Volumetric Survey
of
LAKE KICKAPOO

September 2013 Survey

Texas Water Development Board

February 2014

Texas Water Development Board

Prepared for:

City of Wichita Falls, Texas

With Support Provided by:

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

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Executive summary

In December 2012, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District to perform a volumetric survey of Lake Kickapoo. The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the City of Wichita Falls provided the remaining 50%. Surveying was performed using a multi-frequency (200 kHz, 50 kHz, and 24 kHz), sub-bottom profiling depth sounder, although only the 200 kHz frequency was analyzed for this report.

Lake Kickapoo Dam and Lake Kickapoo are located on the North Fork Little Wichita River in Archer County, approximately 10 miles northwest of Archer City, Texas. The conservation pool elevation of Lake Kickapoo is 1,045.0 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Lake Kickapoo between July 10, 2013, and September 25, 2013. The daily average water surface elevation during the survey ranged between 1,032.78 and 1,032.89 feet above mean sea level.

The 2013 TWDB volumetric survey indicates that Lake Kickapoo has a total reservoir capacity of 86,345 acre-feet and encompasses 5,864 acres at conservation pool elevation (1,045.0 feet above mean sea level, NGVD29). Previous capacity estimates include the original design capacity of 106,000 acre-feet, and the volume obtained from a TWDB survey in 2001. The TWDB volumetric survey conducted in 2001 was re-evaluated using current processing procedures that resulted in an updated capacity estimate of 87,050 acre-feet.

TWDB recommends that a similar methodology be used to resurvey Lake Kickapoo in 10 years or after a major flood event. To further improve estimates of capacity loss, TWDB recommends a volumetric and sedimentation survey. Sedimentation surveys include additional analysis of the multi-frequency data for post-impoundment sediment by correlation with sediment core samples and a map identifying the spatial distribution of sediment throughout the reservoir.

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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 December 2012, 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 Kickapoo (TWDB, 2012). The U.S. Army Corps of Engineers, Fort Worth District, provided 50% of the funding for this survey through their Planning Assistance to States Program, while the City of Wichita Falls provided the remaining 50%. This report describes the methods used to conduct the volumetric survey, including data collection and processing techniques. This report serves as the final contract deliverable from TWDB to the City of Wichita Falls and the U.S. Army Corps of Engineers, Fort Worth District, and contains as deliverables: (1) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality [Appendix A, B], (2) a bottom contour map [Figure 6], and (3) a shaded relief plot of the reservoir bottom [Figure 4].

Lake Kickapoo general information

Lake Kickapoo Dam and Lake Kickapoo are located on the North Fork Little Wichita River in Archer County, approximately 10 miles northwest of Archer City, Texas (Figure 1). The construction of Lake Kickapoo Dam began in January 1945. Deliberate impoundment of water began on February 1, 1946, and the dam was completed in December 15, 1945 (TWDB, 1974). Lake Kickapoo is owned and operated by the City of Wichita Falls (TWDB, 1974).

Lake Kickapoo is a water supply reservoir, providing water primarily for municipal and industrial purposes to the City of Wichita Falls. Additional pertinent data about Lake Kickapoo Dam and Lake Kickapoo can be found in Table 1.

Water rights for Lake Kickapoo have been appropriated to the City of Wichita Falls through Certificate of Adjudication No. 02-5144 and Amendments to Certificate of Adjudication Nos. 02-5144A and 02-5144B. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

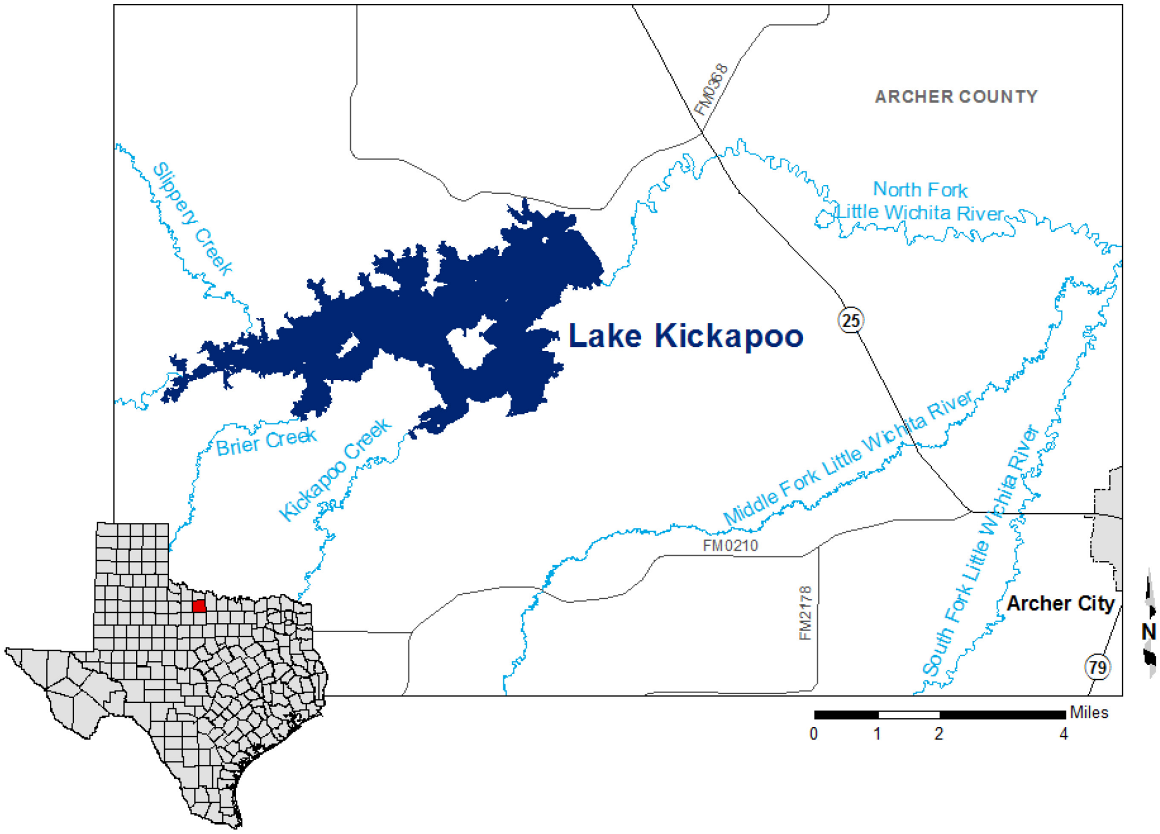


Figure 1. Location of Lake Kickapoo

Table 1. Pertinent data for Lake Kickapoo Dam and Lake Kickapoo

Owner	
City of Wichita Falls	
Engineer (Design)	
F.M. Rugeley	
A.J. Gates	
Location of dam	
On the North Fork Little Wichita River in Archer Country, 10 miles northwest of Archer City, Texas	
Drainage area	
275 square miles	
Dam	
Type	Earthfill
Length (including spillway)	8,200 feet
Maximum height	62 feet
Top width	16 feet
Spillway	
Type	Concrete ogee
Control	None
Crest elevation	1,045.0 feet above mean sea level
Crest length	483± feet
Outlet works	
Type	Tower and two 4 by 5-foot concrete conduits
Control	Sluice gate
Invert of outlets	1,000.92 feet above mean sea level
Purpose	1 conduit for water supply, 1 conduit for stream flow control

