Volumetric and Sedimentation Survey of LAKE WINTERS and ELM CREEK RESERVOIR

September and October 2013 Surveys

Texas Water Development Board

May 2014

Texas Water Development Board

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City of Winters

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Executive summary

In September, 2013, 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 Winters and Elm Creek Reservoir. The City of Winters provided 50% of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50% of the funding through their Planning Assistance to States Program. Surveying was performed using a multi-frequency (208 kHz, 50 kHz, and 24 kHz), sub-bottom profiling depth sounder. In addition, sediment core samples were collected in select locations and correlated with the multi-frequency depth sounder signal returns to estimate sediment accumulation thicknesses and sedimentation rates.

Lake Winters is located on Elm Creek in the Colorado River Basin, approximately five miles east of downtown Winters, in Runnels County, Texas. Elm Creek Reservoir is located immediately downstream of Lake Winters. TWDB collected bathymetric data for Lake Winters on September 24, 2013. TWDB measured a daily average water surface elevation during the survey of 1,787.392 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Elm Creek Reservoir on October 29-30, 2013. TWDB measured a daily average water surface elevation during the survey of 1,779.799 feet and 1,779.730 feet above mean sea level (NGVD29), respectively.

The 2013 TWDB volumetric and sedimentation survey indicates that Lake Winters has a total reservoir capacity of 1,747 acre-feet and encompasses 319 acres at conservation pool elevation (1,790.0 feet above mean sea level, NGVD29) and that Elm Creek Reservoir has a total reservoir capacity of 6,032 acre-feet and encompasses 319 acres at conservation pool elevation (1,790.0 feet above mean sea level, NGVD29).

The 2013 TWDB sedimentation survey estimates Lake Winters to have an average loss of capacity between 7 and 11 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,790.0 feet above mean sea level, NGVD29). The 2013 TWDB sedimentation survey estimates Elm Creek Reservoir to have an average loss of capacity between -3.5 and 11 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,790.0 feet above mean sea level, NGVD29). The heaviest accumulations measured are in Lake Winters. In both lakes, sediment accumulation increases towards the dams. TWDB recommends that a similar methodology be used to resurvey both lakes 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 September 2013, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Winters and Elm Creek Reservoir (TWDB, 2013). The City of Winters provided 50% of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50% of the funding through their Planning Assistance to States Program. This report describes the methods used to conduct the volumetric and sedimentation survey, including data collection and processing techniques. This report serves as the final contract deliverable from TWDB to the City of Winters and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) a shaded relief plot of the reservoir bottom [Figure 4], (2) a bottom contour map [Figure 6], (3) an estimate of sediment accumulation and location [Figure 10], and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality [Appendices A, B, E, and F].

Lake Winters and Elm Creek Reservoir general information

Lake Winters is located on Elm Creek, a tributary of the Colorado River, in the Colorado River Basin, approximately five miles east of downtown Winters, in Runnels County, Texas. Elm Creek Reservoir is located immediately downstream of Lake Winters (Figure 1). Lake Winters and Elm Creek Reservoir (also known as Old Lake Winters and New Lake Winters) are owned and operated by the City of Winters, Texas. Construction of Lake Winters was completed in 1945 (USGS, 1971) and Elm Creek Reservoir was completed in 1983. Both lakes are used for municipal water supply for the City of Winters and for recreational purposes (TCEQ, 1998).

Old Lake Winters City Dam is an earthen structure 3,090 feet long and 41 feet tall, with an uncontrolled spillway 910 feet wide. Elm Creek Dam is an earthen structure 5,640 feet long and 57 feet tall, with an uncontrolled spillway 640 feet wide. Elm Creek Dam controls a drainage area of 65.5 square miles (TCEQ, 1998). Water rights for Lake Winters and Elm Creek Reservoir have been appropriated to the City of Winters through Certificate of

Adjudication No. 14-1095 and Amendments to Certificate of Adjudication Nos. 14-1095A and 14-1095B and to Walter Adami through Certificate of Adjudication No. 14-1096. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

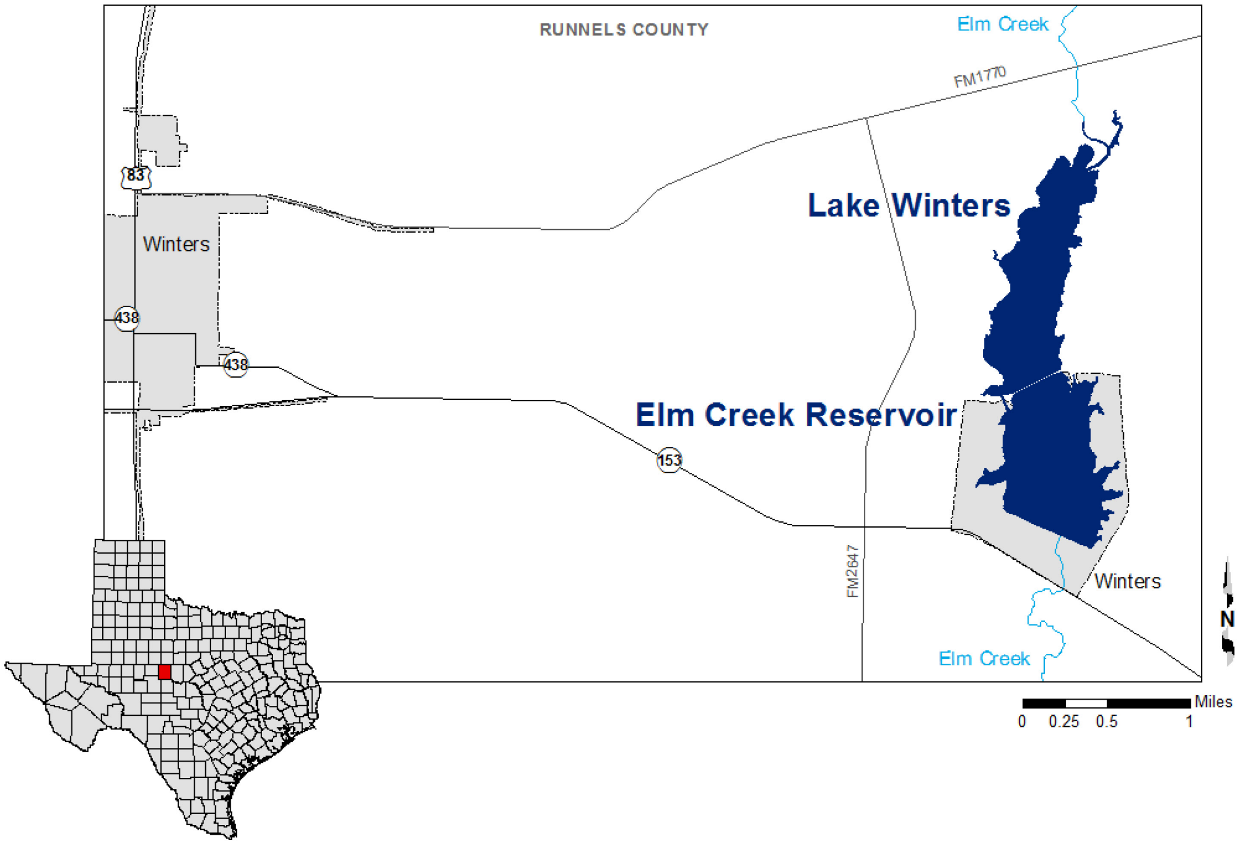


Figure 1. Location of Lake Winters and Elm Creek Reservoir

Volumetric and sedimentation survey of Lake Winters and Elm Creek Reservoir

Datum

The vertical datum used during this survey is the National Geodetic Vertical Datum 1929 (NGVD29). Volume and area calculations in this report are referenced to the water surface elevation which, at the time of the survey, was measured by TWDB using a Trimble® R6 Global Navigation Satellite System (GNSS) survey system. Figure 2 shows where the GPS points were collected. 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 Winters on September 24, 2013. TWDB measured a daily average water surface elevation during the survey of 1,787.392 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Elm Creek Reservoir on October 29-30, 2013. TWDB measured a daily average water surface elevation during the survey of 1,779.799 feet and 1,779.730 feet above mean sea level (NGVD29), respectively. For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data collection occurred while navigating along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 250 feet apart. 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.

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. TWDB selected six locations to collect sediment core samples (Figure 2). The sediment core samples were collected from Lake Winters on September 24, 2013, and from Elm Creek Reservoir on January 9, 2014, 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.

