RECLAMATION

Managing Water in the West

Technical Report No. SRH-2010-3

Tom Steed Reservoir - Mountain Park Dam 2009 Survey

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

March 2010

ACKNOWLEDGMENTS

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

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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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Tom Steed Reservoir - Mountain Park Dam 2009 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

March 2010

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14. ABSTRACT

Reclamation surveyed Tom Steed Reservoir (impounded by Mountain Park Dam) in late May through early June 2009 to develop updated reservoir topography and compute present storage-elevation relationships (area-capacity tables). The underwater survey, conducted between water surface elevations 1,408.2 and 1,408.4 (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 1,403.3 through 1,412.2 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 1,412.0 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 June 2009, at conservation reservoir pool elevation 1,411.0, the surface area was 6,362 acres with a total capacity of 97,322 acre-feet. Since the June 1975 closure of Tom Steed Dam this survey only measured a slight total capacity change below elevation 1,411.0. The minimal measured change was due to accuracy differences between the original and 2009 data sets. This survey measured a minimum elevation of 1,372.6 or 8.6 feet of sediment accumulation near the dam.

15. SUBJECT TERMS

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BUREAU OF RECLAMATION

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

Technical Report No. SRH-2010-3

Tom Steed Reservoir - Mountain Park Dam 2009 Survey

Mountain Park Dam
Snyder, Oklahoma

Prepared: Ronald L. Ferrari
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Date 6/22/2010

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Date 6/22/10

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Introduction

Mountain Park Dam impounds Tom Steed Reservoir. Both are principal features of the Mountain Park Project in Kiowa County located in southwestern Oklahoma (Figure 1). The dam, on West Otter Creek, is about 4 miles north of Snyder, 3 miles northwest of Mountain Park, and 20 miles northeast of Altus, Oklahoma. The project includes the Bretch Diversion Dam and Canal located on Elk Creek about five miles south of Hobart (Figure 2). Bretch Diversion Dam can divert up to 1,000 ft^3/s from Elk Creek into Otter Creek which provides water supplements into Tom Steed Reservoir.

Two saddles with embankment dikes are located east and west of Mountain Park Dam to help impound Tom Steed Reservoir. The East Dike is 1.2 miles east of the left dam abutment and the West Dike is 1.4 miles west of the right abutment. The East Dike length is 10,630 feet with a structural height of 28 feet and the West Dike length is 13,233 feet with a structural height of 20 feet. The crests for both dikes are near elevation 1,428 feet.[1]

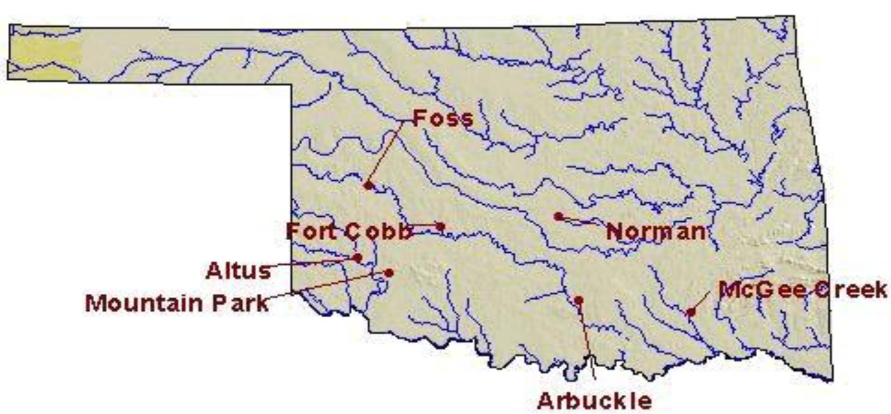

Figure 1 - Reclamation Reservoirs Located in Oklahoma.

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

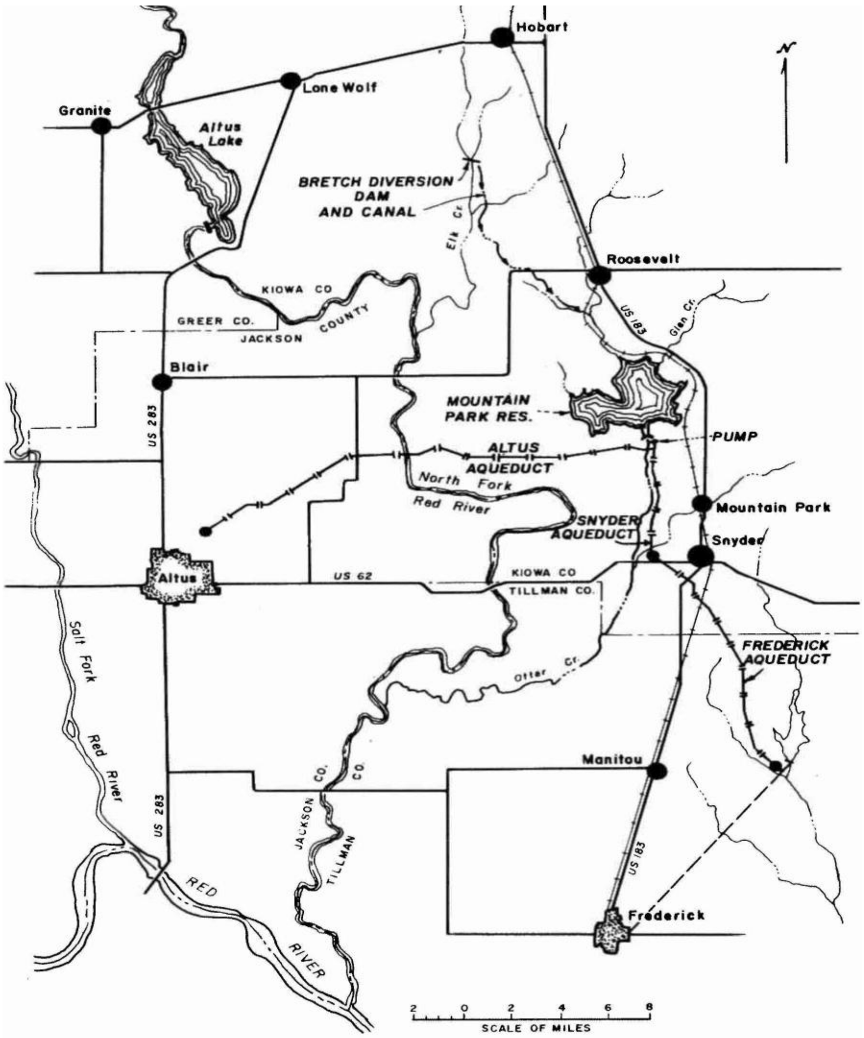

Figure 2 – Mountain Park Project and surrounding features.

Mountain Park Dam is a double curvature thin arch concrete dam built from 1973 through 1975 (Figure 3). The thrust block crests are at elevation 1,423.6 with the parapet wall crest at elevation 1,427.0. The dam's dimensions are:

Hydraulic height[2]	59 feet	Dam crest elevation	1,423.6
Structural height	133 feet	Parapet crest elevation	1,427.0
Crest length	535 feet		

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

Figure 3 - Mountain Park Dam and operating spillway.

An uncontrolled overflow spillway spans 320 feet of the axis of the dam with crest elevation 1,414.0 at top of the exclusive flood control pool. The spillway is designed for maximum discharge 38,300 ft^3/s at maximum reservoir elevation 1,423.6. The outlet works consists of an intake structure near the left abutment and three outlets for river, flood, and municipal water releases.

The Mountain Park Project is operated and maintained to provide water storage for municipal and industrial uses as well as flood control. The project also provides recreation and fish and wildlife conservation benefits. The dam, reservoir, and distribution system are operated by the Mountain Park Master Conservancy District.

The drainage area above the dam is 121 square miles and is generally flat. The upper portion of the basin is crop and pasture land. The lower portion consists primarily of a narrow and steep-sided valley cut through granite bedrock. The reservoir is around 4.5 miles long with an average width of 2.2 miles (Figure 4).

