BUREAU OF RECLAMATION

Technical Report No. ENV-2021-019

Blue Mesa Reservoir 2019 Sedimentation Survey

Colorado River Storage Project, Colorado
Upper Colorado Basin Region

U.S. Department of the Interior **November 2020**

Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgements

This survey was requested and funded by the Upper Colorado Basin Regional office. Kent Collins and Steve Hollenback of the Technical Service Center's Sedimentation and River Hydraulics Group assisted with the survey. Jack Truax (Geographic Applications and Analysis Group) provided the contour maps at the end of this report.

Disclaimer

Cover: Blue Mesa Dam and Reservoir (Reclamation)

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14. SHORT ABSTRACT The 2019 multibeam bathymetric survey of Blue Mesa Reservoir was combined with 2019 airborne LiDAR to produce a combined digital surface of the reservoir bottom. Analysis of these data indicates that at the maximum water surface (7,519.4 feet, Reclamation Project Vertical Datum), the reservoir has a surface area of 9,219 acres and a storage capacity of 938,141 acre-feet. Original reservoir capacity following construction in 1966, was estimated to be 940,800 acre-ft at this same elevation. The dead storage pool volume in the 1961 allocation was 111,200 acre-feet and was measured to be 110,197 acre-feet using the 2019 survey. The sedimentation level at the dam is unknown because a previous survey has not been located but is strongly suspected to be non-existent or negligible.					
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BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Blue Mesa Reservoir 2019 Sedimentation Survey

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Acronyms and Abbreviations

ACAP	Area-Capacity
AF	Acre-feet, volume/capacity measurement
DOI	Department of the Interior
ft	foot or feet
ft^3/s	cubic feet per second (cfs)
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
NAVD 1988	North American Vertical Datum, established 1988
NGS	National Geodetic Survey
NGVD 1929	National Geodetic Vertical Datum, established 1929
OPUS	Online Positioning User Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RTK	Real-Time Kinematic
TSC	Technical Service Center
USGS	U.S. Geological Survey
WY	Water Year

Executive Summary

Blue Mesa Dam and Reservoir are on the Gunnison River about 30 miles west from Gunnison, Colorado.

A survey of Blue Mesa Reservoir was conducted in 2019 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original construction in 1966, 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 2019 multibeam bathymetric survey of Blue Mesa Reservoir was combined with 2019 airborne LiDAR to produce a combined digital surface of the reservoir bottom.

This survey was conducted August 11 – 17, 2019 and September 29-30, 2019. The second survey trip in September 2019 was made necessary by a faulty velocity probe during the early part of the reservoir survey in August. This problem was discovered soon after the August survey began but it was necessary to re-survey the small portion of the reservoir covered during the time that the velocity probe was not operating properly. During the August survey the reservoir water surface elevation ranged between 7,516.16 and 7,516.97 feet, Reclamation Project Vertical Datum (RPVD). During the September survey the water surface ranged between 7,508.94 and 7,509.21 feet RPVD. Maximum (top of joint use) pool elevation is 7,519.4 feet RPVD. The above-water topographic data were measured using airborne LiDAR in May 2019 when the reservoir water surface elevation was approximately 40 feet lower than it was during the bathymetric survey. This provided sufficient overlap for a seamless digital map in most locations along the reservoir shoreline.

Analysis of the combined data sets indicates the following results:

- At the maximum pool elevation (top of joint use,7,519.4 feet, RPVD), the reservoir has a surface area of 9,219 acres and a storage capacity of 938,141 acre-feet.

- Since original filling of the reservoir in 1966, the reservoir is estimated to have lost 2,659 acre-feet of storage capacity (0.28 percent). This loss can be attributed to sedimentation but the difference in survey methods over 50+ years also contributes to the difference in reservoir capacity, perhaps more so than sedimentation. This volume difference represents a very low sediment yield rate, however, it is believed that this small difference is also attributed to varying survey methods. The original method of survey is unknown.

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	Blue Mesa	Region	UCB
Owner	UCB Region	Area Office	Western CO
Stream	Gunnison River	Vertical Datum	RPVD
County	Gunnison	Top of Dam (ft)	7,528.0
State	Colorado	Spillway Crest (ft)	7,487.9
Lat (deg min sec)	38.4533	Power Penstock Elevation (ft)	7,358.0
Long (deg min sec)	-107.3333	Low Level outlet (ft)	7,358.0
HUC4	1402	Hydraulic Height (ft)	342
HUC8	14020002	Total Drainage Area (mi^2)	3,453*
NID ID	CO1675	Date storage began	1966
Dam Purpose	Irrigation	Date for normal operations	1966
*This value obtained from USGS (https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=09124700). Reclamation (1981) indicates a drainage area of 3,470 mi^2.			

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

2019 Survey

Storage Allocation	Elevation (feet, RPVD)	Surface area (acres)	Capacity (acre-feet)	Gross Capacity (acre-feet)
SURCHARGE	7528.0	9,753	81,489	1,019,630
FLOOD CONTROL	'--------------	'--------------	'--------------	'--------------
MULTIPLE USE	'--------------	'--------------	'--------------	'--------------
JOINT USE	7,519.4	9,219	747,904	938,141
CONSERVATION	'--------------	'--------------	'--------------	'--------------
INACTIVE	7,393.0	2,777	80,041	190,237
DEAD	7,358.0	1,845	110,196	110,196

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sedimentation Volume (acre-feet)	Cumulative Sedimentation (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
1961	**Unknown**	**unknown**	**3,453**	**----------------**	**---------------**	**unknown**	**100%**
2019	**Multibeam & LiDAR**	**N/A**	**3,453**	**2,659**	**2,659**	**7,195**	**99%**

Notes

An effort was made to find an original survey report for Blue Mesa Reservoir, none was found. The current allocation table was created in 1961 and dam construction dates were 1962-1966. First filling began in January 1966.

Contents

Tables

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1. Introduction

Blue Mesa Dam is on the Gunnison River 30 miles west of Gunnison, CO (Figure 1). The dam is a zoned, earthfill embankment structure with a structural height of 390 feet. The spillway consists of a concrete intake structure with 2 radial gates. The maximum discharge of the spillway is 34,000 ft^3/s. Blue Mesa Reservoir extends approximately 18 miles (centerline distance) upstream from the dam and occupies 9,219 acres when full (7,519.4 ft, RPVD). Downstream from Blue Mesa Dam the Gunnison River continues approximately 130 miles to its confluence with the Colorado River in Grand Junction, CO. Morrow Point and Crystal Dams are 11.7 and 18.3 miles downstream of Blue Mesa Dam, respectively.

Blue Mesa dam and reservoir are operated by the Curecanti Field Division, Montrose, CO as part of the Colorado River Storage Project that supplies water for irrigation. The dam produces hydropower with two 30,000 kilowatt generators. Blue Mesa Reservoir has 96 miles of shoreline and is a significant attraction for recreation. The reservoir lies within the Curecanti National Recreation Area.

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 Upper Colorado Basin Region requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A complete bathymetric survey was conducted August 11 – 17, 2019 and September 29-30, 2019. The second survey trip in September 2019 was made necessary by a faulty velocity probe during the early part of the first reservoir survey in August. The survey was conducted with these primary objectives:

- Estimate reservoir sedimentation volume since the original reservoir filling began in 1966, and
- Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations

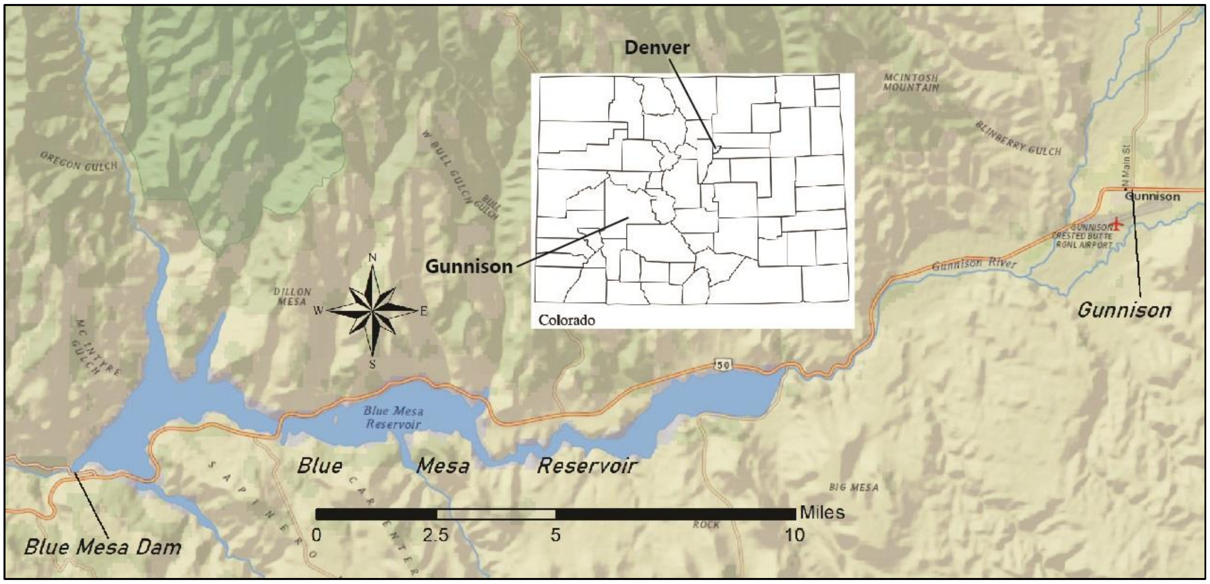

Figure 1. Location map of Blue Mesa Dam and Reservoir. The dam is approximately 30 miles west of Gunnison, Colorado

2. Watershed Description

2.1. Location and Drainage

Total drainage area for Blue Mesa Dam and Reservoir is 3,453 mi^2 (https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=09124700). The whole drainage area contributes sediment with the exception of 254 mi^2 behind Taylor Park Dam in the northeast portion of the watershed (Figure 2). This gives a sediment contributing drainage area of 3,199 mi^2.

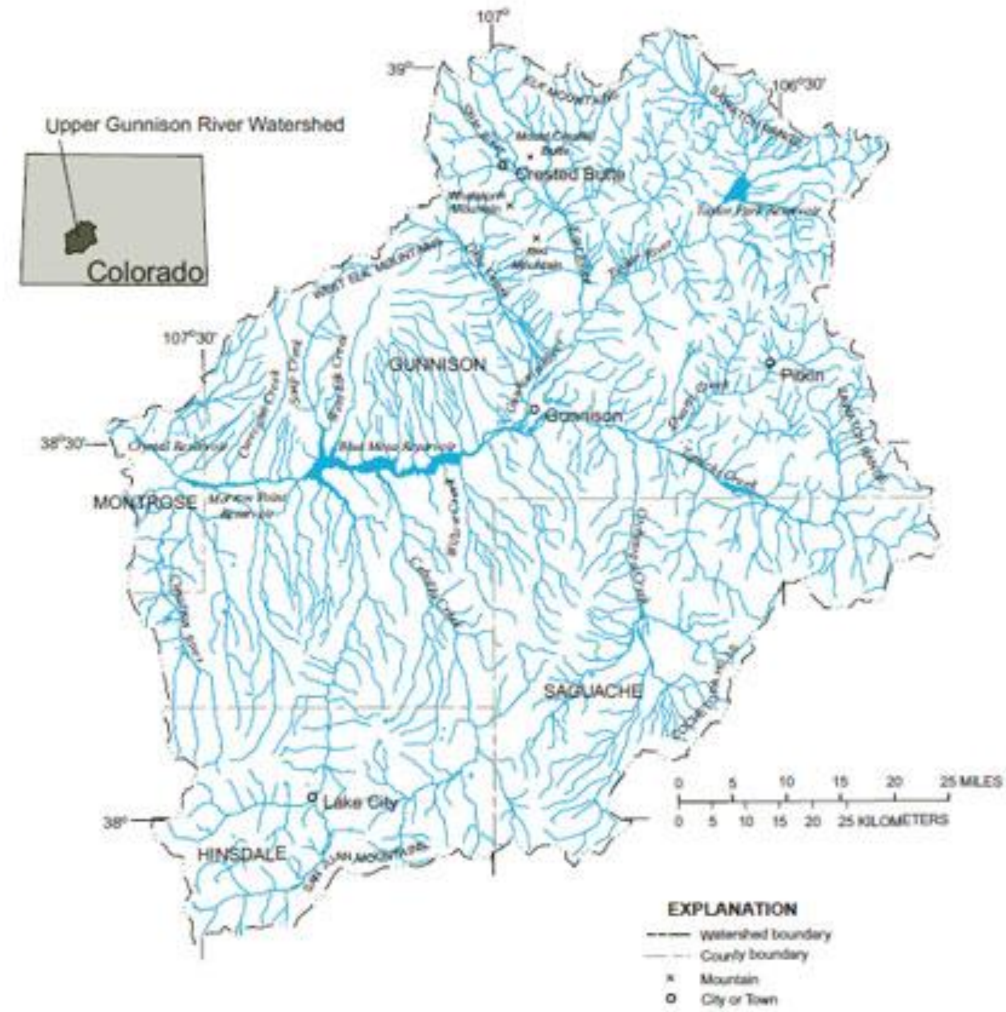

Figure 2. Map showing the upper Gunnison River watershed (https://www.usgs.gov/media/images/upper-gunnison-river-basin).

