Volumetric and Sedimentation Survey of LAKE PALESTINE

July - August 2012 Survey

Texas Water Development Board

February 2014

Texas Water Development Board

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Upper Neches River Municipal Water Authority

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Executive summary

In June 2012, the Texas Water Development Board (TWDB) entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Palestine. 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 Upper Neches River Municipal Water Authority provided the remaining 50%. Surveying was performed using a multi-frequency (200 kHz, 50 kHz, and 24 kHz), sub-bottom profiling depth sounder. In addition, sediment core samples were collected in select locations and correlated with the multi-frequency depth sounder signal returns to estimate sediment accumulation thicknesses and sedimentation rates.

Blackburn Crossing Dam and Lake Palestine are located on the Neches River in Anderson, Cherokee, Henderson, and Smith Counties, approximately four miles east of Frankston, Texas. The conservation pool elevation of Lake Palestine is 345.0 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Lake Palestine between July 10, 2012, and August 22, 2012. The daily average water surface elevations during the survey ranged between 343.84 and 344.67 feet (NGVD29).

The 2012 TWDB volumetric survey indicates that Lake Palestine has a total reservoir capacity of 367,312 acre-feet and encompasses 23,112 acres at conservation pool elevation (345.0 feet above mean sea level, NGVD29). Previous capacity estimates include: the original design estimate of 411,840 acre-feet at the time of dam enlargement completed in 1971; an area-capacity table from Turner Collie & Braden Inc. dated 1989, indicating a capacity of 361,600 acre-feet; and re-analysis of the 2003 TWDB volumetric survey data using current processing procedures that resulted in an updated capacity estimate of 378,099 acre-feet.

Based on two methods for estimating sedimentation rates, the 2012 TWDB sedimentation survey estimates Lake Palestine to have an average loss of capacity between 621 and 1,086 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (345.0 feet NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. The heaviest accumulations measured by this survey are in the submerged river channels and in the main body of the lake between Caney Creek and Cobb Creek. The greatest accumulations are adjacent to the city of Berryville. TWDB recommends that a similar methodology be used to resurvey Lake Palestine in 10 years or after a major flood event.

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

Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. 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 June 2012, TWDB entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Palestine. 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 Upper Neches River Municipal Water Authority provided the remaining 50% (TWDB, 2012). 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 Upper Neches River Municipal Water 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].

Lake Palestine general information

Blackburn Crossing Dam and Lake Palestine are located on the Neches River in Anderson, Cherokee, Henderson, and Smith Counties, approximately four miles east of Frankston, Texas (Figure 1). Blackburn Crossing Dam and Lake Palestine are owned and operated by the Upper Neches River Municipal Water Authority (UNRMWA, 2012a). The Upper Neches River Municipal Water Authority was created by the 53rd Texas Legislature in 1953 as a conservation and reclamation district to "store, control, conserve, protect, distribute, and utilize storm and floodwaters and unappropriated flow of the Neches River and its tributaries" within Anderson, Cherokee, Henderson, and Smith Counties (UNRMWA, 2012a). Construction of the dam began on May 30, 1960, and was completed on June 13, 1962. Deliberate impoundment of water began on May 1, 1962. Enlargement of the dam began on September 26, 1969, and was completed on March 3, 1971 (TWDB, 1973). Lake Palestine water is used primarily for municipal and industrial purposes. The cities of Dallas, Tyler, and Palestine are the main purchasers of the water (UNRMWA, 2012b). Additional pertinent data about Blackburn Crossing Dam and Lake Palestine can be found in Table 1.

Water rights for Lake Palestine have been appropriated to the Upper Neches River Municipal Water Authority through Certificate of Adjudication No. 06-3254 and Amendments to Certificate of Adjudication Nos. 06-3254A, 06-3254B, and 06-3254C. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

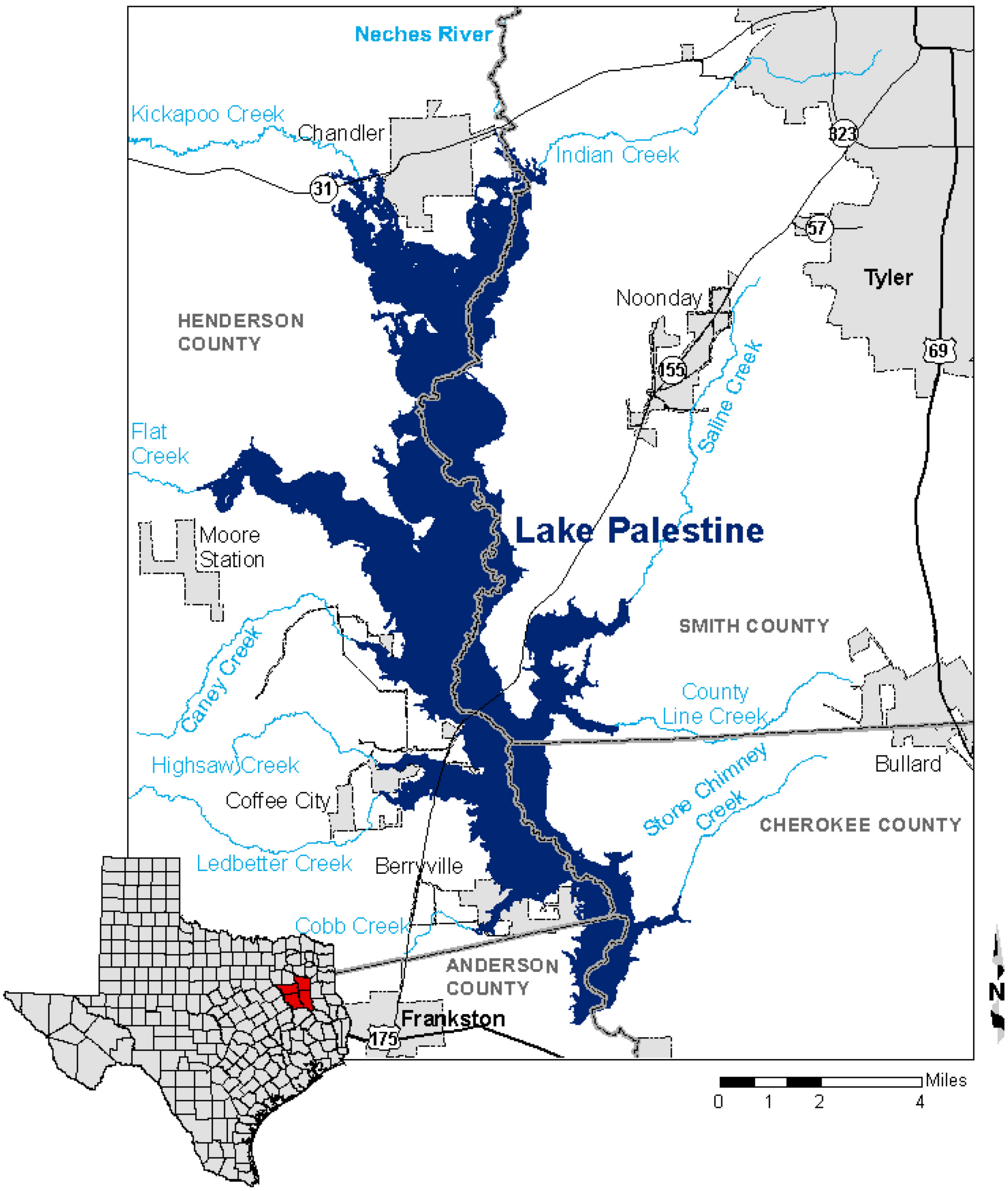


Figure 1. Location of Lake Palestine

Table 1.	**Pertinent data for Blackburn Crossing Dam and Lake Palestine**
Owner	
Upper Neches River Municipal Water Authority	
Design Engineer	
Forrest and Cotton, Inc.	
General contractor for enlargement	
Wm. A. Smith Construction Co., Inc.	
Location of dam	
On the Neches River in Anderson and Cherokee Counties, approximately 4 miles east of Frankston, Texas. The reservoir extends into Henderson and Smith Counties.	
Drainage area	
839 square miles	
Dam	
Type	Earthfill
Length including spillway	5,720 feet
Maximum height	75 feet
Width at crown	24 feet
Spillway (emergency)	
Location	Near the left end of the dam
Type	Concrete ogee weir
Control	None
Crest length	500 feet
Crest elevation	345 feet above mean sea level
Outlet works (service spillway)	
Location	Near the center of the dam
Type	Gated concrete tower
Discharge	Conduit, 8.5-feet diameter
Invert of conduit	298.0 feet above mean sea level
Control	Two 5 by 7 feet gates
Low flow outlet	
Type	2 pipes, 36-inch diameter from tower
Control	Valves operated from tower
Discharge	To outlet conduit
Lowest slide gate invert to tower	309.5 feet above mean sea level
Other slide gates invert to tower	312.5 feet, 322.5 feet, and 332.5 feet above mean sea level
Gate size	Each 3.5 by 5feet

