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Belle Fourche Reservoir 2006 Sedimentation Survey

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

April 2007

Belle Fourche Reservoir
2006 Sedimentation Survey

prepared by

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April 2007

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Reclamation Report

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14. ABSTRACT

Reclamation surveyed Belle Fourche Reservoir in 2006 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The underwater survey, conducted near water surface elevation 2,966 (feet), used sonic depth recording equipment interfaced with 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 contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. RTK GPS above water data was collected along the reservoir shoreline while it was drawn down in fall of 2006. The RTK GPS data was used to develop contours where boat access was not possible and to adjust the digitized USGS quad map contours due to extensive shoreline erosion. This study assumed no change, since the 1949 survey, from elevation 2,975.0 and above. Accurate mapping of the 2,975 contour and above would require aerial data collection.

As of June 2006, at elevation 2,975.0, the surface area was 8,040 acres with a total capacity of 172,873 acre-feet. Since dam closure in April 1910, 36,364 acre-feet of change has occurred below elevation 2,975.0, resulting in 17.4 percent loss in reservoir volume. A large portion of this loss is due to extensive shoreline erosion that has occurred throughout the reservoir.

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Belle Fourche Reservoir
2006 Sedimentation Survey

Introduction

Belle Fourche Dam and Reservoir are principal features of the Belle Fourche Unit located in western South Dakota. Additional project features are Belle Fourche diversion dam, inlet canal, and system of canals and laterals that irrigate acres near Newell, Vale, and Nisland, South Dakota. The reservoir stores water from Owl Creek and diverted flows from the Belle Fourche River. The project was a single purpose development for irrigation, but provides flood control, fish and wildlife conservation, and recreation benefits. Belle Fourche Dam and Reservoir in Butte County near Owl Creek is an offstream reservoir, located on the northern edge of the Black Hills, nine miles east of Belle Fourche, South Dakota (figure 1).

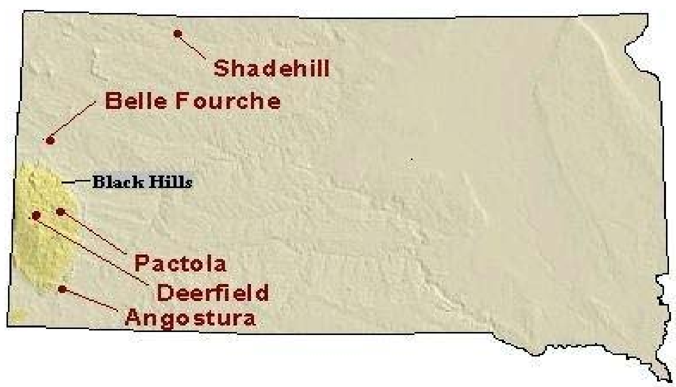

Figure 1 - Reclamation reservoirs located in South Dakota.

Belle Fourche Dam is an earthfill structure that was completed in June of 1911, with first irrigation water delivery in 1908. The dam's dimensions are as follows:

Hydraulic height[1]	97 feet	Structural height	122	feet
Crest length	6,262 feet	Crest elevation	2,990.0	feet[2]

[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 is near the National Geodetic Vertical Datum of 1929 (NGVD29) and around 1.6 feet lower than the North American Vertical Datum of 1988 (NAVD88).

The spillway, reconstructed in 1979 to replace the original spillway on the left abutment, is located in a saddle on the reservoir rim around 1.5 miles south of the right abutment. The spillway, crest elevation 2,977.25, is a 70-foot-wide grass-lined trapezoidal channel with an uncontrolled reinforced-concrete ogee cross section and three 66-inch-diameter culverts for passing spillway discharges beneath the South Canal. The discharge capacity is 4,500 cubic feet per second (cfs) at maximum reservoir elevation 2,984.4.

The outlet works consists of two gated conduits for releasing water to two irrigation canals. The North Canal outlet works is located on the left abutment with a release capacity of 600 cfs and the South Canal outlet works is located on the right abutment with a release capacity of 410 cfs. A 1992 survey conducted during low reservoir elevations measured the North Canal inlet at elevation 2,935.5 and the South Canal inlet at elevation 2,934.7, figure 2.

