Volumetric and Sedimentation Survey of B.A. STEINHAGEN LAKE

October 2011 Survey

Texas Water Development Board

August 2014

Prepared for:

Lower Neches Valley Authority

With Support Provided by:

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

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Published and distributed by the

Texas Water Development Board

P.O. Box 13231, Austin, TX 78711-3231

Executive summary

In October 2011, 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 B.A. Steinhagen Lake. The U.S. Army Corps of Engineers, Fort Worth District, provided 100% of the funding for this survey 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.

Town Bluff Dam and B.A. Steinhagen Lake are located on the Neches River in Tyler and Jasper Counties, one half mile north of Town Bluff, Texas. The conservation pool elevation of B.A. Steinhagen Lake is 83.0 feet above mean sea level (NGVD29). TWDB collected bathymetric data for B.A. Steinhagen Lake between October 20, 2011, and October 30, 2011. Additional data was collected on May 9, 2012. The daily average water surface elevations during October 2011 ranged between 81.58 and 81.94 feet above mean sea level (NGVD29). The daily average water surface elevation on May 9, 2012, was 82.53 feet above mean sea level (NGVD29).

The 2011 TWDB volumetric survey indicates that B.A. Steinhagen Lake has a total reservoir capacity of 69,259 acre-feet and encompasses 10,235 acres at conservation pool elevation (83.0 feet above mean sea level, NGVD29). Previous capacity estimates include multiple surveys conducted by the U.S. Army Corps of Engineers in 1947, 1951, and 1960. These indicate B.A. Steinhagen Lake's total capacity was 94,200 acre-feet, 100,595 acre-feet, and 101,814 acre-feet, respectively. A TWDB volumetric survey conducted in 2003 was re-evaluated using current processing procedures that resulted in an updated capacity estimate of 70,078 acre-feet.

Based on two methods for estimating sedimentation rates, the 2011 TWDB sedimentation survey estimates B.A. Steinhagen Lake to have an average loss of capacity between 522 and 181 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (83.0 feet NGVD29). Sediment accumulation varies throughout the reservoir. North of U.S. Highway 190, sediment accumulation is greatest in the Angelina and Neches River channels. South of U.S. Highway 190, the greatest accumulations of sediment are in the Sandy Creek River arm of the reservoir and within approximately one half mile north of the eastern half of the dam. TWDB recommends that a similar methodology be used to resurvey B.A. Steinhagen Lake in 10 years or after a major flood event.

Table of Contents

List of Tables

List of Figures

Appendices

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, TWDB entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of B.A. Steinhagen Lake. The U.S. Army Corps of Engineers, Fort Worth District, provided 100% of the funding for this survey through their Texas Water Allocation Assessment Program (TWDB, 2011). 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 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].

B.A. Steinhagen Lake general information

Town Bluff Dam and B.A. Steinhagen Lake are located on the Neches River in Tyler and Jasper Counties, one half mile north of Town Bluff, Texas and 14 miles west of Jasper, Texas (Figure 1). Town Bluff Dam and B.A. Steinhagen Lake are owned by the United States Government and operated by the U.S. Army Corps of Engineers, Fort Worth District. Construction on Town Bluff Dam began in March 1947, and deliberate impoundment began on April 16, 1951 (TWDB, 1974). Town Bluff Dam was completed in June, 1953 (USACE, 2014a).

Town Bluff Dam and B.A. Steinhagen Lake were built primarily for flood control of the Angelina and Neches River basins in tandem with Sam Rayburn Reservoir (USACE, 2014b). B.A. Steinhagen Lake is also used to reregulate intermittent releases from Sam Rayburn Reservoir due to the production of hydro-electric power (USACE, 2014a). B.A. Steinhagen Lake and Sam Rayburn Reservoir are operated as a system to supply water to the Lower Neches Valley Authority and the Beaumont area (USACE, 2014b). The Lower Neches Valley Authority, created by the State Legislature in 1933, is responsible for conserving, storing, controlling, preserving, utilizing, and distributing the waters of the basin, benefiting residents of Tyler, Hardin, Liberty, Chambers, and Jefferson Counties that are also within the Neches River Basin and Neches-Trinity Coastal Basin (LNVA, 2014). B.A. Steinhagen Lake also supports hydro-electric power generation and recreation (USACE, 2014b). Construction on the Robert D. Willis Hydropower Project began in March 1987 and began commercial operation on November 17, 1989 (USACE, 2014a). Power is supplied to customers in the cities of Jasper, Liberty, and Livingston, Texas and Vinton, Louisiana by the Sam Rayburn Municipal Power Agency (USACE, 2014a). Additional pertinent data about Town Bluff Dam and B.A. Steinhagen Lake can be found in Table 1.

Water rights for B.A. Steinhagen Lake have been appropriated to the Lower Neches Valley Authority through Certificate of Adjudication No. 06-4411 and amendments to Certificate of Adjudication Nos. 06-4411A-D, and 06-4411F-I. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

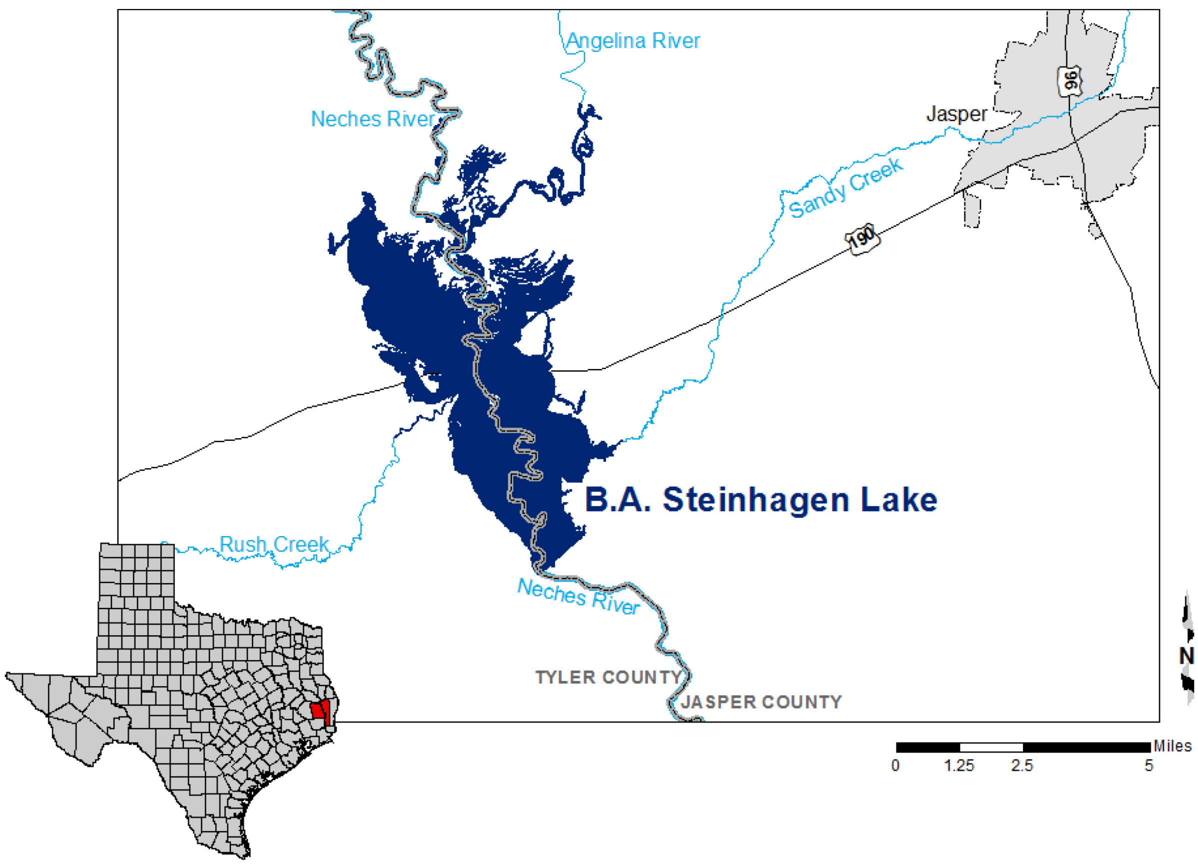


Figure 1. **Location of B.A. Steinhagen Lake**

Table 1. Pertinent data for Town Bluff Dam and B.A. Steinhagen Lake

Owner
U.S. Government, operated by the U.S. Army Corps of Engineers, Fort Worth District
Engineer (design)
U.S. Army Corps of Engineers, Fort Worth District
Location of dam
On the Neches River in Tyler and Jasper Counties, one half mile north of Town Bluff, Texas and 14 miles west of Jasper, Texas on U.S. 190
Drainage area
7,573 square miles

