Volumetric and Sedimentation Survey of LAKE CORPUS CHRISTI

May 2012 Survey

Texas Water Development Board

September 2013

Texas Water Development Board

Prepared for:

City of Corpus Christi

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Executive summary

In March 2012 the Texas Water Development Board (TWDB) entered into agreement with the City of Corpus Christi, Texas, to perform a volumetric and sedimentation survey of Lake Corpus Christi. Surveying was performed using a multi-frequency (200 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.

Wesley E. Seale Dam and Lake Corpus Christi are located on the Nueces River in San Patricio and Jim Wells Counties, approximately 4 miles southwest of the City of Mathis, Texas. The conservation pool elevation of Lake Corpus Christi is 94.0 feet (NGVD29). TWDB collected bathymetric data for Lake Corpus Christi between March 1, 2012, and May 17, 2012. The daily average water surface elevations during the survey ranged between 81.57 and 82.82 feet (NGVD29).

Due to the low water surface elevations of the reservoir at the time of the survey, less than half the surface area of the reservoir was surveyed. The incomplete 2012 survey was augmented with the re-calculated 2002 TWDB survey data indicating a capacity of 254,732 acre-feet encompassing 18,700 acres at conservation pool elevation 94.0 feet (NGVD29). This estimate assumes that no sedimentation has occurred in the area of the reservoir where data could not be collected in 2012. The actual capacity at elevation 94.0 feet is likely less than this since some sedimentation is likely to have occurred since 2002 in areas where data could not be collected in 2012. Several previous capacity estimates for Lake Corpus Christi have been developed, most notably a 1957 survey estimate of 302,100 acre-feet, a 1972 survey estimate by McCaughan & Etheridge of 272,352 acre-feet, a 1987 USGS survey estimate of 266,832 acre-feet, and a re-calculation of the 1987 USGS survey by HDR, Inc. in 1991, of 241,241 acre-feet. The TWDB volumetric survey conducted in 2002 was re-evaluated using current processing procedures resulting in an updated capacity estimate of 262,337 acre-feet.

The total volume of sediment measured during the 2012 sedimentation survey was 22,616 acre-feet. In the area of the reservoir surveyed, the greatest sediment accumulation is occurring downstream of the confluence of Penitas Creek with the Nueces River and upstream of the old La Fruta Dam. Another area of higher accumulation is west of the cities of Lakeside and Lake City. TWDB recommends that a similar methodology be used to resurvey Lake Corpus Christi when it is full again 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. 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 March 2012 TWDB entered into agreement with the City of Corpus Christi, Texas, to perform a volumetric and sedimentation survey of Lake Corpus Christi (TWDB, 2012). 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 Corpus Christi, Texas 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 5], (3) a shaded relief plot of the reservoir bottom [Figure 3], and (4) an estimate of sediment accumulation and location [Figure 10].

Lake Corpus Christi general information

Wesley E. Seale Dam and Lake Corpus Christi are located on the Nueces River in San Patricio and Jim Wells Counties, approximately 4 miles southwest of Mathis, Texas. The reservoir also inundates part of Live Oak County (Figure 1). Wesley E. Seale Dam and Lake Corpus Christi are owned and operated by the City of Corpus Christi (COCC, 2013a). Construction of Wesley E. Seale Dam began on November 19, 1955. The dam was completed and impoundment of water began on April 26, 1958 (TWDB, 1967a).

Approximately 1,000 feet upstream of the Wesley E. Seale Dam, submerged beneath Lake Corpus Christi, are the remains of two previous dams that impounded the waters of the Nueces River (TWDB, 1967b, COCC, 1998). Mathis Dam and Lake Lovenskiold was completed in 1929. A partial failure of the dam in 1930 led to the creation of a new dam, known as La Fruta Dam, at the same location in 1934. The elevation of the crest of the spillway of Mathis Dam was 74.0 feet above mean sea level. Part of the uncontrolled Mathis Dam spillway was replaced with a controlled spillway for La Fruta Dam with a spillway crest of 54.0 feet above mean sea level, and a top-of-gates elevation of 74.0 feet above mean sea level. When Wesley E. Seale Dam was built, the old dam was breached by removing several feet of the embankment and the taintor gates prior to inundation (TWDB, 1967b).

Construction of Lake Corpus Christi was possible due to state legislation creating the Lower Nueces River Water Supply District for the purpose of financing through bond issue a large reservoir for Corpus Christi and the surrounding area. The City of Corpus Christi was then obligated to repay all the bonds by purchasing the water of the reservoir from the District for 30 years. In 1986, at the repayment of all debt, ownership of the dam was transferred to the City of Corpus Christi and the Lower Nueces River Water Supply District dissolved by the Texas Legislature (COCC, 1998, COCC, 2013a, Texas Legislature, 2013, LegiScan, 2013).

Lake Corpus Christi, in conjunction with Choke Canyon Reservoir, is primarily a water supply reservoir for the City of Corpus Christi and the Coastal Bend (COCC, 3013b). The City of Corpus Christi Water Department serves approximately 500,000 citizens with water for municipal and industrial purposes throughout a seven-county service area (COCC, 2013b). Additional pertinent data about Wesley E. Seale Dam and Lake Corpus Christi can be found in Table 1.

Water rights for Lake Corpus Christi have been appropriated to the City of Corpus Christi through Certificate of Adjudication No. 21-2464. The complete certificate is on file in the Information Resources Division of the Texas Commission on Environmental Quality.

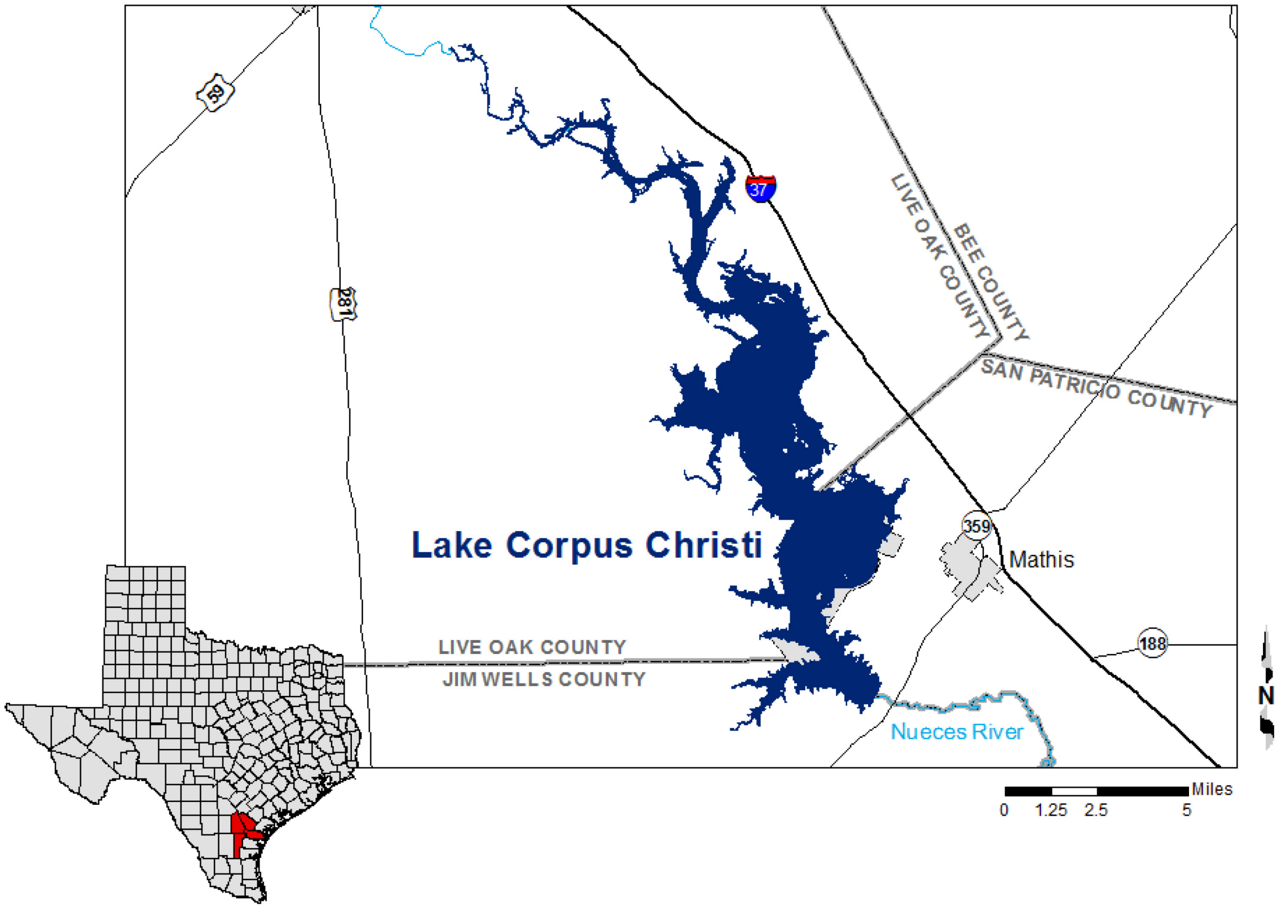


Figure 1. Location of Lake Corpus Christi

Table 1. Pertinent data for Wesley E. Seale Dam and Lake Corpus Christi	
Owner	
City of Corpus Christi, Texas	
Engineer (design)	
Ambursen Engineering Company (dam and original gates)	
Forrest and Cotton, Inc. (modification of gates, completed September 4, 1966)	
General contractor for the dam	
H.B. Zachry Co.	
Location of dam	
On the Neuces River in San Patricio and Jim Wells Counties, approximately 4 miles southwest of Mathis, Texas	
Drainage area	
16,656 square miles	
Dam	
Type	Earthfill and concrete
Length (including gates)	5,980 feet
Height	75 feet
Top width	varies 15 to 51 feet
Spillway (north or emergency)	
Type	Concrete section
Control (screw type hoists, and portable engines)	33 gates, each 37.5 by 8.75 feet
Spillway crest elevation	88.0 feet above mean sea level
Top of gates elevation	94.3 feet above mean sea level
Spillway (south or service)	
Type	Concrete section
Control (screw type hoists, and electric motors)	27 gates, each 37.5 by 8.75 feet
Spillway crest elevation	88.0 feet above mean sea level
Top of gates elevation	93.8 feet above mean sea level
Outlet works	
Type	3 openings, each 2.5 by 4 feet
Control	48-inch cylinder valve
Invert elevation	55.5 feet above mean sea level
Water flows in river channel to treating plant.	

