VOLUMETRIC SURVEY
OF
LAKE LIMESTONE

Prepared for:

THE BRAZOS RIVER AUTHORITY

Prepared by:

The Texas Water Development Board

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INTRODUCTION

Staff of the Hydrologic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Lake Limestone in May, 1993. The purpose of the survey was to determine the capacity of the lake at the normal pool elevation and to establish baseline information for future surveys. From this information, future surveys will be able to determine sediment deposition locations and rates over time. Survey results are presented in the following pages in both graphical and tabular form.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Lake Limestone, owned by the Brazos River Authority, is located in Leon, Limestone and Robertson Counties approximately 18 miles west of Buffalo, Texas. Sterling C. Robertson Dam is located on the Navasota River, a tributary of the Brazos River. Dam Construction commenced in August, 1975 and was completed in October, 1978.

Application No. 3214 was filed May 6, 1974 with the Texas Water Rights Commission by the Brazos River Authority (BRA) to construct a dam and reservoir on the Navasota River and to impound a maximum of 217,494 acre-feet of water at elevation 363.0 feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29). All elevations presented in this report are reported in NGVD '29 unless noted otherwise.

Permit No. 2950 was issued October 1, 1974, and maximum allocations set as follows: 70,000 acre-feet for municipal purposes; 77,500 acre-feet acre-feet for industrial purposes; and

70,000 acre-feet for irrigation, with a priority right of 70,194 acre-feet. Permit No. 2950-A was issued on September 13, 1979, and amended Permit No. 2950 to allow the permittee to use the impounded waters of Lake Limestone for nonconsumptive recreational purposes in addition to the allocated uses.

An application for amendment was filed September 4, 1979, to correct an erroneous impounding capacity. Permit No. 2950B was issued October 30, 1979, authorizing the BRA to maintain Lake Limestone on the Navasota River and to impound a maximum of 225,400 acre-feet at elevation 363.0 feet.

A change in usage required filing an amendment on November 3, 1980. Permit No. 2950C issued November 25, 1980 reduced the annual municipal use to a maximum of 69,500 acre-feet of water and allowed a maximum of 500 acre-feet of water for mining purposes.

Certificate of Adjudication No. 5165 was issued to the Brazos River Authority on December 14, 1987. The owner was authorized to maintain an existing dam and reservoir and impound not to exceed 225,400 acre-feet of water at elevation 363.0 feet. A priority right was authorized to divert and use a maximum of 65,074 acre-feet of water annually for municipal, industrial, irrigation and mining purposes. For purposes of the system operation, the owner was authorized to exceed the priority right and to annually divert and use from Lake Limestone a maximum of 69,500 acre-feet of water for municipal use, 77,500 acre-feet of water for industrial use, 70,000 acre-feet of water for irrigation and 500 acre-feet of water for mining use. All diversions and uses of water from Lake Limestone in excess of 65,074 acre-feet per year would be charged against the sum of the amounts designated as priority rights in the other reservoirs within the Brazos River Basin included in the System Operation Order. The owner was also authorized to use the impounded waters in Lake Limestone for nonconsumptive recreational use.

Sterling C. Robertson Dam is a rolled earthfill structure separated into two sections by the service spillway. The embankment to the west of the service spillway is approximately 5,800 feet long with a maximum height of 57 feet. East of the service spillway, the embankment is approximately 3,300 feet in length and 40 feet in height. The dam's effective crest elevation is

380.0 feet. The service spillway is a gated ogee weir with a concrete chute and stilling basin. The weir crest is 200 feet wide at elevation 337.0 feet. The service spillway is controlled by five tainter gates each 40 feet wide, with a top elevation of 365.0 feet. The gates are separated by eight foot thick piers. Each of the two middle piers contain four foot by eight foot sluice gates. The east pier contains two 36-inch diameter low-flow conduits and the west pier contains a 10-inch diameter bypass outlet. The emergency spillway is a 3000-foot wide earthen channel located at the west end of the embankment. The crest elevation of the emergency spillway is 369.6 feet. Records indicate the reservoir's storage capacity at the normal pool elevation of 363.0 feet is 225,400 acre-feet with a surface area of 14,200 acres.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the equipment and methodology used to conduct this hydrographic survey. Some of the theory behind Global Positioning System (GPS) technology and its accuracy are also addressed.

GPS Information

The following is a brief and simple description of Global Positioning System (GPS) technology. GPS is a new technology that uses a network of satellites, maintained in precise orbits around the earth, to determine locations on the surface of the earth. GPS receivers monitor the broadcasts from the satellites over time to determine the position of the receiver. With only one satellite being monitored, the point in question could be located anywhere on a sphere surrounding the satellite with a radius of the distance measured. Additional satellite readings would also produce a possible location on a sphere surrounding that satellite with a radius of the distance measured. The observation of two satellites from an unknown point decreases the possible location to a finite number of points on a circle where the two spheres intersect. With a third satellite observation, the unknown location is reduced to two points where all three spheres intersect. One of these points is obviously in error because its location is in space, and it is ignored. Although three satellite measurements can fairly accurately locate a point on the earth, the minimum number of satellites required to determine a three dimensional position within the required accuracy is four. The fourth measurement compensates for any time discrepancies between the clock on board the satellites and the clock within the GPS receiver.

GPS technology was first utilized on February 22, 1978, when the initial satellite was launched. The NAVSTAR (NAVigation System with Time And Ranging) satellite constellation will consist of 24 satellites when fully implemented. At the time of the survey, 23 satellites of the constellation were fully functional. The United States Department of Defense (DOD) is responsible for implementing and maintaining the satellite constellation. In an attempt to discourage the use of these survey units as a guidance tool by hostile forces, the DOD has implemented means of false signal projection called Selective Availability (S/A). Positions determined by a single receiver when S/A is active result in errors to the actual position of up to 100 meters. These errors can be reduced to centimeters by performing a static survey with two GPS receivers, one of which is set over a point with known coordinates. The errors induced by S/A are time-constant. By monitoring the movements of the satellites over time (1 to 3 hours), the errors can be minimized during post processing of the collected data and the unknown position computed accurately.

