ELEPHANT BUTTE RESERVOIR
1999 RESERVOIR SURVEY

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The Bureau of Reclamation (Reclamation) surveyed Elephant Butte Reservoir in the spring of 1999 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The underwater survey was conducted between reservoir elevation 4,394.2 and 4,396 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 Elephant Butte Reservoir was developed from the combined 1999 underwater measured topography and the USGS quad contours.

As of April 1999, at reservoir water surface elevation (feet) 4,407.0, the surface area was 35,984 acres with a total capacity of 2,023,358 acre-feet. Since the reservoir's initial filling in 1915, 611,442 acre-feet of sediment have accumulated in Elephant Butte Reservoir. Since the last reservoir survey in 1988, 41,652 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1915 is 7,253 acre-feet and since 1988 3,719 acre-feet.

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ELEPHANT BUTTE RESERVOIR

1999 RESERVOIR SURVEY

by

Kent Collins

and

Ron Ferrari

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

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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 spring of 1999 hydrographic survey of the main body of the reservoir. Personnel from the El Paso and Elephant Butte Field Division Offices assisted in the hydrographic survey. Special thanks to Michael Landis and Raymond Lopez for the field assistance and coordination for conducting the survey. The surveys of the upper reservoir range lines were conducted under an Albuquerque Area Office contractduring the 1999 and 2000 field season. 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. Kent Collins of TSC performed the technical peer review of this documentation.

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

Elephant Butte Dam and reservoir are located in Sierra County on the Rio Grande River about 4 miles northeast of Truth or Consequences and 125 miles north of El Paso, Texas in south central New Mexico (fig. 1). Elephant Butte Dam was one of the first major structures built by the Bureau of Reclamation (Reclamation) after its formation in 1902. Elephant Butte Reservoir is the principal storage component of the multipurpose Rio Grande Project.

Elephant Butte Dam construction began in 1908 and was completed in 1916 with water storage operations beginning in January 1915. The dam is a concrete straight gravity structure with a top of dam elevation of 4,414.0 (feet)[1]. There is a parapet wall on both the upstream and downstream sides of the dam crest with the top of the walls being at elevation 4419.0 feet. The dam dimensions are (fig. 2):

• Hydraulic height[2]	193 feet	• Structural height	301 feet
• Top width	18 feet	• Crest length	1,674 feet
• Crest elevation	4,414.0 feet	• Top of parapet wall	4,419.0 feet

A zoned earthfill and rockfill dike is located in a saddle about one mile northwest of the dam. The dike has a paved crest with dimensions as follows:

• Structural height	59 feet	• Top width	20 feet
• Crest length	2,000 feet	• Crest elevation	4425.0 feet

The Elephant Butte Dam spillway is located in the right abutment and consists of a concrete approach apron, an uncontrolled ogee crest weir structure, and a concrete chute. The weir with a crest elevation of 4,407.0 is separated into five equal bays by concrete piers which support a highway bridge. Four 10-foot 4-inch cylinder gates control four 10-foot diameter concrete conduits through the base of the weir. The weir and conduits provide discharge into a concrete-lined chute that discharges into an unlined stilling basin. At reservoir water surface elevation 4,419.0, the spillway provides a maximum discharge of 47,500 cubic feet per second (cfs) with 39,300 cfs over the weir crest and 8,200 cfs through the four conduits.

The service outlet works are located in the dam near the left abutment and consists of an intake structure shared with the sluice and penstock inlets. There are four service conduits: two upper conduits at centerline elevation 4290.0 and two lower conduits at centerline elevation 4234.0. The combined capacity of the service outlets is 4,680 cfs at reservoir water surface elevation 4,407.0. The sluice outlet works are located in the dam near the left abutment and consists of a shared intake structure, trashracks, two slide gates, and two conduits through the dam with a centerline elevation 4,234.0. The sluice outlet capacity is 2,200 cfs at reservoir water surface elevation 4,314.0.

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[1]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.

[2]The definition of such terms as "hydraulic height," "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*, or ASCE's *Nomenclature for Hydraulics*.

The generation penstock outlets consist of an intake structure and trashrack that are shared with the service and sluice outlets. The penstock outlets consist of six penstocks embedded in the dam at the lower left abutment. The three upper penstocks have inlets centered at elevation 4264.7 and the three lower penstocks have inlets centered at elevation 4234.0. The penstocks are joined in pairs (one upper and one lower) near the downstream face of the dam to form three larger penstocks that enter the powerplant. The capacity of the penstock outlets is 2,400 cfs at reservoir water surface elevation 4,407.0.

Drainage Area

The total drainage area above Elephant Butte Dam is 25,923 square miles. A flood study completed in 1984, as a part of the SEED (Safety Evaluation of Existing Dams) program of Elephant Butte Dam, computed a sediment contributing area of 12,023 mi^2. Subtracting the area of Elephant Butte Reservoir (57 mi^2) would result in a net contributing area of 11,966 mi^2. Sediment from the remaining area upstream is considered to be trapped by upstream dams including Jemez Canyon Dam that closed in 1953 with a drainage area of 1,034 mi^2; Galisteo Dam, closed in 1970 with a drainage area of 596 mi^2; and Cochiti Dam, closed in 1973 with a drainage area of 11,960 mi^2. A noncontributing area of 310 mi^2 along the river channel exists between Albuquerque and Belen. The USGS gauge at Elephant butte Reservoir reports a total drainage area of 29,445 mi^2 with 2,940 mi^2 located in the closed basin of the San Luis Valley, Colorado. This would represent a total drainage area of 26,505 mi^2 compared to above reported drainage area of 25,923 mi^2. This study did not conduct research to explain this difference. The sediment contributing area of 11,966 mi^2 was used for this study to be consistent with the past sediment computation results.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1999 results of the survey of Elephant Butte Reservoir. The 1999 survey was the twelfth 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 parallel offset lines to these sediment range lines for the underwater area of Elephant Butte 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 an above water survey was not conducted for this study the Elephant Butte contours were scanned and 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 Elephant Butte 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 9 through 30 were collected during the 1999 and 2000 field season by a combination of small boat and land survey techniques. The results from this survey along with the range lines developed from the bathymetric survey of the main body of the reservoir 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 2 and 3 contain the summary of the 1999 Elephant Butte Reservoir survey results. The 1999 survey determined that the reservoir has a total storage capacity of 2,023,358 acre-feet and a surface area of 35,984 acres at reservoir elevation 4,407.0. 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 611,442 acre-feet representing a total loss in reservoir capacity of 23.2 percent. The average annual sediment accumulation rate for the 84.3 years of record is 7,253 acre-feet. At this rate of sediment accumulation it will take about 14 years to lose 5 percent of the present capacity of Elephant Butte Reservoir.

RESERVOIR OPERATIONS

Elephant Butte Reservoir inflow and end-of-month stage records are listed in table 2 for water years 1915 through April 1999. The average annual inflow based on the 84.3 years of record was 892,281 acre-feet. The average annual inflow since the last reservoir survey, February 1988, was 991,354 acre-feet. The streamflow records of the gauging station at San Marcial, New Mexico were used to represent the inflow for the period of record through water year 1951. Starting in water year 1952 the combined streamflow records of the flood way and conveyance channel at San Marcial were used. It must be noted that these records do not reflect the total inflow since no records of inflow from the downstream tributaries, such as Monticello and Nogal Canyons, are accounted for. The table shows that since the last survey the reservoir operation has ranged from elevation 4,380.3 in water year 1990 to elevation 4406.7 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 Elephant Butte 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 (Elephant Butte's water surface elevation parameter) was known, which in theory meant only three satellite observations were needed to track the survey vessel. During the Elephant Butte 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 Elephant Butte 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 recently began using Real-time Kinematic (RTK) GPS with the 1999 Elephant Butte Reservoir 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 Elephant Butte survey, 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 twelfth survey of the reservoir with the previous surveys being conducted in 1916, 1925, 1935, 1940, 1947, 1951, 1957, 1969, 1974, 1980, and 1988. A layout of the reservoir sedimentation range line system is shown on figures 3 through 8. The 1999 collection was conducted during the period of March 19 through April 13, 1999. The reservoir water surface elevation varied from 4,394.2 to 4,396.0 (Reclamation project datum) during this time frame. There were only 13 actual survey days during this time frame due to heavy winds and RTK GPS radio problems. 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 31 to range line 90 for a total of 57 sediment range lines. For the purpose of mapping the reservoir bottom, 500-foot offset grid lines parallel to these sediment range lines were also collected to cover the underwater area of the reservoir. Due to the heavy vegetation and shallow water conditions in the upper reservoir area covered by the larger survey vessel, some areas had transect distances greater than 500 feet. Most of the transects (grid lines) were run approximately in a perpendicular direction to the center line of the reservoir at this 500-foot spacing and data was also collected along the shore as the boat traversed to the next transect. See figures 9 through 12 for the areas covered by the large survey vessel. 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 elevations at the dam, recorded by a Reclamation gauge, were 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 9 through 30, were surveyed during the 1999 and 2000 field season under contract with the Albuquerque Area Office. Standard land surveying techniques were used to survey the above water area and a small survey vessel was used to map the underwater portion of each range line. Range lines, 9 through 30, that showed no apparent change west of the San Marcial levee were spot checked by the survey crew to confirm that the 1999-2000 cross sectional geometry was the same as the 1988 surveyed geometry before moving on to survey the next range line.

Elephant Butte Reservoir Datums

Prior to the underwater survey in March of 1999 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 45.3 to 45.6 feet lower. 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 "Airport AZ MK 2". The following table shows the results from the 1999 RTK GPS survey.

U.S. BUREAU OF RECLAMATION SEDIMENTATION & RIVER HYDRAULICS GROUP ELEPHANT BUTTE RESERVOIR 1999 RTK GPS CONTROL SURVEY BASE SET AT NGS "AIRPORT AZMK 2" DS1457									
Point #	Latitude NAD83	Longitude NAD83	Ellipsoid Height (ft)	Date	New Mexico State Plane Central			Water Surface Elevation (ft)	1988 Project Elevation (ft)
					NAD83		NAVD 88		
					Northing (ft)	Easting (ft)	Elevation (ft)		
DS1457	33°14'06.55949 N	107°16' 05.88551 W	4775.297		814602.881	1329056.316	4819.7		
65W-66W	33°17'50.58440 N	107° 10'38.54703" W	4393.067		836986.653	1357060.735	4469.149		4468.87
67W	33°17' 24.16117" N	107°10' 51.94785" W	4409.376		834326.133	1355899.488	4485.485		4482.28
V86	33°10'14.50236" N	107°12'17.74866" W	4396.144		7900965.783	1348219.682	4472.322		
84W	33°10'27.82646" N	107°12'19.88611" N	4273.489		792314.112	1348050.289	4349.672		
90E	33°08'51.49798" N	107°10'35.13370" W	4629.877		782498.192	1356867.717	4705.902		
WS				4/15/99	809367	1347393	4439.7	4394.2	
WS				4/15/99	790173	1349383	4439.7	4394.2	

Notes:
1988 project elevations based on a 1988 control survey.

WS = survey of reservoir water survey on indicated date.
Water surface elevation read at Reclamation gauge published as 43.3 feet less than NGVD29.

Table 1 - RTK GPS control survey

RESERVOIR TOPOGRAPHY DEVELOPMENT

Using ARC/INFO, the topography of Elephant Butte 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 Elephant Butte Reservoir were developed by scanning and digitizing the contour lines labeled elevation 4340, 4360, 4380, 4400, 4420, 4460, 4480, 4500, 4520, and 4540 on the USGS quad maps that covered the lower portion of the Elephant Butte Reservoir area. The contour lines labeled 4440 and 4450 were digitized for the entire reservoir. 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 center 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 project elevation 4,396.7 contour digitized from USGS quad maps (labeled elevation 4,440 on the quads) was 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. This clip was selected because it was the nearest contour elevation during the time of the underwater survey, around elevation 4,395.0.

Contours for elevations 4,396.7 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 Elephant Butte 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 Elephant Butte Reservoir since the areas were calculated from the developed TIN. The contour topography at 10-foot intervals is presented on figures 13 through 18, drawing numbers 24-D-1863 through 24-D-1868.

The USGS quad maps illustrate the different topography of the reservoir area. Most of the reservoir is enclosed by steep canyon wall or steep sloop type topography. The reservoir bottom topography above the narrows is a fairly flat valley type while the narrows and below to the dam is very rugged with a meandering river channel and many high rock outcrops shooting from the reservoir bottom. As seen on figures 9 through 12, the 500-foot collection interval covered most of the reservoir from the dam up through the narrows of the reservoir, but as illustrated, many of the cove areas of the reservoir had only a few profiles where underwater data was collected. The 500-foot profiles also did not provide adequate detail to map the many rock outcrops throughout this portion of the reservoir. To resolve this problem additional data points were added to the underwater data set using the USGS quad controls as a pattern of where to place these points. This method allowed more detailed topographic development for creating the maps for this study, but not the data needed to accurately calculate reservoir contour areas from the contour method. The best means to resolve this issue would be to collect aerial data of the reservoir when and if the reservoir has dropped to elevation 4350 or lower and to collect additional underwater data at a much closer range line offset spacing. This could be accomplished by collecting data at 200- to 300-foot intervals or by utilizing newer technology that allows multi-beam depth collection.

RESERVOIR SEDIMENT DISTRIBUTION

Longitudinal Distribution

To illustrate the sediment distribution throughout the reservoir a longitudinal profile was plotted for the original, 1988 and 1999 reservoir conditions (figure 19). The difference between the original thalweg and the 1988 and 1999 thalweg represents the sediment encroachment into the reservoir since the dam closed in 1915. The plot illustrates the greatest depths of longitudinal sediment deposits occurring between 14 to 16 miles above the dam. The deposit pattern in this region was probably influenced by the "Narrows" area located between 15 and 20 miles above the dam. When the reservoir is full, the narrows divides the reservoir into 2 large water bodies. The narrows has an average width of 0.36 miles compared to an average width of 1.39 miles for the overall reservoir. A major factor influencing the longitudinal pattern of the reservoir is the operational water surface. During 1950 through 1968 there was a severe drought in the region where the reservoir was held at a much lower stage allowing the sediment inflow to be deposited in the lower reaches of the reservoir. The plot of the 1988 and 1999 thalweg illustrates where the majority of sediments have deposited over the last 11 years, which is in the upper reservoir area above mile 26. Since the 1988 survey the reservoir has fluctuated between reservoir elevation 4380.3 and 4406.7. The sediment delta buildup since 1988 starts around elevation 4380.

Lateral Distribution

Ground profiles of the 82 reservoir sedimentation ranges are shown on figures 20 through 101. These profiles illustrate the general lateral distribution of sediments in the reservoir. Plots are from left to right looking upstream to be consistent with previous survey reports. The plots illustrate the survey results from the original, 1988, and 1999 surveys. The original and other profiles do not fully agree in the lateral direction for all ranges mainly due to the fact the original profiles were transcribed from a 1915 topographic map with a contour interval of 10 feet. During the 1988 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 line 32 through 90, the results from the 1988 survey were used to develop the range line plots for the areas not covered by the1999 survey. The 1988 data were also used to complete plots for the range lines above 32 for the areas of the profile that the 1999-2000 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 interpolated data points from the USGS quad contours. Due to the need to interpolate additional points to complete the topography development from the narrows to the dam 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 102, 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 was required to determine whether the change is due to survey inaccuracies or due to actual deposition or erosion. As noted previously the original range line data was scaled from the original 10-foot contour maps.

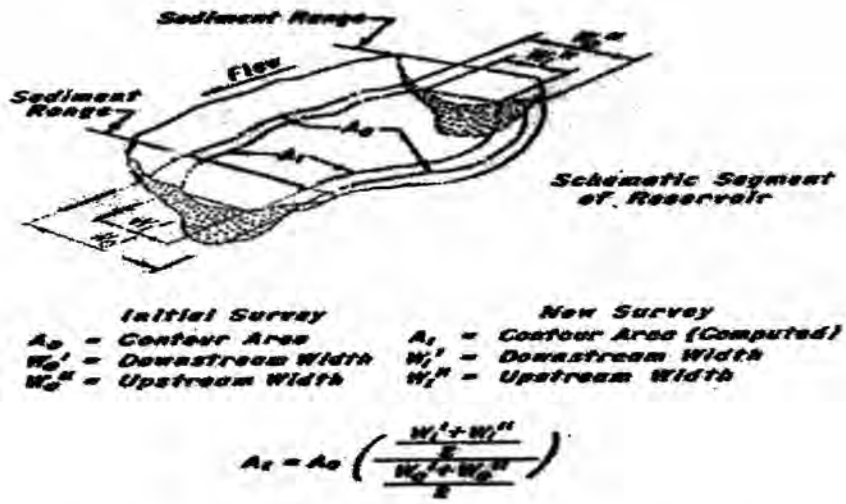

Figure 102 - Width adjustment method for revising contour areas

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 1957 sedimentation study, planimetering determined the original segmental contour surface areas between boundaries for each 10-foot contour from a maximum water surface of 4410 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 10-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 4,245.0, the 1999 measured surface areas at 10-foot contour intervals from elevation 4245.0 to elevation 4,410.0 provided the control parameters for computing the 1999 Elephant Butte 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 Elephant Butte

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 Elephant Butte Reservoir area and capacity computations are listed in table 2 and columns (8) and (9) of table 3. 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 103. As of April 1999, at elevation 4,407.0, the surface area was 35,984 acres with a total capacity of 2,023,358 acre-feet.

ANALYSES OF RESULTS

The Elephant Butte Reservoir original and 1999 area and capacity values are illustrated on figures 19 and 103 and the results are listed on tables 2 and 3. These presentations illustrate the capacity difference that has occurred during the 84.3 years of reservoir operations. This study found that as of April 1999, at reservoir water surface elevation (feet) 4,407.0, the surface area was 35,984 acres with a total capacity of 2,023,358 acre-feet. Since the reservoir's initial filling in 1915, 611,442 acre-feet of sediment have accumulated in Elephant Butte Reservoir. Since the last reservoir survey in 1988, 41,652 acre-feet of sediment have been trapped. The average annual rate of sediment accumulation since 1915 is 7,253 acre-feet and since 1988 it is 3,719 acre-feet.

As illustrated on table 2 the 1999 study found that the average annual sediment inflow since the last survey in 1988 was 3,719 acre-feet. This compares to an average annual inflow of 5,591 acre-feet measured between the 1980 and 1988 surveys and an average annual inflow of 2,493 acre-feet measured between the 1969 and 1980 surveys. As noted previously the same method of analysis was used for the 1980, 1988, and 1999 surveys. Table 2 also illustrates that the mean annual inflow for the 1988 and 1999 surveys was above average being 1,189,815 acre-feet and 991,354 acre-feet respectfully.

At elevation 4,380 the 1980 survey measured a capacity of 1,264,305 acre-feet and the 1988 survey measured a capacity of 1,241,164 acre-feet. The sediment accumulation between the 1980 and 1988 survey at reservoir elevation 4,380 and below was 23,141 acre-feet compared to the total accumulation of 45,288 acre-feet for the same time period at elevation 4,407.0. For the 1988 study, 49 percent of the measured sediment since the 1980 survey was found above elevation 4,380.

The 1999 survey measured a capacity of 1,225,489 acre-feet at elevation 4,380 or a sediment accumulation since 1988 of 15,675 acre-feet. The 1999 survey measured 62 percent of accumulated sediment since 1988 above elevation 4,380. As noted previously, since 1988 the reservoir has been at elevation 4380 or higher which has not allowed the accumulated sediment to be flushed from the upper reservoir area to the lower reservoir areas as illustrated on figure 19.

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RESERVOIR SEDIMENT
DATA SUMMARY

Elephant Butte 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. 30 TWP. 13 S RANGE 3 W	5. NEAREST PO Truth of Consequences	6. COUNTY Sierra
	7. LAT 33° 09' 15" LONG 107° 11' 28"	8. TOP OF DAM ELEVATION 4414[1]	9. SPILLWAY CREST EL 4407.0

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					1/6/15
	c. MULTIPLE USE	4407.0[2]	40,064	2,631,585	2,634,800	
	d. WATER SUPPLY					16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. CONSERVATION					
	g. INACTIVE	4231.5	420[3]	3,215	3,215	2/1/15
	17. LENGTH OF RESERVOIR 41 MILES			AVG. WIDTH OF RESERVOIR 1.39 MILES		

BASIN	18. TOTAL DRAINAGE AREA 25,923 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 8.29[4] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 11,996[5] SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.64[6] INCHES
	20. LENGTH 305 MILES	AV. WIDTH 85 MILES	24. MEAN ANNUAL RUNOFF 892,281[7] ACRE-FEET
	21. MAX. ELEVATION 12,000	MIN. ELEVATION 4,210	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 INTERVAL	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
	1/6/15[8]			Contour (D)	10-ft (CI)	40,064	2,634,800	
	2/12/57	42.1	42.1	Range (D)	73 (R)	35,584	2,206,780	2.20
	4/1/69	12.1	54.2	Range (D)	60 (R)	36,569	2,137,219	2.31
	1/24/80	10.8	65.0	Range (D)	81 (R)	36,897	2,110,298	2.33
	2/17/88	8.1	73.1	Range (D)	82 (R)	36,643	2,065,010	2.24
	4/99	11.2	84.3	Range (D)	82 (R)[9]	35,984	2,023,358	2.29

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
2/12/57[8]		926,137[7]	2,440,000	38,990,350	926,137	38,990,350
4/1/69		646,121	1,391,000	7,818,070	863,624	46,808,420
2/24/80		710,204	1,427,000	7,670,200	838,133	54,478,620
2/17/88		1,189,815	1,732,000	9,637,500	877,102	64,116,120
4/1/99		991,354	1,776,000	11,103,200	892,281	75,219,280

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.
1/6/15						
2/12/57				428,020	10,167	0.393[10]
4/1/69	69,561	5,749	0.257[10]	497,581	9,180	0.363[10]
2/24/80	26,921	2,493	0.208[10]	524,502	8,069	0.337[10]
2/17/88	45,288	5,591	0.480[10]	569,790	7,795	0.351[10]
4/1/99	41,652	3,719	0.310[10]	611,442	7,253	0.330[10]

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.
1/6/15							
2/12/57	60			0.386	16.2		
4/1/69	62	416	490	0.348	18.9		
2/24/80		281	455	0.306	19.9	3490	9566
2/17/88		631	474	0.296	21.6	4670	8830
4/1/99				0.275	23.2		

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

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION.										
		137-197	117-137	97-117	77-97	57-77	37-57	27-37	17-27	7-17	crest-7
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
4/99		2.6	12.2	15.6	8.5	11.9	16.0	9.6	9.3	8.9	5.4

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[11]

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1915	4321.8		1,302,250	1916	4346.8	4306.6	1,421,000
1917	4353.8	4331.8	1,305,000	1918	4337.0	4290.3	379,100
1919	4358.8	4285.5	1,527,000	1920	4393.9	4350.9	1,970,000
1921	4392.5	4377.5	1,470,000	1922	4389.5	4370.7	1,044,000
1923	4377.4	4366.5	964,000	1924	4395.8	4368.9	1,662,000
1925	4382.1	4354.7	321,000	1926	4378.1	4354.6	1,120,000
1927	4374.0	4363.0	1,180,000	1928	4379.1	4359.7	773,000
1929	4374.8	4353.7	1,240,000	1930	4384.5	4372.3	930,000
1931	4374.2	4349.7	418,000	1932	4384.5	4351.8	1,440,000
1933	4377.9	4365.0	717,000	1934	4367.8	4325.0	298,300
1935	4342.2	4322.8	917,600	1936	4354.9	4331.8	872,900
1937	4380.7	4333.9	1,597,000	1938	4377.1	4365.6	1,004,000
1939	4378.4	4351.2	615,700	1940	4357.0	4323.2	333,100
1941	4399.2	4324.3	2,440,000	1942	4409.2	4397.0	2,322,000
1943	4399.0	4380.8	441,600	1944	4385.7	4369.2	982,500
1945	4385.6	4372.3	851,500	1946	4375.7	4339.5	224,900
1947	4339.4	4311.9	419,200	1948	4349.2	4313.1	1,036,000
1949	4351.3	4329.7	1,031,000	1950	4346.1	4315.5	364,100
1951	4315.8	4262.3	132,900	1952	4324.6	4261.6	967,000
1953	4220.5	4283.2	286,800	1954	4297.3	4258.0	198,500
1955	4295.5	4276.6	257,900	1956	4304.4	4268.4	174,800
1957	4337.1	4267.1	972,300	1958	4373.3	4336.2	1,391,000
1959	4362.8	4334.5	341,900	1960	4339.0	4322.4	563,400
1961	4329.1	4302.0	437,700	1962	4329.8	4304.4	748,100
1963	4327.5	4282.1	405,500	1964	4299.2	4275.5	164,200
1965	4323.0	4277.5	821,700	1966	4338.3	4311.0	725,340
1967	4321.8	4293.0	391,600	1968	4319.7	4295.1	646,230
1969	4335.0	4308.8	787,600	1970	4339.4	4303.0	729,200
1971	4326.4	4271.2	413,100	1972	4319.0	4279.7	427,900
1973	4355.5	4319.2	1,309,000	1974	4360.9	4312.2	451,400
1975	4345.9	4326.1	875,900	1976	4353.0	4318.0	580,900
1977	4325.2	4295.8	243,200	1978	4314.7	4290.2	385,100
1979	4365.0	4305.9	1,427,000	1980	4380.5	4363.8	1,280,000
1981	4378.1	4354.3	341,700	1982	4364.7	4354.3	824,300
1983	4383.6	4364.8	1,262,000	1984	4392.3	4381.0	1,052,000
1985	4404.4	4392.0	1,542,000	1986	4407.2	4402.8	1,576,000
1987	4406.6	4402.7	1,732,000	1988	4406.7	4401.4	930,300
1989	4405.1	4393.4	478,200	1990	4397.5	4380.3	347,100
1991	4392.4	4380.6	1,043,000	1992	4405.7	4391.4	1,167,000
1993	4405.7	4398.4	1,254,000	1994	4406.0	4401.1	1,776,000
1995	4406.6	4403.9	1,385,000	1996	4406.5	4394.2	525,700
1997	4401.5	4395.2	943,200	1998	4404.5	4393.1	919,200
1999	4404.5	4398.7	334,500				

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

46. ELEVATION - AREA - CAPACITY DATA FOR **1915 CAPACITY**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4210	0	0	4220	98	490	4230	376	2,960
4240	671	4,660	4250	1,684	15,800	4260	3,157	39,700
4270	4,691	78,600	4280	6,145	132,800	4290	7,715	202,100
4300	8,923	285,400	4310	10,202	380,800	4320	11,894	490,800
4330	14,240	621,400	4340	16,595	775,600	4350	19,194	954,400
4360	22,563	1,162,100	4370	26,620	1,408,000	4380	30,191	1,692,800
4390	33,451	2,010,300	4400	37,328	2,363,900	4407	40,060	2,634,800
4410	41,283	2,756,600						
1999	**Survey**		**1999**	**Survey**		**1999**	**Survey**	
4245	0	0	4250	63	157	4260	822	4,579
4270	2,107	19,220	4280	2,562	42,561	4290	4,171	76,222
4300	6,063	127,388	4310	7,434	194,872	4320	9,563	279,857
4330	11,169	383,516	4340	13,046	504,591	4350	14,784	643,744
4360	17,765	806,489	4370	20,856	999,593	4380	24,323	1,225,489
4390	27,788	1,486,042	4400	32,051	1,785,235	4407	35,984	2,023,358
4410	37,670	2,133,814						

47. REMARKS AND REFERENCES

1 All elevations are project datum which is 43.3 feet less than National Geodetic Vertical Datum of 1929. There is a parapet wall on upstream and downstream sides of the dam crest with top elevation 4419.0.

2 Irrigation and power water supply, except the top 50,000 AF in the summer (April 1 - September 30) and the top 25,000 AF in the winter (October 1 - March 31), which is used for prudent flood control space.

3 Estimated by interpolation.

4 Reclamation Project Data Book, 1981. Reclamation site: http://dataweb.usbr.gov. Annual precipitation at dam of 8.29 inches (1908-1992) from NOAA/NWS.

5 Previous studies report total drainage area as 25,923 mi^2 while USGS gage data at dam indicate 29,445 mi^2 with 2,940 mi^2 as non contributing. Used 1988 and previous study results to be consistent. Represents loss of contributing area since closing of Jemez Dam in 1953 (1,034 mi^2), Galisteo Dam in 1970 (596 mi^2), Cochiti in 1973 (11,960 mi^2), noncontributing are (310mi^2), and reservoir area (57 mi^2).

6 Calculated using mean annual runoff value of 882,832 AF, item 24, water years 1915-1999. Measured Rio Grande River flows from San Marcial gage.

7 Computed annual inflows from 1/15 through 4/99 from measured Rio Grande river flows at San Marcial gage.

8 Values from 1915 through 1988 from 1988 Sedimentation Survey report.

9 Underwater cross sections were run every 500 feet from the dam up to range line 31. To develop a detailed accurate topography of the total reservoir above water data would be needed when reservoir is below elevation 4350. This is due to the detailed topography of this region. For computation purposes the width adjustment method was used to develop new area and capacity tables as was used during previous analysis.

10 Adjusted for reduced sediment contribution area due to upstream reservoir development.

11 From January 1915 through April 1999 from USGS records, by water year.

48. AGENCY MAKING SURVEY Bureau of Reclamation

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

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

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					1988	1988			1999	1999	Sediment	Percent of	Percent of
Elevations	Original	Original	1988	1988	Sediment	Percent of	1999	1999	Sediment	Percent of	Volume	Computed	Reservoir
	Survey	Capacity	Survey	Survey	Volume	Sediment	Survey	Survey	Volume	Sediment	1988-1999	Sediment	Depth
FEET	ACRES	AC-FT	ACRES	AC-FT	AC-FT		ACRES	AC-FT	AC-FT		AC-FT	1988-1999	
4407.0	40,060	2,634,800	36,643	2,065,010	569,790	100.0	35,984	2,023,358	611,442	100.0	41,652	100.0	100.0
4400.0	37,328	2,363,900	33,433	1,819,744	544,156	95.5	32,051	1,785,235	578,665	94.6	34,509	82.9	96.4
4390.0	33,451	2,010,300	28,697	1,509,096	501,204	88.0	27,788	1,486,042	524,258	85.7	23,054	55.3	91.4
4380.0	30,191	1,692,800	24,890	1,241,164	451,636	79.3	24,323	1,225,489	467,311	76.4	15,675	37.6	86.3
4370.0	26,620	1,408,000	20,994	1,011,742	396,258	69.5	20,856	999,593	408,407	66.8	12,149	29.2	81.2
4360.0	22,563	1,162,100	18,011	816,715	345,385	60.6	17,765	806,489	355,611	58.2	10,226	24.6	76.1
4350.0	19,194	954,400	14,872	652,300	302,100	53.0	14,784	643,744	310,656	50.8	8,556	20.5	71.1
4340.0	16,595	775,600	13,210	511,890	263,710	46.3	13,046	504,591	271,009	44.3	7,299	17.5	66.0
4330.0	14,240	621,400	11,260	389,537	231,863	40.7	11,169	383,516	237,884	38.9	6,021	14.5	60.9
4320.0	11,894	490,800	9,535	285,562	205,238	36.0	9,563	279,857	210,943	34.5	5,705	13.7	55.8
4310.0	10,202	380,800	7,503	200,374	180,426	31.7	7,434	194,872	185,928	30.4	5,502	13.2	50.8
4300.0	8,923	285,400	6,205	131,833	153,567	27.0	6,063	127,388	158,012	25.8	4,445	10.7	45.7
4290.0	7,715	202,100	4,263	79,490	122,610	21.5	4,171	76,222	125,878	20.6	3,268	7.8	40.6
4280.0	6,145	132,800	2,660	44,873	87,927	15.4	2,562	42,561	90,239	14.8	2,312	5.6	35.5
4270.0	4,691	78,600	2,142	20,861	57,739	10.1	2,107	19,220	59,380	9.7	1,641	3.9	30.5
4260.3	3,302	40,717	1,007	5,590	35,127	6.2	860	4,831	35,886	5.9	759	1.8	25.5
4260.0	3,157	39,700	971	5,293	34,407	6.0	822	4,579	35,121	5.7	714	1.7	25.4
4250.0	1,684	15,800	55	160	15,640	2.7	63	157	15,643	2.6	3	0.0	20.3
4245.0	1,178	10,230	8	3	10,227	1.8	0	0	10,230	1.7	3	0.0	17.8
4244.2	1,096	9,339	0	0	9,339	1.6	0	0	9,339	1.5	0	0.0	17.4
4240.0	671	4,660			4,660	0.8			4,660	0.8			15.2
4230.0	376	2,960			2,960	0.5			2,960	0.5			10.2
4220.0	98	490			490	0.1			490	0.1			5.1
4210.0	0	0			0	0.0			0	0.0			0.0

1	Elevation of reservoir water surface.
2	Original reservoir surface area.
3	Original calculated reservoir capacity computed using ACAP from original measured surface areas.
4	Reservoir surface area from 1988 survey.
5	Recomputed reservoir capacity computed using ACAP, from 1988 measured surface areas.
6	Measured sediment volume = column (3) - column (5).
7	Measured sediment expressed in percentage of total sediment 569,790 at elevation 4,407.0.
8	Reservoir surface area from 1999 survey for elevations 4,407.0 and below.
9	1999 calculated reservoir capacity computed using ACAP, from 1999 measured surface areas.
10	1999 measured sediment volume = column (3) - column (9).
11	Measured sediment expressed in percentage from original to 1999, sediment volume of 611,442 acre-feet at elevation 4,407.0.
12	Measured sediment volume from 1988 to 1999 = column (5) - column (9).
13	Measured sediment expressed in percentage from 1988 to 1999, sediment volume of 41,652 acre-feet at elevation 4,407.0.
14	Depth of reservoir expressed in percentage of total depth (197), below spillway crest.

Table 3 - Summary of 1999 survey results

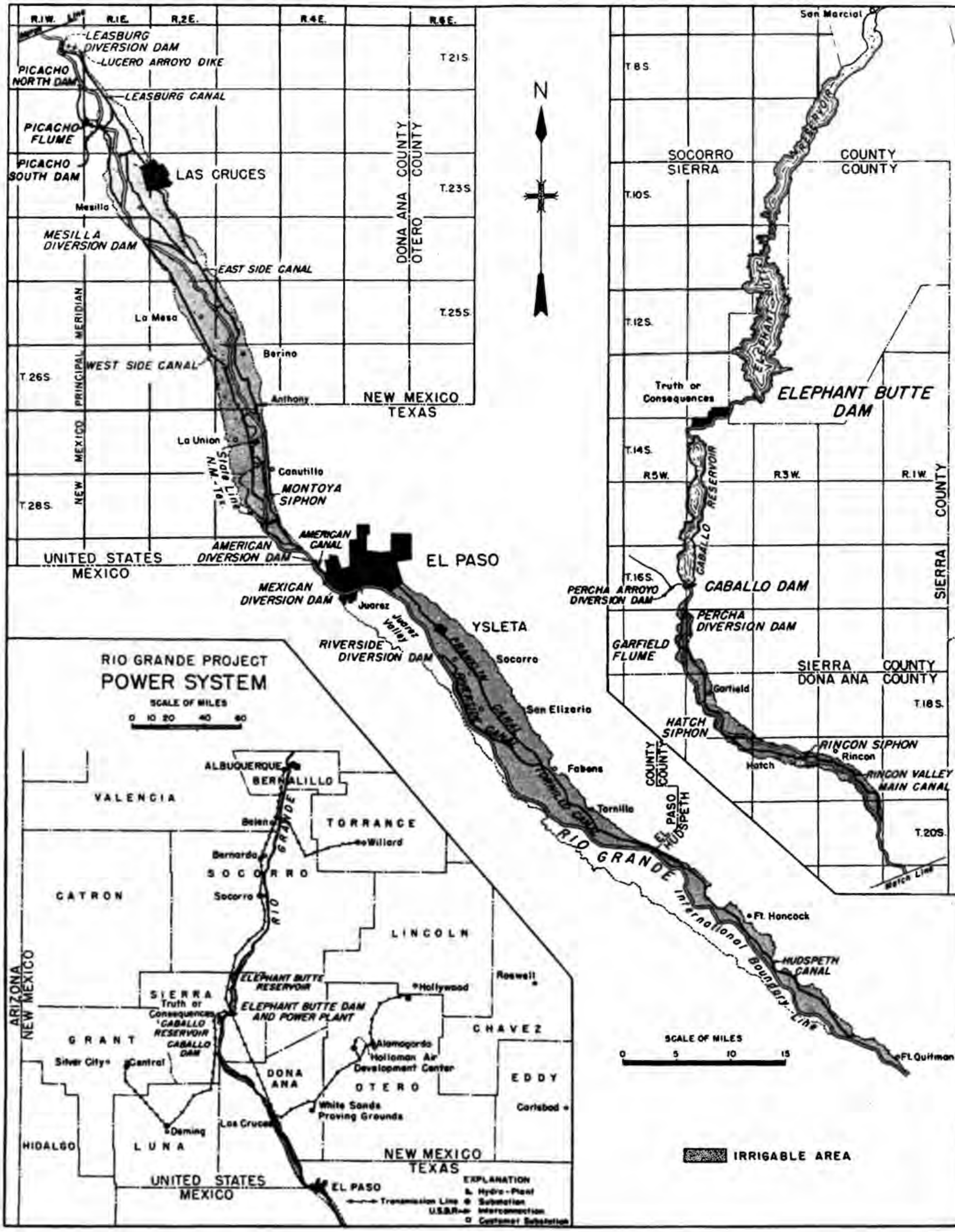


Figure 1 - Elephant Butte Reservoir location map.

