VOLUMETRIC AND SEDIMENTATION STUDY ON WRIGHT PATMAN LAKE

July – August 2018 Survey

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Executive Summary

In July 2018, Arroyo Environmental Consultants, LLC, along with partner firm Aqua Strategies Inc. (project team), was contracted to conduct a volumetric and sedimentation survey on Wright Patman Lake, Texas for Riverbend Water Resources District (Riverbend). This report describes the results and methods used to conduct the volumetric and sedimentation survey, including data collection, processing and analysis techniques.

Wright Patman Lake and Wright Patman Dam are located on the Sulphur River nine miles southwest of Texarkana, Texas and situated in Bowie and Cass Counties. The project team collected bathymetric data for Wright Patman Lake between July 17, 2018 and August 23, 2018 with daily water surface elevations ranging from 225.82 to 226.69 feet above mean sea level (NGVD29).

The 2018 volumetric survey indicates Wright Patman Lake has a total reservoir capacity of 96,430 acre-feet and encompasses 17,907 surface acres at elevation 220.6 feet above mean sea level (NGVD29). Previous capacity estimates include the original design estimate in 1956 of 158,000 acre-feet at elevation 220.6 feet (as reported by TWDB in 2012), the Texas Water Development Board's (TWDB) 1997 volumetric survey estimate of 115,638 acre-feet at elevation 220.6 feet (as revised by TWDB in 2010), and the TWDB's 2010 volumetric survey estimate of 97,927 acre-feet at elevation 220.6 feet (TWDB 2012).

Based on several methods for estimating sedimentation rates, Wright Patman Lake loses between 187 and 915 acre-feet of capacity per year due to sedimentation below elevation 220.6 feet. The sedimentation rate range was determined by performing multiple comparisons of the 2018 survey to the original design estimate and previous survey estimates. The project team determined the sedimentation rate to be 489 acre-feet per year based on the 2018 survey results. Accumulation of sediment is relatively uniform throughout Wright Patman Lake and is higher in areas expected to have higher accumulation (i.e. areas near submerged channels and floodplains).

The project team recommends resurveying Wright Patman Lake in approximately 10 years to further improve capacity estimates and sedimentation rates to aid in long-term resource management and planning efforts. The differences in pre-impoundment surface, sediment thickness calculations and sedimentation rates between the 2018 and 2010 surveys create a scientific dilemma in long-term water planning for Riverbend. Consistency amongst survey results would be ideal and would allow for more confidence in lake volume and sedimentation rate estimates.

Re-evaluation of the 2010 survey may result in scientifically defensible revised 2010 lake volume and 2010 sedimentation rate estimates and provide Riverbend with more reliable lake data for use in future water planning efforts.

Introduction

In July 2018, Arroyo Environmental Consultants, LLC, along with partner firm Aqua Strategies Inc. (project team), was contracted to conduct a volumetric and sedimentation survey on Wright Patman Lake, Texas, for Riverbend Water Resources District (Riverbend). This report describes the results and methods used to conduct the volumetric and sedimentation survey, including data collection, processing and analysis techniques. This report serves as the final contract deliverable from the project team to Riverbend and contains: 1) a shaded relief map of the current lake bottom, 2) a shaded relief map of the pre-impoundment bottom, 3) an estimate of sediment accumulation and location, 4) a bottom contour map, and 5) elevation-area-capacity tables and curves of the lake.

The project team collected bathymetric data for Wright Patman Lake between July 17, 2018 and August 23, 2018 with daily water surface elevations ranging from 225.82 to 226.69 feet above mean sea level (NGVD29; *USGS 07344200 Wright Patman Lk nr Texarkana, TX*).

Wright Patman Lake General Information

Wright Patman Lake and Wright Patman Dam are located on the Sulphur River nine miles southwest of Texarkana, Texas and situated in Bowie and Cass Counties (Figure 1). Wright Patman Lake and Dam are owned and operated by the United States Army Corps of Engineers (USACE), within the Fort Worth District. Their mission is to “supply water to the city of Texarkana and to provide flood control for the Sulphur and Red Rivers” (USACE 2018).

The water resources of Wright Patman Lake are controlled and managed by Riverbend Water Resources District, a locally controlled regional water district that represents 16 member entities. Riverbend was created through State legislation in 2009 with the mission of “providing a regional governance structure for water resources in order to protect the ownership and distribution of water resources of the region and take leadership of the regional water infrastructure issues facing the region” (RWRD 2018).

Wright Patman Lake and Dam was authorized by the Flood Control Act of 1946 and is part of the comprehensive plan for flood control on the Red River below Denison, Texas (USACE 2018). Construction began on Wright Patman Dam on August 20, 1948 and was completed on May 19, 1954. The reservoir served as a temporary detention basin beginning July 2, 1953 and began intentional impoundment June 27, 1956, with an official operating date of July 1, 1956 (see Table 1; USACE 2018, TWDB 1974).

Riverbend controls the water rights for Wright Patman Lake – State of Texas permit numbers 1563, 1563a and 1563b together with Certificate of Adjudication 03-4836 – which were secured by the City of Texarkana to impound, divert and appropriate water resources from the lake (RWRD 2018).

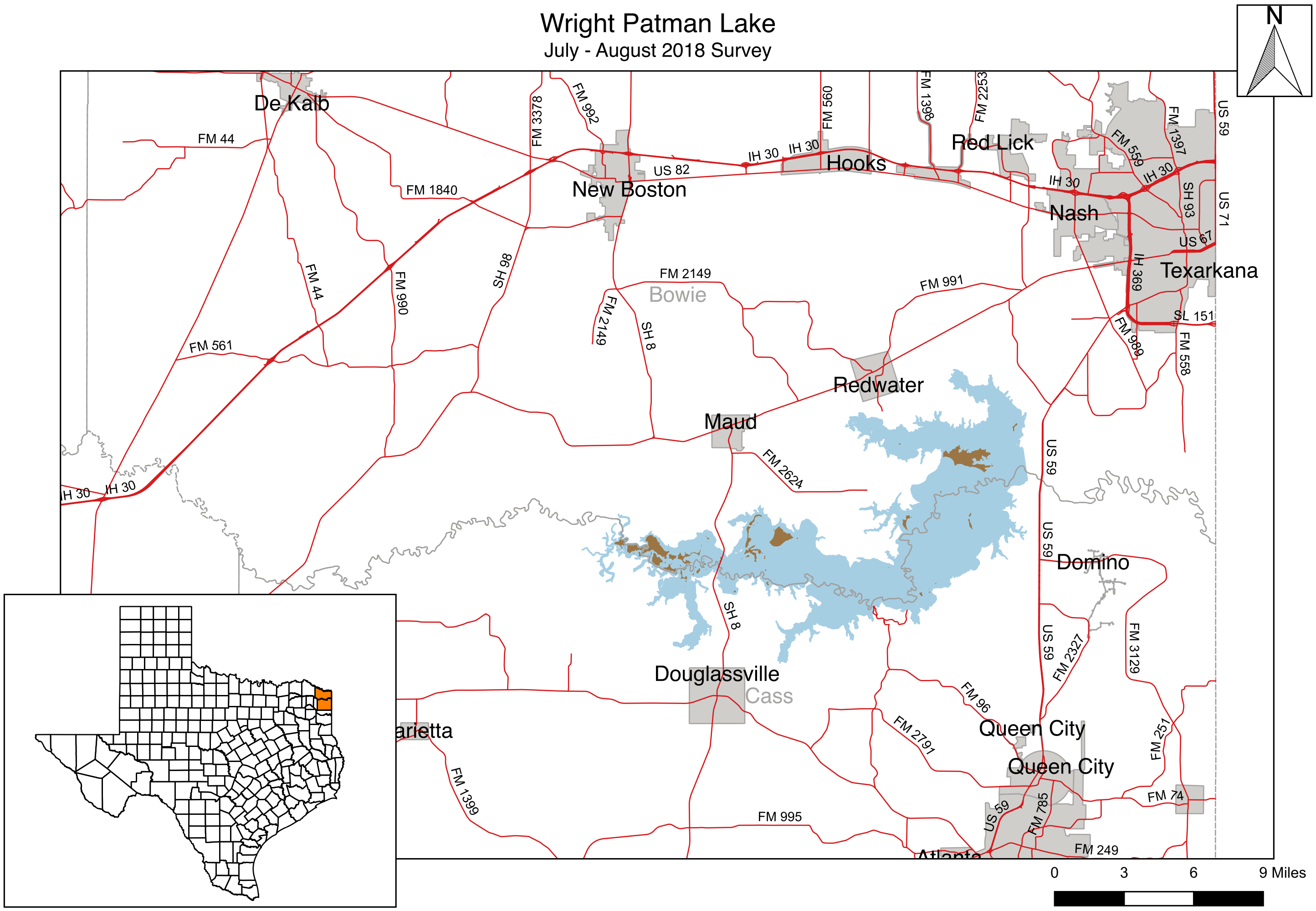

Figure 1. Wright Patman Lake, located in Bowie and Cass Counties, Texas.

Table 1. Pertinent data for Wright Patman Dam and Wright Patman Lake.

Pertinent data for Wright Patman Dam and Wright Patman Lake				
Owner				
U.S. Army Corps of Engineers, Fort Worth District.				
Engineer (Design)				
U.S. Army Corps of Engineers, New Orleans District.				
Location				
On the Sulphur River in Bowie and Cass Counties, 9 miles southwest of Texarkana				
Drainage Area				
3,400 square miles				
Dam				
Type	Earthfill			
Length	18,500 ft			
Maximum height	106 ft			
Top width	30 ft			
Spillway				
Crest elevation	259.5 ft above mean sea level			
Length	200.0 ft			
Type	Concrete chute			
Outlet Works				
Type	2 conduits, each 20-ft diameter			
Invert elevation	200 ft above mean sea level			
Control	4 gates, each 10 by 20 ft			
Reservoir Data (based on 2018 survey)				
Feature		**Elevation (feet NGVD29[a])**	**Capacity (acre-feet)**	**Area (acres)**
Top of dam		286.0	N/A	N/A
Top of surcharge pool		278.9	N/A	N/A
Top of flood control pool		259.5	N/A	N/A
Reservoir operating levels:				
Winter Top of Conservation, Interim Operating Curve		220.6	96,430	17,907
Winter Top of Conservation, Ultimate Operating Curve		224.9	191,156	25,346
Invert of conduits		200.0	N/A	N/A
Streambed		180.0	N/A	N/A

Source: USACE 2018, TWDB 1974

* Area and capacity estimates below elevation 224ft are based on echosounding data; for elevations above 224ft, area and capacity are extrapolated to the boundary, 226.28ft.

