Volumetric and Sedimentation Survey of LAKE LIMESTONE

March – April 2012 Survey

Texas Water Development Board

June 2014

Texas Water Development Board

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Prepared for:

Brazos River Authority

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U.S. Army Corps of Engineers, Fort Worth District

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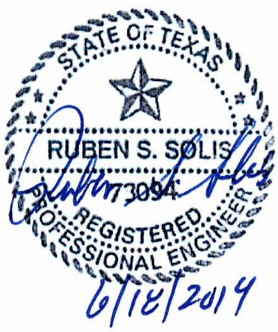

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Executive summary

In March, 2012, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District to perform a volumetric and sedimentation survey of Lake Limestone. The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the Brazos River Authority provided the remaining 50%. Surveying was performed using a multi-frequency (200 kHz, 50 kHz, and 24 kHz), sub-bottom profiling depth sounder. In addition, sediment core samples were collected in select locations and correlated with the multi-frequency depth sounder signal returns to estimate sediment accumulation thicknesses and sedimentation rates.

Sterling C. Robertson Dam and Lake Limestone are located on the upper Navasota River in Limestone, Robertson, and Leon Counties, approximately 15 miles southeast of Groesbeck, Texas. The conservation pool elevation of Lake Limestone is 363.0 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Lake Limestone between March 20, 2012, and April 5, 2012. The daily average water surface elevation during the survey ranged between 363.13 and 363.87 feet above mean sea level.

The 2012 TWDB volumetric and sedimentation survey indicates that Lake Limestone has a total reservoir capacity of 203,780 acre-feet and encompasses 12,486 acres at conservation pool elevation (363.0 feet above mean sea level, NGVD29). Previous capacity estimates include the authorized impoundment volume per Certificate of Adjudication No. 12-5165, of 225,400 acre-feet, and volumes obtained from two TWDB surveys in 1993 and 2002. The TWDB volumetric surveys conducted in 1993 and 2002 were re-evaluated using current processing procedures that resulted in updated capacity estimates of 217,415 acre-feet and 210,489 acre-feet, respectively.

Based on two methods for estimating sedimentation rates, the 2012 TWDB sedimentation survey estimates Lake Limestone to have an average loss of capacity between 481 and 636 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (363.0 feet above mean sea level, NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. There is heavy accumulation near the southwest bank of the reservoir west of FM 3371 and between the dam and the Mine Creek cove of the reservoir, approximately 2 miles north of the dam. TWDB recommends that a similar methodology be used to resurvey Lake Limestone in 10 years or after a major flood event.

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Note: References to brand names throughout this report do not imply endorsement by the Texas Water Development Board

Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. The Texas Water Code authorizes TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In March, 2012, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District to perform a volumetric and sedimentation survey of Lake Limestone (TWDB, 2012). The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the Brazos River Authority provided the remaining 50%. This report describes the methods used to conduct the volumetric and sedimentation survey, including data collection and processing techniques. This report serves as the final contract deliverable from TWDB to the Brazos River Authority and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality [Appendix A, B], (2) a bottom contour map [Figure 6], (3) a shaded relief plot of the reservoir bottom [Figure 4], and (4) an estimate of sediment accumulation and location [Figure 10].

Lake Limestone general information

Sterling C. Robertson Dam and Lake Limestone are located on the upper Navasota River in Limestone, Robertson, and Leon Counties, approximately 15 miles southeast of Groesbeck and 18 miles west of Buffalo, Texas (Figure 1). The construction of Sterling C. Robertson Dam began on July 22, 1975. The deliberate impoundment of water began on October 16, 1978, and the dam was 95.5 percent complete on January 1, 1979 (TDWR, 1979). Lake Limestone is owned and operated by the Brazos River Authority (BRA, 2013a). The Texas Legislature created the Brazos River Authority in 1929, to “develop, manage, and protect the water resources of the Brazos River Basin” (BRA, 2013b).

Lake Limestone is a water supply reservoir, providing water primarily for municipal and industrial purposes in the surrounding area and downstream. The construction of Lake Limestone was financed by the sale of water to Texas Electric Utilities for use at their lignite-burning electric plants nearby. Water from the reservoir is also used at an NRG steam-electric plant east of the lake and at a Texas Municipal Power Agency power plant located near the Navasota River 50 miles downstream (BRA, 2013a). Lake Limestone is open to the public for non-consumptive recreational use. Additional pertinent data about Sterling C. Robertson Dam and Lake Limestone can be found in Table 1.

Water rights for Lake Limestone have been appropriated to the Brazos River Authority through Certificate of Adjudication No. 12-5165. The complete certificate is on file in the Information Resources Division of the Texas Commission on Environmental Quality.

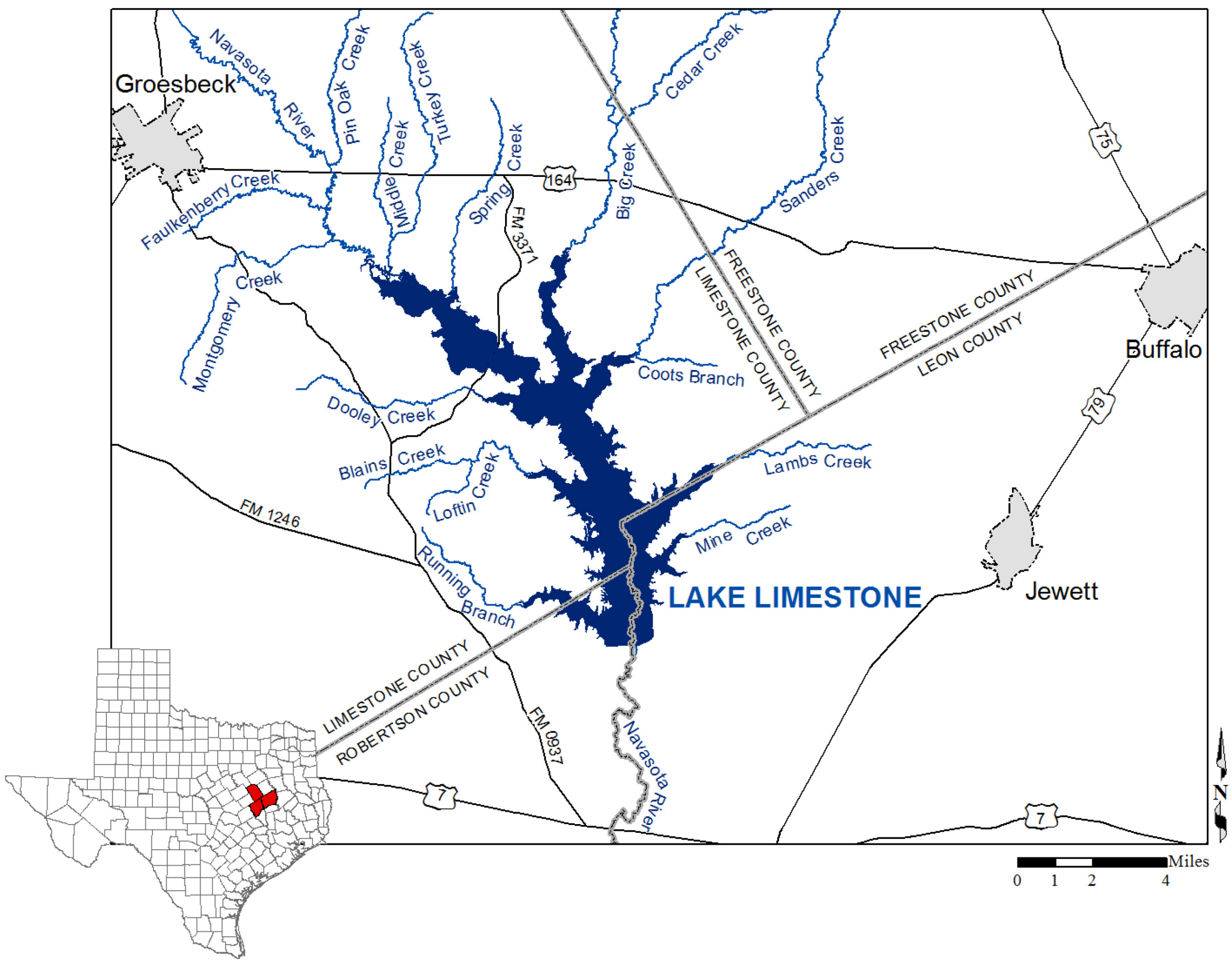


Figure 1. **Location of Lake Limestone**

Table 1.	Pertinent data for Sterling C. Robertson Dam and Lake Limestone
Owner	
Brazos River Authority	
Engineer	
URS/ Forrest and Cotton, Inc.	
Location of dam	
On the upper Navasota River, a tributary of the Brazos River, in Limestone, Robertson and Leon Counties, approximately 15 miles southeast of Groesbeck and 18 miles west of Buffalo, Texas.	
Drainage area	
674 square miles	
Dam	
Type	Zoned earthfill
Length	8,395 feet (excluding emergency spillway)
Maximum height	72 feet
Top width	20 feet
Spillway (emergency)	
Type	Earthcut channel
Width	3,000 feet
Spillway (service)	
Type	Concrete ogee
Control	Five 40-feet by 28-feet tainter gates
Length	200 feet (effective crest)
Outlet works	
Type	Two 4-feet by 8-feet sluice gates
Invert elevation	322.0 feet above mean sea level

Reservoir data (Based on 2012 TWDB survey)

Feature	Elevation (feet NGVD29[a])	Capacity (acre-feet)	Area (acres)
Top of dam	380.0	N/A	N/A
Emergency spillway	369.6	N/A	N/A
Conservation pool elevation	363.0	203,780	12,486
Service spillway	337.0	16,134	2,826
Dead pool elevation	322.0	0	0
Usable conservation storage space[b]	-	203,780	-

Source: (BRA, 2013, TDWR, 1979, TWDB, 1993, TWDB, 2003

[a] NGVD29 = National Geodetic Vertical Datum 1929

[b] Usable conservation storage space equals total capacity at conservation pool elevation minus dead pool capacity. Dead pool refers to water that cannot be drained by gravity through a dam's outlet works.

