RECLAMATION
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Technical Report No. SRH-2012-01

Gibson Reservoir 2009 Bathymetric Survey

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

June 2012

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Gibson Reservoir 2009 Bathymetric Survey

prepared by

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

June 2012

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (Sedimentation) Group of the Technical Service Center (TSC) prepared and published this report. Kent Collins and Ron Ferrari of the Sedimentation Group conducted the bathymetry survey of the reservoir in June 2009. Ron Ferrari completed the data processing to generate the 2009 topographic map and area-capacity tables 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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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
June 2012		

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
Gibson Reservoir 2009 Bathymetric Survey	**5b. GRANT NUMBER**
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Ronald L. Ferrari	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Bureau of Reclamation, Technical Service Center, Denver, CO 80225	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Denver Federal Center, PO Box 25007 Denver, CO 80225-0007	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Reclamation surveyed Gibson Reservoir in June 2009 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The bathymetric survey was conducted near top of conservation pool water surface elevation 4,724.0 (project datum in feet). The collection was conducted using a multibeam sonic depth sounder interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous and detailed sounding positions throughout the underwater portion of the reservoir covered by the survey vessels. The above-water topography was developed from a combination of digital bare earth Interferometric Synthetic Aperture Radar (IFSAR) data and digitized water's edge data from aerial photographs collected by the United States Department of Agriculture (USDA).

As of June 2009, at active conservation pool elevation 4,724.0, the reservoir surface area was 1,334 acres with a total capacity of 98,688 acre-feet. Since the December 1929 dam closure, a total capacity change of 6,172 acre-feet below elevation 4,724.0 was measured, equal to an average annual loss of 77.5 acre-feet. The capacity change is due to sediment deposition and accuracy differences between the 2009 and previous surveys. The 2009 study measured an increase volume of 2,211 acre-feet from the 1996 survey result that was conducted using a single beam system. The 2009 multibeam survey provided much greater detail along the steep vertical banks than what was obtained from previous surveys, possibly accounting for portions of the measured differences.

15. SUBJECT TERMS
reservoir area and capacity/ sedimentation/ reservoir surveys/ global positioning system/ sounders/ contour area/ RTK GPS/ multibeam/

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

BUREAU OF RECLAMATION

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

Technical Report No. SRH-2012-01

Gibson Reservoir 2009 Bathymetric Survey

Gibson Dam
Montana

11/21/2012

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11/21/2012

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Date

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Introduction

Gibson Dam and Reservoir, principal features of the Sun River Project, are located within Teton and Lewis-Clark Counties on the North Fork of the Sun River about 24 miles northwest of Augusta and 75 miles west of Great Falls, Montana (Figure 1). Additional features of the project are the Willow Creek Dam and Reservoir, Pishkun Dikes and Reservoir, Sun River Diversion Dam, and Fort Shaw Diversion Dam. The dam, operated by the Greenfields Irrigation District, releases water to supplement natural river flows used for irrigation of Sun River Project lands for the Greenfields and Fort Shaw irrigation districts.

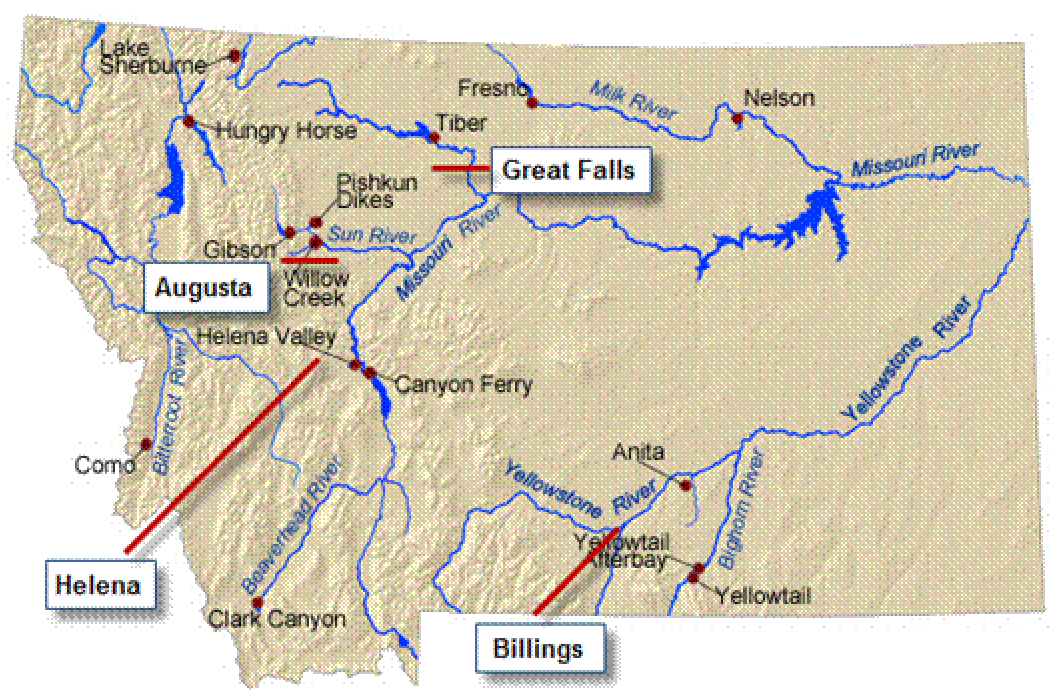

Figure 1 - Reclamation Reservoirs Located in Montana.

Gibson Dam was constructed between 1926 and 1929 with first storage in December 1929, Figure 2. The drainage area above the dam is 575 square miles, ranging from elevation 4,557.5 (feet), top of dead pool, to greater than 8,800 at its head waters. At elevation 4,724 the reservoir length is around 5.2 miles with an average width of 0.4 miles. The dam is a massive concrete arch structure with the following dimensions:

Structural height[1]	199 feet	Hydraulic height	195 feet
Crest length	960 feet	Crest elevation[2]	4,725.0
Top width	15 feet	Top of parapet wall	4,729.0

Figure 2 – Downstream face of Gibson Dam.

The design maximum controllable water surface (top of spillway radial gates) is elevation 4,724.0. The maximum historical water surface, elevation 4,732.23, occurred on June 8, 1964. A record inflow of 60,000 cubic feet per second (cfs) caused Gibson Dam to overtop the parapet wall for 20 hours without serious

[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 by this study to be 7.5 feet lower than the North American Vertical Datum of 1988 (NAVD88). The contour topography presented in this report is tied to NAVD88.

damage. After the 1964 flood event, modifications were made to protect the dam and foundation and provide for safe overtopping of flows greater than the 100-year flood. Gibson Dam's spillway, located through the left abutment, is a drop-type structure controlled by six 34-foot-wide by 12-foot-high radial gates. The radial gates were installed in 1938 to provide 15,000 acre-feet of additional storage. The spillway crest elevation is 4,712.0 with the top of the spillway radial gates at elevation 4,724.0. The spillway provides a discharge of 31,200 cfs at top of active conservation elevation 4,724 and 41,400 cfs at top of the parapet wall elevation 4,729.0. The discharge enters a 29.5-foot-diameter vertical shaft and turns into a horizontal tunnel before discharging into the river below.

The outlet works consist of a trashrack, two 72-inch-diameter steel-lined conduits through the base of the dam, and a 60-inch jet-flow gate in each conduit that controls flows. The jet-flow gates, installed in 1971-72, replaced two original needle valves. Five-foot-square, hydraulically operated, high-pressure emergency slide gates are located upstream of the jetflow gates. The intake elevation of the river outlet is 4,557.5. The discharge capacity is 3,050 cfs at reservoir elevation 4,724.0.

Control Survey Data Information

Prior to the 2009 bathymetric survey, a control network was established by a Reclamation contractor that set two brass caps on top of the dam, Figures 3 and 4. The “Set 2” point was used as the GPS base for the 2009 bathymetric survey. The horizontal control was in Montana’s state plane coordinates, international feet (SI), in NAD83 and the vertical control was tied to NAVD88 in US survey feet. Unless noted, all elevations and computations within this report are referenced to Reclamation’s project datum that is 7.5 feet lower than NAVD88. The developed topographic maps are tied to NAVD88. As a check for this study, collected base information was submitted to the online positioning user service (OPUS) as confirmation of the horizontal and vertical control network. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files to be processed with known point data to determine positions relative to the National Spatial Reference System (NSRS). Following are the provided coordinates of the two set brass caps used by this study:

	Set 1	**Set 2**
North	1,238,860.6 (SI)	1,238,209.9 (SI)
East	1,164,593.4 (SI)	1,164,884.9 (SI)
Elevation	4,733.1 (NAVD88)	4,732.3 (NAVD88)
Elevation	4,725.6 (USBR)	4,724.8 (USBR)

Figure 3 - GPS control point, Set 2, located in the top of the dam near the right abutment.

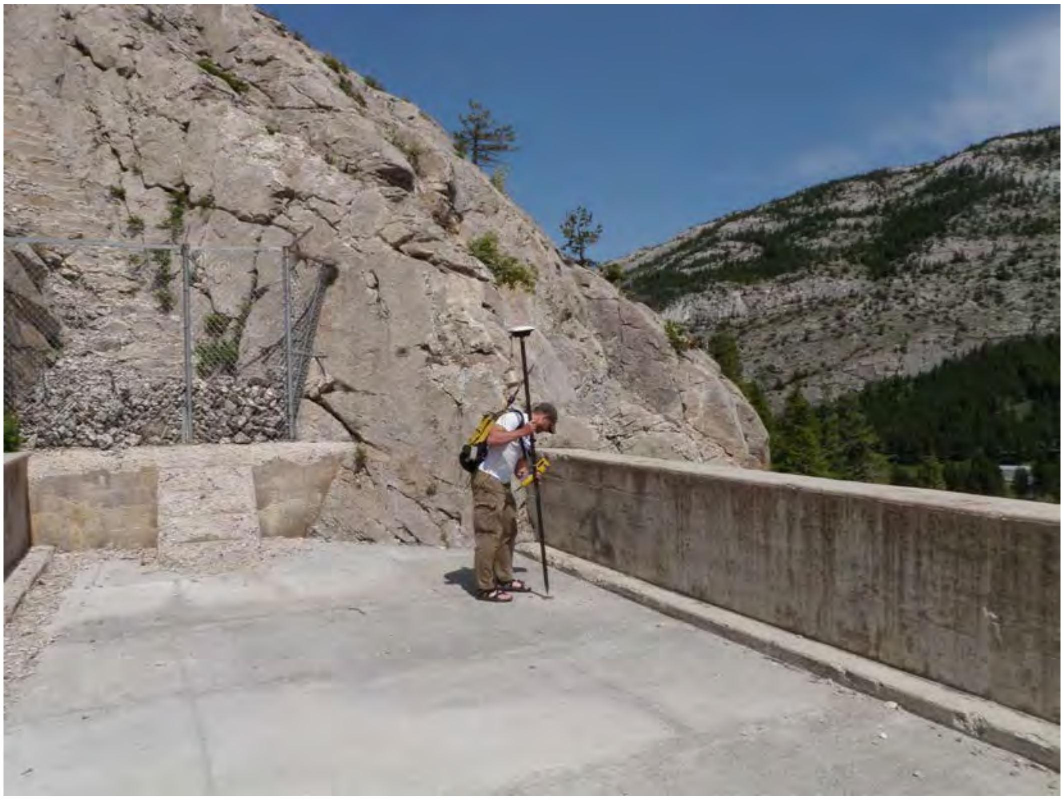

Figure 4 - GPS control point, Set 1, located in the top of the dam near the left abutment.