Source: (TWDB, 1971, CCOC, 2013)
[a] NGVD29 = National Geodetic Vertical Datum 1929

Volumetric and sedimentation survey of Lake Corpus Christi

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 08210500 Lk Corpus Christi nr Mathis, 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 South Central Zone (feet).

TWDB bathymetric and sedimentation data collection

TWDB collected bathymetric data for Lake Corpus Christi between March 1, 2012, and May 17, 2012. The daily average water surface elevations during the survey ranged between 81.57 and 82.82 (NGVD29). 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 collection occurred while navigating 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 survey lines were also surveyed by TWDB during the 2002 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 2012 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. Following the analysis of the sounding data, TWDB selected six locations to collect sediment core samples (Figure 2). The sediment core samples were collected on June 18, 2013, 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, through the accumulated sediment, and to the pre-impoundment surface. After retrieving the sample, a stadia rod is inserted into the top of the tube to assist in locating the top of the sediment in the tube. This identifies the location of the layer corresponding to the current reservoir 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.

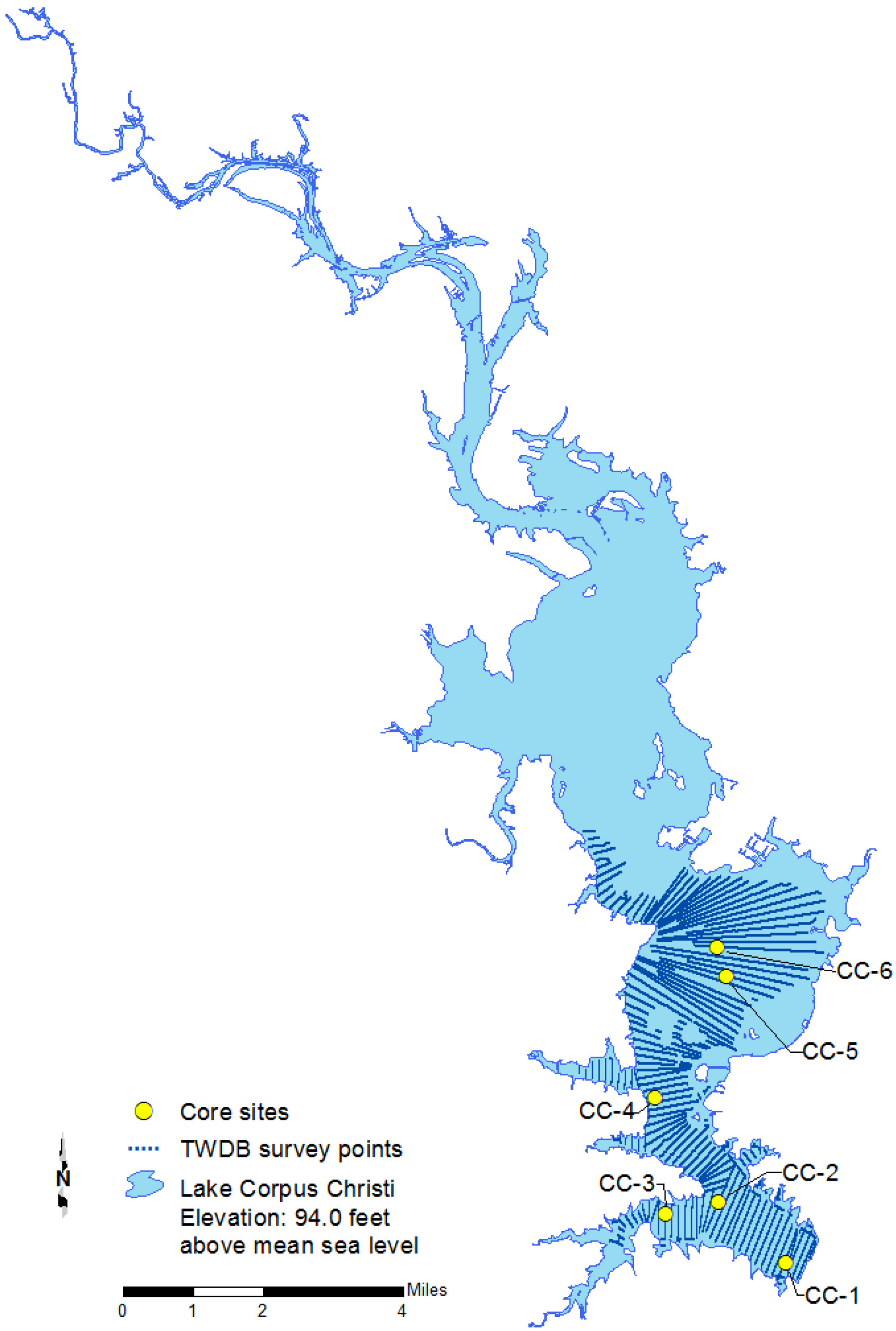


Figure 2. Data collected during 2012 TWDB Lake Corpus Christi survey

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 Corpus Christi are Sandia (NE, NW, SE, SW), Mathis (NW, SW), Tynan (SW), Dinero (NE, NW, SE, SW), Mulos Hills (SW), and George West (SE). The DOQQs were photographed on June 2, 2004 (Sandia NE, Sandia SE, Dinero NE, and Dinero SE), October 11, 2004 (Sandia NW, Sandia SW, Dinero NW, Dinero SW, Mulos Hills SW, and George West SE), and November 3, 2004 (Mathis NW, Mathis SW, and Tynan SW), while the daily average water surface elevation measured 94.04, 94.15, and 93.95 feet, respectively. The 2004 DOQQs have a resolution or ground sample distance of 1.0-meters and a horizontal accuracy within ± 5 meters to existing mosaicked digital orthorectified imagery (USDA, 2013). For this analysis, the boundary was digitized at the land-water interface in the 2004 photographs and given an elevation of 94.0 feet for modeling purposes.

Additional boundary information was obtained from aerial photographs taken on May 19, 2006, while the water surface elevation measured 84.98 feet, and May 22, 2012, while the water surface elevation measured 83.1 feet. Contours were digitized at the land-water interface in the photos to determine the reservoir surface area at these elevations to assist with interpolating the reservoir area where no data was collected due to low water surface elevations during the time of the survey. The contours were also added to the TIN model as points to visually improve the model for mapping purposes. According to metadata associated with the 2006 DOQQs, the photographs have a resolution or ground sample distance of 2.0-meters and a horizontal accuracy within ±10 meters to baseline imagery (USDA, 2007, USDA, 2013). 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). The contours were given elevations of 85.0 feet and 83.1 feet, respectively, to simplify calculations. The 94.0 and 85.0 feet contours were validated against the LIDAR data where LIDAR data was available; see the following section titled "LIDAR".

LIDAR

Light Detection and Ranging Data is available from the Texas Natural Resource Information System (TNRIS, 2013a). LIDAR for San Patricio County was collected between July 10, 2006, and July 15, 2006. The daily average water surface elevation of the reservoir during this period ranged between 84.02 feet and 84.12 feet above mean sea level during this time. The LIDAR data was added to the TIN model solely to visually improve the model for mapping purposes because the extent of the LIDAR data was not much more extensive than the extent of the survey data. To add the points, only LIDAR data with a classification equal to 2, or ground, was extracted from the .las files. Then the LIDAR data was filtered to include only every 10^{th} point to reduce computational burden. All data above elevation 94.0 feet and below elevation 84.0 feet were deleted, as was any remaining data outside the 94.0 foot contour digitized from the 2004 aerial photographs.

The LIDAR data points have an average spacing of 1.4 meters; therefore, using a thinned point dataset did not significantly affect the modeled topography of the coverage area. No interpolation of the data in the areas of LIDAR coverage was necessary. After the points were clipped to within the boundary, the shapefile was projected to NAD83 State Plane Texas South Central Zone (feet), and new attribute fields were added to first convert the elevations from meters NAVD88 to meters NGVD29, then to feet NGVD29. The horizontal datum of the LIDAR data is Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83) Zone 14 and the vertical datum is North American Vertical Datum 1988 (NAVD88). According to the associated metadata, the LIDAR data has a vertical accuracy of ±18 centimeters.