Reservoir data (Based on 2012 TWDB survey)

Feature	**Elevation (feet** NGVD29[a]**)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	364.0	N/A	N/A
Design water surface	355.3	N/A	N/A
Spillway crest (conservation pool)	345.0	367,312	23,112
Invert of low flow outlet	309.5	N/A	N/A
Invert of conduit (service spillway)	298.0	9	6
Usable conservation storage space[b]	-	367,303	-

Source: (TWDB, 1973, TWDB, 2005, TCB Inc., 1989, UNRMWA, 2012b)

[a] NGVD29 = National Geodetic Vertical Datum 1929

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

Volumetric and sedimentation survey of Lake Palestine

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 08031400 Lk Palestine nr Frankston, 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 North Central Zone (feet).

TWDB bathymetric and sedimentation data collection

TWDB collected bathymetric data for Lake Palestine between July 10-12, 2012, July 14-15, 2012, July 31, 2012, August 1-9, 2012, August 14-16, 2012, and August 21-22, 2012. The daily average water surface elevations during the survey ranged between 343.84 and 344.67 feet above mean sea level (NGVD29). For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data 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 2012 TWDB survey.

All sounding data was collected and reviewed before sediment core sampling sites were selected. Sediment core samples are collected at regularly spaced intervals within the reservoir, or at locations where interpretation of the acoustic display would be difficult without site-specific sediment core data. After analyzing the sounding data, TWDB selected eight locations to collect sediment core samples (Figure 2). The sediment core samples were collected on May 17, 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.

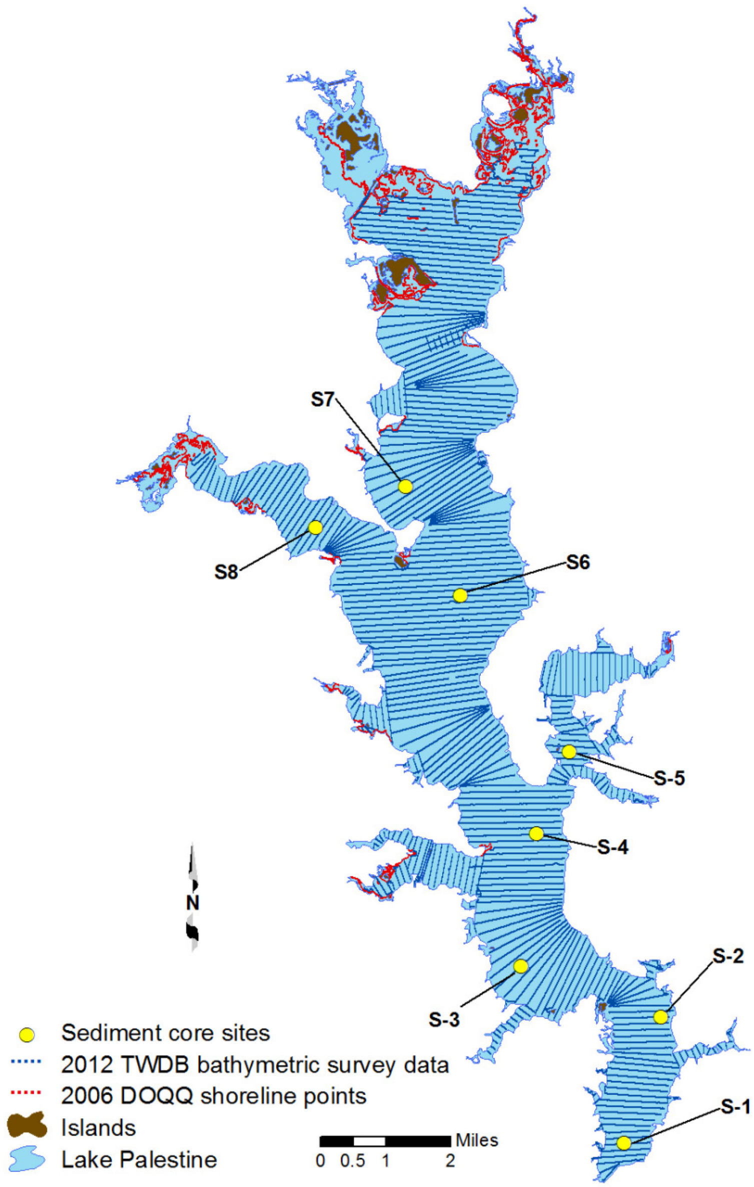


Figure 2. Data collected during 2012 TWDB Lake Palestine survey

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, 2009) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Palestine are Berryville (NE, NW, SE, SW), Poynor (NE), Moore Station (NE, SE), Saline Bay (NW, SE, SW), Chandler (SW), and Brownsboro (SE). The DOQQs were photographed on January 11, 2009, and January 22, 2009, while the daily average water surface elevation measured 345.22 feet and 345.04 feet, respectively (NGVD29). According to metadata associated with the 2009 DOQQs, the photographs have a resolution or ground sample distance of 0.5-meters and a horizontal accuracy within 3-5 meters to true ground (USDA, 2013, TNRIS, 2009). For this analysis, the boundary was digitized at the land-water interface in the 2009 photographs and assigned an elevation of 345.0 feet.

Where survey data alone was not sufficient to model the reservoir topography, additional boundary information was obtained from aerial photographs taken on August 18, 2006, while the daily average water surface elevation measured 341.33 feet. The 2006 boundary information was added to the lake model as points. According to metadata associated with the 2006 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters, rectified to National Mapping Standards at the 1:24,000 scale (USDA, 2006).

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

In areas inaccessible to survey data collection such as small coves and shallow upstream areas of the reservoir, linear extrapolation is used for volumetric and sediment accumulation estimations. The linear extrapolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without extrapolated data, the TIN Model builds flat triangles. A flat triangle is defined as a triangle where all three vertices are equal in elevation, generally the elevation of the reservoir boundary. Reducing flat triangles, by applying linear extrapolation, improves the elevation-capacity and elevation-area calculations. It is not always possible to remove all flat triangles, and linear extrapolation is only applied where adding bathymetry is deemed reasonable. For example, linear extrapolation was deemed reasonable and applied to Lake Palestine 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 aerial photographs taken on August 18, 2006, while the daily average water surface elevation measured 341.33 feet.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear extrapolation techniques to Lake Palestine. 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).

