RECLAMATION

Managing Water in the West

Technical Report No. SRH-2011-01

Foss Reservoir 2009 Sedimentation Survey

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

February 2011

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Foss Reservoir 2009 Sedimentation 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

February 2011

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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. Ben Claggett and Lou Hall of the Reclamation's Texas-Oklahoma Area Office of the Great Plains Region and Ron Ferrari of the Sedimentation Group conducted the bathymetry survey of the reservoir in May of 2009. Ron Ferrari completed the data processing to generate the new topographic map, area-capacity tables, and sediment computations presented in this report. Kent Collins of the Sedimentation Group performed the technical peer review of this documentation.

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

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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14. ABSTRACT

Reclamation surveyed Foss Reservoir (impounded by Foss Dam) in May 2009 to develop updated reservoir topography and compute present storage-elevation relationships (area-capacity tables). The underwater survey, conducted near water surface elevation 1,642.0 (feet), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was obtained by digitizing the reservoir's water edge from several years of aerial photographs collected by the United States Department of Agriculture (USDA). Four years of flights that ranged in reservoir water surface elevations between 1,639.8 through 1,642.5 feet were used. These digitized images enabled contours to be developed where boat access was not possible due to vegetation and shallow water conditions. This study assumed no change since the original survey at elevation 1,642.0 and above. Accurate mapping of the upper reservoir contours would require aerial collection during low reservoir conditions from which detailed reservoir contours could be developed.

As of May 2009, at active conservation reservoir pool elevation 1,642.0, the surface area was 6,801 acres with a total capacity of 168,732 acre-feet. Since the February 1961 closure of Foss Dam this survey measured a total capacity change of 9,263 acre-feet below elevation 1,642.0.

15. SUBJECT TERMS

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Technical Report No. SRH-2011-01

Foss Reservoir 2009 Sedimentation Survey

Foss Dam
Butler, Oklahoma

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4/30/2011
Date

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Date

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Table of Contents

Index of Figures

Index of Tables

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Foss Reservoir 2009 Sedimentation Survey

Introduction

Foss Dam and Reservoir and are principal features of the Washita Basin Project in Custer County located in west central Oklahoma (Figure 1). The other principal feature of the project includes Fort Cobb Dam and Reservoir. Foss Dam, on the Washita River, is about 12 miles west of Clinton and 6 miles south of Butler, Oklahoma. The reservoir provides M&I water to four member cities through three pumping plants and 50.8 miles of pipelines. Project water was initially reserved for the Clinton-Sherman Air Force Base that was later abandoned as a military installation. Irrigation outlet works were constructed, but no distribution system was constructed or irrigation district formed.

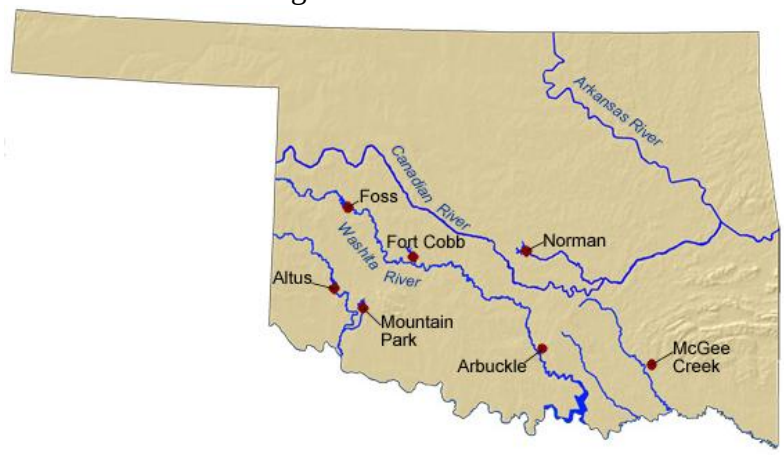

Figure 1 - Reclamation Reservoirs Located in Oklahoma.

Foss Dam is a modified homogeneous earthfill structure that was completed in 1961. The dam's dimensions are:

Dam crest elevation	1,697.0	feet[1]	Crest width	30	feet
Hydraulic height[2]	105.6	feet	Structural height	139	feet
Crest length	18,130	feet			

[1] Elevations in feet based on original project datum established by Reclamation that this study measured around 0.3 feet higher than the National Geodetic Vertical Datum of 1929 (NGVD29) and approximately 0.5 feet lower than the North American Vertical Datum of 1988 (NAVD88).

[2] The definition of such terms as "hydraulic height," "structural height," etc. 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.*

The spillway, located near the right abutment of the dam, is a 22.3 foot ungated glory-hole with crest elevation 1,668.6. Six streamlined piers extend upward from the crest to elevation 1,692.5. The spillway design discharge is 3,150 ft^3/s at reservoir elevation 1,691.0. The river outlet works consist of a tower-type trashracked intake structure with crest elevation of 1,640.95. The river outlet tower is located within the reservoir near the right abutment and the top of the structure sits just below the normal reservoir operating level, elevation 1,642.0. The lowest level of the river and municipal outlets is elevation 1,597.2.

Foss Reservoir is operated and maintained to provide water storage for municipal and industrial uses as well as flood control. Other reservoir benefits include recreational activities and fish and wildlife conservation. The dam, reservoir, and distribution systems are operated by the Foss Reservoir Master Conservancy District. The drainage area above the dam is 1,496 square miles from active conservation pool reservoir elevation 1,642.0 to around elevation 3,000. The entire drainage area is considered sediment contributing. The reservoir is 10.4 miles long with an average width of 1.0 miles (Figure 2).

