RECLAMATION
Managing Water in the West

Caballo Reservoir
2007 Sedimentation Survey

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

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Caballo Reservoir
2007 Sedimentation Survey

prepared by

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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 in the interest of the American public.

Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68240), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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14. ABSTRACT

The Bureau of Reclamation (Reclamation) surveyed Caballo Reservoir in September 2007 to compute a present storage-elevation relationship (area-capacity tables). The underwater survey was conducted at the project's reservoir elevation 4,135.0 feet. The project datum is 43.3 feet lower than National Geodetic Vertical Datum of 1929 (NGVD29) and 45.5 feet lower than North American Vertical Datum of 1988 (NAVD88). The underwater survey 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 standard land surveying methods, using RTK GPS to measure portions of the 32 sedimentation range lines surveyed.

As of September 2007, at reservoir water surface elevation 4,182.0 feet, the surface area was 11,532 acres with a total capacity of 324,934 acre-feet. Since the reservoir's 1938 initial filling, 21,802 acre-feet of sediment have accumulated in Caballo Reservoir. Since the 1999 reservoir survey, 1,738 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1938 is 312.8 acre-feet and since 1999 it is 206.9 acre-feet.

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Introduction

Dam and Reservoir

Caballo Dam and Reservoir are located on the Rio Grande, 25 miles downstream of Elephant Butte Dam and 17 miles south of the city of Truth or Consequences in Sierra County of south central New Mexico (figure 1). Caballo Reservoir is a multi-use reservoir with its main function being water storage for irrigation and flood control. Caballo Reservoir is one of the two storage facilities of the Rio Grande Project that provides water for irrigation, municipal, and industrial use. Storage lost in Elephant Butte Reservoir due to sediment deposition is partially recovered by Caballo Reservoir storage. Recreation activities provided by Caballo Reservoir include year-round camping, boating, and fishing.

Figure 1 - Bureau of Reclamation reservoirs in New Mexico.

Construction of Caballo Dam began in 1936 and was completed in 1938 with first storage beginning in January of 1938. The dam is an earthfill zoned structure whose dimensions are:

Hydraulic height[1]	78 feet	Structural height	96 feet
Crest length	4,558 feet	Crest elevation	4,190.0 feet[2]
Top width	35 feet	Top of parapet wall	4,193.0 feet

The spillway is a concrete-lined open channel in the left abutment controlled by dual 50-foot-wide by 22.5-foot-high radial gates with top of gate (including the 1.5 foot splash plate) at elevation 4,183.5. The spillway has a crest elevation of 4,161.0 and a maximum discharge capacity of 33,200 cubic feet per second (cfs) at reservoir elevation 4,182.0.

The outlet works, located in the left abutment, consist of an intake with trashracks, 13.5 foot diameter concrete-lined upstream tunnel, a gated chamber with four 6-foot-wide by 7.5-foot-high pressure slide gates, a 13.5 foot diameter concrete lined downstream tunnel that is horseshoe shaped, and a concrete stilling basin. The outlet works were designed to pass 5,000 cfs at reservoir elevation 4,182.0.

The total drainage area of the Rio Grande above Caballo Dam is 27,260 square miles of which 1,237 square miles contribute sediment. The majority of the sediment inflow is trapped behind Elephant Butte Dam, but several tributaries flow into Caballo Reservoir, contributing sediment. At elevation 4,182.0, the reservoir length is around 16.7 miles with an average width of 1.1 miles.

Summary and Conclusions

This Reclamation report presents the results of the 2007 survey of Caballo Reservoir. The primary objectives of the survey were to gather data needed to:

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

The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system capable of determining sounding

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[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 around 43.3 feet lower than NGVD29 and 45.5 feet lower than NAVD88.

locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along previously established sediment range 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 on the project's datum.

Standard land surveying techniques were used to measure the upper reservoir sediment range lines that could not be covered during the bathymetric survey. Land portions of range lines 10 through 31 were surveyed in September 2007. The land survey techniques were used to measure any noted changes on these range lines. The results from these surveys were used to develop the 2007 area and capacity tables and to compute the volume of sediment that has accumulated since the previous surveys.

Tables 1 and 2 contain the summary of the 2007 Caballo Reservoir survey results. The 2007 survey determined that the reservoir has a total storage capacity of 324,934 acre-feet and a surface area of 11,532 acres at reservoir elevation 4,182.0. The 2007 area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute the area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985). The volume of sediments that have accumulated in the reservoir since the original (1938) survey is 21,802 acre-feet representing a total loss in reservoir capacity of 6.3 percent. The average annual sediment accumulation rate for the 69.7 years of record is 312.8 acre-feet.

Control Survey Data Information

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 surveys. 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 relative to the national control network. Initially, the GPS base was set over a temporarily driven piece of rebar on the west bank overlooking the reservoir. The coordinates for this point were processed using OPUS, and from this base additional points were established and checked during the survey using OPUS. The OPUS generated coordinates were further verified by RTK GPS observation shots on the NGS datum point "C 366," located downstream of Caballo Dam.

The horizontal control was established in New Mexico state plane coordinates, central zone, on the North American Datum of 1983 (NAD83). The vertical control for the established points was on the National American Vertical Datum of 1988 (NAVD88). RTK GPS water surface measurements were periodically collected and a comparison of the reservoir water surface recorded by the Reclamation gage found they were around 45.5 feet higher. NGS published data in the study area shows the NAVD88 elevations are around 2.2 feet higher than NGVD29 elevations. These values compare well with the previous studies that noted a 43.3 feet difference between the NGVD29 datum and the Reclamation project datum.

Reservoir Operations

Caballo Reservoir is part of the Rio Grand Project that provides storage for irrigation, flood control, and recreation. The September 2007 capacity table lists 324,934 acre-feet of total storage below water surface elevation 4,182.0, table 1. The 2007 survey measured a minimum lake bottom elevation of 4,120.0. The reservoir was designed to provide a minimum of 100,000 acre feet of storage capacity for flood control purposes (Bureau of Reclamation, 2005). The capacity values from elevation 4,182.0 and below are from the 2007 results.

- 47,000 acre-feet of surcharge between elevation 4,182.0 and 4,186.0.
- 100,046 acre-feet of flood control between elevation 4,172.44 and 4,182.0.
- 224,888 acre-foot of conservation between elevation 4,104.0 and 4,172.44.
- 0 acre-foot of dead storage below 4,104.0.

Caballo Reservoir computed annual inflow and reservoir stage records are listed by water year on table 1 for the period of 1938 through 2007. The inflow values computed by the Upper Colorado Region show the annual fluctuation with a computed average inflow of 680,900 acre-feet through September of 2007. The maximum reservoir elevation was 4,182.1 recorded during water year 1942. Since the last survey in 1999, the maximum recorded reservoir elevation was 4,159.6 recorded during water year 2000 with the minimum recorded elevation 4,126.8 during water years 2001 and 2003.

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

The Caballo Reservoir bathymetric survey was conducted on September 22, 2007 at water surface elevation 4,135.0 (Reclamation project datum). The boat was used again on September 26 of 2007 to collect additional data between the sediment range lines that could be used for more detailed mapping of the reservoir. However, with the reservoir nearly twelve feet lower than the 1999 survey; this portion of the reservoir was relatively small compared to the overall reservoir and assumed insignificant to this sediment analysis. That data has been preserved for future analyses if needed. 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 the range lines. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining the course along these predetermined lines. A layout of the reservoir sedimentation range line system is shown on figures 3 and 4. During each range line traverse, the depth and position data were recorded on the notebook computer hard drive for subsequent processing. The water surface elevation at the dam, recorded by a Reclamation gage, was used to convert the sonic depth measurements to lake-bottom elevations. The elevations are all tied to Reclamation's project datum that is 43.3 feet lower than NGVD29 and 45.5 feet lower than NAVD88.

The 2007 underwater data was collected by a depth sounder that was calibrated by adjusting the speed of sound through the water column which can vary with density, salinity, temperature, turbidity, and other conditions. 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. Additional information on collection and analysis procedures are outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006).

The upper portion of the reservoir not covered by the 2007 large boat survey, sediment range lines 10 through 31, were also surveyed in September of 2007. Standard land surveying techniques were used to measure only the portions of these range lines that indicated possible change. Spot check measurements were conducted on other portions of the range lines to confirm there were no significant changes since the previous surveys. Access to portions of some of the range lines was hindered by soft bottom sediments, but these deposits were fairly flat and the sediment elevation was easily projected along the remainder of the range line alignment. The above water data was tied to the same control network as the bathymetric collection with the elevations in NAVD88. During post processing, the elevations were shifted to match the Reclamation vertical datum that is 45.5 feet lower than NAVD88.

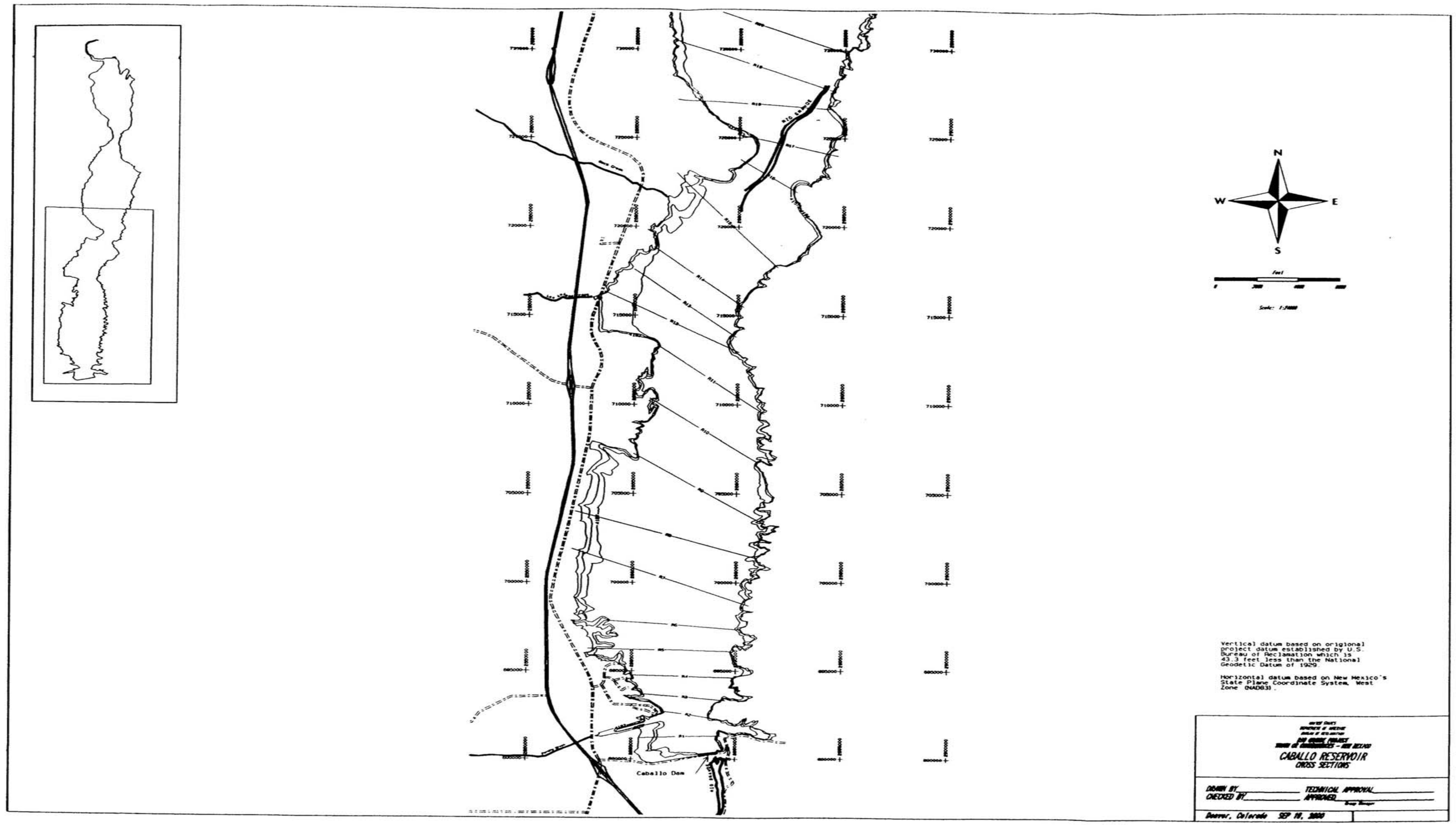

Figure 3 - Caballo Reservoir sedimentation range lines.

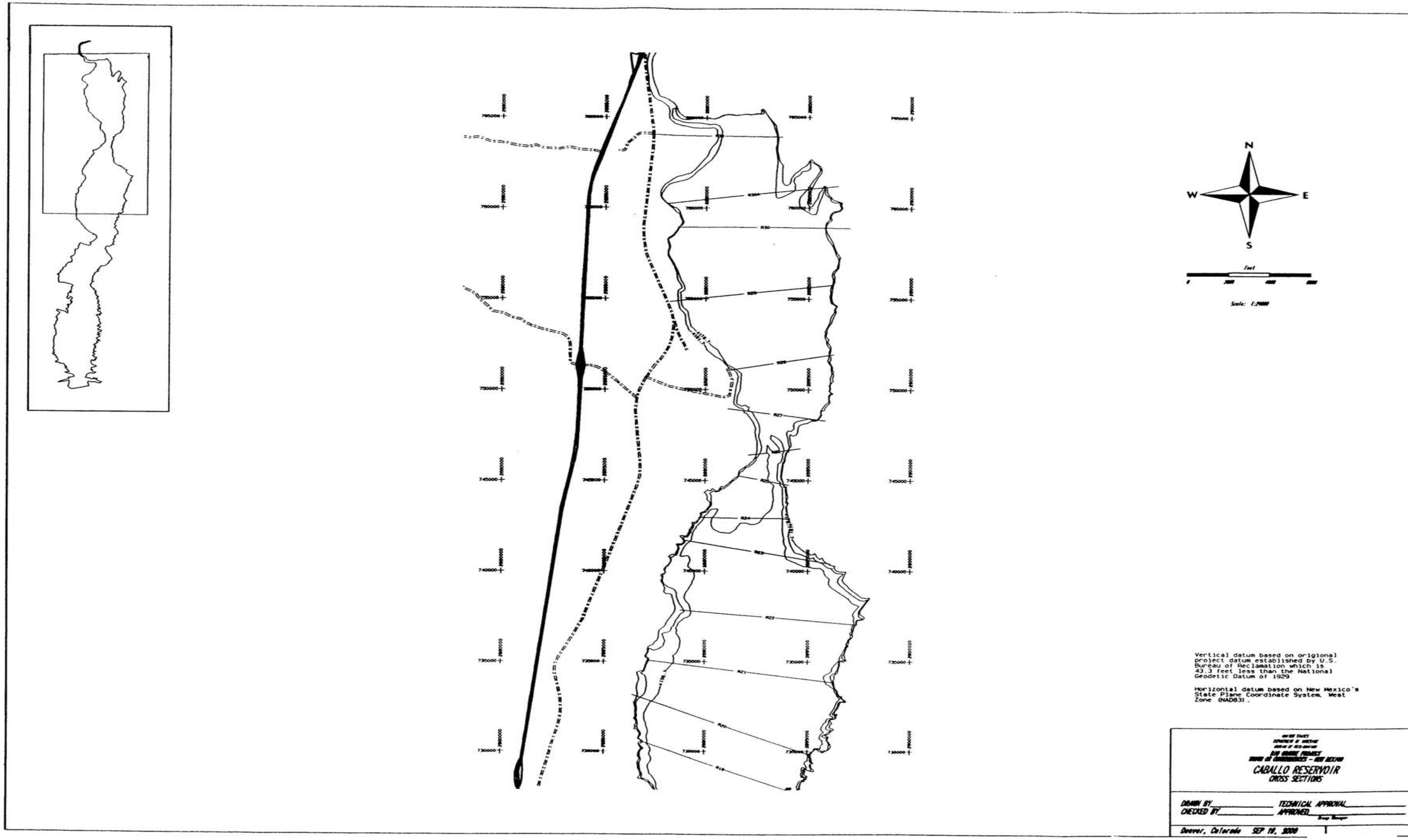

Figure 4 - Caballo Reservoir sedimentation range lines.

