Volumetric and Sedimentation Survey of LAKE BROWNWOOD

June 2013 Survey

Texas Water Development Board

May 2014

Texas Water Development Board

Carlos Rubinstein, Chairman | Bech Bruun, Member | Kathleen Jackson, Member

Kevin Patteson, Executive Administrator

Prepared for:

Brown County Water Improvement District No. 1

With Support Provided by:

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

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6/9/2014

Published and distributed by the

Texas Water Development Board

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

Executive summary

In September 2009, 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 Brownwood. The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the Brown County Water Improvement District No. 1 provided the remaining 50%. Surveying was performed using a multi-frequency (200 kHz, 50 kHz, and 24 kHz), sub-bottom profiling depth sounder. In addition, sediment core samples were collected in select locations and correlated with the multi-frequency depth sounder signal returns to estimate sediment accumulation thicknesses and sedimentation rates.

Brownwood Dam and Lake Brownwood are located on Pecan Bayou in Brown County, approximately eight miles north of Brownwood, Texas. The conservation pool elevation of Lake Brownwood is 1,425.0 feet (NAVD88). TWDB collected bathymetric data for Lake Brownwood on June 10-14, 2013, while the daily average water surface elevations measured between 1,412.31 and 1,412.19 feet (NAVD88). Additional data was collected on August 5, 2013, while the daily average water surface elevation measured 1,416.42 feet (NAVD88).

The 2013 TWDB volumetric survey indicates that Lake Brownwood has a total reservoir capacity of 131,530 acre-feet and encompasses 6,814 acres at conservation pool elevation (1,425.0 feet NAVD88). Previous capacity estimates include: the original capacity estimate of 157,360 acre-feet; a 1959 survey by the U.S. Soil Conservation Service indicating a capacity of 143,400 acre-feet; and re-analysis of the 1997 TWDB volumetric survey data using current processing procedures that resulted in an updated capacity estimate of 134,955 acre-feet.

Based on two methods for estimating sedimentation rates, the 2013 TWDB sedimentation survey estimates Lake Brownwood to have an average loss of capacity between 131 and 323 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,425.0 feet NAVD88). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. Sediment accumulations measured by this survey are greatest in the submerged river channels and in small pockets throughout the reservoir. Of these, the greatest accumulations are in Pecan Bayou north and northeast of Lake Brownwood State Park and in Jim Ned Creek downstream of the confluence with Rocky Creek and north of Flat Rock Park. TWDB recommends that a similar methodology be used to resurvey Lake Brownwood 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 September 2009, TWDB entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Brownwood. The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the Brown County Water Improvement District No. 1 provided the remaining 50% (TWDB, 2009). 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 Brown County Water Improvement District No. 1 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].

Lake Brownwood general information

Brownwood Dam and Lake Brownwood are located on Pecan Bayou in Brown County, approximately eight miles north of Brownwood, Texas (Figure 1). Pecan Bayou is a tributary of the Colorado River, and the dam is located just downstream of the confluence of Jim Ned Creek with Pecan Bayou. Brownwood Dam and Lake Brownwood are owned and operated by Brown County Water Improvement District No. 1 (BCWID, 2013a). Construction of the dam began in 1930, and was completed in 1933. Deliberate impoundment of water began in July 1933 (TWDB, 1971). Lake Brownwood is a water supply reservoir primarily for municipal and irrigation purposes. The Brown County Water Improvement District No. 1 supplies Lake Brownwood water to the Cities of Brownwood, Early, Bangs, Santa Anna, the Brookesmith SUD, and other small systems around the lake (BCWID, 2013a). Additional pertinent data about Brownwood Dam and Lake Brownwood can be found in Table 1.

Water rights for Lake Brownwood have been appropriated to the Brown County Water Improvement District No. 1 through Certificate of Adjudication No. 14-2454 and Amendment to Certificate of Adjudication No. 14-2454A. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

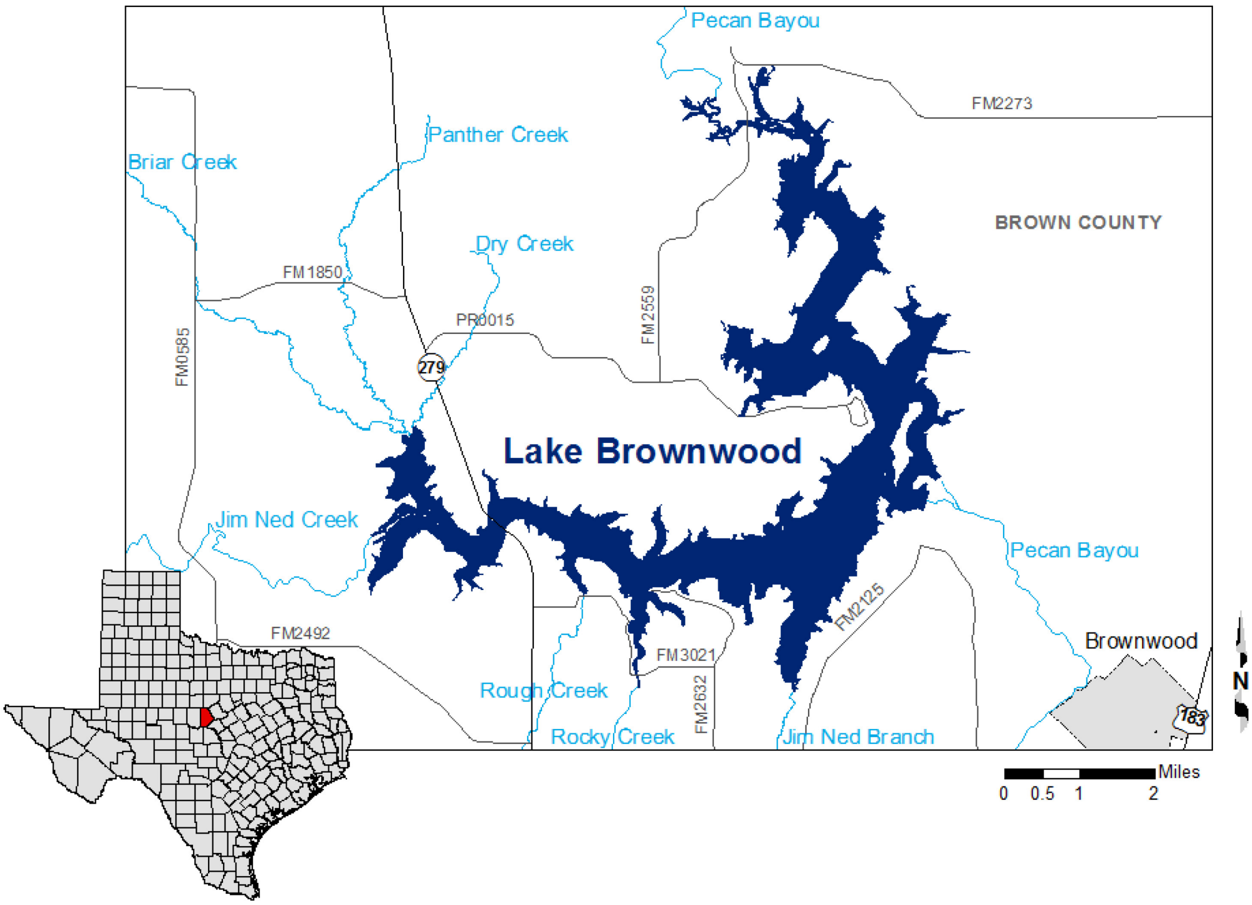

Figure 1. **Location of Lake Brownwood**

Table 1.	**Pertinent data for Brownwood Dam and Lake Brownwood**		
Owner			
Brown County Water Improvement District No. 1			
Design Engineer			
D.W. Ross			
Location of dam			
On Pecan Bayou in Brown County, 8 miles north of Brownwood			
Drainage area			
1,535 square miles			
Dam			
Type	Earthfill		
Length	1,580 feet		
Height	140 feet		
Top width	21 feet		
Spillway (emergency)			
Location	800 feet to left of dam		
Type	Concrete sill on natural cut		
Crest length	479 feet		
Crest elevation	1,425 feet NAVD88		
Spillway (service)			
Type	2 concrete conduits		
Control	2 concrete broome-type gates		
Outlet works			
Type	1 concrete conduit, 5-foot diameter		
Control	Slide gate		
Invert elevation	1,405.5 feet		
Reservoir data (Based on 2013 TWDB survey)			
Feature	**Elevation (feet** NAVD88[a]**)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	1,470.0	N/A	N/A
Spillway crest (conservation pool)	1,425.0	131,530	6,814
Outlet works	1,408.5	46,805	3,604
	1,380.0	1,377	222
	1,360.0	0	0
Usable conservation storage space[b]	-	131,530	-