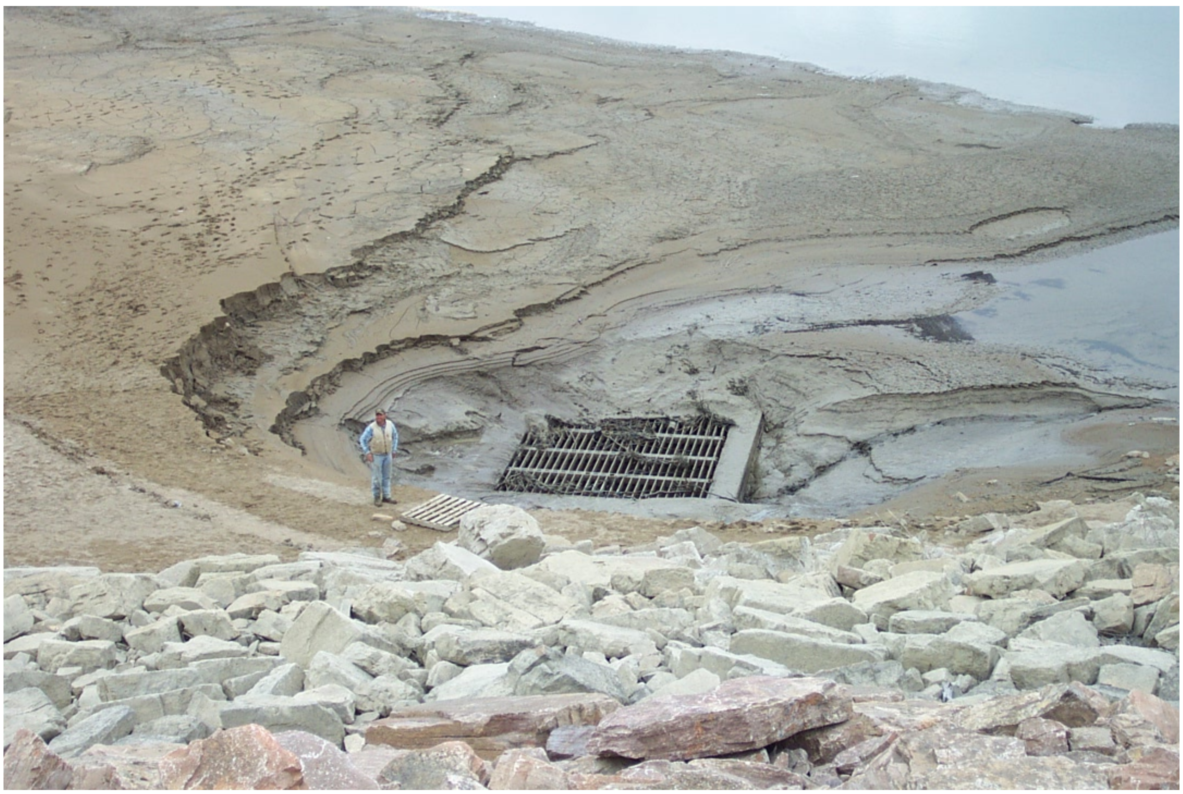

Figure 2 - South Canal intake during low reservoir conditions, exposing sediment deposition.

The drainage area above Belle Fourche Dam is approximately 170 square miles on Owl Creek and 4,310 square miles above the Belle Fourche Diversion Dam. The reservoir is considered two sections with the south section, Inlet Canal Arm, fed from diverted Belle Fourche River flows and the north section being the Owl Creek Arm. The total length of the reservoir is around 11 miles from the southwest inlet of the Belle Fourche River diversions to the upper end of Owl

Creek in the northwest end of the reservoir at elevation 2,770 with an average reservoir width of 1.1 miles.

Summary and Conclusions

This Reclamation report presents the 2006 results of the survey of Belle Fourche Reservoir. The primary objectives of the survey were to gather data needed to:

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

The on-line positioning user service (OPUS) and real-time kinematic (RTK) global positioning system (GPS) control survey were used 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 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 the NGS brass cap “Lake” that is located near the left abutment of the dam. The NGS point “Lake” had a second order horizontal position with an estimated elevation. During the bathymetric survey a temporary point for the base station was established nearer the boat ramp area. This point was established by RTK GPS and verified by OPUS processing. The horizontal control for this study was in feet, South Dakota state plane coordinates, in the North American Datum of 1983 (NAD83). The vertical control was in feet, 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 is near the National Geodetic Vertical Datum of 1929 (NGVD29) and around 1.6 feet lower than NAVD88.

The June 2006 underwater survey was conducted near reservoir elevation 2,966.0, measured by the Reclamation gage at the dam. The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along grid lines covering Belle Fourche Reservoir. The positioning system also provided information to allow the boat operator to maintain a course along these grid lines. The water surface elevations recorded by Reclamation’s reservoir gage during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations. The initial above-water topography was determined by digitizing existing contour lines from the USGS quads of the reservoir area. During the bathymetric survey, the boat location at times plotted outside of these contours, indicating that extensive shoreline erosion has occurred throughout this reservoir. The previous survey in 1949 documented extensive shoreline erosion around the reservoir (Bureau of Reclamation, 1950). In the fall of 2006, the Dakotas Area Office conducted a RTK GPS land survey around the shoreline of the reservoir. The 1949 study estimated the shore line as being 44.45 miles at elevation 2,975.0. The purpose of the above water survey was to document the extensive shoreline erosion by collecting data along the toe and top bank of the reservoir. This data was used to adjust the digitized USGS quad contours to account for the measured changes.

