Volumetric and Sedimentation Survey of LAKE MINERAL WELLS

October 2015 Survey

Texas Water Development Board

August 2016

Texas Water Development Board

Prepared for:

Palo Pinto County Municipal Water District No. 1

With Support Provided by:

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

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Executive summary

In October 2015, 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 Mineral Wells (Parker County, TX). The Palo Pinto County Municipal Water District No. 1 provided 50 percent of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50 percent 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.

Mineral Wells Dam and Lake Mineral Wells are located on Rock Creek, a tributary of the Brazos River, in Parker County, within the city limits of Mineral Wells, Texas. The conservation pool elevation of Lake Mineral Wells is 863.4 feet above mean sea level (NGVD29). The TWDB collected bathymetric data for Lake Mineral Wells on October 1and October 2, 2015. Daily average water surface elevations during the survey measured 861.85 and 861.83 feet above mean sea level (NGVD29), respectively.

The 2015 TWDB volumetric survey indicates that Lake Mineral Wells has a total reservoir capacity of 5,461 acre-feet and encompasses 477 acres at conservation pool elevation (863.4 feet above mean sea level, NGVD29). Previous capacity estimates include the original 1920 design estimate of 8,140 acre-feet (which includes the added capacity from when the dam and spillway crest were raised in 1943), a 1970 estimate of 7,050 acre-feet (which later was adjusted to 6,644 acre-feet through an analysis by HDR Engineering, Inc.), and most recently, prior to the 2015 TWDB survey, a 1990 HDR Engineering, Inc. survey estimate of 5,663 acre-feet.

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Mineral Wells to have an average loss of capacity between 6 and 28 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (863.4 feet NGVD29). Sediment accumulation is greatest in the main basin of the lake approximately 1,400 feet northeast of the dam. The TWDB recommends that a similar methodology be used to resurvey Lake Mineral Wells 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. Texas Water Code section 15.804 authorizes the TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In October 2015, the TWDB entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, to perform a volumetric and sedimentation survey of Lake Mineral Wells. The Palo Pinto County Municipal Water District No. 1 provided 50 percent of the funding for this survey, while the U.S. Army Corps of Engineers, Fort Worth District, provided the remaining 50 percent of the funding through their Planning Assistance to States Program (TWDB 2015). 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 the TWDB to the Palo Pinto County Municipal Water District No. 1 and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) a shaded relief plot of the reservoir bottom (Figure 4), (2) a bottom contour map (Figure 6), (3) an estimate of sediment accumulation and location (Figure 10), and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality (Appendices A and B).

Lake Mineral Wells general information

Mineral Wells Dam and Lake Mineral Wells are located on Rock Creek, a tributary of the Brazos River, in Parker County, within the city limits of Mineral Wells, Texas (Figure 1). Mineral Wells Dam and Lake Mineral Wells are owned and operated by the City of Mineral Wells. Construction on Mineral Wells Dam was first completed in September 1920. Enlargement of the dam occurred between August 18, 1943, and January 31, 1944. Diversion from the Brazos River began on December 31, 1953 (TWDB 1973). Mineral Wells Dam and Lake Mineral Wells were built primarily for water supply storage for the City of Mineral Wells, though at this time the reservoir is not used as a raw water source (MW 2016a). The City of Mineral Wells' municipal supply currently comes from Lake Palo Pinto, owned by the Palo Pinto County Municipal Water District No. 1 (MW 2016a). The Palo Pinto County Municipal Water District No. 1 also owns the Water Treatment Plant and facilities operated by the City of Mineral Wells and acts as the governing body of the water district while providing water to the City of Mineral Wells and its environs (MW 2016b)

Water rights for Lake Mineral Wells have been appropriated to the City of Mineral Wells Water Department through Certificate of Adjudication No. 12-4039. The complete certificate is on file in the Information Resources Division of the Texas Commission on Environmental Quality.

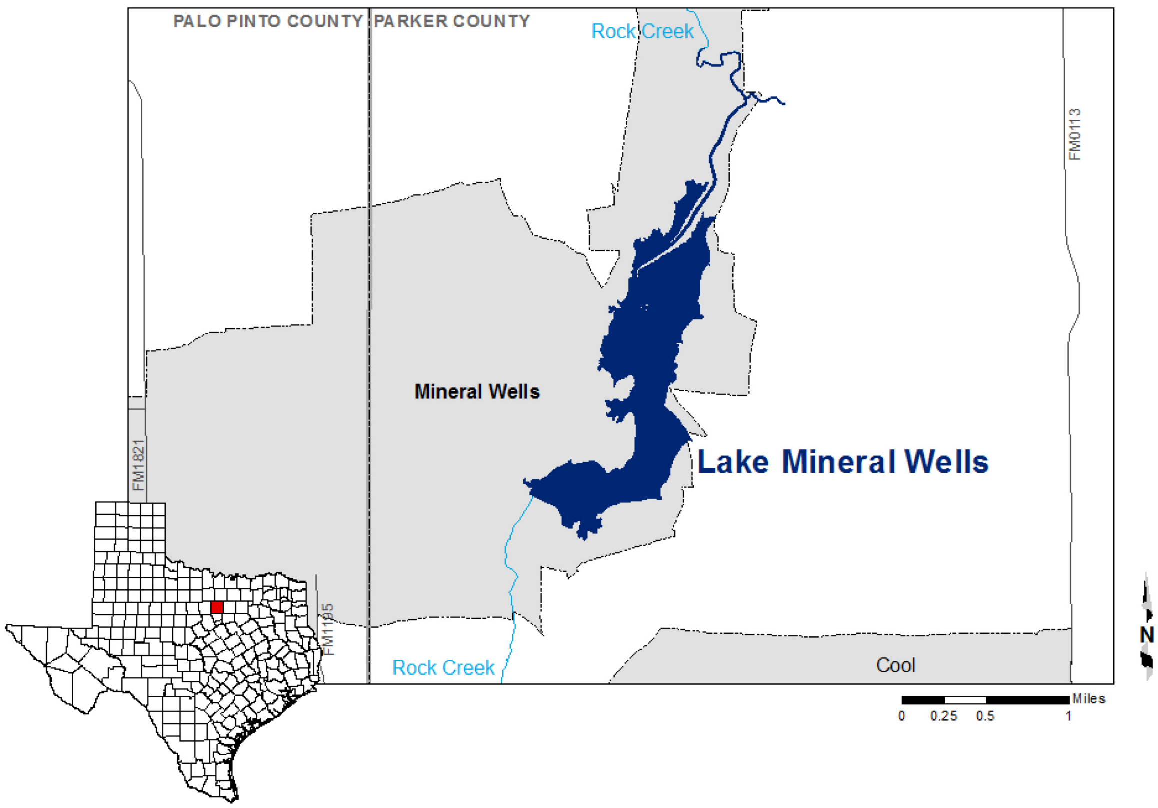


Figure 1. Location map of Lake Mineral Wells.

Table 1. Pertinent data for Mineral Wells Dam and Lake Mineral Wells.

Owner				
City of Mineral Wells				
Design Engineer				
McClendon Engineering Company for the original dam				
Joe Rady for the 1943 spillway and modification				
Location of dam				
On Rock Creek in Parker County, within the city limits of Mineral Wells				
Drainage area				
63 square miles				
Dam				
Type	Earthfill			
Length	1,650 feet			
Height	73.9 feet			
Spillway				
Type	Concrete			
Length	932 feet			
Outlet works				
Type	Concrete conduit 4 by 5 feet			
Control	Sluice gate			
Water supply diversion	Pumped from the lake			
Reservoir data (Based on 2015 TWDB survey)				
Feature		**Elevation (feet NGVD29[a])**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam		873.9	12,019	787
Spillway crest		863.4	5,461	477

Source: (TWDB 1973)

[a] NGVD29 = National Geodetic Vertical Datum 1929

Volumetric and sedimentation survey of Lake Mineral Wells

Datum

The vertical datum used during this survey is the National Geodetic Vertical Datum 1929 (NGVD29). This datum also is utilized by the United States Geological Survey (USGS) for the reservoir elevation gage *USGS 08090700 Lk Mineral Wells nr Mineral Wells, TX* (USGS 2016). Elevations herein are reported in feet relative to the NGVD29 datum. Volume and area calculations in this report are referenced to water levels provided by the USGS gage. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas North Central Zone (feet).

TWDB bathymetric and sedimentation data collection

The TWDB collected bathymetric data for Lake Mineral Wells on October 1 and October 2, 2015. The daily average water surface elevations during the survey measured 861.85 and 861.83 feet above mean sea level (NGVD29), respectively. For data collection, the TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data was collected along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 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 2015 TWDB survey.

All sounding data was collected and reviewed before sediment core sampling sites were selected. Sediment core samples are collected at regularly spaced intervals within the reservoir, or at locations where interpretation of the acoustic display would be difficult without site-specific sediment core data. After analyzing the sounding data, the TWDB selected five locations to collect sediment core samples (Figure 2). The sediment core samples were collected on December 2, 2015, 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 surface, through the accumulated sediment, and to the pre-impoundment surface. After retrieving the sample, a stadia rod is inserted into the top of the aluminum tubes to assist in locating the top of the sediment in the tube. This identifies the location of the layer corresponding to the current reservoir-bottom 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.

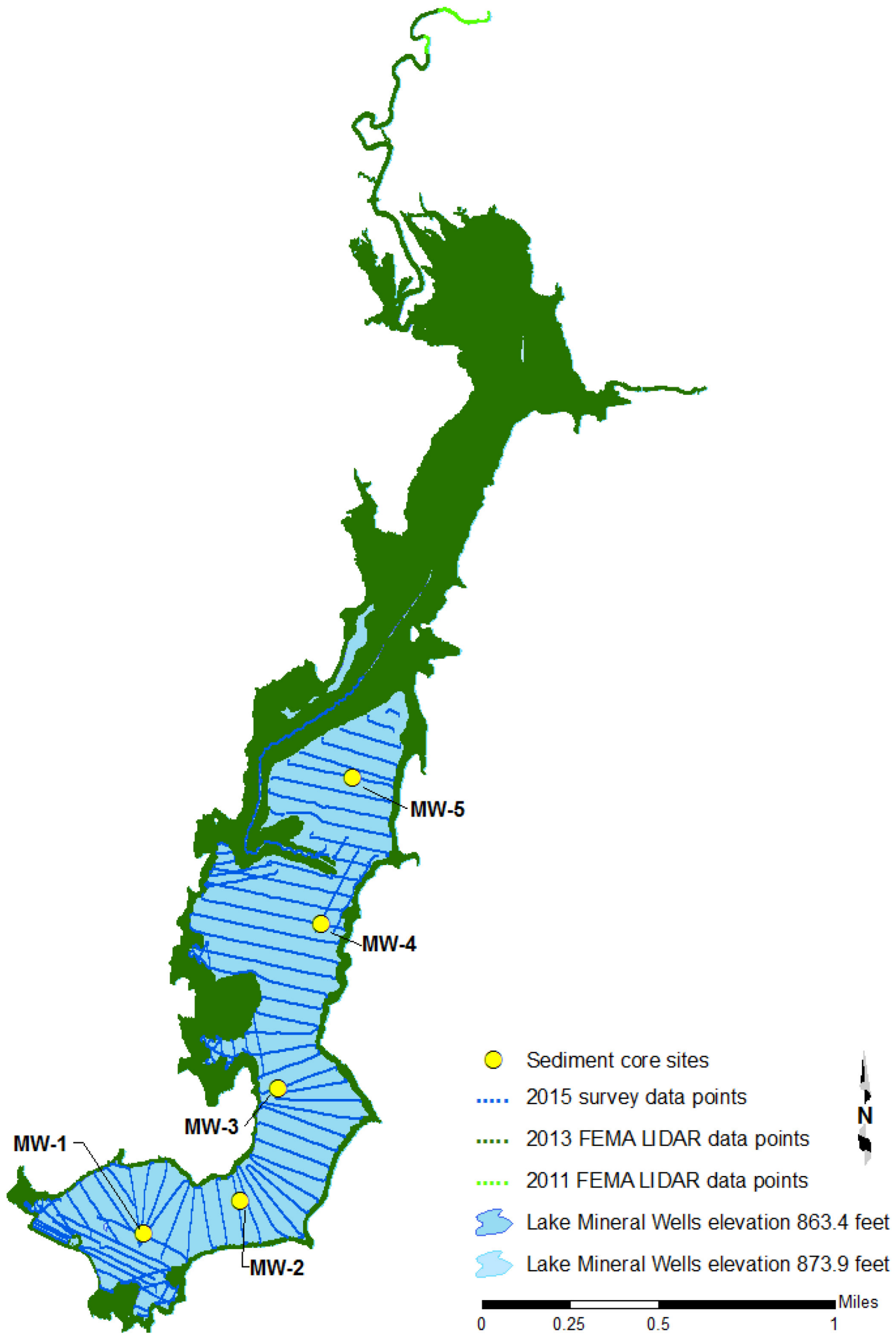


Figure 2. **2015 TWDB Lake Mineral Wells survey data (*blue dots*), sediment coring locations (*yellow circles*), and 2011 and 2013 LIDAR data (*green dots*) between elevations 859.85 and 873.9 feet.**

