# Volumetric and Sedimentation Survey of LAKE OLNEY and LAKE COOPER

## April 2014 Surveys

Texas Water Development Board

February 2015

# Texas Water Development Board



Prepared for:

**City of Onley**

With Support Provided by:

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



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## Executive summary

In April, 2014, 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 Olney and Lake Cooper. The City of Olney 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 Olney is located on Mesquite Creek in the Red River Basin, approximately five miles northwest of Olney, in Archer County, Texas. Lake Cooper is located immediately downstream of Lake Olney. TWDB collected bathymetric data for both lakes on April 15, 2014. TWDB measured a daily average water surface elevation during the survey of 1,146.21 feet NAVD88 on Lake Olney and 1,129.66 feet NAVD88 on Lake Cooper. Topographic data for the dry portions of the lake beds were collected on June 3-4, 2014.

**The 2014 TWDB volumetric and sedimentation survey indicates that Lake Olney has a total reservoir capacity of 1,189 acre-feet and encompasses 158 acres at the spillway elevation of 1,154.2 feet NAVD88 and that Lake Cooper has a total reservoir capacity of 3,357 acre-feet and encompasses 274 acres at the spillway elevation of 1,149.4 feet NAVD88.**

**The 2014 TWDB sedimentation survey estimates a total pre-impoundment capacity for Lake Olney of 1,619 acre-feet at spillway elevation 1,154.2 feet NAVD88. The 2014 TWDB sedimentation survey estimates a total pre-impoundment capacity for Lake Cooper of 4,000 acre-feet at spillway elevation 1,149.4 feet NAVD88. Both pre-impoundment capacity estimates are based both on measured sediment deposition and on assumptions about the distribution of deposited sediment where it was not possible to collect data due to low water elevations during the surveys.** 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 April 2014, 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 Olney and Lake Cooper (TWDB, 2013). The City of Olney 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 Olney and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) a shaded relief plot of the reservoir bottoms [Figures 4 and 5], (2) bottom contour maps [Figures 8 and 9], (3) surveyed sediment accumulation and location [Figures 16 and 17], and (4) elevation-area-capacity tables of the reservoir acceptable to the Texas Commission on Environmental Quality [Appendices A, B, E, and F].

## Lake Olney and Lake Cooper general information

Lake Olney is located on Mesquite Creek in the Red River Basin approximately five miles northwest of Olney in Archer County, Texas. Lake Cooper is located immediately downstream of Lake Olney (Figure 1). Lake Olney and Lake Cooper are owned and operated by the City of Olney, Texas. The exact date of construction of Lake Olney is unknown. Some records suggest the reservoir was completed in 1935 (TCEQ, 1998; Biggs & Mathews, Inc., et. al., 2010; OWAC, 2013). Lake Cooper was completed in 1954 (OWAC, 2013). Both lakes were built for municipal water supply for the City of Olney and for recreational purposes (City of Olney, 2014).

Lake Olney Dam is an earthen structure 1,490 feet long and 20 feet tall, with an uncontrolled spillway (TCEQ, 1998). Based on the TWDB GPS survey, the elevation of the top of the spillway is 1,154.2 feet NAVD88. Lake Cooper Dam is an earthen structure 2,050 feet long and 49 feet tall, with an uncontrolled bell-mouth type spillway (TCEQ, 1998). Based on the TWDB GPS survey the elevation of the top of the spillway is 1,149.4 feet and the elevation of the top of the Lake Cooper Dam is 1,160.3 feet NAVD88. Water rights for Lake Olney and Lake Cooper have been appropriated to the City of Olney through Certificate of Adjudication No. 02-5146. This certificate authorizes the

City of Olney to impound a maximum of 2,150 acre-feet of water in Lake Olney and a maximum of 4,500 acre-feet of water in Lake Cooper. The complete certificate is on file in the Information Resources Division of the Texas Commission on Environmental Quality.

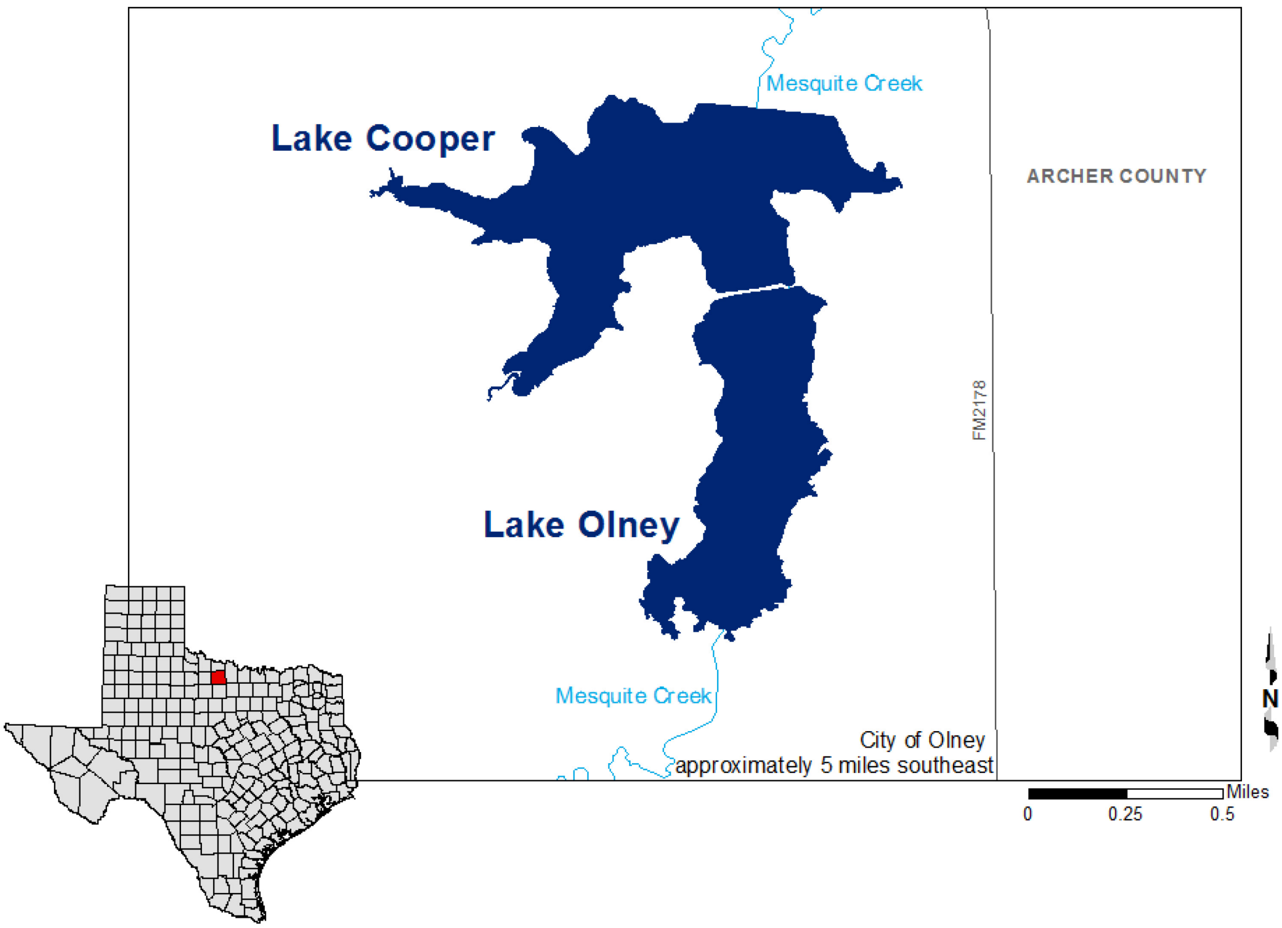



**Figure 1. Location of Lake Olney and Lake Cooper**

# Volumetric and sedimentation survey of Lake Olney and Lake Cooper

## Datum

The vertical datum used during this survey is the North American Vertical Datum 1988 (NAVD88). 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 North Central Zone (feet).

## TWDB topographic, bathymetric and sedimentation data collection

TWDB collected bathymetric data for Lake Olney and Lake Cooper on April 15, 2014. TWDB measured a daily average water surface elevation during the survey of 1,146.21 feet NAVD88 for Lake Olney and 1,129.66 feet NAVD88 for Lake Cooper. For bathymetric survey 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 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.

Due to low lake levels, TWDB also collected terrestrial elevation measurements in the dry portions of the lakes on June 3-4, 2014. The average water surface elevations of Lake Olney measured 1,145.49 feet and 1,145.51 feet NAVD88, respectively. The average water surface elevation of Lake Cooper measured 1,128.79 feet NAVD88 on June 4, 2014. Additional GPS points were collected on December 4, 2014, to measure the elevations of structural features including the tops of the intake structures, the top of Cooper Dam, and the Lake Olney spillway. TWDB returned on January 21, 2015, to measure the elevation of the Lake Cooper spillway. For data collection, TWDB used a Trimble® R6 Global Navigation Satellite System (GNSS) survey system. This Real Time Kinematic with differential GPS (RTK-GPS) system utilizes a base station with multiple rovers collecting data both as continuous topography points (using ATV mounts) and single GPS points (walking with survey pole), depending on area access. Areas of data collection depended on physical accessibility, travel distance from access points, brush cover density, and soil moisture, and included dry upper reaches to near water’s edge and creek bottoms. Figure 2 shows where data collection occurred during the 2014 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 seven locations to collect sediment core samples (Figure 2). The sediment core samples were collected April 17, 2014, with a custom-coring boat and SDI VibeCore system.

Sediment cores are collected in 3-inch diameter clear acrylic 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, the level of sediment in the tube is measured, the core tube is capped, and all cores are transported back to TWDB headquarters for further analysis. During this time, some settling of the upper layer can occur.

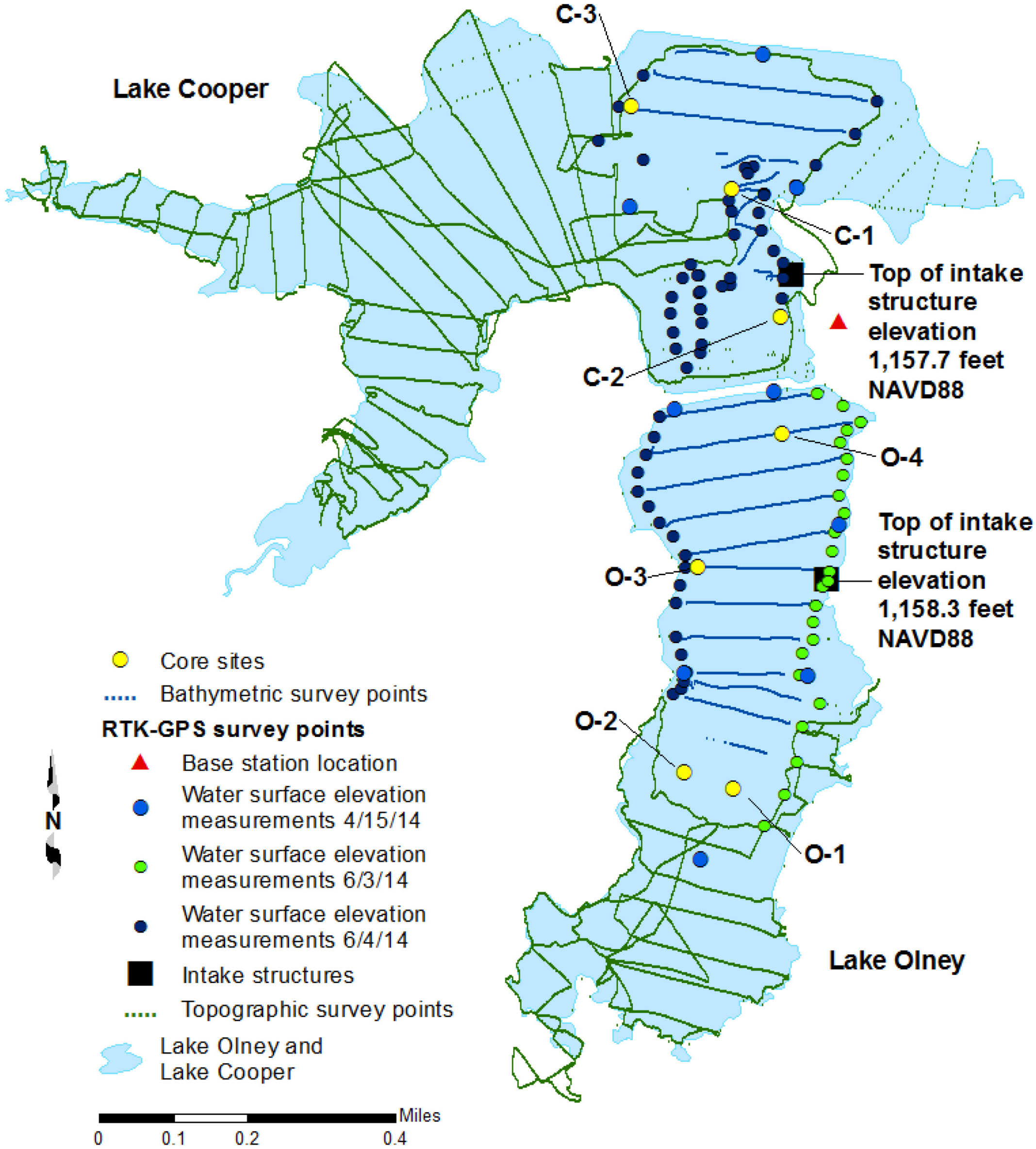



**Figure 2. Data collection during 2014 TWDB surveys**

## 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, 2014) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Olney and Lake Cooper are Lake Olney NE and Lake Olney SE. The DOQQs were photographed on July 19, 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, comparison of the land water interface in the 2010 photos to the change in vegetation seen in photos taken on July 7, 2012, indicates that both reservoirs were 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. The RTK-GPS points were evaluated to determine the elevations of the boundaries. The boundary for Lake Olney was assigned an elevation of 1,153.5 feet NAVD88. The boundary for Lake Cooper was assigned an elevation of 1,146.4 feet NAVD88. Both reservoirs' model boundaries were edited from the original digitization as necessary to match the RTK-GPS data.