Dam	
Type	Paved earthfill
Length (including spillway)	6,698 feet
Maximum height	45 feet
Top width	25 feet
Spillway (gated)	
Type	Ogee concrete slab
Crest elevation	50.0 feet above mean sea level
Length (net)	240 feet
Control	6 tainter gates, each 40 by 35 feet
Location	Right end of dam
Spillway (uncontrolled section of dam)	
Crest elevation	85.0 feet above mean sea level
Length	6,100 feet
Outlet works	
Type	2 conduits, each 4 by 6 feet in right abutment of spillway
Invert elevation	52.0 feet above mean sea level
Control	2 tractor-type gates

Reservoir data (Based on 2011 TWDB survey)

Feature	Elevation (feet NGVD29[a])	Capacity (acre-feet)	Area (acres)
Top of dam (non-overflow)	95.0	N/A	N/A
Maximum design water surface	93.0	N/A	N/A
Top of gates and uncontrolled spillway	85.0	N/A	N/A
Conservation pool elevation	83.0	69,259	10,235
Invert of low-flow outlet	52.0	73	24
Gate sill	50.0	38	13
Usable conservation storage space[b]	-	69,186	-

Source: (TWDB, 1974, TPWD, 2012, USACE, 2014c)
[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 B.A. Steinhagen 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 08040000 B.A. Steinhagen Lk at Town Bluff, TX* (USGS, 2012). Elevations herein are reported in feet above mean sea level 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 B.A. Steinhagen Lake between October 20, 2011 and October 30, 2011, and on May 9, 2012. The daily average water surface elevations during October ranged between 81.58 and 81.94 feet above mean sea level (NGVD29). The daily average water surface elevation on May 9, 2012, was 82.53 feet above mean sea level (NGVD29). 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 were also used by TWDB during the 2003 survey. 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 2011 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 January 31, 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, 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.

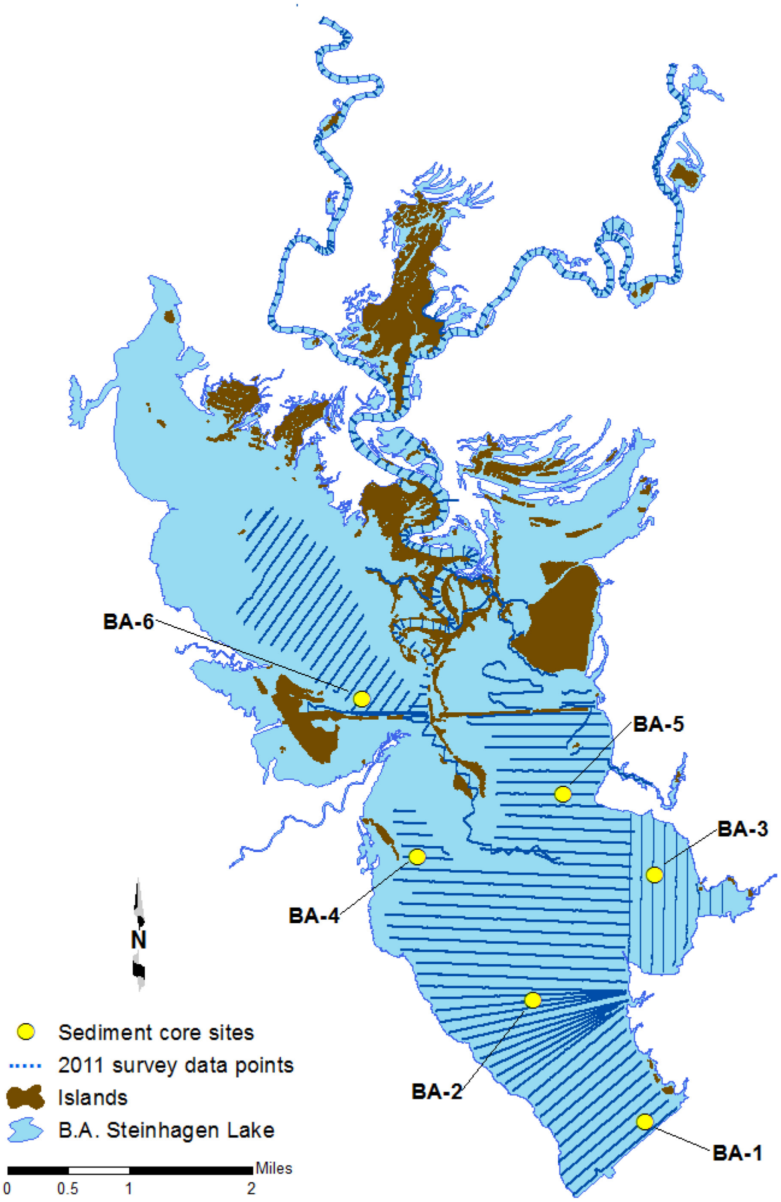


Figure 2. Data collected during 2011 TWDB B.A. Steinhagen Lake survey

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 B.A. Steinhagen Lake are Town Bluff (NW, NE, SW, SE) and Pace Hill (SW, SE). The DOQQs were photographed on July 30, 2012, while the daily average water surface elevation measured 82.58 feet above mean sea level. According to metadata associated with the 2012 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, 2012, USDA, 2013). Due to the abundance of aquatic vegetation, such as hyacinth, American lotus, common salvinia, and alligatorweed (TPWD, 2010), the land-water interface was nearly impossible to identify in the photographs; therefore, the boundary was digitized at the perceived land-water interface and assigned an elevation of 83.0 feet above mean sea level 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., was 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, was 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 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 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 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 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 B.A. Steinhagen Lake in the following situations: in small coves of the main body of the lake; and throughout areas that were inaccessible in 2011 by following obvious channel features indicated by the 2003 TWDB survey, or visible in aerial photographs taken on July 30, 2012 (daily average water surface elevation: 82.58 feet).

