Volumetric and Sedimentation Survey of LAKE RAY HUBBARD

August 2015 Survey

Texas Water Development Board

July 2016

Texas Water Development Board

Prepared for:

City of Dallas

With Support Provided by:

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 Lake Ray Hubbard. The City of Dallas 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.

Rockwall-Forney Dam and Lake Ray Hubbard are located on the East Fork Trinity River in Dallas, Kaufman, Rockwall, and Collin Counties, approximately 15 miles east of downtown Dallas, Texas. The conservation pool elevation of Lake Ray Hubbard is 435.5 feet above mean sea level (NGVD29). TWDB collected bathymetric data for Lake Ray Hubbard between May 28, 2015, and August 7, 2015, while the daily average water surface elevations measured between 435.22 and 436.01 feet above mean sea level (NGVD29). Additional data was collected on February 26, 2016, and March 2, 2016, while the daily average water surface elevations measured 435.51 and 435.53 feet above mean sea level, respectively.

The 2015 TWDB volumetric survey indicates that Lake Ray Hubbard has a total reservoir capacity of 439,559 acre-feet and encompasses 20,947 acres at conservation pool elevation (435.5 feet above mean sea level, NGVD29). Previous capacity estimates include the original design estimate of 490,000 acre-feet, a 1989 estimate by Turner Collie & Braden Inc., of 413,500 acre-feet, and a 2005 TWDB survey. The 2005 TWDB survey data was re-evaluated using current processing procedures resulting in an updated capacity estimate of 455,129 acre-feet.

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Ray Hubbard to have an average loss of capacity between 719 and 1,097 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (435.5 feet NGVD29). Sediment accumulation is greatest near the dam, up to approximately two miles north of the dam. Other heavy pockets of sediment are collecting upstream of the many earthen bridge support peninsulas and historical river levees. The thickest deposits occur north of Terry Park, in Heath, Texas. TWDB recommends that a similar methodology be used to resurvey Lake Ray Hubbard in 10 years or after a major flood event.

Table of Contents

List of Tables

List of Figures

Appendices

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 November 2014, 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 Ray Hubbard. The City of Dallas 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 2014). This report describes the methods used to conduct the volumetric and sedimentation survey in 2015, including data collection and processing techniques. This report serves as the final contract deliverable from the 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].

Lake Ray Hubbard general information

Rockwall-Forney Dam and Lake Ray Hubbard are located on the East Fork Trinity River in Dallas, Kaufman, Rockwall, and Collin Counties, approximately 15 miles east of downtown Dallas, Texas (Figure 1). Rockwall-Forney Dam and Lake Ray Hubbard are owned by the City of Dallas and operated by Dallas Water Utilities, a not-for-profit department of the City of Dallas providing water and wastewater services (Dallas 2014). Construction on Rockwall-Forney Dam started on June 13, 1964, and deliberate impoundment began on December 1, 1968 (TWDB 1973). Rockwall-Forney Dam was completed on January 17, 1969 (TWDB 1973).

Water rights for Lake Ray Hubbard have been appropriated to the City of Dallas through Certificate of Adjudication No. 08-2462 and Amendments to Certificate of Adjudication Nos. 08-2462A, 08-2462B, 08-2462C, 08-2462D, 08-2462E, 08-2462F, 08-

2462G, and 08-2462H. The complete certificates are on file in the Information Resources Division of the Texas Commission on Environmental Quality.

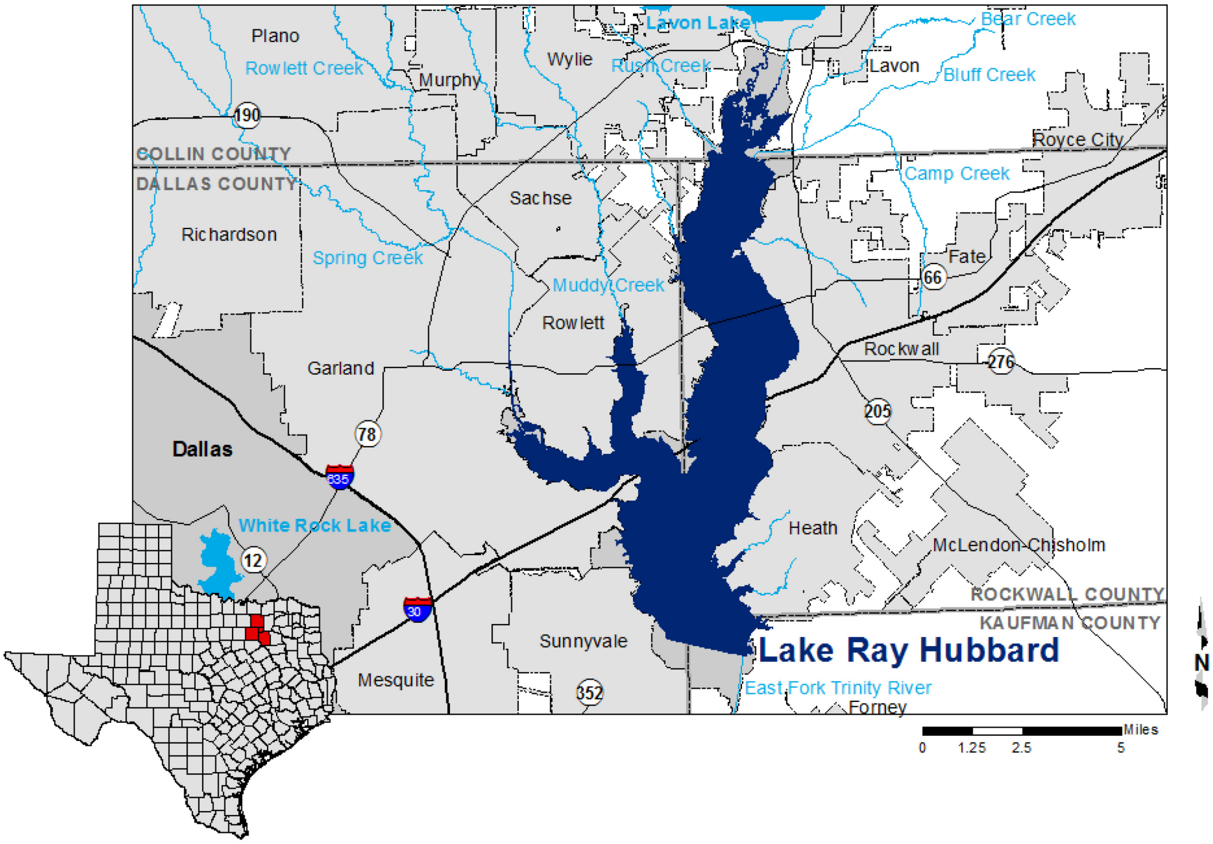


Figure 1. **Location map of Lake Ray Hubbard**

Table 1. Pertinent data for Rockwall-Forney Dam and Lake Ray Hubbard.

Owner

City of Dallas

Design Engineer

Forrest and Cotton, Inc.

Location of dam

On the East Fork Trinity River in Dallas, Kaufman, Rockwall, and Collin Counties, 15 miles east of Dallas

Drainage area

1,074 square miles of which 770 square miles are above Lavon Dam

Dam

Type	Earthfill
Length	12,500 feet
Maximum height	68 feet
Top width	22 feet

Spillway

Type	Concrete Ogee
Control	14 tainter gates, each 40 by 28 feet
Crest length (net)	560 feet
Crest elevation	409.5 feet above mean sea level

Outlet Works (water supply)

Type	Concrete tower structure
Control	Gates openings at several elevations
Elevation low opening	392.0 feet above mean sea level

Outlet Works (low flow)

Type	3 sluiceways through piers
Control	3 slide gates, each 4 by 6 feet
Elevation	388.0 feet above mean sea level

Reservoir data (Based on 2015 TWDB survey)

Feature	**Elevation (feet** NGVD29[a]**)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	450.0	810,247	28,644
Top of gates	437.5	483,783	23,037
Top of conservation pool	435.5	439,559	20,947
Spillway crest	409.5	65,233	8,232
Invert of low flow outlet	388.0	0	0

Source: (TWDB 1973)

[a] NGVD29 = National Geodetic Vertical Datum 1929

Volumetric and sedimentation survey of Lake Ray Hubbard

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 08061550 Lk Ray Hubbard nr Forney, 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 Ray Hubbard between May 28 and August 7, 2015, while daily average water surface elevations measured between 435.22 and 436.01 feet above mean sea level (NGVD29). Additional data was collected on February 26 and March 2, 2016, while daily average water surface elevations measured 435.51 and 435.53 feet above mean sea level, 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 500 feet apart. Many of the same survey lines were also used by the TWDB during the 2005 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. 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 nine locations to collect sediment core samples (Figure 2). The sediment core samples were collected on October 27, 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.