To make the LIDAR data compatible with the bathymetric survey data, it was necessary to transform the LIDAR data to NGVD29 (vertical) and State Plane Texas South Central NAD83 (horizontal) coordinates. Horizontal coordinate transformations were done using the ArcGIS Project tool. Vertical coordinate transformations were done by applying a single vertical offset to all LIDAR data. The offset was determined by applying the National Oceanic and Atmospheric Administration National Geodetic Survey's NADCON software (NGS, 2013a) and VERTCON software (NGS, 2013b) to a single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 08210500 Lk Corpus Christi nr Mathis, TX,* of Latitude 28º02'17", Longitude 97º52'15" NAD27. The resulting conversion factor of 0.076 meters was added to all LIDAR 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 manually digitizing the reservoir-bottom surface at the time of initial impoundment (i.e. pre-impoundment surface). For processing outside of DepthPic©, an in-house software package, HydroTools, is used to identify the current reservoir-bottom surface, pre-impoundment surface, sediment thickness at each sounding location, and output the data into a single file. The water surface 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 spatial interpolation of reservoir bathymetry section below. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen et al., 2011). 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 from direct examination of 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 extrapolation is used for volumetric and sediment accumulation estimations. 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 may not be 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 Corpus Christi in the following situations: in small coves of the main body of the reservoir and in obvious channel features using the 2012 aerial photographs as guidance and the 2002 survey data as needed to extend the lines in the 2012 survey (Figure 3).

Figure 3 illustrates typical results from application of the anisotropic spatial interpolation and linear extrapolation techniques to Lake Corpus Christi. 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 reservoir bathymetry between survey cross-sections.

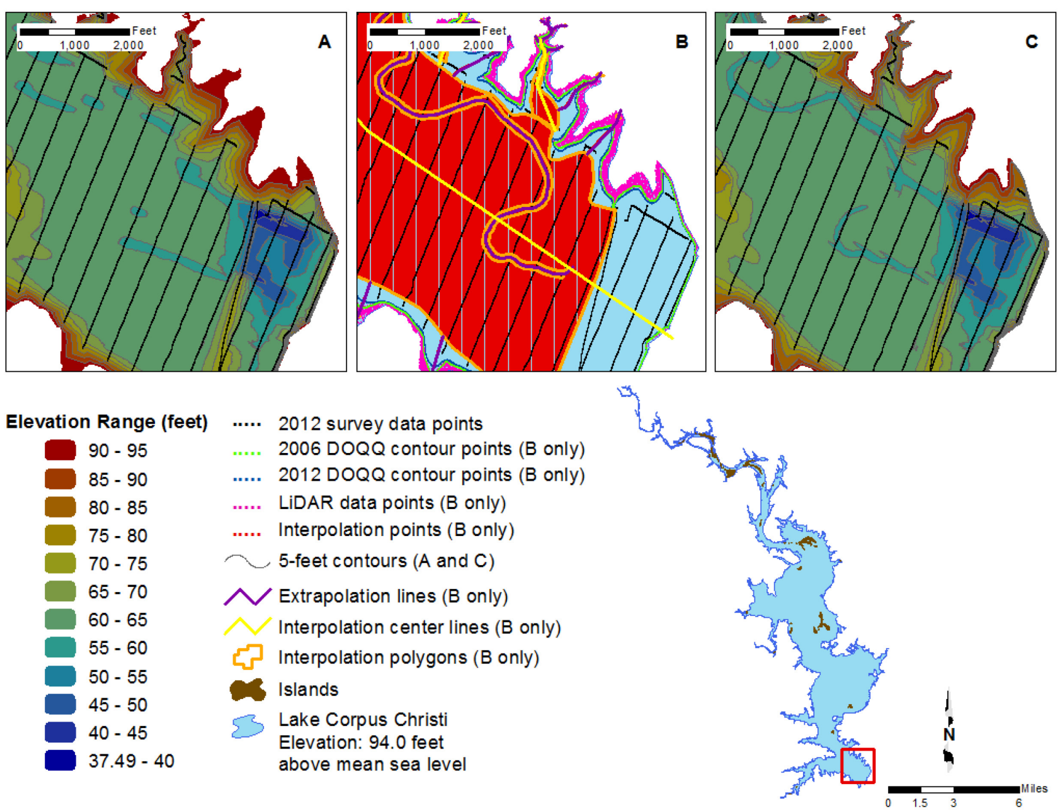


Figure 3. Anisotropic spatial interpolation and linear extrapolation of Lake Corpus Christi sounding data – A) bathymetric contours without interpolated points, B) sounding points(black) and interpolated points (red), C) bathymetric contours with the interpolated points

Area, volume, and contour calculations

Using ArcInfo software and the 2012 volumetric TIN model, volumes and areas were calculated from elevation 37.5 to 94.0 feet. However, these calculations are based on an incomplete survey of the reservoir due to low reservoir water surface elevations during the time of the survey. Because of low reservoir levels, data could not be obtained by conventional bathymetric survey methods for more than half of the reservoir area. While relatively current elevation data beyond the survey data is available from aerial photographs, the addition of only two contours is not enough information to adequately model the relationship between elevation and area. If the TIN model were developed in this area of the reservoir with only two contours, the creation of anomalous "flat triangles", that is triangles whose three vertices all have the same elevation, would likely occur. The flat triangles in turn lead to anomalous calculations of surface area and volume between known elevations.

Therefore, to calculate the elevation-area-capacity tables up to conservation pool elevation, 94.0 feet, the 2012 survey estimates were augmented with the re-calculated estimates from the 2002 TWDB survey. Specifically, the area and capacity calculated from a TIN model of the upper portion of the reservoir using 2002 survey data was added to the area and capacity of a TIN model of the lower portion of the reservoir calculated with the 2012 survey data. The elevation-capacity table and elevation-area table are presented in Appendices A and B, respectively. The area-capacity curves are presented in Appendix C. The area-capacity curves show both the incomplete 2012 curves and the augmented curves resulting from the addition of the 2002 values.

The 2012 volumetric TIN model and the upper half of the 2002 TIN model were 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 Corpus Christi; and a 5-foot contour map (Figure 6 - attached).

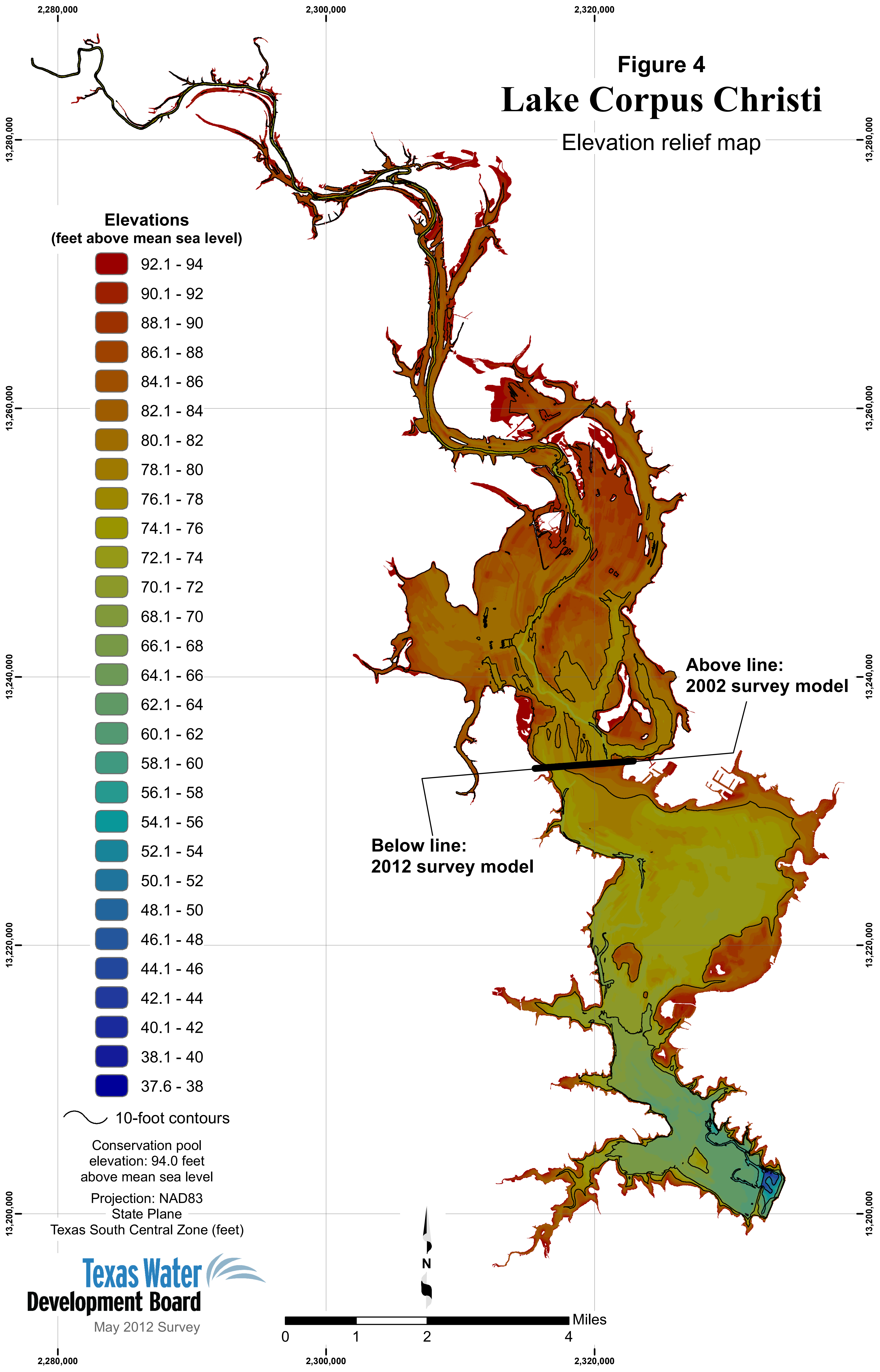


Figure 4
Lake Corpus Christi
Elevation relief map
Elevations
(feet above mean sea level)
92.1 - 94
90.1 - 92
88.1 - 90
86.1 - 88
84.1 - 86
82.1 - 84
80.1 - 82
78.1 - 80
76.1 - 78
74.1 - 76
72.1 - 74
70.1 - 72
68.1 - 70
66.1 - 68
64.1 - 66
62.1 - 64
60.1 - 62
58.1 - 60
56.1 - 58
54.1 - 56
52.1 - 54
50.1 - 52
48.1 - 50
46.1 - 48
44.1 - 46
42.1 - 44
40.1 - 42
38.1 - 40
37.6 - 38
10-foot contours
Conservation pool elevation: 94.0 feet above mean sea level
Projection: NAD83 State Plane Texas South Central Zone (feet)
Above line: 2002 survey model
Below line: 2012 survey model
N
Miles
0
1
2
4
2,280,000
2,300,000
2,320,000
13,280,000
13,260,000
13,240,000
13,220,000
13,200,000
Texas Water Development Board
May 2012 Survey

