BUREAU OF RECLAMATION

Technical Report No. ENV-2021-002

Navajo Reservoir 2019 Sedimentation Survey

Colorado River Storage Project, New Mexico
Upper Colorado Basin Region

U.S. Department of the Interior

February 2021

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

Acknowledgements

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14. SHORT ABSTRACT

The 2019 multibeam bathymetric survey of Navajo Reservoir was combined with 2019 aerial LiDAR (Atlantic, 2019) to produce a combined digital surface of the reservoir bottom. Analysis of this data indicates that at the spillway elevation (6085 feet, project vertical datum), the reservoir has a surface area of 15,773 acres and a storage capacity of 1,647,937 ac-ft excluding the dead storage capacity. Since the original filling in 1962, the live capacity of the reservoir is estimated to have lost 56,470 ac-ft of storage capacity (3.3%) due to sedimentation. The dead storage pool volume has lost 3,107 ac-ft, reducing the dead storage to 75 percent of the original design capacity of 12,600 ac-ft. The sedimentation level at the dam is at 5,731.5 feet (project vertical datum), which is 21 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

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

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Acronyms and Abbreviations

ac-ft	acre-feet
ft^3/s	cubic feet per second (cfs)
DEM	digital elevation model
DOI	Department of the Interior
ft	foot or feet
GIS	Geographic Information System
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
MAF	million acre-feet
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
NRCS	Natural Resources Conservation Service
OPUS	Online Positioning User Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RTK	Real-Time Kinematic
SGMC	State Geologic Map Compilation
TSC	Technical Service Center
U.S.	United States
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WCAO	Western Colorado Area Office
WSE	water surface elevation
WY	water year (October 1 to September 30)
yr	year

Executive Summary

Navajo Dam and Reservoir are on the San Juan River about 21 miles east from Aztec, New Mexico.

A complete bathymetric survey of Navajo Reservoir was conducted in 2019 with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1962,

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

The bathymetric survey was conducted from a boat using a multibeam echosounder that was interfaced with global positioning system (GPS) instruments (for horizontal positioning) to map the reservoir bottom. The 2019 multibeam bathymetric survey of Navajo Reservoir was combined with 2019 aerial LiDAR data (Atlantic, 2019) to produce a combined digital surface representation of the reservoir bottom.

This bathymetric survey was conducted from July 9th to July 16th, 2019, when the reservoir water surface elevation ranged between 6074.75 and 6075.27 feet (Reclamation Project Vertical Datum; RPVD), 10 feet (ft) below the top of joint use pool elevation of 6085 ft. The above-water topographic Light Detection and Ranging (LiDAR) data were measured on May 6th and May 14th, 2019, when the water surface elevations were 6043.59 ft, and 6047.44 ft, respectively.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 6070 ft (RPVD), which is 5 feet below the water level at the time of survey, the reservoir surface area was 13,881 acres with a storage capacity of 1,425,291 acre-feet (excluding dead pool volume).
- At the top of joint use pool elevation (6085 feet, RPVD), the reservoir would have a surface area of 15,773 acres and a storage capacity of 1,647,937 acre-feet (ac-ft).
- Since the start of reservoir filling in 1962, the reservoir is estimated to have lost 56,470 ac-ft of total capacity (3.3 percent) due to sedimentation. This volume represents a sediment yield rate of 0.31 ac-ft per square mile per year (acre-feet/mi^2/year) which is considered low as defined in Reclamation (2006).
- By 2019, the dead storage pool volume had reduced to 9,493 ac-ft, which is 75 percent of the original dead storage volume of 12,600 ac-ft. The sedimentation level at the dam is at 5731.5 feet (RPVD), which is 21 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

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	**Navajo**	Region	Upper Colorado
Owner	Reclamation	Area Office	
Stream	San Juan River	Vertical Datum	RPVD
County	San Juan	Top of Dam (ft)	6,108
State	NM	Spillway Crest (ft)	6,085
Lat (deg min sec)	36° 48′ 13.1″ N	Power Penstock Elevation (ft)	
Long (deg min sec)	107° 36′ 34.2″ W	Low Level outlet (ft)	
HUC4	1408	Hydraulic Height (ft)	
HUC8	14080101	Total Drainage Area (mi^2)	3,210
NID ID	NM00120	Date storage began (yyyy)	1962
Dam Purpose		Date for normal operations	

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

Original Design (4/22/1958, sheet 711-D-37)

Storage Allocation	Elevation (feet)	Surface area (acres)	Capacity (ac-ft)	Gross Capacity (ac-ft)
SURCHARGE	6101.5		273,000	1,985,000
FLOOD CONTROL				
MULTIPLE USE				
JOINT USE				
CONSERVATION	6,085		1,037,000	1,712,000
INACTIVE	5990		500,000	675,000
DEAD			175,000	175,000

Survey Summary

Survey Date	Type of Survey	No. of Range lines or Contour Intervals	Contributing Sediment Drainage Area (mi^2)	Period Sedimentation Volume (ac-ft)	Cumulative Sedimentation (ac-ft)	Lowest Reservoir Elevation (feet)	Remaining Portion of Dead Storage (%)
1962	unknown	Unknown	3,210	0	0	5720	100%
2019	Bathymetric/ LiDAR	N/A	2,919	56,470	56,470	5731.5	75%

Notes

A revision of reservoir allocation was published in September 1967 and supersedes original design data. The original area capacity table was modified in February 2002 due to a method change, not due to a survey.

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1. Introduction

Navajo Dam and Navajo Reservoir are located on the San Juan River about 21 miles east from Aztec, New Mexico, and 21.5 miles east-northeast from Bloomfield, New Mexico (Figure 1). The dam and reservoir are operated by Reclamation's Western Colorado Area Office (WCAO) as part of the Colorado River Storage Project that supplies water for irrigation, municipal and industrial purposes, by oil and gas fields and by thermal powerplants. Water is also released from Navajo Reservoir through a tunnel into an aqueduct for use on the Navajo Indian Irrigation Project. A powerplant at Navajo Dam is owned and operated by the City of Farmington (Reclamation, 2020).

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

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

As part of ongoing operations and sediment monitoring activities, the Upper Colorado Basin Region requested the Technical Service Center's (TSC) Sedimentation and River Hydraulics Group (86-68240) conduct a bathymetric survey of the underwater portions of the reservoir that were accessible by boat. A complete bathymetric survey was conducted from July 9th to July 16th, 2019 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.

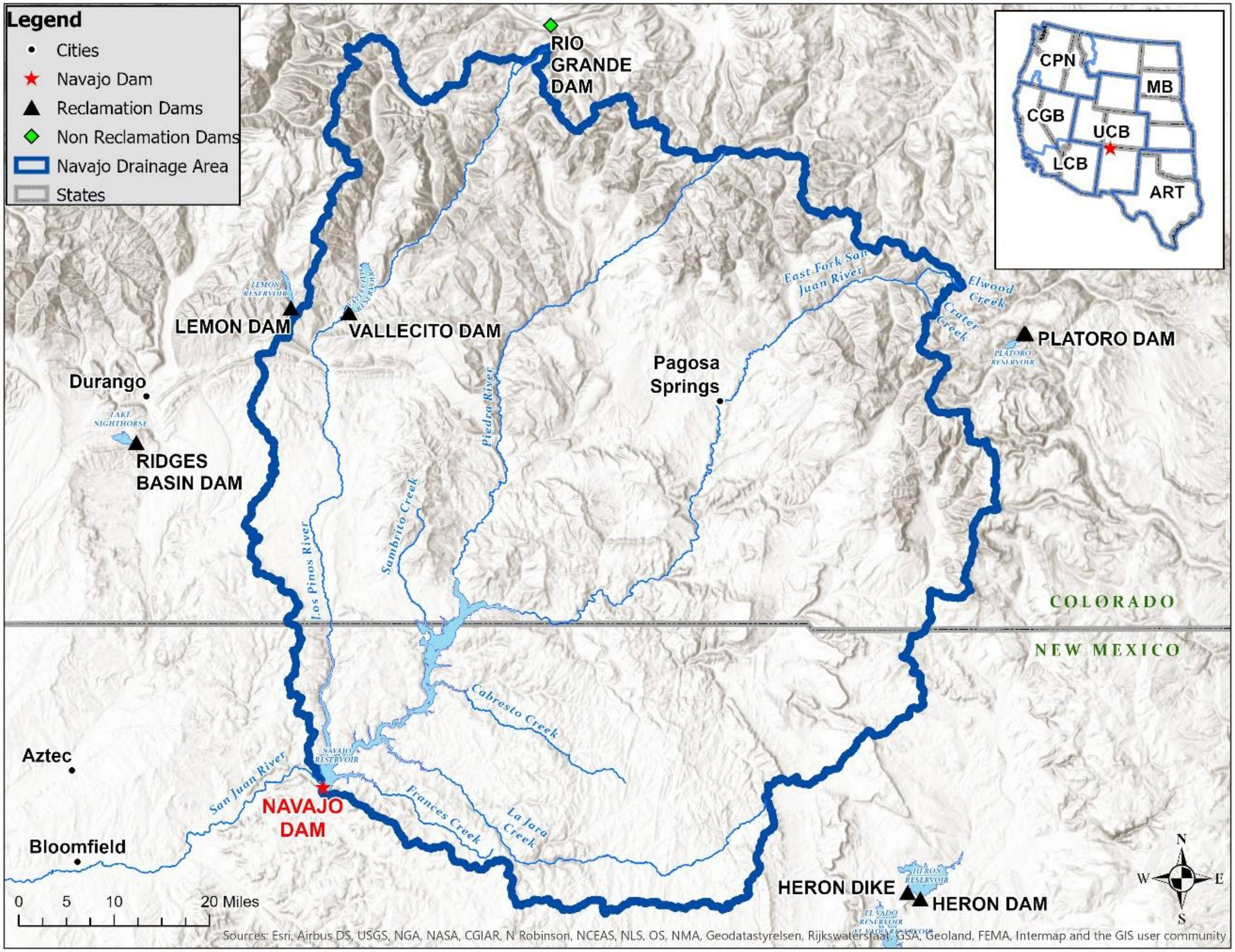

Figure 1. Location map of Navajo Dam and Navajo Reservoir, 21 miles east from Aztec, New Mexico.

2. Watershed Description

This chapter briefly describes the watershed characteristics in terms of sediment contributing drainage area, geology, climate, runoff, and dam and reservoir operations.

2.1. Location and Drainage

The watershed upstream from Navajo Dam has a total contributing drainage area of 3,210 square miles (mi^2) with inflows from the San Juan River, the Piedra River, and Los Pinos River. Because of upstream lakes and reservoirs that trap sediment , the net sediment-contributing drainage area to Navajo Reservoir (as of 2019) is 2,919 mi^2 (Figure 1). This watershed drains the San Juan Mountains, has an average elevation of 8170 feet (stream stats), and includes Summit Peak (Southern San Juan Mountains) in the northeast, Windom Peak (Needle Mountain) in the northwest, and Dulce Mountain and Archuleta Mesa in the southeast. Navajo Reservoir is located in the southwest corner of the drainage basin. Pagosa Springs is on the San Juan River, and Bayfield and Ignacio are on Los Pinos River. The Piedra River runs near the famous Chimney Rock landmark.

2.2. Geology

The geology of the drainage area (Figure 2) consists primarily of San Jose and Animas Formation, along with Mancos Shale, ash-flow, and Pictured Cliffs Sandstone and Lewis Shale (Horton, 2017).

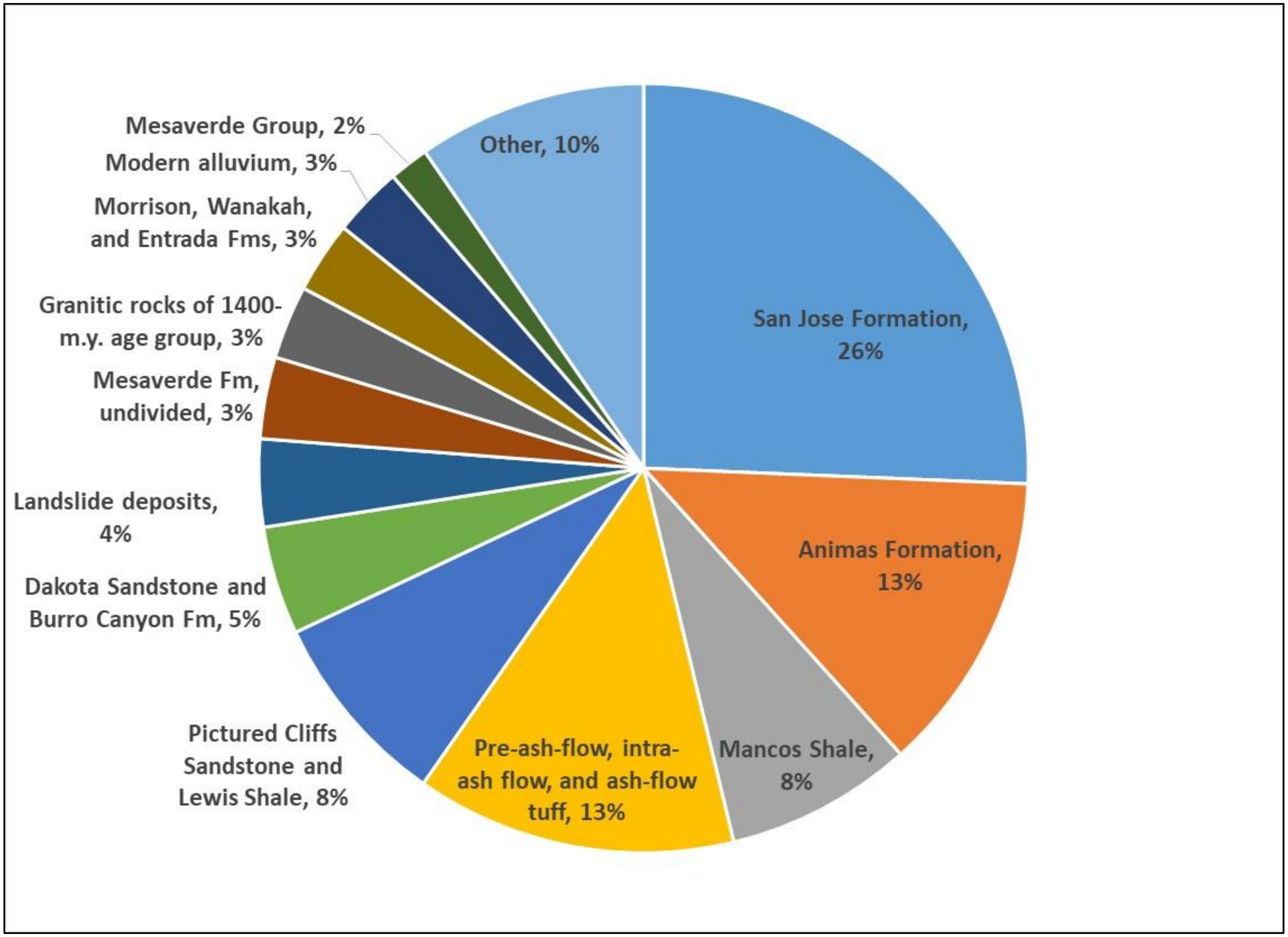

Figure 2 Geology of Navajo Reservoir drainage basin.

2.3. Soils, Vegetation, and Land Use

Soil infiltration rates and runoff potential may be of the most interest at the watershed scale. The USDA provides a simplified assessment of soil based on infiltration rates, grouped into the following four groups:

- 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.
- If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Soil types within the watershed primarily consist of Group C and Group D (Figure 3), which have slow and very slow infiltration rates, respectively. This implies that the runoff potential is high relative to soil groups A and B. The ‘not rated or not available’ category is open water; Navajo Reservoir in the southwest and Vallecito Reservoir in the northwest, for example.

Vegetation and land use within the watershed are provided by the Natural Resources Conservation Service (NRCS). Development is low in this watershed, regardless of intensity; all Development is less than 1 percent of the land cover. Figure 4 shows that most of the watershed is Evergreen Forest (43 percent) and Shrub/Scrub (27 percent). The remainder is Deciduous Forest (9 percent), Herbaceous (8 percent); Open Water is 1 percent and all other categories make up 7 percent of the area.

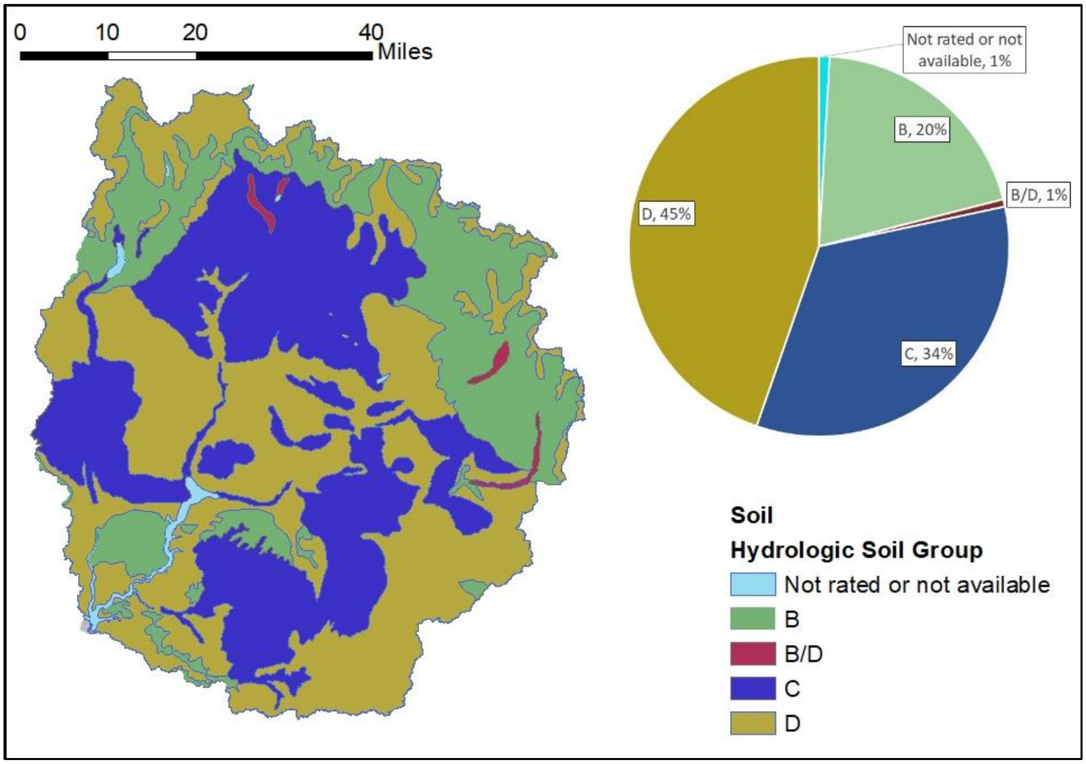

Figure 3. Soil classified by hydrologic group (potential for runoff). Most of the watershed (79 percent) has slow to very slow infiltration rates, indicating higher runoff potential.

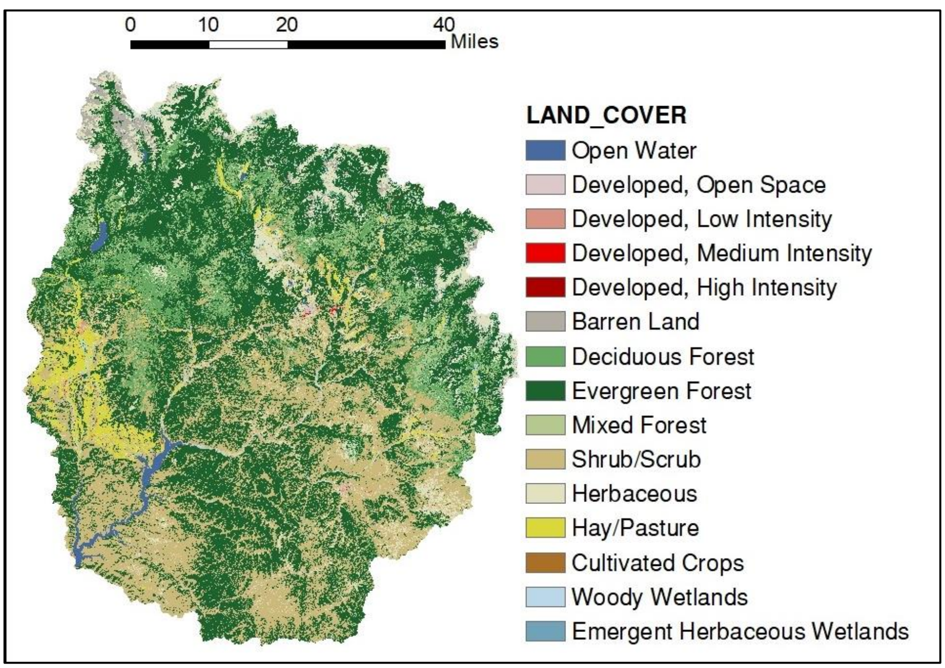

Figure 4. Land cover and use for the Navajo Reservoir watershed.