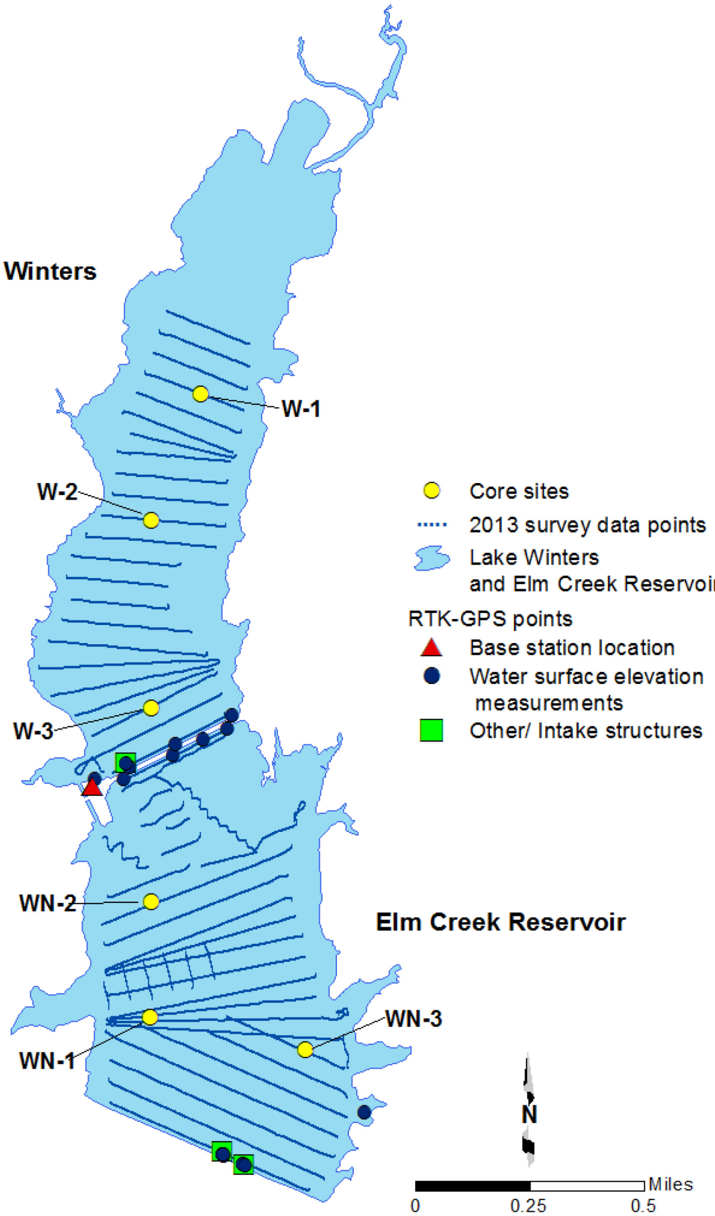


Figure 2. Data collection during 2013 TWDB surveys

Data processing

Model boundaries

The reservoir boundary was digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), obtained from the Texas Natural Resources Information System (TNIRIS, 2013) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Winters and Elm Creek Reservoir are Winters (NE) and Crews (NW). The DOQQs were photographed on August 1, 2010. According to metadata associated with the 2010 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). Although the water surface elevations of the reservoirs at the time of the photos are unknown, it was evident through comparison of the photos with the digital USGS 7.5 minute quadrangle maps and hypsography (the vector format of USGS 7.5 minute quadrangle map contours) that both reservoirs were full or very close to full when photographed. For this analysis, the boundary was digitized at the land-water interface and/ or vegetation line in the 2010 photographs and assigned an elevation of 1,790.0 feet for both Lake Winters and Elm Creek Reservoir. This elevation represents the spillway crest elevation of Old Lake Winters City Dam (USGS, 1971), and the authorized operating level of Elm Creek Reservoir according to Amendment to Certificate of Adjudication Nos. 14-1095A.

RTK-GPS post-processing

Data collected using the Trimble® GPS system was downloaded from the rover's data controller (by day) and post-processed using the Trimble® Business Center (Version 3.1) software. Post-processing entails confirming project settings (e.g. vertical and horizontal datum, horizontal coordinate system) and tying the base station coordinates to Continuously Operating Reference Stations (CORS) sites to improve the precision of the project data from each rover. CORS sites are maintained by the National Geodetic Survey (NGS), an office of the National Oceanographic and Atmospheric Administration's (NOAA) National Ocean Service (NGS, 2014a). To make the RTK-GPS data compatible with the bathymetric survey data, it was necessary to transform the data from vertical datum NAVD88 to NGVD29. Vertical coordinate transformations were done by applying a single vertical offset to all RTK-GPS data. The offset was determined by applying NGS's VERTCON software (NGS, 2014b) to a single reference point in the vicinity of the survey; for example, one of the RTK-GPS points, Latitude 31º57'05.9988", Longitude 99º52'21.9411" NAD83. The resulting conversion factor of 0.367 feet was subtracted from all RTK-GPS data elevations to obtain the transformed vertical elevations.

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by TWDB were edited to remove data anomalies. DepthPic©, software developed by SDI, Inc., is used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface and manually digitizing the reservoir-bottom surface at the time of initial impoundment (i.e. pre-impoundment surface). For processing outside of DepthPic©, an in-house software package, HydroTools, is used to identify the current reservoir-bottom surface, pre-impoundment surface, sediment thickness at each sounding location, and output the data into a single file. The water surface elevations were averaged for each day and used to convert each sounding depth to a corresponding reservoir-bottom elevation. This survey point dataset is then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points are determined using an anisotropic spatial interpolation algorithm described in the next section. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen et al., 2011a). Finally, the point file resulting from spatial interpolation is used in conjunction with sounding and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (ESRI, 1995).

Spatial interpolation of reservoir bathymetry

Isotropic spatial interpolation techniques such as the Delaunay triangulation used by the 3D Analyst extension of ArcGIS are, in many instances, unable to suitably interpolate bathymetries between survey lines common to reservoir surveys. Reservoirs and stream channels are anisotropic morphological features where bathymetry at any particular location is more similar to upstream and downstream locations than to transverse locations. Interpolation schemes that do not consider this anisotropy lead to the creation of several types of artifacts in the final representation of the reservoir bottom surface and hence to errors in volume. These include: artificially-curved contour lines extending into the reservoir where the reservoir walls are steep or the reservoir is relatively narrow; intermittent representation of submerged stream channel connectivity; and oscillations of contour lines in between survey lines. These artifacts reduce the accuracy of the resulting volumetric and sediment TIN models in areas between actual survey data.

To improve the accuracy of bathymetric representation between survey lines, TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining survey data or more robustly by examining scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. For surveys with similar spatial coverage, these interpolation definition files are in principle independent of the survey data and could be applied to past and future survey data of the same reservoir. In practice, however, minor revisions of the interpolation definition files may be needed to account for differences in spatial coverage and boundary conditions between surveys. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing the reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen et al., 2011a) and in McEwen et al., 2011b.

In areas inaccessible to survey data collection, such as small coves and shallow upstream areas of the reservoir, linear extrapolation is used for volumetric and sediment accumulation estimations. The linear extrapolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without extrapolated data, the TIN model builds flat triangles. A flat triangle is defined as a triangle where all three vertices are equal in elevation, generally the elevation of the reservoir boundary. Reducing flat triangles by applying linear extrapolation improves the elevation-capacity and elevation-area calculations. It is not possible to remove all flat triangles, and linear extrapolation is only applied where adding bathymetry is deemed reasonable. For example, linear extrapolation was deemed reasonable and applied to Lake Winters and Elm Creek Reservoir in the following situations: in small coves of the main body of the lake and in obvious channel features visible in aerial photographs taken on August 2, 2012.

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

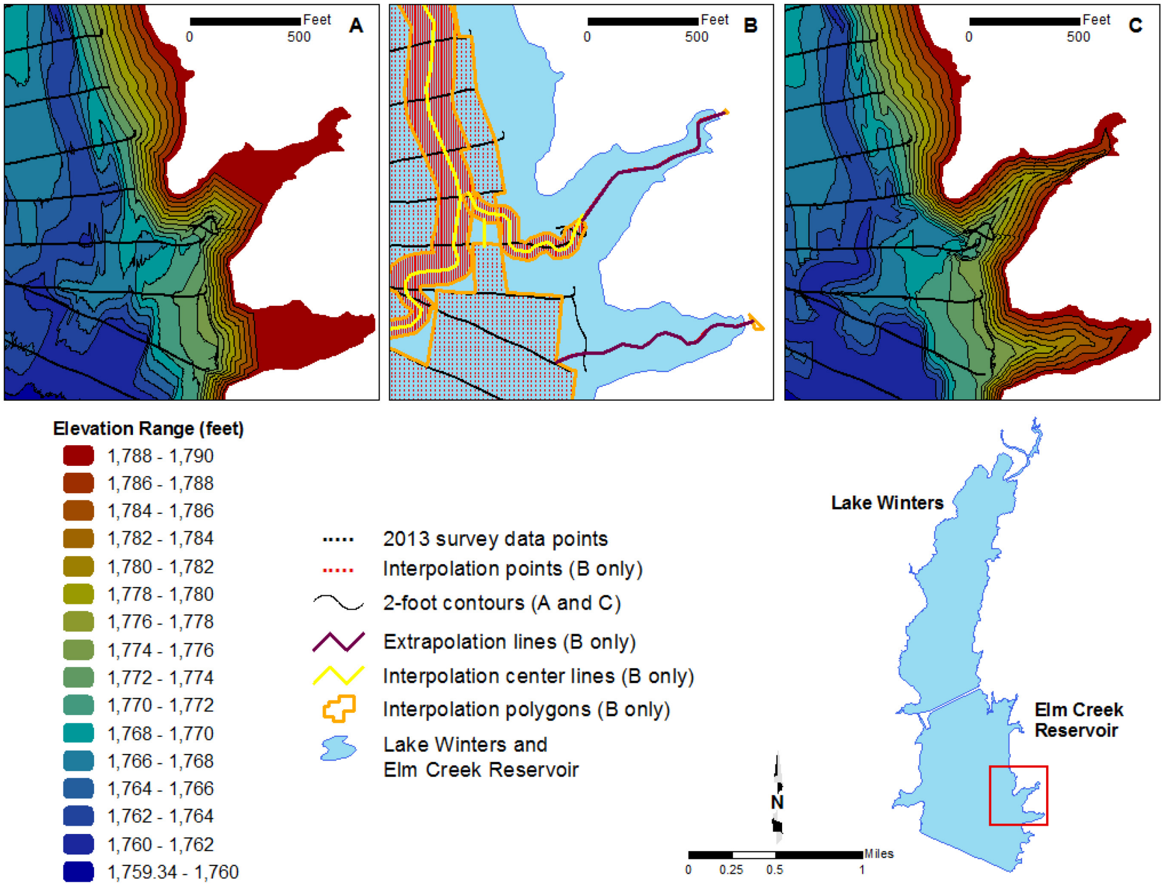


Figure 3. **Anisotropic spatial interpolation and linear extrapolation of Lake Winters and Elm Creek Reservoir sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

Area, volume, and contour calculation

Using ArcInfo software and the volumetric TIN models, volumes and areas were calculated for both reservoirs at 0.1 foot intervals, from 1,779.7 to 1,790.0 feet for Lake Winters and from 1,759.3 to 1,790.0 feet for Elm Creek Reservoir. The elevation-capacity tables and elevation-area tables, updated for 2013, are presented in Appendices A, B, E, and F, respectively. The capacity curves are presented in Appendix C and G, and the area curves are presented in Appendix D and H.

The volumetric TIN models were converted to a raster representation using a cell size of 1 foot by 1 foot. The raster data was then used to produce an elevation relief map (Figure 4), representing the topography of the reservoir bottoms; a depth range map (Figure 5), showing shaded depth ranges for Lake Winters and Elm Creek Reservoir; and a contour map showing 1-foot contours for Lake Winters and 2-foot contours for Elm Creek Reservoir (Figure 6 - attached).