Reservoir data (Based on 2013 TWDB survey)

Feature	**Elevation (feet** NGVD29[a]**)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	1,062.0 and 1,059.0	N/A	N/A
Maximum design flood stage	1,060.0	N/A	N/A
Crest of spillway/ Conservation pool elevation	1,045.0	86,345	5,864
Invert of outlets/ Dead pool elevation	1,000.92	0	0
Usable conservation storage space[b]	-	86,345	-

Source: (TWDB, 1974)

[a] NGVD29 = National Geodetic Vertical Datum 1929

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

Volumetric survey of Lake Kickapoo

Datum

The vertical datum used during this survey is the National Geodetic Vertical Datum 1929 (NGVD29). This datum is also utilized by the United States Geological Survey (USGS) for the reservoir elevation gage *USGS 07314000 Lk Kickapoo nr Archer City, TX* (USGS, 2013). Elevations herein are reported in feet relative to the NGVD29 datum. Volume and area calculations in this report are referenced to water levels provided by the USGS gage. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas North Central Zone (feet).

TWDB bathymetric data collection

TWDB collected bathymetric data for Lake Kickapoo on July 10-11, 2013, July 16, 2013, and September 25, 2013. The daily average water surface elevations during the survey measured 1,032.89, 1,032.88, 1,032.80, and 1,032.78 feet above mean sea level (NGVD29), respectively. For data collection, TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data was collected along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. Many of the same survey lines were also used by TWDB during the 2001 survey. The depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification.

Due to continuous drought conditions in the region and low lake levels, TWDB also collected terrestrial elevation measurements in the upper reaches of Lake Kickapoo on September 10 and 12, 2013. The daily average water surface elevations during the survey measured 1,032.44 and 1,032.39 feet above mean sea level (NGVD29), respectively. 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 and bicycle mounts) and singular 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 2013 TWDB survey.

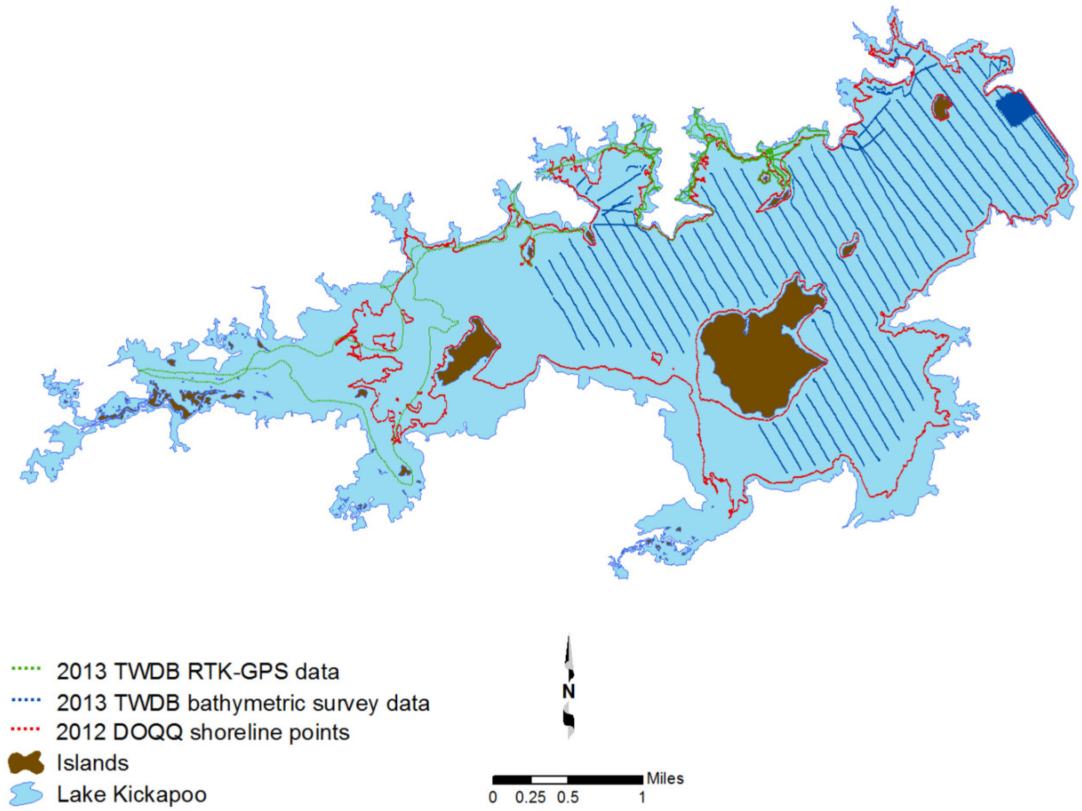


Figure 2. Data collected during 2013 TWDB Lake Kickapoo survey

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, 2013) using Environmental Systems Research Institute's ArcGIS software. The quarter-quadrangles that cover Lake Kickapoo are Lake Kickapoo (SW, SE), Dundee SE (NW, NE), and Dundee (SE). The DOQQs were photographed on July 19, 2010, and August 2, 2010, while the daily average water surface elevation measured 1,044.76 and 1,044.34 feet (NGVD29), respectively. 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 (TNRIS, 2010, USDA, 2013). For this analysis, the boundary was digitized at the land-water interface in the 2010 photographs and assigned an elevation of 1,045.0 feet to facilitate calculating the area-capacity tables up to the conservation pool elevation. Additional boundary information was obtained from aerial photographs taken on July 6, 2012, while the daily average water surface elevation measured 1,035.53 feet. The 2012 boundary information was added to the lake model as points. According to metadata associated with the 2012 DOQQs, the photographs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy within ±6 meters to true ground (TNRIS, 2012, USDA, 2013).

RTK-GPS post-processing

Data collected using the Trimble® GPS system was downloaded from each rover's data controller (by day) and post-processed using the Trimble® Business Center (Version 3.1) software. Post-processing entails confirming project settings (e.g. vertical and horizontal datum, horizontal coordinate system) and tying the base station coordinates to Continuously Operating Reference Stations (CORS) sites to improve the precision of the project data from each rover. CORS sites are maintained by the National Geodetic Survey (NGS), an office of the National Oceanographic and Atmospheric Administration's (NOAA) National Ocean Service (NGS, 2014a). To make the RTK-GPS data compatible with the bathymetric survey data, it was necessary to transform the data from vertical datum NAVD88 to NGVD29. Vertical coordinate transformations were done by applying a single vertical offset to all RTK-GPS data. The offset was determined by applying the National Oceanic and Atmospheric Administration National Geodetic Survey's VERTCON software (NGS, 2014b) to a single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 07314000 Lk Kickapoo nr Archer City, TX, of Latitude 33º39'47", Longitude 98º46'43" NAD27.* The resulting conversion factor of 0.315 feet was subtracted from all RTK-GPS data elevations to obtain the transformed vertical elevations.