2.4. Climate and Runoff

Reservoir inflows are primarily from the San Juan, Piedra, and Los Pinos Rivers. USGS stream gage records are available for the locations presented in Table 1, which represents 75 percent of the total contributing drainage area; the southeast portion of the drainage basin (including part of the Carson National Forest) is largely ungaged, likely due to the ephemeral nature of the streams draining this part of the watershed.

Based on the USGS data presented in Table 1, the mean annual runoff into Navajo Reservoir is 1,208 cubic feet per second (ft^3/s), or 875,420 ac-ft per year. This runoff is primarily from snowmelt. The ratio of live capacity (above dead pool and below spillway crest) to the mean annual runoff is 1.88 years. This means that, when full, the reservoir stores a water volume equivalent to 688 days of mean annual stream flow. Figure 5 presents the annual inflow and peak discharge data for the three gages listed in Table 1.

Table 1. Reservoir Inflow Streams with USGS gages

USGS Stream Gage		Drainage Area (mi^2)	Mean Annual Runoff (ft^3/s)	Period of Record
Name	**Number**			
SAN JUAN RIVER NEAR CARRACAS, CO.	09346400	1,250	585	1961-2020
PIEDRA RIVER NEAR ARBOLES, CO.	09349800	653	390	1962-2020
LOS PINOS RIVER AT LA BOCA, CO.	09354500	519	233	1951-2020

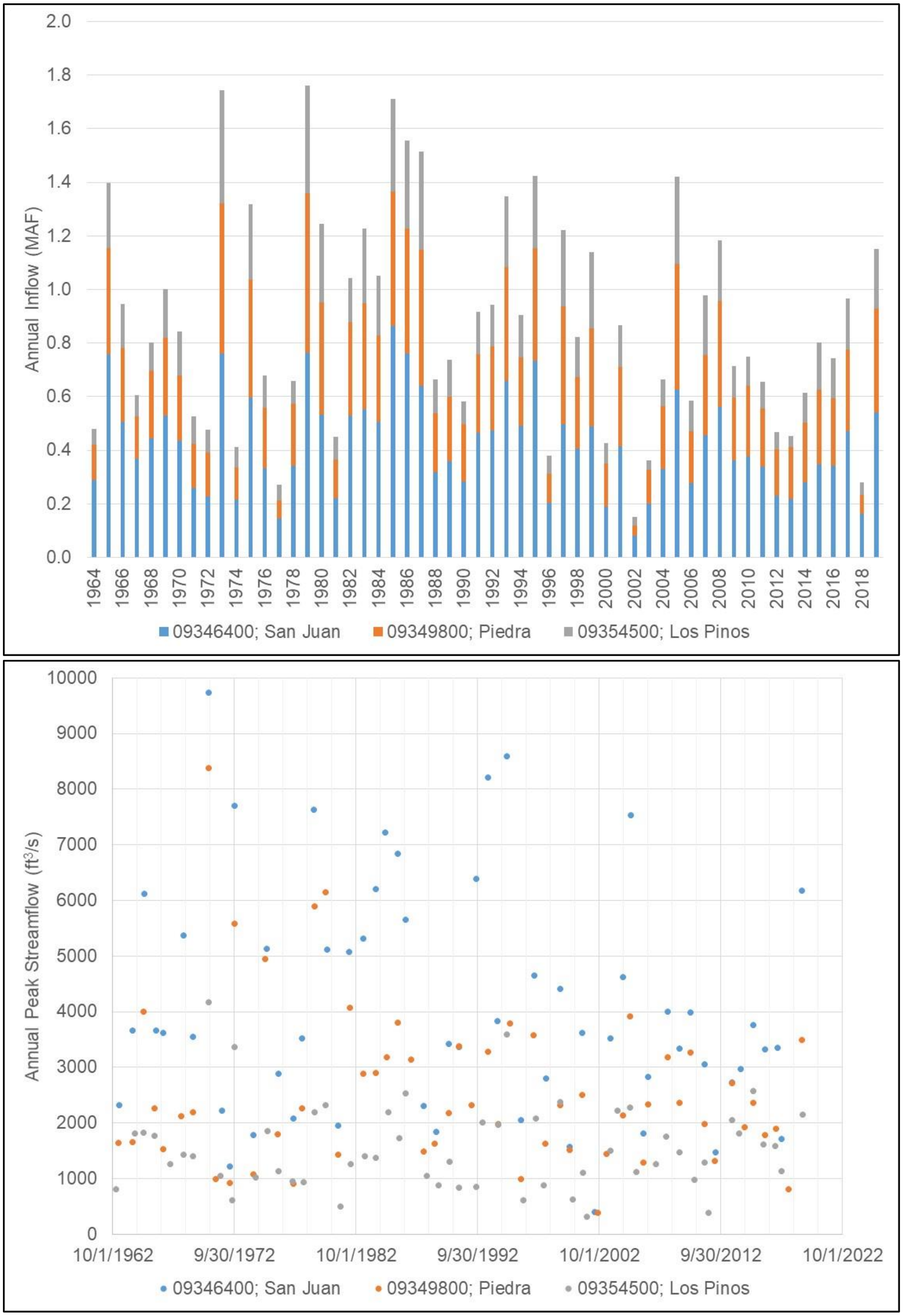

Figure 5. Statistics of USGS gage data as identified in Table 1. Top: Annual inflow volume in million ac-ft (MAF). Bottom: Annual peak flow data.

2.5. Dam Operations and Reservoir Characteristics

Navajo Dam is a rolled earthfill embankment dam. This dam was completed in 1963 yet began storing water in June of 1962. The historic reservoir water surface elevations (WSE) are presented in Figure 6. The water level exceeded the active conservation pool initially in the summer of 1965 for a brief period, and not again until the spring of 1968; the reservoir has not fallen below the top of active conservation pool (RPVD 5990 ft) since. The fluctuation in reservoir surface elevation during a given water year (WY) has a median of 24.6 feet and a mean of 28 feet. The maximum fluctuation was observed in WY 1973 at almost 70 feet, and the smallest fluctuation occurred in WY 1992 at just over 7 feet.

The dam has a height above the original stream bed of 388 feet and the reservoir extends 35 miles up the San Juan arm, 13 miles up Los Pinos arm, and 4 miles up the Piedra arm.

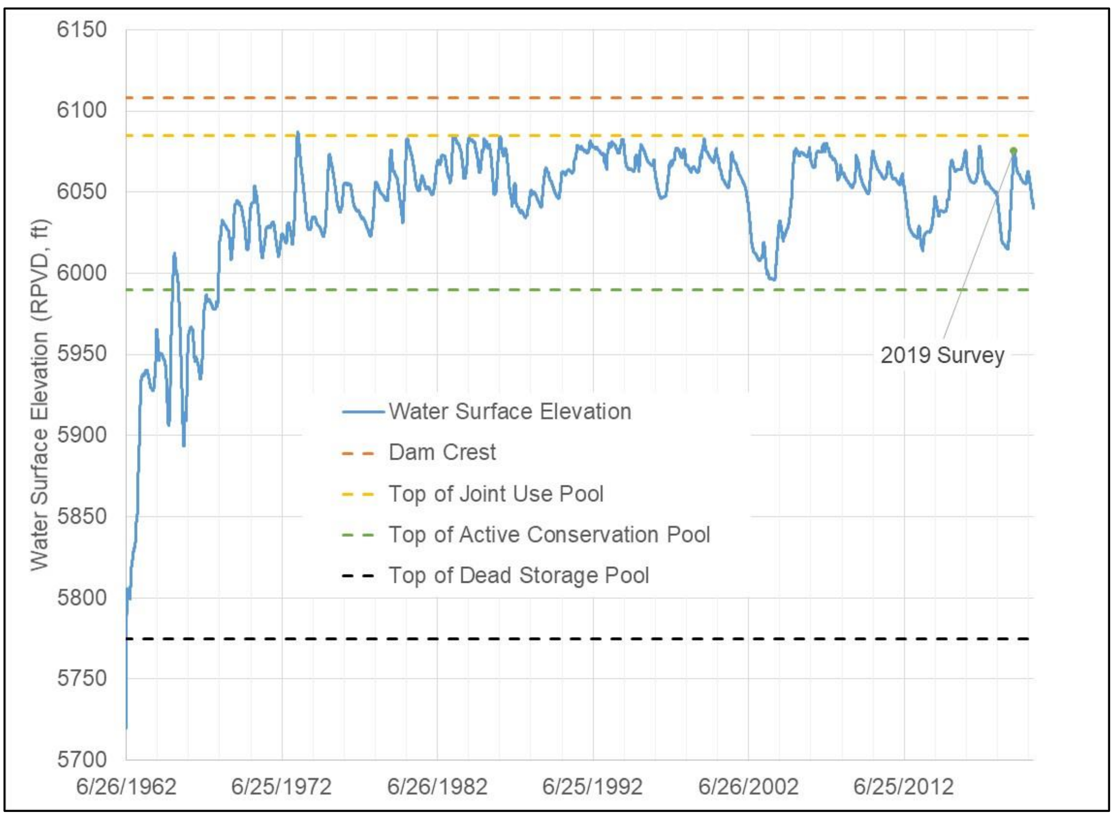

Figure 6. Historic Navajo Reservoir water surface elevations (RPVD). Data web source: https://data.usbr.gov/catalog/2392/item/612.

The dam was constructed downstream of the confluence between the San Juan and Los Pinos. The Navajo Lake Marina is located here, the second-widest part of the reservoir at approximately 4,500 ft. The reservoir width is relatively constant up the first 5.5 miles on the San Juan arm at about 2,000 ft. Then the reservoir narrow upstream of the confluence with La Jara Wash to about 1,200 feet and remains relatively narrow for one mile, before gradually widening again to the widest part of the reservoir at 5,500 ft, about 1.7 miles south of the Two Rivers Marina. The San Juan and the Piedra River confluence is upstream from this marina, and the reservoir width gradually narrows until riverine conditions are observed.

The Los Pinos arm of the reservoir has a consistent tapering down of width from 2,000 ft (just upstream from the confluence with the San Juan and less than a mile north of Navajo Lake Marina) for the 7 or 8 miles (depending on lake level) upstream until riverine conditions are observed. A delta has formed near the upstream ends and has progressed downstream. Without previous survey data, a direct comparison is not possible.

2.6. Reservoir Sediment Management

There is no record of past reservoir sediment management activities. However, the annual drawdown of the reservoir likely progresses the sediment further downstream than if the lake were at a constant elevation. Additionally, significant water and sediment inputs when the reservoir was low would cause deposition further downstream than if the reservoir was high. For example, the dry period of the early 2000s lowered the reservoir to 5995 ft (RPVD) by February of 2004. The subsequent spring runoffs (2004 and 2005) with the addition of a significant monsoon event in the fall of 2004 added significant water volumes back to the reservoir. The sediment that came with that water (especially with the monsoon event) would have deposited lower in the reservoir than if the lake level were higher.

3. Previous Reservoir Survey(s)

It is assumed that a survey was conducted prior to dam closure and initial reservoir filling to measure the original surface areas and corresponding storage capacities. There is no documentation of a survey, with the exception of a survey to identify areas that needed to be cleared of existing infrastructure where crews “marked the 5965 and 6085 contours with survey markers located at not more than one-half mile intervals for the areas to be cleared” (Reclamation, 1963). Although the documentation summarizing the original survey methods has not been located for this analysis, photogrammetry with some ground surveying was the most likely method for this time period. It is possible that the data used for the original area-capacity table were readily available USGS contours at 50-foot intervals for the full reservoir footprint, and level-and-rod surveying was conducted to identify the areas to be cleared.

4. Reservoir Survey Methods and Extent

4.1. Survey Methods

A complete bathymetric survey was conducted during July 2019 from a boat using a multibeam depth sounder to continuously measure water depths. The horizontal position of the moving boat was continually tracked using GPS. Due to the size of Navajo Dam, conducting an RTK-GPS survey of the entire reservoir was deemed inefficient. A map of the data points collected is presented in Figure 7. There are three maps shown at different scales: the main primary image shows the entire reservoir; the upper left inset demonstrates that coverage is not 100 percent, but sufficient for reasonable interpolation; the lower left inset shows the density of points (swath width) exported from the processed bathymetry data.

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with LiDAR data collected above water during May 2019 (Atlantic, 2019) to produce a digital surface of the reservoir bottom surface.

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

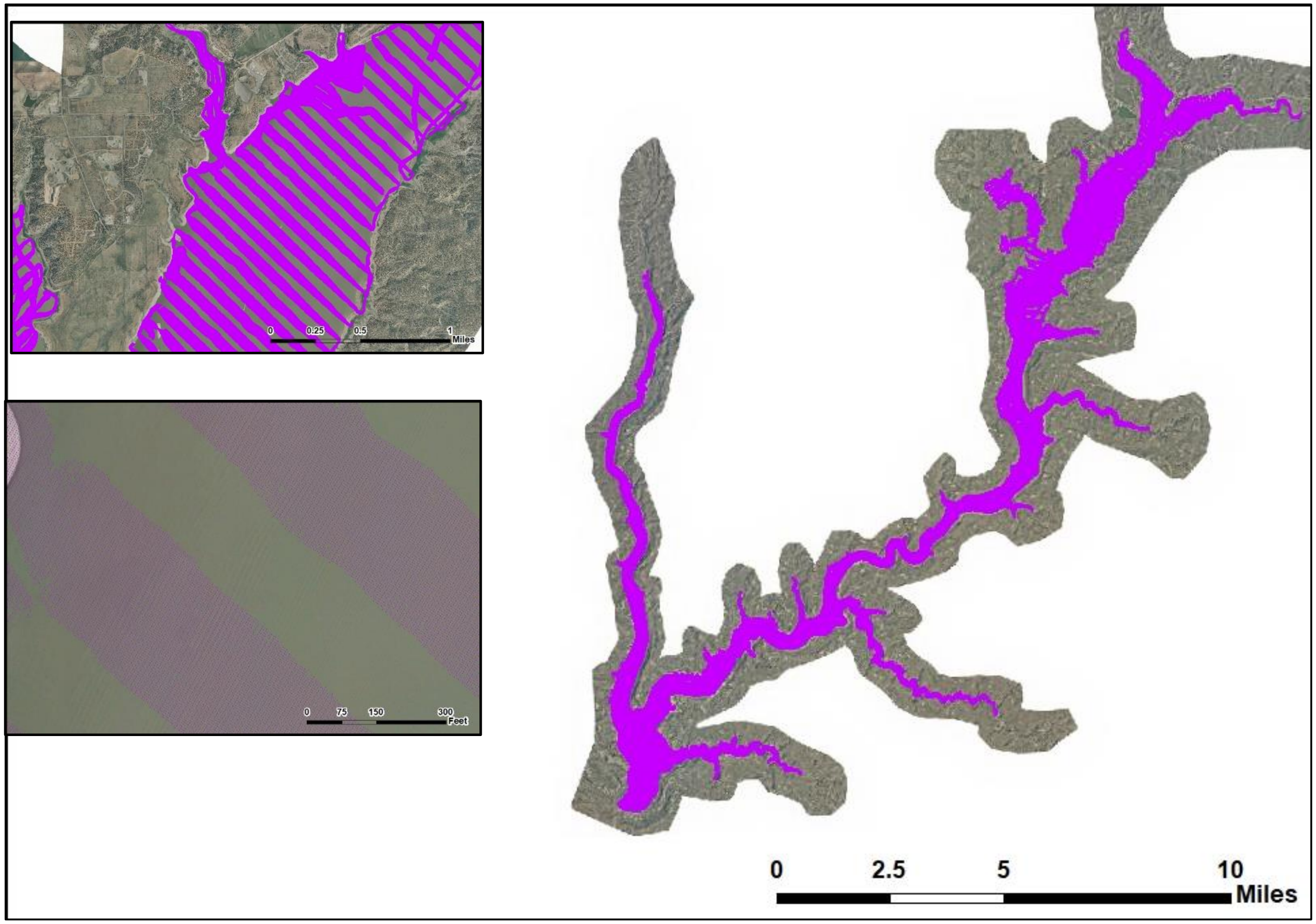

Figure 7. Map of bathymetric survey data coverage.

4.2. Survey Control, Datum, and Monuments

For the 2019 survey, all bathymetry and GPS control measurements were collected in North American Datum 1983 (NAD83) State Plane (horizontal) coordinates, New Mexico West FIPS 3003, US survey feet and North American Vertical Datum 1988 (NAVD88, Geoid 12A, US survey feet elevations). RTK-GPS survey points were periodically collected to obtain water surface elevations, but the bathymetry survey was conducted using autonomous positions; the size of Navajo Reservoir would have made RTK-GPS data collection for the bathymetry too costly. During processing, all bathymetry and GPS measurements were converted to Reclamation Project Vertical Datum (RPVD) for Navajo Dam by applying a time series of WSE (Behery, 2019). The bathymetric processing software allows a time series of water surface elevations to be implemented and the bathymetric elevations are calculated by applying a depth to that series. RTK-GPS water surface elevation data (in NAVD88) were compared to the WSE time series (in RPVD) water surface elevation. The RPVD was determined to be 2.97 feet lower than the NAVD88; Geoid 12A (Figure 8).

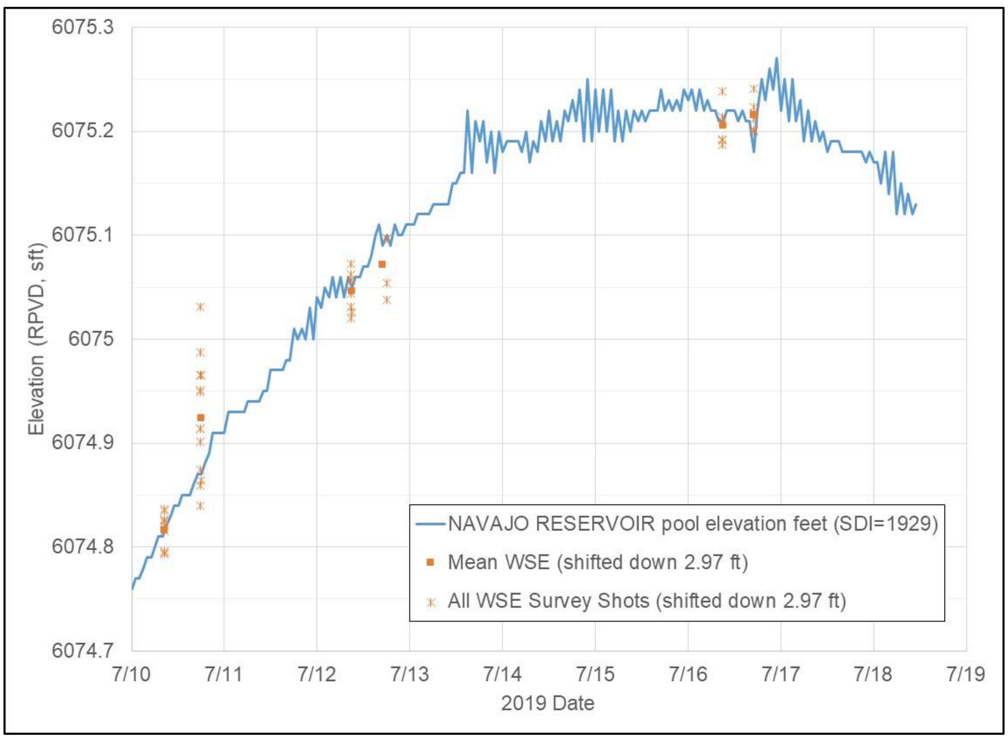

Figure 8. Water surface elevations: orange stars are all RTK-GPS elevations collected in July, 2019 and shifted down from NAVD88 to RPVD by subtracting 2.97 ft to align with RPVD.