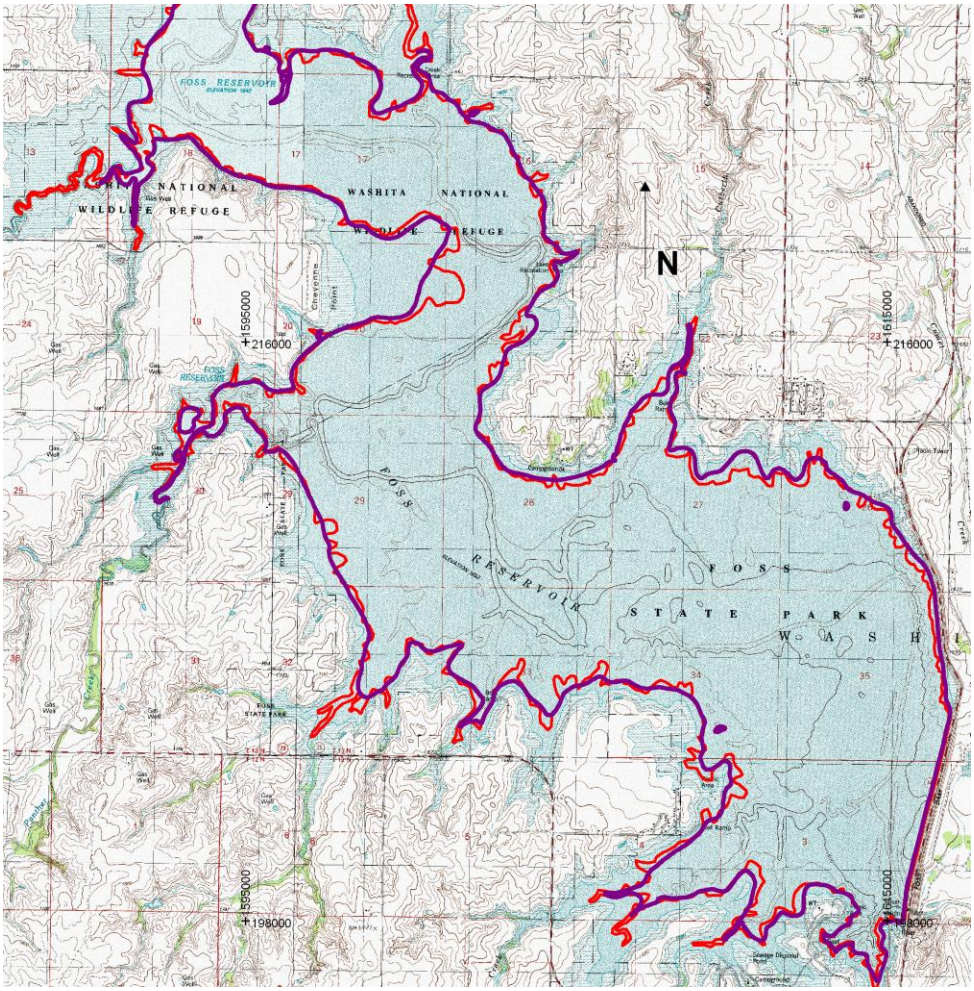

Figure 2 - USGS quad of Foss Reservoir. Red outline is the USGS quad contour, elevation 1,640. The purple line is elevation 1,640.0 contour developed by this 2009 study.

Summary and Conclusions

This Reclamation report presents the results of the 2009 survey of Foss Reservoir. The primary objectives of the survey were to gather data needed to:

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

A control survey was conducted using the on-line positioning user service (OPUS) and a real-time kinematic (RTK) global positioning system (GPS) to establish a 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 for processing with known point data to determine positions relative to the national control network. The GPS base was set over a temporary mark within the camping area north of the marina. This point was used for the GPS base throughout the hydrographic survey. The coordinates for this point were processed using OPUS.

The horizontal control for this study was in feet, Oklahoma North state plane coordinates, in the North American Datum of 1983 (NAD83). The vertical control was in feet tied to the Reclamation project vertical datum. All elevations in this report are referenced to Reclamation's project or construction vertical datum that this study measured as 0.3 feet higher than NGVD29 and 0.5 feet lower than NAVD88.

The bathymetric survey was conducted using sonic depth recording equipment interfaced with a differential global positioning system capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along predetermined grid lines. The positioning system provided information that allowed the boat operator to maintain a course along these grid lines. Water surface elevations recorded by a Reclamation gage during time of collection were used to convert the sonic depth measurements to reservoir bottom elevations tied to the project's vertical datum.

The initial above-water topography for the 2009 survey was determined by digitizing contour lines from the USGS quads of the reservoir area. Orthographic aerial images collected in 2006 and 2008 at water surface elevations 1,640.0 and 1,641.5 respectively were downloaded from the USDA data web site (USDA, 2010) for this analysis. Reservoir contours were developed by digitizing the water surface edge from the aerial images. Other years of aerial data were available, but the resolution of the resolution of the aerial photos collected at high altitudes over the reservoir made it difficult to distinguish the reservoir shoreline. The quality of the aerial photos increased each year with 2006 and 2008 providing the clearest images of the majority of the water's edge. These developed contours

were the best means to accurately locate the present shoreline near the active conservation elevation of 1,642.0. This study assumed no change since the original measured and computed surface areas from elevation 1,642.0 and above.

The new 2009 Foss Reservoir topographic map is a combination of the digitized water surface edges from the USDA orthographic aerial photographs and the 2009 underwater survey data points. A topographic computer program was used to generate the 2009 reservoir surface areas at predetermined contour intervals from the combined reservoir data. The 2009 area and capacity tables were produced through a computer program that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of Foss Reservoir and watershed characteristics for the 2009 study. The 2009 survey determined the reservoir has a total storage capacity of 168,732 acre-feet with a surface area of 6,801 acres at top of the active conservation pool, elevation 1,642.0. Since closure of Foss Dam in February 1962, this survey measured a 9,263 acre-feet change in reservoir capacity at elevation 1,642.0. The losses were computed by comparing the original and the 2009 capacities for the reservoir. It is assumed that a portion of the loss from elevation 1,642.0 and below was due to material from the upper elevation shoreline being eroded over time and settling in the lower elevations of the reservoir. A comparison of the USGS and 2009 elevation 1,640 contours shows shoreline erosion throughout the main reservoir body increasing the surface area there. Many of the original coves and small inlet surface areas have been lost due to sediment deposition from shore erosion. The 2009 survey measured a minimum elevation of 1,575.5 or around 13 feet of sediment accumulation at the dam.

Control Survey Data Information

Prior to the 2009 survey, a temporary point was set in the camp ground area north of the marina using OPUS to establish the horizontal and vertical control datum. OPUS, operated by the NGS, allows users to submit GPS data files that are processed with known data to determine a point's position relative to the national control network. This temporary point was the GPS base for the entire reservoir survey.

The horizontal control was in Oklahoma's north zone state plane coordinates in NAD83 and the vertical control was tied to the Reclamation's project datum. All elevations in this report are referenced to Reclamation's project or construction vertical datum that for this study was measured approximately 0.3 feet higher than NGVD29 and 0.5 feet lower than NAVD88.

Topographic survey points were collected at the water surface and compared to the water surface gage readings. The RTK GPS elevations in NAVD88 averaged 0.5 feet higher than the recorded gage reading. For this area the shift between NGVD29 and NAVD88 is around 0.75 feet. Survey points were also collected on top of the dam or center of the state highway and varied from elevation 1,697.8 to 1,698.0 compared to design crest elevation 1,697.0. The top-of-dam points were collected along the center line of a state road that has obviously experienced significant change over time and isn't the best means to compare elevation differences. Points were not collected on the spillway crest for elevation comparison due to access limitations during this survey.

A topographic point was surveyed on a Reclamation brass cap located downstream of the dam and upstream of the south gate house with the following measurement:

North	198,124.323
East	1,615,931.412
Elevation	1,624.497 (NAVD88)
Elevation	1,623.752 (NGVD29) (computed using US Army Corp of Engineers' program CORPSCON)

As of this report, no elevation or history was located on how this brass cap was originally established.

Reservoir Operations

Foss Reservoir, part of the Washita Basin Project, was designed to provide storage for municipal and industrial use and for flood control. The project also provides recreation facilities along with water for fish and wildlife conservation. The May 2009 analysis computed 871,874 acre-feet of combined storage below the maximum water surface elevation 1,694.0 (Table 1). The 2009 survey measured a minimum lake bottom elevation of 1,575.5. The following values are from the May 2009 capacity table:

- 522,571 acre-feet of surcharge storage, elevation 1,662.2 through 1,694.0.
- 180,571 acre-feet of flood control storage, elevation 1,642.0 through 1,662.2.
- 159,864 acre-feet of active conservation pool storage, elevation 1,597.2 through 1,642.0.
- 8,868 acre-feet of dead pool storage below elevation 1,597.2.

Originally the top of the active conservation pool was elevation 1,652.0, providing an original active capacity of 243,810 acre-feet. The top of the

conservation pool was lowered 10 feet to elevation 1,642.0 as part of the preferred corrective action to address the PMF hydrologic deficiency. This lowering provided additional surcharge pool capacity and increased the probability of safe passage of the probable maximum flood.

During planning, the original sediment deposition estimate over a 75-yeer period was 76,000 acre-feet that would be distributed below elevation 1,668.6. Of that estimated 76,000 acre-feet, 67,000 were projected to deposit above dead pool elevation 1,597.2. The sediment accumulations as measured by the 2009 and future resurveys may change the capacity allocation zones.

