Technical Report No. ENV-2020-005

Tom Steed Reservoir 2018 Sedimentation Survey

Mountain Park Project, Oklahoma
Great Plains Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Sedimentation and River Hydraulics Group
Denver, Colorado

January 2020

Mission Statements

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Acknowledgements

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Disclaimer

Cover: Tom Steed Reservoir behind Mountain Park Dam (photo courtesy of Reclamation)

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14. SHORT ABSTRACT

The 2018 multibeam bathymetric survey of Tom Steed Reservoir was combined with 2011-2012 aerial LiDAR survey data to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the top of flood control pool elevation (1414.0 ft, Reclamation Project Vertical Datum), the reservoir would have a surface area of 7,280 acres and a storage capacity of 119,051 acre-feet. Since the original filling in 1975, the reservoir is estimated to have lost roughly half of its inactive pool storage capacity due to sedimentation. The dead storage pool volume has reduced to roughly 1 percent of the original dead storage volume. The next reservoir survey is recommended by 2038 (20 years) unless operations change at the dam and the reservoir is drawdown below the top of the inactive pool (1386.3 ft), in which case another survey is recommended soon after this operational change.

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Tom Steed Reservoir survey, sedimentation, reservoir area, reservoir capacity

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Tom Steed Reservoir 2018 Sedimentation Survey

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Acronyms and Abbreviations

ACAP	Area-Capacity program
ac-ft	acre-feet
cfs	cubic feet per second
DOI	Department of the Interior
DEM	Digital Elevation Model
FIPS	Federal Information Processing Standard zone ID
ft	feet
GIS	Geographic Information System
GPS	Global Positioning System
hr	hour
HUC	Hydrologic Unit Code
in	inch
LiDAR	Light Detection and Ranging
mi	mile
mi^2	square miles
NAD83	North American Datum, established 1983
NAVD88	North American Vertical Datum, established 1988
NGVD29	National Geodetic Vertical Datum, established 1929
NGS	National Geodetic Survey
NID	National Inventory of Dams
NRCS	Natural Resources Conservation Service
OPUS	Online Positioning User Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RTK	Real-Time Kinematic
SGMC	State Geologic Map Compilation
USGS	U.S. Geological Survey
USDA	U.S. Department of Agriculture
WSS	Web Soil Survey (USDA soil information)

Executive Summary

Mountain Park Dam and Tom Steed Reservoir are on West Otter Creek approximately 4 miles north of Snyder, in southwest Oklahoma. A bathymetric survey of Tom Steed Reservoir was conducted in 2018 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1975 and since the last survey in 2009 and

2. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

The bathymetric survey was conducted from a boat using a multibeam depth sounder that was interfaced with real-time kinematic (RTK) global positioning system (GPS) instruments (for horizontal positioning) to map the reservoir bottom. The 2018 multibeam bathymetric survey of Tom Steed Reservoir was combined with a 2011 through 2012 aerial Light Detection and Ranging (LiDAR) survey for the above-water portions to produce a combined topographic digital surface of the reservoir bottom.

This survey was conducted between May 3 through 6, 2018 when the reservoir water surface elevation ranged from 1410.9-1410.94 feet (Reclamation Project Vertical Datum - RPVD), roughly equal to the top of the active conservation pool elevation at 1411 ft.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 1405 ft (RPVD), roughly 5 feet below the water surface at the time of survey and the bathymetric survey limit, the reservoir surface area was 5,301 acres with a storage capacity of 62,181 acre-feet (ac-ft).

- At the top of flood control pool elevation 1414 ft (RPVD), the reservoir would have a surface area of 7,280 acres and a storage capacity of 119,051 acre-feet.

- The 2018 survey of Tom Steed Reservoir indicates a minimal decrease in storage capacity at elevation 1400 ft. Above elevation 1410 ft, the survey shows the reservoir gained capacity since the original filling in 1975. This is likely due to the improved accuracy of the LiDAR data that was used for this most recent analysis. The biggest capacity differences have occurred at and below the inactive storage pool elevation (1386.3 ft). The inactive pool storage capacity has decreased by roughly half (8,550 to 4,098 ac-ft) since closure of the dam, and the dead pool storage area is nearly filled (1% original capacity remains).

- Historic rates of reservoir sedimentation indicate a marginally decreasing trend in sedimentation rates since original reservoir filling.

A summary description of the dam, reservoir, and survey results is presented in Table ES-1.

Table ES-1. Tom Steed Reservoir survey summary information.

Reservoir Information

Reservoir Name	Tom Steed	**Region**	Great Plains
Owner	Bureau of Reclamation	**Area Office**	Oklahoma-Texas Area Office
Stream	West Otter Creek	**Vertical Datum**	RPVD
County	Kiowa	**Top of Dam (ft)**	1423
State	Oklahoma	**Spillway Crest (ft)**	1414
Lat (decimal deg)	34.7386	**Power Penstock Elevation (ft)**	---
Long (decimal deg)	-98.9875	**Low Level outlet (ft)**	1380.25
HUC4	1112	**Total Drainage Area (mi²)**	126.7
HUC8	11120303	**Date storage began**	1975
NID ID	OK20502	**Date for normal operations**	1975
Dam Purpose	Industrial, Municipal, Recreation, Wildlife, Flood control		

HUC = Hydrologic Unit Code; NID = National Inventory of Dams

Original Design

Storage Allocation	Elevation (feet)	Surface area (acres)	Capacity (acre-feet)	Gross Capacity (acre-feet)
SURCHARGE	1423.6	9,463	80,453	199,504
FLOOD CONTROL	1414.0	7,280	20,805	119,051
CONSERVATION	1411.0	6,589	94,148	98,246
INACTIVE	1386.3	1,178	4,082	4,098
DEAD	1376.5	11	16	16

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi²)	Period Sedimentation Volume (acre-feet)	Cumulative Sedimentation Volume (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
1975	Photogrammetry	10-ft	126.7	--	--	1364.0	100
2009	Single beam	2-ft	126.7	117,606	117,606	1372.6	0.9
2018	Multibeam	1-ft	126.7	1,445	119,051	1373.5	0.9

Notes

Survey summary sedimentation volumes are the volumes below the spillway crest elevation of 1414.0 ft.

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1. Introduction

Mountain Park Dam and Tom Steed Reservoir are on West Otter Creek approximately 4 miles (mi) north of Snyder, in southwest Oklahoma (Figure 1). The dam and reservoir are operated and maintained by the Mountain Park Master Conservancy District as part of the Mountain Park Project (Figure 2) to provide water storage for municipal and industrial water supplies to the Kiowa County cities of Altus, Snyder, and Frederick; Oklahoma. Water is conveyed from the reservoir to the project cities through an aqueduct system that consists of 40 miles of pipeline, two pumping plants, a chlorination station, and other appurtenant facilities. The project also provides flood control, recreation, and fish and wildlife conservation benefits.

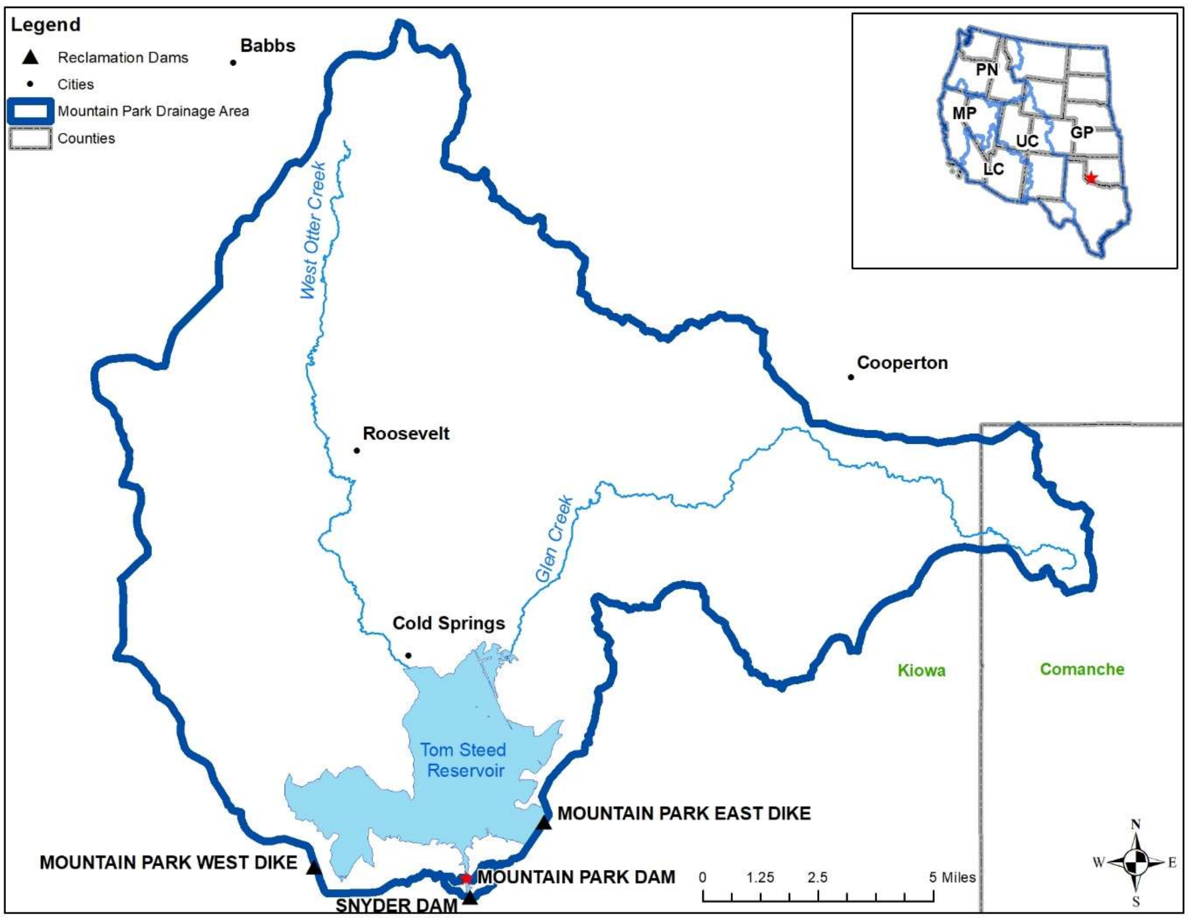

Figure 1. Location map and watershed drainage area of Mountain Park Dam and Tom Steed Reservoir.

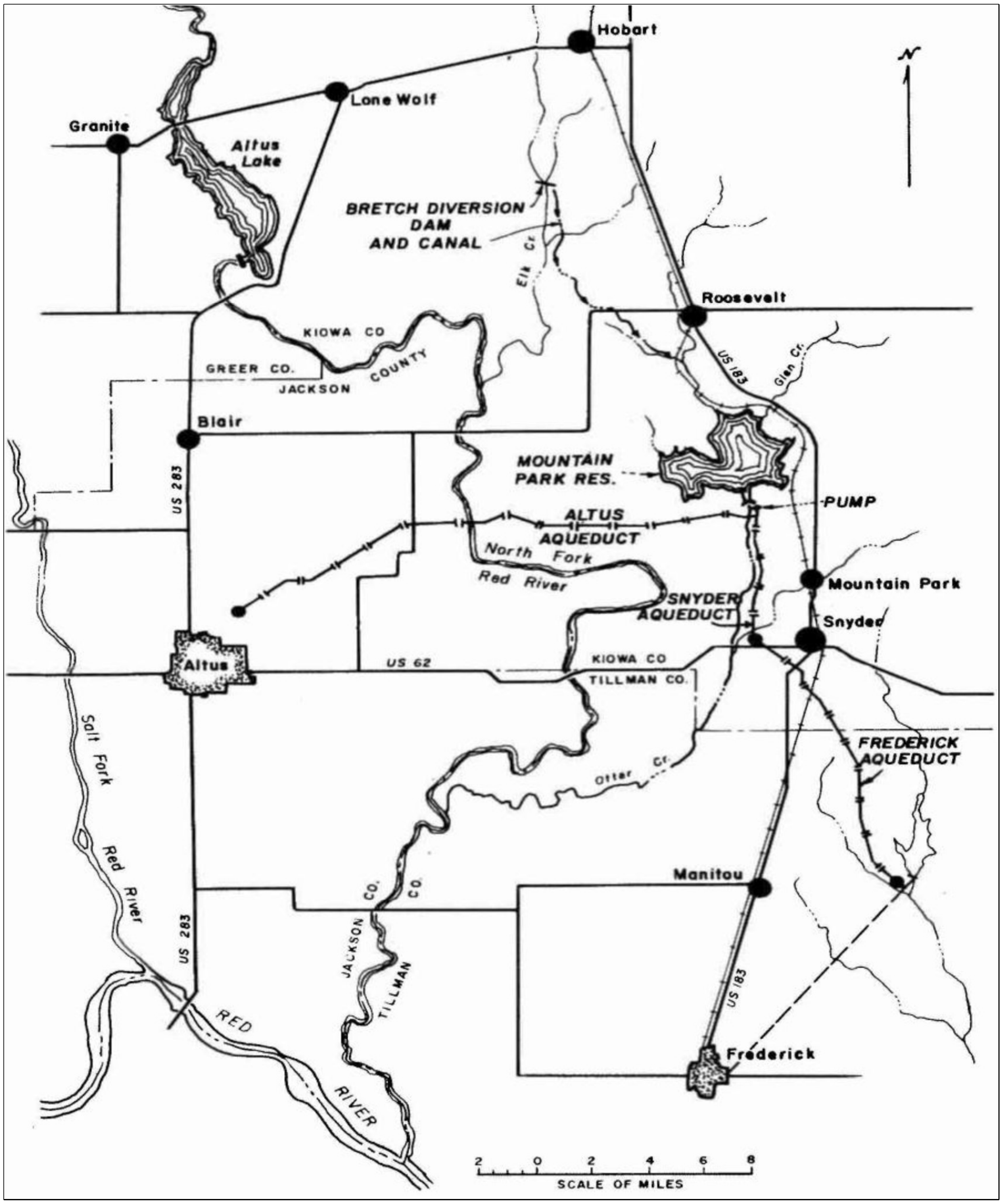

Figure 2. Mountain Park Project and surrounding features [for the purposes of this map, Mountain Park Reservoir is synonymous with Tom Steed Reservoir].

All rivers transport sediment particles (e.g., clay, silt, sand, gravel, and cobble) and reservoirs tend to trap sediment, diminishing the reservoir storage capacity over time. Reservoir sedimentation affects all elevations of the reservoir, even above and upstream of the full pool elevations. Cobble, gravel, and sand particles tend to deposit first forming deltas at the upstream ends of the reservoir while silt and clay particles tend to deposit along the reservoir bottom between the delta and dam.

Periodic reservoir surveys measure the changing reservoir surface area and storage capacity and provide information for forecasting when important dam and reservoir facilities will be impacted by sedimentation.

As part of ongoing operations and sediment monitoring activities, Reclamation's Great Plains Regional Office requested the Technical Service Center's Sedimentation and River Hydraulics Group to conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A complete bathymetric survey was conducted from May 3 through 6, 2018 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1975 and since the last survey in 2009 and

2. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

2. Watershed Description

The watershed upstream from Mountain Park Dam has a total contributing drainage area of 126.7 square miles (mi^2). Due to the lack of regulation and upstream lakes/reservoirs that trap sediment, the net sediment-contributing drainage area to Tom Steed Reservoir was deemed as being the same as the total contributing drainage area. The upper portion of the watershed is generally flat consisting of primarily crop and pasture land, while the lower portion contains the Wichita Mountains and consists of narrow and steep-sided valleys cut into granitic bedrock; the dam is in one such valley. The reservoir occupies roughly 7% of the total watershed area (Figure 1). The watershed characteristics that can impact sedimentation rates were derived from the U.S. Geological Survey (USGS) StreamStats online tool utilizing a 30-meter Digital Elevation Model (DEM) representation of the watershed and are summarized in Table 1. StreamStats is a Web-based Geographic Information System (GIS) application (https://streamstats.usgs.gov/ss/) that provides users with access to an assortment of analytical tools that are useful for a variety of water resources planning and management purposes.

Table 1. Watershed characteristics from USGS StreamStats (USGS, 2019).

Watershed Characteristic	Value
Drainage Area	126.7 mi^2
Unregulated Drainage Area	126.7 mi^2
Mean Annual Precipitation	30.0 in
Mean Basin Elevation	1510 ft
Maximum Elevation*	2000 ft
Minimum Elevation	1370 ft
Percent of Impervious Area determined	3.5%
Percent of drainage area covered by canopy	2.9%
Average Soil Permeability	0.26 in/hr

*estimated from USGS topographic maps

2.1. Geology and Soils

The foundation of Mountain Park Dam consists of Cambrian granite that has been intruded by diabase. Diabase (or dolerite) is a subvolcanic rock that is typically extremely hard and tough, often quarried for crushed stone. The granite is hard, fine to medium crystalline, pink to grayish pink, and weathered to a depth of about 2 inches along joints near the surface. It is intricately cut by joints, shear, and faults. The canyon in which the dam is constructed is fault and joint controlled. A fault zone approximately 62 feet wide is present in the canyon floor and lies beneath the central portion of the dam. This zone is characterized by sheared, pulverized, granular, slicken sided diabase with some granite between the diabase intrusions. The granite in this zone is hard to soft and easily broken.

