Technical Report No. ENV-2020-021

Clark Canyon Reservoir 2016 Sedimentation Survey

Pick-Sloan Missouri Basin Program, East Bench Unit, Montana
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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Acknowledgements

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Disclaimer

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14. SHORT ABSTRACT **The 2016 multibeam bathymetric survey of Clark Canyon Reservoir was combined with National Elevation Dataset, 10-meter, digital elevation model data published in 2013 to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the top of joint use pool elevation (5546.1 feet, Reclamation Project Vertical Datum), the reservoir had a surface area of 5,138 acres and a storage capacity of 174,300 acre-feet. Since dam closure in 1964, the reservoir is estimated to have lost 4,173 acre-feet of storage capacity (2.3 percent) due to sedimentation. The dead storage pool volume has reduced to 6 percent of the original dead storage volume. The sediment level at the dam is 5452.5 feet (RPVD), which represents 71 percent of the height of the dead pool (between the original streambed elevation and the top elevation of the dead storage pool) being filled with sediment.**						
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Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Clark Canyon Reservoir 2016 Sedimentation Survey

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Acronyms and Abbreviations[1]

ft^3/s	cubic feet per second (cfs)
DEM	Digital Elevation Model
DOI	Department of the Interior
ft	foot or feet
GIS	Geographic Information System
GPS	Global Positioning System
GPRO	Great Plains Regional Office
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
MTAO	Montana Area Office
NAD83	North American Datum, established 1983
NAVD88	North American Vertical Datum, established 1988
NED	National Elevation Dataset
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum, established 1929
NID	National Inventory of Dams
NRCS	Natural Resources Conservation Service
OPUS	Online Positioning User Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RSI	Reservoir Sedimentation Information
RTK	Real-Time Kinematic
Sedimentation Group	Sedimentation and River Hydraulics Group
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
USGS	United States Geological Survey

[1] For a complete glossary of terms commonly used in Reclamation hydraulic studies, refer to the Reclamation library website: https://www.usbr.gov/library/glossary/

Executive Summary

Clark Canyon Dam and Reservoir are on the Beaverhead and Red Rock Rivers about 18 miles southwest from Dillon, MT.

A bathymetric survey of Clark Canyon Reservoir was conducted in April 2016 with these primary objectives:

1. Estimate reservoir sedimentation volume since construction was completed in 1964 and since the last survey in 2000; 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 interfaced with real-time kinematic (RTK) global positioning system (GPS) instruments (for horizontal positioning) to map the reservoir bottom. The 2016 multibeam bathymetric survey of Clark Canyon Reservoir was combined with above water data downloaded from the National Elevation Dataset (NED) and a water's edge contour digitized from 2018 aerial photographs to produce a combined digital surface of the reservoir bottom.

This survey was conducted from April 25 through 30, 2016 when the reservoir water surface elevation ranged between 5535.21 and 5535.49 feet, Reclamation Project Vertical Datum (RPVD), 10.5 feet below the top of joint use pool elevation of 5546.1 feet. During the 2016 bathymetric survey, a minimum bottom elevation of 5450.4 feet was measured approximately 1,000 feet upstream of the dam. The mean bed elevation near the dam and outlet works in 2016 was 5452.5 feet, only 2.5 feet below outlet works sill and top of dead pool elevation 5455.0 feet. The above-water topographic data were collected between 1999 and 2013 and were published in 2013.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 5530.4 feet, the maximum elevation of bathymetric data which is 5 feet below the water surface at the time of the 2016 survey and approximately 5 feet lower than the top of active conservation pool elevation 5535.7 feet, the reservoir surface area was 3,943 acres with a storage capacity of 103,190 acre-feet.
- At joint use water surface elevation 5546.1, the 2016 survey measured a surface area of 5,138 acres and a storage capacity of 174,300 acre-feet.
- At the top of flood control pool elevation 5560.4 feet, the reservoir had a surface area of 5,740 acres and a storage capacity of 251,436 acre-feet.
- Since the original filling of the reservoir in 1964, the reservoir is estimated to have lost 4,173 acre-feet of storage capacity (2.3 percent) due to sedimentation below joint use elevation 5546.1. Since the last reservoir survey in 2000, the reservoir is estimated to have lost only 67 acre-feet of storage capacity. These volumes represent sediment yield

rates of 0.07 acre-feet per square mile per year (acre-feet/mi^2/year) and 0.002 acre-feet/mi^2/year, respectively, which is considered very low as defined in Reclamation (2006).

- By 2016, the dead storage pool volume had reduced to 6 percent of the original dead storage volume. The average sediment level at the dam is 5452.5 feet, which represents 71 percent of the height of the dead pool (between the original streambed elevation and the top elevation of the dead storage pool) being filled with sediment. Historical rates of reservoir sedimentation indicate decreasing rates of sedimentation since normal operations began in 1964.

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	Clark Canyon Reservoir	**Region**	Great Plains
Owner	Bureau of Reclamation	**Area Office**	Clark Canyon
Stream	Beaverhead River	**Vertical Datum**	RPVD
County	Beaverhead County	**Top of Dam (ft)**	5578.00
State	Montana	**Spillway Crest (ft)**	5560.40
Lat (deg min sec)	112 51 27	**Power Penstock Elevation (ft)**	N/A
Long (deg min sec)	45 0 06	**Low Level outlet (ft)**	5455.0
HUC4	1706	**Hydraulic Height (ft)**	113.9
HUC8	17062024	**Total Drainage Area (mi^2)**	2321
NID ID	MT00569	**Date storage began (mm/dd/yyyy)**	08/28/1964
Dam Purpose	Irrigation, flood control, recreation	**Date for normal operations (mm/dd/yyyy)**	08/28/1964

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	5571.9	6600	71827	328979
FLOOD CONTROL	5560.4	5903	79090	257152
JOINT USE	5546.1	5160	50436	178626
CONSERVATION	5535.7	4496	126117	127626
INACTIVE	5470.6	367	1448	1509
DEAD	5455.0	23	61	61

Survey Summary

Survey Date	Type of Survey	No. of Range Lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sedimen-tation Volume (acre-feet)	Cumulative Sedimen-tation (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
August 1964	Contour	10-ft	1751	0	0	5446.5	100
June 2000	Contour	5-ft	1751	4106	4106	5508.7	93
April 2016	Contour (D)	5-ft	1751	67	4173	5450.4	6

Notes

Original design areas and capacities do not match as-builts presented later in this report, meaning the dam and reservoir were not built to exact specifications.

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1. Introduction

Clark Canyon Dam and Reservoir are on the Beaverhead River about 18 miles southwest of the town of Dillion in Beaverhead County in Southwest Montana (Figure 1). The dam and reservoir are operated by East Bench Irrigation District as part of the East Bench Unit of the Pick-Sloan Missouri Basin Program that provides full irrigation service to 21,800 acres and supplemental irrigation service to 28,000 acres of farm land (Reclamation, 1981). Though the primary purpose of Clark Canyon Reservoir is irrigation, it also offers flood storage and water for recreational use. The reservoir has no direct connection to water treatment facilities or municipal water sources (Reclamation, 2014).

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

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

As part of ongoing operations and sediment monitoring activities, Reclamation's Great Plains Regional Office (GPRO, GP-4600) requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics (Sedimentation) Group (86-68240) to conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A bathymetric survey of the reservoir was conducted from April 25 to 30, 2016 with these primary objectives:

1. Estimate reservoir sedimentation volume since construction was completed in 1964 and since the last survey in 2000; and

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

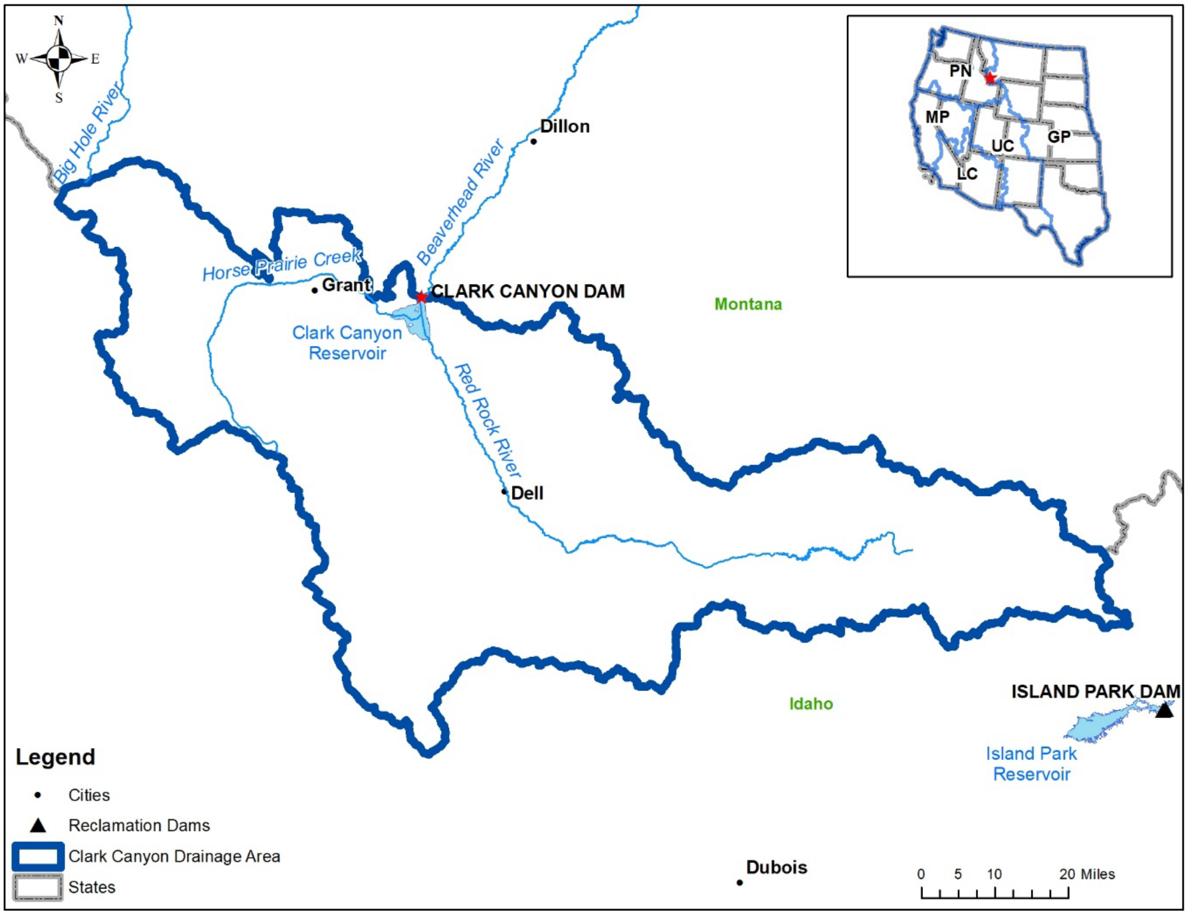

Figure 1. Location map of Clark Canyon Dam, Reservoir and watershed, 18 miles southwest from Dillon, MT. The watershed above Clark Canyon Dam has a total drainage area of 2,321 mi^2 and a sediment-contributing drainage area of 1,751 mi^2.

2. Watershed Description

The watershed upstream from Clark Canyon Dam has a total contributing drainage area of 2,321 square miles (mi^2). Because of upstream lakes and reservoirs that trap sediment (as of 2016), the net sediment-contributing drainage area to Clark Canyon is 1,751 mi^2 (Figure 1). The watershed is located in the Rocky Mountains at the foot of the Bitterroot Range with elevations ranging from 5,526 to 11,107 feet. The watershed is 16.7 percent forested and only 2 percent of the surface is irrigated. The basin receives 19.6 inches of rain annually and has an average annual temperature of 36.6 degrees Fahrenheit (https://streamstats.usgs.gov/ss/).

2.1. Geology

The geology of the Clark Canyon watershed's sediment-contributing drainage area consists primarily of coarse loamy soils with moderate infiltration rates and moderate runoff potential (Figure 2,Figure 3, and Figure 4; NRCS WSS Geodatabase; https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/survey/geo/?cid=nrcs142p2_053620). The soils of this drainage area are comprised mostly of sand, gravel, and cobble sized materials with very little silt and even less clay (Figure 4).

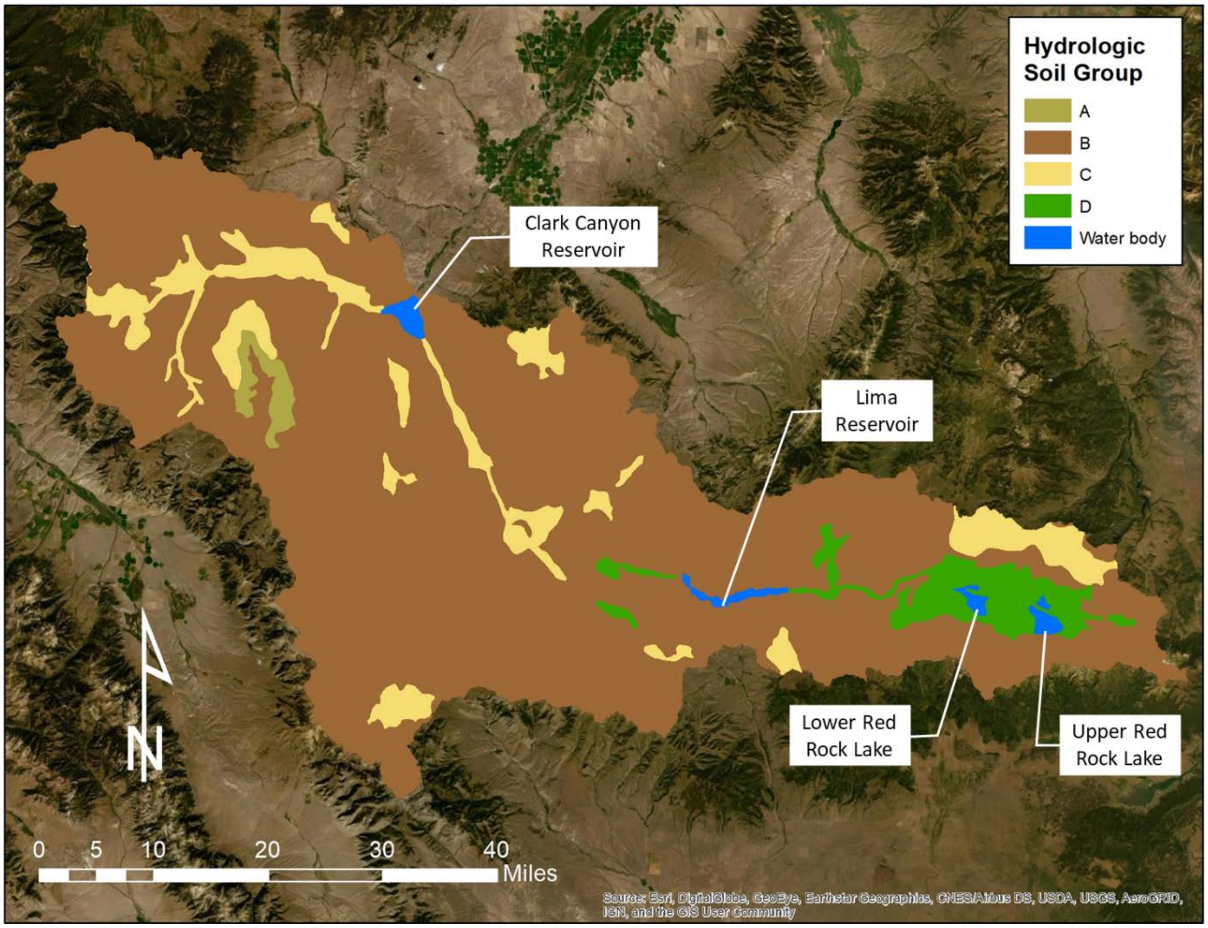

Figure 2. Clark Canyon Dam watershed geology classified by hydrologic soil group.

Hydrologic soil groups from the NRCS WSS Geodatabase are described as follows:

> "Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.
>
> Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
>
> Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
>
> Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission."

