Volumetric and Sedimentation Survey of LAKE LIVINGSTON

September 2018 – November 2019 Survey

Texas Water Development Board

September 2022

Texas Water Development Board

Prepared for:

Trinity River Authority

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Executive summary

In July 2018, the Texas Water Development Board (TWDB) entered into an agreement with the Trinity River Authority to perform a volumetric and sedimentation survey of Lake Livingston (Polk, San Jacinto, Trinity, and Walker counties, 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 in select locations and correlated with sub-bottom acoustic profiles to estimate sediment accumulation thicknesses and sedimentation rates.

Livingston Dam and Lake Livingston are located on the Trinity River in Polk, San Jacinto, Walker, and Trinity counties, approximately 6 miles southwest of Livingston, Texas. The conservation pool elevation of Lake Livingston is 131.0 feet above mean sea level (NGVD29). The TWDB collected bathymetric data for Lake Livingston between September 17, 2018, and November 21, 2019, while daily average water surface elevations measured between 130.97 and 132.93 feet above mean sea level (NGVD29).

The 2019 TWDB volumetric survey indicates Lake Livingston has a total reservoir capacity of 1,603,504 acre-feet and encompasses 77,729 acres at conservation pool elevation (131.0 feet above mean sea level, NGVD29). Previous capacity estimates at conservation pool elevation (131.0 feet above means sea level, NGVD29) include an original design estimate of 1,787,774 acre-feet, a re-calculation of the original design by the U.S. Bureau of Reclamation (USBR) in 1991 of 1,806,094 acre-feet, and a 1991 USBR estimate of 1,741,867 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 2019 TWDB sedimentation survey measured 129,149 acre-feet of sediment. Comparison of the 2019 sedimentation survey results with historical records suggest the TWDB sedimentation survey results are an underestimate of the total sediment volume in Lake Livingston. The sedimentation survey indicates sediment accumulation is thickest in the river channels. Comparison with historical area curves suggest significant sedimentation has occurred in the upper reaches above approximately the 120.5-foot contour. The TWDB recommends that a similar methodology be used to resurvey Lake Livingston in 10 years or after a major flood event.

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

Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. 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 July 2018, the TWDB entered into an agreement with the Trinity River Authority to perform a volumetric and sedimentation survey of Lake Livingston (Texas Water Development Board, 2018). 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 6), (2) a 5-foot bottom contour map (Figure 8), (3) an estimate of sediment accumulation and location (Figure 12), and (4) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality (Appendices A and B).

Lake Livingston general information

Livingston Dam and Lake Livingston are located on the Trinity River in Polk, San Jacinto, Walker, and Trinity Counties, approximately 6 miles southwest of Livingston, Texas (Figure 1). Lake Livingston is owned and operated by the Trinity River Authority. Construction of the dam began on May 28, 1966, and the dam was completed on September 29, 1968. Deliberate impoundment of water began on June 26, 1969 (Texas Water Development Board, 1971; U.S. Bureau of Reclamation, 1992). The reservoir was built solely for water-supply purposes (Trinity River Authority, 2020; U.S. Bureau of Reclamation, 1992). Additional pertinent data about Livingston Dam and Lake Livingston can be found in Table 1.

Water rights for Lake Livingston have been appropriated to the Trinity River Authority through Certificate of Adjudication No. 08-4248 and Amendments to Certificate of Adjudication Nos. 08-4248A, 08-4248B, 08-4248C, 08-4248D, and 08-4248E in conjunction with the City of Houston through Certificate of Adjudication No. 08-4261, and Amendments to Certificate of Adjudication Nos. 08-4262A, 08-4261B, 08-4261C. The complete permits are on file with the Water Availability Division in the Office of Water at the Texas Commission on Environmental Quality.

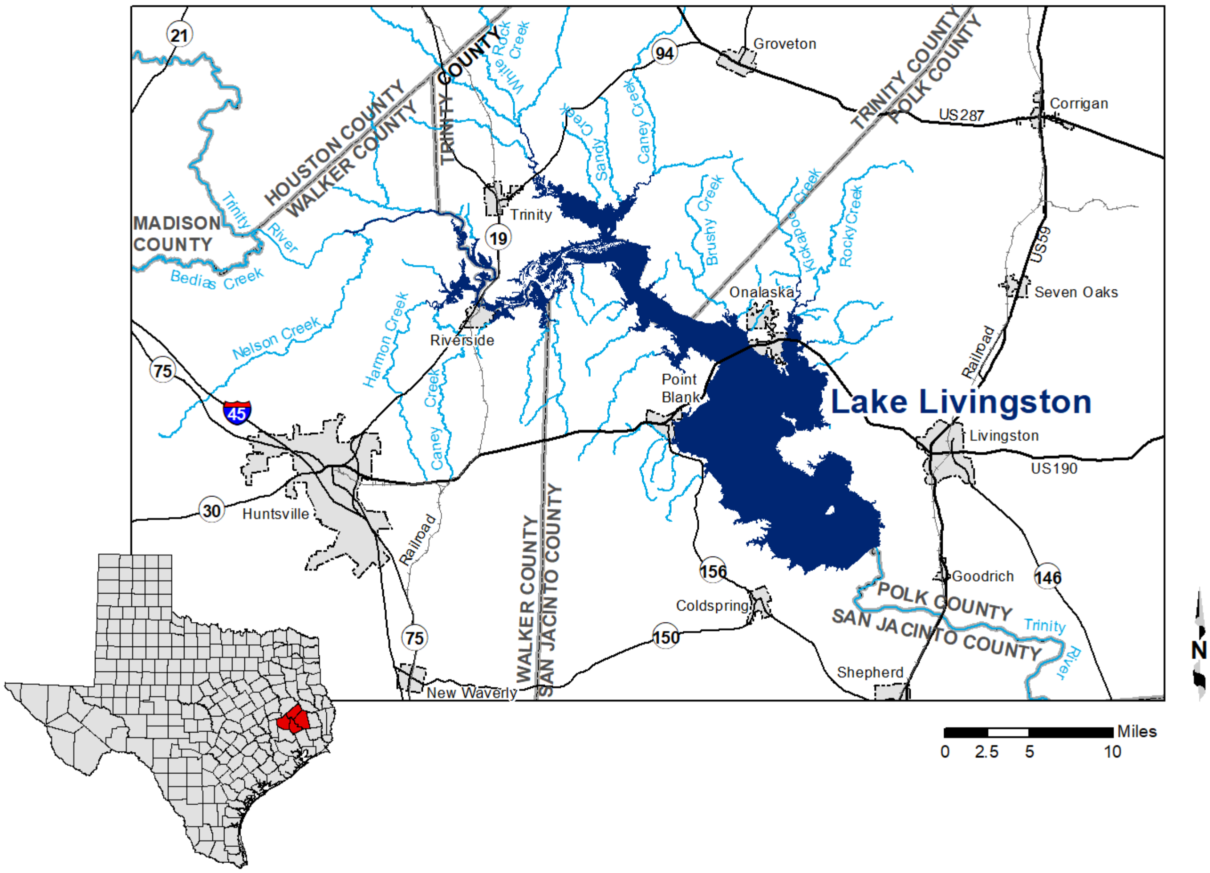

Figure 1. Location map.

Table 1. Pertinent Data for Livingston Dam and Lake Livingston

Owner	
Trinity River Authority and City of Houston	
Engineer (Design)	
Brown and Root, Inc.	
Engineer (Construction)	
Forrest and Cotton, Inc.	
Drainage Area	
16,583 square miles of which 8,423[a] square miles contribute sediment inflow	
Dam	
Type	Rolled earth fill with concrete spillway
Crest Length	13,480 feet including spillway
Average Base Width	310 feet
Maximum Height	90 feet
Top Width	24 feet
Spillway	
Location	Near left end of dam
Crest Elevation	99.0 feet NGVD29[b]
Length (net)	480 feet
Type	Ogee
Control	12 tainter gates, each 40 by 35 feet
Outlet Works	
Type	Multi-gated intake tower and a 10-foot diameter conduit
Control	Slide gates
Lower Invert Elevation	58.0 feet NGVD29

Reservoir Data (Based on 2019 TWDB survey)

Feature	Elevation (feet above NGVD29)	Capacity (acre-feet)	Area (acres)
Top of dam	145.0	3,078,512	133,689
Top of tainter gates	134.0	1,859,310	91,668
Top of conservation pool elevation	131.0	1,603,504	77,729
Spillway Crest	99.0	94,682	15,085
Lower invert/dead pool elevation	58.0	0	0
Conservation storage capacity[c]	—	1,603,504	—

Source(s): (Texas Water Development Board, 1971; United States (U.S.) Bureau of Reclamation, 1992)

[a] Reduction in contributing area based on assumption dams built upstream of Livingston Dam capture 100 percent of sediment inflows. The following reservoirs upstream and the date impounded are Richland-Chambers (1987), Navarro Mills (1963), Bardwell (1965), Cedar Creek (1965), Ray Hubbard (1978), Lavon (1953), Mountain Creek (1937), Arlington (1957), Benbrook (1952), Grapevine (1952), Lewisville (1954), and reservoir area (U.S. Bureau of Reclamation, 1992)

[b] NGVD29 – National Geodetic Vertical Datum 1929

[c] 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 Lake Livingston

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 08066190 Livingston Res nr Goodrich, TX* (U.S. Geological Survey, 2020a). The vertical datum of USGS gage *USGS 08066000 Trinity Rv at Riverside, TX* is North American Vertical Datum of 1988 (NAVD88). This datum is 0.43 feet below the NGVD29 datum (U.S. Geological Survey, 2020b). Therefore, 0.43 feet was added to the gage measurements to convert to NGVD29. Elevations herein are reported in feet relative to the NGVD29 datum. Volume and area calculations in this report are referenced to water levels developed by modeling the surface slope of the reservoir as measured by USGS gage *USGS 08066190 Livingston Res nr Goodrich, TX*, USGS gage *USGS 08066000 Trinity Rv at Riverside, TX*, and three pressure transducers deployed by the TWDB. Figure 2 shows the location of the two USGS gages and three TWDB pressure transducers. Two pressure transducers located at the FM3478 Bridge and Onalaska KOA Holiday Campground were deployed on January 29, 2019, while the Riverside location was deployed on April 2, 2019. A fourth pressure transducer was installed on land at the Riverside location on January 28, 2019, for the purpose of measuring atmospheric pressure, a dataset required for accurate calibration of the submerged pressure transducers.

During times of low inflow into the reservoir, water levels in the reservoir had little to no slope as evidenced by the correlation between the two USGS gage readings at the dam and upstream in the Trinity River. The TWDB pressure transducer data was calibrated by bringing measurements into agreement during times of low inflow. Figure 3 shows all water level measurements plotted together with shaded blocks indicating the days during which data collection occurred. Using the respective relationships between adjacent USGS gages and TWDB pressure transducers, water surface elevations were modeled prior to January 30, 2019.

The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet).

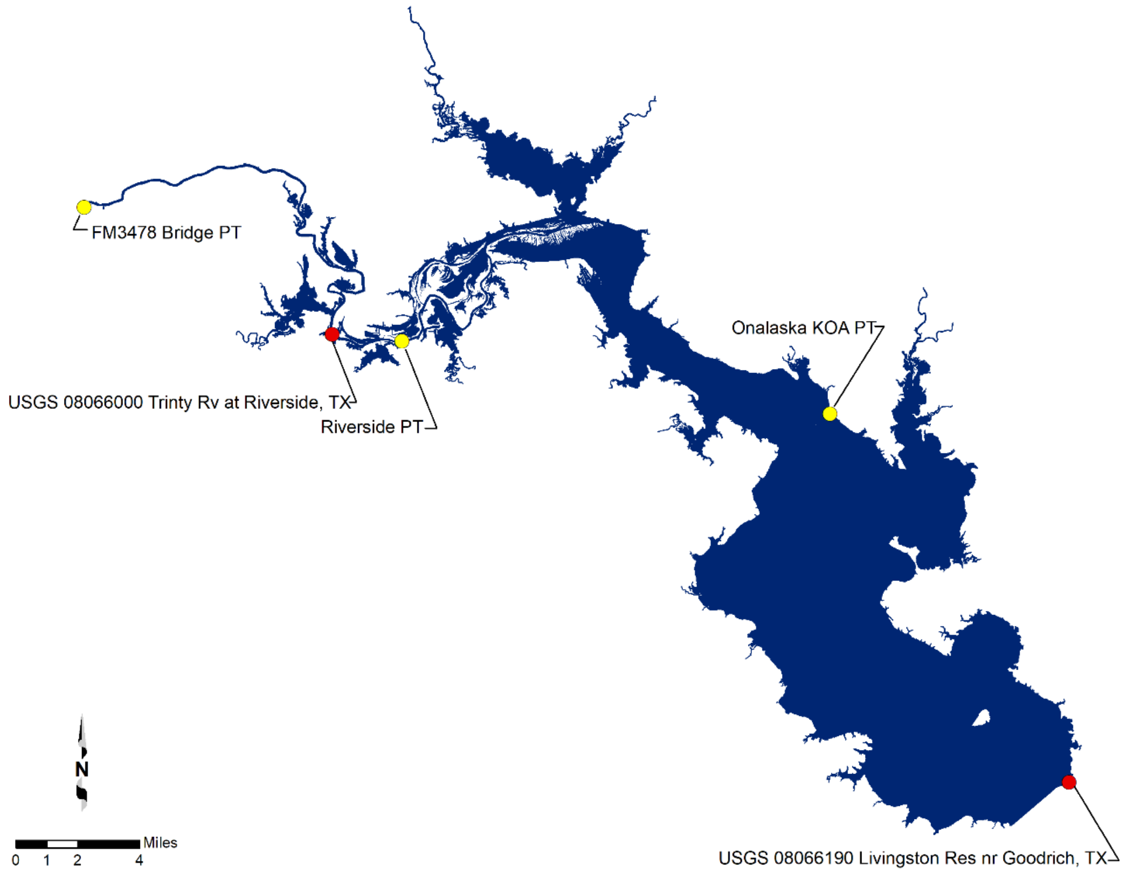

Figure 2. Locations of USGS gages and TWDB pressure transducers used to measure water surface elevations.

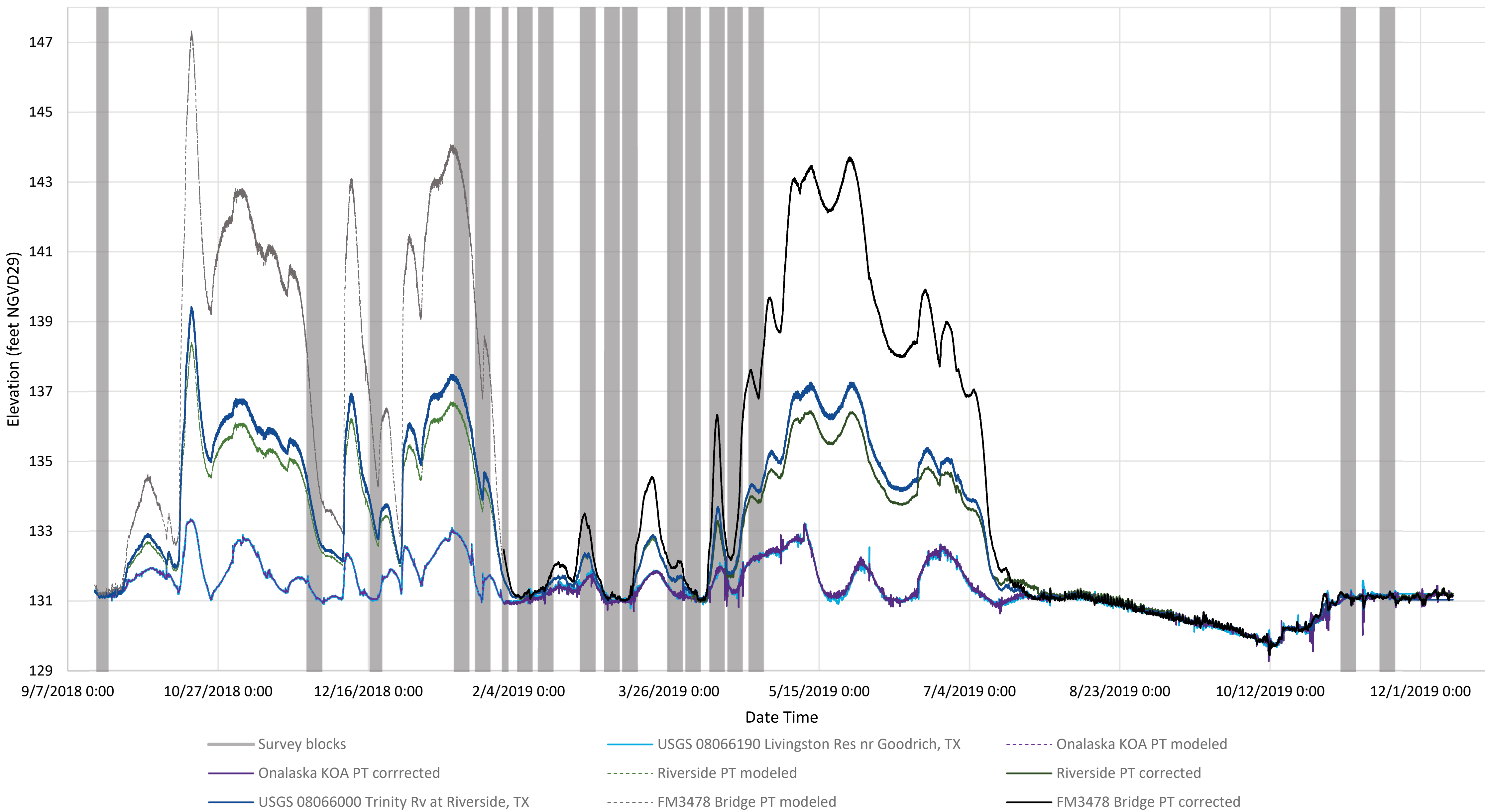

Figure 3. **Plot of water level measurements for each USGS gage and TWDB pressure transducer with shaded blocks indicating the days during which data collection occurred**

TWDB bathymetric and sedimentation data collection

The TWDB collected bathymetric data for Lake Livingston between September 17, 2018, and November 21, 2019, while daily average water surface elevations measured between 130.97 and 132.93 feet above mean sea level (NGVD29). 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 was collected along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. The depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. Each speed of sound profile, or velocity cast, is saved for further data processing. Figure 4 shows the data collection locations for the 2019 TWDB survey.

All sounding data was 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 21 locations to collect sediment core samples (Figure 4). Sediment cores were collected on October 14 – 16, 2019, 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.

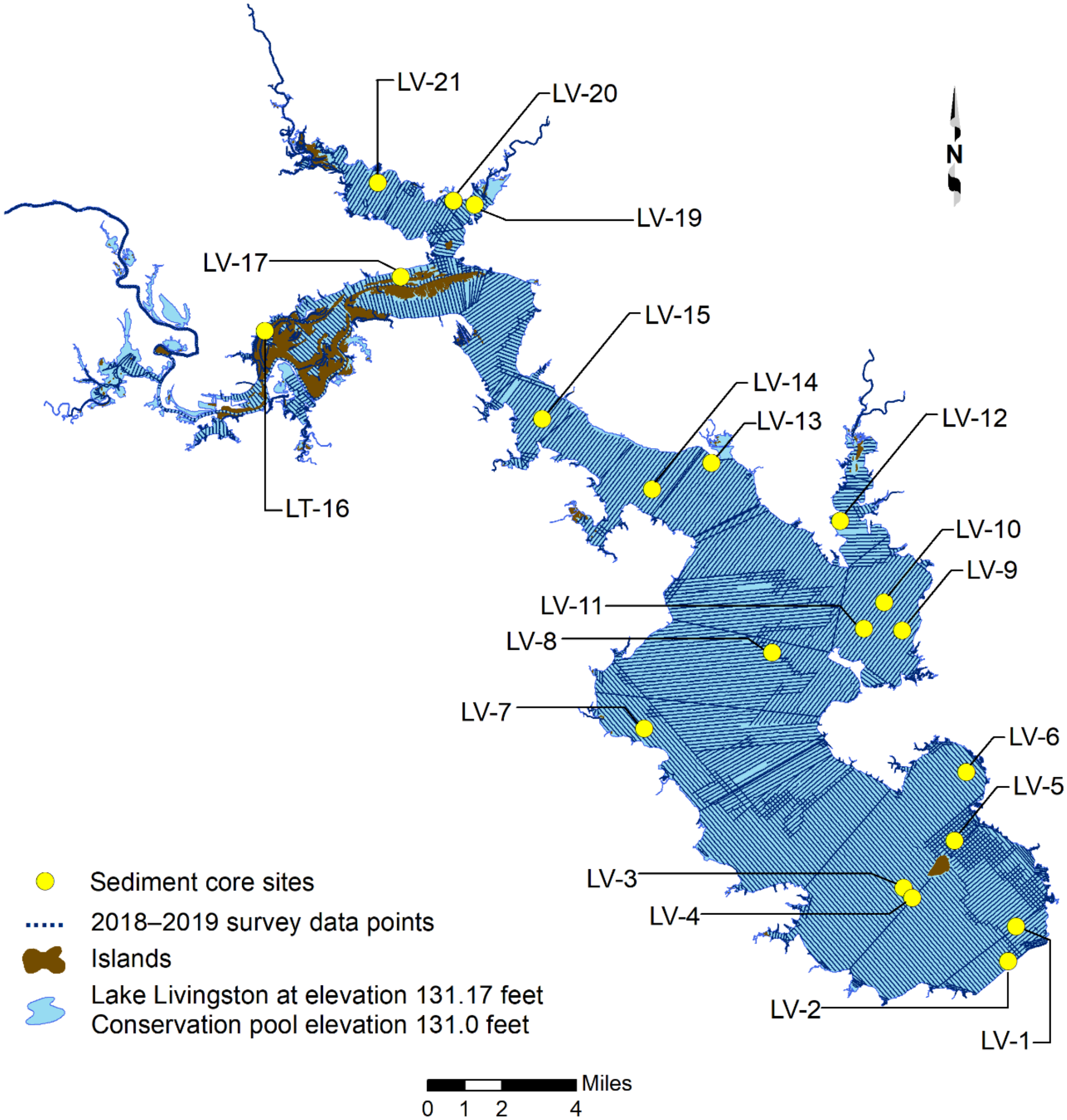

Figure 4. 2019 TWDB sounding data (*blue dots*), and sediment coring locations (*yellow circles*).

Data processing

Model boundary

The reservoir's model boundary was digitized from aerial photographs, also known as digital orthophoto quarter-quadrangle images (DOQQs), obtained through the Texas Imagery Service. The Texas Natural Resources Information System 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). The quarter-quadrangles containing Lake Livingston are Blanchard (NW, NE, SW, SE), Camilla (NW, NE), Carlisle (NW, NE, SW, SE), Chita (NW, SW), Glendale (SW), Onalaska (NW, NE, SW, SE), Riverside (NW, NE), Staley (NW, NE), Stephen Creek (NW, NE, SE), Trinity East (NW, NE, SW, SE), and Trinity West (NW, NE, SW, SE) and Wyser Bottom (SE). TWDB staff identified DOQQs that best reflect the actual reservoir conditions at the time the survey was conducted to digitize the reservoir boundary. DOQQs photographed on September 9, 2017, while the daily average water surface elevation measured 131.10 feet NGVD29, were referenced for digitization of the reservoir contained by quarter-quadrangles Wyser Bottom (SE), Trinity West (NW, NE, SW, SE), Riverside (NW, NE), Staley (NW), Trinity East (NW, SW), and the western half of Trinity East (NE, SE) and Staley (NE). DOQQs photographed on November 18, 2019, while the daily average water surface elevation measured 131.17 feet NGVD29, were referenced for digitization of the eastern half of Trinity East (NE, SE) and Staley (NE) and the remainder of the lake. The DOQQs have a resolution of 6 inches (Texas Natural Resources Information System, 2020b). The model boundary was digitized at the land-water interface in the 2017 and 2019 photographs and assigned an elevation of 131.17 feet NGVD29.