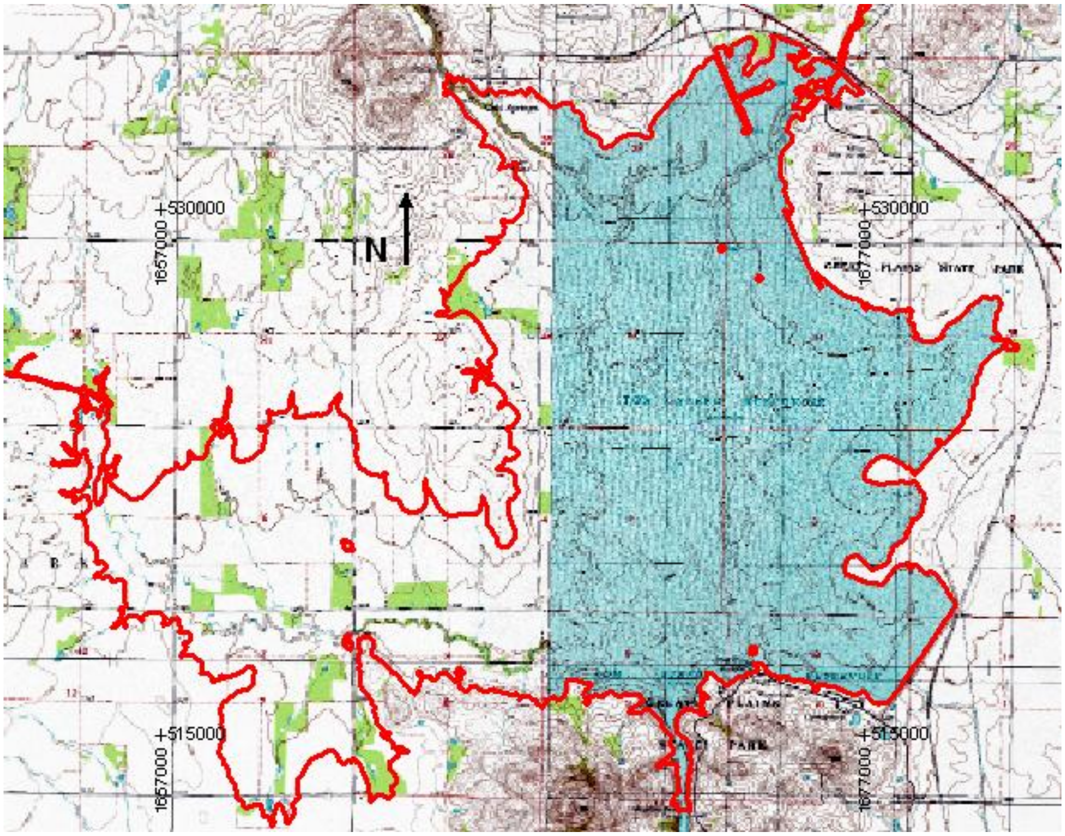

Figure 4 - USGS Quad of Tom Steed Reservoir. The red outlined, blue shaded area is reservoir elevation 1,411. The red outline of the west reservoir area is elevation 4,110.

Summary and Conclusions

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

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

A control survey was conducted using the on-line positioning user service (OPUS) and RTK GPS to establish a horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the 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 on the East Dike. The coordinates for this point were processed using OPUS, and from this base additional points were measured during the May and June 2009 hydrographic survey.

The horizontal control for this study was in feet, Oklahoma South state plane coordinates, in the North American Datum of 1983 (NAD83). The vertical control was in feet, tied to NAVD88 and the Reclamation project vertical datum. All elevations in this report are referenced to Reclamation's project or construction vertical datum that is near NGVD29 and about 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 predetermine 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 the 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 between 2004 and 2008 and between water surface elevations 1,403.3 and 1,412.2 were downloaded from the USDA data web site (USDA, 2010) for this analysis. Reservoir contours were developed at various water surface elevations by digitizing the water surface edge from the aerial images. The aerial images were collected at high altitudes over the reservoir, making it difficult at times to distinguish the reservoir water surface edge. However, it was determined that the developed contours were the best means to accurately locate the present shoreline. The original surface areas for portions of the original reservoir capacity computations were measured from the USGS quad contours at 10-foot intervals. The recent aerial flights provided more accurate detail of the reservoir between elevation 1,403.3 and 1,412.2. This study assumed no change since the original measured and computed surface areas from elevation 1,412.0 and above.

The new 2009 Tom Steed 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 generated the 2009 reservoir surface areas at predetermined contour intervals from the combined reservoir data. The 2009 area and capacity tables were produced by a computer program that used the measured contour surface areas and a curve-fitting technique to compute the area and capacity values at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of Tom Steed Reservoir and watershed characteristics for the 2009 study. The 2009 survey determined the reservoir has a total storage capacity of 97,322 acre-feet with a surface area of 6,362 acres at top of the conservation pool, elevation 1,411.0. Since June 1975 Mountain Park Dam closure, this survey only measured a slight change in reservoir capacity from the original reservoir volume computations at elevation 1,411.0. The 2009 survey measured 4,258 acre-feet of lost capacity below elevation 1,388.0, but the capacity was essentially regained between elevation 1,388.0 and 1,412.0. The losses and gains were computed by comparing the original surface areas and the 2009 surface areas for the reservoir. It is assumed that a small portion of the loss from elevation 1,388.0 and below was due to material from the upper elevation shoreline being eroded over time and settling in the lower elevations of the reservoir. However, it is believed the computed capacity losses and gains are primarily due to accuracy differences between the original and 2009 measured surface areas. The 2009 survey measured a minimum elevation of 1,372.6 or around 8.6 feet of sediment accumulation at the dam.

Control Survey Data Information

Prior to the 2009 survey, a temporary point was set on the East Dike using OPUS to establish the horizontal and vertical control datum (Figure 5). OPUS, operated by the NGS, allows users to submit GPS data files that are processed with known data to determine point positions relative to the national control network. The East Dike temporary point was the base for the entire reservoir survey.

Figure 5 – View of the reservoir from the East Dike.

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

Topographic survey shots were taken of the water surface and compared to the water surface gage readings. The RTK GPS elevations in NAVD88 averaged 0.45 feet higher than the recorded gage reading which is near the 0.5 foot shift between NGVD29 and NAVD88. Survey shots were also taken on top of the East Dike alignment and varied from elevation 1,427.7 to 1,428.2 compared to design crest elevation 1,428.

A topographic shot was also collected on a BOR brass cap, labeled 1,409.889, located downstream of the East Dike (coordinates for the 2009 topographic shot listed below). The measurement was 0.39 feet higher than the stamped elevation on the brass cap. As of this report, no history was located on how the elevation on this brass cap was originally established.

North	518,729.484
East	1,679,651.533
Elevation	1,410.75 (NAVD88)
Elevation	1,410.28 (NGVD29) (computed using US Army Corp of Engineers' program CORPSCON)

Reservoir Operations

Tom Steed Reservoir is part of the Mountain Park Project that was designed to provide storage for municipal, industrial, and flood control. The project also provides recreation facilities along with fish and wildlife conservation. The June 2009 capacity table computed 197,347 acre-feet of total storage below the maximum water surface elevation 1,423.6 (Table 1). The 2009 survey measured a minimum lake bottom elevation of 1,372.6. The following values are from the June 2009 capacity table:

- 79,741 acre-feet of surcharge storage, elevation 1,414.0 through 1,423.6.
- 20,284 acre-feet of flood control storage, elevation 1,411.0 through 1,414.0.
- 92,922 acre-feet of conservation pool storage, elevation 1,386.3 through 1,411.0.
- 4,383 acre-feet of inactive pool storage, elevation 1,376.5 through 1,386.3.
- 17 acre-feet of dead pool storage below elevation 1,376.5.