The geology of the watershed's sediment-contributing drainage area predominantly consists of clastic sedimentary rock formations (Figure 3 and Figure 4; USGS State Geologic Map Compilation (SGMC) Geodatabase [https://doi.org/10.5066/F7WH2N65]), which would tend to lessen sediment yields into the reservoir given their compacted and cemented nature. The soil textures within the watershed area geologic formations consist primarily of erosion-resistant clays (Figure 5 and Figure 6; Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) Geodatabase [http://websoilsurvey.nrcs.usda.gov/]). Vegetation types within the watershed primarily consist of pasture land, especially in the upper half of the watershed, with land use activities primarily consisting of supporting grazing animals. These types of land use practices tend to increase sediment yields above natural levels.

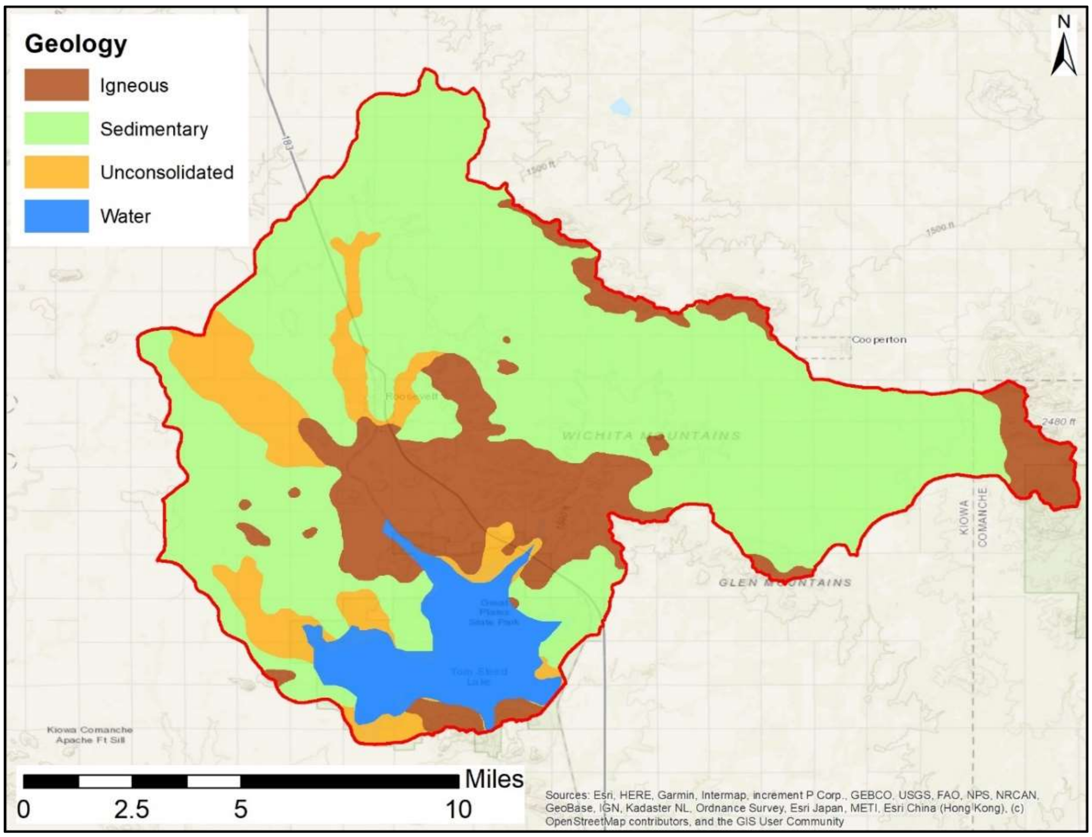

Figure 3. Geology formations in watershed area.

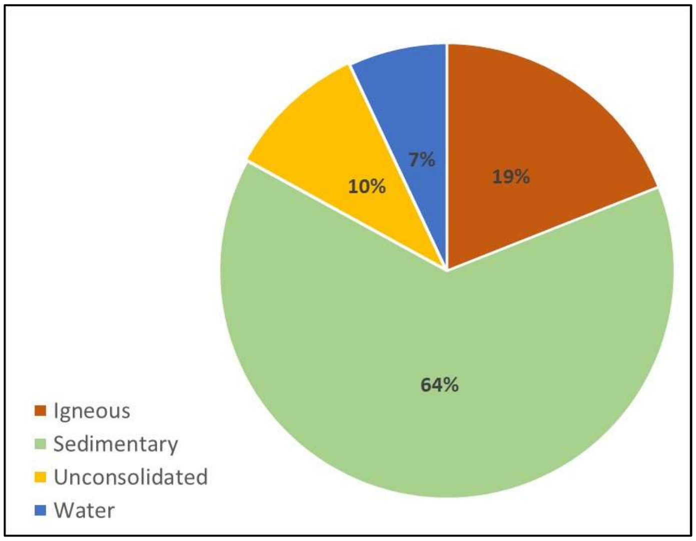

Figure 4. Geologic formations distribution in watershed area.

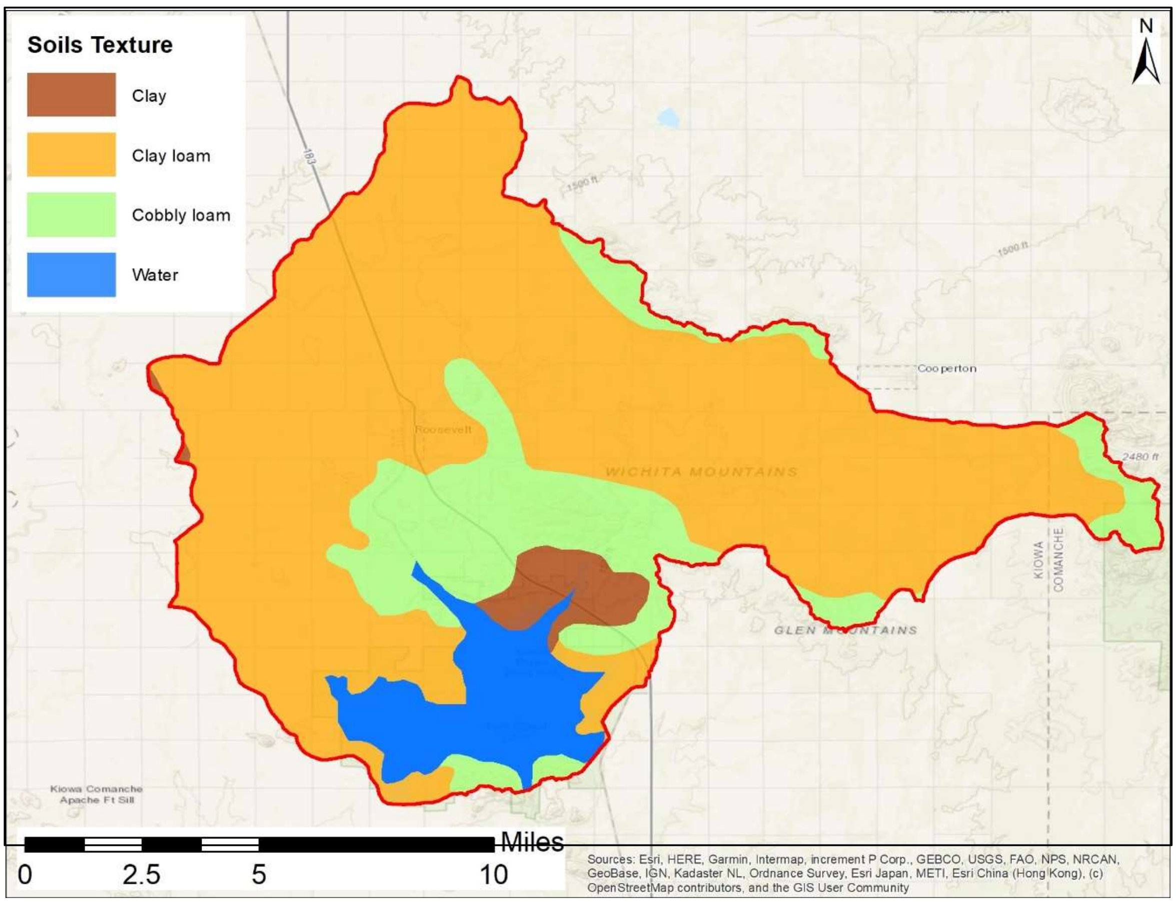

Figure 5. Soil textures in watershed area.

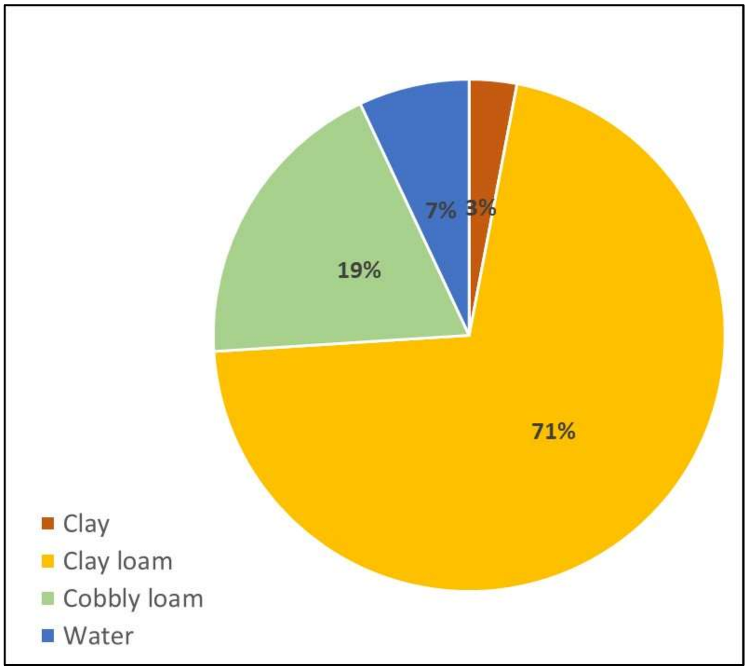

Figure 6. Soil textures distribution in watershed area.

2.2. Climate and Runoff

Reservoir inflows are primarily from West Otter and Glen Creeks. The West Otter and Glen Creeks watersheds are 56.6 mi^2 and 39 mi^2, respectively, accounting for roughly 75% of the total contributing drainage area. There are no USGS stream gage records available upstream of the dam, but there is a gage immediately downstream at Snyder Lake and Dam (07305500; Figure 1). The mean annual flow from this gage is 13 cfs or 9,418 acre-feet per year (Table 2), which is primarily from rainfall. Figure 7 and Figure 8 show historic annual outflow volumes (ac-ft) and monthly average outflows (cfs) from the reservoir according to gage data, respectively.

According to data presented in a previous survey report (Ferrari, 2010), the mean annual inflow to the reservoir is 35,260 ac-ft. The ratio of reservoir storage capacity to the mean annual runoff is 5.5. This means that, at full capacity, the reservoir stores a water volume equivalent to roughly 2,000 days of mean annual stream flow.

Table 2. Nearby (downstream) USGS gage.

USGS Stream Gage		Drainage Area (mi^2)	Mean Annual Flow (cfs)	Period of Record
Name	ID Number			
West Otter Creek at Snyder Lk nr Mt Park, OK	07305500	132	13	1976-2001

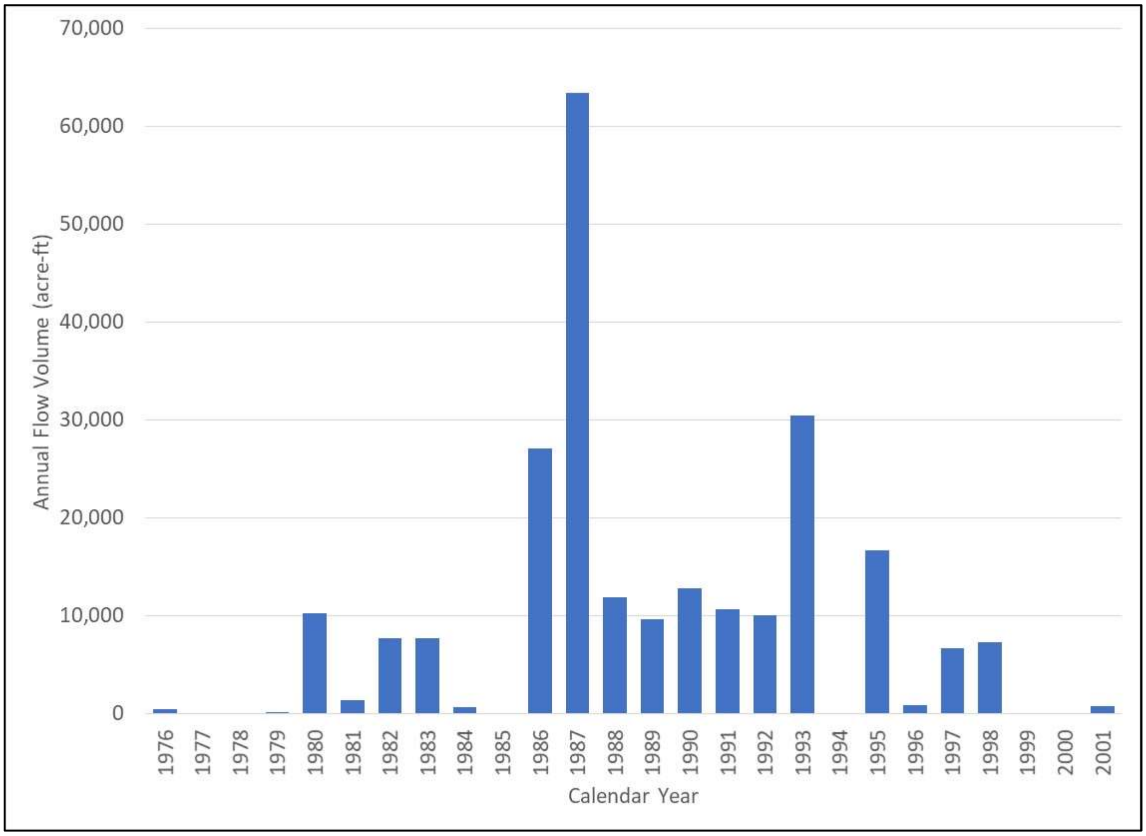

Figure 7. Historic annual outflow volumes from Tom Steed Reservoir as recorded by USGS gage 07305500.

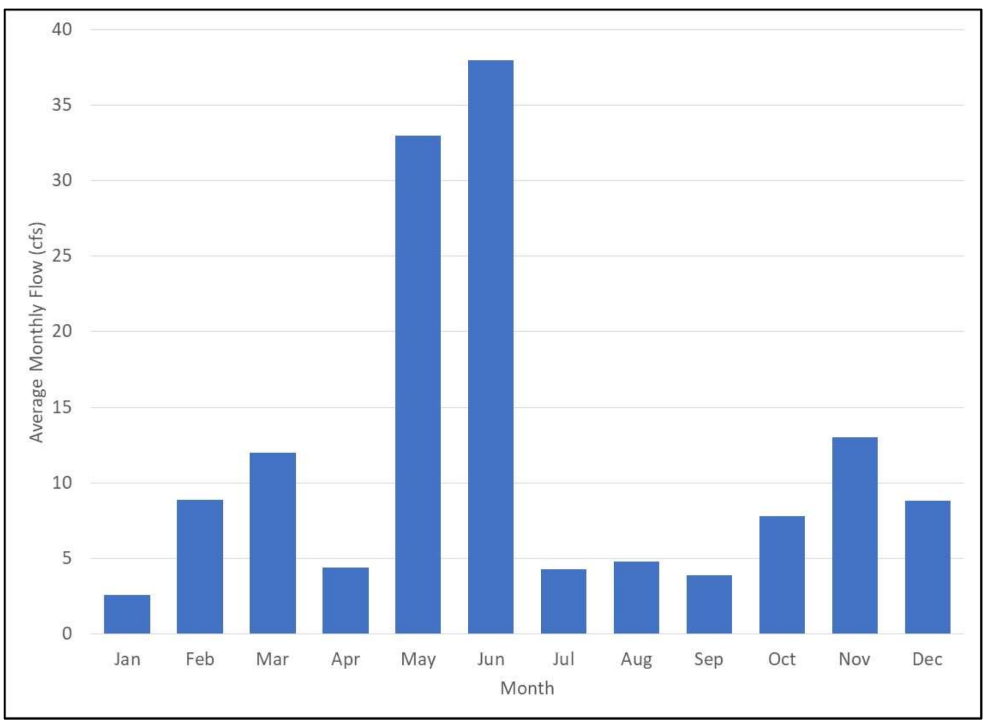

Figure 8. Historic monthly average outflows from Tom Steed Reservoir as recorded by USGS gage 07305500.

2.3. Dam Operations and Reservoir Characteristics

Mountain Park Dam is a double curved thin concrete arch dam constructed between 1973 and 1975. Relevant dam dimensions and elevations are shown in Table 3.

Table 3. Mountain Park Dam dimensions and relevant elevations (Reclamation, 2019b).

