CABALLO RESERVOIR
1999 SEDIMENTATION SURVEY

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed Caballo Reservoir in the spring and fall of 1999 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The underwater survey was conducted at reservoir elevation 4,146.8 feet (project datum is 43.3 feet less than NGVD29). The underwater survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portions of the reservoir covered by the survey vessel. The reservoir topography was determined by importing digital images of the contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. The new topographic map of Caballo Reservoir was developed from the combined 1999 underwater measured topography and the USGS quad contours. In October 1999, standard land surveying methods were used to measure portions of the range lines located above the reservoir water surface.

As of April 1999, at reservoir water surface elevation (feet) 4,182.0, the surface area was 11,532 acres with a total capacity of 326,672 acre-feet. Since the reservoir's initial filling in 1938, 20,064 acre-feet of sediment have accumulated in Caballo Reservoir. Since the last reservoir survey in 1981, 4,838 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1938 is 327 acre-feet and since 1981 it is 265 acre-feet.

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CABALLO RESERVOIR

1999 RESERVOIR SURVEY

by

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and

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Sedimentation and River Hydraulics Group
Water Resources Services
Technical Service Center
Denver, Colorado

September 2000

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Kent Collins and Ronald Ferrari of the TSC conducted the April 1999 hydrographic survey of the main body of the reservoir. Kent Collins conducted the fall of 1999 above water survey. Personnel from the Elephant Butte Field Division Office assisted in the surveys. Special thanks to Raymond Lopez for the field assistance and coordination for conducting the surveys. Kent Collins and Ronald Ferrari completed the data processing needed to generate the new topographic maps, area-capacity tables, and reservoir sediment tables. Sharon Nuanes of the TSC completed the final map development.

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 tribes.

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.

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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 Truth or Consequences in Sierra County of south central New Mexico (fig. 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 in the Rio Grande Project which furnishes a full irrigation water supply for approximately 178,000 acres of land and electric power for surrounding communities and industry. Storage lost in Elephant Butte Reservoir due to sediment deposition is partially recovered by Caballo Reservoir storage. Recreation activities provided by Caballo Dam and Reservoir include year-round camping, boating, and fishing.

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 with dimensions as follows:

•Structural height[1]	96 feet	•Crest length	4,558	feet
•Hydraulic height	78 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 circular, 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 downstream tunnel that is horseshoe shaped and concrete lined, 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 is determined to contribute sediment. The majority of the sediment inflow is trapped behind Elephant Butte Reservoir, but several tributaries flow directly into Caballo Reservoir that contribute sediment inflow. At elevation 4,182.0, the reservoir length is around 16.7 miles and average width is 1.1 miles.

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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]Elevation levels are shown in feet. All elevations shown in this report are based on the original project datum established by U.S. Bureau of Reclamation which is 43.3 feet less than National Geodetic Vertical Datum of 1929.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1999 results of the survey of Caballo Reservoir. The 1999 survey was the fifth survey of the reservoir, but the first survey that collected extensive underwater data throughout the reservoir for topography development. The primary objectives of the 1999 survey were to gather data needed to:

- develop reservoir topography
- compute present area-capacity relationships
- estimate storage depletion caused 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 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. Data was also collected on offset lines parallel to these sediment range lines for the underwater area of Caballo Reservoir that could be navigated by the survey vessel. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by a Reclamation gauge during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations.

Since a complete above water survey was not conducted for this study the Caballo Reservoir contours were digitized from the 1980 photo revised U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps. The assigned USGS quad contour elevations were reduced by 43.3 feet to match the Reclamation project datum. The 1999 topographic maps of Caballo Reservoir are a combination of the USGS quad and underwater measured topography.

Standard land surveying techniques were used to survey the upper reservoir sediment range lines that could not be covered during the bathymetric survey by the larger survey vessel. The survey of range lines 16 through 31 were collected in the fall of 1999 when releases from Elephant Butte Reservoir were minimal. Standard land survey techniques were used to measure any noted changes on these range lines. The results from these surveys were used to develop the 1999 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 1999 Caballo Reservoir survey results. The 1999 survey determined that the reservoir has a total storage capacity of 326,672 acre-feet and a surface area of 11,532 acres at reservoir elevation 4,182.0. The 1999 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 survey is 20,064 acre-feet representing a total loss in reservoir capacity of 5.8 percent. The average annual sediment accumulation rate for the 61.3 years of record is 327 acre-feet.

RESERVOIR OPERATIONS

Caballo Reservoir inflow and end-of-month stage records are listed in table 2 for water years 1938 through April 1999. The average annual inflow based on the 61.3 years of record was 688,700 acre-feet. The average annual inflow since the last reservoir survey, January 1981, was 823,390 acre-feet. The streamflow records of the gauging station located below Elephant Butte Dam, New Mexico were used to represent the inflow for this period of records. It must be noted that these records only reflect the total inflow from Elephant Butte Dam releases. The table shows that since the last survey the reservoir operation has ranged from elevation 4,130.2 in water year 1984 to elevation 4,178.5 in water year 1988.

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. The hydrographic system contained on the survey vessel consisted of a GPS receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting underwater data. Power to the equipment was supplied by an on-board generator.

The shore equipment included an identical second GPS receiver with external radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. To obtain the maximum radio transmission range, known datum points with clear line-of-sight to the survey boat were selected. The power for the shore unit was provided by a 12-volt battery.

GPS Technology and Equipment

The hydrographic positioning system used at Caballo Reservoir was Navigation Satellite Timing and Ranging (NAVSTAR) GPS; an all-weather, radio-based, satellite navigation system that enables users to accurately determine three-dimensional position. The NAVSTAR system's primary mission is to provide passive global positioning and navigation for land-, air-, and sea-based strategic and tactical forces and is operated and maintained by the Department of Defense (DOD). The GPS receiver measures the distances between the satellites and itself and determines the receiver's position from intersections of the multiple-range vectors. Distances are determined by accurately measuring the time a signal pulse takes to travel from the satellite to the receiver.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. The satellites transmit signals to the GPS receivers for distance measurements along with data messages about their exact orbital location and operational status. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time). For this hydrographic survey, the altitude (Caballo's water surface elevation parameter) was known, which in theory meant only three satellite observations were needed to track the survey vessel. During the Caballo Reservoir survey, the best available satellites, usually 5 or more, were used for position calculations.

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision, the geometric position of the satellites, and selective availability. The absolute position determined by a single receiver can have errors of up to 100 meters. A method of collection to resolve or cancel the inherent errors of GPS is called differential GPS (DGPS). DGPS was used during the reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the GPS position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over the geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel. For the Caballo Reservoir survey, position corrections were determined by the master receiver and transmitted via a ultra-high frequency (UHF) radio link every second to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS results in sub-meter to meter positional accuracies for the survey vessel compared to positional accuracies of 100 meters with a single receiver.

The Sedimentation and River Hydraulics Group began using Real-time Kinematic (RTK) GPS with the 1999 Caballo and Elephant Butte Reservoirs being the first major use of the collection system. The major benefit of RTK versus DGPS is that precise heights can be measured in real time for monitoring water surface elevation changes along with precise positions. The basic outputs from an RTK receiver are precise 3D coordinates in latitude, longitude, and height format with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. This output is on the GPS datum of WGS-84 which the hydrographic collection software converted into New Mexico's NAD83 central state plane coordinate zone. A RTK GPS system employs two receivers that track the same satellites simultaneously just like with DGPS. The receivers track the L1 C/A code and full cycle L1 and L2 carrier phases. The additional data logged from the second frequency (L2) allows the on-the-fly centimeter level measurements. Due to internal radio problems with the RTK GPS system during the Caballo and Elephant Butte surveys, the units were mainly used to set the control point locations that were used during the underwater collection. A DGPS system was used during the majority of the underwater collection providing one to two meter position accuracies.

Survey Method and Equipment

The 1999 hydrographic survey was the latest survey of the reservoir with the previous surveys being the original in 1938, 1951, 1957, and 1981 (Bureau of Reclamation, 1984). A layout of the reservoir sedimentation range line system is shown on figures 3 and 4. The 1999 underwater collection was conducted on April 14 at reservoir water surface elevation 4,146.8 (Reclamation project datum). The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS capable of determining sounding locations within the reservoir. The survey system continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across the previously established sediment range lines from range line 1 to range line 15. For the purpose of mapping the reservoir bottom, offset grid lines parallel to these sediment range lines were also collected to cover the underwater area of the reservoir. Most of the transects (grid lines) were run approximately in a perpendicular direction to the center line of the reservoir. Data was also collected along the shore as the boat traversed to the next transect. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined range lines and parallel offsets. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing.

The 1999 underwater data were collected by a depth sounder that was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. 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 printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified. The water surface elevation at the dam, recorded by a Reclamation gauge, was used to convert the sonic depth measurements to lake-bottom elevations. As stated previously the elevations are all tied to the project datum which is published as being 43.3 feet less than National Geodetic Vertical Datum of 1929 (NGVD29).

The upper portion of the reservoir not covered by the 1999 large boat survey, sediment range lines 15 through 31, were surveyed in the fall of 1999. Standard land surveying techniques were used to survey these range lines. The survey of these range lines was mainly conducted on the portions that indicated possible change. Spot check measurements were conducted on the range lines to confirm there were no significant changes since the previous surveys.

Caballo Reservoir Datum

A RTK GPS control survey was conducted to establish horizontal and vertical control points around the reservoir. The horizontal control was established in New Mexico state plane coordinates, central zone, in the North American Datum of 1983 (NAD83). The vertical control for the established points was in the National American Vertical Datum of 1988 (NAVD88). RTK GPS water surface measurements were periodically taken and a comparison of the reservoir water surface recorded by the Reclamation gauge 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. The RTK GPS control was conducted with the base set on the NGS datum point "C 366" located downstream of Caballo Dam.

RESERVOIR TOPOGRAPHY DEVELOPMENT

Using ARC/INFO, the topography of Caballo Reservoir was developed from the 1999 collected underwater data and the 1980 photo revised USGS quad maps of the reservoir area. ARC/INFO is a software package for development and analysis of geographic information system (GIS) layers and development of interactive GIS applications (ESRI, 1992). GIS technology provides a means of organizing and interpreting large data sets.

The upper contours of Caballo Reservoir were developed by digitizing the contour lines labeled elevation 4182, 4200, 4220, and 4225 on the USGS quad maps that covered the Caballo Reservoir area. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The quad contours were transformed to New Mexico's NAD 1983 state plane central coordinate zone using the ARC/INFO PROJECT command. The assigned quad contour elevations were reduced by 43.3 feet to match the Reclamation project datum.

The contours digitized from USGS quad maps were used to perform a clip or boundary around the edge of the 1999 underwater data set such that interpolation was not allowed to occur outside of this boundary. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command.

Contours for elevations 4140.0 and below were computed from the underwater data set 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 a polygon or boundary clip. This 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 preserving all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great 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 Caballo Reservoir TIN. In addition, the contours were generalized by eliminating certain vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had little bearing on the computation of surface areas and volumes for Caballo Reservoir since the areas were calculated from the developed TIN. The contour topography at 2-foot intervals is presented on figures 5 through 7, drawing numbers 24-D-1869 through 24-D-1871.

RESERVOIR SEDIMENT DISTRIBUTION

Longitudinal Distribution

To illustrate the sediment distribution throughout the reservoir a longitudinal profile was plotted for the original, 1981 and 1999 reservoir conditions (figure 8). The difference between the original thalweg and the 1981 and 1999 thalweg represents 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 profiles. The plot illustrates sediment deposits below range line 23 with the greatest depths of longitudinal sediment deposits occurring downstream of range line 17. This pattern of sediment deposition is probably due to reservoir operation since it is usually drawn down below elevation 4140 the majority of the years. Even though Elephant Butte Reservoir traps the majority of the sediment inflow there are several side tributaries into Caballo Reservoir that provide sediment inflow during high flow conditions.

Lateral Distribution

Ground profiles of the 32 reservoir sedimentation ranges are shown on figures 9 through 40. These profiles illustrate the general lateral distribution of sediments in the reservoir. The plots illustrate the survey results from the original, 1981, and 1999 surveys. During the 1981 survey, the above-water portions of each range line from each range end to the water edge were measured. For the main portion of the reservoir, range lines 1 through 15, the results from the 1981 survey were used to develop the range line plots for the areas not covered by the1999 survey. The 1981 data were also used to complete plots for the range lines above 15 for the areas of the profile that the 1999 field crew determined there was no significant change.

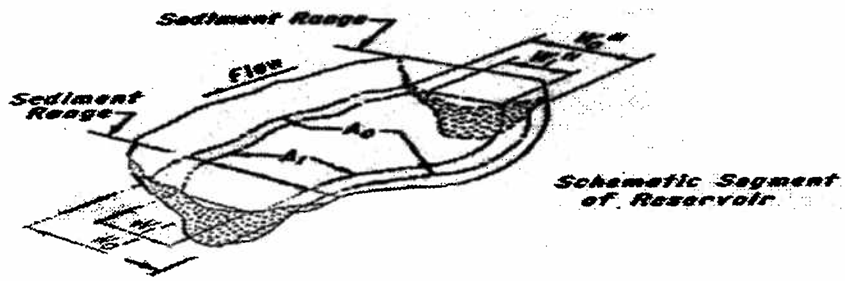
SEDIMENT ANALYSES

As indicated in the reservoir topography development section, new reservoir topography and maps were developed from the 1999 underwater data and the USGS quad contours. Due to the need of using the 1980 USGS contours to complete the topography development of the upper contours of the reservoir, it was decided to utilize the previous method for calculating sediment accumulation which is called the width adjustment method.

Width adjustment method

In some earlier resurveys new contour maps were drawn from range-line survey data where all the contours between collected range-lines for the new map were estimated by 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 abandoned for the constant factor method, which was further modified to the width adjustment method described by Pemberton and Blanton (1980). In the width adjustment method, illustrated on figure 41, 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.



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

$$A_1 = A_o \left(\frac{\frac{W_1' + W_1''}{2}}{\frac{W_o' + W_o''}{2}} \right)$$

Figure 41 - Width adjustment method for revising contour areas

On the original full scale base topography map of the reservoir, 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 for maximum water surface of 4182 and for each 5-foot contour from elevation 4180 to the lowest contour area within each segment. For the original and 1999 measured range lines, the width for all contours for each segment was computed for the 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 were added together to develop the new contour elevation versus 1999 surface areas used in the area-capacity computations.

RESERVOIR AREA AND CAPACITY

1999 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). Starting from the 1999 minimum elevation 4,115, the 1999 measured surface areas at 5-foot contour intervals from elevation 4,120.0 to elevation 4,180.0 and elevation 4,182.0 provided the control parameters for computing the 1999 Caballo Reservoir capacity. The program can compute an area and capacity at elevation increments 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 Caballo Reservoir. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from a 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. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

$$y = a_1 + a_2x + a_3x^2$$

where:

y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the 1999 Caballo Reservoir area and capacity computations are listed in table 1 and columns (8) and (9) of table 2. Listed in columns (2) and (3) of table 2 are the original surface areas and recomputed capacity values. A separate set of 1999 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1999). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1999 area-capacity curves are plotted on figure 42. As of April 1999, at elevation 4,182.0, the surface area was 11,532 acres with a total capacity of 326,672 acre-feet.

ANALYSES OF RESULTS

The Caballo Reservoir original, 1981 and 1999 area and capacity values are illustrated on figures 8 and 42 and the results are listed on tables 1 and 2. These presentations illustrate the capacity difference that has occurred during the 61.3 years of reservoir operations. This study found that as of April 1999, at reservoir water surface elevation (feet) 4,182.0, the surface area was 11,532 acres with a total capacity of 326,672 acre-feet. Since the reservoir's initial filling in 1938, 20,064 acre-feet of sediment have accumulated in Caballo Reservoir. Since the last reservoir survey in 1981, 4,838 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1938 is 327 acre-feet and since 1981 it is 265 acre-feet.

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RESERVOIR SEDIMENT
DATA SUMMARY

Caballo Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Rio Grande River	3. STATE New Mexico
	4. SEC. 19 TWP. 16 S RANGE 4 W	5. NEAREST PO Truth or Consequences	6. COUNTY Sierra
	7. LAT 32° 53' 05" LONG 107° 17' 30"	8. TOP OF DAM ELEVATION 4190[1]	9. SPILLWAY CREST EL 4161.0[2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN
	a. SURCHARGE					
	b. FLOOD CONTROL					
	c. MULTIPLE USE	4182.0[3]	11,532	346,736	346,736	1/6/38
	d. WATER SUPPLY					16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. CONSERVATION					
	g. INACTIVE	4104.0	0	0	0	2/8/38
	17. LENGTH OF RESERVOIR 16.7 MILES			AVG. WIDTH OF RESERVOIR 1.08 MILES		

BASIN	18. TOTAL DRAINAGE AREA 27,260 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 8.71[4] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 1,237[5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.47[6] INCHES
	20. LENGTH 27.5 MILES AV. WIDTH 45 MILES	24. MEAN ANNUAL RUNOFF 688,700[7] ACRE-FEET
	21. MAX. ELEVATION 10,000 MIN. ELEVATION 4,100.5	25. ANNUAL TEMP. MEAN 64°F RANGE -16°F to 111°F[4]

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS.	28. ACCL. YRS.	29. TYPE OF SURVEY	30. NO OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I RATIO, AF/AF
1/6/38[8]			Contour(D)	5-ft(CI)	11,532	346,736	.52
1/15/81	43.0	43.0	Range(D)	32(R)	11,532	331,510	.50
4/14/99	18.3	61.3	Range(D)	32(R)[9]	11,532	326,672	.51

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
1/6/38						
1/15/81[8]		631,380[7]	1,930,000	27,149,333	631,380	27,149,333
4/14/99		823,390	1,693,000	15,067,967	688,700	42,217,300

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.²-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.²-YR.
1/6/38						
1/15/81[8]	15,226	354	0.286	15,226	354	0.286
4/14/99	4,838	265	0.214	20,064	327	0.265

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
1/6/38							
1/15/81[8]	75	467	467	0.102	4.391	673	673
4/14/99				0.094	5.787		

Table 1. - Reservoir sediment data summary (page 1 of 3).

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION.											
	77-67	67-57	57-47	47-37	37-27	27-17	17-7	7-CR				
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
	6.5	35.4	30.2	20.0	4.0	3.3	0.6	0.0				

26. DATE OF SURVEY	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	100-105	105-110	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

45. RANGE IN RESERVOIR OPERATION[10]

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1938	4129.4	4110.2	738,600
1939	4155.2	4108.1	915,600	1940	4154.2	4123.9	714,300
1941	4158.8	4119.7	692,800	1942	4182.1	4133.7	1,930,000
1943	4181.1	4119.2	807,000	1944	4176.4	4123.1	875,800
1945	4178.1	4120.6	843,200	1946	4175.9	4121.1	858,800
1947	4178.8	4119.2	707,900	1948	4165.6	4125.2	742,800
1949	4164.8	4131.8	754,600	1950	4175.2	4132.5	720,800
1951	4162.2	4121.9	451,100	1952	4153.4	4120.0	543,000
1953	4164.4	4122.0	553,700	1954	4138.6	4124.1	245,400
1955	4135.8	4121.5	211,800	1956	4131.2	4121.3	253,600
1957	4133.8	4120.2	384,400	1958	4159.1	4121.7	791,700
1959	4172.6	4133.1	699,500	1960	4160.6	4119.5	681,800
1961	4155.9	4123.7	578,600	1962	4160.1	4129.2	691,500
1963	4154.2	4134.7	509,900	1964	4138.2	4122.3	183,400
1965	4144.2	4125.5	520,900	1966	4162.0	4128.3	660,900
1967	4155.0	4133.7	433,100	1968	4162.6	4134.9	548,500
1969	4150.5	4137.6	687,000	1970	4150.7	4132.7	685,600
1971	4149.0	4122.2	516,500	1972	4143.8	4124.6	300,200
1973	4158.4	4137.0	604,300	1974	4155.2	4132.0	672,900
1975	4152.9	4134.0	646,500	1976	4152.0	4135.8	661.900
1977	4160.0	4126.3	395,900	1978	4145.0	4127.6	375,400
1979	4158.1	4130.1	574,400	1980	4160.9	4130.3	670,300
1981	4162.0	4129.1	635,300	1982	4155.1	4130.8	691,700
1983	4160.9	4139.7	662,500	1984	4158.9	4130.2	650,300
1985	4172.9	4135.9	901,000	1986	4176.7	4173.4	1,101,000
1987	4174.8	4172.3	1,693,000	1988	4178.5	4152.2	685,300
1989	4165.8	4148.1	730,800	1990	4150.1	4135.6	666,100
1991	4148.9	4134.0	573,100	1992	4154.7	4138.1	705,800
1993	4172.4	4136.5	1,061,100	1994	4178.5	4143.9	711,100
1995	4177.3	4138.4	1,184,000	1996	4171.4	4137.9	698,200
1997	4151.8	4140.2	741,300	1998	4150.3	4141.2	825,900
1999	4151.3	4139.1	268,900				

46. ELEVATION - AREA - CAPACITY DATA FOR **1938 CAPACITY**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4105	4	0	4110	71	187	4115	376	1,305
4120	983	4,702	4125	1,576	11,100	4130	2,129	20,362
4135	2,583	32,142	4140	3,176	46,540	4145	3,880	64,180
4150	4,888	86,100	4155	5,998	113,315	4160	7,103	146,067
4165	7,752	183,205	4170	8,784	224,545	4175	9,967	271,442
4180	11,104	324,100	4182	11,532	346,736			
1999	**Survey**		**1999**	**Survey**		**1999**	**Survey**	
4105	0	0	4110	0	0	4115	0	0
4120	110	275	4125	861	2,701	4130	1,546	8,718
4135	2,038	17,678	4140	2,719	29,569	4145	3,733	45,700
4150	4,854	67,170	4155	5,889	94,027	4160	7,031	126,326
4165	7,741	163,255	4170	8,767	204,524	4175	9,967	251,358
4180	11,104	304,036	4182	11,532	326,672			

Table 1. - Reservoir sediment data summary (page 2 of 3).

47. REMARKS AND REFERENCES

[1] All elevations are tied to project datum which is 43.3 feet less than National Geodetic Vertical Datum of 1929. Top of parapet wall is elevation 4193.0.

[2] Spillway crest elevation 4161.0. Top of active conservation pool is elevation 4172.44. Top of exclusive flood control pool is 4182.00, which is top of radial gates. With splash plate, crest elevation is 4183.5.