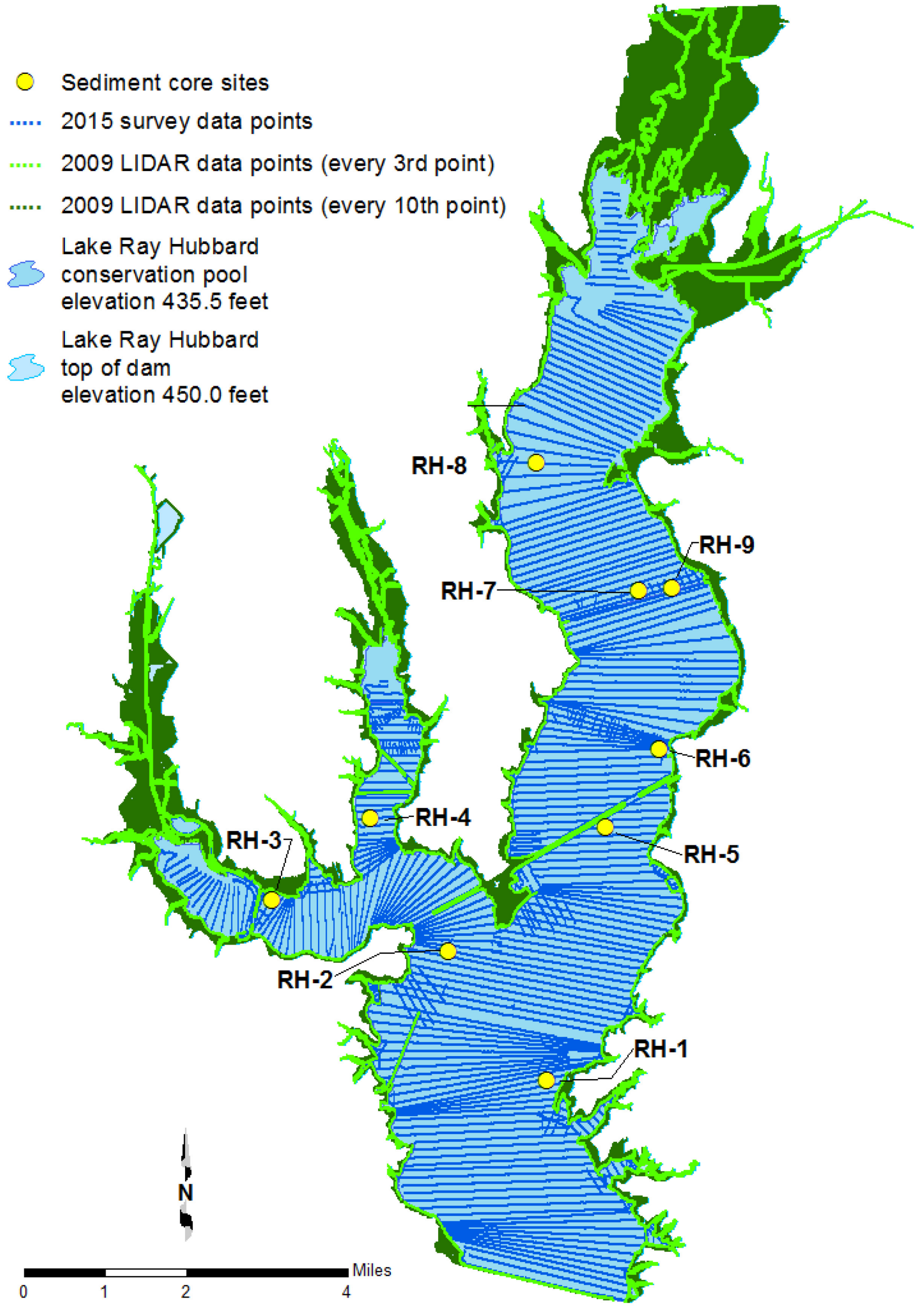


Figure 2. **2015 TWDB Lake Ray Hubbard survey data (*blue dots*), sediment coring locations (*yellow circles*), and 2009 LIDAR data (*green dots*) between elevations 434.0 and 450.0 feet.**

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 2015). LIDAR data was collected between March 29 and April 14, 2009, while daily average water surface elevation of the reservoir measured between 434.09 and 434.23 feet above mean sea level. According to the associated metadata, the LIDAR data has a vertical accuracy of ±7 centimeters and a horizontal accuracy of 1 meter. 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 1.0 meters by 1.0 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 137.143 meters NAVD88, equivalent to 450.0 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 2015a) and VERTCON software (NGS 2015b) to a single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 08061550 Lk Ray Hubbard nr Forney, TX Latitude 30º48'00"N, Longitude 96º29'45"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 450.0-foot contour was necessary to close the contour across the top of the dam and remove other artifacts.

Additional boundary information was required where LIDAR data was insufficient. To model the earthen bridge support peninsulas for State Highway 66, the shoreline representing these features at elevation 435.5 feet was copied from the 2005 TWDB survey boundary as digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), dated March 8, 1995, and March 20, 1995. From an aerial photograph dated August 31, 2004, the breakwater at Chandler's Landing Marina was digitized and assigned an elevation of 435.5 feet. These features were input into the model as hardlines. The DOQQs are available at the Texas Natural Resources Information System (TNRIS 2015).

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 10th point and only data points within the reservoir boundary (Figure 2). The LIDAR data points have an average spacing of 0.57 meters; therefore, using a thinned point dataset did not significantly affect the modeled topography of the coverage area. However, many features, including many river channels and the interior extent of the LIDAR data, did require a higher point density to be properly represented in the model. LIDAR data in these areas, within 100 feet of channel centerlines and 50 feet around the interior extent of the data, was filtered to include every 3rd point. No further 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 adding the VERTCON conversion offset of 0.017 meters, then to feet NGVD29 for compatibility with the bathymetric survey data.

Triangulated Irregular Network model

Following completion of data collection, raw data files collected by the 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. The 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, 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. In practice, however, minor revisions of the interpolation definition files may be needed to account for differences in spatial coverage and boundary conditions between surveys. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing the reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen *et al*. 2011a) and in McEwen *et al*. 2011b.

In areas inaccessible to survey data collection, such as small coves and shallow upstream areas of the reservoir, linear 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 Ray Hubbard, each line intersects with the first LIDAR point in its path and all linearly interpolated points outside the conservation pool elevation contour of 435.5 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 Ray Hubbard. In Figure 3A, deeper channels and ridges indicated by surveyed cross-sections are not continuously represented in areas between survey cross-sections. This is an artifact of the TIN generation routine rather than an accurate representation of the physical bathymetric surface. Inclusion of interpolation points 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).