Additional RTK-GPS data collected on December 4, 2014, indicate the lakes were not completely full at the time of the 2010 photographs. Vegetation suggests that they have not been at capacity in some time. The RTK-GPS survey indicates the elevation of the top of the Olney spillway is 1,154.2 feet NAVD88 and the top of the Cooper spillway is 1,149.4 feet NAVD88. These are the highest elevations at which the lakes will hold water and are used in this study to define capacities for the two lakes. The lake TIN models were only developed up to the surveyed elevations of 1,153.5 feet for Lake Olney and 1,146.4 feet for Lake Cooper, see the section titled "Area, volume, and contour calculation" for a description of how the elevation-area-capacity tables were developed up to their capacity elevations.

### 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 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, 2014). The elevation data collected on top of Olney and Cooper's intakes will allow the City to more accurately measure water surface elevations to determine the lake's areas and volumes.

### 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. The bathymetric survey points and RTK-GPS survey points were combined into one dataset. 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 ,when available, scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics), hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), and aerial photographs taken when the water surface elevations are very low. 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 areas of the reservoir, or areas where data alone did not represent the topography, linear interpolation is used for volumetric and sediment accumulation estimations. The linear interpolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without interpolated 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 interpolation improves the elevation-capacity and elevation-area calculations. It is not possible to remove all flat triangles, and linear interpolation is only applied where adding bathymetry is deemed reasonable. For example, linear interpolation was applied throughout Lake Olney and Lake Cooper following obvious channel features visible in aerial photographs taken on July 6, 2012, and December 1, 2013.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear interpolation techniques to Lake Olney and Lake Cooper. 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.

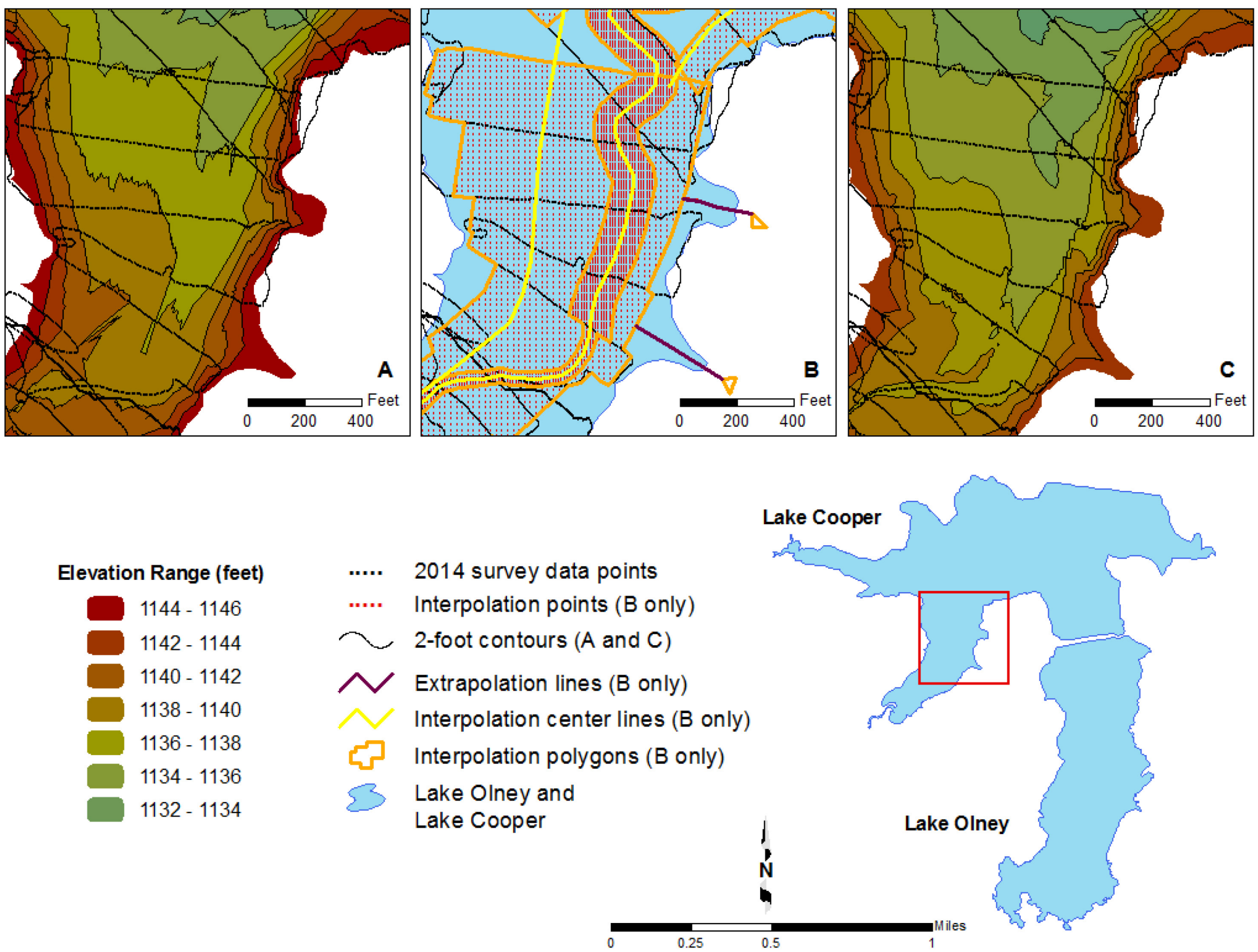



**Figure 3.** **Anisotropic spatial interpolation and linear interpolation of Lake Olney and Lake Cooper sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points**

### 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 1,139.1 to 1,153.4 feet for Lake Olney and from 1,121.9 to 1,146.3 feet for Lake Cooper. To calculate the areas and capacities above 1153.4 feet for Lake Olney and 1,146.3 feet for Lake Cooper, areas were linearly extrapolated and volumes were calculated using the formula:

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

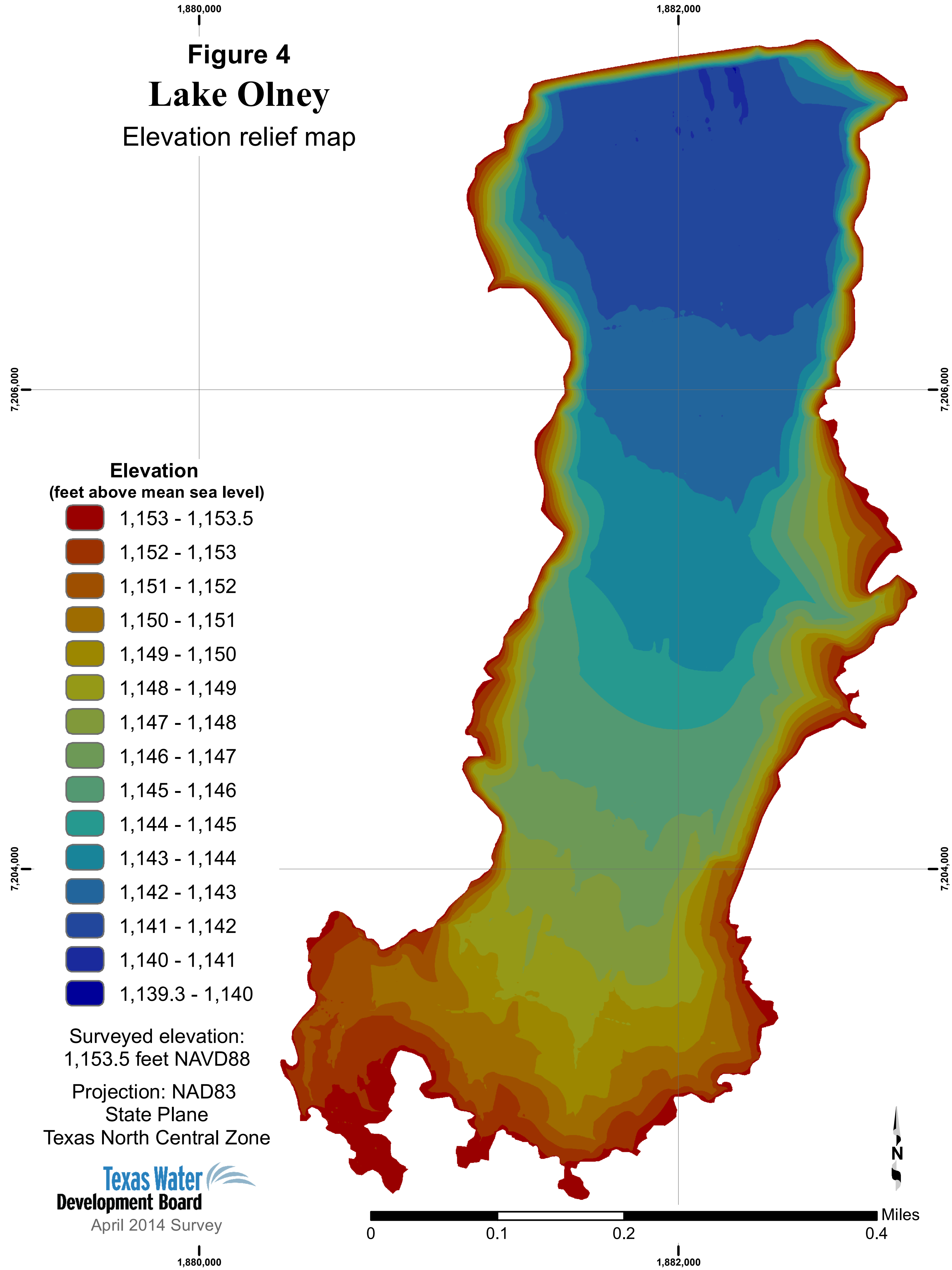
*Where:*

$Area_0$ = *area corresponding to* $Elevation_0$
$Area_1$ = *area corresponding to* $Elevation_1$
$Capacity_0$ = *capacity corresponding to* $Elevation_0$
$Capacity_1$ = *capacity corresponding to* $Elevation_1$

The elevation-capacity tables and elevation-area tables, updated for 2014, 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 elevation relief maps (Figures 4 and 5), representing the topography of the reservoir bottoms; depth range maps (Figures 6 and 7), showing shaded depth ranges for Lake Olney and Lake Cooper; and contour maps showing 1-foot contours for Lake Olney and 2-foot contours for Lake Cooper (Figures 8 and 9).