Structural height	133 ft	Crest width	6 ft
Hydraulic height*	59 ft	Crest elevation	1423.6 ft
Crest length	535 ft	Parapet elevation	1427.0 ft

*normal operating depth at dam

An uncontrolled overflow spillway spans 320 ft of the axis of the dam with a crest elevation of 1414.0 ft (top of exclusive flood control pool; Figure 9). The spillway is designed for a maximum discharge of 38,300 cfs at the maximum reservoir elevation of 1423.6 ft. The outlet works consists of an intake structure near the left abutment and three outlets for river, flood, and municipal water releases with a total capacity of 44 cfs at elevation 1414.0 ft.

Figure 9. Mountain Park Dam and operating spillway (Ferrari, 2010).

Two saddles with embankment dikes are located east and west of Mountain Park Dam to help further impound Tom Steed Reservoir. The east dike is 1.2 miles east of the left dam abutment and the west dike is 1.4 miles west of the right abutment. The east dike length is 10,630 ft with a structural height of 28 ft while the west dike length is 13,233 ft with a structural height of 20 ft. The crest elevations for both dikes are near 1428 ft.

The historic reservoir water surface elevations (Reclamation Project Vertical Datum, RPVD) are presented in Figure 10. Annually, reservoir water surface typically fluctuates about 5 ft in many years. However, in dry years, the drawdown can be 10-15 ft below top of the conversation pool. The spillway was active in 1993, 2007, and 2019.

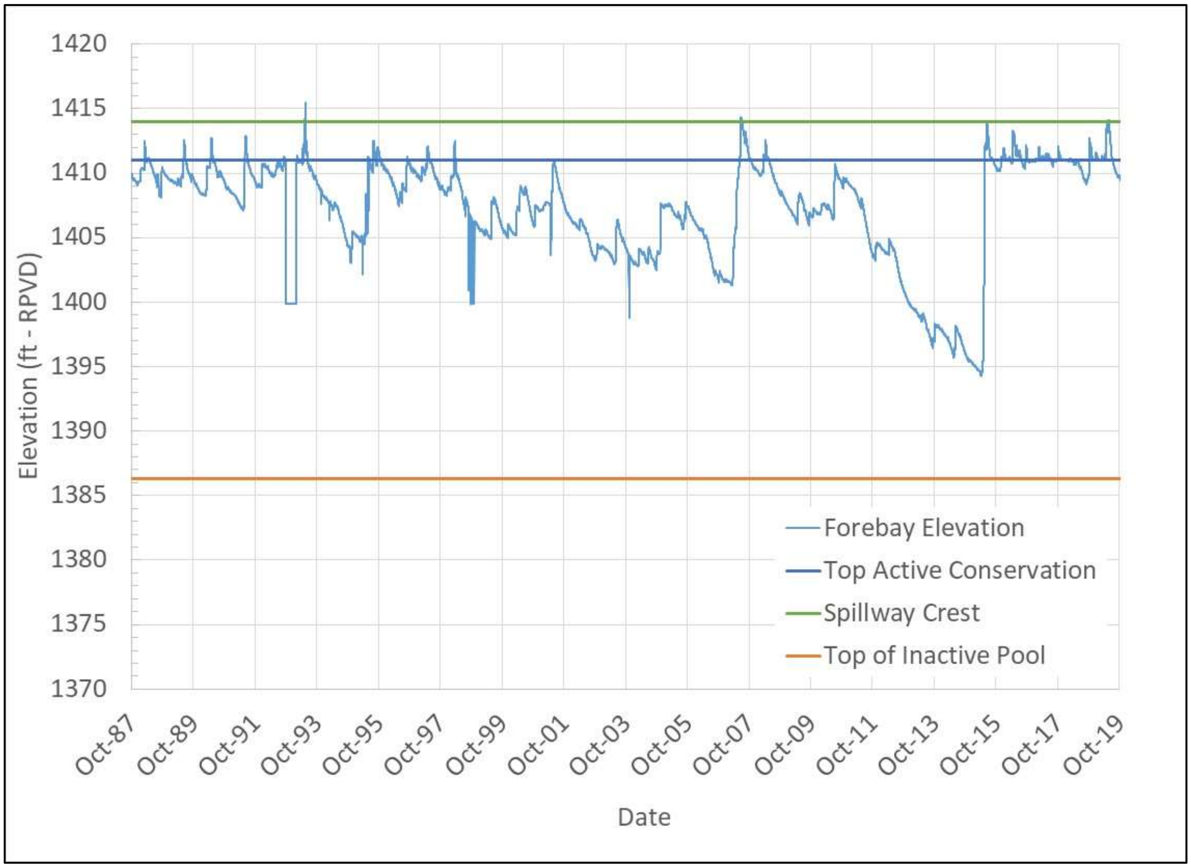

Figure 10. Historic Tom Steed Reservoir forebay water surface elevations (RPVD). Data web source: https://www.usbr.gov/gp/hydromet/archive.html

The reservoir is roughly 4.5 miles long with an average width of 2.2 miles at full pool with 2 main creeks (West Otter and Glen) entering upstream. The sedimentation patterns from each of these tributaries have the typical fan shape delta with the creek cutting a single path through the middle (Figure 11). The deltas appear to have progressed roughly 1 mile into the upper end of the reservoir (as of 2014). There is no record of past reservoir sediment management activities.

Figure 11. Google Earth imagery from 2014 showing exposed deltas on upper end of Tom Steed Reservoir from the two main tributaries.

3. Previous Reservoir Survey(s)

Prior to dam closure and initial reservoir filling, a survey was conducted to measure the original surface areas and corresponding storage capacities. Although the documentation summarizing the original survey methods has not been located for this analysis, USGS 24K (1:24,000 scale) Quadrangles were likely used to develop the original surface areas and capacities. A 10-foot contour interval map was produced from this original survey.

Another (single beam) survey was conducted from May 19 through 21 and June 1 through 4, 2009 (Ferrari, 2010) when the water surface elevation was at 1408.2 and 1408.4 ft (RPVD) using sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. Above-water topography was obtained by digitizing the reservoir's water edge from several years of aerial photographs collected by the U.S. Department of Agriculture (USDA). These digitized images enabled contours to be developed where boat access was not possible due to vegetation and shallow water conditions. This study assumed no change since the original survey at elevation 1412.0 ft and above. Since the June 1975 closure of Mountain Park Dam this survey only measured a slight total capacity change below elevation 1411.0 ft. The minimal measured change was likely due to accuracy differences between the original and 2009 data sets. This survey measured 8.6 ft of sediment accumulation near the dam. The original and subsequent reservoir surveys are described in Table 4.

Table 4. Previous Bathymetric Reservoir Surveys.

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1975	Full	Photogrammetry	NA	Photogrammetry
2009	Full	Sonic Depths	Single Beam	Photogrammetry

4. Survey Control and Datum

For the 2018 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD83) State Plane (horizontal) coordinates, Oklahoma South Federal Information Processing Standard Zone ID (FIPS) 3502, US survey feet and North American Vertical Datum 1988 (NAVD88 - Geoid 12A), US survey feet elevations. During analysis, all bathymetry and GPS measurements were converted to RPVD for Mountain Park Dam. The RPVD was determined to be equal to the National Geodetic Vertical Datum of 1929 (NGVD29) and 0.42 ft lower than NAVD88. A GPS base station receiver was set up over a temporary monument located roughly 0.5 mi directly north of the dam on an elevated bluff overlooking the reservoir (Figure 12).

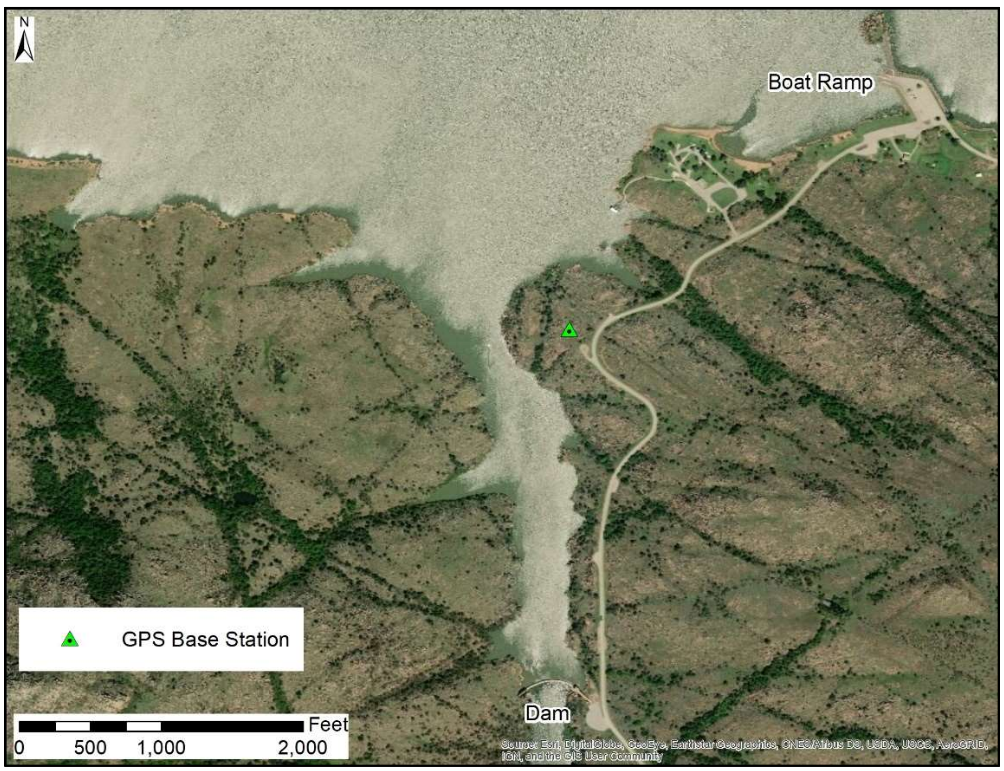

Figure 12. Location of GPS base station(s) along Tom Steed Reservoir.

State plane and elevation coordinates for the GPS base station were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). The RPVD at Tom Steed Reservoir was determined using RTK GPS measurements of the water surface elevations measured at the boat ramp. The difference between NGVD29 and NAVD88 at Mountain Park Dam was computed using the US Army Corps of Engineers conversion program Corpscon v6.0.1. Corpscon uses NGS data and algorithms to convert between various horizontal projections and vertical datums (www.agc.army.mil/Missions/Corpscon.aspx). The Corpscon calculations confirmed that NGVD29 is 0.42 ft lower than NAVD88 at the base station location.

5. Methods Summary

A complete bathymetric survey was conducted during May 2018 from a boat using a Teledyne® MB1 multibeam depth sounder to continuously measure water depths. The horizontal position of the moving boat was continually tracked using RTK GPS. A map of the data points collected is presented in Figure 13. The water surface elevation ranged from 1410.9 – 1410.94 ft (RPVD) at the time of collection (Reclamation Hydromet data).

The bathymetric data were combined with LiDAR data collected by the USGS in 2011 through 2012 used to represent the above-water reservoir topography. The data are available at the following website: https://viewer.nationalmap.gov/advanced-viewer/. Together these data sets were used to produce a digital surface of the reservoir bottom surface. Surface areas at 1-foot contour intervals were computed using GIS software that were input into a separate computer program (ACAP) used to produce reservoir surface area and capacity tables down to 0.01-foot increments.

Appendix A provides more details on the hydrographic survey methods. Appendix B provides more details about the methods used to generate surface area and storage capacity tables.

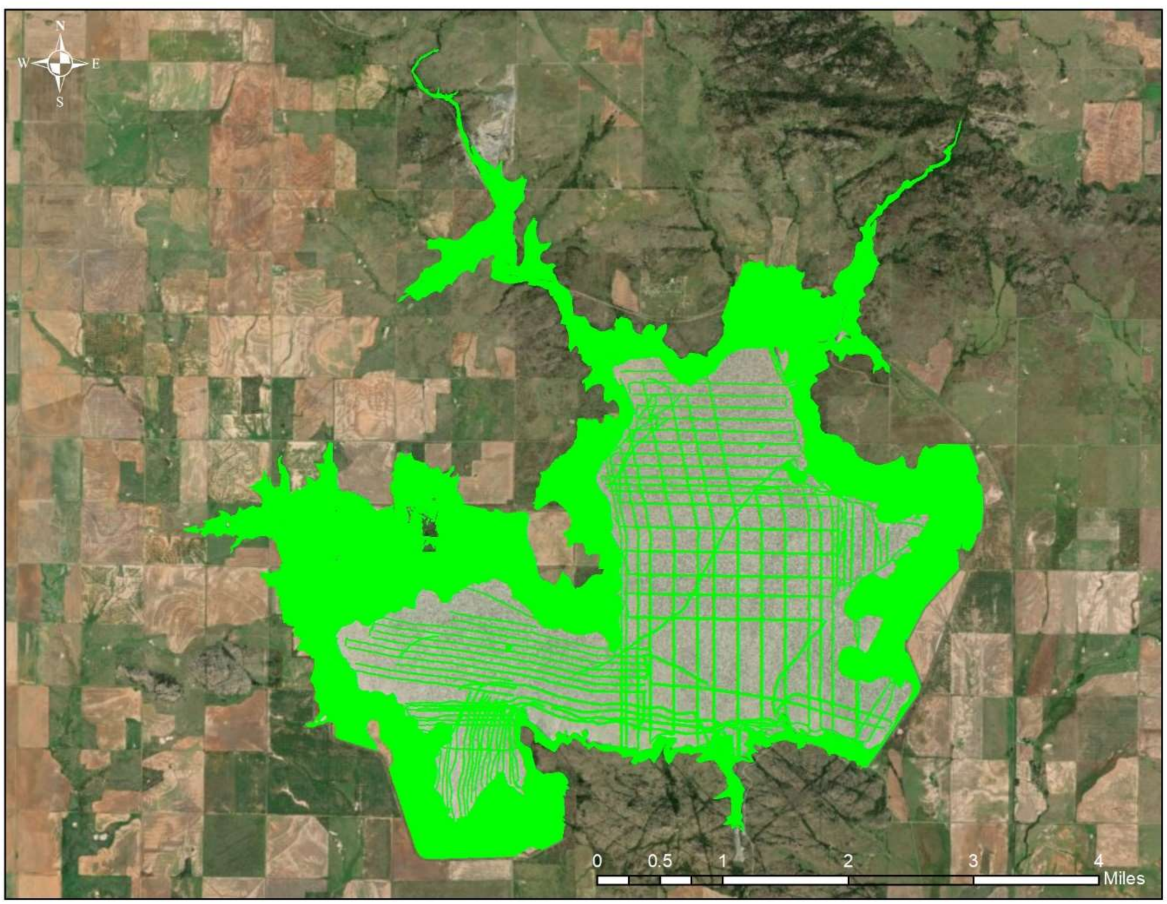

Figure 13. Map of bathymetric survey data coverage.

6. Reservoir Surface Area and Storage Capacity

Detailed tables of reservoir surface area and storage capacity for every 0.01 ft of elevation change were produced for the full range of reservoir elevations (Reclamation, 2019a). Plots of the 2018 area and capacity curves are presented in Figure 14 along with data from the 1975 and 2009 surveys. For the 2018 survey, area and capacity are based on the bathymetric (below-water) survey up to the 1405 ft elevation contour (RPVD), while area and capacity above this elevation are based on the 2011 through 2012 aerial LiDAR survey. A comparison (Table 5 and Table 6) of the 2009 and 2018 below-water (bathymetric) data shows little change between surveys, to the extent that it may not be real, and accounted for due to the difference in data collection methodology (single beam versus multibeam). Similarly, the difference in above-water surface areas and storage capacity volumes can likely be mostly accounted for by the different topographic data source and measurement techniques (photogrammetry versus LiDAR). However, some delta sedimentation and shoreline erosion has likely occurred between surveys.

