RECLAMATION
Managing Water in the West

Harry Strunk Lake
2006 Sedimentation Survey

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Denver, Colorado

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14. ABSTRACT

The Bureau of Reclamation (Reclamation) surveyed Harry Strunk Lake in May 2006 to develop new reservoir topography and compute a present storage-elevation relationship (area-capacity tables). The 2006 underwater survey, conducted between reservoir elevation 2,365.7 and 2,365.9 feet (project datum), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. Above-water topography was mapped by digitizing a reservoir contour from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. Using the 2006 survey data, the digitized contour was adjusted throughout the reservoir due to shoreline erosion and in the upper reservoir area due to the sediment delta. Due to the lack of above water data, this study assumed no change since the 1981 range line survey from elevation 2,366.1 and above.

As of May 2006, at conservation pool elevation 2,366.1, the surface area was 1,840 acres with a total capacity of 34,647 acre-feet. Since dam closure on August 8, 1949, about 6,473 acre-feet of sediment has accumulated below elevation 2,366.1, resulting in a 15.7 percent loss in reservoir volume.

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Harry Strunk Lake
2006 Sedimentation Survey

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Bureau of Reclamation
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Sedimentation and River Hydraulics Group
Denver, Colorado

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

Acknowledgments

Reclamation's Sedimentation and River Hydraulics Group (Sedimentation Group) of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari of the TSC and Mark Rouse of the McCook Field Office in the Great Plains Region conducted the bathymetric survey. Ron Ferrari of the TSC completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC developed digital data sets needed for the final topographic map. Dave Varyu developed a table that provides more accurate means to present the summary of the reservoir sediment data. Kent Collins of the TSC performed the technical peer review of this documentation.

Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68540), PO Box 25007, Denver, Colorado 80225-0007. **http://www.usbr.gov/pmts/sediment/**

Disclaimer

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Harry Strunk Lake 2006 Sedimentation Survey

Introduction

Medicine Creek Dam and Harry Strunk Lake are principal features of the Frenchman-Cambridge Division of the Pick-Sloan Missouri Basin Program located in southwestern Nebraska. Additional storage features are Swanson and Hugh Butler Lakes, and Enders Reservoir. The four dams, reservoirs, and irrigation systems provide storage to irrigate 66,161 acres of project lands, flood control, fish and wildlife conservation, and recreation along the Republican River and its three tributaries of Red Willow and Medicine Creeks, and the Frenchman River.

Medicine Creek Dam and Harry Strunk Lake in Frontier County on Medicine Creek are located about seven miles northwest of Cambridge and 60 miles south east of North Platte, Nebraska (figure 1).

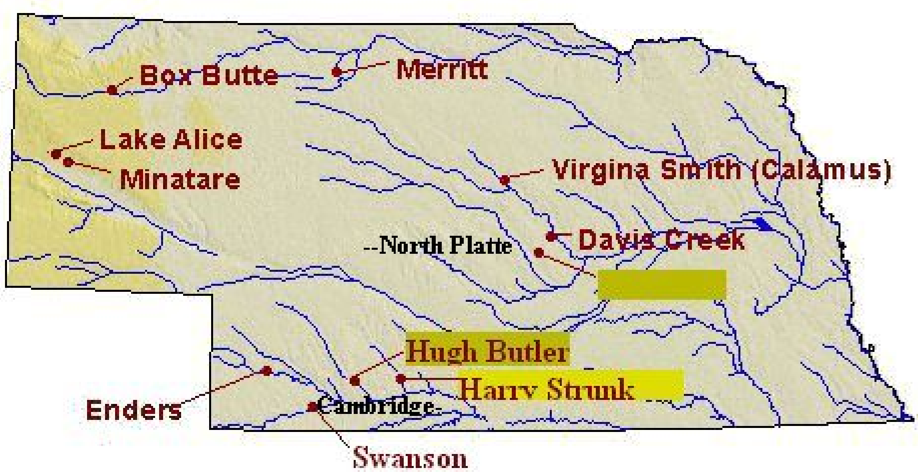

Figure 1 - Reclamation Reservoirs located in Nebraska.

Medicine Creek Dam is an earthfill structure that was completed in August of 1949. The dam's dimensions are as follows:

Hydraulic height[1]	86 feet	Structural height	165	feet
Crest length	5,665 feet	Crest elevation	2,415.0	feet[2]

The spillway, crest elevation 2,386.2, is a concrete uncontrolled ogee overflow crest located in the left abutment of the dam (Bureau of Reclamation, 1964). The discharge capacity is 97,800 cubic feet per second (cfs) at maximum reservoir elevation 2,408.9. A slot 13 feet wide and 20.1 feet deep is provided between the two center piers of the spillway and has a crest elevation of 2,366.1 feet, the normal reservoir water surface. The discharge capacity is 3,780 cfs through the 13-foot center notch with the reservoir at elevation 2,386.2.

A river outlet works is located near the right abutment and consists of a concrete horseshoe conduit 8-feet diameter containing operating valves and a 44-inch steel pipe for controlled releases from the reservoir. The discharge capacity is 390 cfs at spillway crest elevation 2,366.1.