Volumetric and sedimentation survey of Lake Limestone

Datum

The vertical datum used during this survey is the National Geodetic Vertical Datum 1929 (NGVD29). This datum is also utilized by the United States Geological Survey (USGS) for the reservoir elevation gage *USGS 08110470 Lk Limestone nr Marquez, TX* (USGS, 2013). Elevations herein are reported in feet relative to the NGVD29 datum. Volume and area calculations in this report are referenced to water levels provided by the USGS gage. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet).

TWDB bathymetric and sedimentation data collection

TWDB collected bathymetric data for Lake Limestone between March 20, 2012, and April 5, 2012. The daily average water surface elevations during the survey ranged between 363.13 and 363.87 feet above mean sea level (NGVD29). For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data collection occurred while navigating along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. Many of the same survey lines were also used by TWDB during the 1993 and 2002 surveys. The depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. Figure 2 shows where data collection occurred during the 2012 TWDB survey.

All sounding data was collected and reviewed before sediment core sampling sites were selected. Sediment core samples are collected at regularly spaced intervals within the reservoir, or at locations where interpretation of the acoustic display would be difficult without site-specific sediment core data. After analyzing the sounding data, TWDB selected six locations to collect sediment core samples (Figure 2). The sediment core samples were collected on December 13, 2012, with a custom-coring boat and SDI VibeCore system.

Sediment cores are collected in 3-inch diameter aluminum tubes. Analysis of the acoustic data collected during the bathymetric survey assists in determining the depth of penetration the tube must be driven during sediment sampling. The goal is to collect a sediment core sample extending from the current reservoir-bottom, through the accumulated sediment, and to the pre-impoundment surface. After retrieving the sample, a stadia rod is inserted into the top of the tube to assist in locating the top of the sediment in the tube. This identifies the location of the layer corresponding to the current reservoir surface. The aluminum tube is cut to this level, capped, and transported back to TWDB headquarters for further analysis. During this time, some settling of the upper layer can occur.

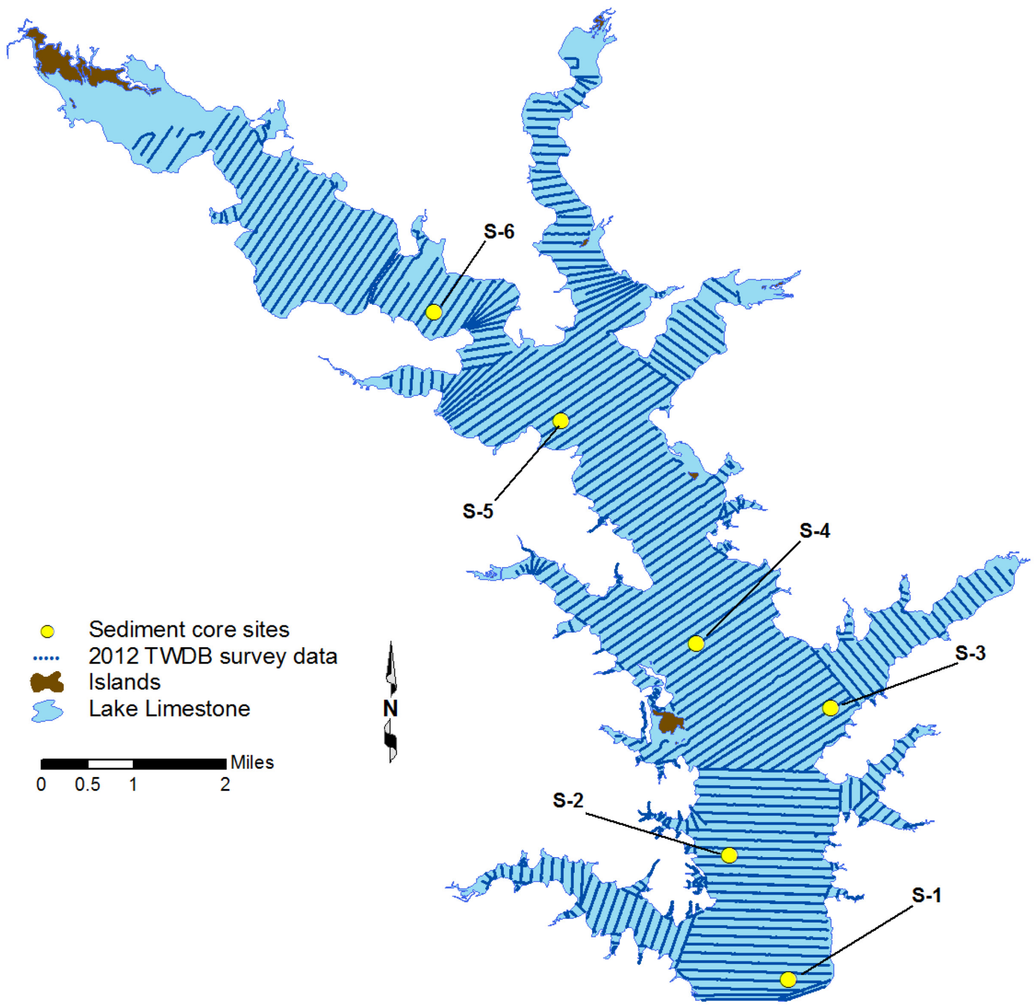


Figure 2. Data collected during 2012 TWDB Lake Limestone

Data processing

Model boundaries

The reservoir boundary was digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), obtained from the Texas Natural Resources Information System (TNIRIS, 2013) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Limestone are Box Church (NE, NW, SE), Farrar (NW, SE, SW), and Round Prairie (NE, NW). The DOQQs were photographed on August 1, 2010, while the daily average water surface elevation measured 362.35 feet (NGVD29). According to metadata associated with the 2010 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy within ± 6 meters to true ground (TNRIS, 2010, USDA, 2013). For this analysis, the boundary was digitized at the land-water interface in the 2010 photographs and assigned an elevation of 363.0 feet to facilitate calculating the area-capacity tables up to the conservation pool elevation. Where survey data alone was not sufficient to model the reservoir topography, additional boundary information was obtained from aerial photographs taken on July 20, 2012, while the daily average water surface elevation measured 361.12 feet. The 2012 boundary information was added to the lake model as points. According to metadata associated with the 2012 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy within ± 6 meters to true ground (TNRIS, 2012, USDA, 2013)

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by TWDB were edited to remove data anomalies. DepthPic©, software developed by SDI, Inc., is used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface and manually digitizing the reservoir-bottom surface at the time of initial impoundment (i.e. pre-impoundment surface). For processing outside of DepthPic©, an in-house software package, HydroTools, is used to identify the current reservoir-bottom surface, pre-impoundment surface, sediment thickness at each sounding location, and output the data into a single file. The water surface elevation at the time of each sounding was used to convert each sounding depth to a corresponding reservoir-bottom elevation. This survey point dataset is then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points are determined using an anisotropic spatial interpolation algorithm described in the next section. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen et al., 2011a). Finally, the point file resulting from spatial interpolation is used in conjunction with sounding and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (ESRI, 1995).

Spatial interpolation of reservoir bathymetry

Isotropic spatial interpolation techniques such as the Delaunay triangulation used by the 3D Analyst extension of ArcGIS are, in many instances, unable to suitably interpolate bathymetries between survey lines common to reservoir surveys. Reservoirs and stream channels are anisotropic morphological features where bathymetry at any particular location is more similar to upstream and downstream locations than to transverse locations. Interpolation schemes that do not consider this anisotropy lead to the creation of several types of artifacts in the final representation of the reservoir bottom surface and hence to errors in volume. These include: artificially-curved contour lines extending into the reservoir where the reservoir walls are steep or the reservoir is relatively narrow; intermittent representation of submerged stream channel connectivity; and oscillations of contour lines in between survey lines. These artifacts reduce the accuracy of the resulting volumetric and sediment TIN models in areas between actual survey data.

To improve the accuracy of bathymetric representation between survey lines, TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining survey data or more robustly by examining scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. For surveys with similar spatial coverage, these interpolation definition files are in principle independent of the survey data and could be applied to past and future survey data of the same reservoir. In practice, however, minor revisions of the interpolation definition files may be needed to account for differences in spatial coverage and boundary conditions between surveys. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing the reservoir bathymetry and sediment accumulation throughout the reservoir.

