RECLAMATION

Managing Water in the West

Technical Report No. SRH-2013-01

Fresno Reservoir 2010 Sedimentation Survey

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

April 2013

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (Sedimentation) Group of the Technical Service Center (TSC) prepared and published this report. Reclamation's Sedimentation Group and Montana Area Office conducted the bathymetry survey of the reservoir in June 2010. Ron Ferrari of the Sedimentation Group completed the data processing to generate the 2010 topography and area-capacity values presented in this report. Kent Collins of the Sedimentation Group performed the technical peer review of this document.

Mission Statements

The U. S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68240), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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Fresno Reservoir 2010 Sedimentation Survey

prepared by

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Technical Service Center
Water and Environmental Resources Division
Sedimentation and River Hydraulics Group
Denver, Colorado

April 2013

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

Technical Report No. SRH-2013-01

Fresno Reservoir 2010 Sedimentation Survey

Fresno Dam
Montana

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Introduction

Fresno Reservoir and Dam, on the Milk River in Hill County, is about 30 miles south of the Canadian border and 15 miles west of Havre in north central Montana (Figure 1). Fresno Reservoir, principal feature of the Milk River Project, provides irrigation water, flood control storage space, and wildlife and recreation benefits.

Figure 1 - Reclamation Reservoirs located in Montana.

Fresno Dam was constructed from 1937 through 1939 with first storage in November 1939. Due to excessive foundation settlement, the crest of the dam was raised in 1943 and again in 1950, from elevation 2,594.5 to 2,596.1. In addition, in 1950 a concrete parapet with curb wall was constructed. The dam is a wide, homogeneous rolled earth embankment with the following dimensions:

Structural height[1]	110 feet	Hydraulic height	57 feet
Crest length	2,070 feet	Crest elevation[2]	2,596.1 feet
Top width	22 feet	Top of parapet wall	2,598.5 feet

The drainage area above Fresno Dam is 3,766 square miles with 2,911 square miles considered sediment contributing. The elevations range from 2,520.0 (outlet sill elevation) to about 10,000 feet. Additional water is diverted from the St. Mary River into the North Fork of the Milk River via the St. Mary Canal. Fresno Reservoir has an average width of 0.5 miles with a length of around 15.5 miles.

The Fresno Dam spillway, located near the left abutment, consists of a riprap-lined inlet channel, concrete overflow crest structure, concrete chute, stilling basin, and a riprap-lined outlet channel to the river. The uncontrolled spillway, crest elevation 2,575.0, has a length of 210 feet and provides a maximum discharge of 51,000 cubic feet per second (cfs) at maximum reservoir water surface elevation 2,591.0.

The outlet works, with a sill elevation of 2,520.0, consist of two 72-inch conduits located in the left abutment and provide the only controlled discharge through the dam. The outlet's total discharge capacity is 2,600 cfs at reservoir elevation 2,575.0. The inactive elevation of 2,530.0 provides the minimum head needed for operation of the river outlet works.

Previous Surveys

A 1978 survey was the first since Fresno Dam closure in 1939. October 1977 aerial photography was collected when the reservoir was near elevation 2,547. A bathymetric survey in spring 1978, near reservoir elevation 2,570, provided adequate overlap for checking the two data sets which generally matched well. The rangeline method of collection and analysis was used with the lines spaced 500-feet apart (Reclamation, 1984). For the 1978 study, 25,665 acre-feet of sediment deposition was computed at elevation 2,575.0 by comparing the 1978 results with the original capacity values. The original data was developed from 5-foot contour maps that were not located for the 1978 or later studies.

[1] The definition of such terms as "top width, "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs,* or ASCE's *Nomenclature for Hydraulics.*

[2] Elevations in feet. Unless noted, all elevations based on the original project datum established during construction and confirmed to be 4.7 feet higher than National Geodetic Vertical Datum of 1929 (NGVD29) and 2.0 feet higher than North American Vertical Datum of 1988 (NAVD88).

A 1999 underwater survey was the first GPS survey of Fresno Reservoir conducted near water surface elevation 2,564. During that study, 5-foot contours were developed from elevation 2,560.0 and below, resulting in 36,210 acre-feet of sediment accumulation at elevation 2,575.0. Since no above water data was collected the study assumed no change in surface area, since the 1978 survey, from elevation 2,575.0 and above. For the 1999 study, surface areas and resulting volumes were interpolated between input elevations 2,560.0 and 2,575.0 (Reclamation, 2000).

Control Survey Data Information

Prior to the 1999 underwater collection, a contracted, static GPS control survey was conducted to establish horizontal and vertical control points around the reservoir. The horizontal control was established in Montana State plane coordinates in NAD83 and the vertical control in NAVD29 and NGVD88. The survey found the average elevations in NGVD29 were 2.7 to 2.8 feet lower than NAVD88 and around 4.7 feet lower than the project vertical datum. The average reservoir water surface, recorded by the Reclamation gage, was around 4.7 feet higher than NGVD29 and 2.0 feet higher than NAVD88 water surfaces. All computations were based on Reclamation’s project construction datum.

Prior to the 2010 bathymetric survey the area near the dam and boat ramp were searched for control points from the 1999 survey. A monument was located, but it appeared to be disturbed and was not used for this survey. The on-line positioning user service (OPUS) and RTK GPS were used to establish horizontal and vertical control on a temporary point near the reservoir that was used for the 2010 bathymetric survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The OPUS generated coordinates were used to determine position and vertical difference between NGVD29, NAVD88, and recorded water surface elevations at the dam that are tied to the project vertical datum. The horizontal control was established in Montana state plane coordinates, NAD83, in feet. Unless noted, all elevations and computations within this report are referenced to Reclamation’s project datum that is around 4.7 feet higher than NGVD29 and 2.0 feet higher than NAVD88. The developed topographic maps in this report are tied to the project vertical datum.

Reservoir Operations

Fresno Reservoir's primary purpose is irrigation with secondary storage space for flood control, recreation, fish, and wildlife. The June 2010 area-capacity tables show 91,746 acre-feet of active conservation storage below elevation 2,575.0 with a total capacity of 204,010 acre-feet below maximum water surface elevation 2,591.0. The 2010 survey measured a minimum bottom elevation 2,524.4, which is above the outlet sill elevation 2,520.0. The following values are from the June 2010 capacity table:

112,264	acre-feet of surcharge pool storage between elevation 2,575.0 and 2,591.0.
33,841	acre-feet of joint use storage between elevation 2,567.0 and 2,575.0.
57,747	acre-feet of conservation use storage between elevation 2,530.0 and 2,567.0.
158	acre-feet of inactive use storage below elevation 2,530.0.

The Fresno Reservoir inflow and end-of-month stage records in Table 1 show the annual fluctuation for water years 1940 through June 2010. The average reservoir inflow during the first survey period, 1940 through June 1978, was 271,160 acre-feet and has since decreased to 260,400 acre-feet for operation period 1940 through June 2010. Water levels listed in Table 1 show fluctuations of Fresno Reservoir over time. Since filling in 1947 the levels have ranged from maximum elevation 2,579.3 in 1952 to minimum elevation 2,532.4 in 1961.

Hydrographic Survey, Equipment, and Method of Collection

Bathymetric Survey Equipment

The bathymetric survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 2). The hydrographic system included a GPS receiver with a built-in radio, depth sounder, helmsman display for navigation, computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the boat equipment. The shore equipment included a second GPS receiver with an external radio. The shore GPS receiver and antenna were mounted on a survey tripod over a known datum point with a 12-volt battery providing power.

The Sedimentation Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS. The basic outputs from a RTK receiver are precise 3-D coordinates in latitude, longitude, and height with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS WGS-84 datum that the hydrographic collection software converted into Montana's state plane coordinates, NAD83, in feet.

The Fresno Reservoir bathymetric survey was conducted from June 14 through June 16, 2010 between water surface elevations 2,575.3 and 2,575.8 (project datum). The bathymetric survey was conducted using sonic depth recording equipment interfaced with RTK GPS that measured the sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along grid lines established to cover the reservoir. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining a course along these predetermined lines. As each line was traversed, the depth and position data were recorded on the laptop computer hard drive for subsequent processing. The water surface elevations at the dam, Reclamation gage records and RTK GPS measurements, were used to convert the sonic depth measurements to lake-bottom elevations. Unless otherwise noted, the elevations in this report are all tied to the project datum that is around 2 feet higher than NAVD88. Final processing of the June 2010 bathymetric data resulted in around 86,900 points, Figures 3 through 5.

Figure 2 - Survey vessel with mounted instrumentation mapping upstream of Grand Coulee Dam on Franklin D. Roosevelt Reservoir, Washington.

The 2010 underwater data was collected using a depth sounder calibrated by adjusting the speed of sound through the water column which varies with density, salinity, temperature, turbidity, and other conditions. The data was digitally transmitted to the computer collection system through RS-232 serial ports. The depth sounder produced analog charts of the measured depths and when the charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified during the analysis. Additional information on collection and analysis procedures is outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006).

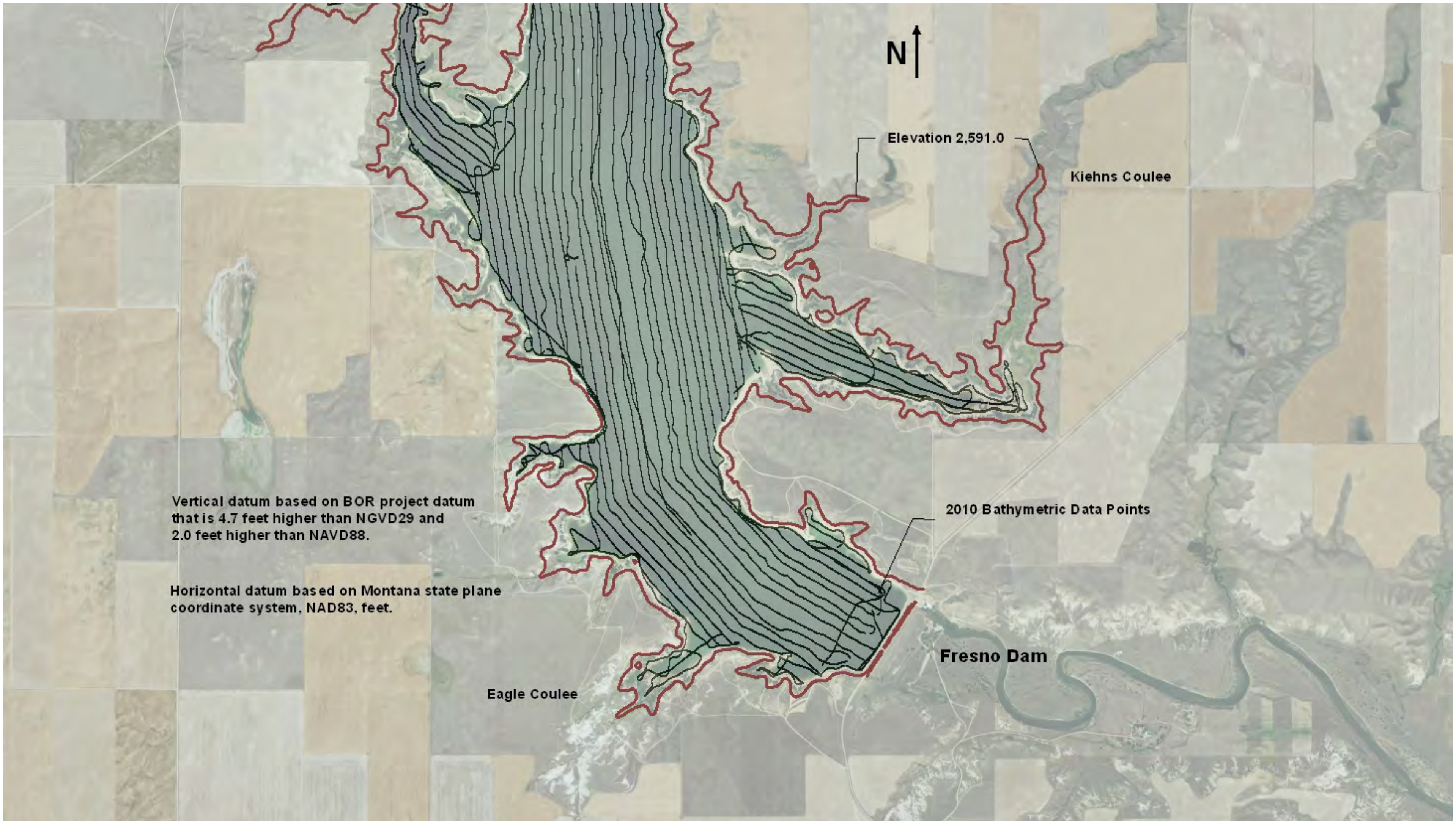

Figure 3 - Fresno Reservoir 2010 bathymetric data from dam upstream (project vertical datum).

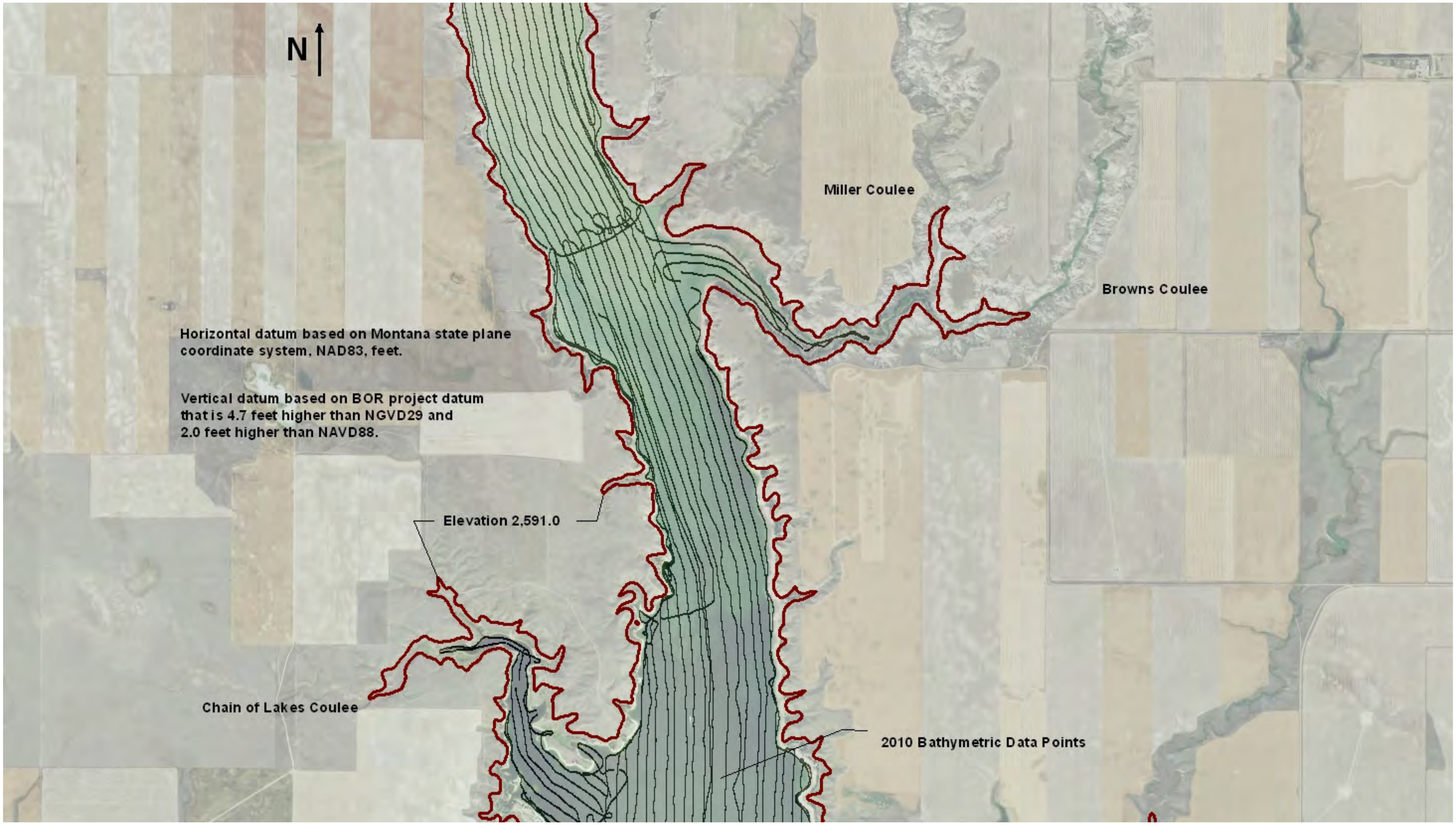

Figure 4 - Fresno Reservoir 2010 bathymetric data (project vertical datum).