Reservoir Sediment Distribution

Lateral Distribution

Ground profiles of the 32 reservoir sedimentation ranges are plotted on figures 5 through 36 where the profiles illustrate the general lateral distribution of sediments in the reservoir. The plots illustrate the survey results from the 1938 (original), 1981, 1999, and 2007 surveys. During the 1981 survey, the above-water portions of each range line from each end point to the water edge were measured. For the main portion of the reservoir, range lines 1 through 10, the results from the 1981 and 1999 surveys were used to develop the range line plots for the areas not covered by the 2007 underwater survey. The 1981 and 1999 data were also used to complete the plots of the remaining range lines (11 through 31) in areas that the 2007 field crew and collected data determined there was no significant change and for portions that were not accessible.

Longitudinal Distribution

To illustrate the sediment distribution throughout the reservoir a longitudinal profile was plotted for the 1938, 1981, 1999, and 2007 reservoir conditions (figure 37). The differences between the profiles represent the sediment encroachment into the reservoir since the dam closed in 1938. The average bottom elevations for each range line were used to plot these longitudinal profiles. As with the lateral plots, the longitudinal plots illustrate minimal change since the 1999 survey. The plots show sediment deposits below range line 23 with the greatest depths of longitudinal sediment deposits occurring downstream of range line 17 for all the surveys. This pattern of sediment deposition is due to reservoir operation as the water surface is usually drawn down below elevation 4,140. Over time it is expected the pivot point near elevation 4,142 will begin to move further downstream, but the 1999 to 2007 survey results measured only minimal movement. Even though Elephant Butte Reservoir traps the majority of the sediment originating upstream, there are several tributaries into Caballo Reservoir contributing sediment during high flow events that deposits within the reservoir.

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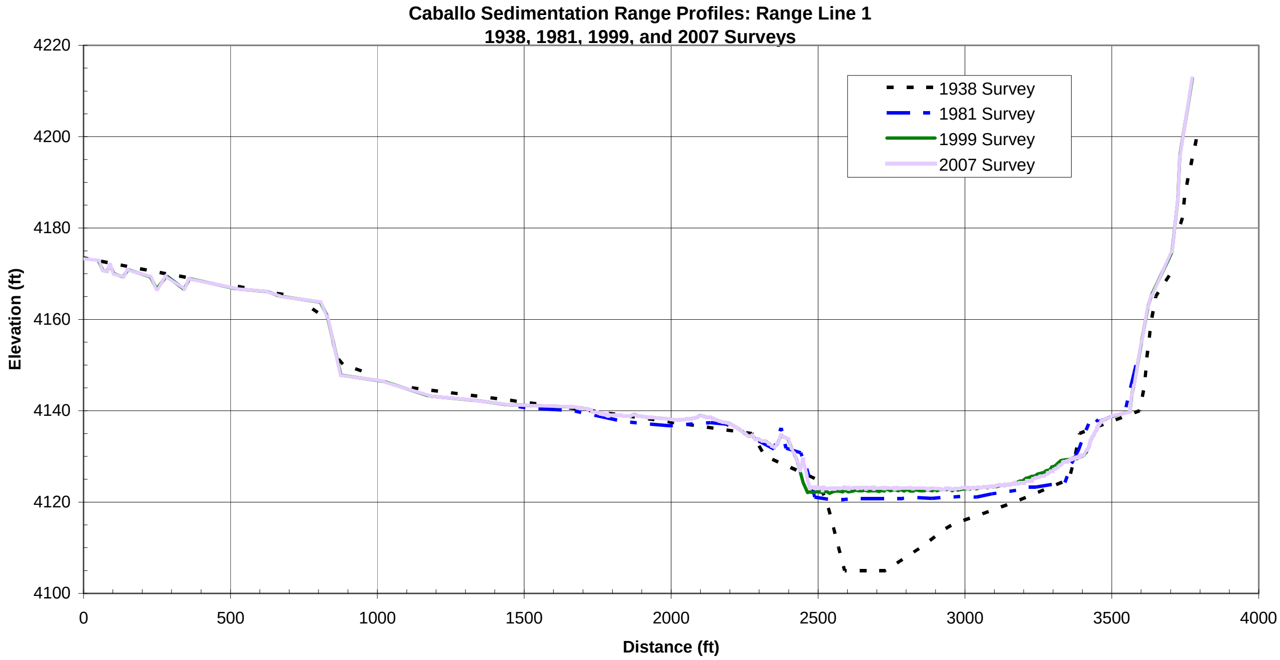


Figure 5 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 1.

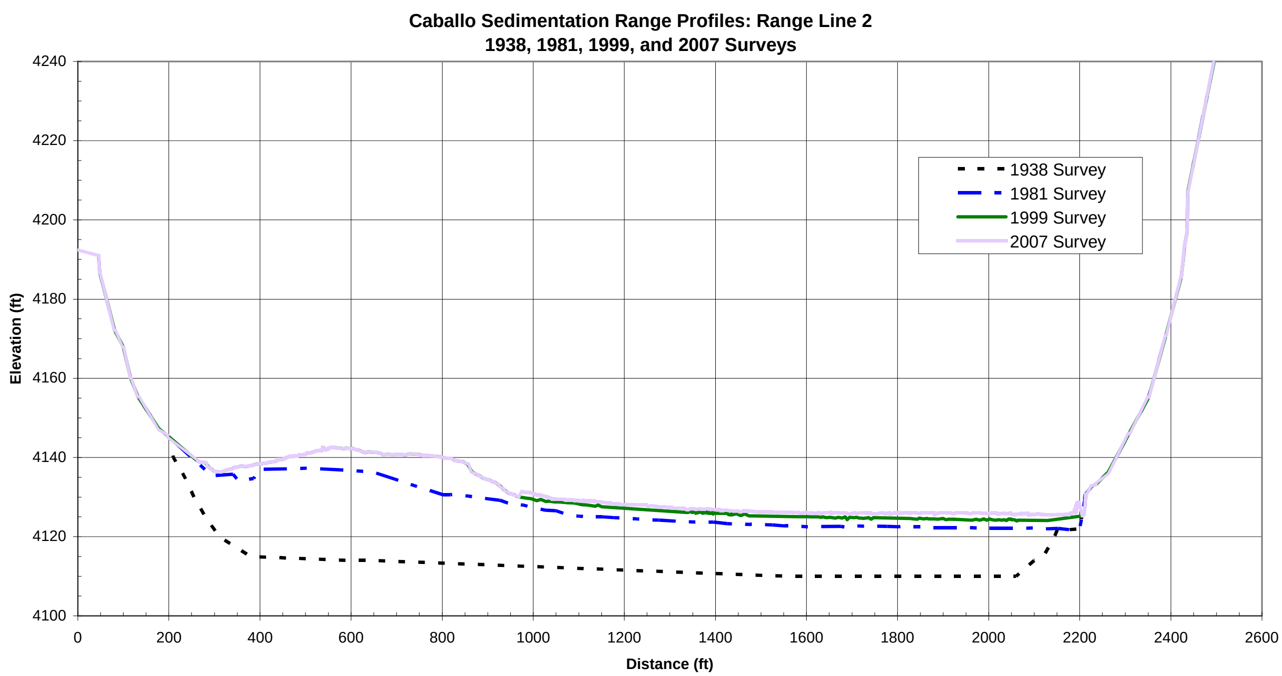


Figure 6 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 2.

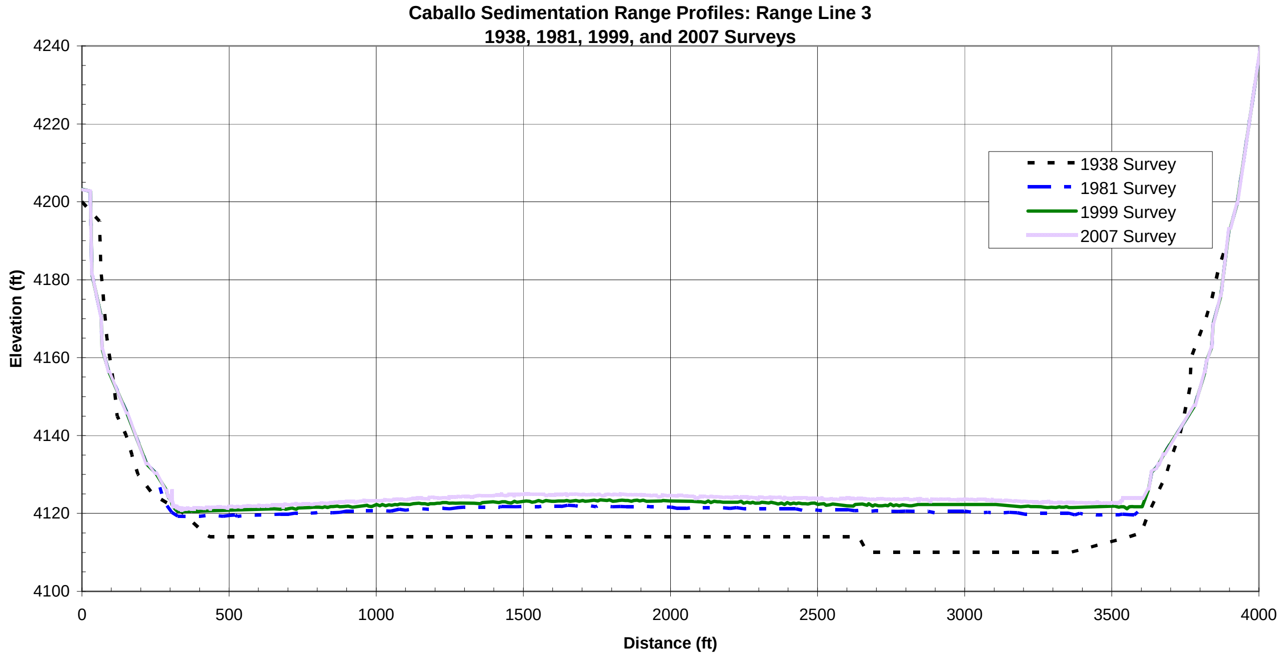


Figure 7 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 3.

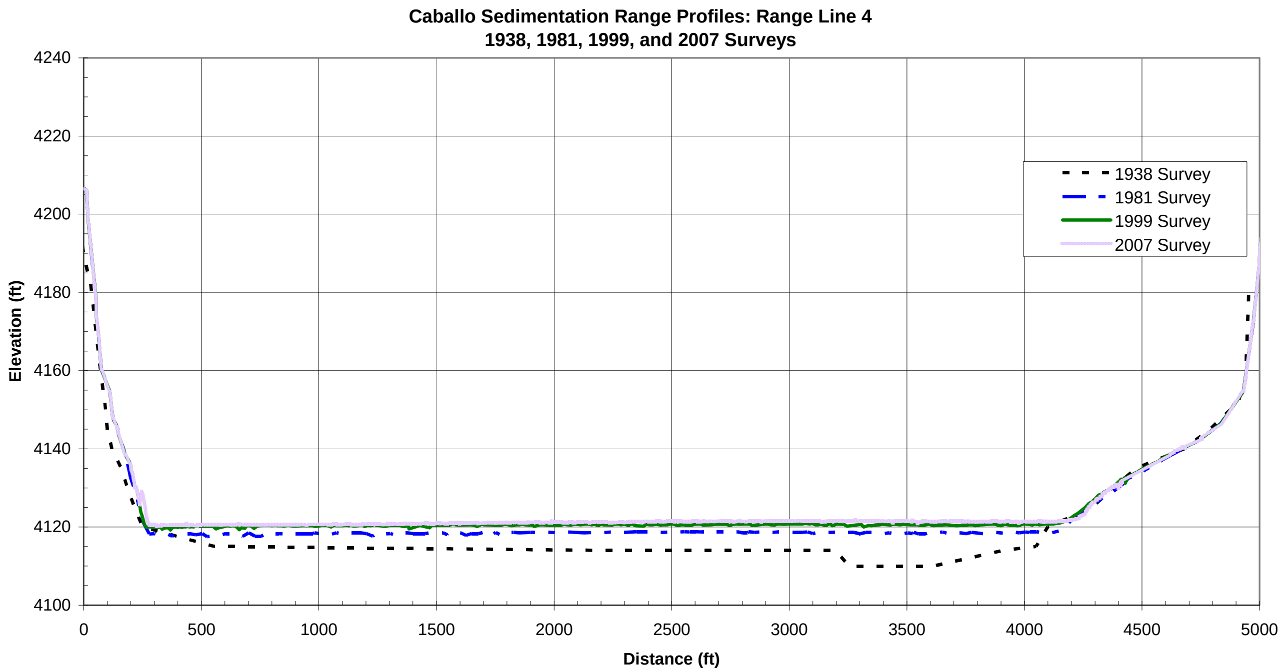


Figure 8 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 4.

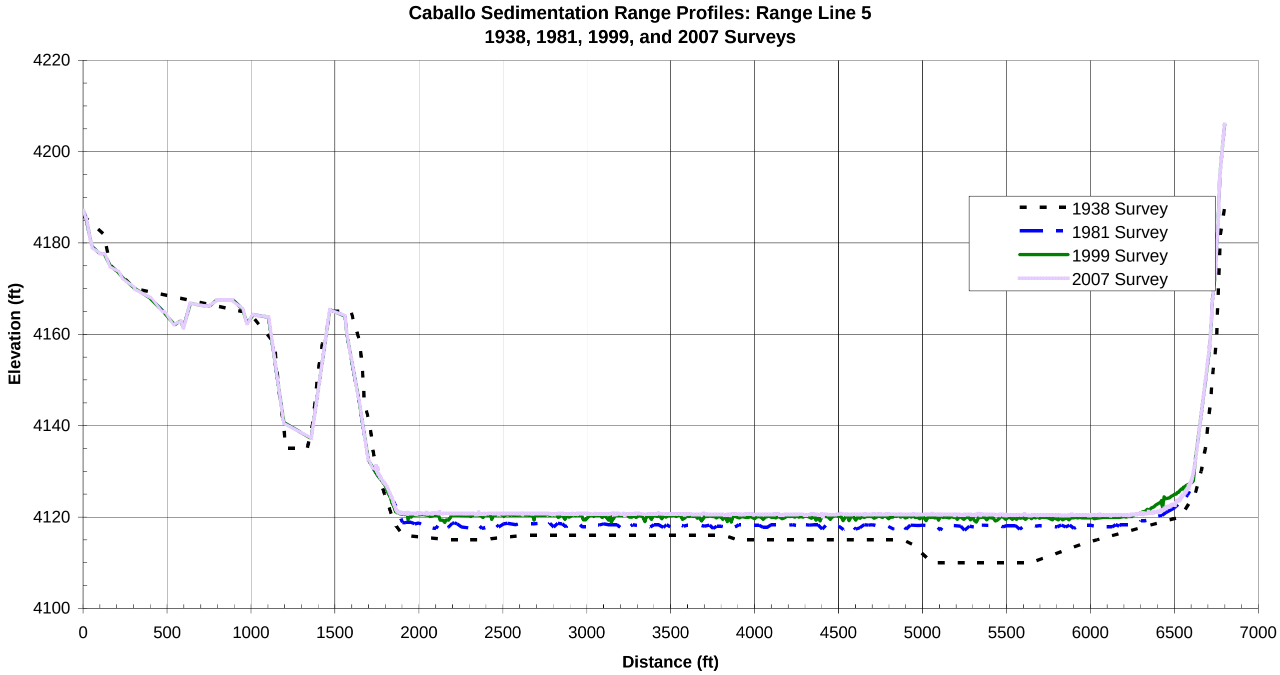


Figure 9 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 5.