[a]NGVD29 = National Geodetic Vertical Datum 1929

Volumetric and Sedimentation Survey

Survey methodology for this volumetric and sedimentation survey follows methods similar to those utilized by the Texas Water Development Board (TWDB) as described in the 2010 Volumetric and Sedimentation Survey of Wright Patman Lake (TWDB 2012). The methodology provided below describes efforts in data collection, data analysis and interpolation for the current survey.

Datum

The National Geodetic Vertical Datum of 1929 (NGVD29) was used during this survey. It is the same datum utilized by the United States Geological Survey (USGS) reservoir elevation gage on Wright Patman Lake: *USGS 07344200 Wright Patman Lk nr Texarkana, TX* (USGS 2018). Elevation throughout this report are thusly provided in feet above mean sea level relative to the NGVD29 datum. All volume and area calculations in this report are referenced to water levels provided by the USGS gage above. The project team installed and took daily readings of a staff gage as a check of the USGS gage levels. A level was used to determine height from a known survey cap benchmark to the water surface. The USGS gage elevations were within acceptable error tolerance limits and were therefore used for all necessary lake data calculations.

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

Methodologies

Bathymetric and Sedimentation Data Collection

The project team collected bathymetric data for Wright Patman Lake between July 17, 2018 and August 23, 2018, with daily water surface elevations ranging from 225.82 to 226.69 feet above mean sea level (NGVD29; *USGS 07344200 Wright Patman Lk nr Texarkana, TX*). Bathymetric surveying was conducted using a Specialty Devices, Inc. (SDI) BSS+ single beam, multi-frequency (200kHz, 50kHz, 12kHz) sub-bottom profiling depth sounder (also called an echosounder) integrated with a corrected WAAS GPS (global positioning system) unit (<2-meter accuracy).

The survey consisted of navigating along pre-planned range lines spaced approximately 500 feet apart and oriented perpendicular to the reported location of the submerged river channels (except for the riverine sections in the far upper reaches of the lake). Generally, the line layout pattern used by TWDB in the 2010 survey was replicated in this 2018 survey. In areas previously identified in the 2010 survey as having higher than expected sedimentation, additional survey lines were added for more intense data collection. Additionally, in the riverine sections of the far upper reaches of the lake, data collection was more intense in order to obtain more data perpendicular to the channel than the pre-planned lines dictated.

The depth sounder was calibrated daily using a Castaway-CTD velocity profiler to measure the speed of sound in the water column. A barcheck was periodically used to confirm speed of sound settings. A stadia rod was used to verify depth readings on a weekly basis. Figure 2 shows all data collected during the 2018 survey.

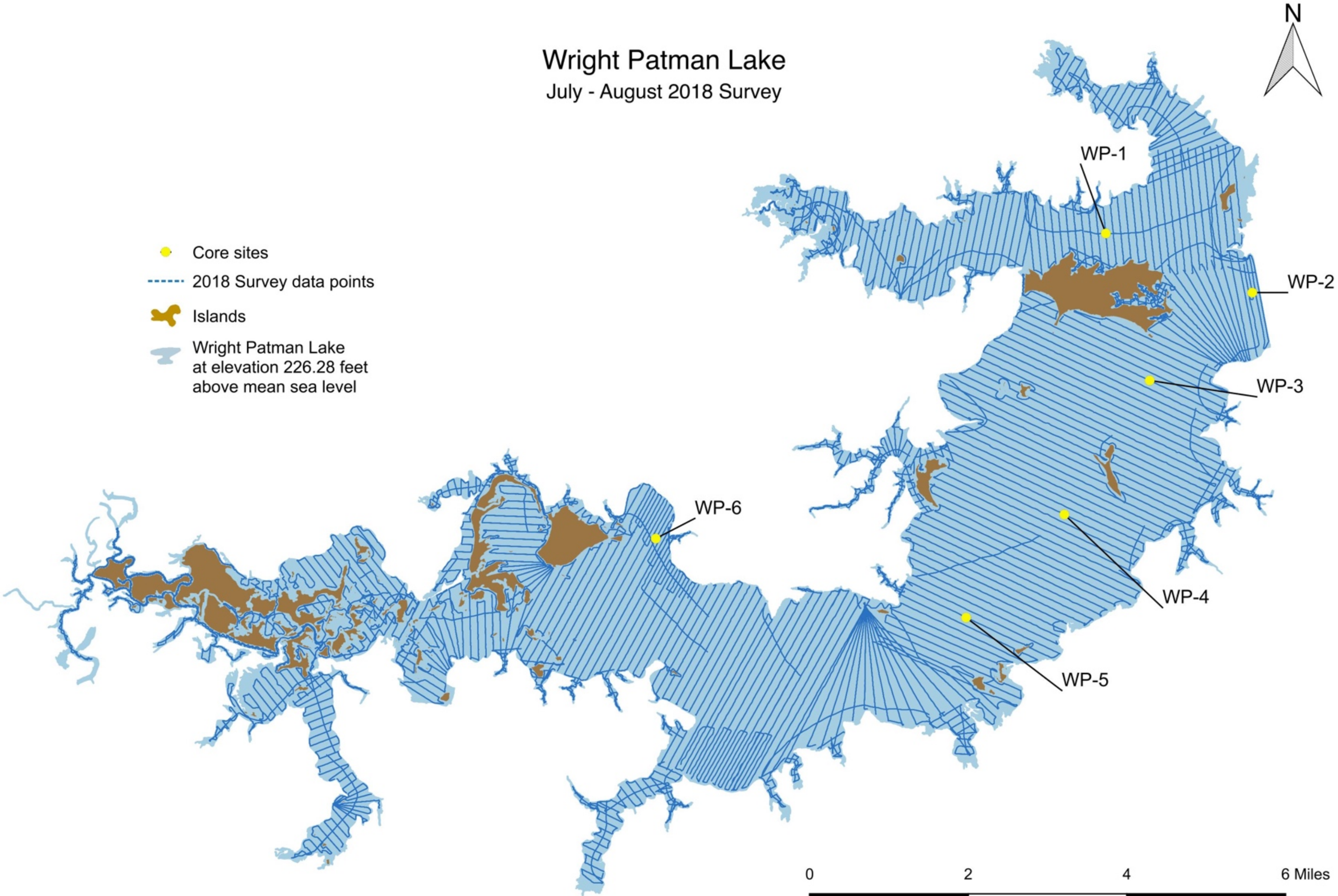

Figure 2. Data collection efforts on Wright Patman Lake during the 2018 survey.

Bathymetric and sedimentation data was collected with SDIDEPTH (Version 6.1.1; SDI 2018a) and HYPACK Max survey software (HYPACK 2014) on the SDI BSS+ equipment. Data was processed and analyzed with DEPTHPIC (Version 5.0.0; SDI 2018b) and Hydropick (TWDB 2016) software packages.

Sediment cores were collected at selected points around the lake on a custom sediment coring boat equipped with the SDI VibeCore-D (SDI 2018c) system on October 6-7, 2018. Core sample locations were determined by first looking at the soundings data collected while surveying, establishing a set of sounding line files that represented the full spectrum of locations (i.e. varying water depths, varying core sample lengths) and soundings (i.e. different soundings returns) around the lake and picking locations along those selected line files to retrieve subsurface cores. Core sample collection aims to aid in determining the pre-impoundment layer in representative areas by driving the core tube down into the sediment and capturing a column of sediment extending from the current bottom surface into the pre-impoundment surface. The project team collected six core samples at selected locations around the lake for the 2018 survey (Figure 2). Cores were collected in 3-inch diameter aluminum tubes which were cut open and analyzed for sediment color and type, and to ground-truth the pre-impoundment depth (original lake depth before impoundment).

Data Processing

There are many steps within the data processing sequence that provide the overall lake surface area, lake volume and sediment volume estimate as well as the elevation-area-capacity tables and curves. Steps generally include: downloading the raw data from the depth sounder equipment, interpreting the raw data to determine the current lake bottom surface, interpreting the raw data to determine the pre-impoundment surface, ground-truthing the raw data using the sediment core samples, interpolating the data (current and pre-impoundment surfaces) across the lake up to the lake boundary, calculating lake volume and surface area, calculating the estimated sediment volume.

Model Boundaries

The reservoir boundary for Wright Patman Lake was based on analyzing the 2010 TWDB hydrographic survey digitized lake boundary and comparing it to recent (1995, 2005, 2008, 2013, 2015) aerial photographs obtained from the Texas Natural Resources Information System (TNRIS 2018) and Google Earth (Google 2018) showing the land-water interface at varying water surface elevations. After minor refinements to update small islands in lake headwaters, the boundary was determined to be suitable for use in the 2018 survey. The boundary shapefile represents an elevation contour of 226.28 ft, as presented by TWDB (2012).

Depth Sounder Data Processing – Current and Pre-impoundment Surfaces

Using an array of single-beam echosounders operating at different frequencies has been shown to be useful in characterizing thickness of accumulated sediment in older Texas reservoirs (Dunbar and Allen 2003). For this project, the current bottom surface of the lake was determined by the data collection software SDIDEPTH and HYPACK. DEPTHPIC software was used to display all data collected and manually edit any anomalous points along the current surface (i.e. random data points not in line with the surrounding current surface). Hydropick was used to select the pre-impoundment surface. Hydropick is a python-based tool used to post-process multi-frequency echosounding data to determine lake bed elevation and pre-impoundment elevation. Hydropick, a software originally developed by TWDB and Enthought Inc (TWDB 2016), was subsequently updated for use by the project team. The software spatially displays raw data as well as provides automated and manual tools for selecting the current surface and pre-impoundment surface. The algorithm automatically picks a pre-impoundment surface using the Otsu method (Otsu 1979) based upon echosounder intensity data and user-specifiable thresholds. The algorithm can be applied to the most appropriate frequency, selected depending upon site conditions, and thresholds can be manually calibrated, based upon pre-impoundment depths observed from sediment cores. Once calibrated for each region of the lake, this algorithm provides a consistent method for selecting the pre-impoundment surface that is less prone to human judgement. The pre-impoundment surface was manually reviewed and edited to remove any data inconsistencies.

Spatial Interpolation – HydroTools

Standard methods for hydrographic surveying and terrain modeling (e.g. USACE 2013) are generally followed by the TWDB and are also followed in this study to determine the relationship of surface area and storage volume to water elevation. These reservoir characteristics are quantified using a combined approach including:

1. mapping the submerged surface in the field using a single-beam echosounder – in this case an array of three single-beam echosounders each operating at a different frequency,
2. developing a digital terrain to represent the surface, including interpolating the terrain in sparse data regions where nearby echosounder data is unavailable, and
3. using the interpolated terrain to calculate a table that relates water elevation, surface area and capacity.

