RECLAMATION
Managing Water in the West

Technical Report No. SRH-2013-19

Nambe Falls Reservoir 2013 Bathymetric Survey

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

July 2013

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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (Sedimentation) Group of the Technical Service Center (TSC) prepared and published this report. Mike Sixta and Ron Ferrari of Reclamation's Sedimentation Group conducted the bathymetry survey in March and a confirmation survey in June of 2013. Assistances provided by Alfredo Roybal of the Pojoaque Valley Irrigation District along with Anthony Vigil and Michael Sanchez of the Reclamation's Albuquerque Area Office. Ron Ferrari completed the data processing to generate the 2013 reservoir topography and area-capacity information presented in this report. Kent Collins of the Sedimentation Group performed the technical peer review of this document.

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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Nambe Falls Reservoir - 2013 Bathymetric Survey

prepared by

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14. ABSTRACT Reclamation surveyed Nambe Falls Reservoir in March 2013 to develop updated reservoir topography and compute present storage-elevation relationships (area-capacity tables). The bathymetric survey, conducted near water surface elevation 6826 feet (project datum tied to National Geodetic Vertical Datum of 1929 (NGVD29)), 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. In June 2013 a one day survey using a multifrequency sounder along with bottom probing confirmed the March 2013 survey results. The above-water topography was developed with limited RTK GPS topographic shots in the inflow channel and along the dam alignment, digitized reservoir water's 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). This study assumed no surface area changes, since 2004, from elevation 6828.0 and above.

As of March 2013, at spillway crest elevation 6826.6, the reservoir surface area was 58.0 acres with a capacity of 1,729 acre-feet. Since dam closure on February 23, 1976, a total capacity change of 297 acre-feet below elevation 6826.6 was measured resulting in a 14.6 percent loss in reservoir volume. The capacity change due to sediment deposition has been an issue since several major fires within the drainage basin. This study computed 100 percent of the dead storage below elevation 6760.9 has been lost due to sediment deposition. Use of outlet works after the March survey observed water running with black ash with no visual sediments being flushed. Water became clearer after extended use that lowered the reservoir about nine feet below the spillway crest by the June survey. In June, multifrequency soundings with bottom probing confirmed the March measurements and sediment material being fairly compact.

15. SUBJECT TERMS
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Technical Report No. SRH-2013-19

Nambe Falls Reservoir 2013 Bathymetric Survey

Nambe Falls Dam
New Mexico

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1/2/2014
Date

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1/6/2014
Date

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Introduction

Nambe Falls Dam and Reservoir, on the Rio Nambe, are within the boundaries of the Nambe Pueblo in Santa Fe County. The dam, reservoir, and facilities are part of the San Juan-Chama Project and located about 12 miles north of the city of Santa Fe in north-central New Mexico (Figure 1). Operation of the dam and facilities are under the direction of the Pojoaque Valley Irrigation District with an onsite dam tender that assisted during this survey.

Figure 1 - Reclamation dams and reservoirs located in New Mexico.

The reservoir, formed by a concrete arch and earthfill dam, had initial storage on February 23, 1976. The zoned earth embankment dam has a 673-foot crest length at elevation 6844.0, a structural height of 144 feet, and a hydraulic height of 127 feet. The concrete arch dam dimensions are:

Structural height[1]	150 feet	Hydraulic height	137 feet
Crest length	320 feet	Crest elevation[2]	6844.0 feet
Top width	25 feet		

The spillway is an uncontrolled overflow section in the center of the concrete arch dam with crest elevation 6826.6 and provides a discharge of 22,500 cubic feet per second (cfs) at maximum reservoir elevation 6839.8, Figure 2. The outlet works are located through the concrete arch dam and consist of two 18-inch-diameter and one 6-inch-diameter conduits. The inlet elevation of the outlets is 6761.5 with a discharge capacity of 107 cfs at reservoir elevation 6826.6. The reservoir is about 3,700 feet in length with an average width of around 690 feet.

The drainage area above Nambe Falls Dam is approximately 34 square miles with all considered to be sediment contributing. The drainage area is orientated east-to-west on the western slope of the Sangre de Cristo Mountains and ranges from elevation 6826.6, at the spillway crest, to over 12,600 feet along the eastern rim of the basin. In June 2003, a major basin fire affected about 1.5 square miles, or 4.4 percent, of the basin (Bureau of Indian Affairs, 2003). A spring 2004 reservoir survey was conducted prior to runoff contributing material from this fire (Bureau of Reclamation, 2004). In July 2011, the Pacheco Fire located primarily in the Pecos Wilderness within the Rio Nambe and Rio Frijoles sub-watersheds, burned a total of 10,250 acres (16 square miles). Almost the entire burn area drains into Nambe Reservoir that is approximately three miles downstream. The 2012 runoff of ash material contributed to a complete fish kill as the material settled within the reservoir eventually silting in the dead pool zone.

Since the 2004 survey, a retaining wall was constructed in the upper reservoir area in an attempt to trap the sediment inflows, but failed under the stress of the inflows, Figure 3. On February 19, 2009, a U.S. Army Corps of Engineers dive team conducted underwater work at the dam's outlet trash-rack that included a hydrographic survey in the immediate area around the intake. From the developed topographic map it appears the bottom was near elevation 6748 compared to the 6742 elevation measured in 2004.

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[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, tied to the National Geodetic Vertical Datum of 1929 (NGVD29), and 3.47 feet lower than North American Vertical Datum of 1988 (NAVD88).

Figure 2 - Nambe Falls spillway, located in the concrete section of Nambe Falls Dam, with spillway crest elevation 6826.6 (NGVD29), March 2013.

Figure 3 - Nambe Falls Reservoir retaining wall located in upper reservoir, June 2013.

Control Survey Data Information

Prior to the 2013 bathymetric survey, a control network was located and used during the 2004 Nambe Falls Reservoir survey (Reclamation, 2004). The horizontal control was established in the New Mexico state plane central coordinate zone in the North American Datum of 1927 (NAD27) with a vertical datum tied to NGVD29. The project features were designed and constructed to these datums. During the RTK GPS collection in 2004 and 2013 the base was set over point “G” and checked by measuring other network points such as “F” and “K”, Figures 4 and 5. The 2004 analysis was conducted using the provided control network tied to NAD27 and NGVD29.

For the 2013 survey, the NAD27 and NGVD29 coordinates were converted to the North American Datum of 1983 (NAD83) and NAVD88 using the Corp of Engineers program CORPSCON. The 2013 survey was conducted using the converted coordinates at base station point “G” that measured points “F” and “K.”

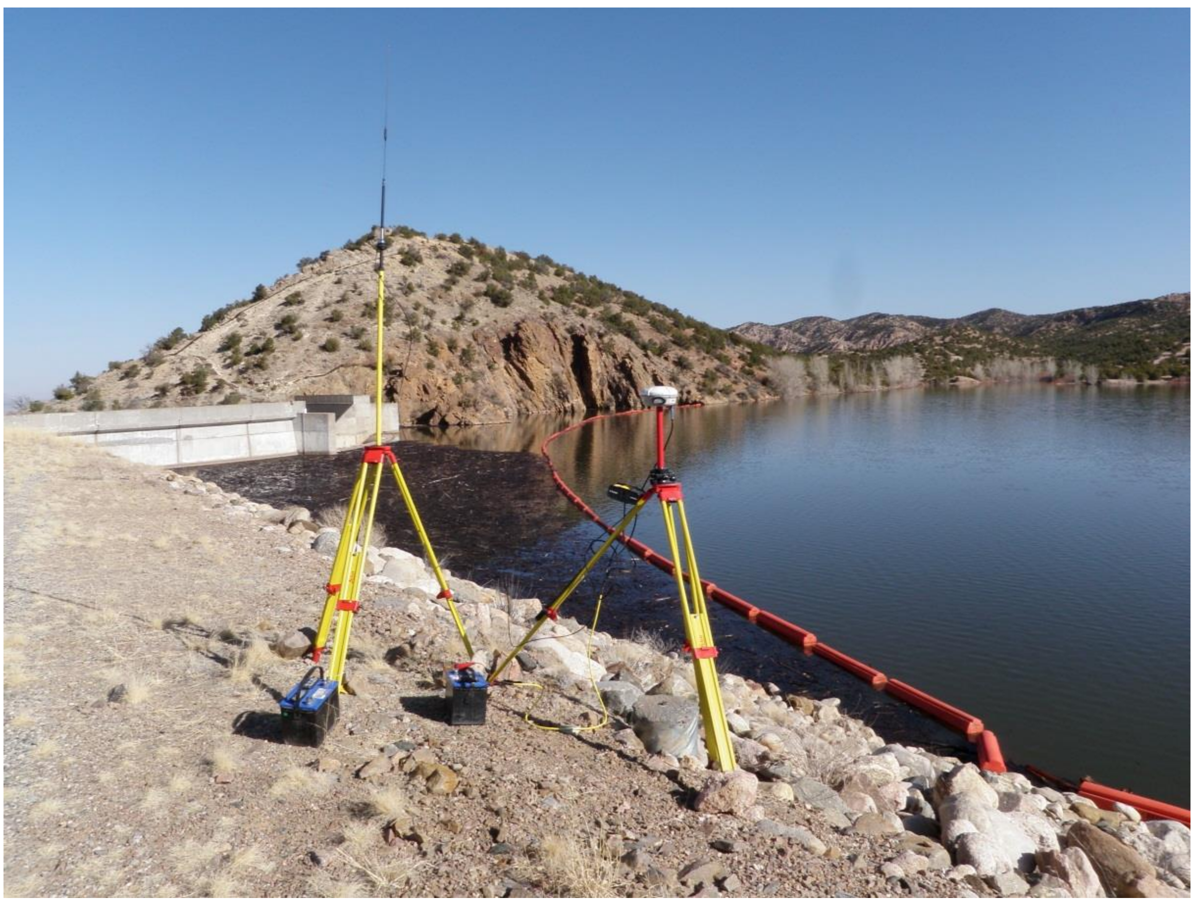

Figure 4 – Base setup over control point "G" located on the earthen portion of Nambe Falls Dam.