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

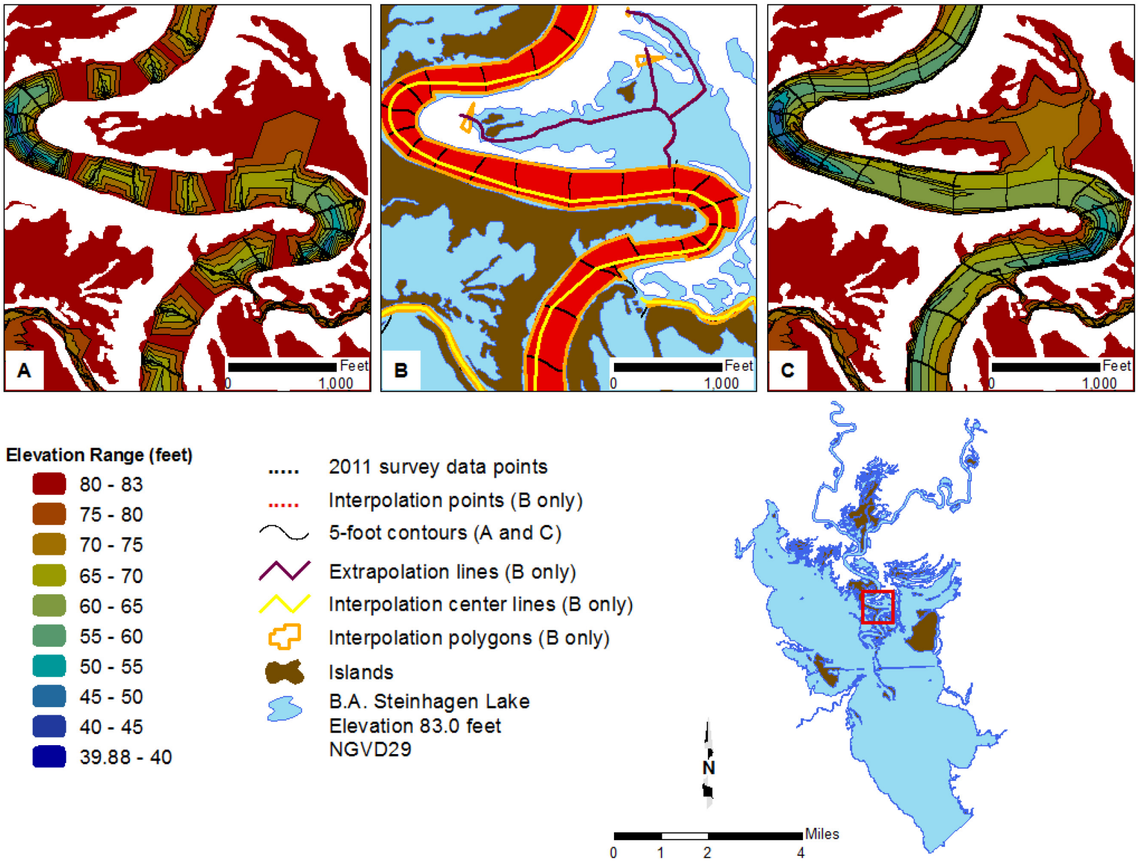


Figure 3. **Anisotropic spatial interpolation and linear extrapolation of B.A. Steinhagen Lake sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

Area, volume, and contour calculation

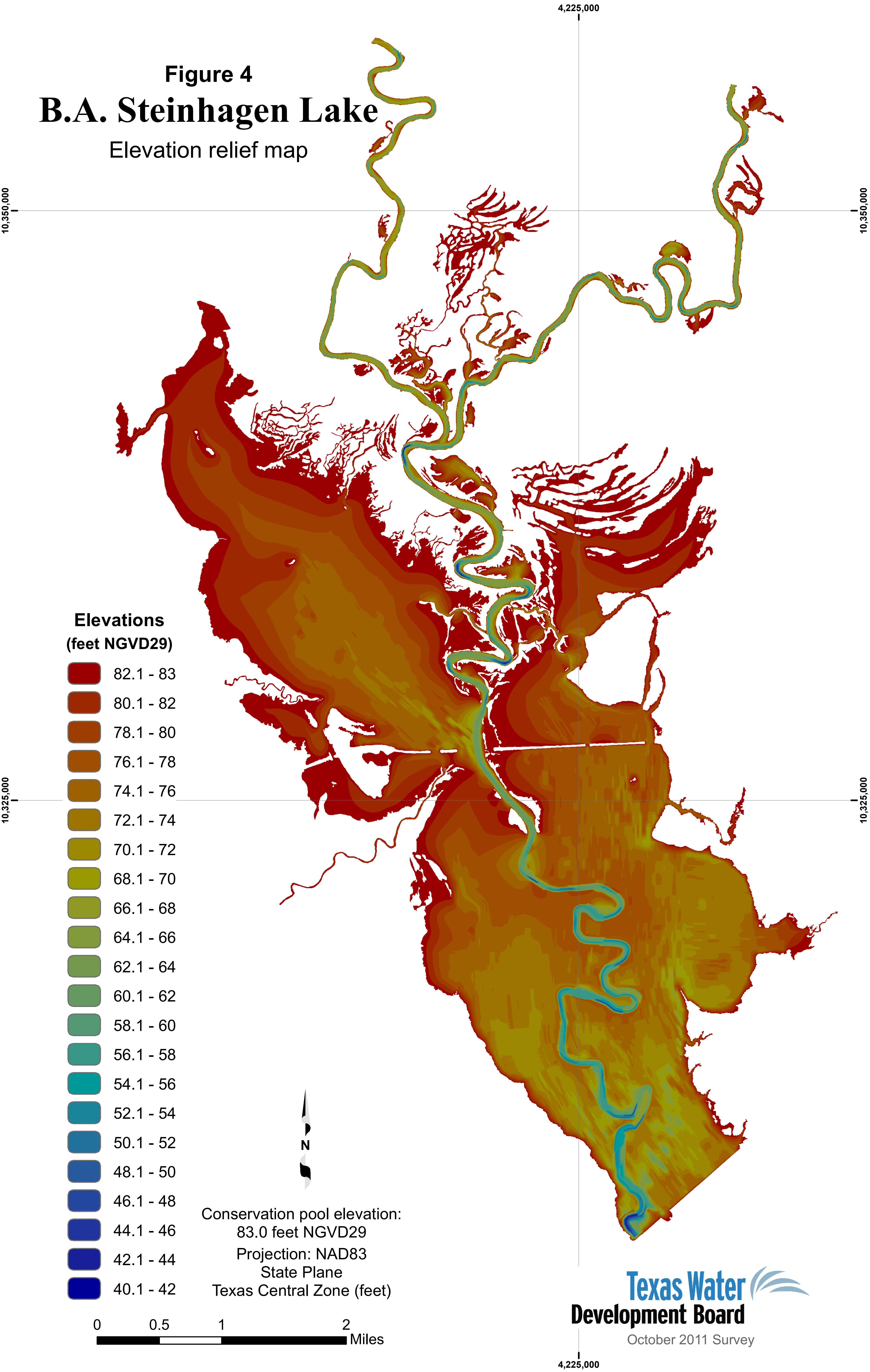
Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1-foot intervals, from 39.8 to 83.0 feet. Due to a lack of data between elevations 78.0 (the approximate upper limit of survey data collected in the main body of the lake in 2011) and 83.0 feet (conservation pool elevation), the TIN models developed in these areas led to the creation of anomalous “flat triangles”, that is triangles whose three vertices all have the same elevation. The flat triangles in turn lead to anomalous calculations of surface area and volume at the boundary elevation, 83.0 feet. To eliminate the effects of the flat triangles on area and volume calculations, areas between elevations 78.0 feet and 83.0 feet were linearly interpolated between the computed values. Volumes above 78.0 feet in elevation were calculated based on the corrected areas. The elevation-capacity table and elevation-area table, updated for 2011, 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 B.A. Steinhagen Lake; and a 5-foot contour map (Figure 6 - attached).

