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Technical Report No. SRH-2008-4

Elephant Butte Reservoir 2007 Sedimentation Survey

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

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Elephant Butte Reservoir 2007 Sedimentation Survey

prepared by

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Bureau of Reclamation
Technical Service Center
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Reclamation Report

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14. ABSTRACT

Reclamation surveyed Elephant Butte Reservoir in October 2007 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The underwater survey was conducted near water surface elevation 4,327 feet (project datum). The project datum is 43.3 feet less than the National Geodetic Vertical Datum of 1929 (NGVD29) and 45.5 feet less than the North American Vertical Datum of 1988 (NAVD88). The underwater survey used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The 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, 2004 and 2007 aerial data that covered large portions of the reservoir, and 2007 bathymetric data.

As of October 2007, at reservoir water surface elevation 4,407.0 feet, the surface area was 35,825 acres with a total capacity of 2,024,586 acre-feet. Since 1915 and the initial reservoir filling, 610,214 acre-feet of sediment have accumulated in Elephant Butte Reservoir. Since the last reservoir survey in 1999, the reservoir volume has increased 1,228 acre-feet due to the dewatering and resulting compaction of the previous measured sediments that have been exposed during the extended drought conditions. The average annual rate of sediment accumulation since 1915 is 6,575.6 acre-feet compared to the 1999 study computation of 7,253.2 acre-feet.

15. SUBJECT TERMS

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Table of Contents

Page

Index of Figures

Page

Index of Tables

Page

Elephant Butte Reservoir
2007 Sedimentation Survey

Introduction

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 (Figure 1). Elephant Butte Dam was one of the first major structures built by Reclamation after its formation in 1902. Elephant Butte Reservoir is the principal storage component of the originally authorized single purpose Rio Grande Project.

Figure 1 - Bureau of Reclamation reservoirs in New Mexico.

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 elevation of 4,414.0 feet[1]. There is a parapet wall on both the upstream and downstream sides of the dam crest with top of wall elevation 4,419.0. The dam's dimensions, in feet, are:

[1]Elevations are shown in feet. Unless noted, all elevations in this report are based on the original project datum established by Reclamation which is 43.3 feet lower than NGVD29 and 45.5 feet lower than NAVD88.

Hydraulic height[2]	193	Structural height	301
Top width	18	Crest length	6,914.5
Crest elevation	4,414.0	Top of parapet wall	4,419.0

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, in feet, as follows:

Structural height	59	Top width	20
Crest length	2,000	Crest elevation	4,425.0

The dam's 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 crest elevation 4,407.0 is separated into five equal bays by concrete piers which support a highway bridge. Four 10.33-foot 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 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 consist of an intake structure shared with the sluice and penstock inlets. There are four service conduits: two upper conduits at centerline elevation 4,290.0 and two lower conduits at centerline elevation 4,234.0. The combined capacity of the service outlets is 4,680 cfs at water surface elevation 4,407.0. The sluice outlet works are located in the dam near the left abutment and consist of a shared intake structure, trashracks, two slide gates, and two conduits through the dam with centerline elevation 4,234.0. The sluice outlet capacity is 2,200 cfs at water surface elevation 4,314.0.

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 4,264.7 and the three lower penstocks have inlets centered at elevation 4,234.0. 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.

The total drainage area above Elephant Butte Dam is 25,923 square miles (mi^2). 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

[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.*

(57 mi^2) would result in a net contributing area of 11,966 mi^2. Sediment from the remaining upstream areas are considered trapped by upstream dams including Jemez Canyon with a drainage area of 1,034 mi^2 that closed in 1953; Galisteo with a drainage area of 596 mi^2 that closed in 1970; and Cochiti with a drainage area of 11,960 mi^2 that closed in 1970. 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 (Reclamation, 2000).

Summary and Conclusions

This Reclamation report presents the results of the October 2007 survey of Elephant Butte Reservoir. The 2007 survey was the thirteenth survey of the reservoir that provides results from a range line analysis similar to the past surveys of the reservoir. This study also provides results from a contour analysis that generated new reservoir topography from extensive above and below water data that covered much of the reservoir area.

The primary objectives of the survey were to gather data needed to:

- compute area-capacity relationships
- estimate storage depletion due to sediment deposition
- develop reservoir topography

A control survey was conducted using the on-line positioning user service (OPUS) and RTK GPS to establish a horizontal and vertical control network near the reservoir for the bathymetric survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over a temporarily driven piece of rebar in an area called Dillard Circle that is located on the west bank overlooking the reservoir. The OPUS generated coordinates were verified by RTK GPS observation shots on the NGS datum point “V 86” that is located on a dike west of the dam. The coordinates for this point were processed using OPUS, and from this base the bathymetric survey was conducted.

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

The October 2007 underwater survey was conducted near reservoir elevation 4,327 that was measured by the Reclamation gage at the dam. The 2007 survey was conducted with the reservoir nearly seventy feet lower than the 1999 survey that was conducted near reservoir elevation 4,395. The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS for determining sounding locations within the reservoir that could be navigated by the survey boat. Due to the low reservoir content, the survey vessel was only able to navigate upstream near sediment range line 65 that is located downstream of the area of the reservoir called the "Narrows." The system continuously recorded depth and horizontal coordinates as the survey boat navigated along previously established sediment range lines that have been resurveyed during prior studies. Additional grid lines that covered much of the underwater portion of reservoir were also surveyed for mapping purposes. The positioning system provided information to allow the boat operator to maintain a course along these lines. The water surface elevations recorded by Reclamation's reservoir gage and confirmed by RTK GPS measurements during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations.

Standard surveying techniques were used to measure the upper reservoir sediment range lines not covered during the 2007 bathymetric survey. These surveys were conducted under contract with Reclamation's Albuquerque Area Office and included surveys on land, small boat bathymetry, and aerial LiDAR **(Li**ght **D**etection **A**nd **R**anging) collected in 2004 and 2007. Computer programs were used to generate the range line data and resulting surface areas presented in this report and to conduct the analysis for developing the 2007 capacity tables with resulting sediment volumes also presented in this report. Since the LiDAR did not cover the total reservoir area, the decision was made to use the collected range line data and the range line width adjustment method versus the contour method for this study (Ferrari and Collins). Detailed Elephant Butte Reservoir topography was developed by combining scanned USGS quad contours, the contract surveys of the above water reservoir area, and the 2007 bathymetric data sets.

The 2007 area and capacity tables were produced from a computer program that used the measured surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985). The results were generated by the range line width adjustment method that has been used since the 1980 Elephant Butte survey. Some form of the range line collection and analysis method has been used for all past reservoir studies. Tables 1 and 2 contain summaries of the Elephant Butte Reservoir and watershed characteristics for the 2007 survey. The 2007 survey determined that the reservoir has a total storage capacity of 2,024,586 acre-feet with a surface area of

35,825 acres at water surface elevation 4,407.0. Since closure in January 1915, the reservoir has an estimated volume change of 610,214 acre-feet below reservoir elevation 4,407.0. This volume change represents a 23.16 percent loss in total original capacity at this elevation.

Control Survey Data Information

A control survey was conducted using OPUS and RTK GPS to establish a horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. Initially, the GPS base was set over a temporarily driven piece of rebar on the west bank overlooking the reservoir. The coordinates for this point were processed using OPUS, and from this base additional points were established and checked during the survey using OPUS. The OPUS generated coordinates were further verified by RTK GPS observations on the NGS datum point “V 86” located on a dike west of Elephant Butte Dam.

The horizontal control, in NAD83, was tied to the New Mexico central state plane coordinate system in feet. The vertical control in feet was tied to NAVD88 and the Elephant Butte Dam project vertical datum. Unless noted all elevations in this report are referenced to the project vertical datum that is 43.3 feet lower than NGVD29 and 45.5 feet lower than NAVD88.

Reservoir Operations

Elephant Butte Reservoir is part of the Rio Grande Project that provides storage for irrigation, flood control, and recreation. The October 2007 capacity was 2,024,586 acre-feet of total storage below water surface elevation 4,407.00, the conservation pool elevation. There is a prudent flood reservation space of 25,000 acre-feet from elevation 4,406.30 to 4,407.00 during winter months of October 1 through March 31, and 50,000 acre-feet from elevation 4,405.59 through 4,407.00 during summer months of April 1 through September 30. The 2007 survey measured a minimum lake bottom elevation near the dam of 4,244.00.

Elephant Butte Reservoir computed annual inflow and reservoir stage records are listed by water year on table 1 for the period 1915 through 2007. The inflow values show the annual fluctuation with a computed average inflow for the total period of 853,600 acre-feet and since the 1999 survey of 504,200 acre-feet. The table list the maximum reservoir elevation was 4,409.2 in 1942 and since 1942, the minimum reservoir elevation was 4,258.0 in 1954. Since the last survey in 1999 the maximum recorded reservoir elevation was 4,397.6 with the minimum elevation 4,294.0 during water year 2004. Figure 2 plots the end of month water surface elevations for the period of record. The plot shows the fuller reservoir period from 1980 through 2000 with the dramatic drop in reservoir elevation that followed with the lowest elevation in 2004.

Hydrographic Survey Equipment and Method

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 3). The hydrographic system included a GPS receiver with a built-in radio, single and multibeam depth sounders, helmsman display for navigation, computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the boat equipment. The shore equipment included a second GPS receiver with an external radio. The GPS receiver and antenna were mounted on a survey tripod over a known datum point and a 12-volt battery provided the power for the shore unit.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The basic output from a RTK receiver are precise 3-D coordinates in latitude, longitude, and height with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS datum of WGS-84 that the hydrographic collection software converted into New Mexico’s state plane coordinates, central zone in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously, just like with differential GPS.