Data processing

Model boundaries

The reservoir's model boundary was generated from Light Detection and Ranging (LIDAR) Data available from the Texas Natural Resource Information System (TNRIS 2016). The LIDAR data was collected during February 8-12, 2013, while the reservoir elevation ranged between 859.85 and 859.96 feet. However, this LIDAR dataset did not cover the full extent of the desired elevation contour so LIDAR data collected during January 2011, while the water surface elevation of Lake Mineral Wells ranged between 862.36 and 862.45 feet, was used to supplement the 2013 LIDAR data. According to the associated metadata, the 2013 LIDAR data has a vertical accuracy of 0.213 meters and a horizontal accuracy of 1 meter. The 2011 LIDAR data has a vertical accuracy of 0.03 meters and a horizontal accuracy of 0.6 meters. Both sets of data were produced for FEMA and adhere to their project specific requirements (TNRIS 2016). To generate the boundary, LIDAR data with a classification equal to 2, or ground, was imported into an Environmental Systems Research Institute's ArcGIS file geodatabase from .las files. A topographical model of the data was generated and converted to a raster using a cell size of 0.5 meters by 0.5 meters. The horizontal datum of the LIDAR data is Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83; meters) Zone 14, and the vertical datum is North American Vertical Datum 1988 (NAVD88; meters). Therefore, a contour of 266.466 meters NAVD88, equivalent to 873.95 feet NGVD29, was extracted from the raster. The vertical datum transformation offset for the conversion from NAVD88 to NGVD29 was determined by applying the National Oceanic and Atmospheric Administration National Geodetic Survey's NADCON software (NGS 2016a) and VERTCON software (NGS 2016b) to single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 08090700 Lk Mineral Wells nr Mineral Wells, TX Latitude 32º49'00.00"N, Longitude 98º02'30.00"W NAD27.* Horizontal coordinate transformations to NAD83 State Plane Texas North Central Zone (feet) coordinates were done using the ArcGIS Project tool. Additional editing of the 873.9-foot contour was necessary to close the contour across the top of the dam and spillway and remove other artifacts.

To model a more accurate conservation pool elevation boundary of Lake Mineral Wells, a small island northeast of the dam was digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), dated July 18, 2010, while the daily average water surface elevation measured 863.32 feet. The island feature was assigned an elevation of 863.4 feet, spillway elevation, and input into the model as a hardline. As the water level in the reservoir drops, more of the peninsula connected to the first island becomes exposed. From DOQQs dated July 5, 2012, a second small island was digitized at elevation 861.88 feet, and input into the model as a hardline. According to metadata associated with the 2010 and 2012 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy with ± 6 meters to true ground (USDA 2015). The DOQQs are available at the Texas Natural Resources Information System (TNRIS 2016).

LIDAR data points

To model the reservoir between conservation pool elevation and top of dam elevation, or model boundary elevation, the .las files were converted to text files with x, y, and z values. To reduce computational burden, the LIDAR data was filtered to include only every 3rd point and only data points within the reservoir boundary (Figure 2). According to the associated metadata, the 2013 LIDAR data have a point spacing no greater than two points per one square meter and the 2011 LIDAR data have an average point spacing of 1.0 meter; therefore, using a thinned point dataset did not significantly affect the modeled topography of the coverage area. No interpolation of the data in the areas of LIDAR coverage was necessary. After the points were clipped to within the boundary, the shapefile was projected to NAD83 State Plane Texas North Central Zone (feet). New attribute fields were added to first convert the elevations from meters NAVD88 to meters NGVD29 by subtracting the VERTCON conversion offset of 0.101 meters, then to feet NGVD29 for compatibility with the bathymetric survey data.

Some inconsistencies were found where the LIDAR data and the TWDB survey points overlapped in the river channel where Rock Creek enters Lake Mineral Wells. The difference in elevations between the data points was as great as two feet in places. The USGS gage data was reviewed for large inflow events. An event occurred between the time the LIDAR data was collected and the time of the TWDB survey in which the water surface elevation of the reservoir increased 5.43 feet in 24 hours. At 18:00 on April 18, 2015, the gage read 856.96 feet. At 18:00 on April 19, 2015, the gage read 862.39 feet (USGS 2016). It is possible that sediment in the channel was scoured out in this location during this event Therefore, all LIDAR data in the immediate channel overlapping with TWDB survey data was removed from the model.

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by the TWDB were edited to remove data anomalies. The reservoir's current bottom surface is automatically determined by the data acquisition software. DepthPic© software, developed by SDI, Inc., was used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface. The TWDB developed an algorithm to automatically determine the pre-impoundment surface based on the intensity of the acoustic returns. Hydropick software, developed by TWDB staff and in collaboration with Enthought, Inc. (GitHub 2015a, 2015b), was used to calibrate the algorithm and manually edit the pre-impoundment surfaces in areas where the algorithm did not perform as expected. For further analysis, all data was exported into a single file, including the current reservoir bottom surface, pre-impoundment surface, and sediment thickness at each sounding location. The water surface elevation at the time of each sounding was used to convert each sounding depth to a corresponding reservoir-bottom elevation. This survey point dataset was then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points were determined using an anisotropic spatial interpolation algorithm described in the next section. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen *et al.* 2011a). Finally, the point file resulting from spatial interpolation was used in conjunction with sounding and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (ESRI 1995).

Spatial interpolation of reservoir bathymetry

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

To improve the accuracy of bathymetric representation between survey lines, the TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining the survey data, or more robustly by examining scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours) when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. For surveys with similar spatial coverage, these interpolation definition files are, in principle, independent of the survey data and could be applied to past and future survey data of the same reservoir. 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 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 interpolation is used for volumetric and sediment accumulation estimations. Linear interpolation follows a line linking the survey points file to the lake boundary file (McEwen *et al.* 2011a). This line can intersect points along its path for consideration. Therefore, for Lake Mineral Wells, each line intersects with the first LIDAR point in its path and all linearly interpolated points outside the bathymetric elevation contour of 859.0 feet, *i.e.* those points overlapping LIDAR points, were not used. Without linearly 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, although it is not always possible to remove all flat triangles.

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

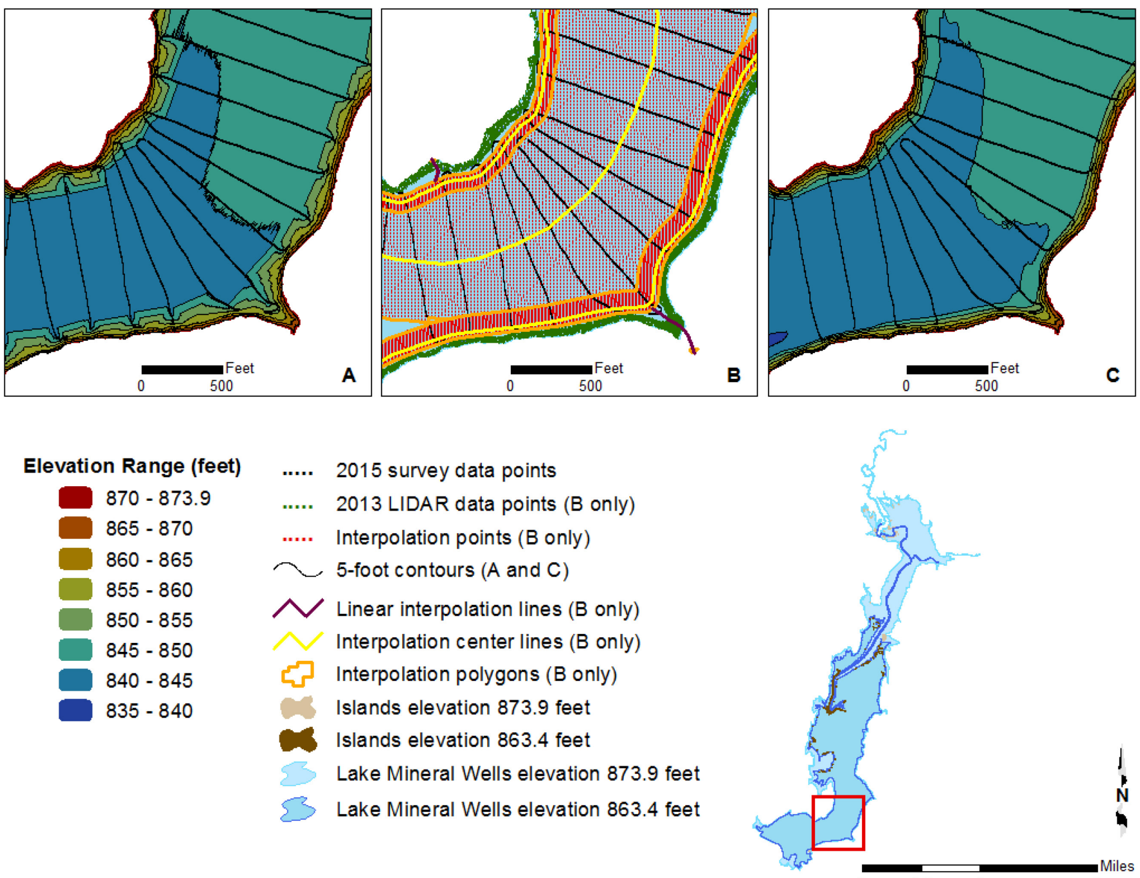


Figure 3. **Anisotropic spatial interpolation and linear interpolation of Lake Mineral Wells sounding data - A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with interpolated points.**

Area, volume, and contour calculation

Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1-foot intervals, from 834.8 to 873.9 feet. The elevation-capacity table and elevation-area table, updated for 2015, are presented in Appendices A and B, respectively. The capacity curve is presented in Appendix C, and the area curve is presented in Appendix D.

To test the accuracy of the reservoir model and area estimates, several DOQQs at varying water surface elevations were reviewed. A boundary was digitized from aerial photographs dated January 15, 2015, when the daily average water surface elevation of the lake measured 854.72 feet. The digitized area is equivalent to the modeled area at 854.7 feet with the actual overall difference less than one acre.

A boundary also was digitized from aerial photographs dated August 13, 2014, when the daily average water surface elevation of the lake measured 855.68 feet. At this elevation there are two distinct water bodies. Based on the modeled contours, the upper body of water could be cut off from the main body of water at approximately 857.8 feet, as measured at the gage. Therefore, the upper body of water in the 2014 photos could have an actual water surface elevation higher than what is read at the gage. Survey data in the upper body of water contradicts the land-water interface shown in the August 13, 2014, aerial photographs, confirming that the water surface elevation of the upper body of water is higher than what is being measured at the gage. The differences in water surface elevation between the upper and lower bodies of water suggested that the comparison of the 2014 digitized boundary and the modeled estimate is unreliable.