Source: (TWDB, 1971; Freese & Nichols, 2014) Note: Dam modification was completed in August 1983. Modification included raising the height of the dam by 20 feet and reducing two flood release tubes from 144-inch diameter to 42-inch diameter and replacing the old aqueduct feeder with a 42-inch diameter pipe. These three 42-inch intakes are on the lake side of the dam at elevations 1,408.5, 1,380.0, and 1,360.0 feet NAVD88 (BCWID, 2013b, Freese & Nichols, 2014)

[a] NAVD88 = North American Vertical Datum 1988

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

Volumetric and sedimentation survey of Lake Brownwood

Datum

The vertical datum used during this survey is the North American Vertical Datum 1988 (NAVD88). Water surface elevations obtained from the United States Geological Survey (USGS) for the reservoir elevation gage *USGS 08143000 Lk Brownwood nr Brownwood, TX* (USGS, 2014) are reported in the National Geodetic Vertical Datum 1929. According to the USGS, "In the past, the U.S. Geological Survey (USGS) has used the datum that was used in the construction of Lake Brownwood, which is known as the 'Reservoir Datum', for reporting reservoir stage for Lake Brownwood (Station No. 08143000) to maintain continuity with the historical record. The 'Reservoir Datum' is 0.50 ft higher than National Geodetic Vertical Datum 1929 (NGVD 1929). The elevation of the crest of the spillway is 1424.6 ft above MSL (NGVD 1929) or 1425.1 ft above 'Reservoir Datum'… As of Feb 23, 1999 all records published for Lake Brownwood are based on National Geodetic Vertical Datum of 1929 and include the remark 'prior to Feb 1999, non-recording gages at same site at datum 0.50 ft higher." Recent surveys of the Brownwood Dam spillway have determined the elevation of the spillway to be 1425.0 feet NAVD88 (D. King, personal communication, March 26, 2014), therefore, water surface elevations obtained from the USGS were converted to NAVD88 by subtracting 0.1 feet from the gage readings. Elevations herein are reported in feet relative to the NAVD88 datum. Volume and area calculations in this report are referenced to the converted water levels provided by the USGS gage. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet).

TWDB bathymetric and sedimentation data collection

TWDB collected bathymetric data for Lake Brownwood on June 10-14, 2013, while the daily average water surface elevations measured between 1,412.31 and 1,412.19 feet (NAVD88). Additional data was collected on August 5, 2013, while the daily average water surface elevation measured 1,416.42 feet (NAVD88). For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data 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 1997 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 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 13, 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.

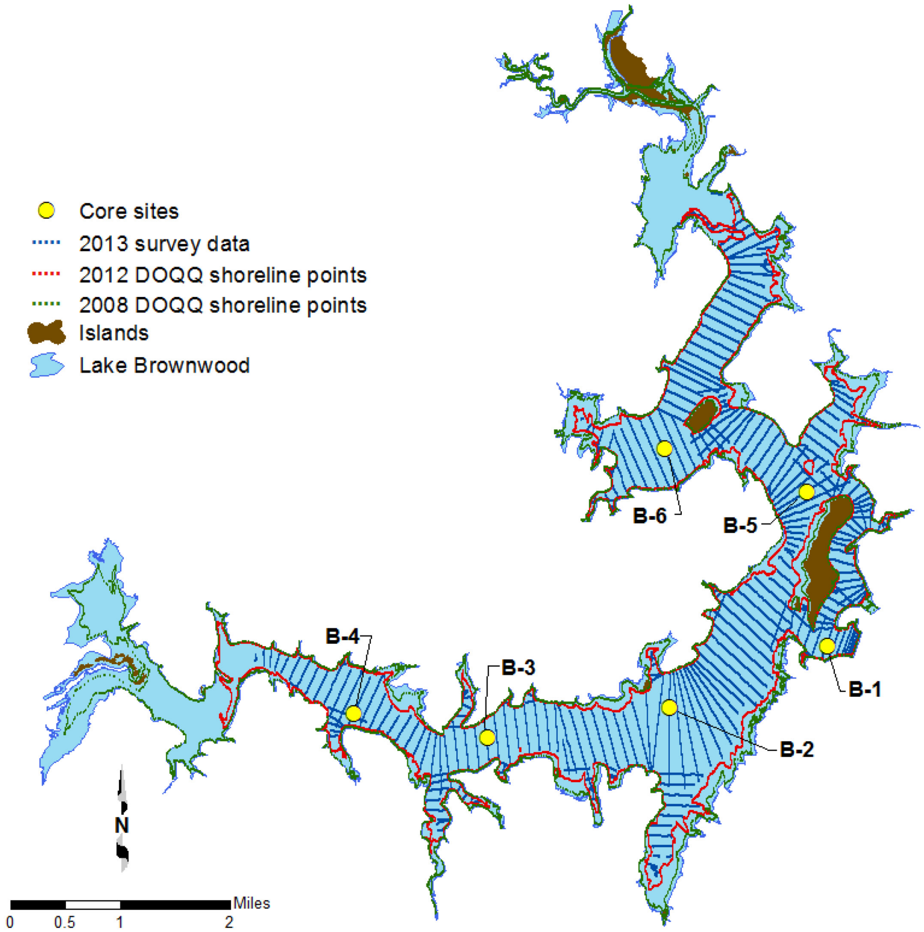

Figure 2. **Data collected during 2013 TWDB Lake Brownwood survey**

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, 2014) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Brownwood are Lake Brownwood (NW, NE, SW, SE), Thrifty (NE), Byrds (SE), and Owens (NW). The DOQQs were photographed on November 4, 2004 (Owens NW), and November 26, 2004, while the daily average water surface elevation measured 1,424.67 feet, and 1,425.69 feet, respectively (NAVD88). According to metadata associated with the 2004 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy of within ±5 meters of reference DOQQs from the National Digital Ortho Program (USDA, 2013). The area of the lake within the Owens NW quarter quadrangle is not significant, therefore, for this analysis; the boundary was digitized at the land-water interface in the 2004 photographs and assigned an elevation of 1,425.7 feet.

Where survey data alone was not sufficient to model the reservoir topography and in areas inaccessible by boat due to reservoir conditions at the time of the survey, additional boundary information was obtained from aerial photographs taken on August 4, 2008, and July 20, 2012, August 2, 2012, and August 3, 2012, while the daily average water surface elevation measured 1,420.74 feet, 1,413.11 feet, 1,412.65 feet, and 1,412.61 feet, respectively. The 2008 and 2012 boundary information was added to the lake model as points with elevations assigned to the points based on water surface elevations when the photographs were taken. According to metadata associated with both the 2008 and 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, 2010, TNRIS, 2012).

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 or DRGs) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. For surveys with similar spatial coverage, these interpolation definition files are in principle independent of the survey data and could be applied to past and future survey data of the same reservoir. In practice, however, minor revisions of the interpolation definition files may be needed to account for differences in spatial coverage and boundary conditions between surveys. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing the reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen et al., 2011a) and in McEwen et al., 2011b.

In areas inaccessible to survey data collection such as small coves and shallow upstream areas of the reservoir, linear extrapolation is used for volumetric and sediment accumulation estimations. The linear extrapolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without extrapolated data, the TIN Model builds flat triangles. A flat triangle is defined as a triangle where all three vertices are equal in elevation, generally the elevation of the reservoir boundary. Reducing flat triangles, by applying linear extrapolation, improves the elevation-capacity and elevation-area calculations. It is not always possible to remove all flat triangles, and linear extrapolation is only applied where adding bathymetry is deemed reasonable. For example, linear extrapolation was deemed reasonable and applied to Lake Brownwood in the following situations: in small coves of the main body of the lake and in obvious channel features from the USGS 7.5 minute quadrangle maps or those visible in the 2008 and 2012 DOQQs.

