Technical Report No. ENV-2021-009

Fontenelle Reservoir 2019 Sedimentation Survey

Seedskadee Project, Wyoming
Upper Colorado Basin Region

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

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Disclaimer

Cover: Fontenelle Dam and Reservoir

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The 2019 multibeam and single beam bathymetric surveys of Fontenelle Reservoir were combined with 2010 aerial LiDAR survey, to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the top of flood control pool elevation (6515 feet, project vertical datum), the reservoir would have a surface area of 8,961 acres and a total storage capacity of 410,127 acre-feet. Since the original filling in 1964, the reservoir is estimated to have lost 12,457 acre-feet of storage capacity (2.7%) due to sedimentation. The dead storage pool volume has reduced to 81 percent of the original dead storage volume. The lowest reservoir elevation at the dam appears to be the same as in 1961.

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Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
ft^3/s	cubic feet per second (cfs)
DOI	Department of the Interior
ft	foot or feet
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
NAD 1983	North American Datum, established 1983
NAVD 1988	North American Vertical Datum, established 1988
NED	National Elevation Data
NGS	National Geodetic Survey
NGVD 1929	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
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
USGS	U.S. Geological Survey

Executive Summary

Fontenelle Dam and Reservoir are on the Green River, 70 highway miles northwest from Rock Springs, Wyoming. A full bathymetric survey of Fontenelle Reservoir was conducted July 29 to August 1, 2019 with two primary objectives:

- Estimate reservoir sedimentation volume since the reservoir filling began in 1964 and
- 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 three boats to map the reservoir bottom using Real-Time Kinematic (RTK) Global Positioning System (GPS) instruments for horizontal positioning. One boat was equipped with a multibeam depth sounder, a second boat with a single beam depth sounder, and a third boat with an Acoustic Doppler Current Profiler (ADCP). The 2019 bathymetric survey of Fontenelle Reservoir was combined with 2010 aerial Light Detection and Ranging (LiDAR) survey data to produce a combined digital surface of the reservoir bottom. Where data overlap occurred, the bathymetric data were used in preference to the processed LiDAR data because the LiDAR data were less dense and measured nine years earlier than the bathymetric data.

The bathymetric survey was conducted between July 29 and August 1, 2019 when the reservoir water surface elevation varied between 6502.3 and 6502.6 feet [Reclamation Project Vertical Datum (RPVD)], which was 3.7 to 3.4 feet below the top of the active conservation pool at elevation of 6506 feet (RPVD). The above water LiDAR data were collected May 15, 2010, when the water surface elevation was at 6470.6 (RPVD). However, the posted LiDAR data did not include any reservoir topography data below elevation 6505 feet (RPVD).

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 6497 feet (RPVD), about 5.5 feet below water at the time of survey, the reservoir surface area was 7,174 acres with a total storage capacity of 266,870 acre-feet.
- At the top of the active conservation pool at elevation 6506 feet (RPVD), the reservoir had a surface area of 7,861 acres and a total storage capacity of 334,411 acre-feet.
- Since the original filling of the reservoir in 1964, the reservoir is estimated to have lost about 12,500 acre-feet of storage capacity (2.7 percent) due to sedimentation. This volume represents a sediment yield rate of 0.06 acre-feet per square mile per year (acre-feet/mi^2/year), which is considered very low (< 0.2 acre-feet/mi^2/year) as defined in Reclamation (2006).
- By 2019, the dead storage pool volume had reduced to 81 percent of the original dead storage volume (560 acre-feet). The lowest reservoir elevation at the dam remains unchanged at 6392 feet (RVPD) (same as predam survey).
- Periodic reservoir surveys are needed to determine how reservoir sedimentation may be changing over time. So far, only the average sedimentation rate between 1964 and 2019 can be estimated.

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	Fontenelle	Region	Upper Colorado Basin
Owner	Bureau of Reclamation	Area Office	Provo Area Office
Stream	Green River	Vertical Datum	Reclamation Project Vertical Datum (RPVD)
County	Lincoln	Top of Dam (ft)	6519
State	Wyoming	Spillway Crest (ft)	6506
Lat	42 ° 1′ 42″ North	Power Penstock Elevation (ft)	6408
Long	110° 3′ 38″ West	Low Level outlet (ft)	6408
HUC4	1404	Hydraulic Height (ft)	121.0
HUC8	14040103	Total Drainage Area (mi^2)	4,280
NID ID	WY01389	Date storage began	Spring 1964
Dam Purpose	Irrigation & hydropower	Date for normal operations	May 1968
HUC = Hydrologic Unit Code; NID = National Inventory of Dams			

Original Design (Reclamation 1969a and 1969b)

Storage Allocation	Elevation (feet)	Surface area (acres)	Incremental Capacity (acre-feet)	Total Capacity (acre-feet)
Top of Dam	6519	9,624	37,379	459,580
Top of Surcharge	6515	9,074	76,769	422,201
Top of Active Capacity	6506	8,058	264,378	345,432
Top of Inactive Capacity	6460	3,366	80,494	81,054
Dead	6408	128	560	560

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sediment-ation Volume (acre-feet)	Cumulative Sediment-ation (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
Prior to 1964	Likely photogram-metry	unknown	4,280	n/a	n/a	n/a	100
July 31, 2019	Multibeam & LiDAR	5-foot contours [1]	4,151	12,500	12,500	6392	81

[1] 5-foot contour intervals are available in GIS files while 10-foot contour intervals are shown in attached maps.

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1. Introduction

Fontenelle Dam and Reservoir are on the Green River in Wyoming (WY). The dam is 24 highway miles downstream and southeast from La Barge, WY, 34 highway miles northeast from Kemmerer, WY and 70 highway miles northwest from Rock Springs, WY (Figure 1). The dam and reservoir are operated by the Bureau of Reclamation (Reclamation), Provo Area Office as part of the Seedskadee Project. Fontenelle Reservoir stores water for cities and industries; generates hydroelectric power, and provides fishing, boating, and other water-based recreation. Cold clear water released downstream supports trout and the Seedskadee National Wildlife Refuge (Reclamation's information sign at Fontenelle Dam).

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 where inflowing streams meet the reservoir while silt and clay particles tend to deposit father downstream 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 Upper Colorado Basin Region requested that the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A complete bathymetric survey was conducted from July 29 to August 1, 2019 with two primary objectives:

- Estimate reservoir sedimentation volume since the reservoir filling began in 1964 and
- Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

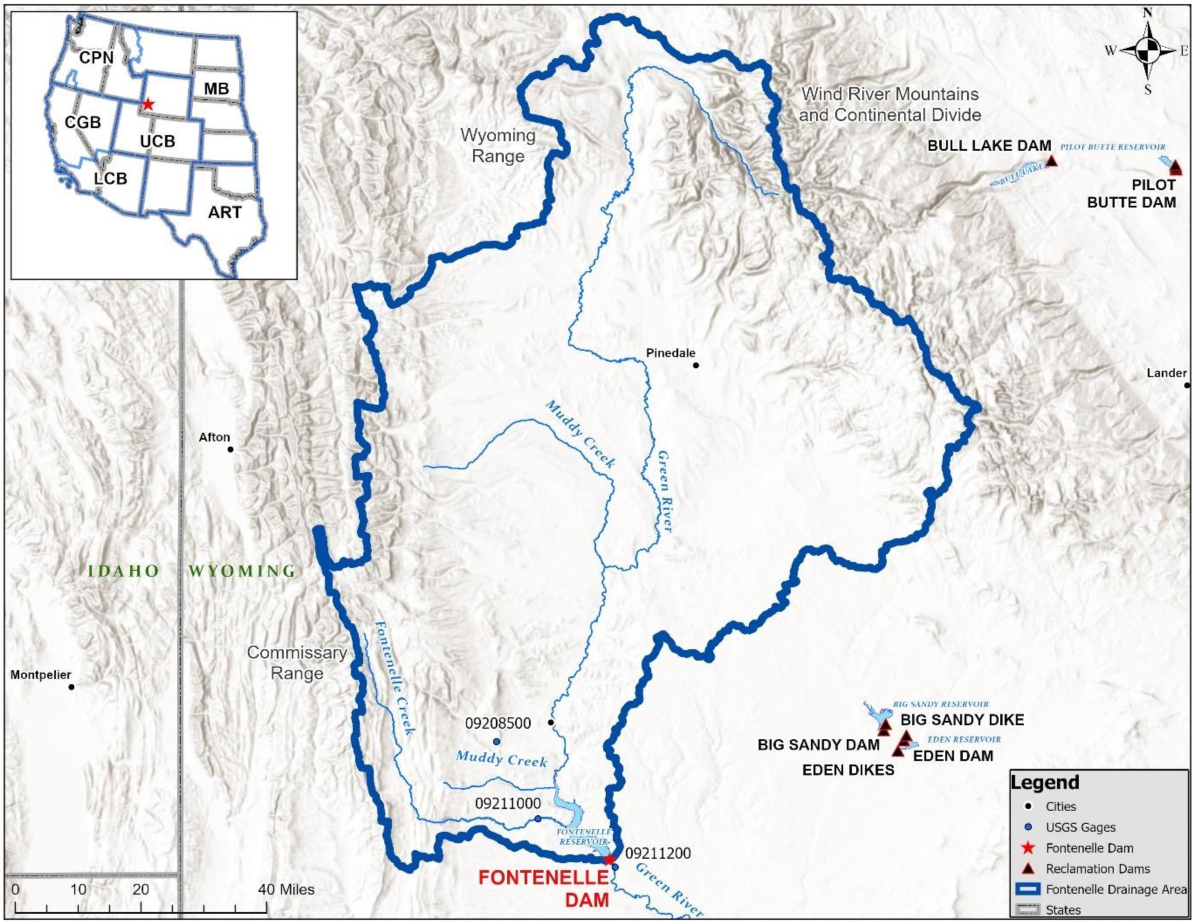

Figure 1. Location of Fontenelle Dam and Reservoir and corresponding watershed map.

2. Watershed Description

The watershed upstream of Fontenelle Dam is bounded by the Wind River Mountains and Continental Divide to the northeast and the Wyoming Range and Commissary Ridge to the west. The area is remote and sparsely populated, but the population is increasing (Hamerlinck, 2013). Small dams exist in the upstream watershed that enlarge natural lakes.

2.1. Location and Drainage

The watershed upstream from Fontenelle Dam has a total contributing drainage area of 4,280 square miles (mi^2) (Figure 1). Because of upstream lakes and reservoirs that trap sediment (as of 2019), the net sediment-contributing drainage area to Fontenelle Reservoir is estimated at 4,000 mi^2. This watershed consists of high plateaus and high rugged mountains. Elevations range from 6390 feet (Green River below Fontenelle Dam) to 13,802 feet on top of Gannett Peak, the highest peak in Wyoming, in the Wind River Mountains. The highest point of the Wyoming range is Wyoming Peak at 11,383 feet elevation.

The Wind River Mountains (Bridger Wilderness) contain over 1,300 lakes, which range in size from less than 3 acres to over 200 acres, with an average size of about 10 acres (U.S. Department of Agriculture, 1979). Leopold (1980) reported there are hundreds of lakes occupying depressions scoured by glacial ice and dammed terminal moraines during the late Pleistocene. All of these lakes are expected to trap at least some of the inflowing sediments, especially sand and gravel. The largest lakes within the watershed and at the base of the mountains, from northwest to southeast, include New Fork, Willow, Soda, Fremont, Half Moon, Little Half Moon, Fayette, Meadow, Burnt, Blueberry, Boulder, and another Soda Lake. Three of the largest are summarized by Leopold (1980) in Table 1. The combined drainage area upstream from these three lakes is 3.0% of the total watershed area.

Table 1. Wind River Mountain lake characteristic and drainage basin area.

Lake Characteristic	Fremont Lake	Willow Lake	New Fork Lakes	Totals
Drainage area, mi^2	76	25	29	129
Portion of Fontenelle watershed area	1.8%	0.6%	0.7%	3.0%
Lake area, acres	5,090	1,790	1,230	8,110
Water elevation, ft, msl	7418	7697	7818	
Lake volume, acre-feet	1,370,000	211,000	130,000	1,711,000
Maximum depth, feet	607	279	203	
Mean depth, feet	269	118	108	
Maximum drawdown, feet	3	9	10	
Useable storage, acre-feet	15,000	15,900	12,100	43,000

About three-quarters of the watershed is public land, managed by the Federal government through the Bureau of Land Management and U.S. Forest Service (Bridger National Forest). The watershed is sparsely populated with a few small cities like La Barge and Pinedale, WY. About half of the population lives within cities while the other half live outside municipal boundaries. Land use consists of agriculture, residential, commercial, industrial, transportation, and recreation (Hamerlinck et al., 2013).

2.2. Geology

The geology of the Wind River Mountains consists of "Precambrian crystalline rocks, mostly gray gneiss extensively cut by quartz, pegmatite, and quartz dikes" (Leopold, 1980). Rock types of the larger watershed area consists primarily of alluvium, unconsolidated deposits, fine-grained mixed clastic, and mudstone (Table 2).

Table 2. Rock types of the Fontenelle Reservoir watershed (State Geologic Map Compilation, 2020) (Green and Drouillard, 1994).

