BUREAU OF RECLAMATION

Technical Report No. ENV-2021-111

Flaming Gorge Reservoir 2019 Sedimentation Survey

Colorado River Storage Project, Utah
Upper Colorado Basin Region

U.S. Department of the Interior

November 2021

Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

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

Acknowledgements

Several people inside and outside of Reclamation were involved in the completion of this study. The survey, analysis, and report were funded by Reclamation's Upper Colorado Basin Regional Office (UCBRO) in Salt Lake City, Utah. Nathan Clifton of the Upper Colorado Resources Administration Group (UC-432) acted as the client contact, provided aerial LiDAR collected by Atlantic under contract with UCB Region, and served as a report reviewer. Kent Collins of the Sedimentation and River Hydraulics Group (86-68240) at Reclamation's Technical Service Center (TSC) in Denver, Colorado led the May-June 2019 and September 2020 bathymetric surveys. David Varyu, Robert Hilldale, Michael Sixta, Travis Hardee, Steven Hollenback, Vincent Benoit, Aaron Hurst, and Caroline Ubing, all of 86-8240, participated in the bathymetric surveys. Data were processed by Kent Collins and Travis Hardee. Colin Byrne (86-68240) combined the bathymetric and LiDAR data and developed the digital surface for analysis. Nate Bradley (86-68240) computed the 2019 areas and capacities. Jack Truax of the Geographic Applications and Analysis Group (86-68260), TSC, Denver, generated the watershed and contour maps for this report. Kent Collins and Colin Byrne prepared the survey report and area and capacity table technical memorandum. Technical peer review of this document was provided by Robert Hilldale (86-68240) and Nathan Clifton (UC-432).

Disclaimer

No warranty is expressed or implied regarding the usefulness or completeness of the information contained in this report. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.

Cover: Flaming Gorge Dam, looking downstream from right bank (photo credit: Reclamation/Collins)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
16-11-2021	Final report	May 2019 to September 2020

4. TITLE AND SUBTITLE
Technical Report No. ENV-2019-111
Flaming Gorge Reservoir 2019 Sedimentation Survey
Colorado River Storage Project, UT
Upper Colorado Basin Region

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Kent Collins
Colin Byrne

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Technical Service Center
Sedimentation and River Hydraulics Group
Building 67, Mail Code: 86-68240
Denver, Colorado

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Fill in only if this was funded by someone other than Reclamation.

10. SPONSOR/MONITOR'S ACRONYM(S)
11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
https://www.usbr.gov/tsc/techreferences/reservoir.html

13. SUPPLEMENTARY NOTES

14. SHORT ABSTRACT

The 2019-2020 multibeam bathymetric survey of Flaming Gorge Reservoir was combined with a 2019 aerial LiDAR survey to produce a continuous digital surface of the reservoir bottom up to dam crest elevation 6047.0 feet (Reclamation Project Vertical Datum [RPVD]). Analysis of this data indicates that at the top of active conservation pool elevation (6040.0 feet, RPVD), the reservoir had a surface area of 42,613 acres and a storage capacity of 3,711,306 acre-feet. Since the original filling began in 1962, the reservoir is estimated to have lost 80,394 acre-feet of storage capacity (2.2%) due to sedimentation. Results indicate Flaming Gorge Reservoir has maintained its dead storage pool volume (below elevation 5740.0 feet) since operations began.

15. SUBJECT TERMS
Flaming Gorge Reservoir survey, sedimentation, surface area, storage capacity, multibeam bathymetry, LiDAR

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	THIS PAGE			Kent Collins
U	U	U		93	19b. TELEPHONE NUMBER *(Include area code)* 303-445-2549

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. ENV-2019-111

Flaming Gorge Reservoir 2019 Sedimentation Survey

KENT COLLINS

Digitally signed by KENT COLLINS
Date: 2021.12.02 08:29:55 -07'00'

Prepared by : Kent Collins, PE, Hydraulic Engineer, Sedimentation and River Hydraulics, 86-68240

COLIN BYRNE

Digitally signed by COLIN BYRNE
Date: 2021.12.02 09:47:06 -07'00'

Prepared by: Colin Byrne, PhD, Hydraulic Engineer, Sedimentation and River Hydraulics, 86-68240

ROBERT HILLDALE

Digitally signed by ROBERT HILLDALE
Date: 2021.12.02 11:40:53 -07'00'

Peer Reviewed by: Robert Hilldale, PE, Hydraulic Engineer, Sedimentation and River Hydraulics Group, 86-68240

Acronyms and Abbreviations

BLM	Bureau of Land Management
ft^3/s	cubic feet per second (cfs)
DOI	Department of the Interior
DGPS	Differential Global Positioning System
ft	foot or feet
FS	Forest Service
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
mi^2	square miles
NAD83	North American Datum, established 1983
NAVD88	North American Vertical Datum, established 1988
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum, established 1929
NID	National Inventory of Dams
NOAA	National Oceanic and Atmospheric Administration
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
WSS	Web Soil Survey

Executive Summary

Flaming Gorge Dam is on the Green River about 40 miles south from Green River, Wyoming (Figure 1) and 32 river miles downstream from the Utah-Wyoming border. Flaming Gorge Dam and Powerplant were constructed between 1958 and 1962 as part of the Colorado River Storage Project, which provides vital water storage and hydropower generation as well as many recreation benefits. Impounding Flaming Gorge Reservoir, the concrete thin-arch dam has a maximum height of 502 feet. The dam and reservoir are operated by the Power Office of Reclamation's Upper Colorado Basin Region.

A bathymetric survey of Flaming Gorge Reservoir was conducted in 2019 and 2020 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1962; and
2. Determine new reservoir surface area and storage capacity tables for the full elevation range of dam and reservoir operations.

The bathymetric survey was conducted from two boats using multibeam depth sounders interfaced with differential global positioning system (DGPS) instruments (for horizontal positioning) to map the reservoir bottom. During processing, depths measured during the bathymetric survey were subtracted from water surface elevations measured at the dam to calculate reservoir bottom elevations. The 2019-2020 multibeam bathymetric survey of Flaming Gorge Reservoir was combined with a 2019 aerial Light Detection and Ranging (LiDAR) survey conducted by Atlantic under contract with Reclamation's Upper Colorado Basin Region to produce a continuous digital surface of the reservoir bottom.

The bathymetric survey was conducted between May 29 and June 7, 2019, when the reservoir water surface elevation ranged between 6030.1 and 6031.0 feet (Reclamation Project Vertical Datum [RPVD]), and September 27 and 28, 2020 between water surface elevations 6026.1 and 6026.0 feet. Water surface elevations fluctuated between 6029.3 and 6029.4 feet during the above-water LiDAR survey on May 12 and 13, 2019.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 6026 feet (RPVD), which is about 5 feet below water at the time of survey, the reservoir surface area was 35,461 acres with a storage capacity of 3,158,466 acre-feet.
- At the top of active conservation pool elevation (6040 feet, RPVD), the reservoir had a surface area of 42,613 acres and a storage capacity of 3,711,306 acre-feet.
- Since the original filling of the reservoir in 1962, the reservoir is estimated to have lost 80,394 acre-feet of storage capacity (2.2 percent) due to sedimentation below elevation 6040 (top of active conservation pool). This volume represents a sediment

yield rate of 0.13 acre-feet per square mile per year (acre-feet/mi^2/year), which is considered very low as defined in Reclamation (2006).

- The 2019 survey results indicate Flaming Gorge Reservoir has maintained its dead storage since initial reservoir filling began in 1962. The sedimentation level near the dam is significantly lower than projected in the standing operating procedures (Reclamation, 2019)

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	Flaming Gorge	**Region**	Upper Colorado Basin
Owner	Bureau of Reclamation	**Area Office**	Provo
Stream	Green River	**Vertical Datum**	RPVD
County	Daggett & Sweetwater	**Top of Dam (ft)**	6047.0
State	Utah & Wyoming	**Spillway Crest (ft)**	6006.0
Lat (deg min sec)	40 54 42	**Power Penstock Elevation (ft)**	5845.0†
Long (deg min sec)	-109 25 12	**Low Level outlet (ft)**	5740.0
HUC4	1404	**Hydraulic Height (ft)**	453
HUC8	14040106; 14040107	**Total Drainage Area (mi^2)**	15,748
NID ID	UT10121	**Date storage began (mm/dd/yyyy)**	12/10/1962
Dam Purpose	Water storage (flood control and water delivery), hydropower, recreation	**Date for normal operations (mm/dd/yyyy)**	09/27/1963

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

Original Design

Storage Allocation	Elevation (feet)	Surface area (acres)	Capacity (acre-feet)	Gross Capacity (acre-feet)
SURCHARGE	6045.0	43,380	213,500	4,005,200
CONSERVATION	6040.0	42,020	3,518,414	3,791,700
INACTIVE	5871.0	5,702	233,586	273,286
DEAD	5740.0	720	39,700	39,700

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Sediment Contributing Drainage Area (mi^2)	Period Sedimentation Volume (acre-feet)	Cumulative Sedimentation (acre-feet)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
Prior to 1962	Photogrammetry*	unknown	15,748	0	0	5592.0	100
2019	Multibeam and LiDAR	10-foot contours	10,728	80,394	80,394	5586.0	100

Notes

†In 1978, a selective withdrawal structure was installed into the upstream faces of each of the three penstocks, allowing them to draw water anywhere from elevation 5913 to 6005 feet (RPVD) providing some control over the downstream water temperature. The original penstock intakes at elevation 5845 are left closed during normal operation.

*No information was located on methods used in original (1962) survey. Based on the time period, it was assumed that photogrammetry was used to map the reservoir area prior to filling.

Contents

Tables

Figures

1. Introduction

Flaming Gorge Dam is on the Green River about 40 miles south from Green River, Wyoming (Figure 1) and 32 river miles downstream from the Utah-Wyoming border. Flaming Gorge Dam and Powerplant were constructed between 1958 and 1962 as part of the Colorado River Storage Project, which provides vital water storage and hydropower generation as well as many recreation benefits. Impounding Flaming Gorge Reservoir, the concrete thin-arch dam has a maximum height of 502 feet. The dam and reservoir are operated by the Power Office of Reclamation's Upper Colorado Basin Region.

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

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

As part of ongoing operations and sediment monitoring activities, Reclamation's Upper Colorado Resources Administration Group (UC-432) 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 complete bathymetric survey was conducted from May 29 to June 7, 2019 and September 27 to 28, 2020 with these primary objectives:

- Estimate reservoir sedimentation volume since the original reservoir filling began in 1962 and

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

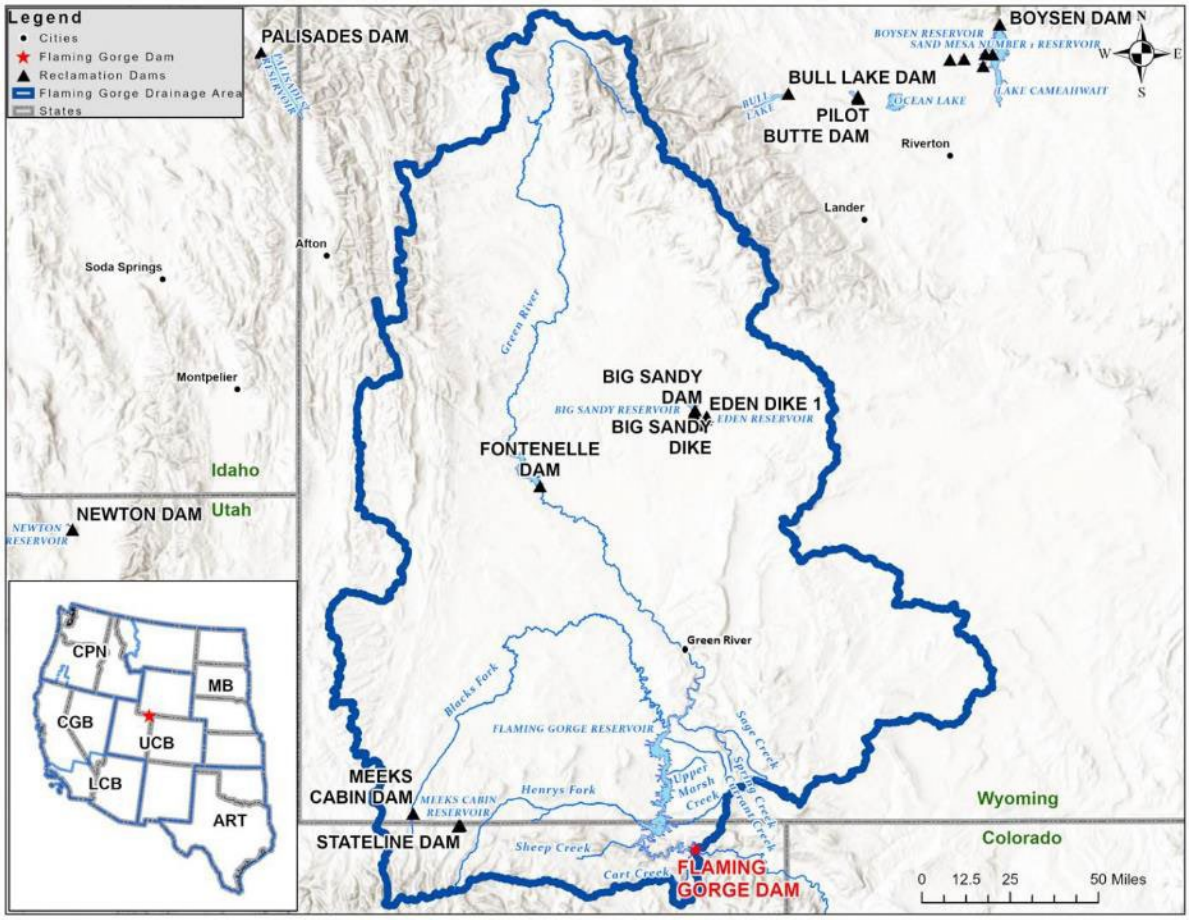


Figure 1. Location map of Flaming Gorge Dam and Reservoir, 40 miles south from Green River, Wyoming. The watershed above Flaming Gorge Dam has a total drainage area of 15,748 mi^2 and a sediment-contributing drainage area of 10,728 mi^2.

2. Watershed Description

2.1. Location and Drainage

The watershed upstream from Flaming Gorge Dam has a total contributing drainage area of 15,748 square miles (mi^2). Because of upstream lakes and reservoirs that trap sediment (as of 2020), the net sediment-contributing drainage area to Flaming Gorge Reservoir is 10,728 mi^2 (Figure 1). This watershed is primarily in southwestern Wyoming with smaller portions originating in Utah and Colorado. The headwaters of the Green River, Big Sandy River, and Blacks Fork Creek all begin in mountainous terrain. Elevations in the sediment-contributing watershed range from approximately 6,028 to 13,453 feet. Approximately 79 percent of the contributing watershed can be classified as high desert and shrubland while the remaining 21 percent is temperate coniferous forest of the Rocky Mountains.

2.2. Geology

The geology of the Flaming Gorge watershed's sediment-contributing drainage area consists primarily of sedimentary rocks including sandstones, oil-shales, and clays (Figure 2). The entire Flaming Gorge watershed is predominantly sedimentary rock (74 percent by area). Some of the headwaters originate in mountainous areas with igneous (4 percent) and metamorphic rock (1 percent), however much of this area first drains to Fontenelle Reservoir, which is upstream of Flaming Gorge Reservoir on the Green River. In addition to the sedimentary rock, a large proportion of the watershed is classified as unconsolidated material (20 percent) including clays, sands, and gravels (Horton, 2017).

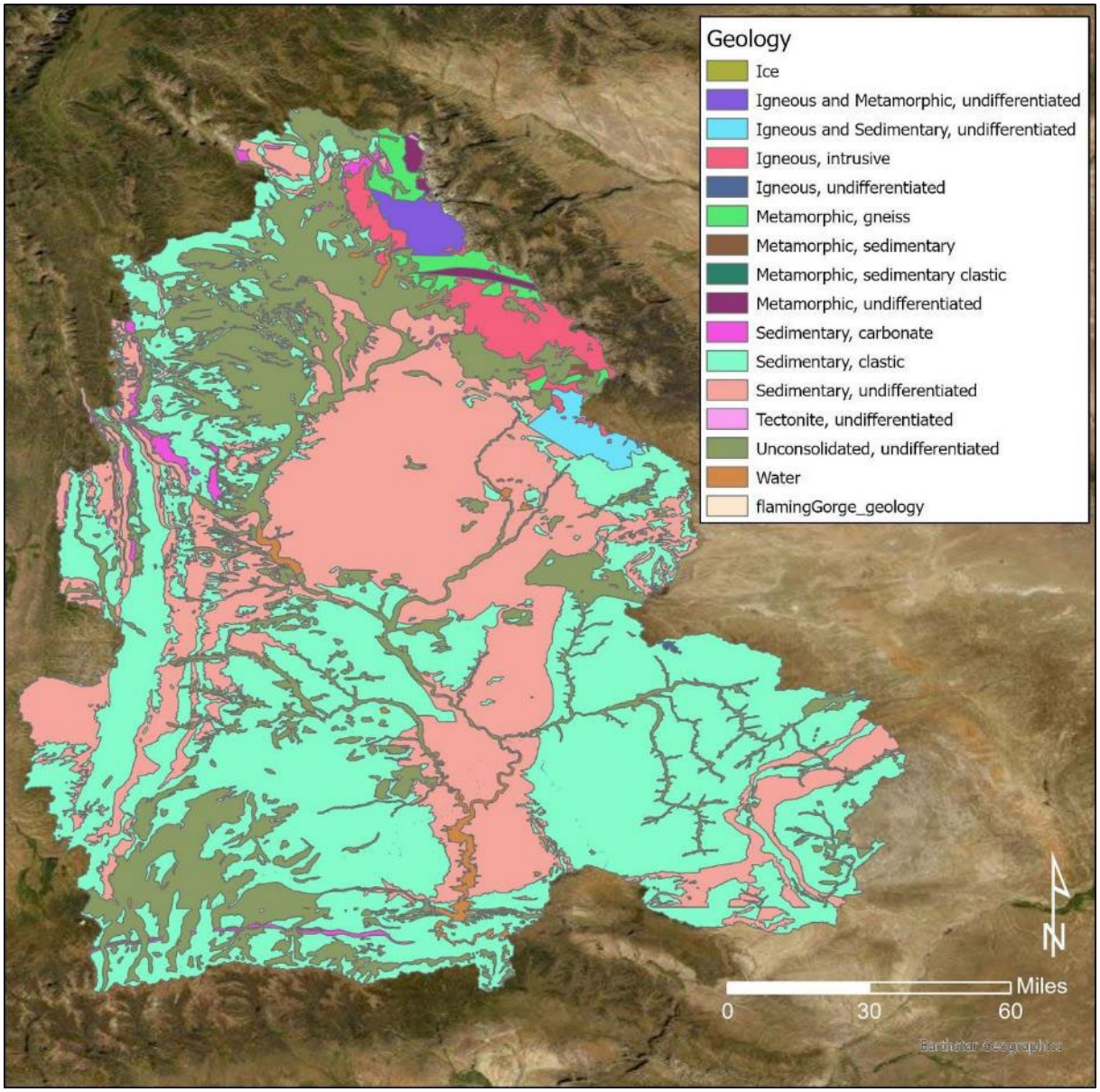


Figure 2. Flaming Gorge watershed geology by material class

Table 1. Geologic characteristics of Flaming Gorge Reservoir watershed.

Geology Type	Percentage of Watershed Area
Sandstone	27.3
Oil-shale	22.0
Clay	8.5
Claystone	6.6
Mudstone	6.6
Sand	4.9
Gravel	3.9
Unconsolidated	2.7
Arenite	2.7
Shale	2.5
Gneiss	1.8
Conglomerate	1.8
Marlstone	1.7
Granite	1.5
Siltstone	1.0
Other rock types	<1.0

2.3. Soils, Vegetation, and Land Use

Figure 3 shows the soil types within the watershed primarily consist of Natural Resources Conservation Service (NRCS) Soil Groups B and D, which account for 37 and 48 percent of the watershed area, respectively. The high proportion of Group D soils corresponds to the large amount of clay within the region and causes low infiltration rates. Locations with Group B soils will be associated with higher infiltration rates. Smaller percentages of Group A (12 percent) and Group C (3 percent) soils are found within the Flaming Gorge watershed.

Hydrologic soil groups from the NRCS Web Soil Survey (WSS) Geodatabase are described as follows:

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

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

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

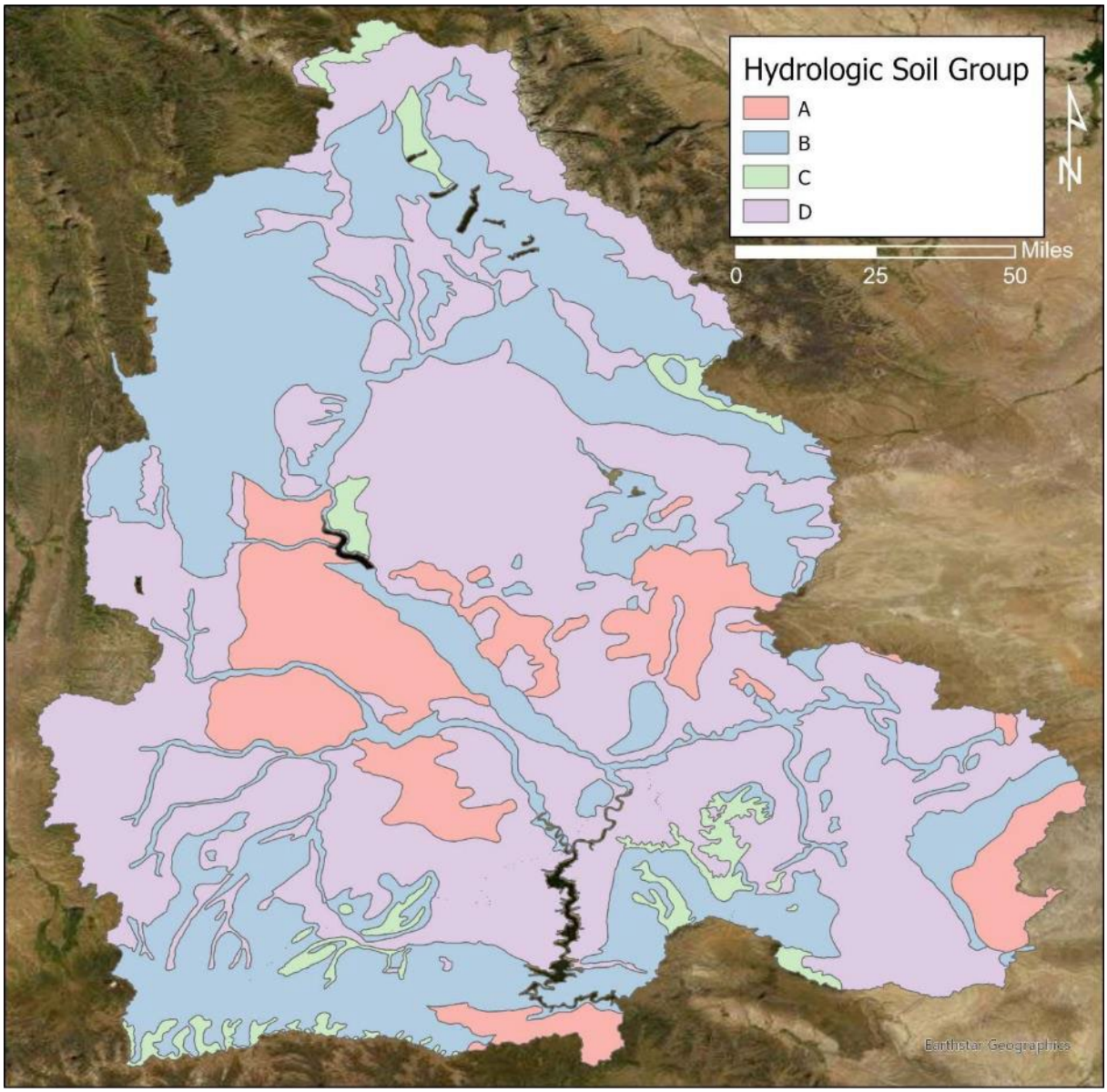


Figure 3. Soil classifications of the Flaming Gorge wathershed.