Interpolation of the terrain is generally required because complete coverage of a lake bottom with observed data is generally not cost-efficient and further, complete coverage has been shown to not be necessary for volume calculations when appropriate echosounding line spacings and terrain interpolation techniques are employed (Dunbar and Estep 2009). To develop digital terrains from echosounder data, a number of interpolation methods have been evaluated in Texas. Interpolation techniques that consider streamlines oriented according to erosion processes (i.e. river sinuosity) all tend to produce better results than interpolation techniques that do not. Anisotropic interpolation methods have been shown to improve representation of river beds (Osting 2004; Merwade et al. 2006) and submerged channels in reservoirs (Furnans and Austin 2008; McEwan et al. 2011).

HydroTools employs anisotropic methods and is a publicly available software program developed in python by TWDB (McEwan et al. 2011) and subsequently updated for use by the project team. HydroTools interpolates reservoir terrain considering land-form erosion processes using a computationally efficient method. The main interpolation technique is the Anisotropic Elliptical Inverse Distance Weighting (AEIDW) method. This method converts input data from a Cartesian coordinate system (i.e. x, y) into a stream coordinate system (i.e. s, n) and uses user-defined weights to prioritize data points running parallel to the stream centerline over data points running perpendicular to the stream center line.

HydroTools inputs include echosounder data (point data collected along transect lines) and geospatial shapefiles. The primary input to the HydroTools program is scatter-point echosounder data for the current lake bottom surface and the pre-impoundment surface. Additional inputs include a lake boundary polygon and additional geo-spatial features that discretize distinct regions of the lake.

The shapefiles developed in GIS define interpolation regions, each region's stream centerlines, and the lake's boundary including islands. Figure 3 shows example shapefile components used in HydroTools for Wright Patman Lake. Large regions and coves are each represented by a polygon and a centerline. Narrow channel regions are also represented by a polygon and centerline, where the centerline was determined using historical National Hydrography Dataset (NHD) streamlines and, in limited areas, interpretation of distinct subsurface channel regions evident in raw echosounding data. Over 50 different regions were used to discretize Wright Patman Lake. Within each region, interpolation parameters were assigned to define grid resolution and search space. The output of HydroTools is a gridded file containing an interpolated current surface and interpolated pre-impoundment surface.

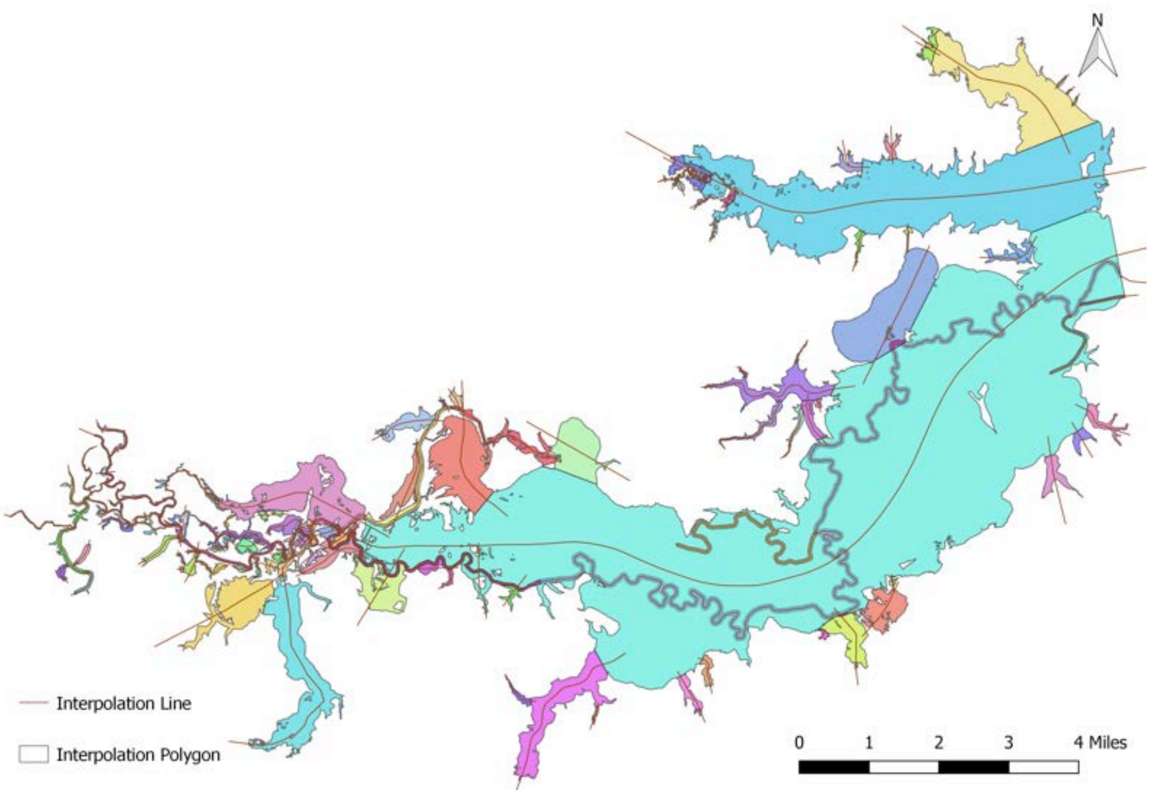

Figure 3. HydroTools inputs for Wright Patman Lake. Each interpolation polygon and accompanying interpolation line represent separate interpolation regions with unique inputs.

In headwater regions where no data was collected due to survey conditions, generally because of shallow water or debris as is often found in the lake's narrow far upper reaches, nearby data were used to assume depths within those regions. After inspecting each cove and headwater region, manually assigning assumed elevations in some narrow, shallow, and/or sinuous headwater regions was found to be more appropriate than omitting those areas entirely. This method was also more appropriate than using automated methods that tended to assign unlikely elevations from echosounder points located in unrelated areas. Assigned elevations in these regions were generally between 221.5 and 224 ft, so the assignment primarily affects lake surface area and capacity for near-full conditions higher than 220.6 feet in elevation.

HydroTools output is a file organized in an irregular grid representing the terrain surface, where the grid spacing changes according to each lake region. Outputs are produced for the current surface and the pre-impoundment surface. Visualization and mapping of the regular grids for this project, as well as other GIS work to develop input shapefiles, were completed using QGIS software (QGIS 2018).

Surfaces and Elevation-Area-Capacity Generation

The gridded data point output from HydroTools was converted into current surface and pre-impoundment raster grid surfaces using the System for Automated Geoscientific Analysis (SAGA 2018). Elevation-area-capacity (EAC) tables were developed from the two surfaces by calculating the area and volume based within the lake boundary at each water elevation increment (0.1 foot; see Appendix A; Table 8 and Table 9). The raster grid surface for the current lake bottom is represented in three ways: an elevation relief map indicating the current surface topography of the lake bottom, a depth range map showing the range of water depths throughout the lake and a 2-foot contour map. A sediment thickness map showing sediment distribution throughout the lake was produced from the pre-impoundment surface raster grid (see attached maps).

Sediment Data Analysis

Sedimentation in Wright Patman Lake was determined by calculating the difference between the interpolated pre-impoundment and current bottom surfaces. As stated previously, core samples were collected in selected lake locations (Figure 2) to ground-truth the depth of the pre-impoundment layer, specifically at which frequency the pre-impoundment layer is visible, in order to have Hydropick choose the correct intensity at which the layer is picked.

After core samples were taken in the field, they were capped as close to the sediment as possible to reduce mixing in the upper portion of the tube. The samples were transported back to project team offices for analysis, at which time they were cut open lengthwise to provide a sediment core sample depth profile. Cores were analyzed to describe sediment color using Munsell color charts (X-Rite 2009), soil type, the presence of any organic matter, water content and finally to determine the pre-impoundment depth based on a combination of differences in these factors. Table 2 provides all sediment core sample analysis data.

The pre-impoundment depth within each core sample was determined by a combination of factors: a change in density of the sediment (from less dense to more dense as depth increases), a change in coloration of sediment material (different layers are at times visible by changes in color), the presence of organic material (this can be indicative of the decayed biotic material that sat on top of the original lake bottom), a change in soil type (a change from silts to clays in deeper layers frequently signal the pre-impoundment layer) and a general visual change in water content (deeper layers often have very little water content). The depth at which the pre-impoundment layer was determined was measured and applied to the corresponding echosounding data to establish which frequency and intensity the pre-impoundment layer is chosen.

Table 2. Sediment core sample descriptions – Wright Patman Lake, 2018 survey.

Core ID	Easting[a] (feet)	Northing[a] (feet)	Total core sample/post-impoundment sediment	Sediment core description	Munsell soil color
WP-1	3283016.41	7192422.90	43.5"/36"	0-10" high water content; muck; loam	5Y 2.5/1
				10-25" lower water content; loam	5Y 2.5/1
				25-31" some organic material present; clay loam	5Y 2.5/1
				31-36" high organic material present (woody debris); 50% structures; loam	5Y 4/1
				36-43.5" dense; 3% organic material; clay	5Y 5/1
WP-2	3292767.63	7188486.27	35"/28.25"	0-17.75" high water content; loam	5Y 2.5/1
				17.75-25.5" lower water content; clay loam	5Y 2.5/1
				25.5-28.25" high organic material (woody debris); 50% structures; loamy clay	2.5Y 2.5/1
				28.25-35" dense; clay	5Y 4/1
WP-3	3285937.97	7182633.51	49.5"/46"	0-18" high water content; muck; loam	5Y 2.5/1
				18-46" lower water content; loam	5Y 2.5/1
				46-49.5" dense; organic material present; clay	2.5Y 3/1
WP-4	3280256.90	7173707.93	35"/27.25"	0-9" high water content; muck; loam	5Y 2.5/1
				9-27.25" lower water content; loam	5Y 3/2
				27.25-35" dense; organic material present (3%); clay	2.5Y 2.5/1
WP-5	3273717.99	7166845.56	35.75"/31.5"	0-11" high water content; muck; loam	5Y 2.5/1
				11-29.5" lower water content; loam	5Y 3/2
				29.5-31.5" high organic material (woody debris); clay loam	2.5Y 2.5/1
				31.5-35.75" dense; clay	2.5Y 2.5/1
WP-6	3253059.24	7172105.98	36"/33"	0-5" high water content; muck; loam	5Y 2.5/1
				5-29" lower water content; clay loam	5Y 3/2
				29-33" high organic material (woody debris); 50% structures; clay loam	2.5Y 2.5/1
				33-36" some organic material present; clay	2.5Y 2.5/1

[a]Coordinates based on NAD83 State Plane Texas North Central (4204)

Figure 4 is a photograph of core sample WP-6 and is representative of the sediment core samples collected from Wright Patman Lake. The total core length was 36 inches, with the pre-impoundment surface at 33 inches. The upper layer, beginning at the current bottom surface (blue line in Figure 4 and Figure 5) and extending to 5 inches, consisted of a visibly high water content mucky loam with a Munsell coloration of 5Y 2.5/1. The next layer, 5 to 29 inches, was made of a lower water content clay loam and had a Munsell color of 5Y 3/2. The third layer, from 29 to 33 inches, contained 50% organic material (mainly in the form of woody debris) within the clay loam base and a Munsell color of 2.5Y 2.5/1. The final layer, from 33 to 36 inches, contained some organic material within its clay base and a Munsell coloration of 2.5Y 2.5/1.