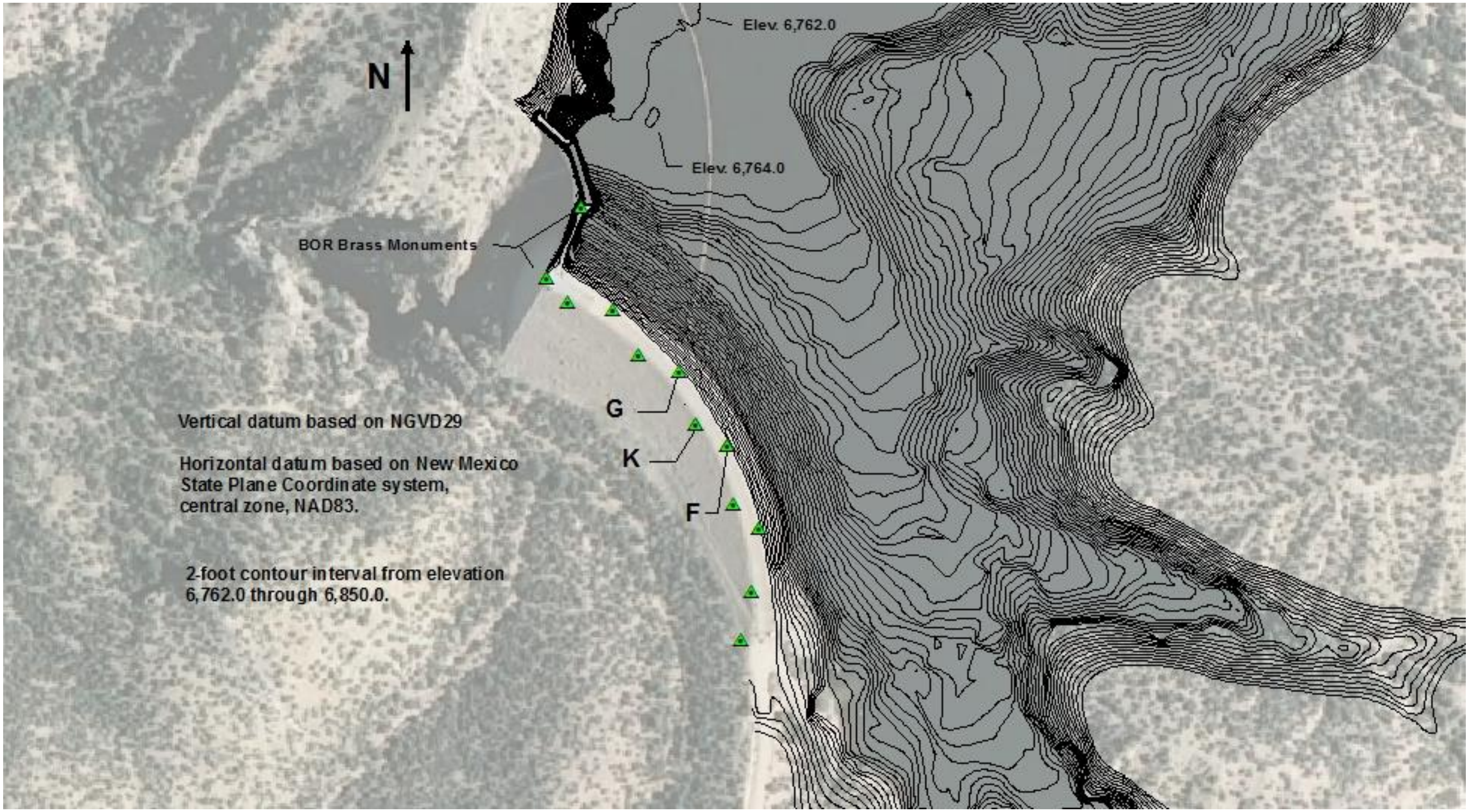

Figure 5 - Nambe Falls Reservoir control points, GPS base set over point "G" (NGVD29).

During the two day March 2013 collection, the base data information was retained at point “G” and submitted to the on-line positioning user service (OPUS). OPUS, operated by the National Geodetic Survey (NGS), 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 OPUS generated NAD83/NAVD88 coordinates to the CORPSCON generated NAD83/NAVD88 coordinates at base station “G.” The OPUS computation for both days measured an average positive shift of 5.73 feet “East” and 0.308 feet “North” from the CORPSCON computed coordinates. These east and north computed shifts were applied to all of the data collected by the 2013 survey. The elevation difference was negligible, 0.005 feet, so no correction or shift was applied to the 2013 measured data point elevations except to shift from NAVD88 to NGVD29.

For this study the horizontal control was established in New Mexico state plane central coordinates, NAD83, in feet. The vertical control was tied to NGVD29. Unless noted, all elevation computations and contour elevations of the topographic maps are referenced to NGVD29 or Reclamation’s construction datum that is roughly 3.47 feet lower than NAVD88 (GEOID2012A). Following are the coordinates for control points used and measured during the 2004 and 2013 reservoir surveys.

Point Name		Original (NAD27)	CORPSCON (NAD83)	March 2013 Measured (NAD83)	OPUS Solution	Shift	Corrected Coordinates (NAD83)
G	East	602,301.04	1,742,544.458	1,742,544.458	1,742,550.188	5.730	1,742,550.188
	North	1,762,975.14	1,763,037.431	1,763,037.431	1,763,037.739	0.308	1,763,037.739
	(NGVD29)	6,843.971	6,843.971				
	(NAVD88)		6,847.442		6,847.437	0.005	6,847.437
F	East	602,383.60	1,742,627.016	1,742,627.019			1,742,632.749
	North	1,762,850.56	1,762,912.851	1,762,912.871			1,762,913.179
	(NGVD29)	6,842.436	6,842.436				
	(NAVD88)		6,845.910	6,845.927			6,845.927
K	East	602,328.98	1,742,572.397	1,742,572.351			1,742,578.081
	North	1,762,886.70	1,762,948.991	1,762,949.005			1,762,949.313
	(NGVD29)	6,841.275	6,841.275				
	(NAVD88)		6,844.749	6,844.802			6,844.802

Reservoir Operations

Nambe Falls Reservoir is part of the San Juan-Chama Project that provides water supply to the middle Rio Grande Valley for municipal, domestic, and industrial uses. The March 2013 capacity table shows 2,600 acre-feet of total storage below the maximum water surface elevation 6839.8. The March 2013 survey measured a minimum lake bottom elevation of around 6761.6 compared to an April 2004 measured minimum lake bottom elevation of 6740.5. The following values are from the March 2013 capacity table:

- 872 acre-feet of surcharge pool storage between elevation 6826.6 and 6839.8.
- 1,548 acre-feet of active conservation between elevation 6780.0 and 6826.6.
- 181 acre-feet of inactive use storage between elevation 6760.9 and 6780.0.
- 0 acre-feet of dead pool storage below elevation 6760.9.

Nambe Falls Reservoir available inflow and end-of-month stage records are listed in Table 1 for operation period 1976 through 2001 showing an average runoff of 10,310 acre-feet. These values are from the USGS gauging station "Rio Nambe below Nambe Falls Dam" and were developed for the 2004 report. The table shows the extreme annual fluctuation of the reservoir as the water surface exceeded the spillway crest elevation (6826.6) during many years with the maximum-recorded elevation being 6827.2 in 1979 and the minimum elevation being 6778.8 in 1996. On average, the annual reservoir elevations range from spillway crest elevation 6826.6 to a minimum elevation 6807 by the end of the water year.