Figure 4
Elevation relief maps

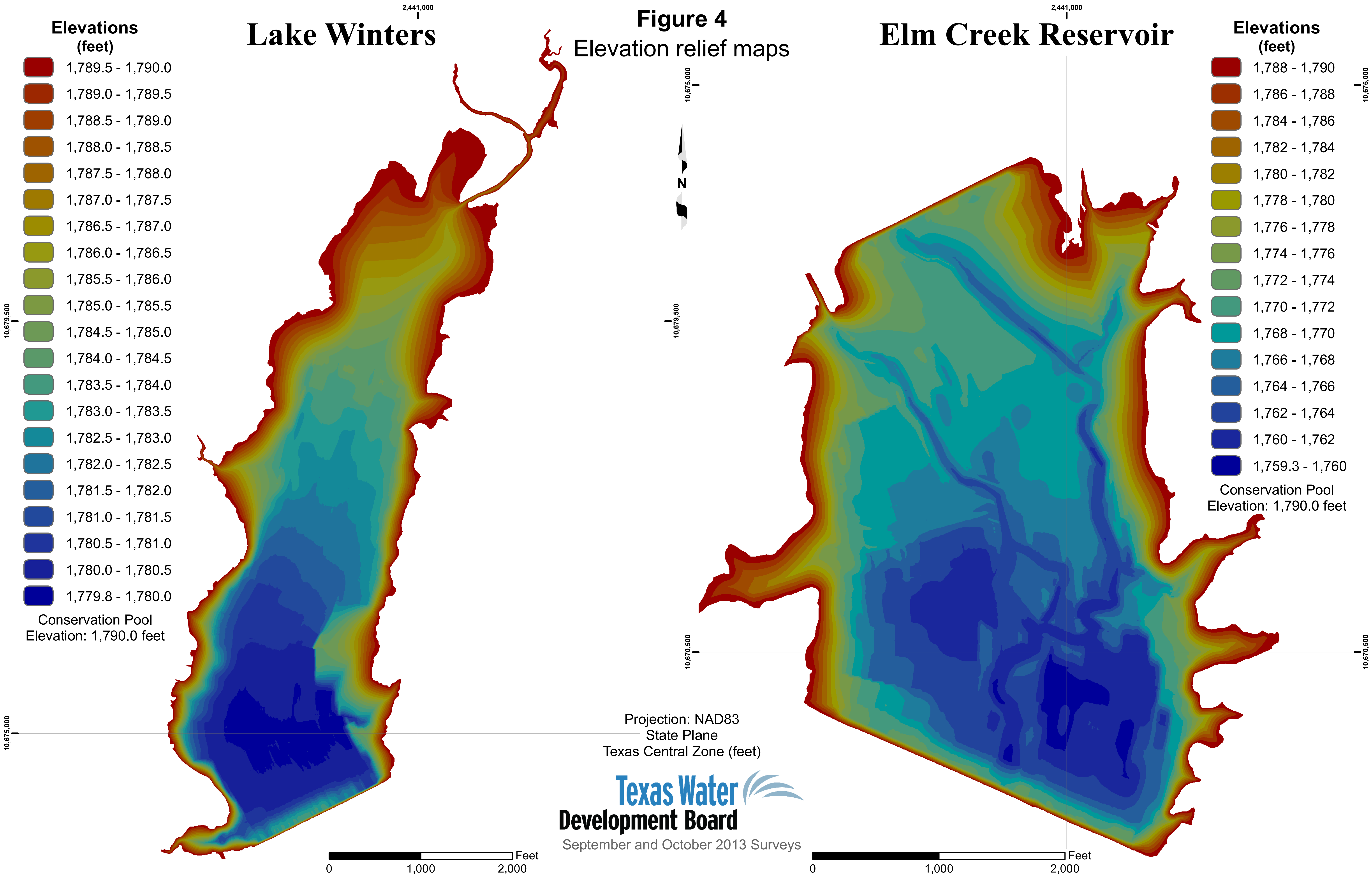
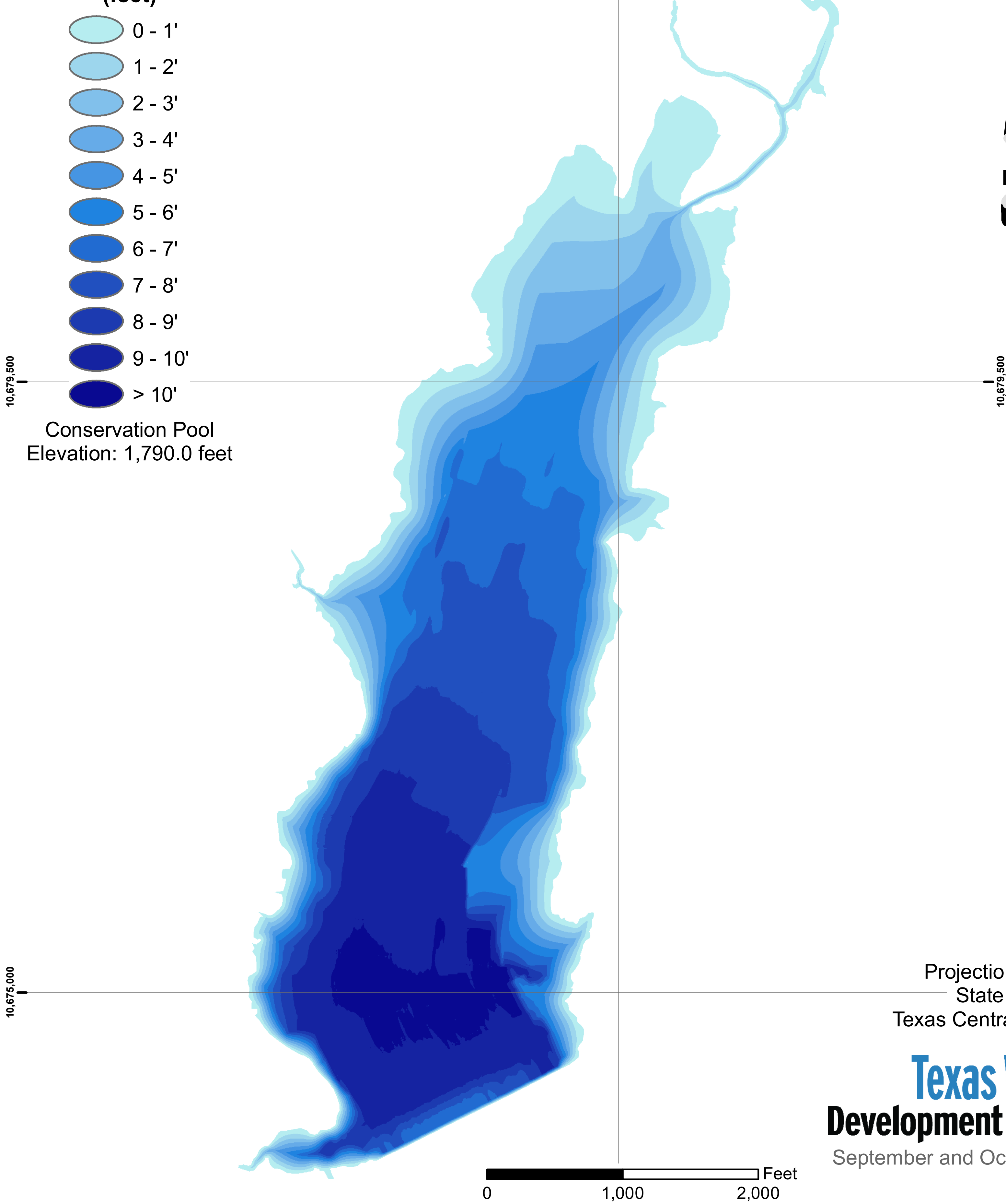
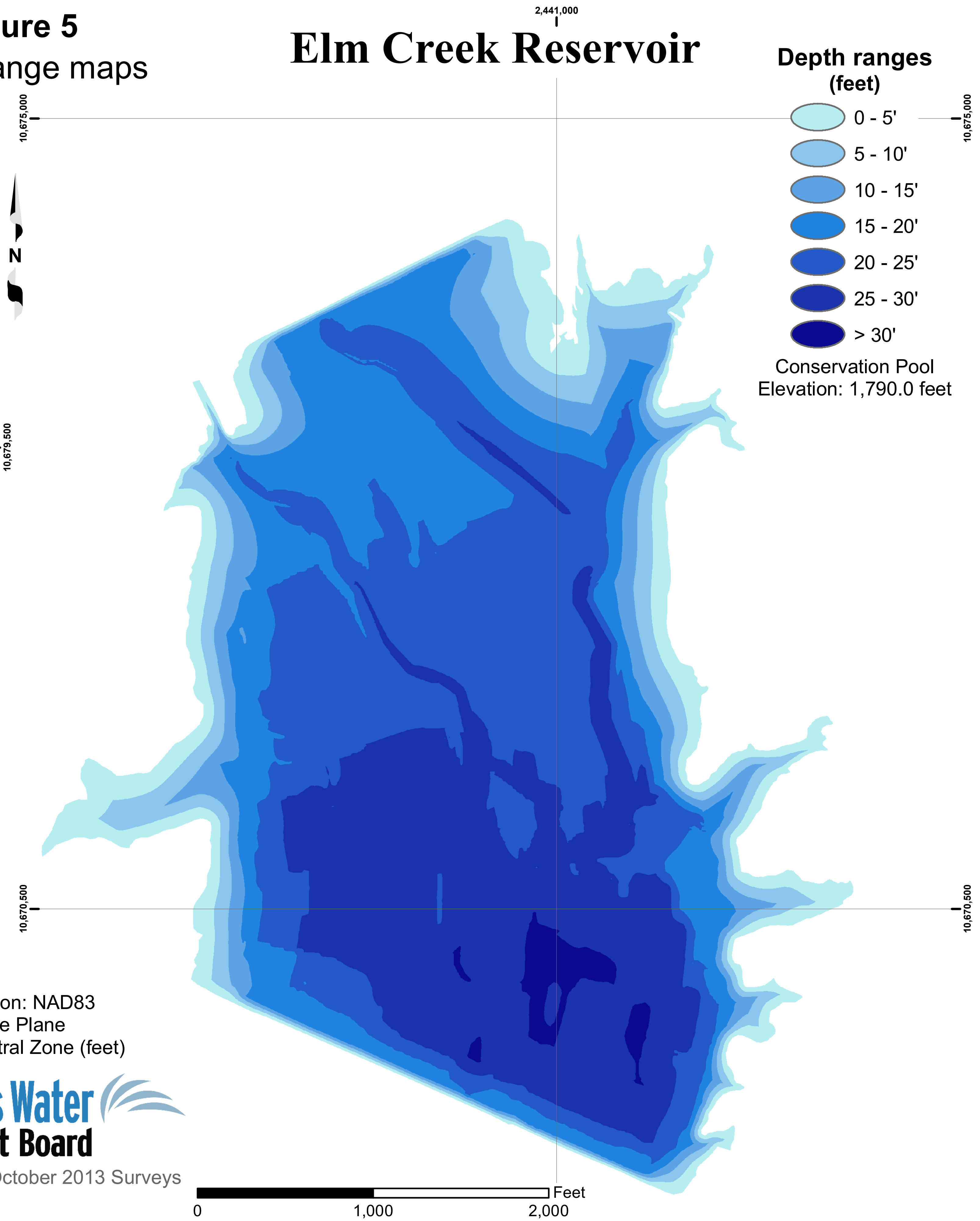


Figure 5
Depth range maps





Projection: NAD83
State Plane
Texas Central Zone (feet)

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Development Board

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Analysis of sediment data from Lake Winters and Elm Creek Reservoir

Sedimentation in Lake Winters and Elm Creek Reservoir was determined by analyzing the acoustic signal returns of all three depth sounder frequencies in the DepthPic© software. The 208 kHz signal was analyzed to determine the current bathymetric surface of the reservoir, while all three frequencies, 208 kHz, 50 kHz, and 24 kHz, were analyzed to determine the reservoir bathymetric surface at the time of initial impoundment (i.e. pre-impoundment surface). Sediment core samples collected in the reservoirs 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 (Tables 1 and 2).

