Technical Report No. ENV-2020-008

Lake Altus 2018 Sedimentation Survey

W.C. Austin Project, Oklahoma
Great Plains Region

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

February 2020

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Disclaimer

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The 2018 multibeam bathymetric survey of Lake Altus was combined with contour data from the National Elevation Database (NED) to produce a combined digital surface of the reservoir bottom. Analysis of these data indicate that at the top of flood control pool elevation (1562 feet, project vertical datum = NGVD29), the reservoir has a surface area of 6,853 acres and a storage capacity of 147,925 acre-feet (NGVD29). Previous studies state the total capacity at the top of the active conservation pool, 1559 feet (NGVD29), at which the 2018 survey indicates a surface area of 6,164 acres and a capacity of 128,410 acre-feet. Since the original filling in 1940, the reservoir is estimated to have lost 30,817 acre-feet of storage capacity (16%) due to sedimentation (at elevation 1,564 ft). The dead storage pool volume has reduced to 11.7 percent of the original dead storage volume. The sedimentation level at the dam is approximately 1,512.5 feet (NGVD29).

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Technical Report No. ENV-2019-008

2018 Lake Altus Survey

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Acronyms and Abbreviations

ATV	All Terrain Vehicle
cfs	cubic feet per second
DOI	Department of the Interior
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
NAD 1983	North American Datum, established 1983
NGVD 1929	National Geodetic Vertical Datum, established 1929
NGVD 1988	National Geodetic Vertical Datum, established 1988
NRCS	Natural Resources Conservation Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RSI	Reservoir Sedimentation Information
RTK	Real-Time Kinematic
TSC	Technical Service Center
USGS	U.S. Geological Survey

Executive Summary

Altus Dam and Lake Altus are on the North Fork of the Red River about 110 miles southwest from Oklahoma City, OK and 18 miles north from Altus, OK.

A bathymetric survey of Lake Altus was conducted in May 2018 with two primary objectives:

1. estimate reservoir sedimentation volume since the original reservoir filling began in 1940 and since the last survey in 2007 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 Lake Altus was combined with LiDAR data to produce a combined digital surface of the reservoir bottom.

This survey was conducted May 7 through May 10, 2018 when the reservoir water surface elevation ranged between 1,552.9 and 1,552.95 feet (NGVD29), 6 feet below the top the active conservation pool elevation (1,559.0 ft, NGVD29).

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 1,548 feet (NGVD29), which is 5 feet below water at the time of survey, the reservoir surface area was 4,125 acres with a storage capacity of 72,770 acre-feet.

- At the top of flood control pool elevation (1,562.0 feet, NGVD29), the reservoir has a surface area of 6,853 acres and a storage capacity of 147,925 acre-feet.

- Since the original filling of the reservoir in 1940, the reservoir is estimated to have lost 30,817 acre-feet due to sedimentation (evaluated at the top of the gates, elevation 1,564 ft). Since initial filling the reservoir has lost 28,258 acre-ft of storage capacity (18 percent) due to sedimentation, evaluated at elevation 1,559 feet NGVD29 (top of the active conservation pool). Since the last reservoir survey in 2007, the reservoir volume has decreased by 501 acre-feet (evaluated at elevation 1,564 ft). This volume represents a sediment yield rate of 0.02 acre-ft per square mile per year (acre-feet/mi^2/year, which is considered very low as defined in Reclamation (2006). Over the life of the reservoir the sedimentation rate is 0.17 acre-feet per square mile per year.

- By 2018, the dead storage pool volume had reduced to 11.7 percent of the original dead storage volume. The bed immediately upstream of the dam varies between 1,508 and 1,511 ft (NGVD29). However, the bed upstream of the irrigation outlet is at 1,512.1 ft (NGVD29). Based on values provided in the Project Data Book (Water and Power Service 1982), the original bed elevation upstream of the dam at the spillway is 1,477ft (NGVD29). This was obtained by subtracting the original hydraulic height (82 ft) from the normal water surface (1,559 ft). The original elevation just upstream of the irrigation outlet is uncertain.

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

Table ES-1. Reservoir Survey Summary Information

Reservoir Information

Reservoir Name	Lake Altus		**Region**	GP
Owner	Reclamation		**Area Office**	OK-TX
Stream	NF Red River		**Vertical Datum**	NGVD29
County	Greer & Kiowa		**Top of Dam (ft)**	1,564
State	OK		**Spillway Crest (ft)**	1,547
Lat (deg min sec)	34° 53′ 11″		**Power Penstock Elevation (ft)**	N/A
Long (deg min sec)	99° 17′ 45″		**Low Level outlet (ft)**	1517.5
HUC4	1112		**Total Drainage Area (mi^2)**	2,515
HUC8	11120302		**Date storage began**	1940
NID ID	OK02500		**Date for normal operations**	6/19/1946
Dam Purpose	Irrigation, flood control, augmented municipal water supply, recreation			

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	1,564	7,705		192,842
Flood Control	1,562	Not Available	Not Available	Not Available
Multiple Use	------	------	------	------
Joint Use	------	------	------	------
Conservation	1,559	6,772	152,060	156,668
Inactive	------	------	------	------
Dead	1,517.5	1,073	4,608	4,608

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sediment-ation Volume (acre-feet)*	Cumulative Sediment-ation (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
1940	Contour	2 – 5 ft	2,116	--------	--------	------	100
1948	Contour & Range Line	26 RL, 5 ft	2,116	8,028	8,028	------	78
1953	Contour & Range Line	25 RL, 5 ft	2,116	5,778	13,806	------	50
1967	Range Line	25 RL	2,116	8,368	22,174	------	36
2007	Contour & Range Line	15 RL 5 ft	2,116	5,575	27,749	------	14
2018	Contour & Range Line	15 RL 5 ft	2,116	509	28,258	1506.7	12

* Evaluation at 1,559 ft, top of conservation pool

Table ES-2. Elevation versus Area Table (evaluated at 1,564 ft, NGVD29)

Survey date	Original	1982	2007	2017
Vertical Datum	NGVD29	NGVD29	NGVD29	NGVD29
Elevation (ft)	**Area (acre)**	**Area (acre)**	**Area (acre)**	**Area (acre)**
1,510	135	59	0	0.1
1,515	678	182	134	124
1517.5	1,073	643	266	253
1,520	1,445	1,103	806	776
1,525	1,991	1,645	1,603	1,608
1,530	2,510	2,165	2,049	2,060
1,535	3,013	2,616	2,610	2,639
1,540	3,720	3,219	3,180	3,195
1,545	4,279	3,823	3,849	3,807
1,550	5,302	4,626	4,570	4,448
1,555	6,007	5,534	5,221	5,285
1,559	6,772	6,260	6,273	6,164
1,562	--------	--------	6,811	6,853
1,564	7,705	7,168	7,170	7,236

Table ES-3. Elevation versus Capacity Table (evaluated at 1,564 ft, NGVD29)

Survey date	Original	1967	2007	2018
Vertical Datum	NGVD29	NGVD29	NGVD29	NGVD29
Elevation (ft)	**Volume (acre-ft)**	**Volume (acre-ft)**	**Volume (acre-ft)**	**Volume (acre-ft)**
1,510	586	30	0	0.1
1,515	2,448	632	185	140
1517.5	4,608	1,663	633	538
1,520	7,732	3,884	1,889	1,795
1,525	16,302	10,752	7,971	7,824
1,530	27,668	20,276	17,065	16,980
1,535	41,678	31,972	28,719	28,742
1,540	58,718	46,560	43,191	43,332
1,545	78,704	64,167	60,796	60,865
1,550	102,872	85,565	81,774	81,278
1,555	131,132	110,963	106,175	105,434
1,559	156,668	134,549	128,919	128,410
1,562	---------	----------	148,545	147,925
1,564	192,842	168,117	162,526	162,025

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1. Introduction

Altus Dam is on the North Fork of the Red River about 110 miles southwest from Oklahoma City and 18 miles north from Altus, Oklahoma (Figure 1). The dam and reservoir are operated by the Bureau of Reclamation as part of the W.C. Austin Project that supplies water for irrigation water to about 46,777 acres (Autobee 1994) of farm land serviced by the Lugert-Altus Irrigation District. The reservoir also provides 4,800 acre-feet for municipal and industrial use. The reservoir provides recreation and lies within Quartz Mountain State Park.

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, the Great Plains Region requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) to conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. The bathymetric survey was conducted from May 7 through May 10, 2018 with two primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1940 and since the last survey in 2007.

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

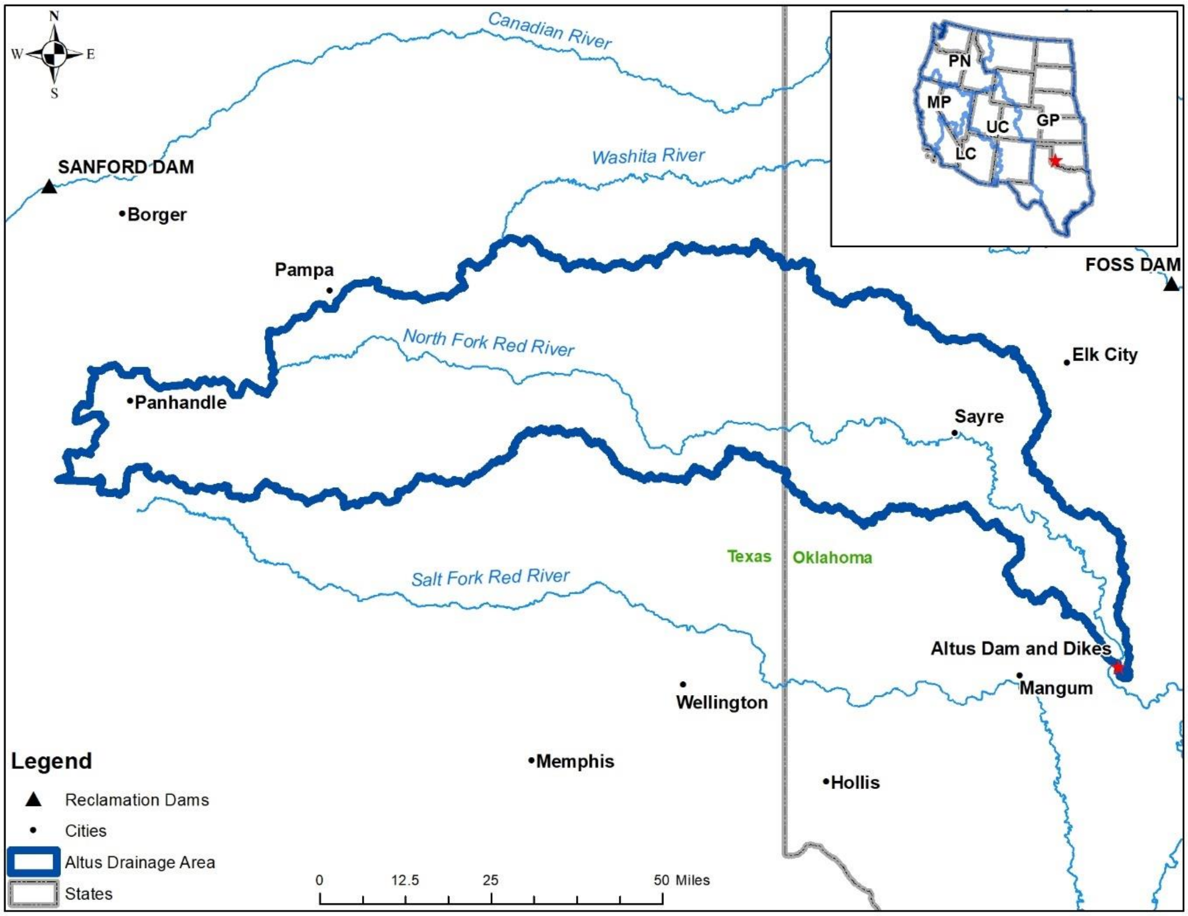


Figure 1. Location map of Altus Dam and Lake Altus, 110 miles southwest of Oklahoma City, OK and 18 miles north of Altus, OK. The watershed above Altus Dam has a total drainage area of 2,515 mi^2 and a total-contributing drainage area, including sediment, of 2,116 mi^2.

The following appendices include greater detail of the survey:

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with LiDAR data collected above water during 2011 and 2016 to produce a digital surface of the reservoir bottom surface.

Appendix B provides more details regarding above-the-water survey data. Surface areas at a 3-foot resolution were computed using GIS software and the computer program the was used to produce the reservoir surface area and capacity tables at 1-foot increments.

Appendix C provides more details about the methods used to generate surface area and storage capacity tables at 0.1 and 0.01-foot increments.

Appendix D provides contour maps of the reservoir.

Appendix E provides the range line cross section comparisons from surveys in 1948, 1967, 2007, and 2018.

2. Watershed Description

The watershed upstream from Altus Dam has a total drainage area of 2,515 square miles (mi^2). with a contributing drainage area of 2,116 mi^2 (https://streamstats.usgs.gov/ss/) (Figure 1). This watershed begins across the Texas border and extends east-south-east to Altus Dam. There are no known major structures within the watershed that would reduce sediment contributions to Lake Altus. Annual precipitation within the basin is 25.4 inches (Water and Power Service 1981).

Granite bridge and the associated approach to the west influence the flow of sediment into the reservoir by decreasing the width and restricting flow to approximately 450 ft at the eastern edge of the reservoir.

2.1. Geology

The North Fork of the Red River is an alluvial terrace aquifer consisting of layers of sand, silt, clay, and gravel. Average layer thickness is 40 feet and is as deep as 150 feet over Permian and Pre-Cambrian age bedrock formations. The North Fork Red River cuts through the bedrock layers in some places throughout the basin (Kent 1980). The surface soils of this drainage area consist primarily of loamy sand with silt and some clay. Aeolian transport of sediment occurs frequently enough to support sand dunes in some areas of the basin. Some bedrock outcrop areas exist within the watershed (https://websoilsurvey.nrcs.usda.gov/app/).

Vegetation types within the watershed primarily consist of water tolerant hardwoods and grasses. Land use activities within the watershed primarily consist of agriculture. In the upper basin near the Texas border there are numerous gas wells north of the river.

2.2. Climate and Runoff

Reservoir inflows are primarily from the North Fork Red River. USGS stream gage records are available for the locations presented in Table 1, which represents 82 percent of the total contributing drainage area.

The mean runoff to Lake Altus is 121 ft^3/s per year or 102,666 acre-feet per year (USGS, Figure 2). This value is adjusted for the missing 13% of the basin between the gage and the reservoir. The runoff to Lake Altus is primarily from rainfall. The North Fork Red River sometimes goes dry, typically in August. During drought years, dry periods can last several months. The ratio of mean annual runoff to the reservoir storage capacity is 0.68. This means that, when full, the reservoir stores a water volume equivalent to 536.5 days of mean annual stream flow. Peak stream flow data for the North Fork Red River are shown in Figure 3.

Table 1. Reservoir Inflow Streams with USGS Gages

USGS Stream Gage		Drainage Area (mi2)	Mean Annual Runoff (cfs)	Period of Record
Name	Number			
North Fork Red River near Carter, OK	07301500	2,073	121*	1944 - current

*This number is affected by an absence of data 10/1/1962 through 7/31/1964.