Figure 4

B.A. Steinhagen Lake

Elevation relief map



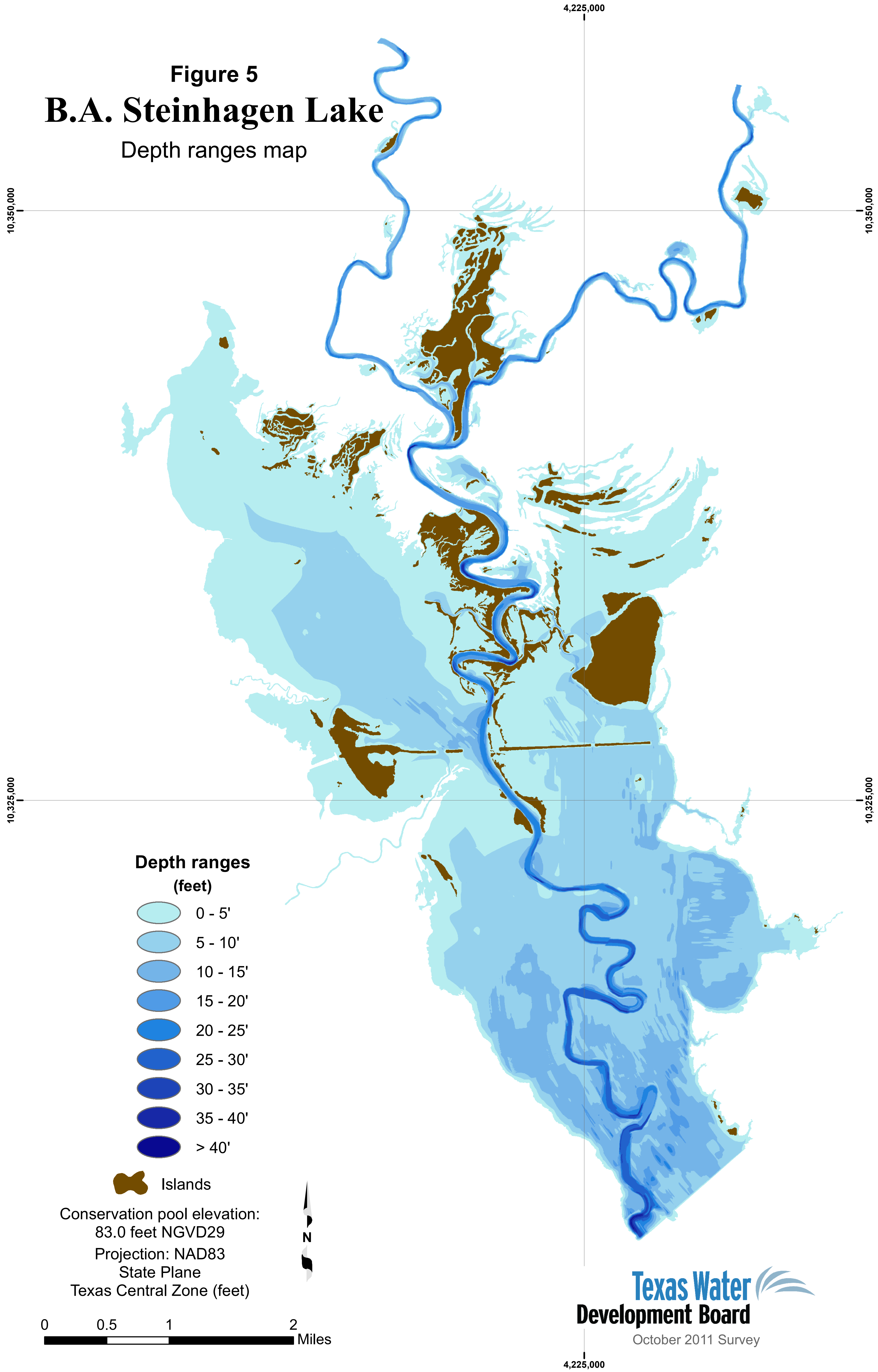


Figure 5
B.A. Steinhagen Lake
Depth ranges map
4,225,000
10,350,000
10,350,000
10,325,000
10,325,000
Depth ranges
(feet)
0 - 5'
5 - 10'
10 - 15'
15 - 20'
20 - 25'
25 - 30'
30 - 35'
35 - 40'
> 40'
Islands
Conservation pool elevation:
83.0 feet NGVD29
Projection: NAD83
State Plane
Texas Central Zone (feet)
N
0
0.5
1
2
Miles
Texas Water
Development Board
October 2011 Survey
4,225,000

Analysis of sediment data from B.A. Steinhagen Lake

Sedimentation in B.A. Steinhagen 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 - B.A. Steinhagen Lake

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
BA-1	4230262.80	10309585.84	34.5"/ 29"	0-1.5" very loose sediment	10YR 4/4
				1.5-19" dense sediment	5Y 4/1
				19-29" dense sediment with organics present	5Y 3/1
				29-34.5" very dense soil, organics present, clay soil	7.5YR 3/1
BA-2	4225468.20	10314823.06	29"/27"	0-1.5" very loose sediment	10YR 4/4
				1.5-27" dense sediment	10 YR 3/1
				27-29" very dense sediment, roots present, organics present	10YR 3/1
BA-3	4230677.06	10320244.19	58.75"/20"	0-0.5" very loose sediment	10YR 4/4
				0.5-20" loose sediment, clay soil	10YR 3/1
				20-51" dense sediment, sandy clay	2.5YR 5/1
				51-58.75" very dense sandy soil	2.5YR 5/1
BA-4	4220458.60	10321044.14	22"/12.5"	0-2" very loose sediment	10YR 4/4
				2-8" medium dense sediment, sandy soil	10YR 4/2
				8-12.5" dense soil	10YR 4/1
				12.5-22" very dense soil	10YR 4/1
BA-5	4226719.78	10323757.66	11"/4.5"	0-3" very loose sediment with sand	10YR 4/4
				3-4.5" dense sediment, sandy clay	10YR 4/6
				4.5-11" very dense soil, sandy clay	10YR 3/4
BA-6	4218025.53	10327845.38	22.75"/17"	0-3" very loose sediment	10YR 4/4
				3-8.5" dense sediment, clay present	10YR 4/1
				8.5-17" dense sediment, organics and roots present	10YR 4/4
				17-22.75" very dense sediment, clay soil	10YR 4/1

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

A photograph of sediment core BA-1 is shown in Figure 7 and is representative of the sediment cores sampled from B.A. Steinhagen Lake. The 208 kHz frequency measures the top layer as the current bottom surface of the reservoir.

Figure 7. Sediment core BA-1 from B.A. Steinhagen Lake

Sediment core sample BA-1 consisted of 34.5 inches of total sediment. The upper sediment layer (horizon), 0–1.5 inches, consisted of loose sediment and measured 10YR 4/4 on the Munsell soil color chart. The second horizon, beginning at 1.5 inches and extending to 19.0 inches below the surface, consisted of dense sediment and measured 5Y 4/1 on the Munsell soil color chart. The third horizon, beginning at 19.0 inches and extending to 29 inches below the surface, consisted of a dense sediment with organics present and a 5Y 3/1 Munsell soil color. The fourth horizon, from 29 inches to the base of the core at 34.5 inches, consisted of a very dense clay soil with organics present and a Munsell soil color of 7.5YR 3/1. 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 29.0 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.

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.