Specific details of this interpolation technique can be found in the HydroTools manual (McEwen et al., 2011a) and in McEwen et al., 2011b.

In areas inaccessible to survey data collection such as small coves and shallow upstream areas of the reservoir, linear extrapolation is used for volumetric and sediment accumulation estimations. The linear extrapolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without extrapolated data, the TIN Model builds flat triangles. A flat triangle is defined as a triangle where all three vertices are equal in elevation, generally the elevation of the reservoir boundary. Reducing flat triangles by applying linear extrapolation improves the elevation-capacity and elevation-area calculations. It is not always possible to remove all flat triangles, and linear extrapolation is only applied where adding bathymetry is deemed reasonable. For example, linear extrapolation was deemed reasonable and applied to Lake Limestone in the following situations: in small coves of the main body of the lake and in obvious channel features visible in aerial photographs taken on July 20, 2012, while the daily average water surface elevation measured 361.12 feet or where 1993 and 2002 survey data indicated channel morphology.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear extrapolation techniques to Lake Limestone. The bathymetry shown in Figure 3C was used in computing reservoir capacity and area tables (Appendix A, B). In Figure 3A, deeper channels indicated by surveyed cross sections are not continuously represented in areas between survey cross sections. This is an artifact of the TIN generation routine rather than an accurate representation of the physical bathymetric surface. Inclusion of interpolation points, represented in Figure 3C, in creation of the volumetric TIN model directs Delaunay triangulation to better represent the lake bathymetry between survey cross-sections.

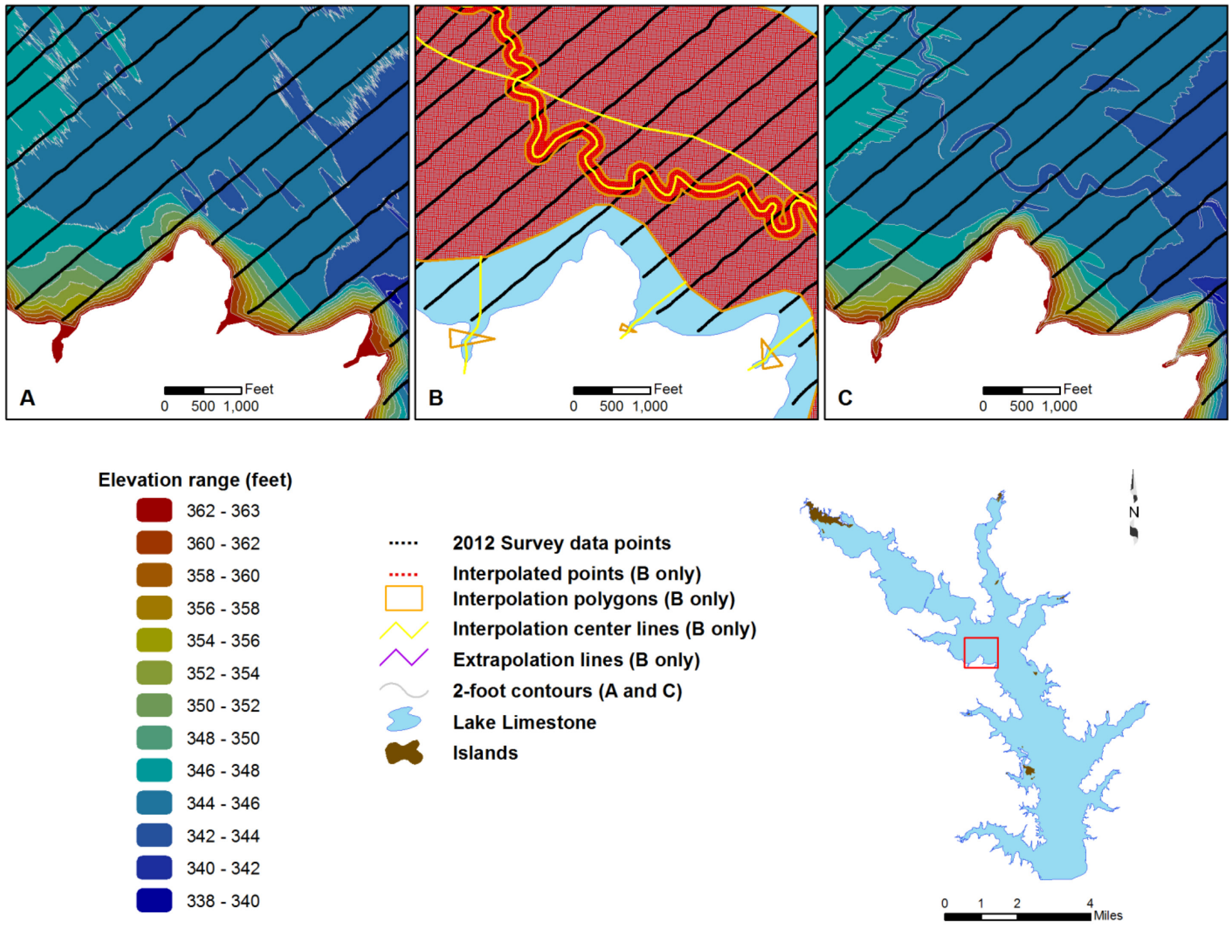
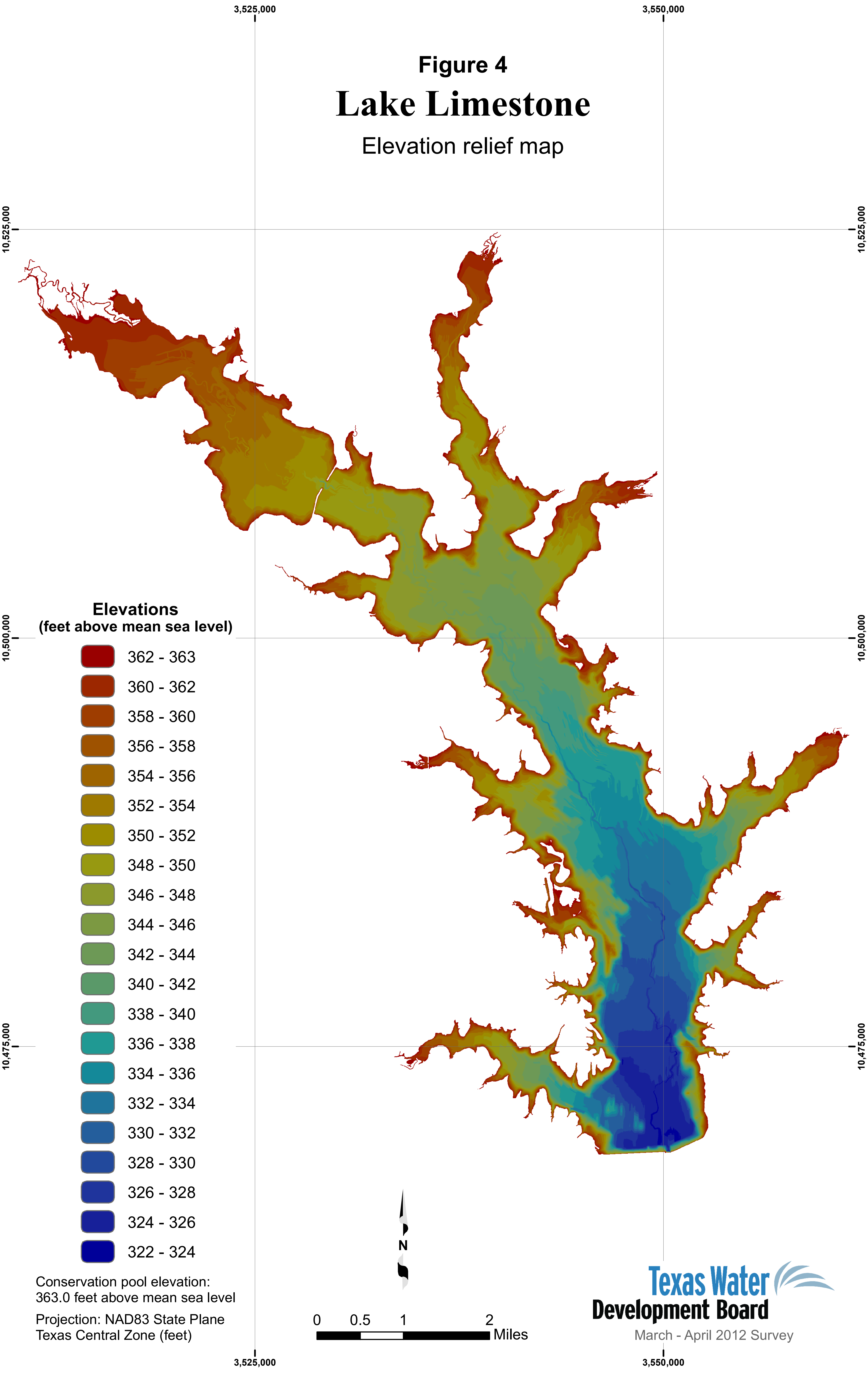


Figure 3. **Anisotropic spatial interpolation and linear extrapolation of Lake Limestone sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

Area, volume, and contour calculation

Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1 feet intervals, from 321.0 to 363.0 feet. The elevation-capacity table and elevation-area table, updated for 2012, are presented in Appendices A and B, respectively. The area-capacity curves are presented in Appendix C.

