Volumetric and Sedimentation Survey of GRANGER LAKE

March 2013 Survey

Texas Water Development Board

July 2014

Texas Water Development Board

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Brazos River Authority

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Executive summary

In October 2011, the Texas Water Development Board (TWDB) entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, and in November 2011, entered into agreement with the Brazos River Authority, to perform a volumetric and sedimentation survey of Granger Lake. The Brazos River Authority provided 50% of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50% of the funding through their Texas Water Allocation Assessment 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.

Granger Dam and Granger Lake, formerly known as Laneport Dam and Laneport Lake, are located on the San Gabriel River in the Brazos River Basin, seven miles east of the City of Granger in Williamson County, Texas, and approximately 10 miles northeast of Taylor, Texas. The conservation pool elevation of Granger Lake is 504.0 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Granger Lake between February 19, 2013, and March 26, 2013. The daily average water surface elevation during the survey ranged between 504.17 and 504.24 feet above mean sea level (NGVD29).

The 2013 TWDB volumetric and sedimentation survey indicates that Granger Lake has a total reservoir capacity of 51,822 acre-feet and encompasses 4,159 acres at conservation pool elevation (504.0 feet above mean sea level, NGVD29). Previous capacity estimates include the original design estimate by the U.S. Army Corps of Engineers of 65,510 acre-feet, and volumes obtained from three TWDB surveys in 1995, 2002, and 2008. All prior TWDB volumetric surveys were re-evaluated using current processing procedures resulting in updated capacity estimates of 54,834 acre-feet, 53,244 acre-feet, and 51,241 acre-feet, respectively.

The 2013 TWDB sedimentation survey estimates Granger Lake to have an average loss of capacity of 152 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (504.0 feet above mean sea level, NGVD29). The heaviest accumulations measured are northwest of Wilson H. Fox Park towards the south end of the dam and approximately one half mile west of the dam. Sediment is greater in the Willis Creek branch of the lake than the San Gabriel River branch. TWDB recommends that a similar methodology be used to resurvey Granger Lake in 5 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. Section 15.804 of 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 October 2011, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, and in November 2011, entered into agreement with the Brazos River Authority, to perform a volumetric and sedimentation survey of Granger Lake (TWDB, 2011a, TWDB, 2011b). The Brazos River Authority provided 50% of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50% of the funding through their Texas Water Allocation Assessment Program. 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) 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 [Appendix A, B].

Granger Lake general information

Granger Dam and Granger Lake, formerly known as Laneport Dam and Laneport Lake, are located on the San Gabriel River in the Brazos River Basin, seven miles east of the City of Granger in Williamson County, Texas, and approximately 10 miles northeast of Taylor, Texas (Figure 1). Granger Dam and Granger Lake are owned by the U.S. Government and operated by the U.S. Army Corps of Engineers, Fort Worth District (TWDB, 1973). The U.S. Congress authorized the construction of Granger Lake for flood control, water conservation, fish and wildlife habitat, and recreation, with the passage of the Flood Control Act of September 3, 1954 (USACE, 2007). Construction of Granger Dam began on October 24, 1972. The deliberate impoundment of water began on January 21, 1980 (USACE, 2013). Additional pertinent data about Granger Dam and Granger Lake can be found in Table 1.

Water rights for Granger Lake have been appropriated to the Brazos River Authority through Certificate of Adjudication No. 12-5163. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

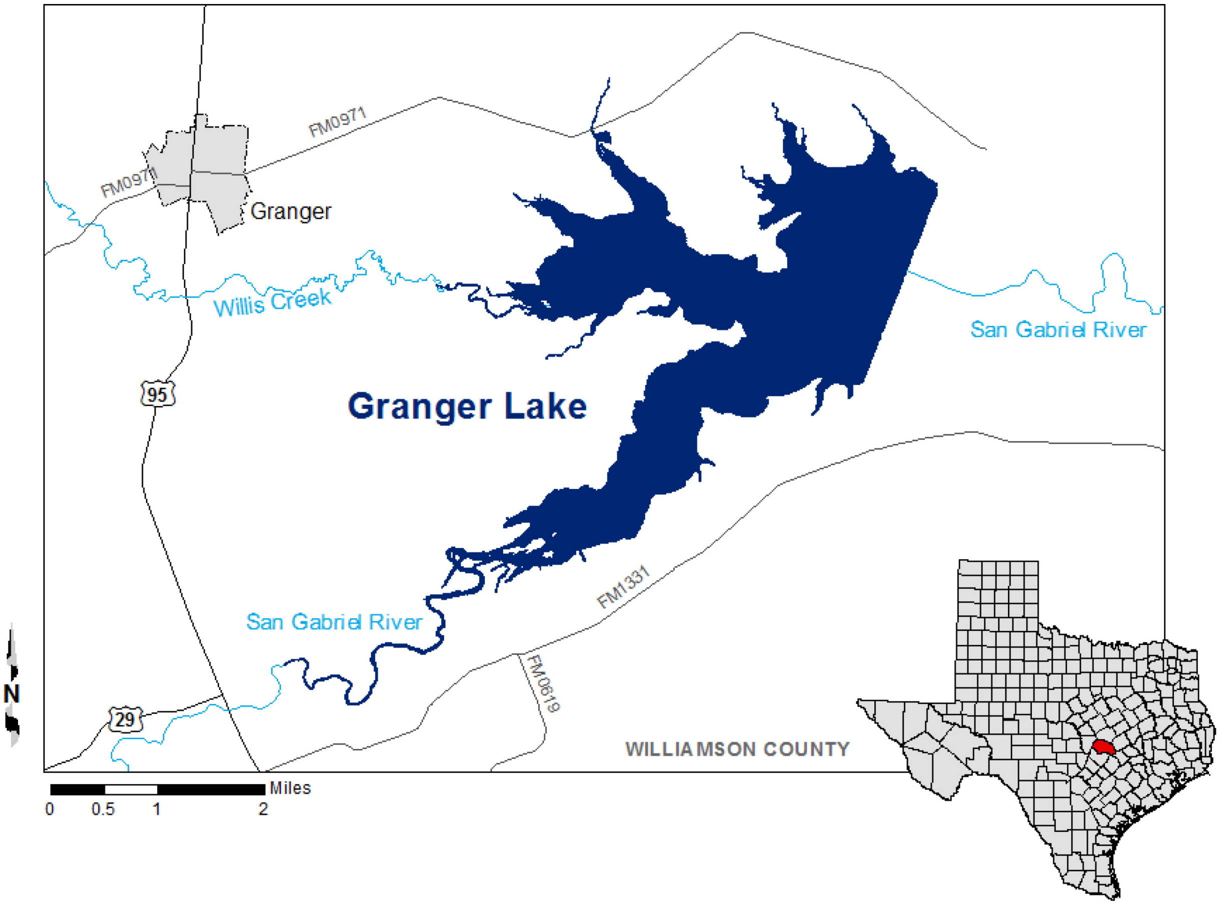

Figure 1. **Location of Granger Lake**

Table 1.	**Pertinent data for Granger Dam and Granger Lake**		
Owner			
The U.S. Government			
Operated by the U.S. Army Corps of Engineers, Fort Worth District			
Engineer			
U.S. Army Corps of Engineers			
General contractor			
J. D. Abrams			
Location of dam			
On San Gabriel River in Williamson County, 7 miles east of the City of Granger, and 10 miles northeast of the City of Taylor, Texas.			
Drainage area			
709 square miles			
Dam			
Type	Earthfill		
Length	16,320 feet including spillway		
Maximum height	115 feet		
Top width	30 feet		
Spillway			
Type	Uncontrolled ogee		
Length	950 feet		
Crest elevation	528.0 feet above mean sea level		
Outlet works			
Type	Conduit		
Dimension	18 feet diameter		
Invert elevation	457.0 feet above mean sea level		
Control	2 slide gates, each 8 by 18 feet		
Low flow outlets (discharges to flood control conduit)			
Number to wet well	3		
Invert elevations	502.0, 494.0, 486.0 feet above mean sea level		
Control	3 slide gates, each 3 by 4 feet		
Number from wet well	1		
Invert elevations	486.0 feet above mean sea level		
Control	1 slide gate, 2 by 4 feet		
Reservoir data (Based on 2013 TWDB survey)			
Feature	**Elevation (feet** NGVD29[a]**)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	555.0	N/A	N/A
Maximum design water surface	549.3	N/A	N/A
Spillway crest	528.0	N/A	N/A
Top of conservation pool	504.0	51,822	4,159
Invert elevation (Low flow outlet)	486.0	7,359	1,177
Invert elevation (Outlet works)	457.0	0	0
Usable conservation storage space[b]	-	51,822	-

Source: (TWDB 1973, TWDB 2003b, TWDB 2009, USACE 2007, USACE, 2013)

[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 Granger Lake

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 08105600 Granger Lk nr Granger, 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 Granger Lake on February 19, February 20, March 13, March 19, and March 26, 2013. The daily average water surface elevation during the survey measured 504.18, 504.17, 504.18, 504.19, and 504.24 feet above mean sea level (NGVD29), respectively. 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 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 1995, 2002, and 2008 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 2013 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 August 12, 2013, 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 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-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.