[3] Exclusive flood control pool is the top 100,000 AF (from elevation 4172.44 to elevation 4182.00). Below elevation 4172.44 is the Conservation Storage amount used for irrigation.

[4] Bureau of Reclamation Project Data Book, 1981. Reclamation site: http://dataweb.usbr.gov. Annual precipitation at dam of 8.71 inches (1936-1992) from NOAA/NWS.

[5] Remove drainage area above Elephant Butte Reservoir.

[6] Calculated using mean annual runoff value of 640,825 acre-feet (item 24), water years 1981 through 1999. Measured Rio Grande flows from gage below Elephant Butte Dam (No. 08361000).

[7] Annual inflows from 2/81 through 4/99 measured Rio Grande river flows at Rio Grande Below Elephant Butte Dam gage (No. 08361000).

[8] Values from 1938 through 1981 from 1981 Sedimentation Survey report.

[9] Parallel lines for underwater cross section data were collected at 300 foot spacing from the dam upstream to range line 5. From range line 5 upstream to range line 15, 600 foot spacing was used for underwater data collection. Range lines 15 through 31 were collected by land survey where accessible. The width adjustment method was used compute new area and capacity tables as was done for previous surveys.

[10] February 1938 through April 1999 USGS records, by water year.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE November 2000

Table 1. - Reservoir sediment data summary (page 3 of 3).

(1) Elevation (ft)	(2) 1938 Original Area (acres)	(3) 1938 Original Capacity (acre-ft)	(4) 1981 Survey Area (acres)	(5) 1981 Survey Capacity (acre-ft)	(6) 1981 Measured Sediment Volume (acre-ft)	(7) 1981 Percent of Sediment (%)	(8) 1999 Survey Area (acres)	(9) 1999 Survey Capacity (acre-ft)	(10) 1999 Measured Sediment Volume (acre-ft)	(11) 1999 Percent of Sediment (%)	(12) Percent of Reservoir Depth (%)
4182.0	11532	346736	11532	331510	15226	100.0	11532	326672	20064	100.0	100.0
4180.0	11104	324100	11104	308874	15226	100.0	11104	304035	20065	100.0	97.4
4175.0	9967	271422	9967	256196	15226	100.0	9967	251358	20064	100.0	90.9
4170.0	8784	224545	8767	209361	15184	99.7	8767	204523	20022	99.8	84.4
4165.0	7752	183205	7730	168119	15086	99.1	7741	163255	19950	99.4	77.9
4160.0	7103	146067	7032	131214	14853	97.6	7031	126325	19742	98.4	71.4
4155.0	5998	113315	5930	98809	14506	95.3	5889	94027	19288	96.1	64.9
4150.0	4888	86100	4874	71799	14301	93.9	4854	67170	18930	94.3	58.4
4145.0	3880	64180	3766	50199	13981	91.8	3733	45700	18480	92.1	51.9
4140.0	3176	46540	2804	33774	12766	83.8	2719	29569	16971	84.6	45.5
4135.0	2583	32142	2226	21199	10943	71.9	2038	17677	14465	72.1	39.0
4130.0	2129	20362	1580	11684	8678	57.0	1546	8718	11644	58.0	32.5
4125.0	1576	11100	1168	4814	6286	41.3	861	2701	8399	41.9	26.0
4120.0	983	4702	505	631	4071	26.7	110	274	4428	22.1	19.5
4115.0	376	1305	0	0	1305	8.6	0	0	1305	6.5	13.0
4110.0	71	187			187	1.2			187	0.9	6.5
4105.0	4	0			0	0.0			0	0.0	0.0
4100.0	0										

Explantation of Columns:

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area.
(3) Original reservoir capacity.
(4) Reservoir surface area determined from 1981 survey.
(5) 1981 survey reservoir capacity computed using ACAP
(6) Measured sediment volume = column (3) - column (5)
(7) Measured sediment expressed as percentage of total measured sediment (15,226 acre-feet).
(8) Reservoir surface area determined from 1999 survey.
(9) 1999 survey reservoir capacity computed using ACAP
(10) Measured sediment volume = column (3) - column (9)
(11) Measured sediment expressed as percentage of total measured sediment (20,064 acre-feet).
(12) Depth of reservoir expressed as percentage of total depth (72.0 feet).

Table 2 - Summary of 1999 survey results

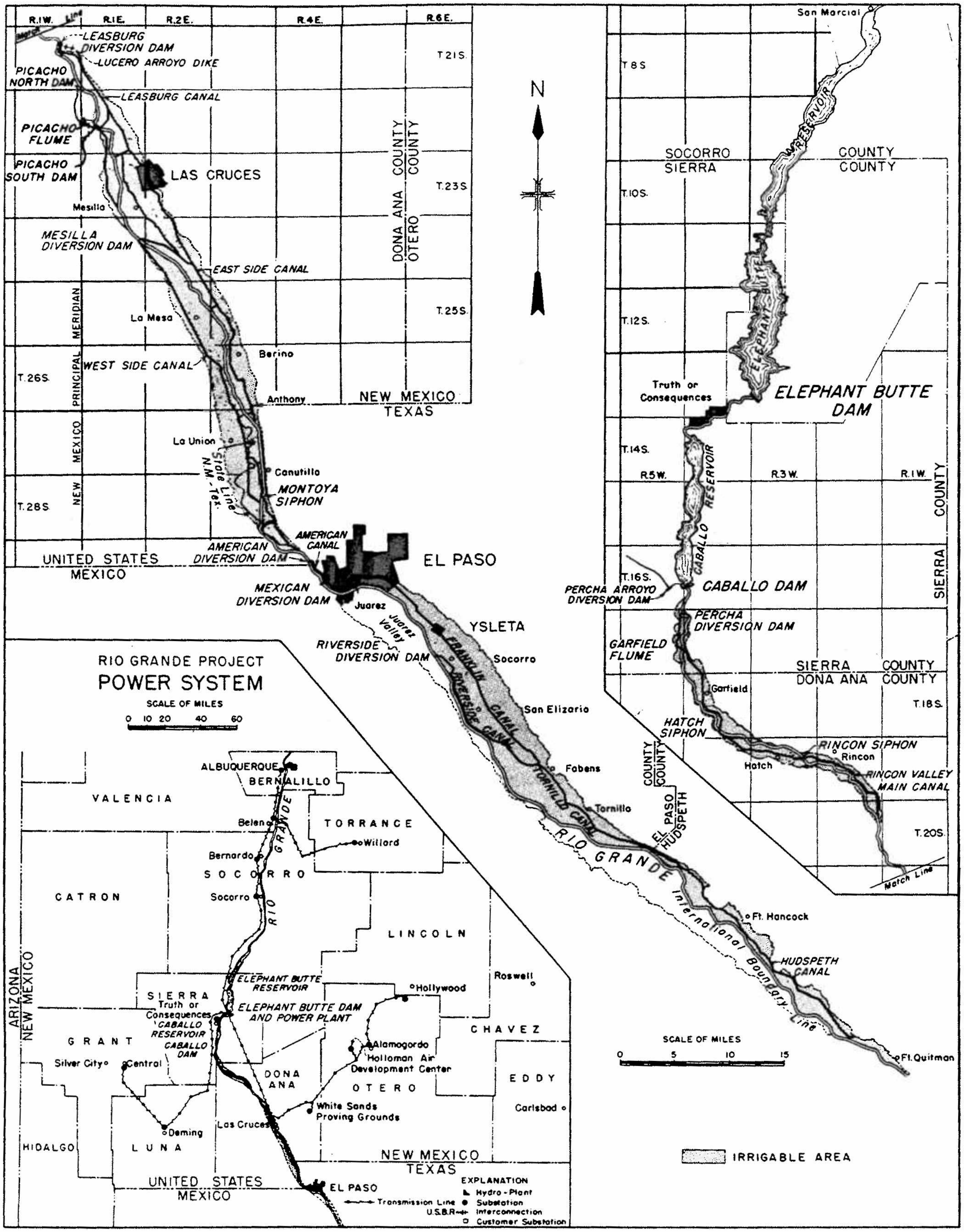

Figure 1 - Caballo Reservoir location map.