Table 1. Sediment core sampling analysis data – Lake Winters

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
W-1	2440256.77	10678196.44	38.25”/34”	0-5” high water content, very dense, clay loam	5YR 3/3
				5-8” high water content, less dense, clay loam	5YR 3/3
				8-34” high water content, dense clay loam, some organics present	5YR 4/2
				34-38.25” dense clay, some organics present	5YR 4/3
W-2	2439694.33	10676729.46	25.5”/17”	0-17” high water content, silty loam	7.5YR 4/4
				17-25.5” high water content, loamy clay	7.5YR 4/4
W-3	2439690.32	10674567.71	43”/37.5”	0-30.5” high water content, silty loam	7.5YR 4/4
				30.5-37.5” high water content, dense silty loam	7.5YR 3/4
				37.5-43” organics present, silty clay	5YR 4/4

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

Table 2. Sediment core sampling analysis data – Elm Creek Reservoir

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
WN-1	2439678.16	10670990.64	21.5”/17”	0-9.25” high water content, silty loam	10YR 3/3
				9.25-11.75” high water content, sandy loam, large grain sizes present	10YR 3/2
				11.75-17” high water content, silty loam	10YR 3/4
				17-21.5” organics present, sandy clay	10YR 3/2
WN-2	2439688.24	10672328.38	8.5”/0”	0-8.5” silty clay, organics present	10YR 3/1
WN-3	2441468.57	10670620.43	14.25”/5.25”	0-5.25” high water content, large clay bits, silty loam	10YR 4/4
				5.25-14.25” some organics present, silty clay	10YR 3/4

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

A photograph of sediment core W-3 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Winters. A photograph of sediment core WN-1 is shown in Figure 8 and is representative of the sediment cores sampled from Elm Creek Reservoir. The 208 kHz frequency measures the top layer as the current bottom surface of the reservoir.

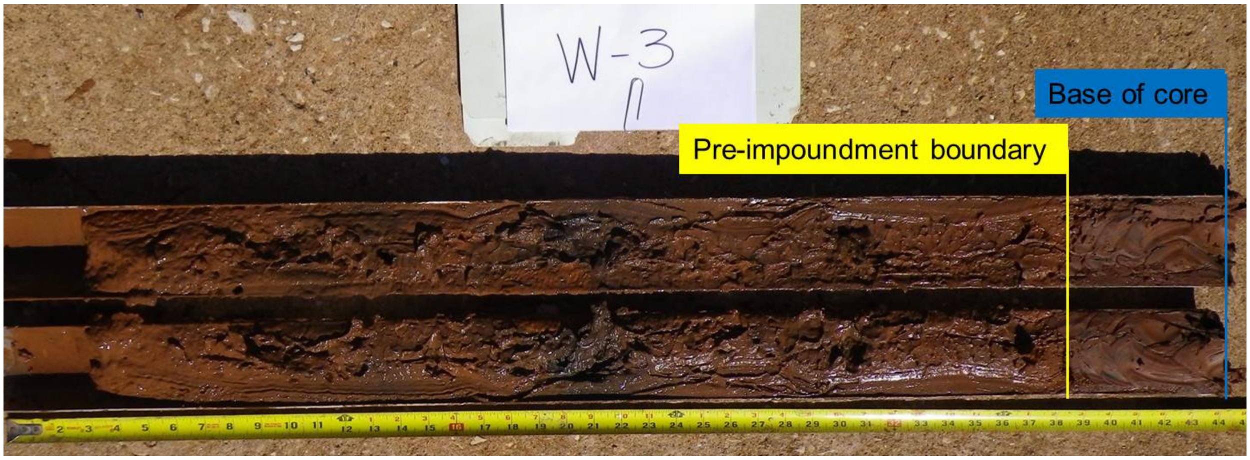

Figure 7. Sediment core W-3 from Lake Winters

Sediment core sample W-3 consisted of 43 inches of total sediment corresponding to the length of the aluminum sampling tube. The upper sediment layer (horizon), 0-30.5 inches, consisted of silty loam with a high water content, and measured 7.5YR 4/4 on the Munsell soil color chart. The second horizon, beginning at 30.5 inches and extending to 37.5 inches below the surface, consisted of a dense silty loam with a high water content, and measured 7.5YR 3/4 on the Munsell soil color chart. The final horizon, from 37.5 inches to 43 inches, consisted of a silty clay with organics present, and a 5YR 4/4 Munsell soil color. The base of the sample is denoted by the blue line in Figure 7.

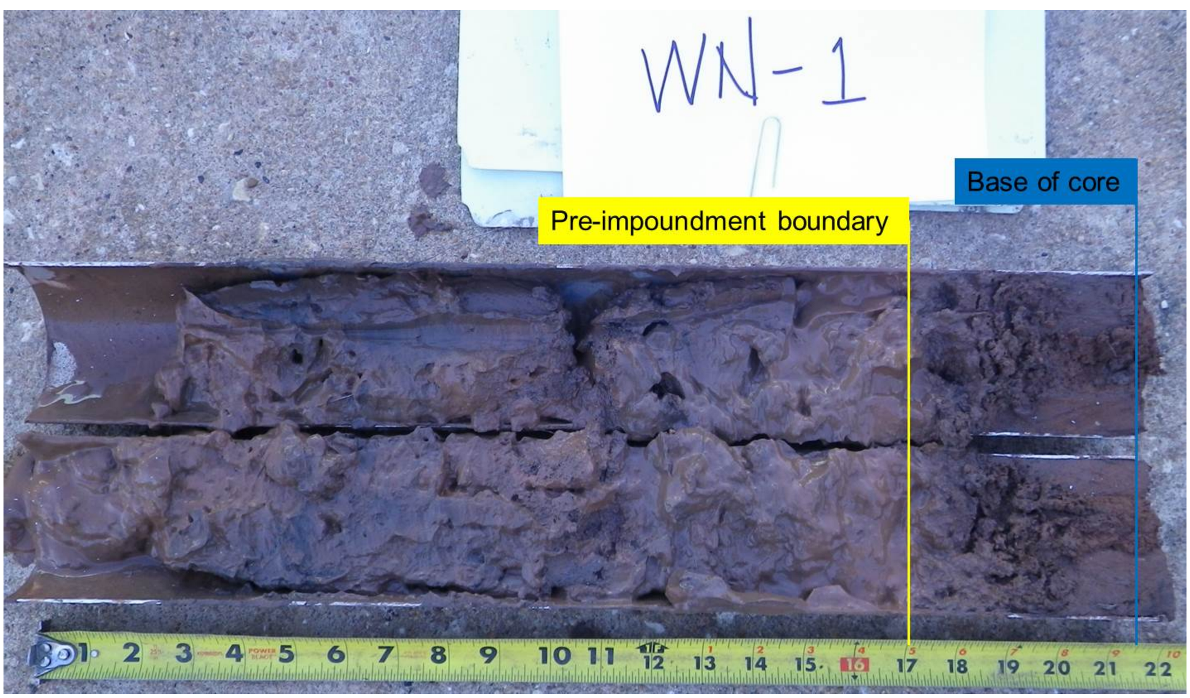

Figure 8. Sediment core WN-1 from Elm Creek Reservoir

Sediment core sample WN-1 consisted of 21.5 inches of total sediment corresponding to the length of the aluminum sampling tube. The upper sediment layer (horizon), 0-9.25

inches, consisted of silty loam with a high water content, and measured 10YR 3/3 on the Munsell soil color chart. The second horizon, beginning at 9.25 inches and extending to 11.75 inches below the surface, consisted of sandy loam with a high water content, and the presence of large grain sizes, and measured 10YR 3/2 on the Munsell soil color chart. The third horizon, from 11.75 inches to 17 inches, consisted of a silty loam with a high water content, and a 10YR 3/4 Munsell soil color. The final horizon, from 17 inches to 21.5 inches, consisted of a sandy clay with organics present, and a 10YR 3/2 Munsell soil color. The base of the sample is denoted by the blue line in Figure 8.

The pre-impoundment boundary (yellow line in Figures 7 and 8) in both reservoirs was identified by the change in soil color, texture, moisture, porosity, and structure. Identification of the pre-impoundment surface for the remaining sediment cores followed a similar procedure.

Figures 9 through 12 illustrate how measurements from sediment core samples are used with sonar data to help identify the interface between the post- and pre-impoundment layers in the acoustic signal. Within DepthPic©, the current surface is automatically determined based on signal returns from the 208 kHz transducer and verified by TWDB staff, while the pre-impoundment surface must be determined visually. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected.