The reservoir's topographic model boundary was generated with Light Detection and Ranging (LIDAR) Data available from the Texas Natural Resource Information System (TNRIS). Four different acquisitions of LIDAR data collected from 2016 to 2018 were referenced. The datasets were acquired between March 9-22, 2018, January 12 and March 22, 2018, February 1 and March 21, 2017, and March 3-5, 2016, and January 25 and February 22, 2017, while the daily average water surface elevation of the reservoir measured between 131.08 feet and 131.38 feet, 131.03 feet and 132.17 feet, 131.07 feet and 131.86 feet, and 131.07 feet and 131.89 feet, respectively (Figure 5). 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. The horizontal datum of the LIDAR data is North American Datum 1983 (NAD83; meters) and the projection is Universal Transverse Mercator (UTM) Zone 15. The vertical datum is North American Vertical Datum 1988 (NAVD88; meters). Therefore, a contour representing top of dam elevation of 44.27 meters NAVD88, equivalent to 145.0 feet NGVD29, was extracted from the raster. The vertical datum transformation offset of 0.074 meters, was used to convert from meters NAVD88 to meters NGVD29. 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, 2021a) and VERTCON software (National Geodetic Survey, 2021b) to a single reference point in the vicinity of the survey, the reservoir elevation gage *USGS 08066190 Livingston Res nr Goodrich, TX Latitude 30º38'00" N, Longitude 95º00'36" W NAD27.* The topographic model contour was edited to close the contour across the dam and remove other artifacts. Horizontal coordinate transformations to NAD83 State Plane Texas Central Zone (feet) coordinates were applied 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 0.5 meters. New attribute fields were added to convert the elevations from meters NAVD88 to meters NGVD29 and then to feet NGVD29 for compatibility with the bathymetric survey data. LIDAR data outside of the 145.00-foot contour and inside the 131.17-foot contour were deleted and the feature class projected to NAD83 State Plane Texas Central Zone (feet).

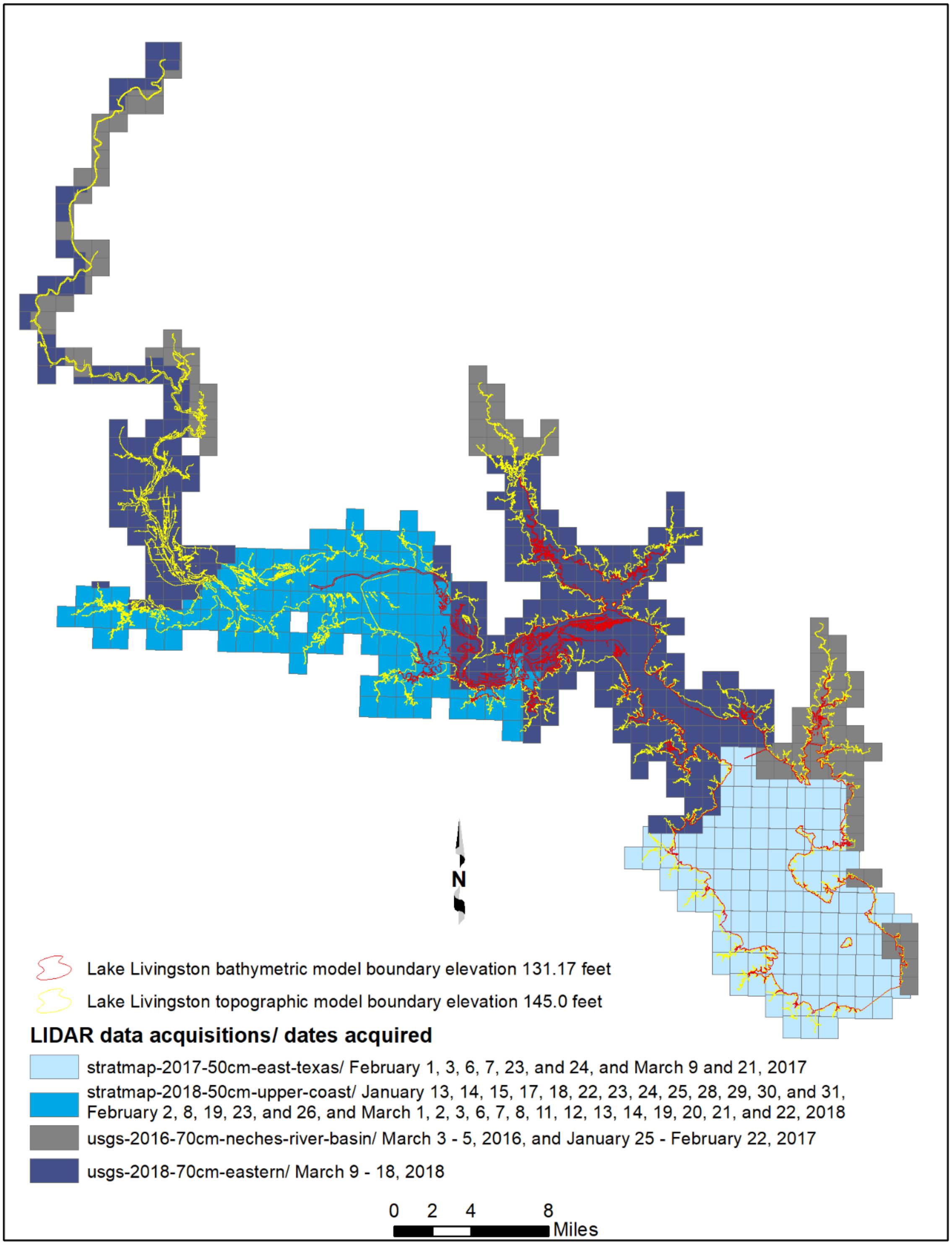

Figure 5. LIDAR data areas of acquisition for topographic model

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 are 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 was exported into a single file, including the current reservoir bottom surface, pre-impoundment surface, and sediment thickness at each sounding location. The water surface elevation at the time of each sounding was used to convert each sounding depth to a corresponding reservoir-bottom elevation. This survey point dataset was 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) models 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).

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 6 illustrates typical results from application of the anisotropic interpolation and linear interpolation as applied to Lake Livingston. In Figure 6A, 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 6B, directs Delaunay triangulation to better represent the reservoir bathymetry between survey cross-sections.

The bathymetry shown in Figure 6C was used in computing reservoir elevation-capacity (Appendix A) and elevation-area (Appendix B) tables.

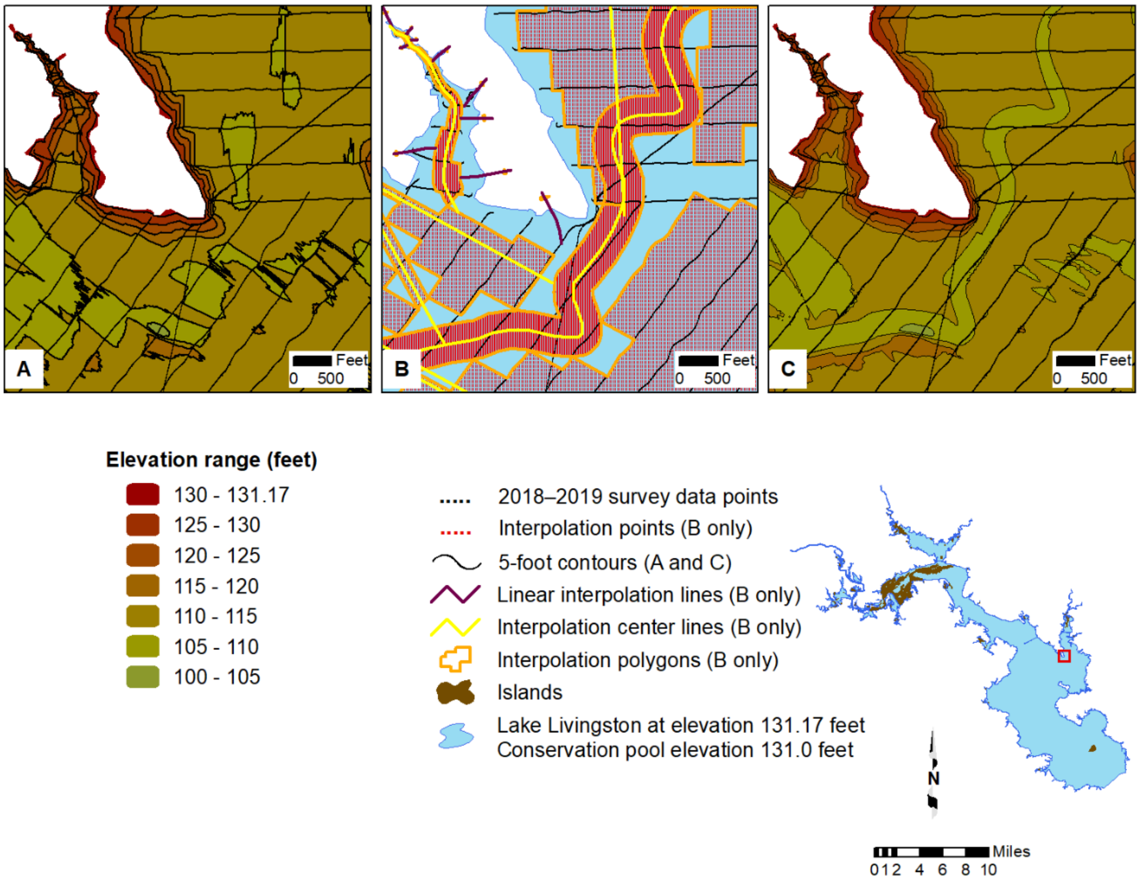

Figure 6. Anisotropic spatial interpolation and linear interpolation as applied to Lake Livingston sounding data; A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with interpolated points.

Area, volume, and contour calculation

Volumes and areas were computed for the entire reservoir at 0.1-foot intervals, from 57.4 to 131.1 feet for the bathymetric TIN model, and from 131.2 to 145.0 feet for the topographic TIN model. The elevation-capacity table and elevation-area table developed from the 2019 survey and analysis are presented in Appendices A and B, respectively. The capacity curve is presented in Appendix C, and the area curve is presented in Appendix D. The topographic elevation-capacity table and topographic elevation-area table developed from the 2020 survey and analysis are presented in Appendices E and F, respectively.

The bathymetric volumetric TIN model was converted to a raster representation using a cell size of 2 feet by 2 feet. The resulting raster data was used to produce three figures: (1) an elevation relief map representing the topography of the reservoir bottom (Figure 7); (2) a depth range map showing depth ranges for Lake Livingston (Figure 8); and (3) a 5-foot contour map (Figure 9).

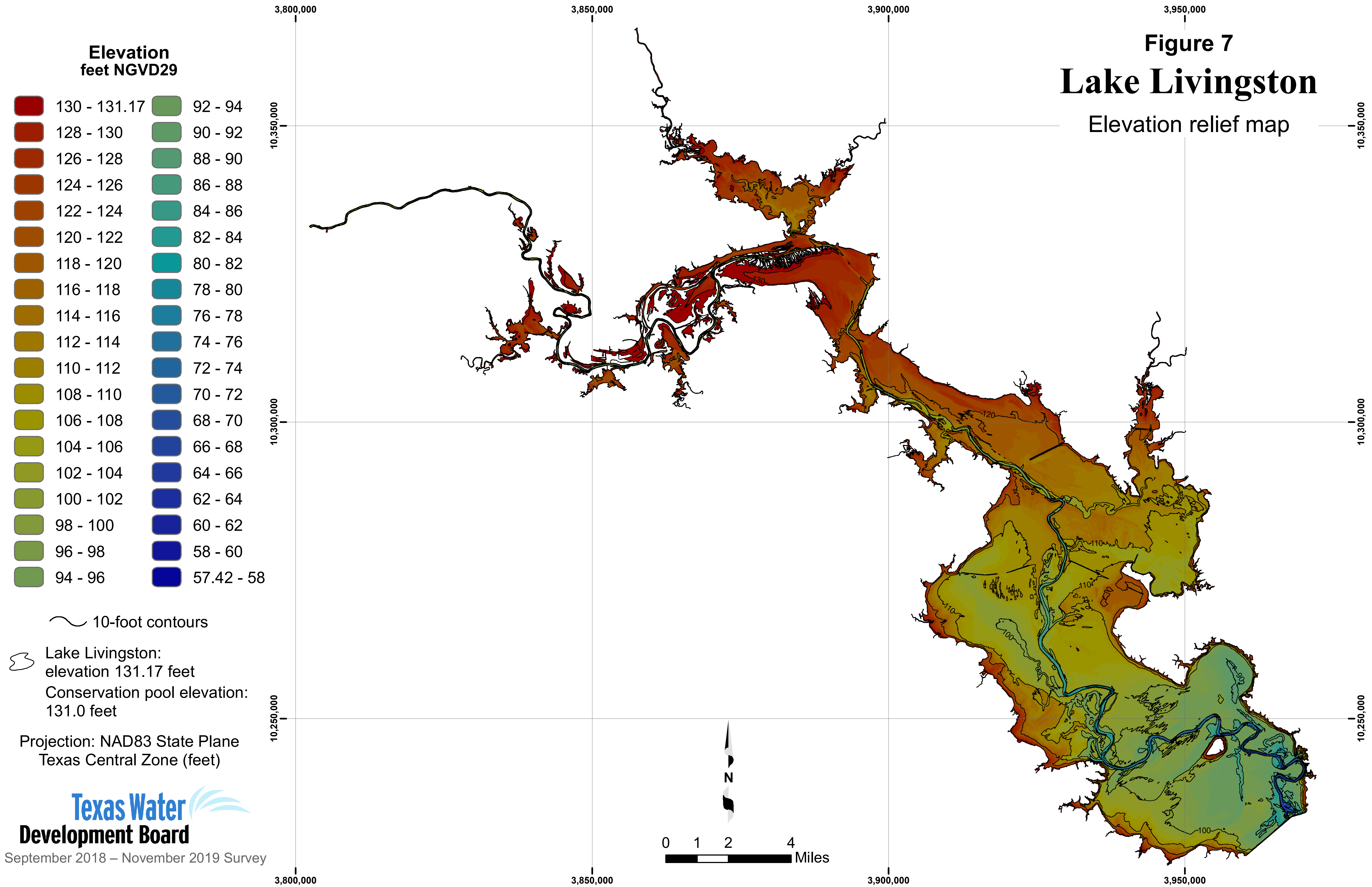

Figure 7

Lake Livingston

Elevation relief map

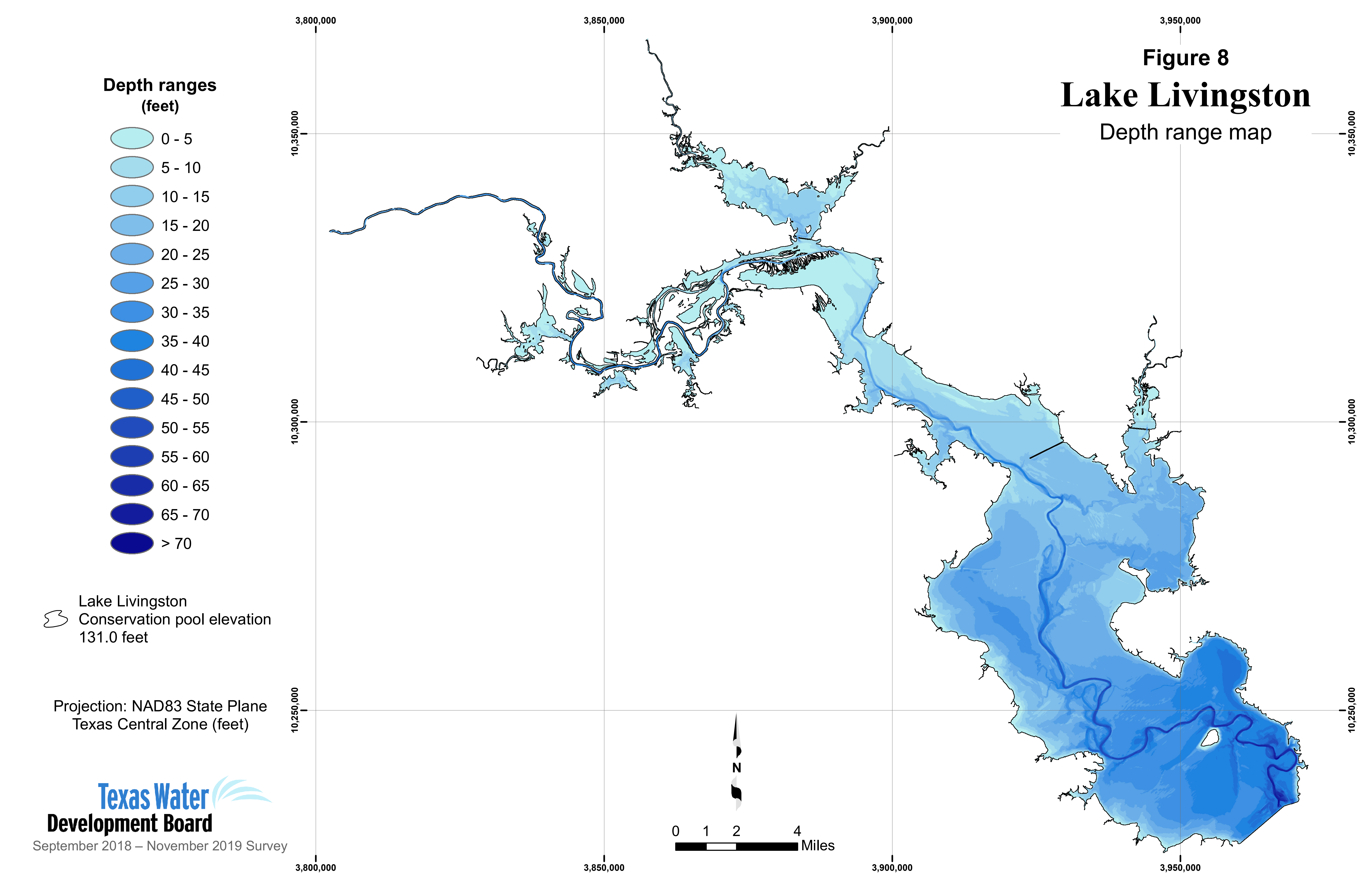

Figure 8
Lake Livingston
Depth range map

Analysis of sediment data from Lake Livingston

Sedimentation in Lake Livingston 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 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 (Hue Value/Chroma)
LV-1	3966110.16	10236632.98	114.0 / N/A	post-impoundment	0.0–114.0" moderate/high water content, uniform color/consistency throughout, pudding like, no organic matter present, sediment lost from bottom of core tube, pre-impoundment not reached	5GY 4/2 dark grayish green
LV-2	3965014.82	10231679.23	24.0 / N/A	post-impoundment	0.0–3.0" high water content, smooth, silky, small sand	GLEY1 3/10Y very dark greenish gray
					3.0–4.0" moderate water content, fine sand/silt mixture	2.5Y 2.5/1 black
					4.0–13.5" low water content, compacted/dense sand	2.5Y 3/2 very dark grayish brown
					13.5–21.0" moderate water content, silt/sand mixture (predominantly silt)	2.5Y 6/2 light brownish gray
					21.0–24.0" low to moderate water content, sand, no clay	2.5Y 6/2 light brownish gray
LV-3	3950089.88	10242123.87	89.0 / 84.0	post-impoundment	0.0–58.0" very high water content, pudding like, smooth, silt, no grit	2.5Y 3/1 very dark gray
					58.0–84.0" high water content, pudding like, smooth texture	2.5Y 3/1 very dark gray
				pre-impoundment	84.0–89.0" very low water content, high clay content, silt, malleable, organic matter present (fibrous roots)	2.5Y 2.5/1 Black
LV-4	3951347.65	10240656.78	21.0 / 2.0	post-impoundment	0.0–2.0" moderate water content, sand and silt mixture, gritty, organic material present (charcoal, charred woody debris)	2.5Y 3/1 very dark gray
				pre-impoundment	2.0–21.0" very low water content, clay/sand mixture, dense, clay clods, organic material present (fibrous roots, woody debris)	2.5Y 6/3 light yellowish brown

[a] Coordinates are based on NAD83 State Plane Texas 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
LV-5	3957357.23	10248784.47	15.5 / 1.5	post-impoundment	0.0–1.5” high water content, silt, smooth, soupy	10YR 4/2 dark grayish brown
				pre-impoundment	1.5–15.5” low water content (decreasing with depth), dense, malleable, silty clay, smooth, organic material present throughout (fibrous roots)	2.5Y 4/1 dark gray
LV-6	3959039.24	10258527.42	53.0 / 47.0	post-impoundment	0.0–11.0” very high water content, pudding like, silt, smooth, no grit	2.5Y 3/1 very dark gray
					11.0–47.0” mottled, high water content, silt/clay mixture, gelatinous	2.5Y 2.5/1 black
				pre-impoundment	47.0–53.0” low water content, malleable, sticky, silty clay, organic material present (woody debris, fibrous roots)	2.5Y 3/1 very dark gray
LV-7	3913210.78	10264734.03	57.5 / 53.5	post-impoundment	0.0–33.5” loosely packed, high water content, sticky, silt, saturated clays, pudding like	2.5Y 2.5/1 black
					33.5–53.5” moderate water content, sticky, mottled gray/green, gelatinous	2.5Y 3/1 very dark gray
				pre-impoundment	53.5–57.5” very low water content, clay, malleable, dense, organic material present (fibrous roots)	2.5Y 4/1 dark gray
LV-8	3931390.65	10275553.70	6.5 / 6.5	pre-impoundment	0.0–6.5” low water content, high clay content, smooth, organic material present (fibrous roots), fine sand, dense	2.5Y 4/1 dark gray
LV-9	3949893.21	10278684.40	12.0 / 10.0	post-impoundment	0.0–1.0” very high water content, smooth, soupy	2.5Y 3/1 very dark gray
					1.0–6.0” moderate water content, smooth, no grit, clay/silt mixture, organics present (fine roots)	2.5Y 3/1 very dark gray
					6.0–10.0” high water content, pudding like, smooth texture, silt, loosely packed, organic material present (fibrous roots)	2.5Y 4/1 dark gray
				pre-impoundment	10.0–12.0” high water content, mixture of clay/silt, no organics present, smooth, sticky	2.5Y 4/1 dark gray

[a] Coordinates are based on NAD83 State Plane Texas 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
LV-10	3947359.40	10282695.25	10.0 / 5.0	post-impoundment	0.0–5.0" high water content, pudding like, silty clay, smooth texture	2.5Y 3/1 very dark gray
				pre-impoundment	0.5–10.0" very low water content, silty clay, smooth texture, organic material present (fibrous roots [tiny pieces])	2.5Y 4/1 dark gray
LV-11	3944457.89	10278888.60	79.0 / 75.0	post-impoundment	0.0–75.0" color and water content gradually change with decrease in depth, very high to moderate water content, smooth, silty clay	2.5Y 3/1 very dark gray to 2.5Y 2.5/1 black
				pre-impoundment	75.0–79.0" very low water content, clay, malleable, dense, organic material present (fibrous roots)	10YR 3/1 very dark gray
LV-12	3941137.07	10294209.87	43.0 / 24.0	post-impoundment	0.0–24.0" moderate water content, putty like, smooth, silty clay, sticky	2.5Y 4/2 dark grayish brown
				pre-impoundment	24.0–43.0" low to moderate water content, silty clay, smooth, malleable, organic material present (fibrous roots)	2.5Y 4/1 dark gray
LV-13	3922820.91	10302467.17	9.0 / 1.0	post-impoundment	0.0–1.0" high water content, gritty, sandy silt	2.5Y 4/1 dark gray
				pre-impoundment	1.0–9.0" low water content, silty clay with fine sand, dense, malleable, organic material presents throughout (large woody debris, fibrous roots)	2.5Y 5/1 gray
LV-14	3914344.57	10298718.66	24.5 / 17.5	post-impoundment	0.0–17.5" high water content, smooth, pudding like	2.5Y 4/1 dark gray with bands of black (2.5Y 2.5/1)
				pre-impoundment	17.5–24.5" very low water content, clay, dense, malleable, organic material present (fibrous roots)	2.5Y 5/1 gray
LV-15	3898755.20	10308754.57	47.5 / 39.5	post-impoundment	0.0–39.5" moderate to high water content (decreases with depth), putty to milkshake consistency, smooth, silty clay, has bands of black throughout layer	2.5Y 4/2 dark grayish brown
				pre-impoundment	39.5–47.5.0" very low water content, silty clay with fine sand, gritty, malleable, dense, organic material present (woody debris, leaf litter, fibrous and dendritic roots)	2.5Y 4/1 dark gray

