VOLUMETRIC SURVEY OF HULAH RESERVOIR

Prepared for:

U. S. Army Corps of Engineers, Tulsa District

Prepared by:
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 Hulah Reservoir during the period of September 15 – 17, 2002. The purpose of the survey was to determine the current volume of the reservoir at the conservation pool elevation (cpe) as part of a reallocation pool study conducted by the United States Army Corps of Engineers. This survey will establish a basis for comparison to future surveys from which the location and rates of sediment deposition in the conservation pool over time can 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 Army Corps of Engineers (USACE) for the reservoir elevation gage at Hulah Dam. The datum for this gage is reported as mean sea level (msl). Thus, elevations are reported here in feet (ft.) above msl. Volume and area calculations in this report are referenced to water levels provided by the USACE gage (http://www.swt-wc.usace.army.mil/webdata/gagedata/HULO2.current.html).

Hulah Reservoir is located on Caney River, a tributary of the Verdigris River in Osage county, 15 miles northwest of Bartlesville, OK (Figure 1). At cpe 733.0 ft. above msl, the reservoir has approximately 62 miles of shoreline. Records indicate the drainage area is approximately 732 square miles (http://www.swt-wc.usace.army.mil/projects/pertdata/hulah/hulah.htm).

The initial area and capacity of Hulah Reservoir were based on a 1949 survey. The designed cpe at that time was 731.0 ft. On July 12, 1957 the top of the conservation pool was raised to elevation 733.0 ft. and is the present cpe for Hulah Reservoir (Corps of Engineers

1958). Results of the 1958 re-survey, 1973 re-survey and the TWDB 2002 volumetric survey will be discussed in the following section.

RESERVOIR HISTORY AND GENERAL INFORMATION

Hulah Dam, appurtenant structures and the surrounding shoreline of Hulah Reservoir are owned by the U. S. Government and operated by the USACE, Tulsa District. The dual-purpose reservoir is used for flood protection and water supplies. Federal authorization for the Hulah Reservoir Project was granted under the Flood Control Act, approved June 22, 1936 and modified by Public Law 843, 84th Congress, 2nd Session, approved July 30, 1956, to provide for the allocation of 15,400 acre-feet (ac-ft) of storage space. The water stored in Hulah Reservoir was to be used by the City of Bartlesville for municipal purposes (USACE 1958).

The City of Bartlesville and Hulah Water District Inc. have contracted with the USACE for use of water stored in the conservation pool between elevation 733.0 ft. and 710.0 ft. The Oklahoma Water Resources Board currently adjudicates the water rights for Hulah Reservoir.

The City of Bartlesville holds permit numbers 19570187, 19660289, 19780169, and 19810111 to use a cumulative amount of 13,819 ac-ft. of water per annum for public water supply purposes (Oklahoma Water Resources Board).

Hulah Water District Inc. own permit numbers 19700004 and 19840058 to use a total of 67 ac-ft. of water per annum for public water supply purposes (Oklahoma Water Resources Board).

Construction started on Hulah Dam in May 1946 and was completed in February 1951. Deliberate impoundment of water began September 23, 1951 and the conservation pool filled on September 24, 1951.

Original design information shows Hulah Dam is a rolled earthfill embankment and a concrete spillway, 5,200 ft. long and rises approximately 94 ft. above the original streambed to a crest elevation of 779.5 ft. The earthen embankment is composed of mostly impervious material and has rock riprap on the upstream face for erosion control. Oklahoma Highway 10 (a two-lane asphalt road) occupies the dam's crest. There is an earthen dike, with a maximum height of 30 ft. that extends 1,115 ft. across a saddle near the right abutment above the dam.

The spillway for Hulah Reservoir consists of a concrete ogee weir, 472 feet wide, has a crest elevation of 740.0 ft. and is gate controlled. This structure is located adjacent to the right abutment. Ten tainter gates control the spillway, each 40- by 25- ft.

The outlet works are designed with nine 5- by 6- ft. 6-in. rectangular sluices that are controlled by hydraulically operated slide gates. There are two gate-controlled 24- in. diameter low-flow pipes and one gated 10- in. diameter water supply pipe.

The original capacity for Hulah Reservoir was based on a 1949 survey by the USACE. The initial area and capacity was calculated at cpe 731.0 ft. The top of the conservation pool was raised to elevation 733.0 ft in 1957. The 1958 re-survey showed the total storage capacity below cpe 733.0 ft. would be 34,670 ac-ft. (Corps of Engineers 1958). The following table summarizes information for Hulah Dam and Hulah Reservoir.

Table 1. Hulah Dam and Hulah Reservoir Pertinent Data

Owner of Hulah Dam and Facilities

United States of America

Operator of Hulah Dam and Facilities

U. S. Army Corps of Engineers, Tulsa District

Engineer

U. S. Army Corps of Engineers (Design)

Location

On Caney River, a tributary of Verdigris River in Osage County, 15 miles northwest of Bartlesville Oklahoma.

Drainage Area

732 square miles

Dam

Type	Earthfill
Length (total)	5,200 ft. (including spillway)
Maximum Height	94 ft.
Top width	31 ft.

Spillway

Type	Ogee (Concrete)
Length	472 ft.
Crest elevation	740.0 ft.
Control	10- Tainter Gates

Outlet Works

Type	9 sluices
Size	5- by 6-ft. 6-in rectangular
Control	slide gates (hydraulically operated)

Reservoir Data (Based on TWDB 2002 volumetric survey)

Feature	**Elevation (Above msl)**	**Capacity (Acre-feet)**	**Area (Acres)**
Conservation Pool Elevation (Total storage)	733.0	22,565	3,120
Conservation Pool (Between elev. 733.0 – 710.0 ft.)		22,553	
Inactive Pool	710.0	12	6

VOLUMETRIC SURVEYING TECHNOLOGY

The equipment used to perform the latest volumetric survey consisted 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 with Omnistar differential GPS correction signal and an on-board PC. A water-cooled 4.5 kW generator provides electrical power through an in-line uninterruptible power supply. In shallow areas and where navigational hazards such as stumps were present, a 20-foot aluminum shallow-draft flat bottom SeaArk craft (River Runner) with cabin and equipped with one 100-horsepower Yamaha 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 with Omnistar differential GPS correction signal and a laptop computer.

The GPS equipment, survey vessel, and depth sounder in combination provide an efficient hydrographic survey system. As the boat travels across the pre-plotted transect lines, the depth sounder takes approximately ten readings of the reservoir bottom each second. The depth readings are stored on the computer along with the 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 one data point per second, and the average depths are converted to elevation readings based on the water-level elevation recorded at the time the data was collected. Accurate estimates of the reservoir volume can then be determined by building a 3-D TIN model of the reservoir from the collected data.

PRE-SURVEY PROCEDURES

The reservoir's boundary was digitized using Environmental Systems Research Institute's (ESRI) Arc/Info Workstation GIS software and digital orthophoto quadrangle images (DOQ). Geo Information Systems, a department of the University of Oklahoma, furnished the DOQ. More information can be obtained on the Internet at http://www.geo.ou.edu/. The HULA, OK (36096H24.sid, 36096H22.sid, 36096H21.sid, 36096H13.sid and 36096H12.sid) DOQ was used to create the reservoir's boundary. The reservoir elevation, at the time the DOQ was photographed (March 27,1995) was 733.55 ft. This photograph (DOQ) was used to digitize the boundary of the reservoir and an elevation of 733.6 ft. was assigned for modeling purposes. The reservoir elevations varied between elevation 733.80 ft. and 733.86 ft. during the field survey.

The survey layout was designed by placing survey track lines at 500-foot intervals within the digitized reservoir boundary using HYPACK software. The survey design required the use of approximately 170 survey lines placed perpendicular to the original creek channel and tributaries along the length of the reservoir. The design also included 7 of the 31 original sediment range lines that were established by the USACE in 1949.

SURVEY PROCEDURES

The following procedures were followed during the volumetric survey of Hulah Reservoir performed by the TWDB. Information regarding equipment calibration and operation, the field survey, and data processing is presented.

Equipment Calibration and Operation

While onboard the Hydro-survey boat and prior to collecting data, 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 probe was first placed in the water to acclimate it. The probe was next raised to the water surface where the depth was considered zero. The probe was then gradually lowered on a cable to a depth just above the reservoir bottom, and then raised again 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 reservoir bottom. The depth was then checked manually with a measuring tape to ensure that the depth sounder was properly calibrated and operating correctly.

Before data were collected onboard the River Runner (shallow draft) boat, the Knudsen depth sounder was calibrated using the DIGIBAR-Pro Profiling Sound Velocimeter by Odem Hydrographic Systems. Basically, the steps to determine the speed of sound are the same as those used for the Innerspace 443 Velocity Profiler. The probe was first placed in the water to acclimate it, raised to the water surface where the depth was considered zero. The probe was then gradually lowered on a cable to a depth just above the reservoir bottom, and then raised again 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 velocimeter. The speed of sound was then entered into the bar check feature in the Knudsen software program. The depth was then checked manually with a stadia (survey) rod or weighted measuring tape to ensure that the depth sounder was properly calibrated and operating correctly.

The speed of sound in the water column ranged from 4,897 feet per second to 4,907 feet per second during the Hulah Reservoir survey. 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 ft. An additional estimated error of $\pm$0.3 ft. arises from variation in boat inclination. These two factors combine to give an overall accuracy of $\pm$0.5 ft. for any instantaneous reading. These errors tend to be fairly minimal over the entire survey, since some errors are positive and some are negative, canceling each other out. Further information on these calculations is presented in Appendix G.