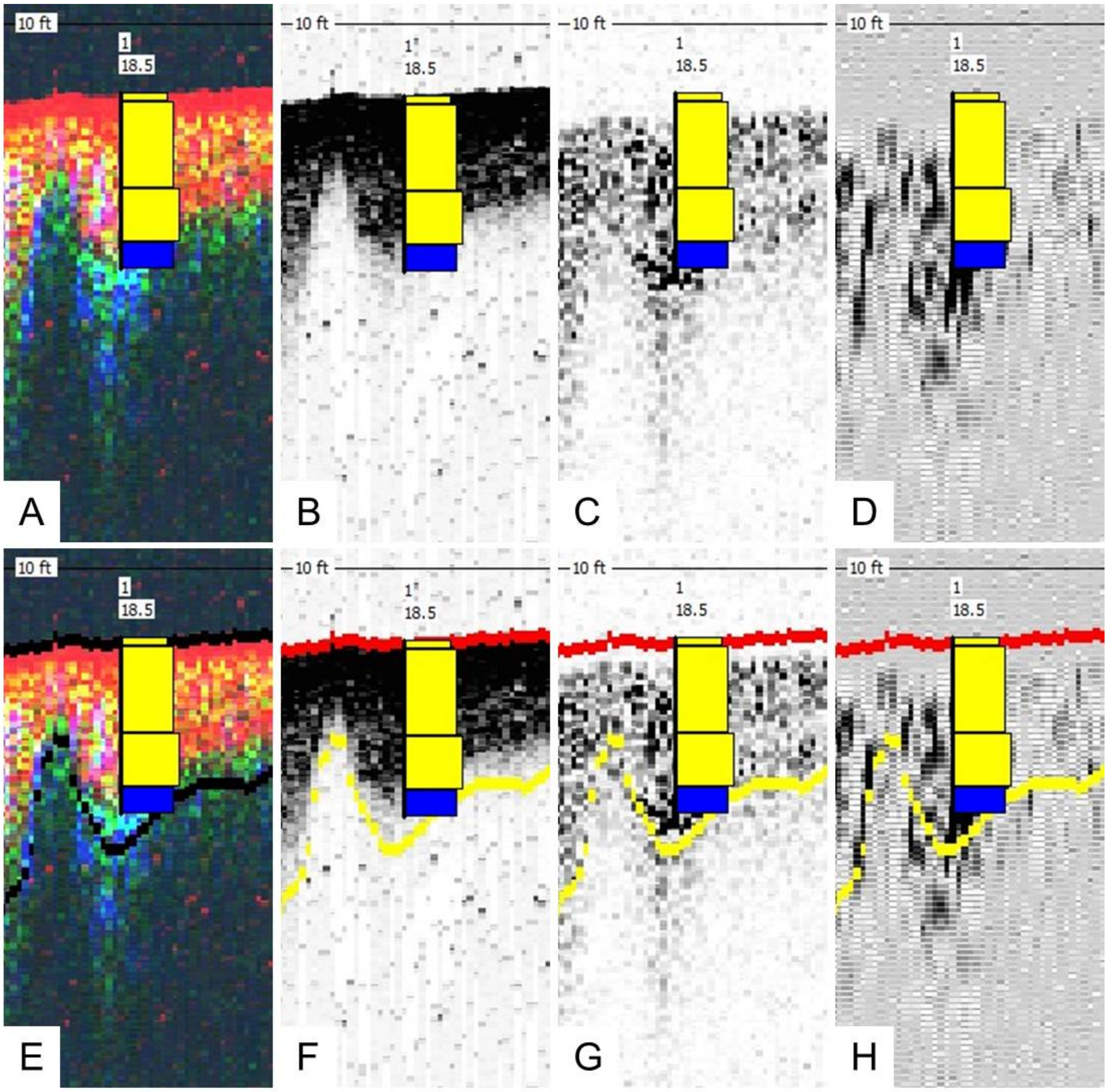


Figure 8. **Comparison of sediment core BA-1 with acoustic signal returns: A,E) combined acoustic signal returns, B,F) 208 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency**

Figure 8 compares sediment core sample BA-1 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 boundary in the 208 kHz signal most closely matched the pre-impoundment interface of the sediment core samples; therefore, the 208 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 BA-1 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.

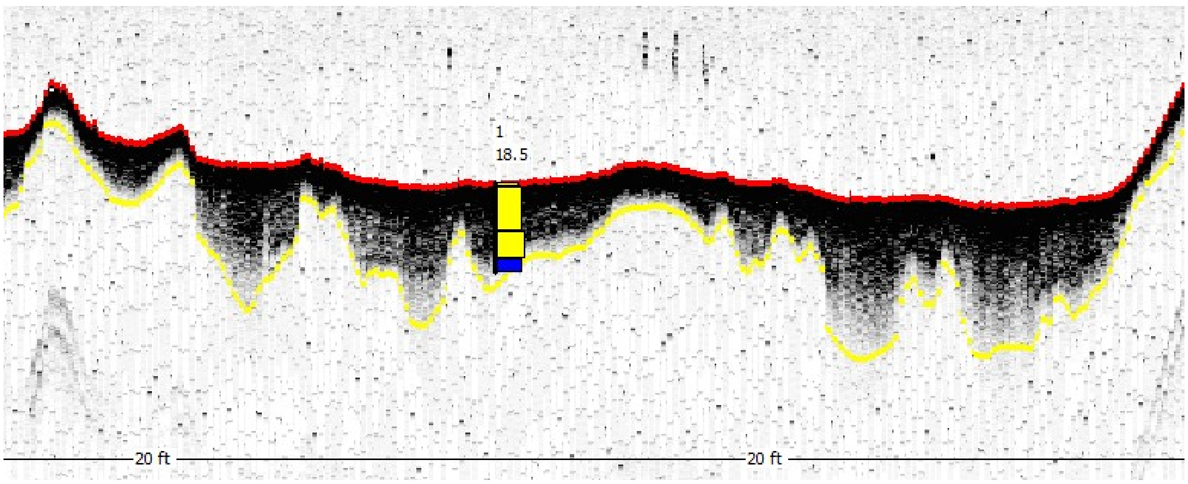
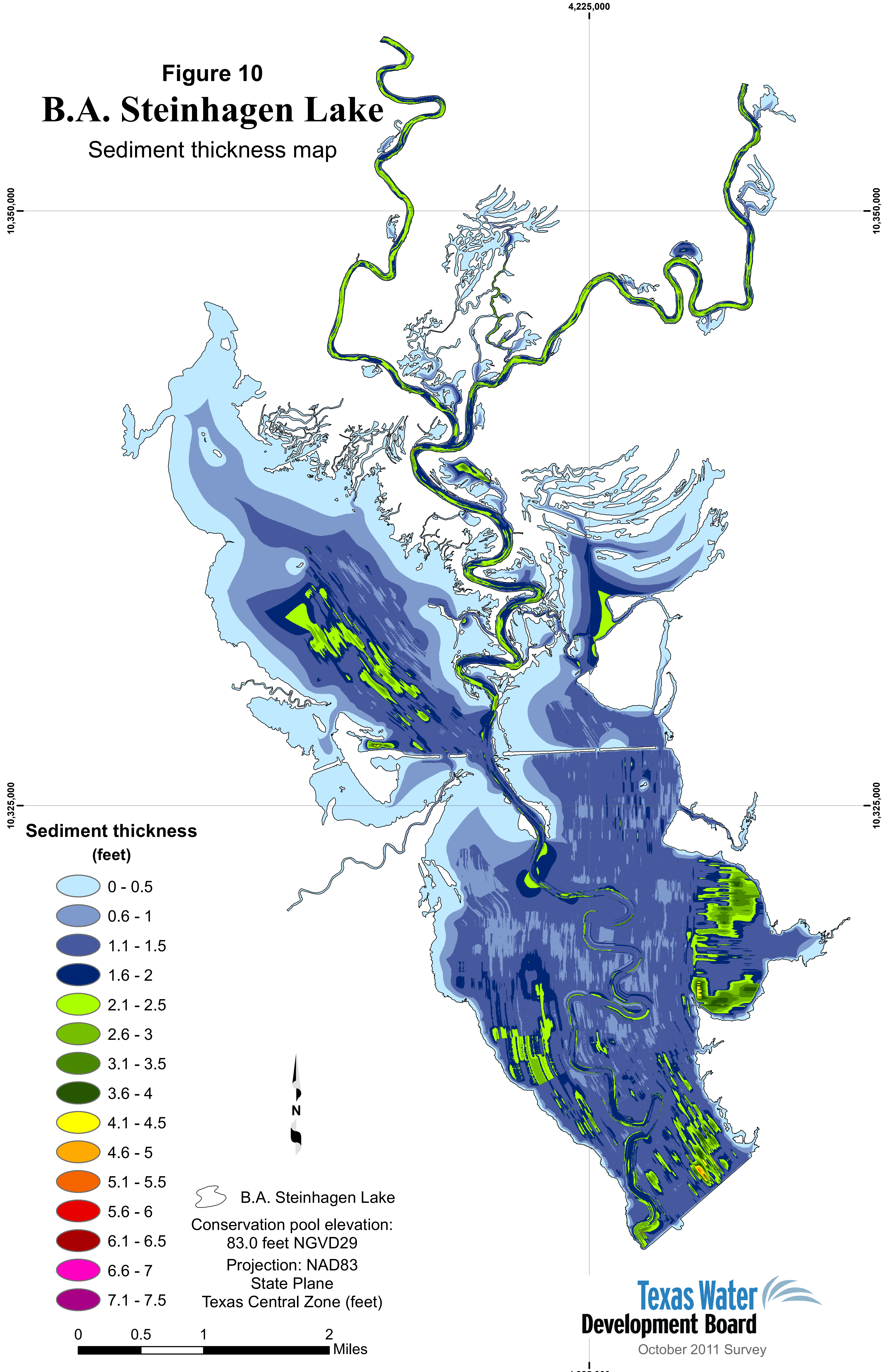