The GPS base station receiver was set up over temporary monuments located near the Navajo Lake Marina and the Two Rivers Marina for RTK-GPS data collection (Figure 9). As can be seen, the water surface during bathymetric data collection was much higher than when the aerial imagery and LiDAR were collected.

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

Figure 9. Location of GPS base stations and WSE points collected near marinas. Green triangles are base station locations and orange asterisks are WSE points.

The LiDAR data (Atlantic, 2019) was provided in the NAVD88 vertical datum. Therefore, the Digital Elevation Model (DEM) derived from the LiDAR was shifted down by the requisite 2.97 feet to get it into RPVD. A check to the original design data was performed to verify the applied shift. The best locations to compare are on the dam; the dam crest itself, and the concrete runup to the spillway. Figure 10 provides a comparison of the elevation on the concrete spillway approach. The top image shows a photograph of the spillway, with an inset of the original design drawing showing the crest elevation of 6085 ft and the concrete pad elevation of 6070 ft. The lower image shows the statistics of the elevation of the concrete, based on the DEM after it has been shifted down 2.97 ft. The histogram demonstrates that the concrete portion leading up to the spillway has an elevation between 6069.7 and 6070. There is no as-built data available, so it is possible that the concrete was poured slightly lower than designed, that there has been some settling over the last few decades, or the vertical shift applied is too great. However, without a recent survey of this concrete pad to verify elevation, this small offset is considered reasonable and verifies that the shift applied to the LiDAR aligns the data with the RPVD.

The other comparison to make would be the road across the dam crest. The design drawings show a dam crest elevation of 6108 ft RPVD. The LiDAR, after being shifted, shows a road elevation across the dam of approximately 6110 ft RPVD (Figure 11). For analysis, a centerline was digitized in ArcMap and a 5-ft buffer was created to subset the LiDAR DEM previously shifted into RPVD. The insets in Figure 11 show that the southern part of the dam has a crest elevation of approximately 6110 ft but that the area closer to the spillway has an elevation closer to 6108.5 ft. The drawing sheet 711-D-37 from the final construction report (Reclamation, 1963) does not show a road across the dam crest, but it does show in a detail labeled "crest detail at maximum camber" that there can be up to 4 feet of camber above the dam crest elevation of 6108 ft. Therefore, the additional elevation of roadway near 6110 does not demonstrate a discrepancy between the design drawings and the provided LiDAR data.

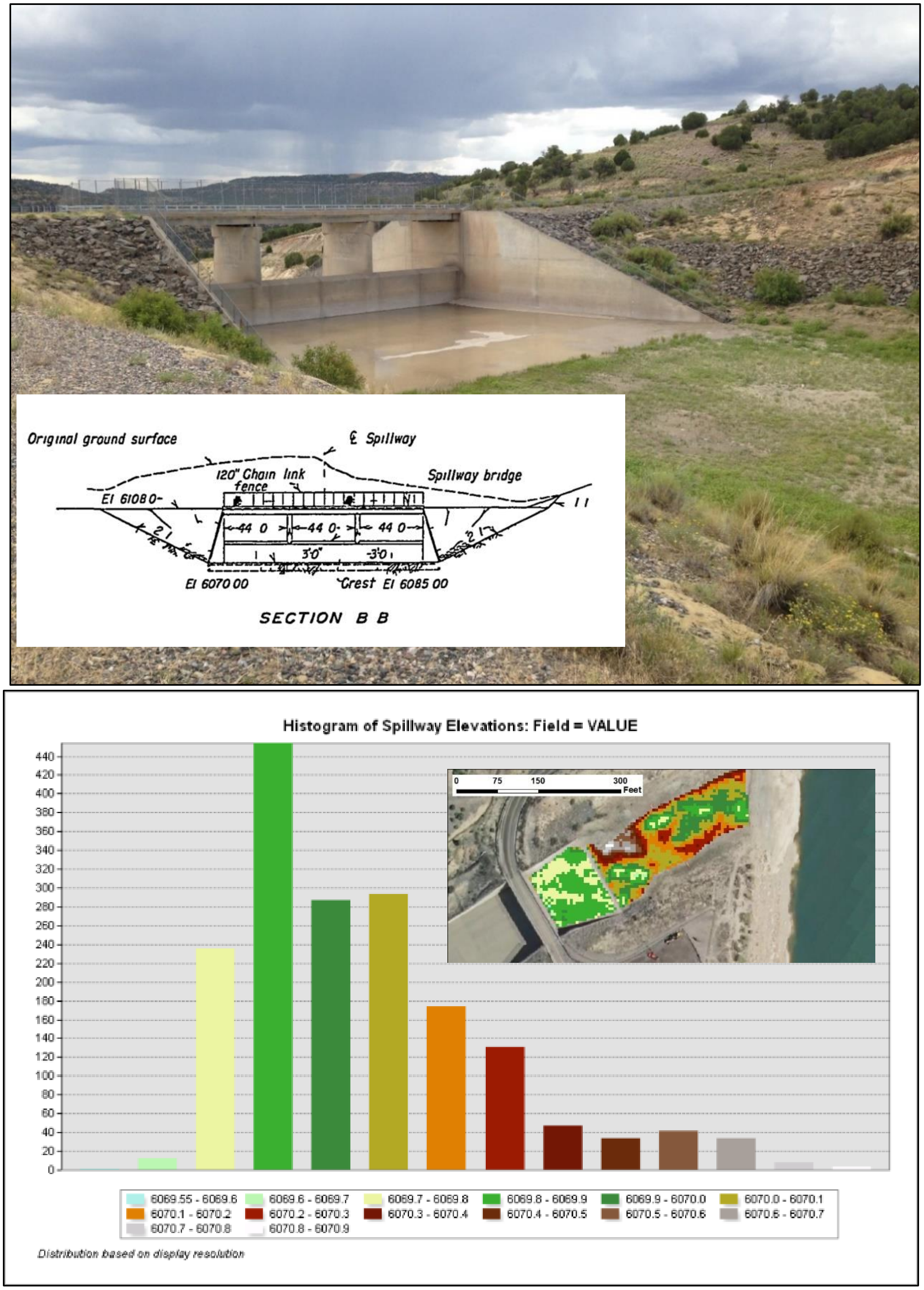

Figure 10. LiDAR verification after shifting down 2.97 ft. Top: photo of the concrete approach to the spillway, along with an inset of the design drawing showing the design elevation of the concrete approach of 6070 ft (RPVD). Bottom: histogram of concrete approaching spillway from LiDAR data (after being shifted down 2.97 ft) aligning with design elevation of 6070 ft (RPVD).

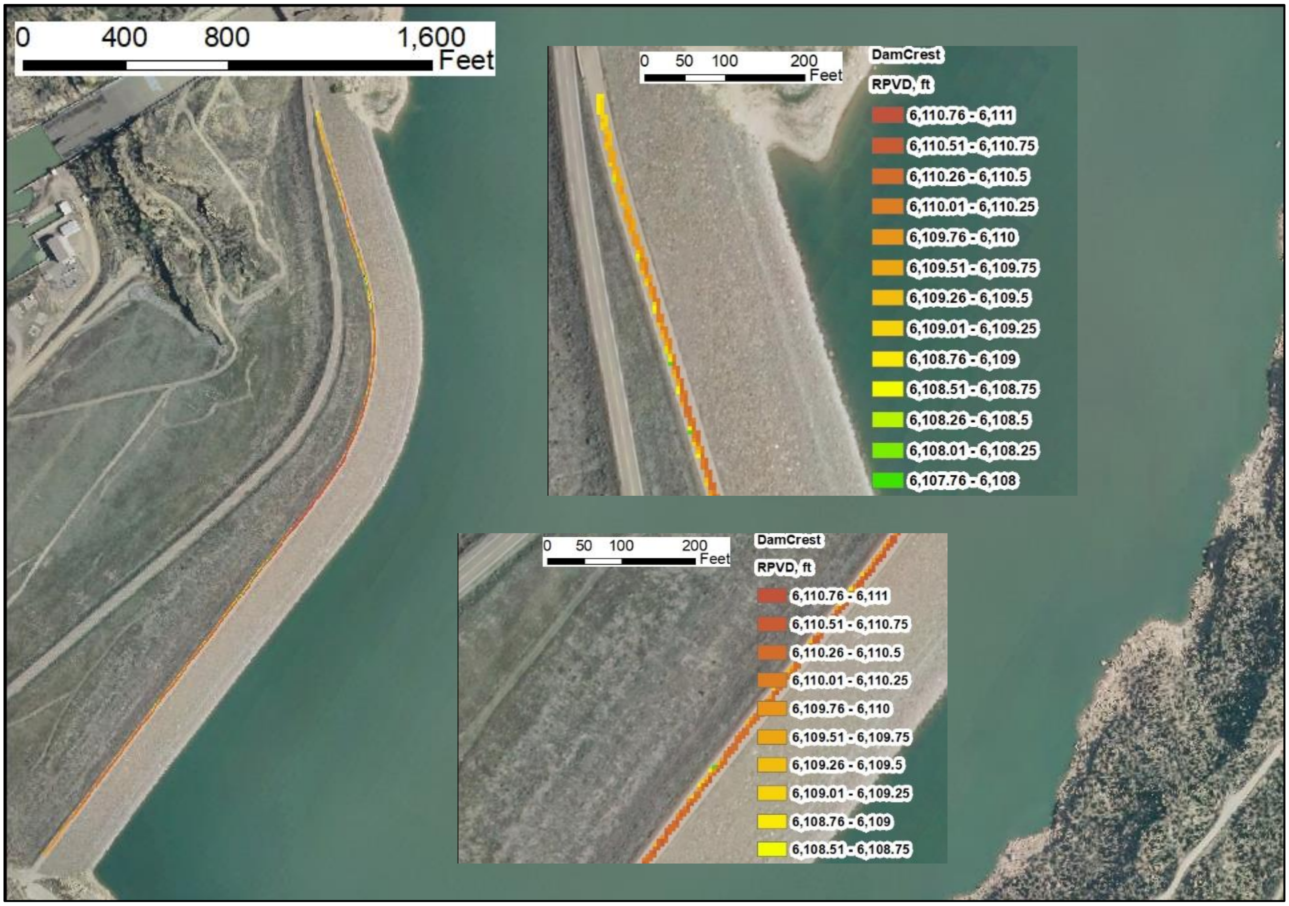

Figure 11. Elevations of the road across the dam from LiDAR after being shifted down 2.97 ft to RPVD.

Because of the low lake level during the LiDAR collection, and the high lake level during bathymetry collection, there are some areas of overlap. Due to the canyon-like nature of this reservoir, a large difference in elevation does not necessarily translate to a large amount of overlapping coverage. Additionally, these steep areas can be a difficult basis for comparison due to the rapidly changing elevations over short distances. However, it is still of value to compare the data from the LiDAR and the bathymetry in the domain where they overlap. Figure 12 shows the 1,275 acres of overlapping domain, with an inset of elevation difference presented as a histogram. The majority of points (60 percent) are within ±0.5 feet showing good correlation, with differences expected along the margins where steep canyon walls can lead to errors.

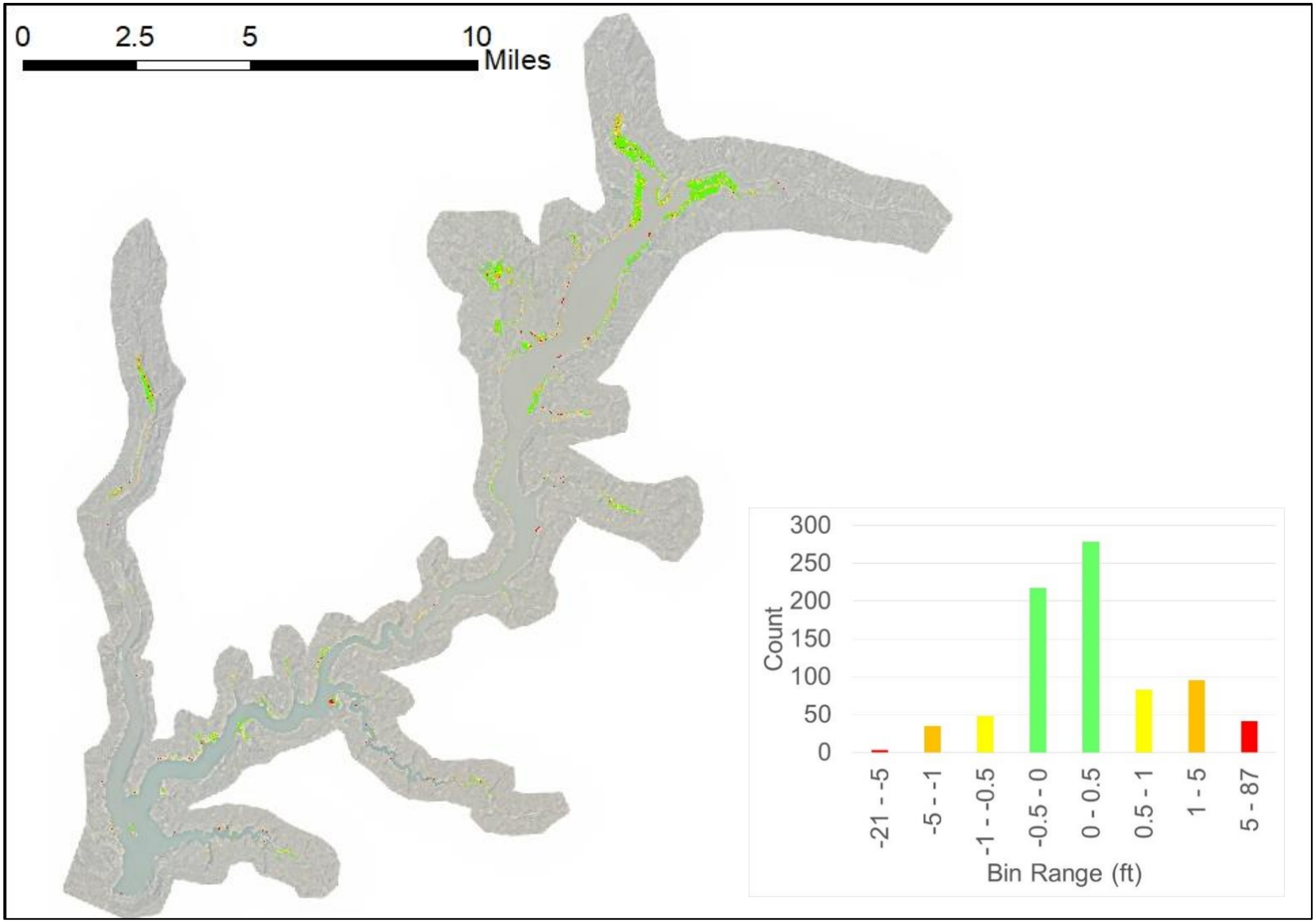

Figure 12. Difference in elevation (RPVD) between LiDAR and bathymetry in overlapping areas.

5. Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations up to the maximum water surface of 6101.5 ft RPVD (Navajo Reservoir Area and Capacity Tables 2019). Plots of the 2019 area and capacity curves are presented in Figure 13 along with curves from 2002. The 2002 data is not from a survey, but rather a modification of the original area and capacity data due to changing the method of modeling and analysis. For the 2019 survey, area and capacity curves are based on the bathymetric survey up to 6073 ft elevation (project datum), while curves above this elevation are based on 2019 aerial LiDAR survey (Atlantic, 2019). A comparison of these curves indicates that largest reduction in surface area and storage capacity occurs between 6010 and 6040 ft RPVD (Figure 13).

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

Table 2 shows that at reservoir water surface elevation 6068 ft (RPVD), which is 5 ft below water at the time of survey, the reservoir surface area was 13,633 acres with a storage capacity of 1,397,777 ac-ft (excluding dead pool volume). At the spillway elevation (6085 feet, RPVD), the reservoir has a surface area of 15,773 acres and a storage capacity of 1,647,937 ac-ft (excluding dead pool volume). Tables of reservoir surface area and capacity are presented at the foot, tenth of a foot, and hundredth of a foot increments in Varyu, 2021.

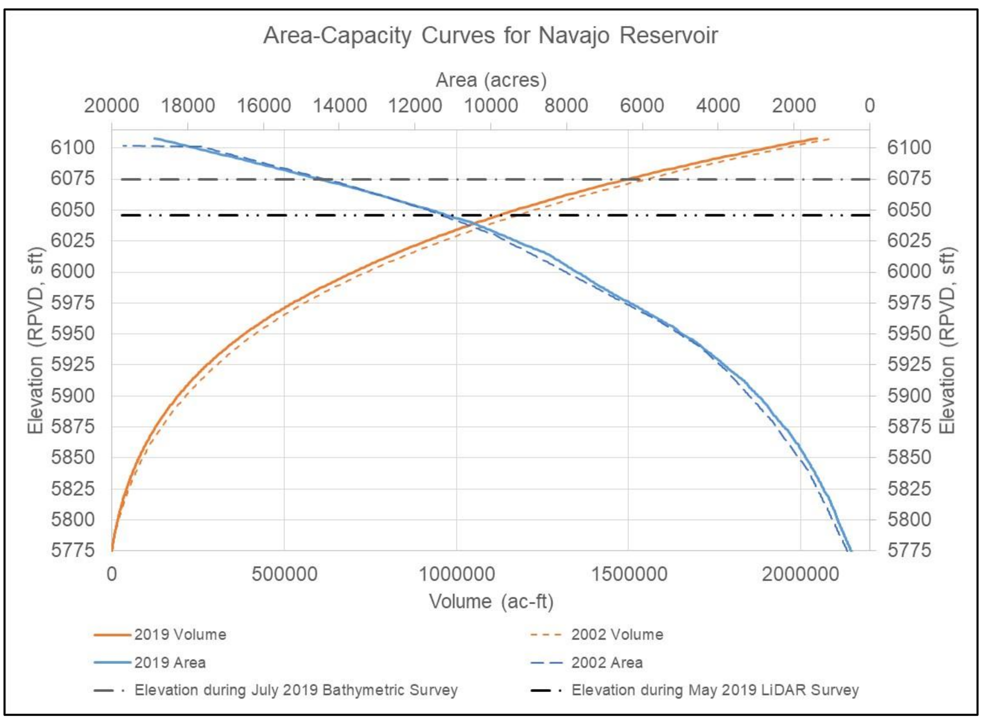

Figure 13. Plot of Navajo Reservoir surface area and storage capacity versus elevation (RPVD).

Table 2. Historical summary of reservoir surface area and storage capacity data. Capacities are cumulative from low to high elevation; and exclude dead pool volumes..

	Surface Area (acres)		Capacity (ac-ft)		Sedimentation Volume (ac-ft)
Elevation (ft)	**1962***	**2019**	**1962***	**2019**	**1962-2019**
6,101.6	19,691	18,006	1,978,600	1,928,417	50,183
6,100	17,492	17,791	1,950,300	1,899,779	50,521
6,090	16,247	16,451	1,781,000	1,728,553	52,447
6,080	15,002	15,174	1,624,800	1,570,562	54,238
6,070	13,757	13,881	1,480,600	1,425,291	55,309
6,060	12,712	12,695	1,347,800	1,292,492	55,308
6,050	11,667	11,583	1,225,600	1,171,106	54,494
6,040	10,785	10,521	1,112,800	1,060,613	52,187
6,030	9,904	9,715	1,008,600	959,528	49,072
6,020	9,269	8,951	911,800	866,191	45,609
6,010	8,635	8,261	822,050	780,582	41,468
6,000	8,015	7,726	738,800	700,638	38,162
5,990	7,395	7,202	661,800	626,034	35,766
5,980	6,775	6,627	591,300	556,864	34,436
5,970	6,155	6,015	527,050	493,655	33,395
5,960	5,535	5,442	468,300	436,322	31,978
5,950	5,014	4,948	415,050	384,570	30,480
5,940	4,493	4,446	367,300	337,815	29,485
5,930	4,130	4,027	324,050	295,442	28,608
5,920	3,768	3,656	284,300	257,020	27,280
5,910	3,473	3,252	247,800	222,655	25,145
5,900	3,178	2,940	214,300	191,643	22,657
5,890	2,882	2,657	183,730	163,776	19,954
5,880	2,587	2,400	156,050	138,461	17,589
5,870	2,348	2,117	131,300	115,939	15,361
5,860	2,109	1,878	109,050	95,982	13,068
5,850	1,870	1,682	89,200	78,203	10,997
5,840	1,631	1,486	71,650	62,384	9,266
5,830	1,467	1,311	56,075	48,432	7,643
5,820	1,303	1,120	42,150	36,240	5,910
5,810	1,138	970	29,925	25,815	4,110
5,800	982	845	19,450	16,744	2,706
5,790	827	705	10,575	8,972	1,603
5,780	671	561	3,083	2,625	458
5,775	593	492	-	-	-

**TSC is interpreting that the modified 2002 ACAP table is meant to be a more accurate reflection of the original survey than what was available prior. That is, the data provided in February 2002 is intended to be representative of 1962.*

6. Reservoir Sedimentation Volume Spatial Distribution

Longitudinal profiles of the 2019 reservoir bottom surface were developed in Geographic Information System (GIS) along the alignments presented in Figure 14. There is no available surface of the previous survey to compare the 2019 profiles to, but a characteristic depositional feature is identifiable at elevation 6020 in both primary arms (San Juan and Los Pinos) of the river (Figure 15).