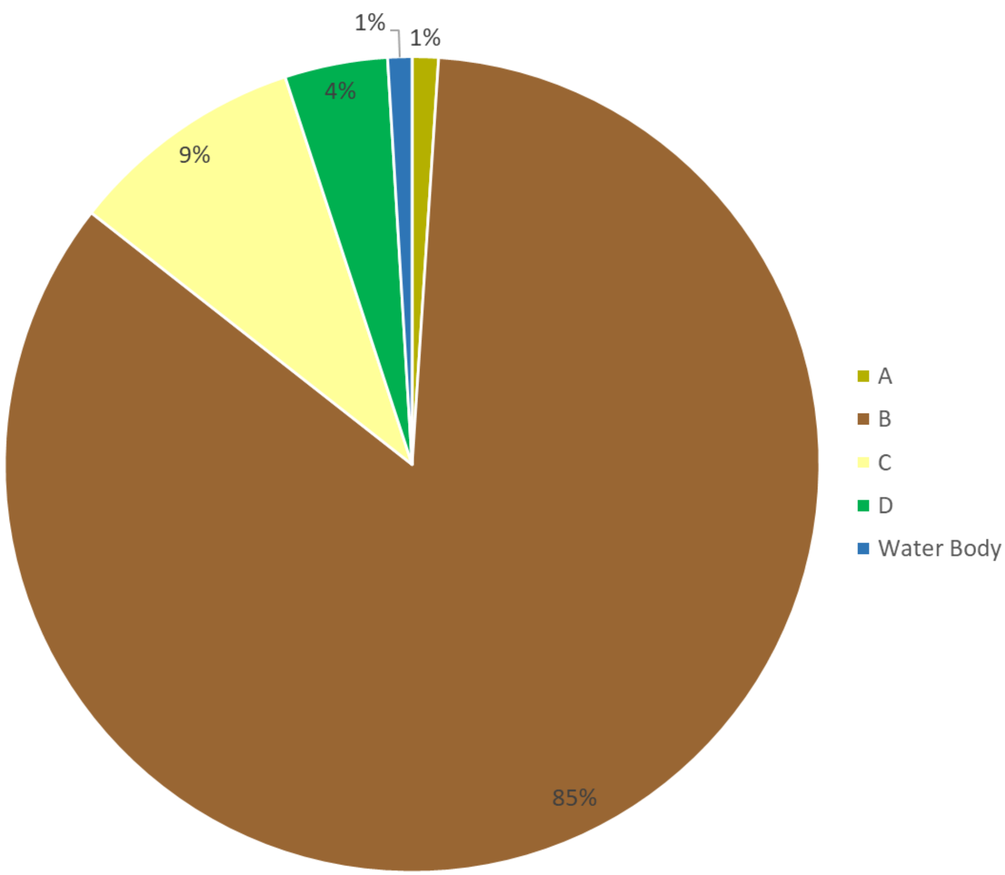

Figure 3. Percentage of hydrologic soil groups present in Clark Canyon Reservoir watershed

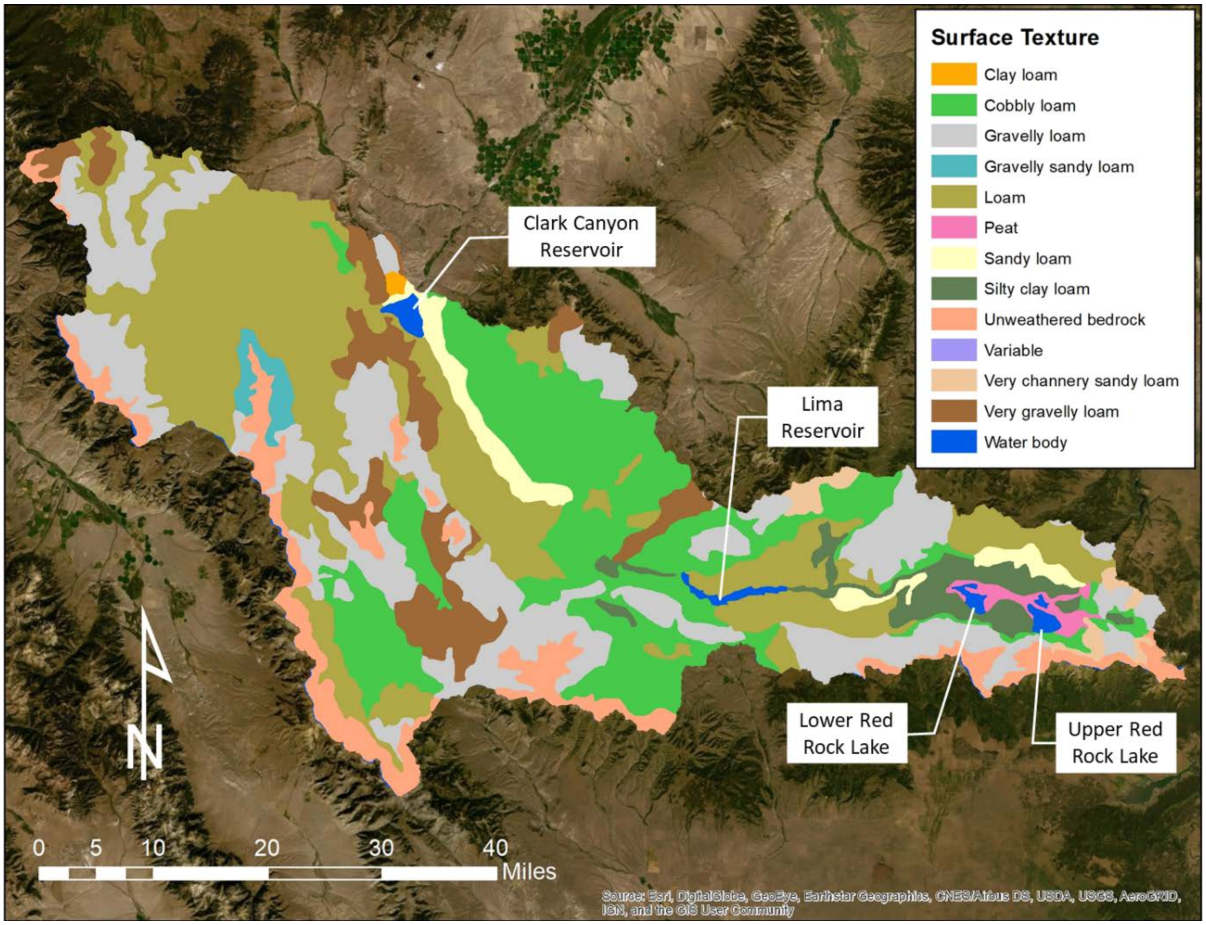

Figure 4. Clark Canyon Reservoir watershed geology classified by soil surface texture

The Clark Canyon drainage basin is steep with 5581 feet of relief, 21.6 percent having a slope greater than 30 percent and 5.5 percent having a slope steeper than 50 percent. The watershed is sparsely populated, 16.7 percent forested and only 2 percent irrigated. The low amount of irrigation, combined with 19.6 inches of average annual rainfall, and soils with mostly moderate runoff potential, tend to decrease sediment yields in the basin. These soil descriptions and basin characteristics are for the entire Clark Canyon watershed, but generally hold true for the sediment contributing area in particular.

2.2. Climate and Runoff

Reservoir inflows are primarily from the Red Rock River and Horse Prairie Creek which join to form the Beaverhead River just upstream of Clark Canyon Dam. Calculated mean daily inflows into Clark Canyon Reservoir downloaded from Reclamation's Hydromet site for the Great Plains Region (www.usbr.gov/gp/hydromet/hydromet_arcread.html) were used to compute annual inflow volumes (Figure 5) and annual maximum daily inflows (Figure 6) since dam closure in 1964. The figures show that 1984 was the wettest water year in the Clark Canyon Reservoir basin since 1964, producing an annual inflow volume over 718,000 acre-feet and maximum daily inflow near 3,500 cubic feet per second (ft^3/s). High flows in 1984 prompted the replacement of the tile drains at the downstream toe of Clark Canyon Dam in 1984-1985.

Annual inflow volumes and maximum daily inflows for 1964 appear low because storage and inflow records did not begin until August 28, 1964, near the end of the water year.

Based on the Hydromet data presented in Figure 5 and Figure 6, the mean annual runoff to Clark Canyon Reservoir since dam closure in 1964 is 247,727 acre-feet per year (342 ft^3/s). This runoff is primarily from snowmelt with some rain. At top of flood pool elevation 5560.4[2] feet, the ratio of reservoir storage capacity to the mean annual runoff is approximately 1.0. This means that when full, the reservoir stores approximately 365 days of mean stream flow of 342 ft^3/s.

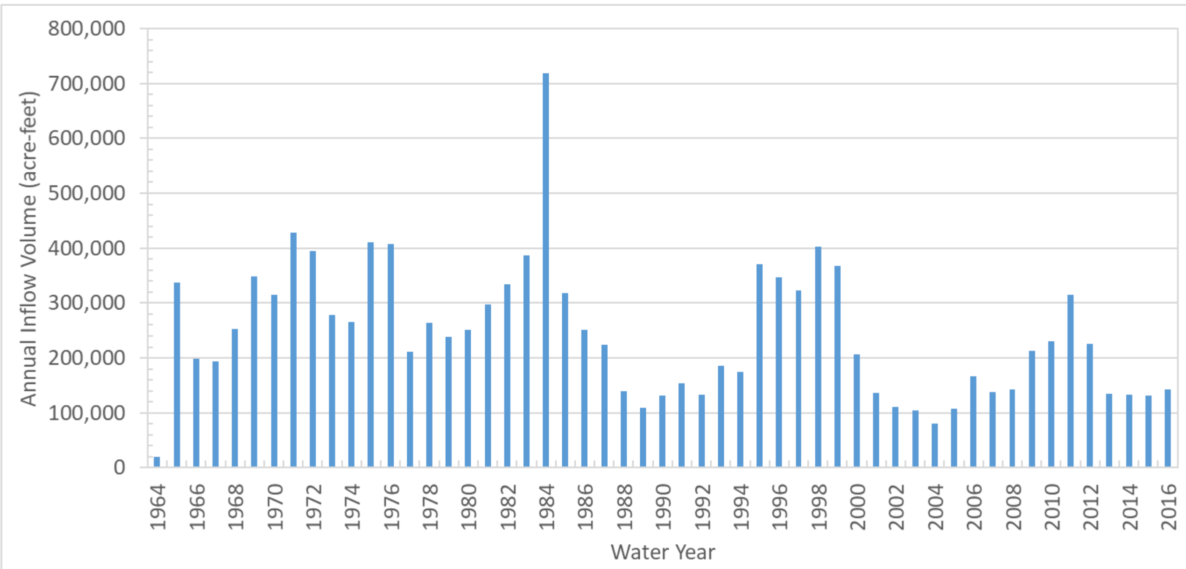

Figure 5. Annual Inflow Volume into Clark Canyon Reservoir. Generated from Hydromet calculated mean daily inflows (www.usbr.gov/gp/hydromet/)

[2] Unless otherwise noted, all elevations in this report are presented in Reclamation Project Vertical Datum (RPVD), which is equivalent to NGVD29 and 3.9 feet lower than NAVD88.

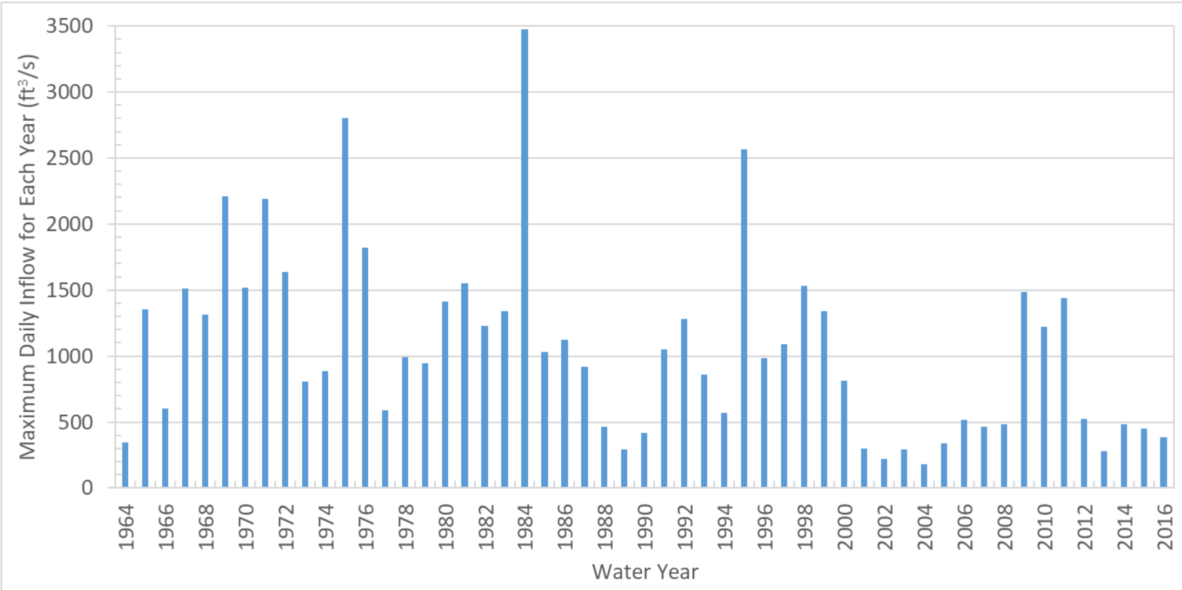

Figure 6. Maximum daily inflow each year into Clark Canyon Reservoir. Derived from Hydromet calculated mean daily inflows (www.usbr.gov/gp/hydromet/)

2.3. Dam Operations and Reservoir Characteristics

Clark Canyon is a zoned earthfill dam. This dam was completed in 1964 and began storing water on August 28, 1964. The dam has a height of 131.5 feet from the original stream bed (5446.5 feet) to the dam crest (5578.0 feet). When construction was completed, the hydraulic height of the dam from the original stream bed to the top of the flood control pool (5560.4) was 113.9 feet.

The historical daily reservoir water surface elevations in Reclamation Project Vertical Datum (RPVD) are presented in Figure 7. Annually, reservoir water surface typically fluctuates about 30 feet. Since 1964, the reservoir has filled to the top of the active conservation pool elevation 5535.7 feet or above nearly every year and has filled to the top of the joint use pool elevation 5546.1 feet in about 50 percent of the water years. High inflow Water Year 1984 (Figure 5 and Figure 6) resulted in the highest recorded reservoir water surface elevation since dam closure, 5564.6 feet. The reservoir reached its lowest elevation of 5490.1 feet in 2003 during the middle of an eight-year relatively dry period.

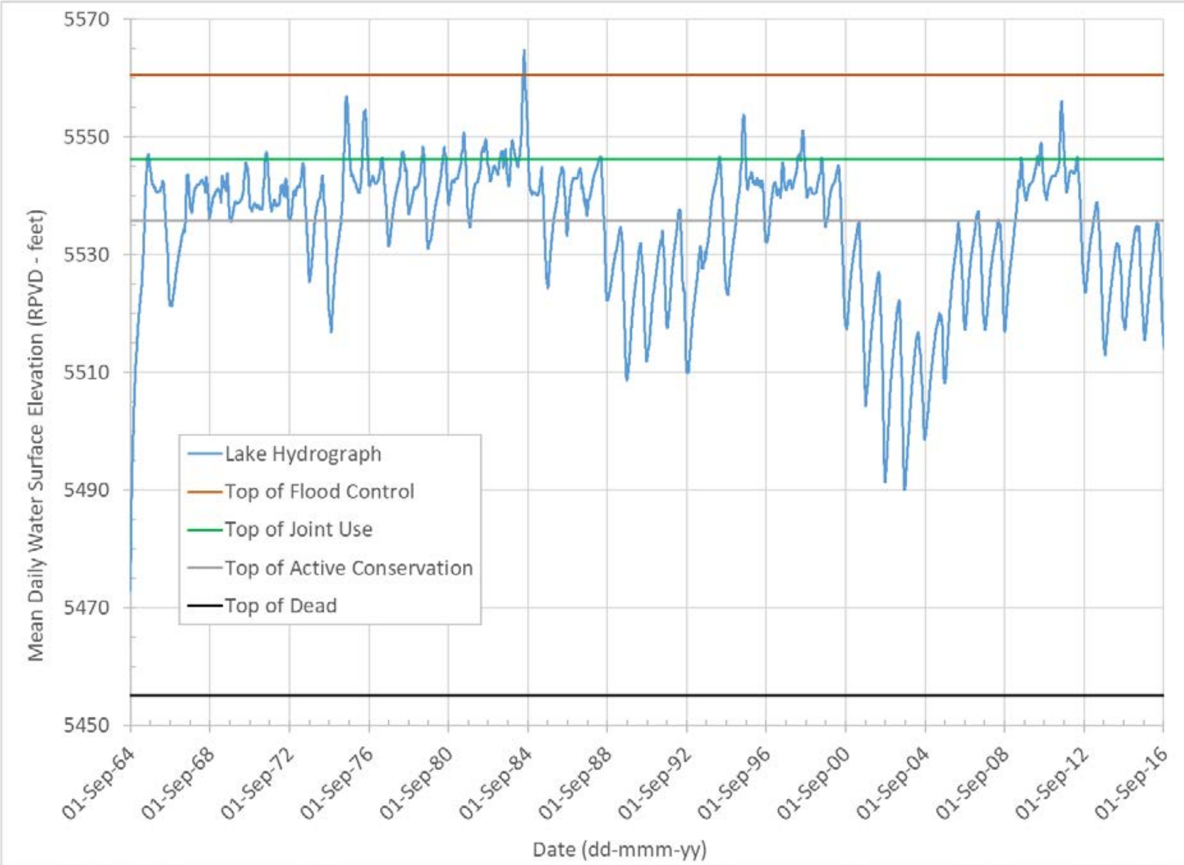

Figure 7. Historical Clark Canyon Reservoir water surface elevations. Data source: Hydromet www.usbr.gov/gp/hydromet/.