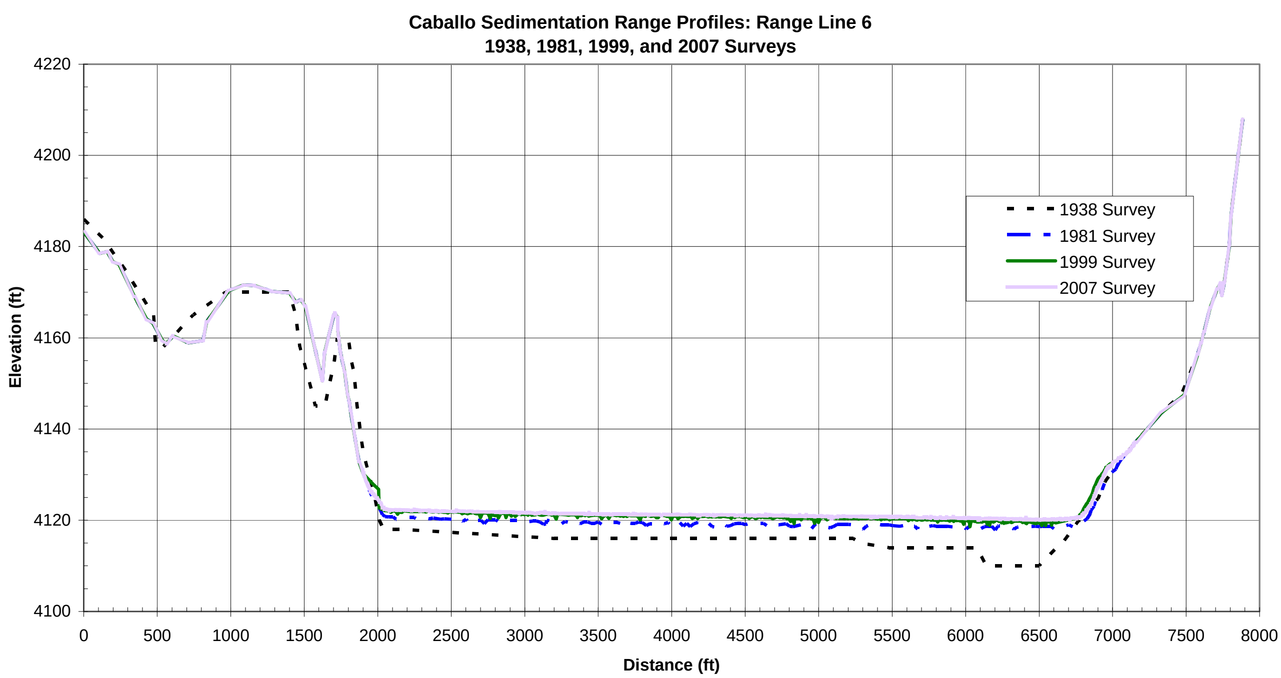
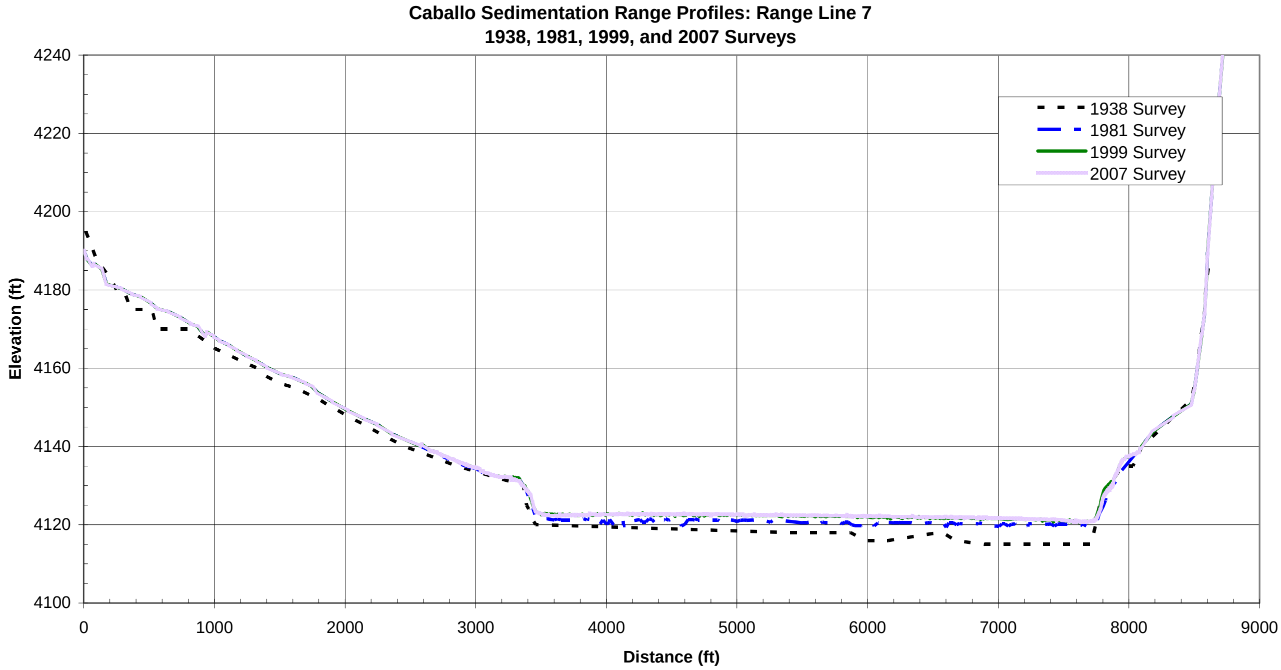


Figure 10 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 6.



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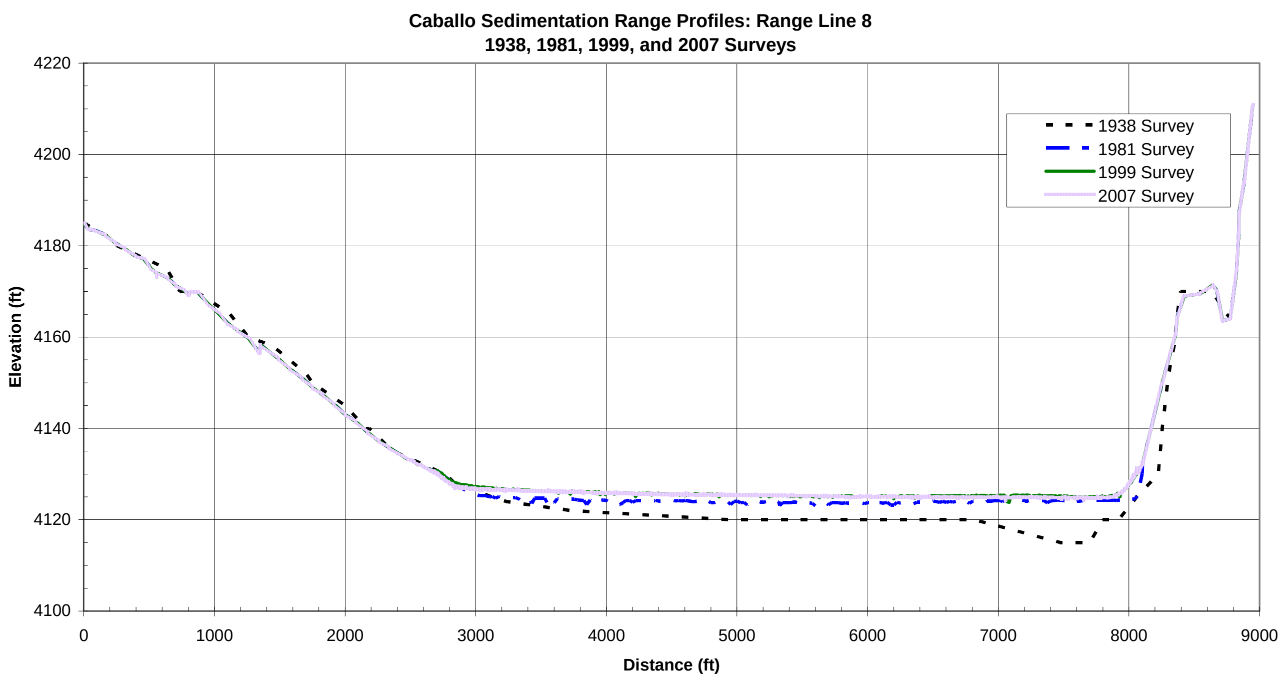


Figure 12 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 8.

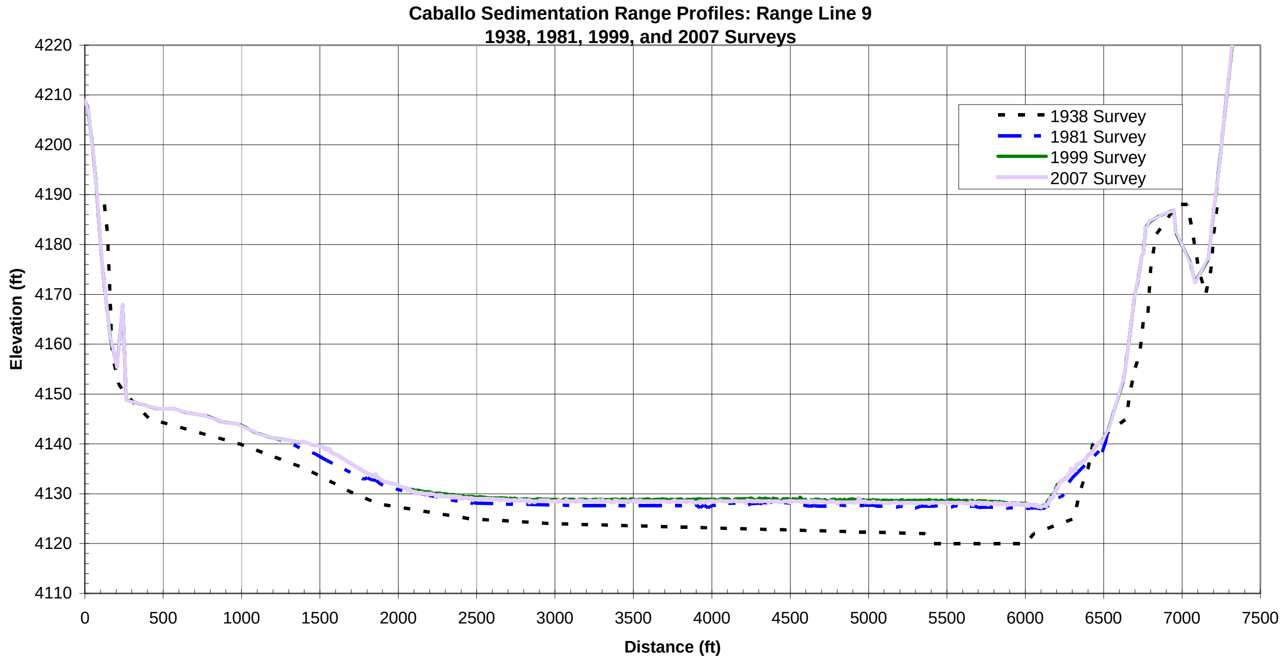


Figure 13 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 9.

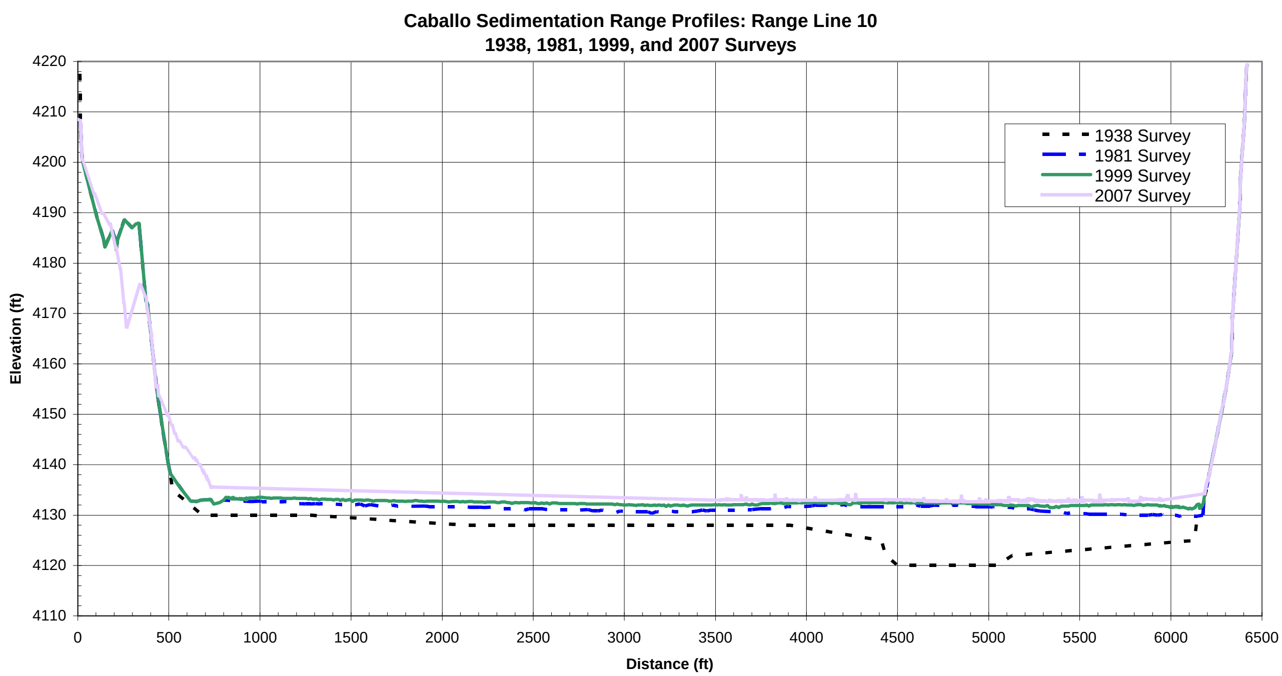


Figure 14 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 10.

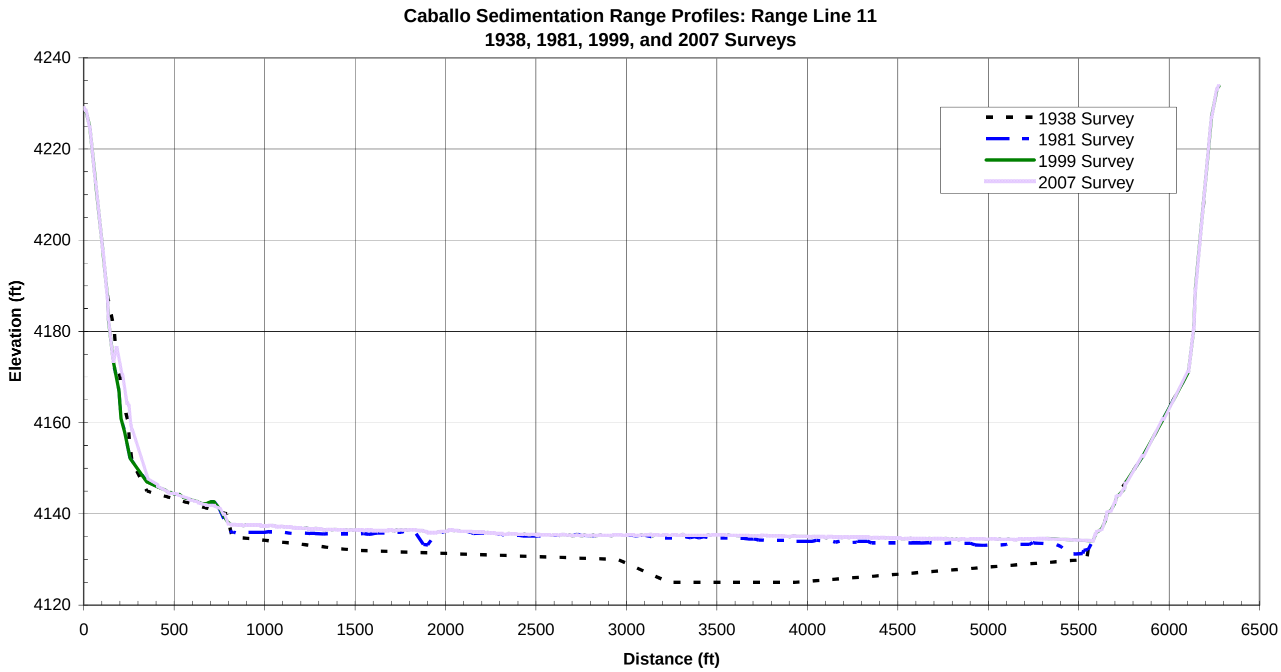


Figure 15 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 11.