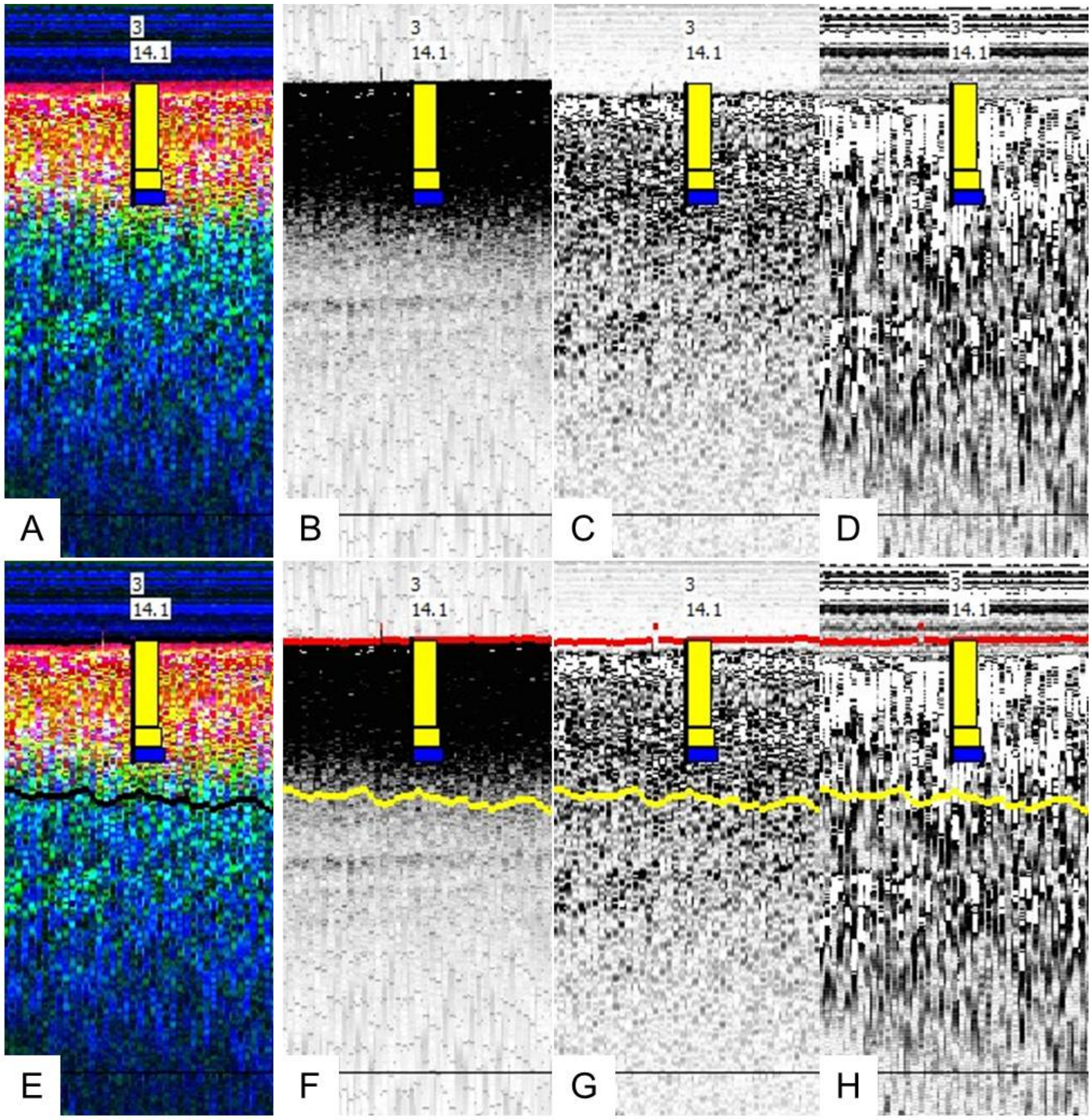

Figure 9. Comparison of sediment core W-3 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 208 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

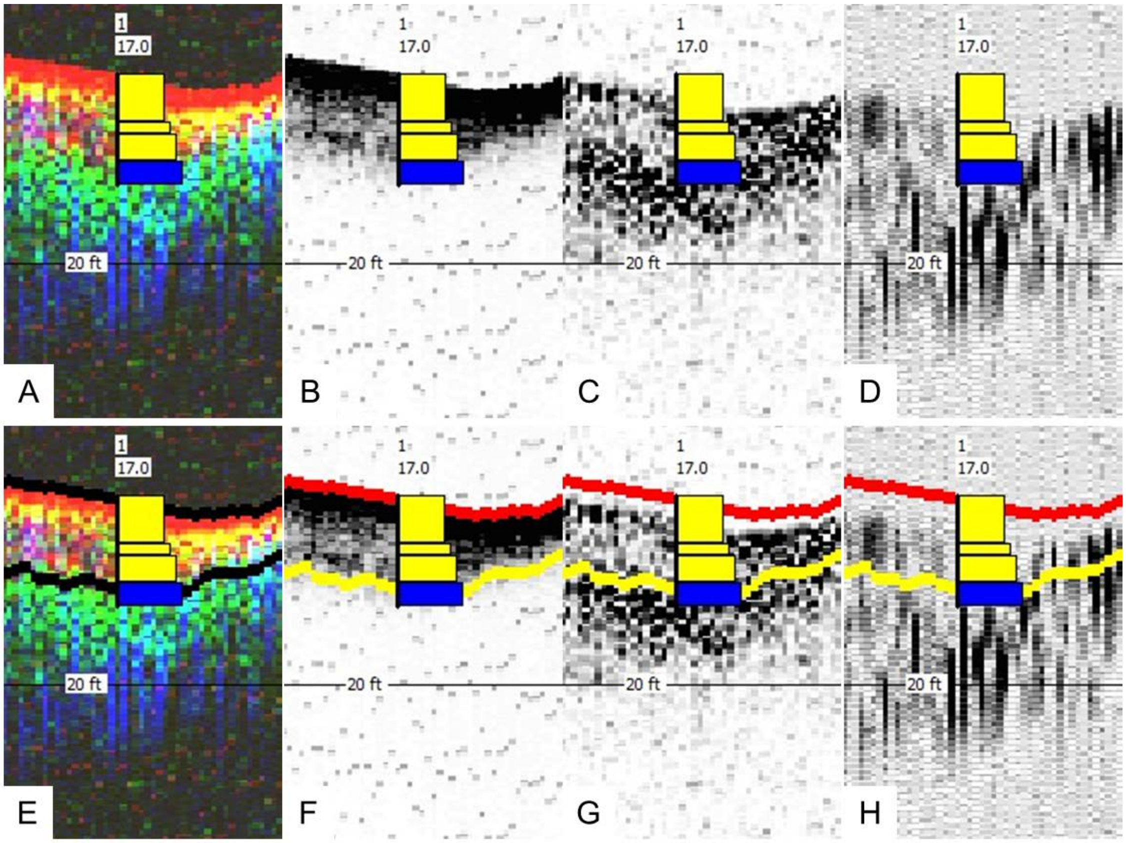

Figure 10. Comparison of sediment core WN-1 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 208 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 9 compares sediment core sample W-3 with the acoustic signals for all frequencies combined (A, E), 208 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). Figure 10 compares sediment core sample WN-1 with the acoustic signals for all frequencies combined (A, E), 208 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). The sediment core sample is represented in each figure as colored boxes. The yellow boxes represent post-impoundment sediment, and the blue box represents the pre-impoundment sediment. In Figure 9A-D and Figure 10A-D, the bathymetric surfaces are not shown. In Figure 9E and Figure 10E, the current bathymetric surface is represented as the top black line and in Figures 9F-H and Figures 10F-H as the top red line. The pre-impoundment surface is identified by comparing boundaries observed in the 208 kHz, 50 kHz and 24 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Each sediment core sample was compared to all three frequencies and the pre-impoundment surface was found to match the bottom of the 208 kHz signal. The pre-impoundment boundary was also visible in the colored display representing all three frequencies. The pre-impoundment surface was manually drawn and is represented by the bottom black line in Figure 9E and Figure 10E, and by the yellow line in Figures 9F-H and Figures 10F-H. Figures 11 and 12 show sediment core samples W-3 and

WN-1 correlated with the 208 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface identified along cross-sections where sediment core samples were collected is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

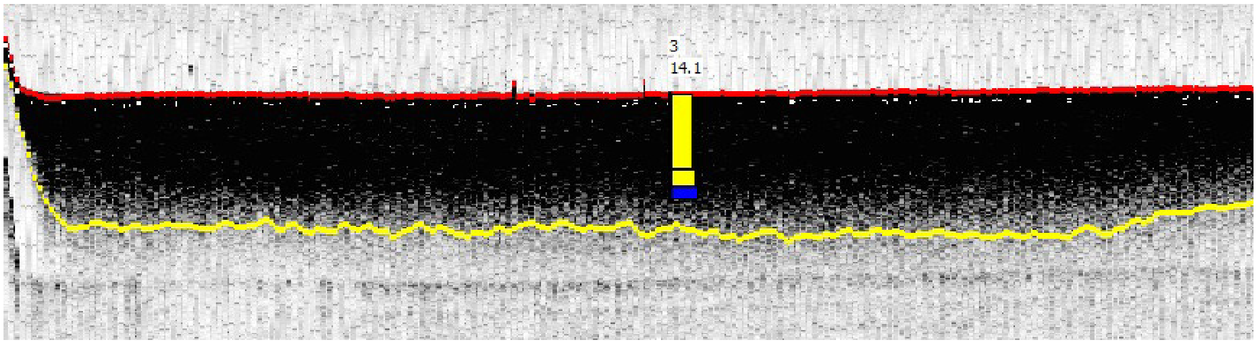

Figure 11. Cross-section of data collected from Lake Winters during 2013 survey, displayed in DepthPic© (208 kHz frequency), correlated with sediment core sample W-3 and showing the current surface in red and pre-impoundment surface in yellow

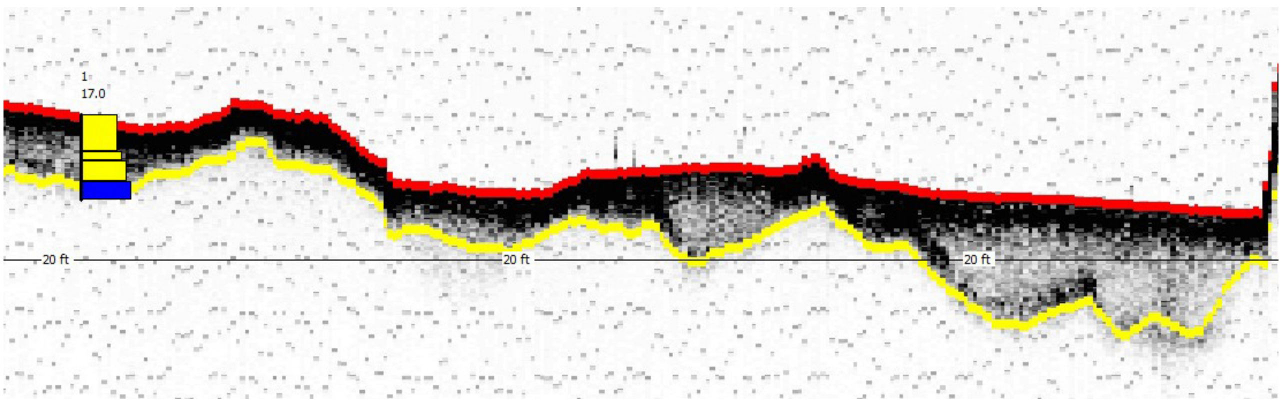

Figure 12. Cross-section of data collected from Elm Creek Reservoir during 2013 survey, displayed in DepthPic© (208 kHz frequency), correlated with sediment core sample WN-1 and showing the current surface in red and pre-impoundment surface in yellow

After the pre-impoundment surface from all cross-sections was identified, a sediment thickness TIN model is created following standard GIS techniques (Furnans, 2007). Sediment thicknesses were interpolated between surveyed cross-sections using HydroTools with the same interpolation definition file used for bathymetric interpolation. For the purposes of the TIN model creation, TWDB assumed sediment thickness at the reservoir boundaries was zero feet (defined as the 1,790.0 foot NGVD29 elevation contour and 1,790.0 foot NGVD29 elevation contour). The sediment thickness TIN models were converted to a raster representation using a cell size of 1 foot by 1 foot and used to produce sediment thickness maps of Lake Winters and Elm Creek Reservoir (Figure 13).