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

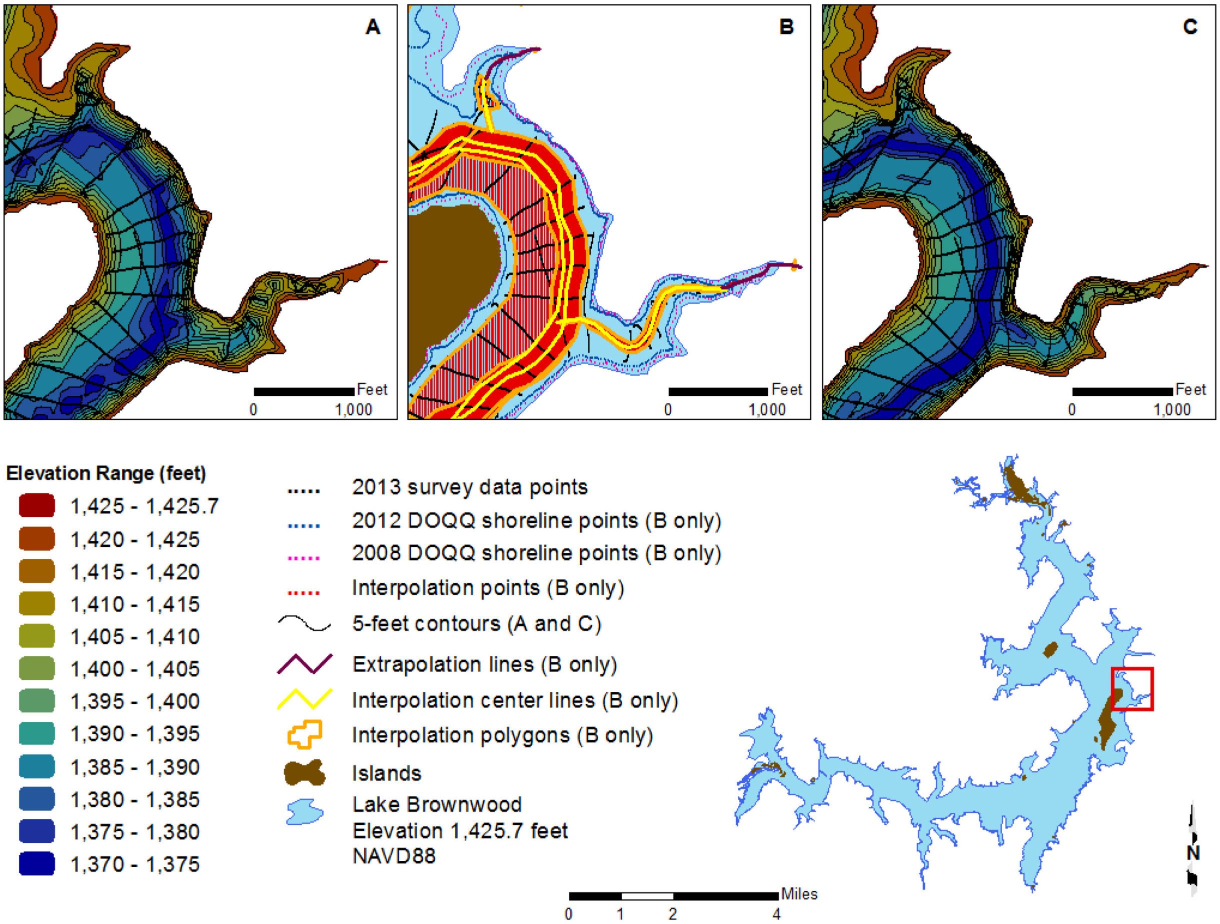

Figure 3. **Anisotropic spatial interpolation and linear extrapolation of Lake Brownwood sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

Area, volume, and contour calculation

Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1 feet intervals, from 1,361.5 to 1,425.7 feet. The use of contour data from the 2008 and 2012 DOQQs helped provide otherwise unavailable topographic data in areas that were inaccessible by boat or too shallow for the instruments to work properly. However, 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 elevations, 1,412.61 feet, 1,412.65 feet, 1,413.11 feet, 1,420.74 feet, and 1,425.7 feet. To eliminate the effects of the flat triangles on area and volume calculations, areas between elevations 1,412.5 feet and 1,425.7 feet were linearly interpolated between the computed values, and volumes above elevation 1,412.5 feet were calculated based on the corrected areas. 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 Lake Brownwood; and a 5-foot contour map (Figure 6 - attached).

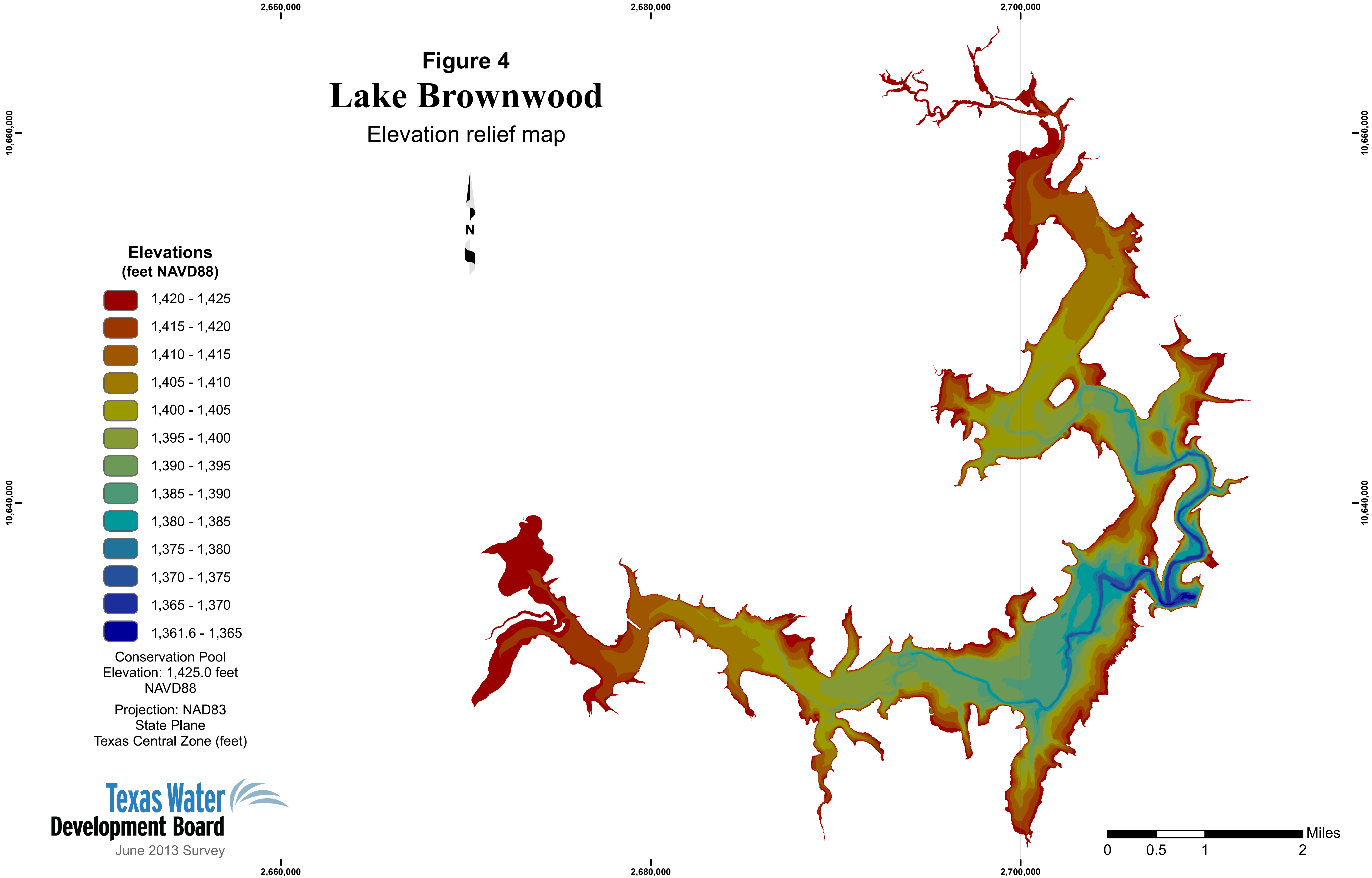
Figure 4
Lake Brownwood
Elevation relief map
N
Elevations
(feet NAVD88)
1,420 - 1,425
1,415 - 1,420
1,410 - 1,415
1,405 - 1,410
1,400 - 1,405
1,395 - 1,400
1,390 - 1,395
1,385 - 1,390
1,380 - 1,385
1,375 - 1,380
1,370 - 1,375
1,365 - 1,370
1,361.6 - 1,365
Conservation Pool
Elevation: 1,425.0 feet
NAVD88
Projection: NAD83
State Plane
Texas Central Zone (feet)
Texas Water
Development Board
June 2013 Survey
2,660,000
2,680,000
2,700,000
10,660,000
10,640,000
Miles
0
0.5
1
2

