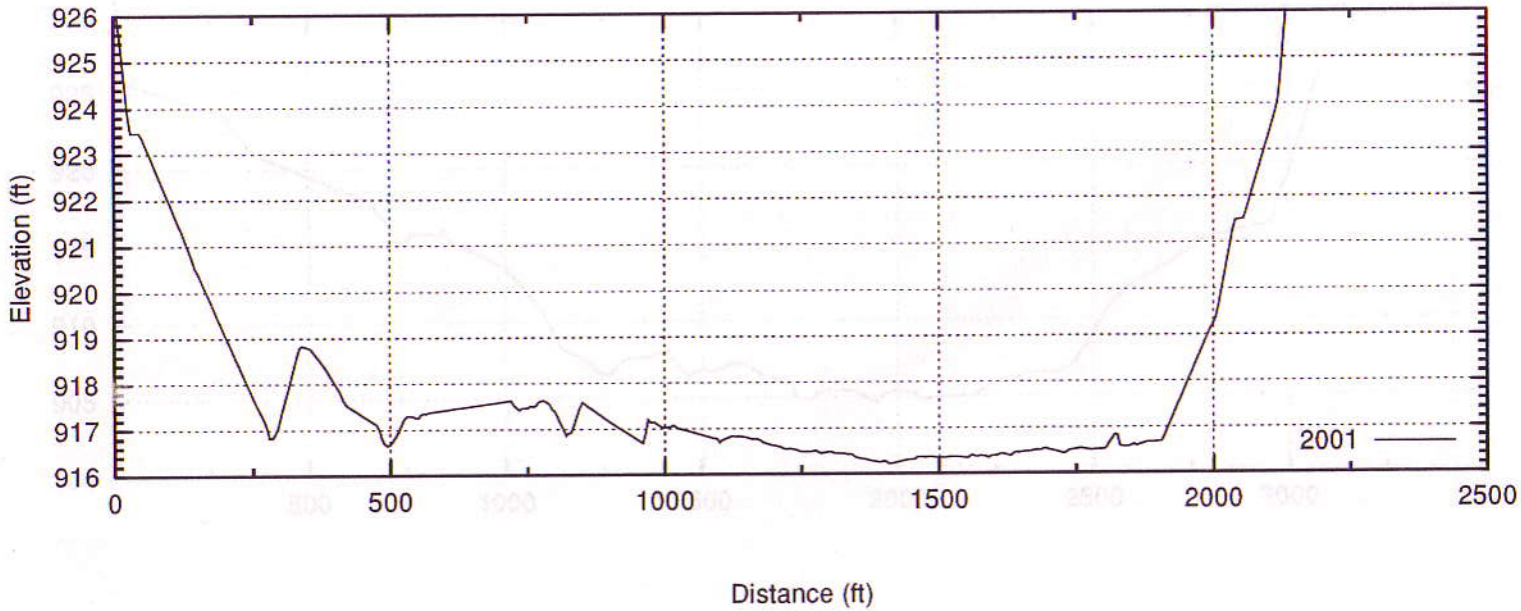


Lake Arrowhead

RL-15

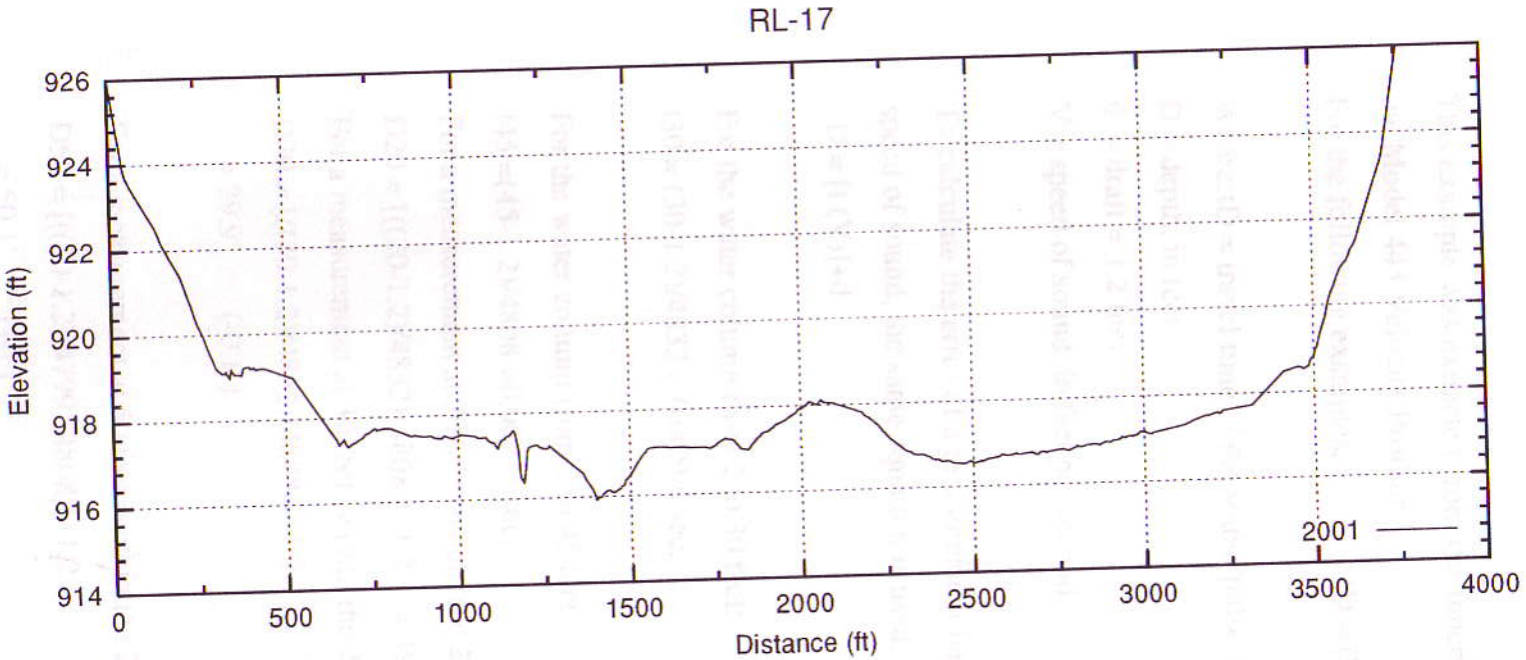


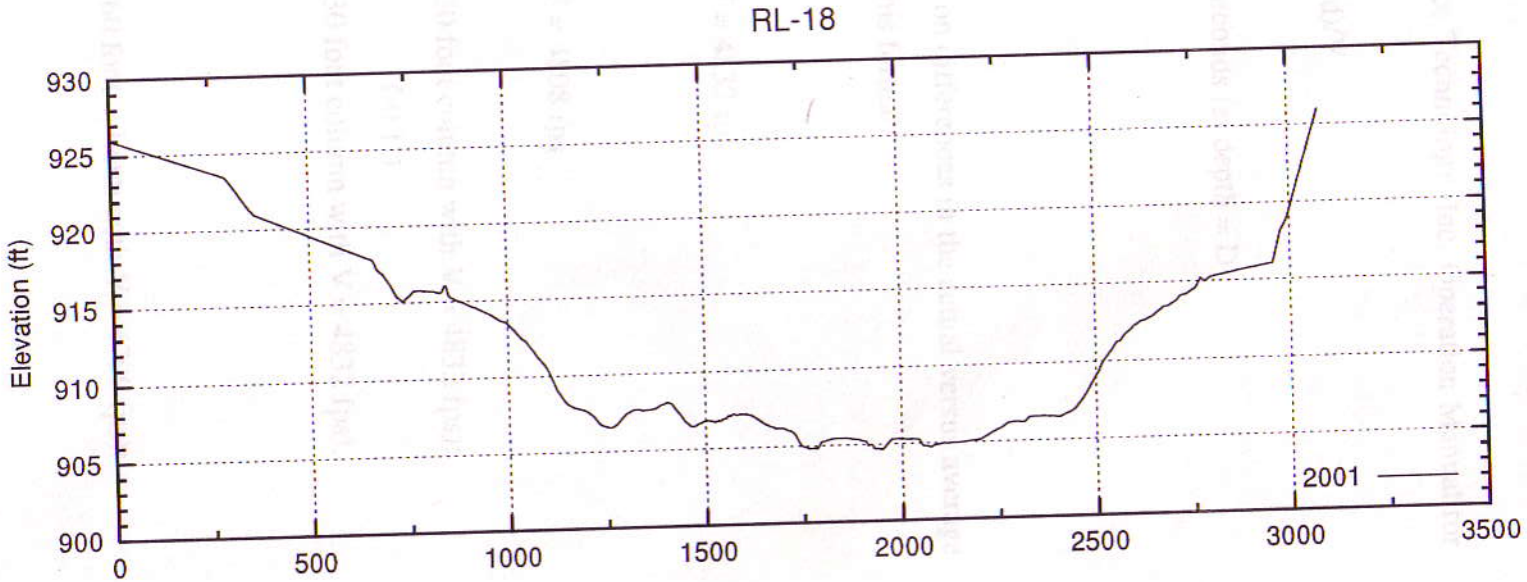
RL-16



Appendix E

Lake Arrowhead





APPENDIX F - DEPTH SOUNDER ACCURACY

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

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

Where: tD = 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

$t30 = (30-1.2)/4832 = 0.00596$ sec.