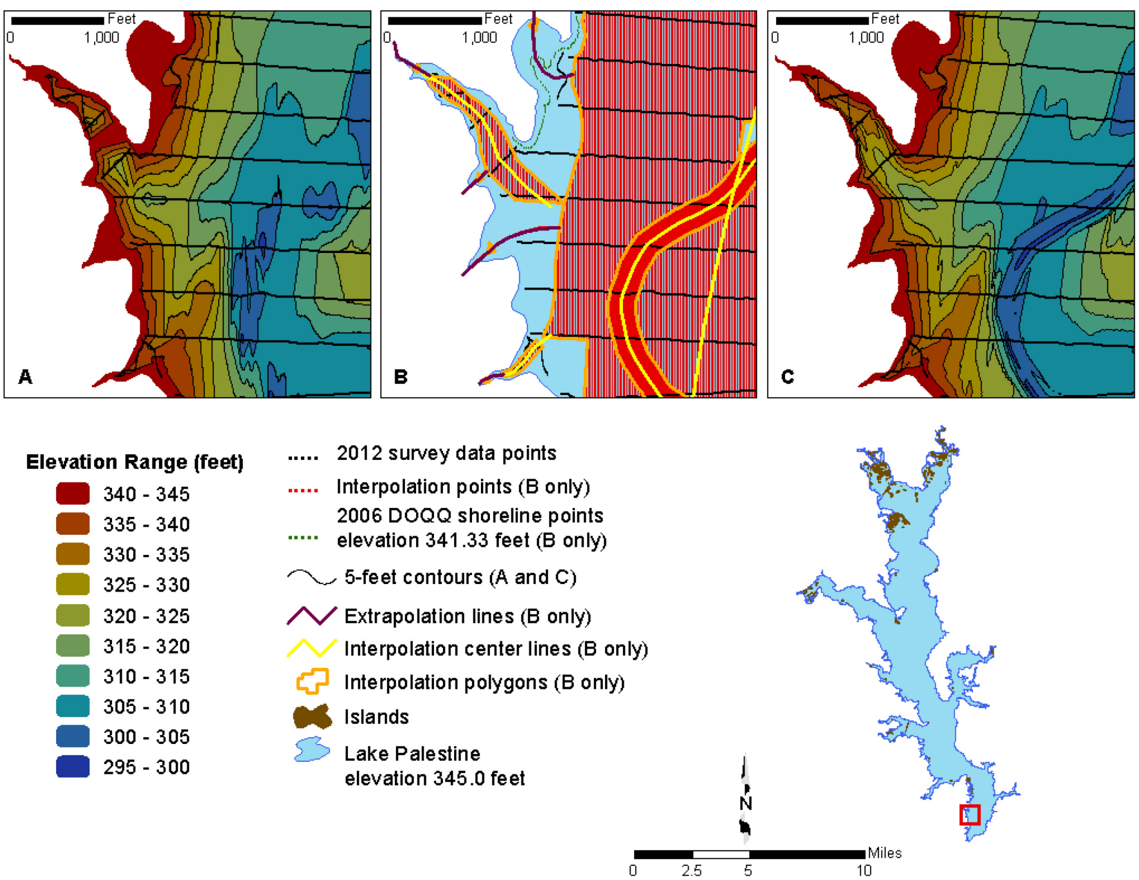


Figure 3. Anisotropic spatial interpolation and linear extrapolation of Lake Palestine sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points

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 292.1 to 345.0 feet. The use of contour data from the 2006 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, 341.33 feet and 345.0 feet. To eliminate the effects of the flat triangles on area and volume calculations, areas between elevations 341.0 feet and 345.0 feet were linearly interpolated between the computed values, and volumes above elevation 341.0 were calculated based on the corrected areas. The elevation-capacity table and elevation-area table, updated for 2012, 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 Palestine; and a 5-foot contour map (Figure 6 - attached).

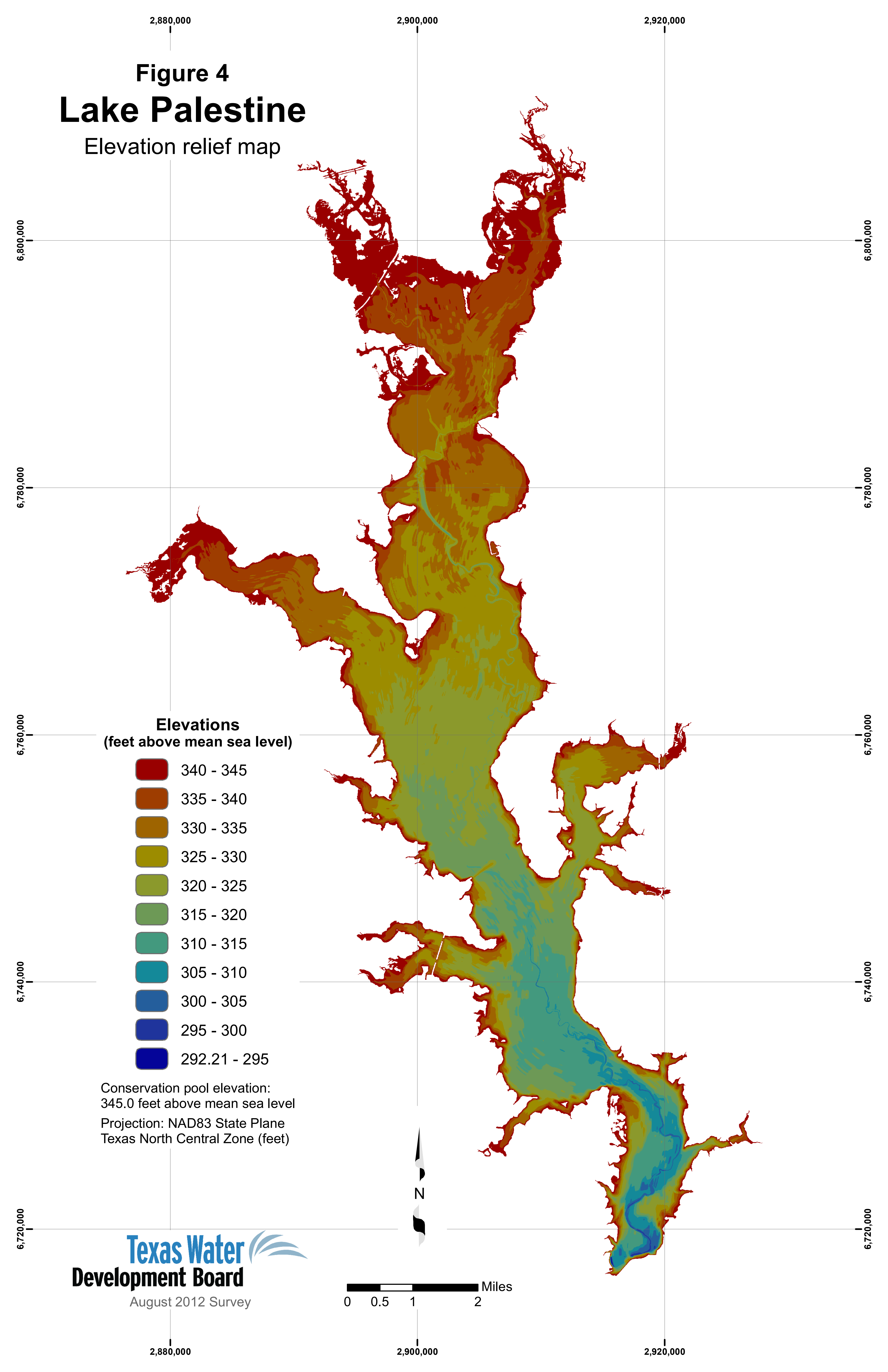
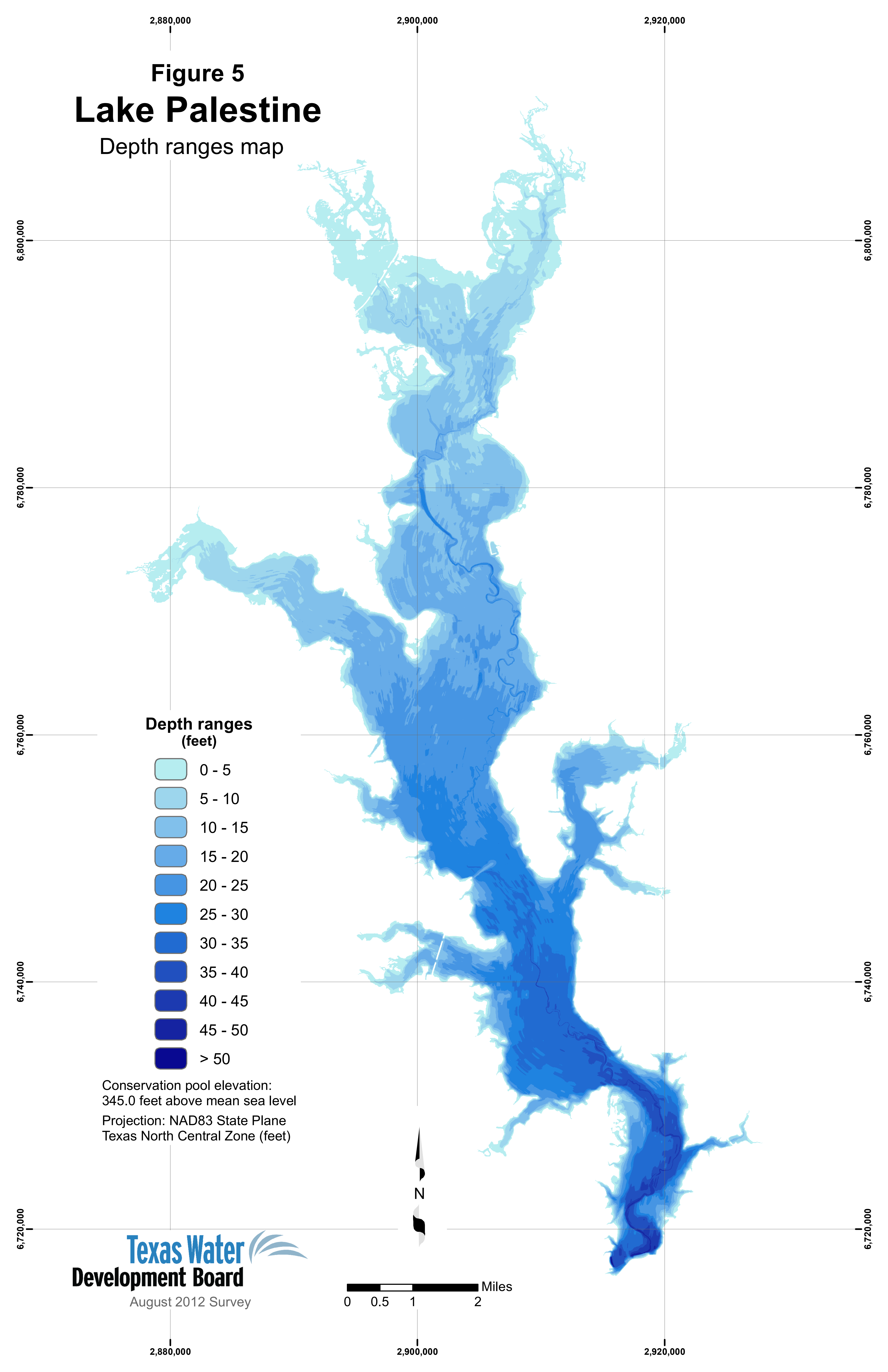


