Technical Report No. ENV-2020-011

Canyon Ferry Reservoir 2016 Sedimentation Survey

Canyon Ferry Unit, Montana
Great Plains Region

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

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14. SHORT ABSTRACT **The 2016 multibeam bathymetric survey of Canyon Ferry Reservoir was combined with topography from photogrammetry to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the top of flood control pool elevation (3,800 feet, project vertical datum), the reservoir would have a surface area of 35,678 acres and a storage capacity of 1,993,036 acre-feet. Since the original filling in 1953, the reservoir is estimated to have lost 75,403 acre-feet of storage capacity (5.3%) due to sedimentation, below elevation 3,780 feet (Reclamation Project Vertical Datum [RPVD]). The dead storage pool volume has reduced to 14.7 percent of the original dead storage volume. The sedimentation level at the dam is at 3,614 feet (RPVD), which is 52 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.**			
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Technical Report No. ENV-2020-011

Canyon Ferry Reservoir 2016 Sedimentation Survey

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Acronyms and Abbreviations

ACAP	Area and Capacity
°F	degrees Fahrenheit
cfs	cubic feet per second
DOI	Department of the Interior
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
NAD 1983	North American Datum, established 1983
NGVD29	National Geodetic Vertical Datum, established 1929
NAVD88	North American Vertical Datum, established 1988
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RTK	Real-Time Kinematic
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
USGS	U.S. Geological Survey

Executive Summary

Canyon Ferry Dam and Reservoir are on the Missouri River about 17 miles northeast of Helena, Montana.

A bathymetric survey of Canyon Ferry Reservoir was conducted in July and August 2016 with these primary objectives:

1. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations and
2. Estimate reservoir sedimentation volume since the original reservoir filling began in 1953 and since the last survey in 1997.

The bathymetric survey was conducted from a boat using a multibeam depth sounder in the main reservoir and cataraft-mounted depth sounder in the four dust abatement ponds. Both systems were interfaced with differential global positioning system (GPS) instruments (for horizontal positioning) to map the reservoir bottom. The 2016 bathymetric survey of Canyon Ferry Reservoir was combined with above water contour data from the 1997 survey report to produce a combined digital surface of the reservoir bottom.

This survey was conducted between July 7, 2016 and August 19, 2016 when the reservoir water surface elevation ranged between 3,789 and 3,796 feet (RPVD[1]). The top of flood pool elevation is 3,800 feet. The 2016 bathymetric survey is limited to elevations below 3,784 feet, which is approximately 5 feet below the water surface elevation at the time of the survey. The above-water topographic data were developed from 1996 aerial photography. Original survey, surface area, and storage capacity data from 1953 were not obtained. In 1978, construction finished on four dust abatement ponds at the upstream end of the reservoir between elevations 3,780 and 3,800 feet. In 1984, the original surface area data were adjusted to remove the area created by the dust abatements and the reservoir surface areas and storage capacities above elevation 3,780 were recomputed.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 3,784 feet, the reservoir surface area was 30,422 acres with a storage capacity of 1,464,780 acre-feet.
- At the top of flood control pool elevation (3,800 feet), the reservoir would have a surface area of 35,678 acres and a storage capacity of 1,993,036 acre-feet.
- Since the original filling of the reservoir in 1953, the reservoir is estimated to have lost 75,403 acre-feet of storage capacity (5.3 percent) due to sedimentation, below elevation 3,780 feet. This volume represents a sediment yield rate of 0.7 acre-feet per square mile per year (acre-feet/mi^2/year) which is considered low as defined in Reclamation (2006).

[1] Unless otherwise noted, all elevations in this report are presented in Reclamation Project Vertical Datum (RPVD), which is 0.08 feet lower than NGVD29 and 3.15 feet lower than NAVD88.

- By 2016, the dead storage pool volume had reduced to 14.7 percent of the original dead storage volume. The sedimentation level at the dam is at 3,614 feet.

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	Canyon Ferry	**Region**	Great Plains
Owner	Bureau of Reclamation	**Area Office**	Canyon Ferry Field Office
Stream	Missouri River	**Vertical Datum**	Reclamation Project Vertical Datum (RPVD)
County	Lewis & Clark	**Top of Dam (ft)**	3,808.5
State	Montana	**Spillway Crest (ft)**	3,766.0
Lat (deg min sec)	46 38 57	**Power Penstock Elevation (ft)**	3,706.03
Long (deg min sec)	111 43 39	**Low Level outlet (ft)**	3,650
HUC4	1003	**Hydraulic Height (ft)**	225
HUC8	10030101	**Total Drainage Area (mi^2)**	15,904
NID	MT00568	**Date storage began**	03/1953
Dam Purpose	Electricity, irrigation, flood control	**Date for normal operations**	03/1953

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

Original Design (Excluding Dust Abatement Ponds)

Storage Allocation	**Elevation (RPVD) (ft)**	**Surface area* (acres)**	**Capacity* (acre-ft)**	**Gross Capacity* (acre-ft)**
SURCHARGE				
FLOOD CONTROL	3,800	33,535	99,602	2,052,723
MULTIPLE USE				
JOINT USE	3,797	32,866	795,492	1,953,121
CONSERVATION	3,770	24,126		1,157,630
INACTIVE	3,728	11,481	438,236	445,736
DEAD	3,650	1,000	7,500	7,500

*Values recorded show original design surface area and storage capacity, adjusted to exclude the dust abatement ponds and recomputed in the 1997 Sedimentation Survey report (page 13, which is Table 2 however there is no Table number on this Table, but with investigation Reclamation has determined based on language in the 1997 Report this is Table 2, columns 2 and 3; Reclamation, 1998) using Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985).

Survey Summary at top of Conservation Pool (Elevation 3,770 feet)

Date	Type of Survey	Contributing Sediment Drainage Area (mi^2)	Period Sedimen-tation Volume (acre-ft)	Cumulative Sedimenta-tion (acre-ft)	Lowest Reservoir Elevation (ft)	Remaining Portion of Dead Storage (%)
1953	Contour	11,248	0	0		
1997	Contour	11,248	60,031	60,031	3,625	14.1
2016	Contour	10,214	10,383	70,414	3,614	14.7

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1. Introduction

Canyon Ferry Dam and Reservoir are on the Missouri River about 17 miles northeast of Helena, Montana (Figure 1). The dam and reservoir are operated by U.S. Bureau of Reclamation as part of the Canyon Ferry Unit that supplies irrigation water to about 155,600 acres of farmland and provides municipal water and hydropower for Helena, Montana (Reclamation, 2019).

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, Great Plains Regional Office requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) to conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A bathymetric survey was conducted from July 7, 2016 to August 19, 2016 with these primary objectives:

1. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations and
2. Estimate reservoir sedimentation volume since the original reservoir filling began in 1953 and since the last survey in 1997.

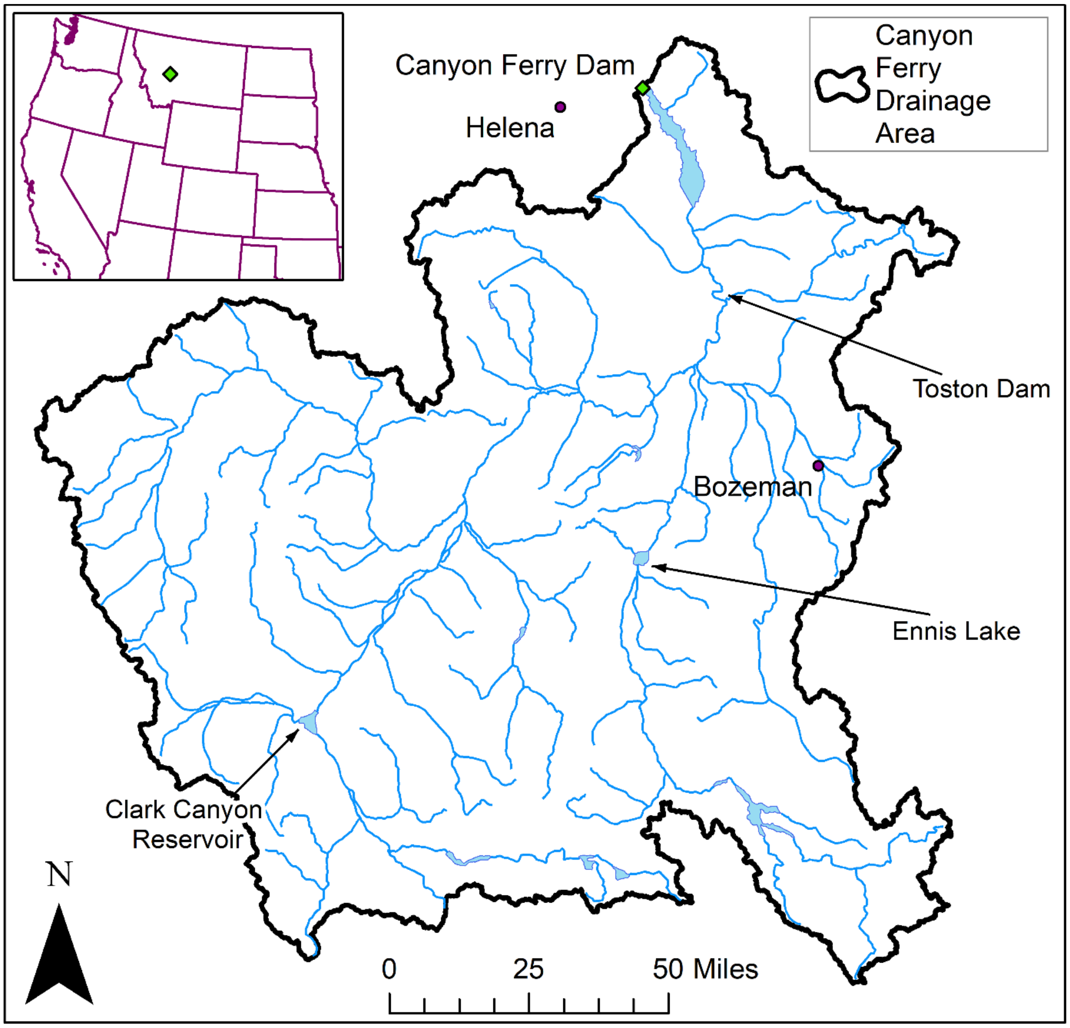

Figure 1. Location map of Canyon Ferry Dam and Reservoir, 17 miles northeast of Helena, Montana.

2. Watershed Description

The watershed upstream from Canyon Ferry Reservoir has a total contributing drainage area of 15,904 square miles (mi^2). The majority of the inflow is from the Missouri River, which forms at the confluence of the Madison, Gallatin, and Jefferson Rivers. Because of various upstream lakes and reservoirs that trap sediment (as of 2019), the area of the regulated watershed is 5,690 mi^2 (Figure 2). The two main reservoirs in the watershed are Clark Canyon Reservoir, built in 1964 and Ennis Lake (formed by Madison Dam, built in 1906). The total drainage area of both reservoirs is approximately 4,400 mi^2. (U.S. Geological Survey, 2019). Therefore, the net sediment-contributing drainage area to Canyon Ferry Reservoir is approximately 10,214 mi^2, or 62 percent of the total watershed (U.S. Geological Survey, 2019). The regulated drainage area is slightly larger than the 1997 survey (5,608 mi^2) as various smaller dams are included here (Reclamation, 1988). Toston Dam, on the Missouri River upstream of Canyon Ferry Reservoir, was not included in the regulated drainage area (Figure 2). The elevations of the watershed range from 3,730 feet to 11,260 feet with a mean elevation of 6,595 feet.

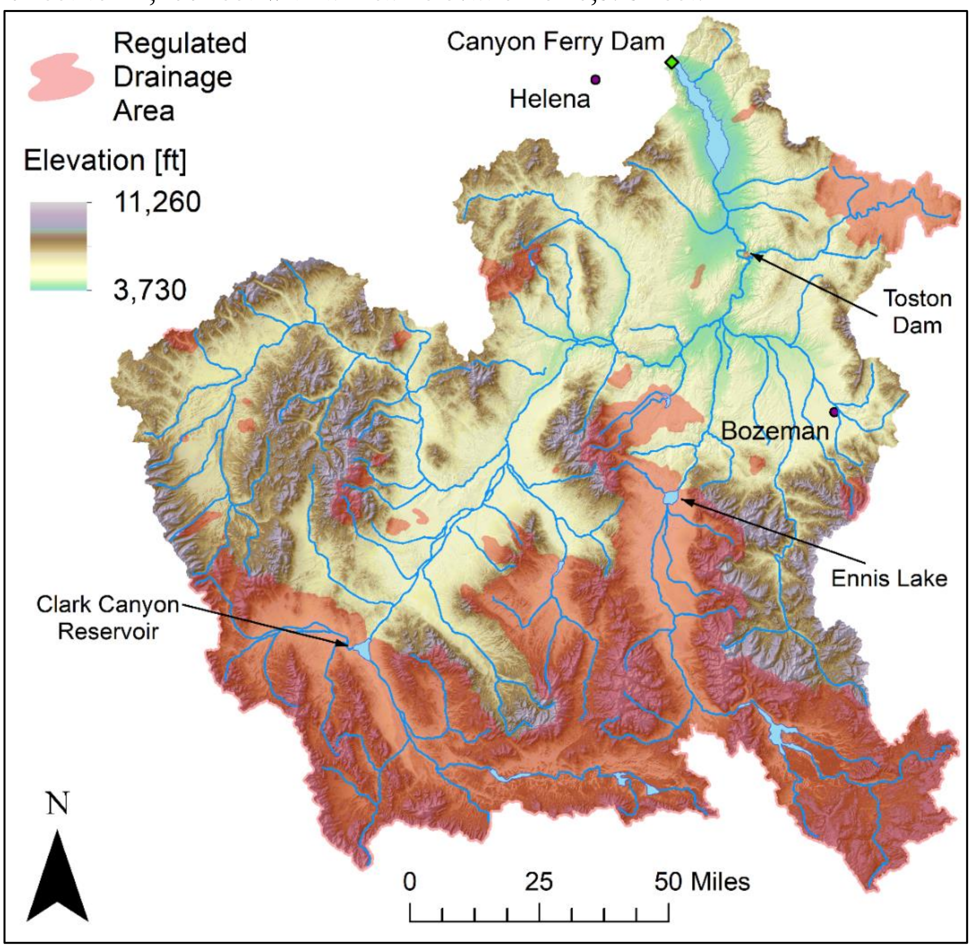

Figure 2. The watershed above Canyon Ferry Reservoir has a total drainage area of 15,904 mi^2 and a sediment-contributing drainage area of 10,214 mi^2, shown as the area outside of the regulated watershed shaded red (U.S. Geological Survey, 2019).