The Flaming Gorge watershed includes large expanses of undeveloped land. Vegetation types within the watershed are primarily desert and xeric shrublands (79 percent) with smaller percentages of coniferous forest at higher elevations (21 percent). The majority of the watershed is owned by the federal government. The Bureau of Land Management (BLM) owns approximately 50 percent of the watershed, while the United States Forest Service (FS), BOR, and the United States Fish and Wildlife Service (FWS) own 17, 3.0 and 0.2 percent, respectively. While much of the watershed is undeveloped, agriculture is present on alluvial surfaces along many of the tributaries in the region.

2.4. Climate and Runoff

Monthly average temperatures near Flaming Gorge Dam (National Oceanic and Atmospheric Administration [NOAA] Station at Flaming Gorge, Utah – USC00422864) suggest the reservoir is subjected to cold winters and hot summers (Figure 4). Precipitation is greatest from spring to fall, but never exceeds 1.4 inches per month. Precipitation is observably lower during the late fall and winter months. Locations within the watershed further from the dam are likely to have different temperature and precipitation patterns, especially in mountainous terrain.

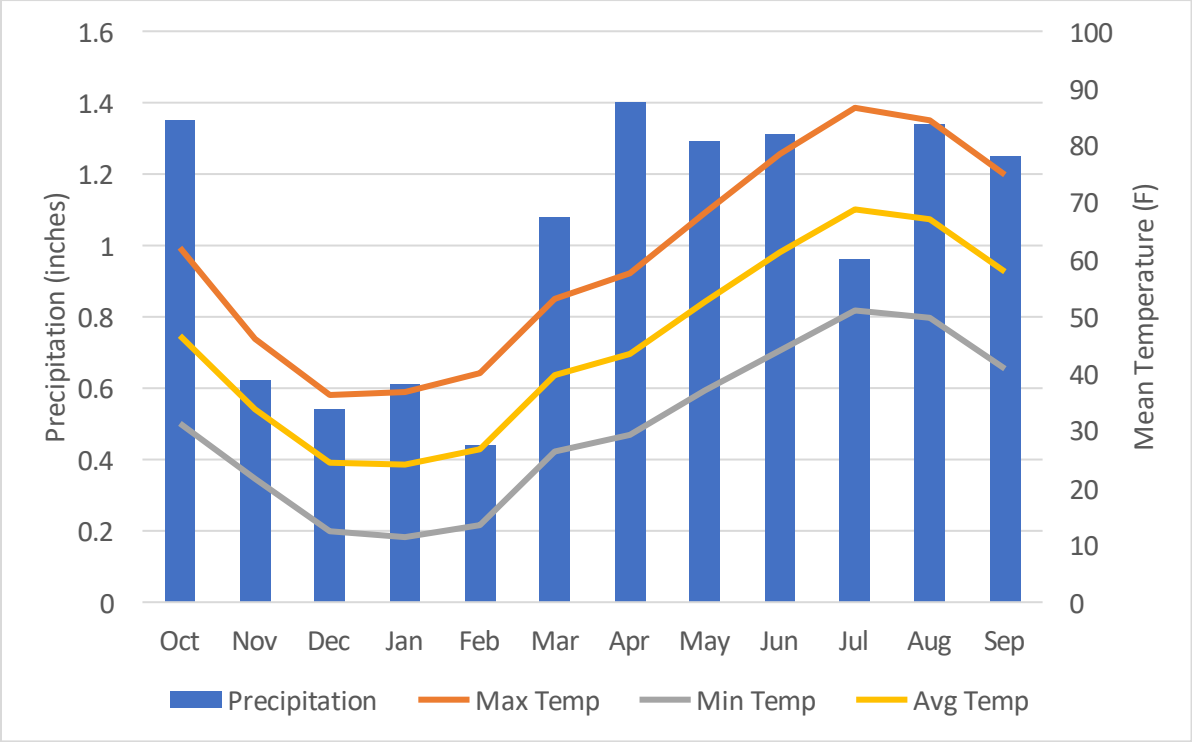


Figure 4. Mean monthly precipitation and temperature by water year at the Flaming Gorge, Utah station based on 1981-2010 data.

Reservoir inflows are primarily from the Green and Blacks Fork Rivers. Because of the upstream Fontenelle Dam, which was completed in 1962, a large proportion of the Green River watershed's sediment-contributing area is derived from the Big Sandy and Bitter Creek tributaries. USGS stream gage records are available for the locations in presented in Table 2, which represents 85 percent of the total contributing drainage area.

Based on Hydromet data, the mean annual runoff to Flaming Gorge Reservoir is 1.8 inches per year or 1,536,349 acre-feet per year (Figure 5). This runoff is primarily from snowmelt. The mean annual stream flow to the reservoir is 2,154 cubic feet per second (cfs [Figure 6]). The ratio of reservoir storage capacity to the mean annual runoff is 2.4 at top of active conservation pool elevation 6040.0[1] feet (RPVD). This means that, when full, the reservoir stores a water volume equivalent to 882 days of mean annual stream flow.

Table 2. Reservoir Inflow Streams with USGS gages. Note that not all of the contributing area to the reservoir is captured by USGS gages.

USGS Stream Gage		**Drainage Area (mi^2)**	**Mean Annual Runoff (cfs)**	**Period of Record**
Name	**Number**			
Henrys Fork near Manila, UT	09229500	520	82	1928 to 1993 & 2002 to present
Blacks Fork near Little America, WY	09224700	3,100	296	1963 to present
Green River near Green River, WY	09217000	9,740	1,612	1952 to present
Totals		13,360	1,990	

[1] Unless otherwise noted, all elevations presented in this report are referenced to the Reclamation Project Vertical Datum (RPVD) in feet measured to be 4.61 feet lower than NAVD88, Geoid 18.

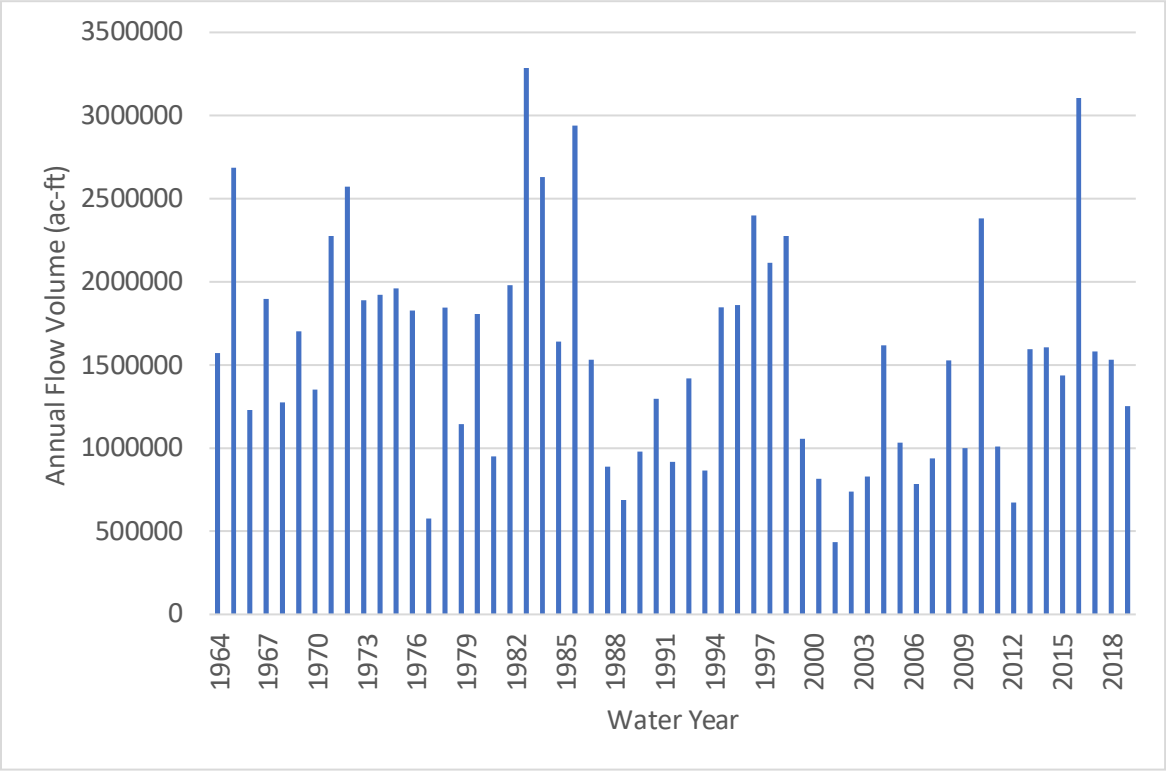


Figure 5. Annual flow volume to Flaming Gorge Reservoir.

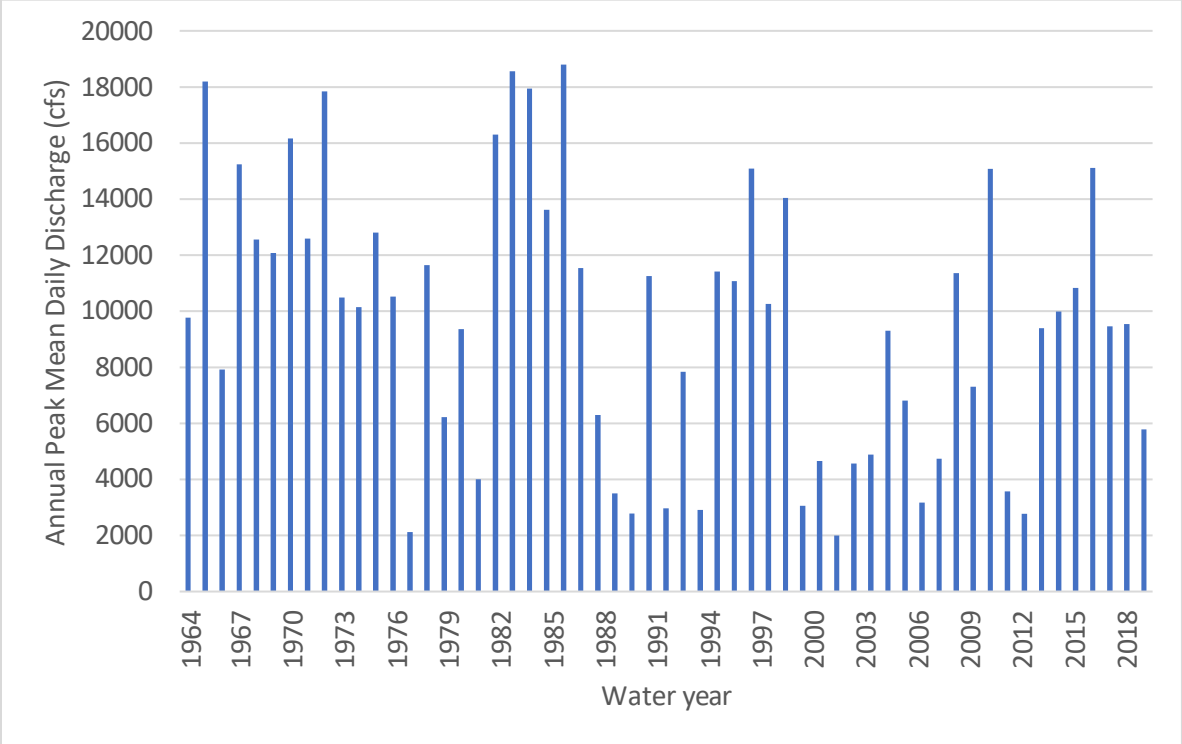


Figure 6. Annual peak mean daily discharge into Flaming Gorge Reservoir.

2.5. Dam Operations and Reservoir Characteristics

Flaming Gorge Dam is a thin-arch concrete dam. This dam was completed in 1962 and began storing water later in the year. Power was first generated at the dam in 1963. The dam has a height above the original stream bed of 455 feet and the reservoir had an original length of about 34 miles long at full pool with three major tributaries. However, there are multiple locations where the reservoir is split by islands and longer meanders exist as well. Important features of the dam are identified by the following elevations in feet (RPVD):

- Dam Crest = 6047.0
- Spillway Crest = 6006.0
- Penstock Inverts = 5845.0
- River Outlet Inverts = 5740.0

The historical daily reservoir water surface elevations (Reclamation Project Vertical Datum) are presented in Figure 7. Annually, reservoir water surface typically fluctuates about 13 feet on average. The highest water surface elevation for reservoir was recorded in 1983 at 6042.5 feet. The lowest water surface elevation after the conservation pool elevation was reached was in 1978 at 5987.9 feet. Since that time pool elevations have fluctuated rather consistently with the exception of 2002 to 2004 when water surface elevations were relatively low and dropped to an elevation of 6008.6 feet due to dry conditions.

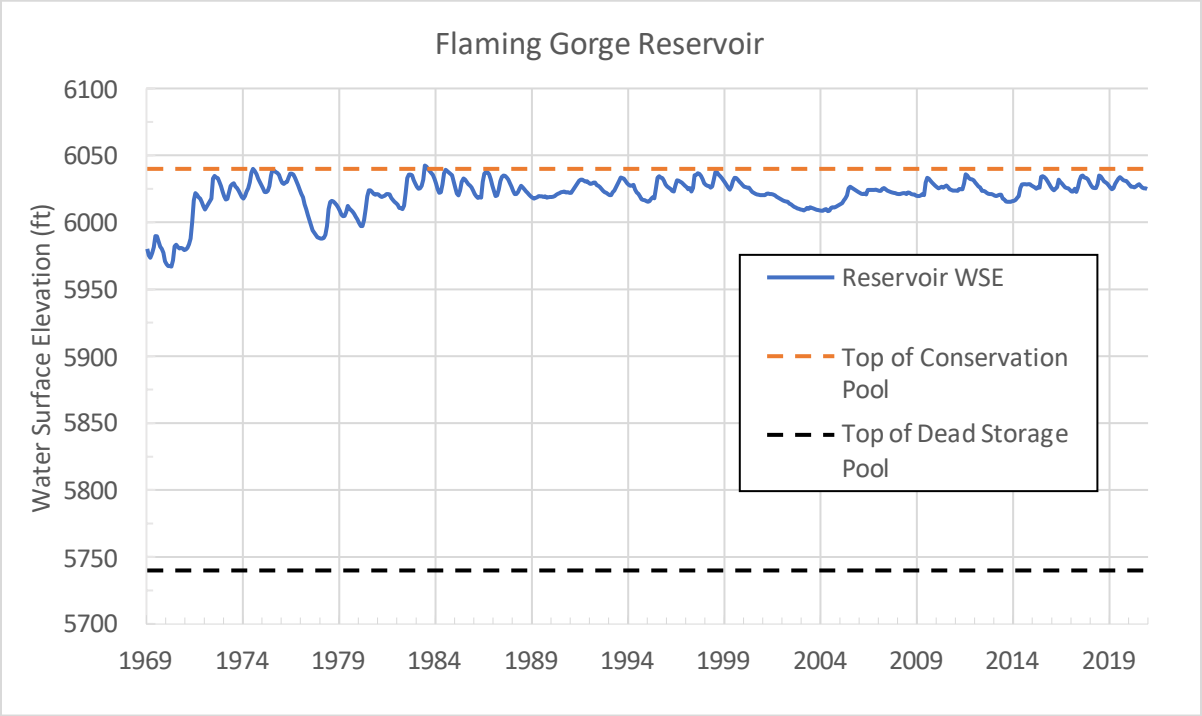


Figure 7. Historic Flaming Gorge water surface elevations (project datum). Data web source: https://www.usbr.gov/rsvrWater/HistoricalApp.html.

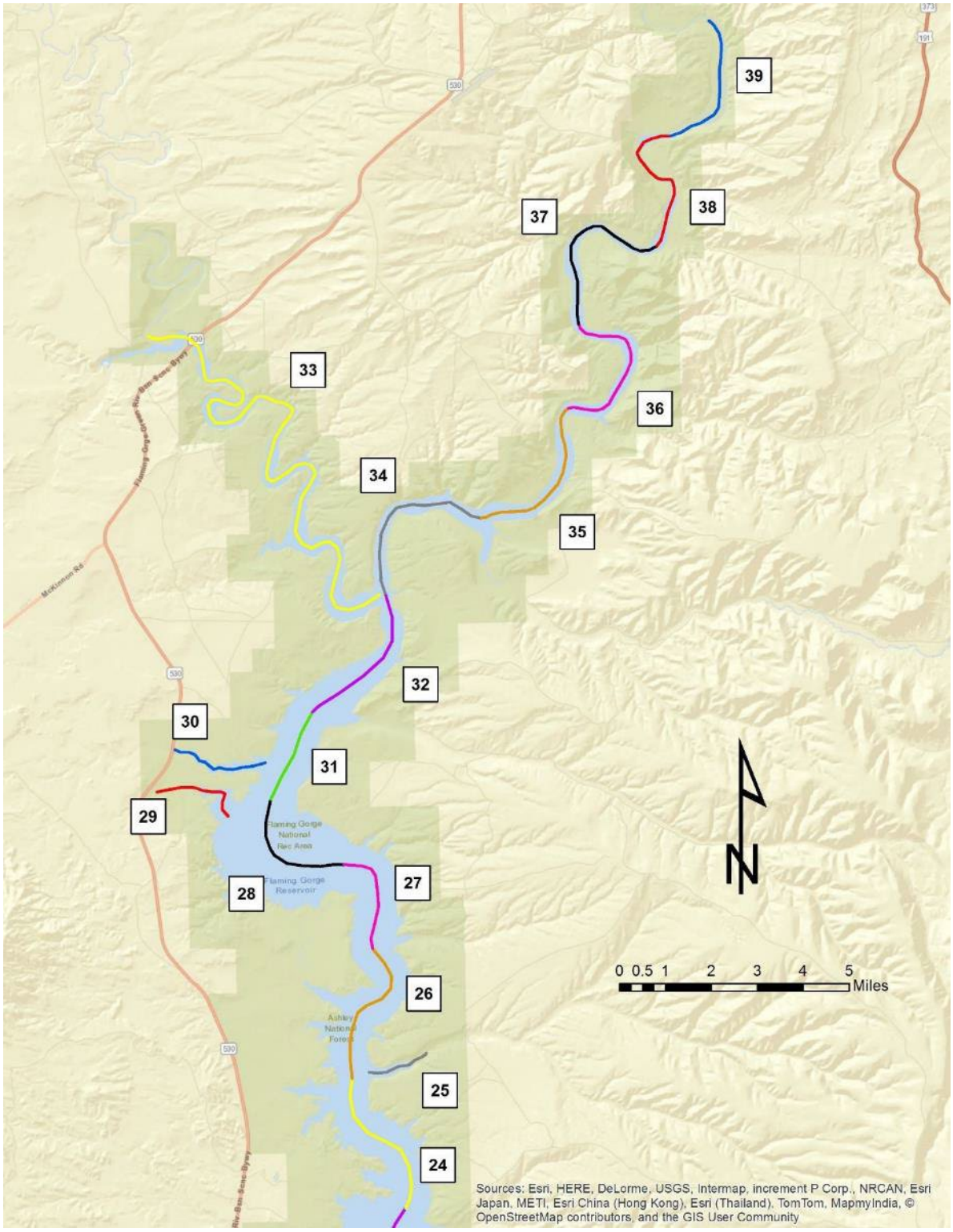


Figure 8. Upper portion of Flaming Gorge Reservoir divided into 2019-2020 bathymetric survey reaches. Map shows variation in reservoir characteristics

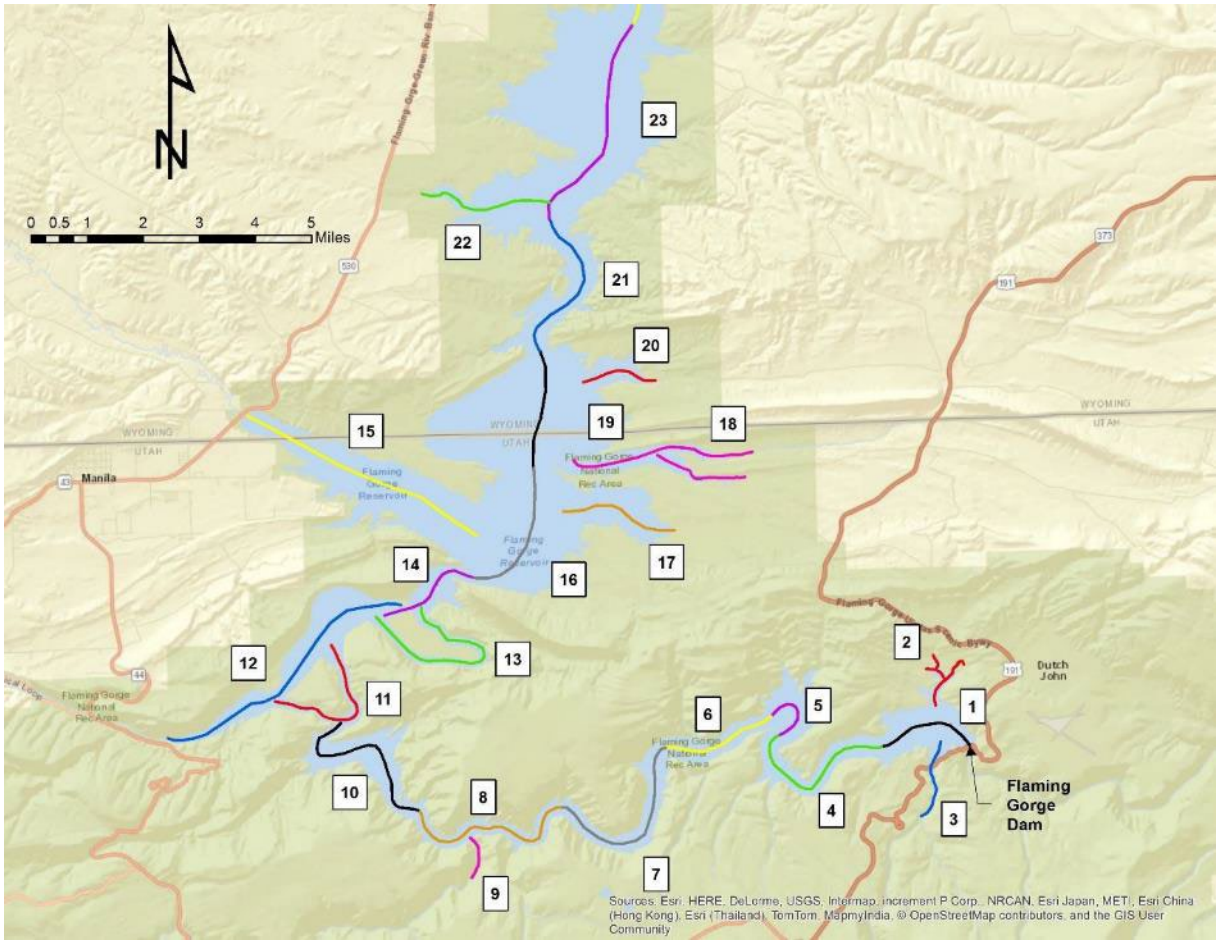


Figure 9. Lower portion of Flaming Gorge Reservoir divided into 2019-2020 bathymetric survey reaches. Map shows variation in reservoir characteristics

The reservoir has highly variable dimensions from north to south. In general, the reservoir's widest sections are in the middle of the reservoir. The widest sections are to the south of Buckboard Marina (Reach 28, Figure 8), to the north of Anvil Draw Boat Launch Area (Reach 23, Figure 9), and to the north and south of Lucerne Campground (Reaches 16 and 19, Figure 9). In addition to narrow segments within the tributary arms of the Green River, Blacks Fork (Reach 33, Figure 8), and Henrys Fork (Reach 15, Figure 9), the reservoir is also narrow surrounding Kingfisher Island (Reach 11, Figure 9), and in the Red Canyon confined stretch at the downstream end near the dam (Reaches 1 through 10, Figure 9).