The volumetric TIN model was converted to a raster representation using a cell size of 2 feet by 2 feet. The raster data was then used to produce an elevation relief map (Figure 4), representing the topography of the reservoir bottom; a depth range map (Figure 5), showing shaded depth ranges for Lake Limestone; and a 2-foot contour map (Figure 6 - attached).

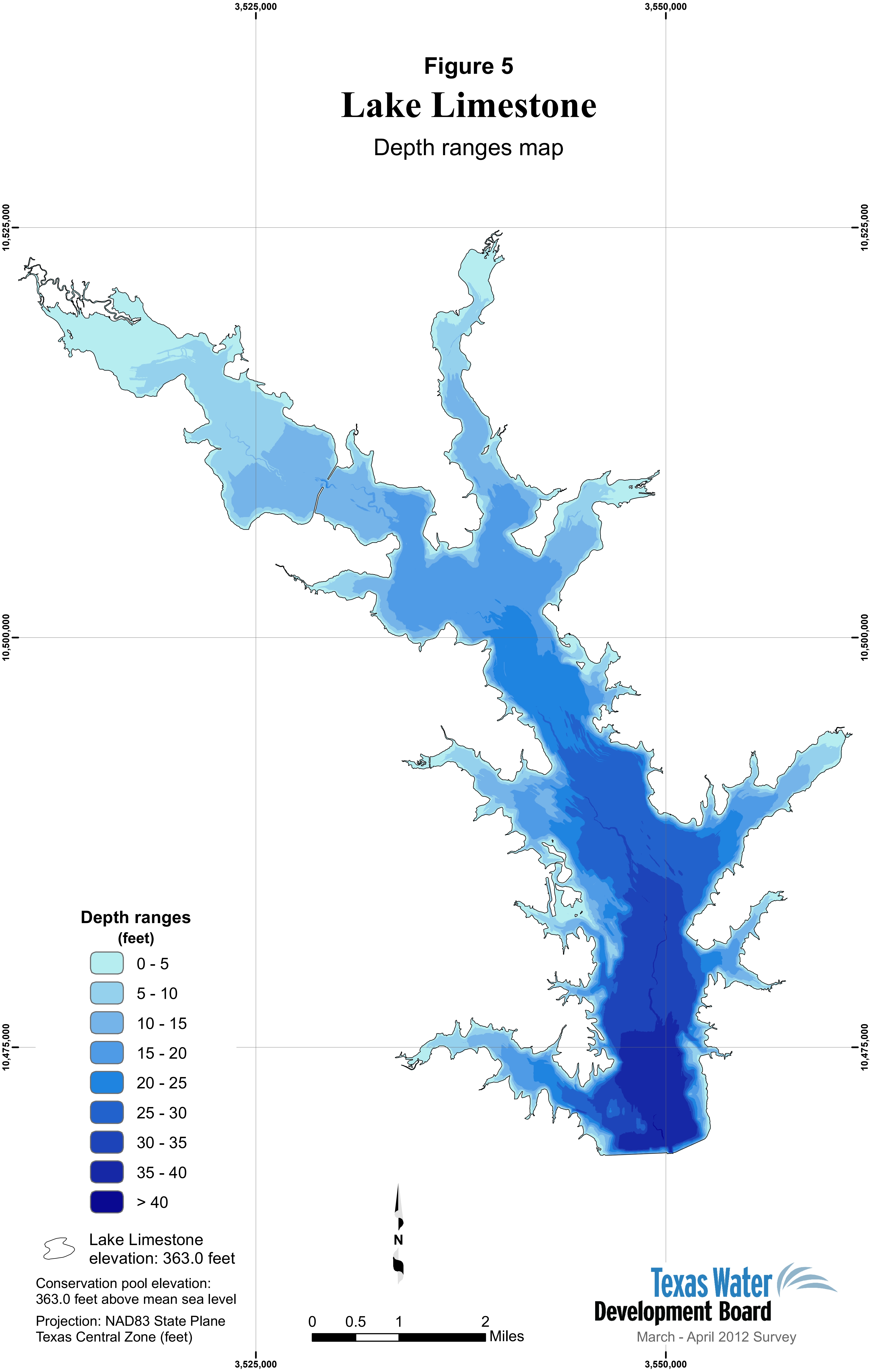


3,525,000
3,550,000
Figure 4
Lake Limestone
Elevation relief map
10,525,000
10,500,000
10,475,000
Elevations
(feet above mean sea level)
362 - 363
360 - 362
358 - 360
356 - 358
354 - 356
352 - 354
350 - 352
348 - 350
346 - 348
344 - 346
342 - 344
340 - 342
338 - 340
336 - 338
334 - 336
332 - 334
330 - 332
328 - 330
326 - 328
324 - 326
322 - 324
Conservation pool elevation:
363.0 feet above mean sea level
Projection: NAD83 State Plane
Texas Central Zone (feet)
N
0 0.5 1 2
Miles
Texas Water
Development Board
March - April 2012 Survey

Figure 5

Lake Limestone

Depth ranges map



Analysis of sediment data from Lake Limestone

Sedimentation in Lake Limestone was determined by analyzing the acoustic signal returns of all three depth sounder frequencies in the DepthPic© software. The 200 kHz signal was analyzed to determine the current bathymetric surface of the reservoir, while all three frequencies, 200 kHz, 50 kHz, and 24 kHz, were analyzed to determine the reservoir bathymetric surface at the time of initial impoundment (i.e. pre-impoundment surface). Sediment core samples collected in the reservoir were used to assist in identifying the location of the pre-impoundment surface in the acoustic signals. The difference between the current surface and the pre-impoundment surface yields a sediment thickness value at each sounding location.

Analysis of the sediment core samples was conducted at TWDB headquarters in Austin. Each sample was split longitudinally and analyzed to identify the location of the pre-impoundment surface. The pre-impoundment surface is identified within the sediment core sample by one or more of the following methods: (1) a visual examination of the sediment core for terrestrial materials, such as leaf litter, tree bark, twigs, intact roots, etc., concentrations of which tend to occur on or just below the pre-impoundment surface; (2) changes in texture from well sorted, relatively fine-grained sediment to poorly sorted mixtures of coarse and fine-grained materials; and (3) variations in the physical properties of the sediment, particularly sediment water content and penetration resistance with depth (Van Metre et al., 2004). The total sample length, sediment thickness, and the pre-impoundment thickness were recorded. Physical characteristics of the sediment core, including color, texture, relative water content, and presence of organic materials, were also recorded (Table 2).

Table 2. Sediment core sampling analysis data - Lake Limestone

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
L-1	3550487.47	10469744.89	31.5”/25.5”	0-25.5” loose sediment, silty clay	10YR 2/1 with bands of 2.5Y 3/1
				25.5-31.5” dense soil, organics present	2.5Y 4/1
L-2	3547336.87	10476701.60	27.5”/23”	0-23” loose sediment, silty clay	2.5Y 3/1 with bands of 10yr 2/1
				23-27.5” dense clay soil, organics present, small peds present	2.5Y 4/1
L-3	3552011.88	10485265.41	22.5”/15”	0-15” loose sediment, silty clay	2.5Y 3/1
				15-22.5” dense soil, clay loam, organics present	2.5Y 4/1
L-4	3545303.05	10488724.68	24”/23”	0-23” loose sediment, silty clay	10YR 2/1, with bands of 2.5Y 3/1
				23-24” small peds, organics and roots present	2.5Y 4/1
L-5	3538226.95	10501185.54	22.5”/18”	0-18” loose sediment, silty clay	2.5Y 3/1, with bands of 10YR 2/1
				18-22.5” dense clay soil with organics present	2.5Y 4/2
L-6	3531767.84	10507175.20	32”/25”	0-25” loose sediment, silty clay	2.5Y 3/2, with bands of 10YR 2/1
				25-32” dense clay soil with organics present	2.5Y 4/1

[a] Coordinates are based on NAD83 State Plane Texas Central System (feet)

A photograph of sediment core L-4 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Limestone. The 200 kHz frequency measures the top layer as the current bottom surface of the reservoir.