The Belle Fourche Reservoir topographic map is a combination of the adjusted digitized contours and the 2006 above and 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 Belle Fourche Reservoir and watershed characteristics for the 2006 survey. The 2006 survey determined that the reservoir has a total storage capacity of 259,012 acre-feet and a surface area of 9,871 acres at surcharge pool elevation 2,984.4. Since closure in May 1910, the reservoir has an estimated volume change of 36,364 acre-feet below top of conservation reservoir elevation 2,975.0. This volume represents a 17.4 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 Dakota Area Office that was used throughout the survey. Initially, the RTK GPS base station was set over marker “Lake” that is located along the left abutment of dam. The coordinates for this point were determined by processing collected raw data through the NGS service OPUS. The bathymetric survey used the “Lake” base station the first few days of collection, then used it to establish a temporary point near the boat ramp used by the survey vessel. The temporary point was submitted to the OPUS web site for computation and verification of the RTK GPS measurements. The horizontal control was in South Dakota north zone 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 near NGVD29 and around 1.6 feet lower than NAVD88. The following “Lake” coordinates (in feet) were used for this survey:

<u>“LAKE”</u>

North	355,815.466
East	1,013,674.652
Elevation	3,042.392

Reservoir Operations

Belle Fourche Reservoir is part of the Belle Fourche Project that provides storage for irrigation, flood control, fish and wildlife conservation, and recreation. The June 2006 capacity table lists 259,012 acre-feet of total storage below the maximum water surface elevation 2,984.4, table 1. The 2006 survey measured a minimum lake bottom elevation of 2,914.0. The following values are from the June 2006 capacity table:

- 86,139 acre-feet of surcharge between elevation 2,975.0 and 2,984.4.
- 169,790 acre-foot of conservation between elevation 2,927.0 and 2,975.0.
- 3,083 acre-foot of dead storage below 2,927.0.

Belle Fourche Reservoir computed annual inflow and reservoir stage records are listed by water year on table 1 for available period 1952 through 2006. The inflow values were computed by the Great Plains Regional Office and show annual fluctuation with a computed average inflow of 141,109 acre-feet per year. The maximum reservoir elevation was 2,975.6, recorded during water year 1996, and minimum recorded elevation was 2,927.0 during water year 1961.

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

Belle Fourche Reservoir bathymetric survey was conducted in June of 2006 between water surface elevation 2,966.0 and 2,966.3 (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 perpendicular to the upstream-downstream inflow alignment of the reservoir at around 200-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 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 which 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 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 listed in the reference, (Corps of Engineers, January 2002) and (Ferrari, R.L., 2006).

In the fall of 2006, after the reservoir had dropped significantly in elevation, a RTK GPS land survey was conducted by Dakota Area Office personnel. This survey was conducted around the shoreline of the reservoir on foot and with the GPS units mounted on all terrain vehicles. The data was tied to the same control network as the bathymetric collection with the elevations tied to NAVD88. During post processing, the elevations were shifted to match the Reclamation vertical datum.

Reservoir Area and Capacity

Topography Development

The topography of Belle Fourche Reservoir was developed from the 2006 above and below water survey data and the digitized contours from the USGS quad maps. The USGS quad contours at elevations 2,970 and 2,976 were developed from aerial photography dated 1940's and 1960's respectively. The 2006 survey data was used to make major adjustments to the digitized 2,970 contour due to the sediment delta that formed on upper reservoir on Owl Creek and the Inlet Canal, with the biggest adjustments along the reservoir shoreline due to the extensive bank erosion that has occurred throughout this reservoir. The best means to truly develop these contours and the rest of the above water reservoir area would be by a detailed aerial survey with the reservoir drawn down, but limited budget usually prevents such collection.

The original digitized 2,970 contour was used during the underwater survey for setting up the collection gridlines guiding the survey vessel to assure complete reservoir coverage. During the 2006 underwater collection, there were times the vessel was outside this contour indicating it was on high ground when in actuality the bank had eroded extensively increasing the surface area of the reservoir in those areas. The 2006 RTK GPS land survey provided adequate detail to allow adjustment of the 2,970 contour, resulting in a surface area of 7,153.9 acres.

The adjusted contour, elevation 2,970, was used to perform a hardclip around the 2006 data of Belle Fourche Reservoir. The hardclip was used during the triangular irregular network (TIN) development to prevent interpolation outside the enclosed polygon. The 2,970 contour was selected for the hardclip boundary since it was the closest data available to represent the water surface during the 2006 survey. Also, there was adequate RTK GPS ground collection data at elevation 2,970.0 to allow adjustments to be made to the USGS quad contour with confidence and accuracy. Using ARCEDIT, the 2006 above and below water data along with the digitized contours were plotted. The plot showed that the underwater data did not lie completely within these digitized USGS quad map contours due to reservoir bank erosion. The 2,970 contour was modified to include the entire underwater data set within the enclosed polygon and the RTK GPS ground elevation data was used to further determine the present location of the 2,970 contour. Using select and move commands within ARCEDIT, the vertices of the initial clip were shifted to develop the final clip that was assigned an elevation of 2,970.0.

Contours for the reservoir below elevation 2,970.0 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 Belle Fourche Reservoir TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the survey data for elevations 2,914.0 through 2,970.0. Since no complete reservoir aerial data was collected, this study assumed no change in reservoir surface area, since the 1949 survey, for elevation 2,975.0 and above. The reservoir contour topography at 2-foot intervals is presented in figure 4.