2.1. Geology, Soils, and Land Cover

The surface geology of the watershed drainage area consists primarily of sedimentary, igneous, unconsolidated, and metamorphic rock (Figure 3). Land cover in the watershed comprises mostly evergreen forest, shrubs, and grasslands.

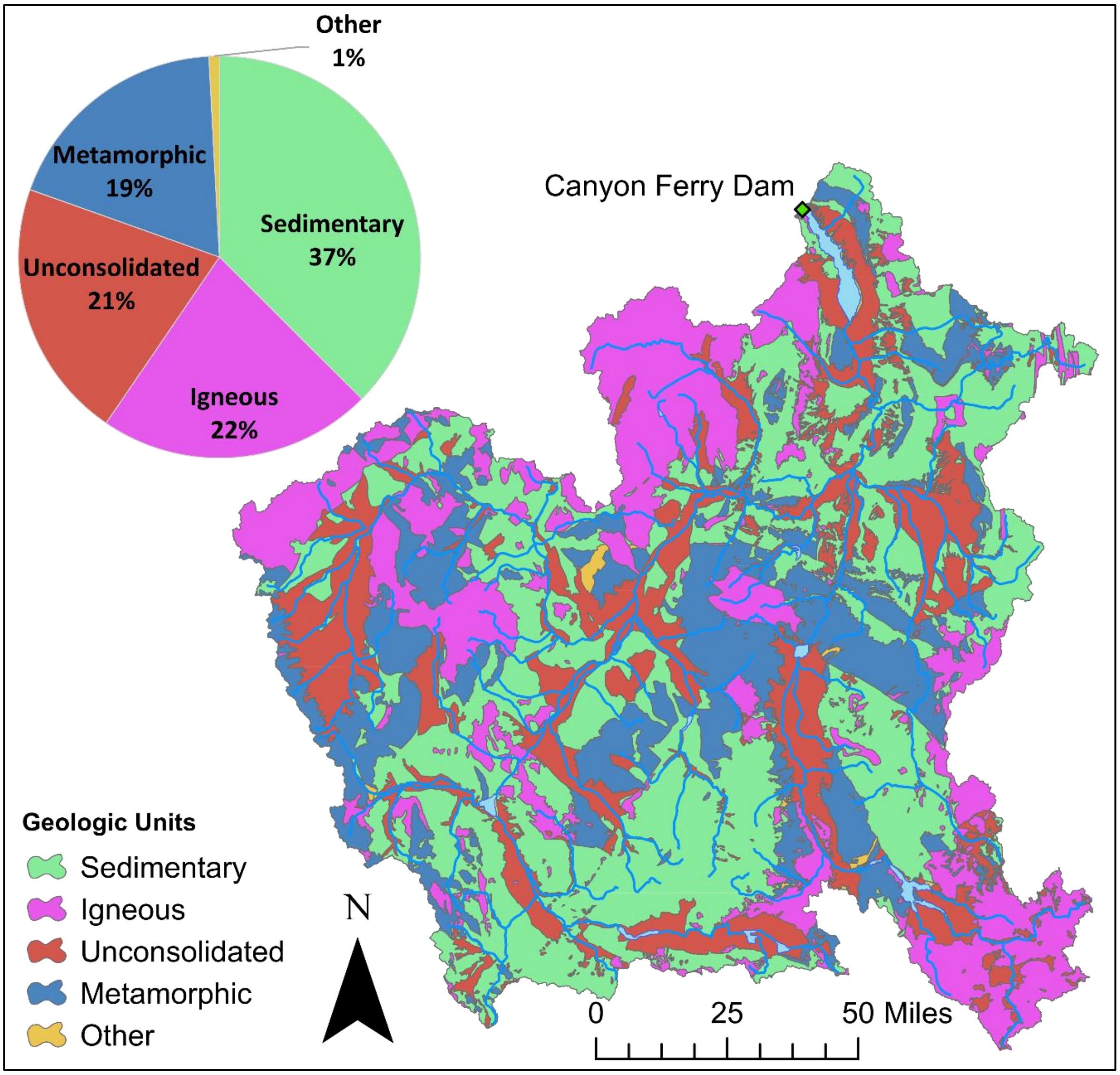

Figure 3. The surface geology in the water watershed above Canyon Ferry Reservoir (from Horton, J.D., 2017).

2.2. Climate and Runoff

Monthly average temperatures and total precipitation show higher temperatures and precipitation in late-spring to early-summer, based on data from the period of record for Townsend weather station (Figure 4). Winter lows average below freezing and summer maximum temperatures average about 70 degrees Fahrenheit (°F). Average monthly rainfall is greatest in June at approximately 2 inches per month.

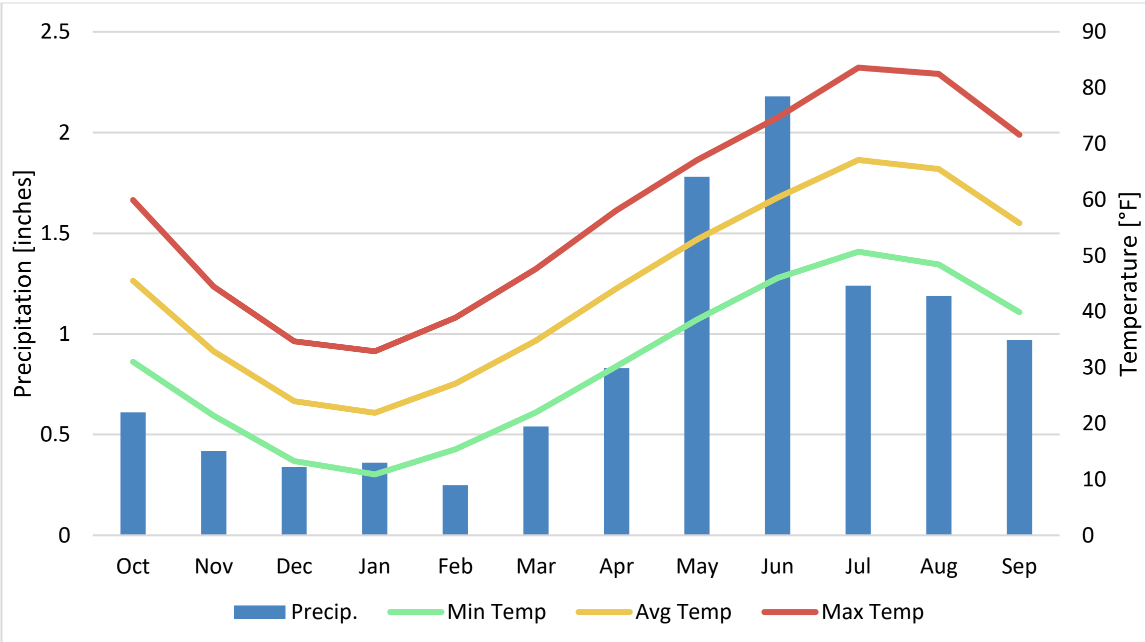

Figure 4. Mean monthly precipitation and temperature by water year in the Townsend station (NOAA) Web Data source: https://nowdata.rcc-acis.org/tfx/

Reservoir inflows are primarily from the Missouri River. The runoff is primarily from snowmelt, with the largest inflows occurring in the early summer. Based on Hydromet calculated inflow data, the mean annual inflow to Canyon Ferry Reservoir is 5135 feet^3/s or 3,720,208 acre-feet/year (Figure 5). Comparison to the U.S. Geological Survey (USGS) stream gage records available, which represents 92 percent of the total contributing drainage area, shows that the USGS streamflow data and Hydromet calculated inflow data agree well (Table 1). Annual peak flows for the Missouri River at Toston (USGS 06054500) are presented in Figure 6. The ratio of reservoir storage capacity to the mean annual runoff is approximately 1.9. This means that, when full, the reservoir stores a water volume equivalent to 681 days of mean annual inflow.

Table 1. Reservoir Inflow Streams with USGS gages.

USGS Stream Gage		Drainage Area (mi^2)	Mean Annual Runoff (cfs)	Period of Record
Name	Number			
Missouri River at Toston	06054500	14,641	4,998	1942-present (data from prior to 1942 were omitted)
Crow Creek near Radersburg Montana	6055500	77.9	48	1920-1929, 1967-1971, *not included in analysis*
Totals		14,538.9	5,046	

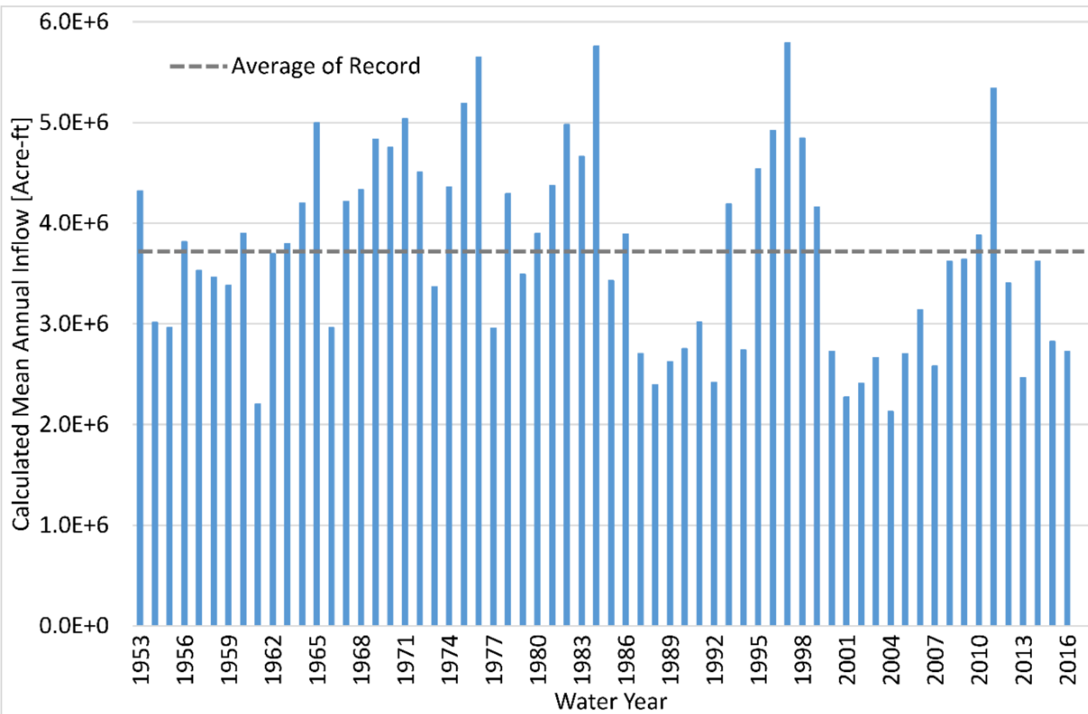

Figure 5. Calculated mean annual inflow to Canyon Ferry. Data web source: www.usbr.gov/gp/hydromet/cfr.html.