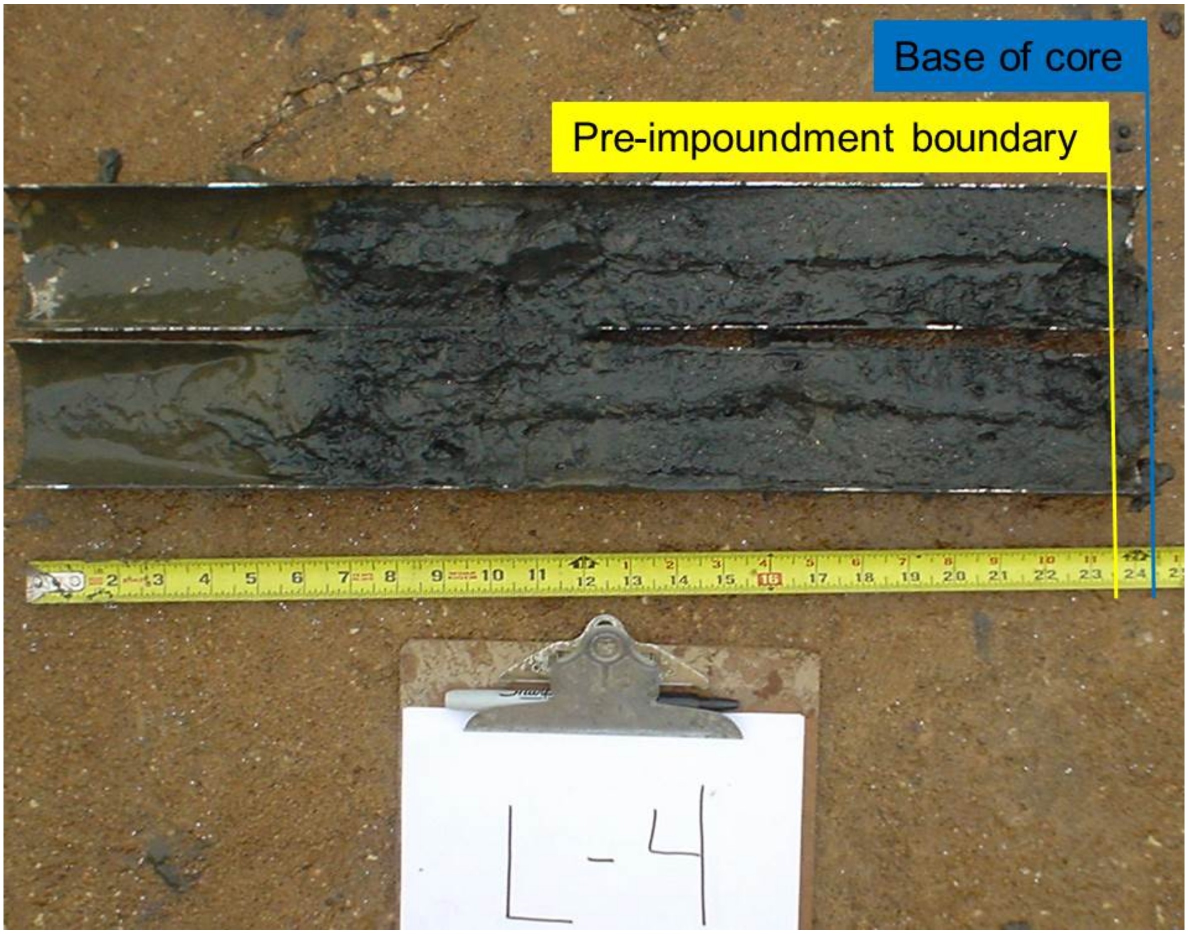


Figure 4. Sediment core L-4 from Lake Limestone

Sediment core sample L-4 consisted of 24 inches of total sediment corresponding to the length of the aluminum sampling tube. The upper sediment layer (horizon), 0-23 inches, consisted of loose sediment, silty clay and measured 10YR 2/1 with bands of 2.5Y 3/1 on the Munsell soil color chart. The second horizon, beginning at 23 inches and extending to 24 inches below the surface, included the presence of small peds, organics, and roots and measured 2.5Y 4/1 on the Munsell soil color chart. The base of the sample is denoted by the blue line in Figure 7.

The pre-impoundment boundary (yellow line in Figure 7) was evident within this sediment core sample at 23 inches and identified by the change in color, texture, moisture, porosity, and structure. Identification of the pre-impoundment surface for the remaining sediment cores followed a similar procedure.

Figures 8 and 9 illustrate how measurements from sediment core samples are used with sonar data to help identify the interface between the post- and pre-impoundment layers in the acoustic signal. Within DepthPic©, the current surface is automatically determined based on signal returns from the 200 kHz transducer and verified by TWDB staff, while the pre-impoundment surface must be determined visually. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected.

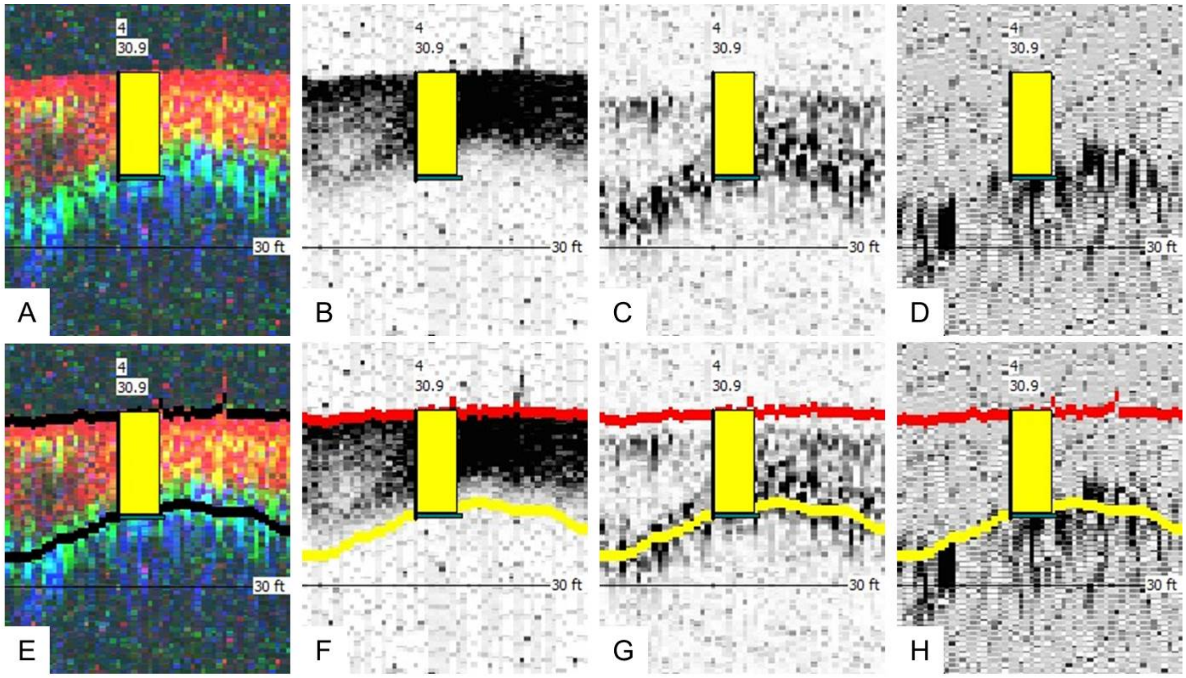


Figure 5. Comparison of sediment core L-4 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 200 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 8 compares sediment core sample L-4 with the acoustic signals for all frequencies combined (A, E), 200 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). The sediment core sample is represented in each figure as colored boxes. The yellow boxes represent post-impoundment sediment, and the blue box represents the pre-impoundment sediment. In Figure 8A-D, the bathymetric surfaces are not shown. In Figure 8E, the current bathymetric surface is represented as the top black line and in Figures 8 F-H as the top red line. The pre-impoundment surface is identified by comparing boundaries observed in the 200 kHz, 50 kHz and 24 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Each sediment core sample was compared to all three frequencies and the boundary in the 200 kHz signal most closely matched the pre-impoundment interface of the sediment core samples; therefore, the 200 kHz signal was used to locate the pre-impoundment layer. The pre-impoundment surface was manually drawn and is represented by the bottom black line in Figure 8E, and by the yellow line in Figures 8F-H. Figure 9 shows sediment core sample L-4 correlated with the 200 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface identified along cross-sections where sediment core samples were collected is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