Both the Horse Prairie Creek arm and Red Rock River arm of Clark Canyon Reservoir are of uniform width. Red Rock River contributes the majority of the inflow to the reservoir and that arm is wider (1.5 miles wide) than the Horse Prairie Creek Arm (0.9 miles wide). Horse Prairie Creek and the Red Rock River come together just upstream of the Dam to form the Beaverhead River continuing downstream. Historical aerial photographs at low reservoir water levels show apparent sediment deltas where both inflows meet the reservoir pool. The deltas likely prograded downstream into the active conservation pool during the extended dry periods between 1988 and 1993 and between 2000 and 2008 when inflows and reservoir water surface elevations were relatively low (Figure 5, Figure 6, and Figure 7).

There is no record of past reservoir sediment management activities at Clark Canyon Reservoir or Dam.

3. Previous Reservoir Surveys

Prior to dam closure in 1964 and initial reservoir filling, the reservoir area was mapped to measure the original surface areas and corresponding storage capacities. Although the documentation summarizing the original survey methods has not been located for this analysis, due to the time period for construction of the dam, it is likely that USGS 7.5-minute quadrangle map contours were used for the 1964 analysis. Reservoir surface areas at 10-foot contour intervals were developed from this original mapping effort. Table 1 summarizes the methods used in the three surveys of Clark Canyon Reservoir.

Table 1. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above Water Survey
1964	Full	Surface	NA	10-foot contours
2000	Full	Surface	Single Beam	USGS Quad Contours
2016	Full	Surface	Multibeam	Contours from Aerial Photos, 2018; 10-Meter NED, 2013

The 2000 survey is described in the following reservoir survey report posted on Reclamation's website:

- Clark Canyon Reservoir 2000 Reservoir Survey (Reclamation, 2001). www.usbr.gov/tsc/techreferences/reservoir/Clark%20Canyon%20Reservoir%202000%20Reservoir%20Survey.pdf

4. Survey Control and Datum

For the 2016 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD83) State Plane (horizontal) coordinates, Montana Zone, FIPS 2500, international feet and North American Vertical Datum 1988 (NAVD88), Geoid 12A, US survey feet elevations. During processing, all bathymetry and GPS measurements were converted to (RPVD) for Clark Canyon. The RPVD was determined to be coincident with NGVD29 and 3.9 feet lower than NAVD88 (Geoid 12A).

The GPS base station receiver was set up over a 3.5-inch brass cap set in concrete, designated "R.P. 7", and located on a hill at the left dam abutment and spillway overlooking the reservoir. The GPS base station was located such that the survey vessel was never more than 4 miles away and always within range of the GPS radio to receive the correction signal from the base. Figure 8 and Figure 9 show the location and monument used for the GPS base during the 2016 bathymetric survey.

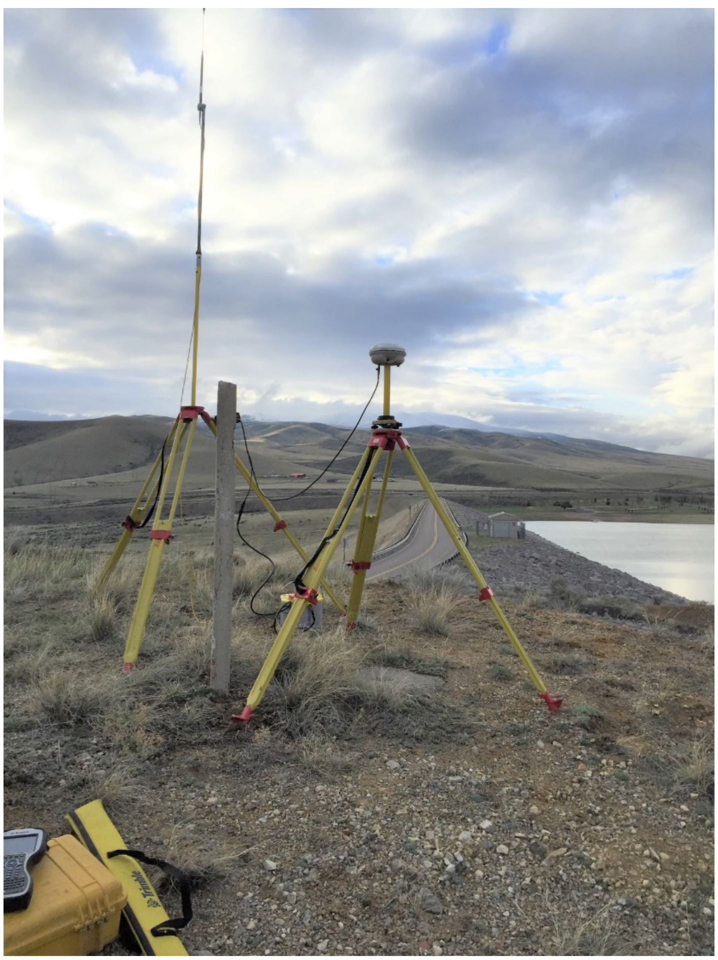

Figure 8. GPS base used during 2016 Clark Canyon bathymetric survey. Survey monument, brass cap set in concrete, shown directly under the GPS receiver (right) tripod

Figure 9. Close-up view of monument R.P. 7 used for the GPS base station during the 2016 bathymetric survey. Photo courtesy of Charles Hardes, Reclamation (MTAO)

State plane and elevation coordinates for the GPS base station were provided by Charles Hardes (MTAO) and were verified using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/).

The RPVD at Clark Canyon Reservoir was determined from a GPS control survey conducted by Charles Hardes and confirmed using RTK GPS measurements of water surface elevations around the boat ramp at Lewis and Clark campground on the on the west shore 0.5 miles upstream of the dam. These RTK GPS water surface elevation measurements were compared to water surface elevations recorded at the dam at the same time to calculate the vertical difference between NAVD88 and RPVD/NGVD29. The difference between NGVD29 and NAVD88 was computed using the US Army Corps of Engineers conversion program Corpscon v6.0.1 to validate the RPVD. Corpscon uses NGS data and algorithms to convert between various horizontal projections and vertical datums (www.agc.army.mil/Missions/Corpscon.aspx).

5. Methods Summary

A complete bathymetric survey was conducted during April 2016 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 bathymetric data points collected and the GPS base location for the 2016 survey is presented in Figure 10.

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with 10-meter digital elevation model (DEM) above water data downloaded from the National Elevation Dataset (NED; http://nationalmap.gov/viewer.html) and a water's edge contour digitized from 2018 aerial photographs to produce a combined digital surface of the reservoir bottom. Above water data used in the 2016 analysis and surface generation are shown in Figure 10.

Appendix B provides more details above the-water survey data. Surface areas at 1-foot contour intervals were computed using GIS software and the computer program ACAP (Reclamation, 1985) was used to produce the reservoir surface area and capacity tables at 0.01-foot increments.

Appendix C provides more details about the methods used to generate surface area and storage capacity tables.

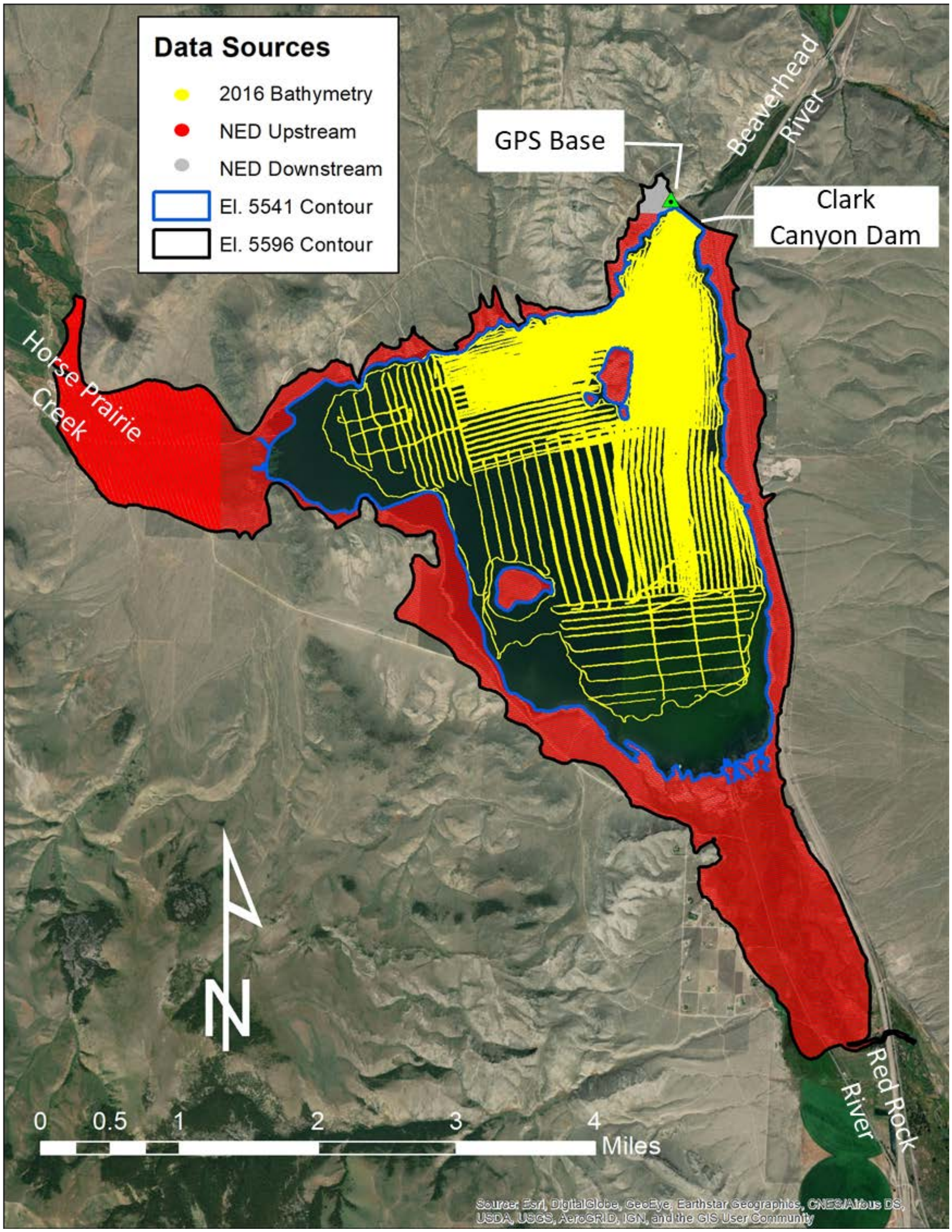

Figure 10. Map of bathymetric data coverage from the 2016 Clark Canyon Reservoir survey. Above water data used in the development of the 2016 surface and GPS base location used for the bathymetric survey are also shown.

6. Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations up to the dam crest elevation 5578.0 feet (Clark Canyon Reservoir 2016 Area and Capacity Tables; Reclamation 2020). Plots of the 2016 area and capacity curves are presented in Figure 11 along with curves from the 1964 and the 2000 surveys. Numbers used in the generation of the area and capacity curves are listed in Table 2 and Table 3 respectively. For the 2016 survey, area and capacity curves are based on the bathymetric (below-water) survey up to 5530.4 feet elevation, while curves above this elevation are based on a water's edge elevation 5541.0 contour digitized from 2018 aerial photographs and 10-meter National Elevation Dataset (NED) DEM data published in 2013 (http://nationalmap.gov/viewer.html). Though the 2000 and 2016 area and capacity curves show minimal difference below elevation 5530.4 feet, detailed comparison of these curves indicates that the largest reduction in surface area and storage capacity occurs between elevations 5535 (water surface elevation during 2016 survey) and 5571.9 feet (maximum water surface/top of surcharge pool).

> The actual surface areas and storage-capacity volumes for above-water elevations may be different than the areas measured in 1964 because of delta sedimentation, shoreline erosion, or use of older methods.

The above water data used for the 2016 surface development (above elevation 5530.4 feet) is more current, more detailed, and presumably more accurate than the above water data used to develop the 2000 surface. Use of updated data in 2016 and the greater level of detail likely explains the difference between the surface areas above the 2016 bathymetry.

Except for the dead pool capacity below elevation 5455.0 feet, the 2016 survey measured slightly greater capacities than the 2000 survey below elevation 5535.7 feet (top of active conservation pool). During the 2016 survey, water surface elevations were near the top of the active conservation pool, ranging between 5535.21 and 5535.49 feet. The greater capacities computed below 5535.7 are likely due to the different methods utilized for the 2000 and 2016 bathymetric surveys. The 2000 bathymetric survey was conducted using a single beam depth sounder collecting data along transects covering the reservoir typically spaced at 400 feet (Ferrari, 2001). The 2016 bathymetry was collected using multibeam depth sounder that achieves far greater bottom coverage for each pass (width of bottom coverage approximately 3.5 times the water depth). The multibeam survey resulted in far greater detailed data along the reservoir bottom with smaller gaps between data, especially in deeper areas of the reservoir where complete coverage was achieved (Figure 10). For surface development, the single beam assumes linear interpolation between passes. The multibeam survey measured more of the bottom topography between the 2000 single beam data, likely resulting in greater volumes computed in those areas.

At reservoir water surface elevation 5530.4 feet, which is 5 feet below the water surface at the time of the 2016 survey, the reservoir surface area was 4,009 acres with a storage capacity of 107,166 acre-feet. At joint use water surface elevation 5546.1 feet, the 2016 survey measured a surface area of 5,138 acres and a storage capacity of 174,300 acre-feet. At the top of flood control pool elevation 5560.4 feet, the reservoir had a surface area of 5,740 acres and a storage capacity of 251,436 acre-feet.

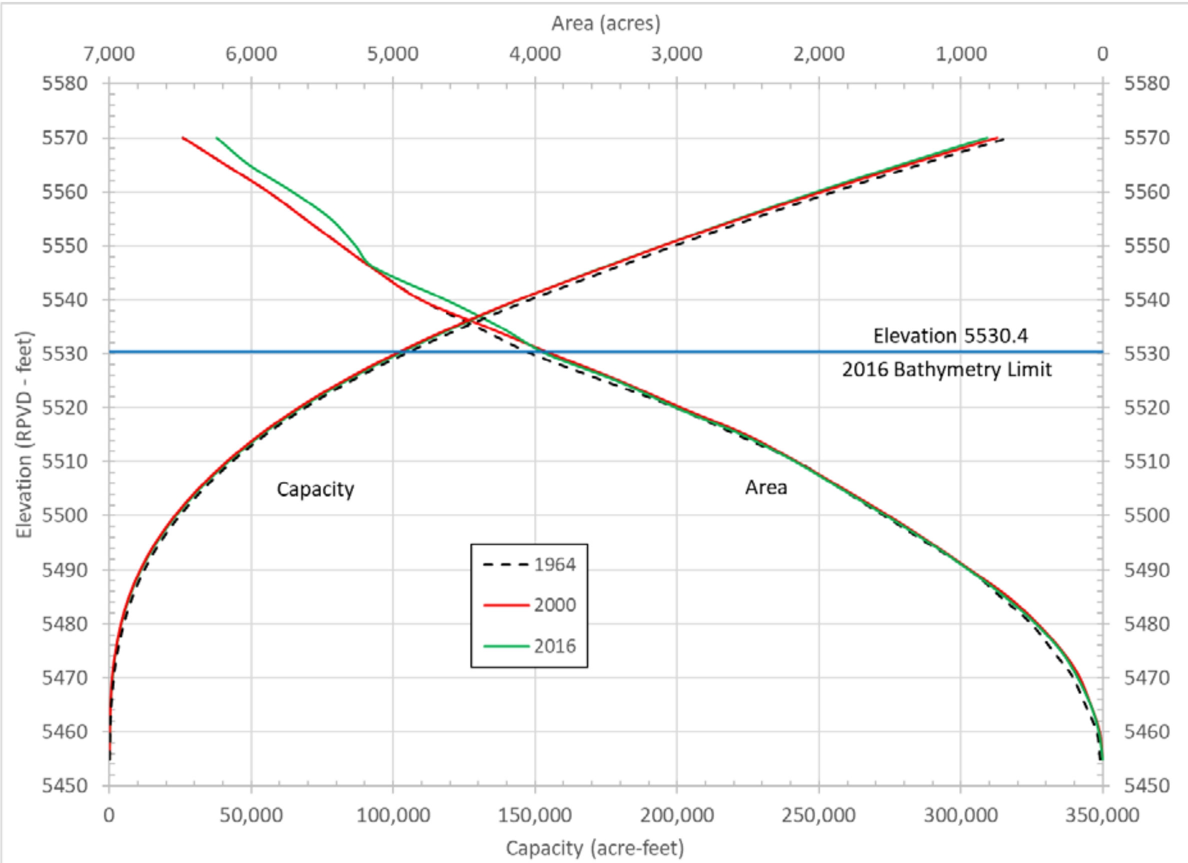

Figure 11. Clark Canyon Reservoir surface area and storage capacity versus elevation (RPVD)

Table 2. Clark Canyon Reservoir elevation versus surface area

Survey date	1964	2000	2016	
Vertical Datum	RPVD	RPVD	RPVD	
Elevation	Area (acre)	Area (acre)	Area (acre)	
5571.9	6606	6606	6335	Surcharge
5570	6481	6481	6242	
5565	6181	6181	6014	
5560.4	5904	5904	5740	Flood Control
5555	5622	5622	5442	
5546.1	5151	5151	5138	Joint Use
5535.7	4468	4407	4298	Active Conservation
5525	3513	3400	3424	
5515	2578	2508	2537	
5505	1845	1824	1844	
5495	1238	1208	1223	
5485	720	662	690	
5475	354	285	298	
5465	125	83	88	
5455	22	1	3	Dead Storage
5446.5	0	0	0	Stream Bed

Table 3. Clark Canyon Reservoir elevation versus storage capacity

Survey date	1964	2000	2016	
Vertical Datum	RPVD	RPVD	RPVD	
Elevation	Volume (acre-ft)	Volume (acre-ft)	Volume (acre-ft)	
5571.9	329430	325324	321133	Surcharge
5570	316997	312891	309184	
5565	285343	281237	278543	
5560.4	257548	253442	251436	Flood Control
5555	226437	222332	221326	
5546.1	178473	174367	174300	Joint Use
5535.7	128136	124160	125016	Active Conservation
5525	85110	82342	83335	
5515	54857	52739	53449	
5505	33048	31151	31715	
5495	17649	16053	16449	
5485	8069	6734	6989	
5475	2871	2093	2172	
5465	648	321	343	
5455	56	4	3	Dead Storage
5446.5	0	0	0	Stream Bed

7. Reservoir Sedimentation Volume Spatial Distribution

Longitudinal profiles of the 2000 and 2016 reservoir bottom surfaces were developed in GIS along the alignments presented in Figure 12. Only the bathymetry (no above water data) were used to plot the longitudinal profiles due to uncertainty in the precision and accuracy of the 2000 above water data and the gap between the 2016 bathymetry and above water data. Reservoir topography from the 1964 (original) analysis was not located for this study and was therefore not included in the longitudinal profiles. Separate profiles were plotted along the Horse Prairie (Figure 13) and Red Rock (Figure 14) arms on the alignments shown in Figure 12.

