BUREAU OF RECLAMATION

Technical Report No. ENV-2022-068

Tiber Reservoir (Lake Elwell)

2021 Sedimentation Survey

Lower Marias Unit (Pick-Sloan Missouri Basin Program), Montana
Missouri Basin and Arkansas-Rio Grande-Texas Gulf Region

U.S. Department of the Interior **May 2022**

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Cover Photo – Marias arm of Tiber Reservoir, looking southeast from near North Bootlegger Campground (David Varyu, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group).

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14. ABSTRACT
The 2021 multibeam bathymetric survey of Tiber Reservoir was combined with 2013 U.S. Geological Survey National Elevation Dataset (NED) data to produce a combined digital surface of the reservoir bottom. Analysis of these data indicates that at the top of flood control pool elevation (3012.5 feet, Reclamation Project Vertical Datum [RPVD]), the reservoir would have a surface area of 23,521 acres and a storage capacity of 1,323,068 acre-feet. Since the original filling in 1956, the reservoir is estimated to have lost 45,562 acre-feet of storage capacity (3.3 percent) due to sedimentation. The dead storage pool volume has reduced to 83 percent of the original dead storage volume. The sedimentation level at the dam is at 2845 feet (RPVD), which is 44.4 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

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Acronyms and Abbreviations

acre-feet/mi^2/year	acre feet per square mile per year
ACAP	Area-CAPacity
cm	centimeter(s)
DEM	digital elevation model
ft	foot/feet
ft^3/s	cubic feet per second
GIS	Geographic Information System
GPS	Global Positioning System
gSSURGO	Gridded Soil Survey Geographic (Database)
HUC	Hydrologic Unit Code
mi^2	square mile(s)
NAD83	North American Datum, established 1983
NAVD88	1988 North American Vertical Datum, established 1988
NED	National Elevation Dataset
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum, established 1929
NID	National Inventory of Dams
NLCD	National Land Cover Database
OPUS	Online Positioning User Service
Reclamation	Bureau of Reclamation
RPVD	Reclamation Project Vertical Datum
RTK-GPS	real-time kinematic Global Positioning System
TSC	Technical Service Center
USGS	U.S. Geological Survey

Symbols

>	greater than
<	less than
±	plus or minus

Contents

Page

Tables

Table Page

Figures

Figure Page

Appendices

Appendix

Executive Summary

Tiber Dam and Reservoir (Lake Elwell) are on the Marias River about 15 miles southwest from the town of Chester, Montana.

A bathymetric survey of Tiber Reservoir was conducted from June 21 to June 27, 2021, with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1956 and since the last survey in 2002

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, each using a multibeam echo sounder that was interfaced with real-time kinematic Global Positioning System (RTK-GPS) instruments to map the reservoir bottom. The 2021 multibeam bathymetric survey of Tiber Reservoir was combined with U.S. Geological Survey National Elevation Dataset topographic data to produce a combined digital surface of the reservoir bottom.

This survey was conducted between June 21 and June 27 when the reservoir water surface elevation ranged between 2990.8 and 2991.1 feet (ft) in Reclamation Project Vertical Datum (RPVD), 2 ft below the top of joint use elevation of 2993 ft. The above-water topographic data were published in 2013.

Analysis of the combined data sets indicates the following results:

- At reservoir water surface elevation 2986 ft (RPVD), which is 5 ft below water at the time of the survey, the reservoir surface area was 15,986 acres with a storage capacity of 799,874 acre-feet.

- At the top of flood control pool elevation (3012.5 ft, RPVD), the reservoir would have a surface area of 23,521 acres and a storage capacity of 1,323,068 acre-feet.

- Since the original filling of the reservoir in 1956, the reservoir is estimated to have lost (with respect to elevation 3012.5 ft, RPVD) 45,562 acre-feet of storage capacity (3.3 percent) due to sedimentation. Since the last reservoir survey in 2002, the reservoir is estimated to have lost 5,655 acre-feet of storage capacity. These volumes represent sediment yield rates of 0.16 and 0.07 acre-feet/mi^2/year (1956–2002 and 2002–2021, respectively), which is considered very low as defined in the Erosion and Sedimentation Manual (Bureau of Reclamation 2006).

- By 2021, the dead storage pool volume had reduced to 82.7 percent of the original dead storage volume. The sedimentation level at the dam is at 2845 ft (RPVD), which is 44 percent of the height between the original reservoir bottom and the top elevation of the dead storage pool.

- Historic rates of reservoir sedimentation indicate a decreasing trend in sedimentation rates since original reservoir filling).

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	Tiber Reservoir	**Region**	Missouri Basin and Arkansas – Rio Grande – Texas
Owner	Bureau of Reclamation	**Area office**	Montana Area Office
Stream	Marias	**Vertical datum**	RPVD (NGVD29)
County	Liberty	**Top of dam (ft)**	3026
State	Montana	**Spillway crest (ft)**	2975
Latitude (deg min sec)	N 48 19 06	**Power penstock elevation (ft)**	Unknown
Longitude (deg min sec)	W 111 05 27	**Low-level outlet (ft)**	2870
HUC4*	1003	**Hydraulic height (ft)**	197
HUC8*	10030203	**Total drainage area (mi^2)**	4395
NID ID*	MT00579	**Date storage began**	10 / 57
Dam purpose	Flood risk reduction, irrigation, recreation, water supply	**Date for normal operations**	10 / 81

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

Original design				
Storage allocation	**Elevation (ft)**	**Surface area (acres)**	**Capacity (acre-feet)**	**Gross capacity (acre-feet)**
Surcharge	3020.2	25,414	187,741	1,555,898
Flood control	3012.5	23,152	400,838	1,368,157
Multiple use				
Joint use	2993.0	17,886	267,994	967,319
Conservation	2976.0	13,787	121,701	699,325
Inactive	2966.4	11,741	556,042	577,624
Dead	2870.0	1,535	21,582	21,582

Survey summary							
Survey date	**Type of survey**	**Number of range lines or contour intervals**	**Contributing sediment drainage area (mi^2)**	**Period sedimentation volume (acre-feet)**	**Cumulative sedimentation (acre-feet)**	**Lowest reservoir elevation (ft)**	**Remaining portion of dead storage (percent)**
1957	Contour	5-ft	4,375				
2002	Contour	2-ft	4,375	39,907	39,907	2810	90
2021			4,295	5,655	45,562	2840	82

Notes: Sediment accumulation is compared at elevation 3012.5 ft (RPVD).

1.0 Introduction

Tiber Dam and Tiber Reservoir (also known as Lake Elwell) are on the Lower Marias River about 15 miles southwest of Chester, Montana (Figure 1). The dam and reservoir are operated by the Bureau of Reclamation (Reclamation) as part of the Pick-Sloan Missouri Basin Project to supply irrigation water to about 127,000 acres of farmland (Ferrari 2005). The dam provides flood risk reduction, recreation, and water supply.

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 as well as provide information for forecasting when dam and reservoir facilities will be impacted by sedimentation.

As part of ongoing operations and sediment monitoring activities, the Missouri Basin and Arkansas-Rio Grande-Texas Gulf Regions requested the Technical Service Center's 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 June 21 to June 27, 2021, with these primary objectives:

1. Estimate reservoir sedimentation volume since the original reservoir filling began in 1956 and since the last survey in 2002

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

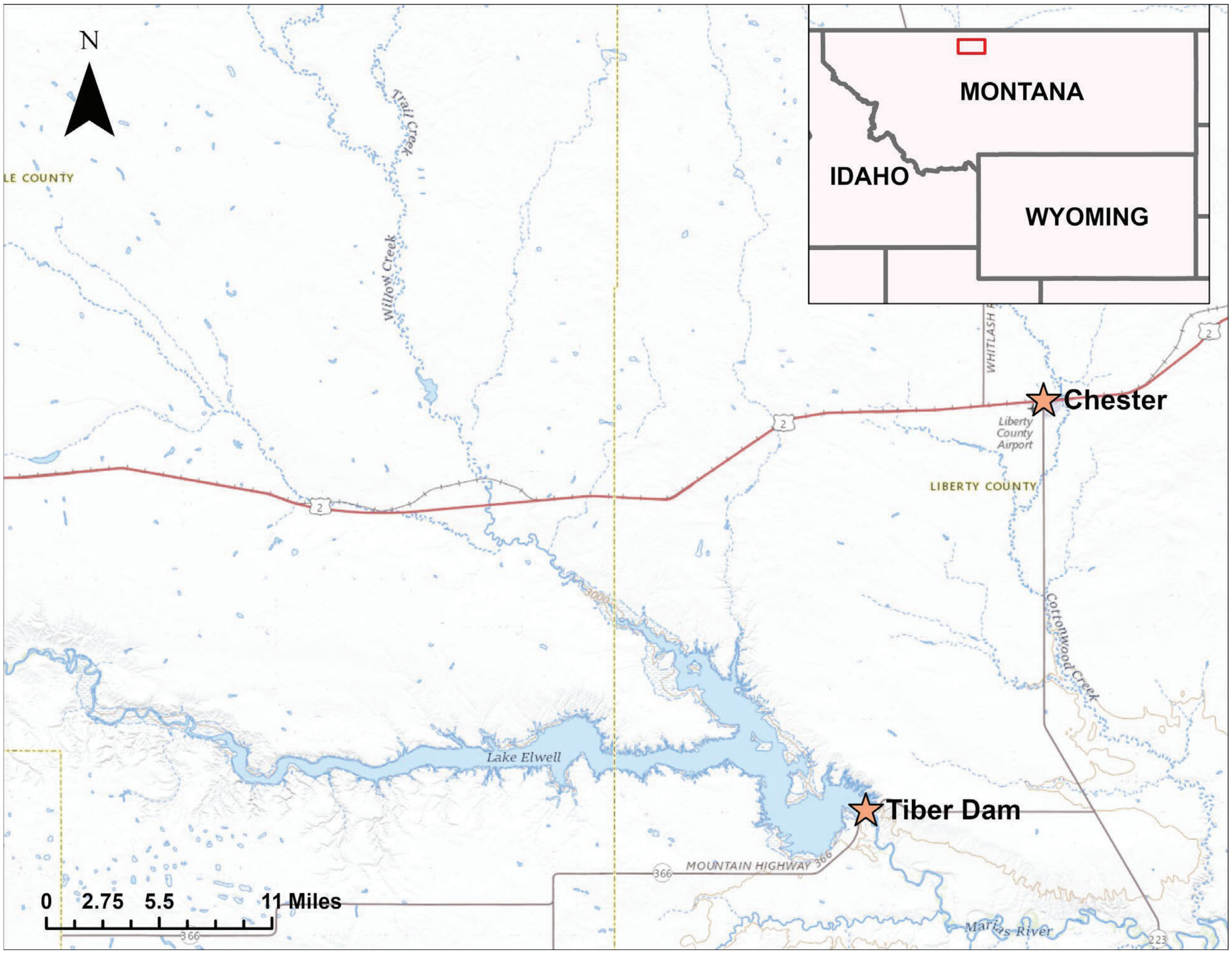

Figure 1.—Location map of Tiber Dam and Lake Elwell (Tiber Reservoir), approximately 15 miles southwest of Chester, Montana.

2.0 Watershed Description

2.1 Location and Drainage

The watershed upstream from Tiber Dam has a total contributing drainage area of 4,395.1 mi^2 (U.S. Geological Survey [USGS] 2022). The majority of the lakes within the watershed have drainage areas of < 1 percent of the total basin drainage area. These small lakes likely block very little sediment from reaching Lake Elwell. Only one lake within the watershed (Lower Two Medicine Lake) exceeds this 1-percent threshold with a drainage area of 52.3 mi^2. If we account for all upstream lakes and reservoirs that trap sediment (as of 2021), the net sediment-contributing drainage area to Lake Elwell is approximately 4,299 mi^2 (Figure 2). This is calculated by subtracting the watershed drainage area from Lower Two Medicine Lake and the surface area for any upstream reservoirs or lakes that would disrupt sediment delivery (which account for 1 percent of the total drainage area; High Resolution National Hydrography Dataset). We assume that these water bodies trap 100 percent of the sediment that is delivered to them.

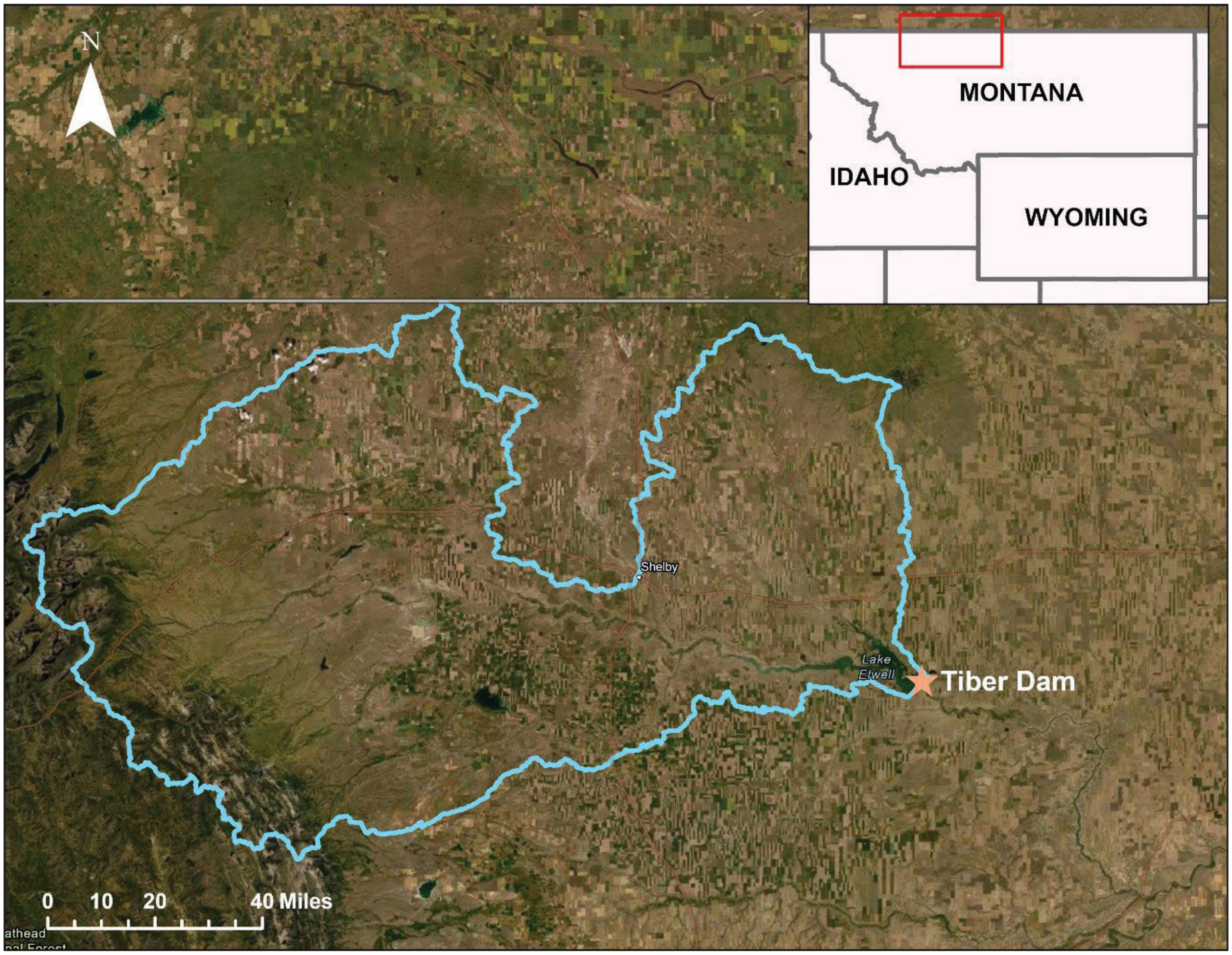

Figure 2.—The watershed above Tiber Dam (blue line) has a total drainage area of 4,395.1 mi^2 and a sediment-contributing drainage area of 4,299 mi^2 (USGS 2022).

Basin elevations for the Tiber Dam watershed range from 9472 ft in the headwaters to 2976 ft at the top of the conservation pool. The basin is bordered by the Rocky Mountains on the west, but most of the basin is relatively flat, and 37 percent of it is used for cultivating crops and hay (Dewitz and USGS 2021).

2.2 Geology

The geology of the Tiber watershed's sediment-contributing drainage area consists primarily of readily erodible sedimentary rock (Figure 3 and Table 1). The unconsolidated material in the headwaters is the most susceptible to sediment transport for subsequent deposition in the reservoir. Quaternary alluvial deposits, gravels, and glacial deposits comprise the unconsolidated portion of the map. These sediments are typically mobile. The bedrock at the dam site is part of the Telegraph Creek Formation, which consists of poorly consolidated sedimentary rocks (shale, mudstone, sandstone, and siltstone) (Fullerton et al. 2013).