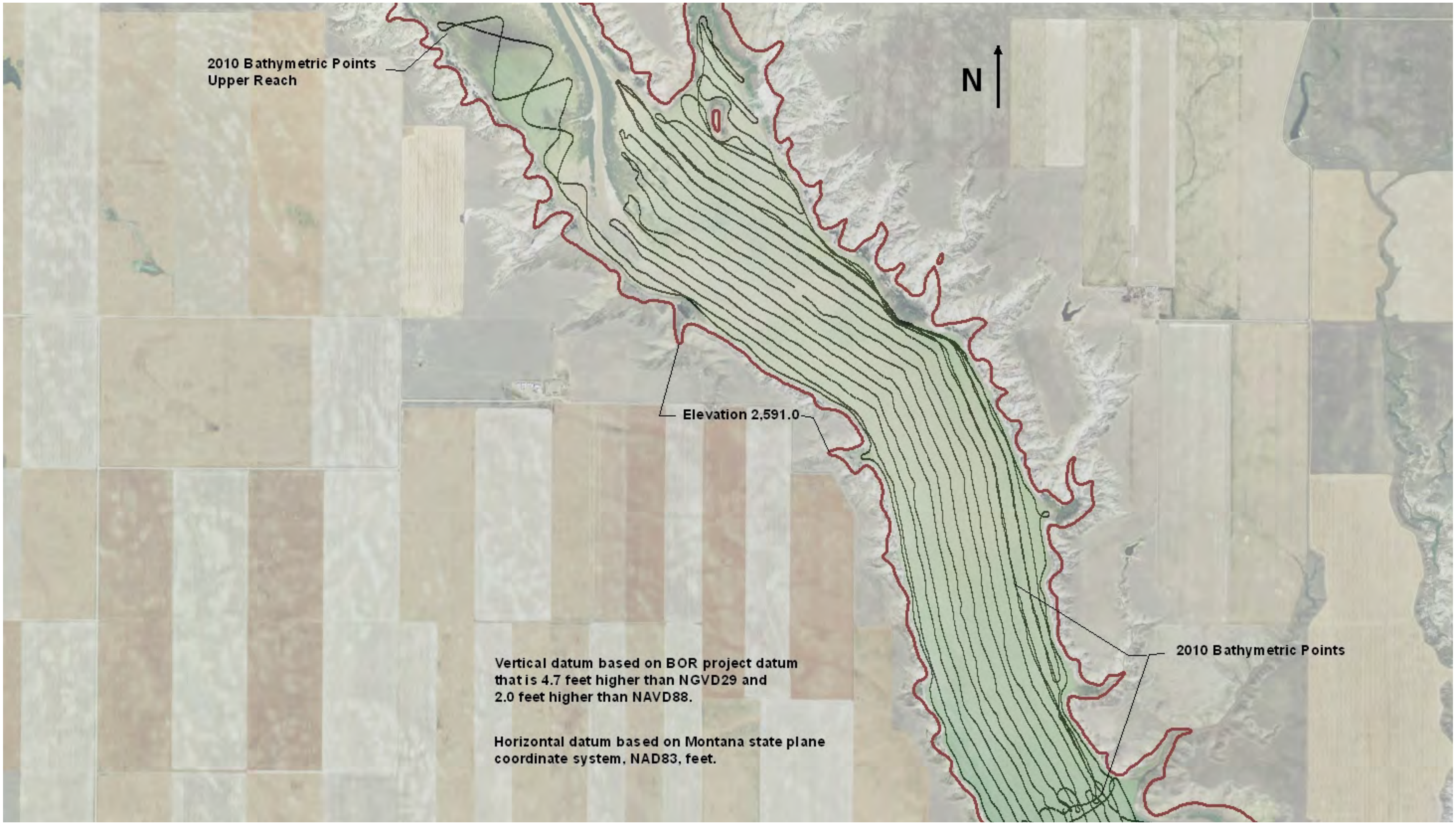

Figure 5 **- Fresno Reservoir 2010 bathymetric data (project vertical datum).**

Above Water Data

Aerial Photographs

The 2010 survey of Fresno Reservoir focused on the collection of the bathymetric or underwater data that was accessible by the survey vessel, requiring acquisition of the best available above water data to complete the topographic development. The 1978 aerial data wasn't available in a digital or hard copy format for this study. Orthographic aerial photos collected in 2009, at water surface elevations 2,561.4 and 2,567.5, along with 2011 aerial photos, at water surface elevation 2,572.8, were downloaded from the USDA data web site (USDA, 2010). Reservoir contours were developed by digitizing the water's edge from these aerial images and assigning the elevation from the day of the flights, Figure 6. In 2009, portions of the reservoir were flown on different days, resulting in different water surface elevations assigned to the digitized line portions. Being lower, the 2009 aerial provided a clear image of the shoreline, enabling digitization of the water surface resulting in the two contours. The 2011 aerial image was also clear, flown near the level of the 2010 bathymetric survey at spillway crest elevation 2,575, allowing a digitized contour to be developed.

Figure 6 - Aerial image of Fresno Reservoir from dam upstream flown in 2011 near elevation 2,572.8 (USDA, 2010).

During analysis, segments of these digitized water surfaces were used to develop the 2010 reservoir topography. The 2009 aerial was flown at a much lower water level than the 2010 bathymetric survey was conducted, resulting in the majority of the digitized contours being overlapped by the bathymetric data. The areas of the digitized contours overlapped by the surveyed bathymetry were removed, leaving only small segments of the digitized contours that were used for the 2010 topography development. These remaining segments were mainly in the upper coves and areas too shallow for boat access. The majority of the 2011 digitized contour was used for developing the 2010 reservoir topography. In the main portion of the reservoir, none of the 2011 contour was overlapped by the 2010 bathymetric data. In the very upper portion of the reservoir a large sediment delta has formed, making this area very complex and impossible to digitize a valid 2011 contour with the inflowing river and wide wetted area. Due to this complexity, no 2011 contour line was digitized in the upper delta area. The contours for that area were developed using the 2010 bathymetric data and high altitude aerial LiDAR data as described below.

Aerial IFSAR

Interferometric Synthetic Aperture Radar (IFSAR) digital bare earth data was obtained in Montana’s state plane zone in NAD83 with vertical elevations tied to NAVD88. IFSAR airborne technology enables mapping of large areas quickly and efficiently resulting in detailed information at a much lower cost than other technologies such as low altitude detailed aerial photogrammetry and LiDAR. The IFSAR data at this site was collected when the reservoir was low (elevation 2,553.5), providing large areas of overlap to compare with the USDA aerial developed contours and 2010 bathymetric survey points. The IFSAR NAVD88 elevations were shifted two feet higher to match the project’s vertical datum, Figures 7 and 8.

The IFSAR data provided detailed topographic images of the main reservoir body and coulees (coves) throughout the reservoir with reported accuracies of 2-meters horizontally and 1-meter vertically for areas of unobstructed flat ground (Intermap, 2011). Coulee formations are usually dry, deep ravines or gulches, formed by running water, and mainly located in western parts of Canada and the United States. As seen on the maps, there are several coulees that have been inundated with the filling of Fresno Reservoir. Throughout the reservoir the developed contours from the IFSAR data matched well with the digitized aerial contours. In the upper portion of the reservoir, spot compaison of the IFSAR data against the 2010 bathymetric data points also found good elevation agreement. In many cases, elevation differences were less than one foot or much less than the IFSAR reported vertical accuracy of one meter. Even though a constant, reliable shift of all IFSAR data to reduce the difference from the bathymetry could not be determined, the IFSAR data was used for the 2010 reservoir analysis due to the close agreement of the elevations. Use of the IFSAR data resulted in reasonable sediment deposit computations for the 2010 analysis, otherwise no change since the 1978 and 1999 surveys would have been assumed for the upper reservoir elevations.

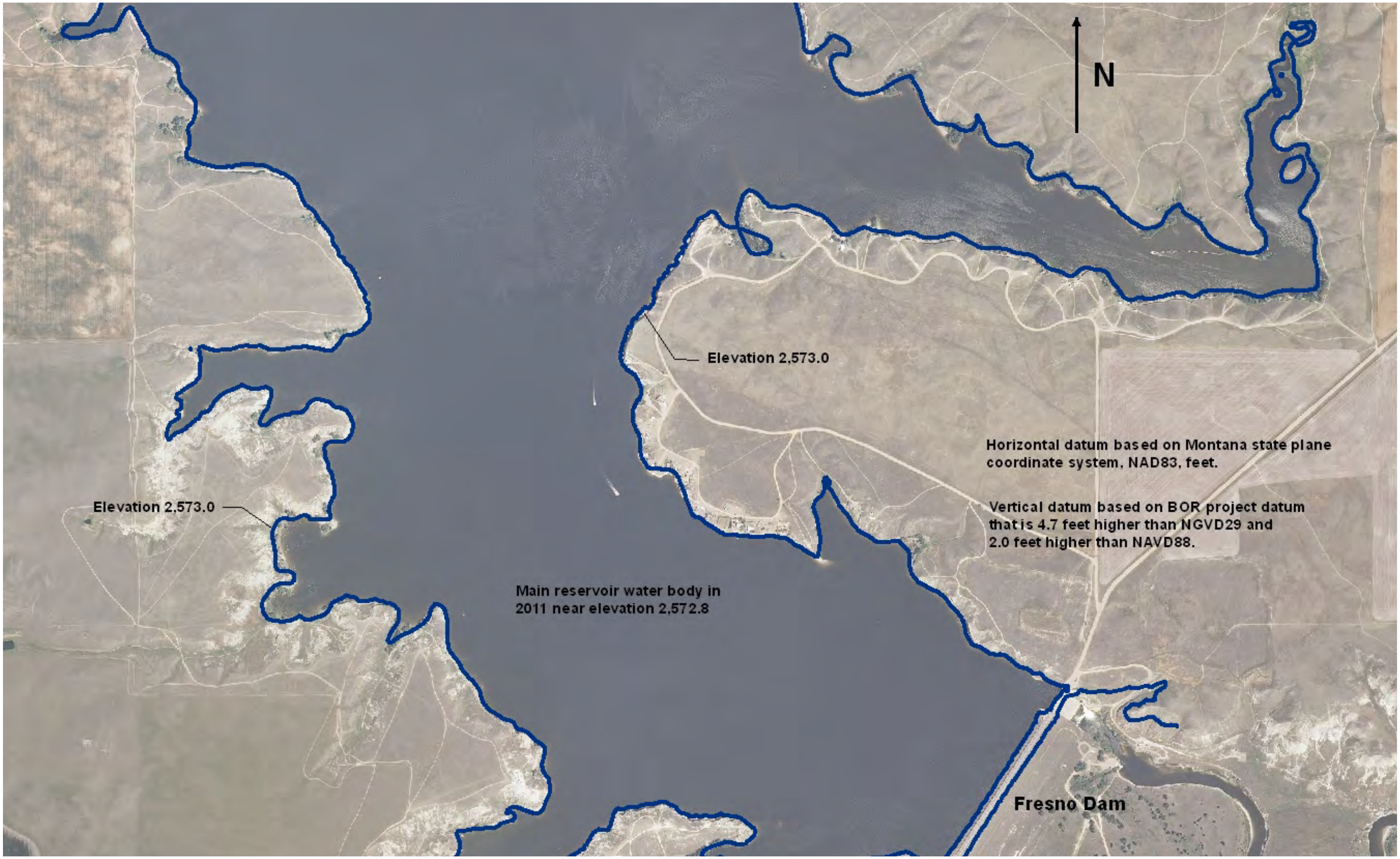

Figure 7 - Fresno Reservoir, 2011 USDA aerial photograph flown at water surface elevation 2,572.8 and the IFSAR developed contour at elevation 2,573.0 (1 of 2).

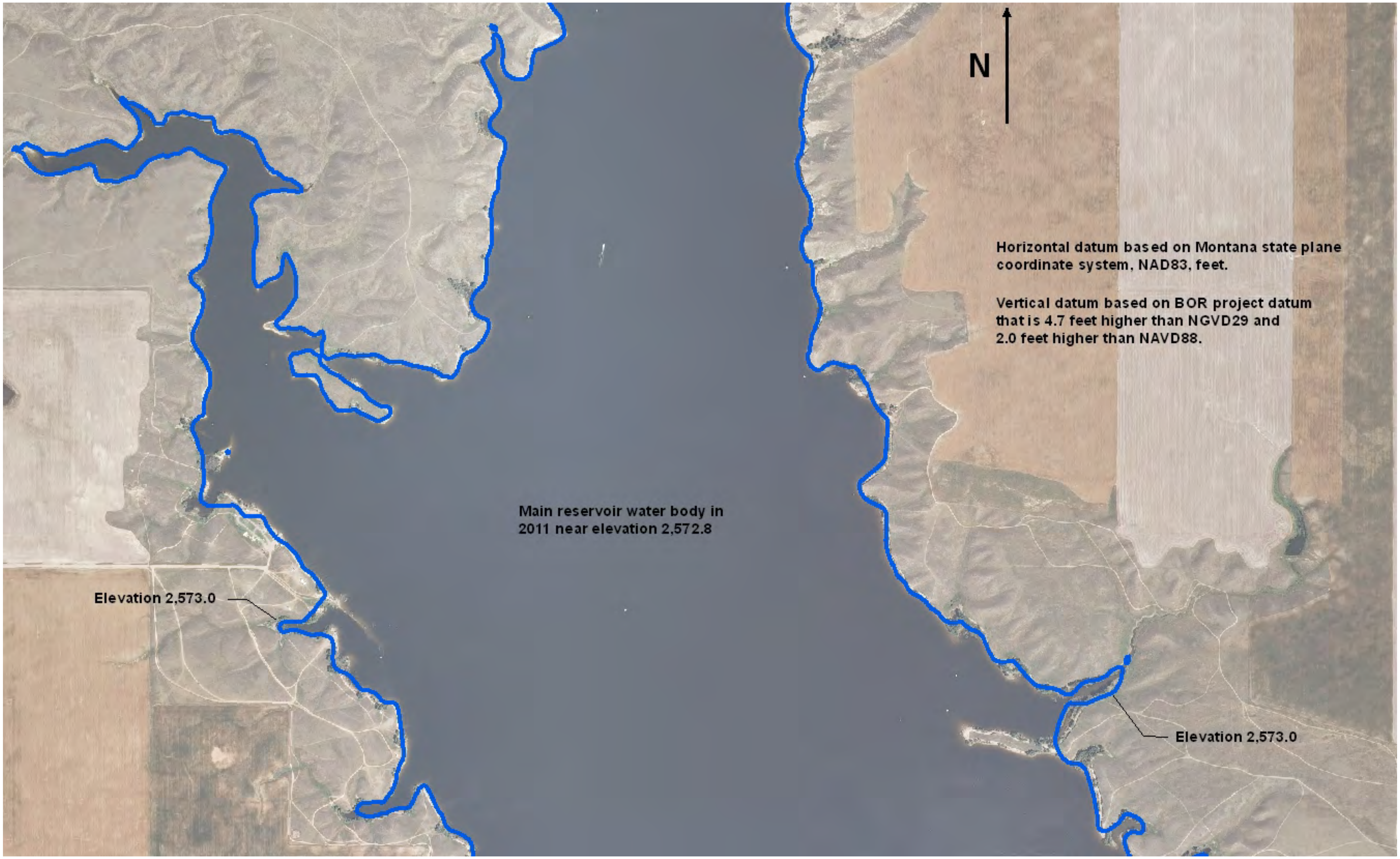

Figure 8 - Fresno Reservoir, 2011 USDA aerial photograph flown at water surface elevation 2,572.8 and the IFSAR developed contour at elevation 2,573.0, (2 of 2).