Figure 4
Lake Palestine
Elevation relief map
2,880,000
2,900,000
2,920,000
6,800,000
6,780,000
6,760,000
6,740,000
6,720,000
Elevations
(feet above mean sea level)
340 - 345
335 - 340
330 - 335
325 - 330
320 - 325
315 - 320
310 - 315
305 - 310
300 - 305
295 - 300
292.21 - 295
Conservation pool elevation:
345.0 feet above mean sea level
Projection: NAD83 State Plane
Texas North Central Zone (feet)
N
Miles
0
0.5
1
2
Texas Water
Development Board
August 2012 Survey


2,880,000
2,900,000
2,920,000
Figure 5
Lake Palestine
Depth ranges map
6,800,000
6,780,000
6,760,000
6,740,000
6,720,000
Depth ranges
(feet)
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
> 50
Conservation pool elevation:
345.0 feet above mean sea level
Projection: NAD83 State Plane
Texas North Central Zone (feet)
N
Texas Water
Development Board
August 2012 Survey
Miles
0
0.5
1
2

Analysis of sediment data from Lake Palestine

Sedimentation in Lake Palestine 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 Palestine

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
P-1	2917685.08	6719363.46	62"/ 14"	0-1.5" higher water content, sandy soil	2.5Y 4/2
				1.5-14" higher water content, sandy soil	5Y 2.5/1
				14-54" low water content, sandy soil	10YR 5/3
				54-62" low water content, sandy soil	10YR 5/6
P-2	2920671.89	6729623.91	48"/14"	0-14" high water content, loose sediment	7.5YR 2.5/1
				14-26" sandy soil, organics present at approximately 21"	2.5YR 4/3
				26-48" fairly high water content, sandy clay, organics present	2.5Y 4/1
P-3	2909313.65	6733757.37	32"/14"	0-11" high water content, very loose sediment	10YR 2/2
				11-14" high water content, clay	10YR 3/1
				14-32" sandy clay, organics present	10YR 2/1
P-4	2910567.20	6744515.65	29"/12"	0-6" high water content, loose sediment	10YR 2/2
				6-12" high water content, loamy clay, some organics	2.5Y 3/2
				12-29" sandy clay	2.5Y 4/3
P-5	2913251.87	6751153.12	31.5"/19"	0-14" high water content, loose sediment	7.5YR 2.5/1
				14-19" sandy clay, organics present	GLEY1 2.5/10Y
				19-31.5" clay loam, organics present	2.5Y 4/1
P-6	2904370.92	6763878.39	23"/11"	0-8" high water content, loose sediment	5Y 2.5/2
				8-11" high water content, sandy loam	5Y 4/1
				11-19" sandy soil, organics present	5Y 5/1
				19-23" sandy clay	FLEY 4/N
P-7	2899917.11	6772746.92	38"/15.5"	0-15.5" high water content, loose sediment	5Y 2.5/2
				15.5-38" sandy clay, organics present	2.5Y 5/1
P-8	2892607.95	6769431.13	37"/12"	0-12" high water content, loose sediment	5Y 2.5/1
				12-37" sandy soil, organics present	10YR 5/2

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

A photograph of sediment core P-5 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Palestine. The 200 kHz frequency measures the top layer as the current bottom surface of the reservoir.

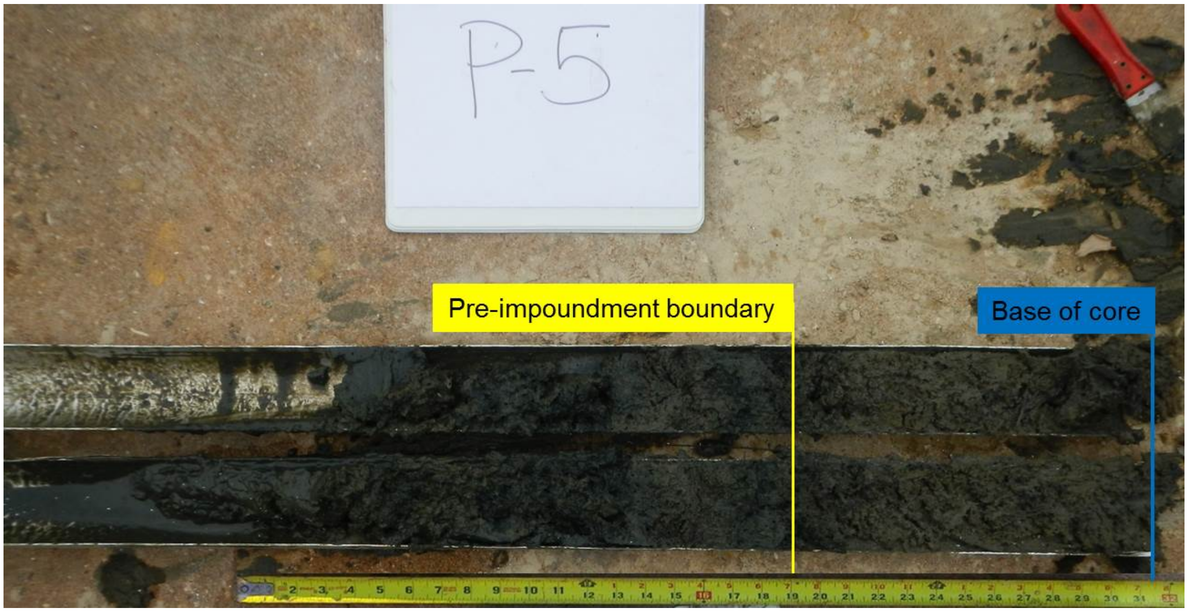


Figure 7. Sediment core P-5 from Lake Palestine

Sediment core sample P-5 consisted of 31.5 inches of total sediment. The upper sediment layer (horizon), 0–14.0 inches, consisted of loose sediment with a high water content and measured 7.5YR 2.5/1 on the Munsell soil color chart. The second horizon, beginning at 14.0 inches and extending to 19.0 inches below the surface, consisted of sandy clay sediment with organics present and measured GLEY1 2.5/10Y on the Munsell soil color chart. The third horizon, beginning at 19.0 inches and extending to 31.5 inches below the surface, consisted of a clay loam soil with organics present and a 2.5Y 4/1 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 19.0 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.

