Volumetric and Sedimentation Survey of BACHMAN LAKE

March 2015 Survey

Texas Water Development Board

January 2016

Texas Water Development Board

Prepared for:

City of Dallas

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

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Executive summary

In November 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 Bachman Lake. The City of Dallas 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.

Bachman Dam and Bachman Lake are located on Bachman Creek, a tributary of the Trinity River, in Dallas County, inside the northwestern city limits of Dallas, Texas. The conservation pool elevation of Bachman Lake is 438.1 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Bachman Lake on February 19, 2015, and March 18, 2015. The daily average water surface elevations during the survey measured 438.1 and 438.2 feet above mean sea level (NGVD29), respectively.

The 2015 TWDB volumetric survey indicates that Bachman Lake has a total reservoir capacity of 959 acre-feet and encompasses 132 acres at conservation pool elevation (438.1 feet above mean sea level, NGVD29). According to Certificate of Adjudication No. 08-2457, the City of Dallas is authorized to impound a maximum of 2,302 acre-feet of water in Bachman Lake.

The 2015 TWDB sedimentation survey measured 244 acre-feet of sediment below conservation pool elevation (438.1 feet NGVD29). Sediment accumulation varies throughout the reservoir with the heaviest deposits north of the cove between Bachman Water Treatment Plant and Dallas Love Field Airport approximately 1,500 feet northeast of the spillway. TWDB recommends that a similar methodology be used to resurvey Bachman Lake 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 November 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 Bachman Lake. The City of Dallas 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 (TWDB, 2014). 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 Dallas and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) a shaded relief plot of the reservoir bottom [Figure 4], (2) a bottom contour map [Figure 6], (3) an estimate of sediment accumulation and location [Figure 10], and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality [Appendix A, B].

Bachman Lake general information

Bachman Dam and Bachman Lake are located on Bachman Creek, a tributary of the Trinity River, in Dallas County, inside the northwestern city limits of Dallas, Texas (Figure 1). Bachman Dam and Bachman Lake are owned and operated by the City of Dallas. Bachman Dam was completed between 1901 (Mills et al., 1966) and 1903 (TPWD, 2014). Bachman Dam and Bachman Lake were built primarily for water supply storage for the City of Dallas. However, the city quickly outgrew the water source and stopped using it in 1911 when White Rock Lake was completed (DBJ, 2007). The lake is currently part of the city's park department and used for recreation (DPR, 2016).

Water rights for Bachman Lake have been appropriated to the City of Dallas through Certificate of Adjudication No. 08-2457 and Amendments to Certificate of Adjudication Nos. 08-2457A, 08-2457B, and 08-2457C. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

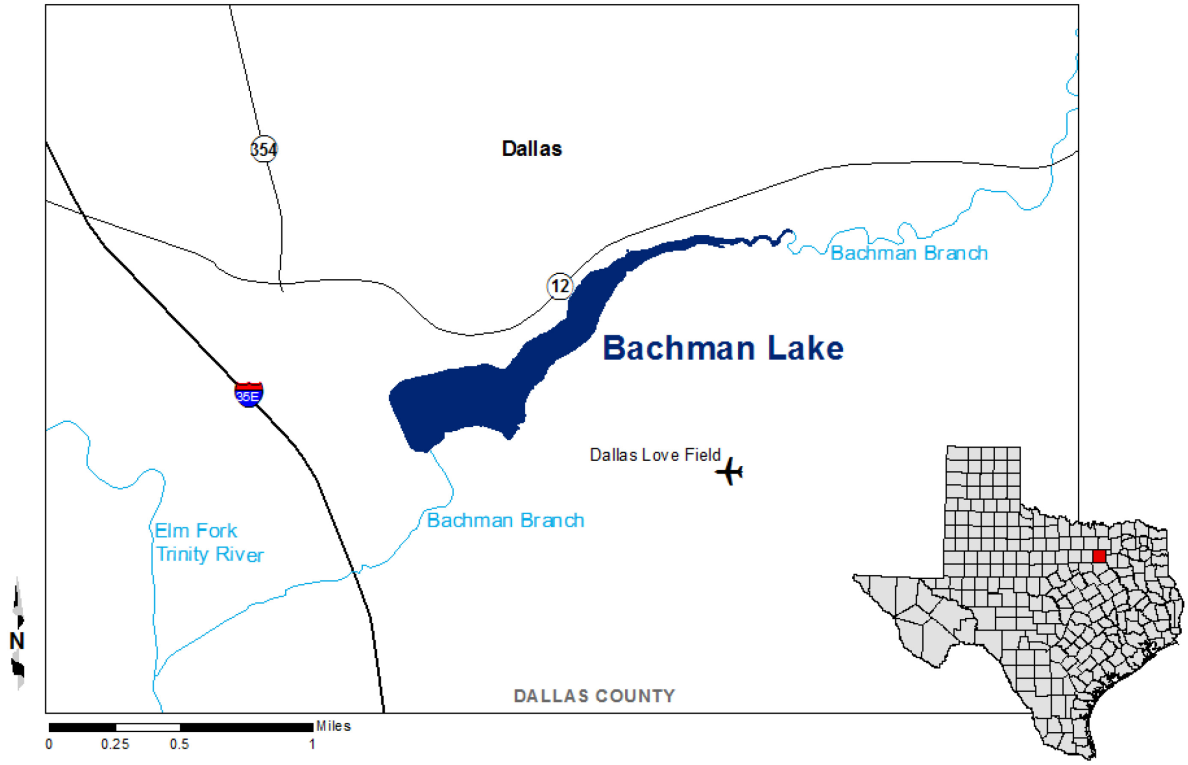


Figure 1. **Location of Bachman Lake**

Volumetric and sedimentation survey of Bachman Lake

Datum

The vertical datum used during this survey is unknown. It is assumed to be equivalent to the National Geodetic Vertical Datum 1929 (NGVD29). Volume and area calculations in this report are referenced to water levels provided by the City of Dallas in feet above mean sea level. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas North Central Zone (feet).

TWDB bathymetric and sedimentation data collection

TWDB collected bathymetric data for Bachman Lake on February 19, 2015, and March 18, 2015. The daily average water surface elevations during the survey measured 438.1 and 438.2 feet above mean sea level (NGVD29), respectively (C. Sanchez, personal communication, May 4, 2015). For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data 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, TWDB selected four locations to collect sediment core samples (Figure 2). The sediment core samples were collected on May 19, 2015, with a custom-coring boat and SDI VibeCore system.