Previous studies conducted by the Sedimentation Group at different project sites were much less successful using IFSAR data. The IFSAR data was initially used for topographic development for these studies, but due to the vertical accuracy issues the computed surface areas from the IFSAR developed contours were not included as part of the final reservoir volumes. These studies include Heron Reservoir in New Mexico, Gibson Reservoir in Montana, Jamestown Reservoir in North Dakota, and Swanson Reservoir in Nebraska. The general conclusion was that IFSAR vertical accuracy was inadiquate at these locations for valid computations. Information on these studies can be found on the Sedimentation Group web site (Reclamation, 2013). The Fresno Reservoir topography is similar to some of these previously studied reservoirs, but the Fresno IFSAR data was found to be of a better accuracy and was used for volume computations.

As seen on Figures 9 and 10, there are areas within the main body of Fresno Reservoir above Cottonwood Coulee where large ponds have formed. The developed contours from the IFSAR data indicate that these ponds are at lower elevations than the sediment delta formation near Cottonwood Coulee. In the 2009 aerial photo (Figure 9), the pond areas appear dry and grassy while the 2011 aerial photo (Figure 10) shows wetted ponds. Even though the ponds don't appear connected to Milk River allowing them to drain directly into the main body of the reservoir, it was assumed that a large portion of the ponded water seeps into the main reservoir following draw down so they were considered part of the total 2010 reservoir volume.

Reservoir Area and Capacity

Topography Development

The Fresno Reservoir topographic contours were generated from data sources including the 2010 bathymetric survey, digitized reservoir water's edge from the USDA aerial photographs, IFSAR data, and digitized contours from the USGS quad maps for small portions of the upper reservoir elevations not covered by the IFSAR data. For the lower portion of the reservoir, the 2010 bathymetric data points, USDA 2011 contour 2,572.8, and IFSAR data above the USDA contours were the base data for contour development. As previously described, the portions of the USDA 2009 contour lines overlapped by the 2010 bathymetric data were removed, leaving the remaining contour segments for 2010 reservoir topography development. The areas of the IFSAR data points covered by the USDA contours and 2010 bathymetric data points were also removed. In the lower reservoir there were a few areas where the IFSAR data below USDA contour elevation 2,572.8 was not removed. These areas were in a few of the upper coulees and a few shallow water areas not accessible by the survey vessel. For the reservoir area with no 2010 bathymetric data or digitized USDA contours, from around Cottonwood Coulee upstream, the IFSAR data was the only available source for the 2010 reservoir topography development.

The data coverages were processed into a triangulated irregular network (TIN) that was used to develop 2-foot contours tied vertically to the project datum, Figures 11 through 17. Surface areas and volumes were developed from the TIN and referenced to the project datum which is 2 feet higher than NAVD88. In preparation for developing the TIN, two polygons were created to enclose the data sets. One polygon enclosed all the data sets allowing contour development of the reservoir study area, including contours downstream of the dam, Figure 18. A second polygon ran along the alignment of the dam for computations of the reservoir surface areas and resulting volumes. These polygons, not assigned an elevation, were used as hard boundary, preventing development of the 2010 TIN and countours outside of the hardclip.

Contours for Fresno Reservoir were developed from the TIN generated within ArcGIS. A TIN is a set of adjacent non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z elevation values. A TIN is designed to deal with continuous data such as elevations. ArcGIS uses a method known as Delaunay's criteria for triangulation where triangles are formed among all data points within the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that all the data points are connected to their nearest neighbors to form triangles, preserving all the data points. The TIN method is described in more detail in the ArcGIS user’s documentation (ESRI, 2012).

The linear interpolation option of the ArcGIS TIN and CONTOUR commands was used to interpolate contours from the Fresno Reservoir TIN. The surface areas of the enclosed contour polygons at 2-foot increments were computed for elevation 2,524.0 and above. The reservoir contour topography at 2-foot intervals is presented in Figures 18 through 23 from elevation 2,528.0 through elevation 2,590.0. The contours below elevation 2,528.0 were too small to visually present at this scale.

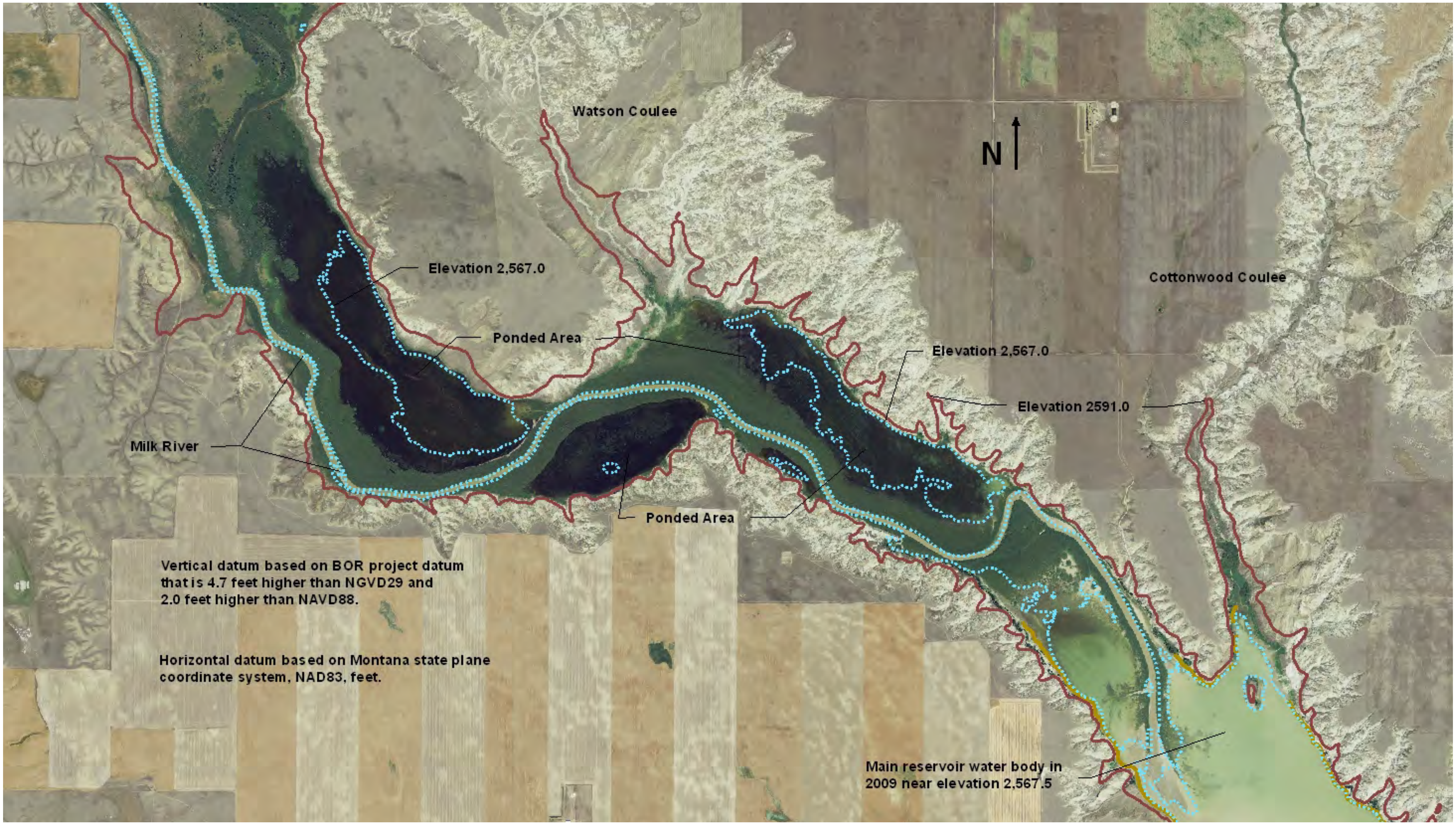

Figure 9 - Fresno Reservoir, 2009 USDA aerial photo near elevation 2,567.5. The dark areas above Cottonwood Coulee show the ponds in the main reservoir body. The 2,567.0 contour is from the IFSAR data shows the measured elevations of the ponds lower than the surrounding area.

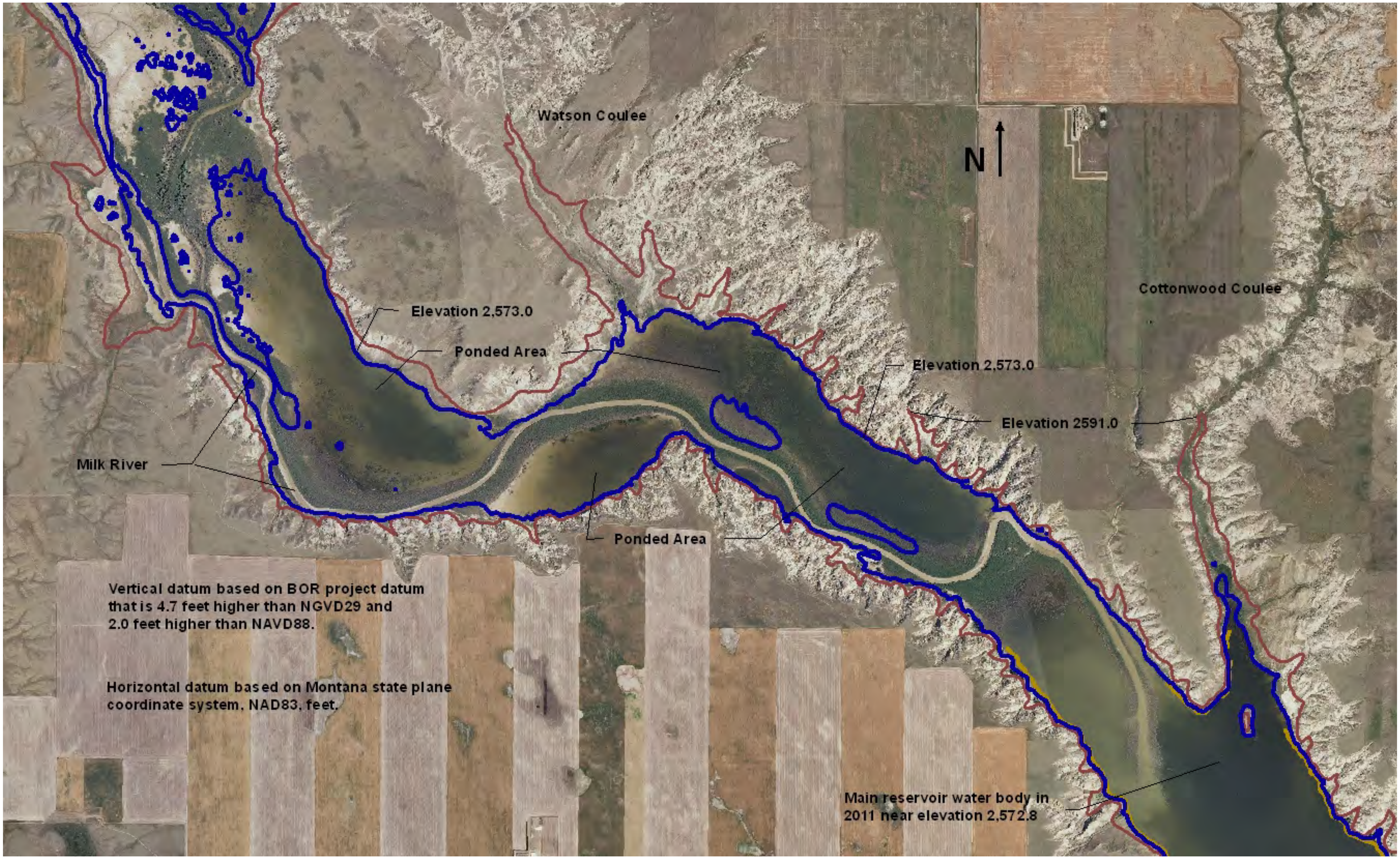

Figure 10 - Fresno Reservoir, 2011 USDA aerial photo near elevation 2,572.8. The dark areas above Cottonwood Coulee show the ponds. The 2,573.0 contour developed from the IFSAR data shows the elevations of the ponds lower than the surrounding area.