Space intentionally left blank due to security concerns

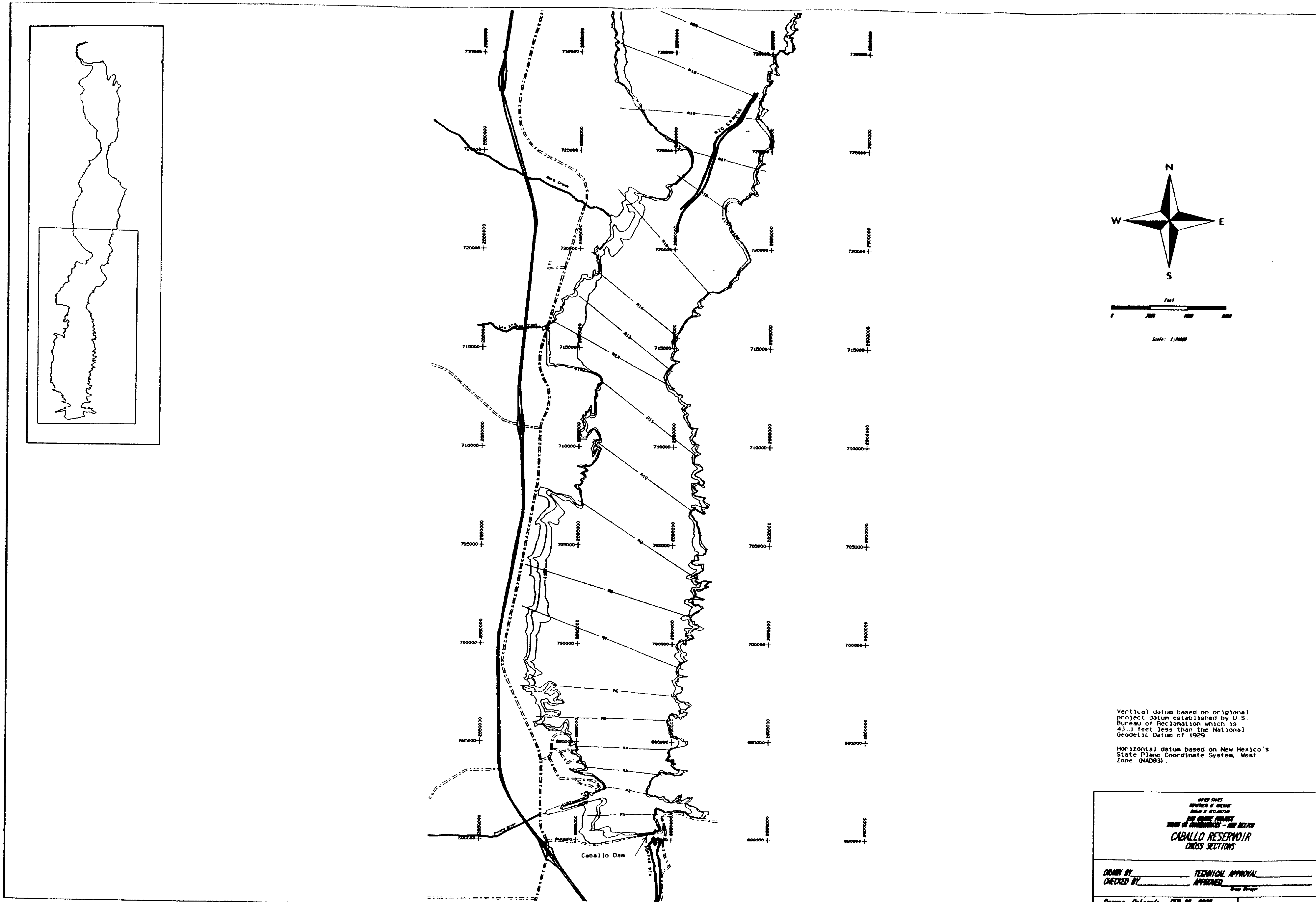

Figure 3 - Caballo Reservoir sedimentation range lines

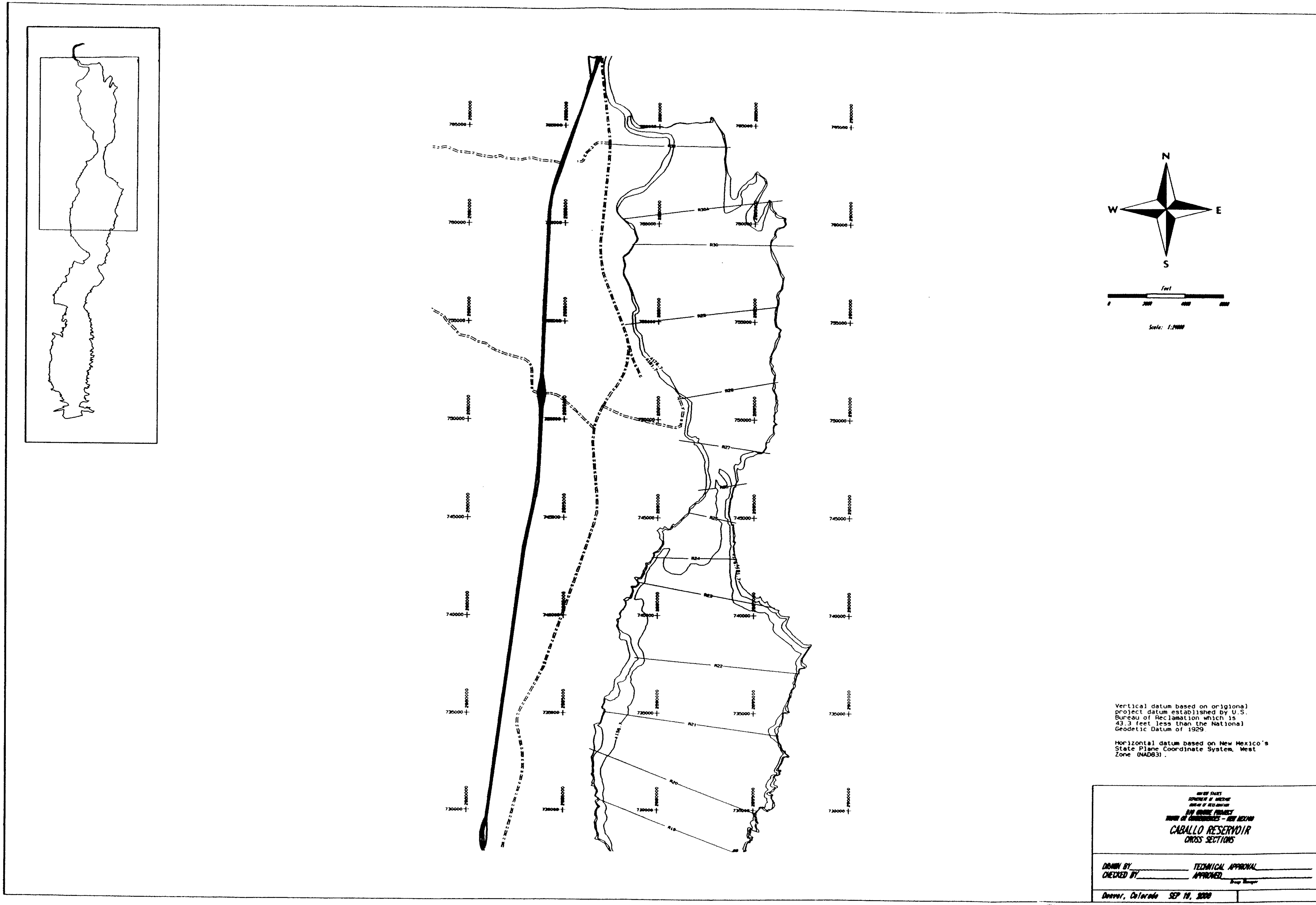

Figure 4 - Caballo Reservoir sedimentation range lines

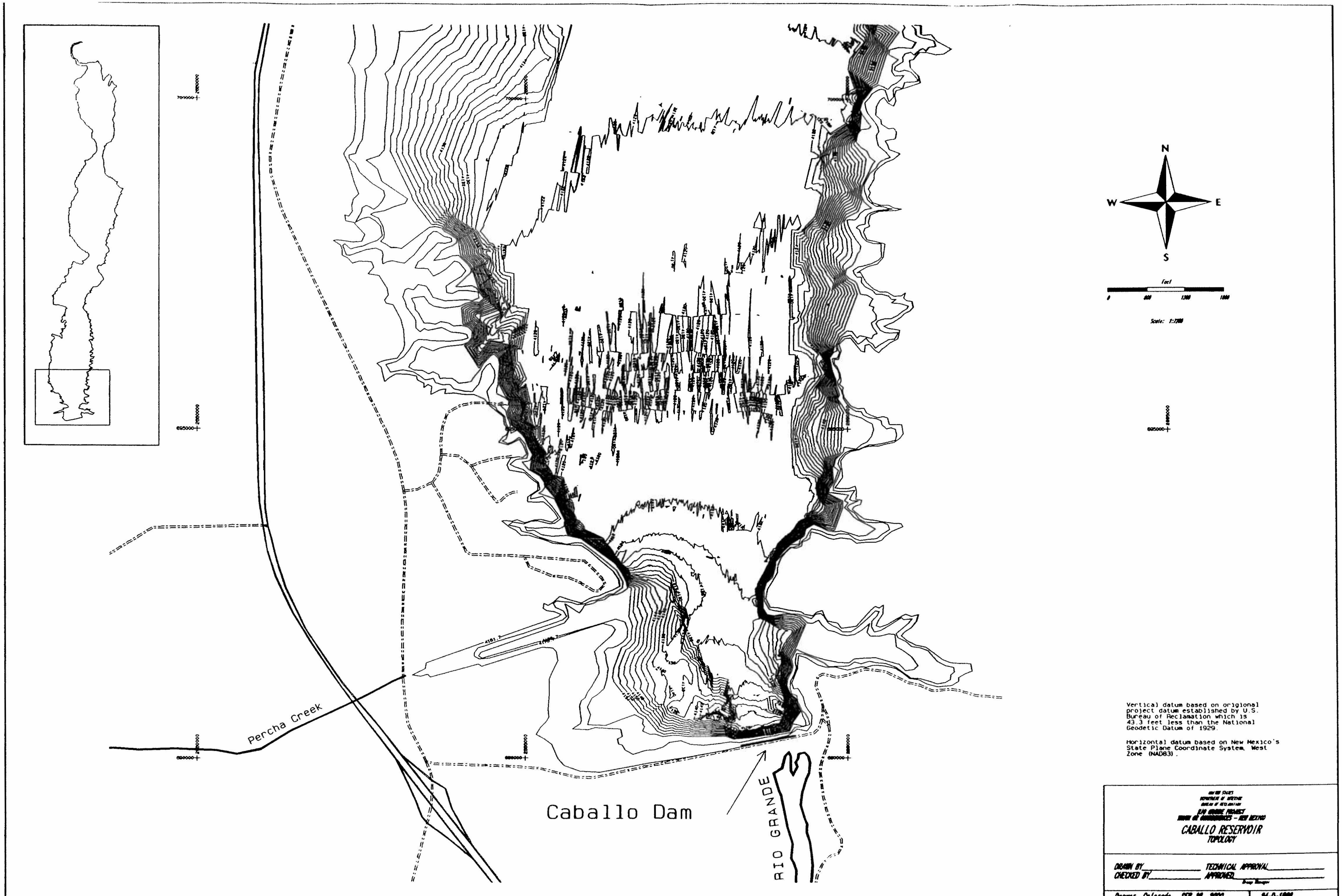

Figure 5 - Caballo Reservoir topographic map, No. 24-D-1869

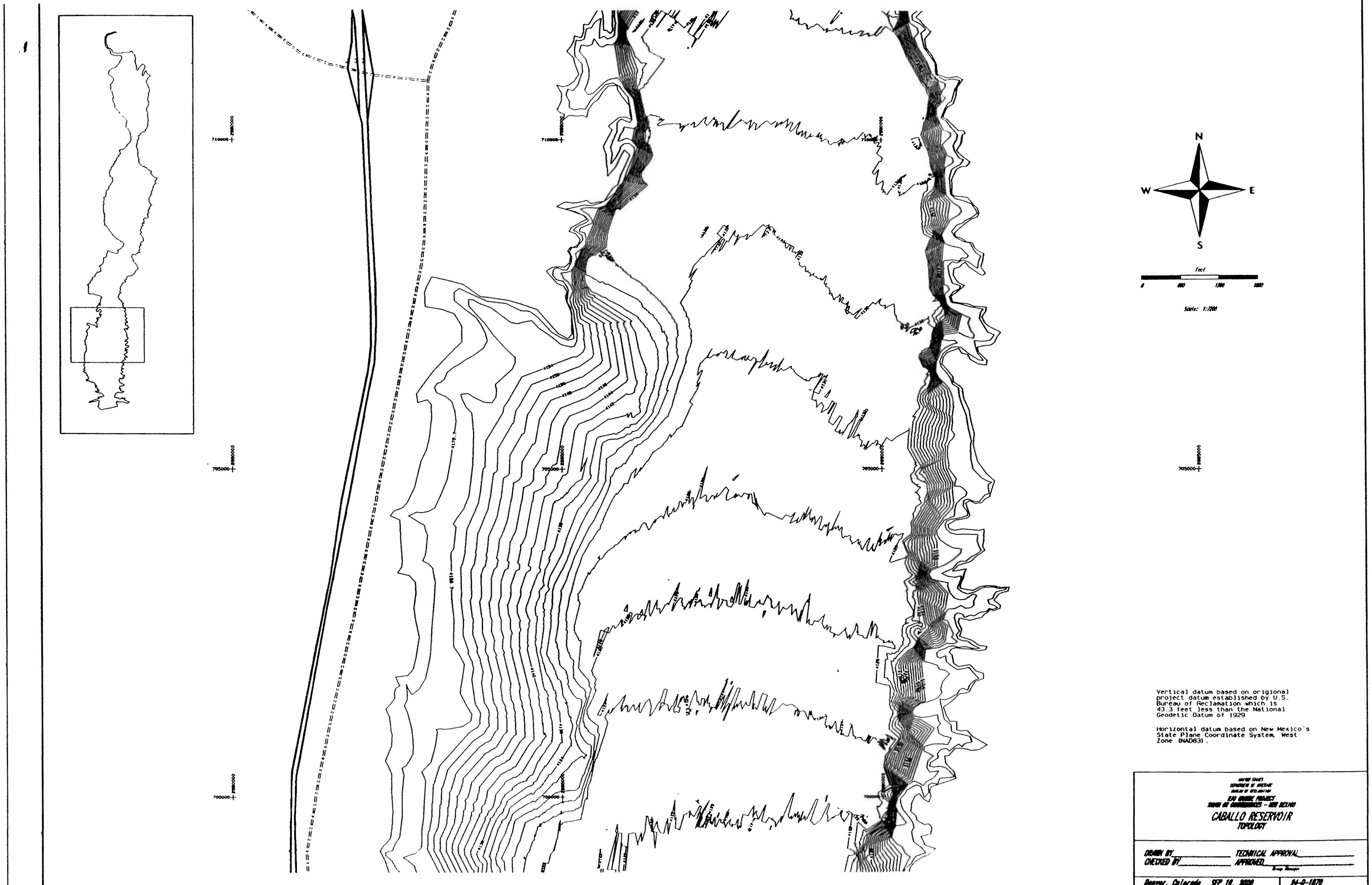

Figure 6 - Caballo Reservoir topographic map, No. 24-D-1870

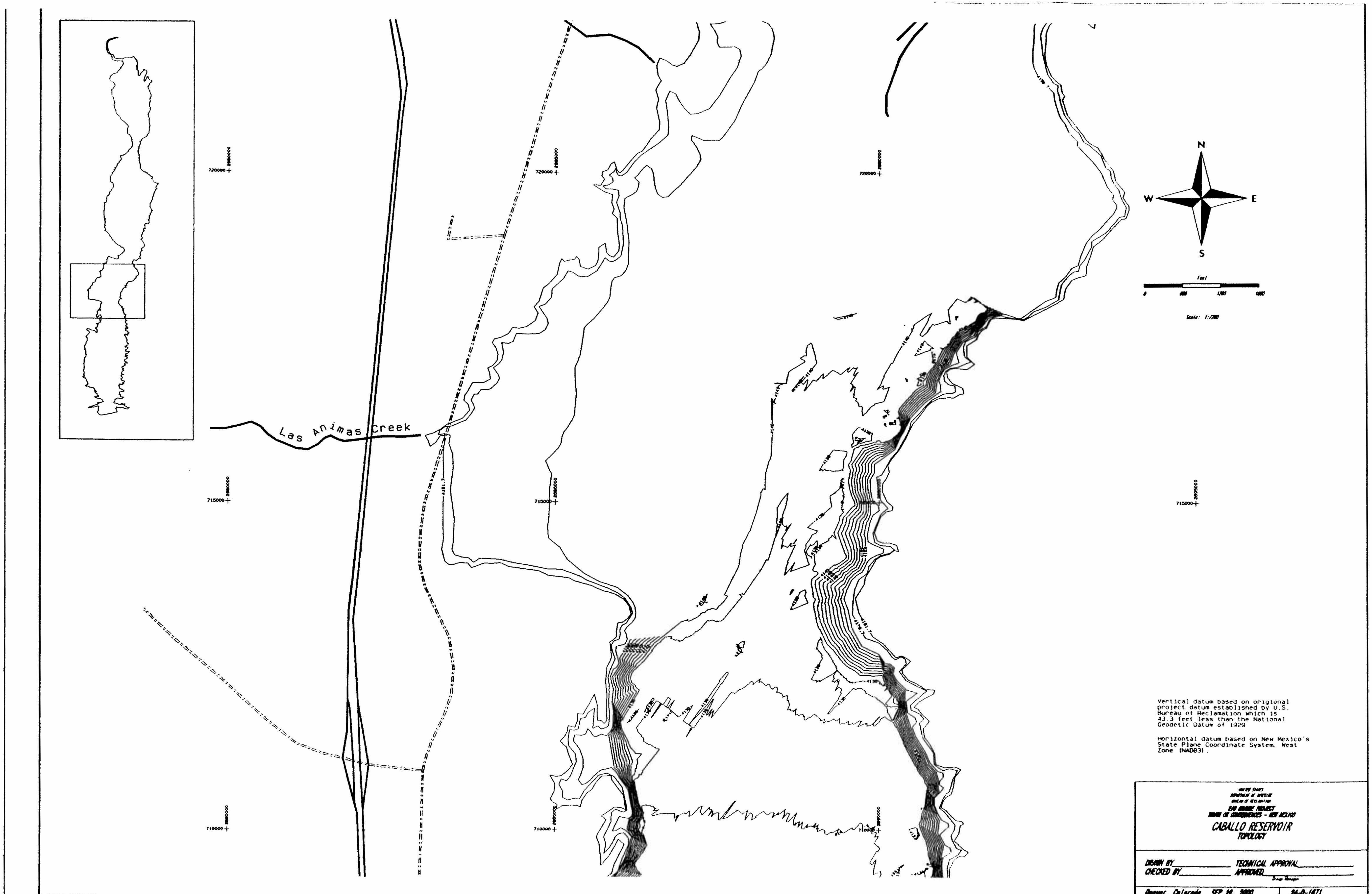

Figure 7 - Caballo Reservoir topographic map, No. 24-D-1871

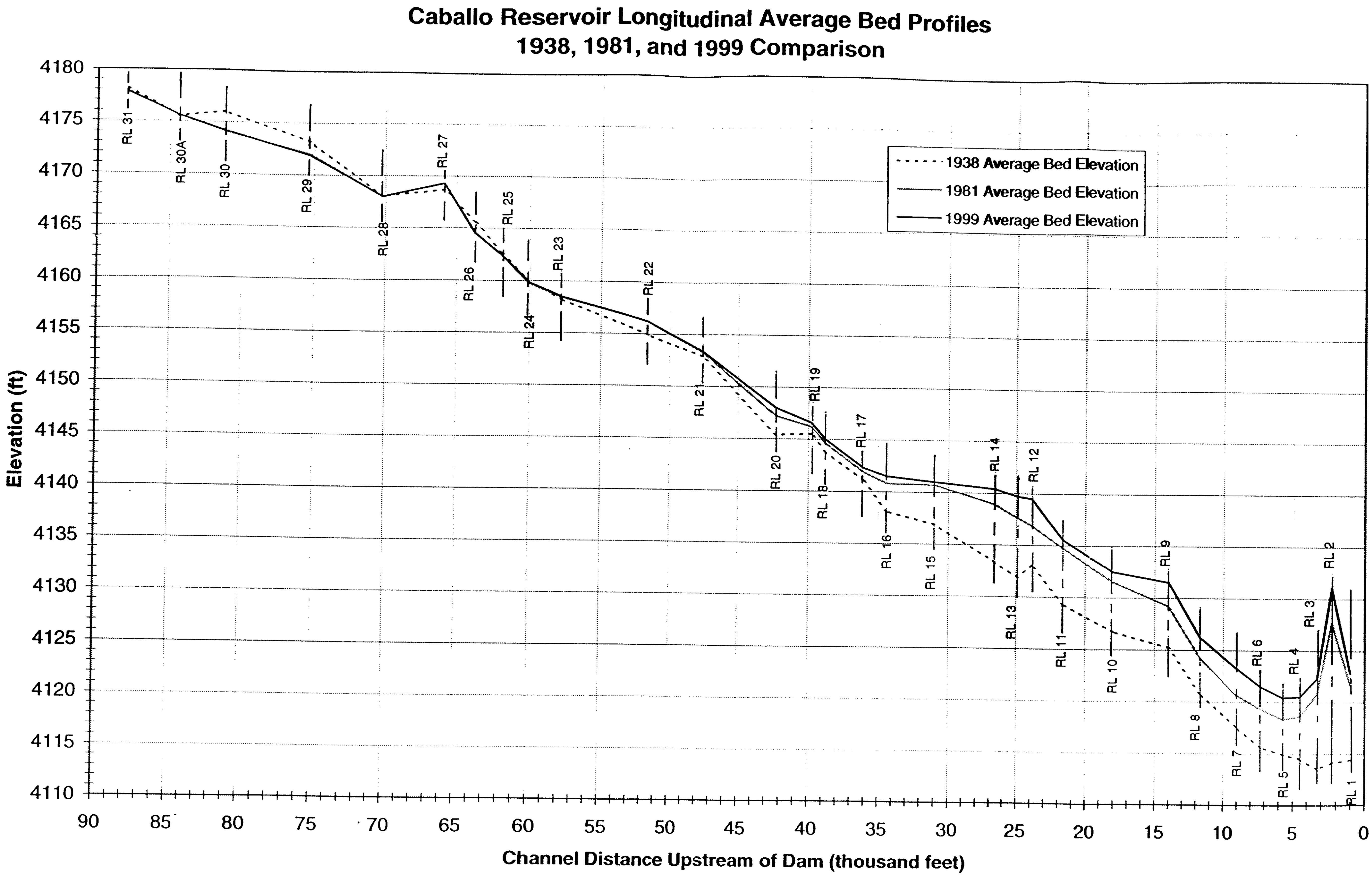

Figure 8. - Caballo Reservoir Longitudinal Profiles

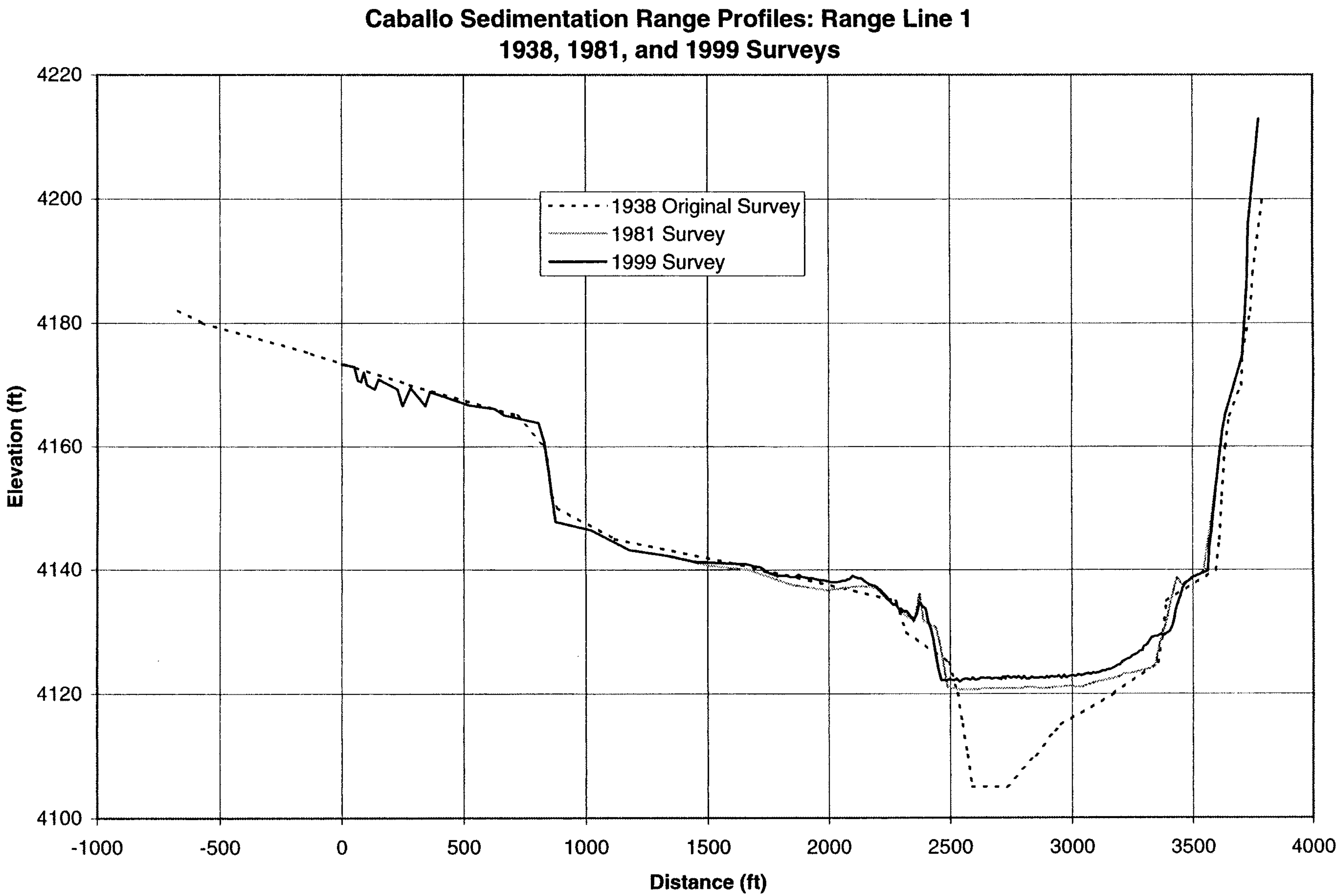

Figure 9. - Sedimentation range profiles for 1938, 1981, and 1999 - range 1.

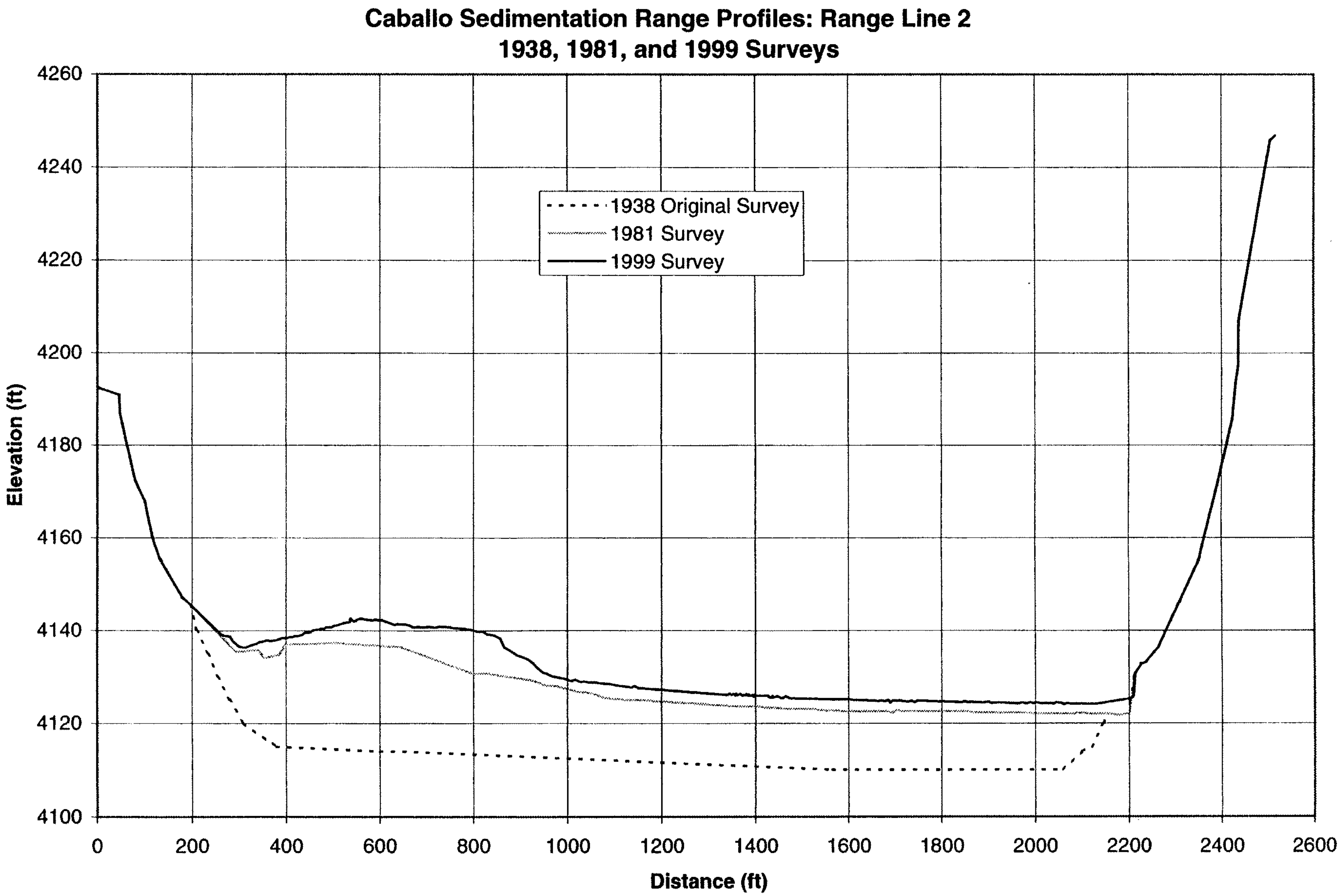

Figure 10. - Sedimentation range profiles for 1938, 1981, and 1999 - range 2.

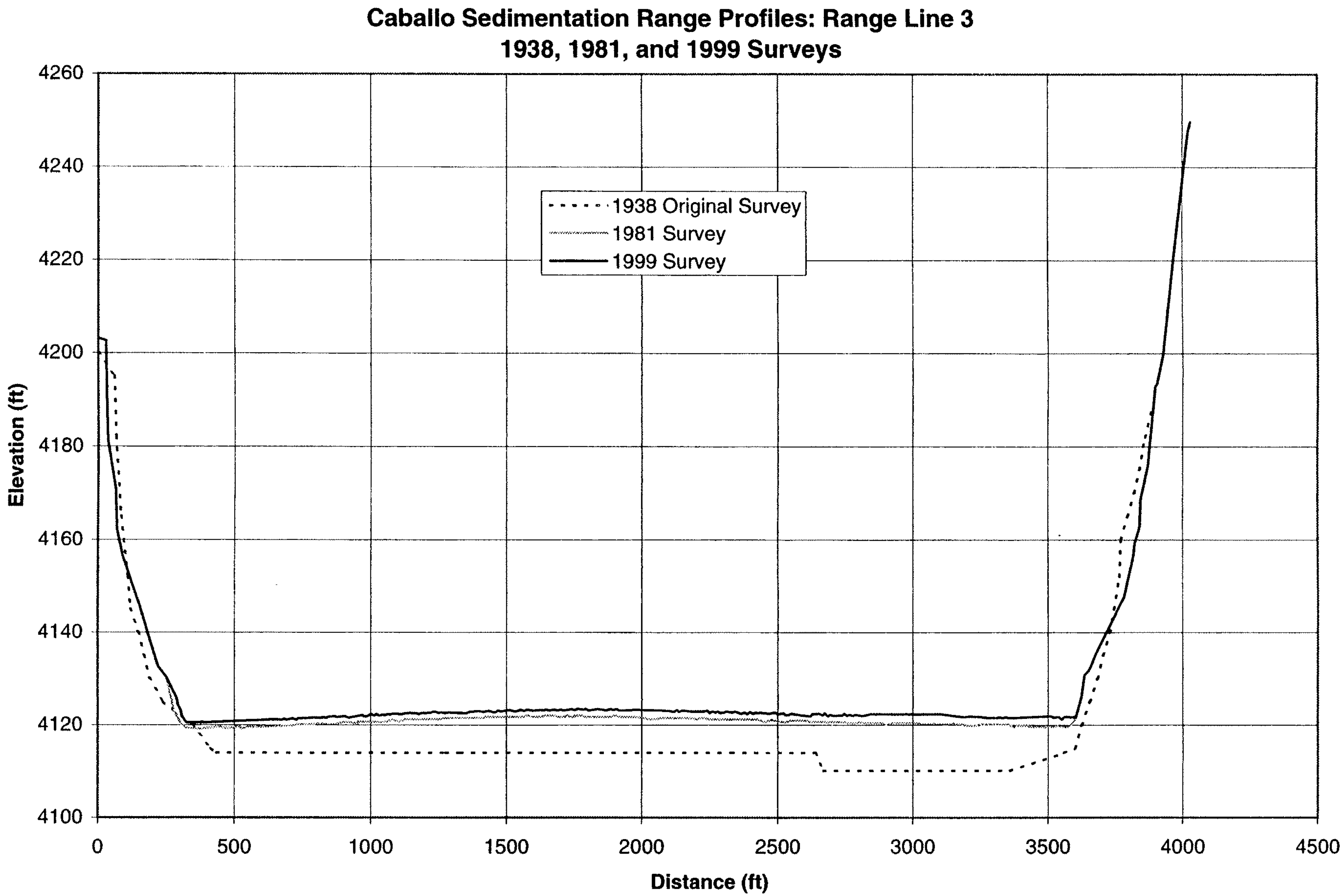

Figure 11. - Sedimentation range profiles for 1938, 1981, and 1999 - range 3.

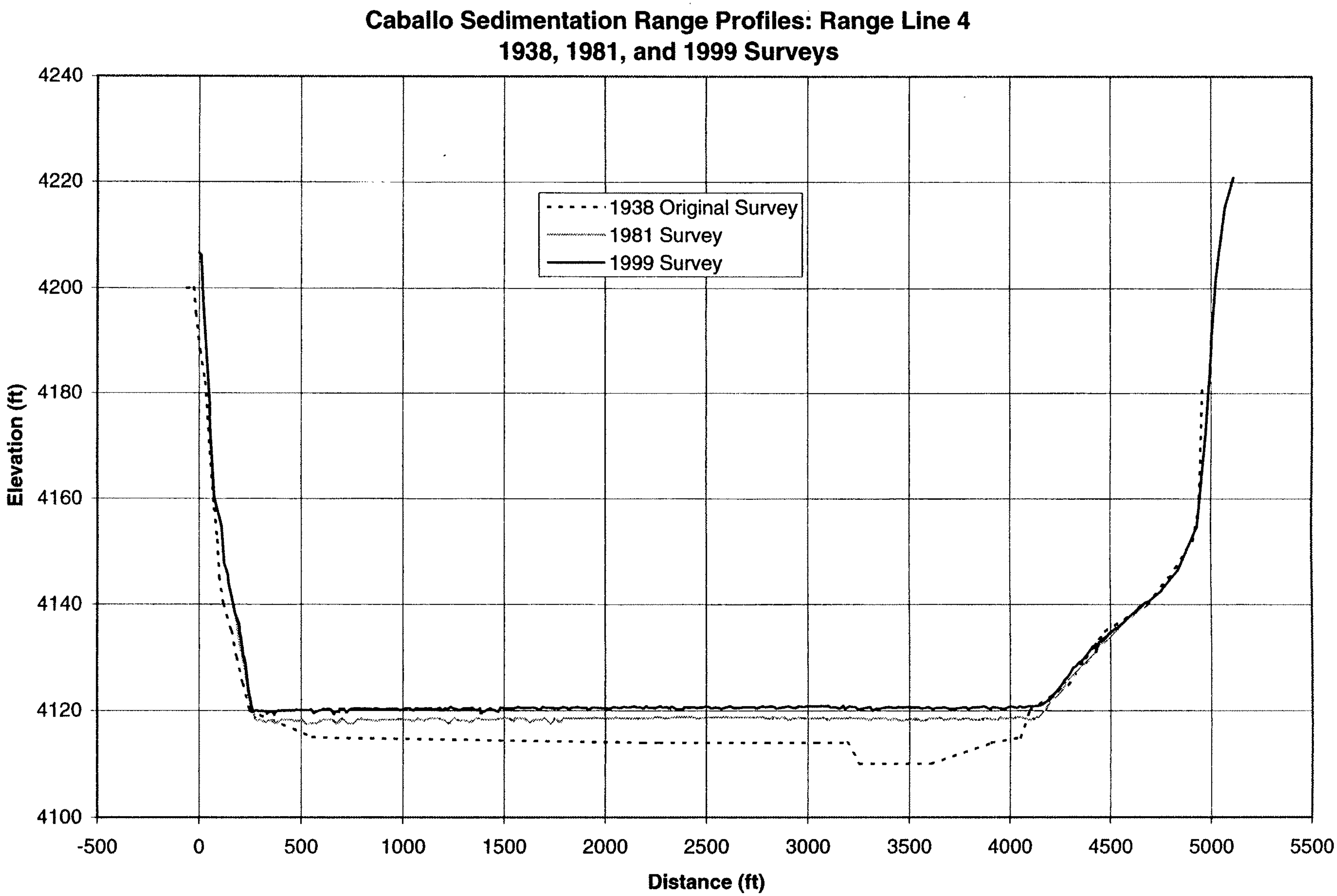

Figure 12. - Sedimentation range profiles for 1938, 1981, and 1999 - range 4.