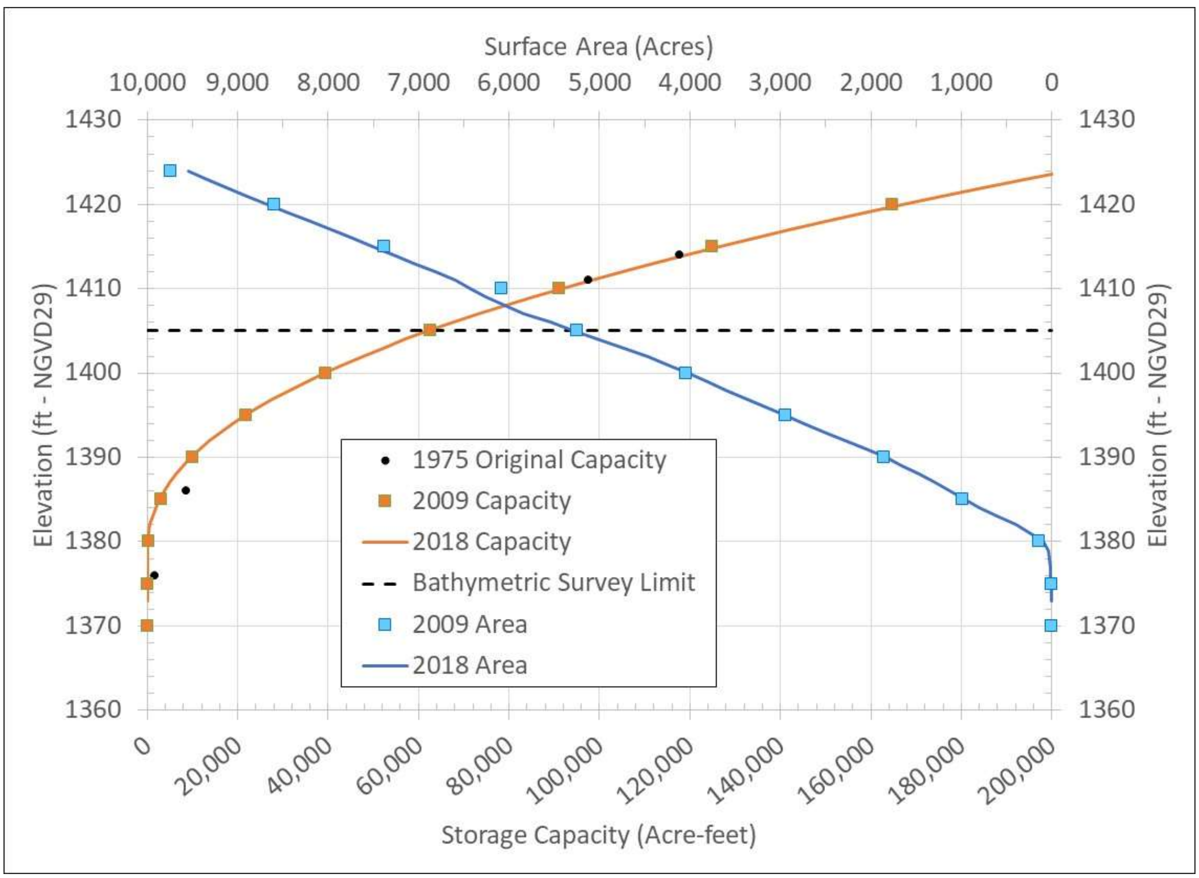

Figure 14. Plot of Tom Steed Reservoir surface area and storage capacity versus elevation.

Table 5. Capacity comparisons between last two surveys.

Elevation (ft)	2009 Capacity (acre-ft)	2018 Capacity (acre-ft)	Change (2018-2009)
1375	4	3	-1
1380	196	135	-61
1385	2,996	2,703	-293
1390	9,964	9,653	-311
1395	21,887	21,643	-244
1400	39,341	39,070	-271
1405*	62,593	62,181	-412
1410	91,101	91,736	635
1415	124,862	126,444	1,582
1420	164,807	166,854	2,047
1424	201,190	203,306	2,116

*2018 bathymetric survey limit

Table 6. Surface area comparisons between last two surveys.

Elevation (ft)	2009 Area (acres)	2018 Area (acres)	Change (2018-2009)
1375	5	5	0
1380	145	98	-47
1385	987	969	-18
1390	1,854	1,838	-16
1395	2,942	2,949	7
1400	4,040	4,015	-25
1405*	5,248	5,301	53
1410	6,079	6,430	351
1415	7,379	7,507	128
1420	8,599	8,670	71
1424	9,738	9,549	-189

*2018 bathymetric survey limit

7. Reservoir Sedimentation Volume Spatial Distribution

Longitudinal and representative cross section profiles of the 2018 reservoir bottom surface were developed in GIS along the alignments presented in Figure 15. The longitudinal profiles (Figure 16 and Figure 17) show that the slope is relatively uniform along the north-south arm before entering the canyon where the dam is located, and the slope becomes adverse. The east-west arm profile has more slope breaks along its path. Minor sediment accumulations are seen in both profiles since the last (2009) survey as you approach the dam.

The delta cross section profiles (Figure 18 and Figure 19) show multiple incoming channels along Delta 1, while Delta 2 is more uniform. This is indicative that more sediment is entering the reservoir in the north-south arm. All profiles show areas of minor (up to 1-ft thick) sediment accumulation and erosion since the last survey in 2009 with the overall volume change being negligible.

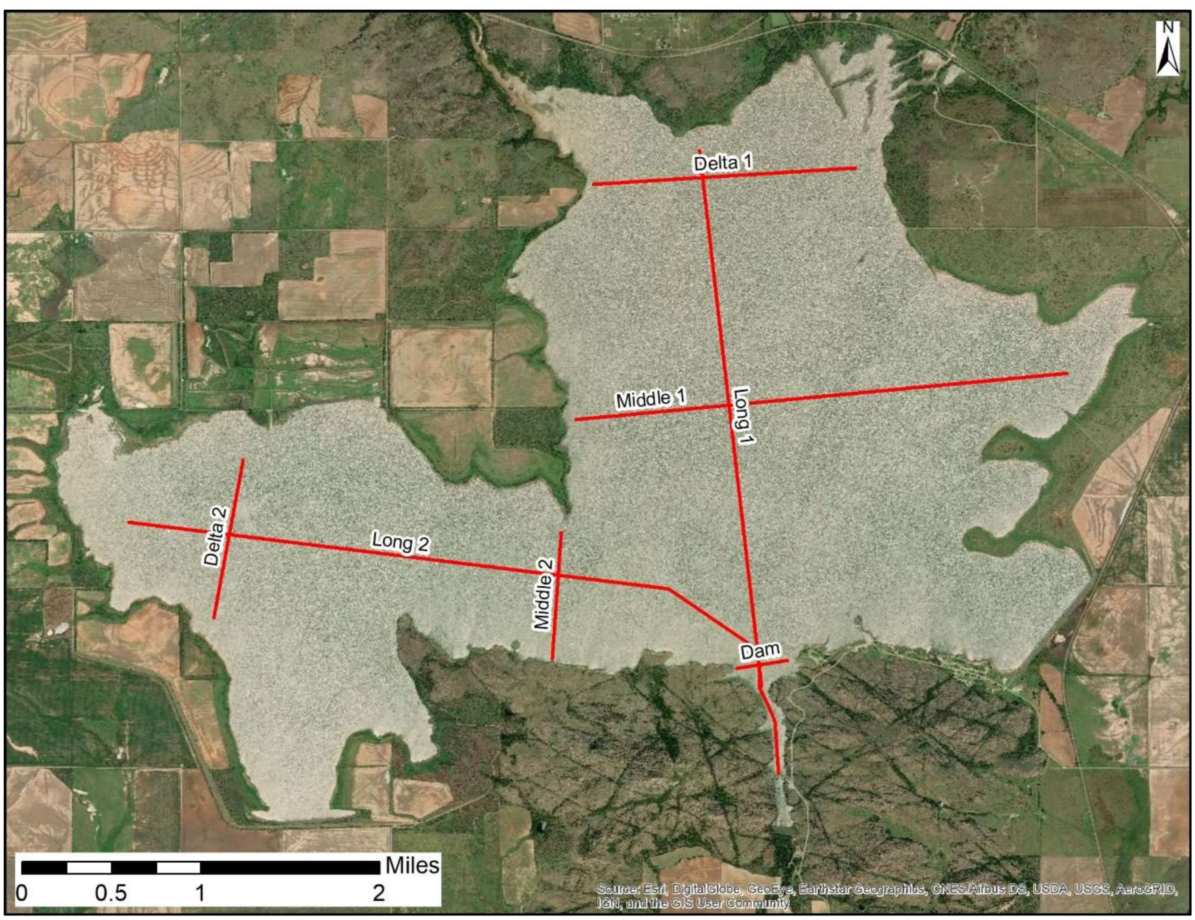

Figure 15. Location map of longitudinal and representative cross section profiles.

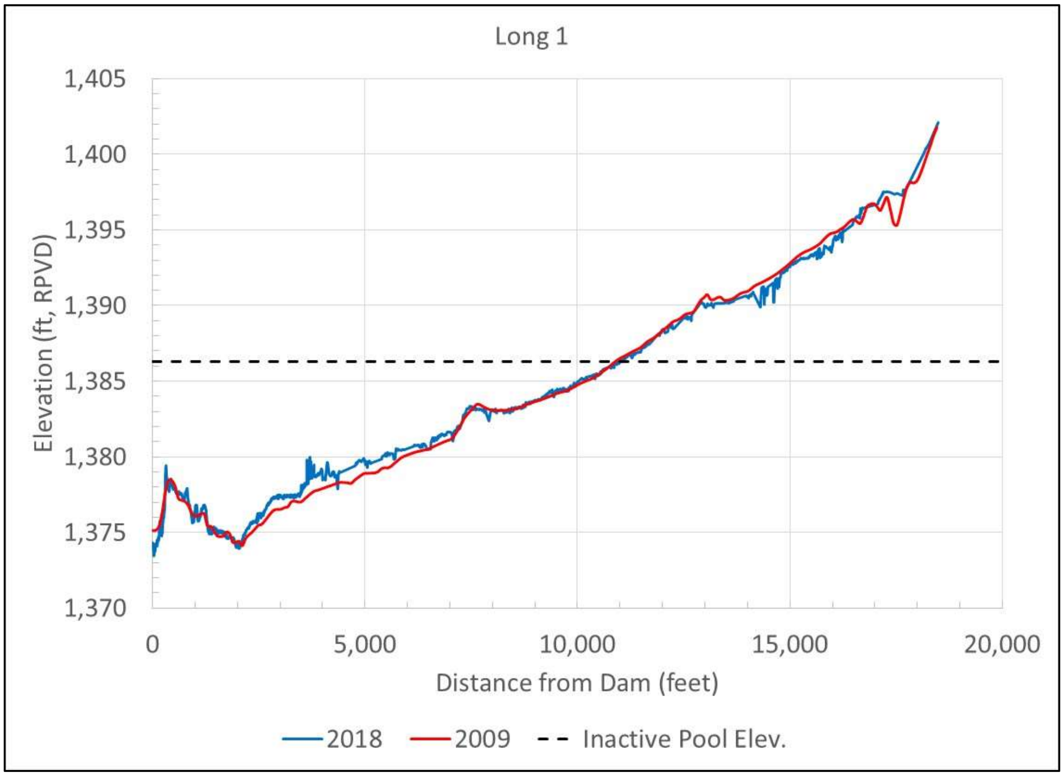

Figure 16. Longitudinal profile of Tom Steed Reservoir bottom as measured from the dam along Long 1 profile.

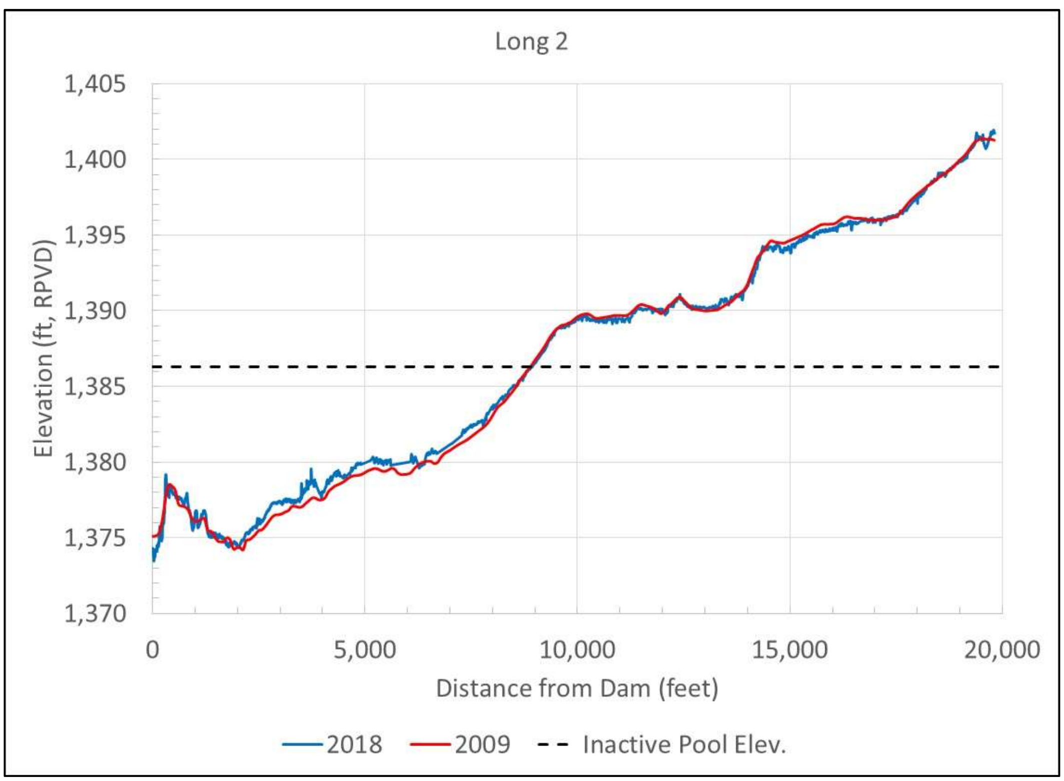

Figure 17. Longitudinal profile of Tom Steed Reservoir bottom as measured from the dam along Long 2 profile.

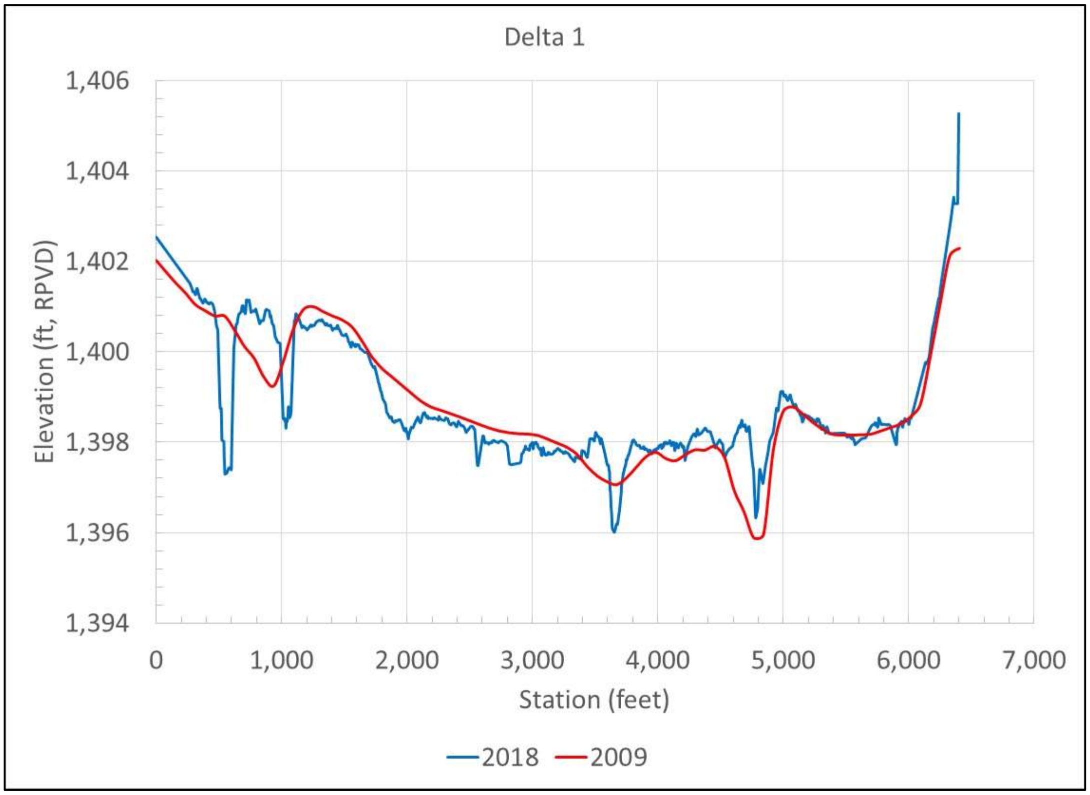

Figure 18. Cross section profile along Delta 1 line.

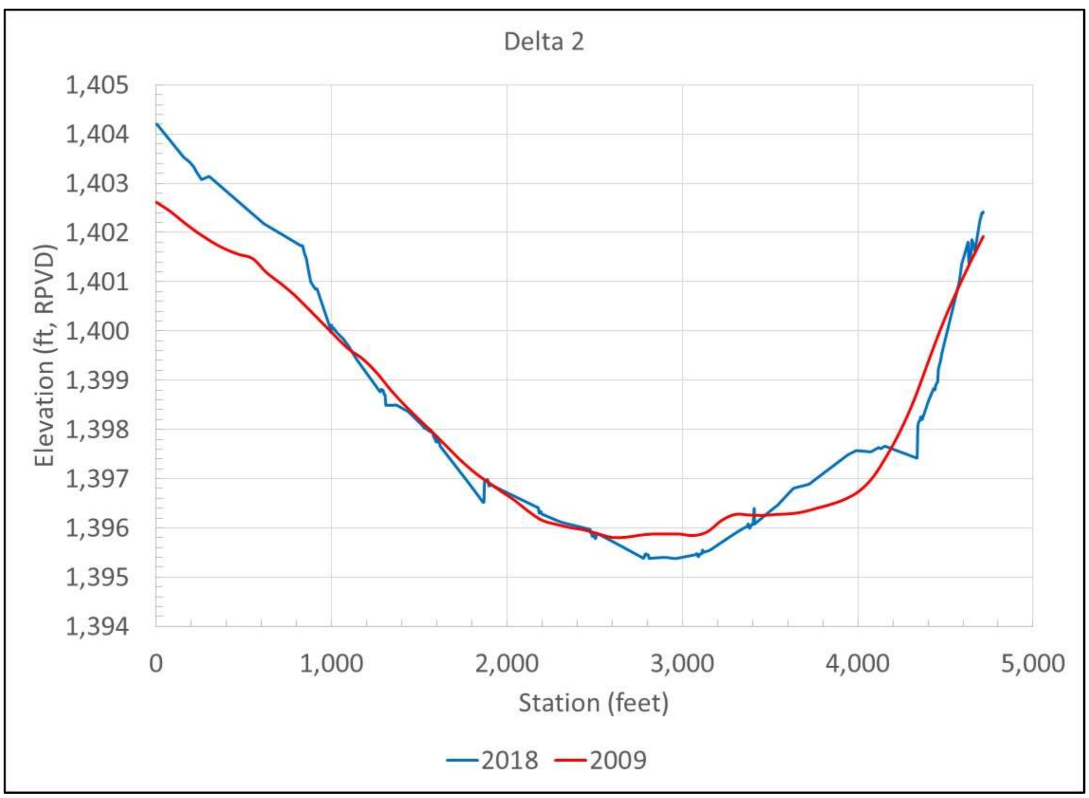

Figure 19. Cross section profile along Delta 2 line.