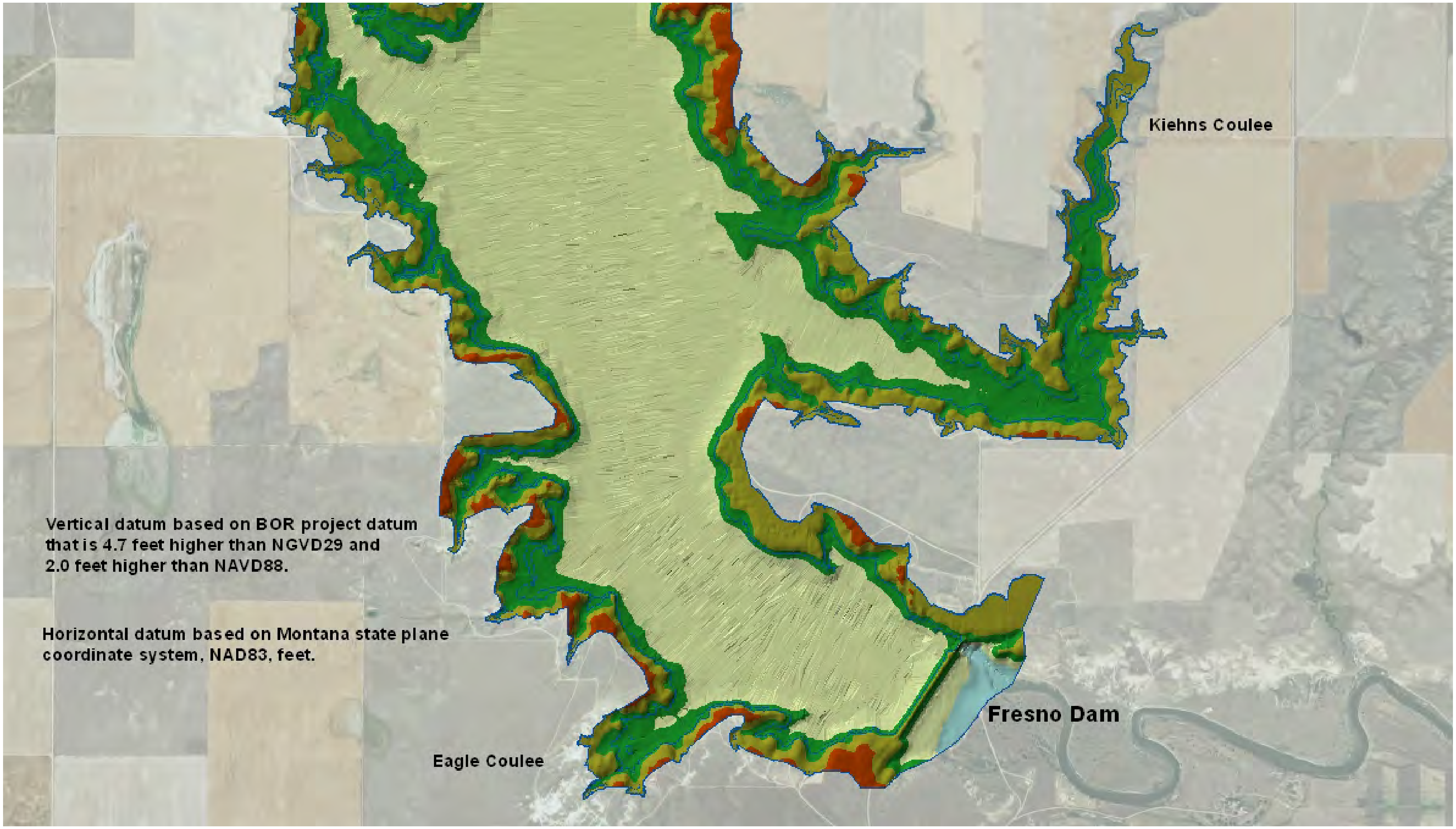

Figure 11 - Fresno Reservoir 2010 TIN, 1 of 7.

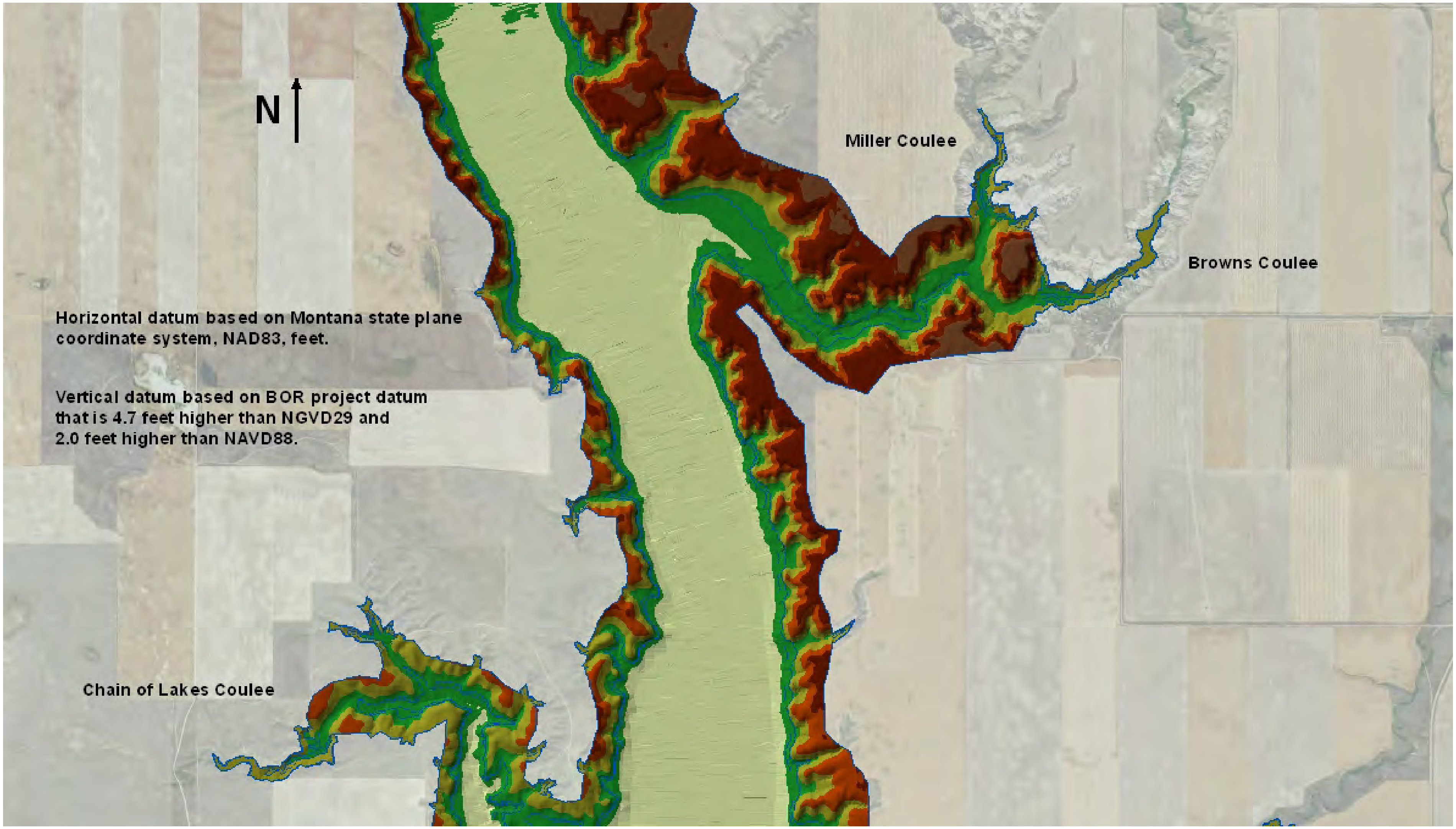

Figure 12 - Fresno Reservoir 2010 TIN, 2 of 7.

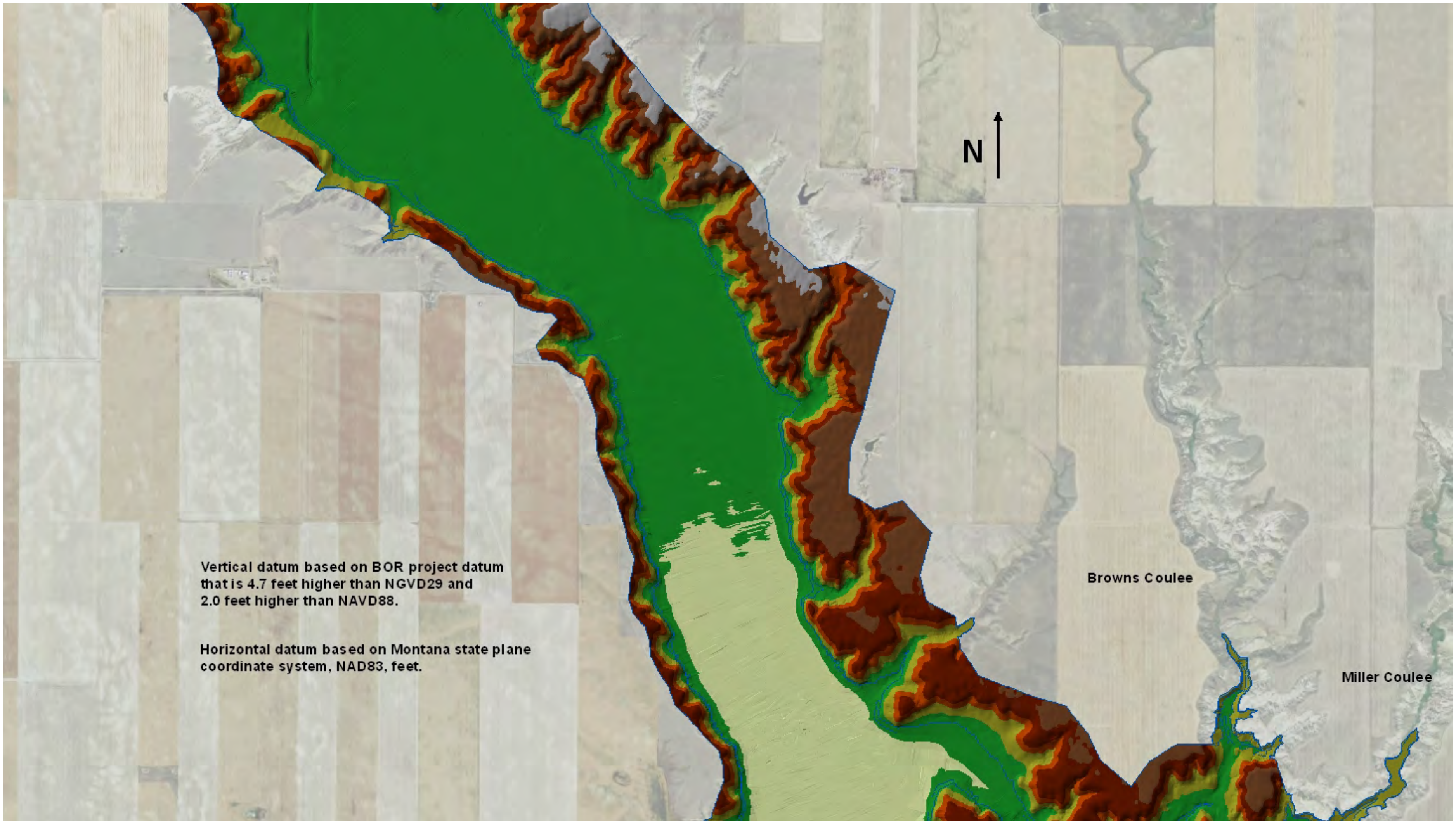

Figure 13 - Fresno Reservoir 2010 TIN, 3 of 7.

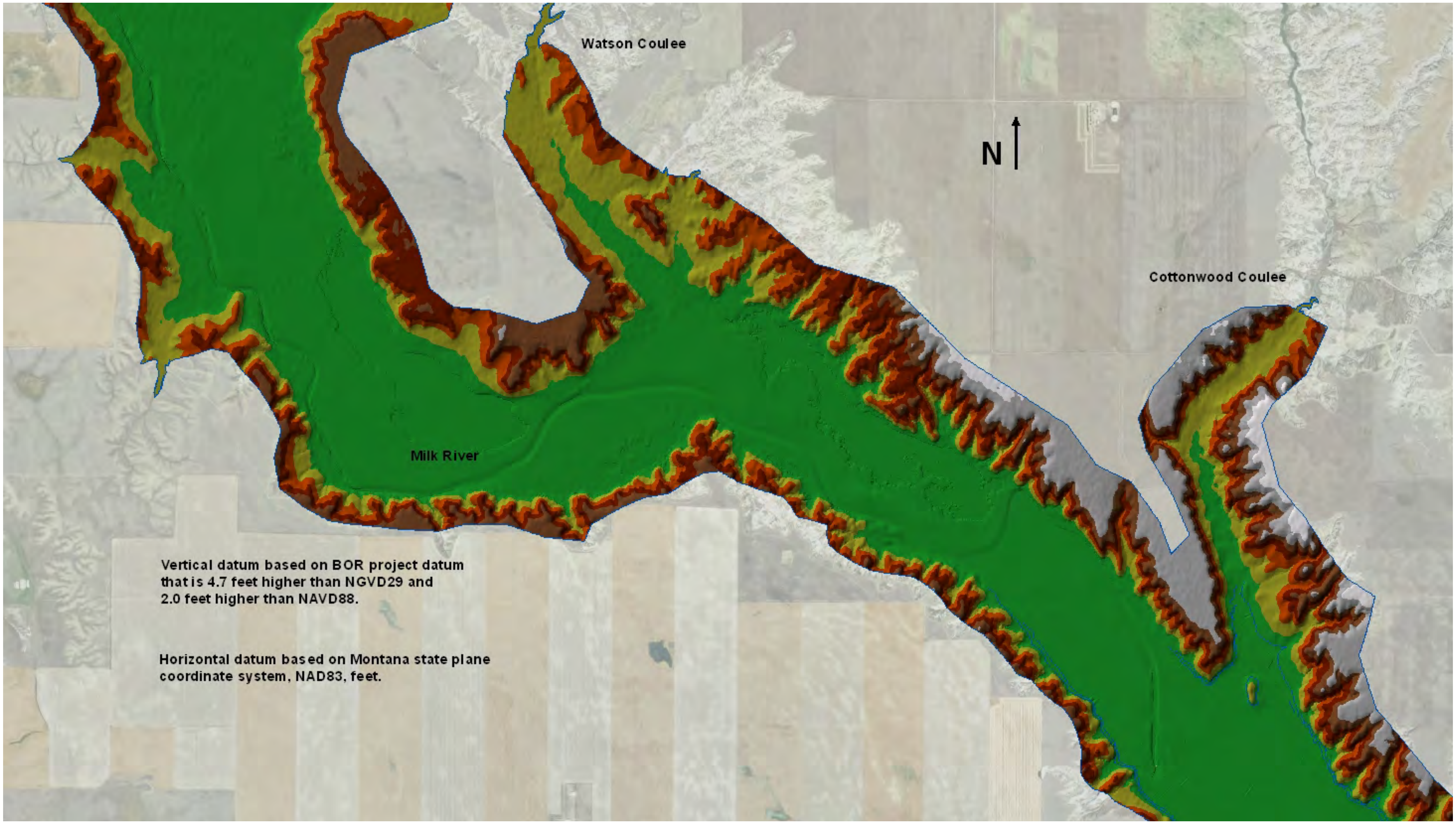

Figure 14 - Fresno Reservoir 2010 TIN, 4 of 7.

Figure 15 - Fresno Reservoir 2010 TIN, 5 of 7.