At elevation 857.8 feet, the modeled upper body of water covers approximately 62 surface acres or 17.8% of the reservoir area. This area represents a total capacity of 107 acre-feet or 3.4% of the total capacity at this elevation. Based on the 2014 aerial photographs and modeled contours, this water could be unavailable for diversion downstream when the reservoir level reaches elevation 857.8 feet. Additional elevation-capacity and elevation-area tables were generated to show the amount of water potentially unavailable for diversion downstream (Appendices E and F, respectively). The areas and capacities of water unavailable for diversion (Appendices E and F) were subtracted from the total areas and capacities found in Appendices A and B to provide an estimate of water available for diversion downstream (Appendices G and H, respectively). The capacity and area curves representing water available for diversion downstream are presented in Appendices I and J, respectively.

A final comparison was made by visually comparing the modeled 862.0 foot contour to DOQQs taken on July 5, 2012, when the daily average water surface elevation measured 861.88 feet. Visually, these matched very well. Vegetation in the upper reaches would have made digitizing a boundary from these photographs difficult, and the 862.0 contour is solely modeled from LIDAR data. The DOQQs and LIDAR data are available at the Texas Natural Resources Information System (TNRIS 2016).

The volumetric TIN model was converted to a raster representation using a cell size of 0.5 foot by 0.5 foot. The raster data then was used to produce three images: (1) an elevation relief map representing the topography of the reservoir bottom (Figure 4); (2) a depth range map showing shaded depth ranges for Lake Mineral Wells (Figure 5); and, (3) a two-foot contour map (Figure 6).

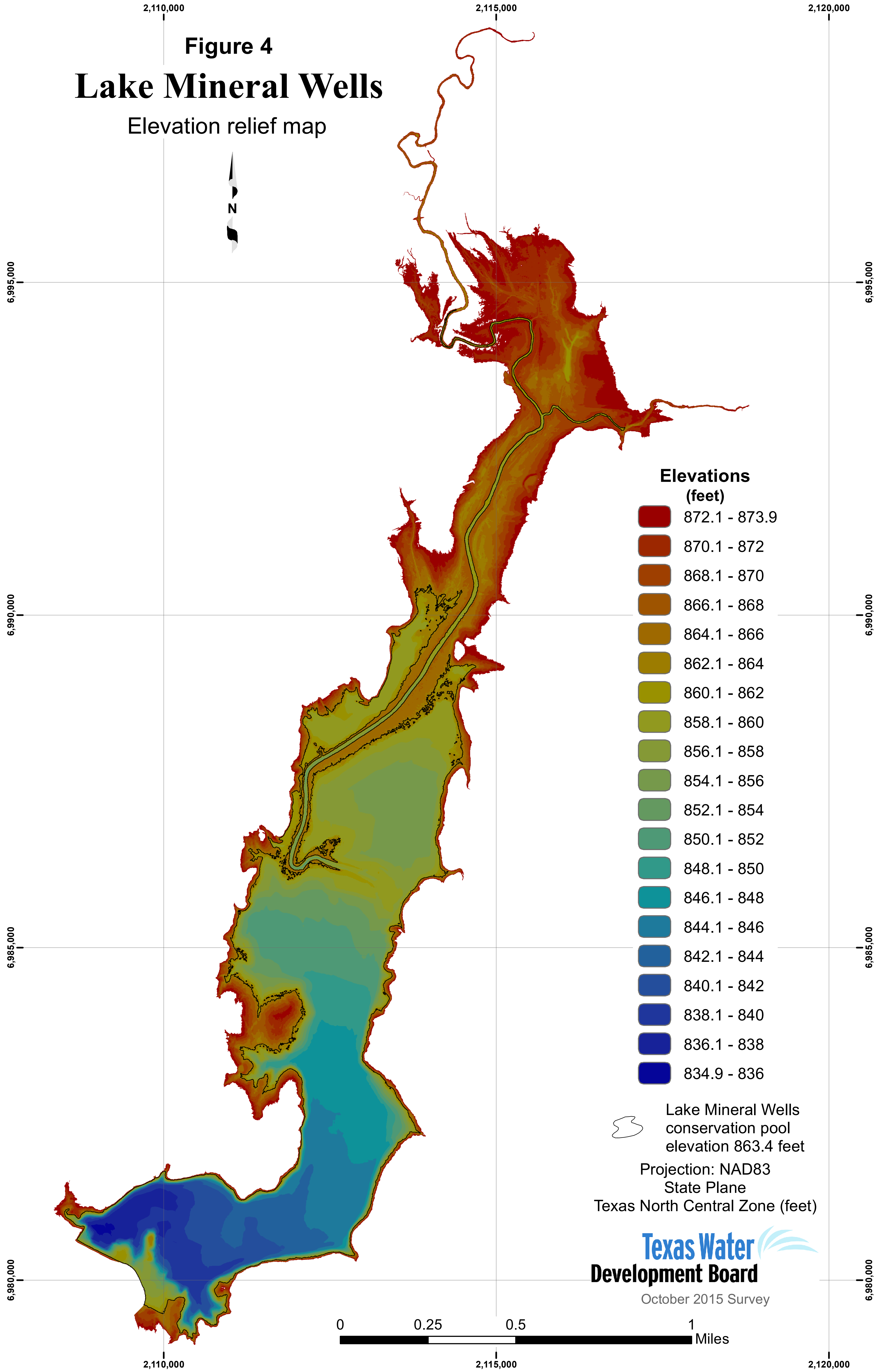
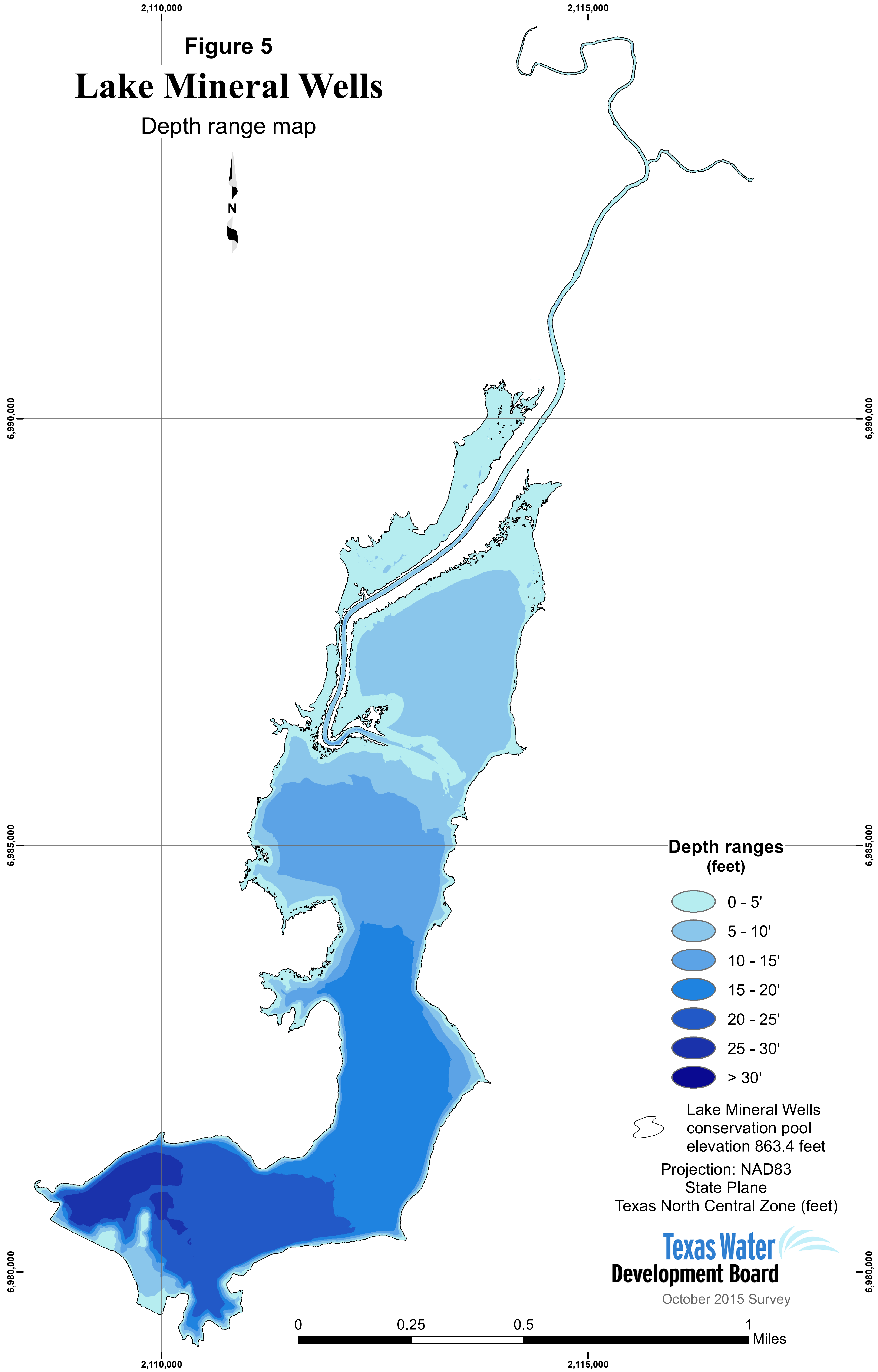
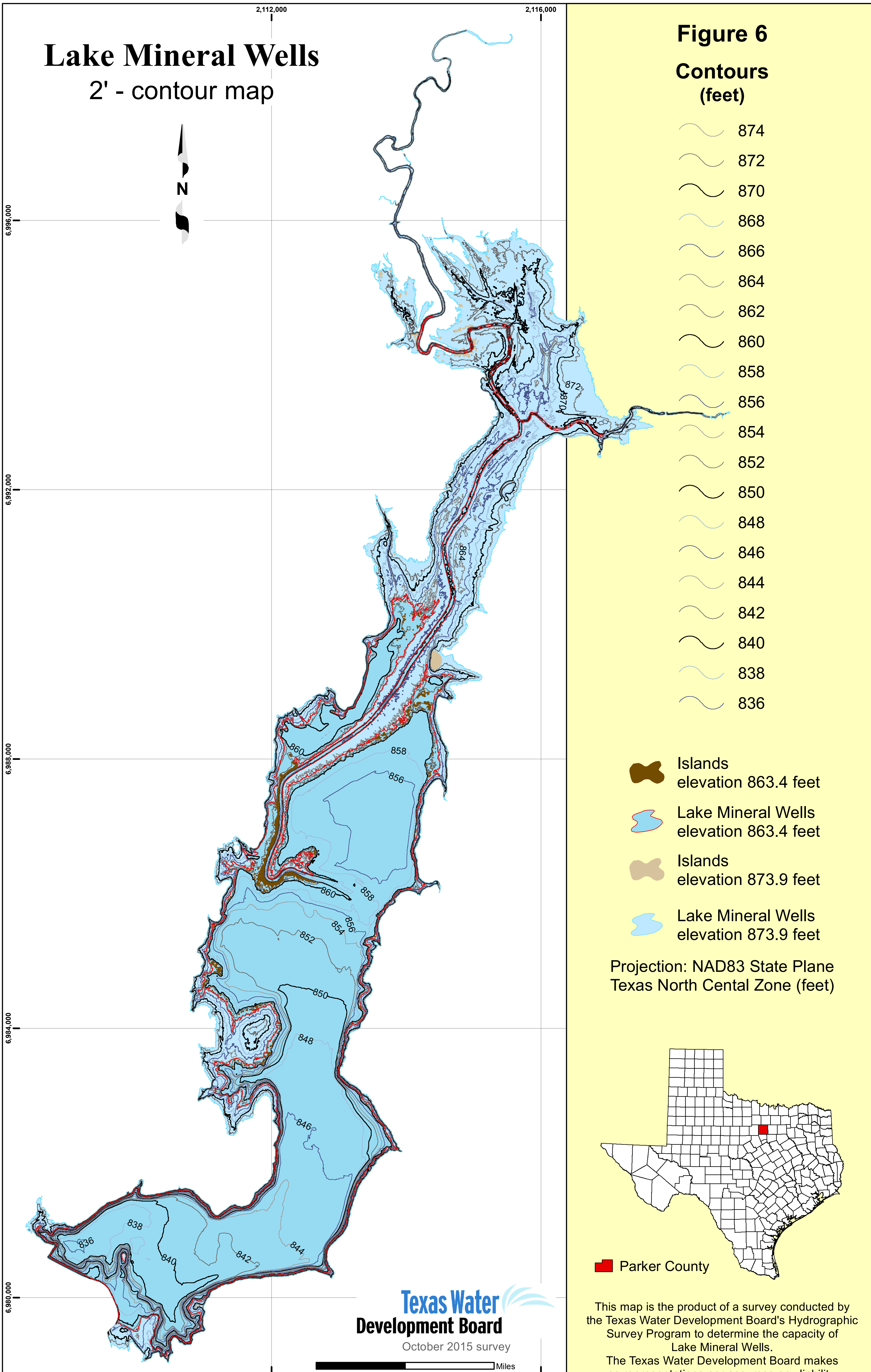