This final layer, beginning at 33 inches, is designated in Figure 4 and Figure 5 as the purple line and identified as the pre-impoundment surface due a combination of its characteristics: dense clay (soil texture and density), presence of organic material (structures), lower visible water content (moisture), coloration change from upper layers. Core sample characteristics are described for each core sample collected and used to determine the pre-impoundment surface.

Figure 4. Sediment core sample WP-6 showing the current surface (blue), pre-impoundment surface (purple) and core sample bottom (yellow); measuring tape is placed for determining layer depths.

Figure 5 and Figure 6 show core sample WP-6 as viewed in Hydropick compared to its corresponding collected line data against the three frequencies (200kHz, 50kHz, 12kHz). The cross-section view in Figure 5 is representative of how core samples are compared to the frequencies within Hydropick and at which frequency the pre-impoundment layer is chosen. The current lake bottom surface (upper blue line) is determined by the data collection software, SDIDEPTH and HYPACK, and inspected and manually edited by the project team if necessary. The pre-impoundment layer (lower purple line) is chosen by Hydropick software after core sample comparison and signal/frequency determinations, then manually edited by the project team if necessary.

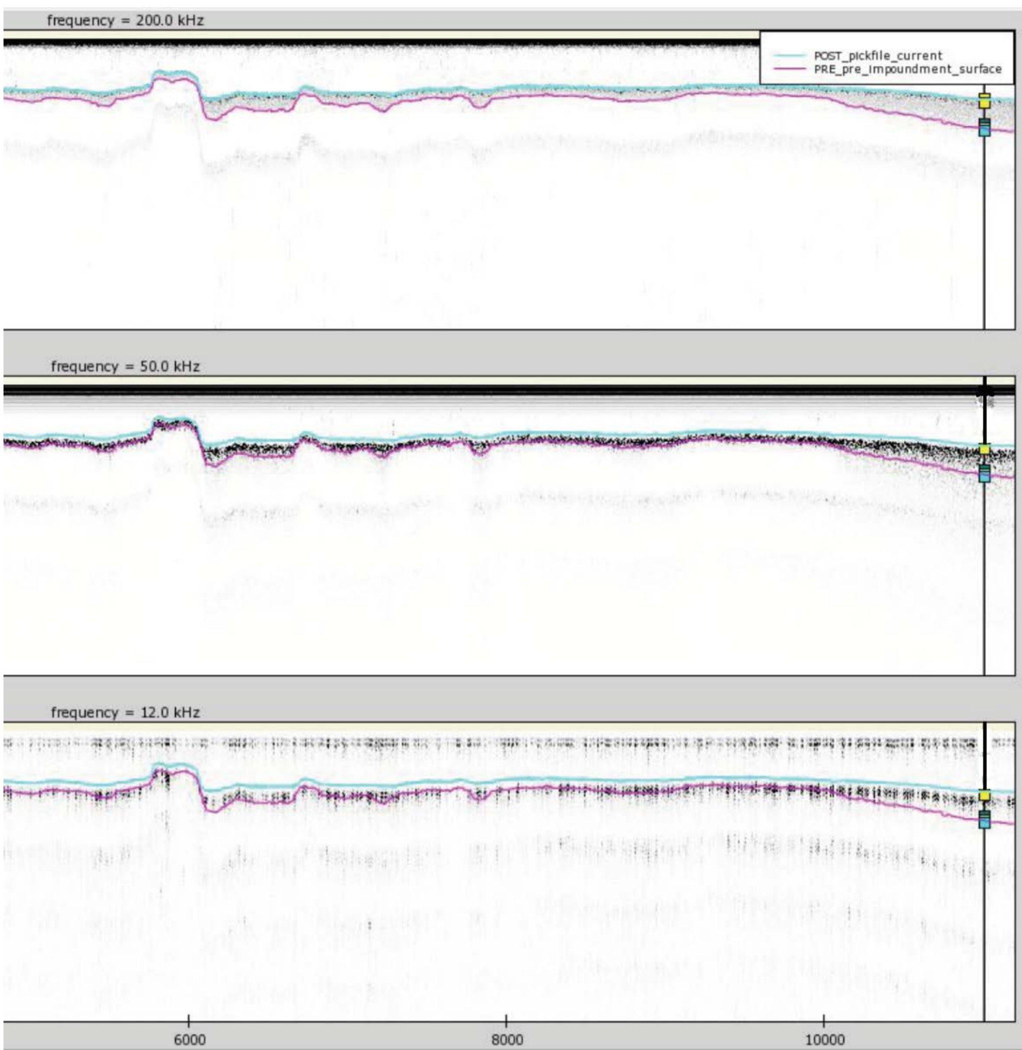

Figure 5. Cross-section view of 2018 survey data showing corresponding sediment core sample WP-6 as output by Hydropick in the three frequencies (200kHz, 50kHz, 12kHz); blue line is the current bottom surface; purple line is the pre-impoundment surface.

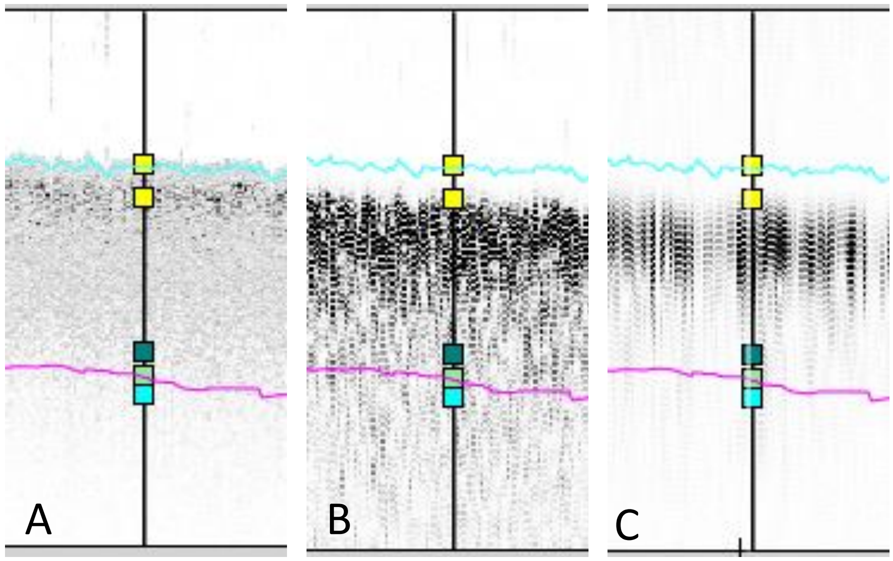

Figure 6. Comparison of core sample WP-6 against (A) 200kHz, (B) 50kHz and (C) 12kHz frequency data; blue line represents the lake bottom surface; purple line represents the pre-impoundment surface.

Figure 6 provides a closer view of core sample WP-6 set against the three echosounder frequencies. The blue line represents the current bottom surface and the purple line represents the pre-impoundment surface, both interpreted from the echosounder signal. The colored boxes represent an observed break in each layer of the core: the top yellow box is set at zero inches (current bottom surface), the second box is set at 5 inches, corresponding to the break between the second and third layers, etc.

The collected core samples correspond well with echosounder processing in areas of high sediment accumulation (WP-6), in deep areas of the lake (WP-2) and in wide areas of the lake (WP-1, WP-3, WP-4, WP-5) (see Figure 2 for core locations). One core (WP-3) indicates more sediment accumulation in a localized depressional area compared to echosoundings, and two cores (WP-4 and WP-5) indicate less sediment accumulation in flatter areas. Collecting additional core samples is recommended to verify sediment thickness processing, particularly in wide flat areas that are typical of most of the lake bottom.

Quality Assurance/Quality Control (QA/QC) Methods

The project team employed multiple methods of quality assurance/quality control (QA/QC) checks throughout the entire study process, from field data collection methods to data processing to final data comparisons (see Appendix B). The various QA/QC procedures include, but are not limited to the following: staff gage installation and verification of daily lake elevation, daily water velocity profile readings to calibrate and verify lake point depths, collection of sediment cores at multiple lake locations to ground truth the determination of pre-impoundment depth, visual inspection of mapped processed data points, comparison of processed data points collected on different days at the same location (Appendix B: Table 10 and Table 11), comparison of selected similar (collected along same pre-planned lines) cross-sections between 2018 and 2010 surveys (Appendix B: Figures 8 – 12), comparison of calculated lake volume and sediment volume between 2018 and 2010 surveys (Table 6 and Table 7), among other processed data checks.

Results

The 2018 volumetric survey indicates Wright Patman Lake has a total reservoir capacity of 96,430 acre-feet and encompasses 17,907 surface acres at elevation 220.6 feet above mean sea level, NGVD29 (Table 3). Previous capacity estimates include the original design estimate in 1956 of 158,000 acre-feet at elevation 220.6 feet (as reported by TWDB in 2012), the Texas Water Development Board's (TWDB) 1997 volumetric survey estimate of 115,638 acre-feet at elevation 220.6 feet (as revised by TWDB in 2010), and the TWDB's 2010 volumetric survey estimate of 97,927 acre-feet at elevation 220.6 feet (TWDB 2012; Table 4). Table 3 provides lake volume, surface area, sedimentation volume and sedimentation rates at the given operating levels. Sedimentation numbers are not provided for the Winter Top of Conservation, Ultimate Operating Curve elevation due to data collection below that elevation during the bathymetry survey.

Table 3. 2018 Lake Volume and Sedimentation at seasonal operating levels, lake boundary.

Wright Patman Lake Volume and Sedimentation					
	Elevation (ft NGVD29)	Current Capacity (acre-ft)	Current Surface Area (acres)	Sedimentation (acre-ft)[a]	Sedimentation Rate (acre-ft/yr)[a]
Winter Top of Conservation, Interim Operating Curve	220.6	96,430	17,907	30,322	489
Winter Top of Conservation, Ultimate Operating Curve	224.9	191,156	25,346	-	-
Lake Boundary	226.28[a]	226,758	26,133	-	-

[a] Area, capacity and sediment thickness below elevation 224ft are based on echosounding data; for elevations above 224ft, area and capacity are extrapolated to the boundary.