Foss Reservoir is generally operated to be near elevation 1,642.0, active conservation pool elevation, by storing all inflow except small releases required to satisfy downstream water requirements and for flood control releases. The computed annual inflow and reservoir stage records for Foss Reservoir are listed by water year in Table 1 for the period of February 1961 through May 2009. These inflow values were computed by Reclamation's Texas-Oklahoma Area Office for this study and are rough estimates of reservoir inflows calculated from measured monthly change in reservoir elevations translated to capacity change and adjusted for estimated monthly reservoir evaporation rates. The inflow values show the annual fluctuation with a computed average annual inflow of 56,000 acre-feet. The maximum end of month reservoir elevation of 1,648.1 was recorded during water year 1997. After initial filling in 1976, a minimum end of month reservoir elevation of 1,634.1 was recorded during water year 1986.

Hydrographic Survey Equipment and Method

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 3). 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. An on-board generator supplied power to all the 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 and a 12-volt battery provided the power for the shore unit.

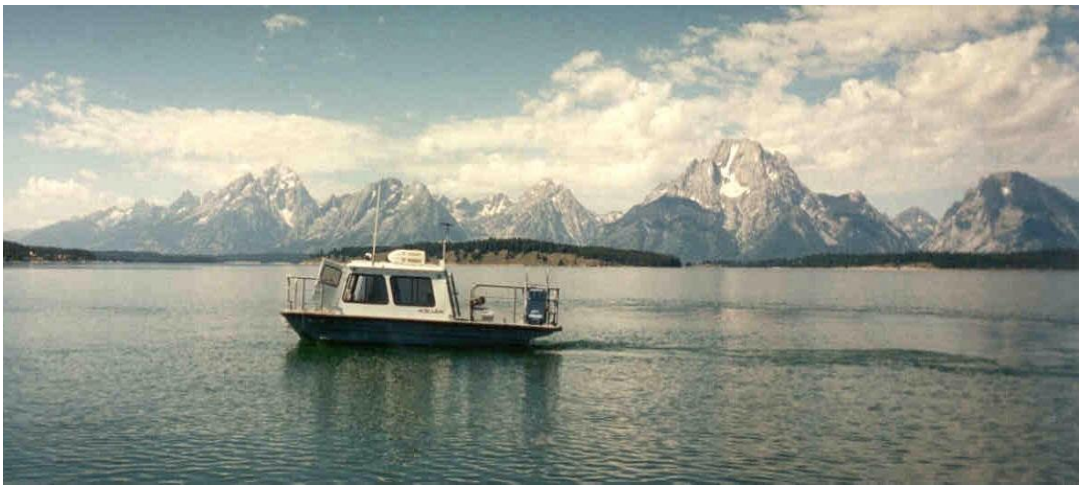

Figure 3 - Survey Vessel with Mounted Instrumentation on Jackson Lake in Wyoming.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being 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 that the hydrographic collection software converted into Oklahoma's state plane coordinates, north zone in NAD83 for this study. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

The Foss Reservoir bathymetric survey was conducted in 2009 from May 11-18 near water surface elevation 1,642.0 (Reclamation project datum). The bathymetric survey was conducted using sonic depth recording equipment, interfaced with a RTK GPS, capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along closely spaced grid lines covering the reservoir area. Depending on the location on the reservoir, the transects (grid lines) were run perpendicular or parallel to the upstream-downstream alignment of the reservoir at around 300-foot spacing. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. Data was also collected along the shore by the survey vessel for the majority of the reservoir. During each course, the depth and position data were recorded on the laptop computer hard drive for subsequent processing. Final processing of the underwater collected data set resulted in approximately 168,000 points (Figure 4).

The 2009 underwater data was collected by a depth sounder calibrated by lowering an instrument that measured the average sound velocity of the reservoir water column. The sounder was further checked by lowering a weighted marked cable to compare the digital depth versus the cable depth. The weighted cable was lowered near the dam and also in the main body of the reservoir at different

depths. The collected depth data were digitally transmitted to the computer collection system through a RS-232 port. The depth sounder also produced an analog hard-copy chart of the measured depths. These graphed analog charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gage, were used to convert the sonic depth measurements to true lake-bottom elevations. Additional information on collection and analysis procedures is included in *Engineer and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

Reservoir Area and Capacity

Topography Development

The topography of Foss Reservoir was developed from combined 2009 bathymetric data and the digitized reservoir water surface edges from aerial photographs collected by the USDA. There were several sets of post-2003 USDA aerial data available that varied in reservoir water surface elevation from around 1,640 to 1,642 as recorded by the Reclamation gage on the day of each aerial flight. The 2008 aerial photographs were the best quality for this analysis and were used to develop a contour at recorded water surface elevation 1,641.5, Figure 5. The 2006 aerial photography was the only other year significantly used for this study and was flown near elevation 1,640.0.

Contours digitized from USGS quads at elevation 1,640 and 1,652 were used during field collection and to evaluate the USDA aerial images of the reservoir. These digitized contours were not used to develop the 2009 topography, but did provided information on areas of bank erosion and sediment deposition by comparing the USGS digitized contour with the 2009 developed contour, Figure 2. During the 2009 survey shoreline erosion was observed, but much of the bank eroded material deposited in the coves, resulting in an insignificant change in surface area measured by the 2009 survey at elevation 1,640.0 relative to the original surface area. The 2009 surface area gains along the main body of the reservoir were offset by losses in the many coves and inlets along the shoreline of the reservoir. The USDA aerial images represent current reservoir conditions near elevation 1,640. Detailed above water collection would be required to measure the actual surface area and resulting volumes above elevation 1,640.0. The reservoir has seldom operated above elevation 1,642.0, so assuming little surface area change since the original is the most appropriate method for this study.