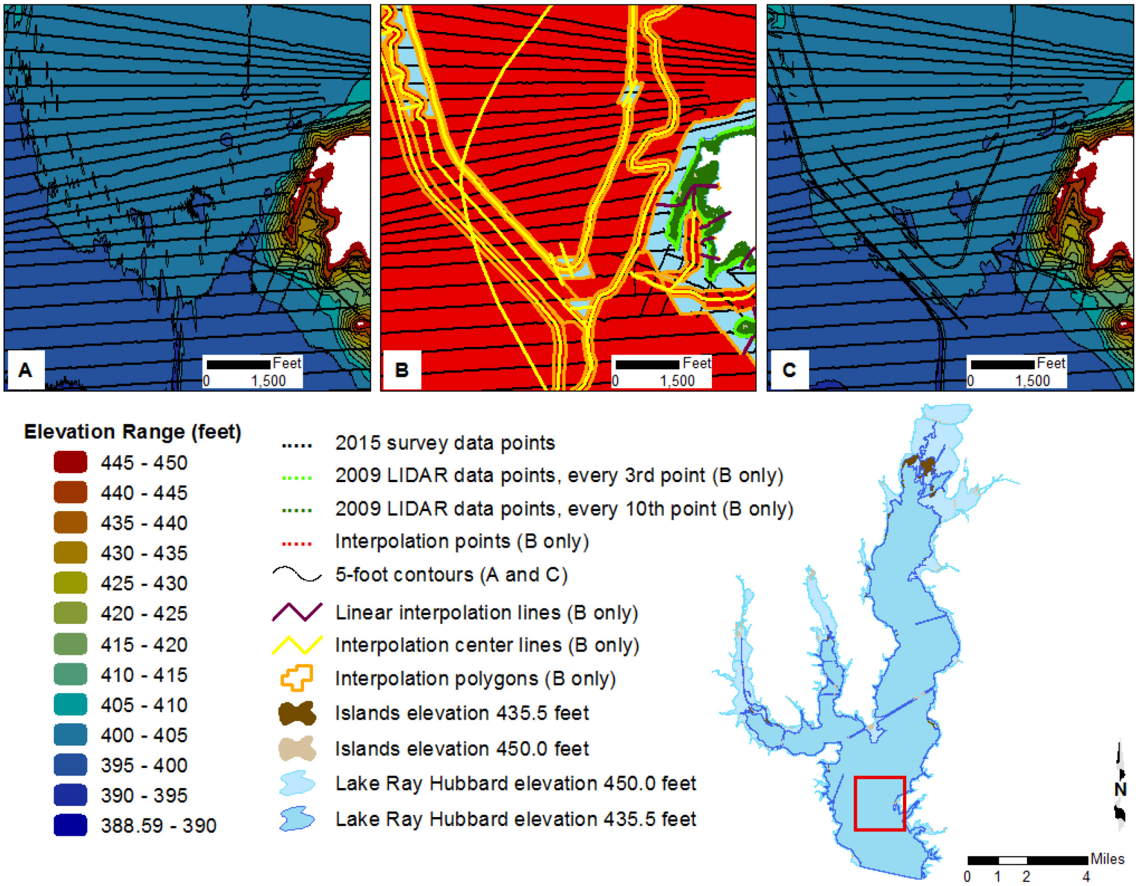
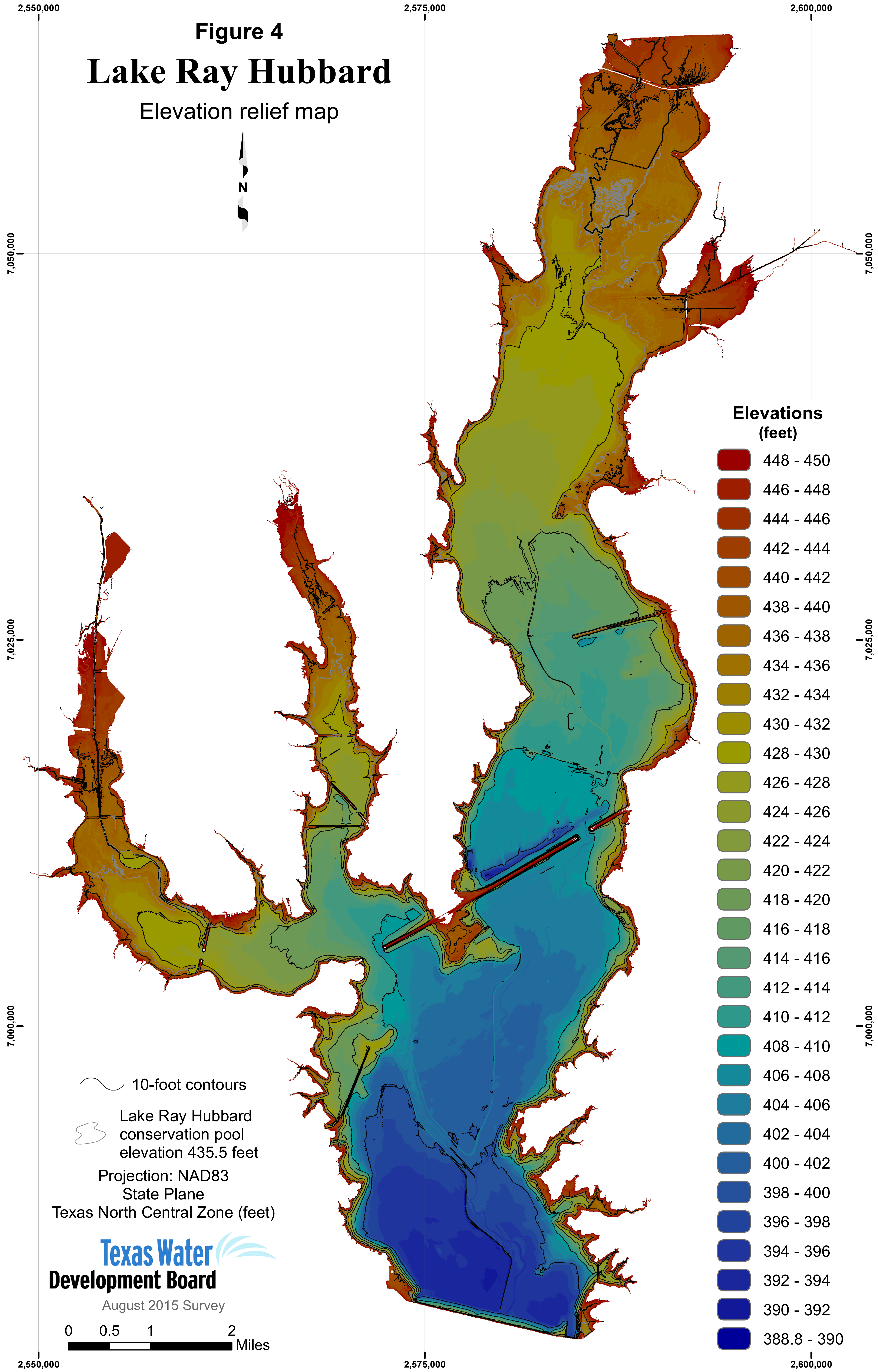


Figure 3. **Anisotropic spatial interpolation and linear interpolation of Lake Ray Hubbard sounding data - A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with the interpolated points.**

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 388.5 to 450.0 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 two feet by two feet. The raster data then was 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 range for Lake Ray Hubbard, and a two-foot contour map (Figure 6 - attachment).

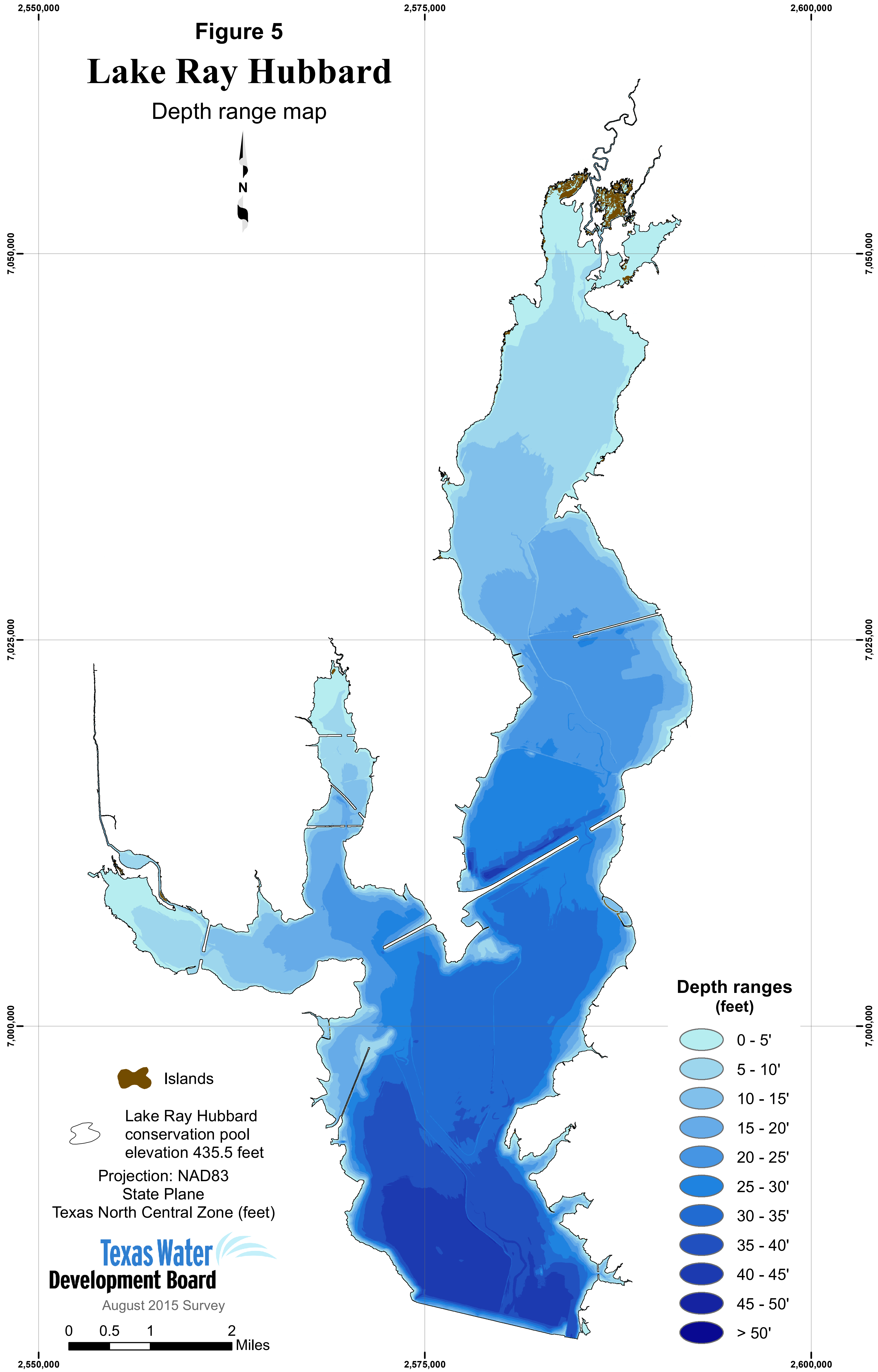


2,550,000
2,575,000
2,600,000
Figure 4
Lake Ray Hubbard
Elevation relief map
N
7,050,000
7,025,000
7,000,000
Elevations
(feet)
448 - 450
446 - 448
444 - 446
442 - 444
440 - 442
438 - 440
436 - 438
434 - 436
432 - 434
430 - 432
428 - 430
426 - 428
424 - 426
422 - 424
420 - 422
418 - 420
416 - 418
414 - 416
412 - 414
410 - 412
408 - 410
406 - 408
404 - 406
402 - 404
400 - 402
398 - 400
396 - 398
394 - 396
392 - 394
390 - 392
388.8 - 390
10-foot contours
Lake Ray Hubbard conservation pool elevation 435.5 feet
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water Development Board
August 2015 Survey
0
0.5
1
2
Miles