For the water column from 2 to 45 feet: V = 4808 fps

$t45 = (45-1.2)/4808 = 0.00911$ sec.

For a measurement at 20 feet (within the 2 to 30 foot column with V = 4832 fps):

$D20 = [((20-1.2)/4832)(4808)]+1.2$ = 19.9’ (-0.1’)

For a measurement at 30 feet (within the 2 to 30 foot column with V = 4832 fps):

$D30 = [((30-1.2)/4832)(4808)]+1.2$

= 29.9’ (-0.1’)

For a measurement at 50 feet (within the 2 to 60 foot column with V = 4799 fps):

$D50 = [((50-1.2)/4799)(4808)]+1.2$

= 50.1’ (+0.1’)

For the water column from 2 to 60 feet: V = 4799 fps Assumed V80 = 4785 fps

t60 =(60-1.2)/4799

=0.01225 sec.

For a measurement at 10 feet (within the 2 to 30 foot column with V = 4832 fps):

D10 = [((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):

D30 = [((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):

D45 = [((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):

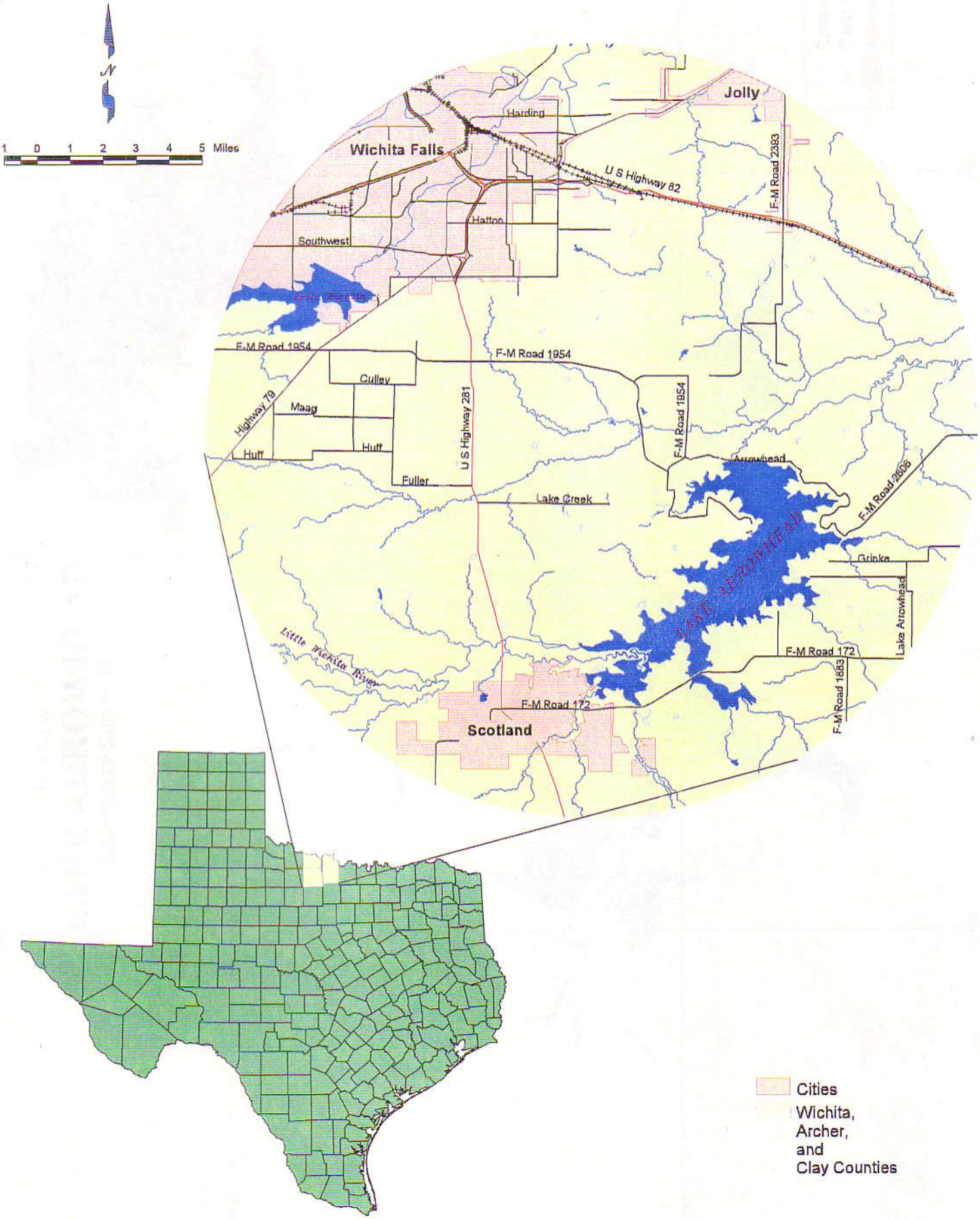
D80 = [((80-1.2)/4785)(4799)]+1.2

= 80.2’ (+0.2’)