Since the initial filling of the active conservation pool in the early 1970's (Figure 7), Flaming Gorge Reservoir has typically been operated between top of active conservation pool elevation 6040.0 and 6008.6 feet (RPVD). The installation of selective withdrawal structures on each penstock in 1978 to control downstream water temperatures allowed power intakes to draw water from the water surface elevation range between 5913 and 6005 feet. Operations since then have focused on maintaining water levels above those upper level power intakes. Operating at higher reservoir levels has resulted in increased sediment deposition in the active conservation pool above the upper penstock intakes.

2.6. Reservoir Sediment Management

Since initial filling, the reservoir elevation has been maintained within the upper portion of the active conservation pool and only varies about 13 feet during a typical operation year. The 2019-2020 survey does not indicate significant sediment deposition near the dam. There is no record of past reservoir sediment management activities at Flaming Gorge Dam or Reservoir.

3. Previous Reservoir Survey(s)

Prior to dam closure and initial reservoir filling, a survey was conducted before 1962 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 would have been the most likely survey methods for this time period. No maps produced from this original survey were located for this study. However, surface areas and capacities representing to original surface were found in the Standing Operating Procedures for Flaming Gorge Reservoir (Reclamation, 2019). The original survey is described in Table 3

Table 3. Previous Bathymetric Reservoir Surveys

Survey Year	Extent of Survey	Survey Method	Depth Sounder	Above water survey
Original - Prior to 1962	Full	Surface Mapping - Photogrammetry	N/A	Photogrammetry – Pre-1962
2019-2020	Full	Surface Mapping – Bathymetry and LiDAR	Multibeam	2019 LiDAR

No documented bathymetric surveys were conducted between the original (pre-1962) and the 2019-2020 survey.

4. Reservoir Survey Methods and Extent

4.1. Survey Methods

A complete bathymetric survey was conducted during May 29 to June 7, 2019 and September 27 to 28, 2020 from two boats using a multibeam depth sounders to continuously measure water depths. The horizontal positions of the moving boats were continually tracked using Differential GPS (DGPS) with accuracies generally within 6 feet. Depths measured during the bathymetric survey were converted to reservoir bottom elevations by subtracting them from water surface elevations recorded at the gage at Flaming Gorge Dam at a coincident time. Real-Time Kinematic Global Positioning System (RTK GPS) measurements were collected throughout the survey along the reservoir to check against dam gage records and to determine the difference between NAVD88, Geoid 18 and Reclamation Project Vertical Datum (RPVD). The May-June 2019 bathymetric survey was conducted between water surface elevations 6030.1 and 6031.0 feet. Water surface elevations fluctuated between 6026.1 and 6026.0 feet during the September 2020 bathymetric survey. Figures 8 and 9 show the extent of the coverage and how Flaming Gorge Reservoir was divided into shorter reaches for the 2019-2020 bathymetric survey. Appendix A provides more details of the hydrographic survey methods.

Above water data was provided in the form of terrestrial (red) LiDAR collected by the geographic mapping firm Atlantic through a contract with Reclamation's Upper Colorado Basin Regional Office (UCBRO). Atlantic used an aerial LiDAR scanner integrated with RTK GPS to survey 214 square miles of the emergent shoreline areas surrounding Flaming Gorge Reservoir and a minimum point density of 2 points per square meter. The aerial LiDAR survey was conducted from May 12 to 13, 2019 while reservoir water surface elevations ranged between 6029.3 and 6029.4 feet. Details of the aerial LiDAR survey are provided in Atlantic (2019) with a brief description of the above water data collection in Appendix B.

The 2019-2020 bathymetry was combined with the 2019 LiDAR to generate a continuous surface from the lowest measured reservoir bottom elevation (5586.0 feet, RPVD) to the dam crest elevation (6047.0 feet). ArcGIS was used to interpolate topography between bathymetry points along the reservoir bottom and in the gaps between bathymetry and LiDAR along the reservoir shoreline. Figure 10 is an example of coverage achieved during 2019-2020 survey, showing typical bathymetric coverage and LiDAR for a wide reach of the reservoir just upstream of Anvil Draw Boat Launch (Reach 23, Figure 9). The resulting 3-dimensional raster, shown in Figure 11 for the entire reservoir, was used to develop contour maps and to compute updated area and capacity relationships. Appendix C provides more details about the methods used to generate surface area and storage capacity tables.

Figure 10. Example of bathymetric and LiDAR coverage achieved during the 2019-2020 survey. North of Anvil Draw Boat Launch

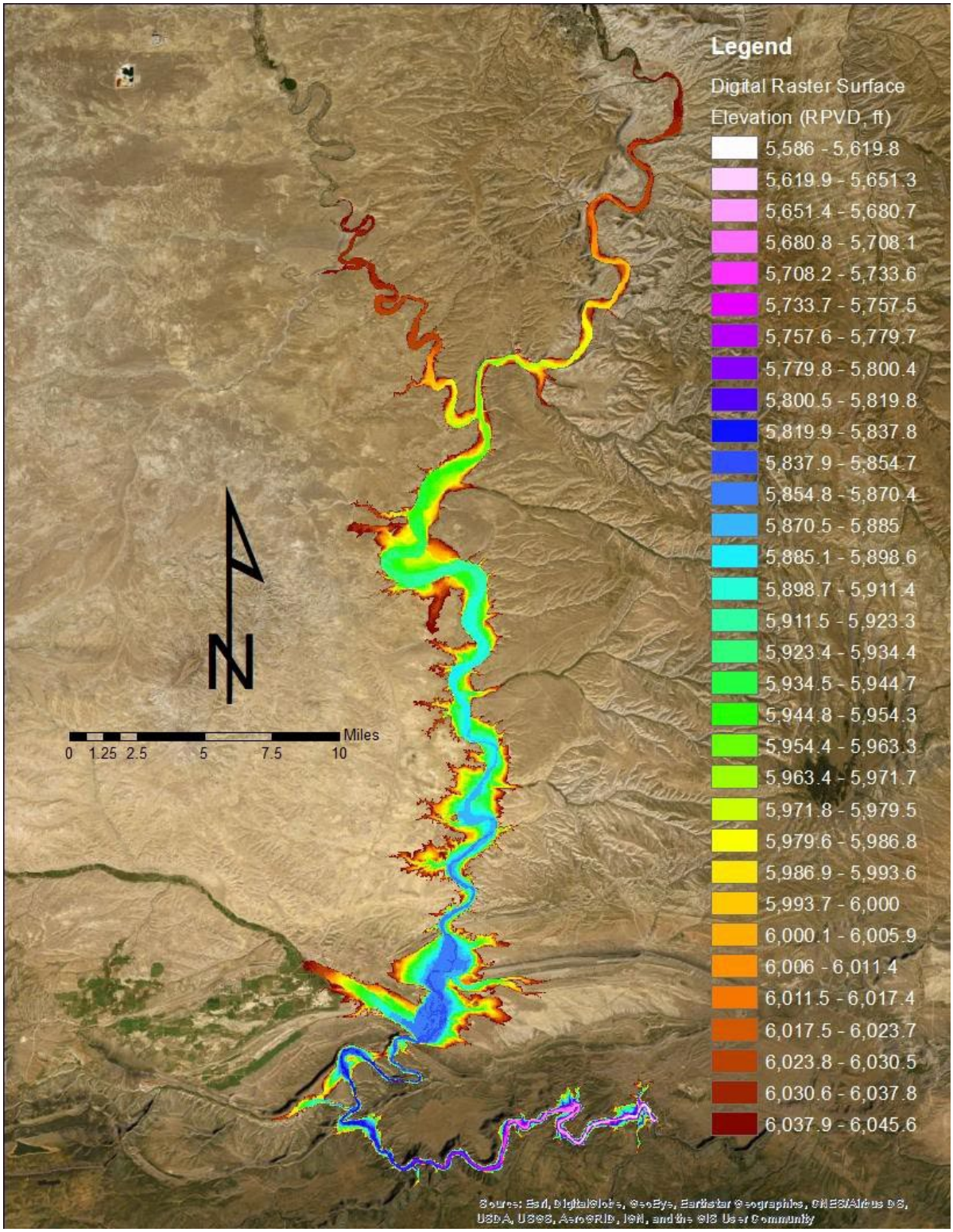


Figure 11. Three-dimensional digital elevation raster of Flaming Gorge Reservoir generated from 2019-2020 bathymetry combined with 2019 LiDAR

4.2. Survey Control, Datum, and Monuments

For the 2019-2020 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD83) State Plane (horizontal) coordinates, Utah North Zone (FIPS 4301) US survey feet and North American Vertical Datum 1988 (NAVD88, Geoid 12A, US survey feet vertically. Although a significant portion of Flaming Gorge Reservoir lies in Wyoming, the Utah North Zone was chosen for the horizontal control as that is where the dam is located.

Differential GPS (DGPS), with accuracies generally within 6 feet, was used to track the horizontal positions of the survey boats. Depths measured during the bathymetric survey were converted to reservoir bottom elevations by subtracting them from water surface elevations recorded at the gage at Flaming Gorge Dam at a coincident time. RTK GPS measurements were collected throughout the survey along the reservoir to check against dam gage records and to help determine the difference between NAVD88, Geoid 18 and Reclamation Project Vertical Datum (RPVD).

The RPVD at Flaming Gorge Reservoir was determined from RTK GPS measurements of permanent monuments and the top of crane rails on the dam crest and water surface elevations measured along the reservoir during the survey. For those vertical control measurements, the GPS base station receiver was set up over an existing large rebar located on the west shore near the right dam abutment with no known coordinates (Figure 12). State plane coordinates and elevations for the GPS base stations used during the 2019 and 2020 surveys were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). The RPVD was determined to be 4.61 feet lower than NAVD88 (Geoid 18). Although bathymetry data was collected in NAVD88, Geoid12A, NAVD88, Geoid 18 was used to determine the difference between NAVD88 and RPVD as it was the most recent and accurate elevation model available at the time of this report.

The difference between NGVD29 and NAVD88 at Flaming Gorge Dam and at the upper end of the reservoir pool 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 indicated NAVD88 varies from 3.27 feet higher than NGVD29 at the dam to 4.25 feet higher at the upstream end of the reservoir. The CorpsCon results were inconclusive in confirming that RPVD is equal to NGVD29 at Flaming Gorge. Therefore, 4.61 feet (difference determined from recent RTK observations) was subtracted from all bathymetry and GPS points to convert them from NAVD88 to RPVD.

Figure 12. RTK GPS base station used to measure water surface elevations near the dam and control points on the dam to reference bathymetric survey vertical datum to RPVD

For vertical reference, several brass caps (Figure 13) and other permanent, stable features on the dam were located and surveyed to relate NAVD88, Geoid 18 to RPVD.

Figure 13. RTK GPS measurement of one of the brass caps located on the dam crest used to vertically reference bathymetry data to RPVD

5. Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Flaming Gorge Reservoir 2019 Area and Capacity Tables). Plots of the 2019 area and capacity curves are presented in Figure 14 along with curves from original (1962) survey. Comparison of the original and 2019 areas and capacities is listed in Table 4. The 2019 area and capacity computations were based on a point cloud combining bathymetric data up to approximate elevation 6026 feet (RPVD), with 2019 aerial LiDAR data from elevation 6029.4 and above. A comparison of the table and curves indicates that largest reduction in surface area and storage capacity occurs in the upper portion of the active conservation pool between elevations 5990 and 6030 and feet (RPVD) where the reservoir has typically been operated since initial filling (Figure 7).

The 2019 surface areas and storage capacities for above-water elevations may be different than those measured in the original survey (pre-1962) because of delta sedimentation, shoreline erosion, or use of older survey methods.

Table 4 shows a slight gain in capacity since 1962 up to elevation 5900 feet, 0.1 percent of the total capacity at that elevation. A number of factors may have contributed to this result:

- Based on the time period of the original survey, it was assumed to be conducted using photogrammetry. However, this could not be confirmed so the methods used, level of detail, and accuracy of the original survey is unknown. Regardless of the original survey techniques, the 2019 bathymetric survey likely provided more accurate and detailed reservoir bottom topography than the original. More detailed reservoir bottom topography can result in larger computed surface areas and storage volumes as some of the lower lying areas that were interpolated in the original survey may have been mapped in the 2019-2020 bathymetry;
- Consistent operation of the reservoir near the top of the active conservation pool (elevation 6040 feet) is encouraging sediment deposition in the upper reservoir preventing sediment from reaching lower reservoir elevations towards the dam;
- The 2019 capacities indicate low sediment yield from the Flaming Gorge watershed, showing a loss of only 80,394 acre-feet (2.2 percent of the total capacity) at top of active conservation pool elevation 6040 feet (Table 4). Low sediment inflows are likely due in part to Fontenelle Dam upstream on the Green River, constructed about the same time as Flaming Gorge; and
- Possible consolidation of finer sediments that may have existed at lower elevations prior to dam construction.

At reservoir water surface elevation 6026 feet, approximately 5 feet below water surface elevation at the time of the 2019 bathymetric survey, the reservoir surface area was 35,461 acres with a storage capacity of 3,158,466 acre-feet. The surface area was 42,613 acres and the storage capacity was 3,711,306 acre-feet at top of active conservation pool elevation 6040 feet. At the maximum water surface elevation 6045 feet (RPVD), the reservoir had a surface area of 44,548 acres and a storage capacity of 3,929,290 acre-feet.

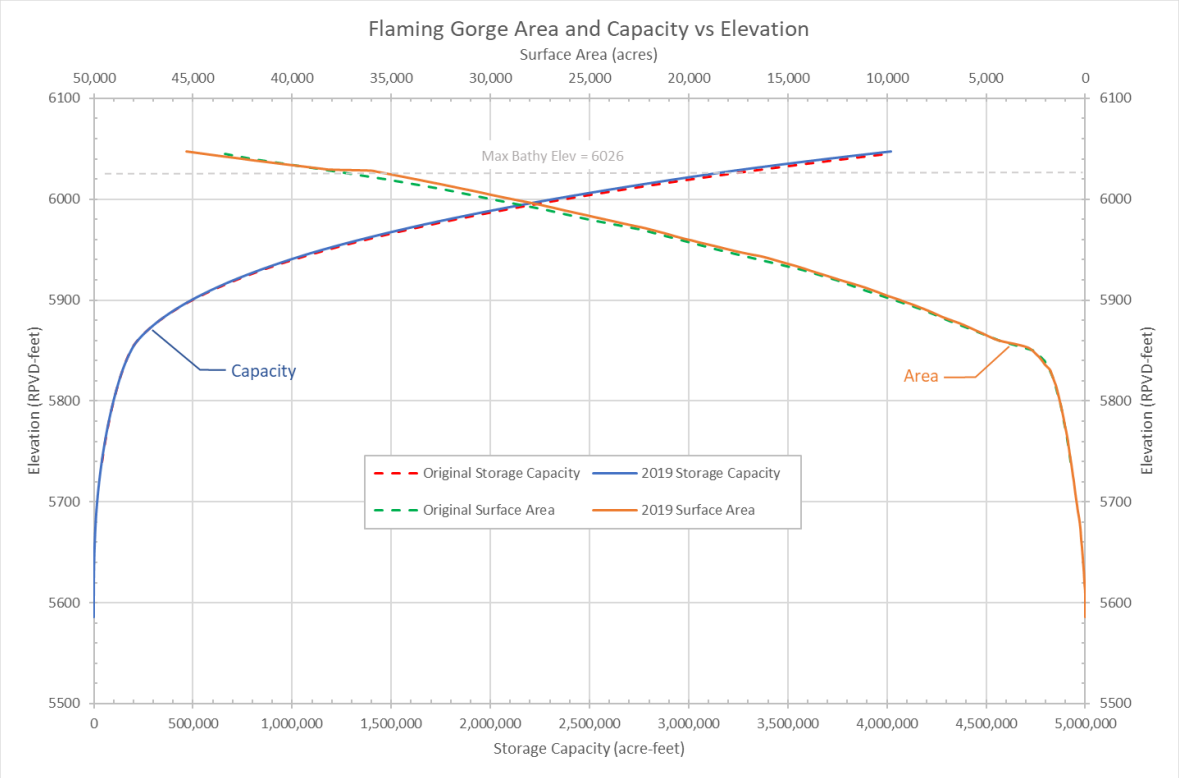


Figure 14. Plot of Flaming Gorge Reservoir surface area and storage capacity versus elevation (RPVD) for the original and 2019 surveys

Table 4. Historical summary of reservoir surface area and storage capacity data. No data available for cells containing "---"

		Reservoir Surface Area (acres)		Reservoir Storage Capacity (acre-ft)		Sedimentation Volume (acre-ft)
	Elevation (ft)	Original Pre-1962	2019	Original Pre-1962	2019	1962 to 2019
Dam Crest	6047	---	45,312	---	4,019,148	---
Max Water Surface	6045	43,380	44,548	4,005,200	3,929,290	75,910
Top of Active Cons	6040	42,020	42,613	3,791,700	3,711,306	80,394
	6030	38,580	38,528	3,388,700	3,305,189	83,511
	6026	37,268	35461	3,237,004	3,158,466	78,538
	6020	35,300	33,892	3,019,300	2,950,435	68,865
	6010	32,380	31,380	2,680,900	2,624,264	56,636
Spillway Crest	6006	31,392	30,393	2,553,356	2,500,762	52,594
	6000	29,910	28,953	2,369,450	2,322,639	46,811
	5990	27,290	26,555	2,083,450	2,045,532	37,918
	5980	25,030	24,275	1,821,850	1,791,342	30,508
	5970	22,380	21,979	1,584,800	1,560,101	24,699
	5960	20,440	20,088	1,370,700	1,349,741	20,959
	5950	18,500	18,001	1,176,000	1,159,366	16,634
	5940	16,380	15,748	1,001,600	990,964	10,636
	5930	14,230	14,011	848,550	842,338	6,212
	5920	12,530	12,404	714,750	710,195	4,555
	5910	11,120	10,788	596,500	594,506	1,994
	5900	9,570	9,355	493,050	493,661	-611
	5890	8,080	8,008	404,800	406,968	-2,168
	5880	6,890	6,775	329,950	332,854	-2,904
Top of Inactive	5871	5,702	5,655	273,286	277,186	-3,900
	5860	4,300	4,375	218,300	221,755	-3,455
	5850	2,540	2,669	184,100	188,155	-4,055
Penstock Inverts	5845	2,285	2,410	172,038	175,465	-3427
	5840	2,030	2,184	161,250	164,014	-2,764
	5830	1,750	1,760	142,350	144,233	-1,883
	5820	1,540	1,576	125,900	127,569	-1,669
	5810	1,410	1,414	111,150	112,704	-1,554
	5800	1,260	1,291	97,800	99,192	-1,392
	5790	1,150	1,174	85,750	86,896	-1,146
	5780	1,060	1,071	74,700	75,692	-992
	5770	950	968	64,650	65,475	-825

	5760	870	878	55,550	56,265	-715
	5750	790	806	47,250	47,836	-586
Top of Dead	5740	720	728	39,700	40,165	-465
	5730	---	654	---	33,269	---
	5720	---	578	---	27,097	---
	5710	---	515	---	21,632	---
	5700	---	443	---	16,829	---
	5690	---	370	---	12,762	---
	5680	---	287	---	9,500	---
	5670	---	234	---	6,915	---
	5660	---	196	---	4,748	---
	5650	---	149	---	3,043	---
	5640	---	111	---	1,748	---
	5630	---	72	---	836	---
	5620	---	45	---	261	---
	5610	---	5	---	15	---
	5600	---	0.1	---	0.3	---
Original Bed at Dam	5592	0.0	0.0	0.0	0.0	0.0
2019 Min Bed	5586	---	0.0	---	0.0	---

As of June 2019, Flaming Gorge Reservoir had lost 80,394 acre-feet of storage, 2.2 percent of the total storage, at top of active conservation pool elevation 6,040 feet (RPVD) since initial filling began in 1962. At maximum water surface elevation 6,045 feet, 75,910 acre-feet (only 1.9 percent of the total storage) of sediment deposition has occurred since 1962. The 2019 area and capacity table computations (Table 4) show that Flaming Gorge has maintained all of its original dead storage below elevation 5740 feet. For the potential reasons stated above, the overall sedimentation rates at Flaming Gorge would be considered "very low" according to the classifications outlined in Reclamation (2006).

6. Reservoir Sedimentation Volume Spatial Distribution

No surface or survey data representing the original data was located for this study. Not having an original surface to compare to the 2019 surface makes it difficult to determine the detailed distribution of sediment deposits at Flaming Gorge. However, based on the area and capacity computations presented in Figure 14 and Table 4, some general conclusions can be drawn about the elevation zones of the reservoir where the majority of the sedimentation has occurred since initial filling began in 1962.

Fontenelle Dam was constructed in 1964 on the Green River approximately 64 river miles upstream of Flaming Gorge Reservoir. With few large tributaries flowing into the Green River between the two reservoirs, Fontenelle Dam likely traps a portion of the sediment that would otherwise reach Flaming Gorge. Operating at near full pool year-round (very little fluctuation in pool elevation) results in deposits primarily in the active conservation pool above elevation 5910 feet (RPVD), with the highest sedimentation rates occurring between elevations 5990 and 6030 feet (Table 4).

7. Sedimentation Trends

According to the original design values in the standing operating procedures (Reclamation, 2019), the estimated 100-year sedimentation volume in Flaming Gorge Reservoir was 201,000 acre-feet, equivalent to an annual rate of 2,010 acre-feet per year (acre-feet/year). At its current sedimentation rate of 1,410 acre-feet/year, the projected 100-year volume lost to sediment deposition would be 141,000 acre-feet, less than originally estimated. The sediment elevation at the dam was predicted to be 5864 feet (RPVD) after 100 years of operation, but the 2019 bathymetric survey indicated that none of the dead storage has been lost and measured average bed elevations of only 5603 feet about 150 feet upstream of Flaming Gorge Dam and 150 feet downstream of the cofferdam after 57 years of operation. The original streambed elevation at the dam axis was listed as 5592 feet (Reclamation, 2019) and bottom elevations as low as 5586 were measured against the upstream dam face during the 2019 bathymetric survey. The actual sediment yield of the watershed appears to be lower than predicted and/or the original operation plan for Flaming Gorge or Fontenelle may have changed since the 1970's or 1980's, resulting in less fluctuation of water levels throughout the course of a typical year.

8. Conclusions and Recommendations

A bathymetric survey was conducted on Flaming Gorge Reservoir from May 29 to June 7, 2019 and from September 27 to 28, 2020. On May 12 and 13, 2019, geographic mapping firm Atlantic collected above water data in the form of terrestrial (red) LiDAR through a contract with Reclamation's Upper Colorado Basin Regional Office (UCBRO). Water surface elevations ranged from 6030.1 to 6031.0 feet (RPVD) during the May-June 2019 bathymetric survey and varied between 6026.1 and 6026.0 feet during the September 2020 collection. During the May 2019 aerial LiDAR survey, water surface elevations fluctuated between 6029.3 and 6029.4 feet. Unfortunately, the similar water surface elevations during the bathymetric and LiDAR surveys resulted in insufficient overlap to compare the accuracy of the two data sets. The bathymetry and aerial LiDAR were combined to generate a continuous surface of the reservoir bottom for the purpose of computing updated surface area and storage capacity values.