Sediment cores are collected in 3-inch diameter aluminum and/or 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 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. Sediment levels in the clear acrylic tubes were measured before transport back to TWDB headquarters. During this time, some settling of the upper layer can occur.

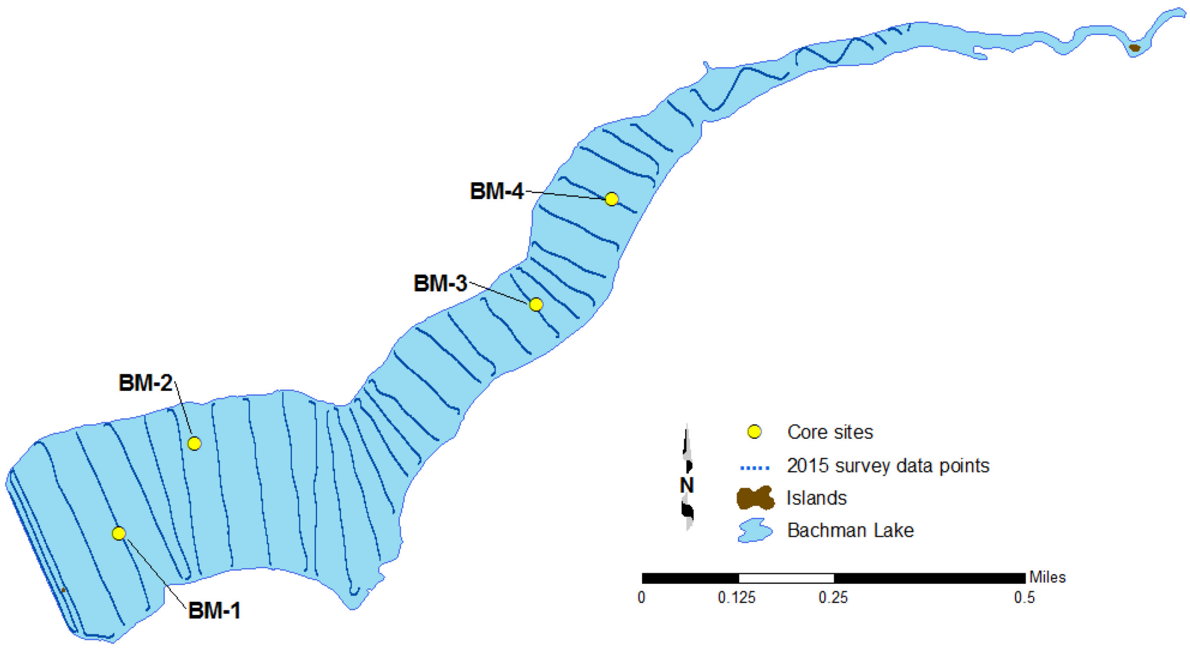


Figure 2. Data collected during 2015 TWDB Bachman Lake survey

Data processing

Model boundaries

The reservoir boundary was digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), obtained from the Texas Natural Resources Information System (TNIRIS, 2015a) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangle that covers Bachman Lake is Dallas NW. The DOQQ was photographed on July 28, 2008, while the daily average water surface elevation measured 438.1 feet above mean sea level (D. Qualls, personal communication, December 9, 2015). According to metadata associated with the 2008 DOQQs, the photographs have a resolution or ground sample distance of 0.5 meter and a horizontal accuracy within 3~5 meters to true ground (TNRIS, 2015b).

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by TWDB were edited to remove data anomalies. The reservoirs 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. TWDB developed an algorithm to automatically determine the pre-impoundment surface, i.e., sediment thickness, based on the intensity of the acoustic returns. Hydropick, software developed in-house and in collaboration with Enthought, Inc. (GitHub, 2015a, GitHub, 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., 2014a). Finally, the point file resulting from spatial interpolation was used in conjunction with sounding and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (ESRI, 1995).

Spatial interpolation of reservoir bathymetry

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

To improve the accuracy of bathymetric representation between survey lines, TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining the survey data, or more robustly by examining scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. For surveys with similar spatial coverage, these interpolation definition files are in principle independent of the survey data and could be applied to past and future survey data of the same reservoir. In practice, however, minor revisions of the interpolation definition files may be needed to account for differences in spatial coverage and boundary conditions between surveys. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing the reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen et al., 2014a) and in McEwen et al., 2014b.

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. The linear interpolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2014a). 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. It is not always possible to remove all flat triangles, and linear interpolation is only applied where adding bathymetry is deemed reasonable.

Figure 3 illustrates typical results from application of the anisotropic interpolation and linear interpolation techniques to Bachman Lake. 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 capacity and area tables (Appendix A, B).