[a] Coordinates are based on NAD83 State Plane Texas 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
LV-16*	3879617.75	10324937.00	0.0 / N/A	N/A	Non-navigable area, too many hazards (stumps, logs, debris) present to collect core	N/A
LV-17	3878604.23	10328925.55	32.0 / 19.0	post-impoundment	0.0–5.0” low water content, silty sand, dense	2.5Y 4/2 dark grayish brown
					5.0–19.0” moderate water content, pudding like, silty clay with fine sand, sticky	2.5Y 4/1 dark gray
				pre-impoundment	19.0–32.0” low water content, stiff, dense, silty clay, smooth, malleable, organic material present (fibrous roots)	2.5Y 4/1 dark gray
LV-18	3859306.61	10321258.91	29.0 / 26.0	post-impoundment	0.0–26.0” low water content, sand, dense	2.5Y 6/2 light brownish gray
				pre-impoundment	26.0–29.0” very low water content, silty clay, smooth, dense, organic material present throughout (fibrous roots)	2.5Y 4/1 dark gray
LV-19	3889122.75	10339156.41	44.5 / 28.5	post-impoundment	0.0–3.5” high water content, silt with a little fine sand, pudding like	2.5Y 3/1 very dark gray
					3.5–8.5” moderate water content, fine sand and silt, depositional layering of organic material (sticks, stems)	2.5Y 4/1 dark gray
					8.5–28.5” moderate water content, silty clay, sticky, putty like, organics present with defined depositional layers (woody debris [bark, twigs])	2.5Y 5/1 gray
				pre-impoundment	28.5–44.5” low water content, clay, malleable, organic material presents throughout (fibrous roots)	2.5Y 4/1 dark gray
LV-20	3886136.53	10339720.41	31.0 / 20.0	post-impoundment	0.0–11.0” high water content, soupy, smooth with very fine grains of sand	2.5Y 3/1 very dark gray
					11.0–20.0” moderate water content, silty clay with very fine sand, pudding like, no organics present	2.5Y 4/1 dark gray
				pre-impoundment	20.0–31.0” low water content, silty clay with very fine sand, putty like (play dough consistency), organic material presents throughout (fibrous roots)	2.5Y 4/1 dark gray

[a] Coordinates are based on NAD83 State Plane Texas 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
LV-21	3875369.94	10342324.33	22.5 / 7.5	post-impoundment	0.0–7.5" high water content, silty sand, pudding like, organics present (sticks, stems [depositional])	2.5Y 3/1 very dark gray
				pre-impoundment	7.5–22.5" moderate water content slowly graduates to very low water content with decrease in depth, silty sand, minimal clay, malleable, organic material presents throughout (fibrous roots and woody debris)	2.5Y 4/1 dark gray

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

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

Photographs of sediment cores LV-3 and LV-4 (for location, refer to Figure 4) are shown in Figure 10 and are representative of sediment cores sampled from Lake Livingston. 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 LV-3 at 84.0 inches and LV-4 at 2.0 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.

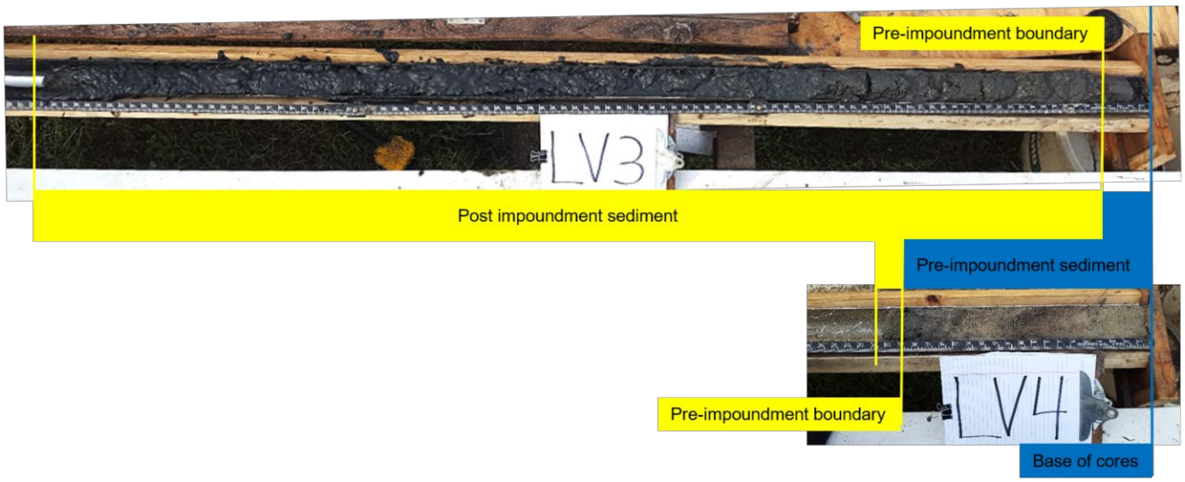

Figure 10. Sediment cores LV-3 and LV-4. Post-impoundment sediment layers are identified by yellow boxes. Pre-impoundment sediment layers are identified by blue boxes.

Figure 11 illustrates the relationships between acoustic signal returns and the layering seen in sediment cores. In this example, sediment cores LV-3 and LV-4 are 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 11. 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.

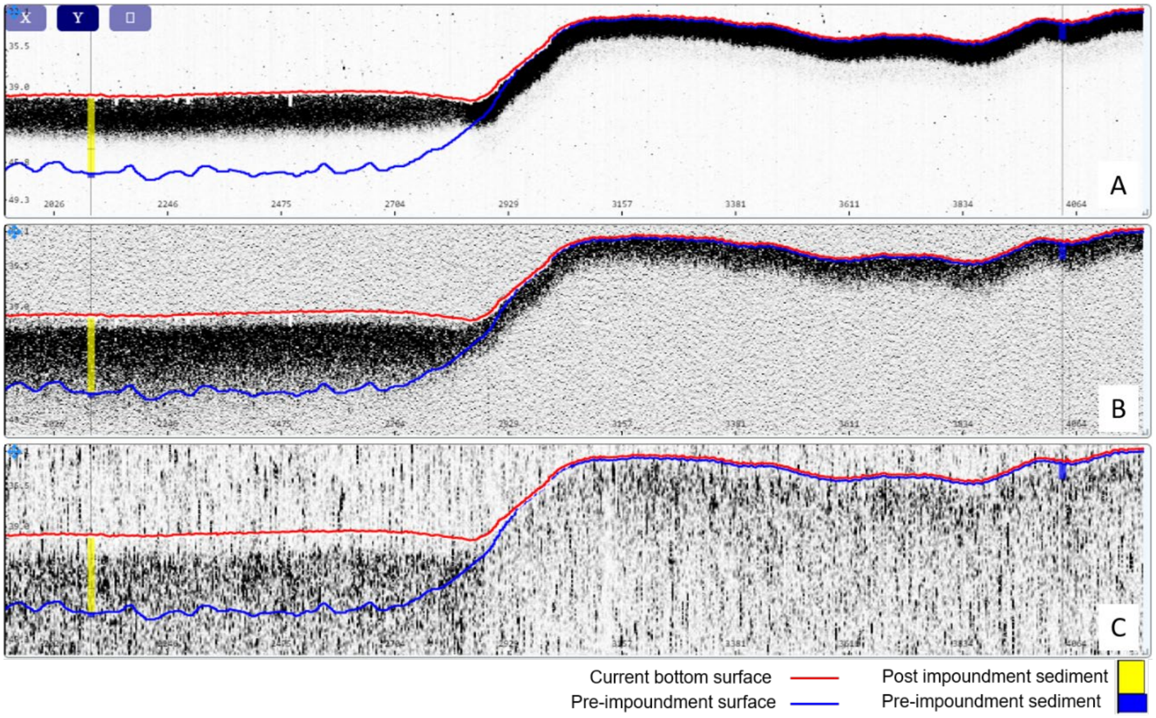

Figure 11. Sediment core samples LV-3 and LV-4 compared with acoustic signal returns. A) 208 kHz frequency, B) 50 kHz frequency, and C) 12 kHz frequency.

The pre-impoundment boundary in sediment cores LV-3 and LV-4 most closely aligned with the different layers picked up by the 50 kHz; therefore, the 50 kHz signal was used to locate the pre-impoundment surface (Figure 11). 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 131.17-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 12). 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.

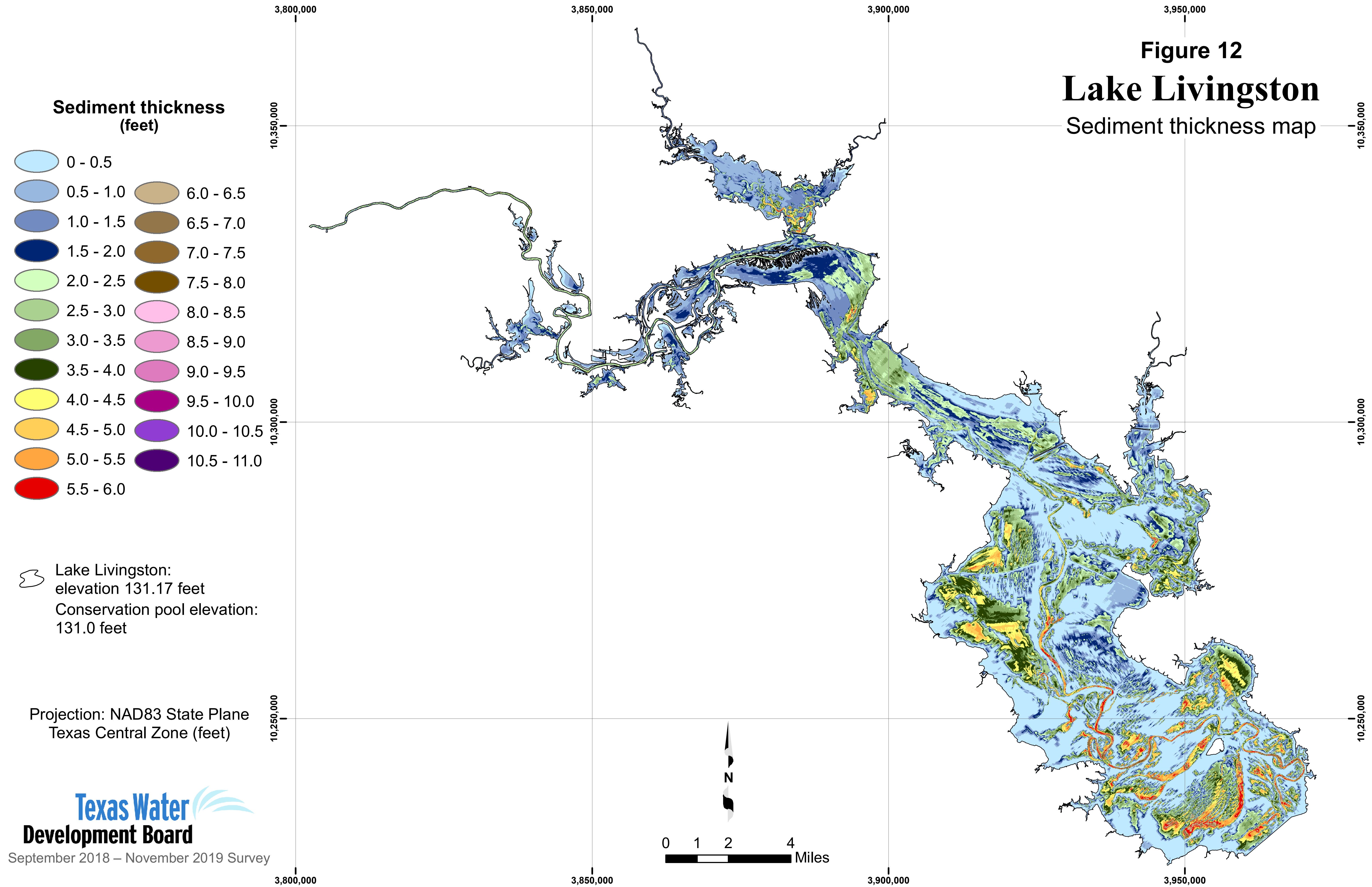

Figure 12
Lake Livingston
Sediment thickness map
Sediment thickness (feet)
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 7.5
7.5 - 8.0
8.0 - 8.5
8.5 - 9.0
9.0 - 9.5
9.5 - 10.0
10.0 - 10.5
10.5 - 11.0
Lake Livingston: elevation 131.17 feet
Conservation pool elevation: 131.0 feet
Projection: NAD83 State Plane Texas Central Zone (feet)
Texas Water Development Board
September 2018 – November 2019 Survey
3,800,000
3,850,000
3,900,000
3,950,000
10,350,000
10,300,000
10,250,000
N
0 1 2 4 Miles

Survey results

Volumetric survey

The 2019 TWDB volumetric survey indicates that Lake Livingston has a total reservoir capacity of 1,603,504 acre-feet and encompasses 77,729 acres at conservation pool elevation (131.0 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. The 2019 survey model boundary does not include many miles of river channel likely within the 131.0-foot contour elevation. Because the LIDAR data was collected while the reservoir water surface elevation was slightly above 131.0 feet, this contour was developed from the model. Additionally, areas and capacities above elevation 120.5 feet have been significantly impacted by sedimentation. Figure 13 illustrates the effect sedimentation has had on the area curve and Figure 14 illustrates how the contours in the reservoir have changed over time, comparing the TWDB model contour with the USGS quarter quadrangle map contour (hypsography) at elevation 120.0 feet.

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	82,600[b]	1,787,774	131.0	U.S. Bureau of Reclamation, 1992
U.S. Bureau of Reclamation 1969	83,277[c]	1,806,094	131.0	U.S. Bureau of Reclamation, 1992
U.S. Bureau of Reclamation 1991	83,277	1,741,867	131.0	U.S. Bureau of Reclamation, 1992
TWDB 2019	77,729	1,603,504	131.0	

[a] Feet NGVD29 – National Geodetic Vertical Datum 1929
[b] Based on the 1960 U.S. Geological Survey 7.5-minute quadrangle maps. These maps were developed using photographic data from 1958.
[c] Based on photo-revised U.S. Geological Survey 7.5-minute quadrangle maps These maps were revised in 1972.

Sedimentation survey

The 2019 TWDB sedimentation survey measured 129,149 acre-feet of sediment. The sedimentation survey indicates sediment accumulation is thickest in the river channels. However, the impact of sedimentation is greatest above elevation 120.5 feet (Figures 13 and 14). Comparison of capacity estimates of Lake Livingston derived using differing methodologies are provided in Table 4 for sedimentation rate calculation. The 2019 TWDB sedimentation survey indicates Lake Livingston has lost capacity at an average of 2,583 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (131.0 feet NGVD29). Previous capacity estimates and comparison with historical cross sections (see section below titled "Sediment range lines") suggest the TWDB sedimentation survey results are an underestimate of the total sediment volume in Lake Livingston. For instance, island formation in the upper reaches is reflected in the loss of area and capacity but is not captured in sediment estimates. Comparison with historical area curves suggest significant sedimentation has occurred in the upper reaches above approximately the 120.5-foot contour (Figures 13 and 14). Additionally, compressive stresses on the sediments may increase sediment density, inhibiting the measurement of the original, pre-impoundment surface. Density stratification in the sediment layers can scatter and attenuate acoustic return signals of the multi-frequency depth sounder (U.S. Army Corps of Engineers, 2013). Long-term trends indicate Lake Livingston loses capacity at an average of 3,797 acre-feet per year since impoundment due to sedimentation below conservation pool elevation (131.0 feet NGVD29) (Figure 15). Differences in methodology developing capacity estimates may also contribute to differences between these surveys.

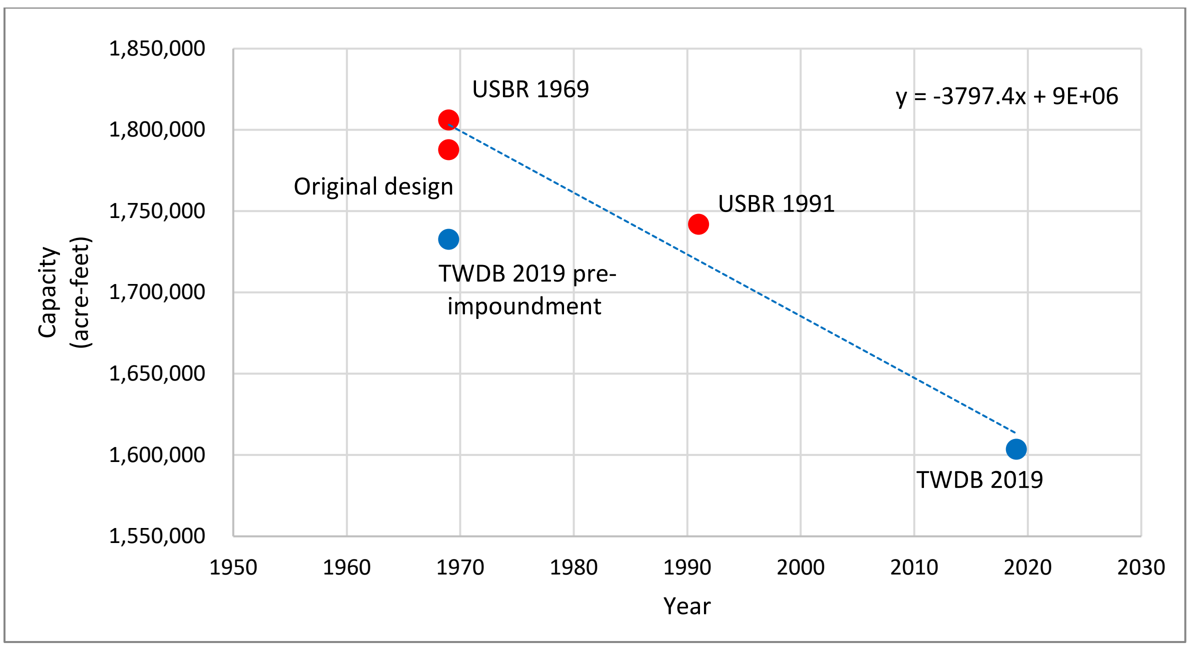

Figure 15. **Plot of current and previous capacity estimates (acre-feet) at elevation 131.0 feet. Capacity estimates for each TWDB survey plotted as blue dots and other surveys as red dots. The blue trend line illustrates the total average loss of capacity through 2019.**

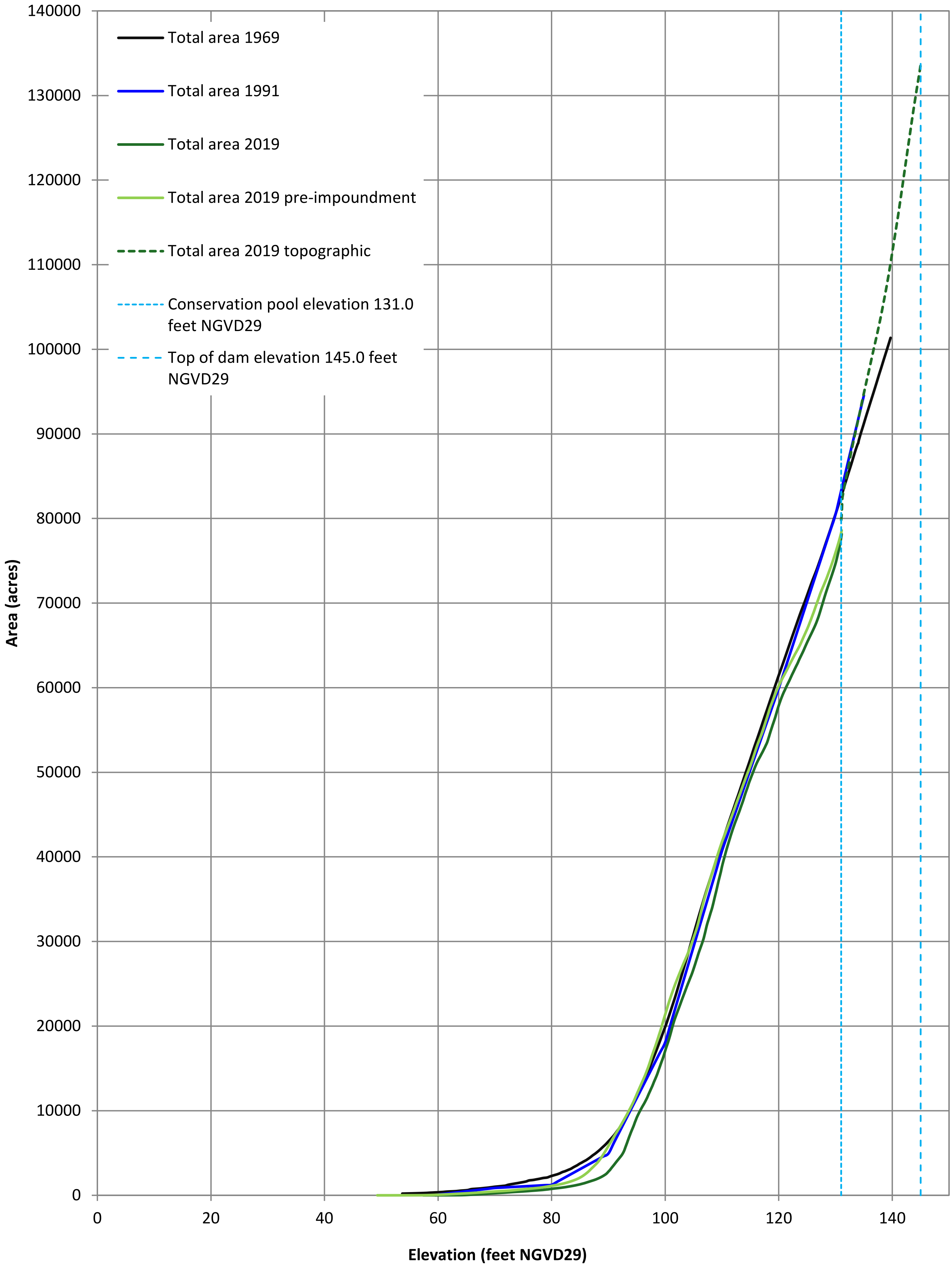

Figure 13. Comparison of current and previous area curves

Figure 14

Lake Livingston

Contour comparison

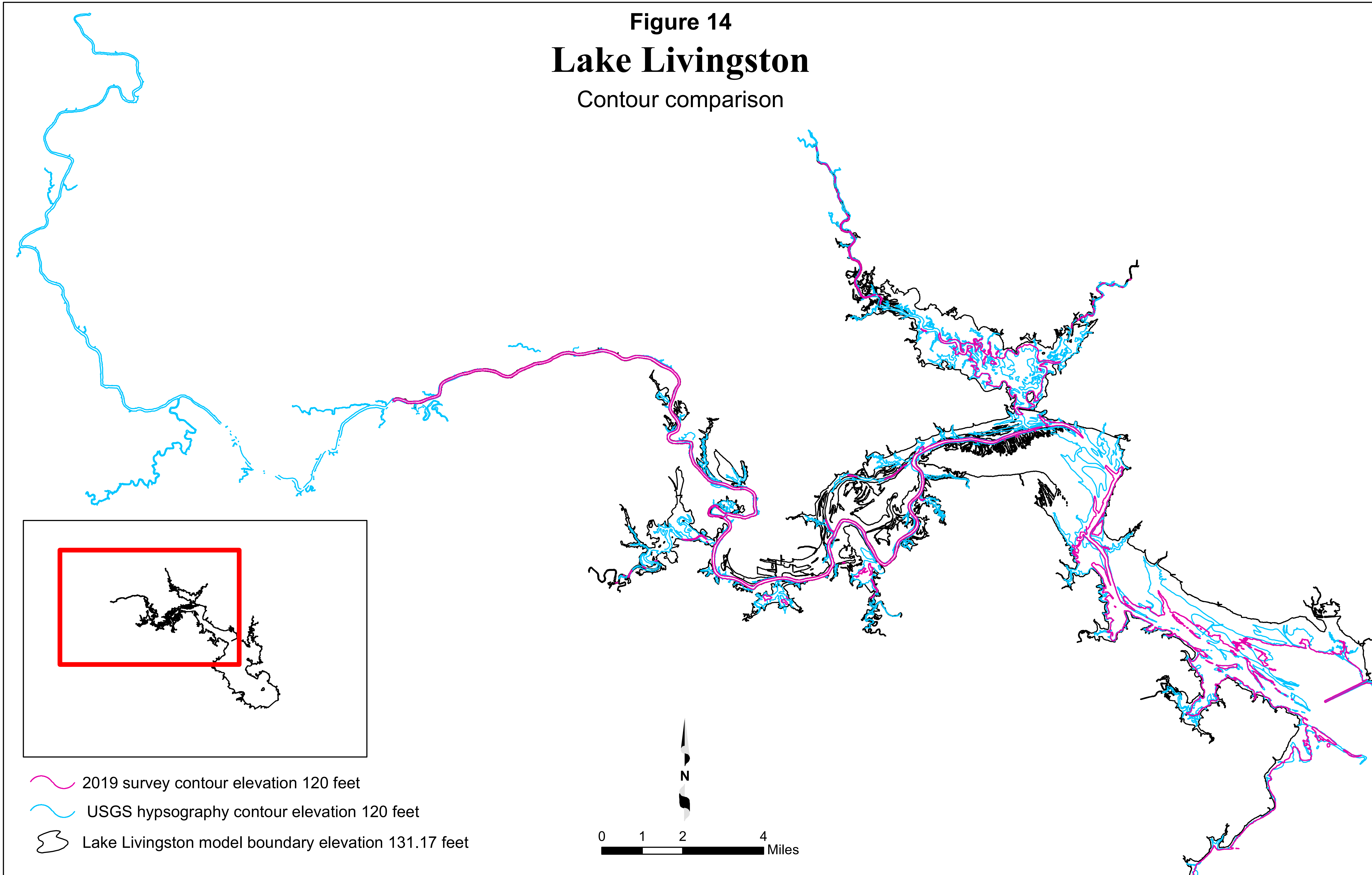

Table 4. Average annual capacity loss comparisons.

