Volumetric and Sedimentation Survey of BARDWELL LAKE

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Executive summary

In September 2020, the Texas Water Development Board (TWDB) entered into an agreement with the City of Waxahachie to perform a volumetric and sedimentation survey of Bardwell Lake (Ellis County, Texas). Surveying was performed using a multi-frequency (208 kHz, 50 kHz, and 12 kHz), sub-bottom profiling depth sounder. Sediment core samples were collected and correlated with sub-bottom acoustic profiles to estimate sediment accumulation thicknesses and sedimentation rates.

Bardwell Dam and Bardwell Lake are located on Waxahachie Creek in Ellis County, approximately 5 miles south of Ennis, Texas. The conservation pool elevation of Bardwell Lake is 421.00 feet above mean sea level (NGVD29). The TWDB collected bathymetric data for Bardwell Lake on July 24 and July 29, 2020, while the daily average water surface elevation measured 421.05 and 420.98 feet above mean sea level (NGVD29), respectively.

The 2020 TWDB volumetric survey indicates Bardwell Lake has a total reservoir capacity of 43,917 acre-feet and encompasses 3,292 acres at conservation pool elevation (421.00 feet above mean sea level, NGVD29).

Previous capacity estimates at conservation pool elevation (421.00 feet above mean sea level, NGVD29) include an original design estimate of 54,877 acre-feet, a 1972 U.S. Army Corps of Engineers estimate of 52,291, a 1981 U.S. Army Corps of Engineers estimate of 46,621, and a 1999 TWDB volumetric survey estimate re-calculated using current processing procedures, of 46,837 acre-feet. Because of differences in past and present survey methodologies, direct comparison of volumetric surveys to others to estimate loss of area and capacity can be unreliable.

The 2020 TWDB sedimentation survey measured 5,396 acre-feet of sediment. The sedimentation survey indicates sediment accumulation is accumulating throughout the reservoir. The TWDB recommends that a similar methodology be used to resurvey Bardwell Lake in 10 years or after a major high flow event.

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Note: References to brand names throughout this report do not imply endorsement by the Texas Water Development Board

Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. Texas Water Code Section 15.804 authorizes the TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In September 2020, the TWDB entered into an agreement with the City of Waxahachie to perform a volumetric and sedimentation survey of Bardwell Lake (Texas Water Development Board, 2020). This report provides an overview of the survey methods, analysis techniques, and associated results. Also included are the following contract deliverables: (1) a shaded elevation relief plot of the reservoir bottom (Figure 4), (2) a 2-foot bottom contour map (Figure 6), (3) an estimate of sediment accumulation and location (Figure 9), and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality (Appendices E and F).

Bardwell Lake general information

Bardwell Dam and Bardwell Lake are located on Waxahachie Creek in Ellis County, approximately 5 miles south of Ennis, Texas (Figure 1). Bardwell Lake is owned by the United States (U.S.) Government and maintained by the U.S. Army Corps of Engineers (USACOE), Fort Worth District. Construction of the Bardwell Lake project began on August 28, 1963. Deliberate impoundment of water began on November 20, 1965, and the dam was completed on March 27, 1966. (Texas Water Development Board, 1971). The reservoir was built for flood control, water conservation, recreation, and other beneficial use (U.S. Army Corps of Engineers, 2021a). Additional pertinent data about Bardwell Dam and Bardwell Lake can be found in Table 1.

Water rights for Bardwell Lake are appropriated to the Trinity River Authority through Certificate of Adjudication 08-5021 and Amendment to Certificate of Adjudication Nos. 08-5021A, 08-5021B, 08-5021C, and 08-5021D. Amendments to Certificate of Adjudication 08-5021 authorize the Ellis County Water Control and Improvement District No. 1 to divert water from Bardwell Lake for municipal and industrial purposes pursuant to a water supply contract with the Trinity River Authority (Texas Commission on Environmental Quality, 2020). The complete permits are on file with the Water Availability Division in the Office of Water at the Texas Commission on Environmental Quality.

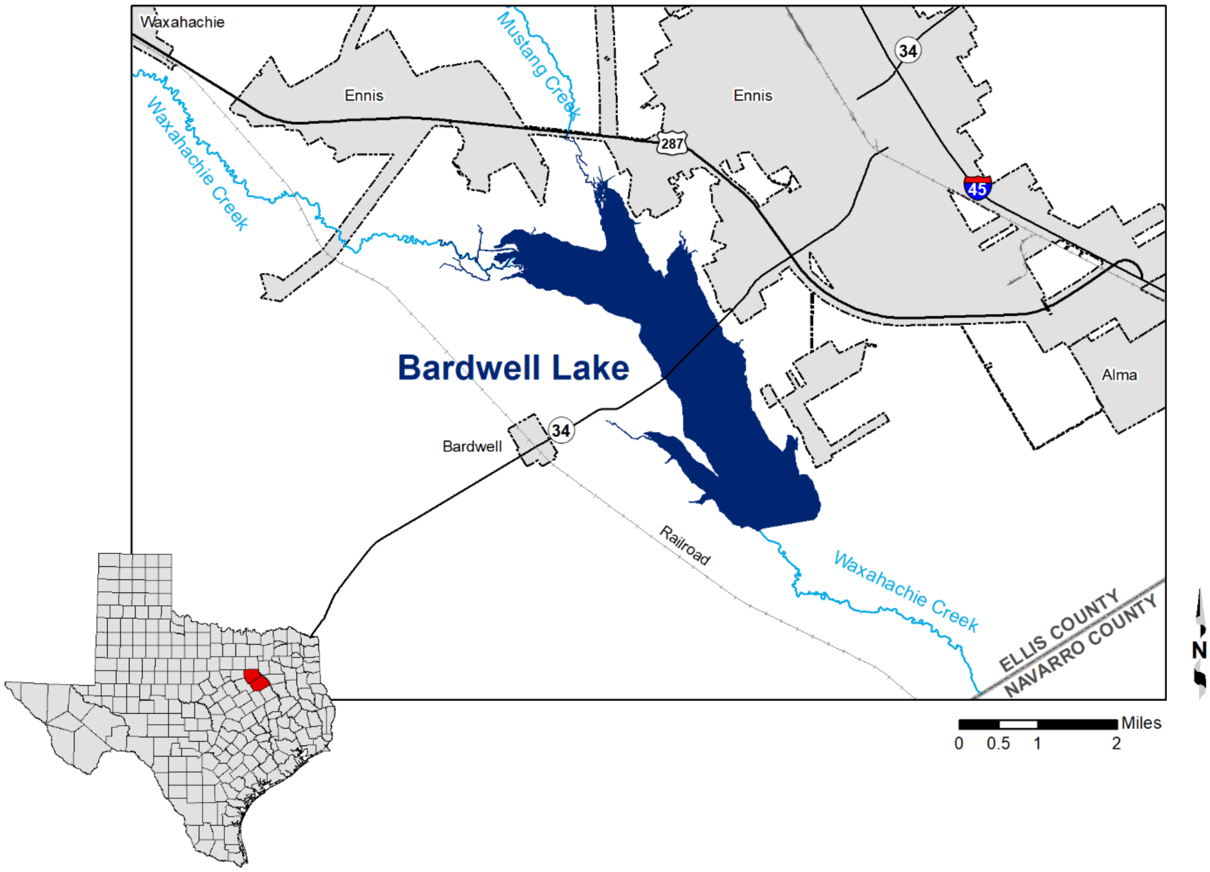


Figure 1. Location map.

Table 1. Pertinent Data for Bardwell Dam and Bardwell Lake

Owner(s)			
United States Government; Operated by the United States Army Corps of Engineers, Fort Worth District			
Engineer (Design)			
United States Army Corps of Engineers			
General Contractor			
M&S Construction Company			
Purpose			
Flood control, water supply, and recreation			
Total drainage area			
178 square miles			
Dam			
Type	Rolled earth fill		
Length	15,400 feet (includes spillway)		
Maximum Height	82 feet		
Top Width	20 feet		
Spillway			
Type	Broad-crested weir		
Crest Length	350 feet		
Crest Elevation	439.0 feet above mean sea level		
Control	None		
Outlet Works			
Type	1 gate-controlled conduit		
Size	10-foot diameter		
Control	2 sluice gates, each 5 by 10 feet		
Invert elevation	391.0 feet above mean sea level		
Reservoir Data (Based on 2020 TWDB survey)			
Feature	**Elevation (feet above MSL)**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam	460.0	296,013	10,718
Maximum design water surface	455.9	254,696	9,514
Top of flood control	439.0	126,315	5,972
Top of conservation pool	421.0	43,917	3,292
Invert of lowest outlet/dead pool	391.0	61	37
Conservation storage capacity[b]	—	43,856	—

Source(s): U.S. Army Corps of Engineers, 2021b, Texas Water Development Board, 1971.

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

Volumetric and sedimentation survey of Bardwell Lake

Datum

The vertical datum used during this survey is the National Geodetic Vertical Datum 1929 (NGVD29). This datum is utilized by the United States Geological Survey (USGS) for the reservoir elevation gage *USGS 08063700 Bardwell Lk nr Ennis, TX* (U.S. Geological Survey, 2021). Elevations herein are reported in feet relative to the NGVD29 datum. Volume and area calculations in this report are referenced to water levels reported by the USGS gage *USGS 08063700 Bardwell Lk nr Ennis, TX.* 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 Bardwell Lake on July 24 and July 29, 2020, while the daily average water surface elevation measured 421.05 and 420.98 feet above mean sea level (NGVD29), respectively. For data collection, the TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 12 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data were collected along pre-planned survey lines oriented perpendicular to the assumed location of the original river channel(s) and spaced approximately 500 feet apart. Many of the same survey lines also were used by the TWDB for the *Volumetric Survey of Bardwell Lake, February 1999 Survey* (Texas Water Development Board, 1999). 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. Each speed of sound profile, or velocity cast, is saved for further data processing. Figure 2 shows the data collection locations for the 2020 TWDB survey.

All sounding data were collected and reviewed before sediment core sampling sites were selected. Sediment core samples are collected throughout the reservoir to assist with interpretation of the sub-bottom acoustic profiles. After analyzing the sounding data, the TWDB selected 10 locations to collect sediment core samples (Figure 2). Sediment cores were collected on September 15, 2020, with a custom-coring boat and an 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. A sediment core extends from the current reservoir-bottom surface, through the accumulated sediment, and into the pre-impoundment surface. After the sample is retrieved, the core tube is cut to the level of the sediment core. The tube is capped, labeled, and transported to TWDB headquarters for further analysis.

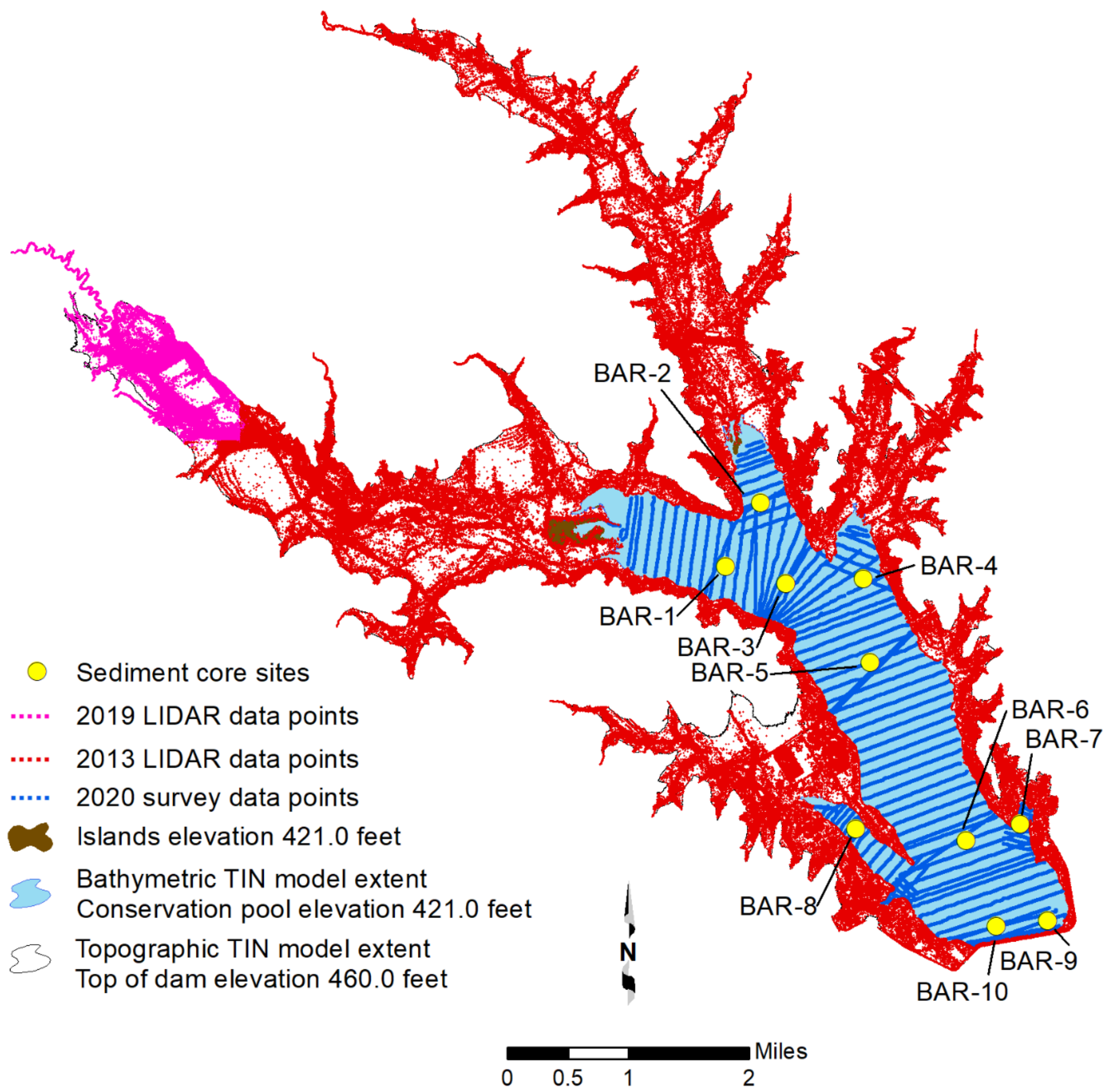


Figure 2. 2020 TWDB sounding data (*blue dots*), 2019 LIDAR data (*pink dots),* 2013 LIDAR data (*red dots),* and sediment coring locations (*yellow circles).*

Data processing

Model boundary

The reservoir's model boundaries were developed from Light Detection and Ranging (LIDAR) Data available from the Texas Natural Resource Information System. LIDAR data collected between February 7 and March 6, 2013 (Texas Water Development Board, 2021), while the daily average water surface elevation of the reservoir measured between 418.51 and 418.64 feet were used to create the bathymetric model boundary. The LIDAR data .las files were imported into an LAS Dataset and the dataset was converted to a raster using a cell size of 1.0 meters by 1.0 meters. A contour at 128.325 meters equivalent to 421.013 feet NAVD88 or 421.00 feet NGVD29, was extracted. Additional LIDAR data collected between January 26 and July 12, 2019 (Texas Water Development Board, 2021), while the daily average water surface elevation of the reservoir measured between 420.88 and 434.79 feet, were used to create the outer boundary of topographic model. The LIDAR data .las files were imported into an LAS Dataset and the dataset was converted to a raster using a cell size of 1.0 meters by 1.0 meters. A contour at 140.211995 meters equivalent to 460.013 feet NAVD88 or 460.00 feet NGVD29, was extracted. The elevation of the top of the dam is 460.00 feet above mean sea level. 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). The vertical datum transformation offset of .013 feet was used to convert from feet NAVD88 to feet above mean sea level. 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 (National Geodetic Survey, 2017a) and VERTCON software (National Geodetic Survey, 2017b) to a single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 08063700 Bardwell Lk nr Ennis, TX Latitude 32º15'00"N, Longitude 96º38'49"W NAD27.* The bathymetric model contour was edited to close the contour and expand the islands in the upper reaches. Digital orthophoto quarter-quadrangle images (DOQQs) photographed on March 21, 2018, while the daily average water surface elevation measured 421.38 feet, obtained through the Texas Imagery Service, were used to update the bathymetric contour. The Texas Natural Resources Information System (TNRIS) manages the Texas Imagery Service, allowing public organizations in the State of Texas to access Google Imagery as a service using Environmental Systems Research Institute's ArcGIS software (Texas Natural Resources Information System, 2020a, Texas Natural Resources Information System, 2020b). The topographic contour was edited to close the contour across the top of the dam. Horizontal coordinate transformations to NAD83 State Plane Texas North Central Zone (feet) coordinates were done using the ArcGIS Project tool.

LIDAR data points

To utilize the LIDAR data in the reservoir topographic model, the LIDAR data .las files were converted to a multipoint feature class in an Environmental Systems Research Institute's ArcGIS file geodatabase filtered to include only data classified as ground points. A topographical model of the data was generated. The ArcGIS tool Terrain to Points was used to extract points from the Terrain, or topographical model of the reservoir. The Terrain was created using the z-tolerance Pyramid Type. Points were extracted from the terrain at the z-tolerance level of 0.25 meters. New attribute fields were added to convert the elevations from meters to feet NAVD88 and then to feet above mean sea level for compatibility with the bathymetric survey data. LIDAR data outside of the 460.00-foot contour and inside the 421.00-foot contour were deleted and the feature class projected to NAD83 State Plane Texas North Central Zone (feet).

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by the TWDB were edited to remove data anomalies. The reservoir's current bottom surface is automatically determined by the data acquisition software. DepthPic© software, developed by SDI, Inc., was used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface. Hydropick software, developed by TWDB staff, was used to display, interpret, identify, and manually edit the pre-impoundment surfaces in the multi-frequency data. The speed of sound profiles, also known as velocity casts, were used to further correct the measured depths. For each location velocity casts are collected, the harmonic mean sound speed of all the casts is calculated. From this, depths collected using one average speed of sound are corrected with an overall optimum speed of sound for each specific depth (Specialty Devices, Inc., 2018).

All data were 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 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 the reservoir (McEwen *et al.* 2011a). The resulting point file was used in conjunction with sounding and boundary data to create both a volumetric and a sediment Triangulated Irregular Network (TIN) model using Delaunay's criteria for triangulation (Environmental Systems Research Institute, 1995).

Spatial interpolation of reservoir bathymetry

Isotropic spatial interpolation techniques such as the Delaunay triangulation are, in many instances, unable to suitably interpolate bathymetry 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 artifacts may 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 (DRGs), hypsography files (the vector format of USGS 7.5-minute quadrangle map contours), and historical aerial photographs, when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining the directionality of interpolation within each segment. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high-resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen and others, 2011a) and in McEwen and others (2011b). No additional interpolation was necessary in the areas where LIDAR data was used for the topographic TIN model.

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 (McEwen and others, 2011a). Linear interpolation is required due to artifacts created at the reservoir boundary elevation during the TIN model generation process, and results in improved elevation-capacity and elevation-area calculations.