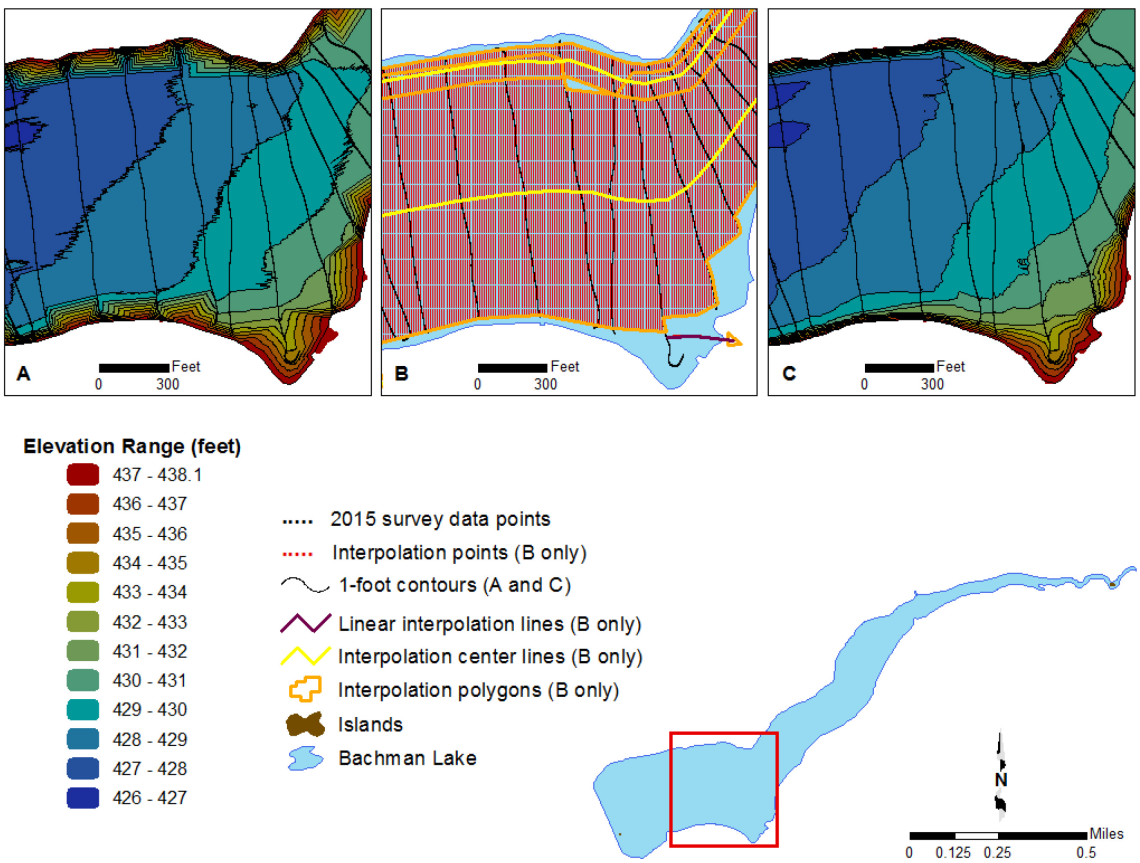


Figure 3. Anisotropic spatial interpolation and linear interpolation of Bachman Lake sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points

Area, volume, and contour calculation

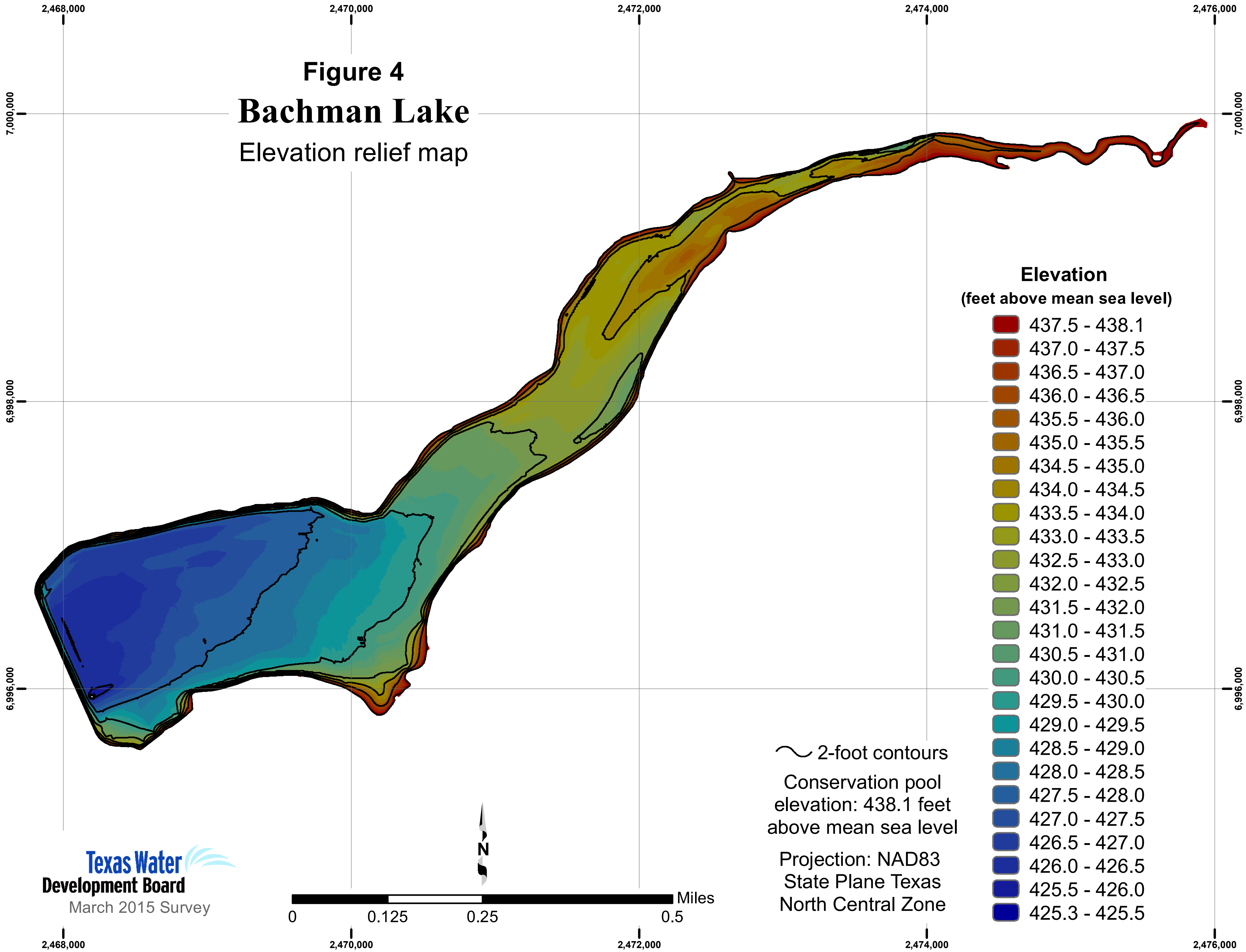
Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1-foot intervals, from 425.2 to 438.1 feet. The elevation-capacity table and elevation-area table, updated for 2015, are presented in Appendices A and B, respectively. The capacity curve is presented in Appendix C, and the area curve is presented in Appendix D.