Survey	Top of conservation pool elevation (131.0 feet NGVD29)			
Original design[a]	1,787,774	<>	<>	<>
U.S. Bureau of Reclamation 1969[b]	<>	1,806,094	<>	<>
U.S. Bureau of Reclamation 1991[c]	<>	<>	1,741,867	<>
TWDB pre-impoundment estimate based on 2019 survey	<>	<>	<>	1,732,653
2019 volumetric survey	1,603,504	1,603,504	1,603,504	1,603,504
Volume difference (acre-feet) Percent change	184,270 10.3%	202,590 11.2%	138,363 7.9%	129,149 7.5%
Number of years	50	50	28	50
Capacity loss rate (acre-feet/year)	3,685	4,052	4,942	2,583

[a] Source: (U.S. Bureau of Reclamation, 1992), note: Lake Livingston Dam was completed on September 29, 1968, and the deliberate impoundment began on June 26, 1969.
[b] Source: (U.S. Bureau of Reclamation, 1992), note: This is a recalculation of the original design estimate.
[c] Source: (U.S. Bureau of Reclamation, 1992)

Sediment range lines

Twenty-four sediment range lines were established in Lake Livingston to measure sediment accumulation over time. These range lines are shown on two maps in the USBR 1991 survey report. Plots of 24 cross-sections comparing the original survey prior to impoundment to USBR 1991 survey data are also available (U.S. Bureau of Reclamation, 1992). The TWDB digitized the USBR maps and the twenty-four range lines. A map depicting these range lines can be found in Appendix G. Table G1 lists the endpoint coordinates for each range line. For comparison, the TWDB digitized the original design and 1991 transects plotted in the USBR 1991 survey report for comparison with the current bottom surface from the 2019 TWDB survey (Appendix G). 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 (U.S. Bureau of Reclamation, 1992) and distortions caused by digitizing the cross-sections from the USBR report.

Recommendations

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

TWDB contact information

More information about the Hydrographic Survey Program can be found at:

http://www.twdb.texas.gov/surfacewater/surveys/index.asp

Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:

Hydrosurvey@twdb.texas.gov

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Appendix A

Lake Livingston

RESERVOIR BATHYMETRIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — September 2018 – November 2019 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 131.0 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
57	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	1	1	1	1
59	1	1	2	2	2	2	2	3	3	3
60	3	4	4	4	5	5	5	6	6	7
61	7	8	9	9	10	11	12	13	14	14
62	15	16	17	18	19	20	21	22	24	25
63	26	27	29	30	31	33	34	36	38	39
64	41	43	45	47	49	52	55	58	61	65
65	69	73	77	82	88	93	99	106	113	120
66	128	136	144	153	162	172	182	192	203	214
67	225	237	249	262	275	288	302	316	331	346
68	361	377	394	410	427	445	462	481	500	520
69	540	562	583	606	628	651	675	698	723	747
70	772	798	823	850	876	903	931	959	987	1,015
71	1,044	1,074	1,103	1,133	1,163	1,194	1,225	1,256	1,288	1,320
72	1,353	1,387	1,420	1,455	1,489	1,525	1,560	1,596	1,633	1,670
73	1,707	1,746	1,784	1,823	1,863	1,903	1,943	1,984	2,025	2,067
74	2,108	2,151	2,193	2,236	2,280	2,323	2,368	2,412	2,457	2,503
75	2,549	2,595	2,642	2,690	2,738	2,786	2,834	2,884	2,933	2,984
76	3,034	3,086	3,137	3,190	3,243	3,296	3,350	3,405	3,459	3,515
77	3,571	3,627	3,684	3,741	3,799	3,857	3,916	3,975	4,035	4,096
78	4,157	4,218	4,280	4,342	4,405	4,469	4,534	4,599	4,665	4,731
79	4,799	4,867	4,936	5,005	5,076	5,147	5,219	5,292	5,366	5,441
80	5,517	5,594	5,672	5,750	5,830	5,910	5,991	6,073	6,156	6,239
81	6,323	6,408	6,493	6,580	6,667	6,755	6,843	6,933	7,023	7,115
82	7,207	7,300	7,394	7,489	7,585	7,682	7,780	7,879	7,979	8,081
83	8,183	8,287	8,392	8,498	8,605	8,713	8,823	8,934	9,045	9,159
84	9,273	9,389	9,506	9,624	9,744	9,866	9,988	10,113	10,238	10,366
85	10,494	10,625	10,757	10,891	11,027	11,165	11,304	11,445	11,588	11,733
86	11,880	12,029	12,180	12,334	12,490	12,647	12,807	12,970	13,134	13,300
87	13,469	13,640	13,813	13,988	14,165	14,344	14,526	14,710	14,897	15,086
88	15,278	15,473	15,670	15,871	16,075	16,281	16,491	16,705	16,921	17,142
89	17,366	17,593	17,825	18,061	18,302	18,547	18,796	19,051	19,312	19,580
90	19,856	20,140	20,430	20,727	21,033	21,347	21,670	22,002	22,342	22,690
91	23,047	23,411	23,785	24,168	24,559	24,958	25,366	25,782	26,206	26,639
92	27,079	27,528	27,986	28,451	28,927	29,412	29,909	30,418	30,941	31,480
93	32,038	32,615	33,209	33,822	34,453	35,104	35,772	36,460	37,165	37,887
94	38,627	39,384	40,156	40,945	41,750	42,572	43,411	44,270	45,146	46,039
95	46,949	47,875	48,816	49,771	50,739	51,722	52,717	53,724	54,744	55,776
96	56,821	57,877	58,945	60,024	61,115	62,218	63,335	64,465	65,608	66,765
97	67,938	69,126	70,331	71,549	72,783	74,032	75,295	76,573	77,867	79,176
98	80,504	81,847	83,207	84,581	85,971	87,378	88,800	90,242	91,702	93,182
99	94,682	96,200	97,736	99,293	100,868	102,461	104,073	105,703	107,354	109,028
100	110,724	112,441	114,180	115,939	117,717	119,514	121,333	123,173	125,036	126,922
101	128,832	130,767	132,726	134,711	136,719	138,751	140,805	142,879	144,973	147,085
102	149,216	151,365	153,531	155,716	157,918	160,138	162,376	164,632	166,907	169,200
103	171,512	173,842	176,189	178,555	180,938	183,339	185,758	188,195	190,650	193,123
104	195,613	198,120	200,643	203,184	205,741	208,316	210,907	213,514	216,140	218,785
105	221,450	224,135	226,841	229,567	232,314	235,084	237,874	240,684	243,517	246,372

Lake Livingston

RESERVOIR BATHYMETRIC CAPACITY TABLE

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

September 2018 – November 2019 Survey
Conservation pool elevation 131.0 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
106	249,246	252,140	255,052	257,983	260,933	263,901	266,890	269,898	272,928	275,983
107	279,064	282,173	285,311	288,478	291,672	294,890	298,130	301,390	304,672	307,977
108	311,304	314,653	318,022	321,414	324,831	328,275	331,746	335,246	338,775	342,330
109	345,913	349,524	353,165	356,835	360,534	364,261	368,015	371,795	375,602	379,438
110	383,306	387,203	391,127	395,077	399,051	403,050	407,074	411,123	415,197	419,294
111	423,413	427,555	431,719	435,905	440,113	444,344	448,596	452,870	457,164	461,479
112	465,814	470,169	474,543	478,935	483,346	487,774	492,220	496,684	501,167	505,667
113	510,185	514,719	519,273	523,847	528,440	533,052	537,682	542,331	547,001	551,691
114	556,404	561,138	565,892	570,665	575,457	580,269	585,099	589,951	594,824	599,715
115	604,624	609,551	614,495	619,456	624,435	629,430	634,444	639,475	644,523	649,588
116	654,669	659,766	664,878	670,004	675,143	680,295	685,460	690,637	695,826	701,028
117	706,243	711,470	716,710	721,963	727,230	732,510	737,804	743,112	748,435	753,771
118	759,123	764,493	769,886	775,299	780,734	786,192	791,672	797,173	802,694	808,236
119	813,799	819,381	824,982	830,604	836,246	841,911	847,598	853,310	859,044	864,801
120	870,579	876,378	882,196	888,033	893,889	899,763	905,654	911,562	917,487	923,426
121	929,381	935,349	941,332	947,330	953,343	959,369	965,410	971,463	977,530	983,611
122	989,706	995,816	1,001,940	1,008,080	1,014,234	1,020,402	1,026,584	1,032,779	1,038,989	1,045,213
123	1,051,451	1,057,702	1,063,967	1,070,246	1,076,538	1,082,845	1,089,169	1,095,507	1,101,860	1,108,226
124	1,114,606	1,120,999	1,127,407	1,133,829	1,140,265	1,146,716	1,153,183	1,159,665	1,166,163	1,172,675
125	1,179,203	1,185,745	1,192,302	1,198,872	1,205,456	1,212,055	1,218,667	1,225,292	1,231,932	1,238,585
126	1,245,253	1,251,935	1,258,631	1,265,342	1,272,068	1,278,809	1,285,566	1,292,339	1,299,130	1,305,940
127	1,312,768	1,319,615	1,326,483	1,333,373	1,340,284	1,347,218	1,354,175	1,361,153	1,368,154	1,375,176
128	1,382,221	1,389,288	1,396,378	1,403,488	1,410,620	1,417,772	1,424,944	1,432,136	1,439,347	1,446,578
129	1,453,828	1,461,098	1,468,387	1,475,696	1,483,025	1,490,374	1,497,744	1,505,133	1,512,544	1,519,976
130	1,527,431	1,534,909	1,542,412	1,549,943	1,557,502	1,565,089	1,572,706	1,580,355	1,588,035	1,595,751
131	1,603,504	1,611,298								

Appendix B

Lake Livingston

RESERVOIR BATHYMETRIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — September 2018 – November 2019 Survey

AREA IN ACRES — Conservation pool elevation 131.0 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
57	0	0	0	0	0	0	0	0	0	0
58	0	0	1	1	1	1	1	1	2	2
59	2	2	2	2	2	2	2	2	3	3
60	3	3	3	3	3	3	4	4	6	6
61	7	7	7	7	8	8	8	8	9	9
62	9	9	10	10	10	11	11	11	12	12
63	12	13	13	14	14	15	16	16	17	17
64	18	19	20	22	25	27	30	32	35	38
65	41	44	48	51	55	59	62	66	70	74
66	78	83	87	91	95	98	101	105	108	112
67	116	120	123	128	132	136	140	144	149	153
68	157	161	164	168	172	176	181	187	195	202
69	209	215	220	224	228	232	236	240	244	247
70	252	257	261	265	269	273	276	280	284	287
71	290	294	297	301	304	308	312	316	321	326
72	331	336	341	345	350	354	358	363	368	374
73	379	383	388	393	398	402	406	410	413	417
74	421	424	428	431	436	440	444	449	453	458
75	463	467	471	476	480	485	490	494	499	505
76	510	515	522	527	532	537	542	547	552	556
77	561	565	570	575	580	586	592	597	602	607
78	611	616	622	627	633	640	648	655	663	670
79	678	685	693	700	708	717	727	736	745	754
80	763	773	782	790	798	807	815	822	829	837
81	844	852	860	867	875	883	891	900	909	918
82	927	936	945	955	964	974	985	997	1,008	1,020
83	1,031	1,042	1,054	1,066	1,077	1,089	1,101	1,113	1,125	1,138
84	1,151	1,164	1,177	1,192	1,207	1,221	1,236	1,250	1,265	1,279
85	1,296	1,314	1,332	1,350	1,368	1,385	1,402	1,420	1,439	1,459
86	1,480	1,503	1,525	1,546	1,567	1,589	1,611	1,632	1,653	1,676
87	1,698	1,718	1,740	1,761	1,783	1,805	1,829	1,853	1,878	1,907
88	1,934	1,962	1,992	2,021	2,052	2,083	2,115	2,150	2,185	2,220
89	2,258	2,299	2,339	2,383	2,426	2,471	2,521	2,579	2,647	2,719
90	2,796	2,870	2,937	3,009	3,102	3,189	3,275	3,357	3,440	3,523
91	3,606	3,693	3,781	3,867	3,952	4,037	4,120	4,202	4,283	4,364
92	4,448	4,533	4,616	4,703	4,799	4,908	5,026	5,157	5,305	5,487
93	5,677	5,856	6,036	6,216	6,409	6,596	6,782	6,962	7,134	7,311
94	7,485	7,649	7,810	7,967	8,130	8,299	8,492	8,676	8,842	9,020
95	9,186	9,336	9,478	9,618	9,756	9,887	10,011	10,139	10,261	10,385
96	10,504	10,619	10,733	10,848	10,972	11,101	11,231	11,365	11,497	11,647
97	11,809	11,966	12,114	12,261	12,410	12,563	12,709	12,856	13,014	13,181
98	13,358	13,514	13,669	13,822	13,982	14,144	14,318	14,505	14,706	14,900
99	15,085	15,272	15,468	15,661	15,843	16,019	16,209	16,407	16,618	16,850
100	17,067	17,281	17,488	17,682	17,880	18,078	18,292	18,512	18,744	18,976
101	19,225	19,471	19,721	19,969	20,201	20,426	20,647	20,842	21,031	21,215
102	21,398	21,577	21,755	21,934	22,110	22,291	22,470	22,654	22,843	23,028
103	23,209	23,386	23,561	23,742	23,919	24,098	24,282	24,459	24,642	24,815
104	24,985	25,150	25,317	25,492	25,660	25,826	25,992	26,167	26,353	26,547
105	26,751	26,953	27,158	27,364	27,585	27,797	28,001	28,218	28,439	28,647

Appendix B (continued)

Lake Livingston

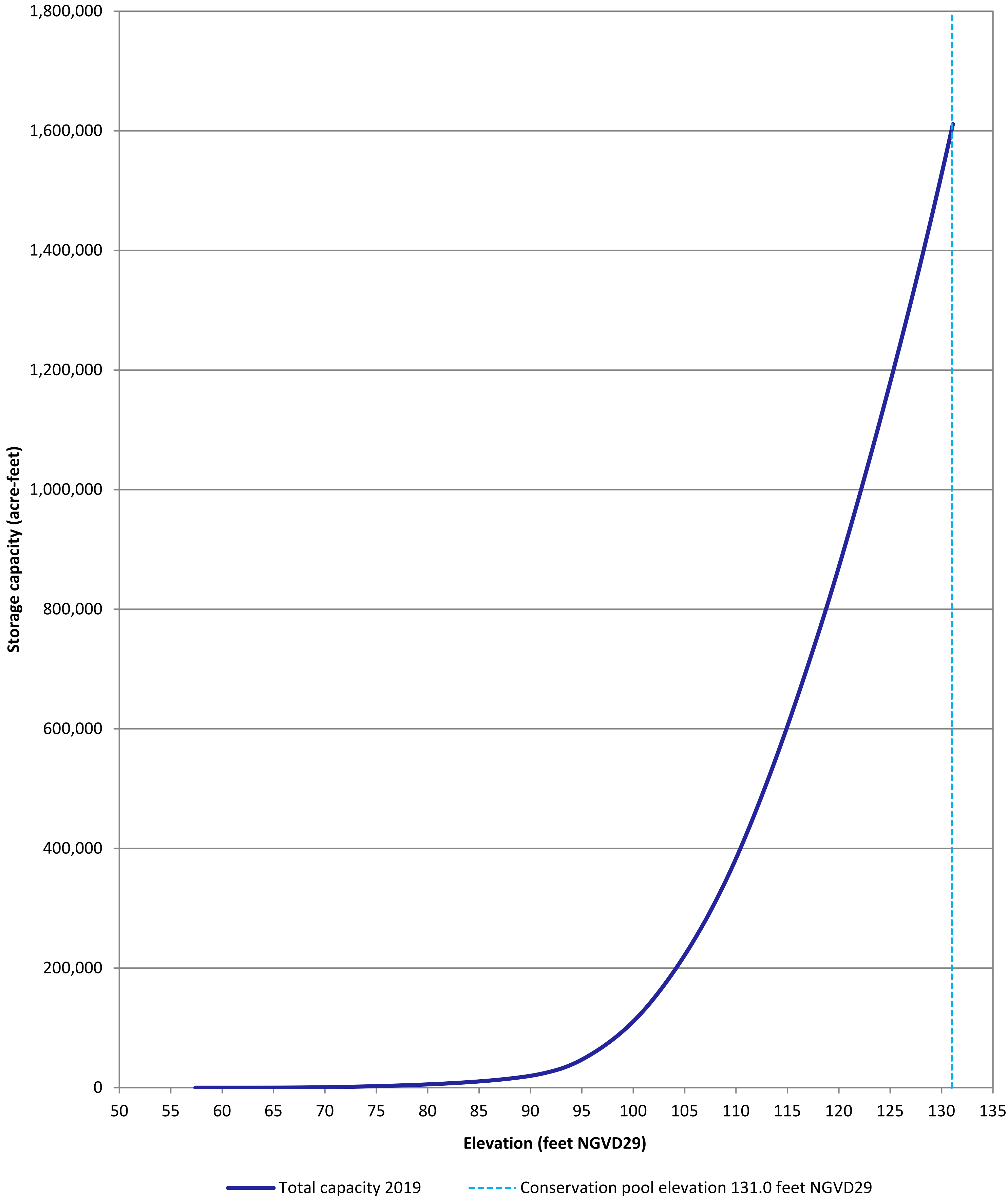
RESERVOIR BATHYMETRIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD | September 2018 – November 2019 Survey

AREA IN ACRES | Conservation pool elevation 131.0 feet NGVD29

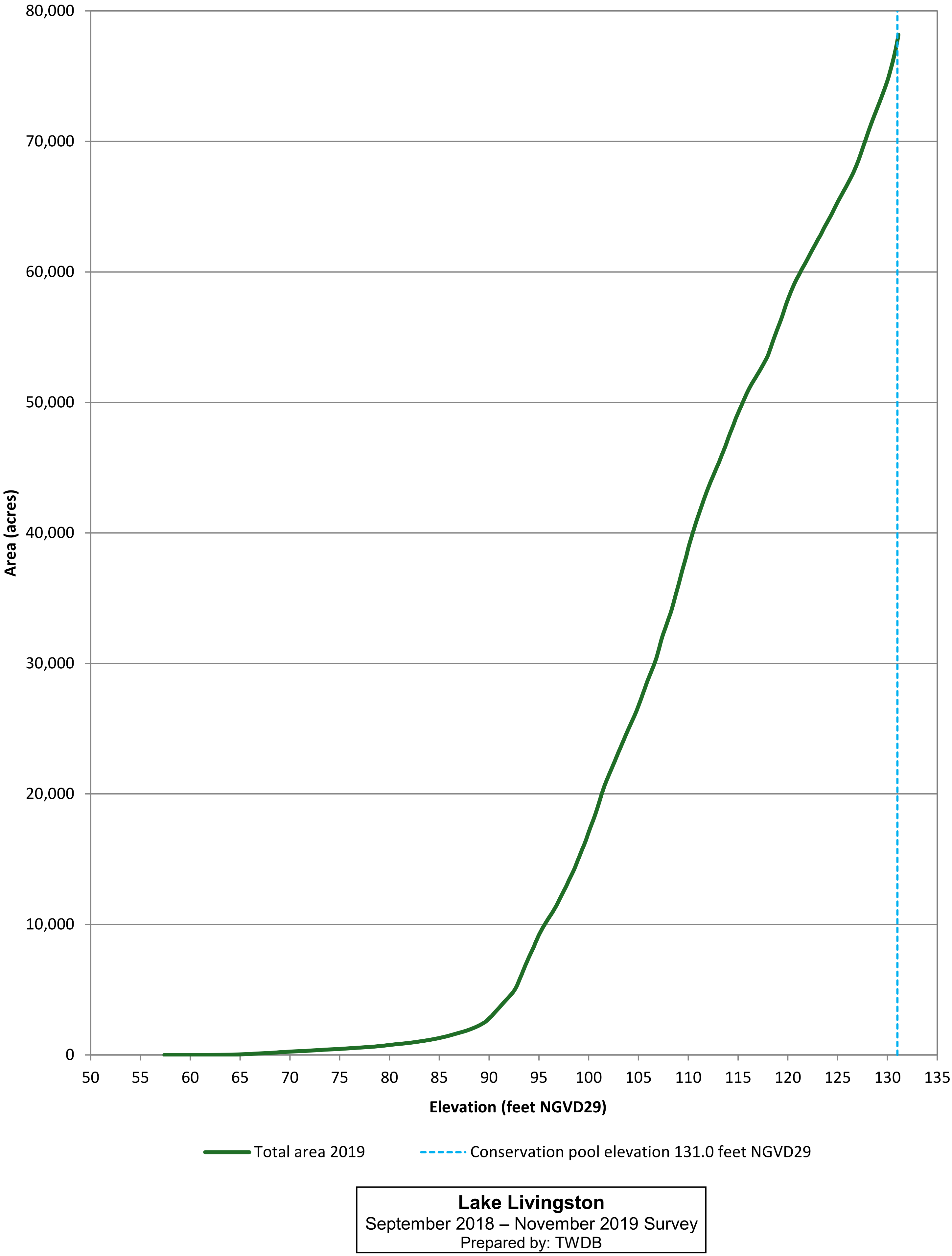
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
106	28,842	29,029	29,216	29,406	29,591	29,779	29,985	30,191	30,413	30,678
107	30,953	31,230	31,529	31,808	32,061	32,291	32,501	32,711	32,936	33,155
108	33,381	33,593	33,804	34,039	34,302	34,572	34,856	35,147	35,422	35,693
109	35,968	36,256	36,552	36,845	37,133	37,406	37,669	37,939	38,208	38,522
110	38,833	39,108	39,368	39,620	39,868	40,116	40,366	40,614	40,854	41,084
111	41,305	41,528	41,753	41,971	42,190	42,414	42,632	42,837	43,048	43,254
112	43,447	43,643	43,833	44,020	44,197	44,368	44,547	44,735	44,914	45,088
113	45,261	45,439	45,637	45,835	46,024	46,210	46,399	46,590	46,797	47,014
114	47,235	47,442	47,639	47,828	48,017	48,210	48,409	48,627	48,822	49,002
115	49,176	49,352	49,529	49,700	49,871	50,042	50,223	50,395	50,571	50,733
116	50,890	51,044	51,187	51,326	51,458	51,585	51,709	51,830	51,956	52,086
117	52,211	52,336	52,464	52,601	52,736	52,867	53,007	53,155	53,293	53,436
118	53,607	53,808	54,032	54,238	54,470	54,688	54,904	55,112	55,314	55,527
119	55,721	55,917	56,116	56,320	56,530	56,758	56,993	57,231	57,459	57,679
120	57,882	58,086	58,275	58,469	58,652	58,826	58,998	59,163	59,320	59,476
121	59,613	59,752	59,904	60,056	60,199	60,335	60,467	60,603	60,737	60,878
122	61,024	61,173	61,321	61,468	61,613	61,747	61,886	62,026	62,168	62,311
123	62,448	62,586	62,715	62,850	62,997	63,157	63,311	63,454	63,594	63,730
124	63,867	64,007	64,145	64,287	64,435	64,588	64,747	64,901	65,051	65,202
125	65,350	65,496	65,634	65,774	65,914	66,052	66,189	66,325	66,465	66,604
126	66,746	66,890	67,036	67,184	67,333	67,488	67,648	67,821	68,005	68,186
127	68,373	68,575	68,789	69,006	69,228	69,454	69,677	69,893	70,112	70,336
128	70,562	70,785	70,999	71,211	71,417	71,621	71,822	72,017	72,211	72,406
129	72,603	72,795	72,989	73,188	73,389	73,593	73,797	74,001	74,213	74,433
130	74,657	74,901	75,172	75,453	75,729	76,017	76,324	76,641	76,978	77,338
131	77,729	78,170								