Figure 9. Cross-section of data collected during survey, displayed in DepthPic© (208 kHz frequency), correlated with sediment core sample BA-1 and showing the current surface in red and pre-impoundment surface in yellow

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 83.0 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 B.A. Steinhagen Lake (Figure 10).

Figure 10
B.A. Steinhagen Lake
Sediment thickness map



Texas Water Development Board

October 2011 Survey

Survey results

Volumetric survey

The results of the 2011 TWDB volumetric survey indicate B.A. Steinhagen Lake has a total reservoir capacity of 69,259 acre-feet and encompasses 10,235 acres at conservation pool elevation (83.0 feet above mean sea level, NGVD29). Previous capacity estimates include multiple surveys conducted by the U.S. Army Corps of Engineers in 1947, 1951, and 1960; indicating B.A. Steinhagen Lake's total capacity was 94,200 acre-feet, 100,595 acre-feet, and 101,814 acre-feet, respectively. The 1951 capacity estimate was a recalculation of the 1947 capacity estimate, and the 1960 capacity estimate was a result of a resurvey by the U.S. Army Corps of Engineers. Differences in past and present survey methodologies make direct comparison of volumetric surveys difficult and potentially unreliable.

To properly compare results from TWDB surveys of B.A. Steinhagen Lake, TWDB applied the 2014 data processing techniques to the survey data collected in 2003. Specifically, TWDB applied anisotropic spatial interpolation to the 2003 survey dataset using the same interpolation definition file as was used for the 2011 survey. A new TIN model was created using the original 2003 survey boundaries. The 2003 survey used the 85.0-foot contour from 7.5 minute USGS quadrangle maps, with a stated accuracy of ± 1/2 the contour interval as an outer model boundary (USBB, 1947). Additional boundary information was digitized from DOQQ's photographed on January 19, 1996 and February 5, 1995. At the time of the photographs, water surface elevations measured 80.03 feet and 82.10 feet, respectively. According to the associated metadata, the 1995 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. To eliminate the effects of flat triangles from the TIN model on area and volume calculations, areas between 80.0 feet and 85.0 feet were linearly interpolated and volumes above 80.0 feet were calculated based on the areas. Re-evaluation of the 2003 survey resulted in a 6.8% increase in the total capacity estimate (Table 3).

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

Survey	Surface area (acres)	Total capacity (acre-feet)
USACE 1947 Original design[a]	13,700	94,200
USACE 1951 Adjusted[a]	13,842	100,595
USACE 1960 Resurvey[a]	13,712	101,814
TWDB 2003[b]	10,687	66,972
TWDB 2003 (re-calculated)	11,681	71,508
TWDB 2011	10,235	69,259

[a] Source: (USACE, personal communication, October 23, 2003)
[b] Source: (TWDB, 2004)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2011 TWDB sedimentation survey estimates B.A. Steinhagen Lake to have an average loss of capacity between 522 and 181 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (83.0 feet NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. North of U.S. Highway 190, sediment accumulation is greatest in the Angelina and Neches River channels. South of U.S. Highway 190, the greatest accumulations of sediment are in the Sandy Creek River arm of the reservoir adjacent to Sandy Creek Park and south of Martin Dies, Jr. State Park, and within approximately one half mile north of the eastern half of the dam. Comparison of capacity estimates of B.A. Steinhagen Lake derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Original design information (USACE, 2014c) for B.A. Steinhagen Lake indicates 16,600 acre-feet of the total capacity of the reservoir below elevation 83.0 feet was designated as sediment reserve. Assuming an effective design life for the sediment reserve of 50 years (equal to the time the Lower Neches Valley Authority was contracted to pay on the project, USACE 2014c), the sediment reserve of 16,600 acre-feet would be depleted at an average sedimentation rate of 332 acre-feet per year. This falls between the two estimated sedimentation rates computed in this study.

Table 4. Capacity loss comparisons for B.A. Steinhagen Lake

Survey	Volume comparisons at conservation pool elevation (acre-feet)				Pre-impoundment (acre-feet)
USACE 1947 Original design[a]	94,200	<>	<>	<>	<>
USACE 1951 Original adjusted[a]	<>	100,595	<>	<>	
USACE 1960 Resurvey[a]	<>	<>	101,814	<>	<>
TWDB 2003 (re-calculated)	<>	<>	<>	71,508	<>
TWDB pre-impoundment estimate based on 2011 survey	<>	<>	<>	<>	80,105[b]
2011 volumetric survey	69,259	69,259	69,259	69,259	69,259
Volume difference (acre-feet)	24,941 (26.5%)	31,336 (31.2%)	32,555 (32.0%)	2,249 (3.1%)	10,846 (13.5%)
Number of years	60	60	51	8	60
Capacity loss rate (acre-feet/year)	416	522	638	281	181

[a] Source: (USACE, personal communication, October 23, 2003), note: Deliberate impoundment began on April 16, 1951 and Town Bluff Dam was completed in June, 1953.
[b] 2011 TWDB surveyed capacity of 69,259 acre-feet plus 2011 TWDB surveyed sediment volume of 10,846 acre-feet

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying B.A. Steinhagen Lake 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 B.A. Steinhagen Lake.