The drainage area above Medicine Creek Dam is approximately 880 square miles of which only 642 square miles is considered contributing runoff. The additional 238 square miles of sand hill area yields base flows through the subsurface drainage, (Bureau of Reclamation, 2003). The reservoir extends 8.5 miles up Medicine Creek at reservoir elevation 2,366.1 with an average reservoir width of 0.34 miles (Bureau of Reclamation, 1964).

Summary and Conclusions

This Reclamation report presents the 2006 results of the survey of Harry Strunk Lake. The primary objectives of the survey were to gather data needed to:

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

The on-line positioning user service (OPUS) with real-time kinematic (RTK) global positioning system (GPS) control survey established a horizontal and

[1]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.*

[2]Elevations in feet. All elevations based on the original project datum established by U.S. Bureau of Reclamation that was reported to be the National Geodetic Vertical Datum of 1929 (NGVD29) and around 0.9 feet lower than the North American Vertical Datum of 1988 (NAVD88).

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 where it is processed with known point data to determine positions of points relative to the national control network. Initially, the GPS base was set over Reclamation brass cap “155 RP” that is located near the right abutment of the dam. To begin the collection process, an absolute position with the single GPS unit was measured. This position data was later corrected using the base station data, collected throughout the day, submitted to OPUS. During the bathymetric survey, three base station locations were used and all three sites were submitted to the OPUS web site for computations and verified, with good results, using RTK GPS. The horizontal control was in Nebraska state plane coordinates in the North American Datum of 1983 (NAD83) and the vertical control was tied to the National American Vertical Datum of 1988 (NAVD88) and the Reclamation project vertical datum. All elevations in this report are referenced to Reclamation’s project or construction vertical datum that appears to be tied to the National Geodetic Vertical Datum of 1929 (NGVD29) that is around 0.9 feet lower than NAVD88.

The May 2006 underwater survey was conducted between reservoir elevation 2,365.7 and 2,365.9. The bathymetric survey used sonic depth recording equipment interfaced with RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along grid lines covering Harry Strunk Lake. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by Reclamation’s reservoir gauge during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations. The above-water topography was determined by digitizing existing contour lines from the USGS quad of the reservoir area. During the bathymetric survey the boat location plotted outside these contours indicating extensive shoreline erosion has occurred throughout this reservoir. The contour locations where adjusted where this occurred. The previous surveys also documented shoreline erosion (Bureau of Reclamation, 1964).

The Harry Strunk Lake topographic map is a combination of the adjusted digitized contour and the 2006 underwater survey data. A computer graphics program generated the 2006 reservoir surface areas at predetermined contour intervals from the collected reservoir area. The 2006 area and capacity tables were produced by a computer program that used measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of Harry Strunk Lake and watershed characteristics for the 2006 survey. The 2006 survey determined that the reservoir has a total storage capacity of 193,020 acre-feet and a surface area of 5,784 acres at surcharge pool elevation 2,408.9. Since closure in August 1949, the reservoir has an estimated volume change of 6,473 acre-feet below conservation reservoir elevation 2,366.1. This volume represents a 15.7 percent loss in total original capacity at this elevation.

Control Survey Data Information

Prior to the bathymetric survey, a control network was set by the bathymetric survey crew and used throughout the survey. Initially, the RTK GPS base station was set over marker “155 RP” that is located in an open field near the right abutment of dam. The coordinates for this point were determined by processing the first day of collected raw data through the NGS service OPUS. During the bathymetric survey, three base station locations were used and all three sites were submitted to the OPUS web site for computations and verified with RTK GPS measurements. The horizontal control was in Nebraska state plane coordinates in NAD83 and the vertical control was 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 reference to NGVD29 and around 0.9 feet lower than NAVD88. Following are the coordinates determined during this survey at the indicated locations.

Location	North	West	Elevation (NAVD88)	Elevation (NGVD29)
155-RP	198,278.56	1,577,534.323	2,402.57	
Westmaster	197,860.39	1,575,856.569	2,418.39	2,417.502
Section 35	220,592.17	1,575,428.521	2,477.26	
RL1-R	198,437.22	1,577,411.486	2,405.12	2,404.22

Reservoir Operations

Harry Strunk Lake is part of the Frenchman-Cambridge Division of the Pick-Sloan Missouri Basin Program that provides storage for irrigation, flood control, fish and wildlife conservation, recreation and sediment control. The May 2006 capacity table shows 193,020 acre-feet of total storage below the maximum water surface elevation 2,408.9, table 2. The 2006 survey measured a minimum lake bottom elevation of 2,320.1. The following values are from the May 2006 capacity table:

- 105,659 acre-feet of surcharge between elevation 2,386.2 and 2,408.9.
- 52,714 acre-feet of flood control between elevation 2,366.1 and 2,386.2.
- 26,750 acre-foot of active storage between elevation 2,343.0 and 2,366.1.
- 4,489 acre-foot of inactive storage between elevation 2,335.0 and 2,343.0.
- 3,408 acre-foot of dead storage below 2,335.0.

Harry Strunk Lake computed annual inflow and reservoir stage records are listed by calendar year on table 1 for the operation period August 1949 through May 2006. The inflow values were computed by the Great Plains Regional Office and show annual fluctuation with a computed average inflow of 46,300 acre-feet per year. The maximum reservoir elevation was 2,374.1, recorded during water year 1960, and after initial filling, minimum recorded elevation was 2,340.4 during water year 1978.