Based on several methods for estimating sedimentation rates, Wright Patman Lake loses between 187 and 993 acre-feet of capacity per year due to sedimentation below elevation 220.6 feet above mean sea level (NGVD29; Table 4 and Table 6). The project team determined the sedimentation rate to be 489 acre-feet per year based on the 2018 survey results. This sedimentation rate was determined from results of the 2018 survey, based upon years since impoundment (62 years) and volume of sediment (30,322 acre-ft) calculated to have accumulated since impoundment. Sedimentation rate can be calculated from the 2018 survey for each operating pool level to consider sediment accumulation up to the limits of 2018 survey data (Table 3). Previous sedimentation estimates were provided in the TWDB 1997 (TWDB 2003) survey report and the TWDB 2010 (TWDB 2012) volumetric and sedimentation survey report. All lake volume comparisons between surveys are presented in Table 4 and Table 5 at elevations 220.6 ft and 224.0 ft, respectively.

Prior studies have estimated sedimentation based upon sequential capacity surveys, such as those provided in the TWDB 1997 (TWDB 2003) survey report and the TWDB 2010 (TWDB 2012) volumetric and sedimentation survey report. All lake volume comparisons between sequential surveys are presented in Table 4 and Table 5. Table 4 and Table 5 compare each survey to another survey at elevations 220.6 ft (Table 4) and 224.0 ft (Table 5), providing the volume difference between surveys and the capacity loss rate for each comparison. A volumetric estimate from 1956 attributed to USACE was reported in the TWDB 2010 survey report and is retained in Table 4; that 1956 documentation is not currently available to the project team and should be verified before relying upon any calculations based upon 1956 values. TWDB Report 126 (TWDB 1974) provides a lake capacity of 145,300 acre-ft at elevation 220.0 feet. A volumetric estimate for the original lake design at elevation 224.0 feet was obtained from a water availability modeling study (LJA, personal communication, 2019) and is provided in Table 5.

Table 4. Comparison of Lake Volume Calculations on Wright Patman Lake at elevation 220.6 ft

Comparison of Lake Volume Calculations					
Survey	Comparisons @ 220.6 ft NGVD29				
	Current Volume (acre-ft)				
	Comparison #1	Comparison #2	Comparison #3	Comparison #4	Comparison #5
Original design estimate	158,000	-	158,000	-	-
1997 TWDB Volumetric survey (revised)	-	115,638	-	115,638	-
2010 Volumetric survey	97,927	97,927	-	-	97,927
2018 Volumetric survey	-	-	96,430	96,430	96,430
Volume Difference (acre-ft)	60,073	17,711	61,570	19,208	1,497
Number of years (since impoundment)	54	13	62	21	8
Capacity loss rate (acre-ft/year)	1,112	1,362	993	915	187

Table 5. Comparison of Lake Volume Calculations on Wright Patman Lake at elevation 224.0 ft

Comparison of Lake Volume Calculations					
Survey	Comparisons @ 224.0 ft NGVD29				
	Current Volume (acre-ft)				
	Comparison #1	Comparison #2	Comparison #3	Comparison #4	Comparison #5
Original design estimate[a]	240,195	-	240,195	-	-
1997 TWDB Volumetric survey (revised)[b]	-	188,255	-	188,255	-
2010 Volumetric survey	171,069	171,069	-	-	171,069
2018 Volumetric survey	-	-	168,736	168,736	168,736
Volume Difference (acre-ft)	69,126	17,186	71,459	19,519	2,333
Number of years (since impoundment)	54	13	62	21	8
Capacity loss rate (acre-ft/year)	1,280	1,322	1,153	929	292

[a]LJA, personal communication, February 13, 2019

[b]TWDB, personal communication, July 27, 2018

Comparison of 2018 survey results to other studies developed using different methodologies should be made with caution due to inherent differences in methodology procedures. Comparison to the TWDB 2010 survey reported results are most suitable due to the fact that they are the only two surveys that include both a volumetric and sedimentation survey, and because data collection and analysis were conducted using comparable methods and equipment (Table 6 and Table 7). The TWDB 1997 survey included a volumetric result but did not include a sedimentation survey and is therefore not considered in the lake sedimentation comparisons in Table 6 and Table 7.

Table 6 and Table 7 provide the total lake capacity, i.e. pre-impoundment volume, for both 2010 and 2018 surveys at elevations 220.6 ft and 224.0 ft, respectively; these values represent current surface volume with accumulated sediment removed. Both of the independent estimates (this 2018 survey and the TWDB 2010 survey) of total lake capacity (pre-impoundment volume) are lower than the TWDB reported 1956 original design capacity estimate of 158,000 acre-ft at 220.6 ft elevation.

Table 6. Comparison of Lake Sedimentation Calculations on Wright Patman Lake at elevation 220.6 ft

Comparison of Sedimentation Calculations		
Survey	Comparisons @ 220.6 ft NGVD29	
	Volume (acre-ft)	
	Comparison #6	Comparison #7
TWDB lake capacity estimate based on 2010 V&S survey	137,336	-
Lake capacity estimate based on 2018 V&S survey	-	126,752
2010 Volumetric survey	97,927	-
2018 Volumetric survey	-	96,430
2010 Sedimentation survey	39,409	-
2018 Sedimentation survey	-	30,322
Number of years (since impoundment)	54	62
Capacity loss rate (acre-ft/year)	730	489

Table 7. Comparison of Lake Sedimentation Calculations on Wright Patman Lake at elevation 224.0 ft

Comparison of Sedimentation Calculations		
Survey	Comparisons @ 224.0 ft NGVD29	
	Volume (acre-ft)	
	Comparison #6	Comparison #7
TWDB lake capacity estimate based on 2010 V&S survey[a]	216,241	-
Lake capacity estimate based on 2018 V&S survey	-	205,121
2010 Volumetric survey	171,069	-
2018 Volumetric survey	-	168,736
2010 Sedimentation survey	45,172	-
2018 Sedimentation survey	-	36,385
Number of years (since impoundment)	54	62
Capacity loss rate (acre-ft/year)	837	587

[a]TWDB, personal communication, February 13, 2019

Recommendations

The project team recommends resurveying Wright Patman Lake in approximately 10 years to further improve capacity estimates and sedimentation rates to aid in long-term resource management and planning efforts. Results of the 2018 Volumetric and Sedimentation Study on Wright Patman Lake indicate a sedimentation or capacity loss rate (due to sediment accumulation) below elevation 220.6 feet of 489 acre-ft/year over the life of the lake (1956 to present).

The differences in pre-impoundment surface, sediment thickness calculations and sedimentation rates between the 2018 and 2010 surveys create a scientific dilemma in long-term water planning for Riverbend. Consistency amongst survey results would be ideal and would allow for more confidence in lake volume and sedimentation rate estimates. Similarly, collection and analysis of additional core tube samples would allow for more validation and confidence in accumulated sediment thickness across more regions of the lake.

Comprehensive QA/QC procedures on 2018 survey data and results by the project team support the results and conclusions presented above. However, preliminary investigations into the 2010 survey data identified several discrepancies within the 2010 survey which could account for significant variability between 2010 and 2018 survey results. This preliminary effort identifies enough concerns about processing and calculation techniques to warrant the opportunity to re-evaluate the 2010 survey more in-depth than what has been conducted for this project.

Re-evaluation of the 2010 survey may result in scientifically defensible revised 2010 lake volume and 2010 sedimentation rate estimates and provide Riverbend with more reliable lake data for use in future water planning efforts.

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Appendix A – Elevation-Area-Capacity Tables and Curves

Table 8. Wright Patman Lake – 2018 Reservoir Area Table

July - August 2018
Volumetric & Sedimentation Survey
AREA IN ACRES

WRIGHT PATMAN LAKE
RESERVOIR AREA TABLE

Elevation in FEET	Elevation Increment is ONE TENTH FOOT 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
193							0	0	0	0
194	0	0	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0	0	0
196	0	0	0	0	0	0	0	0	0	1
197	1	1	1	1	1	1	1	1	1	1
198	1	1	1	2	2	2	2	2	2	2
199	2	2	2	3	3	3	3	3	4	4
200	5	5	6	7	8	8	9	10	11	12
201	13	15	16	17	19	20	22	25	28	31
202	34	36	39	41	44	46	49	52	55	58
203	60	64	67	70	73	76	79	83	86	90
204	94	98	102	106	110	114	119	123	127	131
205	135	140	144	149	155	161	167	173	179	184
206	191	197	203	210	218	225	233	243	253	264
207	275	289	305	325	356	399	450	502	566	633
208	702	768	827	882	944	1,006	1,066	1,133	1,201	1,263
209	1,330	1,396	1,457	1,516	1,569	1,616	1,660	1,702	1,747	1,791
210	1,838	1,885	1,935	1,985	2,035	2,089	2,150	2,207	2,268	2,332
211	2,404	2,477	2,557	2,641	2,736	2,837	2,937	3,044	3,163	3,292
212	3,421	3,561	3,710	3,866	4,023	4,174	4,333	4,477	4,606	4,728
213	4,843	4,949	5,061	5,173	5,292	5,418	5,544	5,675	5,809	5,950
214	6,108	6,266	6,415	6,567	6,742	6,913	7,073	7,210	7,334	7,459
215	7,593	7,731	7,879	8,029	8,188	8,364	8,547	8,752	8,953	9,142
216	9,308	9,472	9,636	9,792	9,947	10,109	10,271	10,437	10,621	10,825
217	11,012	11,202	11,382	11,558	11,761	11,945	12,136	12,351	12,574	12,805
218	13,034	13,254	13,491	13,736	13,986	14,197	14,402	14,601	14,835	15,028
219	15,224	15,416	15,619	15,835	16,025	16,195	16,351	16,511	16,675	16,830
220	16,974	17,116	17,268	17,424	17,583	17,745	17,907	18,073	18,245	18,426
221	18,607	18,805	19,025	19,253	19,472	19,679	19,883	20,093	20,309	20,519
222	20,735	20,950	21,158	21,371	21,585	21,801	22,005	22,200	22,388	22,569
223	22,748	22,923	23,090	23,251	23,408	23,568	23,720	23,868	24,026	24,184
224[a]	24,343									

[a] Area, capacity and sediment thickness below elevation 224ft are based on echosounding data; for elevations above 224ft, area and capacity are extrapolated to the boundary.