Reservoir Operations

Gibson Reservoir is primarily an irrigation facility that also provides water for recreation, fish, and wildlife along with capacity for flood control. The June 2009 area-capacity tables show 98,688 acre-feet of active conservation storage below elevation 4,724.0. The 2009 survey measured a minimum bottom elevation around 4,557, effectively eliminating any volume below the dead pool elevation 4,557.5. Between elevation 4,724.0 and parapet wall elevation 4,729.0 there are 6,837 acre-feet of flood control storage.

The Gibson Reservoir inflow and end-of-month stage records in Table 1 show the inflow and annual fluctuation for operation period 1930 through 2009. The average inflow into the reservoir for the entire operation period was 591,967 acre-feet per water year. The average inflow of 483,995 acre-feet since the previous survey (water year period 1996 through 2009) illustrates the extensive dry conditions in the region during this period.

Table 1 also shows the extreme water level/storage fluctuations of Gibson Reservoir, ranging from elevation 4,560.9 in 1937 to elevation 4,732.2 on June 8, 1964 when the previously mentioned flood inflow caused overtopping of the dam. The records show that in most years the reservoir fills to near elevation 4724.0 (maximum conservation level) and in some years, while supplying irrigation water, drops more than 100 feet in elevation. Even during the drought period since the 1996 survey, the reservoir filled to near elevation 4,724 every year except in 2001 when the reservoir level only reached elevation 4,719.3.

Hydrographic Survey Equipment and Method

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 5). The hydrographic system included a GPS receiver with a built-in radio, multibeam 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 GPS receiver and antenna were mounted on a survey tripod over a known datum point with a 12-volt battery providing the power for the shore unit.

The Sedimentation and River Hydraulics Group uses real-time kinematic (RTK) GPS to obtain precise heights measured in real time to monitor water surface elevation changes. The basic output 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 datum of WGS-84, which the hydrographic collection software converted into Montana's state plane horizontal coordinates, in NAD83, international feet. The RTK GPS system employs two receivers that track the same satellites simultaneously.

Figure 5 - Large survey vessel with mounted instrumentation mapping upstream of Grand Coulee dam on Franklin D. Roosevelt Reservoir, Washington.

Multibeam Survey

In 2001, the Sedimentation and River Hydraulics Group began utilizing an integrated multibeam hydrographic survey system. The system consists of a single transducer mounted on the center bow or forward portion of the boat. From the single transducer, a fan array of narrow beams generates a detailed cross section of bottom geometry as the survey vessel passes over the areas mapped. The system transmits 80 separate 1-1/2-degree slant beams resulting in a 120-degree swath from the transducer. The 200 kHz high-resolution multibeam echo sounder system measures the relative water depth across a wide swath perpendicular to the vessel's track. Figure 6 illustrates the swath on the sea floor that is about 3.5 times as wide as the water depth below the transducer.

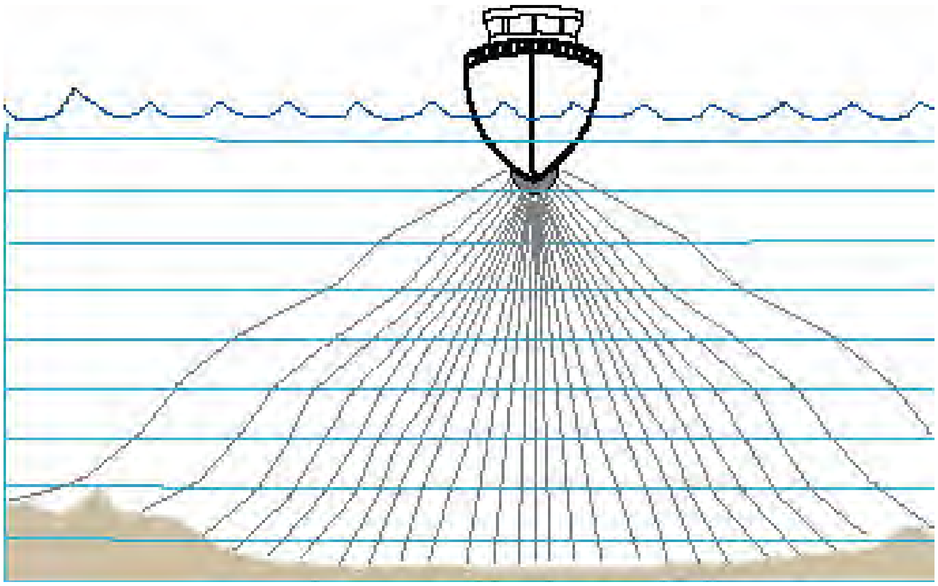

Figure 6 - Multibeam collection system.

The multibeam system is composed of several instruments all in constant communication with a central on-board laptop computer. The components include the RTK GPS for positioning; a motion reference unit to measure the heave, pitch, and roll of the survey vessel; a gyro to measure the yaw or vessel attitude; and a velocity meter to measure the speed of sound through the vertical profile of the reservoir water. The multibeam sounder was calibrated by lowering an instrument that measured the sound velocity through the reservoir water column. The individual depth soundings were adjusted by the measured speed of sound which can vary with density, salinity, temperature, turbidity, and other conditions. With proper calibration, the data processing software utilizes all the incoming information to provide an accurate, detailed xyz data set of the lake bottom.

The multibeam soundings resulted in a detailed data set of around 1,597,000 xyz points representing the reservoir below the water surface elevation at the time of data collection. The multibeam survey system software continuously recorded reservoir depths and horizontal coordinates as the survey vessel moved along closely-spaced grid lines covering the reservoir area. Most transects (grid lines) were run parallel to the reservoir alignment with the multibeam swaths overlapping in the deeper areas to provide full bottom coverage of the areas surveyed. The additional beams provided more reservoir bottom detail than would have been possible using a single beam system only.

Bathymetric Data Set

Figures 7 and 8 show portions of the reservoir areas covered by the multibeam collection system. The underwater collected data was processed using the same hydrographic system software used for the data collection. During processing, all corrections, such as vessel location and roll, pitch, and yaw effects, were applied. Other corrections included applying the sound velocity through the reservoir water column and converting all depth data points to elevations using the measured water surface elevation at the time of collection. To reduce the time required for processing without compromising survey accuracy, the massive amount of multibeam data was filtered into 5-foot cells or grids in the reservoir area surveyed by the multibeam system. Additional information on general bathymetric data collection and analysis procedures can be found in *Engineering and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

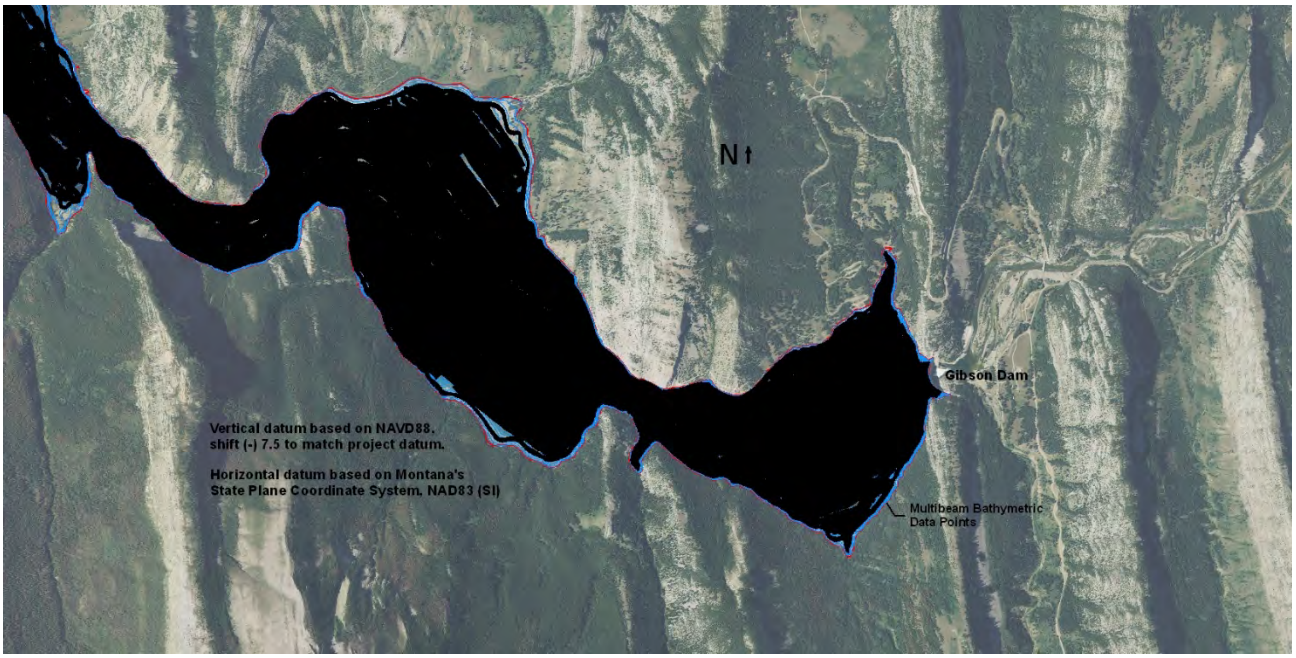

Figure 7 - Gibson Reservoir, multibeam bathymetric data from dam upstream (NAVD88).