During the survey, the horizontal mask setting on the onboard GPS receiver was set to 10 degrees and the PDOP (Position Dilution of Precision) limit was set to seven 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. Further positional accuracy is obtained through differential corrections using the Omnistar receiver. The reservoir's initialization file used by the HYPACK data collection program was set up to convert the collected Differential GPS positions to state-plane coordinates on the fly.

Field Survey

TWDB staff collected data at Hulah Reservoir during the period of September 15 – 17, 2002. The USACE were able to maintain the water levels above cpe during the survey. The water level elevations varied between 733.80 and 733.86 ft., thus allowing the survey crew to collect data in most areas of the reservoir that would not be inundated at cpe 733.0 ft.

The survey crew experienced typical summer-like weather conditions while surveying Hulah Reservoir. Temperatures ranged in the mid 80's to low 90's with winds generally 10 to 20 mph.

Hulah Reservoir is considered a "Finger Lake" with the main stem of the catchment basin being in the floodplain of Caney Creek. Other contributing creeks to the reservoir, upstream of Hulah Dam are Turkey, Hickory and Pond Creeks. The main reservoir is located in a valley surrounded by the Osage Hills of Oklahoma. The Caney River originates from the Flint Hills of Kansas.

The land use for the perimeter of Hulah Reservoir is dedicated for hunting and is under both state and federal regulations. The surrounding land is also leased for grazing. Oil and gas production is present around the reservoir. There is one improved park for camping near Hulah Dam and several designated areas around the reservoir for primitive camping.

Data collection began at the dam and parallel lines were driven in increments of 500 ft. as the crew worked upstream. These parallel lines were designed to be perpendicular to the river or creek bed in order to secure a well-defined cross section on each transect. Data were also collected on parallel lines in the coves and contributing creeks. As the crew collected data along the pre-plotted transects, the bathymetry or reservoir bottom profile was being plotted on an analog chart. As the boat passed over the river and creek beds, the acoustic depth sounder would indicate the location of the thalweg.

In many areas along the shoreline of the creeks and Caney River outcrops of limestone were noted. Both steep grade and gentle slope shorelines were noted around the main basin. The crew was able to collect data in most areas of the reservoir. The only difficult area to collect data was at the delta where the Caney River empties into the main basin of the reservoir. Shallow depths with floating and submerged timber were encountered in this area.

Approximately 47,411 data points were collected over the 118 miles traveled. The crew was able to collect data on all 179 pre-plotted lines. Data were also collected on 7 of the original 31 USACE sediment range lines that were established 1949. Random data were collected in those areas where the crew could not navigate the boat to stay on course. As the banks of the creeks and Caney River became to narrow for perpendicular transects, data was collected and a zigzag pattern. Data were not collected in areas with significant obstructions or where the depths were too shallow to navigate. These data points collected were stored digitally on the boat's computer in 250 data files. Figure 2 shows the actual location of all data points collected.

Data Processing

The collected data were downloaded from diskettes onto TWDB's network computers. 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 files. 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 level elevation varied from 733.86 ft. on September 15, 2002 to 733.80 ft. on September 17, 2002 according to the USACE gage. After all changes had been made to the raw data files, the edited files were saved.

The edited files were then combined into a single X, Y, Z data file, to be used with the GIS software to develop a model of the reservoir bottom elevation.

The resulting data file was imported into Environmental System Research Institute's (ESRI) Arc/Info Workstation GIS software. This 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 bottom surface. With this representation of the bottom, the software then calculates elevations along the triangle surface plane by determining the elevation along each leg of the triangle. The reservoir area and volume can be determined from the triangulated irregular network created using this method of interpolation.

Volumes and areas were calculated from the TIN for the entire reservoir at one-tenth of a foot interval from the lowest elevation to the contour used for the reservoir boundary during the 2002 survey. From elevation 703.2 ft. to 733.6 ft., the surface areas and volumes of the reservoir were computed using Arc/Info software. The computed reservoir volume table is presented in Appendix A and the area table in Appendix B. An elevation-volume graph and an elevation-area graph are presented in Appendix C and Appendix D respectively.

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 2-ft. intervals is presented in Figure 5. Finally, the location of cross-section endpoints in Appendix E and the corresponding cross-section plots in Appendix F were approximated from those sediment range lines established by the USACE in 1949.

RESULTS

Results from the 2002 TWDB survey indicate Hulah Reservoir encompasses 3,120 surface acres and contains a total volume of 22,565 ac-ft. at the conservation pool elevation of 733.0 ft. The shoreline at elevation 733.6 ft. was calculated to be 69 miles. The deepest point physically measured during the survey was at elevation 703.2 ft. and was located approximately 5.5 miles upstream Caney Creek from the point where it enters the main body of the reservoir. The deepest point measured in the main body of the reservoir was approximately 30 ft. upstream of the dam at elevation 707.5 ft.

SUMMARY AND COMPARISONS

Hulah Dam was completed in 1951 and deliberate impoundment began the same year. Original design information was furnished from a 1949 USACE survey. The most recent sediment survey report on Hulah Reservoir was based on a USACE 1973 re-survey. Records indicate that Hulah Reservoir had a total volume of 31,160 ac-ft of water and a surface area of 3,570 acres at conservation pool elevation 733.0 ft. A summary of the comparisons is presented in Table 2.

TWDB staff performed a volumetric survey of Hulah Reservoir on September 15 – 17, 2002. The 2002 survey utilized a differential global positioning system, depth sounder and geographical information system technology to create a digital model of the reservoir's bathymetry. At conservation pool elevation 733.0 ft, the current survey measured 3,120 surface acres, for a reduction of 12.6% surface acres compared to the 1973 USACE sediment survey. The 2002 TWDB survey results indicate that the total volume at the conservation pool elevation of 733.0 ft. is 22,565 ac-ft. The inactive pool below elevation 710.0 feet was found to be 12 ac-ft., and thus the conservation storage found in this survey is 22,553 ac-ft. of water. The 1973 sediment survey results showed the conservation storage capacity to be 31,160 ac-ft. thus, there is a reduction of 8,607 ac-ft of water or approximately 27.6% reduction in conservation storage capacity since 1973. Hulah Reservoir lost 10,837 ac-ft of water or 32.5% percent in conservation storage compared to the results of the 1958 sediment survey.

Comparisons between the historical USACE sediment surveys and the 2002 TWDB volumetric survey are difficult and some apparent changes might simply be due to methodological differences. It is recommended that another survey utilizing modern methods be performed in five to ten years or after major flood events to monitor changes to the reservoir's capacity.

Table 2. Area and Capacity Comparisons Hulah Reservoir

Feature	USACE Original Design[1] **1949**	USACE Re-survey[2] **1958**	USACE Re-survey **1973**	TWDB Volumetric **2002**
Area (acres)	3,200	3,590	3,570	3,120
Total Volume (ac-ft)	30,000	34,670	31,160	22,565
Active Pool storage capacity (ac-ft)[3]		33,390	31,160	22,553
Inactive Pool storage capacity (ac-ft)[4]		1,280	0	12

Notes:
1. Original Design for conservation pool elevation was 731.0 ft.
2. Conservation pool elevation changed from 731.0 to 733.0 ft. on July 12, 1957
3. Active pool storage capacity is between elevations 733.0 and 710.0 ft.
4. Inactive pool storage capacity is below elevation 710.0 ft.
5. All pre-2002 data provided by Tulsa District USACE

REFERENCES

1. Corps of Engineers, U. S. Army. Tulsa District. "Report on Sedimentation Survey Hulah Reservoir Caney River, Oklahoma & Kansas". June 1958
2. http://www.swt.usace.army.mil/projects/pertdata/hulah/hulah.htm
3. http://www.swt-wc.usace.army.mil/webdata/gagedata/HULO2.current.html
4. Oklahoma Water Resources Board Reservoir Summary Sheet

Appendix A

Hulah Reservoir

RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD September 2002 SURVEY

Conservation Pool Elevation - 733.0 ft.

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
703			0	0	0	0	0	0	0	0
704	0	0	0	0	0	0	0	0	0	0
705	0	0	0	0	0	0	0	0	1	1
706	1	1	1	1	1	1	1	1	2	2
707	2	2	2	2	2	3	3	3	3	3
708	4	4	4	4	5	5	5	6	6	6
709	7	7	8	8	8	9	9	10	11	11
710	12	12	13	14	14	15	16	17	17	18
711	19	20	21	22	23	24	25	26	28	29
712	31	32	34	36	39	41	43	46	48	51
713	54	57	60	63	66	69	73	77	81	85
714	90	94	99	104	110	115	121	127	133	139
715	146	153	160	167	175	183	192	200	209	218
716	228	237	248	258	269	280	291	303	315	327
717	340	353	367	381	395	410	425	441	457	474
718	492	509	528	546	566	586	606	628	650	672
719	696	720	744	770	796	823	851	880	910	941
720	973	1007	1042	1078	1117	1159	1204	1250	1299	1350
721	1404	1460	1519	1580	1644	1709	1777	1847	1919	1993
722	2069	2147	2226	2307	2390	2474	2560	2648	2736	2827
723	2919	3013	3108	3205	3303	3403	3504	3608	3713	3820
724	3928	4039	4152	4266	4383	4501	4621	4743	4867	4993
725	5121	5251	5384	5518	5655	5793	5933	6074	6218	6363
726	6510	6660	6811	6963	7118	7275	7434	7594	7757	7921
727	8087	8255	8426	8598	8772	8949	9127	9308	9491	9677
728	9865	10057	10251	10448	10647	10850	11055	11263	11474	11688
729	11905	12124	12347	12571	12798	13027	13258	13493	13729	13968
730	14209	14453	14699	14948	15199	15452	15707	15965	16225	16488
731	16752	17019	17289	17561	17836	18113	18392	18675	18959	19247
732	19537	19829	20125	20423	20723	21025	21330	21636	21944	22253
733	22565	22877	23192	23508	23825	24145	24465			

