Volumetric and Sedimentation Survey of LAKE GRANBURY

May – June 2015 Survey

Texas Water Development Board

August 2016

Texas Water Development Board

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Brazos River Authority

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Executive summary

In March 2012, the Texas Water Development Board (TWDB) entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Granbury (Hood County, TX). The Brazos River Authority provided 50 percent of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50 percent of the funding through their Planning Assistance to States Program. Surveying was performed using a multi-frequency (208 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.

De Cordova Bend Dam and Lake Granbury are located on the Brazos River, approximately 8 miles southeast of the City of Granbury, in Hood County, Texas. The normal operating level of Lake Granbury is 692.7 feet above the Brazos River Authority (BRA) Datum. The BRA Datum is 1.11 feet below the National Geodetic Vertical Datum 1929. The TWDB collected bathymetric data for Lake Granbury between May 18, 2015, and June 12, 2015. Additional data was collected in the upper reaches on November 4, 2015. Daily average water surface elevations during the May/June survey ranged between 692.21 and 692.89 feet, BRA Datum. The daily average water surface elevation on November 4, measured 692.67 feet, BRA Datum.

The 2015 TWDB volumetric survey indicates that Lake Granbury has a total reservoir capacity of 133,858 acre-feet and encompasses 8,172 acres at the normal operating level (692.7 feet, BRA Datum). The 2015 TWDB volumetric survey indicates that Lake Granbury has a total reservoir capacity of 136,326 acre-feet and encompasses 8,282 acres at top of gates/emergency spillway elevation 693.0 feet. Previous capacity estimates, at elevation 693.0 feet, include the original design estimate of 153,500 acre-feet, and two TWDB surveys in 1993 and 2003. The 1993 and 2003 TWDB surveys were re-evaluated using current processing procedures resulting in updated capacity estimates of 143,381 acre-feet and 136,447 acre-feet, respectively, at elevation 693.0 feet.

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Granbury to have an average loss of capacity between 278 and 373 acre-feet per year since impoundment due to sedimentation below top of gates/emergency spillway elevation (693.0 feet, BRA Datum). Sediment accumulation is consistently greater throughout the main thalweg from the dam to approximately Texas State Highway 51. TWDB recommends that a similar methodology be used to resurvey Lake Granbury 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 72^{nd} Texas State Legislature in 1991. Texas Water Code section 15.804 authorizes the TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In March 2012, the TWDB entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Granbury. The Brazos River Authority provided 50 percent of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50 percent of the funding through their Planning Assistance to States Program (TWDB 2012). This report describes the methods used to conduct the volumetric and sedimentation survey in 2015, including data collection and processing techniques. This report serves as the final contract deliverable from the TWDB to the Brazos River Authority and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) a shaded relief plot of the reservoir bottom (Figure 4), (2) a bottom contour map (Figure 6), (3) an estimate of sediment accumulation and location (Figure 10), and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality (Appendices A and B).

Lake Granbury general information

De Cordova Bend Dam and Lake Granbury are located on the Brazos River, approximately 8 miles southeast of the City of Granbury, in Hood County, Texas (Figure 1). De Cordova Bend Dam and Lake Granbury are owned and operated by the Brazos River Authority, Texas. Construction on De Cordova Bend Dam began on December 15, 1966, and was completed on August 30, 1969. Deliberate impoundment began on September 15, 1969 (TWDB 1973). De Cordova Bend Dam and Lake Granbury were built primarily to supply water to Hood and Johnson Counties for municipal use. Lake Granbury also provides cooling water for a TXU Electric Company natural gas-fired steam electric power plant located on the lake and the Comanche Peak nuclear power plant located near Glen Rose (BRA 2016). Additional pertinent data about De Cordova Bend Dam and Lake Granbury can be found in Table 1.

Water rights for Lake Granbury have been appropriated to the Brazos River Authority through Certificate of Adjudication No. 12-5156 and Amendment to Certificate of Adjudication No. 12-5156A. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

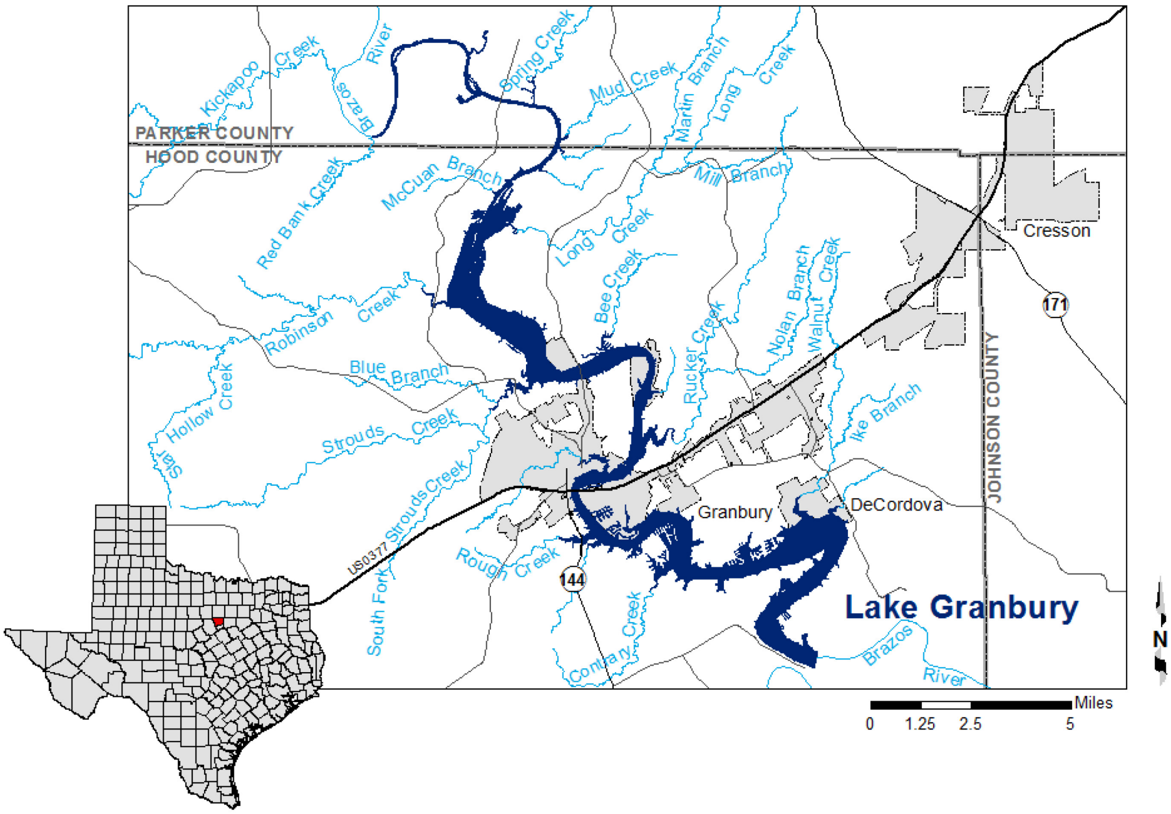


Figure 1. **Location map of Lake Granbury.**

Table 1. Pertinent data for De Cordova Bend Dam and Lake Granbury.

Owner
The Brazos River Authority

Design Engineer
Ambursen Engineering Corporation

Location of dam
On the Brazos River in Hood County, 8 miles southeast of the City of Granbury

Drainage area
24,691 square miles of which 9,240 square miles is likely noncontributing

Dam

Type	Concrete and earthfill
Length	2,200 feet
Maximum height	84 feet
Top width	17 feet

Spillway

Type	Gate controlled ogee weir
Control	16 tainter gates, each 36 by 35 feet
Crest length (net)	576 feet
Crest elevation	658.0 feet, BRA Datum

Outlet Works

Type	Concrete sluiceway
Control	Sluice gate
Invert elevation (lowest gate)	640.0 feet and 652.0 feet, BRA Datum

Reservoir data (Based on 2015 TWDB survey)

Feature	Elevation (feet, BRA Datum[a])	Capacity (acre-feet)	Area (acres)
Top of dam	706.5	N/A	N/A
Top of gates/ emergency spillway elevation	693.0	136,326	8,282
Top of normal operating level	692.7	133,858	8,172
Spillway crest	658.0	11,133	1,058
Invert of low flow outlet	640.0	909	210

Source: (TWDB 1973, P. Price, *pers.comm.*, August 8, 2016)
[a] The Brazos River Authority (BRA) Datum is 1.11 feet below National Geodetic Vertical Datum 1929

Volumetric and sedimentation survey of Lake Granbury

Datum

The vertical datum used during this survey is referred to as the Brazos River Authority (BRA) Datum. The BRA Datum is 1.11 feet below National Geodetic Vertical Datum 1929 (P.Price, *pers. comm.*, January 25, 2017). This datum also is utilized by the United States Geological Survey (USGS) for the reservoir elevation gages *USGS 08090900 Lk Granbury nr Granbury, TX* (USGS 2016a)*, USGS 08090885 Lk Granbury at US Hwy 377, Granbury, TX* (USGS 2016b), and *USGS 08090880 Lk Granbury at SH 51 nr Granbury, TX* (USGS 2016c). Elevations herein are reported in feet relative to the BRA Datum. Volume and area calculations in this report are referenced to water levels provided by the USGS gages. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas North Central Zone (feet).

TWDB bathymetric and sedimentation data collection

The TWDB collected bathymetric data for Lake Granbury between May 18 and June 12, 2015. Additional data was collected in the upper reaches on November 4, 2015. Daily average water surface elevations during the May/June survey ranged between 692.21 and 692.89 feet, BRA Datum. The daily average water surface elevation on November 4 measured 692.67 feet, BRA Datum. For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data was collected 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 also were used by the TWDB during the 1993 and 2003 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 2015 TWDB survey of Lake Granbury.