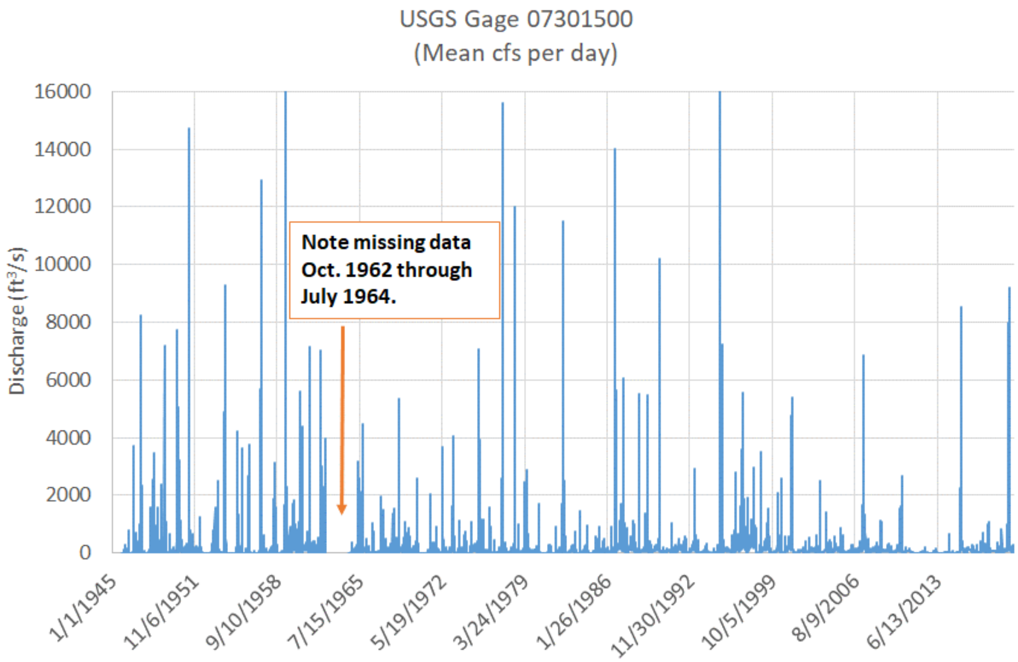


Figure 2. Plot of mean daily discharge at North Fork Red River nr. Carter, OK (USGS #07301500).

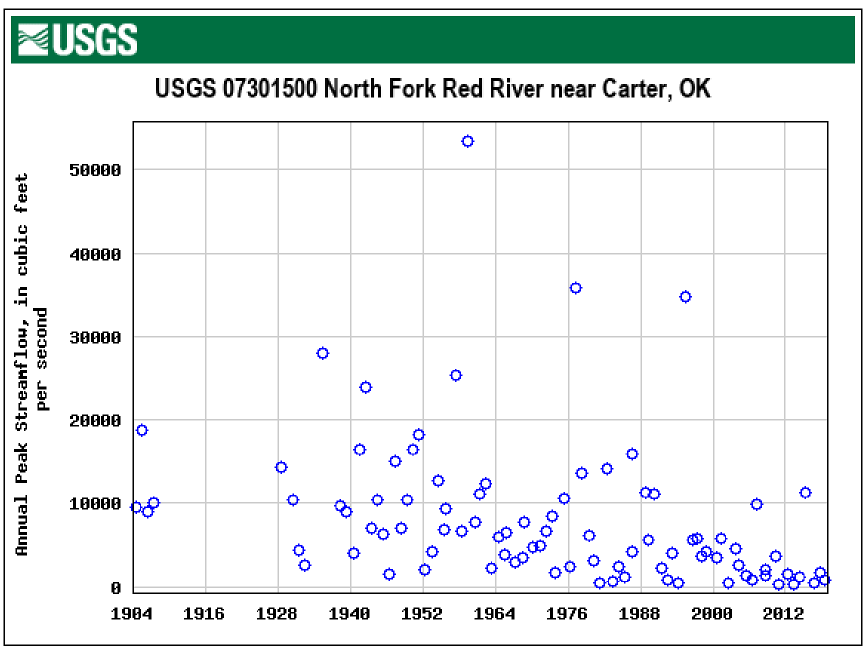


Figure 3. Peak streamflow data for North Fork Red River nr. Carter, OK (USGS #07301500).

2.3. Dam Operations and Reservoir Characteristics

Prior to the current day Altus Dam, Ambursen Dam was built in 1927. This dam was 46 feet high. Sedimentation significantly reduced the storage of this early reservoir from 13,000 to 700 acre-feet (Autobee 1994). This dam was torn down to make way for Altus Dam. Since the construction of Altus Dam there are no known reservoir sediment management activities that have taken place. It is not known if any flushing of sediment took place between the removal of Ambursen Dam and construction of Altus Dam.

Altus Dam is a partially arched, concrete gravity dam faced with masonry. This dam began storing water in 1940 and construction was completed in 1946. The historic reservoir water surface elevations (NGVD29) are presented in Figure 4. Annually, the reservoir water surface typically fluctuates about 15 feet.

The dam has a structural height of 110 feet and an original hydraulic height of 82 feet. The reservoir had an original length of about 13.1 miles long at full pool with no major tributaries. Current measurements indicate that the reservoir is 11.3 miles long at maximum water elevation.

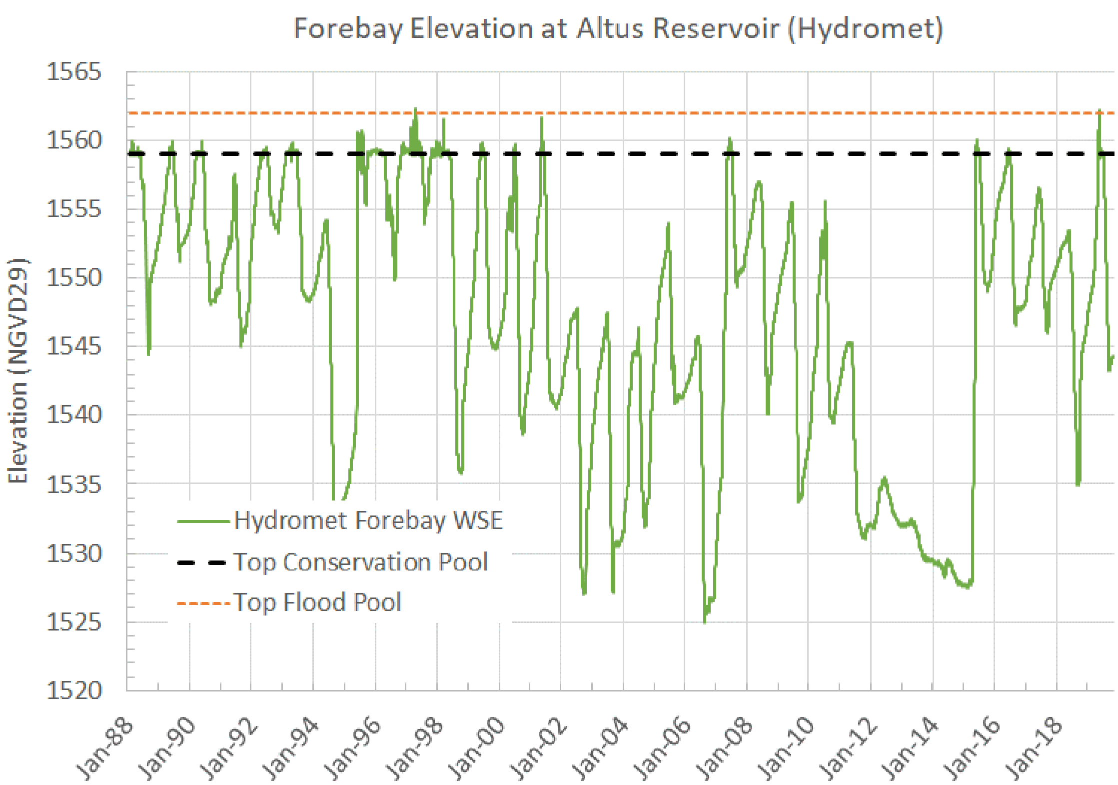


Figure 4. Historic Lake Altus water surface elevations (project datum). Data web source: https://www.usbr.gov/gp/hydromet/altus.html. Top of dead storage pool is 1517.5 feet (NGVD29).

At its widest point the reservoir is 2 miles wide at maximum water surface elevation. Much of the reservoir is approximately 1.5 miles wide downstream of Hwy 9 (Granite Bridge). In the portion of the reservoir upstream from Hwy 9 the reservoir is most commonly 0.75 miles wide. There is a narrow neck in the southern portion of the reservoir where its width is limited to 640 ft between two bedrock outcrops.

3. Survey Control and Datum

For the 2018 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (2011) (NAD 1983) State Plane (horizontal) coordinates, Oklahoma South, US survey feet and North American Vertical Datum 1988 (NAVD 1988, Geoid 12A, US survey feet (vertical). During processing, all bathymetry and GPS measurements were converted to Reclamation Project Vertical Datum (RPVD) for Altus Dam, which is equivalent to the National Geodetic Vertical Datum 1929 (NGVD 1929). NAVD88 (GEIOD 12A) was determined to be 0.59 feet higher than the NGVD 1929. This difference was determined through comparison of multiple RTK GPS ground survey points of the water surface and gage readings of water surface elevation. These measurements were temporally matched for this comparison.

The computed difference between NGVD 1929 and NAVD 1988 at Lake Altus using the US Army Corps of Engineers conversion program Corpscon v6.0.1 results in a difference of 0.52 feet at the dam and 0.53 feet at the Hwy 9 (Granite) Bridge. It was decided to use the measured difference between NAVD88 and NGVD29 and not the Corpscon conversion because the measured difference is more representative of the difference between the RPVD (NGVD29) and NAVD88.

The GPS base station receiver was set up over a temporary monument located near the boat launch (Figure 5*)*. State plane coordinates and elevation (NAD83/NAVD88) 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/).

Figure 5. Location of GPS base station used during the 2018 Lake Altus bathymetric survey.

4. Previous Reservoir Surveys

Prior to dam closure and initial reservoir filling, a survey was conducted in December 1940 to measure the original surface areas and corresponding storage capacities. This survey resulted in a contour map with intervals between 2 and 5 feet. Neither the original survey nor its documentation have been located for this analysis and the survey method is uncertain. The original and subsequent reservoir surveys are described in Table 2.

Table 2. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1940	Full	Contour	N/A	N/A
1948	Full	Contour and Range Line	Unknown	Unknown
1953	Full	Contour and Range Line	Unknown	Unknown
1967	Full	Range Line	Single beam	Level
2007	Full	Contour	Single beam	USGS contours (1970) and some ground survey
2018	Full	Contour	Multibeam	LiDAR 2012 & 2016

More details on these previous surveys are described in these reservoir survey reports:

- 1967 survey (Lara, 1971).
- 2007 survey (Ferrari, 2008)

5. Methods Summary

A complete bathymetric survey was conducted during May 2018 from an 18-foot aluminum boat using a 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 6. The reservoir has emergent trees in the area that is approximately 4,500 feet south of Hwy 9 (Figure 6). This area was very shallow (approximately 3 – 4 ft) and weaving among the trees was the only means to obtain bathymetry in this area. Where accessible, range lines (Figure 7) were surveyed in addition to other longitudinal or lateral planned survey lines.

The area upstream of Hwy 9 was dry during the bathymetric survey. Elevations in this area are generally at or above elevation 1,553 (NGVD29), the water surface elevation during the survey. The top of the conservation pool is 1,559 feet (NGVD29). This portion of the reservoir is covered only by the LiDAR data, which does not include underwater areas.

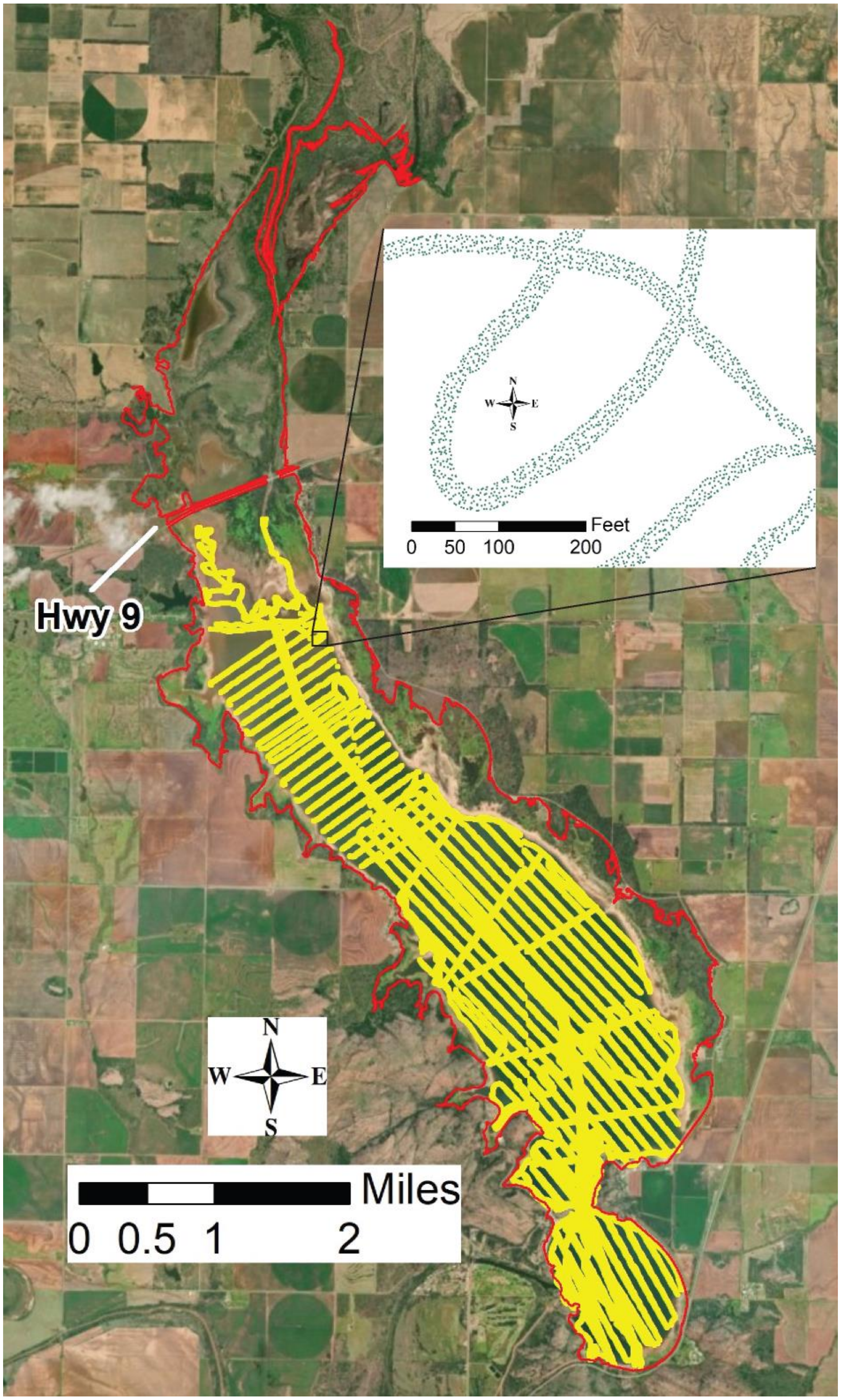


Figure 6. Map of bathymetric survey data coverage (yellow). Outside of the bathymetry and inside the red contour line (elevation 1,564 ft) 2012 and 2016 LiDAR was used to complete the surface up to elevation 1,564 feet (NGVD29). The inset is a zoomed-in view of the multibeam point data.