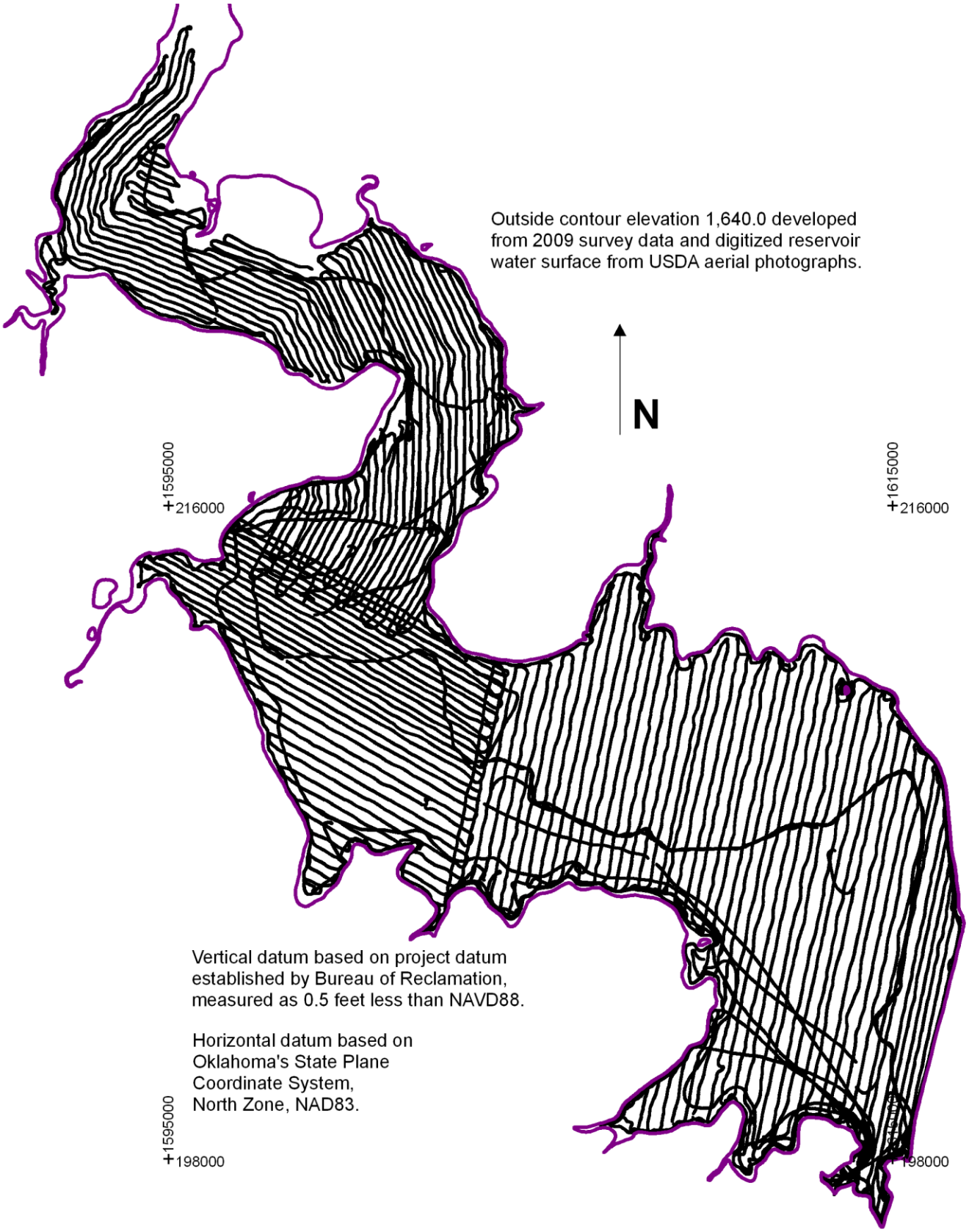

Figure 4 - Foss Reservoir 2009 survey data points.

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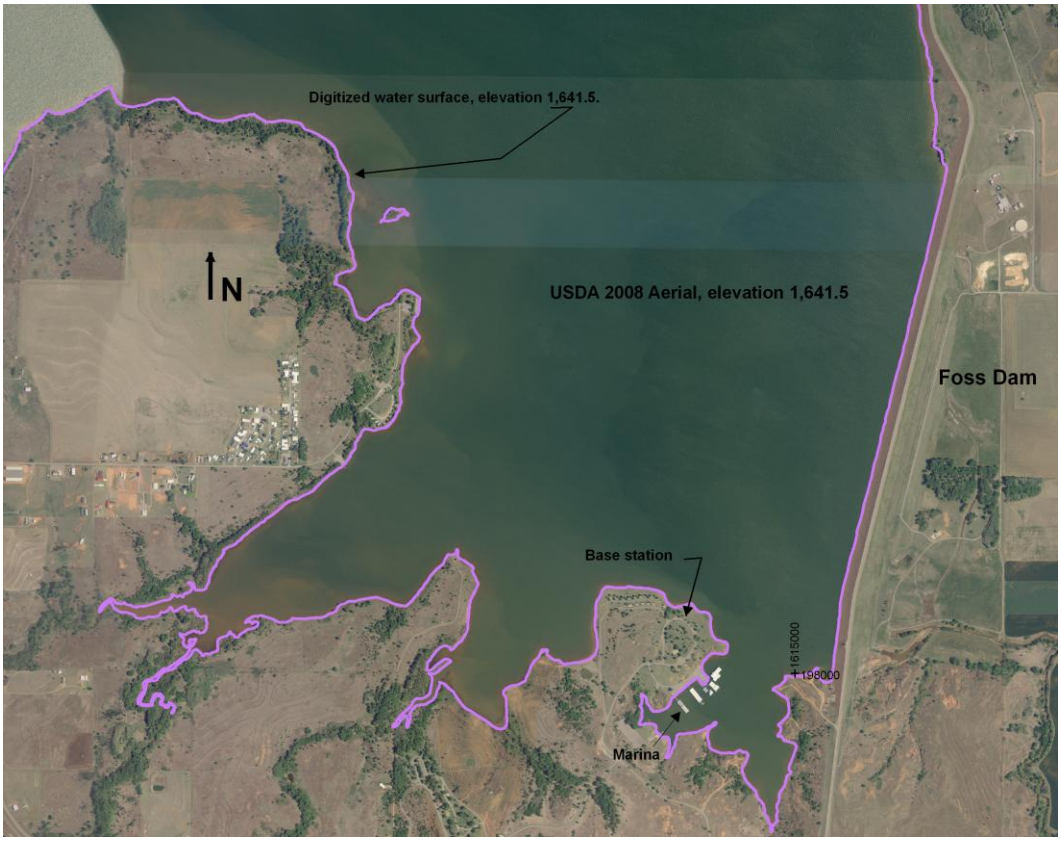

Figure 5 - Foss Reservoir USDA Aerial Photo.

A digitized polygon just outside the highest USDA aerial digitized contour was used as a hard boundary for the 2009 developed contours. This clip was used during the triangular irregular network (TIN) and contour development to prevent interpolation outside the enclosed polygon or reservoir area, and was not assigned an elevation.

Contours for the reservoir from elevation 1,640.0 and below 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. The TIN software 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 and all the collected data points are preserved. The TIN method is discussed in detail in the ARCGIS user's documentation, (ESRI, 2010).

The linear interpolation option of the ARCGIS TIN and CONTOUR commands was used to interpolate contours from the Foss Reservoir TIN. The areas of the

enclosed contour polygons at one-foot increments were computed from the survey data for elevations 1,576.0 through 1,640.0.0. No above water data was collected, so this study assumed no change in reservoir surface area since the 1961 survey at elevation 1,642.0 and higher. The reservoir contour topography at 2-foot intervals from elevation 1,640.0 and below is presented on Figures 6 through 8. Development of the contours within ARCGIS directly from the TIN using all the enclosed data points resulted in a somewhat jagged representation of the contours. The TIN approach includes all data points to produce the most accurate surface area and resulting volume, but jagged contours are often the result. For presentation purposes these contours were smoothed using ACRMAP tools. The best means to develop the upper contours and resulting above water reservoir areas would be conducting a detailed aerial survey with the reservoir drawn down.

Development of the 2009 Foss Reservoir Surface Areas

The 2009 surface areas for Foss Reservoir were computed at 1-foot increments directly from the reservoir TIN from elevation 1,576.0 through 1,640.0. The TIN was developed from the 2009 survey data and digitized data sets within the hardclip polygon (created as previously described). Surface area calculations were performed using ARCGIS commands that compute areas at user-specified elevations directly from the TIN. For the purpose of this study, the measured survey areas at 2- and 5-foot increments from elevation 1,576.0 through 1,640.0 were used in computing the new area and capacity tables. This study assumed no change in surface area, since the original survey, at elevation 1,642.0 and above.

Table 1 provides a summary of the 2009 survey conducted on Foss Reservoir. The area and capacity curves for the original and 2009 surveys are plotted on Figure 9.