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

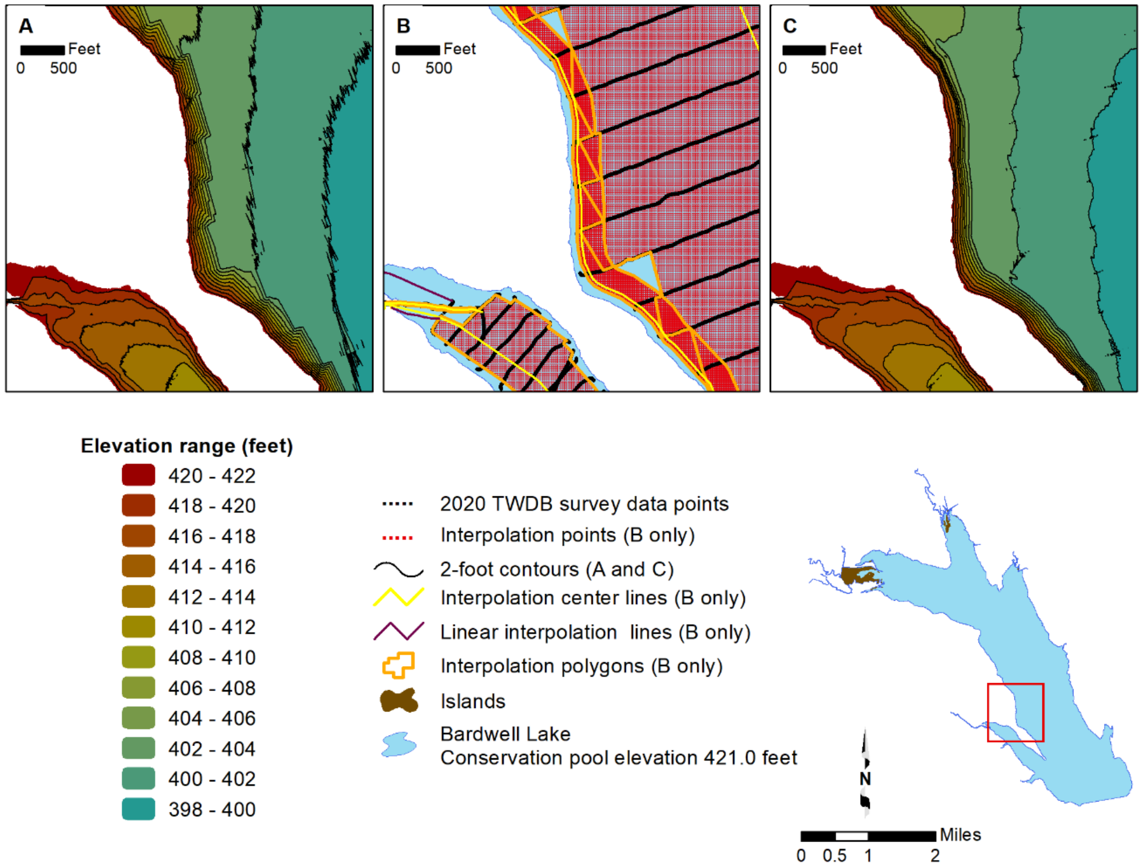


Figure 3. Anisotropic spatial interpolation and linear interpolation as applied to Bardwell Lake sounding data; A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with interpolated points.

To properly compare results from the 1999 TWDB survey of Bardwell Lake, the TWDB applied anisotropic spatial interpolation to the survey data collected in 1999. The 1999 survey boundary was digitized from aerial photographs taken on February 8, 1995. According to the associated metadata, the 1995-1996 aerial photographs 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. The water surface elevation of the reservoir at the time of the photograph was 421.11 feet. For modeling purposes, the boundary was assigned the elevation of 421.10 feet (Texas Water Development Board, 1999). While linear interpolation was used to estimate the topography in areas without data, flat triangles led to anomalous area and volume calculations at the boundary elevation of 421.10 feet. Therefore, areas between 418.00 feet and 421.10 feet were linearly interpolated between the computed values, and volumes above 418.00 feet were calculated based on the corrected areas (Texas Water Development Board, 2016). The 1999 re-calculated elevation-capacity table and elevation-area table are presented in Appendices A and B, respectively.

The re-calculated capacity curve is presented in Appendix C, and the re-calculated area curve is presented in Appendix D.

Area, volume, and contour calculation

Volumes and areas were computed for the entire reservoir at 0.1-foot intervals, from 386.90 to 421.00 feet above mean sea level. While linear interpolation was used to estimate the topography in areas without data, flat triangles led to anomalous area and volume calculations at the boundary elevation of 421.00 feet. Therefore, areas between 419.00 feet and 421.00 feet were linearly interpolated between the computed values, and volumes above 419.00 feet were calculated based on the corrected areas. The bathymetric elevation-capacity table and elevation-area table developed from the 2020 survey and analysis are presented in Appendices E and F, respectively. The bathymetric capacity curve is presented in Appendix G, and the bathymetric area curve is presented in Appendix H. For the topographic TIN model, volumes and areas were computed for the entire reservoir at 0.1-foot intervals, from 386.90 to 460.00 feet above mean sea level. Areas between 419.00 feet and 421.00 feet were linearly interpolated between the computed values, and volumes above 419.00 feet were calculated based on the corrected and computed areas. The topographic elevation-capacity table and topographic elevation-area table developed from the 2020 survey and analysis are presented in Appendices I and J, respectively. The topographic capacity curve is presented in Appendix K, and the topographic area curve is presented in Appendix L.

The volumetric bathymetric TIN model was converted to a raster representation using a cell size of 2 feet by 2 feet. The resulting raster data were used to produce three figures: (1) an elevation relief map representing the topography of the reservoir bottom (Figure 4); (2) a depth range map showing depth ranges for Bardwell Lake (Figure 5); and (3) a 2-foot contour map (Figure 6).

Figure 4

Bardwell Lake

Elevation relief map

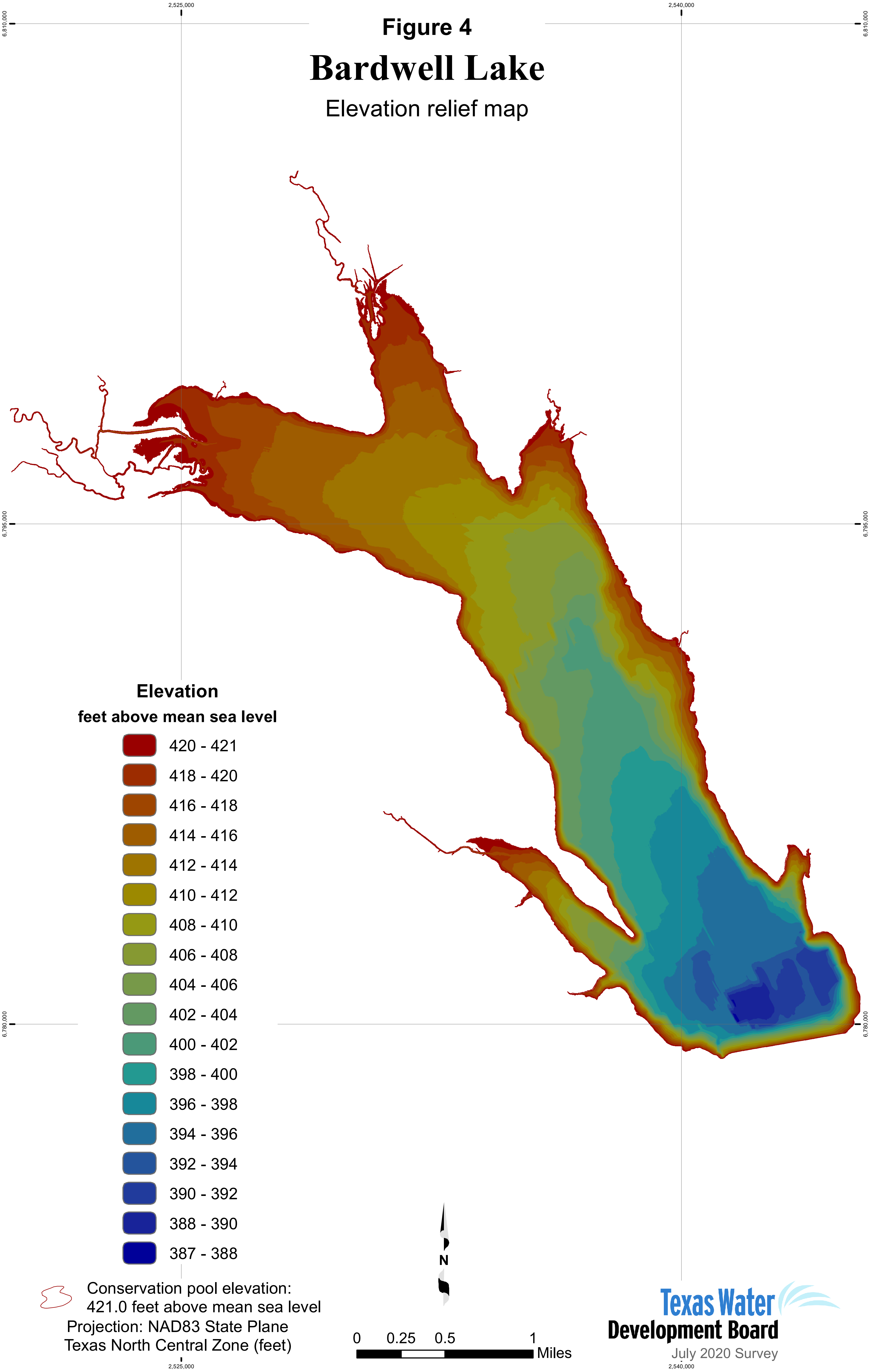
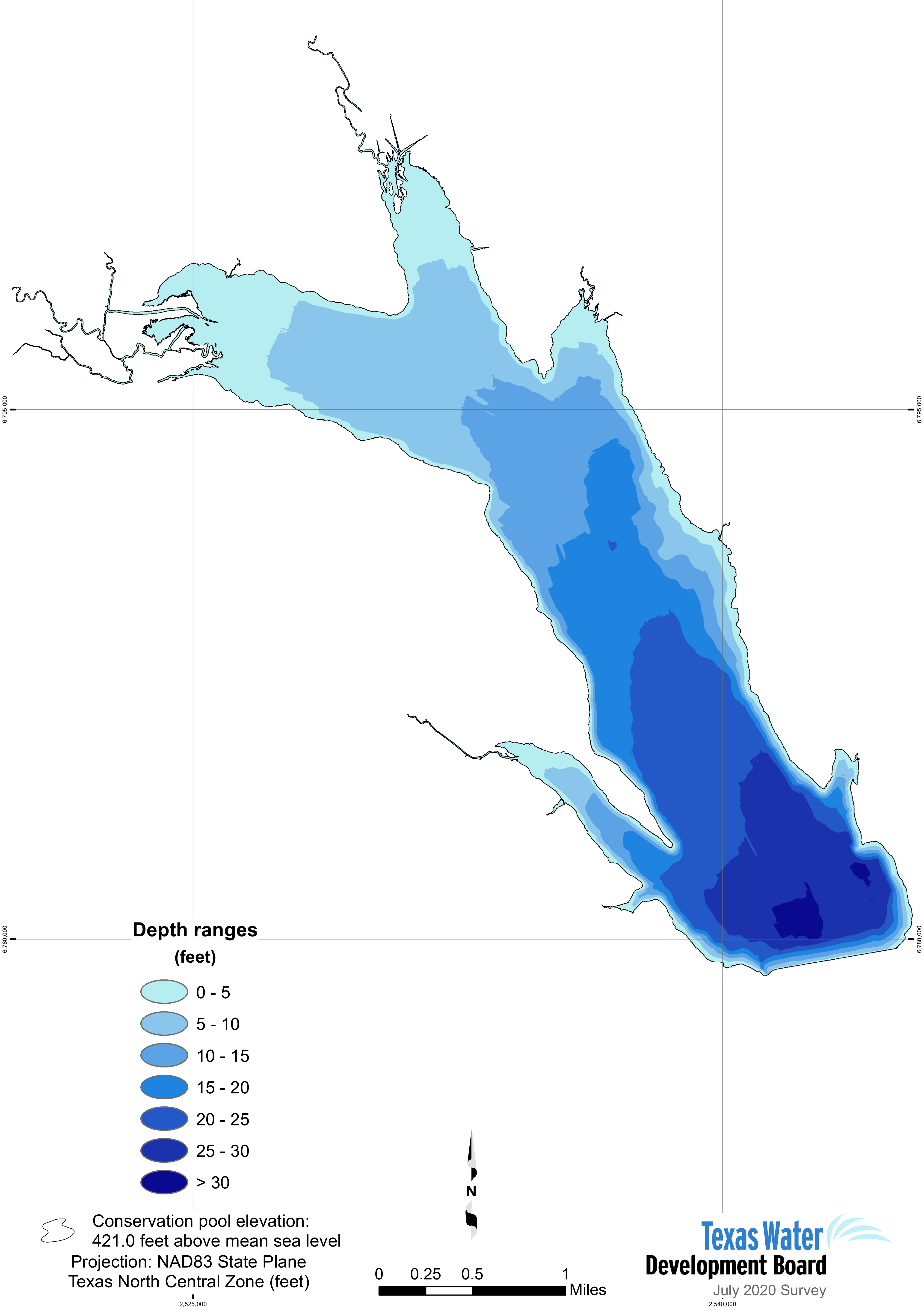


Figure 5

Bardwell Lake

Depth range map



Analysis of sediment data from Bardwell Lake

Sedimentation in Bardwell Lake was determined by analyzing the acoustic signal returns of all three depth sounder frequencies using customized software called Hydropick. While the 208 kHz signal is used to determine the current bathymetric surface, the 208 kHz, 50 kHz, and 12 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 bathymetry and the pre-impoundment surface bathymetry yields a sediment thickness value at each sounding location.

Sediment cores were analyzed at TWDB headquarters in Austin. Each core was split longitudinally and analyzed to identify the location of the pre-impoundment surface. The pre-impoundment surface was identified within the sediment core using the following methods: (1) a visual examination of the sediment core for terrestrial and 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) recording changes in texture from well sorted, relatively fine-grained sediment to poorly sorted mixtures of coarse and fine-grained materials; and, (3) identifying variations in the physical properties of the sediment, particularly sediment water content and penetration resistance with depth (Van Metre and others, 2004). Total sediment core length, post impoundment sediment thickness, and pre-impoundment thickness were recorded. Physical characteristics of the sediment core, such as Munsell soil color, texture, relative water content, and presence of organic materials were recorded (Table 2).

Table 2. Sediment core sample analysis data.

Sediment core sample	Easting[a] (feet)	Northing[a] (feet)	Total core sample / post-impoundment sediment length (inches)	Sediment core description[b]		Munsell soil color
BAR-1	2530357.44	6795641.72	33.0 / 26.0	post-impoundment	0.0-26.0” high to moderate water content, water content decreases with depth, silty clay, smooth, sticky, mottled	10 YR 2/1 black, 10 YR 4/1 dark gray
				pre-impoundment	26.0-33.0” very low water content, silty clay, very dense, fibrous roots, organic matter present	10 YR 2/1 black
BAR-2	2531905.45	6798439.67	18.0 / 8.0	post-impoundment	0.0-8.0” high water content, silty clay, soupy, smooth, sparse roots and organic matter present	10YR 3/1 very dark gray
				pre-impoundment	8.0-18.0” low to very low water content, water content decreases with depth, silty clay, dense, fibrous roots and organic matter present	10YR 2/1 black
BAR-3	2533013.10	6794875.10	32.0 / 25.0	post-impoundment	0.0-25.0” very high to moderate water content, water content decreases with depth, silty clay, dense, smooth, pudding like, organic matter scattered throughout (large woody debris (bark) at 11 inches), mottled	10 YR 2/1 black, 10 YR 4/1 dark gray
				pre-impoundment	25.0-32.0” very low water content, silty clay, dense, fibrous roots, organic matter present	10YR 2/1 black
BAR-4	2536387.19	6795108.10	20.0 / 11.0	post-impoundment	0.0-2.0” very high water content, silt, soupy smooth	10YR 3/1 very dark gray
					2.0-4.0” high water content, silty clay, smooth, pudding like	10YR 3/1 very dark gray
					4.0-11.0” low water content, silty clay, peanut butter consistency, smooth, dense	10YR 2/1 black
				pre-impoundment	11.0-20.0” very low water content, silty clay, very dense, bits of wood debris and organic matter present	10YR 2/1 black

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

[b] Sediment core samples are measured in inches with zero representing the current bottom surface.

Table 2 (continued). Sediment core sample analysis data.

Sediment core sample	Easting[a] (feet)	Northing[a] (feet)	Total core sample / post-impoundment sediment length (inches)	Sediment core description[b]		Munsell soil color
BAR-5	2536707.46	6791445.36	33.0 / 27.0	post-impoundment	0.0-10.0" very high to high water content, water content decreases with depth, silt with bits of clay, soupy, some grit	10YR 3/1 very dark gray
					10.0-27.0" low water content, silty clay, dense, bits of shell with sparse organic material present	10YR 2/1 black
				pre-impoundment	27.0-33.0" very low water content, silty clay, very dense, root throughout layer, organic material present	10YR 2/1 black
BAR-6	2540890.18	6783653.77	45.0 / 40.0	post-impoundment	0.0-40.0" very high to moderate water content, water content decreases with depth, silty clay, smooth, pudding like, uniform consistency.	10YR 2/1 black
				pre-impoundment	40.0-45.0" low water content, silty clay, dense, not compacted, fibrous roots throughout, organic material present	10YR 2/1 black
BAR-7	2543273.42	6784354.86	23.0 / 15.0	post-impoundment	0.0-4.0" very high water content, silt, soupy, smooth	10YR 3/1 very dark gray
					4.0-15.0" moderate water content, silty clay, smooth, peanut butter consistency, sticky, mottled	10 YR 2/1 black 10 YR 3/1 very dark gray
				pre-impoundment	15.0-23.0" very low water content, silty clay, dense, roots throughout, organic material present	10YR 2/1 black
BAR-8	2536067.83	6784161.53	42.0 / 39.0	post-impoundment	0.0-3.0" very high water content, silt, soupy, smooth	10YR 4/1 dark gray
					3.0-39.0" moderate water content, silty clay, smooth, density increases with depth	10YR 2/1 black
				pre-impoundment	39.0-42.0" low water content, silty clay, dense, roots throughout, organic material present	10YR 2/1 black

[a] Coordinates are based on NAD83 State Plane Texas North Central System (feet).
[b] Sediment core samples are measured in inches with zero representing the current bottom surface.

Table 2 (continued). Sediment core sample analysis data.

Sediment core sample	Easting[a] (feet)	Northing[a] (feet)	Total core sample / post-impoundment sediment length (inches)	Sediment core description[b]		Munsell soil color
BAR-9	2544456.96	6780135.23	9.0 / 0.0	pre-impoundment	0.0-9.0” very low water content, clay, very dense, no organics present	10YR 2/1 black
BAR-10	2542218.98	6779891.88	10.0 / N/A	post-impoundment	0.0-10.0” very high to high water content, water content decreases with depth, silty clay, smooth, pudding like	10YR 2/1 black

[a] Coordinates are based on NAD83 State Plane Texas North Central System (feet).
[b] Sediment core samples are measured in inches with zero representing the current bottom surface.

A photograph of sediment core BAR-3 (for location, refer to Figure 2) is shown in Figure 7 and are representative of sediment cores sampled from Bardwell Lake. The base, or deepest part of the sample is denoted by the blue line. The pre-impoundment boundary (yellow line closest to the base) was evident within sediment core sample BAR-3 at 25 inches. Pre-impoundment boundaries are identified by the change in color, texture, moisture, porosity, and structure. Identification of the pre-impoundment surface for each sediment core followed a similar procedure.

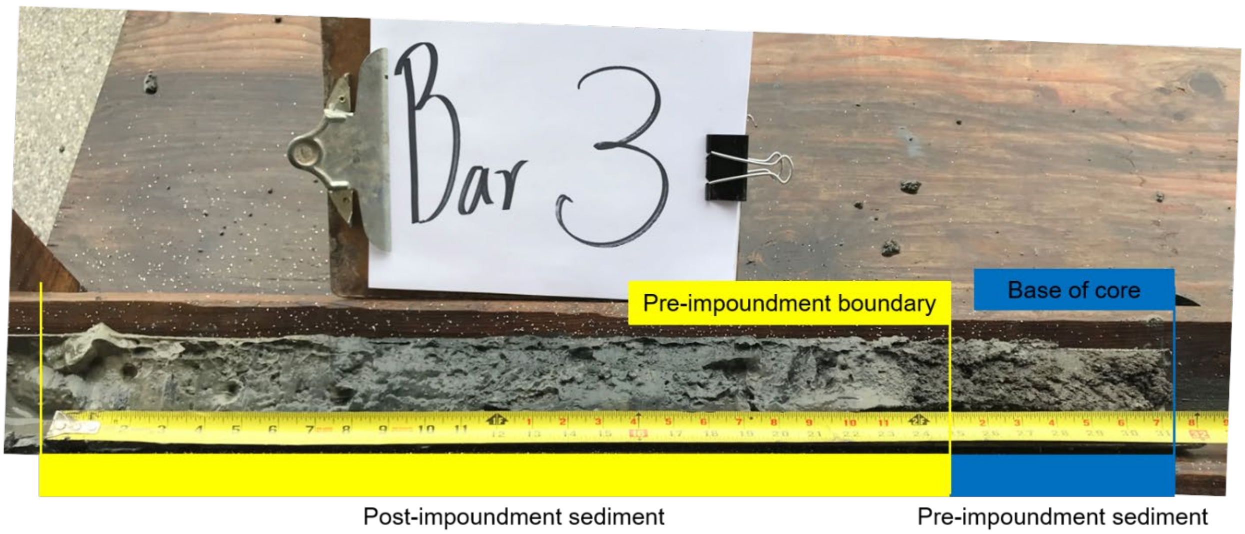


Figure 7. Sediment cores BAR-3. Post-impoundment sediment layers are identified by yellow boxes. Pre-impoundment sediment layers are identified by blue boxes.