Space intentionally left blank due to security concerns

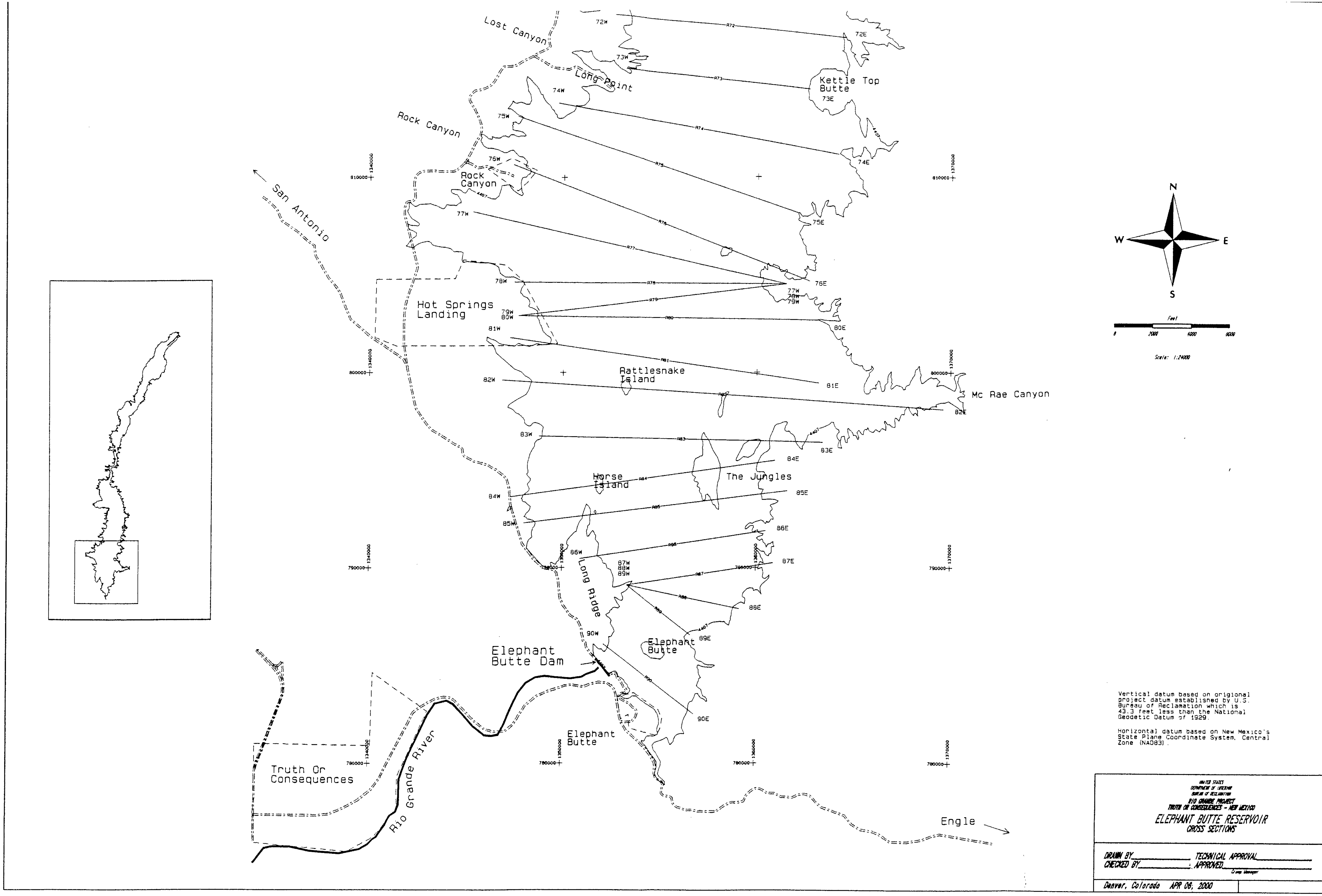


Figure 3 - Elephant Butte Reservoir sedimentation range lines

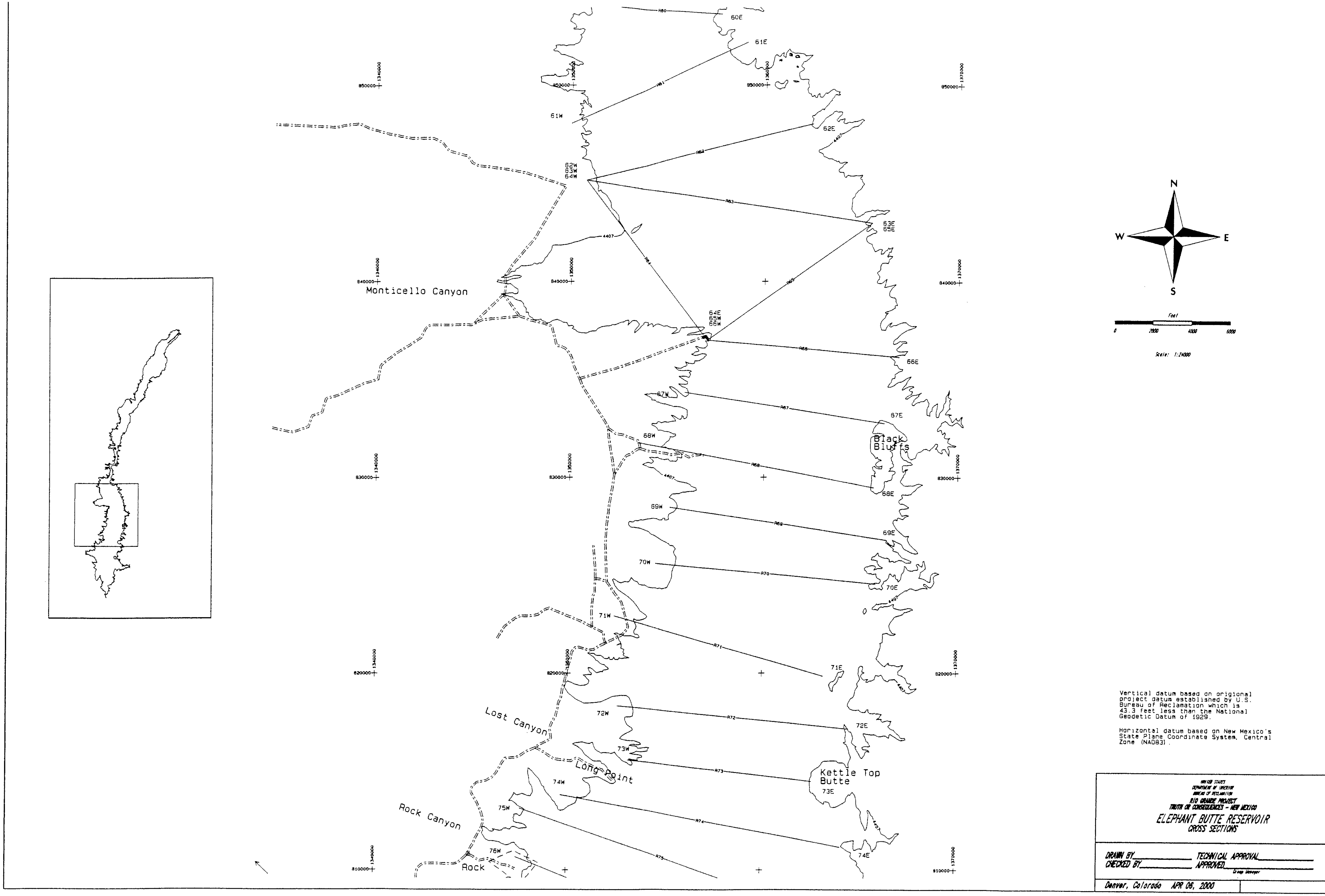


Figure 4 - Elephant Butte Reservoir sedimentation range lines

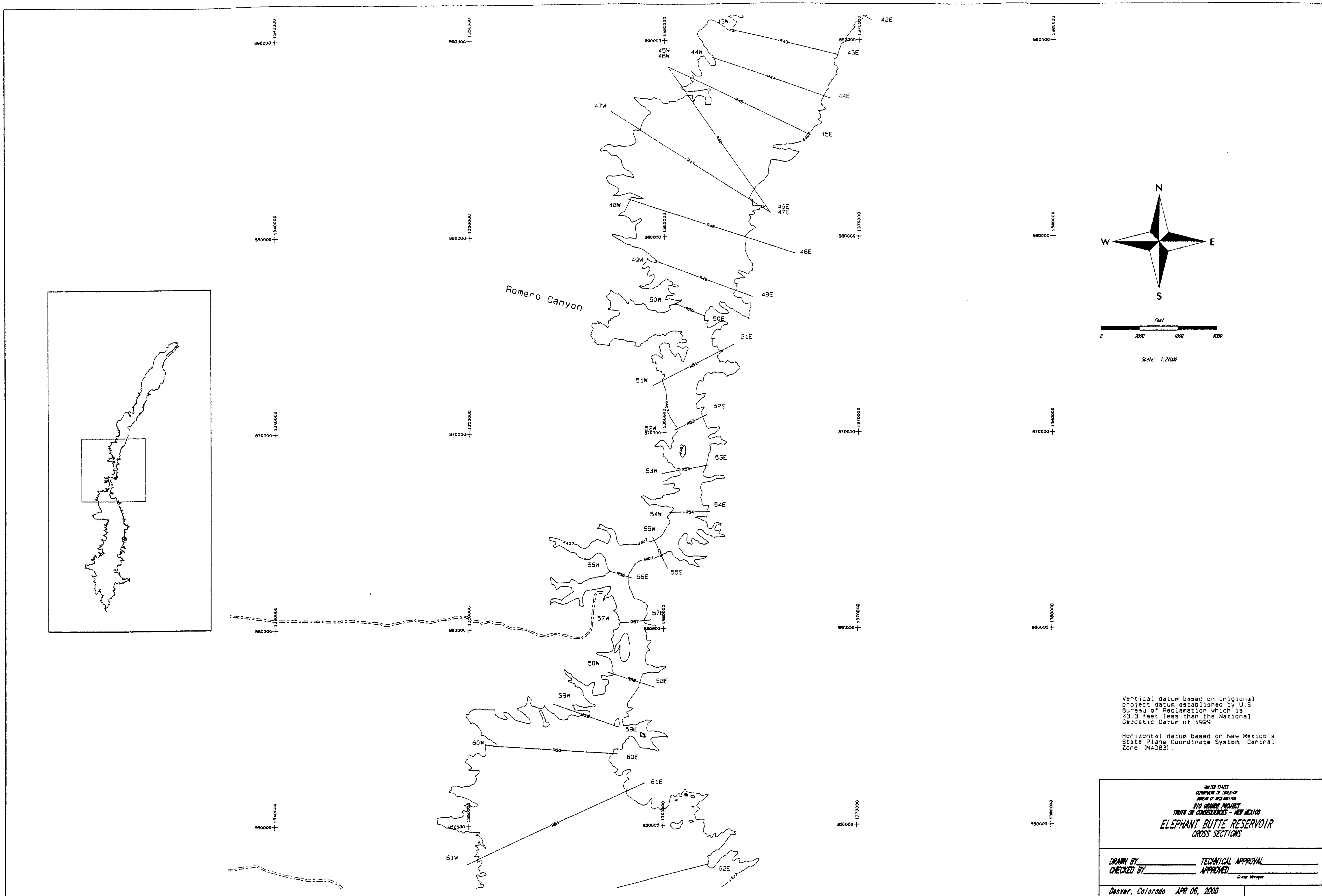


Figure 5 - Elephant Butte Reservoir sedimentation range lines

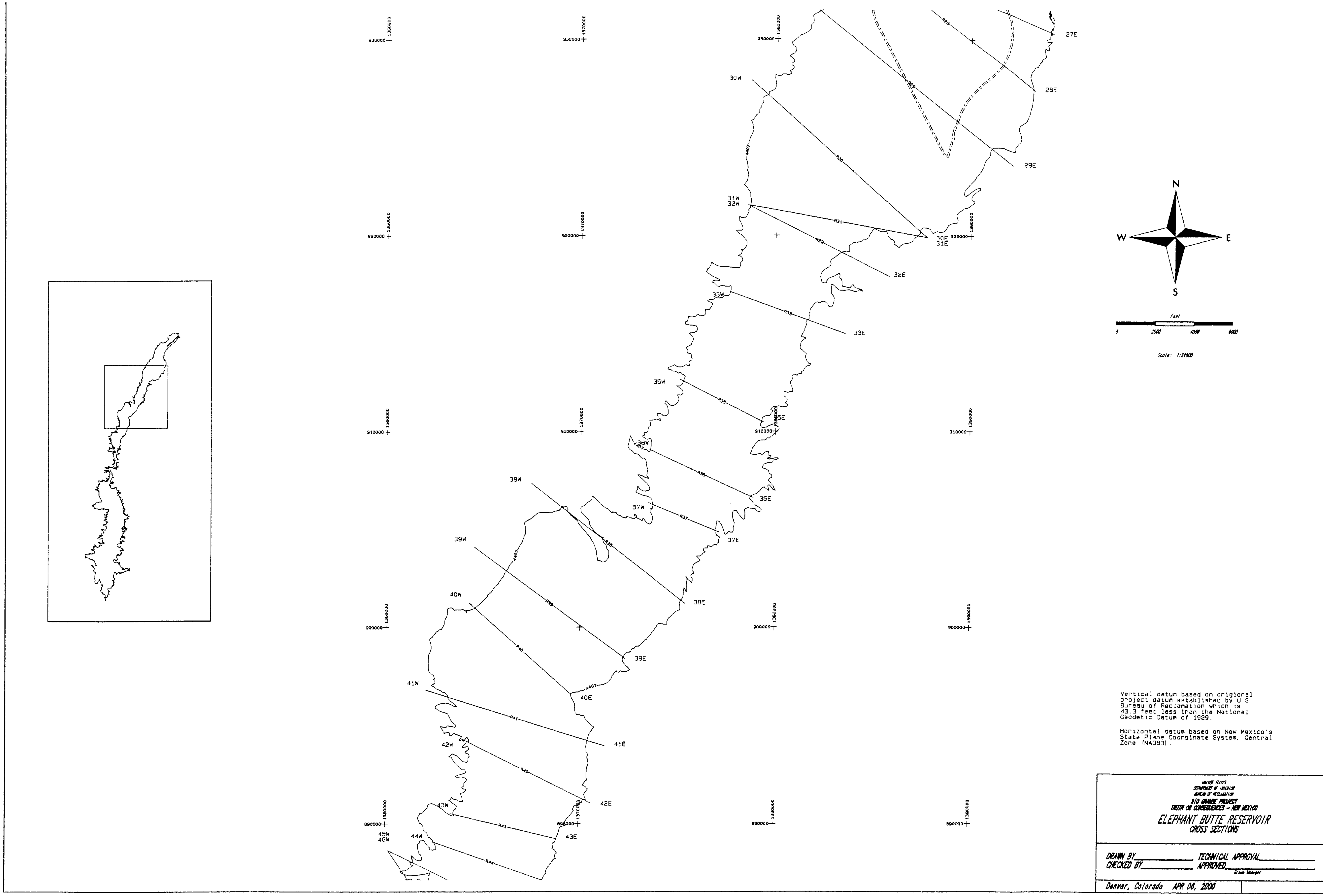


Figure 6 - Elephant Butte Reservoir sedimentation range lines

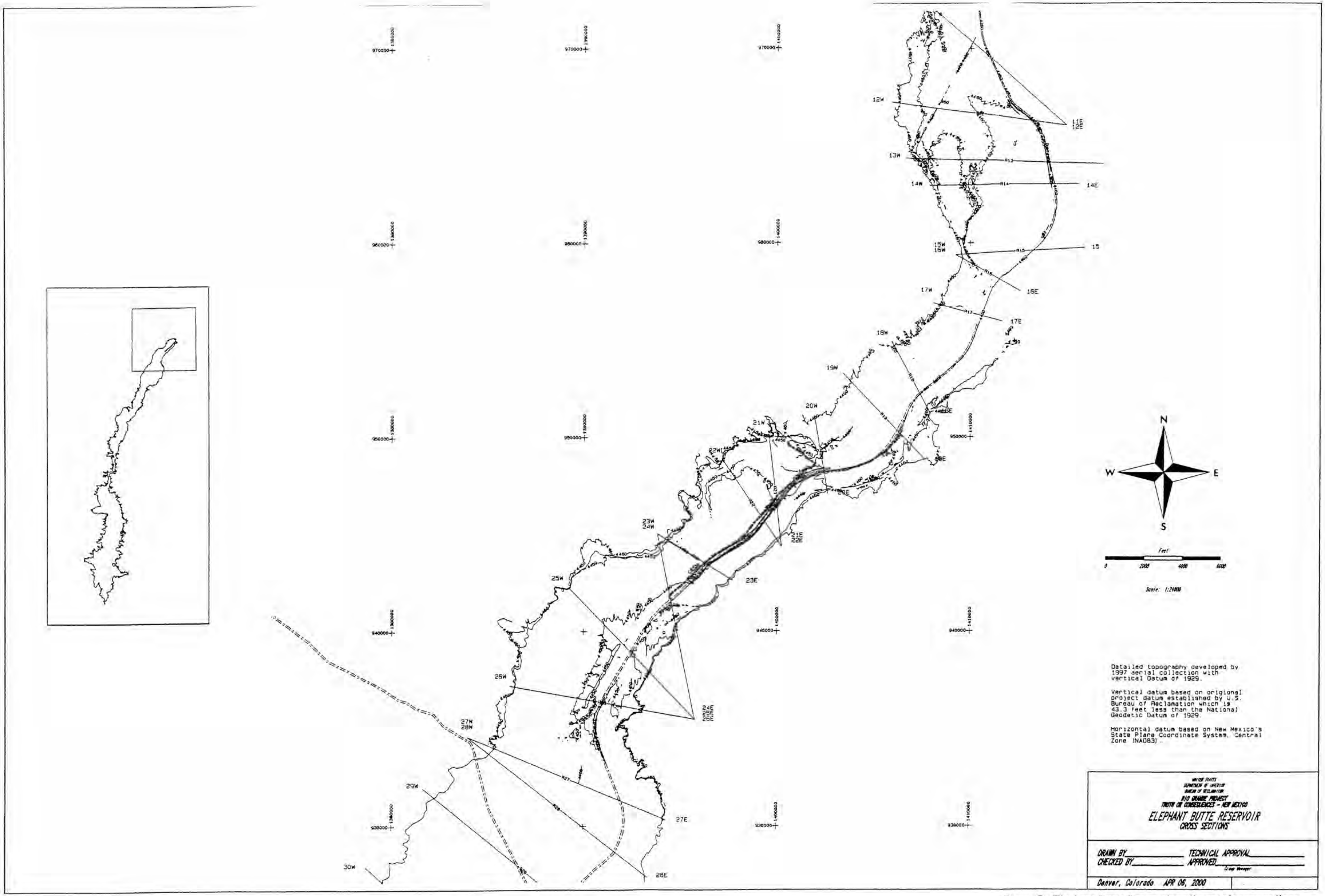


Figure 7 - Elephant Butte Reservoir sedimentation range lines

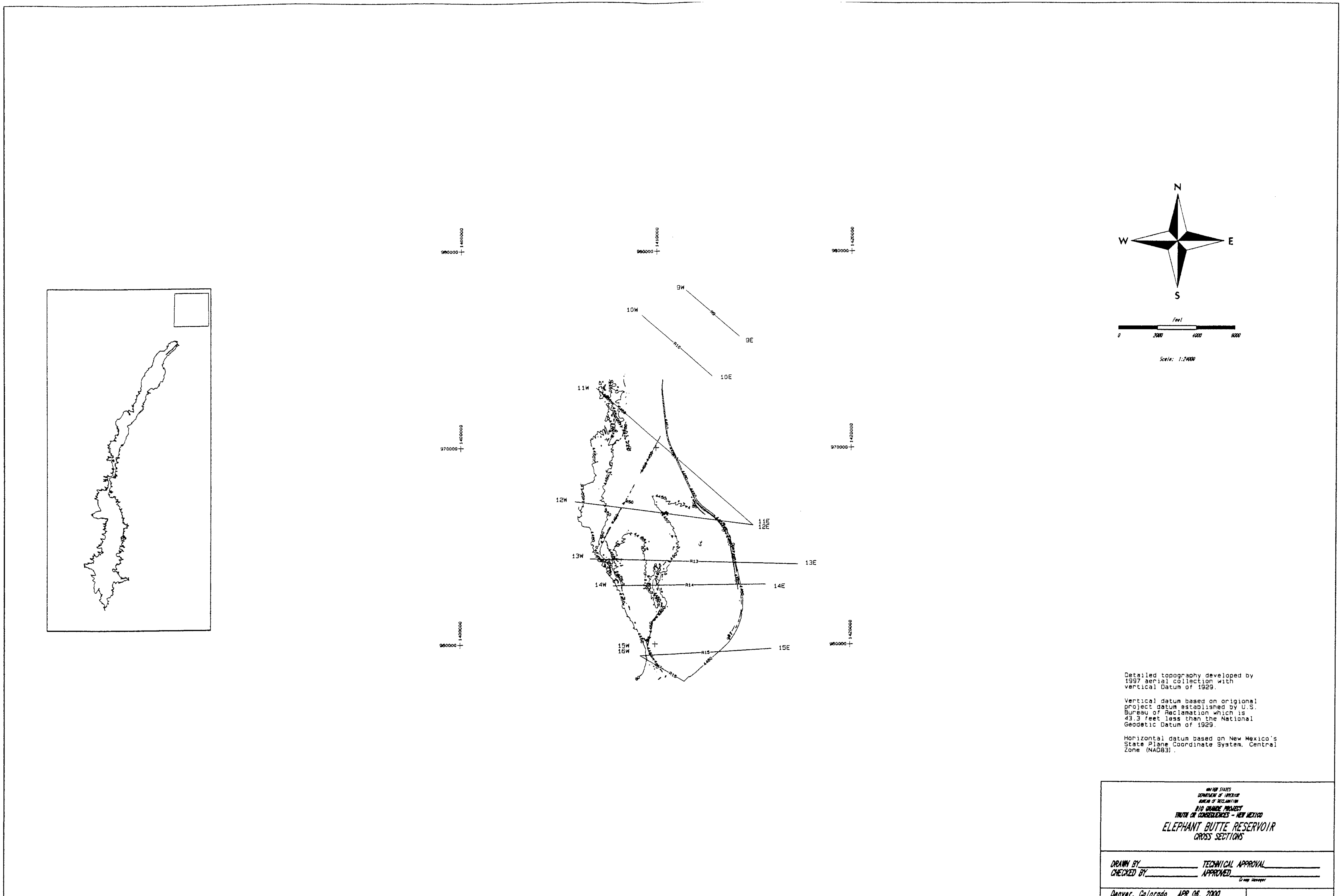


Figure 8 - Elephant Butte Reservoir sedimentation range lines

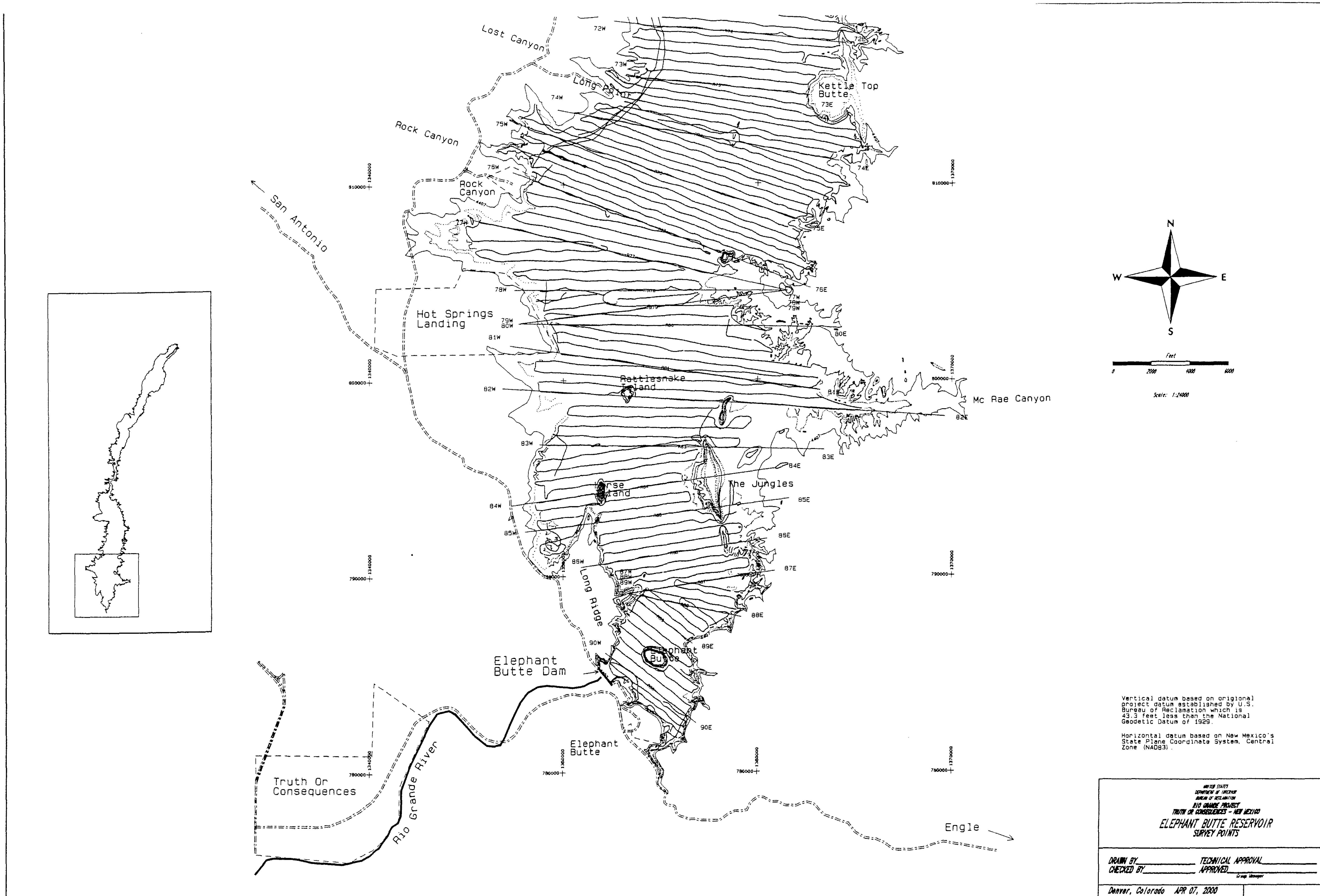


Figure 9 - Elephant Butte Reservoir underwater surveyed data

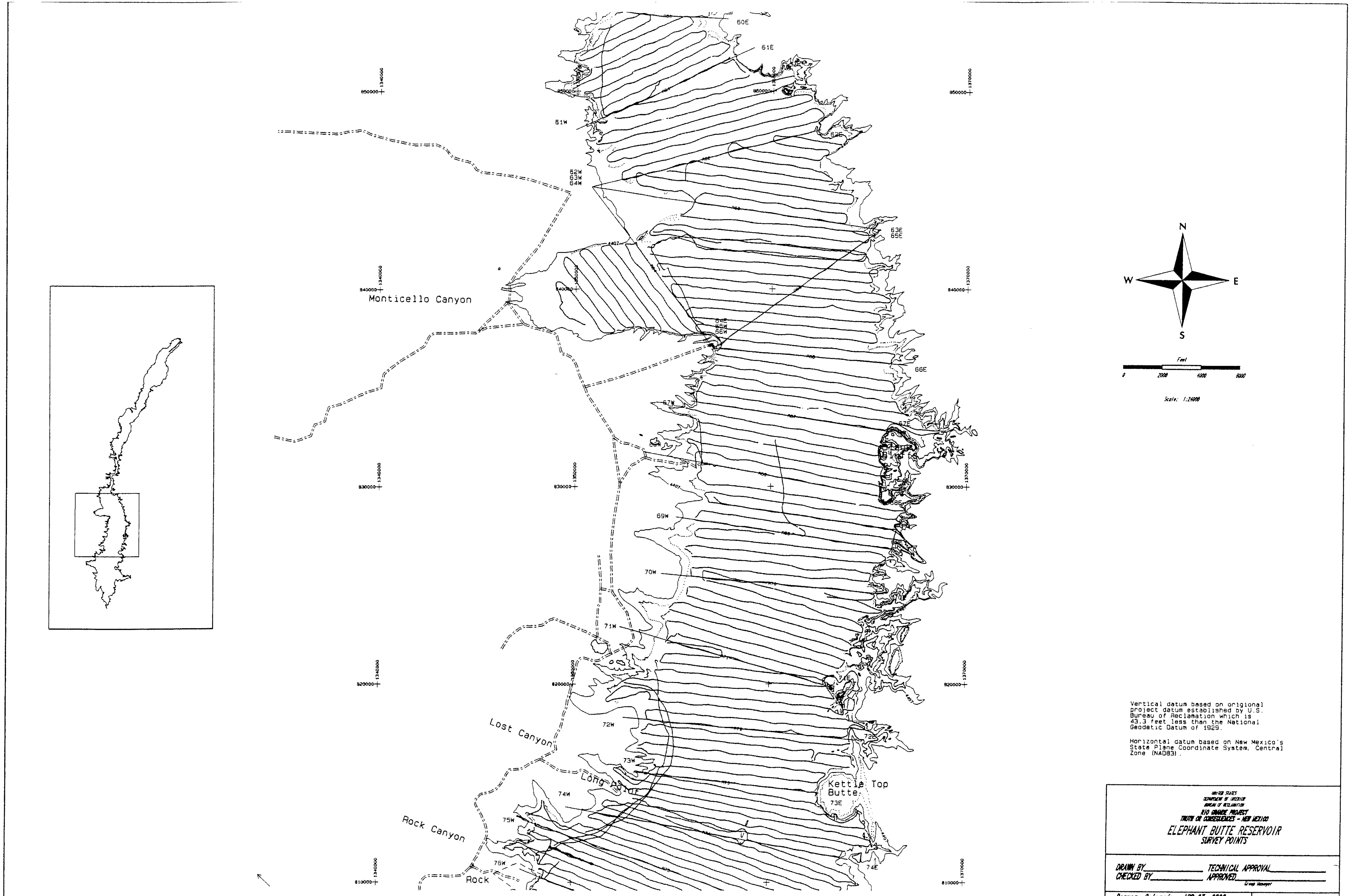


Figure 10 - Elephant Butte Reservoir underwater surveyed data

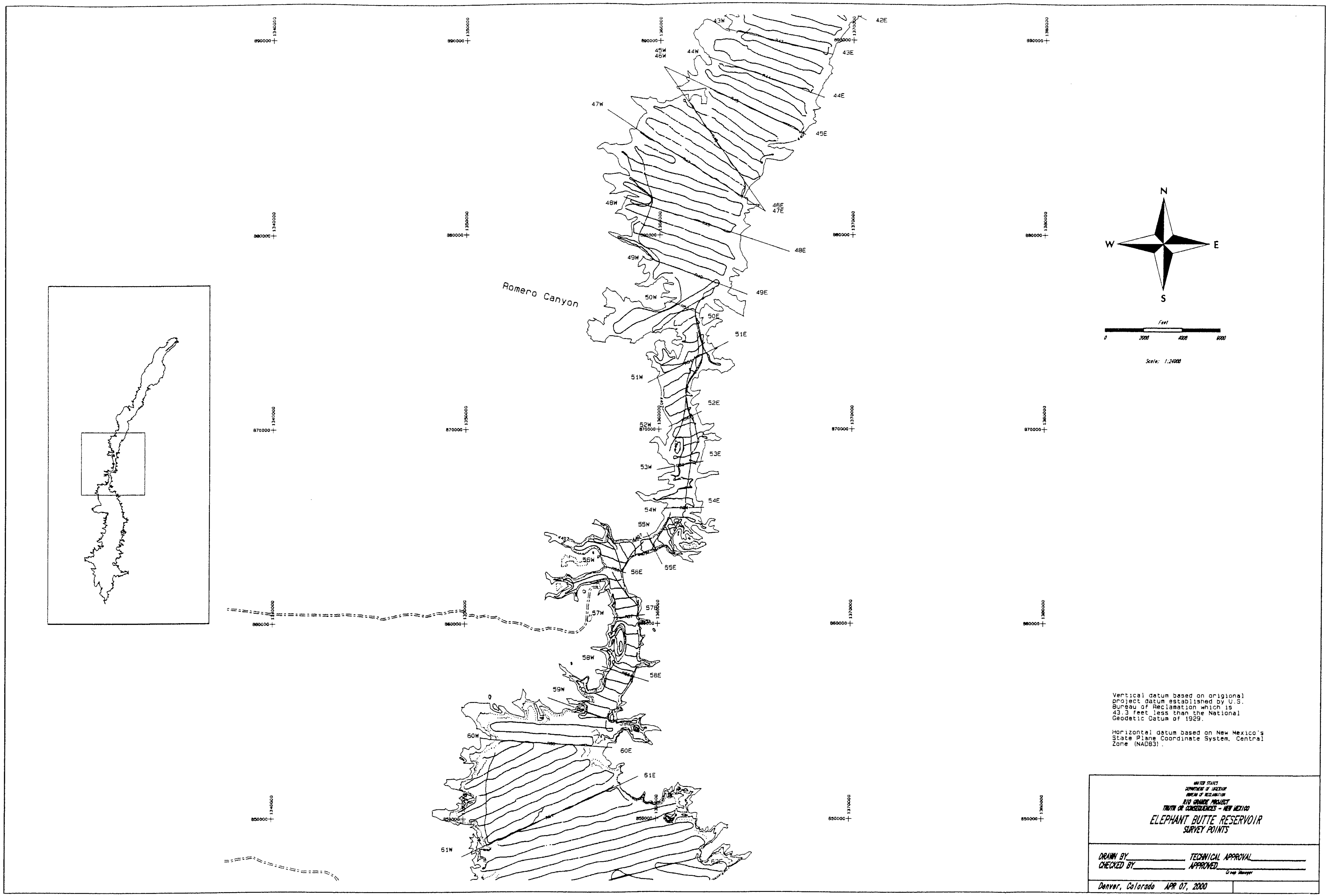


Figure 11 - Elephant Butte Reservoir underwater surveyed data

Figure 12 - Elephant Butte Reservoir underwater surveyed data

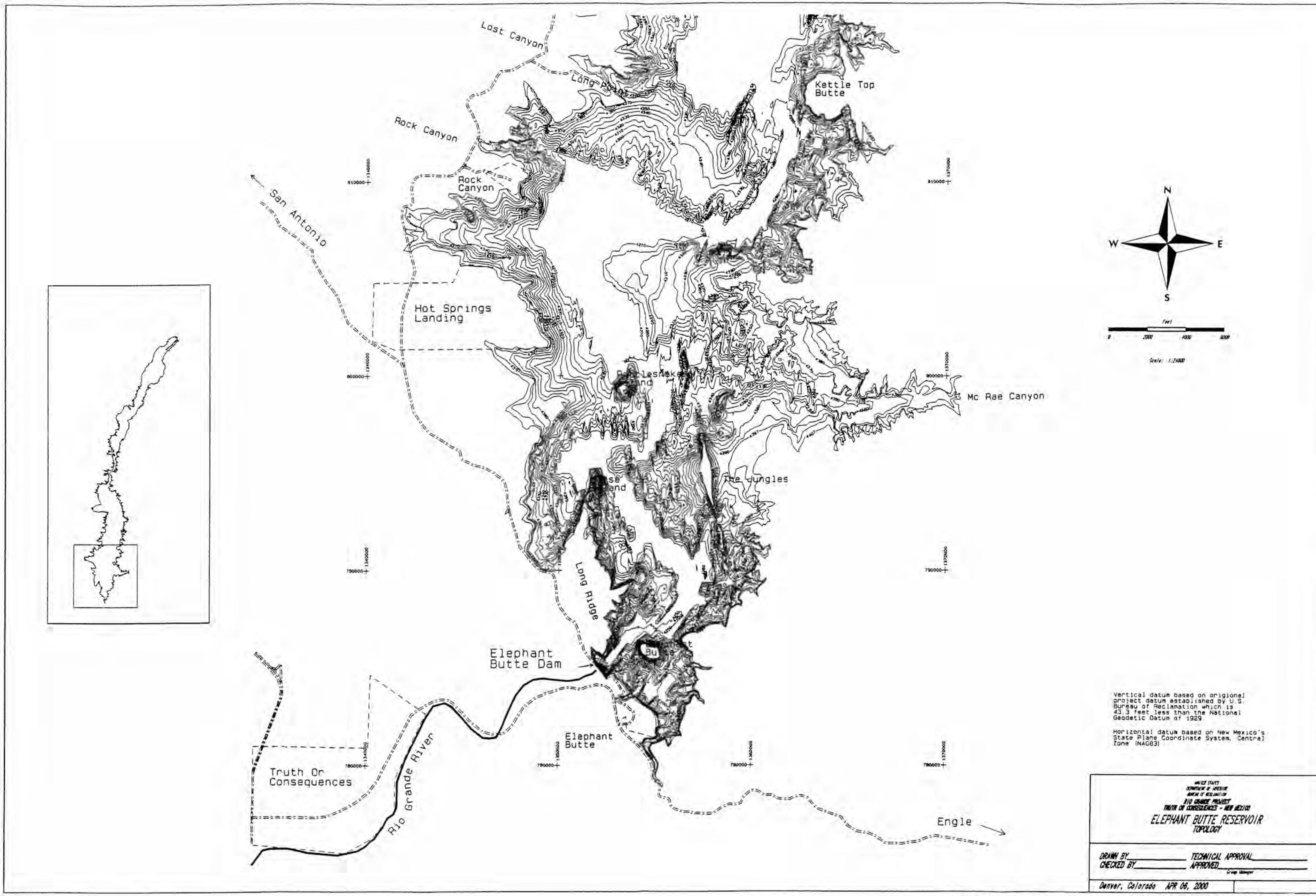


Figure 13 - Elephant Butte Reservoir topographic map, No. 24-D-1863

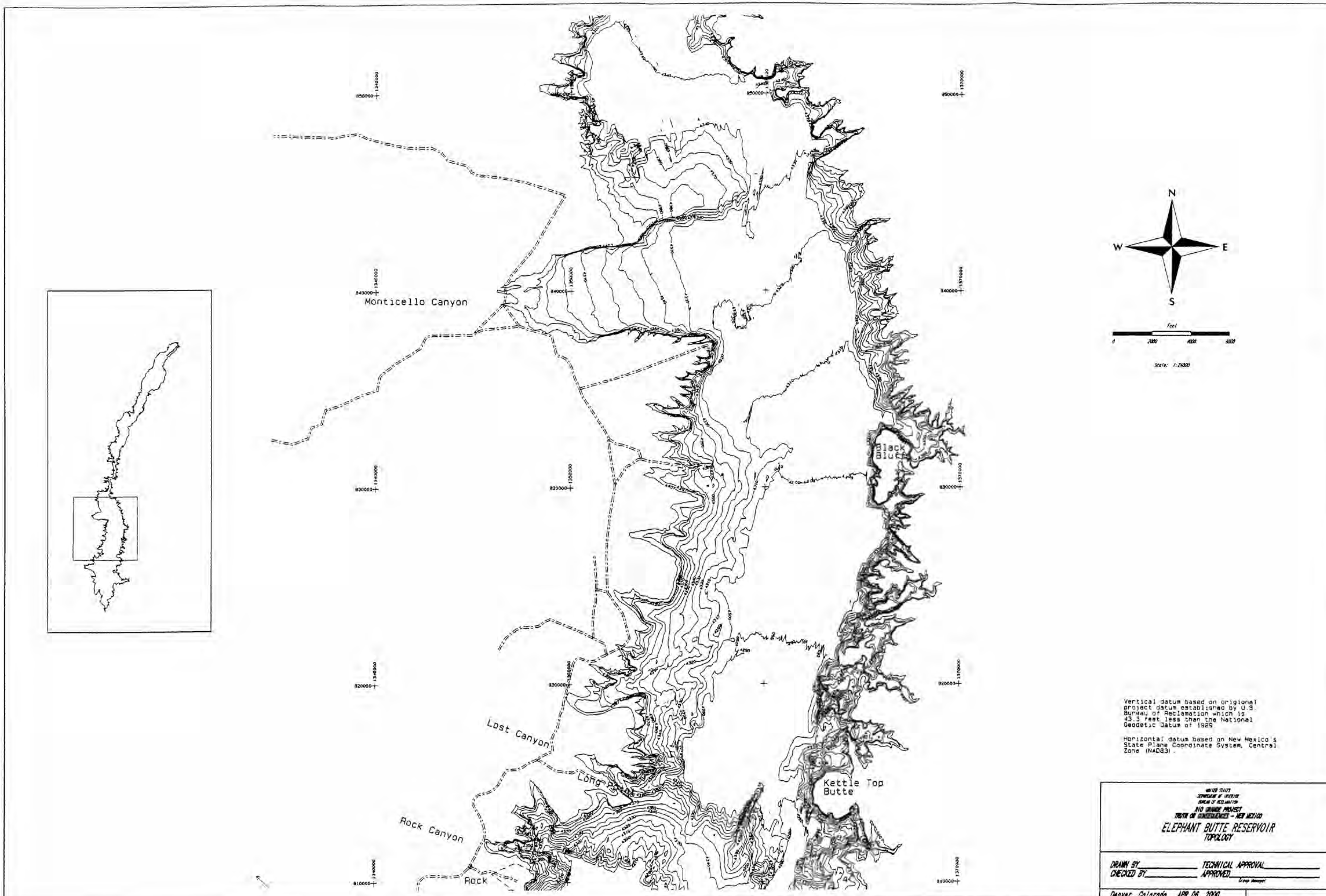


Figure 14 - Elephant Butte Reservoir topographic map, No. 24-D-1864

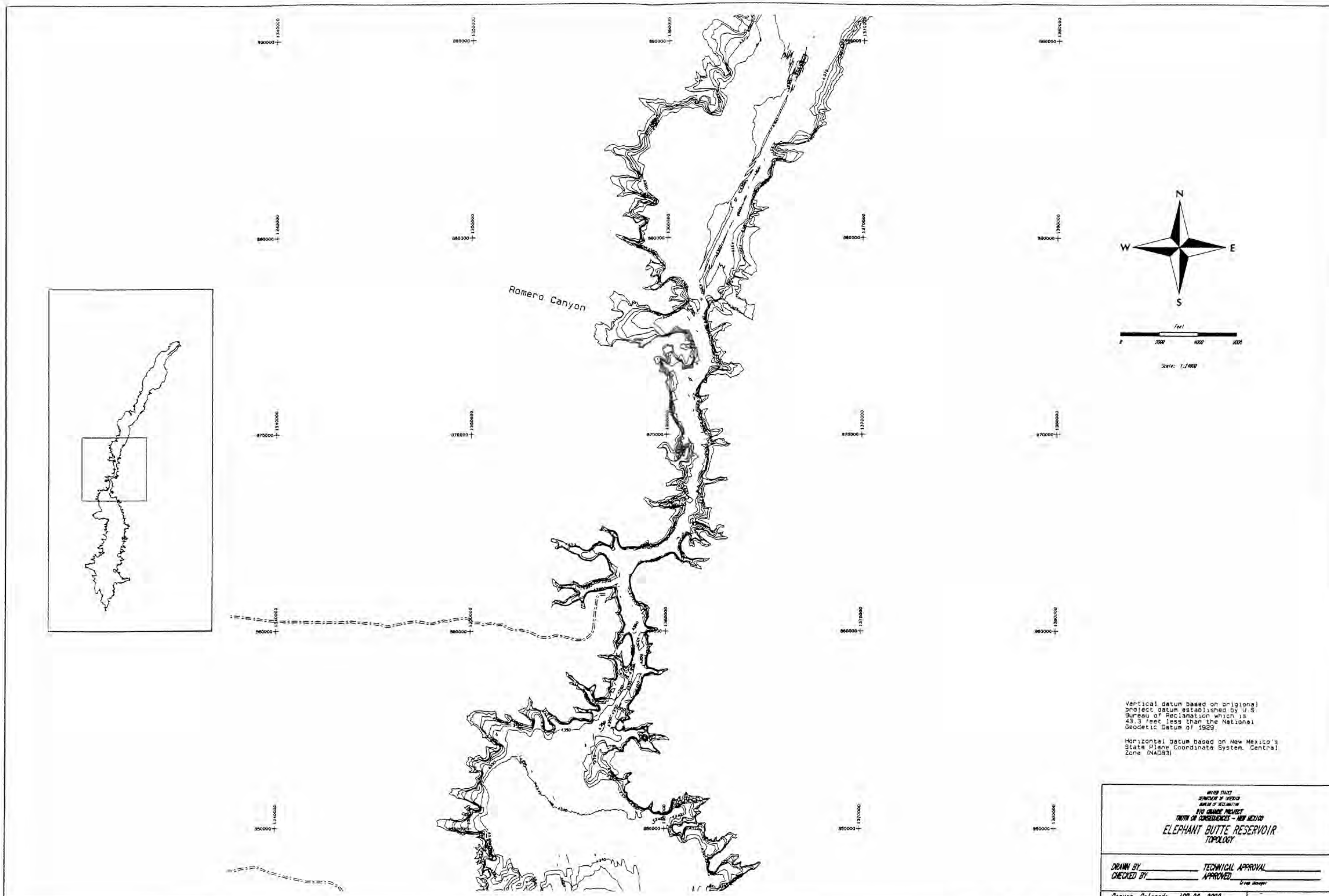


Figure 15 - Elephant Butte Reservoir topographic map, No. 24-D-1865

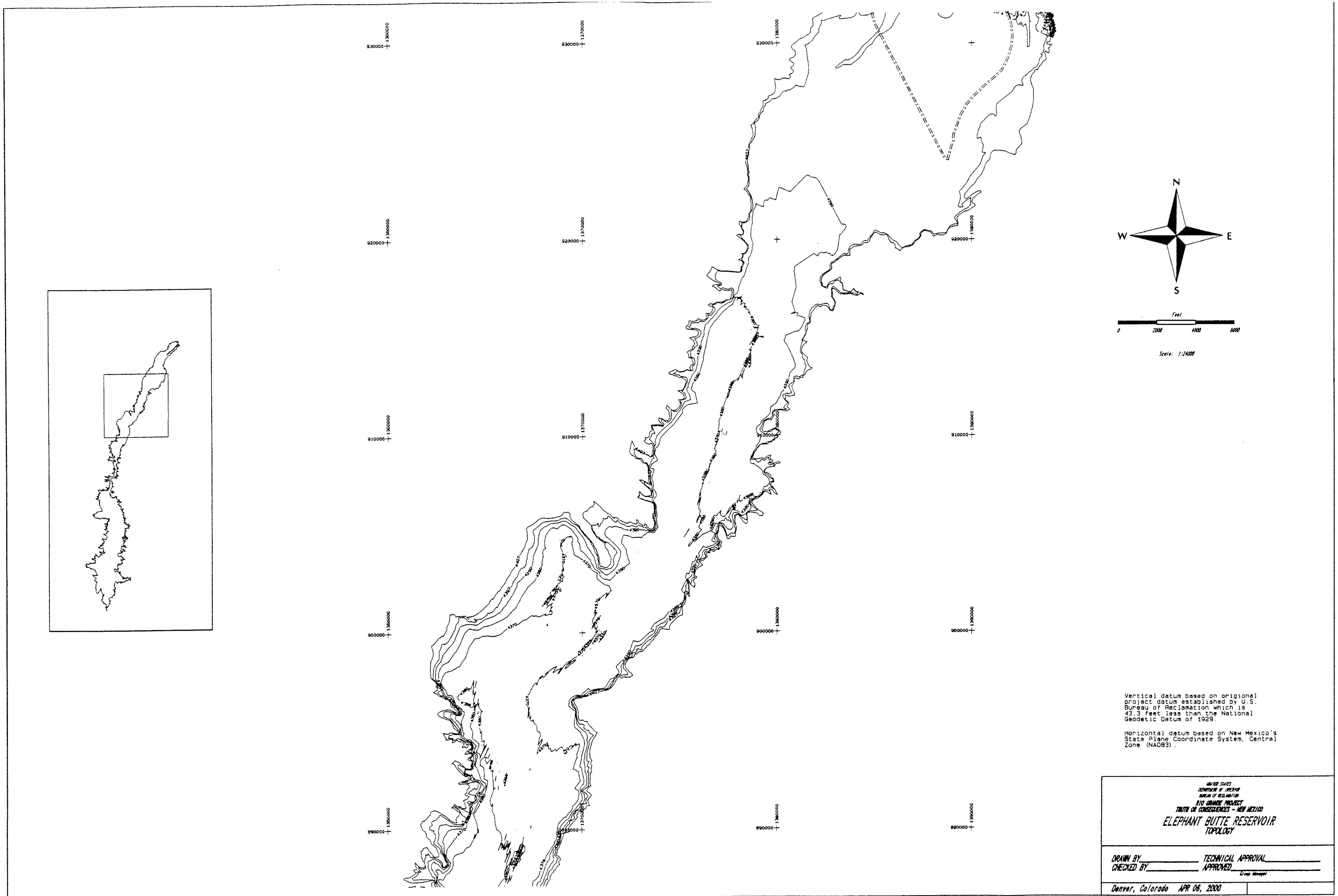


Figure 16- Elephant Butte Reservoir topographic map, No. 24-D-1866

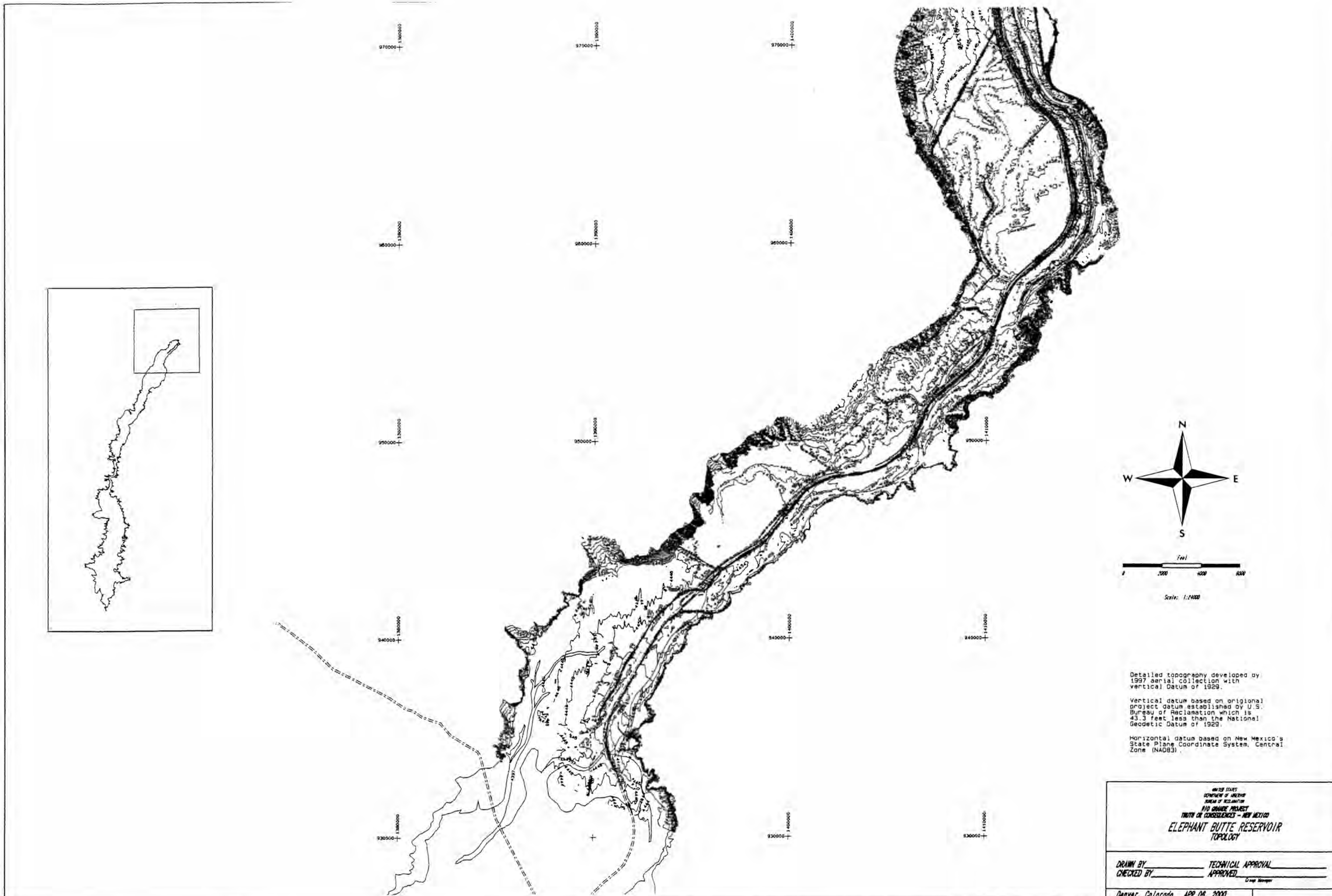
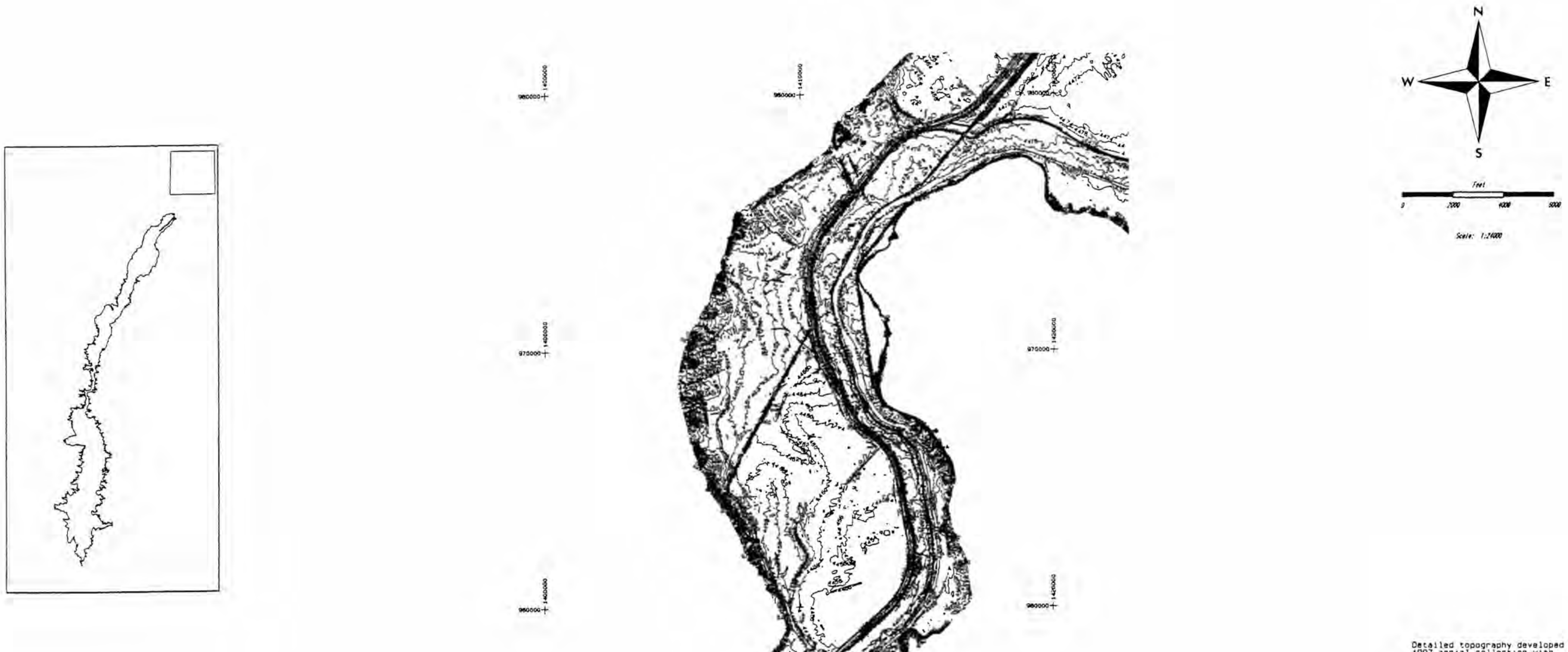


Figure 17 - Elephant Butte Reservoir topographic map, No. 24-D-1867



Detailed topography developed by 1997 aerial collection with vertical Datum of 1929.

Vertical datum based on origional project datum established by U.S. Bureau of Reclamation which is 43.3 feet less than the National Geodetic Datum of 1929.

Horizontal datum based on New Mexico's State Plane Coordinate System, Central Zone (NAD83).

UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE PROJECT
TRUTH OR CONSEQUENCES - NEW MEXICO
ELEPHANT BUTTE RESERVOIR
TOPOLOGY

DRAWN BY________ TECHNICAL APPROVAL________
CHECKED BY________ APPROVED________
Group Manager

Denver, Colorado APR 06, 2000

Figure 18 - Elephant Butte Reservoir topographic map, No. 24-D-1868

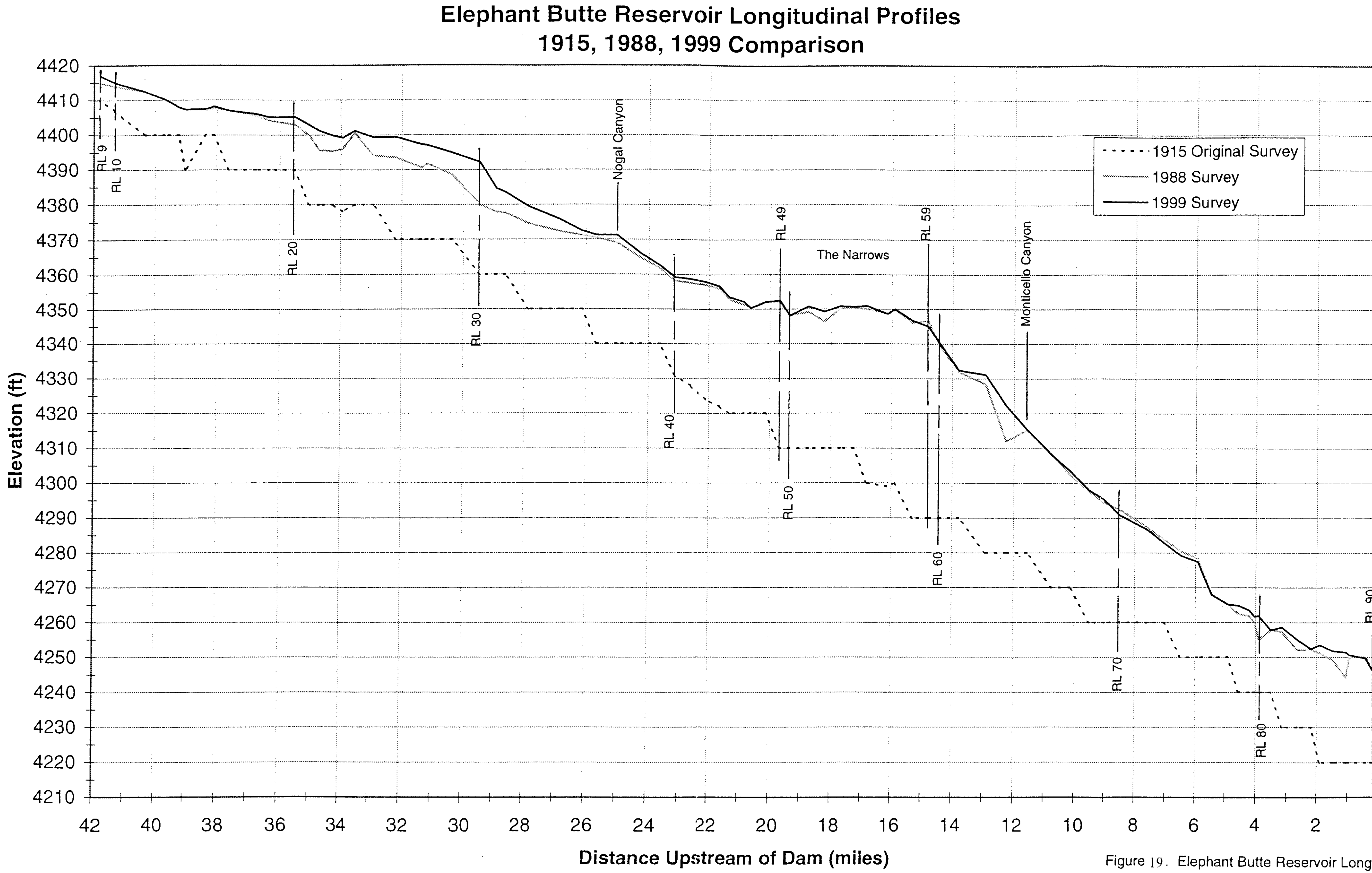


Figure 19. Elephant Butte Reservoir Longitudinal Profiles

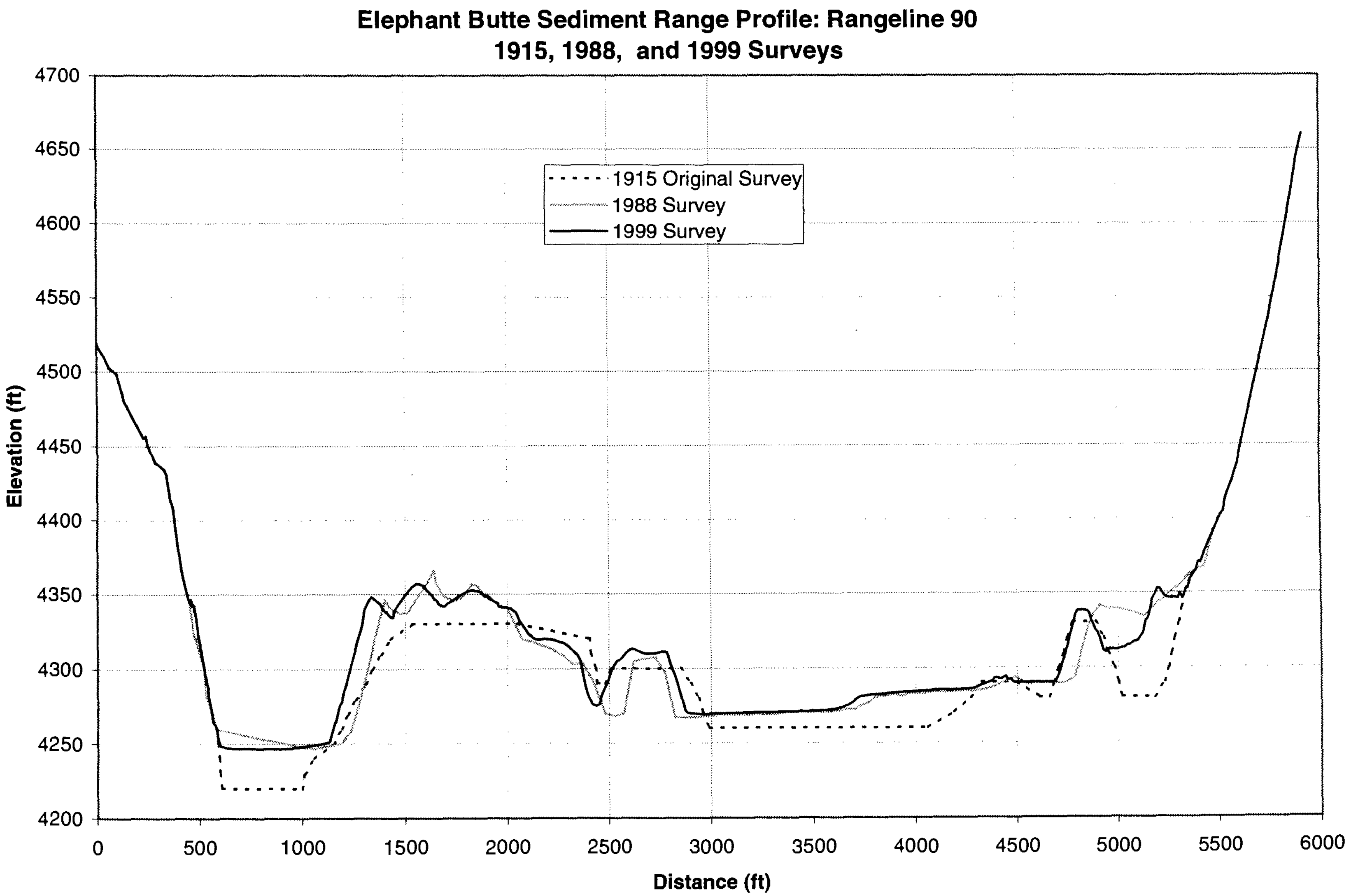


Figure 20. - Sedimentation range profiles for 1915, 1988, and 1999, range 90.