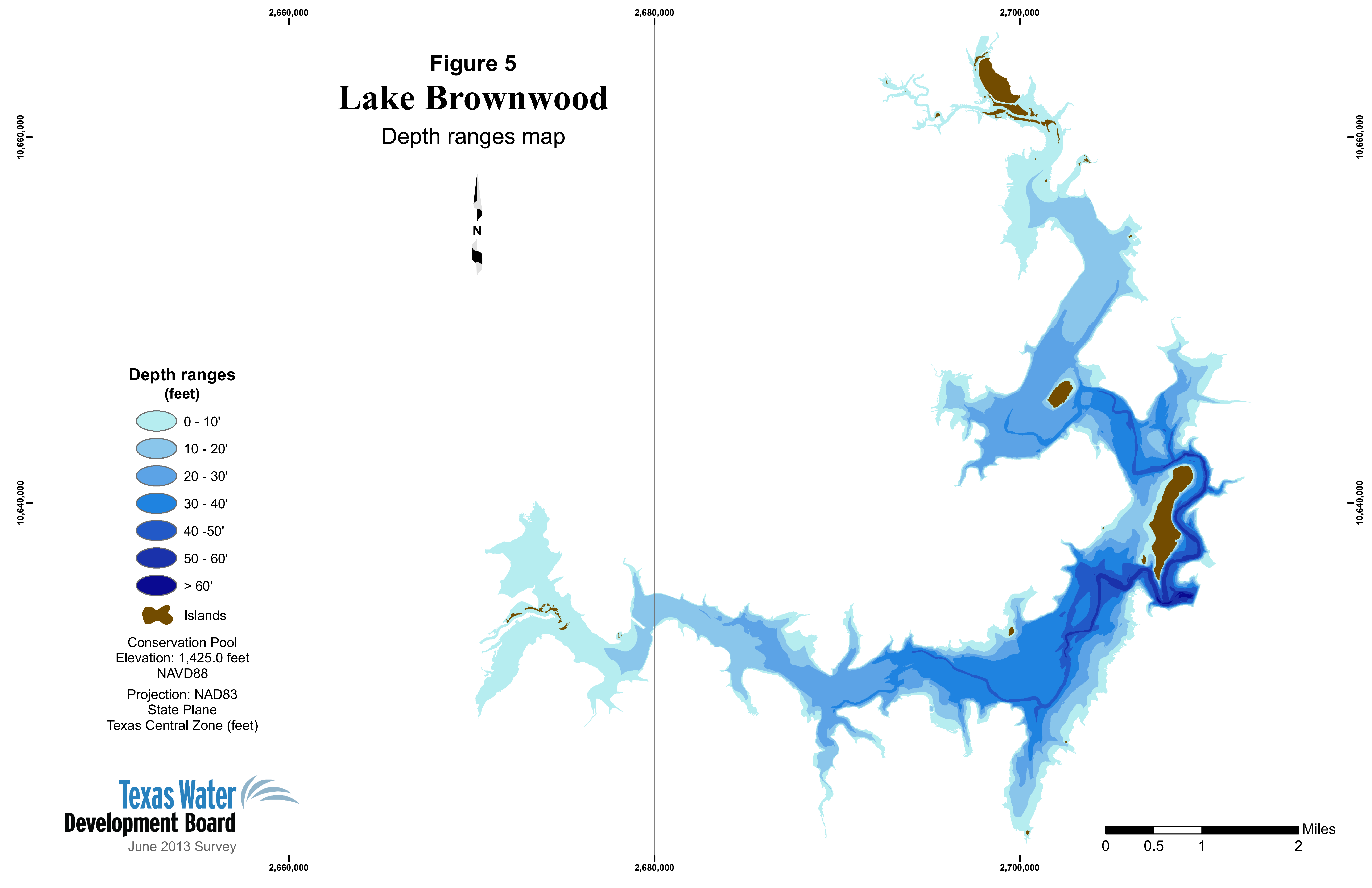

Figure 5
Lake Brownwood
Depth ranges map
N
2,660,000
2,680,000
2,700,000
10,660,000
10,640,000
Depth ranges
(feet)
0 - 10'
10 - 20'
20 - 30'
30 - 40'
40 -50'
50 - 60'
> 60'
Islands
Conservation Pool
Elevation: 1,425.0 feet
NAVD88
Projection: NAD83
State Plane
Texas Central Zone (feet)
Texas Water
Development Board
June 2013 Survey
Miles
0
0.5
1
2

Analysis of sediment data from Lake Brownwood

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

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

Table 2. Sediment core sampling analysis data - Lake Brownwood

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
B-1	2708249.54	10634867.60	61"/ 53.5"	0-23" high water content, silty clay loam	5Y 3/1
				23-53.5" high water content, higher density, silty clay loam	5Y 4/2
				53.5-61" organics present, silty clay	5Y 3/1
B-2	2700654.08	10631906.53	43"/33.5"	0-33.5" high water content, silty loam	2.5Y 3/2
				33.5-43" organics present, silty clay	5Y 2.5/1
B-3	2691833.92	10630447.65	46.5"/37"	0-37" high water content, silty clay loam	5Y 3/2
				37-46.5" organics present, sandy clay	5Y 3/1
B-4	2685405.28	10631581.81	47"/40"	0-17.5" high water content, silty clay loam	5Y 3/2
				17.5-40" high water content, higher density, silty clay loam	5Y 3/2
				40-47" organics present, sandy clay	5Y 2.5/1
B-5	2707242.74	10642308.08	30"/21.5"	0-21.5" high water content, silty clay loam	5Y 3/2
				21.5-30" organics present, sandy clay	2.5Y 3/2
B-6	2700428.61	10644370.38	30.5"/24"	0-24" high water content, silty clay loam	5Y 3/2
				24-30.5" organics present, sandy clay	5Y 2.5/2

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

A photograph of sediment core B-3 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Brownwood. The 200 kHz frequency measures the top layer as the current bottom surface of the reservoir.

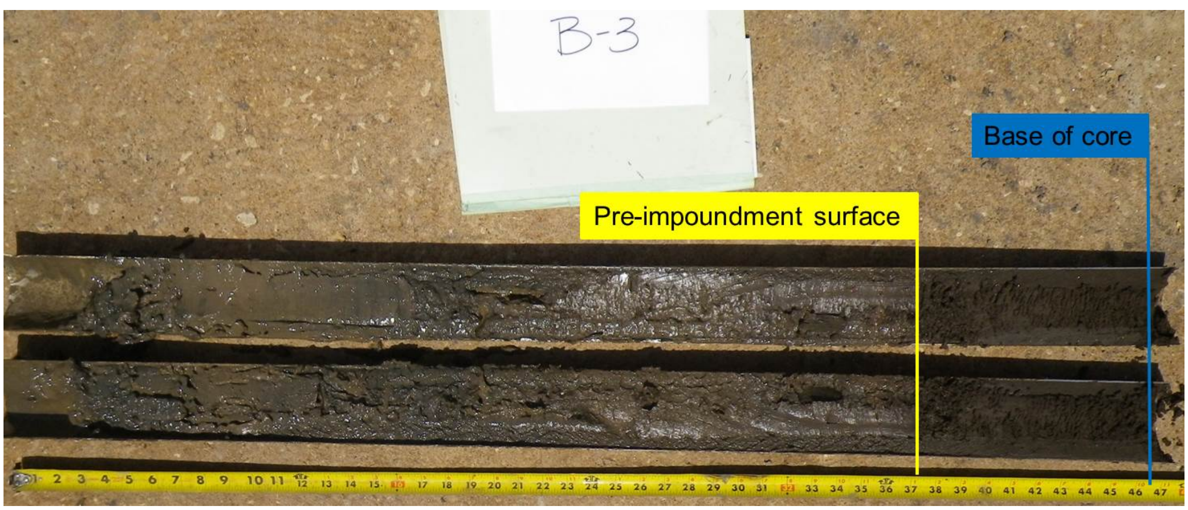

Figure 7. Sediment core B-3 from Lake Brownwood

Sediment core sample B-3 consisted of 46.5 inches of total sediment. The upper sediment layer (horizon), 0–37.0 inches, consisted of silty clay loam sediment with a high water content and measured 5Y 3/2 on the Munsell soil color chart. The second horizon, beginning at 37.0 inches and extending to 46.5 inches below the surface, consisted of a sandy clay soil with organics present and a 5Y 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 37.0 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 200 kHz transducer and verified by TWDB staff, while the pre-impoundment surface must be determined visually. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected.