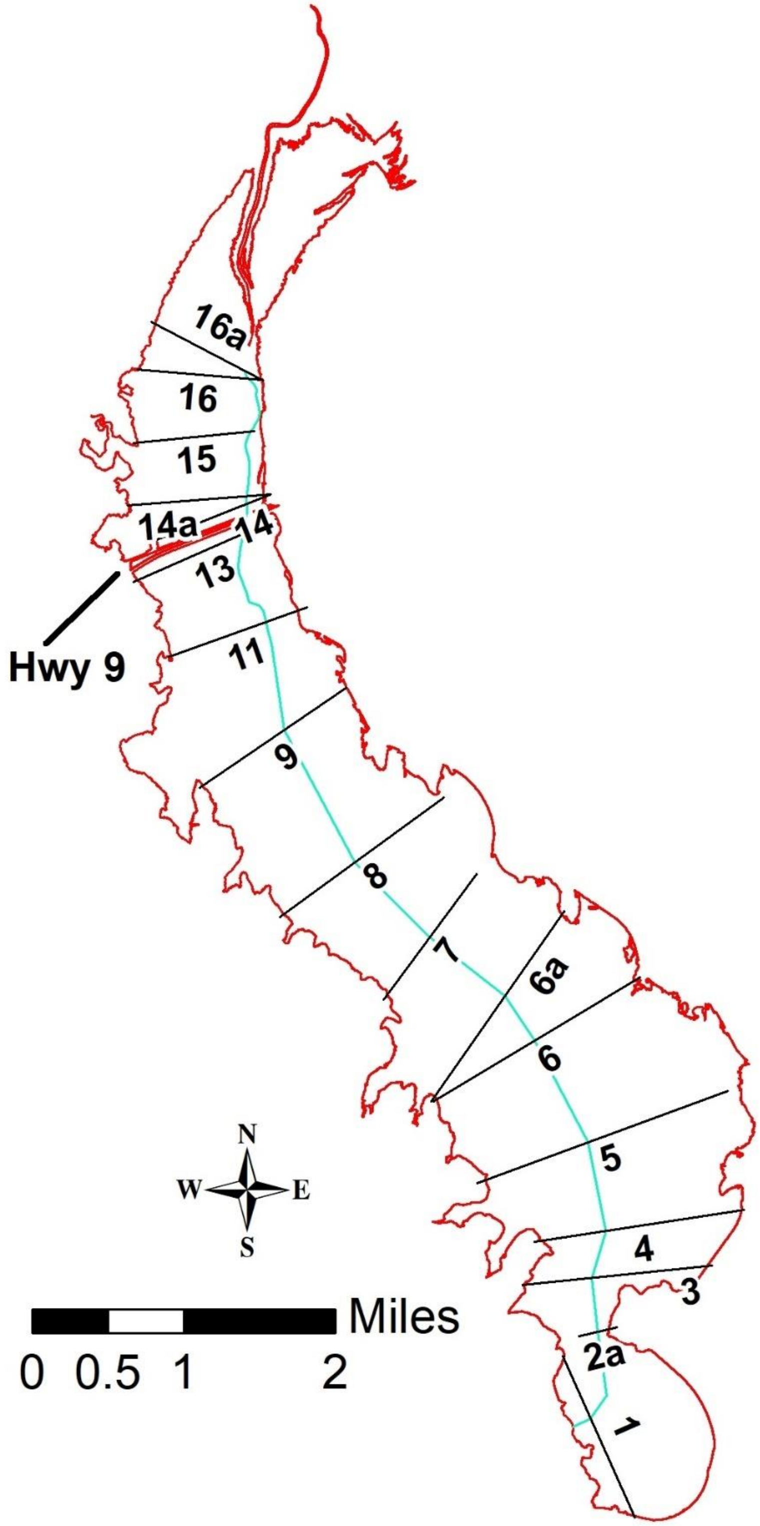


Figure 7. Range lines and longitudinal profile used to determine stationing for the reservoir.

6. Reservoir Surface Area and Storage Capacity

The actual surface areas and storage-capacity volumes for above-water elevations may be different than the areas measured in 2007 because of delta sedimentation, shoreline erosion, or use of different methods.

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Lake Altus Area and Capacity Tables, Reclamation 2020). Plots of the 2018 area and capacity curves are presented in Figure 8 along with curves from 1940, 1967, and 2007 surveys. For the 2018 survey, area and capacity curves are based on the bathymetric (below-water) survey up to 1,548 feet elevation (NGVD29), while curves above this elevation are based on a combination of 2012 and 2016 aerial LiDAR. A comparison of these curves indicates that largest reduction in surface area and storage capacity occurs between elevations 1,545 and 1,550 feet (NGVD29). Additional information on the above-water survey are available in Appendix B.

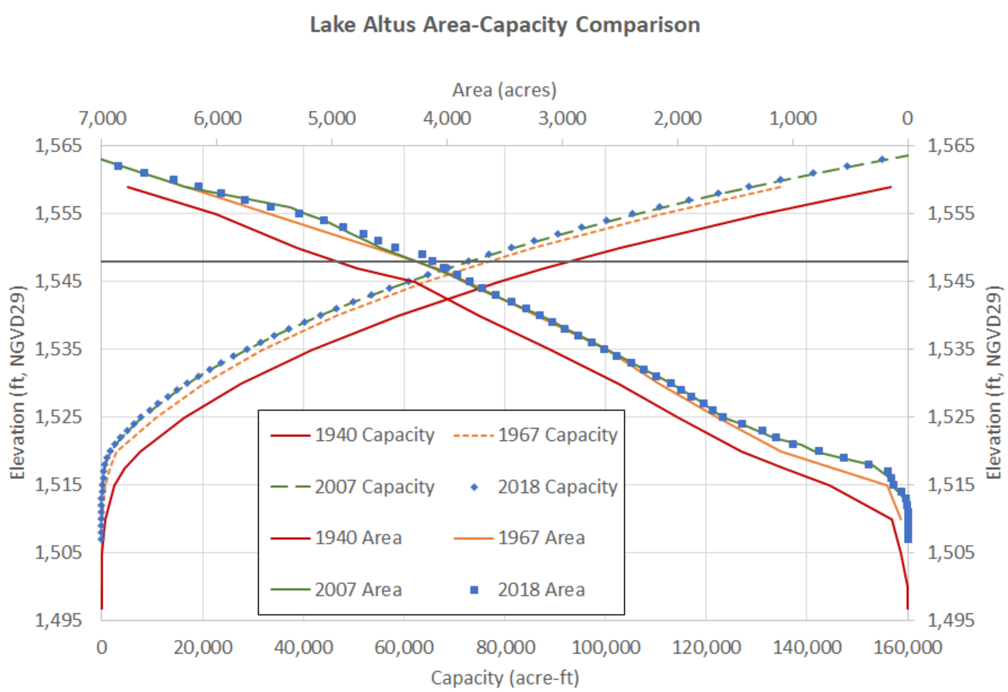


Figure 8. Plot of Lake Altus surface area and storage capacity versus elevation. The gray horizontal line represents the top of the 2018 bathymetric data. Area-Capacity values above this elevation were obtained using LiDAR data.

At reservoir water surface elevation 1,548 feet (NGVD29), which is 5 feet below water at the time of survey, the reservoir surface area was 4,125 acres with a storage capacity of 72,770 acre-feet. At the top of flood control pool elevation (1,562 ft, NGVD29), the reservoir has a surface area of 6,853 acres and a storage capacity of 147,925 acre-feet. Since dam construction the reservoir has lost 28,258 acre-feet due to sedimentation, evaluated at elevation 1,559 ft (NGVD29), the top of the conservation pool. This is a capacity loss of 18%. The loss in area is 721 acres, which represents an 11% loss. A delta has formed at the upstream end of the reservoir on both sides of Hwy 9. This delta has progressed to Range Line 8, which is 12,600 feet downstream from Hwy 9 (Figure 7).

7. Reservoir Sedimentation Volume Spatial Distribution

A longitudinal profile of the 2018 reservoir bottom surface was developed along the alignments presented in Figure 7. The lowest elevation of each range line was used to develop this profile and historic values were taken from Ferrari (2008). The longitudinal profile (Figure 9) shows that sedimentation is thickest upstream of Highway 9 (Granite Bridge, Figure 7). Sediment accumulation is lowest at the narrowest portion of the reservoir at Range Line #2 (Figure 7). Sediment continues to deposit at Range Line #1 near the dam. Reservoir cross section plots (Appendix E) show the lateral distribution of sediment.

Upstream from the Granite Bridge (Figure 7 and Figure 9) the reservoir is mostly filled with sediment. As such, this area and the resultant volume calculations rely on accurate above-ground survey techniques, which previous surveys found difficult to obtain. Past surveys relied on imprecise maps generated by interpolating between range lines (1967 survey, Lara 1971) and coarsely drawn contour maps accompanied by a sparse ground survey using a GPS rover mounted to an ATV (2007 survey, Ferrari 2008). The course that the ATV could take was significantly limited by dense vegetation and areas of standing water, resulting in an incomplete survey. However, recent bare earth LiDAR incorporated in the 2018 surface provides the most accurate and precise elevation measurements of the above-water portion of the reservoir to date, especially the area upstream of the bridge. Figure 9 shows a decrease in elevations in the delta upstream of the Granite Bridge since the 2007 survey, erroneously suggesting that the delta has eroded. It is not believed that erosion of the delta sediment took place. The difference in delta elevations is an artifact of the improved above-water survey methodologies employed in conjunction with the 2018 survey. For further clarification examine the Range Lines cross sections (Appendix E).

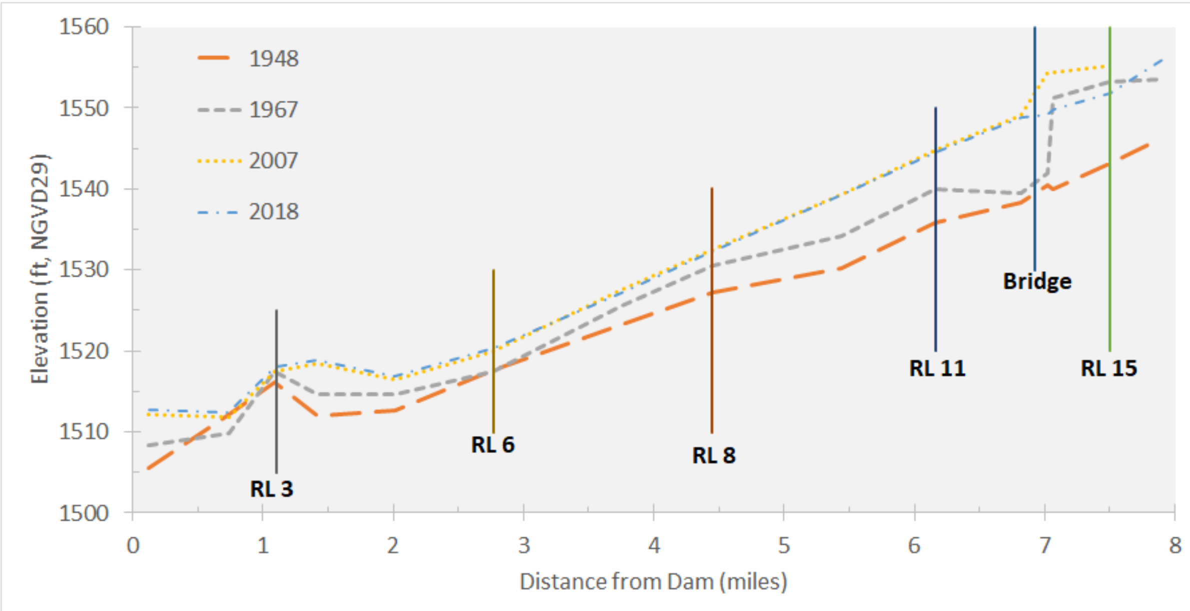


Figure 9. Longitudinal profile of Lake Altus bottom elevations from the dam upstream to Range Line #16. All data are thalweg elevations.

8. Sedimentation Trends

Two plots of historic sedimentation trends for the dead pool capacity are shown in Figure 10. Figure 10(A) shows the decreasing capacity of the dead pool while Figure 10(B) shows the cumulative sedimentation within the dead pool. Both plots show the sedimentation rate of the dead pool is decreasing over time. The initial dead pool capacity was 4,608 acre-feet and has been reduced to 538 acre-feet as of the 2018 survey. Therefore, 11.7% of the dead pool capacity remains. Graphs of the historic reservoir sedimentation rates over time and cumulative reservoir sedimentation volume over time (Figure 11) indicate a decreasing trend in sediment accumulation since construction.

The 2018 survey indicates that bottom elevations immediately upstream of the canal outlet are between 1,512 and 1,512.5 feet. At 500 ft upstream from the canal outlet, the bottom elevation is approximately 1,514.3 ft. The top of the dead pool is 1,517.5 ft (NGVD29). There does not appear to be a channel forming upstream of the canal outlet, which would indicate that sediment is being flushed into the canal. The lowest elevation in the reservoir is 1,506.7 ft and is located immediately upstream of the spillway gates.

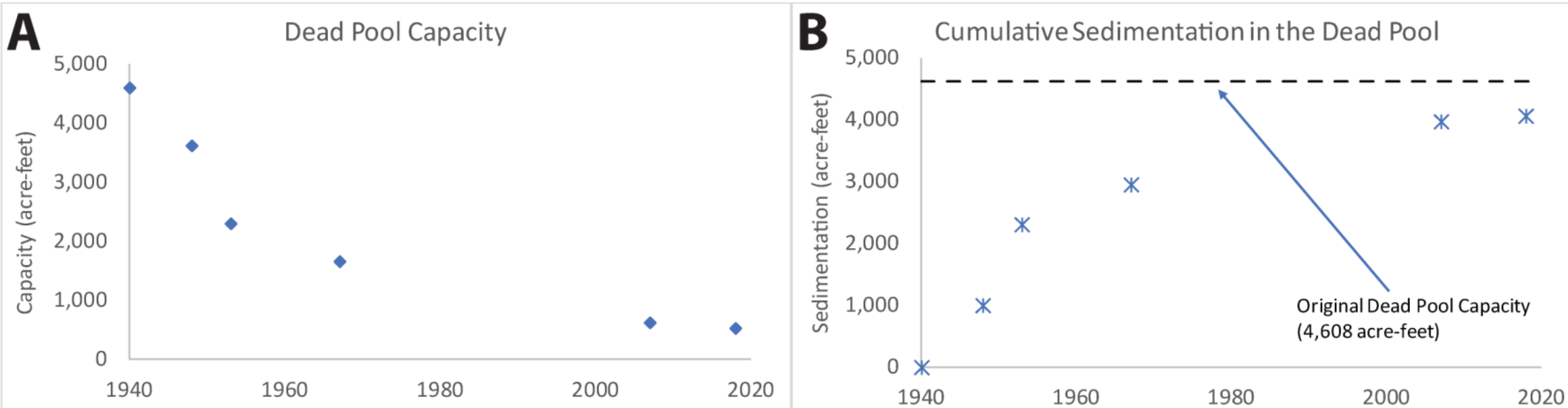


Figure 10. A – Dead pool Capacity since construction. B – Cumulative dead pool sedimentation since construction.