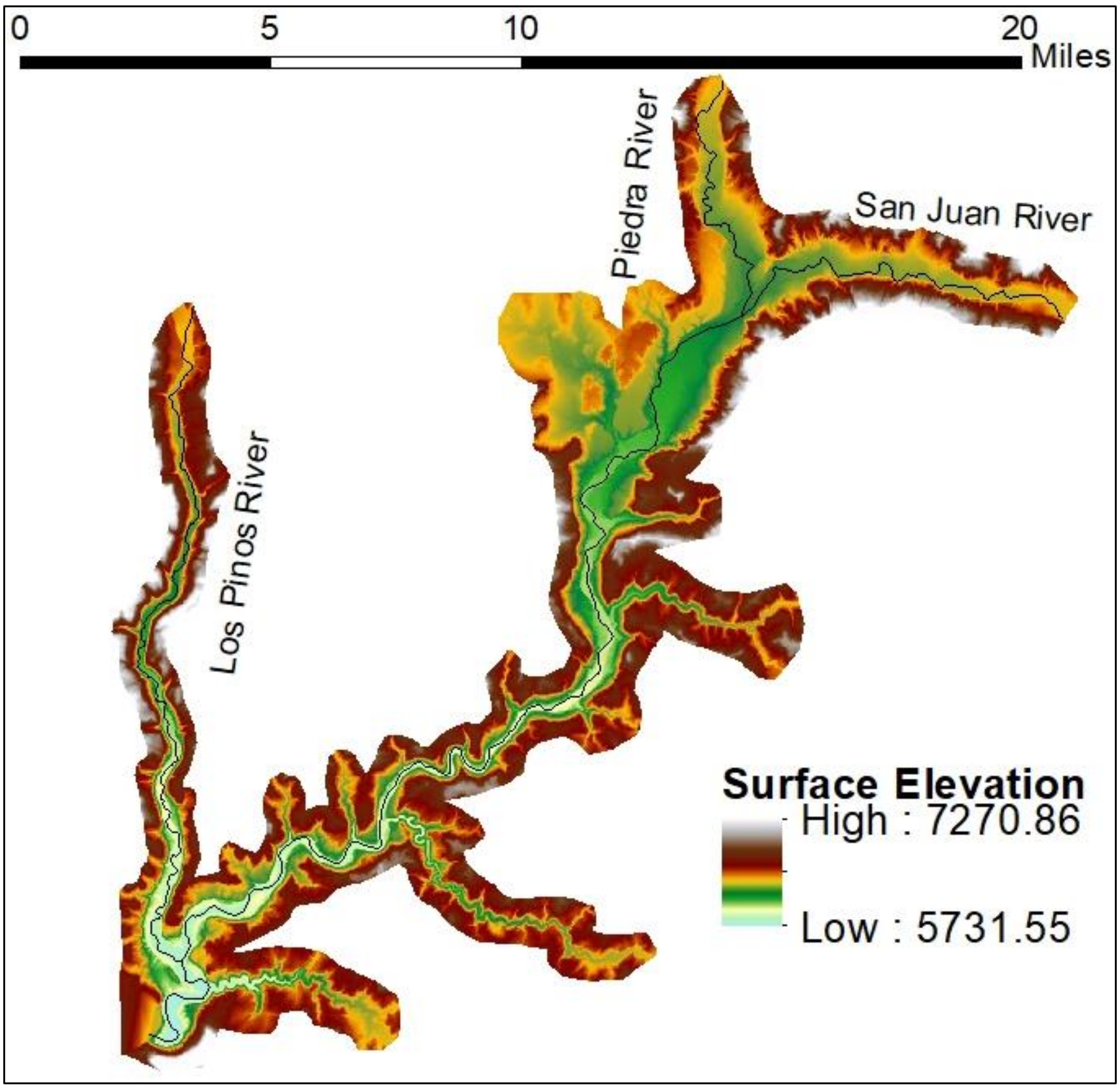

Figure 14. Reservoir surface elevation map and alignments of longitudinal profiles.

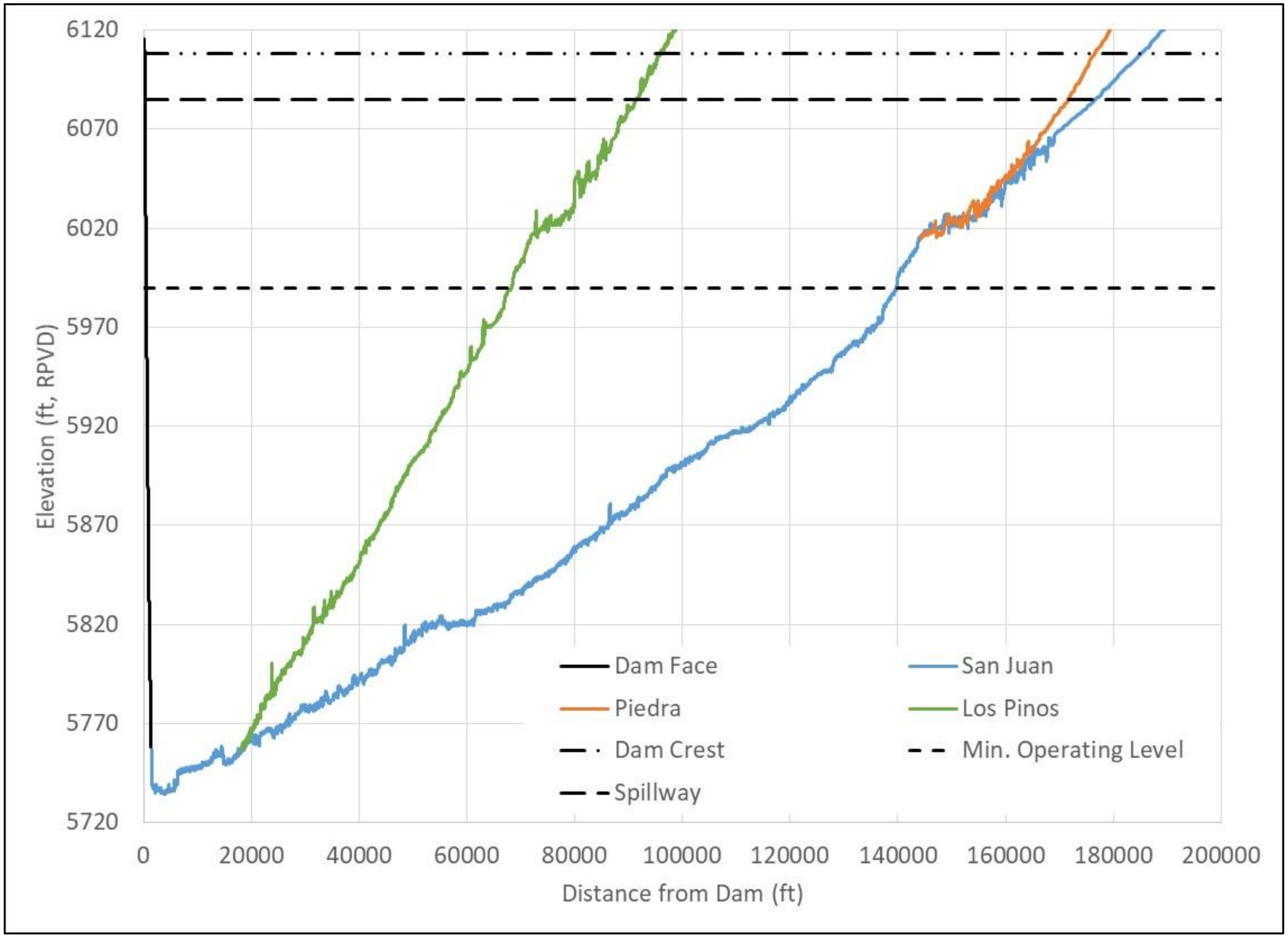

Figure 15. Longitudinal profiles of Navajo Reservoir bottom.

7. Sedimentation Trends

A comparison of the two area-capacity tables suggest an average sedimentation rate of 991 ac-ft/yr for the total capacity of the reservoir (below the spillway elevation at 6085 ft RPVD).

The dead storage capacity, below elevation 5775 ft (RPVD), as originally designed is 12,600 ac-ft. The 2019 survey indicates that 3,107 ac-ft of that volume has been lost to sediment, with a remaining dead pool storage of 9,493 ac-ft. This is a rate of about 55 ac-ft/yr. However, the entire reservoir has lost over 50,000 ac-ft of storage to sedimentation; it's just mostly in the delta elevations (around elevation 6,020) and hasn't yet progressed to the dead pool. If the dead pool continues to accumulate sediment at the rate of 55 ac-ft/yr, it will be completely filled in 175 years.

8. Conclusions and Recommendations

8.1. Survey Methods and Data Analysis

The 2019 bathymetric survey, combined with 2019 LiDAR data (Atlantic, 2019) of the above-water topography, has been used to produce a digital surface of the reservoir bottom. The overlapping bathymetric and above-water topographic data agreed well.

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 latest surface area and storage capacity curves compare well with the original curves. The use of modern survey methods (RTK-GPS, multibeam depth sounder, LiDAR) have produced a more accurate and precise digital surface of the reservoir bottom than past surveys using older methods (plane table, level, photogrammetry) and should therefore supersede original area-capacity data.

8.2. Sedimentation Progression and Location

Over the span of 57 years, sedimentation has filled in three percent of the original storage capacity up to the spillway elevation (including dead storage). The 2019 reservoir survey indicates that most of this sedimentation is located in the deltas of the San Juan and Los Pinos rivers. Sedimentation has also deposited near the dam in the lowest portions of the reservoir, filling in 25 percent of the original dead storage capacity. Past rates of sedimentation are not available for comparison. The lowest dam outlet may not be as reliable after the dead storage has completely filled with sediment because the future deposition of logs and sediment may accumulate on the trash rack. This is estimated to occur in 175 years assuming the observed average rate of 55 ac-ft/yr of dead storage loss continues.

8.3. Recommendation for Next Survey

Based on the past rates of sedimentation, the next survey of Navajo Reservoir is recommended within the next 20 years, 2039.

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Appendix A — Hydrographic Survey Equipment and Methods

The 2019 bathymetric survey was conducted from July 9th to July 16th. During this period, reservoir water surface elevations varied from 6074.75 to 6075.25 feet (RPVD).

The survey was conducted along a series of predetermined lines to ensure as close to complete coverage as required to generate a reliable bathymetric surface. Longitudinal lines were used along the narrow Los Pinos arm, while cross sections were primarily used up the wider San Juan arm (Figure 7).

The survey employed an 18-foot, flat-bottom aluminum Wooldridge boat powered by outboard jet and kicker motors (Figure A-1). Reservoir depths were measured using a multibeam echo sounder that consisted of the following equipment:

- variable-frequency transducer with integrated motion reference unit,
- near-surface sound velocity probe,
- two GPS receivers to measure the boat position and heading,
- processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data.

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

The multibeam transducer emits up to 512 beams (user selectable) capable of projecting a swath width up to 120 degrees in 390 feet (120 meters) of water. Sound velocity profiles were collected over the full water depth at various locations throughout the reservoir. These sound velocity profiles measure the speed of sound through the water column, which can be affected by multiple characteristics such as water temperature and salinity. These sound velocity profiles were used to calibrate the depth sounder.

RTK-GPS survey was only used to obtain water surface and other ground shots. Conducting an RTK-GPS survey for the boat position was deemed an inefficient use of resources to cover a reservoir of this scale. The GPS base station and receiver was set up on a tripod over a point overlooking the reservoir (Figure 9). The coordinates of this point were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (NGS) (www.ngs.noaa.gov/OPUS/)..

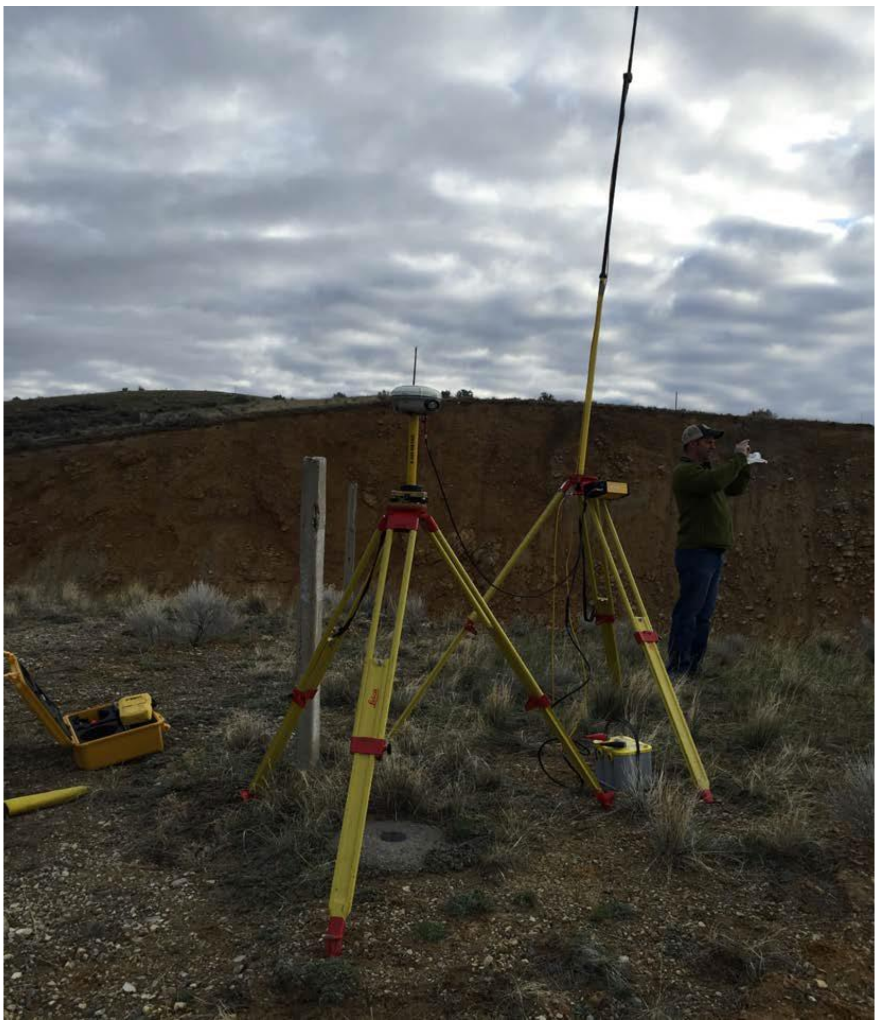


Figure A-2. The RTK-GPS base station set-up used during the survey Clark Canyon Reservoir in Montana is typical of the set up used for other reservoir surveys.

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

The HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the State Plane Coordinate System NAD83 New Mexico West. Water surface elevations from dam gage records and RTK GPS measurements were used to convert the sonar depth measurements to reservoir-bottom elevations in the RPVD. The multibeam depth sounder generates hundreds 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 the post processing. Filtering of this large data file is necessary, so a raster mesh is created in GIS (e.g. 5-foot square cells). For each of the roughly 20 million raster mesh cells, 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 — Computation of Reservoir Surface Area, Storage Capacity, and Sedimentation Volume

A digital surface of the reservoir bottom was generated in GIS using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Horizontal surface areas were then computed at 1-foot increments, using functions within ArcMap v 10.7, for the complete range of remaining reservoir elevations above dead pool (5720 to 6110 feet, RPVD) for sedimentation calculations. These reservoir surface areas were then used in Reclamation's Area-Capacity (ACAP) Program, 2020 Version (Huang, 2020), to compute the storage capacity at these increments and then interpolate surface areas and storage capacities at 0.01-foot increments between each 1-foot interval. Area-Capacity tables are provided in Varyu, 2021 relative to dead pool; that is, volume at elevation 5,775 RPVD has a volume of zero.

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

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

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

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

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

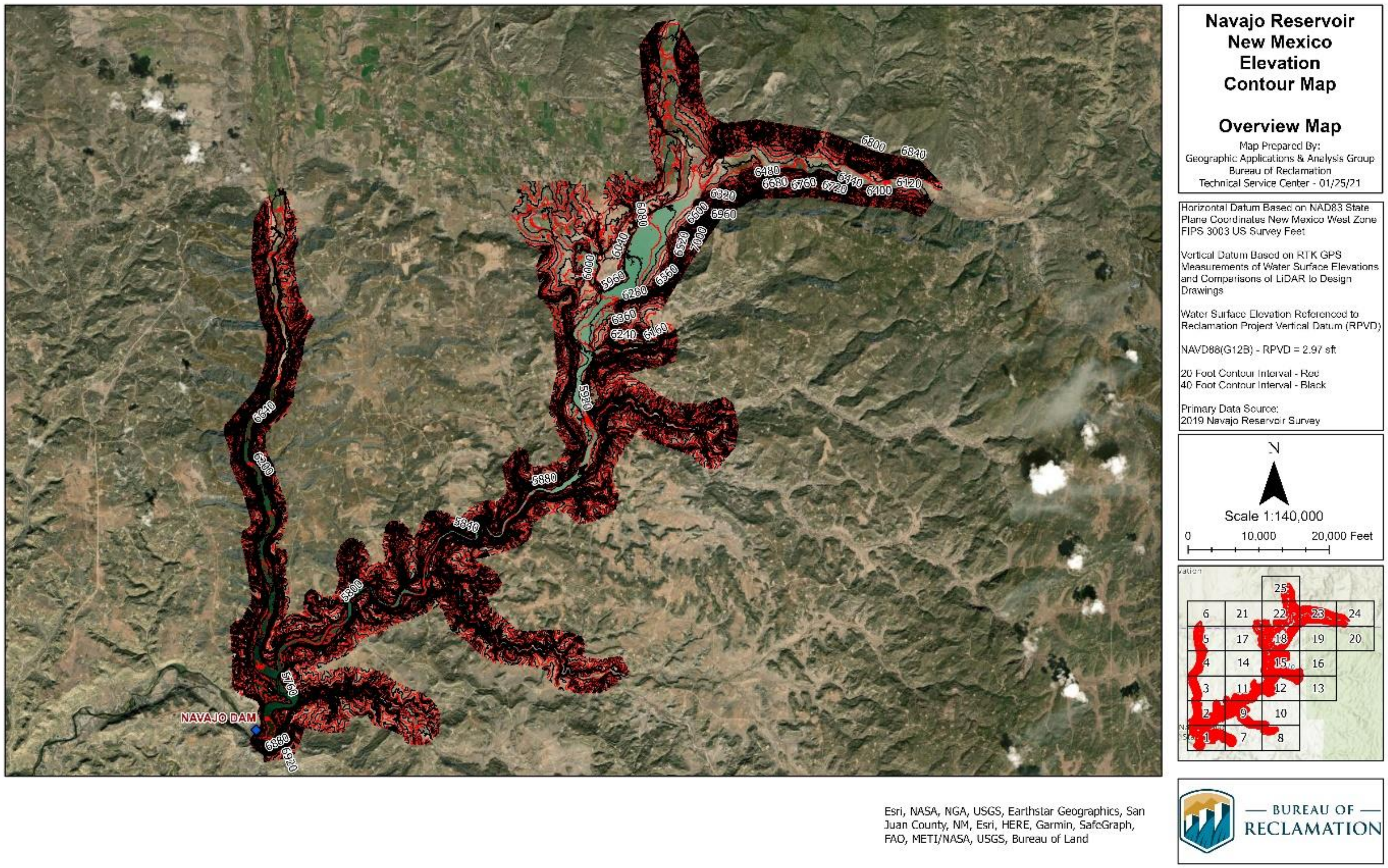
where: S = surface area (acres)