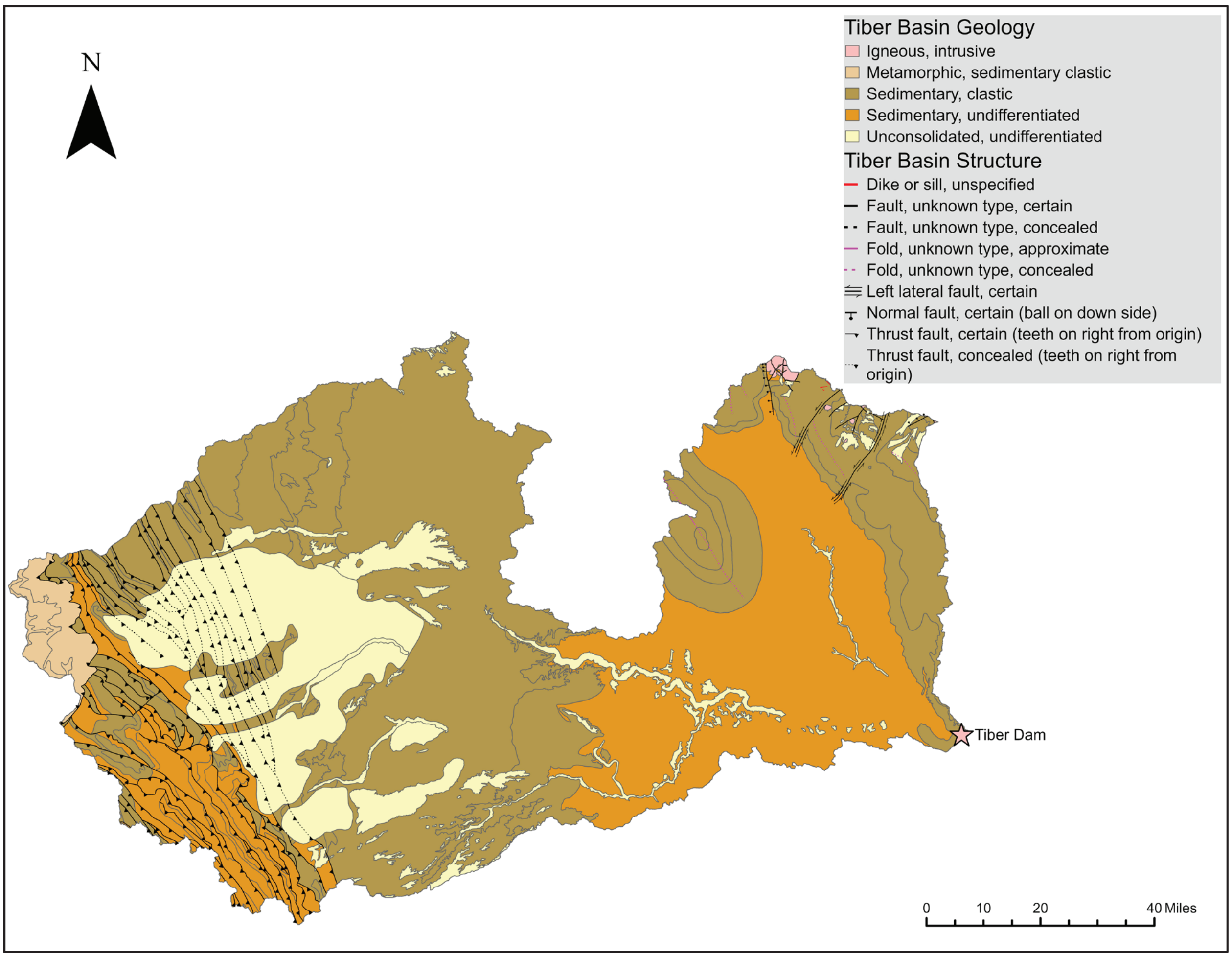

Figure 3.—Generalized geology of the Tiber basin; 18.4 percent of the basin consists of unconsolidated Quaternary deposits.

Table 1.—Total area of generalized lithologies in the Tiber basin

Generalized lithology	Total area (mi^2)	Percentage of basin
Igneous, intrusive	6.8	0.2
Metamorphic, sedimentary clastic	85.7	1.9
Sedimentary, clastic	2,218.7	50.5
Sedimentary, undifferentiated	1,273.3	29
Unconsolidated, undifferentiated	810	18.4

2.3 Soils, Vegetation, and Land Use

The soil textures in the basin from the Gridded Soil Survey Geographic (gSSURGO) Database for Montana (United States Department of Agriculture-Natural Resources Conservation Service 2022) are predominantly loams and clay loams (Figure 4a). Figure 4b shows that the area with the unconsolidated glacial deposits from Figure 3 is more highly erodible (higher k-factor) than the surrounding area, but most of the soil erodibility in the basin has a k-factor of < 0.32. The depth to the soil restrictive layer is > 3.5 ft throughout most of the basin. The combination of clay presence, soil development on the glacial and alluvial fan deposits, and low erodibility indicate that the soils in the basin are likely stable.

Cultivated crops, grassland, and shrubland constitute approximately 85 percent of the area in the watershed (Dewitz and USGS 2021). Only about 7 percent of the basin is forested. The National Land Cover Database (NLCD) land use classes in the basin are listed in Table 2. A high percentage of land used for crop cultivation tends to increase sediment yield above natural levels.

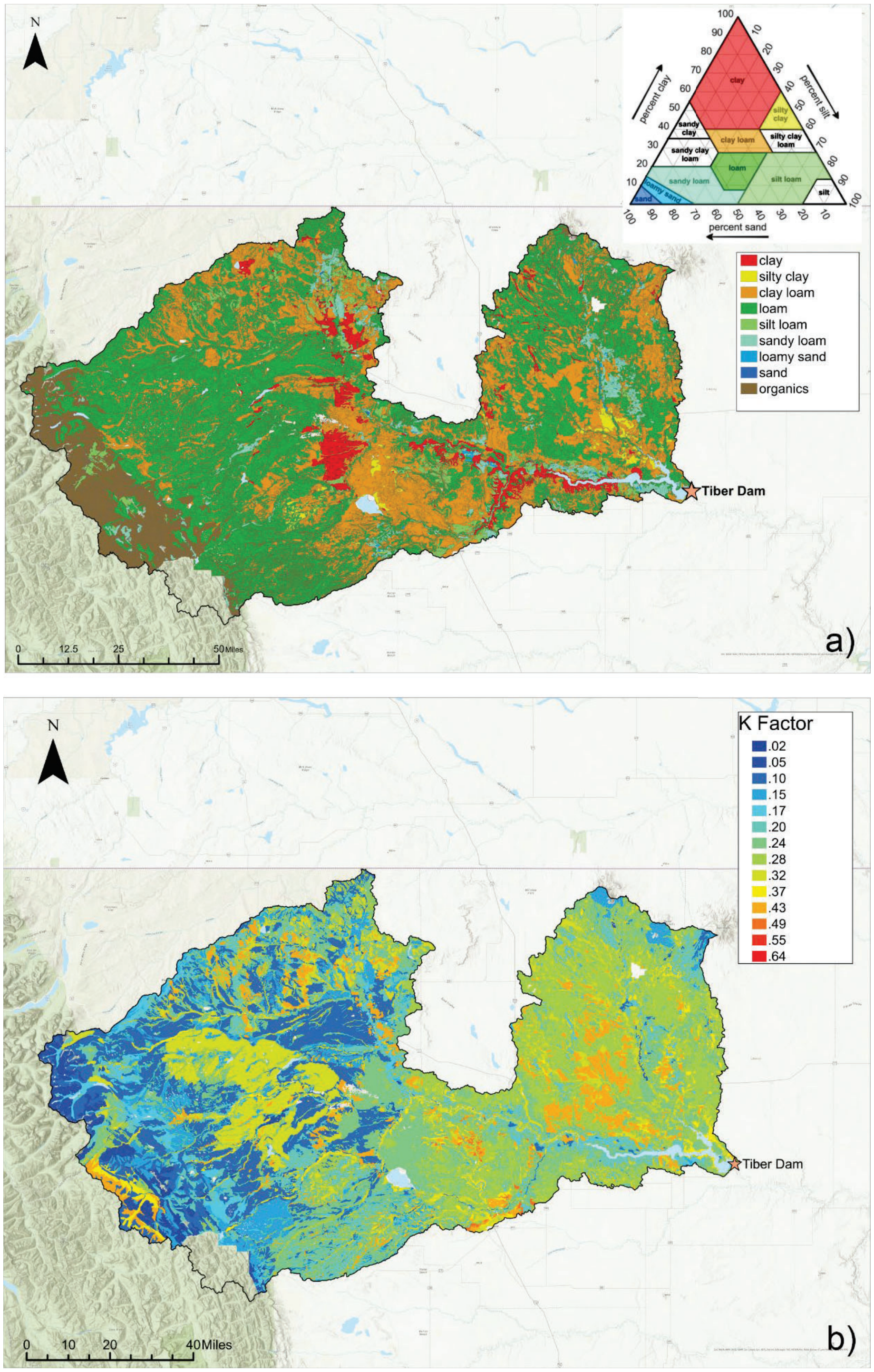

Figure 4.—a) gSSURGO soils texture map for the Tiber basin. Textures have been lumped and colored to match the United States Department of Agriculture soils texture diagram in the upper right of the map. b) Soil erodibility (k-factor) map for the Tiber basin. Low k-factor values (cool colors) represent low erodibility, and high k-factor values (warm colors) represent high erodibility.

Table 2.—Land cover in the Tiber basin according to the 2019 NLCD (Dewitz and USGS 2021)

Fraction of basin (percent)	Land use class	Description
35.7	Cultivated crops	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for > 20 percent of total vegetation. This class also includes all land being actively tilled.
35.2	Grassland/herbaceous	Areas dominated by gramanoid or herbaceous vegetation, generally > 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
14.4	Shrub/scrub	Areas dominated by shrubs; < 5 meters tall with shrub canopy typically > 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
4.6	Evergreen forest	Areas dominated by trees generally > 5 meters tall and > 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
2.3	Pasture/hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for > 20 percent of total vegetation.
1.3	Barren land (rock/sand/clay)	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for < 15 percent of total cover.
1.3	Open water	Areas of open water, generally with < 25 percent cover of vegetation or soil.
1.3	Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for > 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
1.2	Deciduous forest	Areas dominated by trees generally > 5 meters tall and > 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
1	Developed, open space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for < 20 percent of total cover. These areas most commonly include large-lot, single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
0.7	Mixed forest	Areas dominated by trees generally > 5 meters tall and > 20 percent of total vegetation cover. Neither deciduous nor evergreen species are > 75 percent of total tree cover.
0.5	Woody wetlands	Areas where forest or shrubland vegetation accounts for > 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
0.3	Developed, low intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 to 49 percent of total cover. These areas most commonly include single-family housing units.
0.08	Developed, medium intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. These areas most commonly include single-family housing units.
0.01	Developed, high intensity	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.

2.4 Climate and Runoff

Most of the Tiber basin has a cold, arid steppe climate (BSk Köppen-Geiger class). The mountainous western portion and small pockets of the northeastern portion of the basin are classified as having a cold climate with no dry season and either a warm or cold summer (Dfb and Dfc) [Beck et al. 2018]. The mean annual precipitation in the basin is 17.4 inches (USGS 2022).

Reservoir inflows are primarily from the Marias River and Willow Creek, which represent 93.6 percent of the total contributing drainage area (Table 3). The Marias River is forked upstream of Lake Elwell. Daily average discharge records for the Marias River (USGS 06099500) are presented on Figure 5. The Willow Creek gage (USGS 06101200) does not record discharge, and the Dry Fork Marias River (USGS 06100500) only has 11 years of record that ended in 1931, so these discharge records were not plotted. The outflow record on the Marias River downstream from the dam (USGS 06101500) is shown on Figure 6.

Table 3.—Reservoir inflow streams with USGS gages

USGS stream gage		Drainage area (mi^2)	Mean annual runoff (ft^3/s)	Period of record
Name	Number			
Willow Creek near Galata, Montana	06101200	839	N/A	09/22/2021–03/08/2022
Marias River near Shelby, Montana	06099500	2,716	635,933	10/1/1995–03/08/2022
Dry Fork Marias River at Fowler, Montana	06100500	373	N/A	03/25/1920–12/31/1931
	Totals	**3,928**	**635,933**	

The lack of consistent gaging for the Tiber watershed makes it difficult to estimate the total annual runoff. StreamStats (Ries et al. 2017) estimates that the mean annual inflow from Willow Creek and the Marias River combined is 1,370 ft^3/s, which corresponds to a total mean annual runoff volume of 992,514 acre-feet. The Lake Elwell capacity at the top of the conservation pool (2976 ft) is currently estimated to be 655,956 acre-feet. The ratio of reservoir storage capacity to mean annual runoff is < 1, indicating that the reservoir cannot contain as much surface runoff as is generated in the basin in an average year.

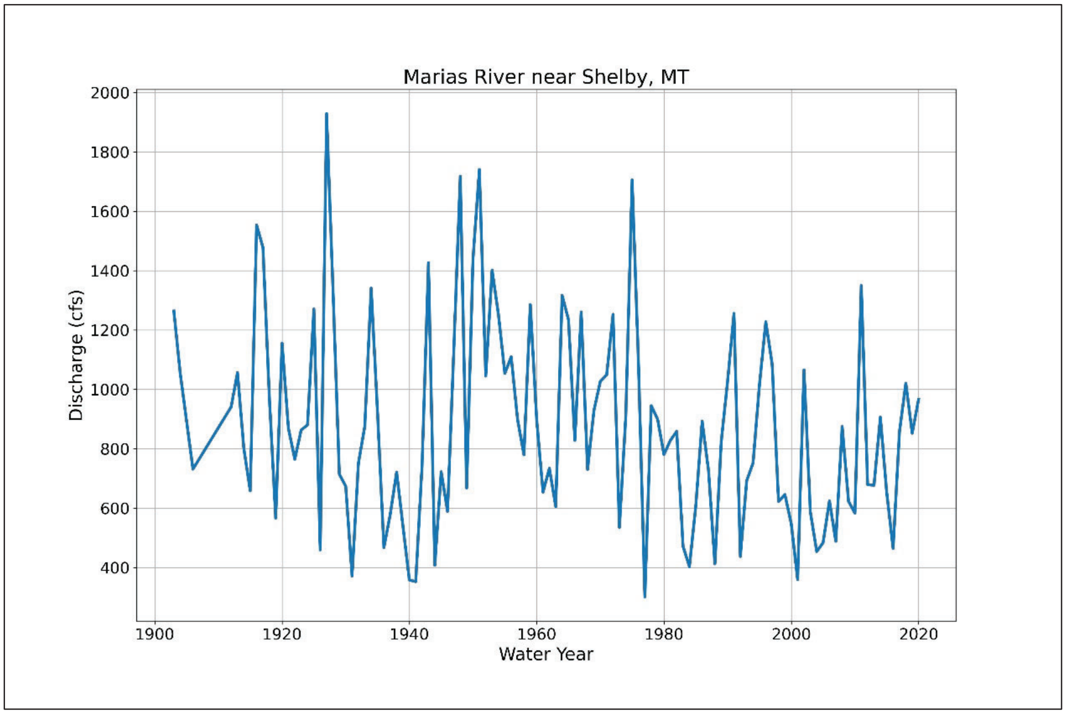

Figure 5.—Average annual discharge at the Marias River near Shelby, Montana (USGS 06099500).

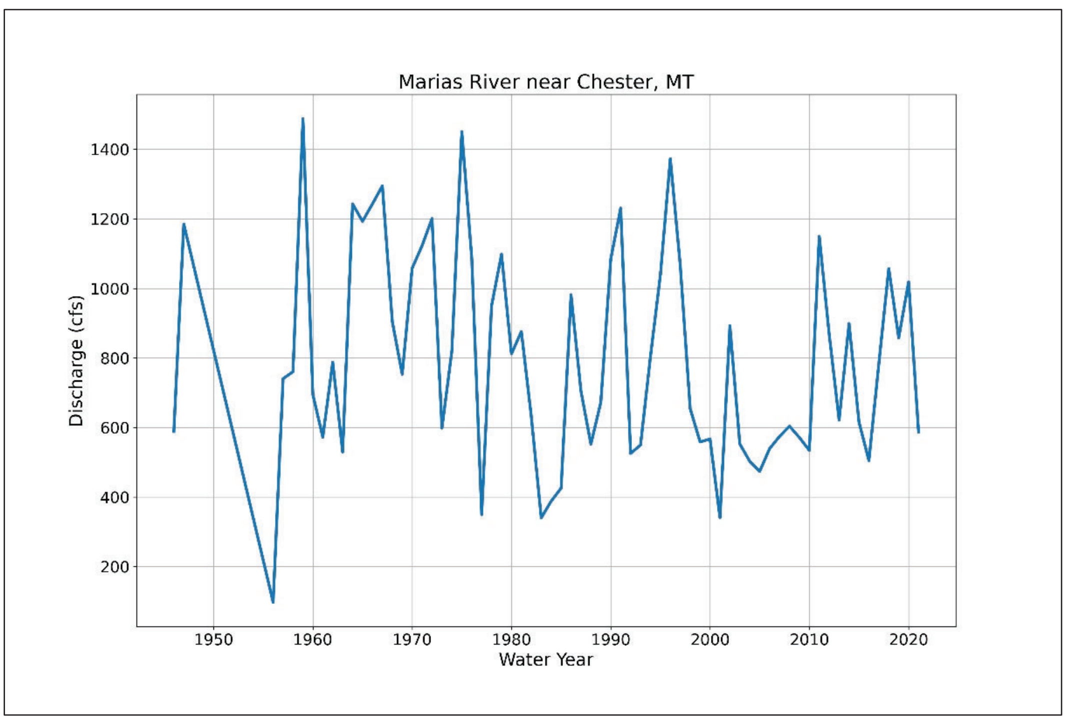

Figure 6.—Average annual discharge at the Marias River near Chester, Montana (USGS 06101500).