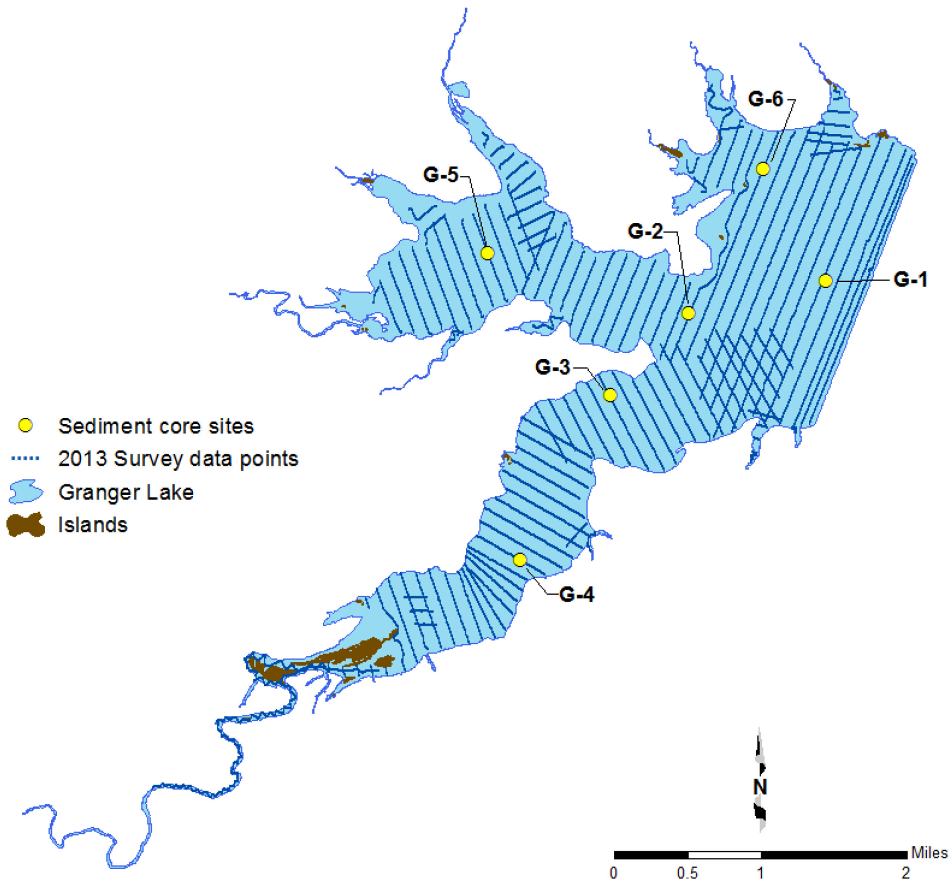

Figure 2. **Data collection during 2013 TWDB Granger Lake survey**

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 Granger Lake are Granger (NE, SE), and Granger Lake (NW, SW). The DOQQs were photographed on June 25, 2012, while the daily average water surface elevation measured 503.72 feet (NGVD29). 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 (USDA, 2013, TNRIS, 2012). For this analysis, the boundary was digitized at the land-water interface in the 2012 photographs and assigned an elevation of 504.0 feet to facilitate calculating the area-capacity tables up to the conservation pool elevation.

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 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 Granger Lake 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 August 31, 2006, and May 3, 2010, while the daily average water surface elevation measured 501.72 feet and 502.06 feet, respectively, or where survey data from prior TWDB surveys indicated channel morphology.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear extrapolation techniques to Granger Lake. The bathymetry shown in Figure 3C was used in computing reservoir capacity and area tables (Appendix A, B). In Figure 3A, deeper channels, depressions, or ridges 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.

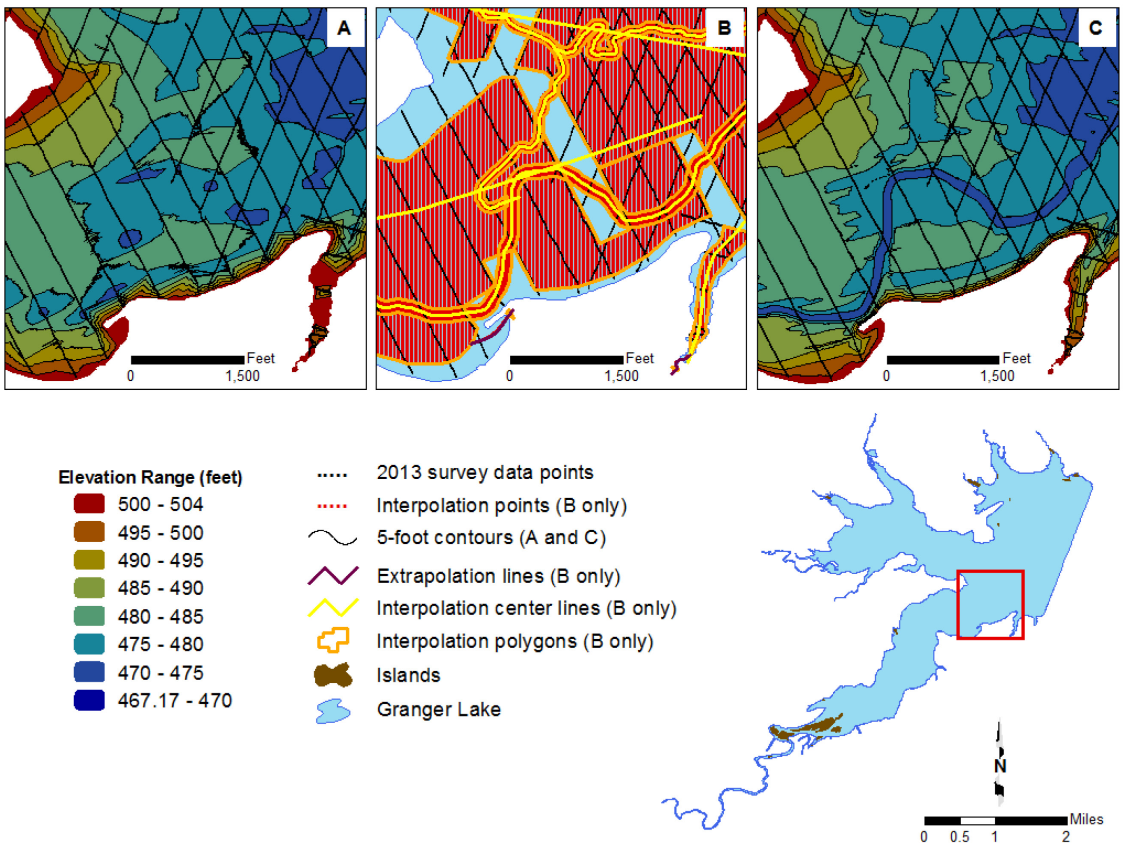

Figure 3. **Anisotropic spatial interpolation and linear extrapolation of Granger Lake sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

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 foot intervals, from 467.0 to 504.0 feet. The elevation-capacity table and elevation-area table, updated for 2013, 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 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 Granger Lake; and a 5-foot contour map (Figure 6 - attached).