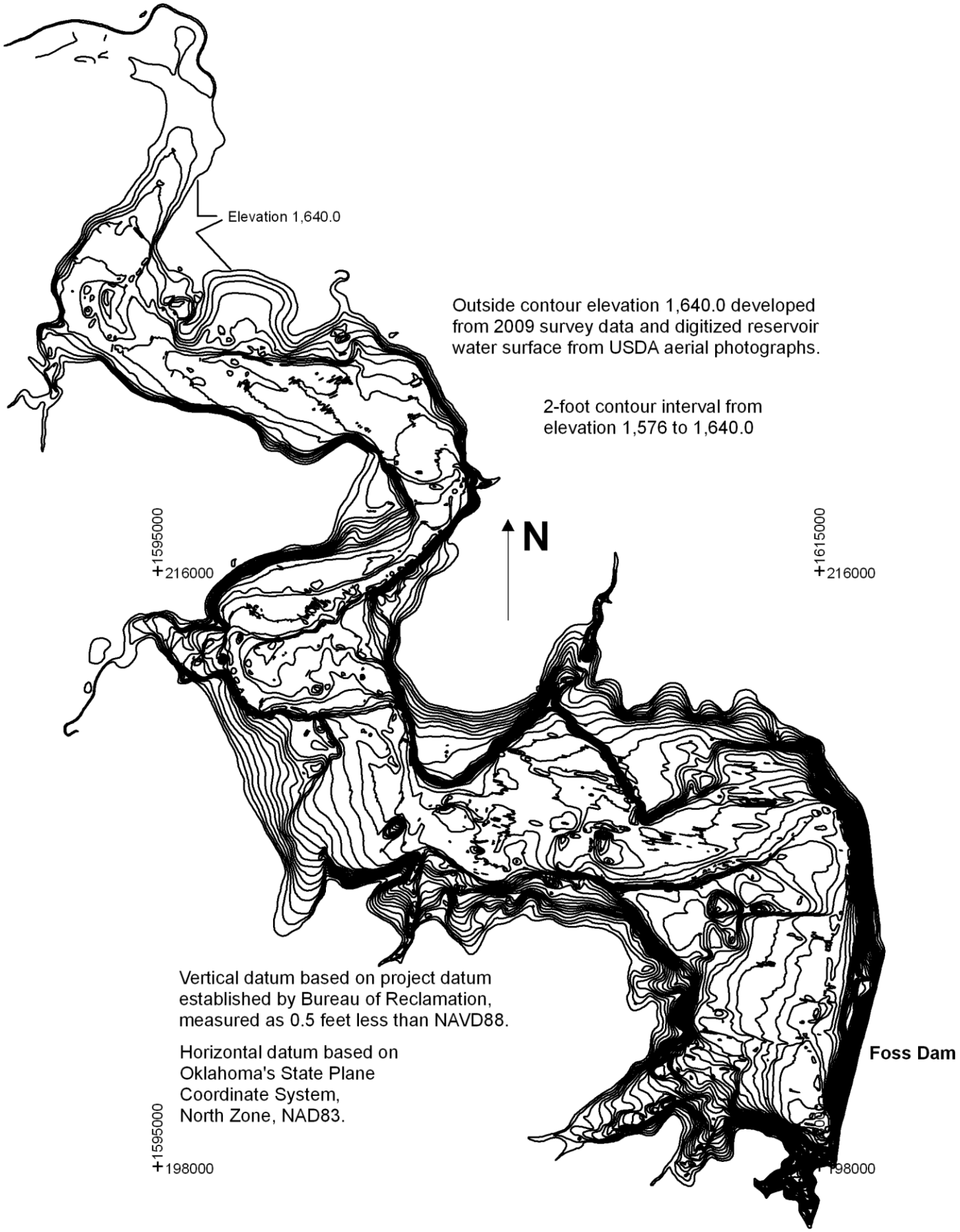

Figure 6 - Foss Reservoir topographic map.

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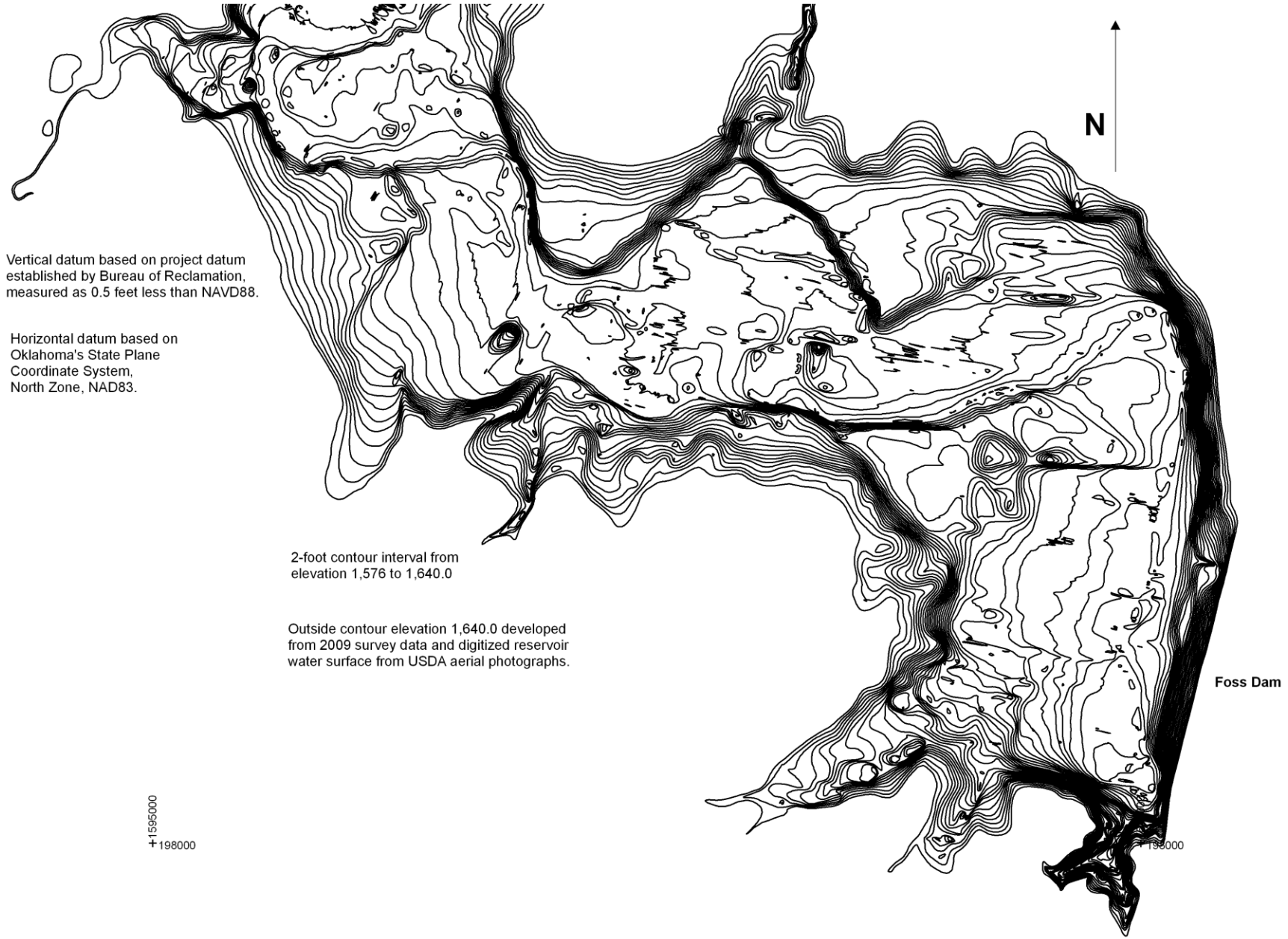

Figure 7 - Foss Reservoir topographic map image.