The computed annual inflow and reservoir stage records for Tom Steed Reservoir are listed by water year in Table 1 for the period 1975 through 2009. The inflow values were computed by Reclamation's Oklahoma Area Office for this study and are rough estimates of reservoir inflows by measured monthly change in reservoir elevations resulting in computed capacity change and adjusted for estimated monthly reservoir evaporation rates. These inflow values show the annual fluctuation with a computed average annual inflow of 35,260 acre-feet. The maximum end of month reservoir elevation of 1,414.5 was recorded during water year 1987. After initial filling in 1980, a minimum end of month reservoir elevation of 1,399.8 was recorded during water years 1993 and 1998.

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 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. 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 6 - 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, south zone in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

The Tom Steed Reservoir bathymetric survey was conducted in 2009 from May 19-21 and June 1-4 between water surface elevation 1,408.2 and 1,408.4 (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. Most transects (grid lines) were run somewhat 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 collected along the shore by the survey vessel for the majority of the reservoir. During each run, 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 139,000 points (Figure 7).

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. Near the dam the sediment laden bottom was very soft allowing the weight to easily sink about 1 foot below the reservoir bottom. In the main part of the reservoir the bottom was much more solid. 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).

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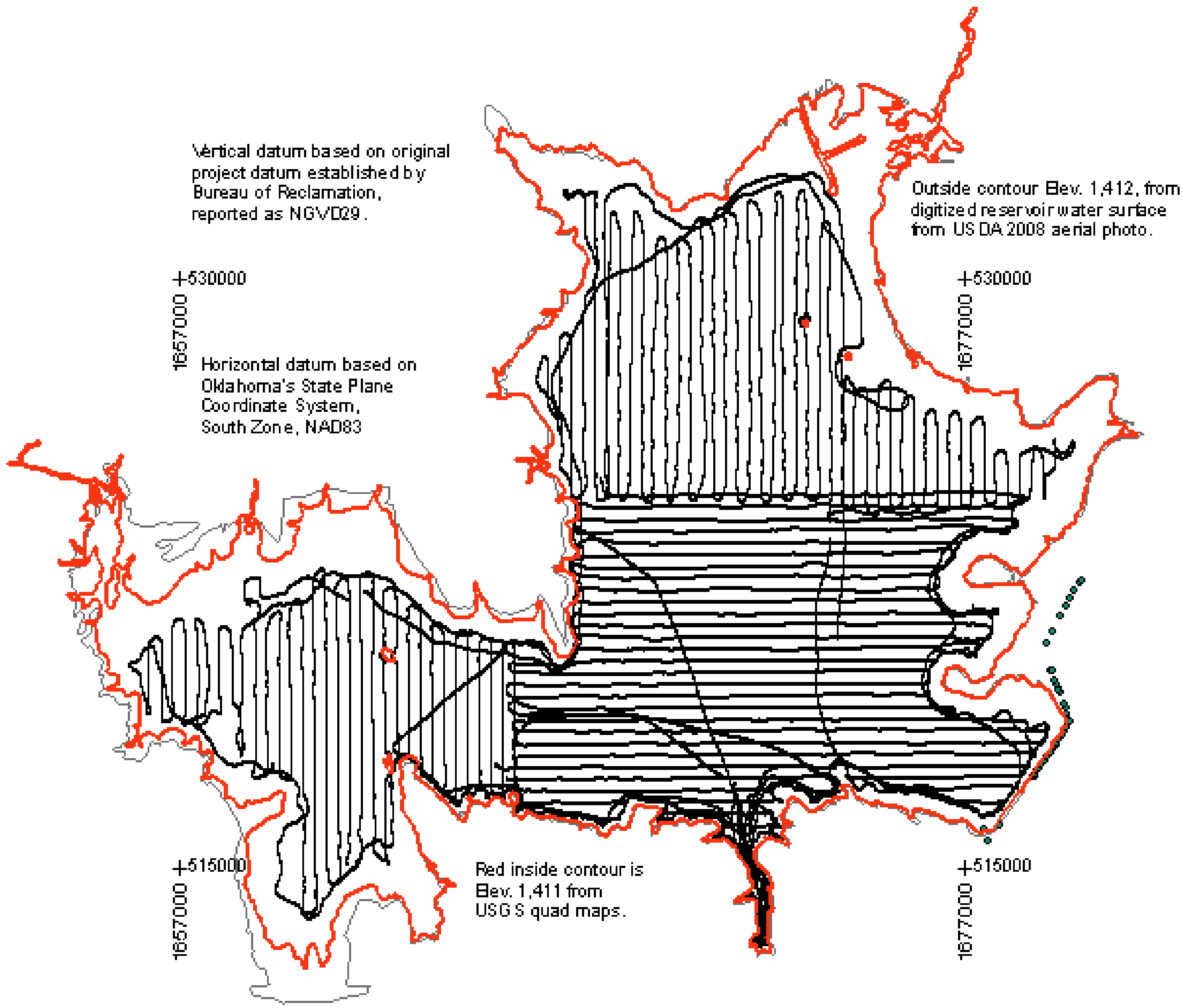

Figure 7 - Tom Steed Reservoir 2009 survey data points.

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Reservoir Area and Capacity

Topography Development

The topography of Tom Steed Reservoir was developed from combined 2009 bathymetric data and the digitized reservoir water surface edge from several sets of aerial photographs collected by the USDA. The reservoir water surface elevation was recorded by the Reclamation gage on the day of each aerial flight:

Year	Water Surface Elevation	
2004	1,403.3	
2005	1,406.7	
2006	1,404.6	
2008	1,412.0	(average of two flight lines)

Contours digitized from USGS quads at elevations 1,410 and 1,411 were used during field collection and to evaluate the USDA aerial images of the reservoir. As part of the analysis, the 1,411 USGS contour was used as a hardclip polygon for the 2009 collected data. The resulting computation values were similar to those using the contours developed from USDA aerials only. Since the digitized contours from the USDA aerial photographs provided more detail and more current upper elevation contours, the USGS quad contours were not used in the development of the final 2009 Tom Steed Reservoir topography for this study.

Following are images that compare the digitized contours from the USGS and USDA data sets. Footnotes on the original area capacity tables for Tom Steed reservoir indicate that some of the surface areas were developed by digitizing the USGS quad contours that for this area are only at 10-foot intervals. As seen on Figure 8, the reservoir area outlined from the digitized USGS contour elevation 1,411 (outlined by the blue shaded area on Figure 4) lines up well with the USDA developed contours. This was the case for the majority of the reservoir. Figures 9 and 10 illustrate areas of the reservoir where the USDA developed contours plotted outside the USGS 1,411 digitized contour. This explains why the original total surface areas in the upper elevations are less than the total surface areas developed by the 2009 survey. The larger surface areas measured for the 2009 survey resulted in the 2009 total reservoir capacity at elevation 1,411.0 being near the original capacity computation even though sediment deposition reduced the capacity in the lower elevation zone of the reservoir. During the 2009 field survey, shoreline erosion was observed, but the majority of the measured change in the upper elevation is likely due to the increased detail of the upper contours developed from the USDA aerial images compared to those developed from the USGS quads. The aerial images represent actual reservoir conditions at given elevations.