RESERVOIR SEDIMENT
DATA SUMMARY

Nambe Falls Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: Rio Nambe	3. STATE: New Mexico
A	4. SEC 29 TWP. 19 N RANGE 10 E	5. NEAREST P.O. Nambe Pueblo	6. COUNTY Santa Fe
M	7. LAT 35 ° 50 ' 46 " LONG 105 ° 54 ' 17 "	8. TOP OF DAM ELEVATION: 6,840.0 [1]	9. SPILLWAY CREST EL. 6,826.6 [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	6,839.8 [3]	74	872	2,898	
E	b. FLOOD CONTROL					2/23/76
S	c. POWER					
E	d. JOINT USE					16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION	6,826.6	59	1,666	2,026	
V	f. INACTIVE	6,780.0	18	237	360	
O	g. DEAD	6,760.9	8	123	123	2/1976
I R	17. LENGTH OF RESERVOIR 0.7 [4] MILES		AVG. WIDTH OF RESERVOIR 0.13 MILES			

B	18. TOTAL DRAINAGE AREA 34.1 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 8 to 30 [6] INCHES	
A	19. NET SEDIMENT CONTRIBUTING AREA 34.1 [4] SQUARE MILES	23. MEAN ANNUAL RUNOFF [7] INCHES	
S	20. LENGTH MILES	AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 10,310 [8] ACRE-FEET
I N	21. MAX. ELEVATION	MIN. ELEVATION	25. ANNUAL TEMP, MEAN °F RANGE -30 °F to 105 °F [6]

	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 V	2/23/76			Contour (D)	5-ft	59	2,026	0.20
E	4/1/04	28.1	28.1	Contour (D)	2-ft	58	1,920	0.19
Y	3/28/13	9.0	37.1	Contour (D)	2-ft	58 [9]	1,729 [9]	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			10,310 [10]				

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.
4/1/04	106 [11]	3.8	0.111	106	3.8	0.111
3/2013	191	21.2		297	8.0	

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.
4/1/04				0.188 [9]	5.23 [9]		
3/2013				1.050	14.60		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW AND ABOVE CREST ELEVATION									
		6,697.0-6,760.9	6,760.0-6,770.0	6,770.0-6,780.0	6,780.0-6,790.0	6,790.0-6,800.0	6,800.0-6,810.0	6,810.0-6,820.0	6,820.0-CREST		
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION									
2004		42.5	2.8	9.4	9.5	7.5	11.3	10.4	6.6		
2013		41.4	10.9	8.0	6.7	7.7	11.5	7.7	6.1		

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
1976				1977	6,809.5	6,780.6	4,470
1978	6,826.8	6,786.3	6,800	1979	6,827.2	6,798.9	6,600
1980	6,826.9	6,807.8	16,600	1981	6,818.8	6,781.3	3,920
1982	6,817.1	6,785.6	4,280	1983	6,827.1	6,817.1	18,130
1984	6,826.9	6,807.7	12,390	1985	6,827.0	6,814.9	18,640
1986	6,826.7	6,820.2	14,000	1987	6,827.0	6,814.9	15,200
1988	6,826.8	6,814.9	14,000	1989	6,826.6	6,801.4	7,600
1990	6,826.7	6,802.7	6,390	1991	6,827.0	6,826.7	11,730
1992	6,826.8	6,812.4	15,760	1993	6,827.0	6,810.7	11,560
1994	6,827.0	6,804.6	12,370	1995	6,826.9	6,808.3	10,390
1996	6,825.2	6,778.8	5,100	1997	6,826.8	6,789.0	5,200
1998	6,826.8	6,806.4	9,800	1999	6,826.9	6,807.3	9,400
2000				2001	6,826.9	6,802.8	7,090
2002				2003			
2004				2005			
2006				2007			
2008				2009			
2010				2011			
2012				2013			

46. ELEVATION - AREA - CAPACITY - DATA FOR								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2004	**SURVEY** [12]		6,740.5	0.0	0	6,745.0	1.6	3
6,750.0	3.4	16	6,755.0	5.7	39	6,760.0	7.4	72
6,760.9	8.0	78	6,765.0	8.9	112	6,770.0	11.1	162
6,775.0	14.0	225	6,780.0	16.8	302	6,785.0	19.6	393
6,790.0	22.9	499	6,795.0	26.4	622	6,800.0	30.7	765
6,805.0	35.1	928	6,810.0	39.8	1,116	6,815.0	45.0	1,328
6,820.0	50.0	1,565	6,826.6	58.0	1,920	6,830.0	62.1	2,124
6,835.0	68.2	2,450	6,839.8	74.0	2,792	6,840.0	74.4	2,807
2013	**SURVEY**							
6,761.0	0.0	0	6,761.5	0.2	0	6,765.0	6.9	13
6,770.0	9.6	55	6,775.0	12.6	110	6,780.0	15.7	181
6,785.0	18.8	267	6,790.0	21.8	368	6,795.0	25.0	485
6,800.0	28.7	619	6,805.0	32.5	772	6,810.0	38.1	948
6,815.0	43.8	1,153	6,820.0	48.9	1,385	6,825.0	53.3	1,641
6,826.6	58.0	1,729	6,830.0	62.1	1,933	6,835.0	68.2	2,259
6,839.8	74.2	2,601	6,840.0	74.4	2,616			

47. REMARKS AND REFERENCES

[1] All elevations are in feet based on original project datum that is tied to NGVD29. Top of earth embankment and parpet wall elevation 6,844.0. Project vertical datum tied to NGVD29 and 3.47 feet lower than NAVD88.

[2] Uncontrolled spillway crest elevation.

[3] Original values recomputed from 5-foot contours with Reclamation's ACAP program.

[4] Length with side tributary.

[5] From USGS water year records, 2001. Drainage runoff affected by major fires in June 2003 and July 2011.

[6] Bureau of Reclamation Project Data Book, 1981. Values for San Juan - Chama Project.

[7] Calculated using mean annual runoff value of 10,310 AF, item 24. 1979 through 2001 average value from USGS gage: "Rio Nambe Below Nambe Falls Dam." Values in item 45 from USGS water reports.

[8] 1979 through 2001 average value from USGS gage "Rio Nambe Below Nambe Falls Dam." Flow affected by Nambe Falls Dam. Values in item 45 from USGS water reports.

[9] Surface area and capacity at elevation 6,826.6, spillway crest elevation.

[10] See remarks #7 and #8. Maximum and minimum elevations from available USGS records by water year.

[11] Total sediment inflow by comparing survey values with recomputed capacity from original survey.

[12] All capcity computed by Reclamation's ACAP computer program. The 1976 or original capacity values were recomputed by ACAP for purpose of computing sedimet accumulation values. 2004 and 2013 surveys assumed no change from original elevations 6,826.6 and above.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE June 2013

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

Hydrographic Survey, Equipment, and Method of Collection

Bathymetric Survey Equipment

The March 2013 bathymetric survey equipment was mounted on a pontoon raft with the transducer and RTK GPS unit located in the center of the vessel, Figure 6. The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. The depth sounder was paperless, 208 kHz, and provided a continuous trace of the bottom. The shore equipment included a second RTK GPS receiver with an external radio. The shore GPS receiver and antenna were mounted on survey tripods over a known datum point and powered by a 12-volt battery. The June confirmation survey used a larger boat that allowed for mounting a more robust multifrequency sounder and transducers that ranged from 12 to 208 kHz. This more stable vessel also allowed the survey crew to probe the bottom of the reservoir to confirm previous depth soundings.

Figure 6 - Survey vessel used for the March 2013 Nambe Falls Survey.

The Sedimentation Group uses RTK GPS with the primary benefit being precise heights measured in real time to monitor water surface changes. The RTK GPS system employs two receivers that track the same satellites simultaneously. The basic outputs from the RTK receiver are 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 New Mexico's state plane central coordinates, NAD83, in feet.

The Nambe Falls Reservoir bathymetric survey was conducted on March 27 and 28 of 2013 between water surface elevation 6825.9 and 6826.0 (NGVD29). The bathymetric survey was conducted using sonic depth recording equipment interfaced with a RTK GPS to determine the sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along established grid lines throughout the reservoir. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining course along these predetermined lines. There were a few coves and areas along the shoreline of the reservoir that were not covered by the survey vessel due to vegetation that grew during lower reservoir levels and driftwood that had accumulated in these areas. As each line was traversed, the depth and position data were recorded on a laptop computer for subsequent processing. The water surface elevations at the dam, recorded by a gage at the dam and RTK GPS measurements, were used to convert the depth measurements to lake-bottom elevations. The elevations were tied to NGVD29 that is, on average, 3.47 feet lower than NAVD88.

The depth data was calibrated by adjusting the speed of sound through the water column, which can vary with density, salinity, temperature, turbidity, and other conditions. The crew returned in June of 2013 to confirm the soundings from the March survey since the results found the dead pool had all but silted in. The depth sounder in March produced a digital analog chart of the measured depths. These charts were analyzed during post-processing; when the charted depths indicated a difference from the computer recorded bottom depths, the data files were modified. Additional information on collection and analysis procedures is outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006). Final processing of the March 2013 data resulted in 17,272 points, Figure 7.