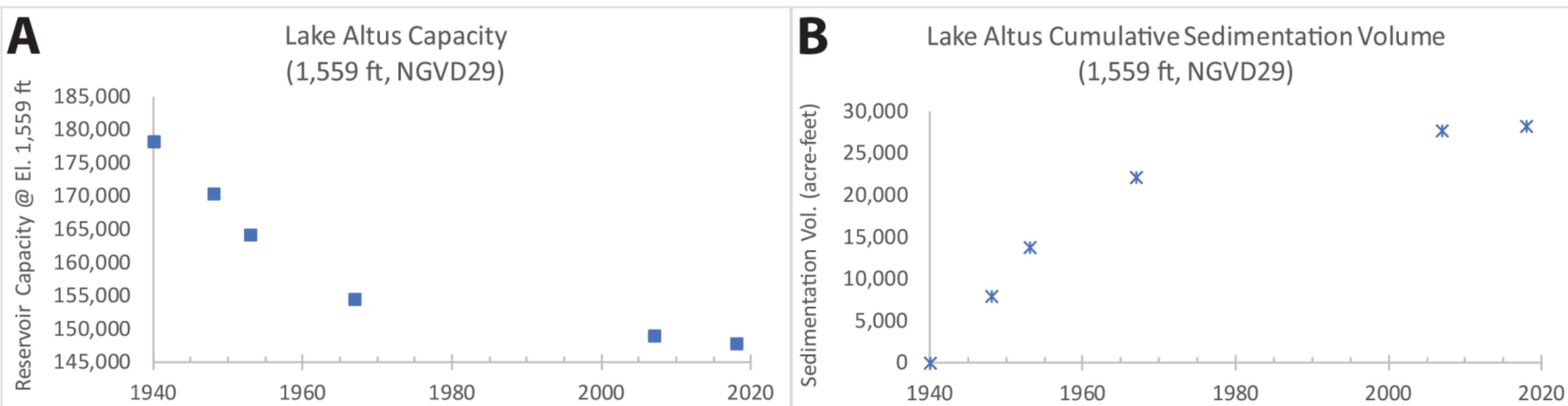


Figure 11. A – Lake Altus capacity since construction. B – Cumulative Lake Altus sedimentation since construction.

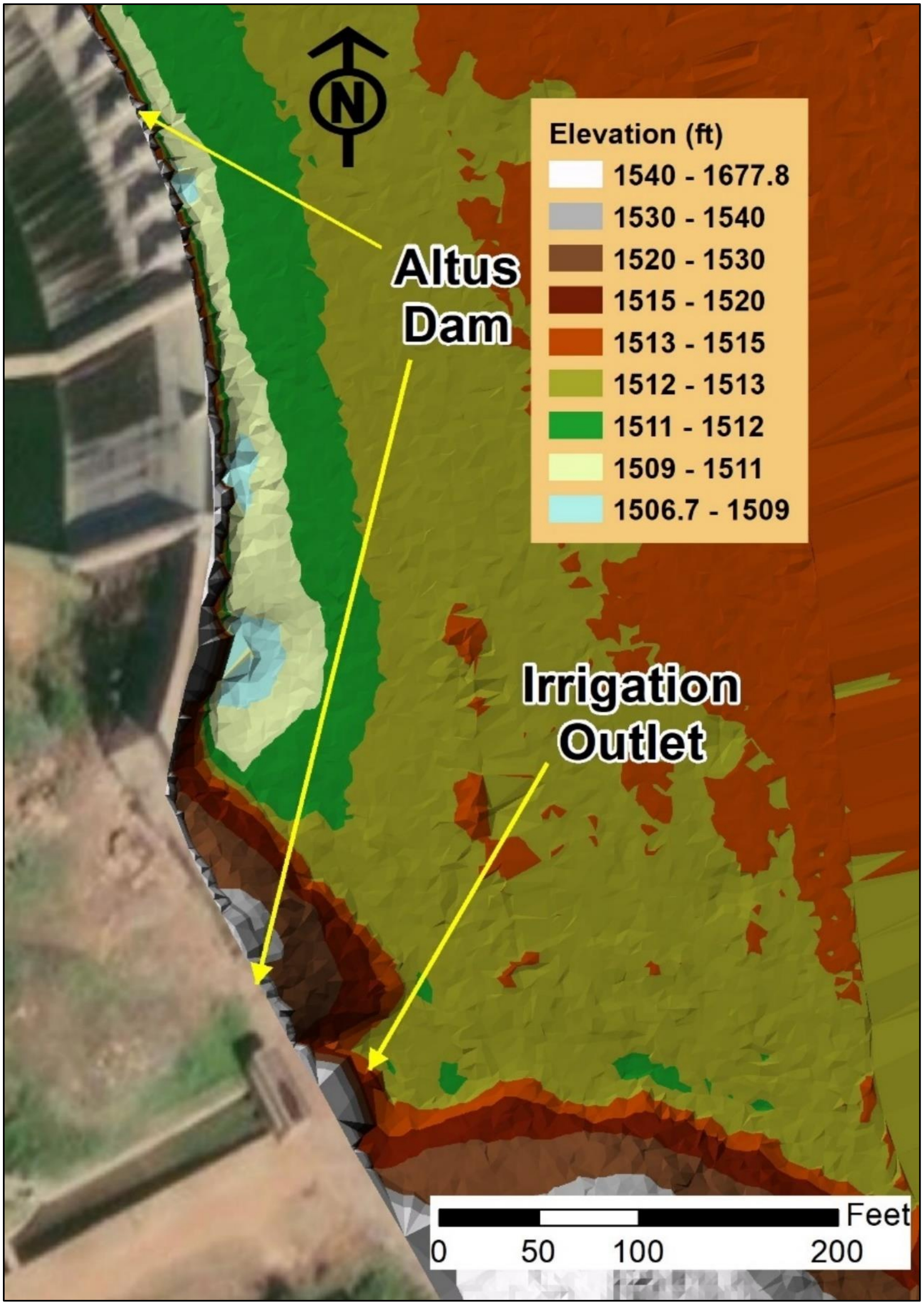


Figure 12. Image showing reservoir bottom elevations at Altus Dam. The irrigation outlet invert is at elevation 1,517.5 ft (NGVD29). The breaks in the elevation color map are set to highlight elevations immediately upstream of the irrigation outlet.

9. Conclusions and Recommendations

9.1. Survey Methods and Data Analysis

The 2018 bathymetric survey, combined with 2012 and 2016 LiDAR data to represent the above-water topography, have been used to produce an accurate digital surface of the reservoir bottom.

Reservoir surface areas were computed from this digital surface at 1-foot intervals to determine the 2018 storage capacity. Surface area and storage capacity were then interpolated at 0.1 and 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but also the differences in survey methods can influence evaluation of reservoir capacity. This is especially true for the upper portion of the reservoir, where LiDAR was used for the most recent survey of this area. Past surveys of this area were much less representative of the complete terrain. The 2018 surface area and storage capacity curves compare reasonably well with the original curves and with curves from other surveys. The use of modern survey methods (multibeam depth sounder and LiDAR) have produced a more accurate and precise digital surface of the reservoir bottom than past surveys using older methods (single beam depth sounder, range line surveys, less accurate above-water data).

9.2. Sedimentation Progression and Location

Over the span of 78 years since the completion of the dam, sedimentation has filled in 18 percent of the original storage capacity. The 2018 reservoir survey indicates that most of this sedimentation is in the delta portion of the reservoir. Sedimentation has also deposited near the dam in the lowest portions of the reservoir and 88 percent of the original dead storage capacity has been lost to sedimentation. The lowest dam outlet may not be as reliable after the dead 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

Based on the past rates of sedimentation, the next survey of Lake Altus is recommended within the next 10 to 20 years (2028 - 2038). High inflow rates to the reservoir are likely to bring in higher sediment loads, which could change the current sedimentation rate in the reservoir. Since the last survey in 2007 reservoir inflow has been lower than normal (Figure 2) since construction, which is expected to produce a lower than average sedimentation rate. If the next decade is substantially wetter than the previous, the next survey should be closer to 2028 than the 2038. Deposition of just 2 or 3 more feet near the dam is expected to cause sediment flushing through the canal outlet, which will result in an increased sediment load delivered to the canal and other irrigation works.

9.4. Other Recommendations

The 2012 and 2016 LiDAR for the above-water portion of the reservoir provides an improved evaluation of the upper reservoir upstream of Highway 9 over past surveys. This area is difficult to survey under any conditions due to dense vegetation, soft sediment, and large pockets of standing water. During analysis and reporting of the 2018 survey, an attempt was made to locate the coordinates for end points of the range lines in the upper reservoir (RL 17-22). These end point coordinates were not located. Range lines 17 - 22 have not been used since the 1967 survey. The end point coordinates are not included in the reports for the 1967 and 2007 survey reports (Lara 1971 and Ferrari 2008, respectively). The 1967 survey (Lara 1971) uses range lines up to RL #22. Current range lines only extend up to RL #16A. Understanding the deposition in the upper reservoir relative to original topography will be important if there is interest in delta sedimentation and possible excavation upstream of Highway 9. End points for RL 17 - 22 may have to be physically relocated on the ground or re-established using historical drawings.

References

Autobee, R. (1994). "W.C. Austin Project", Bureau of Reclamation report.

Ferrari, R.L. (2008). "Altus Reservoir 2007 Sedimentation Survey", Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Kent, D.C. (1980). "Evaluation of aquifer performance and water supply capabilities of alluvial and terrace deposits of the North Fork of the Red River in Beckham, Greer, Kiowa, and Jackson Counties, Oklahoma", report submitted to the Oklahoma Water Resources Board, October.

Lara, J.M. (1971). "The 1967 Altus Reservoir Sediment Survey", Bureau of Reclamation, Engineering and Research Center, Report #REC-ERC-71-21, Denver, Colorado.

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

Reclamation (2006). Erosion and Sedimentation Manual, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado, November 2006.

Reclamation (2020). "Lake Altus 2018 Area and Capacity Tables", Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado, January.

Water and Power Resources Service (1981). "Project Data", U.S. Government printing office, Denver, Colorado.

Appendix A — Hydrographic Survey Equipment and Methods

The 2018 bathymetric survey was conducted from May 7 – 10, 2018. During this period, reservoir water surface elevations varied from 1552.9 to 1552.95 feet (NGVD29).

The survey was conducted along a series of predetermined cross section, longitudinal, and shore line survey lines (Figure 6). The survey lines were spaced closely enough that liner interpolation of single-beam depth data between survey lines would be adequate.

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 which consisted of the following equipment:

- variable-frequency transducer with integrated motion reference unit,
- near-surface sound velocity probe,
- two GPS receivers to measure the boat position and heading,
- an external GSP 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 feet (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 calibrate the depth sounder.

RTK GPS survey instruments were used to continuously measure 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 6). 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 survey of Bighorn Reservoir in Montana is typical of the set up used for other reservoir surveys.

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 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 Oklahoma State Plane South 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 (equivalent to NGVD29). The multibeam depth sounder generates millions 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. Final processing of the bathymetric data resulted in 1.7 million data points used in the development of the reservoir surface. Filtering of this large data file is necessary, so a raster mesh is created in GIS using 5-foot square cells. For each raster mesh cell, the reservoir bottom elevation is assigned equal to the 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 the cell.

Appendix B ─ Above Water Survey Methods

For the above-water portion of the reservoir, LiDAR data were obtained from the National Oceanic and Atmospheric Administration (NOAA, https://coast.noaa.gov/inventory). The northwest portion of the reservoir boundary was not available in the 2012 data set. The missing area was supplemented with more recent 2016 LiDAR data (Figure B-1). Where these data sets overlapped the 2016 LiDAR data was used. These two data sets were combined to create a single point data set to combine with the bathymetric data points.

The 2012 LiDAR has a point density of 4.6 ft (1.4 meters) with a stated vertical accuracy of 1.33 ft. The 2016 LiDAR data has a point density 2.3 ft (0.7 meters) with a stated vertical accuracy of 0.15 ft (4.7 centimeters). These data are available in the NAD83/NAVD88 State Plane projection (Oklahoma South). The vertical projection was shifted by – 0.59 ft to match the NGVD29 vertical datum (equivalent to RPVD). The LiDAR data did not overlap the bathymetry data but was close to the outer edges of the bathymetry data, which resulted in little interpolation between the bathymetry and LiDAR data.

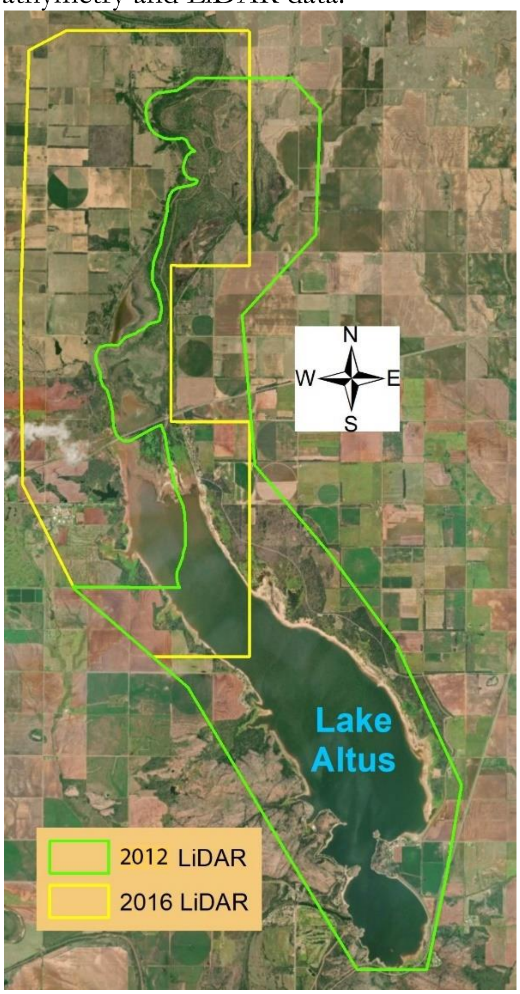


Figure B-1 Polygons showing the available LiDAR data that was used for the above-water portion of the survey.

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

A digital surface of the reservoir (to elevation 1,564 ft, NGVD29) was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Horizontal surface areas were then computed at 1-foot increments, using functions within ArcGIS Pro, for the complete range of remaining reservoir elevations (1,507 to 1,564 feet, NGVD29). 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 0.1 and 0.01-foot increments between each 1-foot interval.