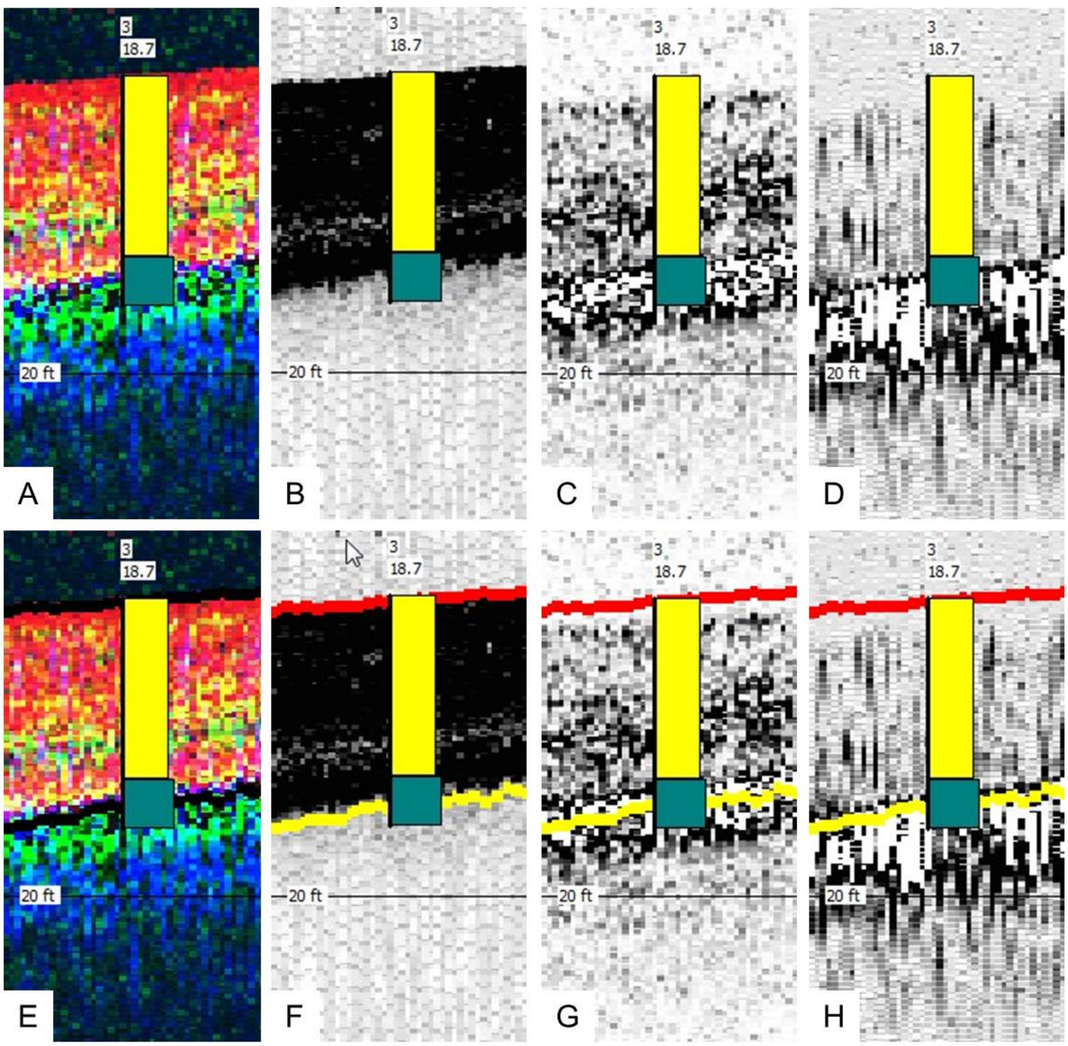

Figure 8. Comparison of sediment core B-3 with acoustic signal returns: A,E) combined acoustic signal returns, B,F) 200 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 8 compares sediment core sample B-3 with the acoustic signals for all frequencies combined (A, E), 200 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). The sediment core sample is represented in each figure as colored boxes. The yellow boxes represent post-impoundment sediment, and the blue box represents the pre-impoundment sediment. In Figure 8A-D, the bathymetric surfaces are not shown. In Figure 8E, the current bathymetric surface is represented as the top black line and in Figures 8 F-H as the top red line. The pre-impoundment surface is identified by comparing boundaries observed in the 200 kHz, 50 kHz and 24 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Each sediment core sample was compared to all three frequencies and the boundary in the 200 kHz signal most closely matched the pre-impoundment interface of the sediment core samples; therefore, the 200 kHz signal was used to locate the pre-impoundment layer. The pre-impoundment surface was manually drawn and is represented by the bottom black line in Figure 8E, and by the yellow line in Figures 8F-H. Figure 9 shows sediment core sample B-3 correlated with the 200 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface identified along cross-sections where sediment core samples were collected is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

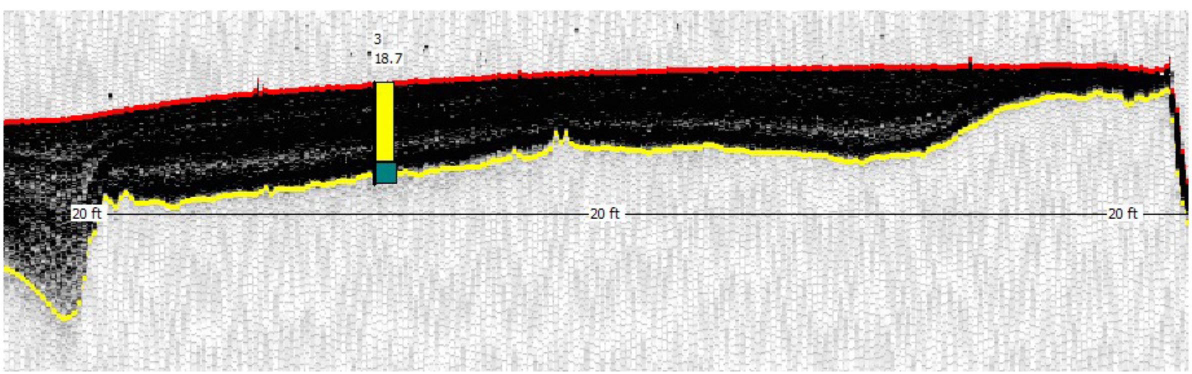

Figure 9. Cross-section of data collected during 2013 survey, displayed in DepthPic© (200 kHz frequency), correlated with sediment core sample B-3 and showing the current surface in red and pre-impoundment surface in yellow

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 1,425.7 foot NAVD88 elevation contour).

The sediment thickness was also assumed zero at each point digitized from the 2008 and 2012 DOQQs. The sediment thickness TIN model was converted to a raster representation using a cell size of 5 feet by 5 feet and used to produce a sediment thickness map of Lake Brownwood (Figure 10).

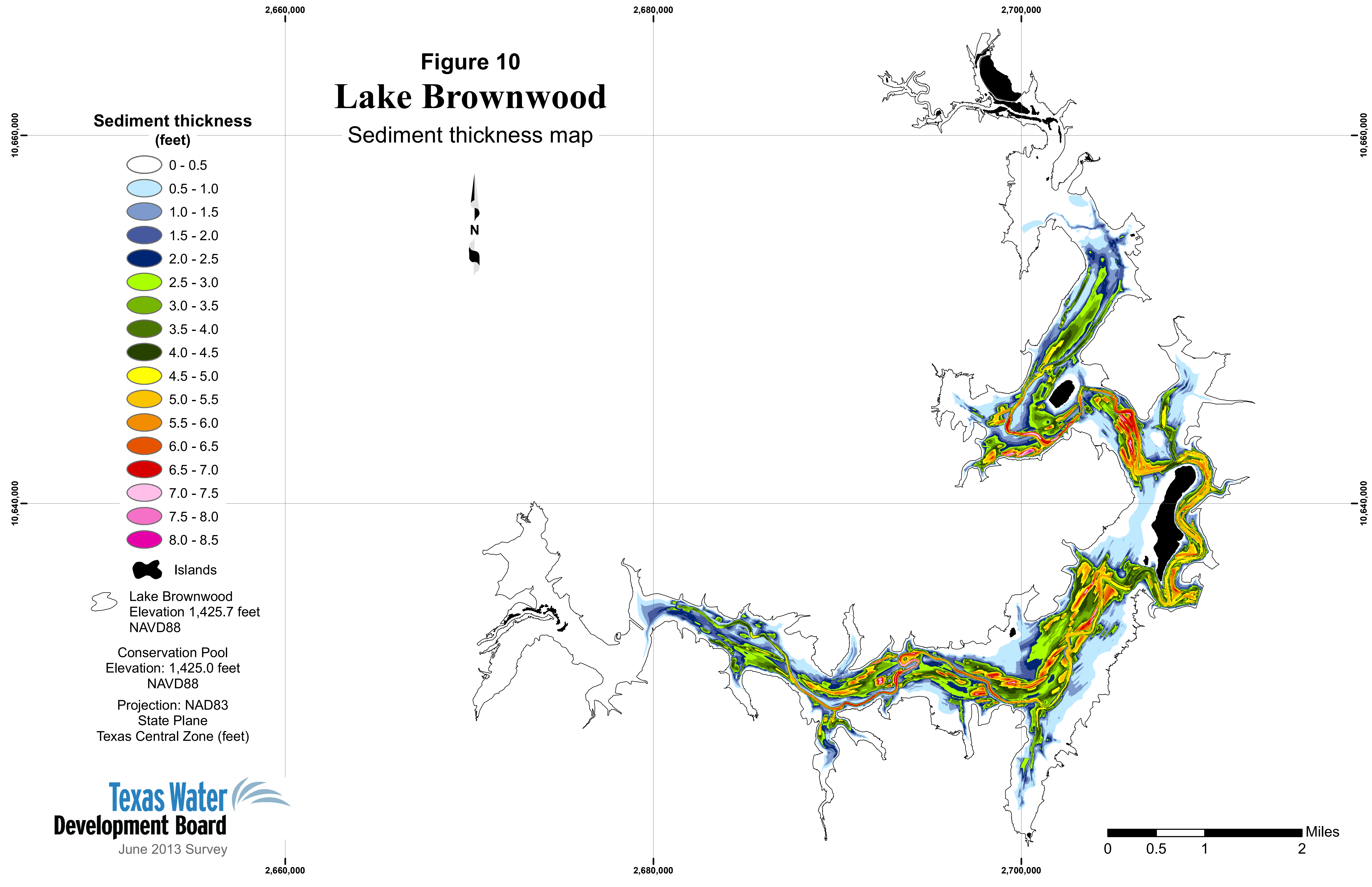
Figure 10
Lake Brownwood
Sediment thickness map
Sediment thickness
(feet)
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 7.5
7.5 - 8.0
8.0 - 8.5
Islands
Lake Brownwood
Elevation 1,425.7 feet
NAVD88
Conservation Pool
Elevation: 1,425.0 feet
NAVD88
Projection: NAD83
State Plane
Texas Central Zone (feet)
N
2,660,000
2,680,000
2,700,000
10,660,000
10,640,000
Miles
0
0.5
1
2
Texas Water
Development Board
June 2013 Survey

Survey results

Volumetric survey

The results of the 2013 TWDB volumetric survey indicate Lake Brownwood has a total reservoir capacity of 131,530 acre-feet and encompasses 6,814 acres at conservation pool elevation (1,425.0 feet, NAVD88). Previous capacity estimates include the original design estimate of 157,360 acre-feet, and a 1959 sediment survey by the U.S. Soil Conservation Service, indicating a capacity of 143,400 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.