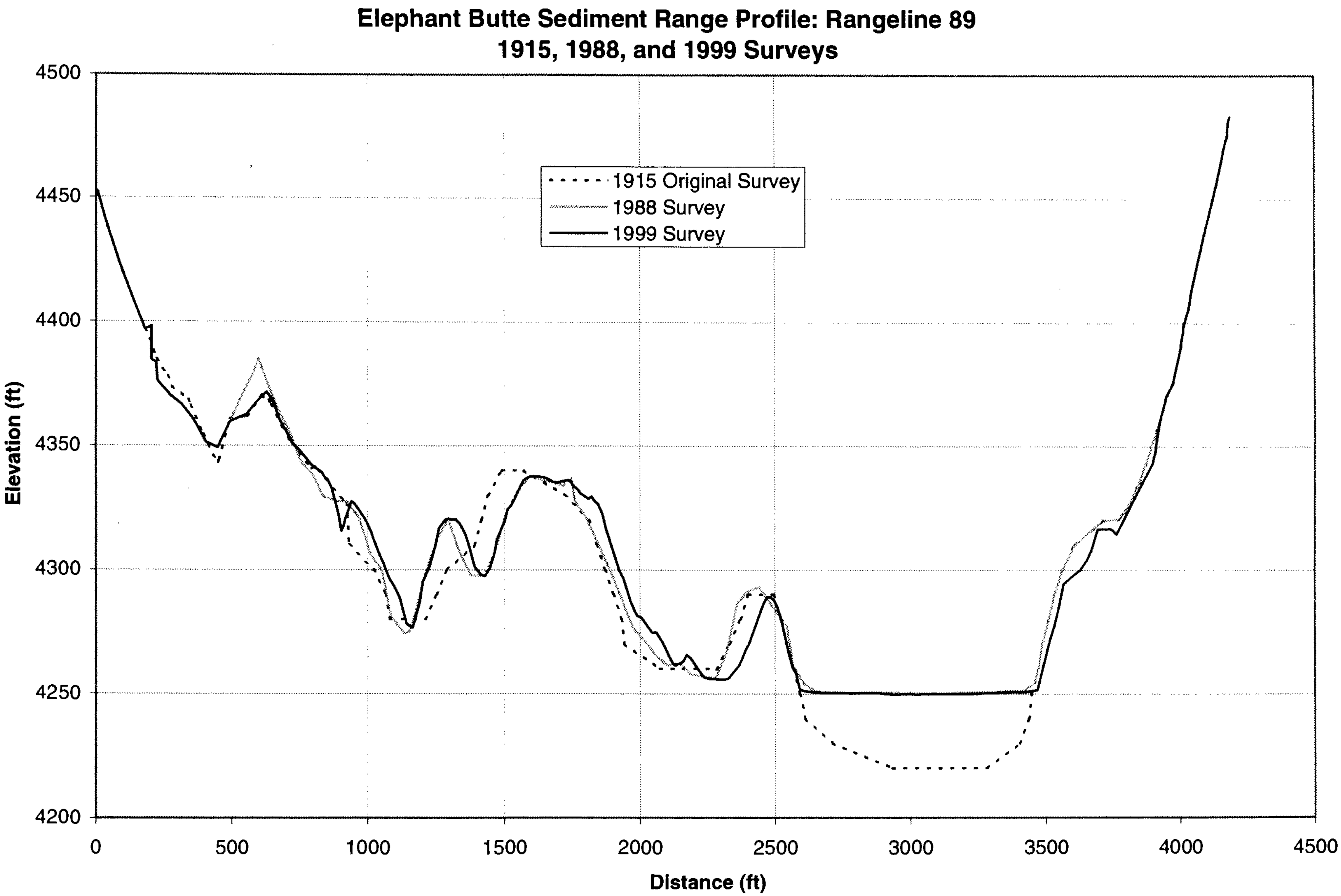


Figure 21. - Sedimentation range profiles for 1915, 1988, and 199, range 89.

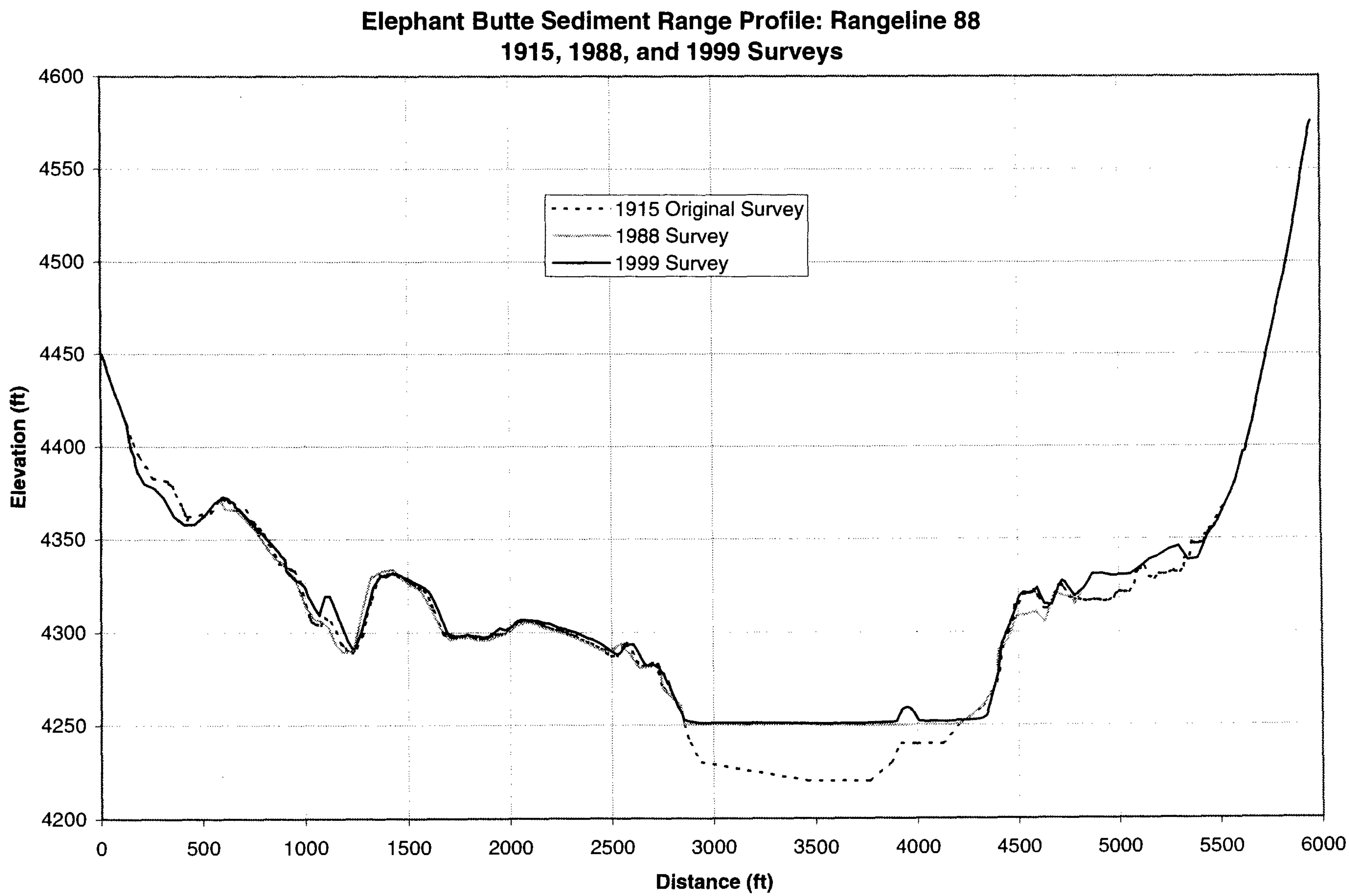


Figure 22. - Sedimentation range profiles for 1915, 1988, and 1999, range 88.

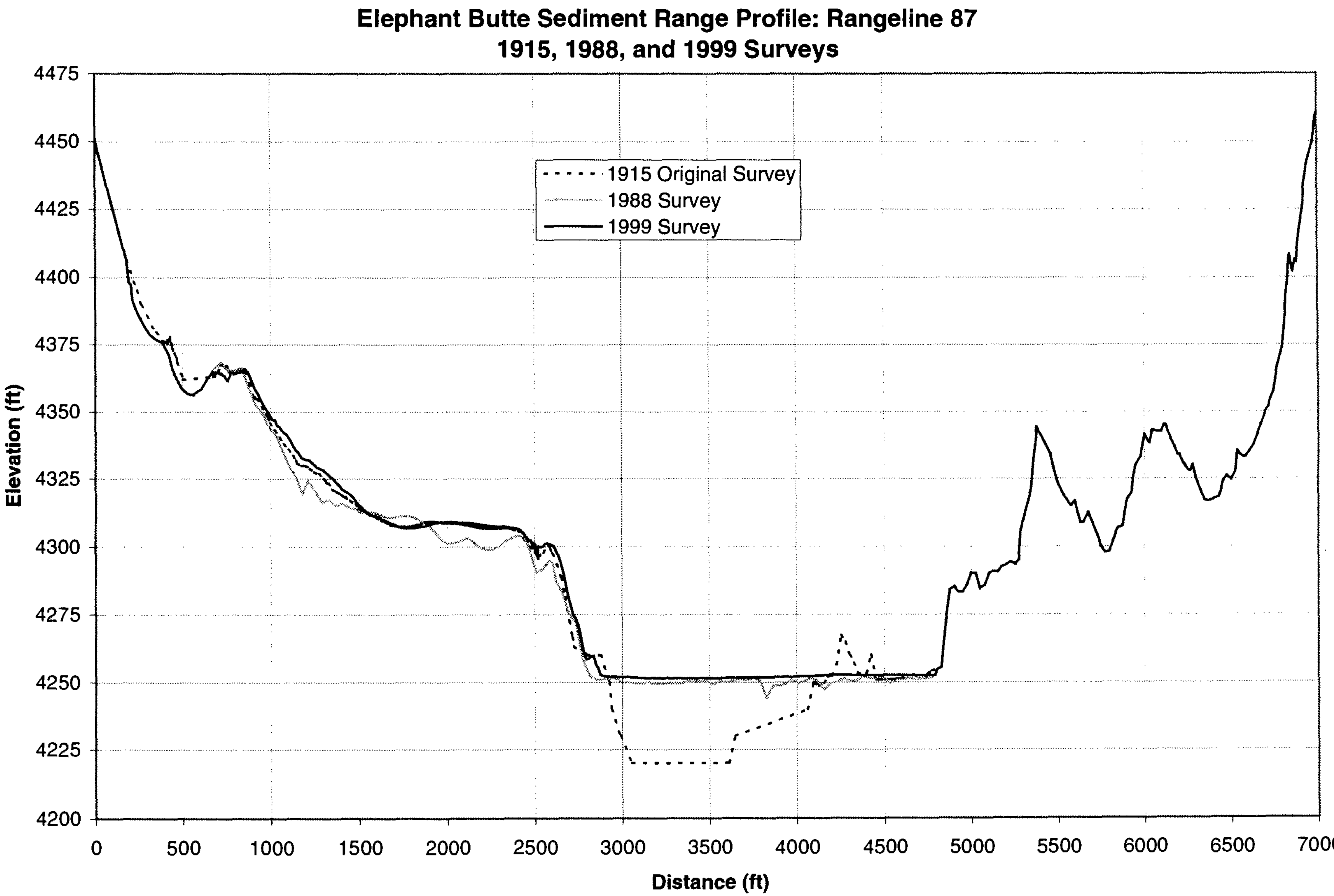


Figure 23. - Sedimentation range profiles for 1915, 1988, and 1999, range 87.

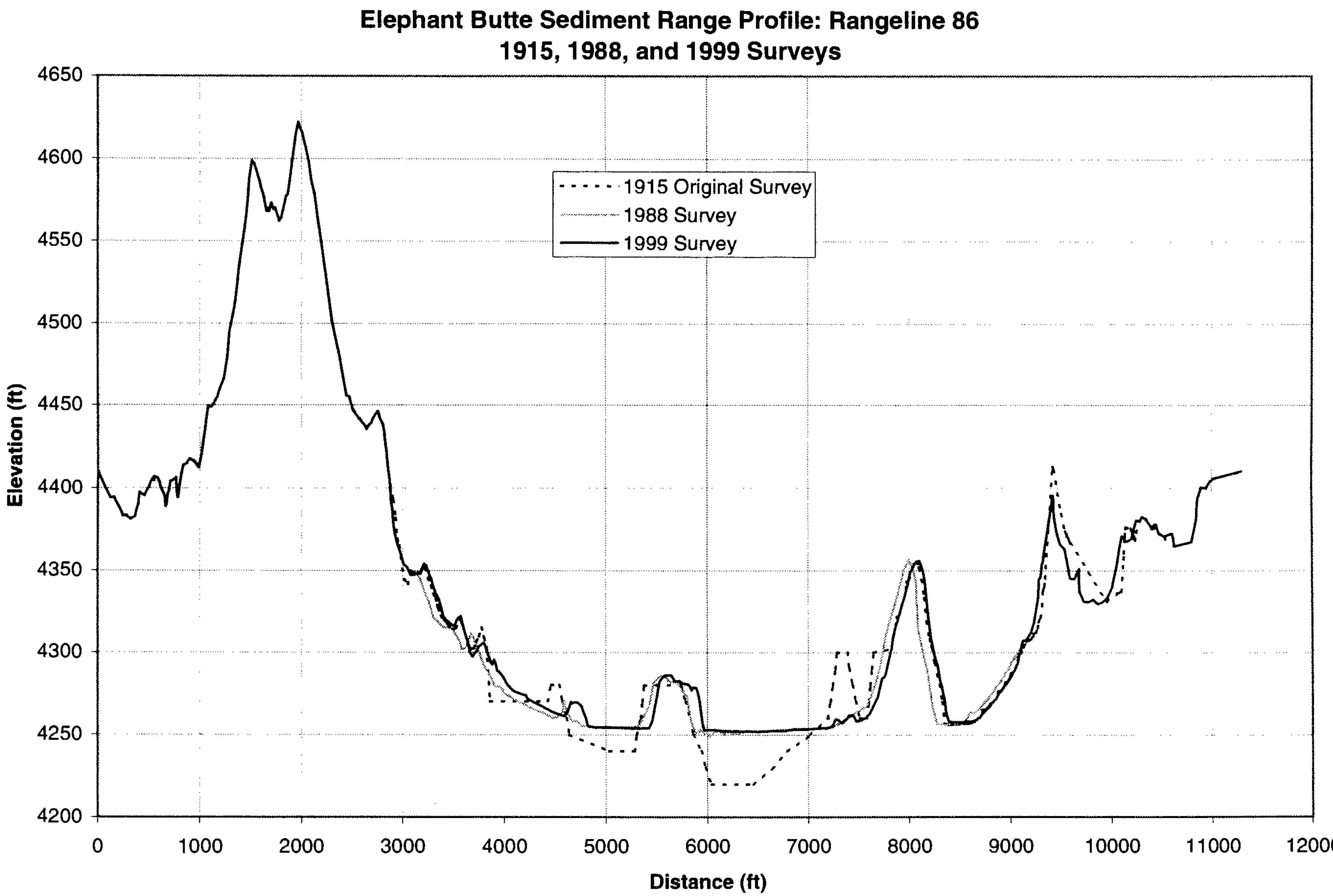


Figure 24. - Sedimentation range profiles for 1915, 1988, and 1999, range 86.

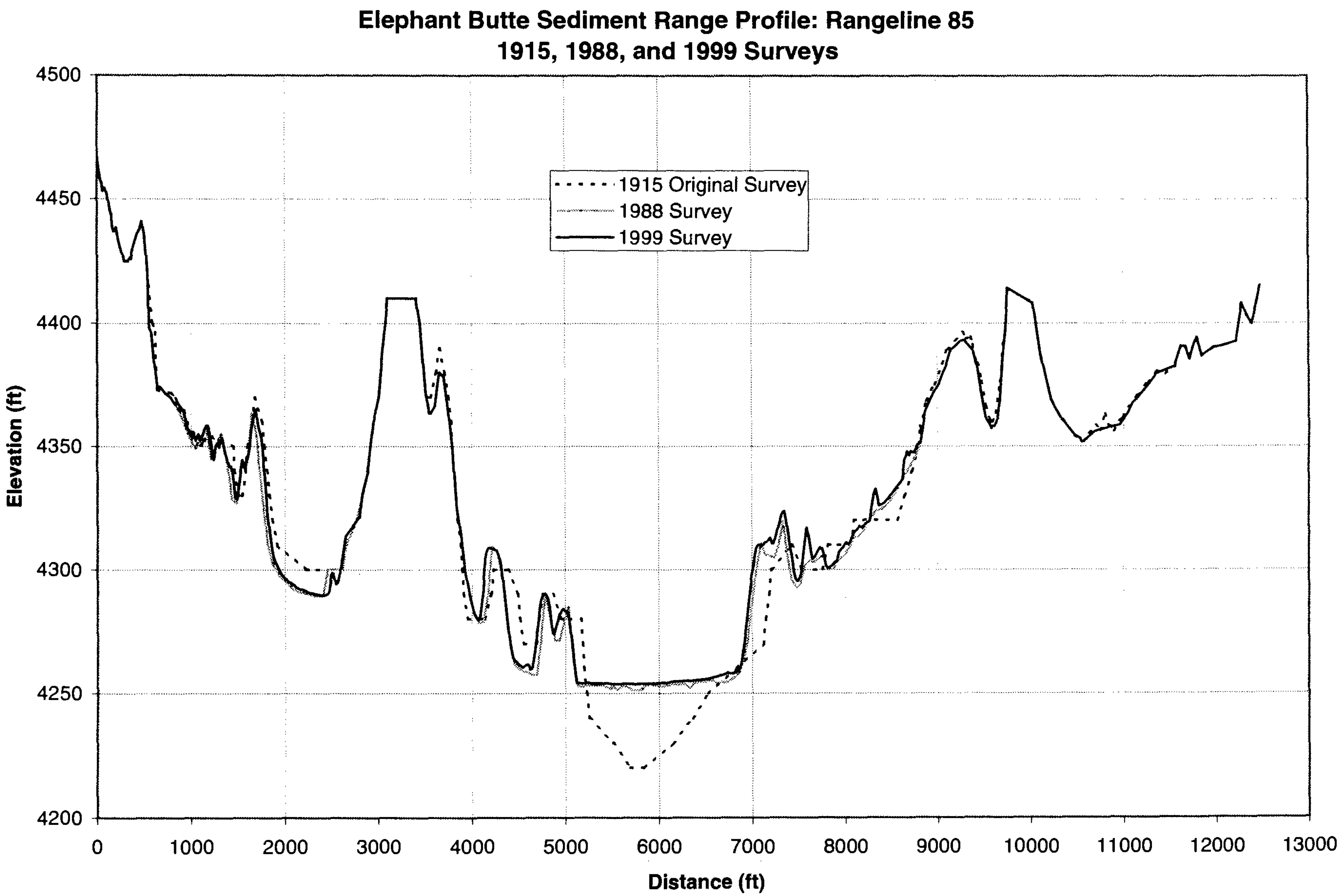


Figure 25. - Sedimentation range profiles for 1915, 1988, and 1999, range 85.

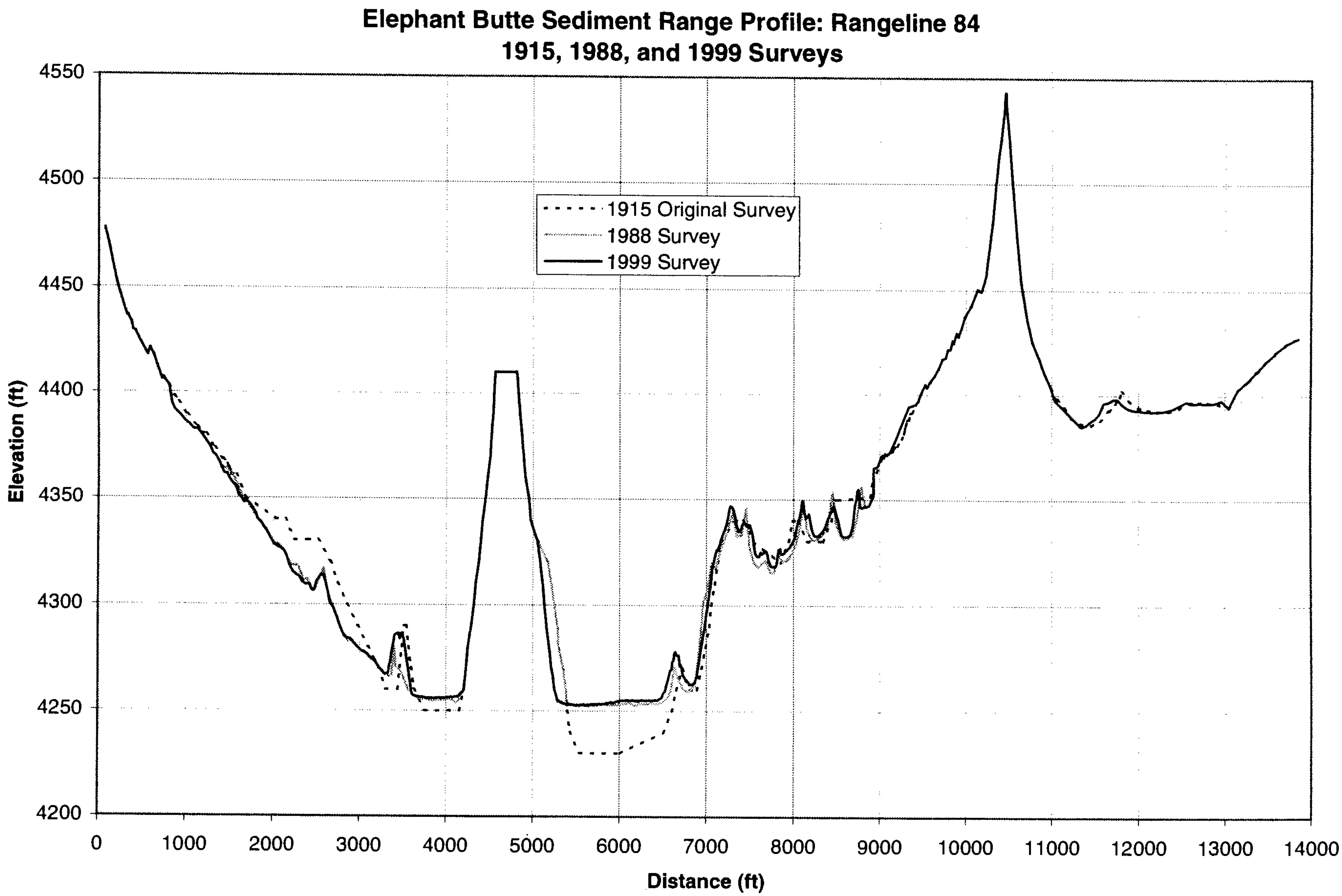


Figure 26. - Sedimentation range profiles for 1915, 1988, and 1999, range 84.

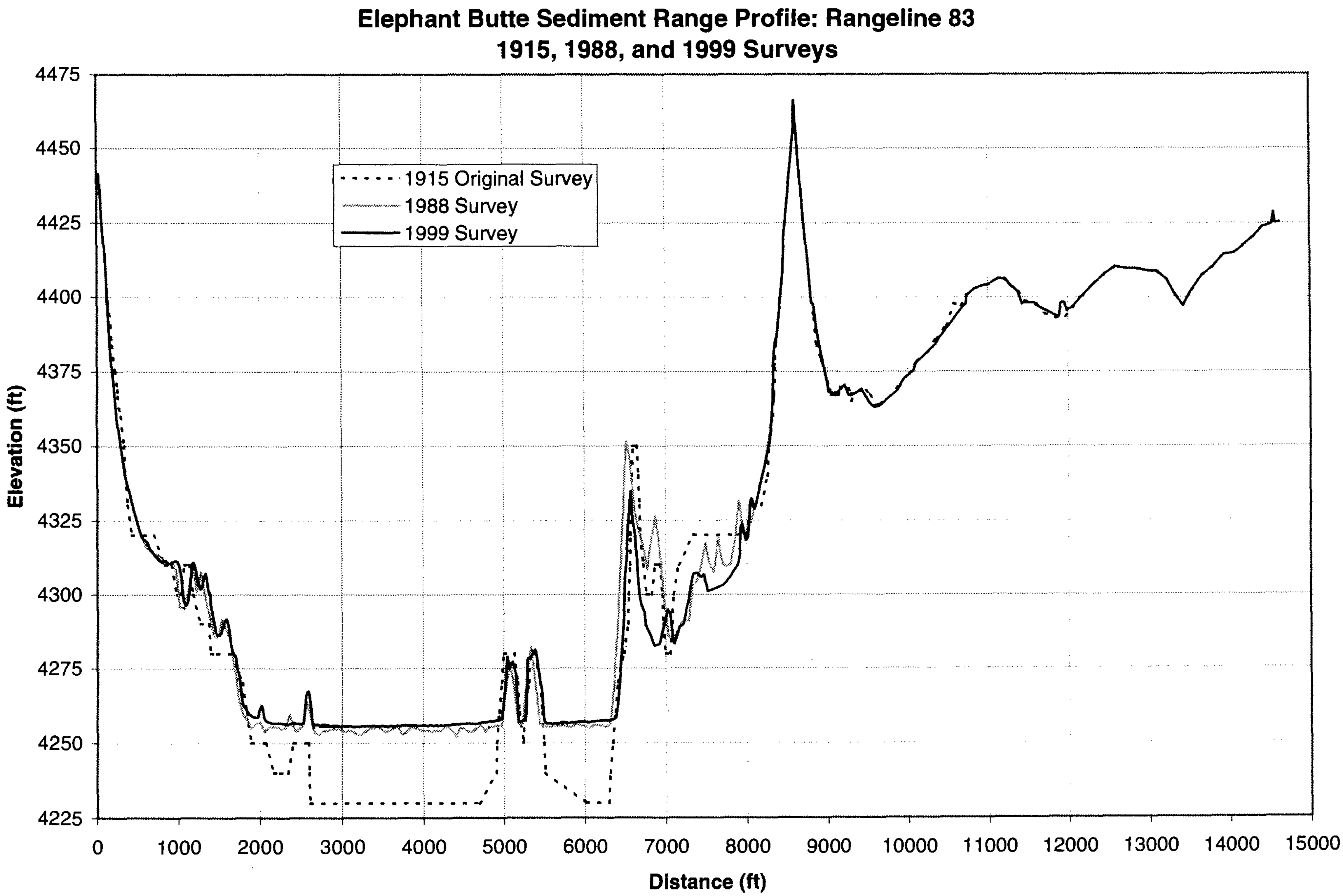


Figure 27. - Sedimentation range profiles for 1915, 1988, and 1999, range 83.

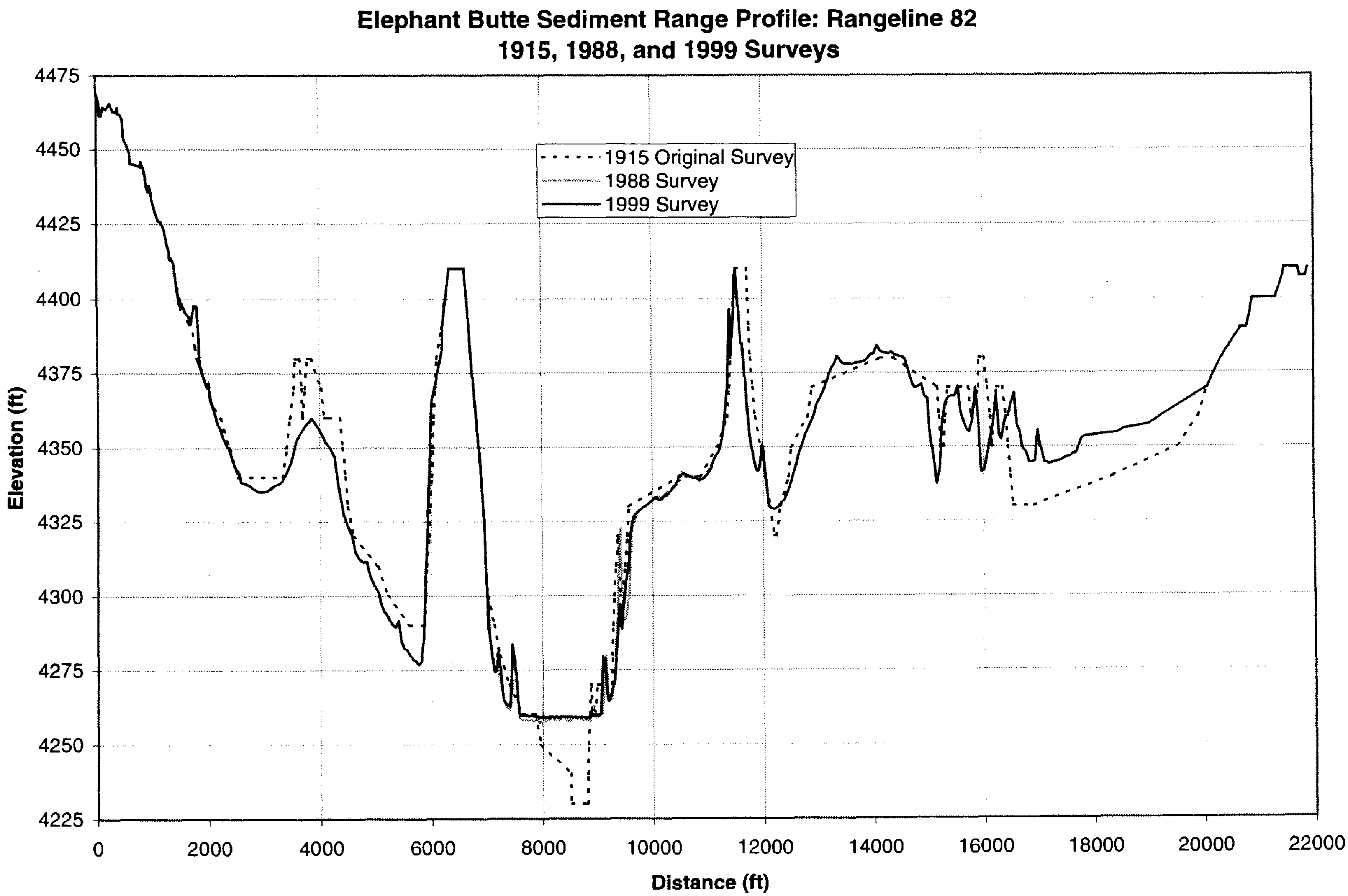


Figure 28. - Sedimentation range profiles for 1915, 1988, and 1999, range 82.

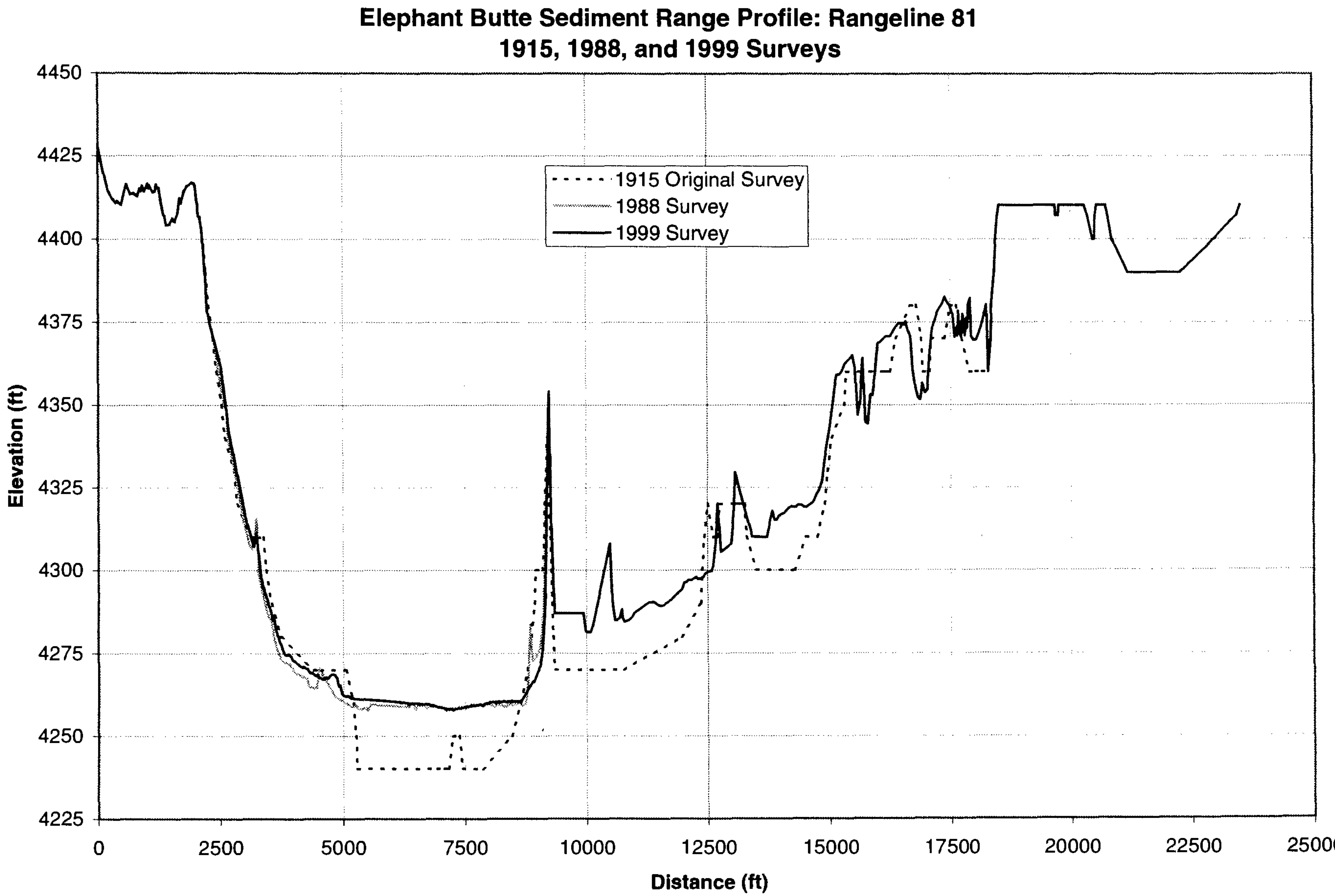


Figure 29. - Sedimentation range profiles for 1915, 1988, and 1999, range 81.

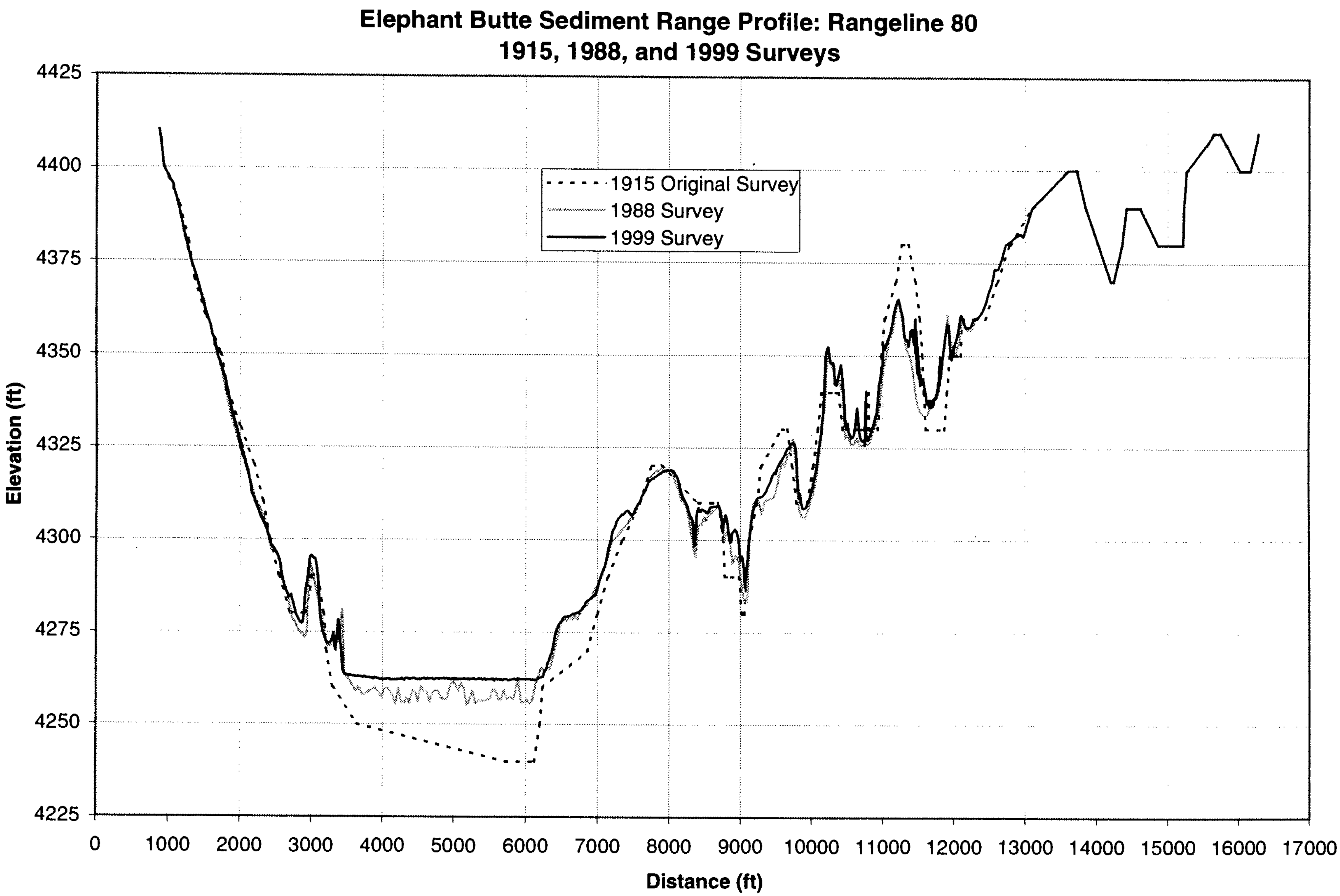


Figure 30. - Sedimentation range profiles for 1915, 1988, and 1999, range 80.

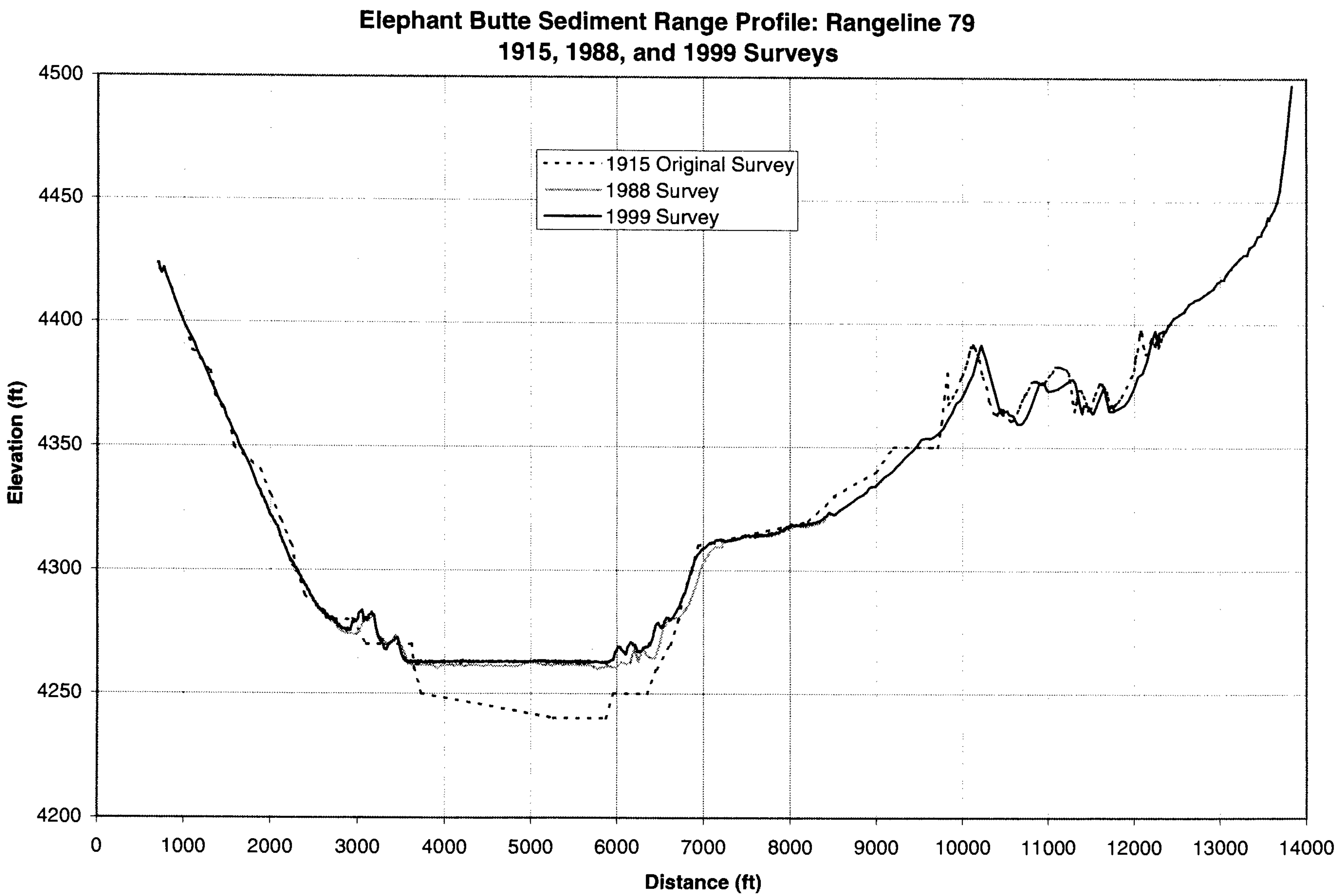


Figure 31. - Sedimentation range profiles for 1915, 1988, and 1999, range 79.

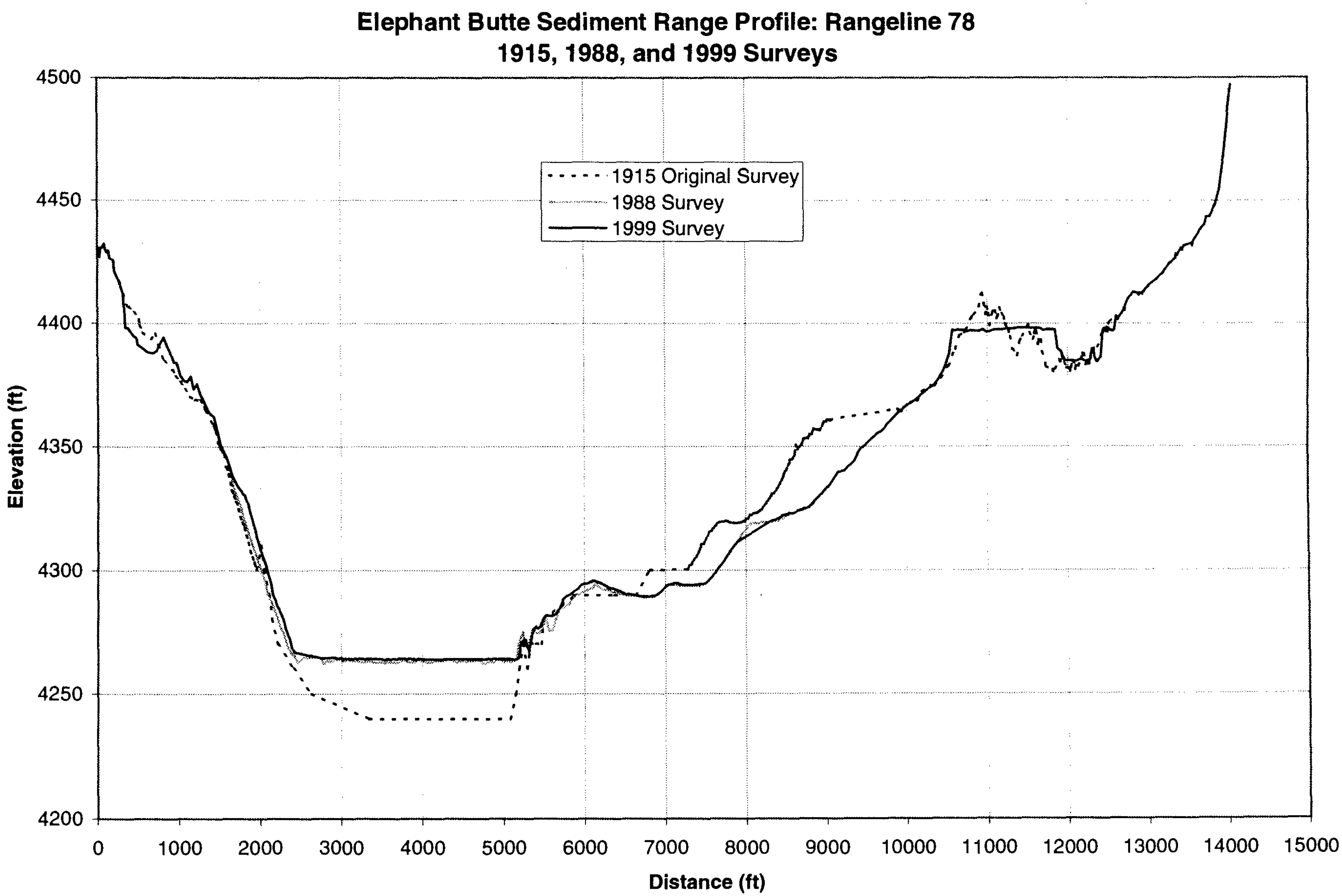


Figure 32. - Sedimentation range profiles for 1915, 1988, and 1999, range 78.

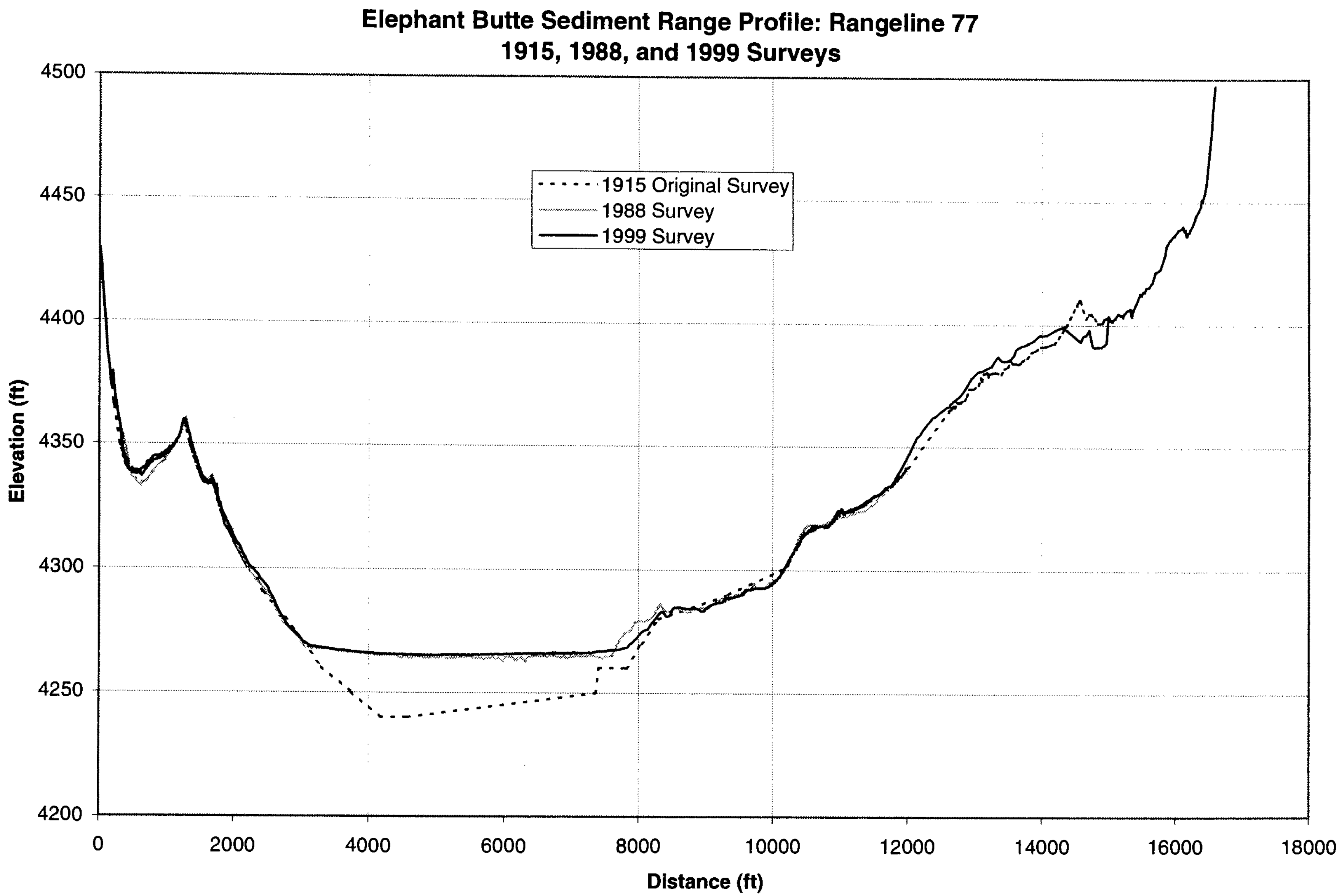


Figure 33. - Sedimentation range profiles for 1915, 1988, and 1999, range 77.

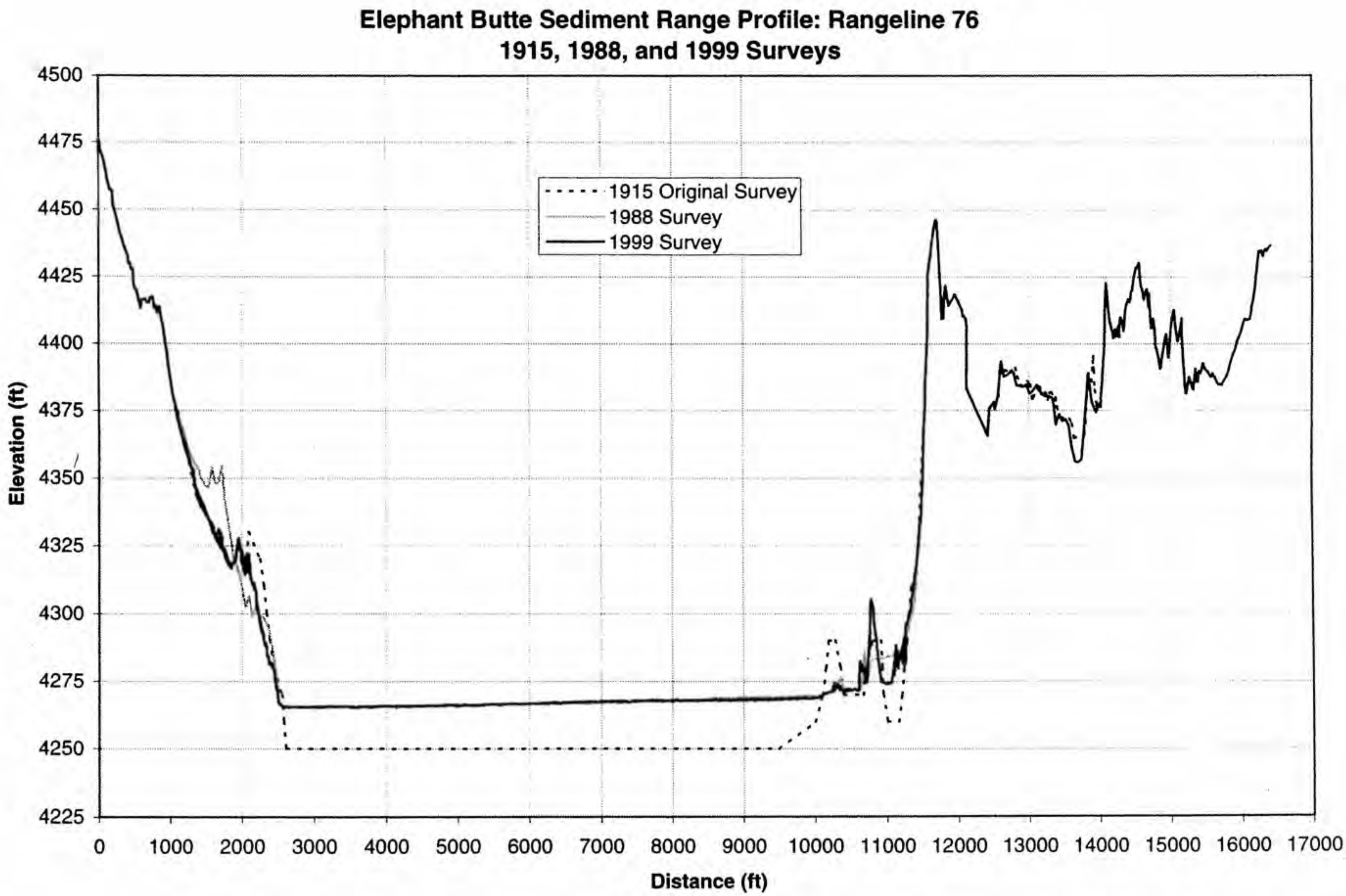


Figure 34. - Sedimentation range profiles for 1915, 1988, and 1999, range 76.