Differential GPS (DGPS) can determine positions of moving objects in real-time or "on-the-fly" and was used during the survey of Lake Limestone. One GPS receiver was set up over a benchmark with known coordinates established by the hydrographic survey crew. This receiver remained stationary during the survey and monitored the movements of the satellites overhead. Position corrections were determined and transmitted via a radio link once per second to a second GPS receiver located on the moving boat. The boat receiver used these corrections, or differences, in combination with the satellite information it received to determine its differential location. The large positional errors experienced by a single receiver when S/A is active are greatly reduced by utilizing DGPS. The reference receiver calculates satellite corrections based on its known fixed position, which results in positional accuracies within 3 meters for the moving receiver. DGPS was used to determine horizontal position only. Vertical information was supplied by the depth sounder.

Equipment

The equipment used in the hydrographic survey of Lake Limestone consisted of a 23 foot aluminum tri-hull SeaArk craft with cabin, equipped with twin 90 Horsepower Johnson outboard motors. Installed within the enclosed cabin are an Innerspace Helmsman Display (for navigation), an Innerspace Technology Depth Sounder and Velocity Profiler, a Trimble Navigation, Inc. 4000SE GPS receiver, a Motorola Radius radio with an Advanced Electronic Applications, Inc. packet modem, and an on-board computer. The computer is supported by a dot matrix printer and a B-size plotter. Power is provided by a water-cooled generator through an in-line uninterruptible power supply. Reference to brand names does not imply endorsement by the TWDB.

The shore station included a second Trimble 4000SE GPS receiver, Motorola Radius radio and Advanced Electronic Applications, Inc. packet modem, and an omni-directional antenna mounted on a modular aluminum tower to a total height of 40 feet. The combination of this equipment provided a data link with a reported range of 25 miles over level to rolling terrain that does not require that line-of-sight be maintained with the survey vessel in most conditions, thereby reducing the time required to conduct the survey.

As the boat traveled across the lake surface, the depth sounder gathered approximately ten readings of the lake bottom each second. The depth readings were averaged over the one-second interval and stored with the positional data to an on-board computer. After the survey, the average depths were corrected to elevation using the daily lake elevation. The set of data points logged during the survey were used to calculate the lake volume. Accurate estimates of the lake volume can be quickly determined using these methods, to produce an affordable survey. The level of accuracy is equivalent to or better than previous methods used to determine lake volumes, some of which are discussed below.

Survey Methods

The Hydrographic Survey crew established coordinates for two benchmarks in May, 1993, to serve as control for the shore station sites. An existing metal cap embedded in concrete marked BRA #1, located near the centerline of the dam's crest on the west bank, was utilized for the first shore station. This location was chosen because of the close proximity to the reservoir, the unobstructed view of the reservoir, and the security of the area. Due to the size of the reservoir, a second shore station site was required to maintain contact with the roving receiver. Once the survey began, the location for the second benchmark was determined from the range of the first shore station. The second benchmark, a brass cap stamped TWDB #007, is embedded in concrete at the water treatment facility of the South Limestone County Water Supply Corporation. This facility is located approximately 0.3 miles south of County Road 3371 in Limestone County.

A static survey using the two Trimble 4000SE GPS receivers was performed to obtain coordinates for BRA #1. One GPS receiver was positioned over a USGS first-order monument named FALLON, located approximately seventeen and one-half miles south of the dam. FALLON was established in 1919. Satellite data were gathered from this station for approximately one and one-half hours, with up to six satellites visible to the receiver. During the same time period, data were gathered from the second receiver positioned over BRA #1.

Once data collection ended, the data were retrieved from the two receivers using Trimble Trimvec software, and processed to determine coordinates for the shore station benchmark. The NAVSTAR satellites use the World Geodetic System (WGS '84) spherical datum. WGS '84 is essentially identical to the North American Datum of 1983 (NAD '83). The WGS' 84 coordinates for BRA #1 were determined to be North latitude 31° 19' 31.73316", West longitude 96° 20' 02.190567", and ellipsoid height of 92.0465 meters. The approximate NGVD '29 elevation is 387.8 feet. Those coordinates were then entered into the shore station receiver located over BRA #1 to fix its location and allow calculation and broadcasting of corrections through the radio and modem to the roving receiver located on the boat.

The same procedure was used to establish coordinates for TWDB #007 benchmark, with BRA #1 as the known point. The WGS '84 coordinates for TWDB #007 are North Latitude 31° 25' 47.19547", West Longitude 96° 22' 47.68978" and ellipsoid height of 97.8247 meters. The approximate NGVD '29 elevation height is 406.18 feet.

The reservoir's surface area was determined by digitizing the lake boundary from 1966 USGS quad sheets that were updated in 1982 from 1978 aerial photographs. Intergraph Microstation CADD software was used to digitize an estimate of the 363.0 contour based on the North American Datum of 1927 (NAD '27) used for this map. The graphic boundary was then transformed from NAD '27 to NAD '83 using Microstation Projection Manager, to get the boundary into a more recent datum compatible with the positions received from the satellites. The area of the boundary shape was the same in both datum. NAD '83, a flat projected representation of the curved earth surface, was chosen to calculate areas and volumes. NAD '27 is also a flat projection, but the two datum have a slightly different point of origin, and distinctly different state plane false northing and false easting coordinate to be able to distinguish coordinate points between the two datum.