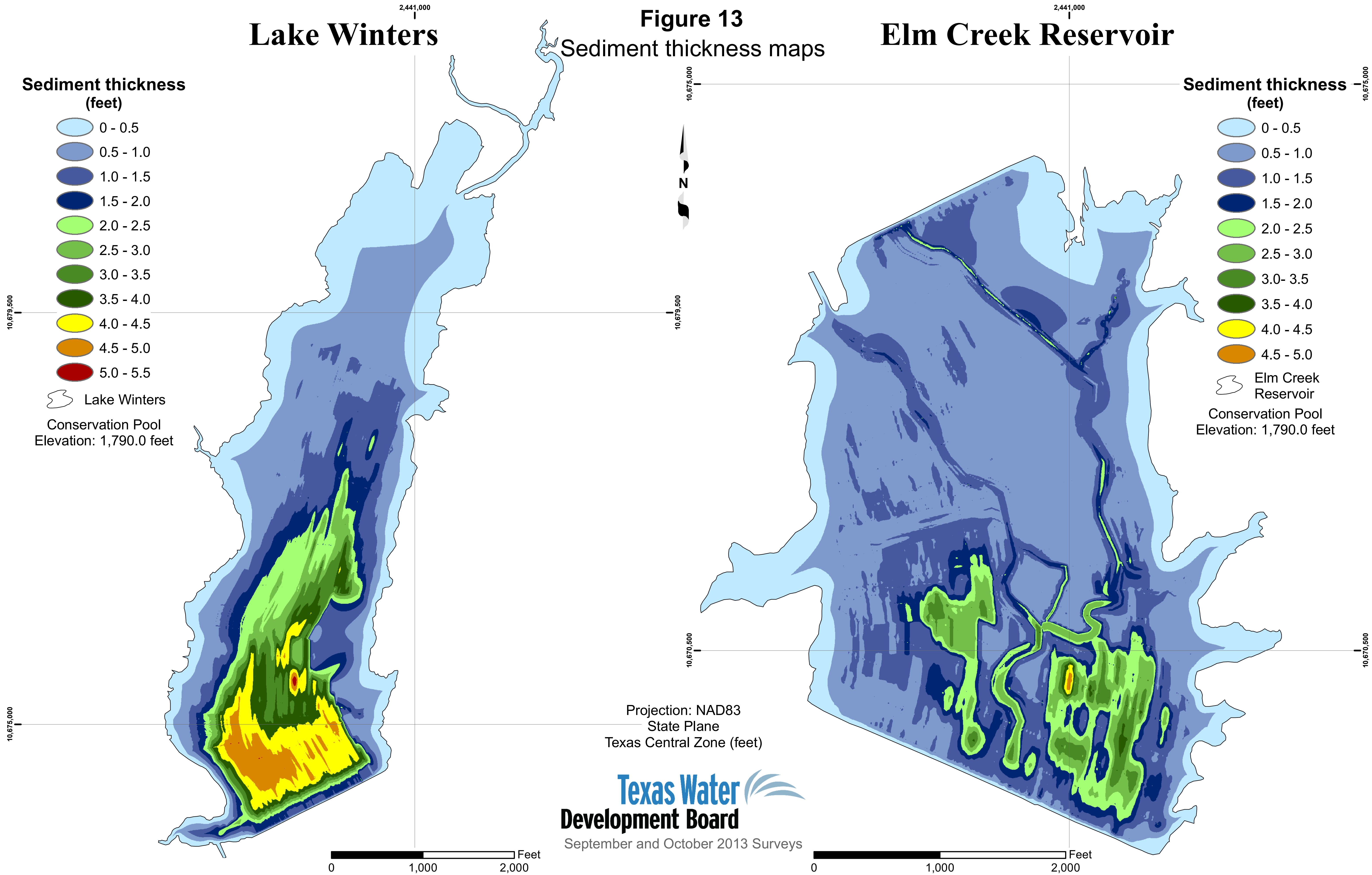

Figure 13
Sediment thickness maps

Survey results

Volumetric survey

The 2013 TWDB volumetric and sedimentation survey indicates that Lake Winters has a total reservoir capacity of 1,747 acre-feet and encompasses 319 acres at conservation pool elevation (1,790.0 feet above mean sea level, NGVD29) and that Elm Creek Reservoir has a total reservoir capacity of 6,032 acre-feet and encompasses 319 acres at conservation pool elevation (1,790.0 feet above mean sea level, NGVD29). Previous capacity estimates for Lake Winters include the original design estimate of 2,518.2 acre-feet and a 1970 estimate of 1,886.2 acre-feet (USGS, 1971). Although no original capacity estimate was found for Elm Creek Reservoir, the City of Winters is authorized to impound 5,927 acre-feet in Elm Creek Reservoir (TWC, 1979). 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.

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

Survey	Surface area (acres)	Total capacity (acre-feet)	Survey	Surface area (acres)	Total capacity (acre-feet)
Lake Winters original[a]	306.6	2,518.2	Elm Creek Reservoir [b]	N/A	5,927
Lake Winters 1970[a]	306.6	1,886.2	Elm Creek Reservoir TWDB 2013	319	6,032
Lake Winters TWDB 2013	319	1,747			

[a] Source: (USGS, 1971)
[b] Source: (TWC, 1979)

Sedimentation survey

The 2013 TWDB sedimentation survey estimates Lake Winters to have an average loss of capacity between 7 and 11 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,790.0 feet above mean sea level, NGVD29). The 2013 TWDB sedimentation survey estimates Elm Creek Reservoir to have an average loss of capacity between -3.5 and 11 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (1,790.0 feet above mean sea level, NGVD29). The heaviest accumulations measured are in Lake Winters. In both lakes, sediment accumulation increases towards the dams. Comparison of capacity estimates of Lake Winters and Elm Creek Reservoir derived using differing methodologies are provided in Tables 4 and 5, respectively, for sedimentation rate calculation

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

Survey	Volume comparisons at conservation pool elevation (ac-ft)		Pre-impoundment (ac-ft)
Lake Winters original	2,518.2	<>	<>
Lake Winters 1970	<>	1,886.2	<>
Lake Winters TWDB pre-impoundment estimate 2013	<>	<>	2,195 [b]
Lake Winters TWDB 2013	1,747	1,747	1,747
Volume difference (acre-feet)	771.2 (30.6%)	139.2 (7.4%)	448 (20.4%)
Number of years	68[a]	43	68[a]
Capacity loss rate (acre-feet/year)	11	3	7

Note: Lake Winters was completed in 1945
[a] Number of years based on difference between 2013 survey date and completion date
[b] 2013 TWDB surveyed capacity of 1,747 acre-feet plus 2013 TWDB surveyed sediment volume of 448 acre-feet

Table 5. **Capacity loss comparisons for Elm Creek Reservoir**

Survey	Volume comparisons at conservation pool elevation (ac-ft)	Pre-impoundment (ac-ft)
Elm Creek Reservoir Authorized	5,927	<>
Elm Creek Reservoir TWDB pre-impoundment estimate 2013	<>	6,360 [b]
Elm Creek Reservoir TWDB 2013	6,032	6,032
Volume difference (acre-feet)	-105 (1.8%)	328 (5.2%)
Number of years	30[a]	30[a]
Capacity loss rate (acre-feet/year)	-3.5	11

Note: Elm Creek Reservoir was completed in 1983
[a] Number of years based on difference between 2013 survey date and completion date
[b] 2013 TWDB calculated capacity of 6,032 acre-feet plus 2013 TWDB calculated sediment volume of 328 acre-feet

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Winters and Elm Creek Reservoir 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 rates for Lake Winters and Elm Creek Reservoir.

TWDB contact information

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

Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:

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Or

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Appendix A

Lake Winters

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | September 2013 Survey

CAPACITY IN ACRE-FEET | Conservation Pool Elevation 1,790.0 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
1,779	0	0	0	0	0	0	0	0	0	0
1,780	1	3	6	10	15	19	25	30	36	42
1,781	48	55	61	68	76	83	91	99	107	116
1,782	125	134	143	153	163	174	184	196	207	219
1,783	231	244	257	270	284	298	312	327	342	357
1,784	373	389	405	422	438	455	473	491	509	527
1,785	545	564	582	601	620	639	659	678	698	718
1,786	739	759	780	800	821	843	864	886	908	930
1,787	953	976	998	1,022	1,045	1,069	1,093	1,117	1,142	1,166
1,788	1,191	1,217	1,242	1,268	1,294	1,320	1,346	1,373	1,400	1,427
1,789	1,455	1,482	1,510	1,539	1,567	1,596	1,626	1,655	1,685	1,716
1,790	1,747									