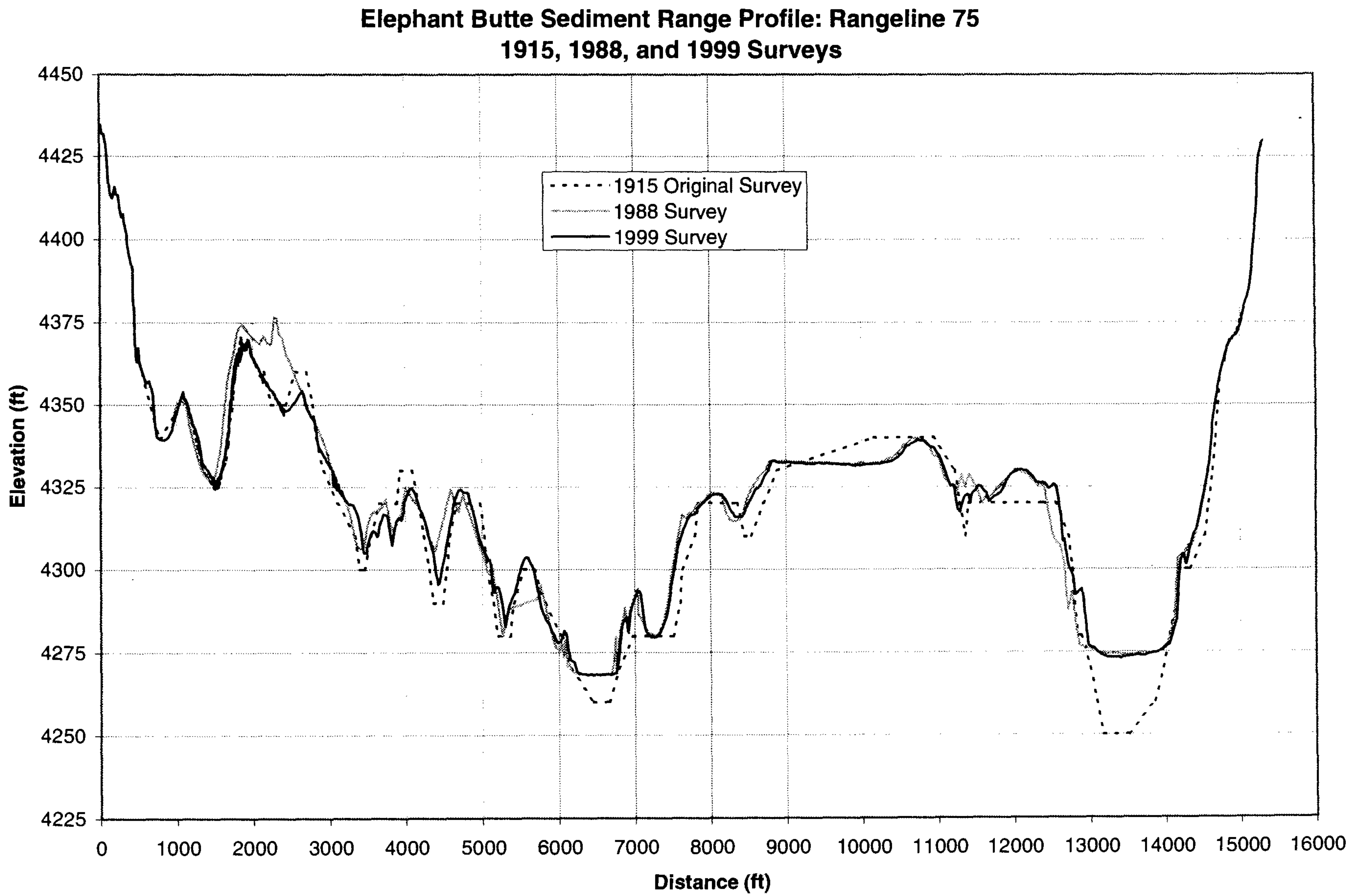


Figure 35. - Sedimentation range profiles for 1915, 1988, and 1999, range 75.

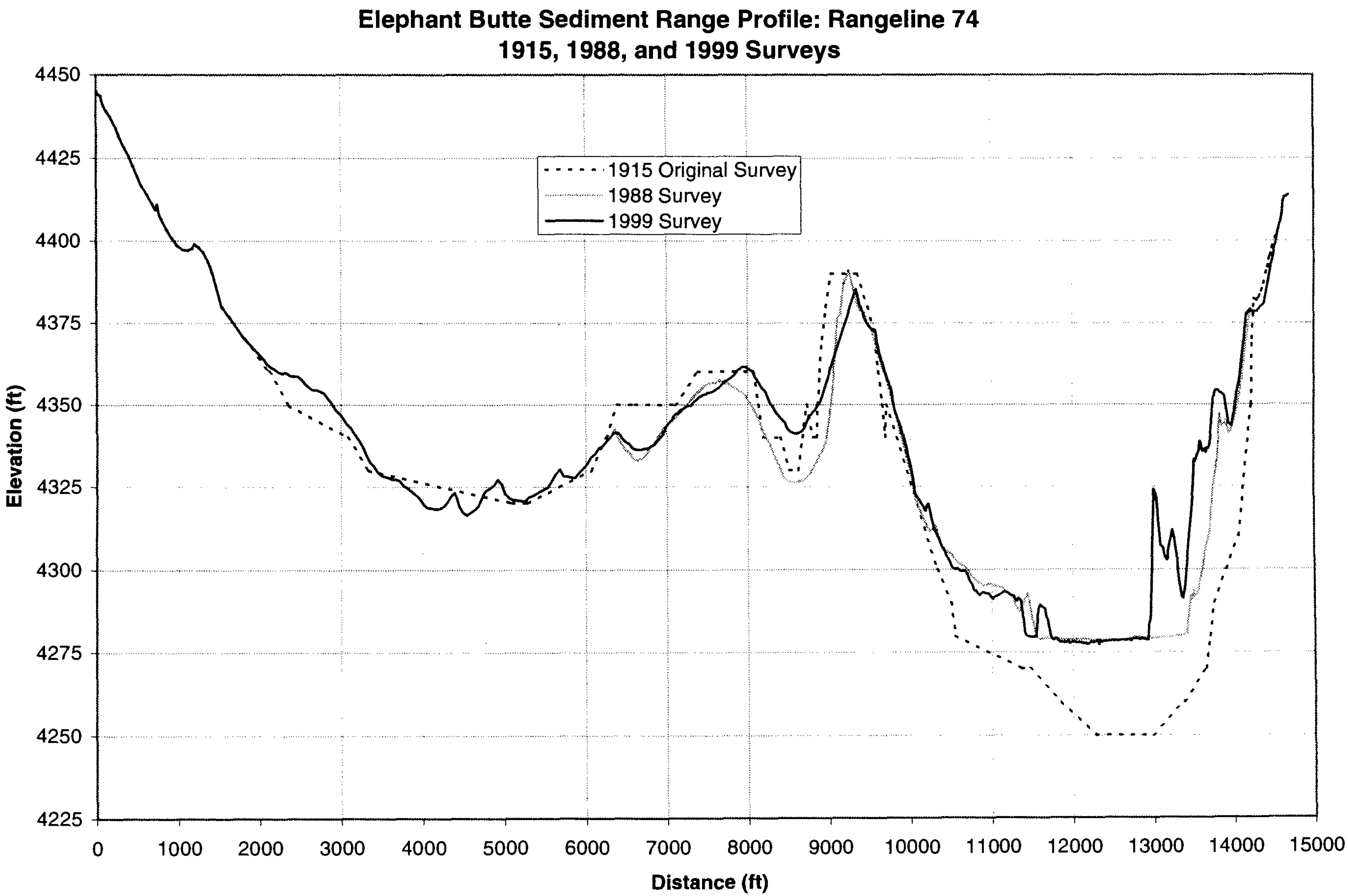


Figure 36. - Sedimentation range profiles for 1915, 1988, and 1999, range 74.

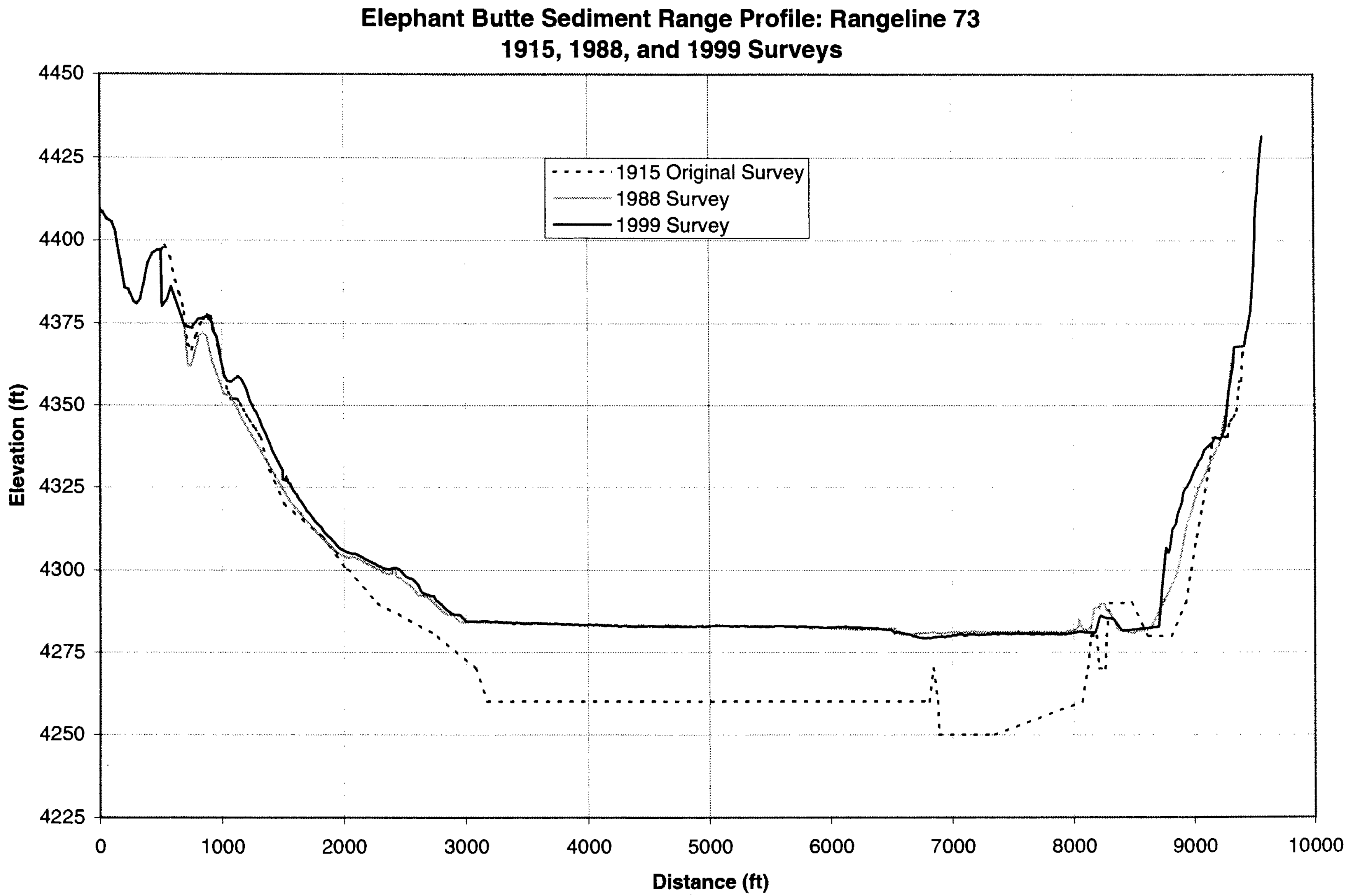


Figure 37. - Sedimentation range profiles for 1915, 1988, and 1999, range 73.

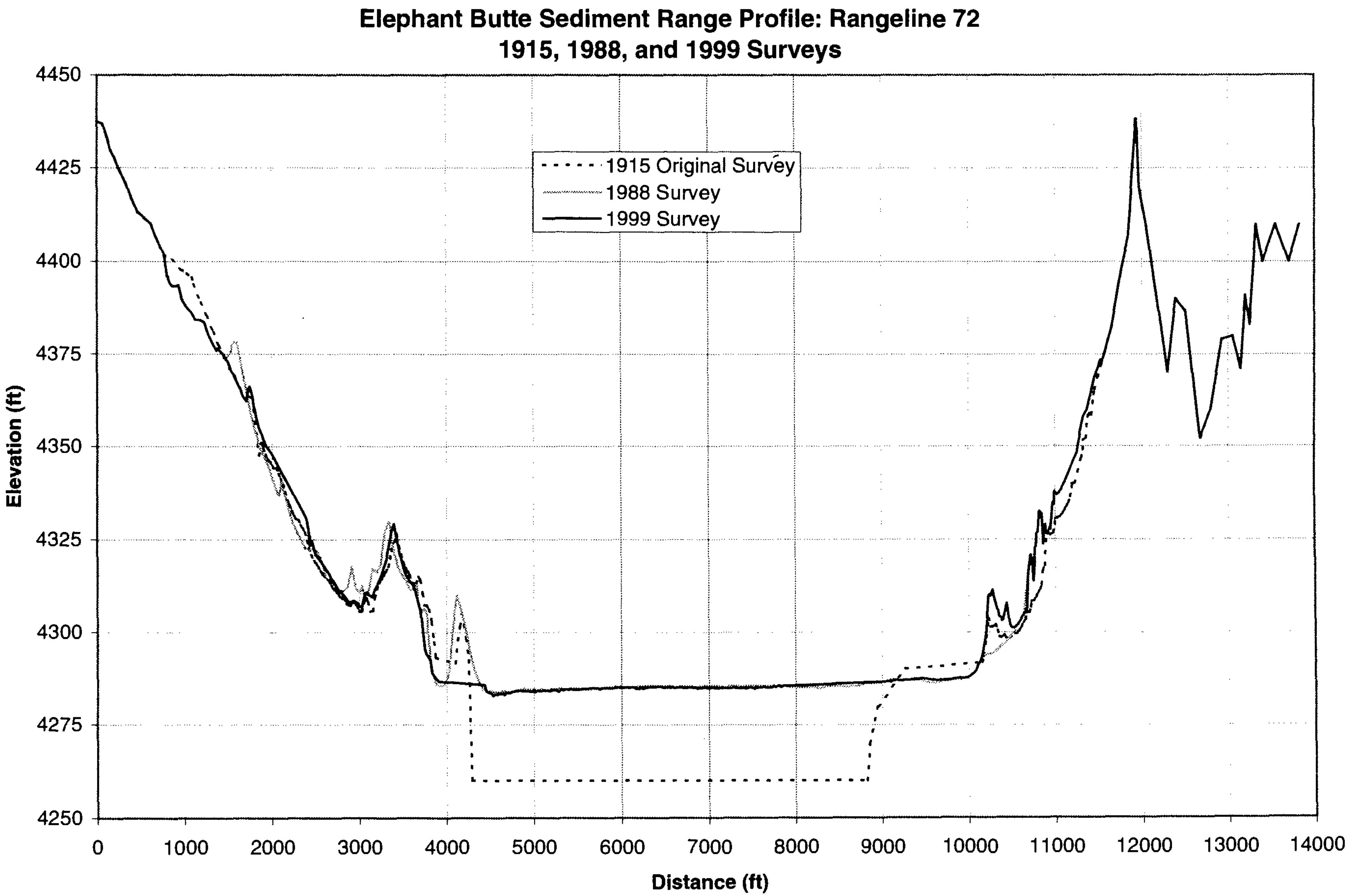


Figure 38. - Sedimentation range profiles for 1915, 1988, and 1999, range 72.

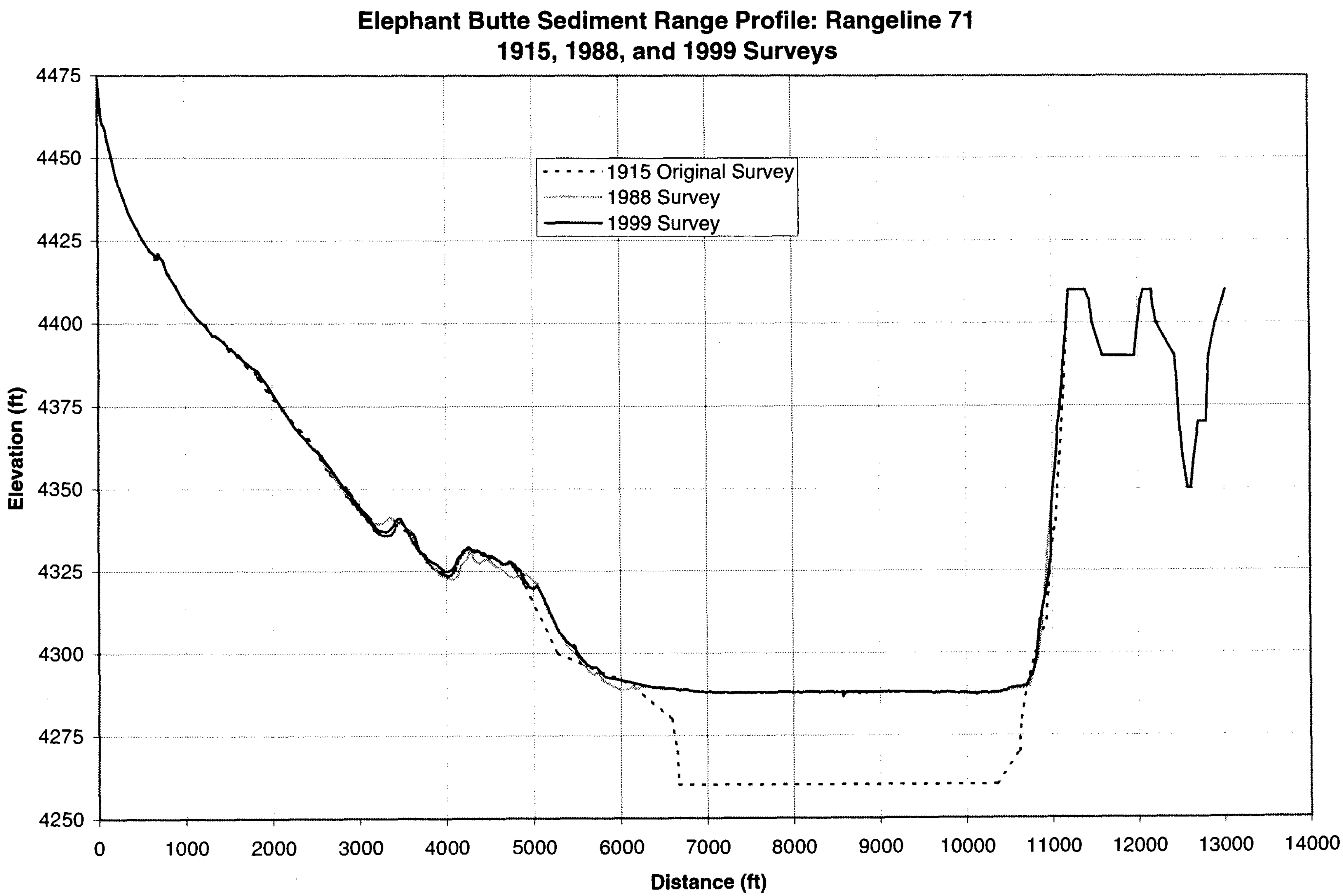


Figure 39. - Sedimentation range profiles for 1915, 1988, and 1999, range 71.

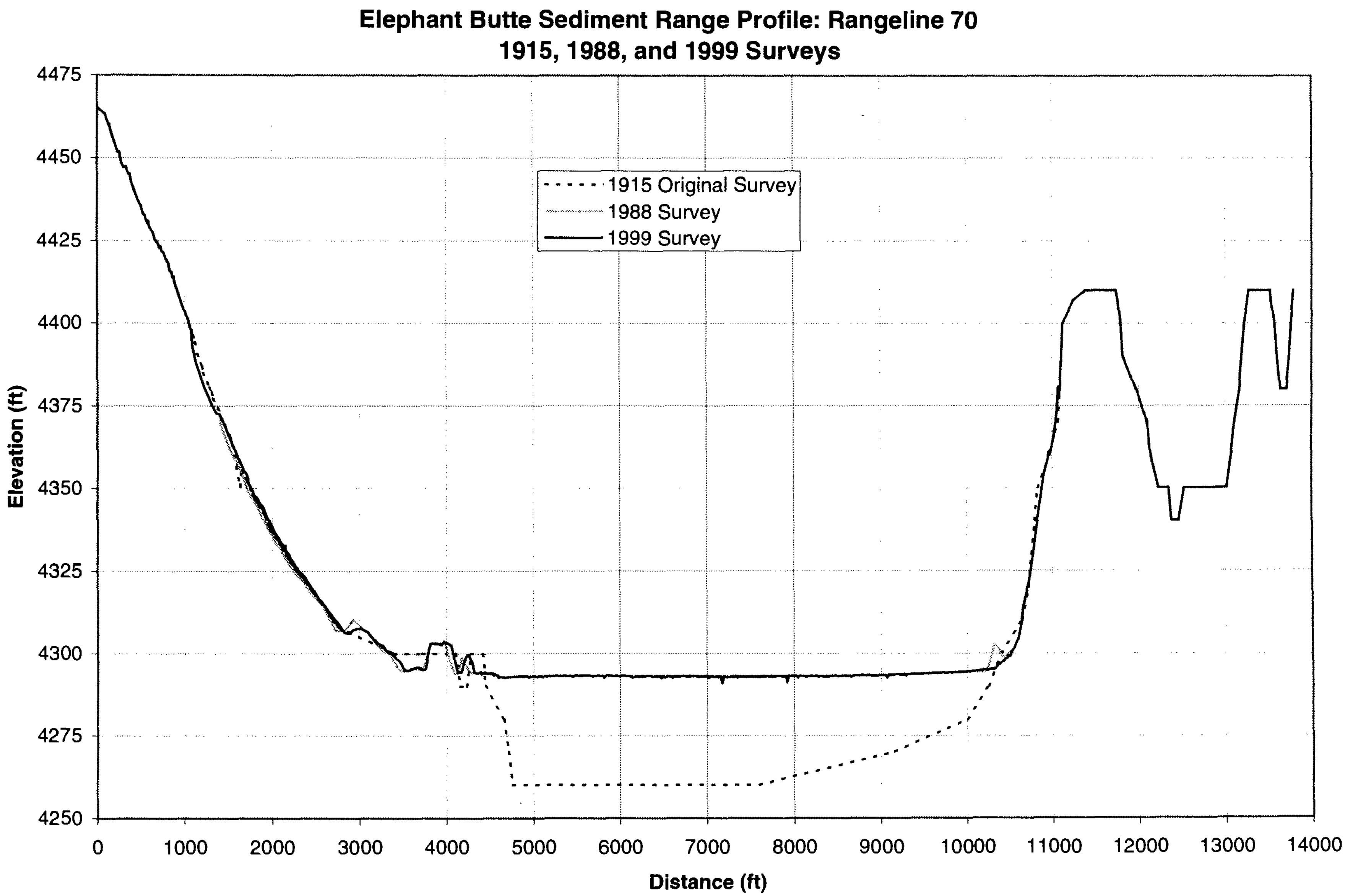


Figure 40. - Sedimentation range profiles for 1915, 1988, and 1999, range 70.

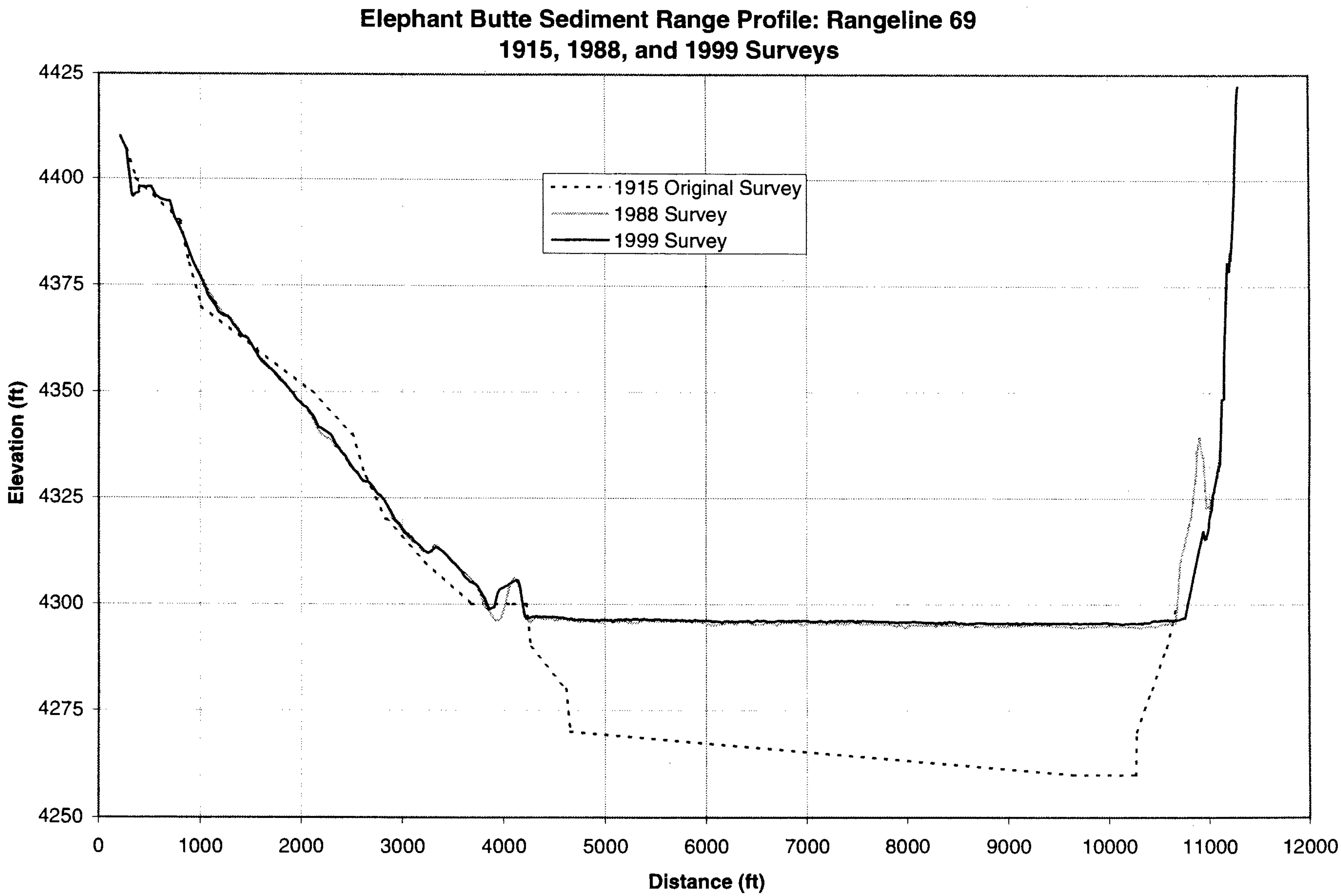


Figure 41. - Sedimentation range profiles for 1915, 1988, and 1999, range 69.

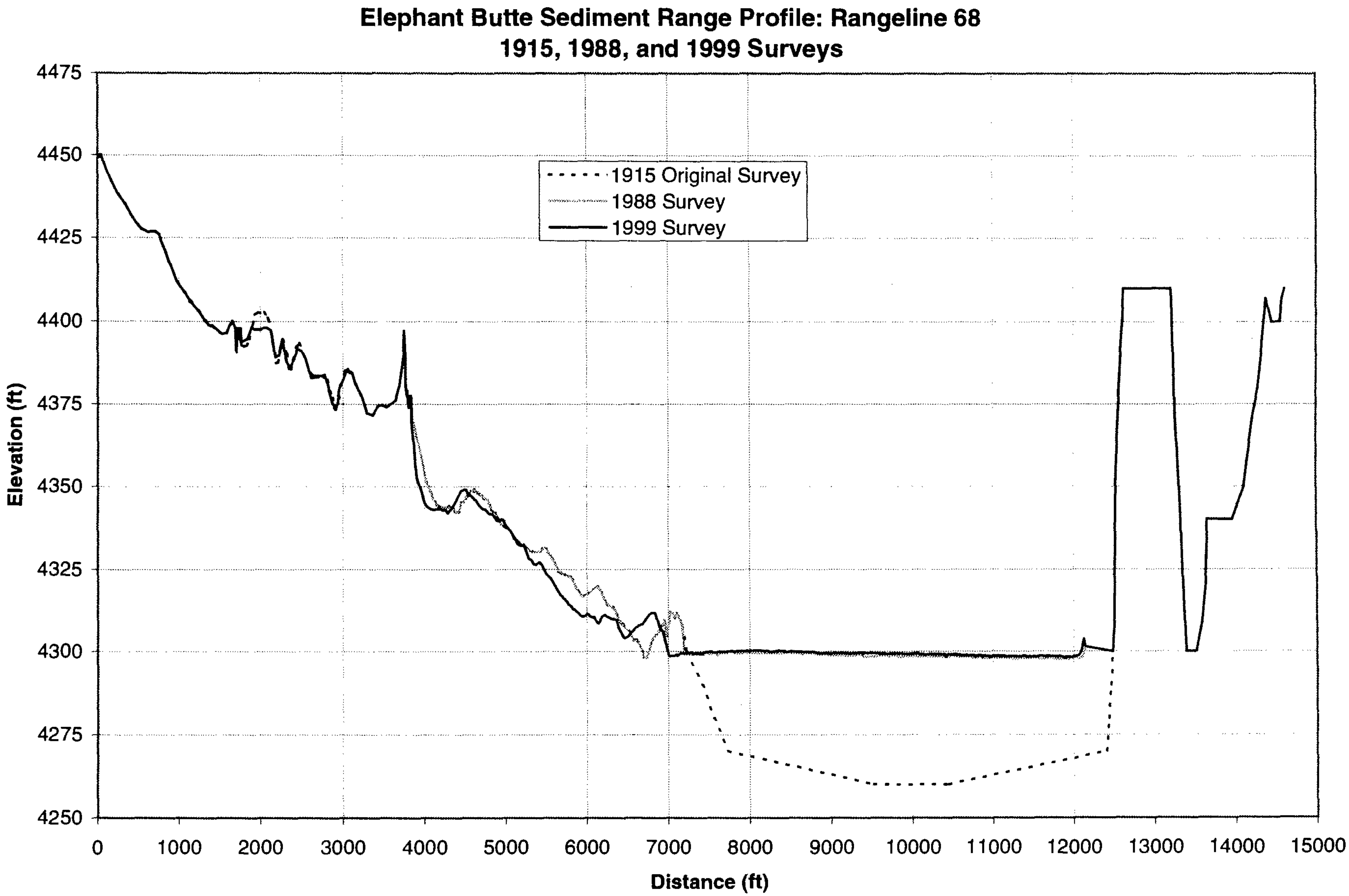


Figure 42. - Sedimentation range profiles for 1915, 1988, and 1999, range 68.

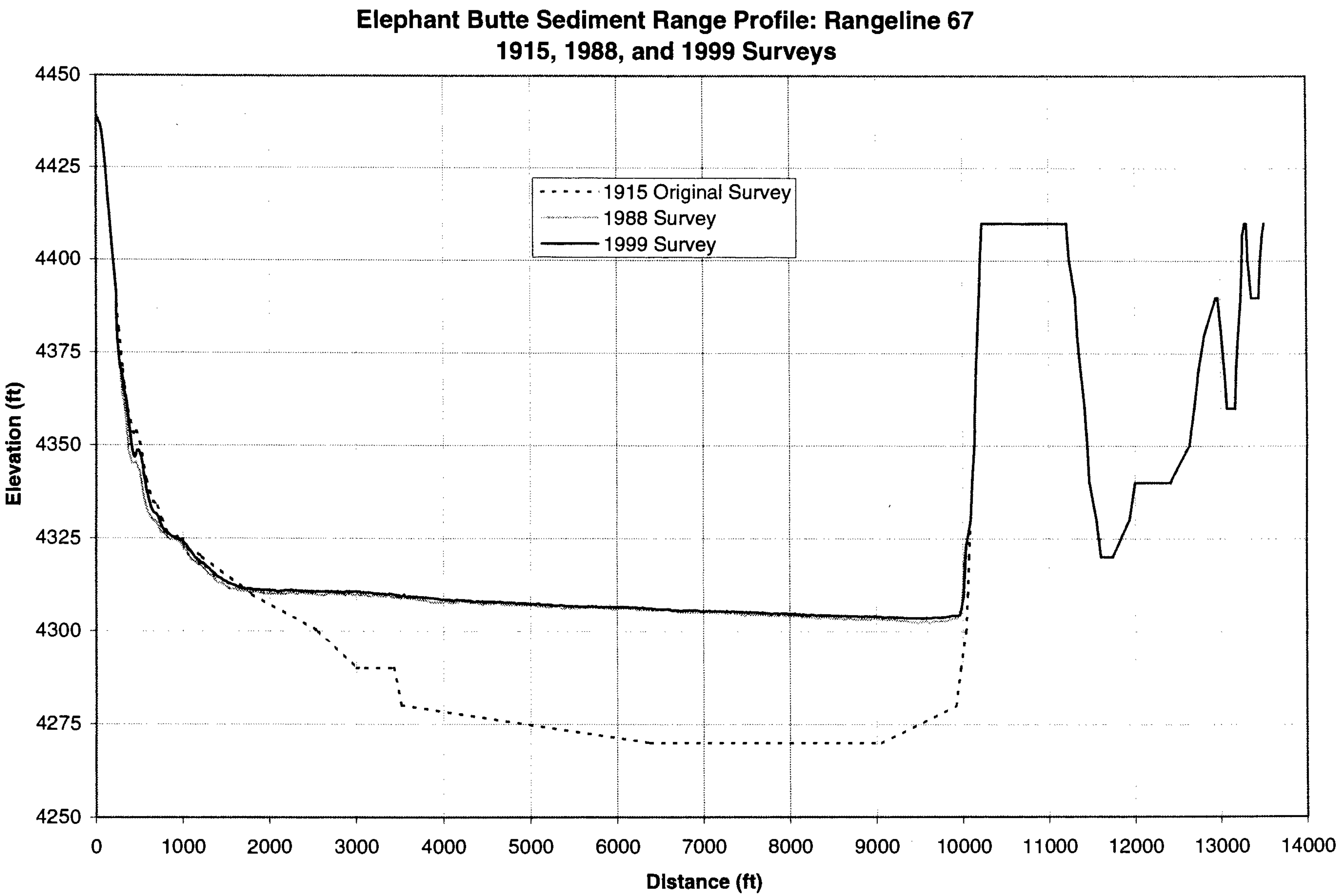


Figure 43. - Sedimentation range profiles for 1915, 1988, and 1999, range 67.

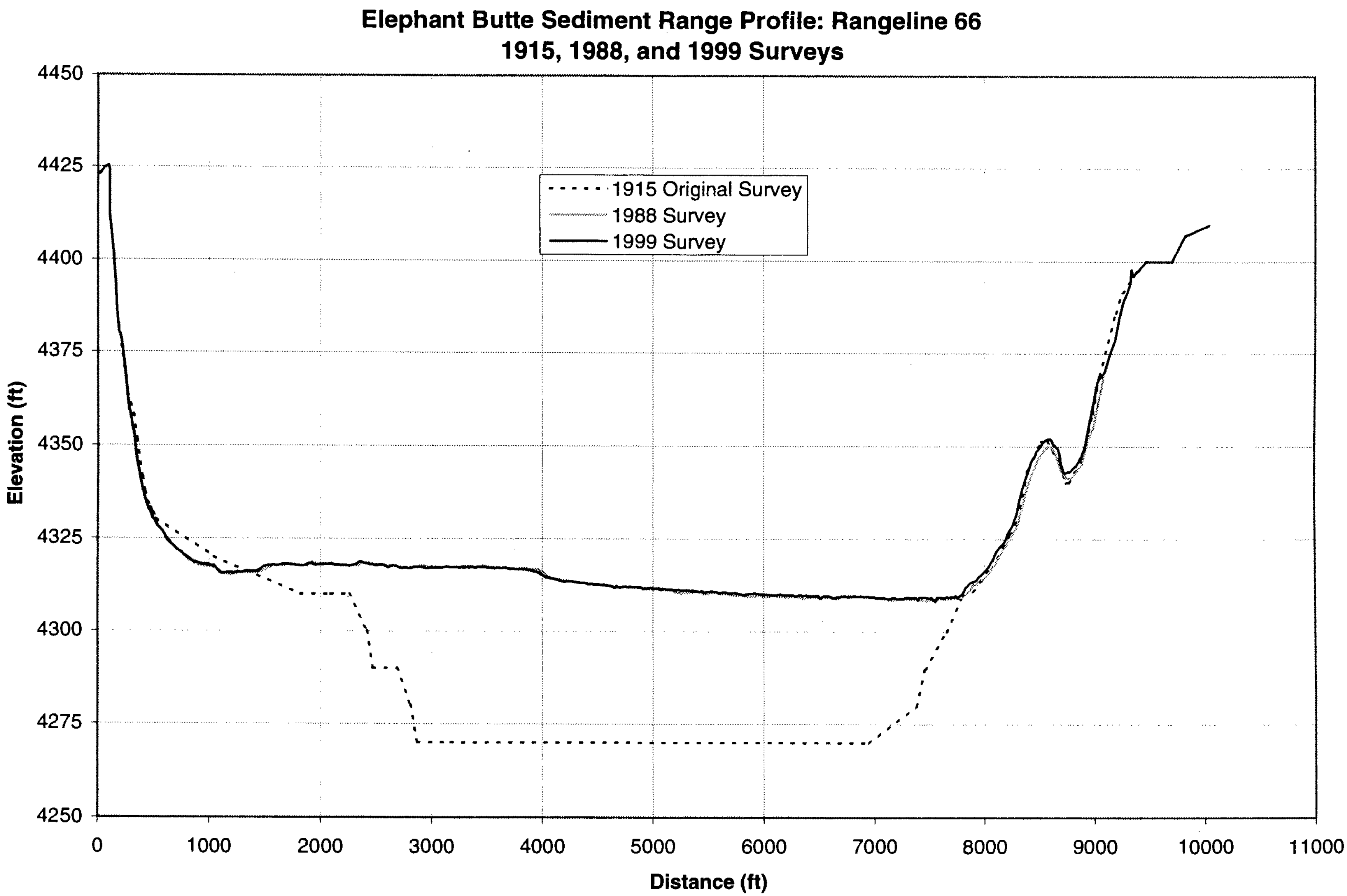


Figure 44. - Sedimentation range profiles for 1915, 1988, and 1999, range 66.

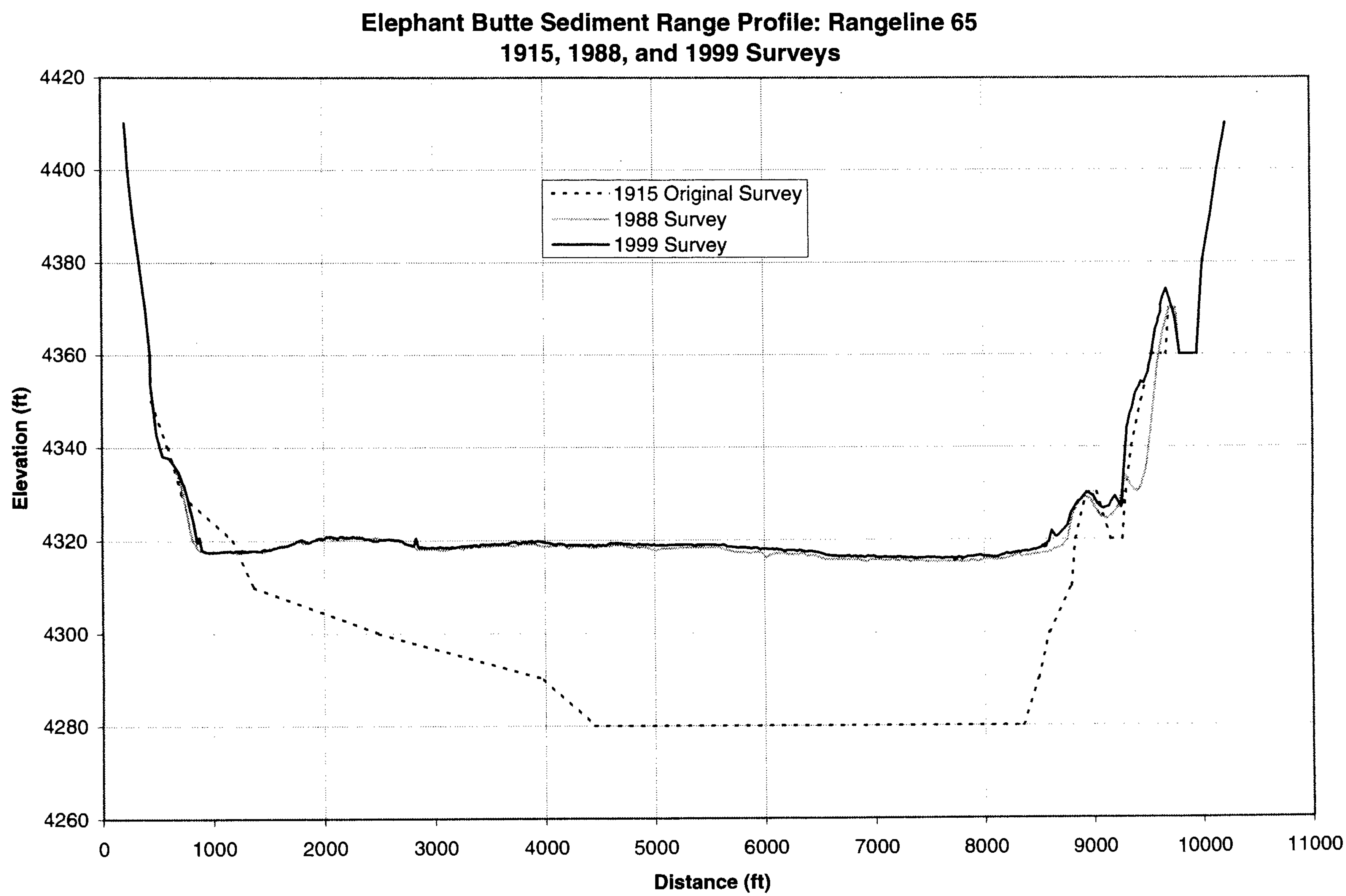


Figure 45. - Sedimentation range profiles for 1915, 1988, and 1999, range 65.

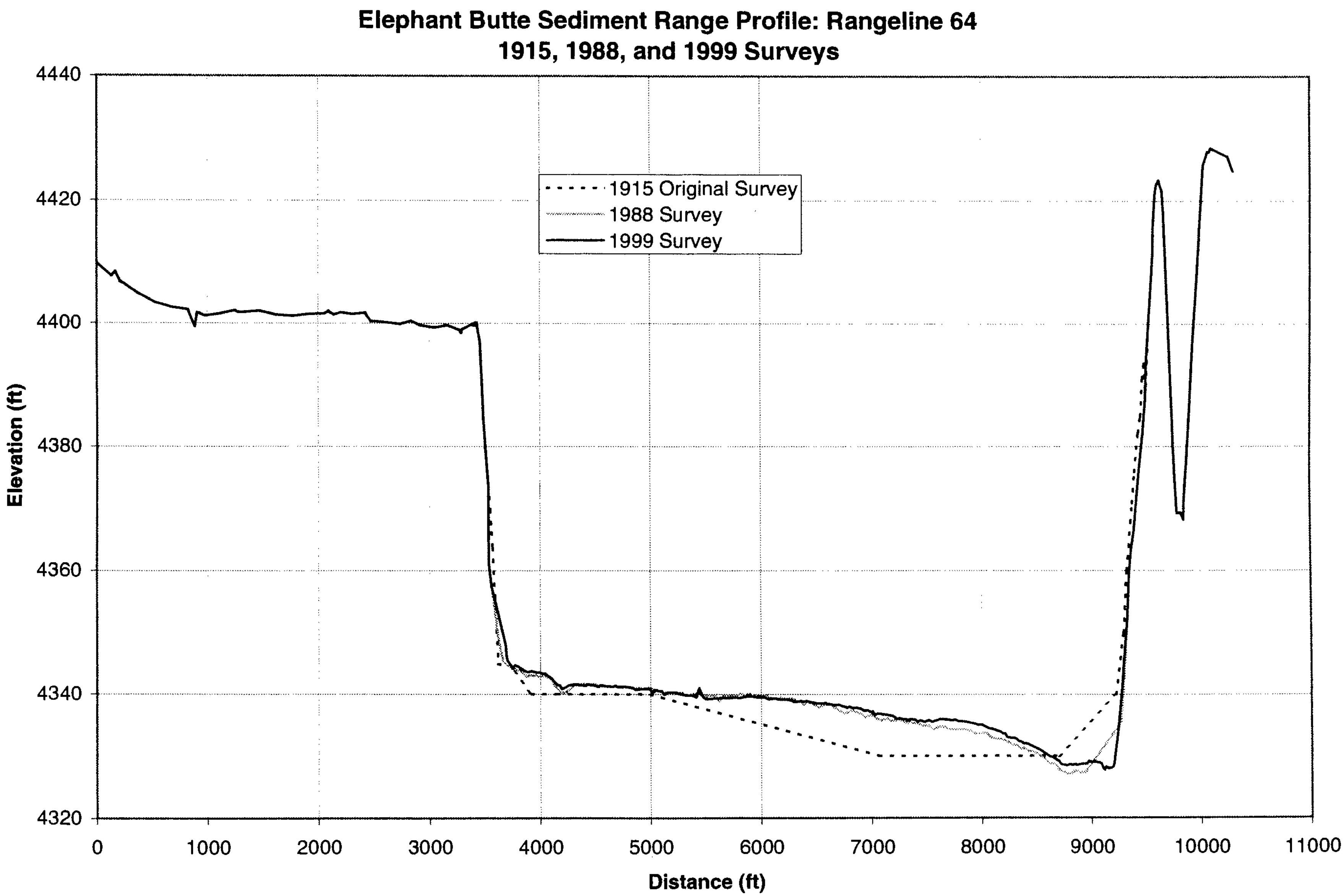


Figure 46. - Sedimentation range profiles for 1915, 1988, and 1999, range 64.

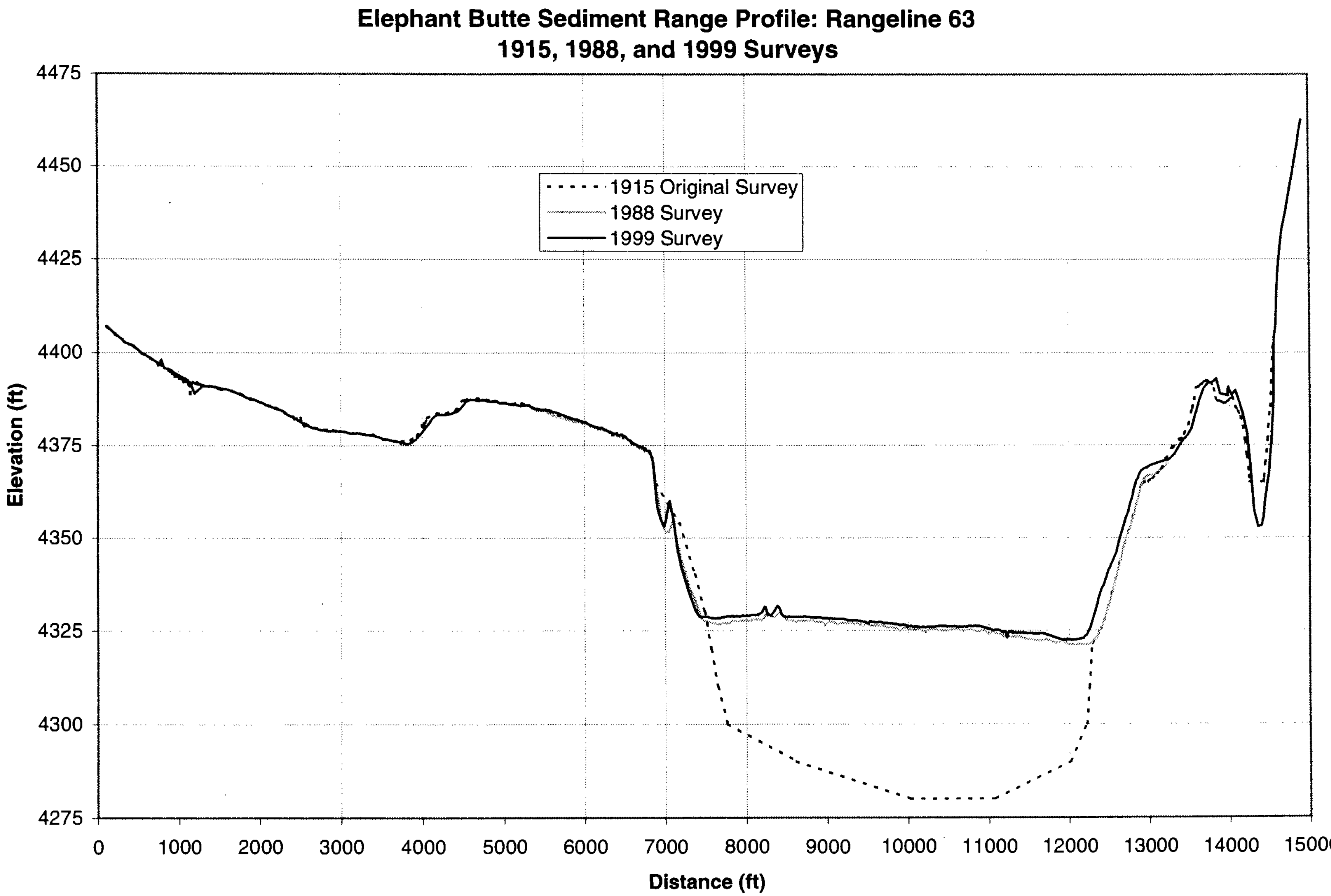


Figure 47. - Sedimentation range profiles for 1915, 1988, and 1999, range 63.