Figure 8 illustrates the relationships between acoustic signal returns and the layering seen in sediment cores. In this example, sediment cores BAR-3 is shown correlated with each frequency: 208 kHz, 50 kHz, and 12 kHz. The current bathymetric surface is determined by signal returns from the 208 kHz transducer as 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 12 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Many layers of sediment were identified during analysis based on changes in observed characteristics such as water content, organic matter content, and sediment particle size, and each layer is classified as either post-impoundment or pre-impoundment. Yellow boxes represent post-impoundment sediments identified in the sediment core. Blue boxes indicate pre-impoundment sediments.

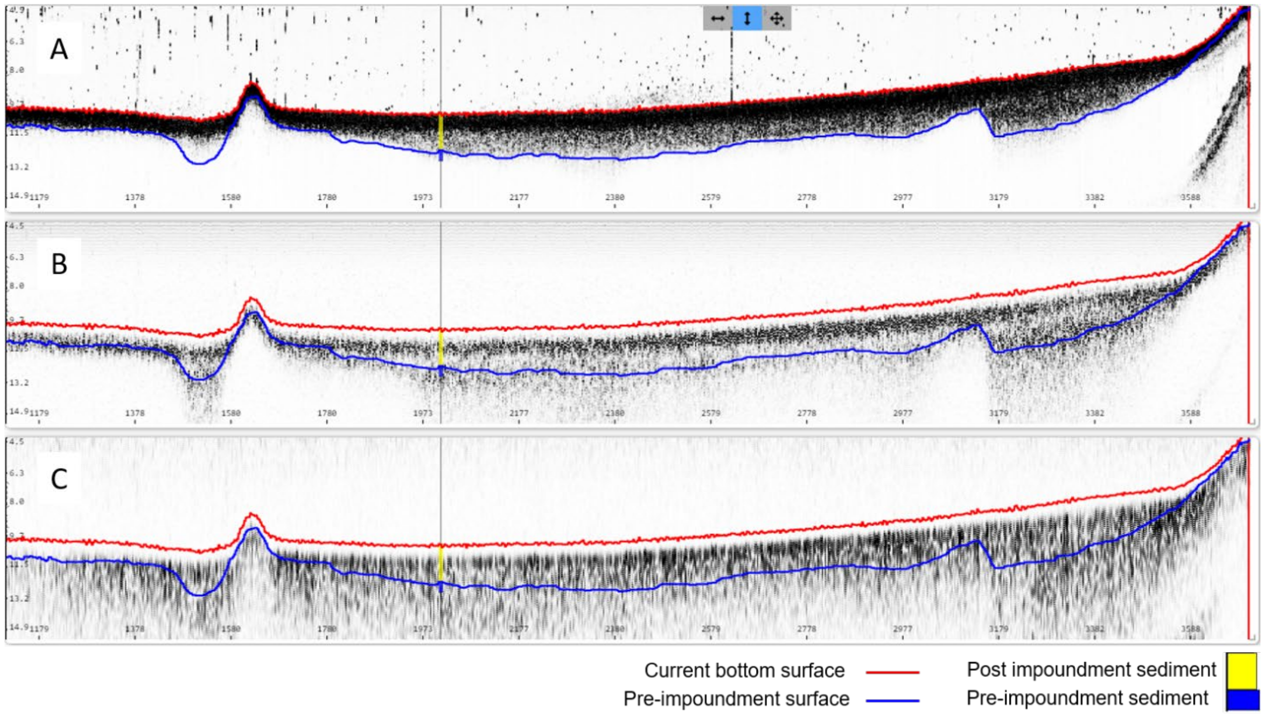


Figure 8. Sediment core sample BAR-3 compared with acoustic signal returns. A) 208 kHz frequency, B) 50 kHz frequency, and C) 12 kHz frequency.

The pre-impoundment boundary in sediment core BAR-3 most closely aligned with the different layers picked up by the 208 kHz; therefore, the 208 kHz signal was used to locate the pre-impoundment surface (Figure 8). The pre-impoundment surface is first identified along cross-sections where sediment core samples were collected. This information is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

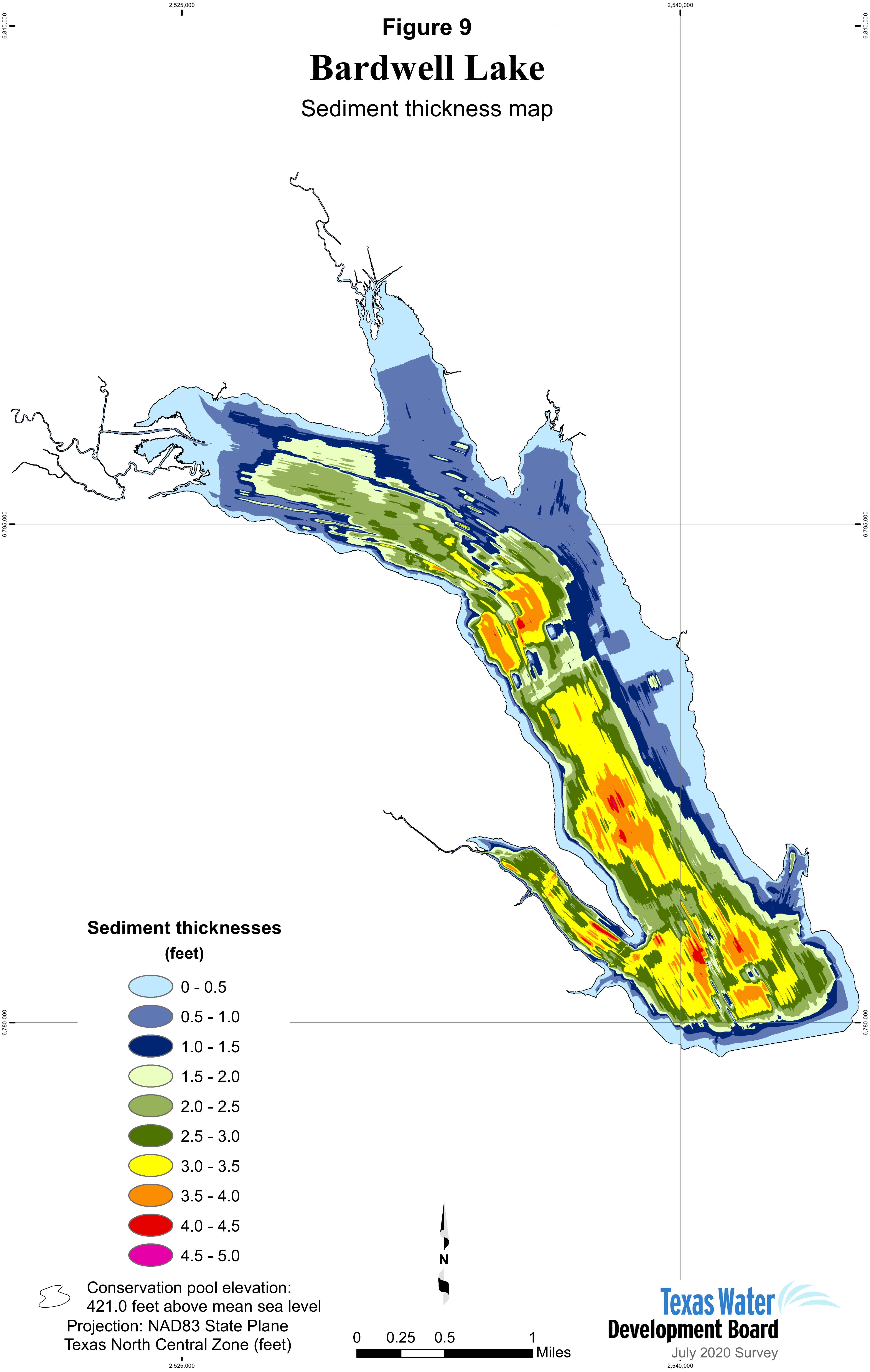
After the pre-impoundment surface for all cross-sections is identified, a pre-impoundment TIN model and a sediment thickness TIN model are created. Pre-impoundment elevations and sediment thicknesses are interpolated between surveyed cross-sections using HydroTools with the same interpolation definition file used for bathymetric interpolation. For the purposes of TIN model creation, the TWDB assumed the sediment thickness at the reservoir boundary was 0 feet (defined as the 421.00-foot elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 5 feet by 5 feet and was used to produce a sediment thickness map (Figure 9). Elevation-capacity and elevation-area tables were computed from the pre-impoundment TIN model for the purpose of calculating the total volume of accumulated sediment. While linear interpolation was used to estimate the topography in areas without data, flat triangles led to anomalous area and volume calculations at the boundary elevation of 421.00 feet.

Therefore, areas between 418.50 feet and 421.00 feet were linearly interpolated between the computed values, and volumes above 418.50 feet were calculated based on the corrected areas.

Figure 9

Bardwell Lake

Sediment thickness map



Survey results

Volumetric survey

The 2020 TWDB volumetric survey indicates that Bardwell Lake has a total reservoir capacity of 43,917 acre-feet and encompasses 3,292 acres at conservation pool elevation (421.00 feet NGVD29). Current area and capacity estimates are compared to previous area and capacity estimates in Table 3. Because of differences in past and present survey methodologies, direct comparison of volumetric surveys to others to estimate loss of area and capacity can be unreliable.

Table 3. Surface area, total capacity, and conservation pool elevation.

Survey	Surface area (acres)	Total capacity (acre-feet)	Conservation Pool Elevation[a]	Source
Original design	3,570	54, 877	421.00	U.S. Army Corps of Engineers, 2021
U.S. Army Corps of Engineers 1972	3,558	52,291	421.00	U.S. Army Corps of Engineers, 1976
U.S. Army Corps of Engineers 1981	3,500	46,621	421.00	U.S. Army Corps of Engineers, 1991
TWDB 1999	3,138	46,472	421.00	Texas Water Development Board, 1999
TWDB 1999 re-calculated	3,247	46,837	421.00	Texas Water Development Board, 2016
TWDB 2020	3,292	43,917	421.00	

[a] Feet NGVD29 – National Geodetic Vertical Datum 1929

Sedimentation survey

The 2020 TWDB sedimentation survey measured 5,396 acre-feet of sediment. The sedimentation survey indicates sediment accumulation is occurring throughout the reservoir. Comparison of capacity estimates of Bardwell Lake derived using differing methodologies are provided in Table 4 for sedimentation rate calculation. The 2020 TWDB sedimentation survey indicates Bardwell Lake has lost capacity at an average of 100 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (421.00 feet NGVD29). Long-term trends indicate Bardwell Lake loses capacity at an average of 155 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (421.00 feet NGVD29) (Figure 10). Differences in methodology may also contribute to differences between these surveys.

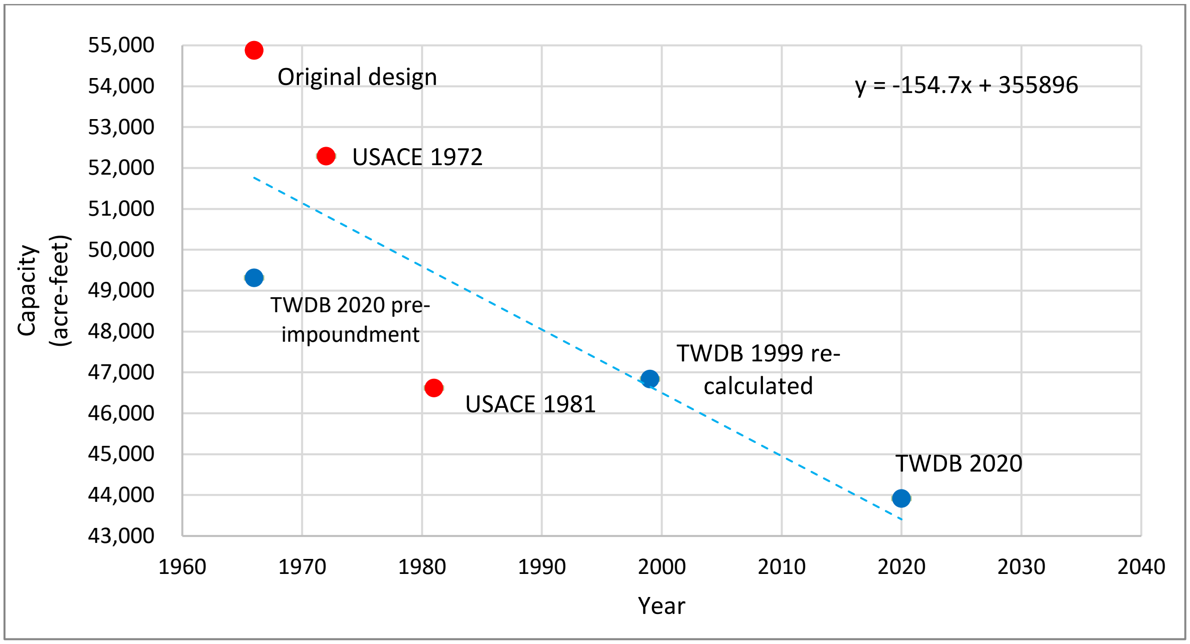


Figure 10. Plot of current and previous capacity estimates (acre-feet) at elevation 421.00 feet. Capacity estimates for each TWDB survey plotted as blue dots and other surveys as red dots. The blue trend line illustrates the total average loss of capacity through 2020.

Table 4. Average annual capacity loss comparisons.

Survey	Top of conservation pool elevation (421.00 feet NGVD29)				
Original design[a]	54,877	<>	<>	<>	<>
U.S. Army Corps of Engineers 1972	<>	52,291	<>	<>	<>
U.S. Army Corps of Engineers 1981	<>	<>	46,621	<>	<>
TWDB 1999 re-calculated[b]	<>	<>	<>	46,837	<>
TWDB pre-impoundment estimate based on 2020 survey	<>	<>	<>	<>	49,313
TWDB 2020 volumetric survey	43,917	43,917	43,917	43,917	43,917
Volume difference (acre-feet)	10,960	8,374	2,704	2,920	5,396
Percent Change	20.0	16.0	5.8	6.2	10.9
Number of years	54	48	39	21	54
Capacity loss rate (acre-feet/year)	203	174	69	139	100
Capacity loss rate (acre-feet/square mile of drainage area of 178 square miles /year)	1.14	0.98	0.39	0.78	0.56

[a] Source: TCEQ, 1964 or TWDB, 1966, Report 48, Bardwell Dam was completed on March 27, 1966.
[b] Source: Texas Water Development Board, 2016.

Sedimentation range lines

In 1965, the U.S. Army Corps of Engineers established 29 sedimentation range lines throughout Bardwell Lake to measure sediment accumulation over time. In 1972 and again in 1981, the U.S. Army Corps of Engineers resurveyed these range lines (U.S. Army Corps of Engineers, 1976, U.S. Army Corps of Engineers, 1991). The TWDB digitized the U.S. Army Corps of Engineers maps and the historical cross-sections for comparison with the TWDB 1999 and 2020 surveys. A cross-sectional comparison of 12 of these sediment range lines is presented in Appendix M. Also presented in Appendix M is a map depicting the historical locations of the sediment range lines and Table M1, a list of the endpoint coordinates for each line. Some differences in the cross-sections may be a result of difficulties interpreting the quadrangle map contours and inaccuracies in the quadrangle maps due to scale and distortions caused by digitizing the cross-sections and their locations from the U.S. Army Corps of Engineers reports. Additionally, some differences between the TWDB cross-sections may be a result of spatial interpolation and the interpolation routine of the TIN Model.

Recommendations

The TWDB recommends a volumetric and sedimentation survey of Bardwell Lake within a 10-year timeframe or after a major high flow event to assess changes in reservoir capacity and to further improve estimates of sediment accumulation rates.

TWDB contact information

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

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Appendix A

Bardwell Lake

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — February 1999 Survey re-calculated August 2015

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
383	0	0	0	0	0	0	0	0	0	0
384	1	2	2	3	4	5	7	8	9	11
385	13	14	16	18	19	21	23	25	27	29
386	31	33	35	37	40	42	44	46	49	51
387	53	56	58	61	64	66	69	72	75	79
388	83	87	92	96	101	106	112	118	124	130
389	137	145	153	161	169	178	187	197	206	217
390	227	238	249	261	273	285	298	311	325	338
391	352	365	379	394	408	422	437	452	468	483
392	499	516	532	549	567	585	603	623	643	665
393	688	712	738	765	793	822	853	884	916	950
394	984	1,020	1,056	1,094	1,133	1,172	1,212	1,254	1,296	1,339
395	1,383	1,428	1,474	1,521	1,569	1,618	1,667	1,718	1,769	1,821
396	1,874	1,928	1,983	2,039	2,096	2,154	2,213	2,273	2,333	2,395
397	2,458	2,521	2,586	2,652	2,719	2,787	2,856	2,926	2,997	3,070
398	3,143	3,217	3,292	3,368	3,445	3,522	3,600	3,679	3,759	3,840
399	3,922	4,005	4,089	4,174	4,260	4,347	4,435	4,524	4,613	4,704
400	4,795	4,888	4,982	5,076	5,172	5,269	5,367	5,467	5,567	5,669
401	5,773	5,878	5,983	6,090	6,198	6,307	6,416	6,527	6,638	6,750
402	6,863	6,976	7,090	7,205	7,320	7,436	7,552	7,670	7,788	7,906
403	8,026	8,147	8,268	8,389	8,512	8,635	8,759	8,884	9,009	9,135
404	9,262	9,390	9,519	9,649	9,780	9,912	10,044	10,178	10,312	10,448
405	10,585	10,722	10,861	11,000	11,140	11,281	11,424	11,567	11,711	11,856
406	12,003	12,151	12,300	12,450	12,601	12,753	12,905	13,059	13,213	13,369
407	13,525	13,682	13,840	14,000	14,160	14,322	14,484	14,648	14,812	14,977
408	15,143	15,310	15,478	15,646	15,816	15,986	16,158	16,331	16,505	16,680
409	16,856	17,033	17,211	17,390	17,570	17,752	17,934	18,118	18,303	18,489
410	18,676	18,865	19,054	19,245	19,437	19,629	19,824	20,019	20,215	20,413
411	20,611	20,811	21,012	21,214	21,418	21,622	21,828	22,034	22,242	22,452
412	22,662	22,874	23,087	23,302	23,517	23,734	23,952	24,172	24,393	24,615
413	24,838	25,063	25,289	25,517	25,746	25,977	26,209	26,443	26,678	26,915
414	27,153	27,393	27,634	27,876	28,119	28,363	28,609	28,856	29,104	29,353
415	29,603	29,854	30,106	30,359	30,613	30,868	31,124	31,381	31,639	31,898
416	32,159	32,421	32,685	32,951	33,218	33,487	33,756	34,027	34,299	34,572
417	34,846	35,121	35,398	35,676	35,954	36,234	36,516	36,798	37,083	37,368
418	37,655	37,943	38,232	38,523	38,814	39,107	39,402	39,697	39,994	40,292
419	40,591	40,891	41,193	41,496	41,800	42,106	42,412	42,720	43,029	43,340
420	43,652	43,964	44,279	44,594	44,911	45,228	45,548	45,868	46,190	46,512
421	46,837	47,162								