2.5 Dam Operations and Reservoir Characteristics

Tiber Dam is a zoned earthfill dam. This dam was completed and filled for storage in 1956. The spillway was diked off and an auxiliary outlet works constructed in 1969 due to excessive spillway settling. The spillway was rehabilitated in 1979 followed by raising the dam and dike 5 ft in 1981. The rehabilitated spillway is concrete lined with a concrete crest and controlled by three radial gates.

The dam crest is at an elevation of 3026 ft (Reclamation Project Vertical Datum [RPVD]). The crest is 4,300 ft long and 30 ft wide. The structural height of the dam is 211 ft, and the normal operating depth is 196.7 ft. The top of the conservation pool is at 2976 ft (RPVD).

The historic reservoir water surface elevations (RPVD) are presented on Figure 7. Annually, the reservoir water surface typically fluctuates about 14 ft between 2980 ft and the top of the joint pool at 2993.0 ft. When full (3020.2 ft), the reservoir has a surface area of 25,752 acres (40.2 mi^2).

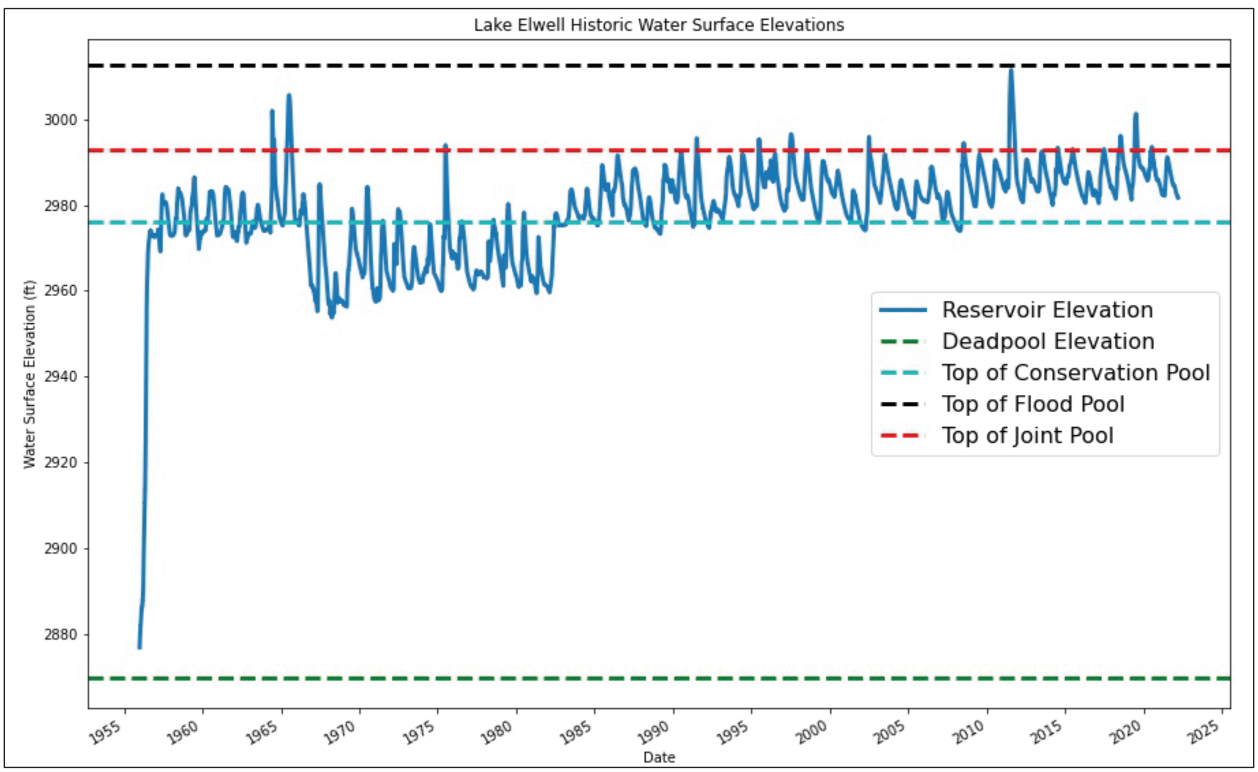

Figure 7.—Historic Lake Elwell water surface elevations (RPVD).
Data web source: data.usbr.gov

2.6 Reservoir Sediment Management

There is no record of past reservoir sediment management activities.

3.0 Previous Reservoir Surveys

Prior to dam closure and initial reservoir filling, a survey was conducted in 1956 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, use of USGS contours would have been the most likely survey methods for this time period. A 5-ft contour interval map was produced from this original survey.

A 2002 survey (Ferrari 2005) was conducted while the lake was at 2993 ft (RPVD). There was no available above-water elevation data, so the assumption was made that there was no change to area and capacity values above 2993 ft (RPVD).

The original and subsequent reservoir surveys are described in Table 4.

Table 4.—Previous bathymetric reservoir surveys

Survey year	Extent of survey	Survey method	Depth sounder	Above water survey
1956	Full	Contour	N/A	Contour
2002	Full	Surface mapping	Multibeam	None
2021	Full	Surface mapping	Multibeam	USGS National Elevation Dataset (2013)

For more details, these previous surveys are described in the reservoir survey report listed below:

- 2002 survey (Ferrari 2005).

4.0 Reservoir Survey Methods and Extent

4.1 Survey Methods

A complete bathymetric survey was conducted during July 2021 from two boats using multibeam depth sounders to continuously measure water depths. The horizontal position of the moving boats was continually tracked using a real-time kinematic Global Positioning System (RTK-GPS). A map of the data points collected is presented on Figure 8.

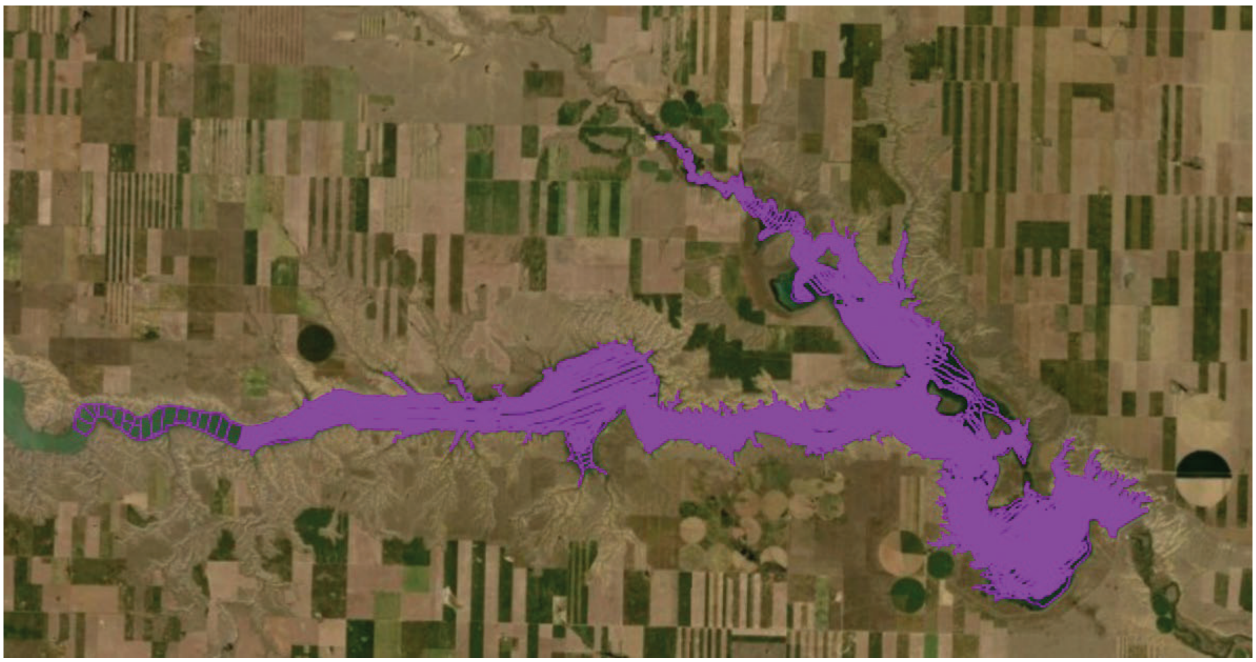

Figure 8.—Map of bathymetric survey data coverage.

Appendix A provides more details of the hydrographic survey methods. These bathymetric data were combined with USGS National Elevation Dataset (NED) data collected above water and published in 2013 to produce a digital surface of the reservoir bottom. Appendix B provides more details about the above-water survey data. Surface areas at 1-ft contour intervals were computed using Geographic Information System (GIS) software, and the computer program was used to produce the reservoir surface area and capacity tables at 0.01-ft increments (Bradley 2021). Appendix C provides more details about the methods used to generate surface area and storage capacity tables.

4.2 Survey Control, Datum, and Monuments

For the 2021 survey, all bathymetry and Global Positioning System (GPS) control measurements were collected in North American Datum 1983 (NAD83) State Plane (horizontal) coordinates, Montana Zone 2500, U.S. survey feet and North American Vertical Datum 1988 (NAVD88, Geoid 18, U.S. survey feet elevations. During processing, all bathymetry and GPS measurements were converted to RPVD for Tiber Reservoir. The RPVD was determined to be equivalent to NGVD29 and 3.02 ft lower than NAVD88 (Geoid 18).

The GPS base station receiver was set up over multiple monuments located near the area to be surveyed on a given day (Figure 9). Existing monuments, if located and accessible, were used. Otherwise, temporary benchmarks were established. In all cases, base station files were collected prior to bathymetric surveying, Online Positioning User Service (OPUS) solutions were submitted and received, and the resulting coordinates were used during bathymetric data collection. Table 5 provides the coordinates for the base locations obtained from OPUS solutions and used during bathymetric surveying.

Figure 9.—Location of GPS base stations along Tiber Reservoir.

Table 5.—Base station coordinates for RTK-GPS bathymetric surveying (NAD83 SPCS 2500; NAVD88 G18)

Point ID	Location	Northing (survey ft)	Easting (survey ft)	Elevation (survey ft)
10	Tiber Marina	1493588.253	1572185.199	3047.95
40	Skunk	1500797.848	1480861.674	3253.15
50	North Bootlegger	1504937.827	1526530.963	3057.23
60	Willow Creek	1520700.777	1543268.308	3043.71

The RPVD at Tiber Reservoir was determined from RTK-GPS measurements on the dam crest and water surface elevations measured at various locations across the reservoir, which were then compared to reservoir stage records and dam design drawings.

The difference between NGVD29 and NAVD88 at Tiber Dam was computed using the National Geodetic Survey (NGS) online tool NCAT (https://geodesy.noaa.gov/NCAT/). NCAT uses NGS data and algorithms to convert between various horizontal projections and vertical datums. The Corpscon calculations confirmed that both NGVD29 and RPVD are 3.02 ft lower than NAVD88.

5.0 Reservoir Surface Area and Storage Capacity

Tables of reservoir surface area and storage capacity were produced for the full range of reservoir elevations (Tiber Reservoir Area and Capacity Tables 2021; Varyu 2022). Plots of the 2021 area and capacity curves are presented on Figure 10 and Table 6 along with curves from the 1956 and 2002 surveys. For the 2021 survey, area and capacity curves are based on the bathymetric (below-water) survey up to elevation 2986 ft (RPVD), while curves above this elevation are based on 2013 U.S. Geological Survey NED data (USGS 2013). A comparison of these curves indicates that largest reduction in surface area and storage capacity occurs between elevations 2945 and 2985 ft (RPVD). The actual surface areas and storage-capacity volumes for above-water elevations may be different than the areas measured in 2002 because of delta sedimentation, shoreline erosion, or use of older surveying methods.

At reservoir water surface elevation 2986 ft (RPVD), which is 5 ft below water at the time of survey, the reservoir surface area was 15,986 acres with a storage capacity of 799,874 acre-feet. At the top of flood control pool elevation (3012.5 ft, RPVD), the reservoir would have a surface area of 23,521 acres and a storage capacity of 1,323,068 acre-feet.

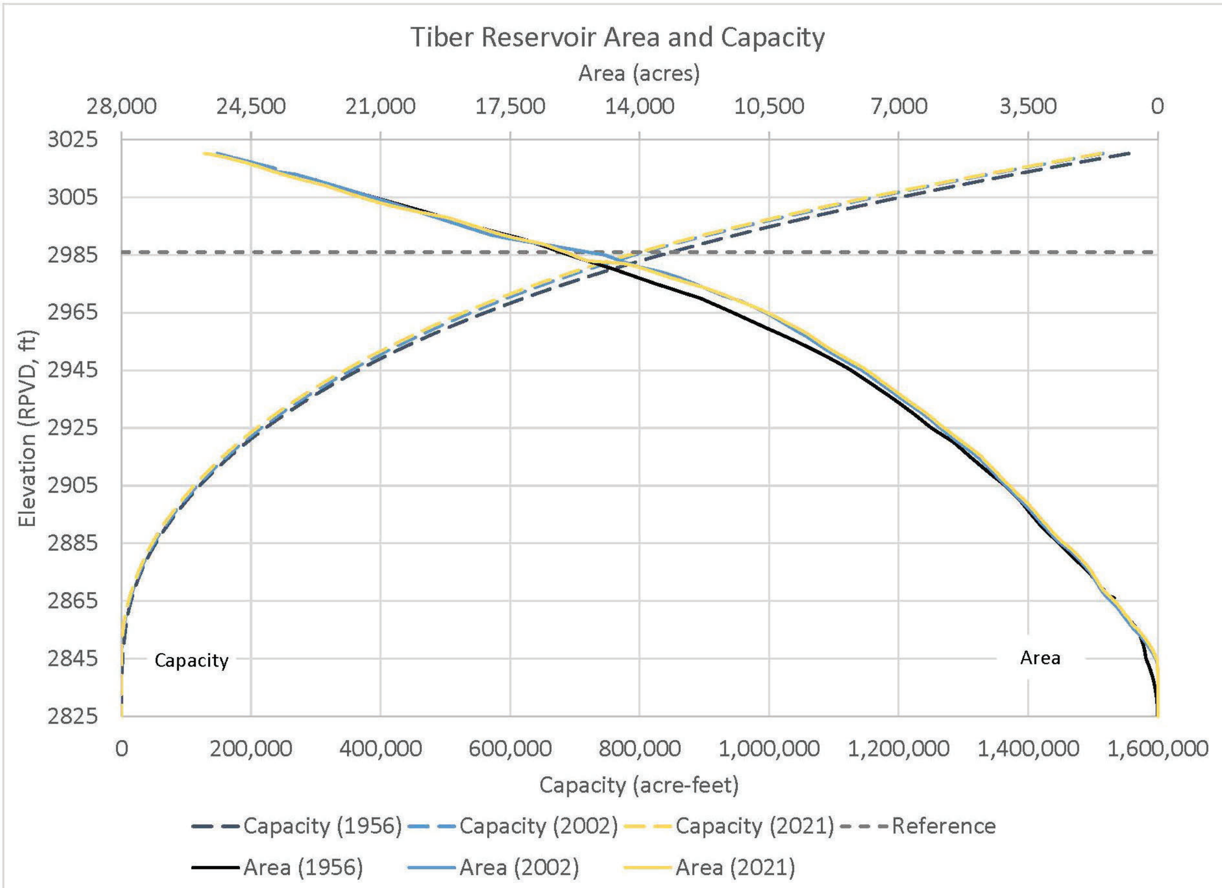

Figure 10.—Plot of Tiber Reservoir surface area and storage capacity versus elevation (RPVD). The "reference" line denotes elevation 2986, which is the upper extent of bathymetric survey data obtained during the 2021 data collection effort.

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

Elevation (ft)	Reservoir surface area (acres)			Reservoir storage capacity (acre-feet)			Sedimentation volume (acre-feet)
	1956	2002	2021	1956	2002	2021	1956 to 2021
3020.2	25,407	25,407	25,752	1,555,429	1,515,522	1,511,838	43,591
3015	23,833	23,833	24,140	1,427,278	1,387,371	1,382,664	44,614
3012.5	23,165	23,165	23,521	1,368,630	1,328,723	1,323,068	45,562
3005	21,189	21,189	21,528	1,202,338	1,162,431	1,154,531	47,807
2995	18,483	18,760	18,458	1,004,208	962,684	954,827	49,381
2993	17,896	18,275	17,968	967,828	925,649	918,394	49,434
2985	15,904	14,941	15,808	833,160	791,813	783,988	49,172
2976	13,786	12,710	12,872	699,754	667,213	655,956	43,798
2975	13,562	12,510	12,610	686,080	654,602	643,213	42,867
2966.4	11,723	10,819	10,786	577,931	554,330	543,079	34,852
2965	11,475	10,589	10,550	561,693	539,344	528,146	33,547
2955	9,757	9,283	9,156	455,462	440,103	430,032	25,430
2945	8,280	7,981	7,859	365,510	353,524	344,794	20,716
2935	7,130	6,904	6,794	288,490	279,119	271,531	16,959
2925	6,113	5,877	5,767	222,378	215,482	208,889	13,489
2915	5,066	4,867	4,759	166,890	161,745	156,349	10,541
2905	4,116	4,098	3,998	120,910	116,963	112,498	8,412
2895	3,414	3,336	3,259	83,455	79,866	76,355	7,100
2885	2,660	2,618	2,524	52,875	49,967	47,269	5,606
2875	1,863	1,821	1,777	30,193	28,126	26,127	4,066
2870	1,535	1,582	1,539	21,582	19,621	17,844	3,854
2865	1,213	1,260	1,167	14,828	12,432	11,033	3,795
2855	537	629	523	6,148	3,112	2,497	3,651
2845	314	51	26	2,070	68	27	2,043
2835	68	0	0	275	0	0	275

6.0 Reservoir Sedimentation Volume Spatial Distribution

Longitudinal profiles of the 2021 reservoir bottom surface were developed in GIS along the alignments presented on Figure 11. There is no available pre-dam surface, but the longitudinal profiles comparing 2002 and 2021 (Figure 12) show that sedimentation is well distributed throughout the length of the reservoir.