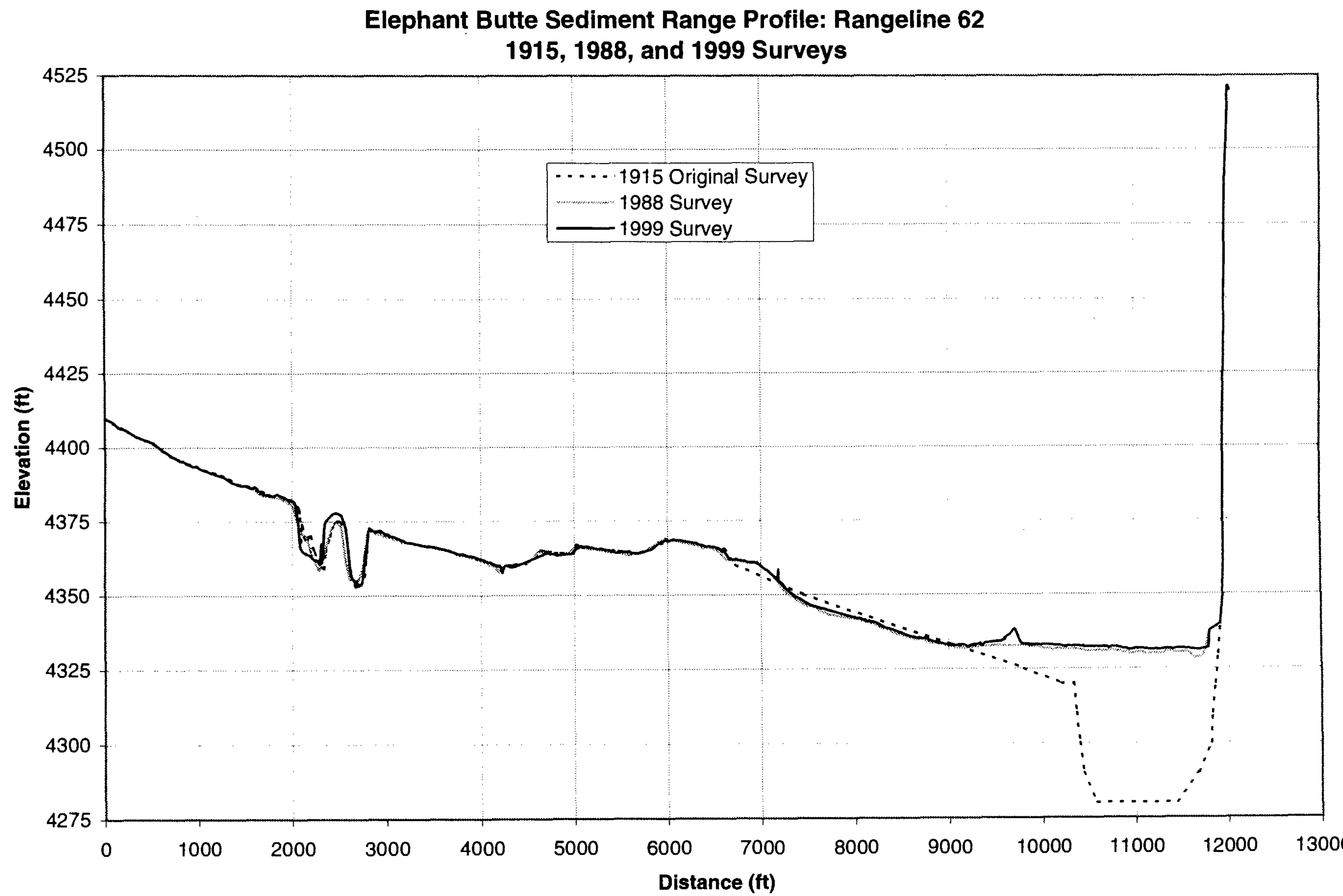


Figure 48. - Sedimentation range profiles for 1915, 1988, and 1999, range 62.

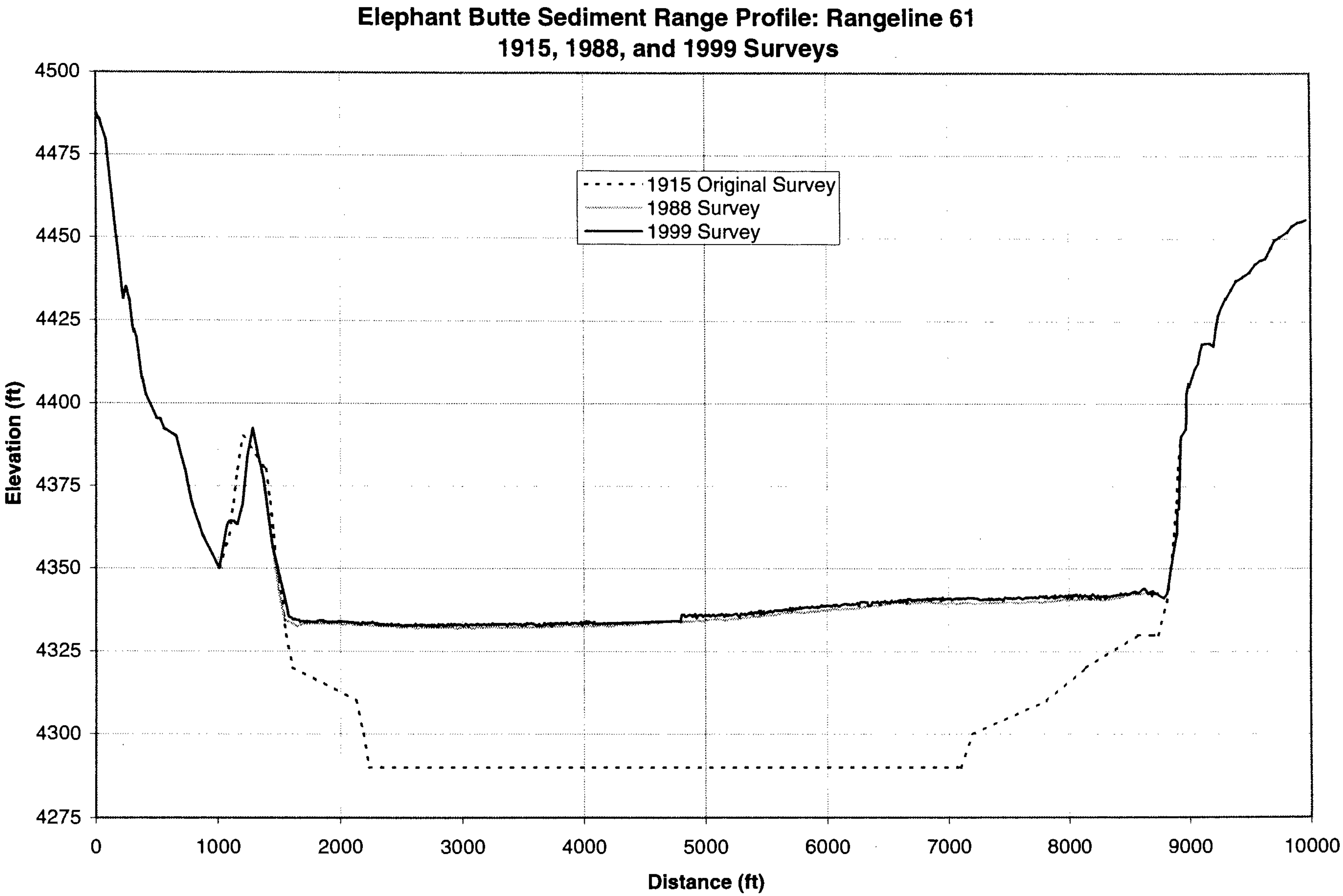


Figure 49. - Sedimentation range profiles for 1915, 1988, and 1999, range 61.

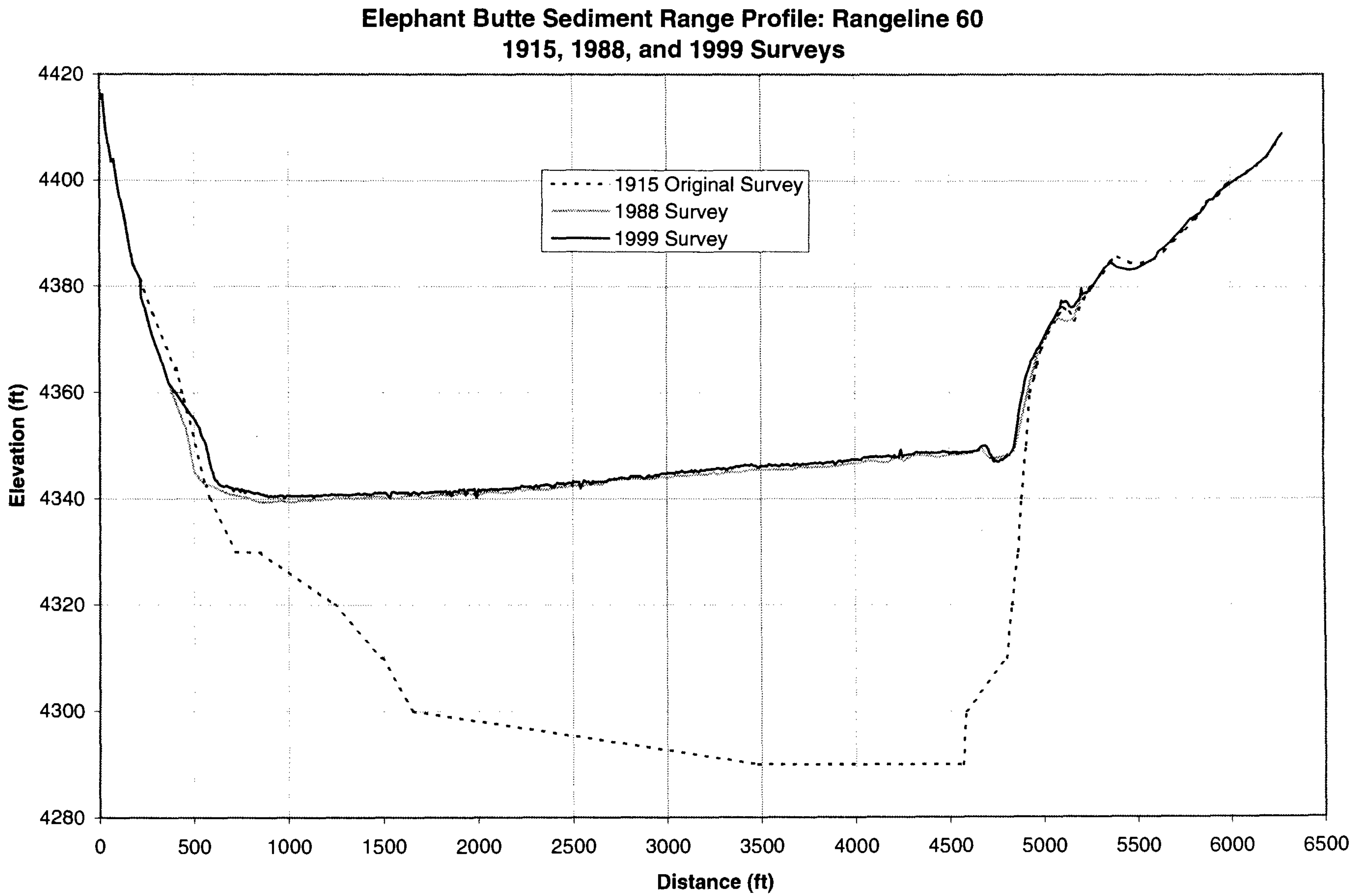


Figure 50. - Sedimentation range profiles for 1915, 1988, and 1999, range 60.

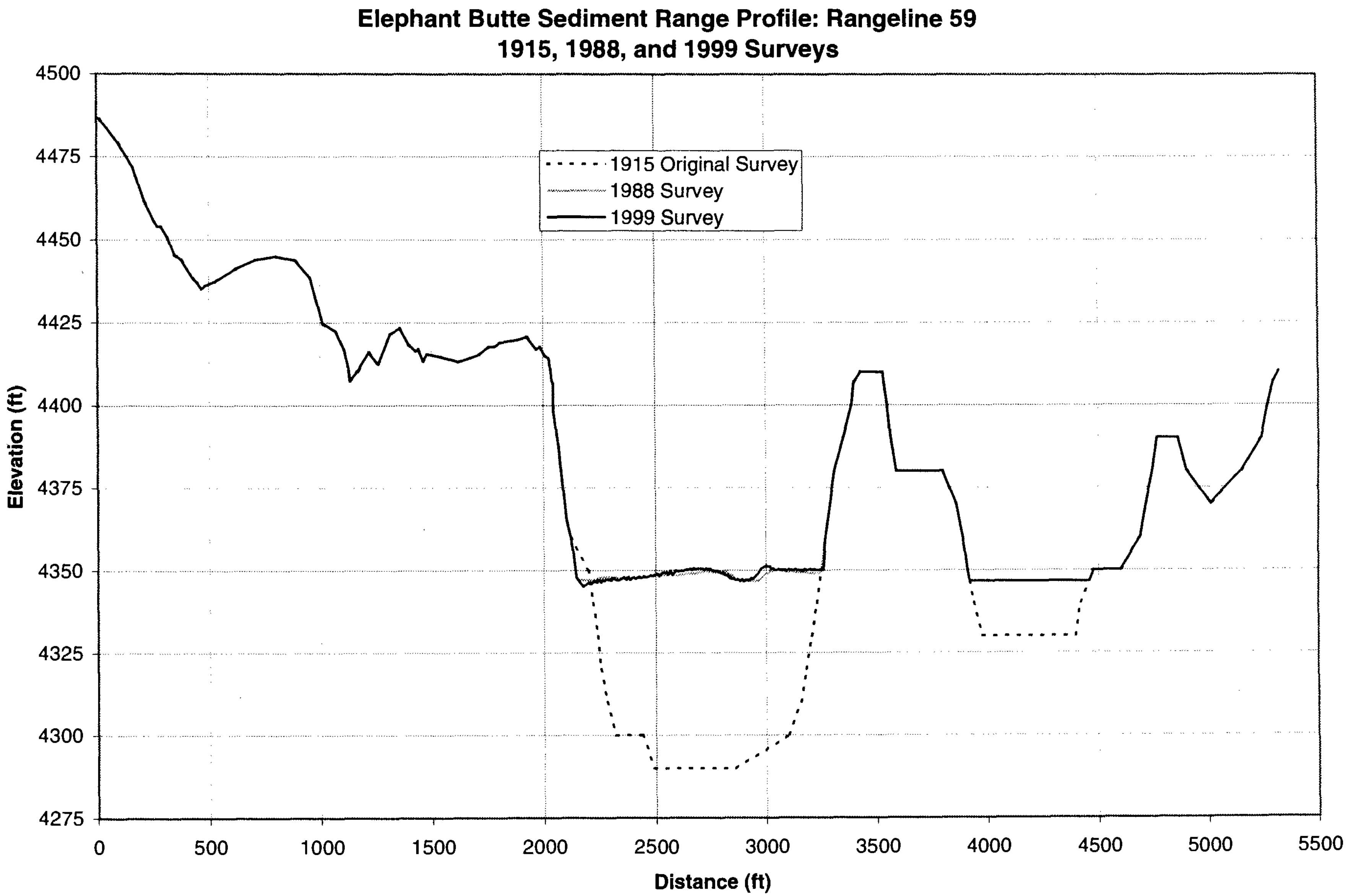


Figure 51. - Sedimentation range profiles for 1915, 1988, and 1999, range 59.

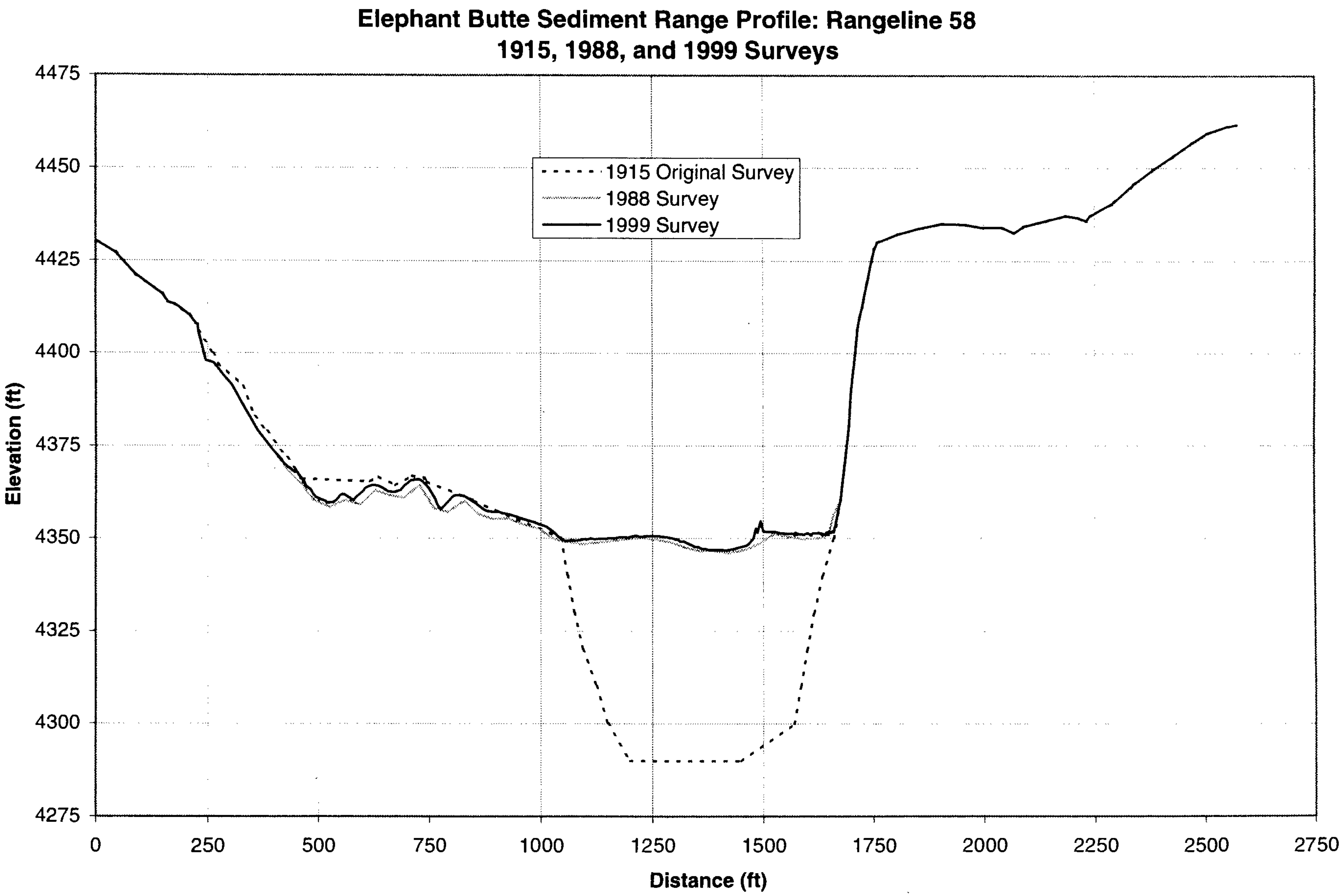


Figure 52. - Sedimentation range profiles for 1915, 1988, and 1999, range 58.

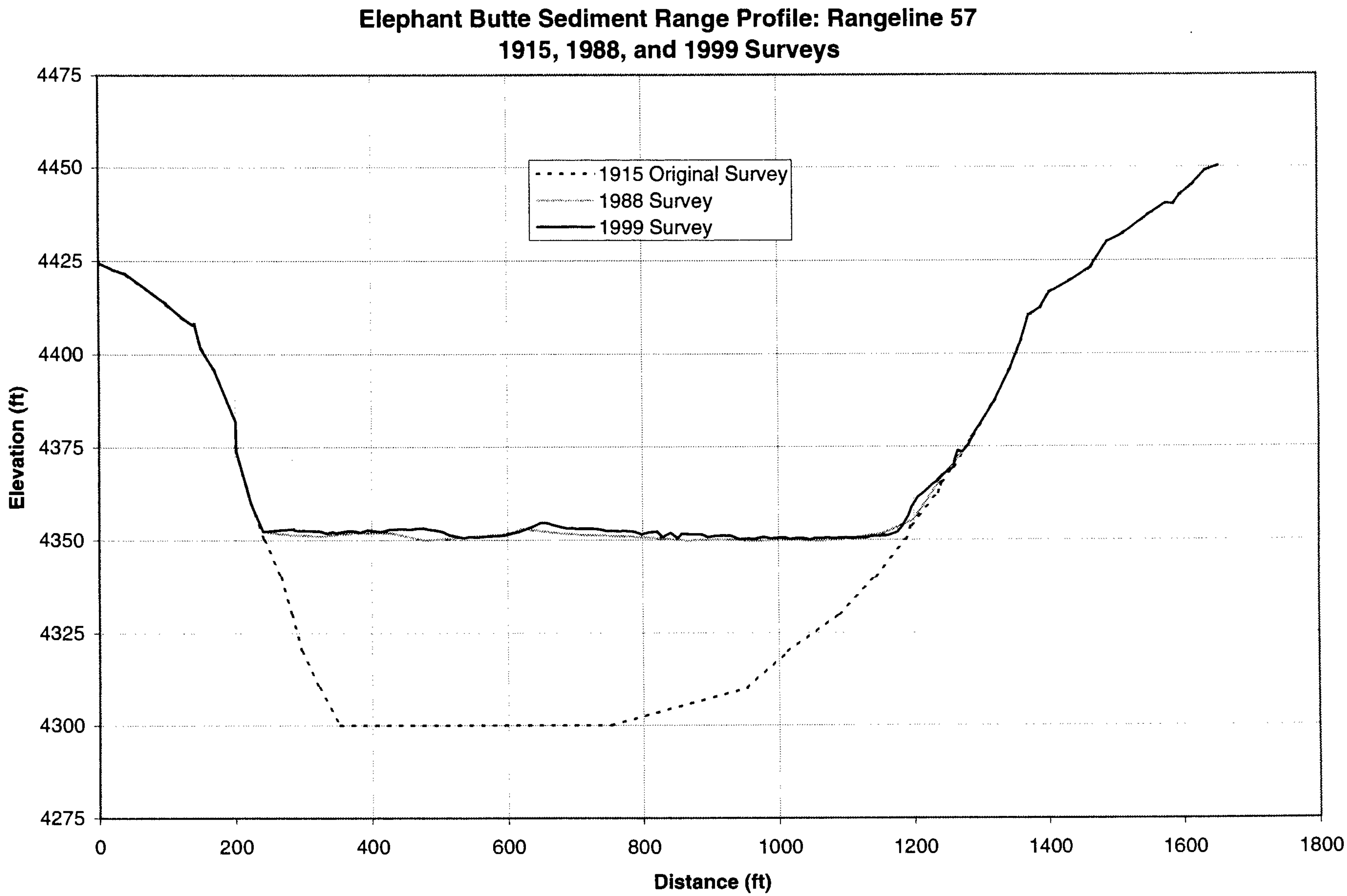


Figure 53. - Sedimentation range profiles for 1915, 1988, and 1999, range 57.

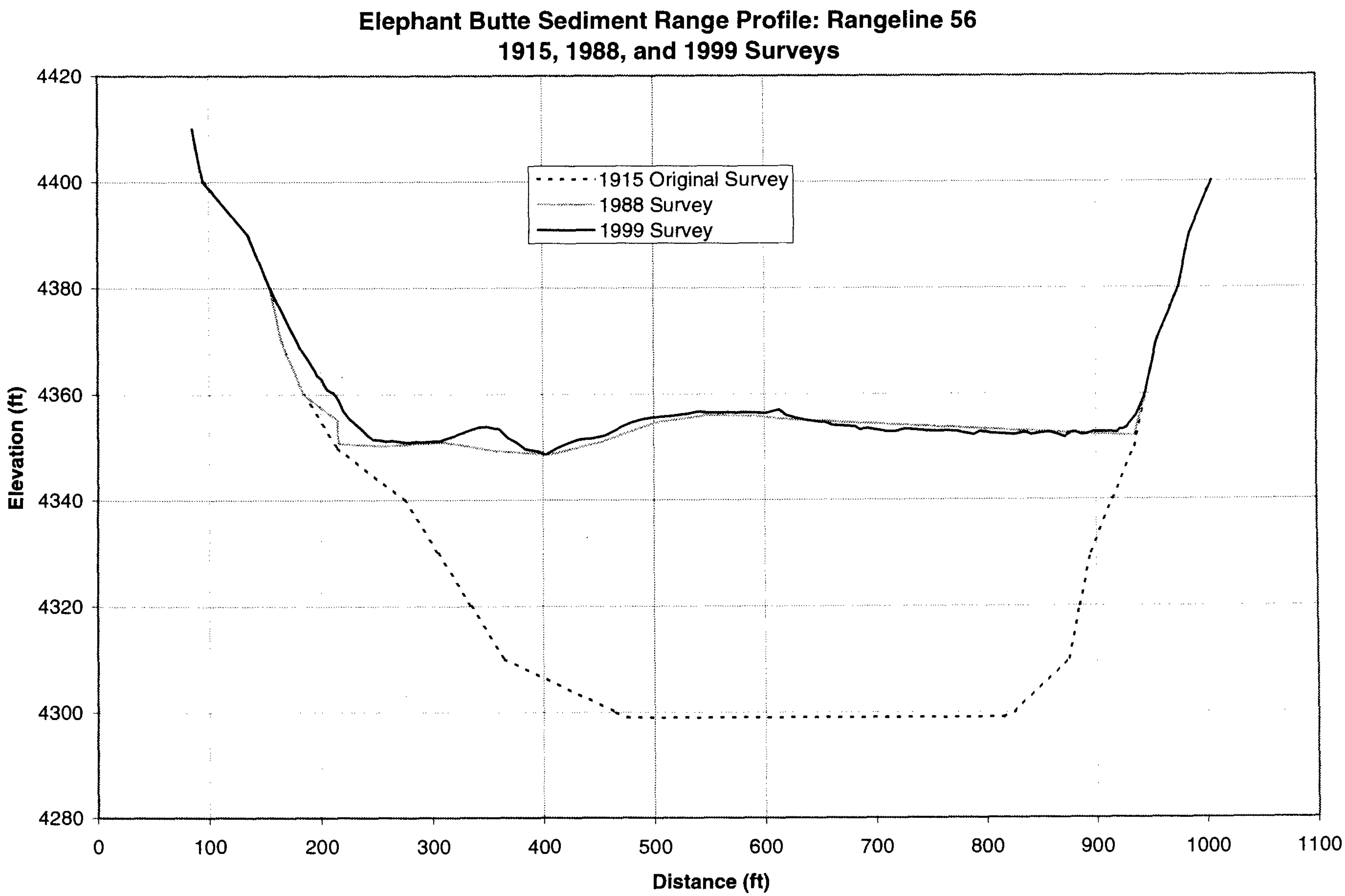


Figure 54. - Sedimentation range profiles for 1915, 1988, and 1999, range 56.

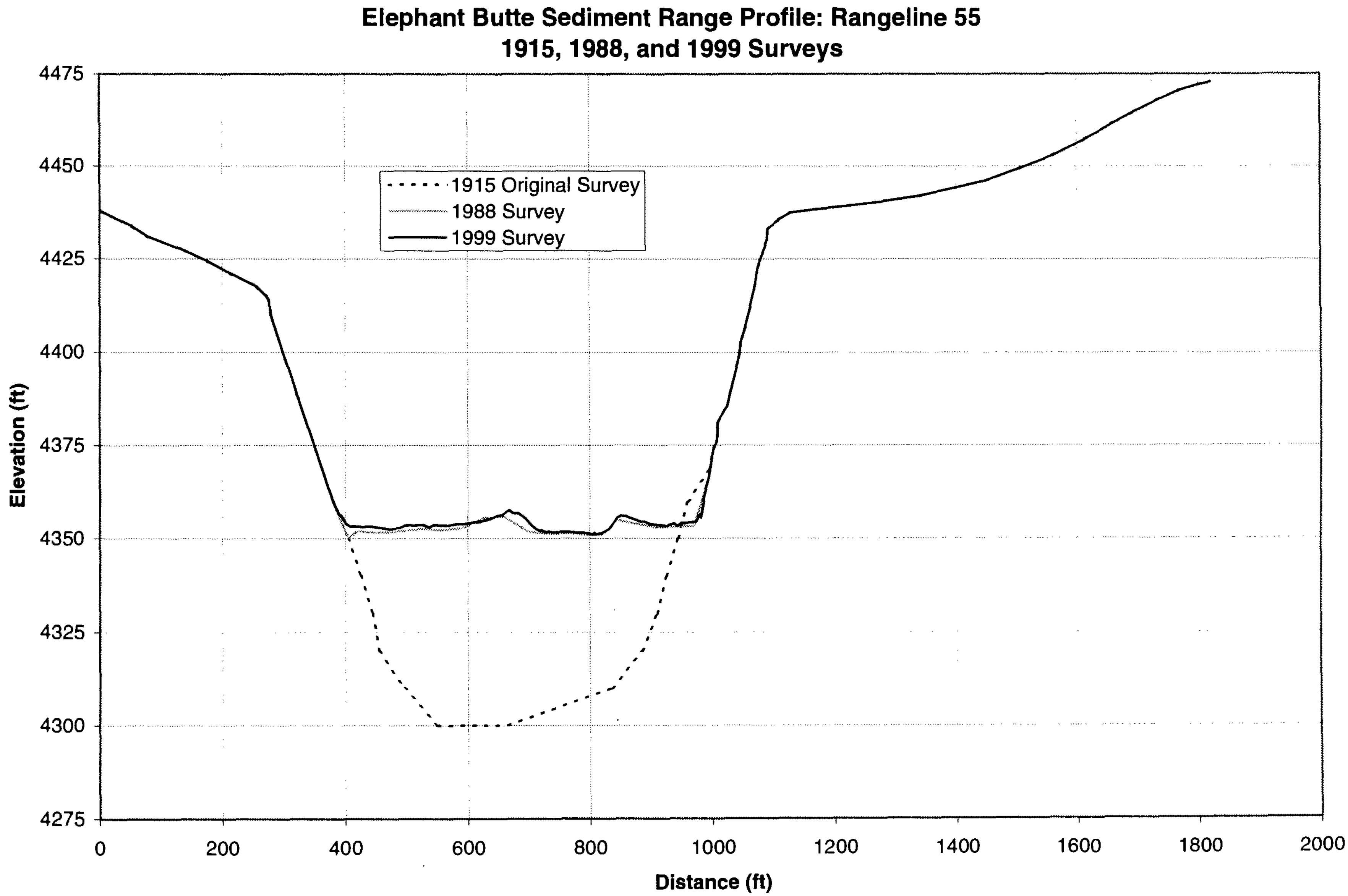


Figure 55. - Sedimentation range profiles for 1915, 1988, and 1999, range 55.

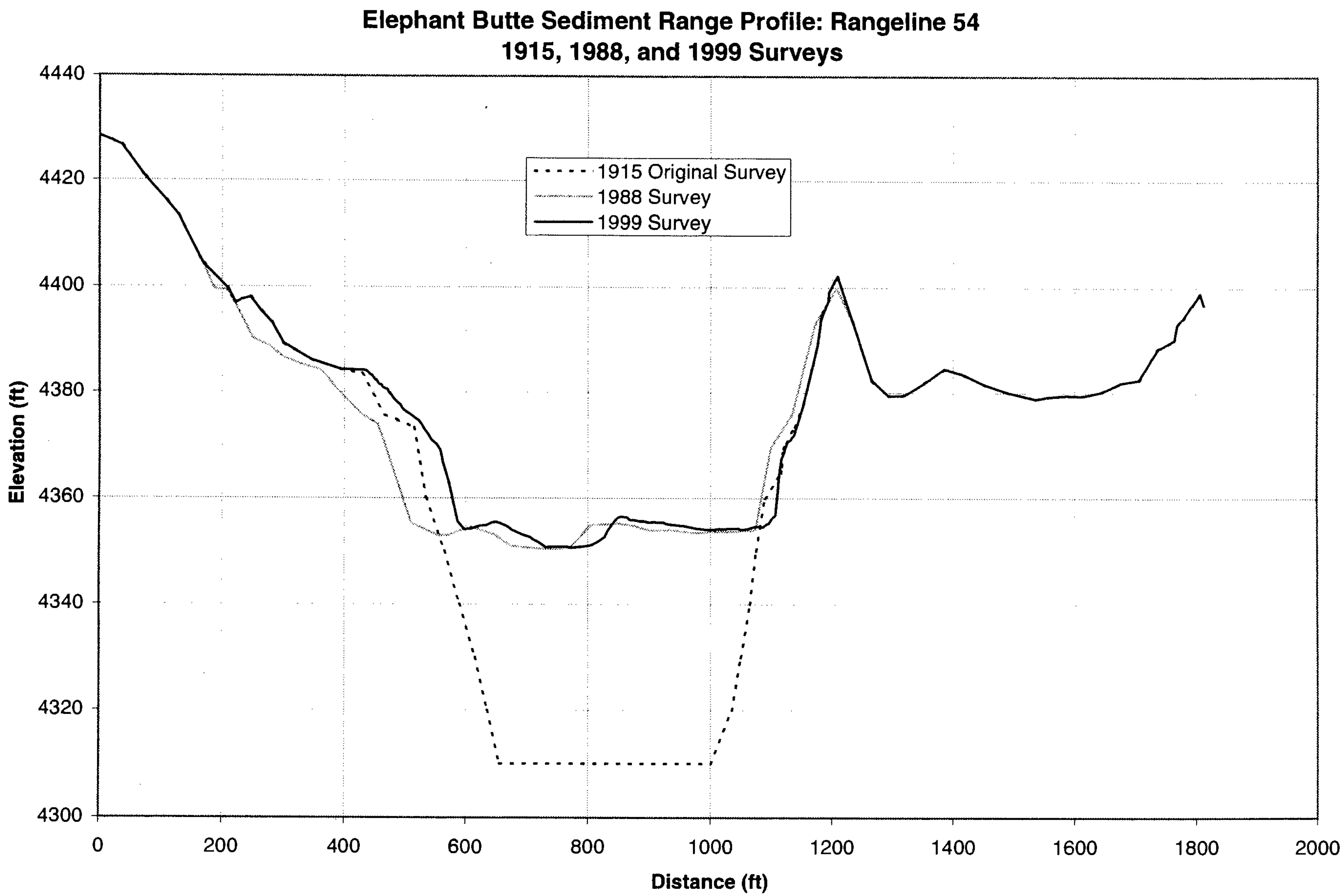


Figure 56. - Sedimentation range profiles for 1915, 1988, and 1999, range 54.

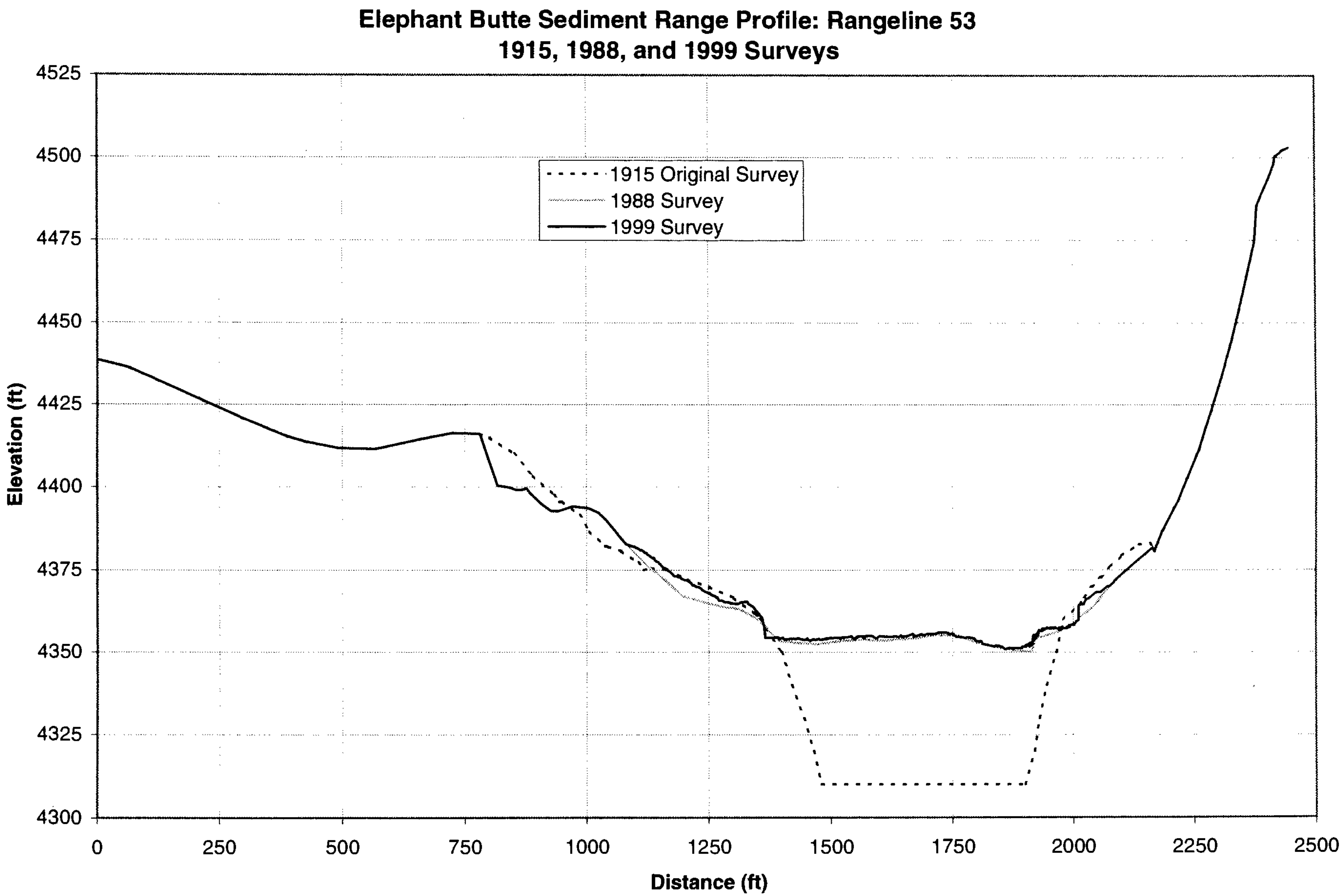


Figure 57. - Sedimentation range profiles for 1915, 1988, and 1999, range 53.

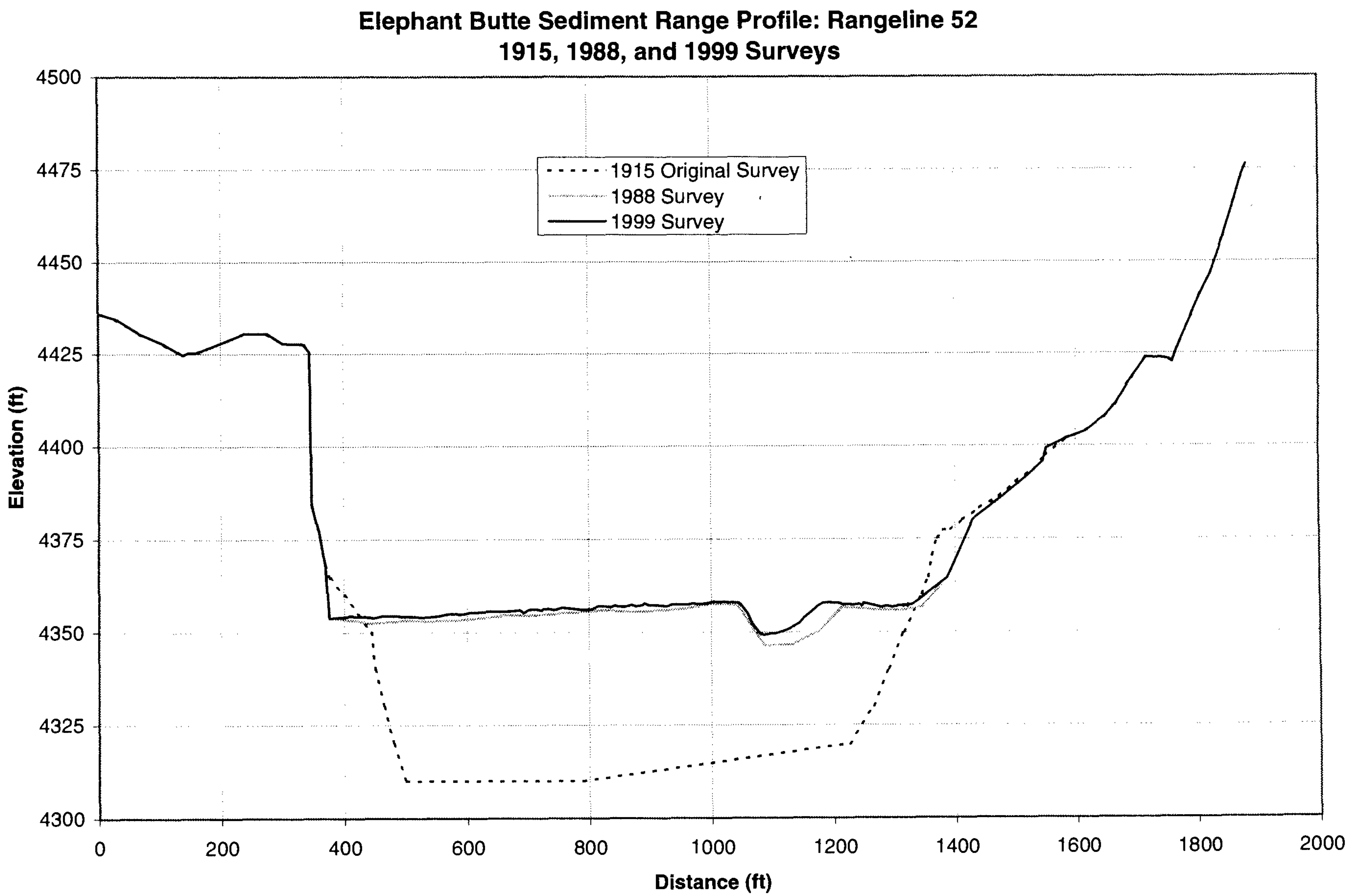


Figure 58. - Sedimentation range profiles for 1915, 1988, and 1999, range 52.

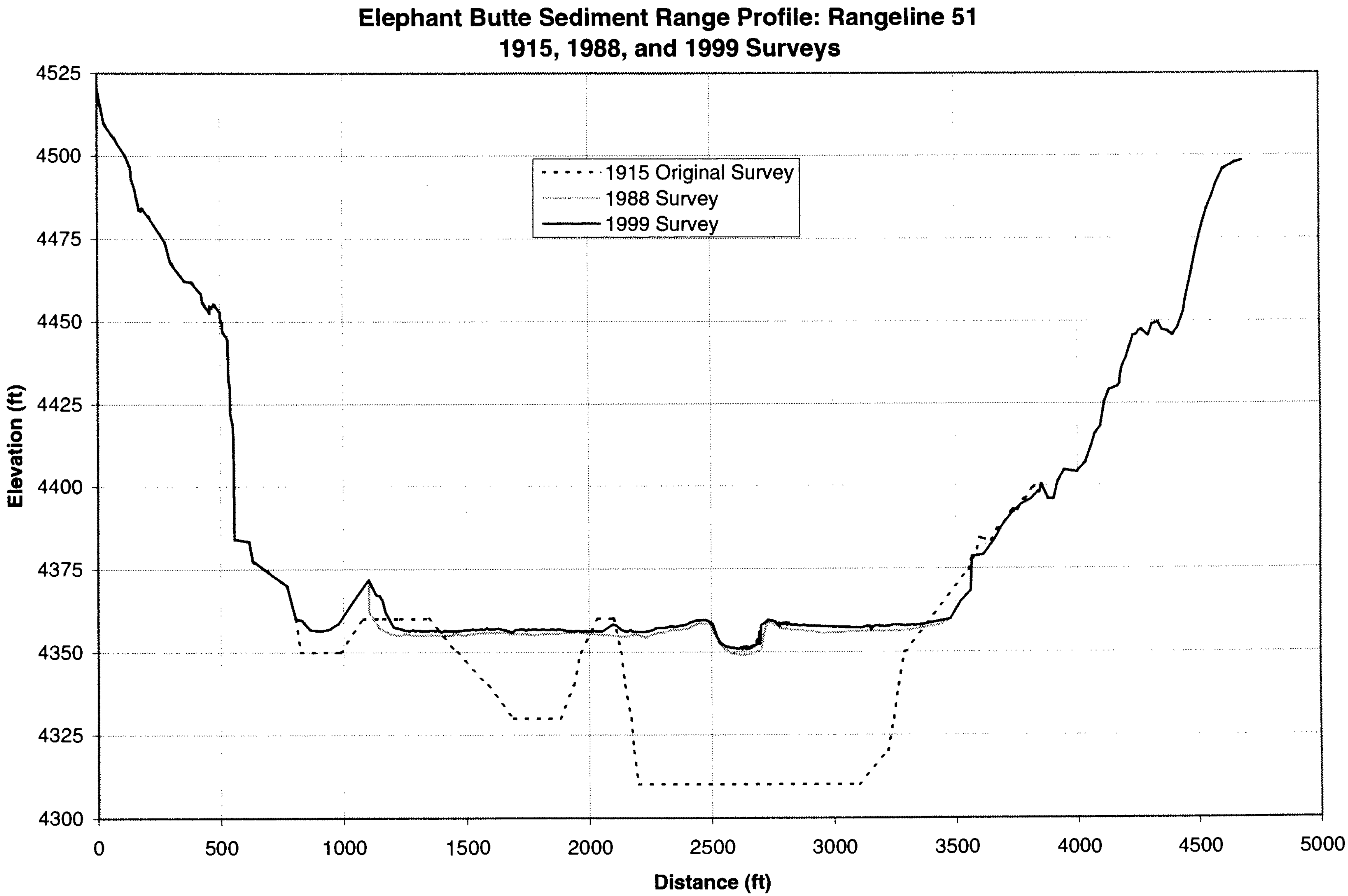
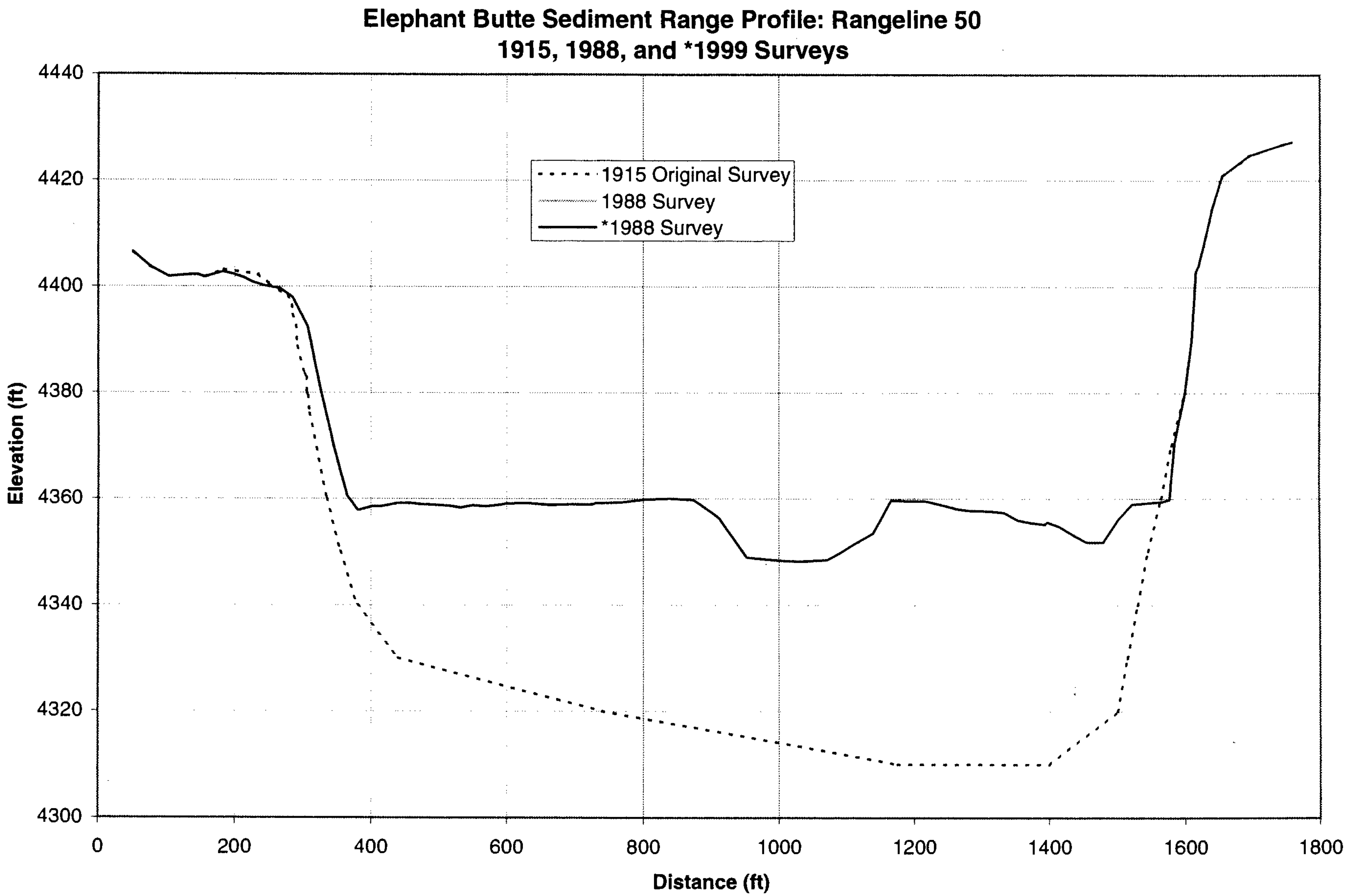


Figure 59. - Sedimentation range profiles for 1915, 1988, and 1999, range 51.



*Rangeline 50 not surveyed in 1999

Figure 60. - Sedimentation range profiles for 1915, 1988, and *1999, range 50.

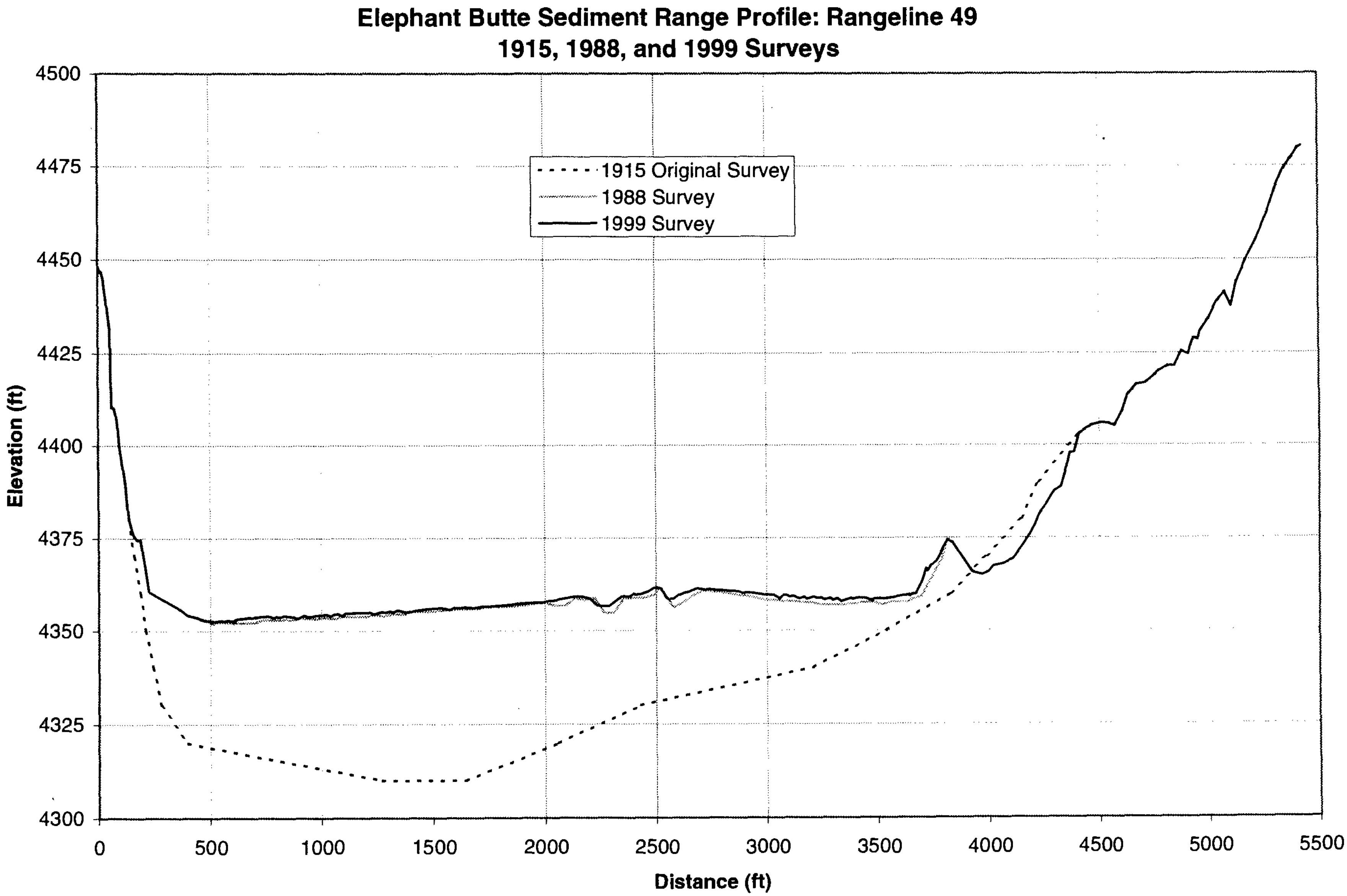


Figure 61. - Sedimentation range profiles for 1915, 1988, and 1999, range 49.