Figure 4
Lake Mineral Wells
Elevation relief map
N
Elevations
(feet)
872.1 - 873.9
870.1 - 872
868.1 - 870
866.1 - 868
864.1 - 866
862.1 - 864
860.1 - 862
858.1 - 860
856.1 - 858
854.1 - 856
852.1 - 854
850.1 - 852
848.1 - 850
846.1 - 848
844.1 - 846
842.1 - 844
840.1 - 842
838.1 - 840
836.1 - 838
834.9 - 836
Lake Mineral Wells
conservation pool
elevation 863.4 feet
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water
Development Board
October 2015 Survey
0
0.25
0.5
1
Miles
2,110,000
2,115,000
2,120,000
6,995,000
6,990,000
6,985,000
6,980,000


2,110,000
2,115,000
Figure 5
Lake Mineral Wells
Depth range map
N
6,990,000
6,985,000
6,980,000
Depth ranges
(feet)
0 - 5'
5 - 10'
10 - 15'
15 - 20'
20 - 25'
25 - 30'
> 30'
Lake Mineral Wells
conservation pool
elevation 863.4 feet
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water
Development Board
October 2015 Survey
0
0.25
0.5
1
Miles


Lake Mineral Wells
2' - contour map
N
2,112,000
2,116,000
6,996,000
6,992,000
6,988,000
6,984,000
6,980,000
872
870
864
860
858
856
858
860
856
854
852
850
848
846
844
842
840
838
836
Texas Water
Development Board
October 2015 survey
0
0.25
0.5
Miles
Figure 6
Contours
(feet)
874
872
870
868
866
864
862
860
858
856
854
852
850
848
846
844
842
840
838
836
Islands
elevation 863.4 feet
Lake Mineral Wells
elevation 863.4 feet
Islands
elevation 873.9 feet
Lake Mineral Wells
elevation 873.9 feet
Projection: NAD83 State Plane
Texas North Cental Zone (feet)
Parker 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 Mineral Wells.
The Texas Water Development Board makes
no representations nor assumes any liability.

Analysis of sediment data from Lake Mineral Wells

Sedimentation in Lake Mineral Wells was determined by analyzing the acoustic signal returns of all three depth sounder frequencies using customized software called Hydropick. While the 208 kHz signal is analyzed to determine the current bathymetric surface, all three frequencies, 208 kHz, 50 kHz, and 24 kHz, are analyzed to determine the reservoir bathymetric surface at the time of initial impoundment, *i.e.*, pre-impoundment surface. Sediment core samples collected in the reservoir are correlated with the acoustic signals in each frequency to assist in identifying the pre-impoundment surface. The difference between the current surface and the pre-impoundment surface yields a sediment thickness value at each sounding location.

Analysis of sediment core samples was conducted at TWDB headquarters in Austin, Texas. 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 Munsell soil color, texture, relative water content, and presence of organic materials, also were recorded (Table 2).

Table 2. Sediment core sampling analysis data - Lake Mineral Wells

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
MW-1	2110376.36	6980502.49	67.25"/ 49.0"	0-38.5" high water content, 30% mottling, loam, post-impoundment	5Y 4/2 & 5Y 2.5/1
				38.5-49.0" high density, 20% mottling, clay, post-impoundment	5Y 4/1 & 5Y 2.5/1
				49.0-67.25" medium water content, 20% mottling, clay loam, pre-impoundment	5Y 4/1 & 5Y 2.5/1
MW-2	2111835.42	6980995.09	53.5"/48.0"	0-48.0" high water content, 30% mottling, clay loam, post-impoundment	5Y 4/2 & 5Y 2.5/1
				48.0-53.5" high density, 10% mottling, clay, pre-impoundment	5Y 4/2 & 5Y 2.5/1
MW-3	2112403.76	6982666.68	37.75"/21.0"	0-21.0" high water content, 30% mottling, clay loam, post-impoundment	5Y 4/2 & 5Y 2.5/1
				21.0-37.75" high density, 10% mottling, clay, pre-impoundment	5Y 4/2 & 5Y 2.5/1
MW-4	2113034.94	6985132.55	26.75"/N/A"	0-4.0" water and fluff, post-impoundment	N/A
				4.0-5.0" high water content, sandy loam, post-impoundment	10YR 4/4
				5.0-26.75" high water content top 2", high density, 15% fine to coarse organic material, sandy clay loam, post-impoundment	2.5Y 4/2
MW-5	2113503.76	6987319.72	22.5"/18.5"	0-2.5" water and fluff, post-impoundment	N/A
				2.5-5.0" high water content, loam with clay pockets, post-impoundment	10YR 4/4
				5.0-7.0" high density, 5% mottling, clay, post-impoundment	5Y 4/1
				7.0-18.5" high density, 10% mottling, clay loam, post-impoundment	5Y 4/2
				18.5-22.5" high density, 10% mottling, clay, pre-impoundment	5Y 4/1

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

A photograph of sediment core MW-3 (for location refer to Figure 2) is shown in Figure 7 and is representative of sediment cores sampled from Lake Mineral Wells. The base of the sample is denoted by the blue line. The pre-impoundment boundary (yellow line) was evident within this sediment core sample at 21.0 inches and identified by the change in color, texture, moisture, porosity, and structure. Identification of the pre-impoundment surface for the other four sediment cores followed a similar procedure.

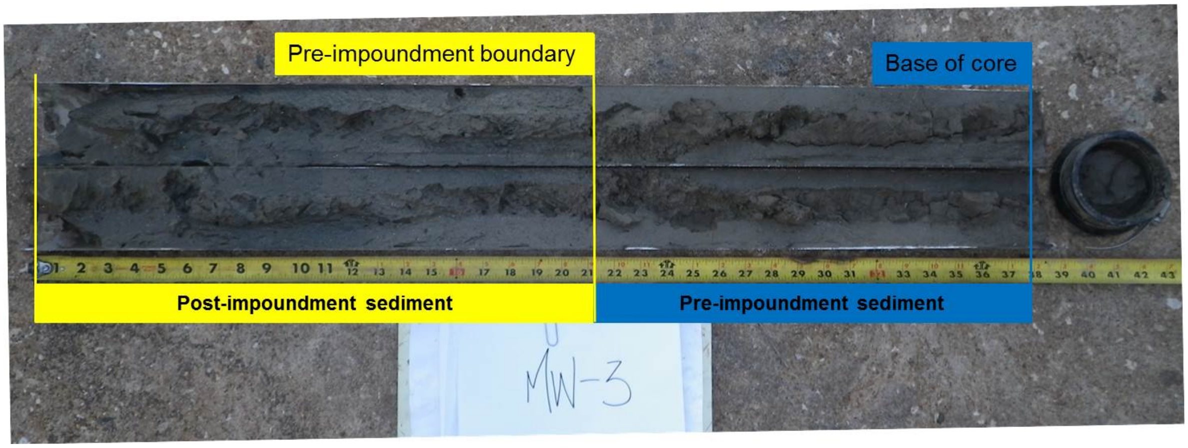


Figure 7. **Sediment core MW-3 from Lake Mineral Wells. Post-impoundment sediment layers occur in the top 21 inches of the sediment core (identified by yellow boxes). Pre-impoundment sediment layers were identified and are defined with blue boxes.**

Figures 8 and 9 illustrate how measurements from sediment core samples are used with sonar data to identify the post- and pre-impoundment layers in the acoustic signal. Figure 8 compares sediment core sample MW-3 with the acoustic signals as seen in Hydropick for each frequency: 208 kHz, 50 kHz, and 24 kHz. The current bathymetric surface is automatically determined based on signal returns from the 208 kHz transducer as represented by the top red line in Figure 8. The pre-impoundment surface is identified by

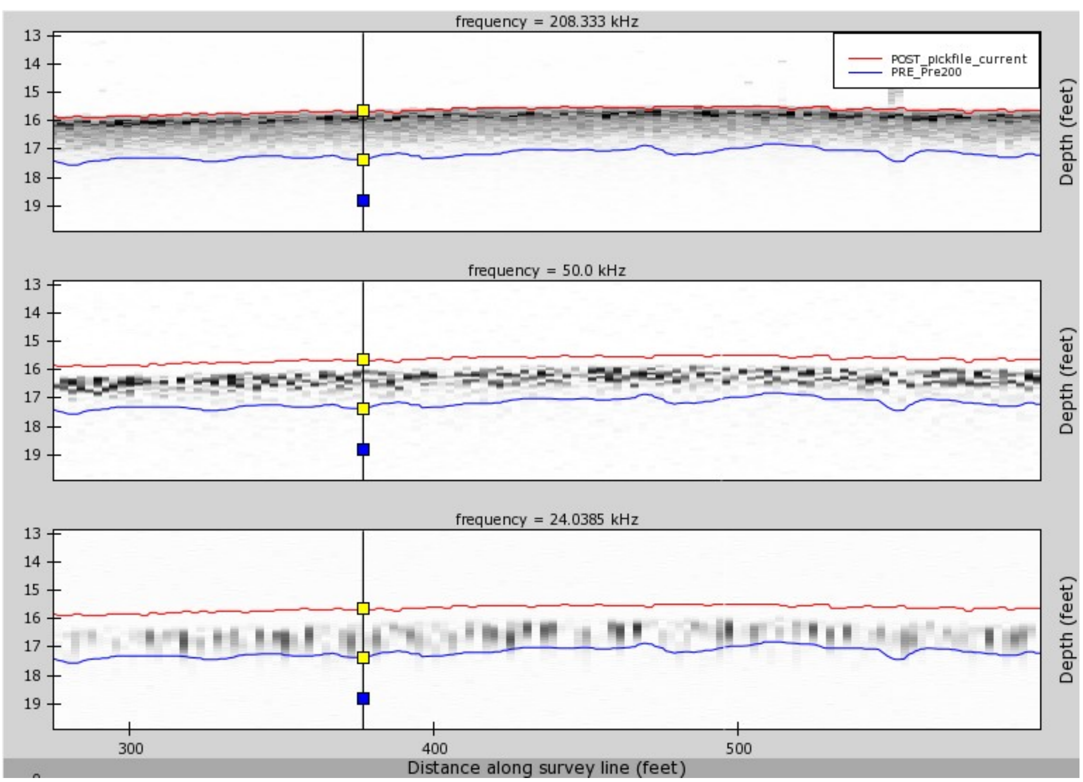


Figure 8. **Comparison of sediment core MW-3 with acoustic signal returns.**

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. Many layers of sediment were identified during analysis based on changes in observed characteristics such as water content, organic matter content, and sediment particle size, and each layer is classified as either post-impoundment or pre-impoundment. The boundary of each layer of sediment identified in the sediment core sample during analysis (Table 2) is represented in Figures 8 and 9 by a yellow or blue box. A yellow box represents post-impoundment sediments. A blue box indicates pre-impoundment sediments that were identified.