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by TWDB were edited to remove data anomalies. DepthPic©, software developed by SDI, Inc., is used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface and in the case of a sedimentation survey, 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, if applicable, and output the data into a single file. The water surface elevation at the time of each sounding was used to convert each sounding depth to a corresponding reservoir-bottom elevation.

This survey point dataset is then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points are determined using an anisotropic spatial interpolation algorithm described in the next section. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen et al., 2011a). Finally, the point file resulting from spatial interpolation is used in conjunction with sounding and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (ESRI, 1995).

Spatial interpolation of reservoir bathymetry

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

To improve the accuracy of bathymetric representation between survey lines, TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining survey data or more robustly by examining scanned USGS 7.5 minute quadrangle maps (known as digital raster graphics or DRGs) and hypsography files (the vector format of USGS 7.5 minute quadrangle map contours), when available. In the case of Lake Kickapoo, the channel sinuosity was modeled based on a USGS 15 minute quadrangle map (Dundee Quadrangle) dated 1932. 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, when applicable, 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 the volumetric TIN model representing the reservoir bathymetry Specific details of this interpolation technique can be found in the HydroTools manual (McEwen et al., 2011a) and in McEwen et al., 2011b.

In areas inaccessible to survey data collection such as small coves and shallow upstream areas of the reservoir, linear extrapolation is used for volumetric The linear extrapolation follows a linear definition file linking the survey points file to the lake boundary file (McEwen et al., 2011a). Without extrapolated data, the TIN Model builds flat triangles. A flat triangle is defined as a triangle where all three vertices are equal in elevation, generally the elevation of the reservoir boundary. Reducing flat triangles by applying linear extrapolation improves the elevation-capacity and elevation-area calculations. It is not always possible to remove all flat triangles, and linear extrapolation is only applied where adding bathymetry is deemed reasonable. For example, linear extrapolation was deemed reasonable and applied to Lake Kickapoo in the following situations: in small coves and throughout the main body of the reservoir using the historical USGS 15 minute quadrangle map channels, 2001 survey data, and aerial photographs taken on July 6, 2012, as guidance.

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

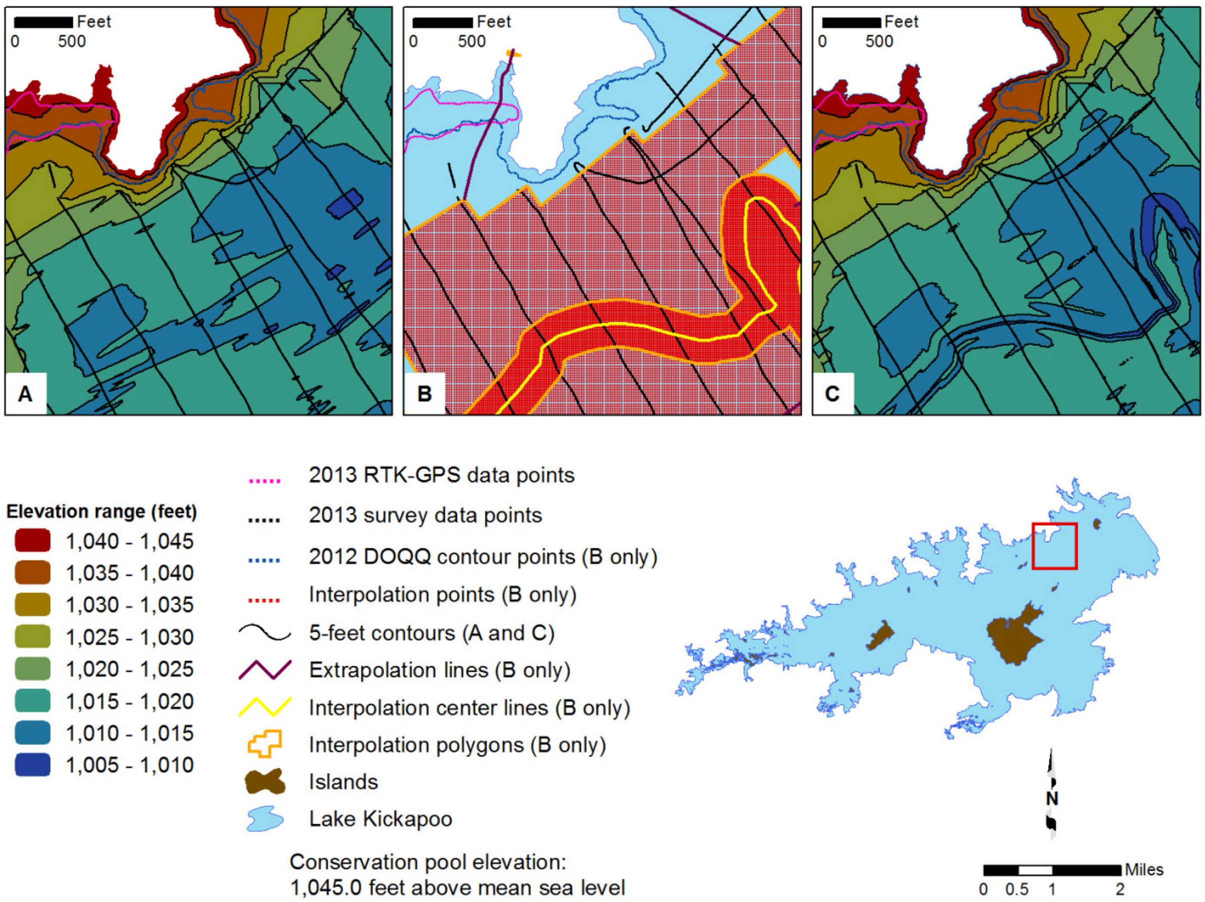
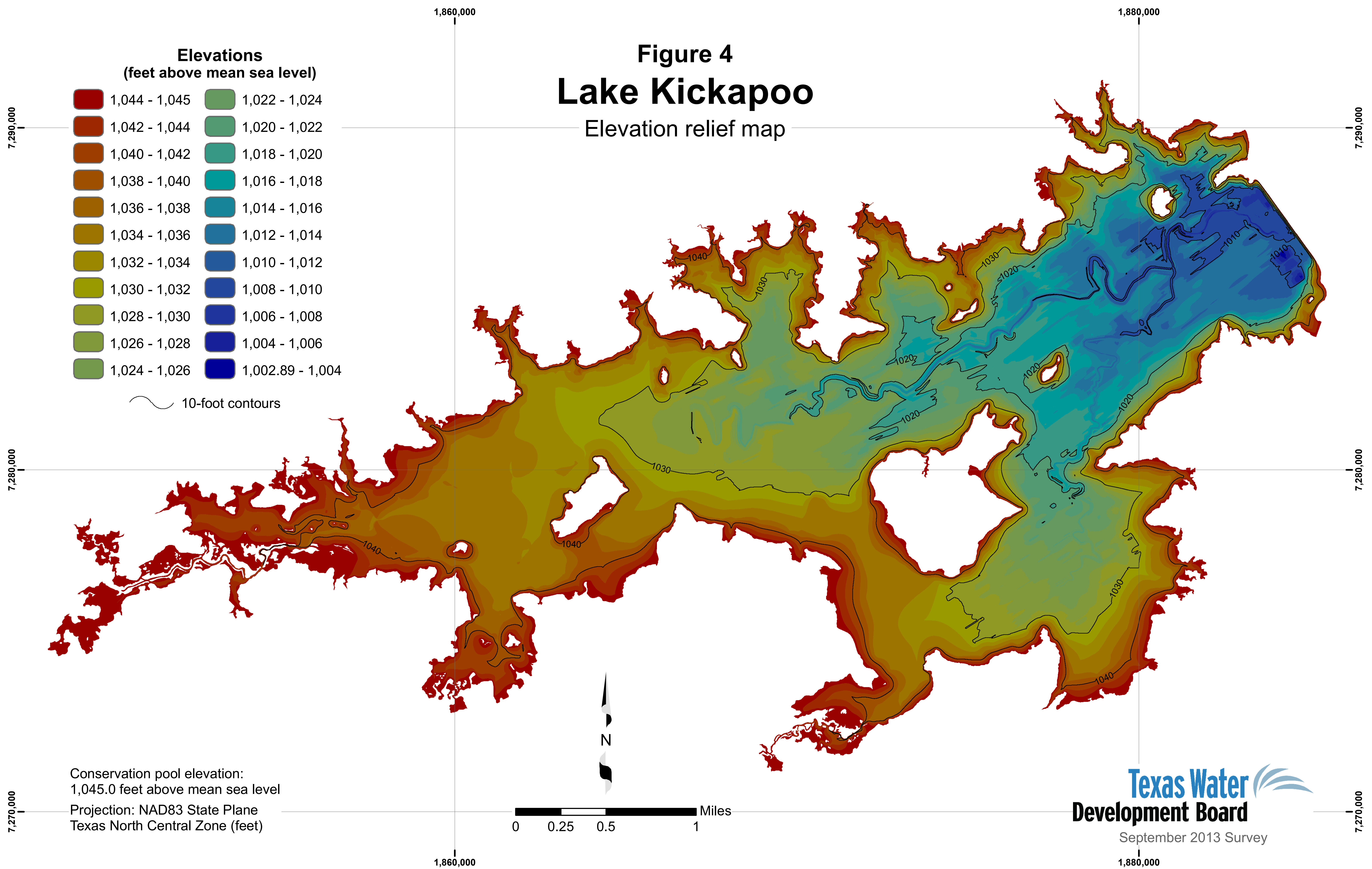