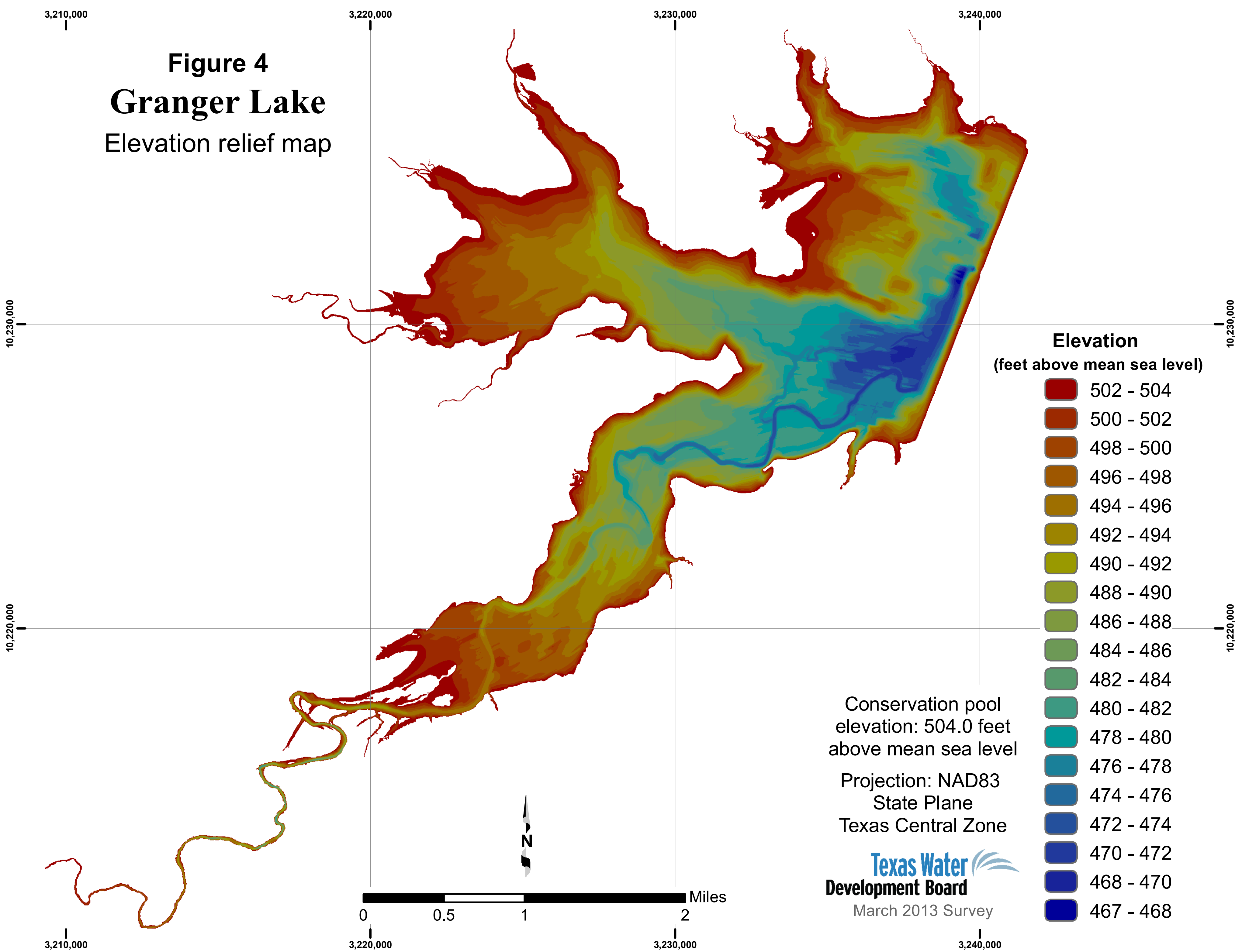

Figure 4
Granger Lake
Elevation relief map
3,210,000
3,220,000
3,230,000
3,240,000
10,230,000
10,220,000
Elevation
(feet above mean sea level)
502 - 504
500 - 502
498 - 500
496 - 498
494 - 496
492 - 494
490 - 492
488 - 490
486 - 488
484 - 486
482 - 484
480 - 482
478 - 480
476 - 478
474 - 476
472 - 474
470 - 472
468 - 470
467 - 468
Conservation pool elevation: 504.0 feet above mean sea level
Projection: NAD83 State Plane Texas Central Zone
Texas Water Development Board
March 2013 Survey
N
Miles
0
0.5
1
2

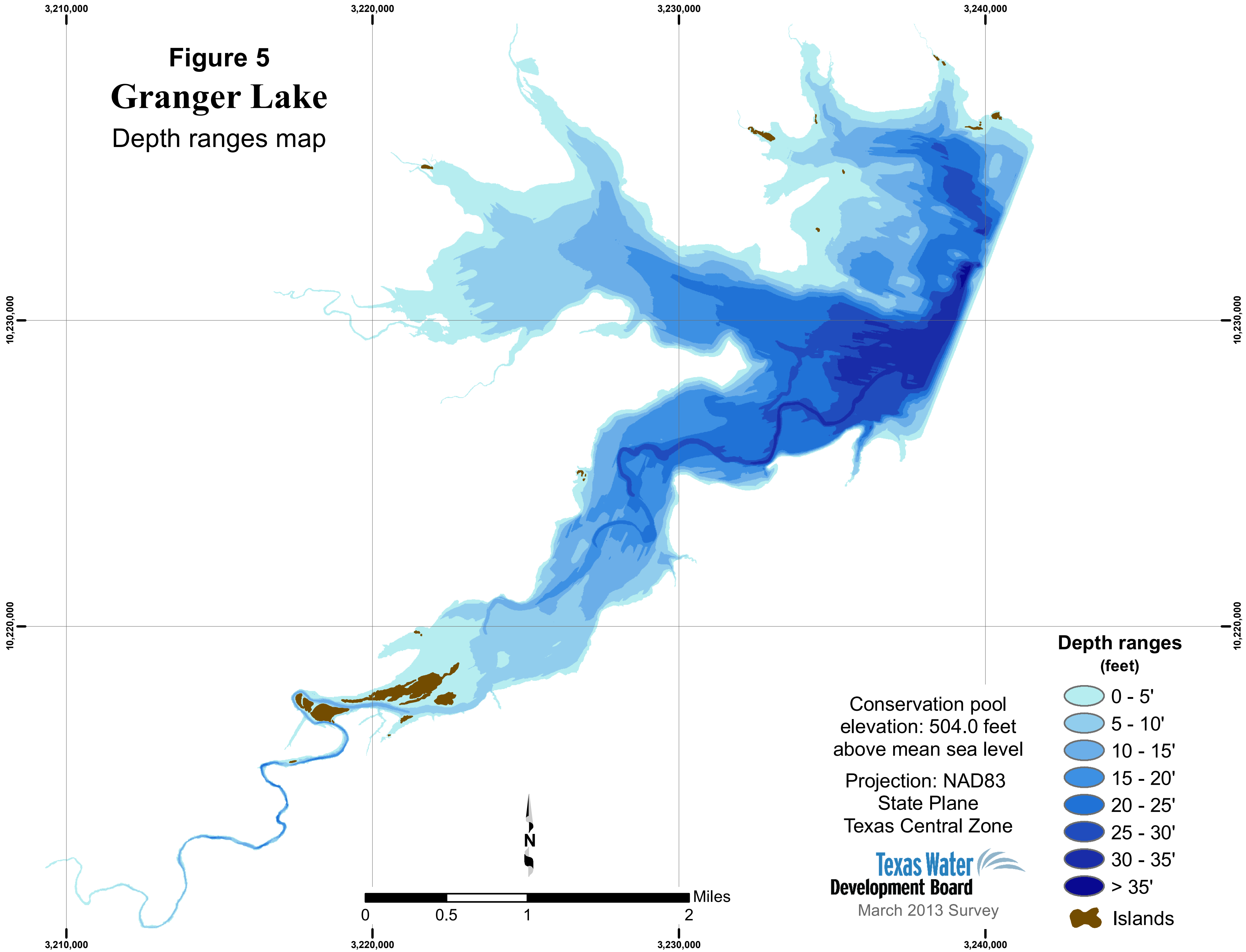

Figure 5

Granger Lake

Depth ranges map

Analysis of sediment data from Granger Lake

Sedimentation in Granger Lake was determined by analyzing the acoustic signal returns of all three depth sounder frequencies in the DepthPic© software. The 208 kHz signal was analyzed to determine the current bathymetric surface of the reservoir, while all three frequencies, 208 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 - Granger Lake