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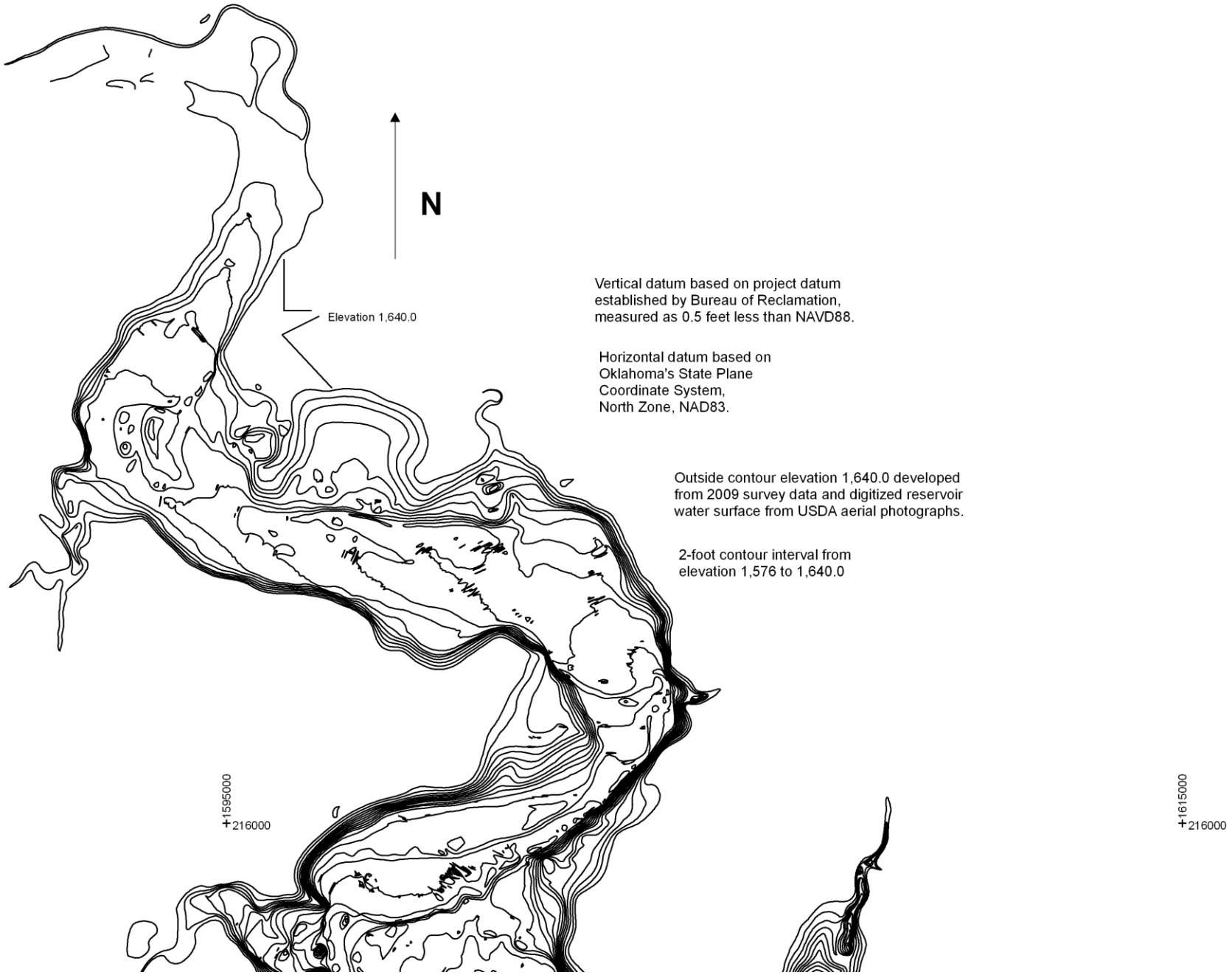

Figure 8 - Foss Reservoir contours.

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RESERVOIR SEDIMENT
DATA SUMMARY

Foss Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER: Bureau of Reclamation		2. STREAM: Washita River			3. STATE: Oklahoma
	4. SEC 2 TWP. 12N RANGE 19W		5. NEAREST P.O. Stafford			6. COUNTY Custer
	7. LAT 35 ° 32 ' 20 " LONG 99 ° 11 ' 39 "		8. TOP OF DAM ELEVATION: 1,697.0 [1]			9. SPILLWAY CREST EL. 1,668.6 [2]
RESERVOIR	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
	a. SURCHARGE	1,694.0 [3]	21,909	522,571	881,137	2/1961
	b. FLOOD CONTROL	1,662.2	11,356	180,571	358,566	
	c. POWER					
	d. JOINT USE					16. DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION	1,642.0 [3]	6,801	165,554	177,995	
	f. INACTIVE					
	g. DEAD	1,597.2	1358	12,441	12,441	2/1961
	17. LENGTH OF RESERVOIR 10.4 [4] MILES		AVG. WIDTH OF RESERVOIR 1.0 MILES			
BASIN	18. TOTAL DRAINAGE AREA 1,496 [5] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 23 [6] INCHES			
	19. NET SEDIMENT CONTRIBUTING AREA 1,496 [5] SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.7 [7] INCHES			
	20. LENGTH MILES	AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 56,000 [7] ACRE-FEET			
	21. MAX. ELEVATION 3000	MIN. ELEVATION 1642	25. ANNUAL TEMP, MEAN 60 °F RANGE -15 °F to 120 °F [6]			

SURVEY	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
	2/1961			Contour (D)		6,801 [8]	177,995 [8]	3.18
	5/2009	48.3		Contour (D)	2-ft	6,801 [9]	168,732 [9]	3.01

DATA	26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFLOW TO DATE, AF	
			a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
	6/2009	23	56,000 [7]	202,200	2,705,000	56,000	2,705,000

	26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
		a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
	6/2009	9,263 [10]	191.8	0.13	9,263	191.8	0.13

	26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR		41. STORAGE LOSS, PCT.		42. SEDIMENT INFLOW, PPM
			a. PERIOD	b. TOTAL TO DATE	a. AVG. ANNUAL	b. TOTAL TO DATE	a. PER. b. TOT.
	6/2009				0.108 [10]	5.20 [10]	

	26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
					1,580.0-1,563.0	1,597.2-1,580.0	1,610.0-1,597.2	1,620.0-1,610.0	1,630.0-1,620.0	1,642.0-1,630.0		
		PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
	5/2009				9.0	29.5	19.2	15.7	14.6	12.0		
	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