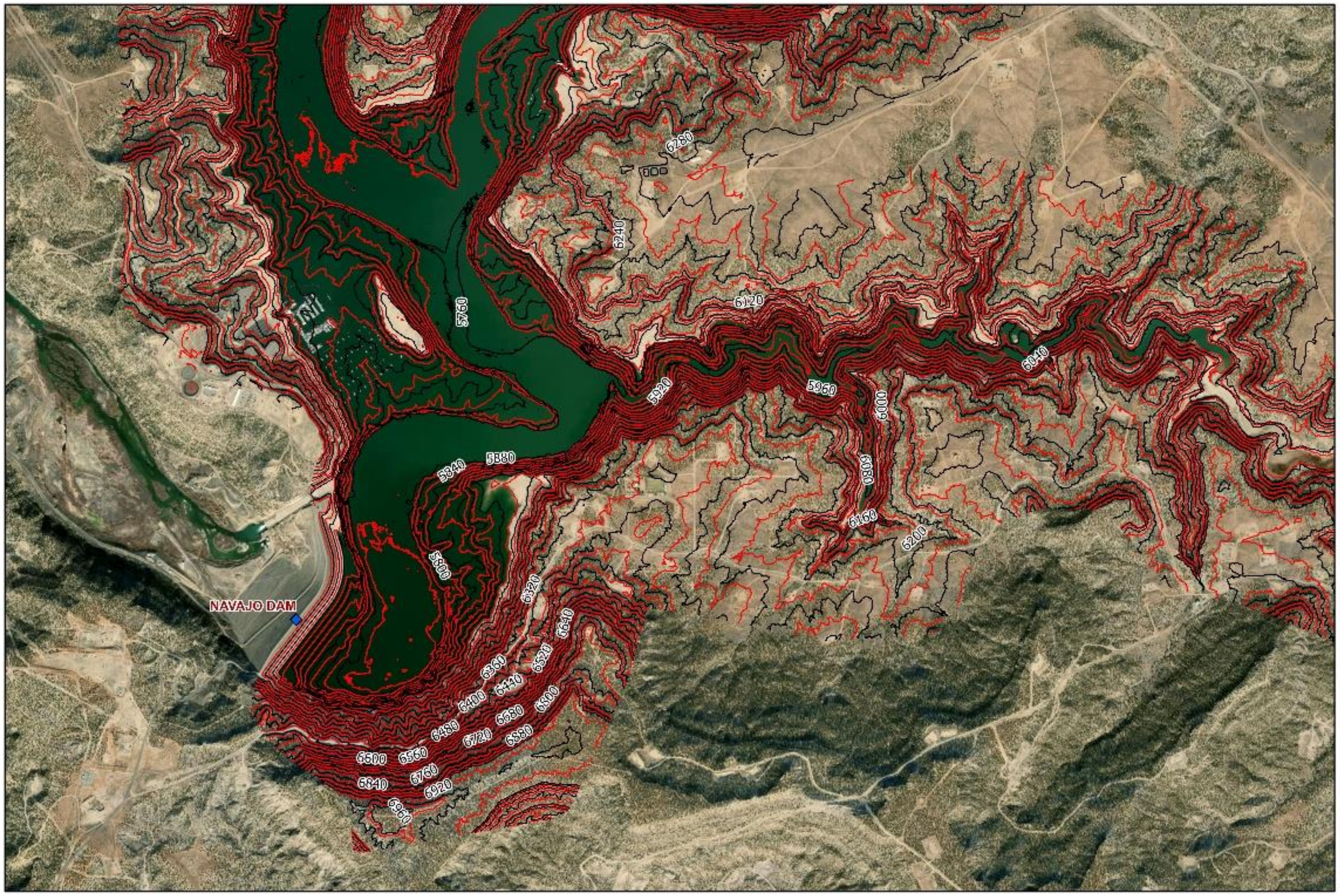
This method ensures that the given surface areas, and corresponding storage capacities, at the 1-foot intervals are not changed and there is a smooth transition in the interpolated values at the 0.01-foot intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in Varyu, 2021.

The sedimentation volume can be computed by subtracting digital surfaces of the predam reservoir surface from the 2019 digital reservoir surface. However, a predam topographic map and surface digital is not always available. The next option is to subtract the storage volume curve produced from the predam surface from the storage volume curve of the 2019 surface. This method works well when the topographic map of the predam surface has good accuracy and precision. In some cases, the original topographic map significantly underestimated the actual storage capacity and subsequent surveys show an increased storage capacity even though reservoir sedimentation had reduced the actual storage capacity. In other cases, the predam topographic map significantly overestimated the actual storage capacity and comparison with subsequent surveys show too large a sedimentation volume. Comparison of predam and post dam digital surface maps can help reveal these problems and provide ideas for correcting the original surface maps.

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

Contour Maps





Navajo Reservoir New Mexico Elevation Contour Map

Sheet 1

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

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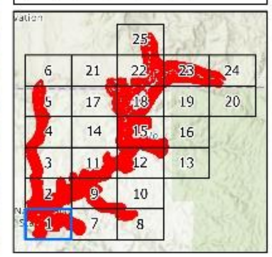

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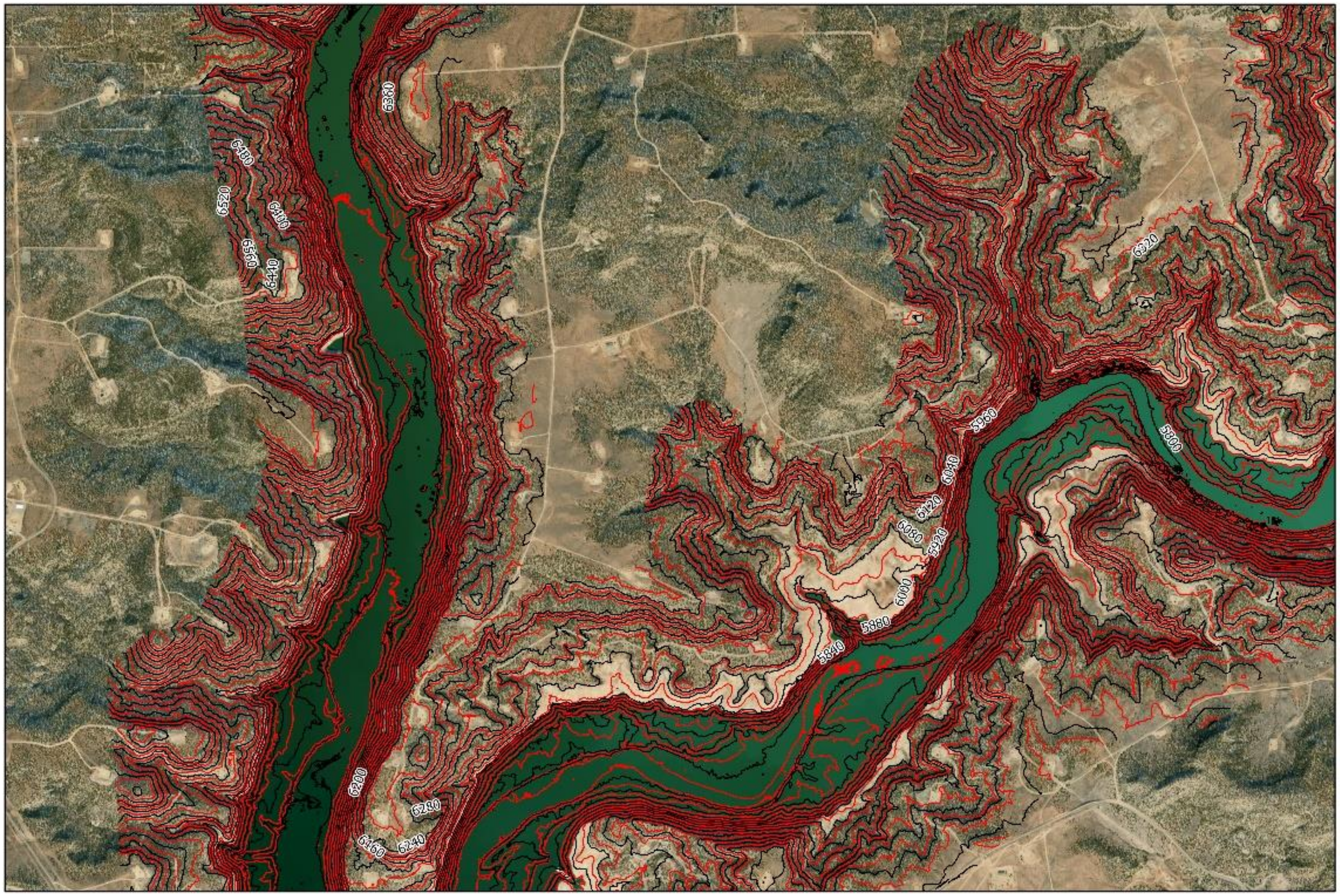

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 2

Map Prepared By:
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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

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40 Foot Contour Interval - Black

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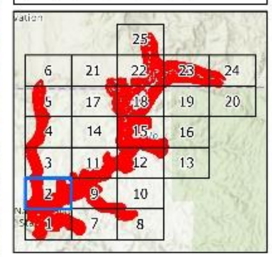
N

Scale 1:20,000

0 1,500 3,000 Feet



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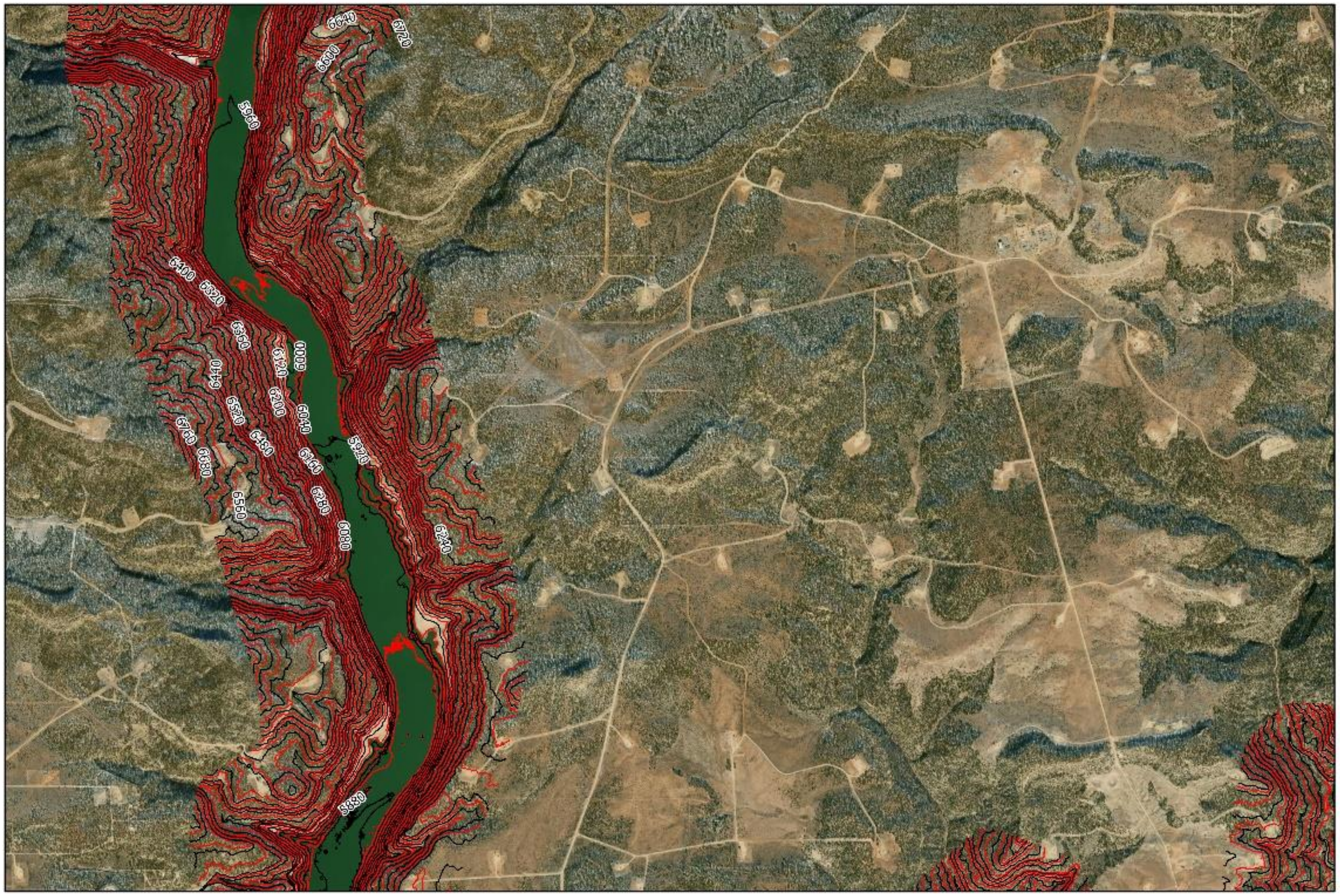

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 3

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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

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40 Foot Contour Interval - Black

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N

Scale 1:20,000

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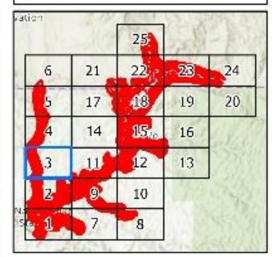

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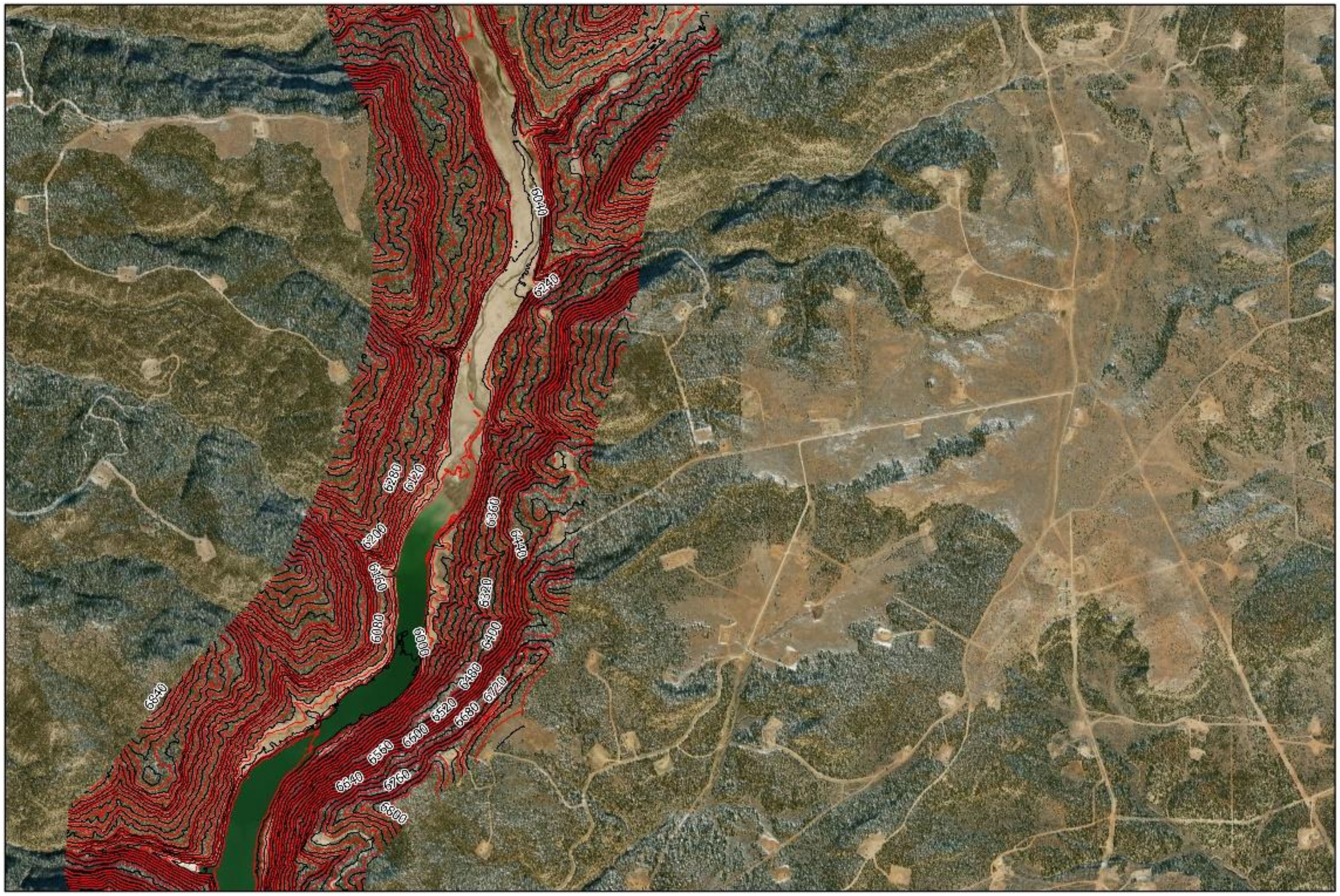

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 4

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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

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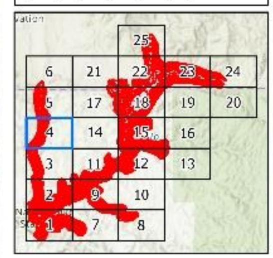
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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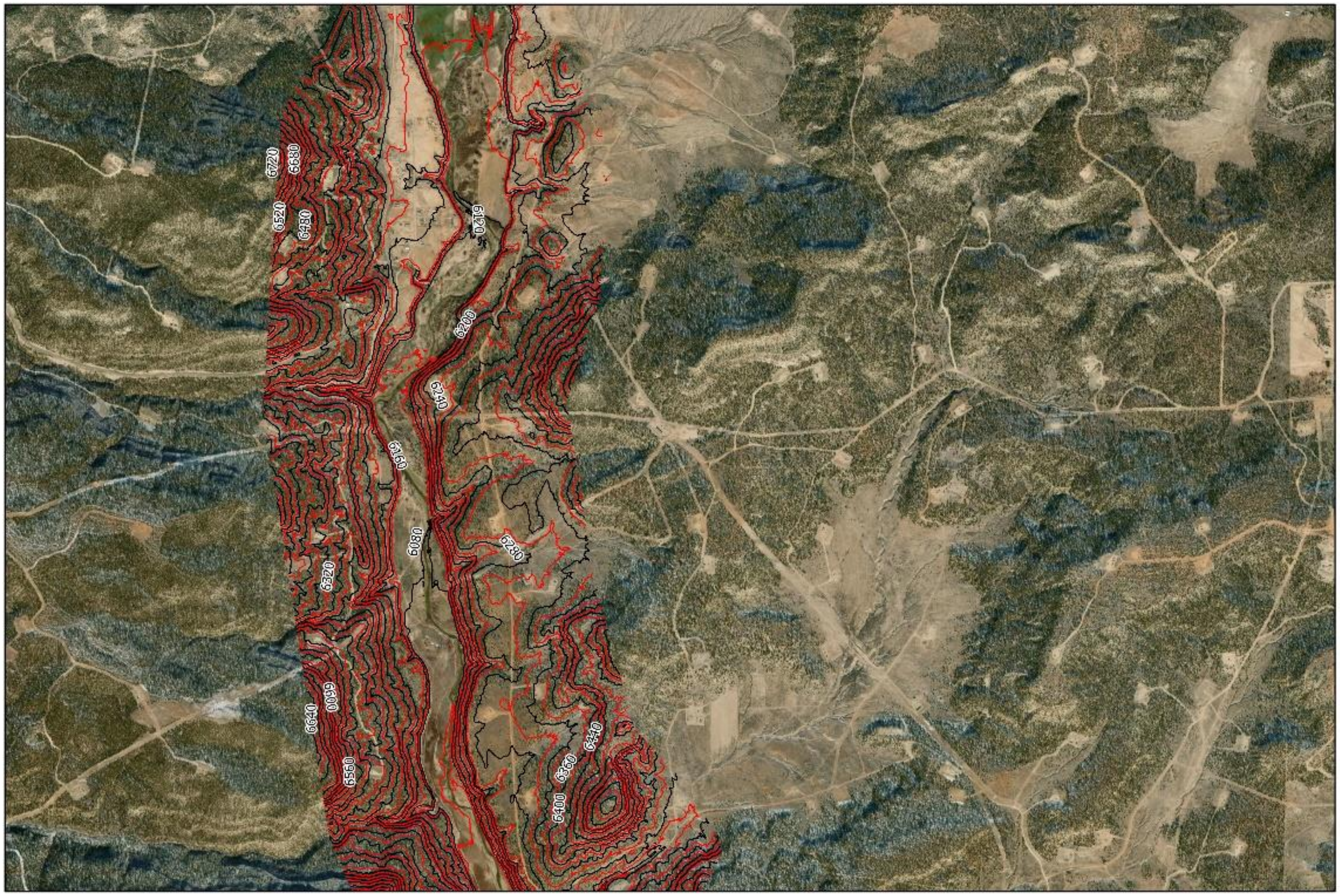