All sounding data was collected and reviewed before sediment core sampling sites were selected. Sediment core samples were collected at regularly spaced intervals within the reservoir, or at locations where interpretation of the acoustic display could be difficult without site-specific sediment core data. After analyzing the sounding data, the TWDB selected six locations to collect sediment core samples (Figure 2). The sediment core samples were collected on July 1and July 2, 2015, 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 surface, through the accumulated sediment, and to the pre-impoundment surface. After retrieving the sample, a stadia rod is inserted into the top of the aluminum tubes to assist in locating the top of the sediment in the tube. This identifies the location of the layer corresponding to the current reservoir-bottom 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.

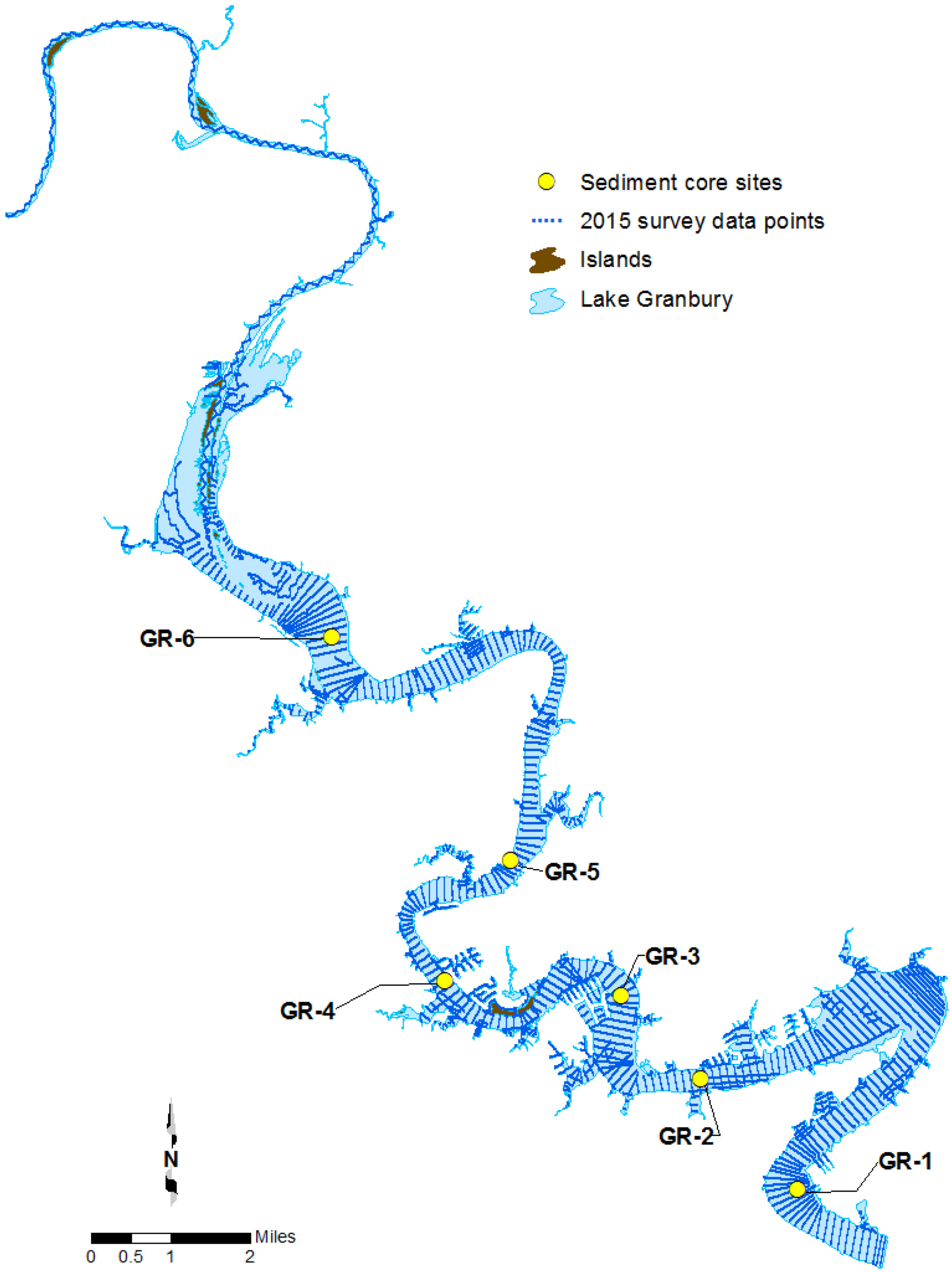


Figure 2. 2015 TWDB Lake Granbury survey data (*blue dots*) and sediment coring locations (*yellow circles*).

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 (TNRIS 2016a) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Granbury are Acton (SE, SW), Granbury (NE, NW, SE), Nemo (NW) and Tin Top (NE, NW, SE, SW). The DOQQs were photographed on July 31, 2010, while the daily average water surface elevation measured 692.6 feet, BRA Datum. According to metadata associated with the 2010 DOQQs, the photographs have a resolution or ground sample distance of 1.0 meter and a horizontal accuracy within ± 6 meters to true ground (TNRIS 2016b, USDA 2016). For this analysis, the boundary was digitized at the land-water interface in the 2010 photographs and assigned an elevation of 693.0 feet.

Triangulated Irregular Network model

Following completion of data collection, raw data files collected by the TWDB were edited to remove data anomalies. The reservoir's current bottom surface is automatically determined by data acquisition software. DepthPic© software, developed by SDI, Inc., was used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface. The TWDB developed an algorithm to automatically determine the pre-impoundment surface, *i.e.*, sediment thickness, based on the intensity of the acoustic returns. Hydropick software, developed by TWDB staff and in collaboration with Enthought, Inc. (GitHub 2015a, 2015b), was used to calibrate the algorithm and manually edit the pre-impoundment surfaces in areas where the algorithm did not perform as expected. For further analysis, all data was exported into a single file, including the current reservoir bottom surface, pre-impoundment surface, and sediment thickness at each sounding location. 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 was then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points were 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 was 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 bathymetry 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, the 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 the 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 interpolation is used for volumetric and sediment accumulation estimations. Linear interpolation follows a line file linking the survey points file to the lake boundary file (McEwen *et al.* 2011a). Without linearly interpolated 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 interpolation improves the elevation-capacity and elevation-area calculations, although it is not always possible to remove all flat triangles.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear interpolation techniques to Lake Granbury. In Figure 3A, deeper channels and steep slopes 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 in creation of the volumetric TIN model, represented in Figure 3B, directs Delaunay triangulation to better represent the reservoir bathymetry between survey cross-sections. The bathymetry shown in Figure 3C was used in computing reservoir elevation-capacity (Appendix A) and elevation-area (Appendix B) tables.

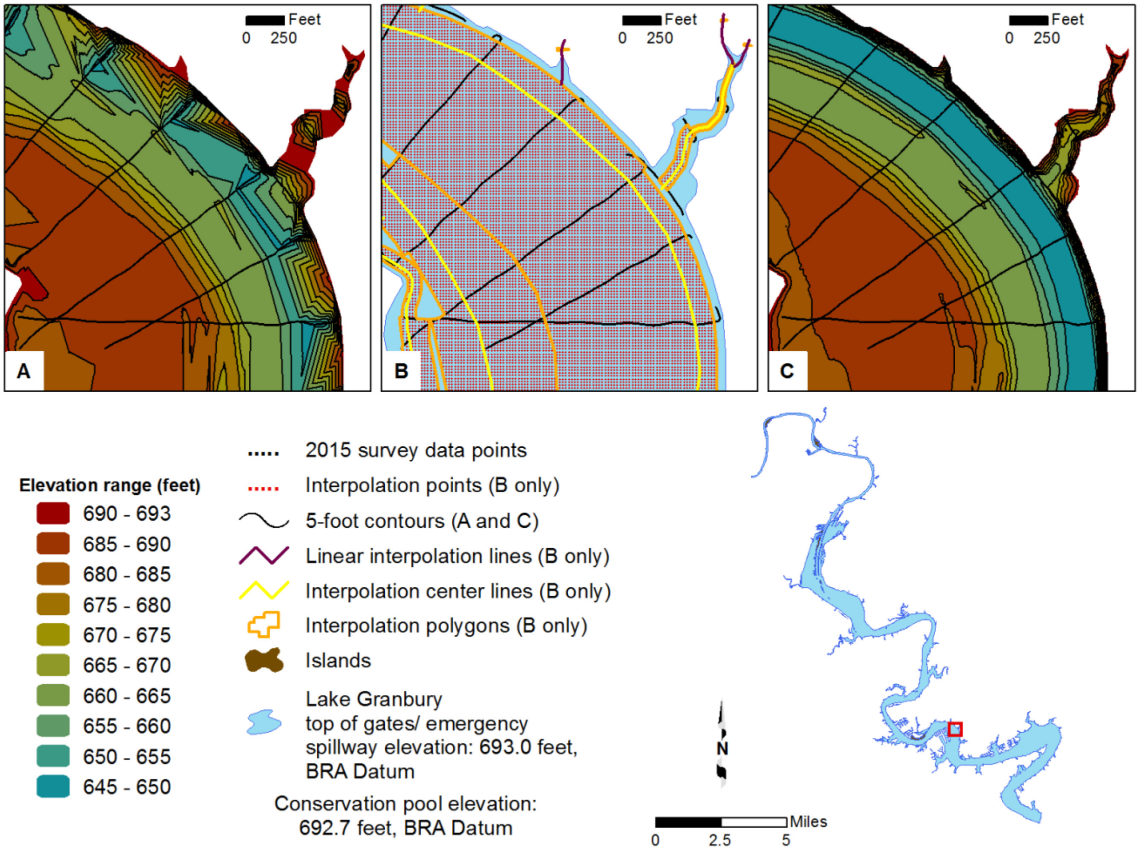


Figure 3. **Anisotropic spatial interpolation and linear interpolation of Lake Granbury sounding data; A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with interpolated points.**