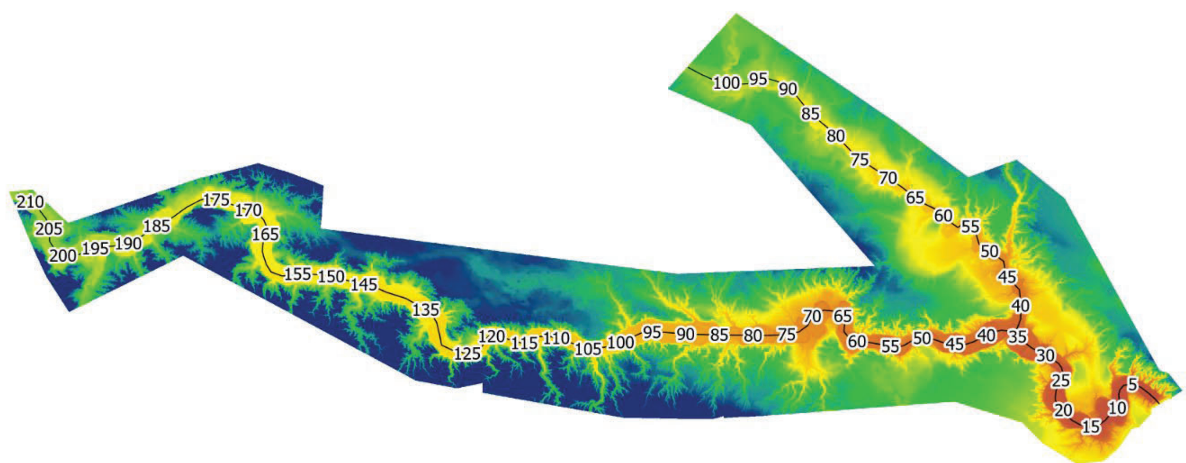

Figure 11.—Reservoir surface elevation map and alignments of longitudinal profiles. Stationing is in thousands of feet.

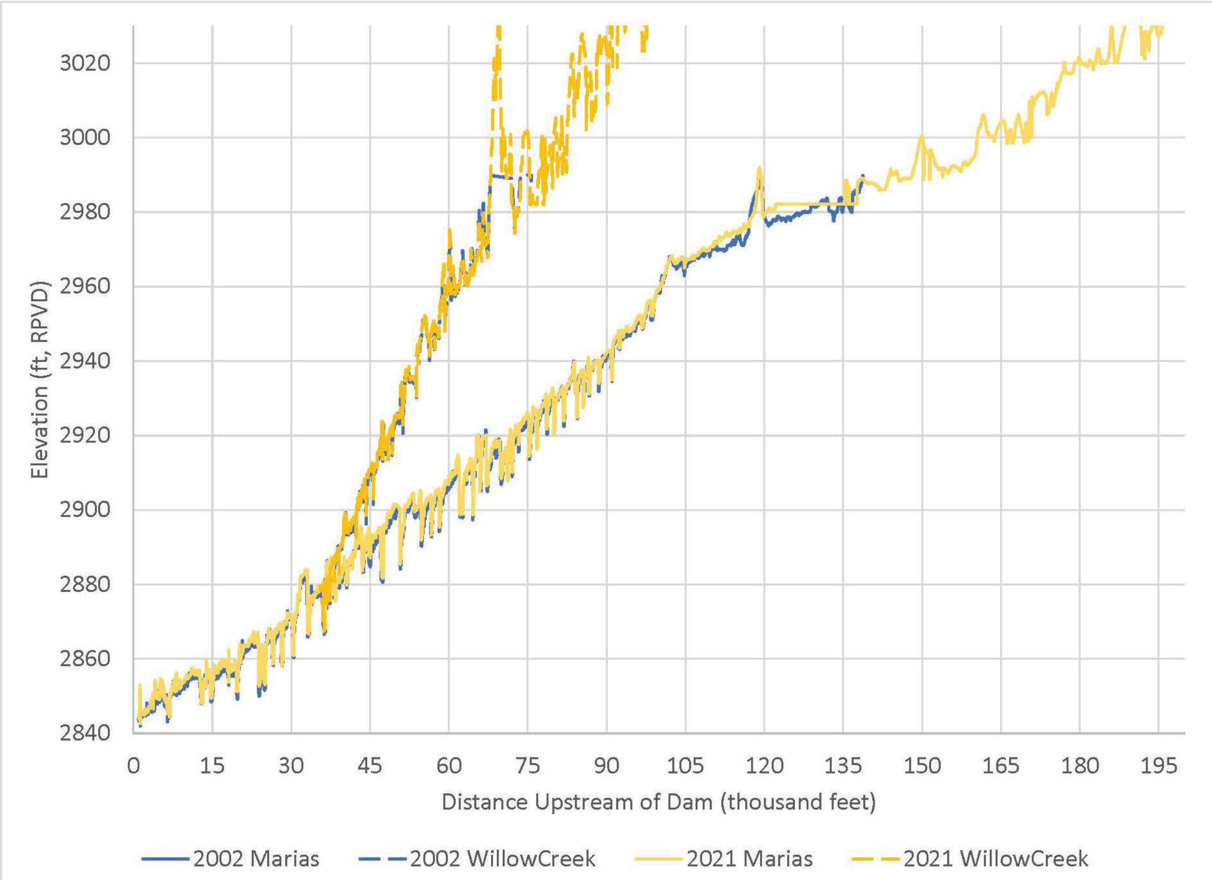

Figure 12.—Longitudinal profiles of Tiber Reservoir. Profiles are along valley centerlines through both the Marias and the Willow Creek arms. The tall peak on Marias Arm (approximate station 70,000) is due to an island that is not well represented in 2002 dataset. The tall peak on the Willow Creek arm (approximate station 120,000) is a significant point bar protruding across the valley centerline.

7.0 Sedimentation Trends

Graphs of the historic reservoir sedimentation rates over time (Figure 13) and cumulative reservoir sedimentation volume over time (Figure 14) indicate a decreasing trend in sedimentation rates since original reservoir filling.

Figure 13.—Average reservoir sedimentation rates over time.

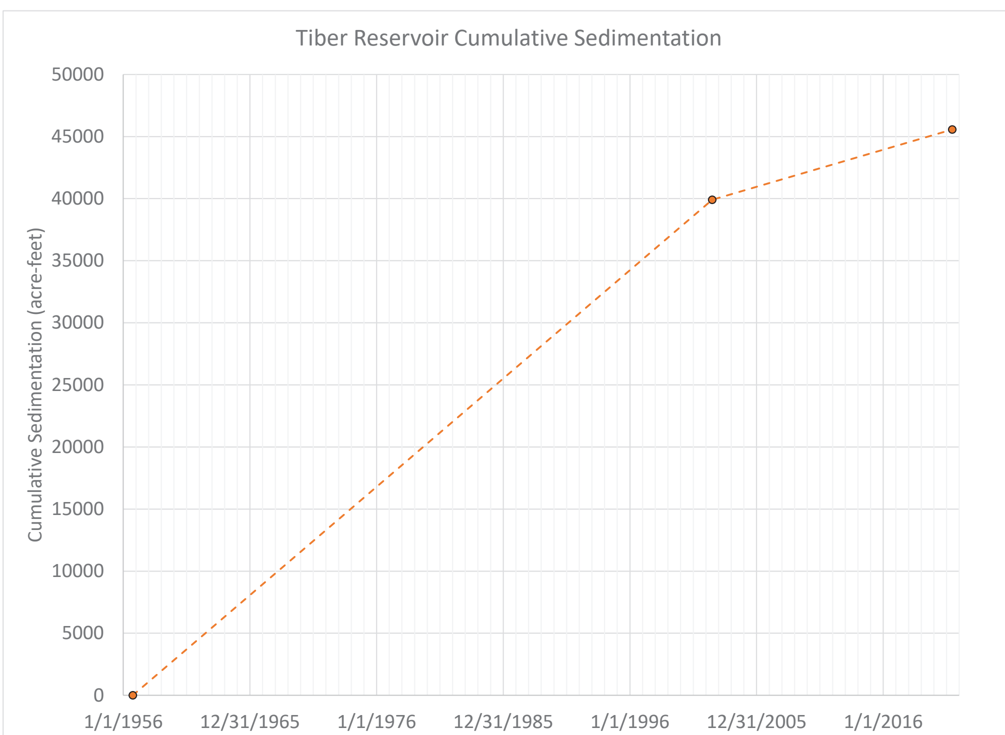

Figure 14.—Cumulative reservoir sedimentation over time based on the maximum water surface elevation of 3012.5 ft.

Sedimentation accumulates at all reservoir elevations and against the dam. Near the dam, sedimentation has been increasing in the lowest reservoir bottom elevation over time (Figure 15), which also reduces the dead storage capacity over time (Figure 16). The historic rates of sedimentation indicate that the dead storage capacity would be lost in 9 to 18 decades, depending on the method of extrapolation employed (polynomial since initial filling or linear since 2002).

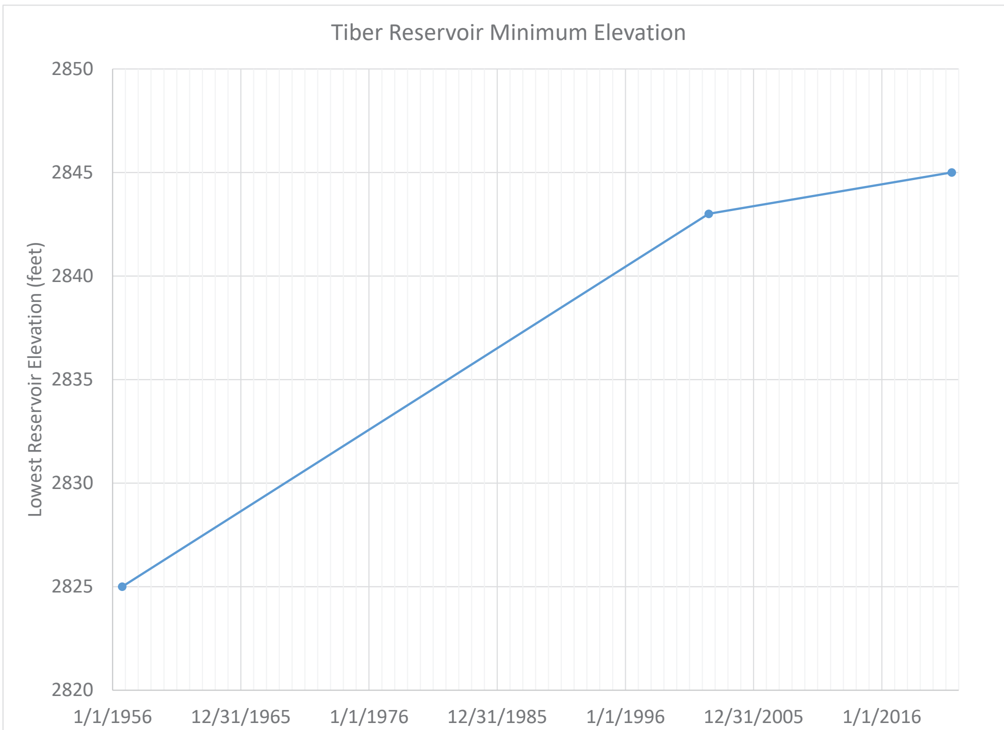

Figure 15.—Sedimentation near the dam increases the lowest reservoir elevation over time.

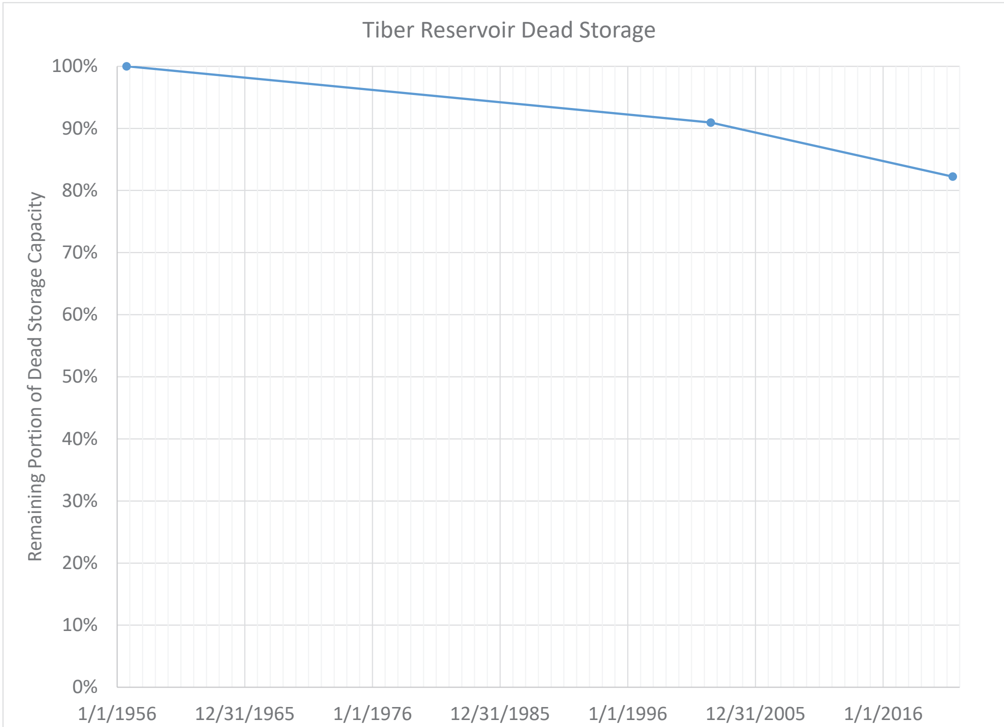

Figure 16.—Sedimentation near the dam decreases the dead storage capacity over time.

8.0 Conclusions and Recommendations

This reservoir survey serves to inform decision makers on many sedimentation concerns at Tiber Reservoir. Based on the comparison of the 2021 surface to previous surfaces, the level of sedimentation concerns at this reservoir are low.

8.1 Survey Methods and Data Analysis

The 2021 bathymetric survey, combined with 2013 USGS digital elevation model data of the above-water topography, has been used to produce an accurate digital surface of the reservoir bottom. The transition between bathymetric and topographic data yielded a reasonably smooth curve, meaning the data agreed quite well.

Reservoir surface areas were computed from this digital surface at 1-ft intervals to determine the 2021 storage capacity. Surface area and storage capacity were then interpolated at 0.01-ft intervals. The difference in reservoir surfaces over time can be attributed to sedimentation and also the differences in survey methods. The latest surface area and storage capacity curves compare reasonably well with the 2002 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 for both the 2002 and 2021 efforts as compared to the original surface, which is presumed to be based on contours from USGS quad maps.

Notable shoreline erosion was occurring during the survey, and shoreline erosion was a noted process in the 2002 survey report, so it is reasonable to assume this is an ongoing process. The most noticeable variation in surface area is between elevations 2970–2985 ft (RPVD). This variation could be based on operating elevations (see Figure 7) coupled with shoreline erosion, best available topographic data (for all years), or a combination of the two.

8.2 Sedimentation Progression and Location

Over the span of 65 years, sedimentation has filled in 2.8 percent of the original storage capacity (with respect to elevation 3020.2 ft, RPVD, top of surcharge pool). Without an original surface to compare to (and with minimal change occurring relative to the 2002 surface) the distribution of sedimentation appears to be reasonably well distributed across the bed of the lake. Sedimentation has also deposited near the dam in the lowest portions of the reservoir, and over 80 percent of the original dead storage capacity remains as of 2021. Past rates of sedimentation suggest that remaining dead storage will be lost within 9 to 18 decades (see “Section 7 Sedimentation Trends”). The lowest dam outlet may not be as reliable after the dead storage has filled with sediment because the future deposition of logs and sediment may accumulate on the trash rack.

8.3 Recommendation for Next Survey

Based on the past rates of sedimentation, the next survey of Tiber Reservoir is recommended within the next 20 years, 2041.

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10.0 Acknowledgments

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Appendix A

Hydrographic Survey Equipment and Methods

The 2021 bathymetric survey was conducted from June 21 to June 27, 2021. The motion reference unit internal to the Odom MB1 malfunctioned during this survey and time was lost while a replacement unit was shipped and installed. During this period, reservoir water surface elevations varied from 2990.8 to 2991.1 ft (Reclamation Project Vertical Datum).

The survey was conducted along a series of predetermined longitudinal and shoreline survey lines, along with cross sections near the dam face and in the shallow areas of the upstream deltas (see Figure 8 in main report). The survey lines were spaced closely enough so there would be overlapping coverage from the multibeam depth sounder or close enough that liner interpolation of multibeam depth data between survey lines would be adequate.