Rock Type	Area Portion
alluvium	16.8%
unconsolidated deposit	14.9%
fine-grained mixed clastic	14.3%
mudstone	14.2%
glacial drift	6.3%
clastic	5.7%
oil shale	4.7%
sandstone	4.3%
limestone	3.0%
mixed clastic/carbonate	2.9%
granitic gneiss	2.9%
shale	2.8%
conglomerate	2.5%
medium-grained mixed clastic	1.8%
granitoid	1.0%
siltstone	0.7%
water	0.6%
landslide	0.2%
ice	0.1%
tectonite	0.0%
gravel	0.0%
Total Area	100.0%

2.3. Soils, Vegetation, and Land Use

Three soil groups (B, C, and D) were identified to exist within the watershed. The proportions of these soil groups are presented in Figure 2. These soil groups are defined by the Natural Resource Conservation Service (USDA, 2020).

- *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 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.*

The moderate infiltration rates of soil Group B (50.7% of drainage area) would limit runoff and soil erosion.

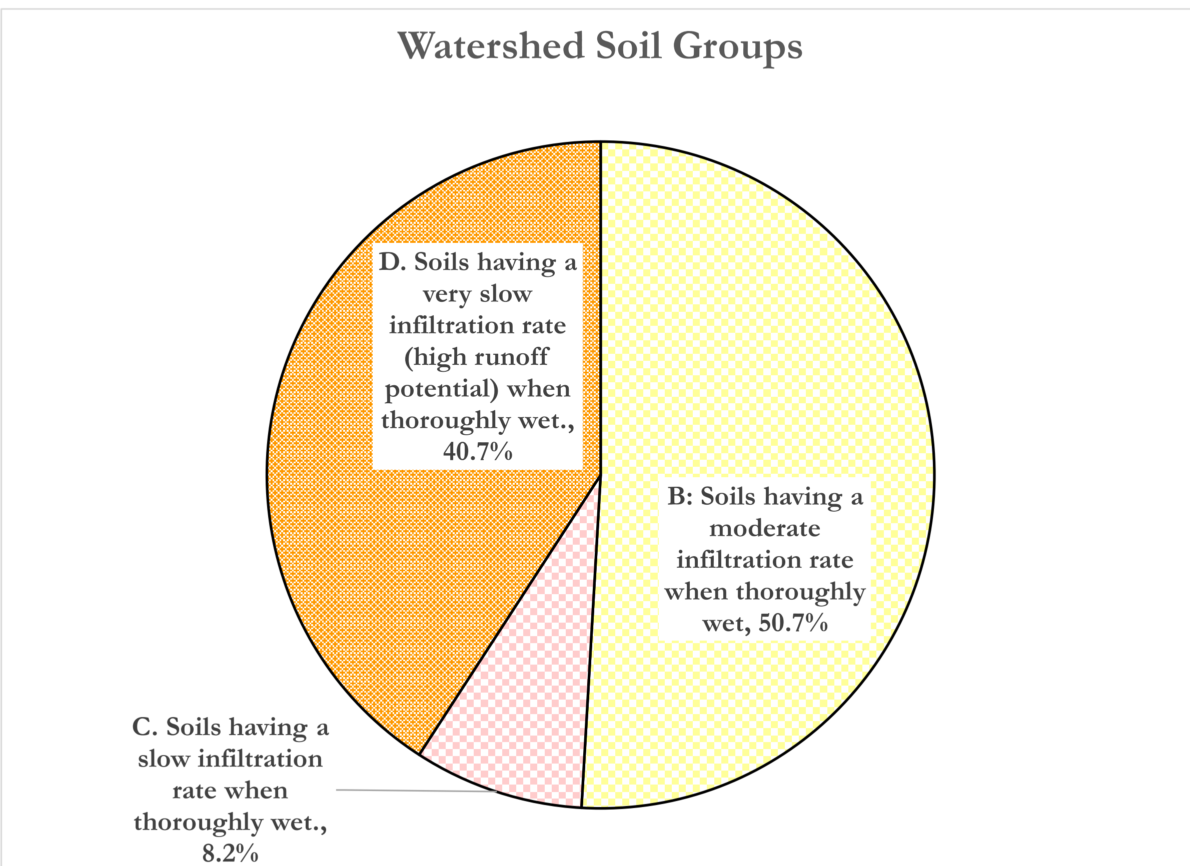

Figure 2. Proportions of soil groups B, C, and D within the watershed.

In the mountainous portions of the watershed, vegetation primarily consists of alpine tundra at the highest elevations and lodgepole pine forest, Douglas fir forest, and aspen forest at lower elevations (University of Wyoming, 2020). Most of the watershed is sagebrush steppe.

Land use for the watershed is primarily grassland pasture and range (72%), urban and special use (12%), forest use (12%), and cropland (4%) (Hamerlinck et al., 2013). These land uses may cause some increase in sediment yield over natural levels, but the extent is unknown.

2.4. Climate and Runoff

Reservoir inflows are primarily from the Green River, which is a gravel-bed river (Figure 1). Fontenelle Creek, and smaller ungagged tributaries, also provide reservoir inflows. USGS stream gage records are available for the Green River near La Barge, WY and Fontenelle Creek near Fontenelle, WY (Table 3). The total drainage area above these two gages represents 96.6 percent of the total drainage area upstream from Fontenelle Dam. Green River annual flow volumes and annual peak discharges are plotted in Figure 3 and Figure 4. Fontenelle Creek enters the reservoir from the west side and downstream from the Green River gage near La Barge, WY. The drainage area upstream from the Fontenelle Creek gage is 5.2 percent of the total drainage area. Smaller ungagged tributaries represent 3.4 percent of the total drainage area.

Based on USGS data presented in **Error! Reference source not found.**, the mean annual r unoff to Fontenelle Reservoir is 5.4 inches per year or 1.19 million acre-feet per year. This runoff is primarily snowmelt with a 2-year flood peak on the Green River of 8,670 ft^3/s. The mean annual stream flow to the reservoir is 1,640 cubic feet per second (ft^3/s). The ratio of original reservoir total storage capacity (344,872 acre-feet at elevation 6506 feet, RPVD) to the mean annual runoff is 0.29 year. This means that, when full, the reservoir stores a water volume equivalent to 106 days of mean annual stream flow.

Table 3. Reservoir Inflow Streams with USGS gages sorted by watershed position from upstream to downstream (USGS, 2020a).

USGS Stream Gage		Drainage Area (mi^2)	Mean Annual Runoff (ft^3/s)	Period of Record
Name	Number			
Green River near La Barge, WY	09209400	3,910	1,574	1964-2020
Fontenelle Creek near Fontenelle, WY	09211000	224	66	1915-1953
Totals above reservoir		4,130	1,640	
Green River below Fontenelle Reservoir, WY	09211200	4,280	1,588	1965-2019

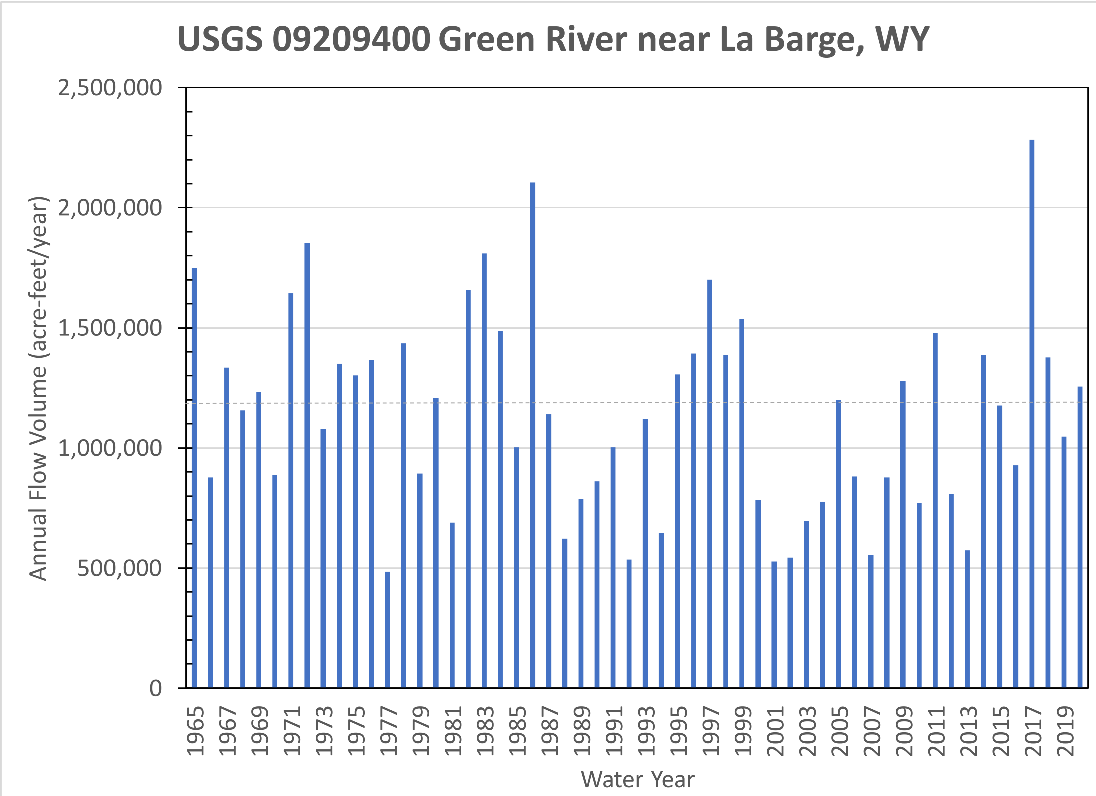

Figure 3. Annual Green River flow volume past the USGS gage near La Barge, Wyoming.

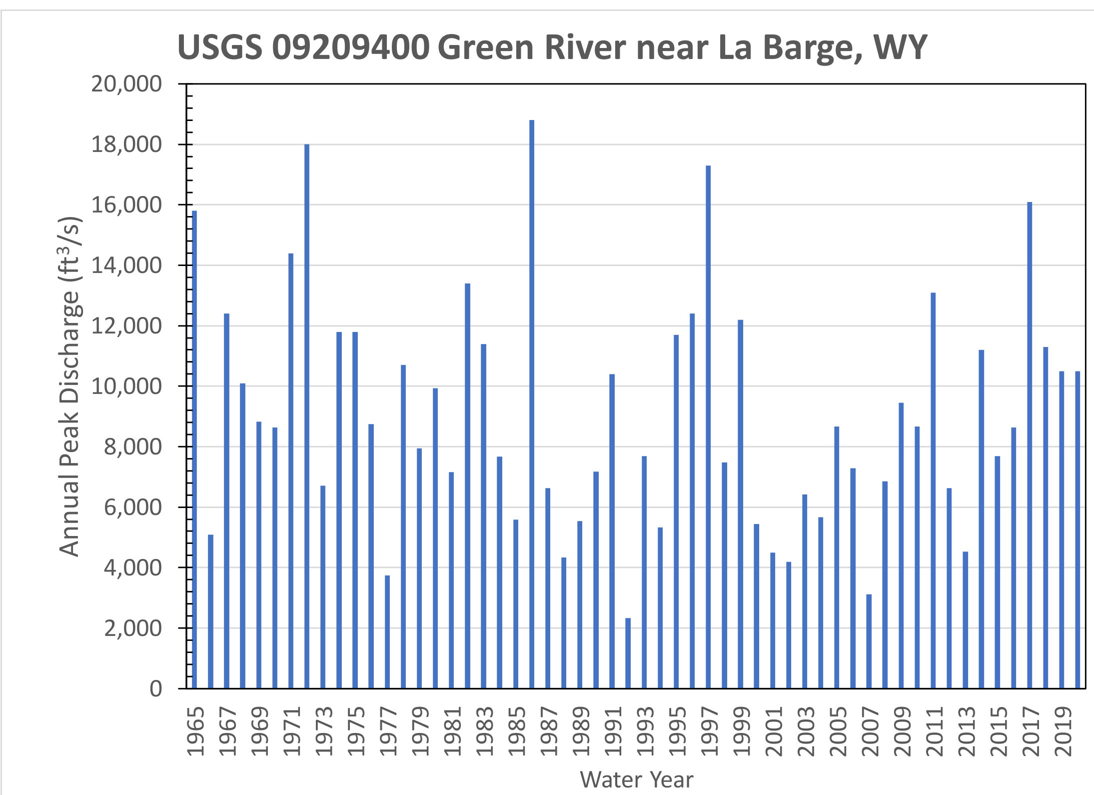

Figure 4. Annual Green River peak discharge past the USGS gage near La Barge, Wyoming.

2.5. Dam Operations and Reservoir Characteristics

Fontenelle Dam is a zoned earthfill structure (Figure 5). This dam was completed in 1964 and began storing water later that year. However, the dam almost failed by internal erosion during first filling in 1965 when the reservoir contained 345,000 acre-feet of water (Baker, 2011). Significant seepage through the dam and embankment slope failures were observed during September 1965 and the reservoir was lowered to avoid failure.

Figure 5. Photograph looking upstream at Fontenelle Dam.

Historic reservoir water surface elevations (RVPD) are available from October 25, 1965 to the present (Figure 6). The reservoir frequently fills during the year with the average annual maximum water surface elevation just 6 feet below the top the conservation pool. Annually, reservoir water surface fluctuates an average of 32 feet. The average annual minimum water surface elevation is 6467 feet, 59 feet above the dead storage pool.

The dam has a height above the original stream bed of 127 feet and the reservoir had an original centerline length of 13 miles (17 meandering miles along the Green River) at full pool with one significant tributary, Fontenelle Creek, and several smaller tributaries.