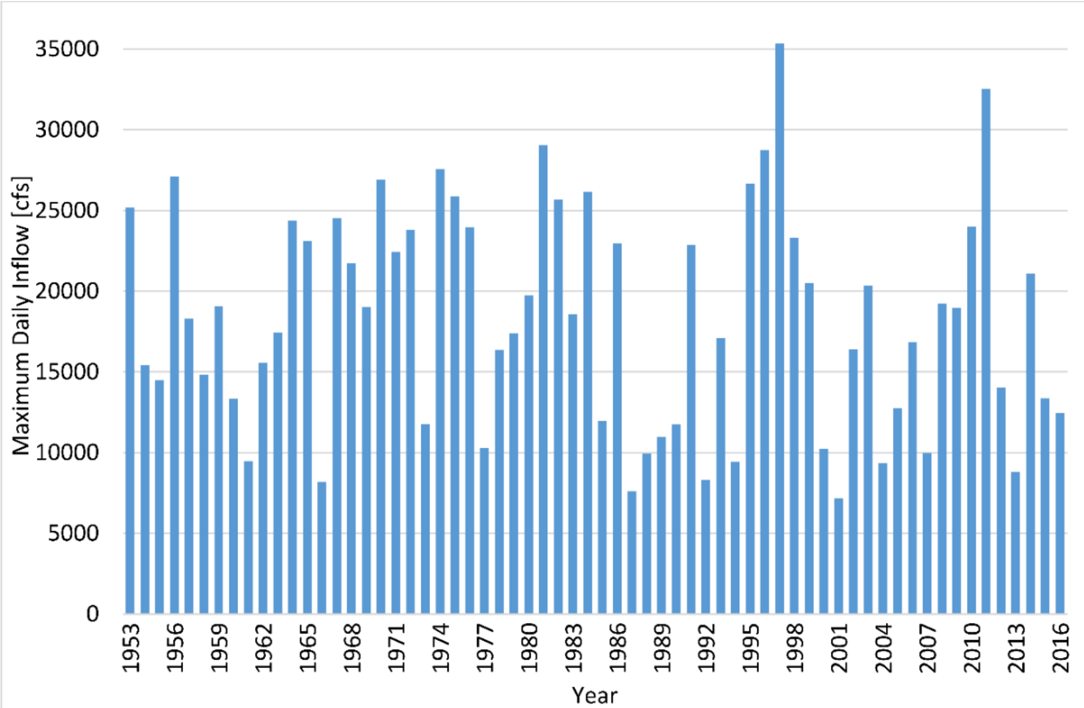

Figure 6. Maximum calculated daily inflow for each year into Canyon Ferry Reservoir. Derived from Hydromet calculated mean daily inflows (www.usbr.gov/gp/hydromet/)

2.3. Dam Operations and Reservoir Characteristics

Canyon Ferry Dam is a 225 feet high concrete gravity dam. The dam began storing water in 1953. As a multi-use project, the Canyon Ferry project produces power while providing flood protection, irrigation, and recreation. The spillway crest elevation is 3,766 feet and flood control storage elevations are from 3,797 feet to the top of flood control at 3,800 feet. Constructed in 1978, the four dust abatement ponds at the upstream end of the reservoir and range in elevation from 3,780 to 3,800 feet. The joint use elevations are between 3,770 feet and 3,797 feet. The active conservation storage is between 3,770.0 feet and 3,728.0 feet. The inactive conservation is between 3,728.0 feet and 3,650.0 feet. The dead storage is below elevation 3,650 feet.

The historic reservoir water surface elevations show that Canyon Ferry Reservoir fills to near full conditions regularly (Figure 7). Annually, reservoir water surface typically fluctuates approximately 15 feet.

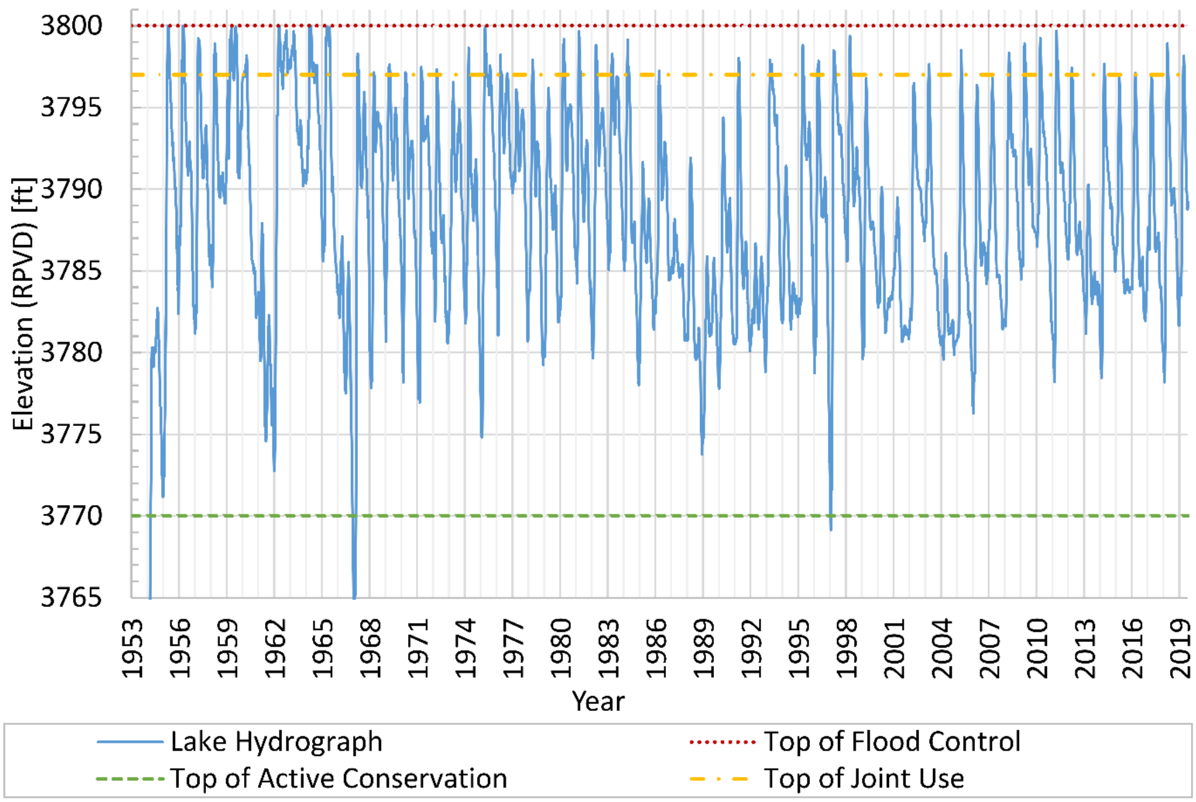

Figure 7. Historic Canyon Ferry water surface elevations (RPVD). Data web source: www.usbr.gov/gp/hydromet/cfr.html.

The current Canyon Ferry Reservoir inundated a small dam built in 1889, located near a large plateau that forms Cemetery Island, approximately 1.25 miles upstream of the Canyon Ferry Dam (Figure 8). The reservoir is widest at the upstream end near the Silos campground and narrowest at the location of the old dam, near Cemetery Island (Figure 8). Dust abatement ponds were constructed in 1978 to aid in dust accumulation in the nearby town of Townsend, Montana. The construction of these ponds led to some change to Canyon Ferry Reservoir capacity above elevations 3,780 feet.

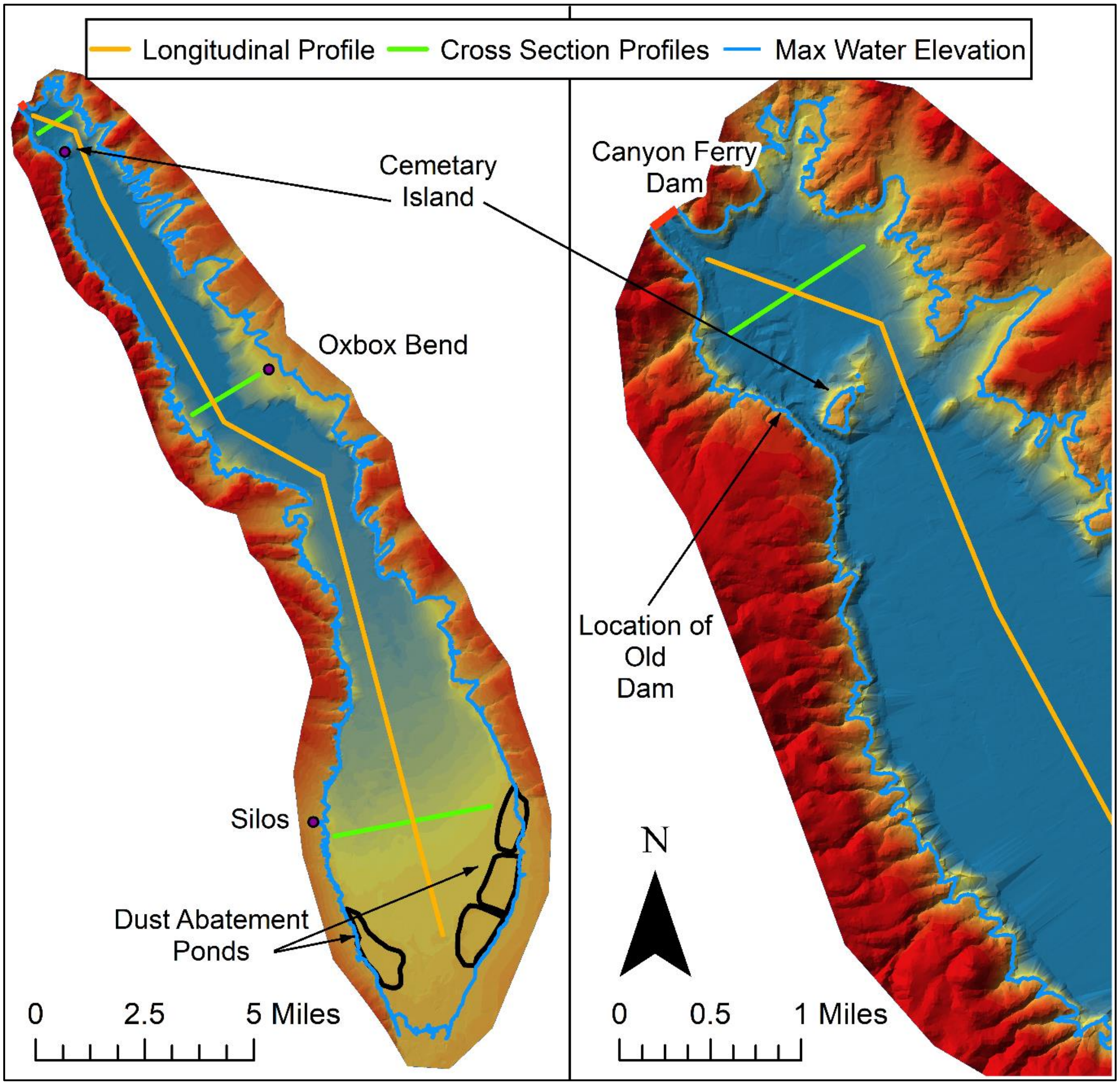

Figure 8. The 2016 surface of Canyon Ferry Reservoir on left with a close-up of the near-dam area on right. The reservoir extent is shown as maximum water surface elevation (3,800 feet) or top of flood pool (blue line). Longitudinal profiles (red) and representative cross-sections (green), dust abatement ponds (black) are shown. The location of the historic dam is also highlighted.

3. Previous Reservoir Surveys

Prior to dam closure and initial reservoir filling, a survey was likely conducted in 1953 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, a plane table and level survey would have likely been the survey methods to develop the original surface during this time period. In 1984, the original 1953 surface area and storage capacity data were adjusted to remove the area of the construction of the dust abatement ponds (Reclamation, 1987). The area capacity tables were updated using the EACAP program using the spline method (page 11, Table 1, columns 10 – 14; Reclamation, 1998). In the 1997 survey report, these values were adjusted again using Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985) to match the 1997 survey methodologies. The final 1953 surface area and capacity data from the ACAP85 program were used in the 97 report and this report to compare sedimentation below the bottom of the dust abatement ponds and dikes, elevation 3,780 feet (page 13, which is Table 2 however there is no Table number on this Table, but with investigation Reclamation has determined based on language in the 1997 Report this is Table 2, columns 2 and 3; Reclamation, 1998).

Reclamation surveyed Canyon Ferry Reservoir in August of 1997 (Reclamation, 1998). The survey used a single beam echosounder and differential Global Positioning System (GPS) to continuously measure depths along pre-determined range lines (cross-sections) across the reservoir. Above water survey data consisted of 1996 photogrammetry and some project features were adjusted using USGS 24k Quadrangle map contours. Above water and bathymetric survey data were combined to create a bottom surface. A 5-foot contour interval map was produced from the 1997 survey to compare the adjusted 1953 survey to the 1997 survey and analyze capacity and sedimentation.

The original 1953 and 1997 reservoir surveys are summarized in Table 2. Please refer to the 1997 report for more detailed information regarding survey methodology and results. Neither the 1953 nor the 1997 areas and capacities account for the dust abatement ponds, and as such, comparisons of sedimentation between 2016 survey and previous surveys are limited to elevations below 3,780 feet.

Table 2. Previous Bathymetric Reservoir Surveys.

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1953	Full	Photogrammetry	None	Photogrammetry
1997	Full	Range-line	Single Beam	Photogrammetry

4. Methods Summary

For the 2016 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD 1983) State Plane (horizontal) coordinates, Montana (FIPS 2500), US survey feet and North American Vertical Datum 1988 (NAVD 1988), Geoid 12A, US survey feet elevations. During processing, all bathymetry and GPS measurements were converted to RPVD for Canyon Ferry. The RPVD at Canyon Ferry Reservoir was determined from RTK GPS measurements of the water surface elevations and compared to the gage elevations at the dam. The RPVD was determined to be 3.15 feet lower than NAVD 1988 (Geoid 12A).

The difference between NGVD 1929 and NAVD 1988 at Canyon Ferry 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 3.23 feet lower than NAVD88.

A complete bathymetric survey was conducted during July 7 – 15 and August 17 – 19, 2016. For the main reservoir, an 18-foot aluminum boat with multibeam sonar was used to continuously measure water depths. In addition to the survey of the main reservoir, the dust abatement ponds were surveyed in 2016 and included in all surface area and capacity calculations. Depth of water, access, and safety were a concern for the aluminum boat in the dust abatement ponds, so a one-person cataraft with a single beam depth sounder was used in those areas. The horizontal position of the moving boat on the main body of the reservoir and dust abatement ponds was continually tracked using a combination of RTK and autonomous GPS. A map of the data points collected is presented in Figure 9.