At the top of active conservation pool elevation (6040 feet, RPVD), the reservoir had a surface area of 42,613 acres and a storage capacity of 3,711,306 acre-feet. Since original filling of the reservoir began in 1962, the reservoir is estimated to have lost 80,394 acre-feet of storage capacity (2.2 percent) due to sedimentation below elevation 6040 feet. Results indicate Flaming Gorge Reservoir has maintained its dead storage pool volume (below elevation 5740 feet) since operations began.

8.1. Survey Methods and Data Analysis

The 2019-2020 bathymetric survey, combined with 2019 LiDAR data of the above-water topography, was used to produce a digital surface of the reservoir bottom from the lowest measured elevation to the top of dam crest elevation 6047.0 feet (RPVD). Reservoir surface areas were computed from this digital surface at 1-foot intervals to determine the 2019 storage capacity. Surface area and storage capacity were then interpolated at 0.01-foot intervals. The difference in reservoir surfaces over time can be attributed to sedimentation, but also the differences in survey methods. The use of modern survey methods (e.g., GPS, multibeam depth sounders, LiDAR) produces a more accurate and precise digital surface of the reservoir bottom than past surveys using older methods (plane table, level, photogrammetry). Due to the age of the original survey, it was assumed to have been conducted using photogrammetry. Table 4 indicates slight gains in storage capacity below elevation 5900 feet since 1962. These volume increases are likely due to differences in survey methods rather than actual gains in storage capacity in that portion of the reservoir.

8.2. Sedimentation Progression and Location

Over the span of 57 years, sedimentation has filled only 80,394 acre-feet or 2.2 percent of the original storage capacity below top of active conservation pool elevation 6040.0 feet (RPVD). The 2019-2020 reservoir survey indicates that most of this sedimentation is located in the upper portion of the active conservation pool between elevations 5990 and 6030 and feet where the reservoir has typically been operated since initial filling (Figure 7). Operation of Flaming Gorge Reservoir at higher water surface elevations may have prevented sediment from being transported to and deposited in the dead pool near the dam below elevation 5740 feet.

8.3. Recommendation for Next Survey

The computed sediment yield rate for the Flaming Gorge watershed since 1962 was 0.13 acre-feet per square mile per year (acre-feet/mi^2/year), which is considered very low as defined in Reclamation (2006). Based on past sedimentation rates and only 2.2 percent of the total storage capacity being lost since dam closure, the next survey of Flaming Gorge is recommended within about the next 20 years, or around year 2039. Extreme hydrologic events, wildfires, or landslides in the drainage basin could necessitate a survey prior to 2039. If significant operational changes are made, outlet works become inoperable, inspections are warranted, or if dam modification, repairs, or construction are necessary, a survey may be required before the recommended 20-year period.

References

Atlantic, 2019. Project Report. Contracted by Bureau of Reclamation, Upper Colorado Basin Region.

Bradley, D.N., 2021. User's manual for Area-Capacity Program (ACAP) Version 2.0. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Horton, J.D., 2017. The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States (ver. 1.1, August 2017): U.S. Geological Survey data release, https://doi.org/10.5066/F7WH2N65. Accessed 05/20/2021.

National Oceanic and Atmospheric Administration (NOAA), 2019. National Weather Service Forecast Office. National Centers for Environmental Information, 2019. Available online at: https://w2.weather.gov/climate/xmacis.php?wfo=oun. Accessed 05/20/2021.

Reclamation, 1985. Area-Capacity Computation Program. Bureau of Reclamation, Division of Planning Technical Services, Engineering Research Center, Denver, Colorado.

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

Reclamation, 2019. Standing Operating Procedures Flaming Gorge Dam and Powerplant. Bureau of Reclamation, Upper Colorado Basin Region Power Office, Salt Lake City, Utah.

Reclamation, 2021. Projects and Facilities Data, Colorado River Storage Project, available at: https://www.usbr.gov/projects/. Accessed 8/25/2021.

Reclamation, 2021. Flaming Gorge Reservoir 2019 Area and Capacity Tables, Technical Memorandum ENV-2021-112. Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado, September 2021.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2019. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed 05/13/2021.

State Geologic Map Compilation (SGMC) (2020). Database. https://www.sciencebase.gov/catalog/item/5888bf4fe4b05ccb964bab9d.

US Geological Survey, StreamStats, available online at: https://streamstats.usgs.gov/ss/ Accessed 05/11/2021.

Appendix A — Hydrographic Survey Equipment and Methods

The 2019 bathymetric survey was conducted from May 29 to June 7, 2019 and September 27 to 28, 2020. The second bathymetric survey trip in September 2020 was required to fill gaps in the coverage from the first survey trip and to collect shallow water data along the shorelines and in the delta area originally planned for Reclamation's Western Colorado Area Office. Due to the COVID-19 pandemic delays in field work and compressed schedules following Reclamation's return to surveying, the Western Colorado Area Office was unable to assist with the bathymetric survey. Reservoir water surface elevations ranged from 6030.1 to 6031.0 feet (RPVD) during the period from May 29 and June 7, 2019, and fluctuated between 6026.1 and 6026.0 feet on September 27 and 28, 2020.

While the multibeam survey achieved 100 percent coverage in some of the deeper areas or areas with features of interest, portions of the reservoir that were relatively flat and/or shallow were not covered completely, and it was determined that interpolating reservoir bottom geometry would be sufficient there. Figures 8 and 9 show the extent of the coverage and how Flaming Gorge Reservoir was divided into shorter reaches for the 2019-2020 bathymetric survey. A general example of typical multibeam coverage in an area where overlap was not achieved is shown in Figure 10.

The survey employed two vessels, both using multibeam depth sounders integrated with survey-grade GPS to map the bottom of Flaming Gorge Reservoir. The smaller of the two boats was an 18-foot, flat-bottom aluminum Wooldridge boat powered by outboard jet and kicker motors (Figure A-1). The larger vessel was a 23-foot aluminum tri-hull SeaArk with twin inboard motors. Both survey boats are shown on the water at Lucerne Valley Marina during the 2019 bathymetric survey in Figure A-2. Reservoir depths were measured using multibeam echo sounder systems consisting 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 (Wooldridge). One GPS receiver for position and a gyrocompass for heading (SeaArk);
- Processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data; and
- Laptop with data collection software (HYPACK).

Survey systems on both boats were powered by generators. The basic components of a typical multibeam sonar system are shown in Figure A-1 below.

Figure A-1. Wooldridge boat with RTK-GPS and multibeam depth sounder system.

Figure A-2. Both survey vessels with multibeam systems mounted during the 2019 bathymetric data collection. The SeaArk is on the left with the Wooldridge on the right of the photo

The multibeam transducers used for the 2019-2020 bathymetric survey emit 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 each depth sounder.

The horizontal positions of the moving boats were continually tracked using Differential GPS (DGPS) with accuracies generally within 6 feet. Depths measured during the bathymetric survey were converted to reservoir bottom elevations by subtracting them from water surface elevations recorded at the gage at Flaming Gorge Dam at the same time.

RTK GPS measurements were collected throughout the survey along the reservoir to check against dam gage records and to determine the difference between NAVD88, Geoid 18 and Reclamation Project Vertical Datum (RPVD). RTK provides accurate horizontal coordinates (±2 centimeters) and elevations (±3 centimeters) in real time for stationary measurements. While RTK measurements were being collected, position corrections were transmitted to the GPS rover receiver using an external GPS radio and UHF antenna (Figure A-3). The base station was powered by a 12-volt battery.

The RTK 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.

The RPVD at Flaming Gorge Reservoir was determined from RTK GPS measurements of permanent monuments and the top of crane rails on the dam crest and water surface elevations measured along the reservoir during the survey. For those vertical control measurements, the GPS base station receiver was set up over an existing large rebar located on the west shore near the right dam abutment with no known coordinates (Figure A-3). State plane coordinates and elevations for the GPS base stations used during the 2019 and 2020 surveys were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/). The RPVD was determined to be 4.61 feet lower than NAVD88 (Geoid 18). Although bathymetry data was collected in NAVD88, Geoid12A, NAVD88, Geoid 18 was used to determine the difference between NAVD88 and RPVD as it was the most recent and accurate elevation model available at the time of this report.

Figure A-3. The RTK-GPS base station set-up used during the survey Clark Canyon Reservoir in Montana is typical of the set up used for other reservoir surveys.

During the bathymetric survey, a laptop computer was connected to the GPS rover receivers and sonar 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 differential GPS coordinates, the HYPACK software provided navigational guidance to the boat operator in real time 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. 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.

On a reservoir the size of Flaming Gorge, the multibeam depth sounder generates tens-of-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 post processing. Filtering of this large data set is necessary to keep file sizes manageable, so a raster mesh is created in GIS (5-foot square cells for Flaming Gorge). 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

An aerial LiDAR survey was conducted on May 12 and 13, 2019 by Atlantic through contract with Reclamation's Upper Colorado Basin Region to map the above water portions of the reservoir. Atlantic used an aerial LiDAR scanner integrated with RTK GPS to survey 214 square miles of the emergent shoreline areas surrounding Flaming Gorge Reservoir and a minimum point density of 2 points per square meter. Water surface elevations during the 2019 LiDAR survey fluctuated between 6029.3 and 6029.4 feet (RPVD).

See Atlantic (2019) "Project Report" for details about the 2019 LiDAR survey of Flaming Gorge Reservoir.

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

The 2019 and 2020 bathymetry were combined with LiDAR collected in May 2019 to generate a 3-dimensional digital surface of the reservoir bottom at Flaming Gorge in ArcGIS. Reservoir surface areas and capacities were then computed at 1-foot increments, using an ArcGIS tool (ACAP Toolset 2.0) based on the ESRI Surface Volume function for the complete range of reservoir elevations (5586.0 to 6047.0 feet, Reclamation Project Vertical Datum [RPVD]). The tool interpolates the reservoir surface areas and capacities to 0.1 foot and 0.01-foot increments between each 1-foot interval following the method of Reclamation's Area-Capacity (ACAP) Program Version 2.0. ACAP V2.0 is a replacement for the ACAP85 program (Reclamation, 1985).

The reservoir storage capacity interpolates the reservoir storage capacity at the i^{th} interpolation point between 1-foot intervals using Equation 1:

$$V_i = V_b + A_b(y_i - y_b) + C(y_i - y_b)^m \quad (1)$$

where: V_i = Storage capacity (acre-feet)
y_i = Reservoir elevation,
y_b = Reservoir elevation at bottom of elevation increment,
V_b = Storage capacity at elevation y_b (acre-feet),
A_b = Surface area at elevation y_b (acres)
C= Coefficient for nonlinear rate of increase in storage capacity
m= Exponent of nonlinearity in the increase in storage capacity

Area is then calculated as the derivative with respect to y_i of the volume Equation 2:

$$A_i = A_b + Cm(y_i - y_b)^{m-1} \quad (2)$$

where: A_i= Surface area (acres),
A_b = Area at elevation y_b

The coefficients C and m are chosen so that the surface areas (determined using GIS software) and the 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. Enforcing that the storage volume (V_t) at the top of the elevation increment equals that from the GIS analysis and then solving equation (1) for C gives Equation 3:

$$C = \frac{V_t - V_b - A_b \Delta y}{\Delta y^m} \quad (3)$$

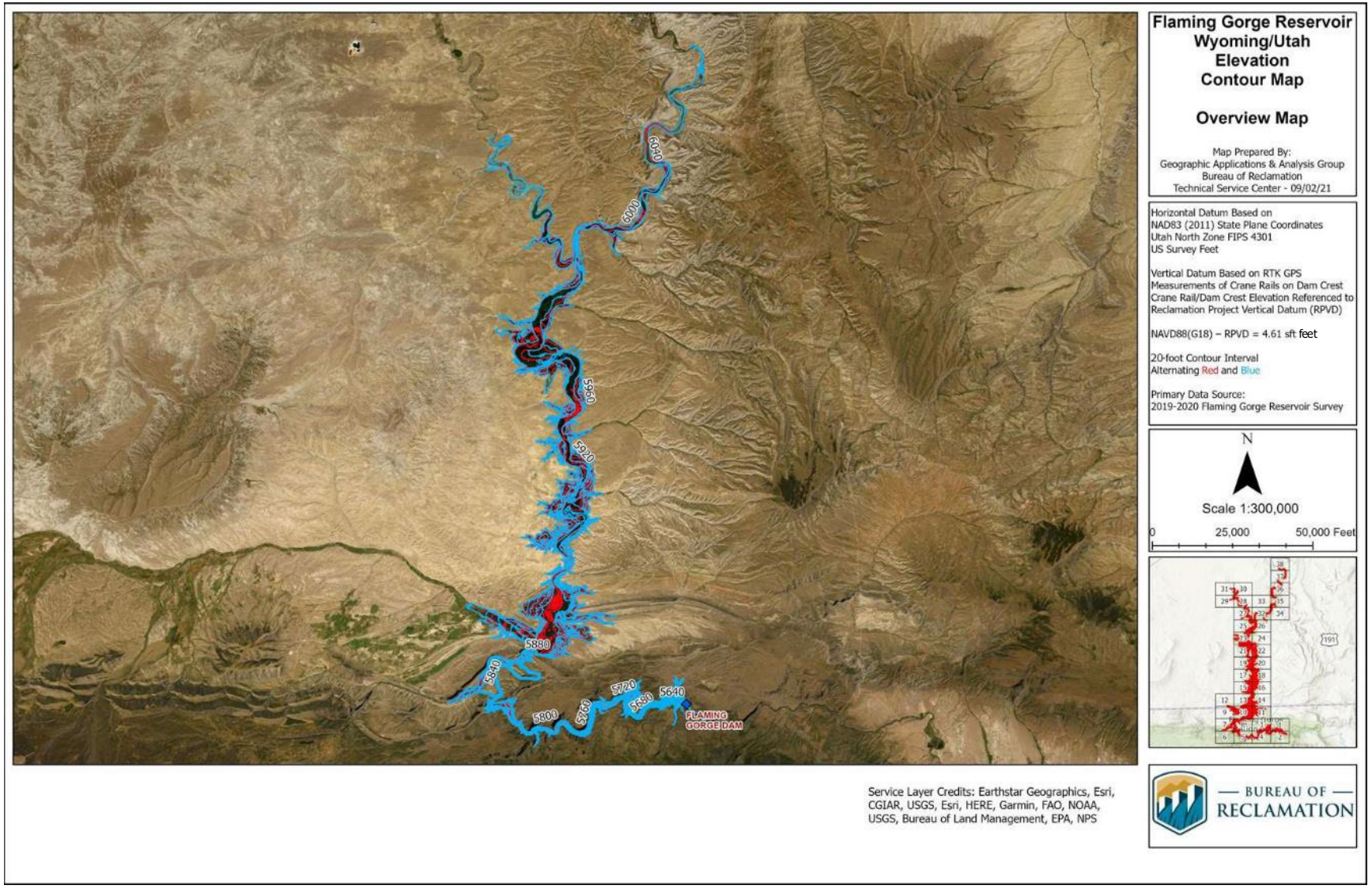
where $\Delta y = y_t - y_b$, and y_t is the elevation at the top of the elevation increment. Enforcing that the surface area (A_t) at the top of the elevation increment equals that from the GIS analysis and then substituting into Equation 2 gives Equation 4 to solve for m:

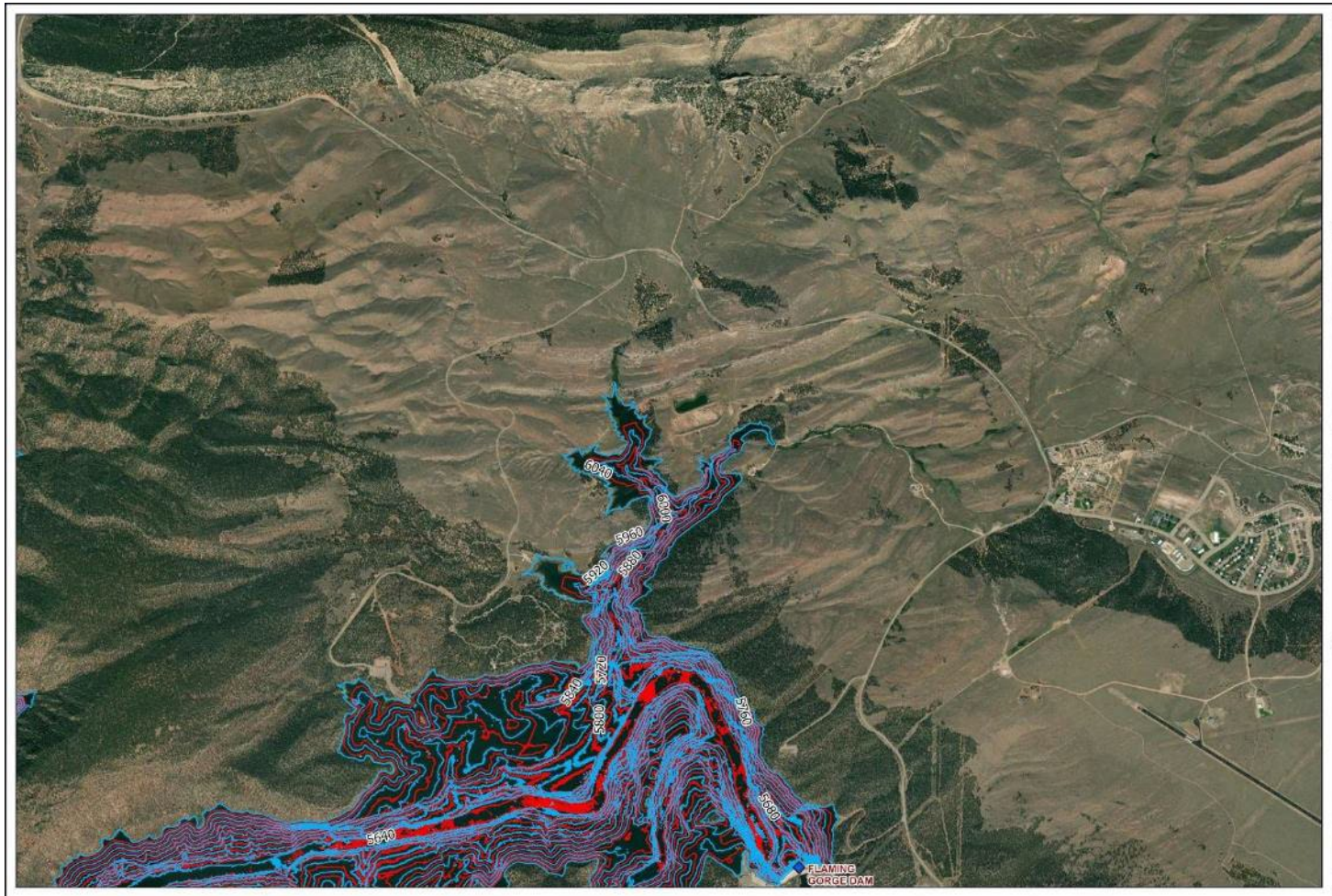
$$m = \frac{(A_t - A_b)\Delta y}{V_t - V_b - A_b \Delta y} \quad (4)$$

The ACAP toolset produced area and capacity tables for the full range of reservoir elevations. These data are documented in the report "Flaming Gorge Reservoir 2019 Area and Capacity Tables" (Reclamation, 2019).

Contour Maps

Contour maps at 10-foot elevation intervals in the flatter areas (upper portion of the reservoir) and 20-foot elevation intervals in the steeper canyon areas (near the dam) were generated from the 2019 Flaming Gorge Reservoir surface developed from 2019-2020 bathymetry combined with 2019 aerial LiDAR. Contours were generated from elevation 5586.0 feet (the lowest reservoir bottom elevation measured during the bathymetric survey) to dam crest elevation 6047.0 feet (RPVD), but contours are only shown at every 10- or 20-foot interval on the maps contained in this report. Contour colors alternate between red and blue for maximum visibility. All contour elevations are presented in Reclamation Project Vertical Datum in US survey feet.