Appendix B

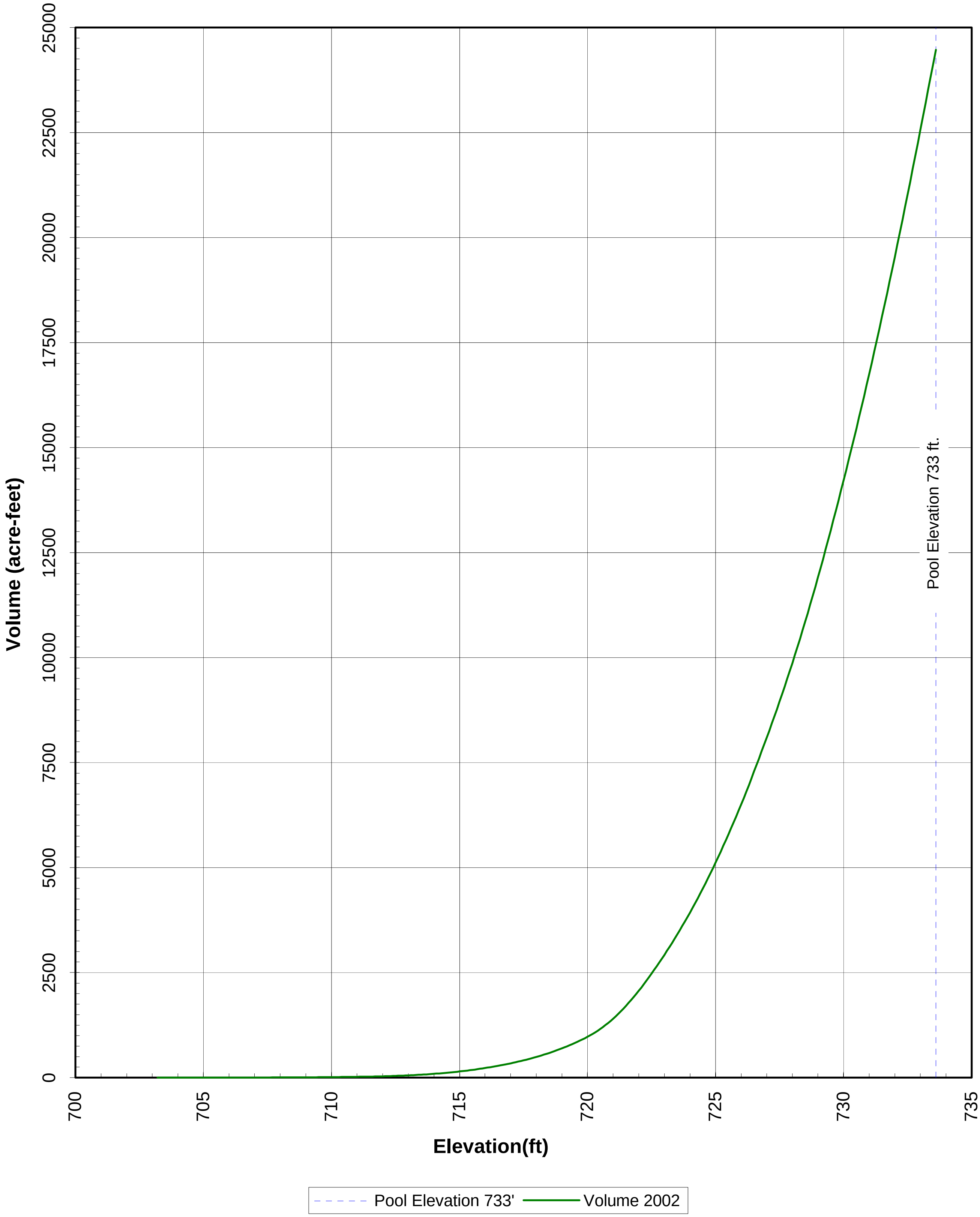
Hulah Reservoir

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD September 2002 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
703			0	0	0	0	0	0	0	0
704	0	0	0	0	0	0	0	0	0	0
705	0	0	0	0	1	1	1	1	1	1
706	1	1	1	1	1	1	1	1	1	1
707	1	1	1	2	2	2	2	2	2	2
708	2	2	3	3	3	3	3	4	4	4
709	4	4	4	5	5	5	5	5	6	6
710	6	6	7	7	7	7	8	8	8	9
711	9	9	10	10	10	11	11	12	13	15
712	17	18	20	21	22	23	24	25	26	27
713	28	30	31	32	33	35	37	39	41	44
714	46	48	50	52	54	56	58	60	62	65
715	68	70	73	76	79	82	84	87	90	93
716	96	99	102	105	108	112	115	119	122	126
717	130	134	138	142	147	151	156	161	165	170
718	175	180	185	191	197	203	209	217	223	230
719	237	244	251	259	267	275	284	295	305	316
720	329	342	355	376	407	432	455	478	500	524
721	550	575	599	624	647	669	690	710	730	749
722	767	784	801	819	836	852	867	882	897	913
723	930	945	959	975	990	1006	1023	1042	1060	1079
724	1098	1116	1136	1156	1174	1192	1211	1230	1249	1269
725	1290	1312	1337	1358	1374	1390	1406	1424	1443	1464
726	1483	1501	1520	1539	1558	1577	1596	1615	1633	1651
727	1672	1692	1712	1733	1754	1775	1798	1821	1844	1869
728	1897	1927	1955	1983	2011	2039	2067	2095	2124	2154
729	2181	2208	2232	2257	2280	2303	2328	2352	2376	2401
730	2427	2451	2474	2497	2521	2544	2566	2589	2612	2635
731	2659	2684	2708	2733	2759	2784	2809	2834	2860	2887
732	2914	2940	2966	2991	3014	3034	3053	3070	3087	3104
733	3120	3136	3152	3168	3184	3201	3260			



Hulah Reservoir
September 2002
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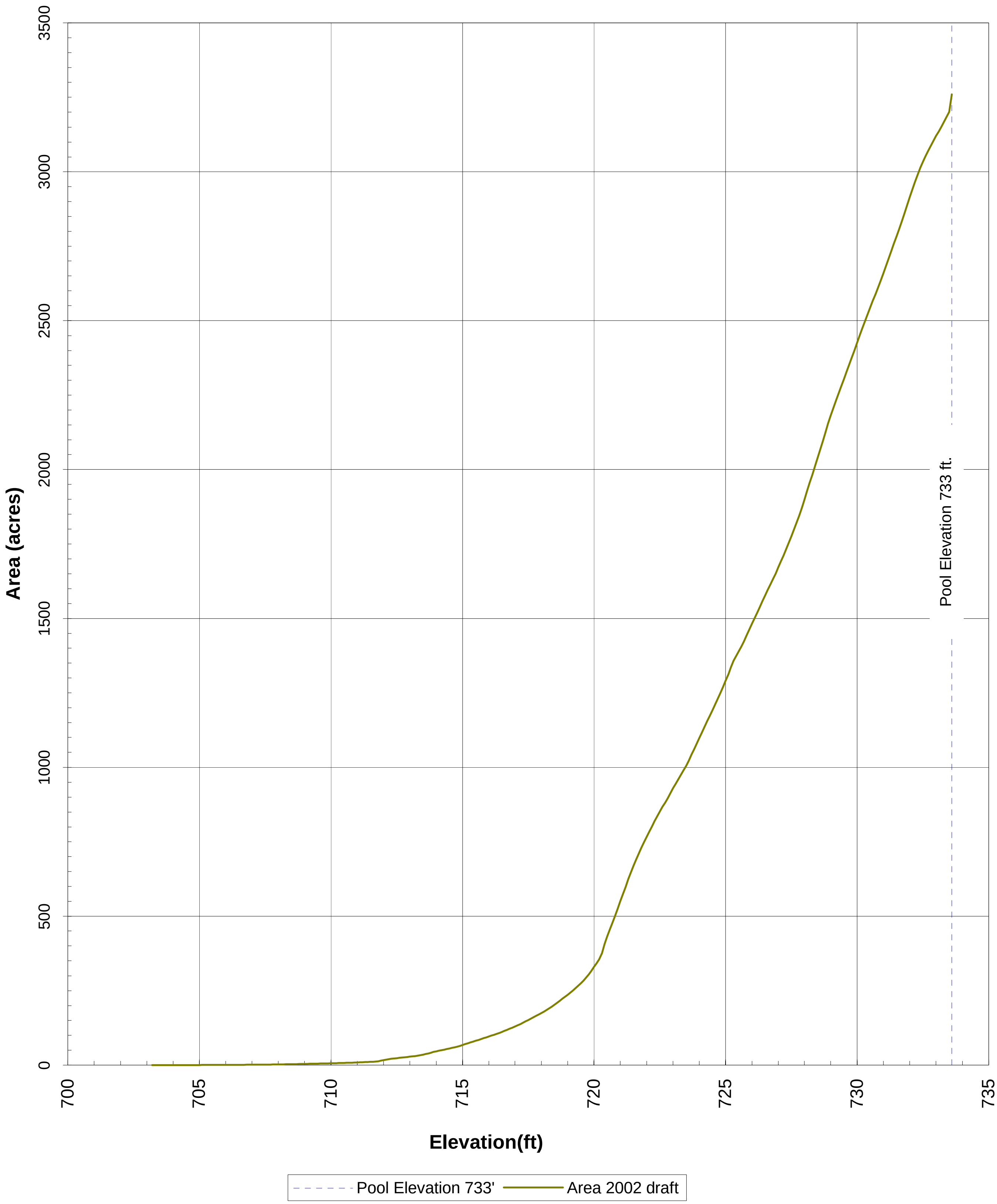
Appendix C Elevation vs. Volume