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

Figure 4

Bachman Lake

Elevation relief map



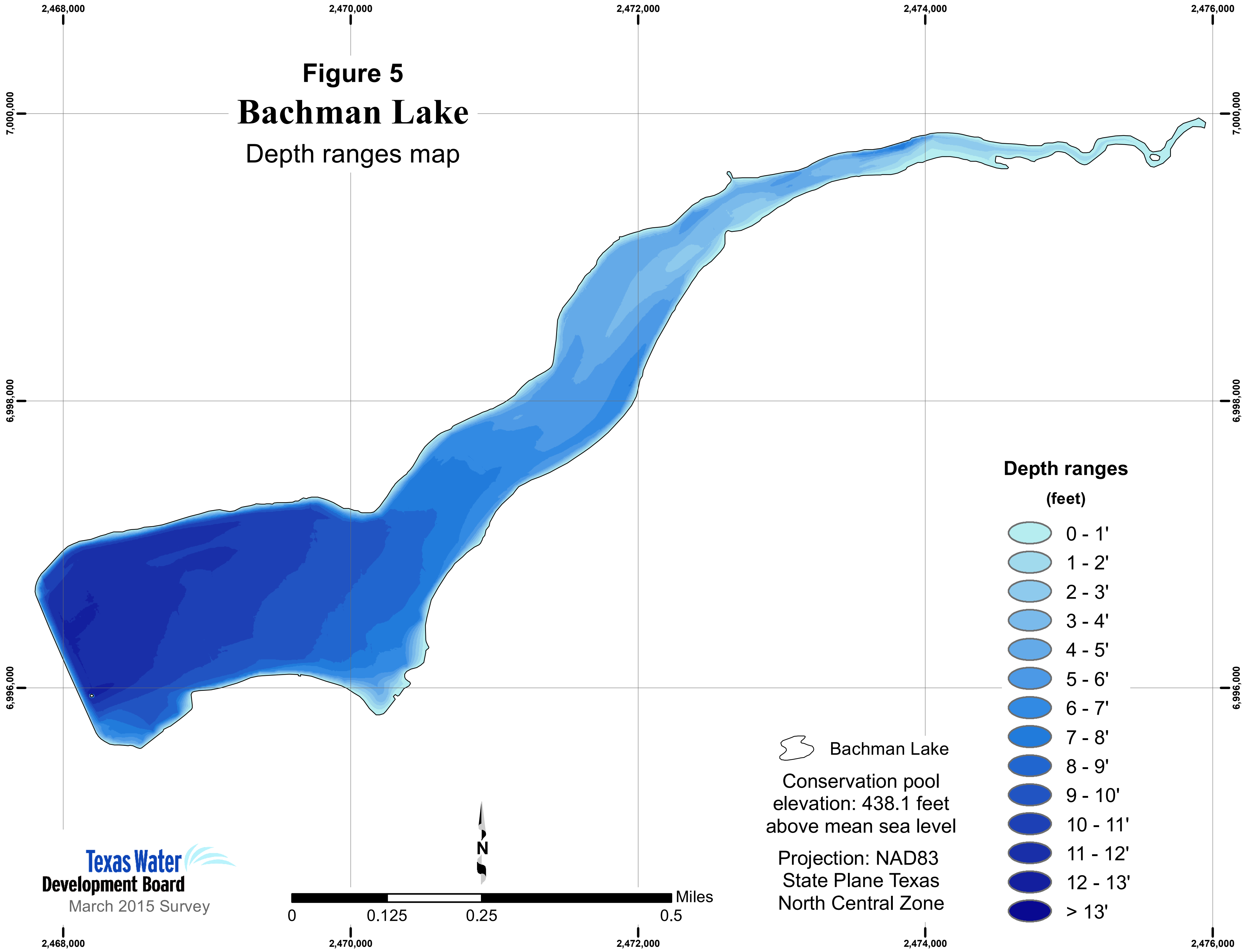


Figure 5
Bachman Lake
Depth ranges map
2,468,000
2,470,000
2,472,000
2,474,000
2,476,000
7,000,000
6,998,000
6,996,000
Depth ranges
(feet)
0 - 1'
1 - 2'
2 - 3'
3 - 4'
4 - 5'
5 - 6'
6 - 7'
7 - 8'
8 - 9'
9 - 10'
10 - 11'
11 - 12'
12 - 13'
> 13'
Bachman Lake
Conservation pool elevation: 438.1 feet above mean sea level
Projection: NAD83 State Plane Texas North Central Zone
N
Miles
0
0.125
0.25
0.5
Texas Water Development Board
March 2015 Survey