The survey employed two boats during data collection; an 18-foot, flat-bottom aluminum Wooldridge boat powered by an outboard jet and kicker motors) (Figure A-1) and a 24-foot tri-hull aluminum SeaArk boat powered by twin inboard motors (figure A-2). Reservoir depths were measured using multibeam echo sounders, each of which consisted of the following equipment:

- Variable-frequency transducer with integrated motion reference unit
- Near-surface sound velocity probe
- Two Global Positioning System (GPS) receivers to measure the boat position and heading
- An external GPS radio
- Processor box for synchronization of all depth, sound velocity, position, heading, and motion sensor data

Figure A-1.—Wooldridge boat with real-time kinematic Global Positioning System and multibeam depth sounder system.

Figure A-2.—SeaArk boat with real-time kinematic Global Positioning System and multibeam depth sounder system.

The multibeam transducer emits up to 512 beams (user selectable) capable of projecting a swath width up to 160 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.

Real-time kinematic Global Positioning System (RTK-GPS) survey instruments were used to continuously measure the survey boat and measure other ground control points. The GPS base station and receiver was set up on a tripod over multiple points around the reservoir (see Figure 9 in main report). The coordinates of these points were computed using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey (www.ngs.noaa.gov/OPUS/). During the survey, position corrections were transmitted to the GPS rover receiver using an external GPS radio and ultra high frequency antenna (Figure A-3). The base station was powered by a 12-volt battery.

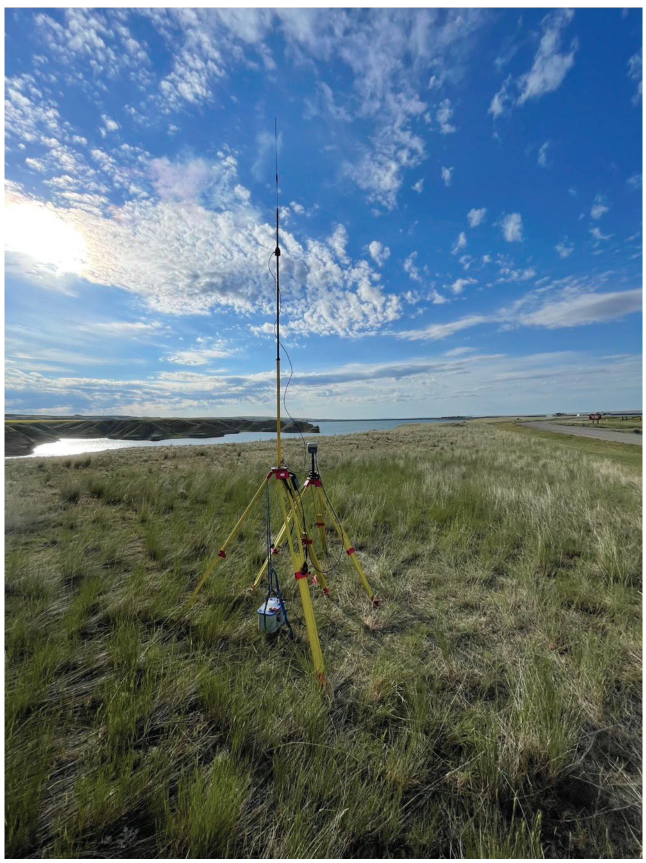


Figure A-3.—The RTK-GPS base station setup used during part of the Tiber Reservoir survey; this is location "10" near Ru's Tiber Marina.

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

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

The HYPACK hydrographic survey software was used to combine horizontal positions and depths to map the reservoir bathymetry in the 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 Reclamation Project Vertical Datum. The multibeam depth sounders generate 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 post-processing. Final processing of the bathymetric data and exporting to a manageable size resulted in 20.8 million bathymetric data points used in the development of the reservoir surface. Filtering of this large data file is necessary, so a raster mesh is created with Geographic Information System software (e.g., 5-foot square cells). For each raster mesh cell, the reservoir bottom elevation is assigned equal to the median elevation of all available data points within that raster cell. The use of the median value reduces the influence of the highest and lowest elevations within the cell.

Appendix B

Above-Water Survey Methods

The best available U.S. Geological Survey National Elevation Data were downloaded from the U.S. Geological Survey National Map website (https://www.usgs.gov/programs/national-geospatial-program/national-map) to represent the above water data reservoir topography, with elevation data in meters. The data in the area of interest have a minimum elevation that appears to represent a water surface of 909 meters. These data were converted from raster to points, then projected horizontally to the project reference frame and vertically to Reclamation Project Vertical Datum (RPVD), representing an RPVD elevation of approximately 2979 feet. These data reasonably represented the ground surface above water. Although there are areas of overlap based on elevation, notable shoreline erosion was occurring during the survey, and shoreline erosion was a noted process in the 2002 survey report. It is reasonable to assume this is an ongoing process. The most noticeable variation in surface area is between elevations 2970–2985 feet (RPVD). This variation could be based on operating elevations (see Figure 7 in main report) coupled with shoreline erosion, best available topographic data (for all years), or a combination of the two.

Surface areas from elevation 2840 through 2986 (RPVD) were computed from the 2021 bathymetric survey. The surface areas above elevation 2986 feet (RPVD) were computed from U.S. Geological Survey digital elevation model data accessed online.

Appendix C

Computation of Reservoir Surface Area, Storage Capacity, and Sedimentation Volume

A digital surface of the reservoir bottom was generated with Geographic Information (GIS) software using the processed bathymetric data points (easting, northing, and elevation) combined with available above-water data. Reservoir surface areas and capacities were computed at 1-foot (ft) vertical increments using an ArcGIS tool (ACAP Toolset 2.0) based on the GIS surface volume function for the complete range of reservoir elevations (2840 to 3026 ft; Reclamation Project Vertical Datum [RPVD]). The tool interpolates the reservoir surface areas and capacities to 0.1- and 0.01-ft increments between each 1-ft interval following the method of the Bureau of Reclamation's Area-CAPacity (ACAP) Program, Version 2.0 (Bradley 2021).

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

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

where:

V_i = Storage capacity (acre-feet)
V_b = Storage capacity at elevation y_b (acre-feet)
A_b = Surface area at elevation y_b (acres)
y_i = Reservoir elevation
y_b = Reservoir elevation at bottom of elevation increment
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 using equation 2:

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

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-ft intervals are not changed, and there is a smooth transition in the interpolated values at the 0.01-ft 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:

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

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:

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

This method ensures that the given surface areas, and corresponding storage capacities, at the 1-ft intervals are not changed, and there is a smooth transition in the interpolated values at the 0.01-ft intervals. The ACAP program produces the area and capacity tables for the full range of reservoir elevations. These data are documented in the main report (Varyu 2022).

The reservoir equation parameters are presented below. The full set of ACAP tables are presented in Varyu (2022).

The reservoir storage capacity table using the equation parameters for the full range of reservoir elevations is presented below in RPVD:

EQ. NUMBER	ELEVATION BASE	CAPACITY V	AREA A	RATE COEFF C	CAPACITY EXP M
1	2840.00	0.1400	0.2400	0.1550	1.7871
2	2841.00	0.5350	0.5170	0.1550	3.8903
3	2842.00	1.2070	1.1200	1.0250	2.7424
4	2843.00	3.3520	3.9310	3.8480	2.0457
5	2844.00	11.1310	11.8030	5.8690	2.4914
6	2845.00	28.8030	26.4250	22.0640	1.9313
7	2846.00	77.2920	69.0380	16.8140	1.9423
8	2847.00	163.1440	101.6960	15.1120	2.2376
9	2848.00	279.9520	135.5110	23.6950	1.9302
10	2849.00	439.1580	181.2480	21.1100	2.0216
11	2850.00	641.5160	223.9230	20.1700	2.0908
12	2851.00	885.6090	266.0950	28.5070	1.9976
13	2852.00	1180.2110	323.0420	29.1290	2.1183
14	2853.00	1532.3820	384.7460	30.2870	1.8202
15	2854.00	1947.4150	439.8740	22.6390	2.0542
16	2855.00	2409.9280	486.3790	30.3120	2.2219
17	2856.00	2926.6190	553.7280	45.0580	1.9384
18	2857.00	3525.4050	641.0680	34.5470	1.9596
19	2858.00	4201.0200	708.7670	31.1730	2.0365
20	2859.00	4940.9600	772.2520	39.6660	1.9159
21	2860.00	5752.8780	848.2490	32.3050	1.9978
22	2861.00	6633.4320	912.7880	28.6220	2.0092
23	2862.00	7574.8420	970.2940	31.5890	2.0693
24	2863.00	8576.7250	1035.6620	31.9590	1.9666
25	2864.00	9644.3460	1098.5110	32.9880	2.1373
26	2865.00	10775.8450	1169.0170	39.1980	2.0157
27	2866.00	11984.0600	1248.0300	40.5440	2.0106
28	2867.00	13272.6340	1329.5460	40.7900	1.9564
29	2868.00	14642.9700	1409.3480	36.8430	1.9328
30	2869.00	16089.1610	1480.5570	30.5860	1.9606
31	2870.00	17600.3040	1540.5230	23.7190	1.9647
32	2871.00	19164.5460	1587.1230	22.7040	2.0372
33	2872.00	20774.3730	1633.3750	22.2880	2.0059
34	2873.00	22430.0360	1678.0830	25.5150	2.0451
35	2874.00	24133.6340	1730.2640	23.7600	1.9953
36	2875.00	25887.6580	1777.6730	26.1340	2.0315
37	2876.00	27691.4650	1830.7640	27.8170	2.1075
38	2877.00	29550.0460	1889.3880	37.5610	1.9639
39	2878.00	31476.9950	1963.1530	32.7460	1.9821
40	2879.00	33472.8940	2028.0600	35.7250	2.0697
41	2880.00	35536.6790	2102.0000	34.8010	1.9876
42	2881.00	37673.4800	2171.1700	35.1100	2.0696
43	2882.00	39879.7600	2243.8330	42.2740	2.0695
44	2883.00	42165.8670	2331.3200	48.3360	1.9987
45	2884.00	44545.5230	2427.9300	45.2960	2.0400
46	2885.00	47018.7490	2520.3320	48.4300	1.9633
47	2886.00	49587.5110	2615.4130	44.1070	1.9628
48	2887.00	52247.0310	2701.9880	36.1270	1.9489
49	2888.00	54985.1460	2772.3970	35.5680	1.9644
50	2889.00	57793.1110	2842.2670	34.8130	2.0176

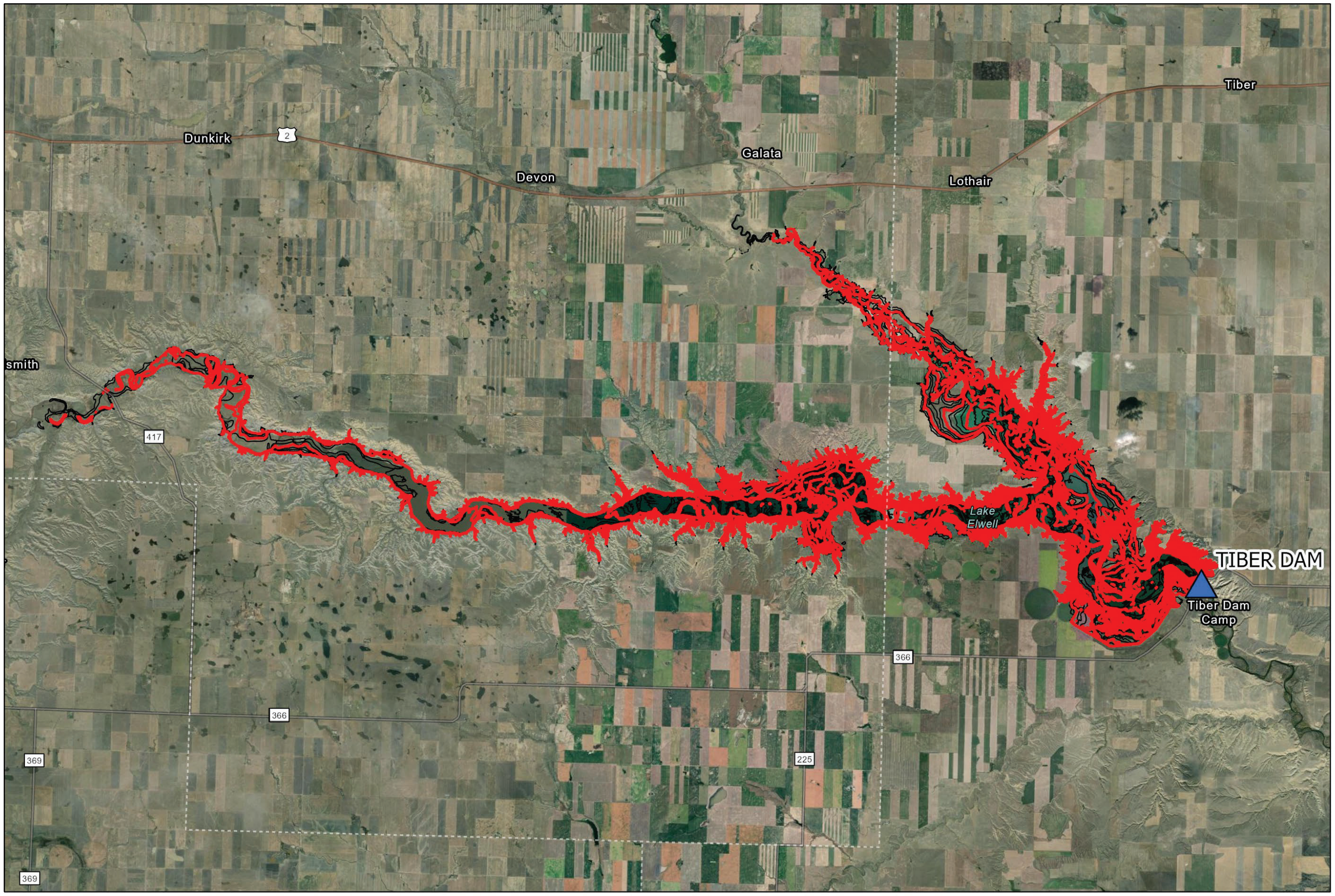
EQ. NUMBER	ELEVATION BASE	CAPACITY V	AREA A	RATE COEFF C	CAPACITY EXP M
51	2890.00	60670.1910	2912.5070	30.6330	1.9628
52	2891.00	63613.3310	2972.6330	30.8560	2.1150
53	2892.00	66616.8200	3037.8930	38.5460	1.9505
54	2893.00	69693.2590	3113.0780	33.3020	2.0477
55	2894.00	72839.6390	3181.2700	36.3110	1.9587
56	2895.00	76057.2200	3252.3940	29.3760	1.9794
57	2896.00	79338.9900	3310.5420	31.2870	2.0702
58	2897.00	82680.8190	3375.3120	35.9180	1.9961
59	2898.00	86092.0490	3447.0070	34.9060	2.0459
60	2899.00	89573.9620	3518.4210	38.6220	2.0264
61	2900.00	93131.0050	3596.6860	40.2710	2.0652
62	2901.00	96767.9620	3679.8520	44.5620	1.9124
63	2902.00	100492.3760	3765.0720	37.5870	1.9735
64	2903.00	104295.0350	3839.2510	38.2160	1.9796
65	2904.00	108172.5020	3914.9040	35.6800	2.0433
66	2905.00	112123.0860	3987.8090	40.5600	2.0323
67	2906.00	116151.4550	4070.2390	43.2330	1.9676
68	2907.00	120264.9270	4155.3030	39.1670	1.9376
69	2908.00	124459.3970	4231.1920	35.3520	2.0077
70	2909.00	128725.9410	4302.1690	32.7250	2.0442
71	2910.00	133060.8350	4369.0660	35.0710	2.0450
72	2911.00	137464.9720	4440.7870	40.3120	2.0514
73	2912.00	141946.0710	4523.4850	42.8100	1.9644
74	2913.00	146512.3660	4607.5820	36.0720	1.9458
75	2914.00	151156.0200	4677.7720	34.5810	2.0872
76	2915.00	155868.3730	4749.9490	40.8870	2.0843
77	2916.00	160659.2090	4835.1680	50.0850	1.9877
78	2917.00	165544.4620	4934.7200	48.8710	2.1089
79	2918.00	170528.0530	5037.7840	54.1240	2.0127
80	2919.00	175619.9610	5146.7170	52.0280	2.0055
81	2920.00	180818.7060	5251.0580	49.2560	2.0497
82	2921.00	186119.0200	5352.0190	54.1110	1.9928
83	2922.00	191525.1500	5459.8530	51.4840	1.9729
84	2923.00	197036.4870	5561.4280	49.0190	1.9988
85	2924.00	202646.9340	5659.4060	51.8720	2.0698
86	2925.00	208358.2120	5766.7690	57.5540	1.9216
87	2926.00	214182.5350	5877.3630	45.7810	1.9220
88	2927.00	220105.6790	5965.3560	42.2260	2.0637
89	2928.00	226113.2610	6052.4980	51.6190	2.0146
90	2929.00	232217.3780	6156.4880	50.3200	1.9776
91	2930.00	238424.1860	6255.9990	49.2750	2.0358
92	2931.00	244729.4600	6356.3130	56.2880	2.1018
93	2932.00	251142.0610	6474.6200	58.0880	1.9589
94	2933.00	257674.7690	6588.4090	55.4660	1.9378
95	2934.00	264318.6440	6695.8930	52.7720	2.0749
96	2935.00	271067.3090	6805.3890	56.5500	1.9752
97	2936.00	277929.2480	6917.0860	50.7320	2.0265
98	2937.00	284897.0660	7019.8940	53.8060	1.9943
99	2938.00	291970.7660	7127.1970	51.5920	1.9935
100	2939.00	299149.5550	7230.0480	53.7810	2.0720
101	2940.00	306433.3840	7341.4820	56.8510	1.9644
102	2941.00	313831.7170	7453.1600	52.2680	1.9730
103	2942.00	321337.1450	7556.2830	49.0050	2.0030
104	2943.00	328942.4330	7654.4400	54.8730	2.0343
105	2944.00	336651.7460	7766.0700	54.8160	1.9806
106	2945.00	344472.6320	7874.6400	55.9000	2.0655
107	2946.00	352403.1720	7990.1020	70.1360	2.0062
108	2947.00	360463.4100	8130.8070	73.6230	1.9838
109	2948.00	368667.8400	8276.8590	69.3810	1.9939
110	2949.00	377014.0800	8415.1950	69.9650	1.9612
111	2950.00	385499.2400	8552.4110	67.6840	2.0218
112	2951.00	394119.3350	8689.2540	66.9950	1.9991