Aerial Photographs

During analysis, orthographic aerial images collected in 2005 at water surface elevation 4,651.5 (NAVD88) and in 2009 at water surface elevations 4,710.9 and 4,716.1 (NAVD88) were downloaded from the USDA data web site (USDA, 2010). Reservoir contours were developed by digitizing the water's edge from these aerial images. These contours were used in areas not covered by the 2009 bathymetric data and used to compare with the developed contours from the 2009 bathymetric data set (Figures 9 through 13). The developed contours from the 2009 bathymetric data compared well with the aerial images.

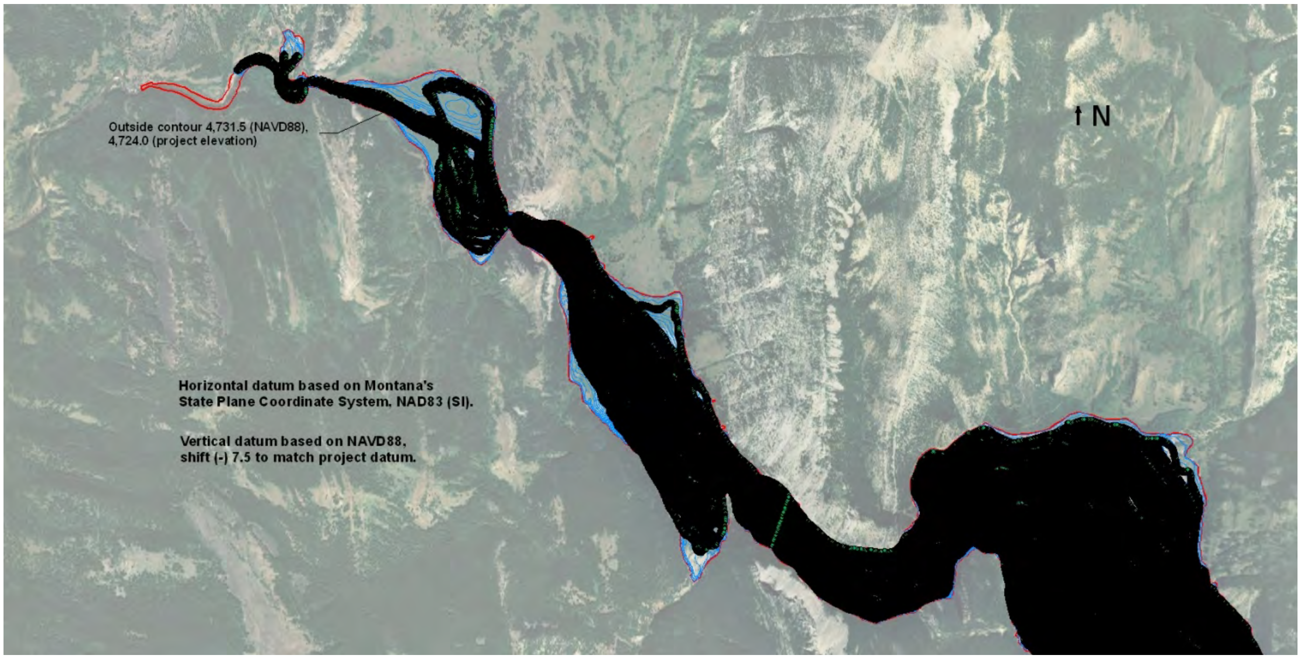

Figure 8 - Gibson Reservoir, multibeam bathymetric data in upstream area (NAVD88).

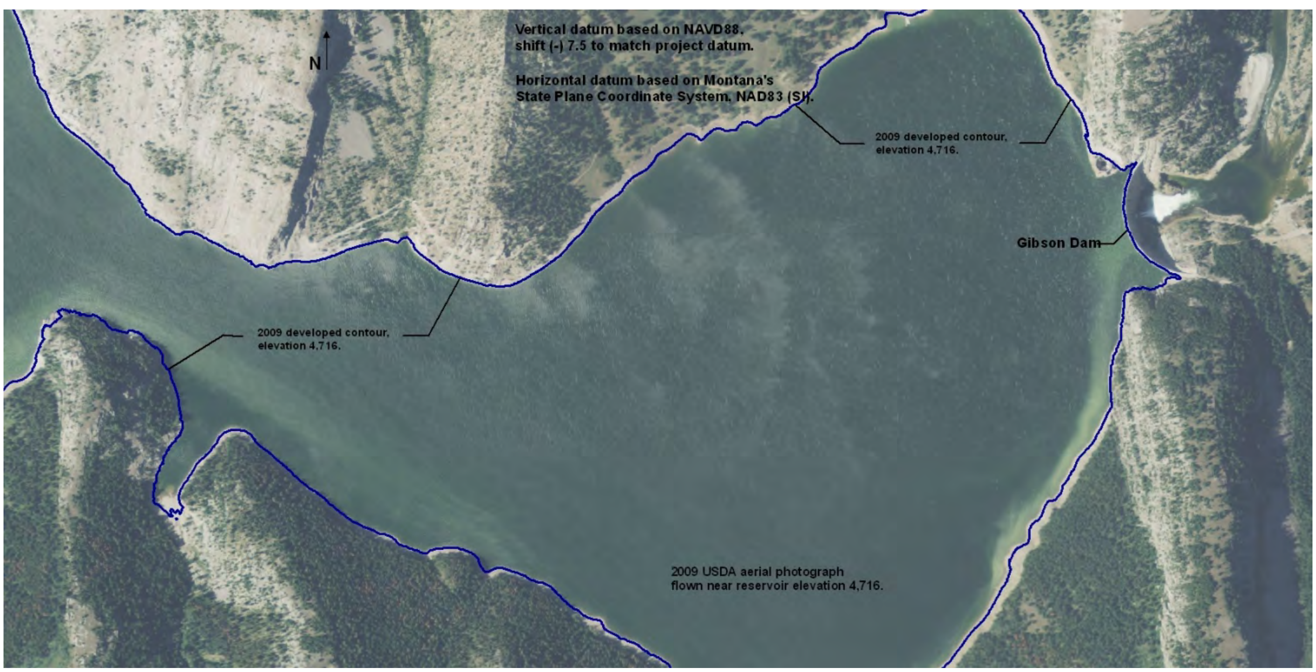

Figure 9 – Aerial image of Gibson Dam and Reservoir at water surface elevation 4,716.1 (NAVD88), flown in 2009 (USDA 2010).

Figure 10 - Aerial image of Gibson Dam and Reservoir at water surface elevation 4,651.5 (NAVD88), flown in 2005 (USDA, 2010).

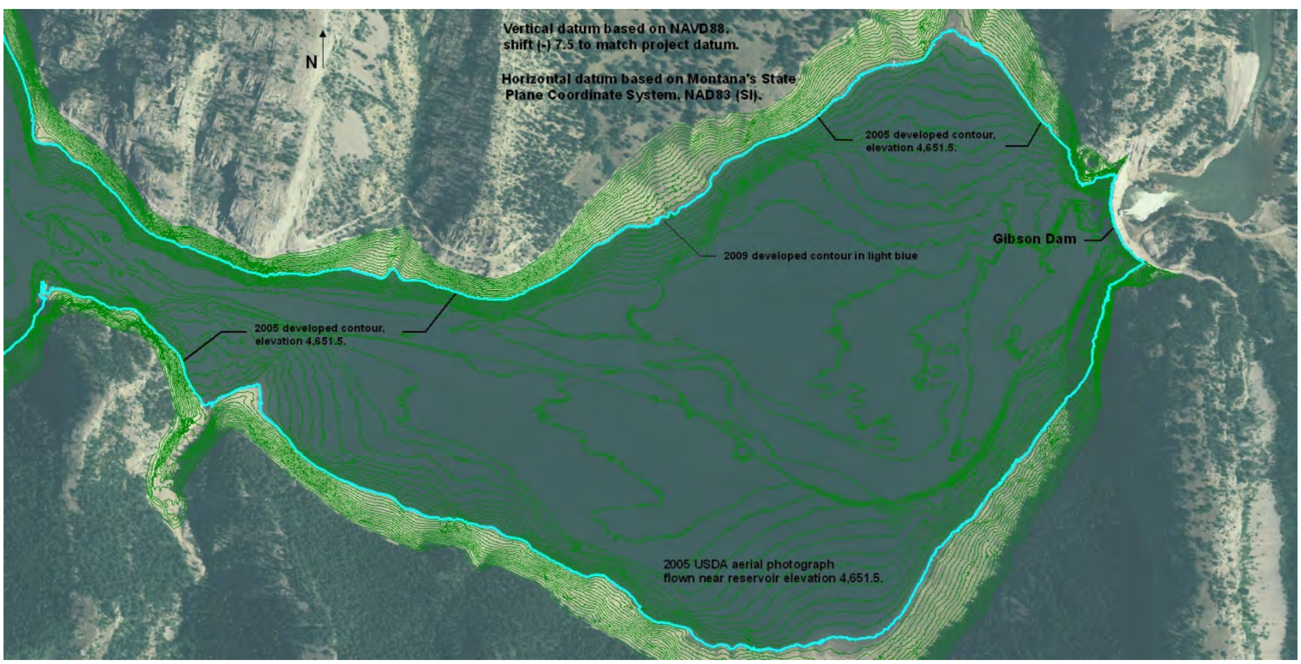

Figure 11 - 2009 Gibson Reservoir contours compared to 2005 aerial image (NAVD88).