2.2. Geology

The watershed has undergone a rather complex geologic development. The stratigraphic column consists of basement, pre-Cambrian granite, gneiss, and schist, overlain uncomfortably by the Jurassic, Entrada sandstone, and shale, In turn progressively overlain by the Morrison Mancos clay shales. Structurally, the sedimentary strata, underlying the volcanics and overlaying the granites, dip to the north, with the horizontal overlaying volcanics covering their erosional truncated edges. The contact between the granite and sedimentary rocks becomes progressively lower in elevation to the north of the river. On the south side of the river, it rises to the ground surface. A large normal fault parallels the canyon on the southwest side, cutting close to the river at Cimarron, below Blue Mesa Dam (https://www.usbr.gov/projects/index.php?id=62). Additional geologic information can be found in Lloyd (1980).

2.3. Climate and Runoff

Reservoir inflows are primarily from the Gunnison River and Tomichi Creek. Tomichi Creek joins the Gunnison River downstream of the town of Gunnison and the USGS stream gage 09114500 (Gunnison R. nr. Gunnison, Colorado). Tomichi creek is gaged by USGS 09119000 (Tomichi Cr. at Gunnison, Colorado). The confluence of Tomichi Creek and the Gunnison River is approximately 4.5 miles upstream of the reservoir head (Figure 3). USGS stream gage records are available for the sites shown in Figure 3 and presented in Table 1, which represent 60 percent of the total contributing drainage area.

Figure 3. Map of USGS gages relative to the confluence of Tomichi Cr. with the Gunnison R. and Blue Mesa Reservoir. Flow direction is from east to west. Only the upstream-most portion of Blue Mesa Reservoir is shown in this image.

Based on USGS data presented in Table 1, the mean annual runoff to Blue Mesa Reservoir from Tomichi Creek and the Gunnison River is 628,139 acre-feet. This runoff is from both rainfall and snowmelt. The mean annual stream flow to the reservoir is 704 ft^3/s from the Gunnison River and 168 ft3/s from Tomichi Creek. The ratio of reservoir storage capacity to the mean annual runoff from these two streams is 67 percent. The remaining inflow comes from ungaged streams in the drainage. A plot of mean annual runoff to Blue Mesa Reservoir since 1966 is shown in Figure 4. Annual peak stream flow for the Gunnison River and Tomichi Creek are shown in Figure 5 and Figure 6.

Table 1. Reservoir Inflow Streams with USGS gages.

USGS Stream Gage		**Drainage Area (mi²)**	**Mean Annual Runoff (acre-ft)**	**Period of Record**
Name	**Number**			
Gunnison R. nr. Gunnison, CO	09114500	1,011	507,537*	1910 - current
Tomichi Cr. @ Gunnison, CO	09119000	1,061	120,602*	1937 - current
Totals		2,072	628,139*	'---------
* Mean annual runoff values are WY1966 – WY2019.				

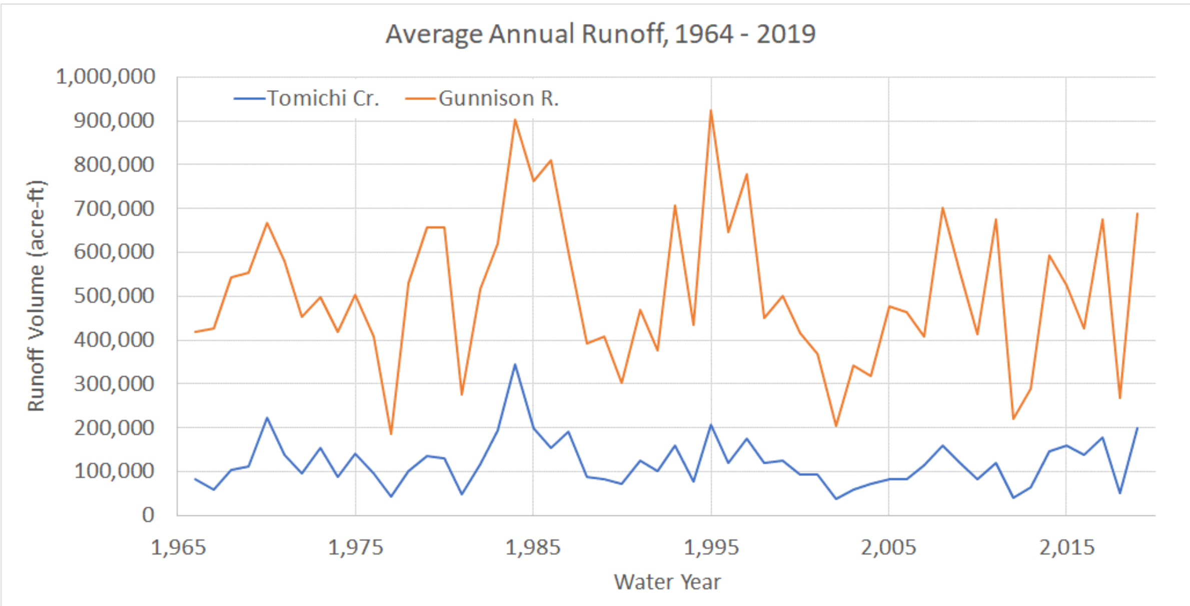

Figure 4. Plot of mean annual runoff from the Gunnison River and Tomichi Creek into Blue Mesa Reservoir. These streams account for 60% of the drainage area and 67% of runoff. The remaining contribution is from ungagged streams in the drainage.

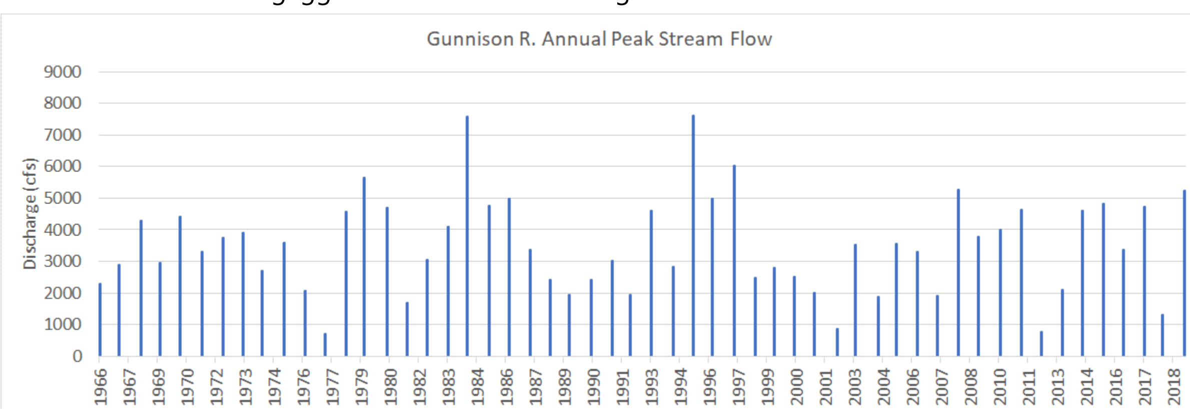

Figure 5. Annual peak stream flow for the Gunnison River (USGS #09114500).

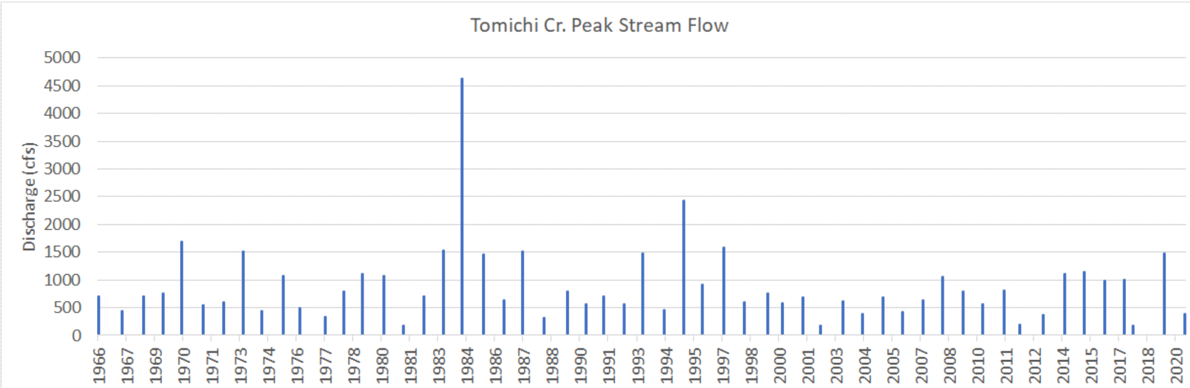

Figure 6. Annual peak stream flow for Tomichi Cr. (USGS #09119000)

2.4. Dam Operations and Reservoir Characteristics

Blue Mesa Dam is a zoned, earth and rock fill embankment dam with a volume of 3,093,000 yd^3 (Reclamation 1981). The dam has a structural height of 390 feet with a crest length of 785 feet. The reservoir had an original length of about 18 miles long at full pool with 2 major tributaries. Construction of this dam began in 1962 and was completed in 1966, when filling began. The historic reservoir storage is presented in Figure 7. Annually, reservoir storage typically fluctuates about 350,000 to 500,000 acre-feet.