The Elephant Butte Reservoir bathymetric survey was conducted the first part of October 2007 near water surface elevation 4,327. The bathymetric survey was conducted using sonic depth recording equipment, interfaced with a RTK GPS, capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along the previously established sediment range lines using a single beam sounder and along closely-spaced grid lines covering the deeper portion of the reservoir using a multibeam depth sounder. For mapping purposes, most transects (grid lines) were run somewhat parallel to the upstream-downstream alignment of the reservoir at around 200-foot spacing. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the laptop computer hard drive for subsequent processing.

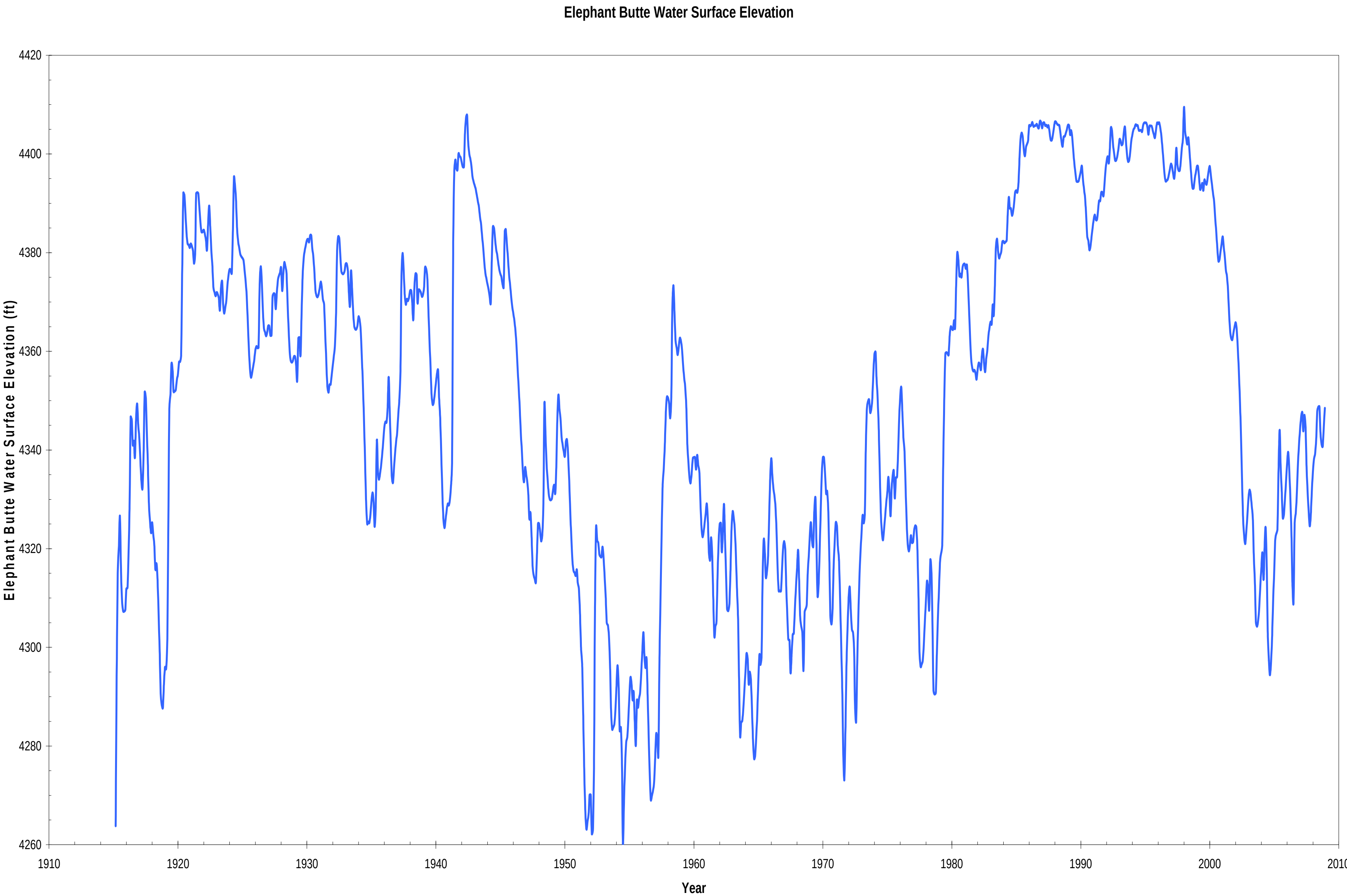

Figure 2 - Elephant Butte Reservoir end of month water surface elevations.

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Figure 3 - Survey Vessel with mounted instrumentation on El Vado Reservoir, New Mexico.

The single beam depth sounder for the 2007 underwater data was calibrated by lowering a weighted cable below the boat with beads marking known depths. The collected data were digitally transmitted to the computer collection system through a RS-232 port. The single beam depth sounder also produced an analog hard-copy chart of the measured depths. These graphed analog charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gage, were used to convert the sonic depth measurements to true lake-bottom elevations.

In 2001, the Sedimentation Group began utilizing an integrated multibeam hydrographic survey system. The system consists of a single transducer mounted on the center bow or forward portion of the boat. From the single transducer a fan array of narrow beams generates a detailed cross section of bottom geometry as the survey vessel passes over the areas mapped. The system transmits 80 separate 1-1/2 degree slant beams resulting in a 120-degree swath from the transducer. The 200 kHz high-resolution multibeam echosounder system measures the relative water depth across the wide swath perpendicular to the vessel's track. Figure 4 illustrates the swath of the sea floor that is about 3.5 times as wide as the water depth below the transducer.

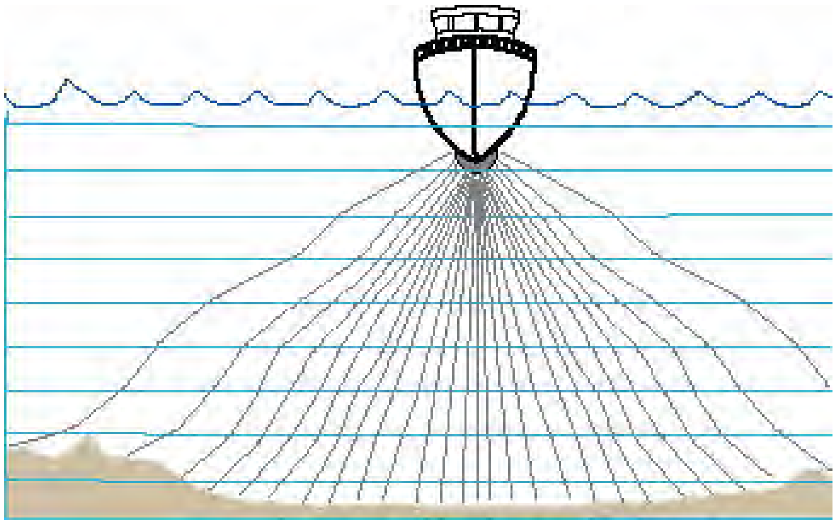

Figure 4 - Multibeam collection system.

The multibeam system is composed of several instruments all in constant communication with a central on-board laptop computer. The components include the RTK GPS for positioning; a motion reference unit to measure the heave, pitch, and roll of the survey vessel; a gyro to measure the yaw or vessel attitude; and a velocity meter to measure the speed of sound through the vertical profile of the reservoir water. The multibeam sounder was calibrated by lowering an instrument that measured the sound velocity through the reservoir water column. The individual depth soundings were adjusted by the speed of sound of the measurements, which can vary with density, salinity, temperature, turbidity, and other conditions. With proper calibration, the data processing software utilizes all the incoming information to provide an accurate, detailed x,y,z data set of the lake bottom.

The multibeam surveyed areas primarily included the main channel from the dam upstream near range line 73 along with a few of the side coves, Figures 5 through 10. The collection concentrated on the deeper portions of the reservoir to provide more detailed mapping than what was provided by the single beam coverage during the 1999 survey. The single beam collection system was used to collect the 2007 underwater data along the sediment range line alignment that included range lines 65 through 90. For mapping purposes, single beam data was also collected along the shoreline and the wide portion of the reservoir from range line 73 upstream to range line 65 before it became too shallow for boat access.

The multibeam and single beam soundings, combined with the LiDAR data created a detailed data set of over 21 million x,y,z points that represented the majority of the reservoir. These data sets were used to generate reservoir topography for this study. The multibeam survey system software continuously recorded reservoir depths and horizontal coordinates as the survey vessel moved along closely-spaced grid lines covering the reservoir area. Most transects (grid lines) were run parallel to the reservoir alignment with the multibeam swaths overlapping in the deeper areas of the reservoir to provide full bottom coverage of the areas surveyed. The multibeam system could have provided more detailed bottom coverage throughout the reservoir, but time and budget did not allow for the remainder of the reservoir to be surveyed by this method. There was also concern of damaging the multibeam transducer when surveying lines near the shore at the time of the 2007 survey. Due to the clarity of the reservoir water at the time of this survey, the survey vessel hit bottom on several occasions.