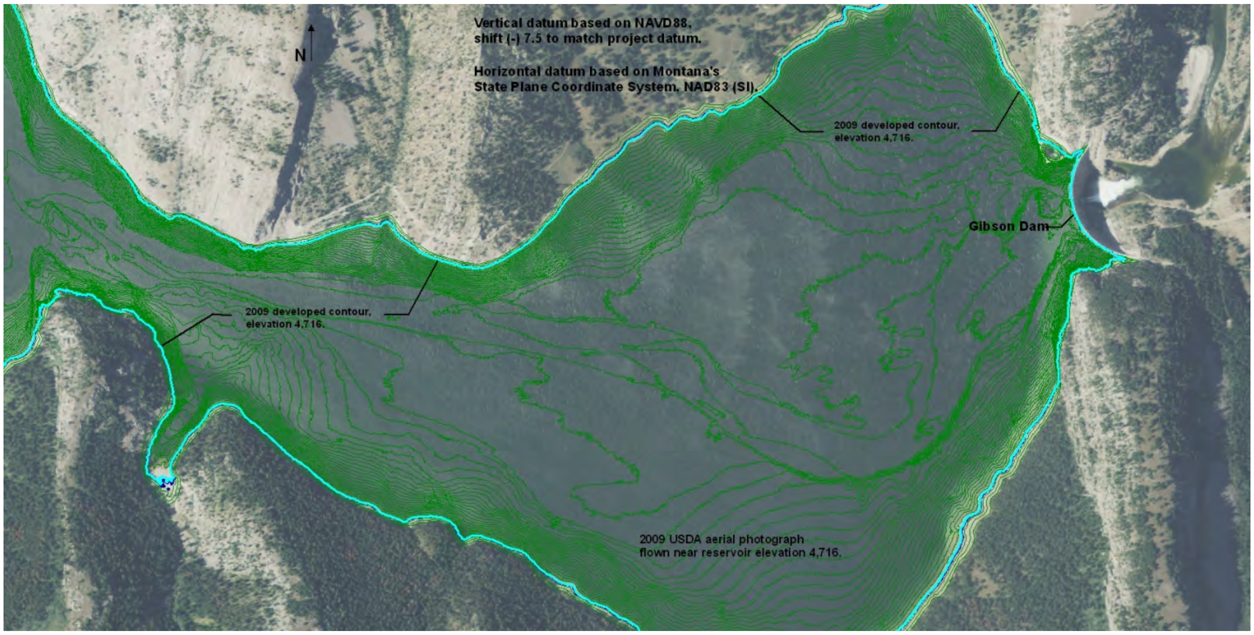

Figure 12 - 2009 Gibson Reservoir contours compared to 2009 aerial image (NAVD88).

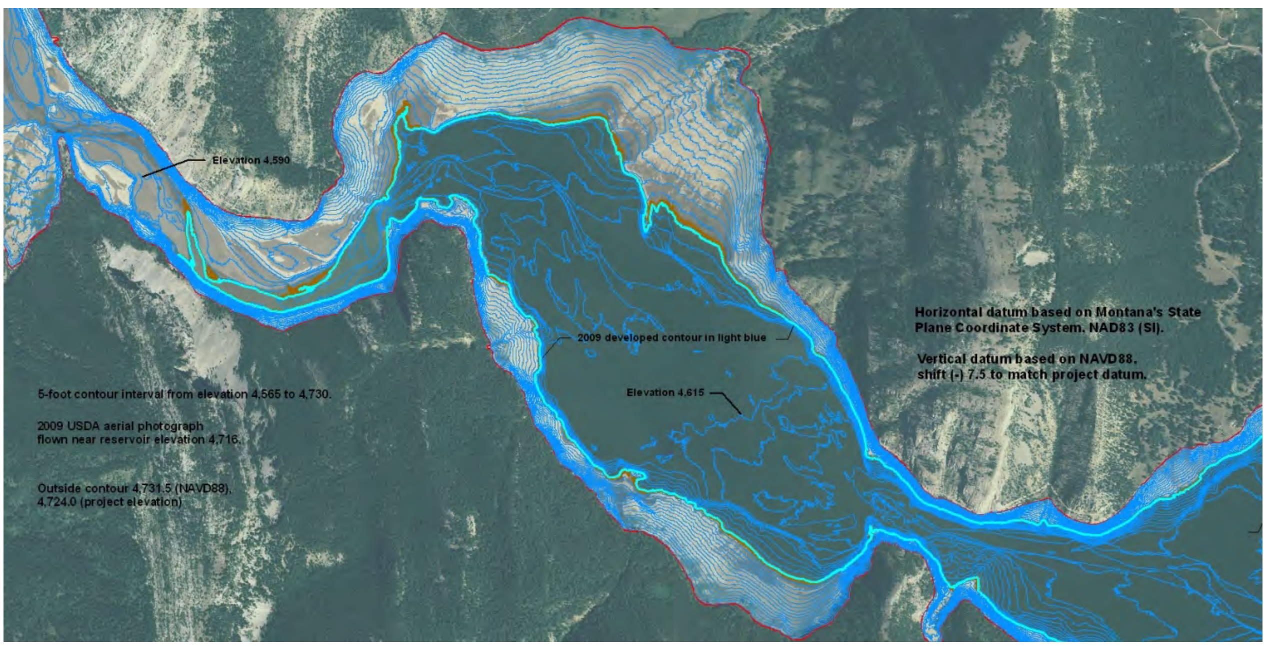

Figure 13 - 2009 Gibson Reservoir contours compared to 2009 aerial images (NAVD88).

IFSAR Data Set

Completion of the topography for areas of the reservoir not covered by the 2009 bathymetric survey required additional data. Interferometric Synthetic Aperture Radar (IFSAR) digital data was obtained as bare earth, 5-meter grid coordinates (east, north, elevation) tied to Montana's state plane zone 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 aerial photogrammetry and LiDAR. The IFSAR data was collected when the reservoir was drawn down, allowing data in areas not covered by the 2009 bathymetric survey to be obtained. Due to the extensive coverage obtained by the 2009 bathymetric survey, the IFSAR data was primarily used in the very upper reach of the reservoir where vegetation did not allow boat access, Figure 14. The IFSAR reported accuracies are 2 meters or better horizontally and 1 meter or better vertically for areas of unobstructed flat ground (Intermap, 2011). Without the IFSAR data, no change from the original surface areas in the upper reservoir elevations could be made without significant assumptions. Due to lack of other data sources, the IFSAR data was the best available information to merge with the 2009 bathymetric data to develop a continuous topographic surface of Gibson Reservoir.

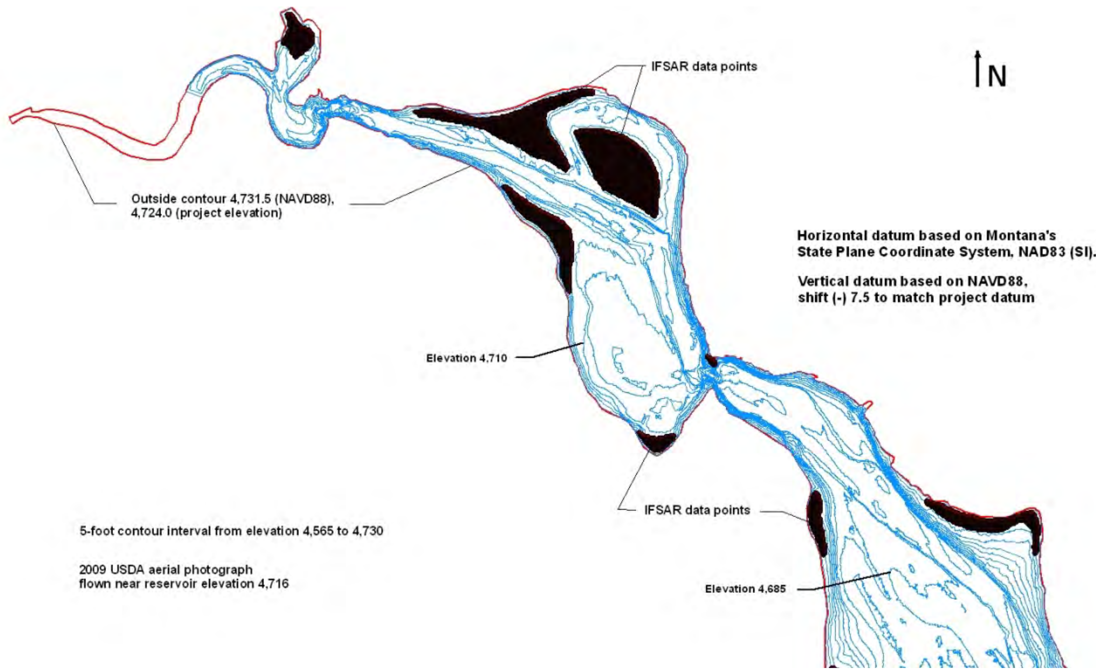

Figure 14 - Upper reach of the reservoir showing the areas where the IFSAR data was used for the 2009 study and development of the contours for Gibson Reservoir.

Reservoir Area and Capacity

Topography Development

This section discusses the methods used for generating topographic contours for Gibson Reservoir. The data sources included the 2009 bathymetric survey, the digitized reservoir water surface edges from the USDA aerial photographs, and the IFSAR bare earth data (Figures 9 through 14). These data were processed into a triangulated irregular network (TIN) that was then used to develop 1-foot contours tied vertically to NAVD88. The resulting surface areas and volumes presented in this report are from the developed TIN where the elevations were shifted -7.5 feet from NAVD88 to match the project vertical datum for reservoir operation use. In preparation for developing the TIN, a polygon was created to enclose all of the data sets. The polygon, not assigned an elevation, was used as a hard boundary for the 2009 developed contours, allowing mapping within the reservoir area outlined by the hardclip polygon only. The hardclip was used during the TIN development to prevent interpolation outside the enclosed polygon (Figure 15).

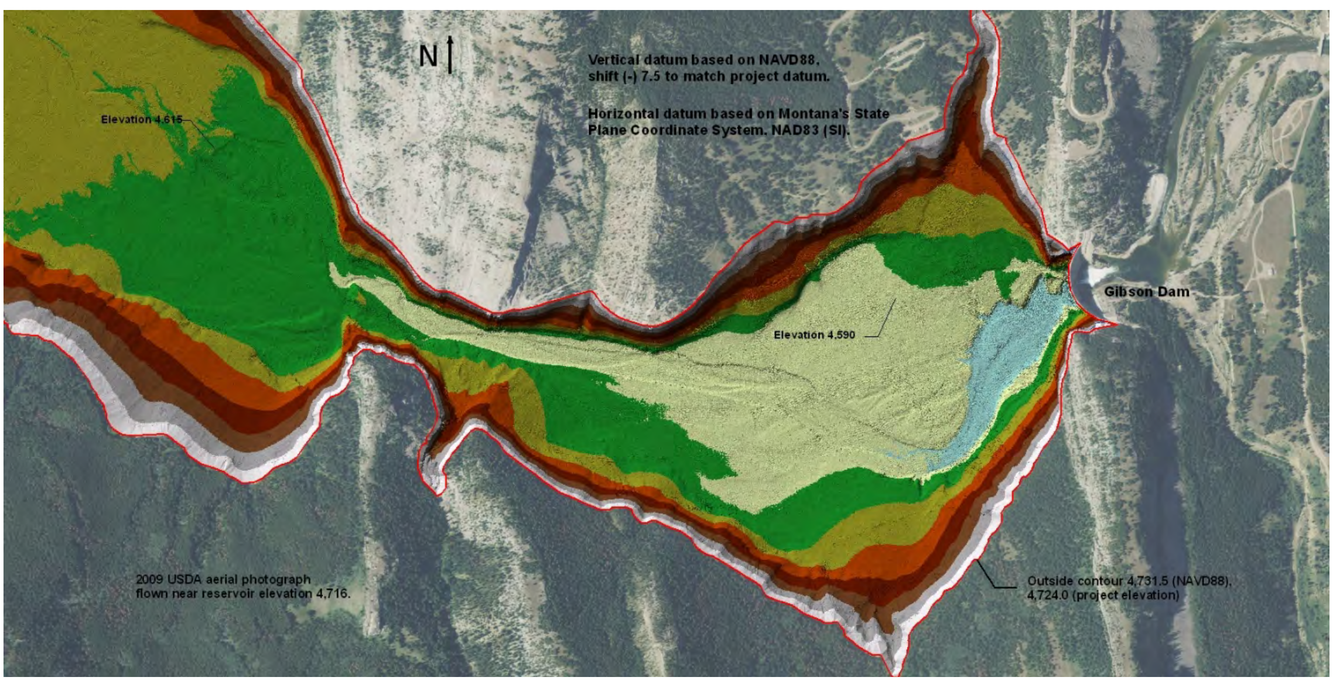

Figure 15 – Gibson Reservoir 2009 TIN (NAVD88).