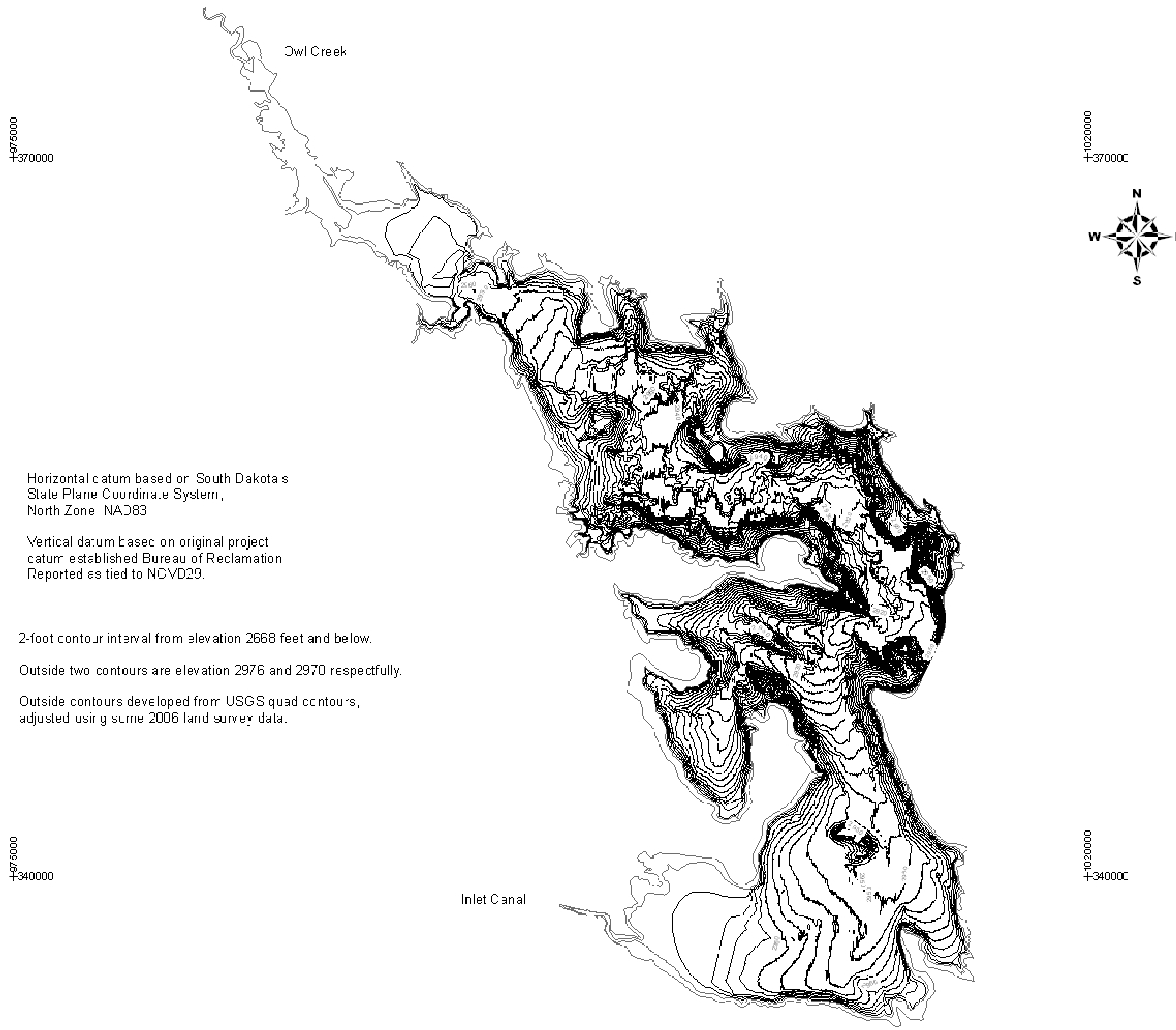

Figure 4 - Belle Fourche Reservoir topographic map.

Shoreline Erosion

The 2006 underwater survey witnessed and measured the extensive erosion along the shoreline of Belle Fourche Reservoir. 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 contours were developed from aerial photography flown in the 1940's and 1960's and at times, the position of the boat was tens-of-feet outside the 2,970 contour boundaries. Even with the extensive shore erosion that has occurred since dam closure in 1910, the survey vessel was able to maneuver close to some vertical banks where previous shore material had collapsed into the reservoir. It appears that over time the collapsed material washed further into the reservoir through wave action, similar to ocean waves smoothing the beaches. This is possible because the material dissipated in the water and consists of little to no gravel or large cobble. The extensive shoreline erosion was documented by the 1949 survey of Belle Fourche Reservoir. At reservoir elevation 2,975.0, the 1949 study measured 44.45 miles of shoreline and estimated that of the 16,880 acre-feet of capacity loss due to sedimentation, 4,320 acre-feet was due to shoreline eroded material settling within the reservoir (Bureau of Reclamation, 1950). Following are pictures showing the shoreline erosion along Belle Fourche taken in March of 2007, figures 5 and 6.

Figure 5 – Extensive eroded shoreline looking towards Belle Fourche Dam.

Figure 6 - Eroded shoreline of Belle Fourche Reservoir, South Dakota.

The above photographs show the extent of the shoreline erosion that has occurred throughout Belle Fourche Reservoir. If the erosion were just below the normal reservoir high water elevation of 2,975.0, the total volume of the reservoir would not be greatly affected from elevation 2,975.0 and below. 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. For Belle Fourche Reservoir, it appears that a large amount of the bank erosion has occurred above the normal or conservation reservoir elevation 2,975.0. This indicates that a portion of the loss of the original total reservoir volume is due to material from the extensive reservoir shoreline erosion along with inflowing river sediments. The only means to accurately measure the extent of the shoreline erosion would be by an extensive above water survey.