EQ. NUMBER	ELEVATION BASE	CAPACITY V	AREA A	RATE COEFF C	CAPACITY EXP M
113	2952.00	402875.5840	8823.1870	63.4480	1.9720
114	2953.00	411762.2190	8948.3040	57.8770	1.9803
115	2954.00	420768.4000	9062.9160	56.0240	1.9949
116	2955.00	429887.3400	9174.6760	57.7940	2.0126
117	2956.00	439119.8100	9290.9900	59.3320	1.9791
118	2957.00	448470.1320	9408.4120	57.7390	2.0308
119	2958.00	457936.2830	9525.6660	66.0750	2.0591
120	2959.00	467528.0240	9661.7190	73.4390	2.0220
121	2960.00	477263.1820	9810.2120	74.7000	1.9934
122	2961.00	487148.0940	9959.1180	73.0060	2.0056
123	2962.00	497180.2180	10105.5370	72.6990	1.9942
124	2963.00	507358.4540	10250.5160	77.5190	2.0162
125	2964.00	517686.4890	10406.8060	77.3350	2.0215
126	2965.00	528170.6300	10563.1410	83.6160	2.0010
127	2966.00	538817.3870	10730.4560	87.8800	2.0562
128	2967.00	549635.7230	10911.1520	100.3310	2.0472
129	2968.00	560647.2060	11116.5470	100.7730	1.9730
130	2969.00	571864.5260	11315.3740	94.0750	2.0008
131	2970.00	583273.9750	11503.5980	90.2740	2.0199
132	2971.00	594867.8470	11685.9420	110.4640	1.9905
133	2972.00	606664.2530	11905.8180	99.4270	1.9948
134	2973.00	618669.4980	12104.1560	119.9890	2.0168
135	2974.00	630893.6430	12346.1540	131.0220	2.0870
136	2975.00	643370.8190	12619.6010	132.5700	1.9653
137	2976.00	656122.9900	12880.1470	131.0940	1.9882
138	2977.00	669134.2310	13140.7900	118.7200	1.9999
139	2978.00	682393.7410	13378.2200	115.7420	1.9890
140	2979.00	695887.7030	13608.4350	112.8450	2.0413
141	2980.00	709608.9830	13838.7850	116.6470	2.0186
142	2981.00	723564.4150	14074.2510	120.3540	2.8192
143	2982.00	737759.0200	14413.5520	760.6960	1.2969
144	2983.00	752933.2680	15400.0800	117.5900	1.9675
145	2984.00	768450.9380	15631.4370	90.4930	1.9522
146	2985.00	784172.8680	15808.0960	78.5120	2.2665
147	2986.00	800059.4760	15986.0470	132.4850	1.7952
148	2987.00	816178.0080	16223.8850	106.4640	2.0092
149	2988.00	832508.3570	16437.7970	107.0330	2.0497
150	2989.00	849053.1870	16657.1820	242.5280	1.6062
151	2990.00	865952.8970	17046.7270	184.2160	2.0045
152	2991.00	883183.8400	17415.9790	143.1040	1.9913
153	2992.00	900742.9230	17700.9430	135.2700	1.9731
154	2993.00	918579.1360	17967.8400	126.0540	1.9891
155	2994.00	936673.0300	18218.5680	120.6540	1.9852
156	2995.00	955012.2520	18458.0900	118.3750	2.0064
157	2996.00	973588.7170	18695.6030	121.9710	2.0019
158	2997.00	992406.2910	18939.7780	126.9520	2.0272
159	2998.00	1011473.0210	19197.1330	182.1500	2.1555
160	2999.00	1030852.3040	19589.7620	176.9640	2.1345
161	3000.00	1050619.0300	19967.4940	224.9810	1.8261
162	3001.00	1070811.5050	20378.3410	156.5540	1.9783
163	3002.00	1091346.4000	20688.0470	148.6570	1.9933
164	3003.00	1112183.1040	20984.3600	145.3940	1.9884
165	3004.00	1133312.8580	21273.4650	129.9330	1.9564
166	3005.00	1154716.2560	21527.6680	119.7110	2.0085
167	3006.00	1176363.6350	21768.1090	117.6280	1.9846
168	3007.00	1198249.3720	22001.5590	117.7300	2.0176
169	3008.00	1220368.6610	22239.0900	123.4670	2.0182
170	3009.00	1242731.2180	22488.2750	133.5710	2.0423
171	3010.00	1265353.0640	22761.0690	167.3350	1.9908
172	3011.00	1288281.4680	23094.2040	150.0890	1.9537
173	3012.00	1311525.7610	23387.4270	133.3920	1.9903
174	3013.00	1335046.5800	23652.9180	127.5670	1.9707

EQ. NUMBER	ELEVATION BASE	CAPACITY V	AREA A	RATE COEFF C	CAPACITY EXP M
175	3014.00	1358827.0650	23904.3160	118.1820	1.9958
176	3015.00	1382849.5630	24140.1780	120.0570	2.0333
177	3016.00	1407109.7980	24384.2890	120.4240	2.0174
178	3017.00	1431614.5110	24627.2360	153.7530	1.9414
179	3018.00	1456395.5000	24925.7290	153.7710	2.0106
180	3019.00	1481475.0000	25234.9000	173.7900	2.2601
181	3020.00	1506883.6900	25627.6800	255.9550	1.8183
182	3021.00	1532767.3250	26093.0930	171.2080	1.9464
183	3022.00	1559031.6260	26426.3240	147.9330	1.9740
184	3023.00	1585605.8830	26718.3400	135.1100	1.9844
185	3024.00	1612459.3330	26986.4550	124.9320	1.9824
186	3025.00	1639570.7200	27234.1180	115.0910	2.0101

Appendix D

Maps



Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Overview Map

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 2 4 Miles

Scale 1:156,000

Esri, FAO, NOAA, Esri, USGS, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Esri Canada, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

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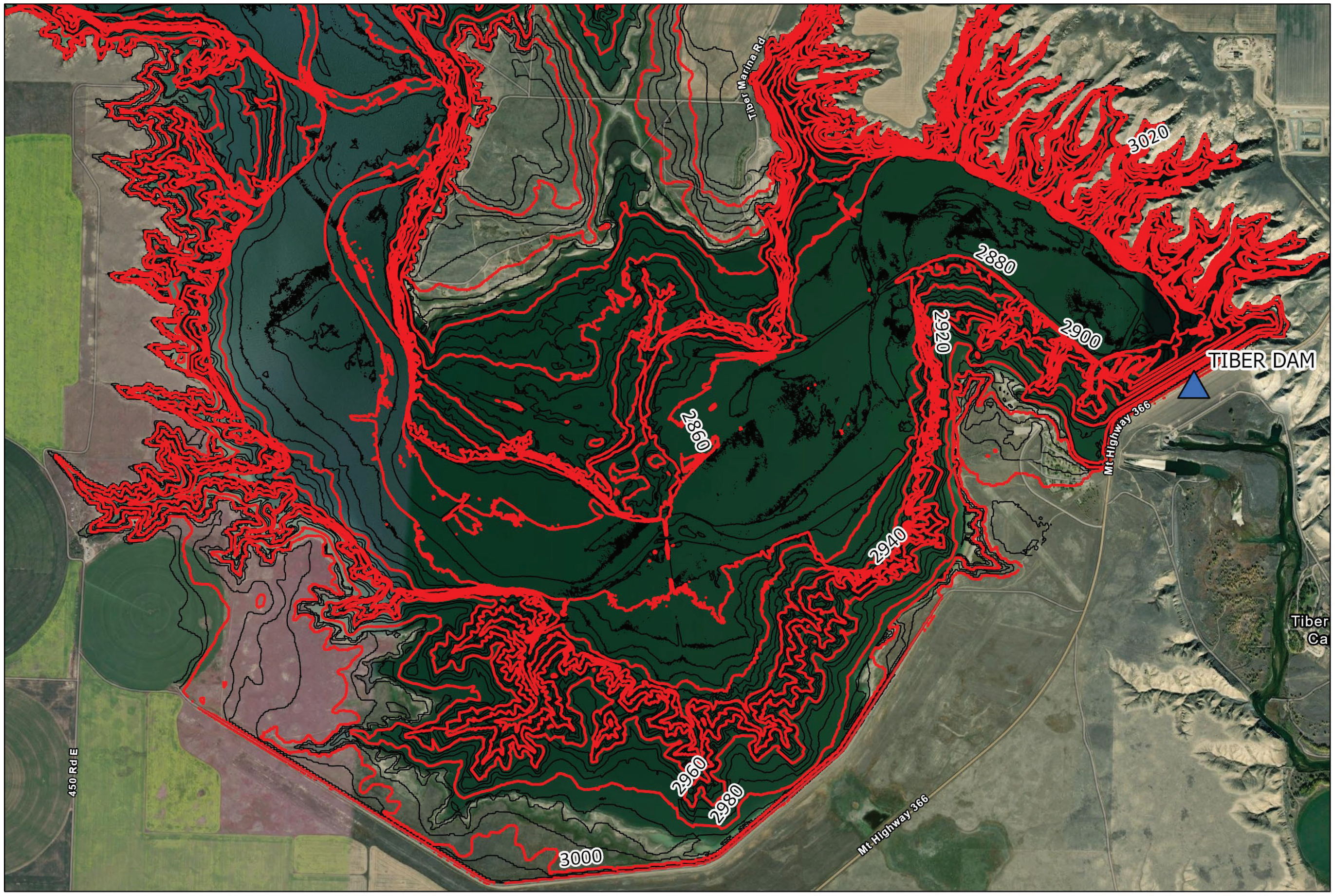


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 1

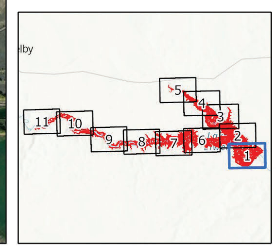
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



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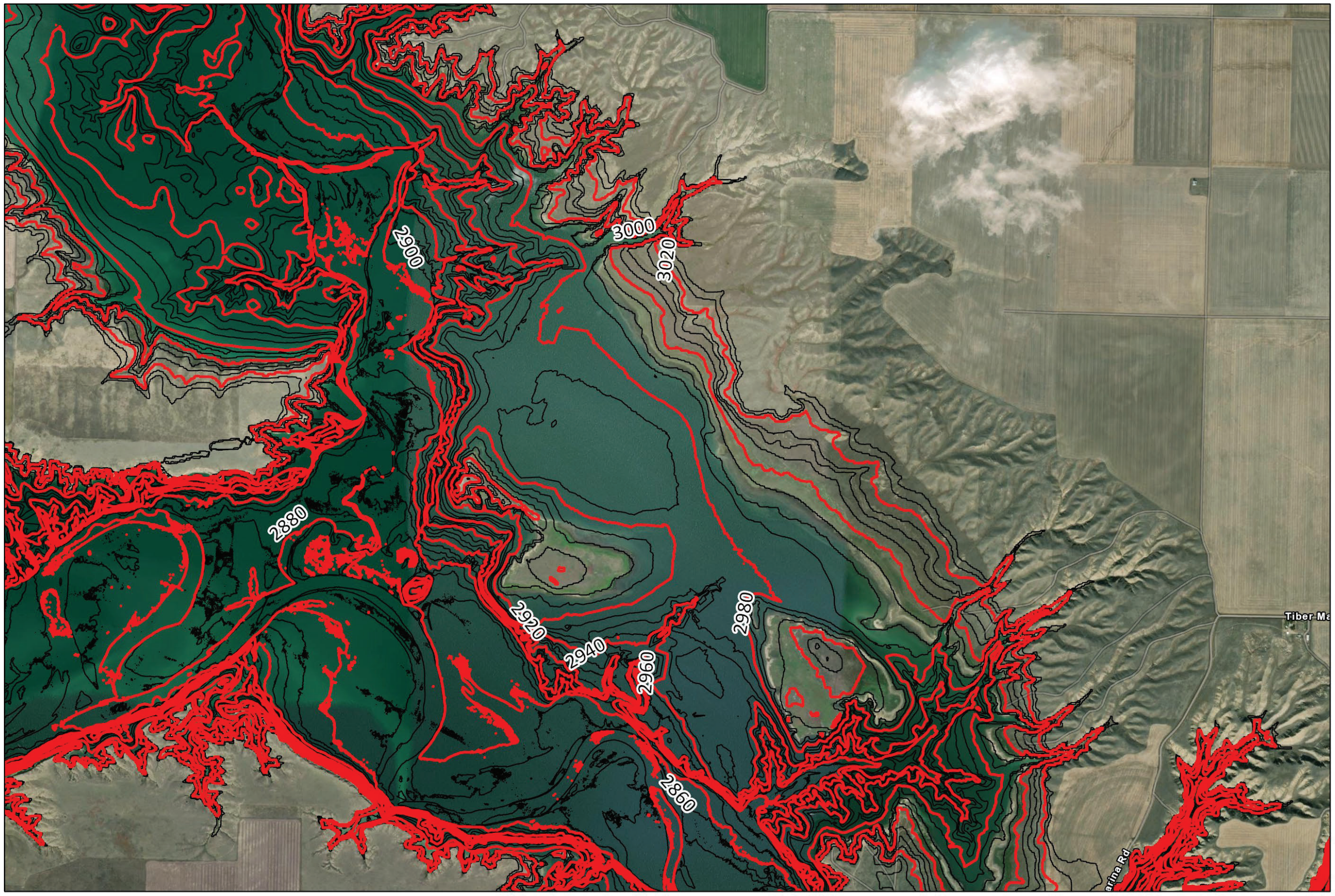


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 2

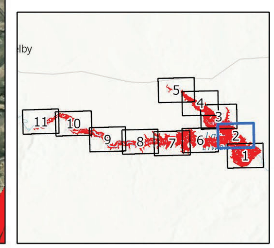
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



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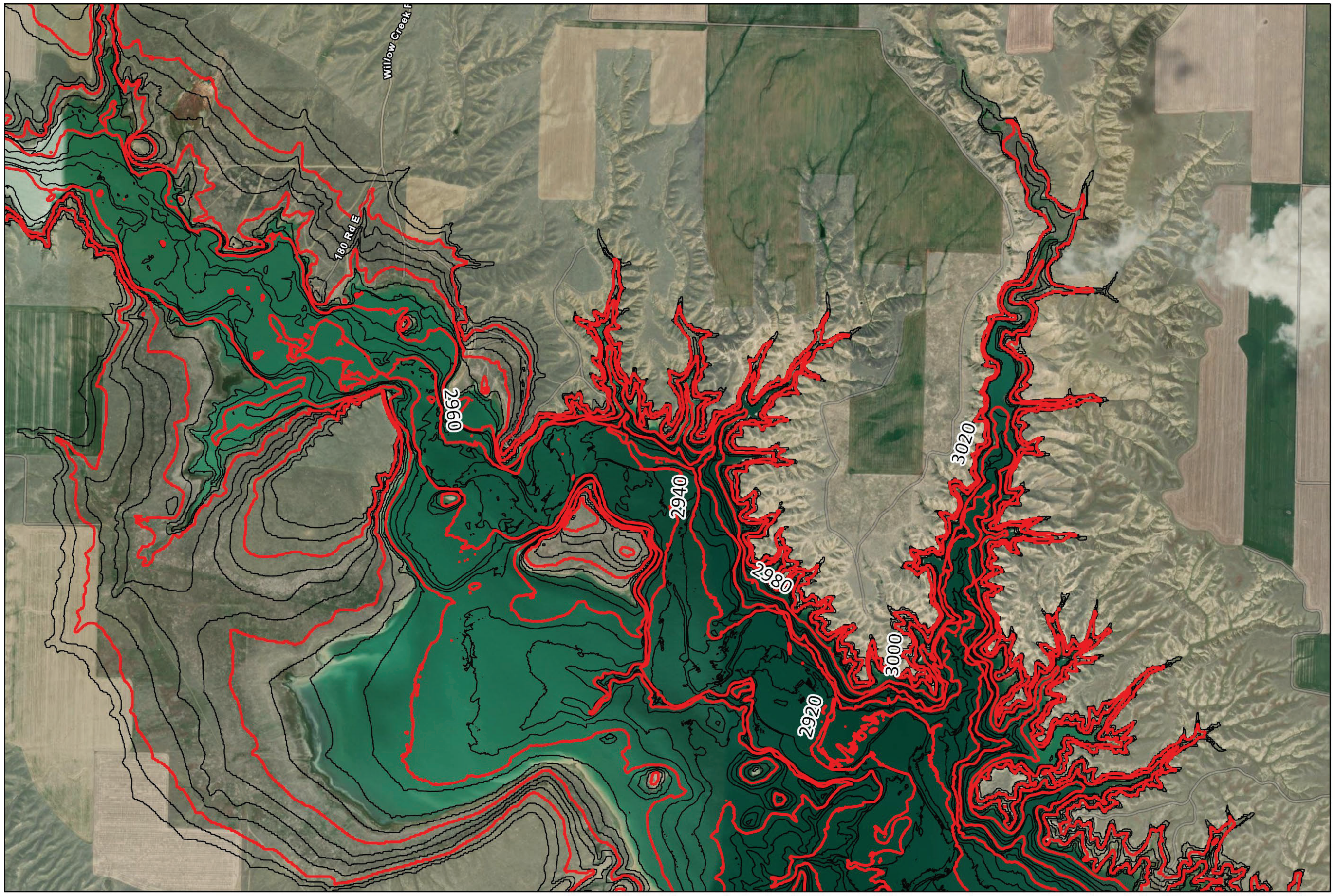