The longitudinal profiles for both reservoir arms (Figure 13 and Figure 14) indicate that sediment deltas had formed near elevations 5510 and 5520 feet by 2000. Historical reservoir elevations plotted in Figure 7 shows that the pool frequently reaches its annual minimum near elevations 5510 and 5520 feet, encouraging sediment deposition at those elevations over time. By 2016, those deltas were not as prominent, even disappearing along the Horse Prairie arm (Figure 13). A portion of the sediment deposits in the deltas at elevations 5510 and 5520 feet in the 2000 profiles likely eroded and redistributed further downstream in the reservoir pool during relatively low inflows (Figure 5 and Figure 6) and reservoir elevations (Figure 7) during the dry period between 2000 and 2008.

Longitudinal profiles in Figure 13 and Figure 14 are both examples of the difference in the detail between the 2000 single beam and 2016 multibeam surveys. Comparison of the profiles near the dam show lower bottom elevations and place the upstream toe of the dam further downstream in 2016. This difference in detail due to survey methods is primarily responsible for the greater storage volumes measured below the active conservation pool (elevation 5535.7 feet) during the 2016 bathymetric survey (Table 3).

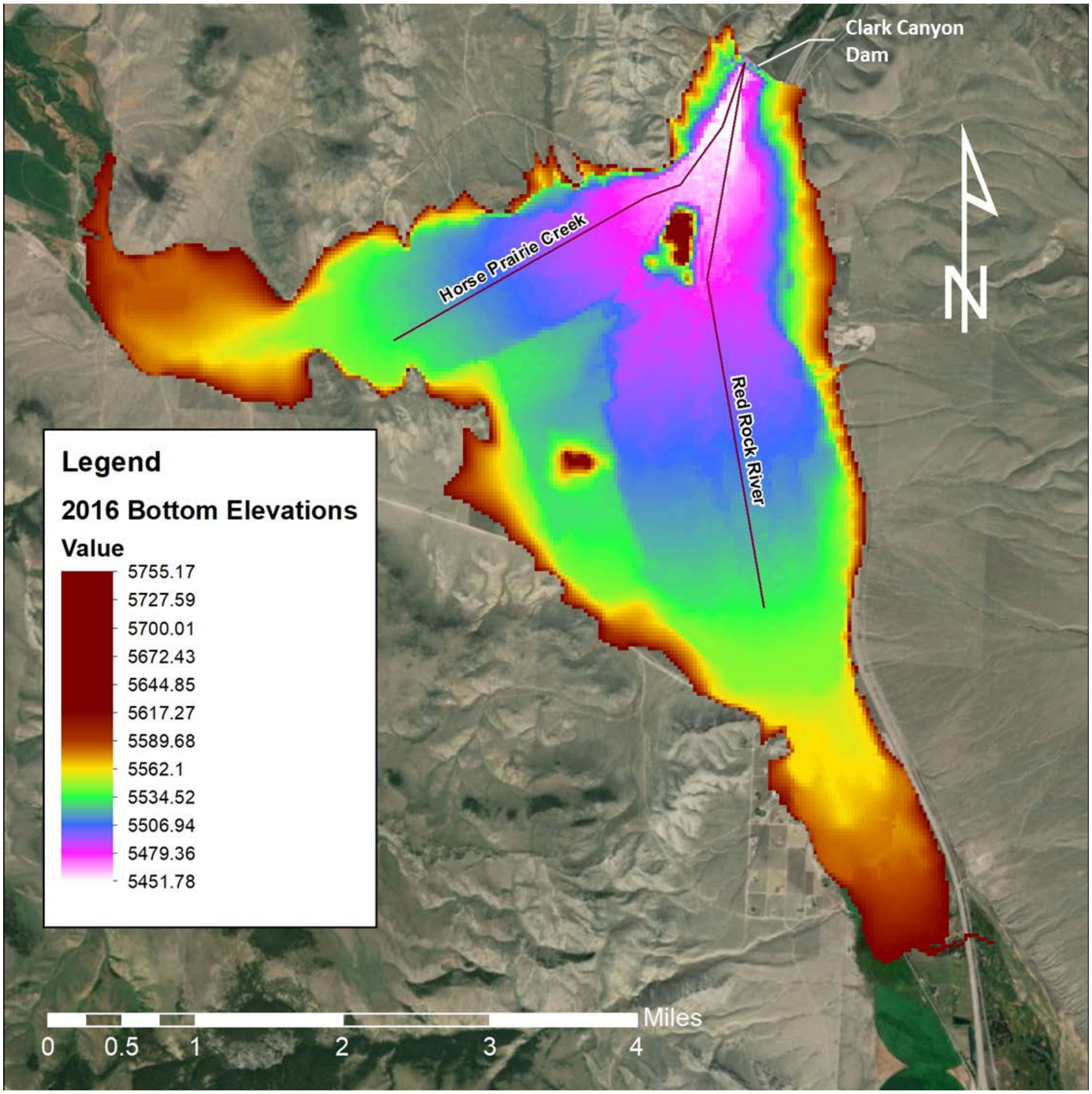

Figure 12. Reservoir surface elevation map and alignments of longitudinal profile. Elevation map ranges from 5450.4 ft (white) near the dam, to 5578.0 ft (red) in the upper reservoir, then up to 5755.2 ft (dark red)_on top of the islands

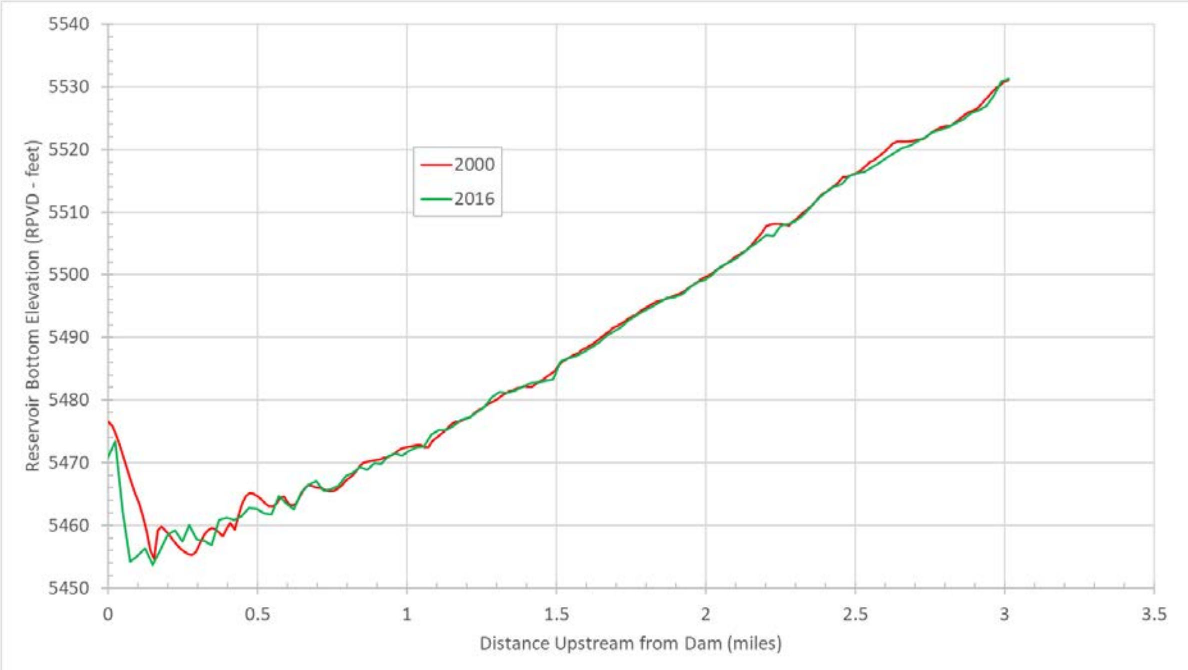

Figure 13. Longitudinal bottom profile of Horse Prairie (north) arm of Clark Canyon Reservoir

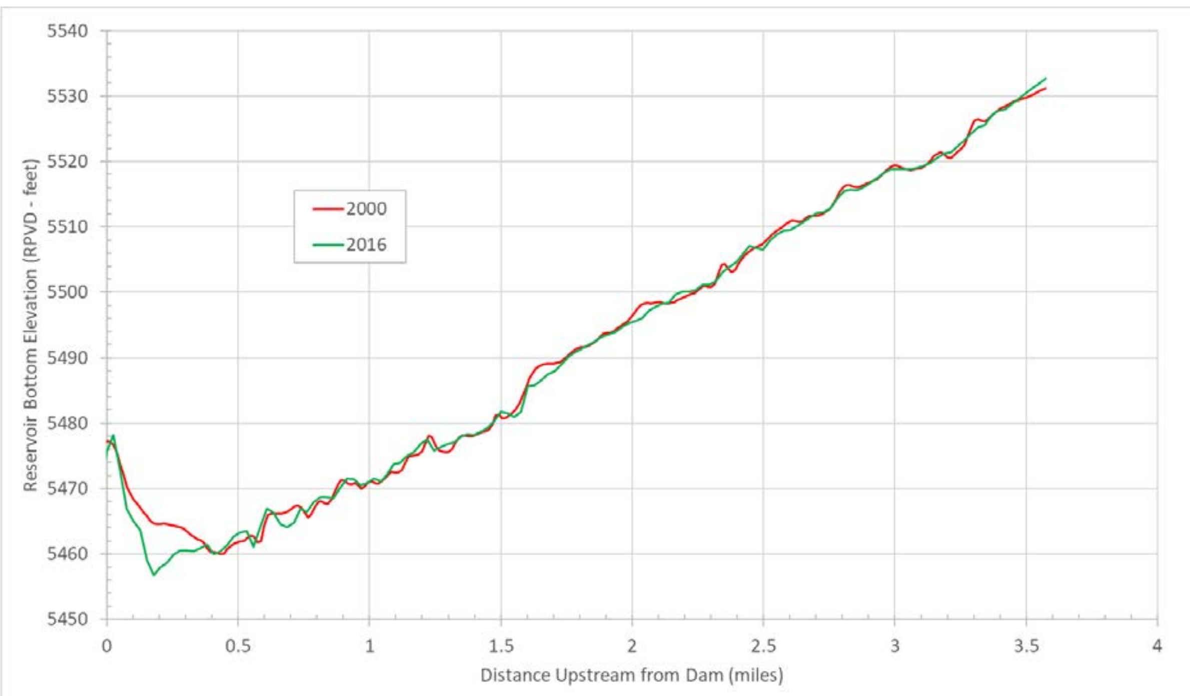

Figure 14. Longitudinal bottom profile of Red Rock (south) arm of Clark Canyon Reservoir

Cross sections of the 2000 and 2016 reservoir bottom surfaces were generated in GIS along the alignments shown in Figure 15 to represent the areas near the dam, midway up the reservoir, and in the deltas. The resulting reservoir cross section plots in Figure 16, Figure 17, and Figure 18 show the lateral distribution of sediment deposits in Clark Canyon Reservoir. The minimal deposition volume occurring between 2000 and 2016 is evident in the cross section plots. The shape of the cross sections and the minimum bottom elevations are nearly identical in each plot. Figure 17 and Figure 18 show slight deposition in the channel in the middle and delta areas of the reservoir respectively since the 2000 survey. Figure 16 shows minimal change in reservoir bed elevation over the 16 years between surveys. Cross sections are plotted looking downstream.

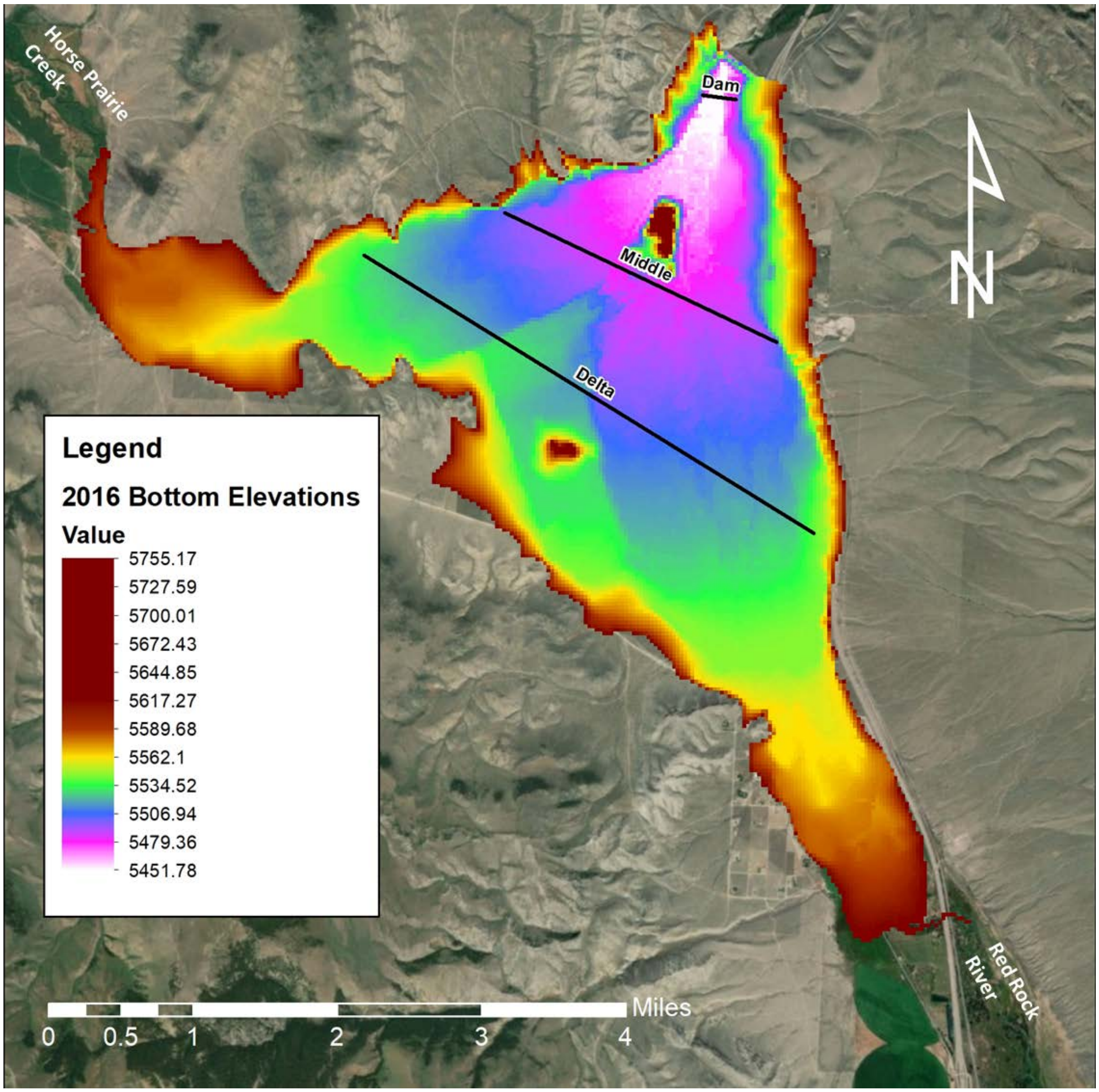

Figure 15. Reservoir surface elevation map and alignments of representative cross sections