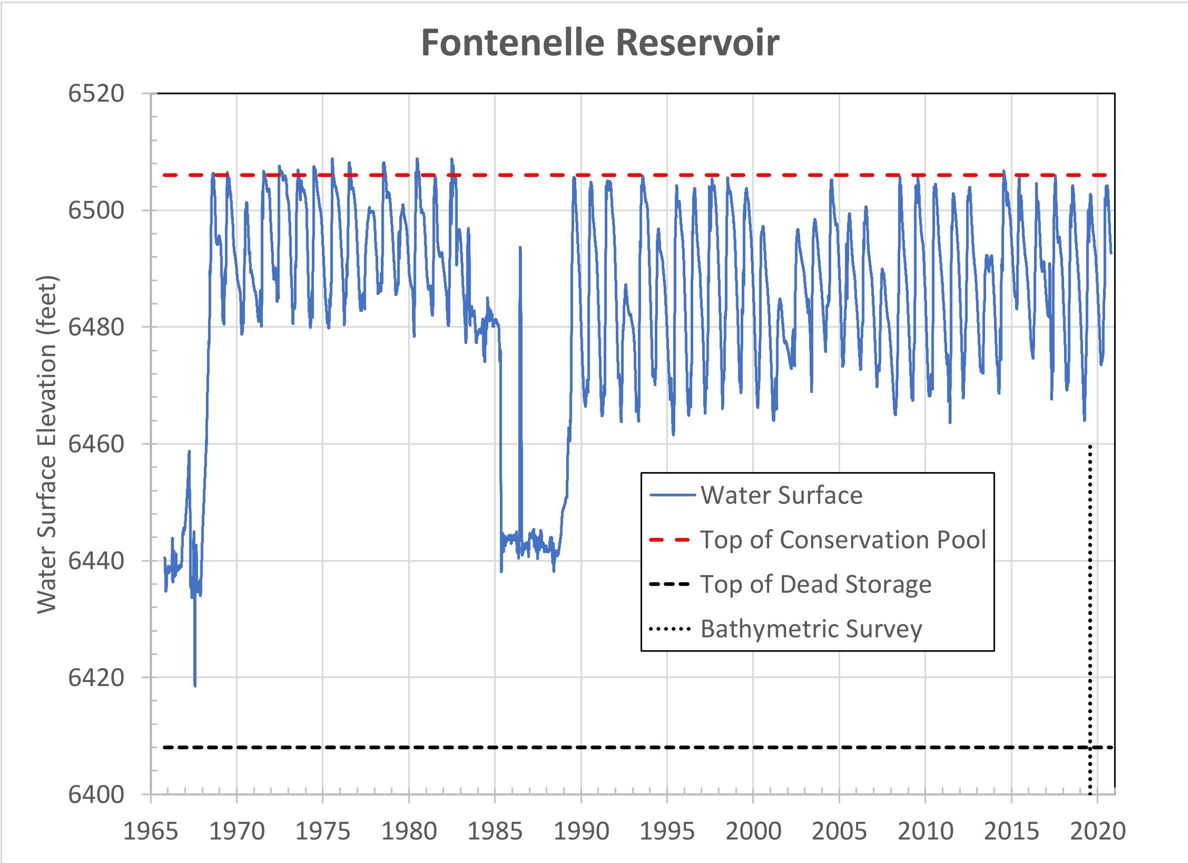

Figure 6. Historic Fontenelle water surface elevations (RPVD). Data web source: https://www.usbr.gov/rsvrWater/HistoricalApp.html.

The reservoir width is widest about 2 miles upstream from the dam at a width of 2.2 miles. The reservoir narrows to a width of 0.7 mile at a distance of 5.5 miles upstream from the dam (downstream from Fontenelle Creek). The upstream half of the reservoir typically has a width of 0.9 mile and the upper portion of the delta is 0.2 mile wide. A delta has formed near the upstream end and has progressed 2 miles downstream from the confluence with Muddy Creek. Annual reservoir water surface fluctuations help to move delta sediments farther downstream into the reservoir.

2.6. Reservoir Sediment Management

There have not been intentional sediment management activities at Fontenelle Reservoir, but reservoir drawdowns have likely moved some delta sediments father downstream and allowed inflowing sediments to deposit in the downstream half of the reservoir. From May 1985 through November 1988, the reservoir was drawn down below elevation 6445 feet (RPVD) due to dam safety concerns. However, the reservoir did significantly refill during June and July 1986 in response to the largest flood peak (18,800 ft^3/s) of the reservoir's history. This peak inflow, during a relatively low reservoir pool, likely would have delivered sediment to the downstream half of the reservoir.

3. Previous Reservoir Survey(s)

Prior to dam closure and initial reservoir filling, a survey was conducted in 1961 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, photogrammetry with some ground surveying was the most likely method for this time period. A 10-foot contour interval map was produced from this original survey (Reclamation, 1961). Reservoir surface and storage capacity tables were produced in 1969 (Reclamation 1969a and 1969b). The original and current reservoir surveys are listed in Table 4.

Table 4. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
1961	Full survey	Surface mapping	No reservoir	Photogrammetry
2010	Full above water survey	Surface mapping	none	LiDAR
2019	Full below water survey	Surface mapping	Multibeam & single beam	none

4. Reservoir Survey Methods and Extent

4.1. Survey Methods

A complete bathymetric survey was conducted over four days (July 29 through August 1, 2019) from three different boats using different depth sounders:

- Multibeam depth sounder on the Wooldridge survey vessel to measure water depths in the deep areas of the reservoir (> 15 feet)
- Acoustic Doppler Current Profiler (ADCP), used as a mini-multibeam depth sounder, on an aluminum survey boat from the Western Colorado Area Office to measure depths in shallow areas of the reservoir such as the delta and shoreline
- Single beam depth sounder (hydrolite) on a one-man cataraft for the Fontenelle Creek arm of the reservoir

The horizontal position of each survey boat was continually tracked using RTK GPS. A map of the data points collected is presented in Figure 7.

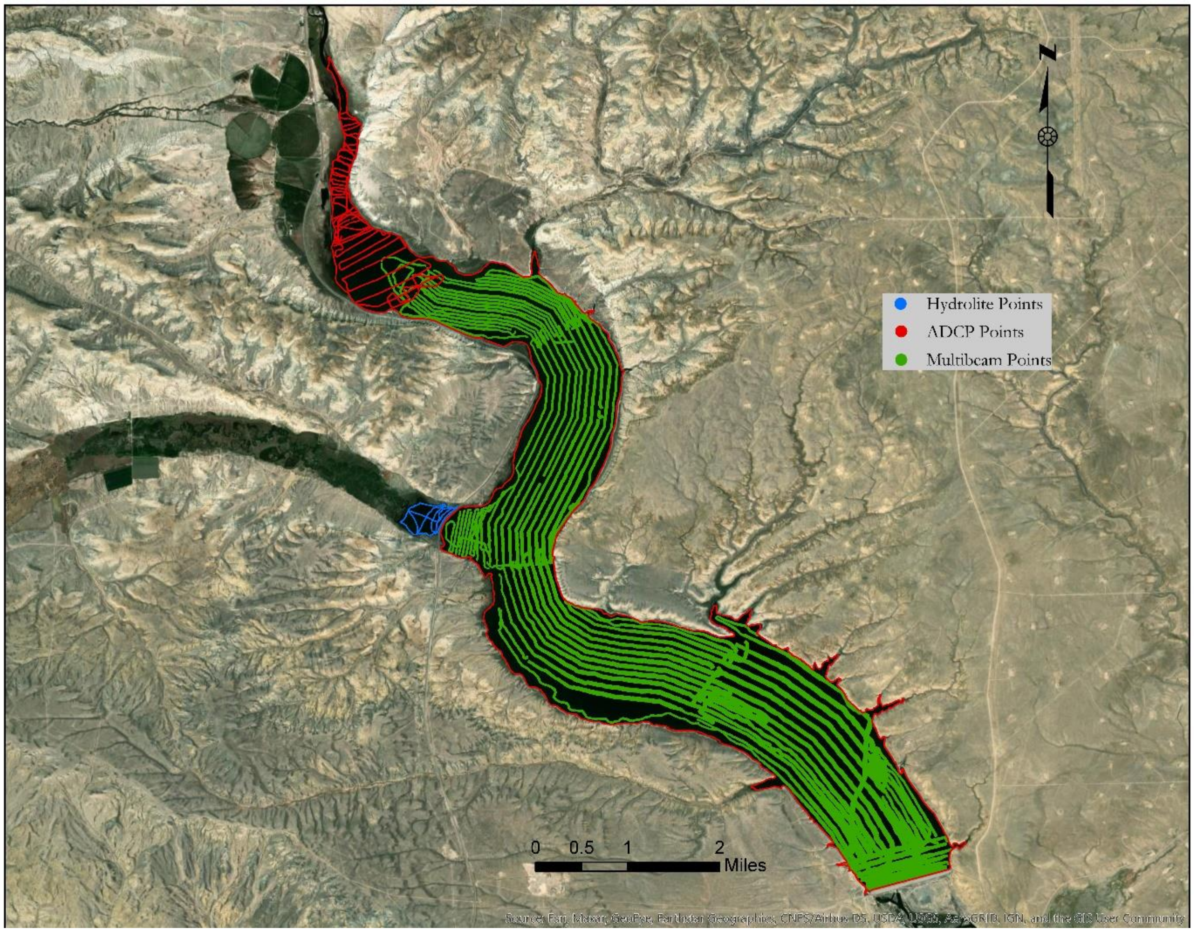

Figure 7. Map of bathymetric survey data coverage.

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with 2010 LiDAR data collected above water (U.S. Geological Survey, 2013) to produce a continuous digital surface of the reservoir bottom surface. The LiDAR data were collected on May 15, 2010 when the reservoir was drawn down to elevation 6470.6 feet (RPVD). However, the digital elevation model was only processed down to elevation 6505 feet (RPVD), so there was little if any overlap with the bathymetric data. The reservoir shoreline may not have changed much between the LiDAR survey of 2010 and the bathymetric survey of 2019, but flood flows and sedimentation over nearly a decade likely caused some changes to the delta.

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

Appendix C provides more details about the methods used to generate surface area and storage capacity tables. Surface area and storage capacity were computed at 1-foot contour intervals using GIS software. Another computer program was used to interpolate surface area and storage capacity and produce the reservoir surface area and capacity tables at 0.1 and 0.01-foot increments (Huang, 2020).

4.2. Survey Control, Datum, and Monuments

For the 2019 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD 1983) State Plane (horizontal) coordinates, Wyoming West Zone (4904), 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 Reclamation Project Vertical Datum (RPVD) for Fontenelle Dam. The RPVD was determined to be 0.25 feet lower than NGVD 1929 and 4.65 feet lower than NAVD 1988 (Geoid 12A).

The GPS base station receiver was set up over multiple temporary monuments all located on the west side of the reservoir (Figure 8*)*. Permanent monuments on or near Fontenelle Dam were surveyed and the coordinates of these monuments are presented in Table 5 with their general locations shown in Figure 9.

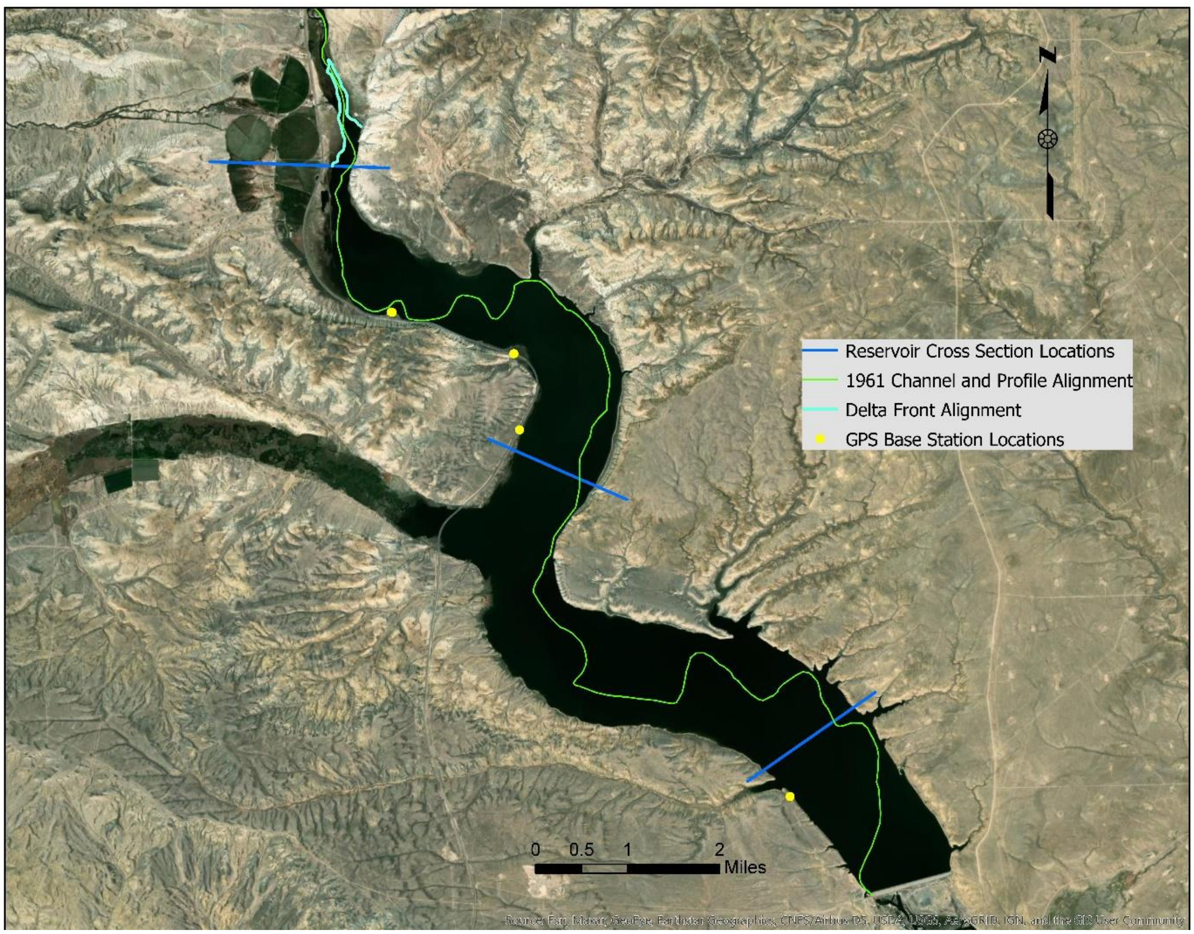

Figure 8. Fontenelle Reservoir alignment of longitudinal profile, cross sections, delta front, and the location of GPS base stations established during the survey.