Navajo Reservoir New Mexico Elevation Contour Map

Sheet 5

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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

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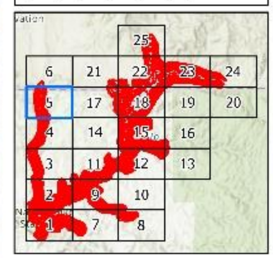
0 1,500 3,000 Feet



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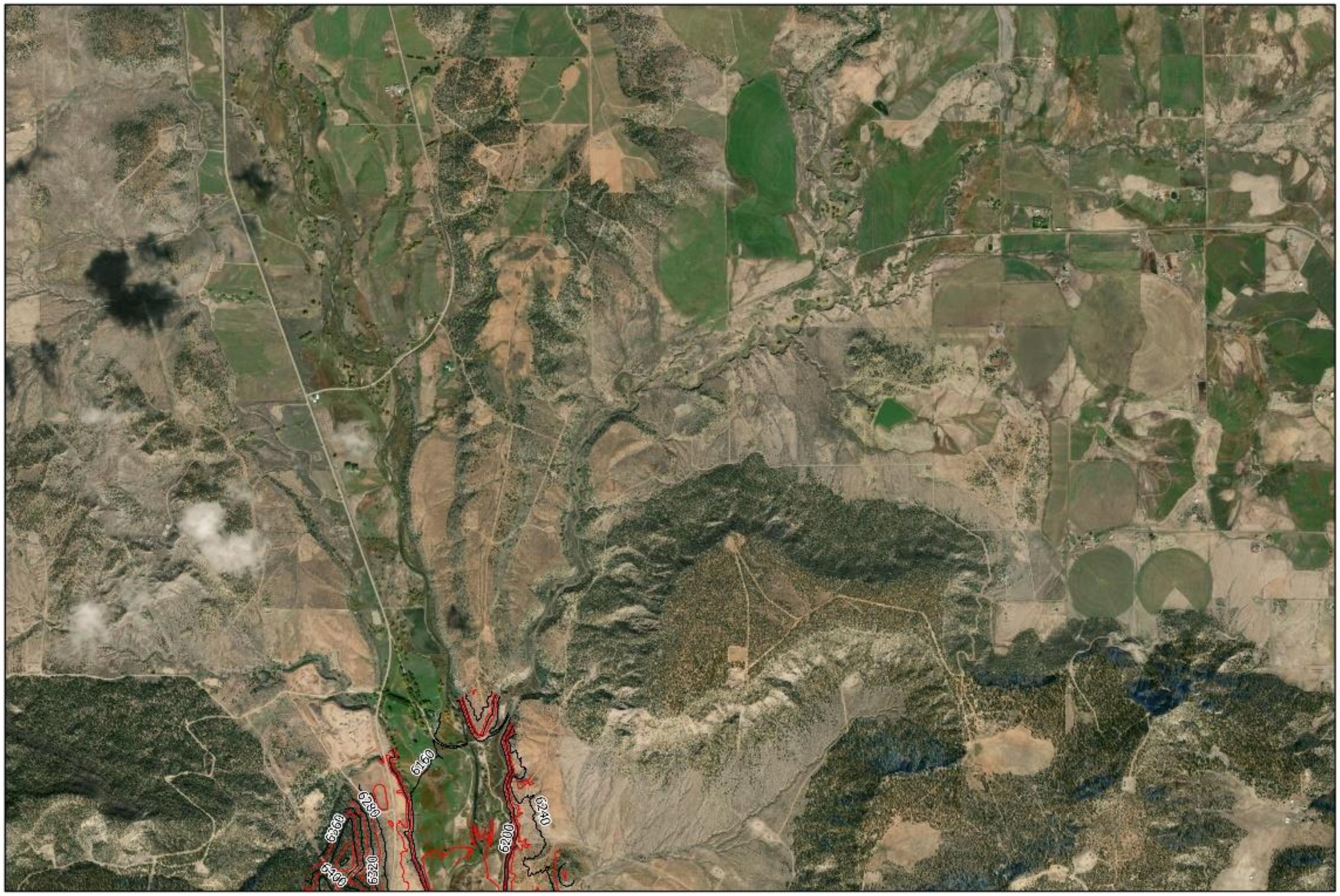

Navajo Reservoir
New Mexico
Elevation
Contour Map

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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

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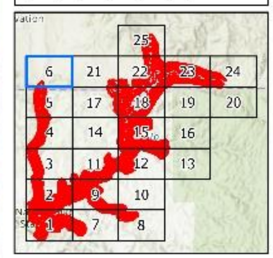
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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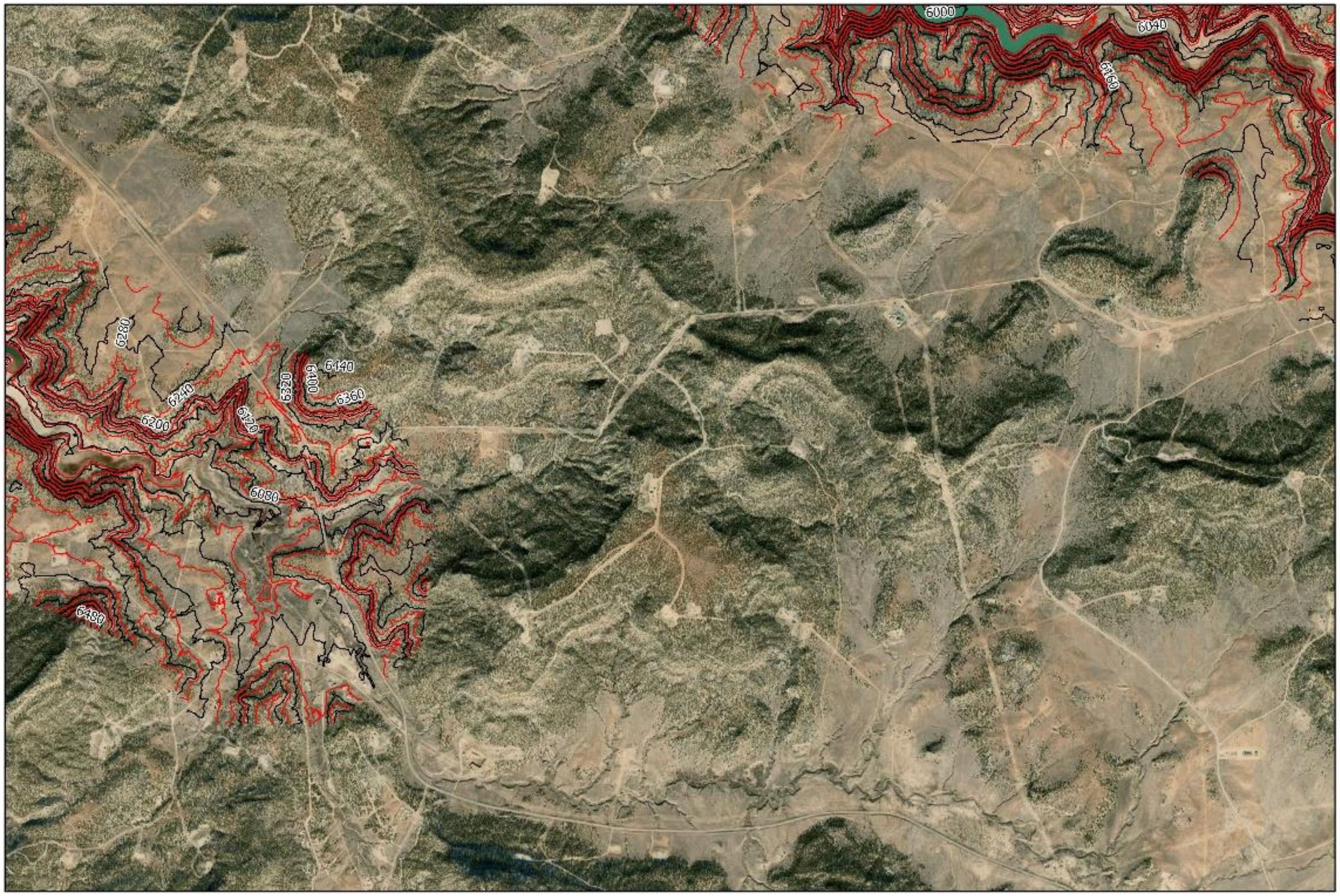

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 7

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Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

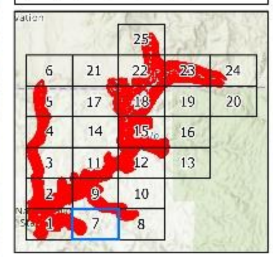
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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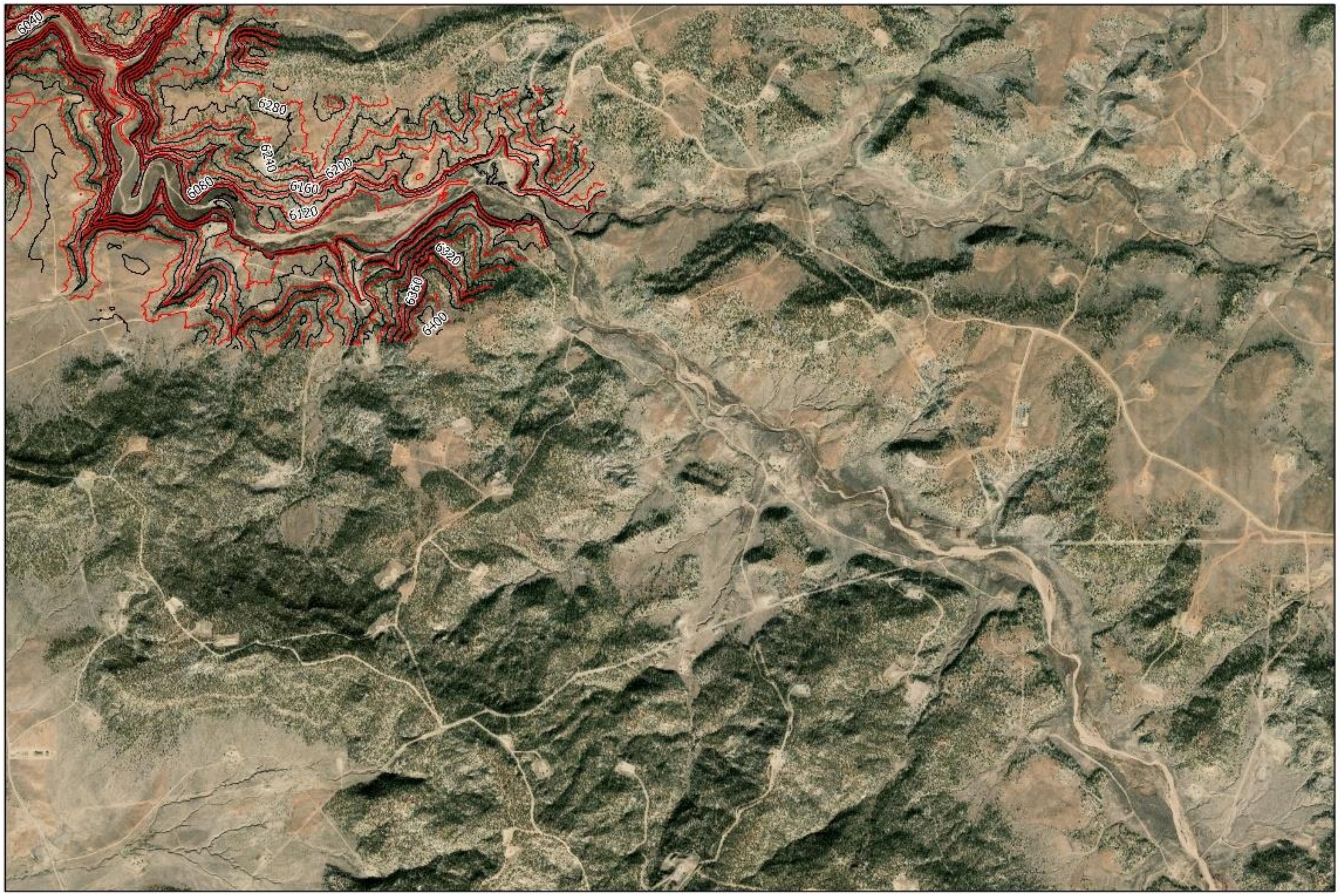


Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 8

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

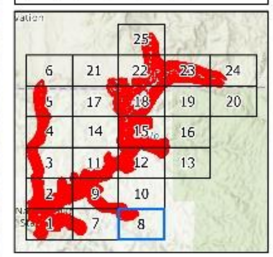
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, USDA FSA, GeoEye, Maxar, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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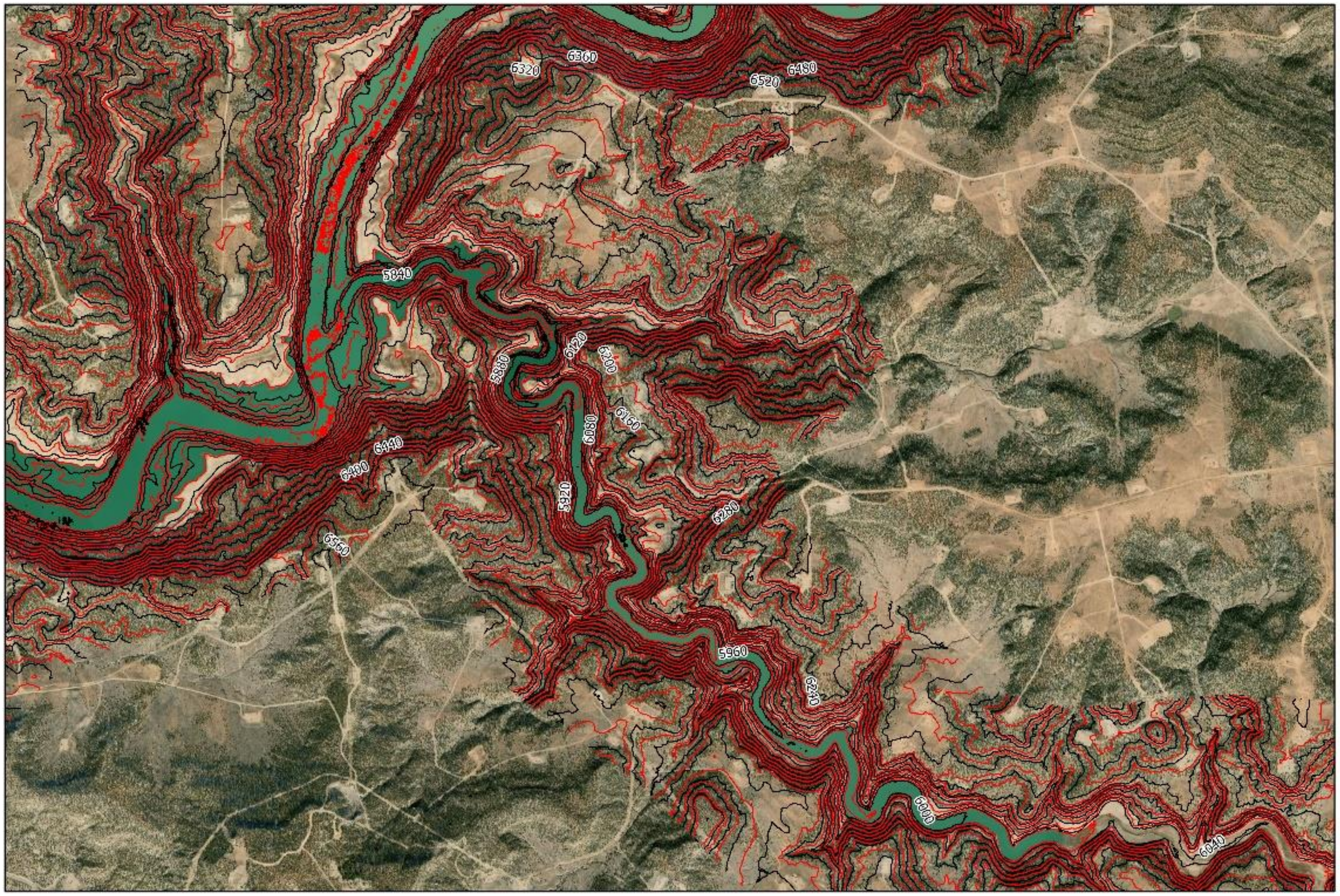


Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 9

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

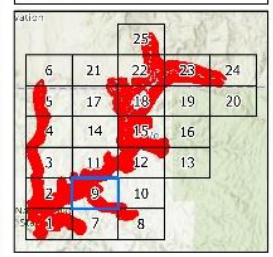
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, USDA FSA, GeoEye, Maxar, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 10

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

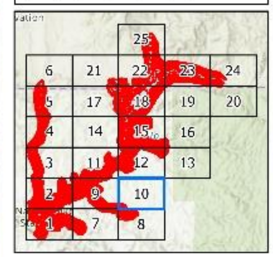
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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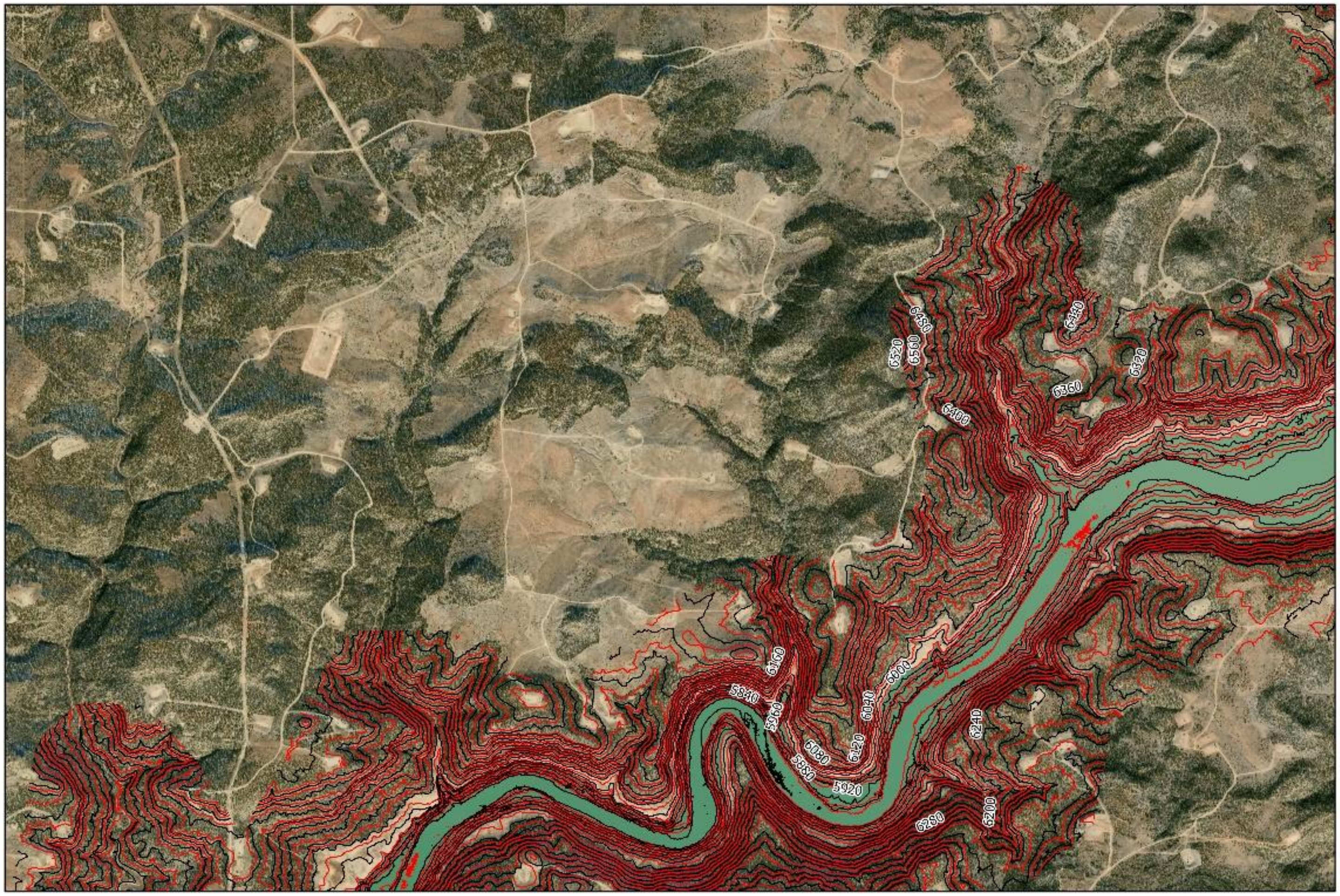