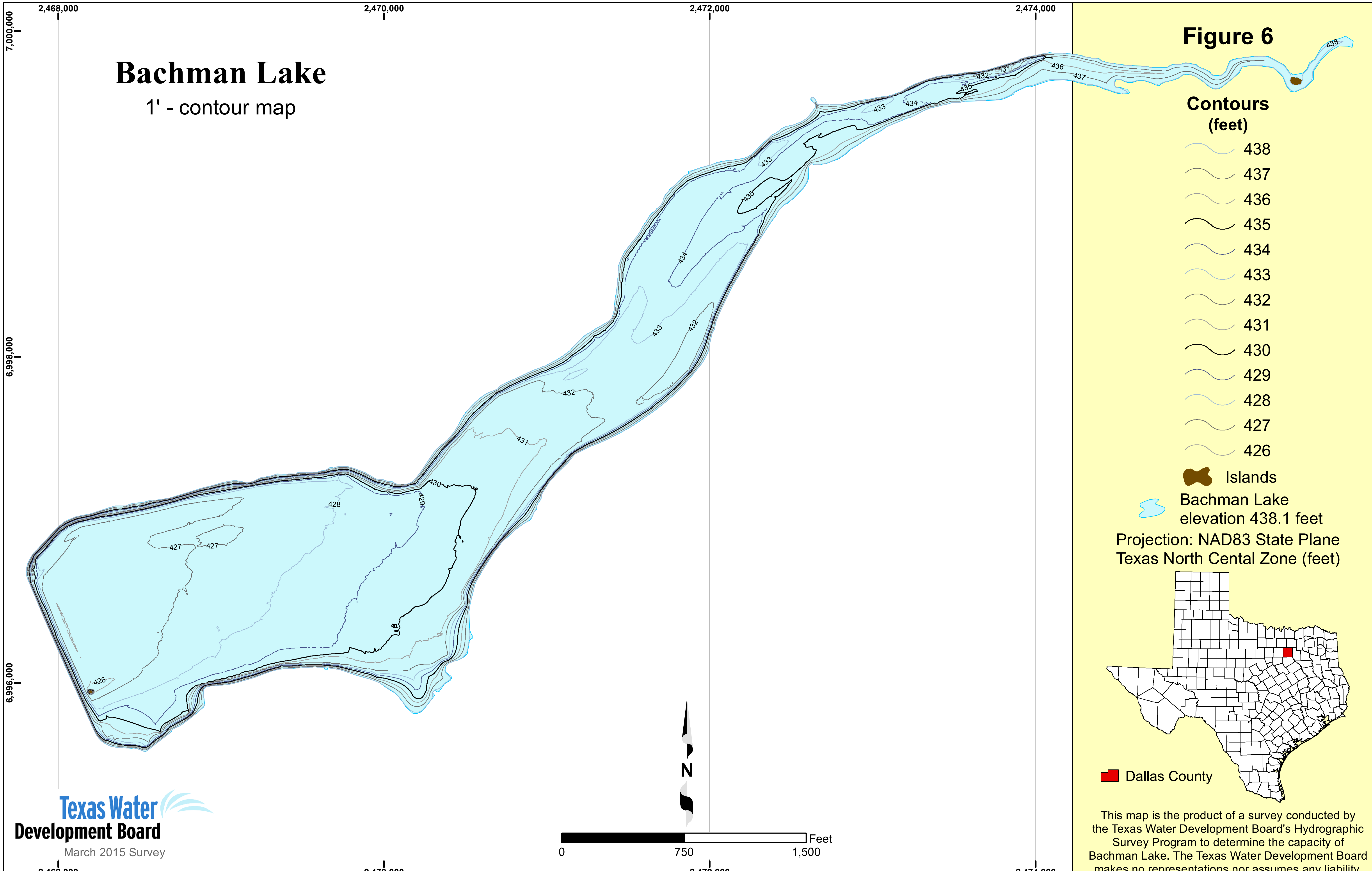


Figure 6
Bachman Lake
1' - contour map
Contours
(feet)
438
437
436
435
434
433
432
431
430
429
428
427
426
Islands
Bachman Lake
elevation 438.1 feet
Projection: NAD83 State Plane
Texas North Cental Zone (feet)
Dallas County
This map is the product of a survey conducted by
the Texas Water Development Board's Hydrographic
Survey Program to determine the capacity of
Bachman Lake. The Texas Water Development Board
makes no representations nor assumes any liability.
N
0
750
1,500
Feet
Texas Water
Development Board
March 2015 Survey
2,468,000
2,470,000
2,472,000
2,474,000
7,000,000
6,998,000
6,996,000

Analysis of sediment data from Bachman Lake

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

Table 1. Sediment core sampling analysis data - Bachman Lake

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
BM-1	2468586.20	6996334.97	120.0"/ N/A	0-23.0" high water content, silty loam	GLEY1 3/10Y
				23.0-106.0" high water content, more dense, additional layers visible at 36" and 58", pre-impoundment possible at either depth	GLEY1 2.5/5GY
				106.0-120.0" high density, no organic matter, loamy clay with clay pockets	GLEY1 2.5/10Y
BM-2	2469105.80	6996953.54	24.0"/20.0"	0-5.5" high water content, silty loam	5Y 3/1
				5.5-12.0" high water content, very dense, organic material (large shell, small twigs)	5Y 2.5/1
				12.0-15.0" high water content, very dense, high in organic matter (small twigs), sandy loam	5Y 3/2
				15.0-20.0" high water content, less dense, tiny organic matter, sandy loam	5Y 3/1
				20.0-24.0" dense, small organic matter present, clay loam	5Y 2.5/1
BM-3	2471467.29	6997915.53	40.5"/37.5"	0-23.0" very high water content, small organics present, silty loam	5Y 2.5/1
				23.0-32.5" high water content, dense, silty clay loam	GLEY1 2.5/5GY
				32.5-37.5" high density, small dry clay pieces, silty clay loam	GLEY1 3/5GY
				37.5-40.5" dense, clay	GLEY1 3/10Y
BM-4	2471991.45	6998642.54	29.0"/26.0"	0-18.5" high water content, organic matter present (twigs, leaves), sandy loam	GLEY1 2.5/10Y
				18.5-26.0" high water content, little organic matter, sandy loam	GLEY1 2.5/5GY
				26.0-29.0" dense, high organic matter content, clay	GLEY1 3/10Y

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

A photograph of sediment core BM-2 is shown in Figure 7 and is representative of the sediment cores sampled from Bachman Lake. 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 20.0 inches and identified by the change in color, texture, moisture, porosity, and structure. Identification of the pre-impoundment surface for the remaining sediment cores followed a similar procedure.

Figure 7. Sediment core BM-2 from Bachman Lake

Figure 8 and 9 illustrate how measurements from sediment core samples are used with sonar data to help identify the interface between the post- and pre-impoundment layers in the acoustic signal.