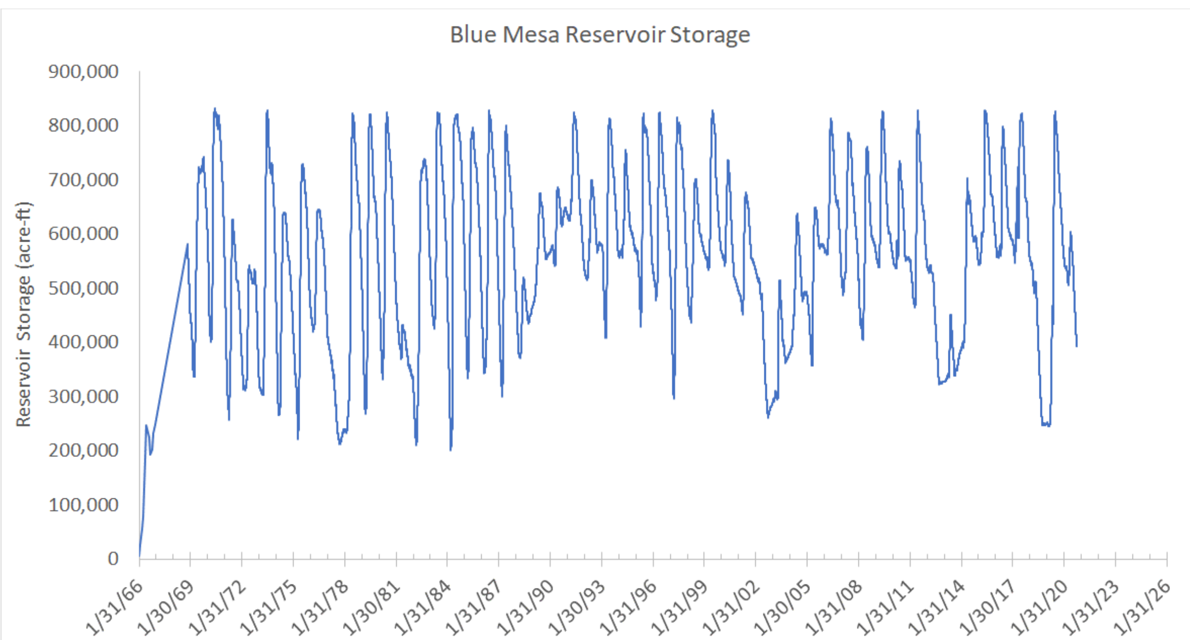

Figure 7. Historic Blue Mesa Reservoir storage volume. Data web source: https://www.usbr.gov/uc/water/hydrodata/reservoir_data/site_map.html

The reservoir is generally narrow throughout its length, with the narrowest portion west of the Elk Creek Marina, 0.12 miles. The widest portion of the reservoir is approximately 1 mile with two other locations that are 0.75 miles (Figure 1) wide. No noticeable delta face has formed at the upstream end of the reservoir. There is no record of past reservoir sediment management activities.

3. Previous Reservoir Survey(s)

Prior to dam closure and initial reservoir filling, a survey was conducted. Based on the most recent reservoir allocation table (dated 1961) this survey must have taken place sometime in 1961 or prior to measure the original surface areas and corresponding storage capacities. The method of survey is unknown. Range lines for the reservoir, if they exist, were not located prior to or following the bathymetric survey. It may be that photogrammetry was used for the initial survey. No report for the original survey was located.

4. Reservoir Survey Methods and Extent

4.1. Survey Methods

A complete bathymetric survey was conducted during August and September 2019 from a 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 8 and Figure 9. Terrestrial LiDAR was flown in the area of Blue Mesa Reservoir in May 2019 when the reservoir level was approximately 40 feet lower than during the bathymetric survey. These data were combined to create a seamless map of the reservoir. This digital map was used for building the updated area-capacity (ACAP) table. In locations where the LiDAR data and bathymetric survey data overlapped, the LiDAR data were deleted so that the bathymetric data were used.

Appendix A provides more details of the hydrographic survey methods.

Appendix B provides more details above the-water survey data.

Appendix C provides more details about the methods used to generate surface area and storage capacity tables. Surface area and capacity at 1-foot contour intervals were computed using GIS software and a separate computer program was used to produce the reservoir surface area and capacity tables at 0.1 and 0.01-foot increments.

Appendix D provides contour maps of the reservoir using the 2019 survey and LiDAR data.

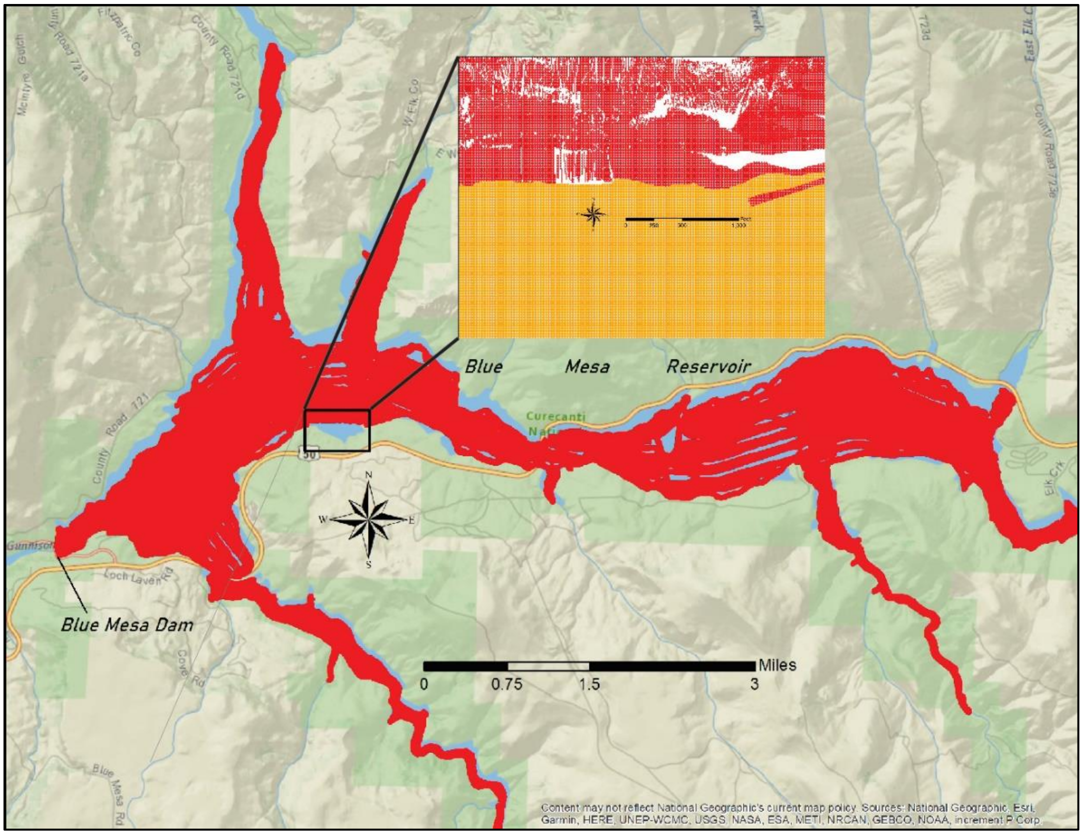

Figure 8. Map of bathymetric survey data coverage of the western end of the reservoir. Red dots are bathymetric data, gold dots are LiDAR data. The inset demonstrates that above and below water topography are seamlessly represented.

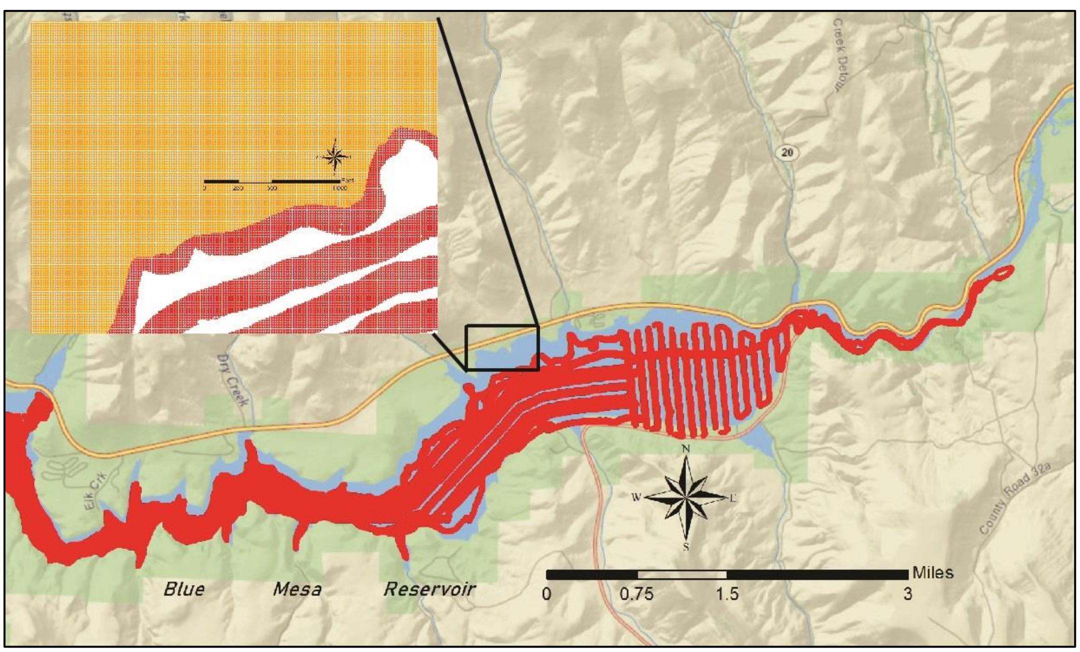

Figure 9. Map of bathymetric survey data coverage of the eastern end of the reservoir. Red dots are bathymetric data, gold dots are LiDAR data. The inset demonstrates that above and below water topography are seamlessly represented.

4.2. Survey Control, Datum, and Monuments

For the 2019 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD 1983) State Plane (horizontal) coordinates, Colorado Central, US survey feet and North American Vertical Datum 1988 (NAVD 1988, Geoid 12B), US survey feet elevations. During processing, all vertical bathymetry and GPS measurements were converted to Reclamation Project Vertical Datum (RPVD) for Blue Mesa Dam. The RPVD was determined to be 4.71 feet lower than NAVD 1988 (Geoid 12B).

The GPS base station receiver was set up over two NGS permanent monuments and one temporary monument located strategically throughout the reservoir survey area (Figure 10). A photograph of one GPS base station set-up is shown in Figure 11.

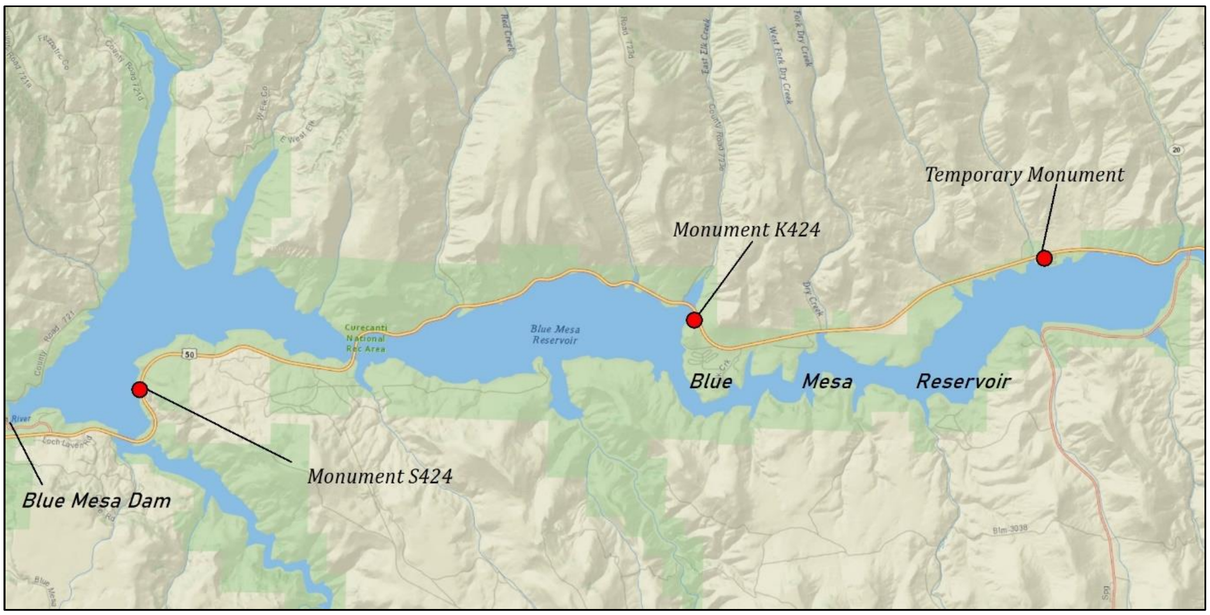

Figure 10. Location of GPS base stations along Blue Mesa Reservoir.