The underwater collected data was processed using the same hydrographic system software used during the data collection. The analysis applied all measurements, such as vessel location and corrections for the roll, pitch, and yaw effects. The other corrections included applying the sound velocity through the reservoir water column and converting all depth data points to elevations using the measured water surface elevation at the time of collection. To make it more manageable, the massive amount of multibeam data was filtered into 5-foot cells or grids of the reservoir area surveyed by the multibeam system. The multibeam data was combined with the single beam data to produce the x,y,z data set used for 2007 Elephant Butte Reservoir underwater map development. This data was filtered further by removing points in the flat bottom portions of the reservoir that were not necessary to produce detailed accuracy in these areas. Additional information on collection and analysis procedures is included in *Engineering and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

For the range lines upstream of range line 65, standard surveying techniques were used to map the reservoir areas. These surveys were conducted under contract with Reclamation's Albuquerque Area Office and included land, small boat bathymetry, and aerial LiDAR **(Li**ght **D**etection **A**nd **R**anging) surveys. The LiDAR was collected in 2004 and 2007. During all of these surveys, the upper reservoir pool was below the "Narrows," meaning the small boat bathymetry was within the inflow channel. The 2004 LiDAR was collected near reservoir water surface elevation 4,340 and covered the above water reservoir area from range line 78 upstream to range line 23. The 2007 LiDAR covered the reservoir area from range line 23 upstream beyond range line 9 that represents the upper extent of the reservoir boundary. The LiDAR resulted in detailed x,y,z data sets of the bare earth in the above water portion of the reservoir. Since 1999 and the drawdown of the reservoir due to drought, the upper reach has become heavily vegetated. There were some issues with the bare earth LiDAR data due to the thick blanket of vegetation in some areas of the reservoir along with reflection off the top of existing water pools, but overall, this analysis found very good results when the 2007 developed range lines were plotted against the 1999 surveys. Previous studies of the 2004 LiDAR data set found very favorable results when comparing the LiDAR with standard land collection data (Aubuchon, 2005, Appendix I). The LiDAR did not cover the whole reservoir, but is the first data set to account for the shoreline erosion changes that have occurred throughout most of the reservoir. The LiDAR is the best information available on the current geometry of the reservoir not covered by the survey vessel.

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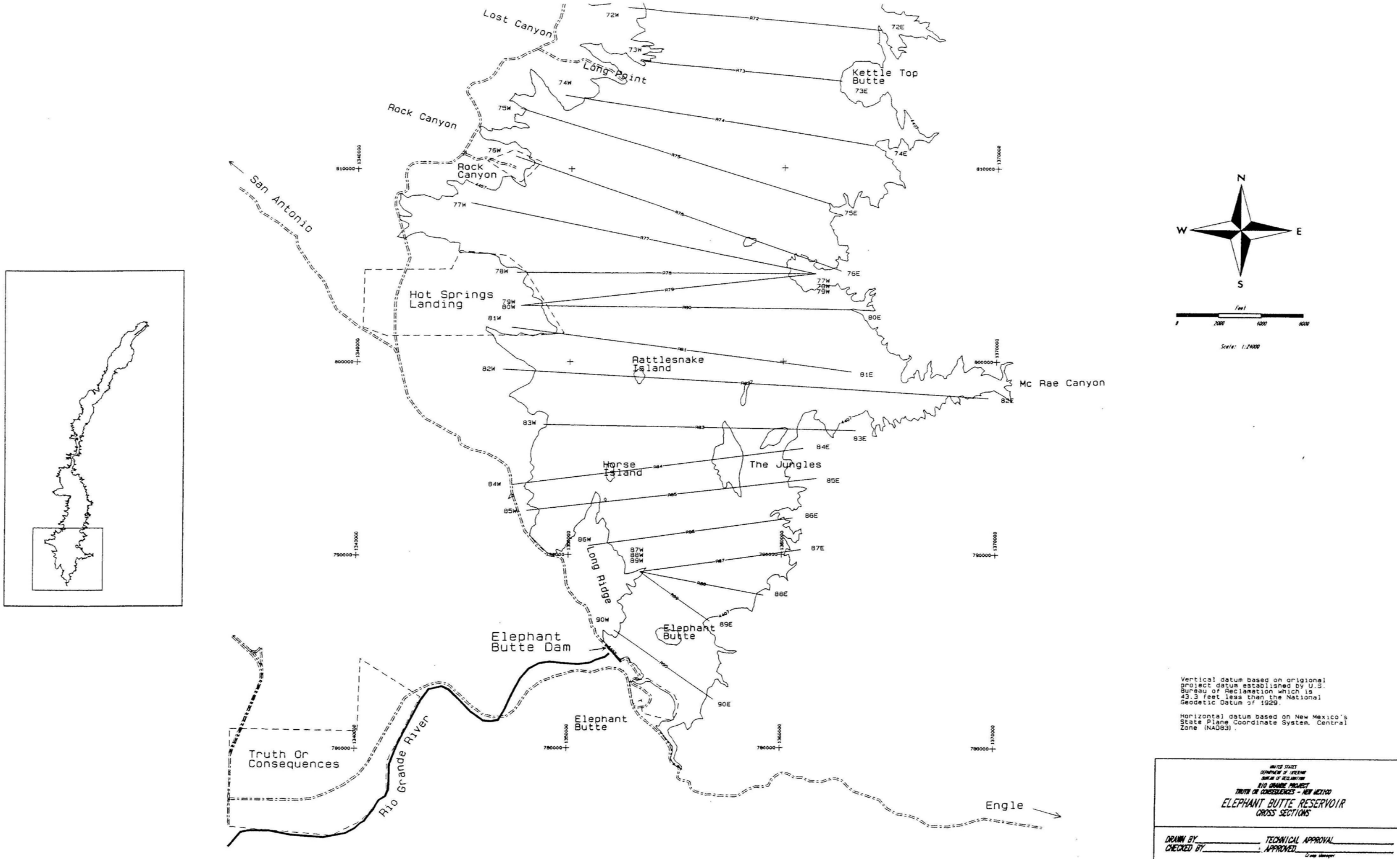

Figure 5 - Elephant Butte Reservoir range line location map, 1 of 6.

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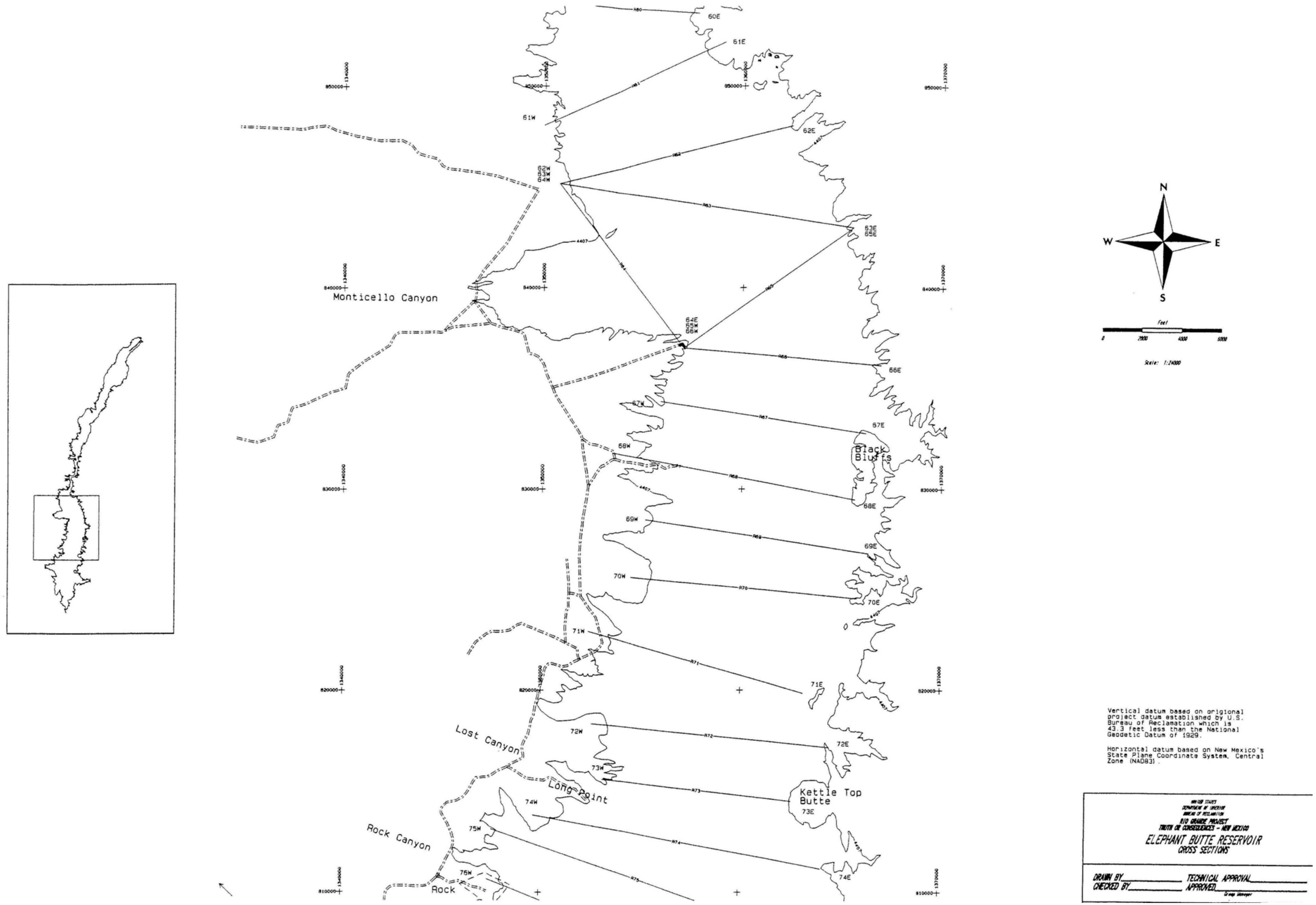

Figure 6 - Elephant Butte Reservoir range line location map, 2 of 6.