Appendix B

Lake Winters

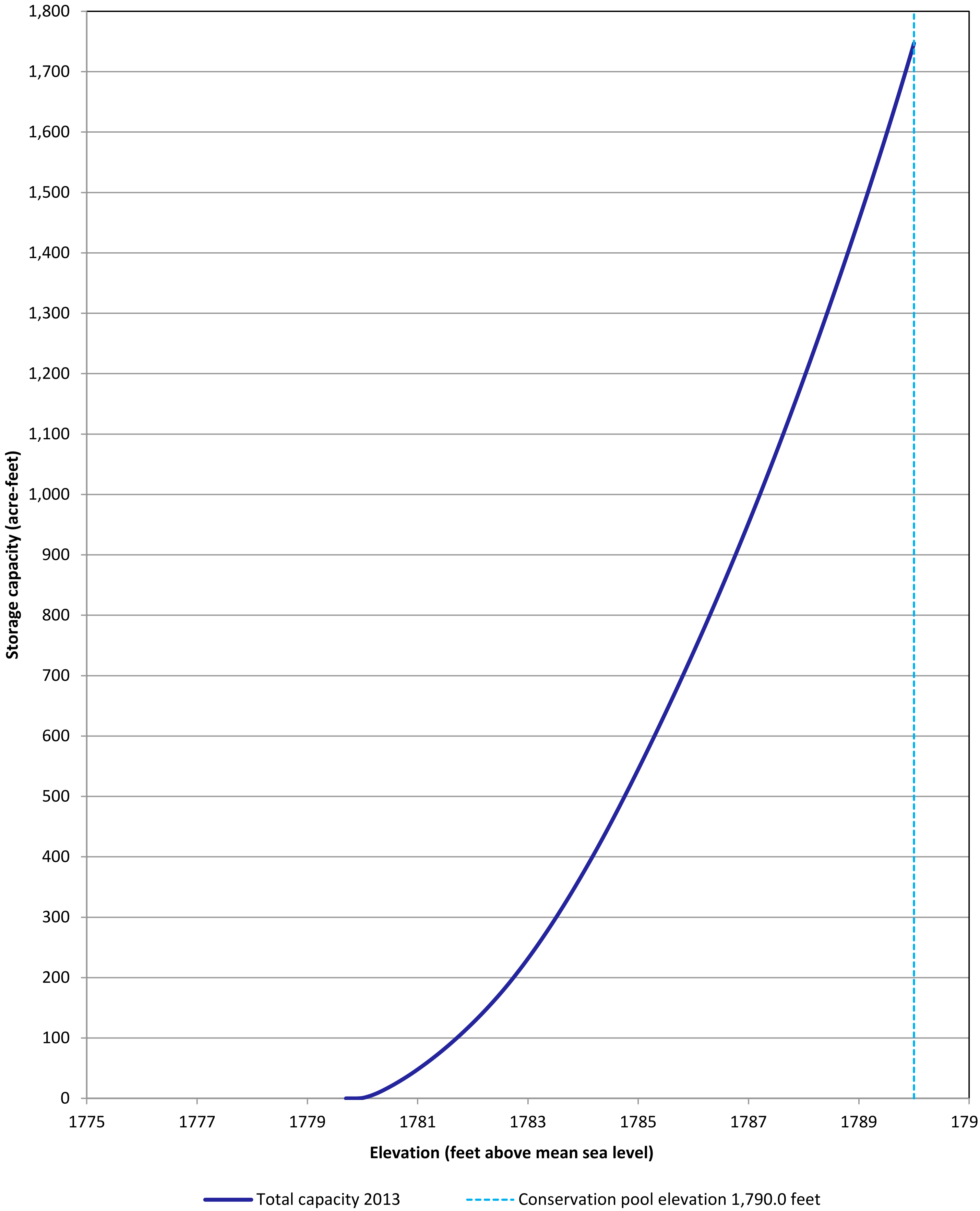
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — September 2013 Survey

AREA IN ACRES — Conservation Pool Elevation 1,790.0 feet NGVD29

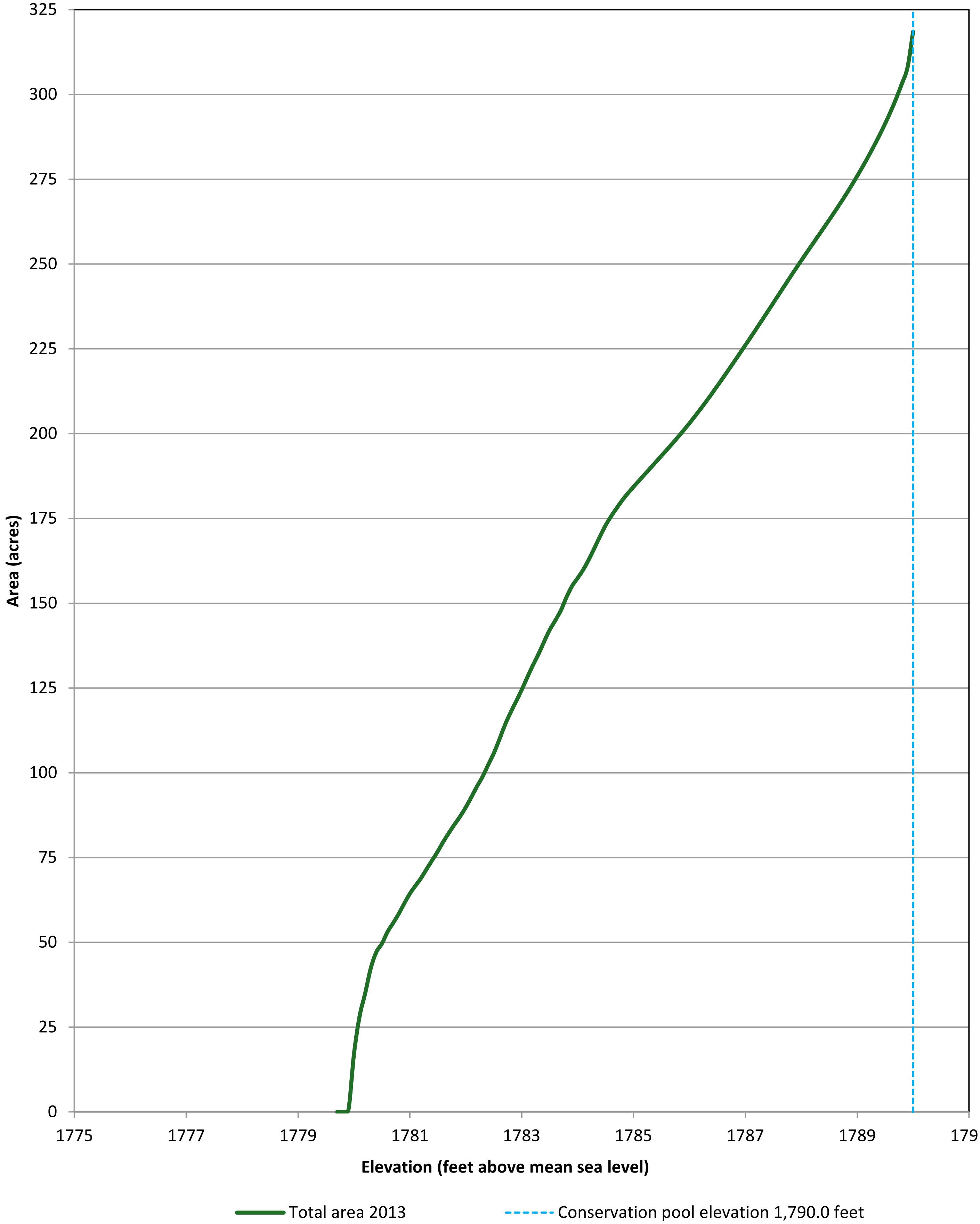
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1,779	0	0	0	0	0	0	0	0	0	0
1,780	17	28	35	42	47	50	53	56	58	61
1,781	64	67	69	72	74	77	80	82	85	87
1,782	90	93	96	99	102	106	110	114	118	121
1,783	124	128	132	135	139	142	145	148	152	155
1,784	157	160	163	166	170	173	176	178	180	182
1,785	184	186	188	190	192	193	195	197	199	201
1,786	203	205	207	209	212	214	216	219	221	224
1,787	226	229	231	234	236	239	241	244	246	249
1,788	251	253	256	258	261	263	265	268	271	273
1,789	276	279	282	285	288	291	295	299	303	308
1,790	319									



Lake Winters
September 2013 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Lake Winters
September 2013 Survey
Prepared by: TWDB

Appendix D: Area curve

Appendix E

Elm Creek Reservoir

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | October 2013 Survey

CAPACITY IN ACRE-FEET | Conservation Pool Elevation 1,790.0 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
1,759	0	0	0	0	0	0	0	0	0	1
1,760	1	2	2	3	5	6	8	10	12	14
1,761	16	19	21	24	27	30	33	36	39	43
1,762	46	50	54	58	62	66	70	75	80	84
1,763	90	95	101	106	112	119	125	132	139	146
1,764	153	160	168	175	183	191	199	207	215	223
1,765	232	240	249	258	267	276	285	294	304	313
1,766	323	333	343	353	363	373	384	395	405	416
1,767	427	439	450	462	474	486	498	510	523	536
1,768	549	562	576	589	603	618	632	647	662	677
1,769	693	708	724	740	756	773	789	806	823	840
1,770	858	875	893	911	929	947	966	984	1,003	1,022
1,771	1,041	1,061	1,080	1,100	1,120	1,140	1,160	1,181	1,201	1,222
1,772	1,243	1,264	1,285	1,306	1,327	1,349	1,370	1,392	1,414	1,436
1,773	1,458	1,480	1,502	1,524	1,546	1,569	1,591	1,614	1,637	1,659
1,774	1,682	1,705	1,728	1,751	1,774	1,797	1,821	1,844	1,868	1,891
1,775	1,915	1,938	1,962	1,986	2,009	2,033	2,057	2,081	2,105	2,129
1,776	2,153	2,177	2,202	2,226	2,250	2,274	2,299	2,323	2,348	2,372
1,777	2,397	2,421	2,446	2,471	2,496	2,520	2,545	2,570	2,595	2,620
1,778	2,645	2,670	2,695	2,721	2,746	2,771	2,797	2,822	2,847	2,873
1,779	2,898	2,924	2,950	2,975	3,001	3,027	3,053	3,079	3,105	3,131
1,780	3,157	3,183	3,209	3,235	3,261	3,288	3,314	3,340	3,367	3,393
1,781	3,420	3,446	3,473	3,500	3,526	3,553	3,580	3,607	3,634	3,661
1,782	3,688	3,715	3,742	3,769	3,797	3,824	3,851	3,879	3,906	3,934
1,783	3,961	3,989	4,016	4,044	4,072	4,100	4,128	4,156	4,184	4,212
1,784	4,240	4,268	4,296	4,324	4,353	4,381	4,410	4,438	4,467	4,495
1,785	4,524	4,553	4,581	4,610	4,639	4,668	4,697	4,726	4,755	4,784
1,786	4,814	4,843	4,872	4,902	4,931	4,961	4,990	5,020	5,049	5,079
1,787	5,109	5,139	5,169	5,199	5,229	5,259	5,289	5,319	5,349	5,380
1,788	5,410	5,441	5,471	5,502	5,532	5,563	5,594	5,625	5,656	5,687
1,789	5,718	5,749	5,780	5,811	5,842	5,874	5,905	5,937	5,968	6,000
1,790	6,032									