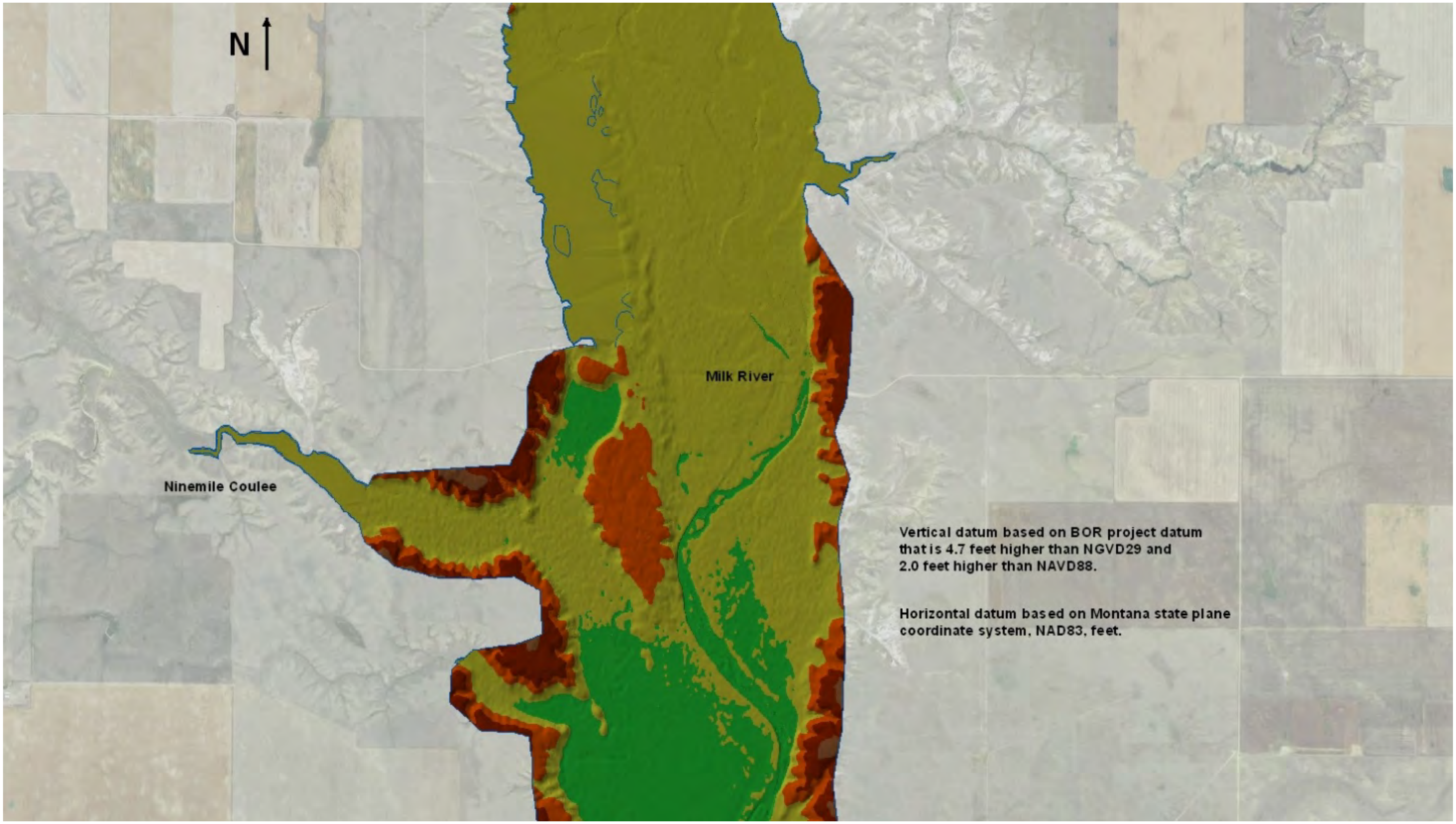

Figure 16 - Fresno Reservoir 2010 TIN, 6 of 7.

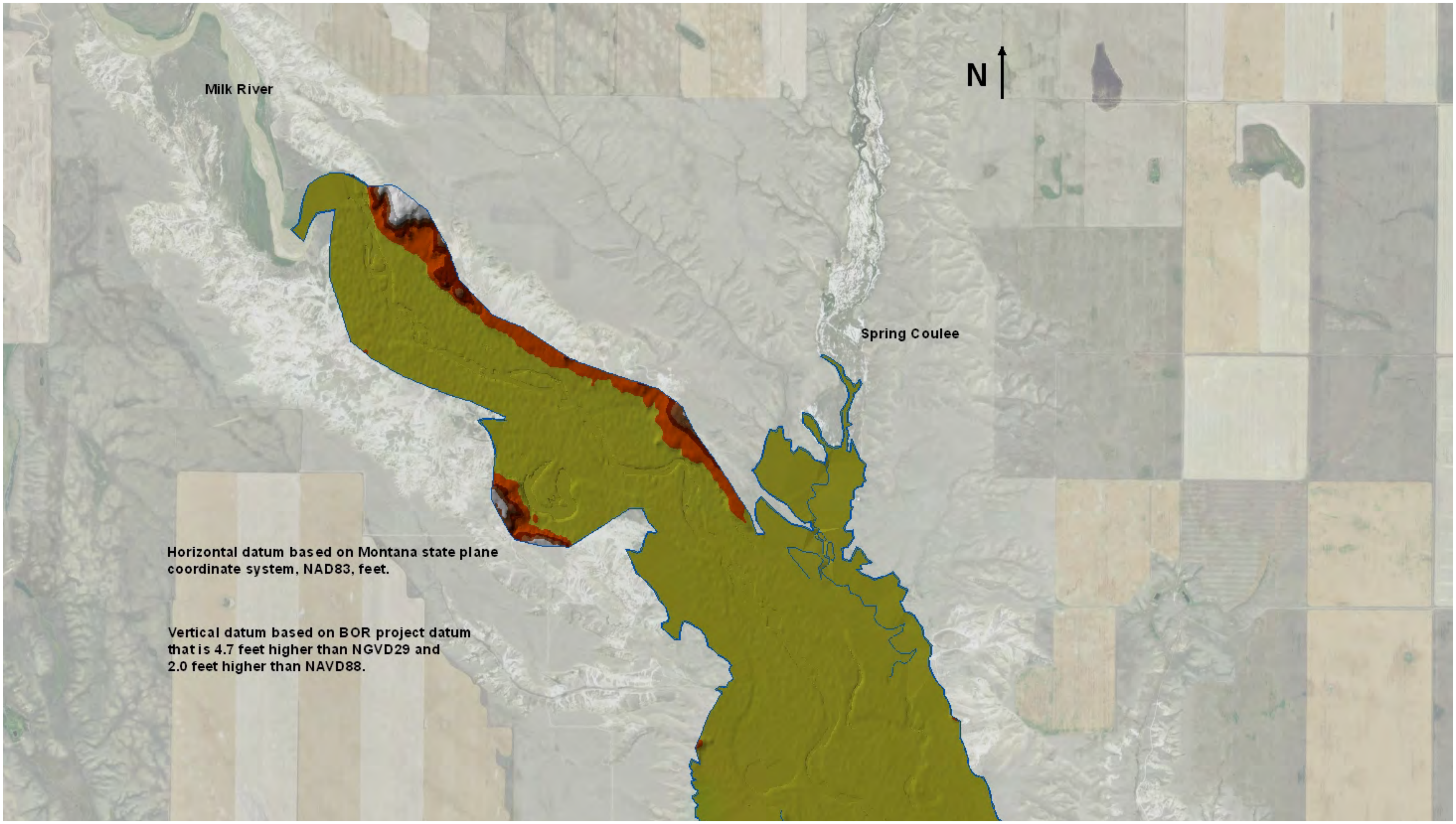

Figure 17 - Fresno Reservoir 2010 TIN, 7 of 7.

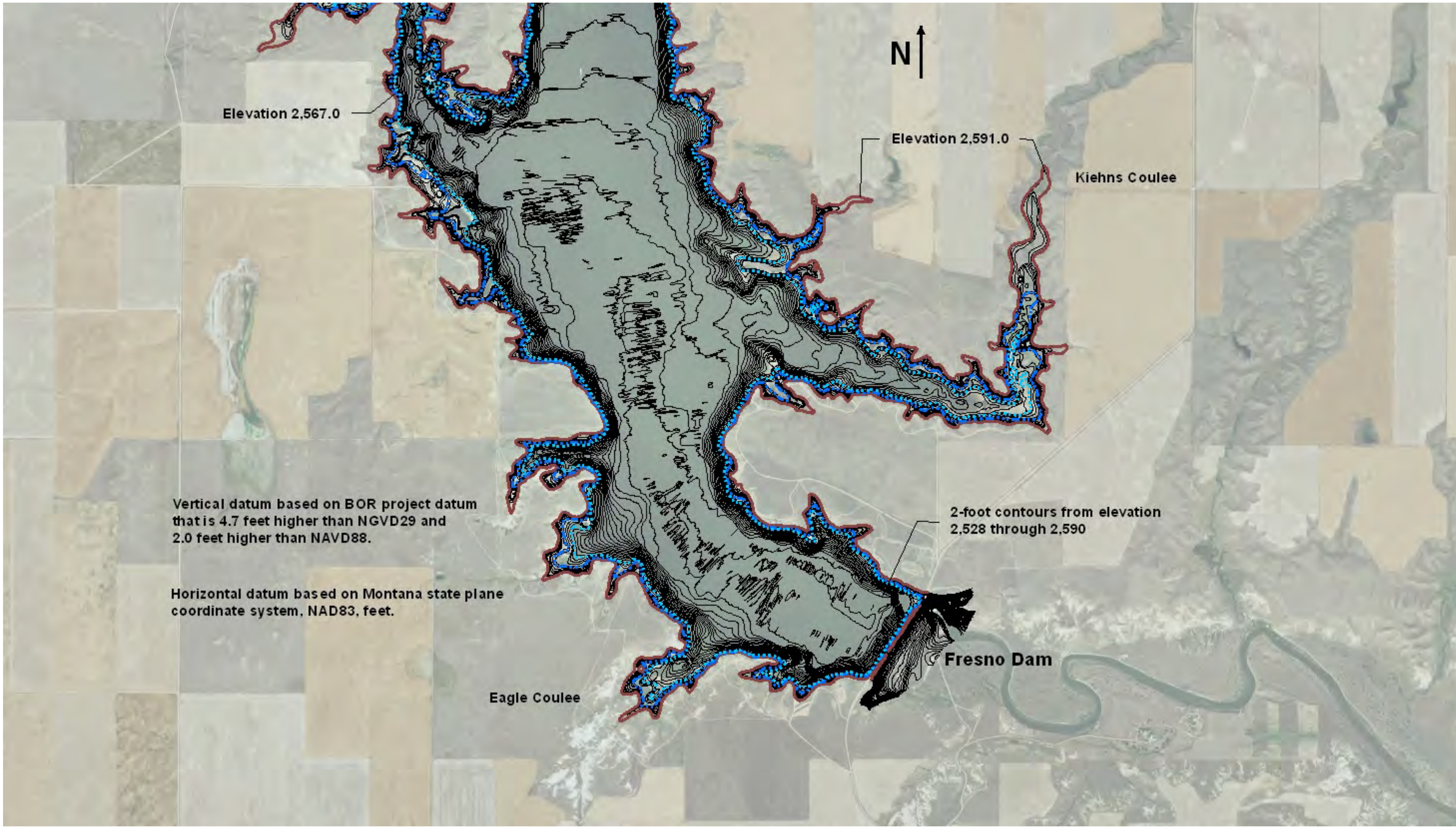

Figure 18 - Fresno Reservoir topography, 2-foot contours for elevation 2,528.0 through 2,590.0 (map 1 of 6).

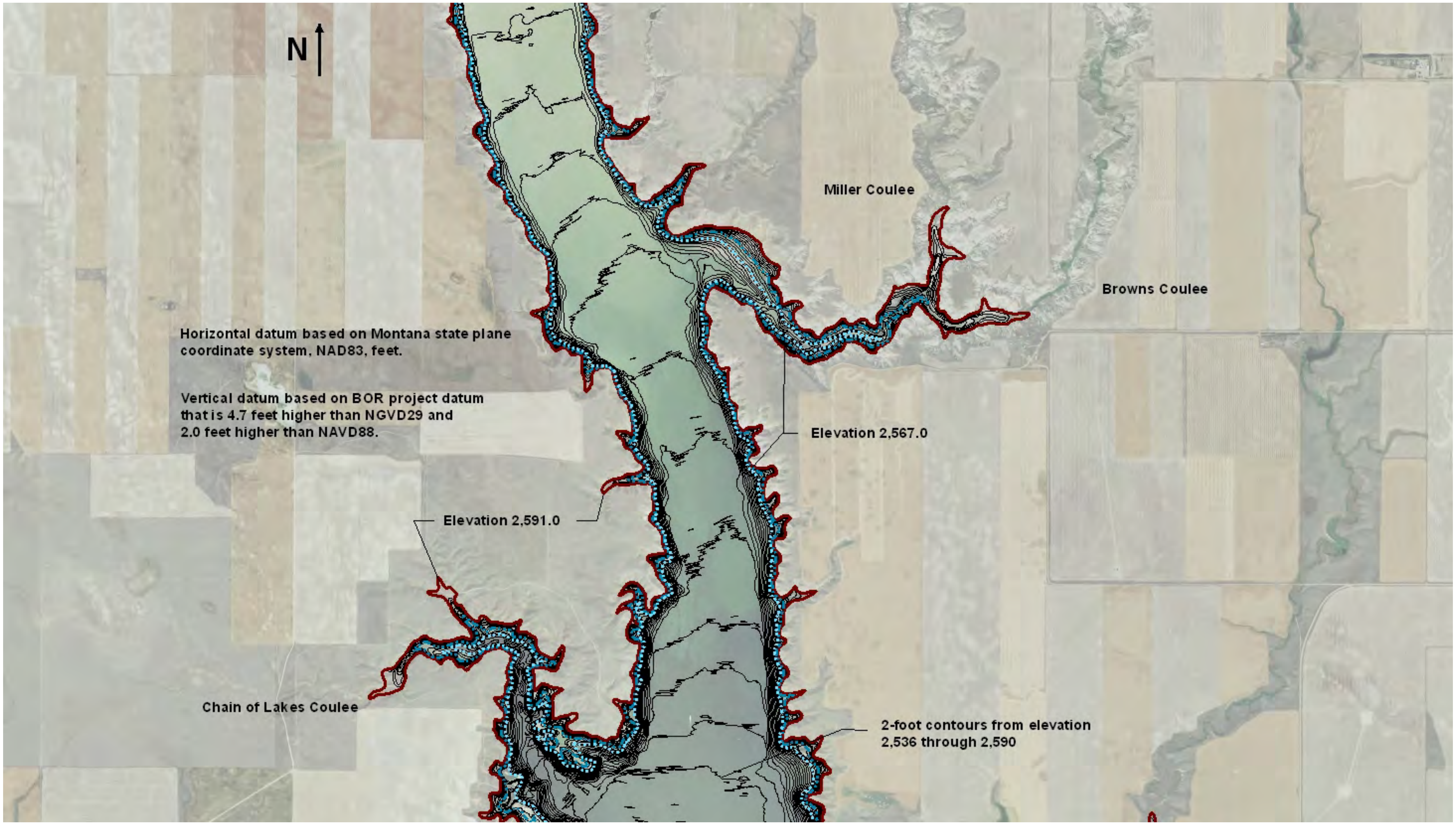

Figure 19 - Fresno Reservoir topography, 2-foot contours for elevation 2,536.0 through 2,590.0 (map 2 of 6).