Coordinates for the temporary monument that was used as a GPS base station were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). Monuments S424 and K424 both have good accuracy standards (< 1 cm horizontal, ~2 cm vertical) and OPUS solutions matched these points well. Given this information the X-Y-Z coordinates published on these data sheets were used as base station coordinates for the survey. All points used for base station monuments were surveyed from other base stations to tie the points together.

The vertical shift to RPVD at Blue Mesa Reservoir was determined from several RTK GPS measurements of water surface elevations (in NAVD 1988) throughout the survey at multiple locations on the reservoir. These water surface elevations were compared to the published reservoir elevations (in RPVD) derived from the gage near Blue Mesa Dam. Comparison of multiple measurements resulted in the shift mentioned above.

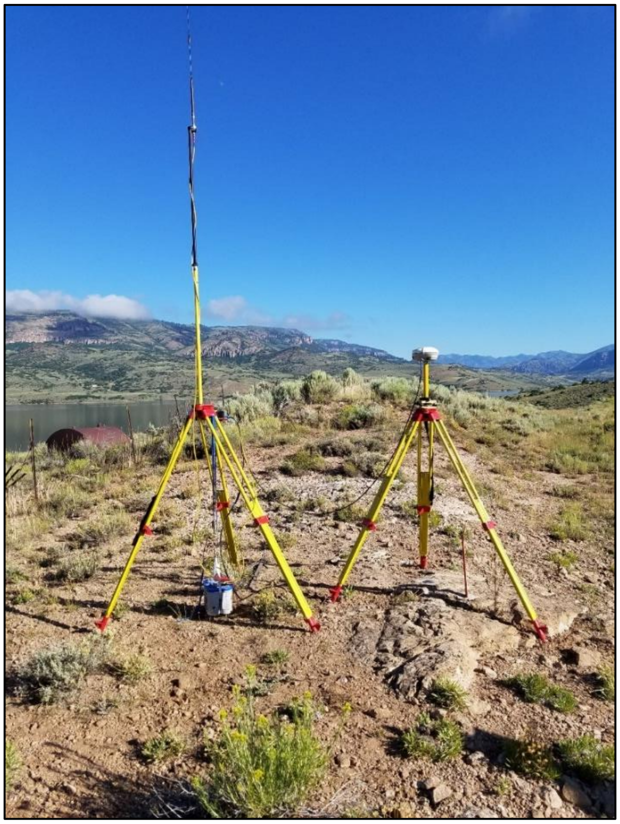

Figure 11. GPS base station set-up over monument S424 near the shoreline of Blue Mesa Reservoir.

The difference between NGVD 1929 and NAVD 1988 at Blue Mesa Reservoir 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 NGVD 1929 is 4.86 feet lower than NAVD 1988.

5. Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Blue Mesa Area and Capacity Tables 2019). Plots of the 2019 area and capacity curves are presented in Figure 12. The surface map used to obtain the area and capacity is shown in Figure 13. For the 2019 survey, area and capacity curves are based on the bathymetric (below-water) survey up to approximately 7,490 feet elevation (RPVD), while curves above this elevation are based on 2019 airborne LiDAR. At the top of the joint use pool (elevation 7519.4 feet, RPVD), the reservoir has a surface area of 9,219 acres and a storage capacity of 938,141 acre-feet. The 1961 area and capacity values are also plotted in Figure 12. These data are shown in Table 2.

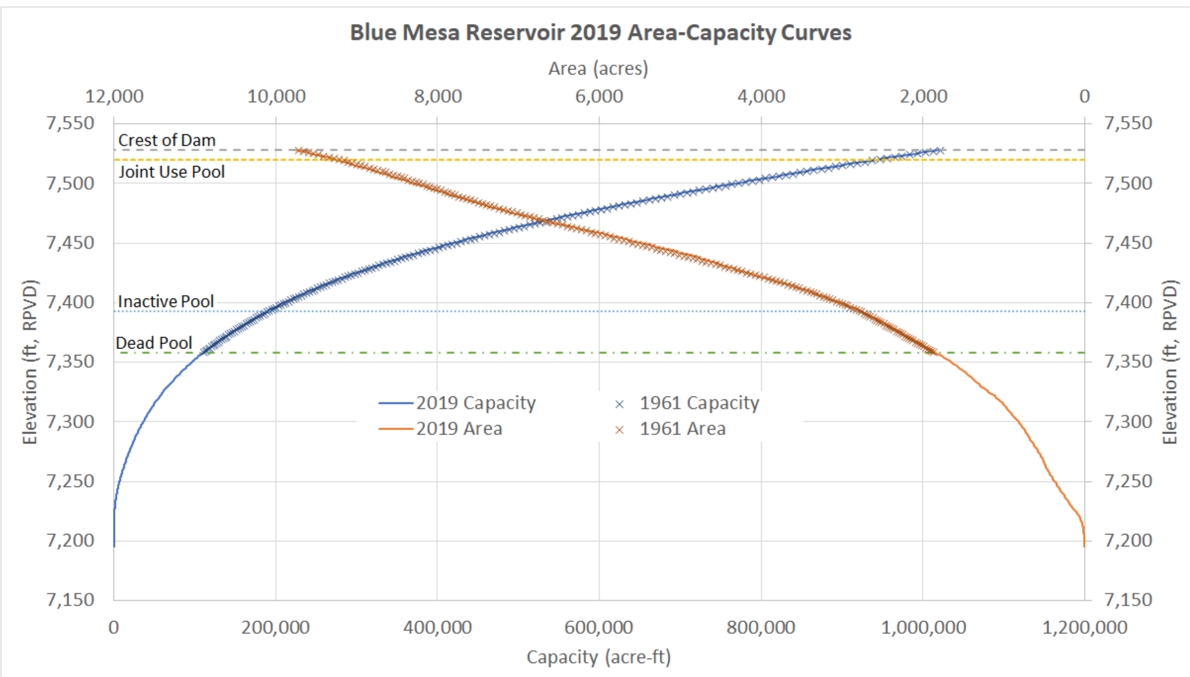

Figure 12. Plot of Blue Mesa Reservoir surface area (orange) and storage capacity (blue) versus elevation (RPVD). Key elevations are also included in the plot. The 1961 values are only available above the dead pool elevation.

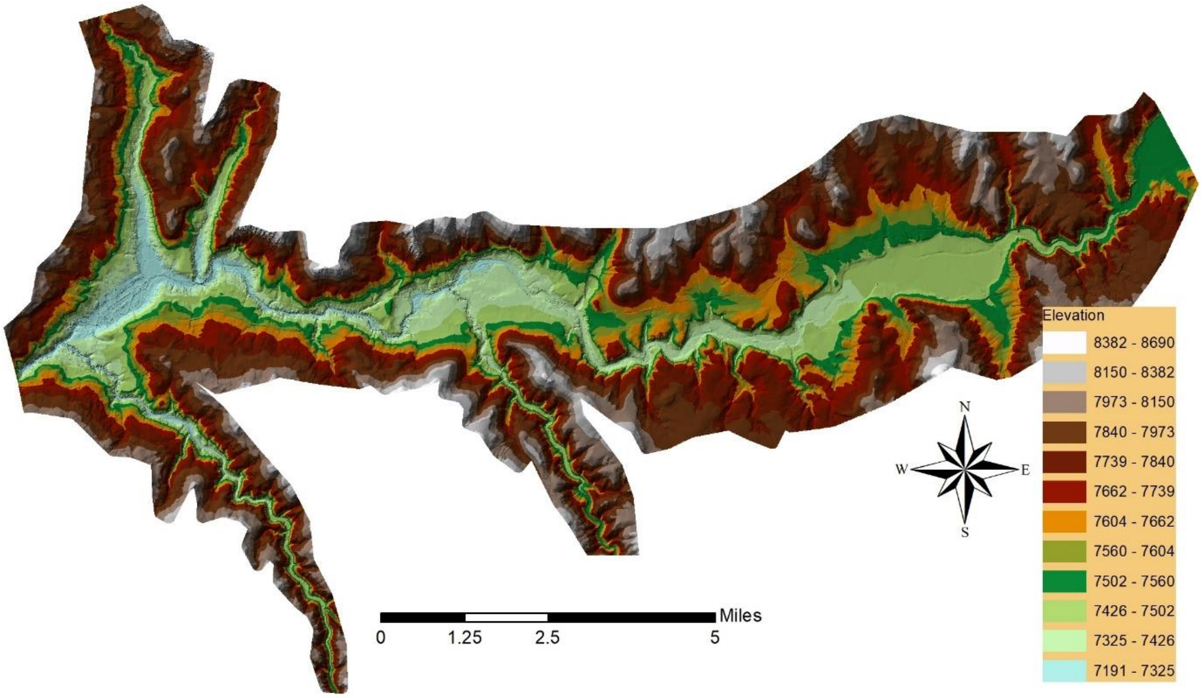

Figure 13. Elevation map using the combined bathymetric and LiDAR points from 2019 surveys.

Table 2. Summary of Blue Mesa Reservoir surface area and storage capacity data for the 2019 survey.

Elevation (ft, RPVD)	**Reservoir Surface Area (acres)**	**Reservoir Storage Capacity (acre-ft)**	**Reservoir Storage Capacity (acre-ft)ǂǂǂ**
	2019	**2019**	**1961 Allocation**
7528*	9,753	1,019,630	1,022,227
7519.4**	9,219	938,141	940,800
7510	8,756	853,607	857,045
7500	8,289	768,398	772,545
7490	7,817	687,874	692,545
7480	7,320	612,214	617,195
7470	6,756	541,706	546,995
7460	6,118	477,368	482,445
7450	5,484	419,500	423,745
7440	4,887	367,666	370,795
7430	4,413	321,201	323,495
7420	3,923	279,489	281,695
7410	3,430	242,863	244,995
7400	3,033	210,533	212,695
7393ǂ	2,777	190,237	192,270
7380	2,402	156,707	158,440
7370	2,140	134,026	135,440
7358ǂǂ	1,889	110,196	111,200
7350	1,649	96,229	-----------
7340	1,449	80,773	-----------
7330	1,283	67,118	-----------
7320	1,087	55,278	-----------
7310	947	45,156	-----------
7300	818	36,348	-----------
7290	717	28,705	-----------
7280	625	21,987	-----------
7270	533	16,221	-----------
7260	462	11,250	-----------
7250	372	7,066	-----------
7240	276	3,823	-----------
7230	172	1,586	-----------
7220	63	446	-----------
7210	17	90	-----------
7200	2	3	-----------
7195	0	0	-----------

* Crest of dam
** Max reservoir elevation, top of joint use pool.
ǂ Top of inactive pool
ǂǂ Top of dead pool
ǂǂǂ 1961 ACAP table only includes live capacity above the dead pool

6. Reservoir Sedimentation Volume Spatial Distribution

A longitudinal profile of the 2019 reservoir bottom surface was developed in GIS along the alignment presented in Figure 14. The longitudinal profile (Figure 15) shows no evidence of a delta face or formation. This is consistent with the lack of significant sedimentation as indicated by the difference between the original and 2019 reservoir capacity values.

Reservoir cross section at three select locations are shown in Figure 16. The lack of historical reservoir cross section data prevents comparison to previous reservoir bed elevations. These cross sections were created in Arc GIS and will allow comparisons in future surveys.