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September 2002
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Appendix D Elevation vs. Area

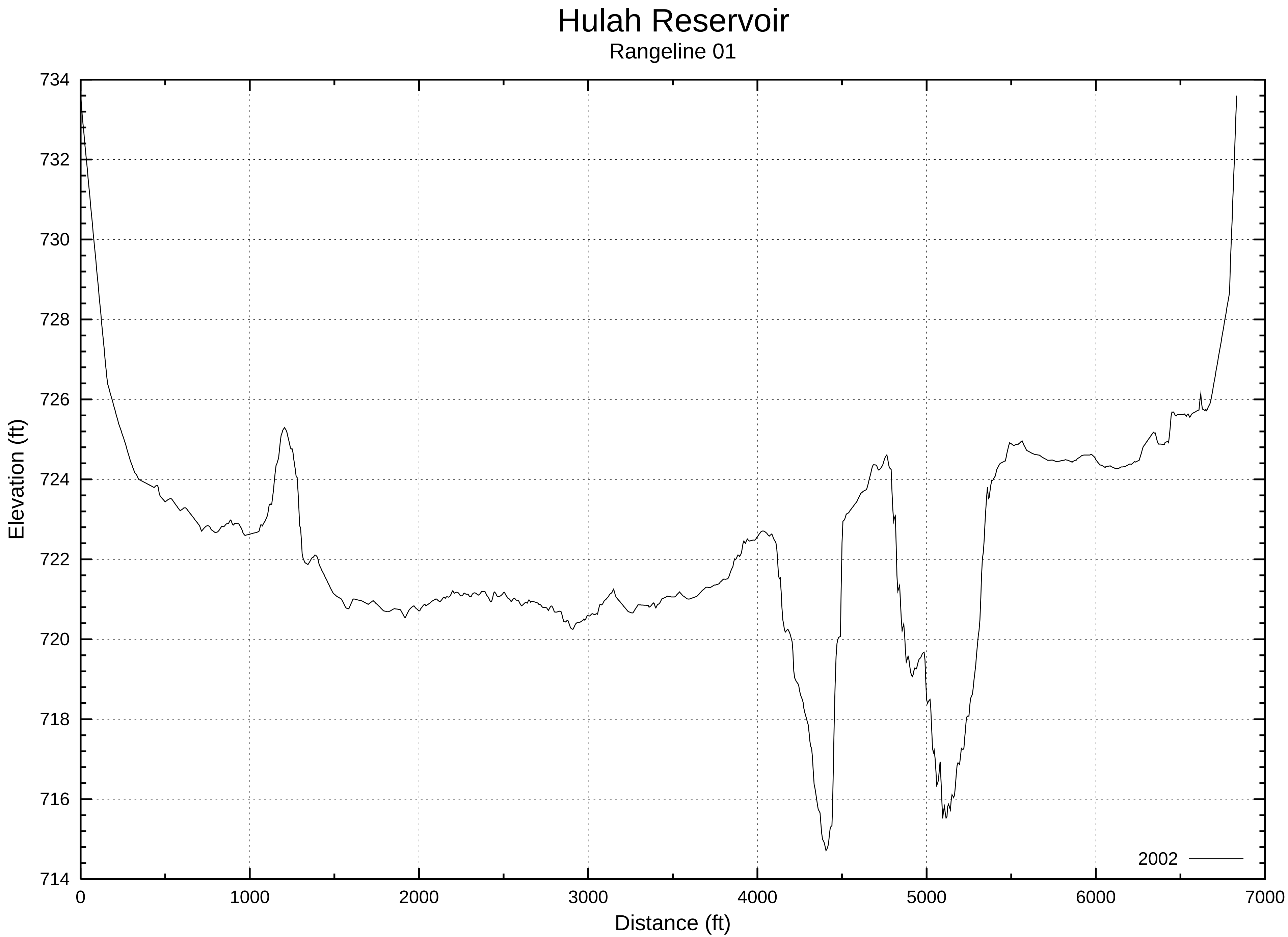
Appendix E
Hulah Reservoir

TEXAS WATER DEVELOPMENT BOARD SEPTEMBER 2002 SURVEY

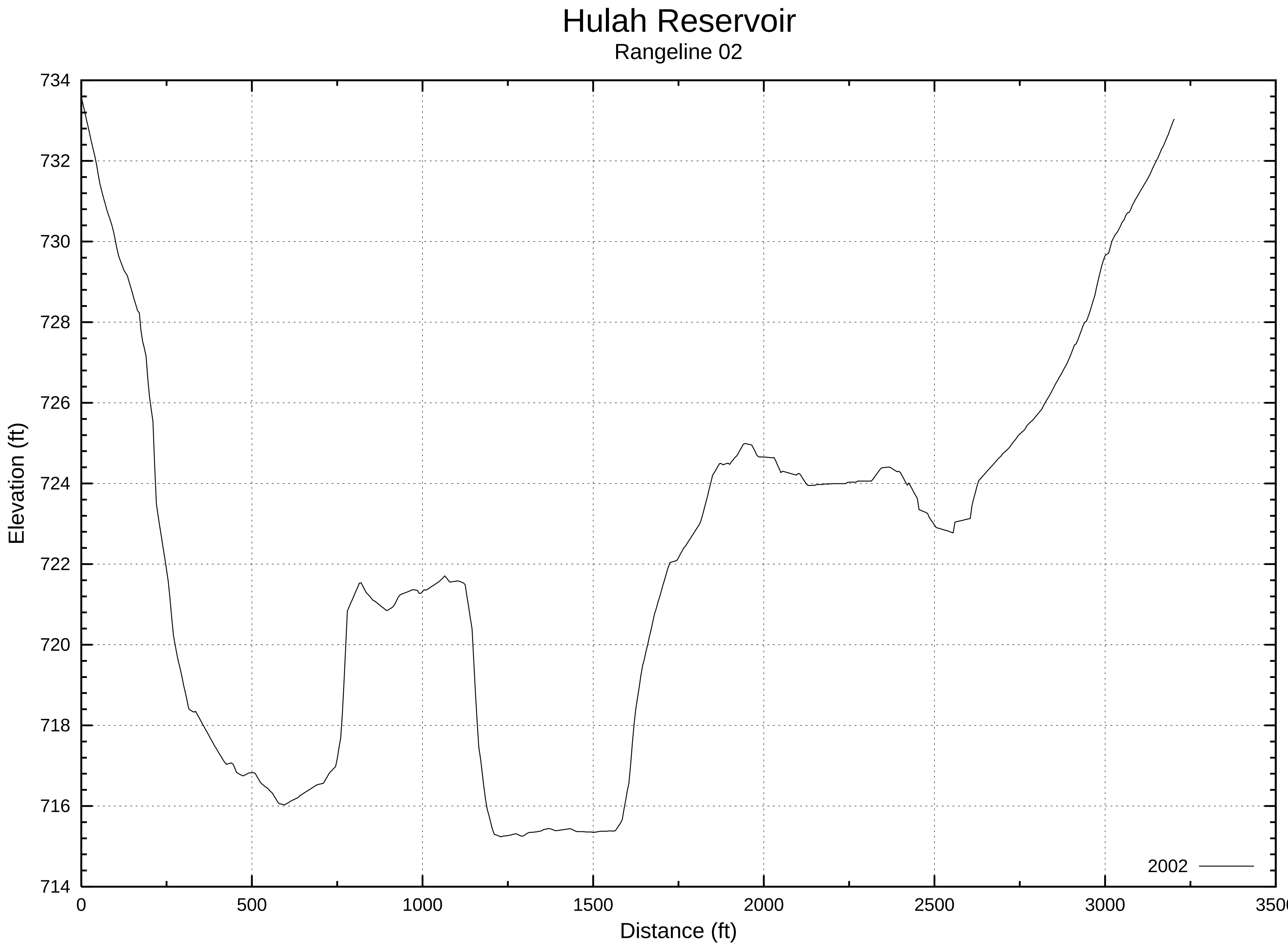
Range Line Endpoints
State Plane NAD83 Units-feet

L-Left endpoint
R-right endpoint

Range Line	X	Y
Line 01-L	2527993.8	713149.0
Line 01-R	2524266.8	707422.8
Line 02-L	2525308.8	713339.8
Line 02-R	2522680.8	711509.6
Line 03-L	2522539.8	717707.9
Line 03-R	2520106.8	717673.6
Line 04-L	2523395.3	719441.8
Line 04-R	2521299.3	720287.4
Line 05-L	2522232.5	709743.9
Line 05-R	2523596.3	707308.4
Line 06-L	2518634.5	708582.7
Line 06-R	2519519.5	703985.1
Line 07-L	2515772.5	709637.8
Line 07-R	2513638.8	706534.4