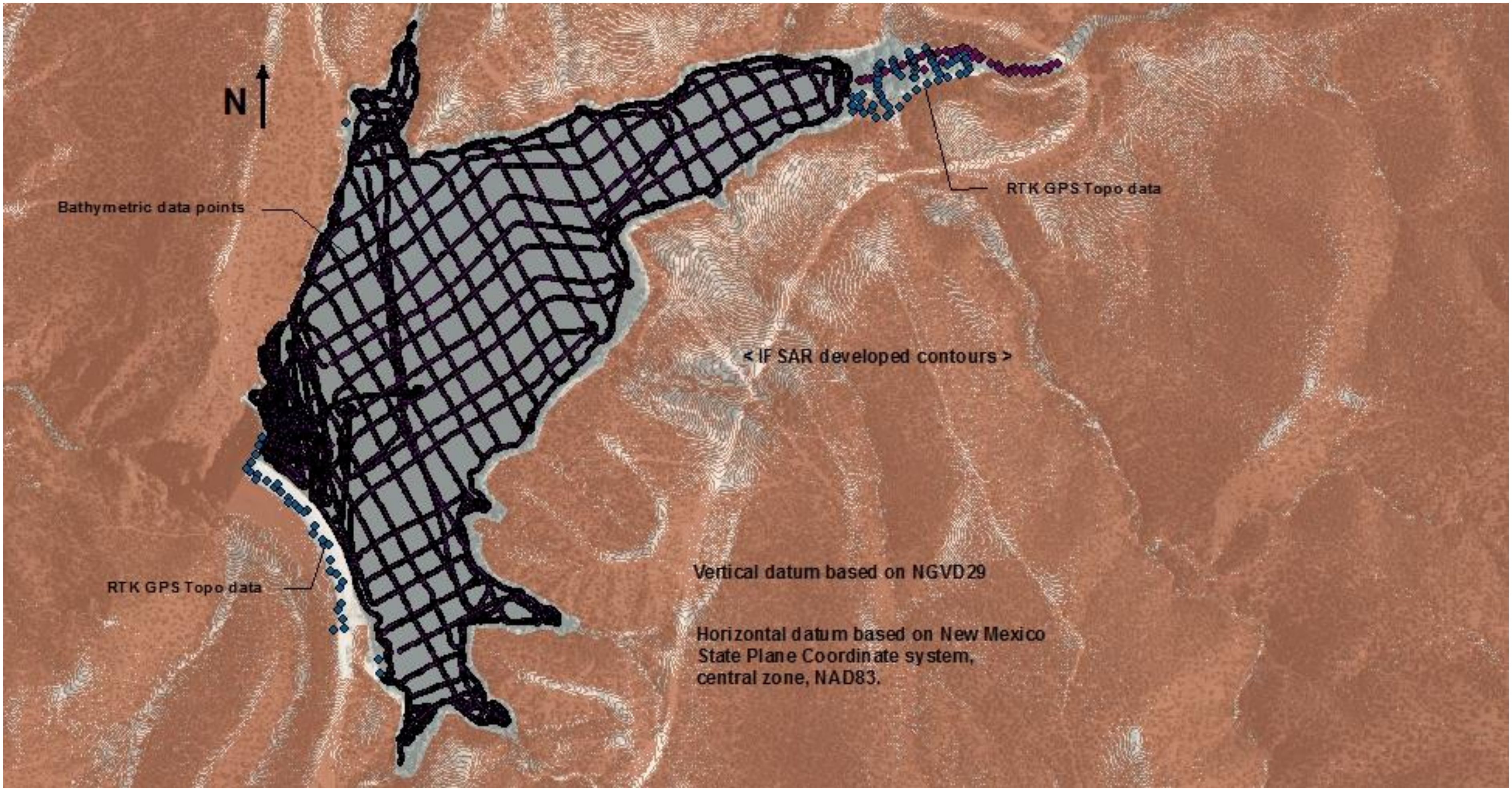

Figure 7 - Nambe Falls Reservoir 2013 data coverages.

Above Water Data

Aerial Photography

The 2013 study of Nambe Falls Reservoir focused primarily on the collection of bathymetric (underwater) data in areas accessible by the survey vessel. Acquisition of the best available above water data was also necessary to complete development of the topographic map. During analysis, orthographic aerial images collected in 2009 when the reservoir was near the spillway crest elevation (6826.6) were downloaded from the USDA data web site (USDA, 2010). Reservoir contours were developed by digitizing the water's edge from this aerial image and assigning a water surface elevation of 6826.6. This contour was near the reservoir pool elevation when the 2013 bathymetric survey was conducted, enclosed the 2013 bathymetric data, and was used during topographic development. Vegetation along portions of the shoreline made it difficult to distinguish the water's edge from the aerial flight, but this was the best available information for this study.

Aerial IFSAR

As part of this analysis, Interferometric Synthetic Aperture Radar (IFSAR) was obtained as digital bare earth data in New Mexico's state plane coordinates with elevations tied to NAVD88. IFSAR airborne technology enables mapping of large areas quickly and efficiently resulting in information at much lower costs than other technologies such as aerial photogrammetry and LiDAR, although the accuracies are not quite as good. The data was collected when the reservoir was near elevation 6812 (NAVD88), providing areas of overlap to compare with the USDA and March 2013 data sets. To match NGVD29 the IFSAR elevations were shifted downward 3.47 feet.

The IFSAR data provided topographic images of the shoreline of the main reservoir body, coves, and around the dam. The IFSAR-reported accuracies are 2-meters horizontally and 1-meter vertically for areas of unobstructed flat ground (Intermap, 2011). For the open areas of the reservoir, with minimal vegetation along the shoreline, the developed contours from the IFSAR data matched with the USDA digitized contours within the accuracies of the data. For areas of dense vegetation, the IFSAR data were erratic and did not match well with the USDA contours. Following examination of the two data sets, it was determined that the USDA data set was the best representation of the present reservoir condition in the densely vegetated and open areas of the reservoir. During processing, the IFSAR data in the vegetated areas and areas near USDA contours, and 2013 bathymetric data points were removed leaving the remaining data to be used in the final 2013 topographic development of the area above the spillway crest elevation. For the 2013 Nambe Falls Reservoir study, the IFSAR data was deemed to match close enough to be used in the contour development, but not for the computation analysis. For the Nambe Falls Reservoir shoreline and cove areas with vegetation, the IFSAR data were removed, leaving the USDA contours as the primary data source for these areas during the reservoir map development.

Reservoir Area and Capacity

Topography Development

The data sources utilized for generating the 2013 topographic contours of Nambe Falls Reservoir included the 2013 bathymetric data points, 2013 RTK GPS topographic shots, digitized reservoir water surface edges from the USDA aerial photography, and IFSAR aerial data points. The USDA and IFSAR data sets were the most accurate available data that enclosed the 2013 data. These data were processed into a triangulated irregular network (TIN) that was used to develop 2-foot contours tied vertically to NGVD29. The resulting surface areas and volumes presented in this report were developed from the TIN. If need be, these elevations can be shifted upward 3.47 feet to match NAVD88. In preparation for developing the TIN, a polygon was created to enclose all of the data sets. This polygon, not assigned an elevation, was used as a hard boundary for the 2013 developed contours, only allowing mapping within the polygon and preventing interpolation outside of it. The TIN method is described in more detail in the ArcGIS user's documentation (ESRI, 2006).

The linear interpolation and CONTOUR commands were used to interpolate contours from the Nambe Falls Reservoir TIN. The surface areas of the enclosed contour polygons at 1-foot increments were computed for elevation 6761.0 and above. The reservoir contour topography at 2-foot intervals is presented in Figures 8 through 11 from elevation 6762.0 and above.

2013 Nambe Falls 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 0.01 to 1.0 foot elevation increments by linear interpolation between the given contour surface areas. For this study the 1-foot computed surface areas from elevation 6761.0 through 6825.0 were used. The 2013 Nambe Falls Reservoir area and capacity tables assumed no change from the 2004 surface areas from elevation 6826.6 and above. There were too many unknowns with vertical accuracies on the above water data sets to make an accurate comparison. Also during the 2013 surveys no major sediment delta was observed in the upper reservoir area. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error tolerance, which was set to 0.000001 for Nambe Falls 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 reservoir area and capacity computations are listed in a separate set of 2013 area and capacity tables and have been published for 0.01, 0.1, and 1-foot elevation increments (Bureau of Reclamation, 2013). A description of the computations and coefficients output from the ACAP program is included with those tables. As of March 2013, at conservation use elevation 6826.6, the surface area was 58.0 acres with a total capacity of 1,726 acre-feet. At maximum and top of surcharge elevation 6839.8, the surface area was 66.6 acres with a total capacity of 2,601 acre-feet.