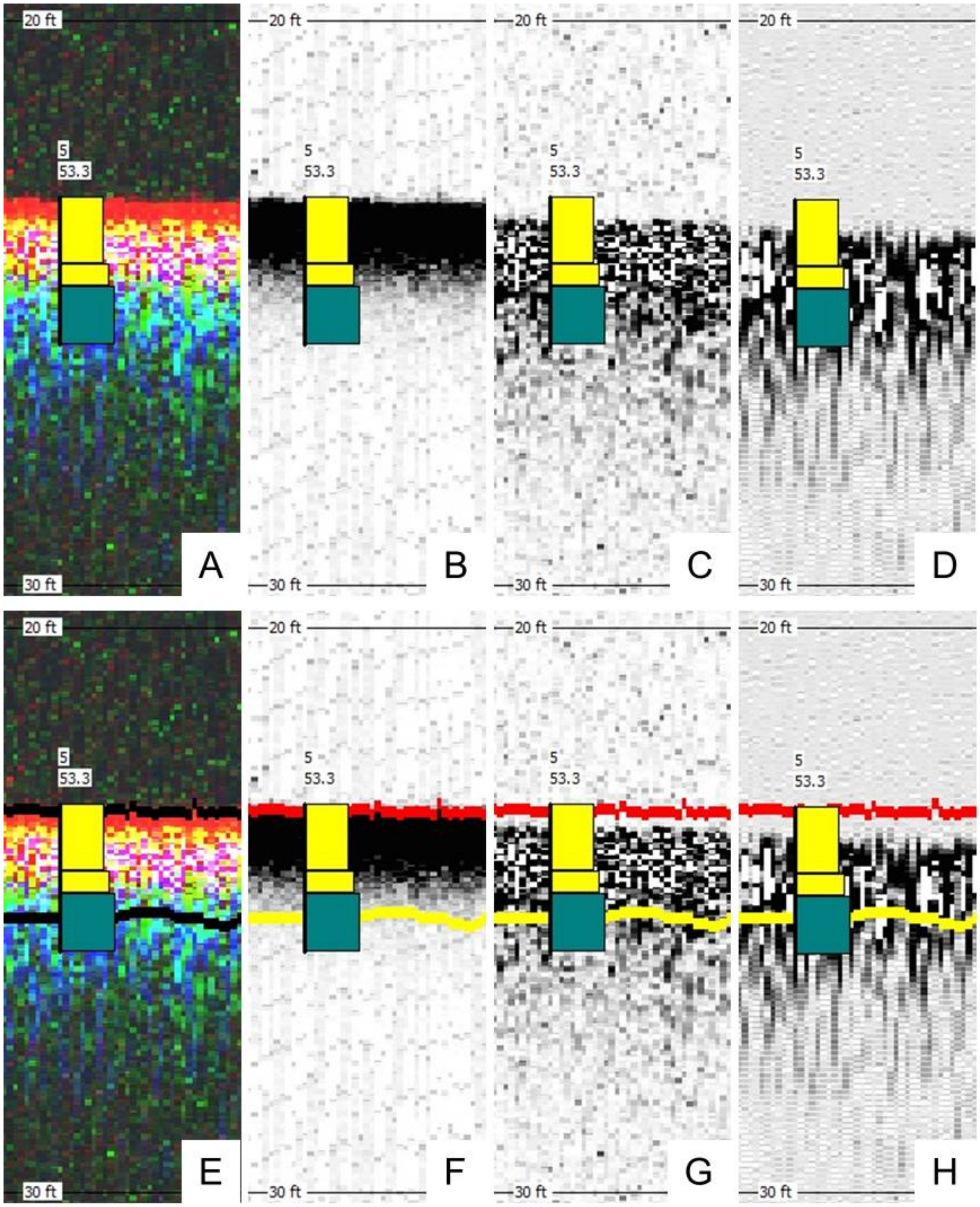


Figure 8. Comparison of sediment core P-5 with acoustic signal returns: A,E) combined acoustic signal returns, B,F) 200 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 8 compares sediment core sample P-5 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 P-5 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.

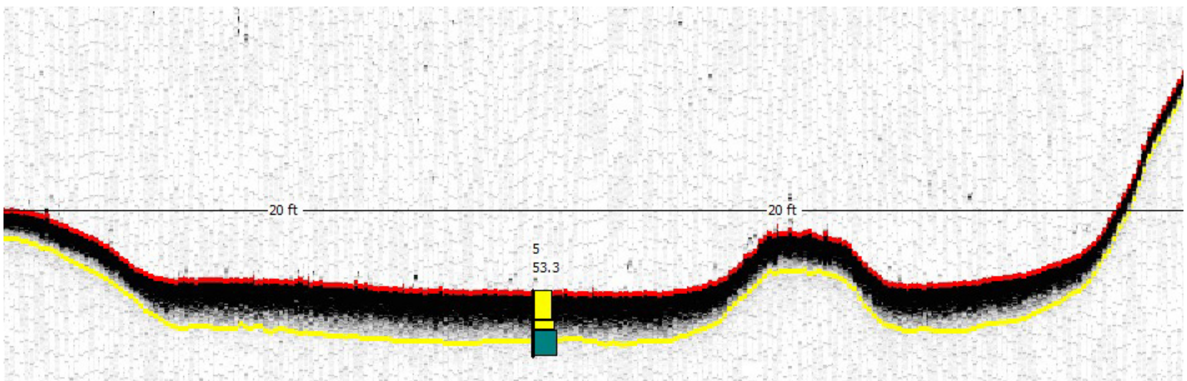
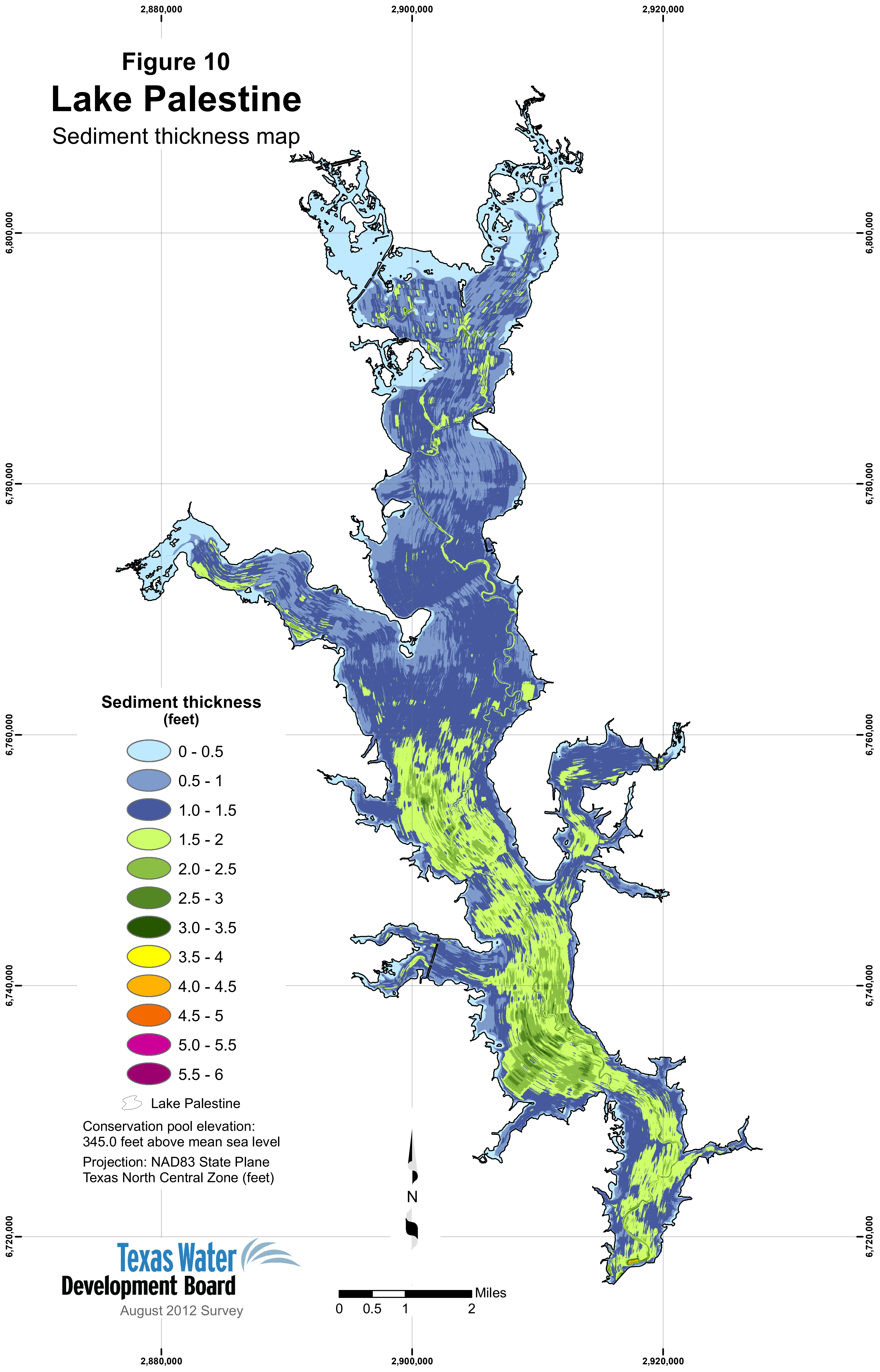