Area, volume, and contour calculation

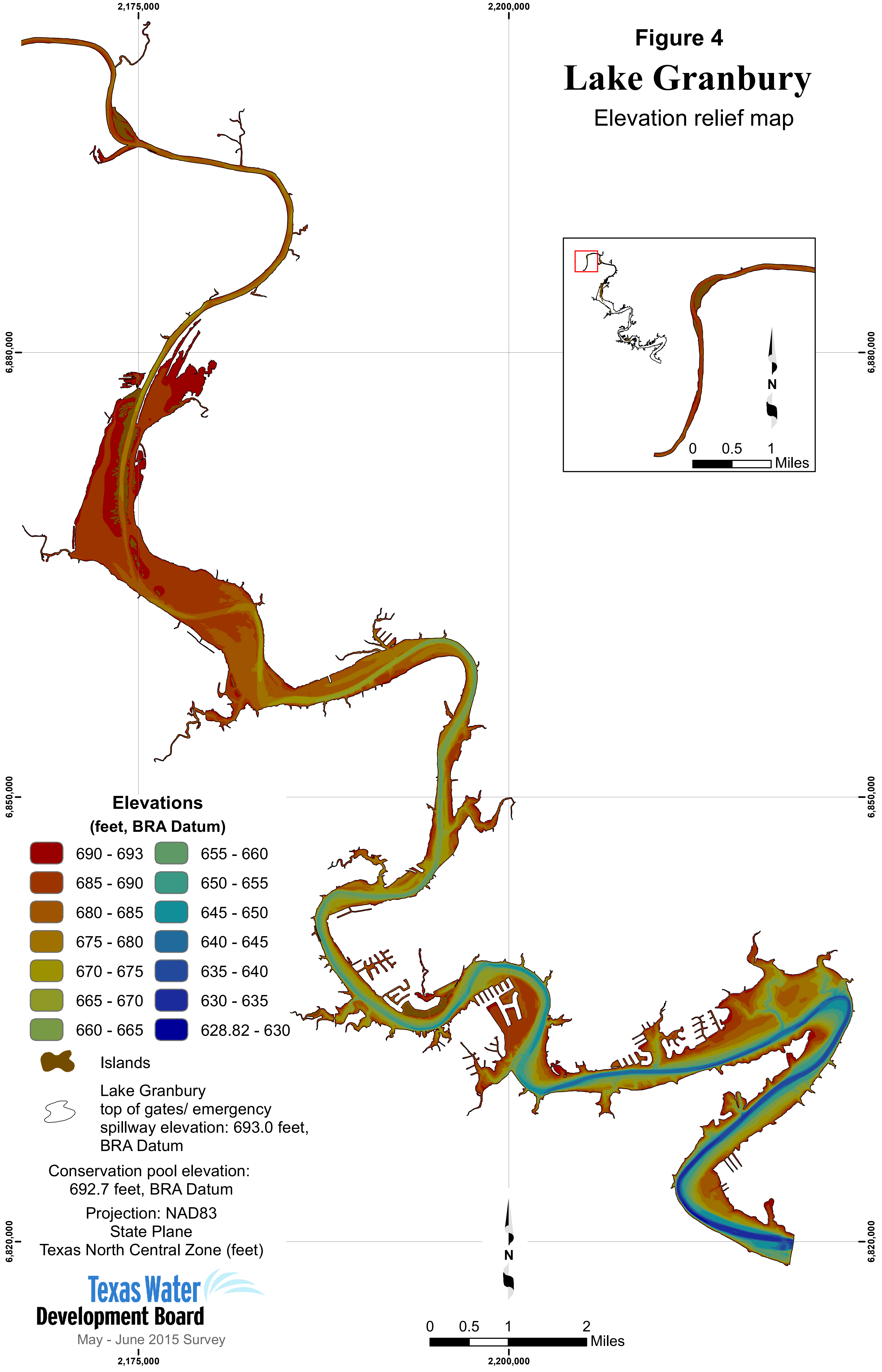
Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1-foot intervals from 625.0 to 693.0 feet. While linear interpolation was used to estimate topography in areas that were inaccessible by boat or too shallow for the instruments to work properly, development of anomalous “flat triangles”, that is triangles whose three vertices all have the same elevation, in the TIN model are unavoidable. The flat triangles in turn lead to anomalous calculations of surface area and volume at the boundary elevation 693.0 feet. To eliminate the effects of the flat triangles on area and volume calculations, areas between elevations 690.0 feet and 693.0 feet were linearly interpolated between the computed values, and volumes above elevation 690.0 feet were calculated based on the corrected areas. The elevation-capacity table and elevation-area table, based on the 2015 survey and analysis, are presented in Appendices A and B, respectively. The capacity curve is presented in Appendix C, and the area curve is presented in Appendix D.

The volumetric TIN model was converted to a raster representation using a cell size of two feet by two feet. The raster data was then used to produce three figures: (1) an elevation relief map representing the topography of the reservoir bottom (Figure 4); (2) a depth range map showing shaded depth ranges for Lake Granbury (Figure 5); and, (3) a five-foot contour map (Figure 6).

Figure 4

Lake Granbury

Elevation relief map



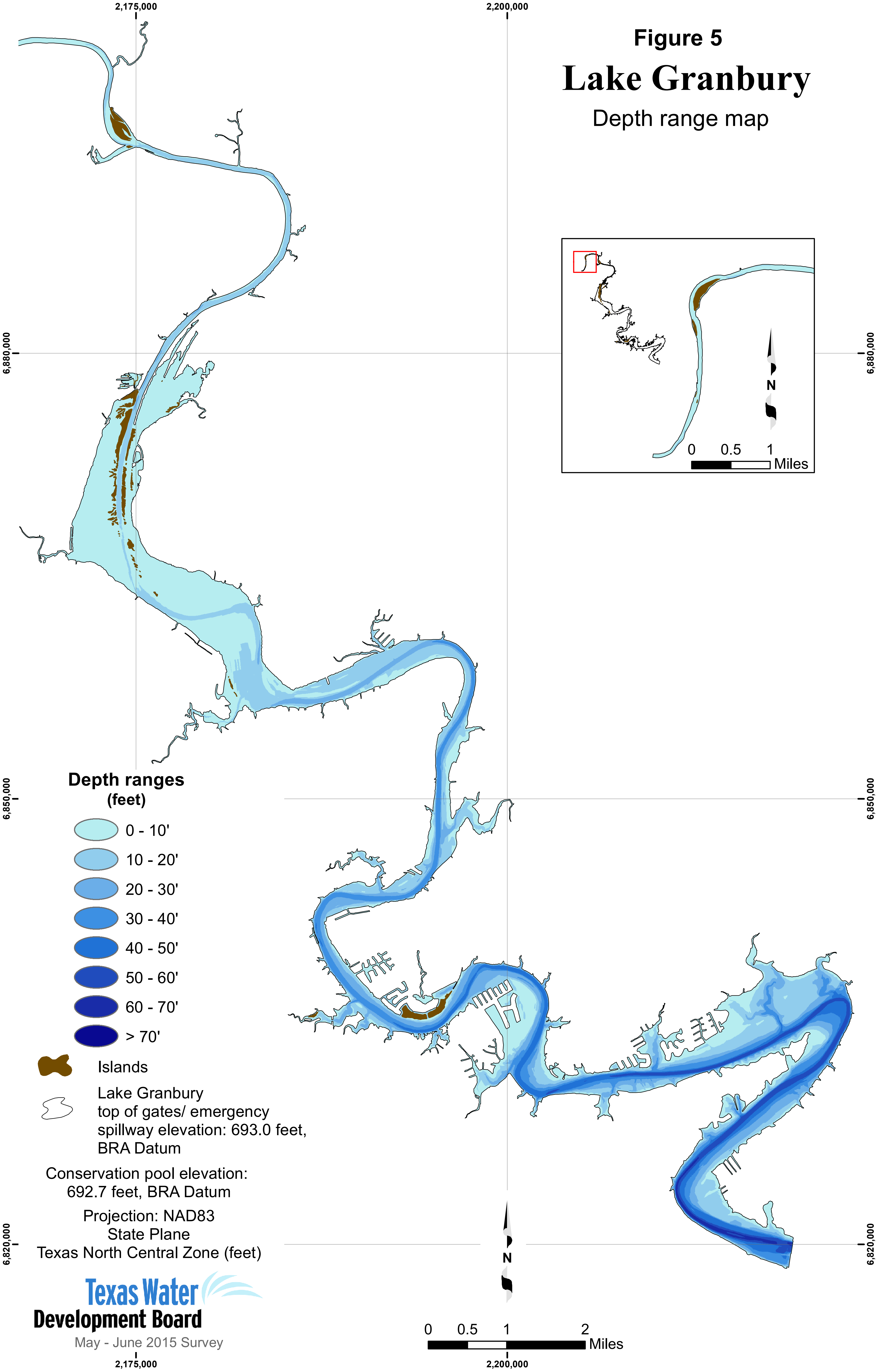


Figure 5
Lake Granbury
Depth range map
2,175,000
2,200,000
6,880,000
6,850,000
6,820,000
0 0.5 1
Miles
N
Depth ranges
(feet)
0 - 10'
10 - 20'
20 - 30'
30 - 40'
40 - 50'
50 - 60'
60 - 70'
> 70'
Islands
Lake Granbury
top of gates/ emergency
spillway elevation: 693.0 feet,
BRA Datum
Conservation pool elevation:
692.7 feet, BRA Datum
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water
Development Board
May - June 2015 Survey
0 0.5 1 2
Miles

Analysis of sediment data from Lake Granbury

Sedimentation in Lake Granbury was determined by analyzing the acoustic signal returns of all three depth sounder frequencies using customized software called Hydropick. While the 208 kHz signal is used to determine the current bathymetric surface, all three frequencies, 208 kHz, 50 kHz, and 24 kHz, are 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 are correlated with the acoustic signals in each frequency to assist in identifying the pre-impoundment surface. The difference between the current surface bathymetry and the pre-impoundment surface bathymetry yields a sediment thickness value at each sounding location.