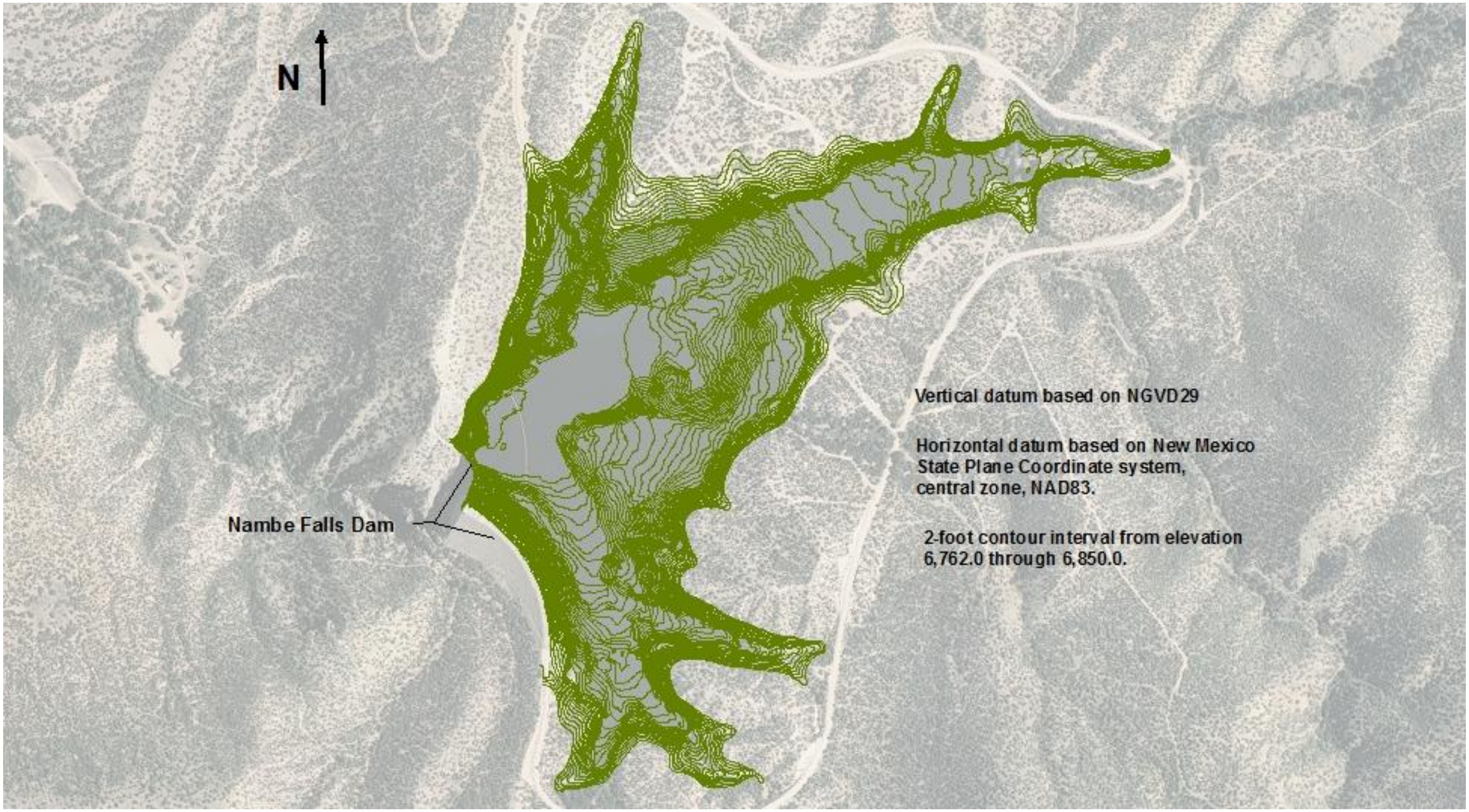

Figure 8 - Nambe Falls Reservoir 2013 contours, NGVD29 (map 1 of 4).

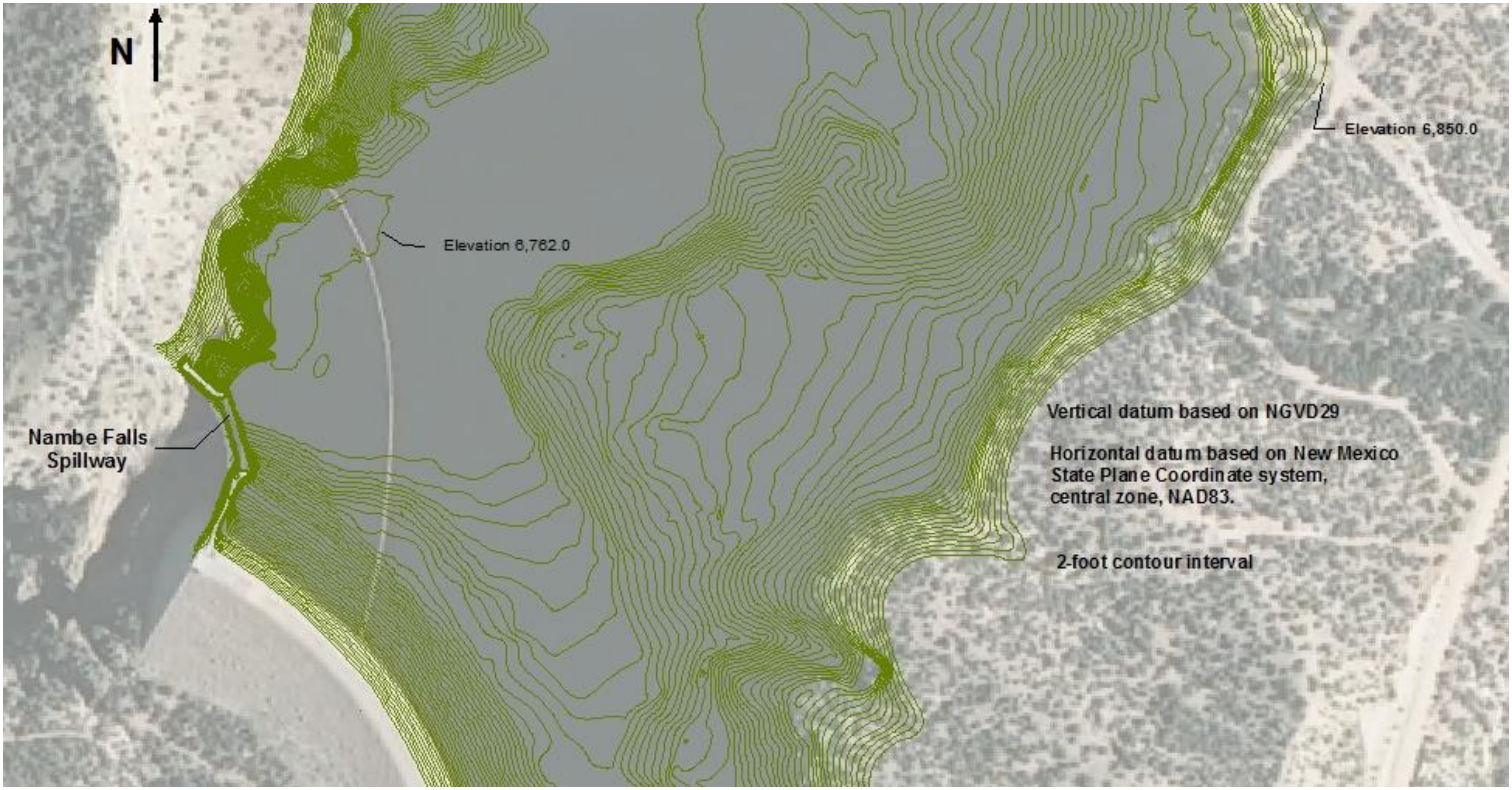

Figure 9 - Nambe Falls Reservoir 2013 contours, NGVD29 (map 2 of 4).