Figure 5

Lake Ray Hubbard

Depth range map



Texas Water Development Board

August 2015 Survey

Analysis of sediment data from Lake Ray Hubbard

Sedimentation in Lake Ray Hubbard 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 Ray Hubbard.

Core	Easting[a] (feet)	Northing[a] (feet)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
RH-1	2579664.36	6994200.71	33.5"/ 32.5"	0-7.0" high water content, 50% mottling, silty loam, post-impoundment	5Y 4/3 & 5Y 2.5/2
				7.0-32.5" high water content, medium density, 50% mottling, silty loam, post-impoundment	5Y 4/2 & 5Y 2.5/2
				32.5-33.5" high water content, medium density, 5% medium fragments organic matter, clay loam, pre-impoundment	5Y 3/2
RH-2	2573320.98	7002610.32	27.5"/17.0"	0-1.0" water, post-impoundment	N/A
				1.0-12.0" high water content, 50% mottling, silty loam, post-impoundment	5Y 4/3 & 5Y 2.5/2
				12.0-17.0" high water content, medium density, 5% fine to medium structures, silty loam, post-impoundment	5Y 2.5/1
				17.0-27.5" high density, 40% fine to coarse structures, clay, pre-impoundment	5Y 3/1
RH-3	2561751.89	7005956.48	36.5"/32.5"	0-16.5" high water content, 50% mottling, silty loam, post-impoundment	2.5Y 4/1 & 2.5Y 2.5/1
				16.5-32.5" high water content, silty loam, post-impoundment	5Y 2.5/2
				32.5-36.5" high density, 40% fine to medium structures, organic material present, clay, pre-impoundment	5Y 2.5/1
RH-4	2568237.58	7011237.61	37.03"/28.5"	0-2.0" water, post-impoundment	N/A
				2.0-12.5" high water content, silty loam	5Y 3/1
				12.5-26.0" high water content, medium density, clay loam, post-impoundment	5Y 2.5/2
				26.0-28.5" high water content, medium density, 20% fine structures, clay loam, post-impoundment	5Y 2.5/1
				28.5-37.0" high density, clay, pre-impoundment	5Y 3/1
RH-5	2583545.42	7010647.16	23.5"/20.5"	0-2.5" water, post-impoundment	N/A
				2.5-15.5" high water content, silty loam, post-impoundment	5Y 2.5/1
				15.5-20.5" high water content, medium density, 5% fine structures, silty loam, post-impoundment	5Y 2.5/1
				20.5-23.5" high density, 50% fine to coarse structures, clay, pre-impoundment	5Y 4/1
RH-6	2587070.31	7015759.34	29.25"/26.0"	0-26.0" high water content, silty loam, post-impoundment	5Y 2.5/2
				26.0-29.25" high density, 50% fine to coarse structures, clay, pre-impoundment	5Y 3/1

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

Table 2. Sediment core sampling analysis data - Lake Ray Hubbard (continued).

Core	Easting[a] (feet)	Northing[a] (feet)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
RH-7	2585746.39	7026106.08	29.5"/22.0"	0-3.0" water, post-impoundment	N/A
				3.0-18.0" high water content, silty loam, post-impoundment	5Y 3/2
				18.0-22.0" high water content, 30% fine structures, silty loam, post-impoundment	2.5Y 2.5/1
				22.0-29.5" high density, 50% medium to coarse structures, clay, pre-impoundment	2.5Y 4/1
RH-8	2579056.02	7034421.01	22.0"/ 16.0"	0-10.0" high water content, 50% mottling, silty loam, post-impoundment	5Y3/1 & 5Y4/2
				10.0-16.0" high water content, organic matter present, silty loam, post-impoundment	2.5Y 3/1
				16.0-22.0" high density, organic matter present, 50% fine to medium structures, pre-impoundment	5Y 3/1
RH-9	2587900.76	7026311.39	52.0"/46.0"	0-16.0" high water content, 50% mottling, silty loam, post-impoundment	5Y 3/2 & 5Y 2.5/1
				16.0-46.0" high water content, medium density, clay loam, post-impoundment	5Y 2.5/1
				46.0-52.0" high density, medium to coarse organic matter, 50% fine to medium structures, clay, pre-impoundment	2.5Y 4/1

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

A photograph of sediment core RH-8 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Ray Hubbard. 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 16.0 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.

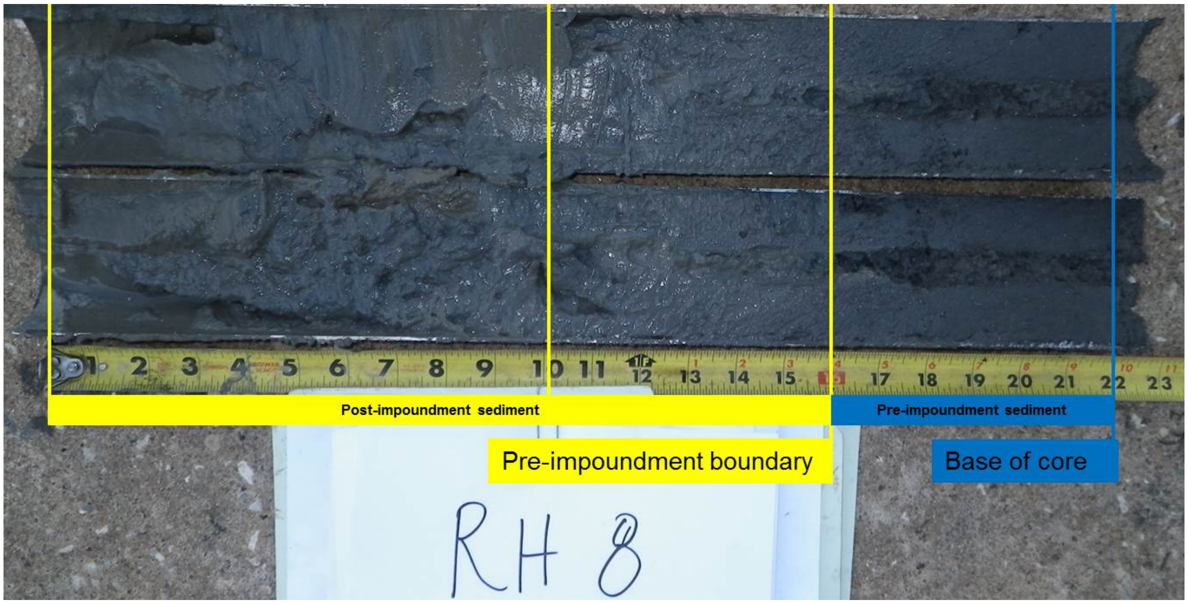


Figure 7. Sediment core RH-8 from Lake Ray Hubbard. Post-impoundment sediments were identified in the top 16 inches of the sediment core.

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.