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 2. 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 2 - 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

Nebraska's state plane coordinates in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

Harry Strunk Lake hydrographic survey was conducted in May of 2006 between reservoir elevation 2,365.7 and 2,365.9 (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 along an upstream-downstream river alignment of the reservoir at around 150-foot spacing. Data was collected along the shore by the survey vessel for the majority of the reservoir. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing.

The 2006 underwater data was collected by a depth sounder that was calibrated by lowering an instrument that measured the sound velocity of the reservoir water column. The individual depth soundings were adjusted by the speed of sound of the measurements that can vary with density, salinity, temperature, turbidity, and other conditions. The soundings were further verified by lowering a weighted cable below the boat with beads marking known depths. The collected data were digitally transmitted to the computer collection system via 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 gauge, were used to convert the sonic depth measurements to true lake-bottom elevations. Additional information on collection and analysis procedures can be found online, (Corps of Engineers, January 2002) and (Ferrari, R.L., 2006).

Reservoir Area and Capacity

Topography Development

The topography of Harry Strunk Lake was developed from the 2006 collected underwater data and the digitized contour from the USGS quad maps developed from aerial photography dated 1952. The digitized contour line was elevation 2,366 and the enclosed contour area, with the island surfaces removed, was within a few percent of the 1951 survey surface area results at the same elevation. The

2006 survey data was used to adjust the digitized contour due to the above water sediment delta that had formed since 1952 in the upper reservoir area and the extensive shoreline erosion that has occurred throughout this reservoir. The best means to truly develop this contour and the rest of the above water reservoir area would be by a detailed aerial survey.

The adjusted contour, elevation 2,366, was used to perform a hardclip around the 2006 data of Harry Strunk Lake. This hardclip was used during the triangular irregular network (TIN) development so interpolation did not occur outside the enclosed polygon. This contour was selected since it was the closest data available to represent the water surface during the 2006 survey. Using ARCEDIT, the 2006 underwater and the digitized 2,366 contour were plotted. The plot showed that the underwater data did not lie completely within the original elevation 2,366 contour from the USGS quad maps. The 2,366 contour was modified to include the entire underwater data set within the enclosed polygon. Using select and move commands within ARCEDIT, the vertices of the clip were shifted to contain the 2006 underwater data. This adjusted clip was assigned an elevation of 2,366.

Contours for the reservoir below elevation 2,366 were computed from the 2006 data sets using the triangular irregular network (TIN) surface-modeling package within ARC/INFO. A TIN is a set of adjacent non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. TIN was 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 sample points are connected to their nearest neighbors to form triangles using all collected data. This method preserves all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in detail in the ARC/INFO V7.0.2 *Users Documentation*, (ESRI, 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Harry Strunk Lake TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the survey data for elevations 2,322.0 through 2,362.0. Since no complete reservoir aerial data was collected, this study assumed no change in reservoir surface area, since the 1981 survey, for elevation 2,366.0 and above. Since there was limited underwater data collected during the 2006 survey, above elevation 2,362, this study only used surface area development from elevation 2,362 and below. The reservoir contour topography at 2-foot intervals is presented on figure 3.