## Figure 4
# Lake Olney
## Elevation relief map



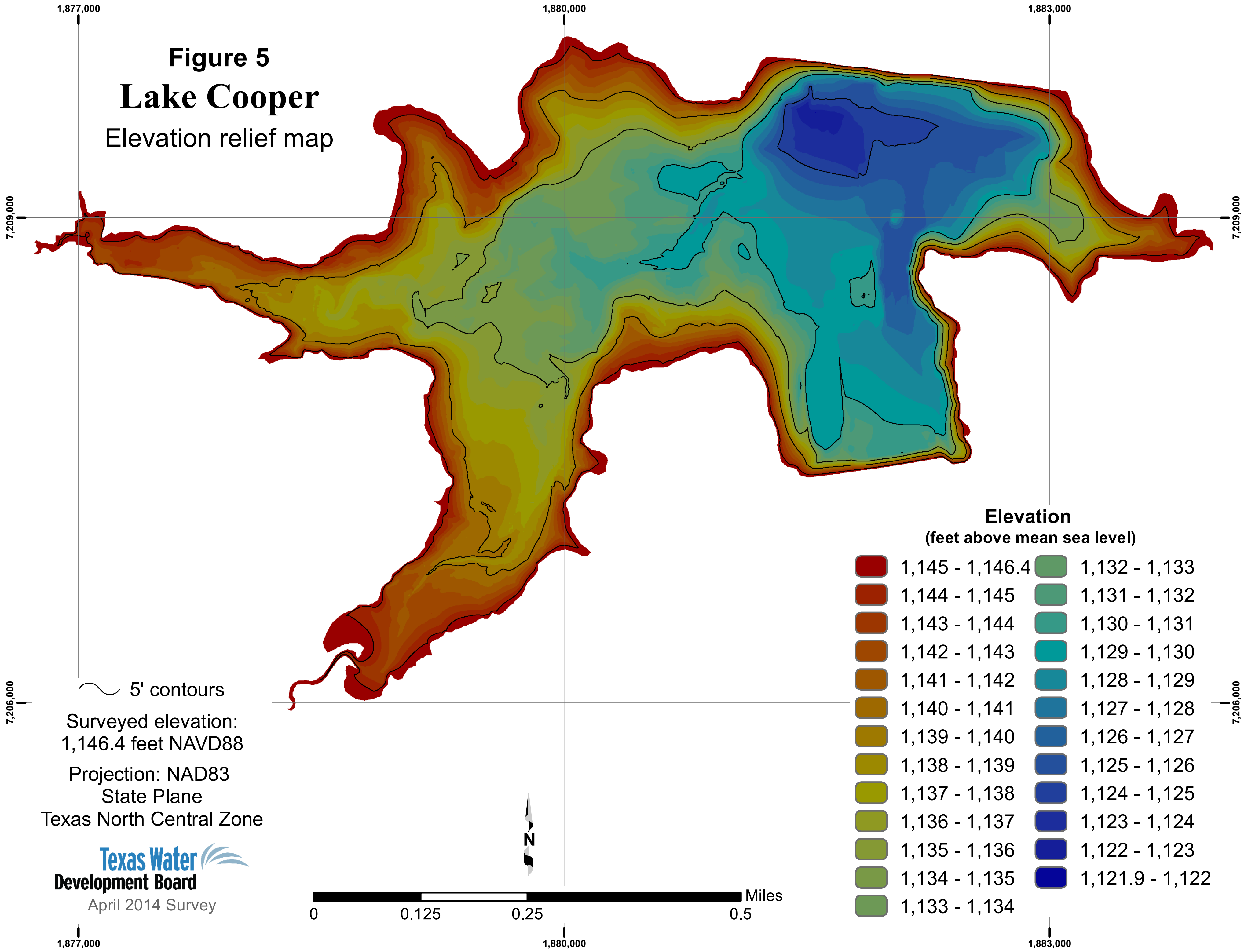
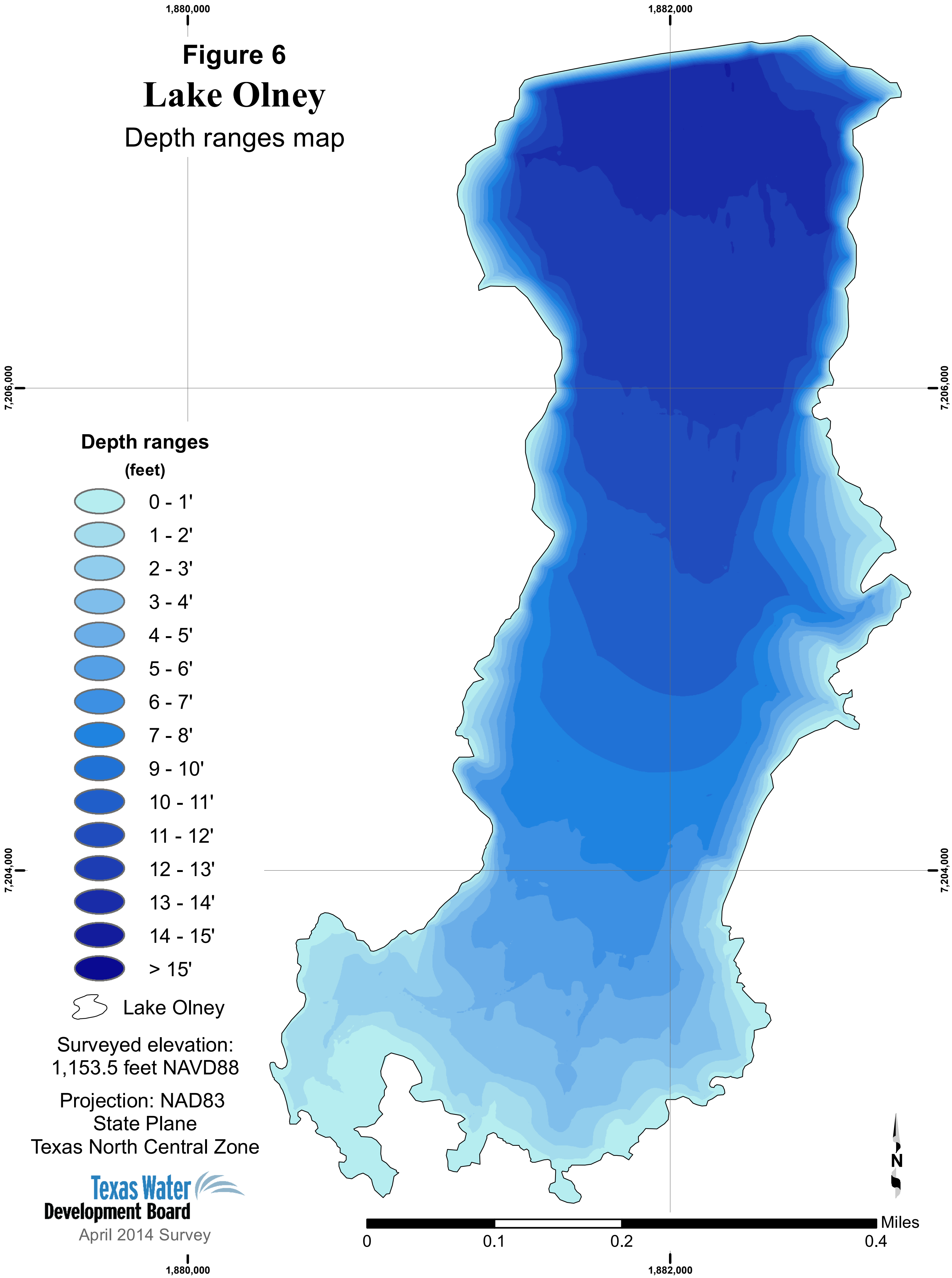


Figure 5
Lake Cooper
Elevation relief map
1,877,000
1,880,000
1,883,000
7,209,000
7,206,000
Elevation
(feet above mean sea level)
1,145 - 1,146.4
1,144 - 1,145
1,143 - 1,144
1,142 - 1,143
1,141 - 1,142
1,140 - 1,141
1,139 - 1,140
1,138 - 1,139
1,137 - 1,138
1,136 - 1,137
1,135 - 1,136
1,134 - 1,135
1,133 - 1,134
1,132 - 1,133
1,131 - 1,132
1,130 - 1,131
1,129 - 1,130
1,128 - 1,129
1,127 - 1,128
1,126 - 1,127
1,125 - 1,126
1,124 - 1,125
1,123 - 1,124
1,122 - 1,123
1,121.9 - 1,122
5' contours
Surveyed elevation:
1,146.4 feet NAVD88
Projection: NAD83
State Plane
Texas North Central Zone
Texas Water
Development Board
April 2014 Survey
N
Miles
0
0.125
0.25
0.5

# Figure 6
# Lake Olney
## Depth ranges map



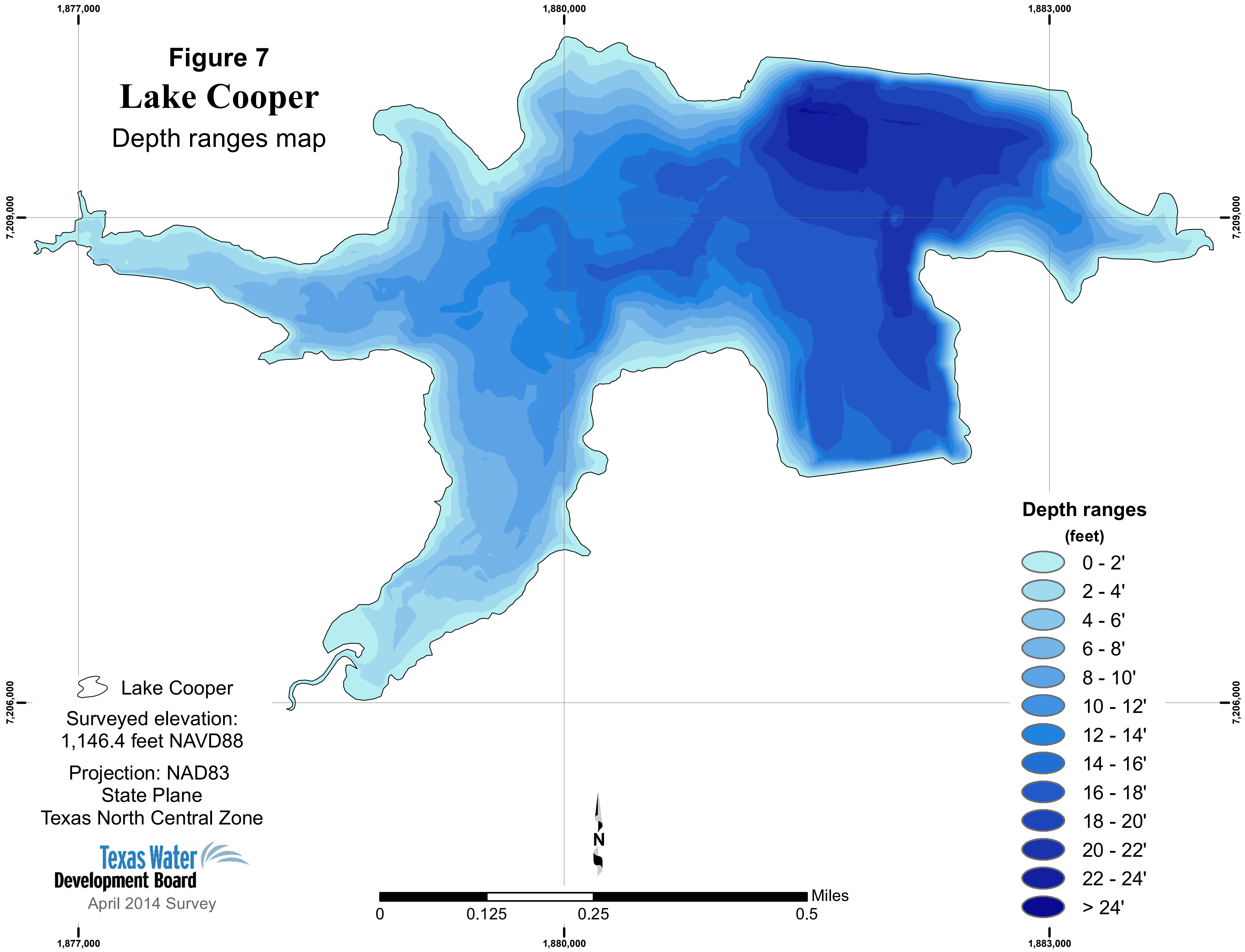


Figure 7
Lake Cooper
Depth ranges map
1,877,000
1,880,000
1,883,000
7,209,000
7,206,000
Depth ranges
(feet)
0 - 2'
2 - 4'
4 - 6'
6 - 8'
8 - 10'
10 - 12'
12 - 14'
14 - 16'
16 - 18'
18 - 20'
20 - 22'
22 - 24'
> 24'
Lake Cooper
Surveyed elevation:
1,146.4 feet NAVD88
Projection: NAD83
State Plane
Texas North Central Zone
Texas Water
Development Board
April 2014 Survey
N
0
0.125
0.25
0.5
Miles