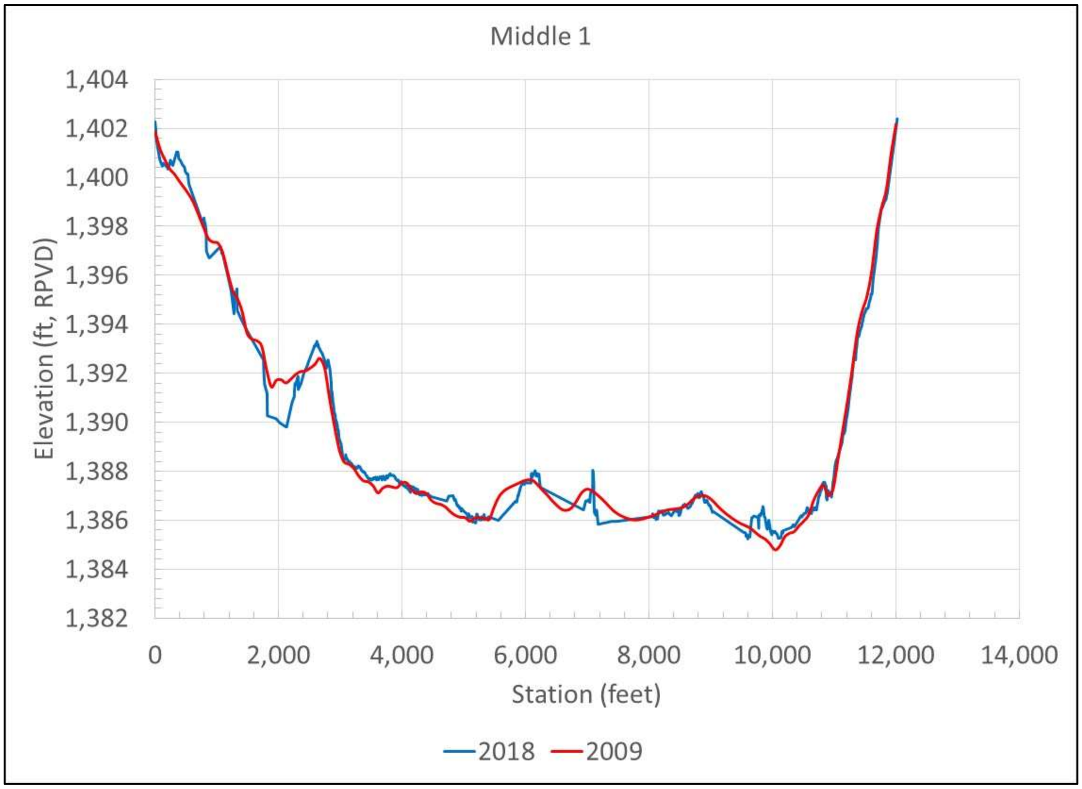

Figure 20. Cross section profile along Middle 1 line.

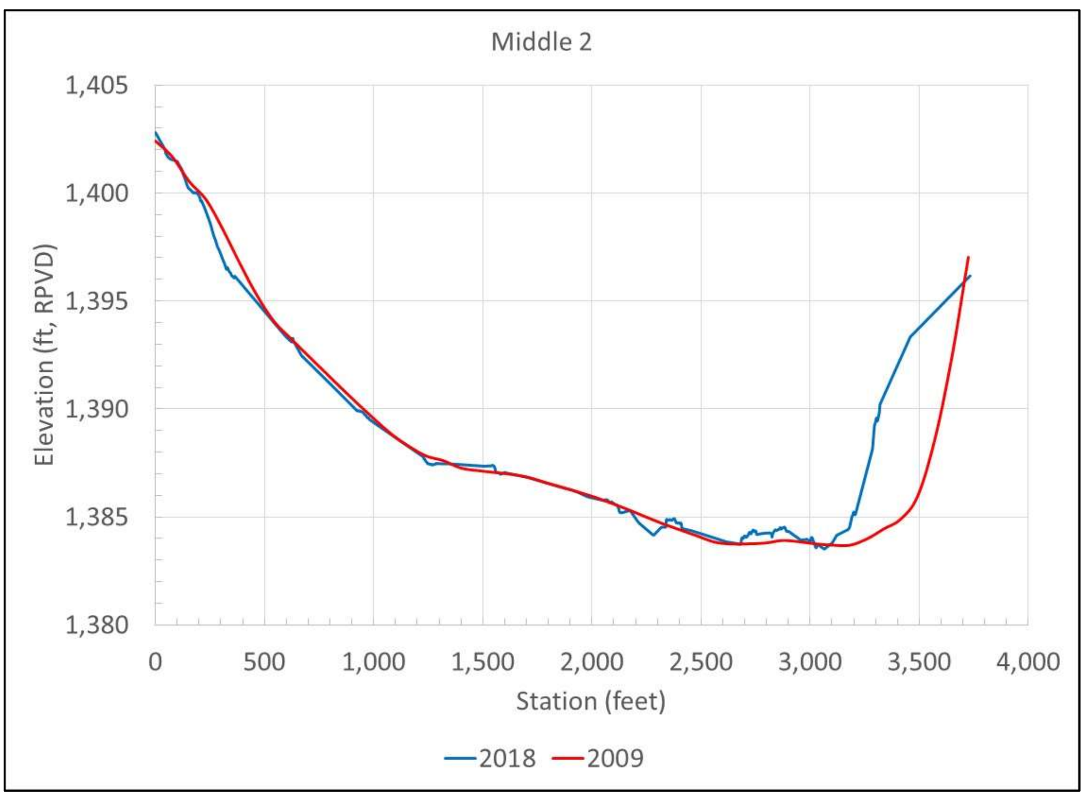

Figure 21. Cross section profile along Middle 2 line.

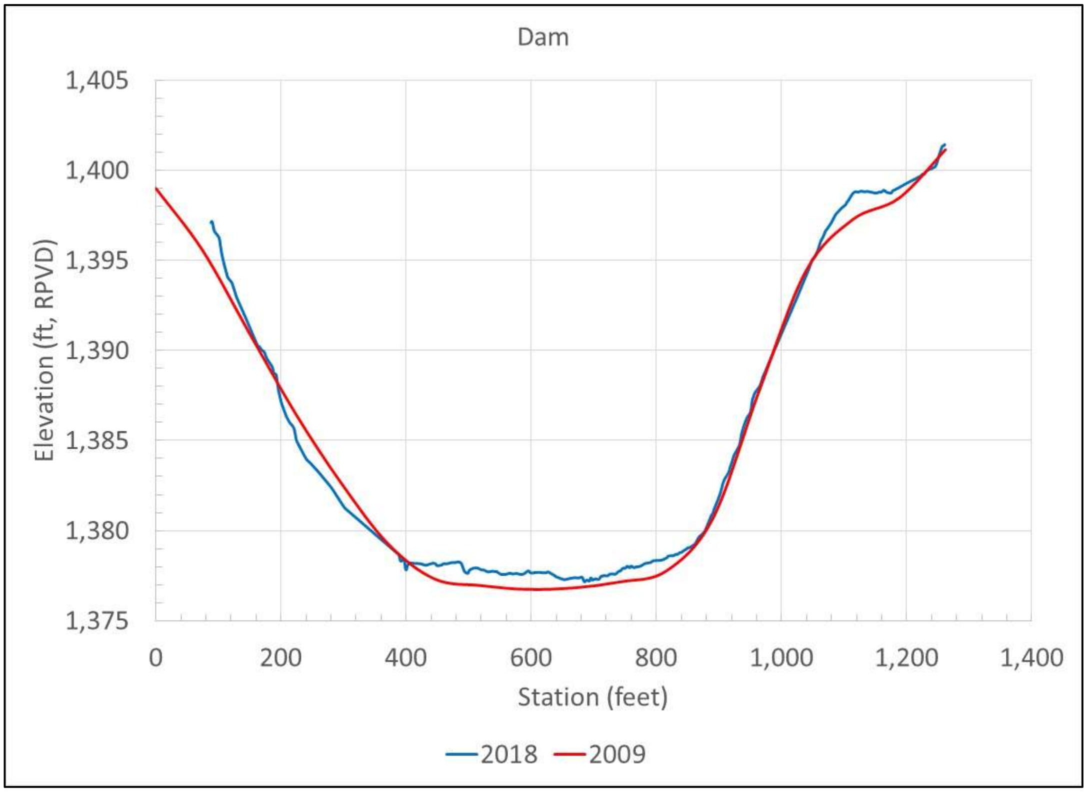

Figure 22. Cross section profile along Dam line.

8. Sedimentation Trends

The 2018 survey of Tom Steed Reservoir indicates minimal decreases in area and capacity of 25 acres and 271 acre-feet, respectively, at a water surface elevation of 1400 ft. Above elevation 1410 ft, area and capacity have increased slightly relative to both the original and 2009 surveys, likely due to the improved accuracy of the 2011 through 2012 LiDAR. The use of LiDAR data allowed for a more accurate measurement of surface area than was possible with coarser resolution data used in previous analyses, especially considering the many dikes and connected ponds at the upstream end of the reservoir. The biggest capacity differences have occurred within the inactive storage pool elevation (below 1386.3 ft). The inactive pool storage capacity has decreased by roughly half (8,550 to 4,115 ac-ft) since closure of the dam.

Sedimentation accumulates at all reservoir elevations throughout the spatial extent. Near the dam, sedimentation has increased the reservoir bottom elevation over time (Figure 23). Sediment has nearly filled the dead pool storage area (Figure 24).

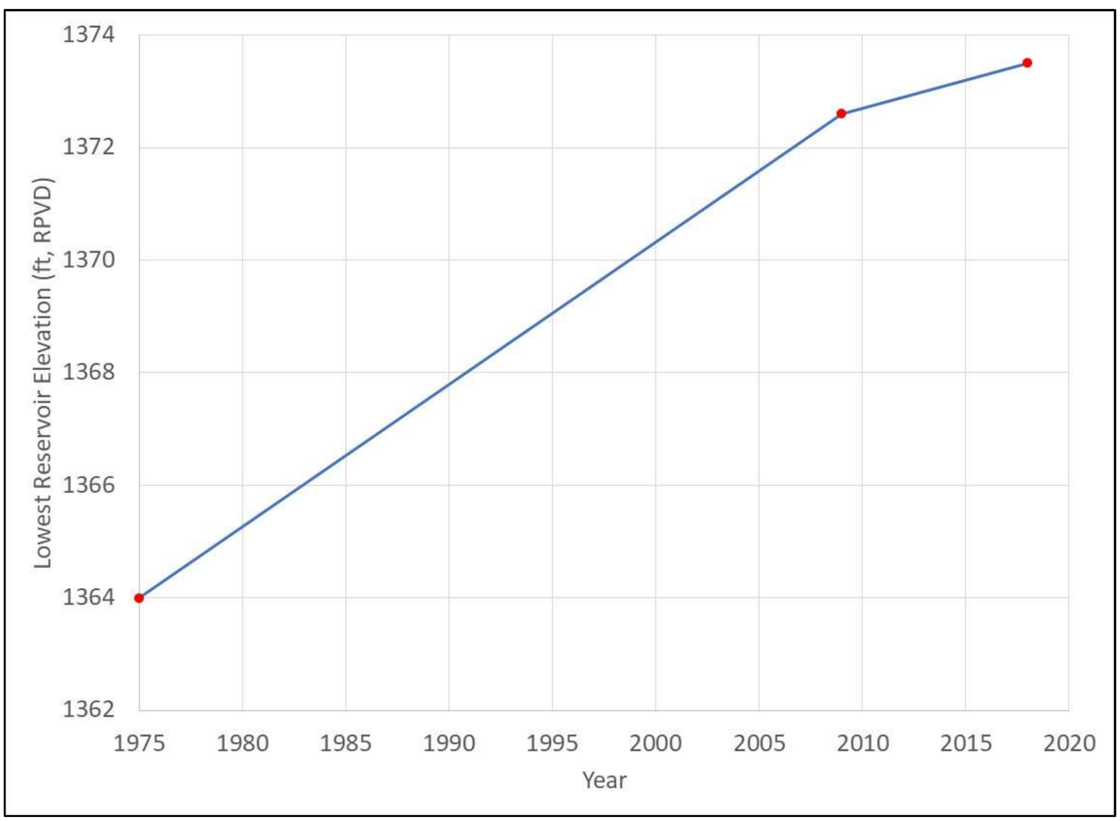

Figure 23. Sedimentation near the dam increasing the reservoir bottom elevation through time.

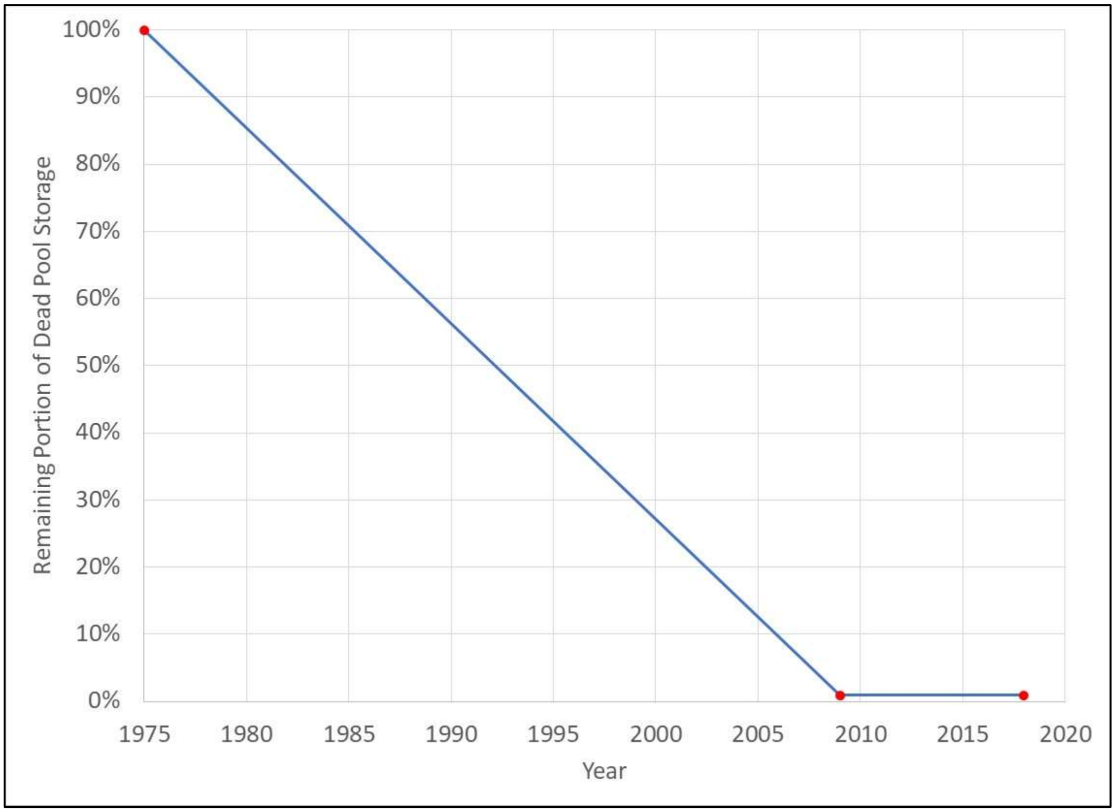

Figure 24. Sedimentation near the dam decreasing the dead pool storage capacity over time.

9. Conclusions and Recommendations

9.1. Survey Methods and Data Analysis

The 2018 bathymetric survey, combined with 2011 through 2012 LiDAR data of the above-water topography, has produced a digital surface of the reservoir bottom. Reservoir surface areas were computed from this digital surface to determine the 2018 storage capacity. Surface area and storage capacity were then interpolated at 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but also the differences in survey methods; the 2009 survey was conducted using single beam equipment whereas the 2018 survey utilized multibeam equipment. The latest surface area and storage capacity curves compare reasonably well with curves from the 2009 survey with the differences likely accounted for based on differences in data and survey methodology.