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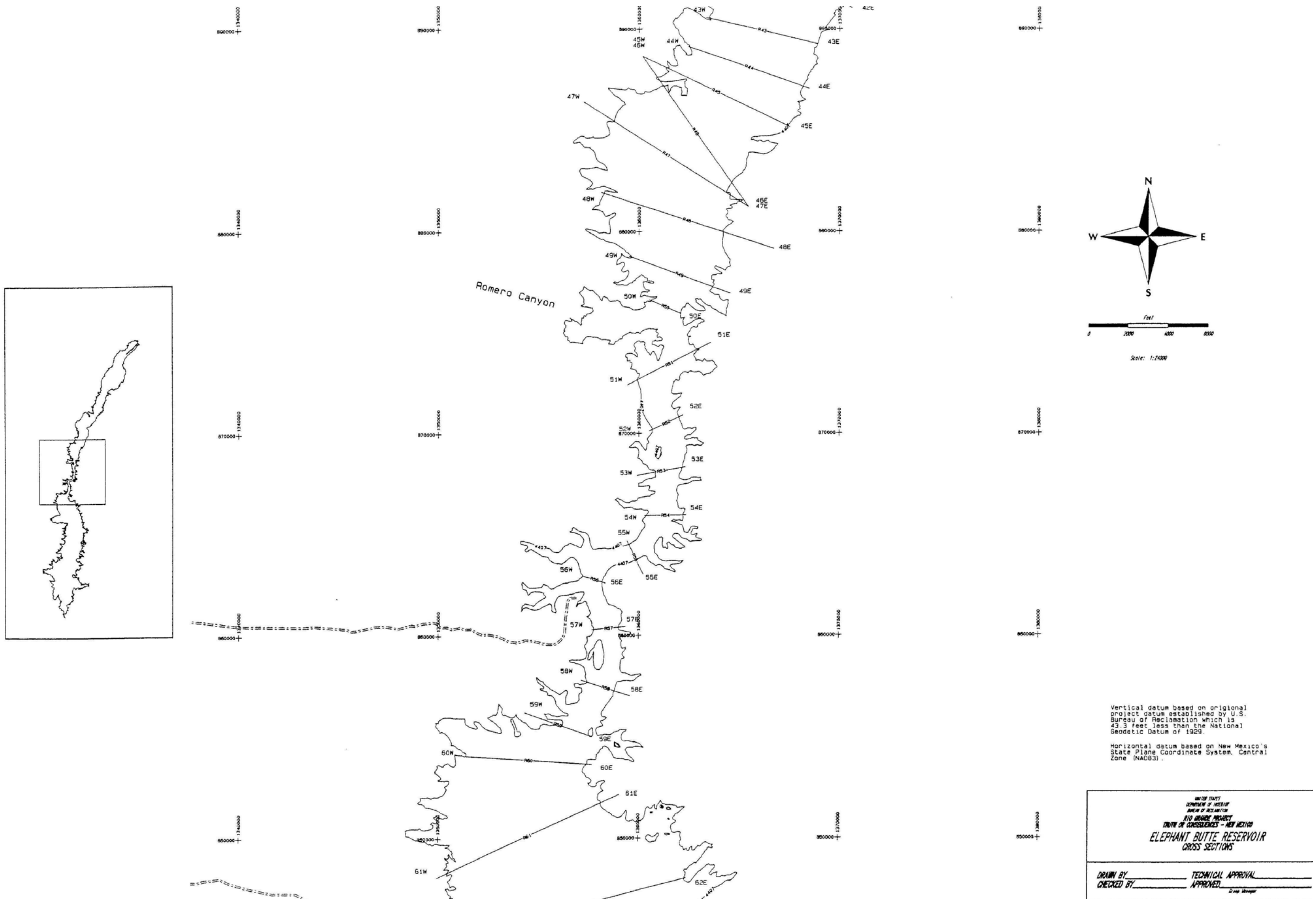

Figure 7 - Elephant Butte Reservoir range line location map, 3 of 6.

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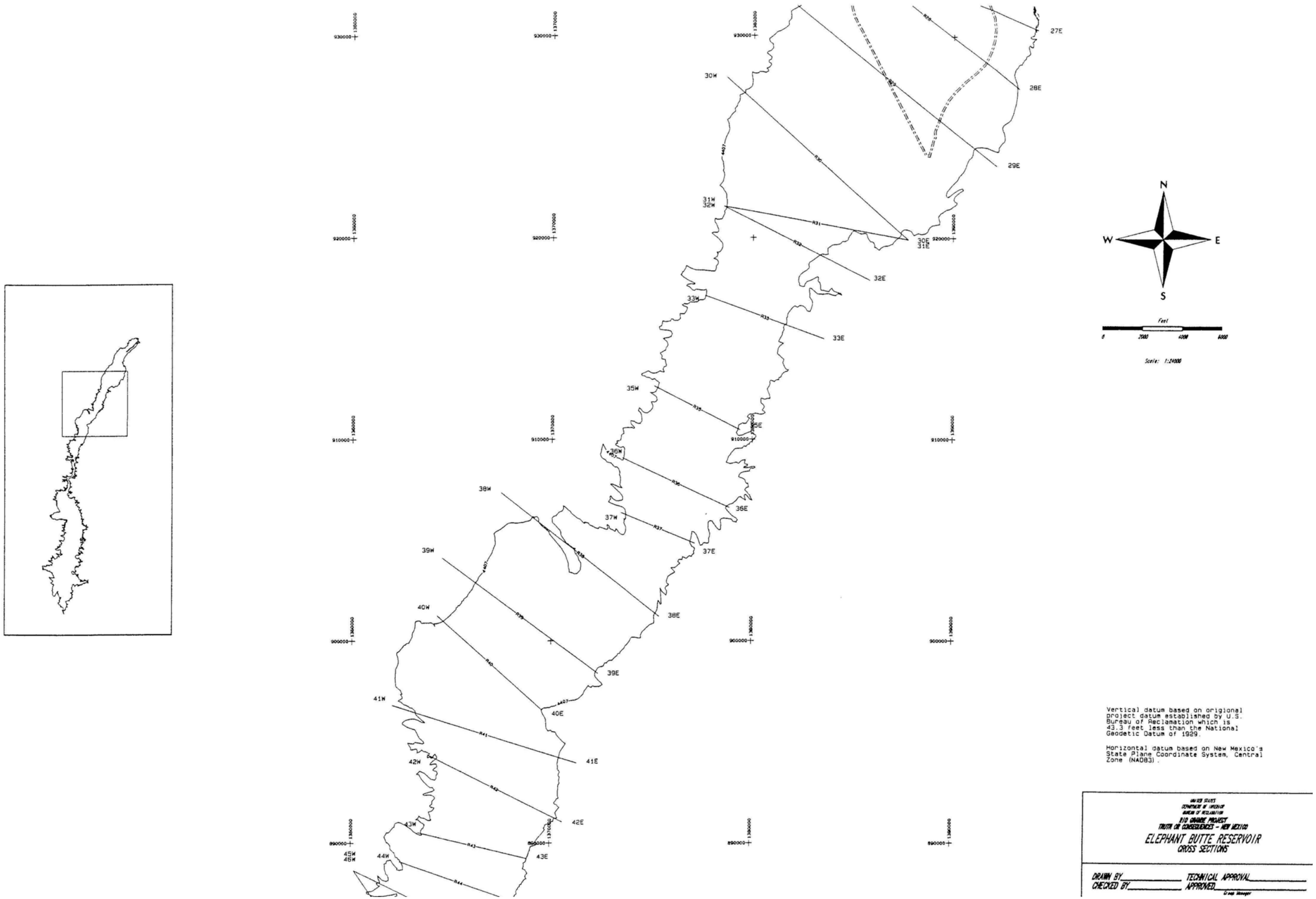

Figure 8 - Elephant Butte Reservoir range line location map, 4 of 6.