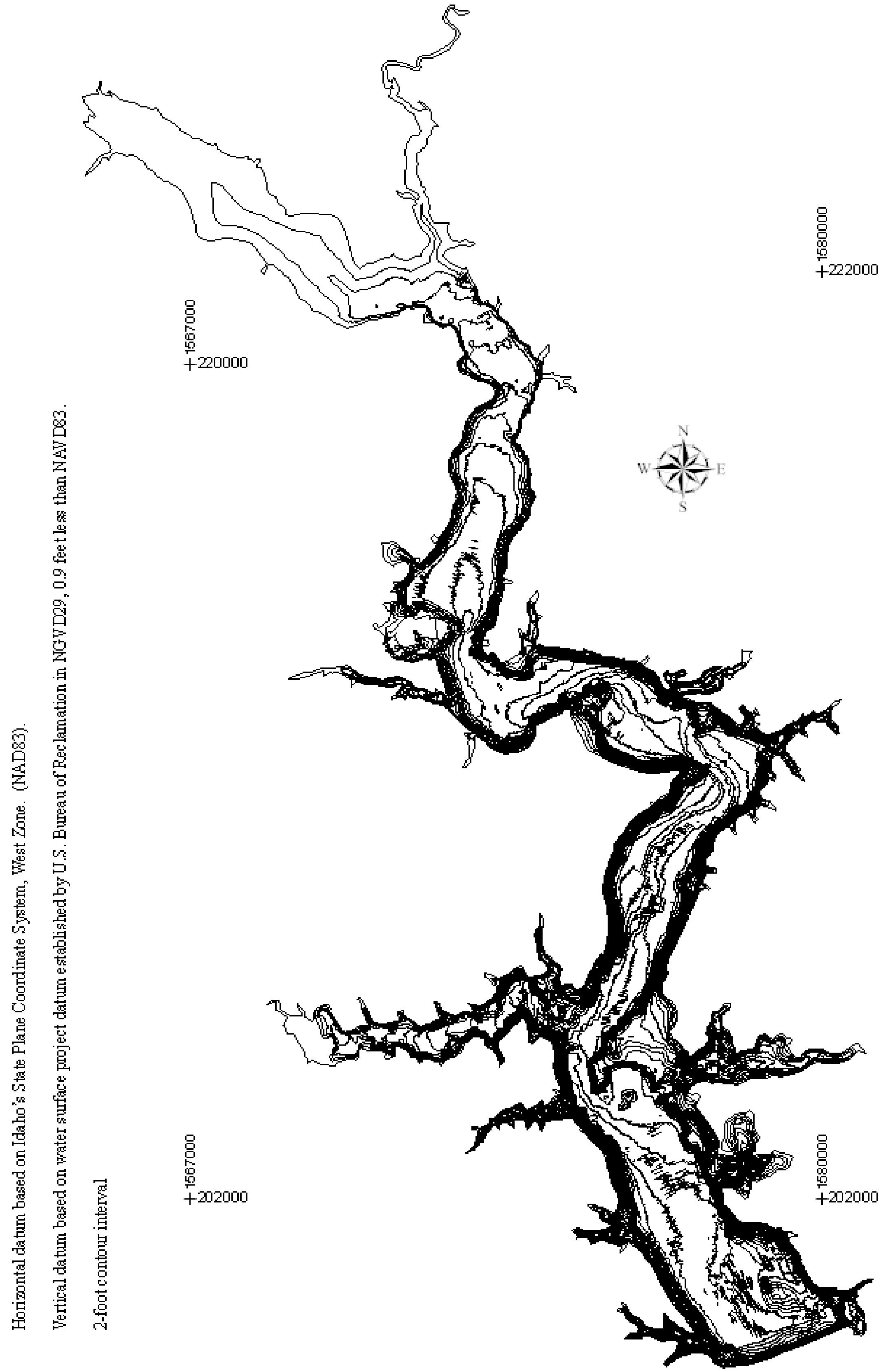

Figure 3 - Harry Strunk Lake topographic map.

Shoreline Erosion

The 2006 underwater survey witnessed extensive shoreline erosion throughout the reservoir area. During collection, the GPS boat positions were found at times to be outside the digitized USGS quad contour locations, indicating the boat was on solid ground. The USGS quad contour was developed from aerial photography flown in the 1950's and at times, the position of the boat was tens of feet outside their boundary. Even with the extensive shore erosion that has occurred since dam closure, the survey vessel was able to maneuver close to the vertical banks in deep water conditions where previous shore material had collapsed into the reservoir. It appears that over time the collapsed material washes further into the reservoir by the wave action, similar to ocean waves smoothing the beaches. This is possible because the material dissipates in the water and consists of little to no rock or large cobble. Following are pictures showing the shoreline erosion and its affect on the reservoir, figures 4 through 6.

Figure 4 - Eroded Shoreline.

Figure 5 - Large areas of erosion occurring above normal reservoir water surface, elevation 2,366.

Figure 6 - View of shoreline erosion over extensive area of reservoir.

The above photographs show the extent of the shoreline erosion that has occurred throughout the reservoir. If the erosion were just below the reservoir high water mark, the total volume of the reservoir would not be greatly affected. In that case, the gain in surface area and resulting volume in the upper reservoir elevation zone would be offset by the loss of surface area and volume in the lower elevations of the reservoir due to the depositing material from the banks. The photographs (figures 4 through 6) show a large amount of the eroded material above the normal or conservation reservoir elevation 2366.1, meaning that a portion of the loss of the original total reservoir volume is due to material from reservoir shoreline erosion along with incoming river sediments. The only means to accurately measure the extent of the shoreline erosion would be by an extensive above water survey.

The shoreline erosion was previously documented in the 1962 sedimentation survey report, with photographs and cross section plots of several of the sediment rangelines revealing the extensive impact of the reservoir wave action. The banks are composed of loessial soil which exhibits the characteristic of being able to stand on almost vertical slopes, but offers little or no resistance to the erosive force of the waves (Bureau of Reclamation, 1964). It is assumed the majority of the bank erosion occurred during the initial filling and early years of the reservoir, but it still occurs today to a lesser extent.

Development of the 2006 Harry Strunk Lake Surface Areas

The 2006 surface areas for Harry Strunk Lake were computed at 1-foot increments, from elevation 2,321.0 through 2,366.0, directly from the TIN that covered the Harry Strunk Lake within the hard clip area only. This TIN was developed within the hardclip area that included the digitized elevation 2,366.0 contour that was modified for the shoreline erosion that has occurred throughout the lake area. These calculations were performed using the ARCGIS surface area and volume command that computes areas at user-specified elevations directly from the TIN and includes all regions of equal elevation. For the purpose of this study, the measured 2006 survey areas at 1-foot increments from elevation 2,321.0 through 2,362.0 were used to compute the new area and capacity tables. There were insufficient 2006 surveyed data points, for accurate computer development of surface areas at elevations above 2,362.0. Straight line interpolation was used to compute the surface areas between elevations 2,362.0 and 2,366.0. This study assumed no change in surface area, since the 1981 survey, from elevation 2,366.0 and above.