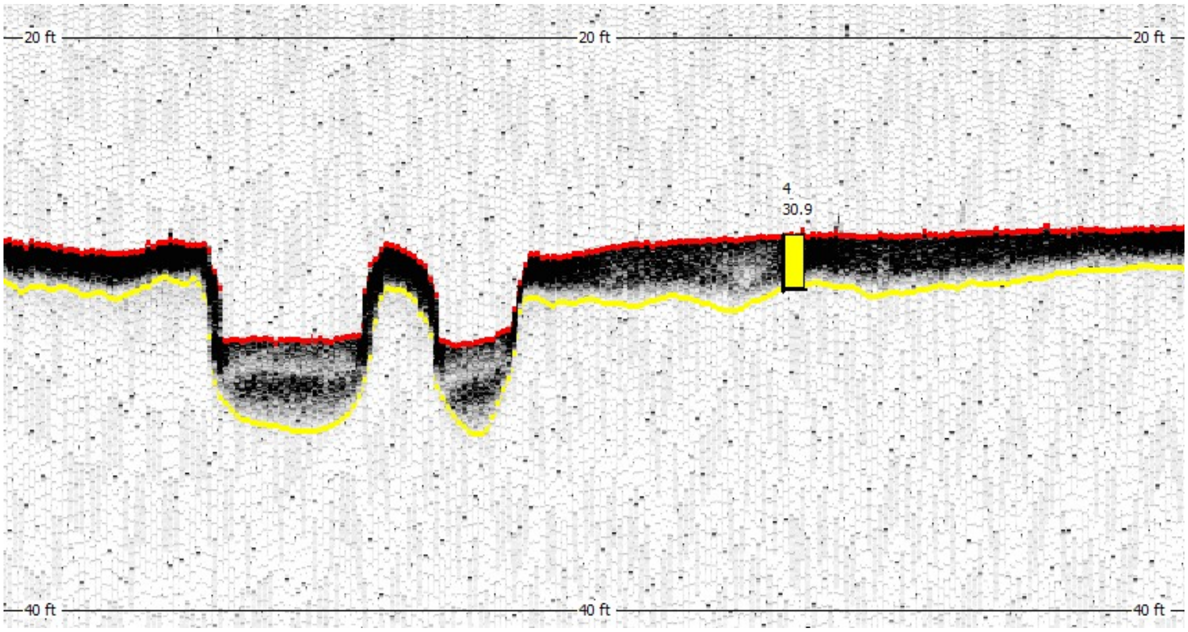


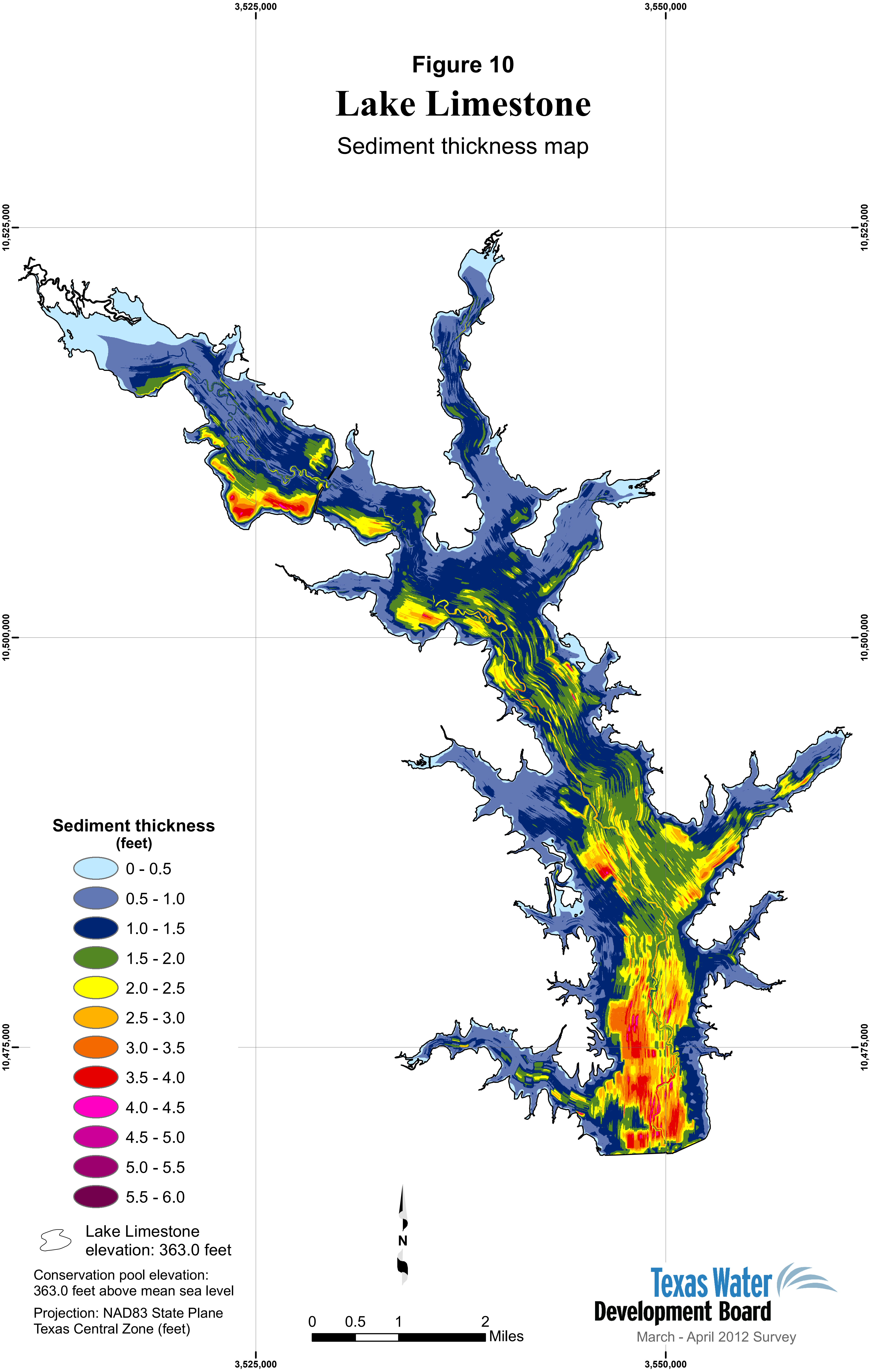
Figure 6. Cross-section of data collected during 2012 survey, displayed in DepthPic© (200 kHz frequency), correlated with sediment core sample L-4 and showing the current surface in red and pre-impoundment surface in yellow

After the pre-impoundment surface from all cross-sections was identified, a sediment thickness TIN model is created following standard GIS techniques (Furnans, 2007). Sediment thicknesses were interpolated between surveyed cross-sections using HydroTools with the same interpolation definition file used for bathymetric interpolation. For the purposes of the TIN model creation, TWDB assumed sediment thickness at the reservoir boundary was zero feet (defined as the 363.0 foot NGVD29 elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 5 feet by 5 feet and used to produce a sediment thickness map of Lake Limestone (Figure 10).

Figure 10

Lake Limestone

Sediment thickness map



Survey results

Volumetric survey

The results of the 2012 TWDB volumetric survey indicate Lake Limestone has a total reservoir capacity of 203,780 acre-feet and encompasses 12,486 acres at conservation pool elevation (363.0 feet above mean sea level, NGVD29). Previous capacity estimates include the authorized impoundment volume per Certificate of Adjudication No. 12-5165, of 225,400 acre-feet, and two TWDB surveys in 1993 and 2002. Because of differences in past and present survey methodologies, direct comparison of volumetric surveys to estimate loss of capacity is difficult and can be unreliable.

To properly compare results of TWDB surveys, TWDB applied the 2013 data processing techniques to the data collected in 1993 and 2002. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 1993 and 2002 using the same interpolation definition file as was used for the 2012 survey with minor edits to account for differences in data coverage and boundary conditions. The 1993 survey boundary was digitized from a combination of 1966 USGS 7.5 minute quadrangle maps revised in 1982 from 1978 aerial photographs and an aerial photograph taken on August 10, 1989, while the water surface elevation of the lake measured 362.7 feet (TWDB, 1993). The USGS quadrangle maps have a stated accuracy of ± ½ the contour interval (USBB, 1947). The accuracy of the 1989 photograph is unknown. The 2002 survey boundary was digitized from aerial photographs taken on February 6, 1995, March 8, 1995, January 24, 1996, and January 27, 1996, while the water surface elevation of the reservoir measured 362.72 feet, 362.90 feet, 362.15 feet, and 362.15 feet above mean sea level. The boundary was defined as 363.0 feet for modeling purposes (TWDB, 2002). According to the associated metadata, the 1995-1996 DOQQs have a resolution of 1-meter, with a horizontal positional accuracy that meets the National Map Accuracy Standards (NMAS) for 1:12,000-scale products. Re-evaluation of the 1993 and 2002 surveys resulted in a 0.8 percent and 1.2 percent increase, respectively, in total capacity estimates (Table 3).

Table 3. Current and previous survey capacity and surface area data

Survey	Surface area (acres)	Total capacity (acre-feet)
1979[a]	14,200	225,400
TWDB 1993[b]	13,379	215,751
TWDB 1993 (re-calculated)	13,379	217,415
TWDB 2002[c]	12,553	208,017
TWDB 2002 (re-calculated)	12,553	210,489
TWDB 2012	12,486	203,780

[a] Source: (TDWR, 1979, TWC, 1979), Note: The original capacity estimate has been reported as 217,494 acre-feet TWDB, 1993). However, according to Amendment to Permit to Appropriate State Water, Application No. 3214B, Permit No. 2950 B, the Brazos River Authority requested the permit be amended to correct and erroneous impounding capacity.
[b] Source: (TWDB, 1993)
[c] Source: (TWDB, 2003)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2012 TWDB sedimentation survey estimates Lake Limestone to have an average loss of capacity between 481 and 636 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (363.0 feet above mean sea level, NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. There is heavy accumulation near the southwest bank of the reservoir west of FM 3371 and between the dam and the Mine Creek cove of the reservoir, approximately 2 miles north of the dam. Comparison of capacity estimates of Lake Limestone derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. Capacity loss comparisons for Lake Limestone

Survey	Volume comparisons at conservation pool elevation (acre-feet)			Pre-impoundment (acre-feet)
Original[a]	225,400	<>	<>	<>
TWDB 1993 (re-calculated)	<>	217,415	<>	<>
TWDB 2002 (re-calculated)	<>	<>	210,489	<>
TWDB pre-impoundment estimate based on 2012 survey	<>	<>	<>	220,130[c]
2012 volumetric survey	203,780	203,780	203,780	203,780
Volume difference (acre-feet)	21,620 (9.6%)	13,635 (6.3%)	6,709 (3.2%)	16,350 (7.4%)
Number of years	34[b]	19	10	34
Capacity loss rate (acre-feet/year)	636	718	671	481

[a] Source: (TDWR, 1979, TWC, 1987), note: The original capacity estimate has been reported as 217,494 acre-feet (TWDB, 1993). However, according to Amendment to Permit to Appropriate State Water, Application No. 3214B, Permit No. 2950B, the Brazos River Authority requested the permit be amended to correct an erroneous impounding capacity.
[b] Number of years based on difference between 2012, year of the current survey and 1978, year impoundment began
[c] 2012 TWDB surveyed capacity of 203,780 acre-feet plus 2012 TWDB surveyed sediment volume of 16,350 acre-feet

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Limestone in approximately 10 years or after a major flood event. To further improve estimates of sediment accumulation, TWDB recommends another sedimentation survey. A re-survey would allow a more accurate quantification of the average sediment accumulation rate for Lake Limestone.