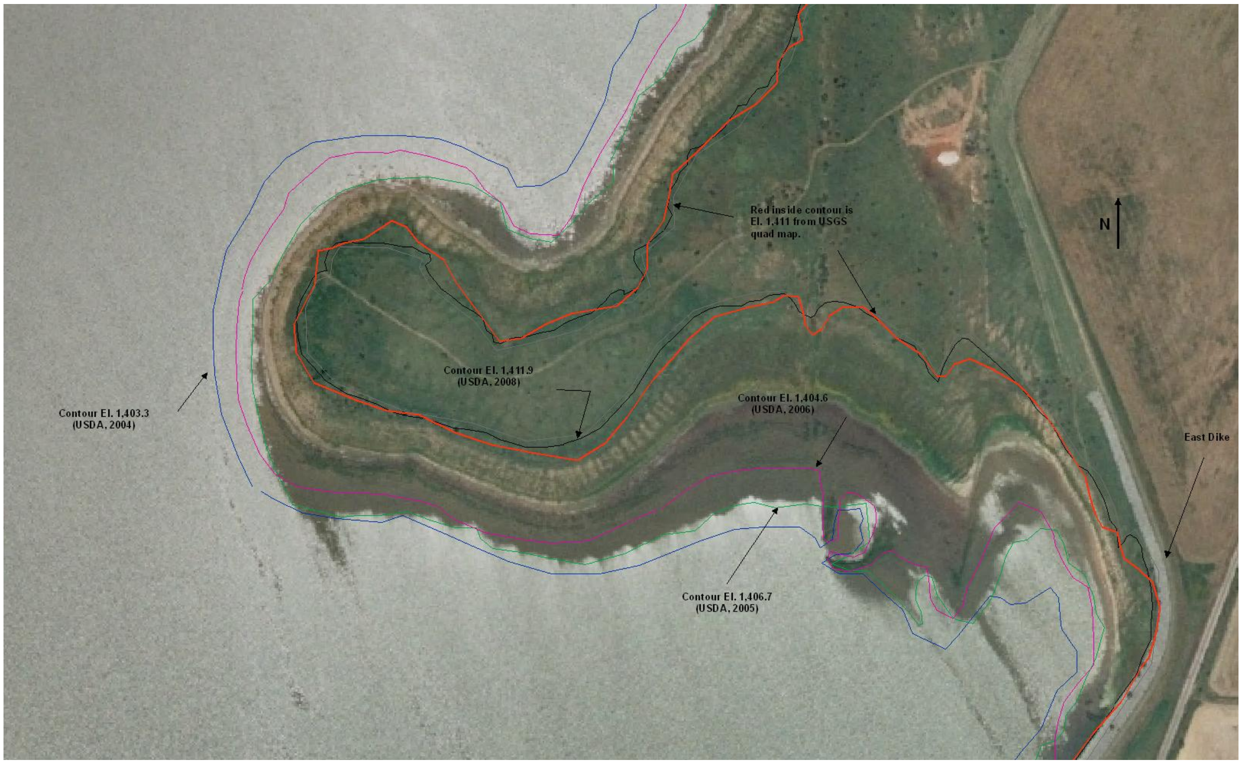

Figure 8 - Tom Steed Reservoir at East Dike.

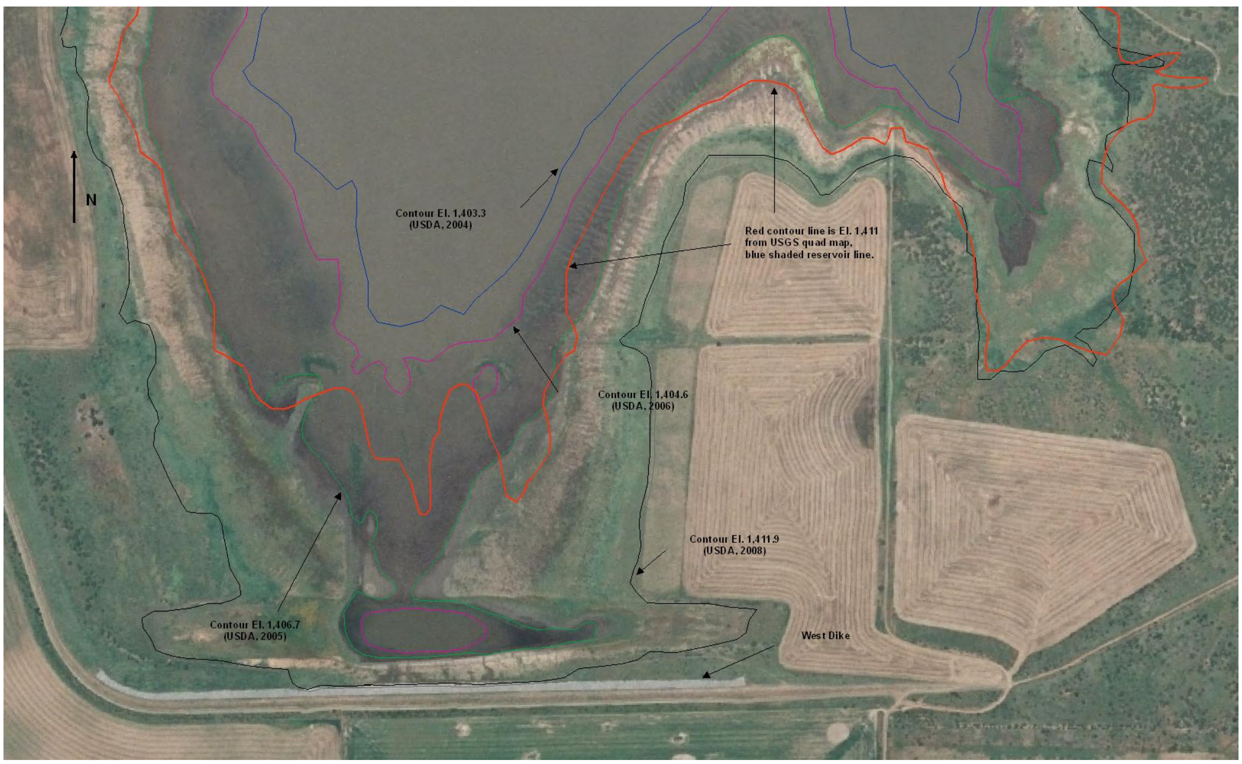

Figure 9 - Mountain Park Reservoir, West Dike.

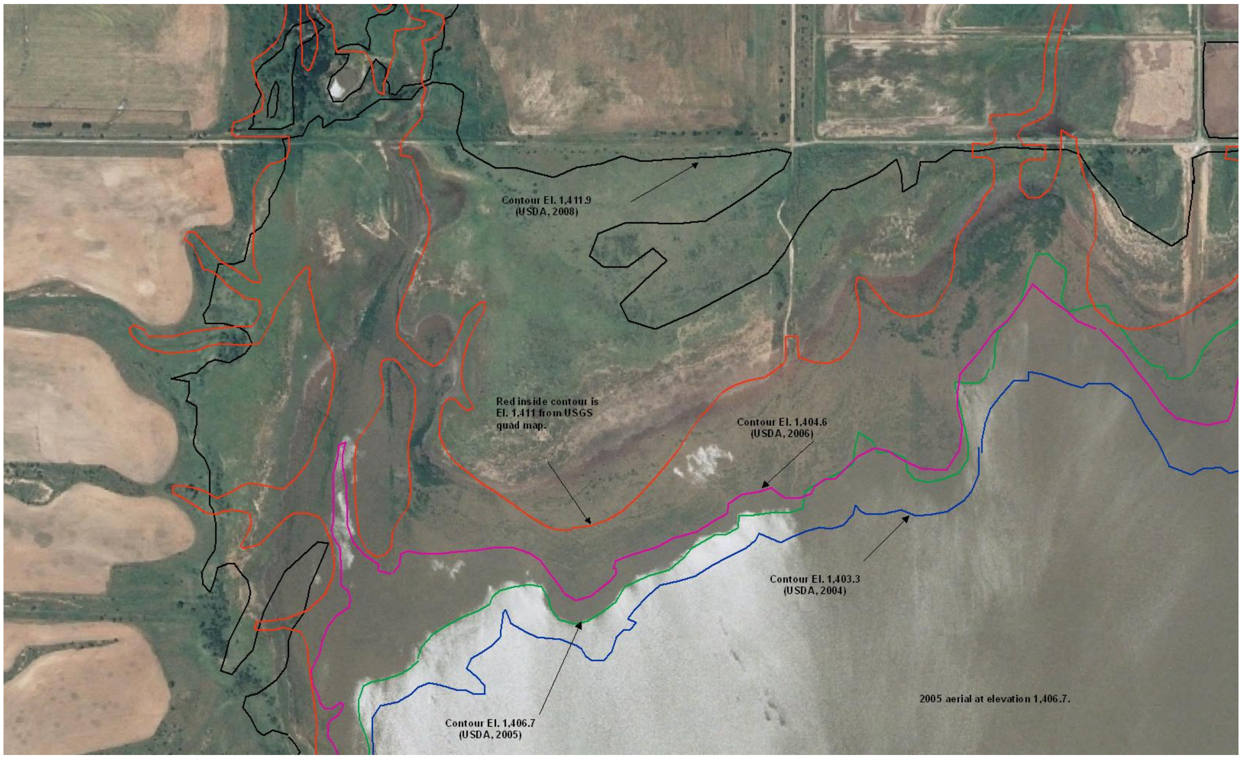

Figure 10 - Tom Steed Reservoir, Otter Creek.