Note: Capacities above elevation 418.0 feet calculated from interpolated areas

Appendix B

Bardwell Lake

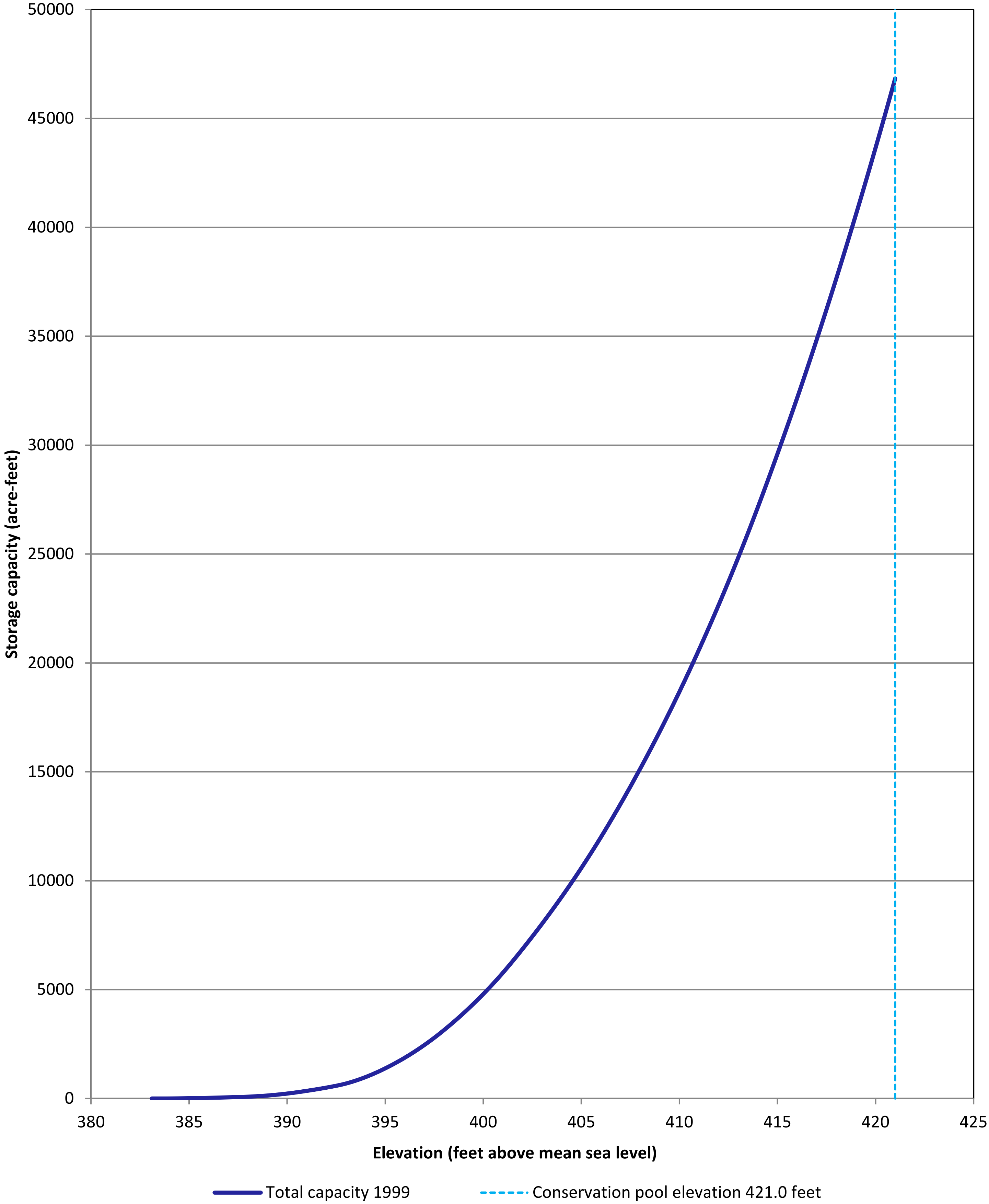
RESERVOIR AREA TABLE

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

February 1999 Survey re-calculated August 2015
Conservation Pool Elevation 421.0 feet NGVD29

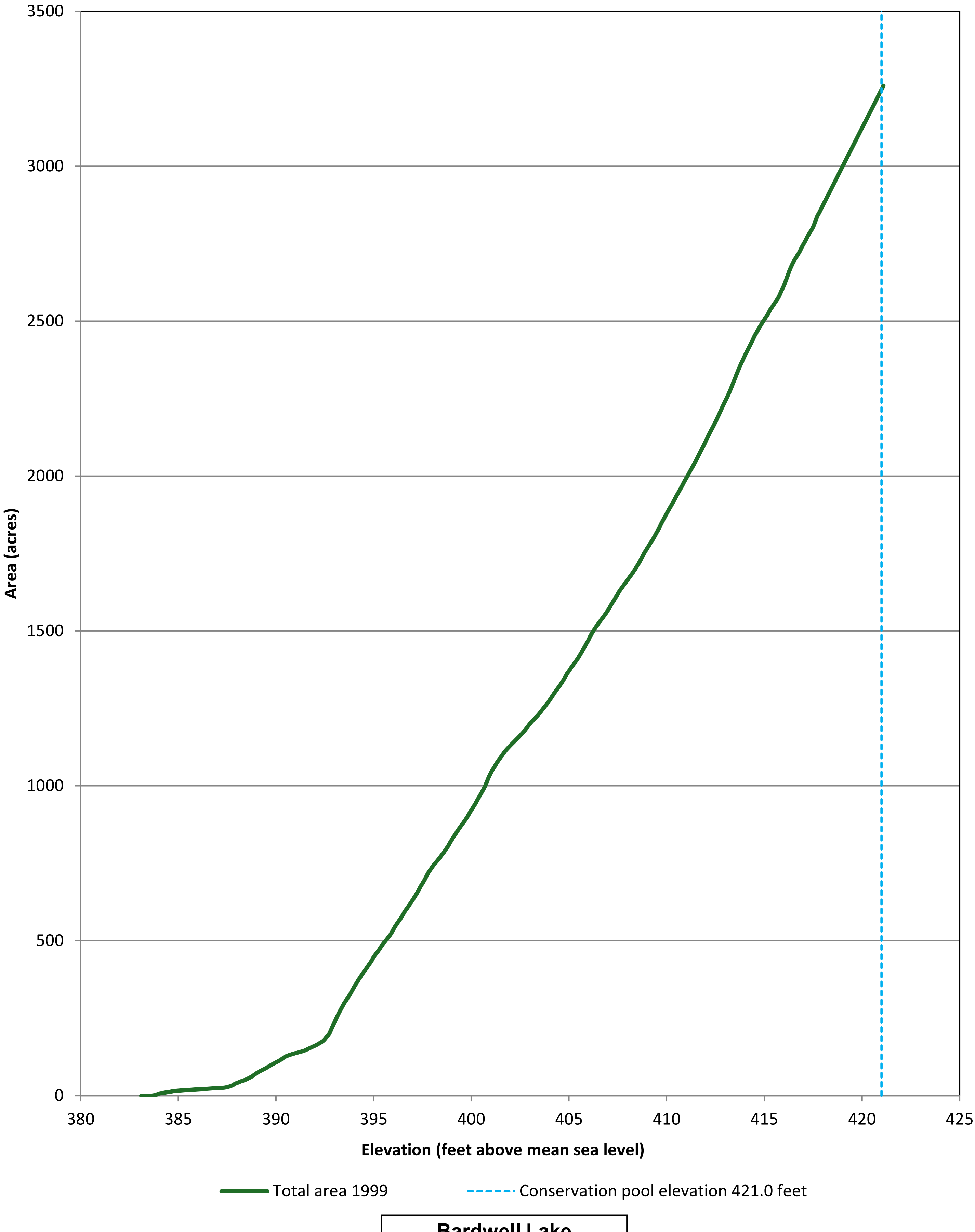
ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
383	0	0	0	0	0	0	0	1	2	4
384	6	8	9	10	11	12	13	14	15	16
385	16	17	17	18	18	19	19	19	20	20
386	21	21	21	22	22	22	23	23	24	24
387	24	25	25	26	26	27	29	32	34	38
388	41	43	46	48	50	53	56	59	63	68
389	72	76	80	83	86	89	93	97	101	104
390	107	111	114	118	123	126	129	131	133	135
391	137	139	141	142	144	147	150	153	156	159
392	161	165	168	172	176	182	190	197	210	224
393	237	251	264	276	288	299	308	318	328	339
394	350	361	371	381	391	400	408	417	426	436
395	448	456	464	473	483	491	499	507	515	524
396	535	546	556	565	574	584	595	604	613	622
397	632	642	652	663	675	685	695	708	720	729
398	738	747	754	761	770	778	786	795	804	815
399	826	836	845	855	864	873	882	891	900	911
400	921	931	942	953	964	975	987	999	1,014	1,029
401	1,042	1,053	1,063	1,074	1,083	1,092	1,100	1,109	1,117	1,124
402	1,130	1,137	1,143	1,149	1,156	1,162	1,169	1,176	1,184	1,192
403	1,201	1,208	1,214	1,221	1,227	1,235	1,243	1,251	1,259	1,267
404	1,276	1,285	1,295	1,304	1,313	1,321	1,330	1,340	1,351	1,362
405	1,371	1,380	1,389	1,398	1,406	1,416	1,427	1,437	1,448	1,460
406	1,471	1,484	1,495	1,505	1,515	1,523	1,532	1,540	1,549	1,558
407	1,567	1,578	1,589	1,598	1,609	1,619	1,630	1,639	1,648	1,656
408	1,664	1,674	1,682	1,691	1,700	1,711	1,721	1,733	1,745	1,756
409	1,766	1,776	1,787	1,796	1,807	1,819	1,830	1,843	1,855	1,867
410	1,879	1,890	1,901	1,912	1,923	1,935	1,947	1,958	1,969	1,982
411	1,993	2,004	2,016	2,027	2,038	2,050	2,062	2,075	2,087	2,099
412	2,112	2,126	2,139	2,150	2,162	2,175	2,188	2,201	2,215	2,229
413	2,242	2,255	2,269	2,284	2,300	2,315	2,331	2,346	2,361	2,375
414	2,388	2,401	2,414	2,425	2,438	2,452	2,463	2,474	2,485	2,495
415	2,505	2,515	2,524	2,537	2,546	2,555	2,564	2,574	2,587	2,601
416	2,614	2,630	2,648	2,665	2,679	2,692	2,703	2,713	2,723	2,736
417	2,748	2,759	2,772	2,782	2,793	2,804	2,820	2,837	2,849	2,861
418	2,874	2,886	2,899	2,911	2,924	2,936	2,949	2,961	2,973	2,986
419	2,998	3,011	3,023	3,036	3,048	3,061	3,073	3,085	3,098	3,110
420	3,123	3,135	3,148	3,160	3,173	3,185	3,197	3,210	3,222	3,235
421	3,247	3,260								

Note: Areas between elevations 418.0 and 421.1 feet linearly interpolated



Bardwell Lake
February 1999 Survey
re-calculated August 2015
Prepared by: TWDB

Appendix C: 1999 Re-calculated capacity curve



Bardwell Lake
February 1999 Survey
re-calculated August 2015
Prepared by: TWDB

Appendix D: 1999 Re-calculated area curve

Appendix E

Bardwell Lake

RESERVOIR BATHYMETRIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | July 2020 Survey

CAPACITY IN ACRE-FEET | Conservation pool elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
386	0	0	0	0	0	0	0	0	0	0
387	0	0	0	0	0	0	0	0	0	0
388	0	0	0	1	2	3	4	6	7	9
389	10	12	14	16	18	20	23	25	27	30
390	32	35	37	40	42	45	48	51	54	58
391	61	65	70	75	80	86	92	100	107	116
392	125	134	144	154	165	177	188	200	213	225
393	238	252	265	279	293	307	322	336	351	367
394	382	398	414	430	447	465	484	503	524	546
395	572	599	628	658	690	723	756	791	827	864
396	902	941	980	1,021	1,063	1,106	1,150	1,195	1,241	1,288
397	1,336	1,385	1,435	1,486	1,538	1,591	1,645	1,700	1,756	1,814
398	1,873	1,933	1,994	2,056	2,119	2,183	2,248	2,315	2,382	2,451
399	2,520	2,590	2,661	2,734	2,807	2,881	2,956	3,032	3,109	3,186
400	3,265	3,344	3,425	3,507	3,589	3,673	3,757	3,842	3,928	4,016
401	4,104	4,193	4,284	4,377	4,470	4,565	4,661	4,758	4,857	4,958
402	5,060	5,164	5,268	5,374	5,480	5,588	5,697	5,807	5,918	6,030
403	6,143	6,256	6,370	6,485	6,601	6,717	6,835	6,952	7,071	7,191
404	7,311	7,432	7,553	7,675	7,798	7,921	8,046	8,170	8,296	8,422
405	8,549	8,677	8,806	8,936	9,066	9,197	9,329	9,462	9,596	9,731
406	9,866	10,002	10,139	10,276	10,415	10,554	10,694	10,834	10,976	11,119
407	11,263	11,407	11,553	11,700	11,848	11,997	12,147	12,298	12,450	12,603
408	12,758	12,914	13,071	13,229	13,389	13,549	13,711	13,873	14,037	14,201
409	14,367	14,533	14,701	14,869	15,039	15,210	15,381	15,554	15,728	15,903
410	16,078	16,255	16,433	16,612	16,791	16,972	17,154	17,337	17,520	17,705
411	17,891	18,078	18,267	18,456	18,646	18,838	19,031	19,225	19,420	19,616
412	19,814	20,013	20,214	20,415	20,619	20,824	21,030	21,238	21,448	21,659
413	21,871	22,085	22,301	22,518	22,737	22,958	23,180	23,404	23,629	23,856
414	24,086	24,317	24,550	24,785	25,021	25,259	25,499	25,741	25,984	26,228
415	26,475	26,723	26,973	27,224	27,477	27,732	27,988	28,246	28,506	28,768
416	29,032	29,297	29,564	29,833	30,103	30,375	30,648	30,923	31,199	31,476
417	31,755	32,034	32,316	32,598	32,882	33,167	33,454	33,742	34,031	34,321
418	34,612	34,905	35,198	35,493	35,789	36,087	36,385	36,685	36,986	37,287
419	37,590	37,895	38,200	38,507	38,815	39,124	39,434	39,746	40,059	40,374
420	40,689	41,006	41,325	41,644	41,965	42,287	42,611	42,935	43,261	43,589
421	43,917									

Note: Capacities above elevation 419.0 feet calculated from interpolated areas

Appendix F

Bardwell Lake

RESERVOIR BATHYMETRIC AREA TABLE

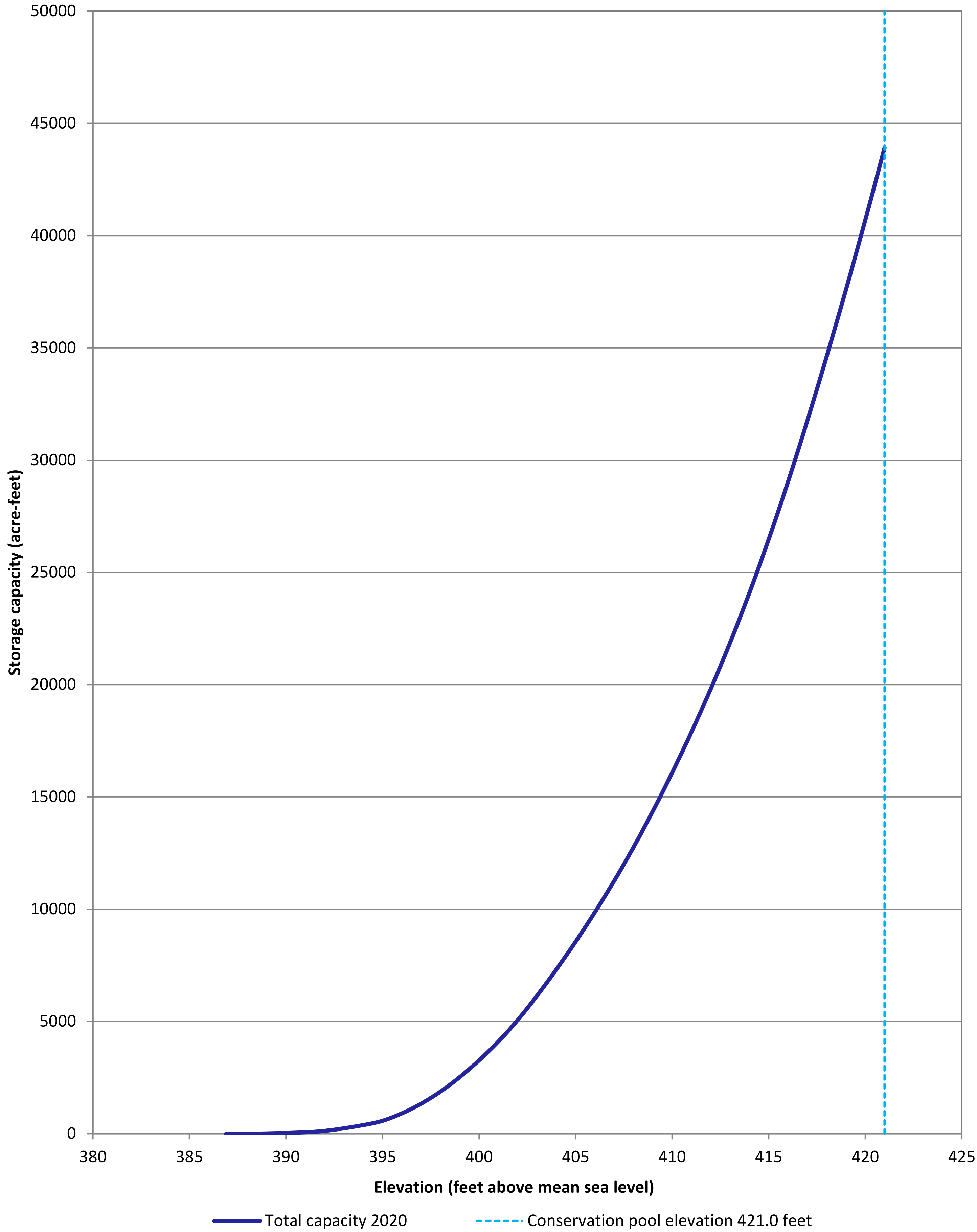
TEXAS WATER DEVELOPMENT BOARD — July 2020 Survey

AREA IN ACRES — Conservation pool elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT

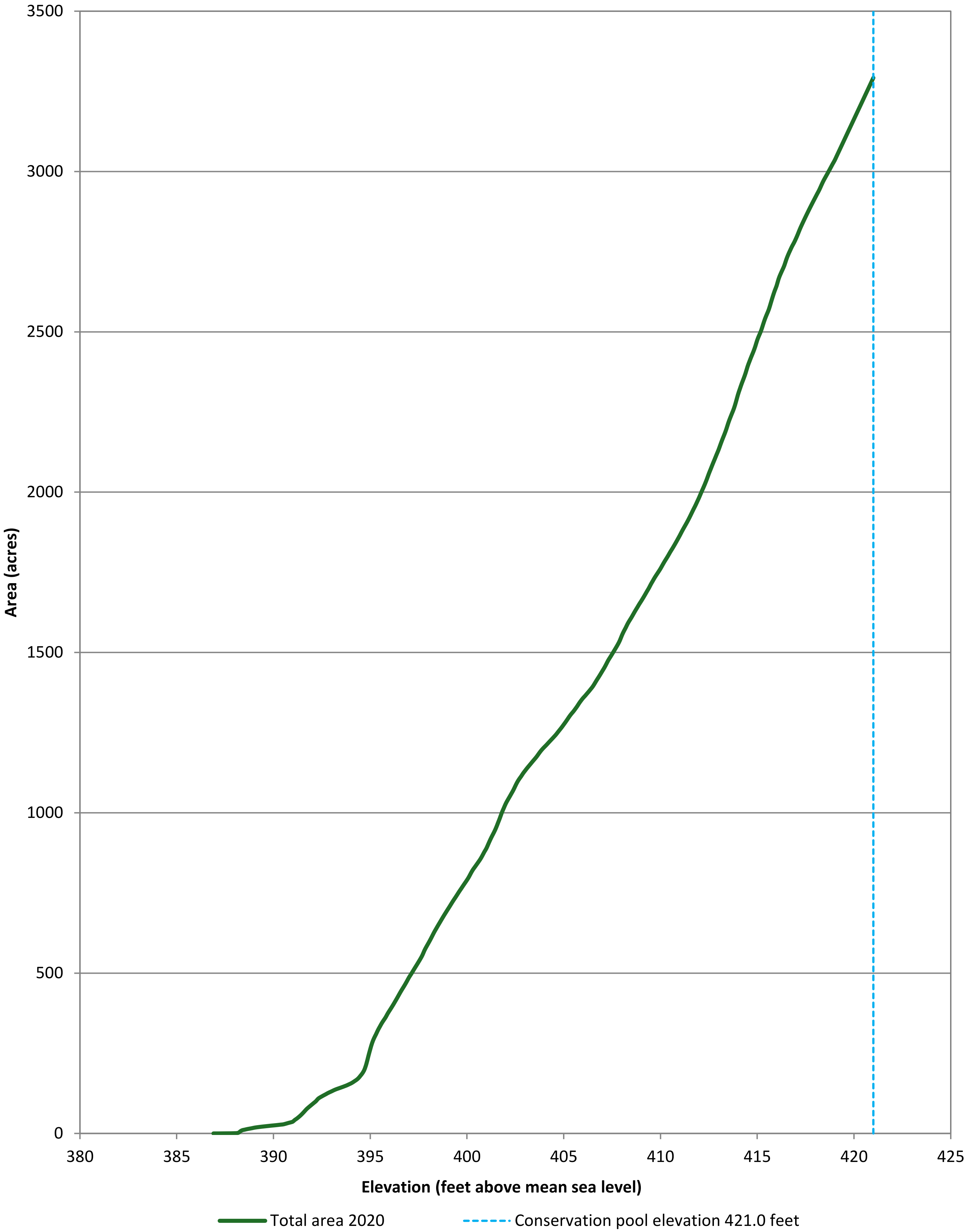
ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
386	0	0	0	0	0	0	0	0	0	0
387	0	0	0	0	0	0	0	0	0	1
388	1	1	2	7	10	12	13	14	15	16
389	18	19	20	20	21	22	22	23	24	24
390	25	26	26	27	28	28	30	31	33	35
391	37	42	46	51	56	62	69	75	81	86
392	91	96	101	108	112	116	119	122	126	128
393	131	134	137	139	141	143	146	148	150	153
394	156	159	163	168	173	180	188	199	217	240
395	262	282	297	309	322	333	344	353	363	374
396	383	393	403	413	423	434	445	454	464	475
397	486	496	506	515	525	535	545	556	570	582
398	593	604	615	627	638	648	658	669	679	688
399	698	707	717	727	736	745	755	763	773	781
400	790	800	811	822	830	839	847	856	867	878
401	889	902	916	928	940	953	968	984	1,000	1,014
402	1,028	1,039	1,050	1,060	1,071	1,084	1,096	1,105	1,114	1,123
403	1,131	1,139	1,146	1,153	1,161	1,168	1,175	1,183	1,192	1,199
404	1,205	1,211	1,218	1,224	1,231	1,237	1,244	1,252	1,259	1,267
405	1,275	1,284	1,292	1,301	1,309	1,316	1,324	1,333	1,342	1,350
406	1,358	1,364	1,372	1,379	1,386	1,394	1,403	1,413	1,423	1,433
407	1,443	1,453	1,464	1,476	1,485	1,495	1,505	1,515	1,526	1,537
408	1,552	1,566	1,577	1,589	1,600	1,609	1,620	1,630	1,640	1,651
409	1,660	1,670	1,680	1,691	1,701	1,712	1,723	1,733	1,743	1,752
410	1,762	1,772	1,783	1,792	1,802	1,813	1,823	1,833	1,843	1,854
411	1,865	1,877	1,888	1,899	1,909	1,921	1,934	1,946	1,958	1,971
412	1,984	1,998	2,012	2,026	2,041	2,058	2,073	2,088	2,103	2,117
413	2,132	2,149	2,165	2,180	2,196	2,215	2,231	2,247	2,262	2,282
414	2,303	2,322	2,339	2,355	2,372	2,392	2,408	2,423	2,438	2,455
415	2,474	2,489	2,504	2,523	2,540	2,555	2,570	2,590	2,610	2,628
416	2,644	2,664	2,680	2,693	2,707	2,725	2,741	2,754	2,767	2,778
417	2,791	2,805	2,820	2,833	2,846	2,859	2,871	2,884	2,896	2,907
418	2,919	2,931	2,942	2,955	2,968	2,980	2,991	3,001	3,013	3,024
419	3,035	3,048	3,060	3,073	3,086	3,099	3,112	3,125	3,138	3,151
420	3,163	3,176	3,189	3,202	3,215	3,228	3,241	3,254	3,266	3,279
421	3,292									

Note: Areas between elevations 419.0 and 421.0 feet linearly interpolated



Bardwell Lake
July 2020 Survey
Prepared by: TWDB

Appendix G: Bathymetric capacity curve



Bardwell Lake
July 2020 Survey
Prepared by: TWDB

Appendix H: Bathymetric area curve

Appendix I

Bardwell Lake

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — July 2020 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT — Top of dam elevation 460.0 feet NGVD29

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
386	0	0	0	0	0	0	0	0	0	0
387	0	0	0	0	0	0	0	0	0	0
388	0	0	0	1	2	3	4	6	7	9
389	10	12	14	16	18	20	23	25	27	30
390	32	35	37	40	42	45	48	51	54	58
391	61	65	70	75	80	86	92	100	107	116
392	125	134	144	154	165	177	188	200	213	225
393	238	252	265	279	293	307	322	336	351	367
394	382	398	414	430	447	465	484	503	524	546
395	572	599	628	658	690	723	756	791	827	864
396	902	941	980	1,021	1,063	1,106	1,150	1,195	1,241	1,288
397	1,336	1,385	1,435	1,486	1,538	1,591	1,645	1,700	1,756	1,814
398	1,873	1,933	1,994	2,056	2,119	2,183	2,248	2,315	2,382	2,451
399	2,520	2,590	2,661	2,734	2,807	2,881	2,956	3,032	3,109	3,186
400	3,265	3,344	3,425	3,507	3,589	3,673	3,757	3,842	3,928	4,016
401	4,104	4,193	4,284	4,377	4,470	4,565	4,661	4,758	4,857	4,958
402	5,060	5,164	5,268	5,374	5,480	5,588	5,697	5,807	5,918	6,030
403	6,143	6,256	6,370	6,485	6,601	6,717	6,835	6,952	7,071	7,191
404	7,311	7,432	7,553	7,675	7,798	7,921	8,046	8,170	8,296	8,422
405	8,549	8,677	8,806	8,936	9,066	9,197	9,329	9,462	9,596	9,731
406	9,866	10,002	10,139	10,276	10,415	10,554	10,694	10,834	10,976	11,119
407	11,263	11,407	11,553	11,700	11,848	11,997	12,147	12,298	12,450	12,603
408	12,758	12,914	13,071	13,229	13,389	13,549	13,711	13,873	14,037	14,201
409	14,367	14,533	14,701	14,869	15,039	15,210	15,381	15,554	15,728	15,903
410	16,078	16,255	16,433	16,612	16,791	16,972	17,154	17,337	17,520	17,705
411	17,891	18,078	18,267	18,456	18,646	18,838	19,031	19,225	19,420	19,616
412	19,814	20,013	20,214	20,415	20,619	20,824	21,030	21,238	21,448	21,659
413	21,871	22,085	22,301	22,518	22,737	22,958	23,180	23,404	23,629	23,856
414	24,086	24,317	24,550	24,785	25,021	25,259	25,499	25,741	25,984	26,228
415	26,475	26,723	26,973	27,224	27,477	27,732	27,988	28,246	28,506	28,768
416	29,032	29,297	29,564	29,833	30,103	30,375	30,648	30,923	31,199	31,476
417	31,755	32,034	32,316	32,598	32,882	33,167	33,454	33,742	34,031	34,321
418	34,612	34,905	35,198	35,493	35,789	36,087	36,385	36,685	36,986	37,287
419	37,590	37,895	38,200	38,507	38,815	39,124	39,434	39,746	40,059	40,374
420	40,689	41,006	41,325	41,644	41,965	42,287	42,611	42,936	43,262	43,589
421	43,918	44,249	44,581	44,914	45,248	45,583	45,919	46,256	46,594	46,934
422	47,275	47,618	47,962	48,308	48,655	49,004	49,354	49,706	50,059	50,414
423	50,770	51,127	51,486	51,846	52,208	52,572	52,937	53,303	53,671	54,040
424	54,411	54,784	55,157	55,532	55,909	56,286	56,666	57,046	57,428	57,810
425	58,195	58,580	58,967	59,354	59,743	60,133	60,524	60,917	61,310	61,705
426	62,100	62,497	62,894	63,293	63,693	64,094	64,496	64,900	65,304	65,710
427	66,117	66,525	66,935	67,346	67,758	68,171	68,586	69,002	69,419	69,837
428	70,257	70,678	71,101	71,525	71,951	72,379	72,808	73,239	73,671	74,106
429	74,542	74,980	75,420	75,861	76,304	76,749	77,195	77,643	78,092	78,543
430	78,996	79,450	79,905	80,362	80,820	81,280	81,742	82,205	82,670	83,137
431	83,605	84,075	84,546	85,019	85,494	85,970	86,447	86,927	87,408	87,890
432	88,374	88,859	89,346	89,835	90,325	90,818	91,311	91,806	92,303	92,802
433	93,302	93,804	94,307	94,813	95,320	95,828	96,339	96,851	97,364	97,880
434	98,397	98,916	99,436	99,959	100,483	101,009	101,536	102,066	102,597	103,129
435	103,663	104,199	104,737	105,276	105,817	106,359	106,903	107,448	107,995	108,544
436	109,094	109,645	110,198	110,753	111,309	111,867	112,426	112,987	113,549	114,114
437	114,679	115,246	115,815	116,385	116,957	117,530	118,105	118,681	119,259	119,839
438	120,420	121,002	121,586	122,172	122,759	123,348	123,938	124,530	125,124	125,719
439	126,315	126,913	127,512	128,113	128,716	129,320	129,925	130,532	131,141	131,751
440	132,363	132,976	133,591	134,208	134,826	135,446	136,068	136,691	137,316	137,944

Appendix I (Continued)

Bardwell Lake

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — July 2020 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT — Top of dam elevation 460.0 feet NGVD29

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
441	138,573	139,204	139,837	140,472	141,108	141,746	142,386	143,028	143,672	144,317
442	144,964	145,613	146,263	146,915	147,569	148,225	148,883	149,542	150,203	150,865
443	151,529	152,196	152,864	153,533	154,205	154,878	155,554	156,231	156,910	157,591
444	158,274	158,958	159,645	160,333	161,023	161,715	162,409	163,104	163,801	164,501
445	165,202	165,904	166,609	167,316	168,024	168,735	169,447	170,161	170,877	171,596
446	172,316	173,038	173,762	174,488	175,216	175,946	176,678	177,412	178,148	178,887
447	179,628	180,371	181,117	181,865	182,614	183,367	184,121	184,878	185,637	186,398
448	187,161	187,926	188,693	189,462	190,234	191,007	191,783	192,561	193,342	194,124
449	194,909	195,696	196,485	197,278	198,072	198,870	199,669	200,471	201,276	202,082
450	202,891	203,703	204,516	205,332	206,150	206,970	207,792	208,617	209,443	210,272
451	211,103	211,936	212,772	213,609	214,449	215,290	216,134	216,980	217,829	218,679
452	219,532	220,387	221,245	222,104	222,966	223,830	224,697	225,566	226,437	227,311
453	228,187	229,065	229,946	230,829	231,715	232,603	233,494	234,387	235,283	236,182
454	237,083	237,986	238,893	239,802	240,713	241,627	242,544	243,464	244,386	245,311
455	246,238	247,168	248,100	249,035	249,972	250,912	251,854	252,799	253,746	254,696
456	255,649	256,605	257,563	258,523	259,486	260,452	261,421	262,393	263,367	264,344
457	265,323	266,305	267,290	268,278	269,268	270,261	271,257	272,255	273,256	274,260
458	275,266	276,276	277,288	278,303	279,321	280,342	281,366	282,393	283,422	284,455
459	285,490	286,528	287,569	288,613	289,661	290,711	291,765	292,822	293,882	294,945
460	296,013									

Note: Capacities above elevation 419.0 feet calculated from interpolated and computed areas

Appendix J

Bardwell Lake

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — July 2020 Survey

AREA IN ACRES — Conservation pool elevation 421.0 feet NGVD29

ELEVATION INCREMENT IS ONE TENTH FOOT — Top of dam elevation 460.0 feet NGVD29

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
386	0	0	0	0	0	0	0	0	0	0
387	0	0	0	0	0	0	0	0	0	1
388	1	1	2	7	10	12	13	14	15	16
389	18	19	20	20	21	22	22	23	24	24
390	25	26	26	27	28	28	30	31	33	35
391	37	42	46	51	56	62	69	75	81	86
392	91	96	101	108	112	116	119	122	126	128
393	131	134	137	139	141	143	146	148	150	153
394	156	159	163	168	173	180	188	199	217	240
395	262	282	297	309	322	333	344	353	363	374
396	383	393	403	413	423	434	445	454	464	475
397	486	496	506	515	525	535	545	556	570	582
398	593	604	615	627	638	648	658	669	679	688
399	698	707	717	727	736	745	755	763	773	781
400	790	800	811	822	830	839	847	856	867	878
401	889	902	916	928	940	953	968	984	1,000	1,014
402	1,028	1,039	1,050	1,060	1,071	1,084	1,096	1,105	1,114	1,123
403	1,131	1,139	1,146	1,153	1,161	1,168	1,175	1,183	1,192	1,199
404	1,205	1,211	1,218	1,224	1,231	1,237	1,244	1,252	1,259	1,267
405	1,275	1,284	1,292	1,301	1,309	1,316	1,324	1,333	1,342	1,350
406	1,358	1,364	1,372	1,379	1,386	1,394	1,403	1,413	1,423	1,433
407	1,443	1,453	1,464	1,476	1,485	1,495	1,505	1,515	1,526	1,537
408	1,552	1,566	1,577	1,589	1,600	1,609	1,620	1,630	1,640	1,651
409	1,660	1,670	1,680	1,691	1,701	1,712	1,723	1,733	1,743	1,752
410	1,762	1,772	1,783	1,792	1,802	1,813	1,823	1,833	1,843	1,854
411	1,865	1,877	1,888	1,899	1,909	1,921	1,934	1,946	1,958	1,971
412	1,984	1,998	2,012	2,026	2,041	2,058	2,073	2,088	2,103	2,117
413	2,132	2,149	2,165	2,180	2,196	2,215	2,231	2,247	2,262	2,282
414	2,303	2,322	2,339	2,355	2,372	2,392	2,408	2,423	2,438	2,455
415	2,474	2,489	2,504	2,523	2,540	2,555	2,570	2,590	2,610	2,628
416	2,644	2,664	2,680	2,693	2,707	2,725	2,741	2,754	2,767	2,778
417	2,791	2,805	2,820	2,833	2,846	2,859	2,871	2,884	2,896	2,907
418	2,919	2,931	2,942	2,955	2,968	2,980	2,991	3,001	3,013	3,024
419	3,035	3,048	3,060	3,073	3,086	3,099	3,112	3,125	3,138	3,151
420	3,163	3,176	3,189	3,202	3,215	3,228	3,241	3,254	3,268	3,281
421	3,296	3,316	3,325	3,334	3,344	3,355	3,366	3,378	3,391	3,405
422	3,420	3,434	3,449	3,464	3,480	3,495	3,510	3,525	3,539	3,553
423	3,567	3,582	3,597	3,612	3,627	3,642	3,657	3,672	3,687	3,701
424	3,715	3,729	3,743	3,757	3,771	3,785	3,798	3,810	3,823	3,835
425	3,848	3,860	3,872	3,883	3,895	3,906	3,917	3,928	3,939	3,950
426	3,961	3,972	3,983	3,994	4,005	4,016	4,028	4,040	4,052	4,064
427	4,077	4,089	4,102	4,115	4,127	4,139	4,152	4,164	4,177	4,190
428	4,205	4,220	4,237	4,253	4,267	4,283	4,299	4,317	4,335	4,353
429	4,371	4,388	4,406	4,422	4,439	4,455	4,470	4,486	4,502	4,516
430	4,531	4,546	4,562	4,577	4,592	4,608	4,624	4,641	4,657	4,673
431	4,690	4,706	4,722	4,738	4,754	4,769	4,785	4,800	4,816	4,831
432	4,847	4,863	4,879	4,895	4,912	4,928	4,945	4,961	4,977	4,994
433	5,010	5,027	5,044	5,061	5,078	5,094	5,111	5,129	5,146	5,163
434	5,180	5,198	5,215	5,233	5,250	5,267	5,284	5,301	5,318	5,334
435	5,352	5,368	5,384	5,400	5,415	5,431	5,446	5,461	5,476	5,491
436	5,507	5,523	5,539	5,554	5,570	5,586	5,601	5,617	5,633	5,648
437	5,664	5,679	5,695	5,710	5,726	5,741	5,756	5,771	5,787	5,802
438	5,817	5,833	5,849	5,864	5,880	5,895	5,911	5,927	5,942	5,957
439	5,972	5,987	6,001	6,017	6,032	6,047	6,063	6,078	6,094	6,110
440	6,126	6,142	6,158	6,174	6,191	6,208	6,225	6,243	6,262	6,282

Appendix J (Continued)

Bardwell Lake

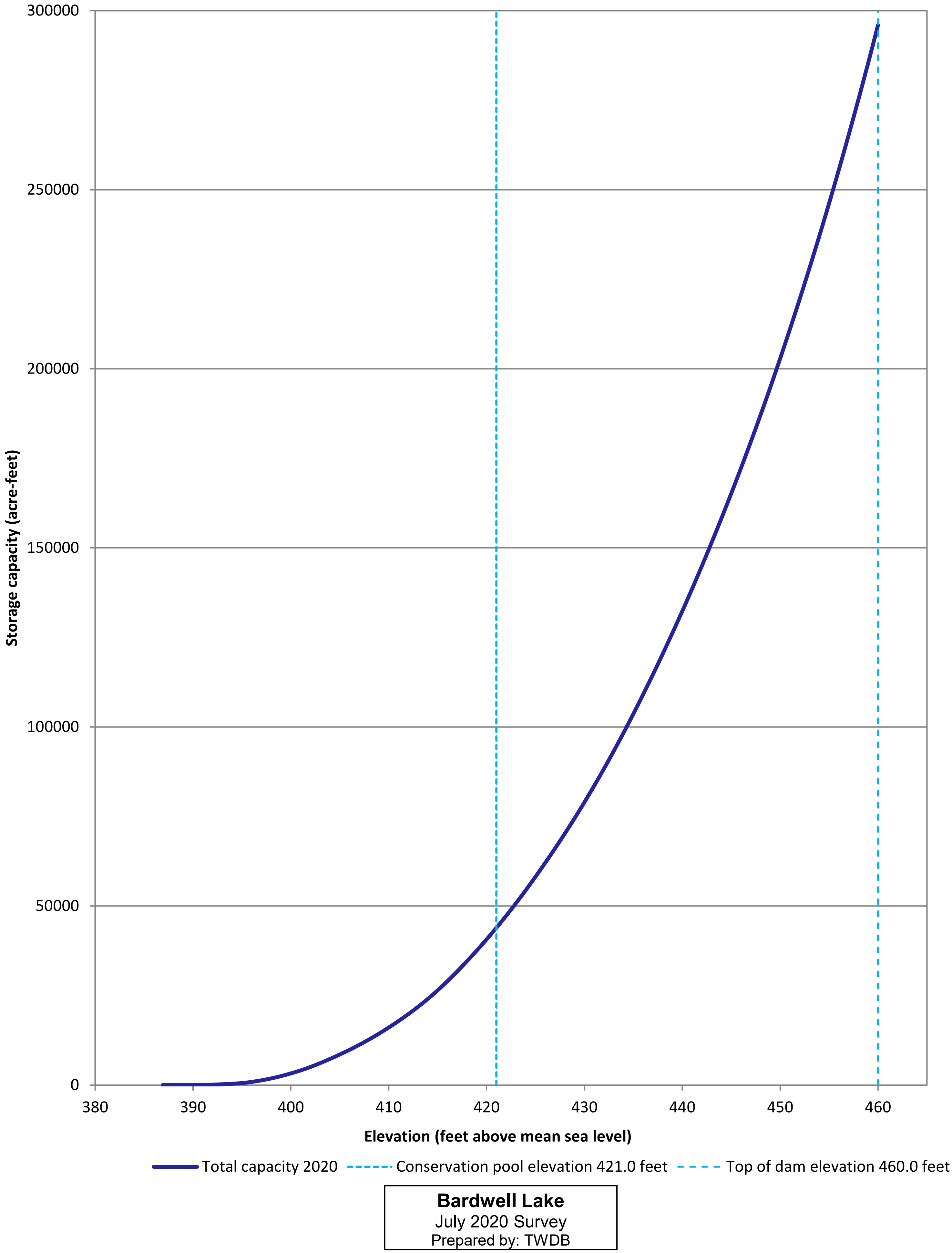
RESERVOIR BATHYMETRIC AND TOPOGRAPHIC AREA TABLE