The program uses the least squares method to predict the reservoir storage capacity between 1-foot 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

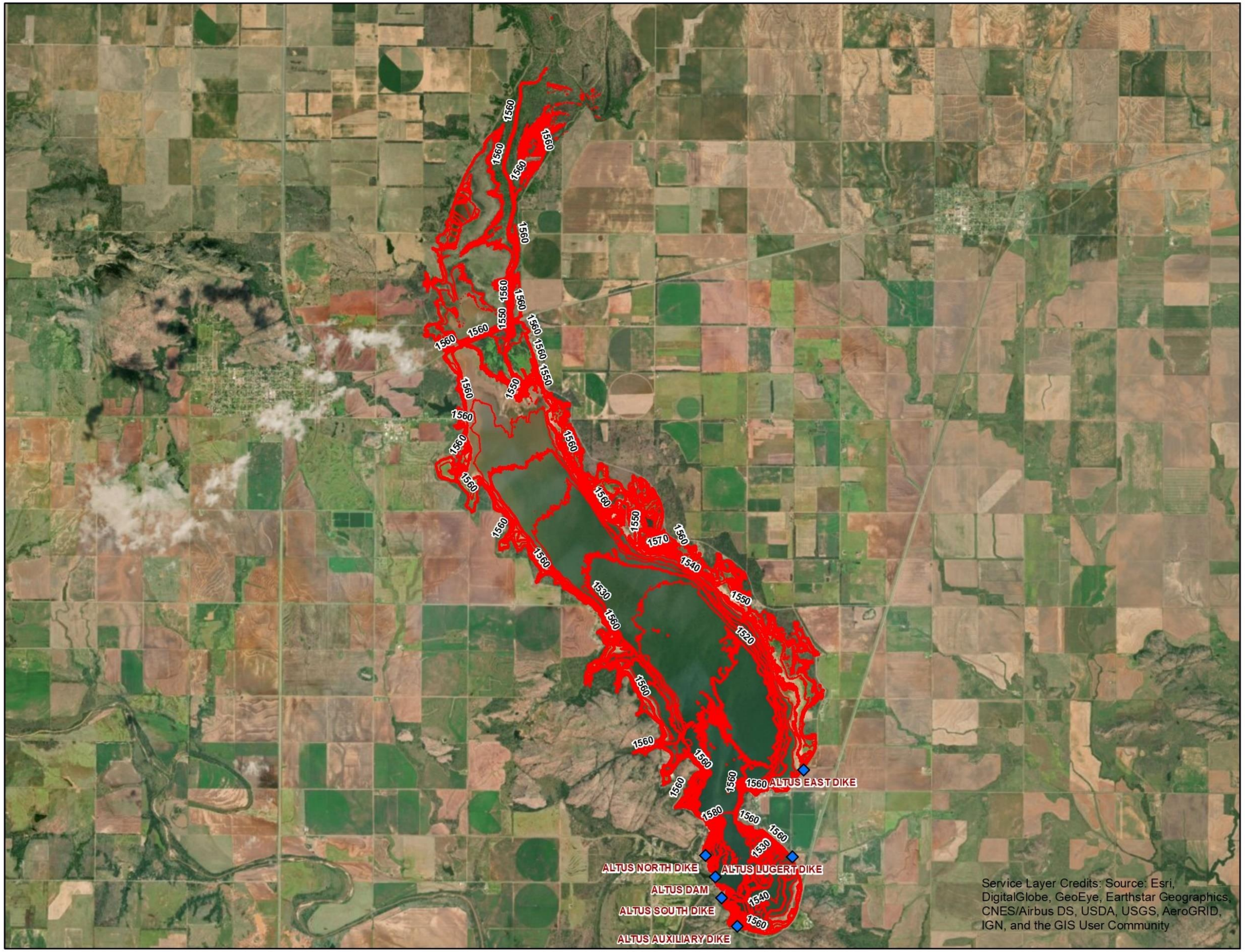
The reservoir surface area is computed from the derivative of the volume equation:

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

where: S = surface area (acres)

This method ensures that the given surface areas, and corresponding storage capacities, at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot 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, 2020).

Appendix D – Contour Maps



Lake Altus Oklahoma Elevation Contour Map

Overview Map

Horizontal: NAVD88, State Plane Oklahoma South
RPVD = NGVD29
NAVD88 – NGVD29 = 0.59 ft

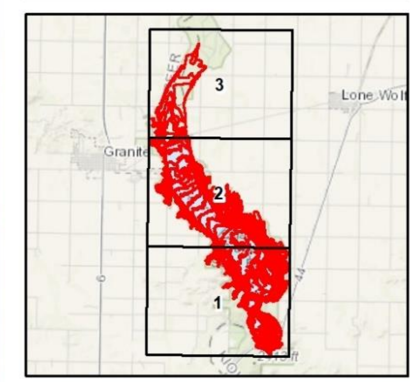
Five Foot Contour Interval

Primary Data Source:
Bathmetry from 2018 Reservoir Survey
Topography provided by OTAO

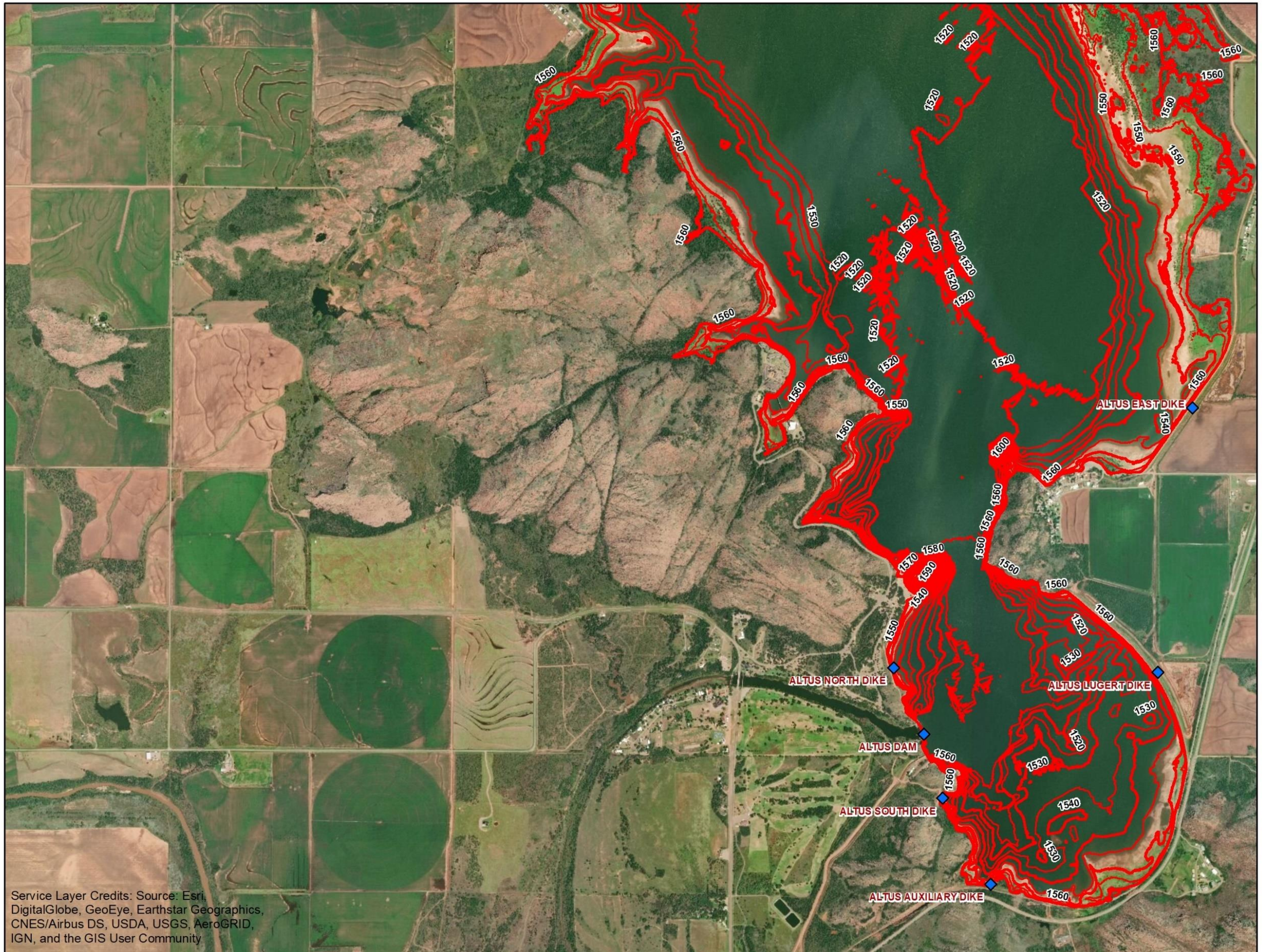
N

Scale 1:60,000

0 4,750 9,500 Feet



BUREAU OF RECLAMATION



Lake Altus Oklahoma Elevation Contour Map

Sheet 1

Horizontal: NAVD88, State Plane Oklahoma South
RPVD = NGVD29
NAVD88 – NGVD29 = 0.59 ft

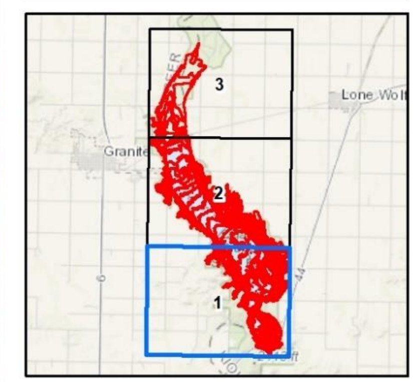
Five Foot Contour Interval

Primary Data Source:
Bathmetry from 2018 Reservoir Survey
Topography provided by OTAO

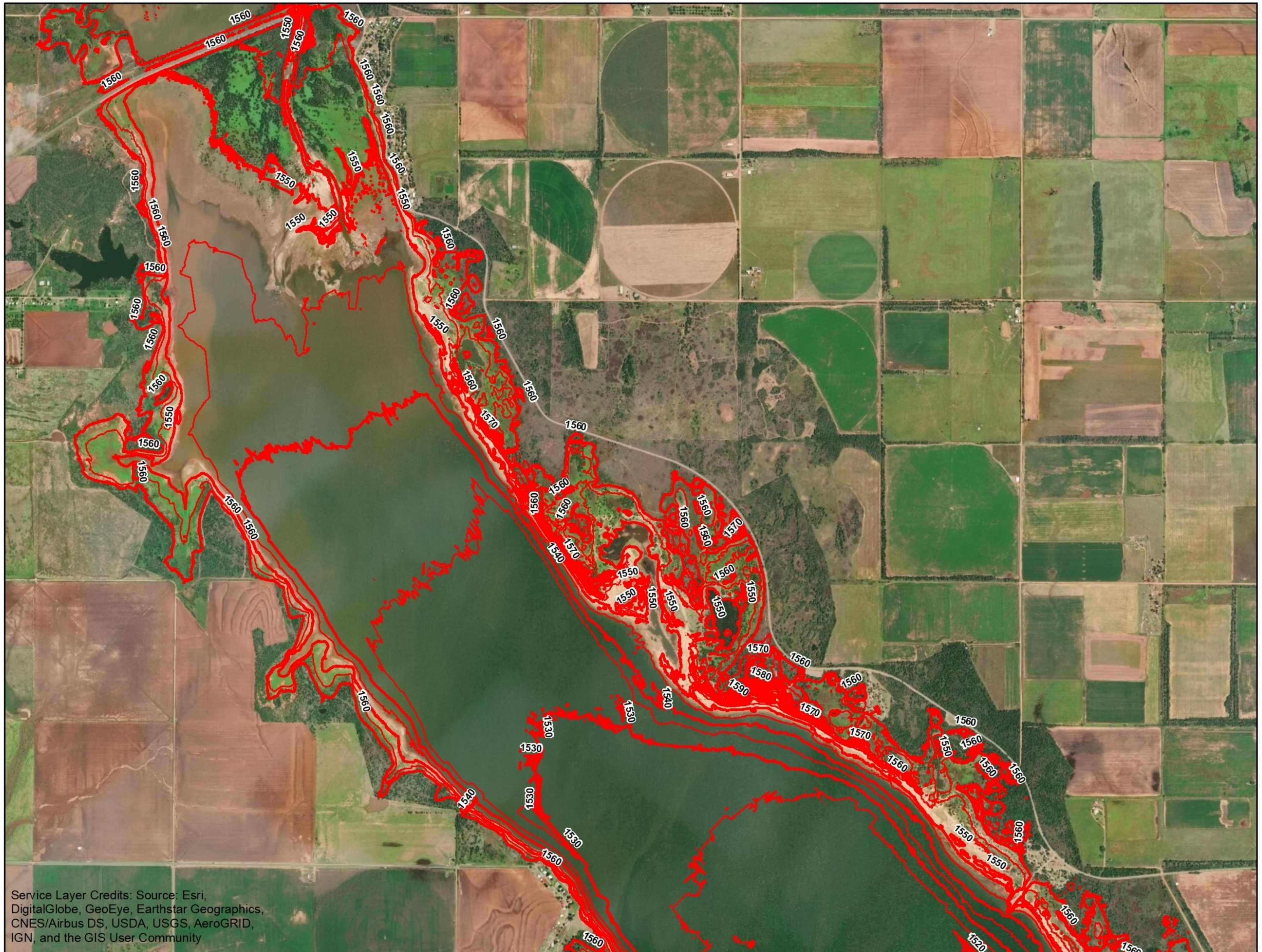
N

Scale 1:20,000

0 1,550 3,100 Feet



BUREAU OF RECLAMATION



Lake Altus Oklahoma Elevation Contour Map

Sheet 2

Horizontal: NAVD88, State Plane Oklahoma South
RPVD = NGVD29
NAVD88 – NGVD29 = 0.59 ft

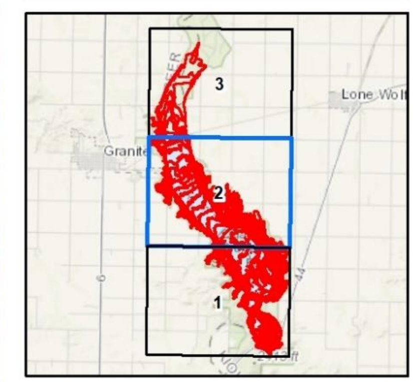
Five Foot Contour Interval

Primary Data Source:
Bathmetry from 2018 Reservoir Survey
Topography provided by OTAO

N

Scale 1:20,000

0 1,550 3,100 Feet



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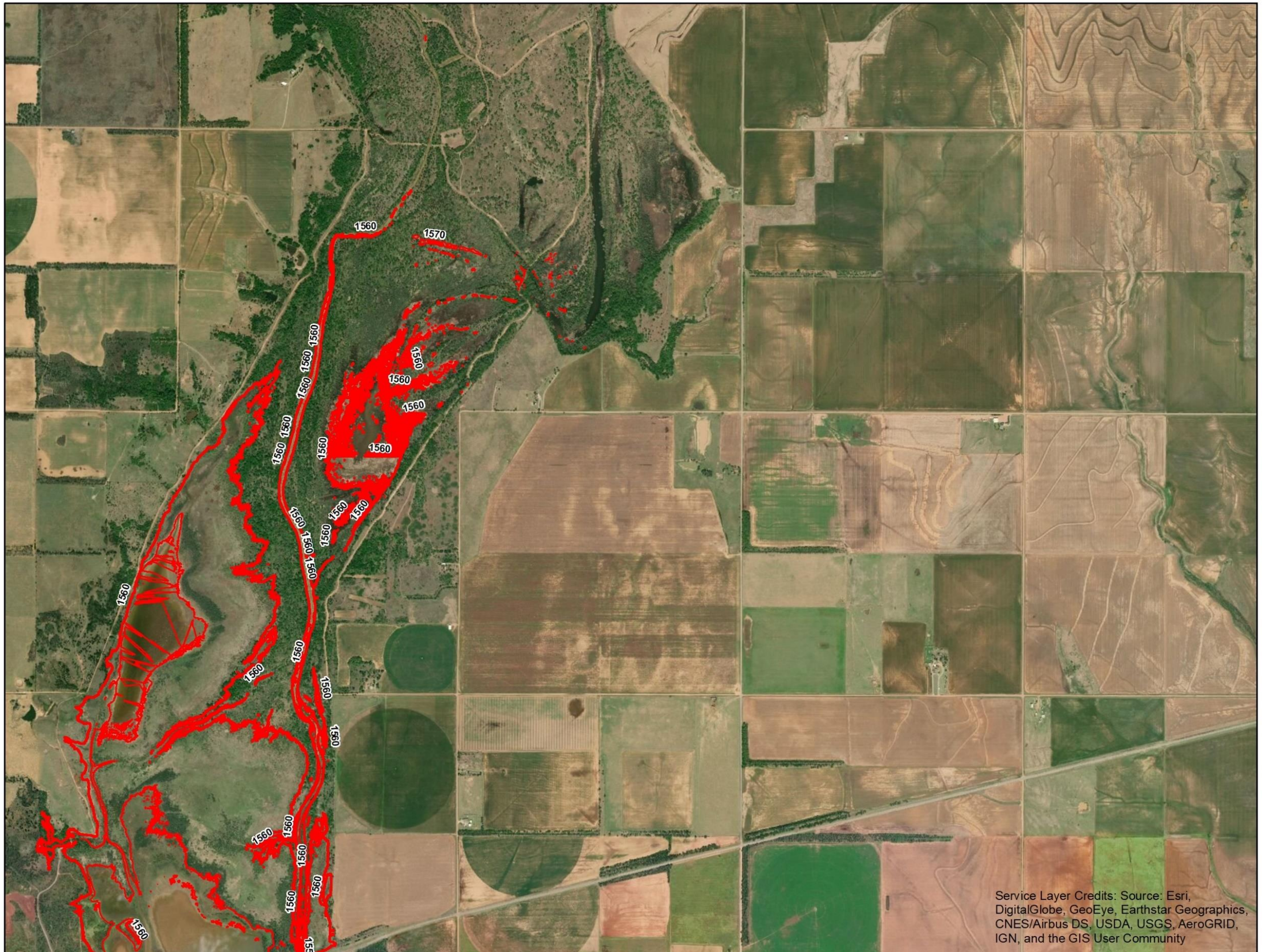