Analysis of sediment core samples was conducted at TWDB headquarters in Austin, Texas. 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). Total sample length, post-impoundment sediment thickness, and pre-impoundment thickness were recorded. Physical characteristics of the sediment core, such as Munsell soil color, texture, relative water content, and presence of organic materials, also were recorded (Table 2).

Table 2. Sediment core sampling analysis data - Lake Granbury.

Sediment Core Sample	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
GR-1	2213289.17	6823536.46	17.5”/ 2.5”	0.0-2.5” water and fluff, post-impoundment	N/A
				2.5-7.5” high water content, dense, sand	5Y 3/1
				7.5-9.5” very dense, medium & coarse structures, large shell pieces, sand, pre-impoundment	10YR 3/3
				9.5-17.5” very dense, sandy clay, pre-impoundment	10YR 3/3
GR-2	2206921.26	6830933.71	65.5”/ 56.5”	0.0-1.5” water and fluff, post-impoundment	N/A
				1.5-4.0” high water content, loam, post-impoundment	5Y 2.5/1
				4.0-56.5” high water content, few medium to coarse structures, silty loam, post-impoundment	5Y 3/1
				56.5-58.0” clay, pre-impoundment	GLEY1 2.5/10Y
				58.0-65.5” sandy clay, pre-impoundment	10YR 3/3
GR-3	2201588.68	6836479.86	33.25”/7.5”	0.0-4.5” water and fluff, post-impoundment	N/A
				4.5-7.5” high water content, sandy loam, post-impoundment	5Y 3/1
				7.5-33.25” very dense, sandy clay, pre-impoundment	10Y 3/3
GR-4	2189902.31	6837401.97	79.0”/58.5”	0.0-1.0” water and fluff, post-impoundment	N/A
				1.0-6.5” high water content, silty loam, post-impoundment	5Y 4/2
				6.5-37.0” high water content, dense, silty loam, post-impoundment	5Y 3/1 & 5Y 4/2
				37.0-58.5” dense, sandy clay loam, post-impoundment	5Y 2.5/1
				58.5-64.5” very dense, sandy loam, pre-impoundment	5Y 3/2
				64.5-79.0” very dense, sandy, pre-impoundment	10YR 3/3
GR-5	2194279.43	6845450.36	112.0”/57.0”	0.0-5.0” water and fluff, post-impoundment	N/A
				5.0-7.0” high water content, silty loam, post-impoundment	5Y 3/2
				7.0-57.0” lower water content, dense, post-impoundment	5Y 3/2 & 5Y 2.5/2
				57.0-112.0” very dense, sand, pre-impoundment	10YR 3/3
GR-6	2182403.48	6860308.14	32.0”/15.0”	0.0-9.0” water and fluff, post-impoundment	N/A
				9.0-15.0” high water content, silty clay loam, post-impoundment	5Y 3/2
				15.0-28.0” very dense, clay loam, pre-impoundment	5Y 2.5/1 & 5Y 3/1
				28.0-32.0” very dense, clay, pre-impoundment	10YR 3/3

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

A photograph of sediment core GR-5 (for location refer to Figure 2) is shown in Figure 7 and is representative of sediment cores sampled from Lake Granbury. The base of the sample is denoted by the blue line. The pre-impoundment boundary (yellow line) was evident within this sediment core sample at 57.0 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.

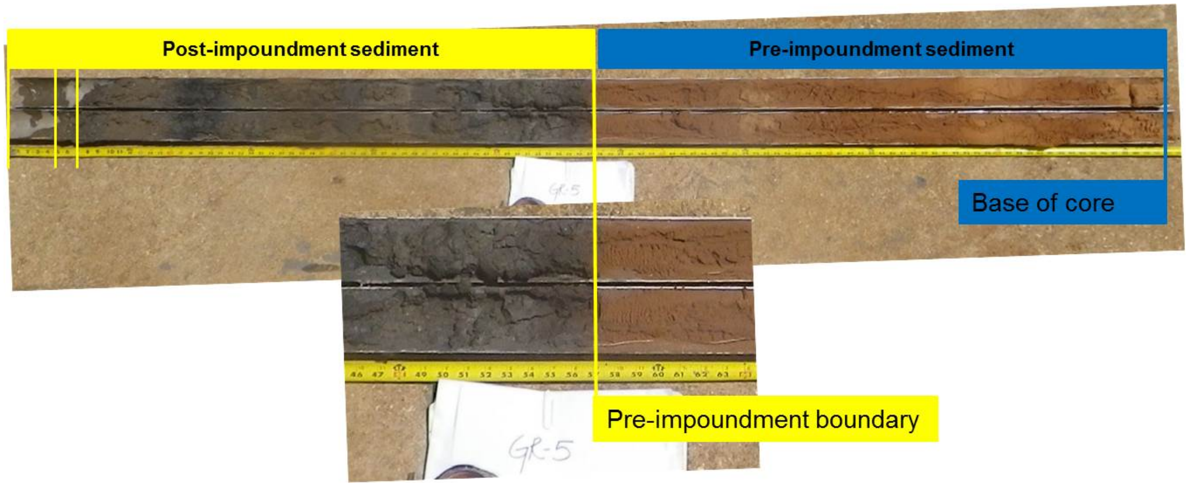


Figure 7. Sediment core GR-5 from Lake Granbury. Post-impoundment sediment layers occur in the top 57 inches of this sediment core. Pre-impoundment sediment was identified and are defined with blue boxes.

Figure 8 and 9 illustrate how measurements from sediment core samples are used with sonar data to identify the post- and pre-impoundment layers in the acoustic signal. Figure 8 compares sediment core sample GR-5 with the acoustic signals as seen in Hydropick for each frequency: 208 kHz, 50 kHz, and 24 kHz. The current bathymetric surface is automatically determined based on signal returns from the 208 kHz transducer and represented by the top red line in Figure 8.The pre-impoundment surface is identified by comparing boundaries observed in the 208 kHz, 50 kHz and 24 kHz signals to the location of the pre-impoundment surface as determined by the sediment core sample. Many layers of sediment may be identified during analysis based on changes in observed characteristics such as water content, organic matter content, and sediment particle size and each layer is classified as either post-impoundment or pre-impoundment. The boundary of each layer of sediment identified in the sediment core sample during analysis (Table 2) is represented in Figures 8 and 9 by a yellow or blue box. A yellow box represents post-impoundment sediment. A blue box indicates pre-impoundment sediments that were identified.

In this case the boundary in the 50 kHz signal most closely matched the pre-impoundment interface of the sediment core sample; therefore, the 50 kHz signal was used to locate the pre-impoundment surface (blue line in center panel in Figure 8). Figure 9 shows sediment core sample GR-5 correlated with the 50 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected. This information then is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

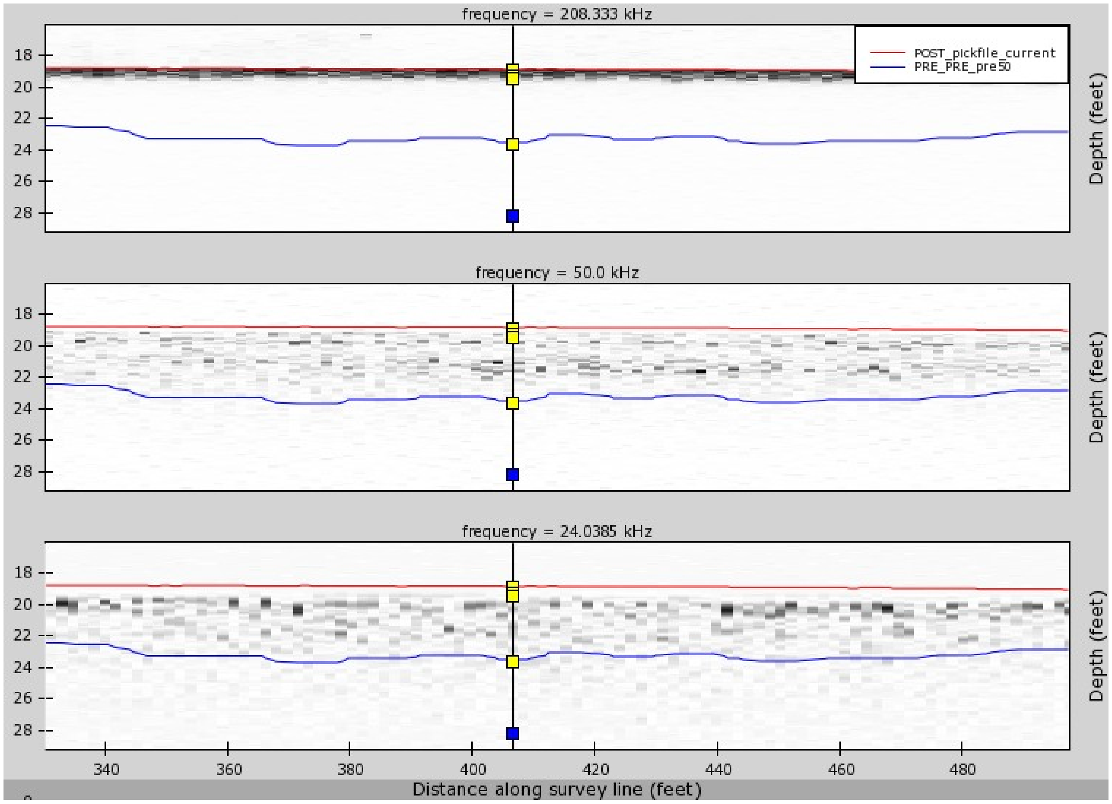


Figure 8. Comparison of sediment core GR-5 with acoustic signal returns.