Contours for the reservoir from Gibson Dam upstream 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 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. This method preserves all the collected data points. The TIN method is described in more detail in the ArcGIS user's documentation (ESRI, 2011).

The linear interpolation option of the ArcGIS TIN and CONTOUR commands was used to interpolate contours from the Gibson Reservoir TIN. The surface areas of the enclosed contour polygons at 1-foot increments were computed for elevation 4,557.5 (NAVD88) and above. The reservoir contour topography at 5-foot intervals is presented on Figures 16 through 18. The ArcGIS software was used to develop contours directly from the TIN using all the enclosed data points presented in this report.

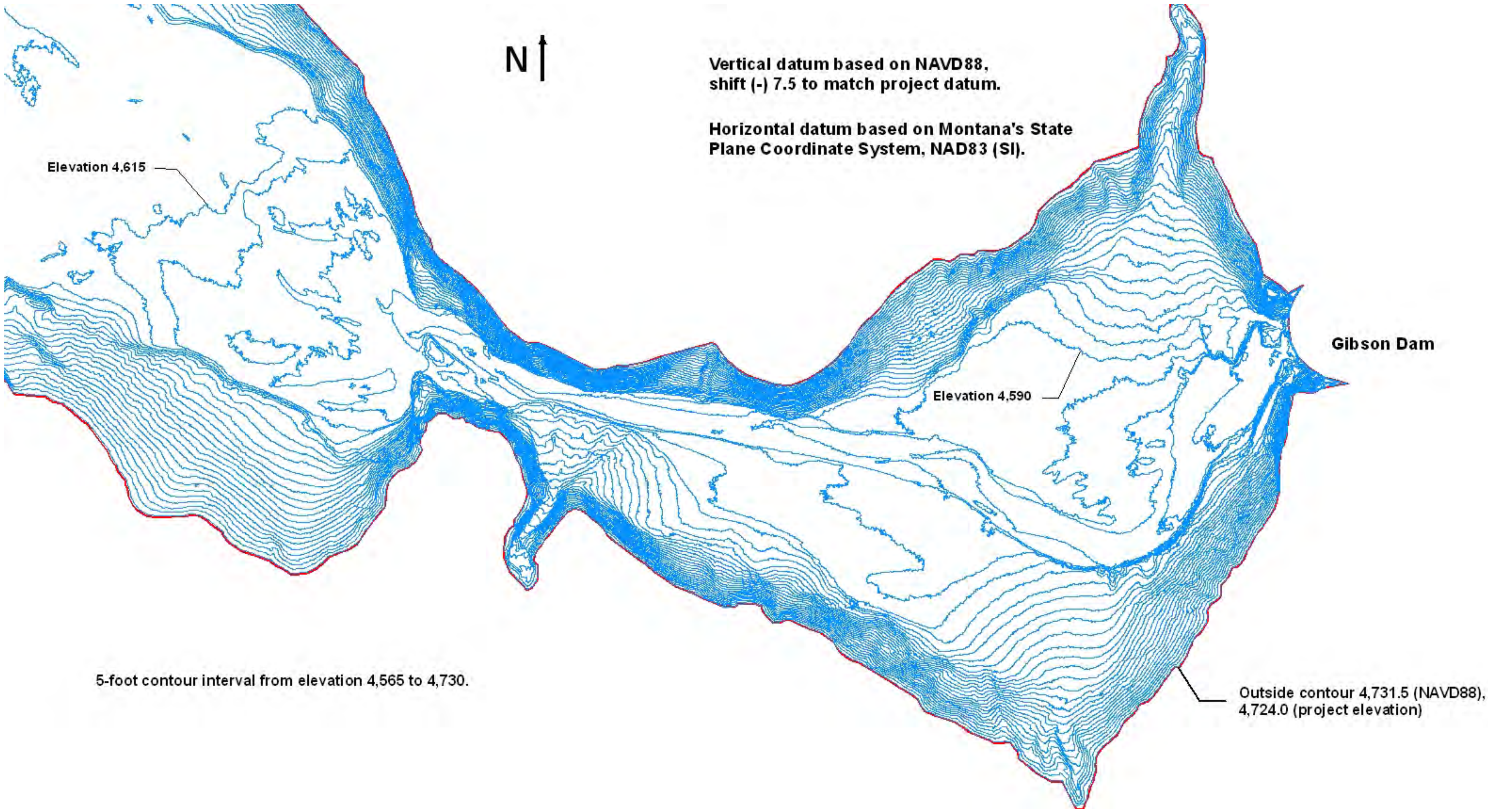

Figure 16 – Gibson Reservoir topography, NAVD88 (map 1 of 3).

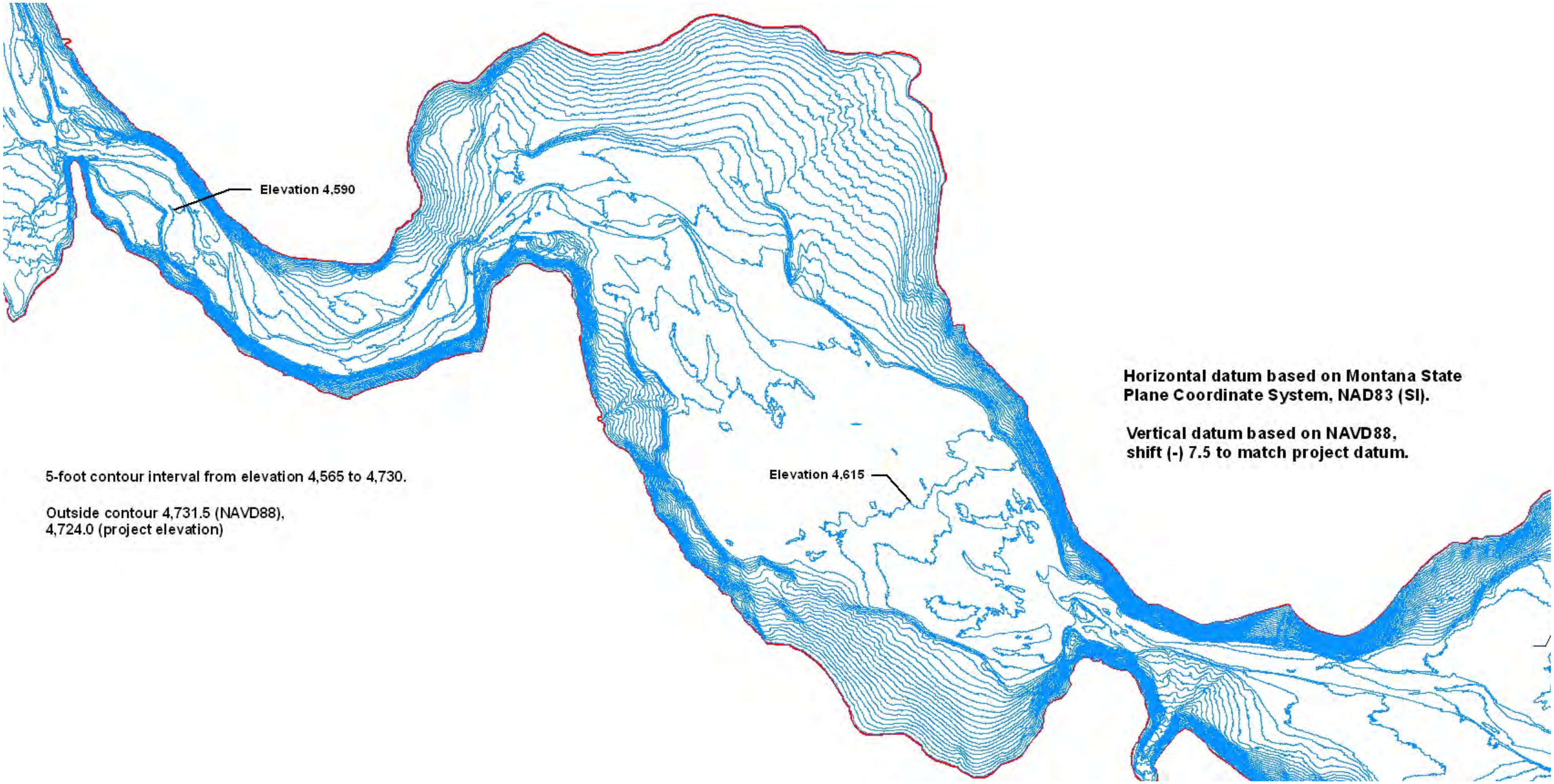

Figure 17 - Gibson Reservoir topography, NAVD88 (map 2 of 3).