Four main differences between the 1997 and 2016 reservoir survey and processing methodology include:

- The dust abatement ponds were not constructed at the time of the 1953 survey and were not included in the 1997 survey analysis even though they were surveyed. As such, the dust abatement ponds were not included in the previous two surveys. The 2016 survey collected measurements in the dust abatement ponds and those surface areas and storage capacities were included in the analysis.
- The 1997 survey was unable to collect measurements near the dam, therefore reservoir bottom elevations were estimated based on USGS Quadrangle contour maps.
- The 1997 survey used a single-beam echosounder while the 2016 survey used a multi-beam echosounder. Multi-beam echosounders provide a wider swath of data and more data points per area than single-beam echosounders, resulting in more complete coverage of the reservoir bottom.
- The 1997 survey collected data along range lines (predetermined lateral lines) whereas the 2016 survey collected data along a combination of range lines and longitudinal lines.
- The recomputed 1953 area-capacity values developed in the 1997 survey report were used for comparison in both the 1997 and the 2016 surveys at elevations below 3,780 feet.

Appendix A provides more details of the 2016 hydrographic survey methods. The 2016 bathymetric data were combined with above water surface contours generated from aerial data obtained from the 1997 bathymetric survey to produce a digital surface of the reservoir bottom surface (Reclamation, 1998). Above elevation 3,784 feet, no change in bottom topography was assumed and surface areas from the 1997 survey analysis were used and assumed to remain unchanged for the surface area and storage capacity tables. This assumption was made because measurements between the 1997 survey and 2016 showed little change. Shoreline bathymetric values align spatially very well with boat paths suggesting that the photogrammetry was able to attain near shoreline data. Also, historical aerial photos show very little change to the delta in the years from 1997 to present. Surface areas at 1-foot contour intervals were computed using Geographic Information System (GIS) software and a computer program was used to produce the reservoir surface area and capacity tables at 0.01-foot increments. Appendix B provides more details about the methods used to generate surface area and storage capacity tables.

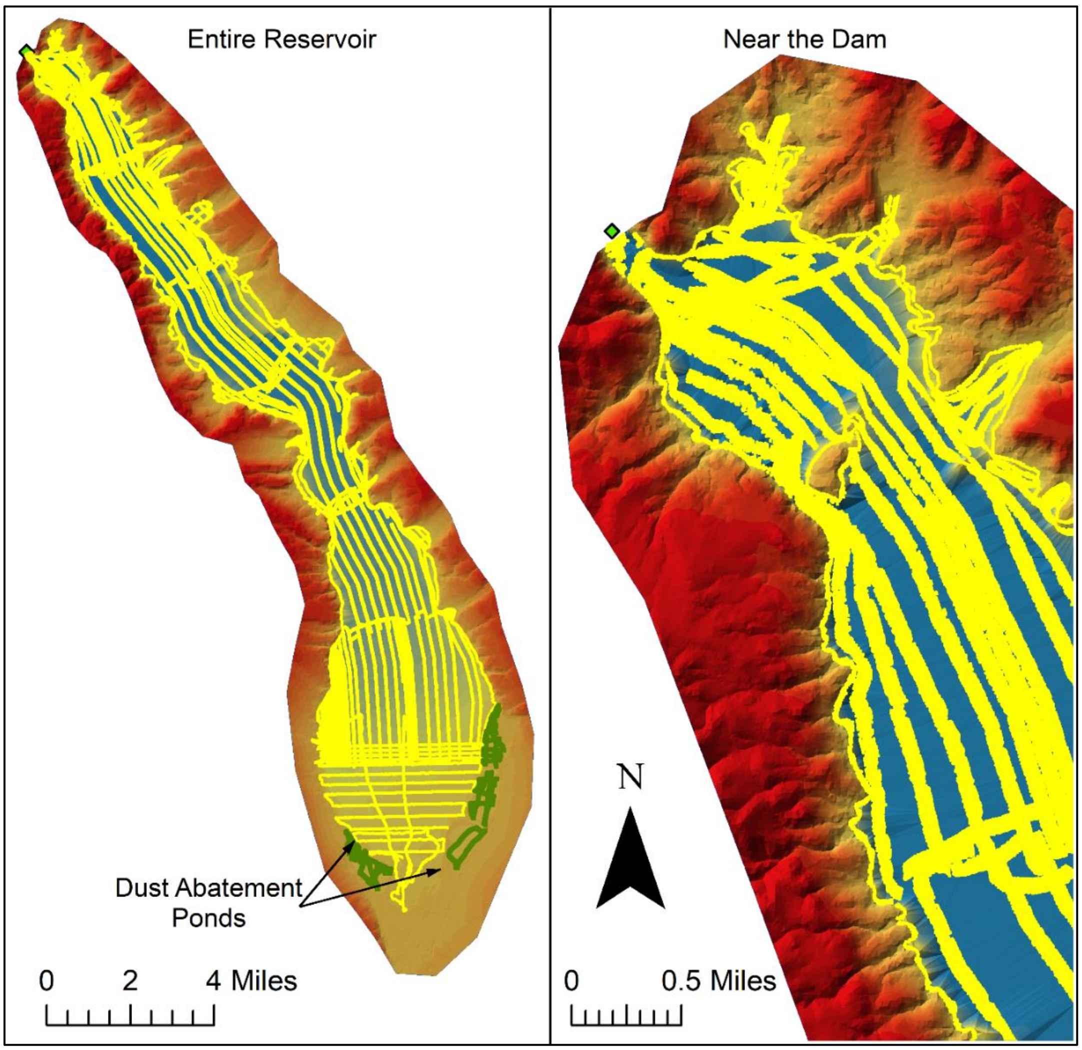

Figure 9. Map of 2016 bathymetric survey data coverage in the main reservoir (yellow) and in the dust abatement ponds (green).

5. Reservoir Surface Area and Storage Capacity

> *The actual surface areas and storage-capacity volumes for above-water elevations may be different than the areas measured in 1997 because of delta sedimentation, shoreline erosion, or use of less-accurate methodology.*

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Reclamation, 2020). Plots of the 2016 area and capacity curves are presented in Figure 10 along with curves from 1953 (recomputed in 1984 and 1997) and 1997 surveys. For the 2016 survey, area and capacity curves are based on the bathymetric (below-water) survey up to 3,784 feet elevation, except at the dust abatement ponds. Curves above this elevation are based on photogrammetry developed in the 1997 reservoir survey (Reclamation, 1998). A comparison of these curves indicates there is nearly uniform sedimentation throughout the reservoir. Contour maps of the entire reservoir are presented in Appendix C.

Differences in survey methodology led to some differences between the 1997 and 2016 area and capacity curves. For instance, capacity at elevations below the dead storage of 3,650 feet increased from 1997 to 2016. This is likely not the reservoir bottom scouring, but an artifact of differing survey methodologies. The 1997 survey estimated bottom elevations using USGS Quadrangle contour maps. The 2016 survey measured the lowest reservoir elevation near the dam at 3,614 feet whereas the 1997 survey estimated the bottom elevation of 3,625 feet. Also, the area values above 3,780 feet were adjusted for the 1953 and 1997 surveys to exclude the dust abatement ponds, which were included in the 2016 survey. Therefore, it is not recommended to compare capacity between the three surveys for values higher than 3,780 feet.

According to 2016 survey results, the reservoir water surface elevation 3,784 feet (limit of 2016 bathymetric survey), which is 5 feet below water at the time of survey, the reservoir surface area was 30,422 acres with a storage capacity of 1,464,779 acre-feet. At the top of flood control pool elevation (3,800 feet) the reservoir would have a surface area of 35,678 acres and a storage capacity of 1,993,036 acre-feet.

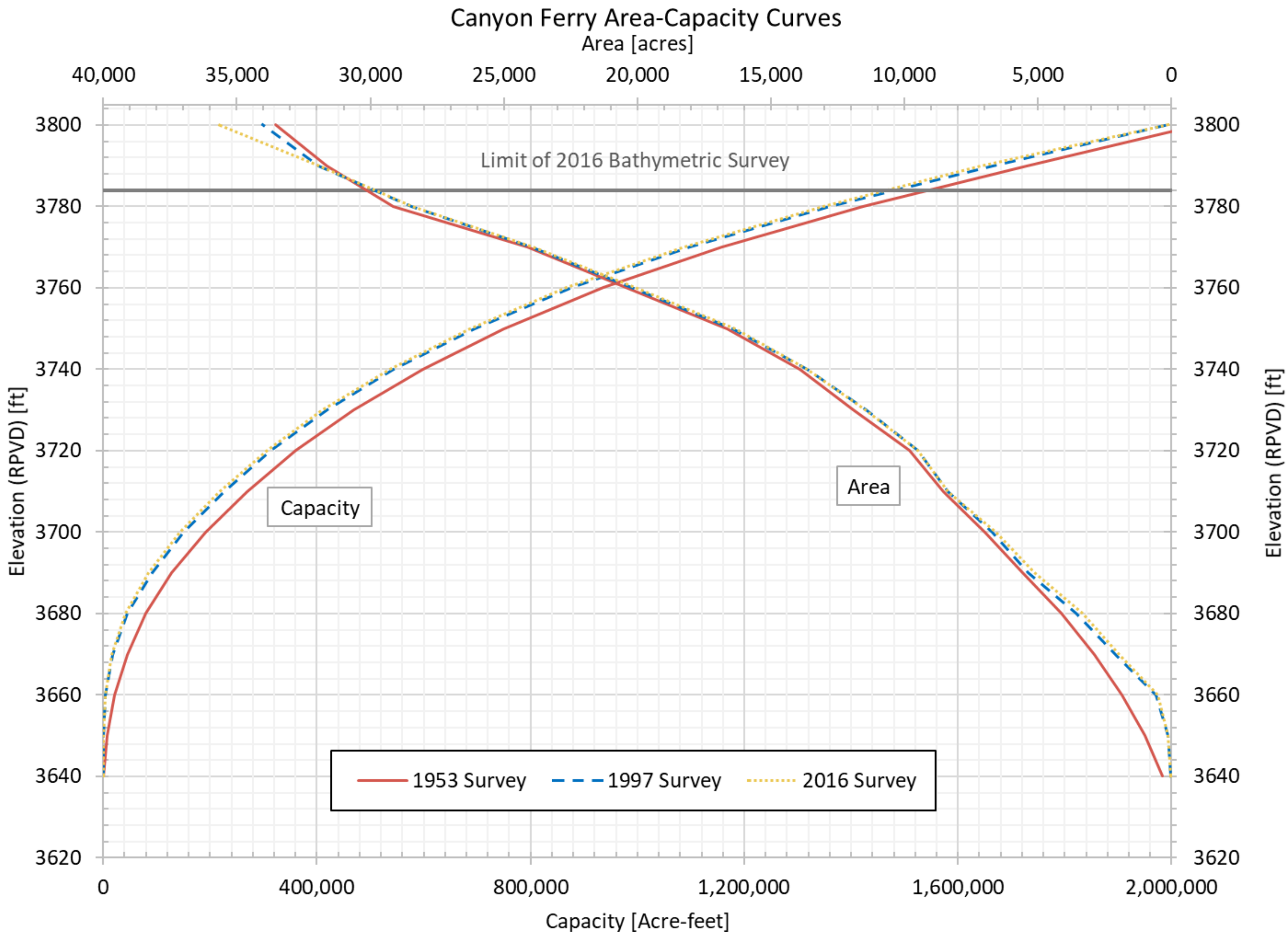

Figure 10. Plot of Canyon Ferry Reservoir surface area and storage capacity versus elevation (RPVD).

Table 3. Elevation versus Area Table (Vertical Datum: RVPD)

Survey date	1953 (ponds excluded) *	1997 (ponds excluded)	2016 (ponds included)
Elevation	Area (acre)	Area (acre)	Area (acre)
3,640	333	32	41
3,650	1,000	144	144
3,660	1,857	581	529
3,670	2,891	2,103	1,954
3,680	4,123	3,572	3,343
3,690	5,573	5,383	5,133
3,700	6,995	6,705	6,576
3,710	8,541	8,354	8,370
3,720	9,798	9,499	9,519
3,730	11,925	11,435	11,470
3,740	13,905	13,643	13,654
3,750	16,622	16,442	16,341
3,760	20,418	20,228	20,082
3,770	24,126	23,964	23,898
3,780	29,125	28,457	28,421
3,790	31,634	31,943	31,891
3,800	33,535	34,048	35,678

Table 4. Elevation versus Capacity Table (Vertical Datum: RPVD)

Survey date	1953 (ponds excluded) *	1997 (ponds excluded)	2016 (ponds included)
Elevation	Volume (acre-ft)	Volume (acre-ft)	Volume (acre-ft)
3,640	833	165	245
3,650	7,500	1,060	1,099
3,660	21,683	4,006	3,679
3,670	45,308	17,934	16,257
3,680	80,248	45,262	41,916
3,690	128,703	90,936	85,533
3,700	191,513	150,519	143,275
3,710	269,243	225,960	218,259
3,720	360,755	314,650	307,142
3,730	469,142	418,444	411,051
3,740	598,108	543,812	536,798
3,750	750,175	693,711	685,598
3,760	935,065	876,516	867,197
3,770	1,157,630	1,097,599	1,087,216
3,780	1,422,153	1,358,973	1,346,750
3,790	1,727,700	1,663,620	1,651,806
3,800	2,052,723	1,992,997	1,993,036

* Values recorded show original design surface area and storage capacity, adjusted to exclude the dust abatement ponds and recomputed in the 1997 Sedimentation Survey report (page 13, which is Table 2 however there is no Table number on this Table, but with investigation Reclamation has determined based on language in the 1997 Report this is Table 2, columns 2 and 3; Reclamation, 1998) using Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985).