Development of the 2006 Belle Fourche Reservoir Surface Areas

The 2006 surface areas for Belle Fourche Reservoir were computed at 1-foot increments, from elevation 2,914.0 through 2,970.0, directly from the TIN that covered the Belle Fourche Reservoir within the hard clip area only. This TIN was developed from the 2006 collected data within the hardclip polygon that was developed from the adjusted digitized contour 2,970 as described previously. 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 2- and 5-foot increments from elevation 2,914.0 through 2,366.0 were used to compute the new area and capacity tables. For elevation 2,970.0, the surface area of the ARCGIS developed contour 2,970 minus the reservoir islands was used. There were insufficient 2006 surveyed data points, for accurate computer development of surface areas for elevations above 2,970.0. Straight line interpolation was used to compute the surface areas between elevations 2,966.0 and 2,970.0. This study assumed no change in surface area, since the 1949 survey, at elevation 2,975.0. During the 2006 study analysis a 1990 area and capacity table was located that extended the previous developed tables above elevation 2,975.0. The table appeared to have been developed as part of flood study, but no detail was provided on how the surface areas above elevation 2,975.0 were computed. The results appeared to be reasonable, and for the purpose of preserving this information it was included in 2006 area and capacity development.

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 Belle Fourche 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. 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 Belle Fourche Reservoir 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, 1949, and 2006 area-capacity relationships are listed on table 2 and the curves are plotted on figure 7. As of June 2006, at conservation use elevation 2,975.0, the surface area was 8,040 acres with a total capacity of 172,873 acre-feet.

2006 Reservoir Sediment Analyses

Results of the 2006 Belle Fourche Reservoir area and capacity computations are listed in table 1 and columns 8 and 9 of table 2. Columns 2 and 3 of table 2 list the original area and capacity values. The results from the 1949 survey are listed on column 4 and 5. Column 10 lists the capacity differences between the original and 2006 survey results due to sediment inflow and bank erosion. Figure 7 is a plot of the Belle Fourche Reservoir surface area and capacity values for all surveys and illustrates the differences. The comparisons show that the total reservoir capacity in 2006 is 36,364 acre-feet less than the original volume at conservation reservoir elevation 2,975.0. It must be noted that the 2006 area and capacity tables were generated assuming no surface area change, since the 1949 survey at elevation 2,975.0. This is probably not the case, but it is assumed any loss due to sediment deposition above this elevation would not be significant and the shoreline erosion is not as great as was documented by the 1949 survey since the reservoir has not operated much above elevation 2,975.0 since that time. The only means to measure this would be by an extensive above water survey using aerial collection techniques. The 2006 RTK GPS land survey data was plotted with the 2,970 and 2,976 USGS quad contours. There were sufficient points to adjust the 2,970 contour with confidence, but not enough data to adjust the 2,976 quad contours. It would require an extensive amount of topography data to accurately adjust the 2,976 USGS contour. Aerial collection would likely be the most efficient method to collect sufficient topography data above elevation 2,970.

The estimated 100 years of sediment accumulation for Belle Fourche Reservoir was 22.5 percent or around 47,000 acre-feet at conservation pool elevation 2,975.0. This computes to an annual loss of 470 acre-feet. Table 1 shows the 1949 survey measured an average annual loss of 418.0 acre-feet. The 2006 survey measured a slightly less average annual loss of 350.0 acre-feet for the operation period of 1949 through 2006. Since closure the average annual loss was computed to be 378.0 acre-feet by the 2006 study analysis. The reason for this slight drop in average annual loss could be reduction in the shoreline erosion rate since it is assumed that the majority of the shoreline eroded during the initial filling and high reservoir stages. Differences in survey methods between the original, 1949 and 2006 surveys also is a contributing factor. As seen in the figure 2 photo at the South Canal intake, sediment is an issue throughout the reservoir and not just along the shoreline or the upper deltas of Owl Creek and the Inlet Canal.

RESERVOIR SEDIMENT
DATA SUMMARY

Belle Fourche Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER Bureau of Reclamation	2. STREAM Owl Creek [1]	3. STATE South Dakota
A	4. SEC 18 TWP. 9N RANGE 4 E	5. NEAREST P.O. Belle Fourche	6. COUNTY Butte
M	7. LAT 44 ° 44 ' 12 " LONG 103 ° 40 ' 27 "	8. TOP OF DAM ELEVATION 2990.0 [2]	9. SPILLWAY CREST EL 2977.25 [3]

	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC-FT	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN
R	a. SURCHARGE	2,984.4 [4]	9,871	87,050	296,287	
E	b. FLOOD CONTROL					4/1910
S	c. POWER					
E	d. JOINT USE					16 DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION	2,975.0	8,010	197,843	209,237	
V	f. INACTIVE					
O	g. DEAD	2,927.0	1,077	11,394	11,394	4/1910
I R	17. LENGTH OF RESERVOIR 11 [5] MILES		AVG. WIDTH OF RESERVOIR 1.1 MILES			