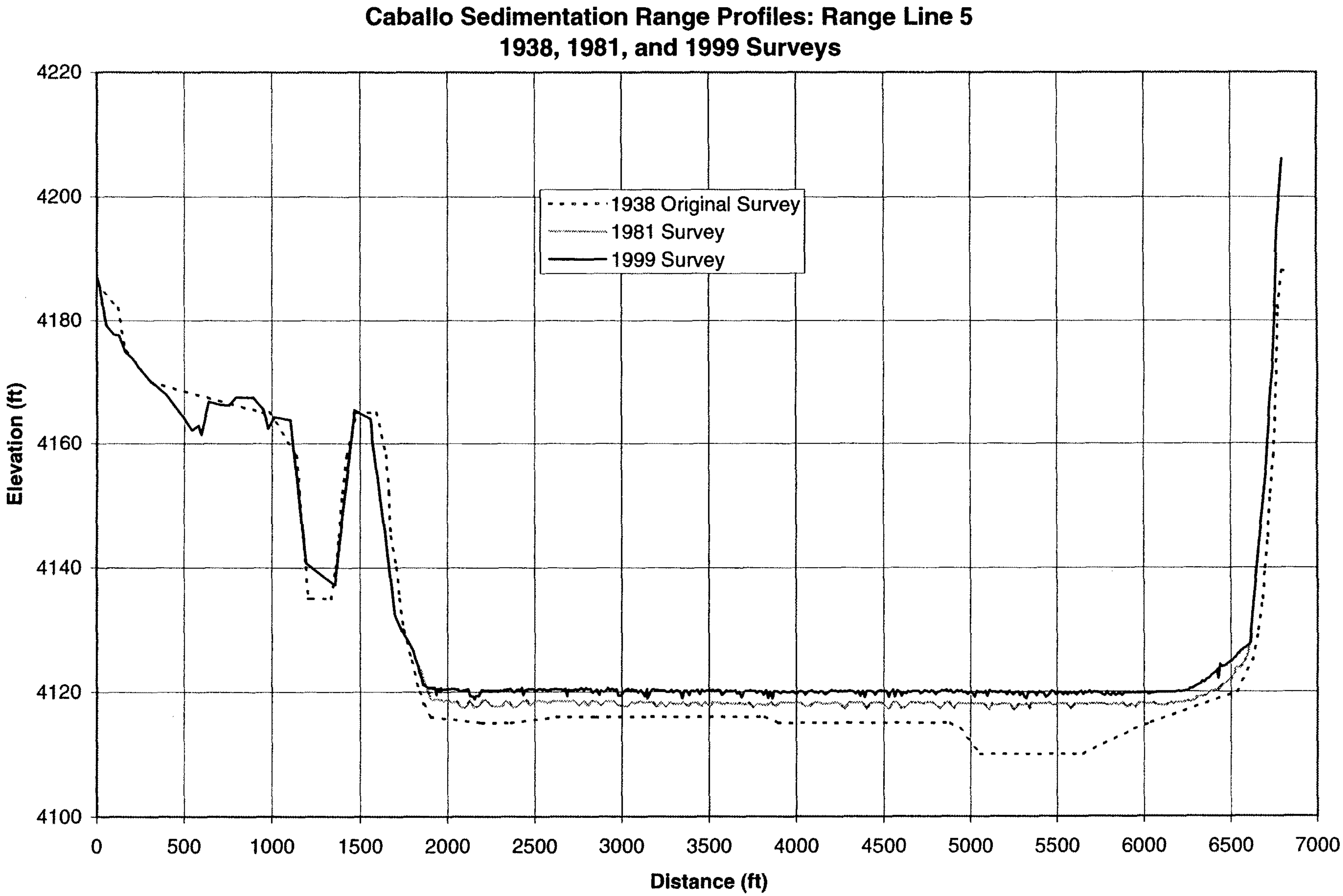

Figure 13. - Sedimentation range profiles for 1938, 1981, and 1999 - range 5.

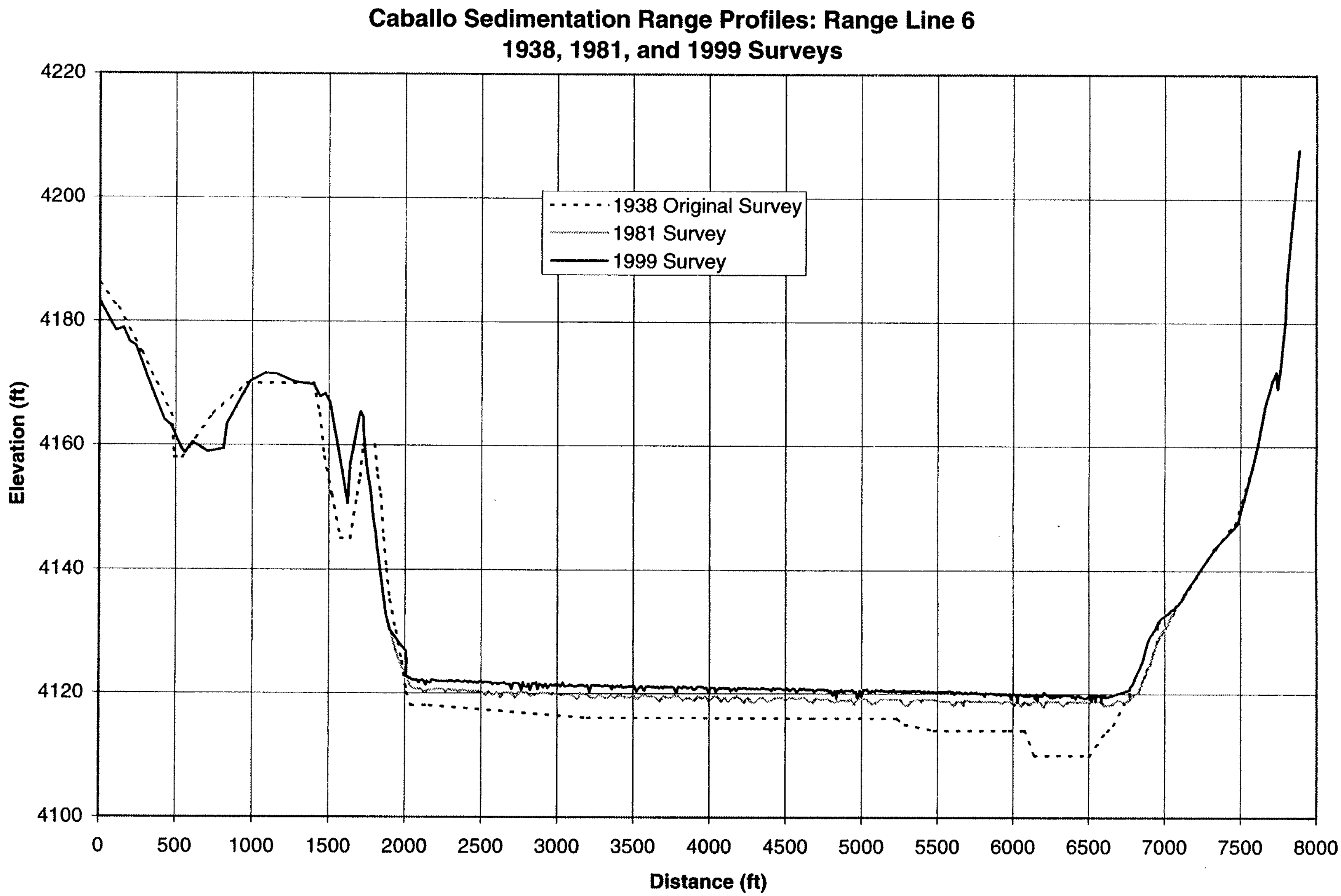

Figure 14. - Sedimentation range profiles for 1938, 1981, and 1999 - range 6.

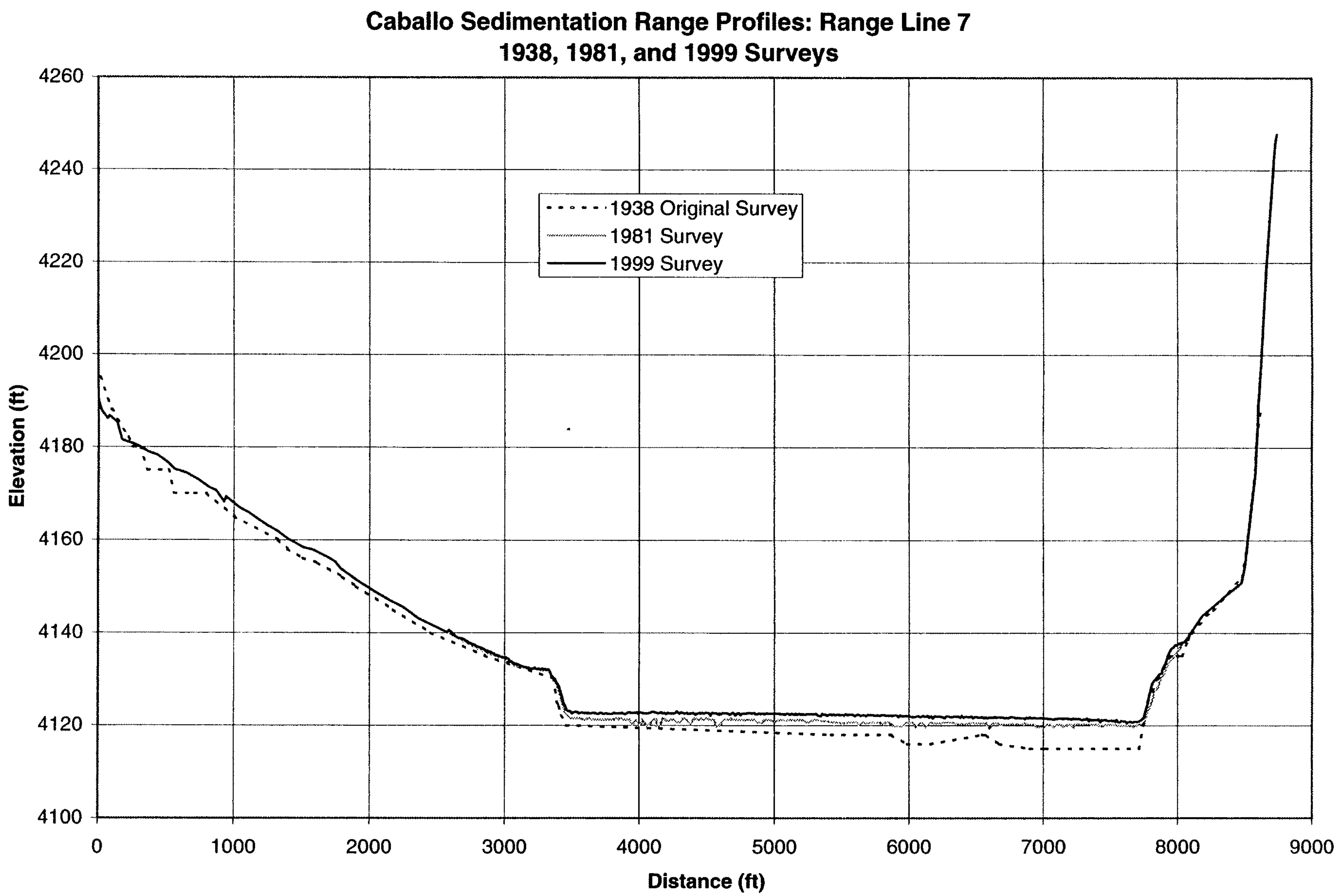

Figure 15. - Sedimentation range profiles for 1938, 1981, and 1999 - range 7.

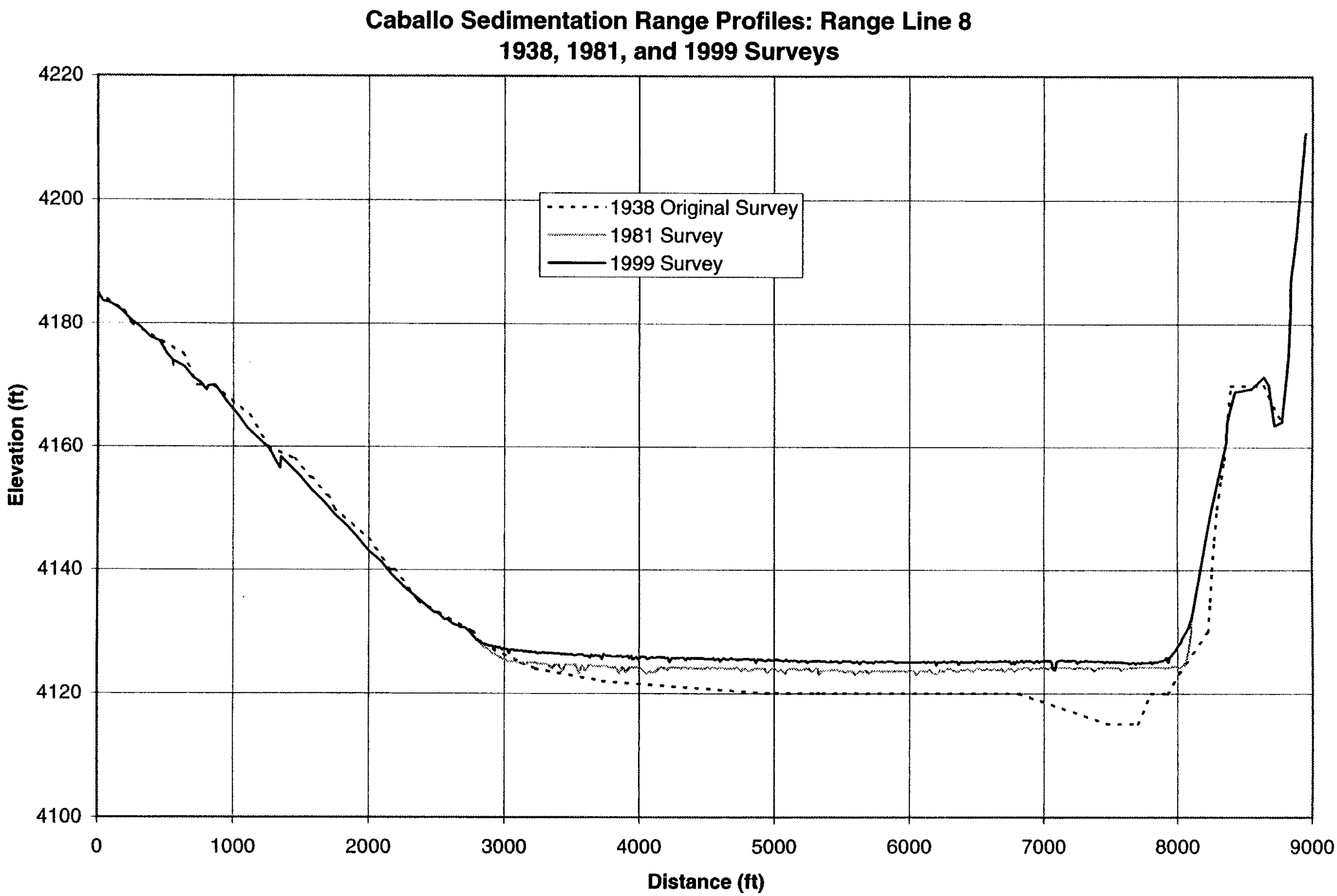

Figure 16. - Sedimentation range profiles for 1938, 1981, and 1999 - range 8.

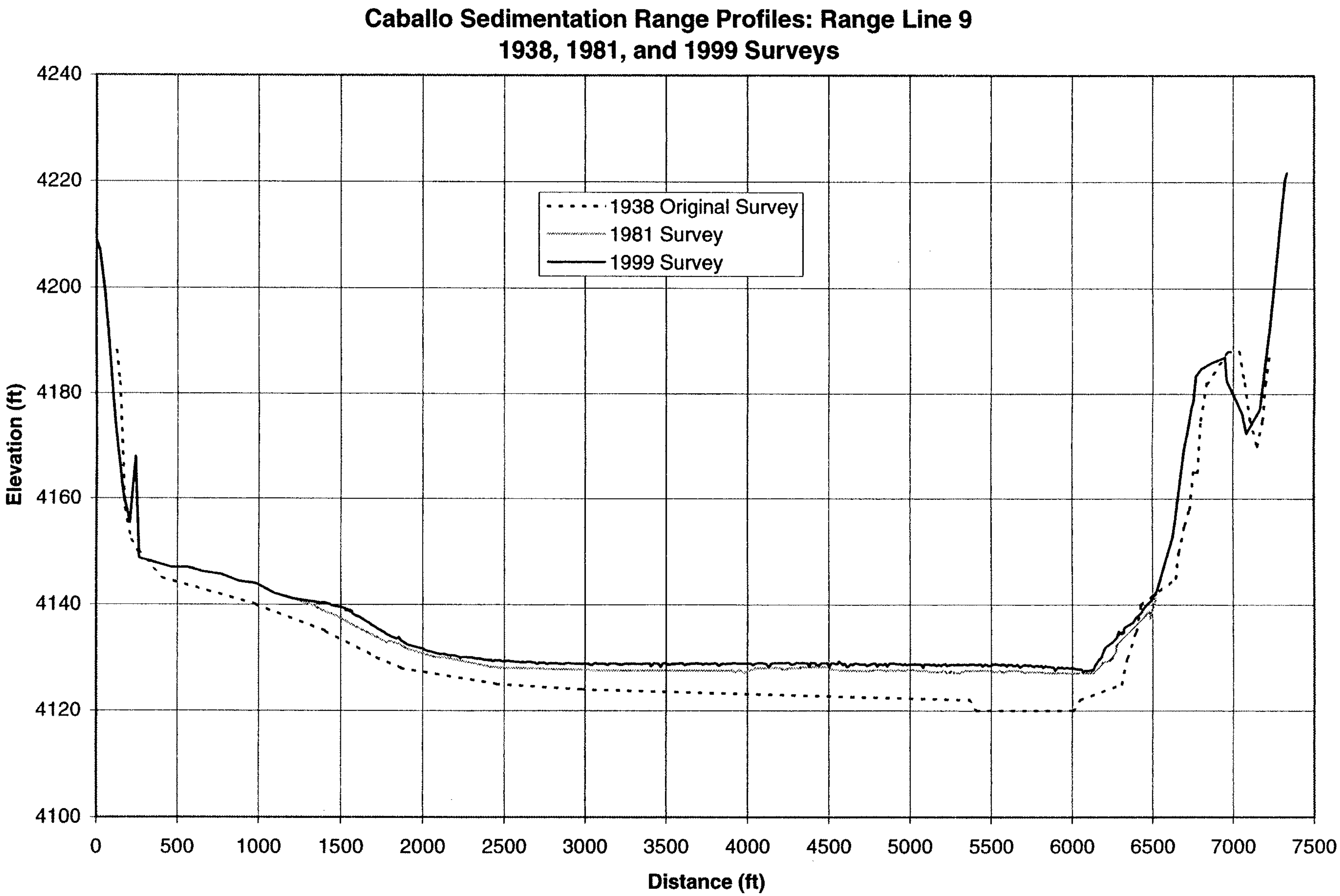

Figure 17. - Sedimentaiton range profiles for 1938, 1981, and 1999 - range 9.

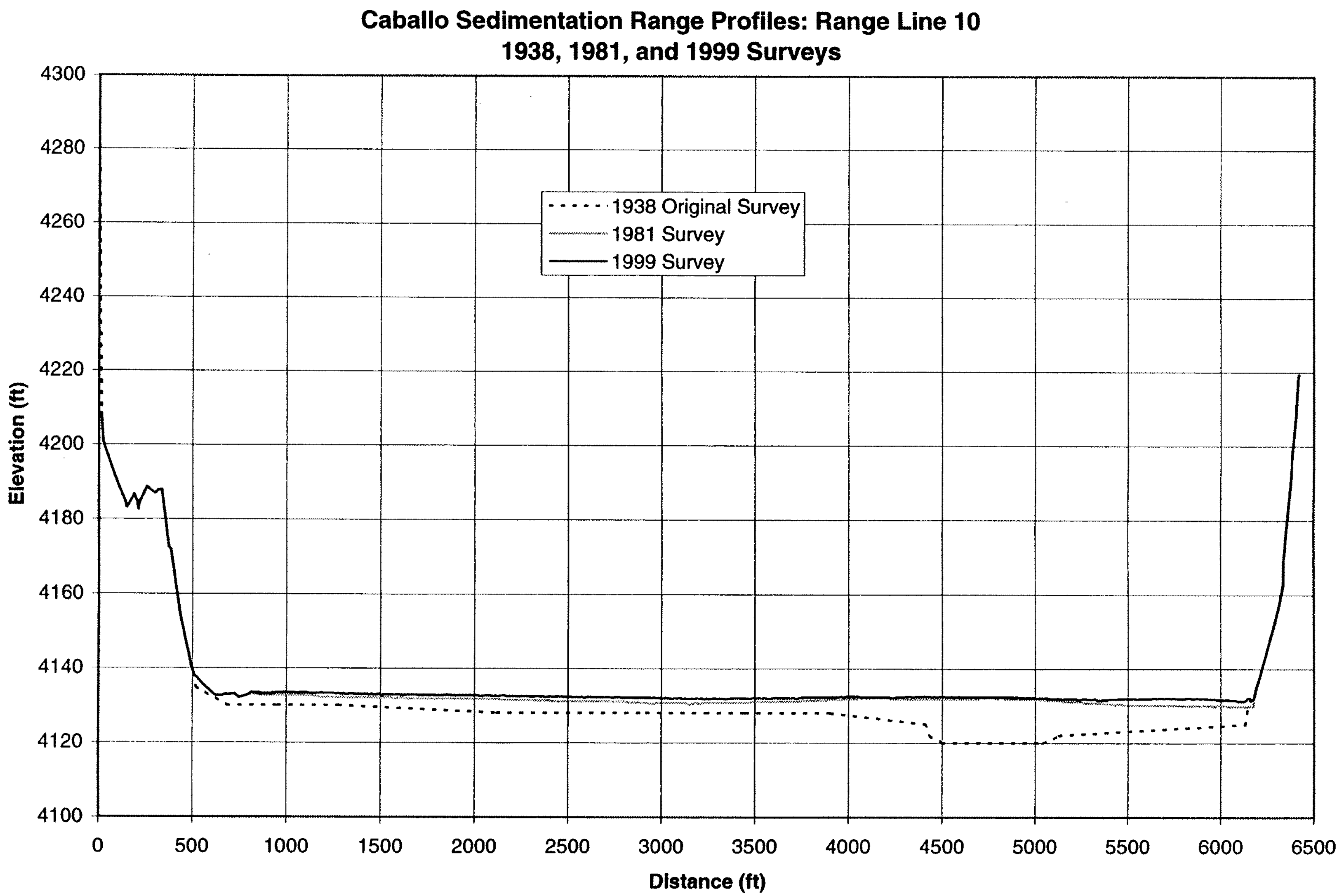

Figure 18. - Sedimentation range profiles for 1938, 1981, and 1999 - range 10.