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
G-1	3238344.07	10231382.67	28"/22.5"	0-17" high water content, silty clay	5Y 4/1
				17-22.5" high water content, some organics present, rocks, silty clay loam	5Y 2.5/1
				22.5-28" organics present, sandy soil	5Y 7/3
G-2	3233401.45	10230214.15	36"/30"	0-16" high water content, silty clay	5Y 3/1
				16-30" high water content, some organics present, silty clay loam	2.5Y 2.5/1
				30-36" organics prevalent, silty clay	10YR 3/1
G-3	3230555.68	10227227.90	16.5"/6.5"	0-6.5" high water content, organics present, sandy clay loam	2.5Y 4/1
				6.5-16.5" some organics present, sandy clay	2.5Y 3/1
G-4	3227302.07	10221307.79	13.5"/6"	0-4" high water content, sandy clay loam	2.5Y 4/2
				4-6" low water content, organics present, sandy clay	2.5Y 3/1
				6-13.5" organics present, rocks present, sandy clay	5Y 4/1
G-5	3226146.29	10232379.50	41"/38.5"	0-16" high water content, silty clay loam	5Y 3/1
				16-38.5" high water content, silty clay	5Y 3/1
				38.5-41" organics present, sandy clay	5Y 2.5/1
G-6	3236080.51	10235397.89	49"/44.5"	0-44.5" high water content, silty clay loam	5Y 4/1
				44.5-49" sandy clay, rocks present	2.5Y 3/1

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

A photograph of sediment core G-2 is shown in Figure 7 and is representative of the sediment cores sampled from Granger Lake. The 208 kHz frequency measures the top layer as the current bottom surface of the reservoir.

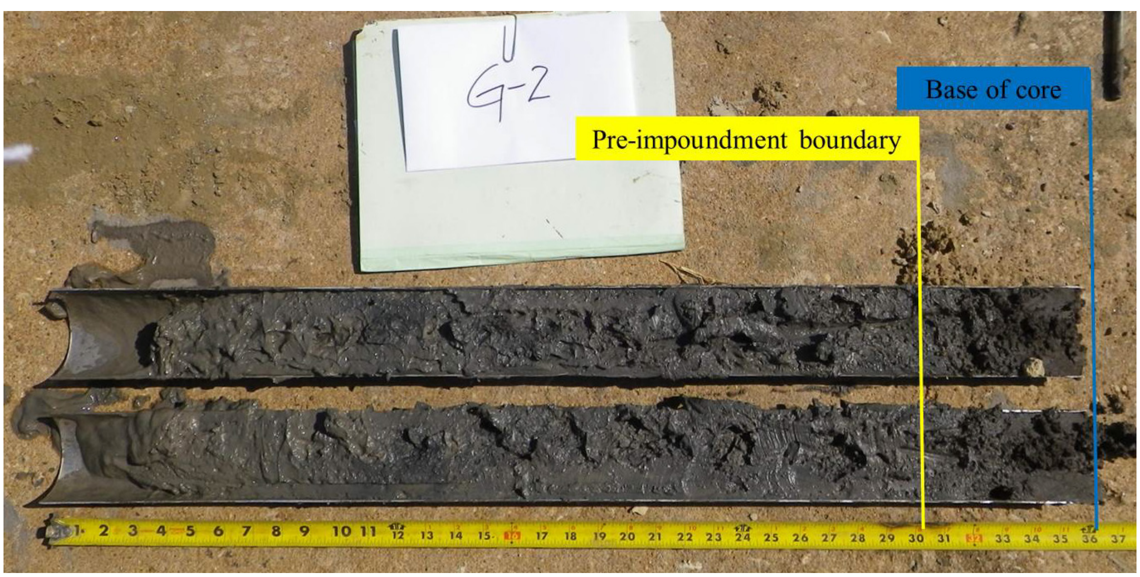

Figure 7. Sediment core G-2 from Granger Lake

Sediment core sample G-2 consisted of 36 inches of total sediment corresponding to the length of the aluminum sampling tube. The upper sediment layer (horizon), 0-16.0 inches, consisted of silty clay with a high water content and measured 5Y 3/1 on the Munsell soil color chart. The second horizon, beginning at 16.0 inches and extending to 30.0 inches below the surface, consisted of silty clay loam with a high water content and the presence of organics and measured 2.5Y 2.5/1 on the Munsell soil color chart. The third horizon, from 30.0 inches to 36.0 inches, consisted of a silty clay, a prevalence of organics, and a 10YR 3/1 Munsell soil color. 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 30.0 inches and identified by the change in 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 208 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.

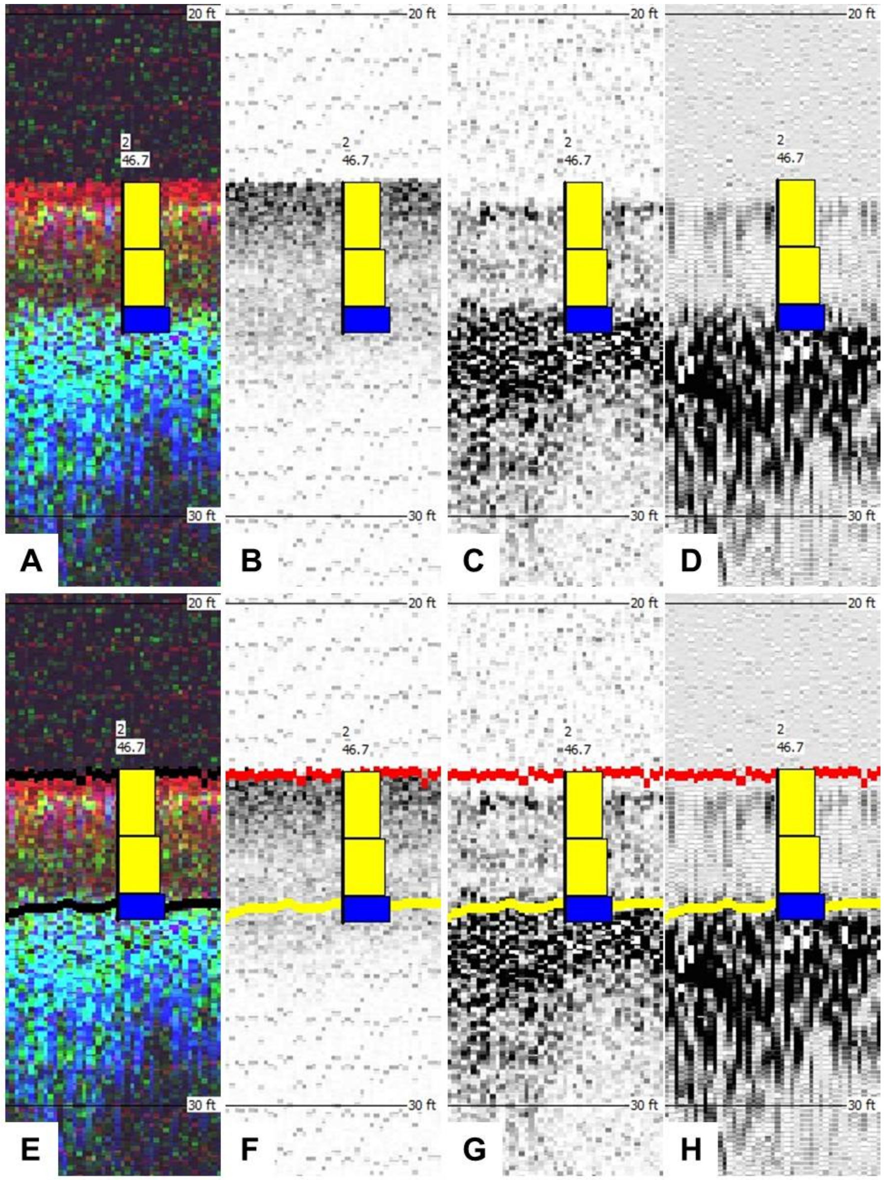

Figure 8. Comparison of sediment core G-2 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 208 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 8 compares sediment core sample G-2 with the acoustic signals for all frequencies combined (A, E), 208 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 208 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 pre-impoundment surface was found to match the bottom of the 208 kHz signal where the 208 kHz signal was strong, but matched the

50 kHz signal where the 208 kHz signal was weak. The pre-impoundment boundary was also visible in the colored display representing all three frequencies. 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 G-2 correlated with the 208 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.