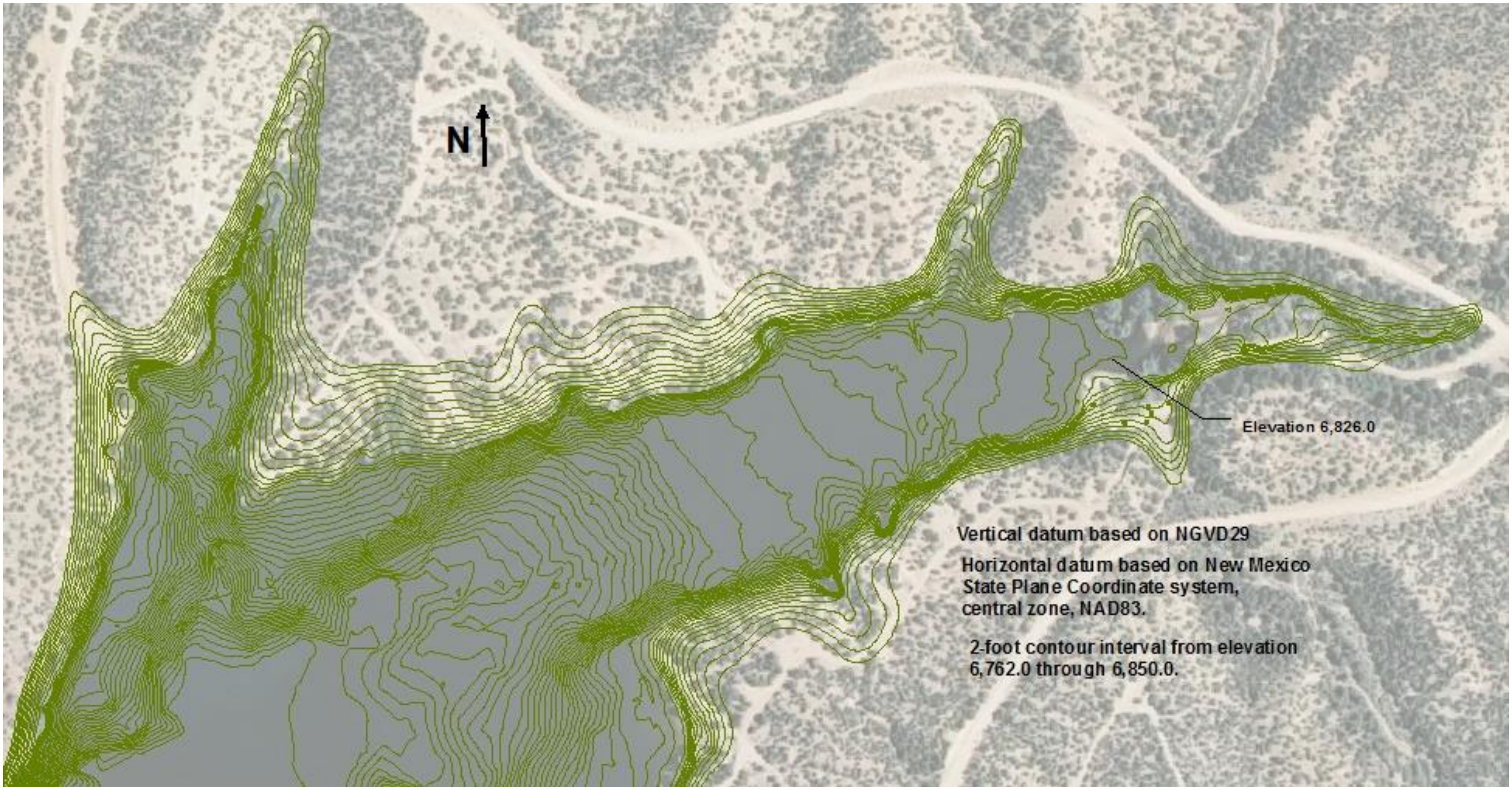

Figure 10 - Nambe Falls Reservoir 2013 contours, NGVD29 (map 3 of 4).

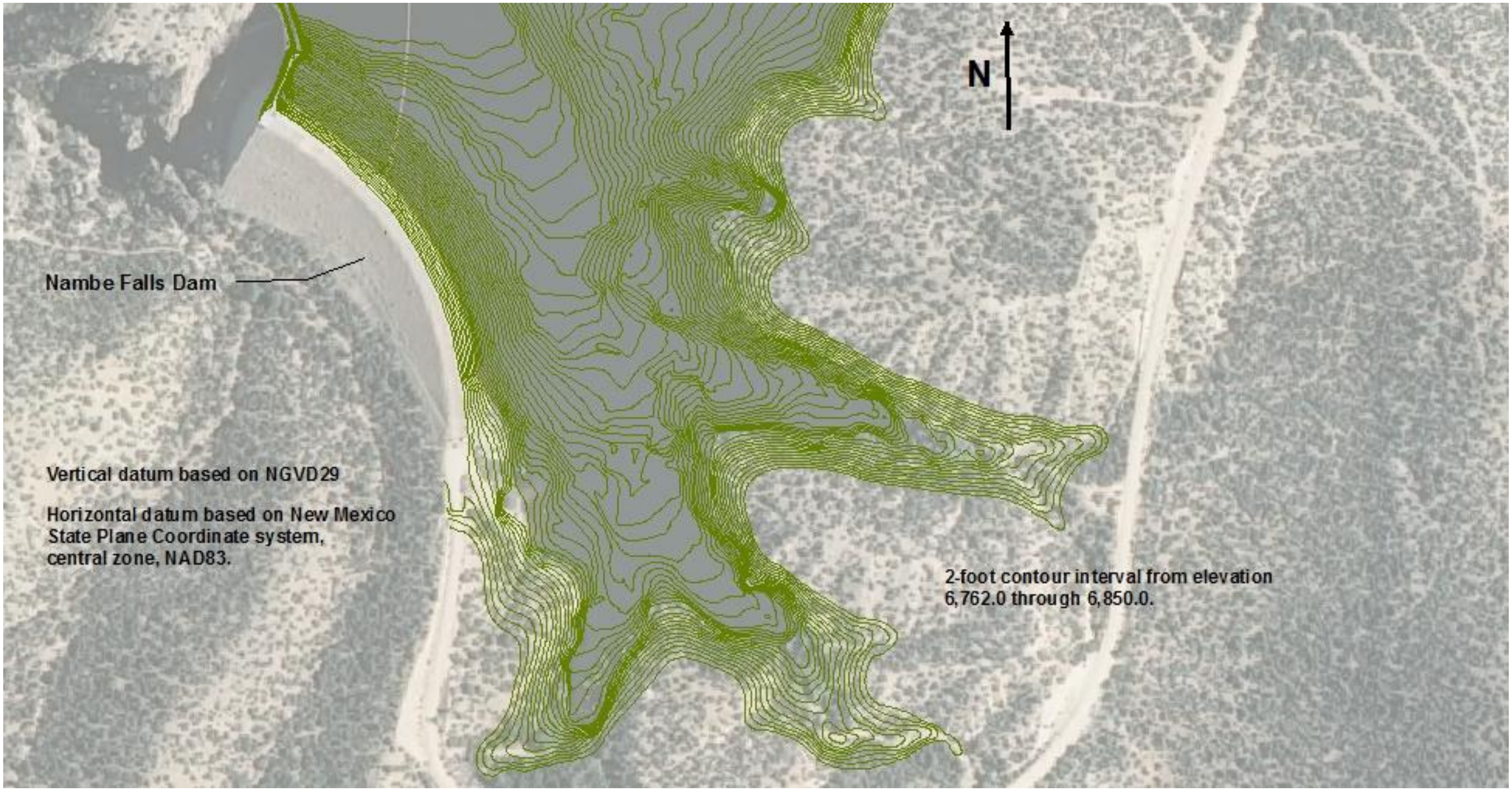

Figure 11 - Nambe Falls Reservoir 2013 contours, NGVD29 (map 4 of 4).

Nambe Falls Reservoir Surface Area and Capacity Results

Table 1 provides a summary of the changes in reservoir storage, inflow, and topography since the time of dam closure in February 1976, which includes the surveys in April 2004 and March 2013. The original area and capacity curves along with the 2004 and 2013 surveys are plotted in Figure 12. Table 2 provides a summary of the original along with the 2004 and 2013 surface areas and capacities.

The 2013 bathymetric survey and the other data sources summarized in the *Topographic Development* section provided adequate information for computing the surface areas from elevation 6826.6 and below. For 2013 computation purposes no change of surface area was assumed at elevations 6826.6 and above since the 2004 survey results. The ACAP program interpolated and computed the area and capacity values between the input surface area values from elevation 6761.0 through 6840.0.

Longitudinal Distribution

To illustrate the present reservoir bottom and change over time, the reservoir thalweg profile was plotted from the dam to the upper reservoir area for the 2004 and 2013 conditions, Figure 13. The original profile was not available, but it appears that starting at the dam the original thalweg was below elevation 6700. The original capacity at elevation 6710.0 was only 0.1 acres, meaning it didn’t take much to fill in this area with sediment. For the 2004 and 2013 longitudinal profiles the thalweg was cut through the developed 2-foot topographic contours from each study with the 2004 contours being used to develop the thalweg alignment starting from the dam and continuing upstream of the Rio Nambe. The 2004 plot ended at elevation 6826.0 using available data while the 2013 plot extended to elevation 6842.0 using the collected RTK GPS topography data.

The 2013 thalweg started near elevation 6764.0 at the dam and dropped to elevation 6762.0 through the developed contours. The 2013 minimum bottom data elevation was around elevation 6761.6 compared to the outlet sill elevation of 6761.5 and the reservoir’s dead pool elevation of 6761.9. The collected March 2013 data, spot checked in June 2013, confirmed that the original dead pool area is currently silted in.

The 2013 thalweg shows the majority of the sediment deposition occurring near the dam since 2004 and then slopes upstream to the top of a typically developed sediment delta near elevation 6774. The 2013 top of the pivot point of the delta is near elevation 6804, which is near the average annual minimum reservoir elevation for the available years of reservoir operations (Table 1). The 2004 plot doesn't show a typical sediment delta formation that was surveyed near reservoir elevation 6803. It must be noted that prior to the 2004 survey the reservoir was much lower in elevation for an extended period due to limited runoff, and land excavation was conducted to move the delta. Some of this material was removed from the reservoir area, but the 2004 survey observed where some of the sediment and other material were placed into large slash piles within the normal reservoir pool. Soon after the 2004 survey the reservoir did fill and spill and it's assumed these slash piles were never removed.

The 2013 plot illustrates the present condition of the reservoir and how the sediment deposition and inflows are impacting the inlet of the outlet works. The plots show nearly 20 feet of sediment deposition at the dam since the 2004 survey and around 14 feet of deposition since the 2009 dive team survey. The 2013 plot also illustrates that sediment inflows have settled in the upper reservoir area where the upper sediment delta has formed and a failed retaining wall was constructed. Sediments have flushed downstream from this formed delta, filling the original dead pool zone and above. With no dead pool area much of the future sediment inflow will deposit throughout the reservoir with small portions being flushed downstream through the outlet works when in operation.