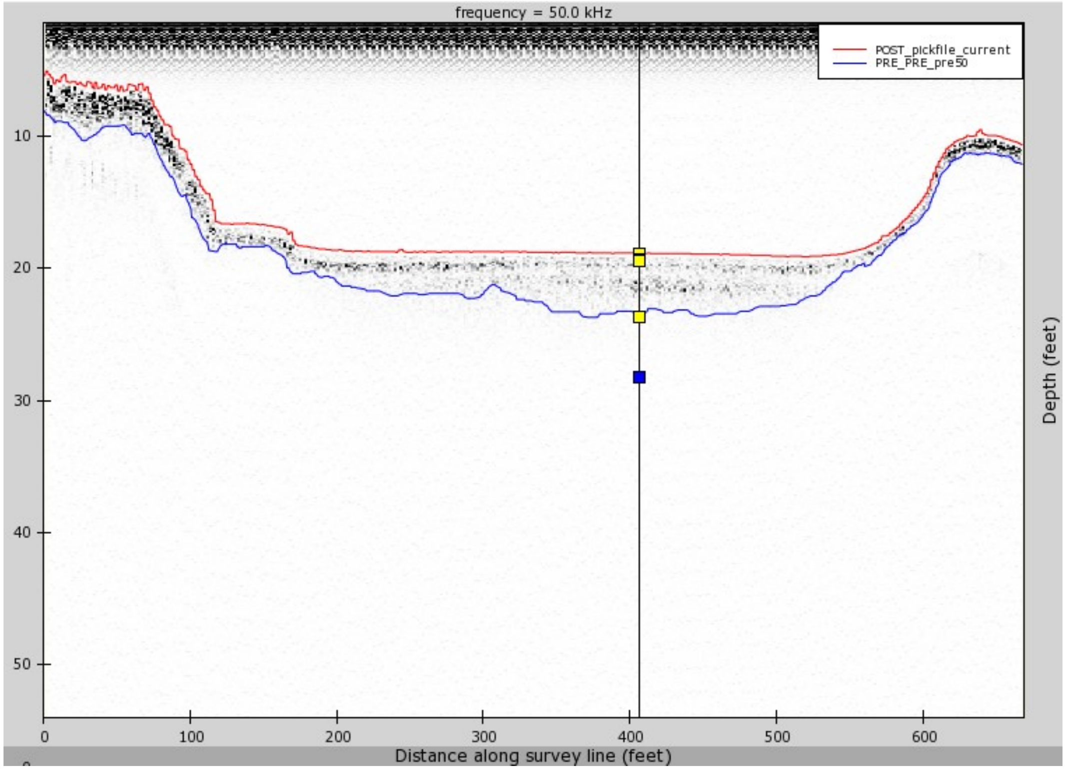


Figure 9. Cross-section of data collected during survey, displayed in Hydropick (50 kHz frequency), correlated with sediment core sample GR-5 and showing the current surface in red and pre-impoundment surface in blue.

The pre-impoundment surface was automatically generated in Hydropick using Otsu's thresholding algorithm of classifying greyscale intensity images into binary (black and white) images based on maximum inter-class variance. The acoustic return images of a selected frequency from each survey line were processed using this technique, and the pre-impoundment surface was identified as the bottom black/white interface (where black is the sediment layer) of the resulting binary image (D. Pothina, *pers. comm.*, October 2, 2014). The pre-impoundment surface is then verified and edited manually as needed.

After the pre-impoundment surface for all cross-sections is 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 TIN model creation, the TWDB assumed sediment thickness at the reservoir boundary was zero feet (defined as the 693.0 foot elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of five feet by five feet and was used to produce a sediment thickness map of Lake Granbury (Figure 10).

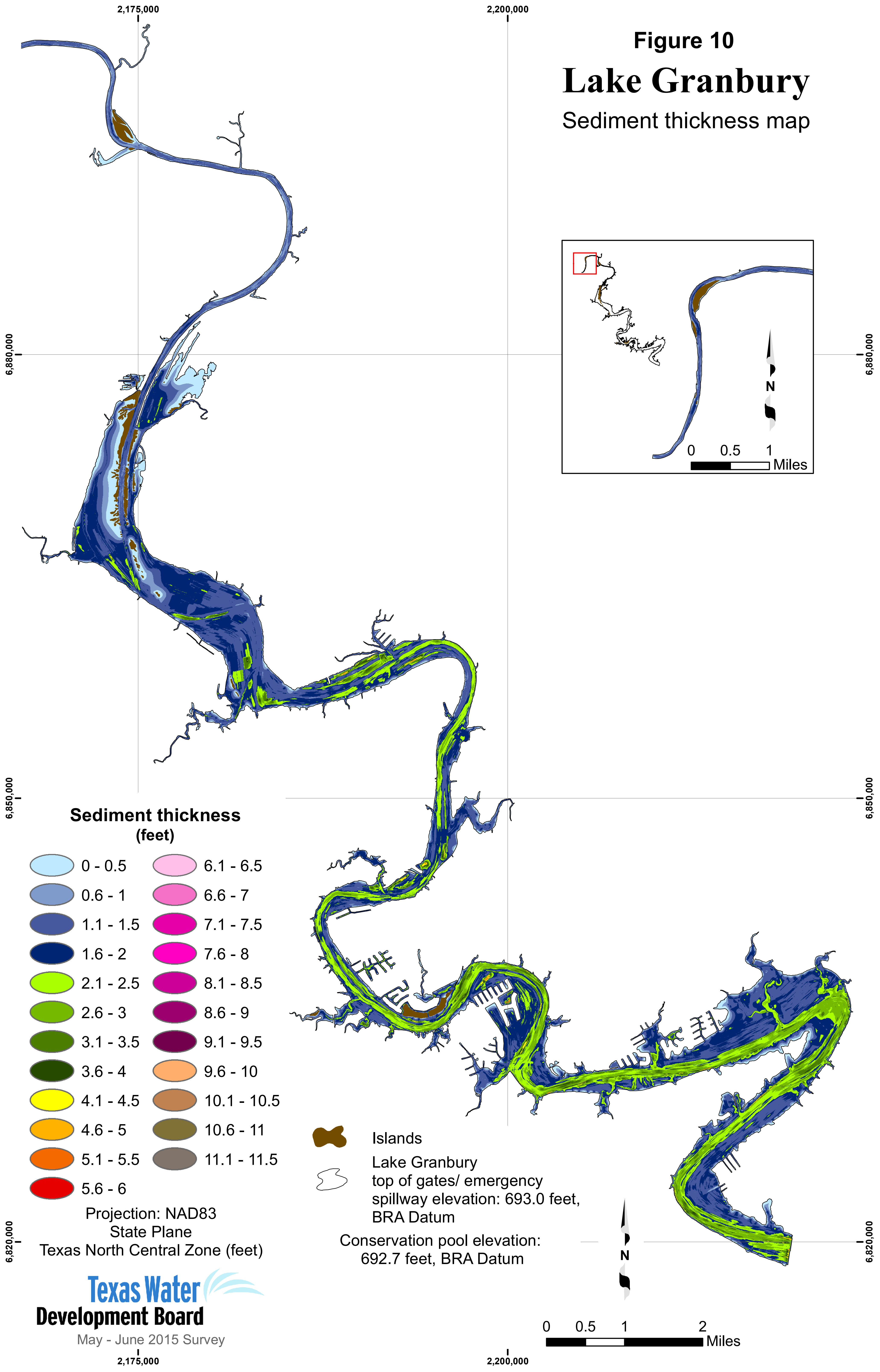


Figure 10
Lake Granbury
Sediment thickness map
2,175,000
2,200,000
6,880,000
6,850,000
6,820,000
0 0.5 1 Miles
N
Sediment thickness (feet)
0 - 0.5
0.6 - 1
1.1 - 1.5
1.6 - 2
2.1 - 2.5
2.6 - 3
3.1 - 3.5
3.6 - 4
4.1 - 4.5
4.6 - 5
5.1 - 5.5
5.6 - 6
6.1 - 6.5
6.6 - 7
7.1 - 7.5
7.6 - 8
8.1 - 8.5
8.6 - 9
9.1 - 9.5
9.6 - 10
10.1 - 10.5
10.6 - 11
11.1 - 11.5
Islands
Lake Granbury top of gates/ emergency spillway elevation: 693.0 feet, BRA Datum
Conservation pool elevation: 692.7 feet, BRA Datum
Projection: NAD83 State Plane Texas North Central Zone (feet)
Texas Water Development Board
May - June 2015 Survey
0 0.5 1 2 Miles

Survey results

Volumetric survey

The 2015 TWDB volumetric survey indicates that Lake Granbury has a total reservoir capacity of 133,858 acre-feet and encompasses 8,172 acres at normal operating level (692.7 feet, BRA Datum). The 2015 TWDB volumetric survey indicates that Lake Granbury has a total reservoir capacity of 136,326 acre-feet and encompasses 8,282 acres at the top of gates/emergency spillway elevation of 693.0 feet, BRA Datum. Previous capacity estimates, at elevation 693.0 feet, include the original design estimate of 153,500 acre-feet, and two TWDB surveys in 1993 and 2003. Because of differences in survey methodologies, direct comparison of this volumetric survey to others to estimate changes in capacity is difficult and can be unreliable. To properly compare results from the TWDB surveys of Lake Granbury, TWDB applied the 2015 data processing techniques to the survey data collected in 1993 and 2003. Specifically, the TWDB applied anisotropic spatial interpolation to the survey data collected in 1993 and 2003 using the same interpolation definition file as was used for the 2015 survey, with minor edits to account for differences in data coverage and boundary conditions.