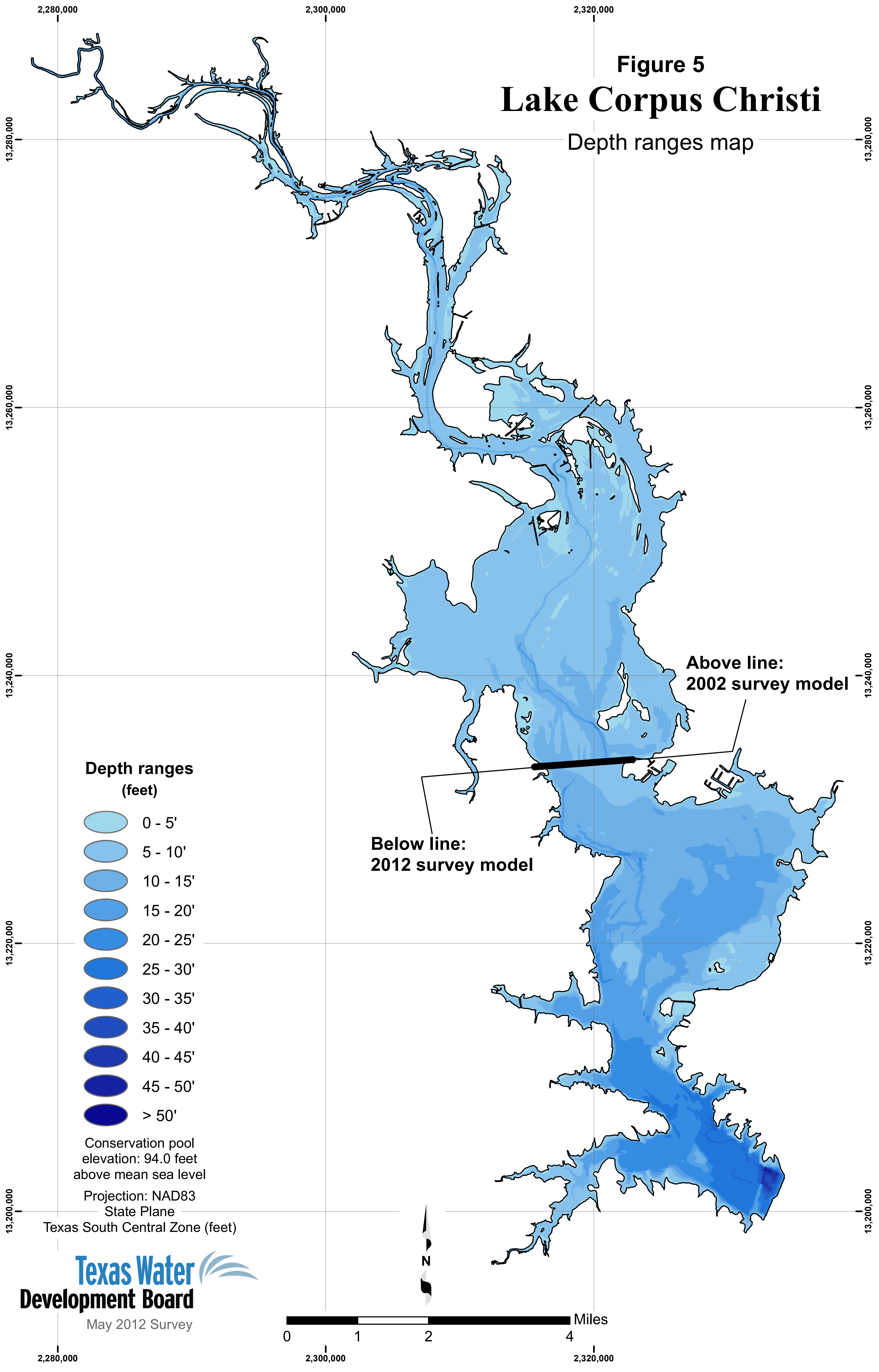


Figure 5
Lake Corpus Christi
Depth ranges map
Above line:
2002 survey model
Below line:
2012 survey model
Depth ranges
(feet)
0 - 5'
5 - 10'
10 - 15'
15 - 20'
20 - 25'
25 - 30'
30 - 35'
35 - 40'
40 - 45'
45 - 50'
> 50'
Conservation pool
elevation: 94.0 feet
above mean sea level
Projection: NAD83
State Plane
Texas South Central Zone (feet)
Texas Water
Development Board
May 2012 Survey
N
Miles
0
1
2
4
2,280,000
2,300,000
2,320,000
13,280,000
13,260,000
13,240,000
13,220,000
13,200,000

Analysis of sediment data from Lake Corpus Christi

Sedimentation in Lake Corpus Christi was determined by analyzing the acoustic signal returns of all three depth sounder frequencies in the DepthPic© software. The 200 kHz signal was analyzed to determine the current bathymetric surface of the reservoir, while all three frequencies, 200 kHz, 50 kHz, and 24 kHz, were analyzed to determine the reservoir bathymetric surface at the time of initial impoundment (i.e. pre-impoundment surface). Sediment core samples collected in the reservoir were used to assist in identifying the location of the pre-impoundment surface in the acoustic signals. The difference between the current surface and the pre-impoundment surface yields a sediment thickness value at each sounding location.

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 both of the following methods: (1) a visual examination of the sediment core for organic 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 color, texture, relative water content, and presence of organic materials, were also recorded (Table 2).

Table 2. Sediment core sampling analysis data – Lake Corpus Christi

Core	Easting[a] (ft)	Northing[a] (ft)	Total core sample/ post-impoundment sediment	Sediment core description	Munsell soil color
CC-1	2331803.78	13200858.61	120”/N/A”	0-120” high water content, silty sediment, some compaction with depth, pre-impoundment surface undefined	2.5Y 4/1
CC-2	2326784.76	13205394.57	38.5”/32.5”	0-24” high water content, silty sediment	2.5Y 4/1
				24-32.5” high water content, denser than layer above, silty sediment	2.5Y 4/1
				32.5-38.5” dense, low water content, organics and roots present, clay soil	5Y 2.5/1
CC-3	2322720.08	13204498.47	36.5”/36.0”	0-36” high water content, silty sediment	2.5Y 4/1
				36-36.5” high water content, sandy clay sediment, some organics present	2.5Y 4/1
CC-4	2321958.46	13213293.97	57.5”/57.5”	0-57.5” high water content, loamy clay sediment, organics found in sediment left in bottom cap	10YR 4/1
CC-5	2327368.30	13222494.34	27.5”/22”	0-22” high water content, silt	10YR 4/1
				22-27.5” sandy clay, organics present	5Y 2.5/1
CC-6	2326691.35	13224720.66	21.5”/16”	0-16” high water content, silt	2.5Y 4/1
				16-21.5” clay loam, organics present	2.5YR 2.5/1

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

A photograph of sediment core CC-3 is shown in Figure 7 and is representative of the sediment cores sampled from Lake Corpus Christi. The 200 kHz frequency measures the top layer as the current bottom surface of the reservoir.