Figure 3. Anisotropic spatial interpolation and linear extrapolation of Lake Kickapoo sounding data - A) bathymetric contours without interpolated points, B) sounding points (black) and interpolated points (red), C) bathymetric contours with the interpolated points

Area, volume, and contour calculation

Using ArcInfo software and the volumetric TIN model, volumes and areas were calculated for the entire reservoir at 0.1 feet intervals, from 1,002.8 to 1,045.0 feet. The use of contour data from the 2012 DOQQs and RTK-GPS data helped provide otherwise unavailable topographic data in areas that were inaccessible by boat or too shallow for the instruments to work properly. However, the TIN models developed in these areas led to the creation of anomalous "flat triangles", that is triangles whose three vertices all have the same elevation. The flat triangles in turn lead to anomalous calculations of surface area and volume at the boundary elevations, 1,035.53 feet and 1,045.0 feet. To eliminate the effects of the flat triangles on area and volume calculations, areas between elevations 1,035.0 feet and 1,045.0 feet were linearly interpolated between the computed values, and volumes above elevation 1,035.0 were calculated based on the corrected areas. The elevation-capacity table and elevation-area table, updated for 2012, are presented in Appendices A and B, respectively. The capacity curve is presented in Appendix C, and the area curve is presented in Appendix D.

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



1,860,000
1,880,000
7,290,000
7,280,000
7,270,000
Figure 4
Lake Kickapoo
Elevation relief map
Elevations
(feet above mean sea level)
1,044 - 1,045
1,042 - 1,044
1,040 - 1,042
1,038 - 1,040
1,036 - 1,038
1,034 - 1,036
1,032 - 1,034
1,030 - 1,032
1,028 - 1,030
1,026 - 1,028
1,024 - 1,026
1,022 - 1,024
1,020 - 1,022
1,018 - 1,020
1,016 - 1,018
1,014 - 1,016
1,012 - 1,014
1,010 - 1,012
1,008 - 1,010
1,006 - 1,008
1,004 - 1,006
1,002.89 - 1,004
10-foot contours
1040
1030
1020
1010
N
0
0.25
0.5
1
Miles
Conservation pool elevation:
1,045.0 feet above mean sea level
Projection: NAD83 State Plane
Texas North Central Zone (feet)
Texas Water Development Board
September 2013 Survey