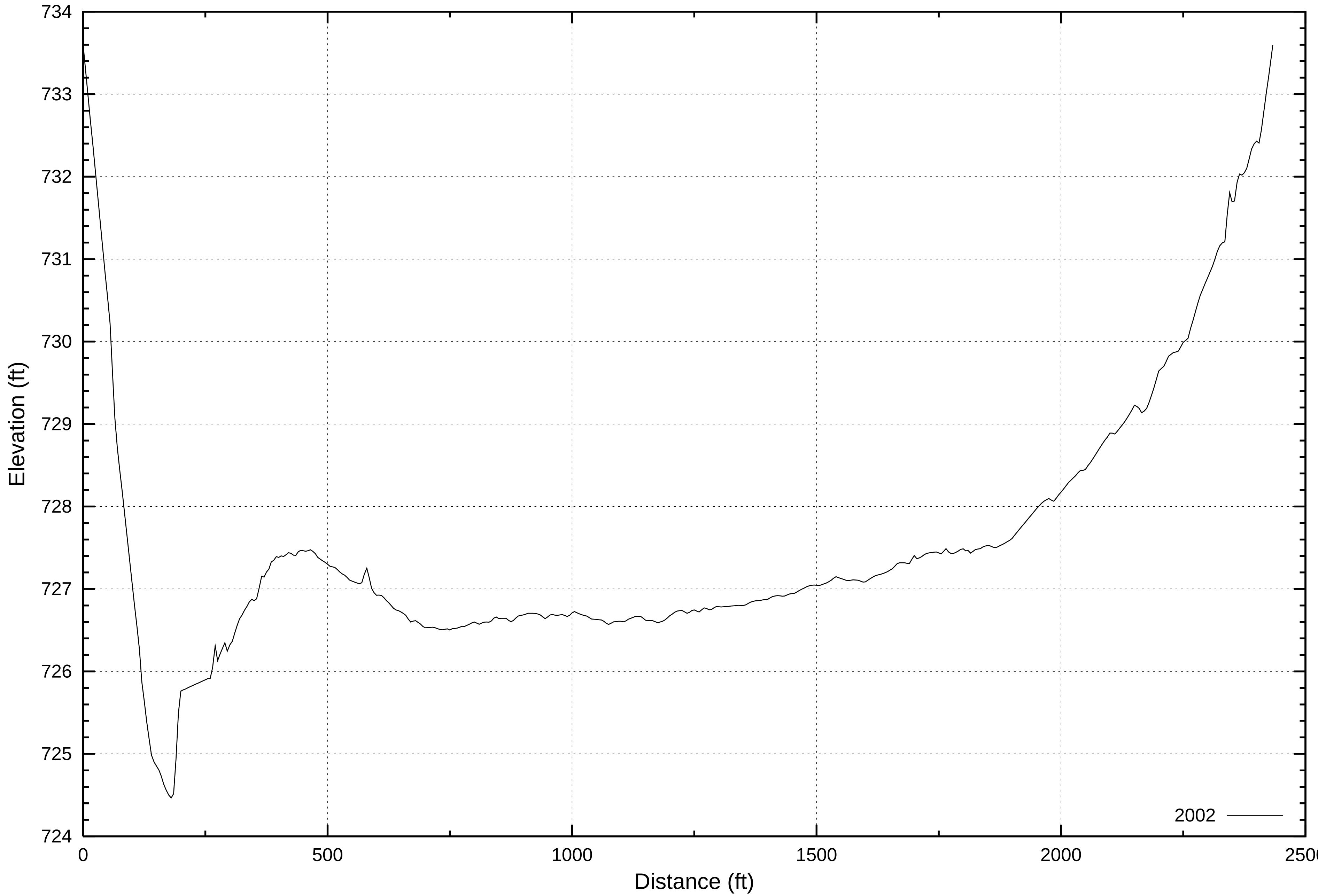
Hulah Reservoir
Rangeline 01
Elevation (ft)
734
732
730
728
726
724
722
720
718
716
714
0
1000
2000
3000
4000
5000
6000
7000
Distance (ft)
2002

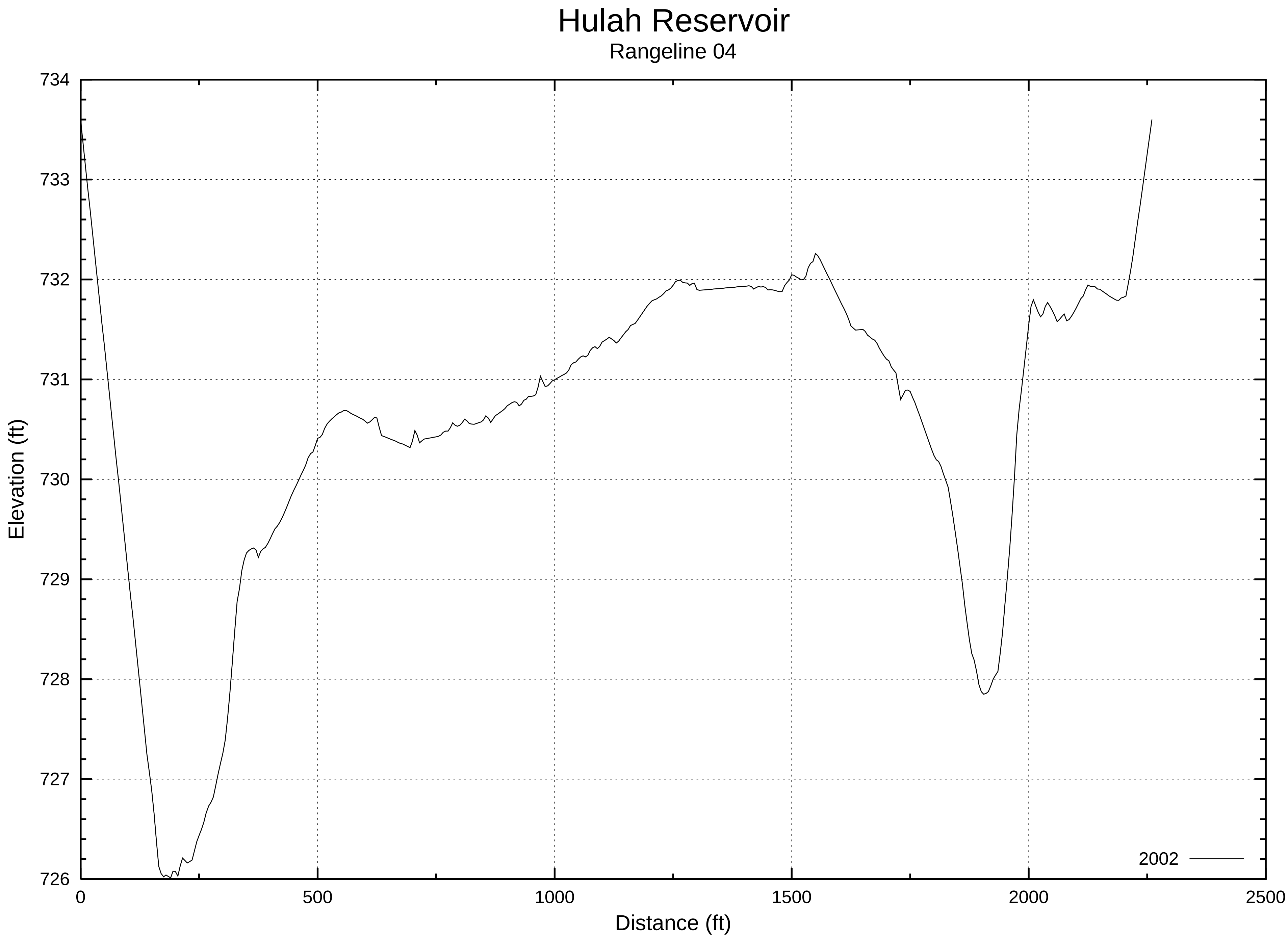


Hulah Reservoir
Rangeline 02
Elevation (ft)
Distance (ft)
734
732
730
728
726
724
722
720
718
716
714
0
500
1000
1500
2000
2500
3000
3500
2002