6. Reservoir Sedimentation

6.1. Spatial Distribution

The 2016 reservoir bottom surface developed in GIS along with the alignments of a longitudinal profile and representative cross-sections are presented in Figure 8. The longitudinal profile shows that sedimentation is nearly uniform throughout the reservoir, relative to the 1997 survey (Figure 11). No large areas of reservoir sedimentation are observed. There is a high spot measured in both the 1997 and the 2016 survey showing the ridge extending into Cemetery Island near the location of the old dam at about 1.25 miles from the dam. Some of the smaller differences between the two surveys could be artifacts from the differing survey methodologies and likely do not constitute large changes in actual sedimentation.

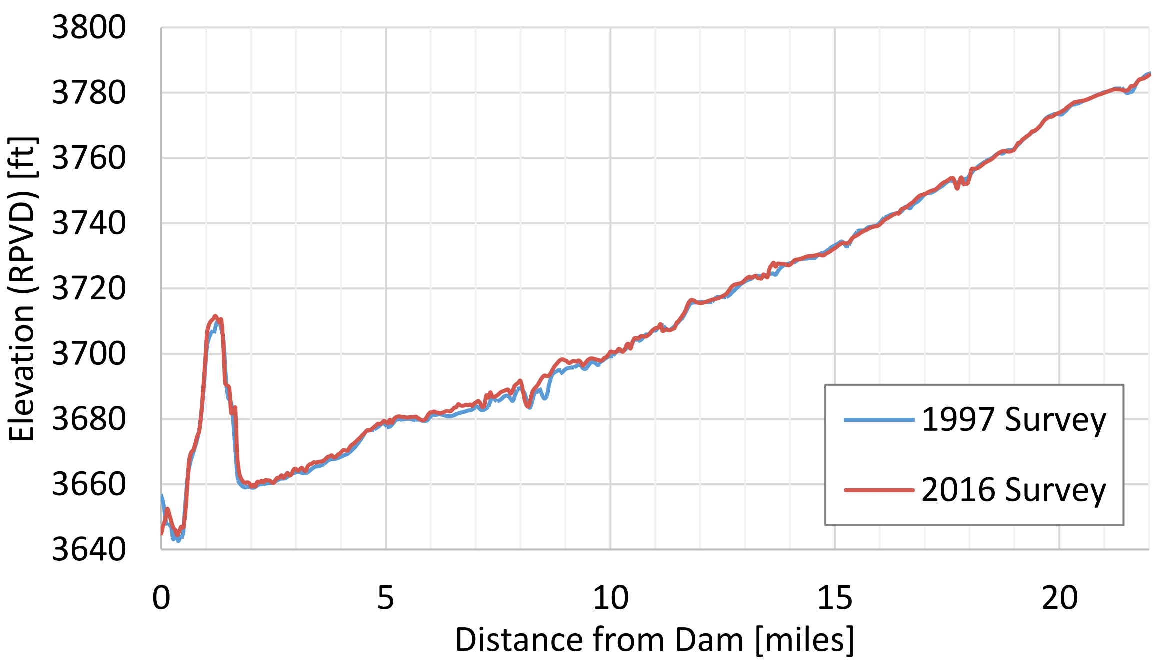

Figure 11. Longitudinal profile of Canyon Ferry Reservoir bottom from the dam to the upstream extent of the reservoir.

Reservoir cross-section plots show the lateral distribution of sedimentation at three locations along the reservoir: between the dam and Cemetery Island (Figure 12), near the reservoir middle at Oxbow Bend (Figure 13), and in the widest section in the upper reservoir at the Silos (Figure 14). Only small changes between the 1997 and 2016 surveys are depicted at these three cross-sections and are likely due to methodology differences and processing interpolation error.

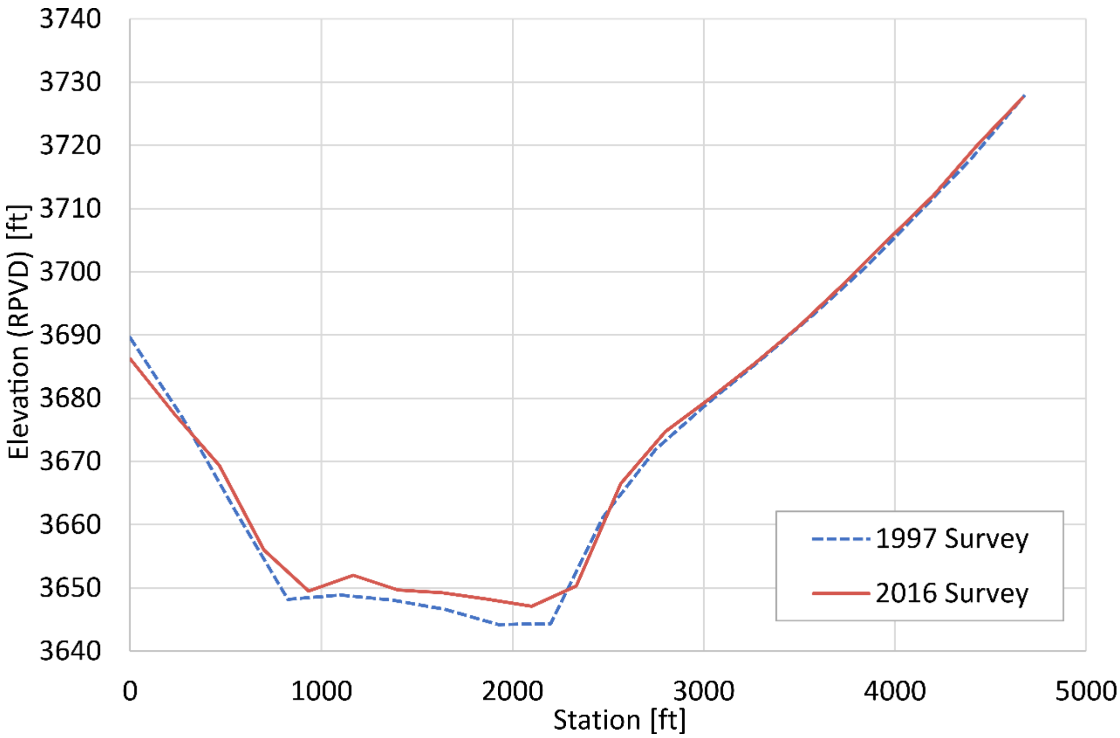

Figure 12. Representative cross-sections between Canyon Ferry Dam and approximately 0.5 miles downstream of Cemetery Island. Sedimentation has formed relatively evenly across the surface.

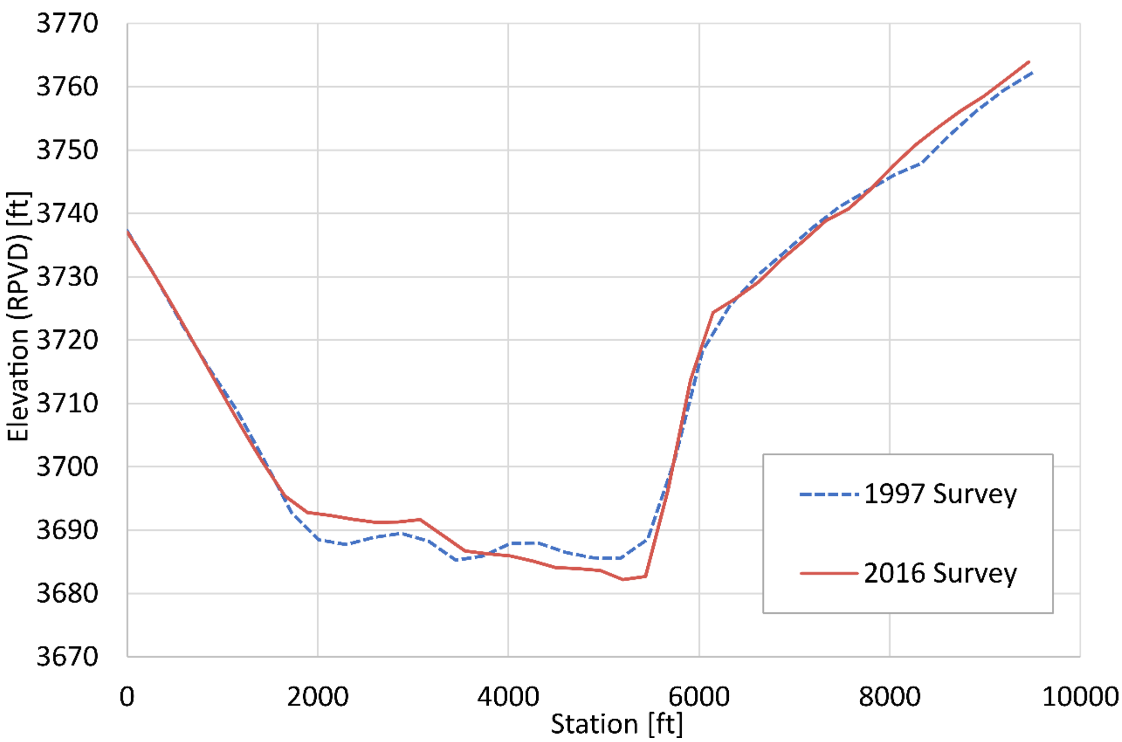

Figure 13. Representative cross-sections near the middle of the reservoir at Oxbow Bend. Sedimentation has formed relatively evenly across the surface.

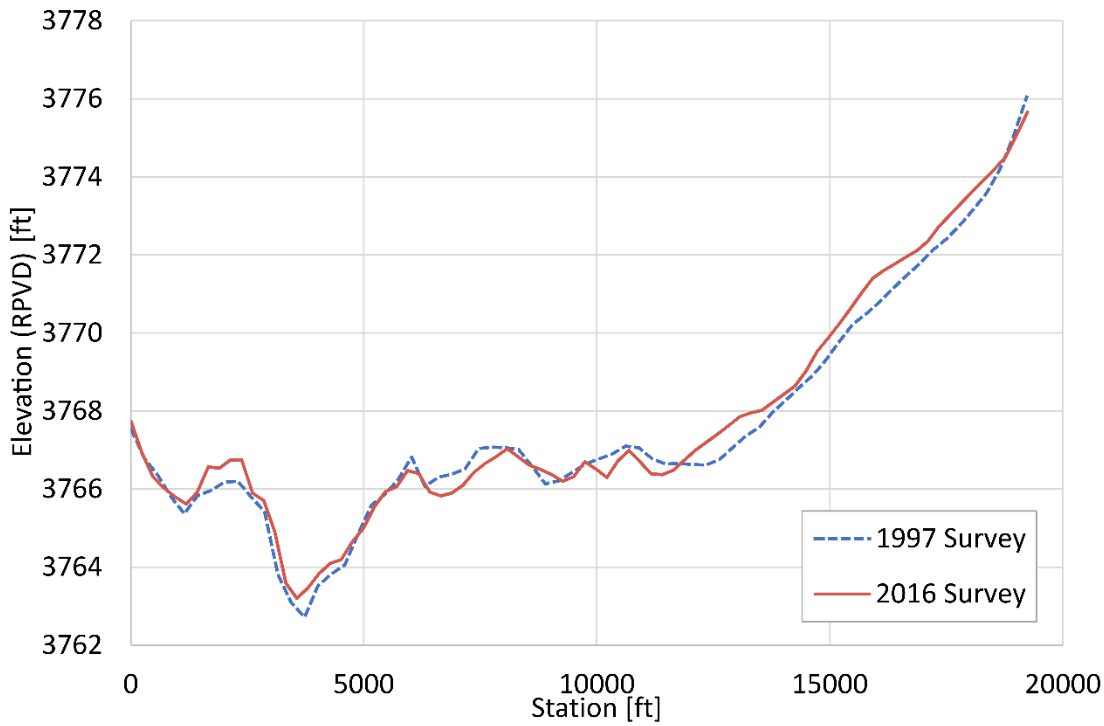

Figure 14. Representative cross-sections at the Silos near the delta area. Sedimentation has formed relatively evenly across the surface.

6.2. Sedimentation Trends

The average annual sedimentation rates in the conservation pool between the 44-year period between 1953 and the 1997 survey and the 63-year period between 1953 and the 2016 survey were 1,364 and 1,117 acre-feet/year, respectively. This might suggest a slight decline in annual average sedimentation rates from 1997 to 2016. The construction of the Clark Canyon Dam in 1964 likely affected sediment trapping upstream of Canyon Ferry. In the 19-year period between the 1997 and the 2016 surveys, the average annual sedimentation rate dropped considerably to 546 acre-feet/year. These are small differences in average annual sedimentation rates, much of which could be attributed to differing survey methodologies and processing interpolation errors. Therefore, it is recommended to consider the rate for the 63-year period between the 1953 survey and the 2016 of 1,117 acre-feet/year to be more accurate.

The total cumulative sedimentation from 1953 for the 1997 and 2016 surveys were calculated as 60,031 acre-feet and 70,415 acre-feet, respectively.

7. Conclusions and Recommendations

7.1. Survey Methods and Data Analysis

The 2016 bathymetric survey, combined with 1996 photogrammetry data of the above-water topography, has been used to produce a digital surface of the reservoir bottom. The bathymetric survey is limited to elevations below 3,784 feet, above which is represented by contours obtained from the 1997 survey. The use of less recent photogrammetry data in combination the 2016 bathymetric data will likely result in some interpolation error between the two datasets, especially in areas with little overlap. The interpolation error was minimized by clipping the photogrammetry data as close as possible to 2016 bathymetric data. Also, where overlap did exist, the two datasets agreed quite well.

The adjusted 1953 and 1997 surveys did not include the dust abatement ponds. All comparisons between the 2016 survey and previous surveys were limited to below elevation 3,780 feet. Comparisons between different surveys is made more difficult with differing methodologies. For example, the 1997 survey did not collect measurements in the dust abatement ponds or the near dam bottom elevations; therefore, survey-to-survey comparisons in these areas are less accurate. Similarly, interpolation errors may occur for areas where the two surveys do not overlap.