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

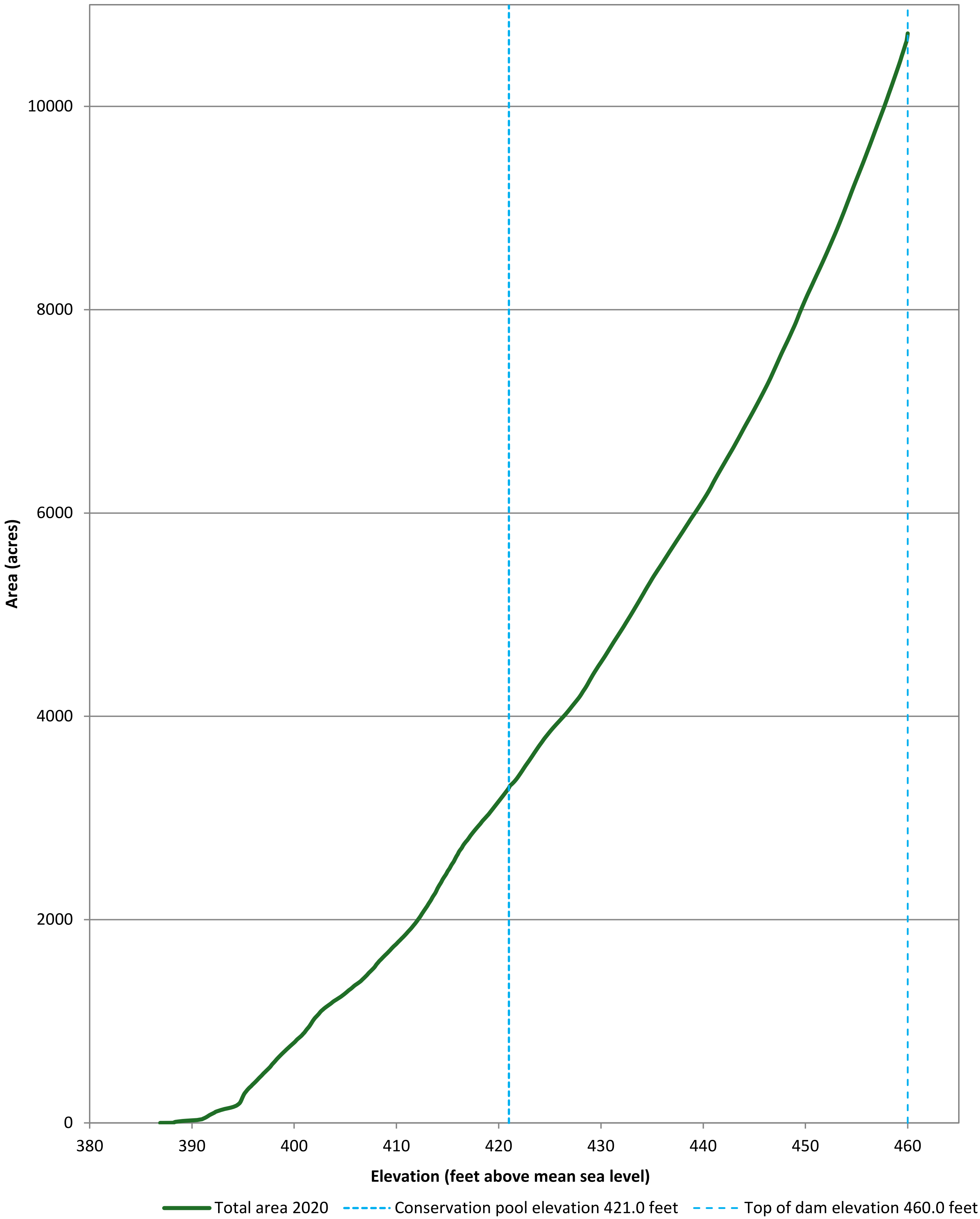
July 2020 Survey
Conservation pool elevation 421.0 feet NGVD29
Top of dam elevation 460.0 feet NGVD29

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
441	6,302	6,320	6,338	6,356	6,374	6,392	6,409	6,426	6,444	6,461
442	6,479	6,496	6,514	6,531	6,548	6,566	6,583	6,600	6,617	6,635
443	6,652	6,670	6,689	6,707	6,725	6,744	6,762	6,781	6,800	6,819
444	6,837	6,856	6,874	6,892	6,910	6,928	6,946	6,964	6,983	7,001
445	7,019	7,038	7,057	7,076	7,095	7,114	7,133	7,152	7,171	7,191
446	7,210	7,230	7,250	7,269	7,290	7,311	7,332	7,354	7,376	7,399
447	7,421	7,443	7,466	7,488	7,511	7,533	7,556	7,578	7,599	7,620
448	7,641	7,662	7,682	7,704	7,725	7,747	7,770	7,792	7,814	7,836
449	7,859	7,883	7,908	7,934	7,960	7,985	8,008	8,032	8,055	8,079
450	8,102	8,125	8,147	8,169	8,190	8,212	8,233	8,255	8,277	8,299
451	8,321	8,342	8,364	8,385	8,407	8,428	8,450	8,472	8,495	8,517
452	8,539	8,562	8,585	8,608	8,631	8,654	8,678	8,701	8,724	8,748
453	8,771	8,796	8,820	8,845	8,870	8,895	8,920	8,946	8,971	8,998
454	9,024	9,050	9,076	9,103	9,129	9,156	9,183	9,208	9,234	9,259
455	9,285	9,310	9,335	9,360	9,385	9,410	9,436	9,462	9,488	9,514
456	9,541	9,567	9,593	9,620	9,646	9,673	9,701	9,728	9,755	9,782
457	9,809	9,836	9,863	9,889	9,916	9,943	9,969	9,996	10,024	10,052
458	10,080	10,109	10,138	10,166	10,194	10,223	10,252	10,281	10,310	10,339
459	10,368	10,397	10,426	10,457	10,490	10,521	10,552	10,584	10,616	10,649
460	10,718									

Note: Areas between elevations 419.0 and 421.0 feet linearly interpolated



Appendix K: Bathymetric and topographic capacity curve



Bardwell Lake
July 2020 Survey
Prepared by: TWDB

Appendix L: Bathymetric and topographic area curve

Appendix M

Bardwell Lake

Sedimentation range lines

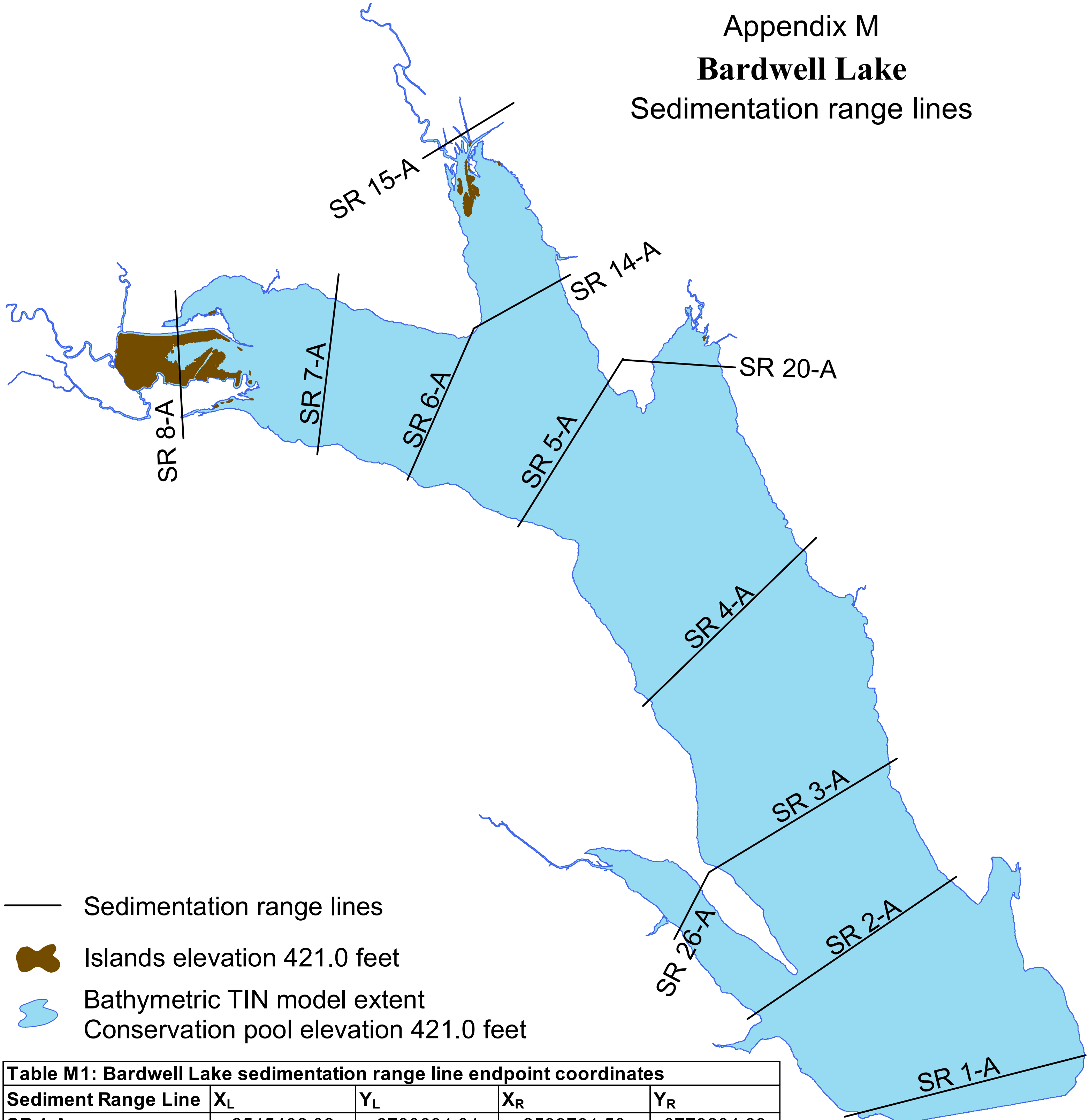
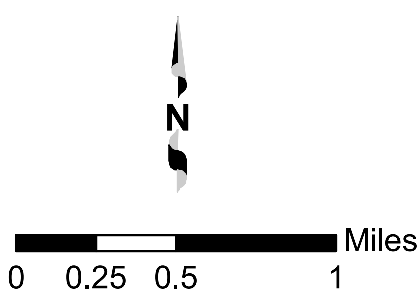
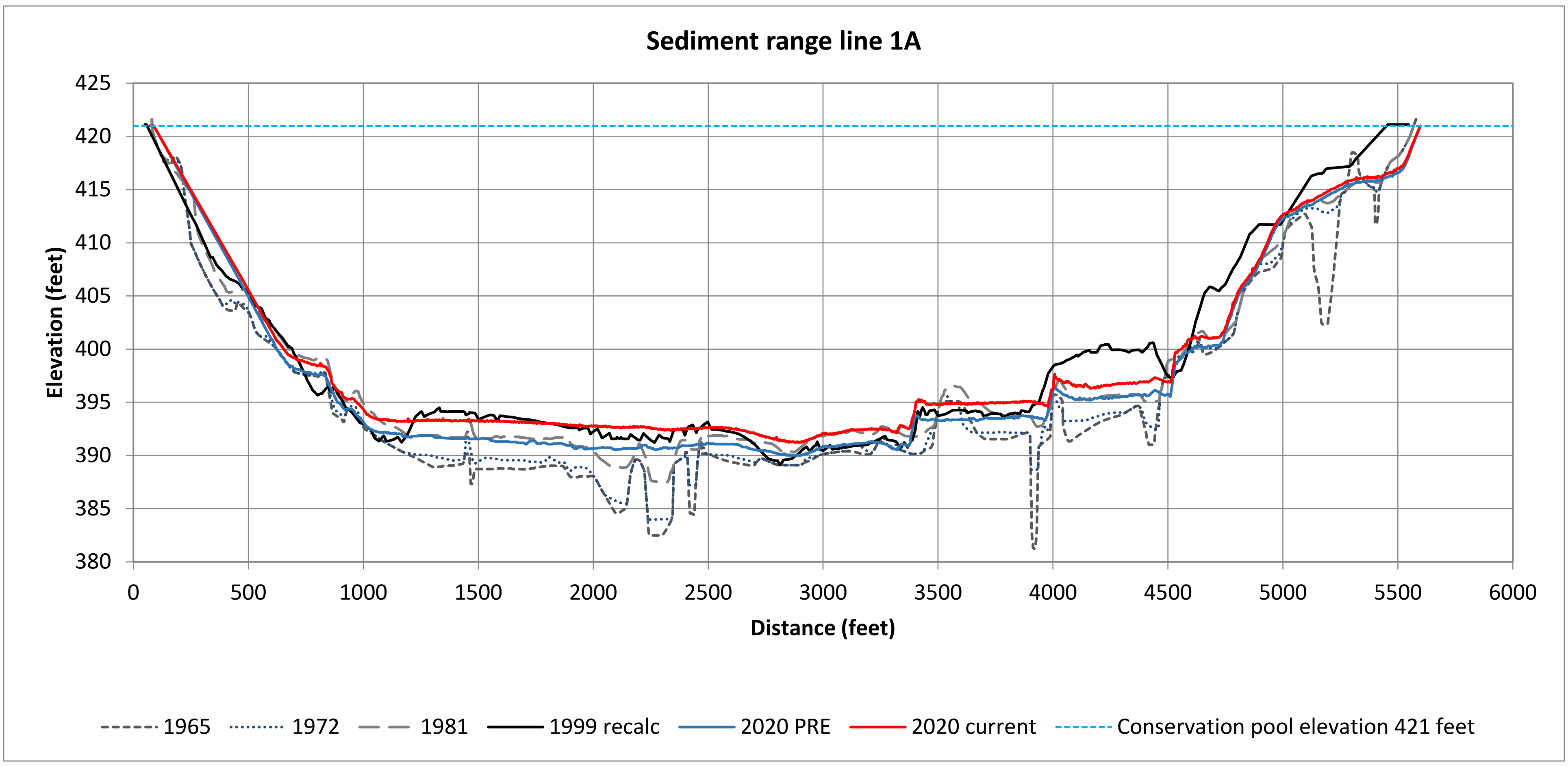
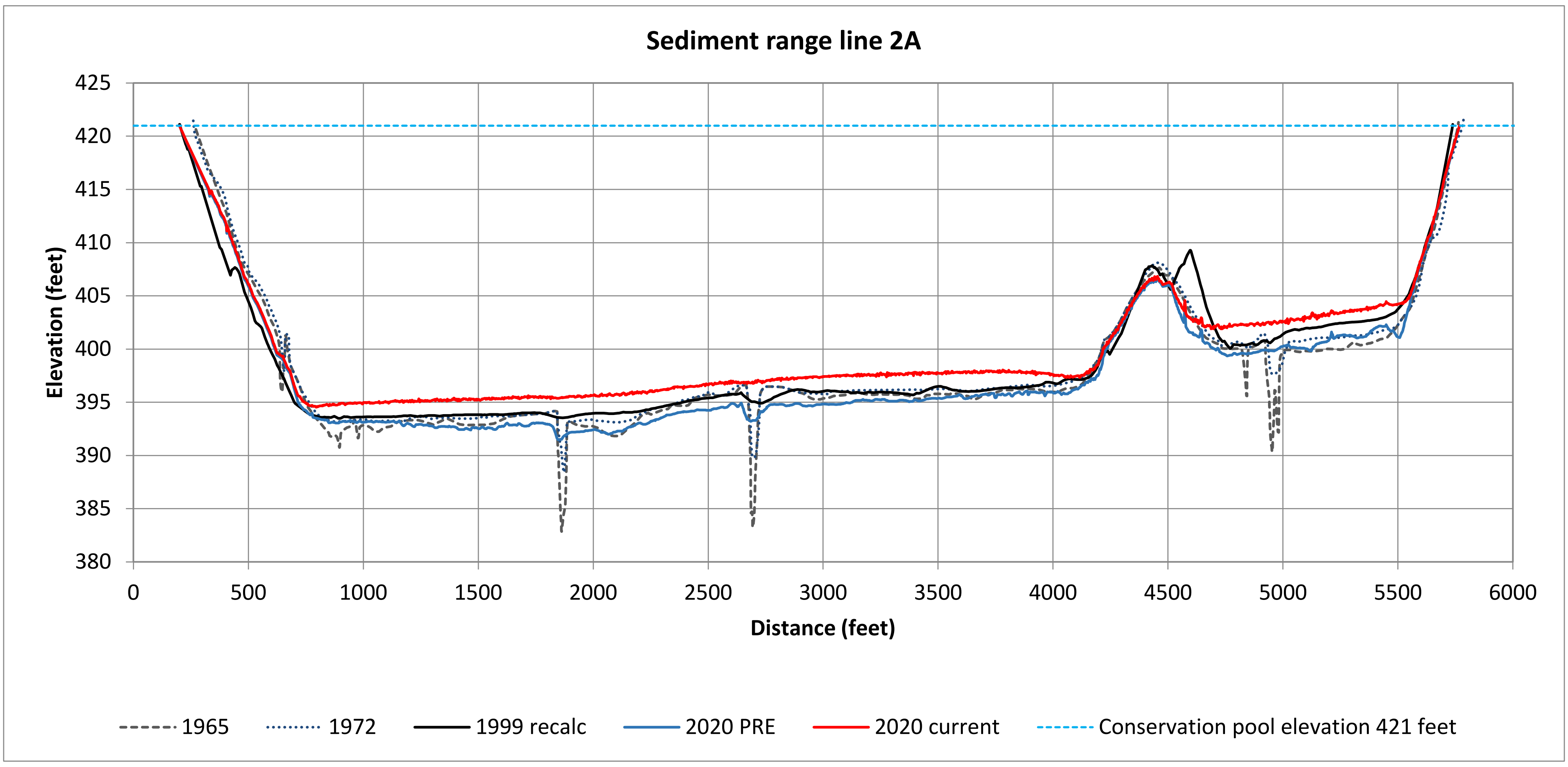
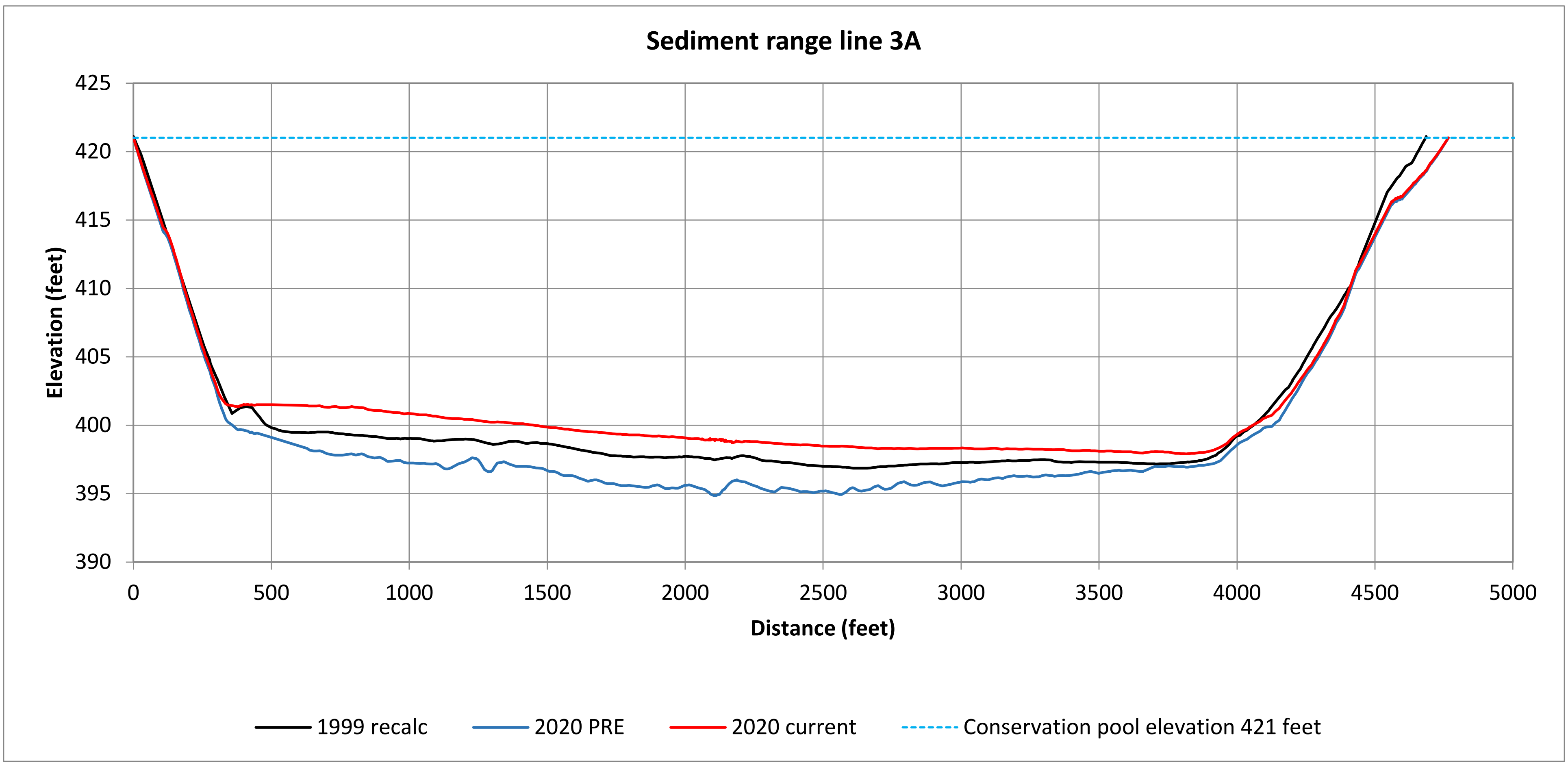