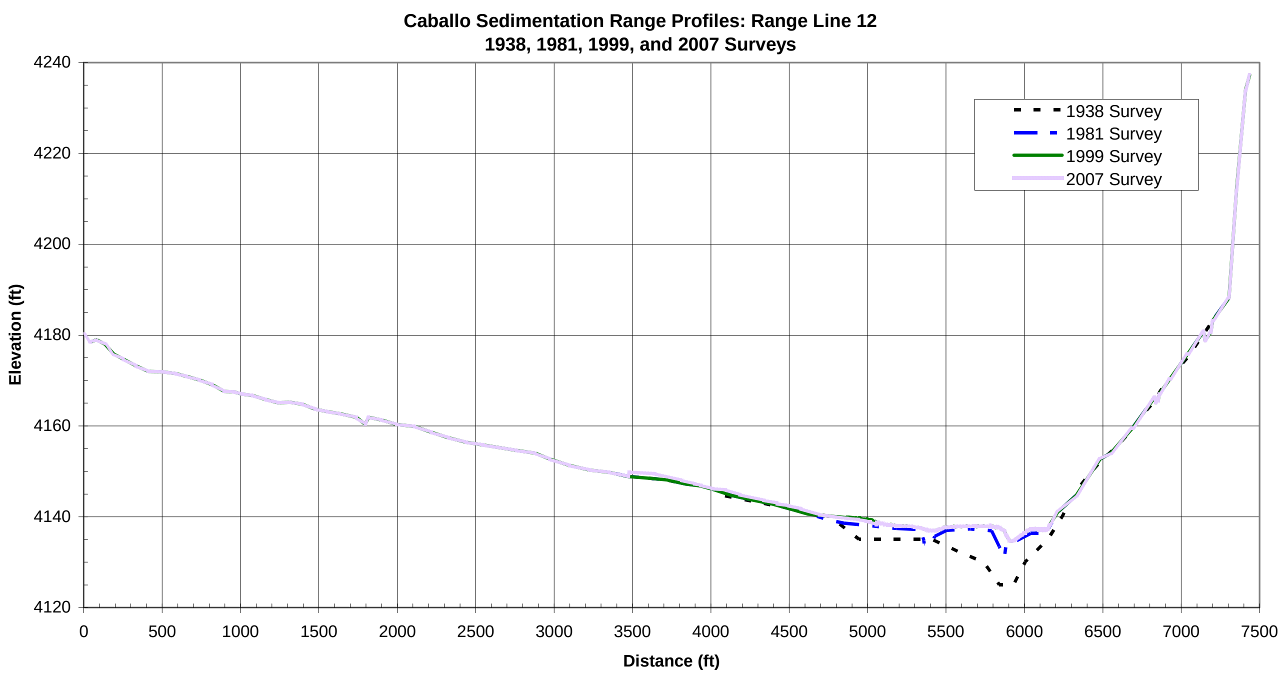


Figure 16 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 12.

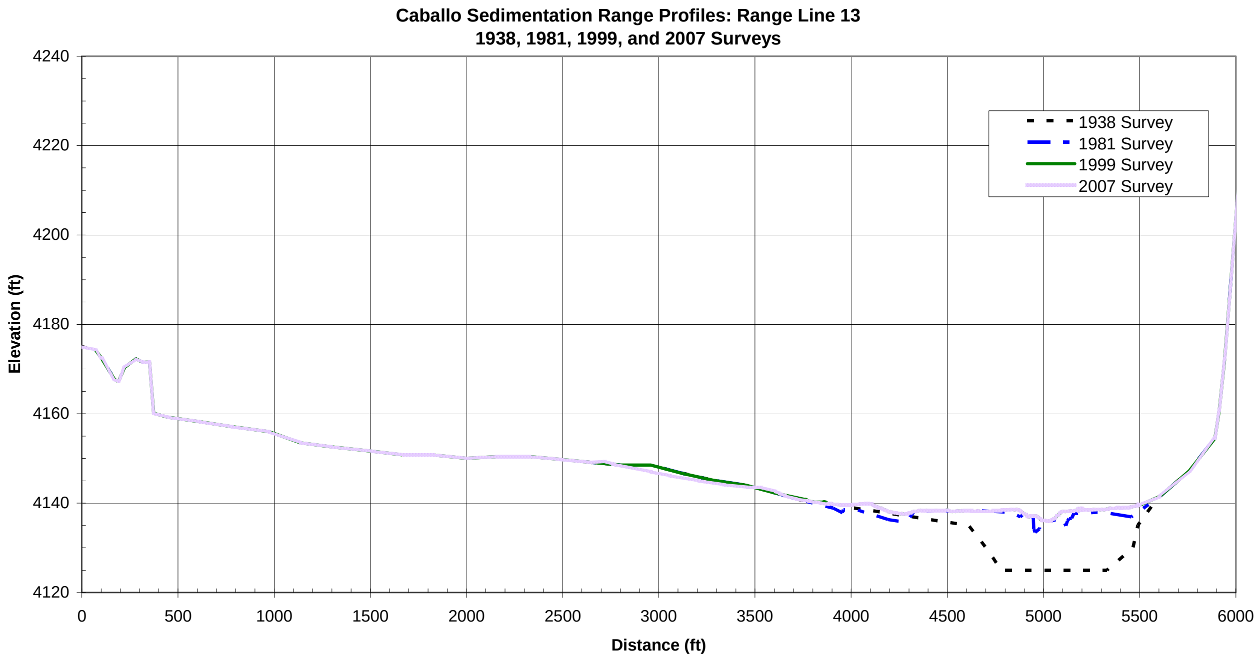


Figure 17 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 13.

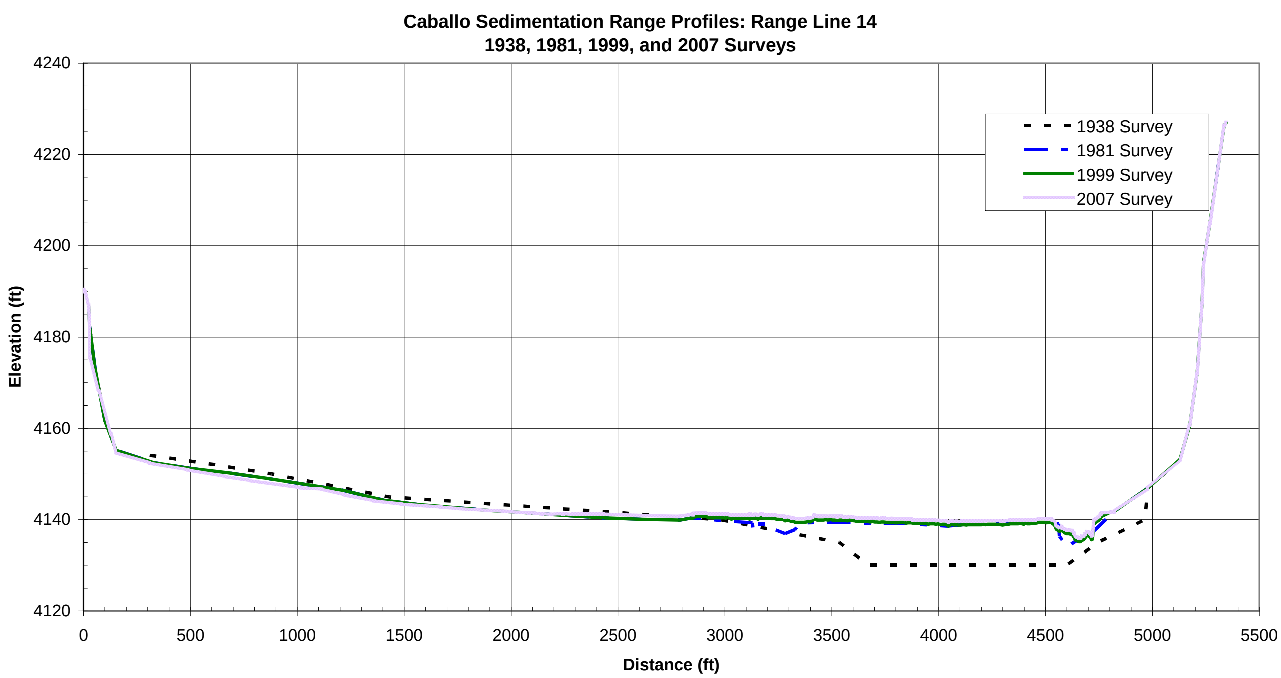
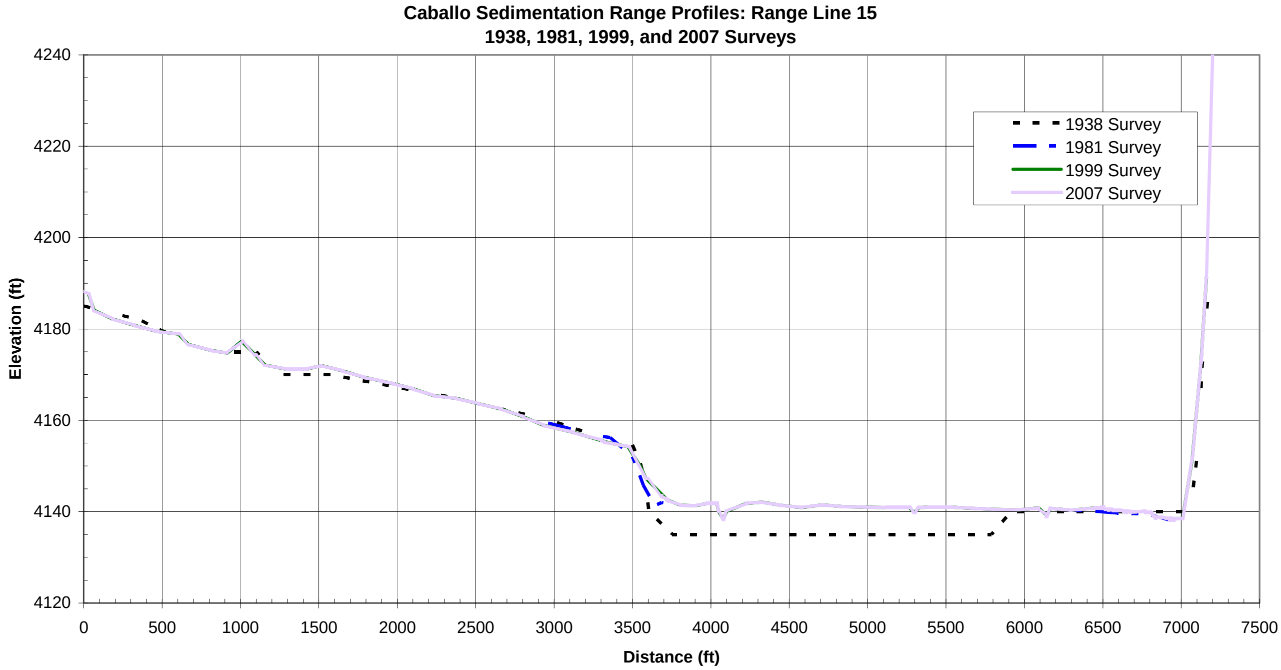


Figure 18 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 14.



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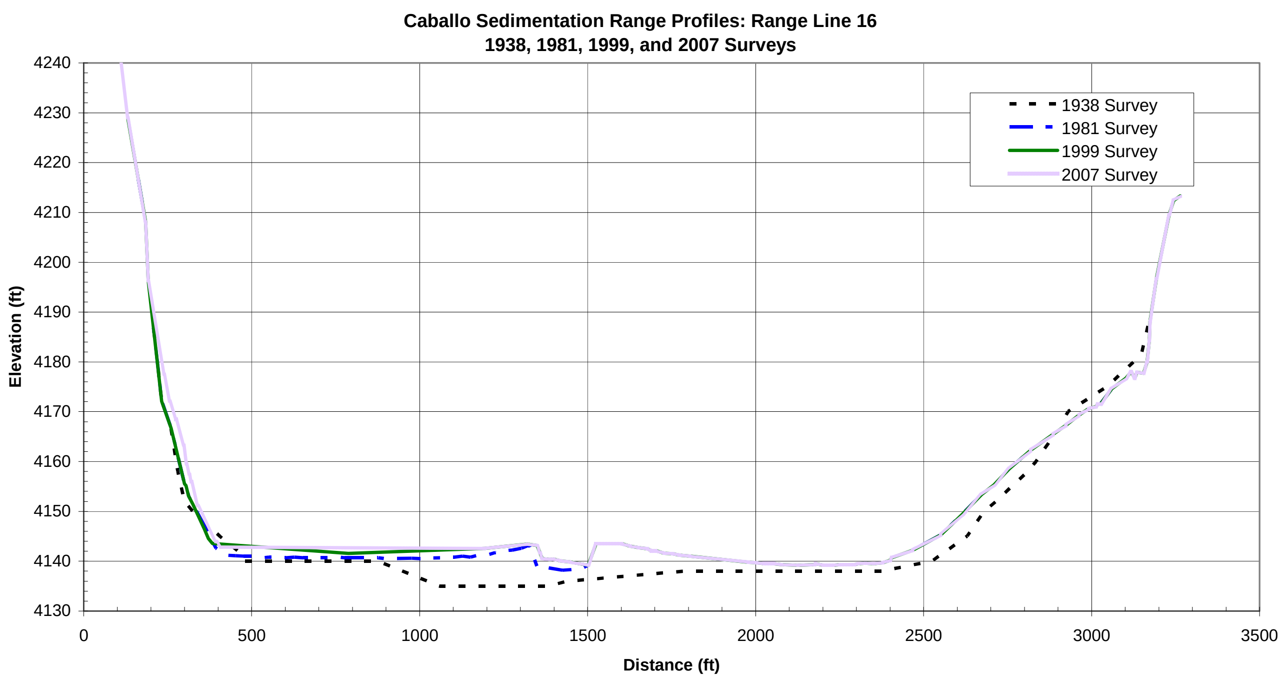

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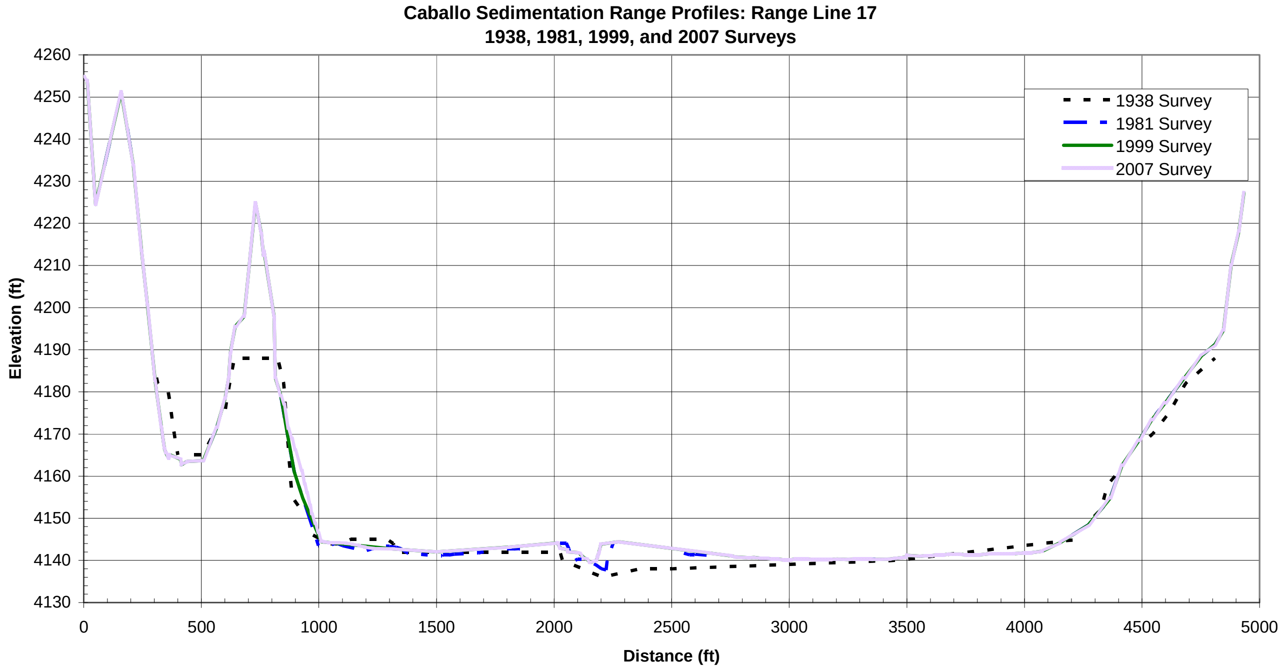