Figure 1

LAKE ARROWHEAD

Location Map

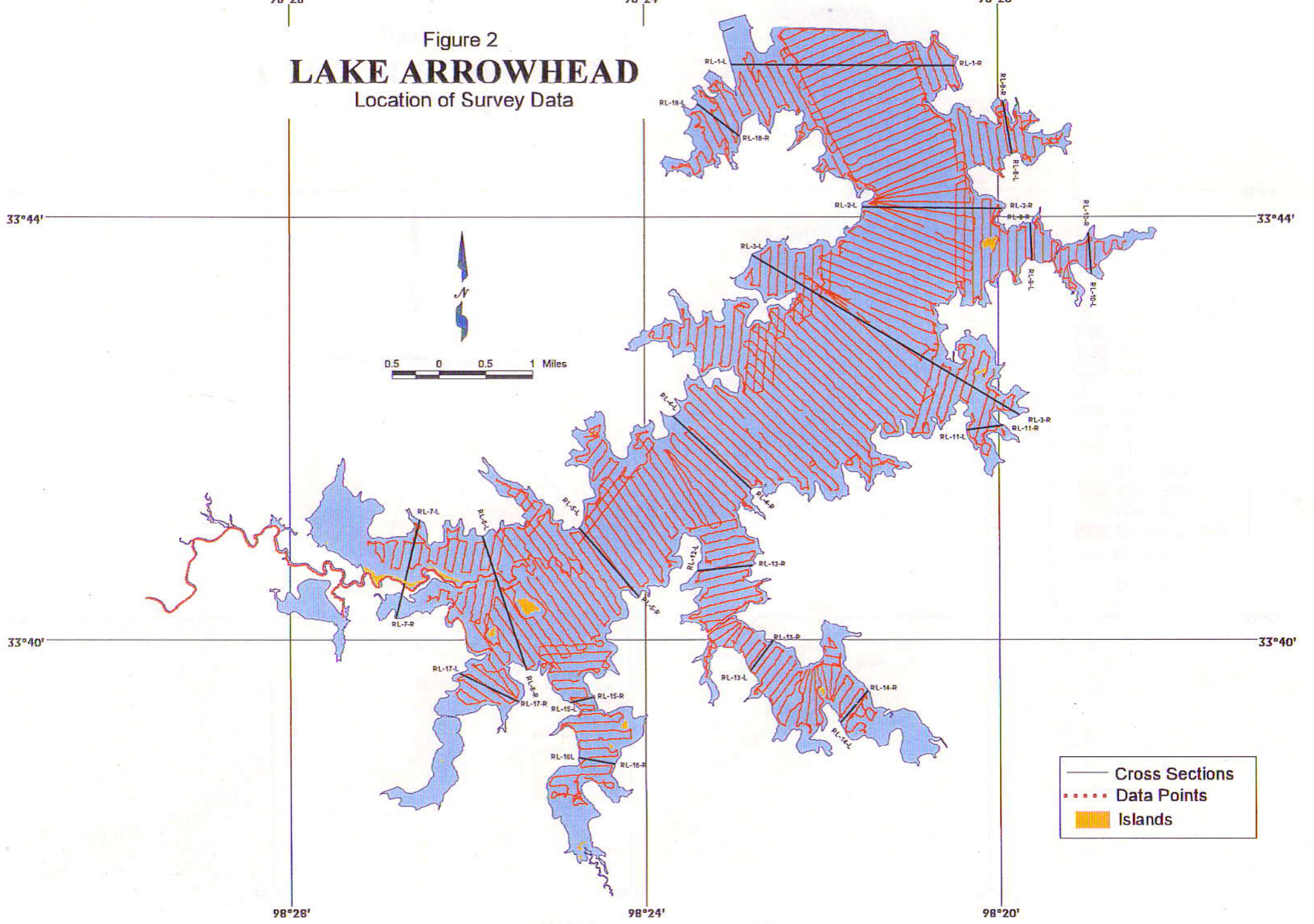


TWDB Survey June 2001

Figure 2

LAKE ARROWHEAD