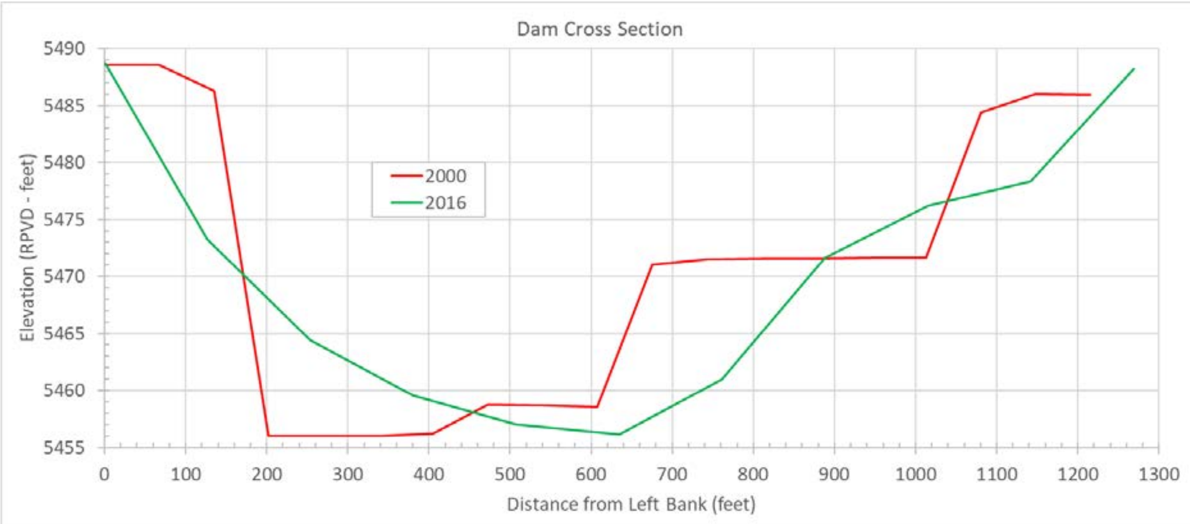

Figure 16. Representative cross section of the lower reservoir near the Clark Canyon Dam (looking downstream). Near-dam cross sections show a relatively small lateral and vertical portion of the reservoir, exaggerating the differences between 2000 and 2016 in that area

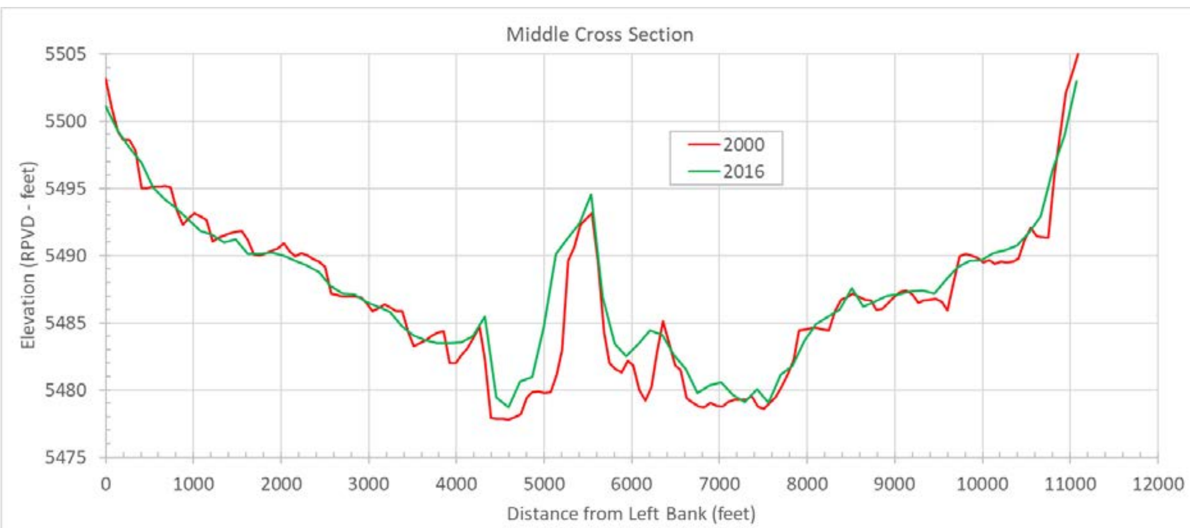

Figure 17. Representative cross section of the middle reservoir (looking downstream). The plot shows 1-2 feet of deposition in the Horse Prairie Creek (left) and Red Rock River (right) channels between 2000 and 2016

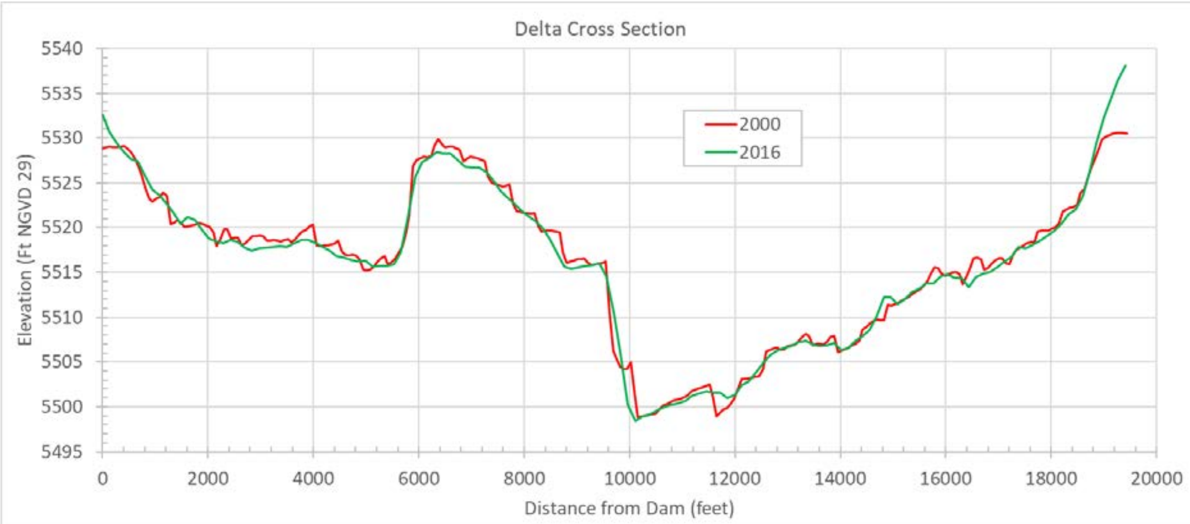

Figure 18. Representative cross section in delta areas (looking downstream). The lower minimum elevation in the Red Rock Creek (right) channel (Station 10,000) measured in 2016 (approximately 1 foot lower) may indicate slight delta erosion occurring since 2000

8. Sedimentation Trends

Graphs of the cumulative reservoir sedimentation over time (Figure 19) and percentage of remaining dead pool storage over time (Figure 20) indicate a decreasing trend in sedimentation rates. It is difficult to draw definitive conclusions about reservoir sedimentation at Clark Canyon with only two resurveys 16 years apart and several decades since dam closure in 1964. However, average sedimentation rates in reservoirs do tend to decrease over time for various reasons: changes in land use practices, initial expenditure of washload, construction of additional dams in the upstream watershed, and changes in hydrology are some of the reasons. The reduction in sedimentation rate over time measured in 2016 is likely primarily due to the relatively dry period experienced in the watershed since the previous survey in 2000 (Figure 5, Figure 6, and Figure 7). Differences in survey methods and level of detail of the bathymetry collected can be primarily responsible for computed differences in sediment deposit volumes rather than actual changes in reservoir storage. The 2000 bathymetric survey was conducted using a single beam sonar while the 2016 survey was conducted using a multibeam sonar, resulting in much greater detail over the 2016 survey area and likely affecting computed sediment volumes. Survey method, bottom coverage, and data resolution should be noted to avoid invalid comparison of survey results.

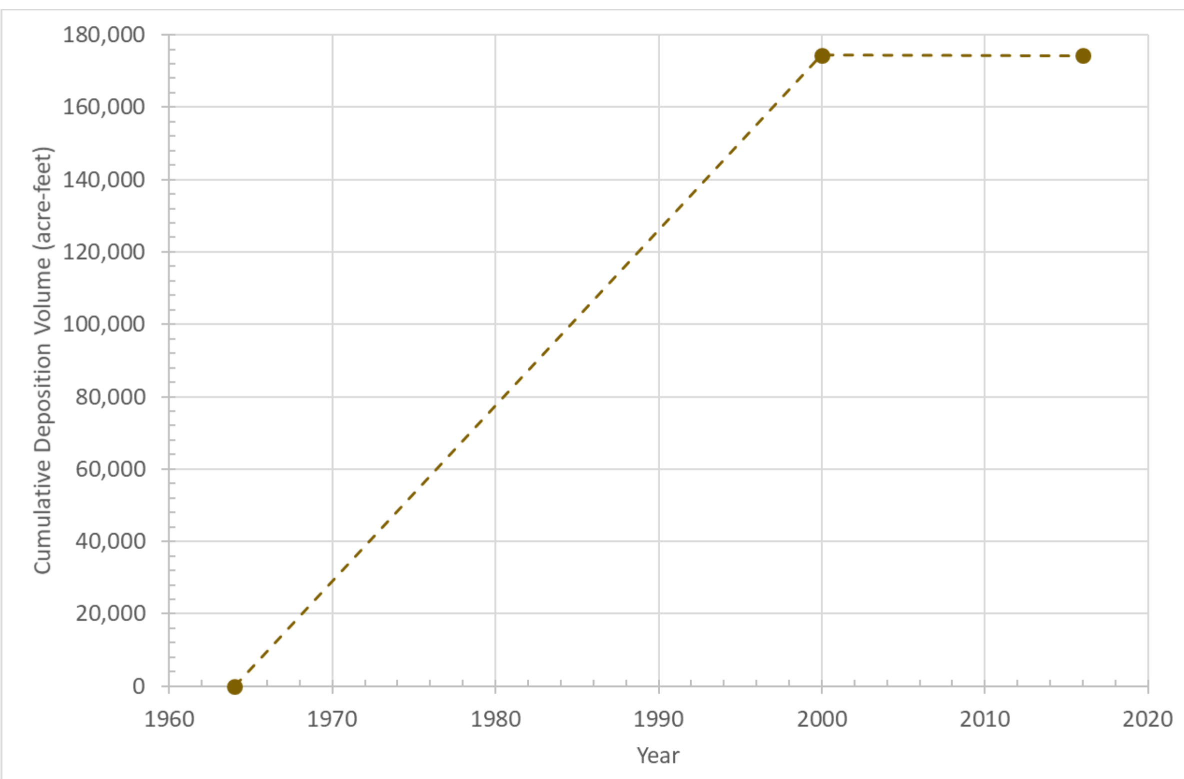

Figure 19. Cumulative reservoir sedimentation over time below reservoir elevation 5546.1 feet (top of joint use pool)

Sedimentation accumulates at all reservoir elevations and against the dam. Near the dam, sedimentation has been increasing the lowest reservoir bottom elevation over time, which also reduces the dead storage capacity over time (Figure 20). During the 2016 bathymetric survey, a minimum bottom elevation of 5450.4 feet was measured approximately 1,000 feet upstream of the dam. However, the mean bed elevation near the dam and outlet works in 2016 was 5452.5 feet, only 2.5 feet below outlet works sill and top of dead pool elevation 5455.0 feet.

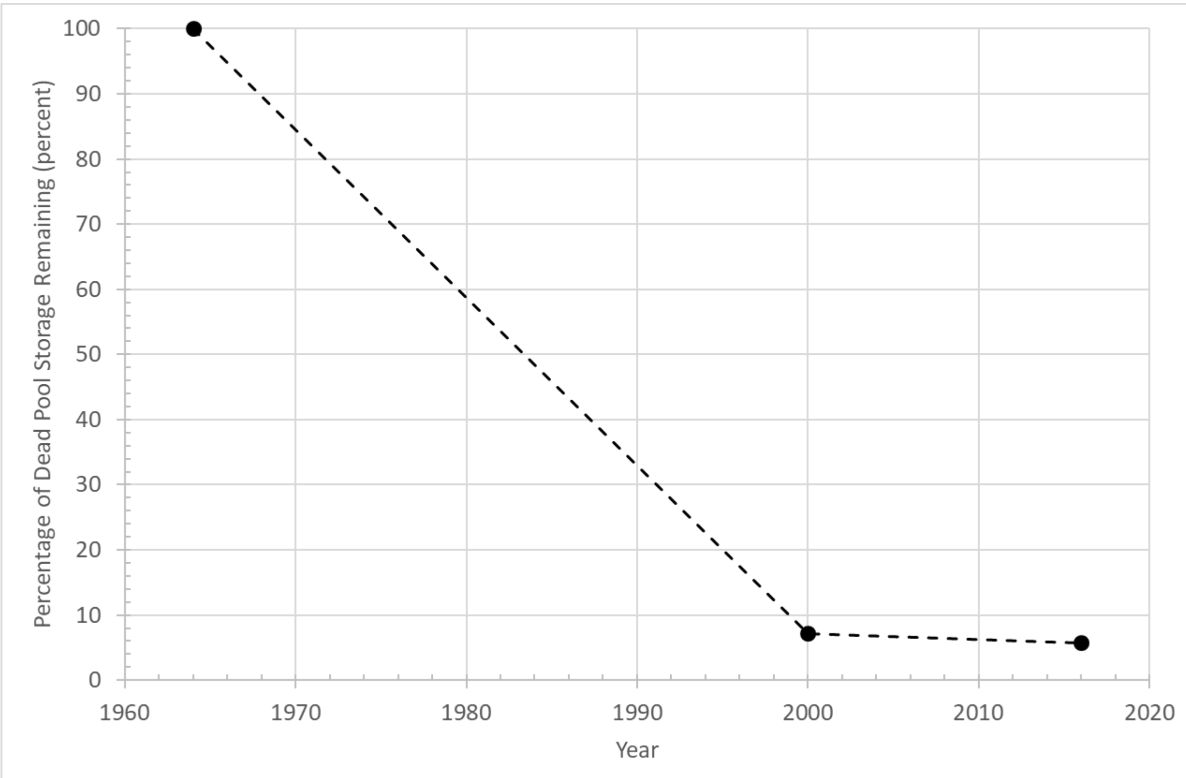

Figure 20. Sedimentation near the dam decreases the dead storage capacity over time

According to personal communication with MTAO personnel (Micek, 2015), highly turbid water was observed exiting the dam through the outlet works by downstream recreators during initial spring releases in 2015, indicating sediment deposition near and possible burial of outlet works. As a result, determining sediment levels at and around the outlet works was important during the 2016 survey. The 2016 bathymetry collected near the dam and outlet works was processed and plotted before any other data to establish current conditions there. Figure 21 is a map of the upstream dam face and reservoir bottom at the outlet works plotted in the same software used to collect and process the 2016 bathymetry data. The 2016 survey confirmed that the dam outlet works were not buried in sediment. An open continuous channel is visible all the way to the intake for the outlet works (Figure 21), indicating that the area near the dam had not yet filled with sediment and the outlet works remained fully functional as of 2016. However, average bed elevations measured at and around the intake suggest that as sedimentation levels continue to rise, the outlet works will be required to pass potentially damaging sediment downstream during normal operations.