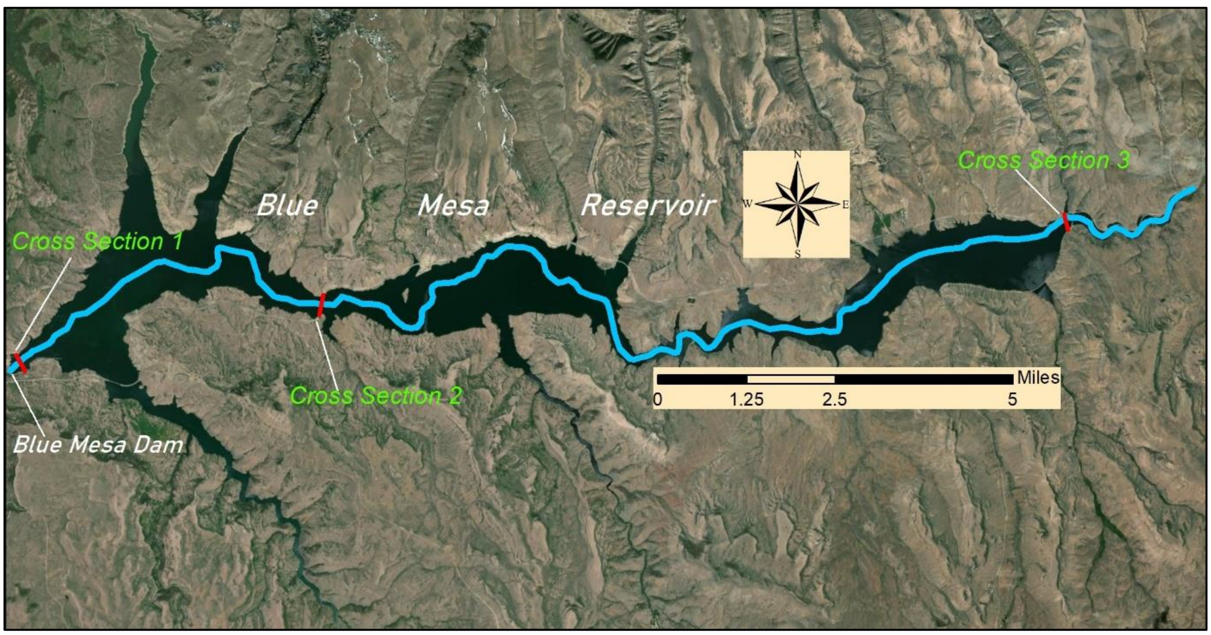

Figure 14. Alignments of longitudinal profile (blue) and representative cross sections (red).

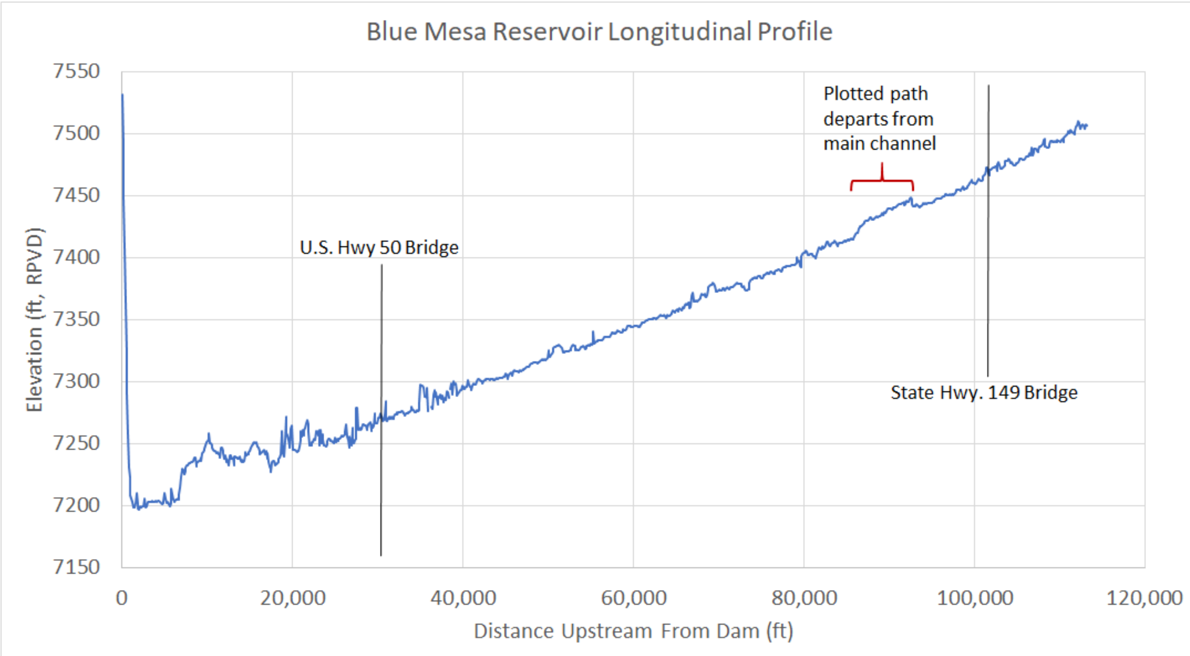

Figure 15. Longitudinal profile of Blue Mesa Reservoir bottom from the dam to the upstream end of the bathymetric survey in the upper reservoir. The red bracket indicates the location where the profile leaves the main channel (sta. 93,100 ft) and rejoins it further downstream (sta. 86,100 ft).

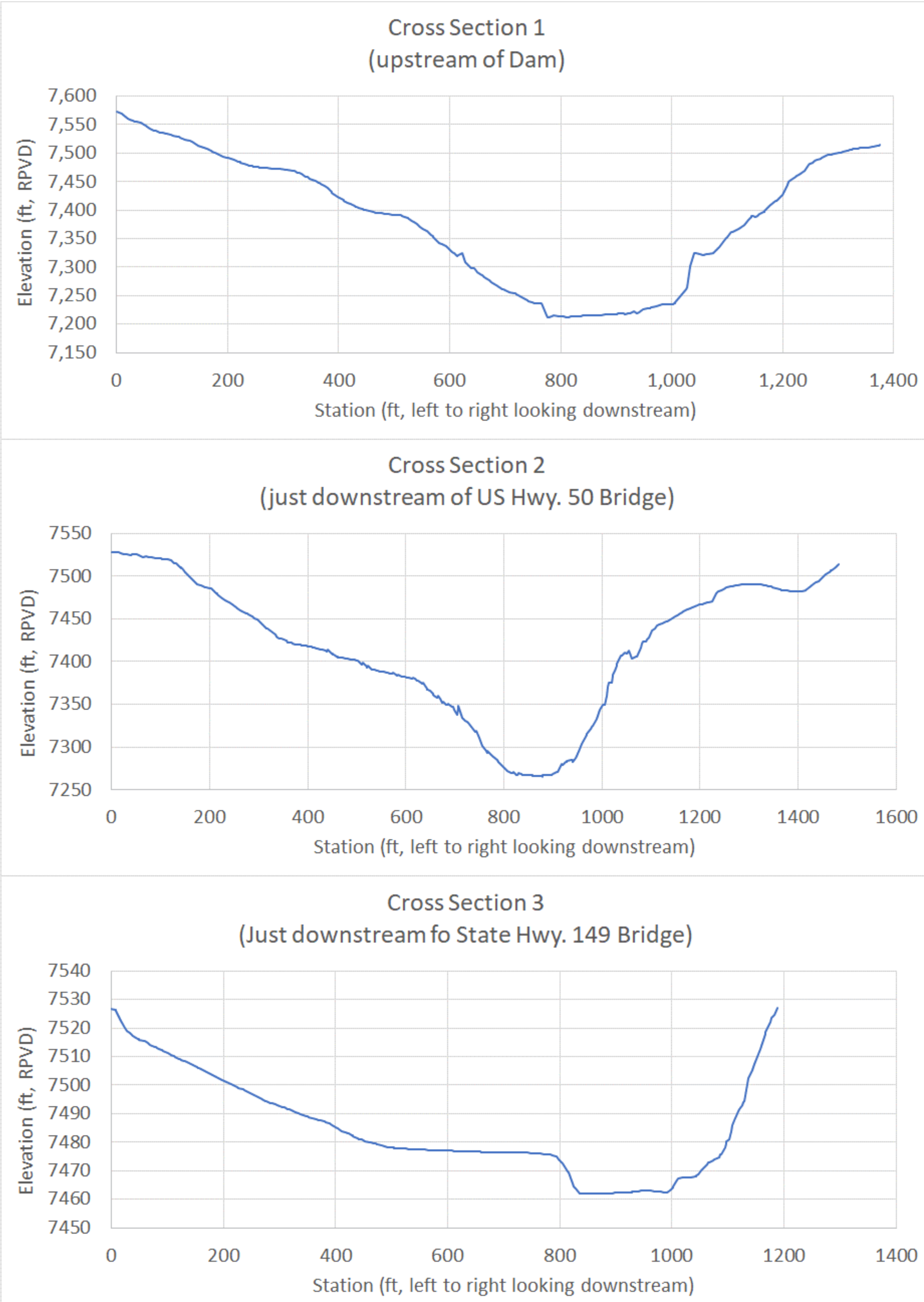

Figure 16. Cross section plots at locations shown in Figure 14.

7. Conclusions and Recommendations

7.1. Survey Methods and Data Analysis

The 2019 bathymetric survey, combined with 2019 LiDAR data to represent above-water topography, has been used to produce a representative digital surface of the reservoir bottom. The overlapping bathymetric and above-water topographic data agreed quite well, with comparisons less than 0.35 ft (See Appendix B for further detail).

Reservoir surface areas were computed from this digital surface at 1-foot intervals to determine the 2019 storage capacity. Surface area and storage capacity were then interpolated at 0.1 and 0.01-foot intervals (Huang 2020). The difference in reservoir capacities over time can be attributed to sedimentation, but also the differences in survey methods. The latest surface area and storage capacity curves compare reasonably well with the original values published in the original allocation (1961, see Table 2). Some minor decrease in reservoir capacity can be seen between the 1961 values and those resulting from the 2019 survey. However, these differences are attributed to both sedimentation and the difference in survey methods. The use of modern survey methods (RTK-GPS, multibeam depth sounder, and LiDAR) have produced a detailed and complete digital surface of the reservoir bottom. The differences seen are within the detection error when comparing the two surveys, making it difficult to comment conclusively on sedimentation since original filling. It appears minimal sedimentation has occurred based on the capacity comparisons and the lack of a pronounced delta.

7.2. Sedimentation Progression and Location

Over the span of 53 years, sedimentation has filled in 0.28 percent of the original total storage capacity (at elevation 7519.4 feet, RPVD), as measured comparing the original 1961 survey with the 2019 survey. The 2019 reservoir survey indicates that sedimentation volume is minimal and within the error of the comparison of the original and current surveys. The survey indicates no discernable delta or sedimentation at the dam.

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Appendix A — Hydrographic Survey Equipment and Methods

The 2019 bathymetric survey was conducted August 11 – 17, 2019 and September 29-30, 2019. The second survey trip in September 2019 was made necessary by a faulty velocity probe discovered during the early part of the reservoir survey in August. This problem was discovered soon after the survey began but it was necessary to re-survey the small portion of the reservoir covered during the time that the velocity probe was not operating properly. During the August survey the reservoir water surface elevation ranged between 7,516.16 and 7,516.97 feet RPVD. During the September survey the water surface ranged between 7,508.94 and 7,509.21 feet RPVD. Maximum (joint use) pool elevation is 7,519.4 feet RPVD.