Location of Survey Data

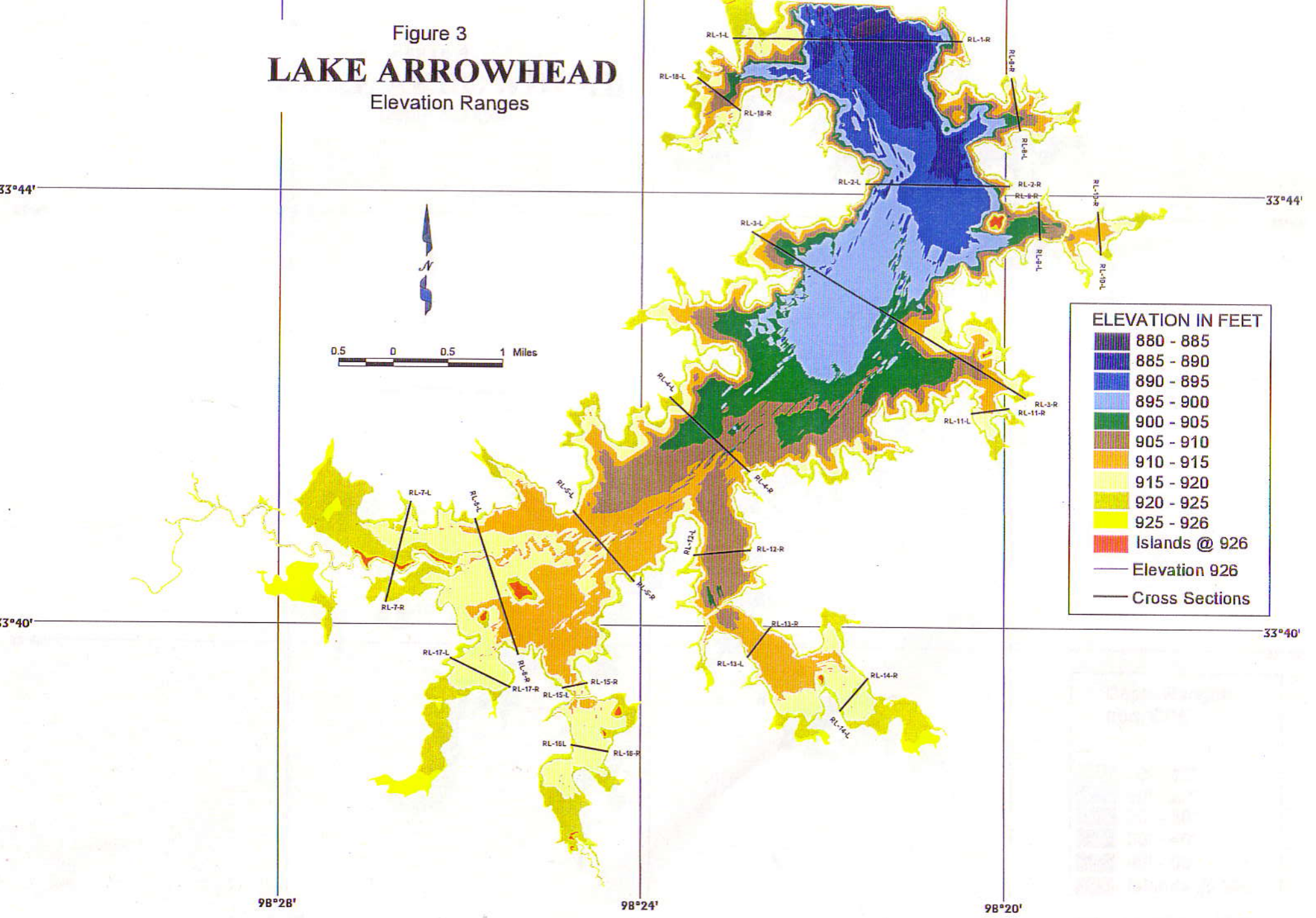


TWDB Survey June 2001

Figure 3

LAKE ARROWHEAD

Elevation Ranges