TWDB contact information

More information about the Hydrographic Survey Program can be found at: http://www.twdb.texas.gov/surfacewater/surveys/index.asp

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Appendix A

Lake Limestone

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD
CAPACITY IN ACRE-FEET
ELEVATION INCREMENT IS ONE TENTH FOOT

March - April 2012 Survey
Conservation Pool Elevation 363.0 feet NGVD29

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
321	0	0	0	0	0	0	0	0	0	0
322	0	0	0	0	0	0	0	0	1	1
323	1	1	2	2	2	3	3	4	5	6
324	8	10	13	17	22	27	33	39	47	55
325	65	76	89	102	118	136	156	180	206	234
326	264	296	330	365	403	443	485	529	574	621
327	670	720	772	826	880	937	995	1,054	1,115	1,176
328	1,238	1,302	1,367	1,433	1,501	1,571	1,642	1,716	1,791	1,869
329	1,949	2,031	2,116	2,203	2,293	2,387	2,482	2,579	2,679	2,781
330	2,885	2,991	3,099	3,210	3,323	3,439	3,558	3,681	3,805	3,933
331	4,062	4,194	4,329	4,466	4,606	4,747	4,890	5,035	5,182	5,330
332	5,479	5,631	5,784	5,939	6,095	6,254	6,414	6,577	6,742	6,909
333	7,078	7,249	7,423	7,600	7,780	7,962	8,147	8,336	8,528	8,724
334	8,924	9,126	9,331	9,540	9,751	9,964	10,181	10,400	10,621	10,845
335	11,071	11,299	11,529	11,761	11,996	12,232	12,472	12,714	12,959	13,207
336	13,458	13,712	13,969	14,229	14,492	14,758	15,027	15,299	15,575	15,853
337	16,134	16,419	16,706	16,996	17,289	17,584	17,881	18,182	18,484	18,789
338	19,096	19,405	19,716	20,029	20,344	20,662	20,982	21,303	21,627	21,953
339	22,281	22,611	22,943	23,277	23,613	23,950	24,289	24,630	24,973	25,318
340	25,665	26,014	26,365	26,717	27,072	27,428	27,786	28,147	28,509	28,874
341	29,242	29,614	29,988	30,365	30,745	31,128	31,513	31,900	32,290	32,682
342	33,077	33,475	33,875	34,278	34,684	35,092	35,503	35,917	36,334	36,755
343	37,179	37,605	38,034	38,466	38,901	39,339	39,780	40,225	40,672	41,123
344	41,579	42,039	42,504	42,975	43,454	43,938	44,426	44,919	45,415	45,916
345	46,420	46,929	47,440	47,956	48,475	48,998	49,525	50,057	50,593	51,132
346	51,675	52,222	52,774	53,330	53,890	54,453	55,020	55,591	56,166	56,744
347	57,327	57,914	58,505	59,100	59,701	60,306	60,917	61,532	62,150	62,771
348	63,396	64,026	64,659	65,296	65,937	66,582	67,232	67,884	68,541	69,201
349	69,866	70,534	71,207	71,882	72,562	73,245	73,931	74,621	75,315	76,013
350	76,714	77,420	78,130	78,842	79,557	80,276	80,997	81,723	82,451	83,184
351	83,920	84,661	85,406	86,154	86,908	87,666	88,429	89,196	89,970	90,749
352	91,534	92,324	93,120	93,920	94,727	95,538	96,355	97,177	98,005	98,837
353	99,673	100,513	101,356	102,202	103,053	103,908	104,767	105,631	106,498	107,370
354	108,245	109,125	110,009	110,897	111,791	112,688	113,589	114,495	115,405	116,320
355	117,238	118,161	119,088	120,019	120,954	121,893	122,836	123,782	124,731	125,684
356	126,640	127,601	128,565	129,533	130,505	131,480	132,461	133,445	134,433	135,426
357	136,422	137,423	138,428	139,437	140,451	141,469	142,492	143,517	144,547	145,582
358	146,621	147,665	148,713	149,766	150,824	151,886	152,952	154,023	155,097	156,176
359	157,259	158,345	159,434	160,527	161,624	162,723	163,827	164,933	166,043	167,156
360	168,273	169,393	170,517	171,645	172,776	173,911	175,051	176,195	177,343	178,496
361	179,655	180,819	181,996	183,178	184,363	185,552	186,745	187,940	189,138	190,340
362	191,546	192,754	193,966	195,180	196,398	197,620	198,845	200,073	201,305	202,541
363	203,780									

Appendix B

Lake Limestone

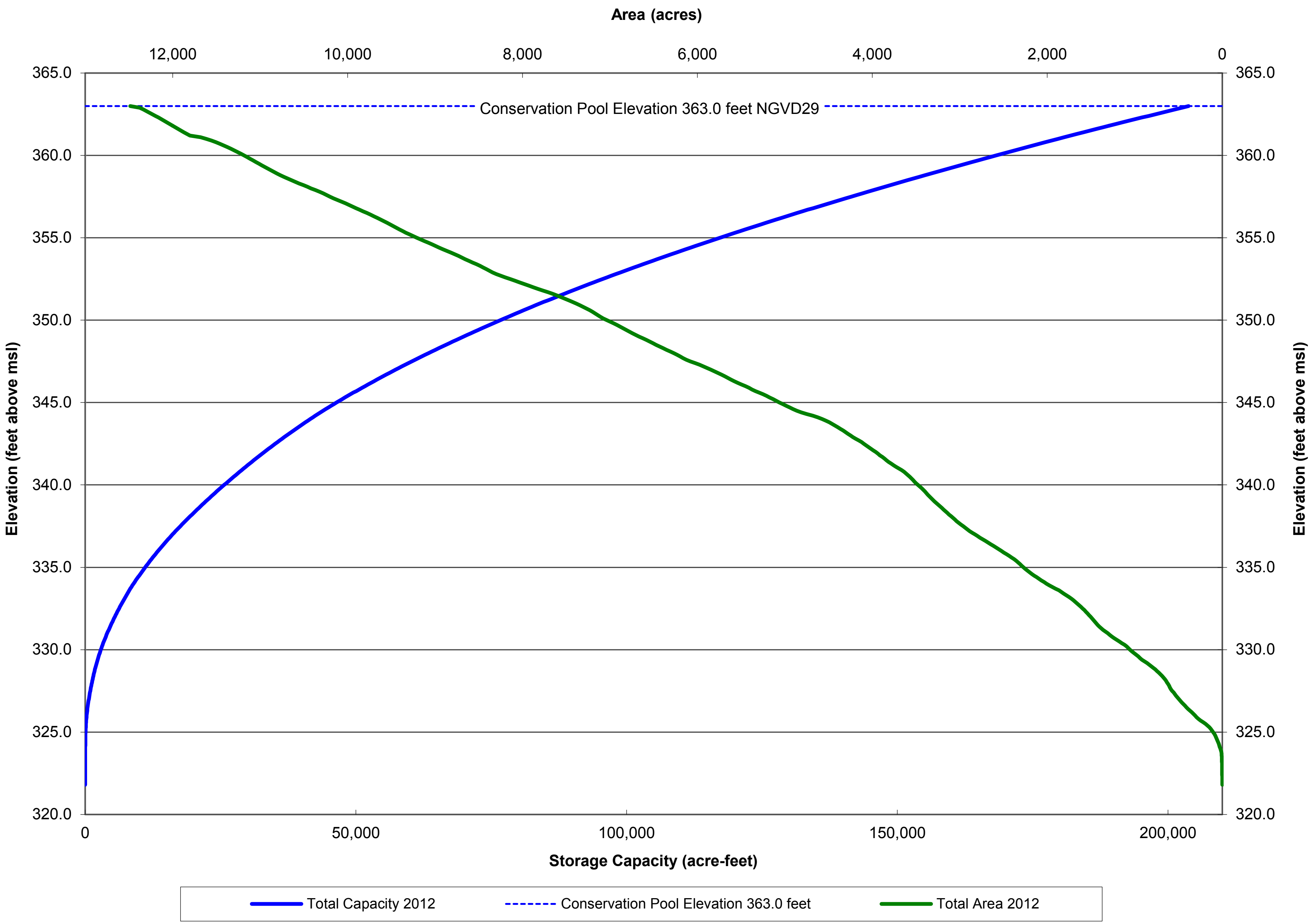
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — March - April 2012 Survey