Table 5. Monuments surveyed at Fontenelle Dam on July 30, 2019 all between 10:00 and 11:00 AM.

ID	Description	Easting (feet)	Northing (feet)	Mea-sured Elev. (feet, RPVD)	Reported Elev. (feet, RPVD)	Lati-tude	Long-itude	Ellipsoid Height (feet)
0	OB-19	2,627,612.1	883,939.2	6541.8	6541.8	42.0256	-110.0725	6499.8
1	ROW House Tabletop	2,629,977.8	884,813.1	6522.0	6522.4	42.0280	-110.0638	6477.2
2	Well Cap	2,629,988.4	884,830.9	6517.5	---	42.0281	-110.0637	6475.5
3	Survey Mark 30+00	2,629,944.1	884,769.4	6519.1	---	42.0279	-110.0639	6477.1
4	Dam Road (crest)	2,629,979.5	884,796.2	6519.5	6519.0	42.0280	-110.0638	6477.5
5	Monument 1	2,628,058.9	884,287.4	6542.4	6543.4	42.0266	-110.0708	6500.4
6	Monument 2	2,628,054.4	884,304.8	6542.5	6543.4	42.0266	-110.0709	6500.5

Figure 9. Aerial photograph location of survey monuments on Fontenelle Dam.

State plane coordinates and elevations for the GPS base stations were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/).

The RPVD shift for Fontenelle Reservoir was determined from RTK GPS measurements of water surface elevation measured at the boat ramp nearest the dam from two different days (July 29th and 30th).

The difference between NGVD 1929 and NAVD 1988 at Fontenelle Dam was computed using the US Army Corps of Engineers conversion program Corpscon v6.0.1. Corpscon uses NGS data and algorithms to convert between various horizontal projections and vertical datums (www.agc.army.mil/Missions/Corpscon.aspx). The Corpscon calculations confirmed that NGVD 1929 is 4.4 feet lower than NAVD 1988 at this location.

5. Reservoir Surface Area and Total Storage Capacity

Tables of reservoir surface area and total storage capacity were produced for the full range of reservoir elevations (Fontenelle Reservoir Area and Capacity Tables 2019). Plots of the 2019 area and capacity curves are presented in Figure 10 along with curves from the 1961 predam survey. For the 2019 survey, area and capacity curves are based on the bathymetric (below-water) survey up to 6497 feet elevation (RPVD), while curves above this elevation are based on 2010 aerial LiDAR survey (U.S. Geological Survey, 2013). A comparison of these curves indicates that largest reduction in surface area and storage capacity occurs between elevations 6435 and 6475 feet (RPVD).

The actual surface areas and storage-capacity volumes for above-water elevations may be less than the areas measured in 2010 because of delta sedimentation, shoreline erosion, or use of older methods.

At reservoir water surface elevation 6497 feet (RPVD), which is 5 feet below water at the time of survey, the reservoir surface area was 7,174 acres with a total storage capacity of 266,870 acre-feet. At the top of flood control pool elevation (6515 feet, RPVD), the reservoir would have a surface area of 8,961 acres and a total storage capacity of 410,127 acre-feet.

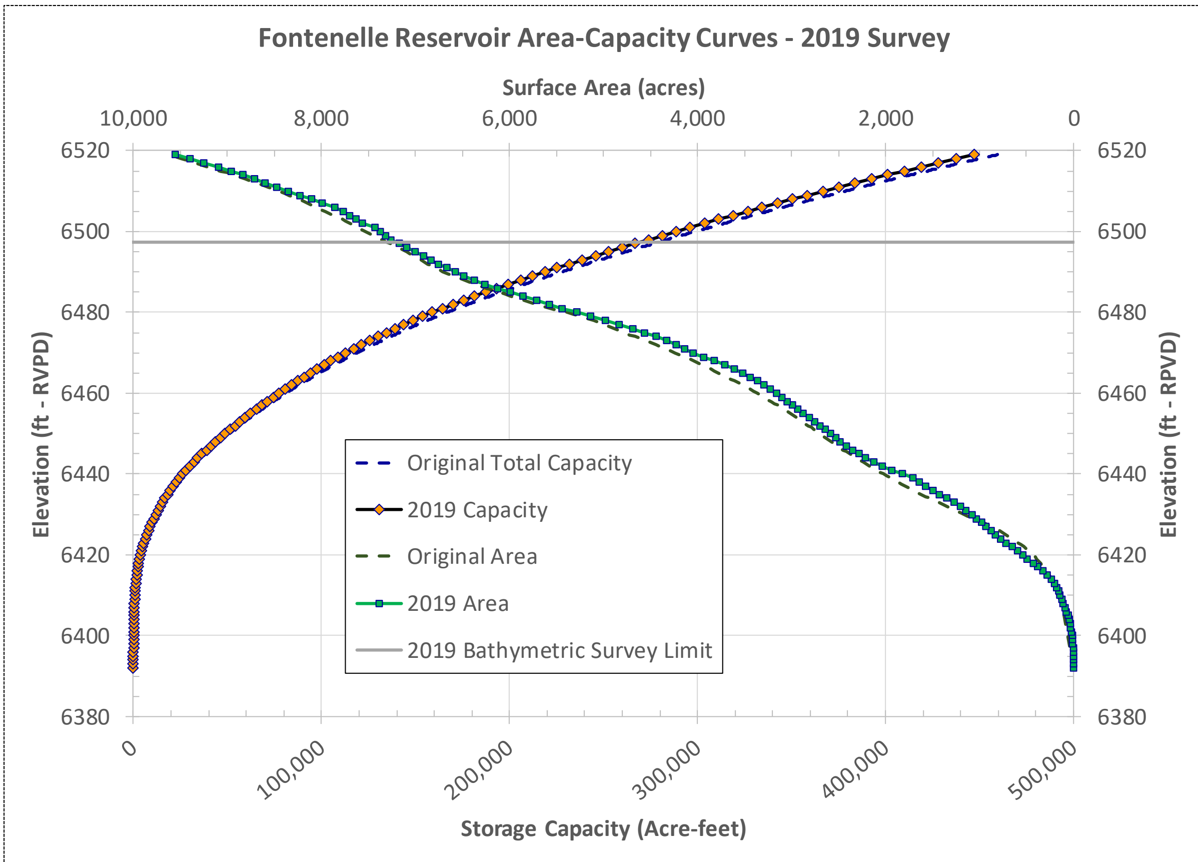

Figure 10. Fontenelle Reservoir surface area and total storage capacity versus elevation (RVPD).

Table 6. Historical summary of reservoir surface area and total storage capacity.

	Reservoir Surface Area (acres)		Reservoir Total Storage Capacity (acre-ft)		Sedimentation Volume (acre-ft)
Elevation (ft)	**1961**	**2019**	**1961**	**2019**	**1961 to 2019**
6519	9,624	9,559	459,580	447,123	12,457
6515	9,074	8,961	422,201	410,127	12,074
6506	8,058	7,861	345,432	334,411	11,021
6500	7,532	7,377	298,706	288,730	9,976
6490	6,709	6,580	227,635	218,739	8,896
6480	5,396	5,282	166,702	158,973	7,729
6470	4,235	4,043	118,887	112,969	5,918
6460	3,366	3,160	81,054	77,459	3,595
6450	2,702	2,582	50,868	48,729	2,139
6440	2,023	1,820	27,127	26,169	958
6430	1,160	1,081	11,028	11,920	-892
6420	429	543	3,577	3,732	-155
6408	128	108	560	455	105
6392	0	0	0	0	0

6. Reservoir Sedimentation Volume Spatial Distribution

Longitudinal profiles of the 1961 and 2019 reservoir bottom (Figure 11) were developed in GIS along the alignment of the 1961 Green River channel (Figure 8). The Green River channel alignment can be seen in the 2019 bathymetric surface and is the same as the 1961 alignment at many locations, but significantly different at other locations. The Green River channel alignment likely changed between 1961 and the first reservoir filling in 1964 or during significant reservoir drawdowns during 1966, 1967, and 1985 through 1989. Sediment has likely filled in the 1961 river channel along locations where the channel significantly migrated to the new alignment observed in the 2019 bathymetry. As a result, the 1961 profile alignment is not always along the 2019 reservoir thalweg (lowest point in the reservoir cross section) and 2019 elevations along the 1961 profile alignment are 5 to 15 feet higher (in one case 30 feet higher). Between river miles 0.5 and 17, the lowest portions of the 2019 profile match closely with elevations of the 1961 profile, which suggest only thin sediment deposits. The average sedimentation thickness over the entire area of the reservoir is only 1.3 feet. Based on a comparison of 1961 and 2019 surface area curves most of the sedimentation occurs between river miles 7 and 13, corresponding to elevations 6435 and 6475 feet (RPVD). A reservoir delta is observed upstream from river mile 17 with a maximum thickness of less than 10 feet. This delta can be seen in the aerial photography.

The 1961 and 2019 cross sections of lower, middle, and upper reservoir (at river miles 2.4, 8.8, and 15.6) closely compare with each other (Figure 12, Figure 13, and Figure 14). Because of LiDAR data, the 2019 cross sections extend well beyond the full reservoir pool elevation of 6515 feet (RPVD). The 1961 topography is based on a 10-foot contour map and lacks the precision necessary to determine sedimentation thickness of just a few feet.

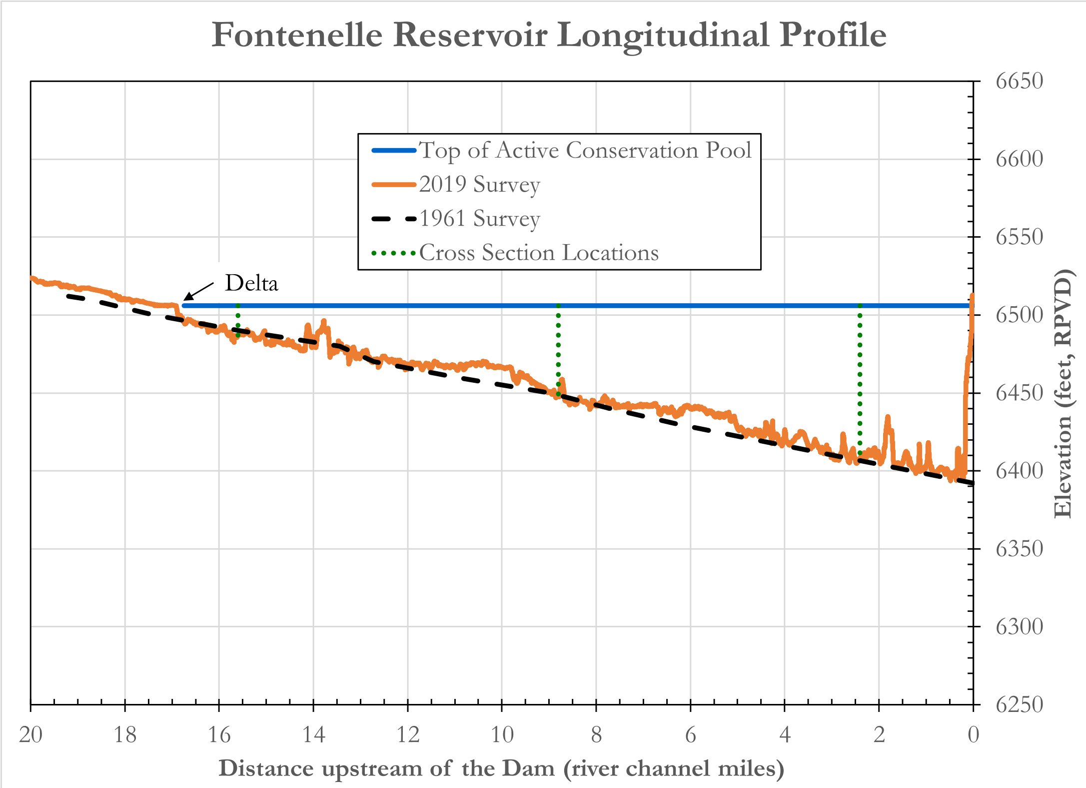

Figure 11. Longitudinal profile of Fontenelle Reservoir, along the alignment of the Green River channel, from the dam (mile 0) upstream through the delta (mile 20).