B	18. TOTAL DRAINAGE AREA 170 [6] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 15.5 [7] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA 170+ [6] SQUARE MILES	23. MEAN ANNUAL RUNOFF [8] INCHES
S	20. LENGTH MILES AVG. WIDTH MILES	24. MEAN ANNUAL INFLOW 114,109 [8] ACRE-FEET
I N	21. MAX. ELEVATION MIN. ELEVATION	25. ANNUAL TEMP, MEAN 45 °F RANGE -38 °F to 110 °F [7]

	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
S U R V E Y	4/1910 [9]			Contour (D)	5 - ft	8,010	209,237	1.83
	10/1949 [10]	39.6	39.6	Range (D)	45	8,040 [10]	192,685	1.69
	6/2006 [11]	56.6	96.2	Contour (D)	2-ft	8,040 [11]	172,873	1.51

	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
D A T A	10/1949		[12]				
	6/06		114,109 [12]	189,100	6,350,305	114,109	6,350,305

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.
10/1949	16,552 [13]	418.0	[13]	16,552	418.0	[13]
6/2006	19,812 [13]	350.0	[13]	36,364	378.0	[13]

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.
10/1949				0.20	7.9		
6/2006				0.18	17.4		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION									
		2,897-2,910	2,910-2,920	2,920-2,930	2,930-2,940	2,940-2,950	2,950-2,960	2,960-2,970	2,970-2,975	
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION									
6/06		3.9	10.0	13.8	17.6	25.0	19.2	10.5	0.0	

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 (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION [12]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1952	2,969.5	2,941.3	120,980	1953	2,977.1	2,943.0	153,510
1954	2,970.2	2,946.3	84,720	1955	2,965.4	2,947.9	133,770
1956	2,965.7	2,929.3	91,250	1957	2,963.0	2,932.8	112,540
1958	2,963.5	2,934.3	100,140	1959	2,958.0	2,927.8	86,614
1960	2,957.8	2,929.3	91,604	1961	2,950.3	2,927.0	45,687
1962	2,972.5	2,932.2	183,318	1963	2,975.0	2,963.4	108,475
1964	2,975.0	2,960.9	104,422	1965	2,975.0	2,963.1	122,872
1966	2,971.2	2,952.3	55,480	1967	2,973.6	2,954.2	161,440
1968	2,971.1	2,956.0	111,910	1969	2,972.5	2,951.7	119,050
1970	2,972.2	2,952.5	131,400	1971	2,972.5	2,954.1	135,638
1972	2,972.6	2,960.9	151,282	1973	2,972.4	2,958.5	104,900
1974	2,972.6	2,949.1	106,415	1975	2,973.3	2,951.8	145,355
1976	2,969.9	2,935.3	129,330	1977	2,966.6	2,942.2	149,500
1978	2,975.2	2,952.7	189,100	1979	2,974.9	2,952.4	115,100
1980	2,964.2	2,943.8	93,300	1981	2,963.1	2,948.3	119,700
1982	2,974.8	2,951.2	155,500	1983	2,975.0	2,956.9	95,100
1984	2,975.5	2,956.9	152,500	1985	2,973.8	2,938.2	104,500
1986	2,973.6	2,952.5	182,800	1987	2,975.2	2,963.5	133,200
1988	2,973.9	2,942.0	75,773	1989	2,966.8	2,936.0	106,555
1990	2,965.4	2,939.4	101,564	1991	2,964.7	2,941.0	90,601
1992	2,959.4	2,934.7	63,646	1993	2,970.7	2,936.5	150,854
1994	2,975.1	2,958.0	84,372	1995	2,975.3	2,958.4	143,847
1996	2,975.6	2,963.9	124,236	1997	2,974.8	2,964.2	104,622
1998	2,974.8	2,965.8	123,728	1999	2,975.0	2,967.2	105,881
2000	2,975.0	2,959.6	73,169	2001	2,974.7	2,959.7	135,476
2002	2,972.8	2,951.0	99,709	2003	2,969.8	2,951.4	111,844
2004	2,965.9	2,943.0	85,704	2005	2,963.4	2,937.2	76,917
2006	2,966.4	2,937.8	109,405				

46. ELEVATION - AREA - CAPACITY - DATA FOR **2006 CAPACITY** [13]								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2006	**SURVEY**		2,914.0	0	0	2,916.0	37	37
2,918.0	127	200	2,920.0	213	540	2,922.0	302	1,054
2,924.0	382	1,738	2,925.0	426	2,142	2,926.0	471	2,590
2,928.0	561	3,621	2,930.0	684	4,866	2,932.0	824	6,374
2,934.0	964	8,162	2,935.0	1,035	9,161	2,936.0	1,116	10,236
2,938.0	1,288	12,641	2,940.0	1,478	15,407	2,942.0	1,644	18,529
2,944.0	1,848	22,021	2,945.0	1,956	23,923	2,946.0	2,078	25,940
2,948.0	2,380	30,398	2,950.0	2,754	35,531	2,952.0	3,237	41,522
2,954.0	3,738	48,496	2,955.0	3,982	52,355	2,956.0	4,216	56,455
2,958.0	4,647	65,318	2,960.0	5,045	75,010	2,962.0	5,388	85,442
2,964.0	5,718	96,548	2,965.0	5,920	102,366	2,966.0	6,102	108,377
2,968.0	6,628	121,107	2,970.0	7,154	134,888	2,972.0	7,508	149,551
2,974.0	7,863	164,922	2,975.0	8,040	172,873	2,976.0	8,319	181,053
2,978.0	8,877	198,249	2,980.0	9,435	216,561	2,982.0	9,629	235,624
2,984.0	9,822	255,075	2,984.4	9,871	259,012	2,985.0	9,919	264,946

47. REMARKS AND REFERENCES

[1] Reservoir is located on Owl Creek. Considered offstream structure. Significant inflows from Belle Fourche River diversions.