Lake Altus
Oklahoma
Elevation
Contour Map

Sheet 3

Horizontal: NAVD88, State Plane Oklahoma South
RPVD = NGVD29
NAVD88 – NGVD29 = 0.59 ft

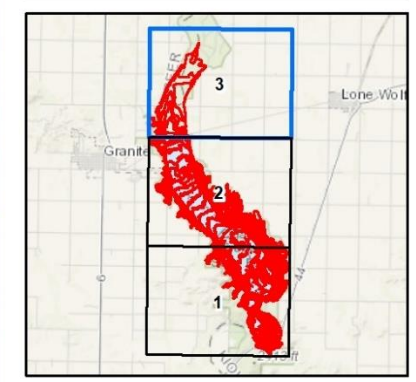
Five Foot Contour Interval

Primary Data Source:
Bathmetry from 2018 Reservoir Survey
Topography provided by OTAO

N

Scale 1:20,000

0 1,550 3,100 Feet



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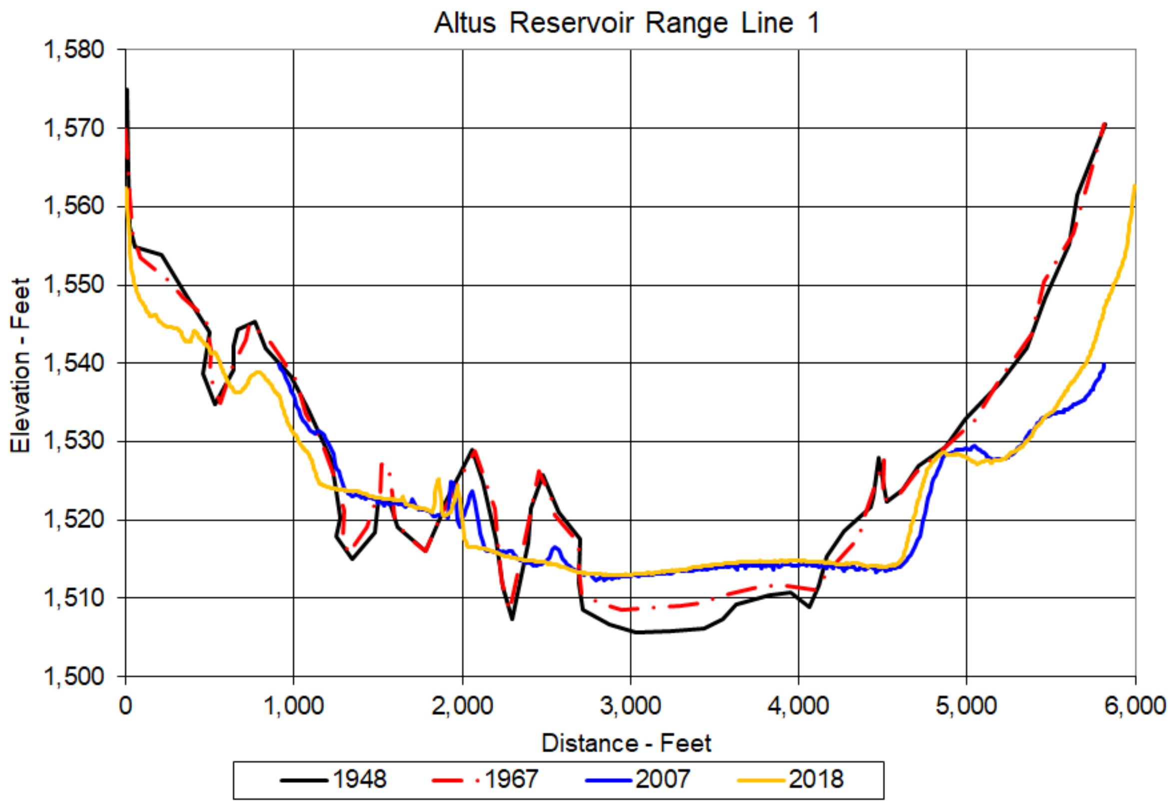
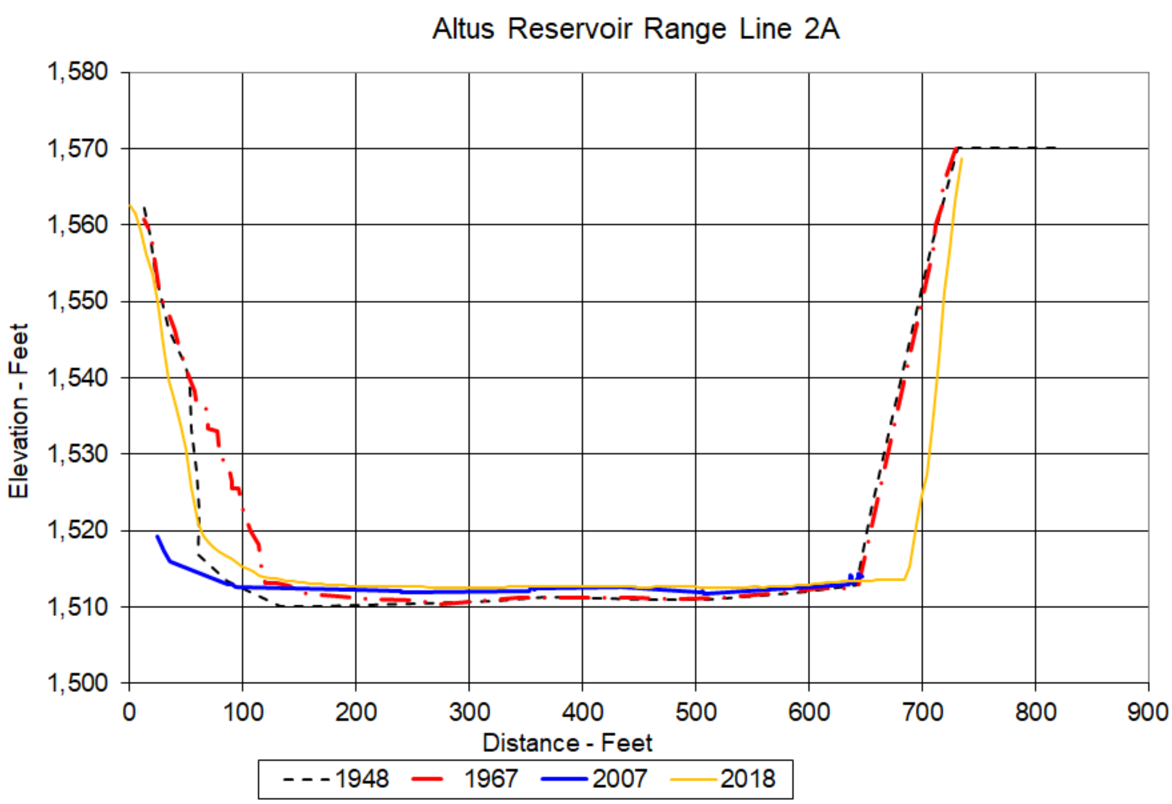
RECLAMATION

Appendix E – Range Line Cross Sections

NOTE: All elevations are given in NGVD29.


Altus Reservoir Range Line 1
Elevation - Feet
1,580
1,570
1,560
1,550
1,540
1,530
1,520
1,510
1,500
0
1,000
2,000
3,000
4,000
5,000
6,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 2A
Elevation - Feet
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1,570
1,560
1,550
1,540
1,530
1,520
1,510
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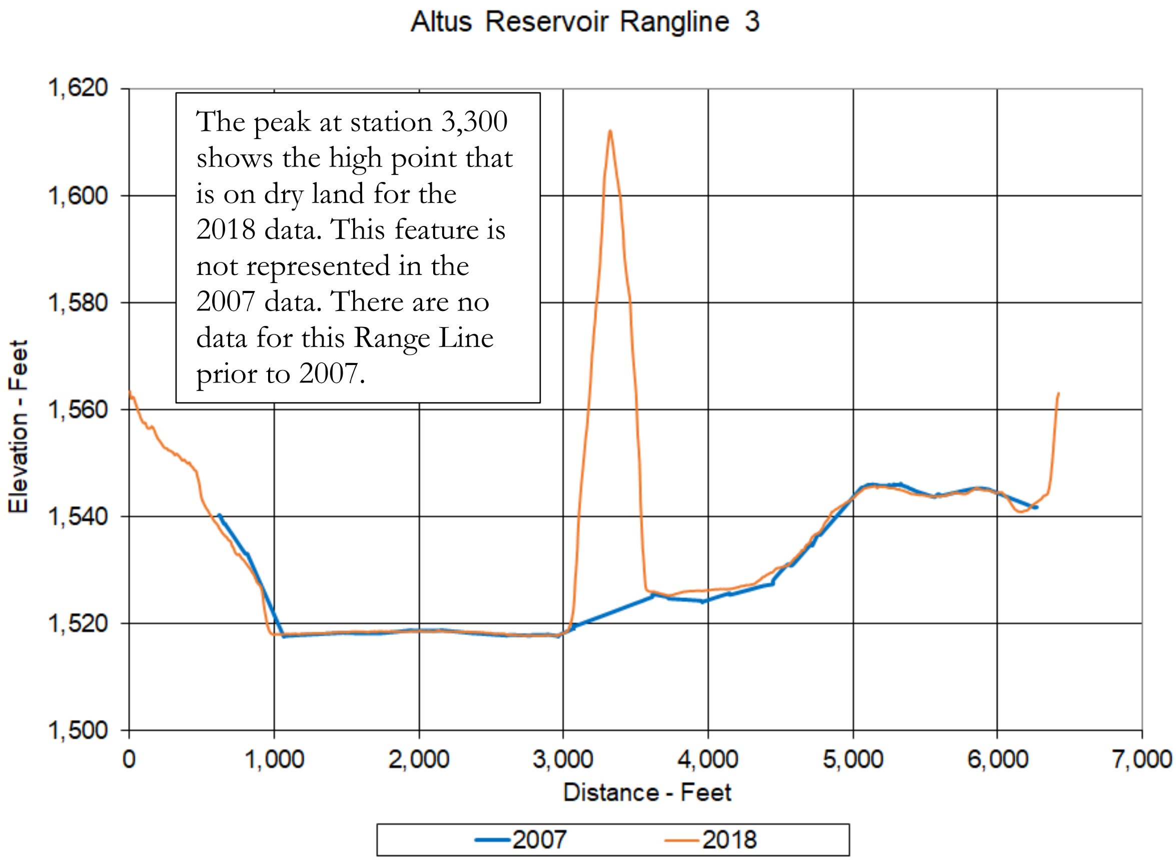
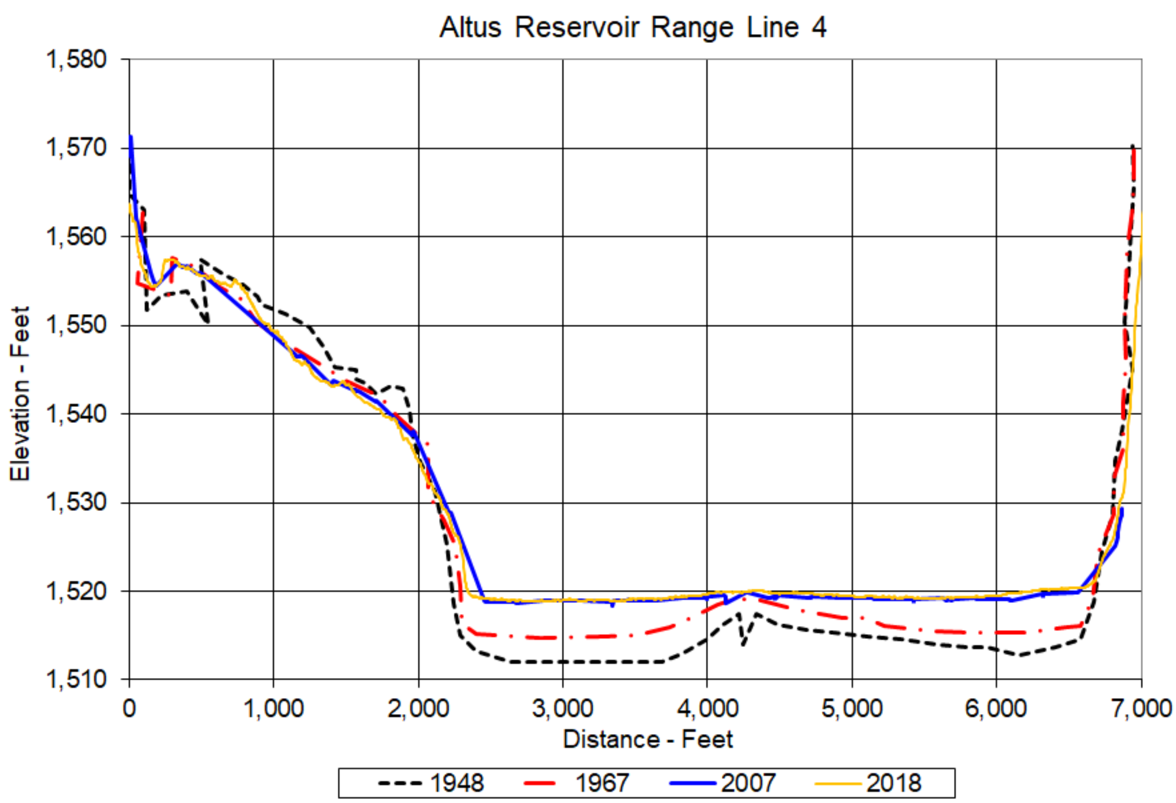
100
200
300
400
500
600
700
800
900
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Rangline 3
The peak at station 3,300 shows the high point that is on dry land for the 2018 data. This feature is not represented in the 2007 data. There are no data for this Range Line prior to 2007.
Elevation - Feet
1,620
1,600
1,580
1,560
1,540
1,520
1,500
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Distance - Feet
2007
2018