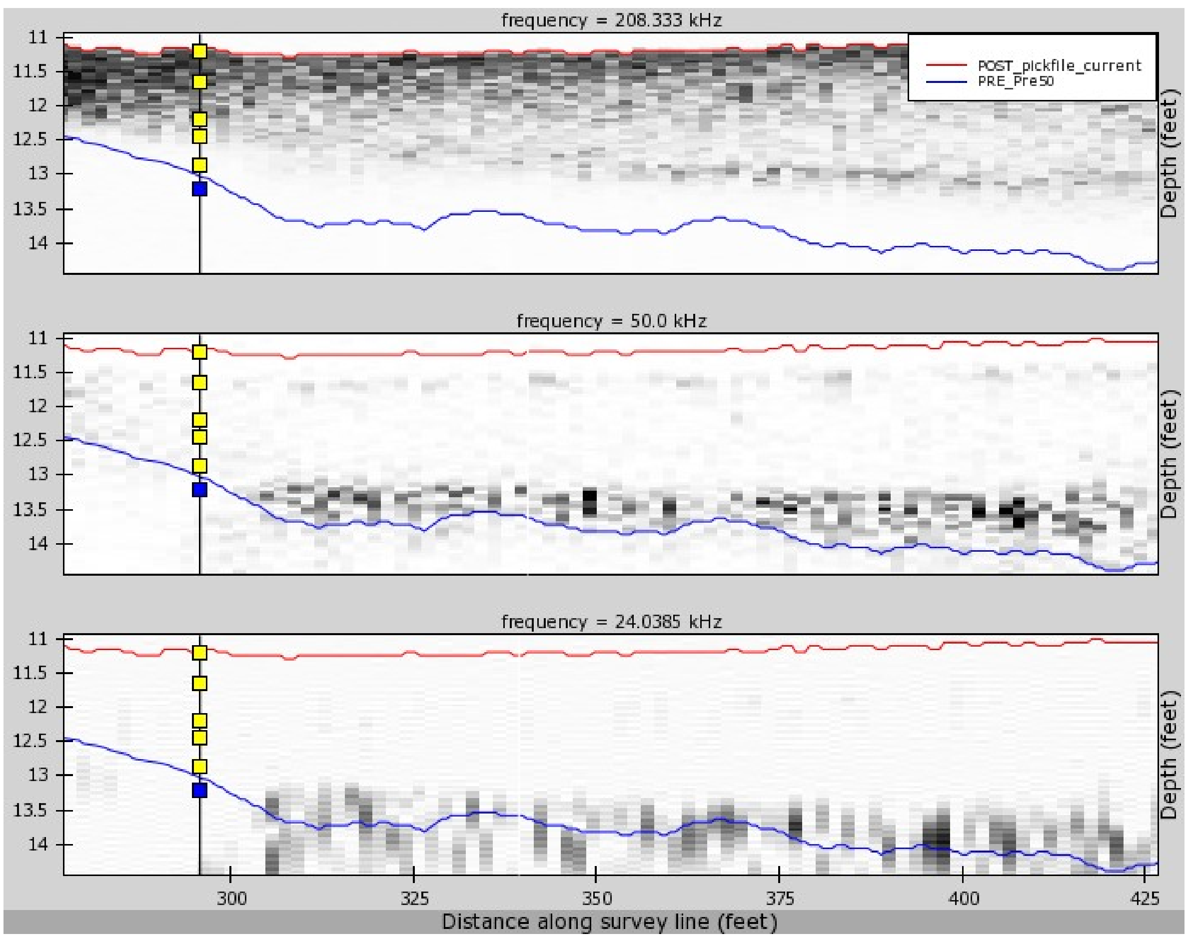


Figure 8. Comparison of sediment core BM-2 with acoustic signal returns

Figure 8 compares sediment core sample BM-2 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 and represented by the top red line in Figure 8.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 layer of sediment identified in the sediment core sample during analysis (Table 1) is represented by a yellow or blue box. The yellow boxes represent post-impoundment sediment. The blue box marks the bottom of the sediment core sample and indicates that pre-impoundment sediment was identified in the final layer.

In this case the boundary in the 50 kHz signal most closely matched the pre-impoundment interface of the sediment core samples; therefore, the 50 kHz signal was used to locate the pre-impoundment surface (blue line in Figure 8). Figure 9 shows sediment core sample BM-2 correlated with the 50 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 and used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

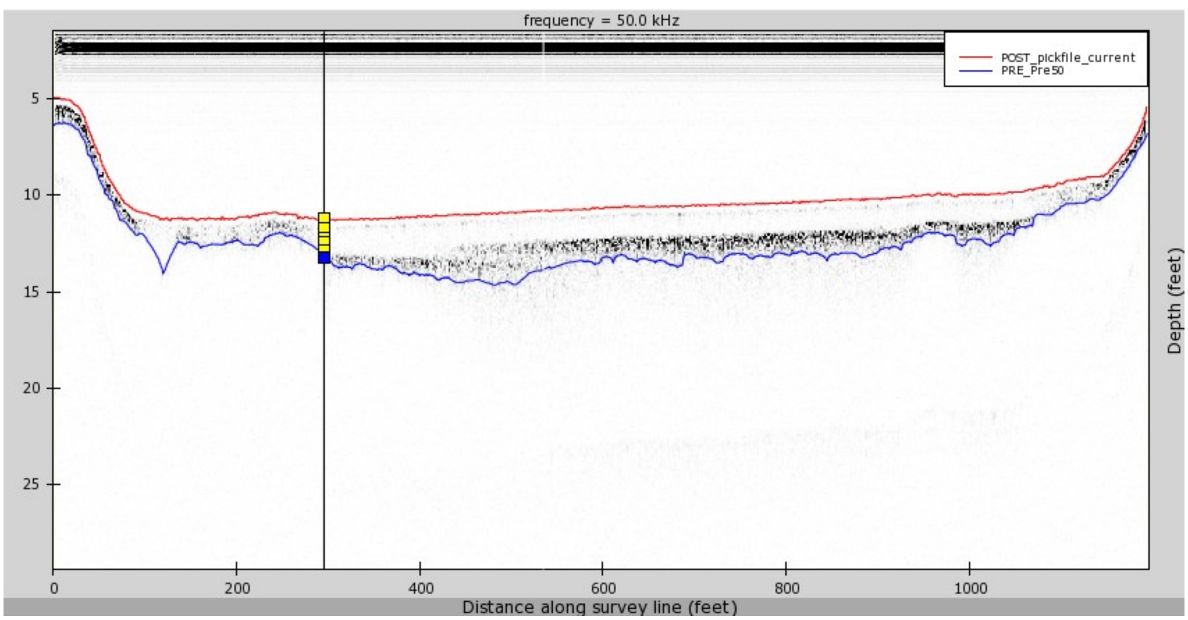
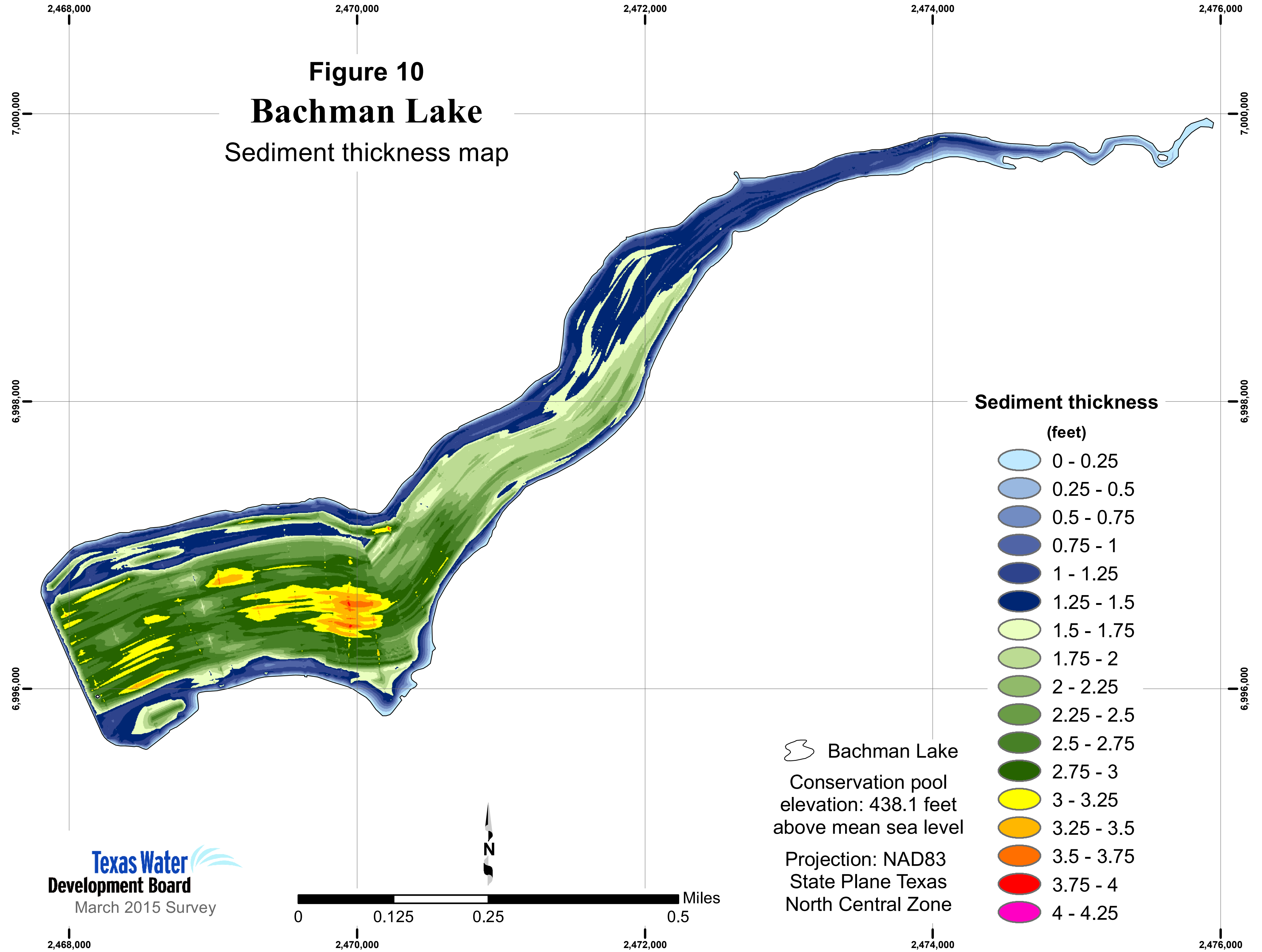