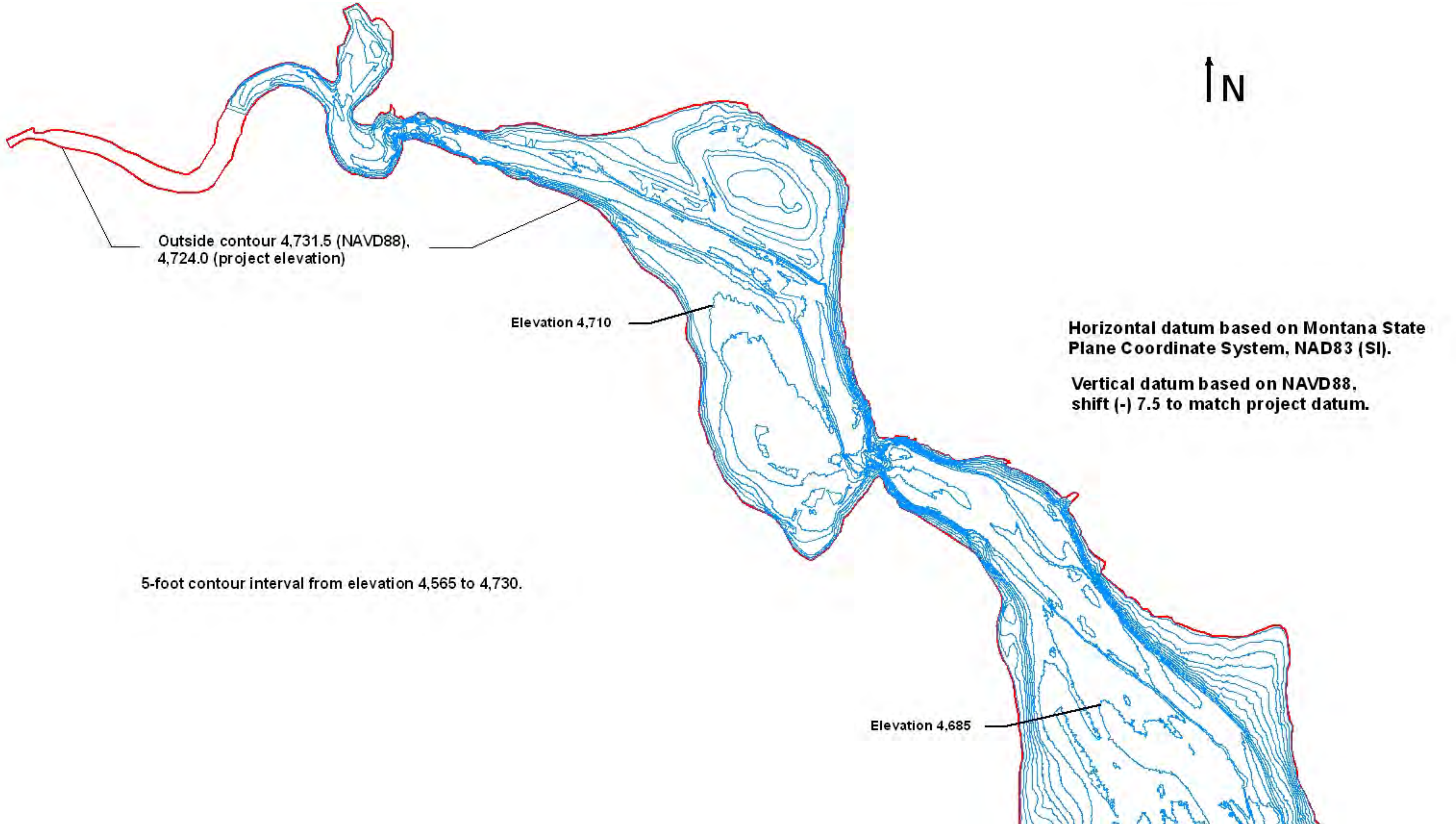

Figure 18 – Gibson Reservoir topography, NAVD88 (map 3 of 3).

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2009 Gibson Reservoir Surface Area Methods

The 2009 surface areas for Gibson Reservoir were computed at 1-foot increments directly from the reservoir TIN from minimum elevation 4,557.5 to elevation 4,727.5 (NAVD88), project elevations 4,550.0 through 4,720.0, to provide information for the area-capacity tables. The upper most 2009 surface area entry was at elevation 4,724.0 that was the computed surface area of the developed polygon to enclose all the data for TIN development. Surface area calculations were performed using ArcGIS commands to compute areas at user-specified elevations directly from the TIN. The 2009 study assumed no change in the reservoir surface area at elevation 4,740.0 measured from the 1973 aerial survey. The surface areas and resulting capacity between elevations 4,724.0 and 4,740.0 were interpolated and computed by the ACAP program as described below. A summary of the 2009 survey results follows and can be compared to previous survey results. Typically, the 2009 measured surface areas were slightly greater than the 1996 survey throughout the elevation range and slightly greater than the 1973 survey results in the upper elevations. The majority of the difference can likely be attributed to the dense data obtained during the 2009 survey, resulting in a more detailed and accurate measurement of the reservoir volume. Slight calibration differences between the 2009 and 1996 methods may account for some of the measured differences as well.

2009 Gibson 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 Gibson 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 Gibson Reservoir area and capacity computations are listed in a separate set of 2009 area and capacity tables and have been published for 0.01, 0.1, and 1-foot elevation increments (Bureau of Reclamation, 2009). A description of the computations and coefficients output from the ACAP program is included with these tables. As of July 2009, at conservation use elevation 4,724.0, the surface area was 1,334.0 acres with a total capacity of 98,688 acre-feet.

Gibson Reservoir Surface Area and Capacity Results

This section provides 2009 surface area and capacity results for Gibson Reservoir and evaluates changes over time. Table 1 provides a summary of the change in Gibson Reservoir topography between the time of original dam closure in 1929 and 2009 along with changes since the two previous surveys in 1973 and 1996. The area and capacity curves for the original and all subsequent surveys are plotted on Figure 19. Table 2 provides a summary of the original, 1973, 1996, and 2009 surface areas and capacities.

For the purpose of this study the 2009 TIN computed surface areas from elevation 4,550.0 through 4,720.0, the digitized surface area at elevation 4,724.0, and the 1973 surface area at elevation 4,740.0 were used in computing the 2009 area and capacity tables. The 2009 bathymetric survey and the other data sources summarized in the *Topographic Development* section provided adequate information for computing the surface areas from elevation 4,724.0 and below. Due to the steep vertical banks of Gibson Reservoir, accurate computation of surface areas and resulting volumes above elevation 4,724.0 would require a more precise aerial surface than what can be obtained from the IFSAR data. However, the IFSAR data greatly helped in the upper reservoir areas where there was no boat access and topography was relatively flat. For computation purposes the surface area result from the 1973 survey at elevation 4,740.0 was used and the ACAP program was allowed to interpolate and compute the area and capacity values between elevation 4,724.0 and 4,740.0.

RESERVOIR SEDIMENT
DATA SUMMARY

Gibson Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER Bureau of Reclamation	2. STREAM Sun River	3. STATE Montana
A	4. SEC 4 TWP. 21N RANGE 9W	5. NEAREST P.O. Augusta	6. COUNTY Teton/Lewis-Clark
M	7. LAT 47 ° 36 ' 09 " LONG 112 ° 45 ' 39 "	8. TOP OF DAM ELEVATION 4,725.0 [1]	9. SPILLWAY CREST EL 4,712.0 [2]

	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC-FT	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
R	a. SURCHARGE					
E	b. FLOOD CONTROL					
S	c. POWER					12/29
E	d. JOINT USE					16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION	4,724.0	1,357	104,768	104,784	
V	f. INACTIVE					
O	g. DEAD	4,557.5	18	16	16	12/29
I R	17. LENGTH OF RESERVOIR 5.2 MILES		AVG. WIDTH OF RESERVOIR 0.4 MILES			

B	18. TOTAL DRAINAGE AREA 575 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 19 [3] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA 575 SQUARE MILES	23. MEAN ANNUAL RUNOFF 19.4 [4] INCHES
S	20. LENGTH 45 MILES AVG. WIDTH 13 MILES	24. MEAN ANNUAL INFLOW 591,967 [5] ACRE-FEET
I	21. MAX. ELEVATION 8800 MIN. ELEVATION 4557.5	25. ANNUAL TEMP, MEAN 45 °F RANGE (-)49°F to 106 °F [7]
N		

	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	12/29			Contour (D)		1,357	104,860	0.18
V	8/73	43.8	43.8	Contour (D)	10-ft	1,296 [6]	99,067 [6]	0.17
E	7/96	22.9	66.7	Contour (D)	5-ft	1,296 [7]	96,477 [7]	0.16
Y	6/09	12.9	79.6	Contour (D)	2-ft	1,334 [8]	98,688 [8]	0.17

	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	8/73	17.62	623,267 [9]	992,099	27,423,728	623,267	27,423,728
	7/09/96	19 [3]	593,117	918,328	13,641,691	612,917	41,065,419
	6/09		483,995	627,573	6,291,931	591,967	47,357,350

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.
8/73	5,793 [9]	132.3	0.23	5,793	132.3	0.23
7/09/96	2,590 [9]	113.1	0.20	8,383	125.7	0.22
6/09	(-) 2,211 [10]	- [10]	- [10]	6,172 [10]	77.5 [10]	0.14 [10]

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.
8/73				0.13	5.5		
7/9/96				0.12	8.0		
6/09				0.07 [10]	5.8 [10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION									
		4,580 - 4,550	4,600 - 4,580	4,620 - 4,600	4,640 - 4,620	4,660 - 4,640	4,680 - 4,660	4,700 - 4,680	4,720 - 4,700	4,724 - 4,720
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION									
7/96		3.3	13.2	7.5	8.4	9.1	12.2	22.9	19.7	3.7
6/09										