Appendix F

Elm Creek Reservoir

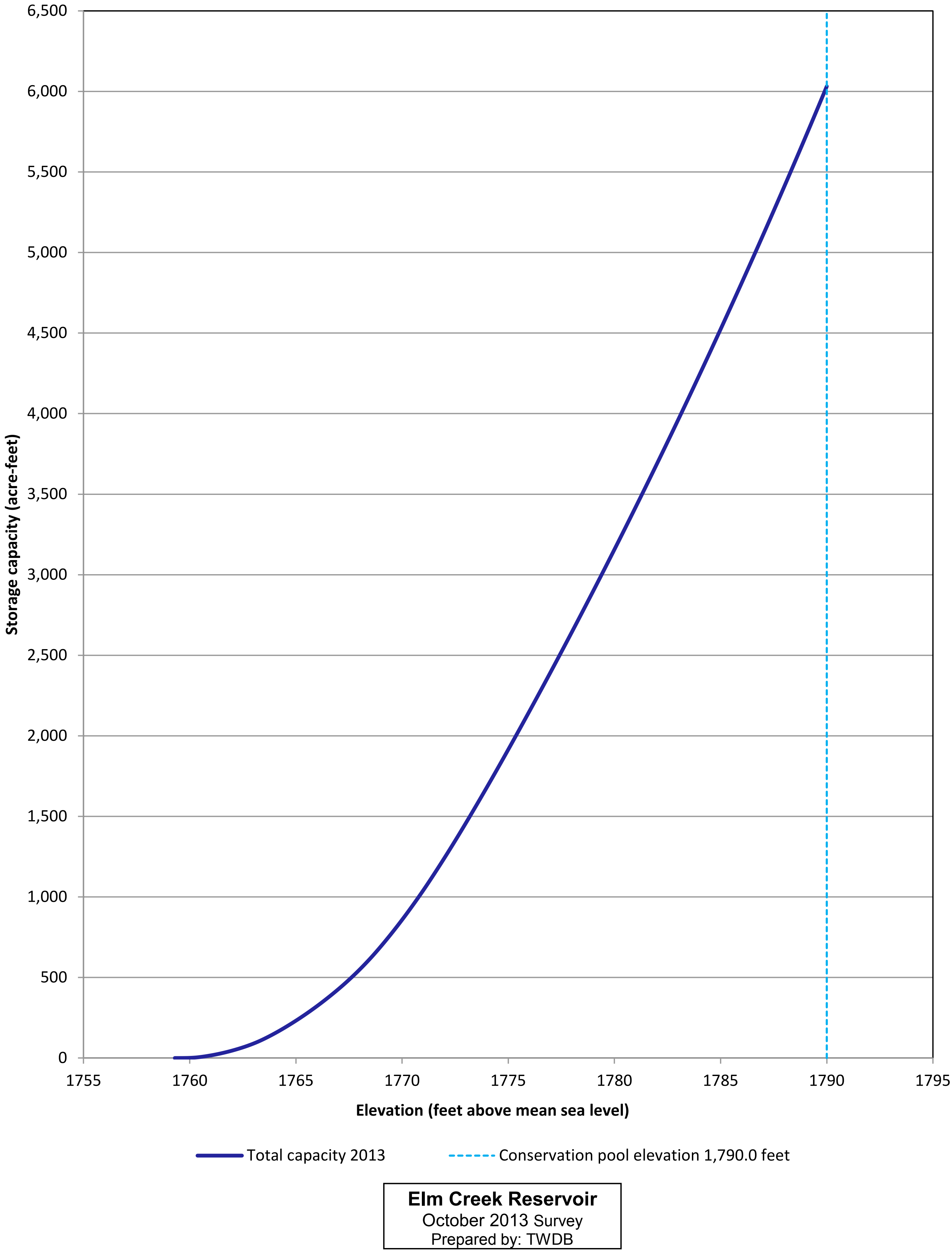
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — October 2013 Survey

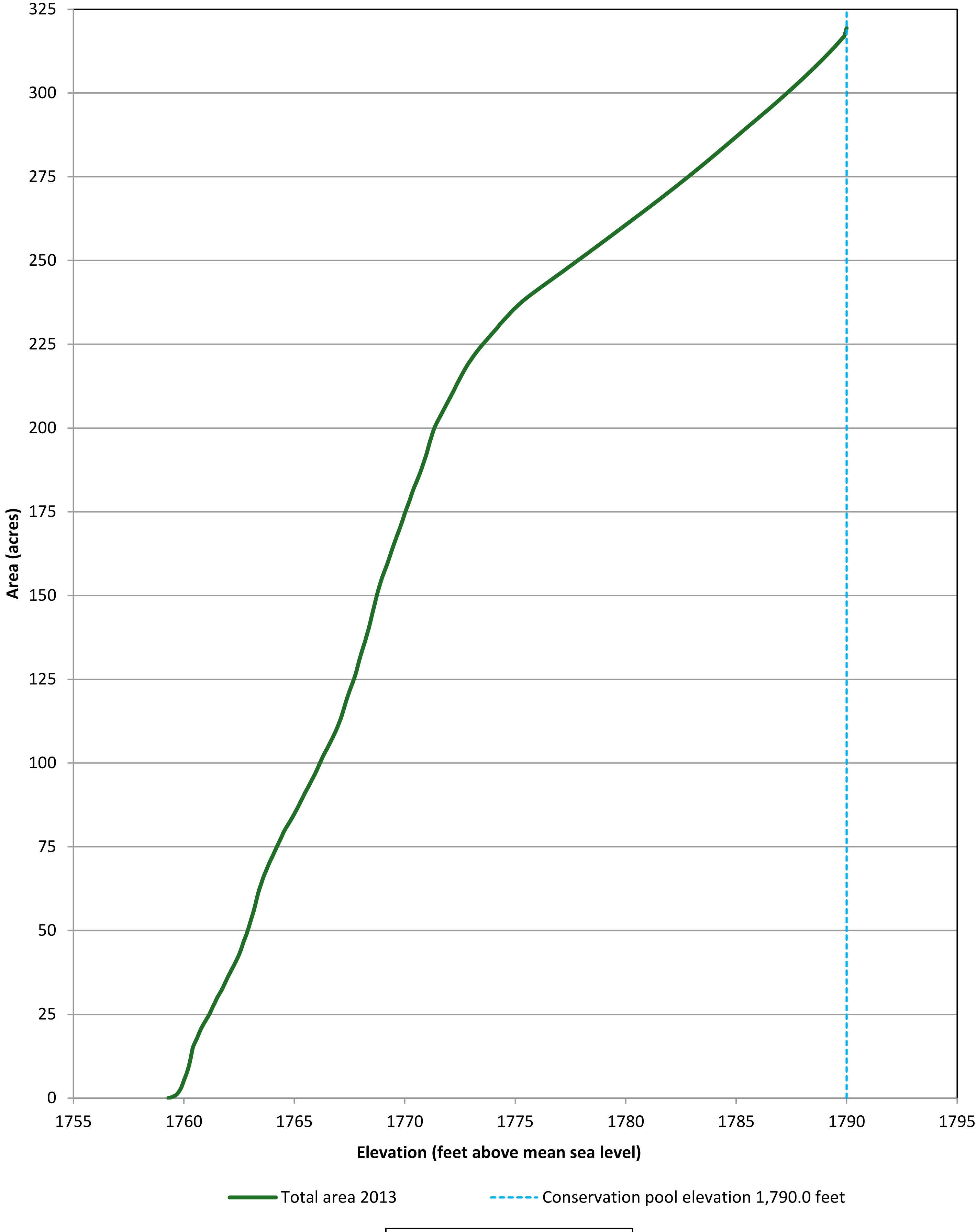
AREA IN ACRES — Conservation Pool Elevation 1,790.0 feet NGVD29

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
1,759	0	0	0	0	0	0	1	1	2	3
1,760	5	7	9	12	15	17	18	20	21	22
1,761	23	24	26	27	28	30	31	32	33	35
1,762	36	38	39	40	41	43	45	47	48	50
1,763	52	55	57	60	62	64	66	68	69	71
1,764	72	73	75	76	78	79	80	81	83	84
1,765	85	86	87	89	90	91	92	94	95	96
1,766	98	99	101	102	103	105	106	107	108	110
1,767	112	113	115	118	120	122	123	125	127	130
1,768	132	134	136	139	141	144	146	149	152	154
1,769	156	158	159	161	163	165	167	169	171	172
1,770	175	176	178	180	182	183	185	187	189	191
1,771	193	195	197	199	201	202	203	205	206	207
1,772	208	210	211	212	214	215	216	217	218	219
1,773	220	221	222	223	224	225	226	226	227	228
1,774	229	229	230	231	232	232	233	234	235	235
1,775	236	236	237	238	238	239	239	240	240	241
1,776	241	242	242	243	243	244	244	245	245	246
1,777	246	246	247	247	248	248	249	249	250	250
1,778	251	251	252	252	253	253	254	254	255	255
1,779	256	256	257	257	258	258	259	259	260	260
1,780	261	261	262	262	263	263	264	264	265	265
1,781	266	266	267	267	268	268	269	269	270	270
1,782	271	271	272	272	273	273	274	274	275	275
1,783	276	276	277	278	278	279	279	280	280	281
1,784	281	282	282	283	284	284	285	285	286	286
1,785	287	287	288	289	289	290	290	291	291	292
1,786	293	293	294	294	295	295	296	296	297	298
1,787	298	299	299	300	301	301	302	302	303	304
1,788	304	305	305	306	307	307	308	309	309	310
1,789	311	311	312	313	313	314	315	316	316	317
1,790	319									



Appendix G: Capacity curve



Elm Creek Reservoir
October 2013 Survey
Prepared by: TWDB

Appendix H: Area curve

Figure 6
Contour map

Contours
(feet)

1789
1788
1787
1786
1785
1784
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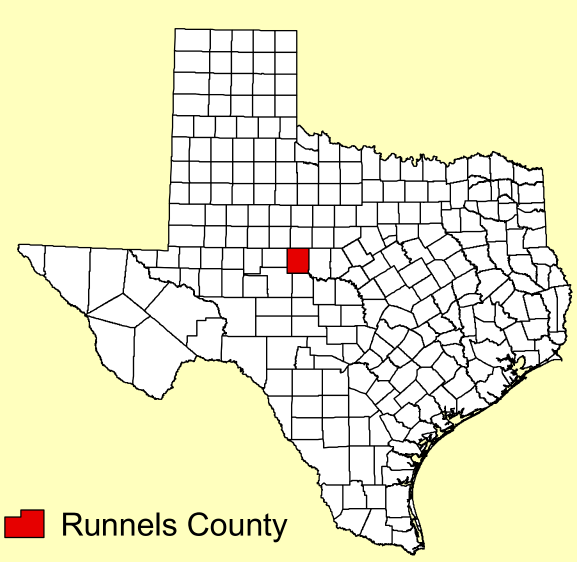
1762
1760

Lake Winters and
Elm Creek Reservoir

Conservation pool elevations:
Lake Winters: 1,790.0 feet
Elm Creek Reservoir: 1,790.0 feet

Projection: NAD83 State Plane
Texas Cental Zone (feet)



Runnels County

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacities of Lake Winters and Elm Creek Reservoir. The Texas Water Development Board makes no representations nor assumes any liability.