Reservoir surface areas were computed from the digital surface at 1-foot intervals to determine the 2016 storage capacity. Surface area and storage capacity were then interpolated at 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but also the differences in survey methods. The latest surface area and storage capacity curves compare reasonably well with the original curves and with curves from the 1997 survey. The use of modern survey methods (multibeam depth sounder) have produced a more accurate and precise digital surface of the reservoir bottom than past surveys using older methods (single beam). It is difficult to develop a meaningful analysis of the sedimentation trends without accurate survey data of the original 1953 reservoir topology.

7.2. Sedimentation Progression and Location

Over the span of 63 years, sedimentation has filled in 5.3 percent of the original storage capacity, below elevation 3,780 feet. Sediment is likely still depositing above elevation 3,780 feet, but the volume of deposition since 1953 is unknown due to the differences in analysis methods between the surveys. Surface areas and storage capacities computed during analysis of the 2016 survey data are considered accurate up to the top of the bathymetry data (elevation 3,784 feet, RPVD). However, most of the deposition appears to be located below this elevation based on analysis of past data. The 2016 reservoir survey indicates that most of this sedimentation is uniform throughout the reservoir. Sedimentation has also deposited near the dam in the lowest portions of the reservoir, resulting in 14 percent of the original dead storage capacity remaining as of

2016. The lowest dam outlet may not be reliable after the dead storage has filled with sediment because of potential for deposition of logs and sediment on the trash rack.

7.3. Recommendation for Next Survey

Based on the past rates of sedimentation, the next survey of Canyon Ferry Reservoir is recommended within the next 20 years, 2036. Extreme hydrologic events or considerable alterations to the watershed (e.g. wildfire, forestry operations, etc.) that could affect sediment transport to the reservoir may suggest a re-survey be conducted prior to 2036. Any future surveys should maintain consistency with the 2016 methods and survey the dust abatement ponds for inclusion in surface area and storage capacity calculations. To improve accuracy of above water topographic data, it is recommended that Light Detection and Ranging (LiDAR) flights be flown in conjunction with the next planned survey and when the reservoir water surface elevation is expected to be low. Steep areas such as near the shoreline or the dam prove most difficult to interpolate. So, extra care should be taken to achieve the best coverage in these areas. It is also recommended to collect sediment samples to better understand the nature of the sediment deposits of the reservoir.

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Appendix A — Hydrographic Survey Equipment and Methods

Appendix A — Hydrographic Survey Equipment and Method

The 2016 bathymetric survey was conducted from July 7 – 15 and August 17 – 19, 2016. During this period, reservoir water surface elevations varied between 3,789 and 3,796 feet .

The survey was conducted along a series of predetermined cross-section, longitudinal, and shoreline survey lines (Figure 9). The survey lines were spaced closely enough so there would be overlapping coverage from the multibeam depth sounder. Where overlapping coverage was not obtained, spacing was maintained such that linear interpolation of multibeam or single beam data between survey lines would be adequate.

The main reservoir survey employed an 18-foot, flat bottom aluminum Wooldridge boat powered by an outboard jet (Figure 15). Reservoir depths were measured using 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, and
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data.

Figure 15. Wooldridge boat with 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.

GPS survey instruments were used to continuously measure the position and heading of the survey vessel as well as ground control points on shore. Survey boat positions were measured using a combination of RTK and autonomous GPS techniques. Although RTK positions are more precise than autonomous positions, where RTK was not practical, autonomous horizontal measurements were determined to be sufficiently accurate for a reservoir the scale of Canyon Ferry. Vertical control was established by subtracting measured depths from water surface elevations recorded at the dam gage during the bathymetric survey, resulting in reservoir bottom elevations in RPVD.

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

The HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the user selected coordinate system. The multibeam depth sounder generated millions of data points. A small portion of depth measurements did not represent the reservoir bottom and these data were deleted during the post processing. Processed survey data were sampled at 5-foot square cells. For each cell, the reservoir bottom elevation was assigned equal to the median elevation of all available data points within that raster cell. The use of the median value reduced the influence of the highest and lowest elevations within the cell. A total of 9,296,846 bathymetric data points were used in the final surface.

Due to shallow depths and limited access in the dust abatement pounds, survey crews employed an 8-foot inflatable, one-person cataraft to map those areas. The one-person cataraft is used for shallow, still water. For bathymetric surveys, a portable single beam transducer, data collector, and GPS receiver are mounted to the pontoon raft which is powered by an electric trolling motor (Figure 16). This system drafts about 8 inches, allowing data collection in extremely shallow water. This raft's compact size allows it to be quickly disassembled and transported from site to site without a trailer.

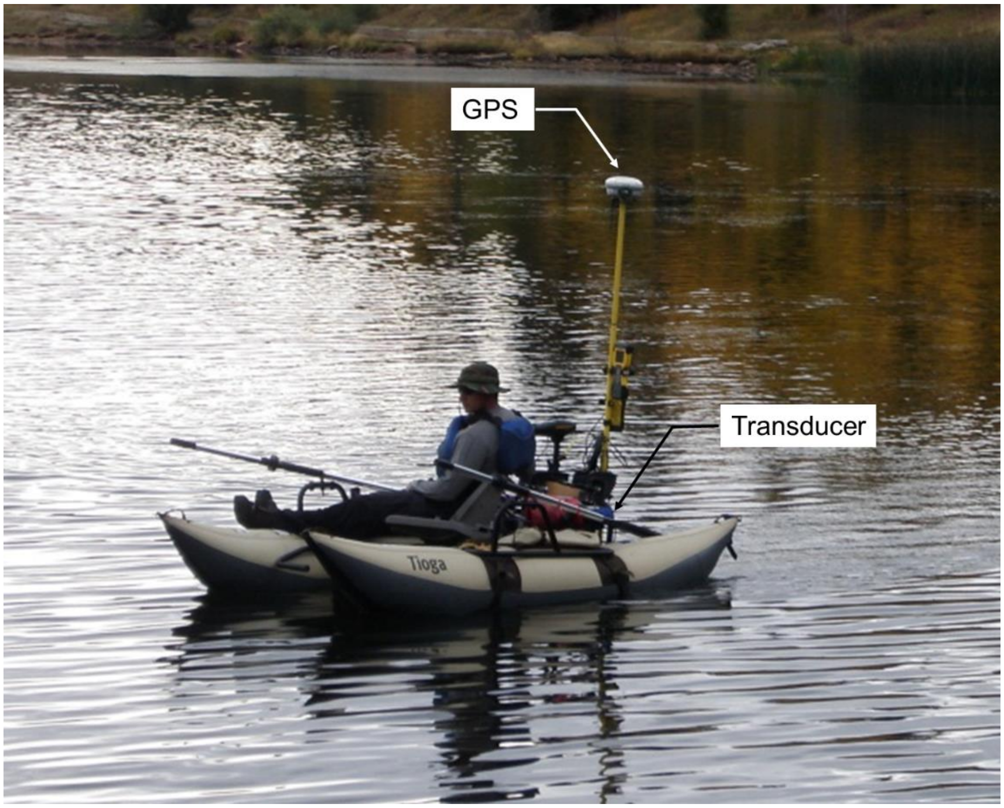


Figure 16. Single-person cataraft with single beam transducer that was deployed on dust abatement ponds at Canyon Ferry.

The position of the one-person cataraft was continuously recorded using RTK GPS. At the same time bathymetry data were being collected, water surface elevations around the perimeter of each pond were measured using RTK GPS. Those water surface elevation measurements were adjusted to match RPVD before subtracting surveyed depths to compute bottom elevations.

When using RTK positioning, the GPS base station was set up on a tripod over a point overlooking the reservoir. 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 17). The base station was powered by a 12-volt battery.

Figure 17. The RTK-GPS base station set-up used during the survey of Flaming Gorge Reservoir in Utah and Wyoming is typical of the set up used for other reservoir surveys.

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

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

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

A digital surface of the reservoir bottom was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Horizontal surface areas were then computed at 1-foot increments, using functions within ArcGIS, for the complete range of remaining reservoir elevations (3,614 feet to 3,800 feet). These reservoir surface areas were then used in Reclamation's Area-Capacity (ACAP) Program, 1985 Version (Reclamation, 1985), to compute the storage capacity at these increments and then interpolate surface areas and storage capacities at 0.01-foot increments between each 1-foot interval.

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

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

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

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

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

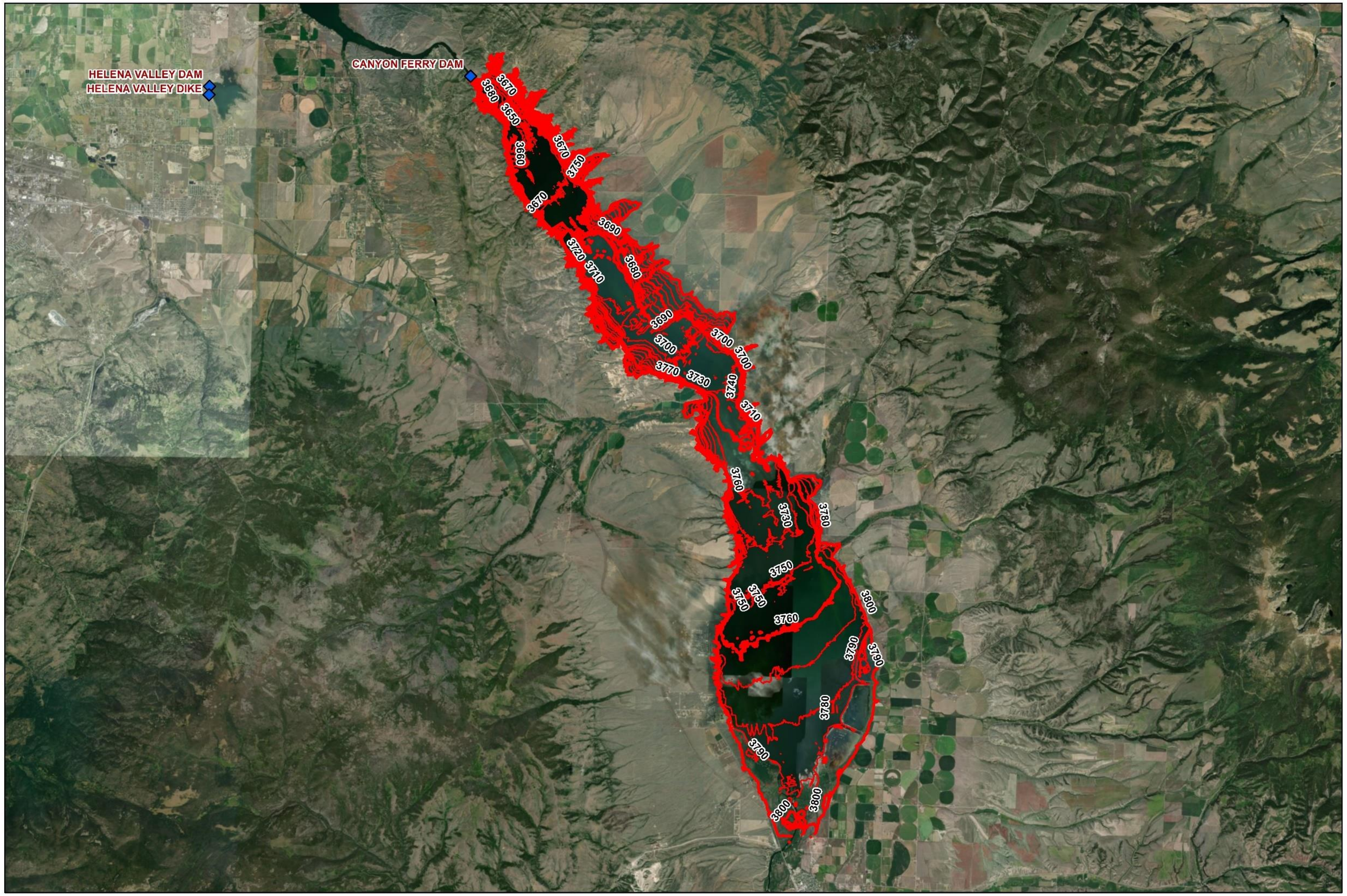
where: S = surface area (acres)

This method ensures that the given surface areas, and corresponding storage capacities, at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in the report (Reclamation, 2016).

The sedimentation volume can be computed by subtracting digital surfaces of the predam reservoir surface from the 2016 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 2016 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 there was no new above water survey.