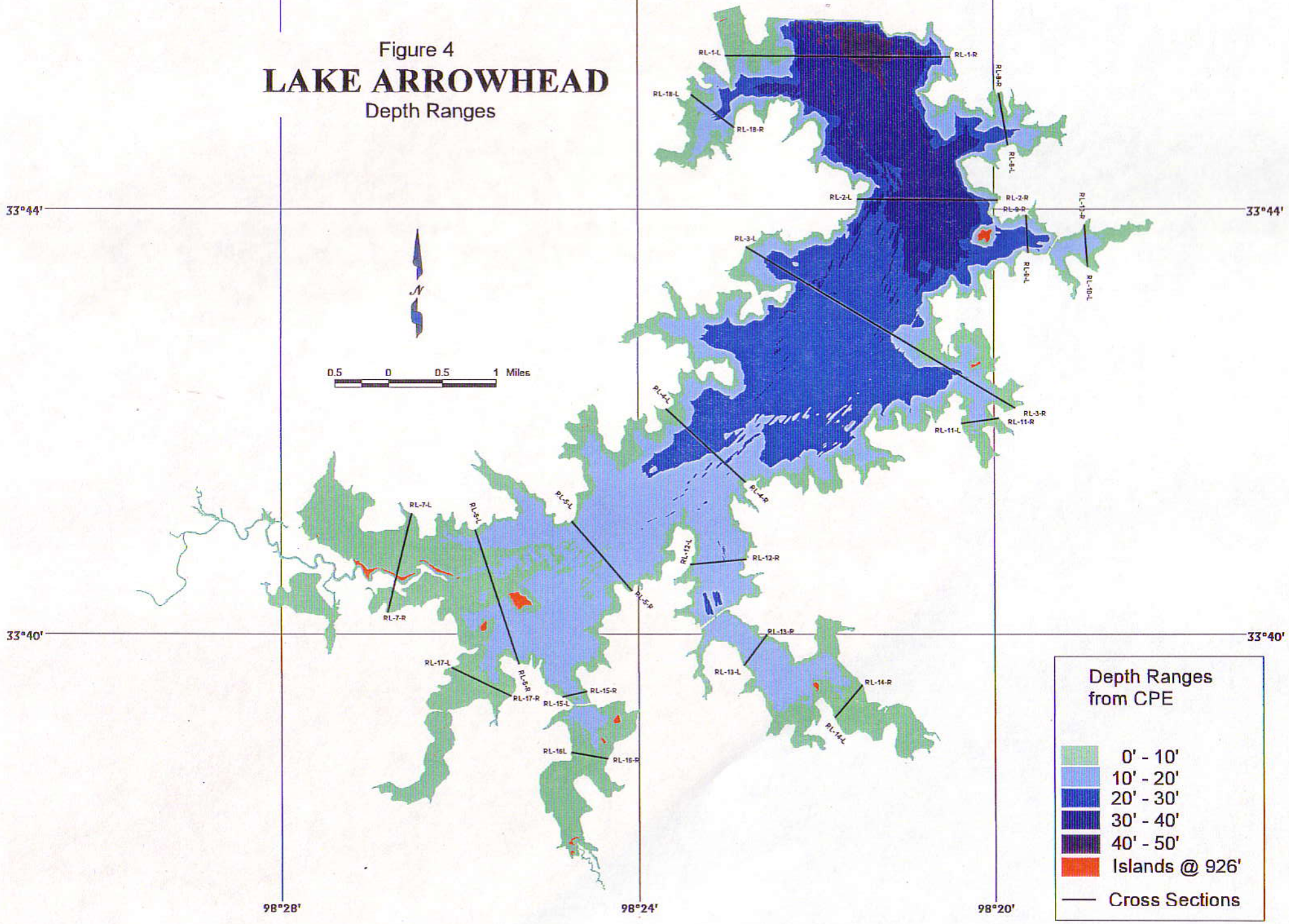


TWDB Survey June 2001

Figure 4

LAKE ARROWHEAD

Depth Ranges



TWDB Survey June 2001