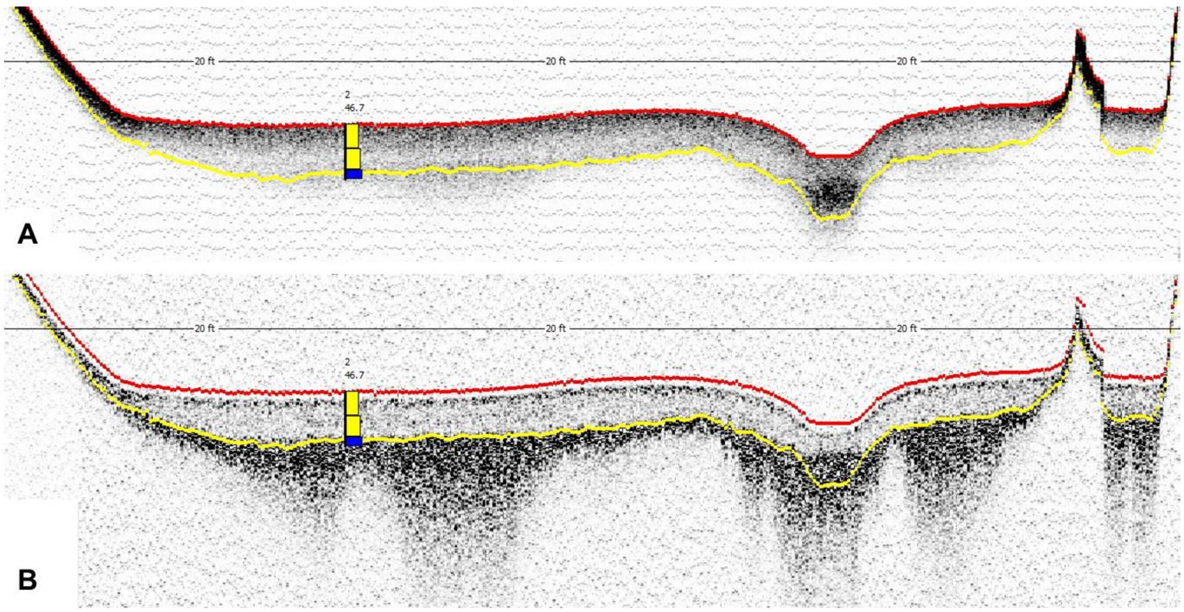

Figure 9. Cross-section of data collected during 2013 survey, displayed in DepthPic© A) 208 kHz frequency, B) 50 kHz frequency, correlated with sediment core sample G-2 and showing the current surface in red and pre-impoundment surface in yellow

After the pre-impoundment surface from all cross-sections was identified, a sediment thickness TIN model was 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 the sediment thickness at the reservoir boundary was zero feet (defined as the 504.0 foot NGVD29 elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 2 feet by 2 feet and used to produce a sediment thickness map of Granger Lake (Figure 10).