Altus Reservoir Range Line 4
Elevation - Feet
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1,540
1,530
1,520
1,510
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4,000
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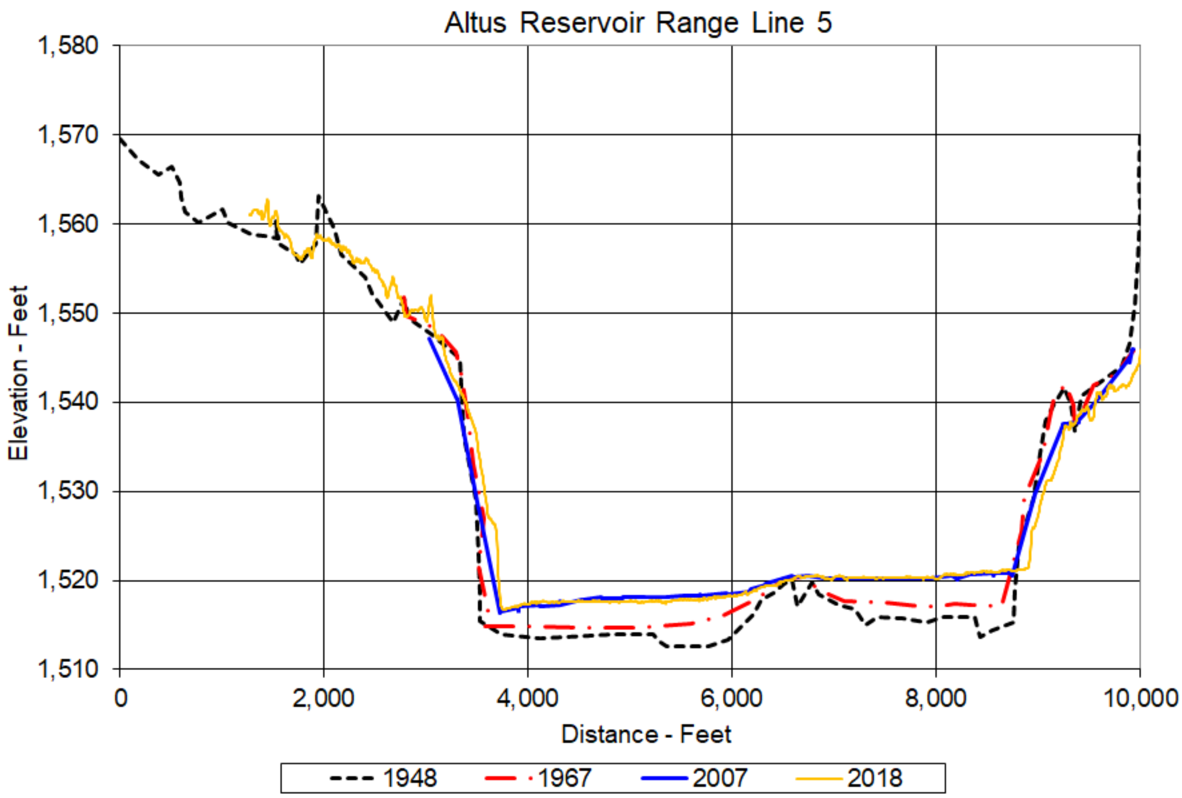
6,000
7,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 5
Elevation - Feet
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1,560
1,550
1,540
1,530
1,520
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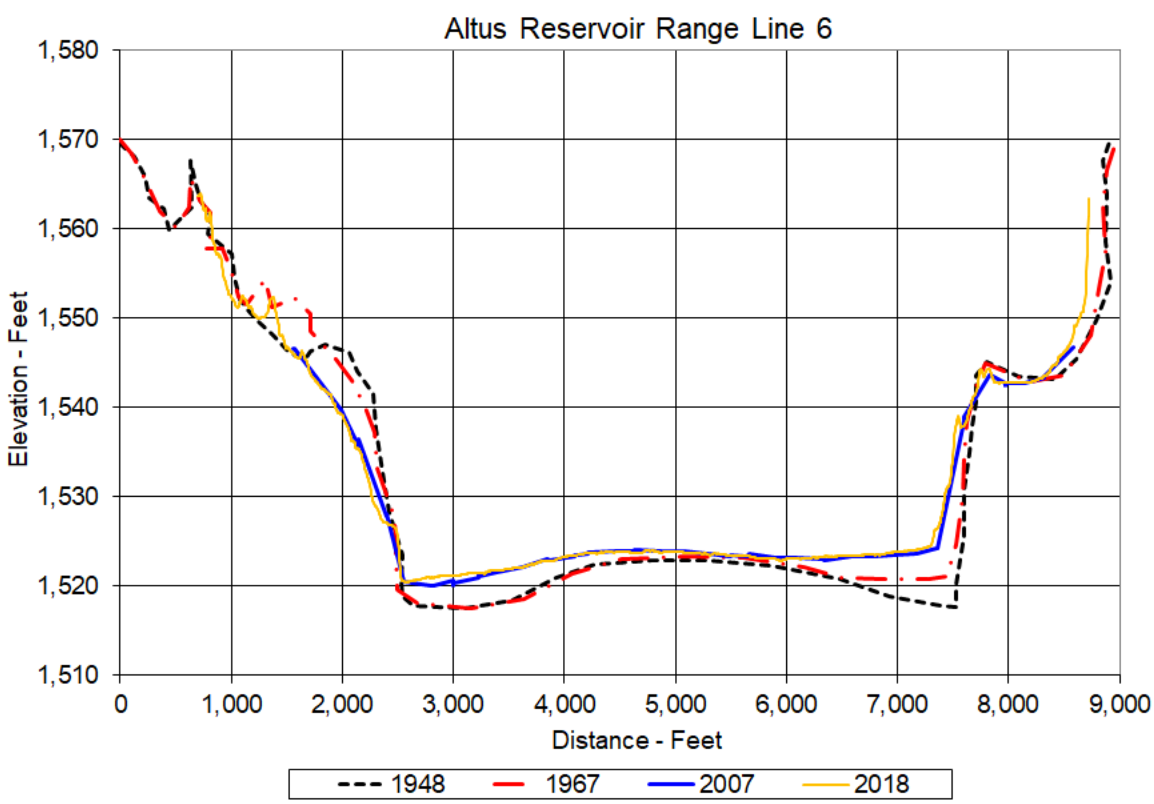
8,000
10,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 6
Elevation - Feet
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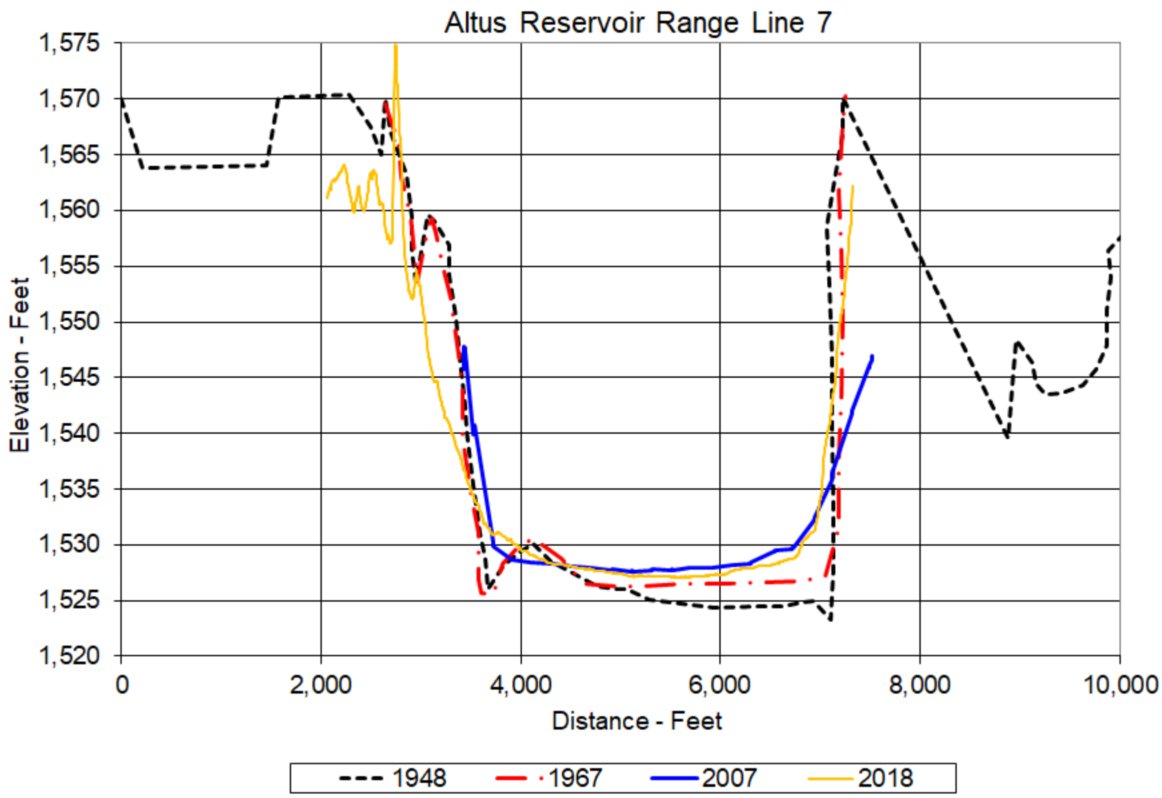
1,560
1,550
1,540
1,530
1,520
1,510
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
Distance - Feet
1948
1967
2007
2018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Elevation - Feet
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1,540
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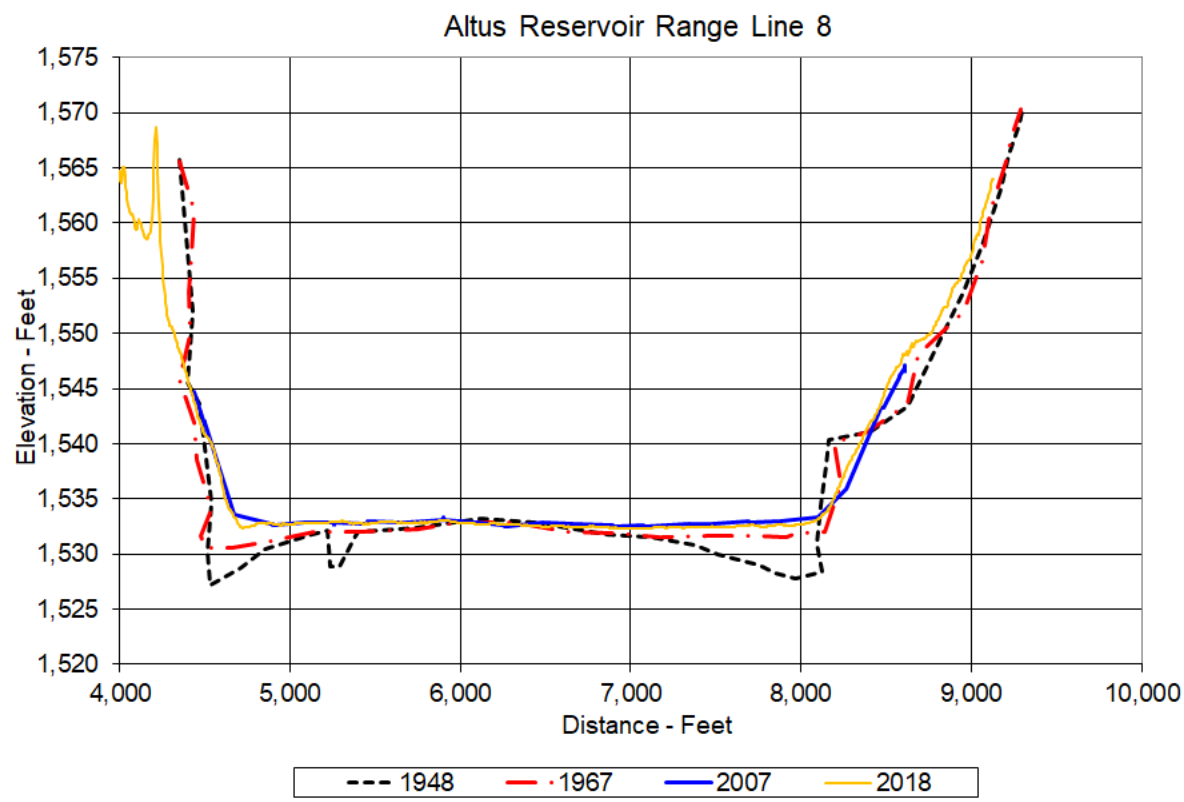
0
2,000
4,000
6,000
8,000
10,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 8
Elevation - Feet
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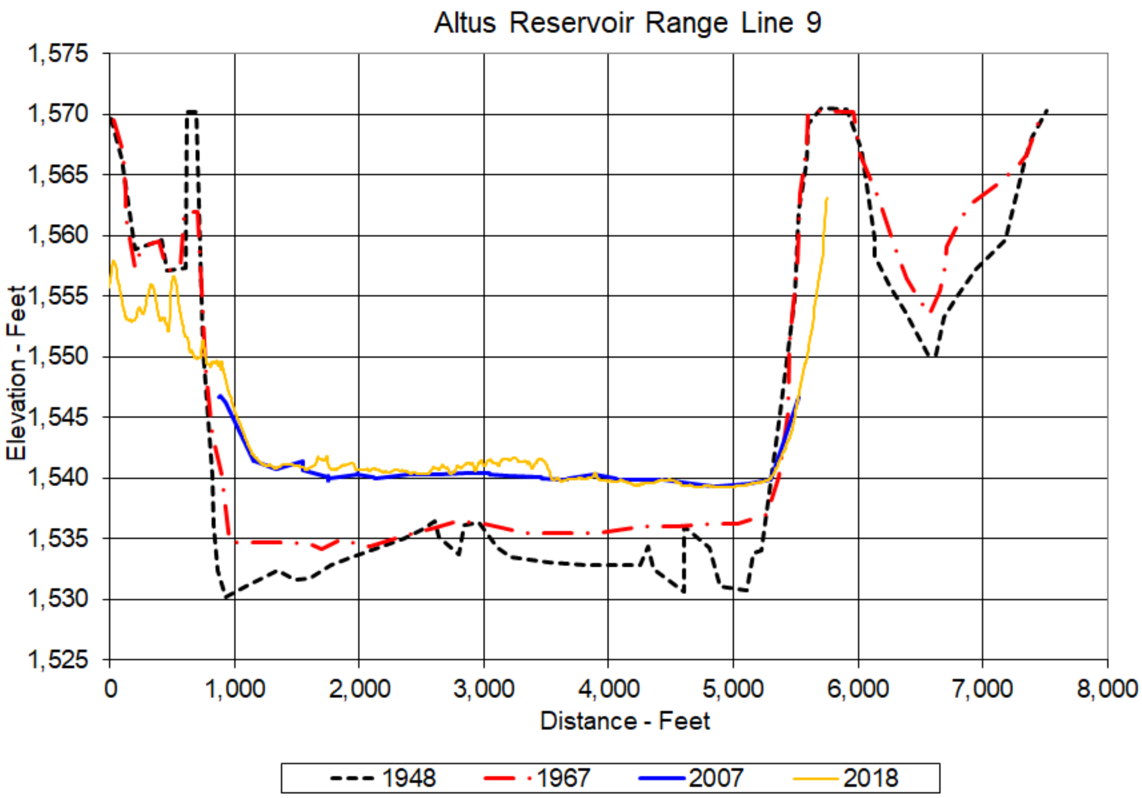
1,555
1,550
1,545
1,540
1,535
1,530
1,525
1,520
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 9
Elevation - Feet