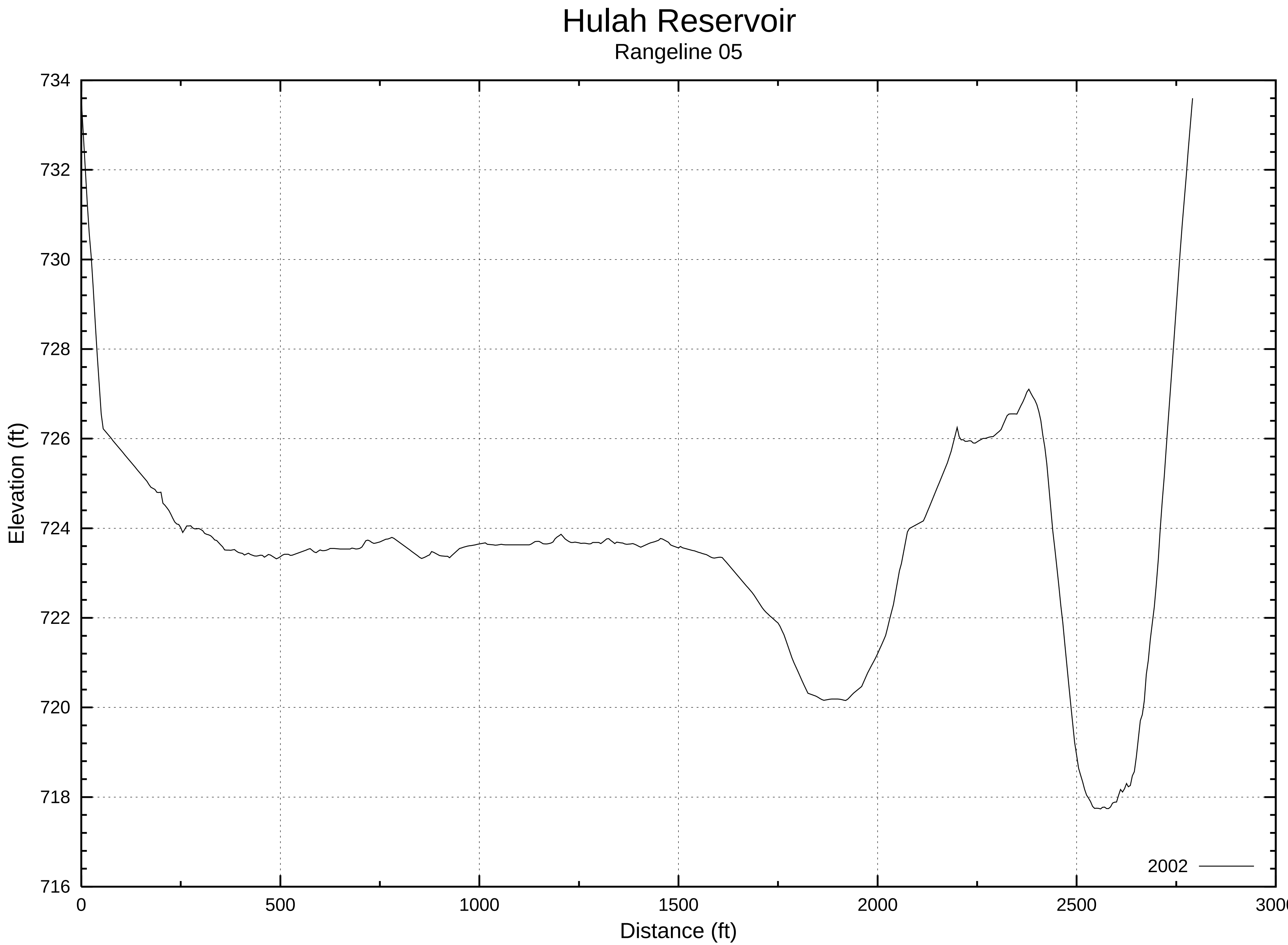
Hulah Reservoir

Rangeline 03

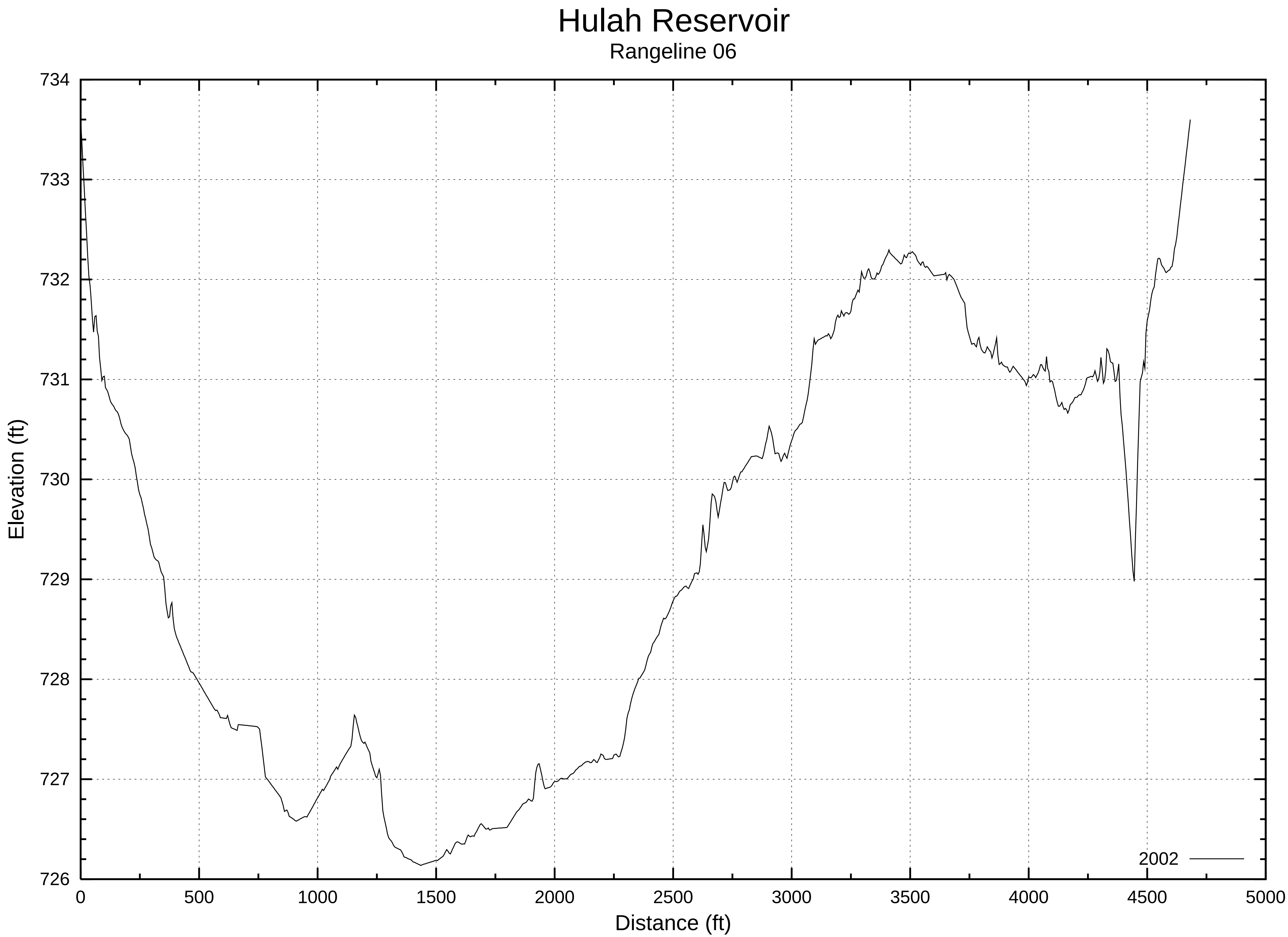


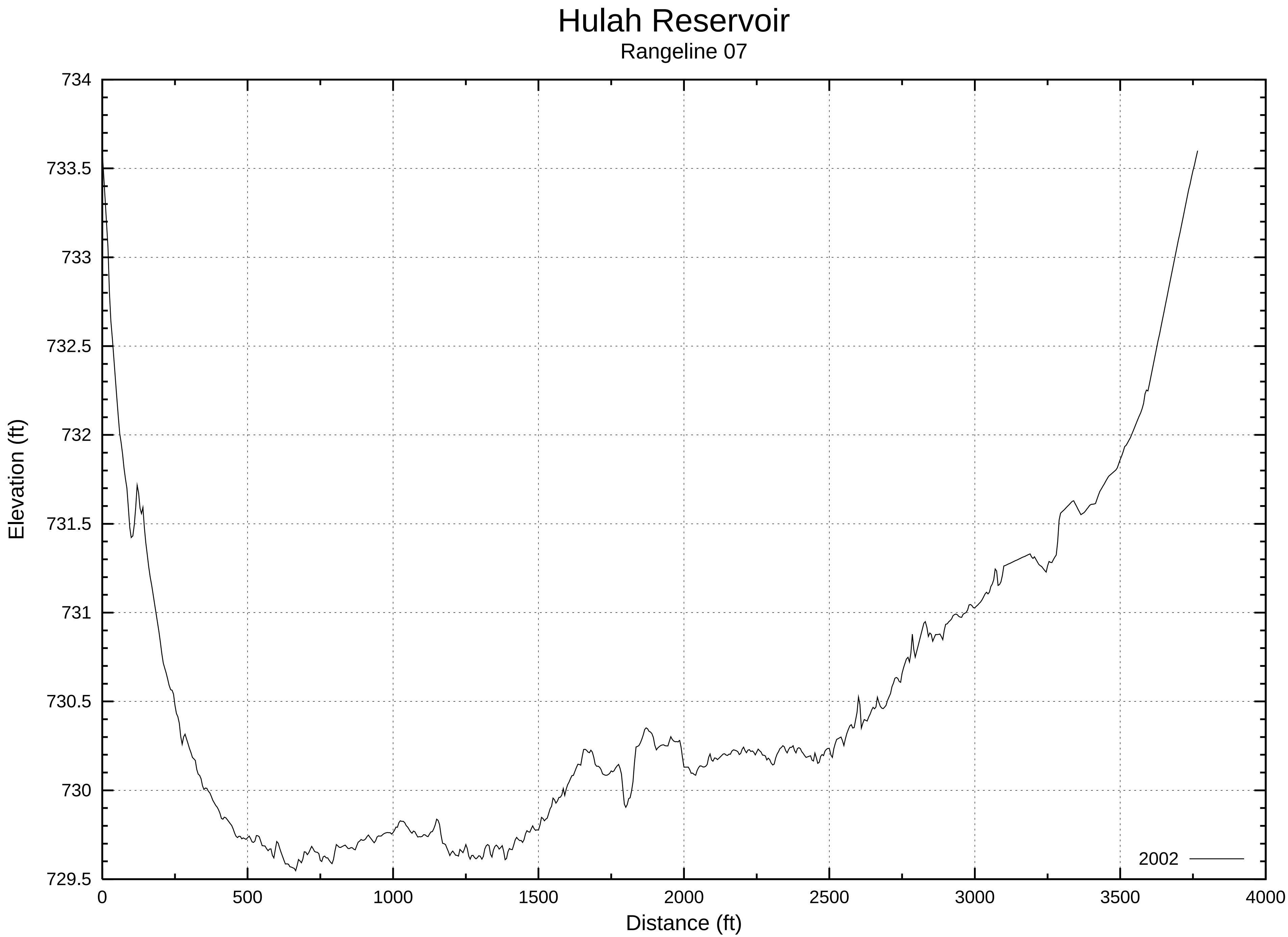


Hulah Reservoir
Rangeline 04
734
733
732
731
730
729
728
727
726
0
500
1000
1500
2000
2500
Elevation (ft)
Distance (ft)
2002