2006 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program can compute the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Harry Strunk Lake. 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. Differentiating 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 Harry Strunk Lake area and capacity computations are listed in a separate set of 2006 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2006). A description of the computations and coefficients output from the ACAP program is included with these tables. The original, 1951, 1962, 1981, and 2006 area-capacity relationships are listed on table 2 and the curves are plotted on figure 8. As of May 2006, at conservation use elevation 2,366.1, the surface area was 1,840 acres with a total capacity of 34,647 acre-feet.

2006 Reservoir Sediment Analyses

Results of the 2006 Harry Strunk Lake area and capacity computations are listed in table 1 and columns 10 and 11 of table 2. Columns 2 and 3 of table 2 list the original area and capacity values and the results from the 1951, 1962, and 1981 surveys are also listed. Column 12 lists the capacity differences between the original and 2006 survey results due to sediment inflow and bank erosion. Figure 8 is a plot of the Harry Strunk Lake surface area and capacity values for all the listed surveys and illustrates the differences between the surveys. The comparisons show that the total reservoir capacity in 2006 is 6,473 acre-feet less than the original volume at conservation reservoir elevation 2,366.1.

It must be noted that the 2006 area and capacity tables were generated assuming no surface area change, since the 1981 survey, from elevation 2,366.0 and above. This is all probably not the case, but it is assumed any loss due to sediment deposition above this elevation would not be significant since the previous surveys. The only means to measure this would be by an extensive above water survey.

The estimated 100 years of sediment accumulation for Harry Strunk Lake was 31.8 percent or 30,000 acre-feet at flood control elevation 2,386.2. This computes to an annual loss of 300 acre-feet. Table 1 show that the 1962 survey measured an average annual loss of 321.3 acre-feet at conservation reservoir elevation 2,366.1. Since 1962, the 1981 and 2006 surveys measured a significantly less average annual loss of reservoir capacity. The 2006 survey measured an average annual loss of 42.3 acre-feet, at elevation 2,366.1, since the 1981 survey. Since closure the average annual loss was computed to be 114.0 acre-feet by the 2006 study analysis. Additional research would be needed to determine the reason for such a drop in average annual loss, but the initial significant impact of the shoreline erosion and the different methods of surveys would be two issues to address.

Figure 7 illustrates a typical reservoir sediment deposition profile where the pivot point of the depositing delta is near the normal water surface of the reservoir that for Harry Strunk Lake is near elevation 2,360 (Bureau of Reclamation, 1982). The 1962 survey developed a longitudinal profile of the upstream river showing this pivot point occurring just upstream of Mitchell Creek. The 2006 contours show that this pivot has only moved a little downstream of Mitchell Creek, indicating that the annual sediment inflow since 1962 has decreased (figure 3).

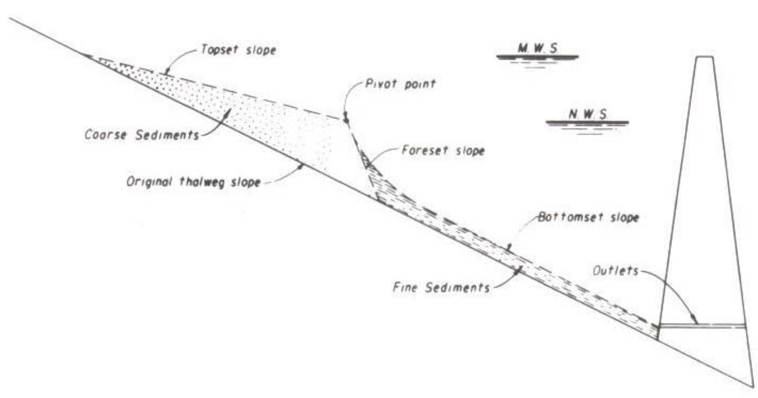

Figure 7 - Typical sediment deposition profile.

RESERVOIR SEDIMENT
DATA SUMMARY

Harry Strunk Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Medicine Creek	3. STATE Nebraska
	4. SEC 25 TWP. 5N RANGE 26 W	5. NEAREST P.O. Cambridge	6. COUNTY Frontier
	7. LAT 40 ° 22 ' 40 " LONG 100 ° 13 ' 00 "	8. TOP OF DAM ELEVATION 2415.0 [1]	9. SPILLWAY CREST EL 2386.2 [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC-FT	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN / 16 DATE NORMAL OPERATIONS BEGAN
	a. SURCHARGE	2,408.9 [3]	5,780	105,734	199,935	15: 8/1949
	b. FLOOD CONTROL	2,386.2	3,486	53,081	94,201	
	c. POWER					
	d. JOINT USE					
	e. CONSERVATION	2,366.1	1,918	29,751	41,120	16: 8/1949
	f. INACTIVE	2,343.0	793	5,249	11,369	
	g. DEAD	2,335.0	530	6,120	6,120	
	17. LENGTH OF RESERVOIR 8.5 [4] MILES		AVG. WIDTH OF RESERVOIR 0.34 MILES			