Lake Livingston
September 2018 – November 2019 Survey
Prepared by: TWDB

Appendix C: Bathymetric capacity curve



Appendix D: Bathymetric area curve

Appendix E

Lake Livingston

RESERVOIR TOPOGRAPHIC CAPACITY TABLE

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

September 2018 – November 2019 Survey
Top of spillway tainter gates elevation 134.0 feet
Top of dam elevation 145.0 feet

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
131			1,615,108	1,623,365	1,631,663	1,639,999	1,648,371	1,656,781	1,665,225	1,673,702
132	1,682,212	1,690,754	1,699,329	1,707,935	1,716,576	1,725,253	1,733,966	1,742,715	1,751,497	1,760,311
133	1,769,157	1,778,034	1,786,942	1,795,881	1,804,851	1,813,852	1,822,883	1,831,945	1,841,037	1,850,158
134	1,859,310	1,868,492	1,877,704	1,886,947	1,896,221	1,905,528	1,914,869	1,924,242	1,933,646	1,943,081
135	1,952,546	1,962,042	1,971,569	1,981,125	1,990,713	2,000,329	2,009,976	2,019,651	2,029,357	2,039,092
136	2,048,858	2,058,653	2,068,479	2,078,336	2,088,224	2,098,142	2,108,090	2,118,069	2,128,078	2,138,116
137	2,148,183	2,158,280	2,168,406	2,178,562	2,188,748	2,198,965	2,209,213	2,219,491	2,229,802	2,240,144
138	2,250,520	2,260,928	2,271,371	2,281,848	2,292,361	2,302,916	2,313,499	2,324,105	2,334,757	2,345,455
139	2,356,175	2,366,942	2,377,732	2,388,567	2,399,449	2,410,376	2,421,327	2,432,323	2,443,365	2,454,454
140	2,465,565	2,476,745	2,487,948	2,499,197	2,510,491	2,521,832	2,533,219	2,544,628	2,556,107	2,567,608
141	2,579,155	2,590,748	2,602,388	2,614,073	2,625,781	2,637,557	2,649,380	2,661,249	2,673,163	2,685,124
142	2,697,130	2,709,183	2,721,281	2,733,425	2,745,615	2,757,874	2,770,156	2,782,484	2,794,858	2,807,300
143	2,819,766	2,832,277	2,844,835	2,857,461	2,870,110	2,882,805	2,895,546	2,908,333	2,921,189	2,934,068
144	2,946,993	2,959,940	2,972,957	2,985,996	2,999,105	3,012,236	3,025,390	3,038,613	3,051,860	3,065,174
145	3,078,512									

Appendix F

Lake Livingston

RESERVOIR TOPOGRAPHIC AREA TABLE

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

September 2018 – November 2019 Survey
Top of spillway tainter gates elevation 134.0 feet
Top of dam elevation 145.0 feet

ELEVATION (Feet NGVD29)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
131			82,350	82,781	83,172	83,545	83,912	84,269	84,611	84,939
132	85,260	85,582	85,903	86,235	86,585	86,950	87,318	87,656	87,982	88,301
133	88,615	88,927	89,235	89,544	89,852	90,162	90,466	90,766	91,067	91,369
134	91,668	91,969	92,273	92,581	92,902	93,241	93,572	93,885	94,195	94,502
135	94,807	95,113	95,416	95,722	96,021	96,316	96,609	96,905	97,204	97,504
136	97,805	98,107	98,414	98,723	99,029	99,333	99,637	99,937	100,233	100,529
137	100,823	101,114	101,409	101,710	102,012	102,321	102,633	102,944	103,263	103,589
138	103,918	104,254	104,600	104,952	105,302	105,650	105,996	106,345	106,703	107,064
139	107,429	107,805	108,188	108,578	108,969	109,370	109,784	110,203	110,622	111,040
140	111,463	111,889	112,316	112,730	113,151	113,572	113,998	114,422	114,843	115,267
141	115,698	116,142	116,608	117,062	117,511	117,966	118,434	118,893	119,352	119,820
142	120,301	120,773	121,242	121,706	122,168	122,632	123,097	123,568	124,027	124,485
143	124,941	125,399	125,859	126,315	126,784	127,239	127,693	128,142	128,579	129,011
144	129,437	129,857	130,280	130,703	131,118	131,528	131,936	132,344	132,760	133,198
145	133,689									

Appendix G

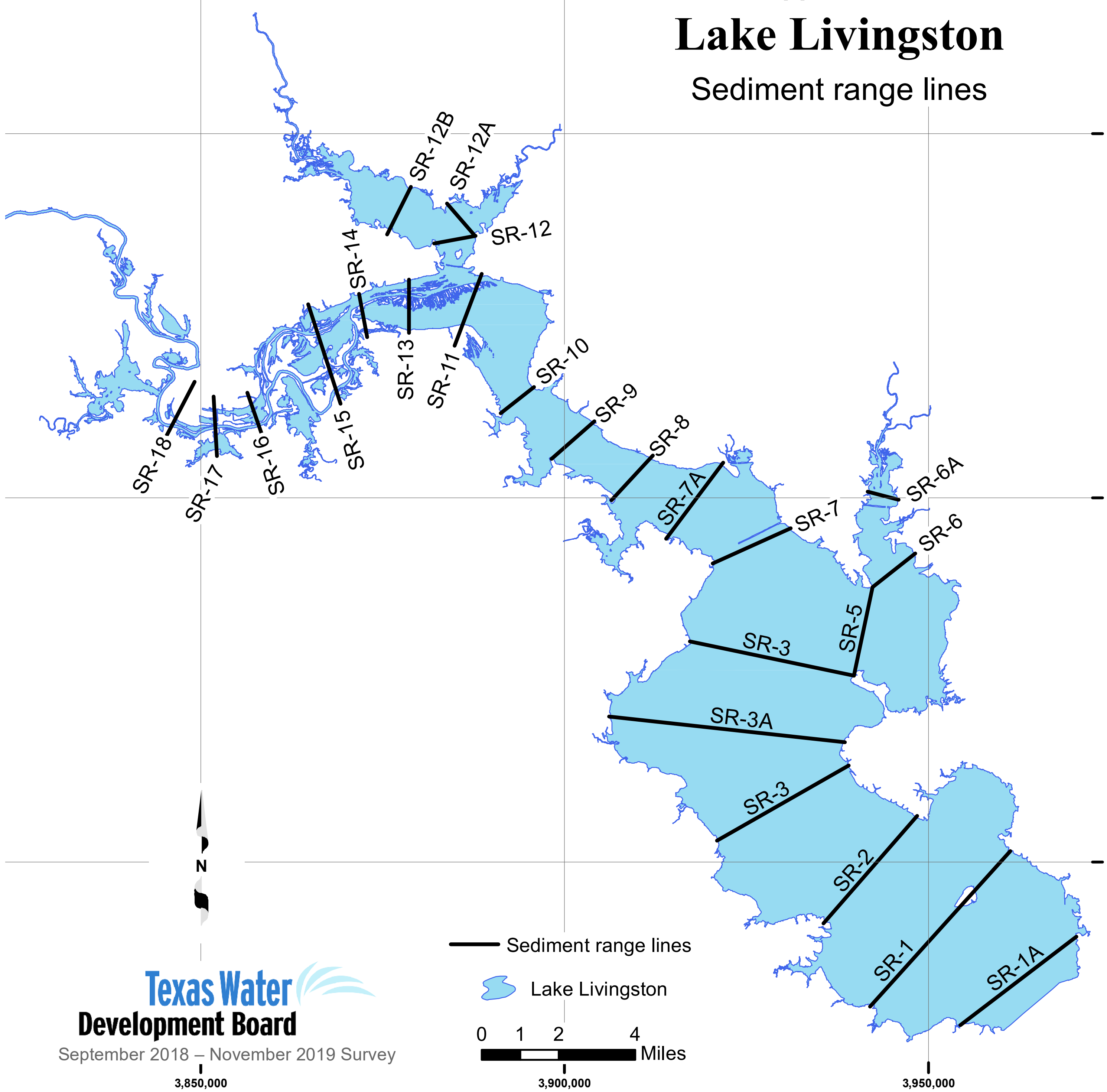
Lake Livingston

Sediment range lines

Table G1. Endpoint Coordinates for Lake Livingston Sediment Range Lines

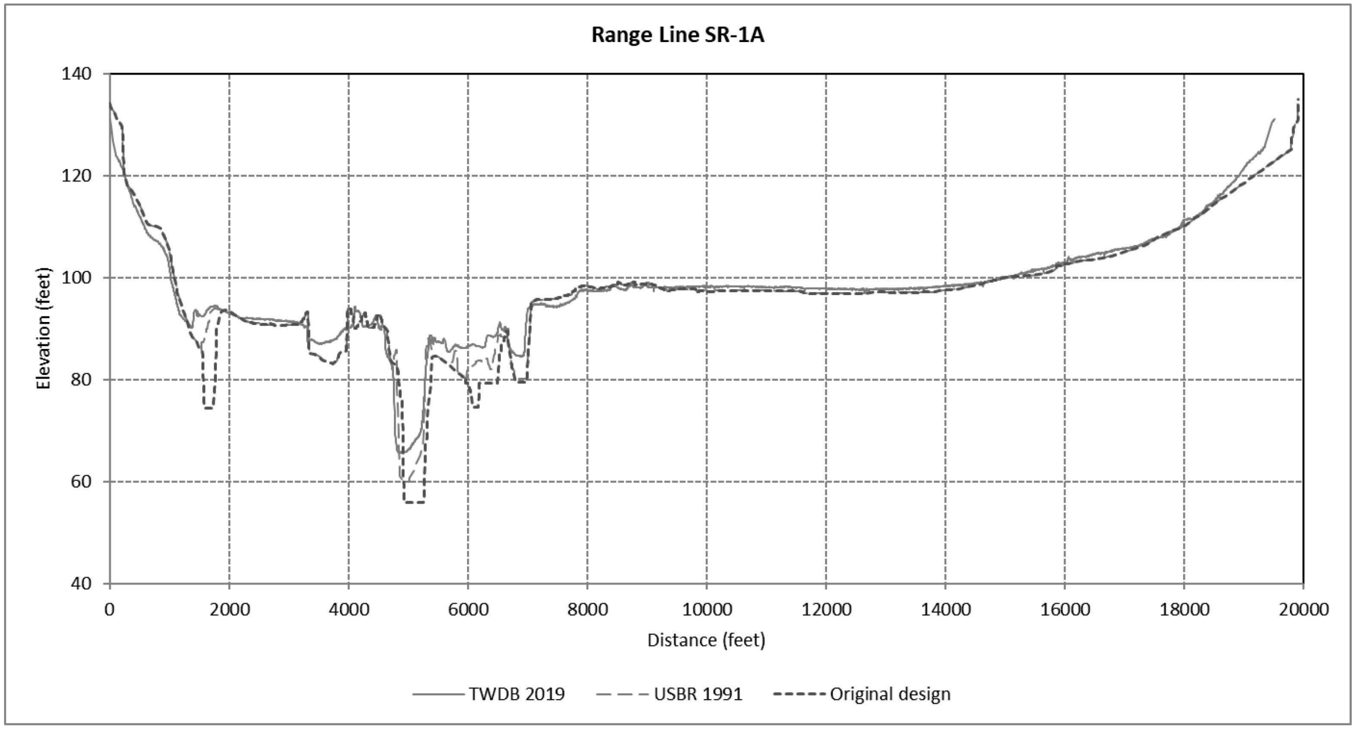
Range	L=Left R=Right	X	Y
SR-1A	L	3,970,288.54	10,239,714.81
	R	3,954,359.09	10,227,587.17
SR-1	L	3,961,183.66	10,251,478.18
	R	3,941,964.91	10,230,106.66
SR-2	L	3,948,400.67	10,256,309.78
	R	3,935,562.13	10,241,562.96
SR-3	L	3,938,976.05	10,263,195.41
	R	3,920,898.79	10,252,892.54
SR-3A	L	3,938,498.93	10,266,389.67
	R	3,906,079.59	10,269,926.63
SR-4	L	3,939,728.79	10,275,539.00
	R	3,917,193.57	10,280,244.14
SR-5	L	3,939,728.79	10,275,539.00
	R	3,942,263.16	10,287,628.26
SR-6	L	3,948,142.43	10,292,317.24
	R	3,942,272.28	10,287,672.20
SR-6A	L	3,945,845.61	10,299,722.50
	R	3,941,632.07	10,300,807.56
SR-7	L	3,931,022.93	10,295,797.85
	R	3,920,302.44	10,290,969.29
SR-7A	L	3,921,792.25	10,304,816.53
	R	3,913,938.09	10,294,379.03
SR-8	L	3,912,123.01	10,305,811.96
	R	3,906,428.56	10,299,631.40
SR-9	L	3,904,063.11	10,310,501.63
	R	3,898,182.04	10,305,336.70
SR-10	L	3,895,765.95	10,315,162.36
	R	3,891,197.80	10,311,559.93
SR-11	L	3,888,627.93	10,330,700.56
	R	3,884,902.23	10,320,869.83
SR-12	L	3,887,729.89	10,335,911.44
	R	3,882,097.95	10,334,918.38
SR-12A	L	3,887,600.99	10,335,977.14
	R	3,883,814.10	10,340,411.01
SR-12B	L	3,878,865.86	10,342,660.14
	R	3,875,610.65	10,336,128.03
SR-13	L	3,878,596.99	10,329,937.37
	R	3,878,610.01	10,322,593.62
SR-14	L	3,871,800.12	10,327,997.27
	R	3,872,880.84	10,322,059.77
SR-15	L	3,864,760.18	10,326,543.28
	R	3,869,213.31	10,312,871.40
SR-16	L	3,856,431.19	10,314,425.22
	R	3,858,471.12	10,308,587.55
SR-17	L	3,851,808.80	10,313,882.69
	R	3,852,264.53	10,305,722.96
SR-18	L	3,849,182.93	10,315,922.62
	R	3,845,037.96	10,308,001.61

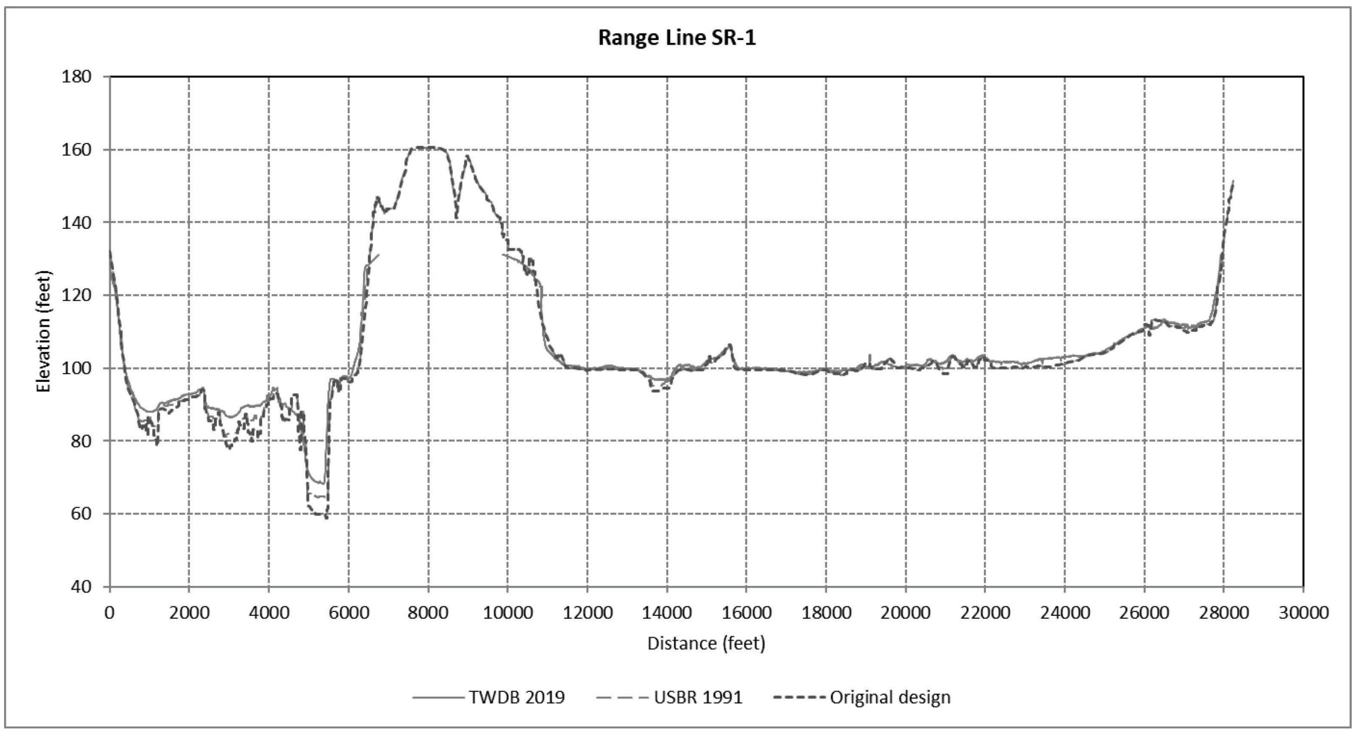
XY Coordinates in NAD83 State Plane Texas Central Zone (feet)