Hulah Reservoir
Rangeline 05
Elevation (ft)
734
732
730
728
726
724
722
720
718
716
0
500
1000
1500
2000
2500
3000
Distance (ft)
2002


Hulah Reservoir
Rangeline 06
Elevation (ft)
734
733
732
731
730
729
728
727
726
Distance (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2002

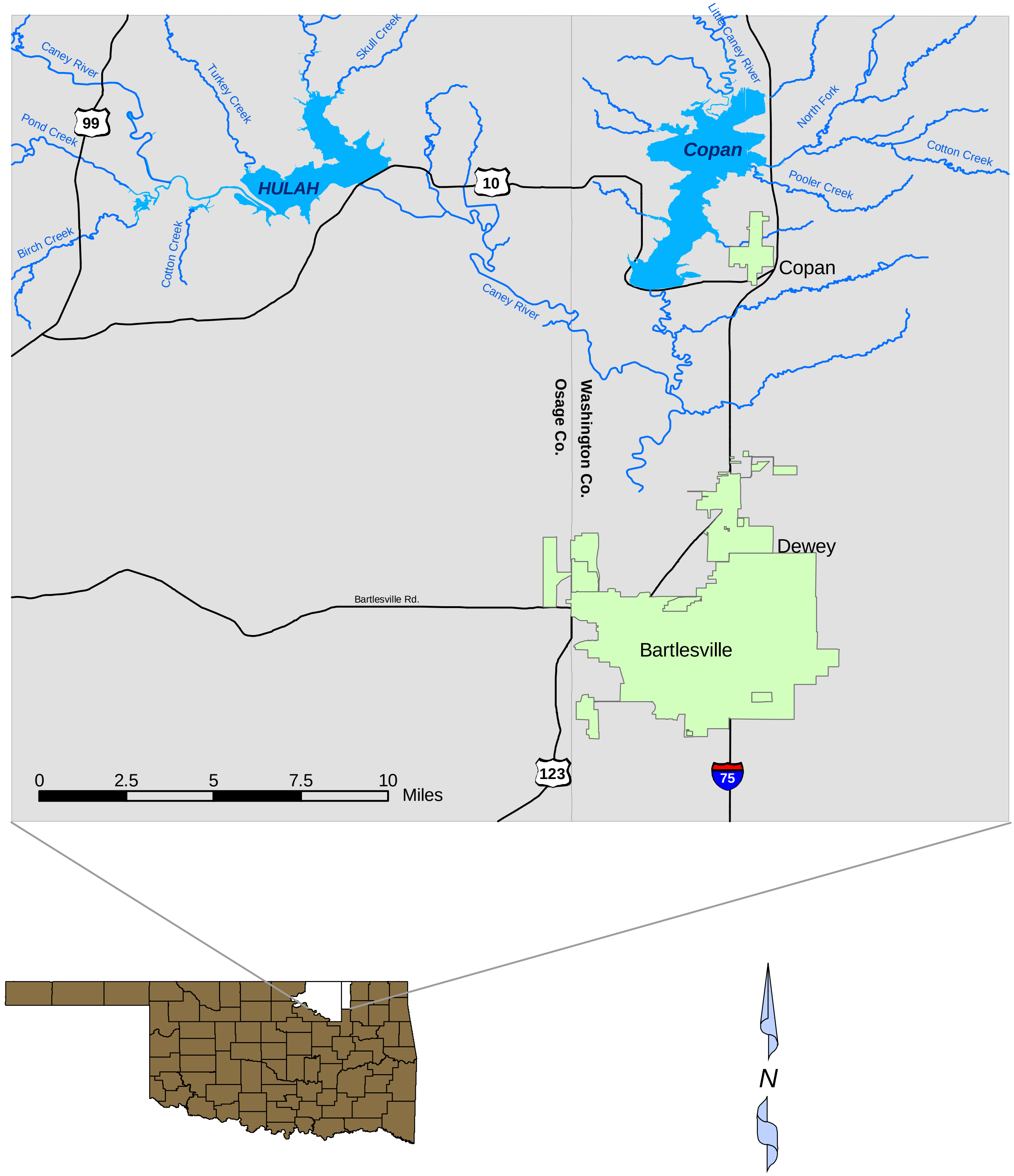


Hulah Reservoir
Rangeline 07
Elevation (ft)
734
733.5
733
732.5
732
731.5
731
730.5
730
729.5
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)
2002

Figure 1

HULAH RESERVOIR AND COPAN LAKE

Location Map



TWDB Survey May 2002

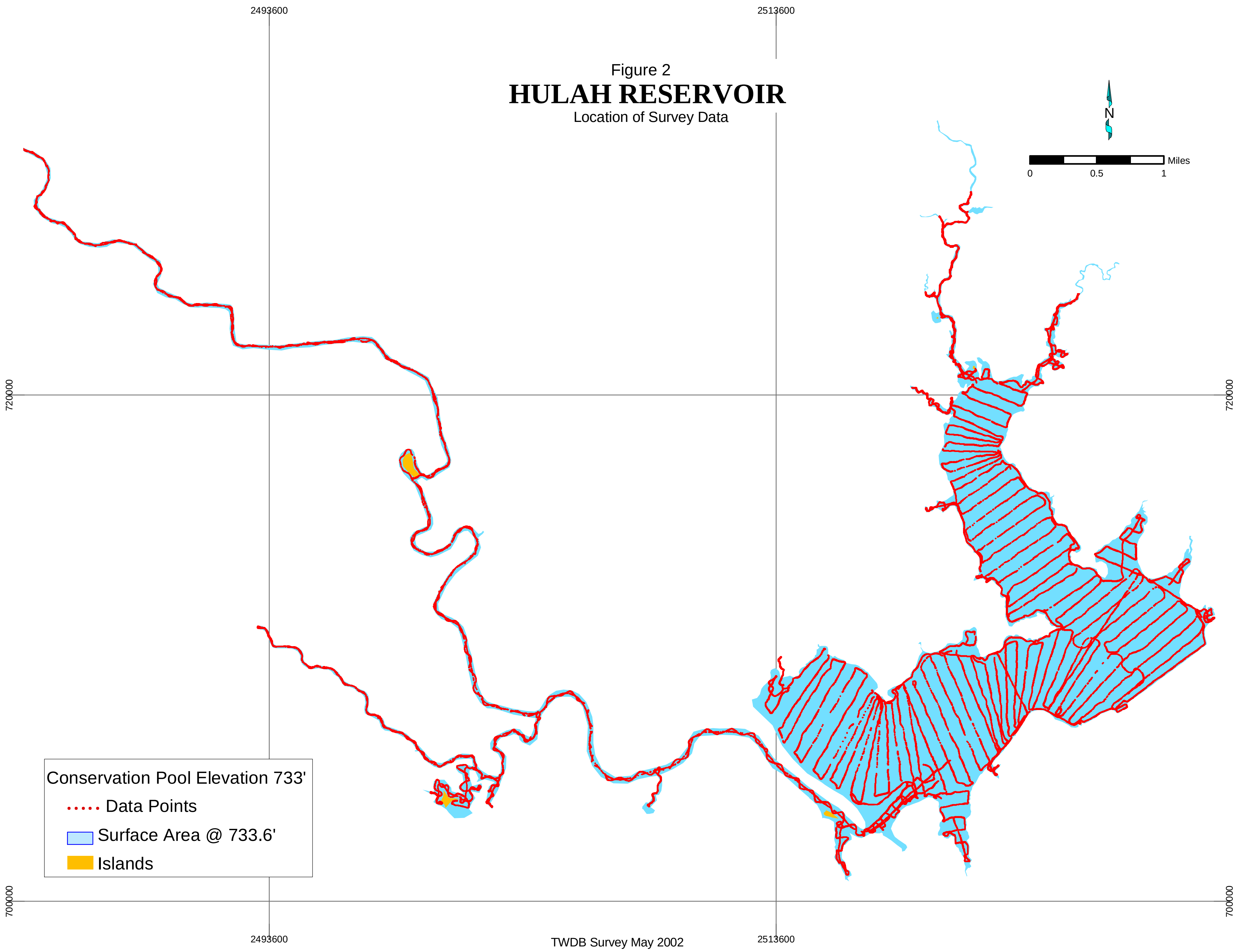
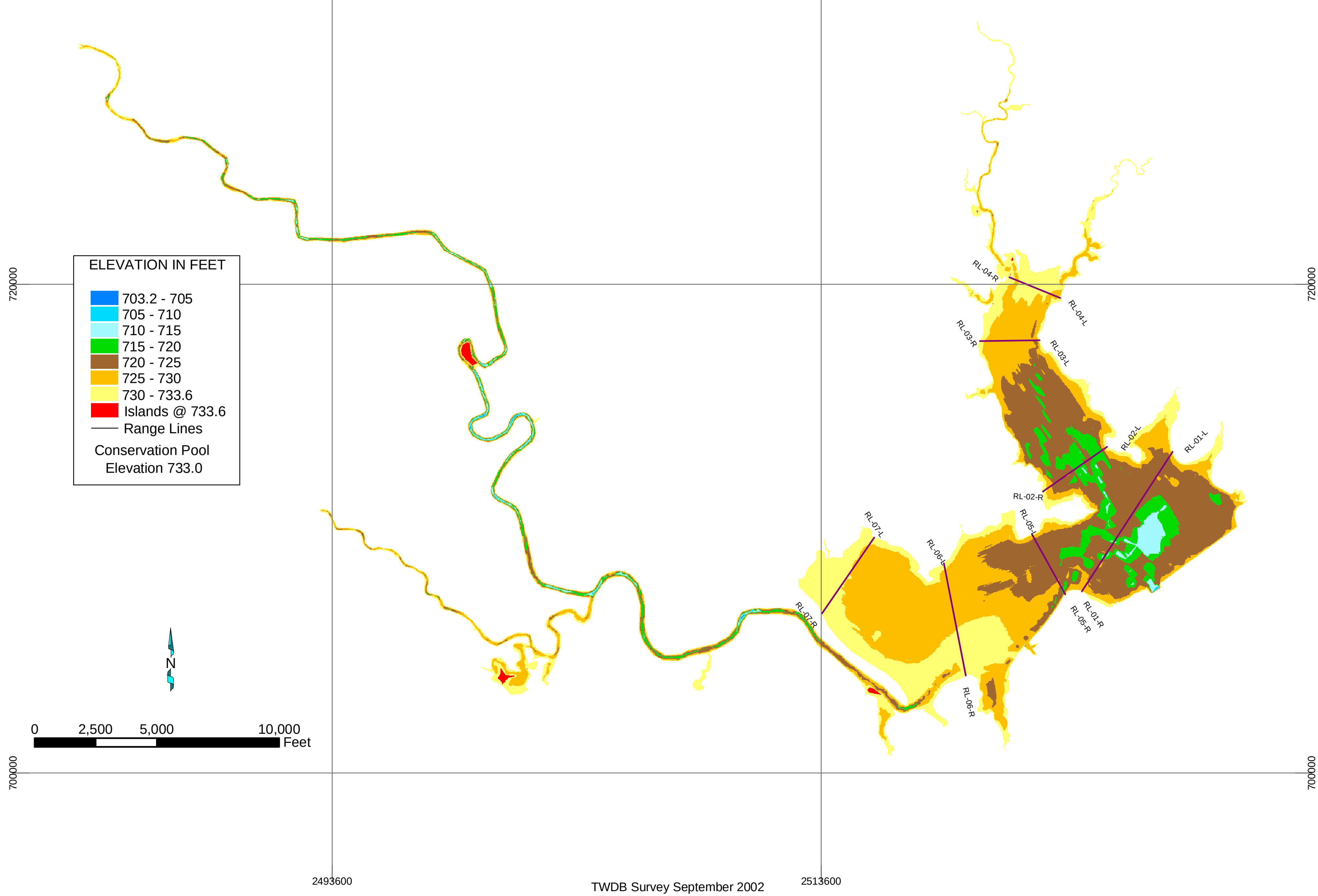