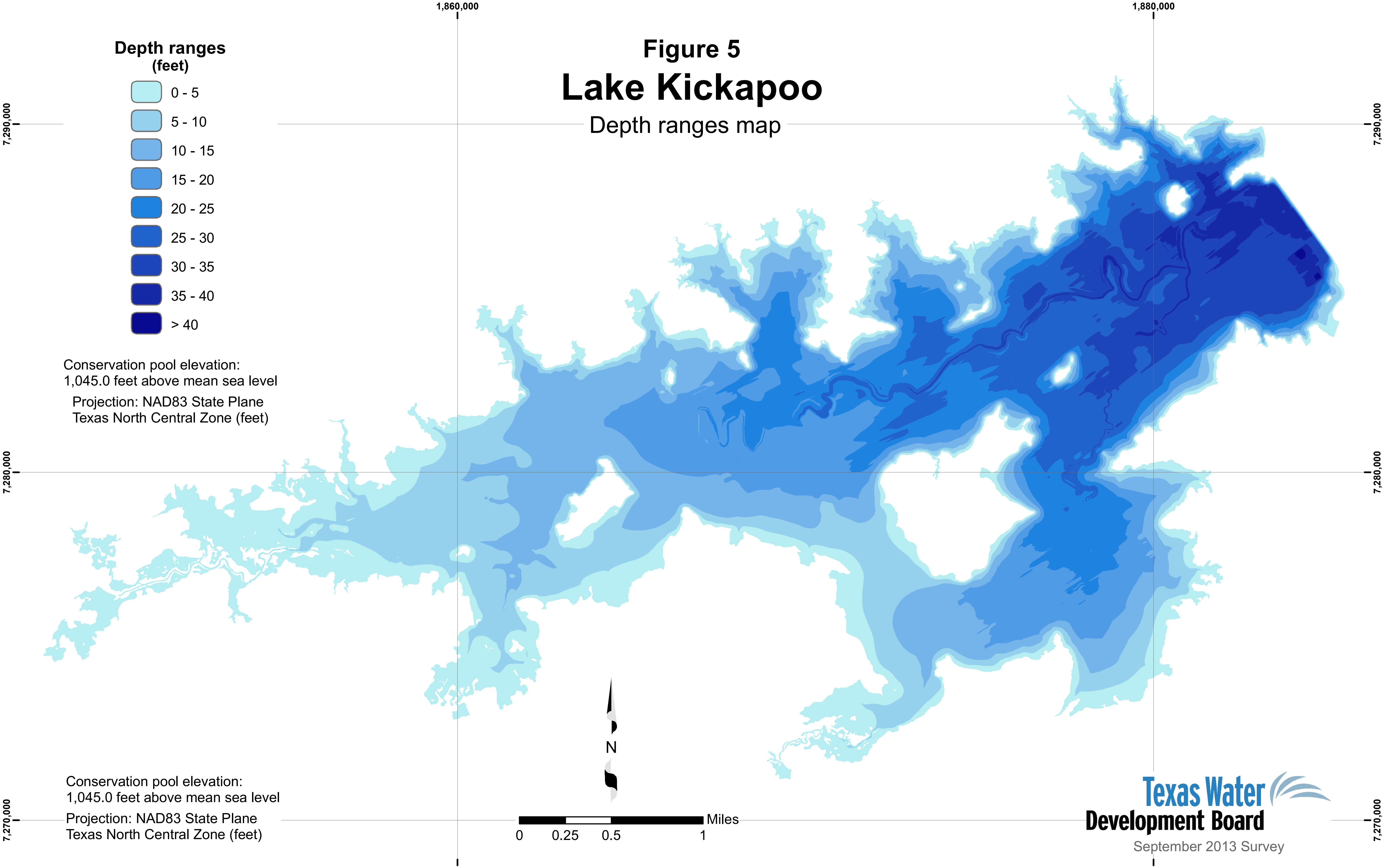


Figure 5
Lake Kickapoo
Depth ranges map

Survey results

Volumetric survey

The results of the 2013 TWDB volumetric survey indicate Lake Kickapoo has a total reservoir capacity of 86,345 acre-feet and encompasses 5,864 acres at conservation pool elevation (926.0 feet above mean sea level, NGVD29). Previous capacity estimates include the original design capacity of 106,000 acre-feet, and the volume obtained from a TWDB survey in 2001. 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.

To properly compare results of TWDB surveys, TWDB applied the 2013 data processing techniques to the data collected in 2001. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 2001 using the same interpolation definition file as was used for the 2013 survey with minor edits to account for differences in data coverage and boundary conditions. The 2001 survey boundary at conservation pool elevation was digitized from the digital USGS 7.5 minute quadrangle maps, or DRGs. The USGS quadrangle maps have a stated accuracy of ± ½ the contour interval (USBB, 1947). Re-evaluation of the 2001 survey resulted in a 1.4 percent increase in the total capacity estimate (Table 2). Comparison of capacity estimates of Lake Kickapoo derived using differing methodologies are provided in Table 3 for sedimentation rate calculation.

Table 2. Current and previous survey capacity and surface area data

Survey	Surface area (acres)	Total capacity (acre-feet)
1945[a]	6,200	106,000
TWDB 2001[b]	6,028	85,825
TWDB 2001 (re-calculated)	6,028	87,050
TWDB 2013	5,864	86,345

[a] Source: (TWDB, 1974)
[b] Source: (TWDB, 2001)

Table 3. Capacity loss comparisons for Lake Kickapoo

Survey	Volume comparisons at conservation pool elevation (acre-feet)	
1945[a]	106,000	<>
TWDB 2001 (re-calculated)	<>	87,050
2013 volumetric survey	86,345	86,345
Volume difference (acre-feet)	19,655 (18.5%)	705 (0.8%)
Number of years	67	12
Capacity loss rate (acre-feet/year)	293	59

[a] Source: (TWDB, 1974). Note: Impoundment of Lake Kickapoo began on February 1, 1946, and the dam was completed in December 15, 1945.

Intake structure

Survey data was collected around the intake structure following planned survey lines oriented parallel to and perpendicular to the intake structure and dam in a 50-foot grid pattern extending approximately 500 feet to the east and west of the intake structure and 1,000 feet southwest of the dam. The structure is located at approximately Latitude 33º39’47.126” N and Longitude 98º46’44.659” W based on NAD83 towards the left end of the dam. Figure 7 shows the elevation relief of the area in detail.