The survey was conducted along a series of predetermined cross section, longitudinal, and shore line survey lines. The survey lines were spaced closely enough so there would be overlapping or near overlapping coverage from the multibeam depth sounder in the deep and variable portions of the reservoir. In the flat and shallow portions of the reservoir the survey lines were close enough that liner interpolation 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 an Odom MB1 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 position and measure other ground control points. The GPS base station and receiver was set up on a tripod over three points overlooking the reservoir (Figure 10 and Figure 11). The coordinates of two of these points utilized published values by the NGS (verified with OPUS (www.ngs.noaa.gov/OPUS/)) following the survey. A third base location was set over a temporary benchmark and its coordinates were computed using OPUS. The data using the temporary benchmark were shifted to match the OPUS solution. Throughout the survey various benchmarks were surveyed while the base station was occupying other bench marks to insure the coordinates for each base station and other NGS bench marks were tied together. This insures accuracy and consistency. During the survey, position corrections were transmitted from the GPS base station to the GPS rover receiver on the survey vessel 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 Blue Mesa Reservoir survey (NGS bench mark designation S424 near Sapinero, Colorado is shown).

The GPS rover receivers include an internal or external 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.

HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the Colorado Central State Plane projection. Water surface elevations from dam gage records and RTK GPS measurements were used to convert the sonar depth measurements to reservoir-bottom elevations in RPVD. The multibeam depth sounder generates millions of data points. Sometimes fish, underwater vegetation, or other anomalies mean that a small portion of depth measurements do not represent the reservoir bottom and these data are deleted during the post processing. Filtering of this large data file is necessary, so a raster mesh is created in GIS (10-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

Data from the 2019 LiDAR survey were used to represent the above-water reservoir topography. These data were originally projected in UTM coordinates with units in meters. It was necessary to re-project these data to match the state plane coordinates of the bathymetric survey with units of feet to also match the units used for reservoir operations. Furthermore, the LiDAR was adjusted vertically to match the RPVD. The difference between the NAVD 1988 vertical datum and the RPVD is 4.71 feet, RPVD is lower. The LiDAR survey points were filtered to a 10-foot spacing, which matches the resolution of the bathymetry.

Comparing overlapping LiDAR and bathymetry data showed that the difference was less than 0.5 feet. Comparing the adjusted LiDAR to ground survey collected during the 2019 survey indicates a difference of 0.29 feet (LiDAR is lower). Comparing the bathymetric survey with overlapping LiDAR points indicates an average difference of 0.31 feet, LiDAR being lower.

Appendix C — Computation of Reservoir Surface Area and Storage Capacity

The surface area and storage capacity tables for Blue Mesa Reservoir were generated from the 2019 bathymetric (August-September 2019) and LiDAR (May 2019) surveys. Reservoir surface areas and capacities at 1-foot increments were first computed using the ArcGIS ACAP toolset, developed at Reclamation using the full range of reservoir topography elevations (7,195 – 7528 feet, RPVD). Reclamation's Area-Capacity Program, ACAP V2.0 (Huang, 2020), was then used to generate the area and capacity tables at 1-foot, 0.1-foot, and 0.01-foot increments for the full range of reservoir elevations.

The reservoir storage capacity interpolates the reservoir storage capacity between 1-foot intervals using the following equation:

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

where:
- V = storage capacity (acre-feet)
- y = reservoir elevation,
- y_b = reservoir elevation at bottom of elevation increment,
- A_1 = storage capacity at elevation y_b (acre-feet),
- A_2 = coefficient for linear rate of increase in storage capacity which also equals surface area at elevation y_b (acres), and
- A_3 = coefficient for nonlinear rate of increase in storage capacity, computed by enforcing that $V = V_t$, where V_t is the volume at the top of the interval (y_t):

$$A_3 = \frac{V_t - A_1 - A_2(y_t - y_b)}{(y_t - y_b)^2}$$

The program uses the linear interpolation method to predict the reservoir surface area between 1-foot intervals using the following equation over a certain elevation interval:

$$S = B_1 + 2B_2(y - y_b)$$

where:
- S = surface area (acres),
- y = reservoir elevation,
- y_b = reservoir elevation at bottom of elevation increment,
- B_1 = surface area at elevation y_b (acres), $B_1 = A_2$, and
- B_2 = coefficient (feet) for linear rate of increase in surface area, computed by enforcing that $S = S_t$, where S_t is the area at the top of the interval (y_t):

$$B_2 = \frac{S_t - B_1}{2(y_t - y_b)}$$

This method ensures that the surface areas and capacities as determined from GIS software at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot intervals.

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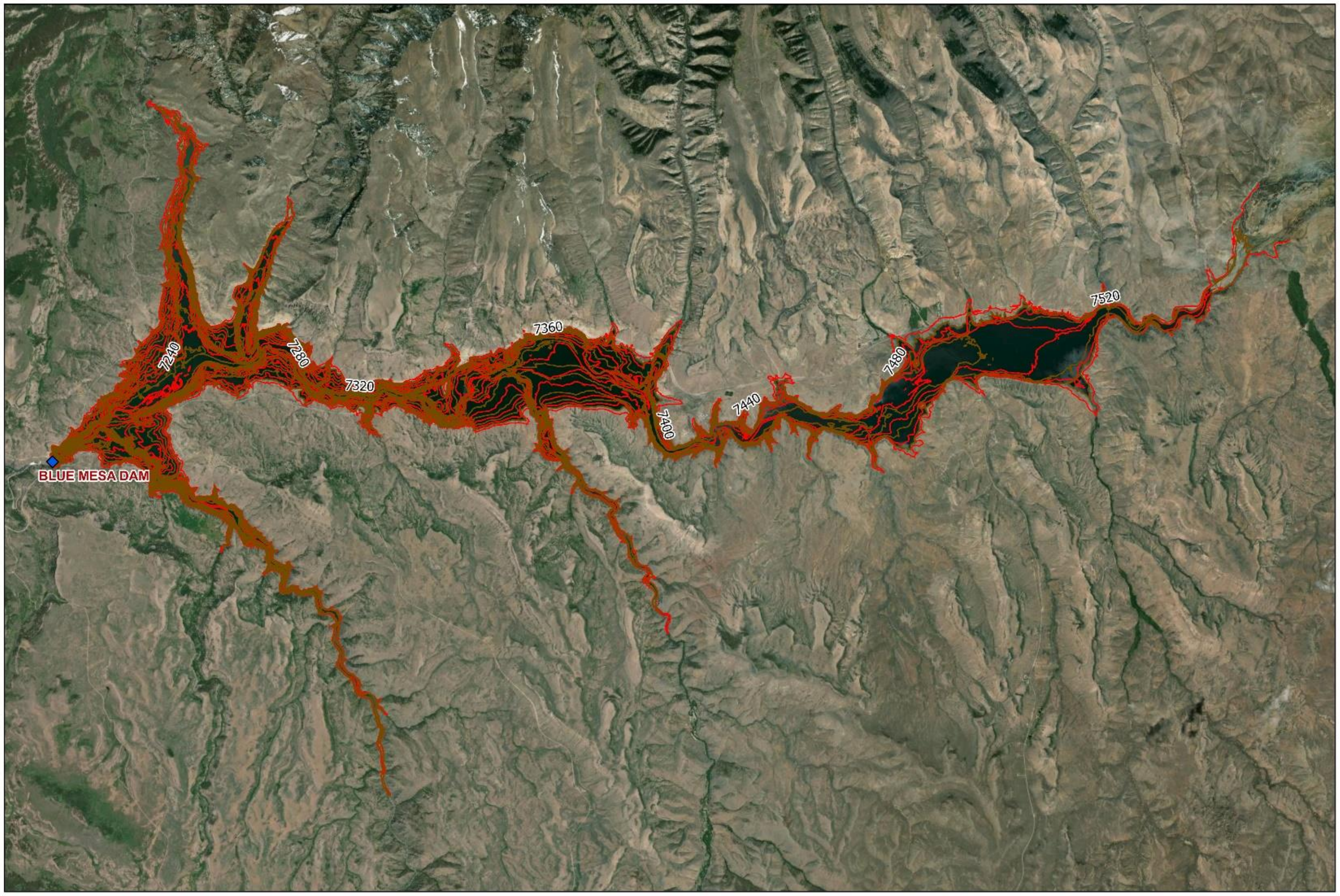
Appendix D – Contour Maps



Blue Mesa Reservoir Colorado Elevation Contour Map

Overview Map

Map Prepared By:
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Technical Service Center - 11/13/20

Horizontal:
NAVD88, State Plane CO Central, US feet
Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

10 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

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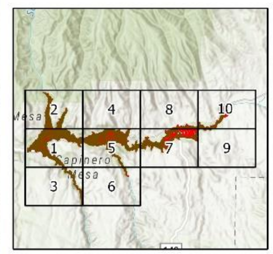

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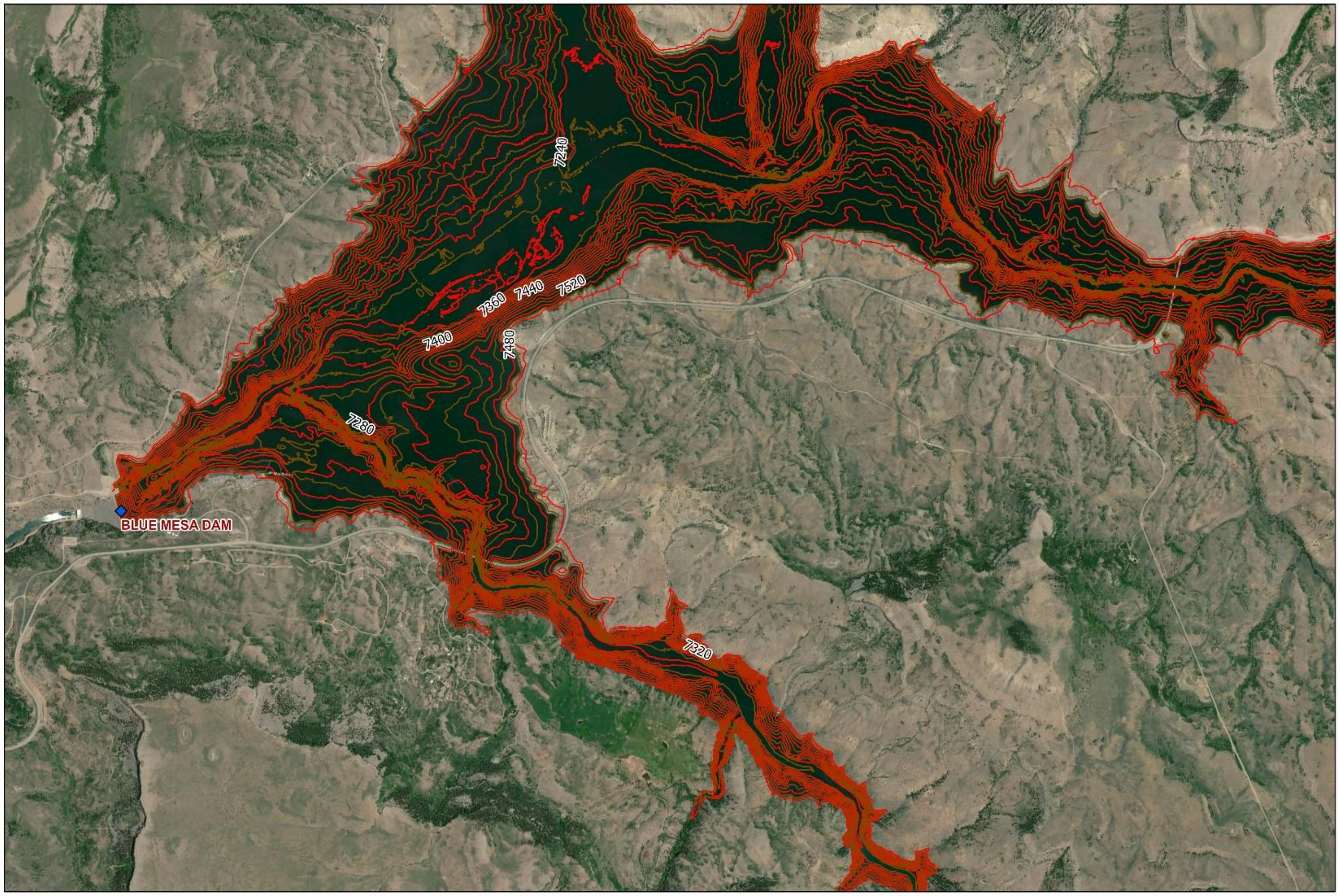
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of