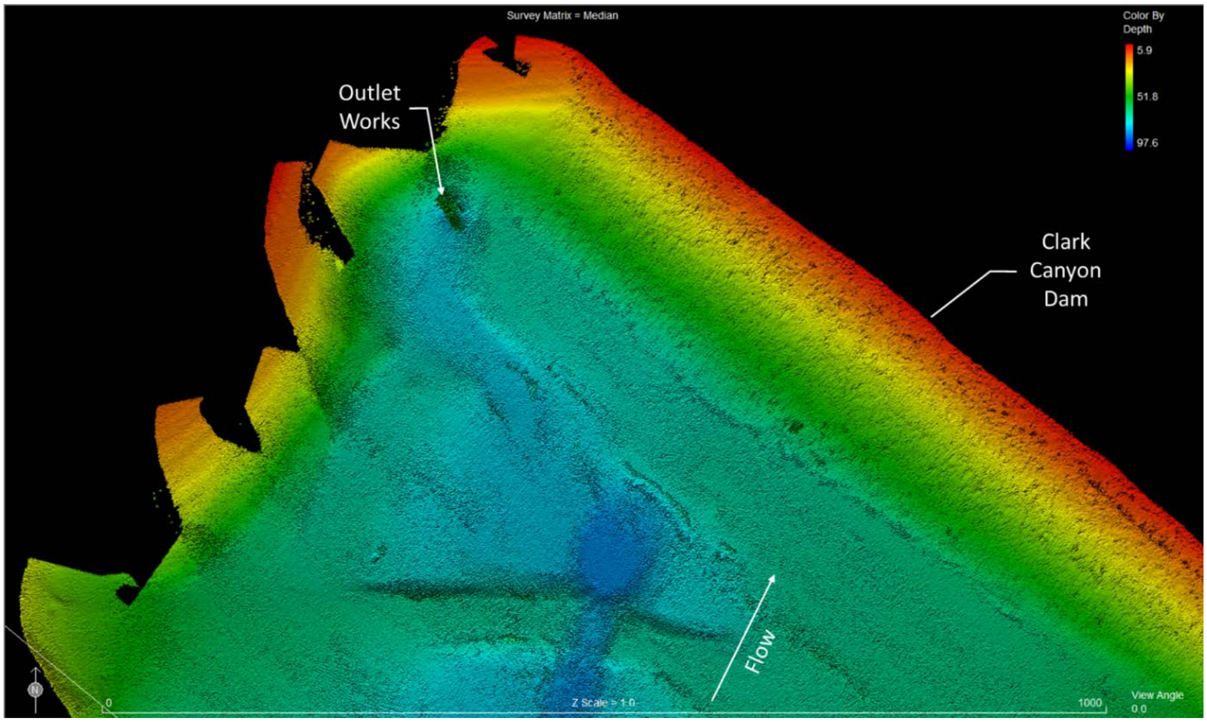

Figure 21. Map of Clark Canyon Dam face and reservoir bottom at outlet works. Note breached cofferdam and continuous channel leading to outlet works

9. Conclusions and Recommendations

9.1. Survey Methods and Data Analysis

The 2016 bathymetric survey, combined with above water data consisting of an elevation 5541.0 contour digitized from 2018 aerial photography and 10-meter DEM data from the NED, has been used to produce an updated digital surface of the reservoir bottom. Below elevation 5530.4 feet, 2016 bathymetry was used to develop a representative surface of the reservoir bottom. Between elevation 5530.4 and 5541.0 feet, water was too shallow to be accessed by the survey vessel and above-water data was not available in that region. NED data downloaded from the USGS National Map (http://nationalmap.gov/viewer.html) was used to map topography above 5541.0 feet.

Reservoir surface areas were computed from this digital surface at 2-foot intervals to determine the 2016 storage capacity. Surface area and storage capacity were then interpolated at 1.0-, 0.1, and 0.01-foot intervals. The slight difference in reservoir surfaces over time can be attributed to sedimentation, but also the differences in survey methods and variations in the precision and accuracy of the above-water data used. The 2016 surface area and storage capacity curves show minor gains below elevation 5535 feet and minor losses above. The minimal changes measured in 2016 are attributed to differences in bathymetric survey methods, above-water data sources, decreasing rates of sedimentation over time, and a prolonged dry hydrologic period between the 2000 and 2016 surveys.

9.2. Sedimentation Progression and Location

Over the span of 52 years, sedimentation has filled in 2.3 percent of the original storage capacity below the top of joint use pool elevation 5546.1 feet. The 2016 reservoir survey indicates that most of this sedimentation is located in the deltas above the top of the active conservation pool (elevation 5535.7 feet). Sediment has also deposited near the dam in the lowest portions of the reservoir and only 6 percent of the original dead storage capacity remained as of 2016. Average reservoir bottom elevations measured near the dam and outlet works in 2016 indicate that the top of the dead pool is only 2.5 feet above the current bed. As sediment levels near the dam continue to rise, the lowest dam outlet (invert elevation 5455.0 feet) may not be as reliable after the dead storage has filled with sediment because 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 Clark Canyon Reservoir is recommended within the next 10 years, 2026. Extreme hydrologic events, wildfires, or landslides in the drainage basin could necessitate a survey prior to 2026. If additional turbid or sediment laden releases are observed, or if outlet works become inoperable due to suspected sediment deposition, a survey may be required before the recommended 10-year period.

No recent LiDAR data was available for the development of the 2016 surface according to the NOAA National Elevation Inventory (https://coast.noaa.gov/inventory/). LiDAR collection recommended for next bathymetric survey to accurately determine sediment deposition volumes above the reservoir pool at the time of the bathymetric survey. The LiDAR survey should be conducted at reservoir water levels well below those during the bathymetric survey to provide sufficient overlap with bathymetry to produce a continuous surface and for validation of both data sets. LiDAR and bathymetry should be collected within one calendar year of each other.

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Appendix A — Hydrographic Survey Equipment and Methods

The 2018 bathymetric survey was conducted from April 23 through 26, 2018. During this period, reservoir water surface elevations varied between 6860.46 and 6860.51 feet (RPVD).

The survey was conducted along a series of predetermined cross section, longitudinal, and shoreline survey lines (Figure 10). The survey lines were spaced closely enough so there would overlapping coverage from the multibeam depth sounder or 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 22). Reservoir depths were measured using a multibeam echo sounder system 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,
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data, and
- laptop with hydrographic surveying software to integrate and store the bathymetry data.

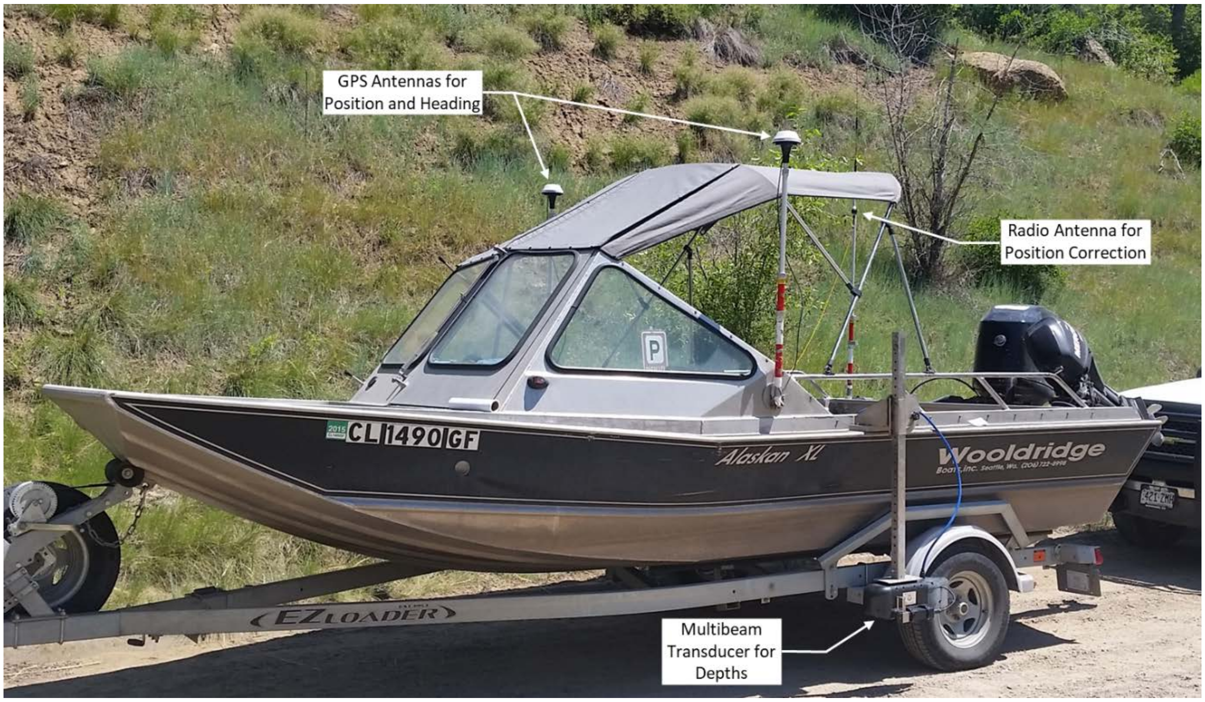


Figure 22. Wooldridge boat with RTK-GPS and multibeam depth sounder system.

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 during post-processing.

RTK GPS survey instruments were used to continuously measure the survey boat position and measure other ground control points. The GPS base receiver was set up on a tripod over a point overlooking the reservoir (Figure 10). 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 23). The base station was powered by a 12-volt battery.

Figure 23. RTK-GPS base station set-up at right dam abutment used during the 2016 bathymetric survey of Clark Canyon Reservoir

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. Positions measured on a moving survey vessel are less accurate.

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 North American Datum of 1983 (NAD83) (2011) State Plane (horizontal) coordinates, New Mexico Central Zone, FIPS 3002, in US survey feet and North American Vertical Datum of 1988 (NAVD88), Geoid 12A, US survey feet elevations. 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 generated many millions of data points. Due to underwater vegetation, signal interference, or other anomalies, a small percentage of the depth measurements did not represent the actual reservoir bottom and were deleted during the post-processing. Final processing of the bathymetric data resulted in tens of millions of data points used in the development of the reservoir surface. Filtering of the large raw data file was necessary, so a raster mesh was 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 measured within the cell.

Appendix B – Above Water Survey Methods

The 2016 bathymetric data were combined with above water data to produce a digital surface of the reservoir bottom surface. Above water data consisted of a 10-meter National Elevation Dataset (NED) Digital Elevation Model published in 2013 from The National Map of the USGS National Geospatial Program (http://nationalmap.gov/viewer.html) and a water's edge contour (elevation 5,541 feet, RPVD) digitized from aerial photos taken in July and August of 2018 and adjusted to contain the bathymetric data.

Unfortunately, no above water data was available that overlapped with the 2016 bathymetry to help verify elevations for both data sets. The area between the bathymetry (approximately elevation 5530.4 feet and below) and the above water data (elevation 5541 feet and above) was interpolated during surface development. Very little public LiDAR data are available in southwestern Montana where Clark Canyon Reservoir is located.

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

A digital surface of the reservoir bottom was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Horizontal surface areas were then computed at 2-foot increments, using functions within ArcGIS Pro, for the complete range of reservoir elevations (5447.0 to 5578.0 feet, RPVD). These reservoir surface areas were then used in Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985), to compute the storage capacity at these increments and then interpolate surface areas and storage capacities at 1.0-, 0.1-, and 0.01-foot increments between each 2-foot interval.

The program uses the least squares method to predict the reservoir storage capacity between 2-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)

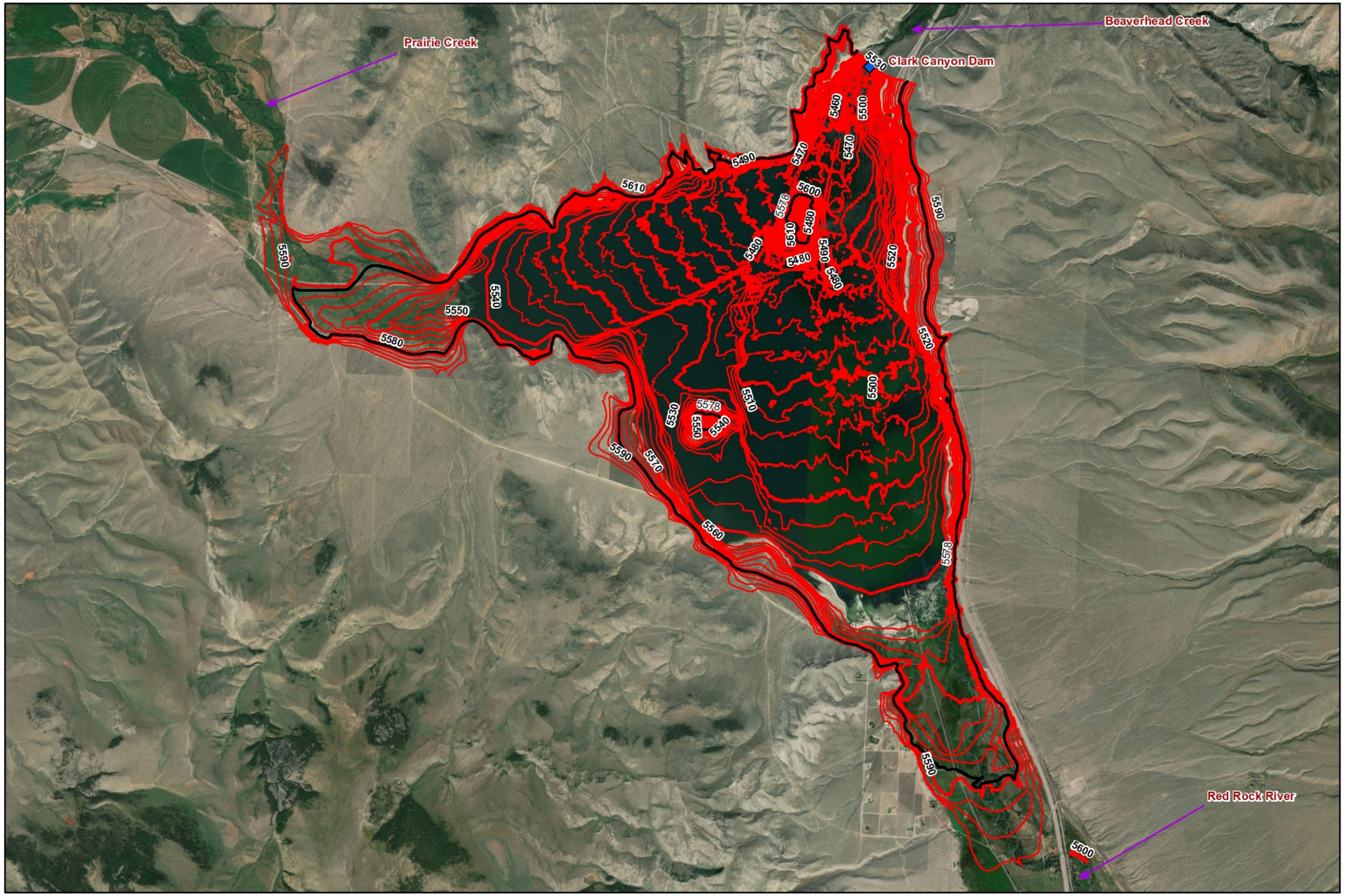
This method ensures that the given surface areas, and corresponding storage capacities, at the 2-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in the report *Clark Canyon Reservoir 2016 Area and Capacity Tables* (Reclamation, 2020).

The sedimentation volume can be computed by subtracting digital surfaces of the predam reservoir surface from the current digital reservoir surface. However, a predam topographic map and surface digital is not always available. The next option is to subtract the storage volume curve produced from the predam surface from the storage volume curve of the current surface. This method works well when the topographic map of the predam surface has good accuracy and precision. In some cases, the original topographic map significantly underestimated the actual storage capacity and subsequent surveys show an increased storage capacity even though reservoir sedimentation had reduced the actual storage capacity. In other cases the predam topographic map significantly overestimated the actual storage capacity and comparison with subsequent surveys show too large a sedimentation volume. Comparison of predam and post dam digital surface maps can help reveal these problems and provide ideas for correcting the original surface maps.

Sedimentation volumes can be computed for the range of elevations surveyed. In some cases, the sedimentation volumes can only be computed for the bathymetric survey because no new above water survey data were available.

Maps

Contour maps at 5-foot elevation intervals were generated from the 2016 Clark Canyon Reservoir surface developed from 2016 bathymetry, a digitized contour from 2018 aerial photography, and 10-meter DEM data from NED published in 2013. The contour at elevation 5578.0 feet represents the top of the dam crest and is shown in black on all contour maps presented herein. All contour elevations are presented in Reclamation Project Vertical Datum in US survey feet.



Clark Canyon Reservoir Montana Elevation Contour Map

Overview Map

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

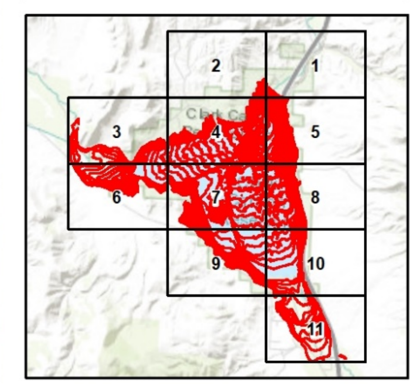
Five foot contour interval

Primary Data Source: 2016 Reservoir Study

N

Scale 1:45,000

0 3,550 7,100 Feet



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Clark Canyon Reservoir
Montana
Elevation
Contour Map

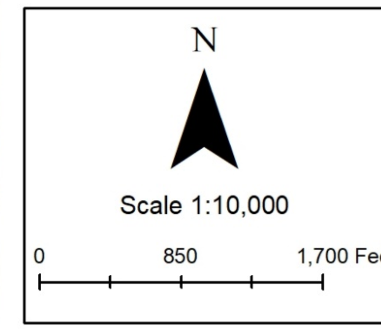
Sheet 1

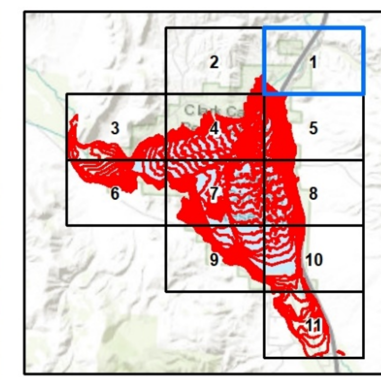
Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

Five foot contour interval

Primary Data Source:
2016 Reservoir Study





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Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 2

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

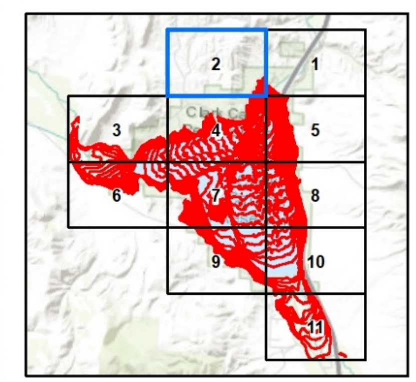
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 3

Horizontal datum based on
NAD 1983 State Plane Montana
FIPS 2500 Feet Intl

Vertical datum based on
Reclamation Project Vertical Datum
(RPVD) equivalent to NGVD, feet.
NGVD29 approximately 3.90
feet lower than NAVD88.