In this case, the boundary in the 208 kHz signal most closely matched the pre-impoundment interface of the sediment core sample; therefore, the 208 kHz signal was used to locate the pre-impoundment surface (blue line in the top panel in Figure 8). Figure 9 shows sediment core sample MW-3 correlated with the 208 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected. This information then is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

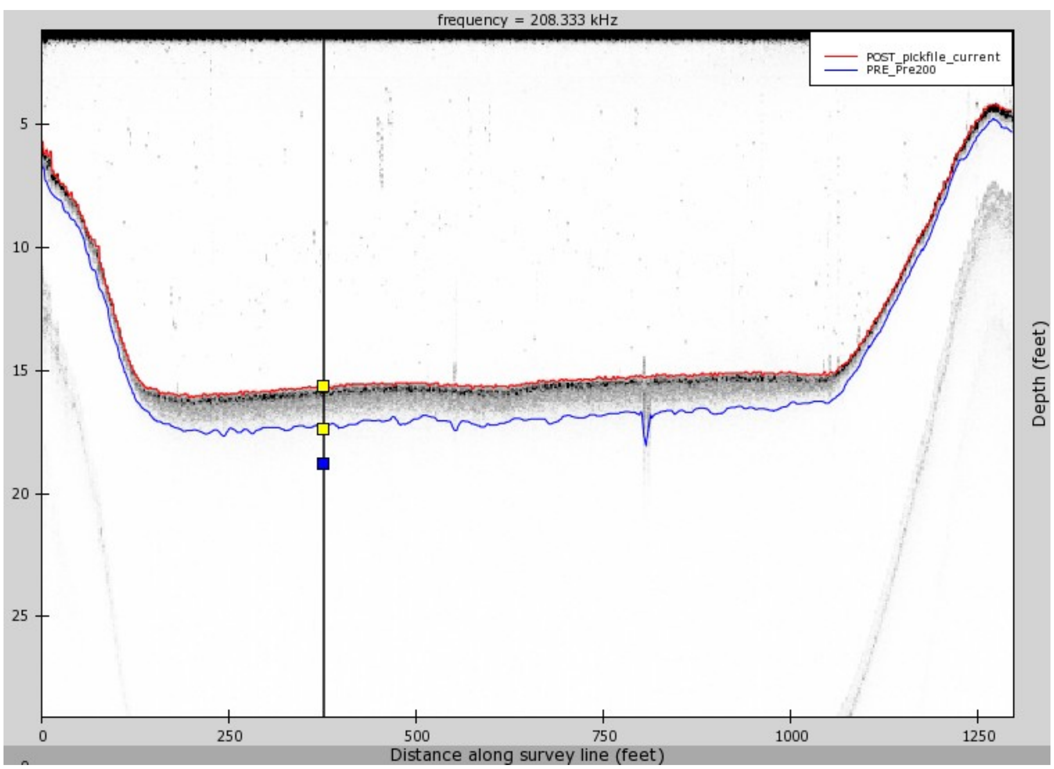


Figure 9. Cross-section of data collected during survey, displayed in Hydropick (208 kHz frequency), correlated with sediment core sample MW-3 and showing the current surface in red and pre-impoundment surface in blue.

The pre-impoundment surface was automatically generated in Hydropick using Otsu's thresholding algorithm of classifying greyscale intensity images into binary (black and white) images based on maximum inter-class variance. The acoustic return images of a selected frequency from each survey line were processed using this technique and the pre-impoundment surface was identified as the bottom black/white interface (where black is the sediment layer) of the resulting binary image (D. Pothina, *pers. comm.*, October 2, 2014). The pre-impoundment surface then is verified and edited manually as needed.

After the pre-impoundment surface from all cross-sections is 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 TIN model creation, the TWDB assumed sediment thicknesses at the reservoir boundaries were zero feet (defined as the 873.9 foot, 863.4 foot, and 861.88 foot elevation contours). The TWDB also assumed zero sediment thickness at each LIDAR point. The sediment thickness TIN model was converted to a raster representation using a cell size of one foot by one foot and was used to produce a sediment thickness map of Lake Mineral Wells (Figure 10).

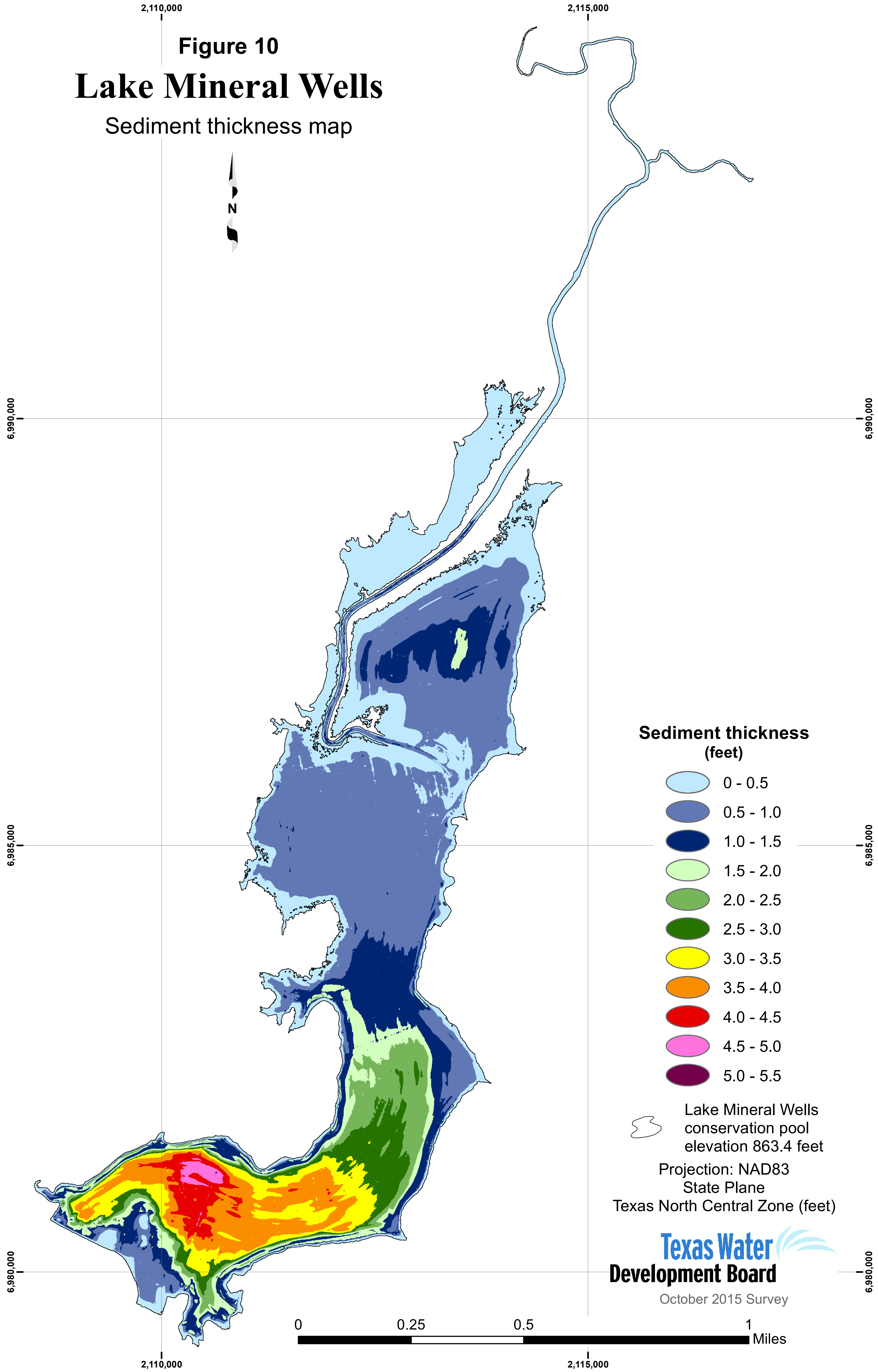


Figure 10
Lake Mineral Wells
Sediment thickness map
N
2,110,000
2,115,000
6,990,000
6,985,000
6,980,000
Sediment thickness
(feet)
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
Lake Mineral Wells
conservation pool
elevation 863.4 feet
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water
Development Board
October 2015 Survey
0
0.25
0.5
1
Miles

Survey results

Volumetric survey

The results of the 2015 TWDB volumetric survey indicate Lake Mineral Wells has a total reservoir capacity of 5,461 acre-feet and encompasses 477 acres at conservation pool elevation (863.4 feet above mean sea level, NGVD29). Previous capacity estimates include the original 1920 design estimate of 8,140 acre-feet (which includes the added capacity from when the dam and spillway crest were raised in 1943), a 1970 estimate of 7,050 acre-feet (which later was adjusted to 6,644 acre-feet through an analysis by HDR Engineering, Inc.), and most recently, prior to the 2015 TWDB survey, a 1990 HDR Engineering, Inc. survey estimate of 5,663 acre-feet (Table 3). Because of differences in survey methodologies, direct comparison of this volumetric survey to others to estimate changes in capacity is difficult and can be unreliable.

Table 3. Current and previous survey capacity and surface area data for Lake Mineral Wells.

Survey	Surface area (acres)	Total capacity (acre-feet)
Original design, 1920[a]	N/A	8,140[b]
Forrest and Cotton 1970[a]	667.6	7,050
1970 adjusted by HDR 1990[a,c]	449	6,655
HDR 1990[a]	449	5,663
TWDB 2015	477	5,461

[a] Source: (HDR 1990)
[b] Note: The original 1920 conservation capacity of 7,300 acre-feet plus the additional capacity of 840 acre-feet added when the dam and spillway crest were raised two feet in 1943 (HDR 1990).
[c] Note: The original 1970 area of 667.6 acres may have overestimated the area. The 1990 boundary was verified using a Texas Parks and Wildlife Department topographic map developed from a 1976 aerial survey and a USGS 7.5 minute quadrangle map. Therefore, the areas from the 1990 survey were substituted into the 1970 table and capacities recalculated (HDR 1990).

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Mineral Wells to have an average loss of capacity between 6 and 28 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (863.4 feet NGVD29). Sediment accumulation is greatest in the main basin of the lake approximately 1,400 feet northeast of the dam. Comparison of capacity estimates of Lake Mineral Wells derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. Capacity loss comparisons for Lake Mineral Wells.

Survey	Volume comparisons at conservation pool elevation (acre-feet)			Pre-impoundment (acre-feet)
Original design[a]	8,140	<>	<>	<>
1970 HDR adjusted[b]	<>	6,655	<>	<>
HDR 1990	<>	<>	5,663	<>
TWDB pre-impoundment estimate based on 2015 survey	<>	<>	<>	6,044[c]
2015 volumetric survey	5,461	5,461	5,461	5,461
Volume difference (acre-feet)	2,679 (32.9%)	1,194 (17.9%)	202 (3.6%)	583 (9.6%)
Number of years	95	45	25	95
Capacity loss rate (acre-feet/year)	28	26.5	8	6

[a] Source: (HDR 1990), note: Construction on Mineral Wells Dam was first completed in September 1920. Enlargement of the dam occurred between August 18, 1943, and January 31, 1944.
[c] 2015 TWDB surveyed capacity of 5,461 acre-feet plus 2015 TWDB surveyed sediment volume of 583 acre-feet

Recommendations

The TWDB recommends another volumetric and sedimentation survey of Lake Mineral Wells within a 10 year time-frame or after a major flood event to assess changes in lake capacity and to further improve estimates of sediment accumulation rates.