Blue Mesa Reservoir
Colorado
Elevation
Contour Map

Sheet 1

Map Prepared By:
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Horizontal:
NAVD88, State Plane CO Central, US feet
Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

20 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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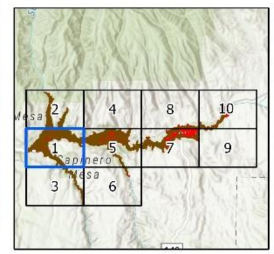

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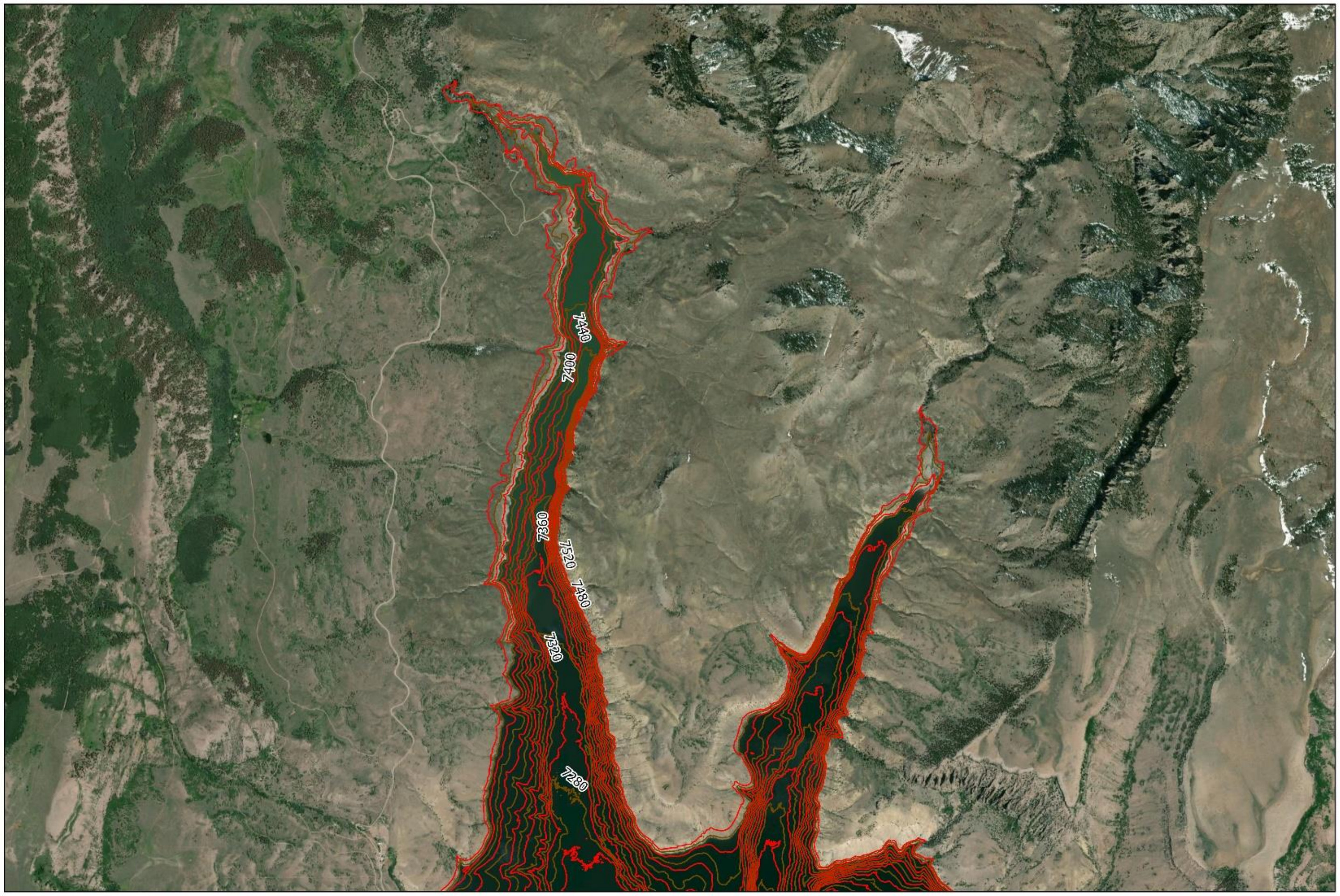

Blue Mesa Reservoir
Colorado
Elevation
Contour Map

Sheet 2

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Horizontal:
NAVD88, State Plane CO Central, US feet
Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

20 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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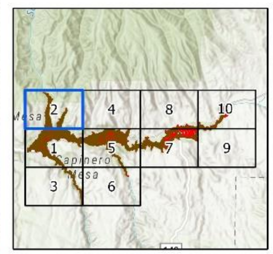

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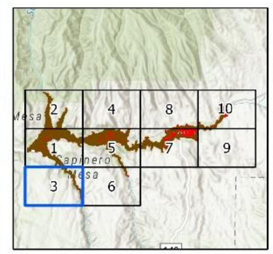

Blue Mesa Reservoir
Colorado
Elevation
Contour Map

Sheet 3

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Horizontal:
NAVD88, State Plane CO Central, US feet
Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

20 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

Scale 1:22,500

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Service Layer Credits: World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS

Blue Mesa Reservoir Colorado Elevation Contour Map

Sheet 4

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Horizontal:
NAVD88, State Plane CO Central, US feet
Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

20 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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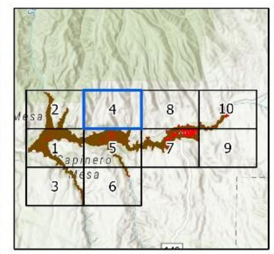

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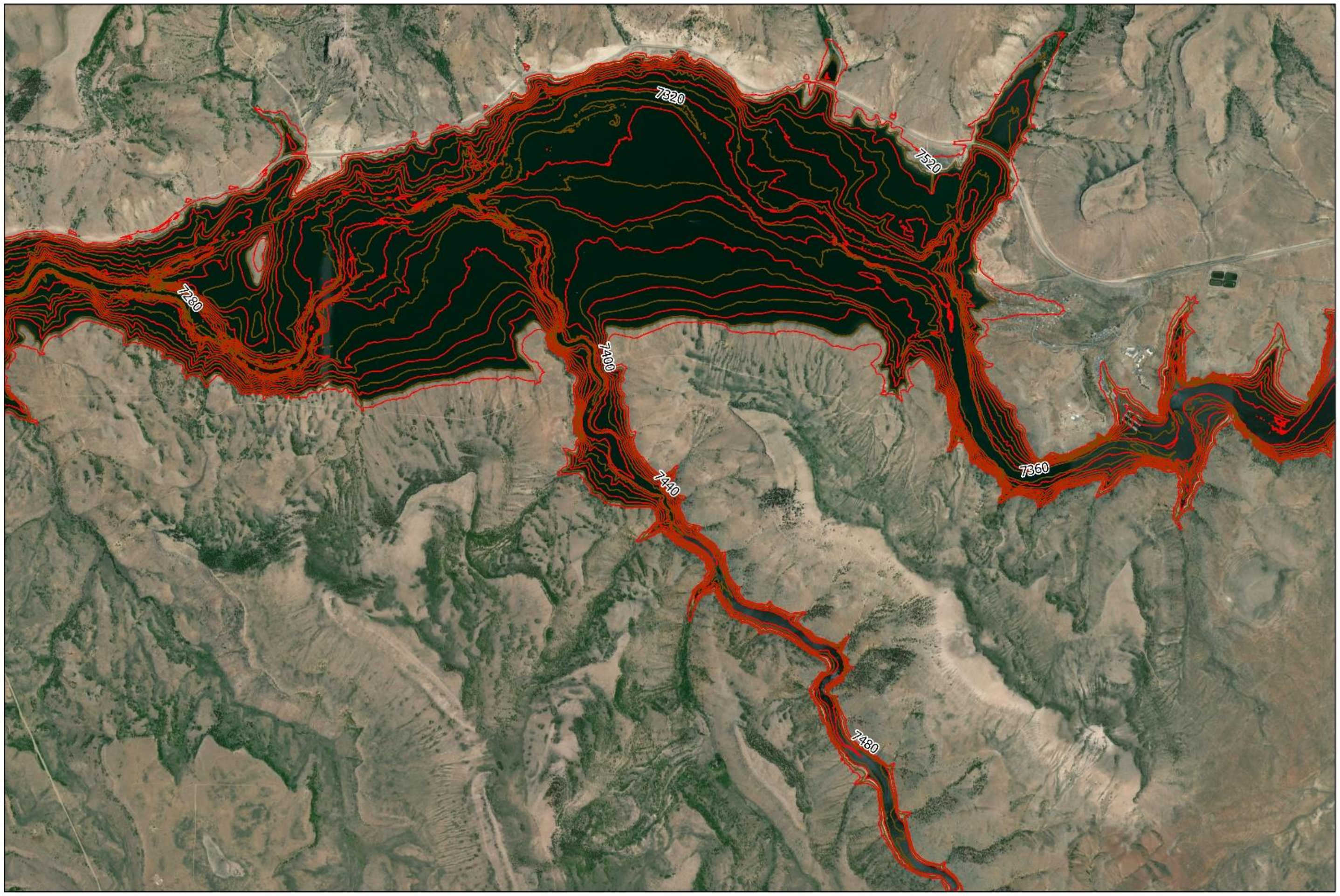

Blue Mesa Reservoir Colorado Elevation Contour Map

Sheet 5

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Vertical:
Reclamation Project Vertical Datum (RPVD)
RPVD = NAVD88 - 7.41 feet
NGVD29 = NAVD88 - 4.86 feet

20 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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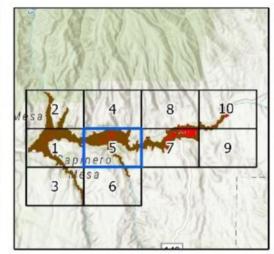

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Horizontal:
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Vertical:
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20 foot contour interval
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LiDAR from 2019 survey

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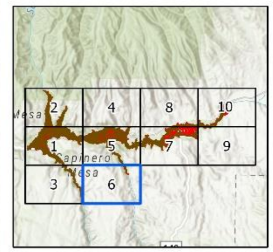