[2] All elevations are in feet based on original project datum that is near NGVD29.

[3] Spillway crest elevation 2,977.25. 70-foot-wide grass-lined trapezoidal channel with uncontrolled reinforced-concrete ogee crest section and three 66-inch-diameter culverts (450 cfs capacity) for passing spillway discharges beneath South Canal.

[4] Elevations from Reservoir Capacity Allocation table. Original surface areas and capacity values recomputed using ACAP program.

[5] Length at elevation 2,975. Consist of two length. One from south diversion inlet and one from Owl Creek to dam.

[6] Total drainage area 170 mi^2 from Owl Creek. Diversions from Belle Fourche River with drainage 4,310 mi^2. Values from SOP.

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

[8] Mean annual runoff of 114,109 acre-feet from available records, water years 1952 through 2006. Computations Great Plains Region.

[9] Surface area and capacity at elevation 2,975.0, conservation elevation. 1903-04 surveys, 5-foot contours developed. Original table recomputed to elevation 2990 using surface area information from a 1990 table and ACAP program. Source for surface areas unknown.

[10] Surface area and capacity at elevation 2,975.0. 1949 range line method showed extensive reservoir bank erosion throughout the reservoir. 1949 table recomputed to elevation 2990 using surface area information from 1990 table and ACAP program.

[11] All 2006 capacities computed by Reclamation's ACAP computer program. 2-foot surface area data from elevation 2,975 below. Assumed no change since 1990 developed table from elevation 2980 and above.

[12] Mean annual runoff 114,109 acre-feet from available records, water years 1952-2006. Significant inflows from Belle Fourche River diversions.

[13] Significant sediment computations with large portion due to diversions and extensive shoreline erosion.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE March 2007

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

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Elevation	1903	1903	1949	1949	Sediment	1949	2006	2006	Sediment	Percent	Sediment	Percent	Percent
	Surface	Capacity	Surface	Capacity	Volume	Percent	Surface	Capacity	Volume	Computed	Volume	Computed	Reservoir
	Area		Area		1903-1949	Computed	Area		1903-2006	Sediment	1949-2006	Sediment	
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Ac-Ft	1949-2006	Depth
2,975	8,010	209,237	8,040	192,685	16,552	100.0	8,040.0	172,873	36,364	100.0	19,812	100.0	100.0
2,970	7,181	171,260	7,260	154,435	16,825	101.6	7,153.9	134,888	36,372	100.0	19,547	98.7	93.6
2,965	6,395	137,320	6,244	120,675	16,645	100.6	5,919.5	102,366	34,954	96.1	18,309	92.4	87.2
2,960	5,513	107,550	5,279	91,868	15,682	94.7	5,045.0	75,010	32,540	89.5	16,858	85.1	80.8
2,955	4,648	82,147	4,366	67,755	14,392	87.0	3,982.2	52,355	29,792	81.9	15,400	77.7	74.4
2,950	3,767	61,110	3,342	48,485	12,625	76.3	2,753.6	35,531	25,579	70.3	12,954	65.4	67.9
2,945	2,886	44,477	2,360	34,230	10,247	61.9	1,956.1	23,923	20,554	56.5	10,307	52.0	61.5
2,940	2,157	31,870	1,851	23,703	8,167	49.3	1,478.0	15,407	16,463	45.3	8,296	41.9	55.1
2,935	1,656	22,337	1,373	15,643	6,694	40.4	1,034.7	9,161	13,176	36.2	6,482	32.7	48.7
2,930	1,297	14,955	974	9,775	5,180	31.3	684.1	4,866	10,089	27.7	4,909	24.8	42.3
2,925	930	9,387	664	5,680	3,707	22.4	425.9	2,142	7,245	19.9	3,538	17.9	35.9
2,920	591	5,585	458	2,875	2,710	16.4	212.6	540	5,045	13.9	2,335	11.8	29.5
2,915	390	3,132	236	1,140	1,992	12.0	18.0	9	3,123	8.6	1,131	5.7	23.1
2,910	302	1,402	110	275	1,127	6.8	0.0	0	1,402	3.9	275	1.4	16.7
2,905	127	330	0	0	330	2.0	0.0	0	330	0.9	0	0.0	10.3
2,900	3	5	0	0	5	0.0	0.0	0	5	0.0	0	0.0	3.8
2,897	0	0	0	0	0	0.0	0.0	0	0	0.0	0	0.0	0.0