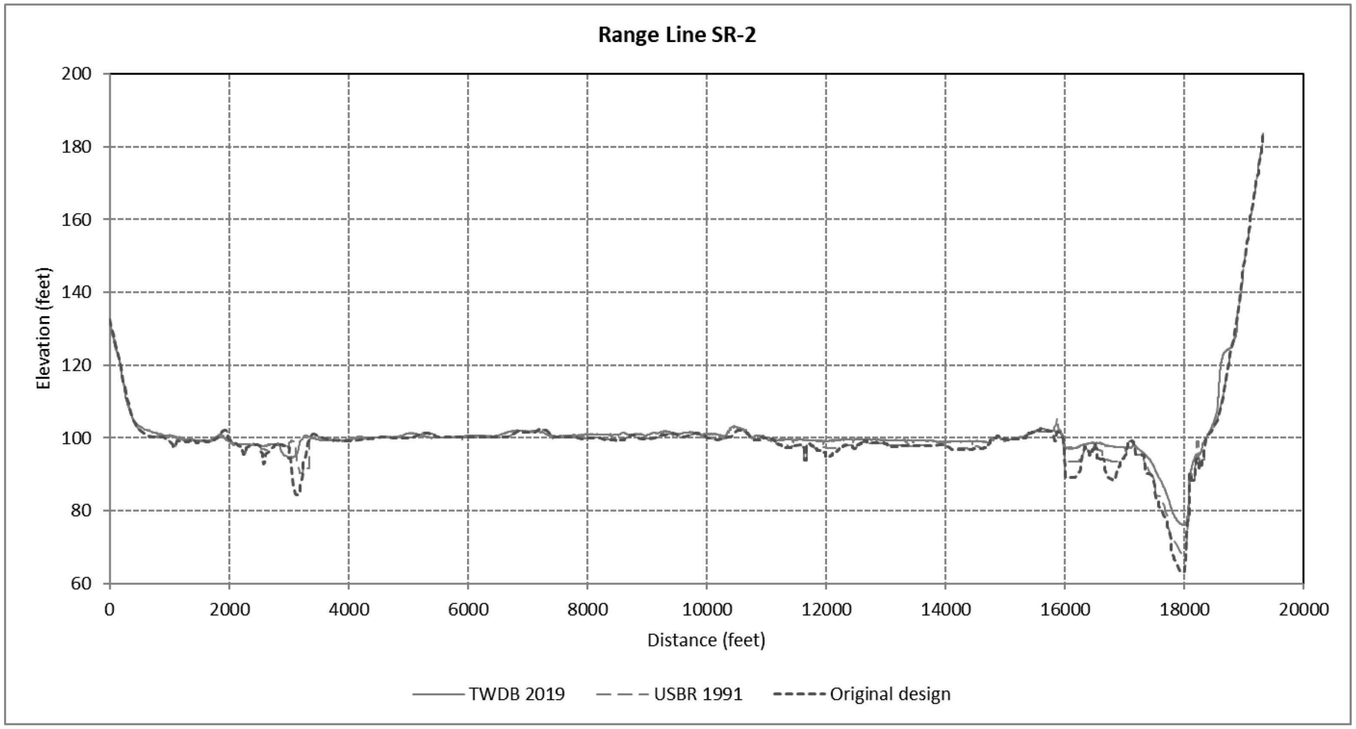


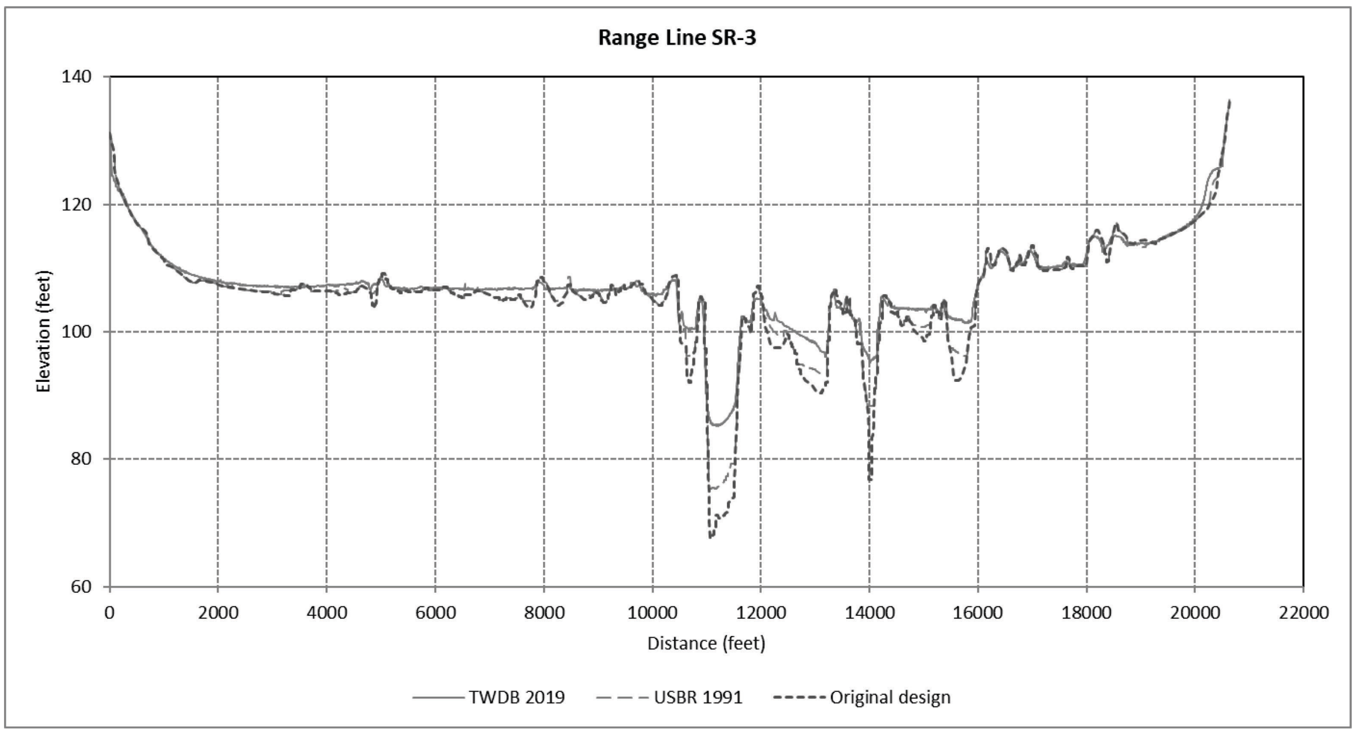
Texas Water Development Board

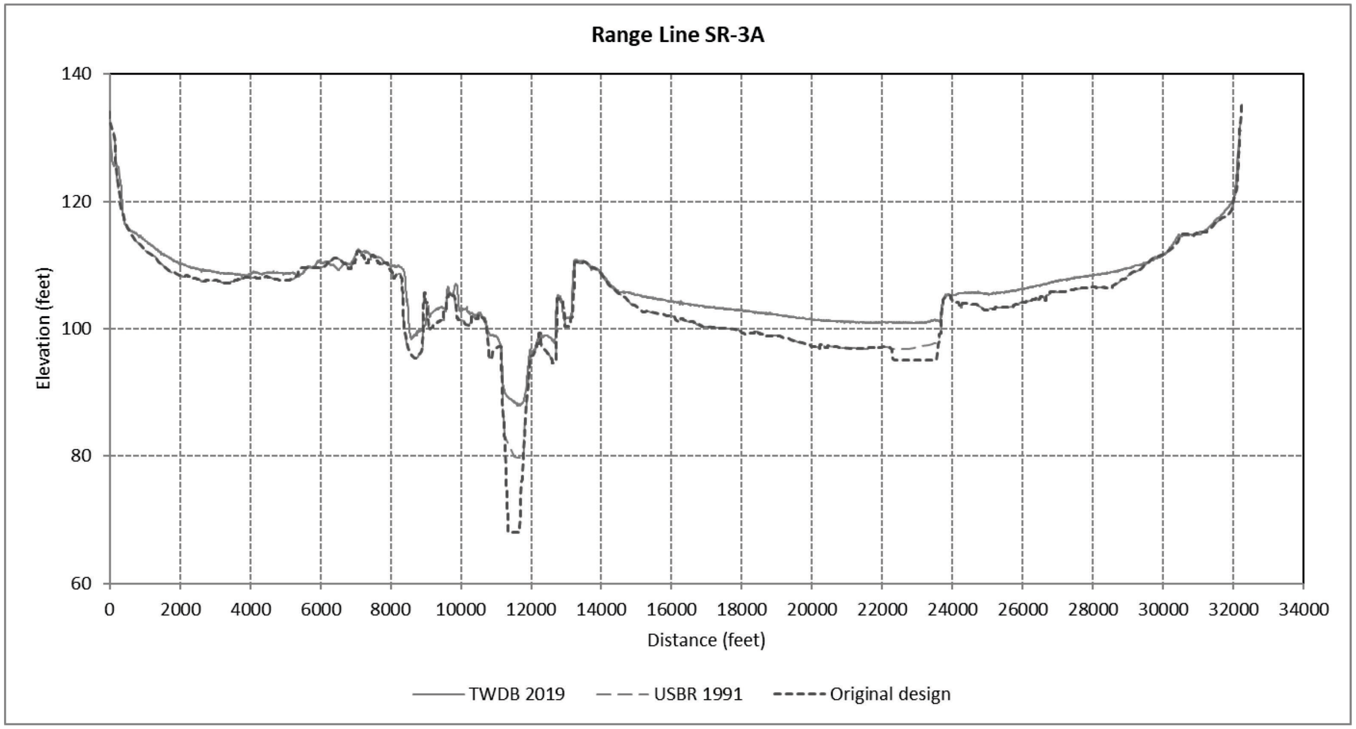
September 2018 – November 2019 Survey


Range Line SR-1A
Elevation (feet)
140
120
100
80
60
40
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance (feet)
TWDB 2019
USBR 1991
Original design

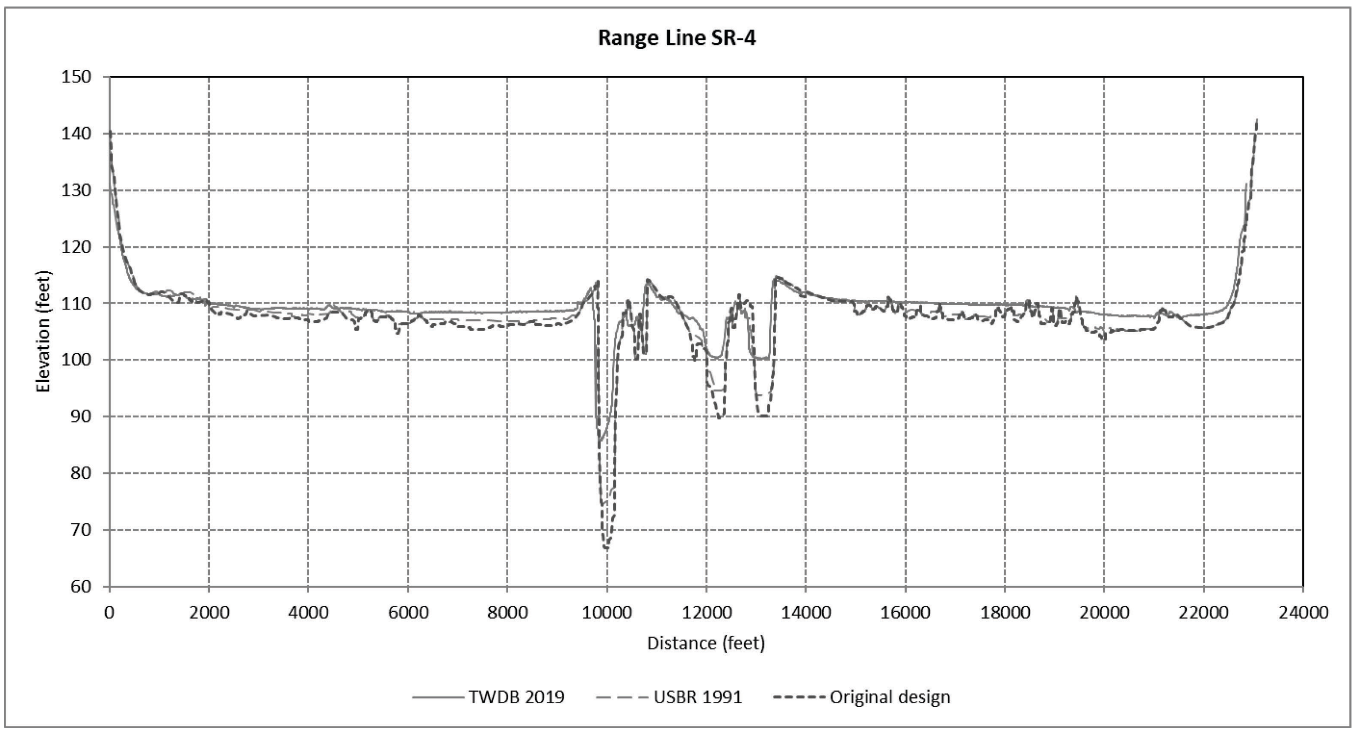

Range Line SR-1
Elevation (feet)
180
160
140
120
100
80
60
40
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
28000
30000
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-2
Elevation (feet)
Distance (feet)
200
180
160
140
120
100
80
60
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
TWDB 2019
USBR 1991
Original design

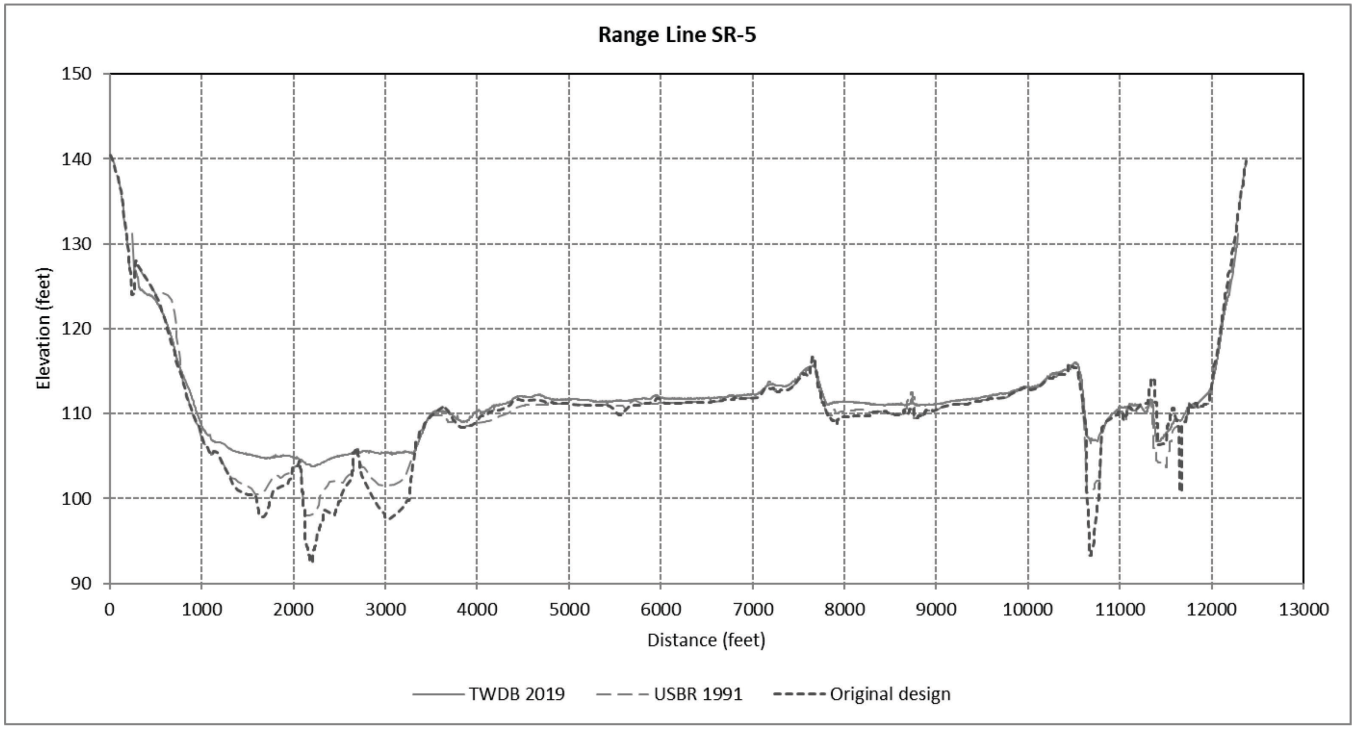

Range Line SR-3
Elevation (feet)
Distance (feet)
140
120
100
80
60
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
TWDB 2019
USBR 1991
Original design

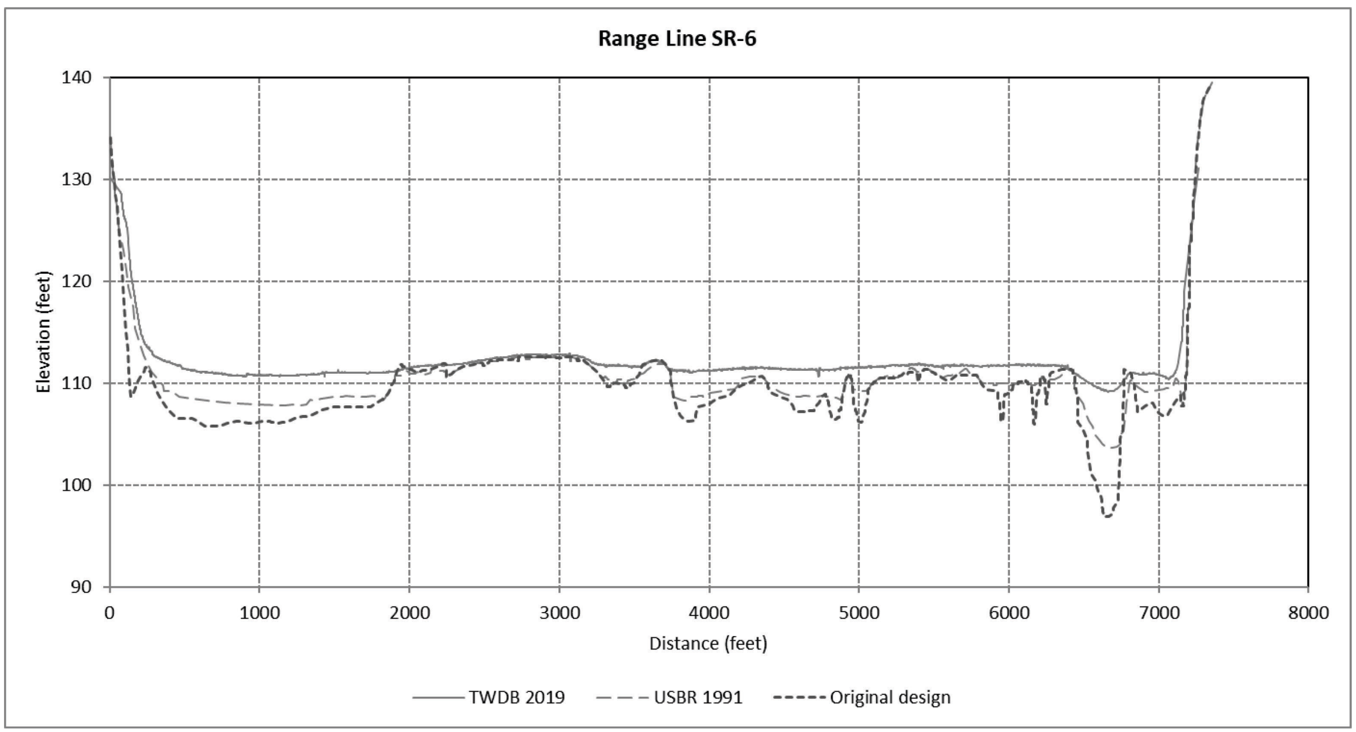


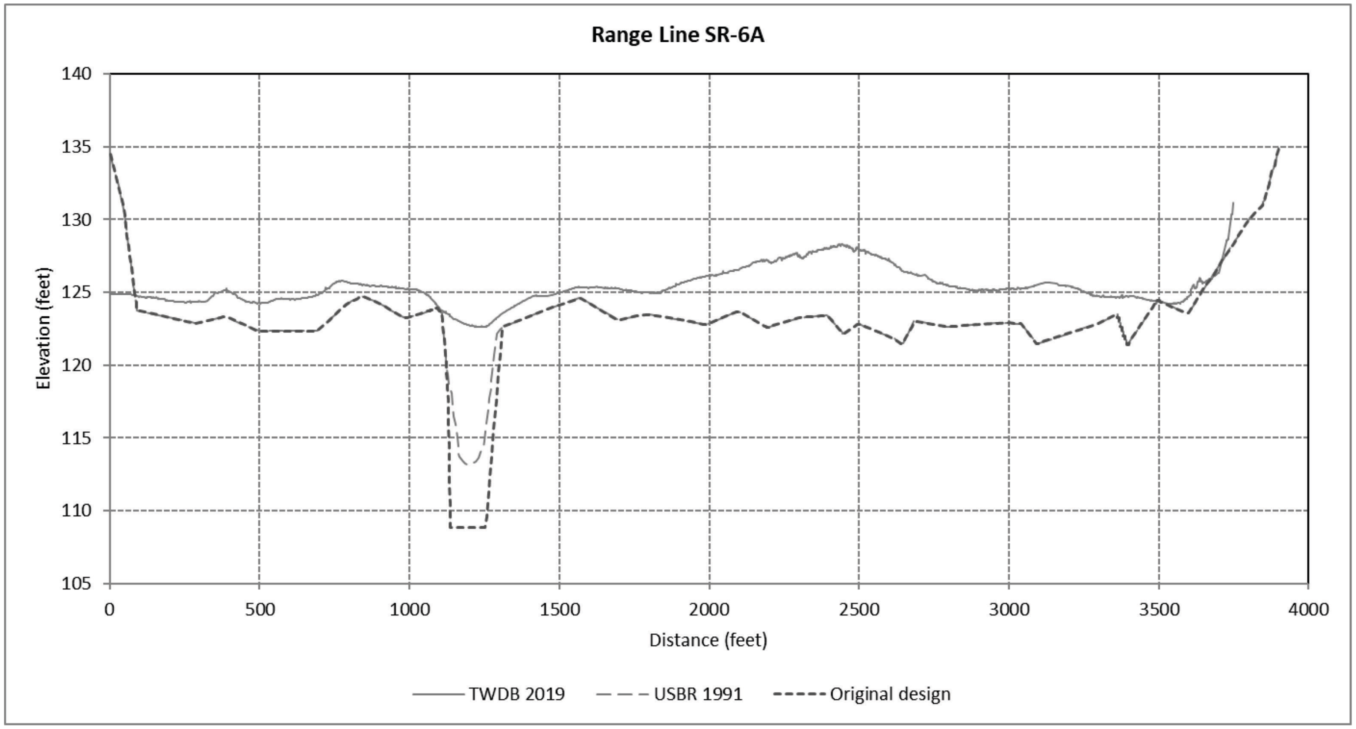
Range Line SR-3A
Elevation (feet)
140
120
100
80
60
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
28000
30000
32000
34000
Distance (feet)
TWDB 2019
USBR 1991
Original design



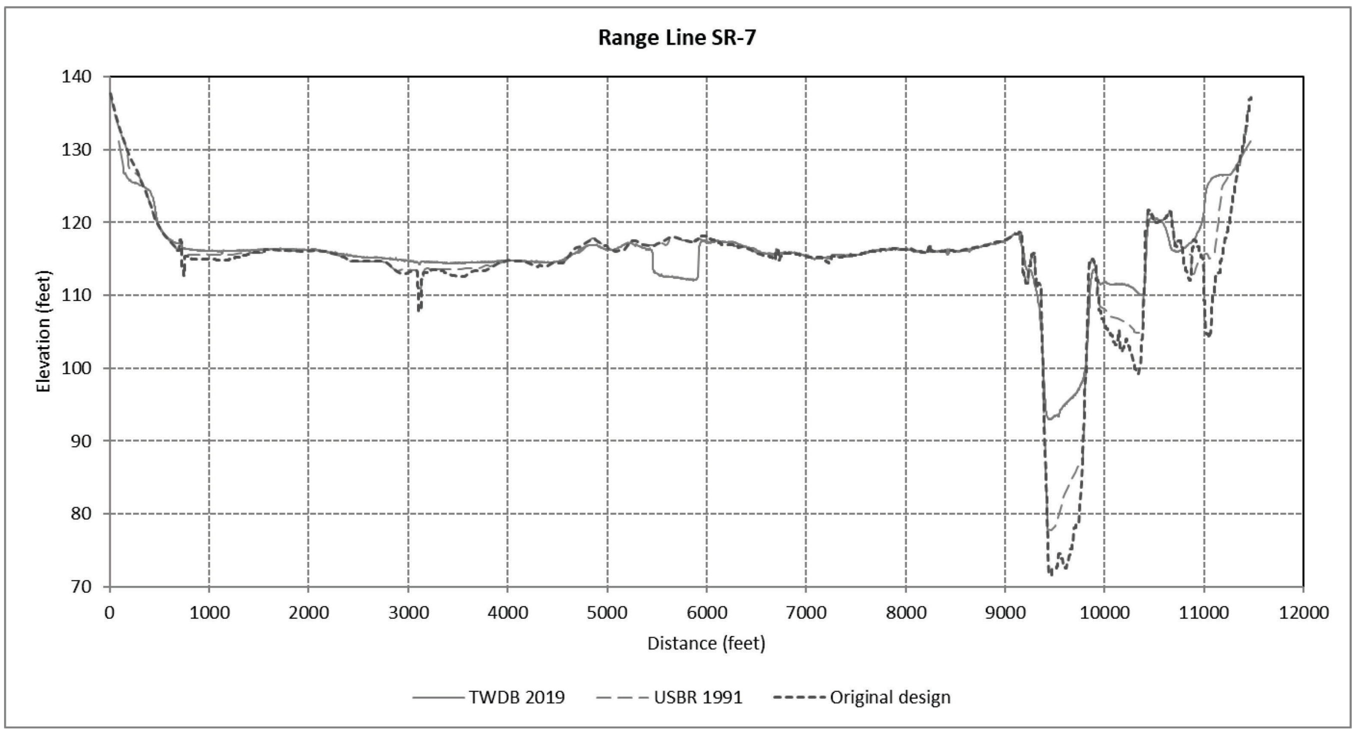
Range Line SR-4
Elevation (feet)
150
140
130
120
110
100
90
80
70
60
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-5
Elevation (feet)
Distance (feet)
150
140
130
120
110
100
90
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
TWDB 2019
USBR 1991
Original design