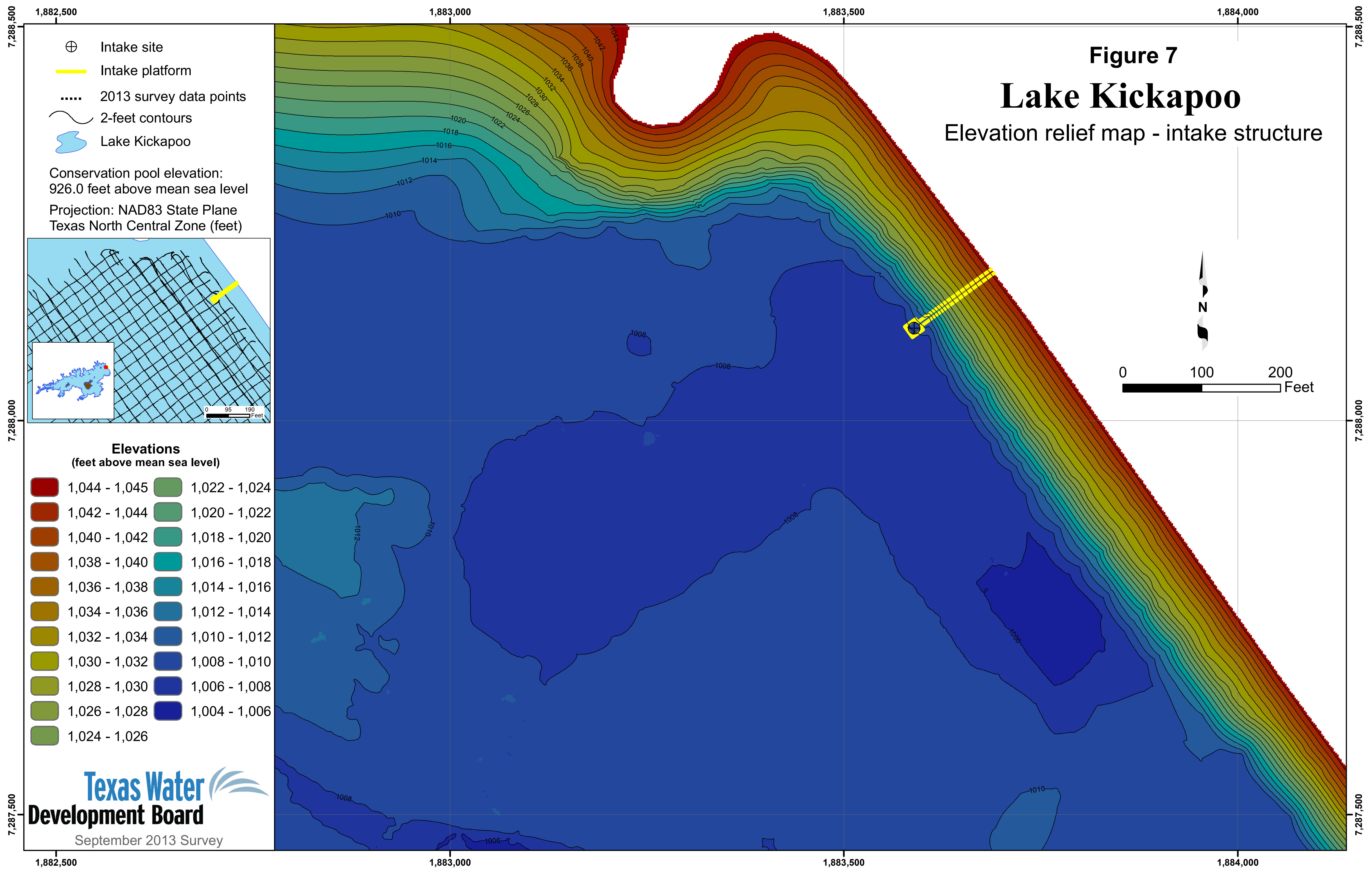


Figure 7
Lake Kickapoo
Elevation relief map - intake structure
Intake site
Intake platform
2013 survey data points
2-feet contours
Lake Kickapoo
Conservation pool elevation:
926.0 feet above mean sea level
Projection: NAD83 State Plane
Texas North Central Zone (feet)
Elevations
(feet above mean sea level)
1,044 - 1,045
1,042 - 1,044
1,040 - 1,042
1,038 - 1,040
1,036 - 1,038
1,034 - 1,036
1,032 - 1,034
1,030 - 1,032
1,028 - 1,030
1,026 - 1,028
1,024 - 1,026
1,022 - 1,024
1,020 - 1,022
1,018 - 1,020
1,016 - 1,018
1,014 - 1,016
1,012 - 1,014
1,010 - 1,012
1,008 - 1,010
1,006 - 1,008
1,004 - 1,006
N
0
100
200
Feet
1,882,500
1,883,000
1,883,500
1,884,000
7,288,500
7,288,000
7,287,500
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Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Kickapoo in approximately 10 years or after a major flood event. To further improve estimates of capacity loss, TWDB recommends a volumetric and sedimentation survey. Sedimentation surveys include additional analysis of the multi-frequency data for post-impoundment sediment by correlation with sediment core samples and a map identifying the spatial distribution of sediment throughout the reservoir.

TWDB contact information

More information about the Hydrographic Survey Program can be found at:
http://www.twdb.texas.gov/surfacewater/surveys/index.asp
Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:

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Email: Jason.Kemp@twdb.texas.gov

Or

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Director, Surface Water Resources Division
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Email: Ruben.Solis@twdb.texas.gov

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Appendix A

Lake Kickapoo

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — September 2013 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 1,045.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1,002	0	0	0	0	0	0	0	0	0	0
1,003	0	0	0	0	0	0	0	0	0	0
1,004	0	0	0	0	1	1	1	1	1	1
1,005	2	2	2	2	3	3	3	4	4	4
1,006	5	5	6	7	8	8	9	10	11	12
1,007	13	15	16	17	19	20	22	24	26	28
1,008	30	33	35	38	40	43	46	50	54	59
1,009	64	70	78	85	94	103	112	123	133	145
1,010	157	170	183	197	211	226	241	257	274	292
1,011	310	328	348	368	390	411	434	458	482	508
1,012	534	562	590	620	651	684	718	753	790	827
1,013	866	906	947	990	1,033	1,078	1,123	1,170	1,218	1,267
1,014	1,316	1,367	1,418	1,471	1,524	1,578	1,634	1,690	1,747	1,805
1,015	1,863	1,923	1,983	2,044	2,106	2,169	2,232	2,297	2,362	2,429
1,016	2,497	2,565	2,635	2,705	2,777	2,849	2,923	2,997	3,072	3,148
1,017	3,225	3,303	3,383	3,463	3,544	3,627	3,711	3,796	3,882	3,970
1,018	4,058	4,148	4,238	4,330	4,423	4,517	4,613	4,709	4,807	4,906
1,019	5,006	5,107	5,209	5,313	5,418	5,524	5,631	5,740	5,850	5,962
1,020	6,075	6,189	6,304	6,421	6,538	6,656	6,775	6,896	7,017	7,140
1,021	7,263	7,388	7,513	7,640	7,768	7,897	8,027	8,159	8,291	8,424
1,022	8,559	8,695	8,832	8,970	9,109	9,250	9,392	9,536	9,682	9,829
1,023	9,978	10,128	10,280	10,433	10,587	10,742	10,899	11,057	11,216	11,377
1,024	11,539	11,702	11,866	12,031	12,198	12,367	12,537	12,708	12,881	13,055
1,025	13,231	13,409	13,587	13,767	13,949	14,131	14,315	14,501	14,688	14,876
1,026	15,067	15,258	15,451	15,646	15,841	16,038	16,237	16,436	16,637	16,840
1,027	17,043	17,249	17,456	17,666	17,877	18,091	18,306	18,524	18,743	18,964
1,028	19,186	19,411	19,637	19,865	20,095	20,326	20,558	20,793	21,029	21,266
1,029	21,505	21,746	21,989	22,233	22,479	22,727	22,976	23,228	23,481	23,736
1,030	23,993	24,251	24,511	24,773	25,037	25,302	25,569	25,837	26,107	26,379
1,031	26,652	26,926	27,202	27,480	27,759	28,039	28,321	28,604	28,889	29,175
1,032	29,462	29,751	30,042	30,334	30,628	30,924	31,221	31,520	31,821	32,124
1,033	32,428	32,735	33,045	33,358	33,673	33,991	34,312	34,635	34,961	35,289
1,034	35,620	35,953	36,289	36,627	36,968	37,311	37,657	38,006	38,357	38,712
1,035	39,069	39,430	39,792	40,157	40,524	40,893	41,265	41,639	42,015	42,394
1,036	42,774	43,157	43,543	43,930	44,320	44,712	45,106	45,503	45,902	46,303
1,037	46,707	47,112	47,520	47,931	48,343	48,758	49,175	49,594	50,016	50,440
1,038	50,866	51,294	51,725	52,158	52,593	53,031	53,471	53,913	54,357	54,804
1,039	55,253	55,704	56,157	56,613	57,071	57,531	57,994	58,458	58,926	59,395
1,040	59,867	60,340	60,817	61,295	61,776	62,259	62,744	63,231	63,721	64,213
1,041	64,708	65,204	65,703	66,204	66,708	67,213	67,721	68,232	68,744	69,259
1,042	69,776	70,295	70,817	71,341	71,867	72,395	72,926	73,459	73,994	74,532
1,043	75,072	75,614	76,158	76,705	77,254	77,805	78,358	78,914	79,472	80,032
1,044	80,595	81,159	81,726	82,296	82,867	83,441	84,017	84,596	85,176	85,759
1,045	86,345									