# Figure 8
## Contour Map
### Contours
**(feet)**

1153
1152
1151
1150
1149
1148
1147
1146
1145
1144
1143
1142
1141
1140

Lake Olney

Surveyed elevation:
1,153.5 feet NAVD88

Spillway elevation:
1,154.2 feet NAVD88

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

Archer County

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

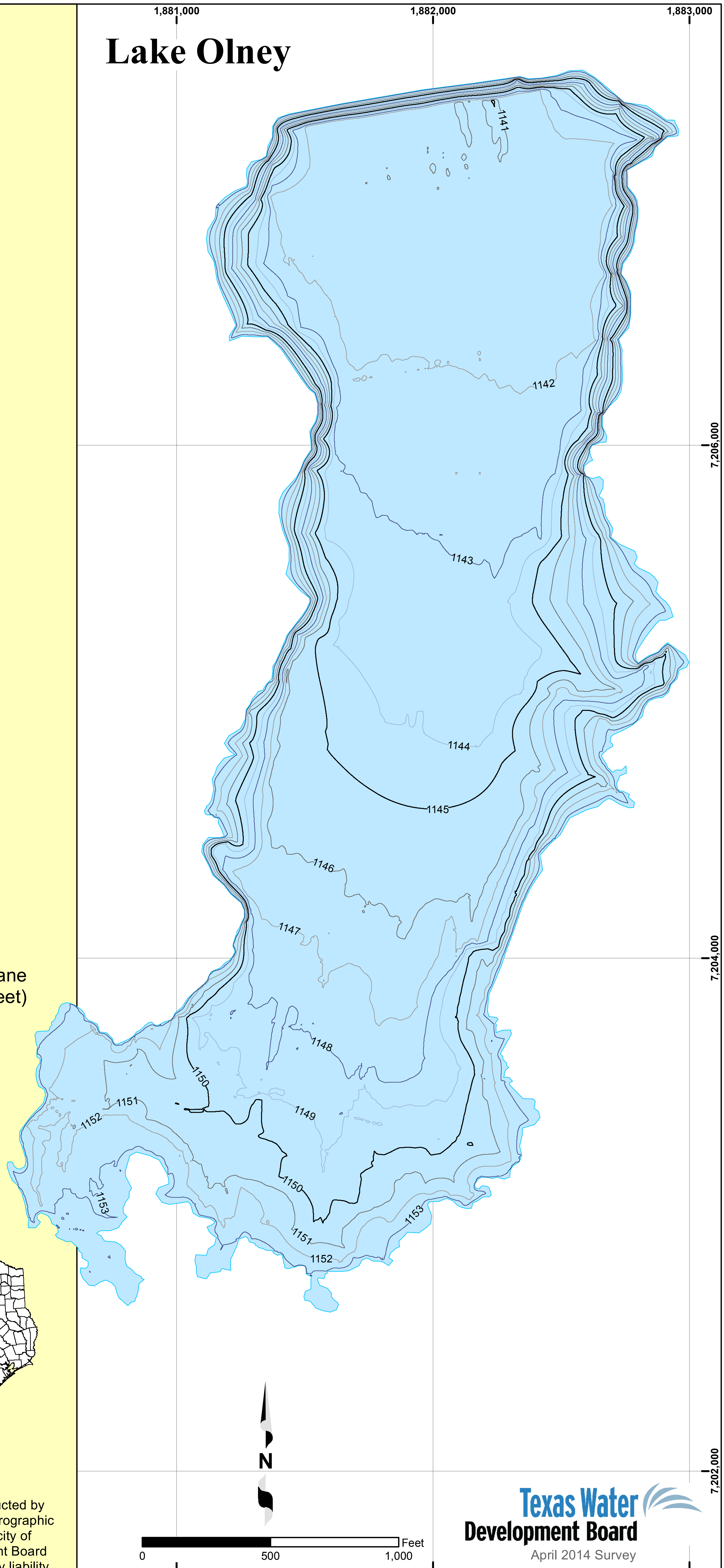


**Figure 9**
Contour Map

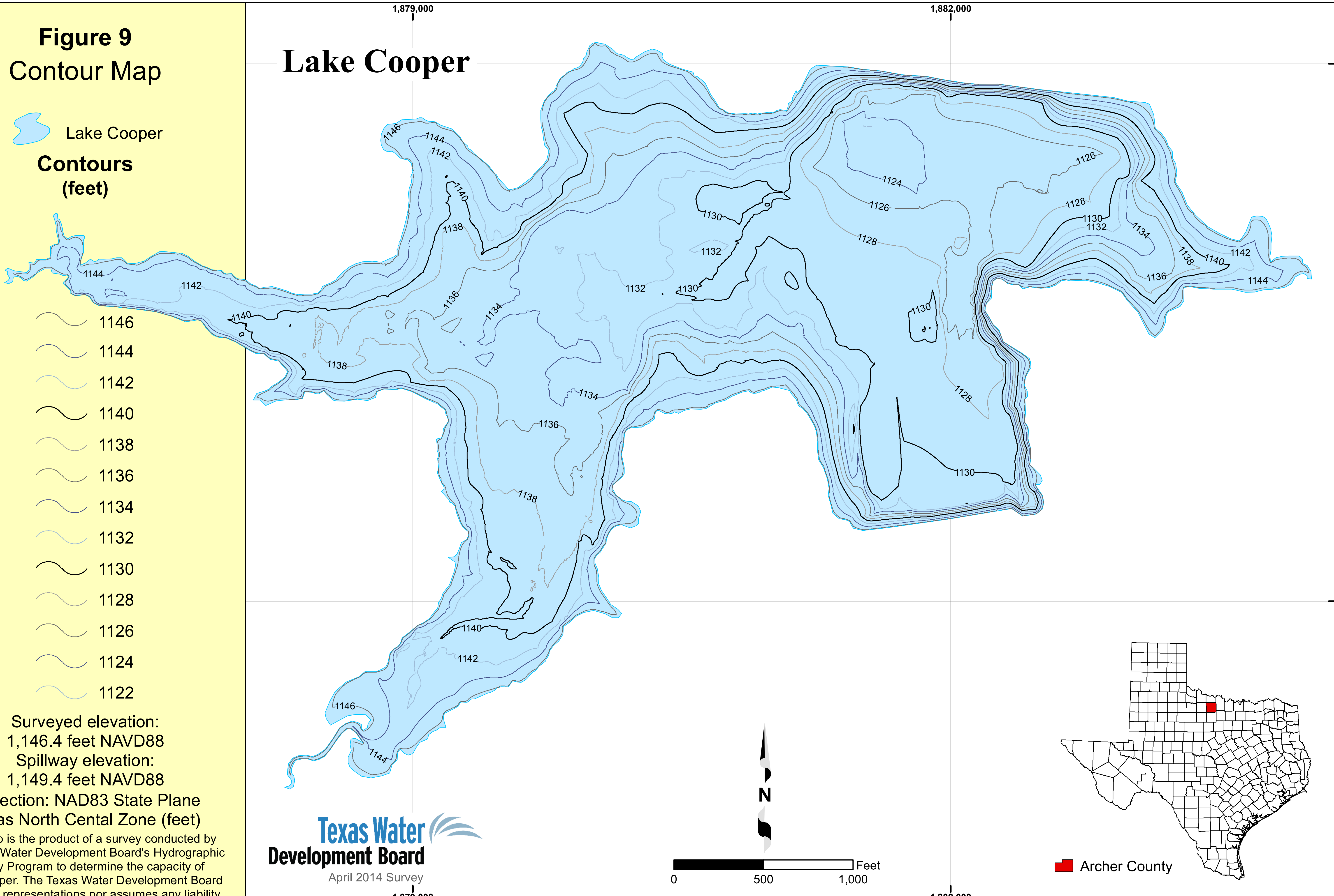
Lake Cooper

**Contours**
**(feet)**

1146
1144
1142
1140
1138
1136
1134
1132
1130
1128
1126
1124
1122

Surveyed elevation:
1,146.4 feet NAVD88
Spillway elevation:
1,149.4 feet NAVD88
Projection: NAD83 State Plane
Texas North Cental Zone (feet)

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



**Analysis of sediment data from Lake Olney and Lake Cooper**

Sedimentation in Lake Olney and Lake Cooper 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.

The sediment core samples were analyzed at TWDB headquarters in Austin. Each sample was plunged from the core tube and analyzed to identify the location of the pre-impoundment surface. During plunging, compression of the cores can occur, therefore, the total length of the sediment core is determined prior to plunging. 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 Munsell soil 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 Olney**

| Core | Easting[a] (ft) | Northing[a] (ft) | Total core sample/ post-impoundment sediment | Sediment core description | Munsell soil color |
|---|---|---|---|---|---|
| O-1 | 1881938.30 | 7204570.64 | 24.5"/15" | 0-4.5" high water content, silty clay loam | 7.5YR 4/3 |
| | | | | 4.5-15" lower water content, very high density clay, some organic matter present, shells present | 7.5YR 4/3 |
| | | | | 15-24.5" lots of organic matter, high density, silty clay loam | 7.5YR 3/2 |
| O-2 | 1881587.20 | 7204681.97 | 25"/N/A | 0-6" high water content, layer was compacted when plunged, dry clumps of clay at 11.25", 12.25", and 15.5" | 7.5YR 4/4 |
| | | | | 6-21" higher density, lower water content, organic matter present at 20-21", clay | 7.5YR 4/3 |
| | | | | 21-25" higher water content than previous layer, organic matter present, silty clay loam | 7.5YR 4/3 |
| O-3 | 1881685.55 | 7206157.81 | 71"/55.5" | 0-8.5" fluff, super high water content, compression of core during plunging, layer left behind in tube | 7.5YR 4/6 |
| | | | | 8.5-55.5" very fine material, silty loam | 7.5YR 4/4 |
| | | | | 55.5-71" higher density, lower water content, organics and roots present, silty clay loam | 7.5YR 3/2 |
| O-4 | 1882290.07 | 7207109.88 | 118.5"/N/A | 0-40" compression during plunging, fluff, very high water content, sediment left in core tube | 7.5YR 4/6 |
| | | | | 40-94.25" high water content. Loam | 7.5YR 4/4 |
| | | | | 94.25-118.5" slight change in density, clay loam | 7.5YR 4/4 |

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

**Table 2. Sediment core sampling analysis data – Lake Cooper**

| Core | Easting[a] (ft) | Northing[a] (ft) | Total core sample/ post-impoundment sediment | Sediment core description | Munsell soil color |
|---|---|---|---|---|---|
| C-1 | 1881927.84 | 7208855.11 | 20”/N/A | 0-4.5” high density, 1” rock, silty loam | 7.5YR 4/2 |
| | | | | 4.5-17.75” higher water content than upper and lower layers, less dense than upper layer, roots present, silty loam | 7.5YR 4/3 |
| | | | | 17.75-20” lower water content, higher density, roots present, silty clay loam | 7.5YR 4/3 |
| C-2 | 1882279.08 | 7207946.51 | 25”/16” | 0-3.5” fluff, very high water content, most left in tube during plunging | 10YR 3/6 |
| | | | | 3.5-16” high water content, silty loam | 10YR 3/3 |
| | | | | 16-25” organic matter and roots present, silty clay loam | 7.5YR 4/2 |
| C-3 | 1881209.36 | 7209447.39 | 27.5”/20.25” | 0-8.25” high water content, silty loam, pre-impoundment possible at 8.25” | 10YR 4/4 |
| | | | | 8.25-20.25” organics present, clay loam, from 12-20.25” mixed with 5Y5/3 | 7.5YR 4/6 |
| | | | | 20.25-27.5” very dense, low water content, organics present, clay loam | 7.5YR 4/6 |

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

A photograph of sediment core O-2 is shown in Figure 10 and is representative of the sediment cores sampled from Lake Olney. A photograph of sediment core C-1 is shown in Figure 11 and is representative of the sediment cores sampled from Lake Cooper. The 208 kHz frequency measures the top layer as the current bottom surface of the reservoir. The base of the sample is denoted by the blue line in the Figures. The pre-impoundment boundaries, although not evident in the examples shown here, were 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.