A developed contour just outside the 2008 aerial digitized contour, elevation 1,411.9, was used as a hard boundary for the 2009 developed contours. This clip was assigned elevation 1,413.0 and was used during the triangular irregular network (TIN) and contour development to prevent interpolation outside the enclosed polygon or reservoir area.

Contours for the reservoir from elevation 1,412.0 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 Tom Steed Reservoir TIN. The areas of the enclosed contour polygons at one-foot increments were computed from the survey data for elevations 1,473.0 through 1,410.0. Since limited above water data was collected, this study assumed no change in reservoir surface area since the 1975 survey at elevation 1,412.0 and higher. The surface area of the contour digitized from USDA aerial photography near elevation 1,412 was very similar to the original computed surface area for that elevation. The reservoir contour topography at 2-foot intervals from elevation 1,412.0 and below is presented on Figures 11 through 13. Development of the contours within ARCGIS was directly from the TIN using all the enclosed data points resulted in a somewhat jagged representation of the contours. There are other mapping packages that can be used to generate smoother contours, but for this study the TIN approach includes all data points to produce the most accurate surface area and resulting volume. The best means to develop the upper contours and resulting above water reservoir areas would be by conducting a detailed aerial survey with the reservoir drawn down.

Development of the 2009 Tom Steed Reservoir Surface Areas

The 2009 surface areas for Tom Steed Reservoir were computed at 1-foot increments directly from the reservoir TIN from elevation 1,374.0 through 1,410.0. The TIN was developed from the 2009 collected data and digitized data sets within the hardclip polygon created from the previously described digitized 1,413.0 contour. 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-foot increments from elevation 1,374.0 through 1,410.0 were used in computing the new area and capacity tables. This study assumed no change in surface area, since the original or 1975 survey, at elevation 1,412.0 and above.

Table 1 provides a summary of the 2009 survey conducted on Tom Steed Reservoir. The area and capacity curves for the original and 2009 surveys are plotted on Figure 14.

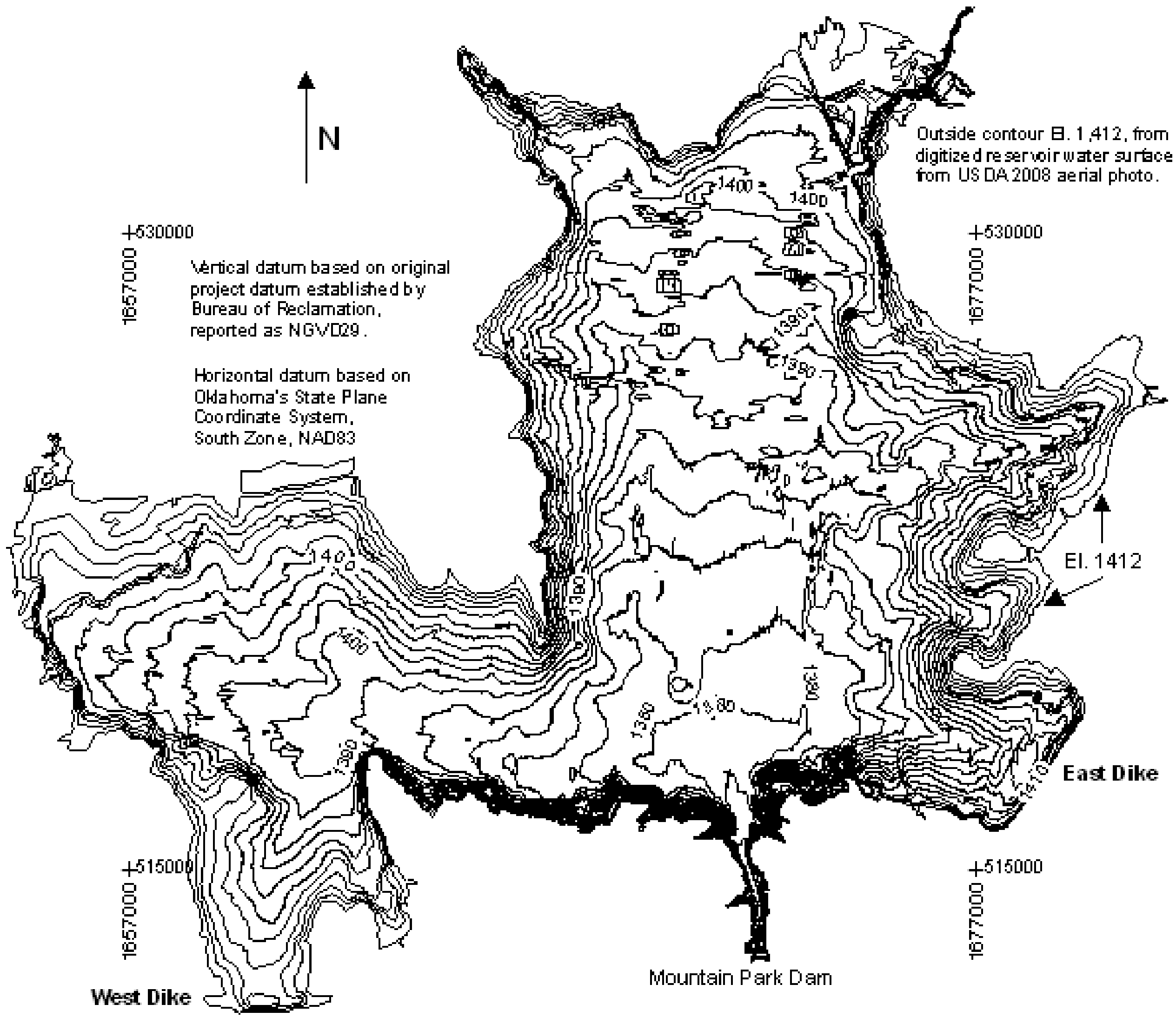

Figure 11 - Tom Steed Reservoir topographic map.