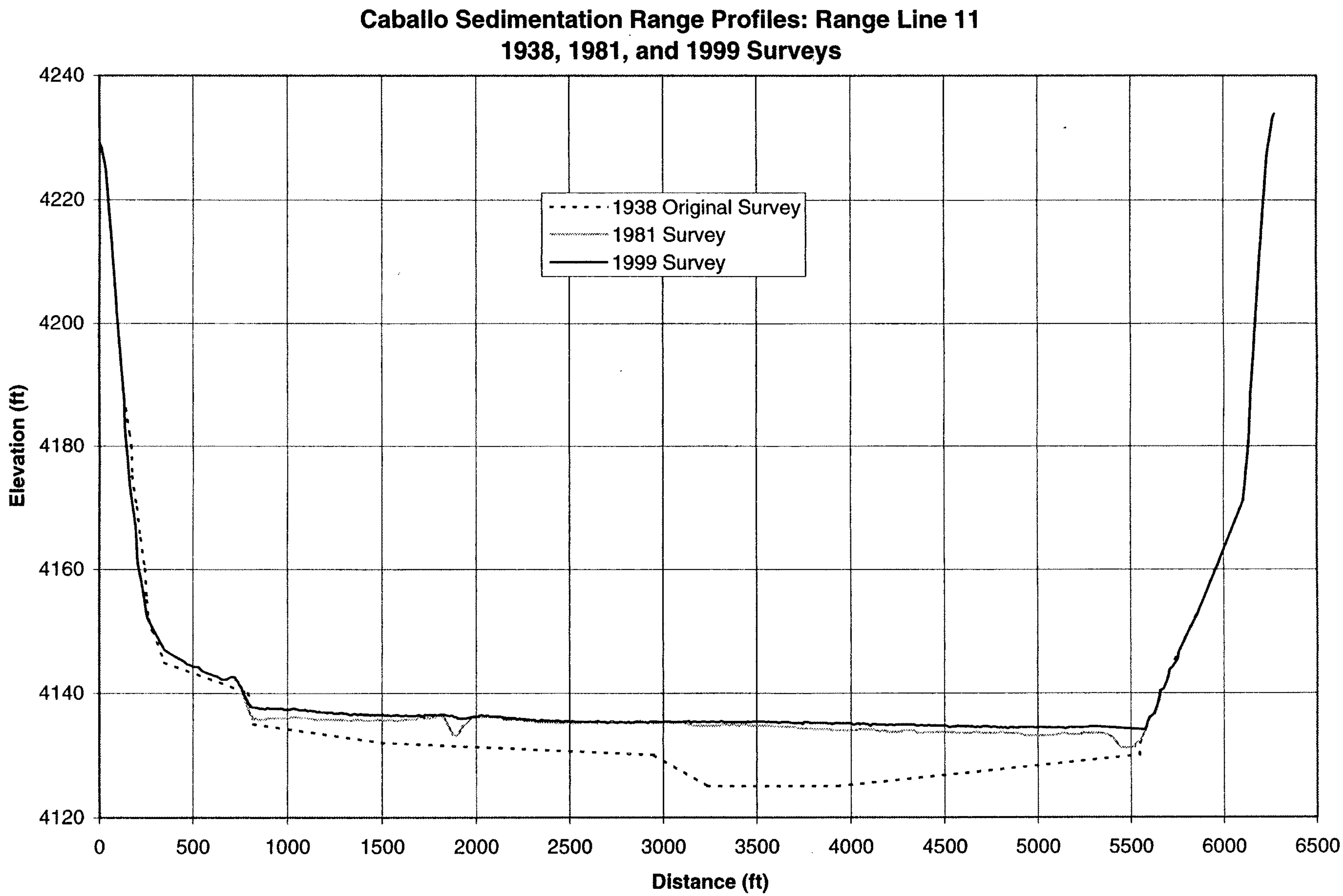

Figure 19. - Sedimentation range profiles for 1938, 1981, and 1999 - range 11.

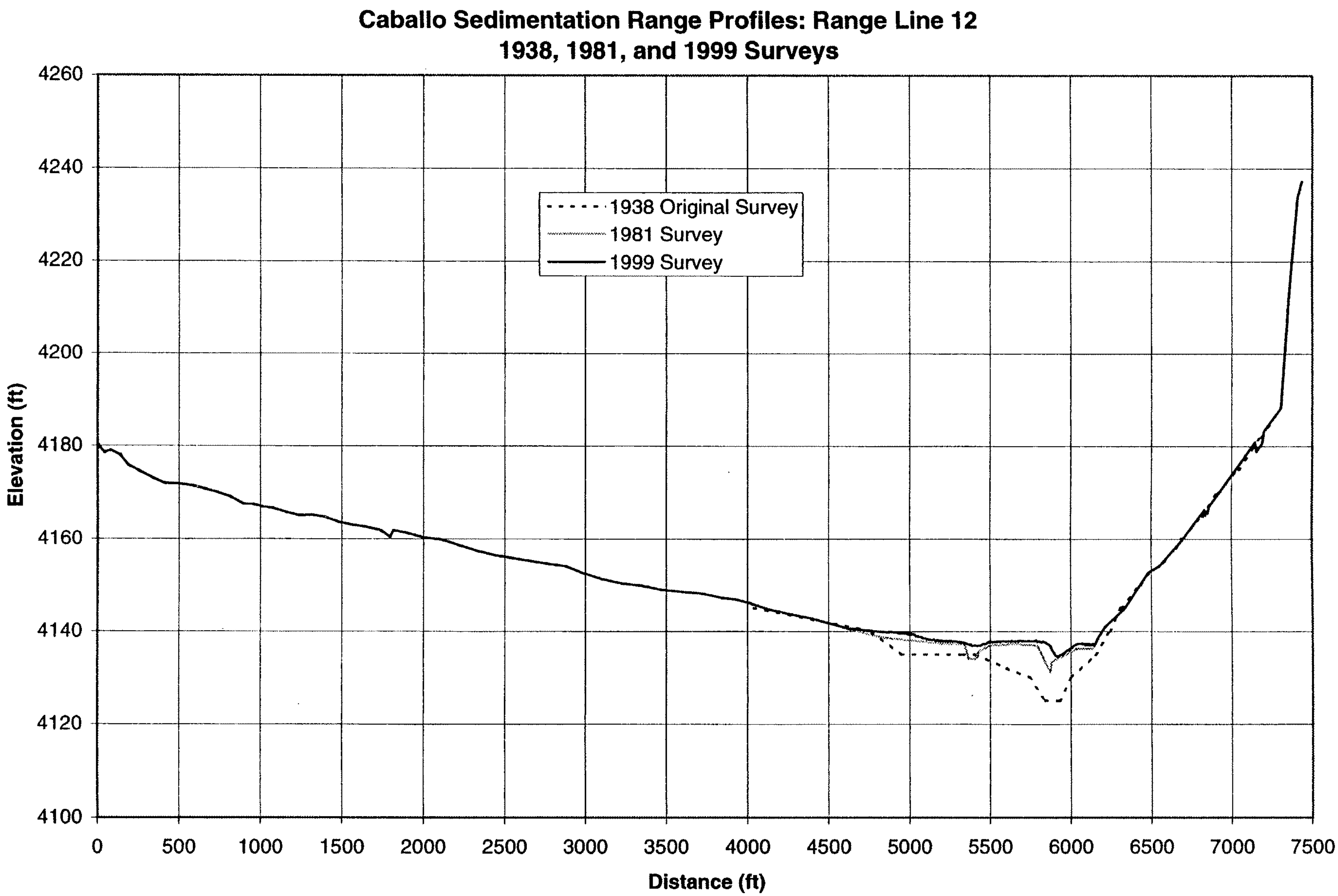

Figure 20. - Sedimentation range profiles for 1938, 1981, and 1999 - range 12.

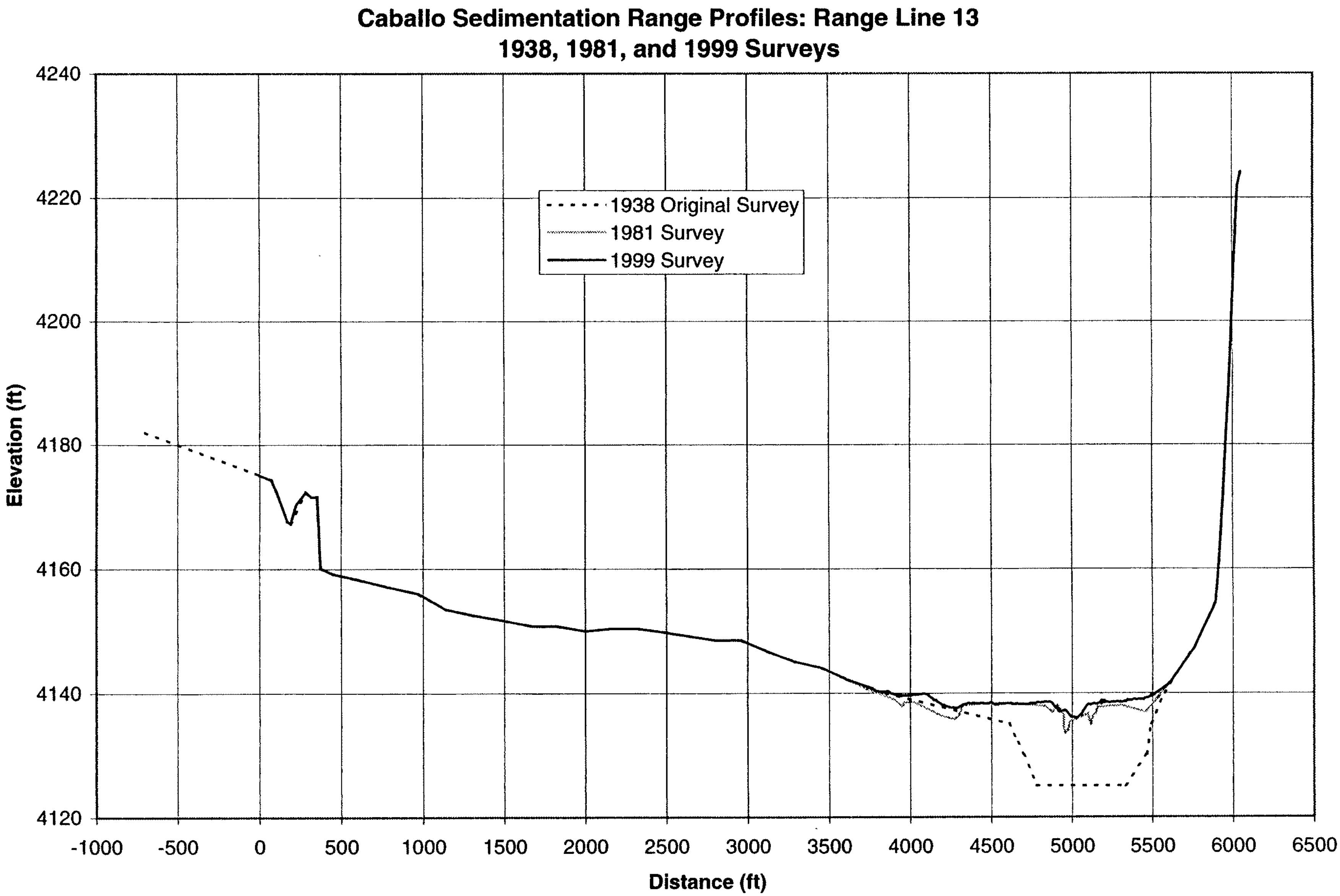

Figure 21. - Sedimentation range profiles for 1938, 1981, and 1999 - range 13.

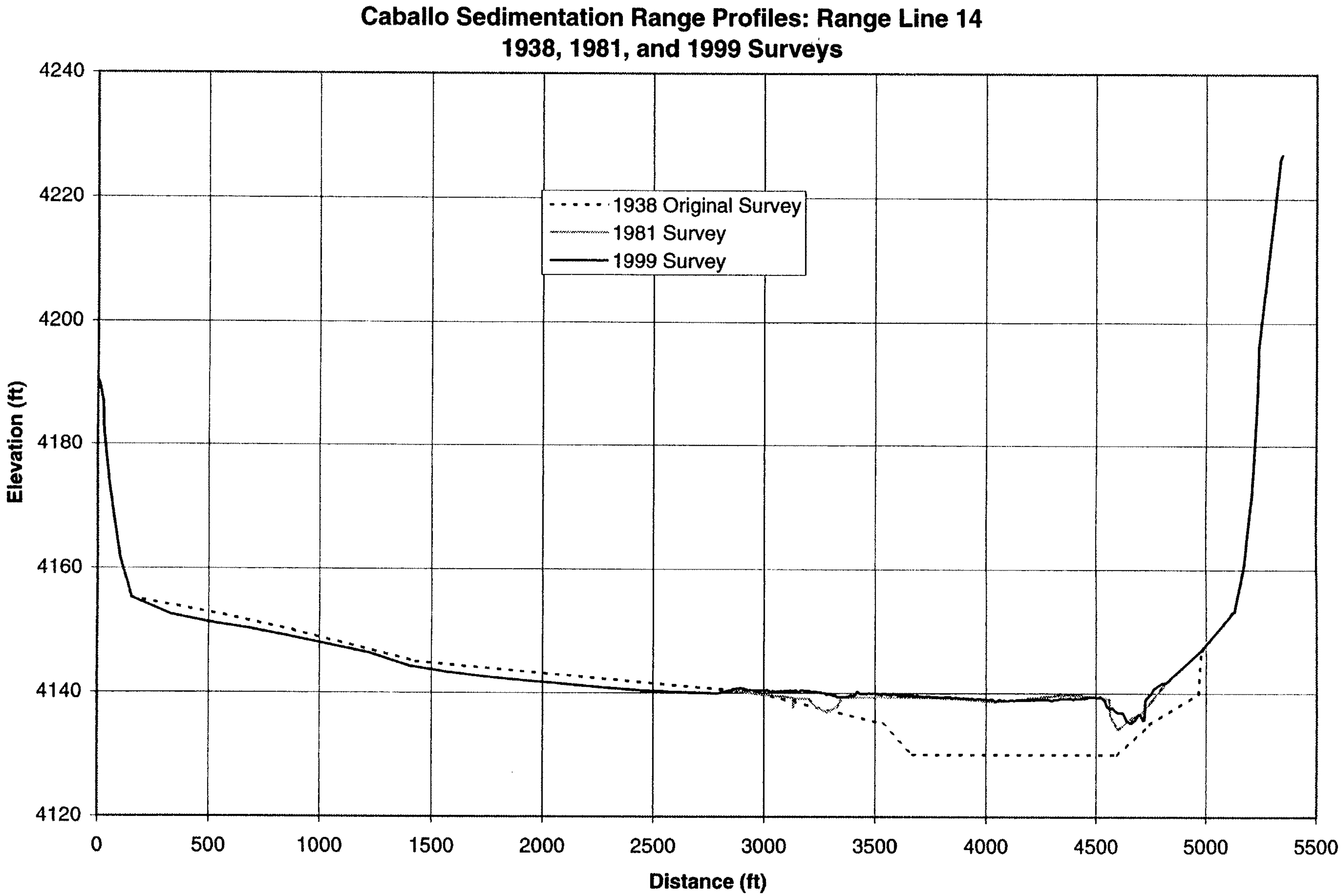

Figure 22. - Sedimentation range profiles for 1938, 1981, and 1999 - range 14.

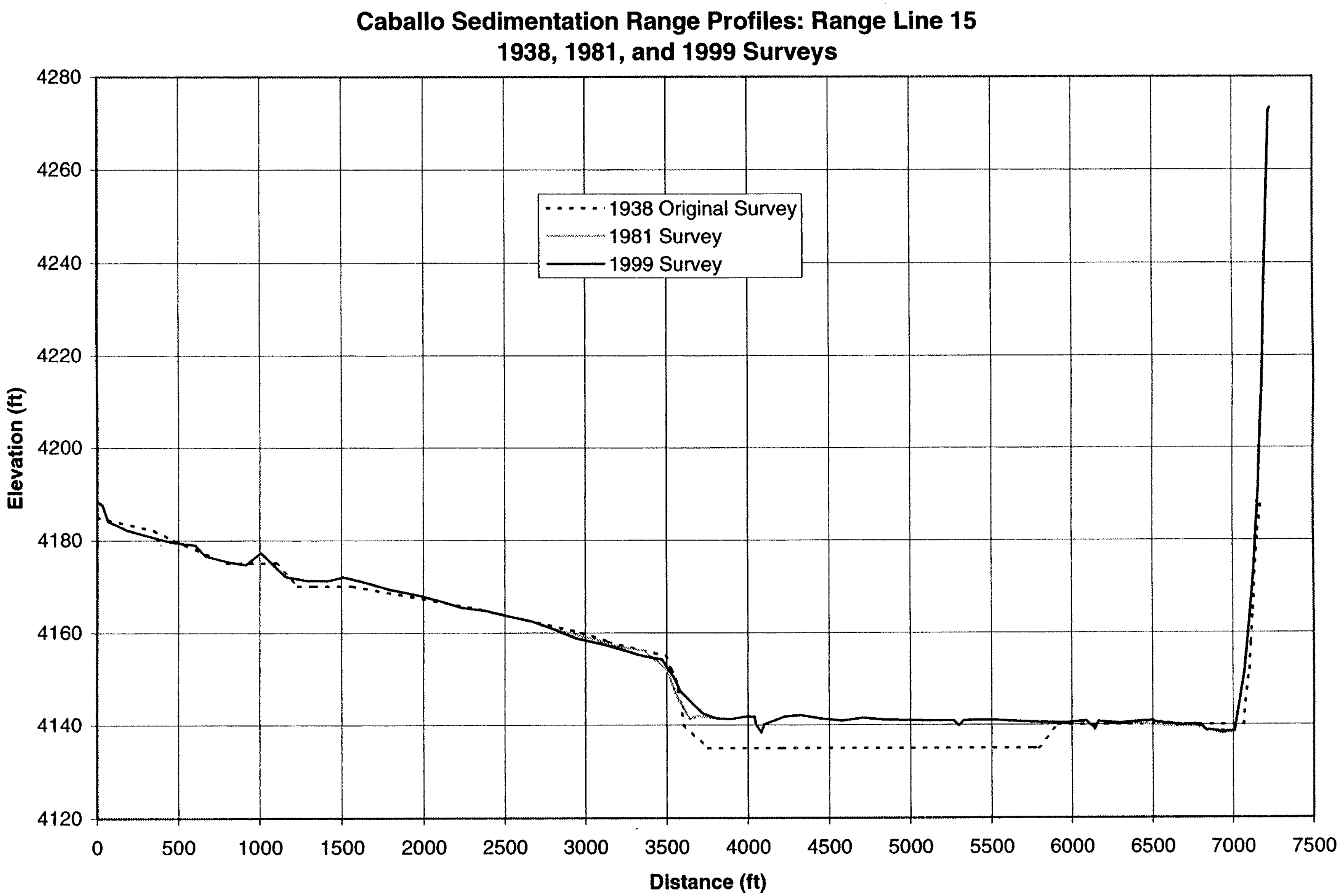

Figure 23. - Sedimentation range profiles for 1938, 1981, and 1999 - range 15.