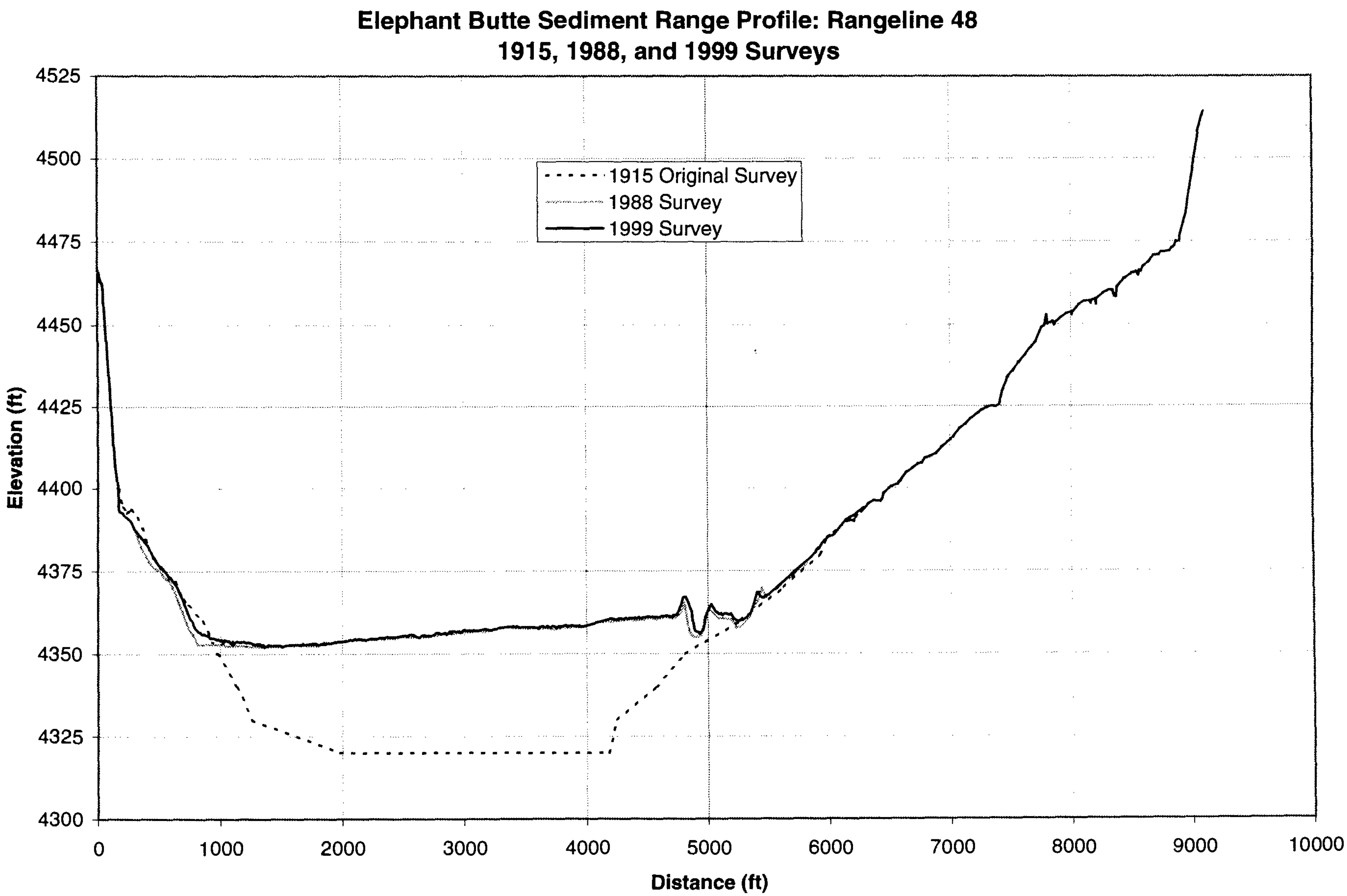


Figure 62. - Sedimentation range profiles for 1915, 1988, and 1999, range 48.

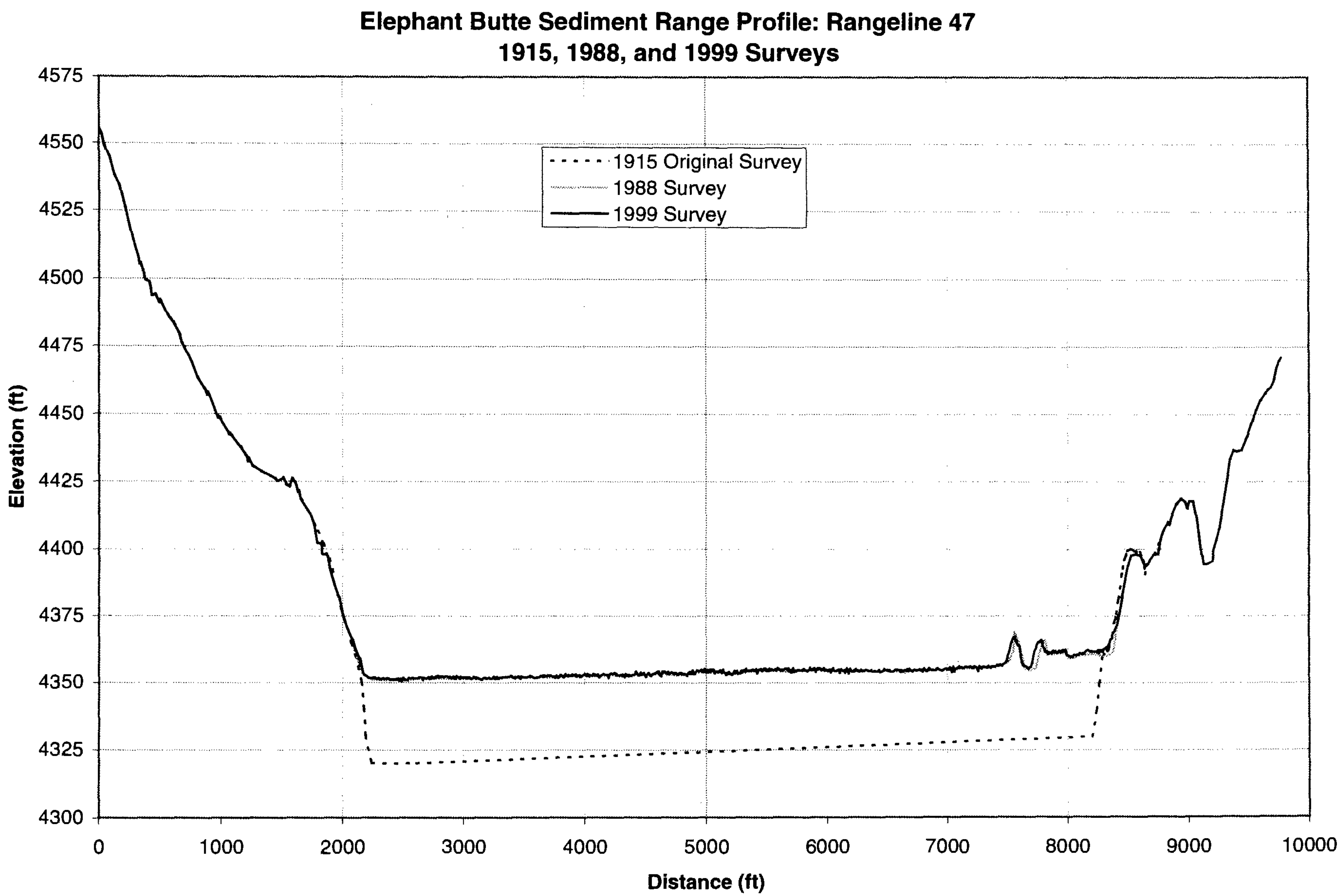


Figure 63. - Sedimentation range profiles for 1915, 1988, and 1999, range 47.

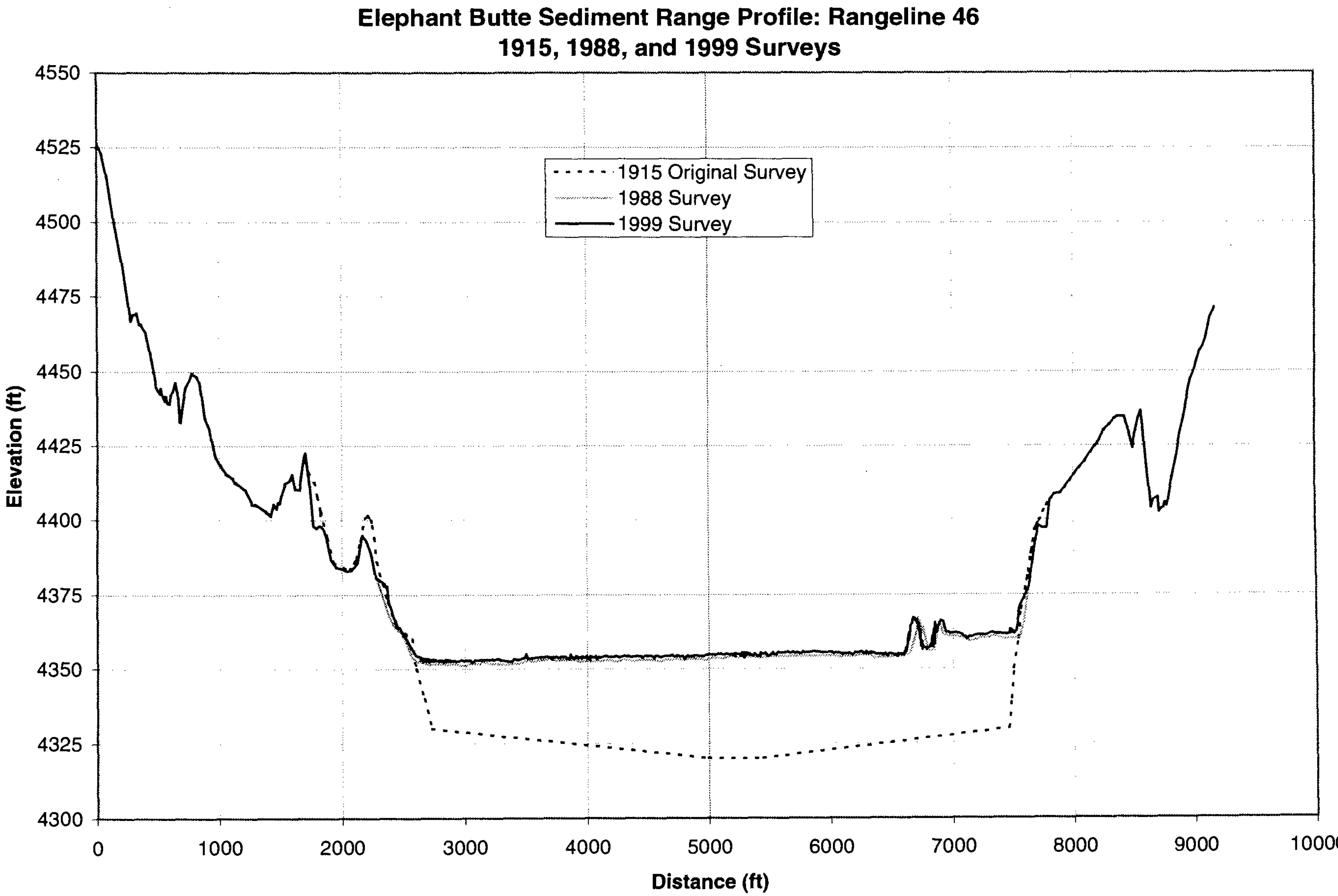


Figure 64. - Sedimentation range profiles for 1915, 1988, and 1999, range 46.

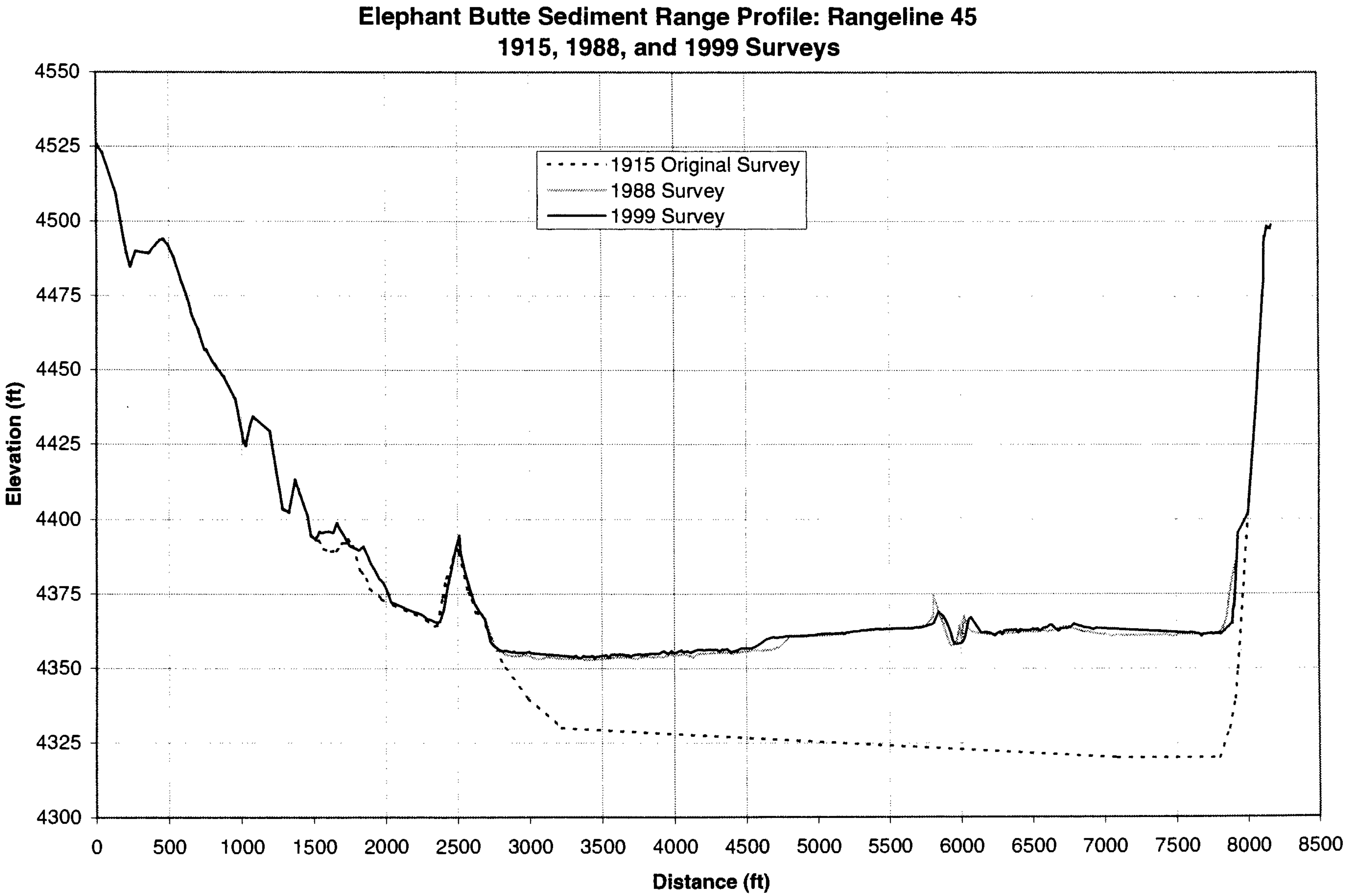


Figure 65. - Sedimentation range profiles for 1915, 1988, and 1999, range 45.

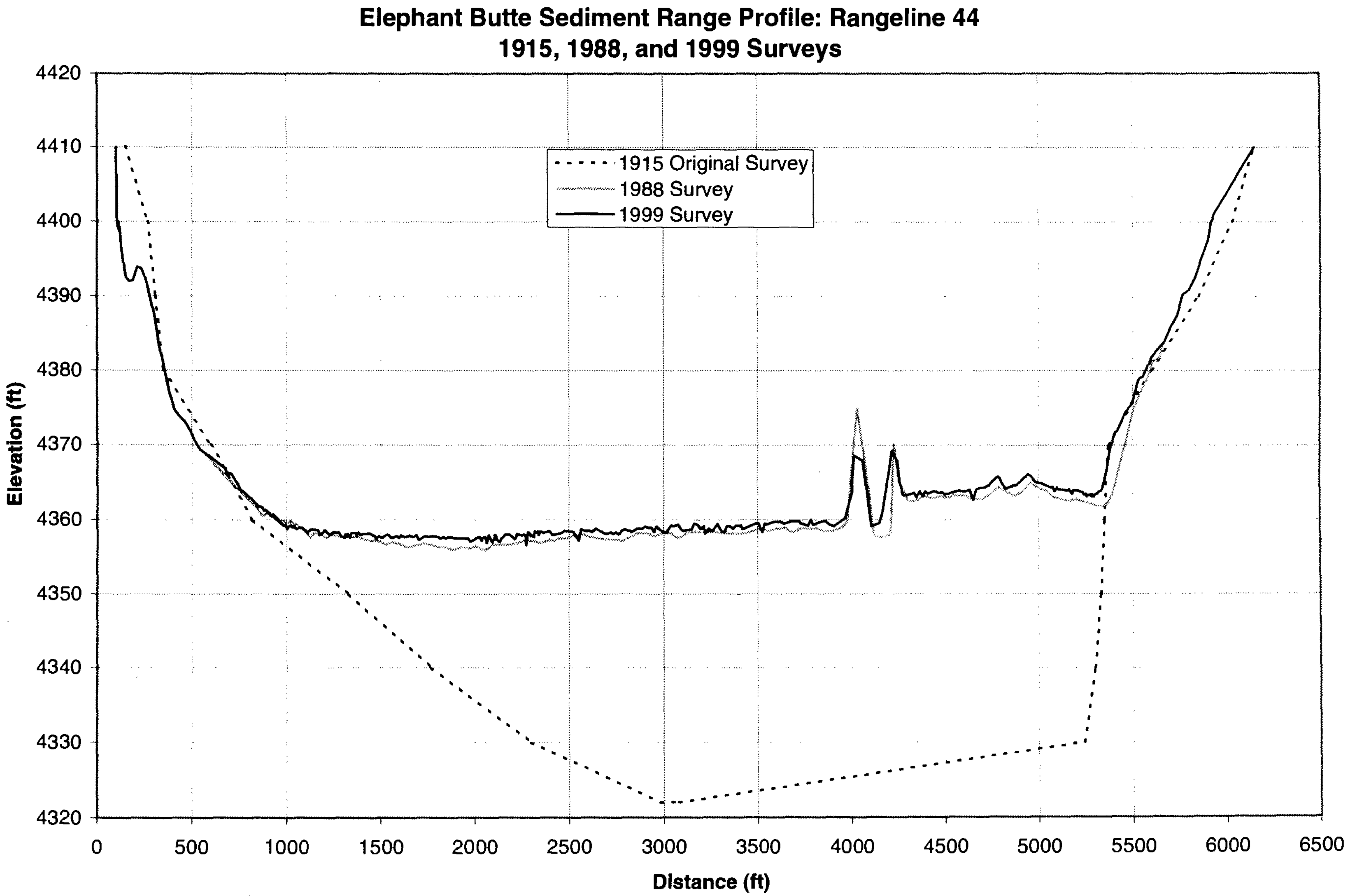


Figure 46. - Sedimentation range profiles for 1915, 1988, and 1999, range 44.

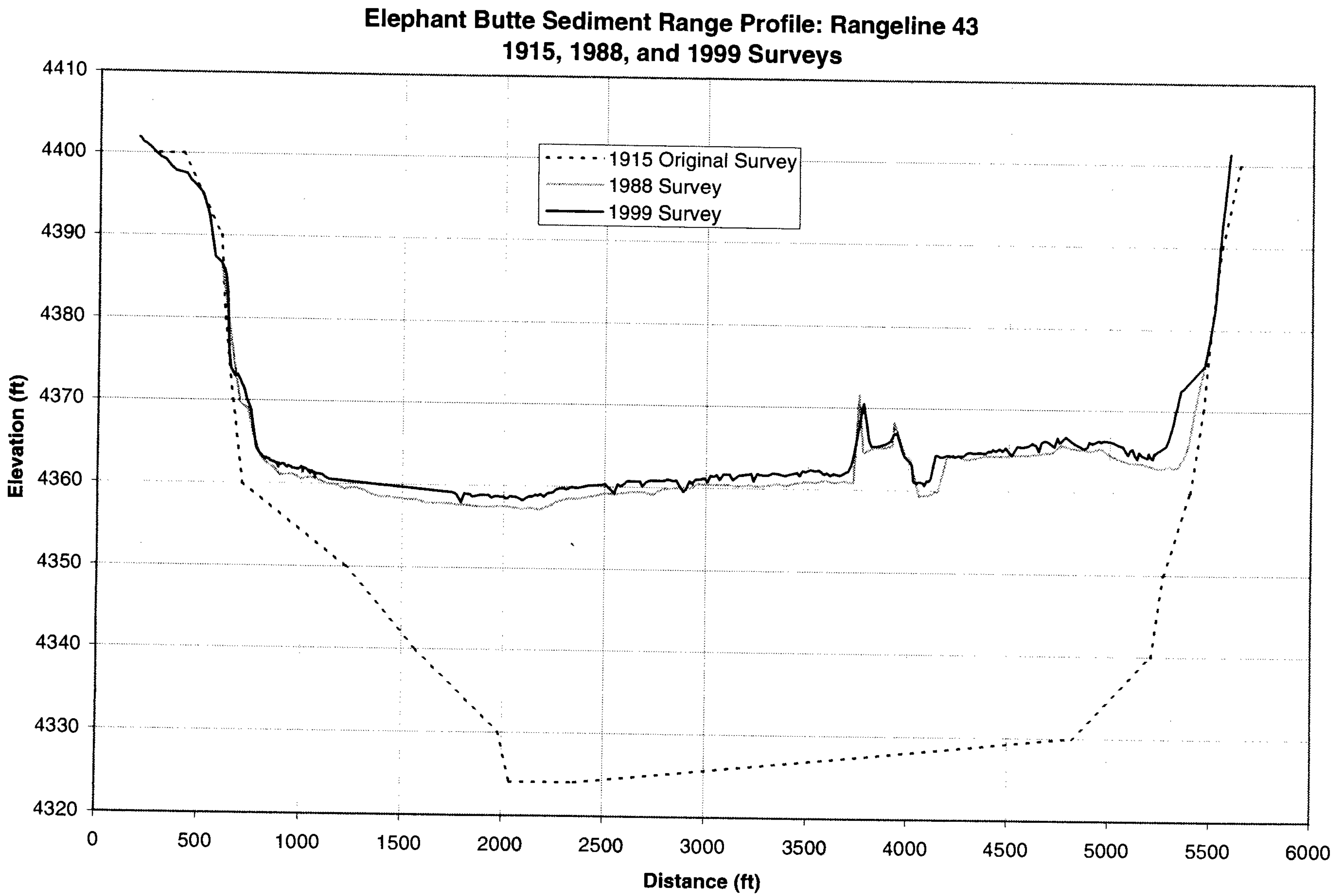


Figure 67. - Sedimentation range profiles for 1915, 1988, and 1999, range 43.

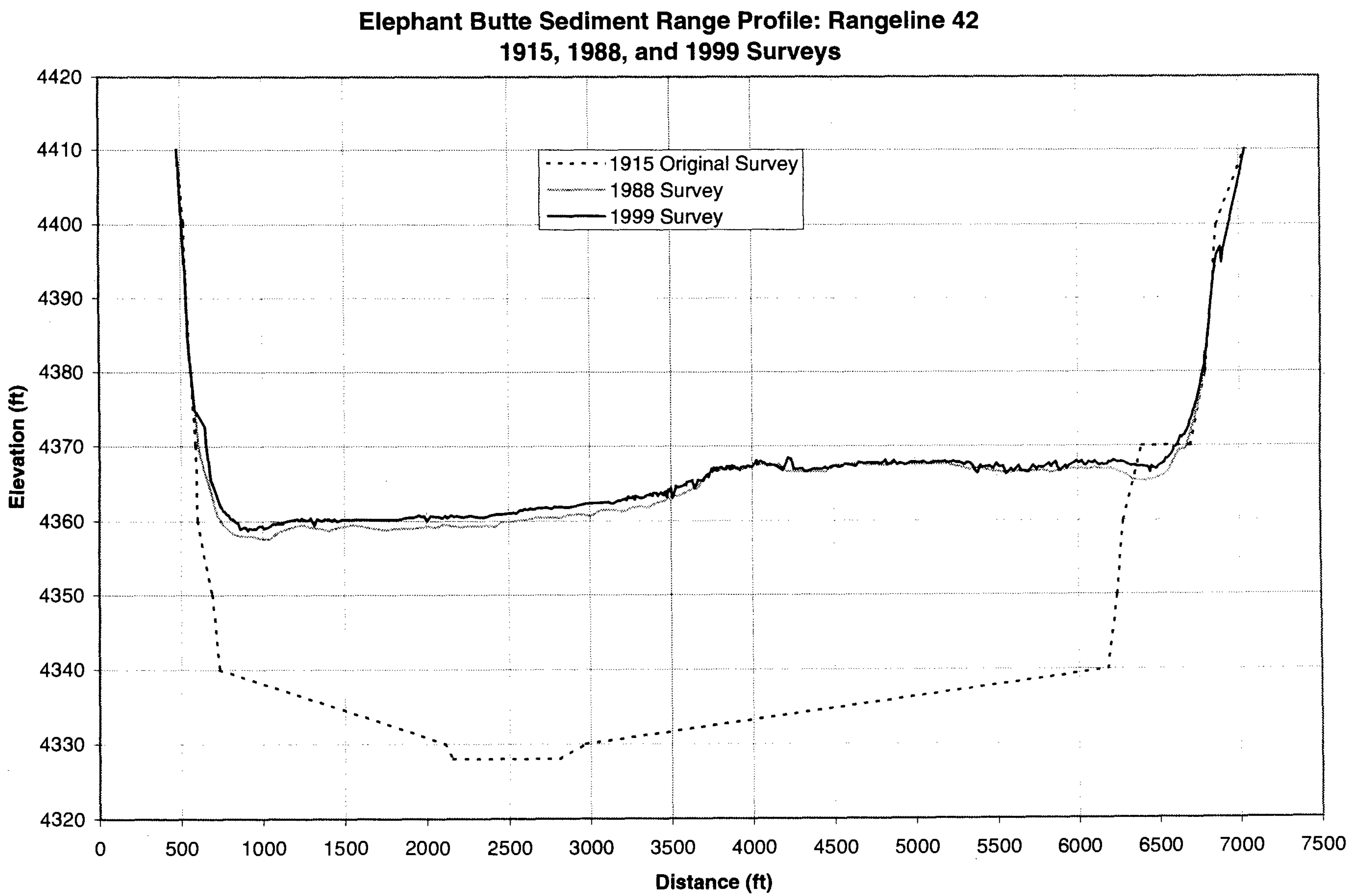


Figure 68. - Sedimentation range profiles for 1915, 1988, and 1999, range 42.

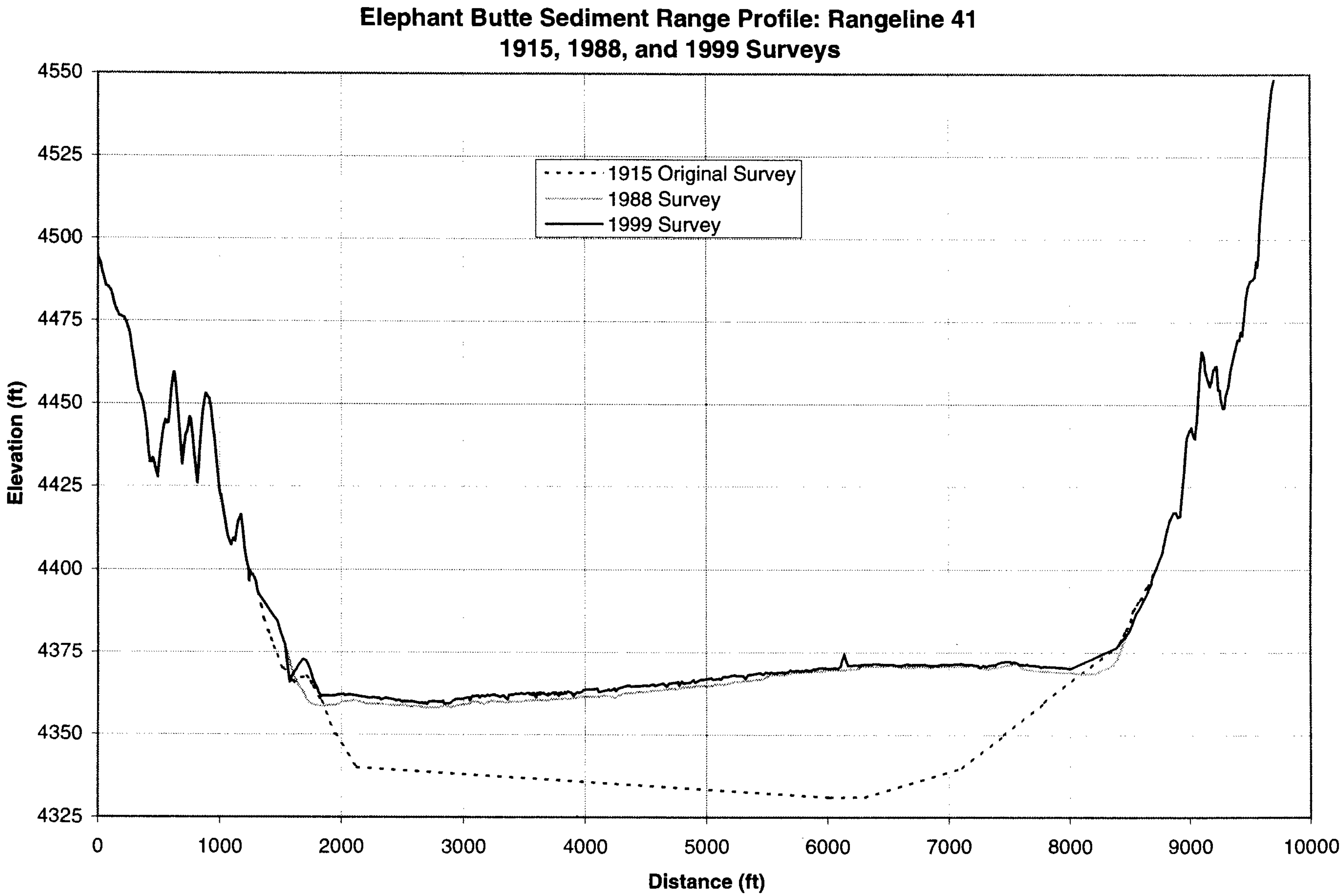


Figure 69. - Sedimentation range profiles for 1915, 1988, and 1999, range 41.

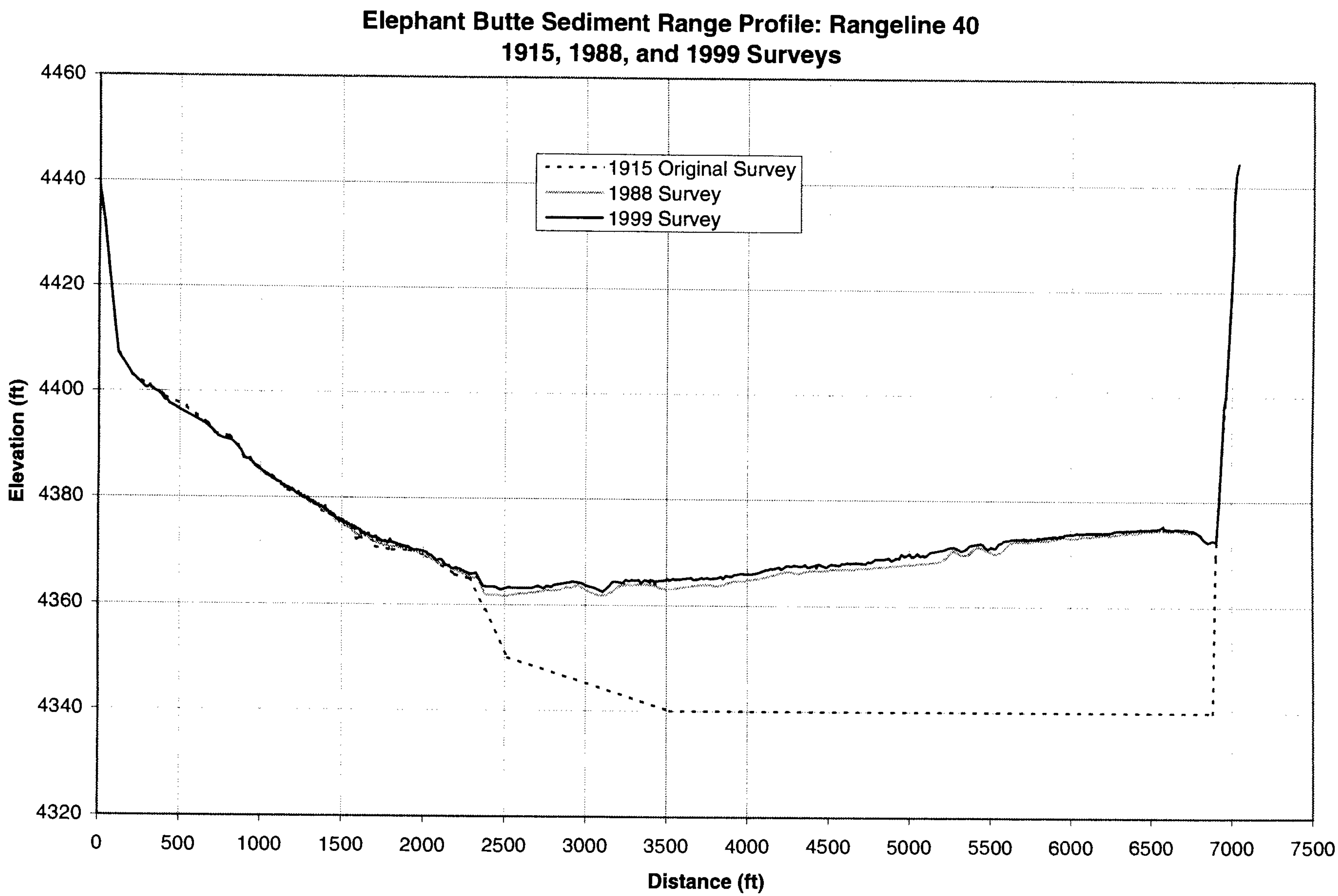


Figure 70. - Sedimentation range profiles for 1915, 1988, and 1999, range 40.

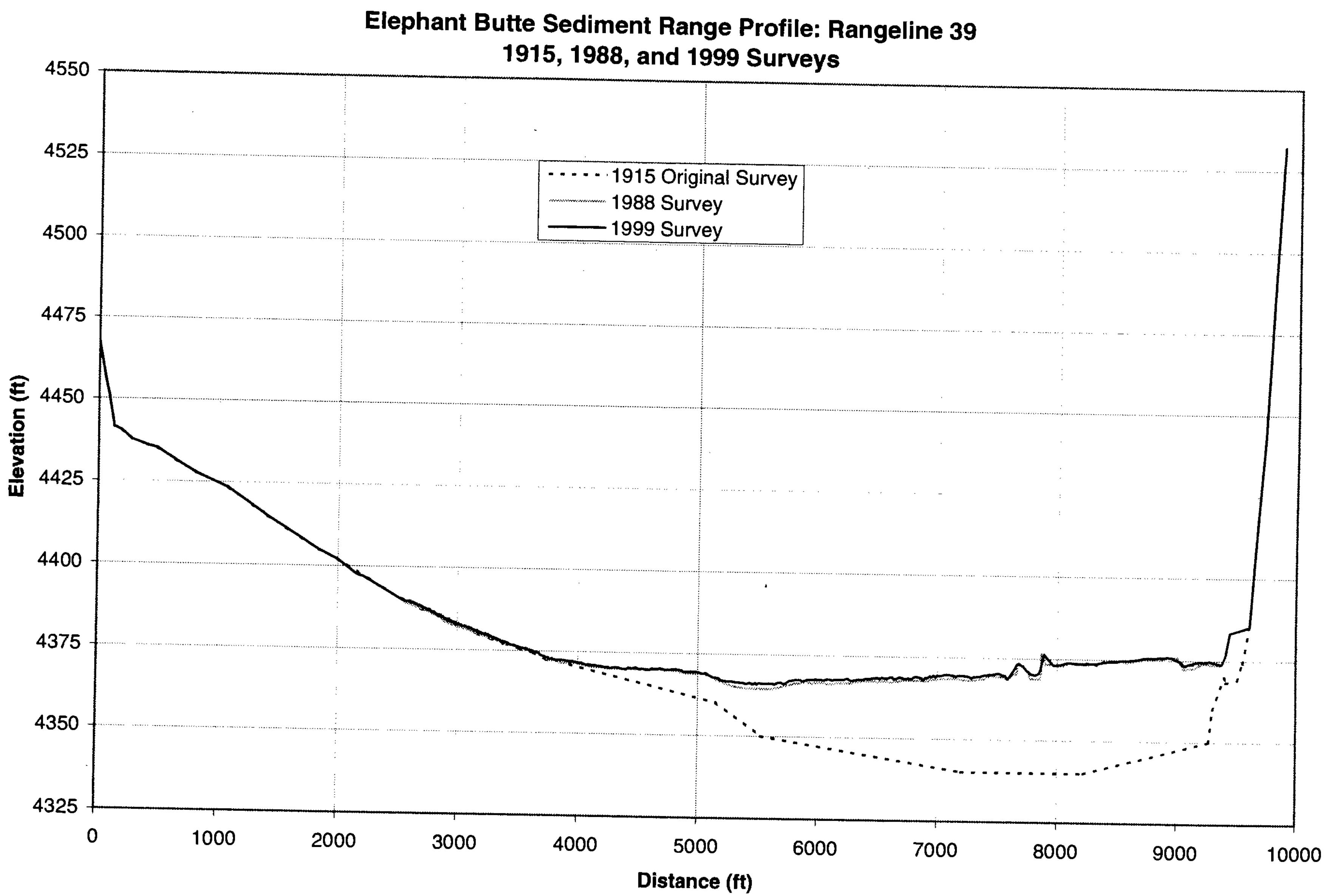


Figure 71. - Sedimentation range profiles for 1915, 1988, and 1999, range 39.

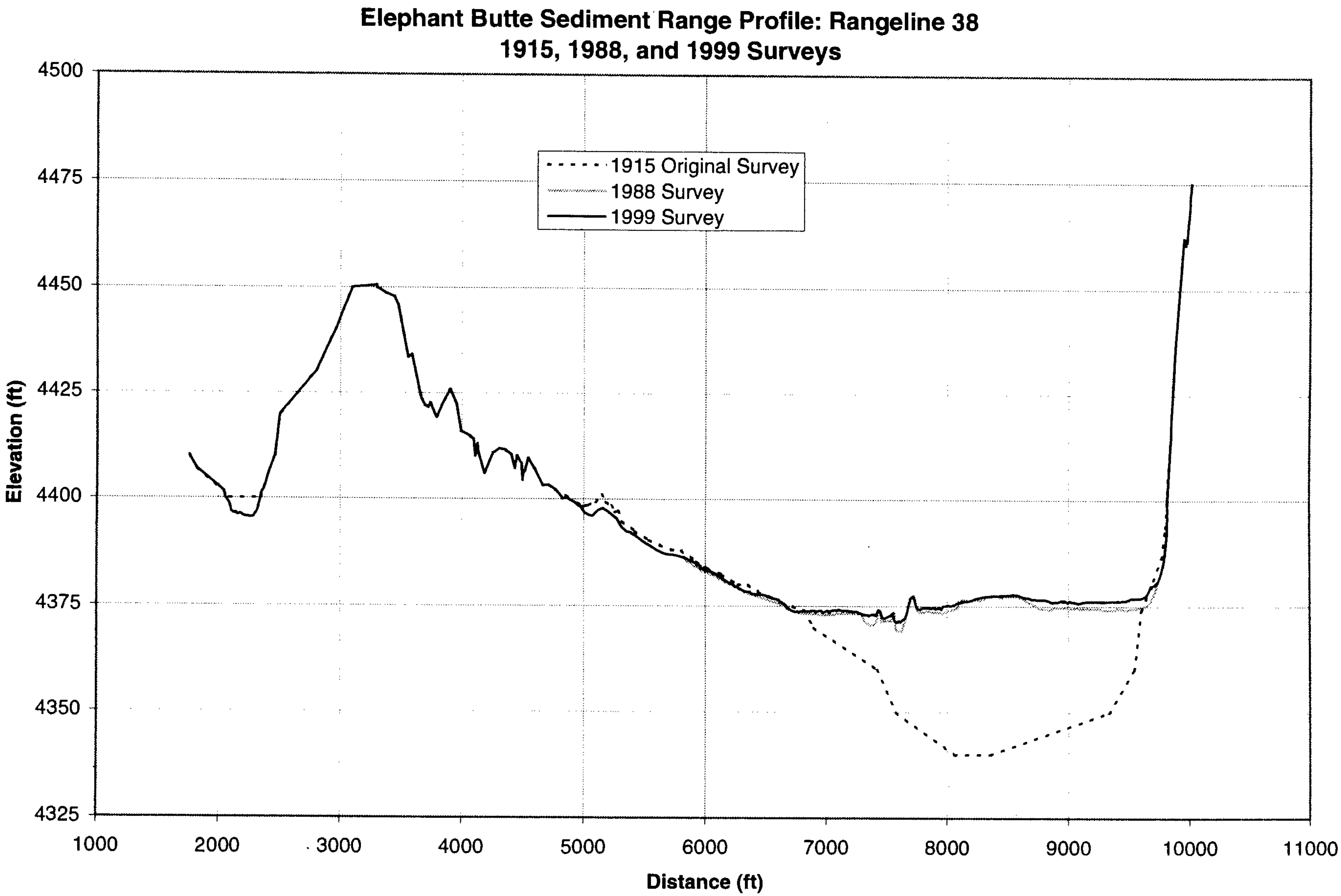


Figure 72. - Sedimentation range profiles for 1915, 1988, and 1999, range 38.

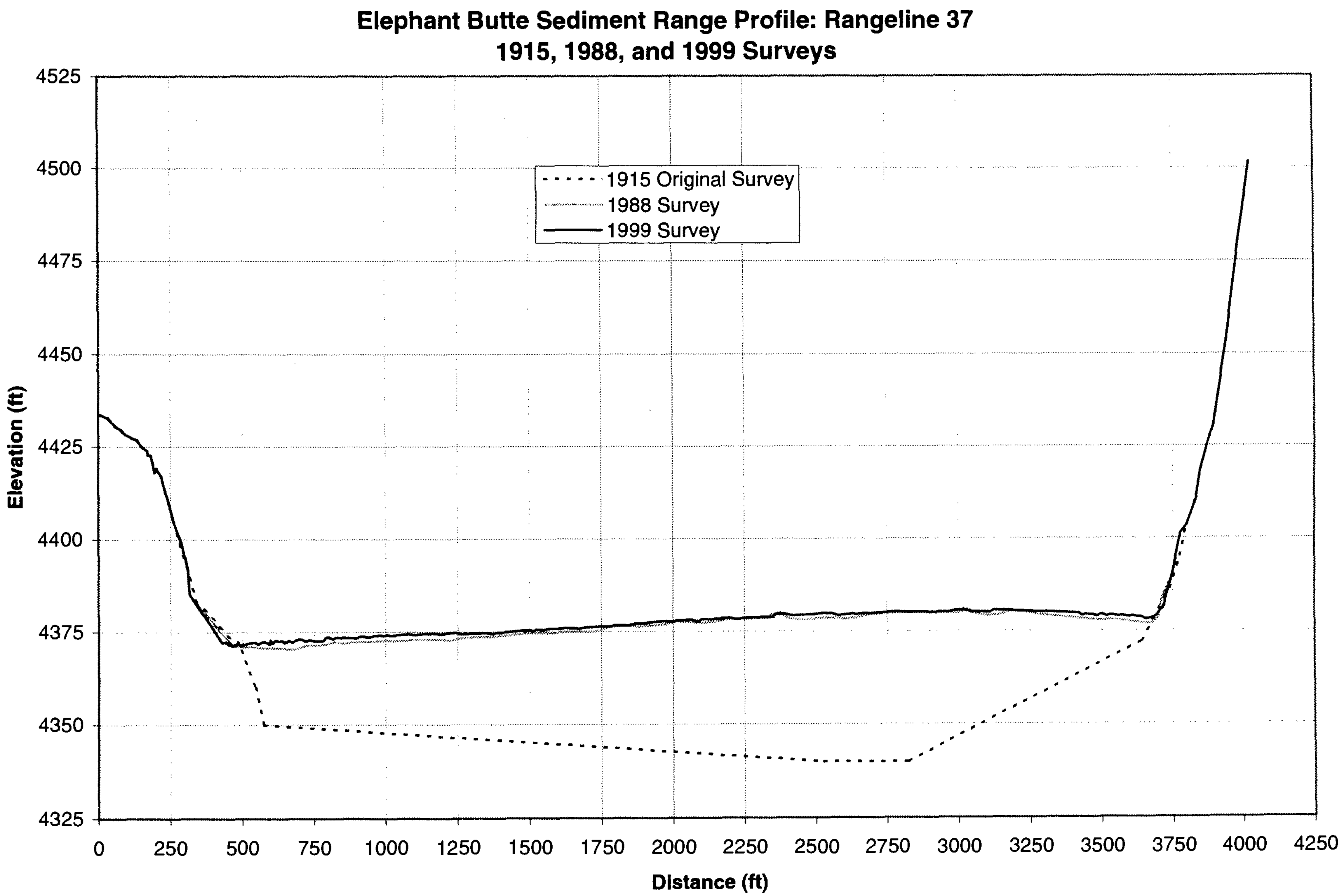


Figure 73. - Sedimentation range profiles for 1915, 1988, and 1999, range 37.

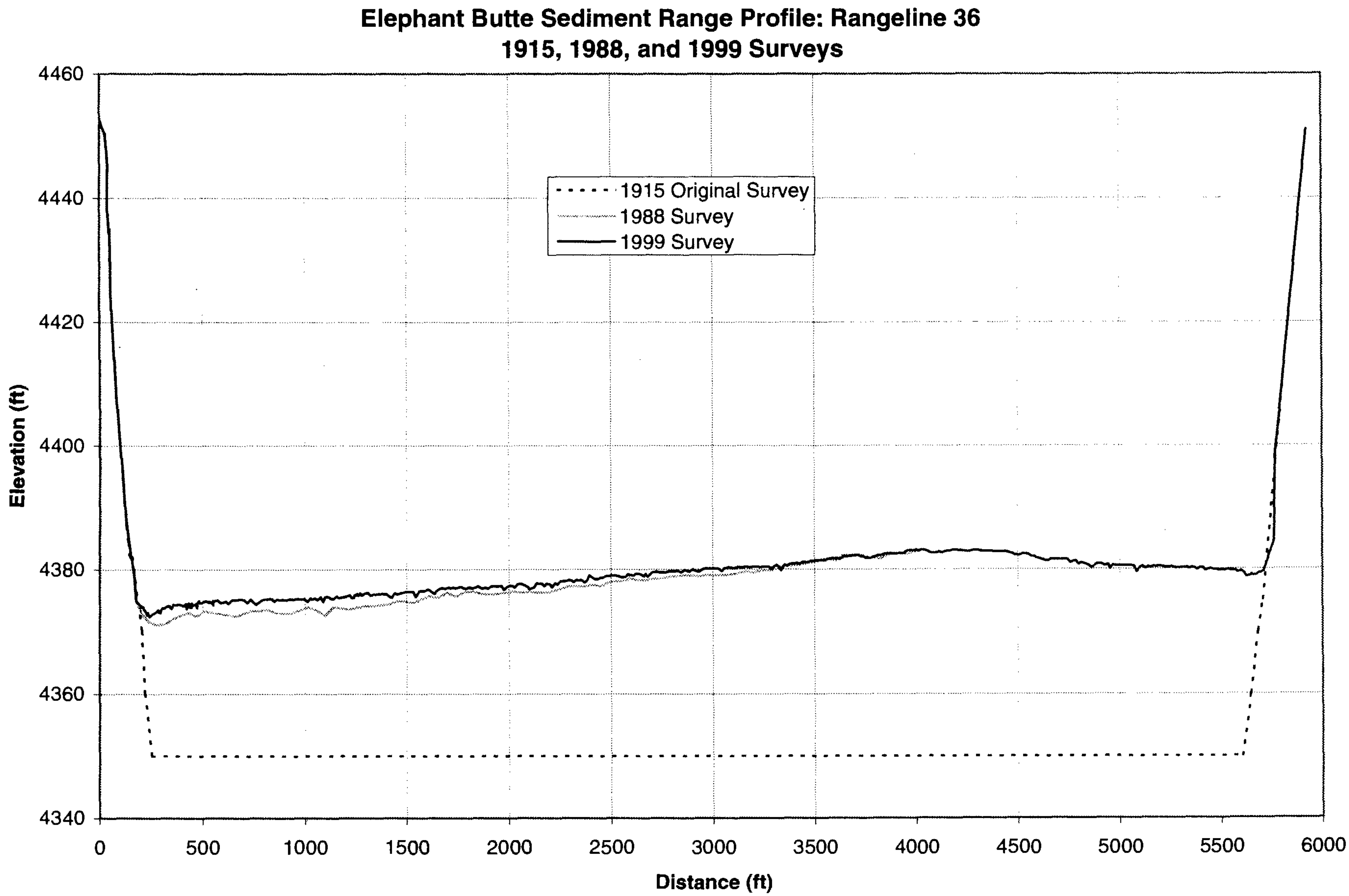


Figure 74. - Sedimentation range profiles for 1915, 1988, and 1999, range 36.