Figure 9. Cross-section of data collected during 2012 survey, displayed in DepthPic© (200 kHz frequency), correlated with sediment core sample P-5 and showing the current surface in red and pre-impoundment surface in yellow

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 345.0 foot NGVD29 elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 5 feet by 5 feet and used to produce a sediment thickness map of Lake Palestine (Figure 10).

Figure 10
Lake Palestine
Sediment thickness map



Survey results

Volumetric survey

The results of the 2012 TWDB volumetric survey indicate Lake Palestine has a total reservoir capacity of 367,312 acre-feet and encompasses 23,112 acres at conservation pool elevation (345.0 feet above mean sea level, NGVD29). Previous capacity estimates include the original design estimate of 411,840 acre-feet at the time of dam enlargement completed in 1971, and an area-capacity table from Turner Collie & Braden Inc. dated 1989, indicating a capacity of 361,600 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 Palestine in 2003. To properly compare results of TWDB surveys, TWDB applied the 2013 data processing techniques to the data collected in 2003. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 2003 using the same interpolation definition file as was used for the 2012 survey, with minor edits to account for differences in data coverage and boundary conditions. A new TIN model was created using the original boundary. The 2003 survey boundary was digitized from aerial photographs taken on January 19, 23, and 25, 1995, while the daily average water surface elevation of the reservoir measured 345.94, 345.98, and 345.98 feet above mean sea level, respectively. The boundary was assigned a value of 346.0 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 2003 survey resulted in a 1.3 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]	25,560	411,840
Turner Collie & Braden Inc. 1989[b]	23,833	361,600
TWDB 2003[c]	22,656	373,202
TWDB 2003 (re-calculated)	22,193	378,099
TWDB 2012	23,112	367,312

[a] Source: (TWDB, 1973)
[b] Source: (TCB, 1989)
[c] Source: (TWDB, 2005)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2012 TWDB sedimentation survey estimates Lake Palestine to have an average loss of capacity between 621 and 1,086 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (345.0 feet NGVD29). The sedimentation survey indicates sediment accumulation varies throughout the reservoir. The heaviest accumulations measured by this survey are in the submerged river channels and in the main body of the lake between Caney Creek and Cobb Creek. The greatest accumulations are adjacent to the city of Berryville. Comparison of capacity estimates of Lake Palestine derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. **Capacity loss comparisons for Lake Palestine**

Survey	Volume comparisons at conservation pool elevation (acre-feet)			Pre-impoundment (acre-feet)
Original	411,840	<>	<>	<>
Turner Collie & Braden Inc. 1989	<>	361,600	<>	<>
TWDB 2003 (re-calculated)	<>	<>	378,099	<>
TWDB pre-impoundment estimate based on 2012 survey	<>	<>	<>	392,770[b]
2012 volumetric survey	367,312	367,312	367,312	367,312
Volume difference (acre-feet)	44,528 (10.8%)	-5,712 (1.6%)	10,787 (2.9%)	25,458 (6.5%)
Number of years	41[a]	23	9	41[a]
Capacity loss rate (acre-feet/year)	1,086	-248	1,199	621

Note: Blackburn Crossing Dam was completed on June 13, 1962, and deliberate impoundment began on May 1, 1962. Enlargement of the dam was completed on March 3, 1971.
[a] Number of years based on difference between 2012 survey date and enlargement date of 1971
[b] 2012 TWDB surveyed capacity of 367,312 acre-feet plus 2012 TWDB surveyed sediment volume of 25,458 acre-feet

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Palestine 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 Palestine.

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 Palestine

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — July - August 2012 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 345.0 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
292	0	0	0	0	0	0	0	0	0	0
293	0	0	0	0	0	0	0	0	0	1
294	1	1	1	1	1	1	1	1	1	1
295	1	1	1	1	2	2	2	2	2	2
296	2	2	2	3	3	3	3	4	4	4
297	4	5	5	5	6	6	7	7	8	8
298	9	10	10	11	11	12	13	13	14	15
299	16	17	17	18	19	20	21	22	23	25
300	26	27	29	30	32	33	35	37	39	41
301	43	45	47	50	52	55	57	60	63	66
302	70	73	76	80	84	88	93	97	102	107
303	112	118	123	130	136	143	150	157	165	174
304	182	191	200	210	220	231	242	253	265	278
305	291	304	319	333	349	365	382	400	419	438
306	458	479	501	523	547	571	597	623	650	679
307	708	738	769	802	835	870	905	942	980	1,019
308	1,058	1,099	1,142	1,185	1,229	1,274	1,320	1,368	1,416	1,466
309	1,517	1,569	1,622	1,677	1,733	1,791	1,850	1,911	1,973	2,037
310	2,102	2,170	2,239	2,311	2,384	2,460	2,538	2,619	2,702	2,787
311	2,875	2,966	3,060	3,157	3,258	3,361	3,468	3,578	3,690	3,806
312	3,926	4,050	4,177	4,309	4,444	4,582	4,724	4,869	5,017	5,169
313	5,323	5,482	5,643	5,807	5,975	6,146	6,321	6,499	6,681	6,867
314	7,057	7,252	7,450	7,653	7,862	8,076	8,296	8,521	8,752	8,987
315	9,226	9,470	9,718	9,970	10,228	10,490	10,756	11,027	11,302	11,582
316	11,867	12,156	12,450	12,748	13,051	13,358	13,670	13,986	14,307	14,632
317	14,961	15,293	15,629	15,969	16,313	16,660	17,012	17,367	17,726	18,090
318	18,458	18,831	19,208	19,590	19,976	20,367	20,761	21,160	21,563	21,971
319	22,384	22,802	23,226	23,654	24,089	24,529	24,975	25,428	25,887	26,352
320	26,824	27,302	27,786	28,276	28,771	29,273	29,780	30,293	30,813	31,339
321	31,872	32,413	32,961	33,515	34,077	34,645	35,220	35,802	36,390	36,985
322	37,586	38,193	38,806	39,425	40,050	40,681	41,319	41,963	42,614	43,273
323	43,937	44,608	45,285	45,968	46,656	47,350	48,051	48,757	49,470	50,189
324	50,916	51,650	52,391	53,138	53,892	54,653	55,421	56,197	56,980	57,771
325	58,568	59,373	60,185	61,004	61,831	62,664	63,503	64,349	65,202	66,063
326	66,930	67,805	68,685	69,572	70,466	71,366	72,273	73,187	74,106	75,032
327	75,964	76,903	77,848	78,799	79,757	80,722	81,694	82,674	83,662	84,658
328	85,661	86,671	87,688	88,712	89,743	90,782	91,829	92,883	93,945	95,017
329	96,097	97,186	98,283	99,388	100,502	101,623	102,753	103,890	105,034	106,187
330	107,347	108,515	109,690	110,872	112,063	113,262	114,469	115,685	116,910	118,143
331	119,385	120,637	121,897	123,167	124,446	125,734	127,031	128,337	129,651	130,974
332	132,305	133,646	134,994	136,350	137,716	139,090	140,472	141,863	143,262	144,668
333	146,083	147,504	148,933	150,368	151,811	153,260	154,717	156,180	157,650	159,127
334	160,612	162,105	163,605	165,112	166,626	168,148	169,676	171,212	172,754	174,304
335	175,860	177,422	178,992	180,569	182,153	183,745	185,344	186,950	188,562	190,181
336	191,808	193,440	195,080	196,727	198,381	200,044	201,713	203,390	205,074	206,765
337	208,465	210,173	211,890	213,613	215,345	217,085	218,831	220,586	222,347	224,116
338	225,893	227,676	229,467	231,265	233,070	234,881	236,699	238,524	240,353	242,189
339	244,031	245,879	247,732	249,590	251,454	253,324	255,200	257,082	258,968	260,860
340	262,758	264,660	266,568	268,480	270,398	272,321	274,250	276,184	278,123	280,068
341	282,018	283,977	285,943	287,919	289,904	291,898	293,900	295,912	297,932	299,962
342	302,000	304,048	306,104	308,169	310,243	312,327	314,419	316,520	318,630	320,749
343	322,876	325,013	327,159	329,314	331,477	333,650	335,831	338,022	340,221	342,430
344	344,647	346,873	349,108	351,353	353,606	355,868	358,139	360,419	362,708	365,005
345	367,312									