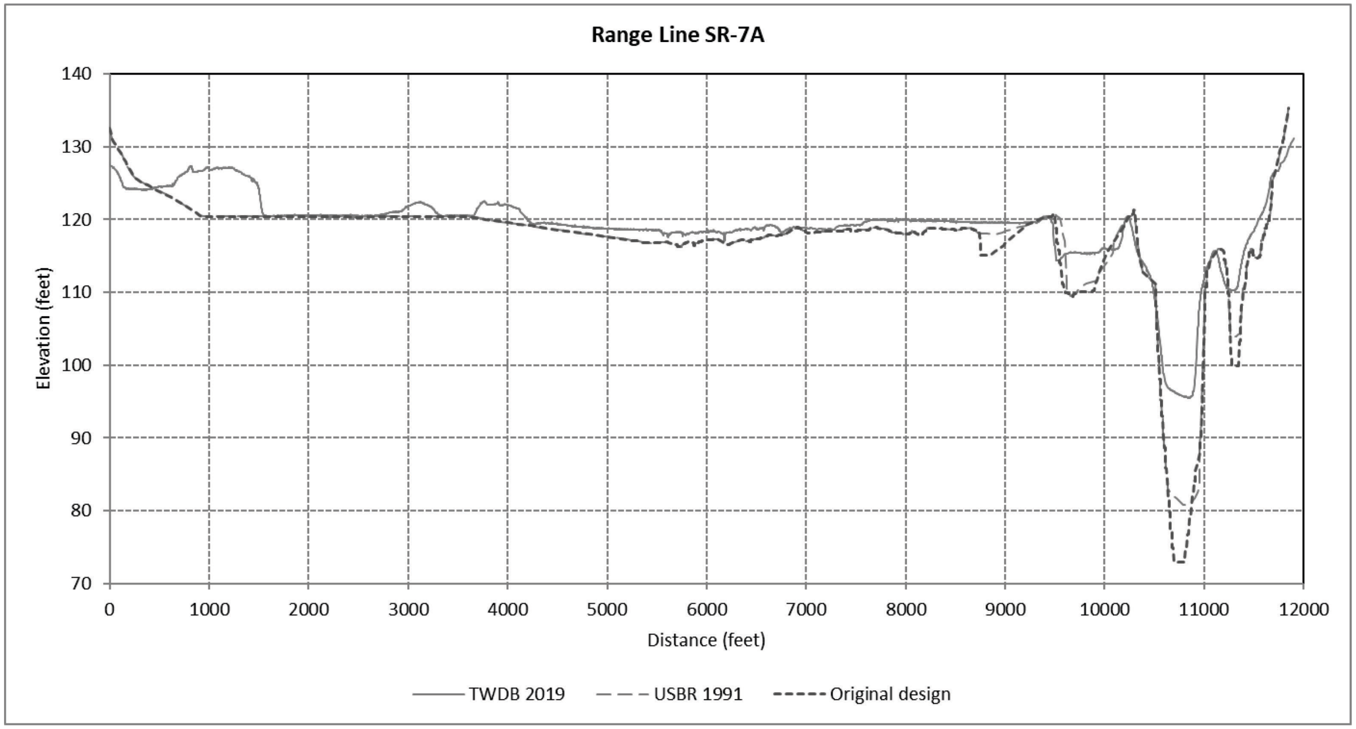

Range Line SR-6
Elevation (feet)
Distance (feet)
140
130
120
110
100
90
0
1000
2000
3000
4000
5000
6000
7000
8000
TWDB 2019
USBR 1991
Original design

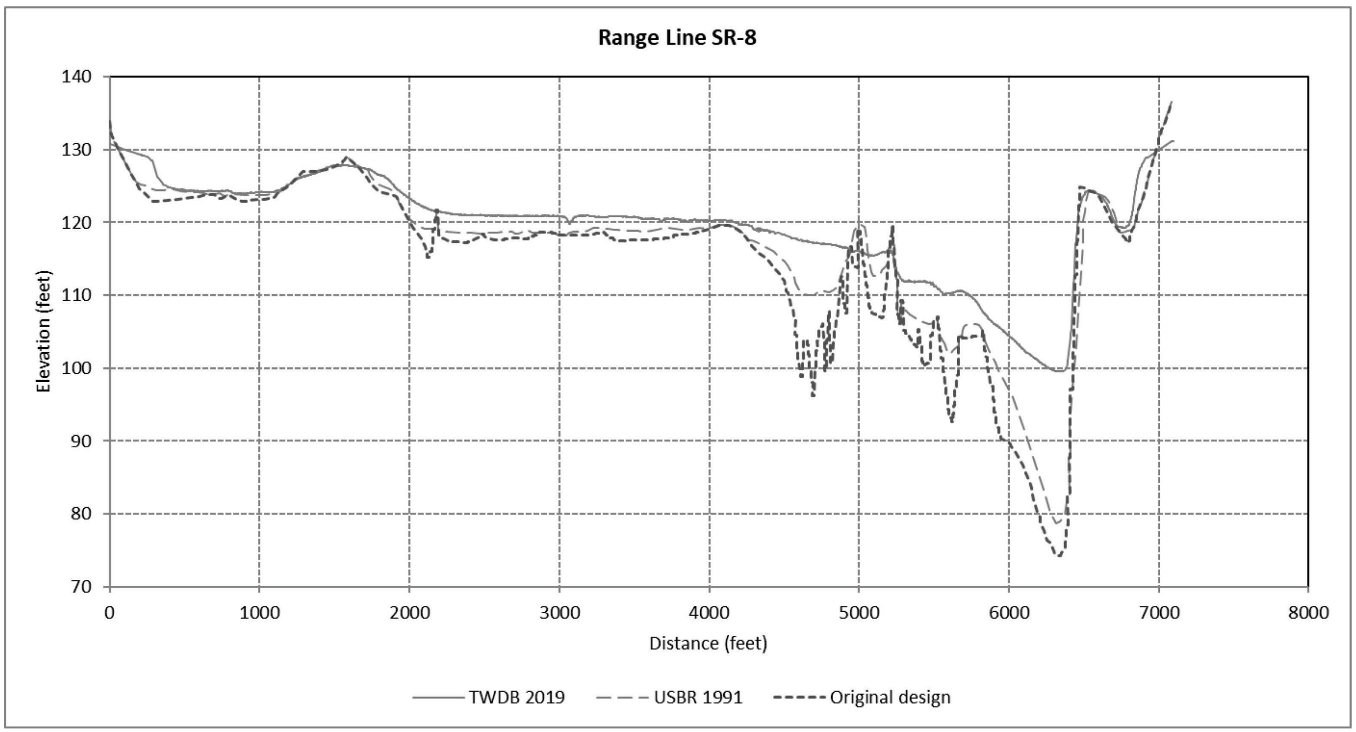


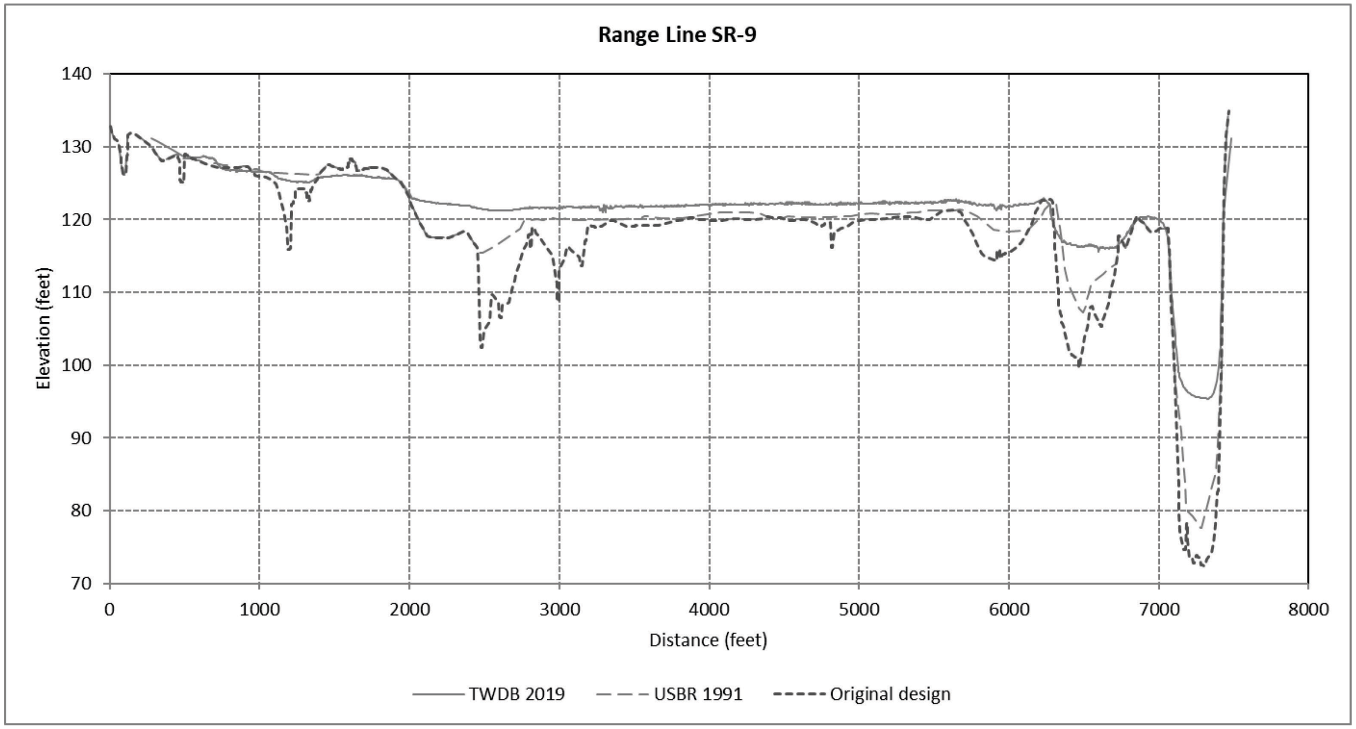
Range Line SR-6A
Elevation (feet)
Distance (feet)
140
135
130
125
120
115
110
105
0
500
1000
1500
2000
2500
3000
3500
4000
TWDB 2019
USBR 1991
Original design

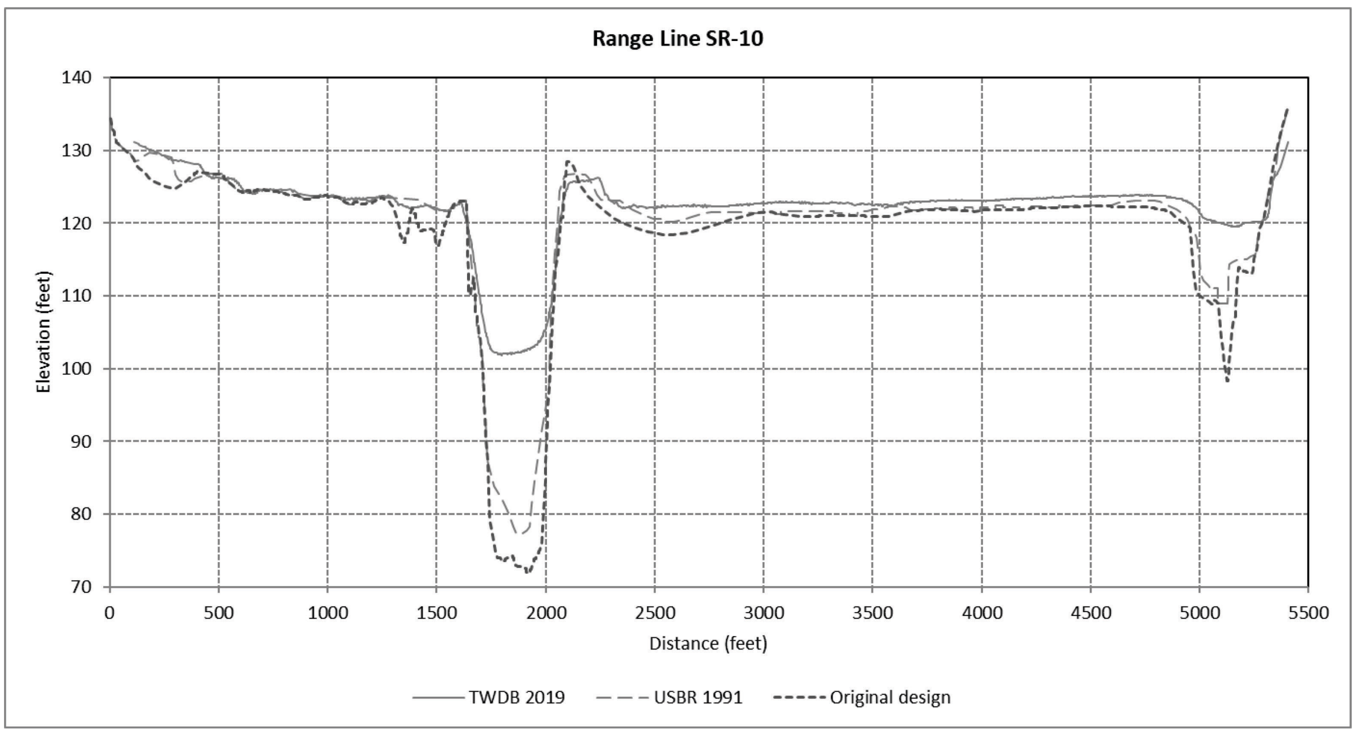


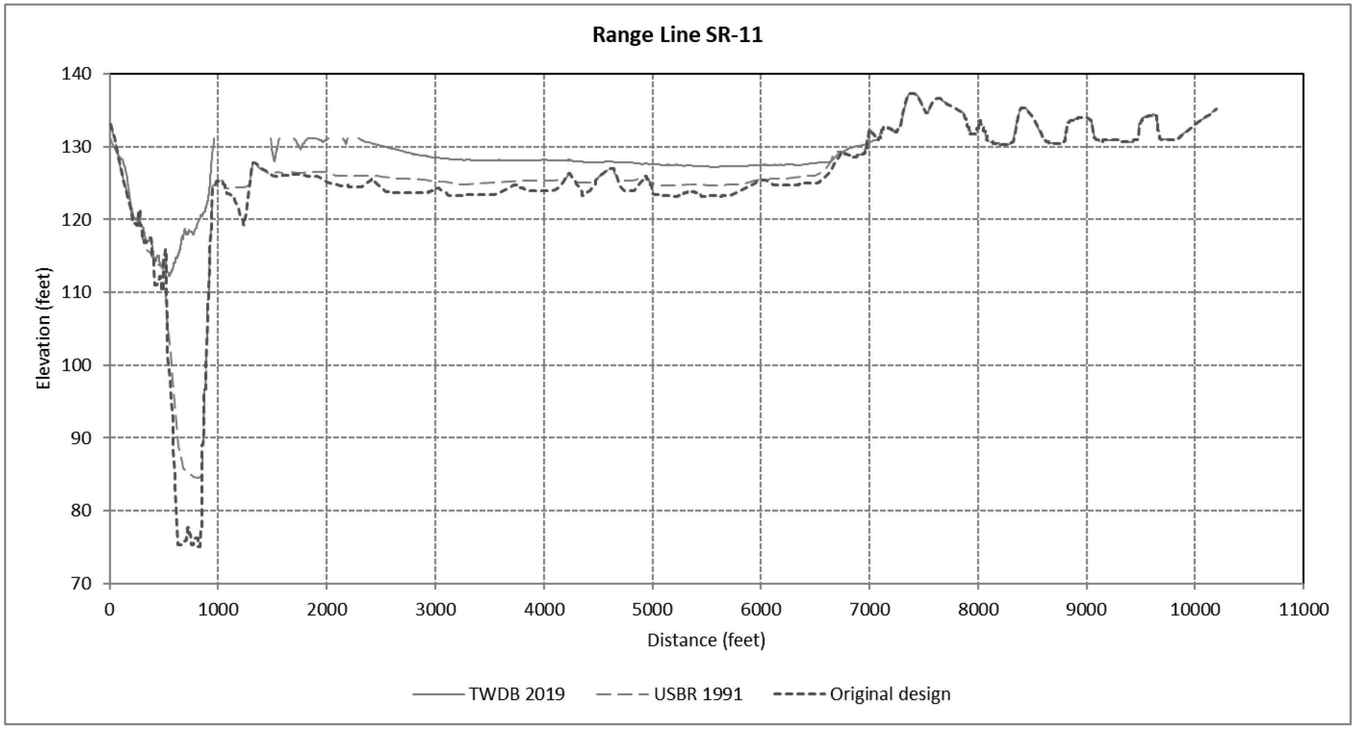
Range Line SR-7
Elevation (feet)
Distance (feet)
140
130
120
110
100
90
80
70
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
TWDB 2019
USBR 1991
Original design

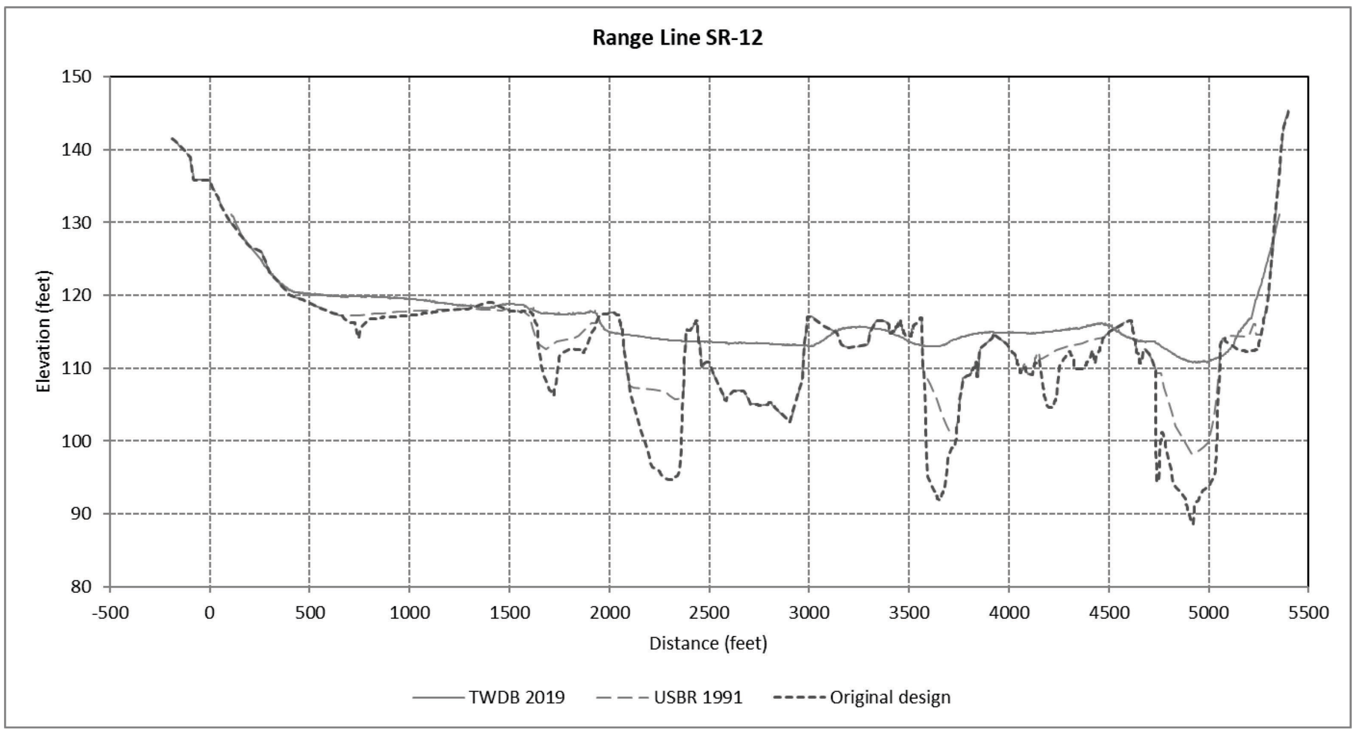

Range Line SR-7A
Elevation (feet)
Distance (feet)
140
130
120
110
100
90
80
70
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
TWDB 2019
USBR 1991
Original design

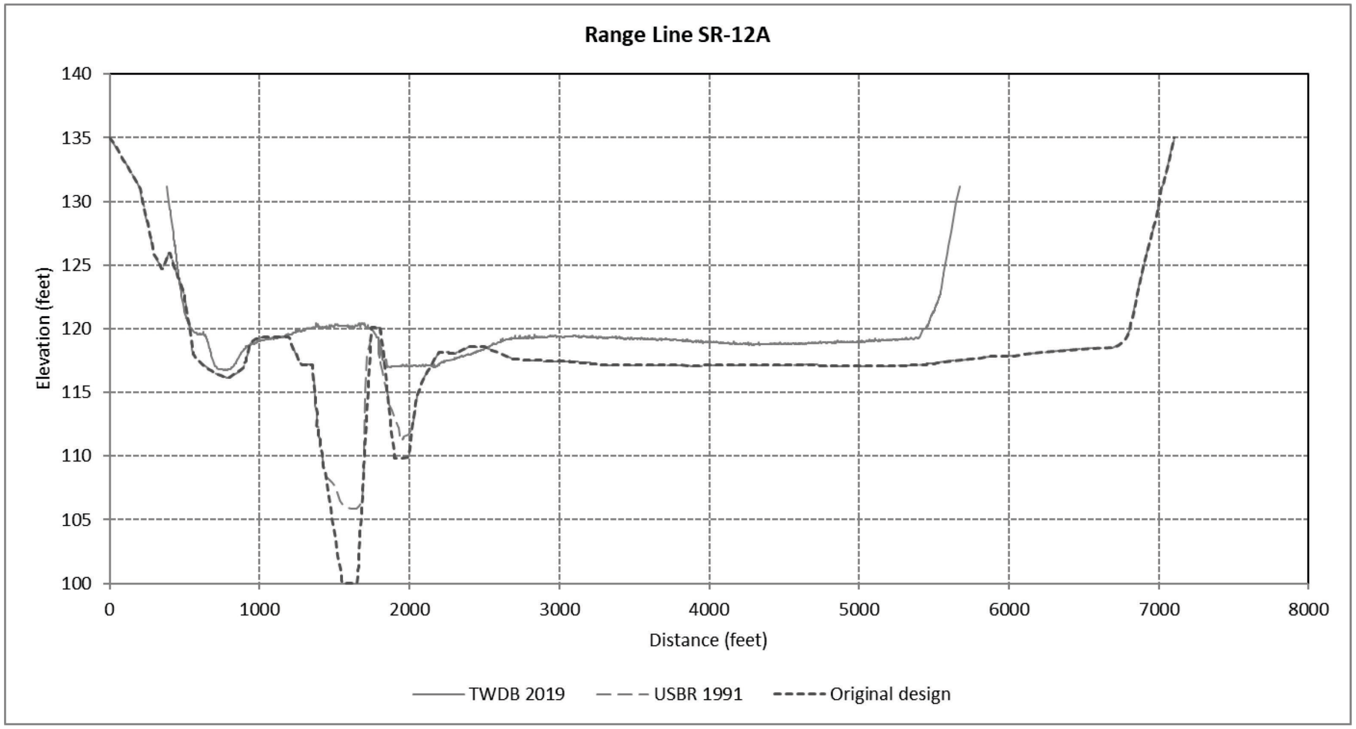

Range Line SR-8
Elevation (feet)
Distance (feet)
140
130
120
110
100
90
80
70
0
1000
2000
3000
4000
5000
6000
7000
8000
TWDB 2019
USBR 1991
Original design