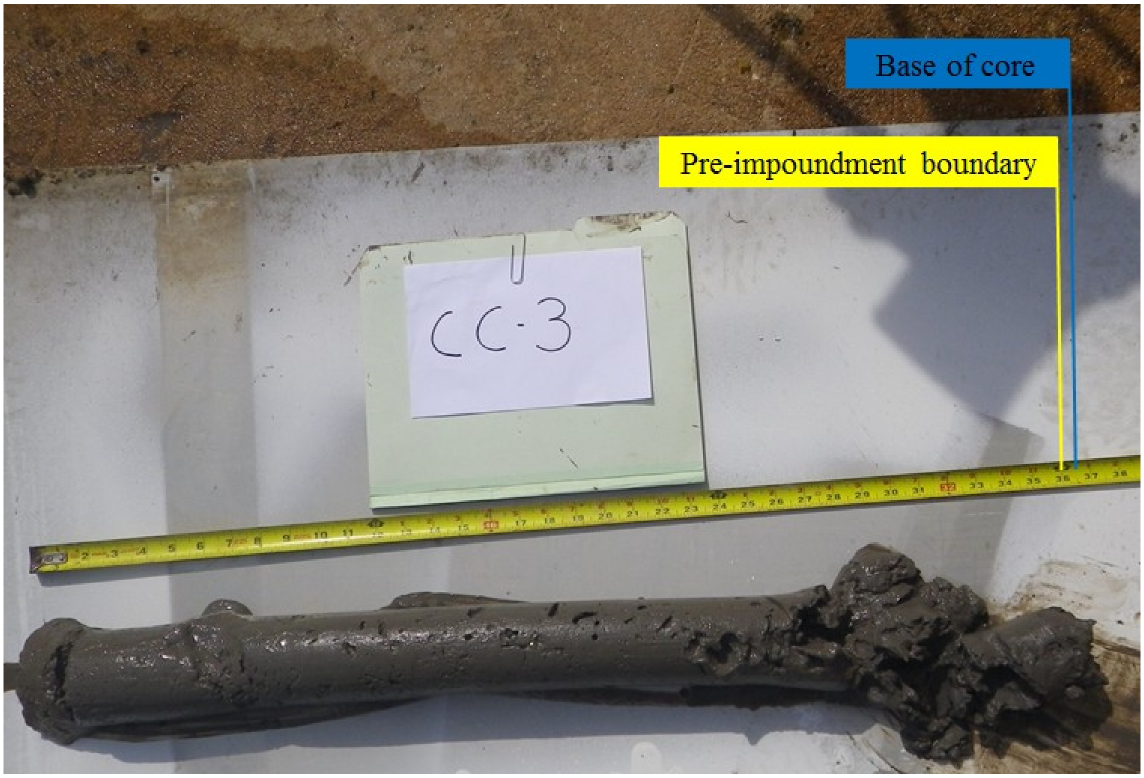


Figure 7. Sediment core CC-3 from Lake Corpus Christi

Sediment core sample CC-3 consisted of 36.5 inches of total sediment. The upper sediment layer (horizon), 0-36.0 inches, consisted of high water content, silty sediment, and measured 2.5Y 4/1 on the Munsell soil color chart. The second horizon, beginning at 36.0 inches and extending to 36.5 inches below the surface, consisted of high water content, sandy clay sediment, organics present, and measured 2.5Y 4/1 on the Munsell soil color chart. The base of the sample is denoted by the blue line in Figure 7.

The pre-impoundment boundary (yellow line in Figure 7) was evident within this sediment core sample at 36.0 inches and identified by the presence of organics. Identification of the pre-impoundment surface for the remaining sediment cores followed a similar procedure.

Figures 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. Within DepthPic©, the current surface is automatically determined based on signal returns from the 200 kHz transducer and verified by TWDB staff, while the pre-impoundment surface must be determined visually. The pre-impoundment surface is first identified along cross-sections for which sediment core samples have been collected.

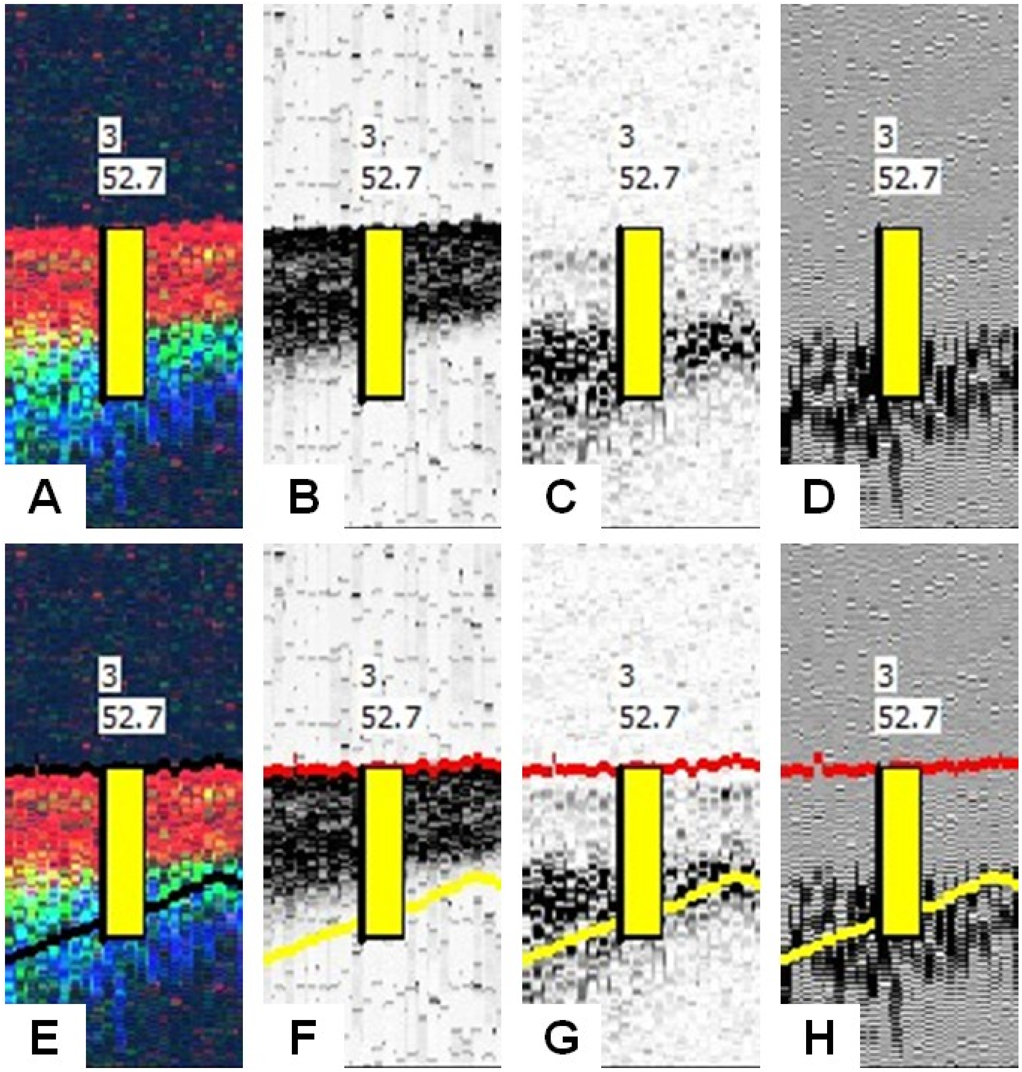


Figure 8. Comparison of sediment core CC-3 with acoustic signal returns A,E) combined acoustic signal returns, B,F) 200 kHz frequency, C,G) 50 kHz frequency, D,H) 24 kHz frequency

Figure 8 compares sediment core sample CC-3 with the acoustic signals for all frequencies combined (A, E), 200 kHz (B, F), 50 kHz (C, G), and 24 kHz (D, H). The sediment core sample is represented in each figure as colored boxes. The yellow box represents post-impoundment sediment. In Figure 8A-D, the bathymetric surfaces are not shown. In Figure 8E, the current bathymetric surface is represented as the top black line and in Figures 8 F-H as the top red line. The pre-impoundment surface is identified by comparing boundaries observed in the 200 kHz, 50 kHz, and 24 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Each sediment core sample was compared to all three frequencies and the boundary in the 200 kHz signal most closely matched the pre-impoundment interface of the sediment core samples; therefore, the 200 kHz signal was used to locate the pre-impoundment layer. The pre-impoundment surface was manually drawn and is represented by the bottom black line in Figure 8E, and by the yellow line in Figures 8F-H. Figure 9 shows sediment core sample CC-3 correlated with the 200 kHz frequency of the nearest surveyed cross-section. The pre-impoundment surface identified along cross-sections where sediment core samples were collected is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