TWDB previously surveyed Lake Brownwood in 1997. To properly compare results of TWDB surveys, TWDB applied the 2014 data processing techniques to the data collected in 1997. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 1997 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. A new TIN model was created using the original boundary, with some edits. The 1997 survey used the 1,425.0-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). However, in 1997, this boundary was edited to include all survey data points and clipped in the upper reaches by a seemingly arbitrary determination of the end of the lake. For re-calculation, the clipped parts of the lake were added back to the 1997 model boundary. Re-evaluation of the 1997 survey resulted in a 2.7 percent 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)
Original[a]	7,300	157,360
U.S. Soil Conservation Service 1932[b]	7,298	149,925
U.S. Soil Conservation Service 1940[b]	7,298	145,720
U.S. Soil Conservation Service 1959[b]	7,298	135,963
TWDB 1997[c]	6,587	131,429
TWDB 1997 (re-calculated)	6,924	134,955
TWDB 2013	6,814	131,530

Note: Conservation pool elevation or spillway crest elevation for Lake Brownwood is reported differently depending on the source. The U.S. Soil Conservation Service reports the spillway crest elevation at 1,424.5 feet above mean sea level (SCS, 1959). TWDB and the USGS report spillway crest elevation at 1,424.6 feet NGVD29 (TWDB, 1971, USGS, 2014). The USGS also reports the spillway crest elevation as 1,425.1 feet "Reservoir Datum" (USGS, 2014). Recent surveys of Brownwood Dam have determined the spillway crest elevation is 1,425.0 feet NAVD88 (D. King, personal communication, March 26, 2014).
[a] Source: (TWDB, 1971)
[b] Source: (SCS, 1959)
[c] Source: (TWDB, 1997)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2013 TWDB sedimentation survey estimates Lake Brownwood to have an average loss of capacity between 131 and 323 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,425.0 feet NAVD88). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. Sediment accumulations measured by this survey are greatest in the submerged river channels and in small pockets throughout the reservoir. Of these, the greatest accumulations are in Pecan Bayou north and northeast of Lake Brownwood State Park and in Jim Ned Creek downstream of the confluence with Rocky Creek and north of Flat Rock Park. Comparison of capacity estimates of Lake Brownwood derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. Capacity loss comparisons for Lake Brownwood

Survey	Volume comparisons at conservation pool elevation (acre-feet)					Pre-impoundment (acre-feet)
Original	157,360	<>	<>	<>	<>	<>
SCS 1932	<>	149,925	<>	<>	<>	<>
SCS 1940	<>	<>	145,720	<>	<>	<>
SCS 1959	<>	<>	<>	135,963	<>	<>
TWDB 1997 (re-calculated)	<>	<>	<>	<>	134,955	<>
TWDB pre-impoundment estimate based on 2013 survey	<>	<>	<>	<>	<>	142,048[a]
2013 volumetric survey	131,530	131,530	131,530	131,530	131,530	131,530
Volume difference (acre-feet)	25,830 (16.4%)	18,395 (12.3%)	14,190 (9.7%)	4,433 (3.3%)	3,425 (2.5%)	10,518 (7.4%)
Number of years	80	81	73	54	16	80
Capacity loss rate (acre-feet/year)	323	227	194	82	214	131

Note: Brownwood Dam was completed in 1933, and deliberate impoundment began in July, 1933.

[a] 2013 TWDB calculated capacity of 131,530 acre-feet plus 2013 TWDB calculated sediment volume of 10,518 acre-feet

Recommendations

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

TWDB contact information

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

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Appendix A

Lake Brownwood

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | June 2013 Survey
CAPACITY IN ACRE-FEET | Conservation Pool Elevation 1,425.0 feet NAVD88
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
1,361	0	0	0	0	0	0	0	0	0	0
1,362	0	0	0	0	0	0	1	1	1	1
1,363	1	2	2	2	2	2	3	3	3	3
1,364	4	4	4	5	5	5	6	6	6	7
1,365	7	8	9	9	10	11	12	13	14	16
1,366	17	19	20	22	24	26	28	30	32	35
1,367	37	40	43	45	48	51	54	57	60	64
1,368	67	70	74	77	81	84	88	92	97	101
1,369	105	110	114	119	123	128	133	138	143	149
1,370	154	159	165	170	176	181	187	193	199	205
1,371	211	217	223	230	236	243	250	258	265	273
1,372	280	288	296	304	312	321	329	337	346	355
1,373	364	373	382	391	400	410	419	429	439	449
1,374	459	469	479	490	501	511	522	534	545	556
1,375	568	580	592	604	617	629	642	654	667	681
1,376	694	707	721	734	748	762	776	791	805	819
1,377	834	849	864	879	894	910	925	941	957	974
1,378	990	1,007	1,024	1,042	1,059	1,077	1,095	1,114	1,132	1,151
1,379	1,170	1,189	1,209	1,229	1,250	1,270	1,291	1,312	1,334	1,355
1,380	1,377	1,400	1,422	1,445	1,468	1,491	1,515	1,539	1,563	1,588
1,381	1,613	1,638	1,664	1,690	1,716	1,743	1,770	1,797	1,825	1,853
1,382	1,882	1,911	1,941	1,971	2,001	2,032	2,064	2,096	2,129	2,162
1,383	2,196	2,230	2,265	2,301	2,337	2,373	2,411	2,449	2,487	2,526
1,384	2,566	2,606	2,647	2,689	2,731	2,774	2,817	2,862	2,907	2,953
1,385	2,999	3,047	3,096	3,145	3,196	3,247	3,299	3,352	3,406	3,461
1,386	3,516	3,573	3,630	3,687	3,746	3,805	3,865	3,926	3,987	4,049
1,387	4,112	4,176	4,240	4,306	4,372	4,439	4,507	4,576	4,646	4,716
1,388	4,788	4,861	4,935	5,010	5,086	5,163	5,241	5,319	5,399	5,480
1,389	5,561	5,644	5,729	5,814	5,901	5,989	6,078	6,169	6,261	6,355
1,390	6,449	6,545	6,643	6,742	6,842	6,943	7,046	7,150	7,255	7,362
1,391	7,470	7,580	7,691	7,803	7,917	8,032	8,148	8,265	8,384	8,504
1,392	8,625	8,748	8,871	8,996	9,122	9,249	9,378	9,507	9,638	9,770
1,393	9,903	10,038	10,173	10,310	10,448	10,587	10,728	10,870	11,013	11,158
1,394	11,304	11,451	11,599	11,749	11,900	12,053	12,206	12,361	12,517	12,674
1,395	12,832	12,991	13,151	13,312	13,474	13,638	13,802	13,967	14,134	14,302
1,396	14,471	14,641	14,812	14,984	15,158	15,333	15,509	15,687	15,866	16,045
1,397	16,226	16,408	16,590	16,774	16,959	17,144	17,331	17,519	17,708	17,898
1,398	18,090	18,282	18,476	18,671	18,866	19,064	19,262	19,461	19,662	19,865
1,399	20,068	20,274	20,480	20,689	20,898	21,109	21,321	21,535	21,750	21,968
1,400	22,187	22,408	22,630	22,855	23,081	23,309	23,539	23,771	24,005	24,242
1,401	24,481	24,722	24,966	25,213	25,460	25,710	25,961	26,214	26,468	26,724
1,402	26,981	27,239	27,498	27,759	28,021	28,284	28,548	28,813	29,079	29,346
1,403	29,615	29,885	30,156	30,428	30,702	30,976	31,253	31,530	31,810	32,090
1,404	32,372	32,655	32,939	33,225	33,512	33,801	34,091	34,383	34,677	34,972
1,405	35,269	35,567	35,867	36,169	36,473	36,778	37,086	37,395	37,706	38,019
1,406	38,333	38,650	38,969	39,290	39,612	39,936	40,263	40,591	40,922	41,254
1,407	41,588	41,924	42,262	42,602	42,944	43,286	43,631	43,976	44,324	44,673
1,408	45,024	45,377	45,732	46,088	46,446	46,805	47,167	47,529	47,894	48,261
1,409	48,628	48,997	49,368	49,741	50,114	50,489	50,865	51,242	51,621	52,001
1,410	52,383	52,765	53,150	53,536	53,923	54,312	54,702	55,093	55,487	55,882
1,411	56,278	56,676	57,075	57,476	57,879	58,283	58,689	59,097	59,506	59,918
1,412	60,331	60,746	61,163	61,582	62,003	62,426	62,851	63,279	63,708	64,139
1,413	64,573	65,009	65,446	65,886	66,328	66,771	67,217	67,665	68,115	68,567
1,414	69,021	69,477	69,936	70,396	70,858	71,322	71,789	72,257	72,728	73,201
1,415	73,675	74,152	74,631	75,111	75,594	76,079	76,566	77,055	77,546	78,040