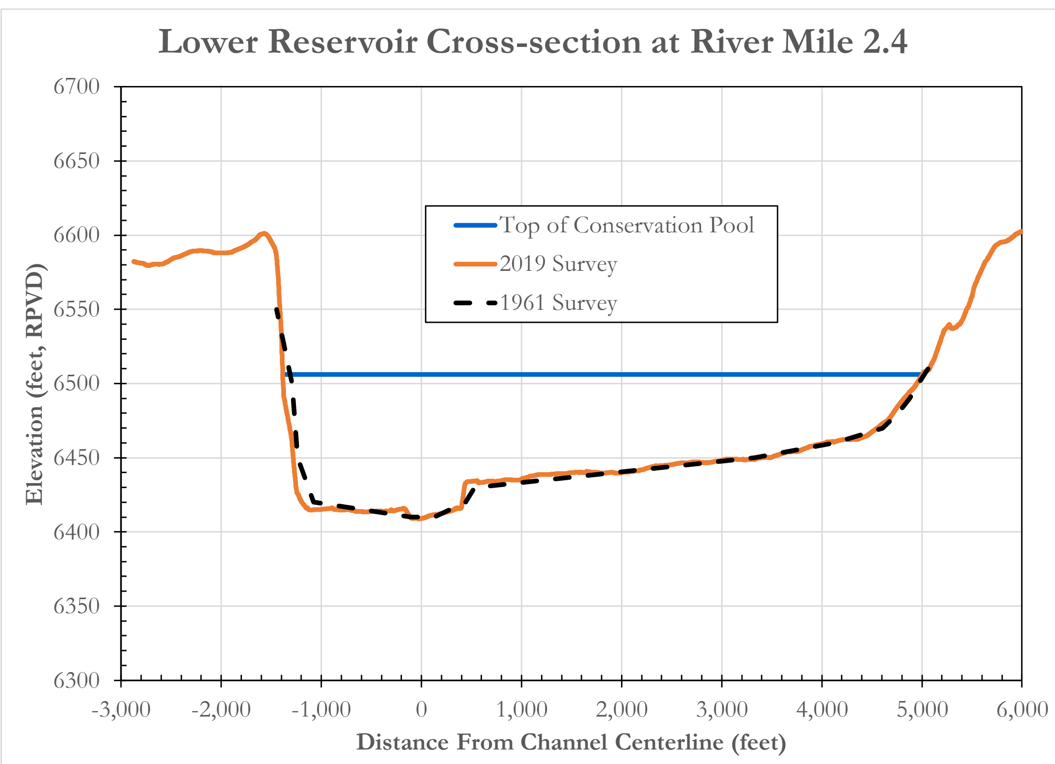

Figure 12. Representative cross section of the lower reservoir (looking downstream), 2.4 river miles upstream from the Fontenelle Dam.

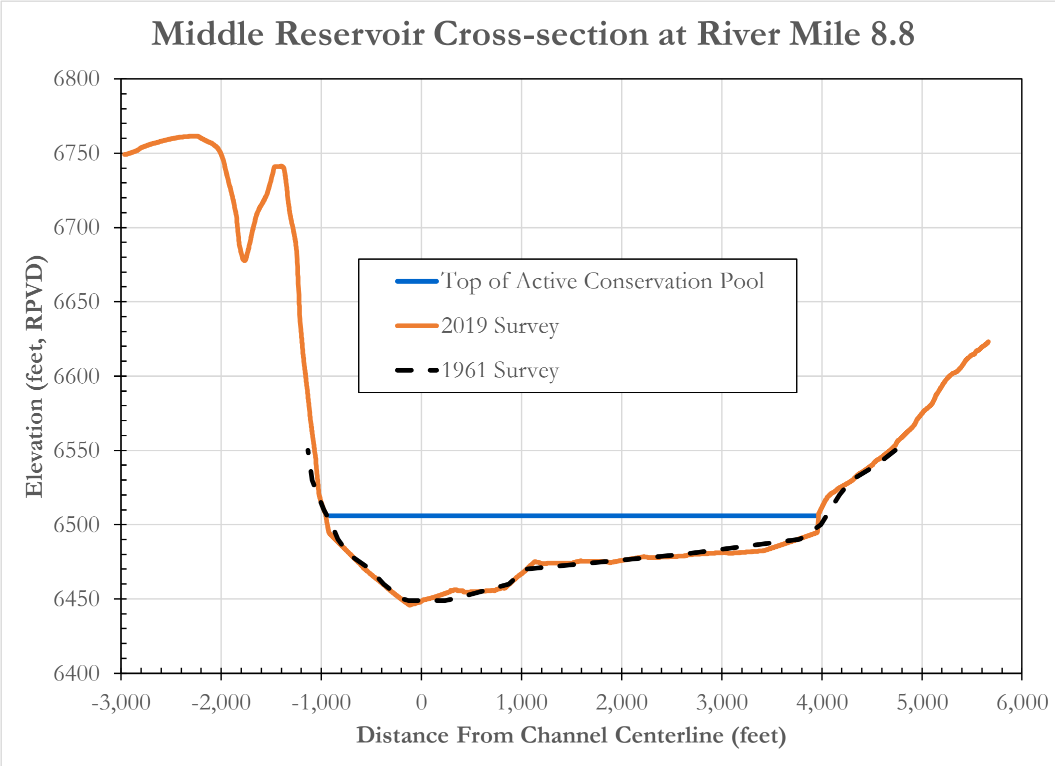

Figure 13. Representative cross section of the middle reservoir (looking downstream), 8.8 river miles upstream from the Fontenelle Dam.

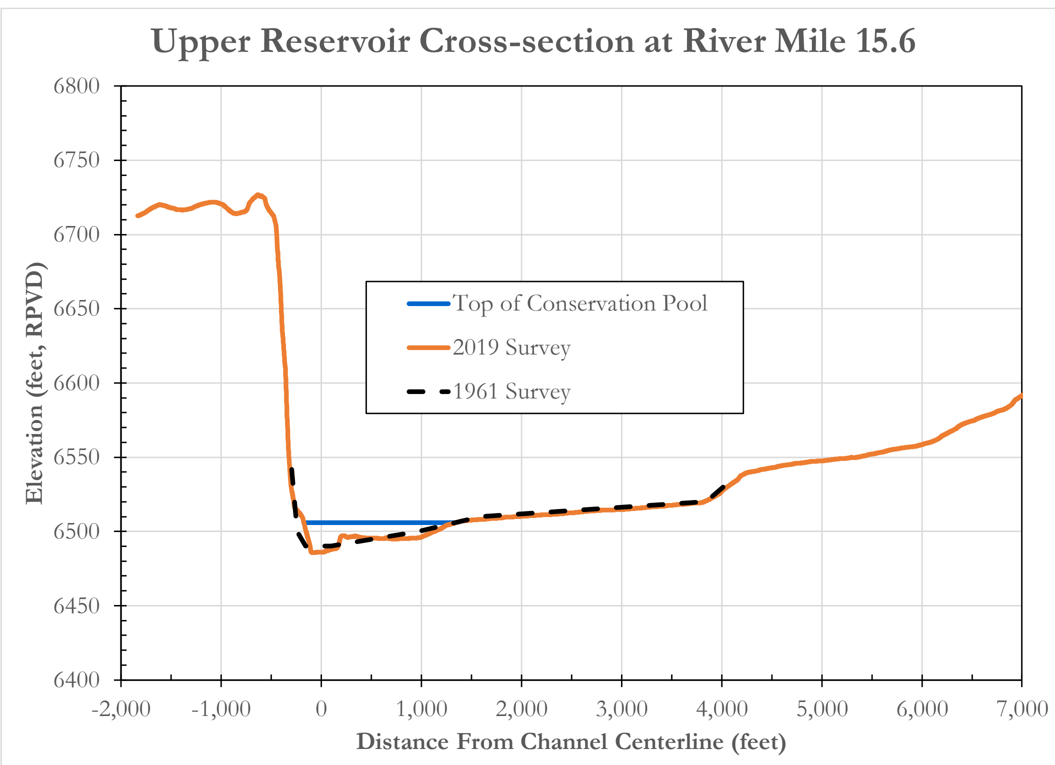

Figure 14. Representative cross section of the upper reservoir (looking downstream), 15.6 miles upstream from the Fontenelle Dam.

7. Sedimentation Trends

Based on a comparison of new and original total reservoir storage capacity curves (Appendix C), Fontenelle Reservoir has been filling with sediment at an average rate of 226 acre-feet per year over the life of the reservoir (1964 to 2019) (Figure 15). A single average sedimentation rate over the 55-year period is due to the infrequency of reservoir surveys. In the future, data from more frequent reservoir surveys (e.g., once every 20 years) would be needed to describe how sedimentation rates might be changing over time. Over the life of the reservoir, the total sedimentation volume has been 12,500 acre-feet (Figure 16), 2.7 percent of the original total storage capacity.

The sediment yield rate from the upstream watershed is very low at 0.06 acre-feet/mi^2/yr. (< 0.2 acre-feet/mi^2/year, Reclamation, 2006). The average annual water runoff from the watershed is also very low at 5.4 inches per year, most of it from mountain snowmelt. The numerous and deep glacially carved lakes within and at the base of the Wind River Mountains likely trap a high percentage of sediment being eroded from these mountains. There are few lakes to trap sediment eroded from the Wyoming Range and Commissary Ridge. Based on comparisons of drainage area, the Wind River Mountains may provide 60 percent of the total snowmelt runoff (1,230 mi^2) while the Wyoming Range and Commissary Ridge provide about 40 percent of the total snowmelt runoff (760 mi^2).

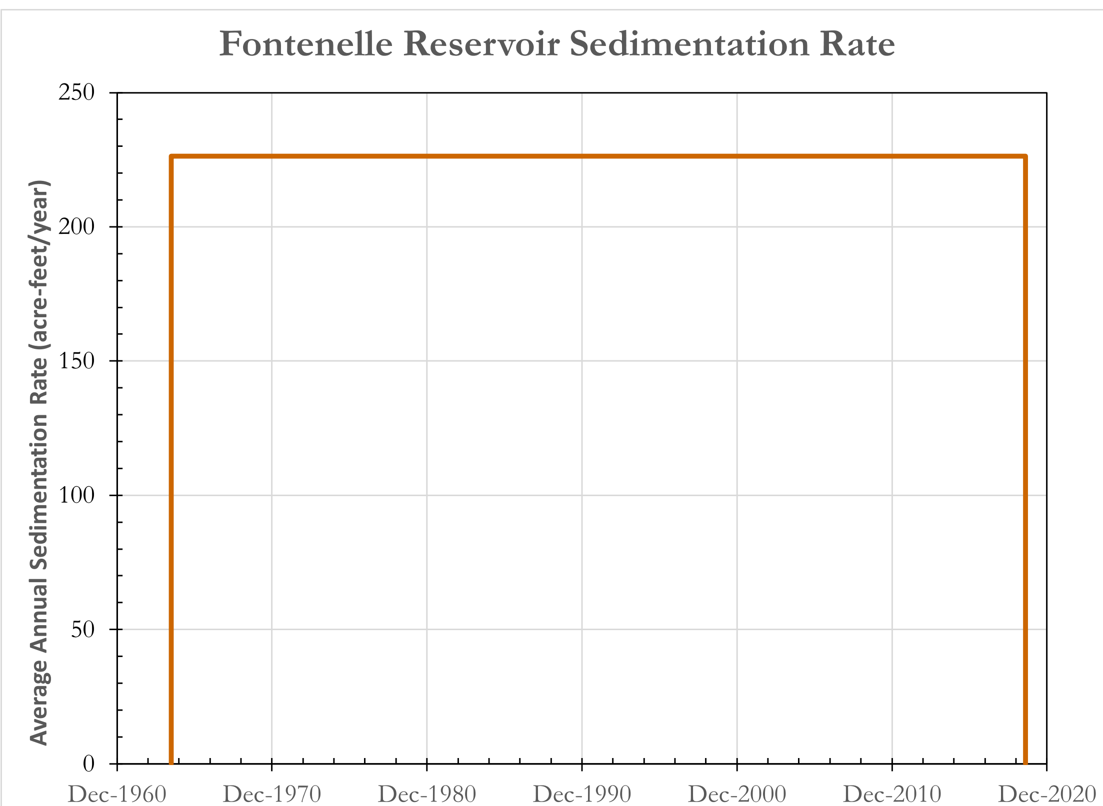

Figure 15. Average reservoir sedimentation rate over time.

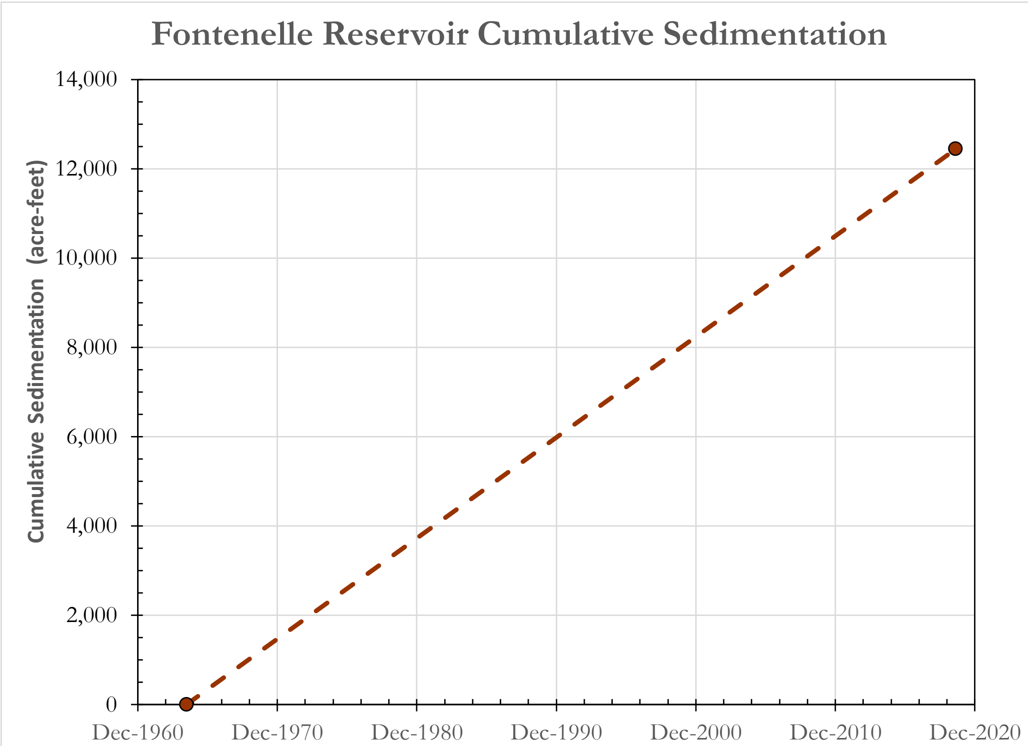

Figure 16. Cumulative reservoir sedimentation over time.