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

B.A. Steinhagen

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — October 2011 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 83.0 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
39	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	1	1	1	1	1	1
44	2	2	2	2	2	3	3	3	3	4
45	4	4	4	5	5	5	6	6	6	7
46	7	7	8	8	9	9	9	10	10	11
47	11	12	13	13	14	14	15	16	16	17
48	18	19	19	20	21	22	23	23	24	25
49	26	27	28	29	30	32	33	34	35	36
50	38	39	40	42	43	44	46	47	49	51
51	52	54	56	58	60	62	64	66	68	71
52	73	76	78	81	84	87	89	93	96	99
53	102	106	109	113	117	121	125	129	134	138
54	143	147	152	157	162	168	173	179	185	191
55	197	203	210	216	223	230	238	246	254	262
56	271	280	290	299	309	320	330	341	352	364
57	376	388	401	414	428	442	457	472	487	502
58	518	535	551	568	586	604	622	640	659	678
59	698	718	738	758	779	801	823	845	867	890
60	914	938	962	987	1,012	1,037	1,063	1,090	1,117	1,145
61	1,173	1,201	1,230	1,260	1,290	1,321	1,352	1,383	1,416	1,449
62	1,482	1,516	1,551	1,586	1,621	1,657	1,694	1,732	1,770	1,808
63	1,847	1,887	1,927	1,968	2,009	2,051	2,094	2,137	2,181	2,225
64	2,270	2,316	2,363	2,409	2,457	2,505	2,554	2,603	2,653	2,704
65	2,756	2,808	2,861	2,915	2,969	3,025	3,081	3,137	3,195	3,253
66	3,312	3,372	3,432	3,493	3,555	3,617	3,680	3,744	3,808	3,873
67	3,939	4,005	4,072	4,139	4,208	4,277	4,346	4,417	4,489	4,561
68	4,634	4,707	4,782	4,857	4,933	5,010	5,088	5,166	5,246	5,326
69	5,407	5,489	5,572	5,656	5,741	5,827	5,915	6,003	6,093	6,185
70	6,277	6,372	6,468	6,567	6,668	6,771	6,876	6,983	7,093	7,205
71	7,320	7,438	7,559	7,684	7,812	7,943	8,079	8,218	8,361	8,507
72	8,658	8,813	8,972	9,136	9,306	9,482	9,664	9,852	10,047	10,248
73	10,455	10,668	10,888	11,112	11,343	11,579	11,822	12,069	12,323	12,582
74	12,847	13,119	13,398	13,684	13,978	14,278	14,587	14,903	15,226	15,557
75	15,896	16,244	16,601	16,966	17,339	17,719	18,106	18,500	18,901	19,309
76	19,724	20,146	20,575	21,012	21,457	21,909	22,369	22,837	23,313	23,796
77	24,286	24,784	25,289	25,802	26,322	26,850	27,385	27,927	28,475	29,030
78	29,590	30,158	30,735	31,322	31,917	32,522	33,136	33,759	34,391	35,033
79	35,683	36,343	37,012	37,691	38,378	39,075	39,781	40,496	41,220	41,954
80	42,697	43,449	44,210	44,980	45,760	46,549	47,347	48,154	48,970	49,796
81	50,631	51,475	52,328	53,190	54,062	54,943	55,833	56,732	57,640	58,558
82	59,485	60,421	61,366	62,321	63,284	64,257	65,239	66,230	67,231	68,241
83	69,259									

Note: Capacities above elevation 78.0 calculated from interpolated areas

Appendix B

B.A. Steinhagen

RESERVOIR AREA TABLE

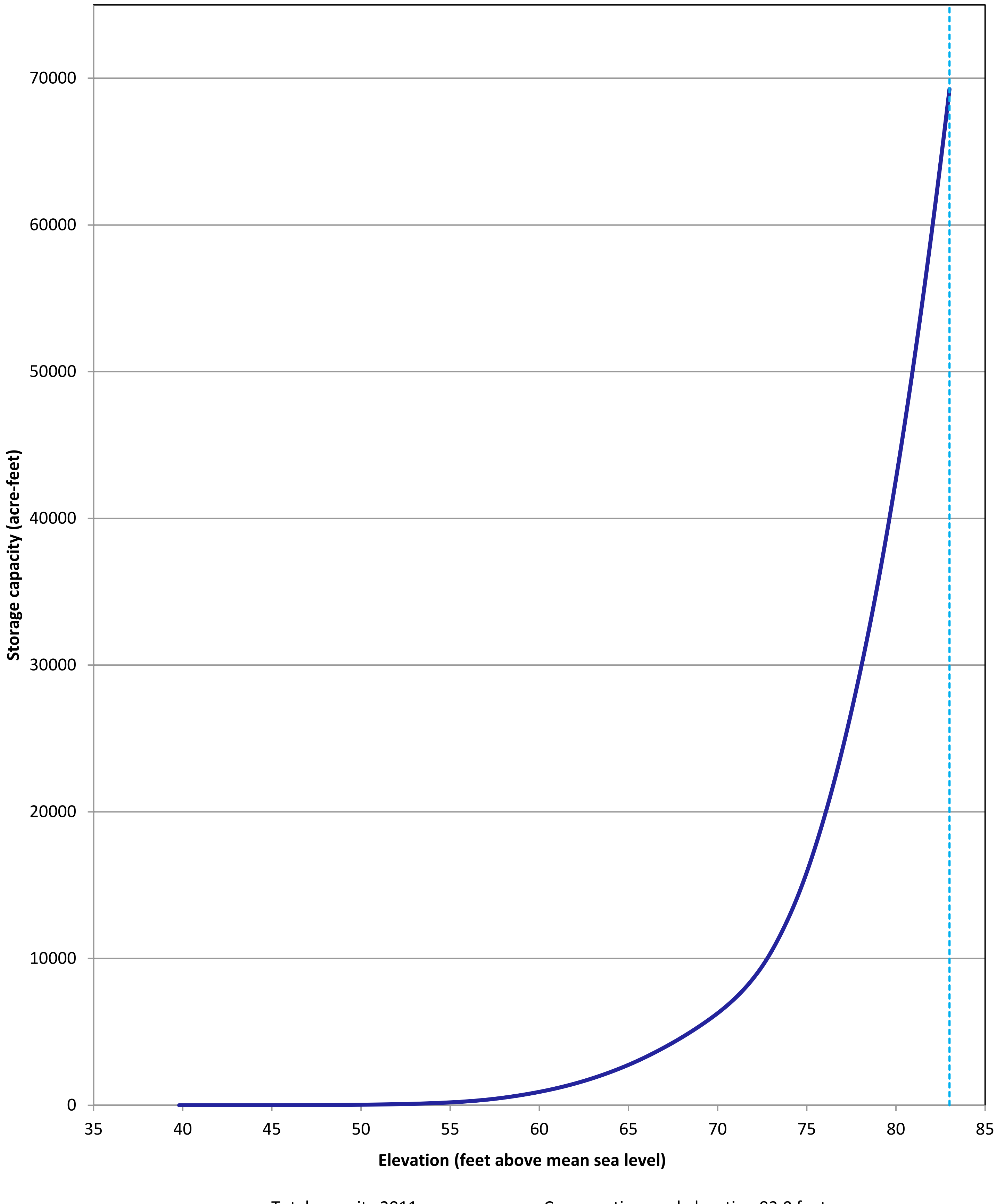
TEXAS WATER DEVELOPMENT BOARD — October 2011 Survey

AREA IN ACRES — Conservation Pool Elevation 83.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