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1,560
1,555
1,550
1,545
1,540
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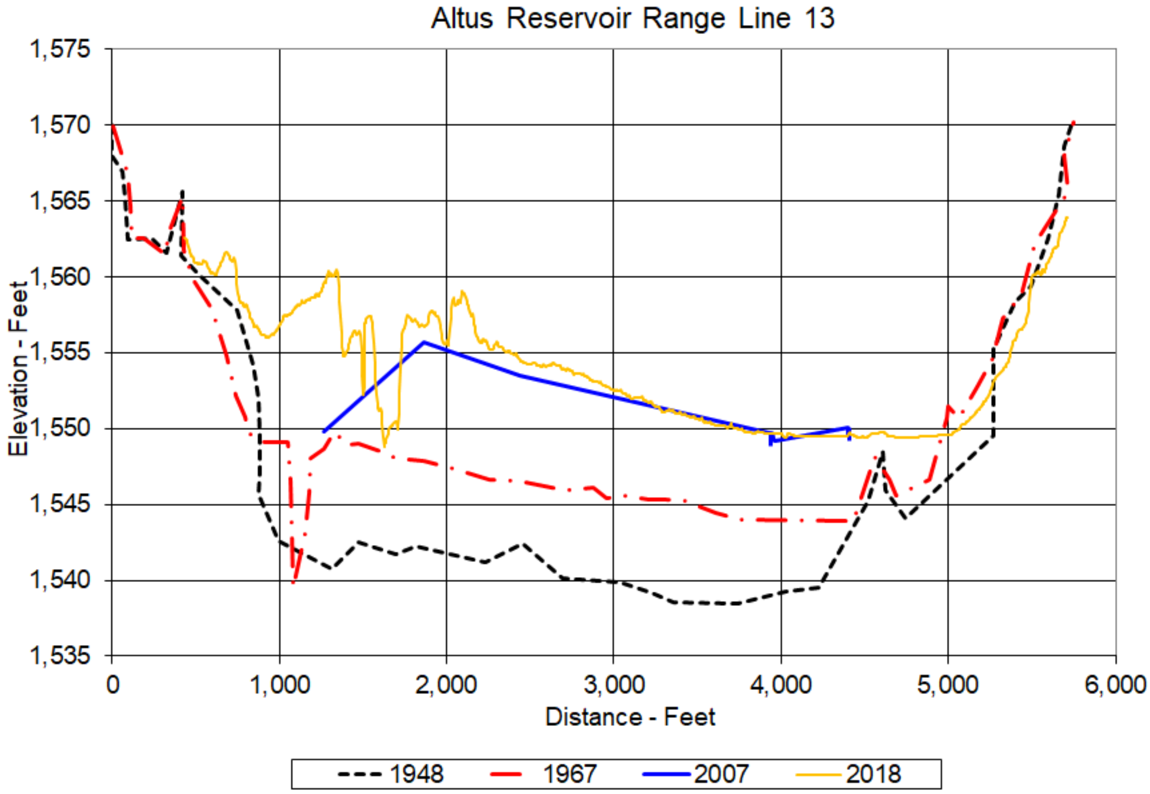
1,530
1,525
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 11
Elevation - Feet
1,575
1,570
1,565
1,560
1,555
1,550
1,545
1,540
1,535
1,530
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 13
Elevation - Feet
Distance - Feet
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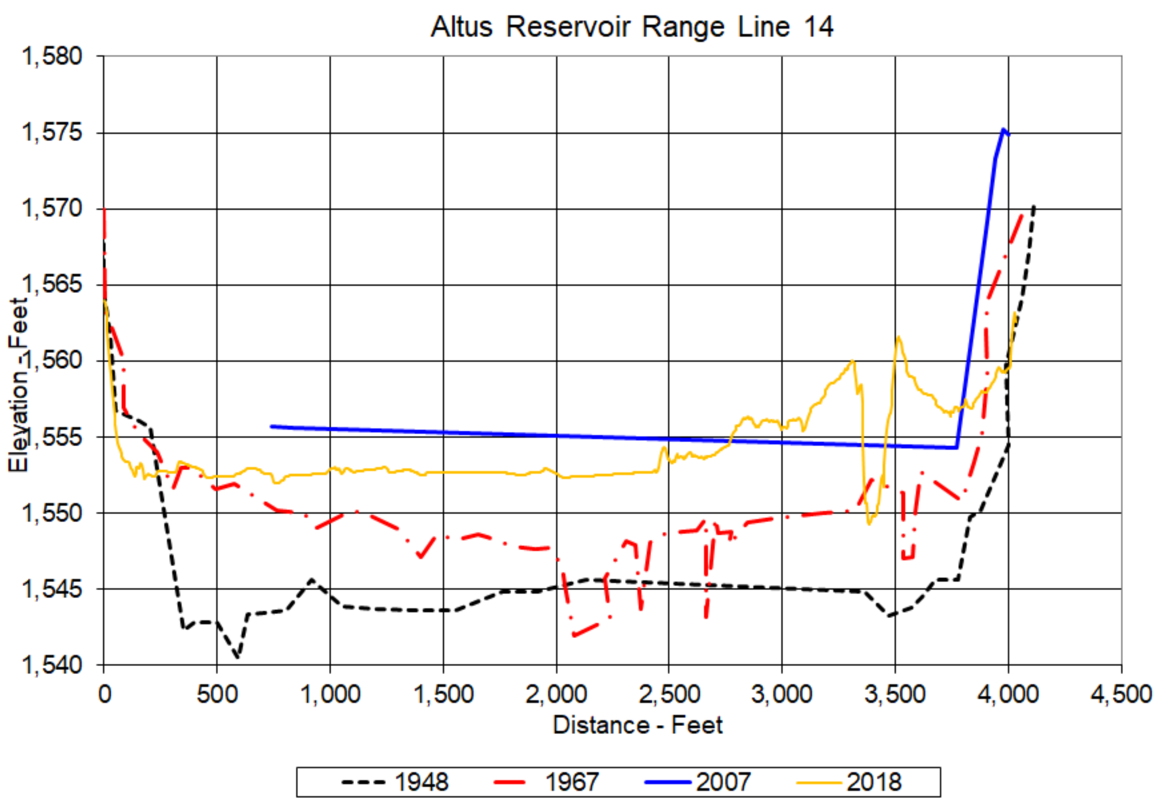
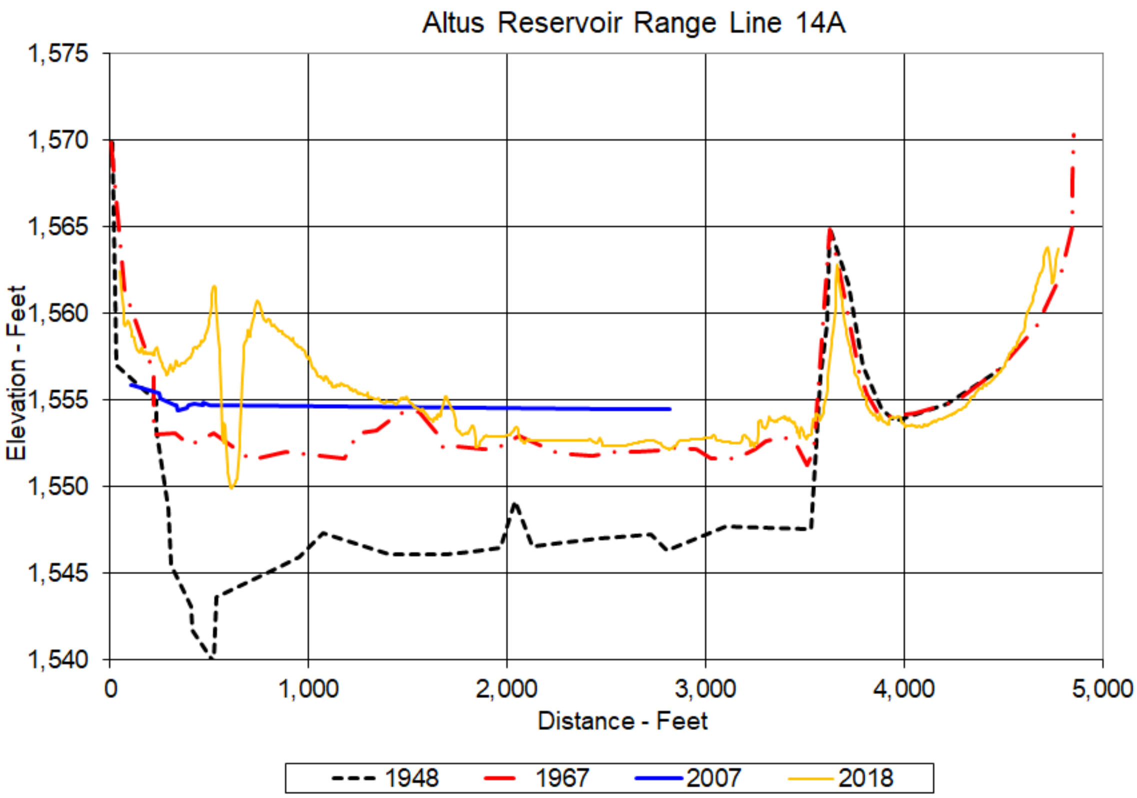
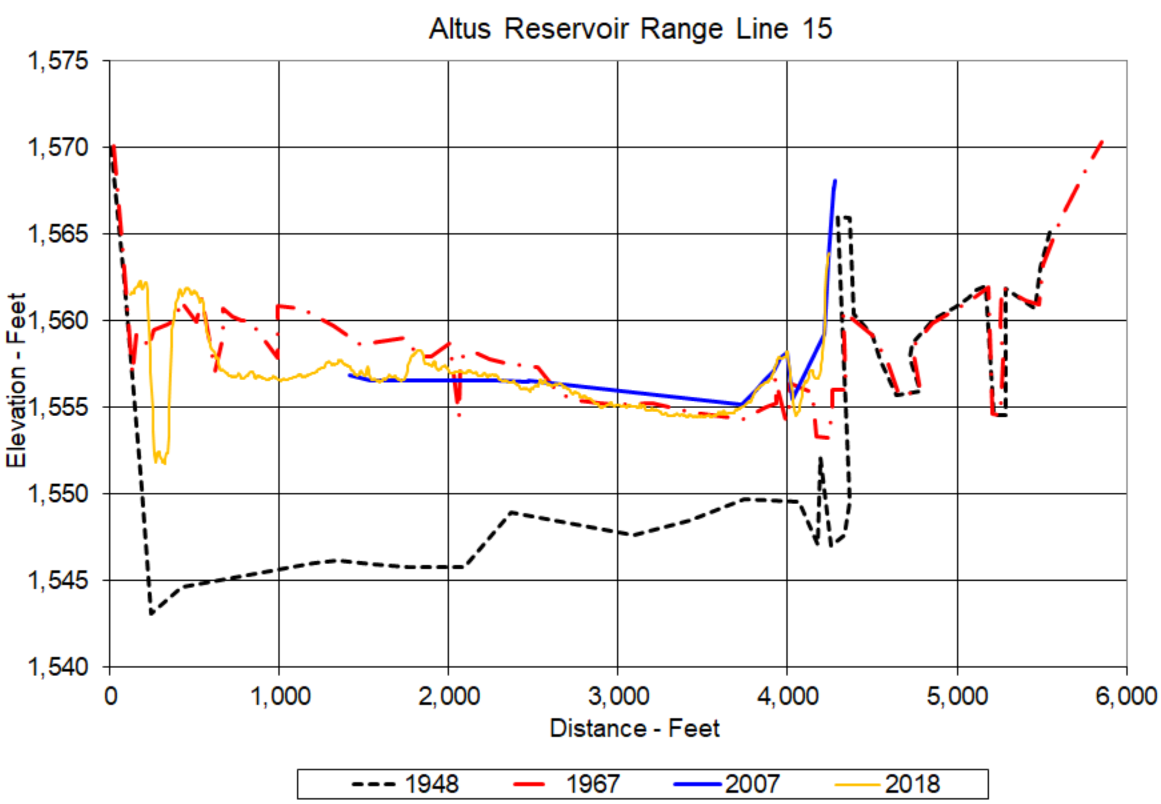
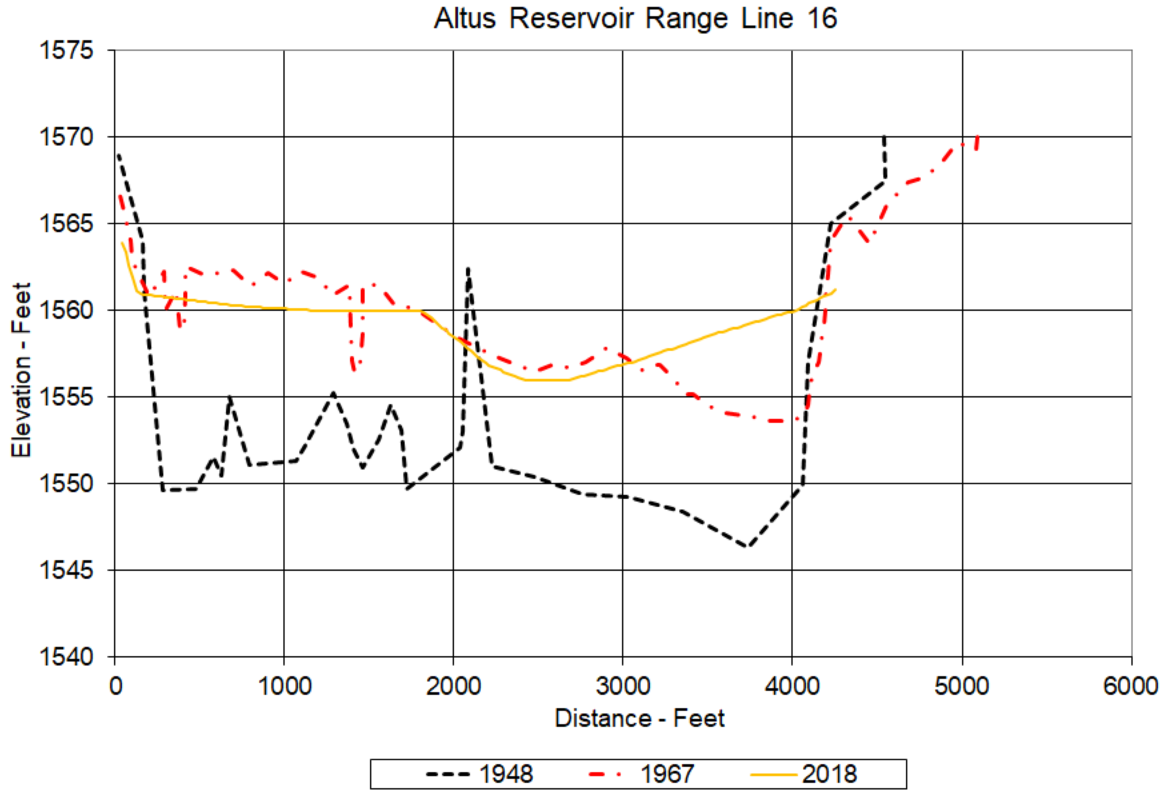
1,565
1,560
1,555
1,550
1,545
1,540
1,535
0
1,000
2,000
3,000
4,000
5,000
6,000
1948
1967
2007
2018


Altus Reservoir Range Line 14
Elevation - Feet
Distance - Feet
1,580
1,575
1,570
1,565
1,560
1,555
1,550
1,545
1,540
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
1948
1967
2007
2018


Altus Reservoir Range Line 14A
1,575
1,570
1,565
1,560
1,555
1,550
1,545
1,540
Elevation - Feet
0
1,000
2,000
3,000
4,000
5,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 15
1,575
1,570
1,565
1,560
1,555
1,550
1,545
1,540
Elevation - Feet
0
1,000
2,000
3,000
4,000
5,000
6,000
Distance - Feet
1948
1967
2007
2018


Altus Reservoir Range Line 16
1575
1570
1565
1560
1555
1550
1545
1540
Elevation - Feet
0
1000
2000
3000
4000
5000
6000
Distance - Feet
1948
1967
2018