Appendix C – Contour Maps



Canyon Ferry Reservoir Montana

Elevation Contour Map

Overview Map

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface Elevation Gage at Canyon Ferry Dam Referenced to Reclamation Project Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

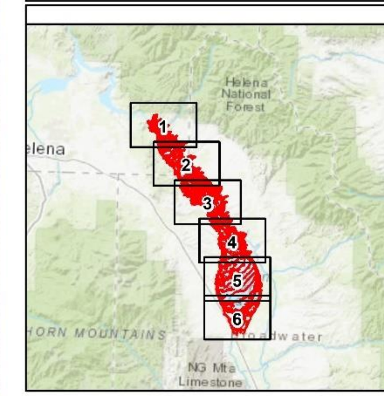
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:170,000

0 12,500 25,000 ft



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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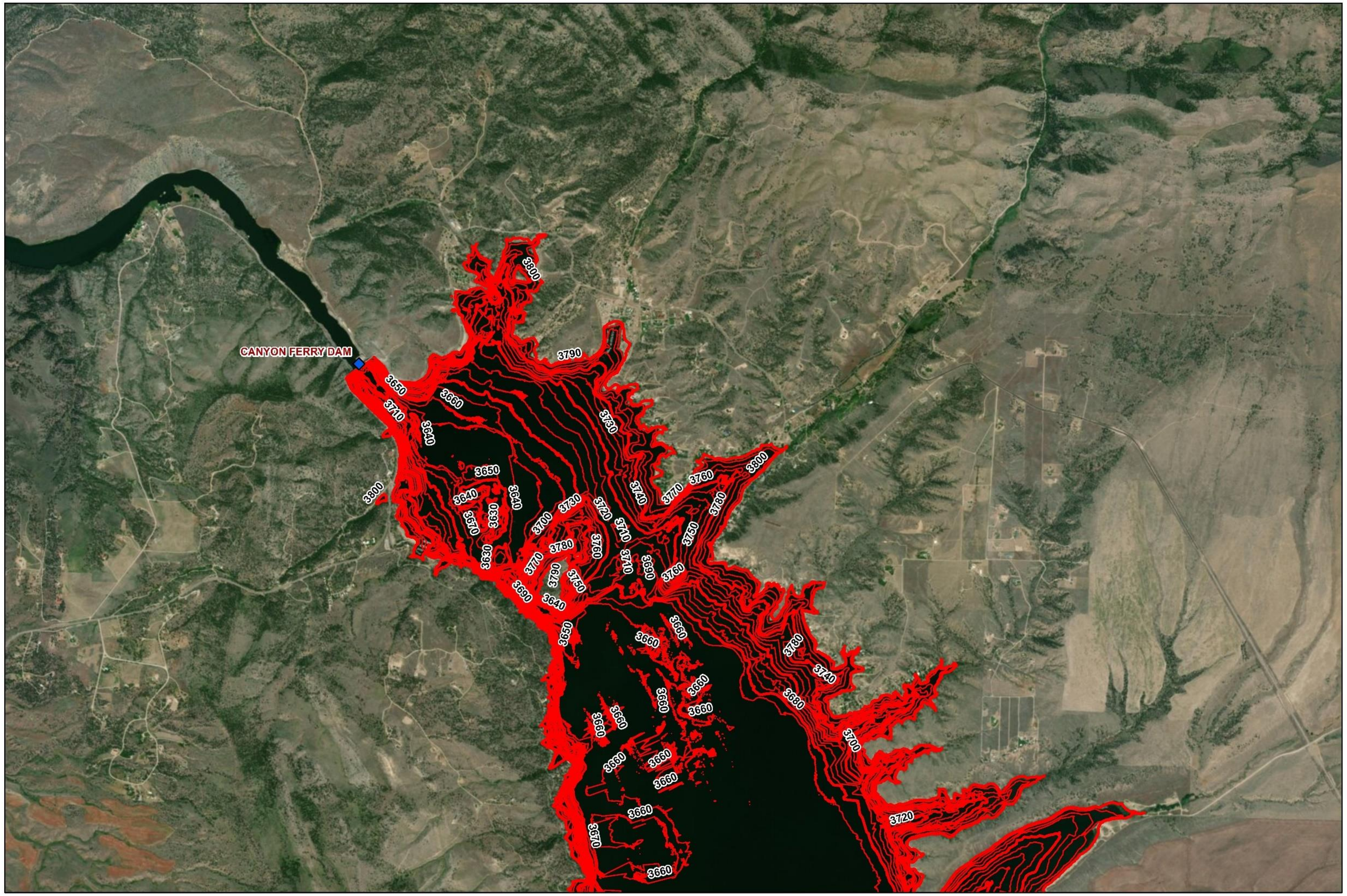


Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 1

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface
Elevation Gage at Canyon Ferry Dam
Referenced to Reclamation Project
Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

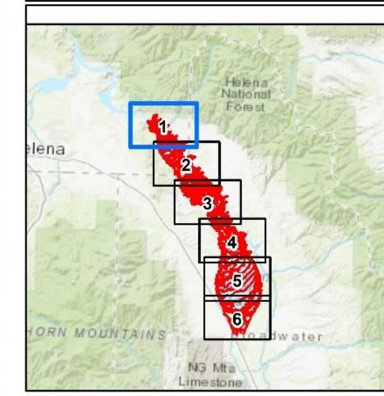
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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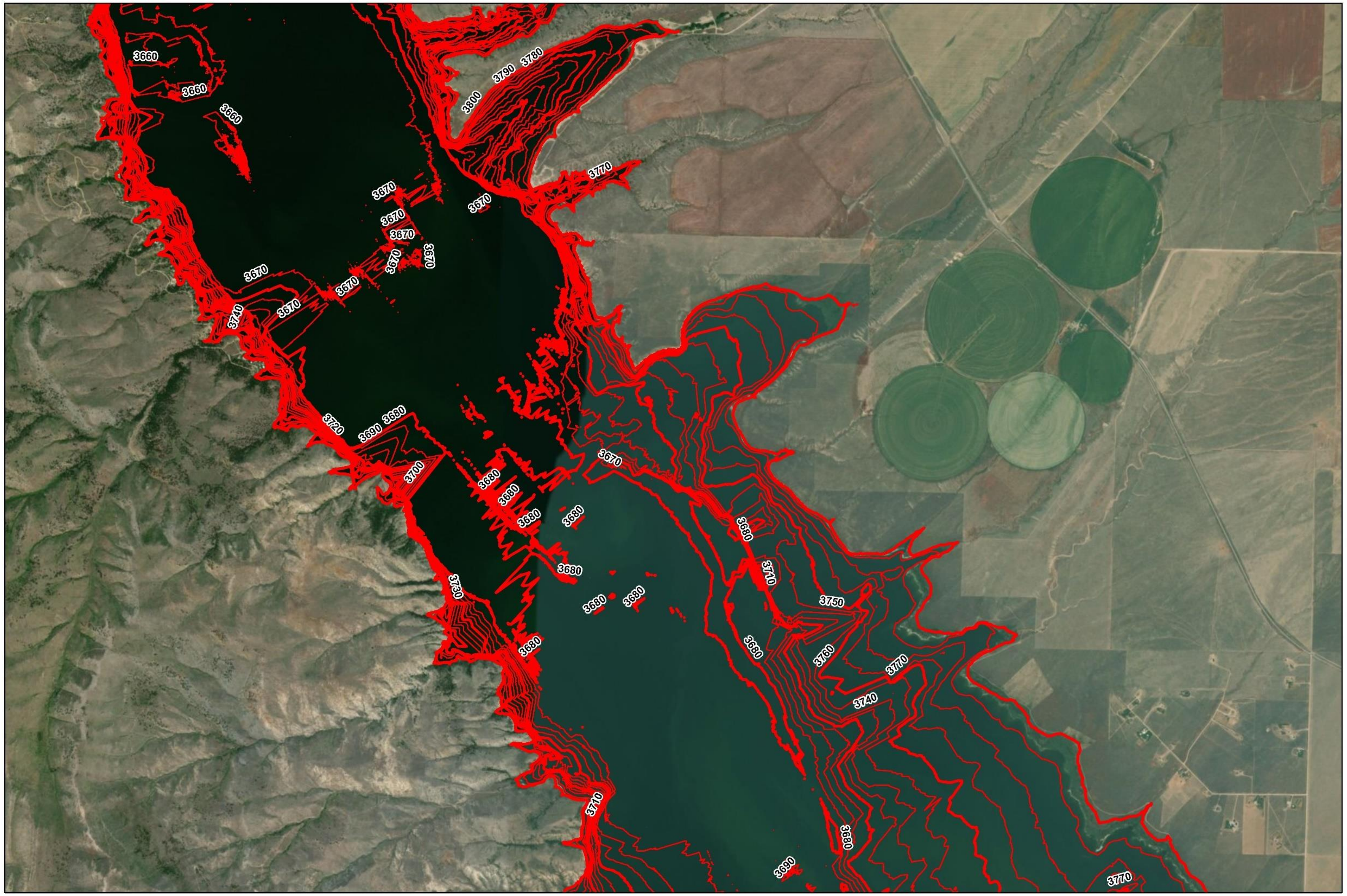


Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 2

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface Elevation Gage at Canyon Ferry Dam Referenced to Reclamation Project Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

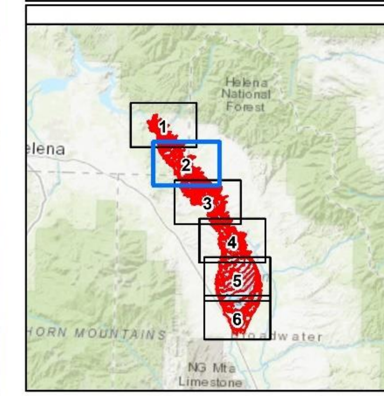
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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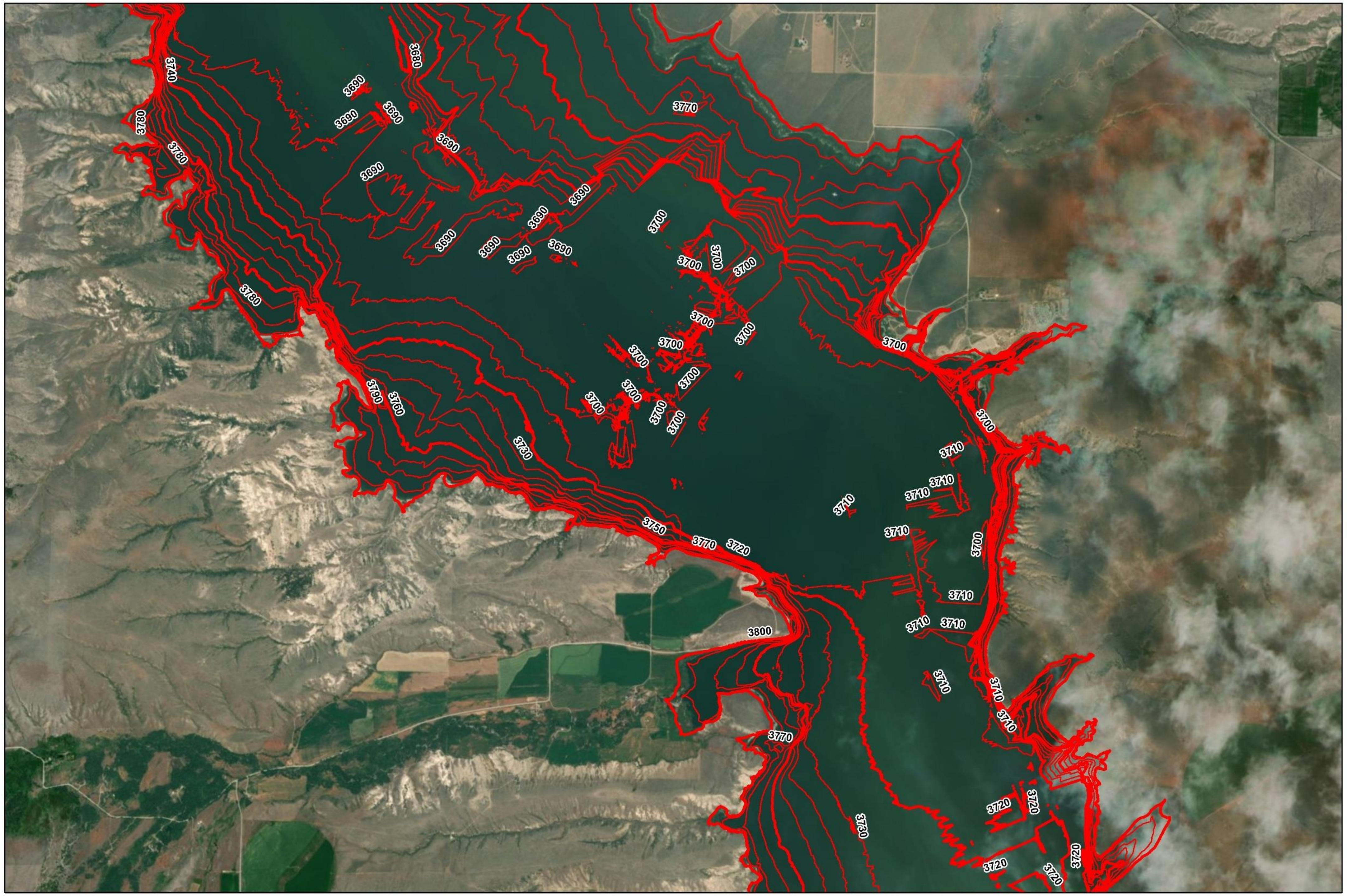


Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 3

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface Elevation Gage at Canyon Ferry Dam Referenced to Reclamation Project Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