**Figure 10. Sediment core O-2 from Lake Olney**

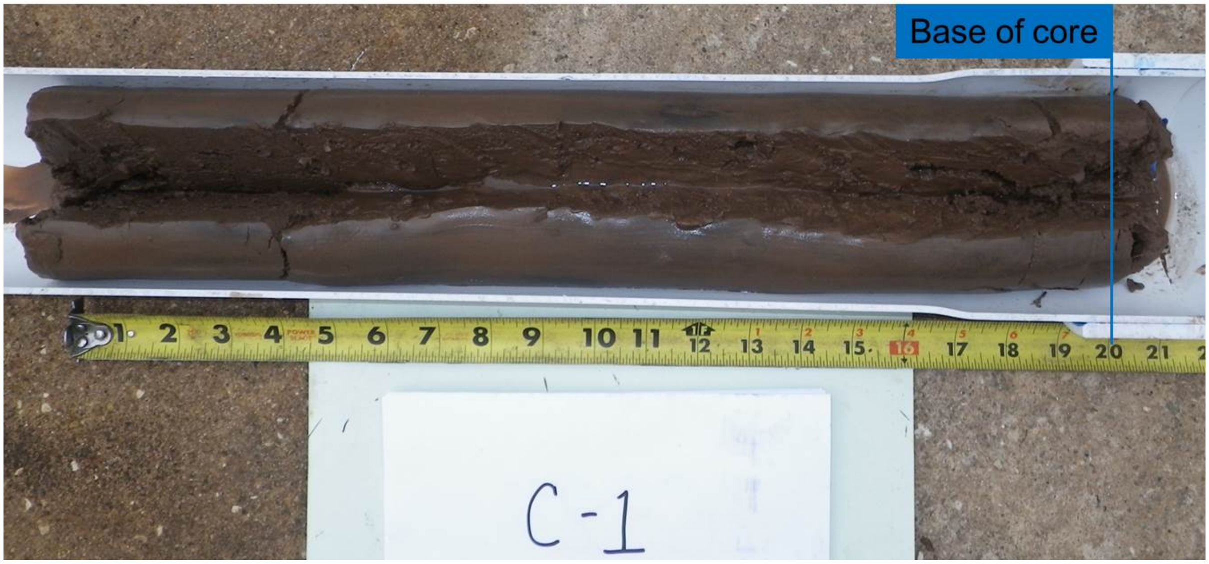



**Figure 11. Sediment core C-1 from Lake Cooper**

Figures 12 through 15 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.

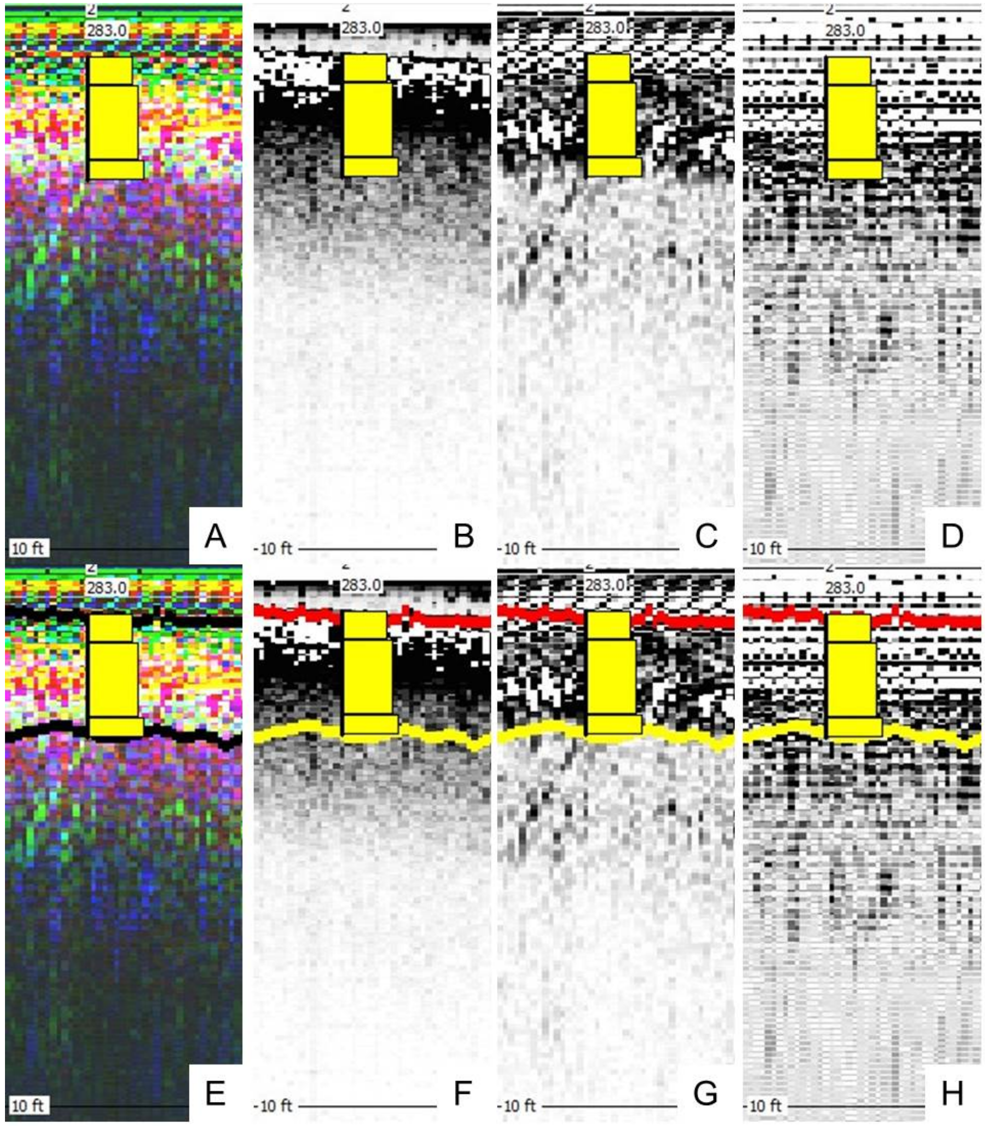



**Figure 12. Comparison of sediment core O-2 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 208 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency**

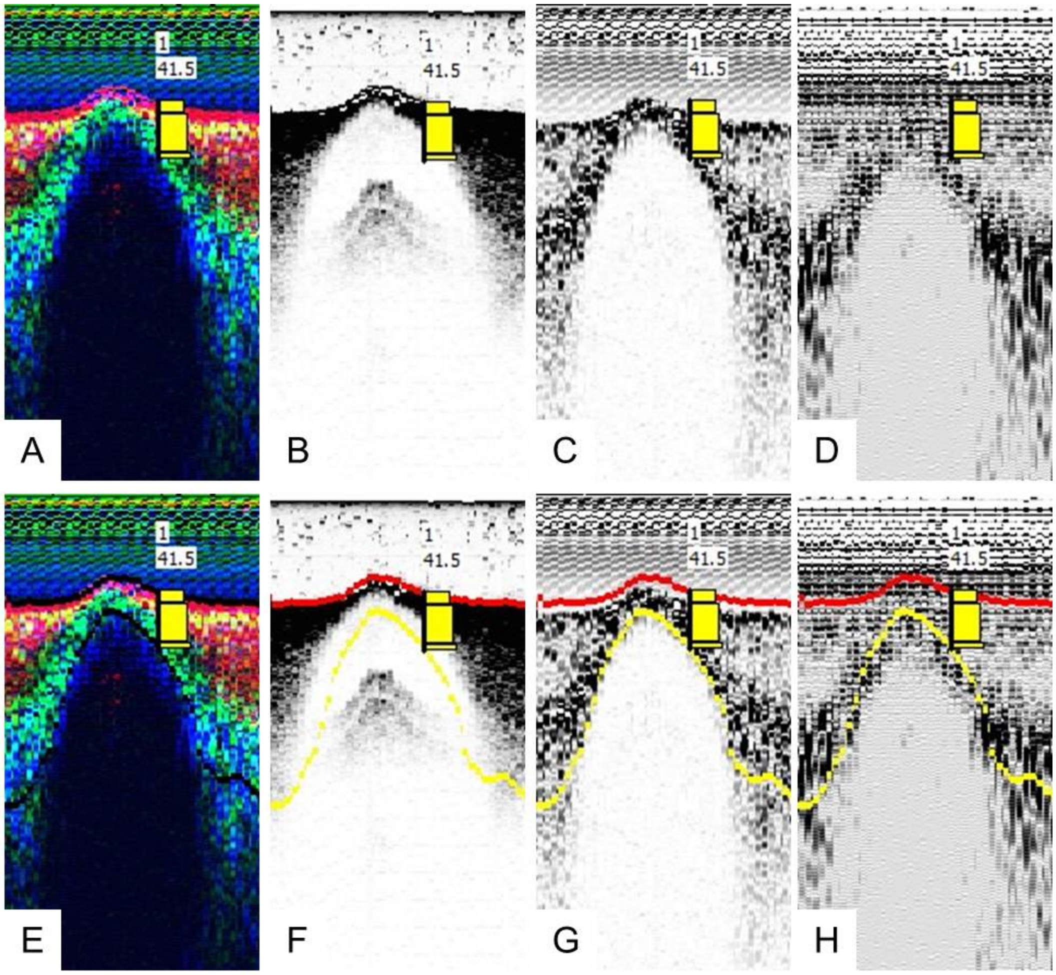



**Figure 13. Comparison of sediment core C-1 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 208kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency**

Figure 12 compares sediment core sample O-2 with the acoustic signals for all frequencies combined (A, E), 208 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). Figure 13 compares sediment core sample C-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 layers. Pre-impoundment sediment was not identified in these cores during analysis. In Figure 12A-D and Figure 13A-D, the bathymetric surfaces are not shown. In Figure 12E and Figure 13E, the current bathymetric surface is represented as the top black line and in Figures 12F-H and Figures 13F-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 50 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 12E and Figure 13E, and by the yellow line in Figures 12F-H and Figures 13F-H. Figures 14 and 15 show sediment core samples O-2 and C-1 correlated with the 50 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.

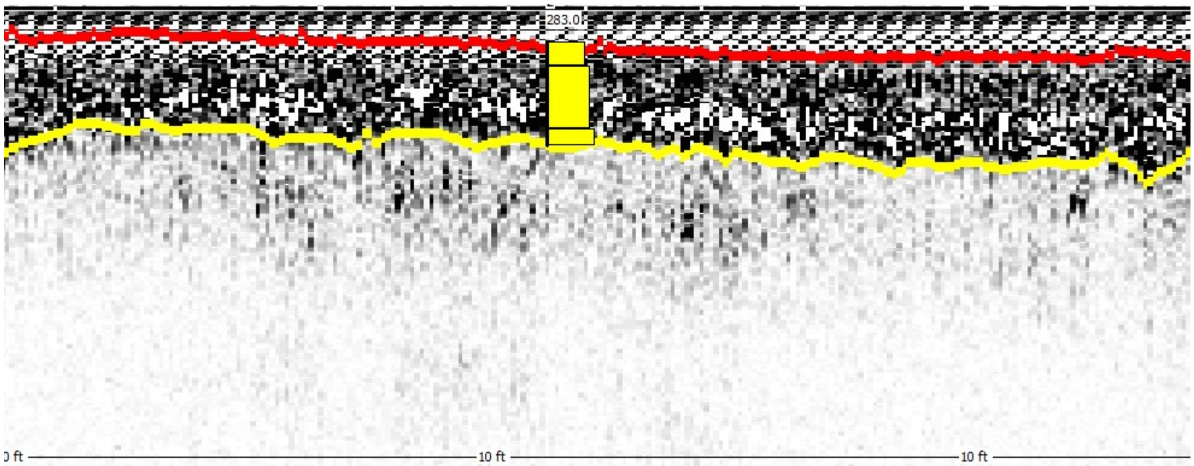



**Figure 14. Cross-section of data collected from Lake Olney during 2014 survey, displayed in DepthPic© (50 kHz frequency), correlated with sediment core sample O-2 and showing the current surface in red and pre-impoundment surface in yellow**