The resulting shape was modified slightly to insure that all data points gathered were within the boundary. An aerial photo dated August 10, 1989 indicated significant sedimentation along the upper reaches of the Navasota River. Since the elevation on the date of the photo was 362.7 feet, or 0.3 feet below normal pool, the boundary from the photo was assumed to be the boundary for the Navasota River fork of the reservoir, and agreed quite well with the location of the data collected. The boundary along Big Creek and Sanders Creek was also modified based on the extent of data collected (see Figure 2). The resulting acreage at the normal pool elevation was thereby estimated to be 13,379 acres, or within 5.8 percent of the recorded 14,200 acres. An aerial topo of the upper four feet of the lake or an aerial photo taken when the lake is at the normal pool elevation would more closely define the present boundary. However, the minimal increase in accuracy does not appear to offset the cost of those services at this time.

The survey layout was pre-planned, using approximately 150 survey lines at a spacing of 500 feet. Innerspace Technology Inc. software was utilized for navigation and to integrate and store positional data along with depths. In areas where vegetation or obstructions prevented the boat from traveling the planned line, random data were collected wherever the boat could maneuver. Additional random data were collected lengthwise in the reservoir. Data points were entered into the data set utilizing the DGPS horizontal position and manually poling the depth in shallow areas where the depth was less than the minimum recordable depth of the depth sounder, which is about 3.5 feet. Figure 2 shows the actual location of the data collection sites. Data were not collected in areas that were inaccessible due to shallow water or obstructions. The data set included approximately 138,000 data points.

TWDB staff verified the horizontal accuracy of the DGPS used in the Lake Limestone survey to be within the specified accuracy of three meters. The shore station was set up over a known United States Geological Service (USGS) first order monument and placed in differential mode. The second receiver, directly connected to the boat with its interface computer, was placed over another known USGS first order monument and set to receive and process the corrections. Based on the differentially-corrected coordinates obtained and the published coordinates for both monuments, the resulting positions fell within a three meter radius of the actual known monument position. For DGPS operation the reference station receiver was set to a horizontal mask of 0°, to acquire information on the rising satellites. A horizontal mask of 10° was used on the roving receiver for better satellite geometry and thus better horizontal positions. The DGPS positions were within acceptable limits of horizontal accuracy with a PDOP (Position Dilution of Precision) of seven (7) or less. The GPS receivers have an internal alarm that sounds if the PDOP rises above the maximum entered by the user, to advise the field crew that the horizontal position has degraded to an unacceptable level.

The depth sounder measures depth by measuring the time between the transmission of the sound pulse and the reception of its echo. The depth sounder was calibrated with the Innerspace Velocity Profiler typically once per day, unless the maximum depth varied by more than twenty feet. The velocity profiler calculates an average speed of sound through the water column of interest (typically set at a range of two feet below the surface to about ten feet above the maximum encountered depth), and the draft value or distance from the transducer to the surface. The velocity profiler probe is placed in the water to wet the transducers, then raised to the water surface where the depth is zeroed. The probe is then lowered on a cable to just below the maximum depth set for the water column, and then raised to the surface. The unit reads out an average speed of sound for the water column and the draft measurement, which are then entered into the depth sounder. The speed of sound can vary based on temperature, turbidity, density, or other factors. 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, plus an estimated error of ±0.3 feet due to the plane of the boat for a total accuracy of ±0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some are plus readings and some are minus readings. Further information on these calculations is presented in Appendix A, Page 1. Manual poling of depths within shallow areas agreed with the depth obtained by the depth sounder typically within ± 0.3 feet, and since the boat is moving much slower, the plane of the boat has much less effect.

Analog charts were printed for each survey line as the data were collected. The gate mark, which is a known distance above the actual depth that was recorded in the data file, was also printed on the chart. Each analog chart was analyzed, and where the gate mark indicated that the recorded depth was other than the bottom profile, depths in the corresponding data files were modified accordingly. The depth sounder was set to record bad depth readings as 0, and all points with a zero depth were deleted.

Each data point consisted of a latitude, longitude and depth. The depths were transformed to elevations with a simple awk Unix command based on the water surface elevation each day, rounded to the nearest tenth of a foot since the depth sounder reads in tenths of a foot, and ranged from 363.0 to 363.4 feet. The data set was then loaded into an existing Microstation design file with the Microstation ASCII Loader product. The design file contained the NAD '83 boundary previously discussed in this report. The data points along with the boundary were used to create a digital terrain model (DTM) of the reservoir's bottom surface using the Microstation Terrain Modeler product. This software uses 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. This method preserves all data points for use in determining the solution. The set of three-dimensional triangular planes represents the actual bottom surface. Once the triangulated irregular network (TIN) is formed, the software then calculates elevations along the triangle surface plane by solving the equations for elevation along each leg of the triangle. Areas that were too shallow for data collection or obstructed by vegetation were estimated by the Modeler product using this method of interpolation. Any difference between the estimated volume and the actual volume is believed to be minor because the shallow areas do not contain significant amounts of water. From this three-dimensional triangular plane surface representation, the Modeler product calculated the surface area and volume of the entire reservoir at one-tenth of a foot intervals.

The three-dimensional triangular surface was then converted to a regular matrix of elevation values, or a grid. A grid spacing of one hundred feet was chosen for this presentation, to produce an illustration that would be easy to visualize, but not so dense that it would obscure features. A vertical exaggeration of fifty was used to create a perception of depth within the draawing. Figure 3 is a graphical representation of a grided version of the three-dimensional DTM. Figure 4 presents a two-dimensional version of the same map, using bands of color increasing in intensity from shallow to deep water.

The DTM was then smoothed and linear smoothing algorithms were applied to the smoothed model to produce smoother contours. The following smoothing options were chosen for this model: Douglas-Peucker option with a zero tolerance level to eliminate any duplicate points, and Round Corners with a delta of 50 feet in an attempt to smooth some of the angularity of the contours. Contours of the bottom surface at two foot intervals are presented in Figure 5.