Note: Capacities above elevation 341.0 calculated from interpolated areas

Appendix B

Lake Palestine

RESERVOIR AREA TABLE

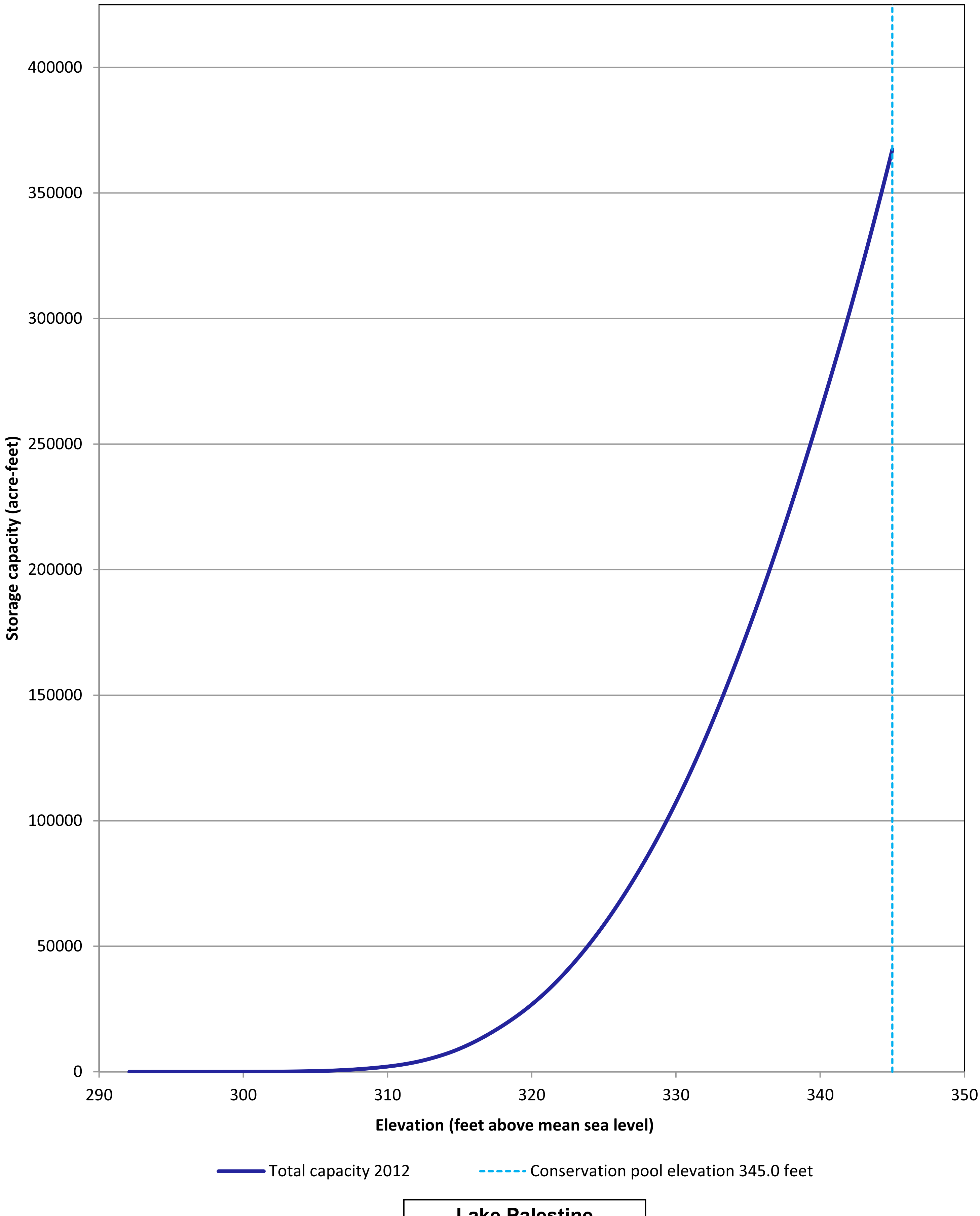
TEXAS WATER DEVELOPMENT BOARD — July - August 2012 Survey

AREA IN ACRES — Conservation Pool Elevation 345.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