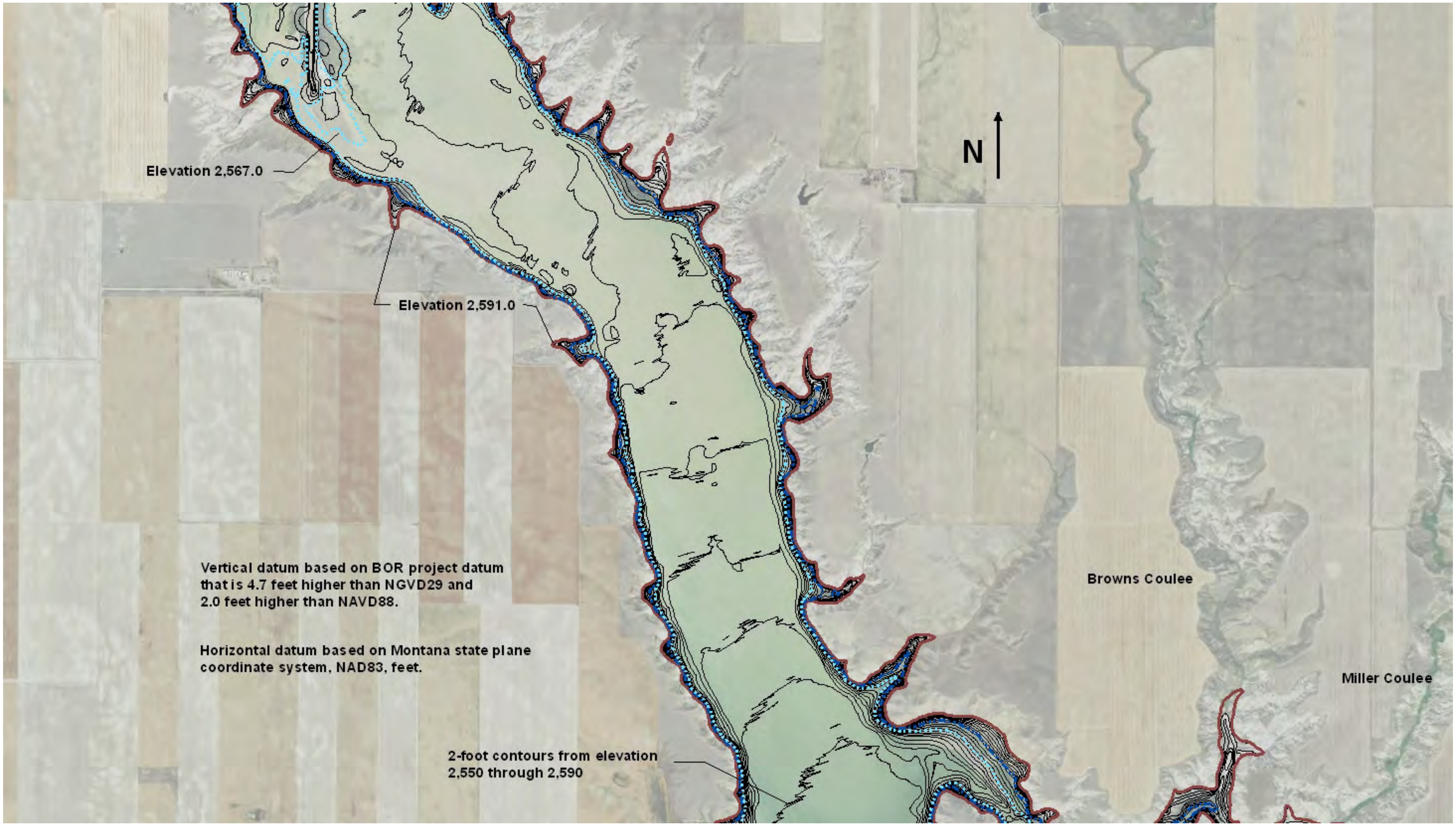

Figure 20 - Fresno Reservoir topography, 2-foot contours for elevation 2,550.0 through 2,590.0 (map 3 of 6).

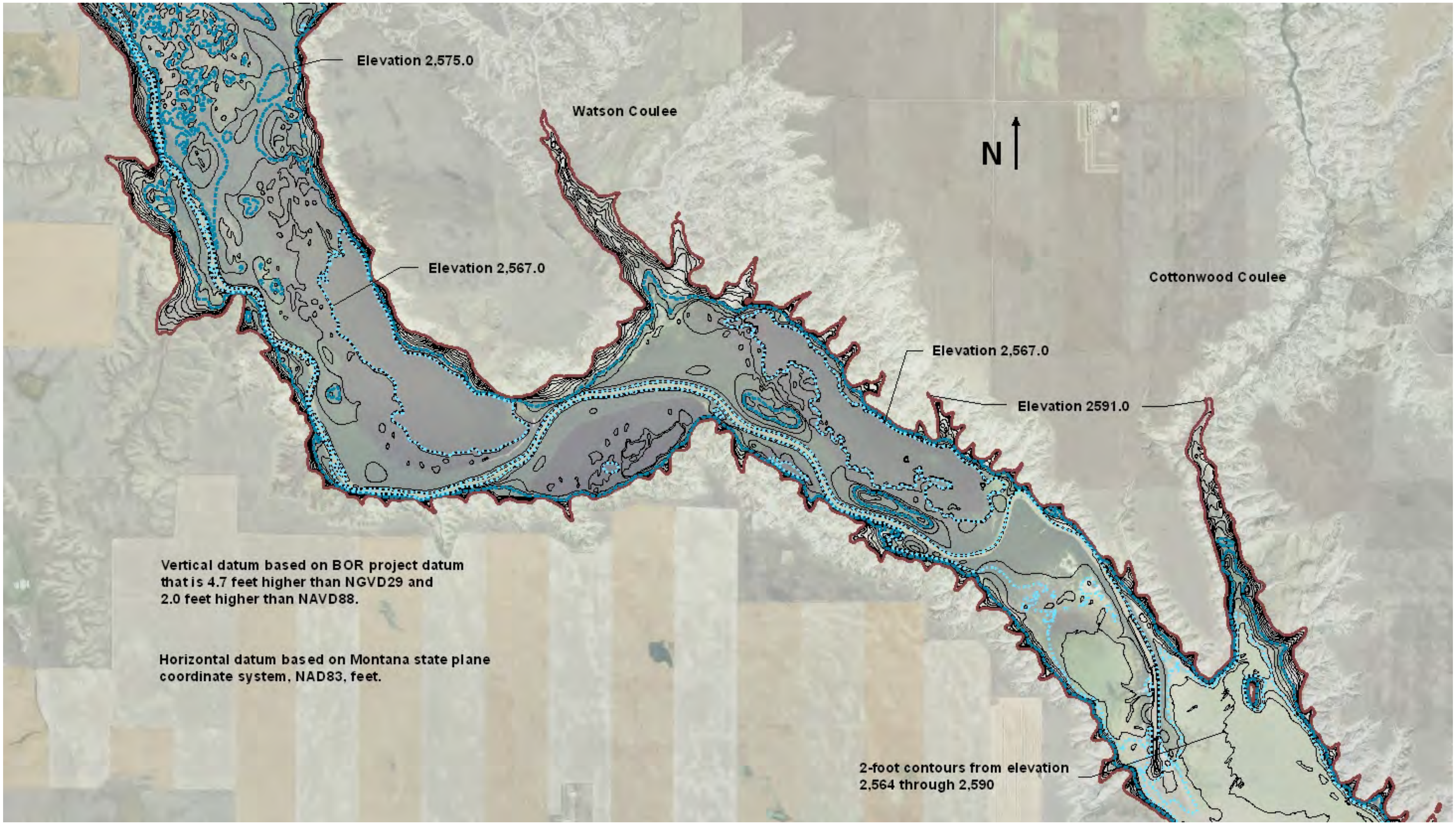

Figure 21 - Fresno Reservoir topography, 2-foot contours for elevation 2,564.0 through 2,590.0 (map 4 of 6).

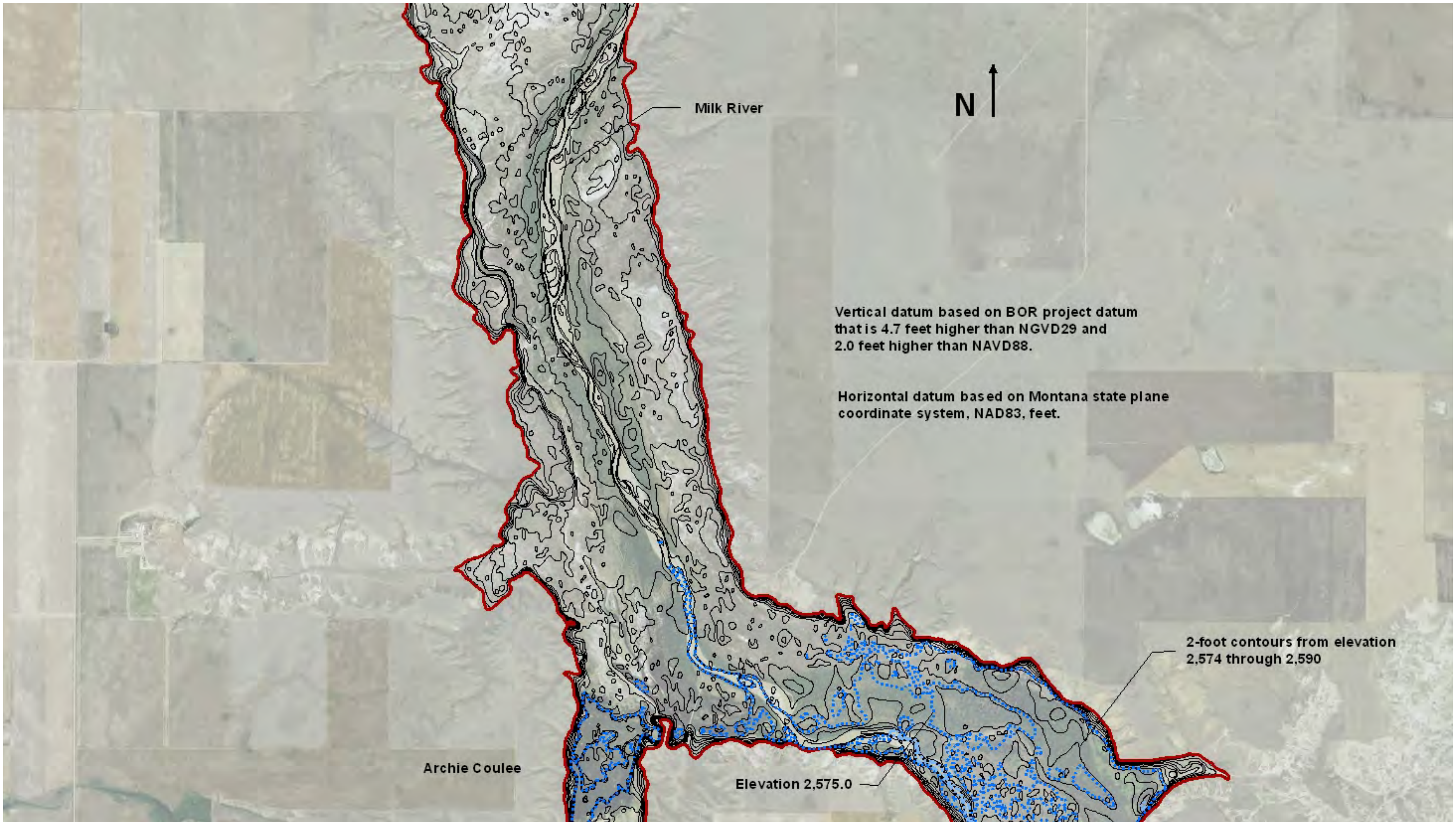

Figure 22 - Fresno Reservoir topography, 2-foot contours for elevation 2,574.0 through 2,590.0 (map 5 of 6).

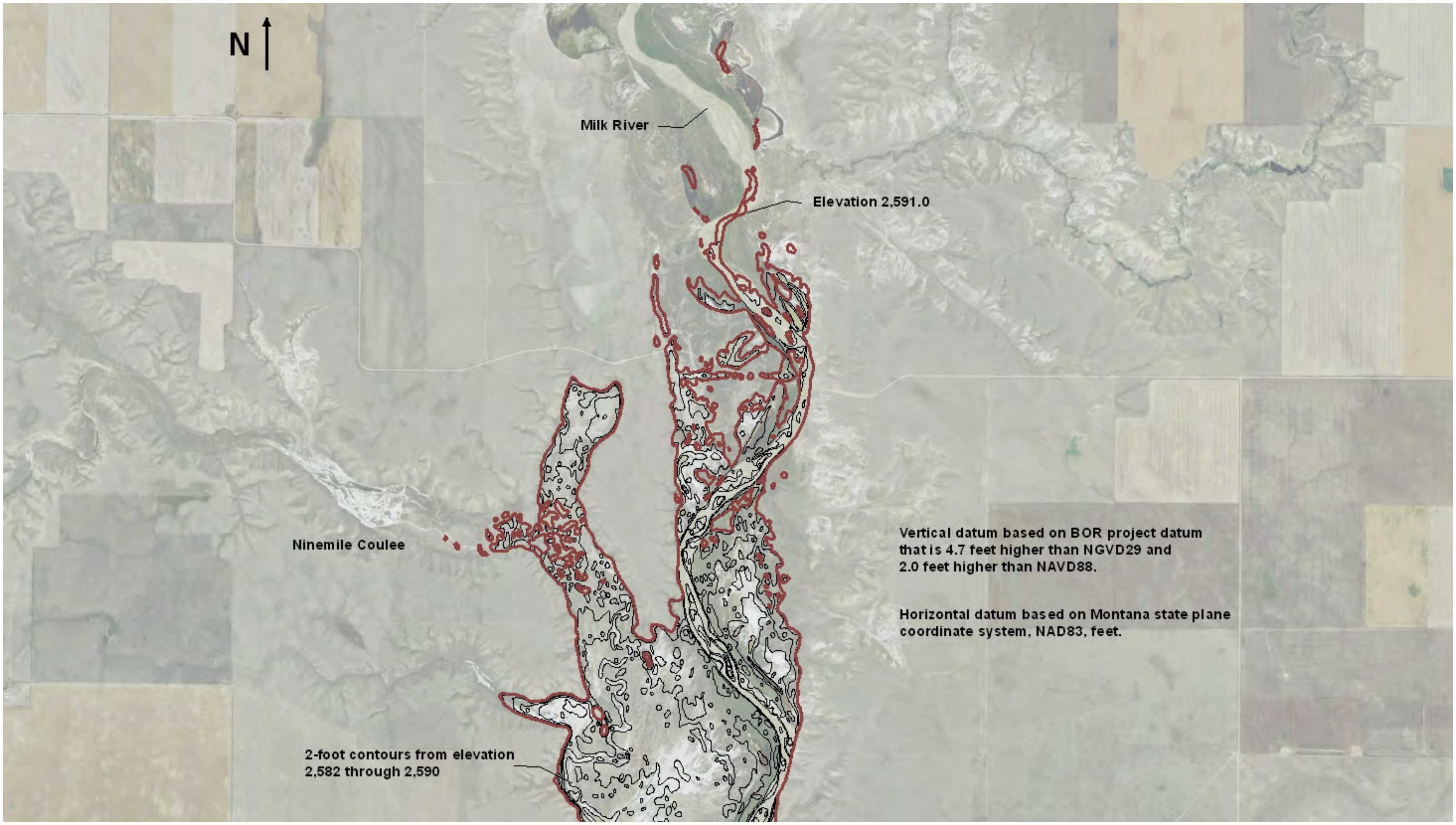

Figure 23 - Fresno Reservoir topography, 2-foot contours for elevation 2,582.0 through 2,590.0 (map 6 of 6)

2010 Fresno Reservoir Surface Area Methods

Using ArcGIS commands to compute areas at user-specified elevations, the 2010 surface areas for Fresno Reservoir were computed at 2- and 5-foot increments directly from the reservoir TIN from minimum elevation 2,528.0 to elevation 2,592.0 to provide information for the area-capacity tables. The upper most 2010 surface area entry was at elevation 2,592.0, developed from the IFSAR data set. A summary of the 2010 survey results and how they compare to previous survey results follows.