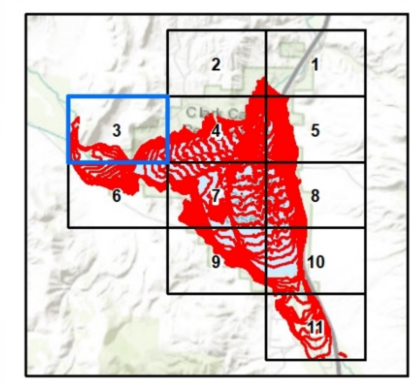
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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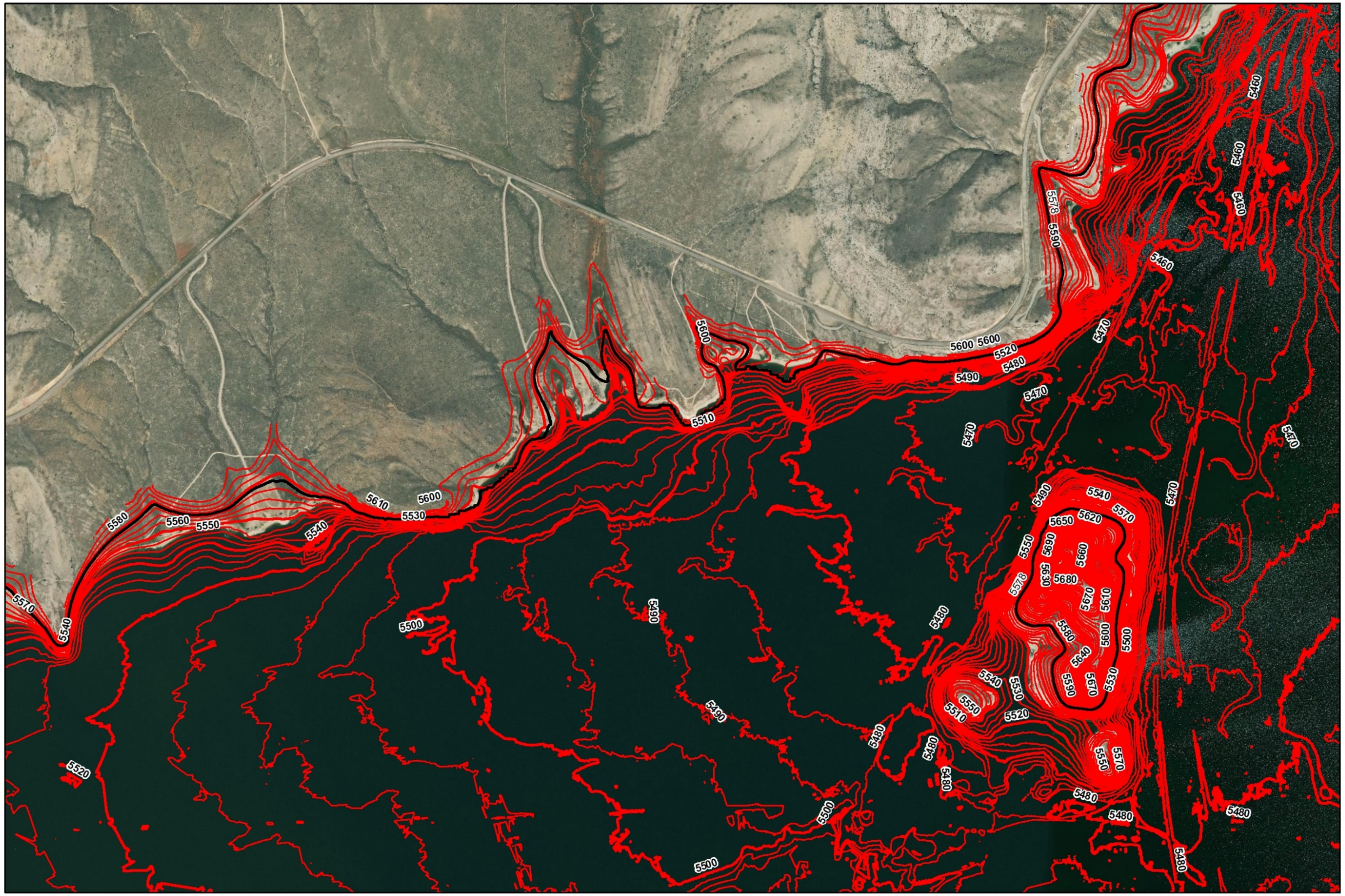


Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 4

Horizontal datum based on
NAD 1983 State Plane Montana
FIPS 2500 Feet Intl

Vertical datum based on
Reclamation Project Vertical Datum
(RPVD) equivalent to NGVD, feet.
NGVD29 approximately 3.90
feet lower than NAVD88.

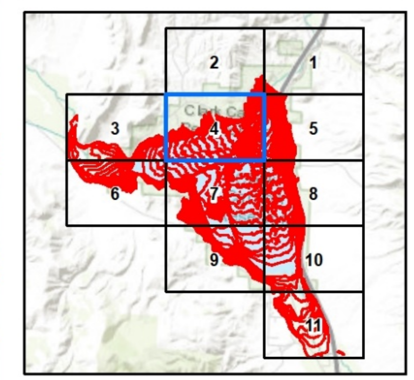
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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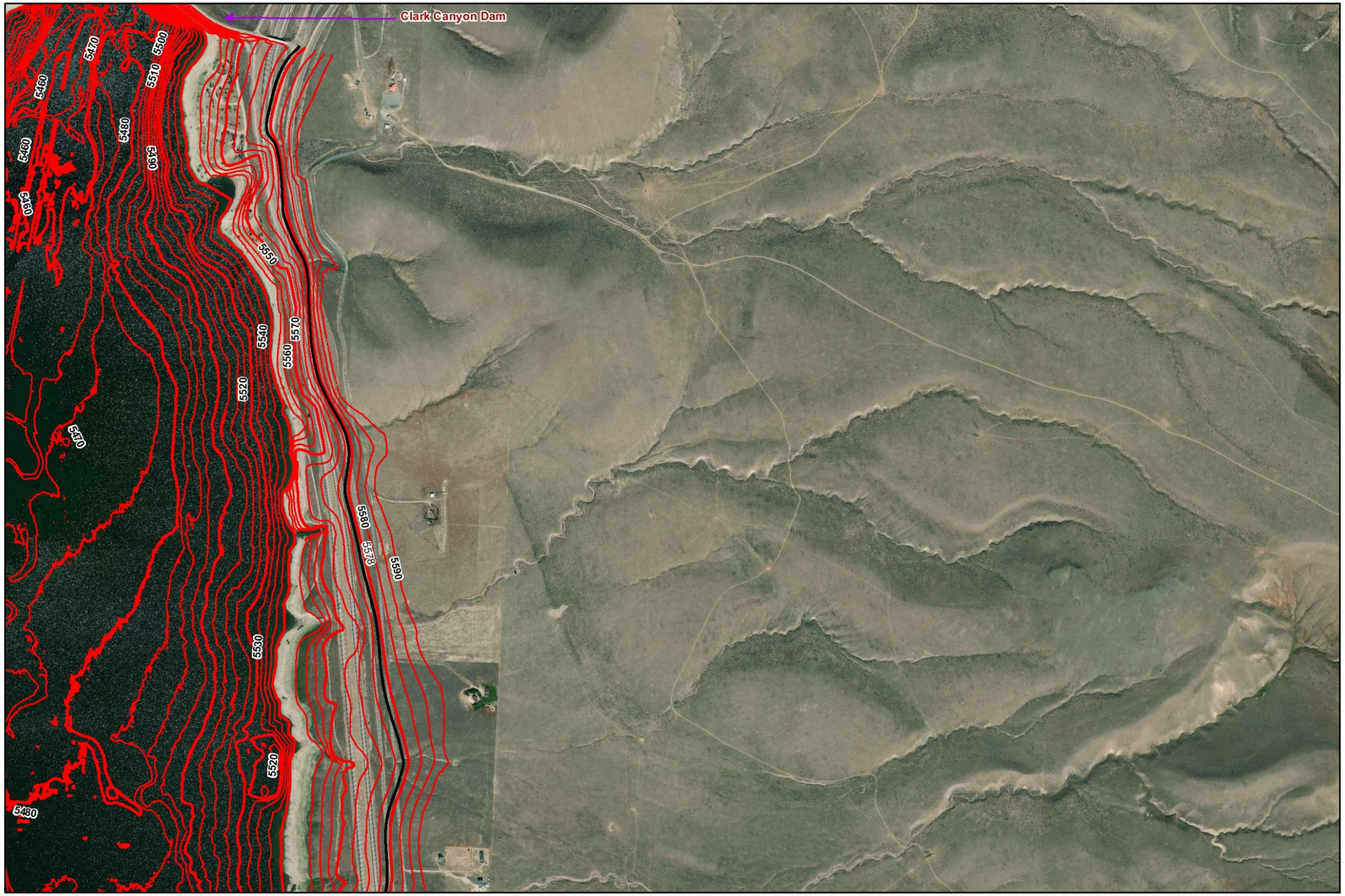


Clark Canyon Reservoir Montana Elevation Contour Map

Sheet 5

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

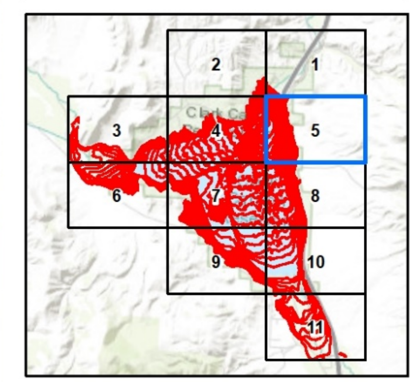
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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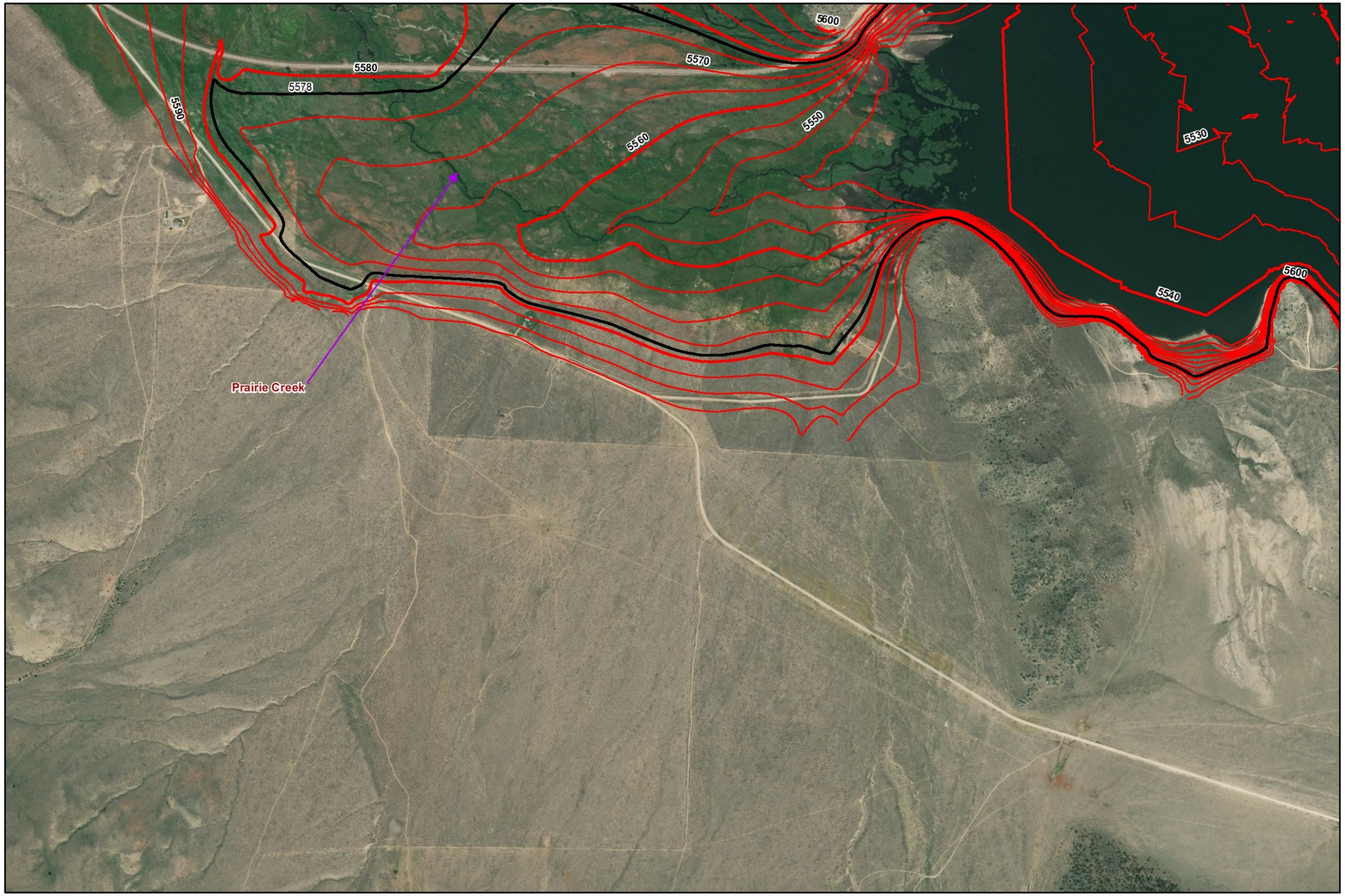
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 6

Horizontal datum based on
NAD 1983 State Plane Montana
FIPS 2500 Feet Intl

Vertical datum based on
Reclamation Project Vertical Datum
(RPVD) equivalent to NGVD, feet.
NGVD29 approximately 3.90
feet lower than NAVD88.