9.2. Sedimentation Progression and Location

The biggest differences with the original (1975) curves are reductions in capacity of the inactive storage pool (below 1386.3 ft). Sedimentation has decreased the inactive pool storage capacity by roughly half (8,550 to 4,098 ac-ft) since closure of the dam. Sediment deposits near the dam has increased the lowest portions of the reservoir by roughly 10 ft since dam closure filling in 99% of the original dead pool storage capacity. The lowest dam outlet may not be as reliable after the dead pool storage has filled with sediment because the future deposition of logs and sediment may accumulate on the trash rack.

9.3. Recommendation for Next Survey

The frequency of survey is partially dependent upon the risks imposed by loss of capacity and loss of operational flexibility. Based upon the minor changes to the active storage capacity, the next survey of Tom Steed Reservoir is recommended within 20 years of the last one, 2038. If, however, operations change at the dam and the reservoir is drawdown below the top of the inactive pool (1386.3 ft), then another survey is recommended soon after this operational change.

References

Ferrari, R.J., 2010. Tom Steed Reservoir – Mountain Park Dam 2009 Survey. Technical Report No. SRH-2010-3. U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado. March 2010.

Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey (WSS) geodatabase. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed (12/9/2019).

Reclamation, 1985. Surface Water Branch, ACAP85 User's Manual, Technical Service Center, Denver, CO.

Reclamation, 2019a. Tom Steed Reservoir 2018 Area and Capacity Tables. Mountain Park Project, Oklahoma. U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado. December 2019.

Reclamation, 2019b. Projects and Facilities Data, Mountain Park Project, available at: https://www.usbr.gov/projects/. Accessed 12/5/2019.

Reclamation Hydromet data. https://www.usbr.gov/gp/hydromet/archive.html. Accessed 12/12/2019.

State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States (ver. 1.1, August 2017): U.S. Geological Survey data release, https://doi.org/10.5066/F7WH2N65.

US Geological Survey, StreamStats, available online at: https://streamstats.usgs.gov/ss/ Accessed (12/11/2019).

Appendix A — Hydrographic Survey Equipment and Methods

The 2018 bathymetric survey was conducted from May 3 through 6. During this period, the reservoir water surface elevation ranged from 1410.9 to 1410.94 ft (RPVD).

The survey was conducted along a series of predetermined cross section, longitudinal, and shore line survey lines (Figure 13). The survey lines were spaced closely enough so there would overlapping coverage from the multibeam depth sounder or close enough that linear interpolation of data between survey lines would adequately represent the bottom surface.

The survey employed an 18-foot, flat-bottom aluminum Wooldridge boat powered by outboard jet and kicker motors) (Figure A-1). Reservoir depths were measured using a multibeam echo sounder that consisted of the following equipment:

- variable-frequency transducer with integrated motion reference unit,
- near-surface sound velocity probe,
- two GPS receivers to monitor the boat position and heading,
- an external GPS radio, and
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data.

Figure A-1. Wooldridge boat with RTK-GPS and multibeam depth sounder system.

The multibeam transducer emits up to 512 beams (user selectable) capable of projecting a swath width up to 120 degrees in 390 ft (120 meters) of water. Sound velocity profiles were collected over the full water depth at various locations throughout the reservoir. These sound velocity profiles measure the speed of sound through the water column, which can be affected by multiple characteristics such as water temperature and salinity. These sound velocity profiles were used to correct the depth measurements.

RTK GPS survey instruments were used to continuously track the survey boat and measure other ground control points. The GPS base station and receiver was set up on a tripod over a point overlooking the reservoir (Figure 12). The coordinates of this point were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). During the survey, position corrections were transmitted to the GPS rover receiver using an external GPS radio and UHF antenna (Figure A-2). The base station was powered by a 12-volt battery.

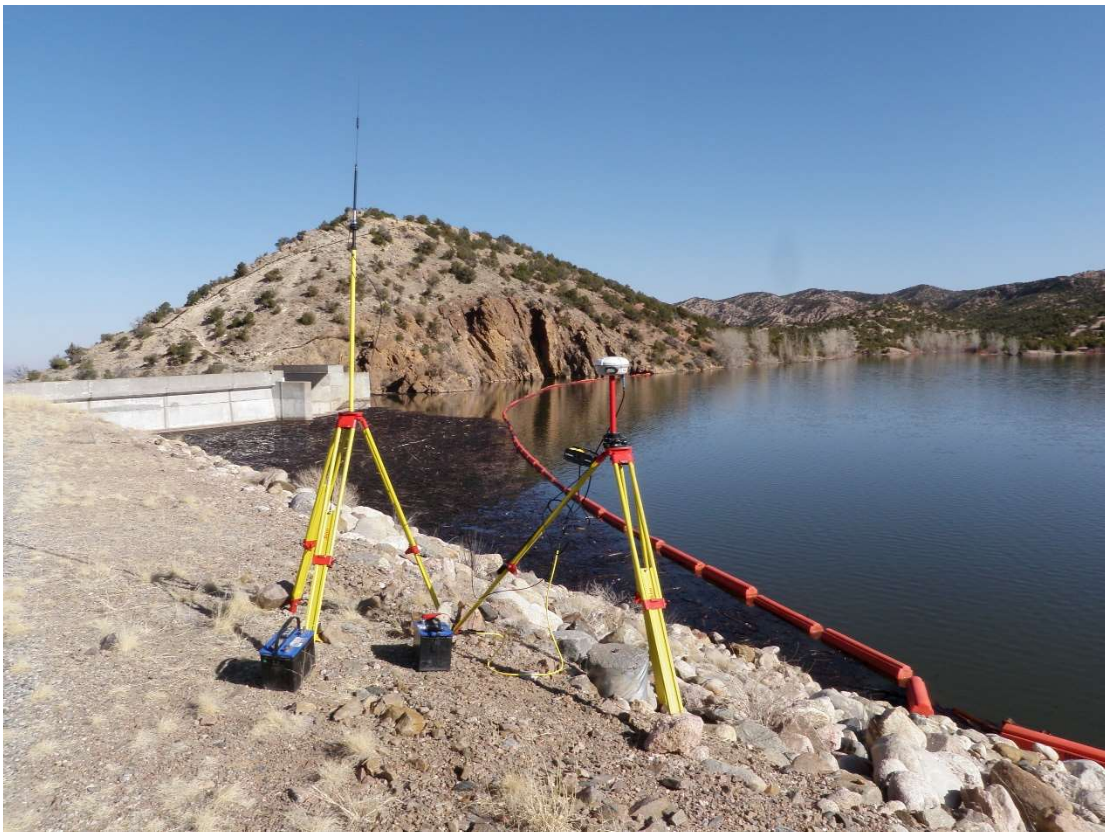

Figure A-2. The RTK-GPS base station set-up used during the Nambe Reservoir survey in New Mexico is typical of the set up used at Tom Steed Reservoir.

The GPS rover receivers include an internal radio and external antenna mounted on a range pole (ground survey) or survey vessel (bathymetric survey). The rover GPS units receive the same satellite positioning data as the base station receiver, and at the same time. The rover units also receive real-time position correction information from the base station via radio transmission. This allows rover GPS units to measure accurate positions with precisions of ±2 cm horizontally and ±3 cm vertically for stationary points and within ±20 cm for the moving survey boat.

During the bathymetric survey, a laptop computer was connected to the GPS rover receivers and echo sounder system. Corrected positions from one GPS rover receiver and measured depths from the multibeam transducer were transmitted to the laptop computer through cable connections to the processor box. Using real-time GPS coordinates, the HYPACK software provided navigational guidance to the boat operator to steer along the predetermined survey lines.

The HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the user selected coordinate system. Water surface elevations from dam gage records and RTK GPS measurements were used to convert the sonar depth measurements to reservoir-bottom elevations in the RPVD. The multibeam depth sounder generates hundreds of thousands of data points. Sometimes fish, underwater vegetation, or anomalies mean that a small portion of depth measurements do not represent the reservoir bottom and these data are deleted during the post processing. Processing of the bathymetric data and combining them with the 2011 through 2012 LiDAR data resulted in millions of data points that were used in the development of the final reservoir surface. Filtering of this large data file is necessary, so a raster surface was created in GIS with a 1-ft cell resolution. For each raster cell, the reservoir bottom elevation was assigned a median elevation of all available data points within that raster cell. The use of the median value reduces the influence of the highest and lowest elevations within each cell.

Appendix B — Computation of Reservoir Surface Area, Storage Capacity, and Sedimentation Volume

A digital surface of the reservoir bottom was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water LiDAR data. Horizontal surface areas were then computed at 1-ft increments, using functions within ArcGIS Pro, for the complete range of remaining reservoir elevations (1373.5 to 1405 ft, RPVD). These reservoir surface areas were then used in Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985), to compute the storage capacity at these increments and then interpolate surface areas and storage capacities at 0.01-ft increments between each 1-ft interval.

The program uses the least squares method to predict the reservoir storage capacity between 1-ft intervals using the following equation over a certain elevation interval:

$$V = A_1 + A_2(y - y_b) + A_3(y - y_b)^2$$

where: V = storage capacity (acre-feet)
y = reservoir elevation
y_b = reservoir elevation at bottom of elevation increment
A_1 = intercept and storage capacity at elevation y_b (acre-feet)
A_2 = surface area at elevation y_b (acres) and coefficient for linear rate of increase in storage capacity
A_3 = coefficient (feet) for nonlinear rate of increase in storage capacity

The reservoir surface area is computed from the derivative of the volume equation:

$$S = A_2 + 2A_3(y - y_b)$$

where: S = surface area (acres)

This method ensures that the given surface areas, and corresponding storage capacities, at the 1-ft intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-ft intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in the report (Reclamation, 2019a).

The sedimentation volume can be computed by subtracting digital surfaces of the predam reservoir surface from the 2018 digital reservoir surface. However, a predam topographic map and surface digital is not available for Tom Steed Reservoir. The next option is to subtract the storage volume curve produced from the predam surface from the storage volume curve of the 2018 surface. This method works well when the topographic map of the predam surface has good accuracy and precision. The accuracy and precision of the original storage capacity curve is unknown for Tom Steed Reservoir. In this case, the original topographic map may have underestimated the actual storage capacity that resulted in the 2018 survey showing an increased overall flood control (1414 ft) storage capacity even though reservoir sedimentation has likely reduced the actual storage capacity. Comparison of predam and post dam digital surface maps can help reveal these problems and provide ideas for correcting the original surface maps.

Appendix C – Contour Maps

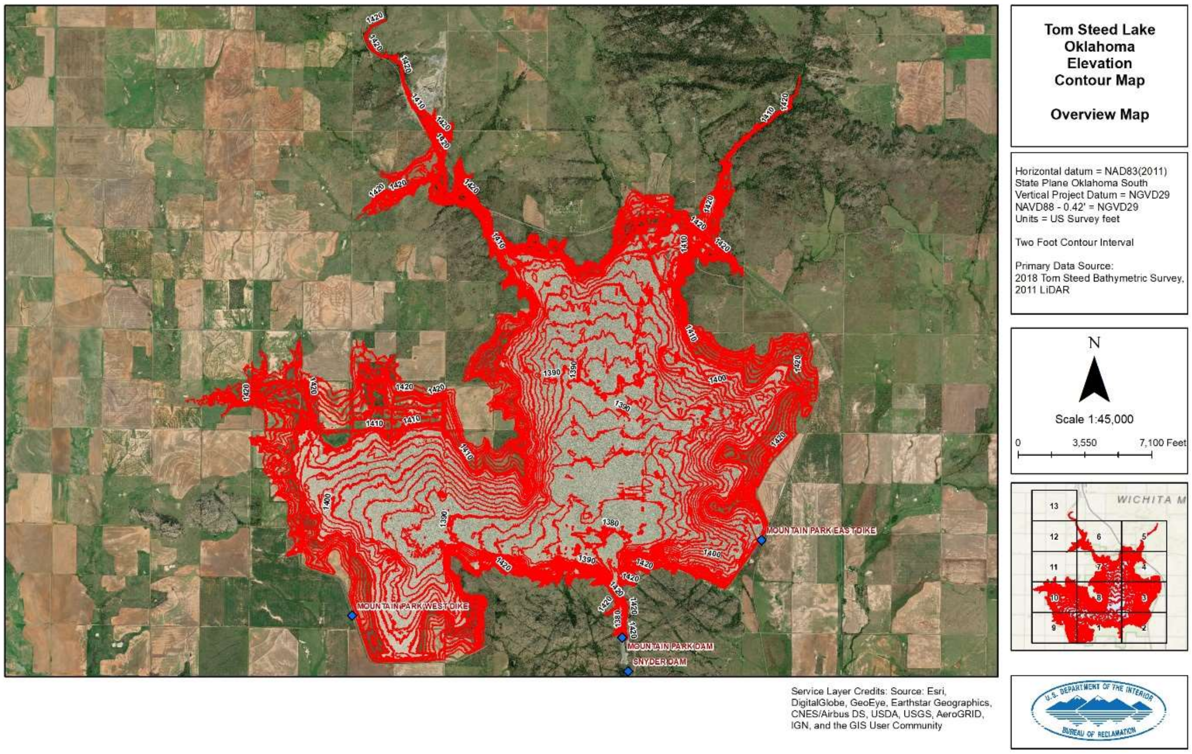

Figure C-1. Contour overview map for Tom Steed Reservoir.

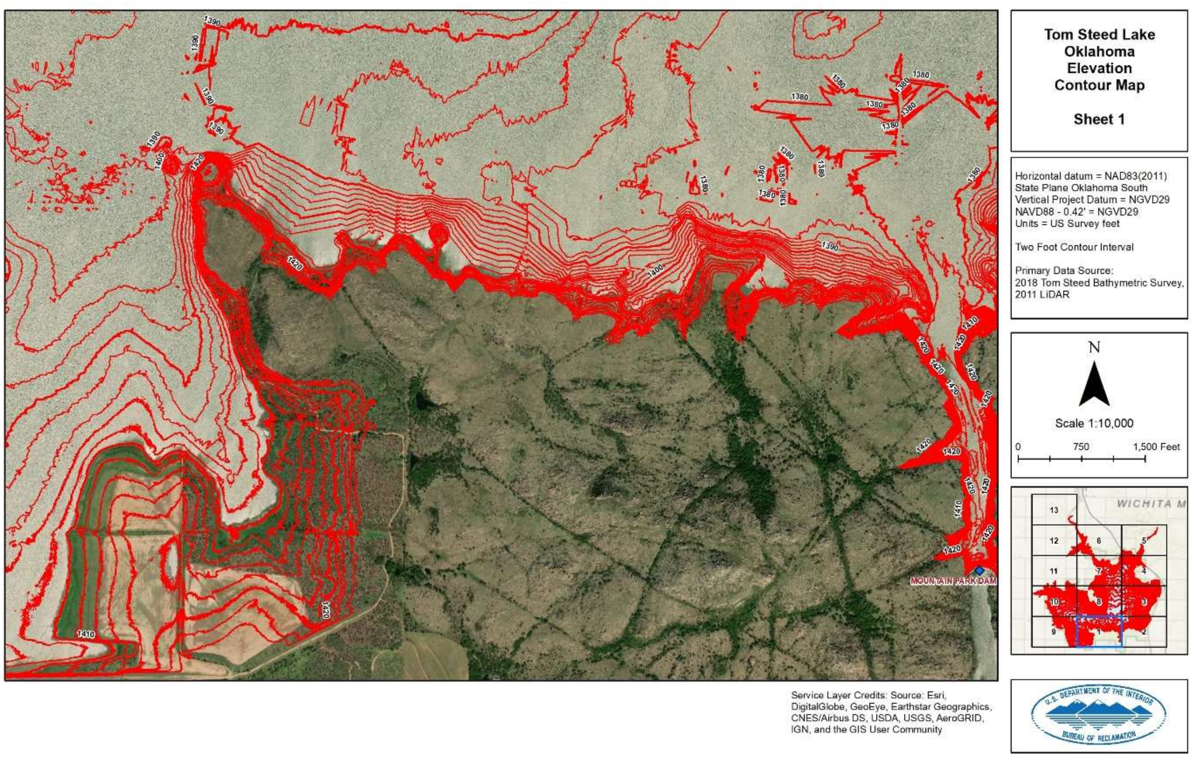

Figure C-2. Contour map sheet 1 of 13 for Tom Steed Reservoir.