Appendix A (continued)

Lake Brownwood

RESERVOIR CAPACITY TABLE

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

June 2013 Survey
Conservation Pool Elevation 1,425.0 feet NAVD88

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1,416	78,535	79,032	79,531	80,033	80,536	81,042	81,549	82,059	82,571	83,084
1,417	83,600	84,118	84,638	85,160	85,684	86,210	86,738	87,268	87,801	88,335
1,418	88,871	89,410	89,950	90,493	91,037	91,584	92,133	92,684	93,236	93,791
1,419	94,348	94,907	95,468	96,031	96,597	97,164	97,733	98,304	98,878	99,453
1,420	100,031	100,610	101,192	101,776	102,362	102,949	103,539	104,131	104,725	105,321
1,421	105,919	106,519	107,122	107,726	108,332	108,940	109,551	110,163	110,778	111,395
1,422	112,013	112,634	113,257	113,882	114,508	115,137	115,768	116,401	117,037	117,674
1,423	118,313	118,954	119,598	120,243	120,890	121,540	122,192	122,845	123,501	124,159
1,424	124,818	125,480	126,144	126,810	127,478	128,148	128,820	129,495	130,171	130,849
1,425	131,530	132,212	132,897	133,583	134,272	134,962	135,655	136,350		

Note: Capacities above elevation 1,412.5 feet calculated from interpolated areas

Appendix B

Lake Brownwood

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — June 2013 Survey

AREA IN ACRES — Conservation Pool Elevation 1,425.0 feet NAVD88

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
1,361	0	0	0	0	0	0	0	0	0	0
1,362	0	1	1	1	1	1	2	2	2	2
1,363	2	2	2	2	2	2	2	3	3	3
1,364	3	3	3	3	3	3	4	4	5	5
1,365	6	6	7	7	8	9	10	12	13	14
1,366	14	15	17	18	19	20	22	23	24	25
1,367	26	26	27	27	28	30	31	31	32	33
1,368	33	34	35	36	37	37	40	41	42	43
1,369	44	45	46	47	48	49	50	51	52	52
1,370	53	54	55	55	56	57	58	58	59	60
1,371	61	62	63	65	67	70	72	74	75	76
1,372	78	79	80	81	82	83	84	86	87	88
1,373	89	90	91	93	94	95	96	97	99	100
1,374	102	103	105	106	108	109	111	112	114	116
1,375	118	120	121	122	124	125	127	129	131	132
1,376	133	135	136	137	139	140	142	143	144	146
1,377	147	149	151	152	154	155	157	160	162	165
1,378	167	170	172	175	177	180	182	185	187	190
1,379	193	196	199	202	205	208	210	213	216	219
1,380	222	224	227	229	232	235	237	241	244	248
1,381	251	254	258	261	265	269	272	276	280	285
1,382	289	293	298	303	308	313	319	324	330	336
1,383	341	346	352	358	364	370	376	382	388	395
1,384	401	407	412	418	425	432	439	447	455	463
1,385	472	480	490	500	509	518	527	535	543	551
1,386	558	566	574	582	589	596	603	610	618	625
1,387	632	640	648	658	667	676	685	693	703	714
1,388	724	734	744	755	764	773	782	792	802	812
1,389	824	837	849	861	874	887	900	914	928	941
1,390	955	967	980	994	1,008	1,021	1,034	1,047	1,062	1,075
1,391	1,088	1,102	1,117	1,131	1,143	1,154	1,167	1,180	1,193	1,207
1,392	1,219	1,231	1,242	1,253	1,265	1,279	1,291	1,302	1,315	1,327
1,393	1,338	1,349	1,361	1,374	1,386	1,399	1,413	1,426	1,440	1,452
1,394	1,465	1,479	1,492	1,504	1,517	1,529	1,541	1,553	1,564	1,575
1,395	1,586	1,596	1,607	1,617	1,627	1,638	1,649	1,660	1,671	1,684
1,396	1,695	1,707	1,719	1,731	1,744	1,756	1,770	1,781	1,792	1,802
1,397	1,812	1,821	1,832	1,841	1,852	1,862	1,874	1,885	1,896	1,907
1,398	1,919	1,931	1,942	1,953	1,965	1,977	1,989	2,002	2,016	2,030
1,399	2,046	2,060	2,074	2,088	2,102	2,116	2,131	2,146	2,162	2,183
1,400	2,200	2,218	2,236	2,253	2,270	2,288	2,309	2,331	2,353	2,377
1,401	2,403	2,428	2,454	2,471	2,488	2,504	2,519	2,533	2,550	2,564
1,402	2,578	2,590	2,601	2,612	2,622	2,634	2,645	2,656	2,667	2,680
1,403	2,692	2,704	2,716	2,729	2,742	2,756	2,771	2,785	2,798	2,811
1,404	2,824	2,837	2,851	2,865	2,881	2,897	2,912	2,927	2,944	2,960
1,405	2,975	2,992	3,010	3,028	3,047	3,064	3,083	3,100	3,119	3,137
1,406	3,156	3,177	3,197	3,216	3,235	3,255	3,275	3,294	3,314	3,333
1,407	3,352	3,371	3,388	3,405	3,421	3,436	3,451	3,467	3,484	3,501
1,408	3,518	3,537	3,554	3,570	3,587	3,604	3,623	3,639	3,654	3,669
1,409	3,685	3,701	3,715	3,728	3,741	3,754	3,768	3,781	3,795	3,809
1,410	3,823	3,837	3,851	3,865	3,880	3,894	3,909	3,924	3,940	3,955
1,411	3,971	3,987	4,003	4,018	4,035	4,051	4,068	4,086	4,104	4,122
1,412	4,141	4,160	4,179	4,200	4,220	4,243	4,263	4,284	4,304	4,325
1,413	4,345	4,366	4,387	4,407	4,428	4,448	4,469	4,489	4,510	4,531
1,414	4,551	4,572	4,592	4,613	4,633	4,654	4,675	4,695	4,716	4,736
1,415	4,757	4,777	4,798	4,819	4,839	4,860	4,880	4,901	4,921	4,942

Appendix B (continued)