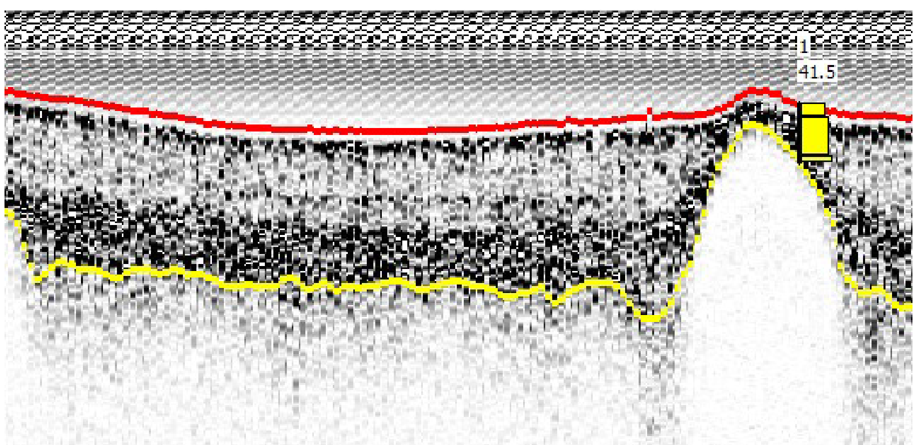
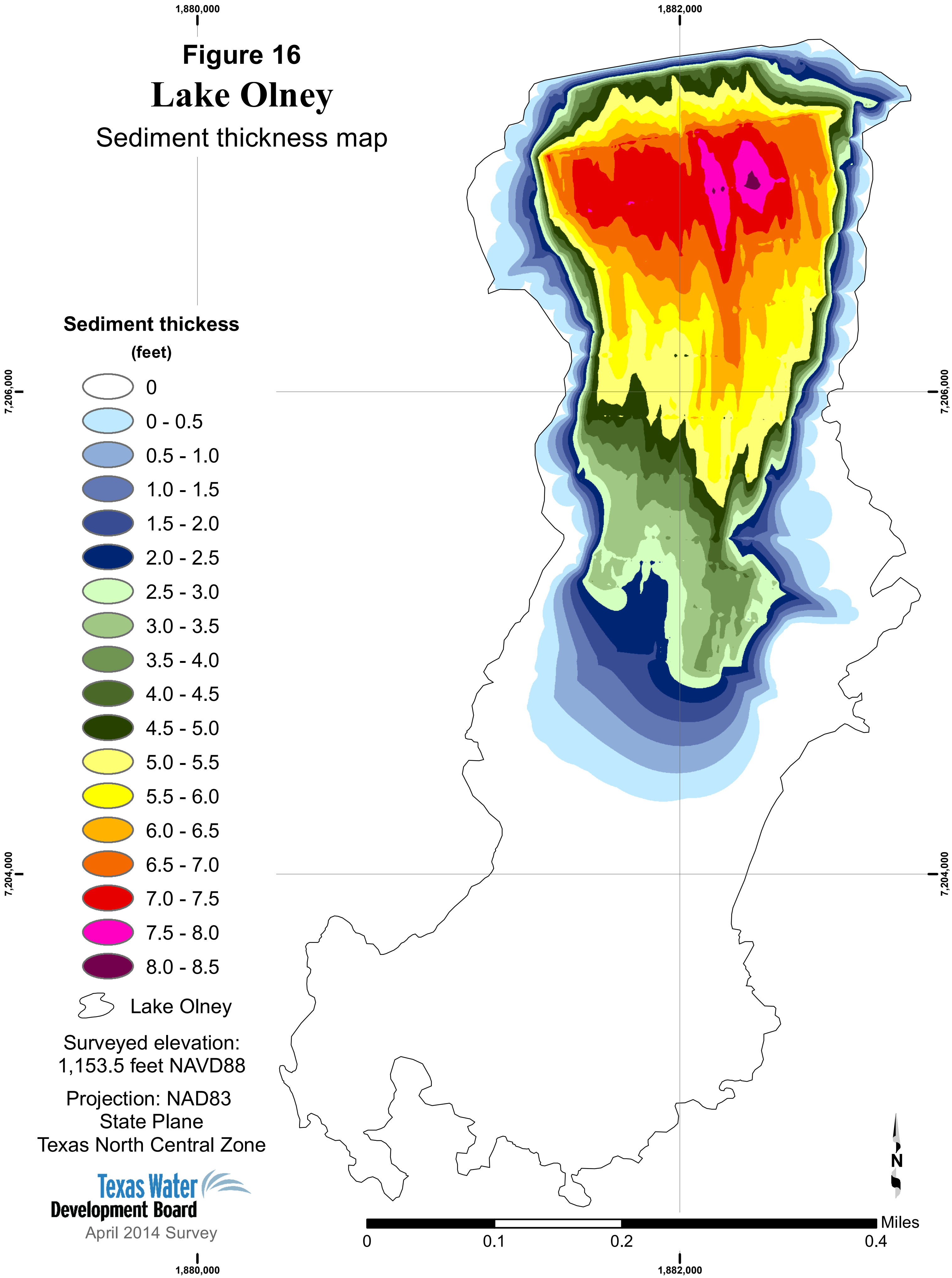



**Figure 15. Cross-section of data collected from Lake Cooper during 2014 survey, displayed in DepthPic© (50 kHz frequency), correlated with sediment core sample C-1 and showing the current surface in red and pre-impoundment surface in yellow**

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 for all topographic survey points and at the reservoir boundaries was zero feet (defined as the 1,153.5 foot NAVD88 elevation contour and 1,146.4 foot NAVD88 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 Olney and Lake Cooper (Figures 16 and 17).

# Figure 16
# Lake Olney
## Sediment thickness map



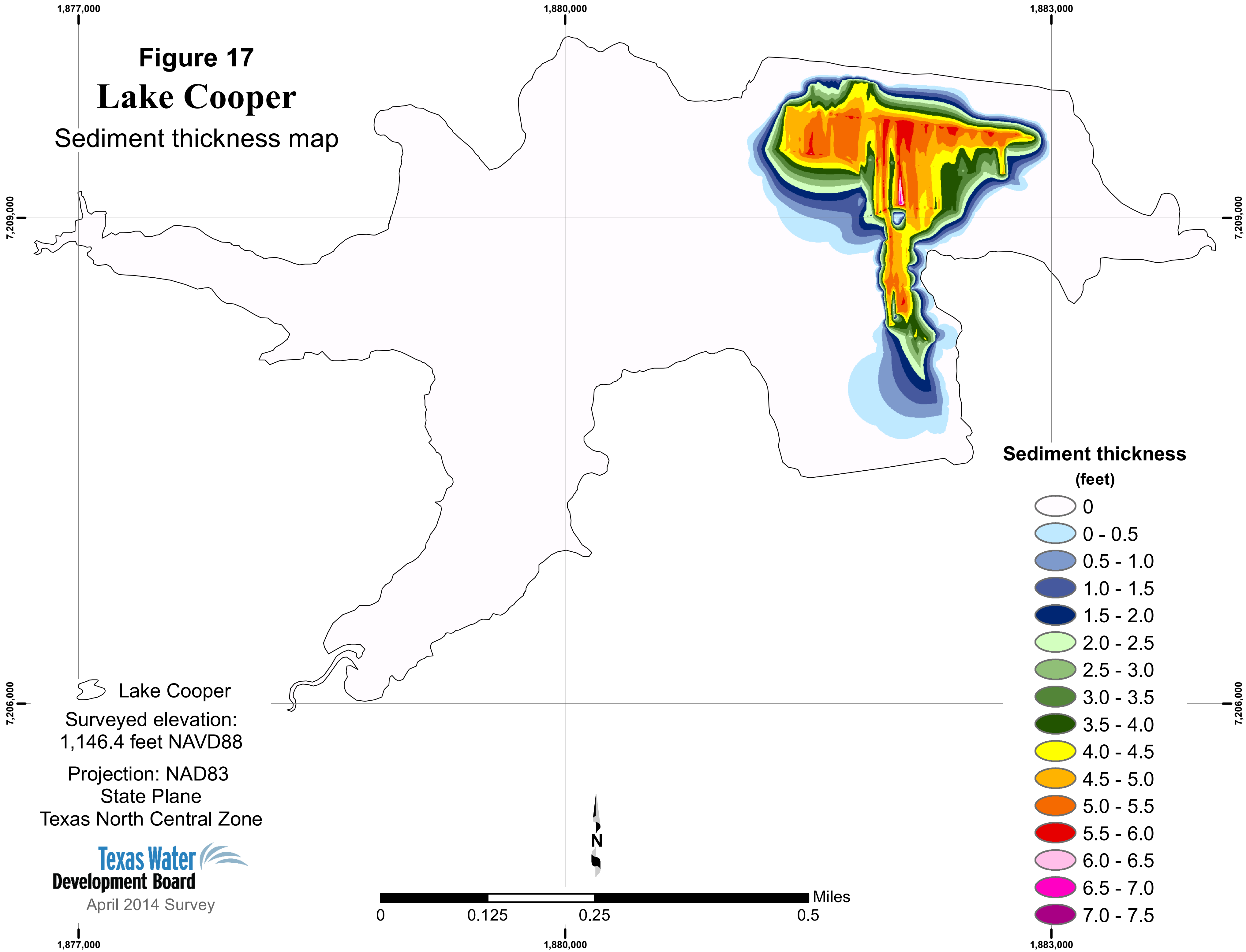



**Figure 17**

**Lake Cooper**

Sediment thickness map

## Survey results

### Volumetric survey

**The 2014 TWDB volumetric and sedimentation survey indicates that Lake Olney has a total reservoir capacity of 1,189 acre-feet and encompasses 158 acres at spillway elevation 1,154.2 feet NAVD88 and that Lake Cooper has a total reservoir capacity of 3,357 acre-feet and encompasses 274 acres at spillway elevation 1,149.4 feet NAVD88.** Previous capacity estimates include a combined estimate for Lake Olney and Lake Cooper of 6,650 acre-feet (Biggs & Mathews, Inc., et. al., 2010), and 1978 estimates of 1,700 acre-feet for Lake Olney and 3,740 acre-feet for Lake Cooper (OWAC, 2013) (Table 3). According to Certificate of Adjudication No. 02-5146 the City of Olney is authorized to impound 2,150 acre-feet of water in Lake Olney and 4,500 acre-feet of water in Lake Cooper (TWC, 1987), a total of 6,650 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.

**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 Olney original[a] | 134 | 2,150 | Lake Cooper original[a] | N/A | 4,500 |
| Lake Olney 1978[b] | N/A | 1,700 | Lake Cooper 1978[b] | N/A | 3,740 |
| Lake Olney 2014 | 158 | 1,189 | Lake Cooper 2014 | 274 | 3,357 |

[a] Source: (TCEQ, 1998, TWC, 1987)
[b] Source: (OWAC, 2013)

### Sedimentation survey

Due to the low water levels during the time of the bathymetric survey, it was not possible to measure the complete pre-impoundment surface of the lakes. Although no sediment could be measured throughout the dry areas of the lakes, it is assumed sediment has been deposited throughout these areas, below and up to the spillway elevation. Assuming the thickness of the sediment becomes zero at the spillway elevation, pre-impoundment capacities were developed for Lake Olney and Lake Cooper by linearly interpolating the areas to spillway elevation and calculating the capacities using the equation described in the section titled “Area, volume, and contour calculation”. For Lake Olney the areas were interpolated from 1,140.9 feet and the value came from the table generated from the pre-impoundment surface TIN model where the pre-impoundment surface of the topographic survey points is equal to the current bottom surface. The area at 1,154.2 feet is the result of extrapolating the area curve of the current bottom surface; see Appendix B. The resulting pre-impoundment capacity estimate for Lake Olney is 1,619 acre-feet. For Lake Cooper the areas were interpolated from 1,122.0

feet and the resulting pre-impoundment capacity estimate is 4,000 acre-feet. Comparison of capacity estimates of Lake Olney and Lake Cooper derived using differing methodologies are provided in Tables 4 and 5, respectively, for sedimentation rate calculation. We assume in our calculations that the previous capacity estimates correspond with the spillway elevations.

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

| Survey | Volume comparisons at spillway elevation 1,154.2 feet (acre-feet) | | Pre-impoundment (acre-feet) |
|---|---|---|---|
| Lake Olney Authorized 1935 | 2,150 | <> | <> |
| Lake Olney 1978 | <> | 1,700 | <> |
| Lake Olney TWDB pre-impoundment estimate 2014 | <> | <> | 1,619 |
| Lake Olney TWDB 2014 | 1,189 | 1,189 | 1,189 |
| Volume difference (acre-feet) | 961 (44.7%) | 511 (30.1%) | 430 (26.6%) |
| Number of years | 79[a] | 36 | 79[a] |
| Capacity loss rate (acre-feet/year) | 12 | 14 | 5 |

Note: Lake Olney was completed in 1935
[a] Number of years based on difference between 2014 survey date and completion date

**Table 5.** **Capacity loss comparisons for Lake Cooper**

| Survey | Volume comparisons at spillway elevation 1,149.4 feet (acre-feet) | | Pre-impoundment (acre-feet) |
|---|---|---|---|
| Lake Cooper Authorized 1954 | 4,500 | <> | <> |
| Lake Cooper 1978 | <> | 3,740 | <> |
| Lake Cooper TWDB pre-impoundment estimate 2014 | <> | <> | 4,000 |
| Lake Cooper TWDB 2014 | 3,357 | 3,357 | 3,357 |
| Volume difference (acre-feet) | 1,143 (25.4%) | 383 (10.2%) | 643 (16.1%) |
| Number of years | 60[a] | 36 | 60[a] |
| Capacity loss rate (acre-feet/year) | 19 | 11 | 11 |

Note: Lake Cooper was completed in 1954
[a] Number of years based on difference between 2014 survey date and completion date

## Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Olney and Lake Cooper when both lakes are full or in flood stage, 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 Olney and Lake Cooper.