45. RANGE IN RESERVOIR OPERATION [7, 11]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1961	1,608.8	1,593.4	19,900
1962	1,620.1	1,608.8	34,900	1963	1,624.2	1,620.6	31,600
1964	1,622.5	1,620.6	16,300	1965	1,626.5	1,620.3	49,100
1966	1,630.2	1,628.0	39,400	1967	1,627.9	1,626.3	23,900
1968	1,628.4	1,625.8	29,400	1969	1,631.8	1,628.7	37,700
1970	1,632.5	1,630.6	22,700	1971	1,630.3	1,628.4	16,100
1972	1,628.6	1,626.2	12,000	1973	1,629.6	1,628.5	44,100
1974	1,631.5	1,628.9	32,300	1975	1,638.6	1,630.3	66,300
1976	1,639.7	1,637.6	13,500	1977	1,644.5	1,636.3	60,000
1978	1,644.2	1,640.9	46,400	1979	1,642.2	1,640.1	39,100
1980	1,643.2	1,639.3	46,000	1981	1,638.9	1,636.3	16,300
1982	1,642.4	1,636.1	98,700	1983	1,641.0	1,637.5	57,100
1984	1,638.6	1,636.4	31,500	1985	1,637.1	1,635.0	24,400
1986	1,635.0	1,634.1	32,800	1987	1,645.6	1,641.2	167,000
1988	1,643.1	1,639.6	58,900	1989	1,646.6	1,639.5	102,500
1990	1,643.0	1,639.9	75,000	1991	1,642.5	1,640.9	41,800
1992	1,641.6	1,640.5	39,800	1993	1,641.6	1,639.7	61,800
1994	1,640.7	1,638.3	48,900	1995	1,641.8	1,638.1	75,000
1996	1,644.2	1,641.4	58,400	1997	1,648.1	1,640.2	202,200
1998	1,642.0	1,639.2	158,900	1999	1,642.3	1,640.8	105,800
2000	1,642.5	1,640.2	59,000	2001	1,642.9	1,640.0	91,000
2002	1,641.2	1,639.4	26,900	2003	1,642.2	1,640.6	56,400
2004	1,641.7	1,639.9	30,600	2005	1,641.7	1,640.0	58,300
2006	1,640.4	1,637.6	16,700	2007	1,643.5	1,636.9	111,800
2008	1,642.3	1,641.3	85,700	2009	1,642.3	1,641.5	30,800

46. ELEVATION - AREA - CAPACITY - DATA FOR **2009** **CAPACITY**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2009	**SURVEY**	[9]	1,575.0	0	0	1,580.0	65	90
1,585.0	254	805	1,590.0	561	2,785	1,595.0	976	6,517
1,597.2	1,157	8,868	1,600.0	1,429	12,467	1,605.0	1,915	20,886
1,610.0	2,275	31,326	1,615.0	2,828	44,065	1,620.0	3,443	59,762
1,625.0	4,109	78,607	1,630.0	4,714	100,626	1,635.0	5,481	126,089
1,640.0	6,379	155,552	1,642.0	6,801	168,732	1,645.0	7,459	190,101
1,650.0	8,441	229,790	1,655.0	9,486	274,434	1,660.0	10,794	324,941
1,662.2	11,356	349,303	1,665.0	12,099	382,146	1,670.0	13,550	446,259
1,675.0	15,277	518,295	1,680.0	17,069	599,076	1,685.0	18,800	688,640
1,690.0	20,511	787,026	1,694.0	21,909	871,874			

47. REMARKS AND REFERENCES

[1] Elevations in feet based on project vertical datum. Study measured gage readings around 0.3 feet higher than NGVD29 & 0.5 lower than NAVD88.

[2] Glory-hole with ungated crest.

[3] Elevations from Reservoir Capacity Allocation in SOP, dated 1/2010. Capacity values recomputed for 2009 analysis using ACAP.

[4] Reservoir length at elevation 1,642.0.

[5] Total drainage area from USGS Water Resource Data. All considered sediment contributing.

[6] Bureau of Reclamation Project Data Book, 1981. Values for Washita Basin Project.

[7] Mean annual runoff from 2/1961 through May 2009 from Reclamation's Regional computed inflows. Rough estimate from operation records.

[8] Surface area and capacity at elevation 1,642.0, conservation capacity. (Original elevation was 1,652.0, revised to 1,642.0 on 4/17/1991.

[9] 2009 capacities computed by Reclamation's ACAP program. Assumed no surface area change from original from El. 1,642.0 and above.

[10] Reservoir capacity losses computed by comparing original recomputed capacity with 2009 measured capacity values.

[11] End of month maximum and minimum elevations.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE January 2011

Table 1 – Reservoir Sediment Data Summary (page 2 of 2)

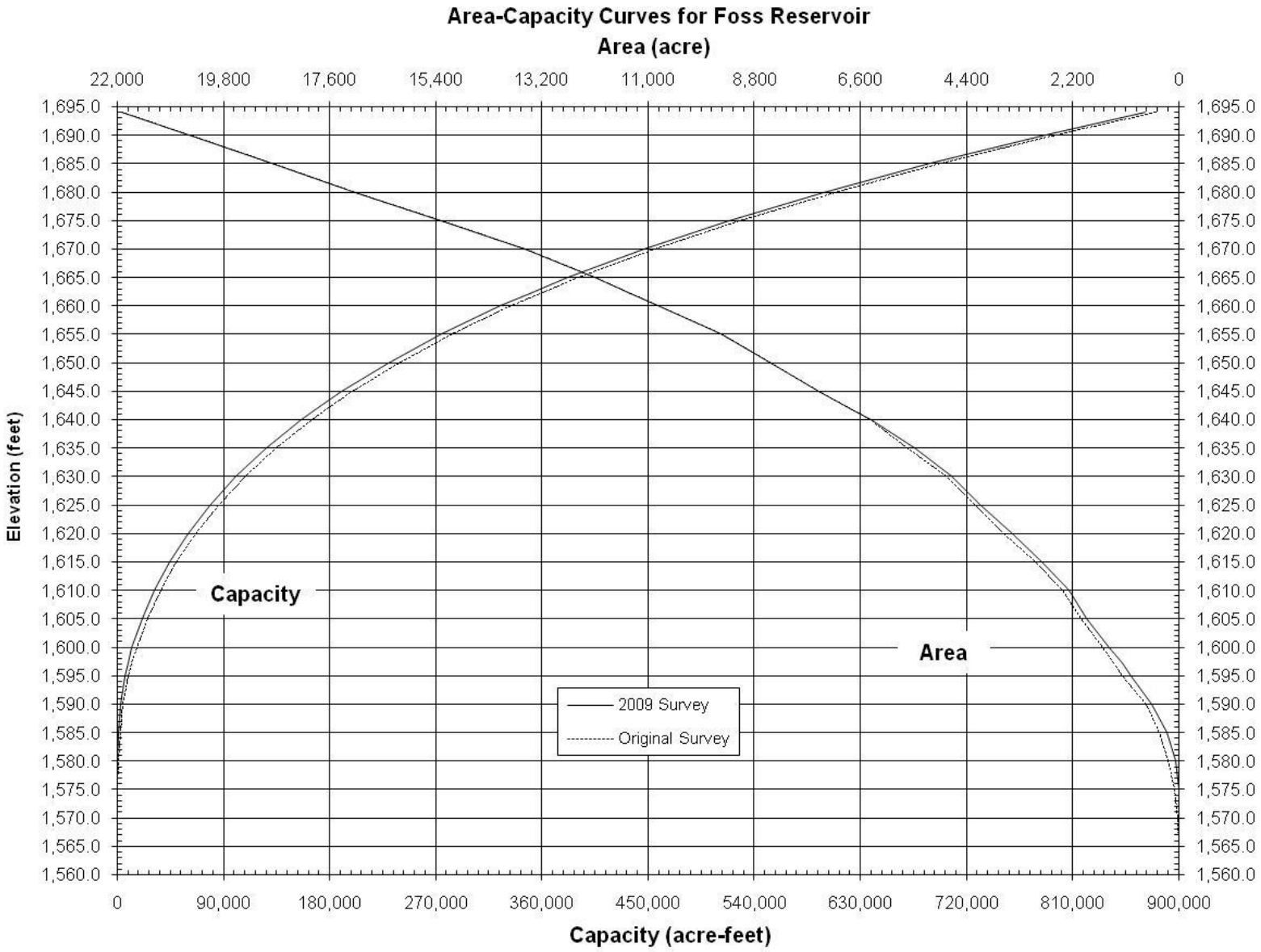

Figure 9 - Foss Reservoir Area and Capacity Plots.