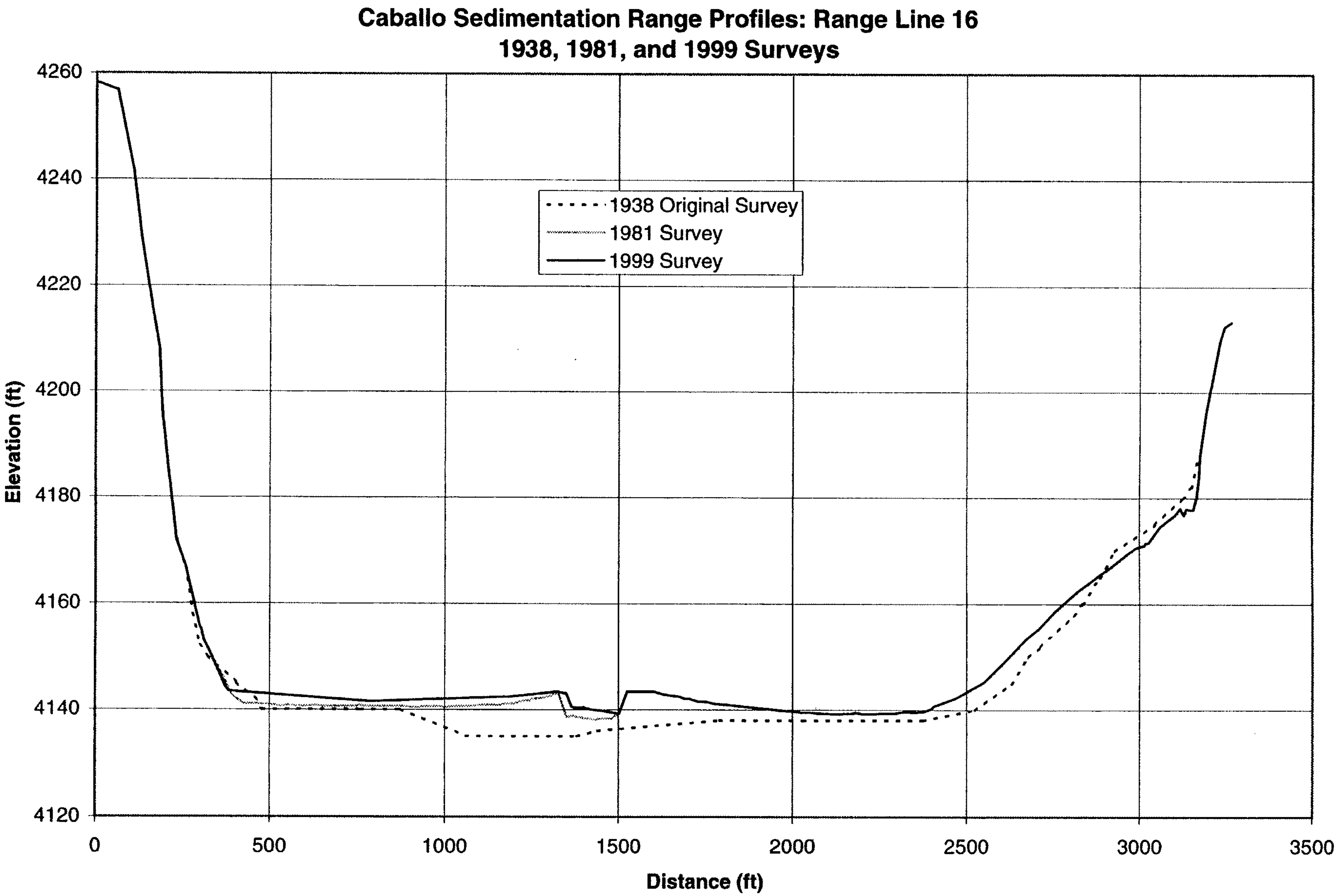

Figure 24. - Sedimentation range profiles for 1938, 1981, and 1999 - range 16.

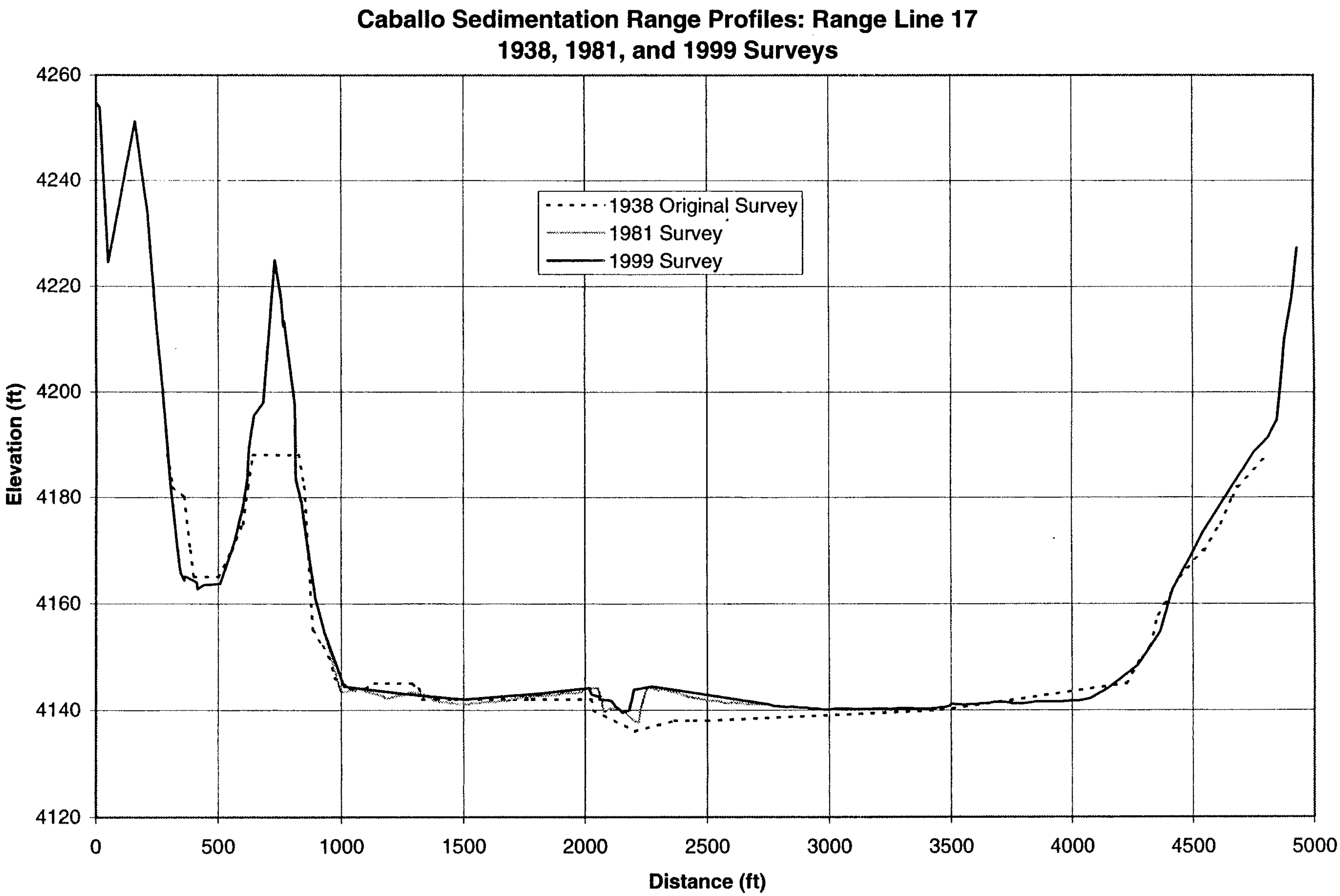

Figure 25. - Sedimentation range profiles for 1938, 1981, and 1999 - range 17.

Caballo Sedimentation Range Profiles: Range Line 18
1938, 1981, and 1999 Surveys

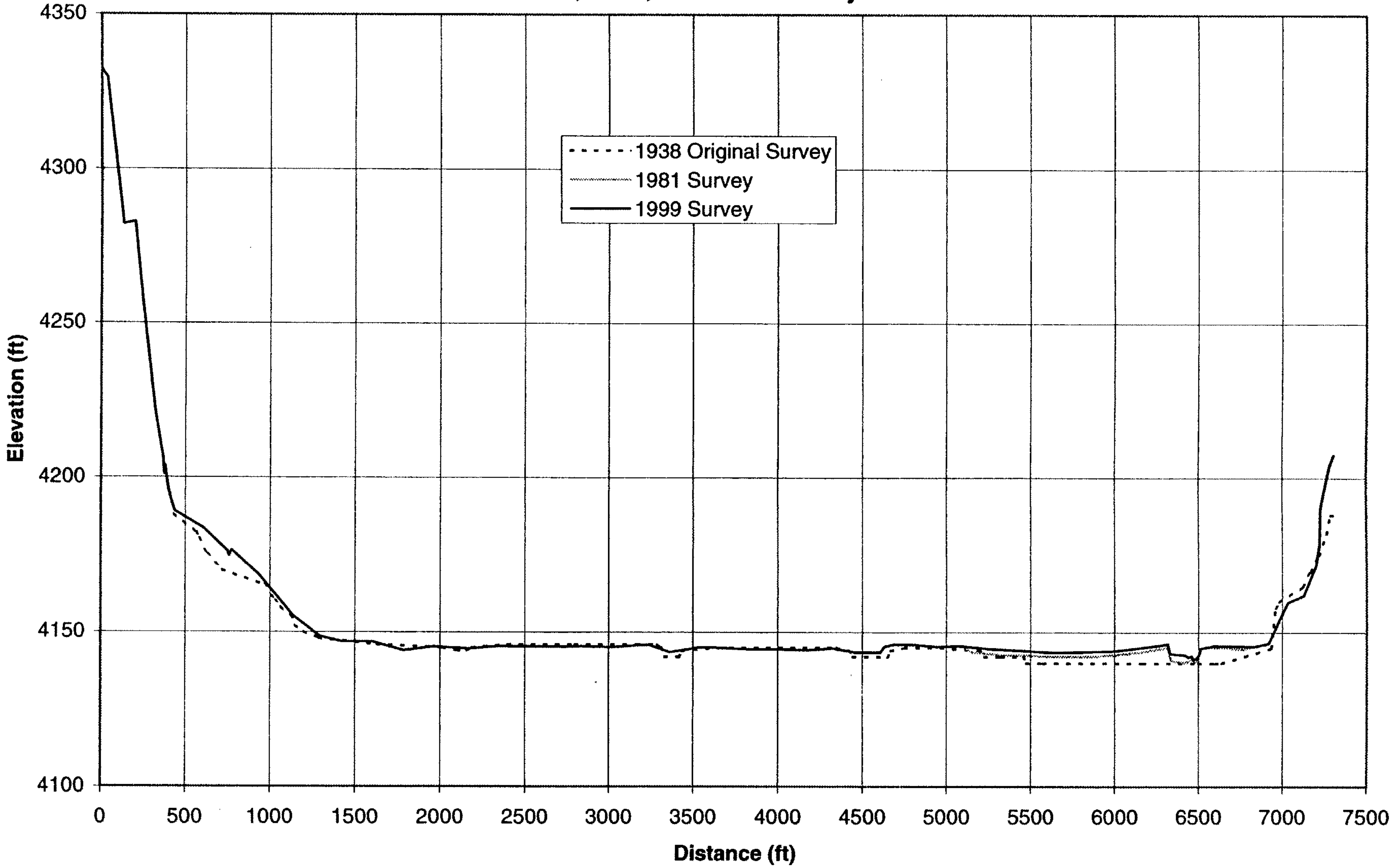

Figure 26. - Sedimentation range profiles for 1938, 1981, and 1999 - range 18.

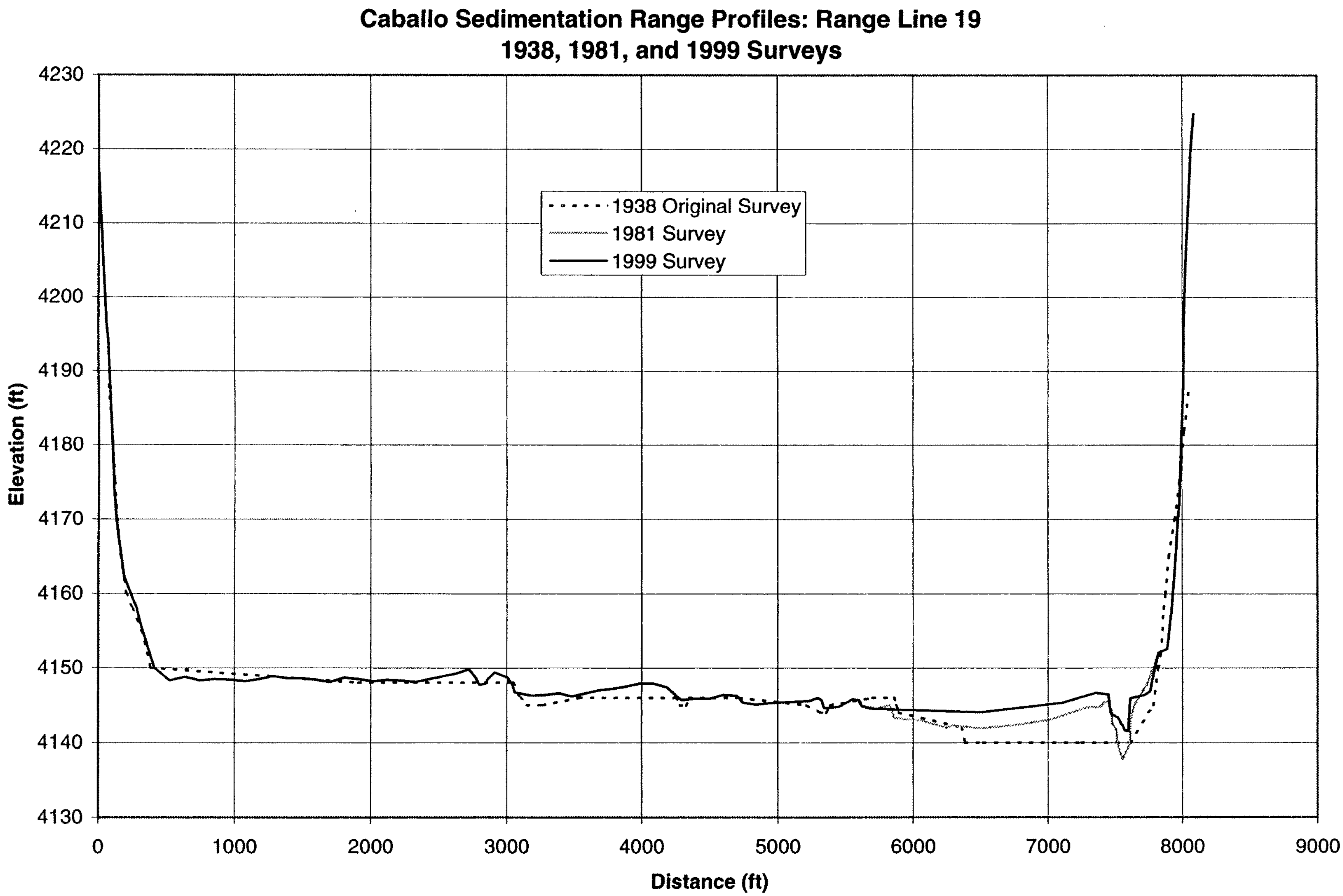

Figure 27. - Sedimentation range profiles for 1938, 1981, and 1999 - range 19.

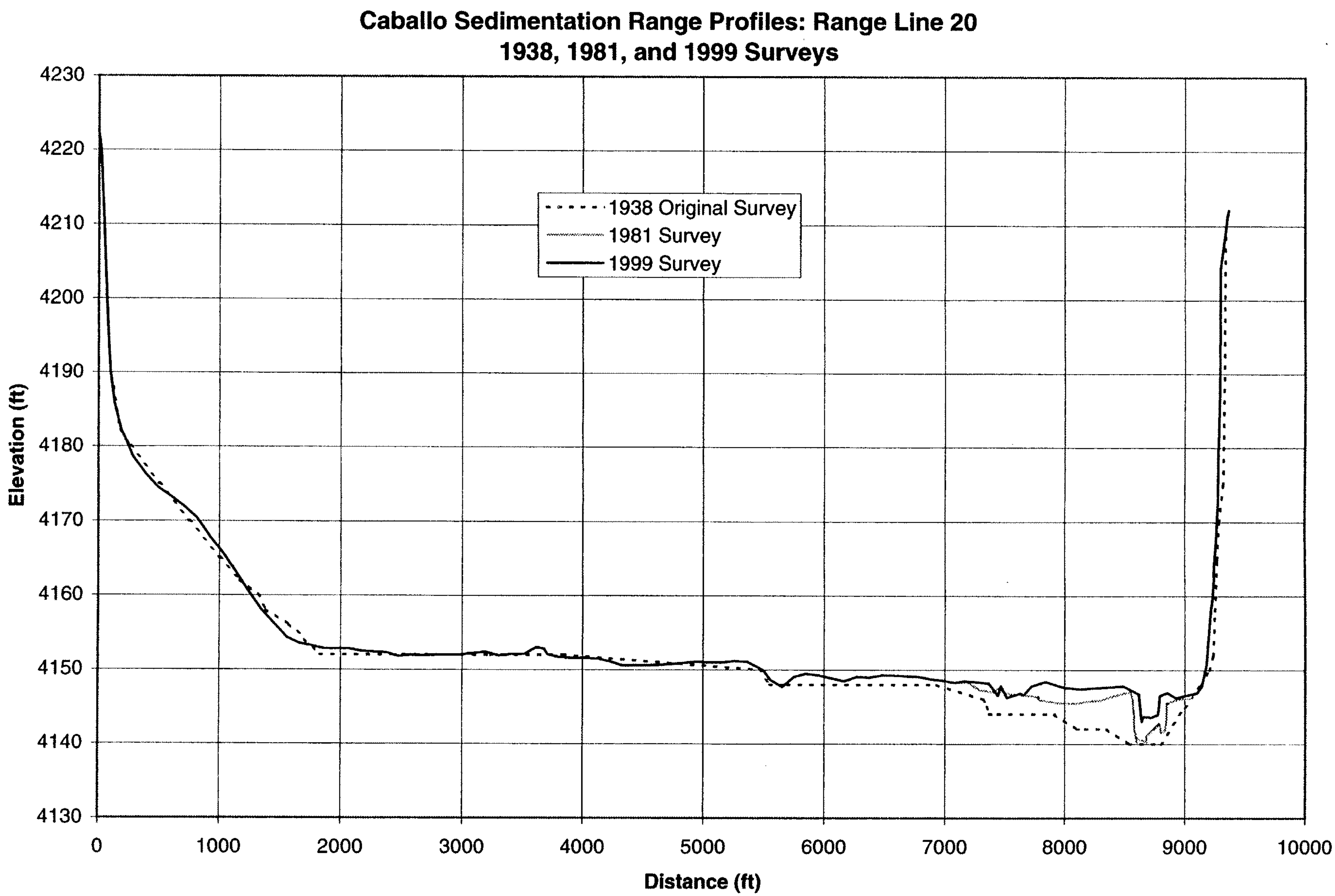

Figure 28. - Sedimentation range profiles for 1938, 1981, and 1999 - range 20.

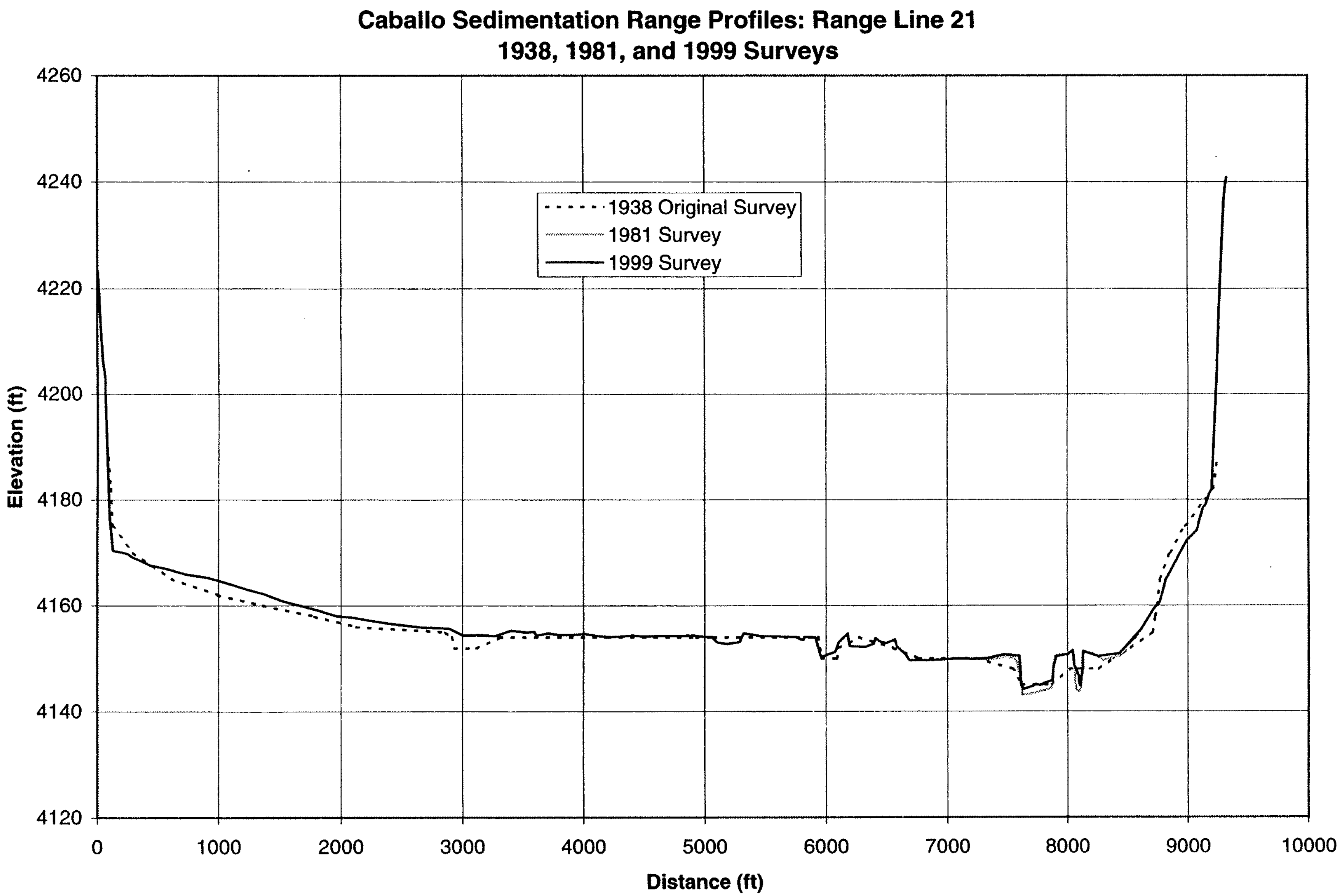

Figure 29. - Sedimentation range profiles for 1938, 1981, and 1999 - range 21.