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 3

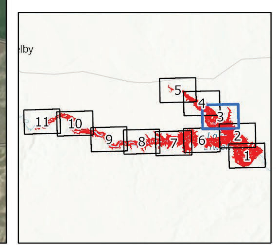
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

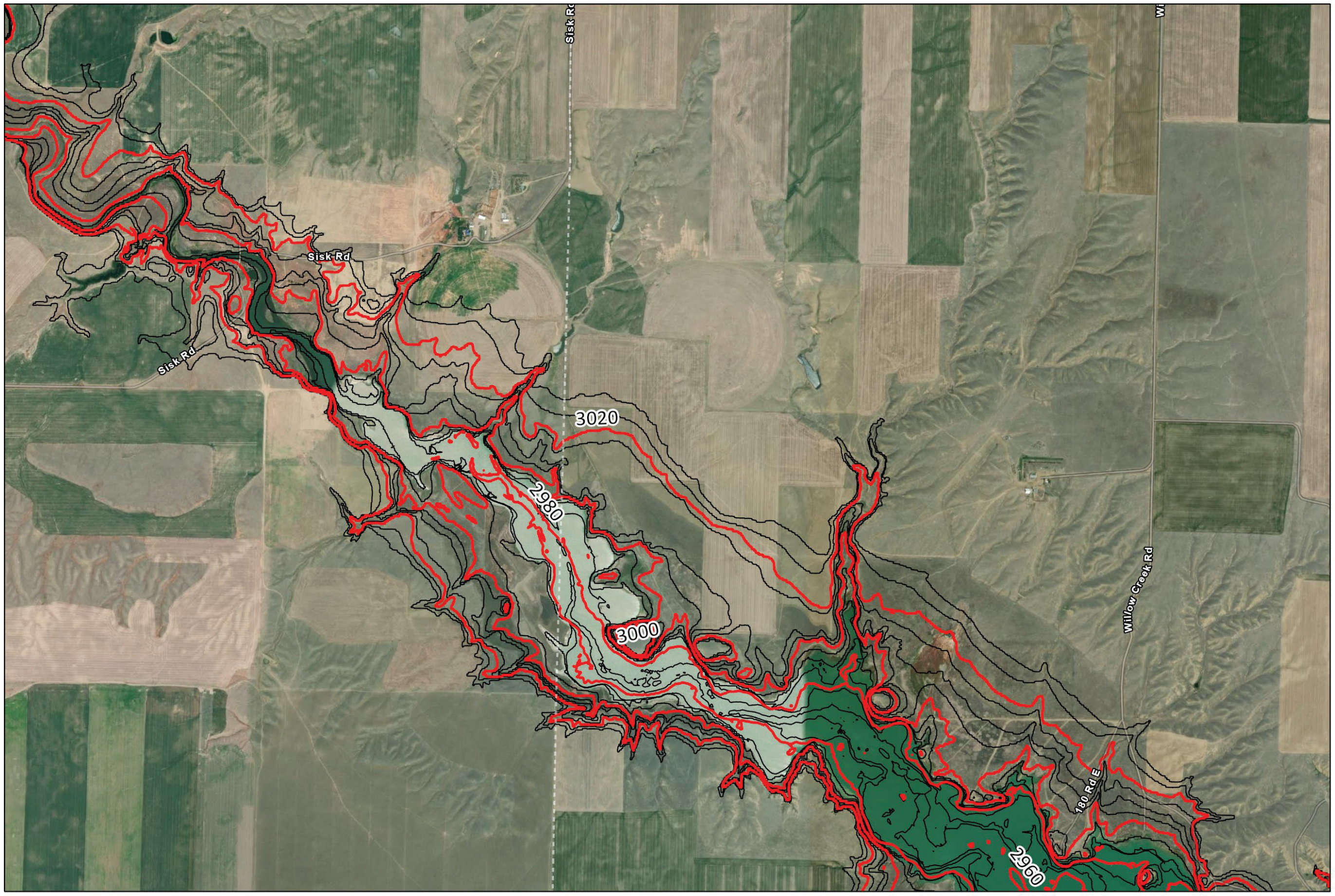
0 0.25 0.5 Miles

Scale 1:20,000



Esri Canada, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS, Esri Canada, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, Esri, USGS, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

— BUREAU OF —
RECLAMATION



Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 4

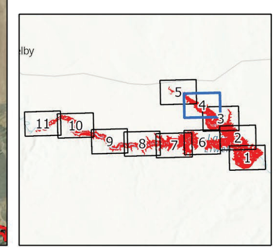
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



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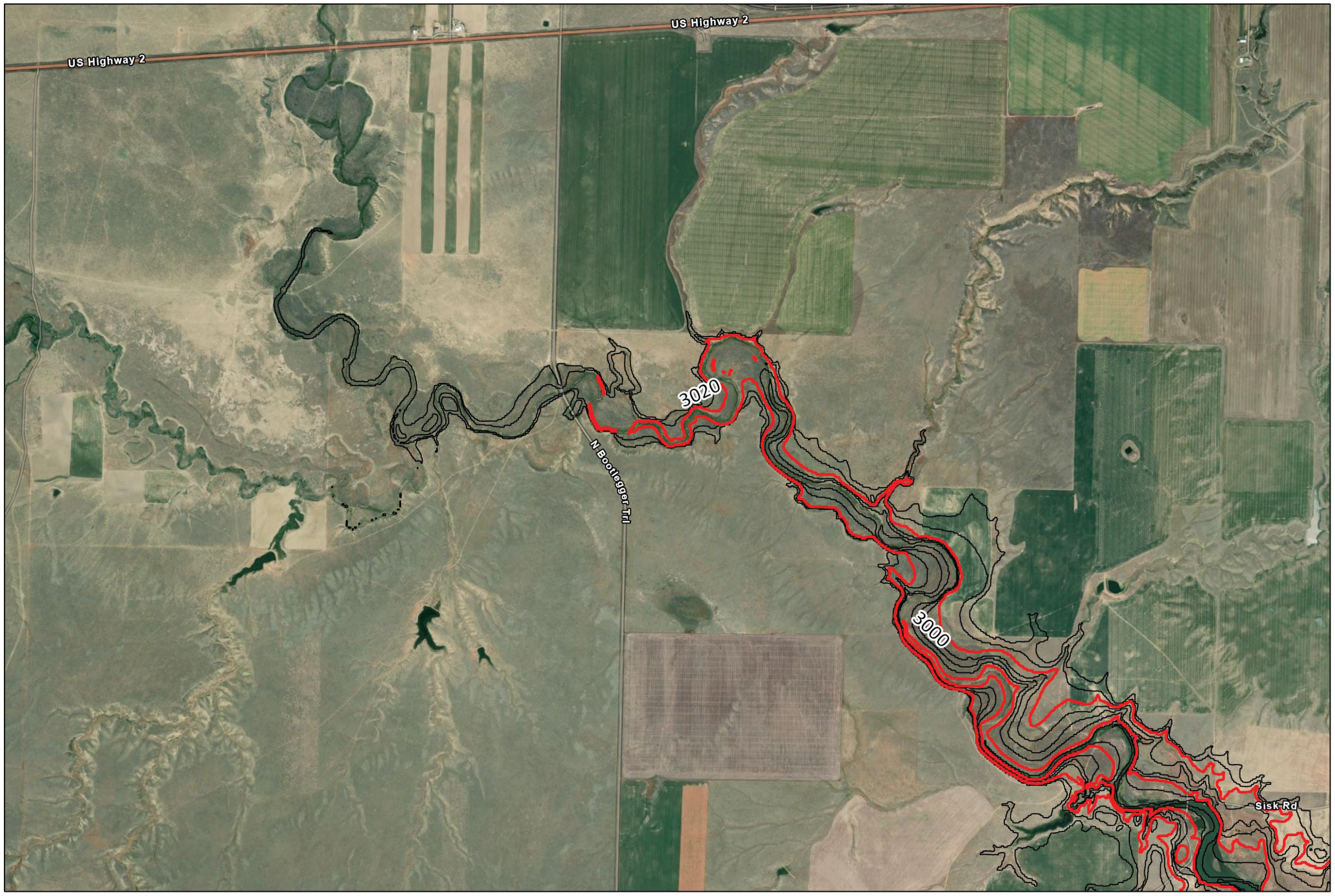
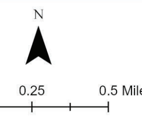


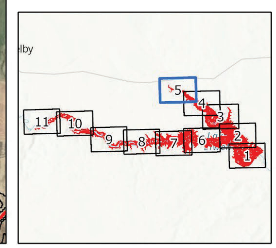
Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 5

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)





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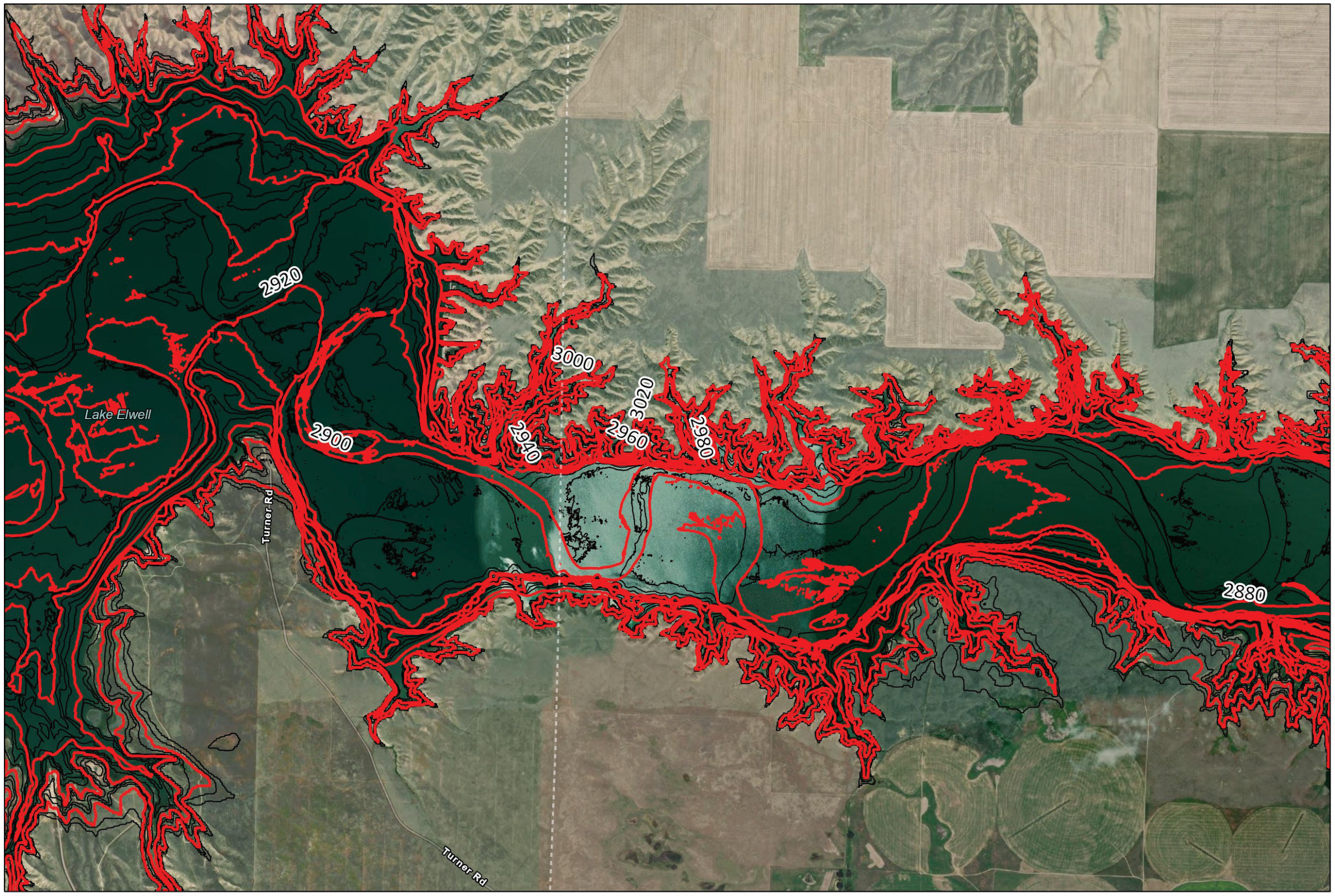
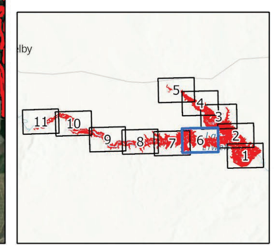


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 6

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)



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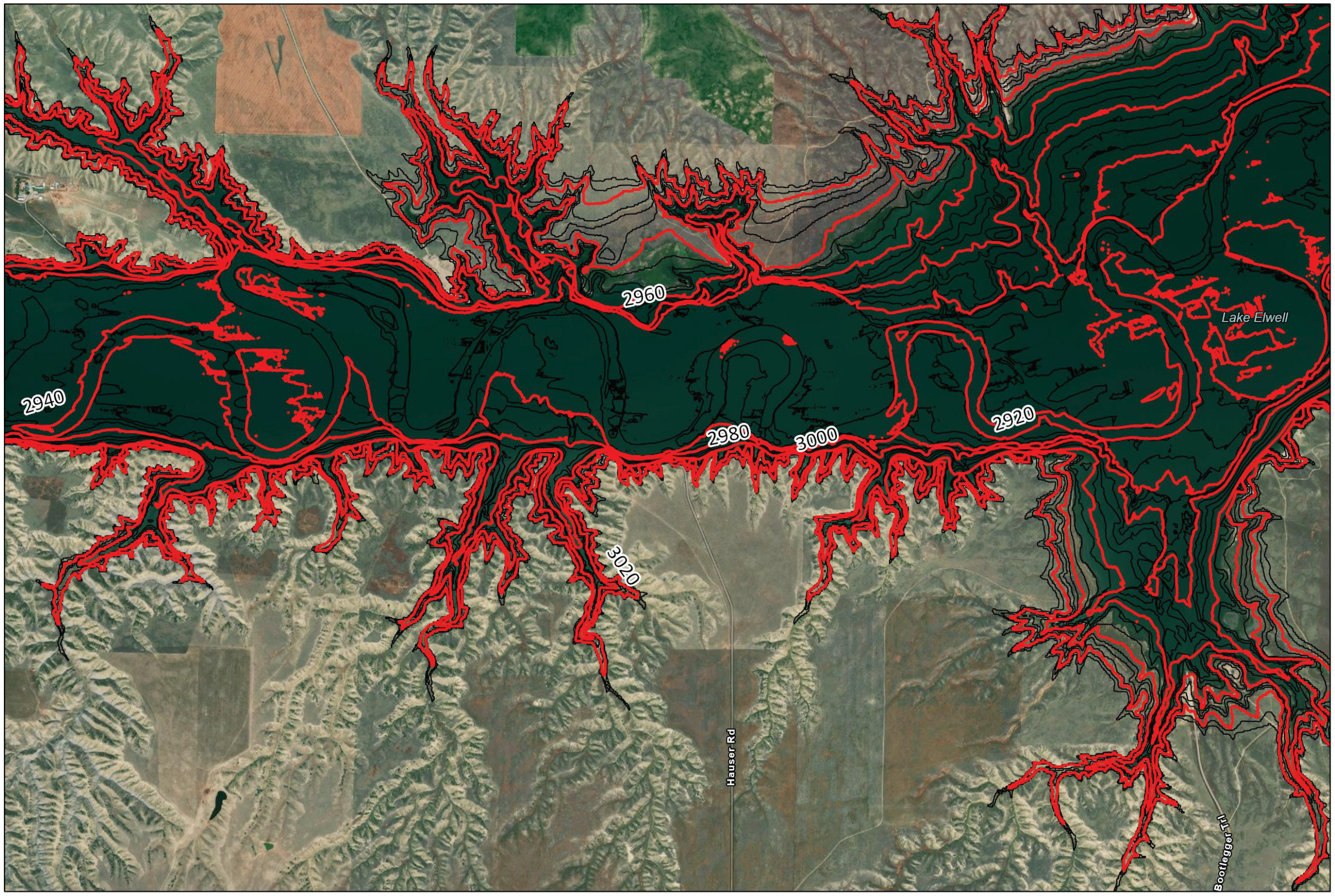
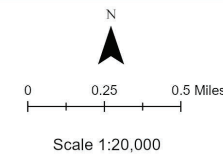