DATA

Many of the trees in the fifteen-year-old lake have rotted off at the water line, but have not been submerged long enough to decompose. The submerged branches posed a significant hazard to navigation, and resulted in an increased survey collection time. Lake Limestone inundates approximately 14 river miles of the Navasota River upstream of Sterling C. Robertson Dam. The deepest portions of the lake are found within the area immediately adjacent to the dam. The DTM shows a fairly well-defined channel characterized by intermittent deep pockets. This channel lies within a a wide, flat floodplain that is bounded by relatively steep side slopes.

The 1989 aerial photo reflects significant sedimentation along the Navasota River. The data collected in this area corresponds with the aerial photo and the revised boundary. Lake Limestone was estimated by this survey to encompass 13,379 acres and to contain a volume of 215,751 acre-feet at the normal pool elevation of 363.0 feet. The reservoir volume table is presented in Appendix B, Page 1 and the area table in Appendix C, Page 1. The one-tenth foot intervals are based on actual calculations from the model. An elevation-area-volume graph is presented in Appendix D, Page 1. The surface elevation of the lake was at or above the normal pool elevation during the survey. Since the boat cannot negotiate in shallow water, at a minimum the upper two feet are based on a straight-line interpolation from the last data points collected to the normal pool elevation lake boundary as digitized. The positional data collected in the field corresponds well with the boundary obtained from the photo-revised USGS map and aerial photo. The Board does not represent the boundary, as depicted in this report, to be a detailed actual boundary. It is an approximation of the actual boundary used to compute the volume and area within the upper elevations.

The storage volume calculated by this survey is approximately 4.3 percent less than the previous record information for the lake. The low flow outlet is at elevation 320.0 feet, resulting in dead storage of three acre-feet. Therefore the conservation storage for the reservoir is calculated to be 215,748 acre-feet.

SUMMARY

The lowest elevation encountered during this survey was 317.5 feet, or 45.5 feet of depth. The conservation storage was calculated to be 215,748 acre-feet. The estimated reduction in storage capacity is 9,652 acre-feet, or 4.3 percent less than that recorded in the permit. It is assumed that the reduction in estimated storage is due to both a combination of sedimentation, and improved data and calculation methods. Repeating this survey with the same calculation methodology in five to ten years or after major flood events should remove any noticeable error due to improved calculation techniques and will help isolate the storage loss due to sedimentation.

CALCULATION OF DEPTH SOUNDER ACCURACY

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

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

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 45 feet (within the 2 to 45 foot column with V = 4808 fps):

D_{80} = [((80-1.2)/4785)(4799)]+1.2
= 80.2' (+0.2')