2493600
2513600
Figure 2
HULAH RESERVOIR
Location of Survey Data
N
Miles
0
0.5
1
720000
720000
700000
700000
Conservation Pool Elevation 733'
Data Points
Surface Area @ 733.6'
Islands
2493600
2513600
TWDB Survey May 2002

Figure 3

HULAH RESERVOIR

Elevation Relief



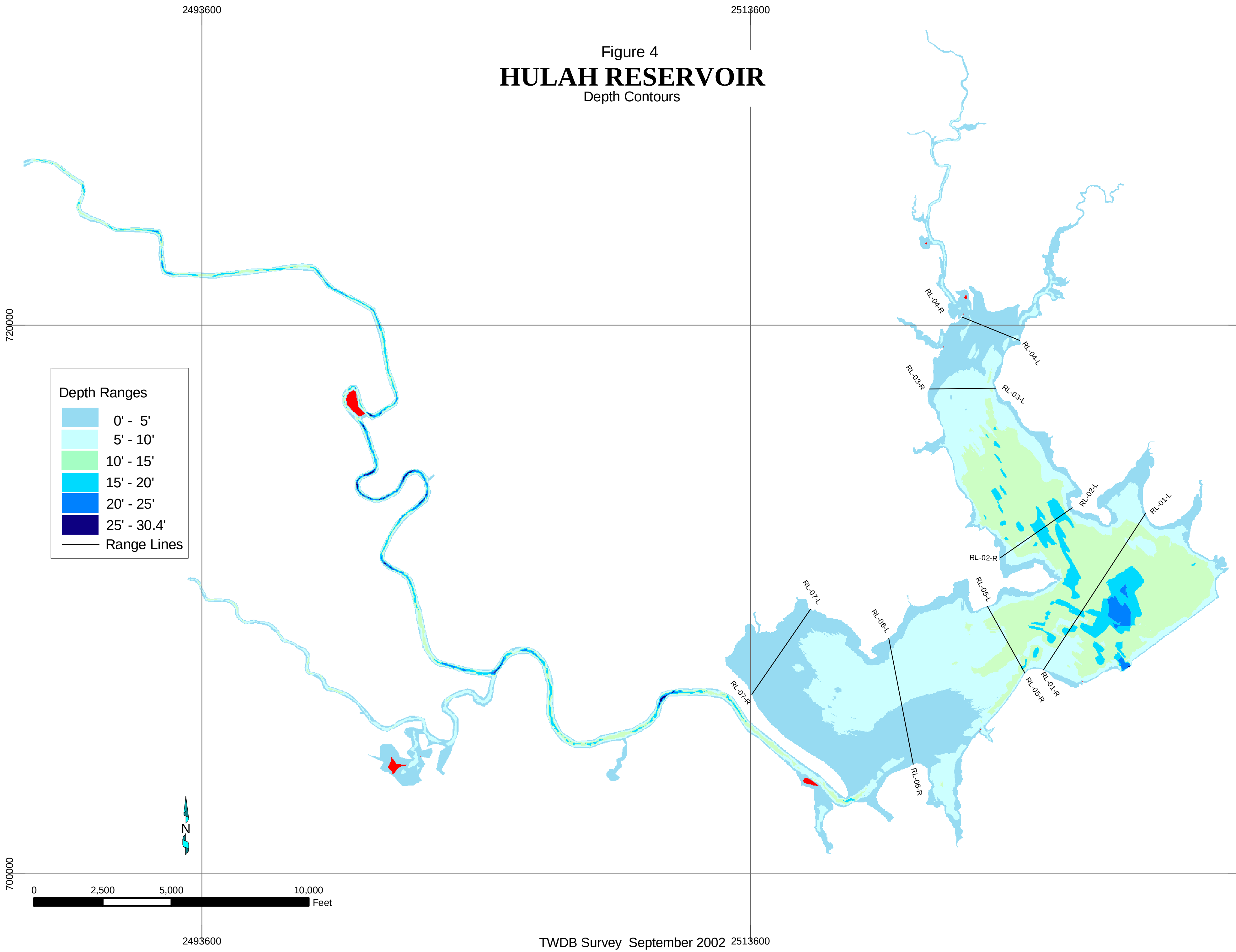

2493600
2513600
Figure 4
HULAH RESERVOIR
Depth Contours
720000
700000
Depth Ranges
0' - 5'
5' - 10'
10' - 15'
15' - 20'
20' - 25'
25' - 30.4'
Range Lines
RL-01-L
RL-01-R
RL-02-L
RL-02-R
RL-03-L
RL-03-R
RL-04-L
RL-04-R
RL-05-L
RL-05-R
RL-06-L
RL-06-R
RL-07-L
RL-07-R
N
0
2,500
5,000
10,000
Feet
TWDB Survey September 2002

Figure 5

HULAH RESERVOIR

2' - Contour Map

Water Surface @ 733.6'

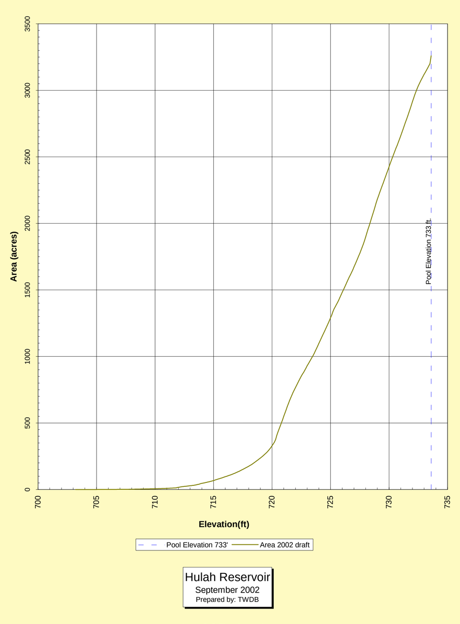
Islands

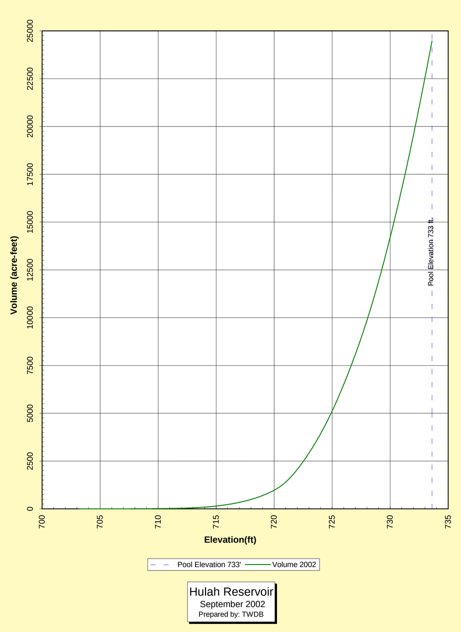
Conservation Pool 733.0'

Cross Sections

Contours

710
712
714
716
718
720
722
724
726
728
730
732





TEXAS WATER DEVELOPMENT BOARD SEPTEMBER 2002 SURVEY