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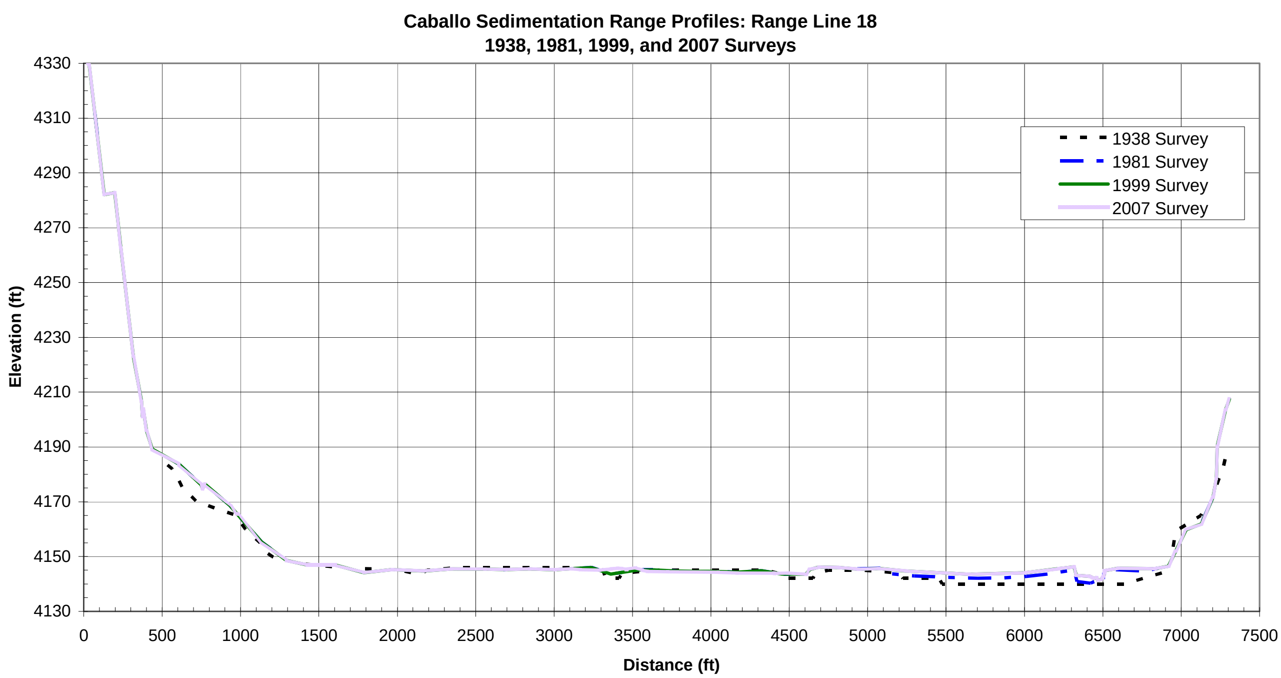
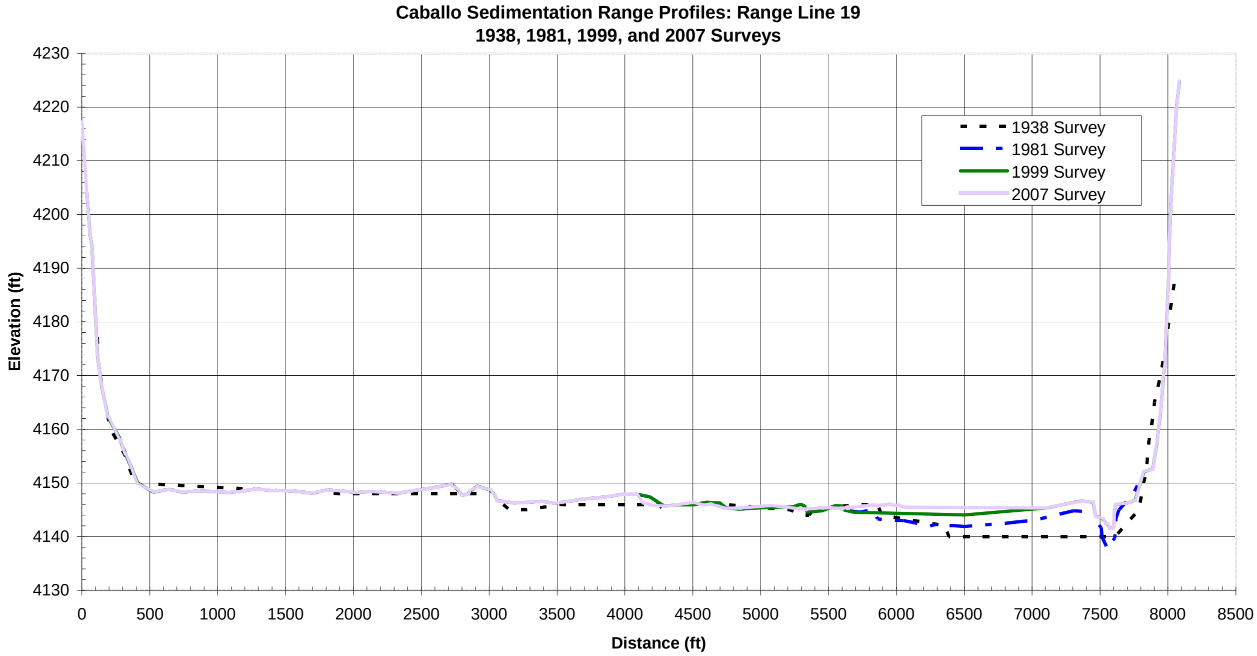


Figure 22 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 18.



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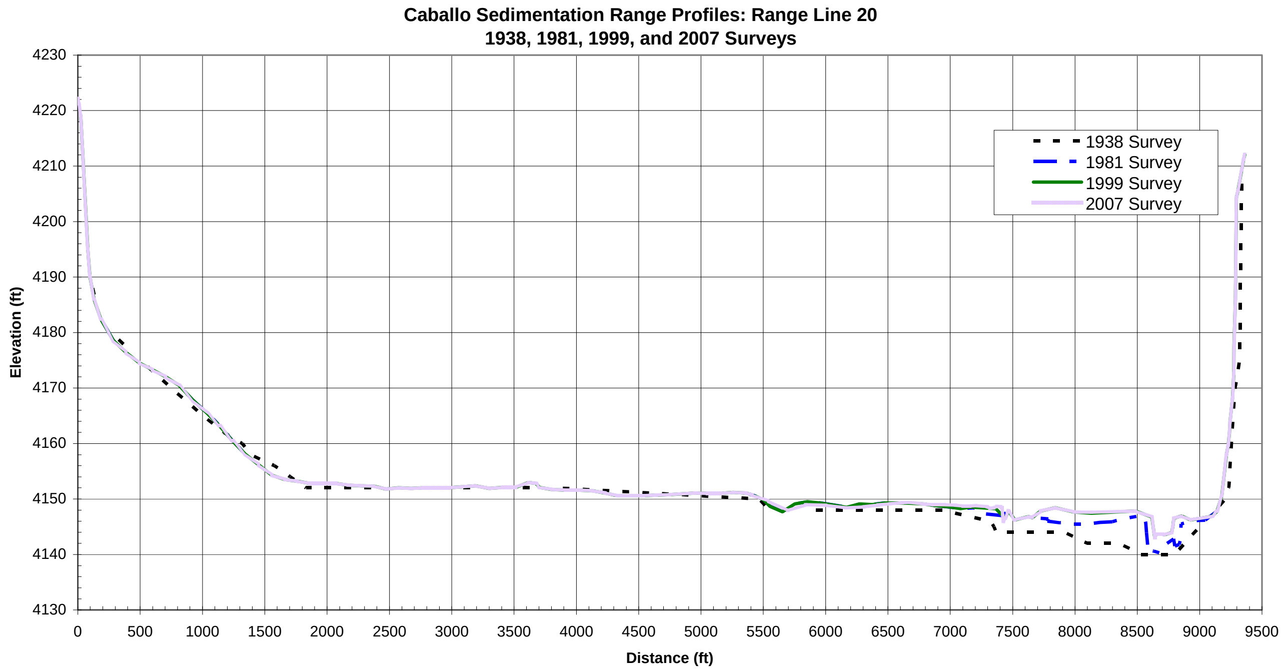


Figure 24 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 20.

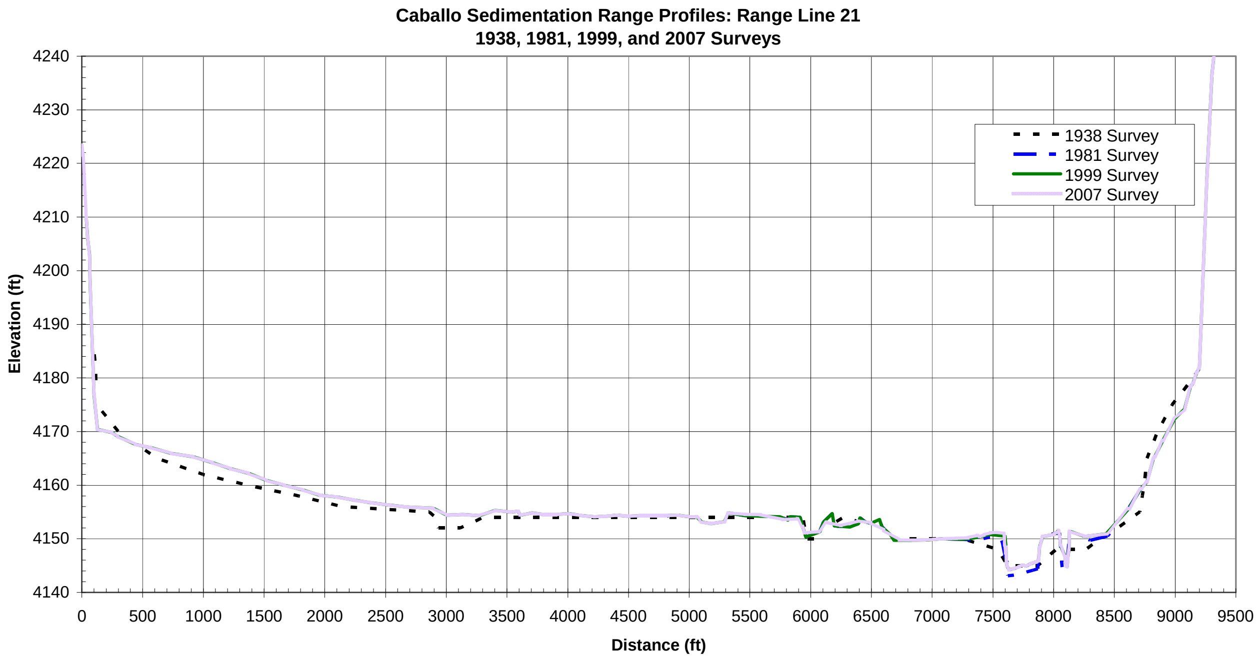


Figure 25 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 21.

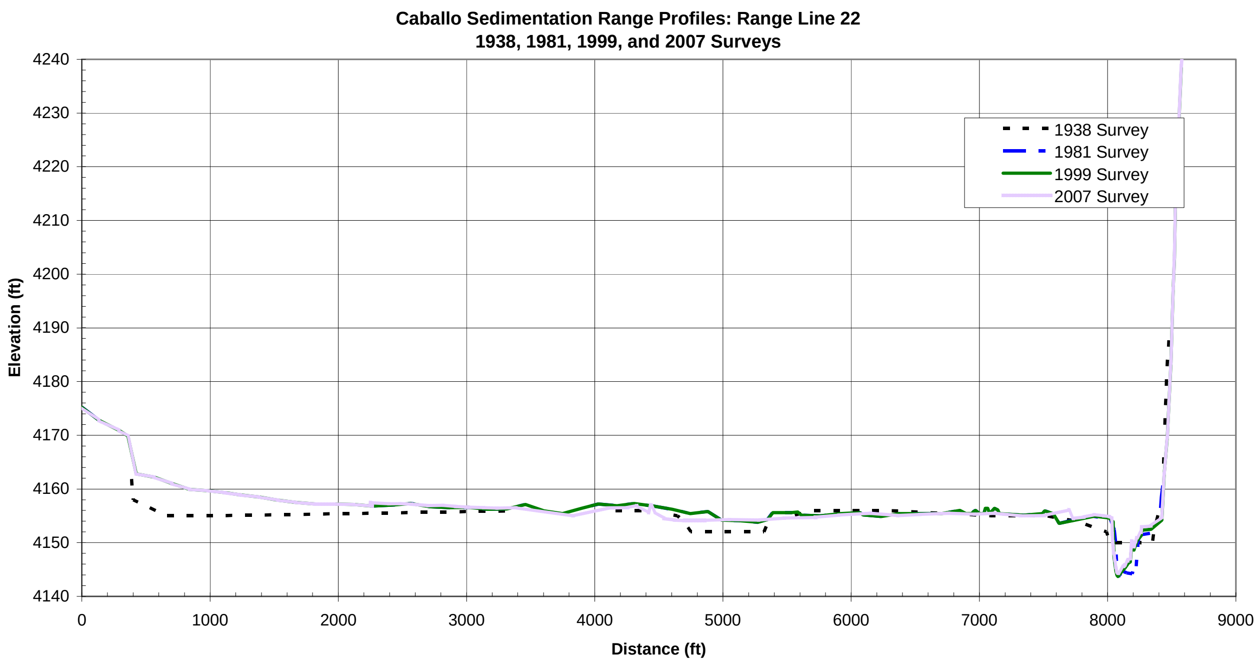
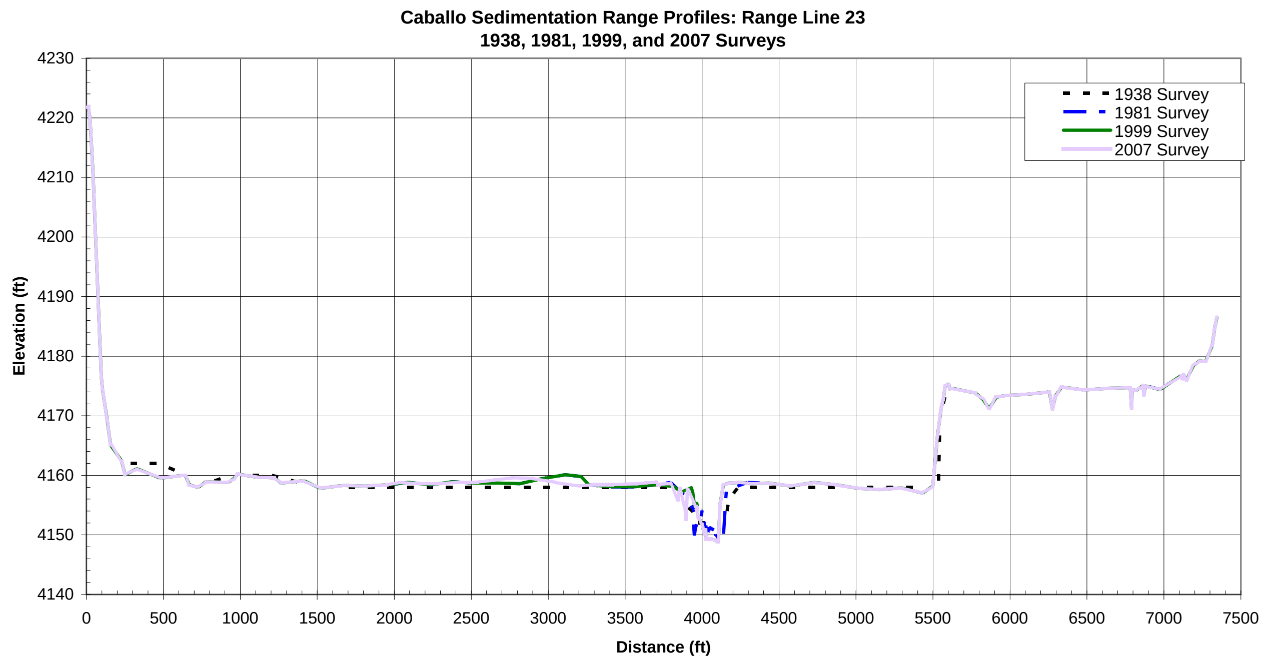


Figure 26 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 22.