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR VOLUME TABLE

Aug 23 1993

LAKE LIMESTONE

VOLUME IN ACRE-FEET

ELEVATION INCREMENT IS ONE TENTH FOOT

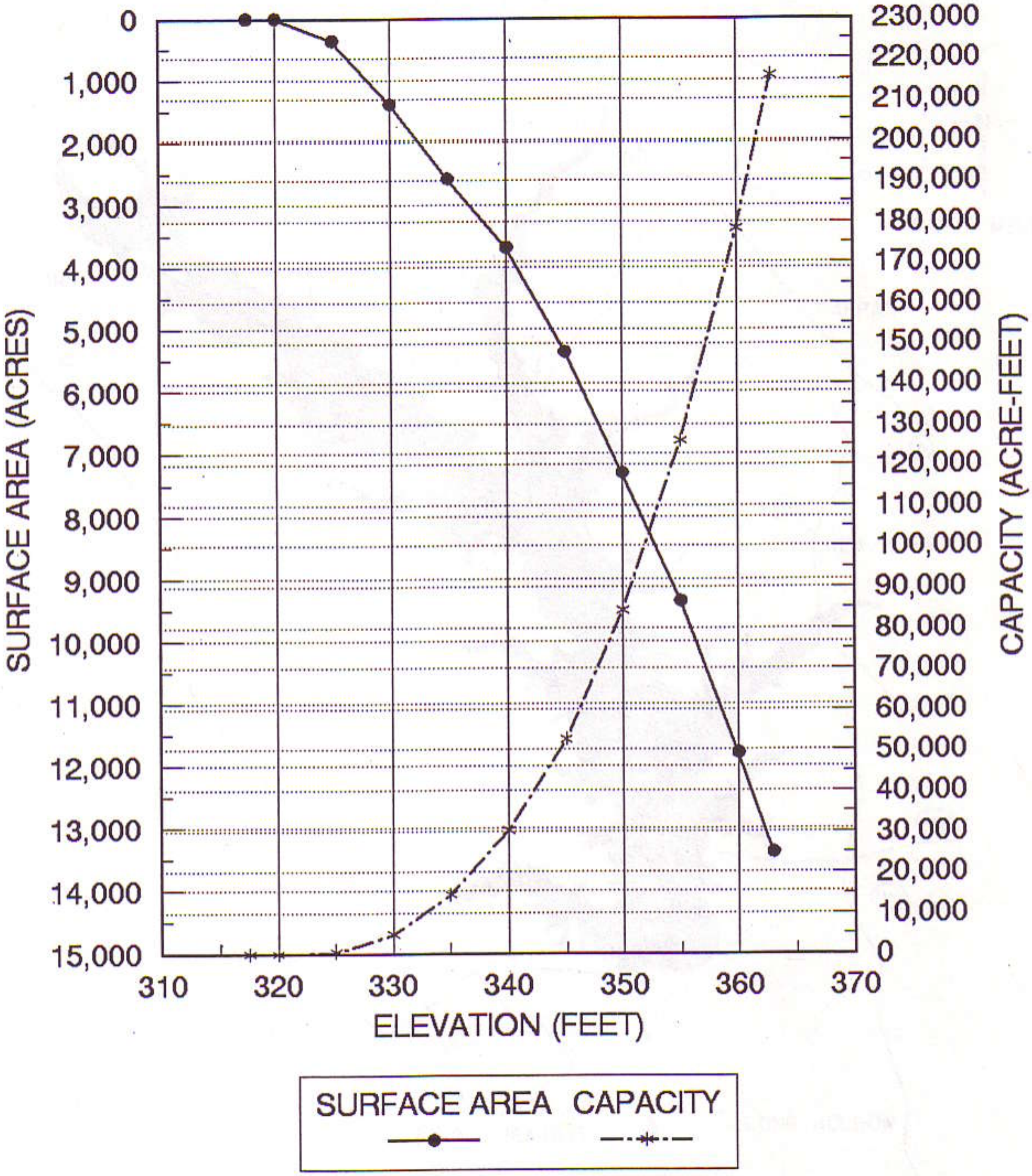
ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
317										
318										
319	1	1	1	1	1	1	2	2	2	2
320	3	3	3	4	4	5	5	6	6	7
321	8	8	9	10	11	12	13	15	16	18
322	19	22	24	27	31	35	40	45	51	57
323	64	72	80	90	101	113	126	141	157	175
324	194	215	238	263	289	317	347	378	411	445
325	481	518	557	597	639	682	727	773	821	871
326	922	976	1032	1089	1148	1210	1274	1340	1408	1478
327	1551	1626	1703	1783	1865	1949	2036	2125	2216	2310
328	2405	2502	2601	2702	2804	2909	3016	3124	3236	3349
329	3464	3582	3702	3824	3949	4076	4204	4335	4468	4604
330	4741	4880	5022	5164	5309	5455	5603	5753	5905	6058
331	6213	6371	6530	6692	6857	7023	7192	7363	7536	7712
332	7890	8071	8254	8440	8628	8819	9013	9209	9407	9609
333	9813	10019	10228	10438	10651	10867	11085	11305	11529	11755
334	11983	12214	12447	12683	12923	13165	13409	13657	13907	14161
335	14417	14676	14938	15203	15471	15742	16017	16293	16573	16855
336	17140	17427	17716	18007	18300	18595	18893	19192	19494	19798
337	20103	20411	20721	21032	21346	21662	21979	22299	22620	22944
338	23269	23595	23923	24254	24587	24920	25255	25595	25932	26274
339	26618	26965	27312	27663	28014	28370	28726	29086	29447	29812
340	30179	30546	30918	31295	31671	32050	32433	32821	33209	33602
341	33999	34396	34798	35204	35611	36022	36435	36850	37268	37691
342	38115	38542	38972	39403	39839	40278	40721	41166	41616	42071
343	42530	42994	43462	43937	44415	44897	45383	45875	46368	46866
344	47369	47874	48382	48891	49405	49924	50445	50969	51497	52027
345	52562	53101	53641	54187	54736	55292	55847	56410	56974	57546
346	58120	58701	59284	59869	60459	61054	61653	62254	62860	63471
347	64084	64702	65324	65948	66577	67211	67847	68487	69130	69775
348	70425	71079	71736	72397	73060	73728	74399	75073	75753	76437
349	77126	77817	78512	79213	79917	80627	81338	82055	82775	83501
350	84231	84963	85698	86439	87183	87932	88682	89438	90197	90962
351	91729	92500	93276	94056	94842	95629	96423	97222	98023	98832
352	99642	100457	101276	102103	102932	103763	104601	105441	106286	107135
353	107989	108845	109704	110567	111435	112307	113182	114061	114945	115833
354	116726	117622	118522	119426	120335	121249	122167	123088	124013	124943
355	125877	126814	127755	128698	129646	130597	131554	132514	133476	134444
356	135416	136391	137371	138354	139343	140335	141334	142335	143343	144353
357	145367	146387	147413	148444	149479	150519	151566	152617	153673	154734
358	155801	156871	157948	159029	160115	161205	162300	163402	164506	165618
359	166733	167856	168988	170124	171267	172415	173570	174731	175898	177068