1	2	3	4	5	6	7	8	9	10	11
Elevation Feet	Original Area Acres	Original Capacity Ac-Ft	2004 Area Acres	2004 Capacity Ac-Ft	2004 Sediment Volume Ac-Ft	2013 Area Acres	2013 Capacity Ac-Ft	2013 Sediment Volume Ac-Ft	Percent Reservoir Sediment	Percent Reservoir Depth
6,839.8	74.0	2,898	74.0	2,792	106	74.2	2,601	297		100.0
6,835.0	68.2	2,556	68.2	2,450	106	68.2	2,259	297		96.6
6,830.0	62.1	2,231	62.1	2,124	107	62.1	1,933	298		93.1
6,828.0	60.0	2,109	60.0	2,002	107	60.0	1,811	298		91.7
6,826.6	59.0	2,026	58.0	1,920	106	58.0	1,729	297	100.0	90.8
6,820.0	50.7	1,664	50.0	1,565	99	48.9	1,385	279	93.9	86.1
6,815.0	45.7	1,423	45.0	1,328	95	43.8	1,153	270	90.9	82.6
6,810.0	42.1	1,204	39.8	1,116	88	38.1	948	256	86.2	79.1
6,805.0	35.9	1,009	35.1	928	81	32.5	772	237	79.8	75.6
6,800.0	31.3	841	30.7	765	76	28.7	619	222	74.7	72.1
6,795.0	27.0	695	26.4	622	73	25.0	485	210	70.7	68.6
6,790.0	24.1	567	22.9	499	68	21.8	368	199	67.0	65.1
6,785.0	20.5	456	19.6	393	63	18.8	267	189	63.6	61.6
6,780.0	17.9	360	16.8	302	58	15.7	181	179	60.3	58.1
6,775.0	15.3	277	14.0	225	52	12.6	110	167	56.2	54.6
6,770.0	11.2	210	11.1	162	48	9.6	55	155	52.3	51.1
6,765.0	9.4	159	8.9	112	47	6.9	13	146	49.1	47.6
6,760.9	8.0	123	8.0	78	45	0	0	123	41.4	44.7
6,760.0	8.0	115	7.4	72	43	0	0	115	38.7	44.1
6,755.0	6.5	79	5.7	39	40	0	0	79	26.6	40.6
6,750.0	5.1	50	3.4	16	34	0	0	50	16.8	37.1
6,745.0	2.9	30	1.6	3	27	0	0	30	10.1	33.6
6,740.0	2.1	18	0.0	0	18	0	0	18	6.1	30.1
6,735.0	1.1	10	0.0	0	10	0	0	10	3.4	26.6
6,730.0	0.6	5	0.0	0	5	0	0	5	1.7	23.1
6,725.0	0.2	3	0.0	0	3	0	0	3	1.0	19.6
6,715.0	0.2	1	0.0	0	1	0	0	1	0.3	12.6
6,710.0	0.1	1	0.0	0	1	0	0	1	0.3	9.1
6,697.0	0.0	0	0.0	0	0	0	0	0	0.0	0.0

1 Reservoir water surface elevation tied to NGVD29 that is 3.47 feet less than NAVD88.
2 Original reservoir surface area from 4/1/1976 memorandum.
3 Original reservoir capacity recomputed using ACAP.
4 2004 reservoir surface areas.
5 2004 reservoir capacity computed using ACAP.
6 2004 computed sediment volume, column (3) - column (5).
7 2013 reservoir surface area.
8 2013 reservoir capacity.
9 2013 computed sediment volume, column (3) - column (9).
10 2013 percent of total sediment, 297 acre-feet, by indicated elevation zone.
11 Depth of reservoir expressed in percentage of total depth of 142.8 feet.

Table 2 - Nambe Falls Reservoir 2013 survey summary.

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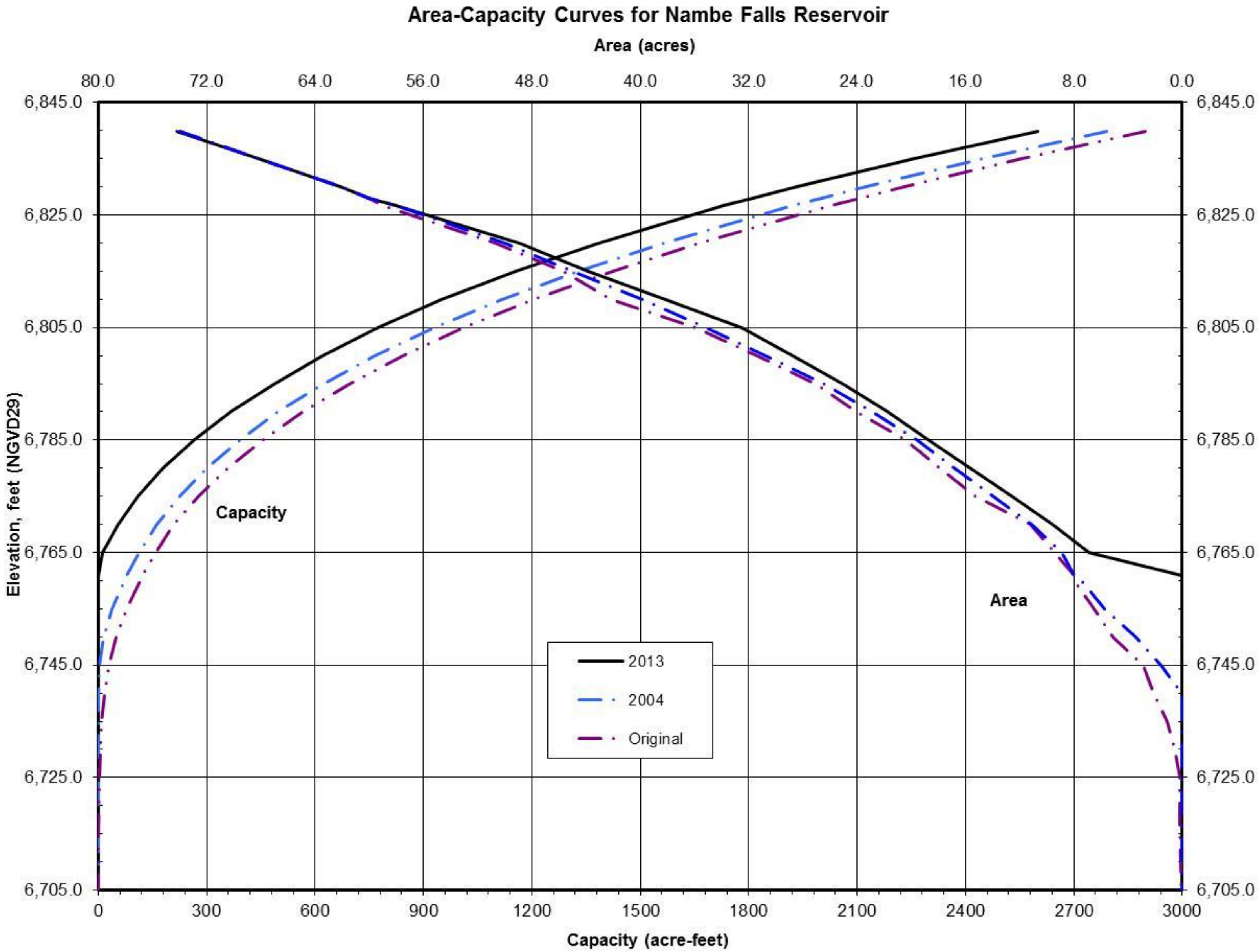