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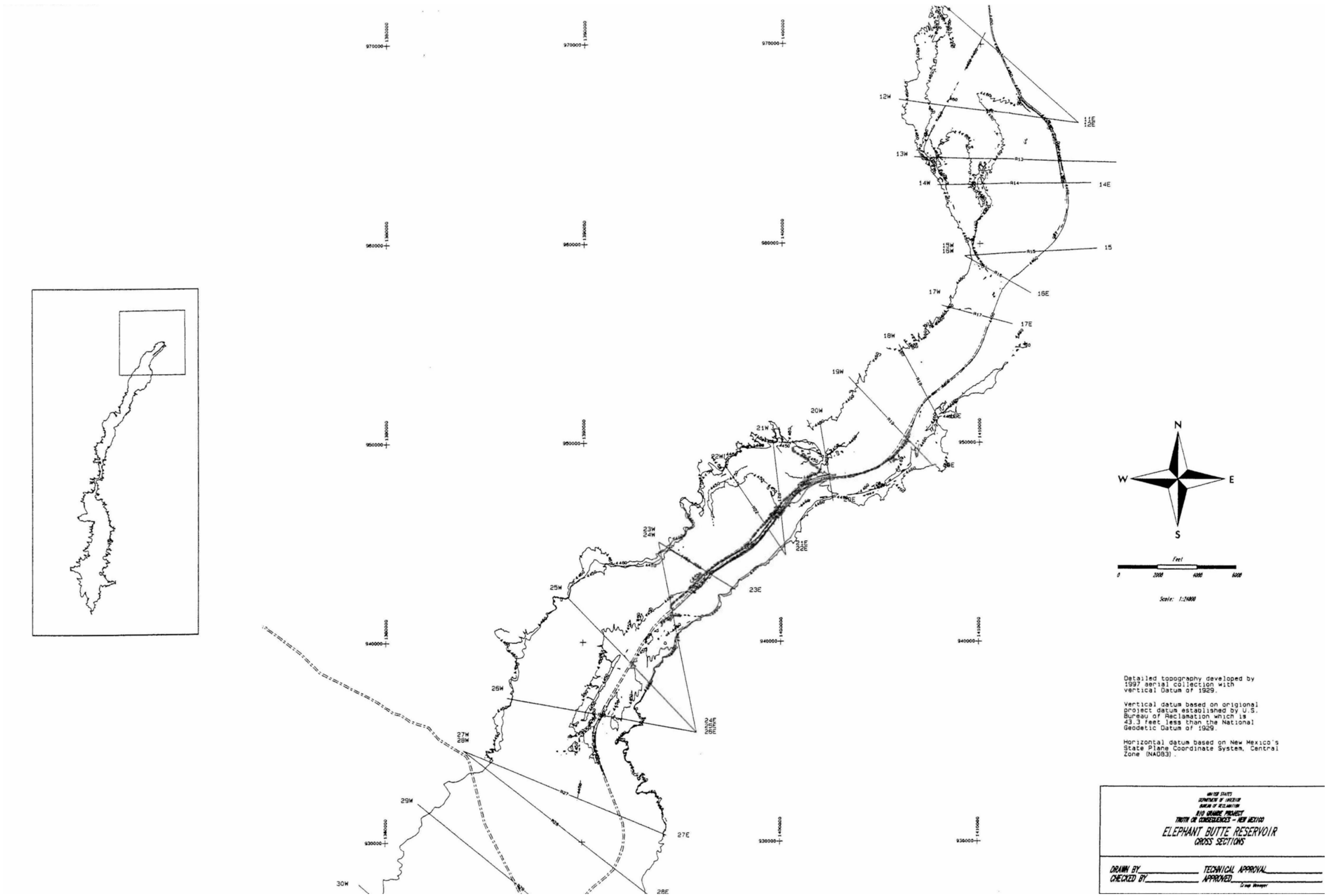

Figure 9 - Elephant Butte Reservoir range line location map, 5 of 6.

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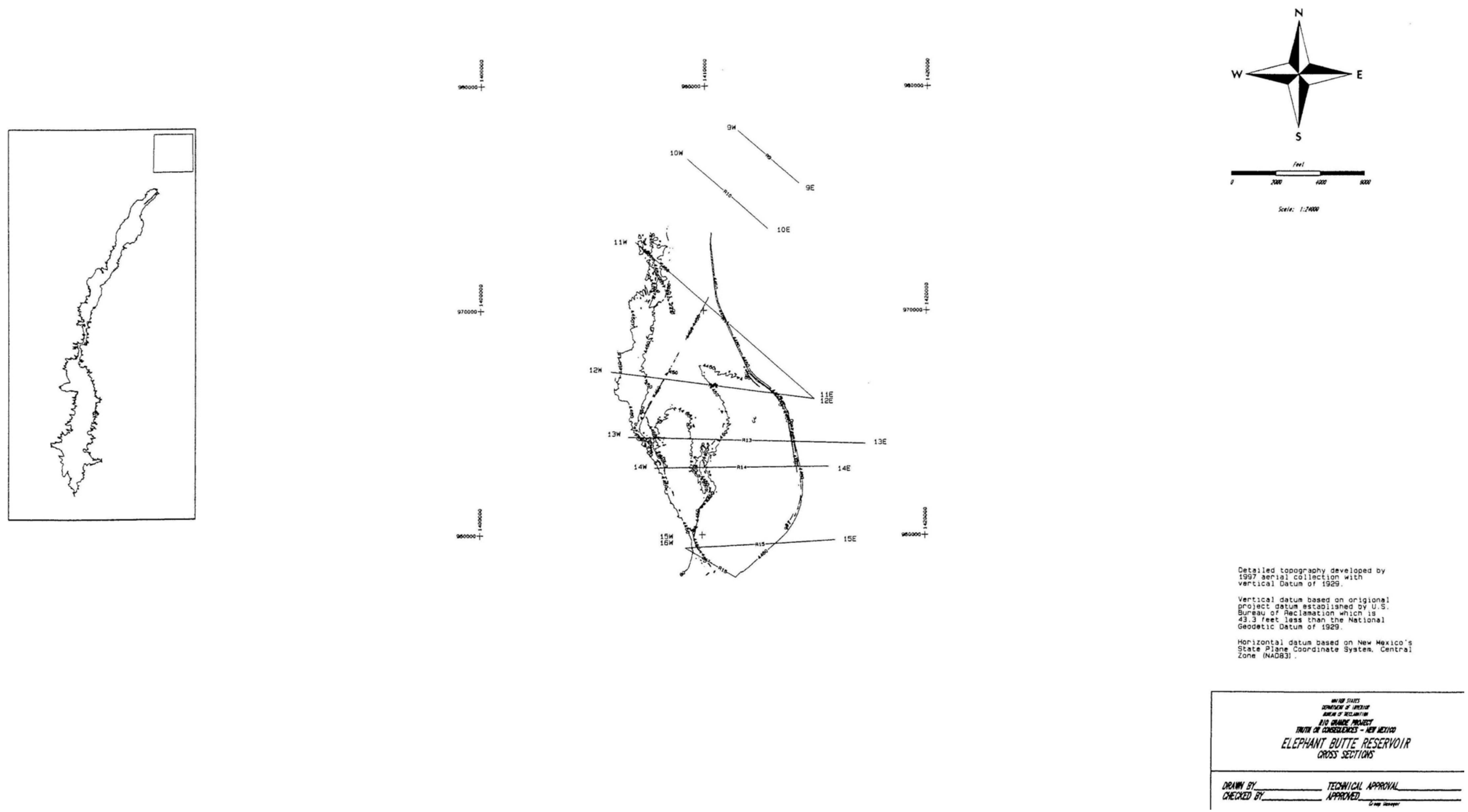

Figure 10 - Elephant Butte Reservoir range line location map, 6 of 6.

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Development of the 2007 Elephant Butte Reservoir Surface Areas

As previously discussed, the 2007 study analysis for computing the reservoir surface areas and resulting capacity used both the range line and contour methods (Ferrari and Collins, 2006). For the 1999 study, the contour method was attempted, but lack of above water data (except for the USGS quad maps) did not allow computation of accurate topography even though the underwater survey was conducted near reservoir full condition (elevation 4,395). Since the 1999 survey, the reservoir content has severely decreased due to the persistent drought in New Mexico. In 2004 the reservoir level dropped to elevation 4,294, exposing previously measured reservoir bottom sediments and allowing them to dewater and compact. The October 2007 reservoir study was conducted near reservoir elevation 4,327 allowing the survey vessel to measure the wetted bottom from range line 90 upstream to range line 65. The remaining upstream range lines have been exposed to the atmosphere since the extreme drawdown except for the wetted perimeter of the river inflows. To complete the 2007 analysis, data collected by contracted surveys were utilized and included:

- 2004 LiDAR data, collected near reservoir water surface elevation 4,300, covered from range line 78 upstream to range line 23

- 2007 LiDAR data covered from range line 23 upstream to beyond range line 9 and the very upper reach of the reservoir

- 2004, 2005 and 2007 range line data that mainly covered the wetted perimeter of several of the range lines using small boat bathymetric systems. For a few reaches, range line land survey data that extended above the water level was collected. The results from these above water surveys were compared with the LiDAR data sets with very good results (Aubuchon, 2005, Appendix I).

The combined LiDAR data sets covered about eighty five percent of the reservoir shore line area, but for consistency with past survey analysis, it was determined the range line width adjustment method would be used to generate the 2007 study results. If future surveys are conducted with the same above water detail, contour volume comparisons may be the best method for computing the updated reservoir capacity and resulting sediment deposition.

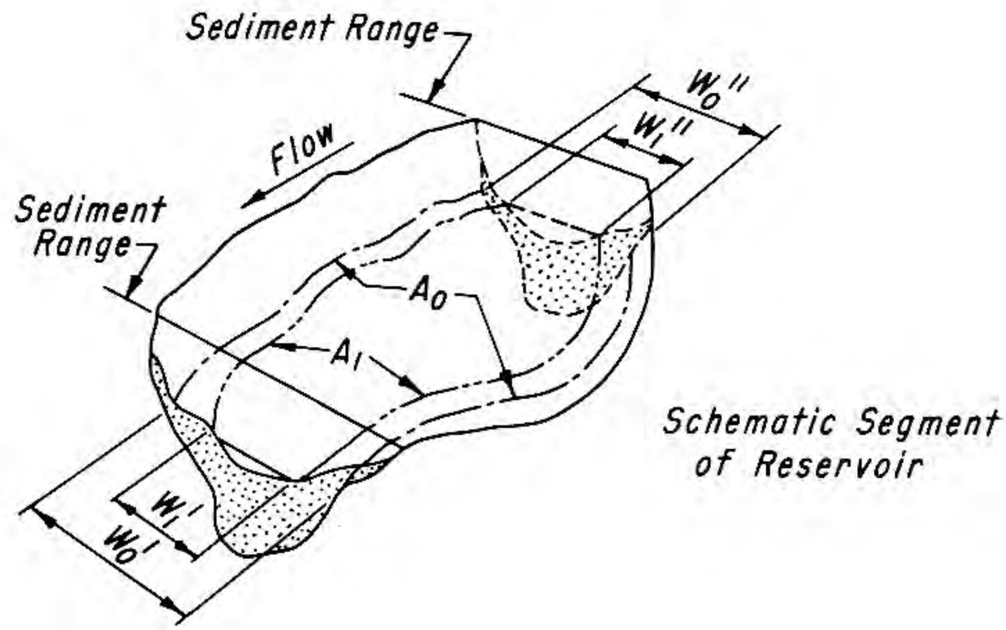
Width adjustment method

For some of the previous Elephant Butte Reservoir resurveys, new contour maps were drawn from the range-line survey data. These contours between the collected range-lines for the updated maps were drawn using the original contour map as a guide or control and estimating the new contour location based on changes that occurred at each range-line. This method was eventually abandoned for the constant factor method, which was further modified to the width adjustment method (Ferrari and Collins, 2006). Since the 1980 study, some form of the width adjustment method has been used for the Elephant Butte Reservoir analysis.