6040
6000
5960
5920
5880
5840
5800
5760
5720
5680
5640
FLAMING GORGE DAM
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Overview Map
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
20-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:300,000
0
25,000
50,000 Feet
191
Service Layer Credits: Earthstar Geographics, Esri,
CGIAR, USGS, Esri, HERE, Garmin, FAO, NOAA,
USGS, Bureau of Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 1

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

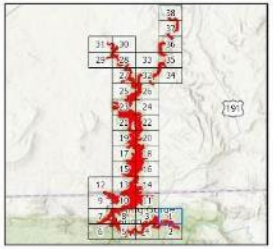
NAVD88(G18) – RPVD = 4.61 sfifeet

20-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

N

Scale 1:20,000
0 1,500 3,000 Feet



Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

— BUREAU OF —
RECLAMATION

Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 2

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

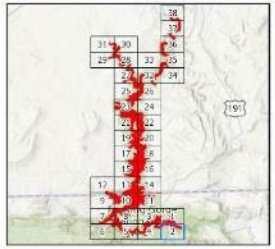
NAVD88(G18) – RPVD = 4.61 sftfeet

20-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

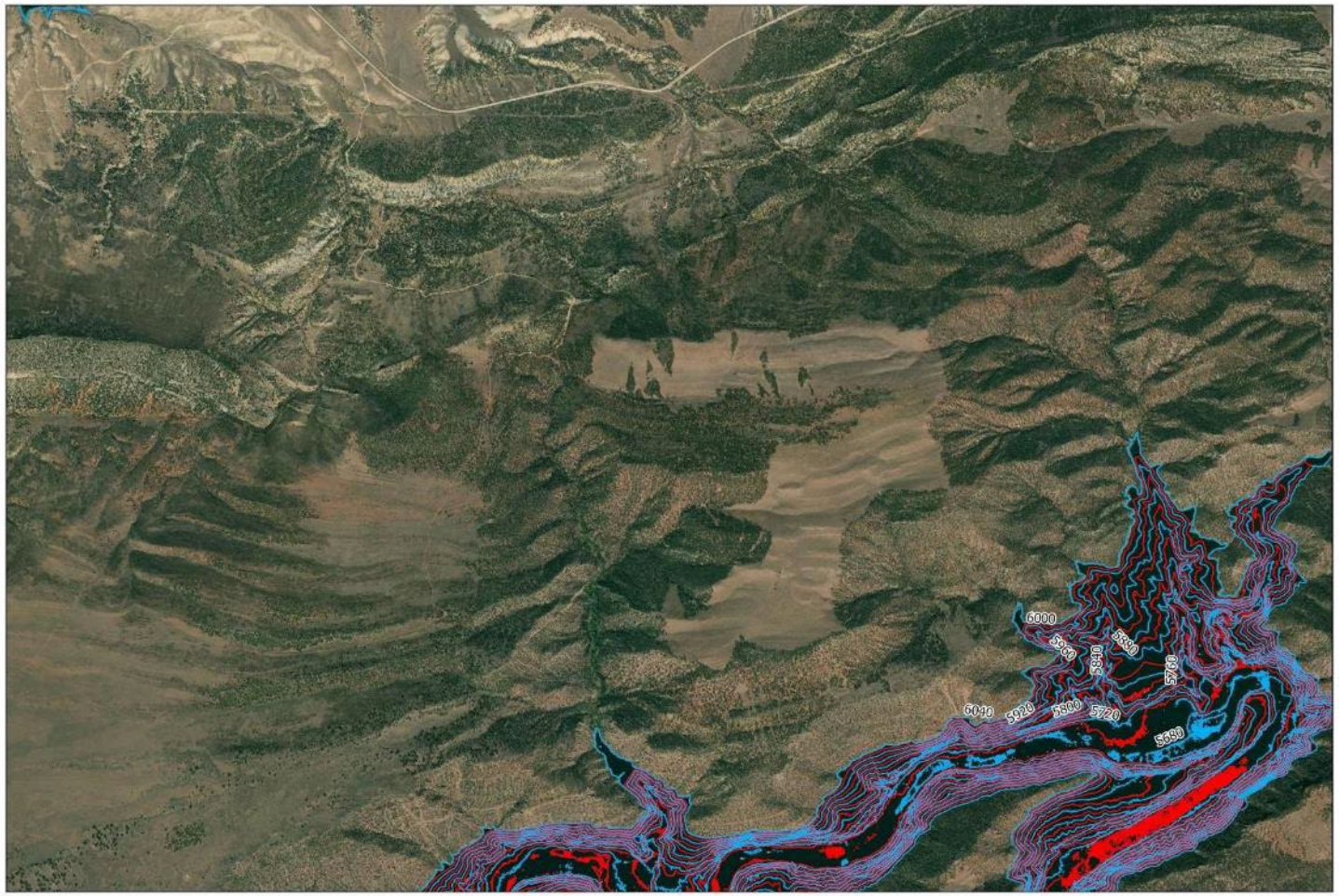
N

Scale 1:20,000
0 1,500 3,000 Feet



Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

BUREAU OF RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 3

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

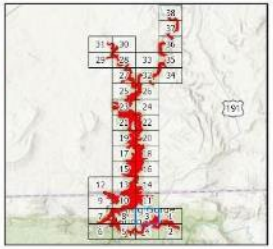
NAVD88(G18) – RPVD = 4.61 sftfeet

20-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

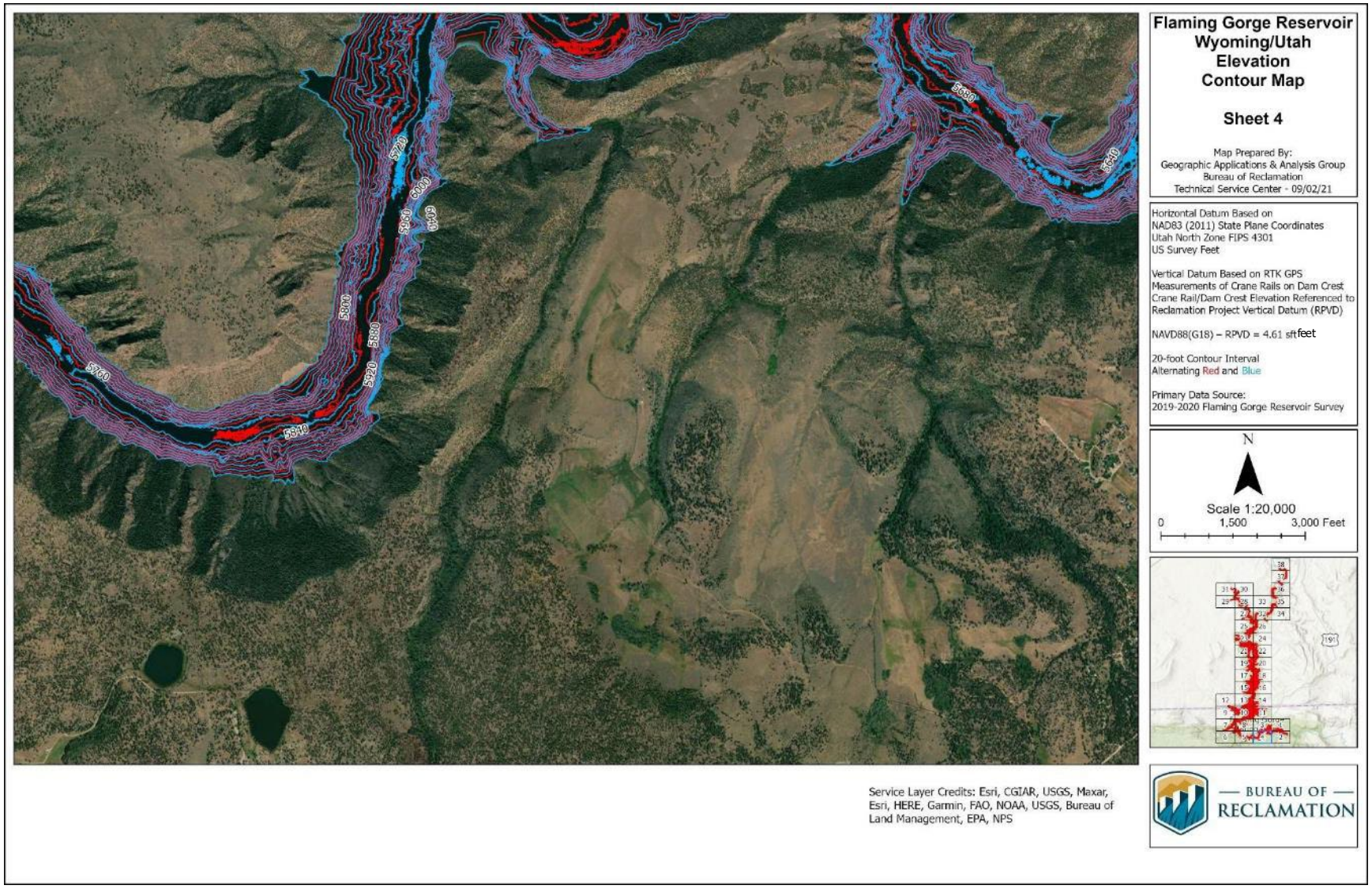
N

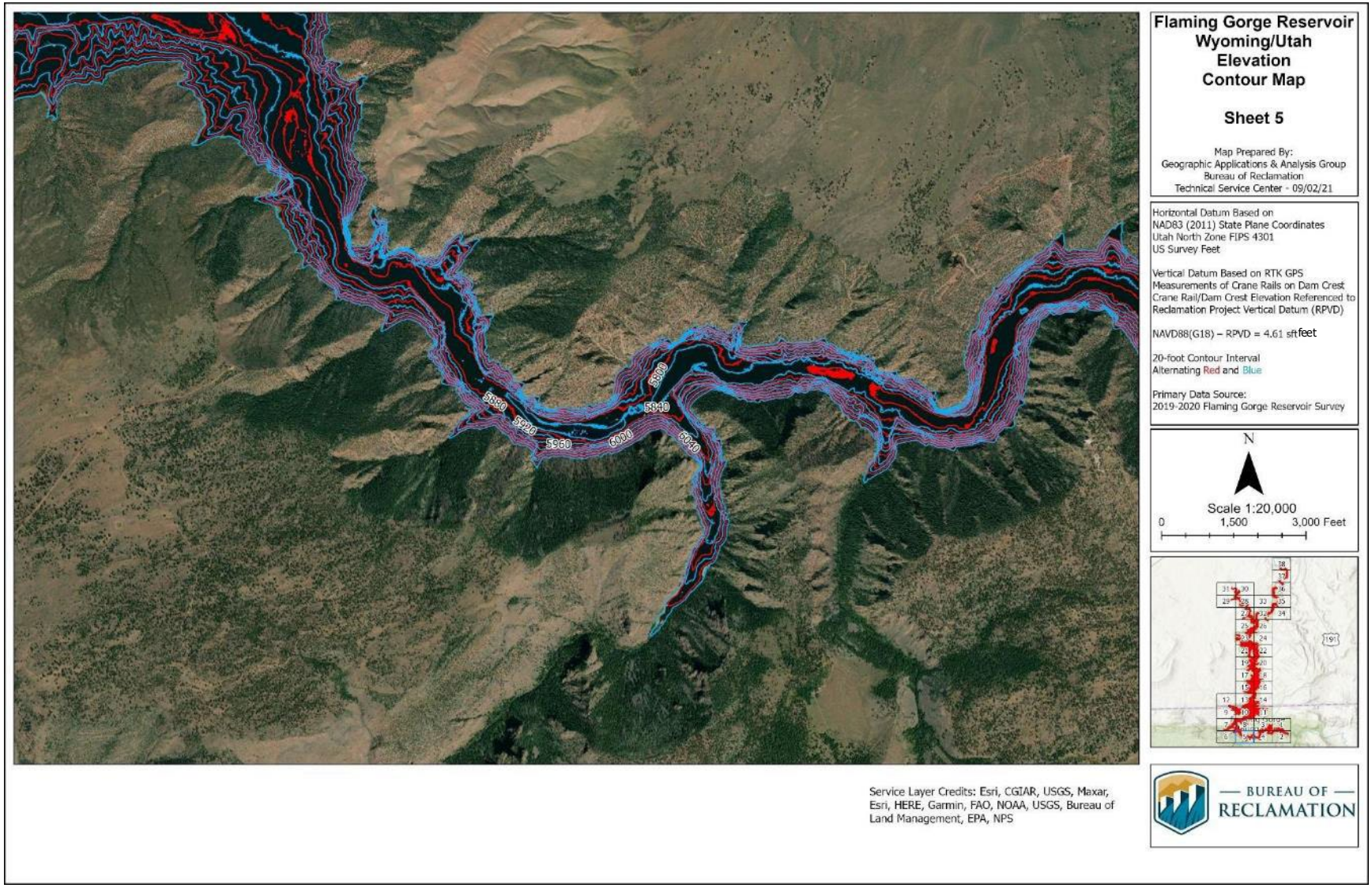
Scale 1:20,000
0 1,500 3,000 Feet



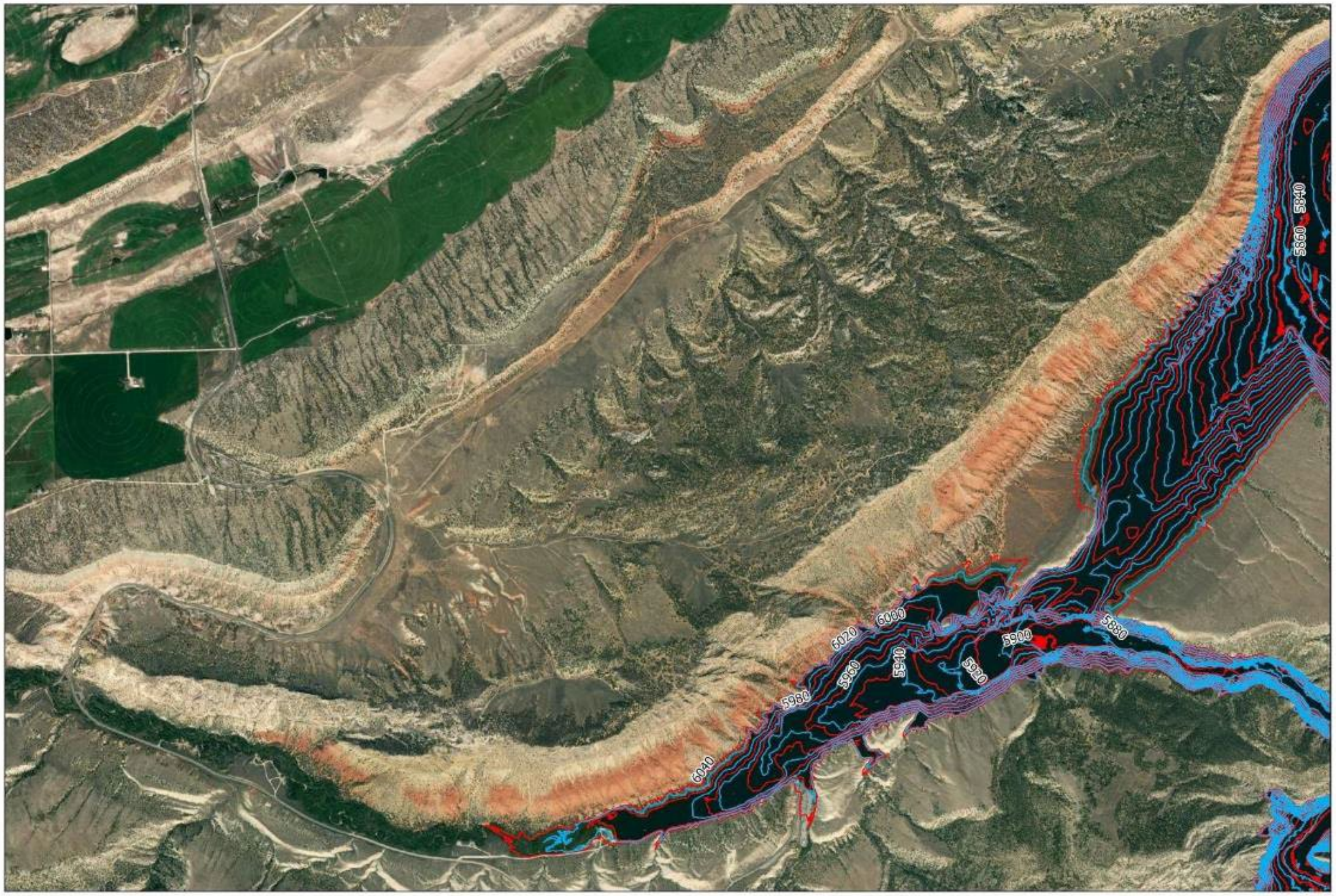
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

— BUREAU OF —
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 4
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sftfeet
20-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
5720
6000
6040
5800
5880
5920
5760
5640
5640
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


5980
5920
5960
6000
6040
5940
5880
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 5
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sftfeet
20-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6000
5940
5880
5960
5920
6040
6020
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 6
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sftfeet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
191
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir Wyoming/Utah Elevation Contour Map

Sheet 7

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

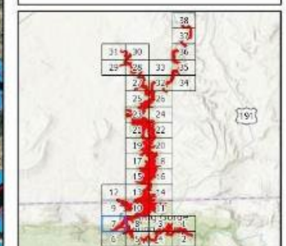
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

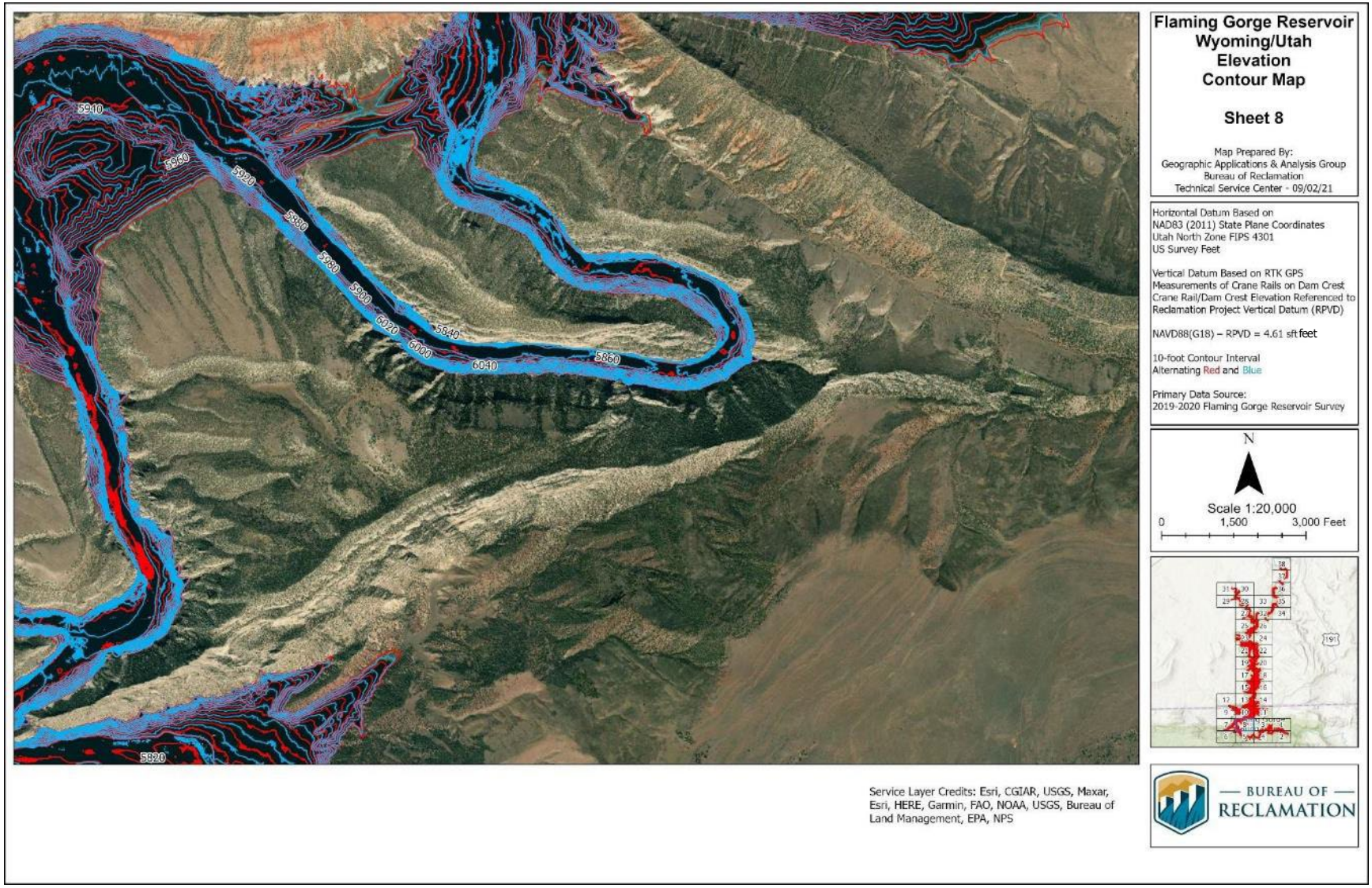
N

Scale 1:20,000
0 1,500 3,000 Feet



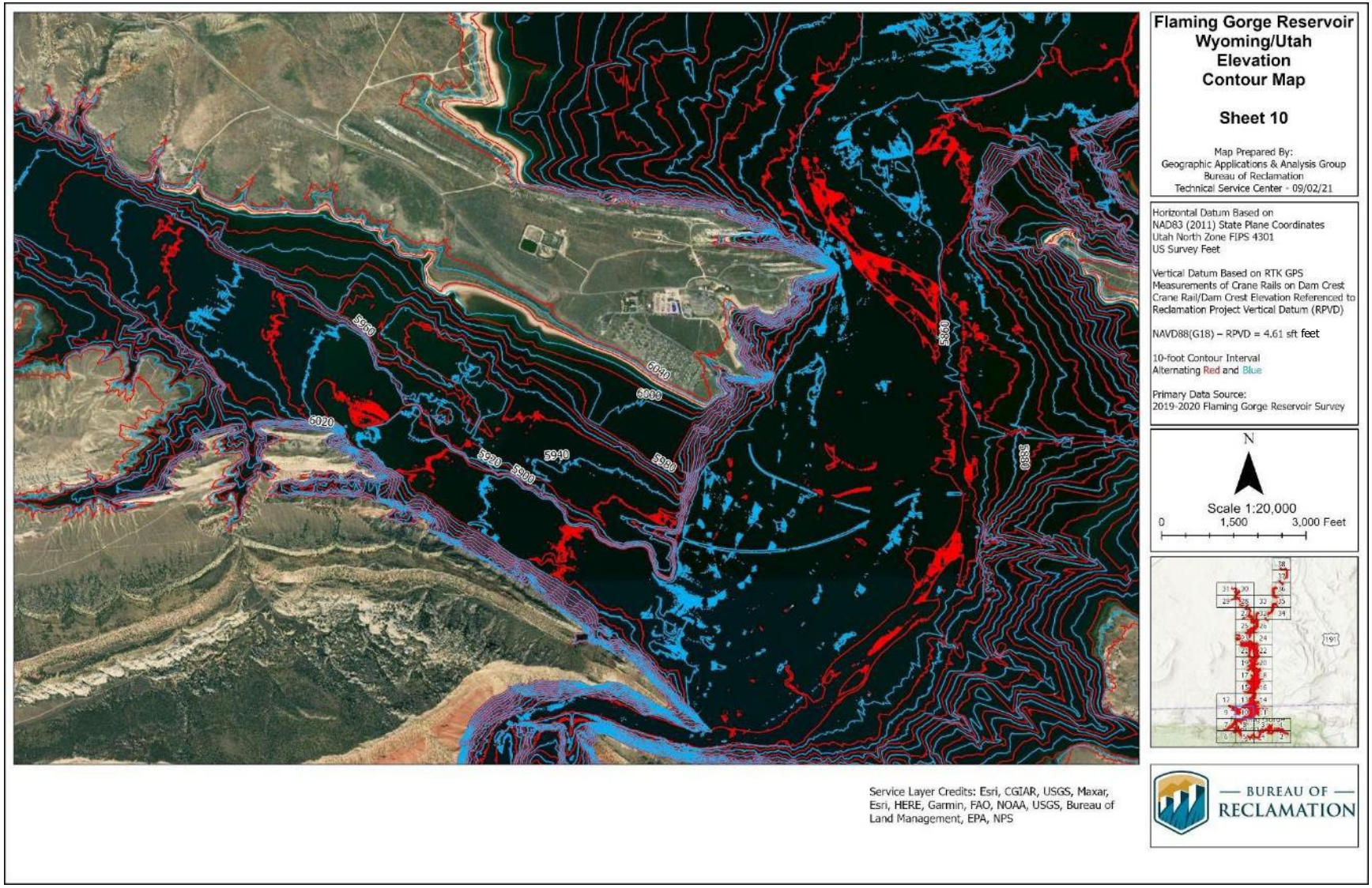
BUREAU OF RECLAMATION

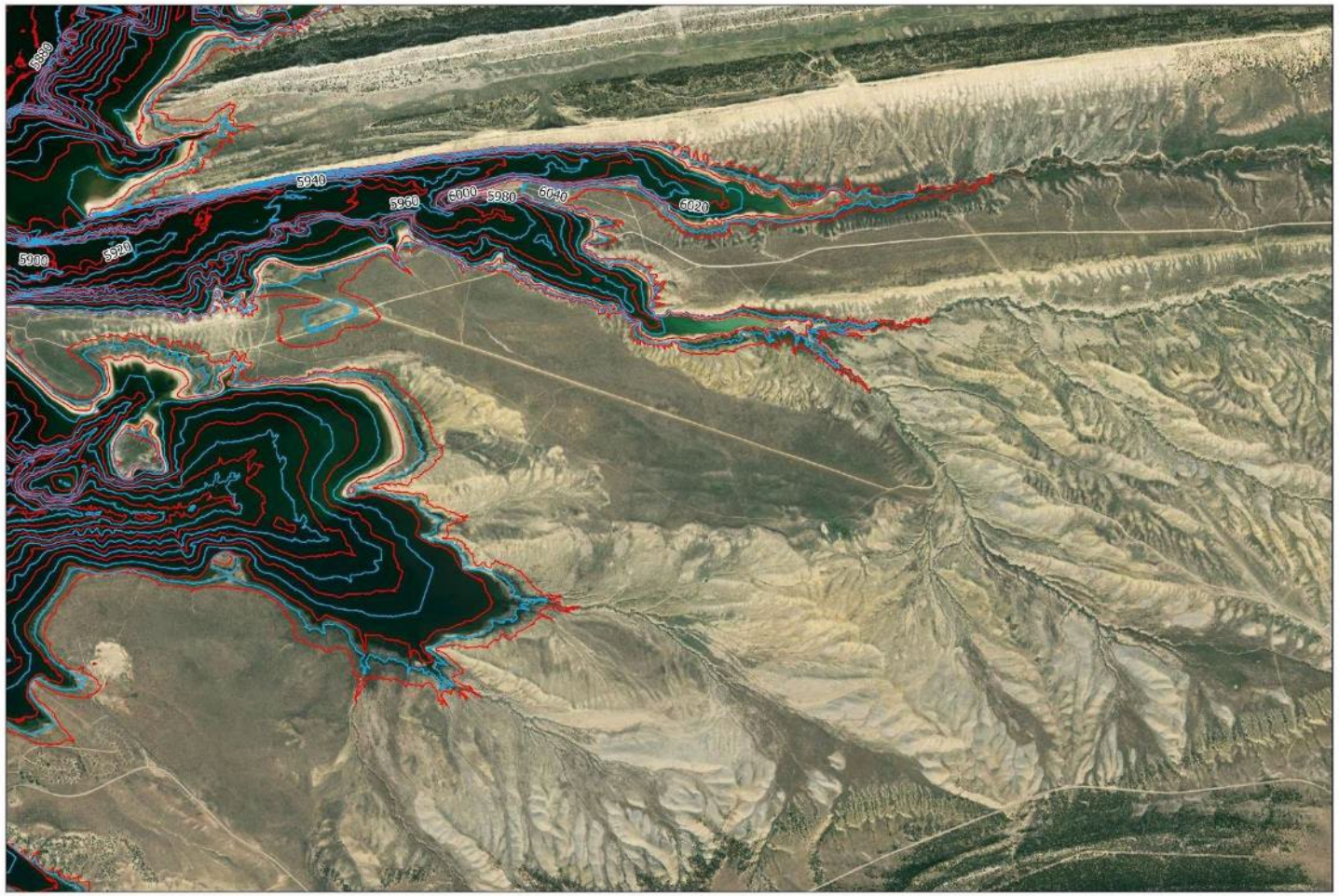
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS


5940
5950
5920
5930
5980
5900
6020
6000
5840
6040
5860
5820
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 8
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6040
6030
6020
6000
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 9
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION

feet


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 10
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6060
6040
6000
6020
5920
5940
5900
5960
5880
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 11

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

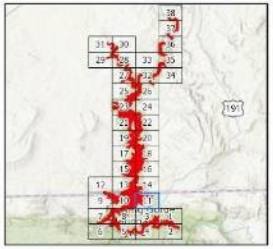
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

N

Scale 1:20,000
0 1,500 3,000 Feet



Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

BUREAU OF RECLAMATION

Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 12

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

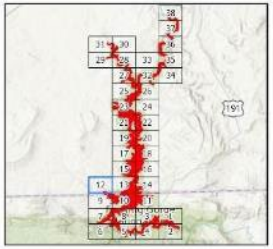
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

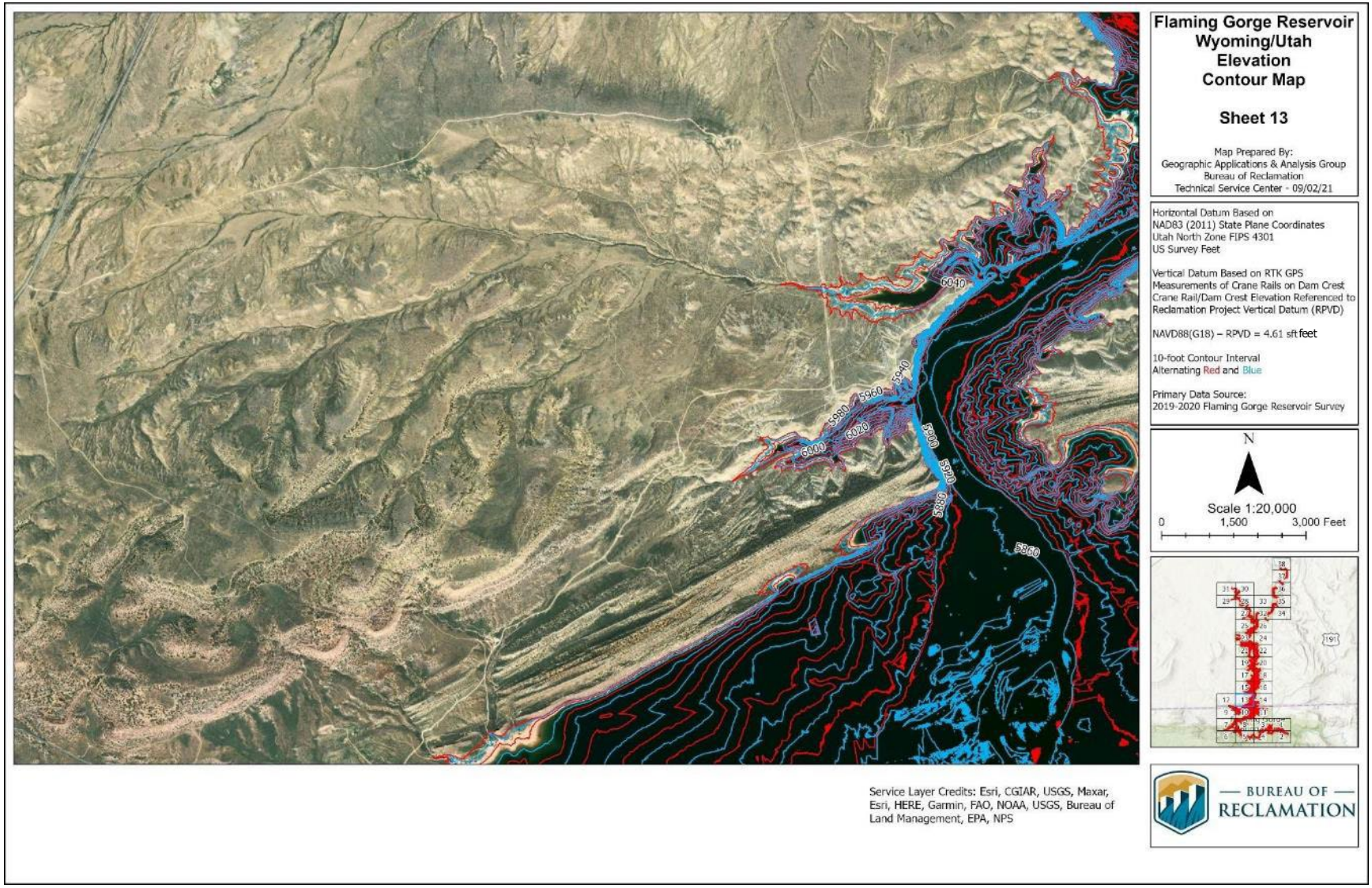
N

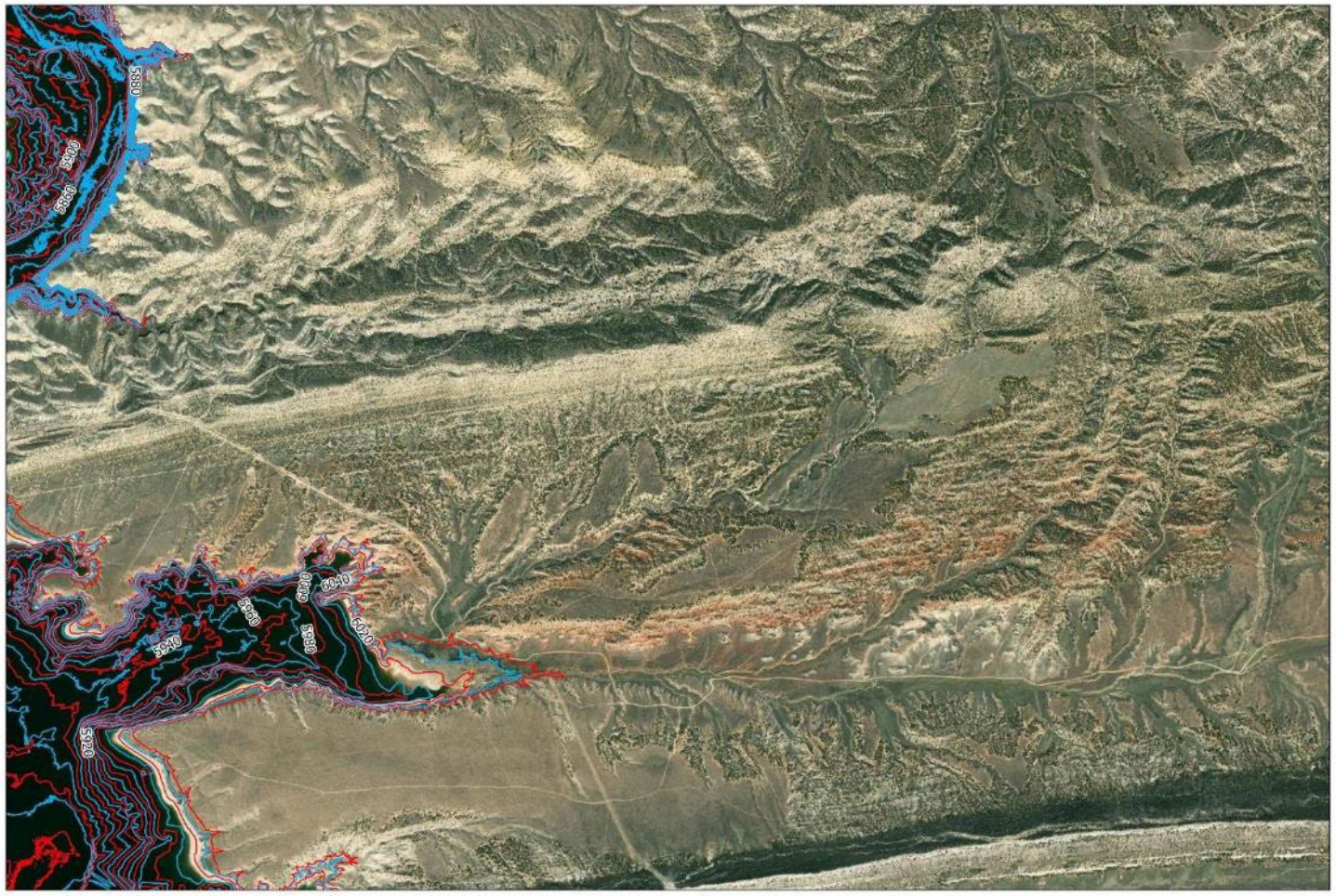
Scale 1:20,000
0 1,500 3,000 Feet



Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

BUREAU OF RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 13
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6040
5940
5960
5980
6020
6000
5900
5920
5880
5960
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 14

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

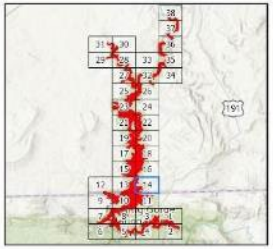
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

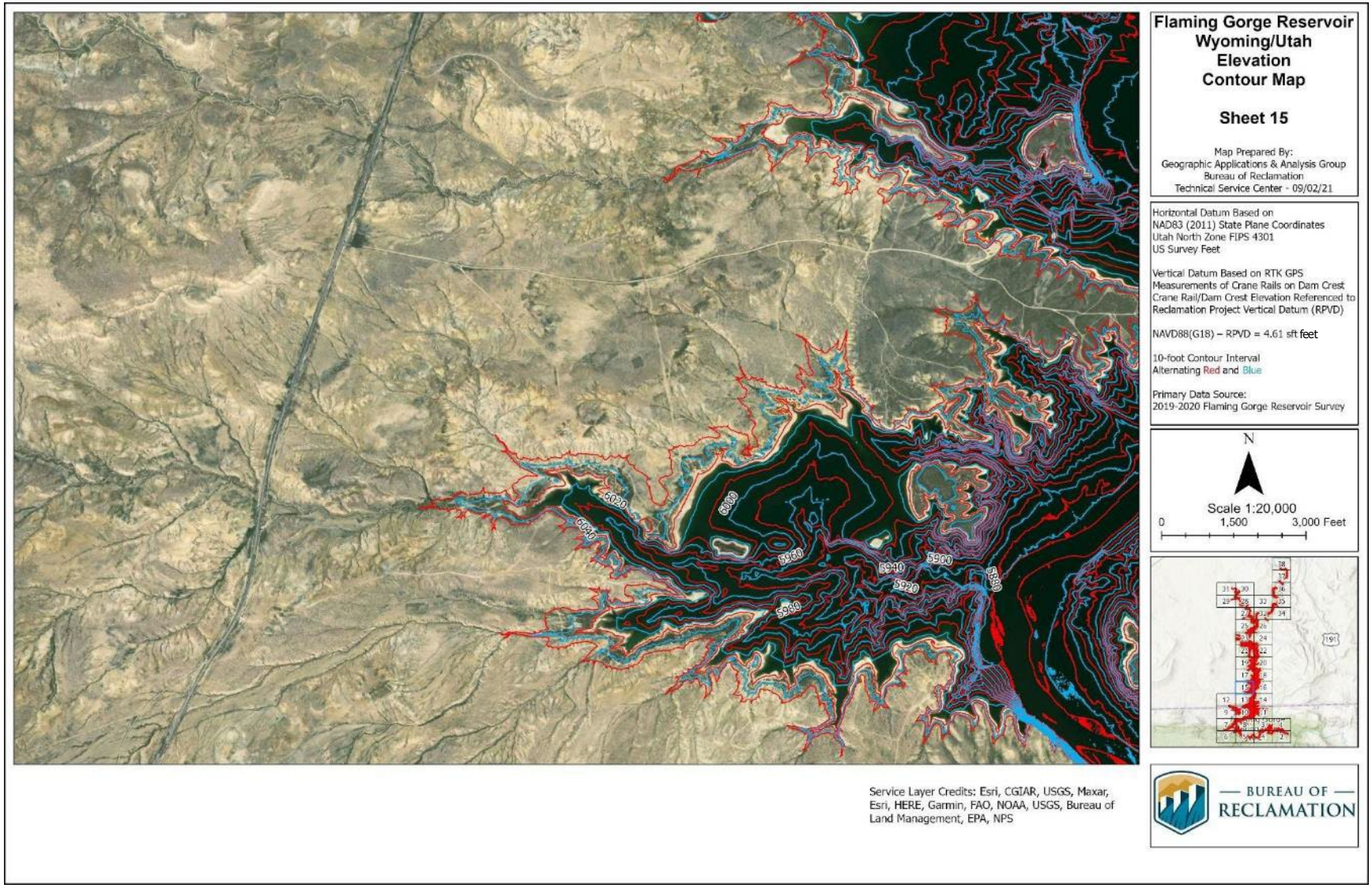
N

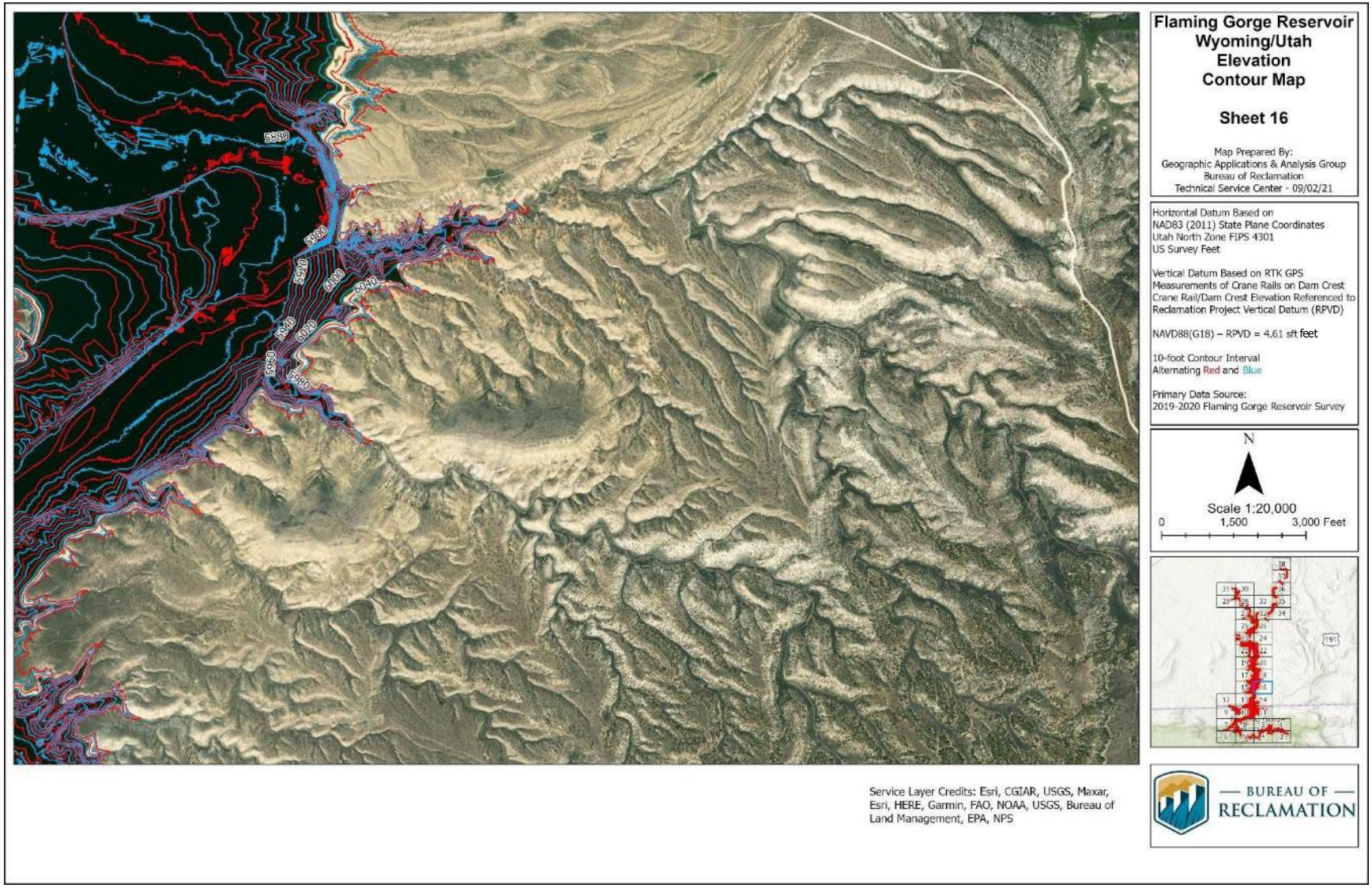
Scale 1:20,000
0 1,500 3,000 Feet

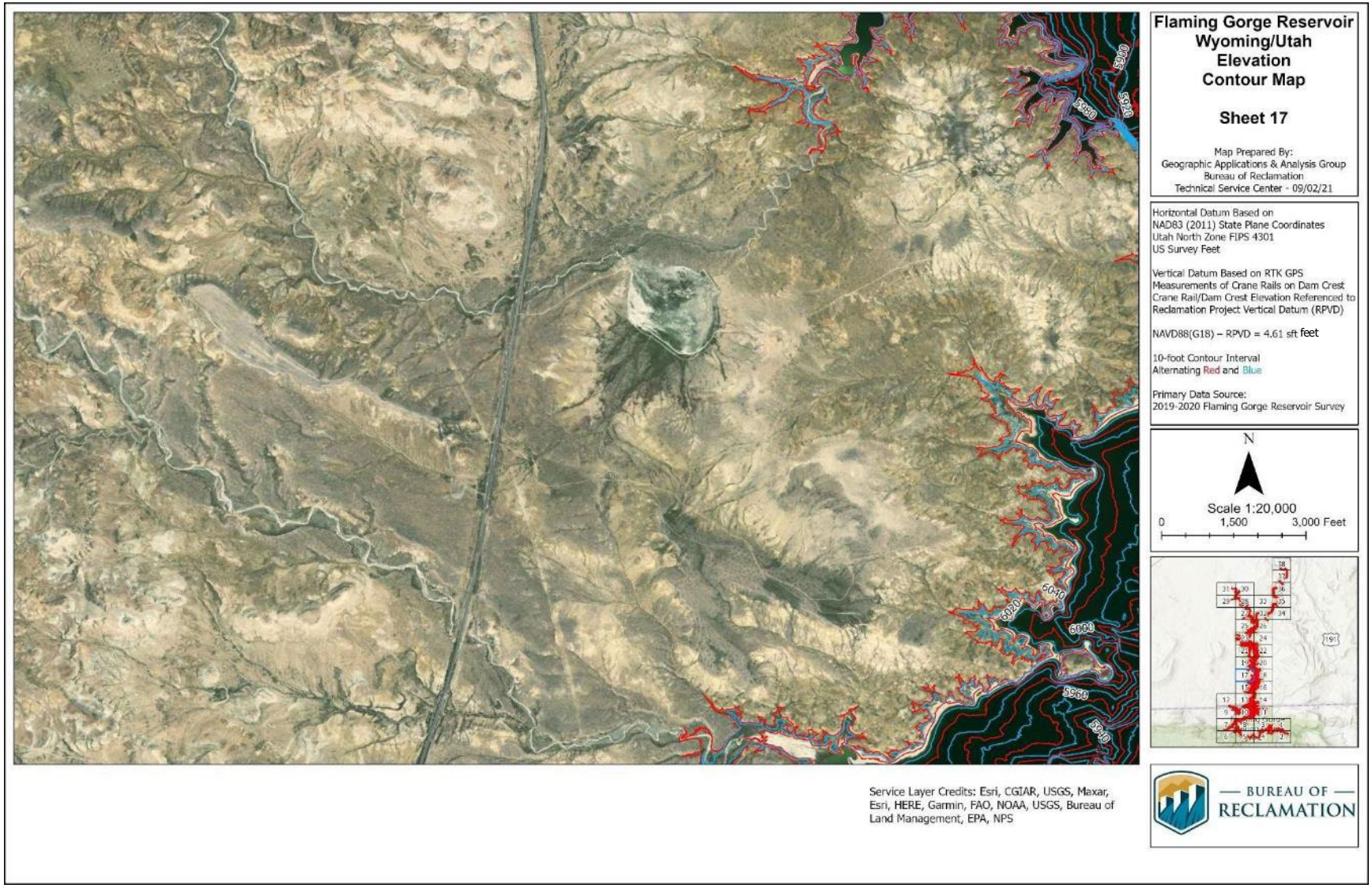


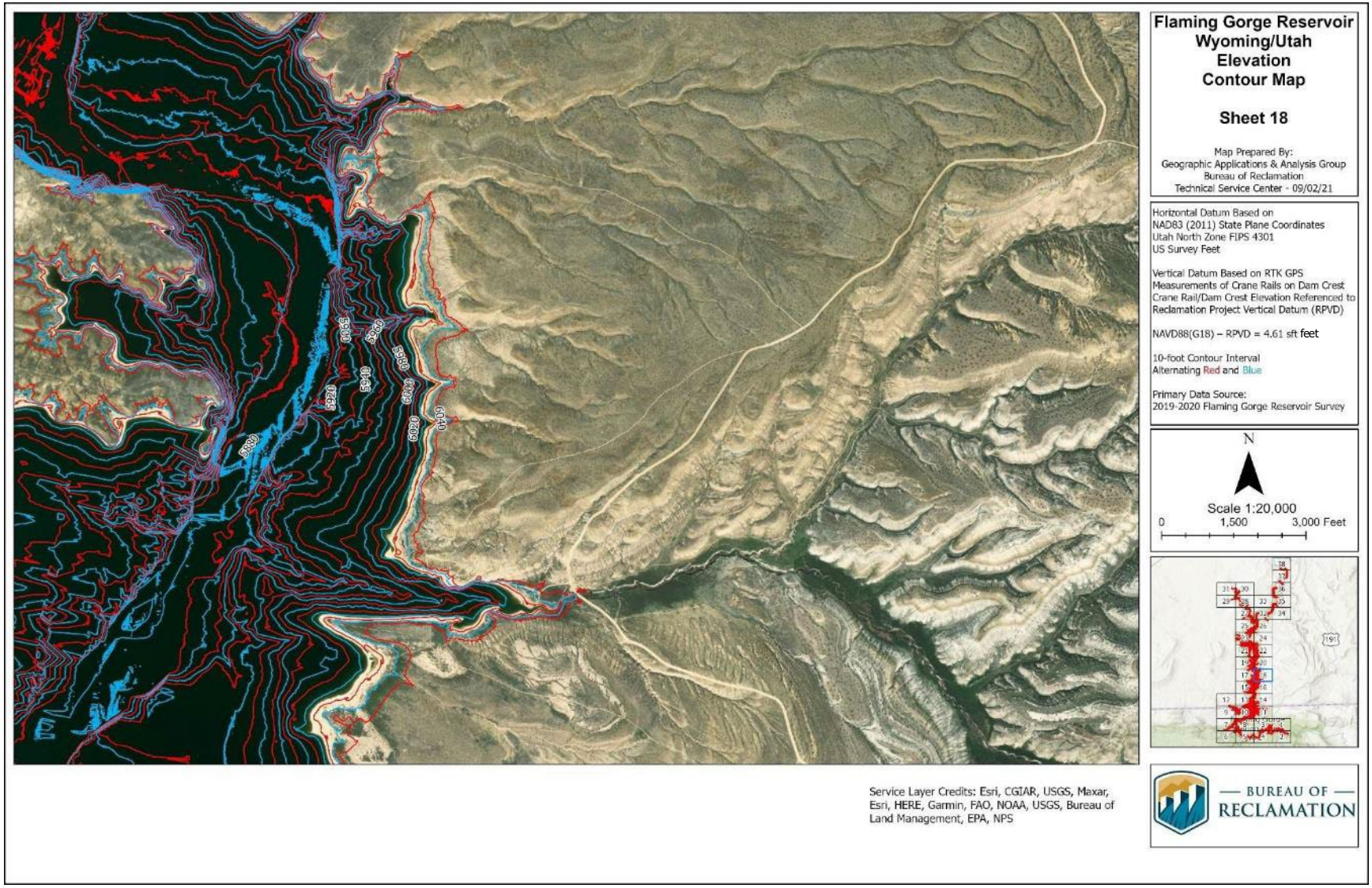
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