Table 9. Wright Patman Lake – 2018 Reservoir Capacity Table

WRIGHT PATMAN LAKE
RESERVOIR CAPACITY TABLE

July - August 2018
Volumetric & Sedimentation Survey
CAPACITY IN ACRE-FEET

Elevation in FEET	Elevation Increment is ONE TENTH FOOT 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
193							0	0	0	0
194	0	0	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0	0	0
196	0	0	0	0	0	0	0	0	0	1
197	1	1	1	1	1	1	1	1	1	1
198	1	2	2	2	2	2	2	3	3	3
199	3	3	4	4	4	4	5	5	5	6
200	6	7	7	8	9	10	10	11	12	14
201	15	16	18	19	21	23	25	28	30	33
202	36	40	44	48	52	56	61	66	72	77
203	83	89	96	103	110	117	125	133	142	150
204	160	169	179	190	200	212	223	235	248	261
205	274	288	302	317	332	348	364	381	399	417
206	435	455	475	496	517	539	562	586	611	636
207	663	691	721	753	787	824	867	914	968	1,028
208	1,094	1,168	1,248	1,333	1,424	1,522	1,625	1,735	1,852	1,975
209	2,105	2,241	2,384	2,533	2,687	2,846	3,010	3,178	3,351	3,528
210	3,709	3,895	4,086	4,282	4,483	4,689	4,901	5,119	5,343	5,573
211	5,810	6,054	6,305	6,565	6,834	7,113	7,401	7,700	8,010	8,333
212	8,669	9,017	9,381	9,760	10,154	10,564	10,989	11,430	11,884	12,351
213	12,830	13,319	13,820	14,331	14,855	15,390	15,938	16,499	17,073	17,661
214	18,264	18,883	19,517	20,166	20,831	21,514	22,214	22,928	23,655	24,395
215	25,147	25,913	26,694	27,489	28,300	29,127	29,973	30,838	31,723	32,628
216	33,550	34,489	35,445	36,416	37,403	38,406	39,425	40,460	41,513	42,585
217	43,677	44,788	45,917	47,065	48,229	49,415	50,619	51,843	53,089	54,358
218	55,650	56,965	58,301	59,663	61,049	62,458	63,889	65,338	66,810	68,303
219	69,816	71,349	72,900	74,473	76,066	77,677	79,305	80,947	82,607	84,282
220	85,972	87,677	89,396	91,130	92,881	94,647	96,430	98,229	100,045	101,878
221	103,730	105,599	107,491	109,405	111,342	113,299	115,278	117,276	119,297	121,338
222	123,401	125,485	127,590	129,716	131,864	134,034	136,224	138,434	140,664	142,912
223	145,178	147,462	149,762	152,080	154,412	156,761	159,125	161,505	163,901	166,310
224[a]	168,736									

[a] Area, capacity and sediment thickness below elevation 224ft are based on echosounding data; for elevations above 224ft, area and capacity are extrapolated to the boundary.

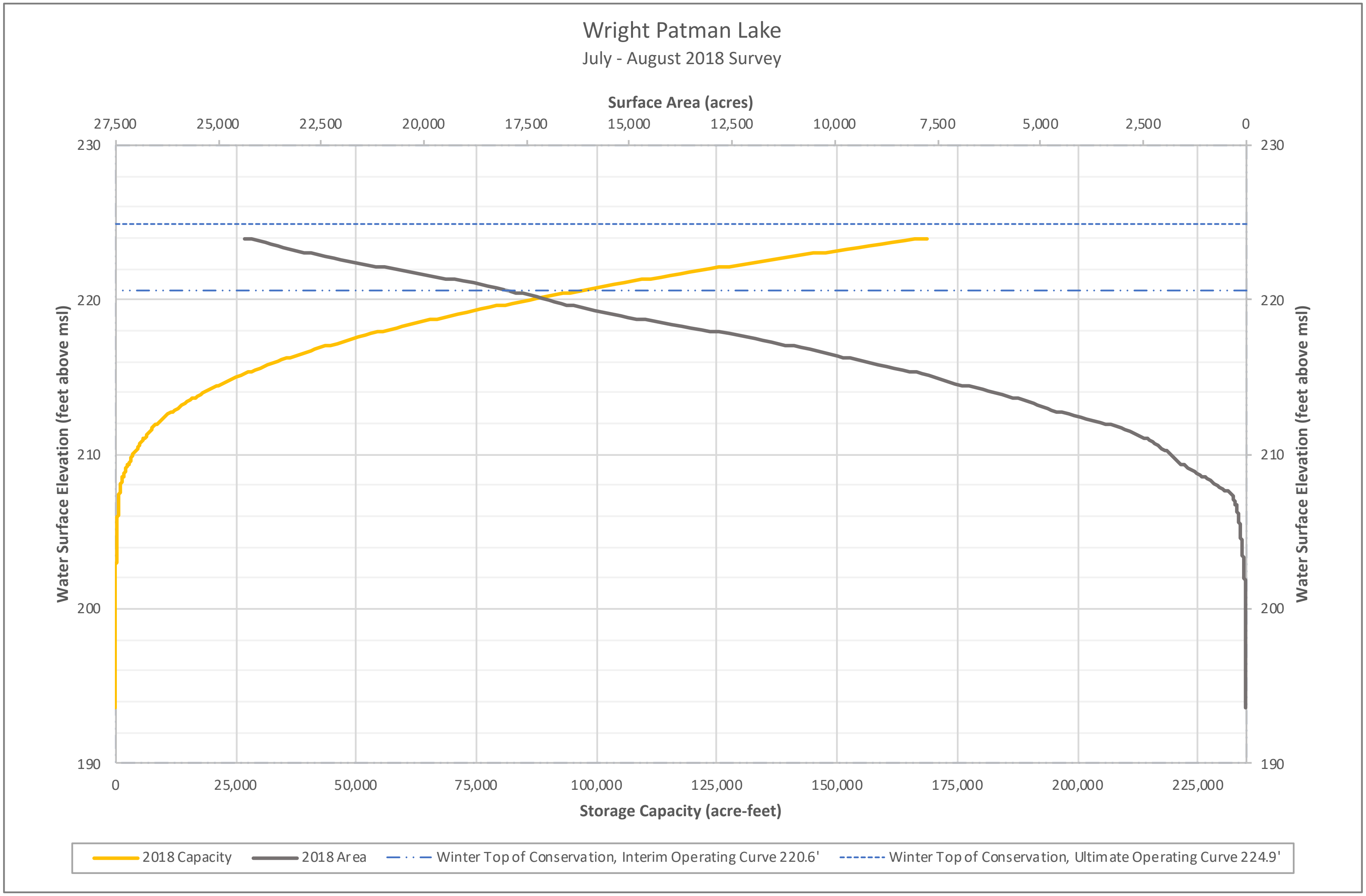

Figure 7. Wright Patman Lake – 2018 Area and Capacity Curves

Appendix B – Quality Assurance/Quality Control (QA/QC) Methods

Quality Assurance/Quality Control Methods

The project team employed multiple methods of quality assurance/quality control (QA/QC) checks throughout the entire study process, from field data collection methods to data processing to final data comparisons. The various QA/QC procedures include, but are not limited to the following: staff gage installation and verification of daily lake elevation, daily water velocity profile readings to calibrate and verify lake point depths, collection of sediment cores at multiple lake locations to ground truth the determination of pre-impoundment depth, visual inspection of mapped processed data points, comparison of processed data points collected on different days at the same location (Table 8 and Table 9), comparison of selected similar (collected along same pre-planned lines) cross-sections between 2018 and 2010 surveys (Figures 8 – 12), comparison of calculated lake volume and sediment volume between 2018 and 2010 surveys (Table 5), among other processed raw data checks.

Data Point Comparisons

Table 8 is an example of one of the many comparisons of data points in close proximity collected on different days of the 2018 survey. The last row provides the difference on one data point pair in the given parameters (x/y location, lake elevation, etc.). This comparison shows good internal consistency in data collection and processing methods throughout the 2018 survey.

Table 10. Comparison of Data Points

x[a]	y[a]	Lake Elevation (ft)	Current Surface (ft)	Pre-impoundment Surface (ft)	Sediment Thickness (ft)	sdi_filename	Date	Time
3286915.078	7172755.257	226.2	217.27	215.88	1.39	18080221	8/2/18	48:02.1
3286914.962	7172755.189	226.23	217.21	215.85	1.36	18080129	8/1/18	16:41.5
0.116	**0.068**	**-0.03**	**0.06**	**0.03**	**0.03**			

[a] Coordinates based on NAD83 State Plane Texas North Central (4204)

Thirteen comparisons of crossing line data points were made along the cross-sections chosen for further QA/QC analysis (Table 9). Seven of the 13 comparisons were between lines taken on different survey days; the six remaining comparisons were between different lines on the same survey day.

Table 9 provides a summary of the calculated differences between the values for each parameter of the data point comparison: x coordinate, y coordinate, lake elevation, current surface, pre-impoundment surface and sediment thickness. With a standard deviation ranging from 0.044 to 0.131 for the surfaces and sediment thickness, these comparisons provide further evidence of good internal consistency in the data collection and processing methods throughout the 2018 survey.

Table 11. Comparison of Crossing Data Point Differences – 2018 Wright Patman Lake Volumetric and Sedimentation Survey

Comparison of Crossing Point Differences										
Cross Section	**x**	**y**	**Lake Elevation (ft)**	**Current Surface (ft)**	**Pre-impoundment Surface (ft)**	**Sediment Thickness (ft)**	**Filename A**	**Filename B**	**Date A**	**Date B**
M-1	0.116	0.068	-0.030	0.060	0.030	0.030	18080221	18080129	8/2/18	8/1/18
D-1	-0.028	1.777	0.010	0.060	0.130	-0.080	18071733	18071715	7/17/18	7/17/18
U-1	-1.647	-0.675	0.000	0.020	0.150	-0.120	18081350	18081331	8/13/18	8/13/18
U-2	-0.172	1.796	0.000	0.050	0.120	-0.060	18081350	18081331	8/13/18	8/13/18
U-3	1.959	0.779	0.000	-0.010	0.110	-0.110	18081331	18081324	8/13/18	8/13/18
U-4	0.001	1.192	0.000	-0.070	0.110	-0.170	18081331	18081324	8/13/18	8/13/18
U-5	0.860	-1.058	0.000	0.010	0.120	-0.110	18081331	18081324	8/13/18	8/13/18
U-6	-1.098	-0.645	0.000	-0.050	0.120	-0.170	18081331	18081324	8/13/18	8/13/18
A-1	0.154	0.338	-0.070	0.010	0.010	0.000	18072434	18072604	7/24/18	7/26/18
A-2	-0.828	0.355	0.070	0.060	-0.150	0.210	18072604	18072434	7/26/18	7/24/18
A-3	0.069	0.610	0.070	0.120	-0.130	0.240	18072604	18072434	7/26/18	7/24/18
A-4	-0.265	-0.661	0.070	0.020	0.100	-0.090	18072604	18072436	7/26/18	7/24/18
A-5	-0.138	0.303	0.070	0.000	0.100	-0.100	18072604	18072435	7/26/18	7/24/18
Min	-1.647	-1.058	-0.070	-0.070	-0.150	-0.170				
Max	1.959	1.796	0.070	0.120	0.150	0.240				
Avg	-0.078	0.321	0.015	0.022	0.063	-0.041				
SD	0.879	0.922	0.044	0.050	0.098	0.131				

Cross-section Comparisons – 2018 vs. 2010

Figures 8 through 12 below provide a graphical view of comparisons conducted on one of the many pre-planned survey lines followed in both the 2010 TWDB and 2018 surveys. Both surveys collected and processed lake current and pre-impoundment surfaces.