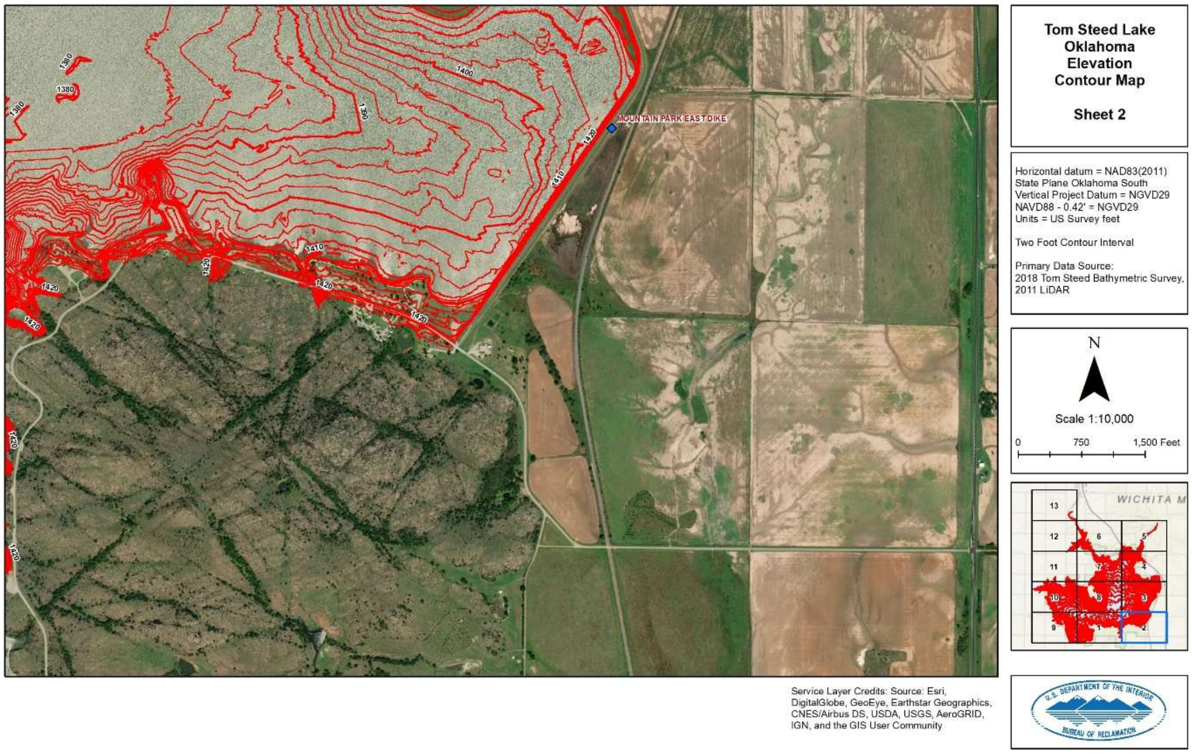

Figure C-3. Contour map sheet 2 of 13 for Tom Steed Reservoir.

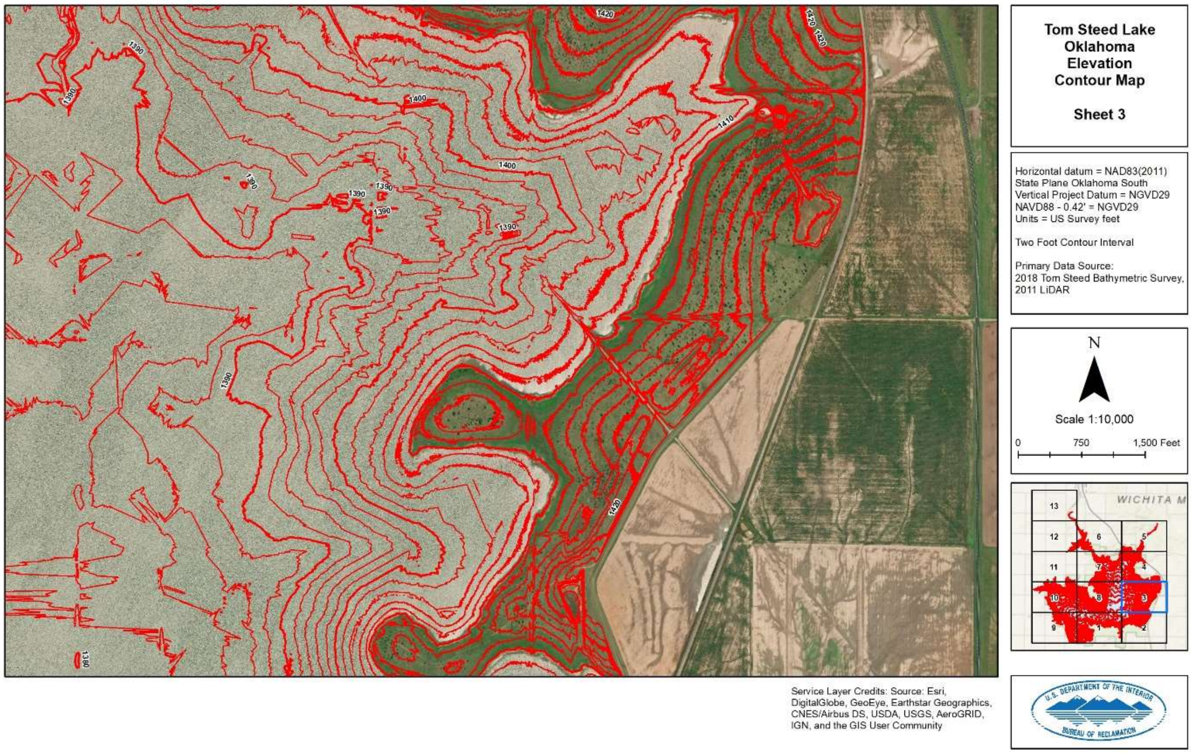

Figure C-4. Contour map sheet 3 of 13 for Tom Steed Reservoir.

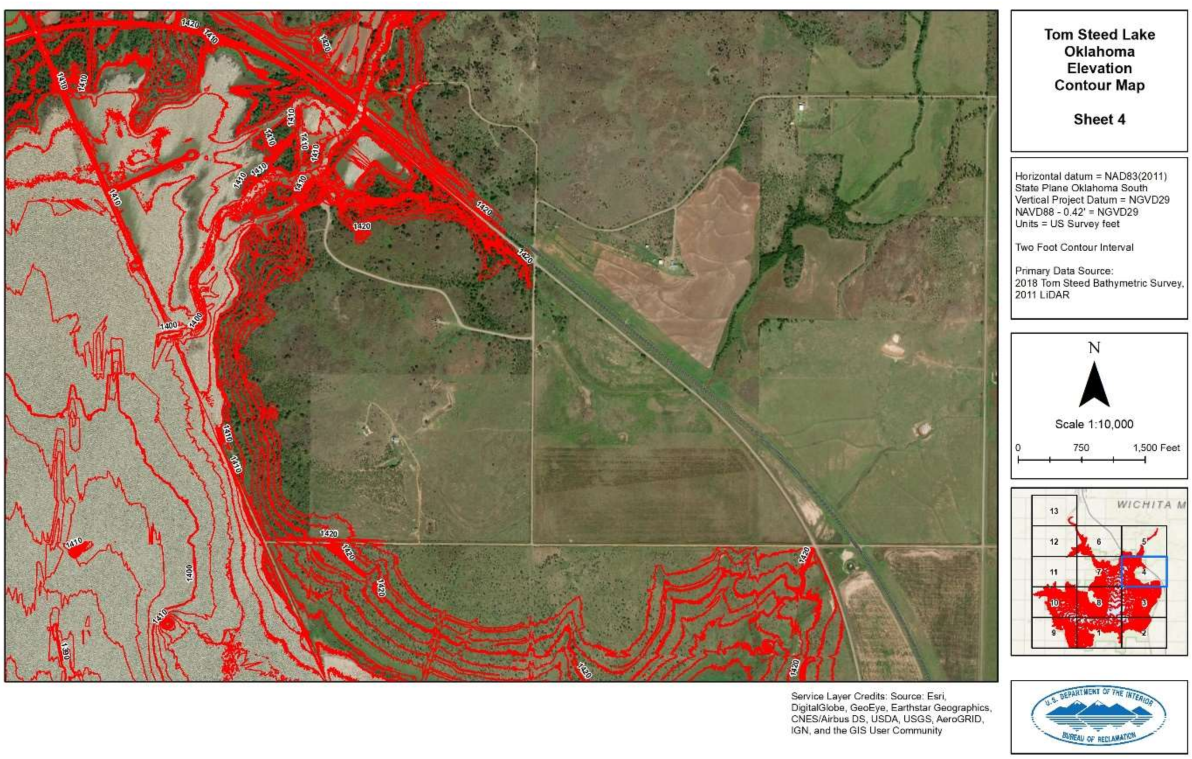

Figure C-5. Contour map sheet 4 of 13 for Tom Steed Reservoir.

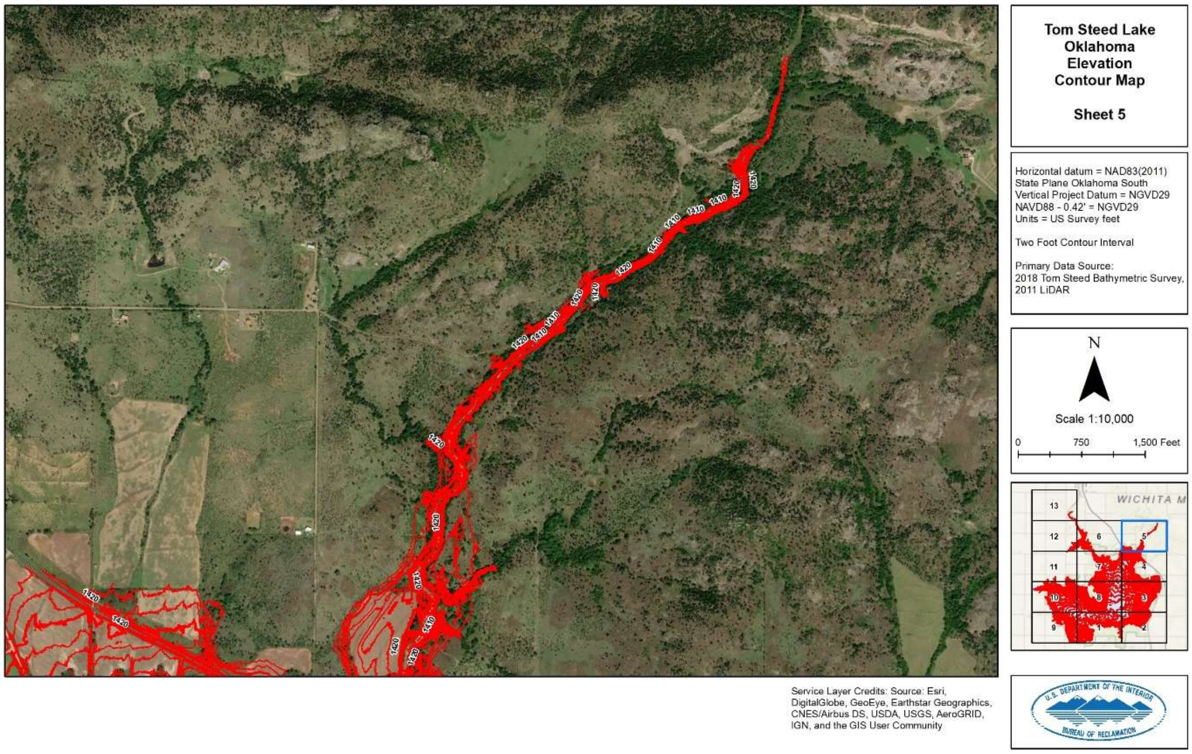

Figure C-6. Contour map sheet 5 of 13 for Tom Steed Reservoir.

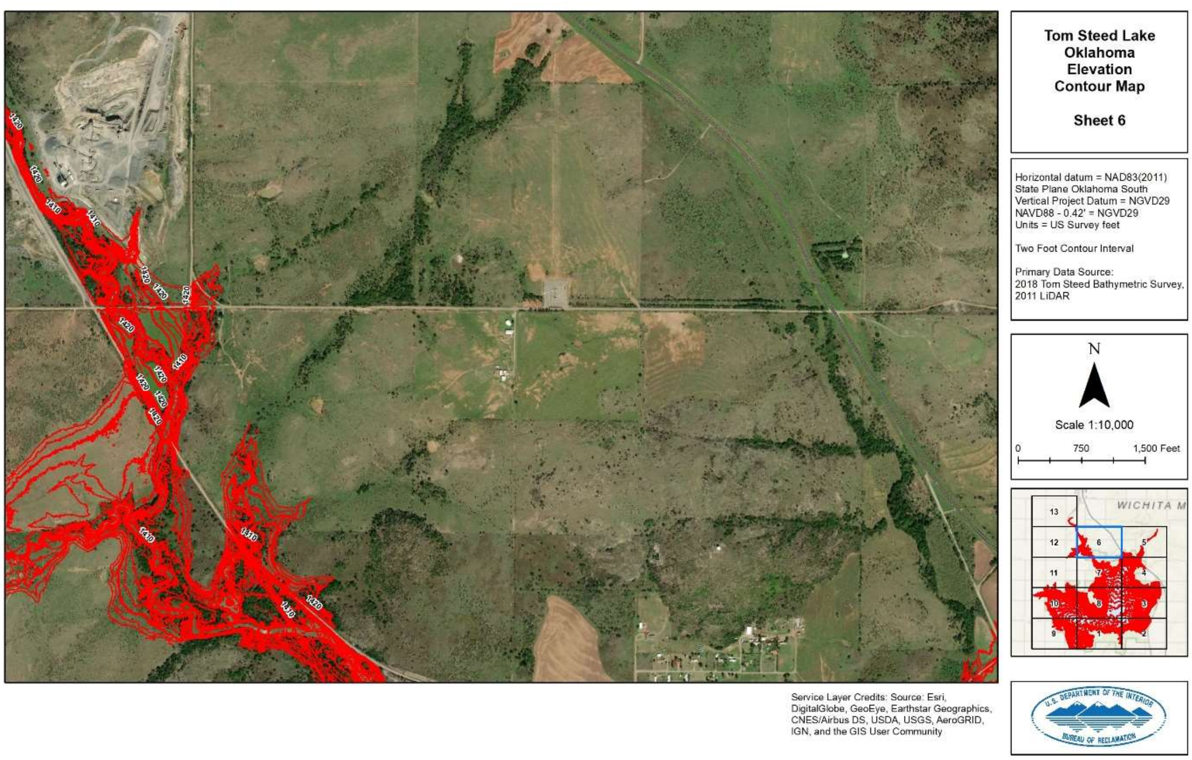

Figure C-7. Contour map sheet 6 of 13 for Tom Steed Reservoir.

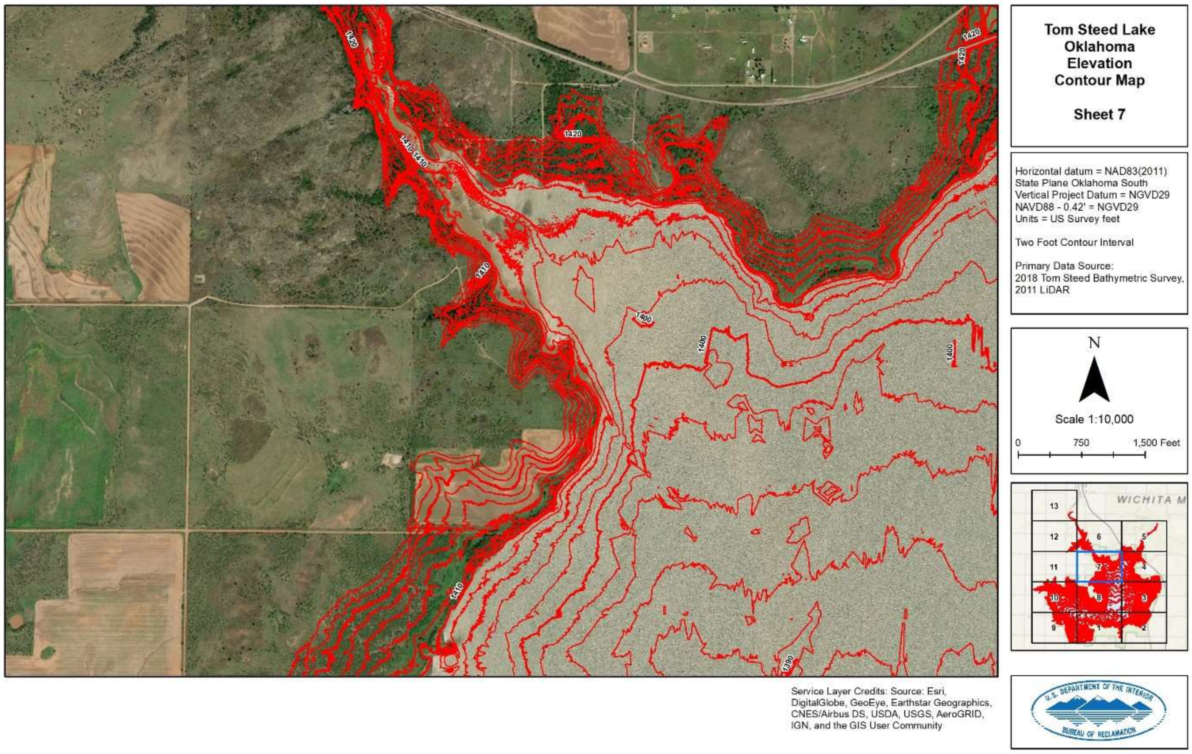

Figure C-8. Contour map sheet 7 of 13 for Tom Steed Reservoir.