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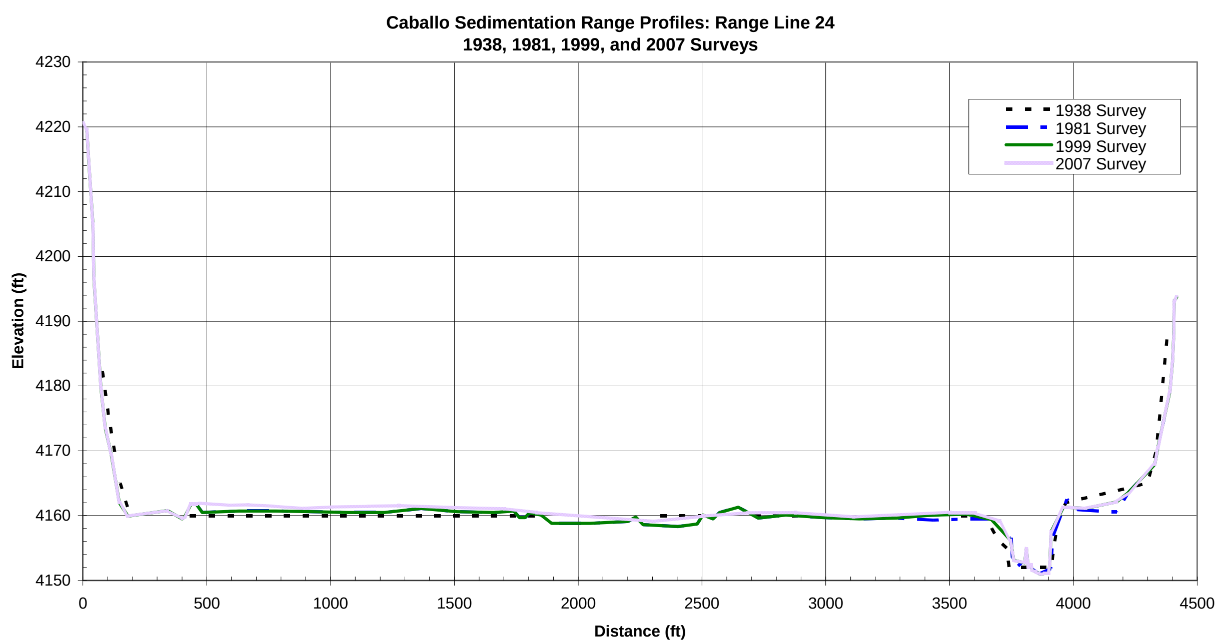


Figure 28 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 24.

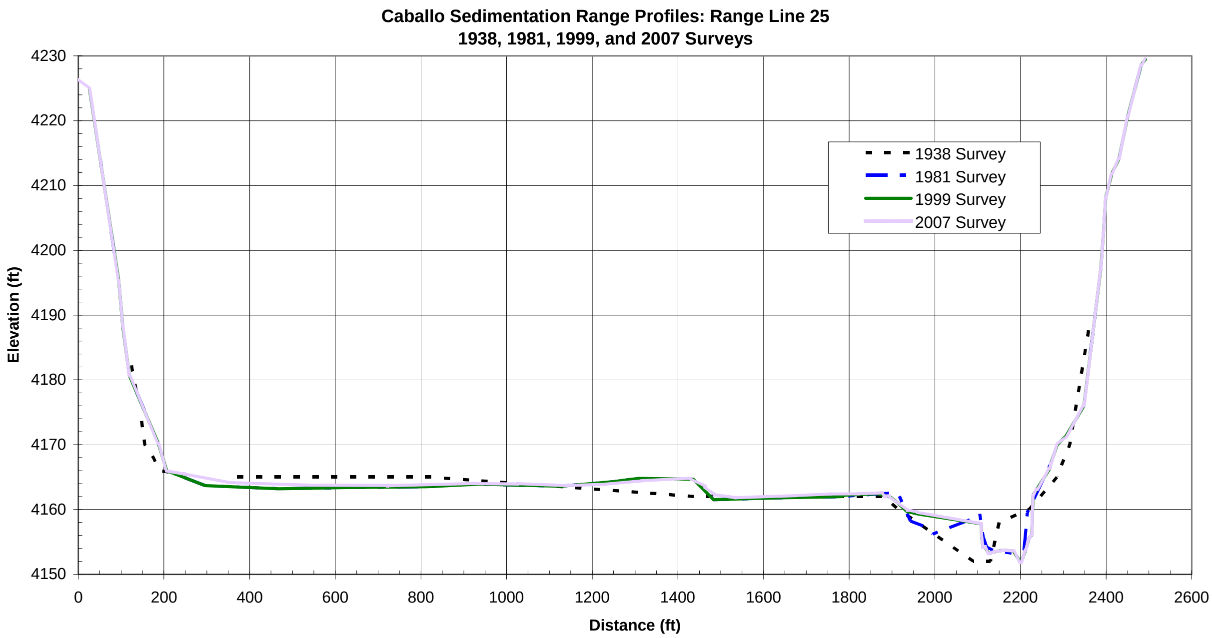
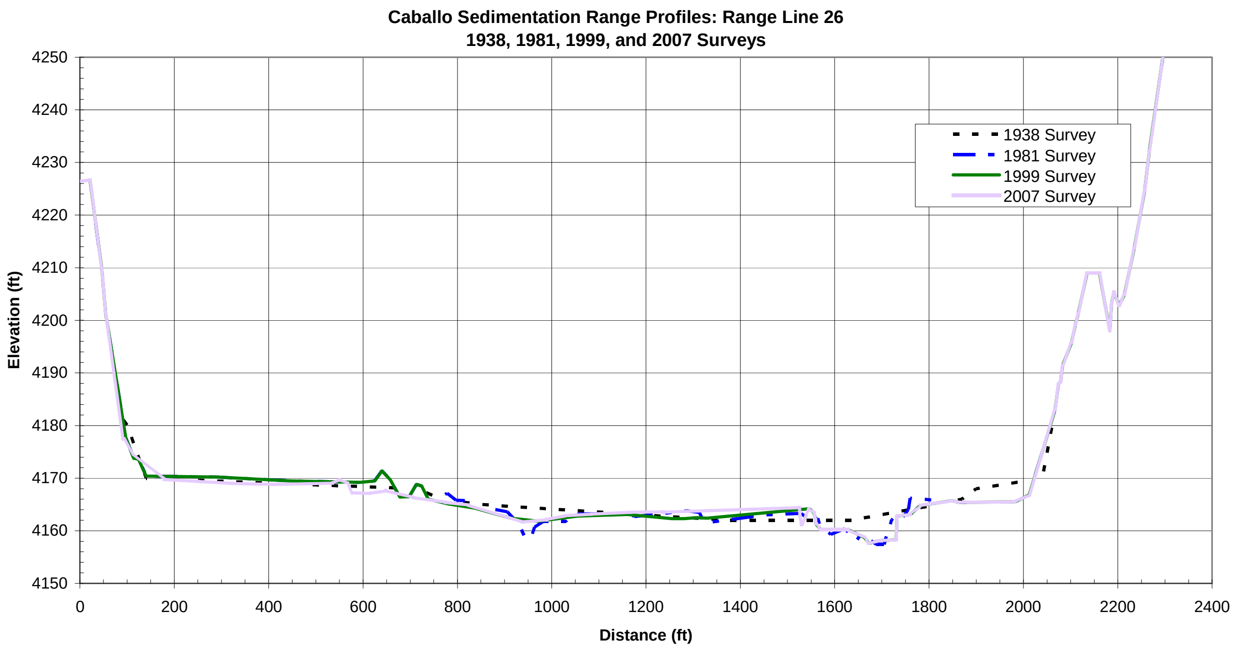


Figure 29 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 25.



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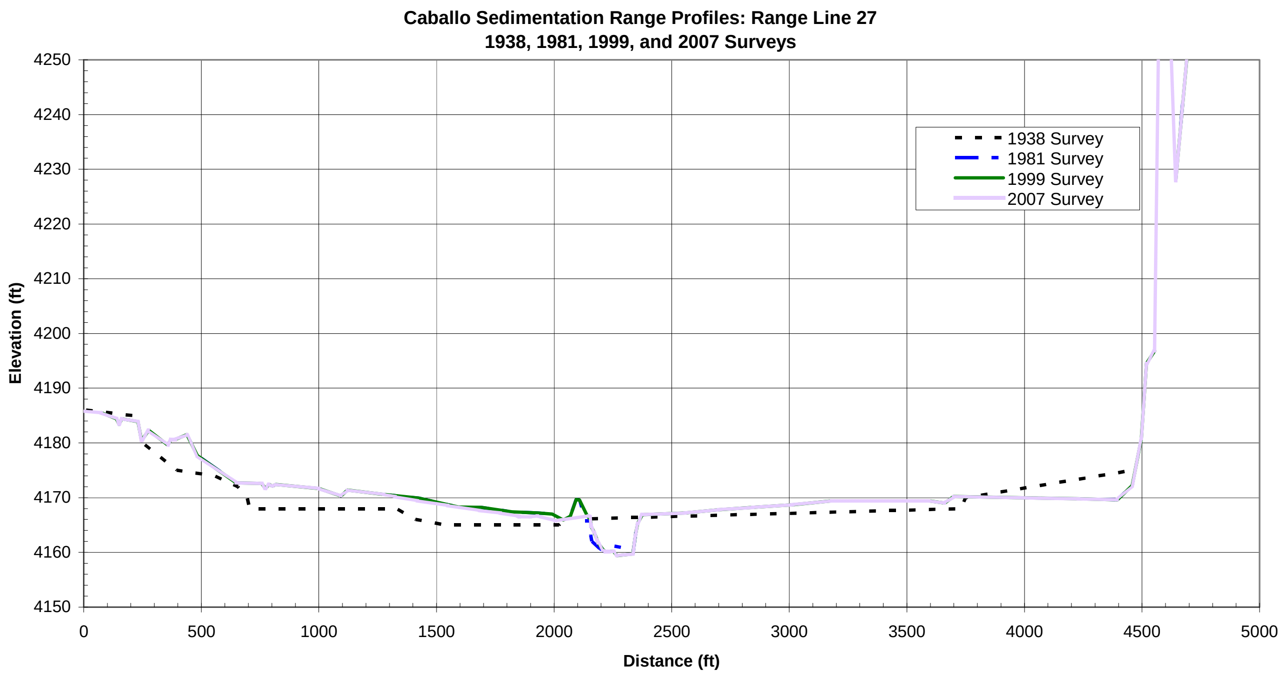

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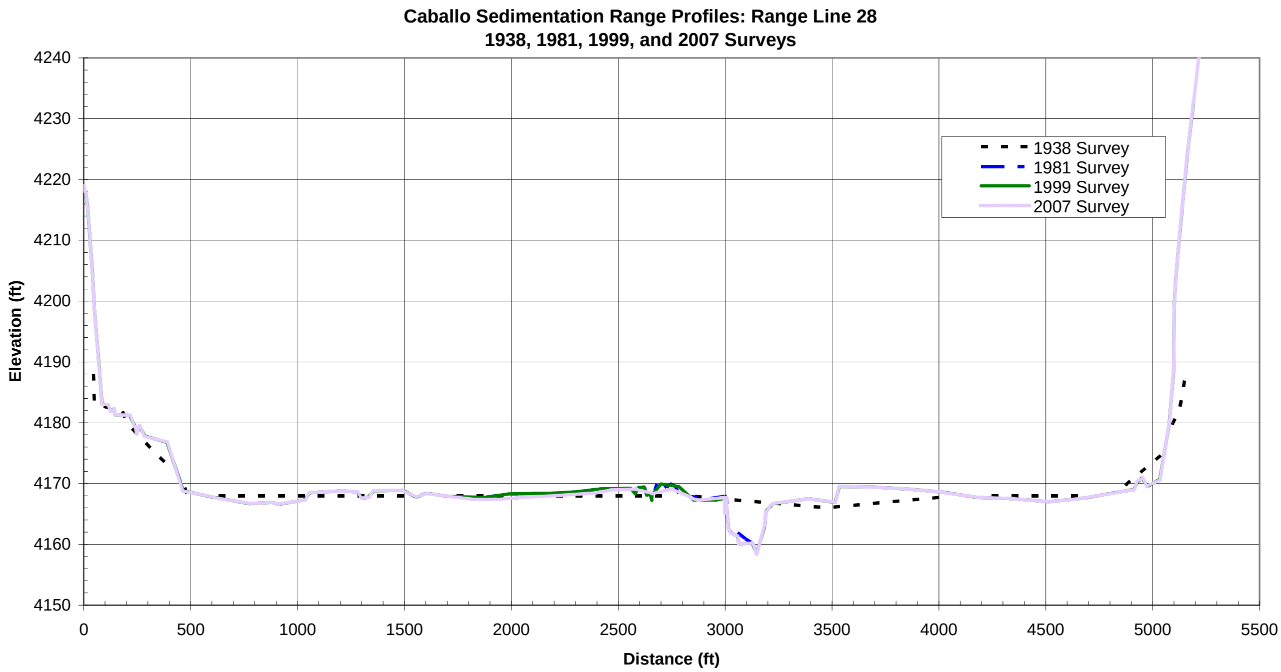

Figure 32 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 28.

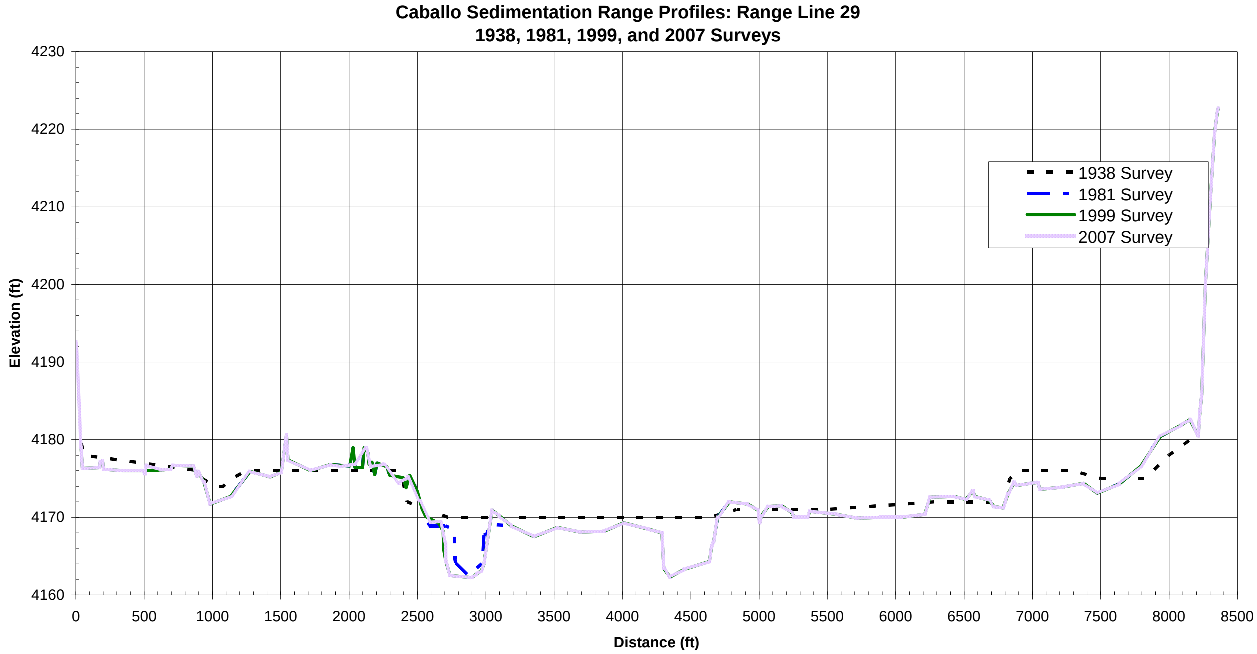

Figure 33 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 29.

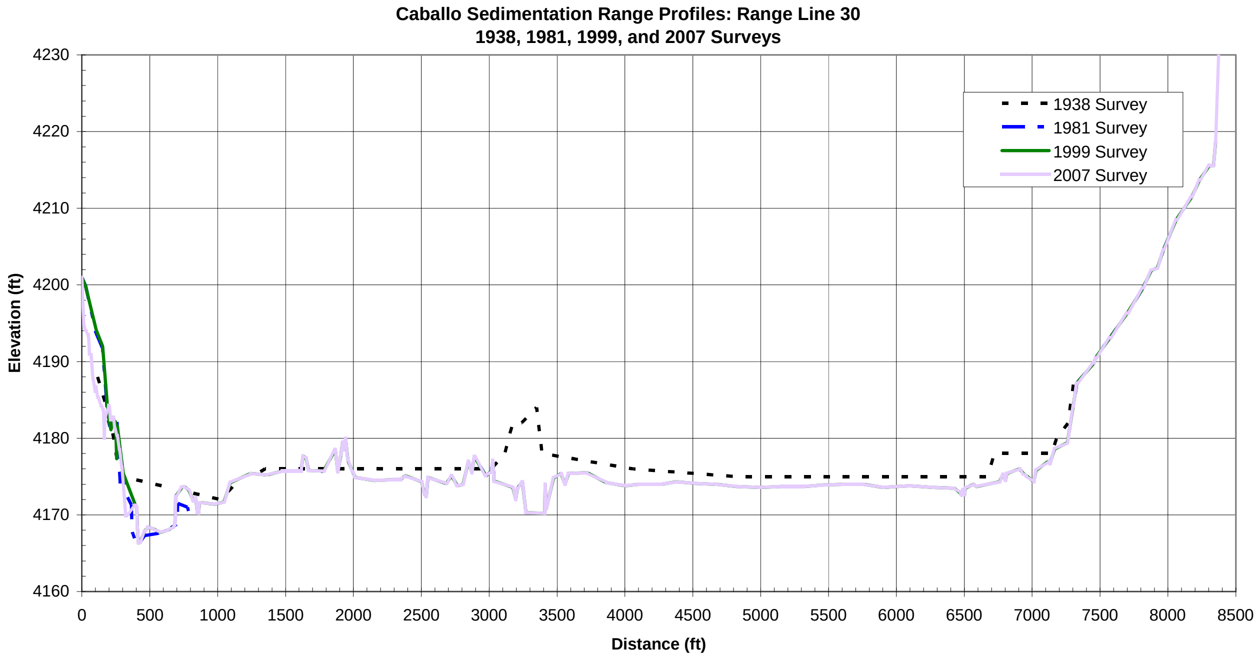

Figure 34 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 30.