Figure 8 shows the comparison of the current surface of the lake in both surveys along one cross-section. Overall, the current surface is similar in elevation over most of the cross-section. However, differences are present and can be due to a variety of reasons: offset in the horizontal location of the data point (some points were up to 15 feet away from each other between the two surveys), and data processing differences (e.g. methodology of choosing the current surface can vary with the use of different software and among different users).

Figure 9 provides a comparison of the pre-impoundment surface of the lake in both surveys. Although some point comparisons are similar in elevation, which would be expected in the pre-impoundment elevations between surveys, there is a noticeable difference in these layers, particularly in deeper, possible thalweg (river bottom) areas. Some differences could be explained in point areas where the horizontal differences are greater (e.g. survey data points are over 10 feet apart between survey lines). Larger differences in pre-impoundment elevations (original lake bottom) might be better explained by looking at differences in methodologies between surveys.

Figure 10 provides a view of a 2018 survey sediment layer along the cross-section by showing both the current surface and pre-impoundment surface together. The graph shows a relatively smooth current surface layer following the terrain of the pre-impoundment layer, with no major spikes.

Figure 11 provides a view of a 2010 survey sediment layer along the cross-section by showing both the current surface and pre-impoundment surface together. The graph shows a rather smooth current surface; however, there are various places along the pre-impoundment line that do not correspond well with what is seen in the current surface and in comparison to what is seen in the 2018 graph (Figure 10). Again, these larger differences in the pre-impoundment layer might be better explained with a more in-depth look at differences in survey methodologies.

Figure 12 provides a comparison of the cross-section of the sediment thickness for each survey. There are many spikes of greater sediment thickness along the 2010 survey line data than for the 2018 data. The variation of sediment thickness along this cross-section implies differences in sediment accumulation estimates that warrant additional future study.

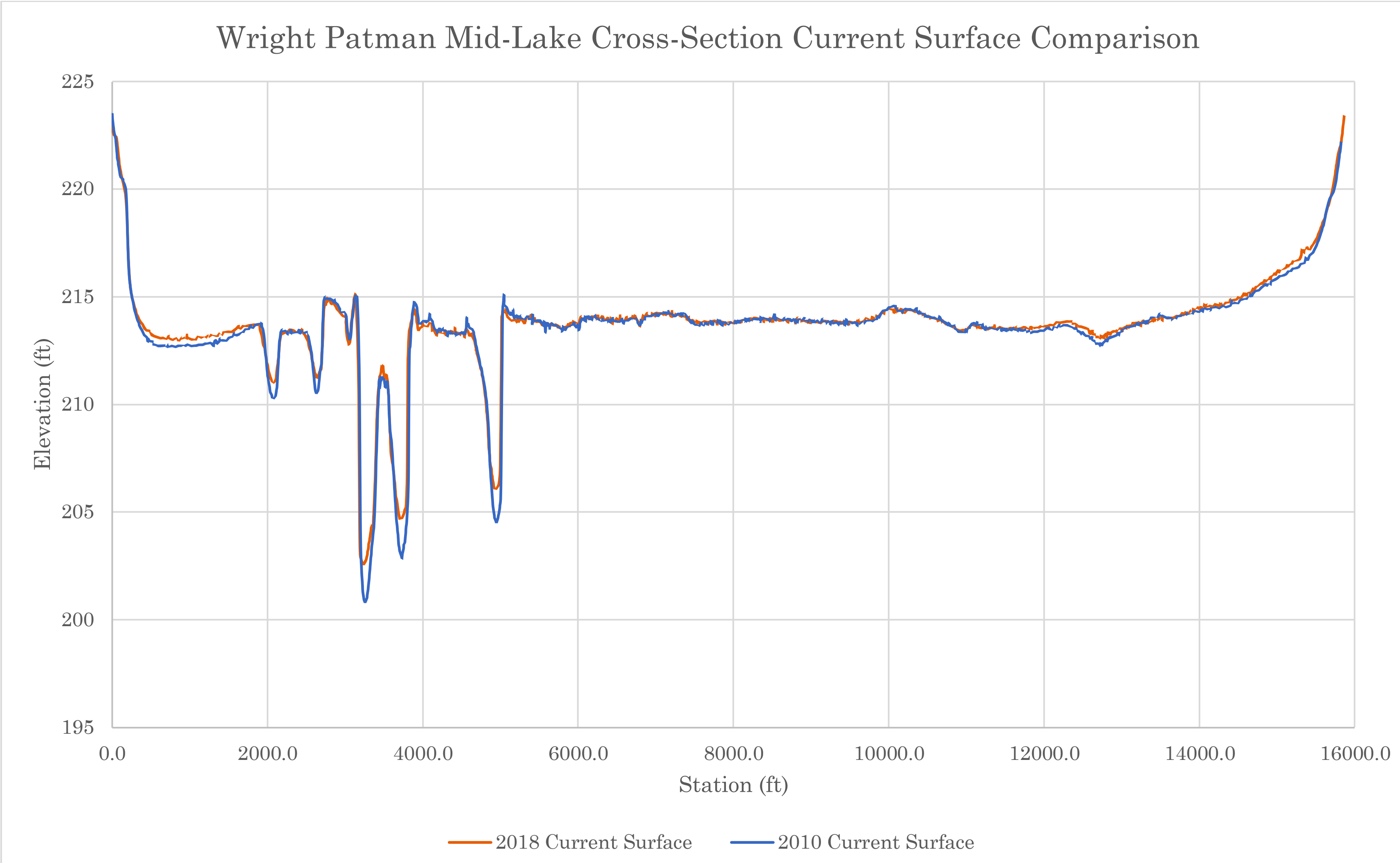

Figure 8. Comparison of 2018 and 2010 current surface cross-section.

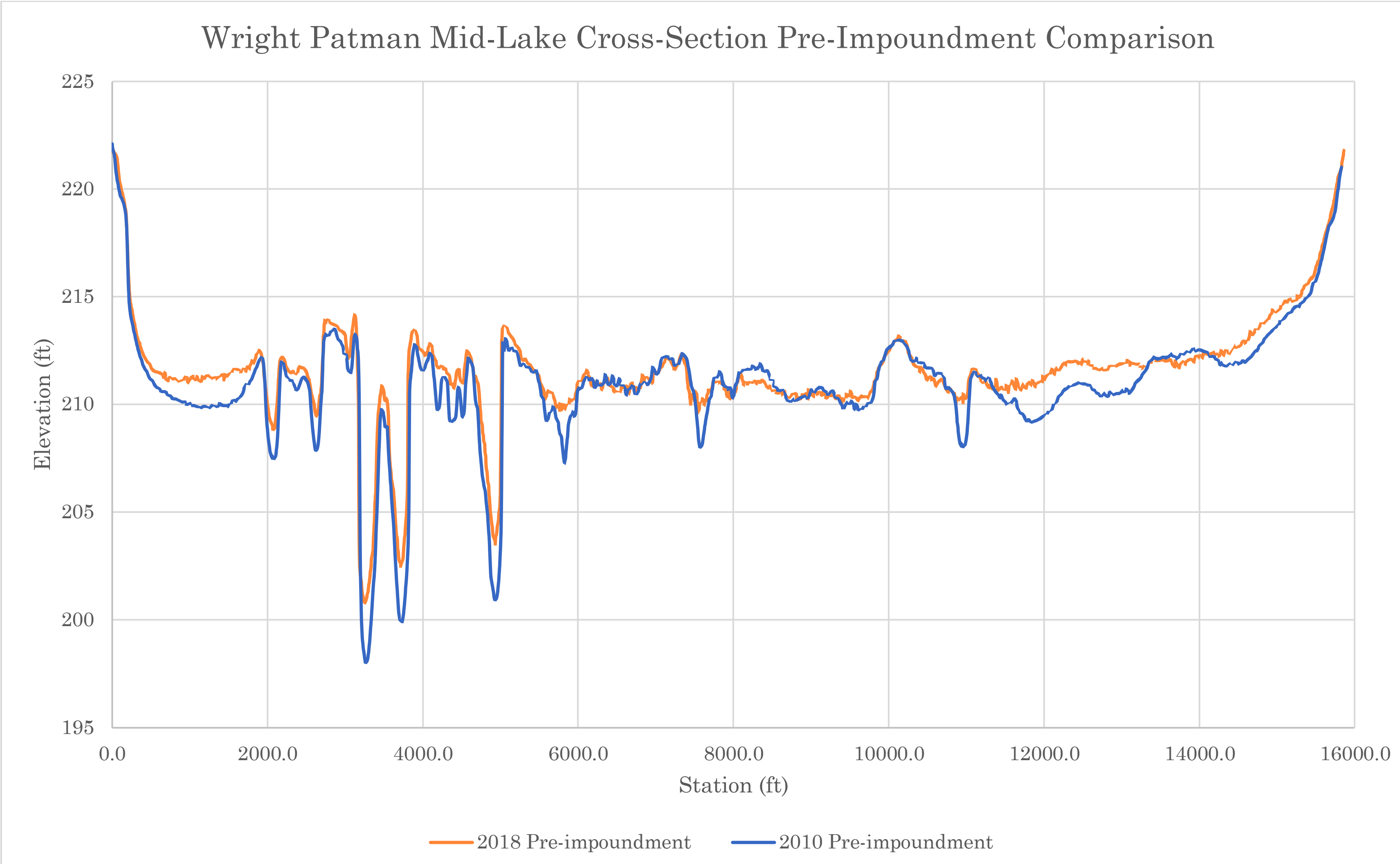

Figure 9. Comparison of 2018 and 2010 pre-impoundment surface cross-section.