BASIN		
	18. TOTAL DRAINAGE AREA 880 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 20 [6] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 642 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 1.16 [7] INCHES
	20. LENGTH MILES AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 46,300 [7] ACRE-FEET
	21. MAX. ELEVATION MIN. ELEVATION	25. ANNUAL TEMP, MEAN 52 °F RANGE -22 °F to 110 °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/ RATIO AF/AF
8/49 [3]			Contour (D)	10 - ft	1,918	41,120	0.89
10/51 [8]	2.2	2.2	Range (D)	34	1,768	39,226	0.85
12/62 [9]	11.1	13.3	Range (D)	31	1,842	36,847	0.80
5/81 [10]	18.4	31.7	Range (D)	34	1,840	35,704	0.77
5/06 [11]	25.0	56.7	Contour (D)	1 - ft [11]	1,840	34,647	0.75

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	35. b. MAX. ANN.	35. c. TOTAL	36 WATER INFLOW TO DATE, AF a. MEAN ANN.	36. b. TOTAL
12/62		56,500	105,400	751,600	56,500	751,600
5/81		50,000	74,200	920,000	52,700	1,671,600
6/06		38,300 [7]	75,200	960,600	46,300	2,632,200

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	37. b. AVG. ANN.	37. c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	38. b. AVG. ANN.	38. c. /MI.^{2}-YR.
10/51	[12]					
12/62	4,273 [12]	321.3	0.50	4,273	321.3	0.50
5/81	1,143 [12]	62.1	0.10	5,416	170.9	0.27
6/06	1,057 [12]	42.3	0.07	6,473	114.2	0.18

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	40. b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	41. b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	42. b. TOT.
10/51	71.4	2,084	2,084			14,063	14,063
12/62	70.3	475	735	0.78	10.4	4,404	6,396
5/81				0.42	13.2		
6/06				0.28	15.7		

43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION

26. DATE OF SURVEY		2320.1- 2,301.0	2330.0- 2,320.1	2,340.0 2,330.0	2,350.0 2,340.0	2,360.0 2,350.0	2,366.1 2,360.0	2,375.0 2,366.1	2,386.2 2,375.0	2,400.0 2,386.2	2,408.9 2,400.0
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
5/00		16.2	17.5	12.0	15.6	19.1	13.2	4.9	0.4	1.1	0.0

44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR

26. DATE OF SURVEY	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 [12]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1949	2,329.2	2,300.0	17,800
1950	2,362.6	2,329.3	50,100	1951	2,372.4	2,362.5	100,300
1952	2,367.4	2,364.9	41,300	1953	2366.5	2,357.3	38,800
1954	2,366.1	2,354.0	39,900	1955	2,369.2	2,347.4	37,400
1956	2,363.5	2,348.2	41,100	1957	2,371.9	2,352.5	68,000
1958	2,367.9	2,363.7	47,700	1959	2,367.4	2,354.8	40,800
1960	2,374.1	2,353.2	74,700	1961	2,368.0	2,354.0	48,300
1962	2,372.7	2,356.6	105,400	1963	2,369.7	2,353.8	64,400
1964	2,367.8	2,354.0	49,100	1965	2,367.3	2,356.0	57,600
1966	2,367.1	2,363.1	57,800	1967	2,369.9	2,362.6	74,200
1968	2,367.1	2,357.2	50,000	1969	2,370.0	2,358.7	71,500
1970	2,367.0	2,350.6	42,800	1971	2,367.2	2,351.5	42,000
1972	2,367.1	2,352.4	41,600	1973	2,367.5	2,351.1	51,300
1974	2,367.2	2,348.9	36,800	1975	2,368.6	2,350.5	46,200
1976	2,367.0	2,343.2	40,300	1977	2,368.0	2,345.4	45,300
1978	2,368.4	2,340.4	43,900	1979	2,368.1	2,341.4	48,400
1980	2,369.2	2,345.2	39,200	1981	2,367.8	2,346.6	42,900
1982	2,367.7	2,361.0	39,200	1983	2,368.0	2,355.6	39,800
1984	2,368.4	2,354.6	48,800	1985	2,367.5	2,355.3	35,300
1986	2,367.5	2,350.9	38,800	1987	2,367.6	2,352.3	39,000
1988	2,367.6	2,355.0	41,700	1989	2,367.2	2,351.8	34,700
1990	2,367.2	2,348.7	30,100	1991	2,367.1	2,348.5	35,300
1992	2,365.4	2,348.6	34,200	1993	2,371.5	2,362.6	75,200
1994	2,368.2	2,354.0	41,600	1995	2,368.3	2,348.3	38,400
1996	2,368.3	2,349.8	44,100	1997	2,368.8	2,353.0	41,900
1998	2,368.3	2,351.2	35,600	1999	2,368.2	2,352.0	40,600
2000	2,367.6	2,352.0	35,900	2001	2,367.1	2,352.6	37,700
2002	2,366.6	2,347.2	28,800	2003	2,365.3	2,348.1	30,400
2004	2,359.9	2,356.7	28,600	2005	2,366.6	2,350.7	30,900
2006	2,365.4	2,357.5	8,700				