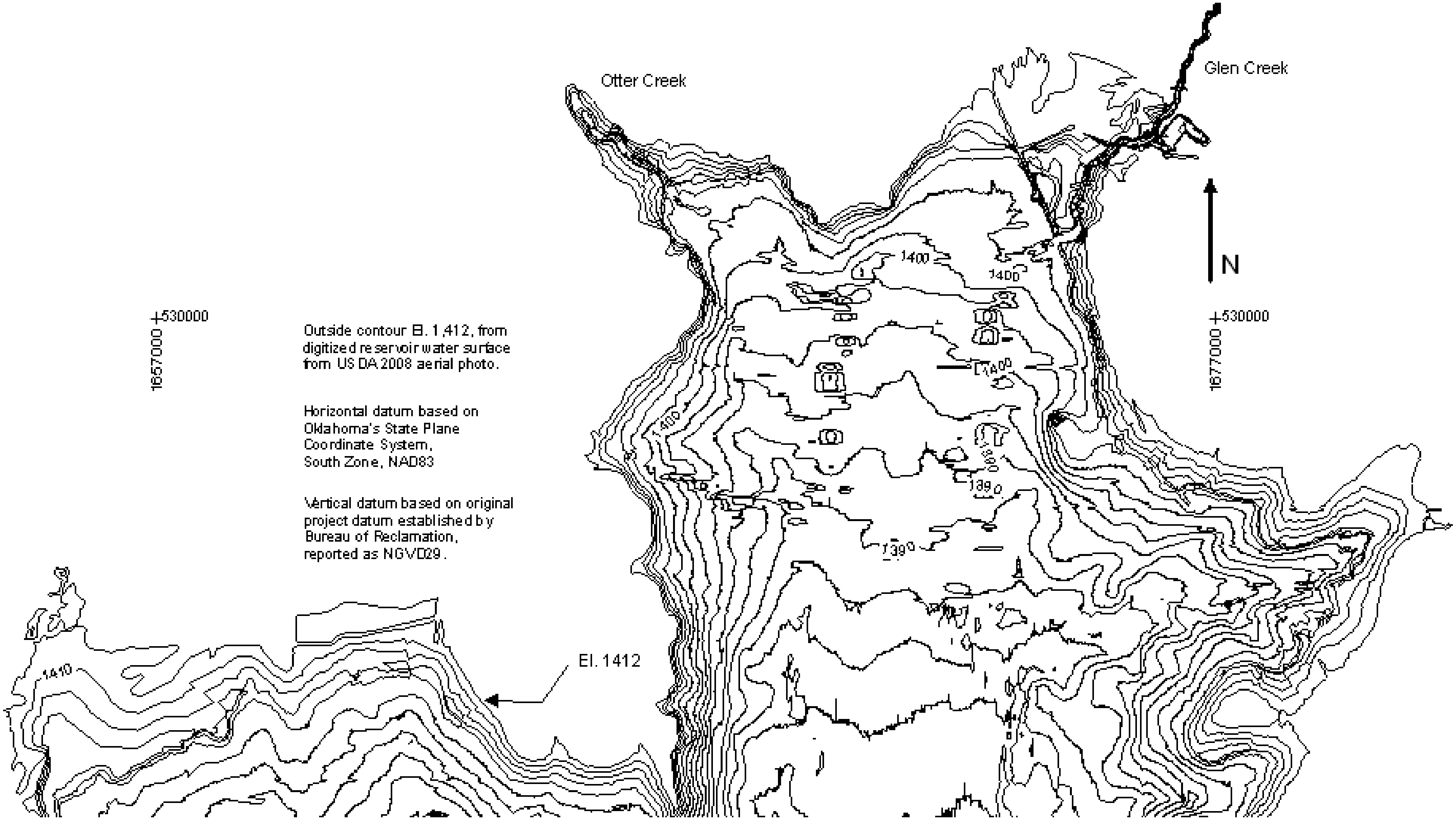

Figure 12 - Tom Steed Reservoir topographic map image.

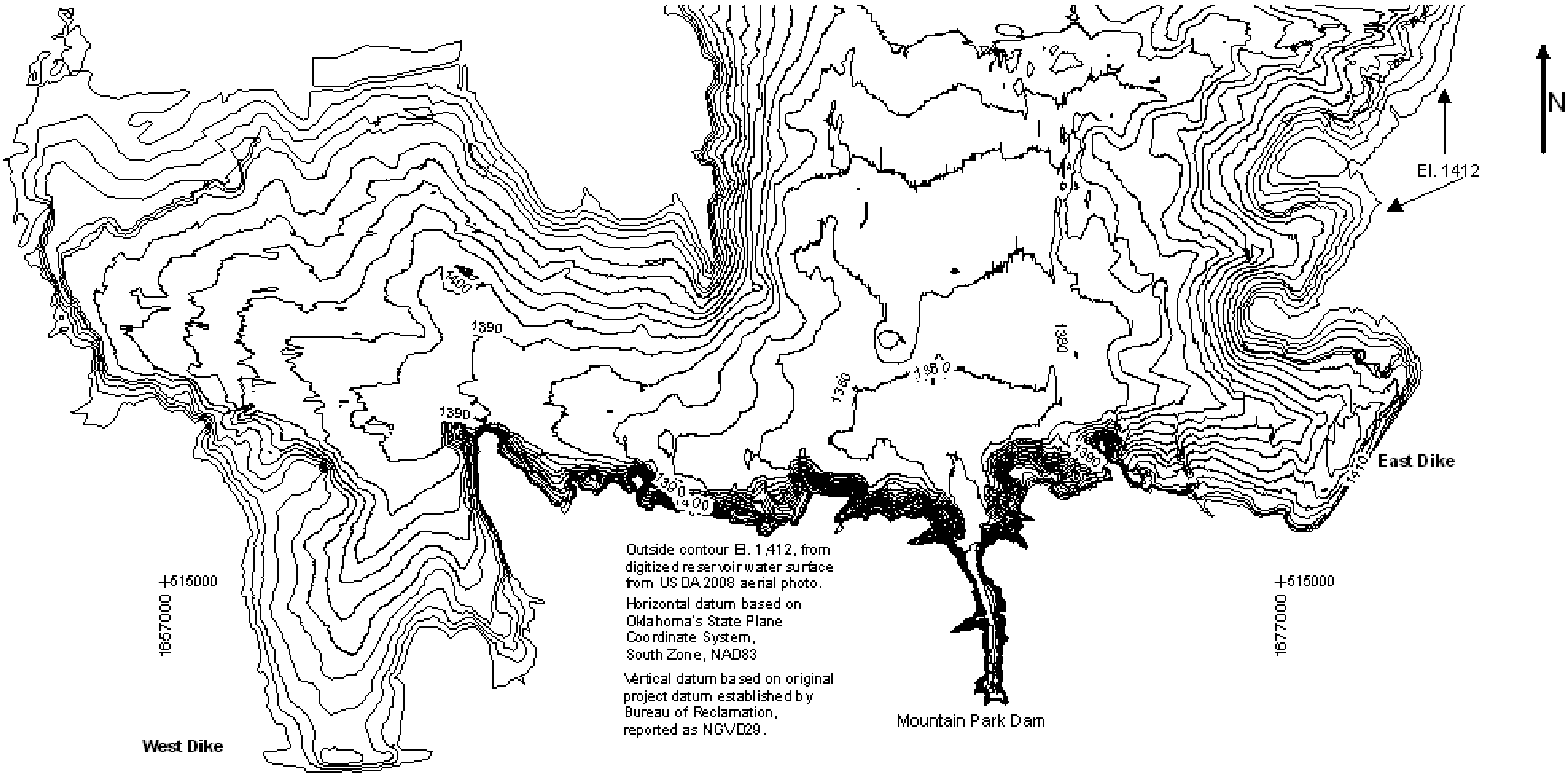

Figure 13 - Tom Steed Reservoir topography.