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:
Hydrosurvey@twdb.texas.gov

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Appendix A

Lake Mineral Wells

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — October 2015 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 863.4 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
834	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0
836	0	0	0	1	1	1	1	2	2	3
837	3	4	5	5	6	7	8	9	10	11
838	12	14	15	16	18	19	21	23	25	27
839	29	31	34	36	39	42	44	47	50	54
840	57	60	64	67	71	75	79	83	87	91
841	95	99	104	108	113	118	123	128	134	139
842	145	151	157	163	169	176	183	189	196	203
843	210	218	225	232	240	247	255	263	271	279
844	287	295	304	313	321	330	339	348	358	367
845	377	387	397	407	417	428	439	450	462	473
846	485	497	510	522	535	548	562	575	589	604
847	618	633	648	663	678	693	708	724	740	755
848	771	787	804	820	837	853	870	887	904	921
849	938	956	973	990	1,008	1,025	1,043	1,061	1,079	1,097
850	1,115	1,134	1,152	1,171	1,189	1,208	1,227	1,246	1,265	1,284
851	1,304	1,323	1,343	1,363	1,384	1,405	1,426	1,448	1,470	1,492
852	1,514	1,536	1,558	1,581	1,604	1,627	1,650	1,673	1,697	1,721
853	1,744	1,768	1,792	1,816	1,841	1,865	1,889	1,914	1,939	1,964
854	1,989	2,014	2,039	2,064	2,089	2,115	2,140	2,166	2,192	2,217
855	2,243	2,270	2,297	2,325	2,353	2,382	2,411	2,440	2,469	2,499
856	2,529	2,560	2,590	2,621	2,652	2,683	2,715	2,747	2,779	2,811
857	2,844	2,876	2,910	2,943	2,976	3,010	3,044	3,079	3,113	3,148
858	3,183	3,219	3,254	3,290	3,326	3,363	3,400	3,437	3,475	3,514
859	3,553	3,592	3,632	3,672	3,712	3,753	3,794	3,835	3,876	3,917
860	3,959	4,000	4,042	4,084	4,126	4,168	4,211	4,253	4,296	4,339
861	4,381	4,424	4,468	4,511	4,554	4,598	4,642	4,685	4,729	4,774
862	4,818	4,862	4,907	4,952	4,997	5,042	5,088	5,134	5,180	5,226
863	5,273	5,319	5,367	5,414	5,461	5,509	5,557	5,606	5,655	5,703
864	5,753	5,802	5,852	5,902	5,952	6,003	6,054	6,105	6,156	6,208
865	6,260	6,313	6,365	6,418	6,471	6,525	6,579	6,633	6,687	6,742
866	6,797	6,852	6,908	6,964	7,020	7,077	7,133	7,190	7,248	7,305
867	7,363	7,421	7,479	7,537	7,596	7,655	7,714	7,774	7,833	7,893
868	7,954	8,014	8,075	8,136	8,197	8,258	8,320	8,382	8,444	8,507
869	8,569	8,632	8,696	8,759	8,823	8,887	8,951	9,016	9,081	9,146
870	9,212	9,277	9,344	9,410	9,477	9,543	9,611	9,678	9,746	9,815
871	9,883	9,952	10,021	10,091	10,160	10,231	10,301	10,372	10,443	10,515
872	10,586	10,659	10,731	10,804	10,877	10,951	11,025	11,099	11,174	11,249
873	11,324	11,400	11,476	11,553	11,630	11,707	11,784	11,862	11,940	12,019

Appendix B

Lake Mineral Wells

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD

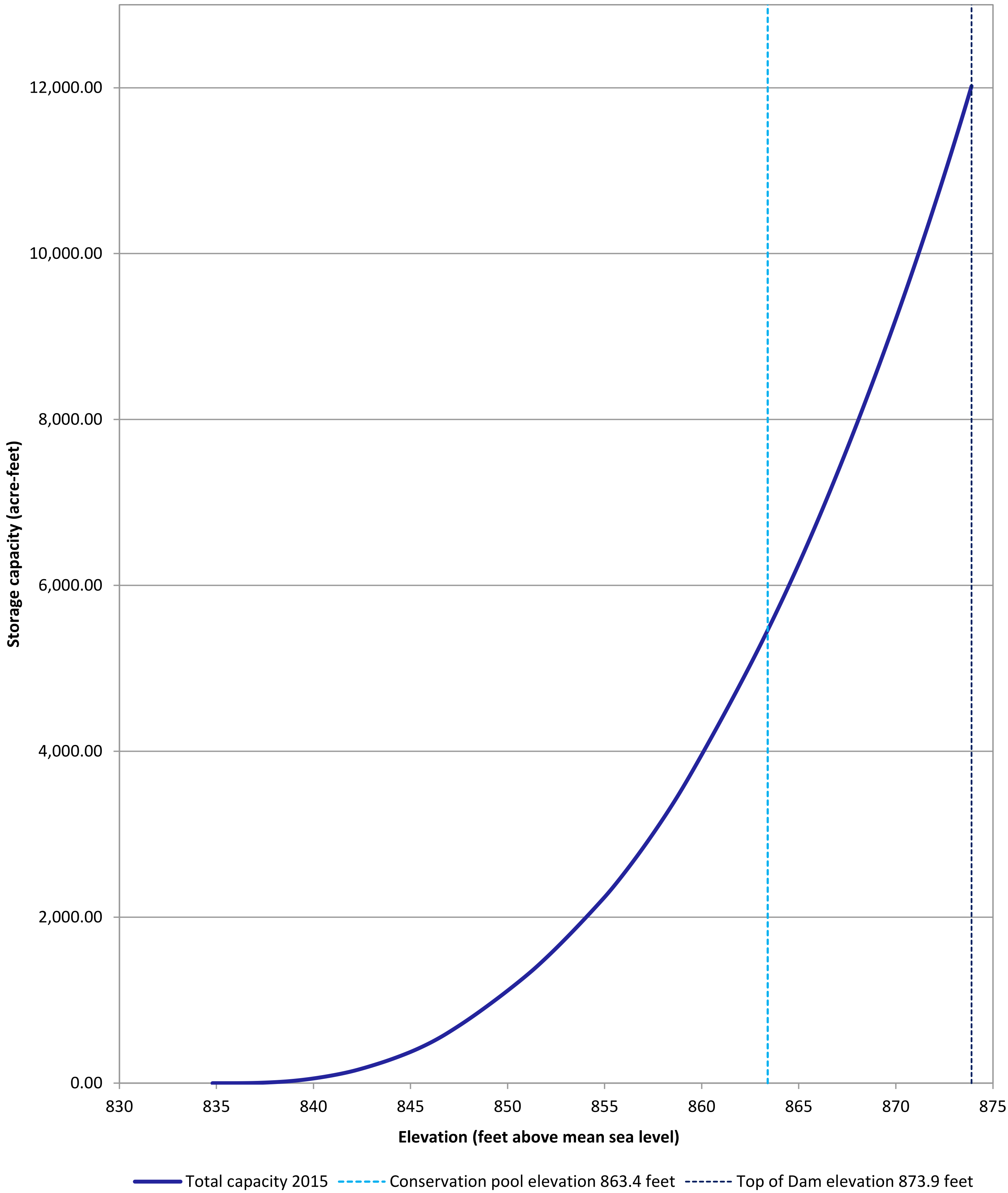
AREA IN ACRES

ELEVATION INCREMENT IS ONE TENTH FOOT

October 2015 Survey

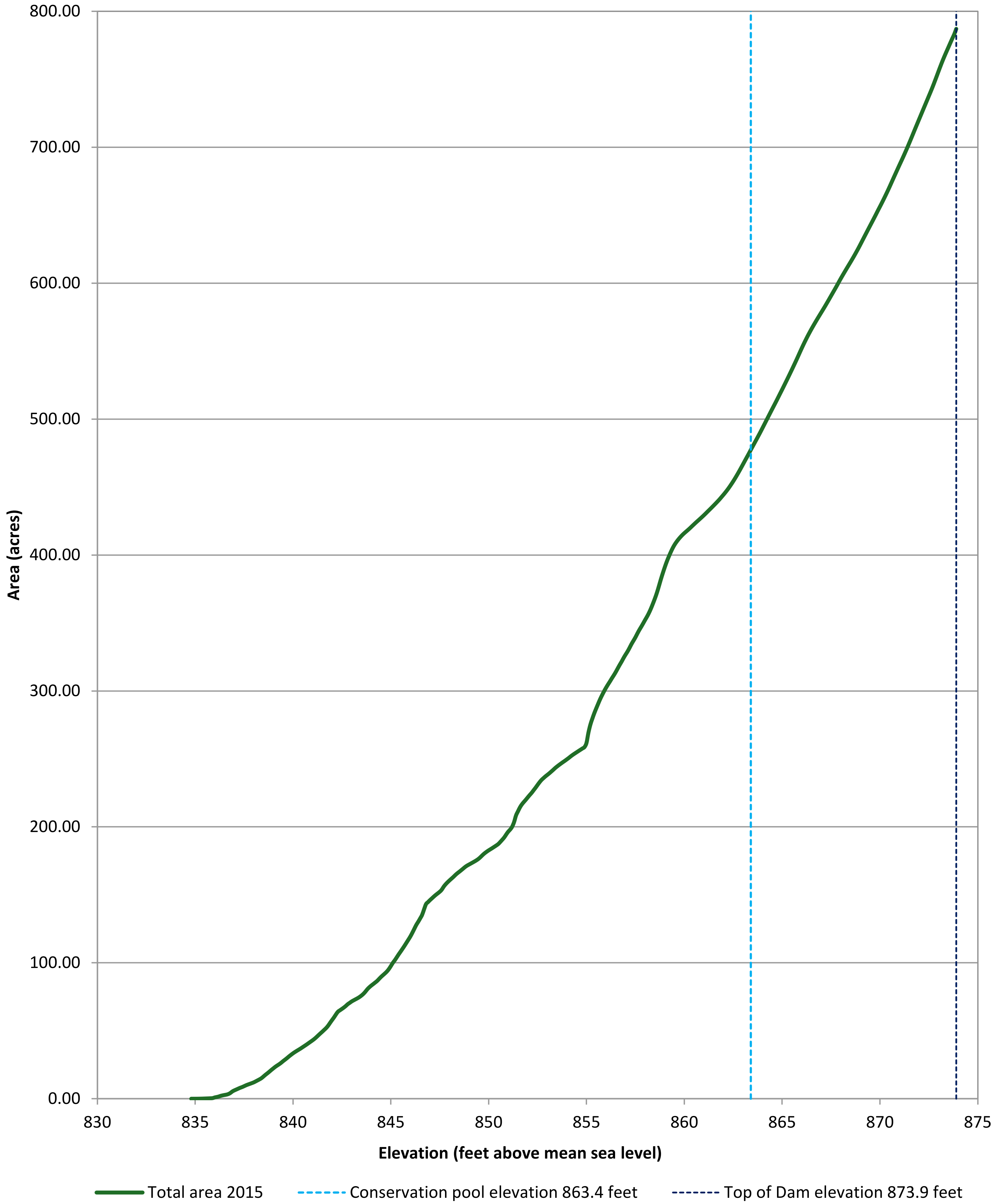
Conservation Pool Elevation 863.4 feet NGVD29