The 1993 survey boundary was digitized from the 693.0-feet contour from 7.5 minute USGS quadrangle maps, with a stated accuracy of ± ½ the contour interval (USBB 1947). The 1993 survey boundary was revised near the De Cordova Power Plant to remove the cooling water outlet channel from the model and a new TIN model was created using the revised boundary. While linear interpolation was used to estimate the topography in areas without data, flat triangles led to anomalous area and volume calculations at the boundary elevation of 693.0 feet. Therefore, areas between 691.0 feet and 693.0 feet were linearly interpolated between the computed values, and volumes above 691.0 feet were calculated based on the corrected areas. The 2003 survey boundary was digitized from aerial photographs taken on January 19, 1995, February 02, 1995, and January 9, 1996, while the water surface elevation of the reservoir measured 692.3 feet, 692.65 feet, and 692.43 feet, respectively. The boundary was assigned an elevation of 693.0 feet for modeling purposes. 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.

The 2003 survey boundary was revised near the De Cordova Power Plant to remove the cooling water outlet channel from the model and a new TIN model was created using the revised boundary. Additionally, survey points with anomalous elevations were removed from the new model. While linear interpolation was used to estimate the topography in areas without data, flat triangles led to anomalous area and volume calculations at the boundary elevation of 693.0 feet. Therefore, areas between 690.5 feet and 693.0 feet were linearly interpolated between the computed values, and volumes above 690.5 feet were calculated based on the corrected areas. Re-evaluation of the 1993 and 2003 survey resulted in a 4.8 percent and 5.8 percent increase in total capacity estimates at top of gates/emergency spillway elevation 693.0 feet (Table 3).

Table 3. Current and previous survey capacity and surface area data for Lake Granbury.

Survey		Surface area (acres)	Capacity (acre-feet)
Top of gates/emergency spillway elevation (feet, BRA Datum) 693.0	Original design 1969 [a]	8,700	153,500
	TWDB 1993 [b]	8,310	136,823
	TWDB 1993 (re-calculated)	8,274	143,381
	TWDB 2003 [c]	7,945	129,011
	TWDB 2003 (re-calculated)	7,924	136,447
	TWDB 2015	8,282	136,326
Normal operating level (feet, BRA Datum) 692.7	TWDB 1993 [b]	8,012	134,527
	TWDB 1993 (re-calculated)	8,187	140,911
	TWDB 2003 [c]	7,816	126,721
	TWDB 2003 (re-calculated)	7,840	134,082
	TWDB 2015	8,172	133,858

[a] Source: (TWDB 1973)
[b] Source: (TWDB 2003)
[c] Source: (TWDB 2005)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Granbury to have an average loss of capacity between 278 and 373 acre-feet per year since impoundment due to sedimentation below the top of the gates/emergency spillway elevation (693.0 feet, BRA Datum). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. Sediment accumulation is consistently greater throughout the main thalweg from the dam to approximately Texas State Highway 51. Comparison of capacity estimates of Lake Granbury derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. Capacity loss comparisons for Lake Granbury.

Survey	Volume comparisons at top of gates/emergency spillway elevation 693.0 feet (acre-feet)			
Original design[a]	153,500	<>	<>	<>
TWDB 1993 (re-calculated)	<>	143,381	<>	<>
TWDB 2003 (re-calculated)	<>	<>	136,447	<>
TWDB pre-impoundment estimate based on 2015 survey	<>	<>	<>	149,091[b]
2015 volumetric survey	136,326	136,326	136,326	136,326
Volume difference (acre-feet)	17,174 (11.2%)	7,055 (4.9%)	121 (0.1%)	12,765 (8.6%)
Number of years	46	22	12	46
Capacity loss rate (acre-feet/year)	373	321	10	278

[a] Source: (TWDB 1973), note: Deliberate impoundment began on September 15, 1969, and De Cordova Bend Dam was completed on August 30, 1969.
[b] 2015 TWDB surveyed capacity of 136,326 acre-feet plus 2015 TWDB surveyed sediment volume of 12,765 acre-feet below elevation 693.0 feet

Recommendations

The TWDB recommends another volumetric and sedimentation survey of Lake Granbury within a 10 year time-frame or after a major flood event to assess changes in lake capacity and to further improve estimates of sediment accumulation rates.

TWDB contact information

More information about the Hydrographic Survey Program can be found at:
http://www.twdb.texas.gov/surfacewater/surveys/index.asp
Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:
Hydrosurvey@twdb.texas.gov

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Appendix A

Lake Granbury

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | May - June 2015 Survey
CAPACITY IN ACRE-FEET | Normal operating level 692.7 feet, BRA Datum
ELEVATION INCREMENT IS ONE TENTH FOOT | Top of gates/Emergency spillway elevation 693.0 feet

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
627	0	0	0	0	0	0	0	0	0	0
628	0	0	0	0	0	0	0	0	0	0
629	0	0	0	0	0	0	1	1	1	2
630	2	2	3	3	4	5	6	6	7	8
631	9	11	12	13	14	16	17	19	20	22
632	24	26	28	30	32	35	38	41	45	49
633	53	58	63	68	73	79	85	90	96	102
634	108	115	121	128	134	141	148	155	163	170
635	178	186	194	202	211	220	230	240	251	261
636	272	284	296	307	320	332	345	358	371	385
637	398	412	426	441	455	470	485	500	516	532
638	547	563	580	596	613	630	647	664	682	699
639	717	735	754	772	791	809	829	848	868	889
640	909	931	952	974	996	1,019	1,042	1,065	1,089	1,113
641	1,137	1,162	1,187	1,212	1,238	1,264	1,290	1,317	1,344	1,371
642	1,399	1,426	1,454	1,483	1,511	1,540	1,569	1,599	1,629	1,659
643	1,689	1,720	1,751	1,782	1,814	1,846	1,879	1,912	1,945	1,979
644	2,013	2,047	2,081	2,116	2,151	2,186	2,222	2,257	2,293	2,329
645	2,366	2,402	2,439	2,476	2,514	2,551	2,589	2,627	2,666	2,705
646	2,744	2,783	2,822	2,862	2,903	2,943	2,984	3,026	3,067	3,110
647	3,152	3,195	3,239	3,282	3,327	3,371	3,417	3,462	3,509	3,555
648	3,603	3,651	3,699	3,748	3,798	3,848	3,898	3,949	4,001	4,053
649	4,106	4,159	4,213	4,267	4,321	4,376	4,432	4,488	4,545	4,602
650	4,659	4,717	4,776	4,834	4,894	4,954	5,014	5,075	5,136	5,199
651	5,261	5,324	5,388	5,452	5,517	5,582	5,648	5,715	5,781	5,849
652	5,917	5,985	6,054	6,123	6,194	6,264	6,335	6,407	6,479	6,552
653	6,626	6,700	6,775	6,850	6,926	7,003	7,080	7,158	7,236	7,316
654	7,395	7,476	7,557	7,639	7,722	7,805	7,889	7,974	8,059	8,146
655	8,233	8,320	8,409	8,498	8,587	8,678	8,769	8,860	8,952	9,045
656	9,138	9,232	9,327	9,422	9,518	9,614	9,711	9,809	9,907	10,006
657	10,106	10,206	10,306	10,408	10,509	10,612	10,715	10,818	10,923	11,028
658	11,133	11,239	11,346	11,453	11,562	11,671	11,780	11,891	12,002	12,114
659	12,227	12,341	12,456	12,571	12,687	12,805	12,923	13,042	13,162	13,283
660	13,405	13,528	13,653	13,777	13,903	14,030	14,158	14,287	14,417	14,548
661	14,679	14,812	14,946	15,080	15,216	15,352	15,490	15,628	15,768	15,909
662	16,050	16,192	16,336	16,480	16,625	16,771	16,918	17,066	17,215	17,365
663	17,516	17,668	17,820	17,974	18,129	18,285	18,441	18,599	18,757	18,917
664	19,077	19,238	19,400	19,563	19,728	19,892	20,058	20,225	20,393	20,561
665	20,731	20,901	21,072	21,244	21,417	21,591	21,765	21,941	22,117	22,295
666	22,472	22,651	22,831	23,012	23,193	23,376	23,559	23,743	23,929	24,115
667	24,302	24,490	24,679	24,869	25,060	25,252	25,445	25,639	25,834	26,030
668	26,226	26,424	26,623	26,822	27,023	27,224	27,426	27,630	27,834	28,039
669	28,245	28,452	28,660	28,868	29,078	29,289	29,500	29,713	29,927	30,141
670	30,357	30,573	30,791	31,010	31,230	31,451	31,673	31,896	32,120	32,346
671	32,572	32,800	33,028	33,258	33,489	33,721	33,954	34,188	34,423	34,660
672	34,898	35,137	35,378	35,620	35,863	36,107	36,352	36,599	36,847	37,097
673	37,347	37,599	37,853	38,108	38,364	38,622	38,881	39,143	39,405	39,670
674	39,936	40,203	40,472	40,743	41,015	41,289	41,565	41,842	42,121	42,402
675	42,684	42,968	43,253	43,540	43,829	44,119	44,411	44,704	44,999	45,296
676	45,594	45,894	46,196	46,499	46,805	47,111	47,420	47,731	48,043	48,358
677	48,674	48,993	49,313	49,636	49,960	50,287	50,615	50,946	51,278	51,613
678	51,950	52,288	52,629	52,972	53,317	53,664	54,012	54,363	54,716	55,071
679	55,428	55,787	56,149	56,513	56,880	57,249	57,620	57,995	58,373	58,754
680	59,137	59,523	59,912	60,303	60,697	61,094	61,493	61,895	62,299	62,706
681	63,115	63,527	63,942	64,359	64,778	65,200	65,625	66,052	66,482	66,914
682	67,349	67,787	68,228	68,671	69,118	69,567	70,019	70,474	70,933	71,395