46. ELEVATION - AREA - CAPACITY - DATA FOR **2006 CAPACITY** [13]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2006	**SURVEY**		2,320.1	0	0	2,322.0	28	15
2,324.0	135	182	2,326.0	196	512	2,328.0	255	961
2,330.0	307	1,520	2,332.0	363	2,191	2,334.0	420	2,976
2,335.0	444	3,408	2,336.0	475	3,867	2,338.0	530	4,874
2,340.0	594	5,994	2,342.0	643	7,235	2,343.0	680	7,897
2,344.0	713	8,593	2,346.0	782	10,083	2,348.0	875	11,739
2,350.0	955	13,571	2,352.0	1,029	15,554	2,354.0	1,100	17,684
2,356.0	1,190	19,975	2,358.0	1,274	22,441	2,360.0	1,359	25,075
2,362.0	1,453	27,893	2,364.0	1,643	30,989	2,366.0	1,832	34,463
2,366.1	1,840	34,647	2,370.0	2,140	42,407	2,375.0	2,518	54,052
2,380.0	2,896	67,587	2,385.0	3,369	83,250	2,386.2	3,483	87,361
2,390.0	3,842	101,277	2,395.0	4,397	121,875	2,400.0	4,952	145,247
2,405.0	5,419	171,175	2,408.9	5,783	193,020	2,409.0	5,793	193,599

47. REMARKS AND REFERENCES

[1] All elevations are in feet based on original project datum that is around 1 foot lower than NAVD88.

[2] Spillway crest elevation 2,386.2 of four 50-foot wide ungated openings located at left abutment. Structure consist of 13-foot center notch with crest elevation 2,366.1.

[3] Elevations from Reservoir Capacity Allocation table. Original surface areas and capacity values recomputed using ACAPprogram.

[4] Length at elevation 2,366.1.

[5] Total drainage area 880 mi^2 with 642 mi^2 considered contributing to surface runoff. Values from SOP (Standard Operation Procedures).

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

[7] Mean annual runoff of 46,300 acre-feet, item 24, August 1949 through May 2006. From Reclamation's Great Plains Region by calendar year.

[8] Surface area and capacity at elevation 2,366.1, spillway crest elevation. 1951 survey obtained data to prepare new area-capacity curves. Results don't conform to other surveys, leading to questionable results in upper reservoir elevations.

[9] Surface area and capacity at elevation 2,366.1. 1962 survey obtained data to prepare updated area-capacity curves and sediment computations. Range line method showed some consolidation of sediments in lower reservoir area and extensive reservoir bank erosion throughout the reservoir.

[10] Surface area and capacity at elevation 2,366.1. 1981 survey produced new area-capacity curves by range line method. No report of results.

[11] All 2006 capacities computed by Reclamation's ACAP computer program. 1-foot surface area data from elevation 2,321.0 through 2,362.0. Assumed no change since 1982 survey in upper elevations. Surface area results from 1982 survey used for elevation 2,366.0 and the 10-foot increments from elevation 2,370.0 through 2,400.0.

[12] Due to differences of detail between original and following resurveys, computing capacity loss by comparing differences is questionable. 1951 results not used due to questions on upper elevation data. All survey results recomputed using ACAP for comparison purposes. 1962 survey shows extensive loss due to sedimentation. 1962 also documented extensive shoreline erosion that contributes to the loss in the lower elevation zones of the reservoir. 2006 survey also documents extensive shoreline erosion.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE October 2006

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

1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Original	Original	1951	1951	1962	1962	1981	1981	2006	2006	Sediment	Percent	Percent
Elevation	Survey	Capacity	Survey	Survey	Survey	Survey	Survey	Survey	Survey	Survey	Orig-06	Sediment	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Total	Depth
2408.9	5780	199935	6205	197493	5749	194832	5784	194080	5784.0	193020	6915		100.0
2405.0	5418	178100	5608	174458	5462	172971	5419	172234	5419.0	171175	6925		96.4
2400.0	4955	152167	4823	148381	4981	146864	4952	146306	4952.0	145247	6920		91.8
2390.0	3850	108140	3908	104908	3847	102674	3842	102336	3842.0	101277	6863		82.5
2386.2	3486	94201	3457	90916	3451	88807	3483	88420	3483.0	87361	6840		79.0
2380.0	2893	74427	2915	71281	2854	69291	2896	68646	2896.0	67587	6840		73.2
2370.0	2173	49097	2054	46678	2113	44559	2140	43466	2140.0	42407	6690		63.9
2366.1	1918	41120	1768	39226	1842	36847	1840	35705	1840.0	34647	6473	100.0	60.3
2360.0	1519	30637	1459	29461	1445	26839	1371	25911	1358.9	25075	5562	85.9	54.7
2350.0	1047	17807	1046	16943	924	15101	911	14501	954.6	13571	4236	65.4	45.4
2340.0	684	9155	684	8388	605	7539	611	6891	594.5	5994	3161	48.8	36.1
2330.0	377	3852	380	3108	352	2781	352	2076	306.6	1520	2332	36.0	26.9
2320.1	174	1122	135	547	120	483	58	47	0.0	0	1122	17.3	17.7
2320.0	172	1105	132	533	118	471	55	41	0.0	0	1105	17.1	17.6
2318.5	150	863	104	356	96	311	0	0	0.0	0	863	13.3	16.2
2315.0	99	427	38	108	44	66	0	0	0.0	0	427	6.6	13.0
2312.0	55	196	18	24	0	0	0	0	0.0	0	196	3.0	10.2
2310.0	26	115	4	2	0	0	0	0	0.0	0	115	1.8	8.3
2309.0	23	90	0	0	0	0	0	0	0.0	0	90	1.4	7.4
2305.0	11	22	0	0	0	0	0	0	0.0	0	22	0.3	3.7
2301.0	0	0	0	0	0	0	0	0	0.0	0	0	0.0	0.0
1	Elevation of reservoir water surface.												
2	Original reservoir surface areas.												
3	Original reservoir capacity recomputed using ACAP.												
4	1951 measured reservoir surface area. (Questions on upper elevation surface areas)												
5	1951 reservoir capacity recomputed by ACAP.												
6	1962 measured reservoir surface areas.												
7	1962 reservoir capacity recomputed by ACAP.												
8	1981 measured reservoir surface areas.												
9	1981 reservoir capacity.												
10	2006 reservoir surface areas. (Elevation 2366.1 and above from 1981 survey results).												
11	2006 reservoir capacity computed using ACAP.												
12	2006 computed sediment volume, column (3) - column (11).												
13	Measured sediment in percentage my elevation from original to 2006. Total sediment volume of 6,473 acre-feet.												
14	Depth of reservoir expressed in percentage of total depth (107.9), from maximum water surface.												