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RESERVOIR SEDIMENT
DATA SUMMARY

Tom Steed
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: West Otter Creek	3. STATE: Oklahoma
A	4. SEC 16 TWP. 3N RANGE 17W	5. NEAREST P.O. Mountain Park	6. COUNTY Kiowa
M	7. LAT 34 ° 44 ' 19 " LONG 98 ° 59 ' 15 "	8. TOP OF DAM ELEVATION: 1,423.0 [1]	9. SPILLWAY CREST EL. 1,414.0 [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 / 16. DATE NORMAL OPERATIONS BEGAN
	a. SURCHARGE	1,423.6 [3]	9,478	197,363	79,741	15. 6/1975
	b. FLOOD CONTROL	1,414.0	7,134	117,622	20,268	
	c. POWER					
	d. JOINT USE					
	e. CONSERVATION	1,411.0	6,330	97,354	88,804	
	f. INACTIVE	1,386.3	1,268	8,550	6,749	
	g. DEAD	1,376.5	330	1,801	1,801	16. 6/1975
	17. LENGTH OF RESERVOIR 4.5 [4] MILES		AVG. WIDTH OF RESERVOIR 2.2 MILES			

BASIN		
	18. TOTAL DRAINAGE AREA 121 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 26.5 [6] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 121 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 5.5 [7] INCHES
	20. LENGTH MILES; AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 35,260 [7] ACRE-FEET
	21. MAX. ELEVATION 14,000; MIN. ELEVATION 560	25. ANNUAL TEMP, MEAN °F RANGE -11 °F to 120 °F [6]

SURVEY DATA	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
	6/1975			Contour (D)	5-ft	6,330 [8]	97,354 [8]	2.76
	6/2009	34.0	34.0	Contour (D)	2-ft	6,362 [9]	97,322 [9]	2.76

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
6/2009		35,260 [7]	114,295	11,989,800	35,260	11,989,800

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

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

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

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

45. RANGE IN RESERVOIR OPERATION [7, 11]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1975	1,390.7		8,117
1976	1,393.1	1,388.9	9,668	1977	1,402.8	1,392.1	38,900
1978	1,406.9	1,399.9	35,979	1979	1,409.0	1,404.3	31,690
1980	1,412.8	1,406.4	42,125	1981	1,407.9	1,405.8	18,878
1982	1,411.8	1,406.4	38,776	1983	1,409.0	1,406.7	12,100
1984	1,412.1	1,406.8	45,319	1985	1,407.9	1,406.1	30,332
1986	1,410.9	1,407.2	41,248	1987	1,414.5	1,410.0	114,295
1988	1,410.9	1,408.2	46,148	1989	1,411.2	1,409.3	31,974
1990	1,411.0	1,408.4	65,775	1991	1,411.2	1,407.6	37,765
1992	1,410.9	1,409.1	35,022	1993	1,412.2	1,399.8	63,881
1994	1,408.9	1,404.4	8,786	1995	1,411.8	1,402.2	74,605
1996	1,410.8	1,407.5	31,763	1997	1,412.0	1,408.7	29,089
1998	1,411.2	1,399.8	31,974	1999	1,408.1	1,400.4	26,842
2000	1,408.7	1,405.0	30,846	2001	1,411.1	1,407.1	31,905
2002	1,407.0	1,403.4	8,888	2003	1,405.4	1,403.3	24,397
2004	1,404.0	1,402.6	12,930	2005	1,407.6	1,403.8	26,739
2006	1,407.1	1,401.9	7,491	2007	1,414.3	1,401.5	61,760
2008	1,411.4	1,408.4	27,824	2009	1,408.4	1,406.6	15,152

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

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2009	**SURVEY**	[9]	1,372.6	0	0	1,374.0	1	1
1,376.0	10	12	1,376.5	13	17	1,378.0	28	47
1,380.0	145	196	1,382.0	448	802	1,384.0	835	2,085
1,386.0	1,129	4,054	1,386.3	1,176	4,400	1,388.0	1,463	6,636
1,390.0	1,854	9,964	1,392.0	2,271	14,078	1,394.0	2,716	19,058
1,396.0	3,157	24,936	1,398.0	3,602	31,696	1,400.0	4,040	39,341
1,402.0	4,532	47,898	1,404.0	5,020	57,459	1,406.0	5,441	67,937
1,408.0	5,801	79,222	1,410.0	6,079	91,101	1,411.0	6,362	97,322
1,412.0	6,646	103,826	1,414.0	7,134	117,606	1,416.0	7,623	132,363
1,418.0	8,111	148,097	1,420.0	8,599	164,807	1,422.0	9,088	182,494
1,423.6	9,478	197,347						

47. REMARKS AND REFERENCES

[1] Elevations in feet based on original project datum reported as NGVD29; around 0.5 feet lower than NAVD88. Parapet wall crest, el. 1,427.0.

[2] Concrete arch portion of dam functions as uncontrolled overflow spillway with crest elevation 1,414.0.

[3] Elevations from Reservoir Capacity Allocation in SOP, dated 1/2000. Capacity values recomputed for 2009 analysis using ACAP.

[4] Reservoir length at elevation 1,411.

[5] Total drainage area from Reclamation's SOP report. Reservoir water supplements from Bretch Diversion Dam, drainage area of 549 mi^2.

[6] Bureau of Reclamation Project Data Book, 1981. Values for Mountain Park Project.

[7] Mean annual runoff from 1975 through May 2009 from Reclamation's Regional computed inflows. Rough estimate. Supplemental water from Bretch Diversion Dam.

[8] Surface area and capacity at elevation 1,411.0, conservation capacity.

[9] 2009 capacities computed by Reclamation's ACAP program. Assume no surface area change from original values from el. 1412.0 and above.

[10] Due to detail difference between original and 2009 surveys, computing capacity loss due to sediment deposition by comparing survey results is not possible.

[11] End of month maximum and minimum elevations.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE March 2010