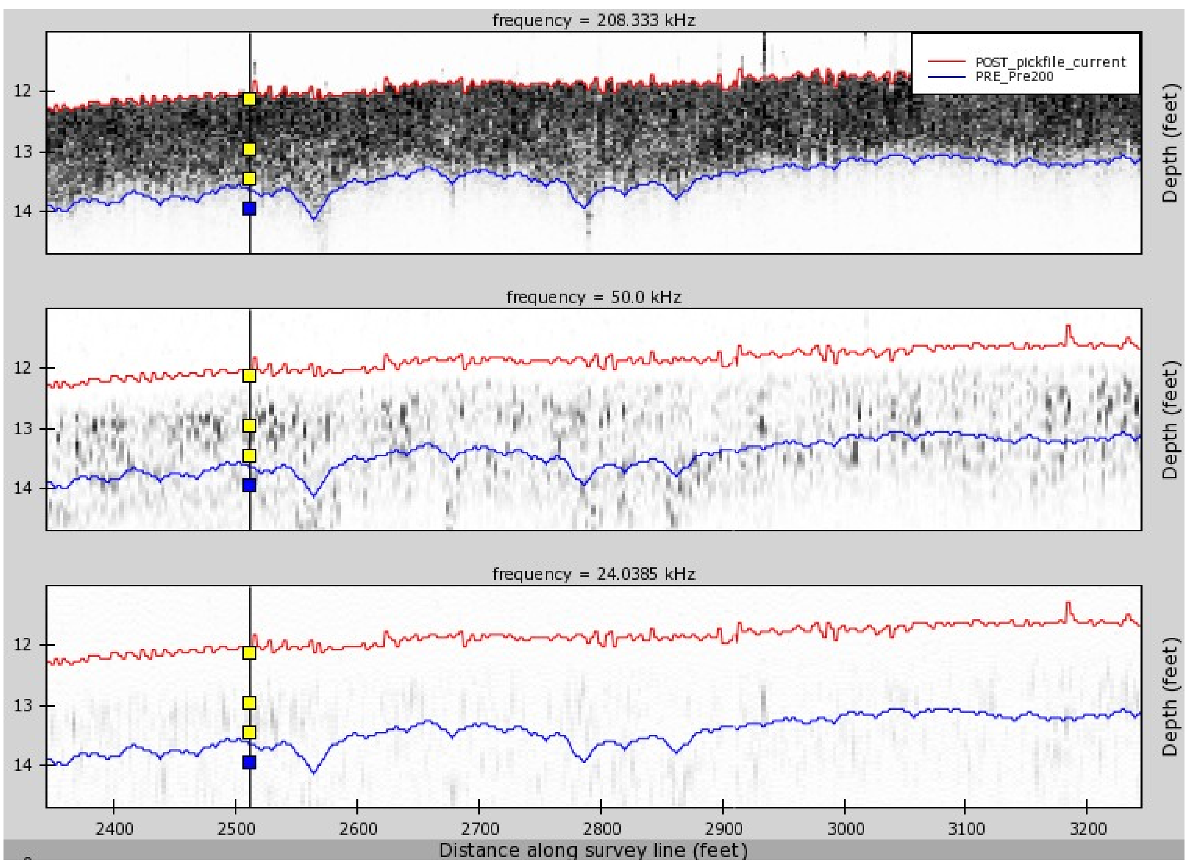


Figure 8. Comparison of sediment core RH-8 with acoustic signal returns.

Figure 8 compares sediment core sample RH-8 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. Many layers of sediment may be 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. Yellow boxes represent post-impoundment sediments. The blue box marks the bottom of the sediment core sample and indicates that pre-impoundment sediments were identified in the final layer.

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 Figure 8). Figure 9 shows sediment core sample RH-8 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.

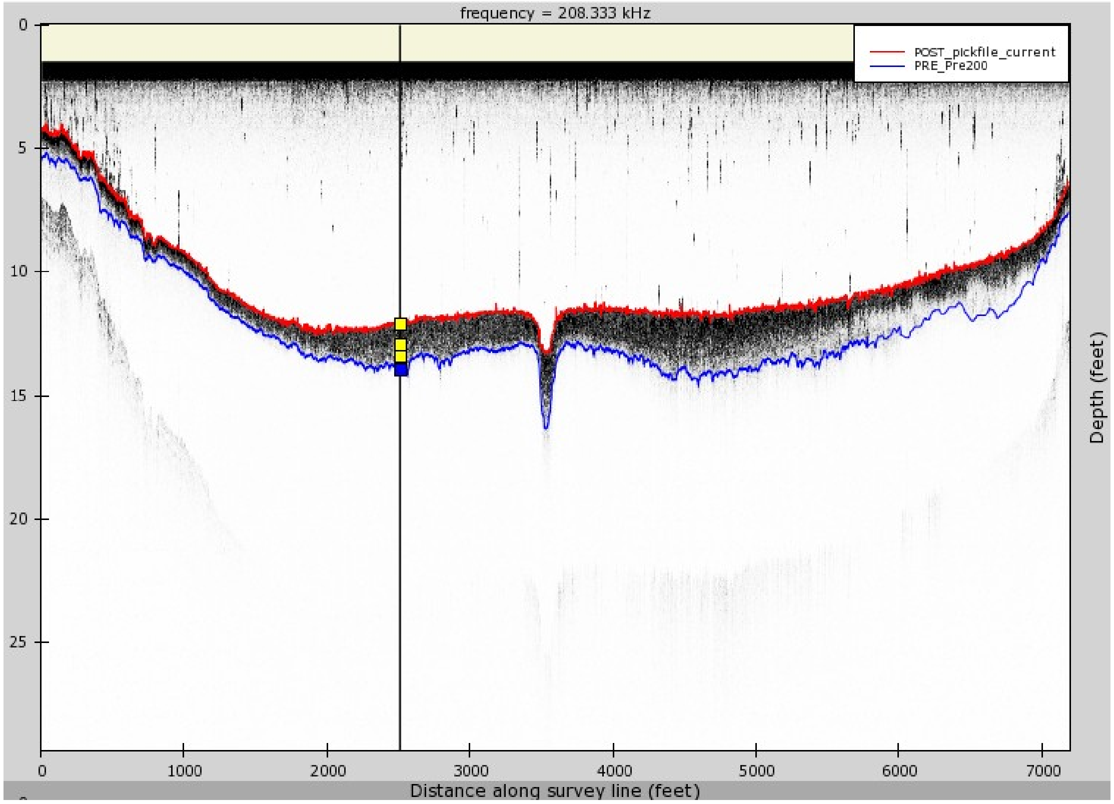


Figure 9. **Cross-section of data collected during survey, displayed in Hydropick (208 kHz frequency), correlated with sediment core sample RH-8 and showing the current surface in red and pre-impoundment surface in blue.**

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 the TIN model creation, TWDB assumed sediment thickness at the reservoir boundary was zero feet (defined as the 450.0 foot elevation contour). 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 five foot by five foot and used to produce a sediment thickness map of Lake Ray Hubbard (Figure 10).