Figure 9. Cross-section of data collected during survey, displayed in Hydropick (50 kHz frequency), correlated with sediment core sample BM-2 and showing the current surface in red and pre-impoundment surface in blue

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 identified as the bottom black/white interface (where black is the sediment layer) of the resulting binary image (D. Pothina, personal communication, October 2, 2014). The pre-impoundment surface is then 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 the TIN model creation, TWDB assumed sediment thickness at the reservoir boundary was zero feet (defined as the 438.1 foot elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 1 foot by 1 foot and used to produce a sediment thickness map of Bachman Lake (Figure 10).

Figure 10
Bachman Lake
Sediment thickness map



Survey results

Volumetric survey

The results of the 2015 TWDB volumetric survey indicate Bachman Lake has a total reservoir capacity of 959 acre-feet and encompasses 132 acres at conservation pool elevation (438.1 feet above mean sea level, NGVD29). According to Certificate of Adjudication No. 08-2457, the City of Dallas is authorized to impound a maximum of 2,302 acre-feet of water in Bachman Lake. Because of differences in past and present survey methodologies, and dredging since the lake was built, direct comparison of these values to estimate loss of capacity is difficult and can be unreliable.

Sedimentation survey

The 2015 TWDB sedimentation survey measured 244 acre-feet of sediment below conservation pool elevation (438.1 feet NGVD29). Because Bachman Lake was dredged in 1975 and again in 2003 (DBJ, 2007), a reliable sedimentation rate could not be calculated. Sediment accumulation varies throughout the reservoir with the heaviest deposits north of the cove between the Bachman Water Treatment Plant and Dallas Love Field Airport approximately 1,500 feet northeast of the spillway.

Recommendations

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

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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Manager, TWDB Hydrographic Survey Program
Phone: (512) 463-2456
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Appendix A

Bachman Lake

RESERVOIR CAPACITY TABLE

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

March 2015 Survey
Conservation Pool Elevation 438.1 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
425	0	0	0	0	0	0	0	0	0	0
426	0	0	0	1	1	2	3	4	5	6
427	8	10	12	14	16	19	21	24	27	31
428	34	38	41	45	49	54	58	63	67	72
429	77	82	88	93	98	104	110	115	121	127
430	133	140	146	152	159	166	172	179	186	193
431	200	208	215	223	230	238	246	254	262	270
432	278	287	295	304	312	321	330	339	348	358
433	367	377	386	396	406	415	425	435	446	456
434	467	478	488	499	510	521	533	544	555	566
435	578	589	601	613	624	636	648	660	672	684
436	696	708	720	732	744	756	768	781	793	805
437	818	830	843	856	868	881	894	907	920	933
438	946	959								