Appendix A (continued)

Lake Granbury

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | May - June 2015 Survey
CAPACITY IN ACRE-FEET | Normal operating level 692.7 feet, BRA Datum
ELEVATION INCREMENT IS ONE TENTH FOOT | Top of gates/Emergency spillway elevation 693.0 feet

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
683	71,859	72,327	72,797	73,270	73,745	74,223	74,704	75,188	75,673	76,162
684	76,654	77,147	77,645	78,144	78,647	79,153	79,662	80,174	80,689	81,208
685	81,730	82,257	82,788	83,322	83,861	84,403	84,950	85,501	86,056	86,615
686	87,178	87,746	88,318	88,894	89,474	90,057	90,645	91,237	91,834	92,436
687	93,042	93,651	94,266	94,885	95,508	96,137	96,771	97,410	98,054	98,704
688	99,357	100,013	100,674	101,339	102,007	102,677	103,351	104,028	104,708	105,392
689	106,078	106,769	107,463	108,160	108,860	109,563	110,269	110,979	111,691	112,406
690	113,123	113,843	114,568	115,295	116,027	116,762	117,501	118,243	118,989	119,739
691	120,492	121,249	122,010	122,774	123,542	124,314	125,089	125,868	126,651	127,437
692	128,227	129,020	129,818	130,618	131,423	132,231	133,043	133,858	134,677	135,500
693	136,326									

Note: Capacities above elevation 690.0 feet calculated from interpolated areas

Appendix B

Lake Granbury

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD
AREA IN ACRES
ELEVATION INCREMENT IS ONE TENTH FOOT

May - June 2015 Survey
Normal operating level 692.7 feet, BRA Datum
Top of gates/Emergency spillway elevation 693.0 feet

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
627	0	0	0	0	0	0	0	0	0	0
628	0	0	0	0	0	0	0	0	0	0
629	0	0	1	1	1	2	2	3	3	4
630	4	5	5	6	7	8	8	9	10	10
631	11	12	12	13	13	14	15	16	17	18
632	19	20	21	23	24	27	30	35	39	43
633	46	48	51	52	54	56	57	58	60	61
634	62	64	65	66	68	69	71	72	74	76
635	78	80	83	85	89	94	99	103	107	110
636	113	115	118	120	123	126	129	132	134	136
637	139	141	143	145	147	149	151	153	155	158
638	160	162	164	166	168	170	172	174	176	178
639	179	181	183	185	187	190	194	198	202	206
640	210	213	216	220	224	227	231	235	239	242
641	246	249	253	256	259	262	265	268	271	273
642	276	279	281	284	288	291	293	296	299	302
643	305	309	314	317	321	324	328	331	335	338
644	340	343	346	348	351	353	356	358	360	363
645	365	367	370	372	375	377	380	383	386	389
646	391	394	397	401	405	408	412	416	420	424
647	428	432	436	441	445	450	455	460	465	470
648	476	481	487	492	498	503	508	514	520	525
649	529	534	539	544	549	553	558	563	568	572
650	577	582	587	591	596	601	606	612	618	624
651	629	635	640	645	650	656	661	666	671	676
652	681	687	692	698	703	709	715	720	726	732
653	739	745	751	757	763	769	776	782	789	795
654	802	808	815	822	829	837	845	853	860	867
655	873	880	886	893	899	906	912	919	925	931
656	937	943	949	955	961	967	973	979	985	991
657	998	1,003	1,009	1,015	1,021	1,027	1,033	1,039	1,045	1,052
658	1,058	1,064	1,071	1,078	1,086	1,094	1,102	1,110	1,118	1,126
659	1,134	1,142	1,150	1,158	1,167	1,177	1,187	1,197	1,207	1,217
660	1,226	1,236	1,245	1,254	1,264	1,274	1,284	1,294	1,303	1,313
661	1,322	1,332	1,341	1,351	1,360	1,370	1,380	1,391	1,401	1,410
662	1,420	1,429	1,438	1,447	1,456	1,465	1,475	1,484	1,493	1,503
663	1,513	1,523	1,533	1,543	1,552	1,561	1,571	1,580	1,589	1,598
664	1,608	1,617	1,627	1,636	1,645	1,654	1,663	1,672	1,681	1,690
665	1,698	1,707	1,716	1,725	1,734	1,742	1,751	1,759	1,768	1,776
666	1,785	1,794	1,802	1,811	1,820	1,828	1,838	1,847	1,857	1,867
667	1,877	1,886	1,896	1,905	1,915	1,924	1,934	1,944	1,953	1,963
668	1,973	1,982	1,991	2,000	2,009	2,018	2,027	2,036	2,046	2,055
669	2,065	2,074	2,083	2,092	2,102	2,112	2,122	2,131	2,141	2,151
670	2,161	2,172	2,183	2,193	2,204	2,215	2,227	2,237	2,248	2,259
671	2,269	2,280	2,291	2,302	2,313	2,325	2,337	2,348	2,361	2,374
672	2,386	2,399	2,411	2,423	2,436	2,449	2,461	2,474	2,487	2,500
673	2,513	2,528	2,542	2,556	2,571	2,587	2,604	2,620	2,635	2,651
674	2,667	2,683	2,699	2,715	2,731	2,748	2,764	2,781	2,797	2,814
675	2,830	2,846	2,862	2,878	2,894	2,911	2,927	2,942	2,958	2,975
676	2,991	3,009	3,026	3,043	3,060	3,077	3,096	3,115	3,135	3,155
677	3,176	3,196	3,215	3,235	3,254	3,275	3,295	3,316	3,336	3,357
678	3,378	3,398	3,419	3,438	3,457	3,477	3,496	3,517	3,538	3,561
679	3,583	3,606	3,629	3,652	3,676	3,705	3,734	3,763	3,791	3,819
680	3,848	3,875	3,901	3,927	3,953	3,980	4,005	4,030	4,055	4,080
681	4,106	4,132	4,158	4,184	4,208	4,233	4,258	4,284	4,311	4,337
682	4,366	4,393	4,421	4,449	4,476	4,508	4,538	4,571	4,602	4,631

Appendix B (continued)