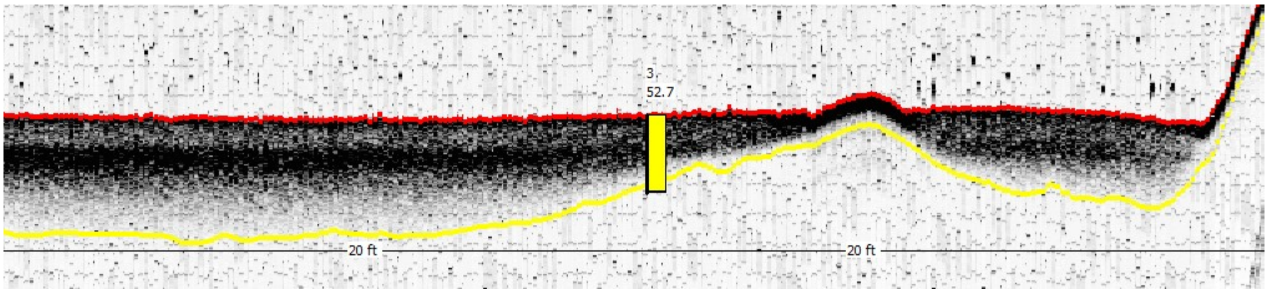


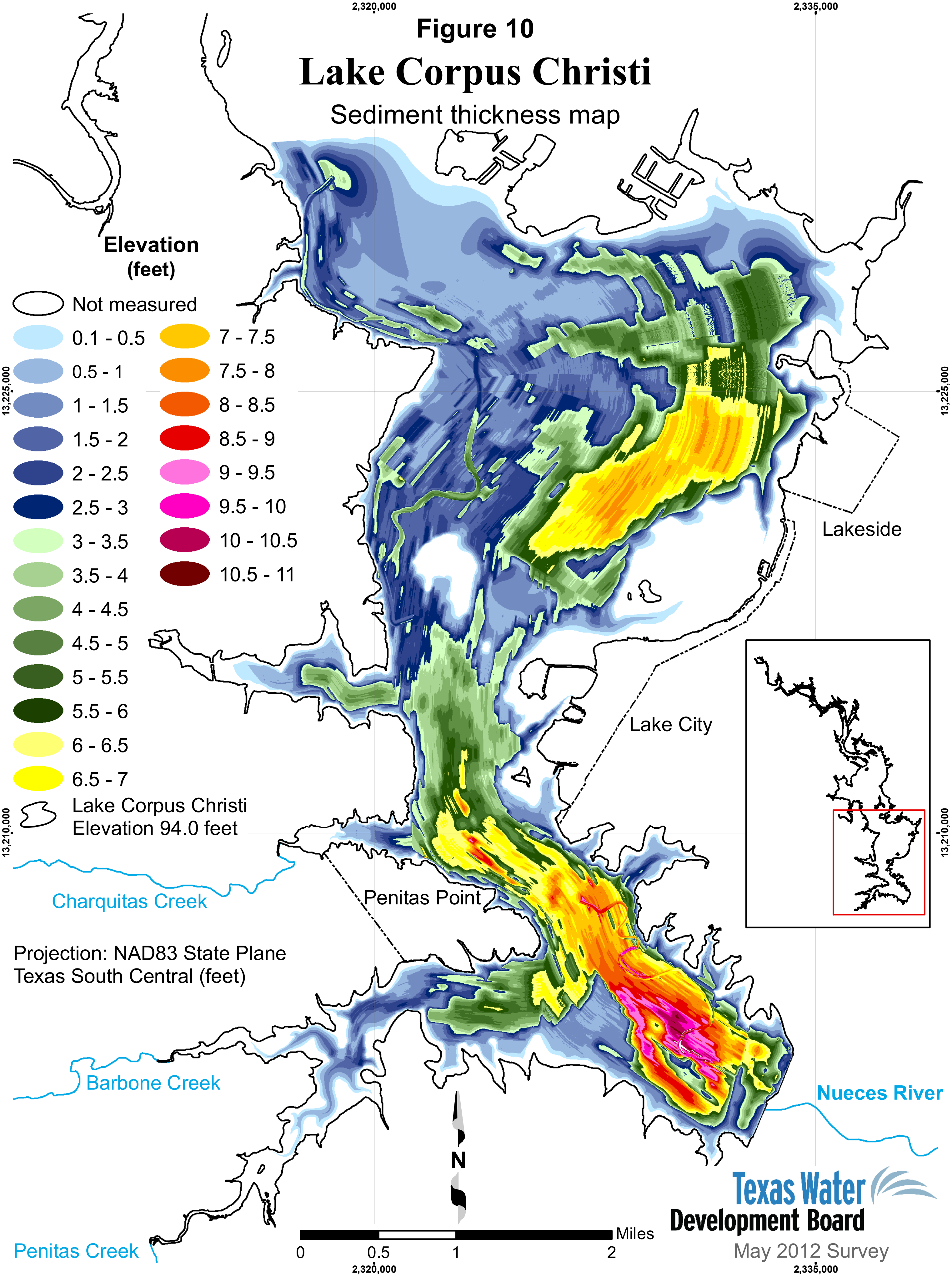
Figure 9. Cross-section of data collected during 2012 survey, displayed in DepthPic© (200 kHz frequency), correlated with sediment core sample CC-3 and showing the current surface in red and pre-impoundment surface in yellow

After the pre-impoundment surface from all cross-sections was identified, a sediment thickness TIN model is created following standard GIS techniques (Furnans, 2007). Sediment thicknesses were interpolated between surveyed cross-sections using HydroTools with the same interpolation definition file used for bathymetric interpolation. For the purposes of the TIN model creation, TWDB assumed sediment thickness at the reservoir boundary and contours was zero feet (defined as the 94.0 foot NGVD29, 83.1 foot, and 85.0 foot elevation contours). The sediment thickness TIN model was converted to a raster representation using a cell size of 5 feet by 5 feet and used to produce a sediment thickness map of Lake Corpus Christi (Figure 10).

Figure 10

Lake Corpus Christi

Sediment thickness map



Projection: NAD83 State Plane Texas South Central (feet)

Texas Water Development Board

May 2012 Survey

Survey results

Volumetric survey

Due to the low water surface elevations of the reservoir at the time of the survey, less than half the surface area of the reservoir was surveyed. The incomplete 2012 survey was augmented with the re-calculated 2002 survey data to estimate a capacity of 254,732 acre-feet encompassing 18,700 acres at conservation pool elevation 94.0 feet (NGVD29). This estimate assumes that no sedimentation has occurred in the area of the reservoir where data could not be collected in 2012. The actual capacity at elevation 94.0 feet is likely less than this since some sedimentation is likely to have occurred since 2002 in areas where data could not be collected in 2012.

Lake Corpus Christi has been surveyed several times since impoundment and many area and capacity tables have been generated in an effort to understand sedimentation within the reservoir (Table 3). A 1957 survey indicated the reservoir had a capacity of 302,100 acre-feet encompassing 22,050 acres (TWDB, 1967b). In 1972, McCaughan & Etheridge conducted a survey resulting in a reservoir capacity of 272,352 acre-feet encompassing 19,336 acres. McCaughan & Etheridge re-calculated the 1957 capacities using the original areas but applying a modified prismoidal formula instead of the typical average area method. The re-calculation of the 1957 tables resulted in a capacity of 297,776 acre-feet (McCaughan & Etheridge, 1973). In addition, McCaughan & Etheridge created a topographic map of the reservoir for 1948 conditions and generated area and capacity tables based on the contours resulting in a capacity estimate of 292,758 acre-feet encompassing 19,860 acres (McCaughan & Etheridge, 1972). The USGS conducted a survey in 1987, resulting in a total reservoir capacity of 266,832 acre-feet encompassing 18,883 acres. The City of Corpus Christi discovered an error in the USGS calculations and in 1991, HDR, Inc. planimetered the USGS contours developed during the 1987 survey, and developed new tables with a re-calculated total capacity of 241,241 acre-feet encompassing 19,251 acres (COCC, 1991, HDR, 2002). The city used the re-calculated tables until the reservoir was surveyed by TWDB in 2002. HDR, Inc. also reviewed TWDB's 2002 survey results and determined they were reasonable by plotting the results of each of the previous capacity estimates, 302,100 (1957), 272,352 (1972), 266,832 (1988), 241,241 (1991), and 257,260 (2002) to visualize the slope of the change between surveys. HDR, Inc. determined that the 1957 estimate is probably questionable because it was likely developed using USGS 15-minute quadrangle map contours rather than more accurate USGS 7.5-minute contours

(HDR, 2002). However, according to McCaughan & Etheridge, the 1957 tables were generated by Reagan & McCaughan at the request of the Lower Nueces River Water Supply District using more up-to-date cross-sectional information used by the Soil Conservation Service in their 1942 and 1948 survey reports (McCaughan & Etheridge, 1973). HDR, Inc. also determined that the 1988 USGS estimate, while it may have contained an error, still resulted in a reasonable estimate of the reservoir capacity at that time (HDR, 2002). The 1991 re-calculated capacity calculations resulted in generated sedimentation rates that were higher than all other previous surveys (USDI, 1992), but deemed reasonable due to the difference between the 1957 and 1972 surveys (HDR, 2002). 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 Corpus Christi, TWDB applied the 2013 data processing techniques to the survey data collected in 2002. Specifically, TWDB applied anisotropic spatial interpolation to the 2002 survey dataset. However, the interpolation polygons had to be expanded to include data in areas that were accessible for data collection in 2002, but not in 2012. A new volumetric TIN model was created using the original 2002 survey boundary. The 2002 survey boundary was digitized from aerial photographs taken by Tobin International of San Antonio on January 25, 2002, while the daily average water surface elevation measured 94.1 feet. The original 2002 TIN model also incorporated contours digitized from aerial photos taken on January 15, 1995, January 31, 1995, February 1, 1995, and January 21, 1996, while the daily average water surface elevation generated from an 0800 and 1600 hour reading measured 88.13, 88.07, 88.04, and 87.32 feet respectively (TNRIS, 2013b, TWDB, 2002). These contours were not added to the new TIN model because the interpolation of the survey data was sufficient to represent the bathymetry. Re-evaluation of the 2002 survey using current TWDB data processing methods resulted in a 5,077 acre-feet (2.0 percent) increase in reservoir capacity (Table 3).

Table 3. Current and previous survey capacity and surface area data

Survey*	Surface area (acres)	Total capacity (acre-feet)
1948[a]	19,860	292,758
1957[b]	22,050	302,100
1957 re-calculated by McCaughan & Etheridge[a]	22,050	297,776
McCaughan & Etheridge 1972[a]	19,336	272,352
USGS 1987[c]	18,883	266,832
USGS 1987 re-calculated by HDR Inc. 1991[d]	19,251	241,241
TWDB 2002	18,286	257,260
TWDB 2002 re-calculated	18,487	262,337
TWDB 2012[e]	18,700	254,732

[a] Source: (McCaughan & Etheridge, 1973)
[b] Source: (TWDB, 1966)
[c] Source: (West, et al., 1987)
[d] Source: (COCC, 1991)
[e] Note: this is based on an incomplete survey of the lake in 2012 and is based partially on survey data from 2002.

Sedimentation survey

Due to the low water surface elevations of the reservoir at the time of the survey, sediment could only be measured throughout a relatively small section of the reservoir. The total volume of sediment measured during the 2012 survey was 22,616 acre-feet. In the area of the reservoir surveyed, the greatest sediment accumulation occurred downstream of the confluence of Penitas Creek with the Nueces River and upstream of the old La Fruta Dam. Another area of higher accumulation was west of the cities of Lakeside and Lake City.

Recommendations

To improve estimates of sediment accumulation rates, TWDB recommends resurveying Lake Corpus Christi when it is full again or after a major flood event. To further improve estimates of sediment accumulation, TWDB recommends another sedimentation survey. A resurvey would allow a more accurate quantification of the average sediment accumulation rate for Lake Corpus Christi.