Figure 12 **- Nambe Falls Reservoir area and capacity plots.**

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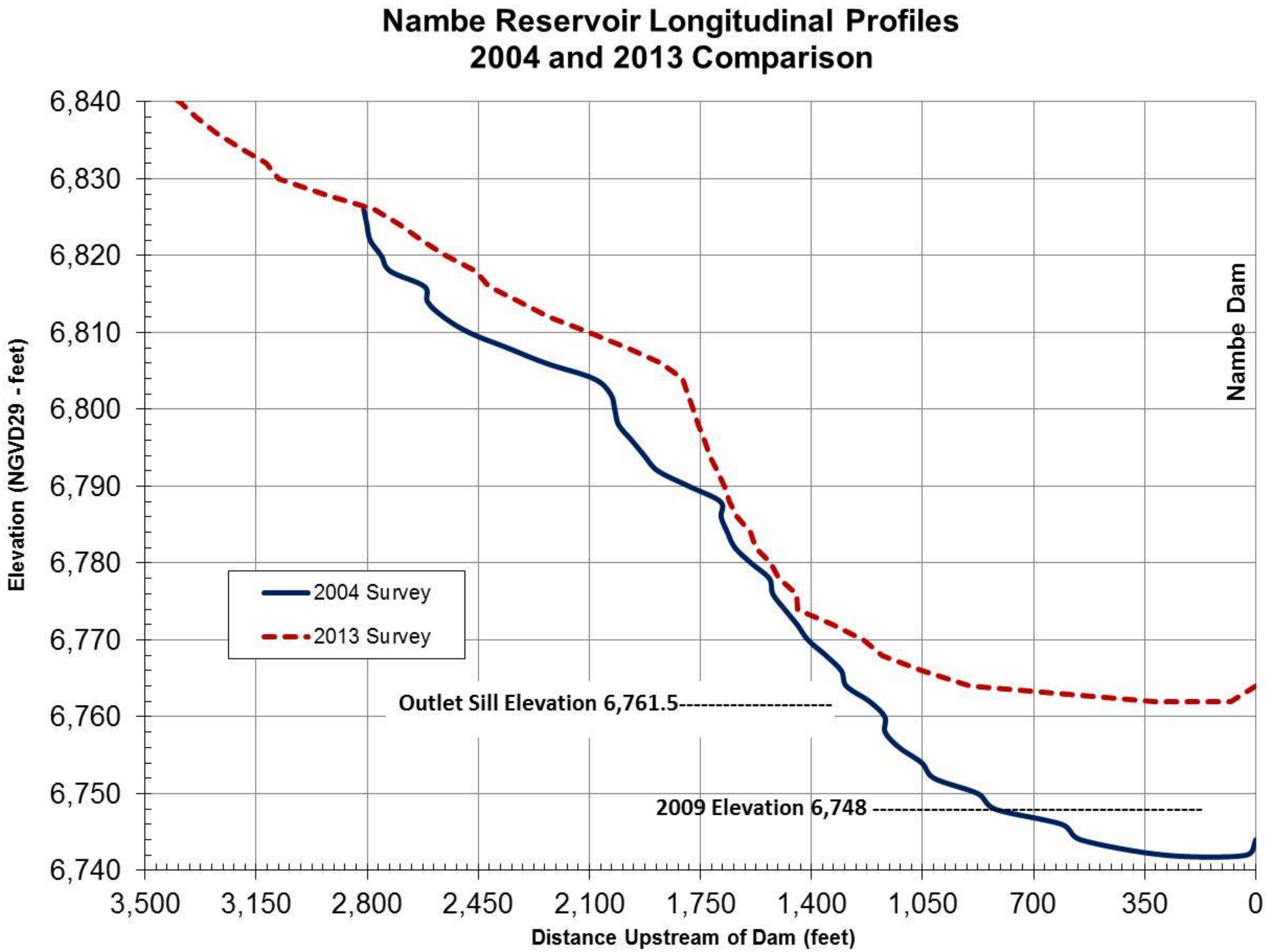

Figure 13 - Longitudinal profile of the Rio Nambe from the dam upstream.

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2013 Nambe Falls Reservoir Analyses

Figure 12 is a plot comparison of the surface areas and capacities of the reservoir's original, 2004, and 2013 survey results. For calculating the 2004 and 2013 sediment accumulation, the original capacities were recomputed using *ACAP85* that was also used to compute the 2004 and 2013 capacities. Since dam closure in 1976, the measured total volume change at reservoir elevation 6826.6 was 106 acre-feet in 2004 and 297 acre-feet in 2013. The 2013 estimated average annual rate of capacity lost for the 37-year operation period was 8.0 acre-feet per year. The 2013 storage loss in terms of percent of original storage capacity was 14.6 percent at elevation 6826.6.

The original survey measured a minimum elevation of 6667 compared to a 2004 minimum elevation 6740.5 and 2013 minimum elevation of 6761.6. This indicates nearly 95 feet of sediment deposition at the dam since the original survey, but the original surface area at elevation 6710 was only 0.1 acres and 1.1 acres at elevation 6735, meaning limited sediment inflow would fill in this original zone. Of the total measured sediment in 2013, about 60.3 percent has deposited below inactive elevation 6780.0 and 100 percent of the dead pool has been lost due to sediment deposition. Figure 13 illustrates the 2004 and 2013 sediment accumulation in relation to the outlet location and reservoir pool elevations.

The Nambe Falls reservoir capacity allocation sheet lists the projected 100-year sediment deposition to be a total of 400 acre-feet below elevation 6826.6 of which 230 acre-feet, or 57.5 percent, was projected to deposit below elevation 6780.0. The 100-year estimate equates to 4 acre-feet per year, which was close to the 2004 survey result of 3.8 acre-feet per year. The 2004 survey measured a normal accumulation pattern compared to the 100-year projections, but the June 2003 drainage fire had not yet affected the sediment inflow due to the ongoing drought condition at that time and a portion of the sediment delta had been removed by land excavation. The 2013 survey measured an average annual change of 21.2 acre-feet per year since the 2004 survey that was the result of the runoff from the two major fires within the drainage basin. The 2013 results increased the measured average accumulation since dam closure to 8.0 acre-feet with the majority of the sedimentation occurring since 2004.

As indicated previously, the 2004 and 2013 area and capacity tables were generated assuming no change in area and capacity since the 1976 original survey from elevation 6828 and above due to the lack of updated detailed survey data. This is likely not the case, but from the 2004 and 2013 collected data and visual observation, it appears there has been minimal change at the upper reservoir elevations since 1976 due to shoreline erosion.

The 2004 survey noted a minimal sediment delta in the upper reservoir area and only a minor amount of shoreline erosion. The delta that previously existed was excavated in the winter of 2003 with some of the material deposited within the reservoir boundaries below the spillway crest elevation of 6826.6. The land excavation of the reservoir area was conducted when the water surface was below elevation 6790. Most of these spoils were completely submerged shortly after the 2004 survey and assumed that over time the majority of this material has redistributed in the lower elevations of the reservoir due to wind and wave actions.

Summary and Conclusions

This report presents the results of the March 2013 survey of Nambe Falls 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 OPUS and RTK GPS to confirm the horizontal and vertical control network near the reservoir for the hydrographic survey. A GPS base station was set over an existing survey control point with provided coordinates tied to NAD27 and NGVD29. The OPUS solution found a slight shift in the provided horizontal coordinates and no shift with the vertical elevations. All 2013 collected data was adjusted horizontally to match the OPUS computed shift. The study's horizontal control was in feet, New Mexico state plane central coordinates, in NAD83. The vertical control, in US survey feet, was tied to the project's vertical datum in NGVD29, 3.47 feet lower than NAVD88. Unless noted, all elevations in this report are referenced to the project (NGVD29) vertical datum.

The March 2013 underwater survey was conducted near reservoir water surface elevation 6826; just below the spillway crest elevation of 6826.6. The water surface at the time of the survey was measured by the 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 the reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Data was also collected along the shoreline and within the restricted area near the dam. Even though the March 2013 survey was conducted during a normal high reservoir level, there were portions of the reservoir where the boat could not gain access due to vegetation, floating driftwood, and sand bars that blocked entry to some of the coves.

The above-water 2013 topography was from several sources such as digitized water surface edges of orthographic aerial images of the reservoir (USDA, 2010). Airborne digital data was also obtained as IFSAR bare-earth data for the upper reservoir area (Intermap, 2011). There are other technologies available that would produce more accurate data than IFSAR, but this study did not have the funding to acquire these types of data sets. Better upper reservoir data would not greatly change the results, especially considering the main concern is within the lower elevation portions of the reservoir where the sediments are depositing. In the open areas of the reservoir the IFSAR data points matched well with known elevation information and were retained for this analysis to develop the upper reservoir contours. In areas with dense vegetation around the reservoir the IFSAR data did not match well and was removed. The remaining IFSAR data points along with the other data sources were used to develop the 2013 Nambe Falls Reservoir topography. These data sets were necessary to enclose the 2013 data for contour development. The 2013 study assumed no change since the 2004 developed surface areas from elevation 6826.6 and above.

The final 2013 Nambe Falls Reservoir topographic map is a combination of the digitized water surface edge from the USDA photographs, IFSAR developed contours, and the 2013 survey data, all tied vertically to NGVD29. The USDA and IFSAR data sets were the most accurate available data and enclosed the 2013 data that was necessary for topography development. A computer program was used to generate the 2013 topography and resulting reservoir surface areas at pre-determined contour intervals from the combined reservoir data from elevation 6850.0 and below. Assuming no change, the 2004 developed surface areas for elevation 6826.6 and above were used to complete the 2013 area and capacity tables. The 2013 input from the 2-foot surface areas was from elevation 6826.0 and below. The 2013 area and capacity tables were produced using the computer program ACAP that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique that interpolated values between the input elevation surface areas.

Tables 1 and 2 contain summaries of the Nambe Falls Reservoir and watershed characteristics for the 2013 survey. The 2013 survey determined the reservoir has a total storage capacity of 2,600 acre-feet with a surface area of 74.2 acres at maximum reservoir water surface elevation 6839.8. At conservation water surface elevation 6826.6 the total capacity was 1,729 acre-feet with a surface area of 58.0 acres. Since closure of Nambe Falls Dam in February 1976, this survey measured a 297 acre-foot loss in reservoir capacity below elevation 6826.6. For the first 37 years of reservoir operation, the average annual loss was 8 acre-feet. The design annual sediment accumulation was 4 acre-feet, or 50 percent of the 2013 measured annual sediment inflow. Information on how the design sediment accumulation was computed was not found, but it is assumed large basin fires were not part of the calculations. The volume losses for this study were computed by comparing the original with the 2004 and 2013 capacities for the reservoir. It is assumed the measured loss was mainly due to sediment deposition with some variation due to accuracy differences between methods of collection and analysis.

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