2010 Fresno Reservoir Storage Capacity Methods

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program can compute the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Fresno Reservoir. The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Through differentiation of the capacity equations, which are of second order polynomial form, final area equations are derived:

$$y = a_1 + a_2x + a_3x^2$$

where:

y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the Fresno Reservoir area and capacity computations are listed in a separate set of 2010 area and capacity tables and have been published for 0.01, 0.1, and 1-foot elevation increments (Bureau of Reclamation, 2010). A description of the computations and coefficients output from the ACAP program is included with those tables. As of June 2010, at joint use elevation 2,575.0, the surface area was 5,163 acres with a total capacity of 91,746 acre-feet. At maximum and top of surcharge elevation 2,591.0, the surface area was 8,769 acres with a total capacity of 204,010 acre-feet.

Fresno Reservoir Surface Area and Capacity Results

This section provides 2010 surface area and capacity results for Fresno Reservoir and evaluates changes over time. Table 1 provides a summary of the changes in Fresno Reservoir storage, inflow, and topography between the time of dam closure in November 1939, the June 1978 range line survey, May 1999 topographic survey, and the June 2010 topographic survey. The area and capacity curves for the original and all subsequent surveys are plotted on Figure 24. Table 2 provides a summary of all survey computed surface area and capacity values.

The 2010 bathymetric survey and the other data sources summarized in the *Topographic Development* section provided sufficient information for computing the surface areas from elevation 2,524.0 through 2,591.0. The ACAP program computed the area and capacity values from the 2- and 5-foot elevation input surface areas.

Longitudinal Distribution

To illustrate the reservoir bottom the Milk River thalweg was plotted from the dam upstream to around Cottonwood Coulee. The longitudinal profile (Figure 25) was developed by cutting a line through the 1999 and 2010 developed contours in ArcGIS. The 1999 profile ended at elevation 2,560, the upper contour developed from the survey data. The 2010 profile was cut through the developed 2-foot contours from the dam upstream through elevation 2,560, extending upstream to elevation 2,568 where the thalweg alignment could easily be distinguished. Developing the 2010 profile became complicated upstream of elevation 2,568 near Cottonwood Coulee where the upper sediment delta has formed, making it much more difficult to locate the thalweg. There is a distinguishable channel, similar to a canal, that meanders upstream, cutting through the reservoir sediment deposits and around the ponded areas, Figures 21 through 23. The channel width is small compared to the total width of the reservoir and allows low inflows to reach the main reservoir body. A thalweg could be developed through the canal alignment, but an average bottom elevation across the entire reservoir width would be a better representation. However, there is no previously collected data to compare to above elevation 2,560. Due to the lack of a clear thalweg upstream of Cottonwood Coulee, the 2010 thalweg profile was plotted from the dam upstream to the sediment delta, just above the end of the 1999 profile. The profiles provide a visual summary of the bottom of the reservoir for the normal operation levels, below elevation 2,575. The original topography was not available for comparison, but the 1999 and 2010 plots illustrate the change since 1999 and the current bottom condition from the dam upstream. The inlet sill to the outlet works, elevation 2,520, is currently below the measured top of sediment deposition near the dam. The lowest elevation measured during the 2010 survey was 2,524.2 with the first contour developed from the data near the dam at elevation 2,527.0, indicating the intake is surrounded by over 4 feet of deposited sediment. Minimum elevations from the 1978 and 1999 area and capacity tables(Table 2) suggest the sediment has been above the intake sill elevation since early dam operations. The original capacity table had a minimum elevation of 2,518, so the intake sill was likely designed to be near the original reservoir bottom. It appears the reservoir operations flush inflowing sediments entering near the intake downstream, allowing continuous operations. The minimum or inactive reservoir elevation is 2,530.0 which provides the minimum head needed for operation. All surveys how little change in sediment deposition at toe of the dam since the 1978 survey. The longitudinal profiles show little to no change from the dam upstream to around elevation 2,535. The 2010 profile does plot above the 1999 profile in this range, but the 1999 plot was developed from 5-foot contours while the 2010 profile was cut through 2-foot contours, so a true comparison is only possible at 10-foot increments.

RESERVOIR SEDIMENT
DATA SUMMARY

Fresno Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: Milk River	3. STATE: Montana
A	4. SEC 19 TWP. 33 N RANGE 14 E	5. NEAREST P.O. Havre	6. COUNTY Hill
M	7. LAT 48 ° 36 ' 30 " LONG 109 ° 56 ' 50 "	8. TOP OF DAM ELEVATION: 2,596.1 [1]	9. SPILLWAY CREST EL. 2,575.0 [2]

	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. Original SURFACE AREA, ACRES	13. Original CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
R	a. SURCHARGE	2,591.0 [3]				
E	b. FLOOD CONTROL					
S	c. POWER					11/1939
E	d. JOINT USE	2,575.0	5,757	40,430	129,062	16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION	2,567.0	4,374	86,770	88,632	
V	f. INACTIVE	2,530.0	505	1,862	1,862	
O	g. DEAD					4/1943
I R	17. LENGTH OF RESERVOIR 15 MILES		AVG. WIDTH OF RESERVOIR 0.5 MILES			

B	18. TOTAL DRAINAGE AREA 3,766 [4] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 13 [3] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA 2,911 [4] SQUARE MILES		23. MEAN ANNUAL RUNOFF 1.7 [5] INCHES
S	20. LENGTH MILES	AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 260,400 [6] ACRE-FEET
I N	21. MAX. ELEVATION 6,000	MIN. ELEVATION 2,500	25. ANNUAL TEMP, MEAN 42 °F RANGE -56 °F to 109 °F [3]

	26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/I RATIO AF/AF
S U R	11/39			Contour (D)	5-ft	5,757	129,090 [7]	0.50
V	6/78	38.7	38.7	Range (D)	223	4,878	103,980 [7]	0.40
E	5/99	20.9	59.5	Contour (D)	5-ft	4,878	92,880 [7]	0.36
Y	6/10	11.1	70.6	Contour (D)	2-ft	5,163 [8]	91,746 [8]	0.35

	26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	36. WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
D A T A	6/78	11.7	271,160 [6]	389,100	10,575,300	271,160	10,575,300
	5/99	13.0 [3]	247,620	362,000	5,175,200	264,700	15,750,300
	6/10		242,100	324,500	2,633,800	260,400	18,384,100

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
6/78	25,110 [9]	648.8	0.222	25,110	648.8	0.222
5/99	11,100	531.1	0.182	36,210	608.6	0.209
6/10	1,134	102.2	0.035	37,344	529.0	0.182

26. DATE OF SURVEY	39 AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	b. TOT.
6/78				0.500 [9]	19.40 [9]		
5/99				0.470	28.00		
6/10				0.410	28.90		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW AND ABOVE CREST ELEVATION										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	50-60	60-70	70-80	80-90	90-100	100-105	105-111	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

Table 1 - Reservoir sediment data summary (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION [10]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1940	2,548.8	2,531.0	175,200	1941	2,549.4	2,540.2	151,300
1942	2,567.6	2,542.0	265,100	1943	2,573.5	2,554.8	246,600
1944	2,564.8	2,554.3	128,900	1945	2,564.0	2,553.4	217,566
1946	2,560.7	2,555.0	230,000	1947	2,576.6	2,558.2	310,200
1948	2,577.3	2,562.6	288,200	1949	2,568.7	2,539.0	241,100
1950	2,563.4	2,538.0	264,400	1951	2,576.6	2,551.6	376,000
1952	2,579.3	2,556.7	370,700	1953	2,578.7	2,563.0	380,000
1954	2,576.4	2,564.2	256,800	1955	2,577.2	2,563.8	268,300
1956	2,575.3	2,561.4	249,200	1957	2,576.0	2,560.1	259,000
1958	2,576.4	2,549.7	284,600	1959	2,576.6	2,548.7	334,600
1960	2,576.4	2,553.8	297,400	1961	2,558.2	2,532.4	210,500
1962	2,564.9	2,542.2	243,200	1963	2,562.6	2,550.9	237,500
1964	2,571.6	2,552.0	266,200	1965	2,577.8	2,560.6	343,300
1966	2,575.8	2,565.6	269,700	1967	2,576.8	2,559.4	389,000
1968	2,571.4	2,562.0	285,100	1969	2,577.9	2,565.0	330,500
1970	2,575.2	2,561.4	219,200	1971	2,574.6	2,543.2	246,500
1972	2,575.2	2,552.2	360,700	1973	2,568.4	2,543.4	176,300
1974	2,575.8	2,540.1	275,600	1975	2,577.4	2,564.8	333,800
1976	2,575.6	2,560.0	287,700	1977	2,565.2	2,540.6	116,200
1978	2,577.2	2,543.5	333,500	1979	2,576.6	2,558.6	262,900
1980	2,572.0	2,547.5	250,400	1981	2,568.8	2,552.0	285,400
1982	2,575.5	2,543.9	227,500	1983	2,564.0	2,541.4	184,700
1984	2,563.8	2,537.2	151,300	1985	2,561.3	2,536.5	231,800
1986	2,575.8	2,556.5	241,300	1987	2,575.5	2,563.7	198,000
1988	2,573.7	2,540.2	164,600	1989	2,568.6	2,536.6	296,400
1990	2,576.6	2,556.3	321,400	1991	2,575.9	2,557.9	325,000
1992	2,572.4	2,551.8	161,300	1993	2,575.1	2,549.0	319,100
1994	2,577.4	2,557.8	305,400	1995	2,575.6	2,559.7	245,100
1996	2,577.6	2,556.6	362,000	1997	2,576.6	2,561.5	320,800
1998	2,572.7	2,557.8	247,400	1999	2,571.8	2,557.9	208,200
2000	2,567.8	2,540.8	181,600	2001	2,556.5	2,540.7	124,000
2002	2,576.6	2,536.0	324,500	2003	2,575.3	2,549.2	239,800
2004	2,569.5	2,546.3	187,000	2005	2,575.6	2,558.0	216,200
2006	2,575.5	2,553.9	258,600	2007	2,575.3	2,558.9	218,700
2008	2,575.9	2,554.0	235,300	2009	2,575.2	2,556.7	221,000
2010	2,577.7	2,557.3	292,500				

46. ELEVATION - AREA - CAPACITY - DATA FOR **2010**								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2010	**SURVEY**		2,524.0	0	0	2,525.0	3	1
2,526.0	5	5	2,528.0	11	22	2,530.0	126	158
2,532.0	277	561	2,534.0	505	1,343	2,535.0	626	1,908
2,536.0	747	2,594	2,538.0	905	4,246	2,540.0	1,022	6,172
2,542.0	1,120	8,313	2,544.0	1,228	10,661	2,545.0	1,290	11,920
2,546.0	1,353	13,241	2,548.0	1,463	16,057	2,550.0	1,615	19,135
2,552.0	1,737	22,487	2,554.0	1,842	26,066	2,555.0	1,901	27,938
2,556.0	1,960	29,868	2,558.0	2,108	33,937	2,560.0	2,285	38,330
2,562.0	2,450	43,064	2,564.0	2,817	48,331	2,565.0	3,078	51,279
2,566.0	3,339	54,487	2,567.0	3,496	57,905	2,568.0	3,653	61,480
2,570.0	3,898	69,031	2,572.0	4,446	77,374	2,575.0	5,163	91,746
2,576.0	5,430	97,043	2,578.0	5,911	108,384	2,580.0	6,320	120,616
2,582.0	6,717	133,653	2,584.0	7,242	147,612	2,585.0	7,514	154,990
2,586.0	7,786	162,640	2,588.0	8,197	178,623	2,590.0	8,537	195,357
2,591.0	8,769	204,010						

47. REMARKS AND REFERENCES

[1] Design elevations tied to project vertical datum. Raised 2 feet in 1943 to restore original camber due to excessive foundation settlement. Project vertical datum 4.71 feet higher than NGVD29 and 2.0 feet higher than NAVD88.

[2] Uncontrolled spillway crest elevation.

[3] Bureau of Reclamation Project Data Book, www.usbr.gov, and SOP for Fresno Dam and Reservoir, September 2000.

[4] Total drainage area and contributing from Reclamation flood studies. Some areas within basin are closed and do not contribute inflow.

[5] Calculated using mean annual runoff value, item 24.

[6] Computed annual inflow from 1940 through June 2010. Some inflow diverted through St. Mary's canal.

[7] Surface area and capacity values at elevation 2,575.0 computed by ACAP.

[8] 2010 capacities computed by Reclamation's ACAP program. Surface areas from bathymetric survey and high flight LiDAR.

[9] Capacity loss calculated by comparing capacity at reservoir elevation 2,575.0 by year of survey.

[10] Maximum and minimum elevations and inflow values in acre-feet by water year, from 1940 through June 2010.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE September 2012

Table 1 - Reservoir sediment data summary (page 2 of 2).

1	2	3	4	5	6	7	8	9	10	11	12	13
					1978			1999			2010	
	Original	Original	1978	1978	Sediment	1999	1999	Sediment	2010	2010	Sediment	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Area	Capacity	Volume	Area	Capacity	Volume	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Depth
2,591.0			8,601	212,209		8,601	202,117		8,769	204,010		100.0
2,590.0			8,369	204,733		8,369	193,633		8,537	195,357		98.6
2,585.0	8,250	195,962	7,397	165,318	30,644	7,397	154,218	41,744	7,514	154,990	40,972	91.8
2,580.0	6,674	160,144	6,130	131,500	28,644	6,130	120,400	39,744	6,320	120,616	39,528	84.9
2,575.0	5,757	129,090	4,878	103,980	25,110	4,878	92,880	36,210	5,163	91,746	37,344	78.1
2,570.0	4,882	102,502	3,904	82,025	20,477	3,864	71,025	31,477	3,898	69,031	33,471	71.2
2,567.0	4,374	88,632	3,504	70,913	17,719	3,256	60,346	28,286	3,496	57,905	30,727	67.1
2,565.0	4,043	80,220	3,237	64,173	16,047	2,850	54,240	25,980	3,078	51,279	28,941	64.4
2,560.0	3,398	61,768	2,752	49,200	12,568	2,342	41,260	20,508	2,285	38,330	23,438	57.5
2,555.0	2,930	45,963	2,357	36,428	9,535	2,001	30,403	15,560	1,901	27,938	18,025	50.7
2,550.0	2,523	32,389	2,040	25,435	6,954	1,701	21,148	11,241	1,615	19,135	13,254	43.8
2,545.0	2,088	20,761	1,753	15,953	4,808	1,399	13,398	7,363	1,290	11,920	8,841	37.0
2,540.0	1,511	11,775	1,254	8,435	3,340	1,096	7,160	4,615	1,022	6,172	5,603	30.1
2,535.0	983	5,561	784	3,340	2,221	705	2,658	2,903	626	1,908	3,653	23.3
2,530.0	505	1,862	275	693	1,169	179	448	1,414	126	158	1,704	16.4
2,525.0	115	377	1	0	377	0	0	377	3	1	376	9.6
2,520.0	36	0	0	0	0	0	0	0	0	0	0	2.7
2,518.0	0	0	0	0	0	0	0	0	0	0	0	0.0

1 Reservoir water surface elevations tied to project datum that are 4.7 feet higher than NGVD29 and 2.0 feet higher t

2 Original 1939 reservoir surface area.

3 Original 1939 reservoir capacity recomputed using ACAP.

4 1978 reservoir surface areas by a combined bathymetric and aerial surveys.