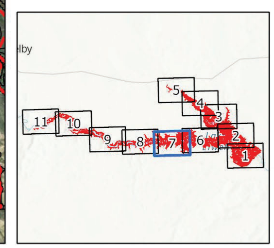
Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 7

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)





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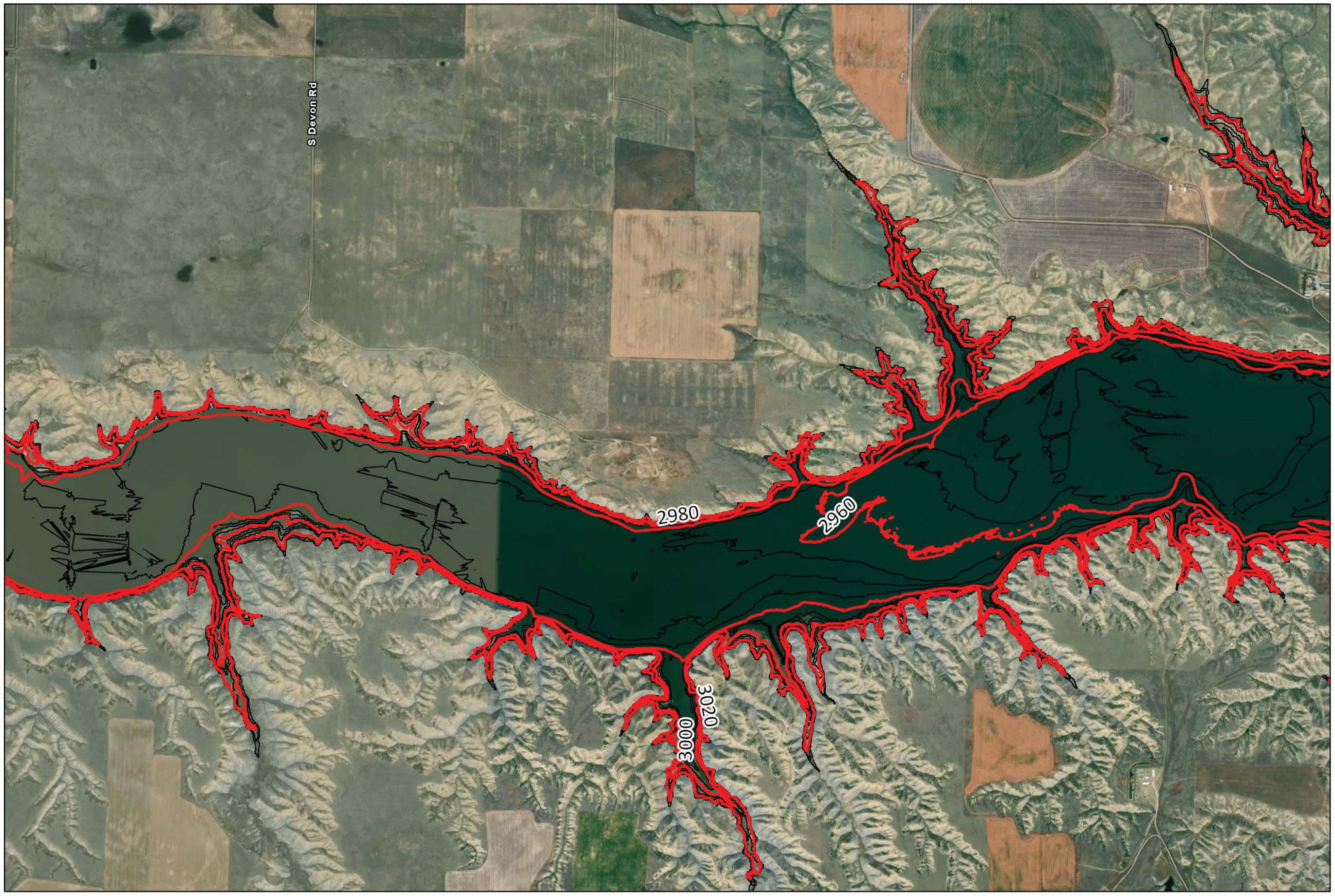
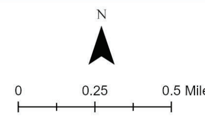


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 8

Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)



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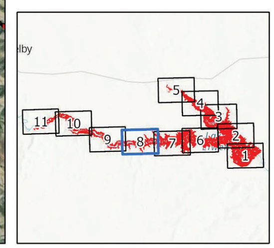

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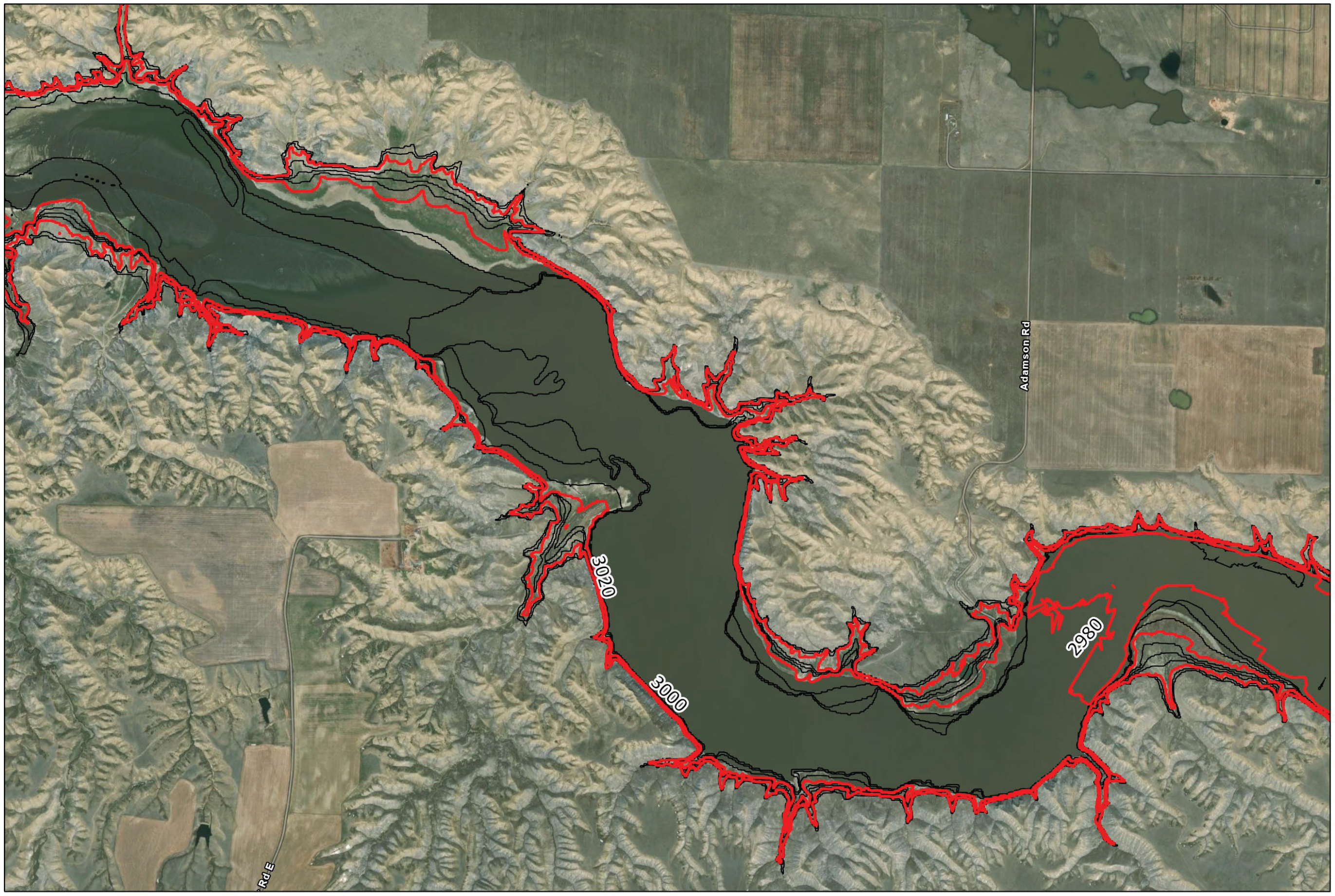


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 9

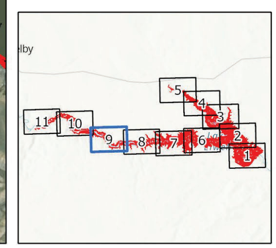
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



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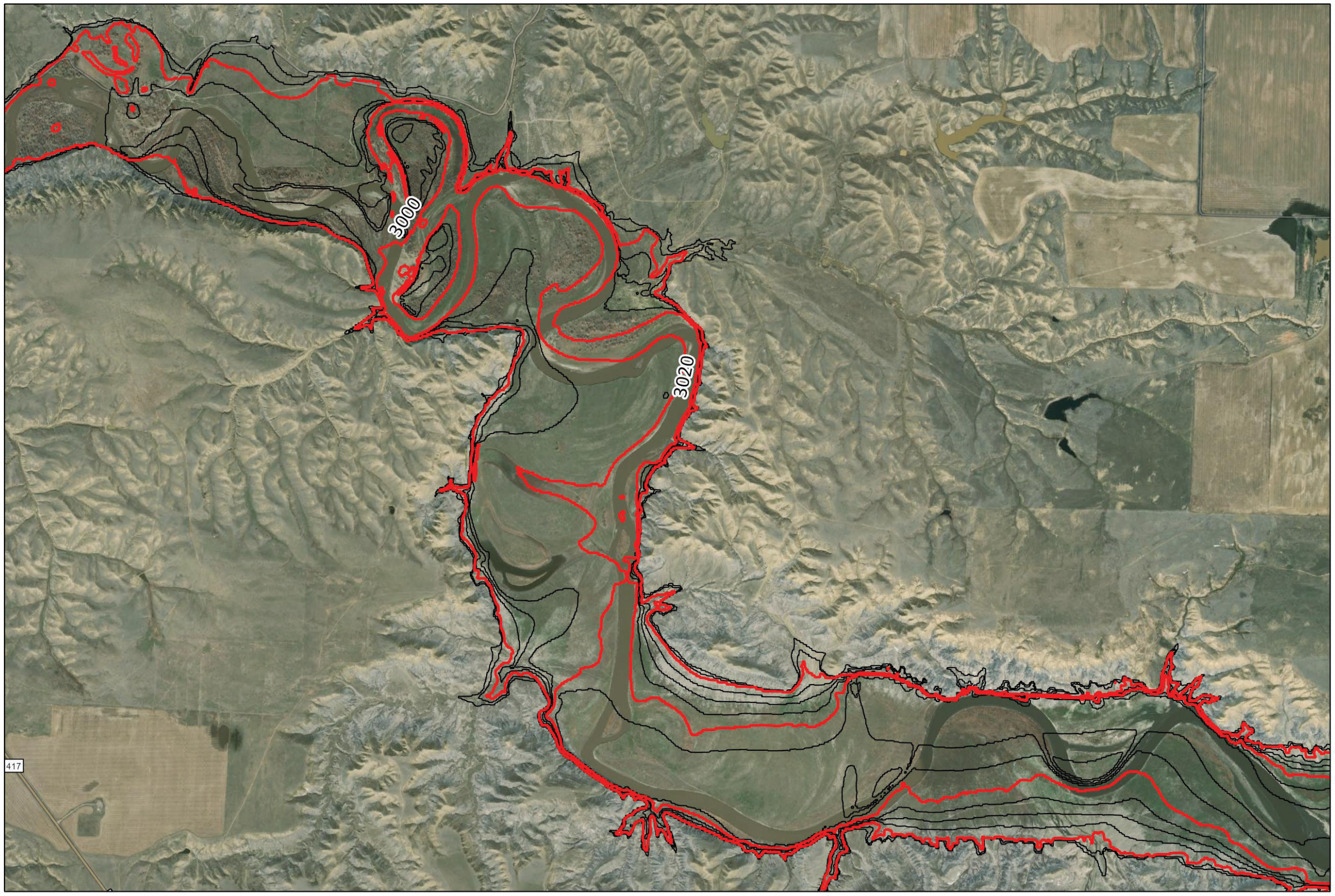


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 10

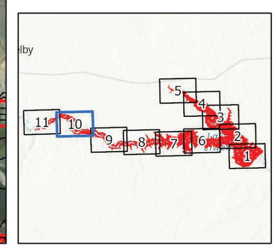
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



Esri Canada, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS, Esri, CGIAR, USGS, Esri Canada, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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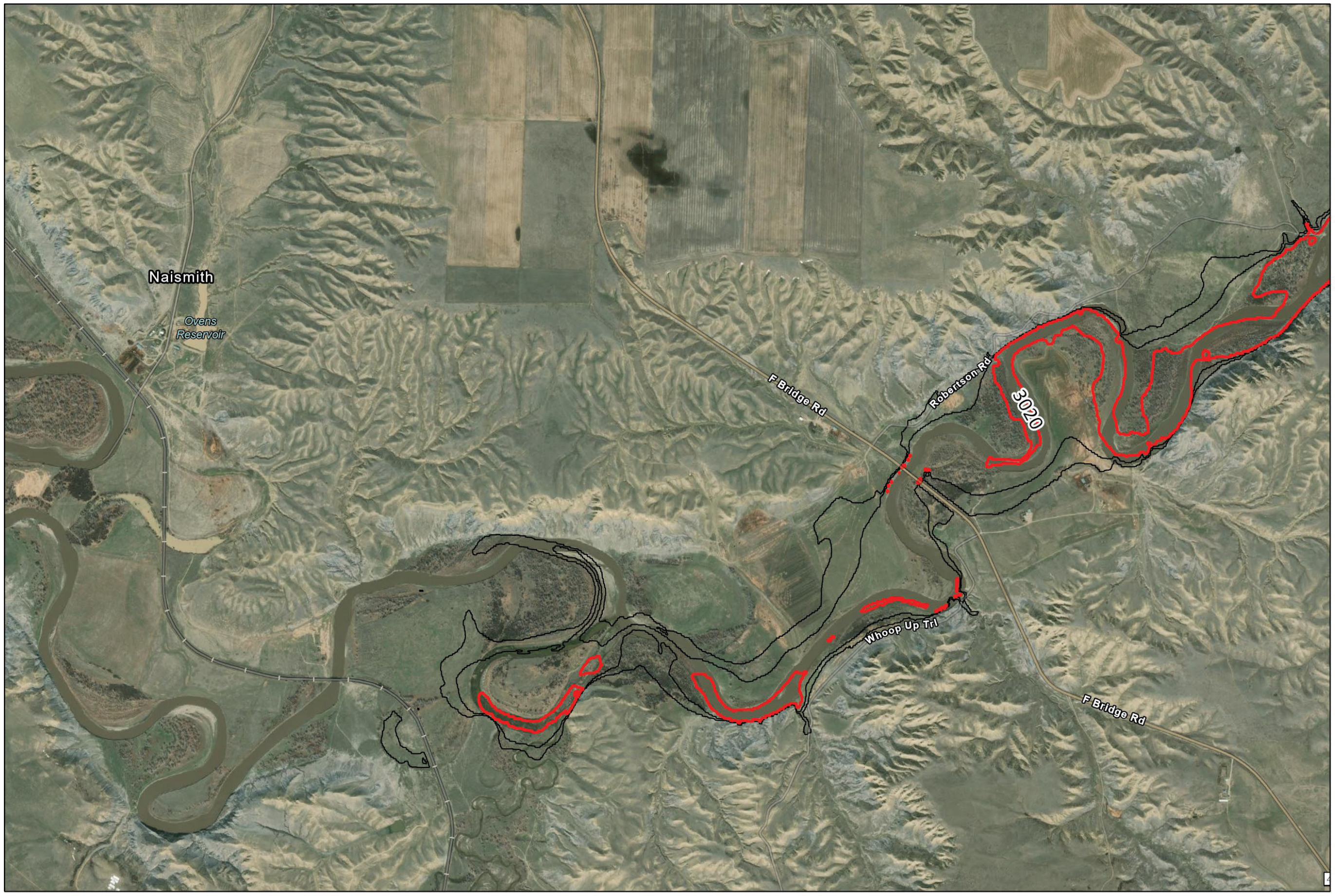


Tiber Reservoir (Lake Elwell)
Montana, USA
Elevation
Contour Map

Sheet 11

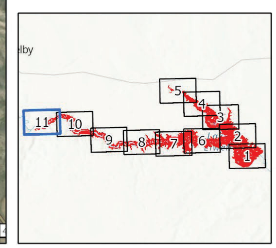
Map Prepared By:
Geographic Applications & Analysis Group
Bureau of Reclamation
Technical Service Center - 04/07/2022

Horizontal: NAD83, State Plane Montana US feet
Vertical: Reclamation Project Vertical Datum (RPVD)
RPVD= NGVD 1929 = NAVD88-3.02 feet
Contour interval: 5 feet (black)
Index contour interval: 20 feet (red)
Bathymetric data from 2021 reservoir survey
Above water data from the NED (USGS, 2013)

N

0 0.25 0.5 Miles

Scale 1:20,000



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