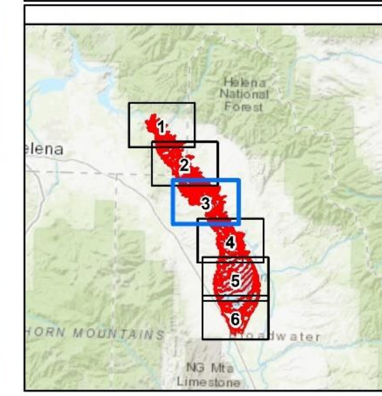
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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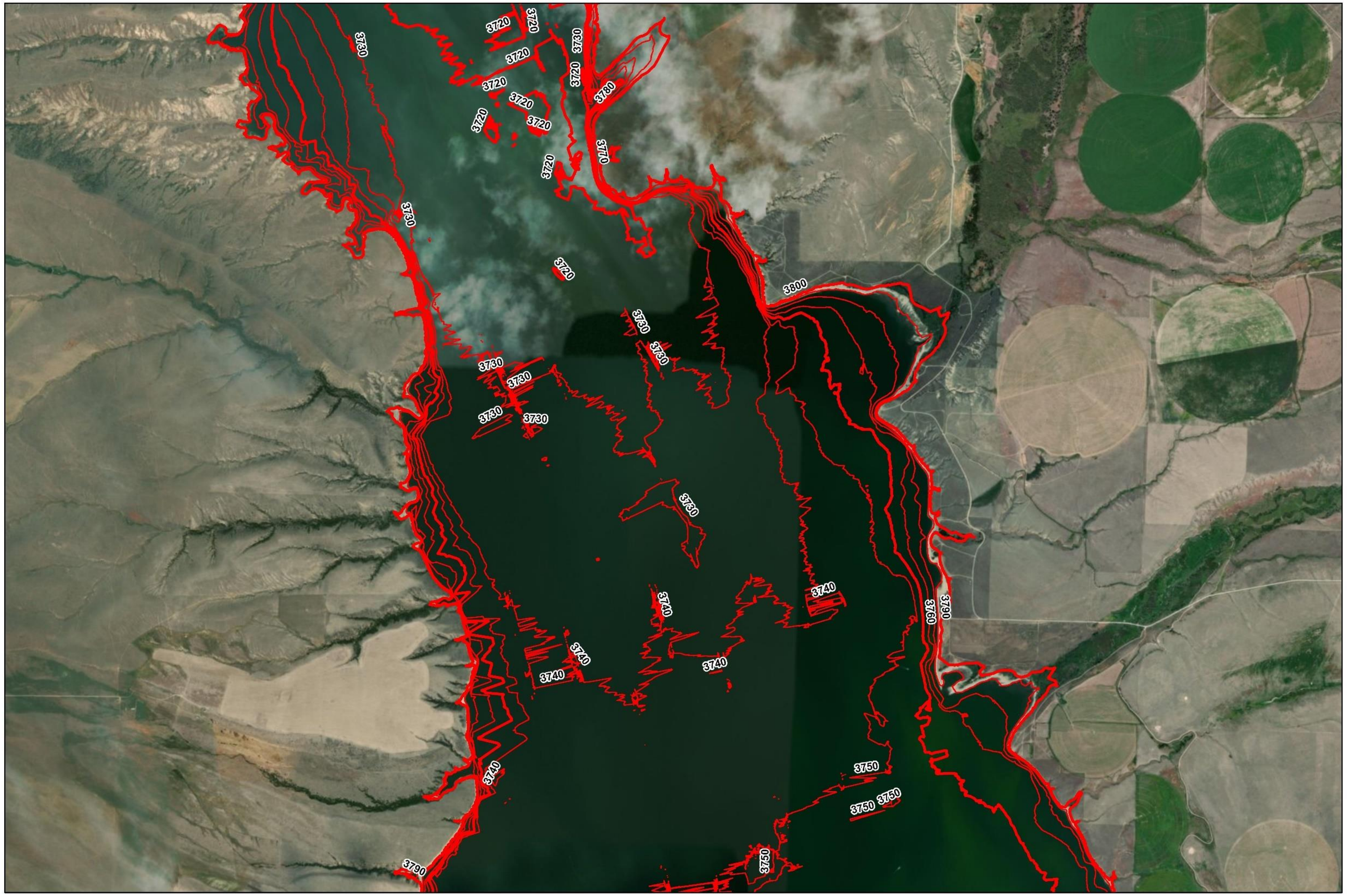


Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 4

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface
Elevation Gage at Canyon Ferry Dam
Referenced to Reclamation Project
Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

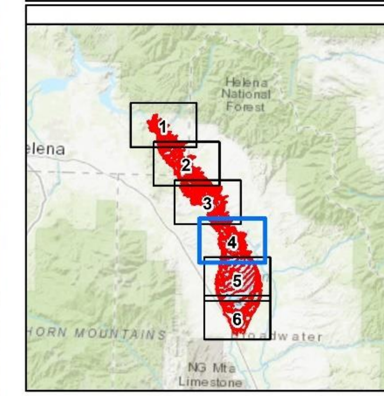
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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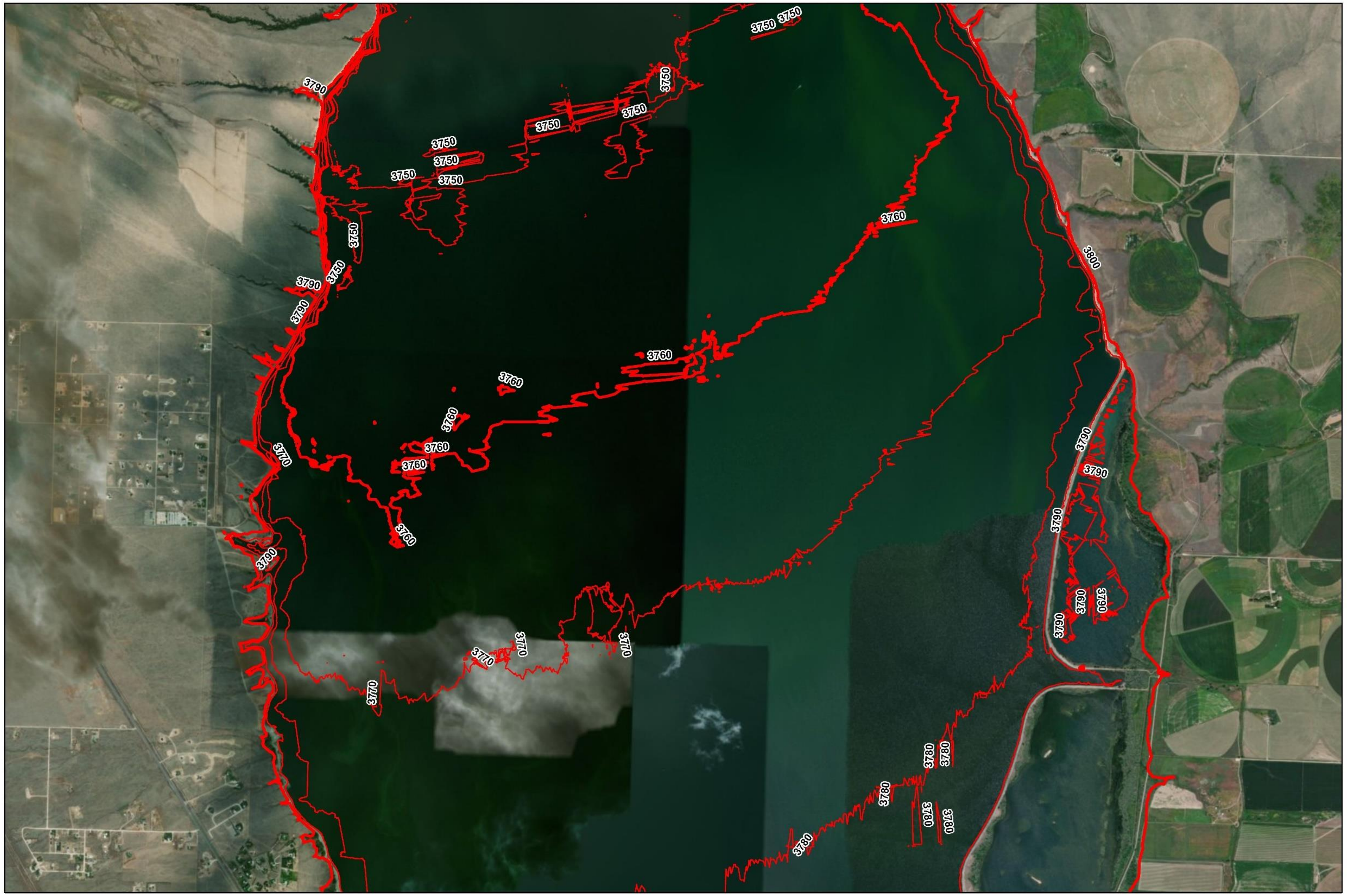


Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 5

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface Elevation Gage at Canyon Ferry Dam Referenced to Reclamation Project Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

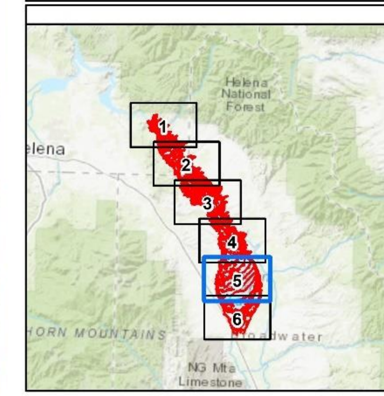
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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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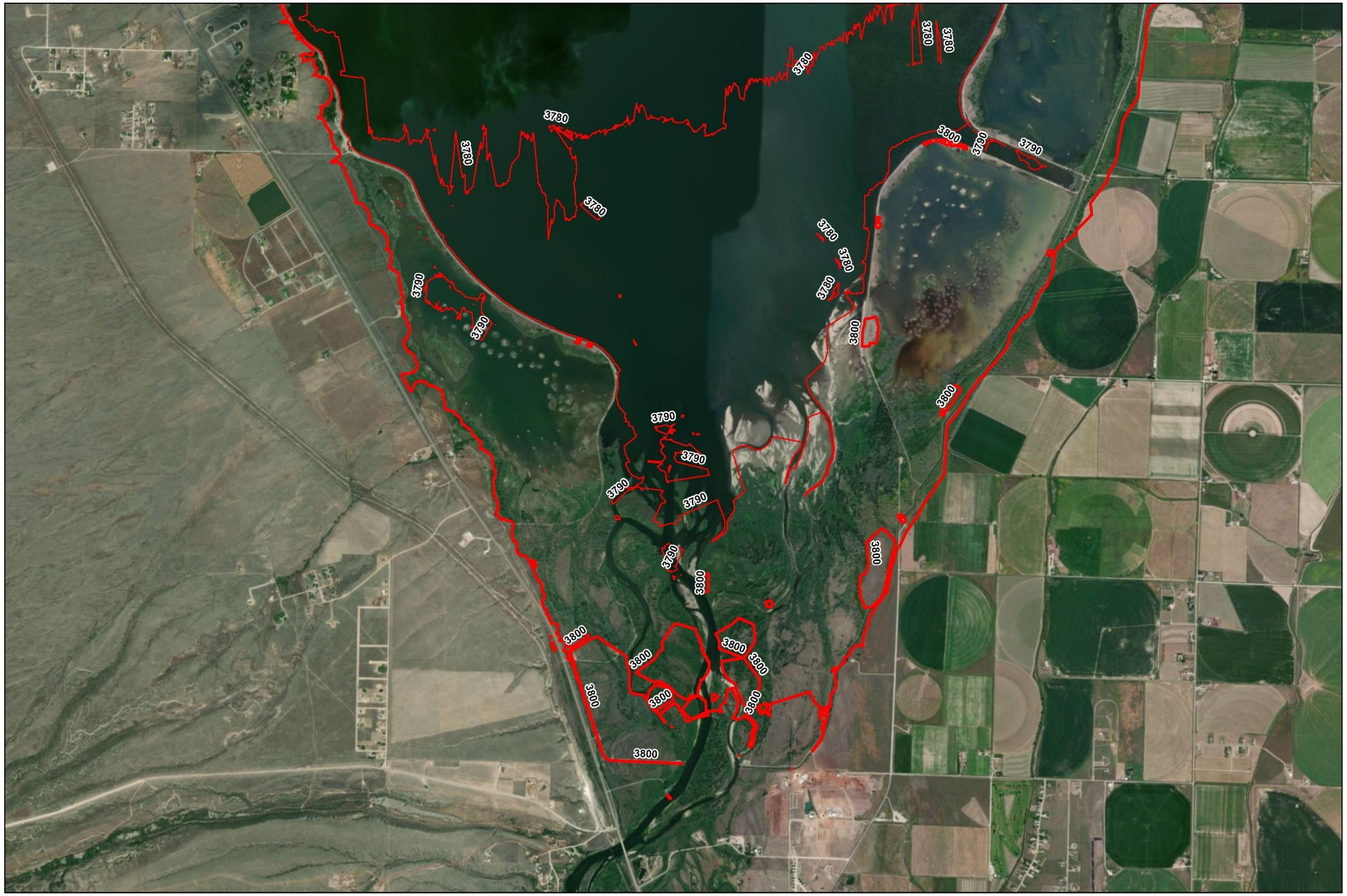
RECLAMATION



Canyon Ferry Reservoir Montana

Elevation Contour Map

Sheet 6

Horizontal Datum: NAD83 (2011)
State Plane Coordinates
Montana Zone FIPS 2500
International Feet

Vertical Datum Based on Water Surface Elevation Gage at Canyon Ferry Dam Referenced to Reclamation Project Vertical Datum (RPVD)
US Survey Feet
NAVD88 – RPVD = 3.15 sft
NAVD88 – NGVD29 = 3.23 sft

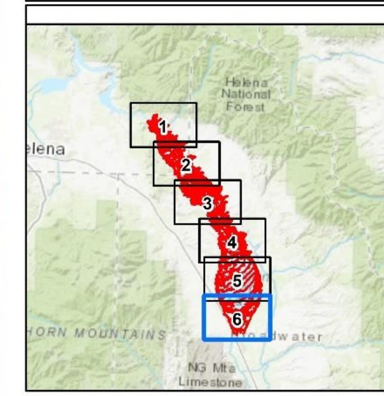
Ten Foot Contour Intervals

Primary Data Source:
Canyon Ferry Reservoir
2016 Sedimentation Survey

N

Scale 1:30,000

0 2,500 5,000 ft



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