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

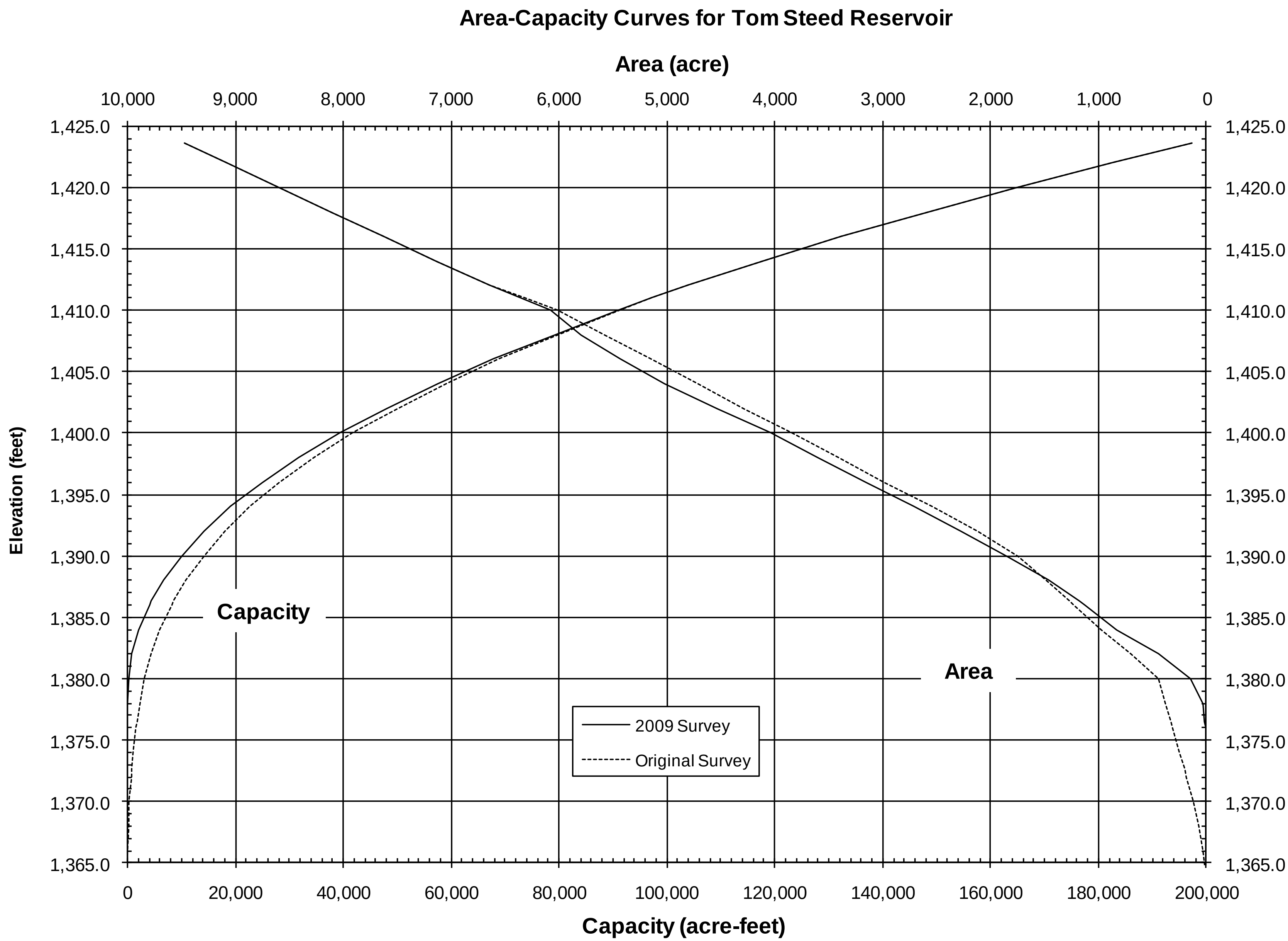

Figure 14 **– Tom Steed Reservoir Area and Capacity Plots**

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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 Tom Steed 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 Tom Steed 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 14. As of June 2009, at conservation use elevation 1,411.0, the surface area was 6, 362 acres with a total capacity of 97,322 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
1,423.6	9,478	197,363	9,478	197,347	0	16	100.0
1,422.0	9,088	182,510	9,088	182,494	0	16	97.3
1,420.0	8,599	164,823	8,599	164,807	0	16	94.0
1,418.0	8,111	148,113	8,111	148,097	0	16	90.6
1,416.0	7,623	132,379	7,623	132,363	0	16	87.2
1,414.0	7,134	117,622	7,134	117,606	0	16	83.9
1,412.0	6,646	103,842	6,646	103,826	0	16	80.5
1,411.0	6,330	97,354	6,362	97,322	32	32	78.9
1,410.0	6,015	91,181	6,079	91,101	64	80	77.2
1,408.0	5,582	79,584	5,801	79,222	219	362	73.8
1,406.0	5,148	68,854	5,441	67,937	293	917	70.5
1,404.0	4,715	58,991	5,020	57,459	305	1532	67.1
1,402.0	4,282	49,994	4,532	47,898	250	2096	63.8
1,400.0	3,849	41,863	4,040	39,341	191	2522	60.4
1,398.0	3,416	34,598	3,602	31,696	186	2902	57.0
1,396.0	2,982	28,200	3,157	24,936	175	3264	53.7
1,394.0	2,549	22,669	2,716	19,058	167	3611	50.3
1,392.0	2,116	18,004	2,271	14,078	155	3926	47.0
1,390.0	1,752	14,136	1,854	9,964	102	4172	43.6
1,388.0	1,490	10,894	1,463	6,636	-27	4258	40.3
1,386.3	1,268	8,550	1,176	4,400	-92	4150	37.4
1,386.0	1,229	8,175	1,129	4,054	-100	4121	36.9
1,384.0	967	5,979	835	2,085	-132	3894	33.6
1,382.0	706	4,306	448	802	-258	3504	30.2
1,380.0	444	3,156	145	196	-299	2960	26.8
1,378.0	379	2,333	28	47	-351	2286	23.5
1,376.5	330	1,801	13	17	-317	1784	21.0
1,376.0	314	1,640	10	12	-304	1628	20.1
1,374.0	250	1,076	1	1	-249	1075	16.8
1,372.6	204	758	0	0	-204	758	14.4
1,372.0	185	641	0	0	-185	641	13.4
1,370.0	120	336	0	0	-120	336	10.1
1,368.0	72	144	0	0	-72	144	6.7
1,366.0	36	36	0	0	-36	36	3.4
1,364.0	0	0	0	0	0	0	0.0
1	Elevation of reservoir water surface. (Project vetical datum, near NGVD29).						
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, 59.6 feet.						

Table 2 - Tom Steed Reservoir survey results.

2009 Reservoir Analyses

Results of the 2009 Tom Steed 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 as used to compute the 2009 capacities, ACAP (Reclamation, 1985). Only limited information was located on how the original surface areas and capacities were developed, but a footnote on one table indicated contour surface areas were measured from a 1975 survey and USGS quad contours that were at 10-foot intervals. Column 7 lists the capacity differences between the original and 2009 surveys. Figure 14 is a plot of the Tom Steed Reservoir surface area and capacity values for the surveys and illustrates the differences. The comparisons show that the total reservoir capacity in 2009 was 197,347 acre-feet or only 16 acre-feet less than the original volume at maximum reservoir elevation 1,423.6. It must be noted that the 2009 area and capacity tables were generated assuming no surface area change since the 1975 or original survey at elevation 1,412.0 and above. Column 6 lists the surface area differences between the original and 2009 surveys. Assuming no change at elevation 1,412.0 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 never operated above elevation 1,415 and rarely operates above elevation 1,412. Also, only the limited detailed information on the actual reservoir topography in these upper elevation areas was available for the 2009 study.

During the planning phase for this reservoir, the original estimated 100 year sediment accumulation for Tom Steed Reservoir was 17,000 acre-feet from elevation 1,414.0 and below. Of this amount it was estimated that 11,700 acre-feet would deposit above pool elevation 1,386.3 meaning 5,300 acre-feet would be deposited below the inactive reservoir area below elevation 1,386.3. From Table 2, a comparison of the original and 2009 results show that for the first 34 years of reservoir operations 4,150 acre-feet of sediment has already deposited below elevation 1,386.3. As stated previous data comparisons between the original and the 2009 survey data may be statistically invalid, but the 2009 study did measure a significantly smaller inactive and dead storage capacity than originally computed. The 2009 study measured a minimum bottom elevation of 1,372.6 compared to the original minimum bottom elevation of 1,364.0 or nearly 9 feet of sediment accumulation near the dam. During the 2009 data collection a weighted probe was dropped from the boat to confirm depth sounder readings. The light weighted probe sunk well over a foot into the reservoir bottom sediment deposits indicating the material was not very consolidated at this time. Future build up of this material near the dam will eventually affect the outlet operations. Future collection will be required to better monitor and project the sediment buildup at the dam and throughout the reservoir.

The results of the 2009 Tom Steed Reservoir study provide up-to-date surface area and capacity information for the reservoir from elevation 1,412.0 and below. This study had enough information to develop the current surface areas and resulting capacity as presented in this report. Aerial collection would be required for total reservoir topography development.

References

American Society of Civil Engineers, 1962. ***Nomenclature for Hydraulics***, ASCE Headquarters, New York.

Bureau of Reclamation, 1981. ***Project Data,*** Denver Office, Denver CO.

Bureau of Reclamation, 1985. Surface Water Branch, ***ACAP85 User's Manual***, Technical Service Center, Denver CO.

Bureau of Reclamation, 1987(a). ***Guide for Preparation of Standing Operating Procedures for Bureau of Reclamation Dams and Reservoirs***, U.S. Government Printing Office, Denver, CO.

Bureau of Reclamation, 1987(b). ***Design of Small Dams***, U.S. Government Printing Office, Denver CO.

Bureau of Reclamation July 1998. ***Standing Operating Procedures (SOP), Mountain Park Dam and Tom Steed Reservoir, Mountain Park Project, Oklahoma***, GP Region, Billings, MT.

Bureau of Reclamation, June 2009. ***Tom Steed Reservoir Area and Capacity Tables, Mountain Park Project***, Great Plains Region, Billings, MT.

Corps of Engineers, January 2002. *Engineer and Design* ***Hydrographic Surveying***, EM 1110-2-1003, Department of the Army, Washington DC, (www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1003/toc.htm).

ESRI, 2010. **Environmental Systems Research Institute, Inc.** (www.esri.com)

Ferrari, R.L. and Collins, K. (2006). ***Reservoir Survey and Data Analysis,*** Chapter 9, Erosion and Sedimentation Manual, Bureau of Reclamation, Sedimentation and River Hydraulics Group. Denver, Colorado. www.usbr.gov/pmts/sediment

USDA, 2010. United States Department of Agriculture, **Online GIS Services,** http://datagateway.nrcs.usda.gov/