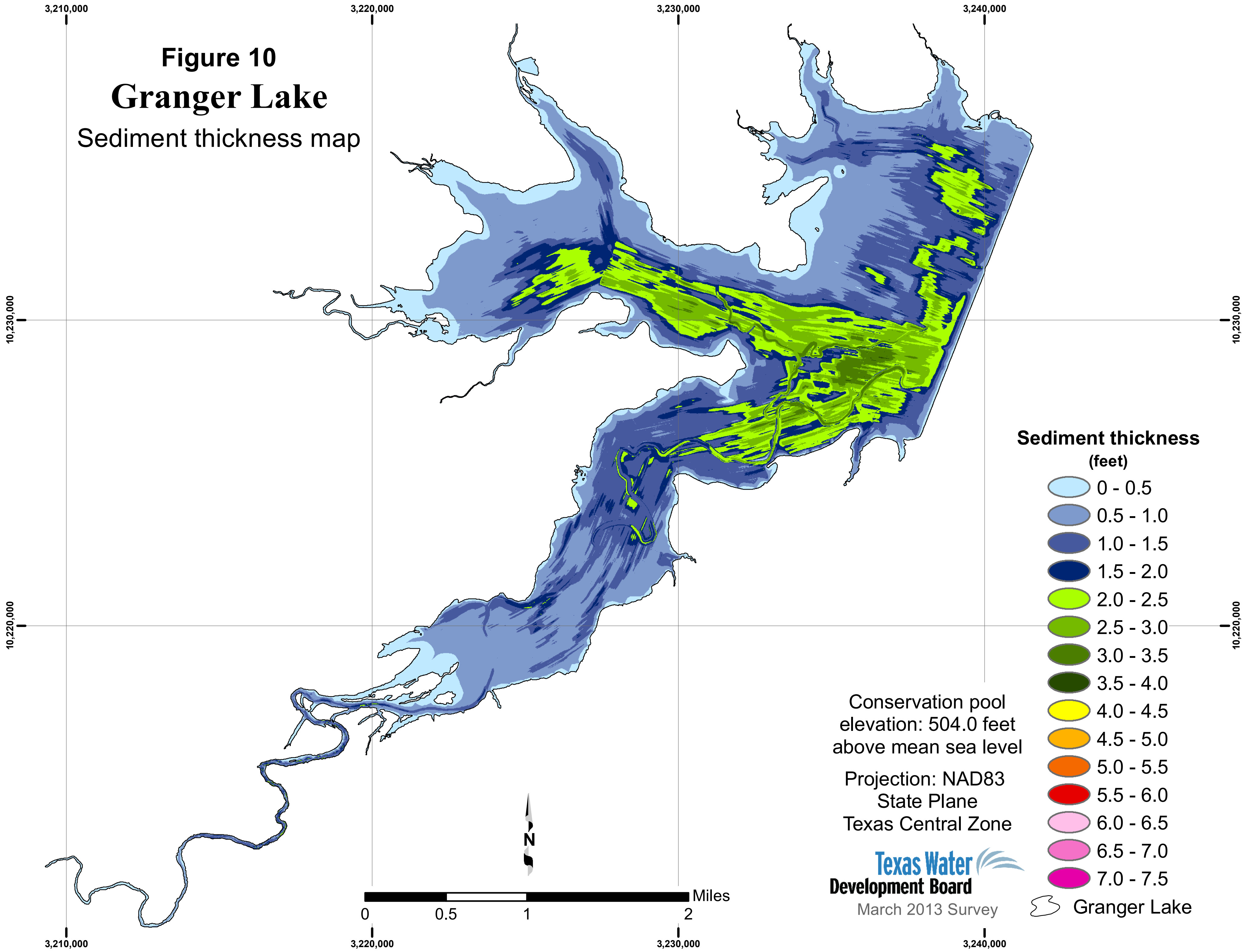

Figure 10
Granger Lake
Sediment thickness map

Survey results

Volumetric survey

The results of the 2013 TWDB volumetric survey indicate Granger Lake has a total reservoir capacity of 51,822 acre-feet and encompasses 4,159 acres at conservation pool elevation (504.0 feet above mean sea level, NGVD29). The original design estimate by the U.S. Army Corps of Engineers indicates Granger Lake encompassed 4,400 acres with a total reservoir capacity of 65,510 acre-feet. 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 1995, 2002, and 2008. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 1995, 2002, and 2008 using the same interpolation definition file as was used for the 2013 survey, with minor edits to account for differences in data coverage and boundary conditions. The 1995 survey boundary was digitized from the 504.0-foot contour from 7.5 minute USGS quadrangle maps: Granger Lake-1963 (Photo-Revised 1988) and Granger-1964 (Photo-Revised 1988), with a stated accuracy of ± ½ the contour interval (USBB, 1947). The 2002 survey boundary was digitized from aerial photographs taken on January 23, 1995, while the water surface elevation of the reservoir measured 504.18 feet above mean sea level. The boundary was assigned an elevation of 504.2 feet for modeling purposes. The 2008 survey boundary was re-digitized from the aerial photographs taken on January 23, 1995, while the water surface elevation of the reservoir measured 504.18 feet above mean sea level. The 2008 boundary was assigned an elevation of 504.0 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. Re-evaluation of the 1995, 2002, and 2008 surveys resulted in a 1.0 percent, 1.4 percent and 0.9 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)
Original[a]	4,400	65,510
TWDB 1995[b]	4,009	54,280
TWDB 1995 (re-calculated)	4,009	54,834
TWDB 2002[c]	4,064	52,525
TWDB 2002 (re-calculated)	4,145	53,244
Texas AgriLife Research 2007[d]	4,075	51,144
TWDB 2008[e]	4,203	50,779
TWDB 2008 (re-calculated)	4,203	51,241
Texas AgriLife Research 2010[d]	3,820	49,971
TWDB 2013	4,159	51,822

[a] Source: (TWDB, 1973)
[b] Source: (TWDB, 1995)
[c] Source: (TWDB, 2003)
[d] Source: (McAlister, 2010, BRA, 2011)
[e] Source: (TWDB, 2009)

Sedimentation survey

The 2013 TWDB sedimentation survey estimates Granger Lake to have an average loss of capacity of 152 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (504.0 feet above mean sea level, NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. The heaviest accumulations measured are northwest of Wilson H. Fox Park towards the south end of the dam and approximately one half mile west of the dam. Sediment is greater in the Willis Creek branch of the lake than the San Gabriel River branch. Comparison of TWDB capacity estimates of Granger Lake are provided in Table 4 for sedimentation rate calculation

The 2013 TWDB sedimentation survey indicates the total pre-impoundment capacity of Granger Lake was 56,828 acre-feet. The 2013 sedimentation survey represents the third sedimentation survey completed on Granger Lake. TWDB previously completed a sedimentation survey in 2008 and the Texas A&M Blackland Research Center completed a sedimentation survey in 2007. After applying AEIDW interpolation to the 2008 data, the re-calculated pre-impoundment capacity of Granger Lake was 57,383 acre-feet. The Blackland Research Center estimated the pre-impoundment capacity at 56,189 acre-feet (McAlister, 2010). Differences between the three estimates are within approximately 1-2 percent. This indicates that the original estimate of 65,510 acre-feet may have overestimated of the capacity of Granger Lake. The method of calculating this value is unknown; therefore several attempts were made to reproduce it using topographic data that was likely available at the time the original estimate was made. This includes USGS 7.5 minute quadrangle maps.

In 2008, the hypsography, or vector format of USGS 7.5 minute quadrangle map contours, were used to: 1) generate a TIN model from which capacity was calculated, and 2) apply the average-area method to the contour areas computed in MATLAB. These methods resulted in capacity estimates between 61,000 and 62,000 acre-feet (TWDB, 2009). This effort was repeated in this study. In 2014, a new boundary was digitized from the scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics) titled Granger Lake, Tex. and Granger, Tex. dated 1963 (photo-revised in 1988) and 1964 (photo-revised in 1988), respectively. The digitized USGS boundary encompassed 4,188 acres, 4.8% less than the U.S. Army Corps of Engineers original estimate. The areas of the USGS boundary and contour polygons as calculated in ArcGIS were used to linearly interpolate the areas in between at 0.1-foot increments and the corresponding capacities were calculated using the formula:

$$Capacity_1 = Capacity_0 + \left(\frac{Area_0 + Area_1}{2}\right) \times (Elevation_1 - Elevation_0)$$

The resulting total capacity estimate was 58,699 acre-feet. This further confirms that the original volume may have been over estimated.

Table 4. Capacity loss comparisons for Granger Lake

Survey	Volume comparisons at conservation pool elevation (acre-feet)			Pre-impoundment (acre-feet)
TWDB 1995 (re-calculated)	54,834	<>	<>	<>
TWDB 2002 (re-calculated)	<>	53,244	<>	<>
TWDB 2008 (re-calculated)	<>	<>	51,241	<>
TWDB pre-impoundment estimate based on 2013 survey	<>	<>	<>	56,828[b]
2013 volumetric survey	51,822	51,822	51,822	51,822
Volume difference (acre-feet)	3,012 (5.5%)	1,422 (2.7%)	-581 (-1.1%)	5,006 (8.8%)
Number of years	18	11	5	33[a]
Capacity loss rate (acre-feet/year)	167	129	-116	152

Note: Construction on Granger Dam began on October 24, 1972 and deliberate impoundment began on January 21, 1980

[a] Number of years based on difference between 2013 survey date and deliberate impoundment date of 1980

[b] 2013 TWDB surveyed capacity of 51,822 acre-feet plus 2013 TWDB surveyed sediment volume of 5,006 acre-feet

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Granger Lake in approximately 5 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 Granger Lake.

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:

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Appendix A

Granger Lake

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — March 2013 SURVEY

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 504.0 Feet NGVD 29

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
467	0	0	0	0	0	0	0	0	0	0
468	0	1	1	1	1	1	1	2	2	2
469	2	3	3	3	4	4	4	5	5	6
470	7	8	9	11	13	15	17	20	22	26
471	29	33	37	41	46	52	58	64	71	78
472	85	93	102	110	119	128	137	147	158	169
473	181	193	205	218	231	245	258	272	287	301
474	316	332	348	364	381	399	416	434	453	471
475	490	510	529	549	570	590	611	632	653	675
476	697	719	742	766	790	814	839	865	891	917
477	944	972	1,001	1,030	1,061	1,091	1,123	1,155	1,188	1,222
478	1,256	1,292	1,328	1,364	1,402	1,440	1,479	1,519	1,560	1,601
479	1,644	1,687	1,731	1,777	1,823	1,870	1,918	1,967	2,017	2,068
480	2,121	2,175	2,230	2,287	2,344	2,404	2,465	2,527	2,590	2,655
481	2,721	2,789	2,857	2,927	2,998	3,071	3,145	3,220	3,296	3,373
482	3,452	3,531	3,612	3,693	3,775	3,858	3,942	4,027	4,113	4,200
483	4,288	4,376	4,466	4,557	4,649	4,742	4,835	4,929	5,024	5,120
484	5,217	5,315	5,413	5,512	5,613	5,714	5,816	5,919	6,024	6,129
485	6,236	6,343	6,452	6,562	6,672	6,784	6,897	7,011	7,126	7,242
486	7,359	7,477	7,597	7,717	7,839	7,962	8,085	8,210	8,336	8,464
487	8,592	8,721	8,852	8,984	9,117	9,251	9,386	9,522	9,659	9,798
488	9,937	10,078	10,220	10,363	10,506	10,651	10,797	10,944	11,092	11,241
489	11,391	11,543	11,695	11,850	12,005	12,162	12,320	12,480	12,640	12,802
490	12,966	13,130	13,296	13,463	13,630	13,799	13,970	14,141	14,313	14,486
491	14,661	14,837	15,014	15,192	15,372	15,553	15,735	15,918	16,103	16,290
492	16,477	16,666	16,857	17,048	17,242	17,436	17,632	17,830	18,029	18,229
493	18,431	18,634	18,839	19,045	19,253	19,461	19,672	19,884	20,097	20,312
494	20,528	20,745	20,964	21,185	21,407	21,631	21,857	22,085	22,314	22,545
495	22,778	23,013	23,249	23,487	23,727	23,969	24,212	24,458	24,706	24,956
496	25,208	25,462	25,719	25,977	26,237	26,499	26,762	27,028	27,295	27,564
497	27,836	28,109	28,385	28,662	28,942	29,224	29,509	29,795	30,083	30,373
498	30,665	30,959	31,255	31,553	31,853	32,155	32,459	32,765	33,073	33,383
499	33,695	34,010	34,327	34,646	34,967	35,291	35,617	35,945	36,274	36,606
500	36,940	37,276	37,614	37,954	38,296	38,639	38,985	39,333	39,683	40,035
501	40,389	40,744	41,102	41,461	41,822	42,185	42,549	42,915	43,282	43,651
502	44,022	44,394	44,769	45,144	45,522	45,901	46,283	46,666	47,050	47,437
503	47,825	48,216	48,608	49,002	49,399	49,797	50,197	50,600	51,005	51,412
504	51,822									