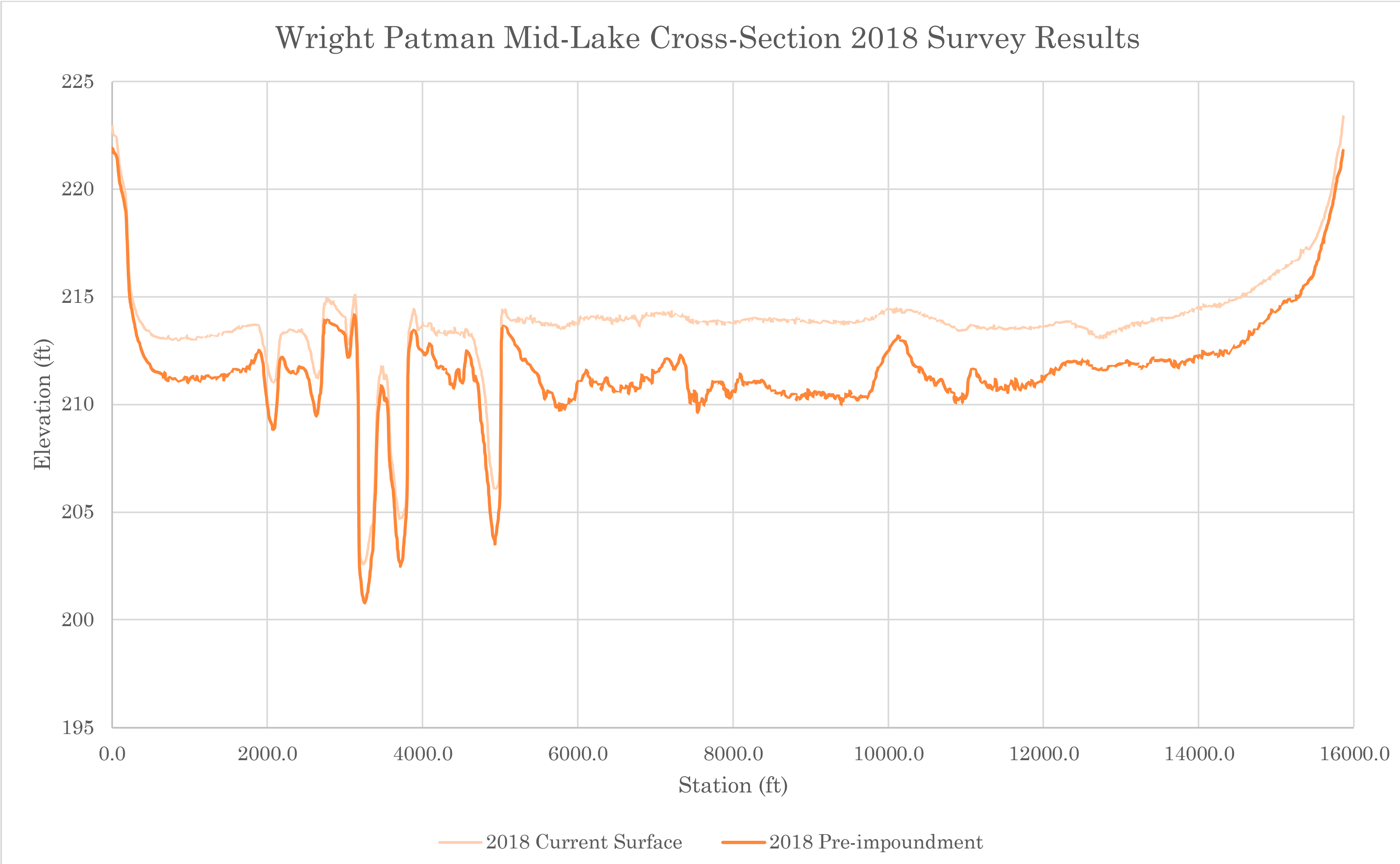

Figure 10. Cross-section view of 2018 current and pre-impoundment surfaces.

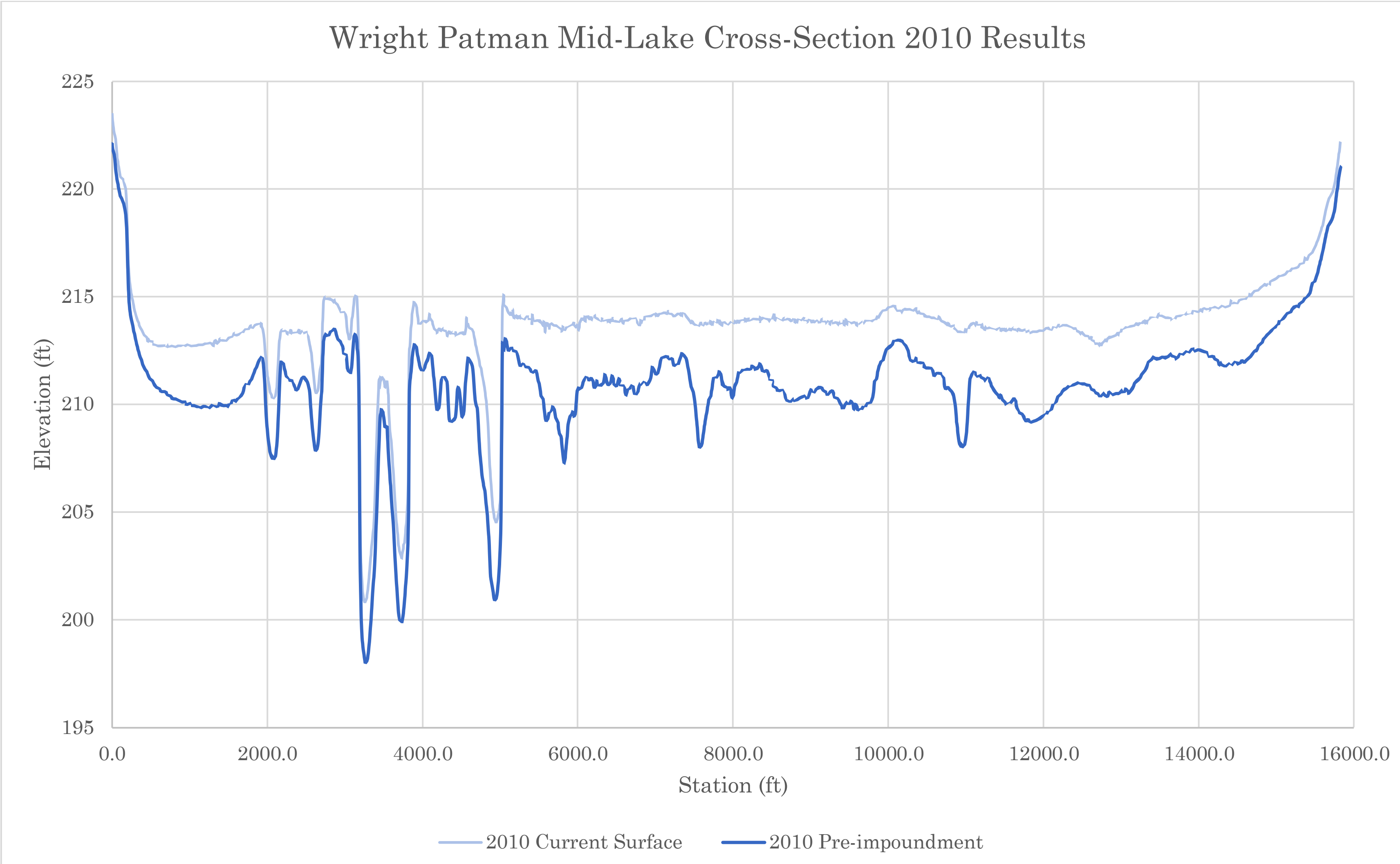

Figure 11. Cross-section view of 2010 current and pre-impoundment surfaces.

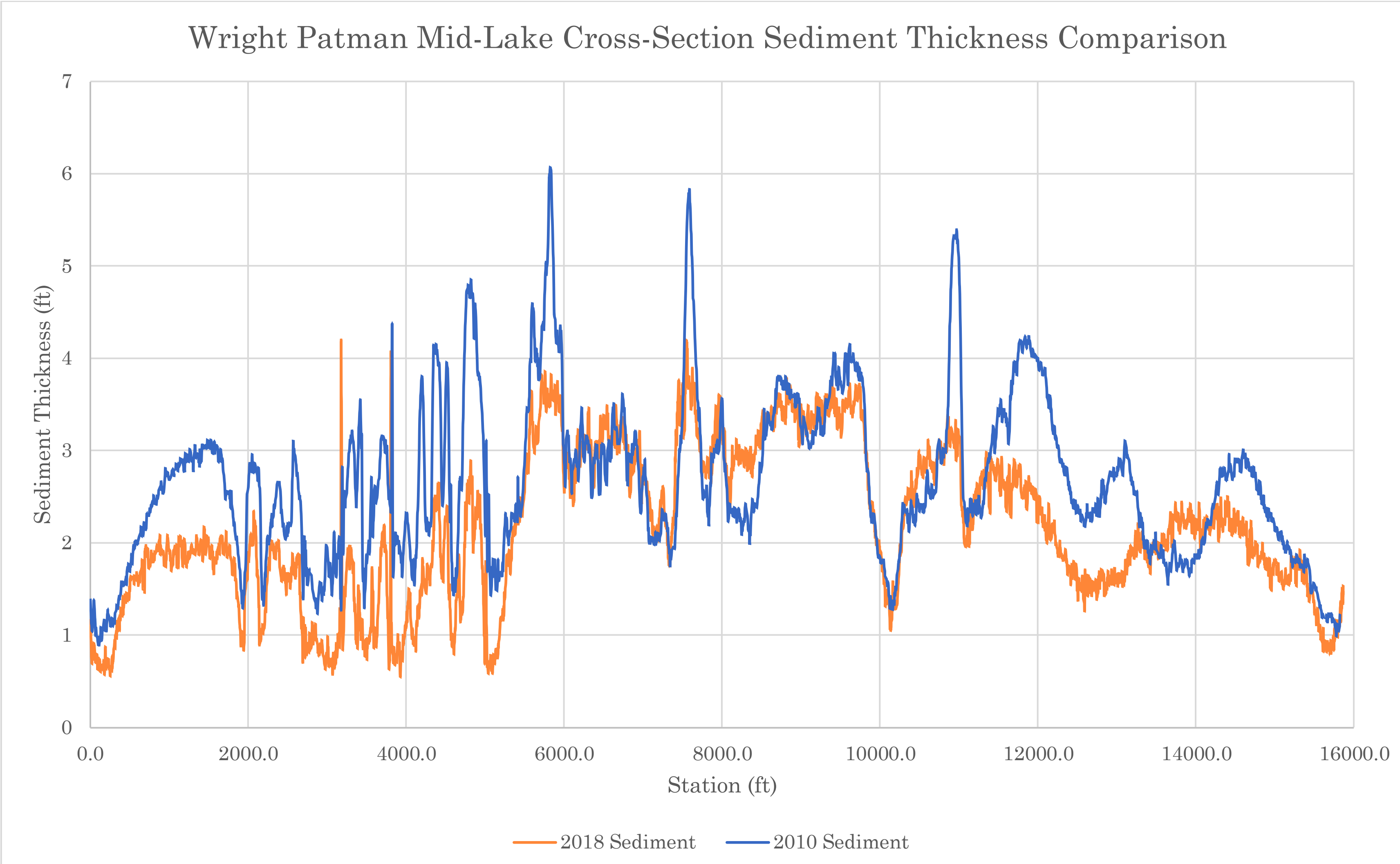

Figure 12. Comparison of 2018 and 2010 calculated sediment thickness along cross-section.

Providing Creative Solutions to a Variety of Environmental Concerns