In general, sedimentation accumulates at all reservoir elevations and against the dam. However, sedimentation rates at Fontenelle Reservoir are low enough that that the deepest elevation of the reservoir near the dam has not significantly changed. Between 1964 and 2019, the dead storage capacity has reduced to 81 percent. Extrapolation of the historic sedimentation rate would suggest that the dead storage capacity would be lost after three more centuries (Figure 17).

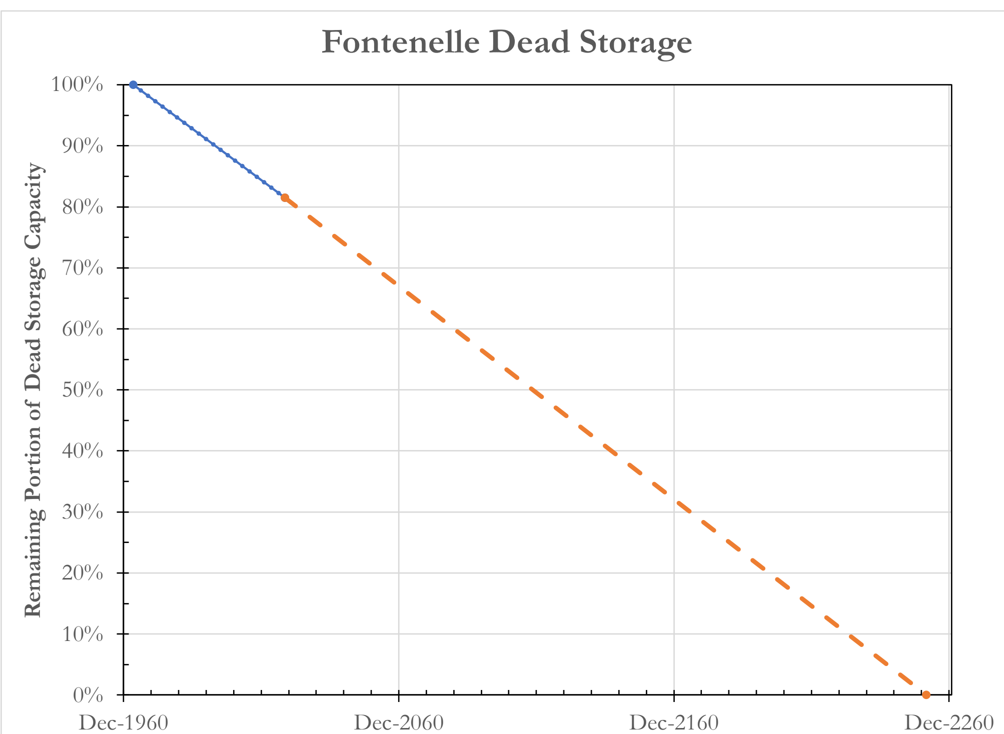

Figure 17. Sedimentation near the dam decreases the dead storage capacity over time.

8. Conclusions and Recommendations

8.1. Survey Methods and Data Analysis

The 2019 bathymetric survey, combined with 2010 LiDAR data of the above-water topography, has been used to produce an accurate digital surface of the reservoir bottom. The new reservoir surface matched well with the predam topographic map.

Reservoir surface areas were computed from this digital surface at 1-foot intervals to determine the 2019 total storage capacity. Surface area and storage capacity were then interpolated at 0.1 and 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but there are also some likely differences due to different survey methods. The latest surface area and storage capacity curves compare reasonably well with the original curves. The use of modern survey methods (RTK GPS, multibeam depth sounder, LiDAR) have produced a more accurate and precise digital surface of the reservoir bottom with better detail than the original predam survey using photogrammetry.

8.2. Sedimentation Progression and Location

Over the span of 55 years, sedimentation has filled in 2.7 percent of the original total storage capacity for an average deposition thickness of 1.3 feet. The 2019 reservoir survey indicates that a delta exists 17 river miles upstream from Fontenelle Dam with a maximum thickness of less than 8 feet. Downstream from the delta, sedimentation thickness is too thin to be detected by comparisons of 2019 and 1961 reservoir cross section, given that the 1961 topography is based on 10-foot contours. Reservoir sedimentation has reduced the dead storage capacity to 81 percent of the original capacity remains. Past rates of sedimentation suggest that remaining dead storage will be lost after three more centuries *(see Section 7* Sedimentation Trends*)*. The dam outlet may not be as reliable after the dead storage has filled with sediment because the future deposition of logs and sediment may accumulate on the trash rack.

8.3. Recommendation for Next Survey

Based on the past rates of sedimentation, the next survey of Fontenelle Reservoir is recommended within the next 20 years, even though the sedimentation rates have been very low. Surveys less frequently than once every 20 years may be difficult to compare because of advancing survey technologies.

The methods of the 2019 bathymetric survey provided good results. For the next reservoir survey, an additional survey swath following the alignment of the Green River channel is recommended. This alignment could be digitized from the 2019 bathymetric surface prior to conducting the survey.

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Appendix A — Hydrographic Survey Equipment and Methods

The 2019 bathymetric survey was conducted over four days from July 29 through August 1, 2019. During this period, reservoir water surface elevations only varied 0.3 feet, from elevations 6502.3 to 6502.6 feet (RPVD). Three different boats were used during the survey, each with a different depth sounder:

- A multibeam depth sounder was mounted on the Wooldridge survey vessel to measure water depths in the deep areas of the reservoir (> 15 feet)
- An acoustic Doppler current profiler (ADCP) was used as a mini-multibeam sounder and mounted on an aluminum survey vessel (similar to the Wooldridge) from the Western Colorado Area Office (WCAO) to measure depths in shallow areas of the reservoir such as the delta and shoreline
- A single beam depth sounder was mounted on a one-man cataraft to survey the Fontenelle Creek arm of the reservoir

A boat ramp was available on the west reservoir shoreline, 0.4 miles upstream from Fontenelle Dam Figure 18.

Figure 18. Photograph looking downstream at Fontenelle Reservoir, west shoreline boat map (right foreground) and Fontenelle Dam (background).

The bathymetric survey was conducted along a series of predetermined survey lines, mostly parallel to the longitudinal axis of reservoir, and along the reservoir shorelines (Figure 7). Near the dam, eight lines were surveyed parallel to the dam axis. Use of the multibeam depth sounder provided a data swath of 30 to 250 feet wide. The widest data swaths correspond to the deepest depths. In the deeper areas of the reservoir, the bottom was found to be relatively smooth and flat. Therefore, the multibeam survey lines were widely spaced between 200 and 300 feet apart. Although this spacing of the multibeam survey lines didn't always allow for overlap in data swaths, linear interpolation of reservoir bottom surface between the survey data swaths was judged to be adequate.

The shallower reservoir delta was surveyed along parallel cross section lines spaced about 100 feet apart. Use of the ADCP as a mini-multibeam depth sounder provided a data swath of 5 to 20 feet. Linear interpolation of reservoir delta surface between these survey lines swaths was judged to be adequate.

An 18-foot long, flat-bottom aluminum Wooldridge boat (Figure 19) (powered by outboard jet and kicker motors) was used to survey the deepest areas of the reservoir. 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,
- an external GSP radio, and
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data.

Figure 19. 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.

An aluminum survey vessel from WCAO (Figure 20) (powered by an outboard propeller motor) was used to survey the reservoir delta and shoreline. Reservoir depths were measured using a RiverSurveyor M9 Multi-beam Multi-frequency ADCP by SonTek with the following equipment characteristics:

- Frequencies: Dual 4-beam 3.0 MHz/1.0 MHz at 25 degrees slant angle; single vertical beam at 0.5 MHz
- Depth Range: 0.2 - 80 meters
- Depth Accuracy: 1%

Figure 20. WCAO survey vessel used to measure depths using an ADCP instrument.

A 9-foot long cataraft (Figure 21) (powered by a small 1.5 horsepower electric outboard trolling motor) was used to survey the Fontenelle Creek arm of reservoir upstream from U.S. Highway 189 which traverses across this tributary arm of the reservoir. Reservoir depths were measured using a single beam depth sounder (HydroLite) with the following characteristics:

- Frequency: 200 KHz
- Beam Width: 9 degrees
- Ping Rate: 6 Hz with 2Hz output
- Depth Accuracy: 1%

Figure 21. Cataraft survey boat on the Fontenelle Creek arm of the reservoir with RTK-GPS and single beam depth sounder.

RTK GPS survey instruments were used to continuously measure the survey boat position and to measure other ground control points. The GPS base station and receiver were set up on a tripod over a point overlooking the reservoir (Figure 22). 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 22). The base station was powered by a 12-volt battery.

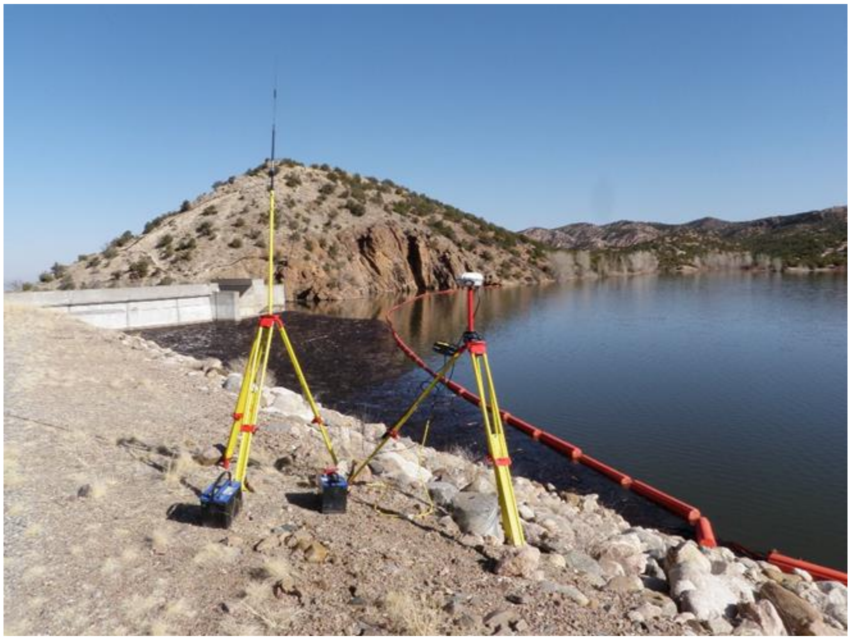


Figure 22. The RTK-GPS base station set-up used during the survey of Nambe Falls Reservoir in New Mexico is typical of the set up used for other reservoir surveys.

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

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

The HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the NAD83 State Plane Wyoming West 4904 coordinate system. Water surface elevations from dam gage records and RTK GPS measurements were used to convert the sonar depth measurements to reservoir-bottom elevations in the RPVD. The multibeam depth sounder generates millions of data points. Sometimes fish, underwater vegetation, or anomalies mean that a small portion of depth measurements do not represent the reservoir bottom and these data are deleted during the post processing. Final processing of the bathymetric data resulted in 4.2 million data points used in the development of the reservoir surface. Filtering of this large data file is necessary, so a 5 ft × 5 ft size raster mesh was created in GIS. For each raster mesh cell, the reservoir bottom elevation is assigned equal to the median elevation of all available data points within that raster cell. The use of the median value reduces the influence of the highest and lowest elevations within the cell.

Appendix B – Above Water Survey Methods

A LiDAR survey of the above-water topography surrounding Fontenelle Reservoir was conducted May 15, 2020. The individual points data points were not obtained from this LiDAR survey, but a digital elevation model (10 m × 10 m raster) of the LiDAR data was obtained from the National Elevation Data (NED) Set (USGS, 2020b). The NED is an elevation dataset that consists of seamless layers and a high-resolution layer. Each of these layers are composed of the best available raster elevation data of the conterminous United States, Alaska, Hawaii, territorial islands, Mexico and Canada. The NED is updated continually as new data become available. All NED data are in the public domain. The NED are derived from diverse source data that are processed to a common coordinate system and unit of vertical measure. These data are distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and, over the continental United States, are referenced to the North American Vertical Datum of 1988 (NAVD 1988). NED data are available nationally (except for Alaska) at resolutions of 1 arc-second (approx. 30 meters) and 1/3 arc-second (approx. 10 meters), and in limited areas at 1/9 arc-second (approx. 3 meters).

Above elevation 6497 feet (RPVD), the reservoir shoreline topography was assumed to remain unchanged from the digital elevation model based on the 2010 LiDAR survey. Even though Fontenelle Reservoir water surface elevation on May 15, 2010 was drawn down to elevation 6470.6 feet (RPVD), the digital elevation model was only processed down to elevation 6505 feet (RPVD). Therefore, there was little if any overlap with the 2019 bathymetric survey data. The NED 10 m × 10 m raster and the predam survey are both too coarse to detect any reservoir shoreline erosion.