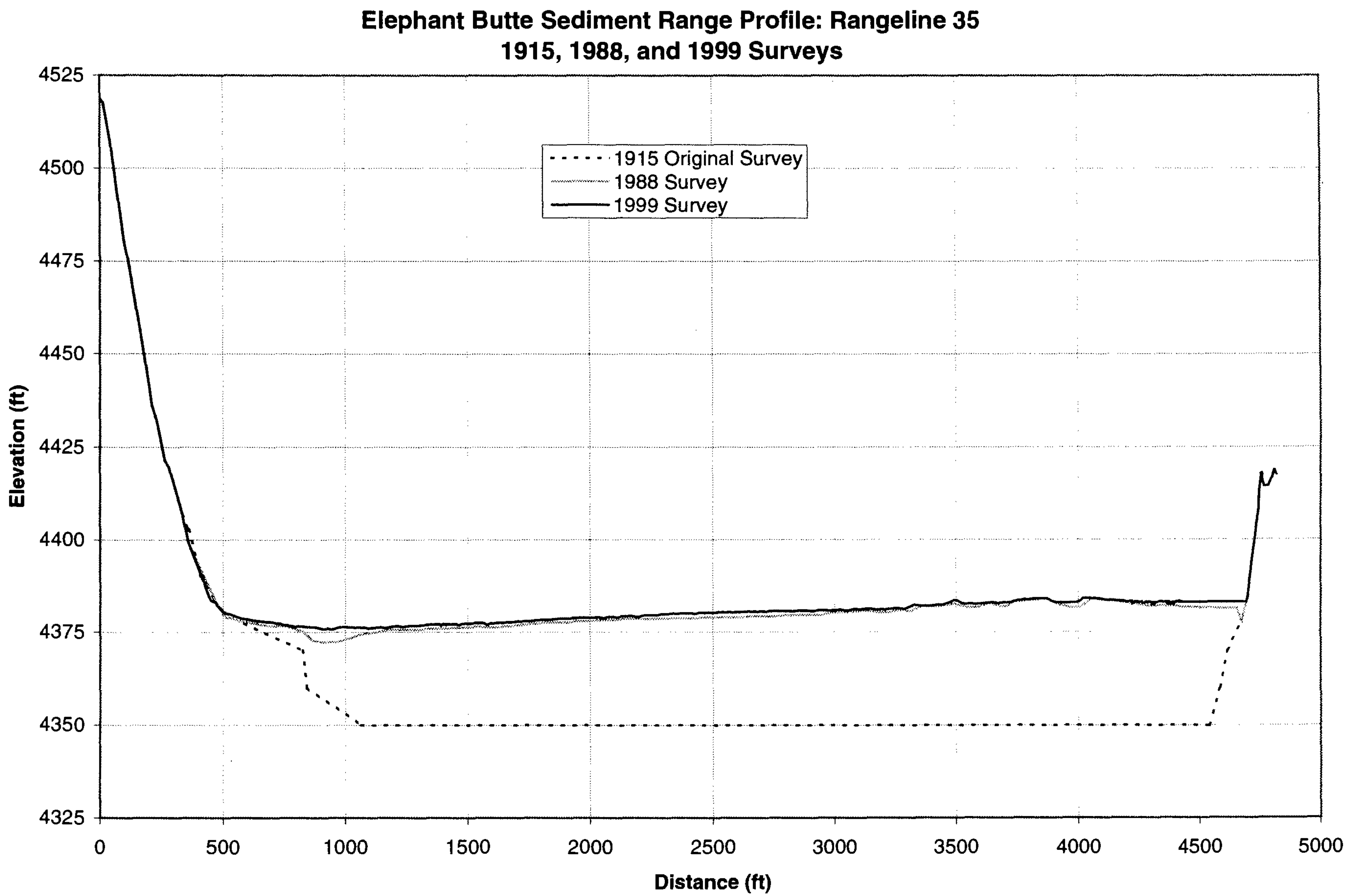


Figure 75. - Sedimentation range profiles for 1915, 1988, and 1999, range 35.

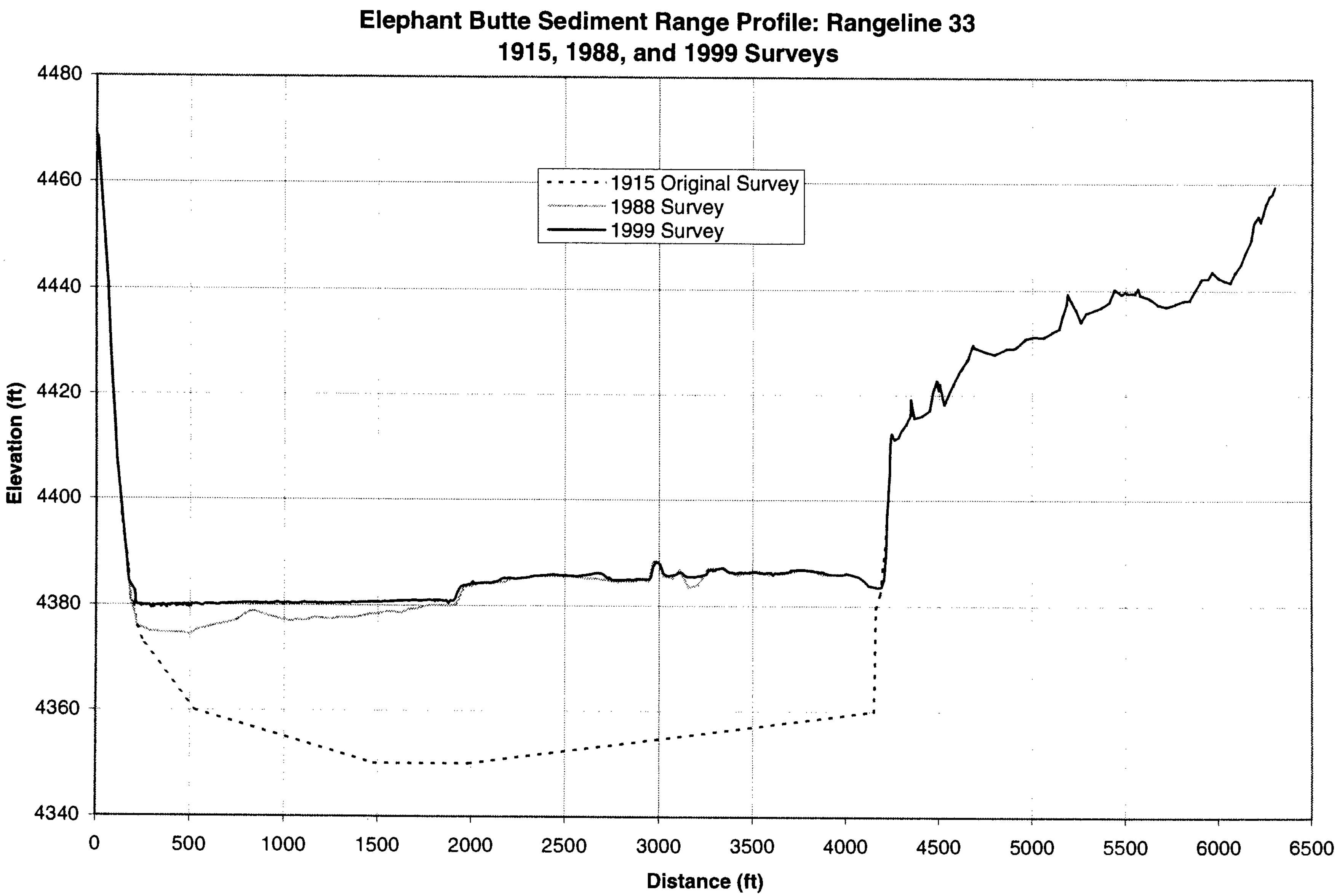


Figure 76. - Sedimentation range profiles for 1915, 1988, and 1999, range 33.

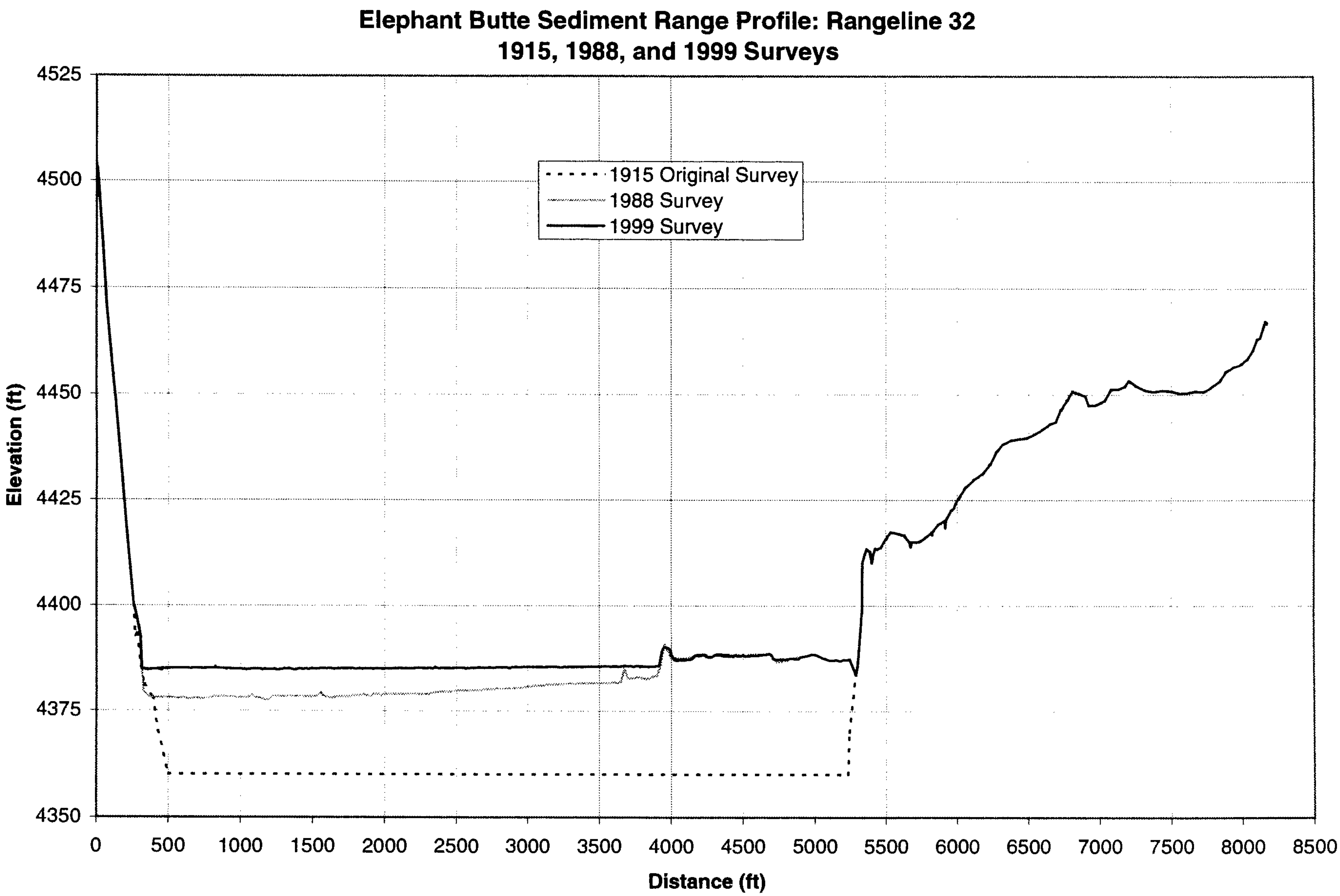


Figure 77. - Sedimentation range profiles for 1915, 1988, and 1999, range 32.

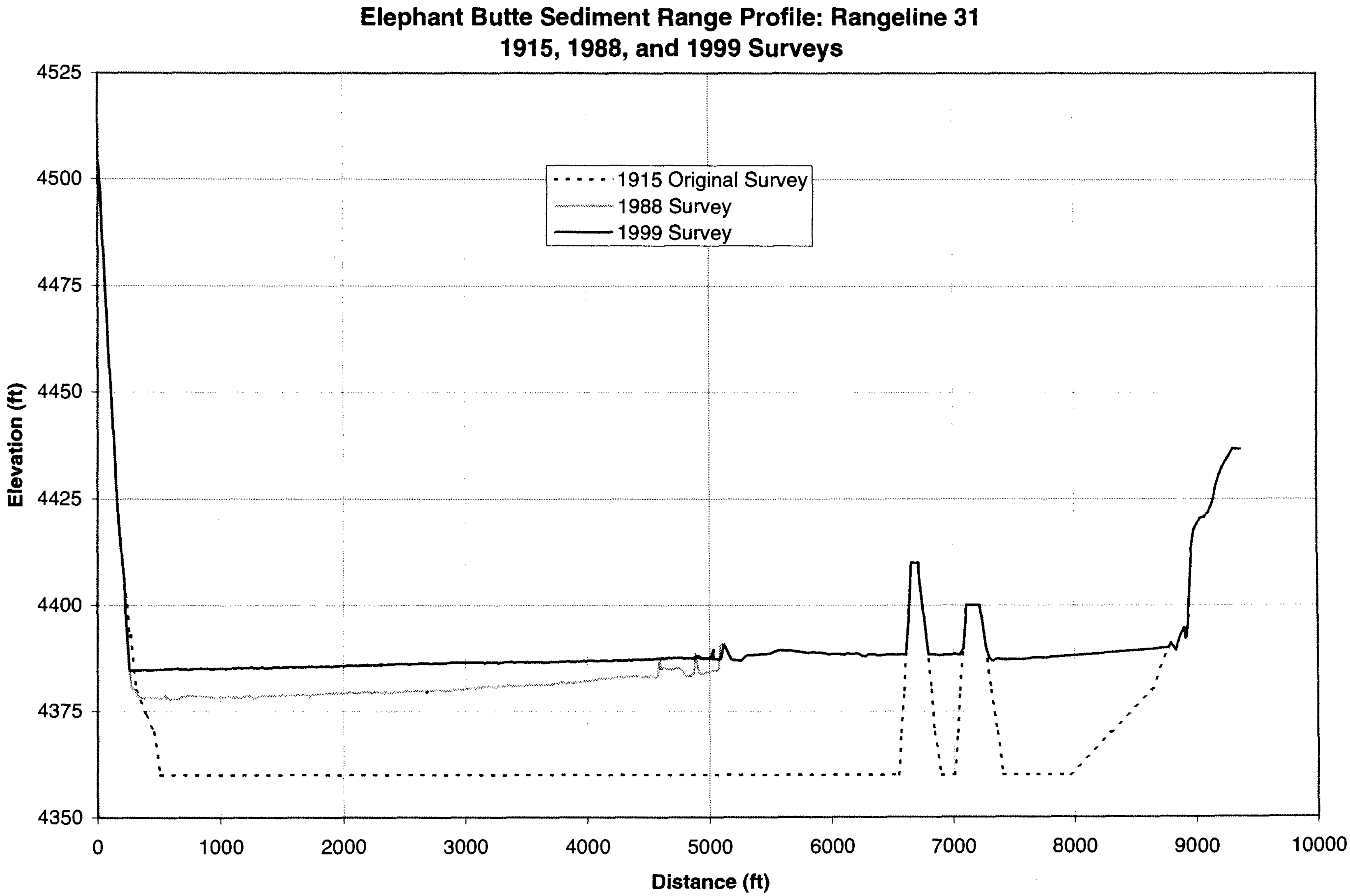


Figure 78. - Sedimentation range profiles for 1915, 1988, and 1999, range 31.

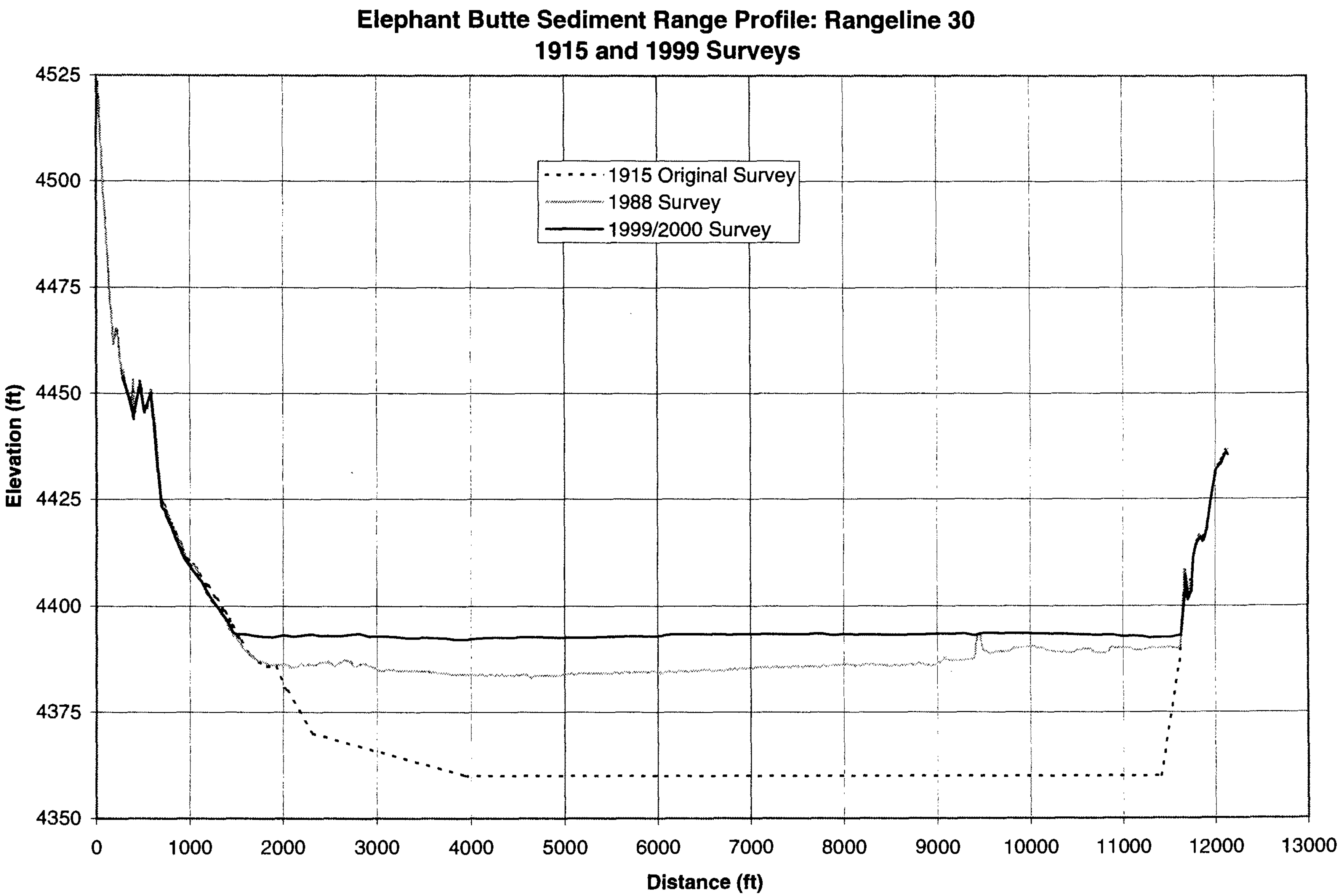


Figure 79. - Sedimentation range profiles for 1915, 1988, and 1999, range 30.

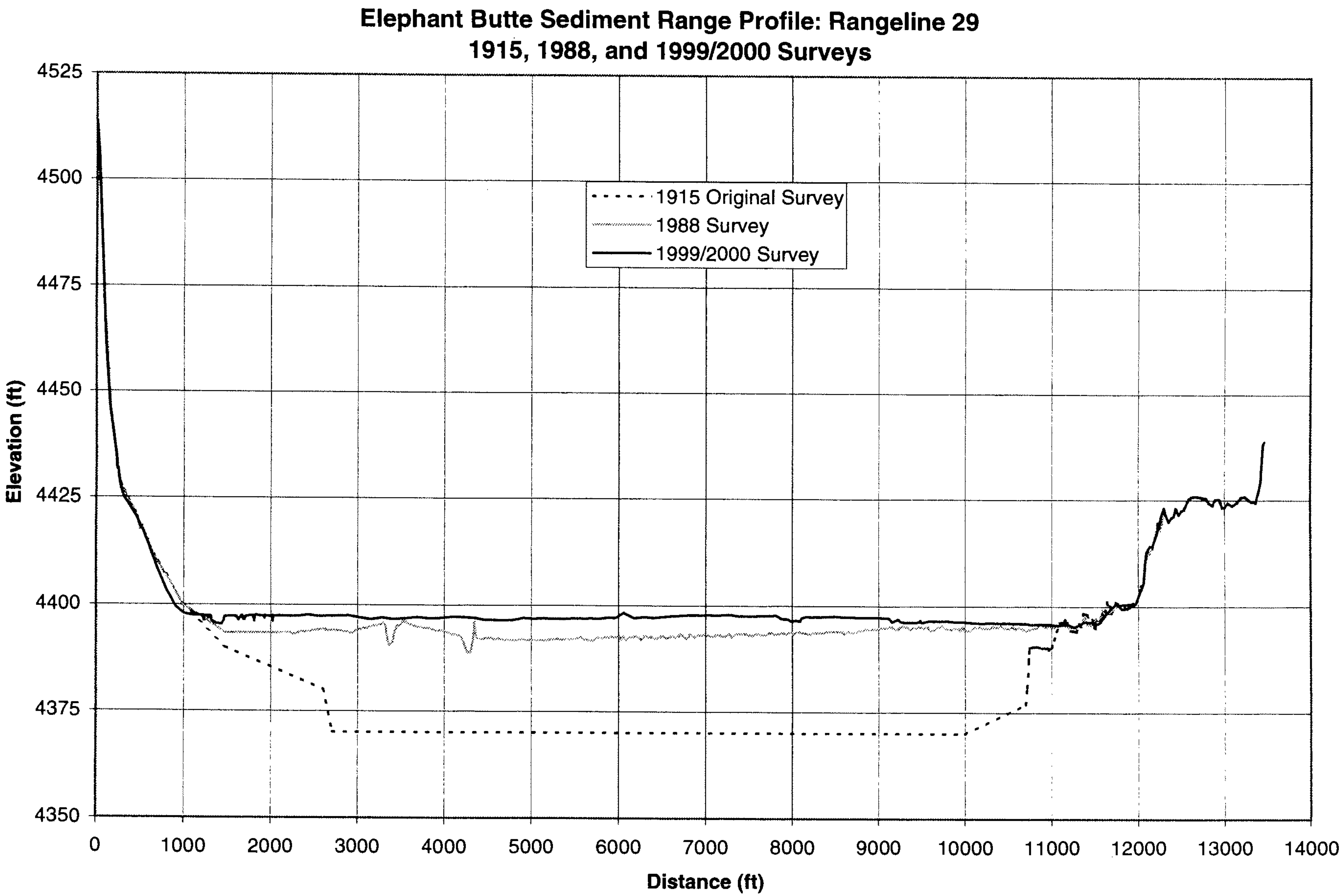


Figure 80. - Sedimentation range profiles for 1915, 1988, and 1999, range 29.

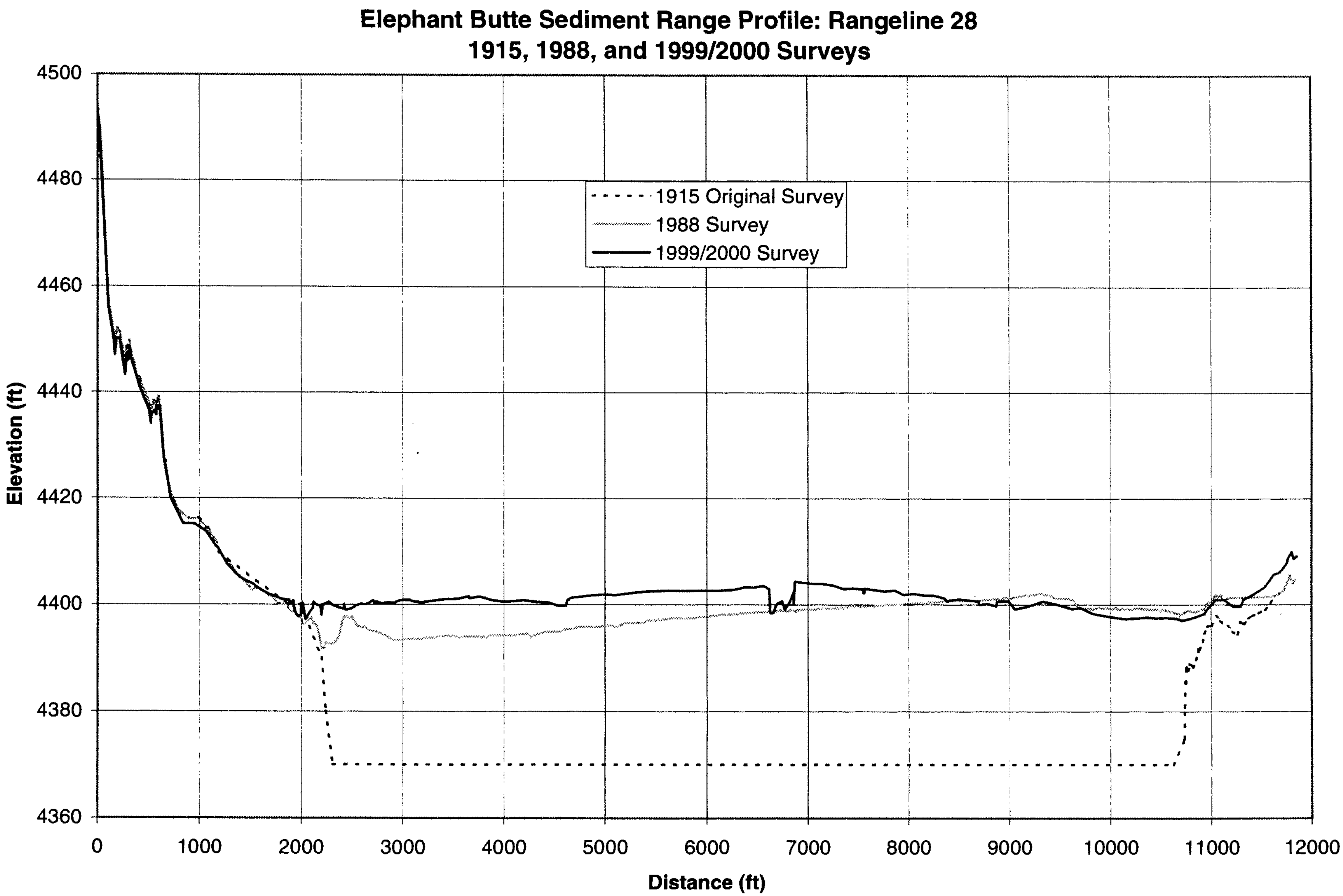


Figure 81. - Sedimentation range profiles for 1915, 1988, and 1999, range 28.

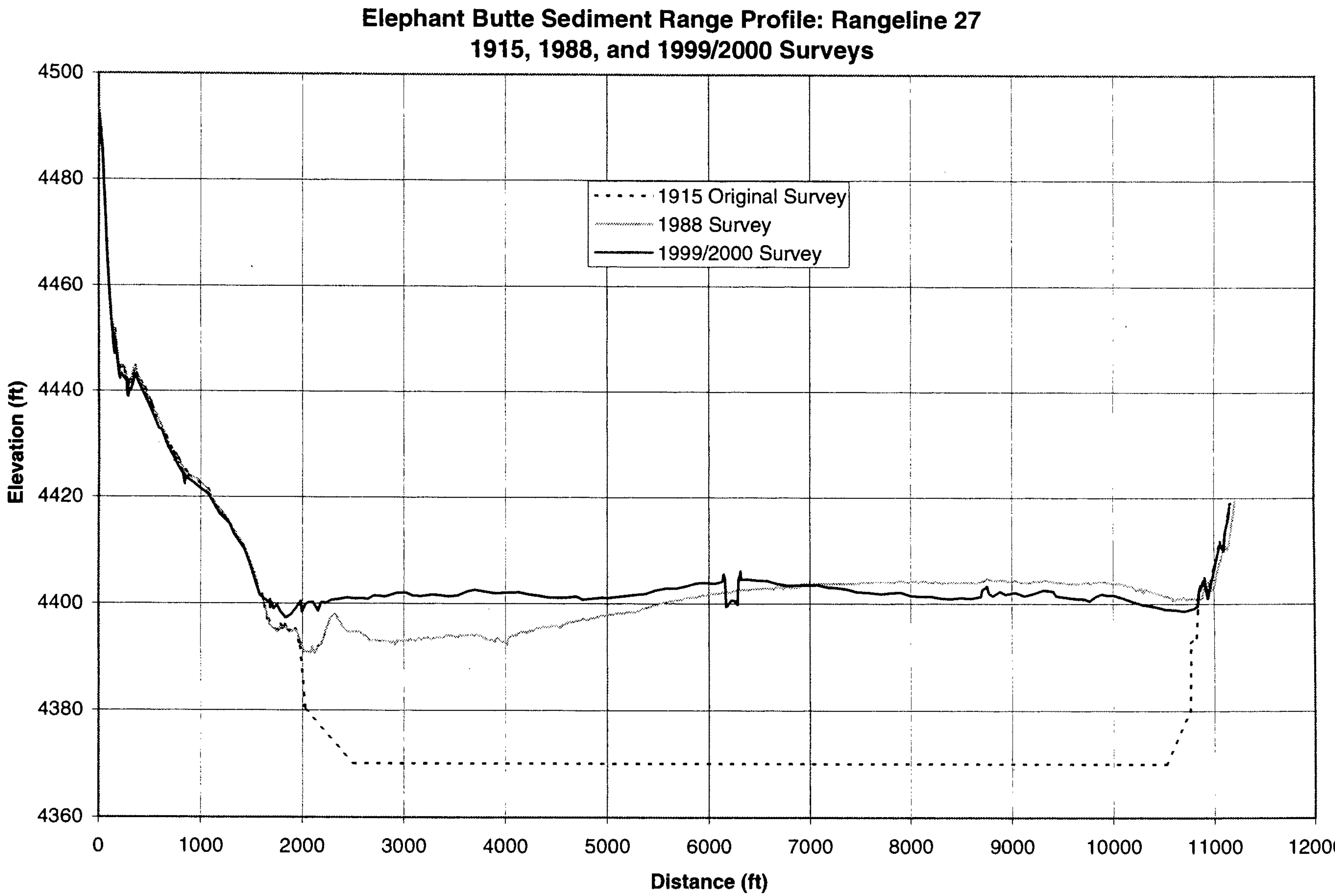


Figure 82. - Sedimentation range profiles for 1915, 1988, and 1999, range 27.

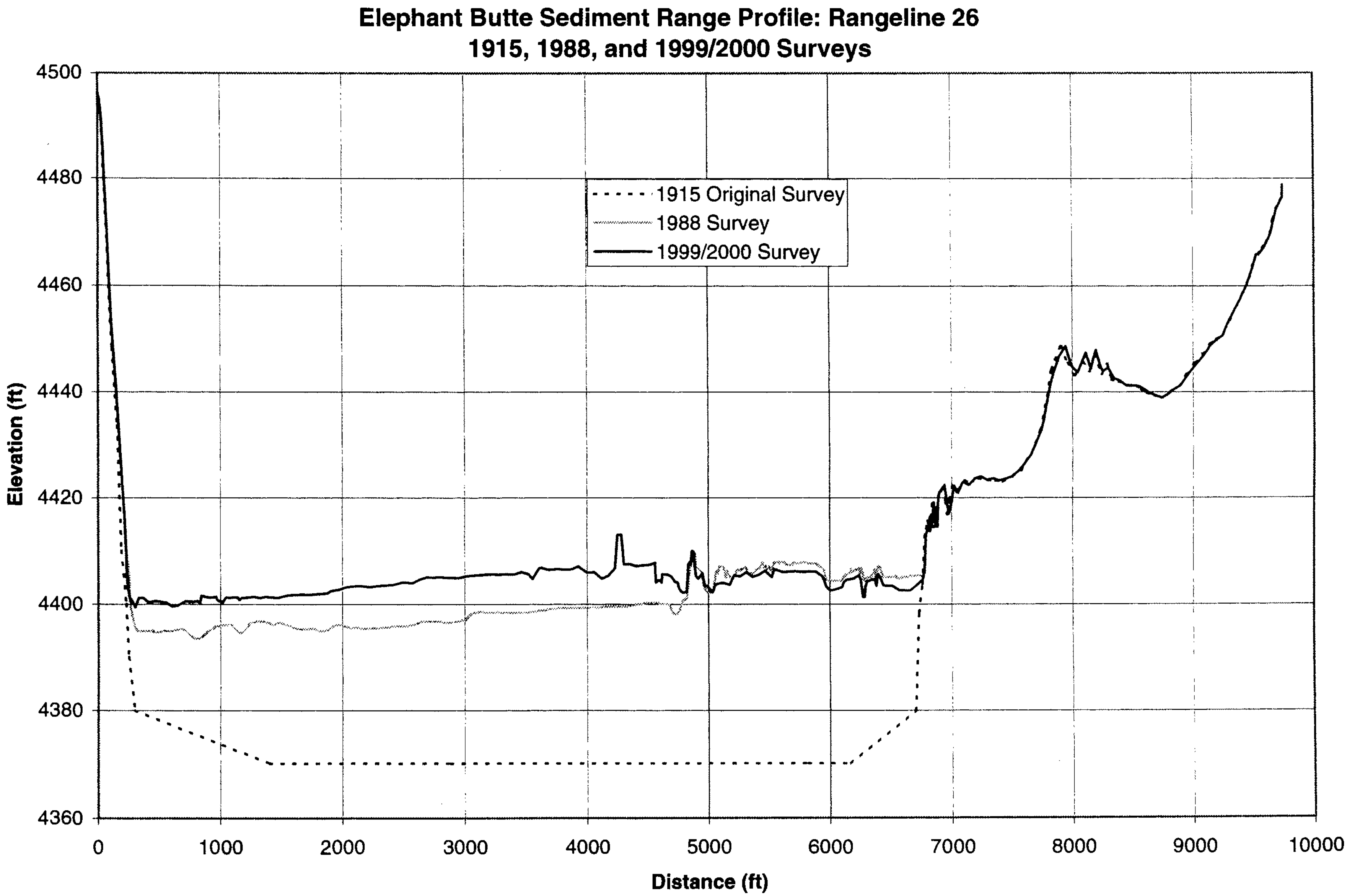


Figure 83. - Sedimentation range profiles for 1915, 1988, and 1999, range 26.

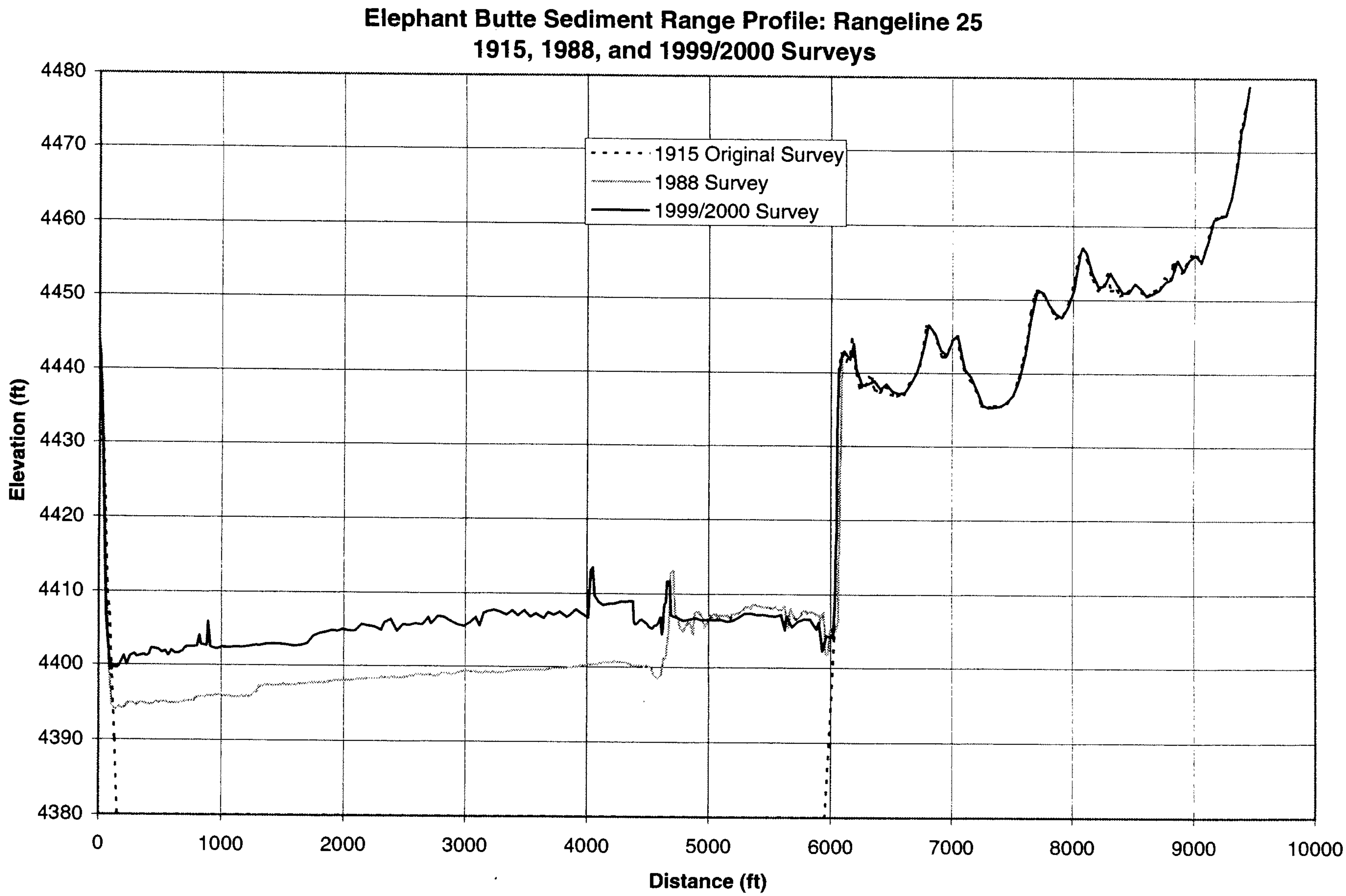


Figure 84. - Sedimentation range profiles for 1915, 1988, and 1999, range 25.

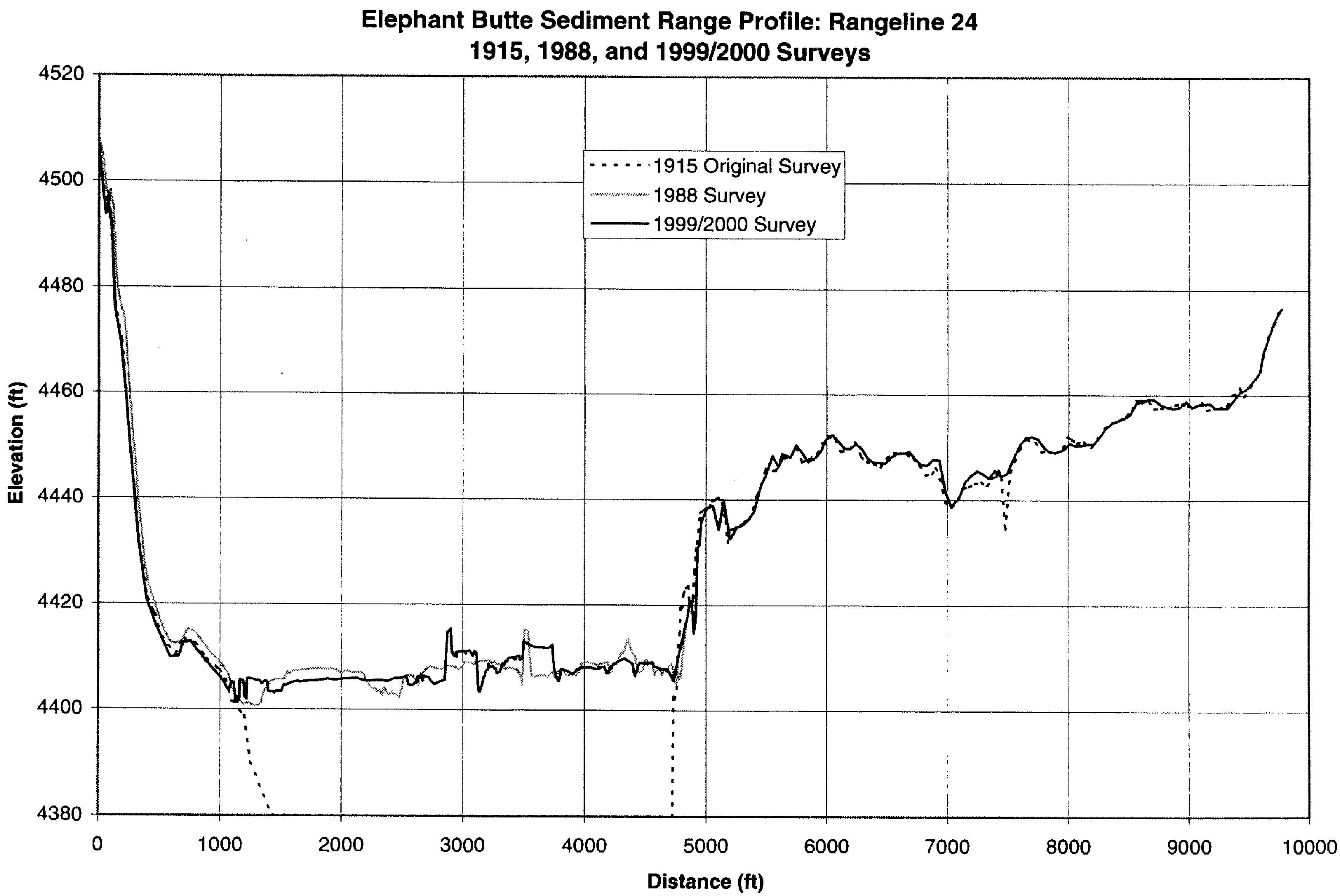


Figure 85. - Sedimentation range profiles for 1915, 1988, and 1999, range 24.

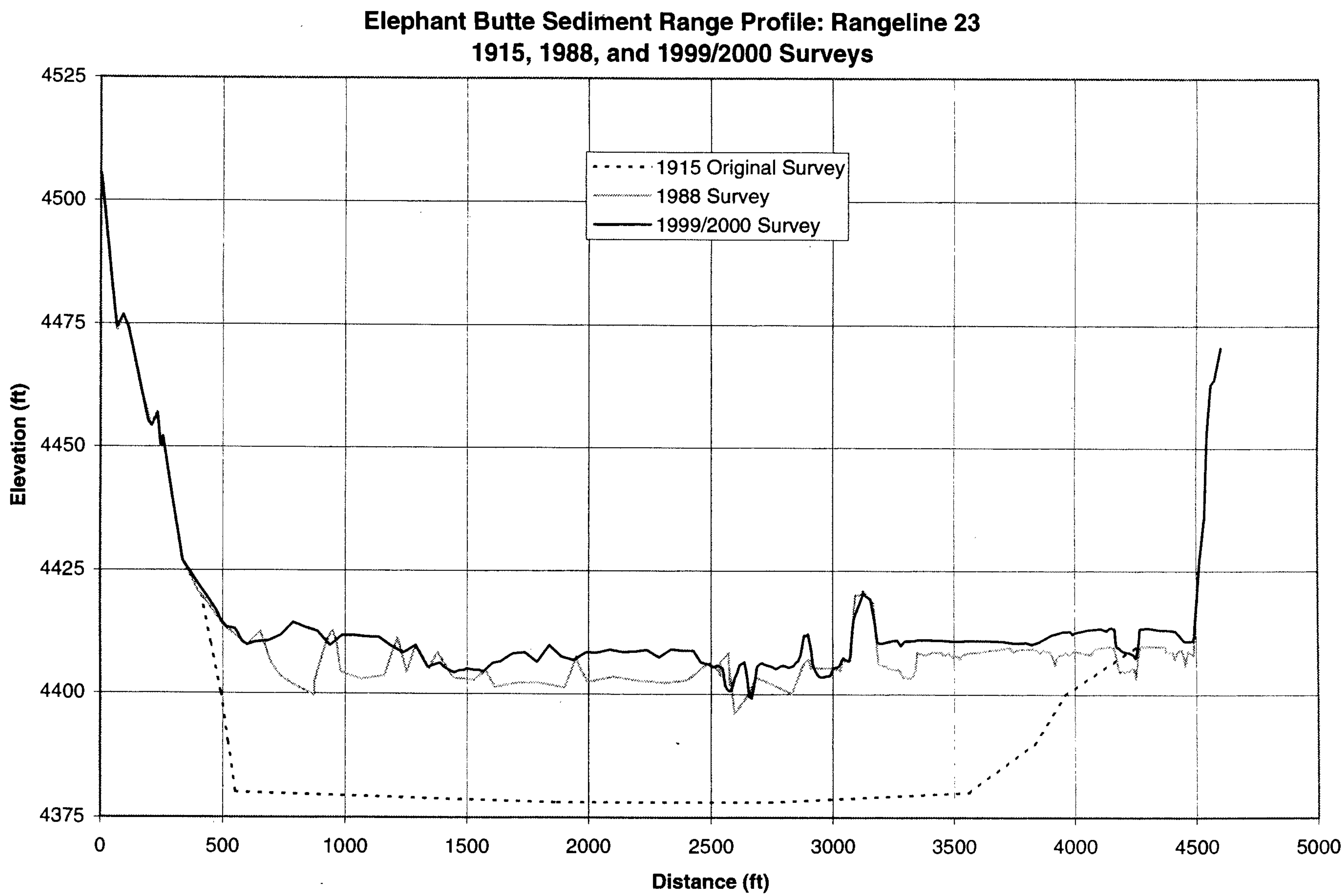


Figure 86. - Sedimentation range profiles for 1915, 1988, and 1999, range 23.

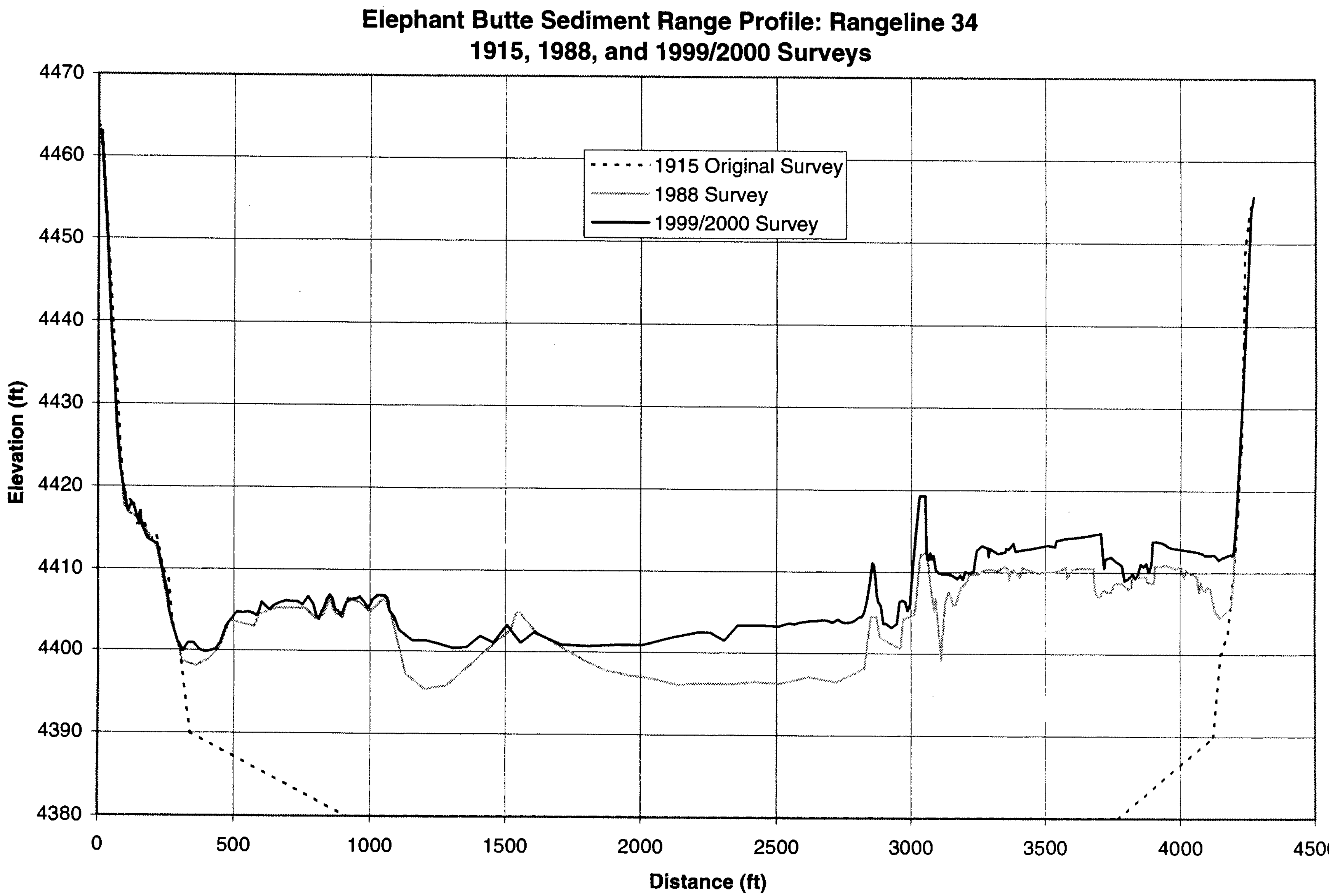


Figure 87. - Sedimentation range profiles for 1915, 1988, and 1999, range 34.

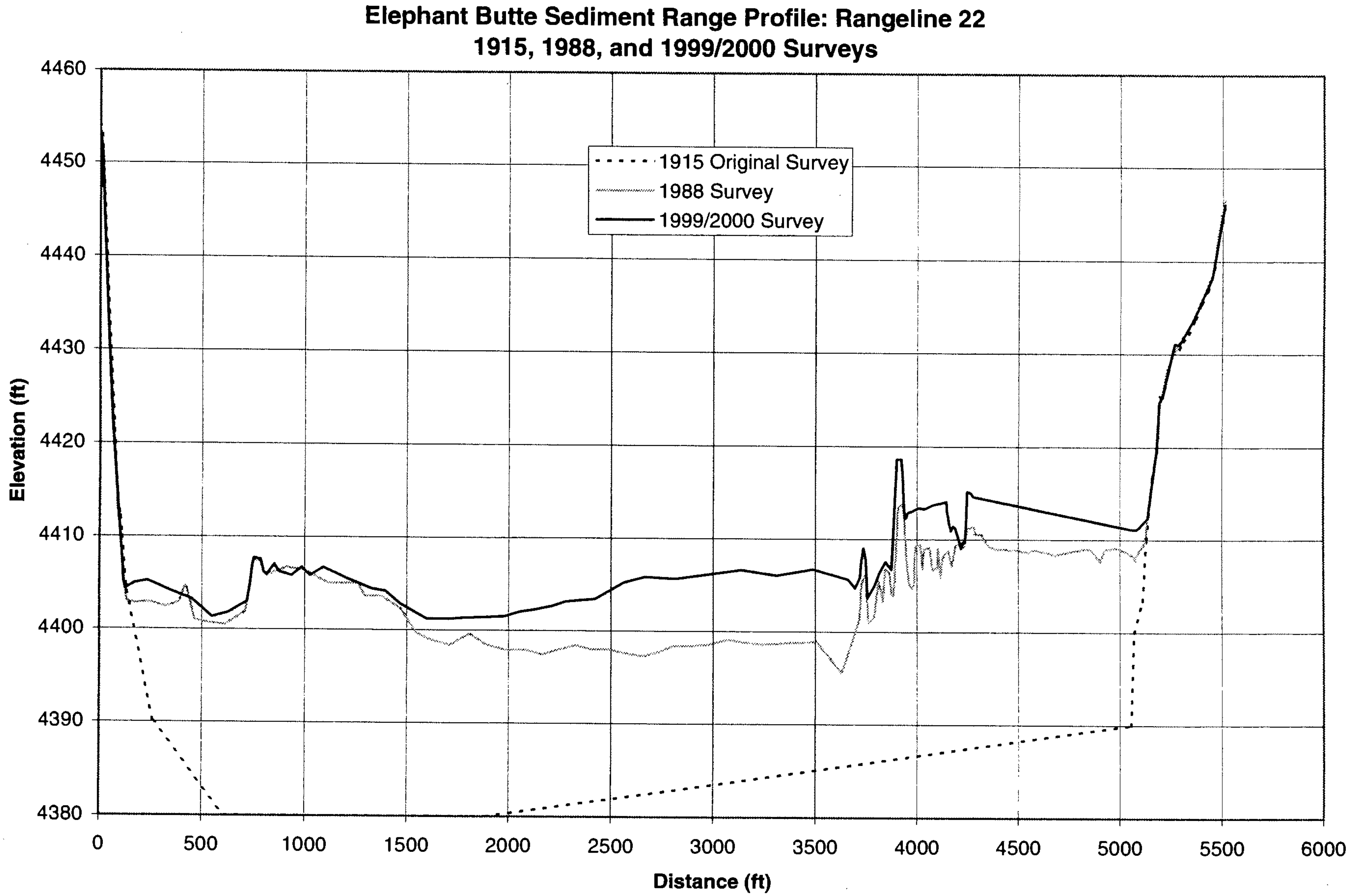


Figure 88. - Sedimentation range profiles for 1915, 1988, and 1999, range 22.