Lake Granbury

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD

AREA IN ACRES

ELEVATION INCREMENT IS ONE TENTH FOOT

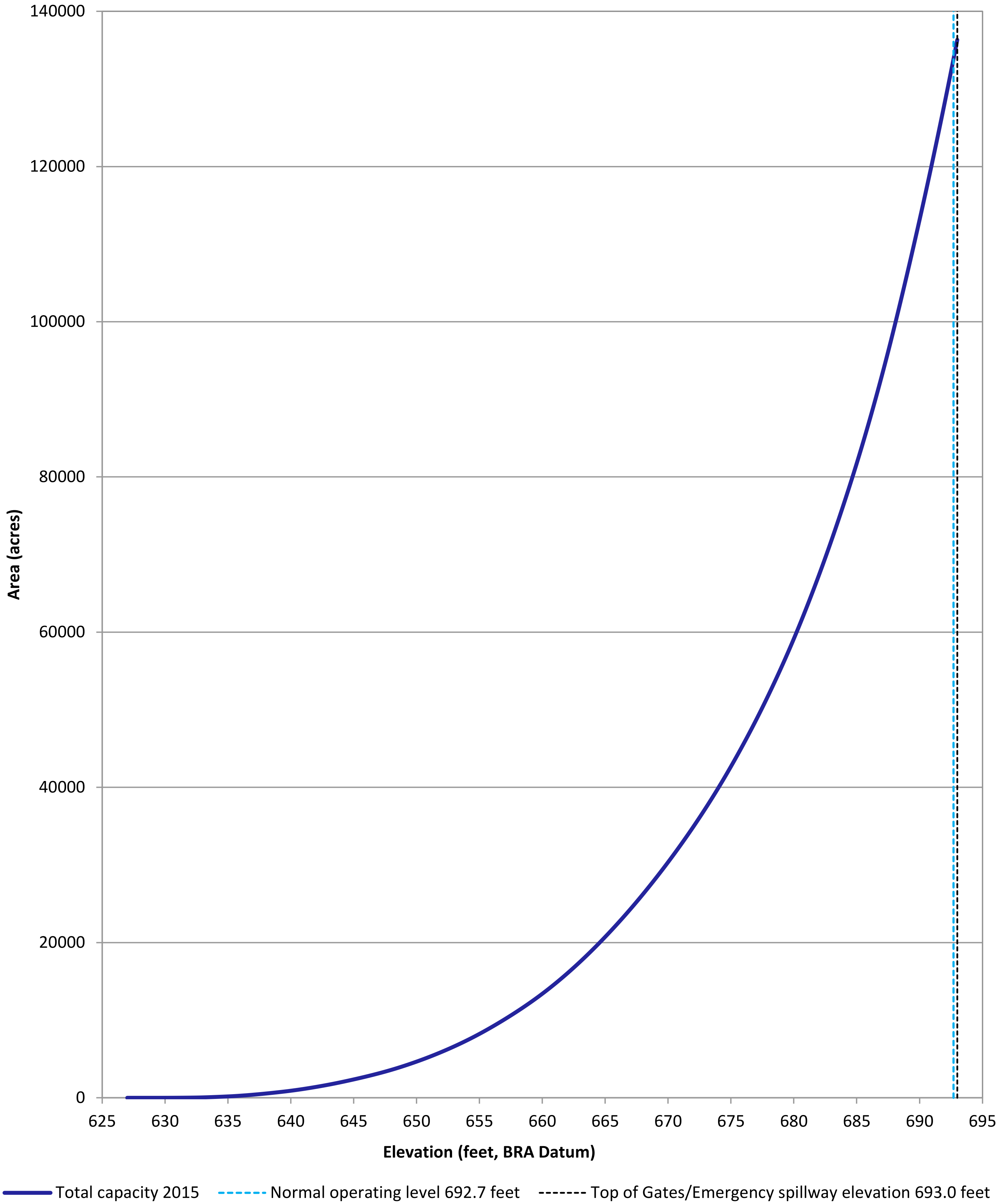
May - June 2015 Survey

Normal operating level 692.7 feet, BRA Datum

Top of gates/Emergency spillway elevation 693.0 feet

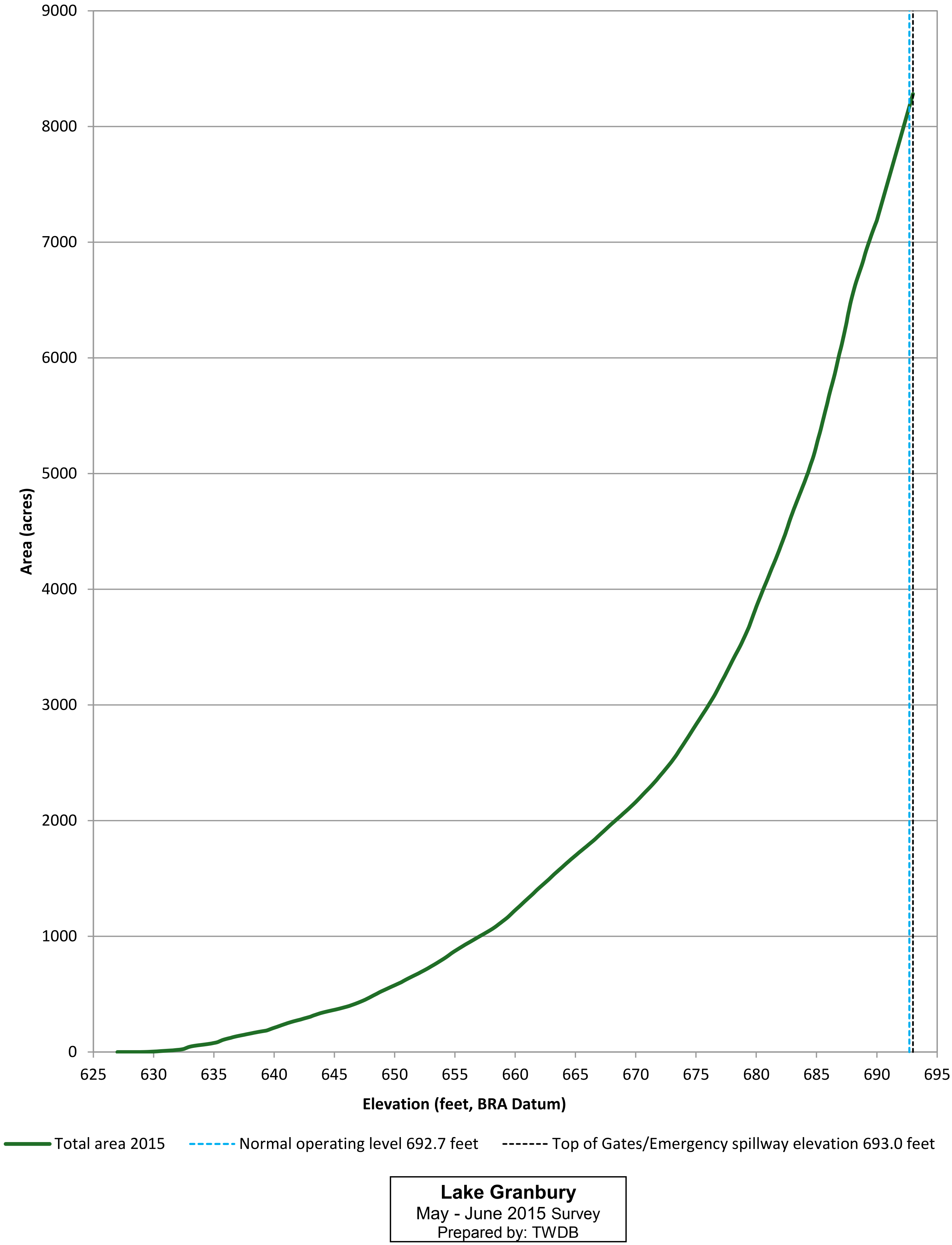
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
683	4,659	4,688	4,715	4,741	4,768	4,794	4,821	4,847	4,874	4,900
684	4,926	4,955	4,983	5,010	5,043	5,075	5,105	5,135	5,169	5,207
685	5,247	5,289	5,326	5,363	5,404	5,447	5,488	5,530	5,571	5,612
686	5,658	5,700	5,739	5,776	5,816	5,856	5,900	5,947	5,993	6,038
687	6,077	6,119	6,166	6,213	6,261	6,311	6,369	6,417	6,468	6,511
688	6,551	6,589	6,627	6,661	6,693	6,724	6,754	6,784	6,816	6,851
689	6,888	6,924	6,955	6,986	7,016	7,047	7,077	7,105	7,133	7,160
690	7,187	7,224	7,260	7,297	7,333	7,370	7,406	7,443	7,479	7,516
691	7,552	7,589	7,625	7,662	7,698	7,734	7,771	7,807	7,844	7,880
692	7,917	7,953	7,990	8,026	8,063	8,099	8,136	8,172	8,209	8,245
693	8,282									

Note: Areas between elevations 690.0 and 693.0 feet linearly interpolated

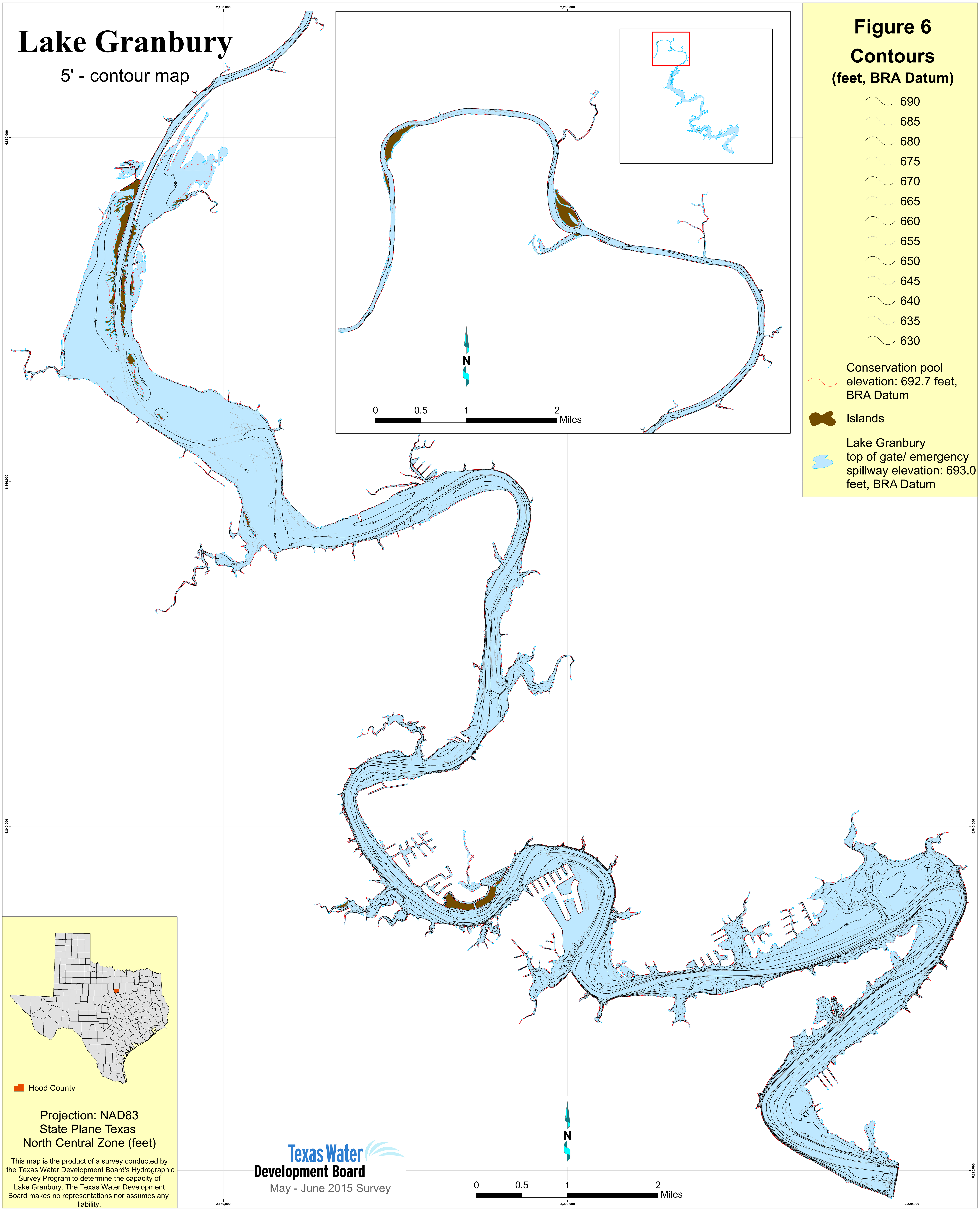


Lake Granbury
May - June 2015 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Appendix D: Area curve



Lake Granbury
5' - contour map
Figure 6
Contours
(feet, BRA Datum)
690
685
680
675
670
665
660
655
650
645
640
635
630
Conservation pool elevation: 692.7 feet, BRA Datum
Islands
Lake Granbury top of gate/ emergency spillway elevation: 693.0 feet, BRA Datum
N
0 0.5 1 2 Miles
Hood County
Projection: NAD83
State Plane Texas
North Central Zone (feet)
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 Granbury. The Texas Water Development Board makes no representations nor assumes any liability.
Texas Water Development Board
May - June 2015 Survey