AREA IN ACRES — Conservation Pool Elevation 363.0 feet NGVD29

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
321	0	0	0	0	0	0	0	0	0	0
322	0	0	0	0	1	1	1	1	2	2
323	2	3	4	4	5	6	6	7	9	14
324	21	28	35	41	47	56	63	71	80	91
325	103	117	130	147	169	191	218	247	272	292
326	309	327	348	369	390	410	427	445	463	478
327	496	512	527	541	555	574	587	598	607	618
328	629	642	656	671	688	705	725	746	766	786
329	811	835	859	890	920	941	960	984	1,010	1,032
330	1,053	1,073	1,093	1,117	1,148	1,174	1,206	1,235	1,262	1,285
331	1,308	1,334	1,361	1,384	1,405	1,423	1,439	1,456	1,472	1,488
332	1,505	1,523	1,541	1,557	1,576	1,596	1,616	1,638	1,659	1,680
333	1,701	1,725	1,753	1,783	1,812	1,838	1,868	1,907	1,942	1,977
334	2,009	2,037	2,068	2,097	2,122	2,151	2,178	2,201	2,226	2,249
335	2,270	2,292	2,311	2,333	2,356	2,379	2,408	2,436	2,464	2,497
336	2,526	2,555	2,584	2,615	2,645	2,675	2,706	2,739	2,770	2,798
337	2,826	2,861	2,889	2,913	2,937	2,963	2,989	3,014	3,036	3,057
338	3,079	3,100	3,123	3,144	3,165	3,186	3,206	3,227	3,249	3,270
339	3,291	3,310	3,329	3,349	3,367	3,383	3,400	3,418	3,438	3,459
340	3,480	3,500	3,517	3,534	3,553	3,573	3,594	3,615	3,638	3,664
341	3,697	3,728	3,758	3,786	3,814	3,838	3,860	3,885	3,914	3,937
342	3,961	3,990	4,016	4,044	4,071	4,097	4,123	4,155	4,190	4,222
343	4,249	4,279	4,306	4,334	4,364	4,396	4,427	4,459	4,493	4,532
344	4,575	4,623	4,682	4,750	4,814	4,864	4,907	4,947	4,985	5,024
345	5,064	5,100	5,135	5,174	5,210	5,251	5,295	5,337	5,376	5,410
346	5,450	5,497	5,540	5,578	5,617	5,653	5,689	5,725	5,766	5,807
347	5,848	5,889	5,932	5,977	6,028	6,082	6,128	6,164	6,198	6,234
348	6,271	6,310	6,353	6,393	6,433	6,472	6,509	6,547	6,583	6,625
349	6,668	6,704	6,742	6,777	6,812	6,847	6,882	6,917	6,957	6,997
350	7,038	7,076	7,109	7,139	7,169	7,200	7,232	7,269	7,307	7,346
351	7,386	7,428	7,466	7,511	7,557	7,602	7,651	7,707	7,764	7,822
352	7,877	7,928	7,981	8,034	8,087	8,141	8,197	8,250	8,300	8,342
353	8,378	8,414	8,450	8,486	8,527	8,572	8,614	8,656	8,694	8,732
354	8,774	8,818	8,864	8,910	8,952	8,992	9,035	9,078	9,124	9,167
355	9,208	9,249	9,290	9,332	9,369	9,406	9,441	9,477	9,512	9,547
356	9,585	9,622	9,660	9,699	9,738	9,779	9,825	9,865	9,904	9,944
357	9,984	10,025	10,071	10,117	10,162	10,202	10,240	10,277	10,322	10,366
358	10,417	10,460	10,505	10,556	10,600	10,641	10,684	10,728	10,769	10,806
359	10,842	10,878	10,912	10,947	10,981	11,015	11,048	11,082	11,116	11,150
360	11,185	11,221	11,257	11,294	11,333	11,373	11,415	11,460	11,506	11,557
361	11,616	11,681	11,801	11,838	11,872	11,905	11,938	11,971	12,003	12,035
362	12,067	12,099	12,132	12,164	12,198	12,231	12,266	12,301	12,338	12,377
363	12,486									



Lake Limestone
March - April 2012 Survey
Prepared by: TWDB

Appendix C: Area and Capacity Curves

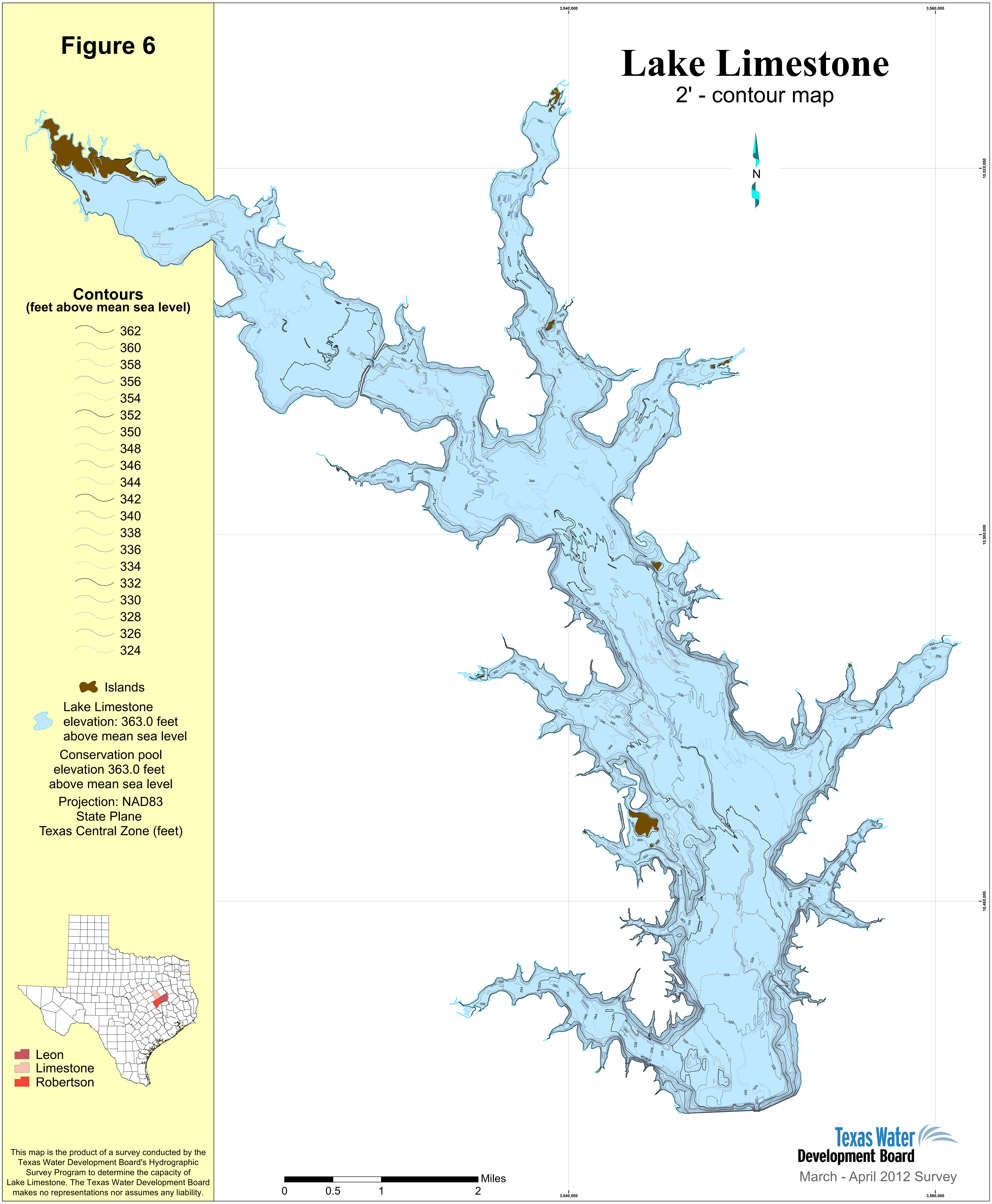


Figure 6
Lake Limestone
2' - contour map
N
Contours
(feet above mean sea level)
362
360
358
356
354
352
350
348
346
344
342
340
338
336
334
332
330
328
326
324
Islands
Lake Limestone elevation: 363.0 feet above mean sea level
Conservation pool elevation 363.0 feet above mean sea level
Projection: NAD83 State Plane Texas Central Zone (feet)
Leon
Limestone
Robertson
This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Lake Limestone. The Texas Water Development Board makes no representations nor assumes any liability.
0
0.5
1
2
Miles
Texas Water Development Board
March - April 2012 Survey