Appendix B

Granger Lake

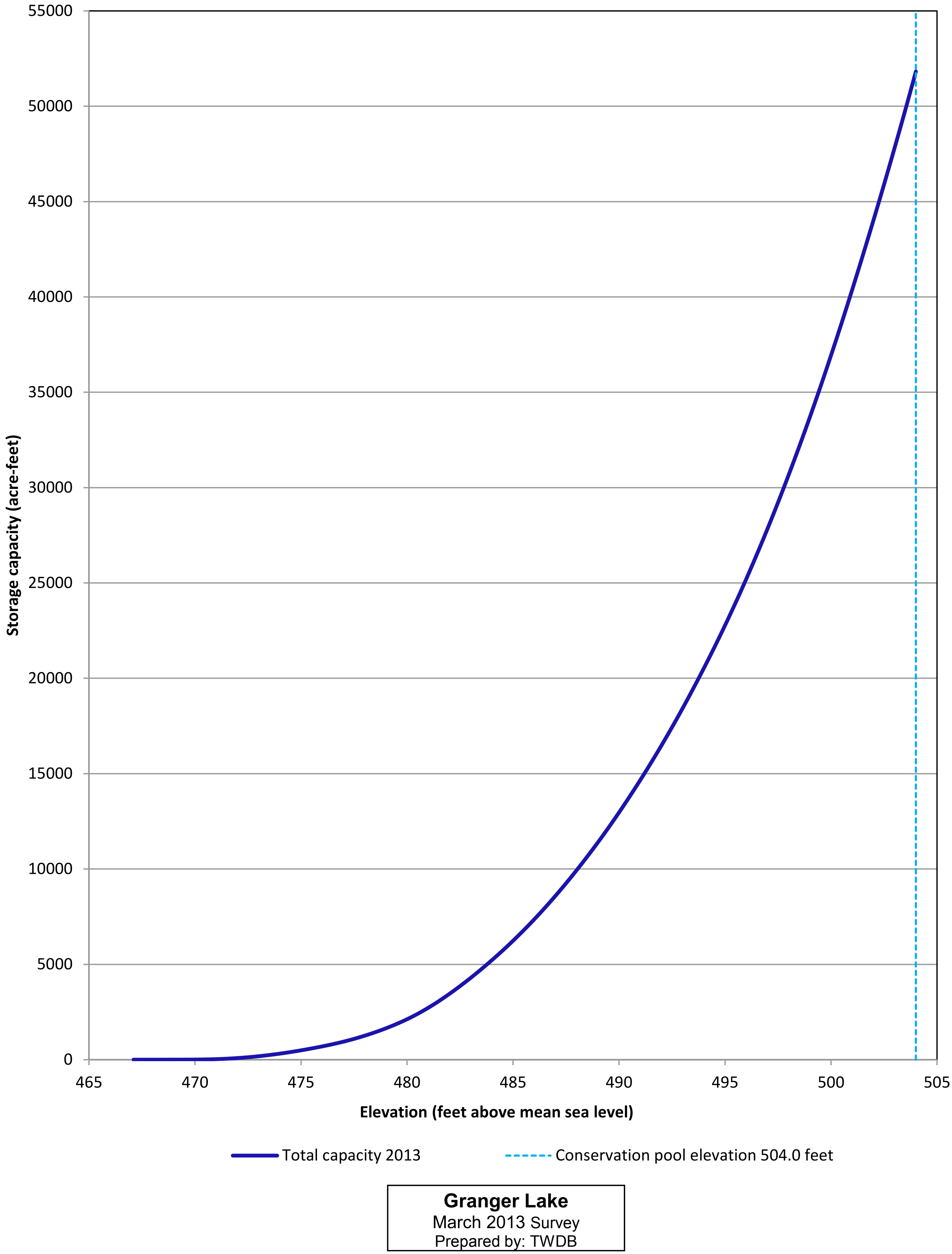
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD | March 2013 SURVEY

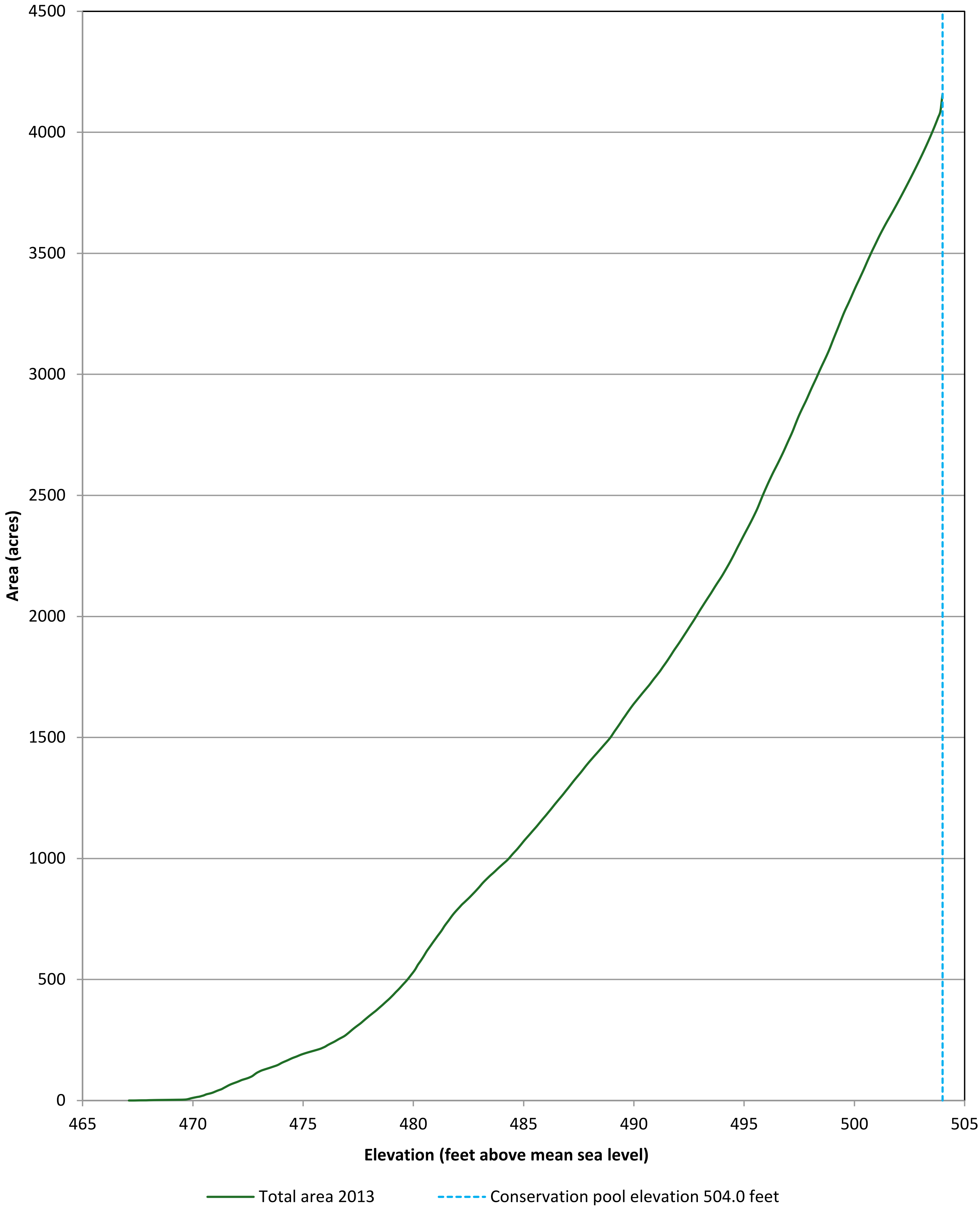
AREA IN ACRES | Conservation Pool Elevation 504.0 Feet NGVD 29