5 1978 reservoir capacity recomputed using ACAP.

6 1978 computed sediment volume, column (3) - column (5).

7 1999 surface area. Study projected areas at el. 2,565 through 2,570. Assume no change since 1978 from el. 2,575 a

8 1999 reservoir capacity.

9 1999 computed sediment volume, column (3) - column (9).

10 2010 measured reservoir surface area.

11 2010 reservoir capacity computed using ACAP.

12 2010 measured sediment volume, column (3) - column (13).

13 Depth of reservoir expressed in percentage of total depth, 73 feet.

Table 2 - Fresno Reservoir 2010 survey summary.

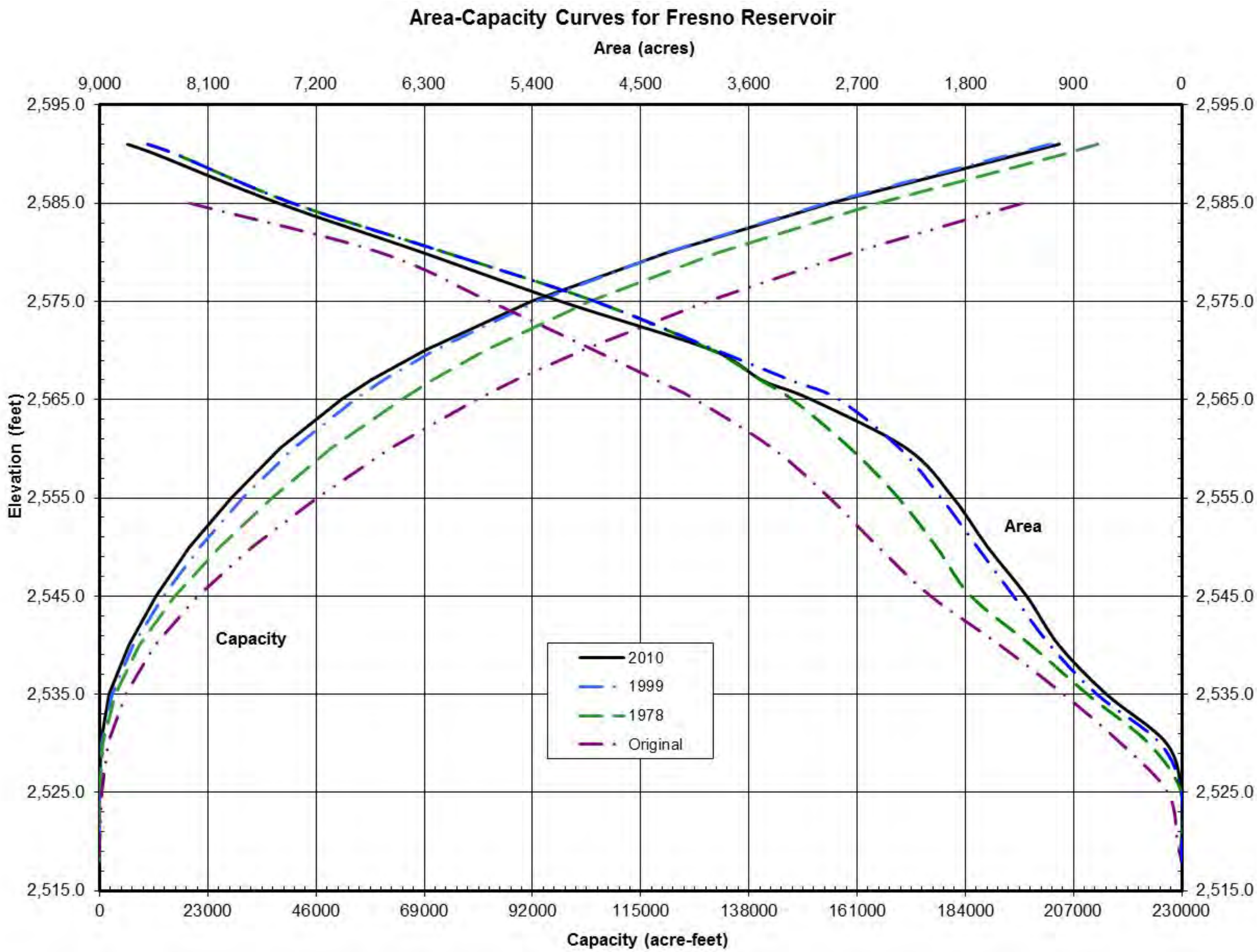

Figure 24 - Fresno Reservoir area and capacity plots.

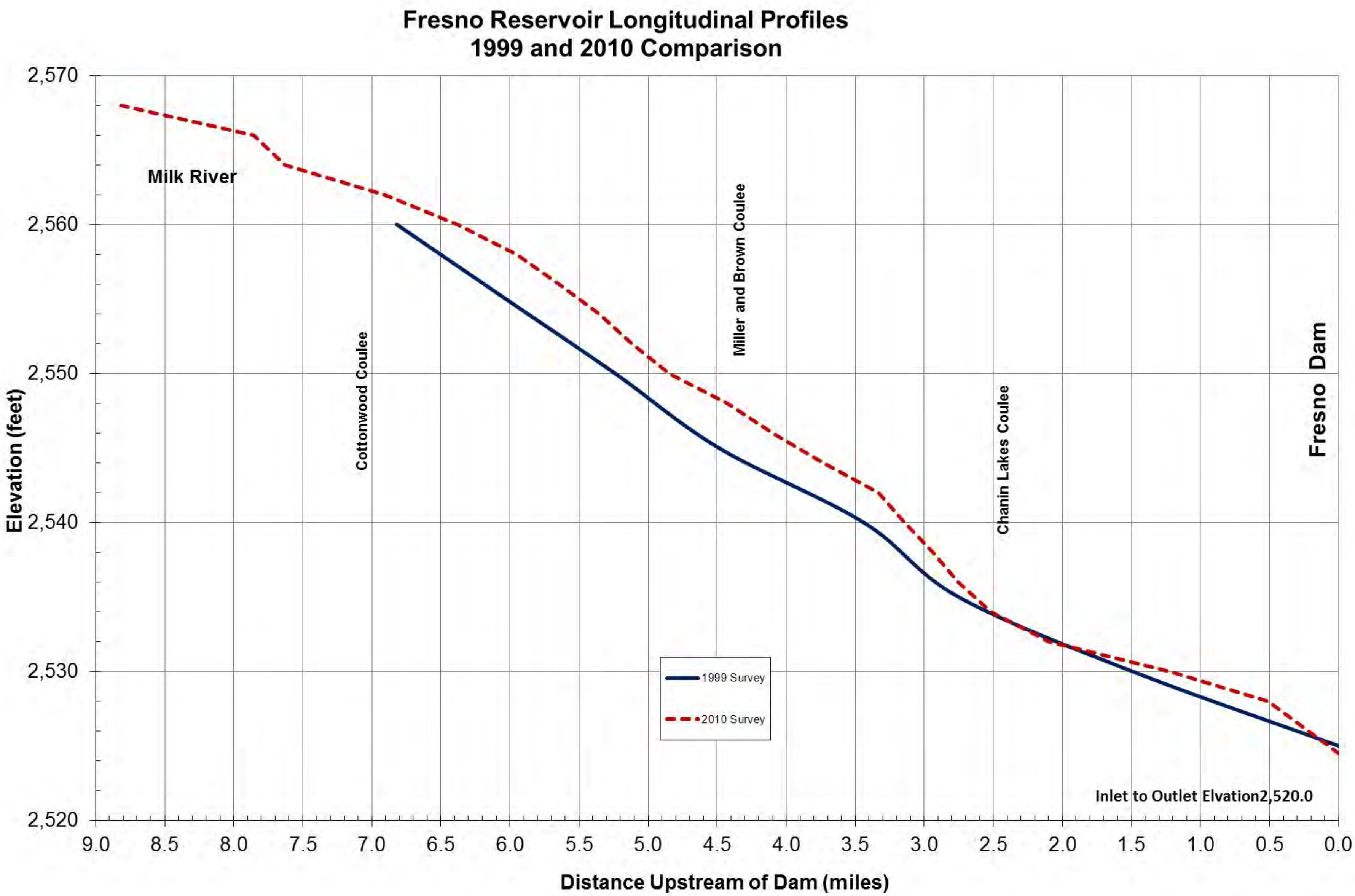

Figure 25 **- Longitudinal profile of the Milk River from the dam upstream.**

2010 Fresno Reservoir Analyses

Results of the 2010 Fresno Reservoir area and capacity computations are listed in Table 1 and columns 10 and 11 of Table 2. Columns 2 and 3 in Table 2 list the original area and capacity values recomputed using the ACAP program. The tables also list the area and capacity results for the 1978 and 1999 surveys. Figure 24 is a plot illustrating the differences in the Fresno Reservoir surface area and capacity values for the various surveys.

Table 1 lists the joint use capacity at elevation 2,575.0 for all surveys along with the computed differences due to sediment deposition and methods of data collection for all survey years. The 2010 survey only measured a small decrease in capacity, 1,134 acre feet, since the 1999 survey. The minor capacity loss might have been a result of lower sediment inflow, but it was more likely due to an over estimation of the storage loss during the 1999 survey analysis. The 1999 study only surveyed up to elevation 2,560, requiring changes from the 2,560.0 contour to elevation 2,575.0 to be projected using the surface area results from the 1978 survey. Due to the limited above water information, the 1999 study assumed no change from elevation 2,575 and above.

Table 2 compares results from the original, 1978, 1999 and 2010 surveys. As stated previously, due to lack of reliable above water data, the 1999 study assumed no change from the 1978 survey from elevation 2,575.0 and above. The 2010 survey used the IFSAR data for developing the total reservoir contours from around elevation 2,575 and above. As seen on the surface area plots, Figure 24, there appears to be little change from elevation 2,570 and above since the 1978 survey. Most of the plotted change may be due to differences in data collection methods between the surveys. The biggest plotted changes were between the original surface areas and the 1978 survey results. The 1978 above water topography was collected using aerial techniques and a large portion of the plotted change could be due to accuracy and precision differences between the two methods of collection. Fresno Dam closed in 1939 and it's possible the original topography was developed using a plane table type survey which wouldn't capture the detail of the deep canyons or coulees that form the reservoir.

A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted. Due to the relatively minor measured change in reservoir capacity since the 1978 survey at elevation 2,530 and below, it appears present reservoir operations are effectively flushing the finer sediments downstream through the outlets and not allowing material to deposit in the lower elevations near the outlet. However, the 2010 survey does show the deposited sediments are above the intake where a possible collapse could affect the outlet operations.

Summary and Conclusions

This Reclamation report presents the results of the June 2010 survey of Fresno Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography;
- compute area-capacity relationships; and
- estimate storage depletion by sediment deposition since dam closure.

A control survey was conducted using the online positioning user service (OPUS) and RTK GPS to establish a horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the NGS and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over a temporary rebar and cap located where it provided continuous radio link throughout the bathymetric survey.

The study's horizontal control was in international feet, Montana state plane coordinates, in NAD83. The vertical control, in US survey feet, was tied to the project's vertical datum that is around 4.7 feet higher than NGVD29 and 2.0 feet higher than NAVD88. Unless noted, all elevations and the developed reservoir topography presented in this report are referenced to the project vertical datum. The June 2010 underwater survey was conducted near reservoir elevation 2,575.0 as measured by the Reclamation gage at the dam and confirmed by RTK GPS measurements.

The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates as the survey boat navigated along grid lines covering Fresno Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines.

The above-water topography for the 2010 field survey was determined by digitizing contour lines from the USGS quads of the reservoir area. These contour outlines were used to assure coverage of the reservoir during the June survey. During analysis, the water surface edges of orthographic aerial images (USDA, 2010) were digitized for topographic development. The water surface elevation for these aerial photos ranged from elevation 2,761.4 to 2,572.8.

Airborne collected digital data was obtained as IFSAR bare-earth information for the reservoir area (Intermap, 2011). IFSAR technology enables mapping of large areas quickly and efficiently, resulting in detailed information at a much reduced cost compared to other technologies such as aerial photogrammetry and LiDAR. The reported accuracies for the IFSAR data are 2 meters or better horizontally and 1 meter or better vertically in unobstructed flat-ground areas. Other technologies would produce more accurate data than IFSAR, but funding was not available for this study to acquire those other data sets. The IFSAR data produced detailed topography of the upper reservoir area and the elevations matched well with the USDA aerial images and 2010 bathymetric data setsfor this study.

The 2010 Fresno Reservoir topographic map is a combination of the digitized water surface edge from the USDA photographs, IFSAR data, and 2010 underwater survey data, all tied to the project vertical datum. A computer program was used to generate the 2010 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data from elevation 2,591.0 and below. The 2010 area and capacity tables were produced by a computer program (ACAP) that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique.

Tables 1 and 2 contain summaries of the Fresno Reservoir and watershed characteristics for the 2010 survey. The 2010 survey determined the reservoir has a total storage capacity of 204,010 acre-feet with a surface area of 8,769 acres at maximum reservoir water surface elevation 2,591.0. At joint use water surface elevation 2,575.0 the total capacity was 91,746 acre-feet with a surface area of 5,163 acres. Since closure of Fresno Dam in November 1939, this survey measured a 37,344 acre-foot of total loss in reservoir capacity below elevation 2,575.0. The losses were computed by comparing the original recomputed capacities and the 2010 capacities for the reservoir. The measured loss was due to sediment deposition and data accuracy differences between methods of collection and analysis.

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14. ABSTRACT

Reclamation surveyed Fresno Reservoir in June 2010 to develop updated reservoir topography and compute present storage-elevation relationships (area-capacity tables). The bathymetric survey, conducted near water surface elevation 2,575.5 (project datum in feet), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was developed by digitizing the reservoir’s water edge from aerial photographs collected by the United States Department of Agriculture (USDA) and high altitude bare earth data from Interferometric Synthetic Aperture Radar (IFSAR).

As of June 2010, at joint use elevation 2,575.0, the reservoir surface area was 5,163 acres with a capacity of 91,746 acre-feet. Since November 1939 dam closure, a total capacity change of 37,344 acre-feet below elevation 2,575.0 was measured, equal to an average annual loss of 529.0 acre-feet. The capacity change is due to sediment deposition and methodology differences between the various survey studies.

15. SUBJECT TERMS

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