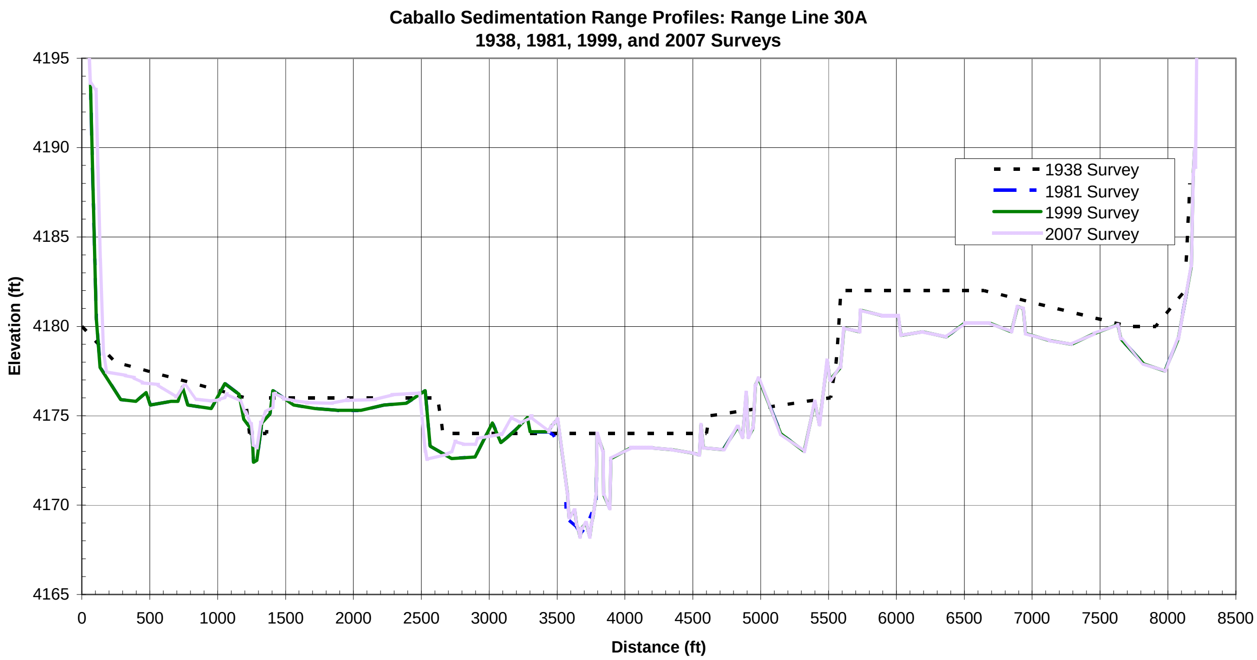

Figure 35 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 30A.

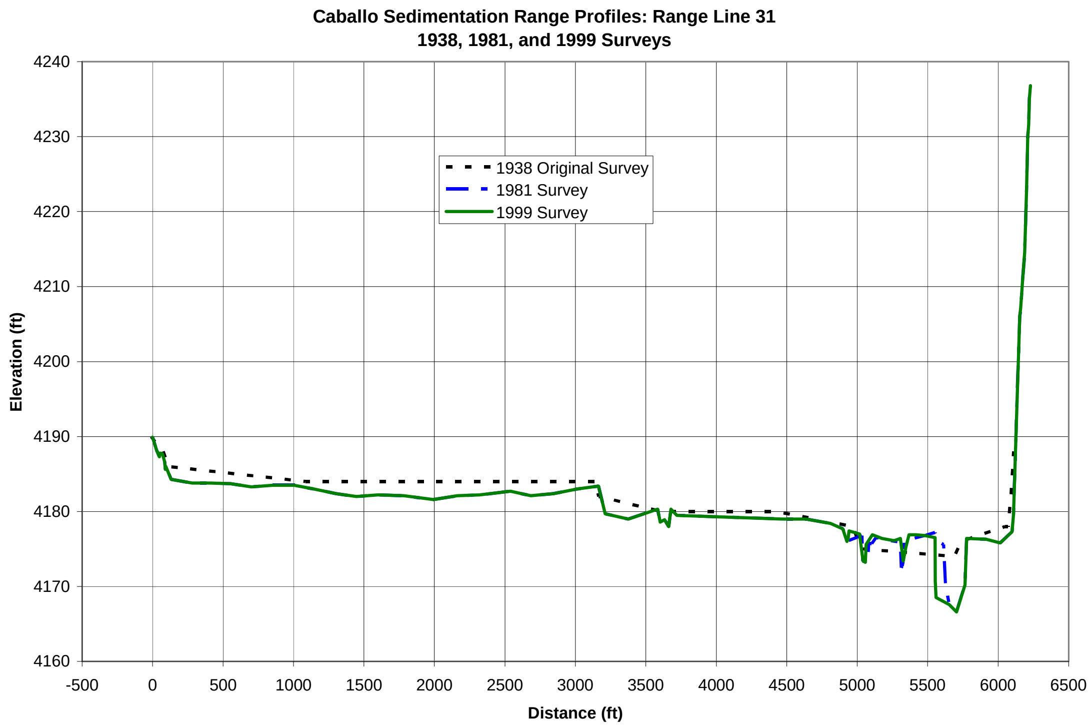

Figure 36 - Sedimentation range profiles for 1938, 1981, 1999, and 2007 - range 31.

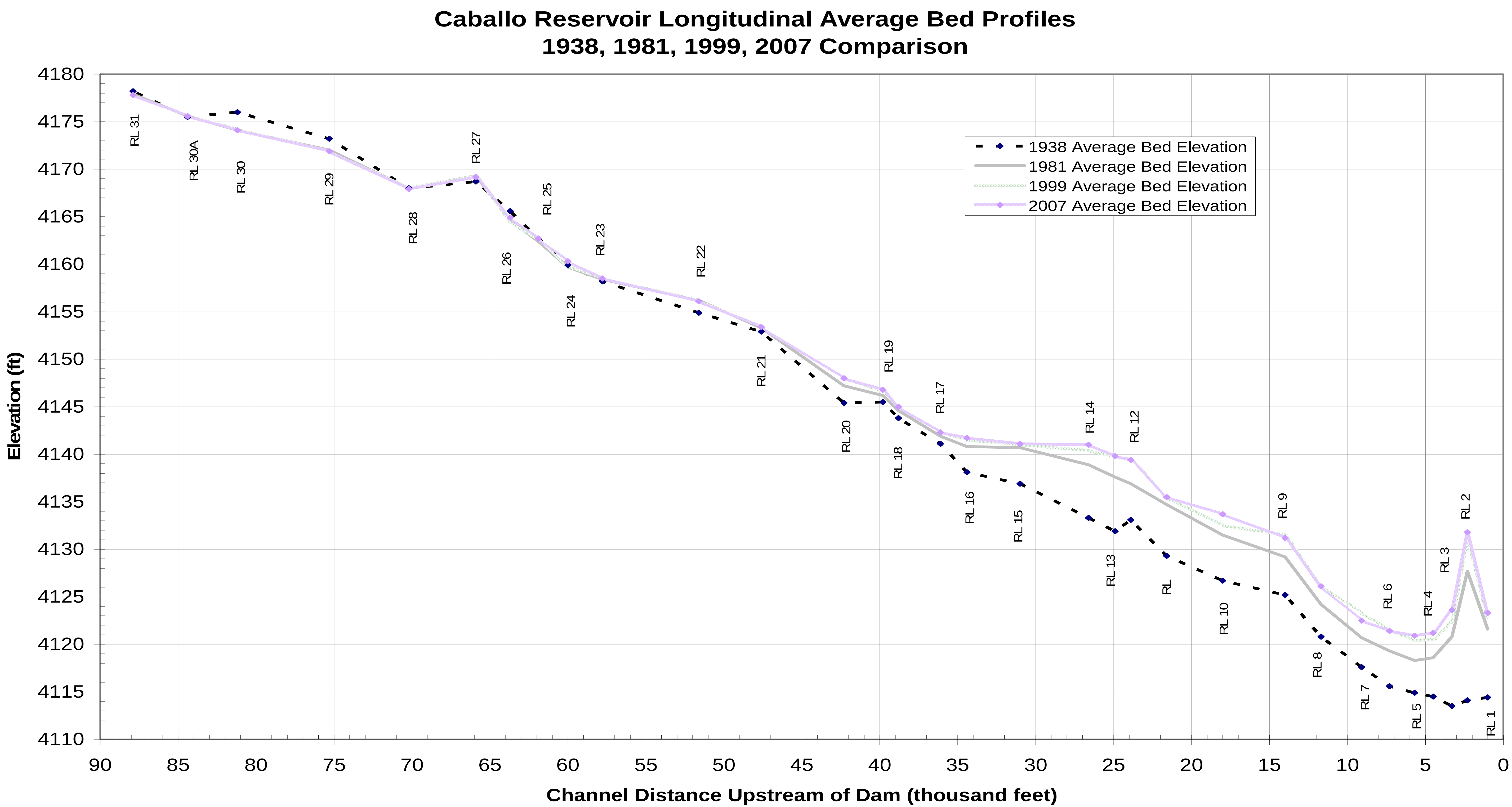

Figure 37 - Altus Reservoir longitudinal profile.

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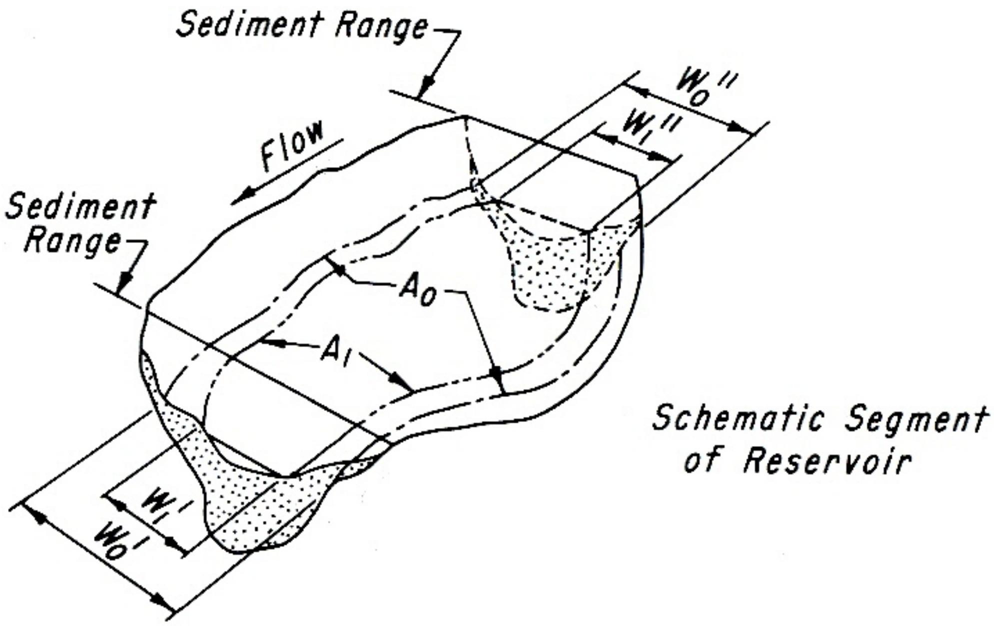
Development of the 2007 Caballo Reservoir Surface Areas

Width adjustment method

In some previous Caballo Reservoir resurveys, new contour maps were drawn from the range-line survey data. Contours between collected range-lines for new maps were drawn using the original contour map as a guide or control and estimating the new contour location based on changes that occurred at each range-line. This method was eventually abandoned for the constant factor method, which was further modified to the width adjustment method (Ferrari and Collins, 2006). In the width adjustment method, illustrated on figure 38, the new contour area, A_1, between any two ranges is computed by applying an adjustment factor to the original contour area, A_0, between the two ranges. This adjustment factor is defined as the ratio of the new average width to the original average width for both upstream and downstream ranges at the specified contour. The revised segmented surface areas for each contour are then summed for the whole reservoir. The summarized segmented surface area versus elevation becomes the basic input for volume computations.

A comparison of the simultaneous plots of original range profiles against the resurveyed range profiles indicates the lateral distribution of the sediment at the measured points. Where these plots indicate changes have occurred on the side slopes of the reservoir, an engineering judgment decision is required to determine whether the change is due to survey inaccuracies or due to actual deposition or erosion.

On the original full scale base topography map of Caballo Reservoir, the finalized location of all reservoir sediment ranges were marked. This divided the reservoir into storage segments defined either by adjacent range lines and/or by terminal ends of the reservoir, such as the dam or upstream ends of surface area contours. For the 1981 sedimentation study, planimetering determined the original segmental contour surface areas between boundaries at a maximum water surface elevation of 4,182 and for each 5-foot contour from elevation 4,180 to the lowest original contour area within each segment. For the 1938 and 2007 measured range lines, the width of all contours for each segment was computed at 5-foot contour intervals. From these values, adjustment factors were computed by dividing the new survey average width by the original survey average width for each contour interval within each segment. The new segmental contour areas were computed by multiplying the original contour area by the adjustment factor. All segment areas, by elevation increments, were added together to develop the 2007 surface areas used in the area-capacity computations.



Initial Survey	New Survey
A_o = Contour Area	A_1 = Contour Area (Computed)
W_o' = Downstream Width	W_1' = Downstream Width
W_o'' = Upstream Width	W_1'' = Upstream Width

$$A_1 = \left[\frac{\left(W_1^{'} + W_1^{''}\right)}{\left(W_0^{'} + W_0^{''}\right)} \right]$$

Figure 38 - Width adjustment method for revising contour areas.