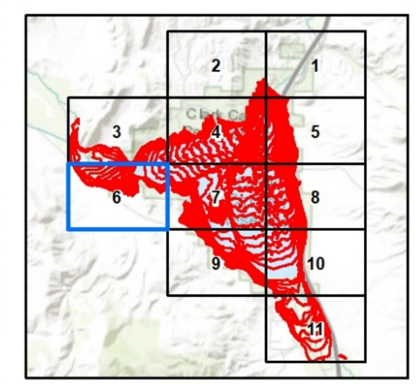
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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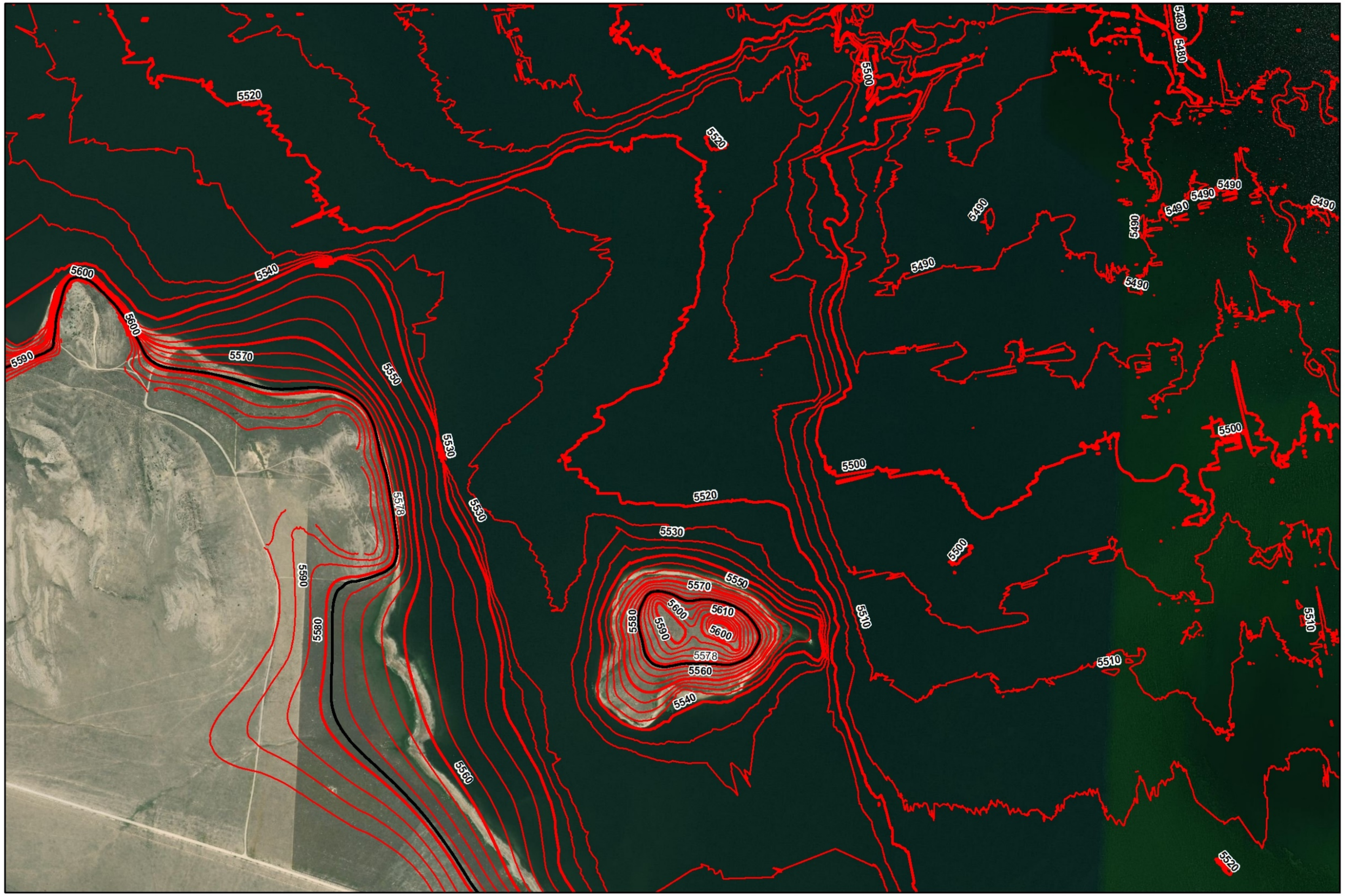
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 7

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

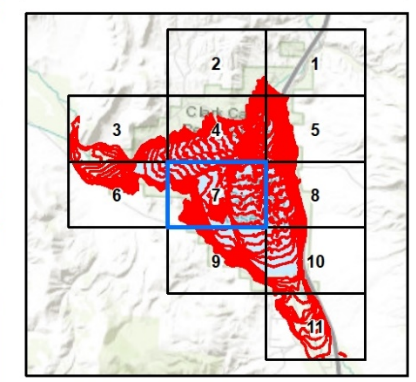
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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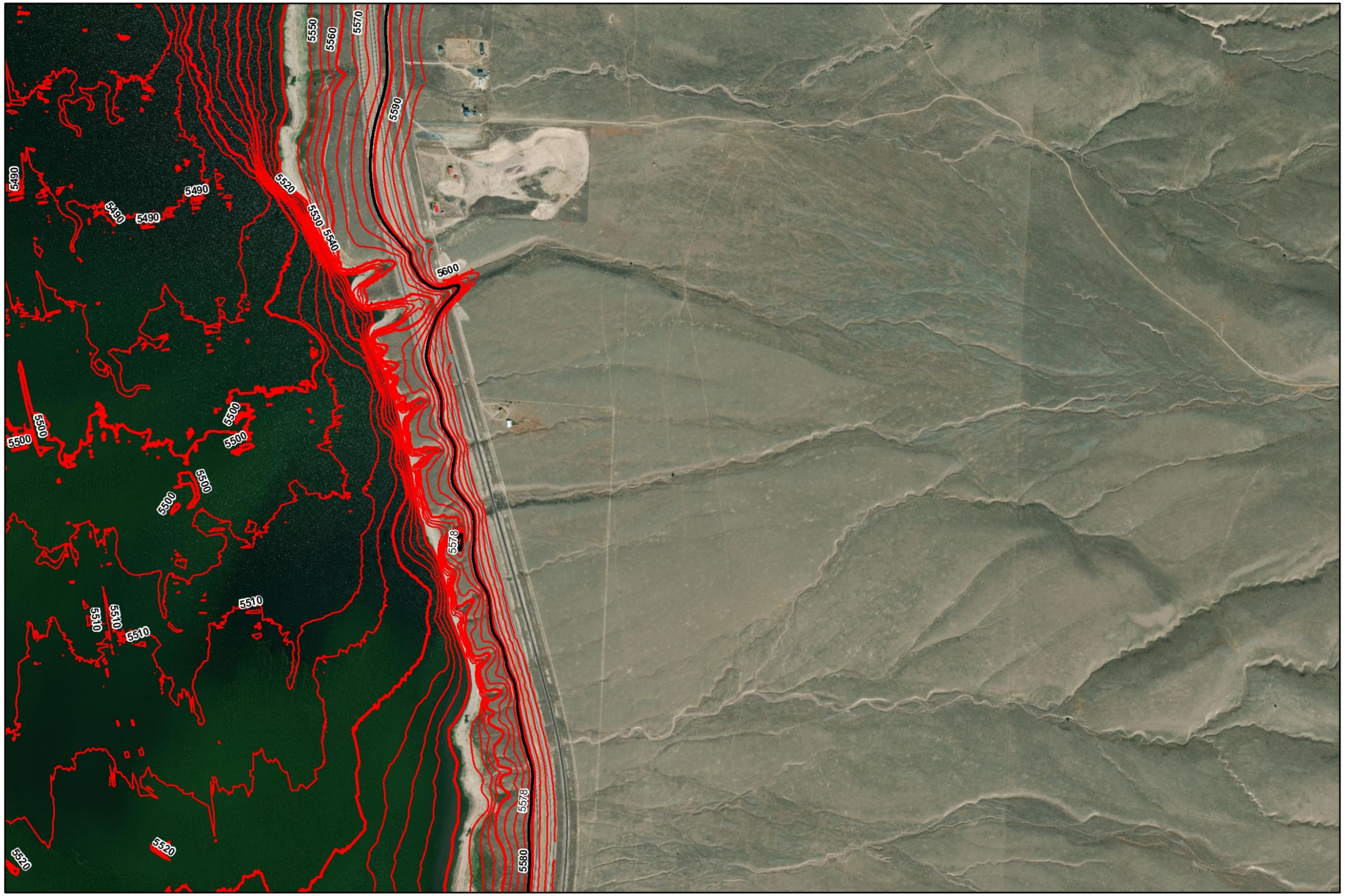
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 8

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

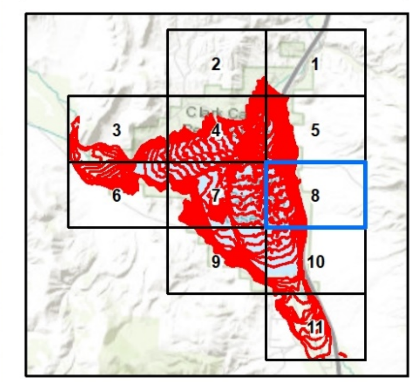
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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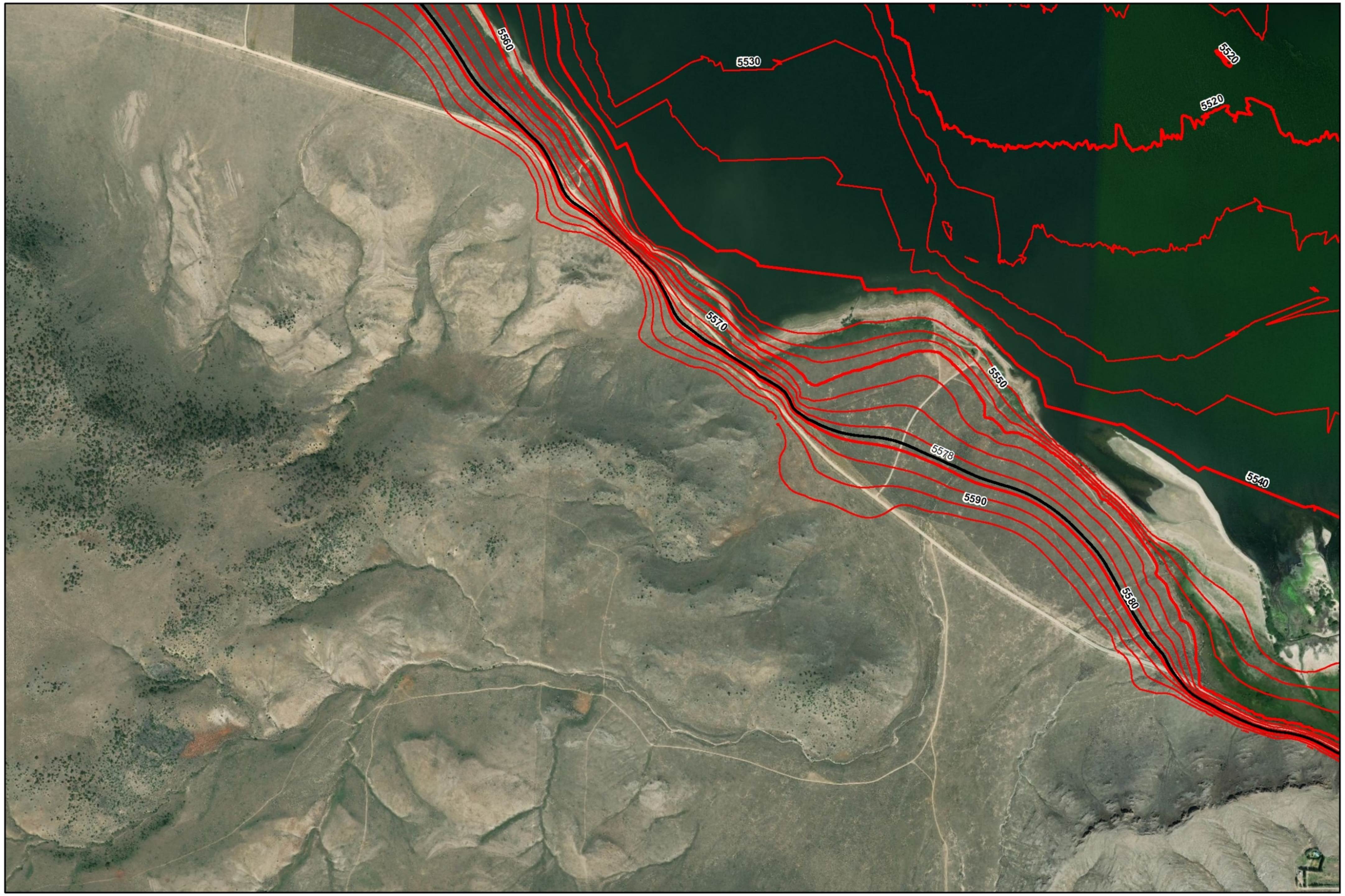


Clark Canyon Reservoir Montana Elevation Contour Map

Sheet 9

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

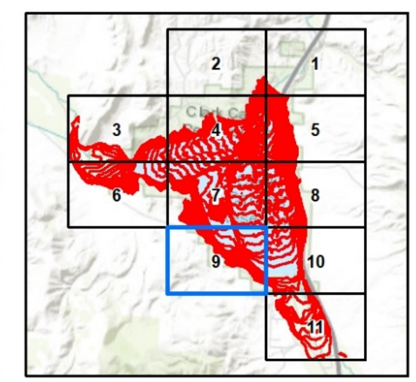
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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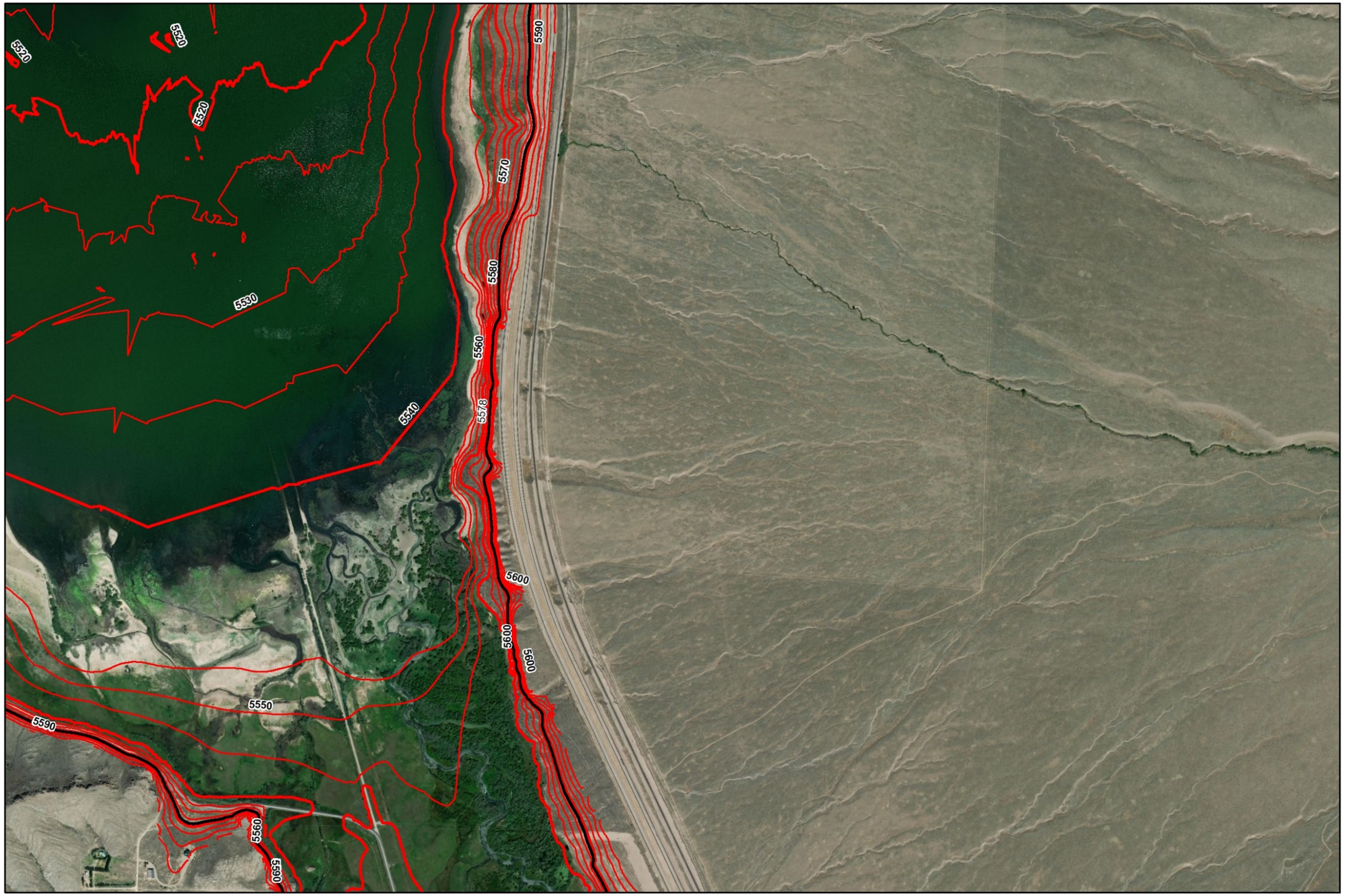


Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 10

Horizontal datum based on
NAD 1983 State Plane Montana
FIPS 2500 Feet Intl

Vertical datum based on
Reclamation Project Vertical Datum
(RPVD) equivalent to NGVD, feet.
NGVD29 approximately 3.90
feet lower than NAVD88.

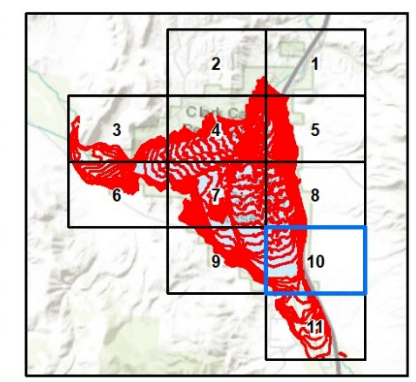
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Clark Canyon Reservoir
Montana
Elevation
Contour Map

Sheet 11

Horizontal datum based on NAD 1983 State Plane Montana FIPS 2500 Feet Intl

Vertical datum based on Reclamation Project Vertical Datum (RPVD) equivalent to NGVD, feet. NGVD29 approximately 3.90 feet lower than NAVD88.

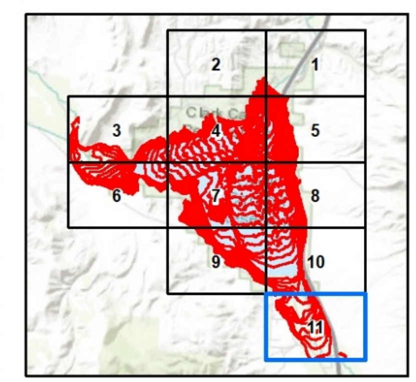
Five foot contour interval

Primary Data Source:
2016 Reservoir Study

N

Scale 1:10,000

0 850 1,700 Feet



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Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community