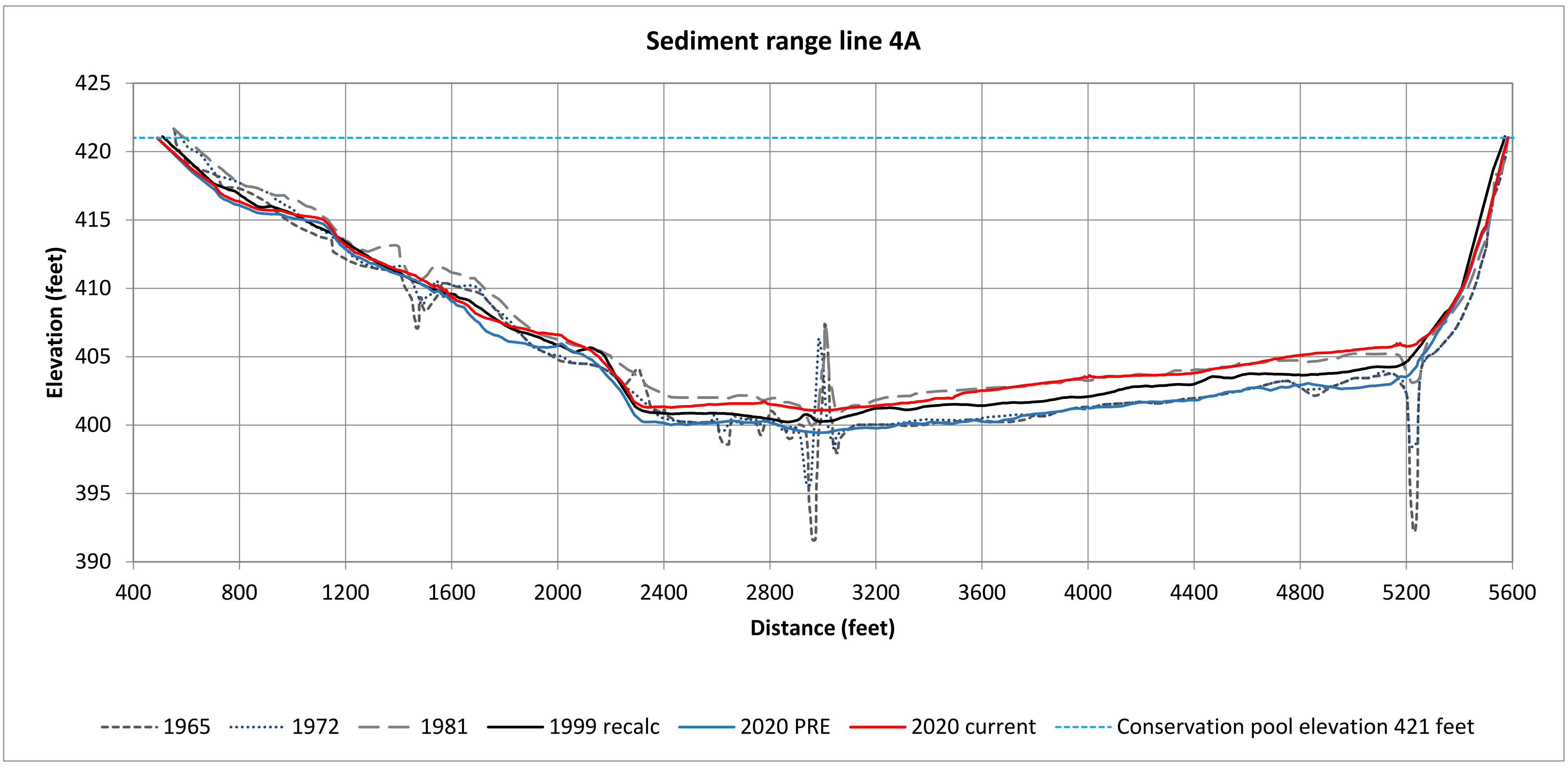
Table M1: Bardwell Lake sedimentation range line endpoint coordinates				
Sediment Range Line	**X_L**	**Y_L**	**X_R**	**Y_R**
SR 1-A	2545402.02	6780694.64	2539701.53	6779234.63
SR 2-A	2542340.13	6784912.88	2537398.08	6781544.35
SR 3-A	2540932.18	6787717.73	2536487.53	6785019.37
SR 4-A	2539027.98	6792943.25	2534931.16	6788953.69
SR 5-A	2534457.82	6797176.52	2531969.29	6793198.95
SR 6-A	2530925.28	6797892.96	2529358.11	6794313.80
SR 7-A	2527726.04	6799181.83	2527224.60	6794913.84
SR 8-A	2523862.54	6798771.42	2524057.07	6795290.27
SR 14-A	2533204.29	6799171.34	2530920.75	6797888.48
SR 15-A	2531868.64	6803230.23	2529727.05	6801921.73
SR 20-A	2537111.38	6796974.69	2534444.31	6797154.16
SR 26-A	2536487.53	6785019.37	2535668.61	6783441.00
XY: NAD83 State Plane Texas North Central Zone (feet)			L= Left End Point R= Right End Point	

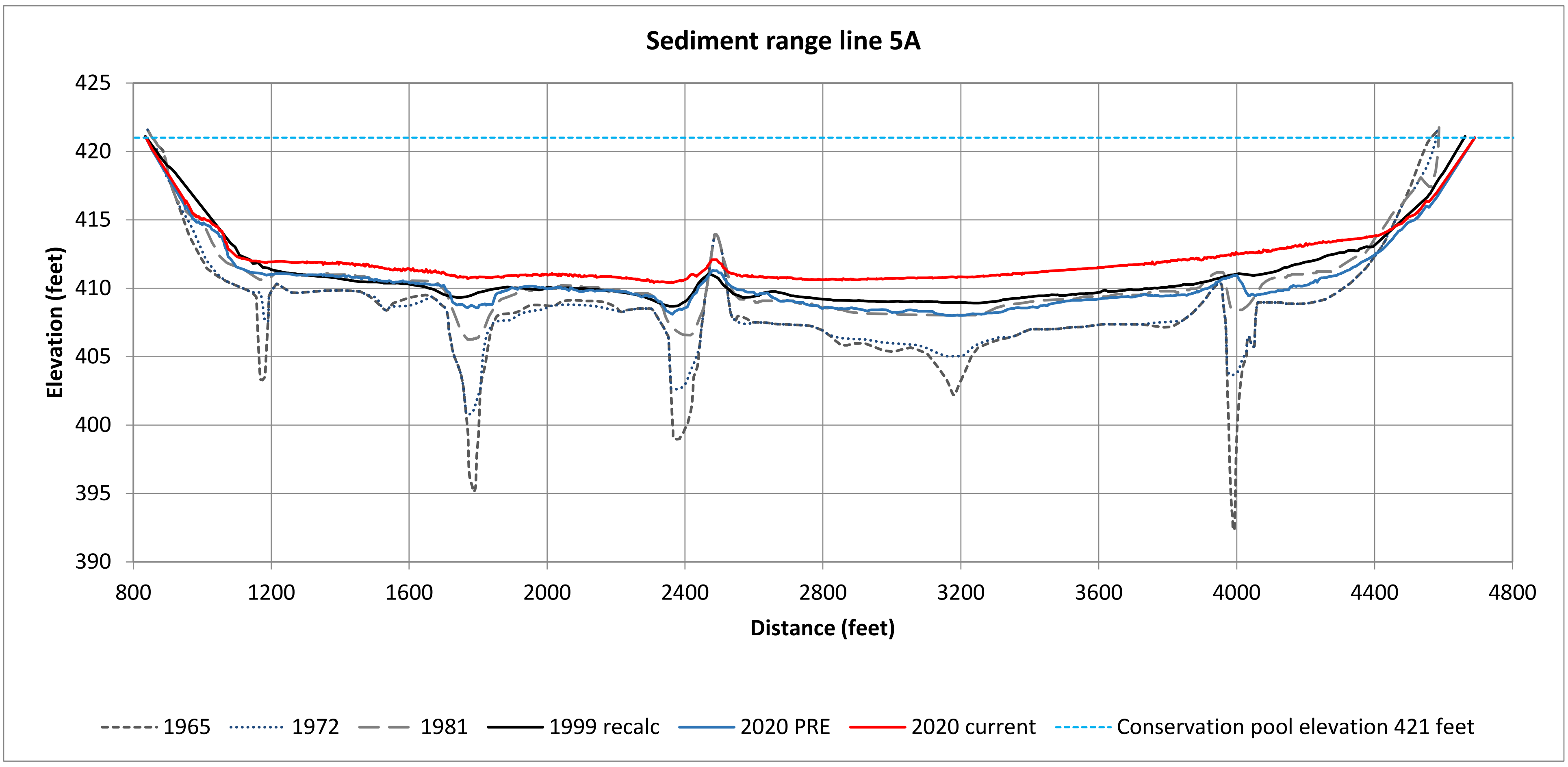


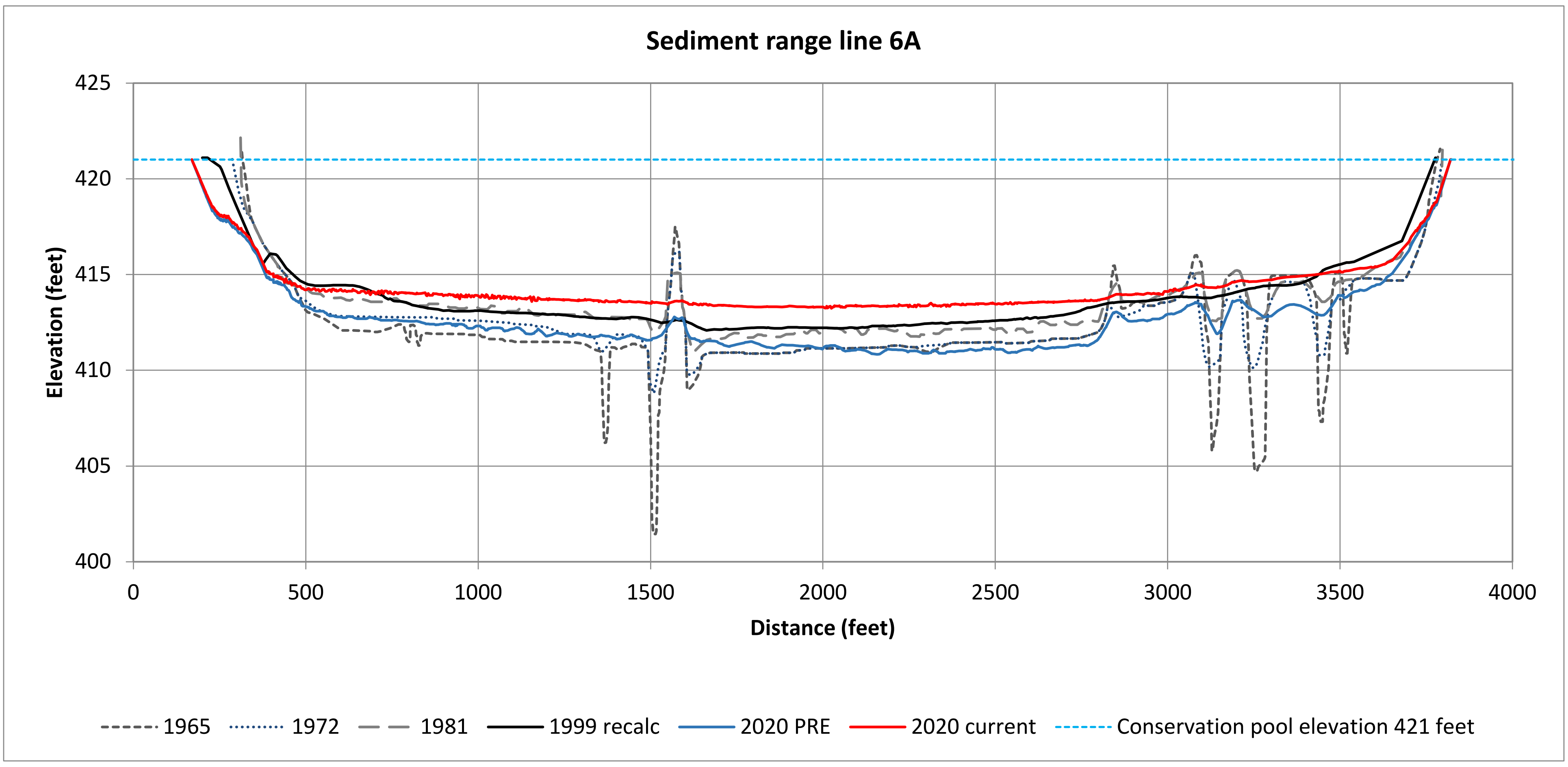

Sediment range line 1A
Elevation (feet)
Distance (feet)
425
420
415
410
405
400
395
390
385
380
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet

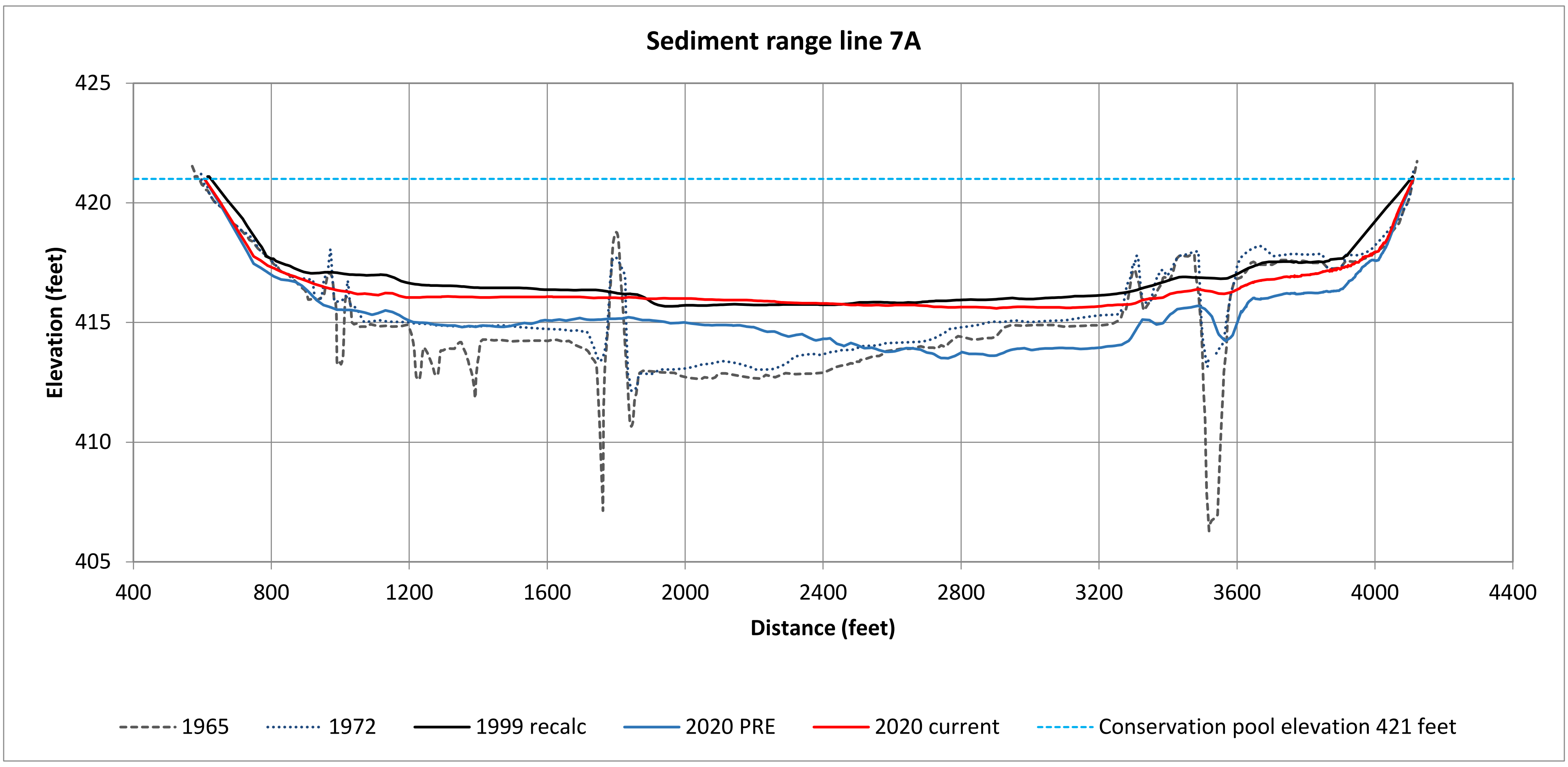

Sediment range line 2A
Elevation (feet)
Distance (feet)
425
420
415
410
405
400
395
390
385
380
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
1965
1972
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet


Sediment range line 3A
Elevation (feet)
Distance (feet)
425
420
415
410
405
400
395
390
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet