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
467	0	0	0	0	0	0	1	1	1	1
468	1	1	2	2	2	2	2	2	2	3
469	3	3	3	3	3	3	4	4	6	9
470	11	13	15	16	19	21	25	27	30	32
471	36	40	43	47	52	57	62	66	70	73
472	76	80	84	87	90	93	97	101	108	114
473	119	123	127	130	132	135	139	142	145	149
474	154	158	162	166	171	175	178	182	185	189
475	192	195	198	201	203	206	209	211	214	218
476	222	228	233	238	242	247	253	258	262	268
477	275	282	290	298	305	312	318	326	334	342
478	349	356	364	371	379	387	395	403	411	419
479	428	438	447	456	466	476	486	496	507	519
480	531	544	560	573	586	601	616	629	642	655
481	667	680	692	705	719	732	744	757	769	779
482	789	799	809	818	826	835	844	854	863	873
483	883	894	904	913	922	930	938	947	955	964
484	972	980	988	997	1,007	1,018	1,028	1,038	1,048	1,059
485	1,071	1,081	1,092	1,102	1,113	1,123	1,133	1,144	1,156	1,166
486	1,177	1,188	1,199	1,210	1,222	1,233	1,244	1,255	1,266	1,277
487	1,289	1,300	1,312	1,323	1,335	1,345	1,356	1,368	1,380	1,391
488	1,402	1,412	1,423	1,433	1,443	1,453	1,464	1,474	1,485	1,496
489	1,508	1,522	1,535	1,548	1,561	1,575	1,588	1,602	1,615	1,627
490	1,639	1,650	1,662	1,673	1,684	1,695	1,706	1,717	1,729	1,741
491	1,752	1,764	1,776	1,789	1,802	1,815	1,829	1,843	1,857	1,870
492	1,883	1,897	1,911	1,925	1,939	1,953	1,967	1,981	1,996	2,011
493	2,026	2,040	2,055	2,069	2,083	2,096	2,111	2,126	2,140	2,154
494	2,168	2,183	2,199	2,215	2,231	2,249	2,267	2,285	2,302	2,320
495	2,337	2,355	2,372	2,389	2,407	2,426	2,446	2,468	2,490	2,512
496	2,532	2,553	2,572	2,591	2,609	2,627	2,645	2,664	2,684	2,704
497	2,724	2,744	2,765	2,788	2,811	2,833	2,852	2,871	2,890	2,910
498	2,931	2,951	2,970	2,990	3,011	3,031	3,050	3,069	3,089	3,111
499	3,134	3,157	3,180	3,202	3,225	3,248	3,269	3,288	3,308	3,329
500	3,349	3,370	3,388	3,408	3,428	3,449	3,470	3,490	3,509	3,528
501	3,547	3,566	3,584	3,601	3,618	3,634	3,650	3,666	3,682	3,699
502	3,716	3,733	3,750	3,767	3,785	3,802	3,820	3,838	3,857	3,875
503	3,894	3,913	3,933	3,953	3,973	3,994	4,016	4,038	4,062	4,086
504	4,159									



Appendix C: Capacity curve



Granger Lake
March 2013 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

CONTOURS
(feet)

- 500
- 495
- 490
- 485
- 480
- 475
- 470
- Islands
- Granger Lake

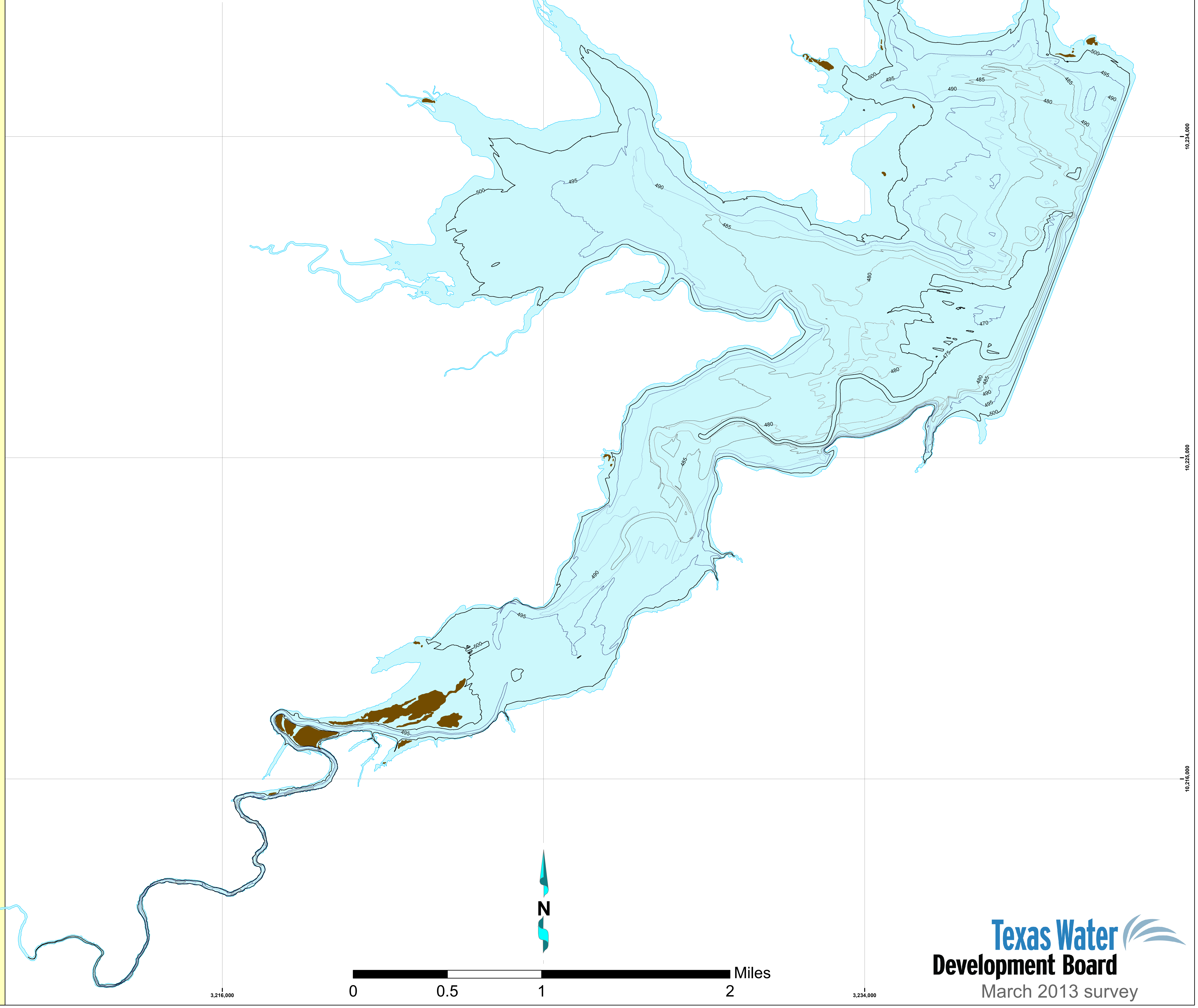
Conservation Pool Elevation
504.0 feet NGVD29

Projection: NAD83
State Plane
Texas Central Zone

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Granger Lake. The Texas Water Development Board makes no representations nor assumes any liability.

Granger Lake

5' - contour map



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March 2013 survey