360	178246	179426	180611	181802	182996	184197	185399	186607	187819	189036
361	190257	191481	192711	193946	195184	196428	197677	198930	200188	201451
362	202720	203997	205275	206563	207856	209153	210459	211770	213090	214417
363	215751									

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR AREA TABLE

LAKE LIMESTONE

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
317										
318						1	1	1	1	1
319	1	1	1	2	2	2	2	3	3	3
320	3	4	4	4	4	5	5	6	6	7
321	7	8	9	9	10	11	12	13	15	17
322	20	24	29	34	39	44	49	53	59	66
323	74	82	91	102	113	126	140	154	170	185
324	201	220	239	256	272	288	304	321	337	352
325	365	379	395	410	423	438	454	470	489	508
326	527	545	564	584	605	627	649	670	692	714
327	738	762	783	806	830	856	880	903	924	944
328	961	979	997	1017	1037	1057	1078	1100	1121	1143
329	1166	1189	1213	1235	1256	1277	1298	1320	1342	1364
330	1384	1404	1421	1437	1454	1472	1488	1505	1524	1543
331	1564	1585	1608	1632	1654	1676	1700	1722	1745	1768
332	1793	1819	1845	1871	1898	1922	1948	1973	2000	2027
333	2051	2074	2096	2119	2142	2166	2192	2220	2245	2271
334	2295	2322	2348	2376	2405	2433	2461	2490	2519	2547
335	2576	2604	2636	2669	2697	2725	2754	2783	2810	2834
336	2857	2879	2900	2920	2942	2965	2986	3006	3028	3047
337	3067	3087	3107	3126	3146	3165	3185	3206	3224	3242
338	3259	3276	3294	3312	3330	3348	3366	3386	3407	3426
339	3446	3468	3490	3514	3536	3559	3581	3605	3629	3654
340	3680	3706	3731	3757	3787	3816	3847	3878	3910	3942
341	3972	4002	4032	4061	4090	4118	4145	4173	4200	4227
342	4255	4283	4312	4341	4372	4405	4440	4477	4518	4565
343	4615	4666	4715	4759	4801	4844	4889	4928	4964	4999
344	5031	5062	5093	5126	5159	5193	5226	5261	5294	5327
345	5362	5398	5436	5475	5514	5553	5593	5635	5679	5730
346	5773	5809	5847	5887	5925	5962	6000	6041	6081	6119
347	6157	6197	6234	6270	6308	6345	6380	6413	6447	6482
348	6517	6551	6586	6621	6655	6691	6730	6773	6816	6859
349	6901	6942	6983	7024	7063	7103	7146	7189	7230	7267
350	7305	7345	7384	7422	7460	7498	7535	7572	7612	7653
351	7695	7737	7780	7823	7867	7913	7960	8004	8046	8089
352	8132	8176	8224	8267	8309	8349	8391	8430	8468	8507
353	8545	8581	8617	8656	8695	8735	8775	8816	8858	8901
354	8941	8982	9024	9067	9110	9152	9195	9237	9276	9314
355	9351	9387	9424	9461	9499	9537	9576	9615	9655	9695
356	9735	9775	9817	9861	9907	9951	9995	10040	10085	10130
357	10176	10226	10277	10327	10380	10436	10489	10539	10589	10637
358	10686	10735	10784	10833	10882	10931	10981	11031	11082	11135
359	11191	11257	11333	11399	11463	11523	11580	11635	11686	11736
360	11785	11832	11879	11925	11969	12013	12057	12100	12143	12186
361	12230	12274	12320	12366	12413	12460	12509	12559	12610	12663
362	12719	12775	12833	12894	12956	13020	13086	13155	13225	13300
363	13379									