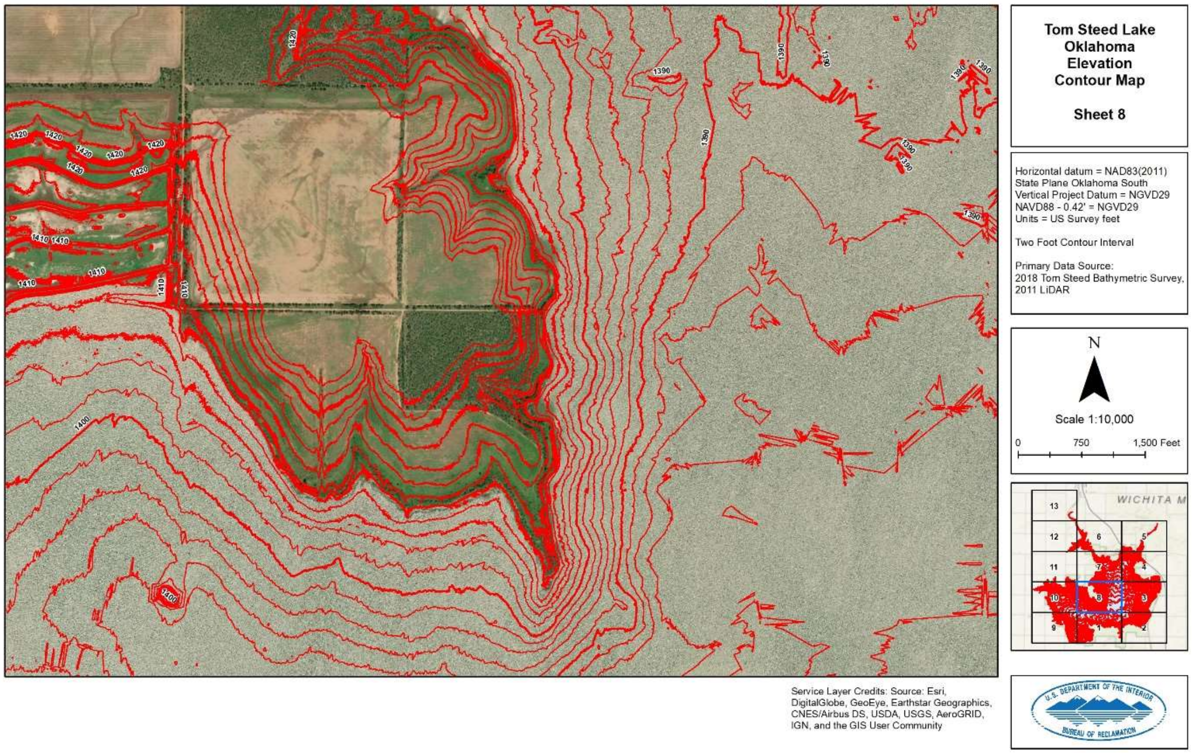

Figure C-9. Contour map sheet 8 of 13 for Tom Steed Reservoir.

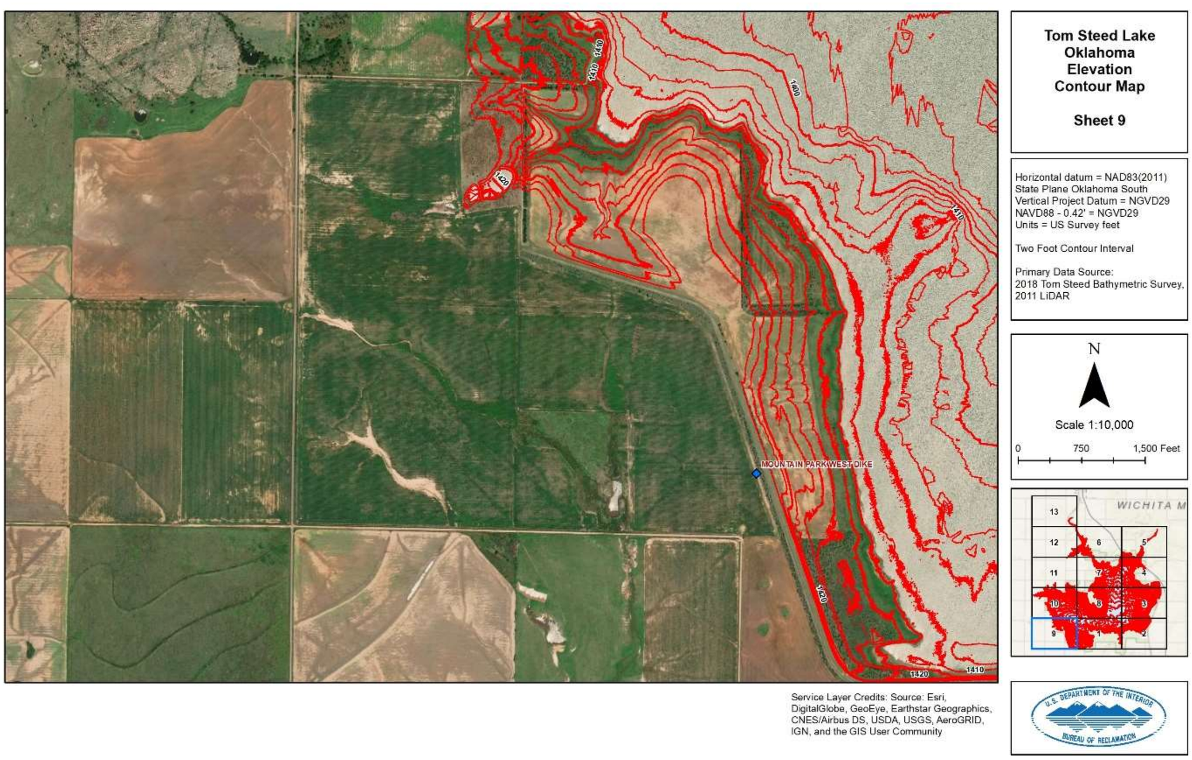

Figure C-10. Contour map sheet 9 of 13 for Tom Steed Reservoir.

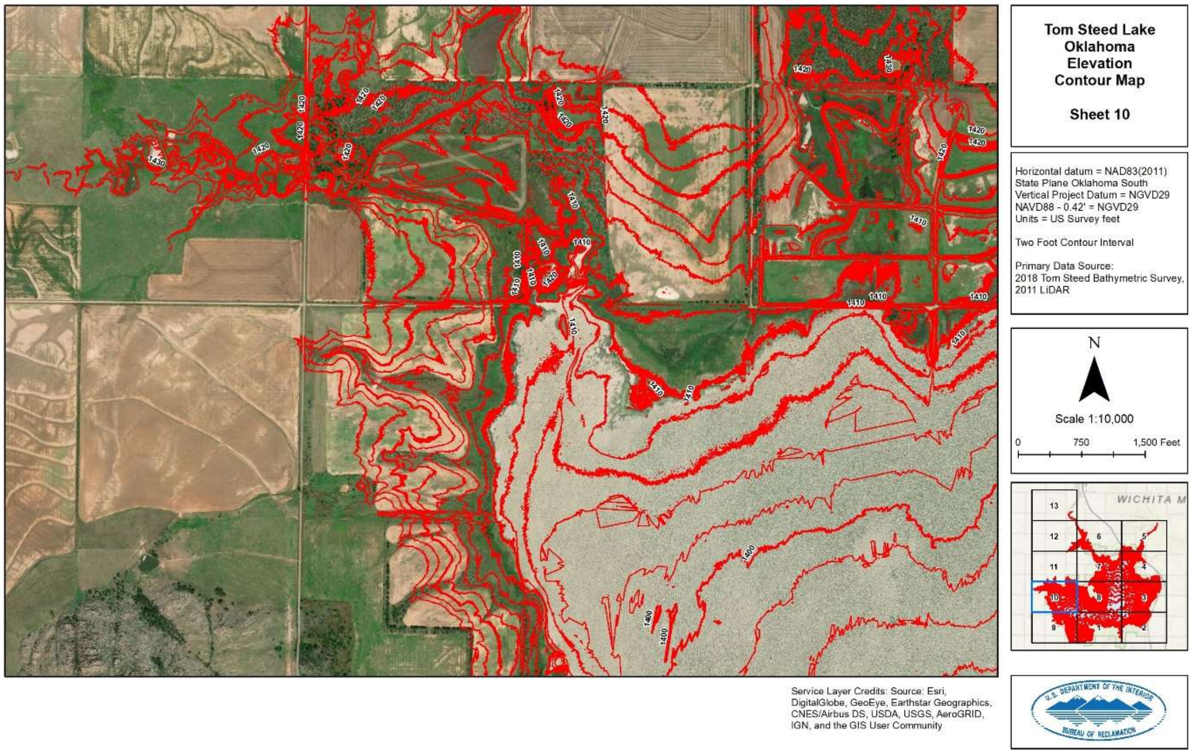

Figure C-11. Contour map sheet 10 of 13 for Tom Steed Reservoir.

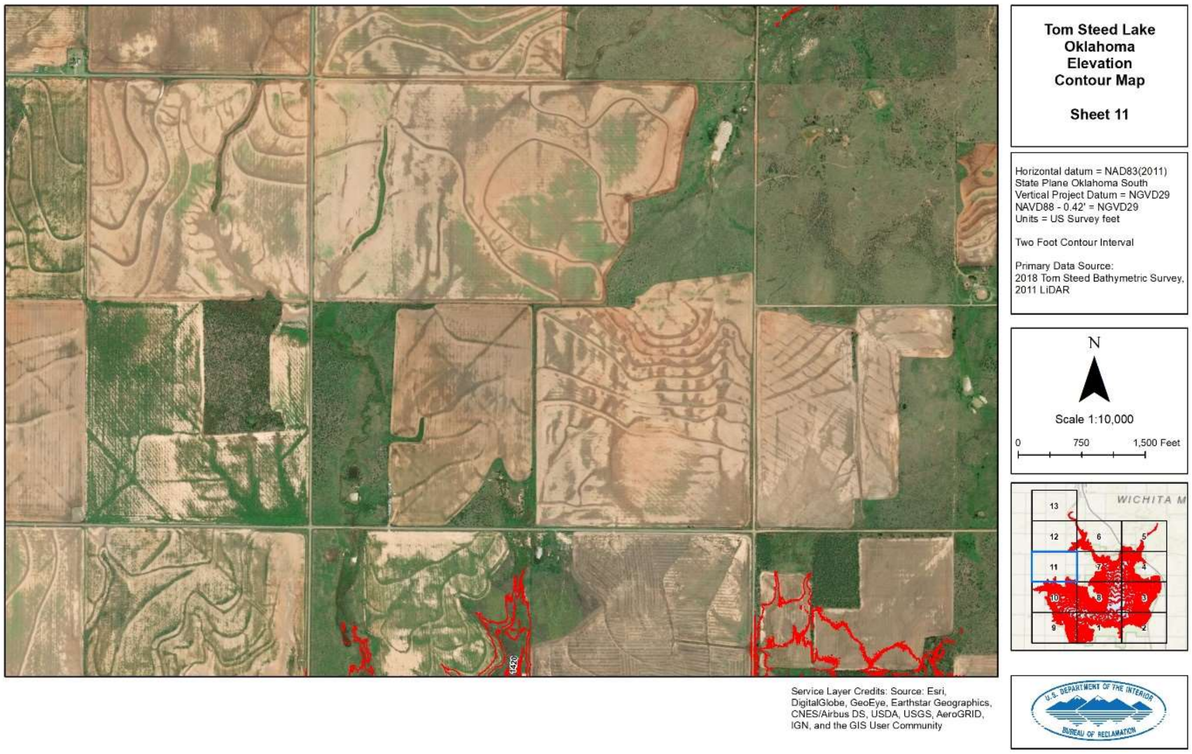

Figure C-12. Contour map sheet 11 of 13 for Tom Steed Reservoir.

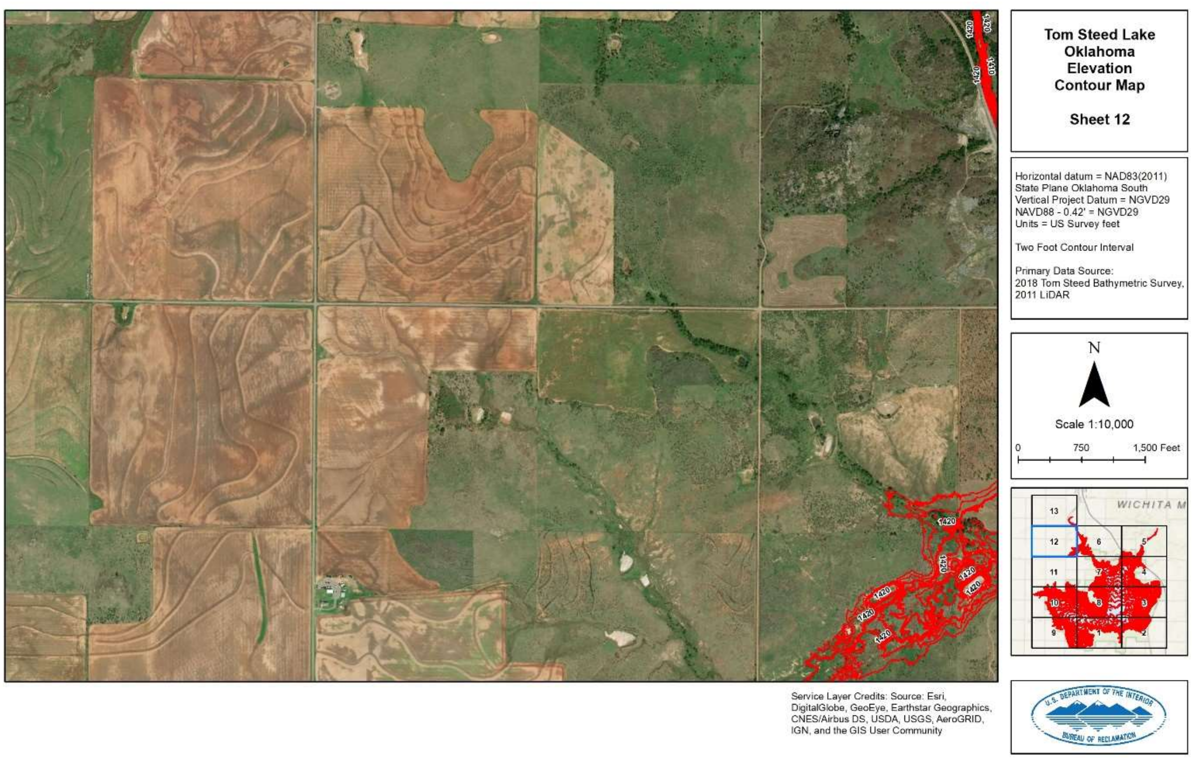

Figure C-13. Contour map sheet 12 of 13 for Tom Steed Reservoir.

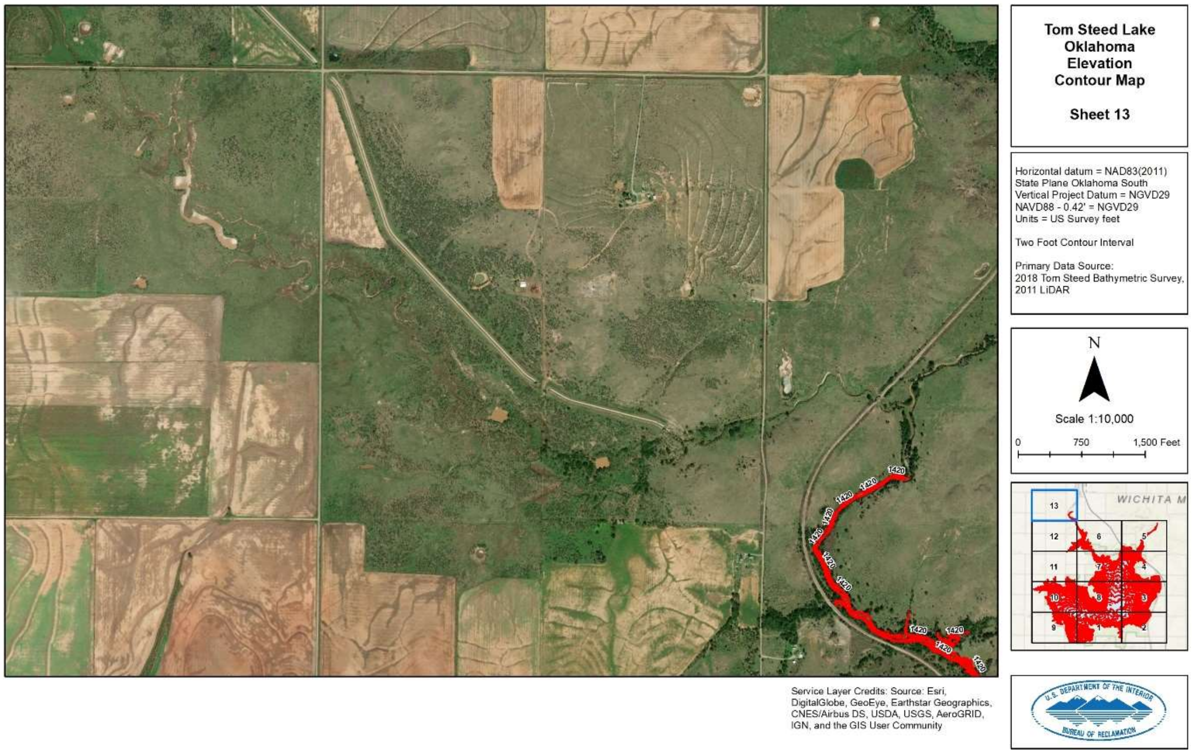

Figure C-14. Contour map sheet 13 of 13 for Tom Steed Reservoir.