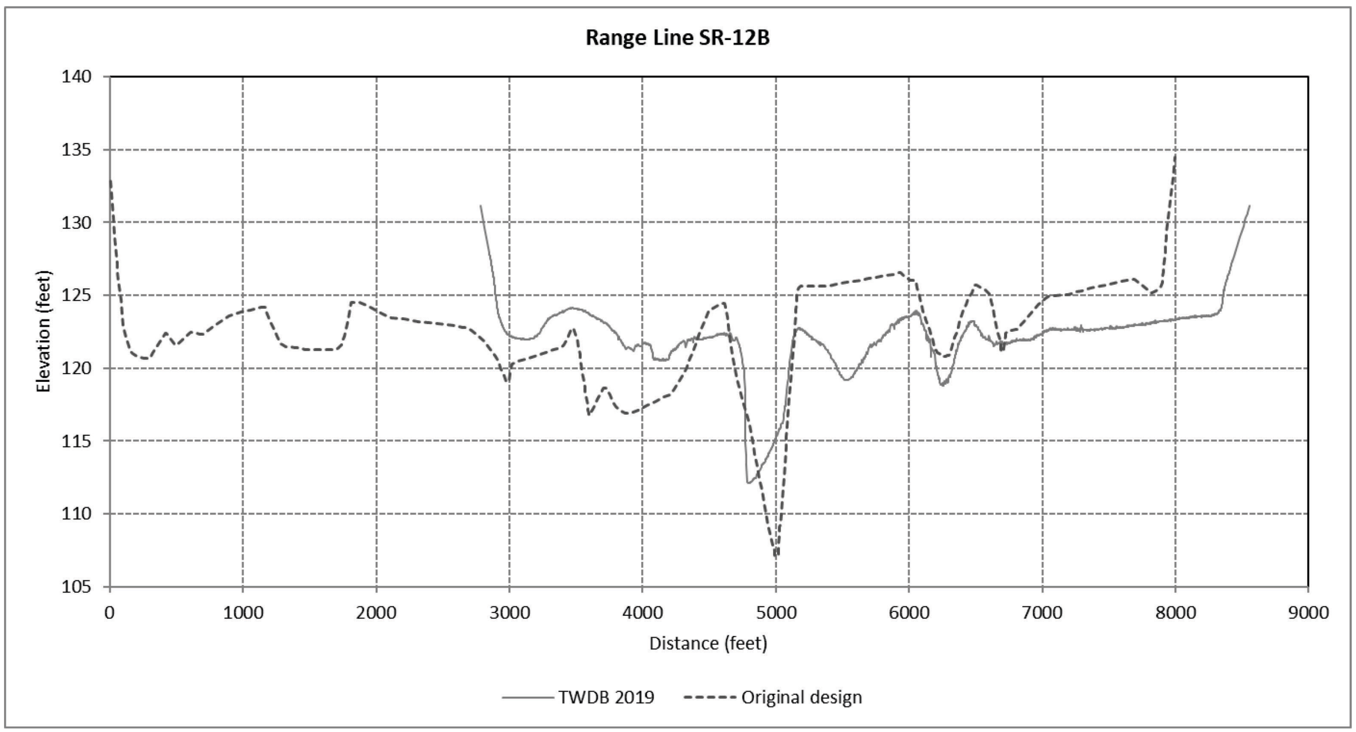

Range Line SR-9
140
130
120
110
100
90
80
70
Elevation (feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-10
140
130
120
110
100
90
80
70
Elevation (feet)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (feet)
TWDB 2019
USBR 1991
Original design

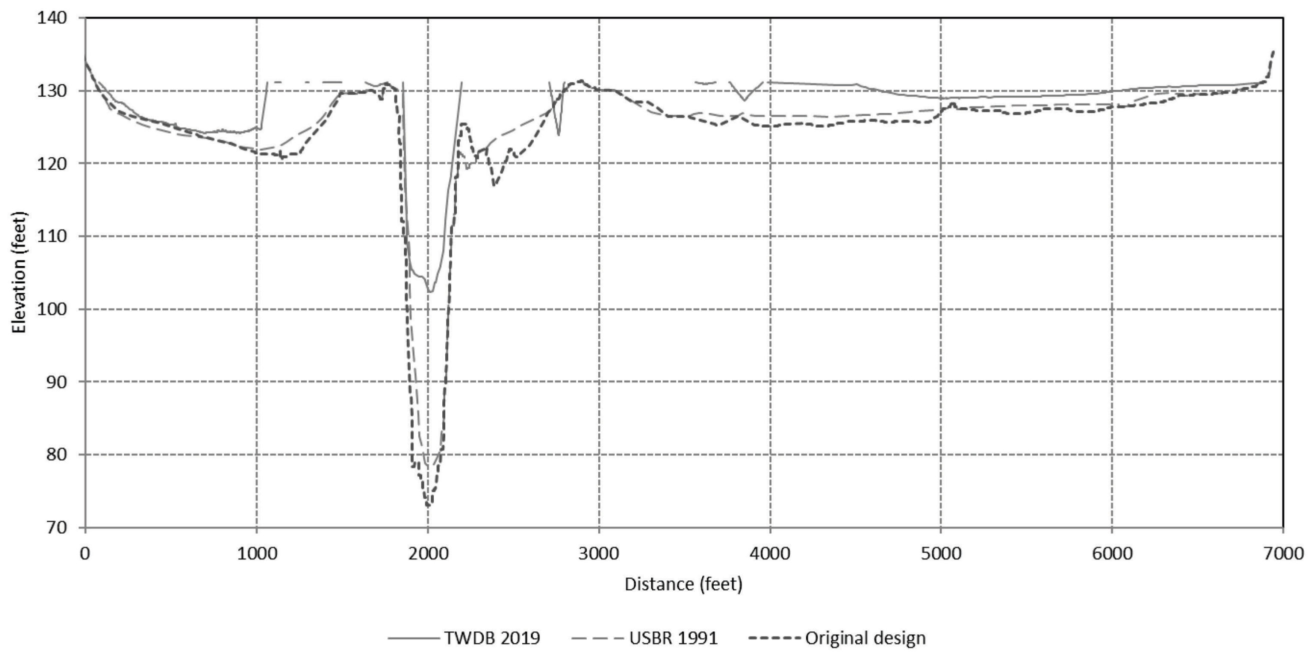

Range Line SR-11
Elevation (feet)
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-12
Elevation (feet)
Distance (feet)
TWDB 2019
USBR 1991
Original design

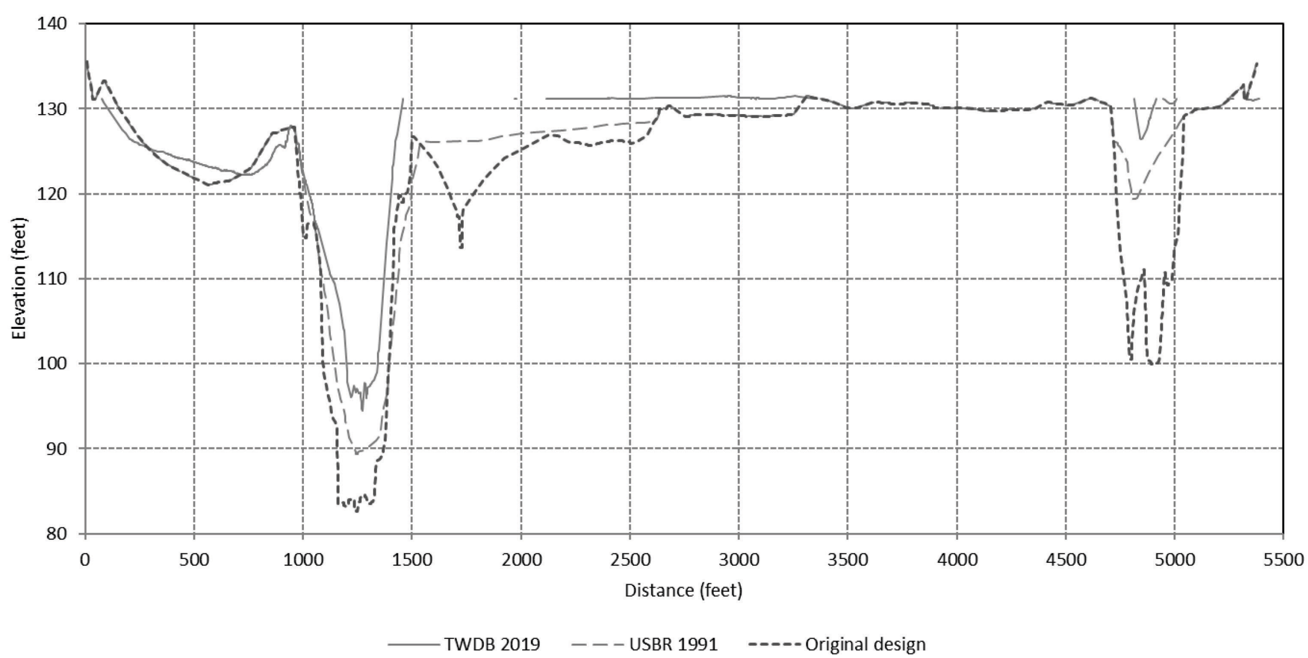

Range Line SR-12A
140
135
130
125
120
115
110
105
100
Elevation (feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
Distance (feet)
TWDB 2019
USBR 1991
Original design

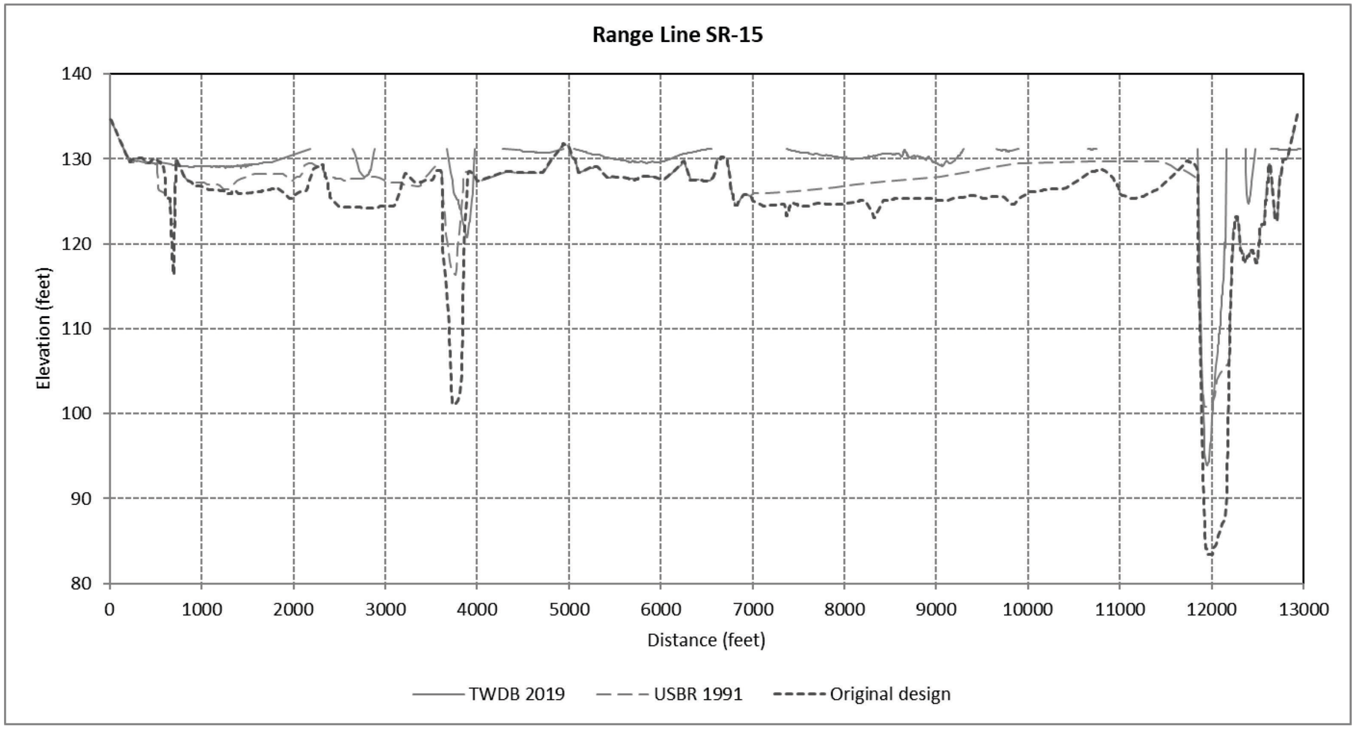

Range Line SR-12B
140
135
130
125
120
115
110
105
Elevation (feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Distance (feet)
TWDB 2019
Original design

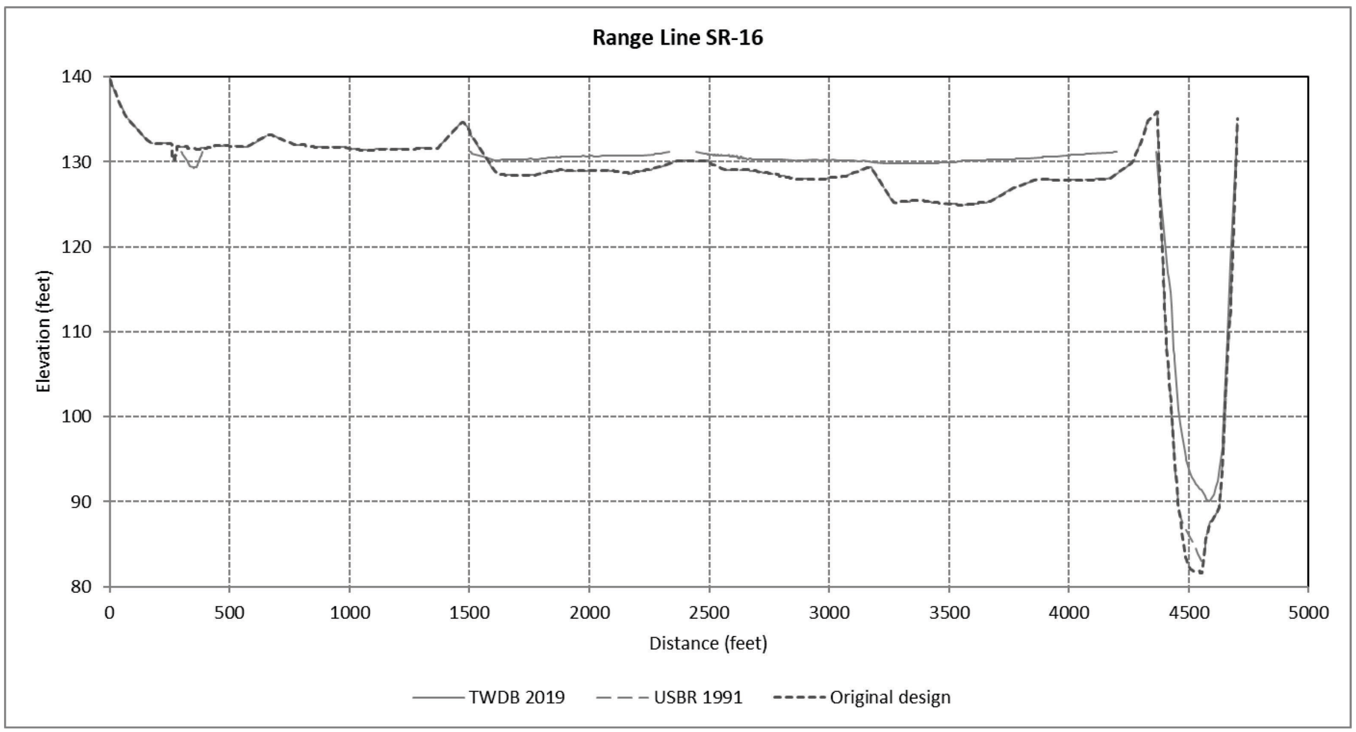
Range Line SR-13

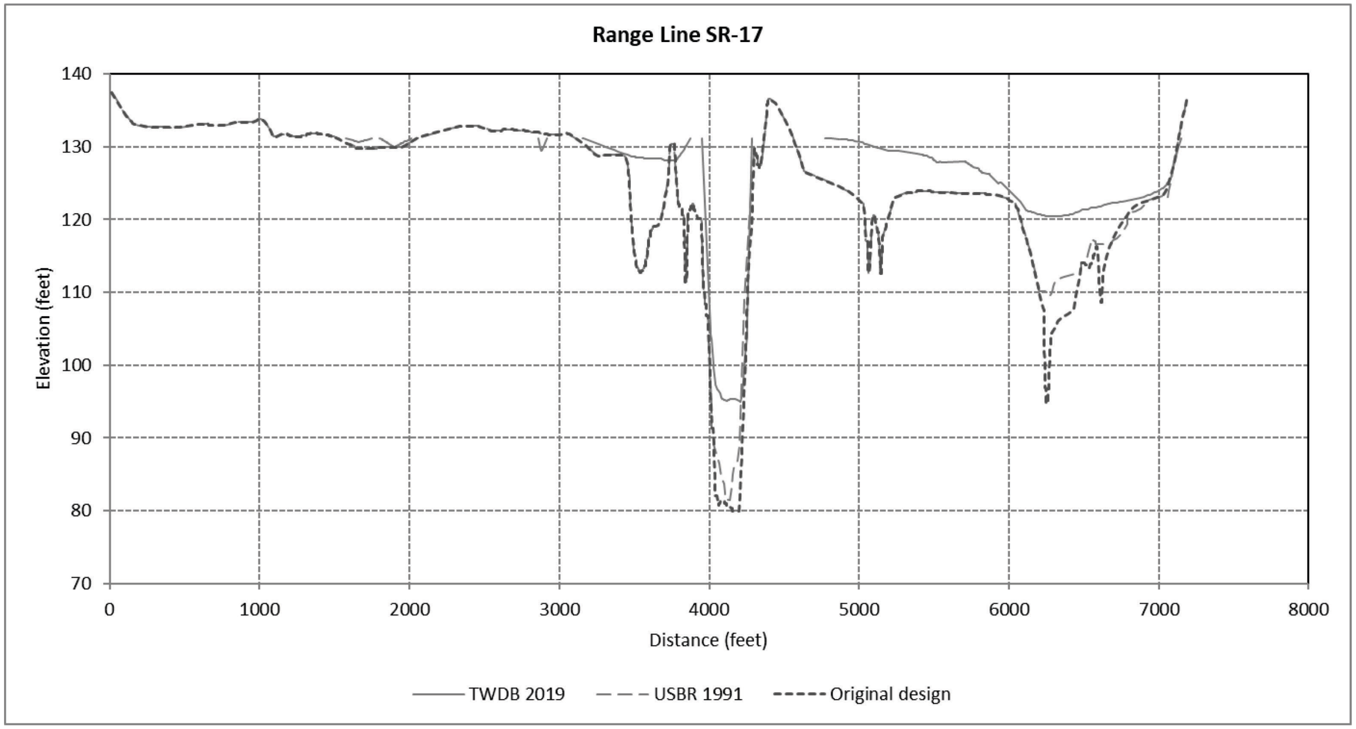


Range Line SR-14




Range Line SR-15
Elevation (feet)
140
130
120
110
100
90
80
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-16
Elevation (feet)
140
130
120
110
100
90
80
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (feet)
TWDB 2019
USBR 1991
Original design


Range Line SR-17
Elevation (feet)
Distance (feet)
140
130
120
110
100
90
80
70
0
1000
2000
3000
4000
5000
6000
7000
8000
TWDB 2019
USBR 1991
Original design

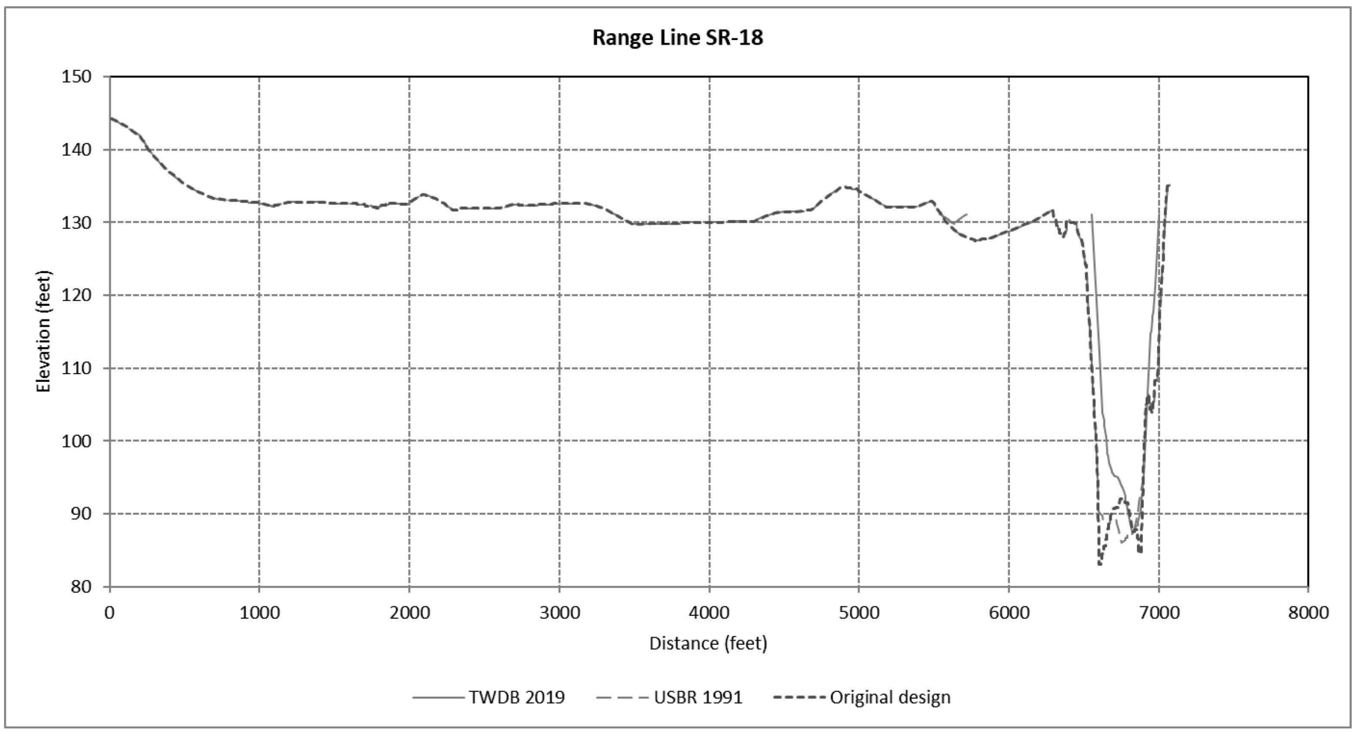

Range Line SR-18
Elevation (feet)
Distance (feet)
150
140
130
120
110
100
90
80
0
1000
2000
3000
4000
5000
6000
7000
8000
TWDB 2019
USBR 1991
Original design

Figure 9

Contours

feet above mean sea level

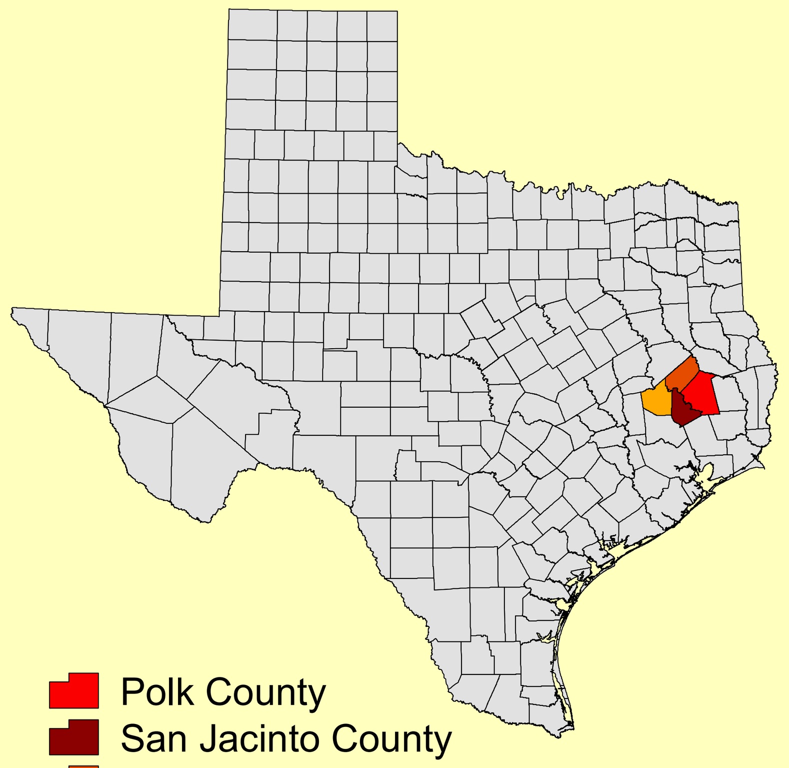
131
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60

Islands

Lake Livingston: elevation 131.17 feet

Conservation pool elevation: 131.0 feet

Projection: NAD83
State Plane Texas
Central Zone (feet)



Polk County
San Jacinto County
Trinity County
Waller County

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