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

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1930	4,713.1	4,600.0	392,998	1931	4,674.6	4,565.1	285,769
1932	4,715.3	4,596.5	487,896	1933	4,716.1	4,664.2	753,287
1934	4,715.8	4,650.4	992,099	1935	4,715.0	4,639.6	508,712
1936	4,715.4	4,563.5	483,268	1937	4,713.5	4,560.9	348,657
1938	4,715.4	4,594.3	568,186	1939	4,725.1	4,640.0	524,911
1940	4,725.5	4,596.2	312,003	1941	4,723.3	4,592.4	275,273
1942	4,725.1	4,607.2	573,115	1943	4,724.5	4,655.3	878,476
1944	4,725.2	4,649.0	387,620	1945	4,725.4	4,620.8	411,647
1946	4,725.4	4,638.1	482,202	1947	4,723.0	4,660.8	764,652
1948	4,718.8	4,662.3	857,757	1949	4,719.4	4,597.2	488,391
1950	4,725.3	4,600.6	796,399	1951	4,724.2	4,688.1	894,763
1952	4,718.6	4,654.2	629,605	1953	4,725.2	4,654.1	818,093
1954	4,719.7	4,676.4	834,096	1955	4,724.5	4,668.6	585,849
1956	4,723.0	4,650.8	760,454	1957	4,724.7	4,634.8	617,919
1958	4,725.0	4,634.8	627,210	1959	4,717.0	4,650.1	877,260
1960	4,722.7	4,657.0	597,272	1961	4,725.3	4,630.6	554,324
1962	4,724.0	4,630.6	703,431	1963	4,725.0	4,629.0	493,122
1964	4,732.2	4,615.0	844,882	1965	4,717.2	4,653.0	798,049
1966	4,718.5	4,622.7	572,183	1967	4,716.1	4,611.6	831,815
1968	4,724.2	4,641.8	532,946	1969	4,724.0	4,615.7	610,018
1970	4,724.0	4,615.7	627,841	1971	4,721.4	4,634.1	856,481
1972	4,723.8	4,635.5	851,617	1973	4,709.7	4,569.2	331,180
1974	4,723.9	4,595.1	709,597	1975	4,720.4	4,672.7	902,624
1976	4,724.2	4,673.4	824,023	1977	4,715.4	4,595.5	285,475
1978	4,724.0	4,596.8	739,616	1979	4,724.0	4,609.4	570,198
1980	4,724.0	4,618.1	595,985	1981	4,724.0	4,628.8	600,438
1982	4,723.5	4,637.8	677,500	1983	4,724.0	4,656.9	442,786
1984	4,723.9	4,626.3	418,953	1985	4,723.9	4,626.3	503,216
1986	4,724.0	4,631.8	657,641	1987	4,724.1	4,641.8	429,862
1988	4,722.0	4,606.0	356,955	1989	4,723.8	4,605.7	663,432
1990	4,724.0	4,653.0	737,146	1991	4,723.7	4,651.0	918,328
1992	4,720.9	4,621.8	416,014	1993	4,724.0	4,622.0	530,823
1994	4,720.0	4,607.5	435,423	1995	4,724.0	4,610.0	483,788
1996	4,724.0	4,656.1	741,868	1997	4,723.9	4,656.5	747,773
1998	4,724.0	4,631.8	479,738	1999	4,724.0	4,634.0	564,748
2000	4,724.0	4,609.3	478,676	2001	4,719.3	4,610.2	331,608
2002	4,724.0	4,617.2	524,878	2003	4,724.0	4,607.4	386,619
2004	4,723.9	4,610.9	398,784	2005	4,724.0	4,609.2	380,617
2006	4,723.9	4,609.2	444,008	2007	4,724.0	4,608.5	417,094
2008	4,724.0	4,613.1	627,573	2009	4,724.3	4,608.5	509,814

46. ELEVATION - AREA - CAPACITY - DATA FOR 2009

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2009	**SURVEY**		4,555.0	0	0	4,557.5	0	0
4,560.0	2	2	4,565.0	9	27	4,570.0	17	89
4,575.0	32	208	4,580.0	63	440	4,585.0	96	844
4,590.0	133	1,415	4,595.0	156	2,138	4,600.0	204	3,028
4,605.0	237	4,134	4,610.0	307	5,441	4,615.0	392	7,228
4,620.0	431	9,296	4,625.0	473	11,550	4,630.0	508	14,002
4,635.0	539	16,621	4,640.0	569	19,390	4,645.0	598	22,310
4,650.0	633	25,386	4,655.0	672	28,646	4,660.0	712	32,107
4,665.0	753	35,770	4,670.0	806	39,659	4,675.0	874	43,853
4,680.0	937	48,391	4,685.0	989	53,217	4,690.0	1,034	58,277
4,695.0	1,072	63,540	4,700.0	1,124	69,037	4,705.0	1,178	74,788
4,710.0	1,222	80,789	4,715.0	1,263	87,000	4,720.0	1,303	93,415
4,724.0	1,334	98,688	4,725.0	1,338	100,024	4,725.5	1,340	100,693
4,729.0	1,353	105,405	4,730.0	1,357	106,759	4,735.0	1,375	113,589
4,740.0	1,394	120,512						

47. REMARKS AND REFERENCES

[1] Parapet wall elevation 4,729.0.

[2] Top of movable radial gates is 4,724.0.

[3] Bureau of Reclamation's Project Data Book, 1981.

[4] Calculated using mean annual runoff value of 594,942 AF, item 24, 1930-2009.

[5] Computed annual inflow from 1930 through 2009. Used available inflow information.

[6] Original surface area and capacity at elevation 4,724.0. Original and 1973 recomputed by BOR ACAP program. Original areas projected from 1961 area curve. 1973 areas measured from aerial photography.

[7] Surface area and capacity at elevation 4,724.0. Surface areas from elevation 4,724.0 and above from 1973 survey. Single beam collection.

[8] 2009 survey by multibeam depth sounder provided more detail than previous surveys.

[9] Values from available records starting in 1930. Values and computations by water year for year of the survey.

[10] The 2009 underwater survey, conducted using a multibeam depth sounder, captured more detailed reservoir information than previous surveys throughout the underwater portion of the reservoir resulting in a larger computed capacity than the 1996 survey results. The 1996 survey used a single beam system that was not able to capture detailed reservoir information along the shoreline possible with a multibeam system. The differences are due to sediment deposition and accuracy differences between methods of collection and analysis.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE April 2012

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

1	2	3	4	5	6	7	8	9	10	11	12	13
	1929	1929			1973			1996			2009	
	Original	Original	1973	1973	Sediment	1996	1996	Sediment	2009	2009	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
4,724	1,357	104,860	1,296	99,067	5,793	1,296	96,477	8,383	1,334	98,688	6,172	100.0
4,720	1,319	99,508	1,272	93,930	5,578	1,280	91,325	8,183	1,303	93,415	6,093	97.8
4,710	1,263	86,598	1,214	81,500	5,098	1,217	78,806	7,792	1,222	80,789	5,809	92.2
4,700	1,192	74,323	1,109	69,885	4,438	1,105	67,198	7,125	1,124	69,037	5,286	86.6
4,690	1,091	62,908	1,016	59,260	3,648	1,009	56,668	6,240	1,034	58,277	4,631	81.0
4,680	972	52,593	939	49,485	3,108	917	47,016	5,577	937	48,391	4,202	75.4
4,670	870	43,383	825	40,665	2,718	784	38,498	4,885	806	39,659	3,724	69.8
4,660	728	35,393	710	32,990	2,403	691	31,142	4,251	712	32,107	3,286	64.2
4,650	666	28,423	636	26,260	2,163	610	24,631	3,792	633	25,386	3,037	58.7
4,640	597	22,108	570	20,230	1,878	554	18,818	3,290	569	19,390	2,718	53.1
4,630	534	16,453	510	14,830	1,623	494	13,571	2,882	508	14,002	2,451	47.5
4,620	461	11,478	438	10,090	1,388	416	9,013	2,465	431	9,296	2,182	41.9
4,610	385	7,248	377	6,015	1,233	312	5,319	1,929	307	5,441	1,807	36.3
4,600	262	4,013	215	3,055	958	200	2,833	1,180	204	3,028	985	30.7
4,590	168	1,863	126	1,350	513	125	1,283	580	133	1,415	448	25.1
4,580	72	663	50	407	256	60	376	287	63	440	223	19.6
4,570	24	183	18	130	53	13	62	121	17	89	94	14.0
4,560	5	38	4	20	18	1	2	36	2	2	36	8.4
4,557	4	24	3	10	14	0	0	24	0	0	24	6.7
4,550	2	4	0	0	4	0	0	4	0	0	4	2.8
4,545	0	0	0	0	0	0	0	0	0	0	0	0.0

1 Reservoir water surface elevation. Elevations tied to project datum that are 7.5 feet less than NAVD88.
2 Original 1929 reservoir surface area projected from area curve.
3 Original 1929 reservoir capacity recomputed using ACAP.
4 1973 reservoir surface areas by aerial survey.
5 1973 reservoir capacity recomputed using ACAP.
6 1973 computed sediment volume, column (3) - column (5).
7 1996 reservoir surface area.
8 1996 reservoir capacity.
9 1996 computed sediment volume, column (3) - column (9).
10 2009 measured reservoir surface area. Detailed multibeam survey resulted in larger computed surface areas since the 1996 survey
11 2009 reservoir capacity computed using ACAP.
12 2009 measured sediment volume, column (3) - column (13).
13 Depth of reservoir expressed in percentage of total depth, 179 feet, from conservation water surface 4,724.0.

Table 2 - Gibson Reservoir 2009 survey summary.