Table 2 - Summary of 2006 survey results.

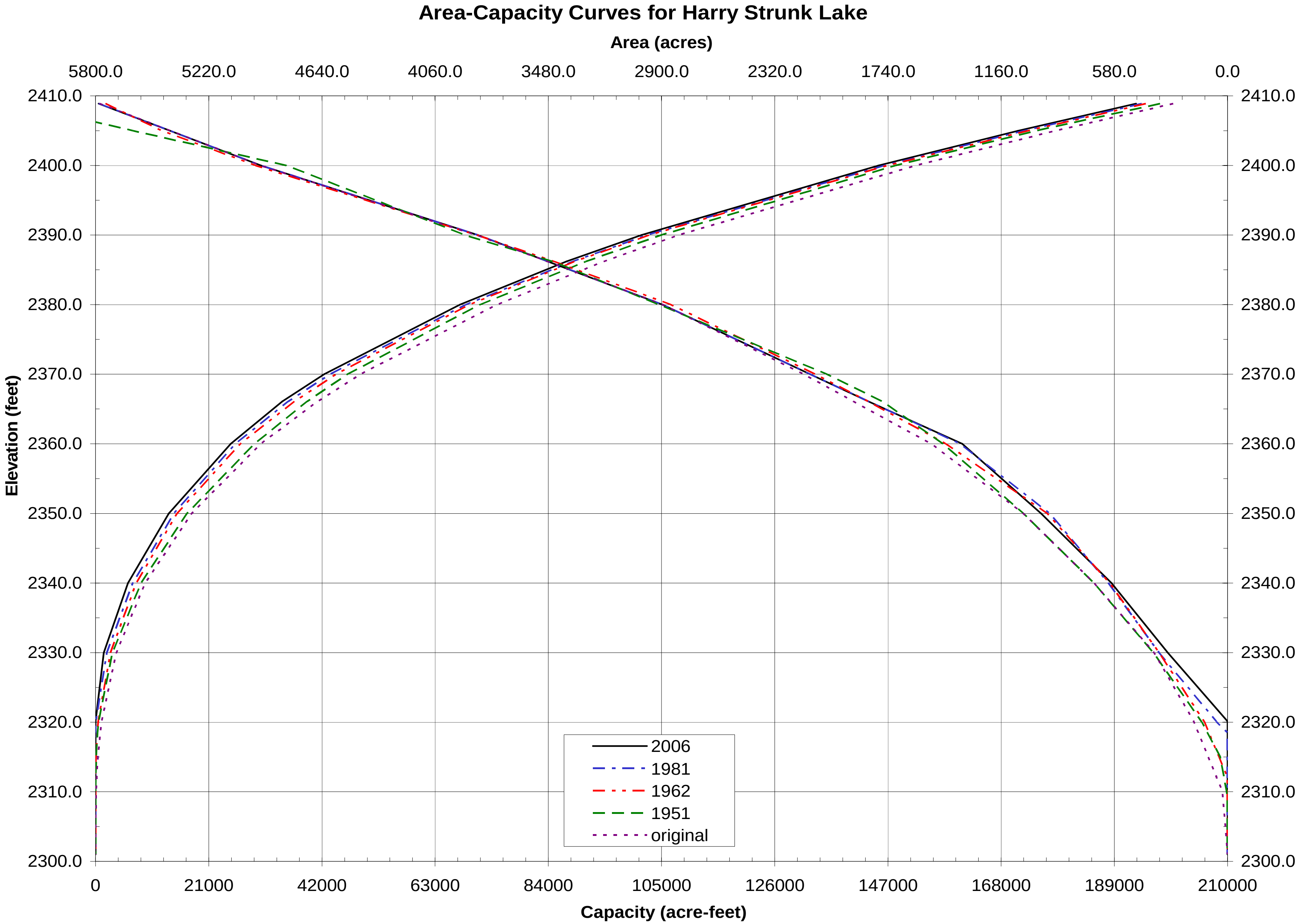

Figure 8 - Harry Strunk Lake area and capacity plots.

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