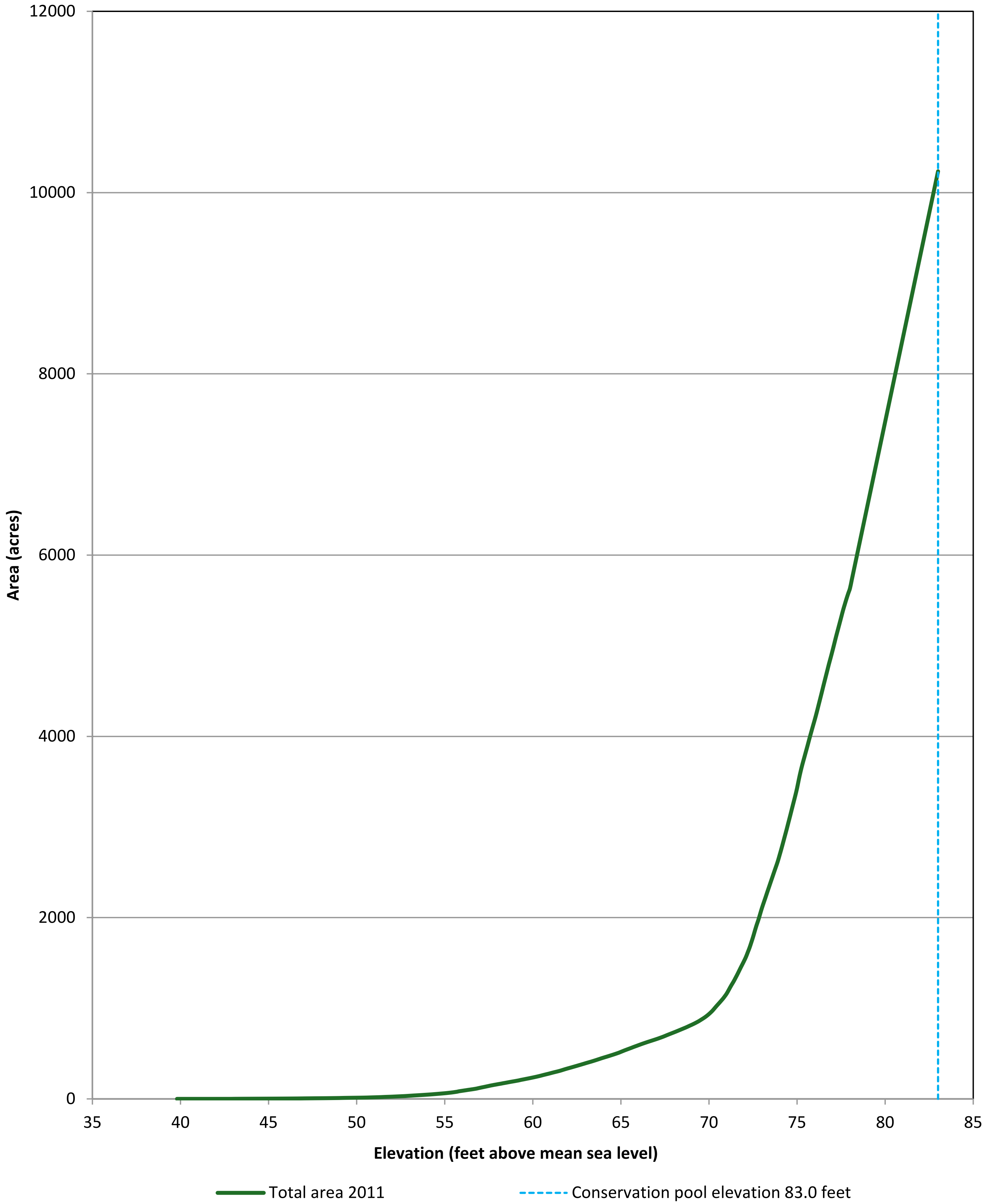
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
39	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0
43	1	1	1	1	1	1	1	2	2	2
44	2	2	2	2	2	2	2	2	2	3
45	3	3	3	3	3	3	3	3	4	4
46	4	4	4	4	4	4	5	5	5	5
47	5	6	6	6	6	6	7	7	7	7
48	7	7	8	8	8	8	9	9	9	9
49	10	10	11	11	11	12	12	12	12	13
50	13	13	13	14	14	15	15	16	16	17
51	17	18	18	19	20	21	22	22	23	24
52	24	25	26	27	28	29	30	31	32	33
53	34	36	37	38	39	40	42	43	44	45
54	47	48	49	51	52	54	55	57	59	61
55	62	64	66	68	71	73	76	79	84	87
56	90	93	95	99	101	104	107	110	114	118
57	122	126	130	134	139	143	147	151	155	158
58	162	165	168	172	176	179	183	187	190	193
59	197	200	204	209	213	216	220	224	228	232
60	236	240	244	249	254	259	264	269	273	278
61	283	288	293	298	303	308	314	320	326	332
62	337	343	348	354	359	365	371	376	382	388
63	394	400	405	411	417	423	429	435	442	448
64	454	460	466	472	478	485	491	497	504	511
65	519	527	535	542	549	557	564	571	579	586
66	593	600	607	614	620	627	633	640	646	652
67	659	665	672	679	686	694	702	710	718	726
68	733	741	749	757	765	773	781	789	798	807
69	816	825	835	845	855	867	880	892	906	920
70	937	955	974	997	1,019	1,041	1,063	1,085	1,108	1,134
71	1,161	1,195	1,231	1,265	1,297	1,334	1,371	1,410	1,449	1,487
72	1,526	1,568	1,618	1,668	1,727	1,787	1,854	1,918	1,975	2,040
73	2,105	2,163	2,219	2,278	2,335	2,393	2,449	2,507	2,562	2,620
74	2,686	2,754	2,825	2,898	2,970	3,045	3,120	3,197	3,273	3,349
75	3,431	3,527	3,614	3,691	3,762	3,833	3,903	3,977	4,046	4,116
76	4,183	4,255	4,332	4,408	4,485	4,564	4,641	4,717	4,794	4,865
77	4,939	5,015	5,093	5,166	5,239	5,313	5,387	5,453	5,517	5,576
78	5,633	5,725	5,817	5,909	6,001	6,093	6,185	6,277	6,369	6,461
79	6,553	6,645	6,737	6,829	6,921	7,013	7,105	7,197	7,289	7,382
80	7,474	7,566	7,658	7,750	7,842	7,934	8,026	8,118	8,210	8,302
81	8,394	8,486	8,578	8,670	8,762	8,854	8,946	9,038	9,130	9,222
82	9,314	9,406	9,499	9,591	9,683	9,775	9,867	9,959	10,051	10,143
83	10,235									

Note: Areas above elevation 78.0 feet interpolated



B.A. Steinhagen Lake
October 2011 Survey
Prepared by: TWDB

Appendix C: Capacity curve



B.A. Steinhagen Lake
October 2011 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

Contours

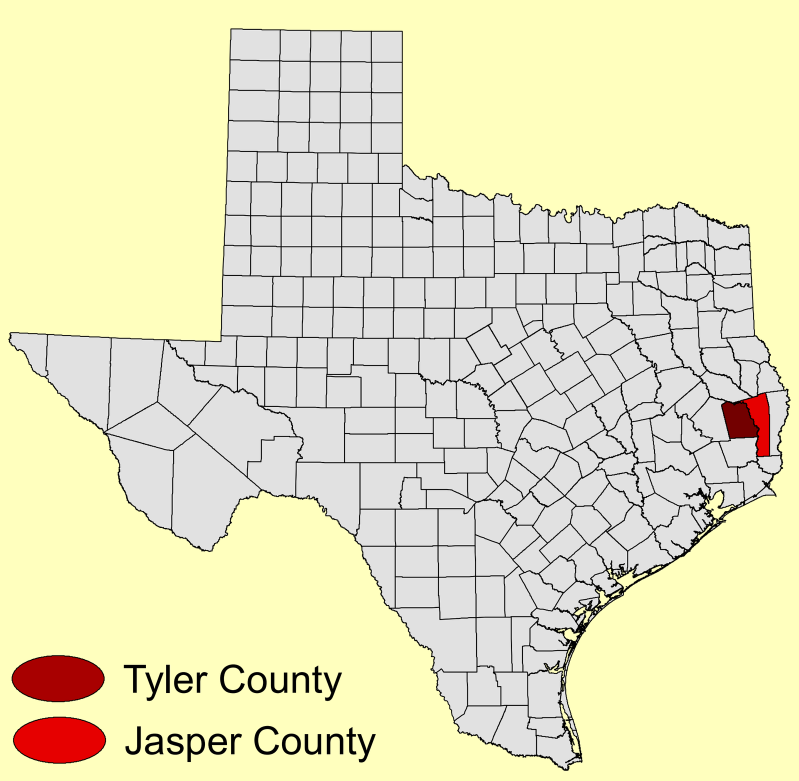
(feet NGVD29)

45
50
55
60
65
70
75
80

B.A. Steinhagen Lake Conservation pool elevation 83.0 feet NGVD29

Islands

Projection: NAD83 State Plane Texas 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 B.A. Steinhagen Lake. The Texas Water Development Board makes no representations nor assumes any liability.