TWDB contact information

More information about the Hydrographic Survey Program can be found at:
http://www.twdb.texas.gov/surfacewater/surveys/index.asp
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Appendix A

Lake Corpus Christi

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — May 2012 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 94.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

Table developed from incomplete 2012 survey estimates augmented with re-evaluated 2002 TWDB survey estimates

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	1	1
40	1	1	1	1	1	1	1	2	2	2
41	2	2	2	3	3	3	3	4	4	4
42	5	5	5	6	6	7	7	7	8	8
43	9	9	10	10	11	11	12	12	13	13
44	14	14	15	16	16	17	17	18	19	19
45	20	21	22	22	23	24	25	26	27	28
46	29	30	31	32	33	34	36	37	38	39
47	41	42	43	45	46	48	49	51	53	54
48	56	58	60	61	63	65	67	69	71	73
49	75	77	79	82	84	86	89	91	93	96
50	98	101	103	106	109	111	114	117	120	123
51	126	128	131	134	137	141	144	147	150	153
52	157	160	163	167	170	173	177	180	184	187
53	191	195	198	202	206	210	213	217	221	225
54	229	233	237	241	245	250	254	258	262	267
55	271	276	280	285	289	294	299	304	309	314
56	319	324	329	334	339	345	350	355	361	366
57	372	378	383	389	395	401	407	413	420	426
58	433	440	447	454	461	469	476	484	493	501
59	510	519	528	538	548	558	568	578	589	600
60	611	622	634	646	659	672	686	700	715	730
61	746	763	781	800	819	839	861	883	906	930
62	955	982	1,009	1,037	1,066	1,096	1,127	1,161	1,197	1,235
63	1,276	1,320	1,367	1,417	1,471	1,526	1,583	1,642	1,703	1,765
64	1,828	1,893	1,960	2,028	2,097	2,168	2,241	2,315	2,392	2,470
65	2,551	2,633	2,718	2,804	2,892	2,981	3,073	3,166	3,261	3,359
66	3,458	3,559	3,661	3,766	3,873	3,981	4,092	4,206	4,322	4,441
67	4,562	4,685	4,812	4,940	5,071	5,203	5,337	5,472	5,609	5,748
68	5,889	6,032	6,177	6,324	6,472	6,622	6,774	6,927	7,082	7,237
69	7,394	7,552	7,712	7,873	8,035	8,199	8,364	8,531	8,700	8,871
70	9,043	9,218	9,396	9,576	9,758	9,942	10,128	10,317	10,508	10,701
71	10,896	11,094	11,295	11,499	11,708	11,920	12,136	12,356	12,579	12,807
72	13,038	13,274	13,514	13,758	14,008	14,264	14,528	14,799	15,078	15,367
73	15,667	15,976	16,291	16,614	16,944	17,282	17,629	17,985	18,351	18,727
74	19,111	19,504	19,907	20,320	20,743	21,174	21,615	22,065	22,524	22,991
75	23,467	23,952	24,444	24,945	25,453	25,968	26,489	27,017	27,550	28,090
76	28,635	29,185	29,742	30,305	30,873	31,448	32,028	32,615	33,209	33,808
77	34,414	35,026	35,644	36,267	36,897	37,532	38,172	38,819	39,471	40,130
78	40,796	41,468	42,147	42,834	43,528	44,229	44,938	45,655	46,380	47,111
79	47,850	48,594	49,345	50,102	50,866	51,636	52,411	53,192	53,979	54,773
80	55,573	56,381	57,198	58,023	58,856	59,699	60,552	61,416	62,290	63,175
81	64,070	64,977	65,896	66,825	67,765	68,718	69,682	70,658	71,645	72,644
82	73,653	74,672	75,702	76,742	77,792	78,852	79,922	81,001	82,090	83,189
83	84,296	85,413	86,547	87,690	88,842	90,004	91,175	92,356	93,546	94,746
84	95,955	97,173	98,401	99,642	100,894	102,156	103,426	104,706	105,994	107,291
85	108,598	109,917	111,244	112,579	113,921	115,272	116,631	117,996	119,369	120,748
86	122,134	123,527	124,927	126,333	127,747	129,167	130,594	132,028	133,469	134,917
87	136,371	137,833	139,302	140,778	142,261	143,752	145,250	146,756	148,270	149,792
88	151,322	152,860	154,405	155,959	157,520	159,088	160,664	162,248	163,840	165,440
89	167,049	168,666	170,291	171,923	173,564	175,211	176,866	178,527	180,196	181,870
90	183,551	185,238	186,930	188,628	190,332	192,041	193,756	195,476	197,202	198,931
91	200,666	202,405	204,148	205,896	207,648	209,405	211,166	212,931	214,701	216,474
92	218,253	220,035	221,822	223,614	225,410	227,210	229,015	230,824	232,638	234,455
93	236,277	238,102	239,932	241,767	243,605	245,448	247,296	249,148	251,005	252,866
94	254,732									

Appendix B

Lake Corpus Christi

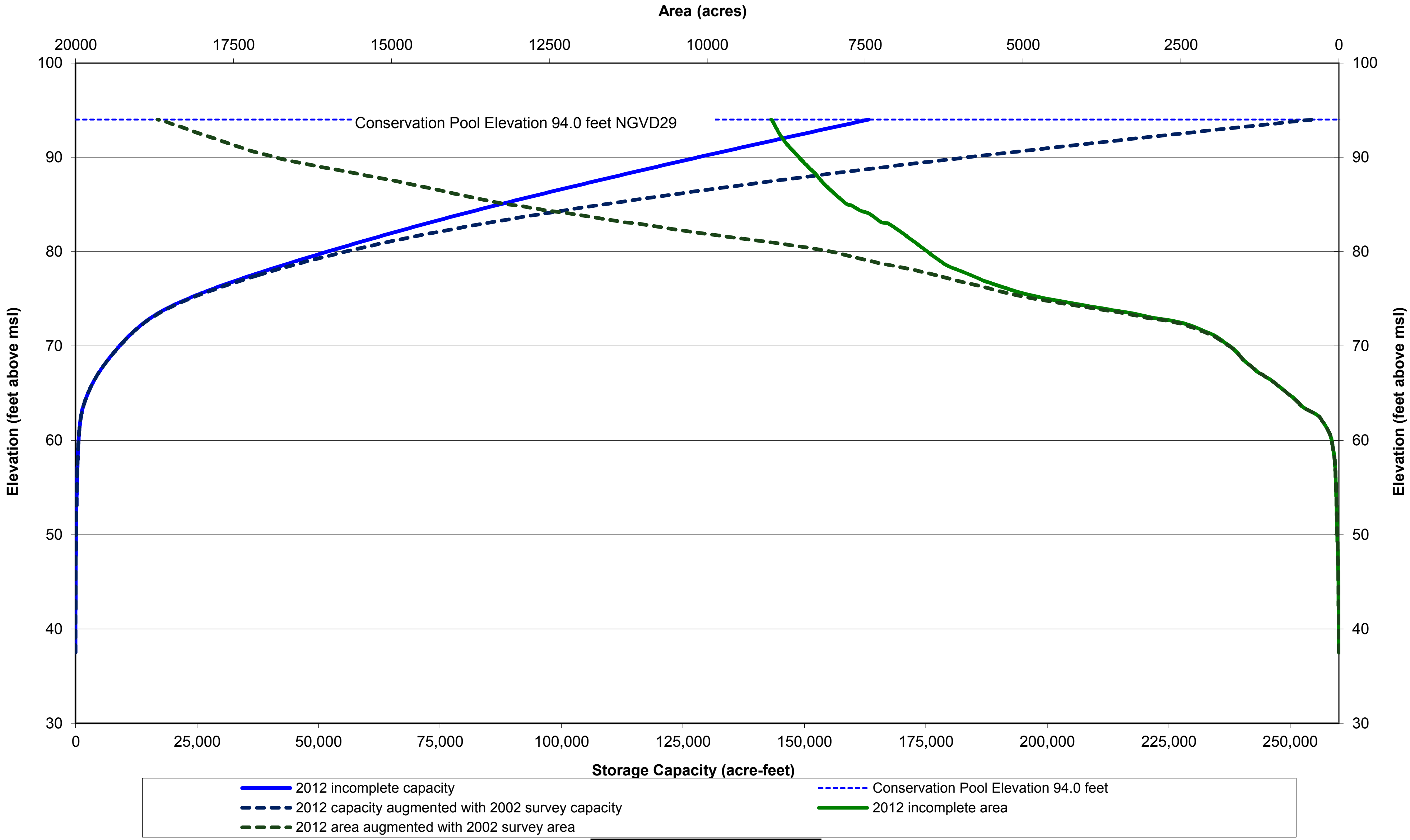
RESERVOIR AREA TABLE

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

May 2012 Survey
Conservation pool elevation 94.0 feet NGVD29

Table developed from incomplete 2012 survey estimates augmented with re-evaluated 2002 TWDB survey estimates