## 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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Phone: (512) 463-2456
Email: Jason.Kemp@twdb.texas.gov

Or

Ruben S. Solis, Ph.D., P.E.
Director, Surface Water Resources Division
Phone: (512) 936-0820
Email: Ruben.Solis@twdb.texas.gov

## References


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Appendix A

# LAKE OLNEY

## RESERVOIR CAPACITY TABLE

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

April 2014 Survey
Spillway Elevation 1,154.2 feet NAVD88

| ELEVATION (Feet) | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,139 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,141 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 10 |
| 1,142 | 12 | 15 | 18 | 21 | 25 | 28 | 32 | 35 | 39 | 43 |
| 1,143 | 47 | 52 | 56 | 60 | 65 | 69 | 74 | 79 | 84 | 90 |
| 1,144 | 95 | 101 | 107 | 112 | 118 | 124 | 130 | 136 | 143 | 149 |
| 1,145 | 156 | 162 | 169 | 176 | 183 | 190 | 197 | 204 | 212 | 219 |
| 1,146 | 227 | 235 | 243 | 251 | 259 | 268 | 276 | 285 | 293 | 302 |
| 1,147 | 310 | 319 | 328 | 337 | 346 | 356 | 365 | 374 | 384 | 394 |
| 1,148 | 403 | 413 | 423 | 433 | 443 | 453 | 463 | 474 | 484 | 494 |
| 1,149 | 505 | 516 | 526 | 537 | 548 | 559 | 571 | 582 | 593 | 605 |
| 1,150 | 616 | 628 | 639 | 651 | 663 | 675 | 687 | 700 | 712 | 724 |
| 1,151 | 737 | 749 | 762 | 775 | 788 | 801 | 814 | 827 | 841 | 854 |
| 1,152 | 867 | 881 | 895 | 908 | 922 | 936 | 950 | 964 | 979 | 993 |
| 1,153 | 1,007 | 1,022 | 1,037 | 1,051 | 1,066 | 1,081 | 1,096 | 1,112 | 1,127 | 1,142 |
| 1,154 | 1,158 | 1,173 | 1,189 | | | | | | | |

Note: Volumes calculated from extrapolated areas above elevation 1,153.4 feet

Appendix B

# LAKE OLNEY

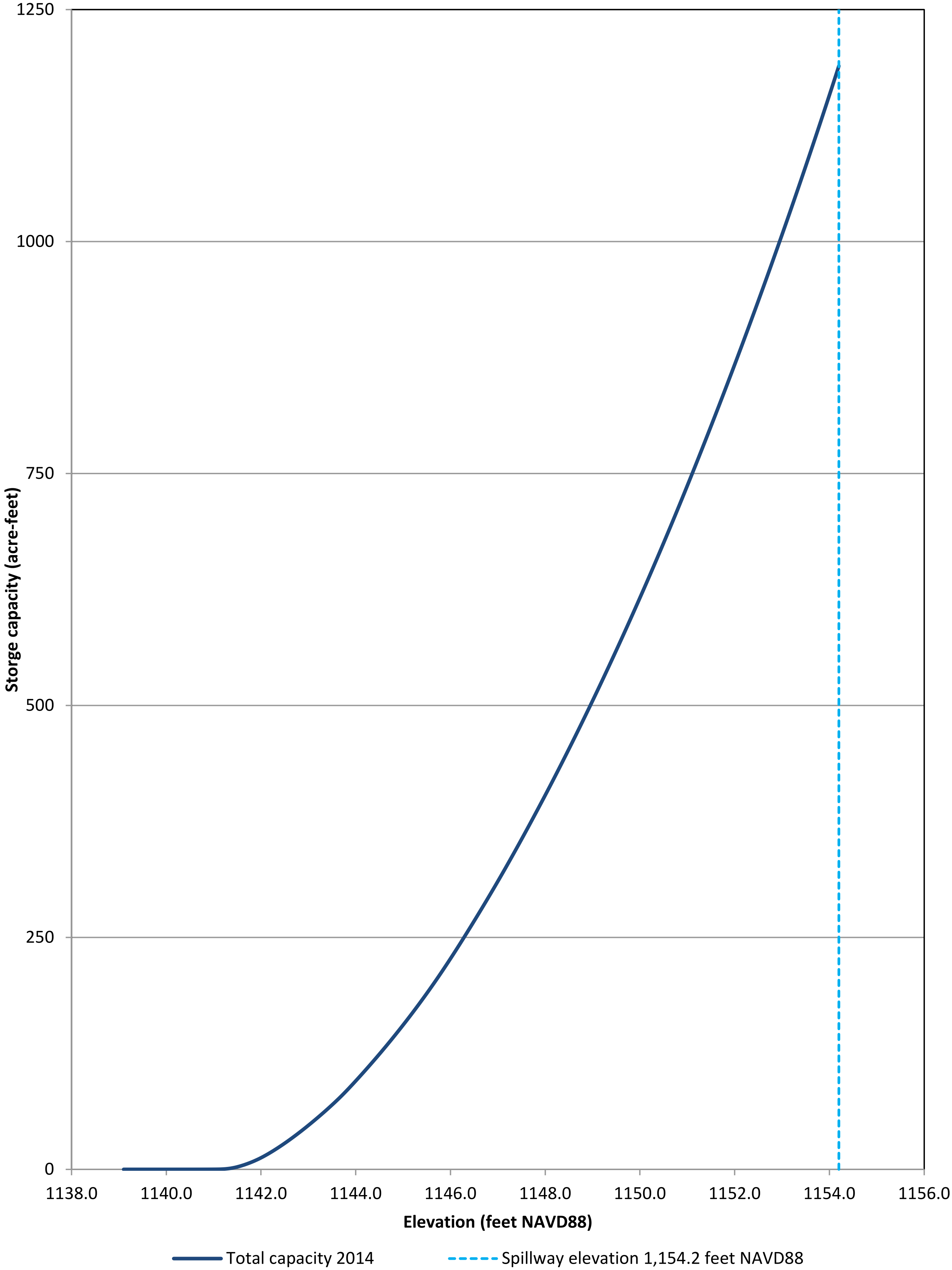
## RESERVOIR AREA TABLE

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

April 2014 Survey
Spillway Elevation 1,154.2 feet NAVD88

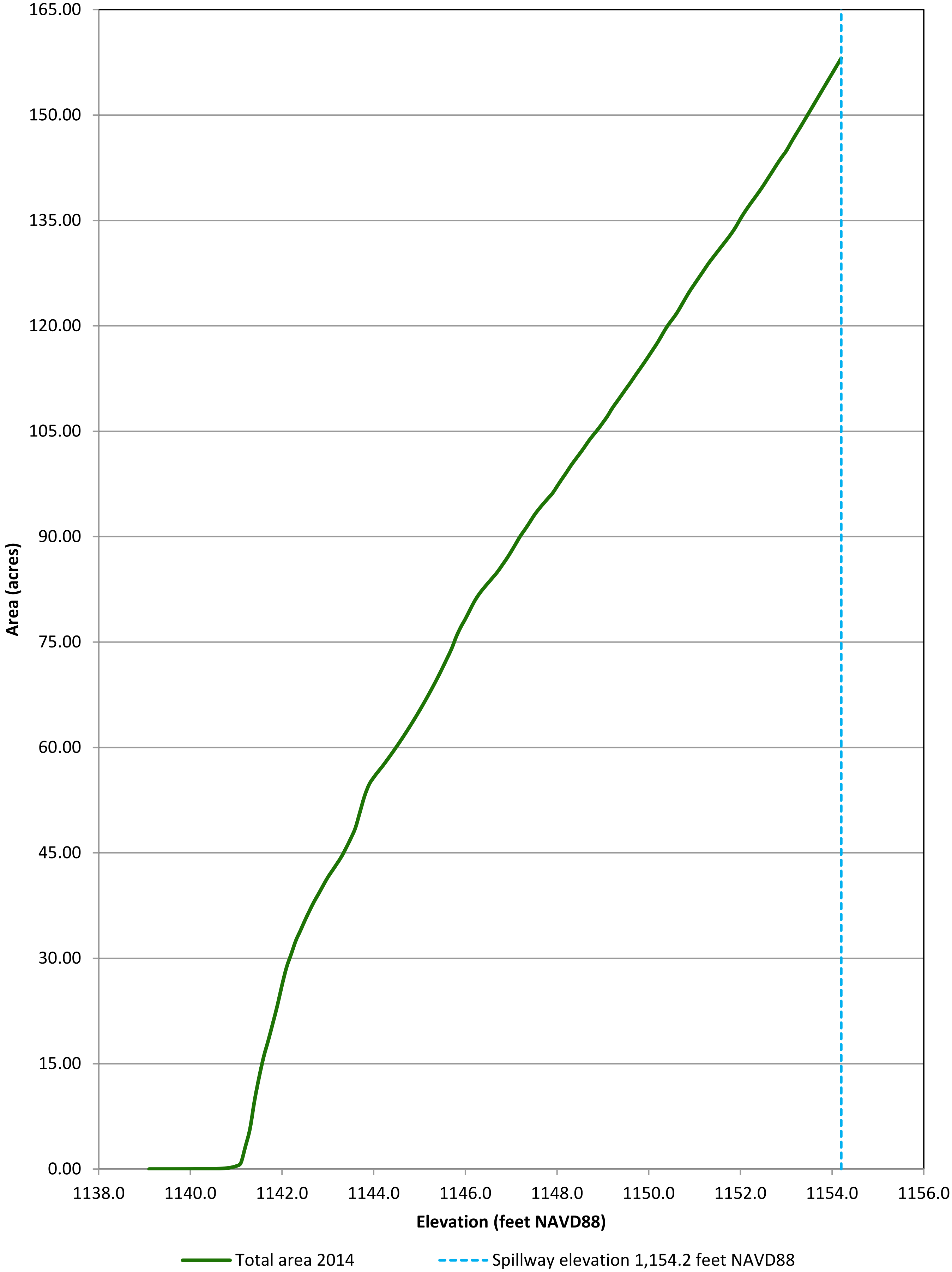
| ELEVATION (Feet) | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,139 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,141 | 0 | 1 | 3 | 6 | 10 | 13 | 16 | 18 | 21 | 23 |
| 1,142 | 26 | 29 | 31 | 32 | 34 | 35 | 37 | 38 | 39 | 40 |
| 1,143 | 42 | 42 | 43 | 44 | 46 | 47 | 49 | 51 | 53 | 55 |
| 1,144 | 56 | 57 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 |
| 1,145 | 65 | 66 | 68 | 69 | 70 | 71 | 73 | 74 | 76 | 77 |
| 1,146 | 78 | 80 | 81 | 82 | 83 | 83 | 84 | 85 | 86 | 87 |
| 1,147 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 95 | 96 |
| 1,148 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 105 |
| 1,149 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 |
| 1,150 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 |
| 1,151 | 126 | 127 | 128 | 129 | 130 | 131 | 131 | 132 | 133 | 134 |
| 1,152 | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 |
| 1,153 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 153 | 154 | 155 |
| 1,154 | 156 | 157 | 158 | | | | | | | |