1 Elevation of reservoir water surface. All elevations tied to project datum.
2 1903 or original reservoir surface areas, acres. Surface areas from table 9 of 1949 survey report.
3 1903 or original reservoir capacity, acre-feet. Capacity recomputed using original surface areas and ACAP program.
4 1949 reservoir surface areas in acres. Surface areas from table 9 of 1949 survey report.
5 1949 reservoir capacity, acre-feet. Capacity recomputed using 1949 surface areas and ACAP program.
6 1949 computed sediment volume, column (3) - column (5).
7 1949 measured sediment in percentage of total sediment, 16,552 acre-feet, by elevation.
8 2006 measured reservoir surface area. Study assumed no change at elevation 2,975.
9 2006 reservoir capacity computed using ACAP program.
10 2006 measured sediment volume = column (3) - column (9).
11 2006 measured sediment in percentage of total sediment, 36,364 acre-feet, by elevation.
12 Measured sediment volume from 1948 to 2006, column (5) - column (9).
13 Measured sediment in percentage by elevation from 1948 to 2006. Total sediment volume of 19,812 acre-feet.
14 Depth of reservoir expressed in percentage of total depth (78.0), from maximum water surface.

Table 2 - Summary of 2006 survey results.

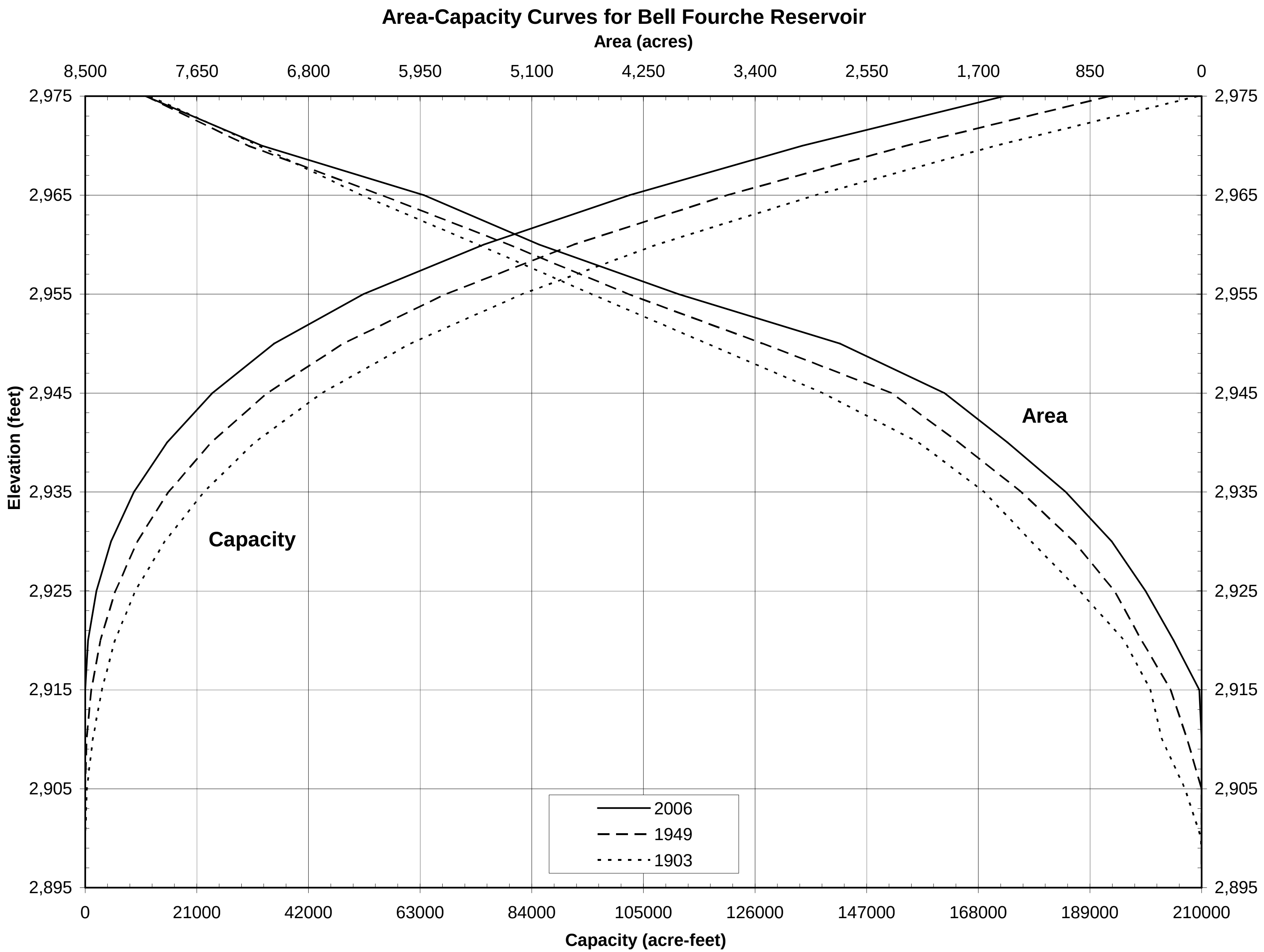

Figure 7 - Belle Fourche Reservoir area and capacity plots.

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