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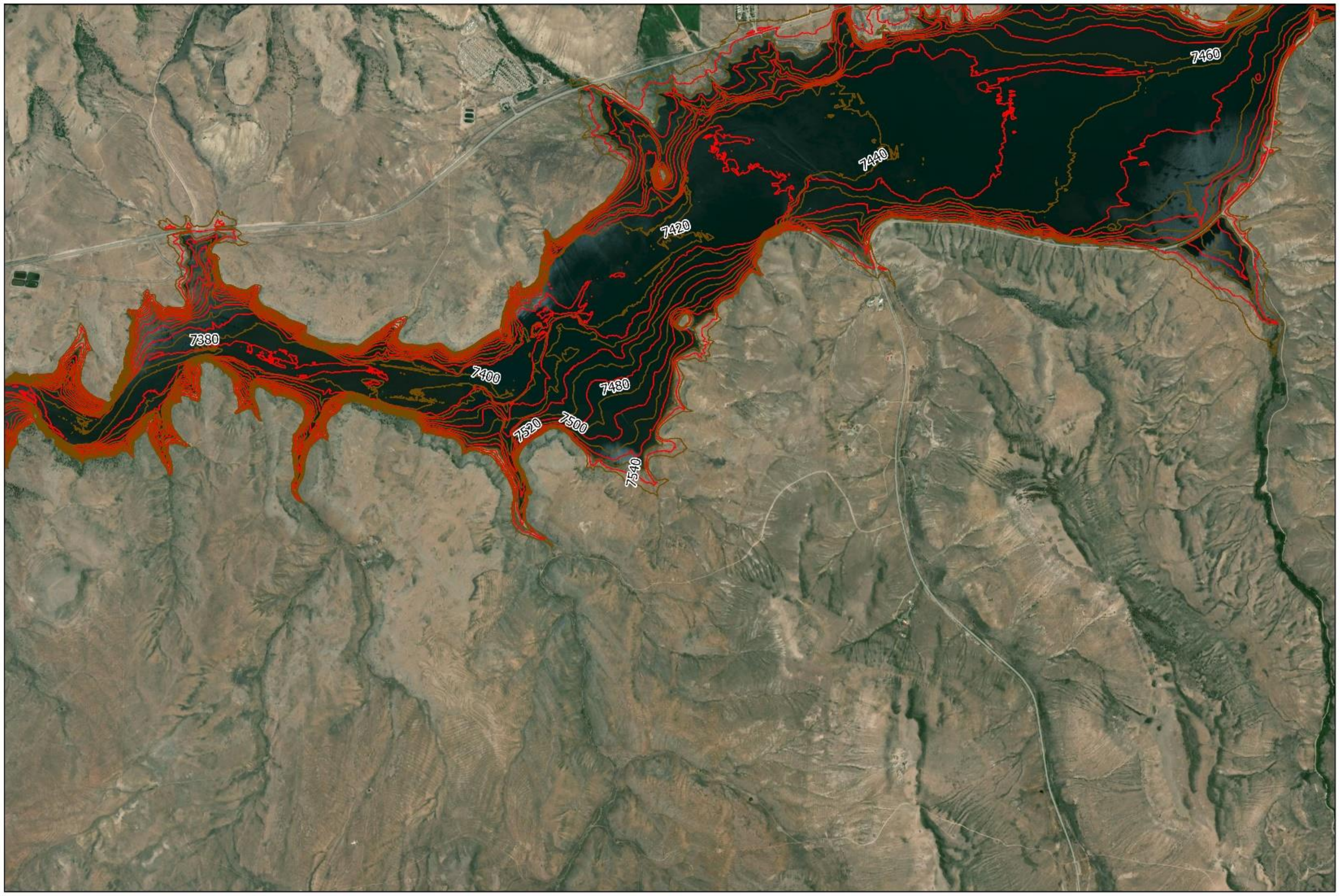

Blue Mesa Reservoir Colorado Elevation Contour Map

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Vertical:
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NGVD29 = NAVD88 - 4.86 feet

10 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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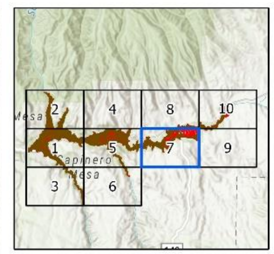

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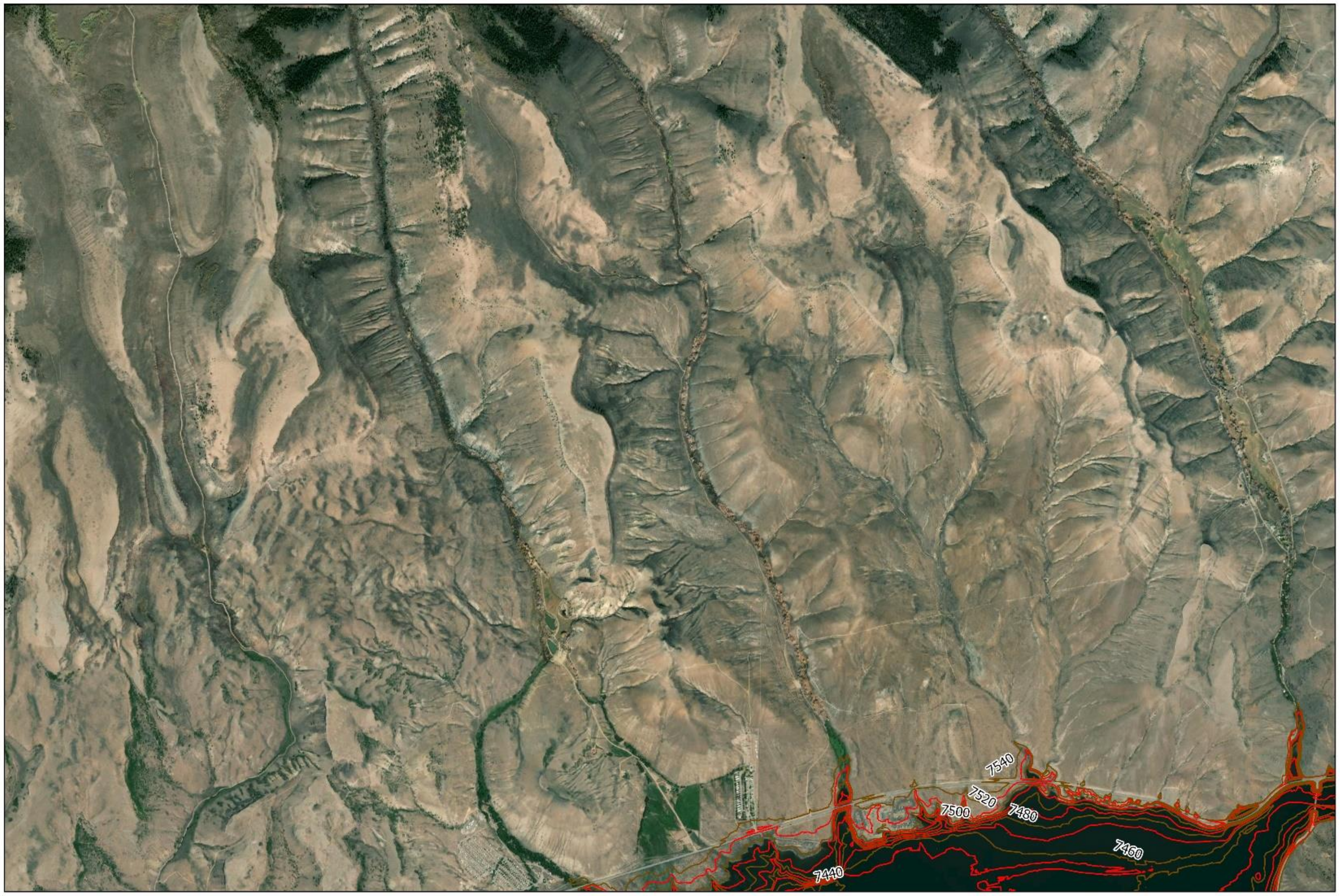

Blue Mesa Reservoir
Colorado
Elevation
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10 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

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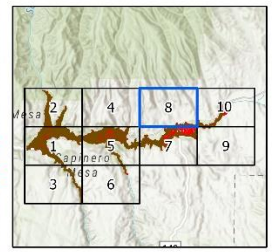

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Colorado
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NAVD88, State Plane CO Central, US feet
Vertical:
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NGVD29 = NAVD88 - 4.86 feet

10 foot contour interval
Bathymetry from 2019 Reservoir Survey
LiDAR from 2019 survey

N

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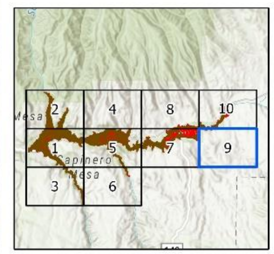

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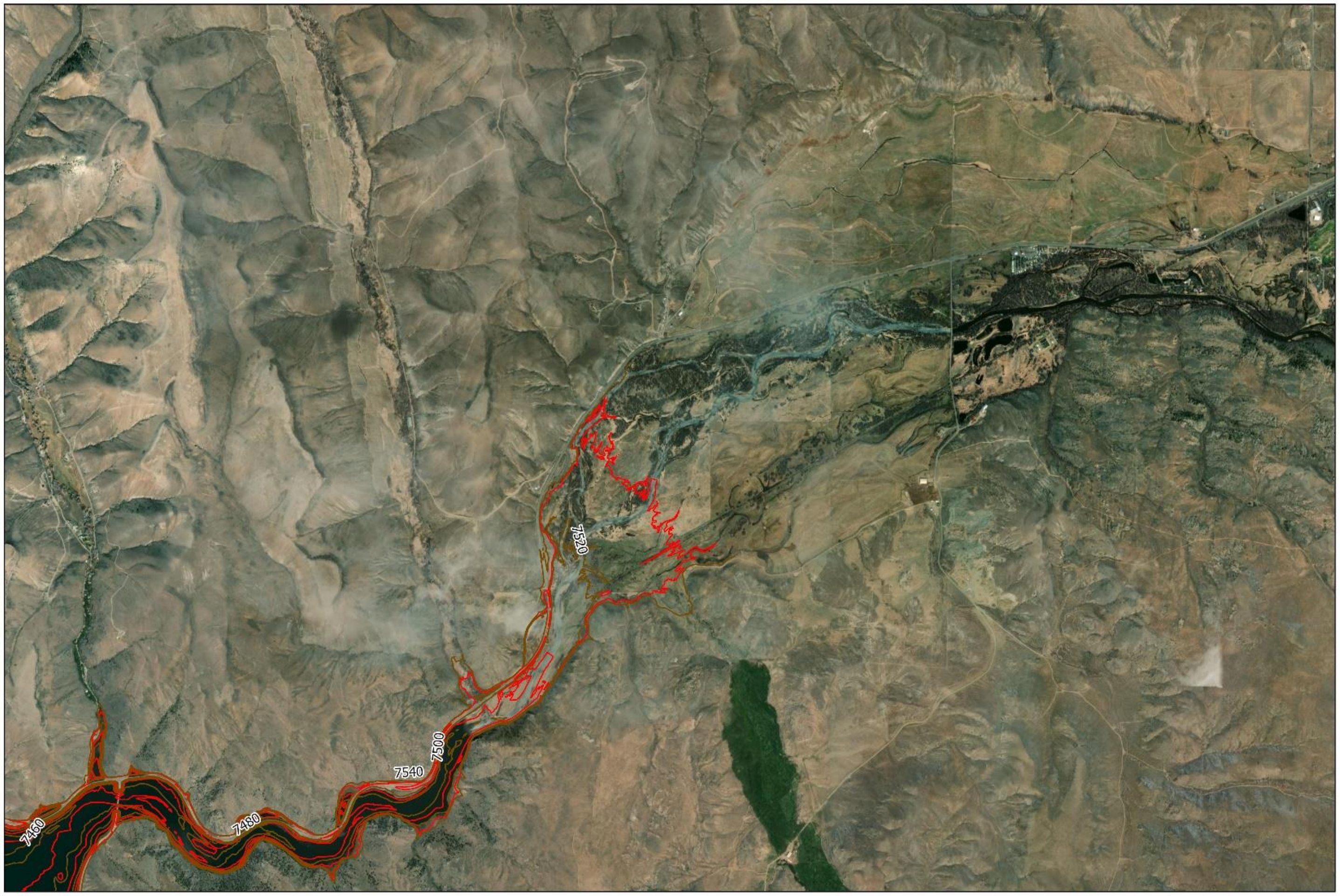

Blue Mesa Reservoir
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10 foot contour interval
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LiDAR from 2019 survey

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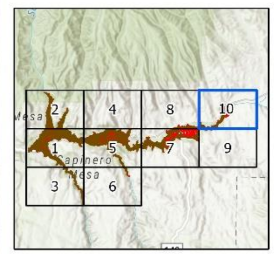

Service Layer Credits: World Imagery: Earthstar Geographics
World Topographic Map: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of

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