Note: Areas above elevation 1.153.4 feet extrapolated




**LAKE OLNEY**
April 2014 Survey
Prepared by: TWDB

Appendix C: Capacity curve




**LAKE OLNEY**
April 2014 Survey
Prepared by: TWDB

Appendix D: Area curve

Appendix E

# LAKE COOPER

## RESERVOIR CAPACITY TABLE

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

April 2014 Survey
Spillway Elevation 1,149.4 feet NAVD88

| ELEVATION (Feet) | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,123 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| 1,124 | 2 | 3 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 |
| 1,125 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 14 | 15 | 16 |
| 1,126 | 18 | 20 | 21 | 23 | 25 | 27 | 29 | 32 | 34 | 36 |
| 1,127 | 39 | 41 | 43 | 46 | 49 | 51 | 54 | 57 | 60 | 62 |
| 1,128 | 65 | 68 | 72 | 75 | 78 | 81 | 85 | 89 | 92 | 96 |
| 1,129 | 101 | 105 | 110 | 115 | 120 | 125 | 131 | 136 | 142 | 148 |
| 1,130 | 154 | 160 | 166 | 173 | 179 | 186 | 192 | 199 | 206 | 213 |
| 1,131 | 220 | 227 | 234 | 241 | 249 | 256 | 264 | 272 | 279 | 287 |
| 1,132 | 295 | 303 | 312 | 320 | 328 | 337 | 345 | 354 | 363 | 372 |
| 1,133 | 381 | 390 | 400 | 409 | 419 | 428 | 438 | 448 | 458 | 468 |
| 1,134 | 478 | 488 | 499 | 509 | 520 | 530 | 541 | 552 | 563 | 574 |
| 1,135 | 585 | 596 | 608 | 619 | 631 | 643 | 654 | 666 | 678 | 691 |
| 1,136 | 703 | 715 | 728 | 740 | 753 | 765 | 778 | 791 | 804 | 818 |
| 1,137 | 831 | 844 | 858 | 871 | 885 | 899 | 913 | 927 | 941 | 955 |
| 1,138 | 970 | 984 | 999 | 1,014 | 1,029 | 1,044 | 1,059 | 1,074 | 1,089 | 1,105 |
| 1,139 | 1,121 | 1,136 | 1,152 | 1,168 | 1,184 | 1,201 | 1,217 | 1,233 | 1,250 | 1,266 |
| 1,140 | 1,283 | 1,300 | 1,317 | 1,334 | 1,351 | 1,368 | 1,386 | 1,403 | 1,421 | 1,439 |
| 1,141 | 1,457 | 1,475 | 1,493 | 1,511 | 1,529 | 1,548 | 1,566 | 1,585 | 1,603 | 1,622 |
| 1,142 | 1,641 | 1,660 | 1,679 | 1,699 | 1,718 | 1,737 | 1,757 | 1,777 | 1,797 | 1,817 |
| 1,143 | 1,837 | 1,857 | 1,878 | 1,898 | 1,919 | 1,939 | 1,960 | 1,981 | 2,002 | 2,023 |
| 1,144 | 2,045 | 2,066 | 2,088 | 2,109 | 2,131 | 2,153 | 2,175 | 2,197 | 2,219 | 2,241 |
| 1,145 | 2,264 | 2,286 | 2,309 | 2,331 | 2,354 | 2,377 | 2,400 | 2,423 | 2,446 | 2,469 |
| 1,146 | 2,493 | 2,516 | 2,540 | 2,564 | 2,588 | 2,612 | 2,636 | 2,660 | 2,684 | 2,709 |
| 1,147 | 2,733 | 2,758 | 2,783 | 2,808 | 2,833 | 2,858 | 2,883 | 2,909 | 2,934 | 2,960 |
| 1,148 | 2,985 | 3,011 | 3,037 | 3,063 | 3,089 | 3,116 | 3,142 | 3,169 | 3,195 | 3,222 |
| 1,149 | 3,249 | 3,276 | 3,303 | 3,330 | 3,357 | | | | | |

Note: Volumes calculated from extrapolated areas above elevation 1,146.3 feet

Appendix F

# LAKE COOPER

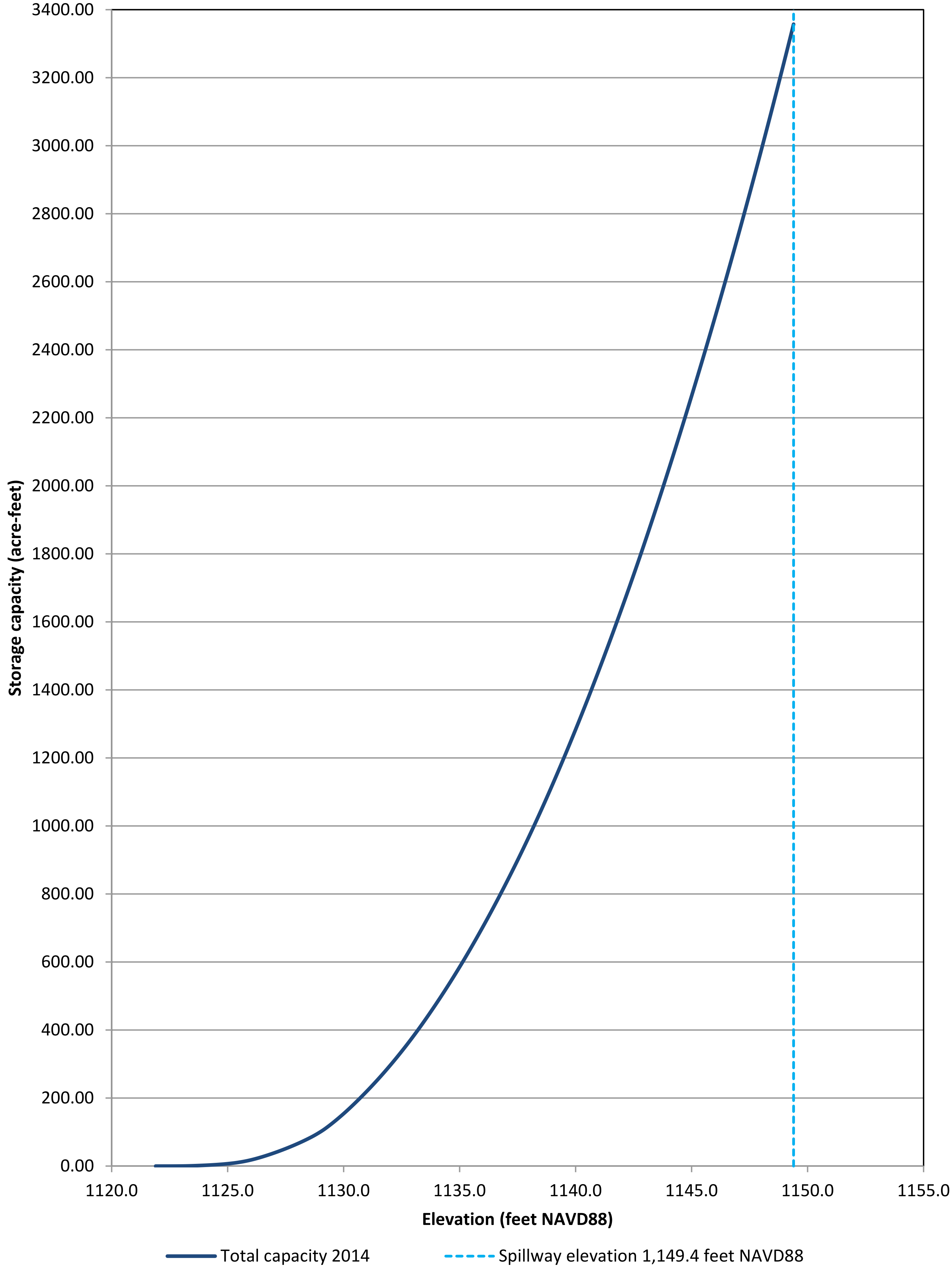
## RESERVOIR AREA TABLE

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

April 2014 Survey
Spillway Elevation 1,149.4 feet NAVD88

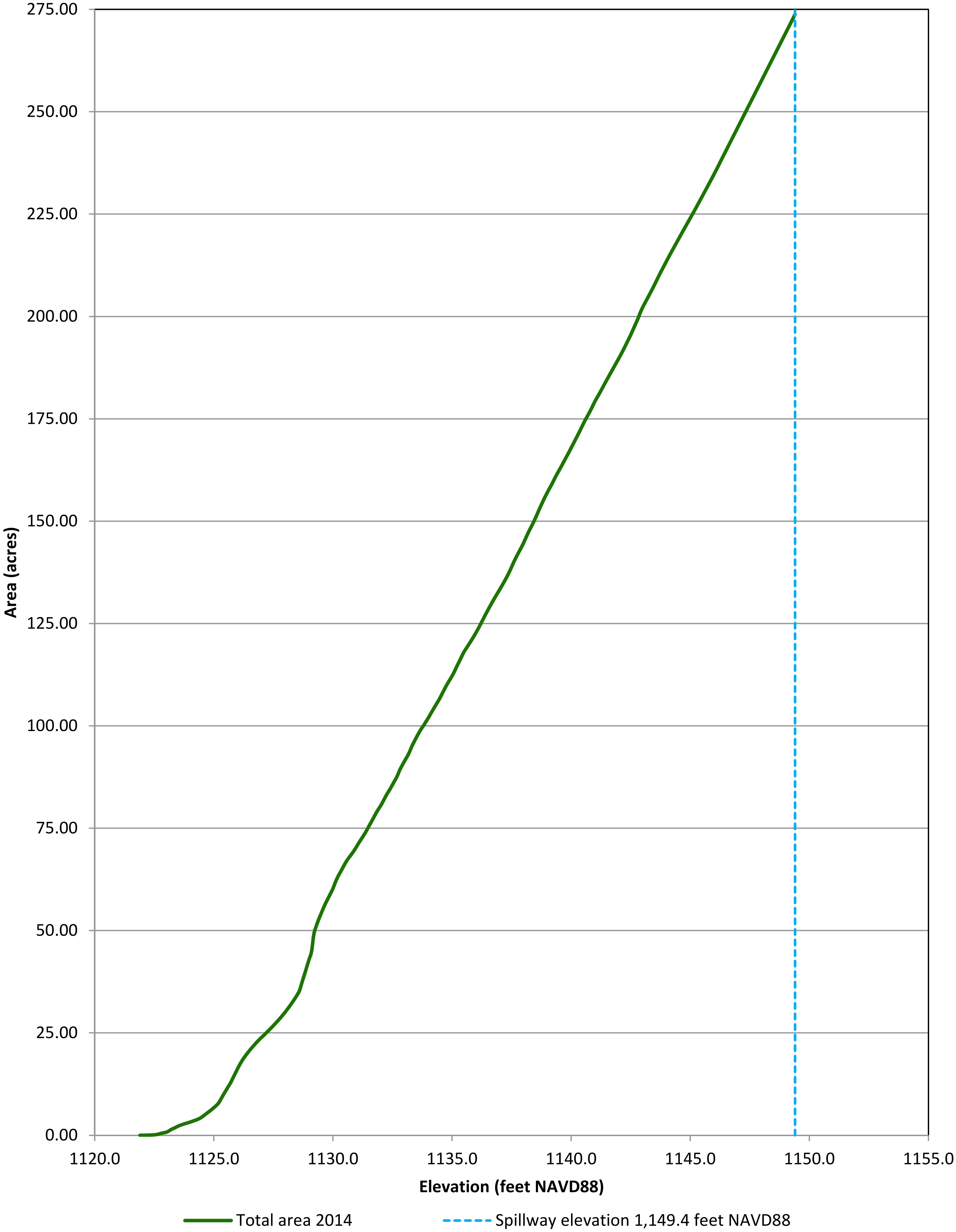
| ELEVATION (Feet) | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 1,123 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |
| 1,124 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 6 | 6 |
| 1,125 | 7 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1,126 | 16 | 17 | 18 | 19 | 20 | 21 | 21 | 22 | 23 | 23 |
| 1,127 | 24 | 24 | 25 | 26 | 26 | 27 | 27 | 28 | 29 | 29 |
| 1,128 | 30 | 31 | 32 | 33 | 33 | 34 | 35 | 37 | 39 | 41 |
| 1,129 | 43 | 45 | 49 | 51 | 53 | 54 | 56 | 57 | 58 | 59 |
| 1,130 | 60 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| 1,131 | 71 | 72 | 72 | 73 | 74 | 75 | 76 | 78 | 79 | 80 |
| 1,132 | 80 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
| 1,133 | 91 | 92 | 93 | 95 | 96 | 97 | 98 | 99 | 100 | 101 |
| 1,134 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 |
| 1,135 | 112 | 113 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 |
| 1,136 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 |
| 1,137 | 133 | 134 | 135 | 136 | 138 | 139 | 140 | 141 | 142 | 143 |
| 1,138 | 145 | 146 | 147 | 148 | 150 | 151 | 152 | 153 | 155 | 156 |
| 1,139 | 157 | 158 | 159 | 160 | 161 | 162 | 164 | 165 | 166 | 167 |
| 1,140 | 168 | 169 | 170 | 171 | 172 | 174 | 175 | 176 | 177 | 178 |
| 1,141 | 179 | 180 | 181 | 182 | 183 | 185 | 186 | 187 | 188 | 189 |
| 1,142 | 190 | 191 | 192 | 193 | 194 | 196 | 197 | 198 | 199 | 201 |
| 1,143 | 202 | 203 | 204 | 206 | 207 | 208 | 209 | 210 | 211 | 212 |
| 1,144 | 213 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 |
| 1,145 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 233 | 234 |
| 1,146 | 235 | 236 | 237 | 238 | 239 | 241 | 242 | 243 | 244 | 245 |
| 1,147 | 246 | 247 | 249 | 250 | 251 | 252 | 253 | 254 | 255 | 257 |
| 1,148 | 258 | 259 | 260 | 261 | 262 | 263 | 265 | 266 | 267 | 268 |
| 1,149 | 269 | 270 | 271 | 273 | 274 | | | | | |

Note: Areas above elevation 1.146.3 feet extrapolated




**LAKE COOPER**
April 2014 Survey
Prepared by: TWDB

Appendix G: Capacity curve




**LAKE COOPER**
April 2014 Survey
Prepared by: TWDB

Appendix H: Area curve