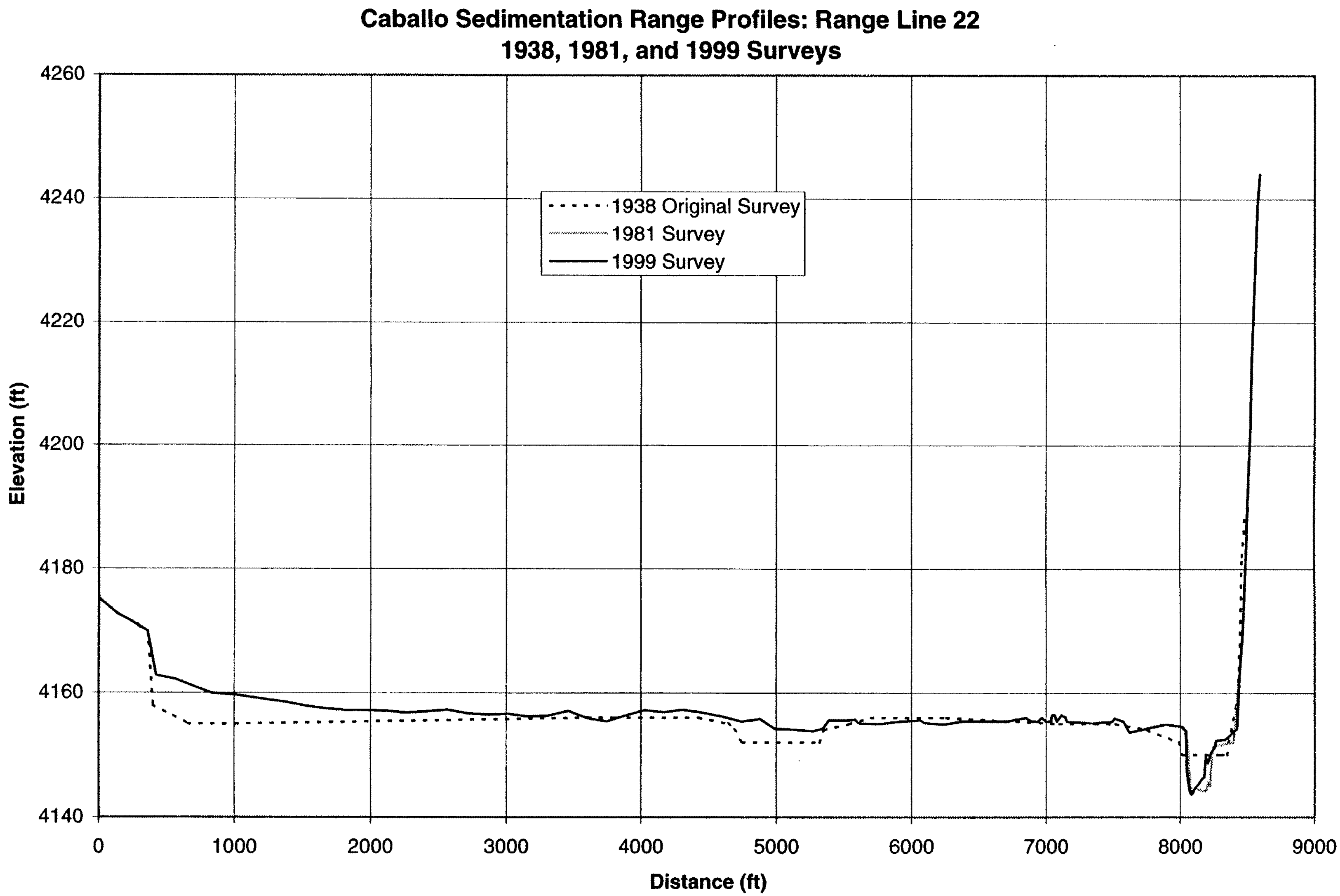

Figure 30. - Sedimentation range profiles for 1938, 1981, and 1999 - range 22.

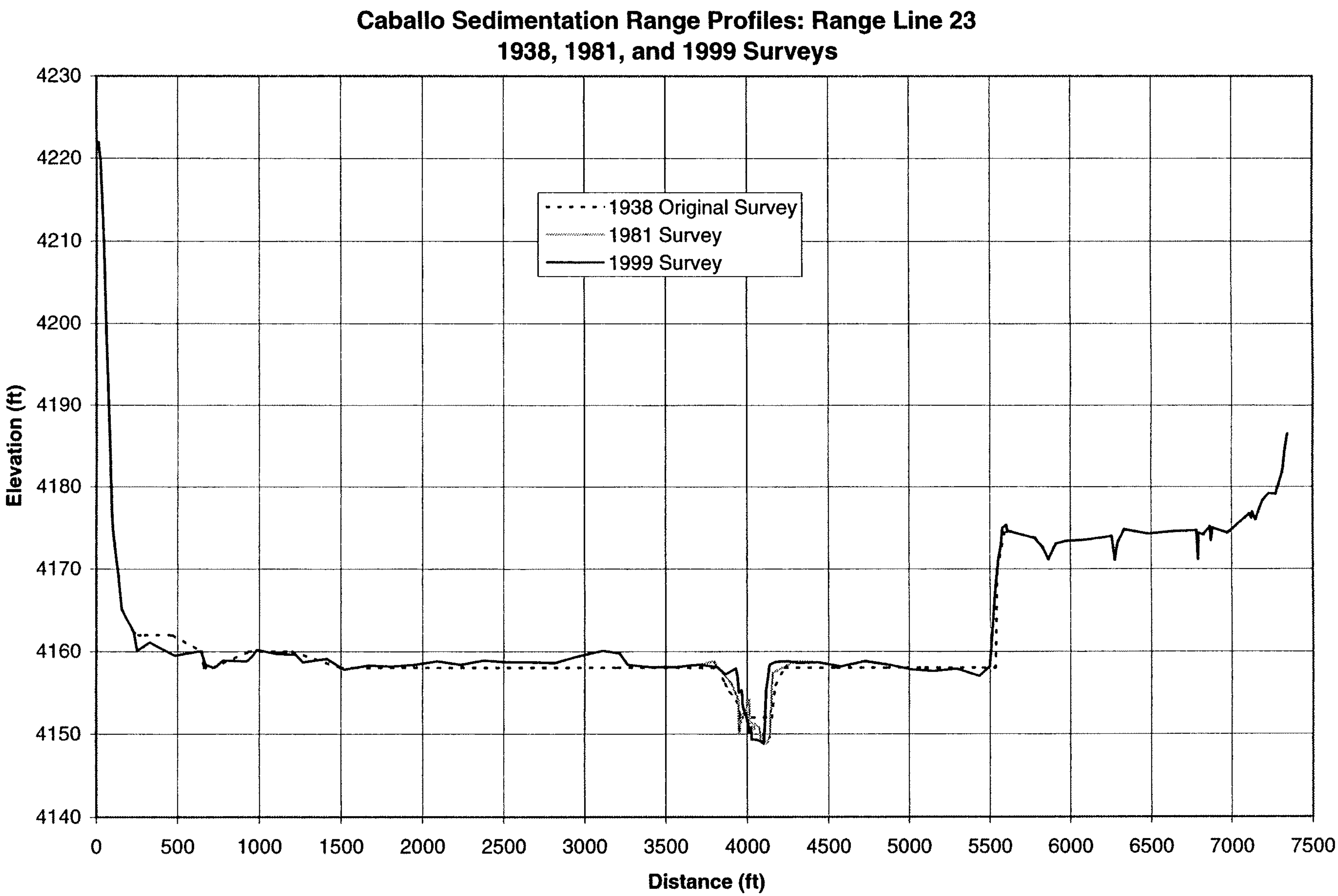

Figure 31. - Sedimentation range profiles for 1938, 1981, and 1999 - range 23.

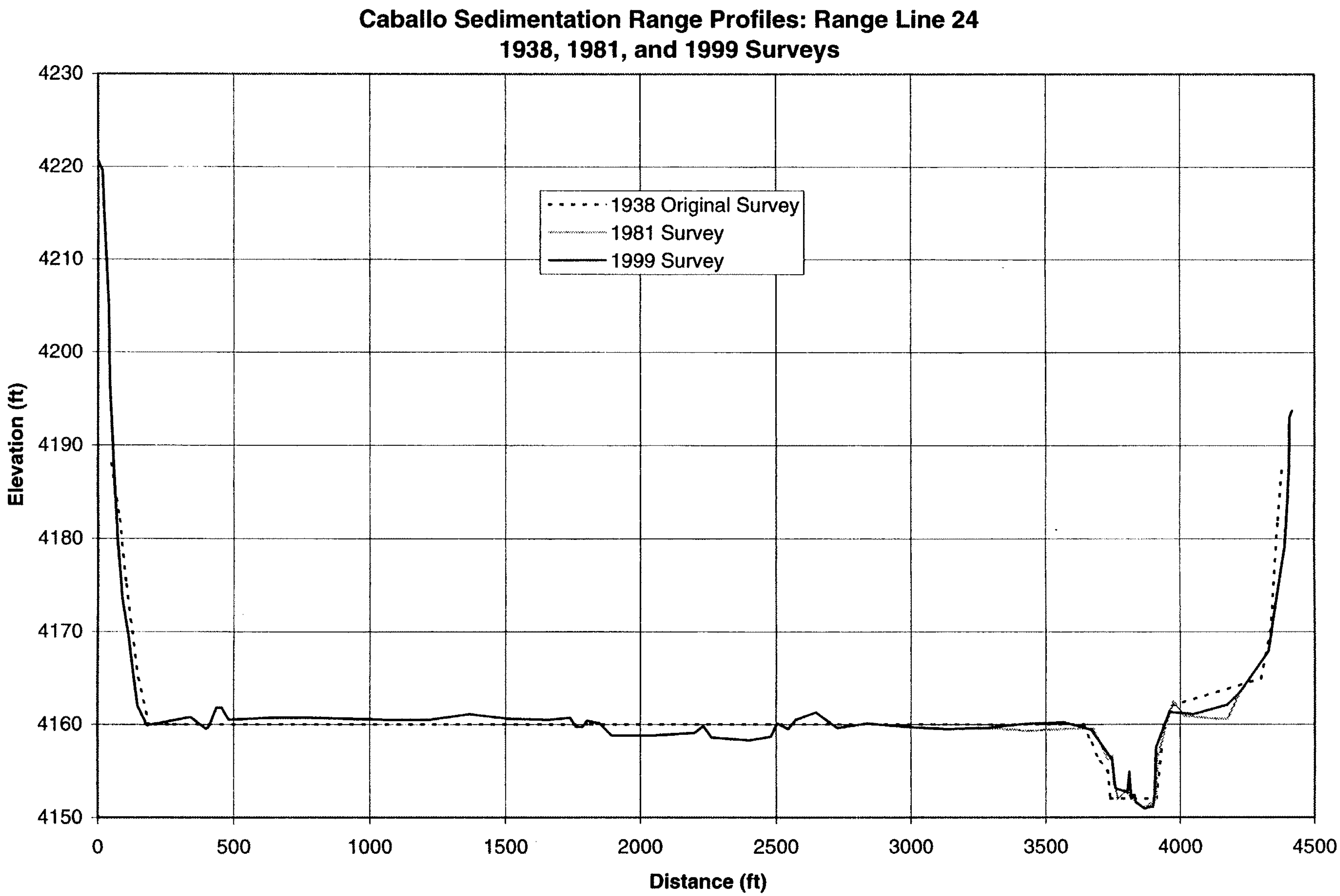

Figure 32. - Sedimentation range profiles for 1938, 1981, and 1999 - range 24.

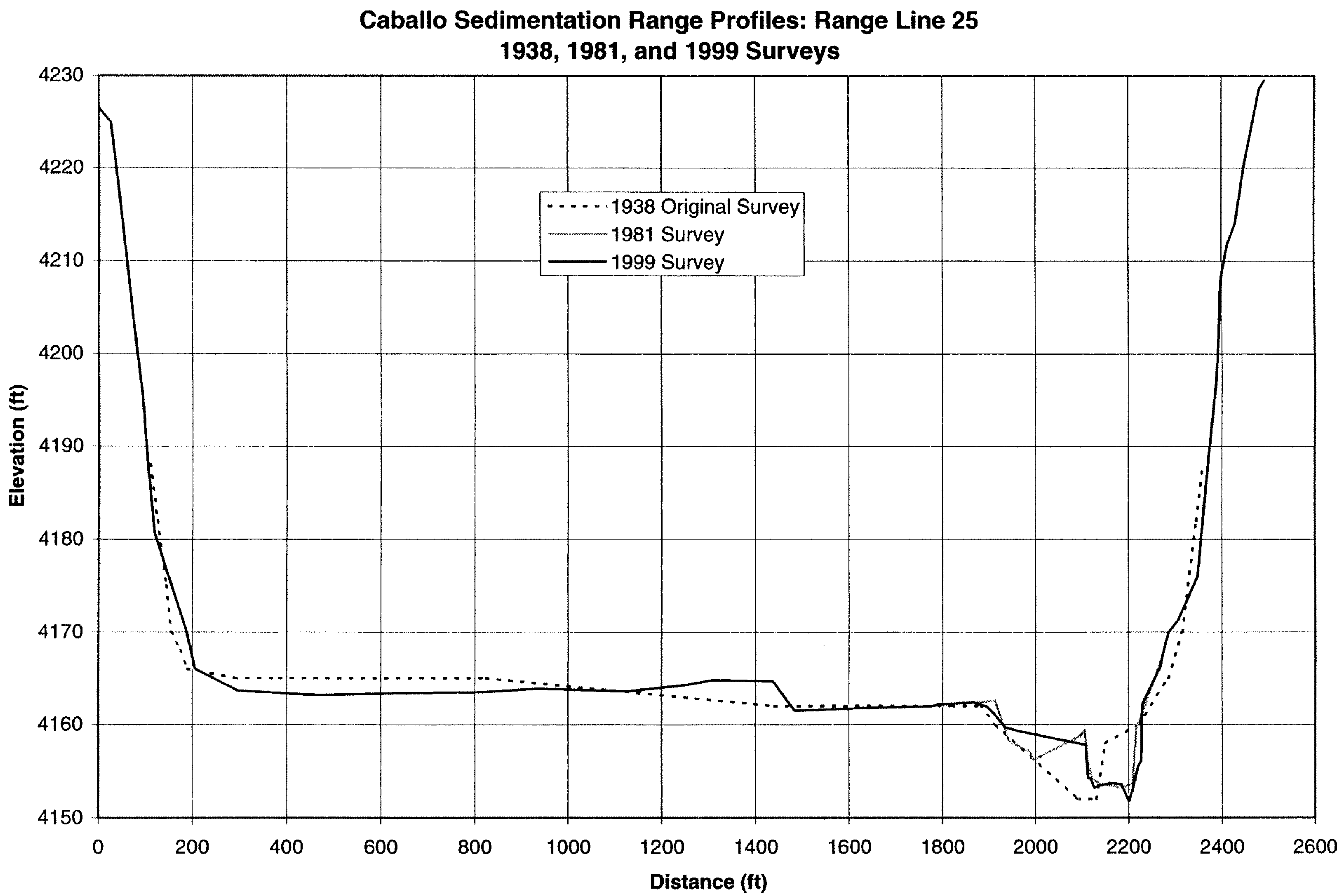

Figure 33. - Sedimentation range profiles for 1938, 1981, and 1999 - range 25.

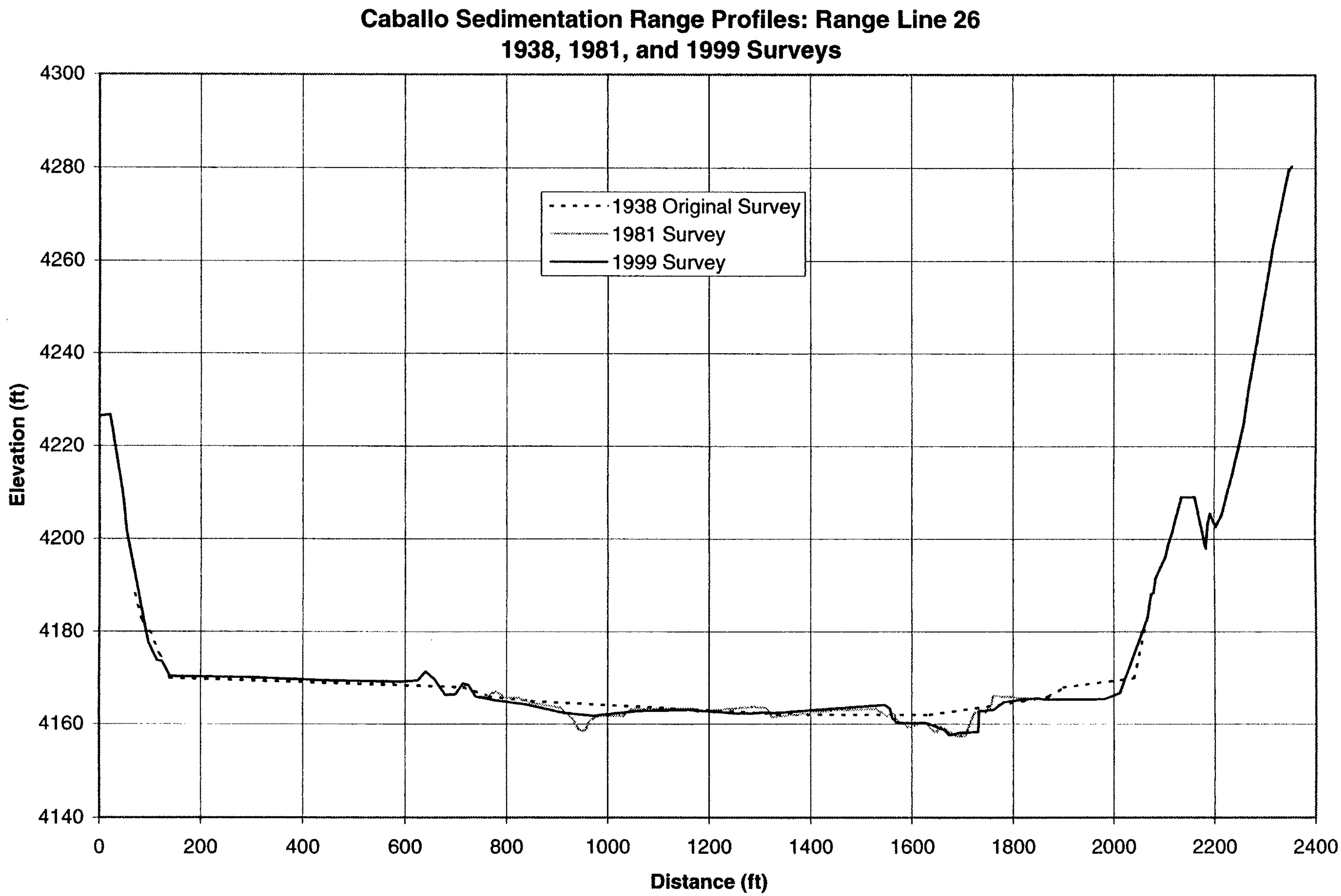

Figure 34. - Sedimentation range profiles for 1938, 1981, and 1999 - range 26.

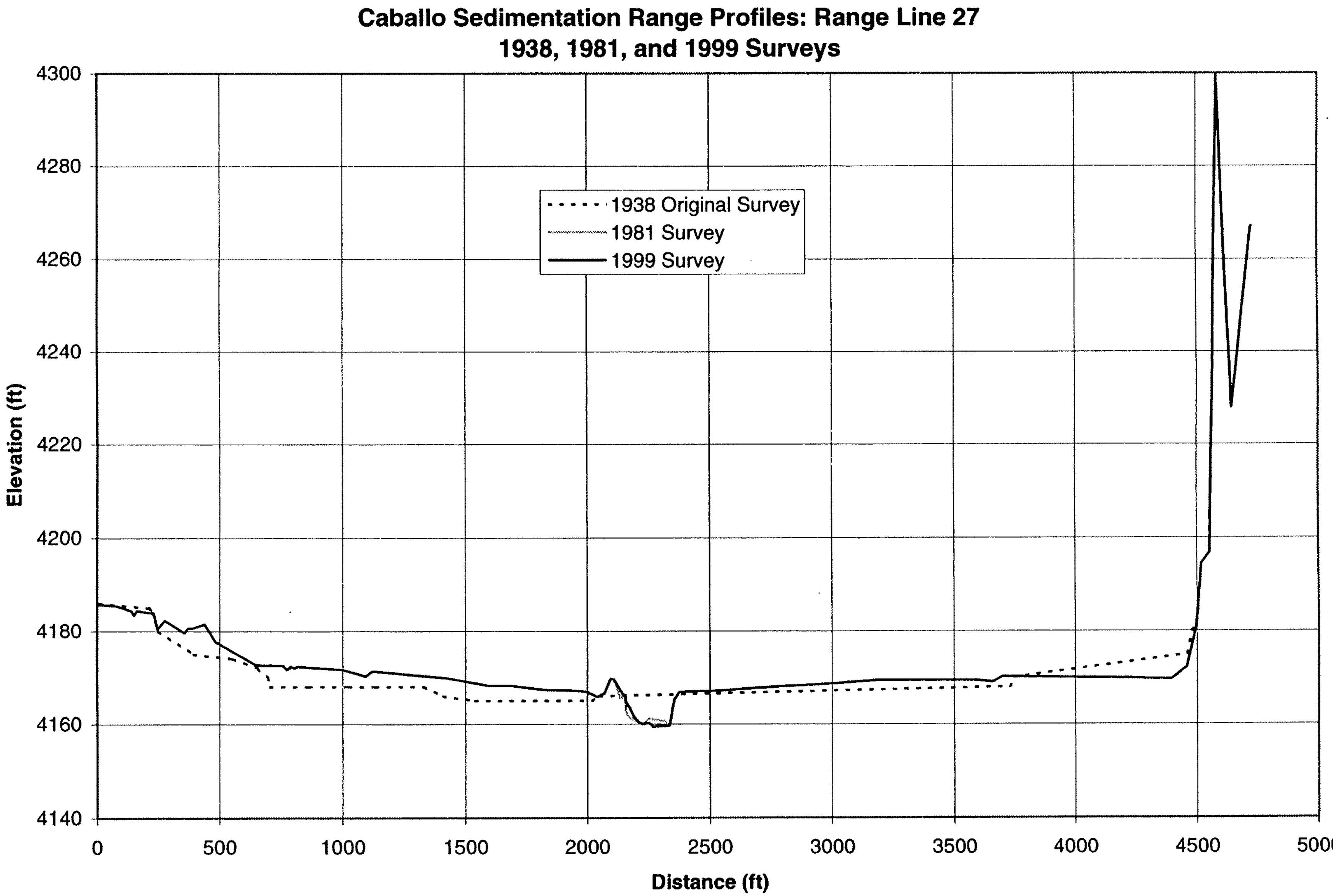

Figure 35. - Sedimentation range profiles for 1938, 1981, and 1999 - range 27.