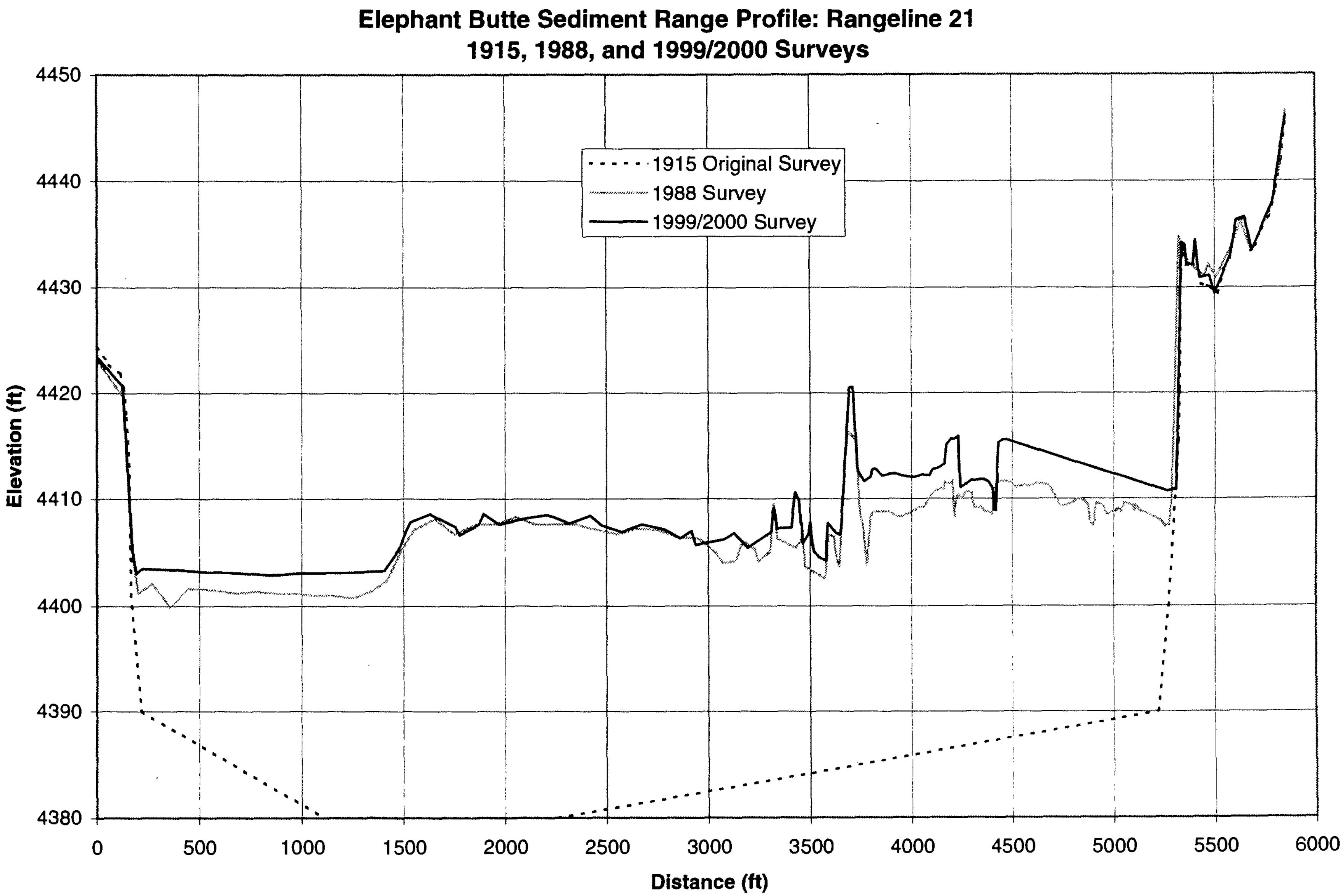


Figure 89. - Sedimentation range profiles for 1915, 1988, and 1999, range 21.

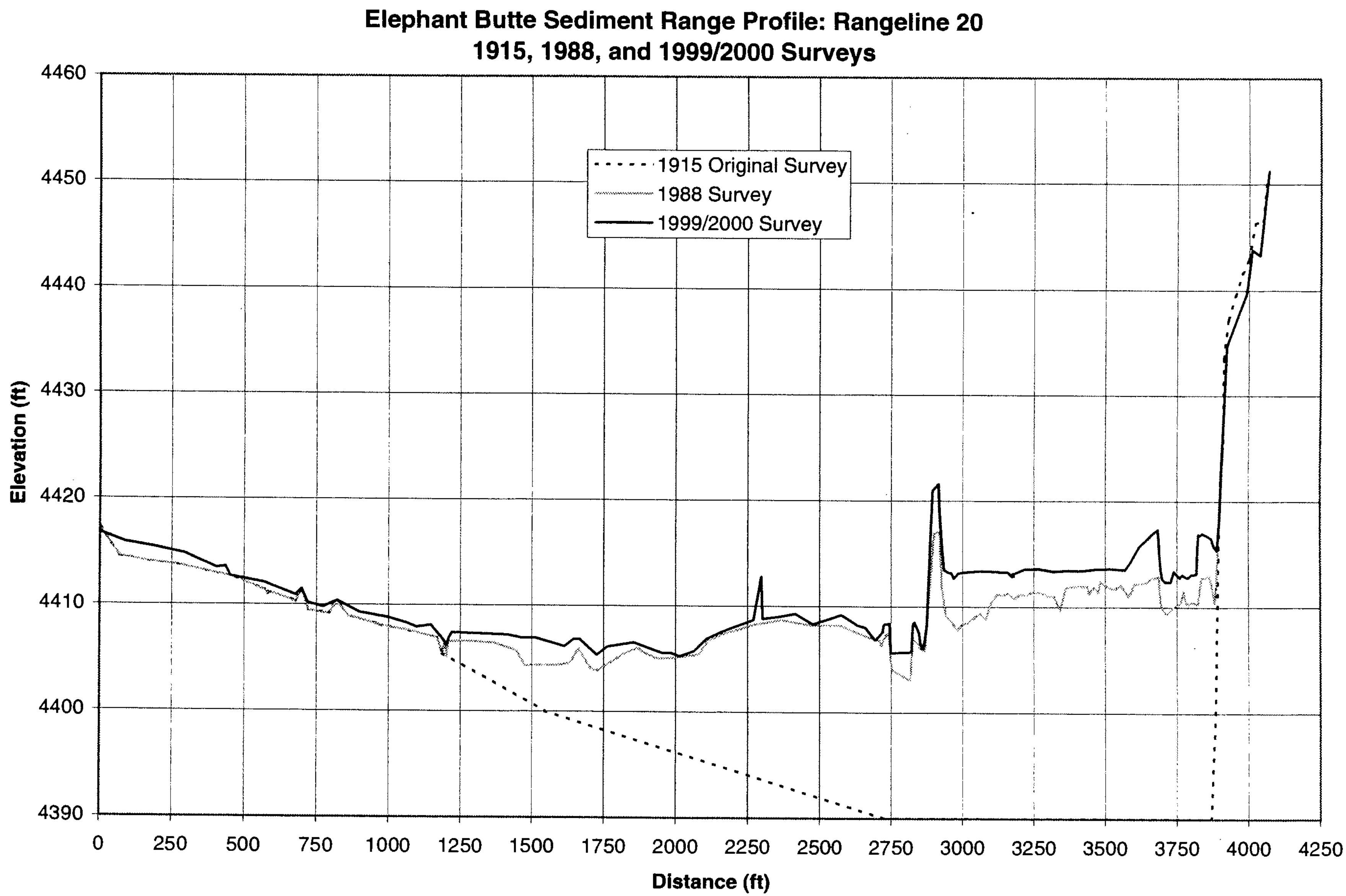


Figure 90. - Sedimentation range profiles for 1915, 1988, and 1999, range 20.

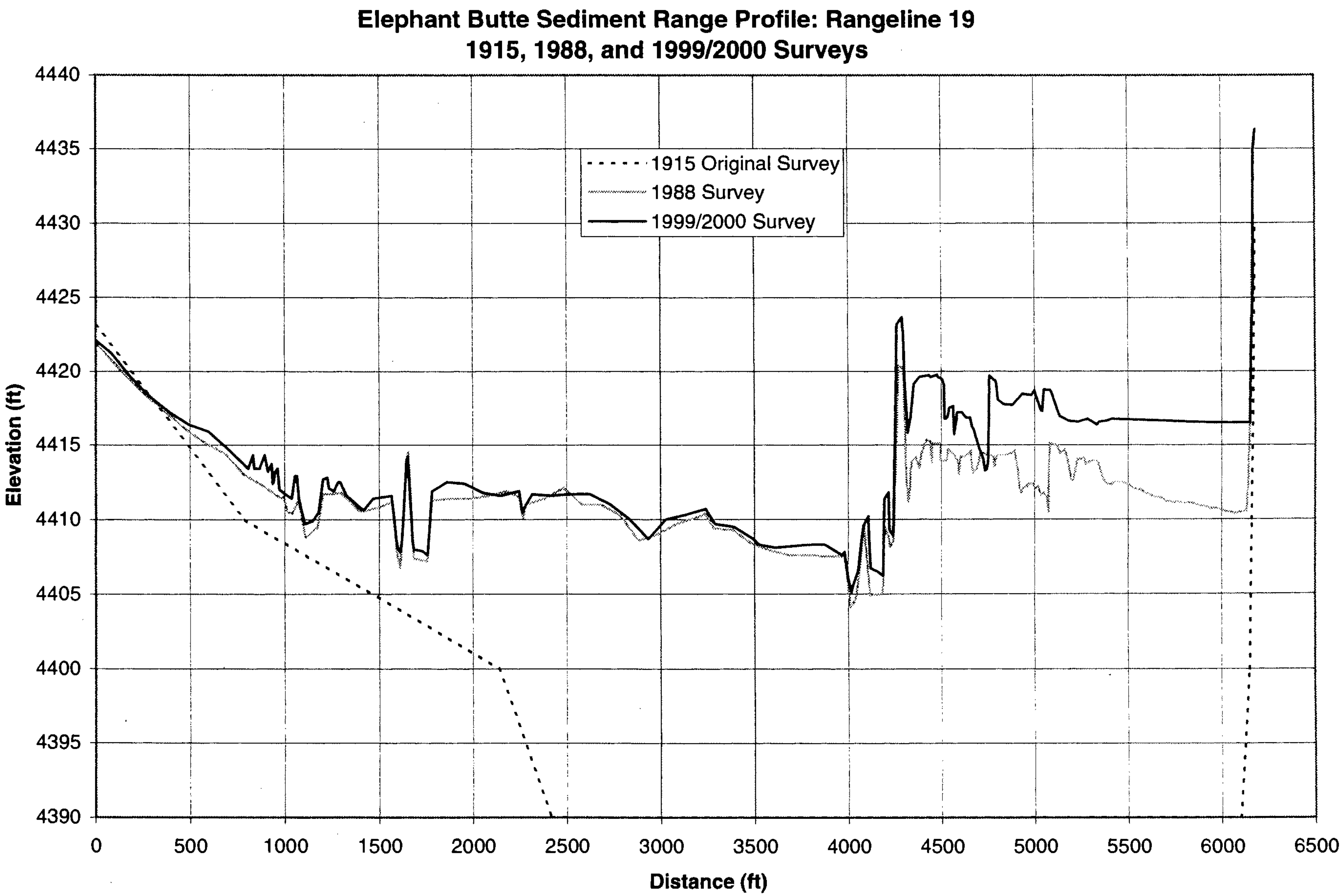


Figure 91. - Sedimentation range profiles for 1915, 1988, and 1999, range 19.

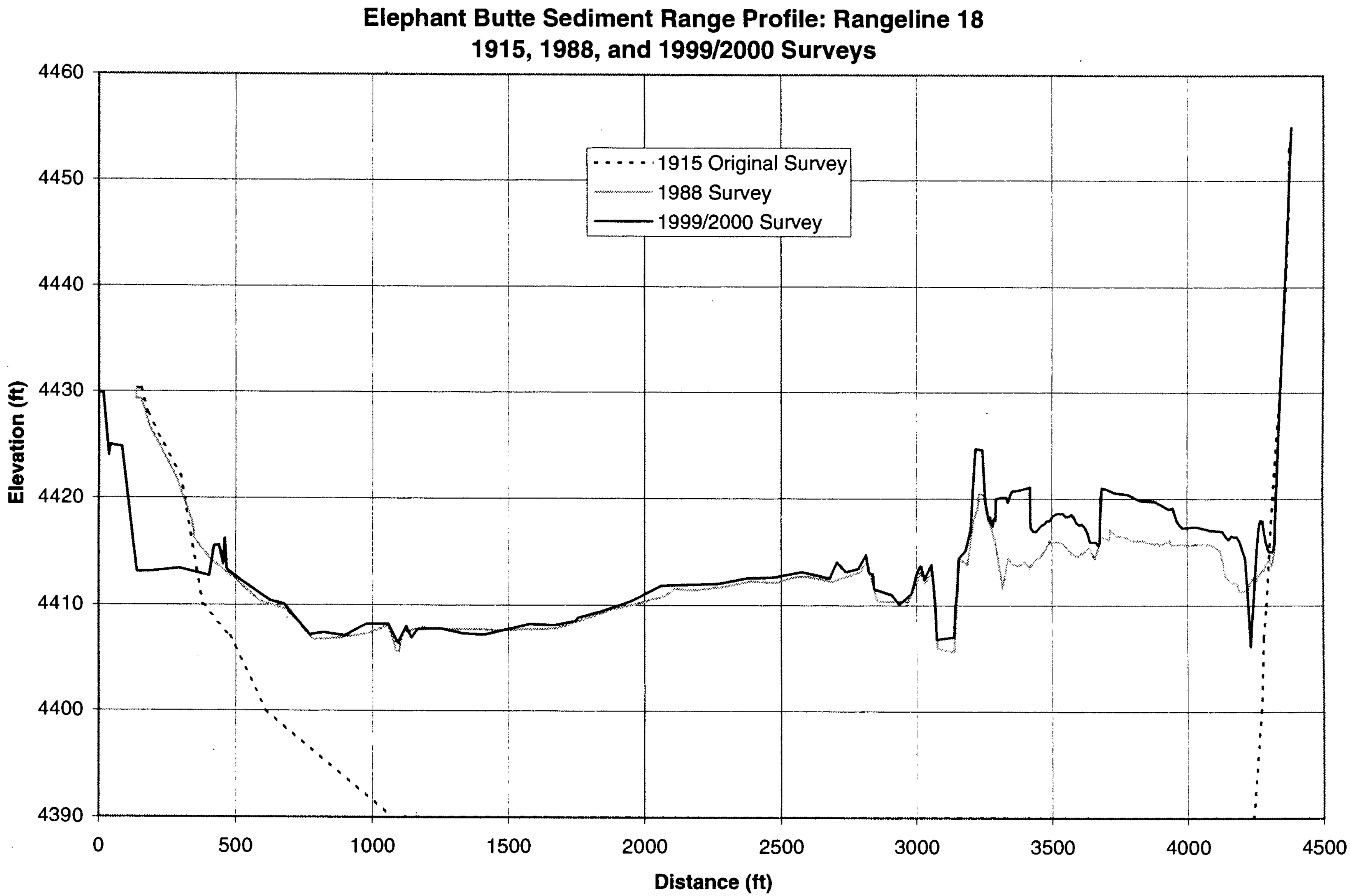


Figure 92. - Sedimentation range profiles for 1915, 1988, and 1999, range 18.

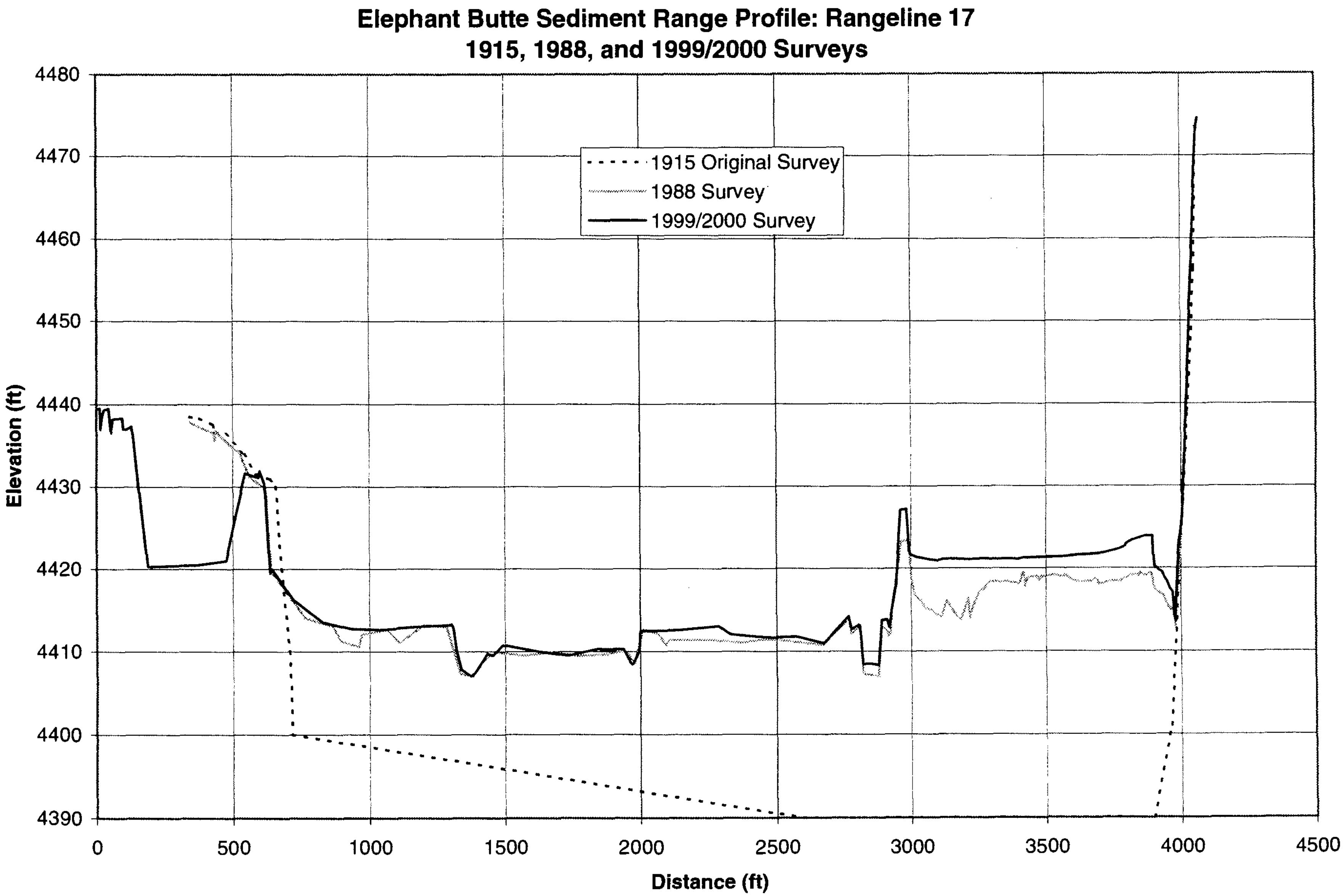


Figure 93. - Sedimentation range profiles for 1915, 1988, and 1999, range 17.

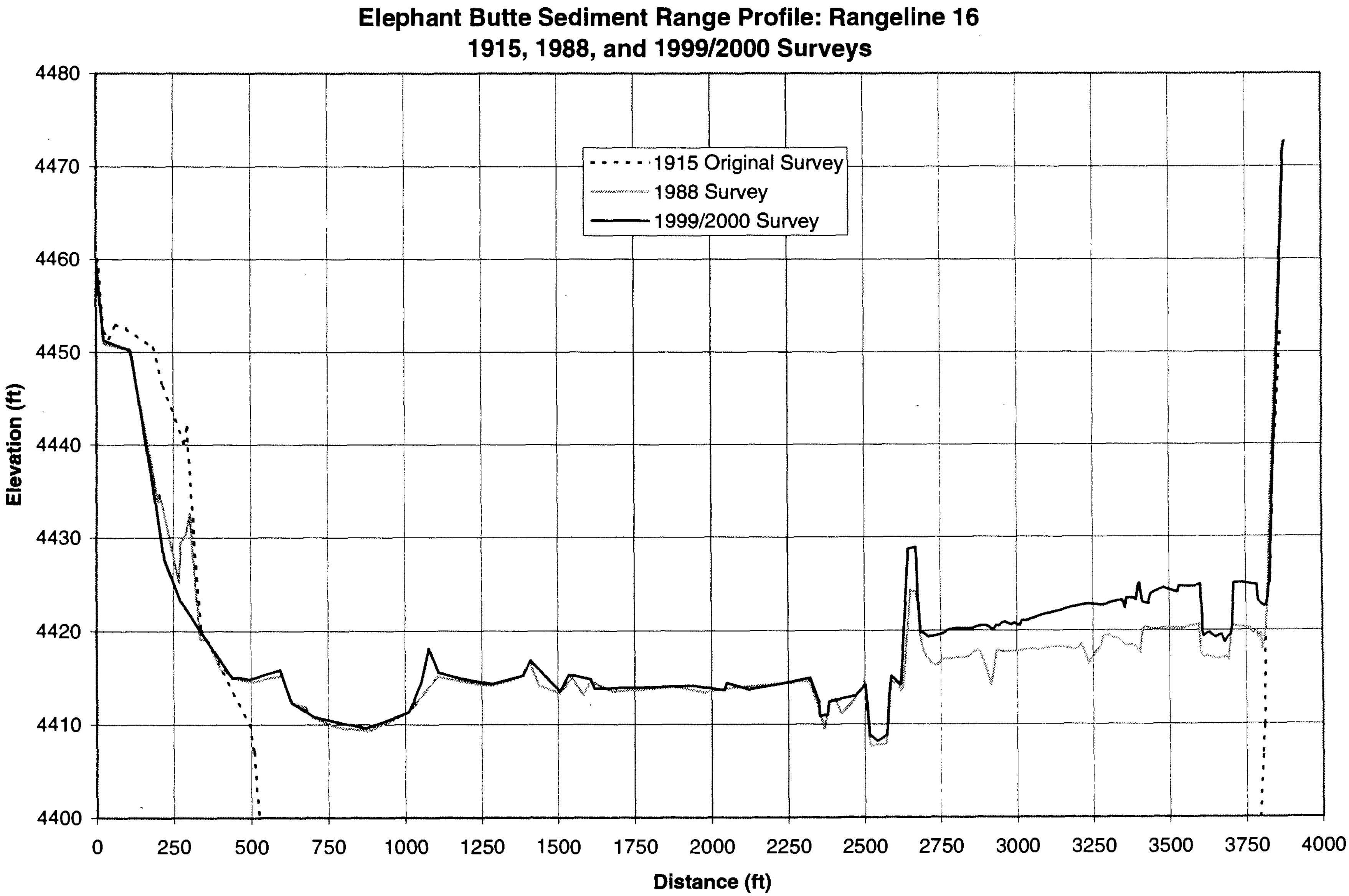


Figure 94. - Sedimentation range profiles for 1915, 1988, and 1999, range 16.

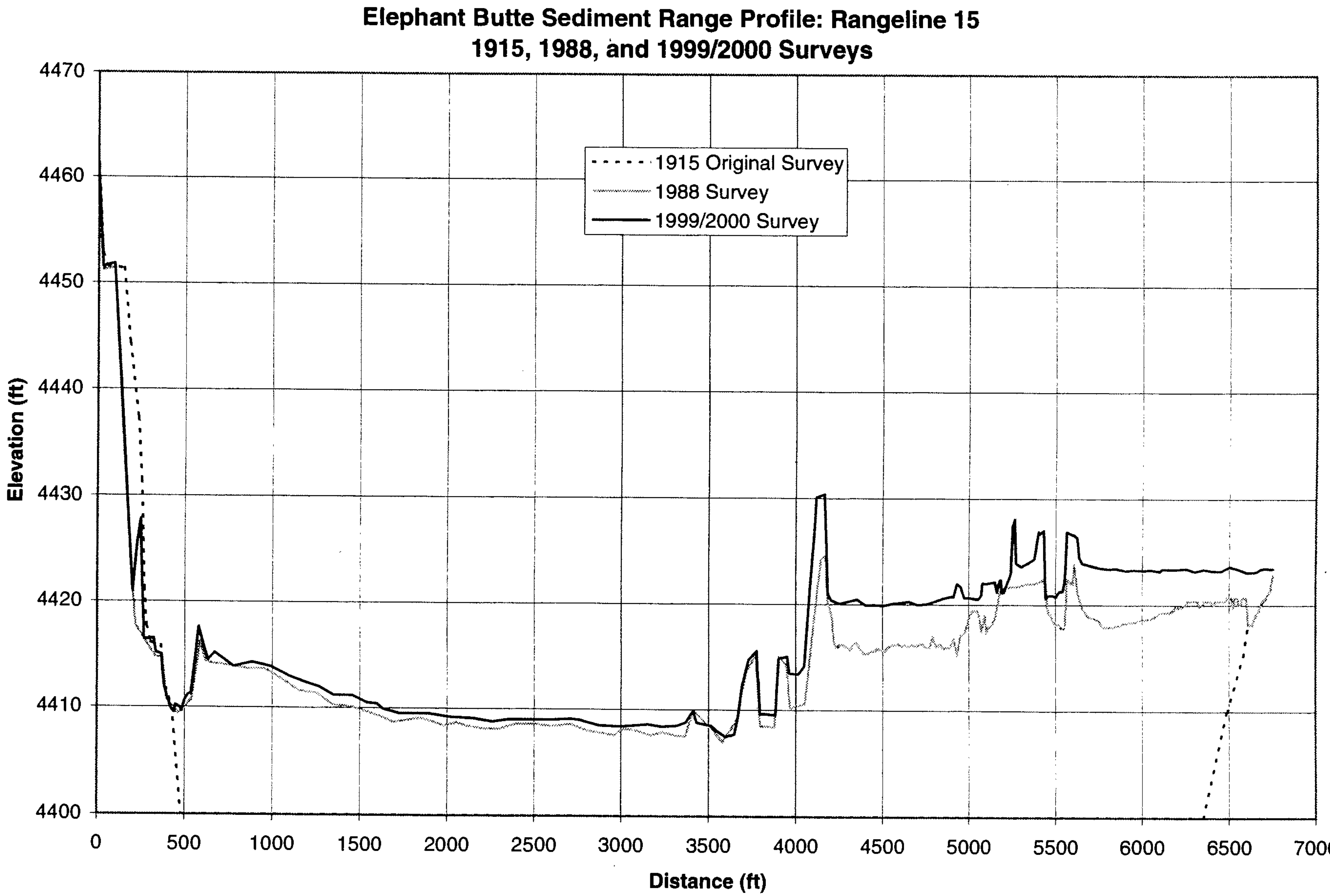


Figure 95. - Sedimentation range profiles for 1915, 1988, and 1999, range 15.

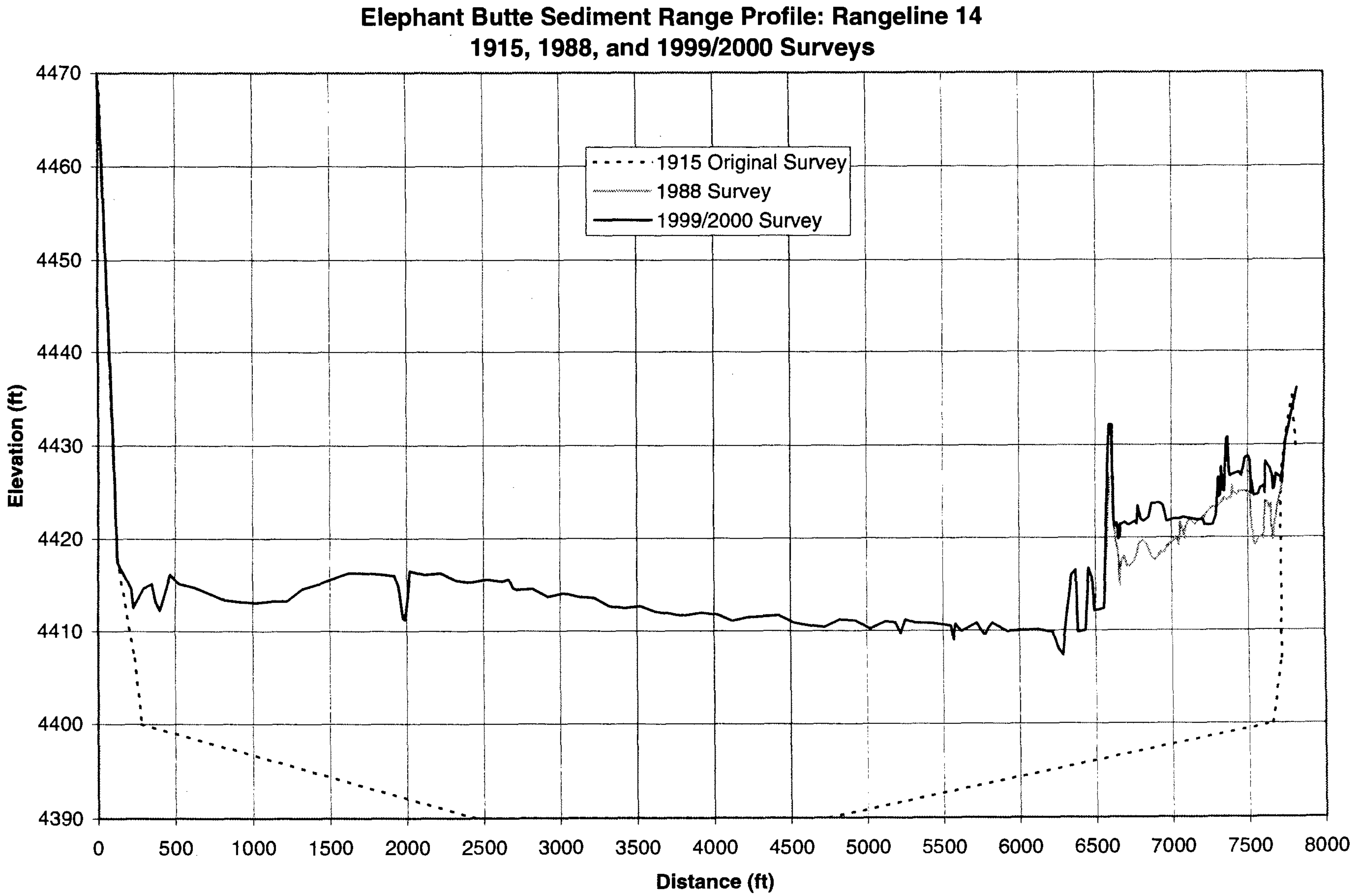


Figure 96. - Sedimentation range profiles for 1915, 1988, and 1999, range 14.

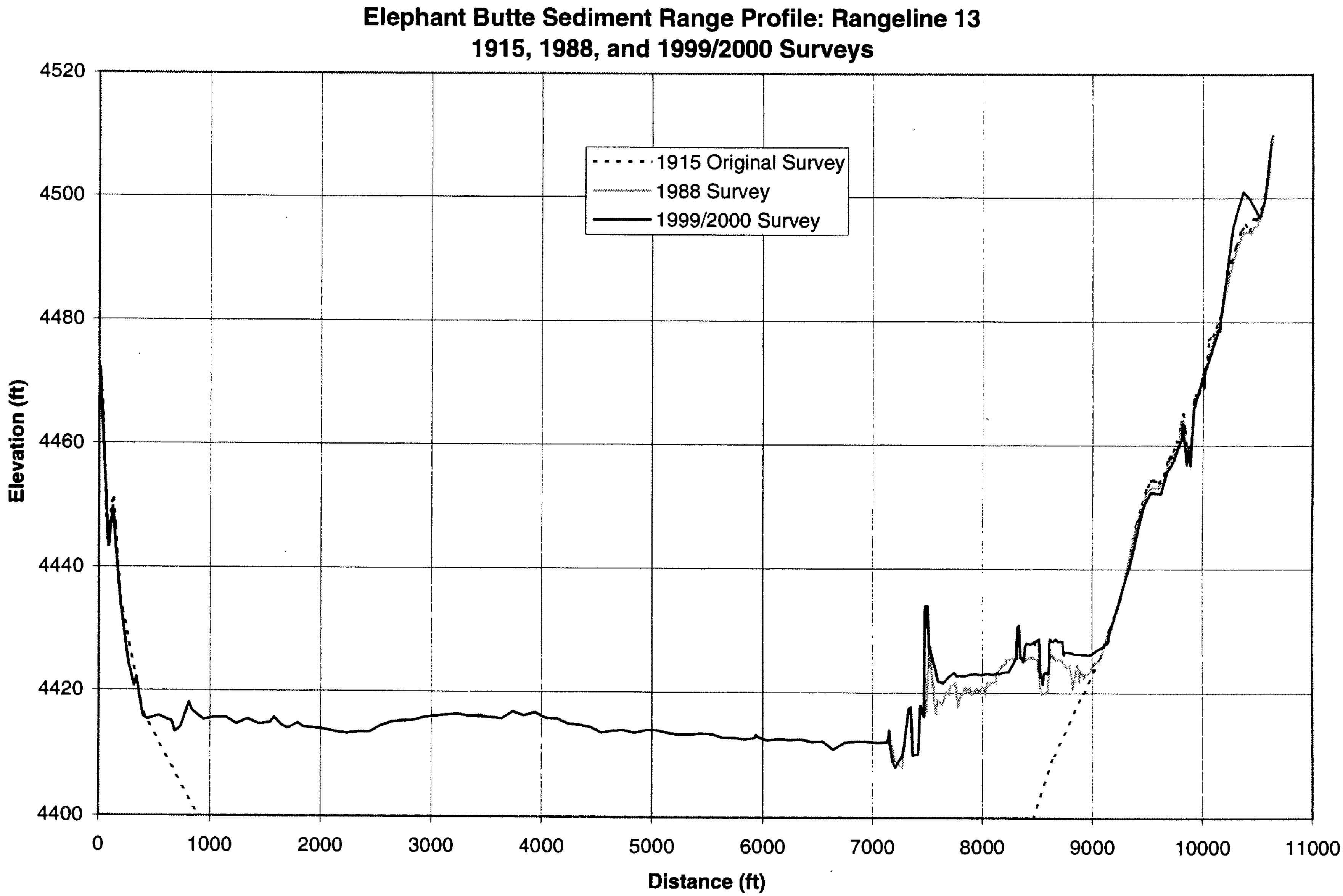


Figure 97. - Sedimentation range profiles for 1915, 1988, and 1999, range 13.

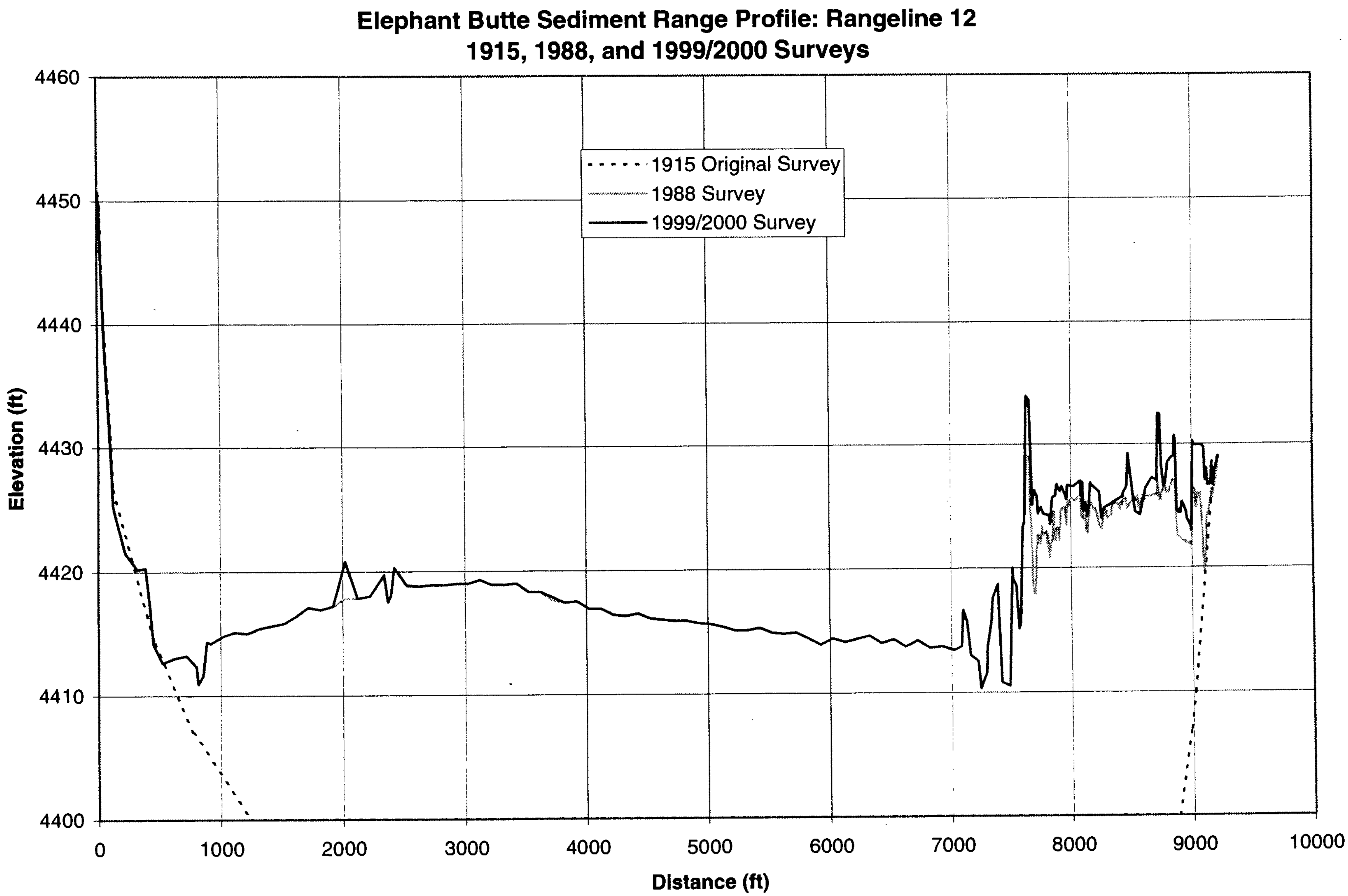


Figure 98. - Sedimentation range profiles for 1915, 1988, and 1999, range 12.

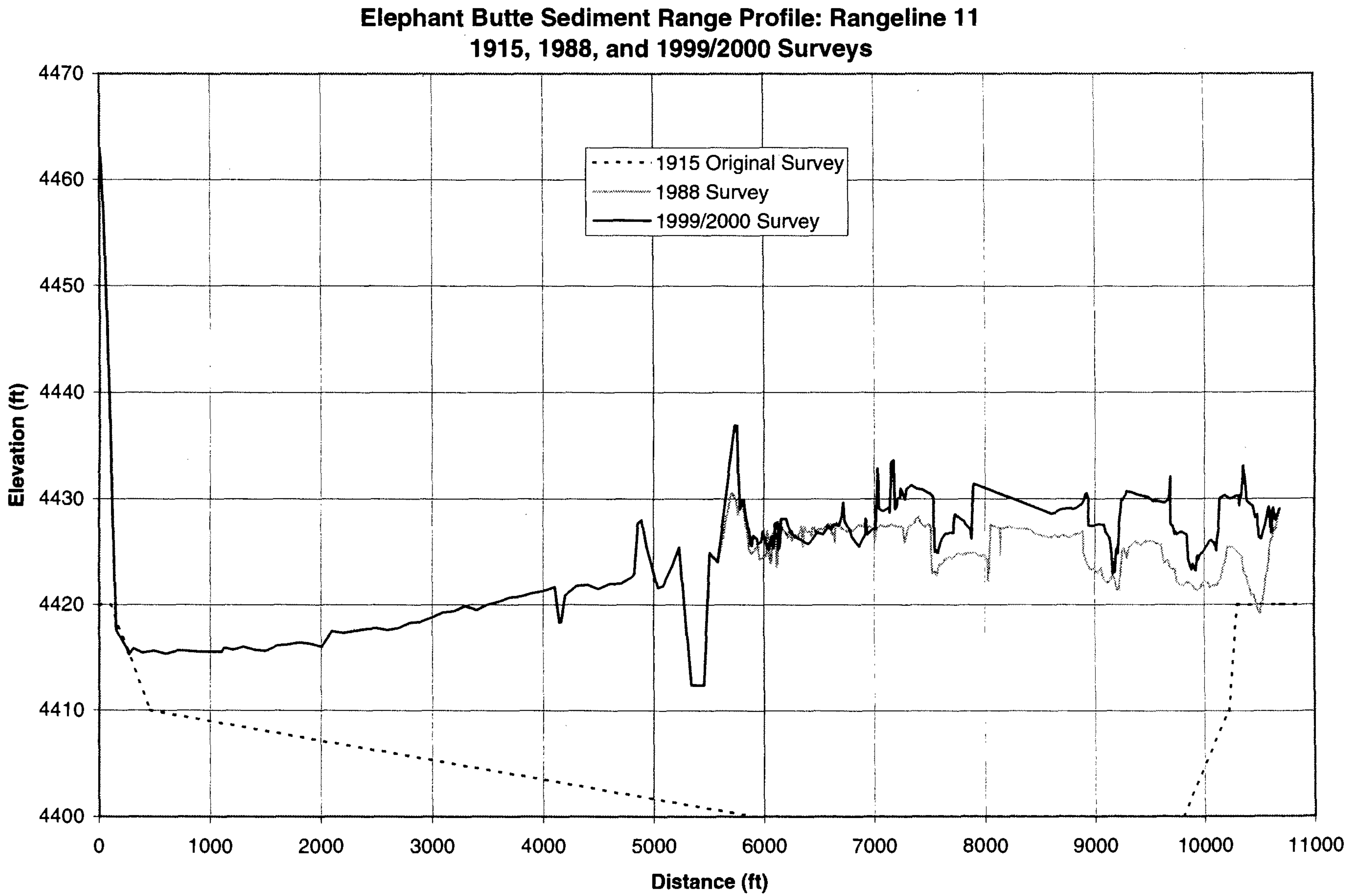


Figure 99. - Sedimentation range profiles for 1915, 1988, and 1999, range 11.

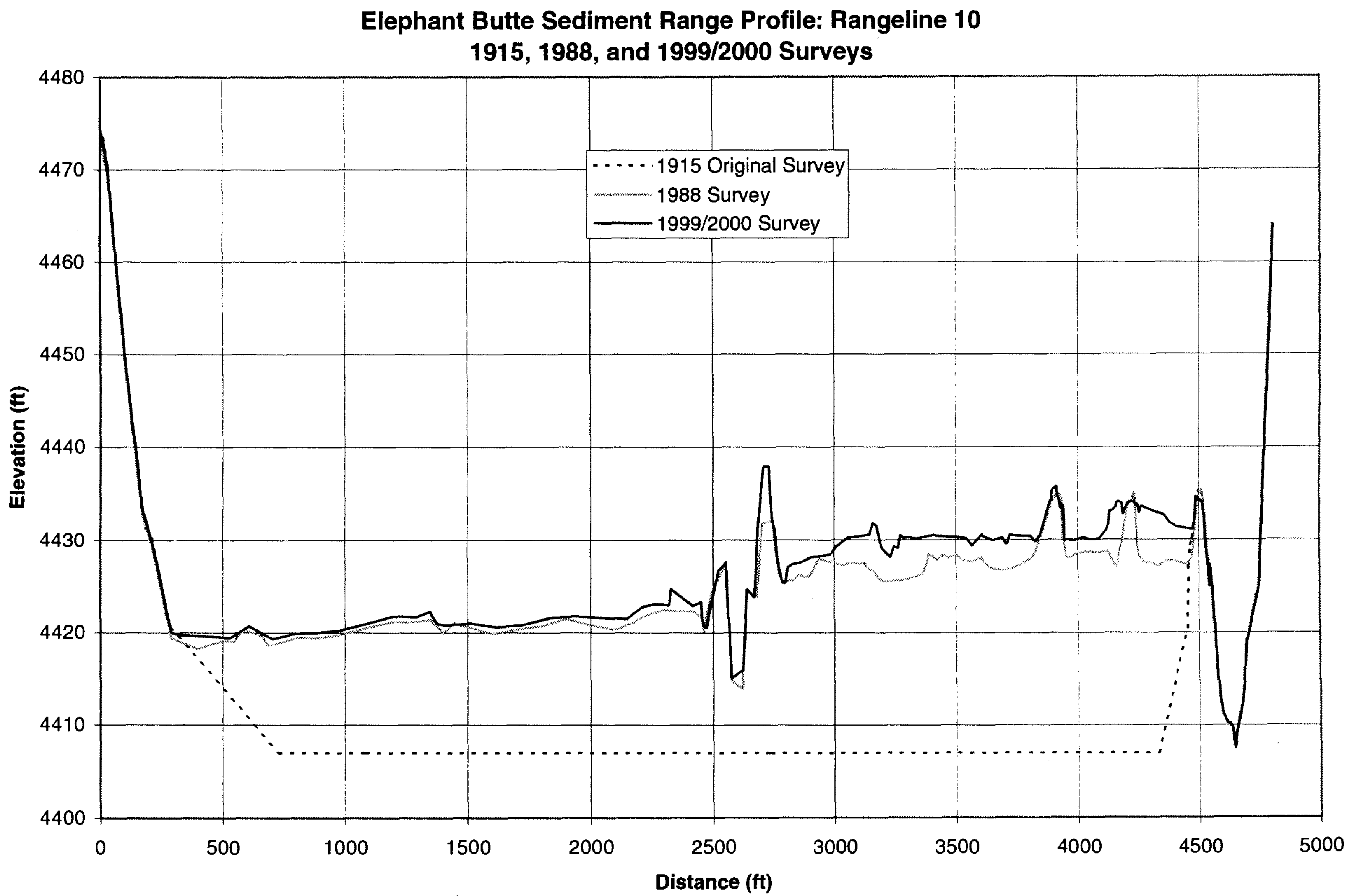


Figure 100. - Sedimentation range profiles for 1915, 1988, and 1999, range 10.

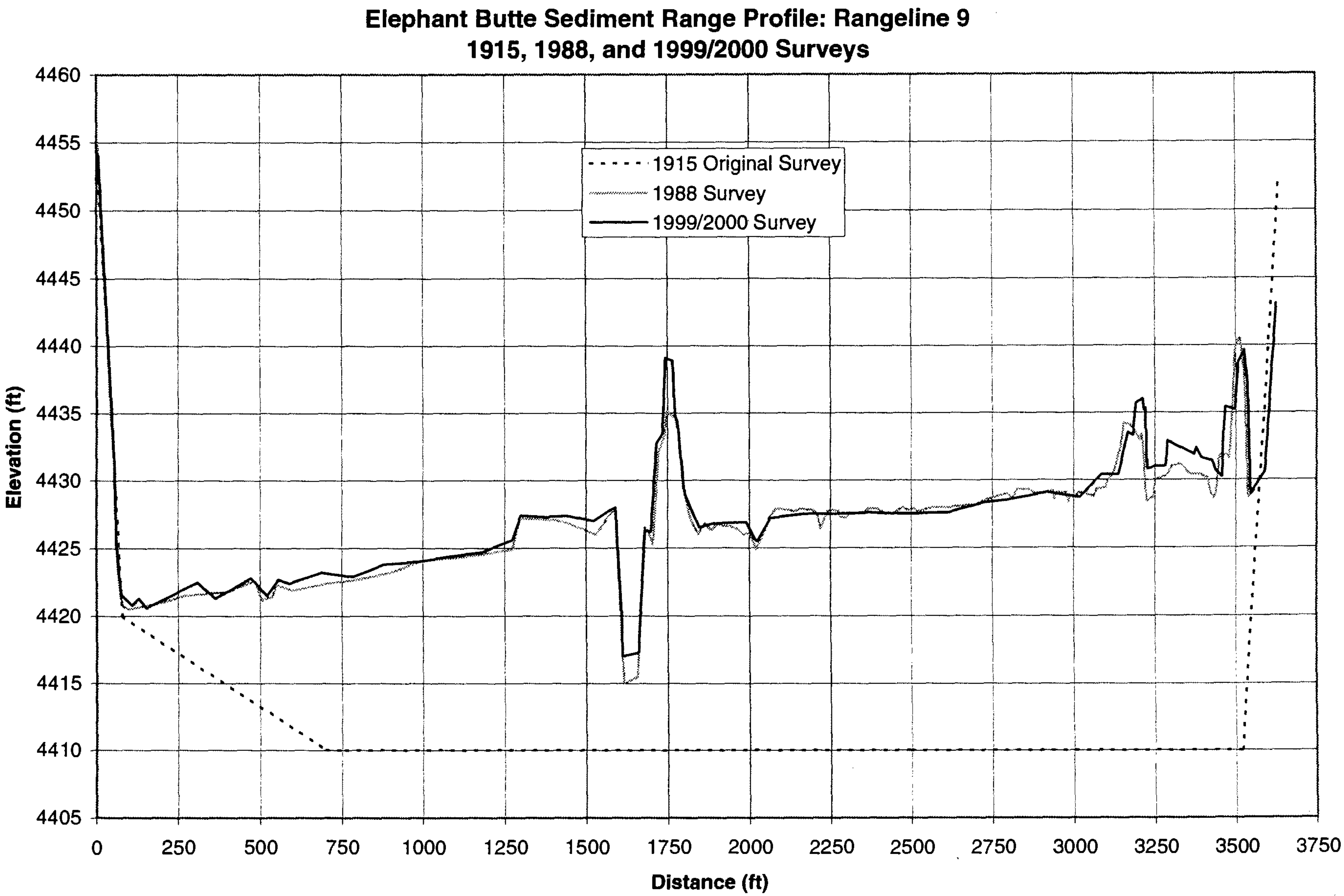


Figure 101. - Sedimentation range profiles for 1915, 1988, and 1999, range 9.

Area-Capacity Curves for Elephant Butte Reservoir