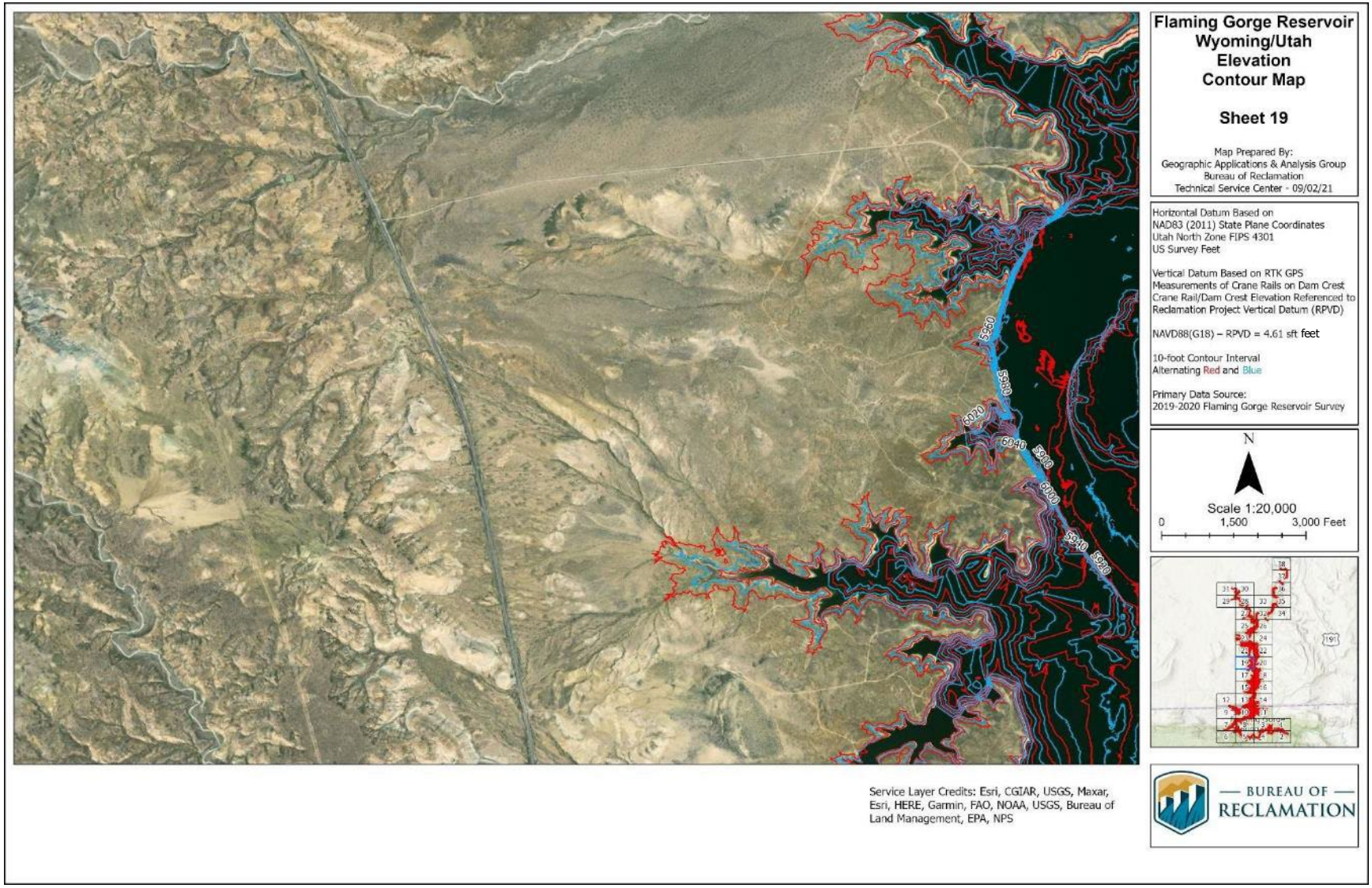
BUREAU OF RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 15
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6020
6000
5980
5960
5940
5920
5900
5880
5940
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS
BUREAU OF
RECLAMATION


5880
5900
5920
5940
5960
5980
6000
6020
6040
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 16
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 17
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6030
6020
6000
5990
5980
5960
5950
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 18
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 19
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
5950
5960
5970
6040
5980
6000
5940
5920
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS
BUREAU OF
RECLAMATION

Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 20

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

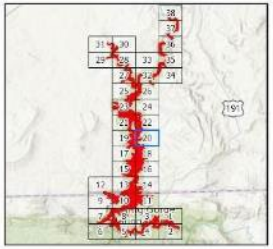
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

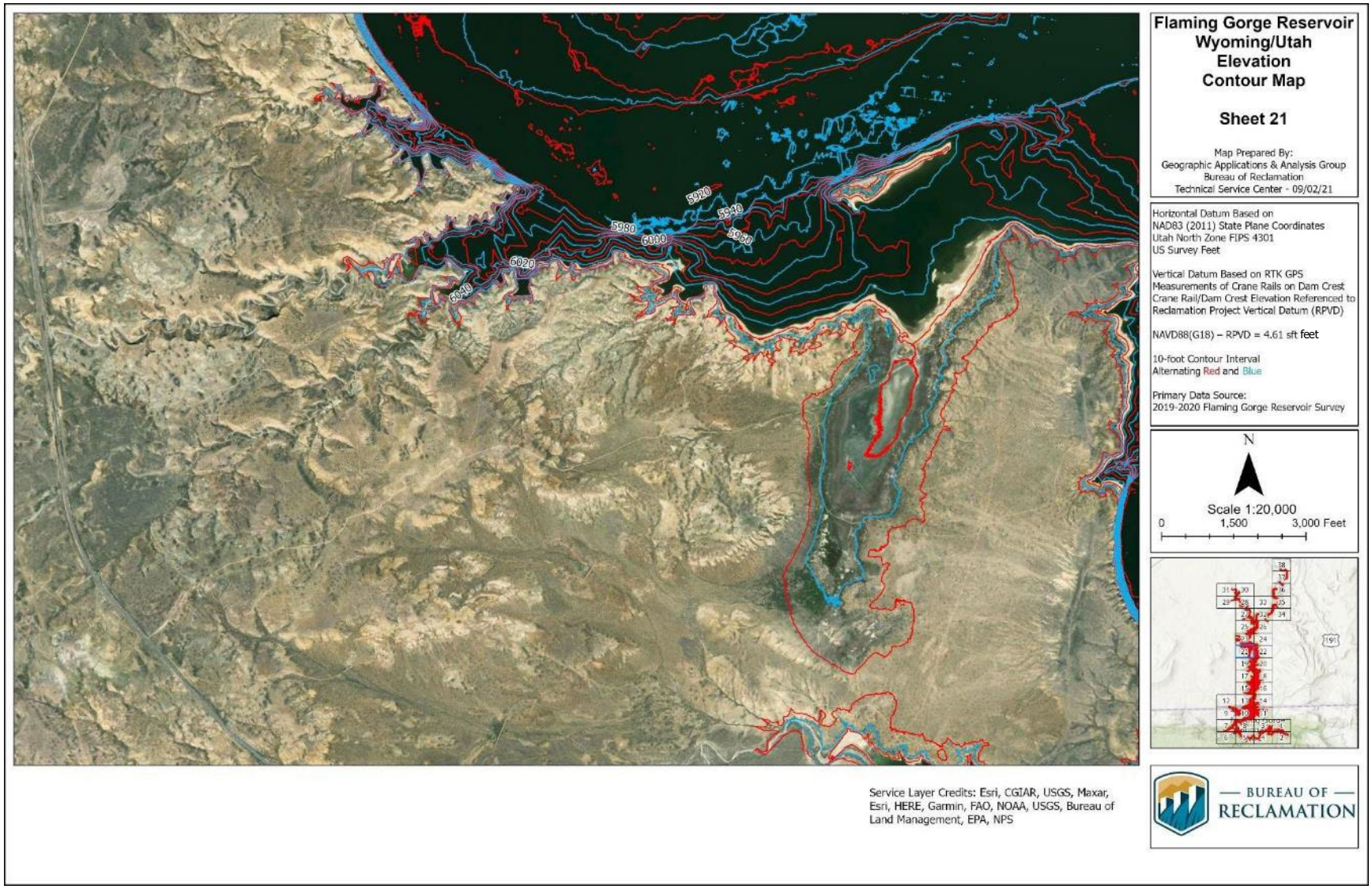
N

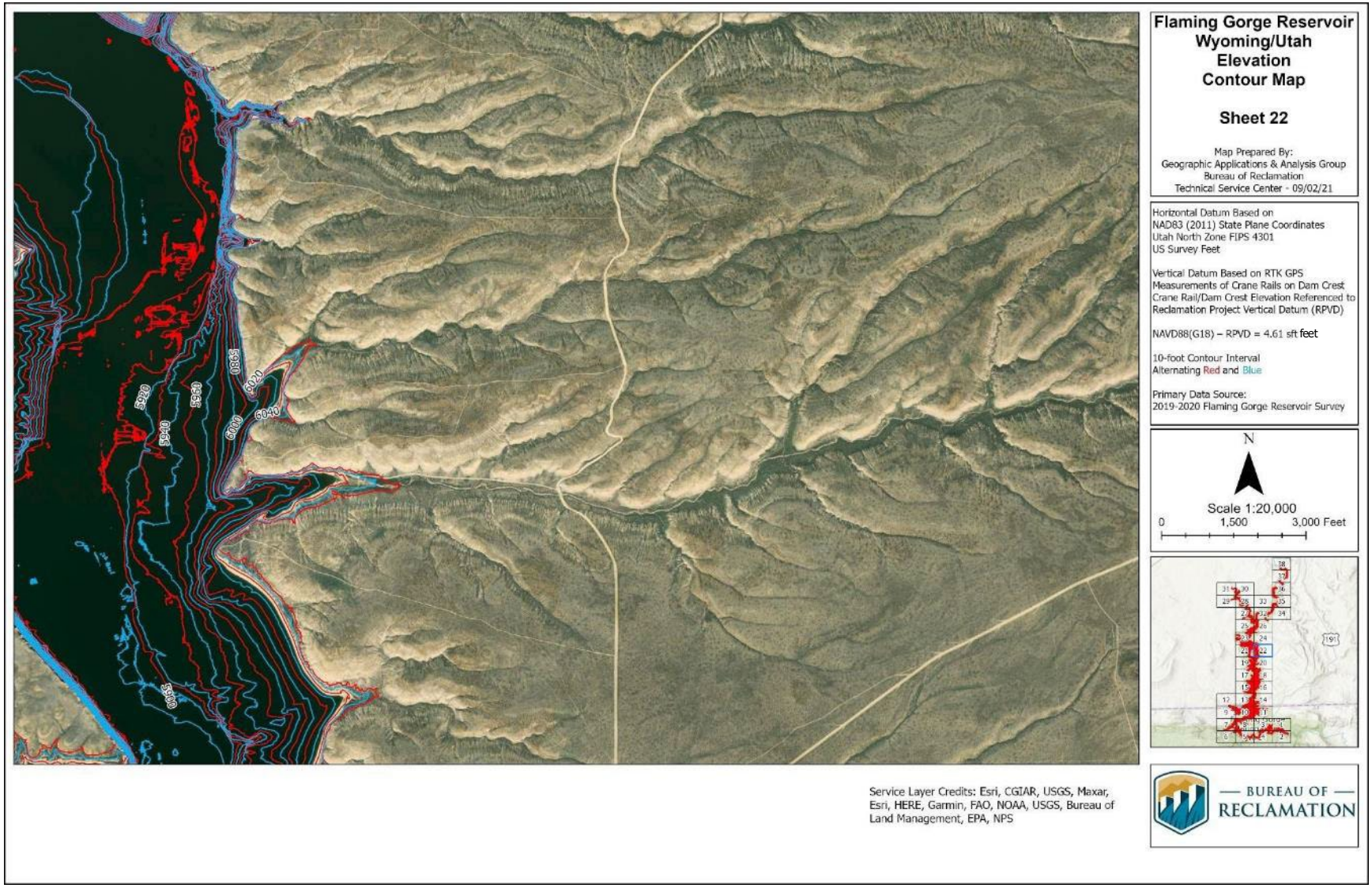
Scale 1:20,000
0 1,500 3,000 Feet

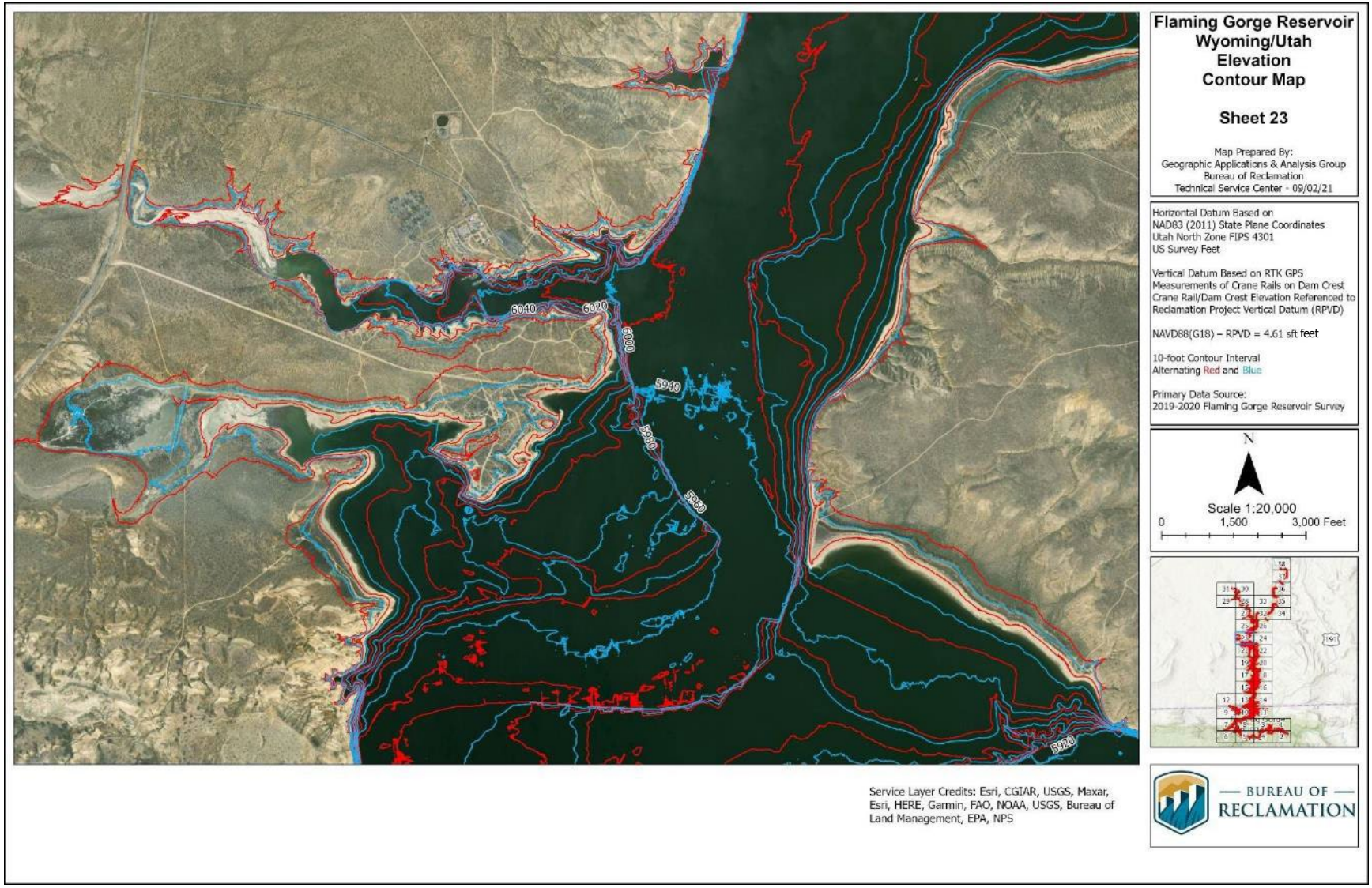


Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

BUREAU OF RECLAMATION


5920
5940
5960
5980
6000
6020
6040
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 21
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 22
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6040
6060
6080
6100
6120
6140
6160
6180
6200
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6040
6020
6000
5940
5900
5880
5920
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 23
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION

Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 24

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

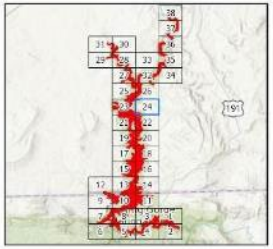
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