Note: Capacities above elevation 1,035.0 calculated from interpolated areas

Appendix B

Lake Kickapoo

RESERVOIR AREA TABLE

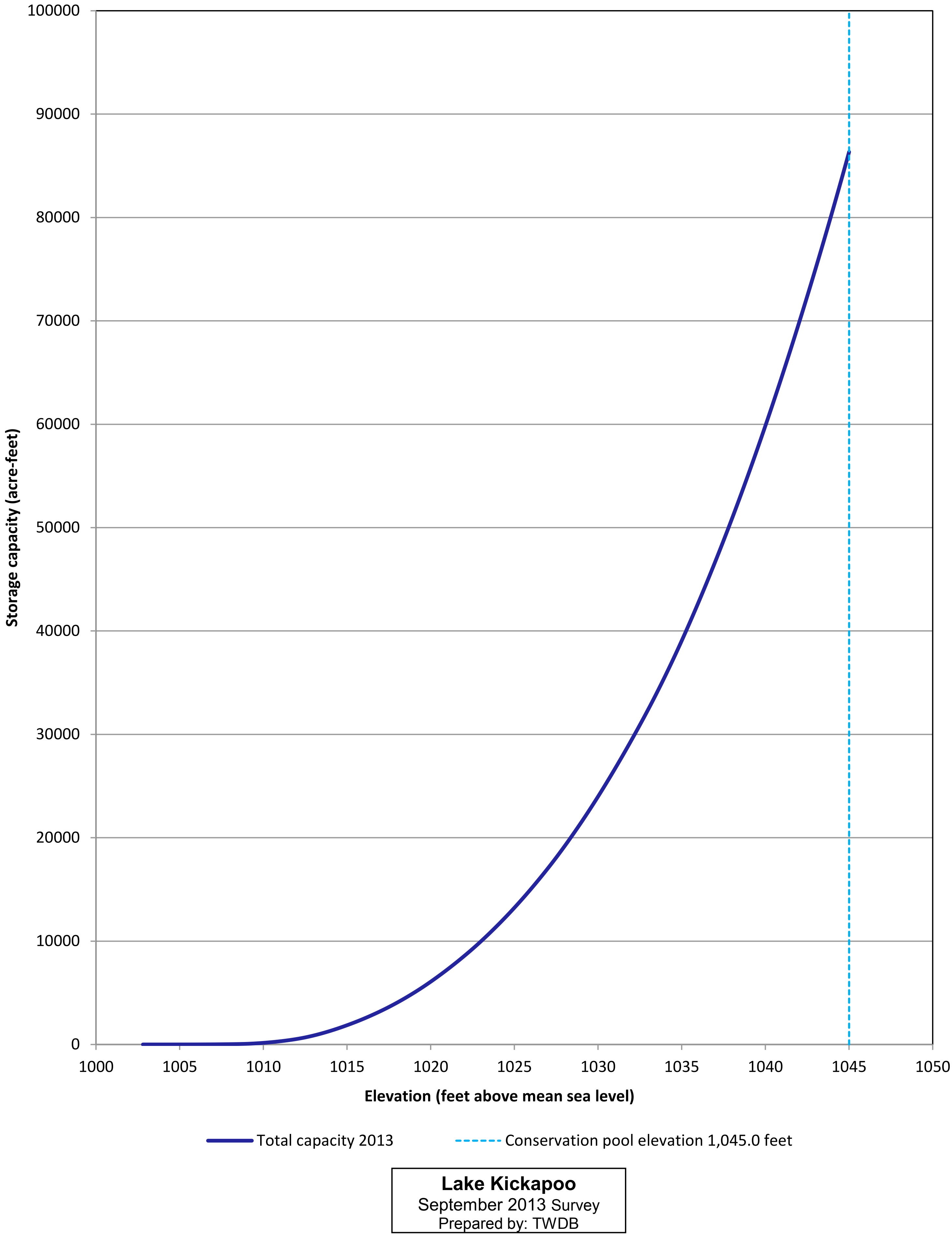
TEXAS WATER DEVELOPMENT BOARD — September 2013 Survey