Lake Brownwood

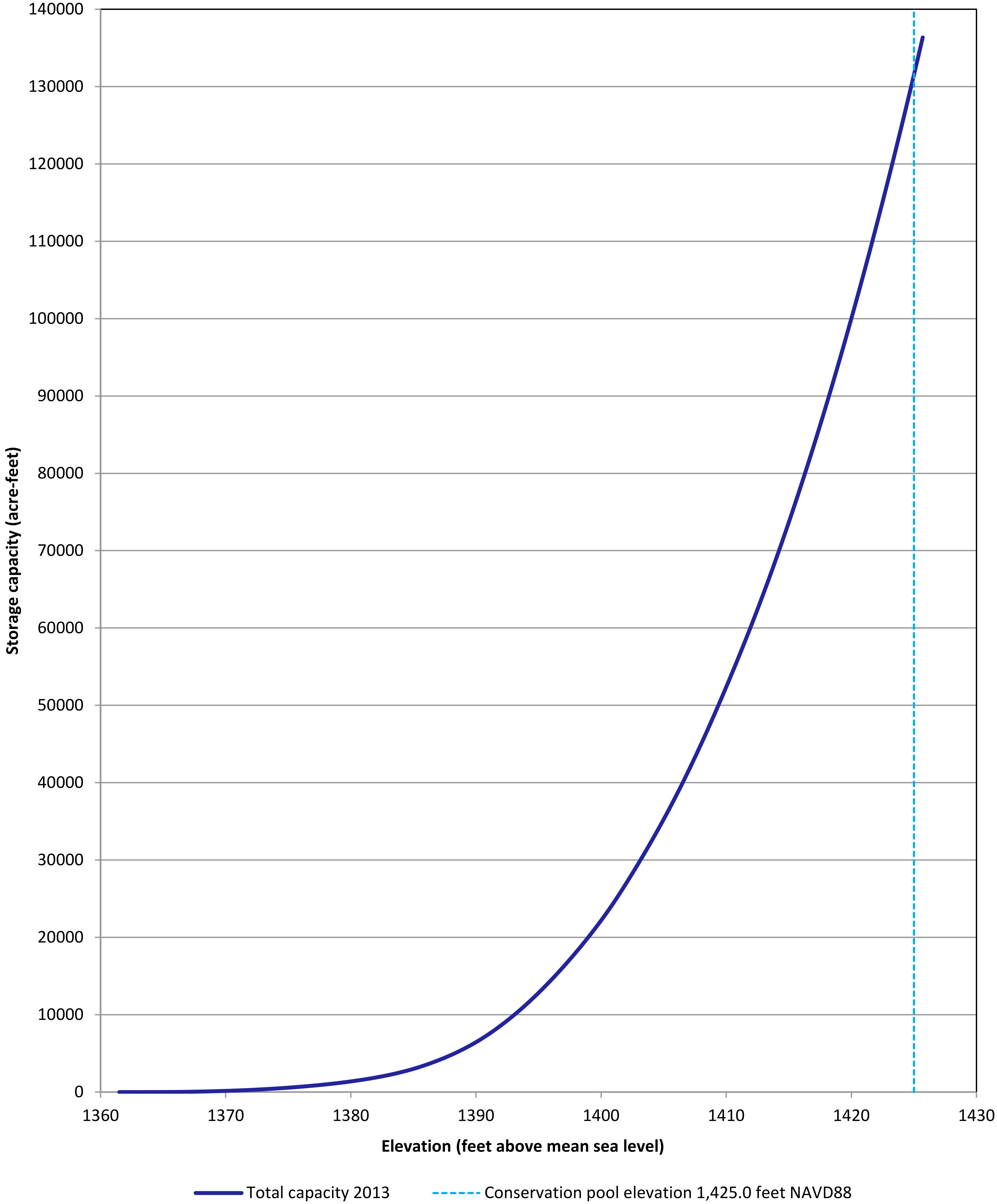
RESERVOIR AREA TABLE

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

June 2013 Survey
Conservation Pool Elevation 1,425.0 feet NAVD88

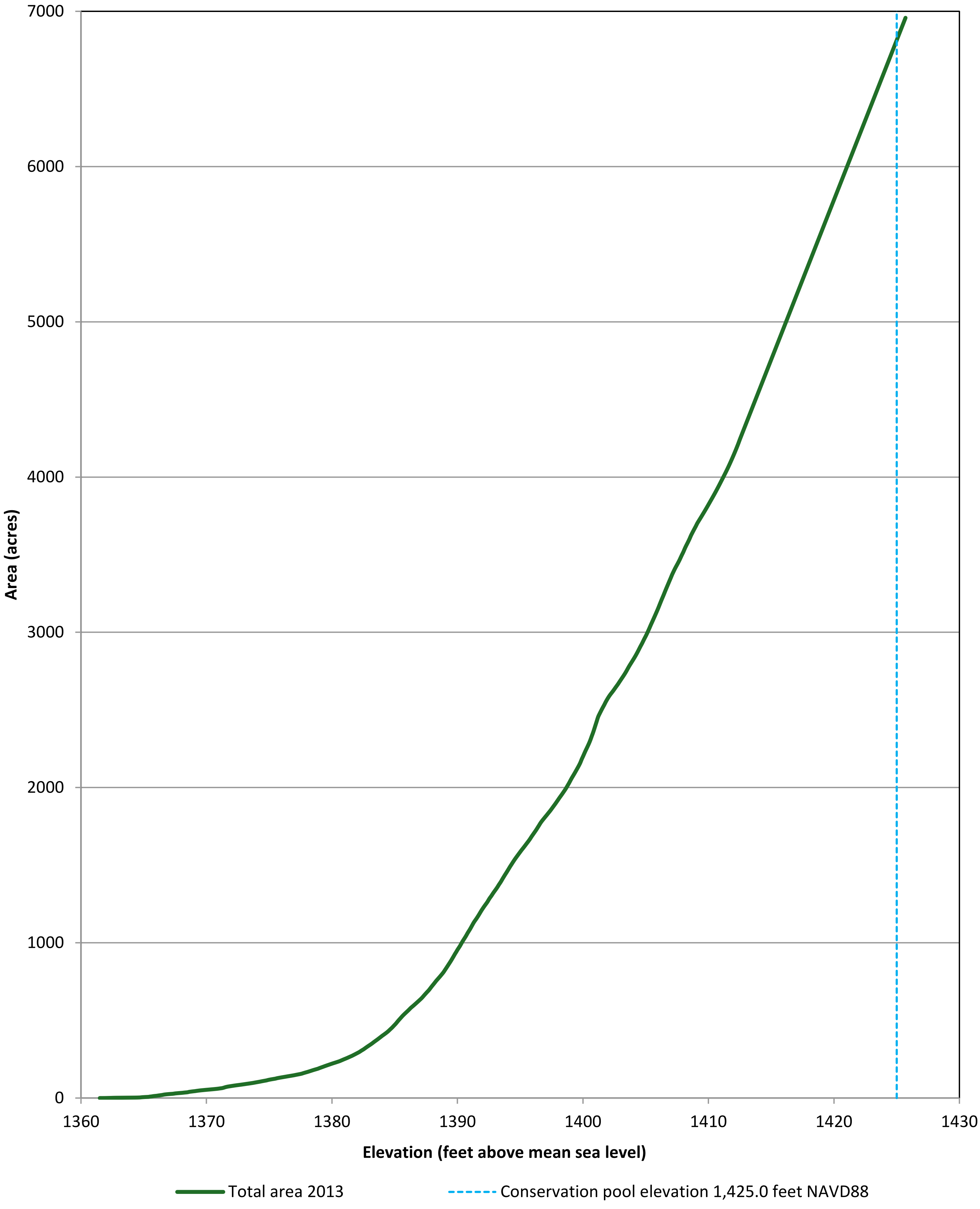
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1,416	4,963	4,983	5,004	5,024	5,045	5,065	5,086	5,107	5,127	5,148
1,417	5,168	5,189	5,209	5,230	5,251	5,271	5,292	5,312	5,333	5,353
1,418	5,374	5,395	5,415	5,436	5,456	5,477	5,497	5,518	5,539	5,559
1,419	5,580	5,600	5,621	5,641	5,662	5,683	5,703	5,724	5,744	5,765
1,420	5,785	5,806	5,827	5,847	5,868	5,888	5,909	5,929	5,950	5,971
1,421	5,991	6,012	6,032	6,053	6,073	6,094	6,115	6,135	6,156	6,176
1,422	6,197	6,217	6,238	6,259	6,279	6,300	6,320	6,341	6,361	6,382
1,423	6,403	6,423	6,444	6,464	6,485	6,505	6,526	6,547	6,567	6,588
1,424	6,608	6,629	6,649	6,670	6,691	6,711	6,732	6,752	6,773	6,793
1,425	6,814	6,835	6,855	6,876	6,896	6,917	6,937	6,958		

Note: Areas above elevation 1,412.5 feet interpolated



Lake Brownwood
June 2013 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Lake Brownwood
June 2013 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

CONTOURS
(feet NAVD88)

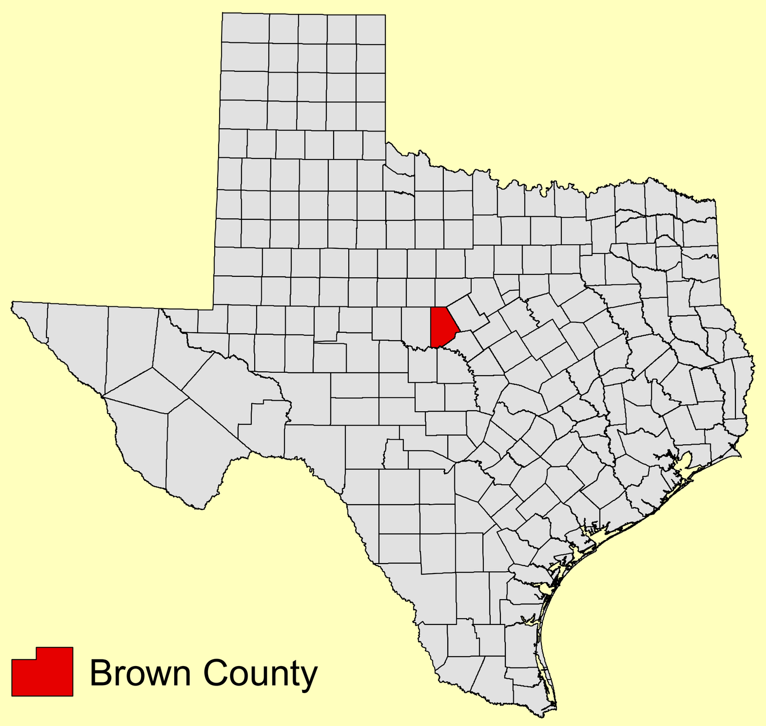
- 1425
- 1420
- 1415
- 1410
- 1405
- 1400
- 1395
- 1390
- 1385
- 1380
- 1375
- 1370
- 1365

Islands

Lake Brownwood
Elevation 1,425.7 feet
NAVD88

Conservation Pool Elevation
1,425.0 feet NAVD88

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 Lake Brownwood. The Texas Water Development Board makes no representations nor assumes any liability.

Lake Brownwood

5' - contour map