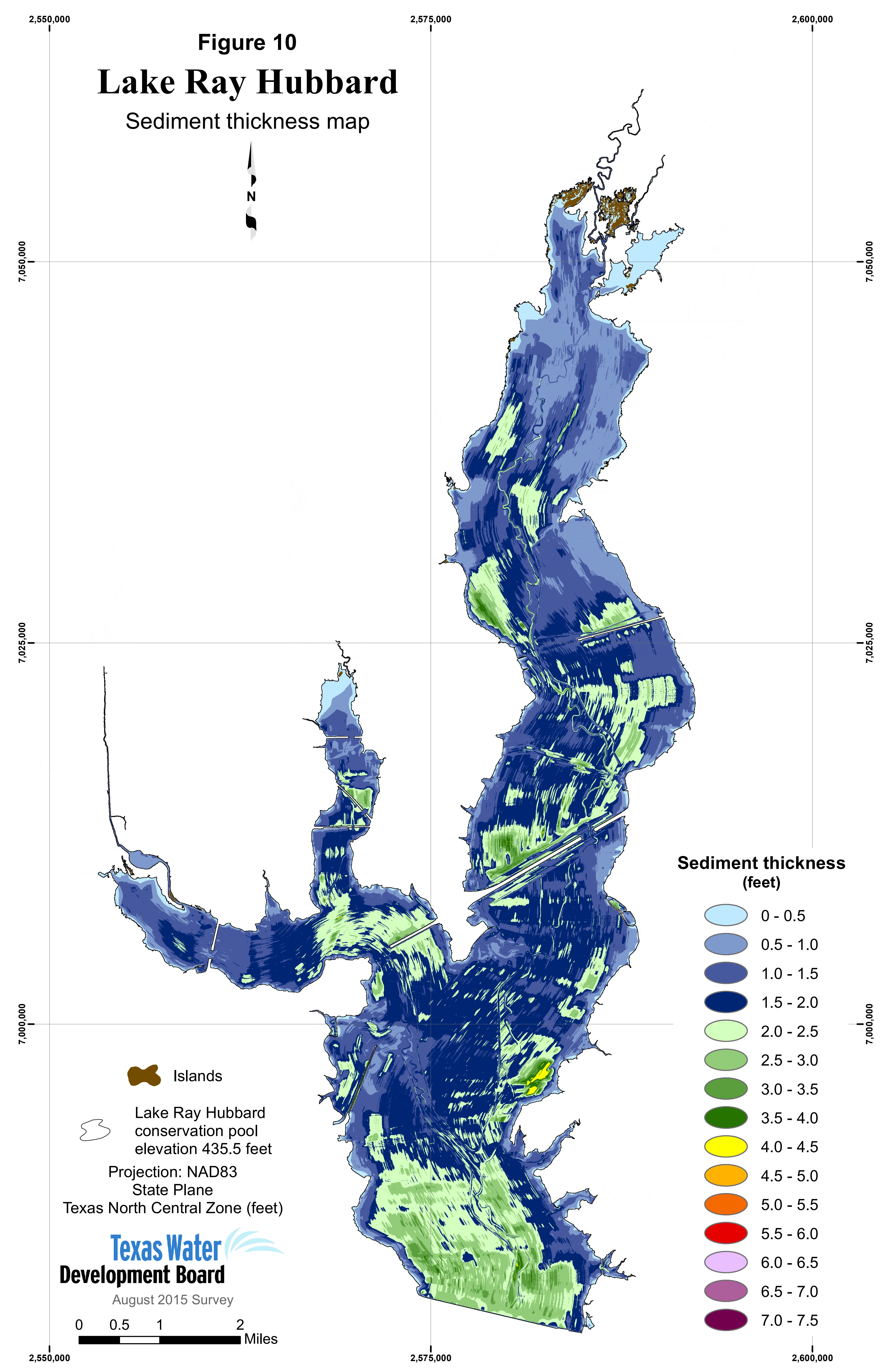


Figure 10
Lake Ray Hubbard
Sediment thickness map
N
2,550,000
2,575,000
2,600,000
7,050,000
7,025,000
7,000,000
Sediment thickness
(feet)
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 7.5
Islands
Lake Ray Hubbard
conservation pool
elevation 435.5 feet
Projection: NAD83
State Plane
Texas North Central Zone (feet)
Texas Water
Development Board
August 2015 Survey
0
0.5
1
2
Miles

Survey results

Volumetric survey

The results of the 2015 TWDB volumetric survey indicate Lake Ray Hubbard has a total reservoir capacity of 439,559 acre-feet and encompasses 20,947 acres at conservation pool elevation (435.5 feet above mean sea level, NGVD29). Previous capacity estimates include the original design estimate of 490,000 acre-feet and a 1989 capacity estimate by Turner Collie & Braden, Inc. of 413,500 acre-feet (Table 3). 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 from TWDB surveys of Lake Ray Hubbard, TWDB applied the 2015 data processing techniques to the survey data collected in 2005. Specifically, TWDB applied anisotropic spatial interpolation to the survey data collected in 2005 using the same interpolation definition file as was used for the 2015 survey, with minor edits to account for differences in data coverage and boundary conditions. The 2005 survey boundary was digitized from aerial photographs taken on March 8, 1995, and March 20, 1995, while the water surface elevation of the reservoir measured 435.73 and 435.62 feet above mean sea level, respectively. The boundary was assigned an elevation of 435.5 feet for modeling purposes. According to the associated metadata, the 1995-1996 DOQQs have a resolution of 1-meter, with a horizontal positional accuracy that meets the National Map Accuracy Standards (NMAS) for 1:12,000-scale products. For the recalculation analysis, this boundary was edited to add the breakwater at Chandler's Landing Marina. Re-evaluation of the 2005 survey resulted in a 0.7 percent increase in total capacity estimates at conservation pool elevation 435.5 feet (Table 3).

Table 3. Current and previous survey capacity and surface area data for Lake Ray Hubbard.

Survey	Surface area (acres)	Total capacity (acre-feet)
Original design, 1968[a]	22,745	490,000
Turner Collie & Braden, Inc. 1989[b]	21,683	413,500
TWDB 2005[c]	20,963	452,040
TWDB 2005 (re-calculated)	20,963	455,129
TWDB 2015	20,947	439,559

[a] Source: (TWDB 1973)
[b] Source: (TCB 1989)
[c] Source: (TWDB 2006)

Sedimentation survey

Based on two methods for estimating sedimentation rates, the 2015 TWDB sedimentation survey estimates Lake Ray Hubbard to have an average loss of capacity between 719 and 1,097 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (435.5 feet NGVD29). Sediment accumulation is greatest near the dam, up to approximately two miles north of the dam. Other heavy pockets of sediment are collecting upstream of the many earthen bridge support peninsulas and historical river levees. The thickest deposits occur north of Terry Park, in Heath, Texas. Comparison of capacity estimates of Lake Ray Hubbard derived using differing methodologies are provided in Table 4 for sedimentation rate calculation.

Table 4. Capacity loss comparisons for Lake Ray Hubbard.

Survey	Volume comparisons at conservation pool elevation (acre-feet)			Pre-impoundment (acre-feet)
Original design[a]	490,000	<>	<>	<>
TCB 1989[b]	<>	413,500	<>	<>
TWDB 2005 (re-calculated)	<>	<>	455,129	<>
TWDB pre-impoundment estimate based on 2015 survey	<>	<>	<>	472,644[c]
2015 volumetric survey	439,559	439,559	439,559	439,559
Volume difference (acre-feet)	50,441 (10.3%)	-26,059 (-6.3%)	15,570 (3.4%)	33,085 (7.0%)
Number of years	46	26	10	46
Capacity loss rate (acre-feet/year)	1,097	-1,002	1,557	719

[a] Source: (TWDB 1973), note: Deliberate impoundment began on December 1, 1968, and Rockwall-Forney Dam was completed on January 17, 1969.
[b] Source: (TCB 1989)
[c] 2015 TWDB surveyed capacity of 439,559 acre-feet plus 2015 TWDB surveyed sediment volume of 33,085 acre-feet

Recommendations

TWDB recommends resurveying Lake Ray Hubbard using a similar methodology within a 10 year time-frame or after a major flood event to assess changes in lake volume based on changes in sedimentation. To further improve estimates of sediment accumulation rates, TWDB recommends another volumetric and sedimentation survey.

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 Ray Hubbard

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — August 2015 Survey

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 435.5 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
388	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	0	0	0	0	0	0
390	0	0	0	0	0	1	1	1	1	1
391	2	2	2	3	3	4	4	5	6	7
392	10	15	22	31	43	58	74	94	116	140
393	167	196	227	262	300	344	393	446	504	565
394	630	700	774	855	939	1,028	1,120	1,216	1,316	1,420
395	1,527	1,637	1,751	1,868	1,991	2,118	2,251	2,388	2,531	2,680
396	2,832	2,990	3,152	3,318	3,486	3,658	3,833	4,010	4,190	4,372
397	4,557	4,744	4,933	5,126	5,321	5,519	5,720	5,923	6,130	6,341
398	6,555	6,772	6,992	7,215	7,441	7,669	7,901	8,136	8,374	8,615
399	8,860	9,108	9,360	9,615	9,873	10,133	10,397	10,664	10,933	11,205
400	11,480	11,756	12,036	12,318	12,604	12,893	13,187	13,485	13,789	14,098
401	14,413	14,735	15,063	15,398	15,741	16,092	16,454	16,825	17,206	17,595
402	17,992	18,397	18,808	19,226	19,652	20,085	20,525	20,972	21,426	21,886
403	22,353	22,826	23,306	23,793	24,286	24,787	25,293	25,806	26,324	26,848
404	27,377	27,911	28,453	29,000	29,553	30,112	30,677	31,248	31,824	32,407
405	32,996	33,592	34,196	34,807	35,425	36,050	36,681	37,320	37,964	38,614
406	39,269	39,928	40,592	41,259	41,932	42,610	43,293	43,982	44,676	45,375
407	46,081	46,792	47,508	48,229	48,955	49,684	50,417	51,155	51,896	52,642
408	53,392	54,148	54,908	55,673	56,442	57,217	57,997	58,782	59,572	60,367
409	61,167	61,972	62,781	63,594	64,412	65,233	66,058	66,887	67,718	68,553
410	69,390	70,231	71,074	71,920	72,768	73,619	74,474	75,331	76,192	77,058
411	77,928	78,802	79,680	80,563	81,451	82,344	83,243	84,148	85,060	85,977
412	86,901	87,832	88,768	89,710	90,659	91,614	92,574	93,539	94,510	95,487
413	96,469	97,457	98,449	99,447	100,450	101,457	102,471	103,491	104,515	105,545
414	106,580	107,619	108,663	109,710	110,761	111,816	112,873	113,934	114,997	116,064
415	117,133	118,206	119,281	120,360	121,442	122,527	123,616	124,710	125,808	126,911
416	128,019	129,132	130,251	131,374	132,503	133,638	134,779	135,926	137,077	138,234
417	139,397	140,564	141,737	142,914	144,096	145,282	146,472	147,667	148,866	150,070
418	151,279	152,493	153,711	154,934	156,161	157,394	158,631	159,874	161,121	162,374
419	163,631	164,894	166,162	167,434	168,713	169,996	171,283	172,576	173,872	175,174
420	176,480	177,790	179,105	180,423	181,746	183,072	184,402	185,736	187,074	188,418
421	189,766	191,120	192,479	193,843	195,212	196,585	197,964	199,348	200,737	202,131
422	203,530	204,935	206,345	207,758	209,177	210,600	212,028	213,460	214,896	216,337
423	217,781	219,228	220,679	222,134	223,592	225,055	226,522	227,992	229,466	230,943
424	232,424	233,909	235,397	236,888	238,385	239,887	241,394	242,905	244,422	245,944
425	247,472	249,005	250,544	252,089	253,642	255,201	256,766	258,338	259,916	261,501
426	263,093	264,691	266,296	267,906	269,523	271,147	272,776	274,411	276,051	277,697
427	279,350	281,007	282,670	284,337	286,010	287,687	289,370	291,058	292,751	294,451
428	296,156	297,870	299,590	301,317	303,050	304,790	306,537	308,290	310,049	311,816
429	313,589	315,368	317,154	318,944	320,742	322,546	324,356	326,173	327,997	329,830
430	331,669	333,516	335,369	337,228	339,093	340,964	342,840	344,723	346,610	348,504
431	350,403	352,308	354,218	356,130	358,047	359,968	361,892	363,820	365,750	367,685
432	369,623	371,565	373,510	375,457	377,408	379,362	381,319	383,279	385,241	387,206
433	389,175	391,146	393,120	395,097	397,078	399,061	401,048	403,038	405,030	407,026
434	409,025	411,028	413,034	415,043	417,057	419,074	421,096	423,121	425,151	427,186
435	429,227	431,274	433,330	435,394	437,470	439,559	441,660	443,774	445,901	448,042