In the width adjustment method, illustrated on Figure 11, the new contour area, A_1, between any two ranges is computed by applying an adjustment factor to the original contour area, A_0, between the two ranges. This adjustment factor is defined as the ratio of the new average width to the original average width for both upstream and downstream ranges at the specified contour. The revised segmented surface areas for each contour are then summed for the whole reservoir. The summarized segmented surface area versus elevation becomes the basic input for volume computations.

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

On the original full scale base topography map of the reservoir, finalized location of all reservoir sediment ranges were marked. This divided the reservoir into storage segments defined 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 water surface of 4,410.0 to the lowest contour area within each segment. For the original and 2007 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 2007 surface areas used in the area-capacity computations.



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

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

Figure 11 - Width adjustment method for revising contour areas.

Reservoir Sediment Distribution

Lateral Distribution

Ground profiles of the 82 reservoir sedimentation ranges are shown on Figures 12 through 94. 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, 1999, and 2007 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 79 through 90, the results from the 1988 survey were used to develop the range line plots for the areas not covered by the1999 survey.

Using tools within ARCGIS, the 2007 cross sections were located and profiles were developed by cutting lines through the surveyed data points. The routine stored the nearest data points along each sediment range line alignment. The stored point density, within 5 feet of the projected range line alignment, was dependent on available data near the cross section, which for the LiDAR data sets was very dense. This routine was used for range lines 9 through 78 where LiDAR was available, and from the plots one can see a very good comparison throughout the range lines. The LiDAR produced portions of the range lines compared very well along the steep banks of the 1999 plots that were developed from the 1988 land survey data and one would not expect change there due to sediment deposition. To account for changes at each range line, the latest bathymetric survey data was inserted into the LiDAR developed range lines. For range lines 65 through 78 this included the October 2007 bathymetry. For most cases upstream of range line 65, data inserted into the LiDAR included the changes in the inflowing river channel geometry from the contract surveys of some of the range lines (the latest contract surveys were also conducted in 2007).

The range line plot comparisons illustrate some interesting results when comparing the 1999 and 2007 survey results. The plots appear to indicate minimal change from range line 90 upstream through range line 73, but the 2007 computations did measure a small increase of sediment volume in this portion of the reservoir. From range line 72 upstream through 65, located in the upper reach of the reservoir pool during the time of the 2007 survey, a delta has formed since the 1999 survey. This is the area where the reservoir widens significantly downstream of the “Narrows,” meaning the inflow velocities decrease and inflowing sediments deposit, forming a new reservoir delta.

The range line plots upstream of 65 show varied results with the 2007 sediment level plotting below the 1999 results in many cases. This is likely due to significant compaction or consolidation of the previous deposited sediments that occurred since 1999 from the long exposure and drying out during the recent low reservoir content period. In some cases the average consolidation across the range line was as much as five feet. As shown on some of the plots, the river has scoured the previously deposited sediments in these upper range lines during this period of low reservoir content, but the biggest impact on the 2007 capacity computations resulted from the large areas of sediment consolidation that increased the reservoir volume of these portions of the reservoir. This is not the first time this significant consolidation has occurred. The 1957 survey was conducted after an extended drought and ten years after the last survey in 1947. The 1957 study measured an increase in total reservoir volume since the 1947 survey of over 9,000 acre-feet (Bureau of Reclamation, 1960).

Also apparent on the plots are the low flow conveyance channel dikes that have been developed over the years to convey river inflows to the reservoir. Channelization in the headwaters of Elephant Butte Reservoir began in the 1950s when severe drought conditions and salt cedar infestation resulted in the river channel becoming disconnected from the reservoir pool. The river disconnection has always been an issue at the headwaters of Elephant Butte. Some of the contributing factors for the occurrence of disconnection are the valley slope being very slight, the incoming sediment load high, and vegetation growth extremely aggressive. During dry climactic periods when the reservoir pool surface area decreases rapidly, all of these factors make it difficult for the river channel to cut its own channel to the reservoir pool.

With the channelization work 1950s and the 1960s, in combination with an increasing reservoir pool, the river was able to maintain a connection of its own until the early 1990s when New Mexico entered another period of dry conditions, resulting in the construction of two temporary channels. In the summer of 2000, construction began on additional temporary channels which are illustrated on the following plots.

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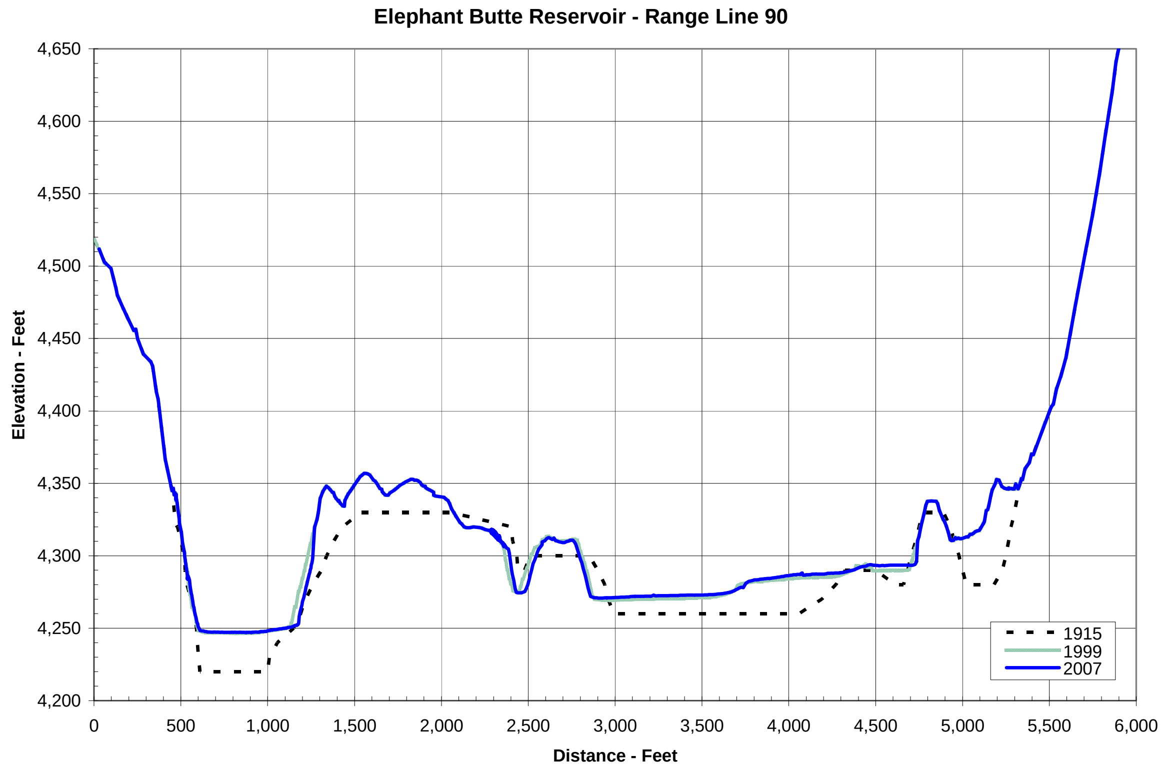


Figure 12 - Range Line 90.