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 11

Map Prepared By:
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Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

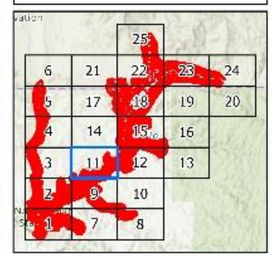
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, Esri, USGS

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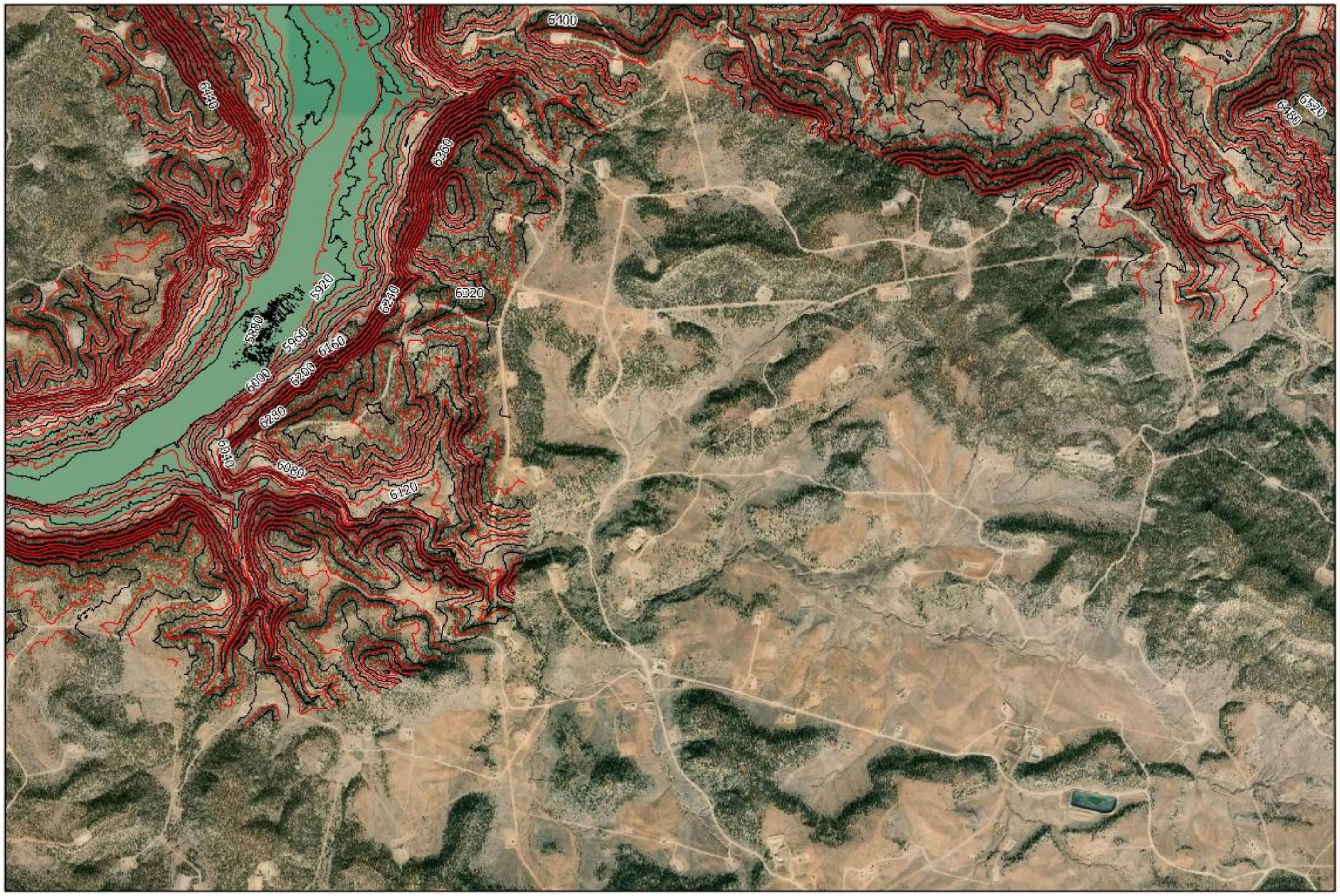


Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 12

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

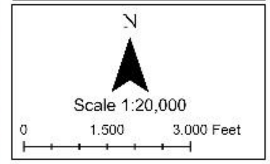
Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

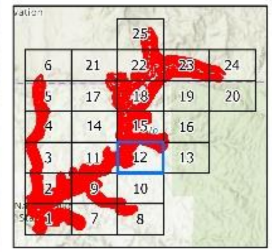
Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey





Esri, NASA, NGA, USGS, Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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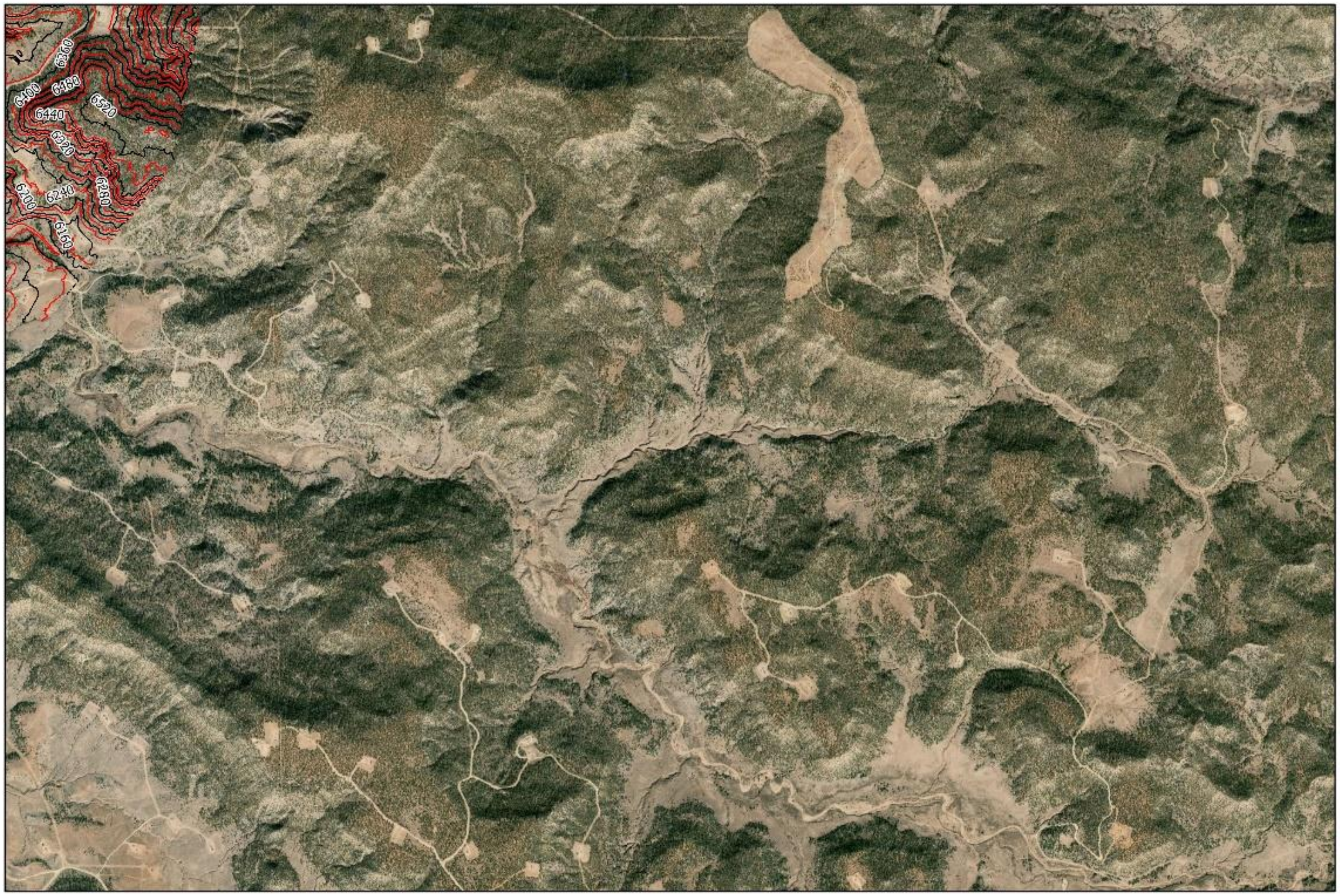

Navajo Reservoir New Mexico Elevation Contour Map

Sheet 13

Map Prepared By:
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Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

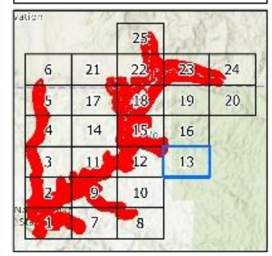
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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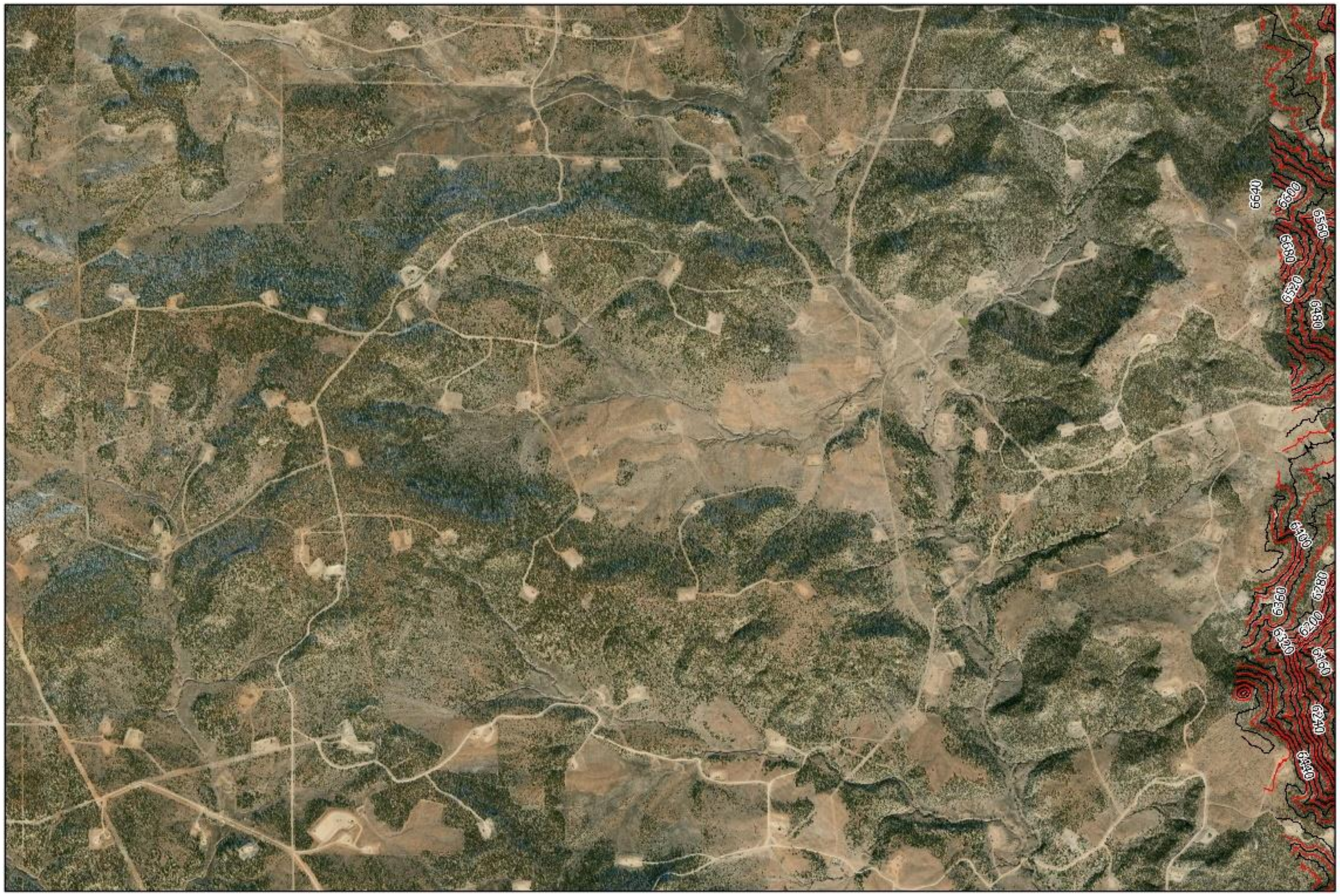

Navajo Reservoir New Mexico Elevation Contour Map

Sheet 14

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

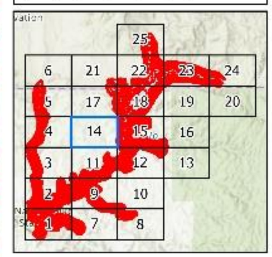
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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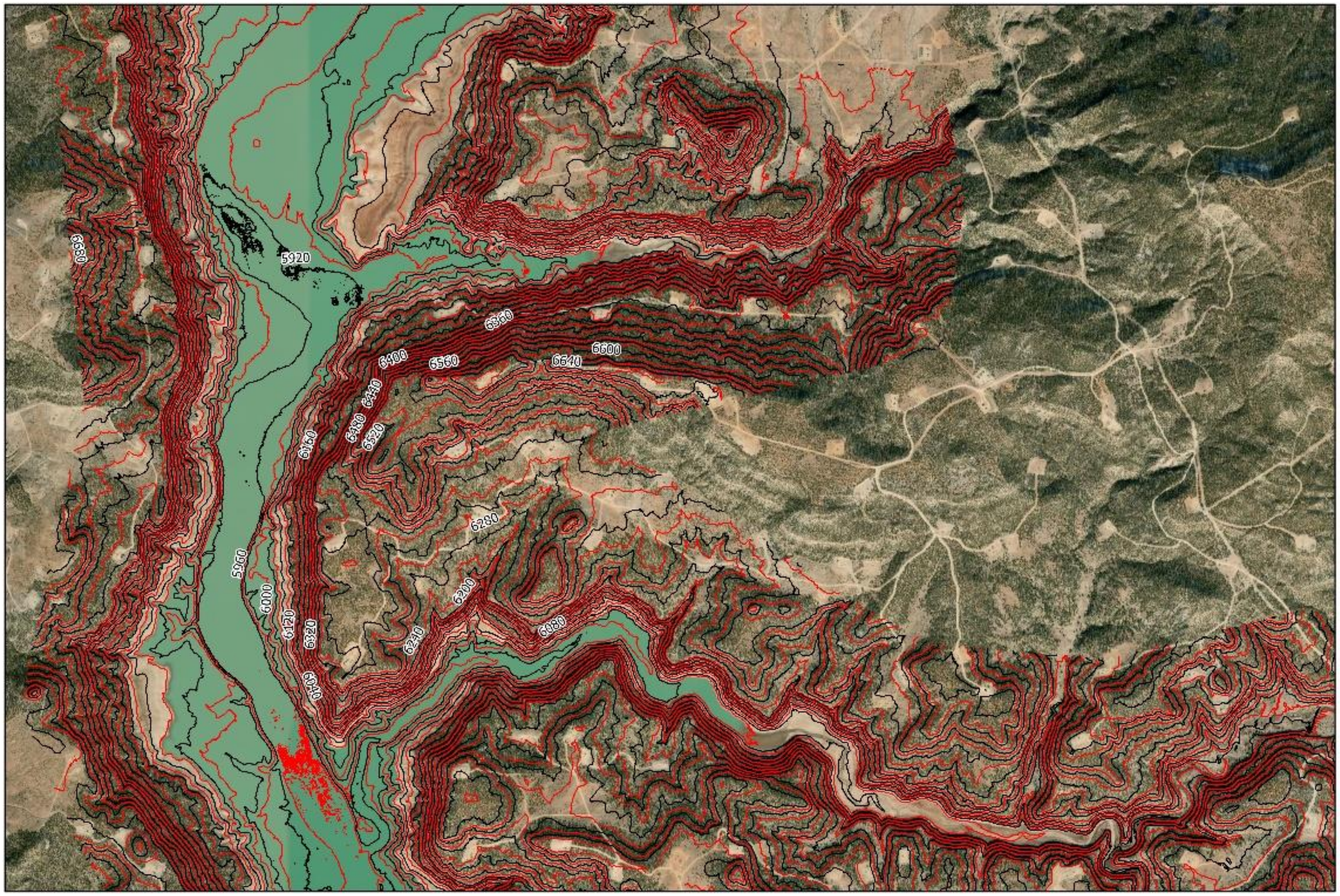

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 15

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

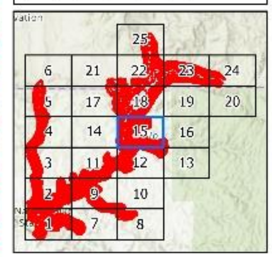
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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Navajo Reservoir New Mexico Elevation Contour Map

Sheet 16

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet

Esri, NASA, NGA, USGS, USDA FSA, GeoEye, Maxar, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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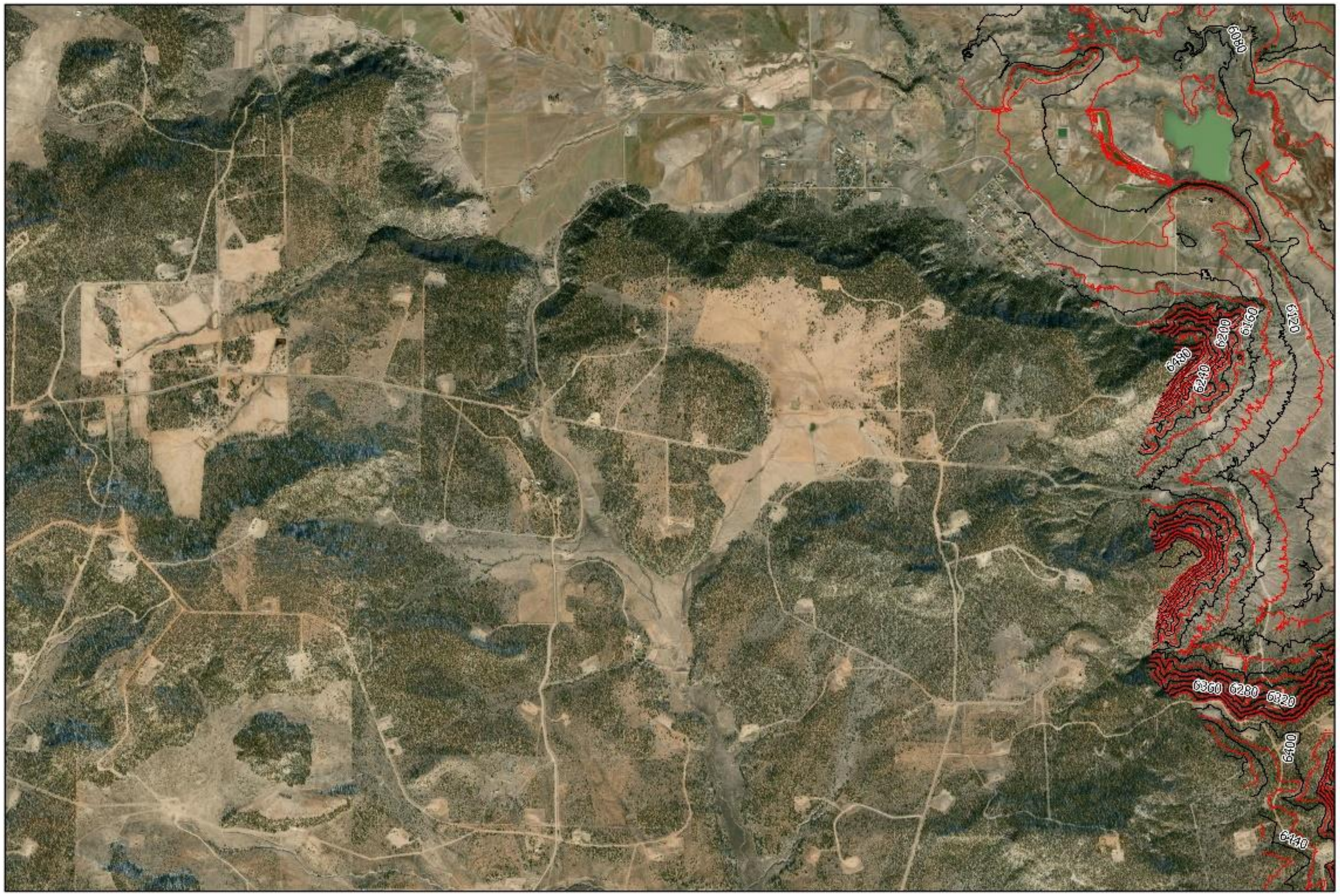

Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 17

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

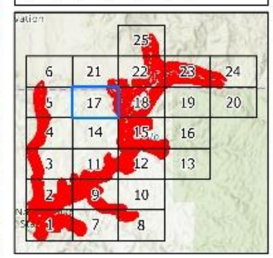
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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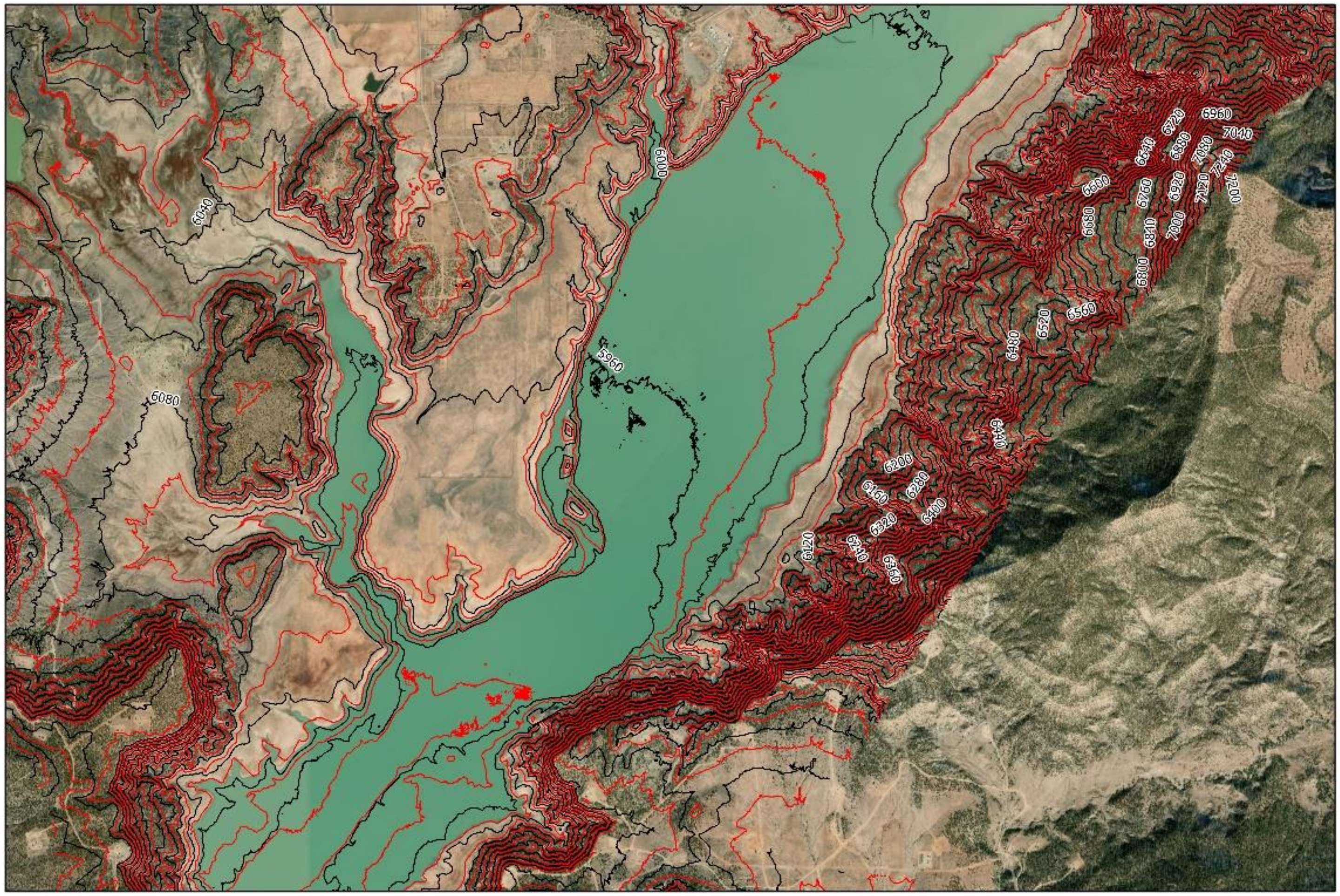

Navajo Reservoir New Mexico Elevation Contour Map

Sheet 18

Map Prepared By:
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Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

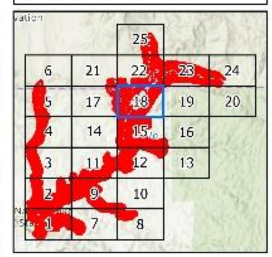
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 19

Map Prepared By:
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Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

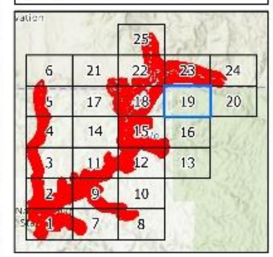
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, Earthstar Geographics, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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RECLAMATION

Navajo Reservoir New Mexico Elevation Contour Map

Sheet 20

Map Prepared By:
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Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

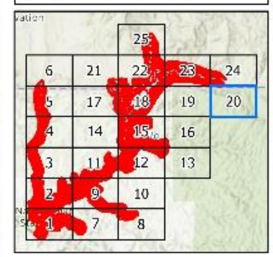
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 21

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

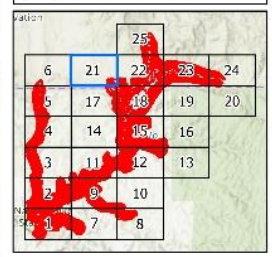
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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Navajo Reservoir New Mexico Elevation Contour Map

Sheet 22

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

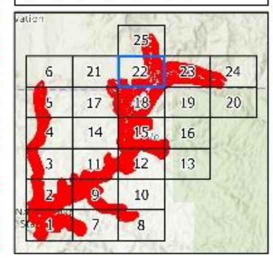
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



Esri, NASA, NGA, USGS, USDA FSA, GeoEye, Maxar, San Juan County, NM, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land

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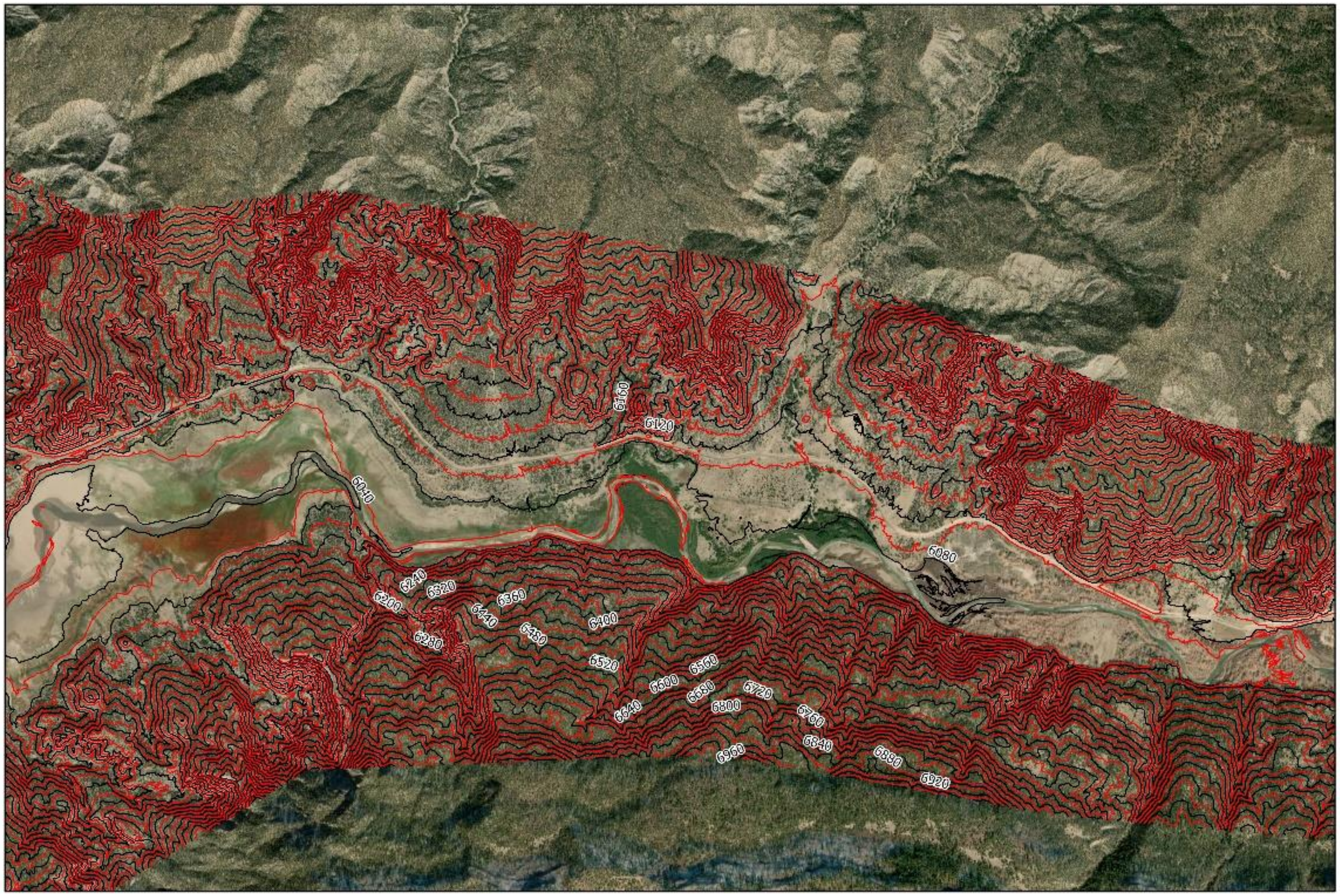


Navajo Reservoir New Mexico Elevation Contour Map

Sheet 23

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

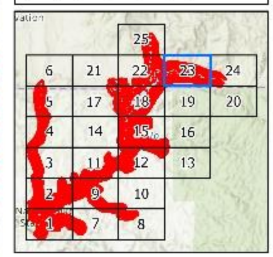
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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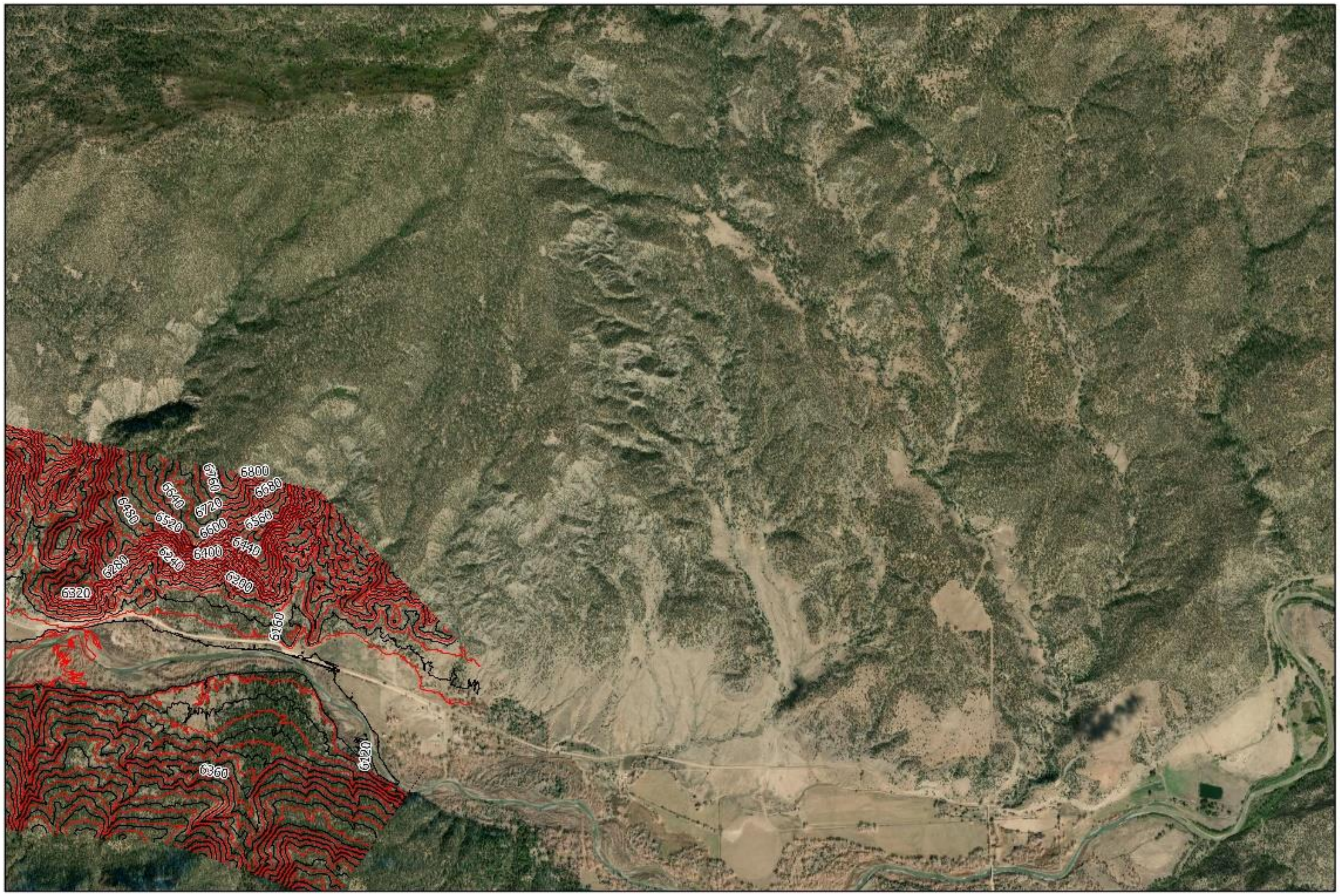


Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 24

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

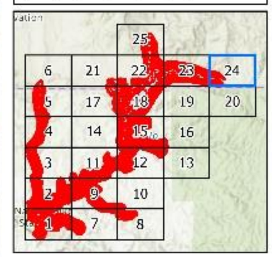
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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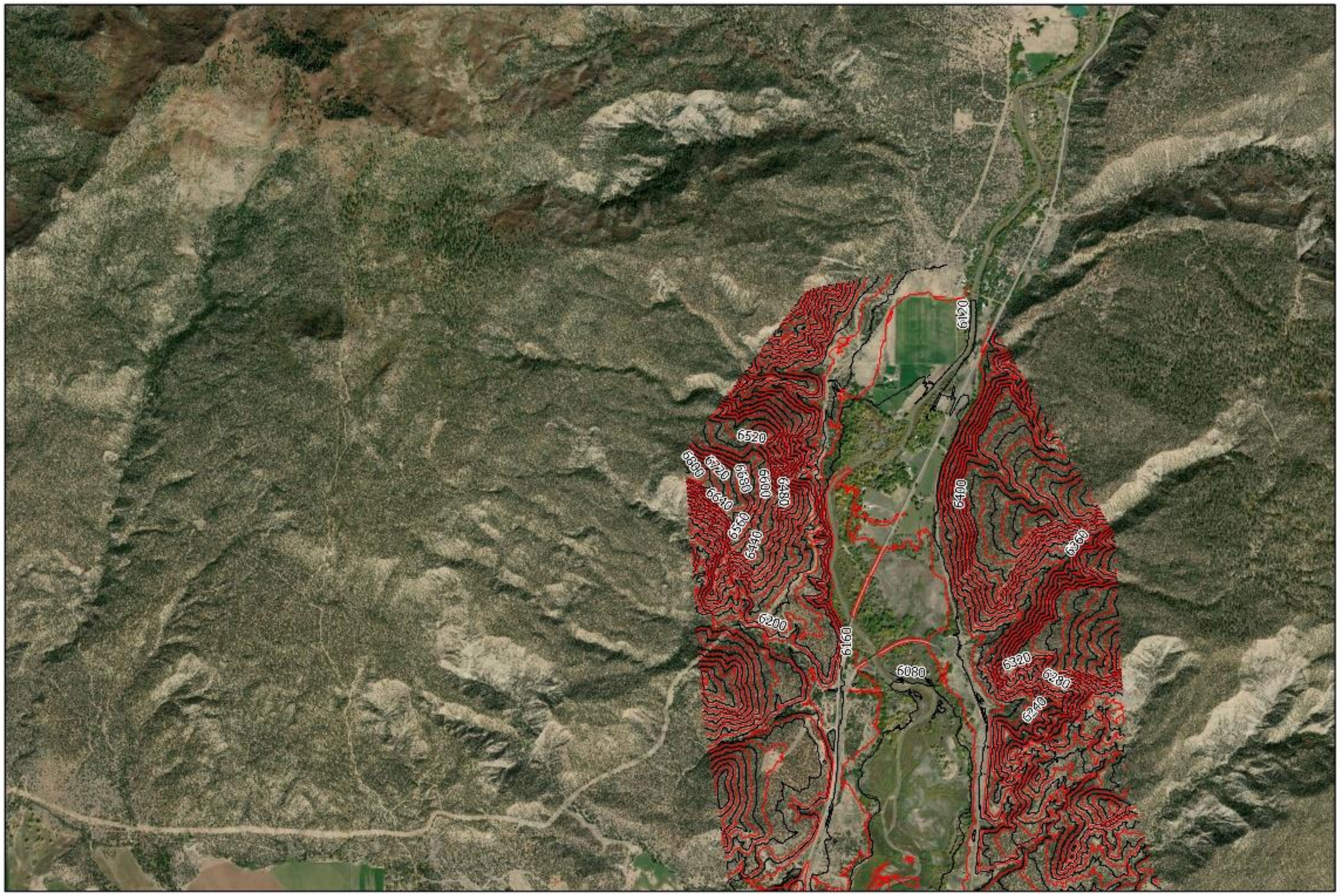


Navajo Reservoir
New Mexico
Elevation
Contour Map

Sheet 25

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 01/25/21

Horizontal Datum Based on NAD83 State Plane Coordinates New Mexico West Zone FIPS 3003 US Survey Feet

Vertical Datum Based on RTK GPS Measurements of Water Surface Elevations and Comparisons of LiDAR to Design Drawings

Water Surface Elevation Referenced to Reclamation Project Vertical Datum (RPVD)

NAVD88(G12B) - RPVD = 2.97 sft

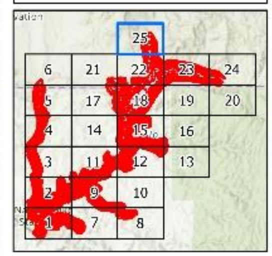
20 Foot Contour Interval - Red
40 Foot Contour Interval - Black

Primary Data Source:
2019 Navajo Reservoir Survey

N

Scale 1:20,000

0 1,500 3,000 Feet



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