RESERVOIR SEDIMENT
DATA SUMMARY

Caballo Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER Bureau of Reclamation	2. STREAM Rio Grande River	3. STATE New Mexico
A	4. SEC 19 TWP. 16 S RANGE 4 W	5. NEAREST P.O. Truth or Consequences	6. COUNTY Sierra
M	7. LAT 32 ° 53 ' 0 5 " LONG 107 ° 17 ' 30 "	8. TOP OF DAM ELEVATION 4190.0 [1]	9. SPILLWAY CREST EL 4161.00 [2]

	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					
E	b. FLOOD CONTROL					1/6/38 [4]
S	c. MULTIPLE USE	4,182.0 [3]	11,532	346,736	346,736	
E	d. JOINT USE					16 DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION					
V	f. INACTIVE	4,104.0	0	0	0	
O	g. DEAD					2/8/38
I	17. LENGTH OF RESERVOIR 16.7 MILES	AVG. WIDTH OF RESERVOIR 1.08 MILES				

B	18. TOTAL DRAINAGE AREA 27260 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 8.71 [4] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA 1237 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.47 [6] INCHES
S	20. LENGTH 27.5 MILES AVG. WIDTH 45 MILES	24. MEAN ANNUAL INFLOW 680,900 [7] ACRE-FEET
I N	21. MAX. ELEVATION 10000 MIN. ELEVATION 4100.5	25. ANNUAL TEMP, MEAN 64 °F RANGE -16 °F to 111 °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
1/6/1938			Contour (D)	5-ft (CI)	11,532 [8]	346,736	0.51
1/15/1981	43	43	Range (D)	32 (RL)	11,532 [8]	331,510	0.49
4/14/1999	18.3	61.3	Range (D)	32 (RL)	11,532 [8]	326,672	0.48
9/30/2007	8.4	69.7	Range (D)	32 (RL)	11,532 [9]	324,934	0.48

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
1/6/1938						
1/15/1981 [8]		631,380 [8]	1,930,000	27,149,333	631,380	27,149,333
4/14/1999		823,390 [9]	1,693,000	15,067,967	688,700	42,217,300
9/30/2007		624,000	813,100	5,241,800	680,900	47,459,100

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.
1/6/1938						
1/15/1981 [8]	15,226	354.1	0.286	15,226	354.1	0.286
4/14/1999	4,838	264.4	0.214	20,064	327.3	0.265
9/30/2007	1,738	206.9	0.167	21,802	312.8	0.253

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.
1/6/1938							
1/15/1981 [8]	75	467	467	0.102	4.39	673	673
4/14/1999				0.094	5.79		
9/30/2007				0.090	6.29		

26. DATE OF SURVEY	43. DEPTH DESIGNATION ELEVATION RANGE IN FEET										
	4,105 4,115	4,115 4,125	4,125 4,135	4,135 4,145	4,145 4,155	4,155 4,165	4,165 4,175	4,175 4,182			
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
1/15/81	8.6	32.7	30.6	19.9	3.5	3.8	0.9	0.0			
4/14/99	6.5	35.4	30.2	20.0	4.0	3.3	0.6	0.0			
9/30/07	6.0	34.5	27.7	21.8	6.2	3.3	0.5	0.0			

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

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

45. RANGE IN RESERVOIR OPERATION [10]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1938	4,129.4	4,110.2	738,600
1939	4,155.2	4,108.1	915,600	1940	4,154.2	4,123.9	714,300
1941	4,158.8	4,119.7	692,800	1942	4,182.1	4,133.7	1,930,000
1943	4,181.1	4,119.2	807,000	1944	4,176.4	4,123.1	875,800
1945	4,178.1	4,120.6	843,200	1946	4,175.9	4,121.1	858,800
1947	4,178.8	4,119.2	707,900	1948	4,165.6	4,125.2	742,800
1949	4,164.8	4,131.8	754,600	1950	4,175.2	4,132.5	720,800
1951	4,162.2	4,121.9	451,100	1952	4,153.4	4,120.0	543,000
1953	4,164.4	4,122.0	553,700	1954	4,138.6	4,124.1	245,400
1955	4,135.8	4,121.5	211,800	1956	4,131.2	4,121.3	253,600
1957	4,133.8	4,120.2	384,400	1958	4,159.1	4,121.7	791,700
1959	4,172.6	4,133.1	699,500	1960	4,160.6	4,119.5	681,800
1961	4,155.9	4,123.7	578,600	1962	4,160.1	4,129.2	691,500
1963	4,154.2	4,134.7	509,900	1964	4,138.2	4,122.3	183,400
1965	4,144.2	4,125.5	520,900	1966	4,162.0	4,128.3	660,900
1967	4,155.0	4,133.7	433,100	1968	4,162.6	4,134.9	548,500
1969	4,150.5	4,137.6	667,000	1970	4,150.7	4,132.7	685,600
1971	4,149.0	4,122.2	516,500	1972	4,143.8	4,124.6	300,200
1973	4,158.4	4,137.0	604,300	1974	4,155.2	4,132.0	672,900
1975	4,152.9	4,134.0	646,500	1976	4,152.0	4,135.8	661,900
1977	4,160.0	4,126.3	395,900	1978	4,145.0	4,127.6	375,400
1979	4,158.1	4,130.1	574,400	1980	4,160.9	4,130.3	670,300
1981	4,162.0	4,129.1	635,300	1982	4,155.1	4,130.8	691,700
1983	4,160.9	4,139.7	662,500	1984	4,158.9	4,130.2	650,300
1985	4,172.9	4,135.9	901,000	1986	4,176.7	4,173.4	1,101,000
1987	4,174.8	4,172.3	1,693,000	1988	4,178.5	4,152.2	685,300
1989	4,165.8	4,148.1	730,800	1990	4,150.1	4,135.6	666,100
1991	4,148.9	4,134.0	573,100	1992	4,154.7	4,138.1	705,800
1993	4,172.4	4,136.5	1,061,100	1994	4,178.5	4,143.9	711,100
1995	4,177.3	4,138.4	1,184,000	1996	4,171.4	4,137.9	698,200
1997	4,151.8	4,140.2	741,300	1998	4,150.3	4,141.2	825,900
1999	4,151.3	4,139.1	736,200	2000	4,159.6	4,138.9	751,900
2001	4,158.4	4,126.8	773,600	2002	4,154.4	4,138.1	813,100
2003	4,150.1	4,126.8	338,300	2004	4,151.7	4,131.6	411,700
2005	4,146.5	4,131.3	668,200	2006	4,150.9	4,134.0	461,800
2007	4,151.9	4,132.7	570,900				

46. ELEVATION - AREA - CAPACITY - DATA FOR								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
1938	**SURVEY**		4,105.0	0	0	4,110.0	71	187
4,115.0	376	1,305	4,120.0	983	4,702	4,125.0	1,576	11,100
4,130.0	2,129	20,362	4,135.0	2,583	32,142	4,140.0	3,176	46,540
4,145.0	3,880	64,180	4,150.0	4,888	86,100	4,155.0	5,998	113,315
4,160.0	7,103	146,067	4,165.0	7,752	183,205	4,170.0	8,784	224,545
4,175.0	9,967	271,442	4,180.0	11,104	324,100	4,182.0	11,532	346,736
2007	**SURVEY**							
4,115.0	0	0	4,120.0	0	0	4,125.0	909	2,271
4,130.0	1,554	8,429	4,135.0	1,982	17,270	4,140.0	2,657	28,869
4,145.0	3,617	44,554	4,150.0	4,794	65,581	4,155.0	5,913	92,348
4,160.0	7,006	124,646	4,165.0	7,737	161,504	4,170.0	8,771	202,775
4,175.0	9,967	249,620	4,180.0	11,104	302,298	4,182.0	11,532	324,934

47. REMARKS AND REFERENCES

[1] Elevations tied to project datum that is 43.3 feet less than NGVD29 and 45.5 feet less than NAVD88. Top parapet wall, elevation 4,193.0.

[2] Spillway crest, El. 4,161.0. Top active conservation, El. 4,172.44. Top flood pool and radial gates, El. 4,182.0. Splash plate crest, El. 4,183.5.

[3] Exclusive flood pool is top 100,000 AF, El. 4,172.44 to El. 4,182.0. Below 4,172.44 is conservation storage for irrigation.

[4] BOR Project Data Book, 1981. Annual precipitation at dam, 8.71 inches (1936-1992) from NOAA/NWS.

[5] Removed drainage area above Elephant Butte Reservoir.

[6] Calculated using mean annual runoff value of 680,900 AF (item 24).

[7] Annual inflow from 1938 through 2007, item 45.

[8] Values from 1981 Sedimentation Survey report.

[9] Range lines 1 through 9 by bathymetric survey. Ranges line 10, combination of RTK GPS land and bathymetric survey. Range lines 11 through 30 by RTK GPS land survey for portions of the lines accessible. Width adjustment method used to compute new area and capacity values.

[10] February 1938 through 1998 from 1999 report. 1999 through October 1, 2007 computed by Reclamation regional office.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE April 2008

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

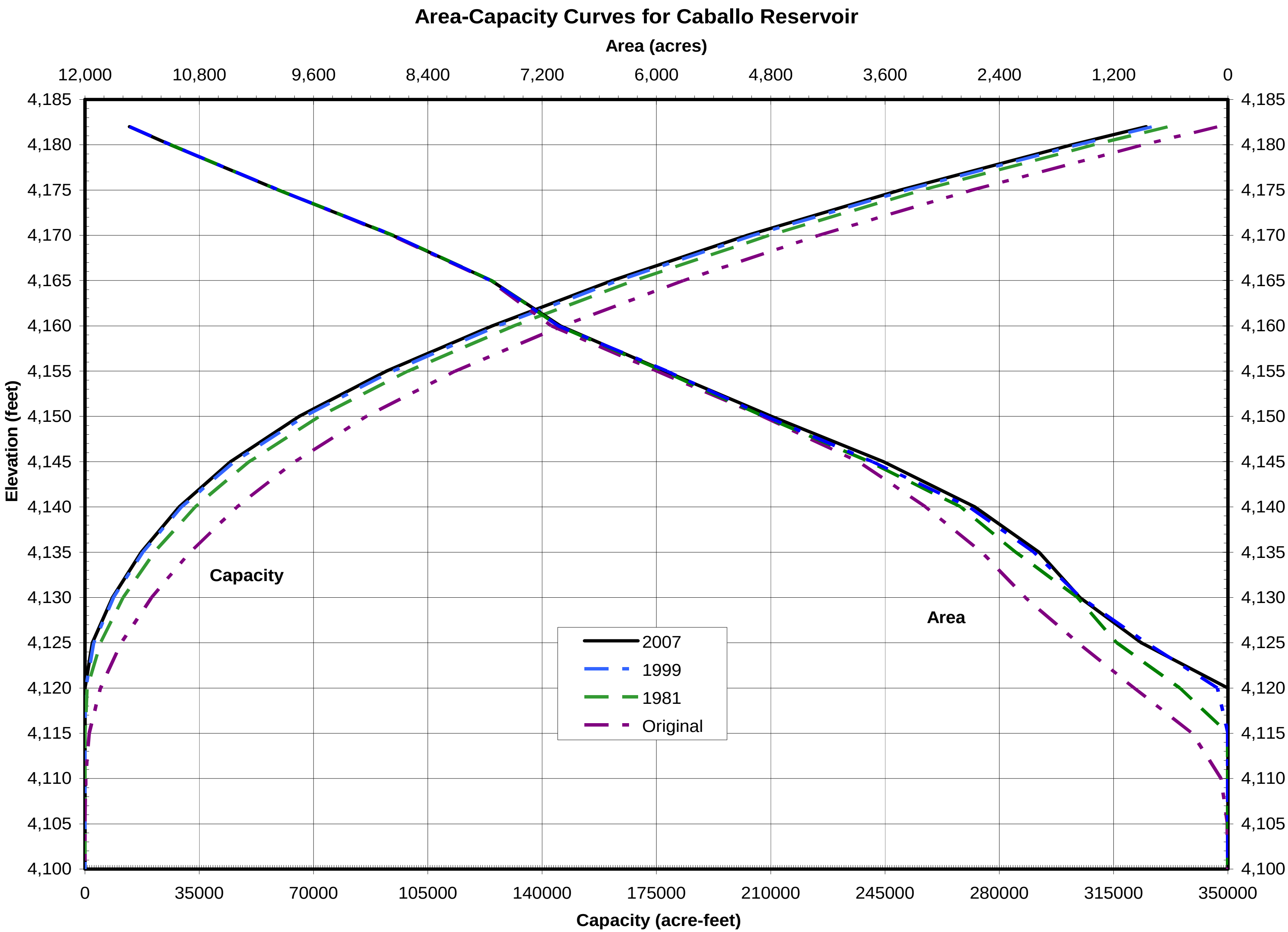


Figure 39 - Caballo Reservoir area and capacity plots.

2007 Storage Capacity

The storage-elevation relationships for Caballo Reservoir, based on the measured surface areas, were generated in the area-capacity program ACAP using the least squares method of curve fitting (Bureau of Reclamation, 1985). This program computes the surface area at 1.0-, 0.1-, and 0.01-foot increments by linear interpolation between basic data contours. The respective capacities and capacity equations are than obtained by integration of the area equations. The initial capacity equation is tested over successive intervals to check whether it fits within an allowable error term (set at 0.000001 for Caballo 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, the final capacity 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 Caballo Reservoir area and capacity computations are listed in a separate set of 2007 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2007). A description of the computations and coefficients output from the ACAP program is included with these tables. The 1938, 1981, 1999 and 2007 area-capacity relationships are listed on table 2 and the curves are plotted on figure 39. As of September 2007, at reservoir water surface elevation 4,182.0, the surface area was 11,532 acres with a total capacity of 324,934 acre-feet.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1938	1938			1981	1981			1999	1999			2007	2007	
	Original	Original	1981	1981	Sediment	Percent	1999	1999	Sediment	Percent	2007	2007	Sediment	Percent	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Computed	Area	Capacity	Volume	Computed	Area	Capacity	Volume	Computed	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Depth
4,182	11,532	346,736	11,532	331,510	15,226	100.0	11,532	326,672	20,064	100.0	11,532	324,934	21,802	100.0	100.0
4,180	11,104	324,100	11,104	308,874	15,226	100.0	11,104	304,035	20,065	100.0	11,104	302,298	21,802	100.0	97.6
4,175	9,967	271,422	9,967	256,196	15,226	100.0	9,967	251,358	20,064	100.0	9,967	249,620	21,802	100.0	91.5
4,170	8,784	224,545	8,767	209,361	15,184	99.7	8,767	204,523	20,022	99.8	8,771	202,775	21,770	99.9	85.4
4,165	7,752	183,205	7,730	168,119	15,086	99.1	7,741	163,255	19,950	99.4	7,737	161,504	21,701	99.5	79.3
4,160	7,103	146,067	7,032	131,214	14,853	97.6	7,031	126,325	19,742	98.4	7,006	124,646	21,421	98.3	73.2
4,155	5,998	113,315	5,930	98,809	14,506	95.3	5,889	94,027	19,288	96.1	5,913	92,348	20,967	96.2	67.1
4,150	4,888	86,100	4,874	71,799	14,301	93.9	4,854	67,170	18,930	94.3	4,794	65,581	20,519	94.1	61.0
4,145	3,880	64,180	3,766	50,199	13,981	91.8	3,733	45,700	18,480	92.1	3,617	44,554	19,626	90.0	54.9
4,140	3,176	46,540	2,804	33,774	12,766	83.8	2,719	29,569	16,971	84.6	2,657	28,869	17,671	81.1	48.8
4,135	2,583	32,142	2,226	21,199	10,943	71.9	2,038	17,677	14,465	72.1	1,982	17,270	14,872	68.2	42.7
4,130	2,129	20,362	1,580	11,684	8,678	57.0	1,546	8,718	11,644	58.0	1,554	8,429	11,933	54.7	36.6
4,125	1,576	11,100	1,168	4,814	6,286	41.3	861	2,701	8,399	41.9	909	2,272	8,828	40.5	30.5
4,120	983	4,702	505	631	4,071	26.7	110	274	4,428	22.1	0	0	4,702	21.6	24.4
4,115	376	1,305	0	0	1,305	8.6	0	0	1,305	6.5	0	0	1,305	6.0	18.3
4,110	71	187	0	0	187	1.2	0	0	187	0.9	0	0	187	0.9	12.2
4,105	4	0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	6.1
4,100	0	0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	0.0

1 Reservoir water surface elevation. Elevations tied to project datum that is 43.3 feet less than NGVD29 and 45.5 feet less than NAVD88.
2 Original, 1938 reservoir surface area.
3 Original, 1938 reservoir capacity.
4 1981 reservoir surface area.
5 1981 reservoir capacity.
6 1981 computed sediment volume, column (3) - column (5).
7 1981 measured sediment in percentage of total sediment of 15,226 acre-feet.
8 1999 reservoir surface area.
9 1999 reservoir capacity.
10 1999 computed sediment volume, column (3) - column (9).
11 1999 measured sediment in percentage of total sediment of 20,064 acre-feet.
12 2007 measured reservoir surface area.
13 2007 reservoir capacity computed using ACAP.
14 2007 measured sediment volume, column (3) - column (13).
15 2007 measured sediment in percentage of total sediment of 21,802 acre-feet.
16 Depth of reservoir expressed in percentage of total depth, 82 feet, from maximum water surface 4,182.0.

Table 2 - Summary of 2007 survey results.

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2007 Reservoir Sediment Analyses

The Caballo Reservoir 1938 (original), 1981, 1999, and 2007 area and capacity values are illustrated on figures 39 and the results are listed on tables 1 and 2. These presentations illustrate the capacity loss that has occurred during the 69.7 years of reservoir operations. This study found that as of September 2007, at reservoir water surface elevation 4,182.0, the surface area was 11,532 acres with a total capacity of 324,934 acre-feet. Since the reservoir's initial filling in 1938, 21,802 acre-feet of sediment have accumulated in Caballo Reservoir. Since the 1999 reservoir survey, 1,738 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1938 is 312.8 acre-feet and since 1999 it is 206.9 acre-feet.

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