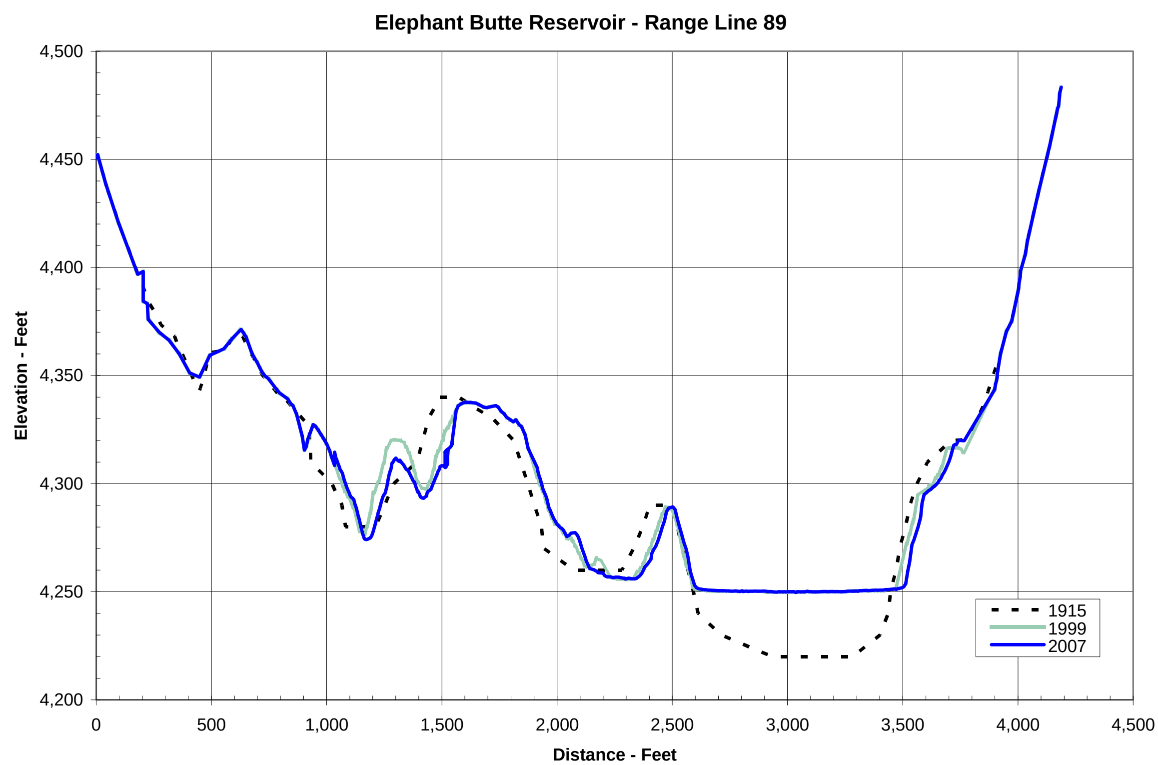


Figure 13 - Range Line 89.

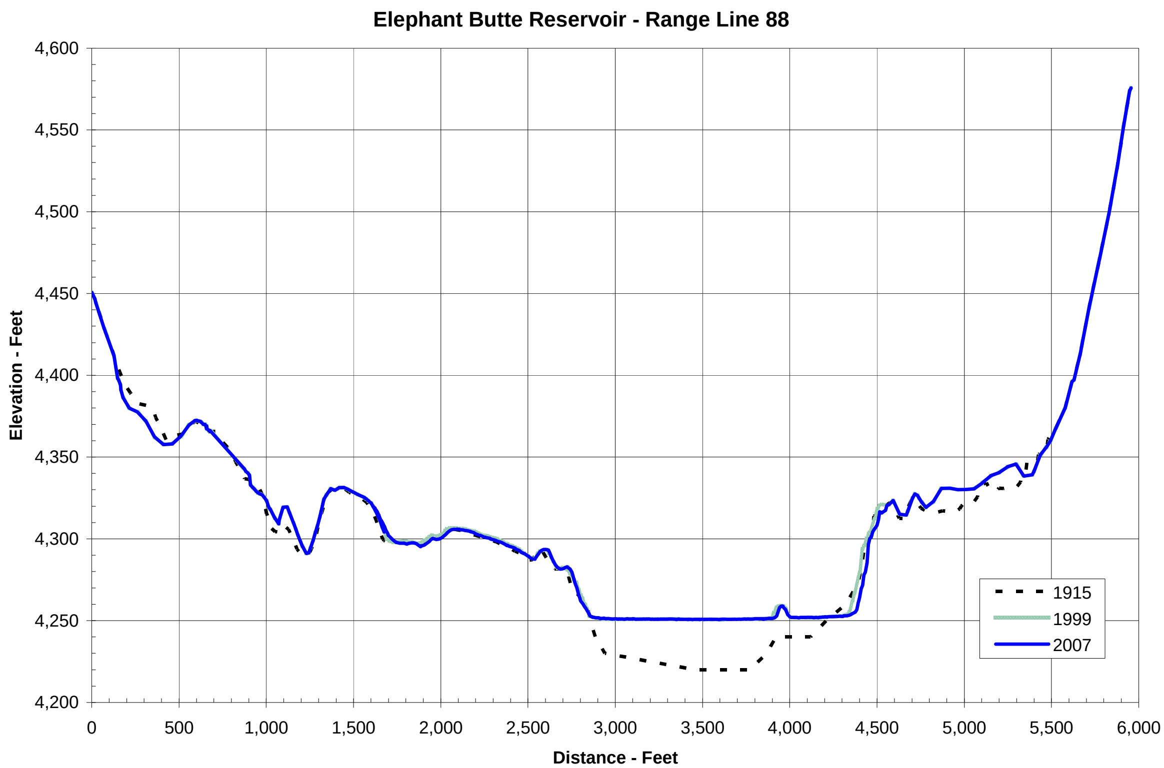
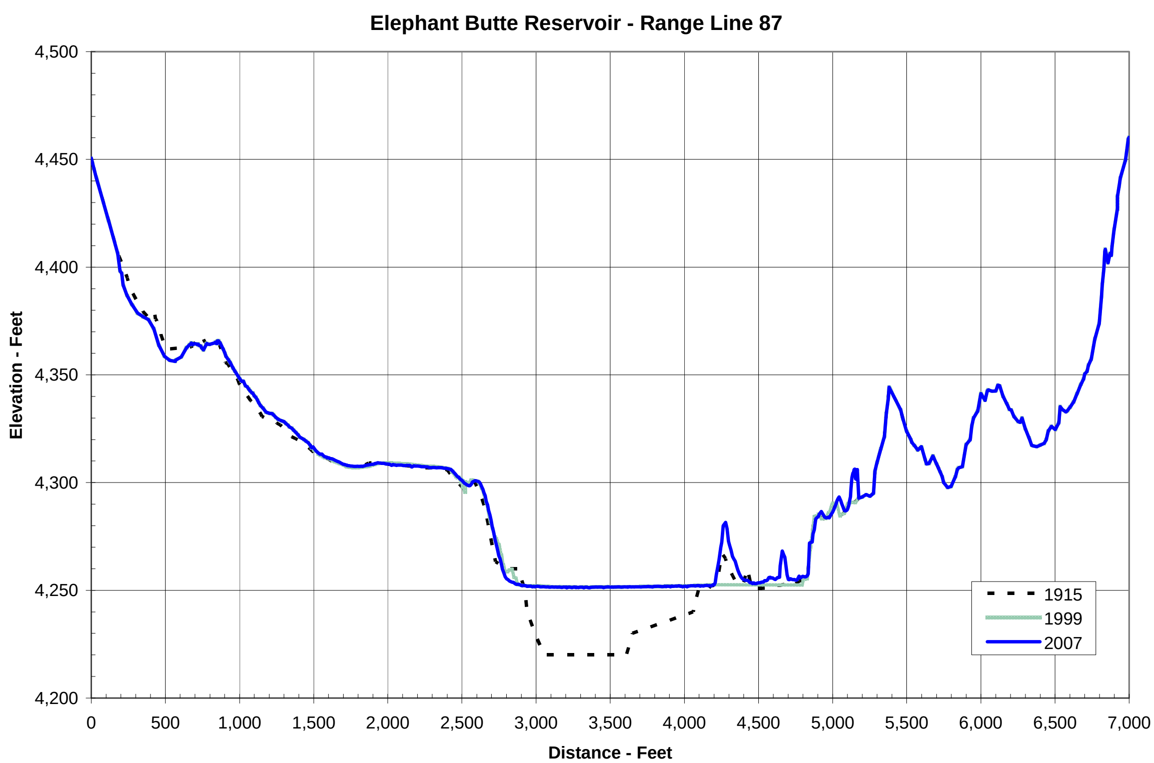


Figure 14 - Range Line 88.



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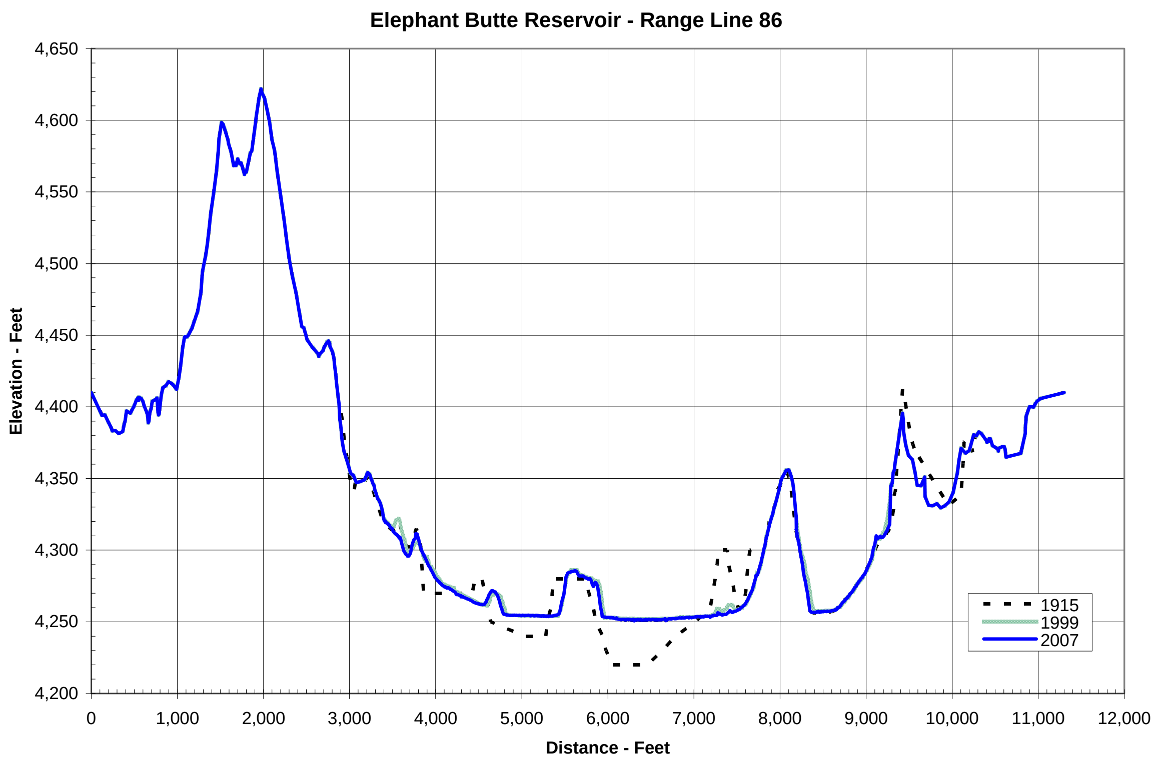