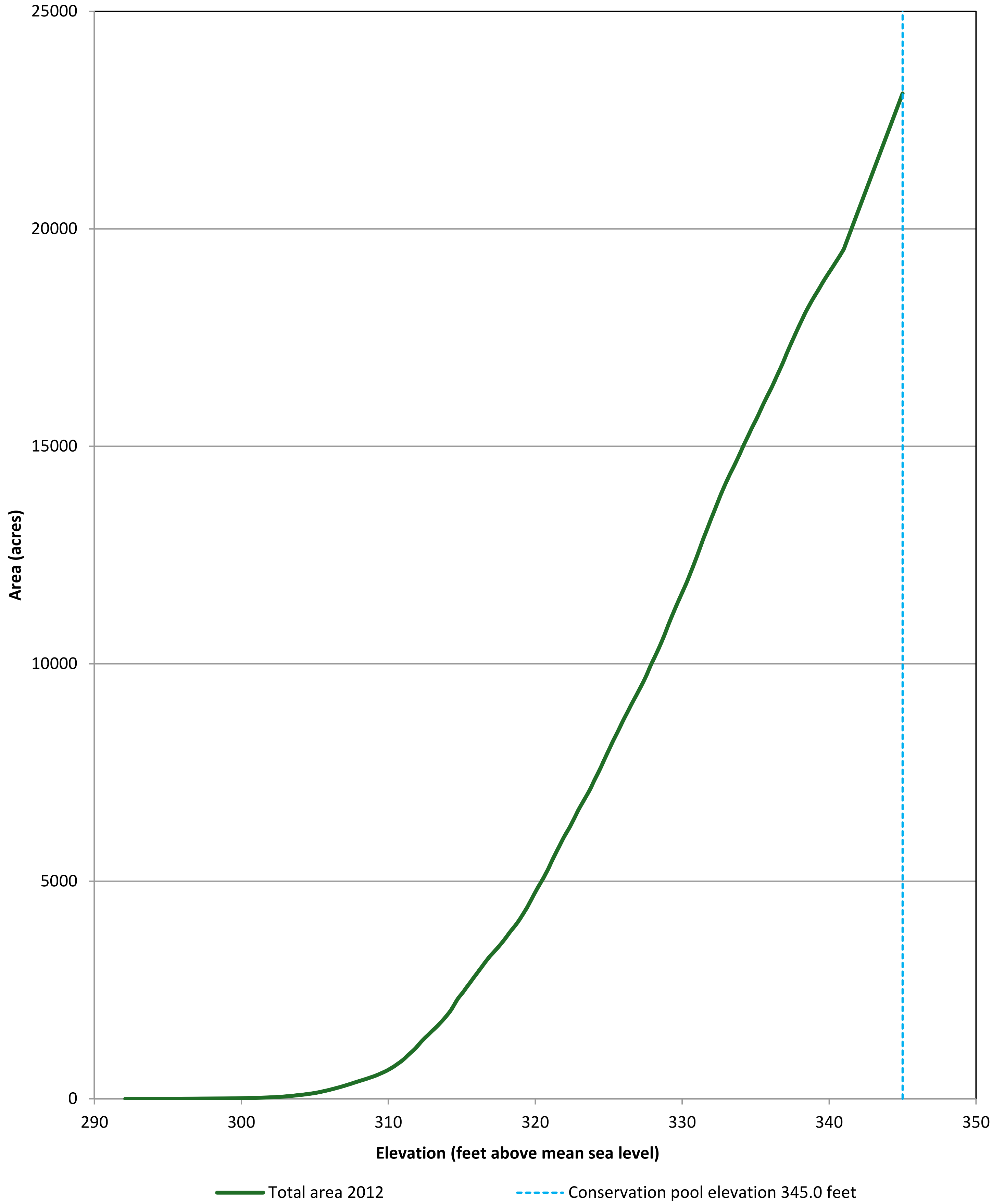
ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
292	0	0	0	0	0	0	0	0	0	0
293	0	0	0	0	0	0	0	1	1	1
294	1	1	1	1	1	1	1	1	1	1
295	1	1	1	1	1	1	1	1	1	1
296	1	2	2	2	2	2	2	2	3	3
297	3	4	4	4	4	5	5	5	5	6
298	6	6	6	6	7	7	7	7	7	8
299	8	8	9	9	9	10	10	11	12	13
300	13	14	15	15	16	17	18	18	19	20
301	21	22	23	24	25	27	28	29	30	32
302	33	35	36	38	40	42	44	46	49	51
303	54	57	60	63	66	70	73	77	80	84
304	88	91	95	99	104	108	113	117	122	127
305	133	139	145	152	159	166	174	182	189	197
306	205	214	223	231	240	250	258	267	277	288
307	297	308	318	329	339	350	362	373	383	394
308	405	416	425	436	447	457	468	480	492	503
309	515	527	541	554	569	584	599	614	631	647
310	666	685	705	725	746	770	794	818	841	867
311	894	924	955	989	1,020	1,051	1,081	1,111	1,143	1,178
312	1,217	1,256	1,296	1,333	1,367	1,401	1,433	1,465	1,499	1,532
313	1,565	1,595	1,627	1,660	1,694	1,730	1,766	1,803	1,841	1,881
314	1,921	1,964	2,007	2,057	2,113	2,169	2,228	2,282	2,331	2,372
315	2,414	2,456	2,503	2,551	2,596	2,640	2,685	2,732	2,779	2,824
316	2,867	2,914	2,959	3,004	3,050	3,096	3,141	3,185	3,229	3,269
317	3,307	3,343	3,381	3,418	3,454	3,493	3,533	3,574	3,616	3,659
318	3,703	3,749	3,796	3,841	3,884	3,925	3,966	4,008	4,055	4,104
319	4,155	4,209	4,262	4,318	4,372	4,431	4,496	4,557	4,621	4,686
320	4,748	4,809	4,869	4,926	4,984	5,042	5,101	5,167	5,229	5,295
321	5,370	5,443	5,514	5,581	5,649	5,716	5,781	5,848	5,916	5,982
322	6,043	6,102	6,159	6,216	6,278	6,345	6,410	6,478	6,547	6,616
323	6,679	6,739	6,797	6,855	6,914	6,973	7,032	7,094	7,159	7,232
324	7,305	7,373	7,438	7,505	7,575	7,646	7,723	7,795	7,868	7,941
325	8,012	8,083	8,157	8,229	8,296	8,362	8,428	8,497	8,568	8,640
326	8,708	8,775	8,838	8,903	8,970	9,038	9,102	9,165	9,227	9,289
327	9,354	9,418	9,482	9,547	9,614	9,685	9,758	9,839	9,919	9,994
328	10,065	10,134	10,205	10,277	10,351	10,427	10,505	10,586	10,667	10,755
329	10,845	10,931	11,013	11,095	11,174	11,255	11,333	11,410	11,487	11,562
330	11,637	11,712	11,788	11,865	11,948	12,033	12,119	12,202	12,289	12,378
331	12,466	12,558	12,651	12,745	12,839	12,927	13,012	13,098	13,184	13,273
332	13,360	13,441	13,526	13,611	13,696	13,782	13,868	13,947	14,026	14,103
333	14,179	14,249	14,324	14,394	14,460	14,526	14,596	14,667	14,739	14,811
334	14,886	14,963	15,038	15,107	15,178	15,247	15,319	15,392	15,461	15,527
335	15,592	15,661	15,733	15,807	15,880	15,954	16,023	16,093	16,161	16,226
336	16,294	16,361	16,434	16,507	16,584	16,656	16,730	16,804	16,879	16,957
337	17,039	17,123	17,200	17,279	17,355	17,430	17,504	17,581	17,654	17,728
338	17,801	17,871	17,942	18,015	18,084	18,148	18,210	18,271	18,332	18,390
339	18,447	18,502	18,557	18,613	18,671	18,730	18,786	18,841	18,894	18,947
340	18,998	19,049	19,101	19,153	19,206	19,258	19,311	19,365	19,419	19,476
341	19,534	19,624	19,713	19,803	19,892	19,982	20,071	20,161	20,250	20,339
342	20,429	20,518	20,608	20,697	20,787	20,876	20,966	21,055	21,144	21,234
343	21,323	21,413	21,502	21,592	21,681	21,771	21,860	21,949	22,039	22,128
344	22,218	22,307	22,397	22,486	22,576	22,665	22,754	22,844	22,933	23,023
345	23,112									

Note: Areas above elevation 341.0 feet interpolated



Lake Palestine
July - August 2012 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Lake Palestine
July - August 2012 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

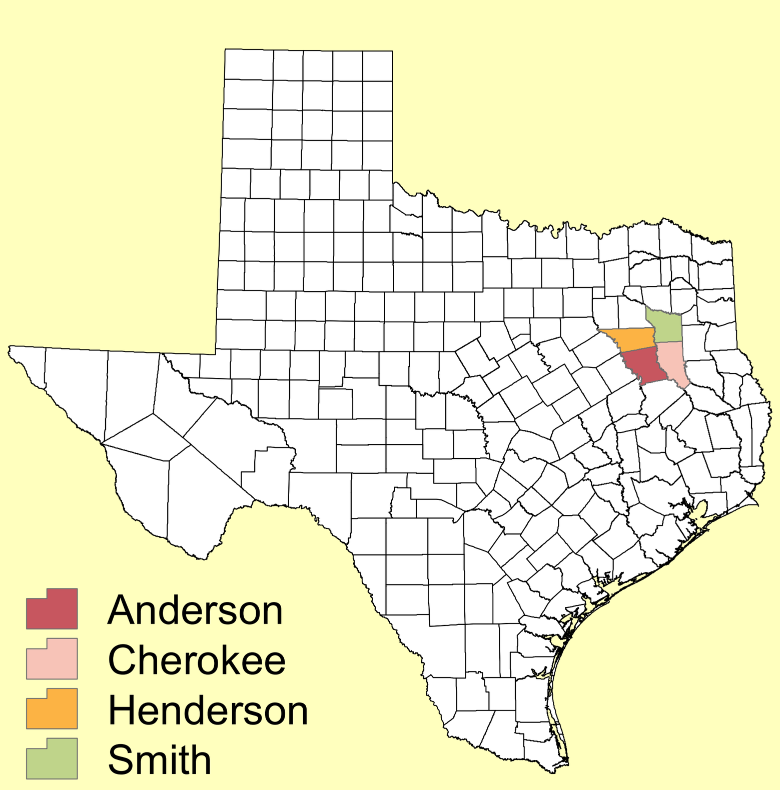
Contours
(feet above mean sea level)

340
335
330
325
320
315
310
305
300
295

Lake Palestine
Islands

Conservation pool
elevation: 345.0 feet

Projection: NAD83
State Plane Texas
North Central Zone (feet)



Anderson
Cherokee
Henderson
Smith

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