Appendix A (continued)

Lake Ray Hubbard

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | August 2015 Survey

CAPACITY IN ACRE-FEET | Conservation Pool Elevation 435.5 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
436	450,197	452,365	454,545	456,736	458,938	461,151	463,374	465,607	467,849	470,100
437	472,360	474,629	476,906	479,190	481,483	483,783	486,091	488,405	490,725	493,053
438	495,386	497,726	500,071	502,422	504,779	507,141	509,509	511,883	514,262	516,647
439	519,037	521,434	523,836	526,243	528,656	531,075	533,499	535,928	538,362	540,801
440	543,246	545,696	548,151	550,610	553,075	555,544	558,018	560,496	562,978	565,466
441	567,959	570,456	572,958	575,464	577,976	580,492	583,013	585,539	588,069	590,605
442	593,146	595,693	598,243	600,798	603,359	605,924	608,495	611,071	613,651	616,237
443	618,827	621,421	624,020	626,623	629,231	631,843	634,460	637,081	639,706	642,336
444	644,970	647,608	650,251	652,897	655,548	658,204	660,864	663,528	666,196	668,869
445	671,546	674,227	676,913	679,601	682,295	684,992	687,692	690,397	693,105	695,817
446	698,534	701,254	703,978	706,705	709,437	712,173	714,914	717,658	720,405	723,157
447	725,913	728,673	731,436	734,202	736,972	739,746	742,523	745,304	748,087	750,874
448	753,665	756,459	759,257	762,058	764,864	767,673	770,486	773,303	776,123	778,947
449	781,775	784,607	787,443	790,281	793,124	795,970	798,819	801,671	804,526	807,385
450	810,247									

Appendix B

Lake Ray Hubbard

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — August 2015 Survey

AREA IN ACRES — Conservation Pool Elevation 435.5 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
388	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	0	0	0	0	0	0
390	0	1	1	1	1	1	2	2	2	3
391	3	3	4	4	5	5	6	8	12	19
392	34	58	85	108	130	157	182	204	230	255
393	279	302	330	362	409	461	516	558	593	632
394	674	717	776	825	865	905	943	979	1,017	1,054
395	1,088	1,119	1,153	1,199	1,251	1,299	1,350	1,402	1,457	1,506
396	1,551	1,600	1,640	1,674	1,704	1,733	1,760	1,785	1,809	1,833
397	1,858	1,883	1,912	1,938	1,964	1,992	2,021	2,054	2,090	2,126
398	2,154	2,183	2,214	2,244	2,272	2,300	2,333	2,366	2,397	2,431
399	2,464	2,498	2,532	2,564	2,595	2,624	2,652	2,680	2,707	2,732
400	2,755	2,779	2,809	2,841	2,874	2,914	2,962	3,007	3,062	3,122
401	3,184	3,247	3,314	3,390	3,471	3,563	3,666	3,762	3,849	3,933
402	4,007	4,079	4,149	4,219	4,294	4,367	4,432	4,503	4,572	4,636
403	4,697	4,764	4,835	4,903	4,973	5,032	5,095	5,153	5,212	5,264
404	5,316	5,381	5,440	5,505	5,564	5,615	5,678	5,739	5,795	5,854
405	5,924	5,997	6,077	6,150	6,215	6,279	6,349	6,415	6,476	6,525
406	6,570	6,612	6,655	6,702	6,755	6,804	6,857	6,915	6,969	7,024
407	7,081	7,140	7,191	7,233	7,271	7,313	7,354	7,393	7,434	7,481
408	7,533	7,579	7,624	7,669	7,720	7,772	7,825	7,881	7,928	7,972
409	8,022	8,069	8,112	8,154	8,193	8,232	8,269	8,301	8,331	8,361
410	8,390	8,418	8,444	8,472	8,498	8,526	8,557	8,594	8,635	8,676
411	8,719	8,763	8,808	8,853	8,901	8,957	9,021	9,085	9,144	9,206
412	9,274	9,334	9,392	9,457	9,518	9,574	9,626	9,683	9,742	9,796
413	9,849	9,900	9,949	10,003	10,052	10,104	10,167	10,220	10,274	10,325
414	10,372	10,413	10,455	10,494	10,528	10,559	10,591	10,621	10,650	10,680
415	10,709	10,740	10,770	10,800	10,835	10,873	10,914	10,959	11,005	11,054
416	11,106	11,159	11,209	11,260	11,320	11,382	11,440	11,493	11,542	11,596
417	11,651	11,699	11,748	11,795	11,840	11,883	11,927	11,971	12,016	12,064
418	12,112	12,159	12,206	12,252	12,299	12,347	12,399	12,449	12,501	12,550
419	12,603	12,652	12,701	12,755	12,807	12,855	12,898	12,943	12,992	13,037
420	13,083	13,125	13,166	13,206	13,244	13,282	13,320	13,363	13,409	13,459
421	13,510	13,564	13,615	13,663	13,708	13,760	13,814	13,869	13,916	13,964
422	14,020	14,071	14,117	14,164	14,208	14,251	14,301	14,346	14,384	14,420
423	14,455	14,491	14,530	14,568	14,606	14,648	14,684	14,722	14,757	14,791
424	14,827	14,862	14,899	14,941	14,991	15,042	15,091	15,142	15,196	15,251
425	15,298	15,359	15,421	15,494	15,560	15,620	15,681	15,750	15,815	15,888
426	15,952	16,015	16,076	16,138	16,202	16,264	16,321	16,375	16,434	16,494
427	16,549	16,600	16,651	16,700	16,749	16,802	16,856	16,907	16,963	17,021
428	17,093	17,170	17,236	17,301	17,366	17,432	17,496	17,563	17,631	17,700
429	17,760	17,824	17,884	17,944	18,006	18,067	18,133	18,209	18,285	18,358
430	18,432	18,500	18,562	18,619	18,678	18,737	18,794	18,852	18,907	18,965
431	19,020	19,071	19,114	19,152	19,187	19,223	19,259	19,293	19,326	19,361
432	19,397	19,432	19,465	19,494	19,523	19,552	19,581	19,610	19,639	19,669
433	19,698	19,728	19,759	19,789	19,819	19,849	19,880	19,911	19,942	19,974
434	20,008	20,043	20,079	20,116	20,154	20,193	20,234	20,277	20,325	20,376
435	20,438	20,510	20,599	20,704	20,822	20,947	21,074	21,205	21,340	21,481

Appendix B (continued)