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
834	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0
836	1	1	2	2	2	3	3	3	4	5
837	6	7	7	8	9	9	10	10	11	12
838	12	13	14	14	15	16	18	19	20	21
839	22	24	25	25	27	28	29	30	31	32
840	33	34	35	36	37	38	39	40	41	42
841	43	44	45	47	48	49	51	52	54	56
842	58	60	62	64	65	66	67	68	70	71
843	72	72	73	74	75	76	77	79	81	82
844	83	84	85	87	88	90	91	92	94	95
845	98	100	102	104	106	108	110	113	115	117
846	119	122	125	128	130	133	135	139	143	145
847	146	147	149	150	151	152	154	156	158	159
848	161	162	163	165	166	167	168	169	171	172
849	172	173	174	175	176	177	178	179	181	182
850	183	184	185	185	186	187	189	191	192	194
851	196	198	200	204	208	211	214	217	218	220
852	222	223	225	227	229	231	233	235	236	237
853	238	239	241	242	243	244	246	247	248	249
854	250	251	252	253	254	255	256	257	258	259
855	262	269	275	280	284	287	291	294	297	300
856	302	305	307	309	312	314	317	319	322	324
857	327	329	332	334	337	339	342	345	347	350
858	352	355	358	361	364	368	372	377	382	387
859	391	395	399	402	405	408	410	412	413	415
860	416	417	419	420	421	423	424	425	427	428
861	429	431	432	434	435	436	438	439	441	443
862	444	446	448	450	452	454	457	459	462	464
863	467	469	472	475	477	480	483	485	488	491
864	494	496	499	502	505	508	510	513	516	519
865	522	525	528	530	533	536	539	543	546	549
866	552	555	558	561	564	566	569	571	574	576
867	578	581	583	586	588	591	593	596	598	601
868	603	606	608	611	613	616	618	621	623	626
869	629	631	634	637	640	642	645	648	651	654
870	656	659	662	665	668	671	674	678	681	684
871	687	690	693	697	700	703	707	710	714	717
872	721	724	727	731	734	738	741	745	748	752
873	756	760	764	767	770	774	777	780	783	787



Lake Mineral Wells
October 2015 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Lake Mineral Wells
October 2015 Survey
Prepared by: TWDB

Appendix D: Area curve

Appendix E

Lake Mineral Wells

RESERVOIR CAPACITY TABLE : Water unavailable at and below elevation 857.8 feet

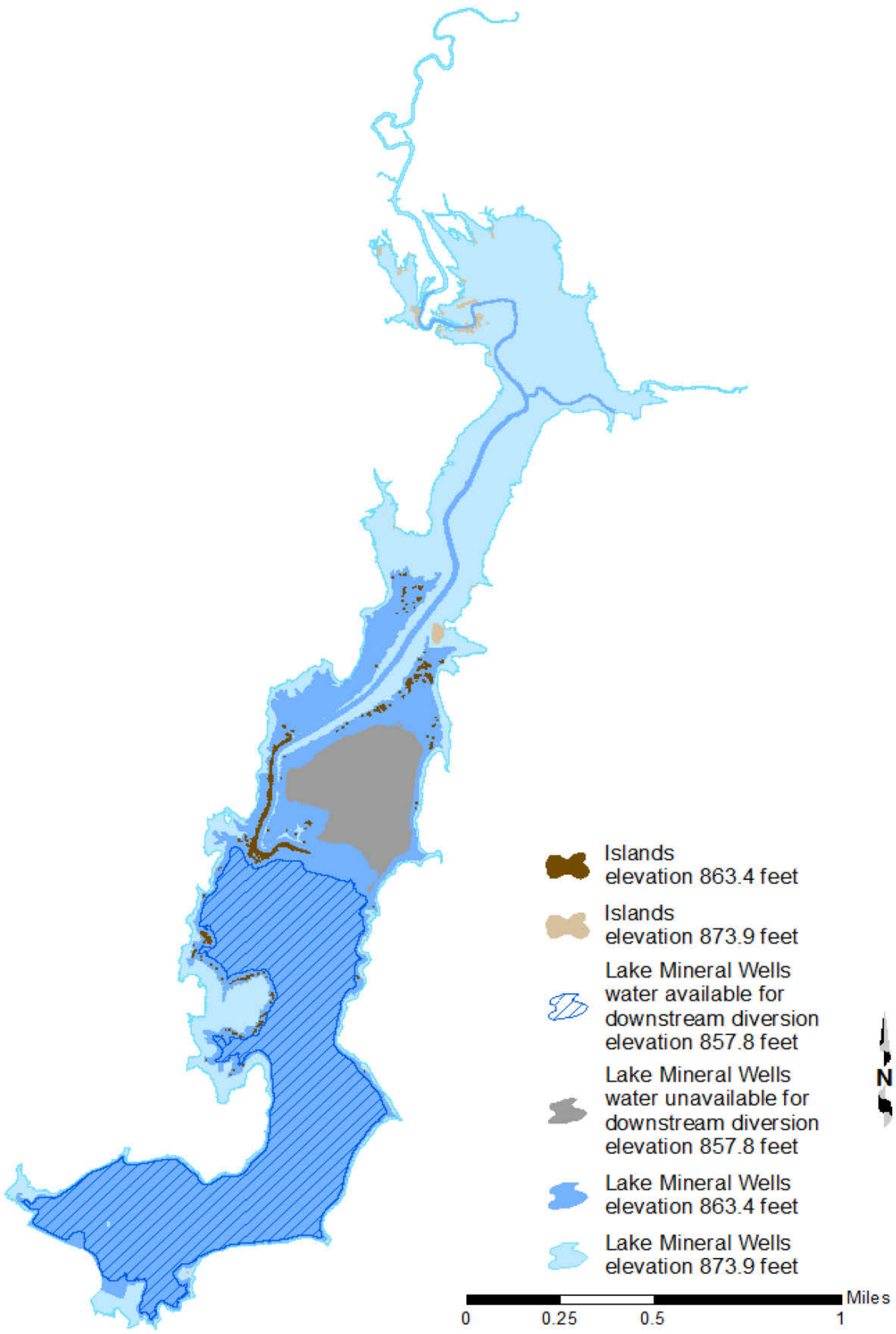
TEXAS WATER DEVELOPMENT BOARD — October 2015 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 863.4 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
854	0	0	0	0	0	0	0	0	0	0
855	0	1	2	3	5	7	10	13	15	19
856	22	25	29	33	37	41	45	49	53	58
857	63	68	73	78	84	89	95	101	107	

Note: Based on the 2014 aerial photographs and modeled contours, Lake Mineral Wells becomes two distinct water bodies at approximately elevation 857.8 feet. This table represents the upper body of water that could be unavailable for downstream diversion. The figure below shows the extent of the unavailable pool of water.



Appendix F

Lake Mineral Wells

RESERVOIR AREA TABLE: Water unavailable at and below elevation 857.8 feet

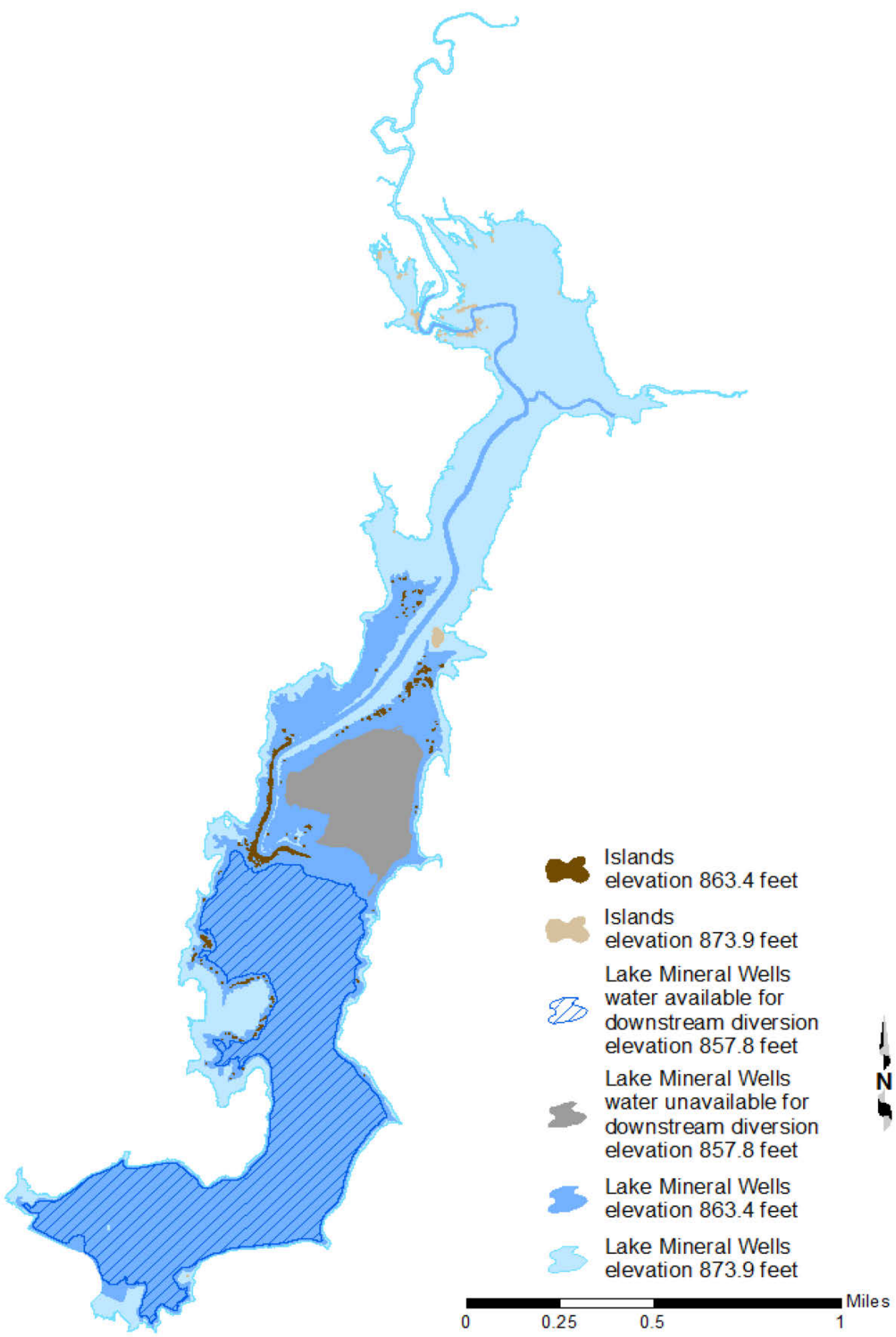
TEXAS WATER DEVELOPMENT BOARD — October 2015 Survey

AREA IN ACRES — Conservation Pool Elevation 863.4 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
854	0	0	0	0	0	0	0	0	0	0
855	2	9	14	17	20	23	26	28	30	32
856	34	35	37	38	39	41	42	44	45	47
857	49	50	52	54	55	57	59	60	62	

Note: Based on the 2014 aerial photographs and modeled contours, Lake Mineral Wells becomes two distinct water bodies at approximately elevation 857.8 feet. This table represents the upper body of water that could be unavailable for downstream diversion. The figure below shows the extent of the unavailable pool of water.