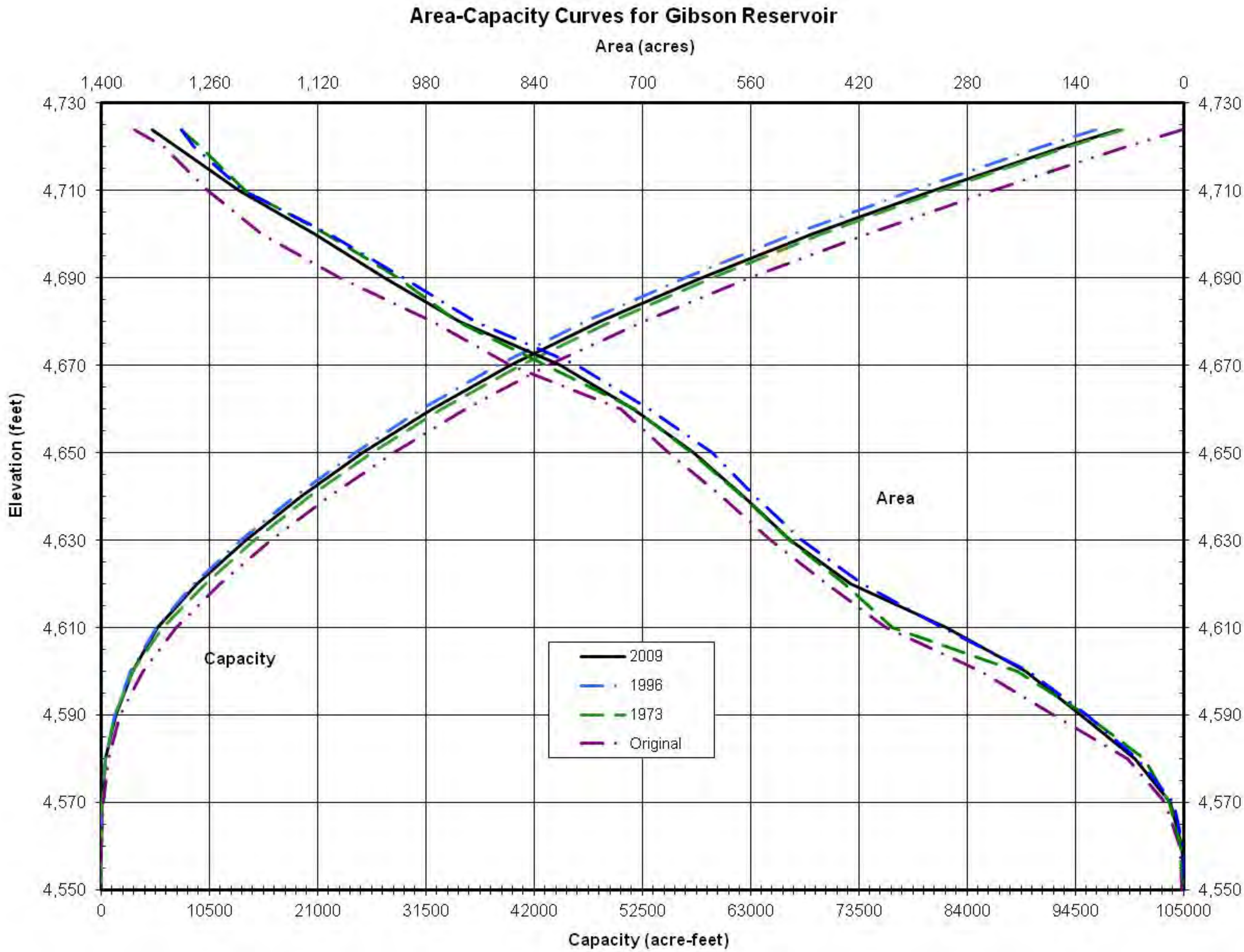

Figure 19 – Gibson Reservoir area and capacity plots.

Longitudinal Distribution

To illustrate the bottom conditions along the Sun River thalweg from the dam upstream to the upper contour reach, a longitudinal profile was cut through the 1996 and 2009 developed contours, Figure 20. Distances along the thalweg were measured from the 2009 survey results that provided a continuous alignment of the deepest portion of the channel through the reservoir. The same alignment through the 1996 developed contours was used for common distances between the developed 5-foot contours from both studies. The elevations for the longitudinal profile plot are tied to the project datum that is 7.5 feet less than NAVD88.

The profile showed little change between the two surveys in the lower reach of the reservoir. In the upper reach, the 2009 thalweg plotted slightly below the 1996 survey data indicating little sediment has settled in the upper reservoir since 1996. Reservoir operation records (primarily since 1996, Table 1) indicate a typical reservoir drawdown of over 100 feet from elevation 4,724.0 to near elevation 4,610 and lower each operational year. With the extreme annual drawdown of the reservoir, the majority of the sediment would be expected to be flushed downstream towards the dam. A small sediment deposit has developed in the lower elevations of the reservoir with a pivot point near elevation 4,607 and sediment delta sloping upstream from there (Figure 20). The 1996 and 2009 surveys both measured no volume in the dead pool of the reservoir, below elevation 4,557.5. It appears that any sediments transported past the small delta have been flushed downstream of the dam through the operation of the river outlet.

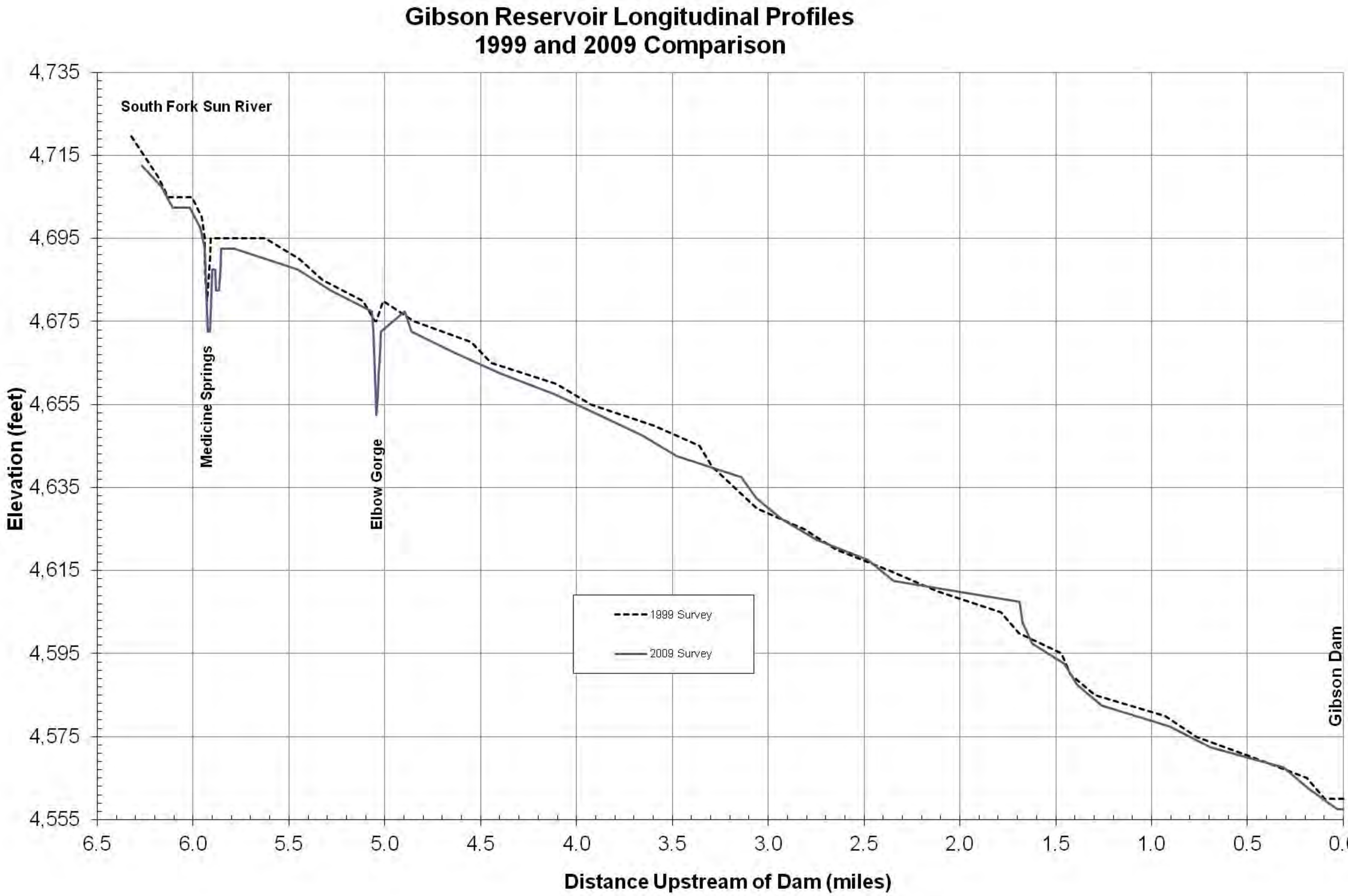

Figure 20 - Longitudinal profile of Sun River from Gibson Dam upstream (project datum).

2009 Gibson Reservoir Analyses

Results of the 2009 Gibson 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 table also lists the area and capacity results for the 1973 and 1996 surveys. Figure 19 is a plot of the Gibson Reservoir surface area and capacity values for the surveys and illustrates the differences in surface area and storage between them.

Table 1 shows the conservation use capacity at elevation 4,724.0 for all surveys along with the computed differences due to sediment deposition and methods of collections for all survey years. The 2009 survey actually measured an increase in capacity of 2,211 acre-feet since the 1996 survey results. The measured increase was likely due to the more detailed data collection using the multibeam depth sounder in 2009 compared to the single beam collection in 1996 and the improved GIS capability to utilize other data sources to more accurately represent upper reservoir topography. A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted, but it appears the present operation of the reservoir is flushing the majority of the finer sediments downstream through the river outlets.

Summary and Conclusions

This Reclamation report presents the results of the July 2009 survey of Gibson 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 confirm the horizontal and vertical control network near the reservoir for the hydrographic 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 NSRS. A previous contract survey set two survey caps on the dam that were validated during this study. The GPS base was set over a permanent cap located where it could provide good radio link throughout the hydrographic 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

NAVD88 and the project's vertical datum that is 7.5 feet lower than NAVD88. Unless noted, all elevations in this report are referenced to the project vertical datum. The developed reservoir topography presented in this report was tied to NAVD88. The computed surface areas and reservoir volumes from the developed reservoir topography were shifted -7.5 feet to the project vertical datum for reservoir water operation purposes.

The June 2009 underwater survey was conducted at near full reservoir condition, elevation 4,724, that was 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 boats navigated along grid lines covering Gibson Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines.

The initial above-water topography for the 2009 field survey was determined by digitizing contour lines from the USGS quads of the reservoir area. This outline was used to assure coverage of the reservoir during the June survey. During analysis, the water surface edges of previous orthographic aerial images (USDA, 2010) were digitized for topographic development and confirmation of the developed contours from the 2009 bathymetric data.

The shallow water areas not covered by the 2009 bathymetric survey vessels required additional data to complete the reservoir topographic development. Airborne collected digital data was obtained as IFSAR bare-earth information in east, north coordinates and elevation values (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 this study did not have the funding to acquire these other data sets. The IFSAR data was primarily used in the very upper reach of the reservoir, in the shallow grassy areas not accessible by the survey vessel.

The 2009 Gibson Reservoir topographic map is a combination of the IFSAR digital data, the digitized water surface edge from the USDA photographs, and the 2009 underwater survey data, all tied to the vertical datum NAVD88. A computer program was used to generate the 2009 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data. The 1973 surface area at elevation 4,740 was used to interpolate the 2009 area and capacity values for the upper elevations between elevation 4,724.0 and 4,740.0. For reservoir operation purposes the resulting reservoir surface areas were shifted -7.5 feet to the project vertical datum. The 2009 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 Gibson Reservoir and watershed characteristics for the 2009 survey. The 2009 survey determined the reservoir has a total storage capacity of 98,688 acre-feet with a surface area of 1,334 acres at conservation water surface elevation 4, 724.0. Since closure of Gibson Dam in December of 1929, this survey measured a 6,172 acre-foot loss in reservoir capacity below elevation 4, 724.0. The losses were computed by comparing the original and the 2009 capacities for the reservoir. The measured loss was due to sediment deposition and data accuracy differences between methods of collection.

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