AREA IN ACRES — Conservation Pool Elevation 1,045.0 feet NGVD29

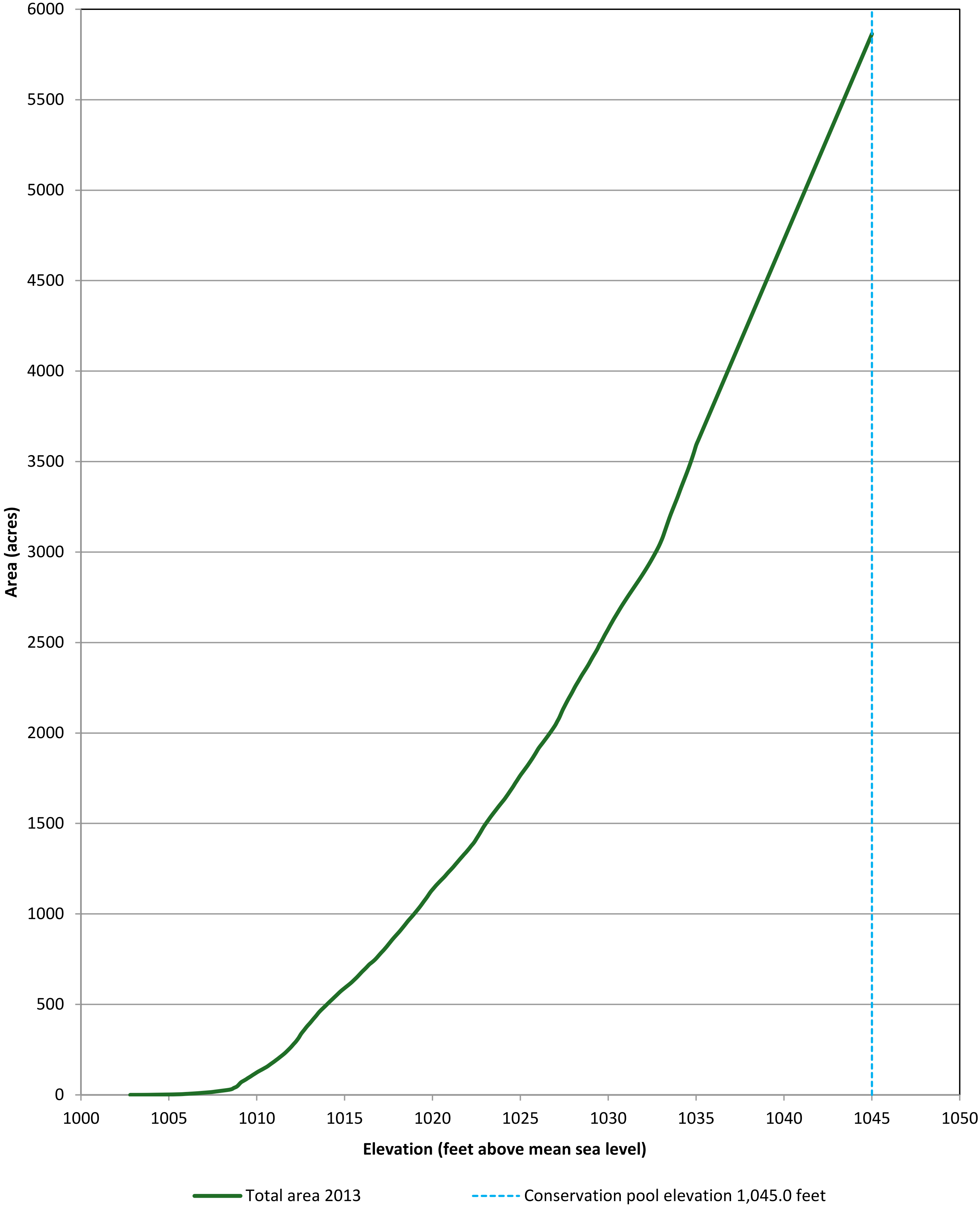
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1,002	0	0	0	0	0	0	0	0	0	0
1,003	0	0	0	0	0	0	0	0	0	0
1,004	1	1	1	1	1	1	2	2	2	2
1,005	2	2	2	3	3	3	3	4	4	5
1,006	5	6	7	7	8	8	9	10	11	11
1,007	12	13	14	14	15	16	18	19	20	22
1,008	23	24	25	27	28	30	33	39	43	49
1,009	59	69	75	81	87	93	99	105	112	118
1,010	124	130	135	140	146	151	157	164	171	178
1,011	185	192	199	207	215	223	231	240	250	259
1,012	270	281	292	304	318	334	347	359	372	383
1,013	394	405	417	428	440	452	463	473	482	491
1,014	501	510	520	529	538	547	557	566	575	583
1,015	591	598	606	614	623	632	641	651	661	671
1,016	681	691	701	711	721	729	737	745	755	766
1,017	777	788	798	809	821	833	845	857	868	879
1,018	890	901	912	924	936	948	961	972	983	994
1,019	1,006	1,017	1,030	1,042	1,055	1,069	1,081	1,095	1,109	1,123
1,020	1,135	1,146	1,158	1,168	1,178	1,188	1,198	1,208	1,219	1,230
1,021	1,241	1,251	1,262	1,273	1,285	1,296	1,308	1,318	1,330	1,340
1,022	1,352	1,363	1,376	1,387	1,400	1,416	1,431	1,447	1,464	1,480
1,023	1,495	1,509	1,522	1,536	1,549	1,561	1,574	1,587	1,599	1,611
1,024	1,623	1,635	1,649	1,663	1,677	1,691	1,706	1,722	1,737	1,752
1,025	1,766	1,780	1,793	1,806	1,819	1,833	1,848	1,863	1,878	1,894
1,026	1,911	1,925	1,937	1,950	1,963	1,976	1,989	2,003	2,017	2,031
1,027	2,046	2,065	2,082	2,104	2,127	2,146	2,164	2,183	2,200	2,217
1,028	2,235	2,254	2,271	2,287	2,304	2,320	2,336	2,351	2,366	2,383
1,029	2,400	2,418	2,434	2,451	2,468	2,489	2,504	2,523	2,541	2,558
1,030	2,576	2,594	2,611	2,628	2,644	2,660	2,676	2,692	2,708	2,723
1,031	2,738	2,753	2,767	2,782	2,796	2,810	2,825	2,839	2,854	2,868
1,032	2,884	2,899	2,915	2,931	2,947	2,964	2,982	2,999	3,018	3,037
1,033	3,059	3,083	3,111	3,139	3,167	3,195	3,220	3,245	3,269	3,293
1,034	3,319	3,346	3,371	3,396	3,421	3,446	3,473	3,500	3,529	3,559
1,035	3,591	3,614	3,637	3,659	3,682	3,705	3,728	3,750	3,773	3,796
1,036	3,819	3,841	3,864	3,887	3,909	3,932	3,955	3,978	4,000	4,023
1,037	4,046	4,069	4,091	4,114	4,137	4,159	4,182	4,205	4,228	4,250
1,038	4,273	4,296	4,318	4,341	4,364	4,387	4,409	4,432	4,455	4,478
1,039	4,500	4,523	4,546	4,568	4,591	4,614	4,637	4,659	4,682	4,705
1,040	4,728	4,750	4,773	4,796	4,818	4,841	4,864	4,887	4,909	4,932
1,041	4,955	4,977	5,000	5,023	5,046	5,068	5,091	5,114	5,137	5,159
1,042	5,182	5,205	5,227	5,250	5,273	5,296	5,318	5,341	5,364	5,387
1,043	5,409	5,432	5,455	5,477	5,500	5,523	5,546	5,568	5,591	5,614
1,044	5,636	5,659	5,682	5,705	5,727	5,750	5,773	5,796	5,818	5,841
1,045	5,864									

Note: Areas above elevation 1035.0 feet interpolated



Appendix C: Capacity curve



Lake Kicapoo
September 2013 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

Contours
(feet above mean sea level)

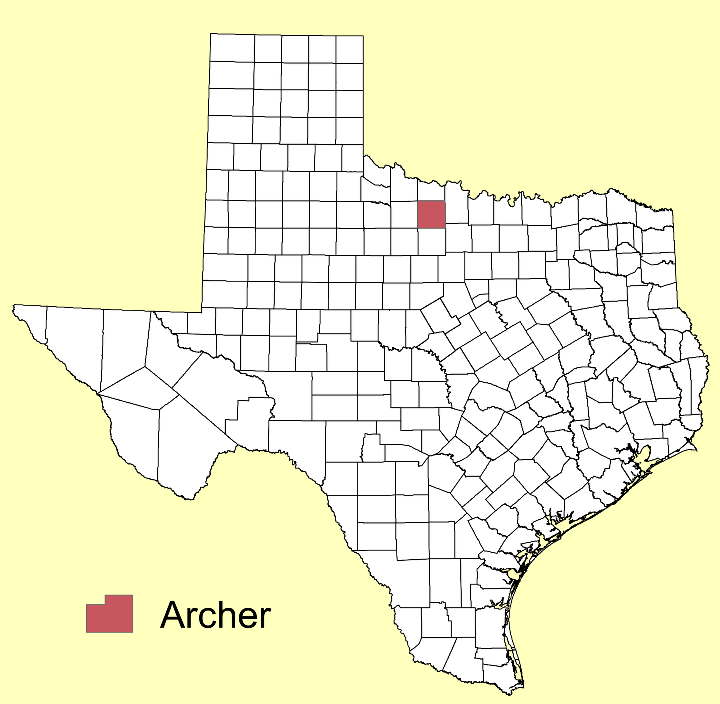
- 1,040
- 1,035
- 1,030
- 1,025
- 1,020
- 1,015
- 1,010
- 1,005

Lake Kickapoo

Islands

Conservation pool
elevation: 1,045.0 feet

Projection: NAD83
State Plane Texas
North Central 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 Kickapoo. The Texas Water Development Board makes no representations nor assumes any liability.