Appendix C — Computation of Reservoir Surface Area, Total 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 elevation (LiDAR) data. Horizontal surface areas and reservoir storage volumes were then computed at 1-foot elevation increments, using functions within ArcGIS, for the complete range of reservoir elevations (6392 to 6519 feet, RPVD).

The computed reservoir surface areas and storage volumes were then used in Reclamation's Area-Capacity (ACAP) Excel Program, 2020 Version (Huang, 2020), to interpolate surface areas and storage capacities at 0.1 and 0.01-foot increments between each 1-foot interval. Surface area and total storage capacity (ACAP) tables were then generated for the full range of Fontenelle Reservoir elevations. The ACAP Excel program interpolates the reservoir storage capacity between 1-foot intervals using the following equation:

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

where: V = storage capacity (acre-feet)

y = reservoir elevation,

y_b = reservoir elevation at bottom of elevation increment,

A_1 = storage capacity at elevation y_b (acre-feet),

A_2 = coefficient for linear rate of increase in storage capacity which also equals surface area at elevation y_b (acres), and

A_3 = coefficient for nonlinear rate of increase in storage capacity, computed by enforcing that V = Vt, where Vt is the volume at the top of the interval (y_t):

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

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

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

where: S = surface area (acres),

y = reservoir elevation,

y_b = reservoir elevation at bottom of elevation increment,

B_1 = surface area at elevation y_b (acres), $B_1 = A_2$, and

B_2 = coefficient (feet) for linear rate of increase in surface area, computed by enforcing that S = St, where St is the area at the top of the interval (y_t):

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

This method ensures that the surface areas and capacities as determined from GIS software at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.1 and 0.01-foot intervals.

The sedimentation volume can be computed by subtracting the digital surface of the predam reservoir from the 2019 digital reservoir surface. A predam topographic map of Fontenelle Reservoir is available at 10-foot contour intervals (Reclamation, 1961). However, the development of a digital surface map (rectified in Wyoming State Plane Coordinates) was beyond the scope of this study.

The 2019 bathymetric surface of the reservoir still shows the alignment of the Green River and this alignment matches well with the channel alignment of the predam map. Because the 2019 and predam maps are comparable, the reservoir sedimentation volume was estimated by subtracting the predam storage volume curve from the 2019 storage volume curve (Table 7).

Table 7. Surface area and total storage capacity loss between 1964 and 2019. The original reservoir surface area and storage capacity data are from Reclamation (1969a and 1969b). No detailed data were found for the original reservoir surface area and storage capacity below elevation 6408 feet (RPVD).

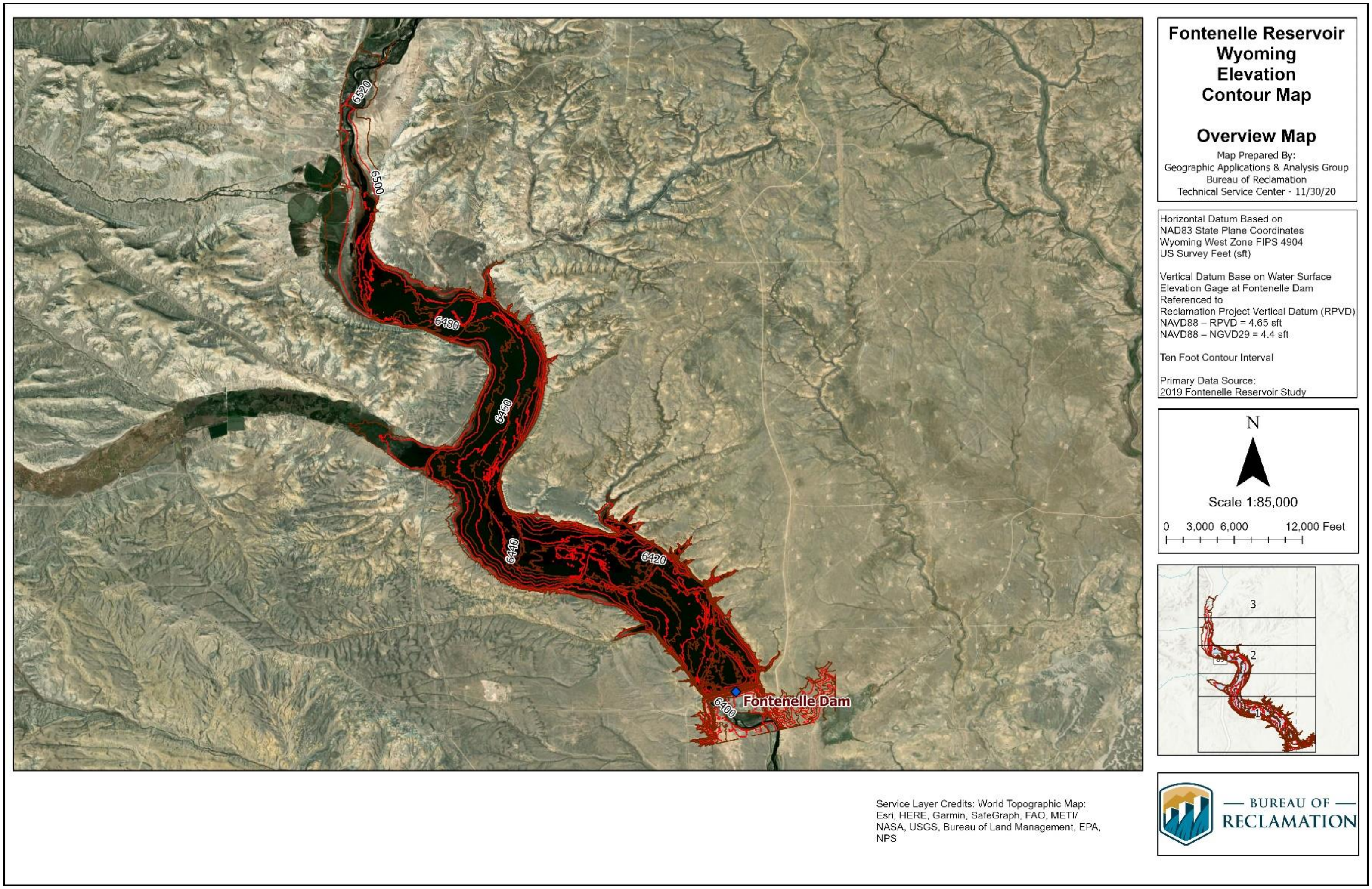
	2019 Survey Results		Original					
Elevation (feet, RPVD)	Area (acres)	Capacity Volume (acre-feet)	Area (acres)	Capacity Volume (acre-feet)	Area Loss (acres)	Area Loss	Sedimentation Volume (acre-feet)	Storage Loss
6392	0.02	0.00						
6393	0.1	0.05						
6394	0.5	0.29						
6395	1.3	1.1						
6396	2.7	3.1						
6397	4.9	6.8						
6398	8.1	13						
6399	12	23						
6400	16	37						
6401	22	56						
6402	29	81						
6403	38	114						
6404	47	157						
6405	58	209						
6406	73	274						
6407	91	356						
6408	108	455	128	560	20	15.8%	105	18.8%
6409	126	572	148	698	22	15.0%	126	18.1%
6410	144	706	168	856	24	14.6%	150	17.5%
6411	160	858	182	1,031	22	11.9%	173	16.7%
6412	179	1,028	196	1,220	17	8.5%	192	15.7%
6413	205	1,219	215	1,426	10	4.6%	207	14.5%
6414	237	1,440	234	1,650	-3	-1.4%	210	12.7%
6415	279	1,697	259	1,897	-20	-7.5%	200	10.5%
6416	328	2,000	284	2,168	-44	-15.4%	168	7.8%
6417	377	2,352	316	2,468	-61	-19.3%	116	4.7%
6418	430	2,755	348	2,800	-82	-23.7%	45	1.6%
6419	490	3,215	389	3,168	-101	-25.9%	-47	-1.5%
6420	543	3,732	429	3,577	-114	-26.6%	-155	-4.3%
6421	596	4,301	479	4,031	-117	-24.3%	-270	-6.7%
6422	653	4,925	528	4,534	-125	-23.6%	-391	-8.6%
6423	714	5,608	589	5,092	-125	-21.2%	-516	-10.1%

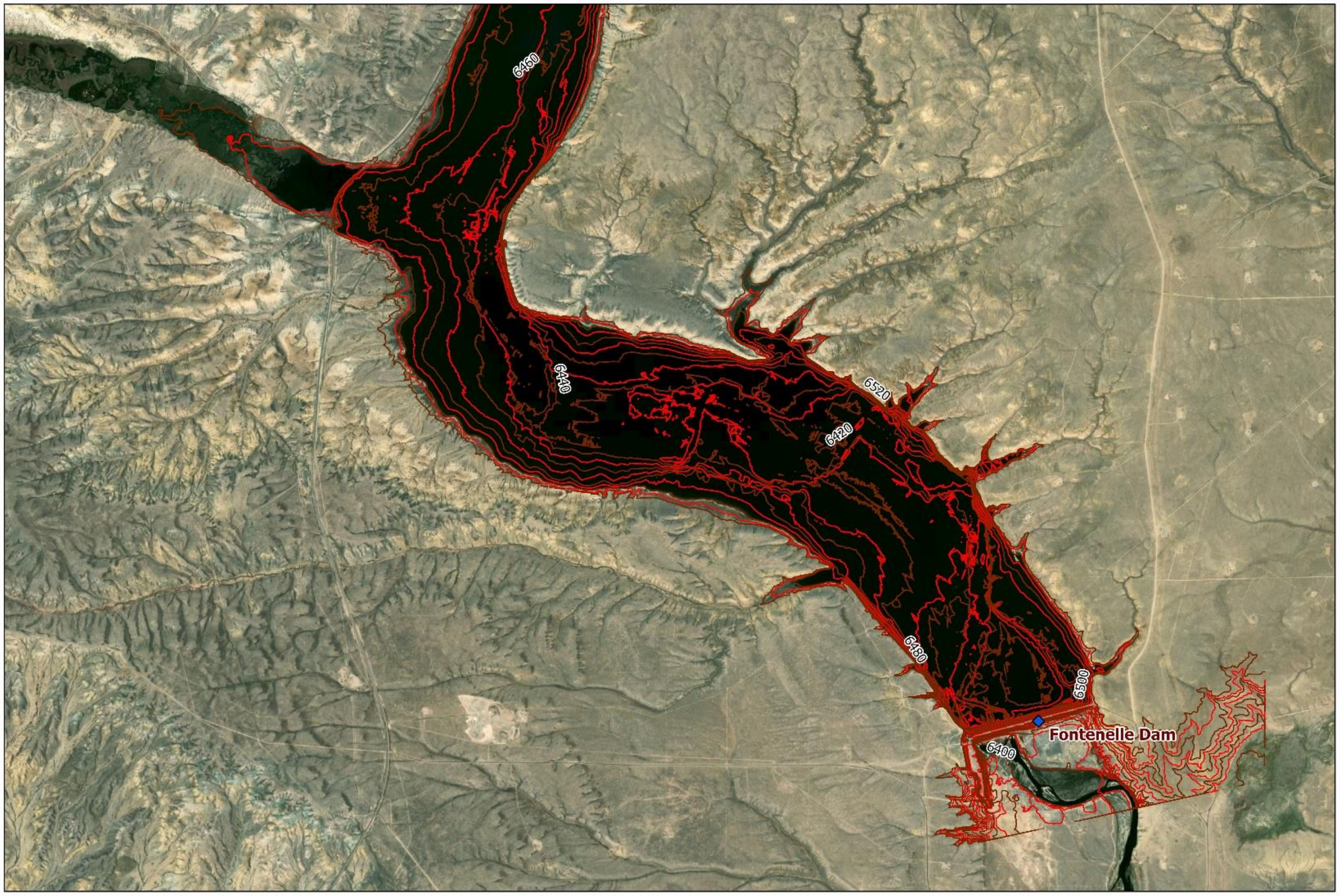
	2019 Survey Results		Original					
Elevation (feet, RPVD)	Area (acres)	Capacity Volume (acre-feet)	Area (acres)	Capacity Volume (acre-feet)	Area Loss (acres)	Area Loss	Sedimentation Volume (acre-feet)	Storage Loss
6424	773	6,352	649	5,711	-124	-19.1%	-641	-11.2%
6425	829	7,153	721	6,396	-108	-14.9%	-757	-11.8%
6426	878	8,007	792	7,152	-86	-10.9%	-855	-11.9%
6427	927	8,910	877	7,987	-50	-5.7%	-923	-11.6%
6428	977	9,861	962	8,906	-15	-1.5%	-955	-10.7%
6429	1,029	10,864	1,061	9,918	32	3.0%	-946	-9.5%
6430	1,081	11,920	1,160	11,028	79	6.8%	-892	-8.1%
6431	1,141	13,030	1,256	12,236	115	9.1%	-794	-6.5%
6432	1,202	14,202	1,352	13,540	150	11.1%	-662	-4.9%
6433	1,269	15,436	1,443	14,937	174	12.0%	-499	-3.3%
6434	1,348	16,745	1,533	16,425	185	12.1%	-320	-1.9%
6435	1,424	18,131	1,619	18,001	195	12.0%	-130	-0.7%
6436	1,499	19,593	1,705	19,663	206	12.1%	70	0.4%
6437	1,570	21,129	1,787	21,409	217	12.1%	280	1.3%
6438	1,639	22,732	1,868	23,236	229	12.3%	504	2.2%
6439	1,712	24,406	1,946	25,143	234	12.0%	737	2.9%
6440	1,820	26,169	2,023	27,127	203	10.1%	958	3.5%
6441	1,931	28,044	2,097	29,187	166	7.9%	1,143	3.9%
6442	2,033	30,027	2,171	31,321	138	6.4%	1,294	4.1%
6443	2,127	32,108	2,242	33,527	115	5.1%	1,419	4.2%
6444	2,209	34,278	2,312	35,804	103	4.5%	1,526	4.3%
6445	2,279	36,522	2,380	38,150	101	4.2%	1,628	4.3%
6446	2,347	38,835	2,448	40,564	101	4.1%	1,729	4.3%
6447	2,420	41,219	2,513	43,044	93	3.7%	1,825	4.2%
6448	2,479	43,668	2,577	45,589	98	3.8%	1,921	4.2%
6449	2,531	46,173	2,640	48,197	109	4.1%	2,024	4.2%
6450	2,581	48,729	2,702	50,868	121	4.5%	2,139	4.2%
6451	2,637	51,338	2,761	53,600	124	4.5%	2,262	4.2%
6452	2,700	54,006	2,820	56,390	120	4.2%	2,384	4.2%
6453	2,756	56,734	2,882	59,241	126	4.4%	2,507	4.2%
6454	2,813	59,519	2,944	62,154	131	4.5%	2,635	4.2%
6455	2,874	62,362	3,011	65,131	137	4.6%	2,769	4.3%
6456	2,934	65,266	3,077	68,175	143	4.7%	2,909	4.3%
6457	2,990	68,228	3,148	71,287	158	5.0%	3,059	4.3%
6458	3,049	71,248	3,218	74,470	169	5.2%	3,222	4.3%