Appendix B

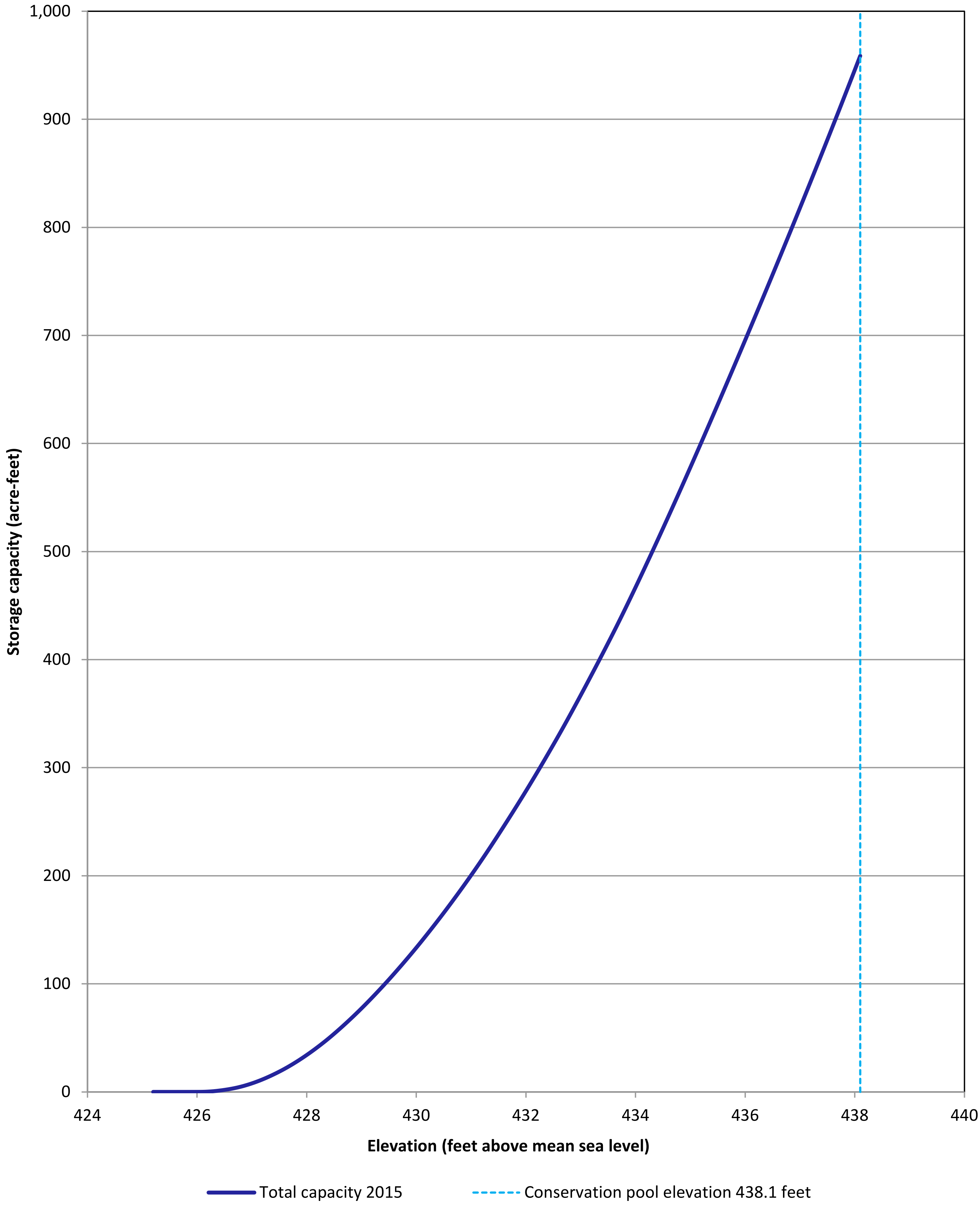
Bachman Lake

RESERVOIR AREA TABLE

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

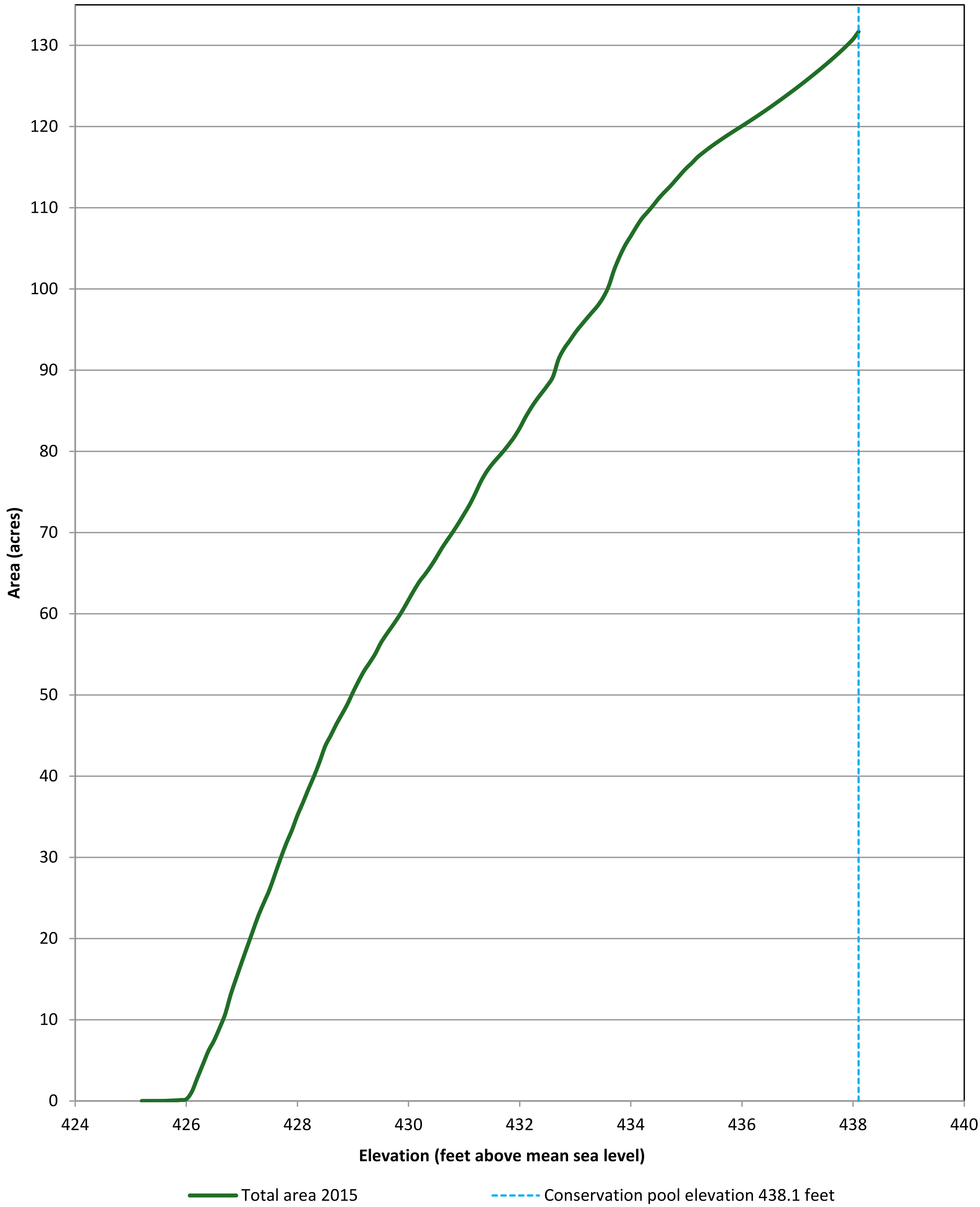
March 2015 Survey
Conservation Pool Elevation 438.1 feet NGVD29

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
425	0	0	0	0	0	0	0	0	0	0
426	0	1	3	5	6	7	9	11	13	15
427	17	19	21	23	24	26	28	30	32	33
428	35	37	38	40	42	44	45	46	48	49
429	50	52	53	54	55	56	57	58	59	60
430	62	63	64	65	66	67	68	69	70	71
431	72	73	75	76	77	78	79	80	81	82
432	83	84	85	86	87	88	89	91	93	94
433	95	95	96	97	98	99	100	102	104	105
434	107	108	109	109	110	111	112	113	113	114
435	115	116	116	117	117	118	118	119	119	120
436	120	121	121	121	122	122	123	123	124	124
437	125	125	126	126	127	128	128	129	129	130
438	131	132								



Bachman Lake
March 2015 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Bachman Lake
March 2015 Survey
Prepared by: TWDB

Appendix D: Area curve