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2009 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Reclamation, 1985). The ACAP program computes 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 Foss 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 Foss Reservoir area and capacity computations are listed in a separate set of 2009 area and capacity tables and have been published for the 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. The original and 2009 area-capacity relationships are listed on Table 2 and the curves are plotted on Figure 9. As of May 2009, at active conservation elevation 1,642.0, the surface area was 6,801 acres with a total capacity of 168,732 acre-feet.

1	2	3	4	5	6	7	8
					2009	2009	
Elevations	Original	Original	2009	2009	Area	Volume	Percent of
	Survey	Capacity	Survey	Survey	Difference	Difference	Reservoir
(feet)	(acres)	(acre-feet)	(acres)	(acre-feet)	(acres)	(acre-feet)	Depth
1,694.0	21,909	881,137	21,909	871,874	0	9263	100.0
1,690.0	20,511	796,289	20,511	787,026	0	9263	96.9
1,685.0	18,800	697,903	18,800	688,640	0	9263	93.1
1,680.0	17,069	608,339	17,069	599,076	0	9263	89.3
1,675.0	15,277	527,558	15,277	518,295	0	9263	85.5
1,670.0	13,550	455,522	13,550	446,259	0	9263	81.7
1,665.0	12,099	391,408	12,099	382,146	0	9262	77.9
1,662.2	11,356	358,566	11,356	349,303	0	9263	75.7
1,660.0	10,794	334,204	10,794	324,941	0	9263	74.0
1,655.0	9,486	283,697	9,486	274,434	0	9263	70.2
1,650.0	8,441	239,053	8,441	229,790	0	9263	66.4
1,645.0	7,459	199,364	7,459	190,101	0	9263	62.6
1,642.0	6,801	177,995	6,801	168,732	0	9263	60.3
1,640.0	6,391	164,803	6,379	155,552	-12	9251	58.8
1,635.0	5,625	134,856	5,481	126,089	-144	8767	55.0
1,630.0	4,820	108,780	4,714	100,626	-106	8154	51.1
1,625.0	4,221	86,208	4,109	78,607	-112	7601	47.3
1,620.0	3,630	66,563	3,443	59,762	-187	6801	43.5
1,615.0	2,978	50,121	2,828	44,065	-150	6056	39.7
1,610.0	2,412	36,677	2,275	31,326	-137	5351	35.9
1,605.0	2,031	25,576	1,915	20,886	-116	4690	32.1
1,600.0	1,581	16,550	1,429	12,467	-152	4083	28.2
1,597.2	1,358	12,441	1,157	8,868	-201	3573	26.1
1,595.0	1,170	9,648	976	6,517	-194	3131	24.4
1,590.0	672	5,051	561	2,785	-111	2266	20.6
1,585.0	400	2,425	254	805	-146	1620	16.8
1,580.0	212	932	65	90	-147	842	13.0
1,575.0	77	278	0	0	-77	278	9.2
1,570.0	14	57	0	0	-14	57	5.3
1,565.0	6	6	0	0	-6	6	1.5
1,563.0	0	0	0	0	0	0	0.0
1	Elevation of reservoir water surface. (Project vetical datum, 0.5 feet less than NAVD88)						
2	Original reservoir surface area.						
3	Original reservoir capacity recomputed using ACAP.						
4	Reservoir surface area from 2009 survey.						
5	Reservoir 2009 capacity computed using ACAP.						
6	Area difference between original and 2009 survey = column (3) - column (5).						
7	Volume difference between original and 2009 survey = column (4) - column (5).						
8	Depth of reservoir expressed in percentage of total depth, 131.0 feet.						

Table 2 - Foss Reservoir Survey Results.

2009 Reservoir Analyses

Results of the 2009 Foss Reservoir area and capacity computations are listed in Table 1 and columns 4 and 5 of Table 2. Columns 2 and 3 of Table 2 list the original area and capacity values. For this study the original capacities were recomputed using the same program used to compute the 2009 capacities, ACAP (Reclamation, 1985). Only limited information was located on how the original surface areas and capacities were developed. Column 7 lists the capacity differences between the original and 2009 surveys. Figure 9 is a plot of the Foss Reservoir surface area and capacity values for the surveys and illustrates the differences. The comparisons show that the total reservoir capacity in 2009 was 871,874 acre-feet or only 9,263 acre-feet less than the original volume at maximum reservoir elevation 1,694.0. It must be noted that the 2009 area and capacity tables were generated assuming no surface area change since the original survey at elevation 1,642.0 and above. Column 6 lists the surface area differences between the original and 2009 surveys. Assuming no change at elevation 1,642.0 and above is not entirely accurate, but any loss due to sediment deposition above this elevation is not likely to be significant since the reservoir has seldom operated above elevation 1,645.

During the planning phase for this reservoir, the original estimated 75 year sediment accumulation for Foss Reservoir was 76,000 acre-feet from elevation 1,668.6 and below or around 1,013 acre-feet of sediment accumulation per year. Of this amount it was estimated that 67,000 acre-feet would deposit above dead pool elevation 1,597.2, meaning 9,000 acre-feet would be deposited within the inactive reservoir area. Additional information was not located on how these values were determined during project planning.

From Tables 1 and 2, a comparison of the original and 2009 results show that for the first 48.3 years of reservoir operations 9,263 acre-feet of sediment has deposited below elevation 1,642.0. The measured average annual sediment accumulation was 191.8 acre feet or around 18.9 percent of the original annual projection The 2009 study measured a minimum bottom elevation of 1,575.5 compared to the original minimum bottom elevation of 1,563 or about 13 feet of sediment accumulation near the dam. Future build up of this material near the dam will eventually affect the outlet operations that have a minimum elevation of 1,597.2. Future collection will be required to better monitor and project the sediment buildup at the dam and throughout the reservoir.

The detailed bathymetric data collected for the 2009 Foss Reservoir study allowed development of the current surface areas and resulting capacity below elevation 1,642.0 as presented in this report. Aerial collection would be required for updated, total reservoir topography development in the reservoir area above elevation 1,642.0.

The 2009 analysis showed a significant change in the average annual sediment accumulation rate, reducing the original planning projected rate of 1,013 acre-feet to the current calculated rate of 191.8 acre-feet annually. In most cases there is little supporting data on how these planning rates were determined during reservoir planning adding to the uncertainty of their accuracy. It is assumed the planners had limited sediment information on the Foss Reservoir basin and surrounding river basins that were used to compute the original sediment projections. Possible reasons for the initial planning error are they may have predicted a much wetter hydrological cycle than what has occurred or a change in land use practices within the basin. Over the first 75 years of operation, the reservoir was designed to have up to 9,000 acre-feet of sediment deposited within the inactive reservoir area per year, below elevation 1,597.2. The 2009 study measured a total of 9,263 acre-feet of sediment deposition below active reservoir elevation 1,642.0 over the first 48.3 years of operations. Due to the detailed underwater data collection below elevation 1,642.0, the 2009 computed rate of 191.8 acre-feet per year best reflects the current annual sediment deposition rate in Foss Reservoir below this elevation. A future survey of Foss Reservoir after 2019 or after a significant inflow flood event should be conducted to better refine this estimate.

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