	2019 Survey Results		Original					
Elevation (feet, RPVD)	Area (acres)	Capacity Volume (acre-feet)	Area (acres)	Capacity Volume (acre-feet)	Area Loss (acres)	Area Loss	Sedimentation Volume (acre-feet)	Storage Loss
6459	3,106	74,326	3,292	77,725	186	5.7%	3,399	4.4%
6460	3,160	77,459	3,366	81,054	206	6.1%	3,595	4.4%
6461	3,223	80,649	3,445	84,459	222	6.5%	3,810	4.5%
6462	3,294	83,907	3,523	87,943	229	6.5%	4,036	4.6%
6463	3,366	87,238	3,606	91,507	240	6.6%	4,269	4.7%
6464	3,437	90,640	3,688	95,154	251	6.8%	4,514	4.7%
6465	3,515	94,115	3,775	98,885	260	6.9%	4,770	4.8%
6466	3,606	97,674	3,861	102,703	255	6.6%	5,029	4.9%
6467	3,709	101,330	3,953	106,610	244	6.2%	5,280	5.0%
6468	3,825	105,097	4,044	110,608	219	5.4%	5,511	5.0%
6469	3,937	108,979	4,140	114,700	203	4.9%	5,721	5.0%
6470	4,043	112,969	4,235	118,887	192	4.5%	5,918	5.0%
6471	4,138	117,060	4,340	123,174	202	4.7%	6,114	5.0%
6472	4,231	121,244	4,444	127,566	213	4.8%	6,322	5.0%
6473	4,332	125,524	4,554	132,065	222	4.9%	6,541	5.0%
6474	4,445	129,910	4,663	136,673	218	4.7%	6,763	4.9%
6475	4,566	134,417	4,772	141,390	206	4.3%	6,973	4.9%
6476	4,688	139,044	4,881	146,217	193	4.0%	7,173	4.9%
6477	4,830	143,801	4,933	151,154	103	2.1%	7,353	4.9%
6478	4,981	148,705	5,104	156,202	123	2.4%	7,497	4.8%
6479	5,134	153,766	5,250	161,379	116	2.2%	7,613	4.7%
6480	5,282	158,973	5,396	166,702	114	2.1%	7,729	4.6%
6481	5,446	164,341	5,554	172,177	108	1.9%	7,836	4.6%
6482	5,579	169,854	5,712	177,810	133	2.3%	7,956	4.5%
6483	5,711	175,497	5,851	183,591	140	2.4%	8,094	4.4%
6484	5,856	181,279	5,989	189,511	133	2.2%	8,232	4.3%
6485	5,994	187,206	6,113	195,562	119	1.9%	8,356	4.3%
6486	6,127	193,265	6,236	201,736	109	1.7%	8,471	4.2%
6487	6,259	199,460	6,357	208,032	98	1.5%	8,572	4.1%
6488	6,374	205,776	6,477	214,449	103	1.6%	8,673	4.0%
6489	6,483	212,207	6,593	220,984	110	1.7%	8,777	4.0%
6490	6,580	218,739	6,709	227,635	129	1.9%	8,896	3.9%
6491	6,671	225,365	6,787	234,383	116	1.7%	9,018	3.8%
6492	6,752	232,077	6,865	241,209	113	1.6%	9,132	3.8%
6493	6,829	238,867	6,939	248,111	110	1.6%	9,244	3.7%

	2019 Survey Results		Original					
Elevation (feet, RPVD)	Area (acres)	Capacity Volume (acre-feet)	Area (acres)	Capacity Volume (acre-feet)	Area Loss (acres)	Area Loss	Sedimentation Volume (acre-feet)	Storage Loss
6494	6,914	245,739	7,013	255,087	99	1.4%	9,348	3.7%
6495	7,000	252,695	7,098	262,142	98	1.4%	9,447	3.6%
6496	7,088	259,739	7,182	269,282	94	1.3%	9,543	3.5%
6497	7,174	266,870	7,269	276,507	95	1.3%	9,637	3.5%
6498	7,260	274,087	7,355	283,819	95	1.3%	9,732	3.4%
6499	7,322	281,380	7,444	291,218	122	1.6%	9,838	3.4%
6500	7,377	288,730	7,532	298,706	155	2.1%	9,976	3.3%
6501	7,430	296,133	7,616	306,280	186	2.4%	10,147	3.3%
6502	7,567	303,615	7,700	313,938	133	1.7%	10,323	3.3%
6503	7,631	311,214	7,784	321,680	153	2.0%	10,466	3.3%
6504	7,697	318,877	7,868	329,506	171	2.2%	10,629	3.2%
6505	7,765	326,608	7,963	337,421	198	2.5%	10,813	3.2%
6506	7,861	334,411	8,058	345,432	197	2.4%	11,021	3.2%
6507	7,988	342,348	8,153	353,537	165	2.0%	11,189	3.2%
6508	8,111	350,397	8,248	361,738	137	1.7%	11,341	3.1%
6509	8,231	358,567	8,343	370,034	112	1.3%	11,467	3.1%
6510	8,354	366,858	8,438	378,424	84	1.0%	11,566	3.1%
6511	8,477	375,271	8,565	386,926	88	1.0%	11,655	3.0%
6512	8,598	383,808	8,692	395,554	94	1.1%	11,746	3.0%
6513	8,712	392,463	8,819	404,309	107	1.2%	11,846	2.9%
6514	8,831	401,232	8,945	413,191	114	1.3%	11,959	2.9%
6515	8,961	410,127	9,074	422,201	113	1.2%	12,074	2.9%
6516	9,098	419,154	9,203	431,339	105	1.1%	12,185	2.8%
6517	9,246	428,325	9,344	440,612	98	1.0%	12,287	2.8%
6518	9,397	437,646	9,484	450,026	87	0.9%	12,380	2.8%
6519	9,559	447,123	9,624	459,580	65	0.7%	12,457	2.7%

Contour Maps





Fontenelle Reservoir
Wyoming
Elevation
Contour Map

Sheet 1

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 11/30/20

Horizontal Datum Based on
NAD83 State Plane Coordinates
Wyoming West Zone FIPS 4904
US Survey Feet (sft)

Vertical Datum Base on Water Surface
Elevation Gage at Fontenelle Dam
Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88 – RPVD = 4.65 sft
NAVD88 – NGVD29 = 4.4 sft

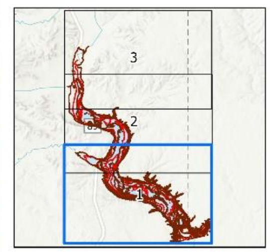
Ten Foot Contour Interval

Primary Data Source:
2019 Fontenelle Reservoir Study

N

Scale 1:40,000

0 1,500 3,000 6,000 Feet



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

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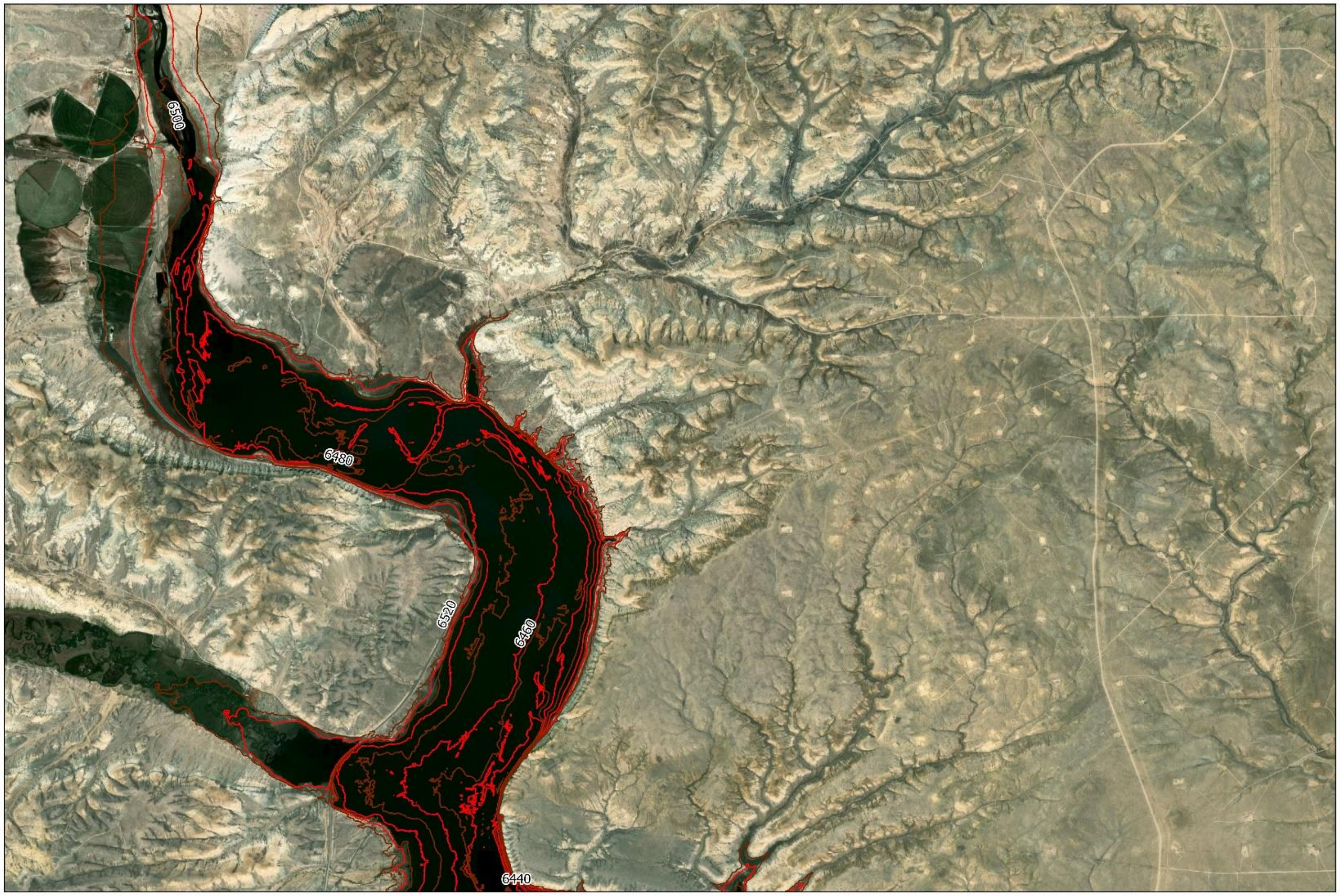


Fontenelle Reservoir Wyoming Elevation Contour Map

Sheet 2

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 11/30/20

Horizontal Datum Based on
NAD83 State Plane Coordinates
Wyoming West Zone FIPS 4904
US Survey Feet (sft)

Vertical Datum Base on Water Surface
Elevation Gage at Fontenelle Dam
Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88 – RPVD = 4.65 sft
NAVD88 – NGVD29 = 4.4 sft

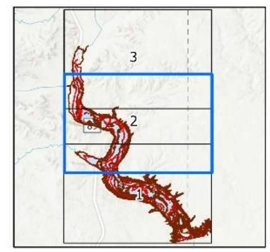
Ten Foot Contour Interval

Primary Data Source:
2019 Fontenelle Reservoir Study

N

Scale 1:40,000

0 1,500 3,000 6,000 Feet



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NPS

Fontenelle Reservoir Wyoming Elevation Contour Map

Sheet 3

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 11/30/20

Horizontal Datum Based on
NAD83 State Plane Coordinates
Wyoming West Zone FIPS 4904
US Survey Feet (sft)

Vertical Datum Base on Water Surface
Elevation Gage at Fontenelle Dam
Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88 – RPVD = 4.65 sft
NAVD88 – NGVD29 = 4.4 sft

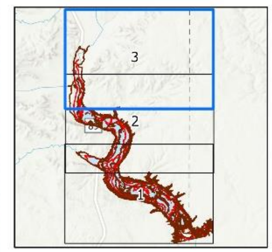
Ten Foot Contour Interval

Primary Data Source:
2019 Fontenelle Reservoir Study

N

Scale 1:40,000

0 1,500 3,000 6,000 Feet



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