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	1	1	1
40	1	1	1	1	1	1	1	2	2	2
41	2	2	2	2	3	3	3	3	3	3
42	3	3	4	4	4	4	4	4	4	4
43	5	5	5	5	5	5	5	5	5	6
44	6	6	6	6	6	6	6	6	7	7
45	7	7	8	8	8	9	9	9	10	10
46	10	11	11	11	11	12	12	12	13	13
47	14	14	14	15	15	15	16	16	16	17
48	17	18	18	18	19	19	20	20	20	21
49	21	22	22	22	23	23	24	24	24	25
50	25	26	26	26	27	27	28	28	28	29
51	29	29	30	30	31	31	31	32	32	32
52	33	33	34	34	34	35	35	35	36	36
53	36	37	37	37	38	38	38	39	39	39
54	40	40	41	41	42	42	42	43	43	44
55	45	45	46	46	47	47	48	48	49	50
56	51	51	52	52	53	54	54	55	55	56
57	56	57	58	58	59	60	61	63	64	65
58	67	69	71	73	74	77	79	81	84	86
59	89	92	94	97	99	101	103	106	108	110
60	113	116	120	124	128	134	140	145	151	157
61	165	173	181	191	200	208	217	227	236	247
62	258	267	275	285	295	307	326	347	370	396
63	423	455	488	520	542	562	583	600	614	628
64	640	656	672	689	704	718	732	754	777	796
65	816	834	850	869	889	906	924	943	963	982
66	1,000	1,018	1,037	1,056	1,076	1,098	1,122	1,151	1,174	1,195
67	1,223	1,252	1,276	1,296	1,314	1,328	1,344	1,362	1,382	1,400
68	1,419	1,440	1,458	1,475	1,494	1,509	1,524	1,538	1,550	1,563
69	1,575	1,588	1,601	1,616	1,632	1,647	1,662	1,678	1,696	1,716
70	1,739	1,762	1,785	1,810	1,833	1,854	1,876	1,898	1,919	1,941
71	1,967	1,994	2,023	2,060	2,102	2,143	2,181	2,216	2,252	2,292
72	2,335	2,379	2,422	2,470	2,528	2,602	2,670	2,743	2,843	2,951
73	3,049	3,122	3,186	3,261	3,343	3,424	3,513	3,609	3,715	3,794
74	3,882	3,980	4,079	4,182	4,273	4,364	4,457	4,541	4,625	4,719
75	4,805	4,888	4,967	5,043	5,117	5,182	5,244	5,306	5,365	5,422
76	5,478	5,538	5,598	5,656	5,712	5,776	5,840	5,901	5,964	6,028
77	6,089	6,148	6,207	6,265	6,321	6,377	6,434	6,494	6,557	6,622
78	6,688	6,758	6,830	6,903	6,976	7,051	7,126	7,206	7,286	7,350
79	7,413	7,478	7,541	7,605	7,667	7,725	7,782	7,842	7,903	7,968
80	8,041	8,123	8,208	8,294	8,379	8,480	8,579	8,691	8,796	8,899
81	9,015	9,128	9,235	9,344	9,471	9,585	9,700	9,816	9,928	10,035
82	10,145	10,249	10,350	10,450	10,550	10,647	10,746	10,844	10,937	11,029
83	11,122	11,296	11,384	11,475	11,570	11,665	11,759	11,857	11,951	12,044
84	12,136	12,227	12,348	12,468	12,569	12,661	12,752	12,840	12,927	13,017
85	13,148	13,230	13,310	13,389	13,468	13,547	13,621	13,690	13,758	13,826
86	13,896	13,964	14,032	14,099	14,167	14,238	14,307	14,375	14,443	14,511
87	14,580	14,653	14,724	14,796	14,872	14,946	15,021	15,099	15,177	15,259
88	15,339	15,417	15,497	15,571	15,645	15,723	15,799	15,876	15,963	16,045
89	16,130	16,209	16,286	16,366	16,441	16,511	16,582	16,649	16,716	16,779
90	16,838	16,895	16,951	17,008	17,063	17,118	17,179	17,228	17,275	17,321
91	17,367	17,412	17,457	17,501	17,544	17,588	17,631	17,674	17,717	17,761
92	17,805	17,849	17,893	17,938	17,982	18,026	18,069	18,112	18,154	18,195
93	18,237	18,279	18,322	18,365	18,408	18,452	18,497	18,543	18,590	18,638
94	18,700									



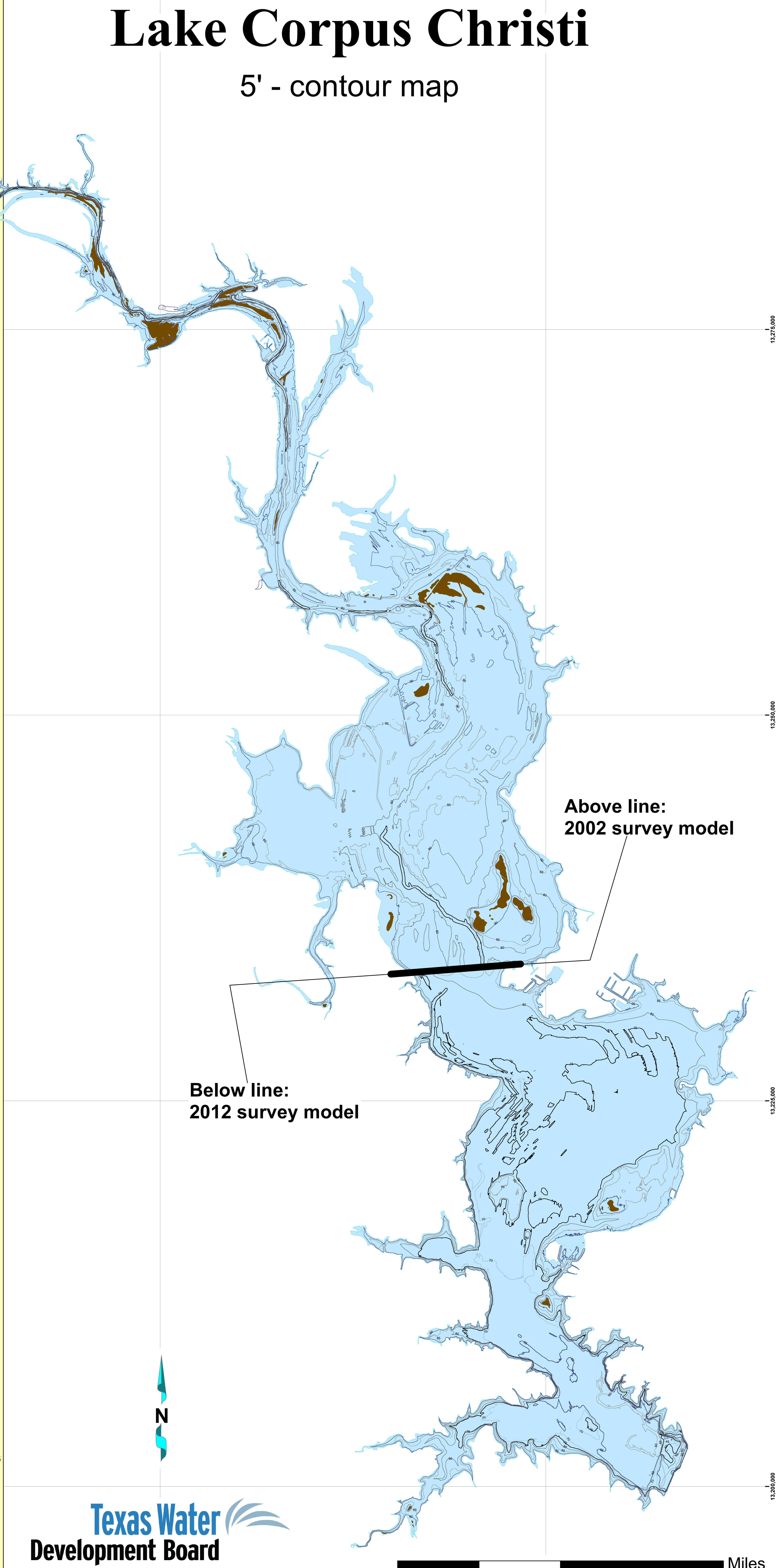
Lake Corpus Christi
May 2012 Survey
Prepared by: TWDB

Appendix C: Area and Capacity Curves

Figure 6

Lake Corpus Christi

5' - contour map



CONTOURS
(feet above mean sea level)

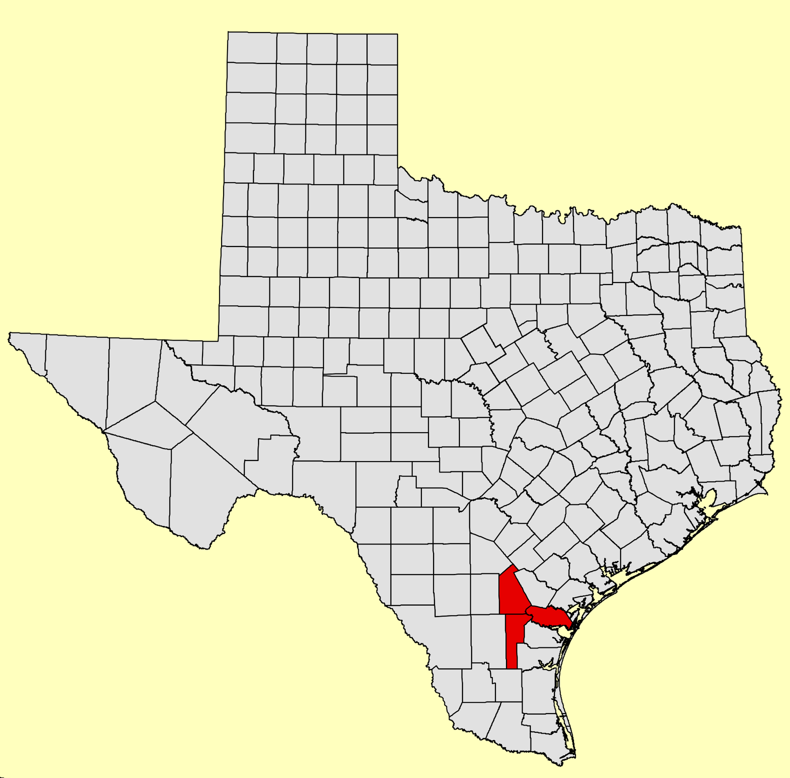
90
85
80
75
70
65
60
55
50
45
40

Islands

Lake Corpus Christi

Conservation Pool Elevation
94.0 feet above mean sea level

Projection: NAD83
State Plane
Texas South Central Zone



San Patricio, Jim Wells, and Live Oak Counties

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

Texas Water Development Board

May 2012 survey