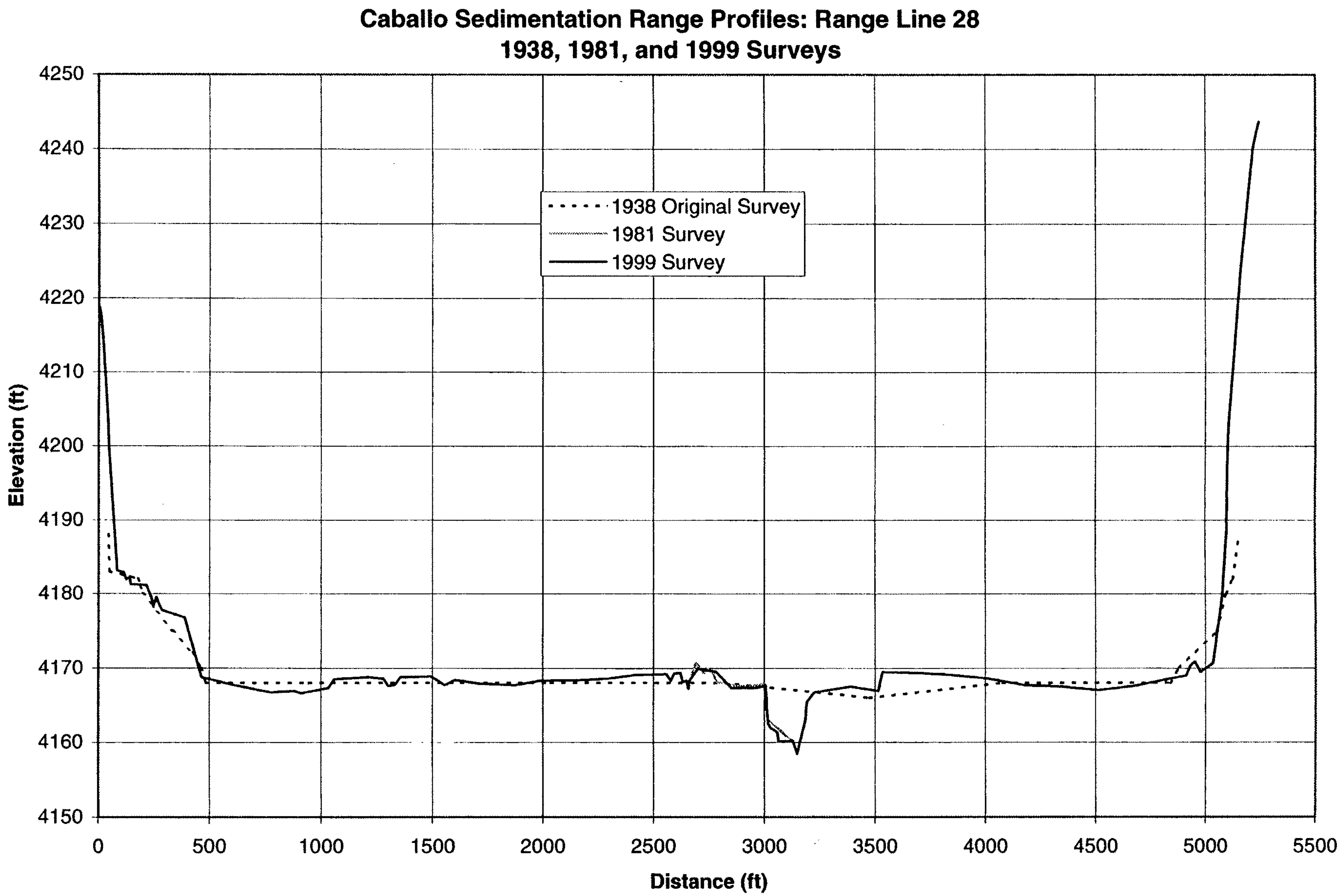

Figure 36. - Sedimentation range profiles for 1938, 1981, and 1999 - range 28.

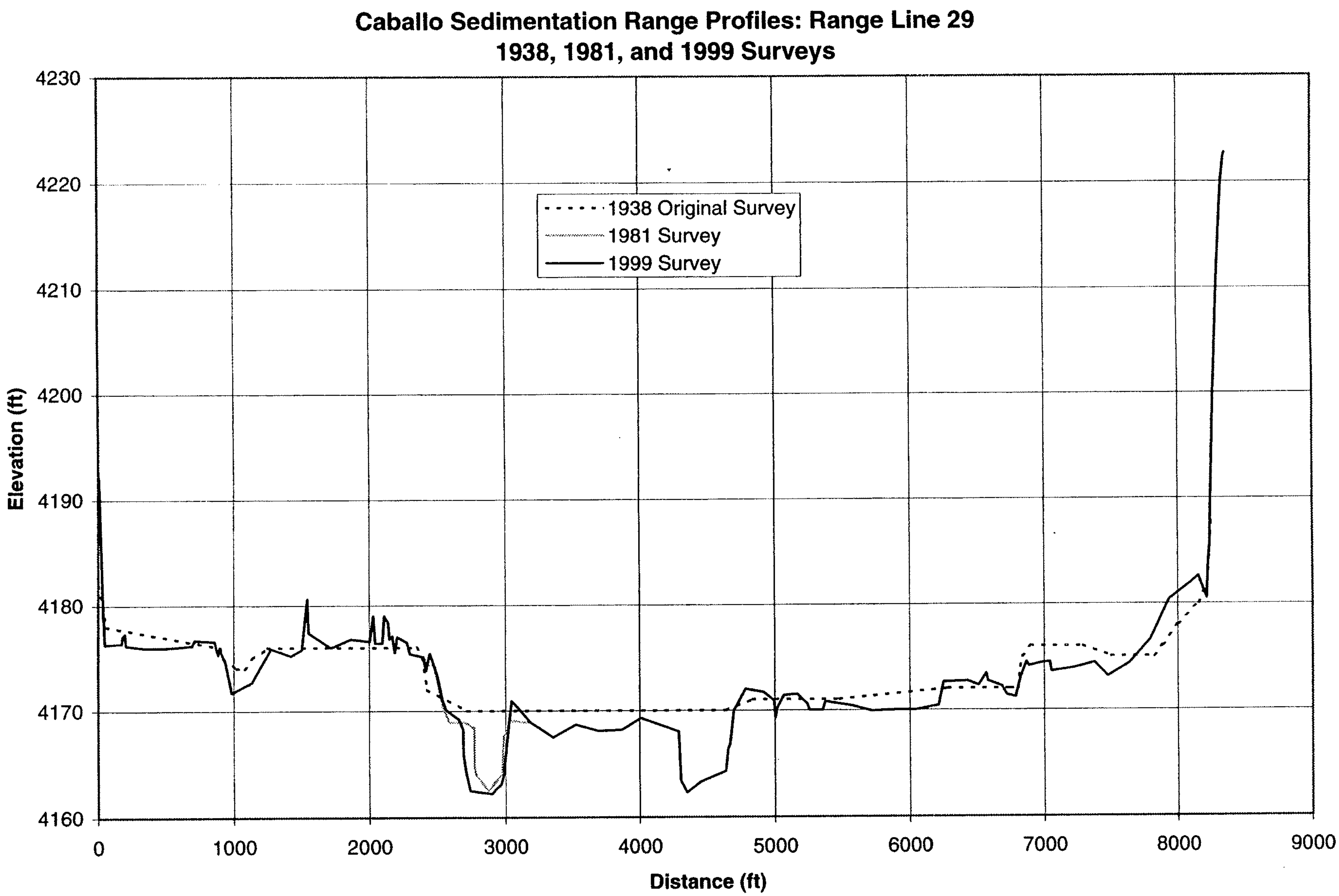

Figure 37. - Sedimentation range profiles for 1938, 1981, and 1999 - range 29.

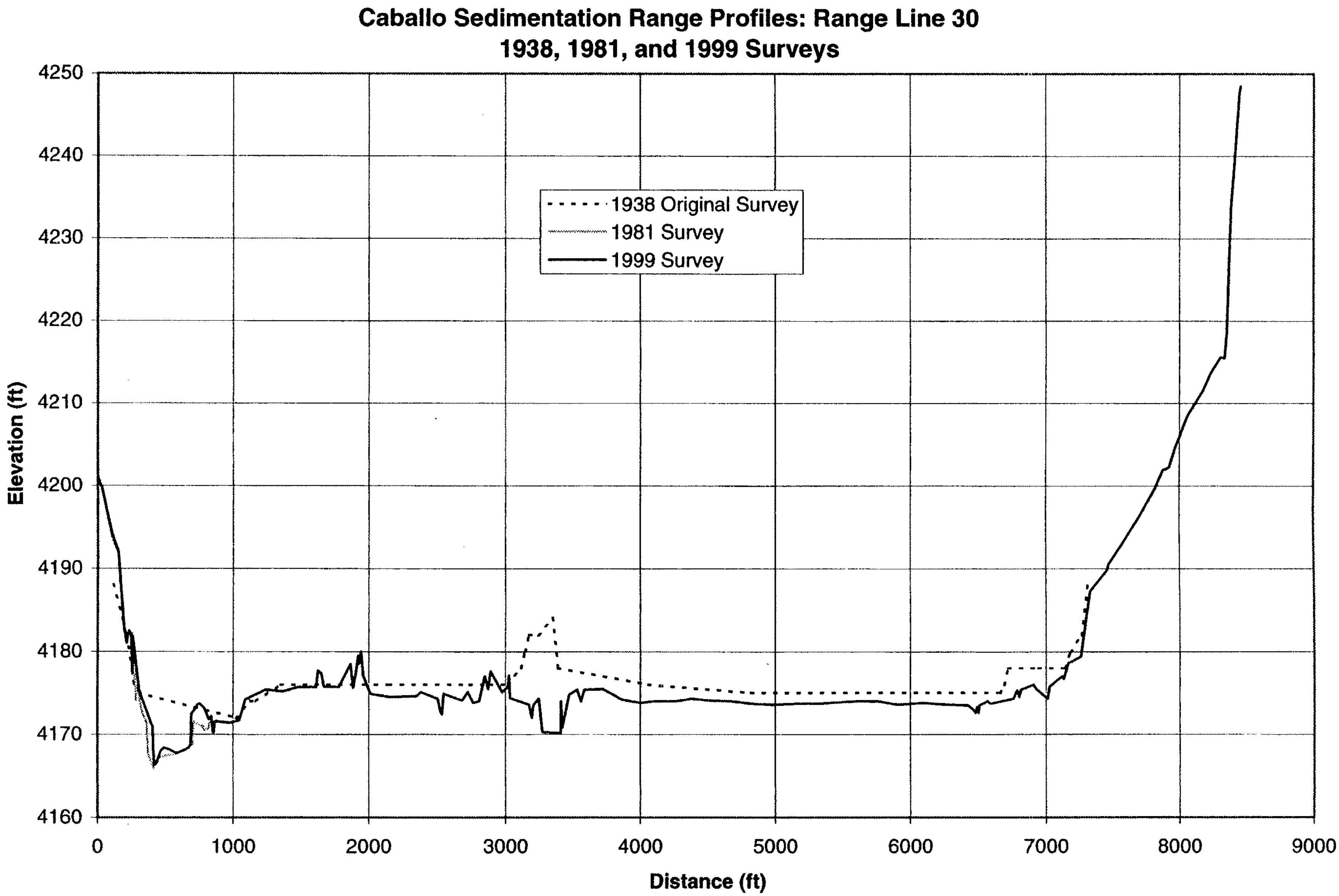

Figure 38. - Sedimentation range profiles for 1938, 1981, and 1999 - range 30.

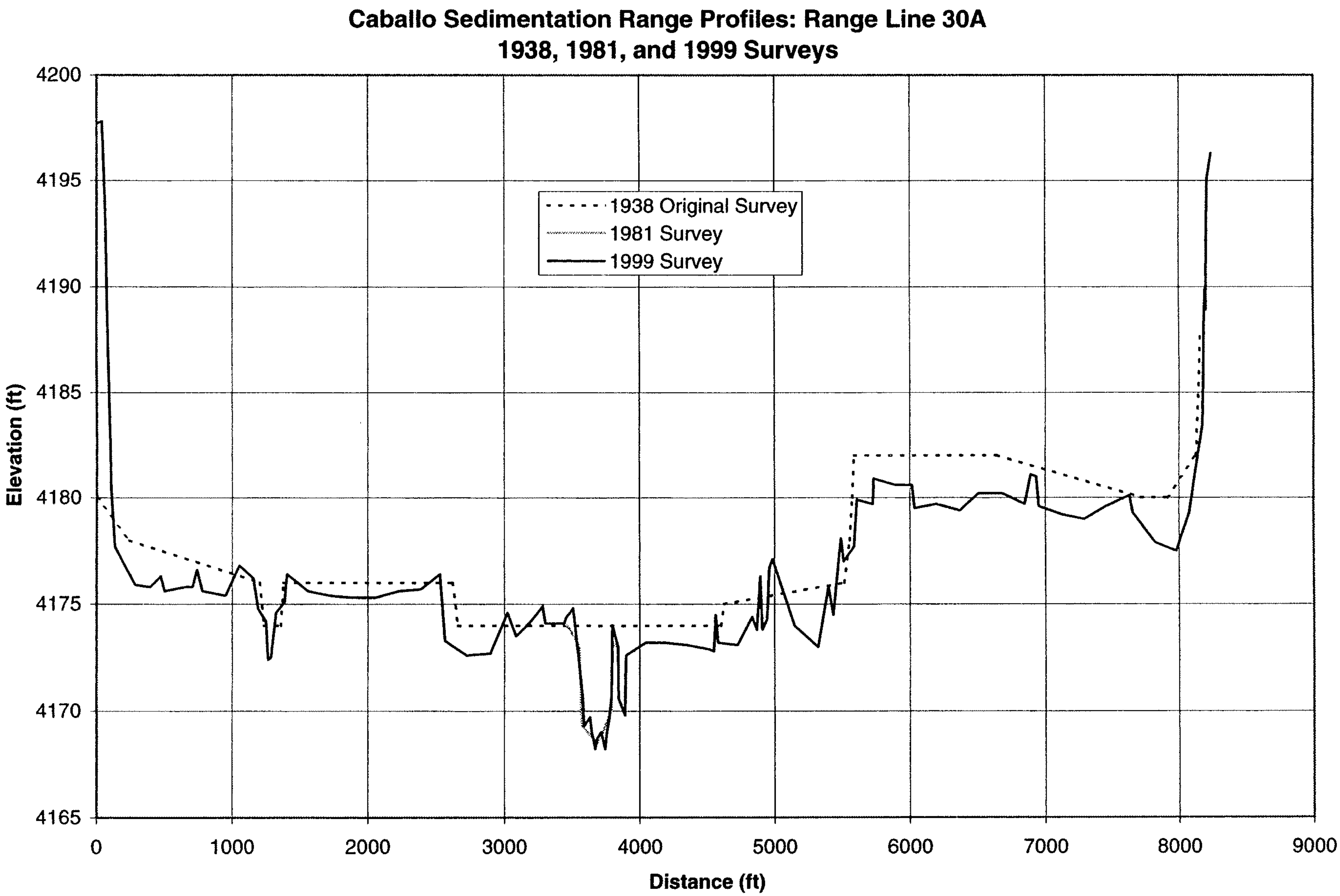

Figure 39. - Sedimentation range profiles for 1938, 1981, and 1999 - range 30A.

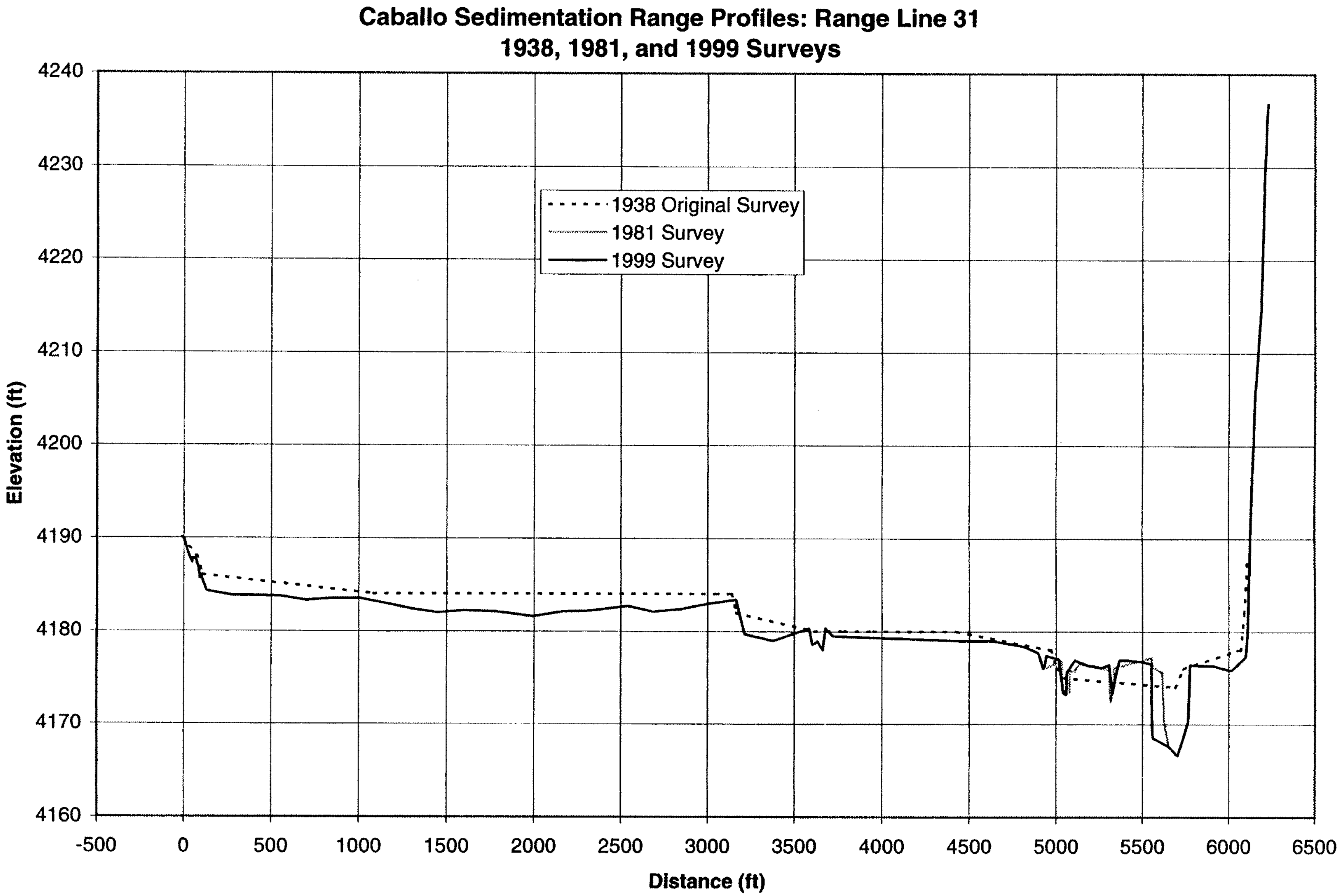

Figure 40. - Sedimentation range profiles for 1938, 1981, and 1999 - range 31.

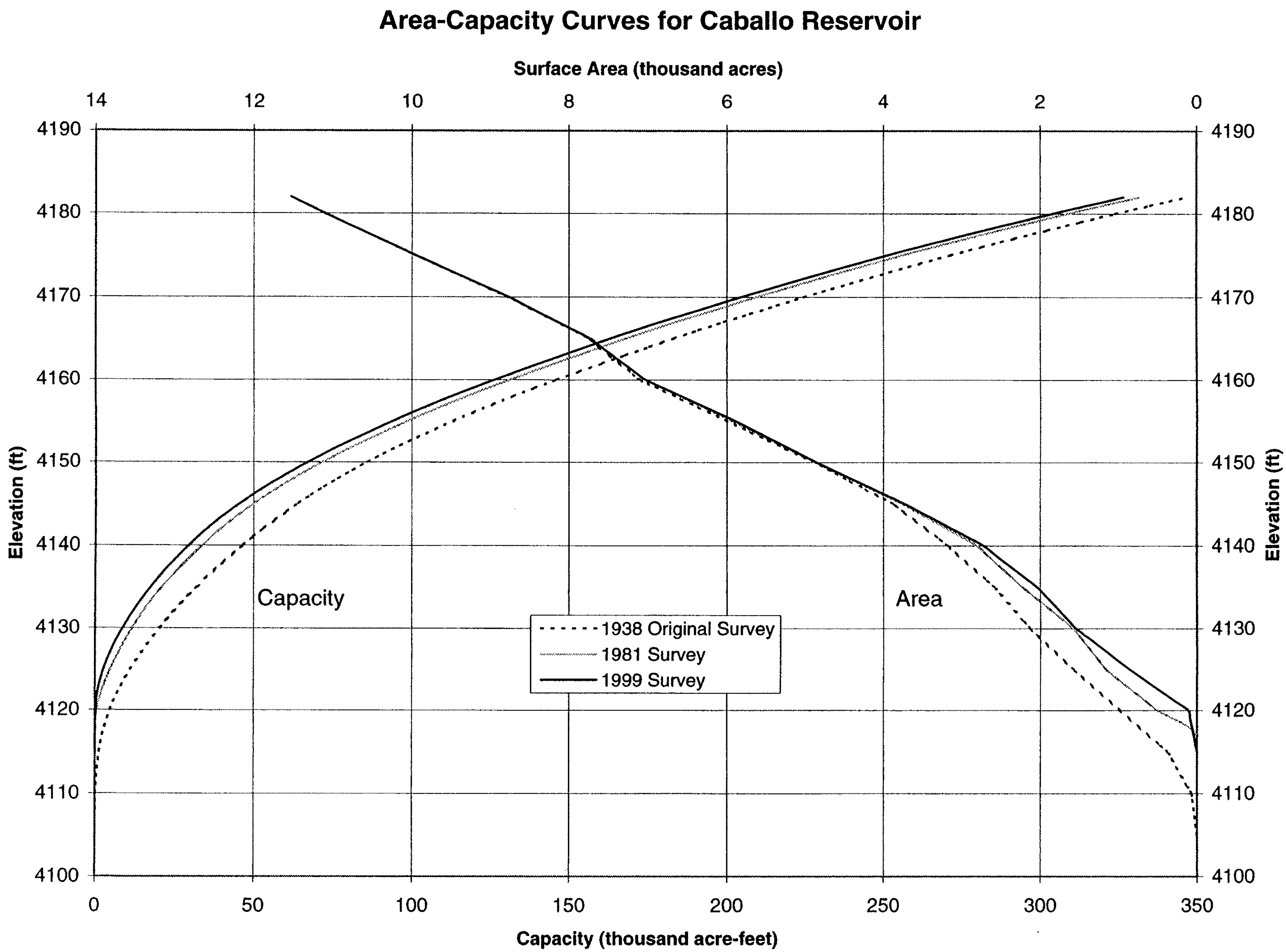

Figure 42. - Area-capacity curves for Caballo Reservoir.