LAKE LIMESTONE

Prepared by: TWDB August 1993

FIGURE 1

LAKE LIMESTONE

LOCATION MAP

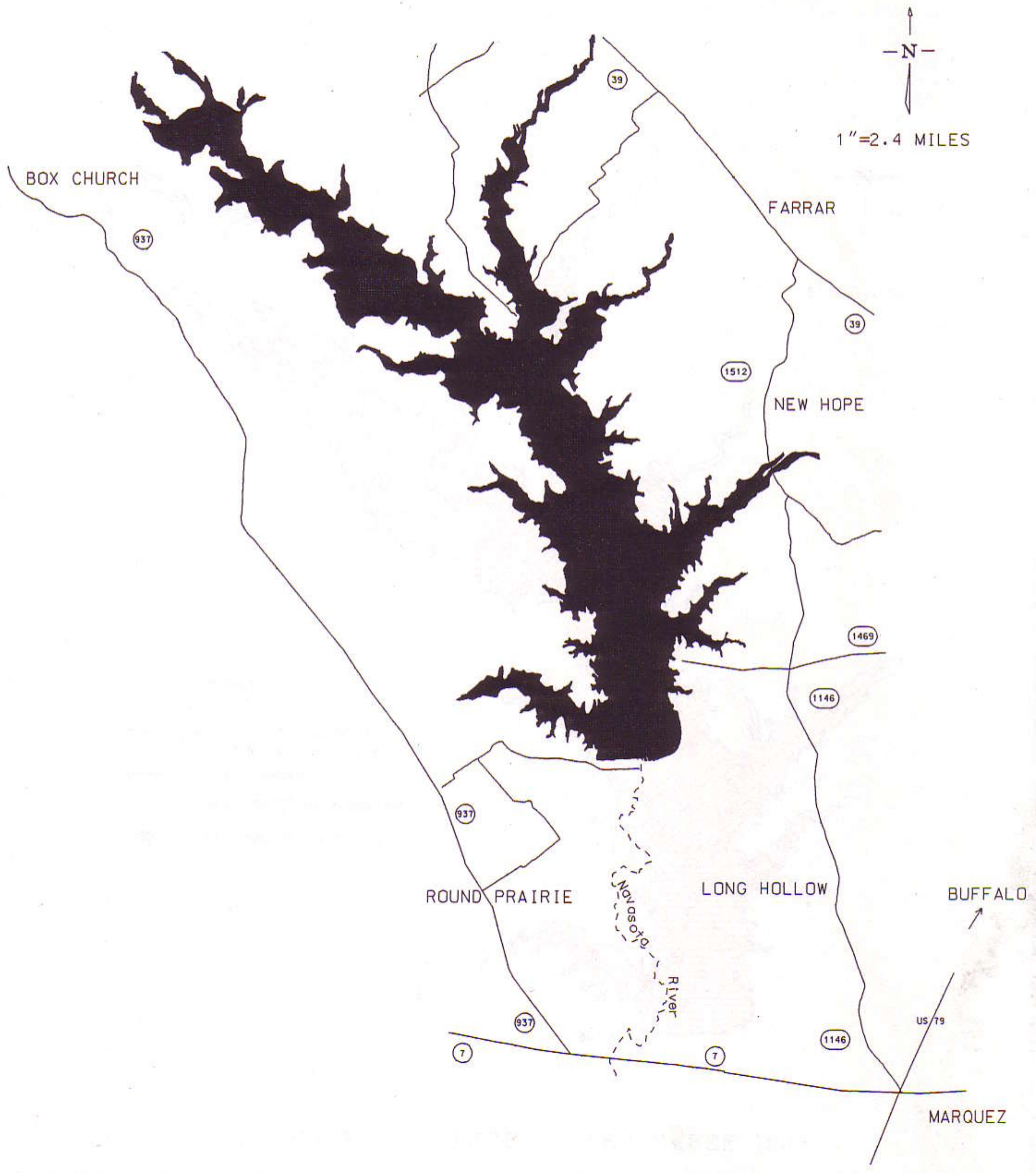
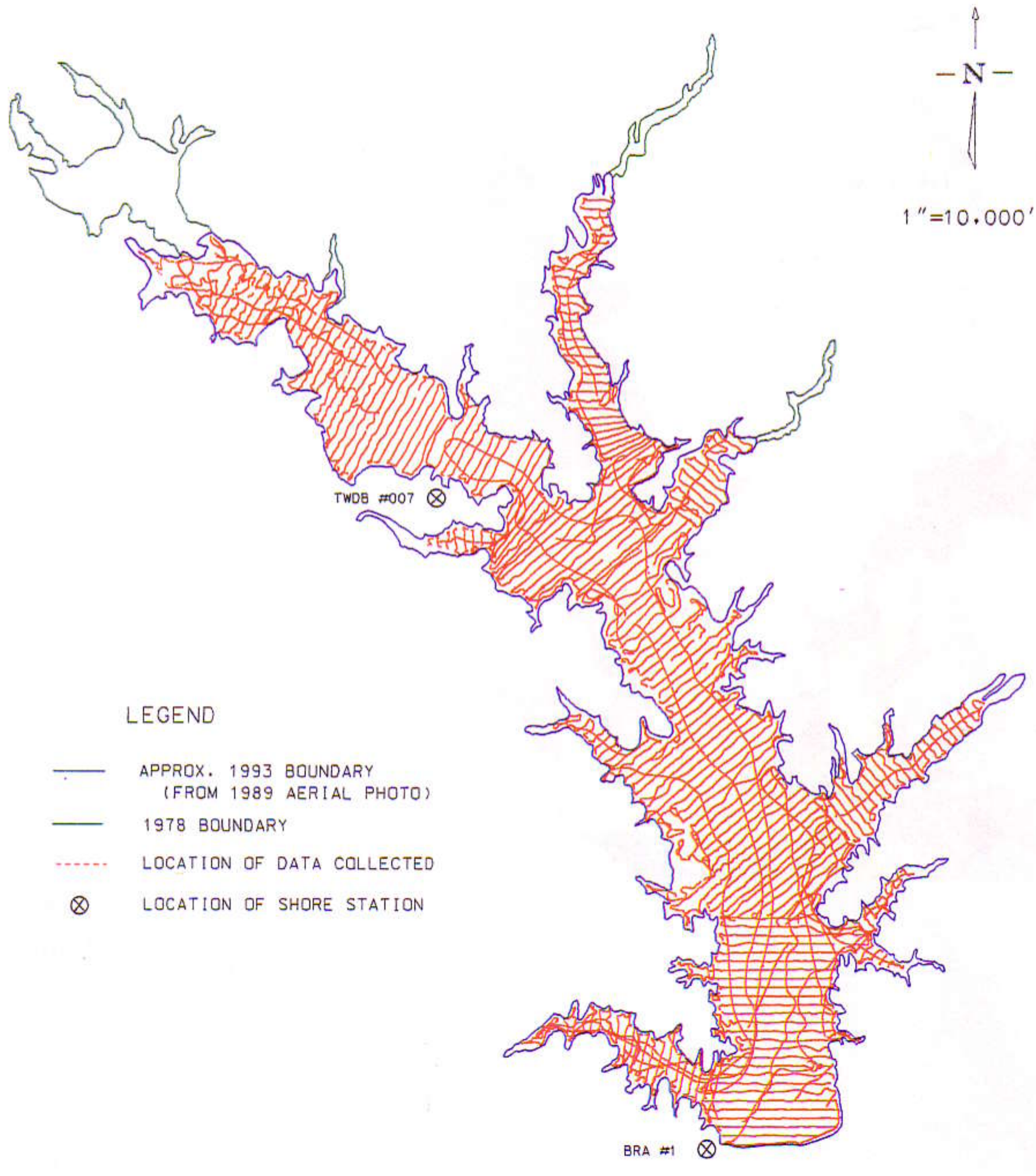