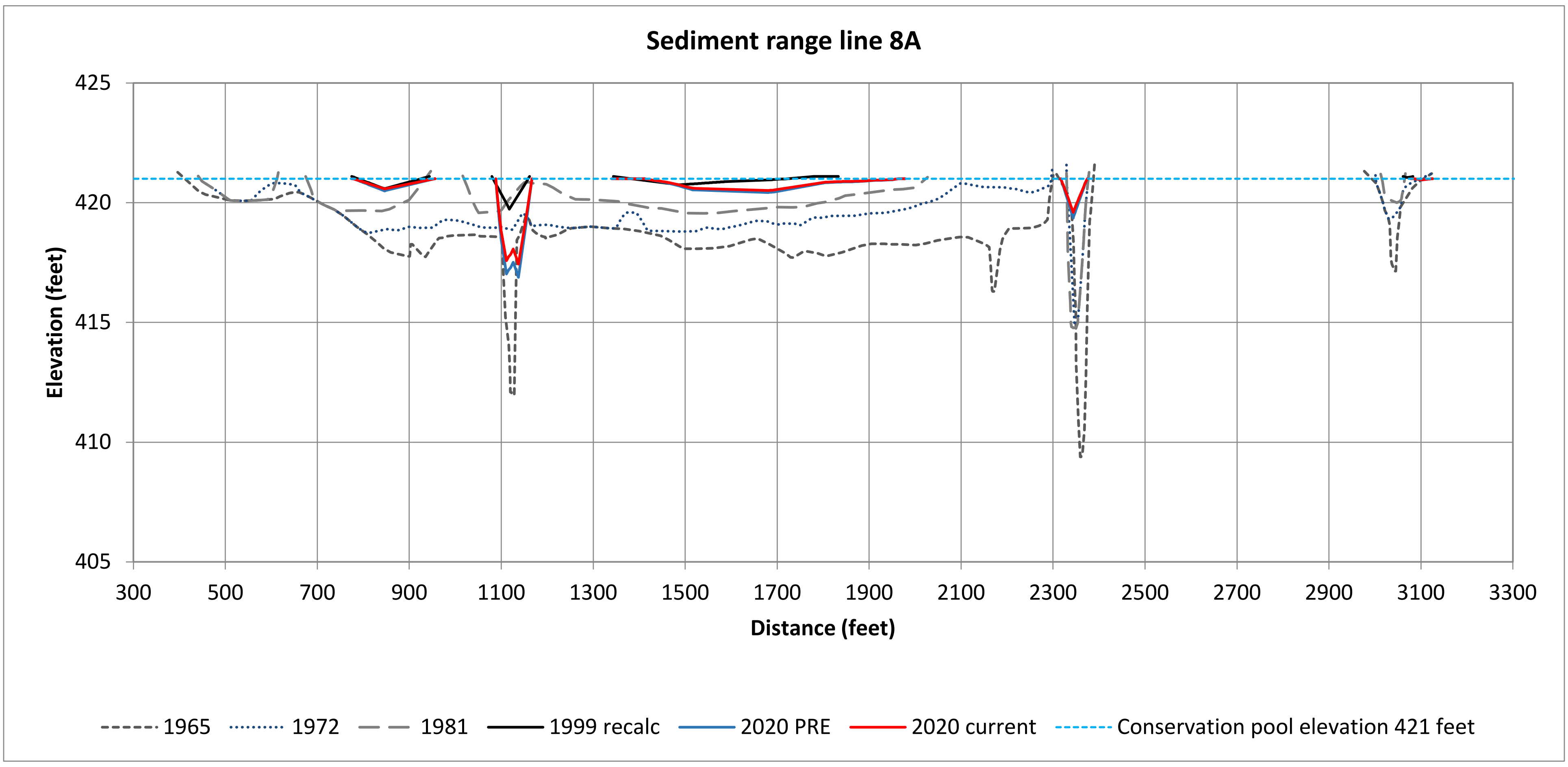

Sediment range line 4A
Elevation (feet)
425
420
415
410
405
400
395
390
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
4800
5200
5600
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet


Sediment range line 5A
Elevation (feet)
425
420
415
410
405
400
395
390
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
4800
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet

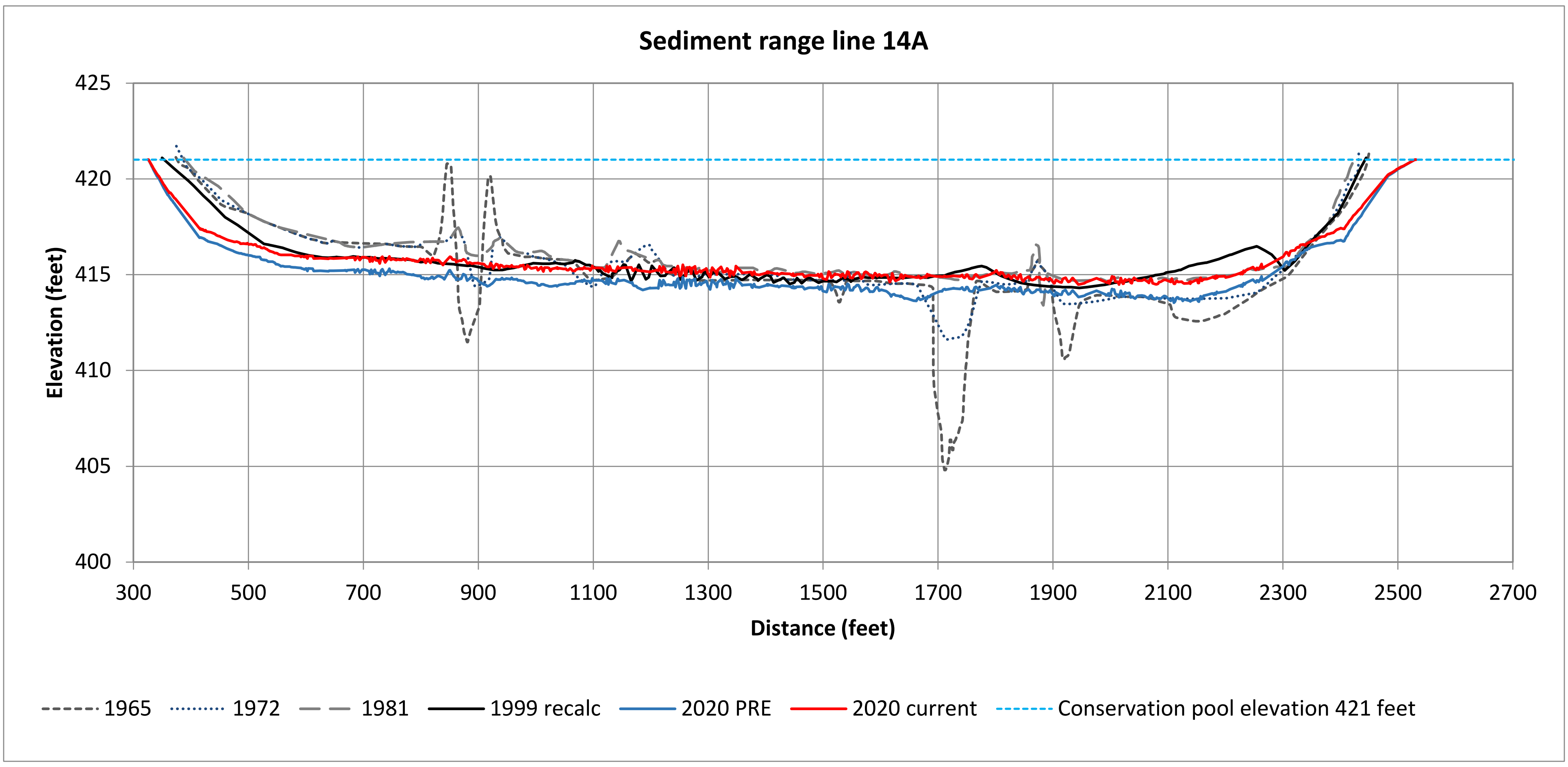

Sediment range line 6A
Elevation (feet)
425
420
415
410
405
400
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



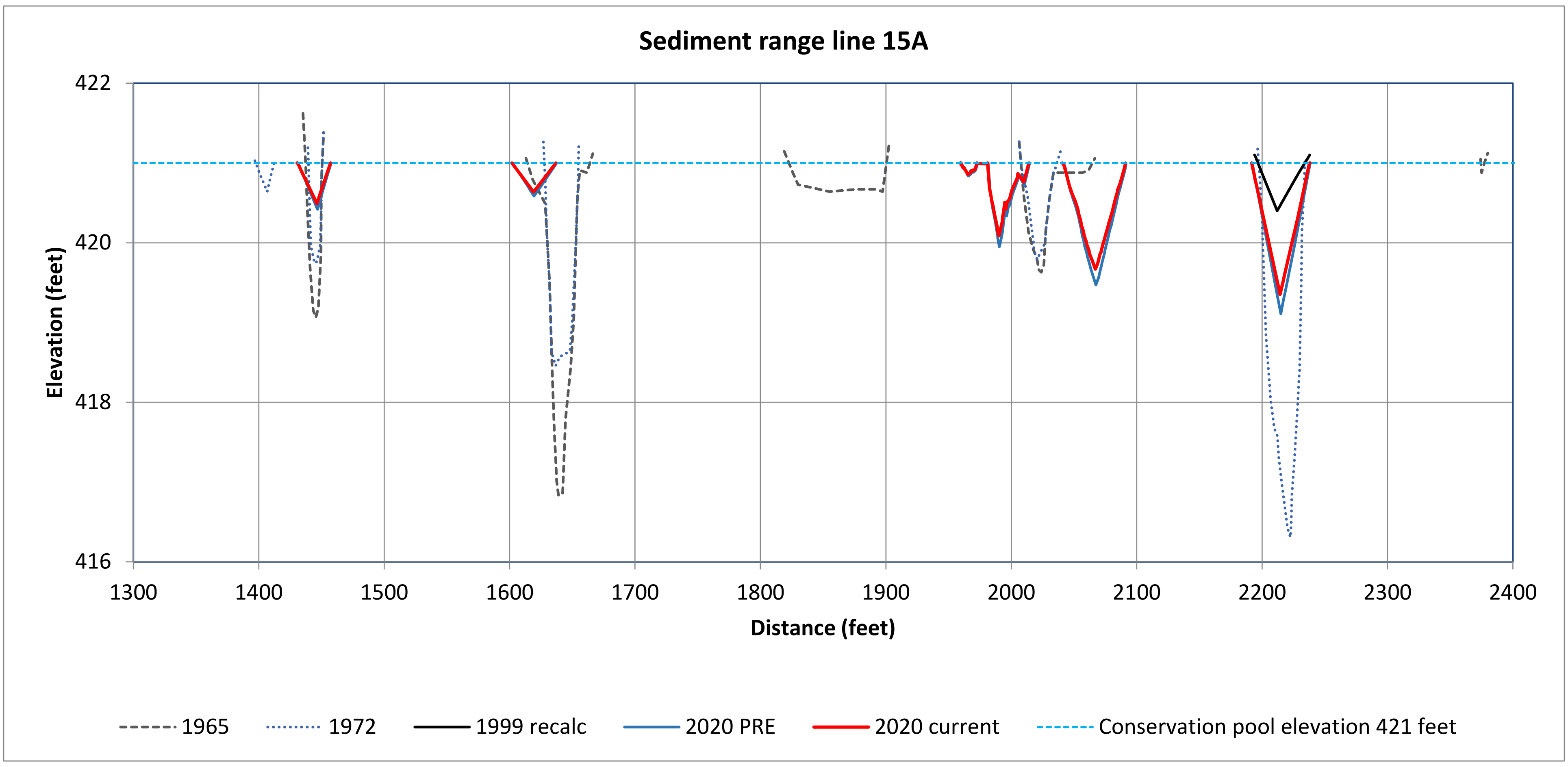
Sediment range line 7A
Elevation (feet)
425
420
415
410
405
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
Distance (feet)
1965
1972
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



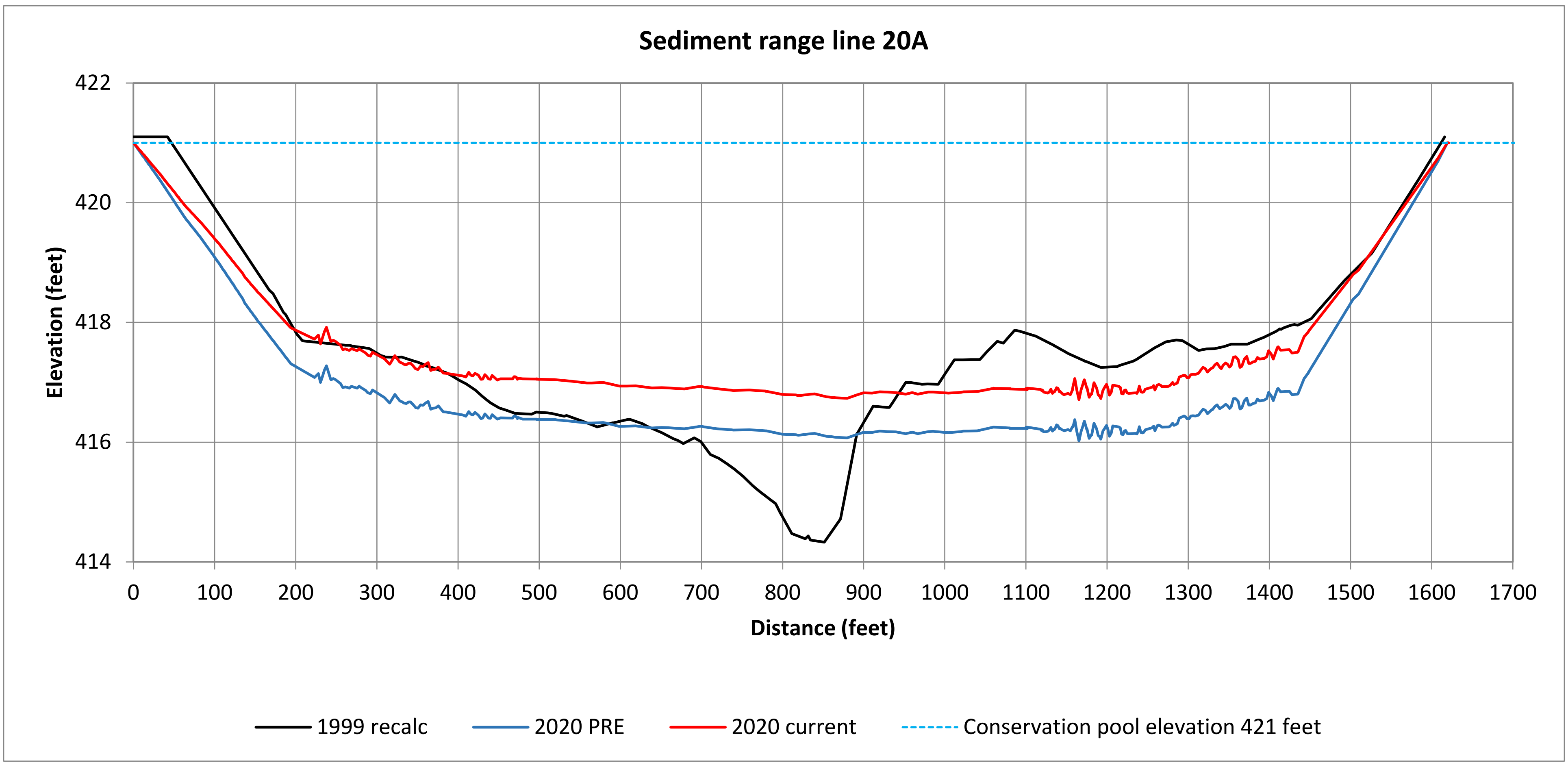
Sediment range line 8A
Elevation (feet)
425
420
415
410
405
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
2700
2900
3100
3300
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



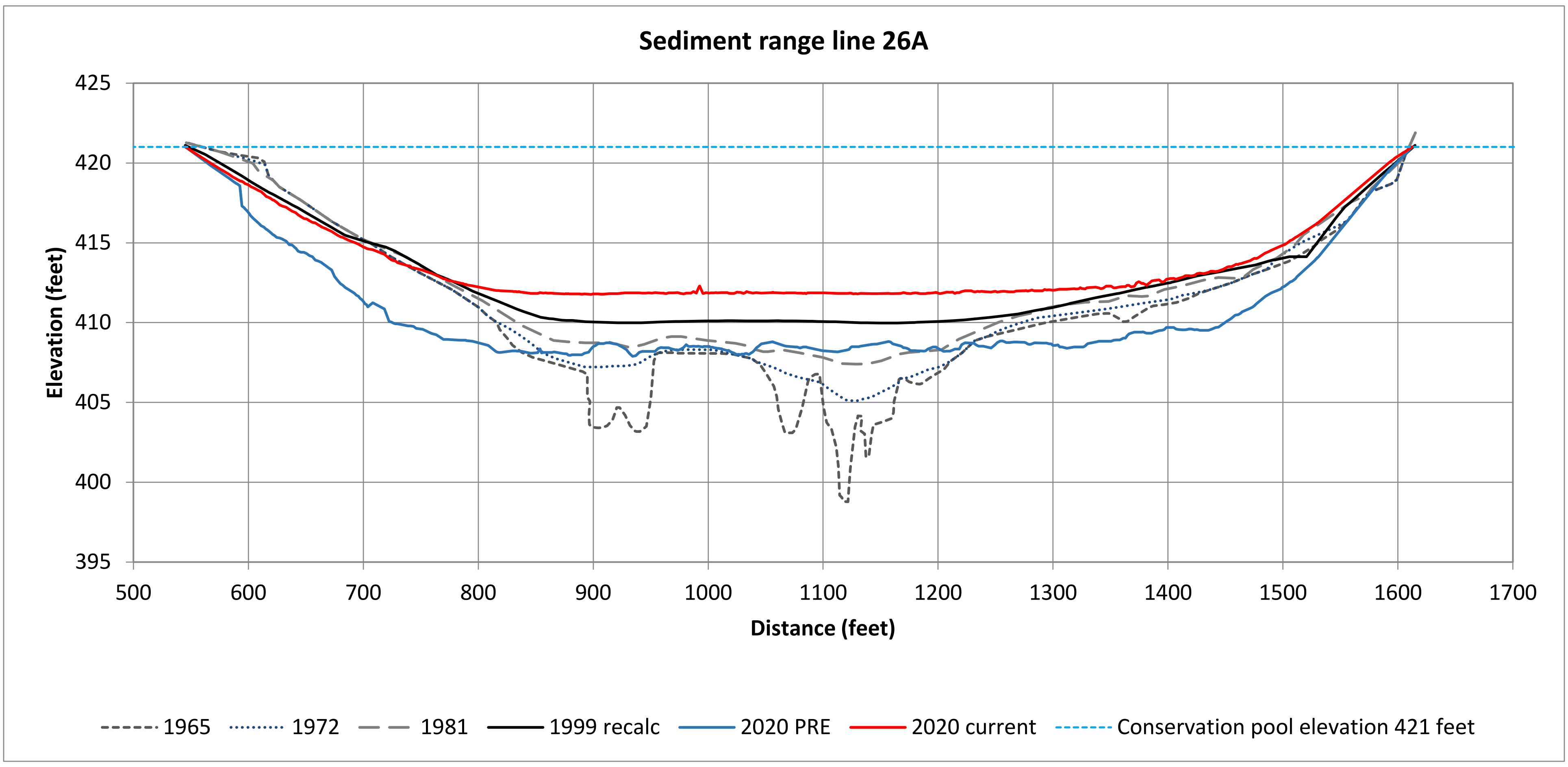
Sediment range line 14A
Elevation (feet)
425
420
415
410
405
400
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
2700
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



Sediment range line 15A
Elevation (feet)
422
420
418
416
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Distance (feet)
1965
1972
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



Sediment range line 20A
Elevation (feet)
422
420
418
416
414
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
Distance (feet)
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet



Sediment range line 26A
Elevation (feet)
425
420
415
410
405
400
395
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
Distance (feet)
1965
1972
1981
1999 recalc
2020 PRE
2020 current
Conservation pool elevation 421 feet

Figure 6

CONTOURS
(feet above mean sea level)

420
418
416
414
412
410
408
406
404
402
400
398
396
394
392
390
388

Islands

Bardwell Lake
Conservation pool
elevation 421.0 feet

Projection: NAD83 State Plane
Texas North Central Zone (feet)

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Bardwell Lake. The Texas Water Development Board makes no representations nor assumes any liability.