Lake Ray Hubbard

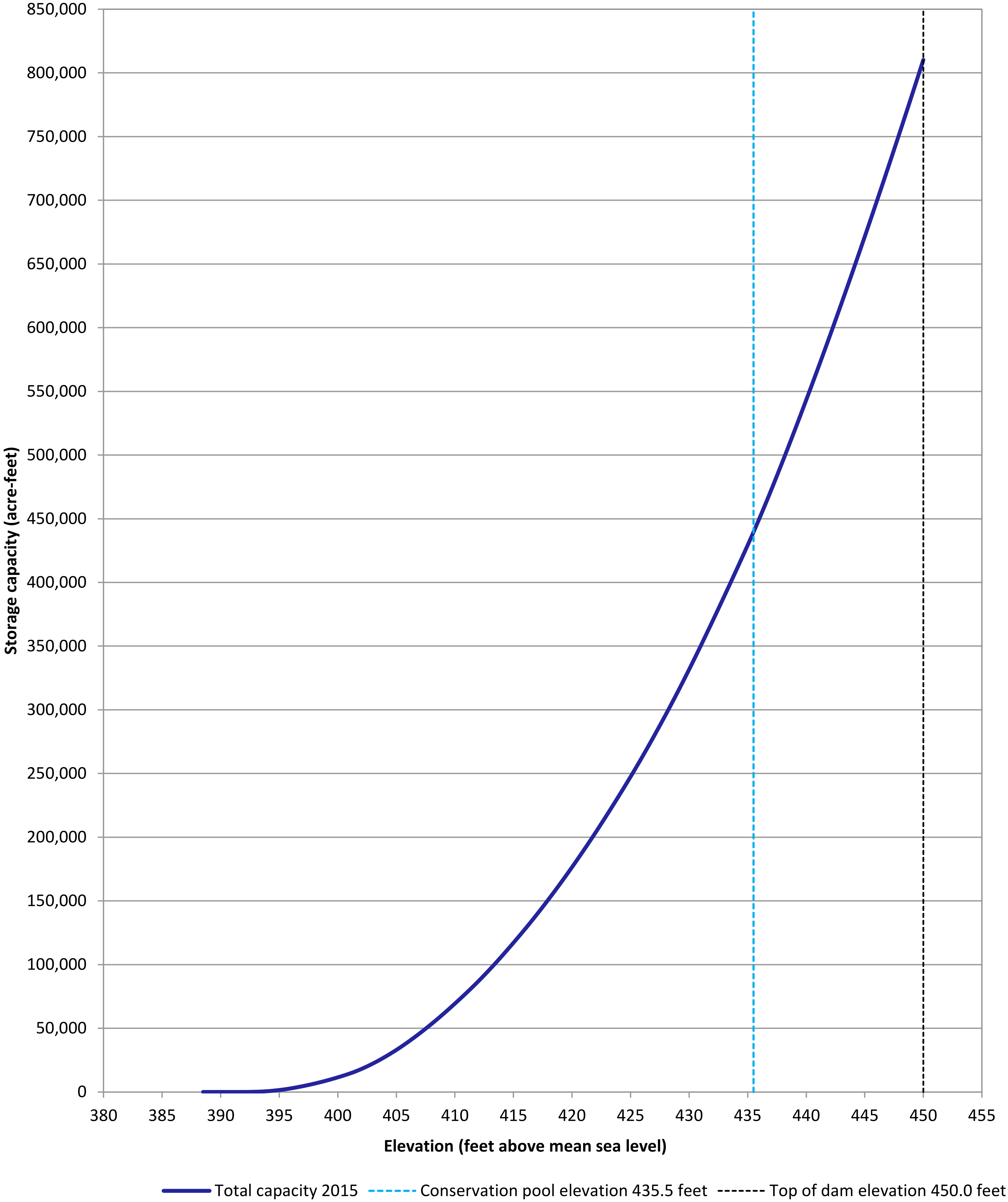
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — August 2015 Survey

AREA IN ACRES — Conservation Pool Elevation 435.5 feet NGVD29

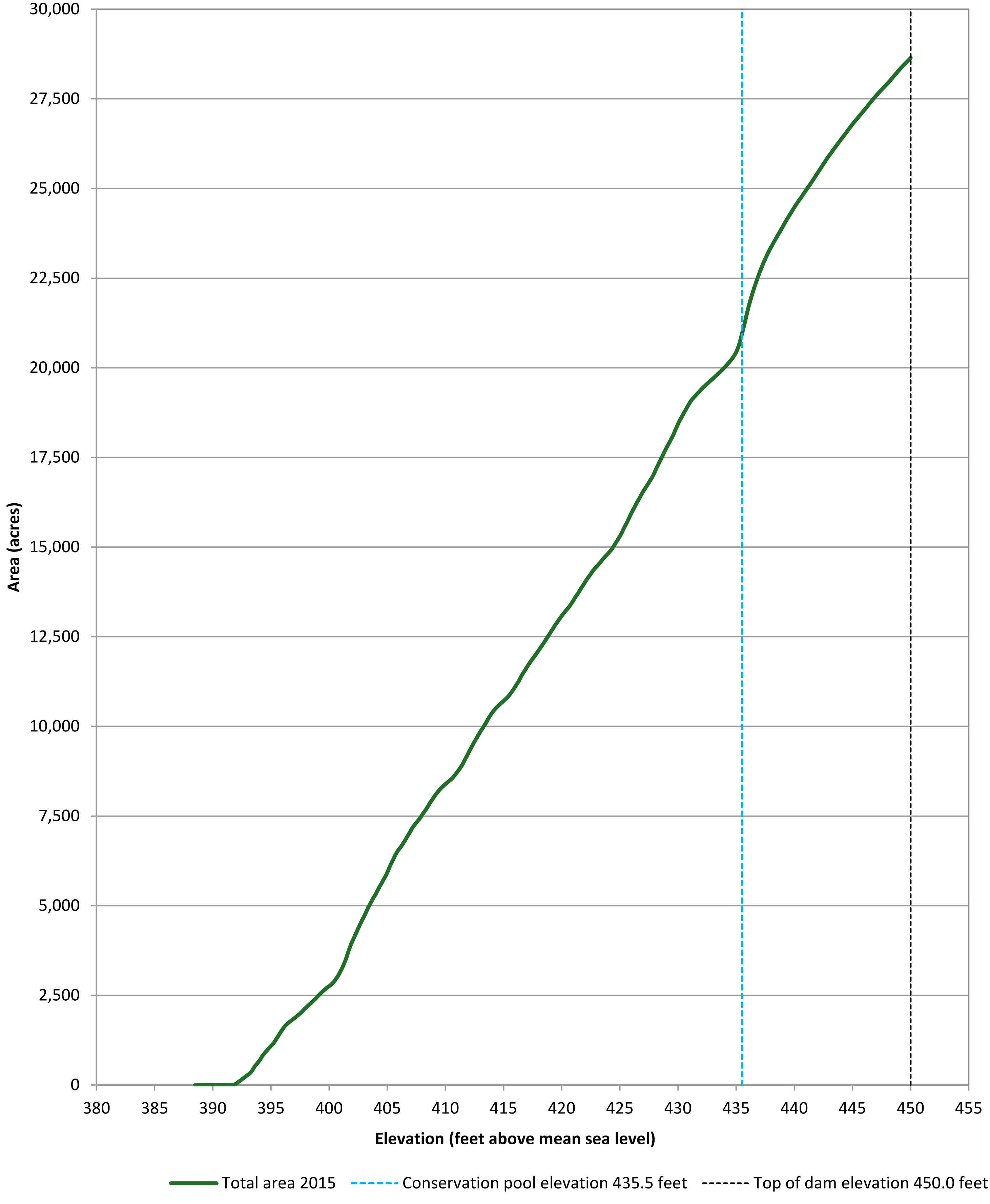
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
436	21,615	21,742	21,861	21,971	22,074	22,179	22,279	22,375	22,465	22,557
437	22,646	22,732	22,810	22,889	22,964	23,037	23,107	23,175	23,241	23,304
438	23,364	23,422	23,481	23,539	23,597	23,653	23,708	23,764	23,819	23,875
439	23,933	23,991	24,049	24,104	24,158	24,211	24,266	24,317	24,369	24,421
440	24,474	24,524	24,573	24,621	24,668	24,712	24,758	24,805	24,854	24,901
441	24,949	24,997	25,044	25,088	25,136	25,184	25,234	25,284	25,334	25,384
442	25,434	25,483	25,531	25,580	25,629	25,680	25,731	25,782	25,831	25,877
443	25,921	25,965	26,010	26,056	26,100	26,144	26,188	26,232	26,275	26,318
444	26,361	26,405	26,447	26,490	26,533	26,576	26,618	26,663	26,706	26,750
445	26,792	26,832	26,872	26,912	26,949	26,988	27,026	27,065	27,104	27,142
446	27,180	27,218	27,256	27,297	27,342	27,382	27,421	27,460	27,499	27,538
447	27,576	27,613	27,649	27,684	27,719	27,753	27,787	27,821	27,855	27,889
448	27,924	27,960	27,997	28,035	28,073	28,111	28,149	28,186	28,224	28,262
449	28,299	28,336	28,372	28,406	28,440	28,472	28,505	28,538	28,571	28,604
450	28,644									



Lake Ray Hubbard
August 2015 Survey
Prepared by: TWDB

Appendix C: Capacity curve



Lake Ray Hubbard
August 2015 Survey
Prepared by: TWDB

Appendix D: Area curve

Figure 6

Contours (feet)

450
448
446
444
442
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436
434
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424
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392
390

Lake Ray Hubbard elevation 435.5 feet NGVD29

Lake Ray Hubbard elevation 450.0 feet NGVD29

Islands at elevation 435.5 feet NGVD29

Islands at elevation 450.0 feet NGVD29

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