FIGURE 2

LAKE LIMESTONE

LOCATION OF SURVEY DATA



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LAKE LIMESTONE

3-D BOTTOM SURFACE

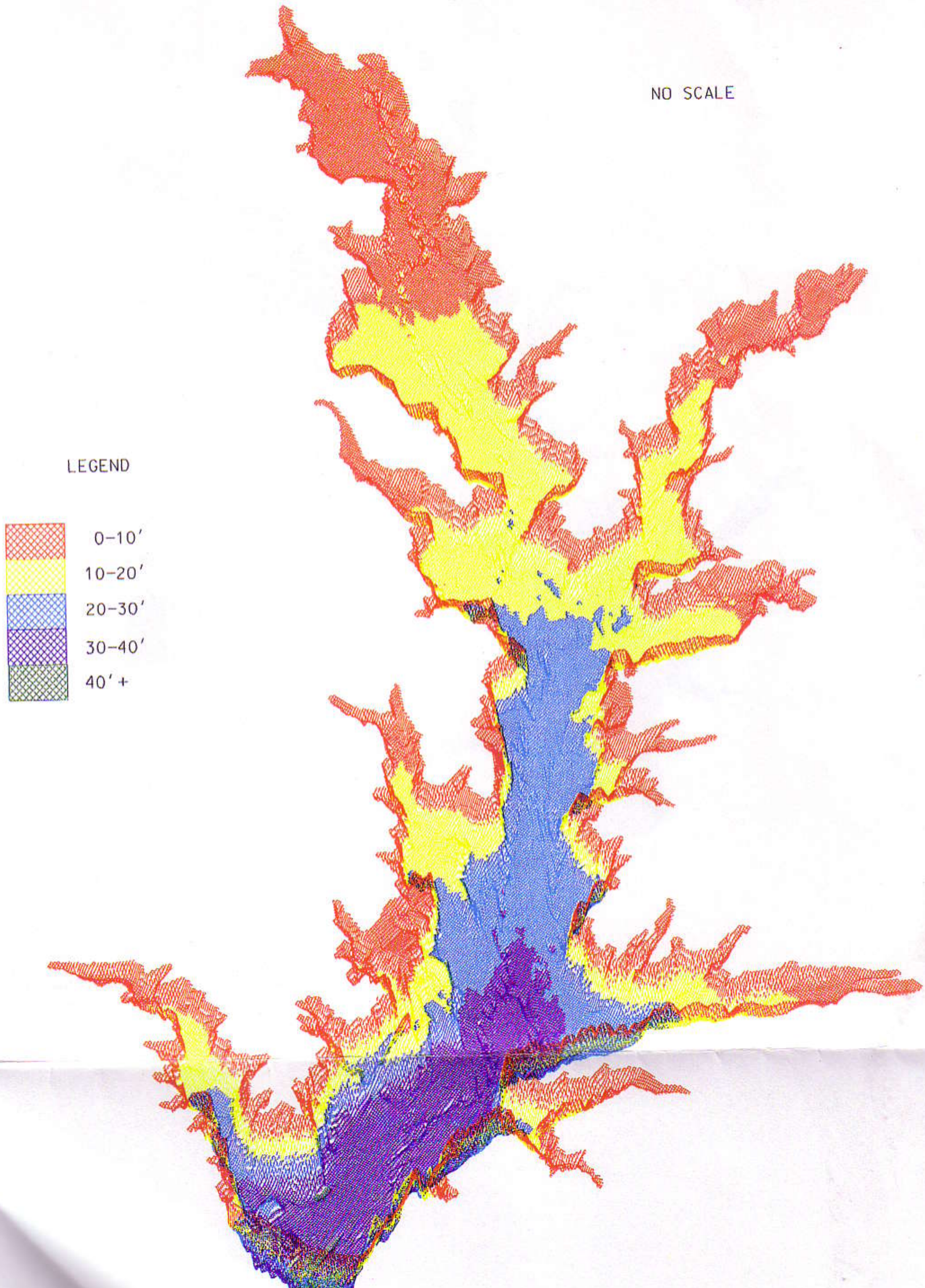
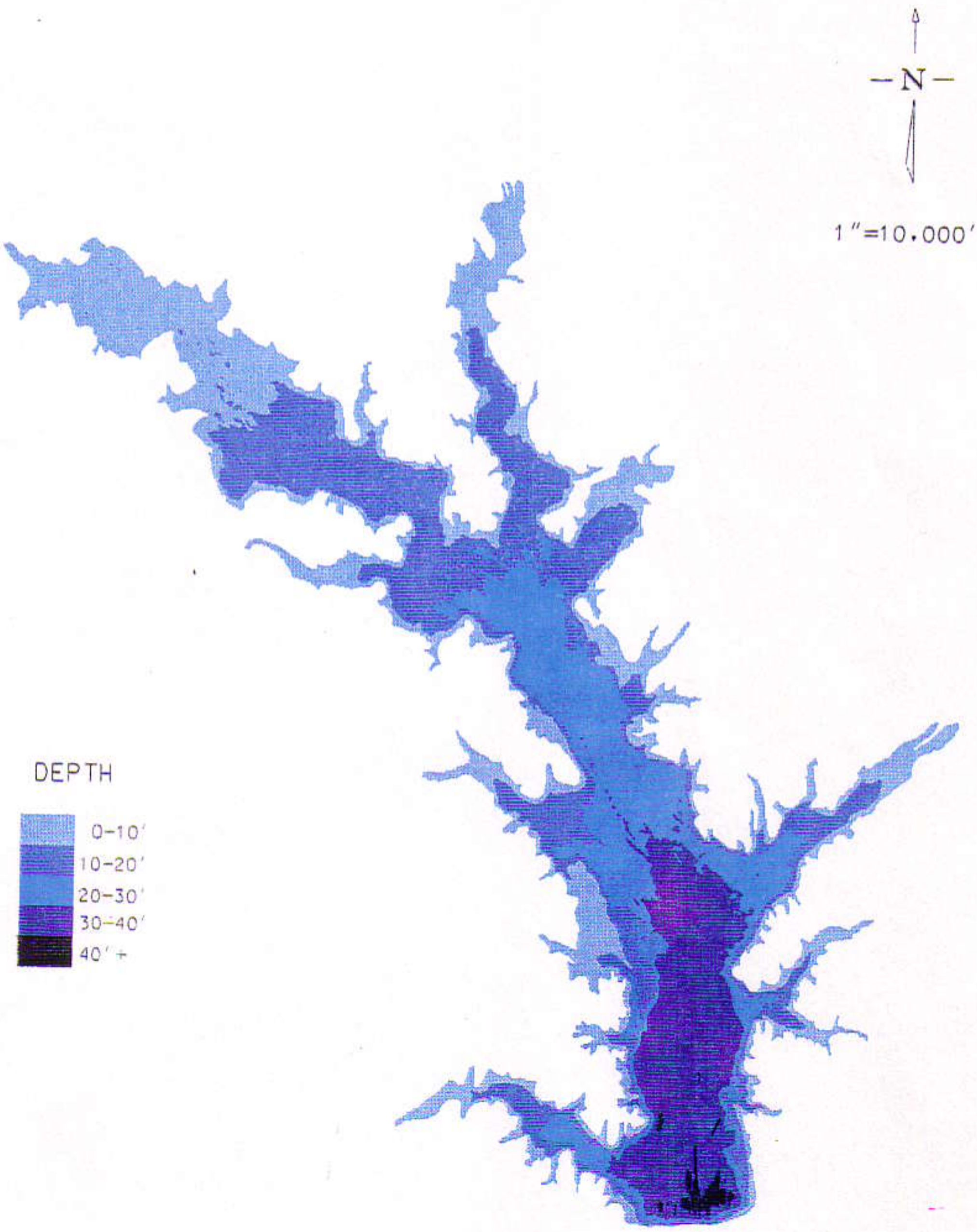


FIGURE 4

LAKE LIMESTONE

DEPTH RANGES



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