Appendix G

Lake Mineral Wells

ADJUSTED RESERVOIR CAPACITY TABLE: Water available for downstream diversion

TEXAS WATER DEVELOPMENT BOARD — October 2015 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 863.4 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
834	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0
836	0	0	0	1	1	1	1	2	2	3
837	3	4	5	5	6	7	8	9	10	11
838	12	14	15	16	18	19	21	23	25	27
839	29	31	34	36	39	42	44	47	50	54
840	57	60	64	67	71	75	79	83	87	91
841	95	99	104	108	113	118	123	128	134	139
842	145	151	157	163	169	176	183	189	196	203
843	210	218	225	232	240	247	255	263	271	279
844	287	295	304	313	321	330	339	348	358	367
845	377	387	397	407	417	428	439	450	462	473
846	485	497	510	522	535	548	562	575	589	604
847	618	633	648	663	678	693	708	724	740	755
848	771	787	804	820	837	853	870	887	904	921
849	938	956	973	990	1,008	1,025	1,043	1,061	1,079	1,097
850	1,115	1,134	1,152	1,171	1,189	1,208	1,227	1,246	1,265	1,284
851	1,304	1,323	1,343	1,363	1,384	1,405	1,426	1,448	1,470	1,492
852	1,514	1,536	1,558	1,581	1,604	1,627	1,650	1,673	1,697	1,721
853	1,744	1,768	1,792	1,816	1,841	1,865	1,889	1,914	1,939	1,964
854	1,989	2,014	2,039	2,064	2,089	2,115	2,140	2,166	2,192	2,217
855	2,243	2,269	2,295	2,322	2,348	2,374	2,401	2,427	2,454	2,481
856	2,507	2,534	2,561	2,588	2,616	2,643	2,670	2,698	2,725	2,753
857	2,781	2,809	2,837	2,865	2,893	2,921	2,949	2,978	3,006	3,041
858	3,076	3,112	3,147	3,183	3,219	3,256	3,293	3,330	3,368	3,407
859	3,446	3,485	3,525	3,565	3,605	3,646	3,687	3,728	3,769	3,810
860	3,852	3,893	3,935	3,977	4,019	4,061	4,104	4,146	4,189	4,232
861	4,274	4,317	4,361	4,404	4,447	4,491	4,534	4,578	4,622	4,667
862	4,711	4,755	4,800	4,845	4,890	4,935	4,981	5,027	5,073	5,119
863	5,166	5,212	5,259	5,307	5,354	5,402	5,450	5,499	5,547	5,596
864	5,646	5,695	5,745	5,795	5,845	5,896	5,947	5,998	6,049	6,101
865	6,153	6,206	6,258	6,311	6,364	6,418	6,472	6,526	6,580	6,635
866	6,690	6,745	6,801	6,857	6,913	6,970	7,026	7,083	7,141	7,198
867	7,256	7,314	7,372	7,430	7,489	7,548	7,607	7,667	7,726	7,786
868	7,847	7,907	7,968	8,029	8,090	8,151	8,213	8,275	8,337	8,400
869	8,462	8,525	8,589	8,652	8,716	8,780	8,844	8,909	8,974	9,039
870	9,105	9,170	9,236	9,303	9,369	9,436	9,504	9,571	9,639	9,707
871	9,776	9,845	9,914	9,984	10,053	10,123	10,194	10,265	10,336	10,408
872	10,479	10,552	10,624	10,697	10,770	10,844	10,918	10,992	11,067	11,142
873	11,217	11,293	11,369	11,446	11,523	11,600	11,677	11,755	11,833	11,912

Appendix H

Lake Mineral Wells

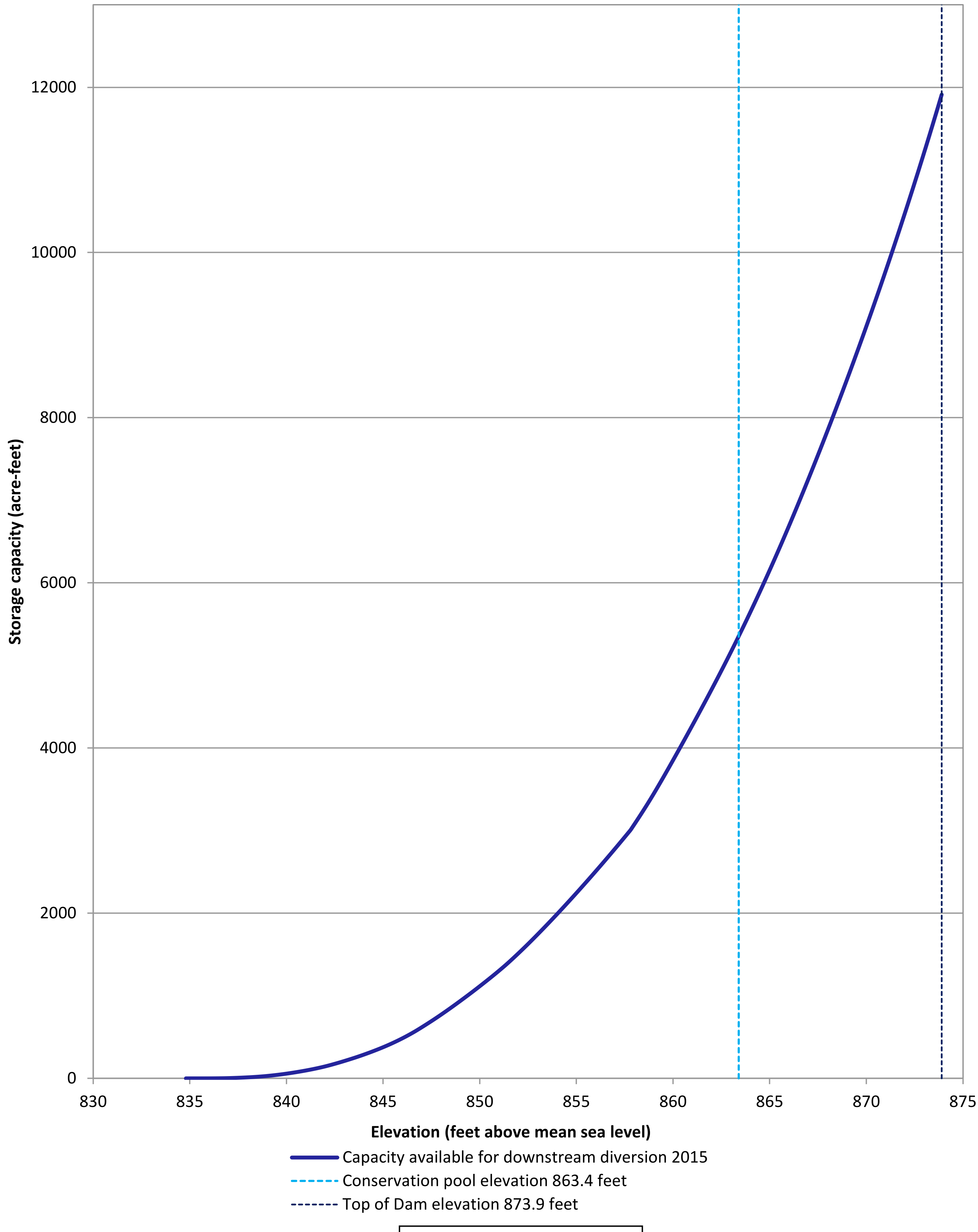
ADJUSTED RESERVOIR AREA TABLE: Water available for downstream diversion

TEXAS WATER DEVELOPMENT BOARD — October 2015 Survey

AREA IN ACRES — Conservation Pool Elevation 863.4 feet NGVD29

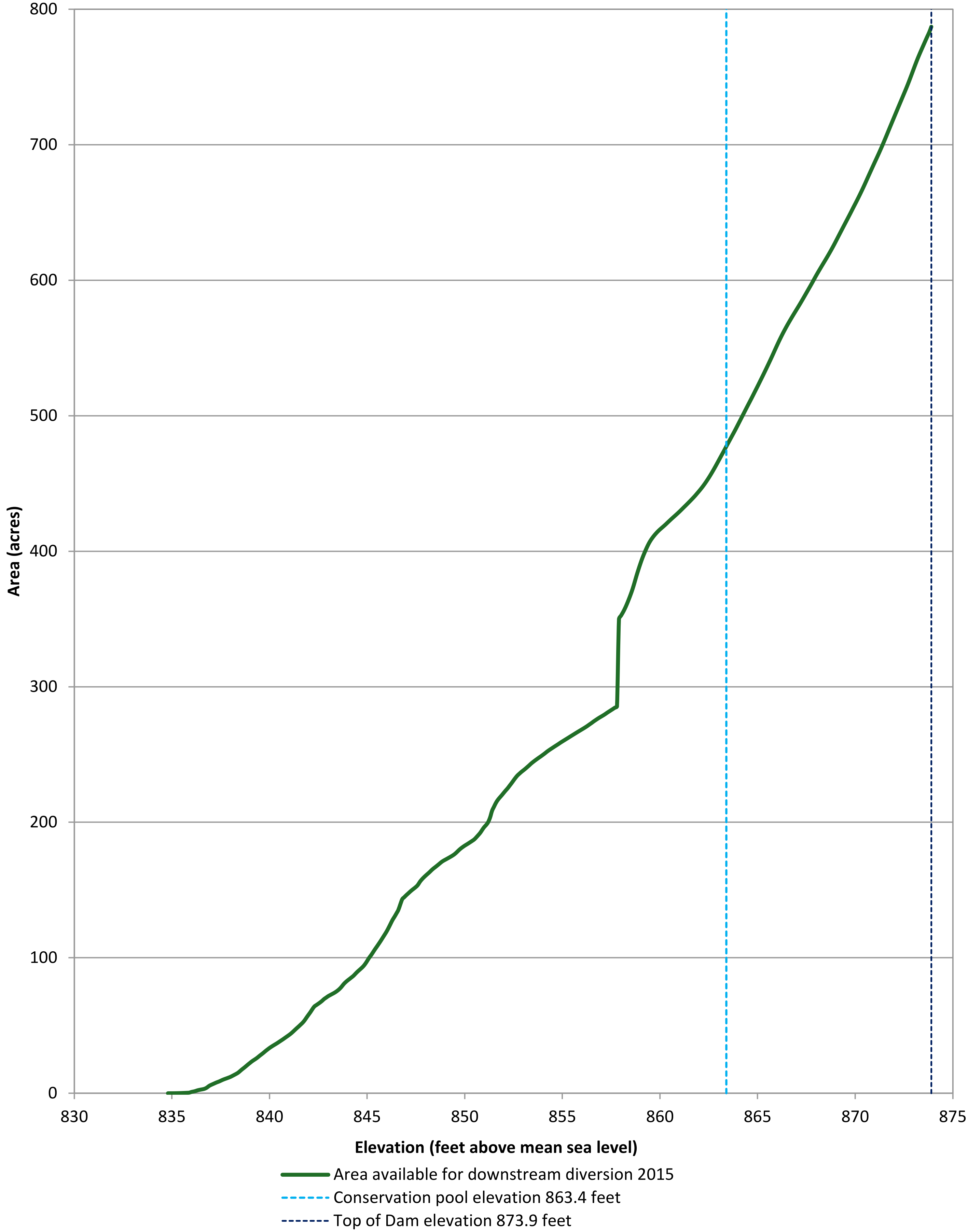
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
834	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0
836	1	1	2	2	2	3	3	3	4	5
837	6	7	7	8	9	9	10	10	11	12
838	12	13	14	14	15	16	18	19	20	21
839	22	24	25	25	27	28	29	30	31	32
840	33	34	35	36	37	38	39	40	41	42
841	43	44	45	47	48	49	51	52	54	56
842	58	60	62	64	65	66	67	68	70	71
843	72	72	73	74	75	76	77	79	81	82
844	83	84	85	87	88	90	91	92	94	95
845	98	100	102	104	106	108	110	113	115	117
846	119	122	125	128	130	133	135	139	143	145
847	146	147	149	150	151	152	154	156	158	159
848	161	162	163	165	166	167	168	169	171	172
849	172	173	174	175	176	177	178	179	181	182
850	183	184	185	185	186	187	189	191	192	194
851	196	198	200	204	208	211	214	217	218	220
852	222	223	225	227	229	231	233	235	236	237
853	238	239	241	242	243	244	246	247	248	249
854	250	251	252	253	254	255	256	257	258	259
855	260	261	261	262	263	264	265	266	267	268
856	269	269	270	271	272	273	274	275	276	277
857	278	279	280	281	282	283	284	285	286	350
858	352	355	358	361	364	368	372	377	382	387
859	391	395	399	402	405	408	410	412	413	415
860	416	417	419	420	421	423	424	425	427	428
861	429	431	432	434	435	436	438	439	441	443
862	444	446	448	450	452	454	457	459	462	464
863	467	469	472	475	477	480	483	485	488	491
864	494	496	499	502	505	508	510	513	516	519
865	522	525	528	530	533	536	539	543	546	549
866	552	555	558	561	564	566	569	571	574	576
867	578	581	583	586	588	591	593	596	598	601
868	603	606	608	611	613	616	618	621	623	626
869	629	631	634	637	640	642	645	648	651	654
870	656	659	662	665	668	671	674	678	681	684
871	687	690	693	697	700	703	707	710	714	717
872	721	724	727	731	734	738	741	745	748	752
873	756	760	764	767	770	774	777	780	783	787



Lake Mineral Wells
October 2015 Survey
Prepared by: TWDB

Appendix I: Adjusted capacity curve



Lake Mineral Wells
October 2015 Survey
Prepared by: TWDB

Appendix J: Adjusted area curve