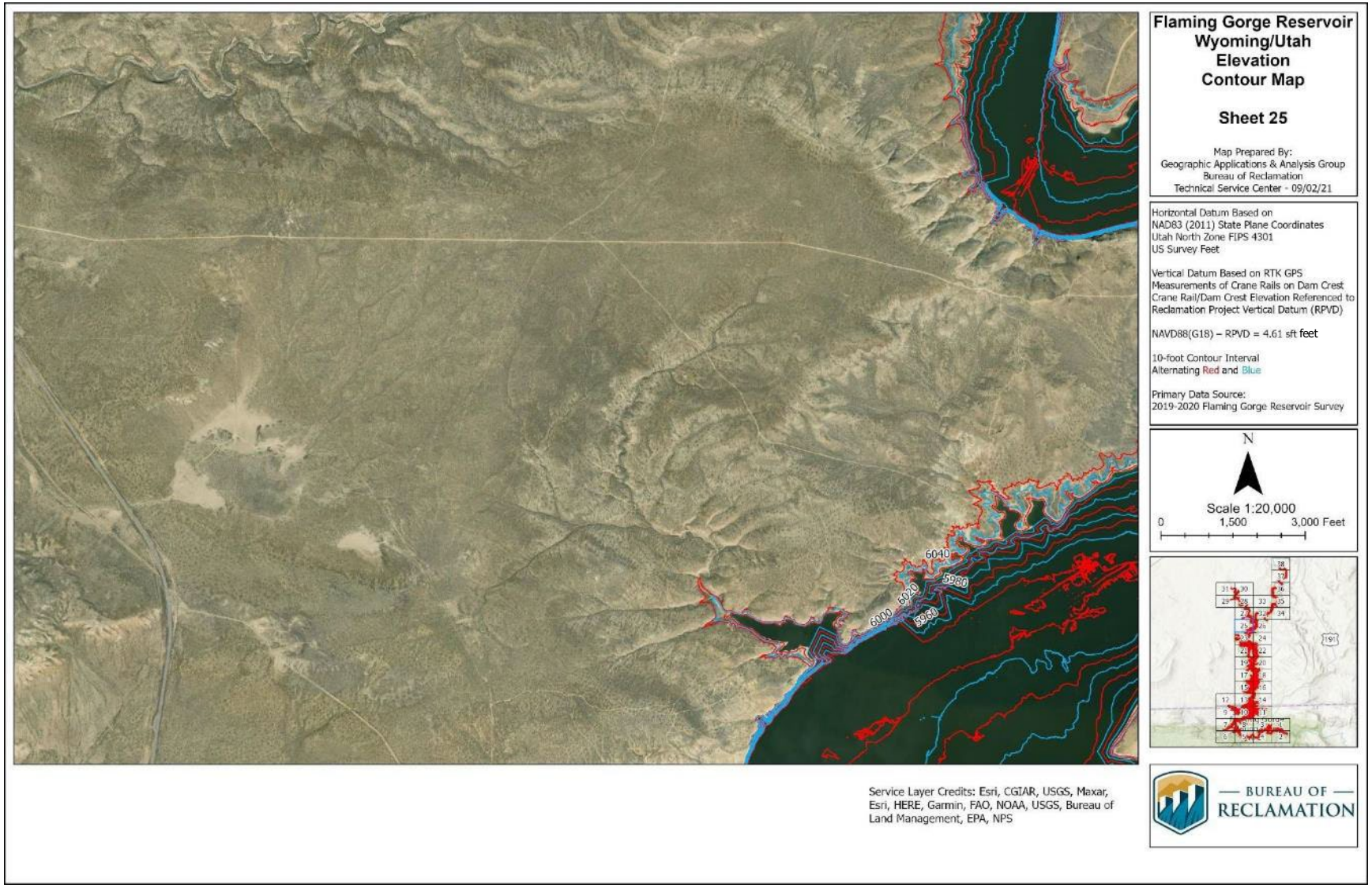
N

Scale 1:20,000
0 1,500 3,000 Feet

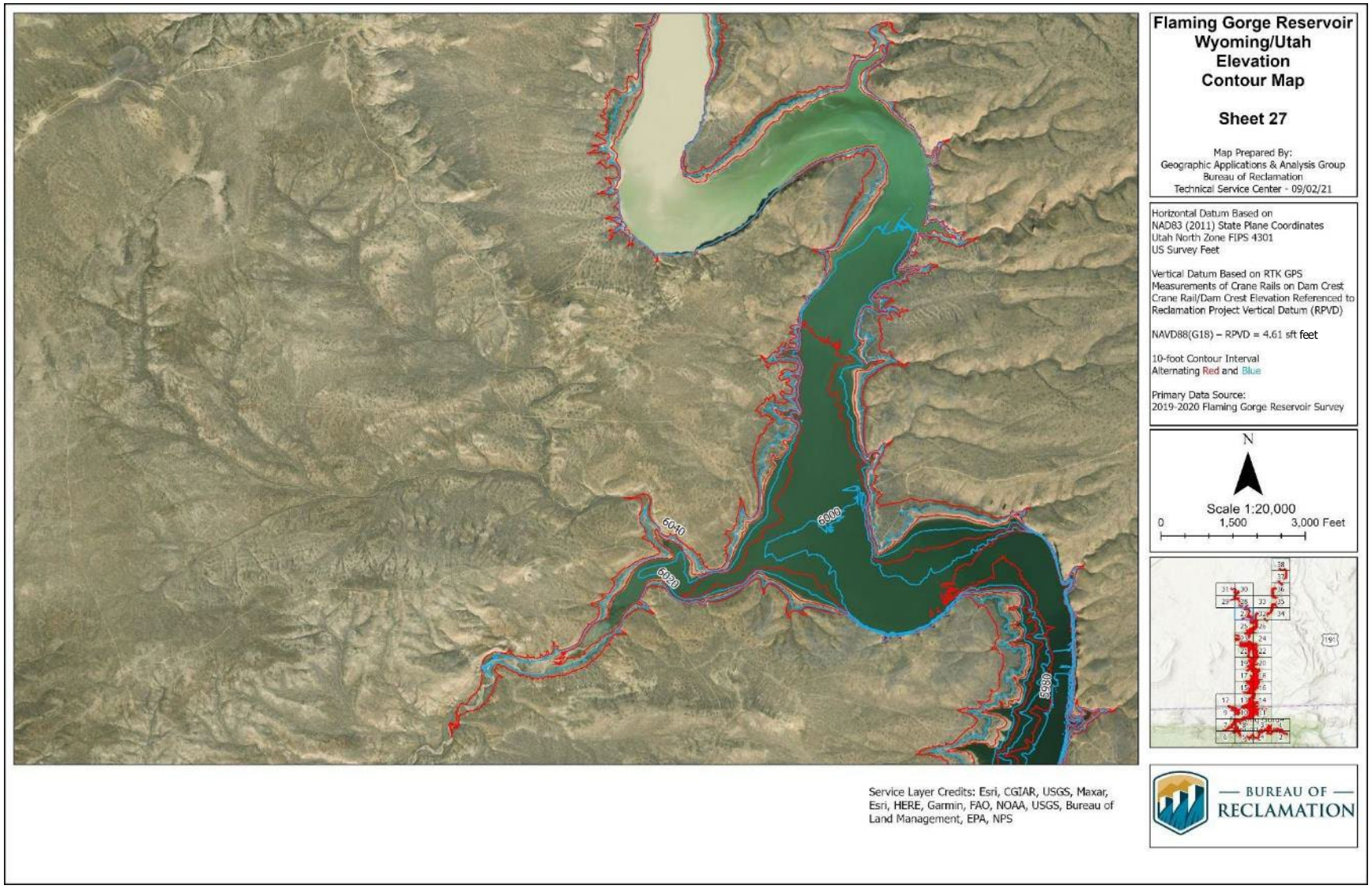


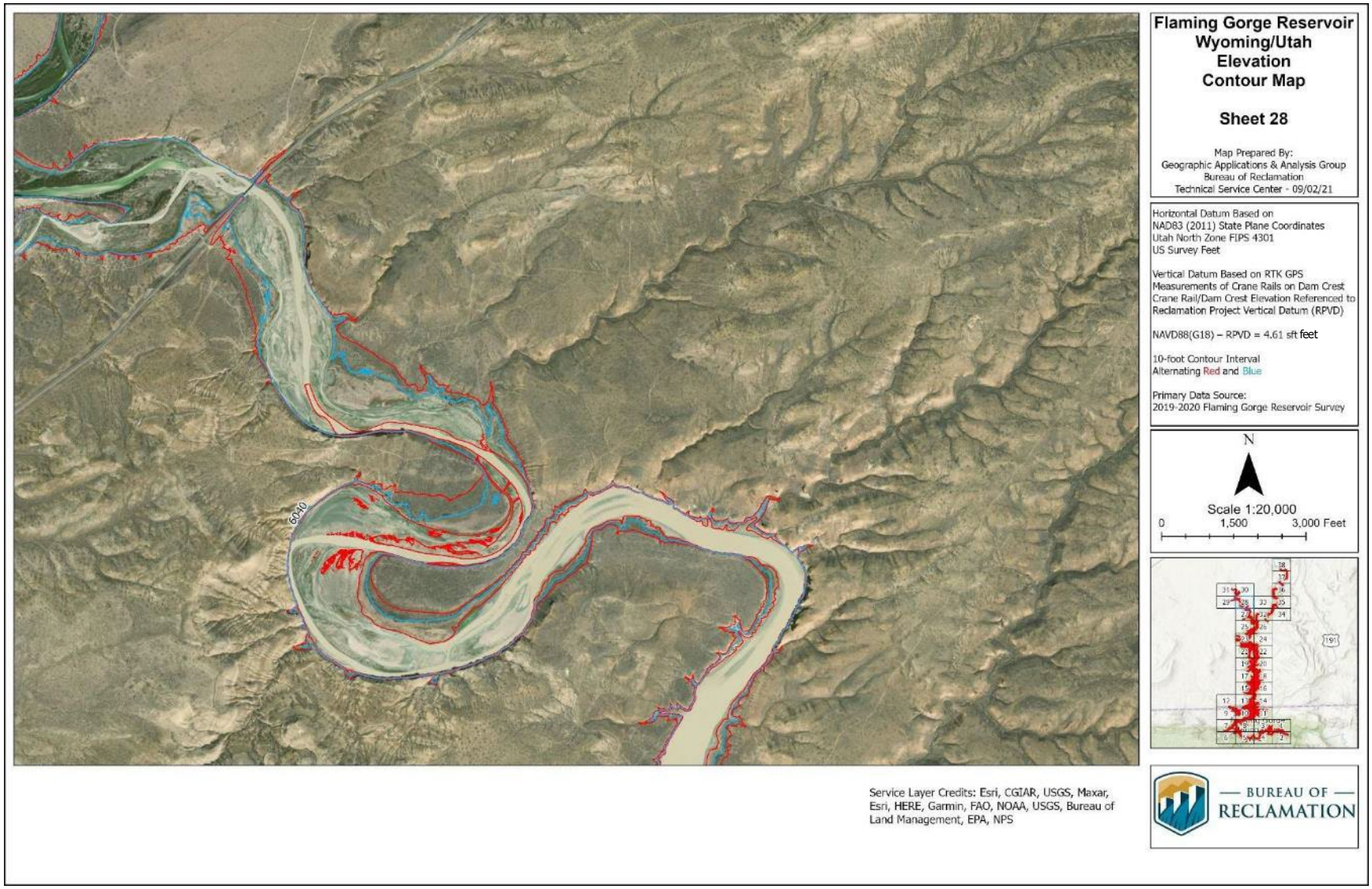
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

— BUREAU OF —
RECLAMATION


6040
5980
6020
6000
5960
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 25
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


5980
6000
6020
6040
6060
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 26
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION

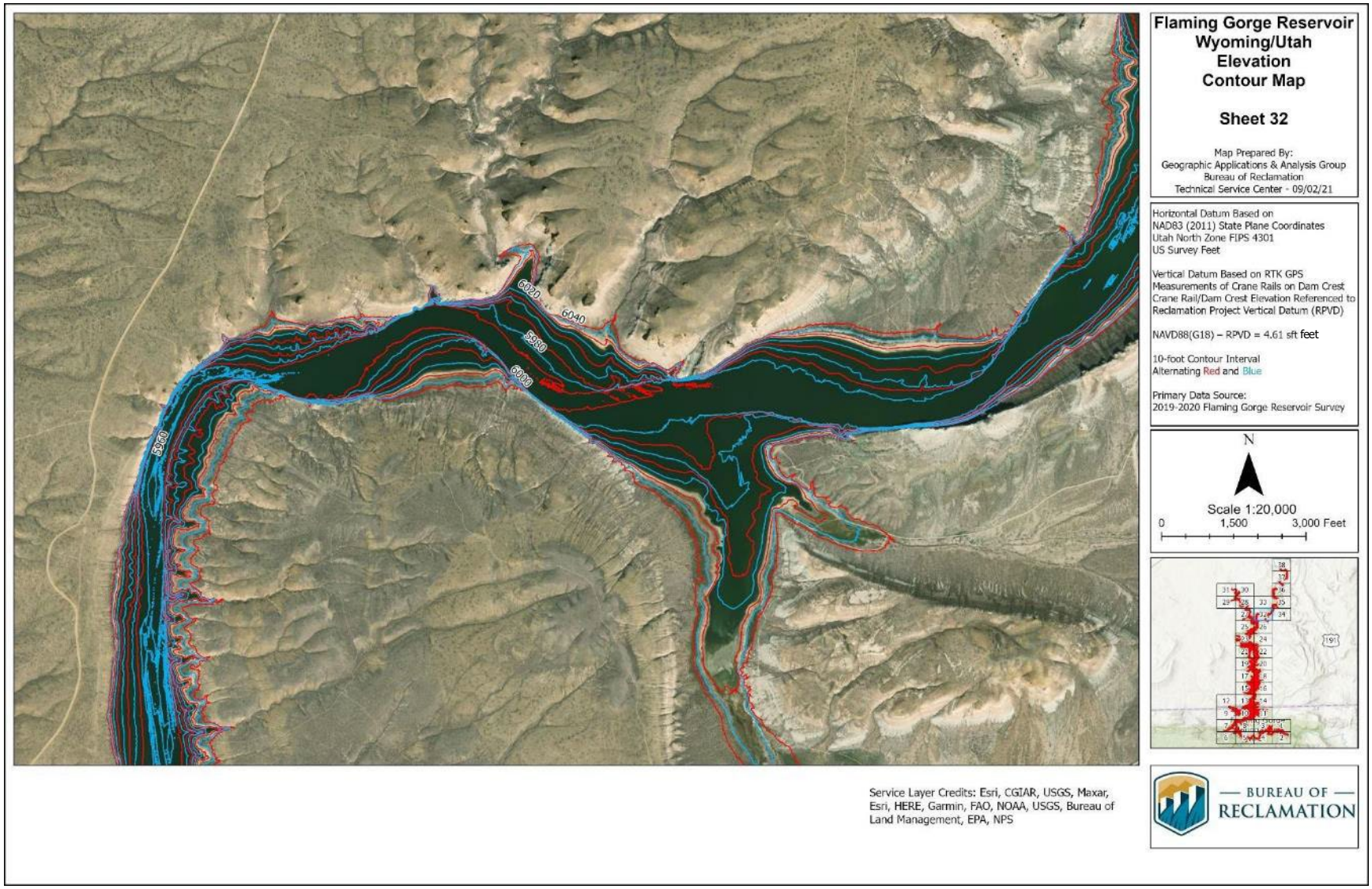

6040
6000
6020
5980
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 27
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION

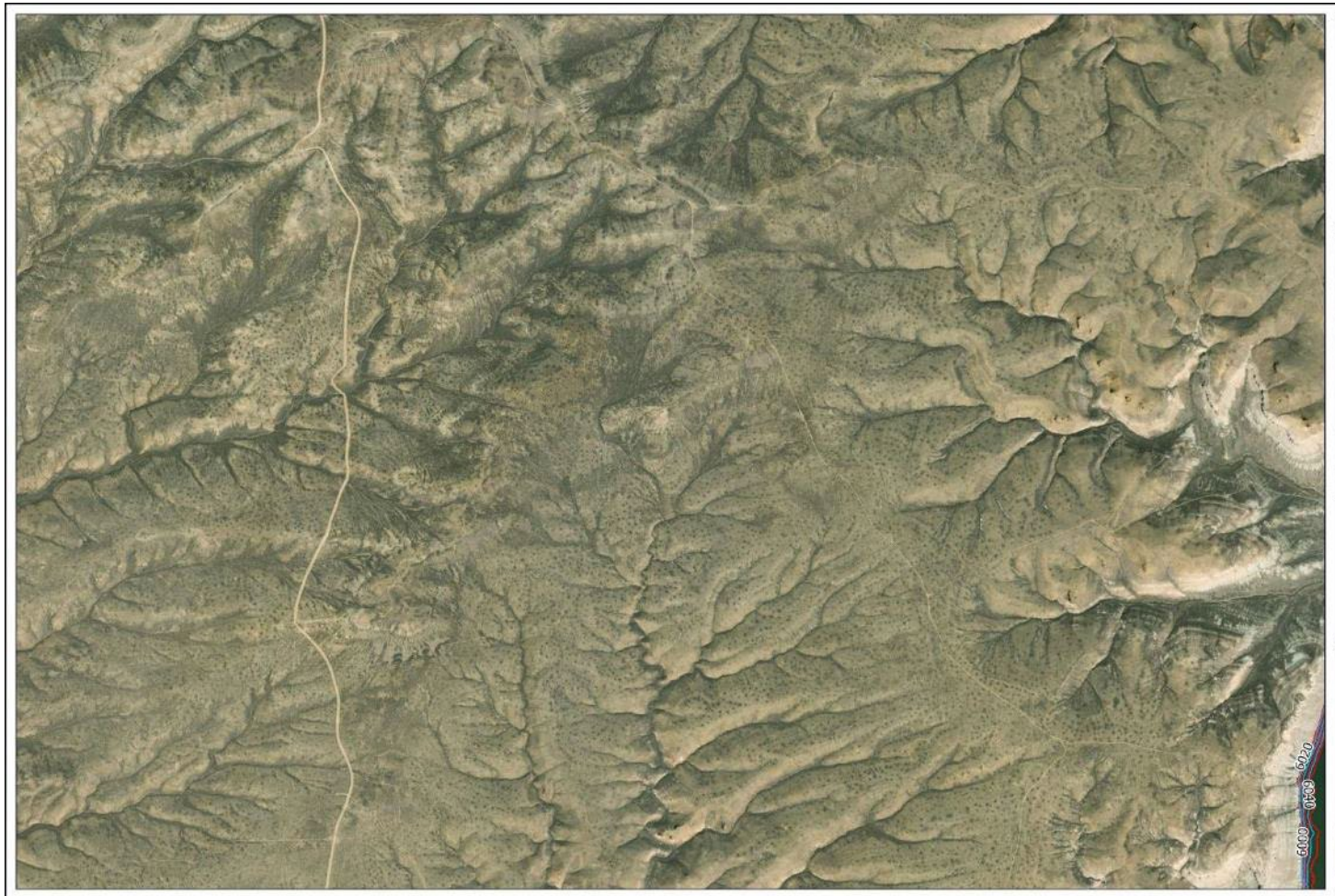

Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 28
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6040
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6040
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 29
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
191
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 30
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6040
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 31
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6040
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6020
6040
5980
6000
5960
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 32
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 33

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

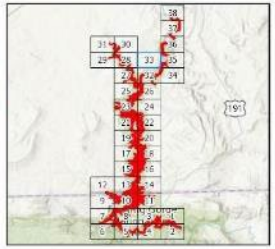
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

N

Scale 1:20,000
0 1,500 3,000 Feet



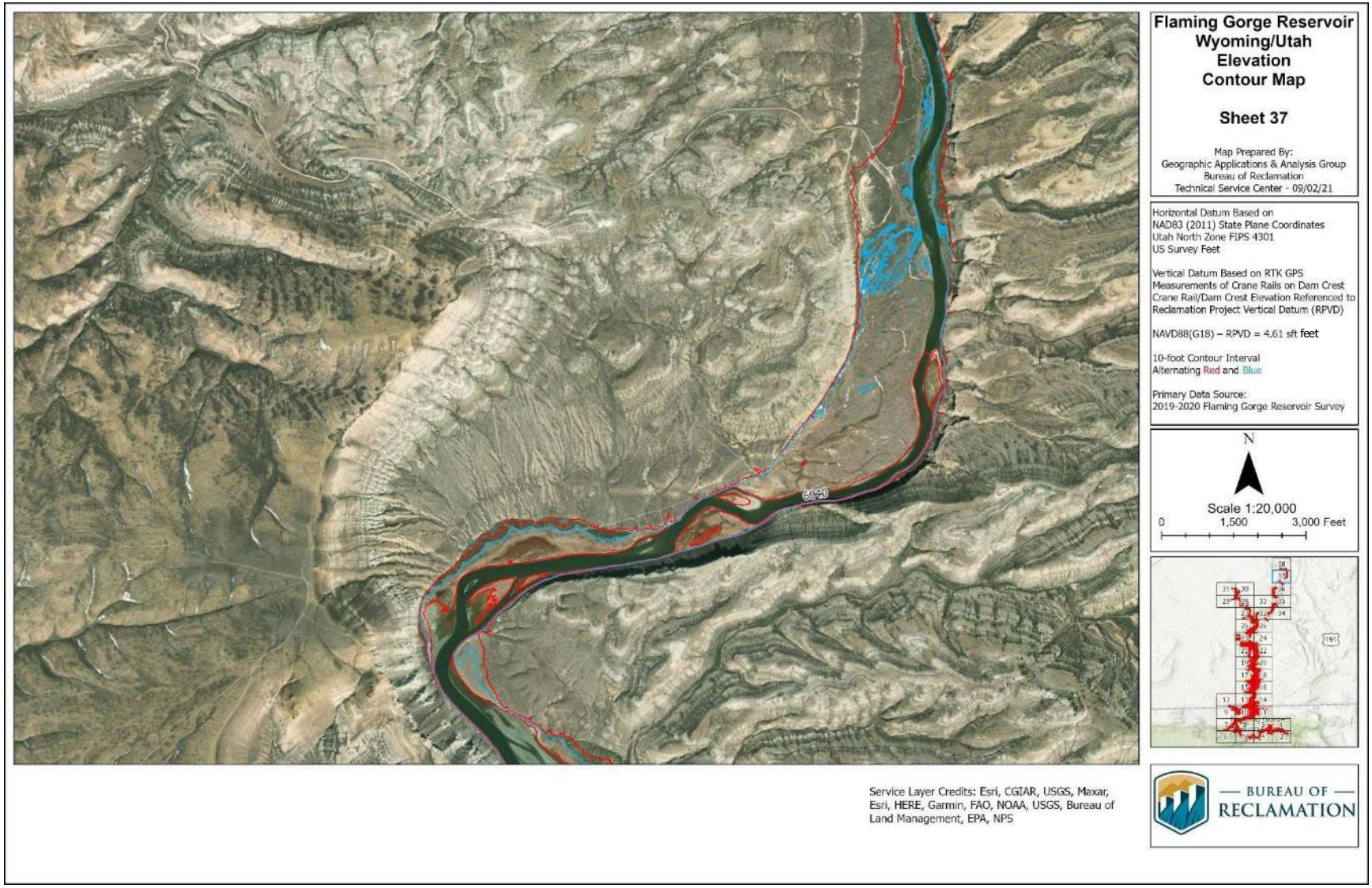
Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

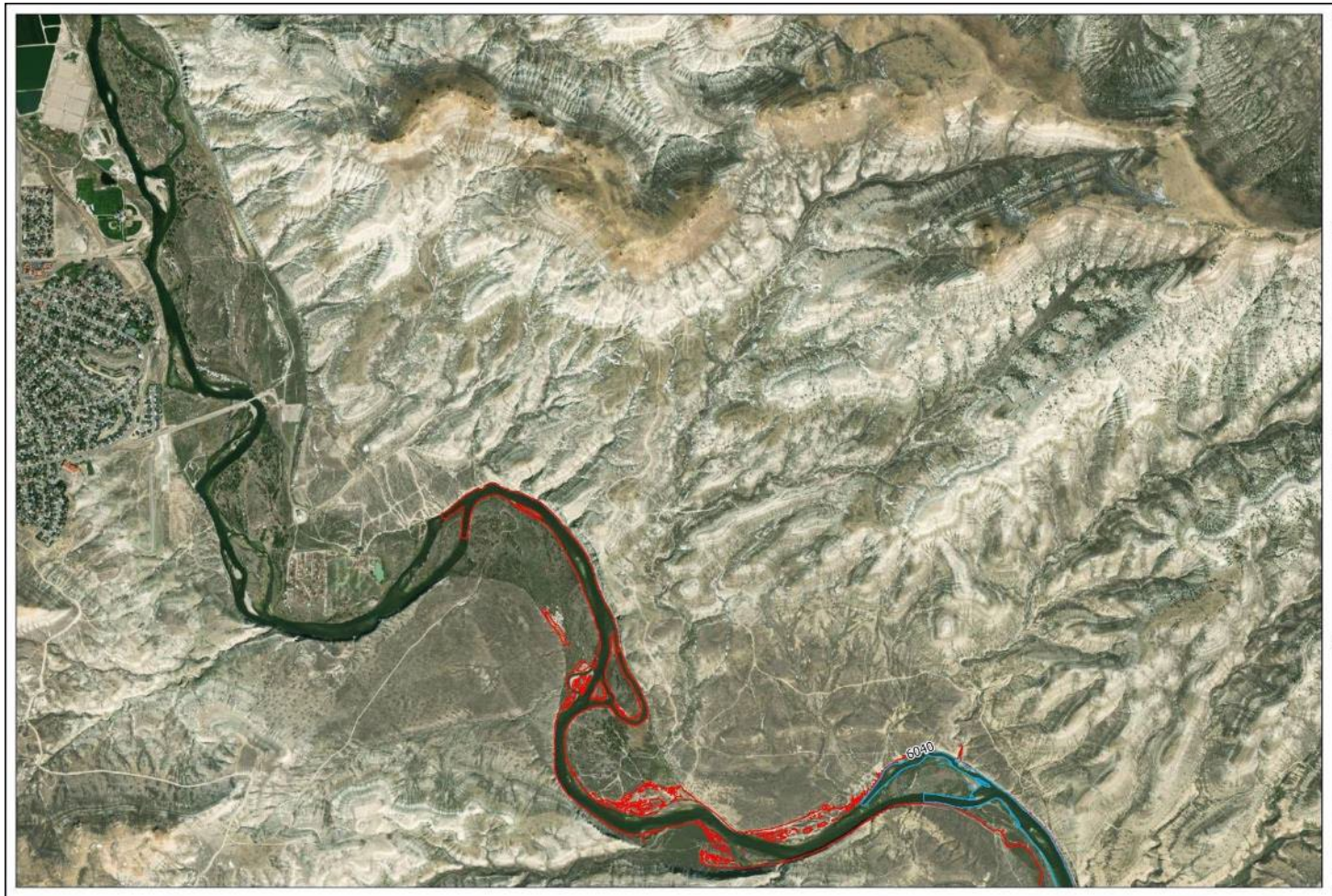
— BUREAU OF —
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 34
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6000
6020
6040
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 35
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


6040
6020
Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 36
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION


Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map
Sheet 37
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21
Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet
Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)
NAVD88(G18) – RPVD = 4.61 sft feet
10-foot Contour Interval
Alternating Red and Blue
Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey
N
Scale 1:20,000
0
1,500
3,000 Feet
6049
Service Layer Credits: Esri, CGIAR, USGS, Maxar,
Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of
Land Management, EPA, NPS
BUREAU OF
RECLAMATION



Flaming Gorge Reservoir
Wyoming/Utah
Elevation
Contour Map

Sheet 38

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 09/02/21

Horizontal Datum Based on
NAD83 (2011) State Plane Coordinates
Utah North Zone FIPS 4301
US Survey Feet

Vertical Datum Based on RTK GPS
Measurements of Crane Rails on Dam Crest
Crane Rail/Dam Crest Elevation Referenced to
Reclamation Project Vertical Datum (RPVD)

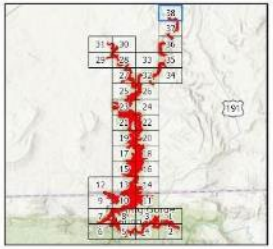
NAVD88(G18) – RPVD = 4.61 sft feet

10-foot Contour Interval
Alternating Red and Blue

Primary Data Source:
2019-2020 Flaming Gorge Reservoir Survey

N

Scale 1:20,000
0 1,500 3,000 Feet



Service Layer Credits: Esri, CGIAR, USGS, Maxar, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

— BUREAU OF —
RECLAMATION