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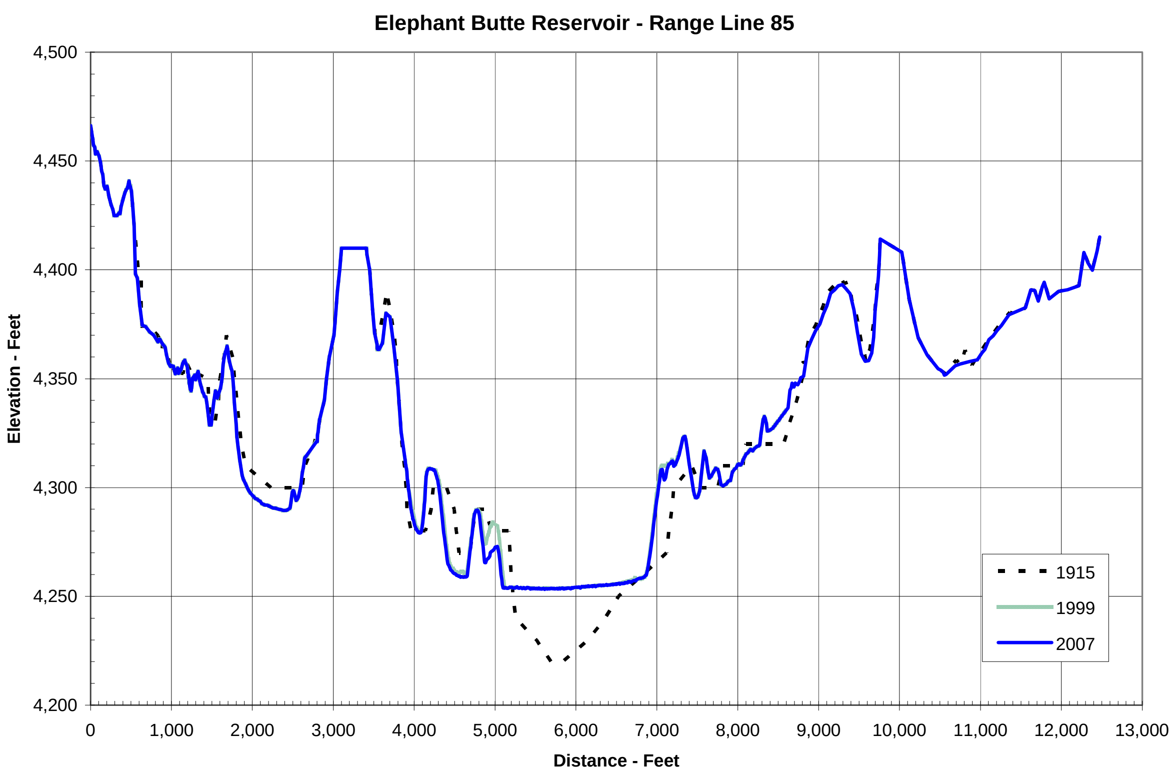

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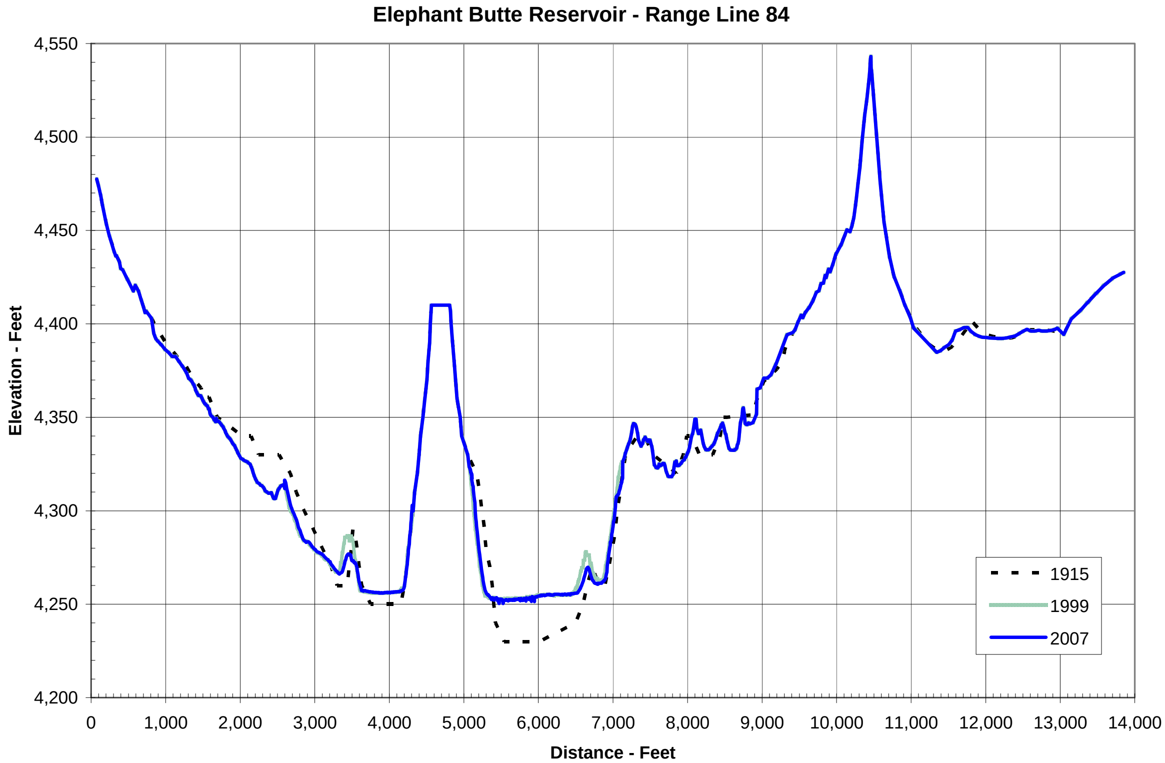
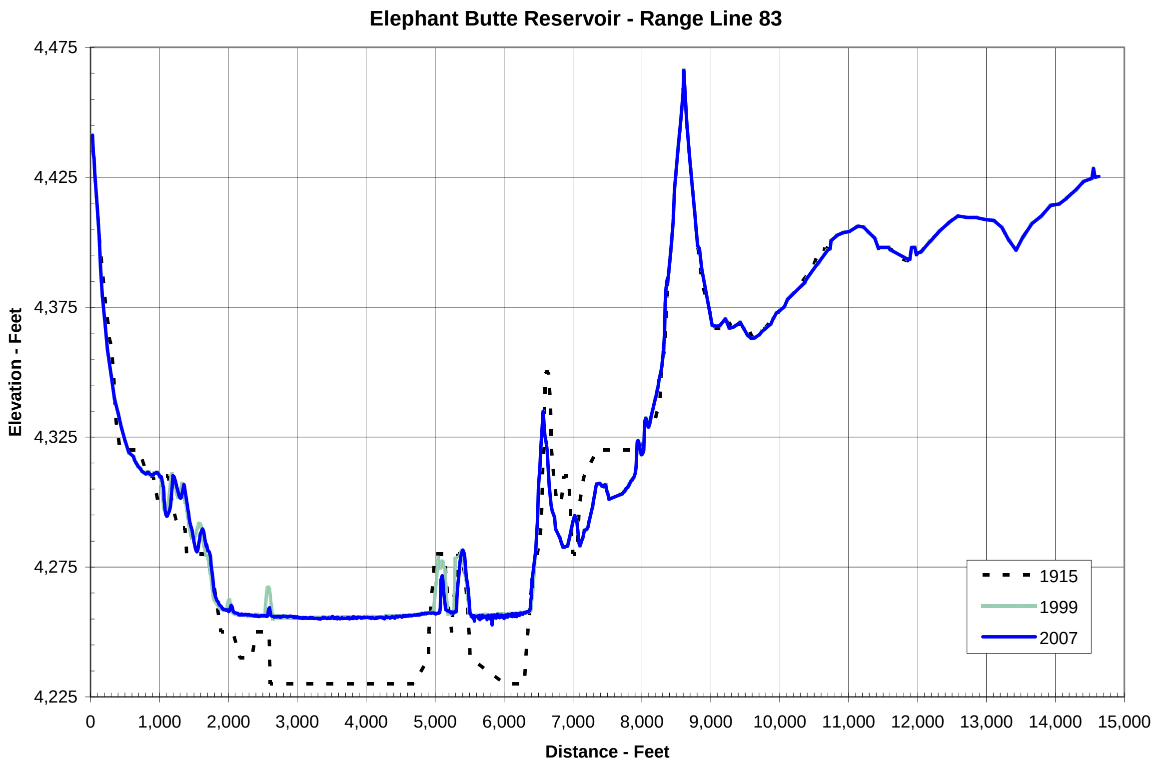


Figure 18 - Range Line 84.



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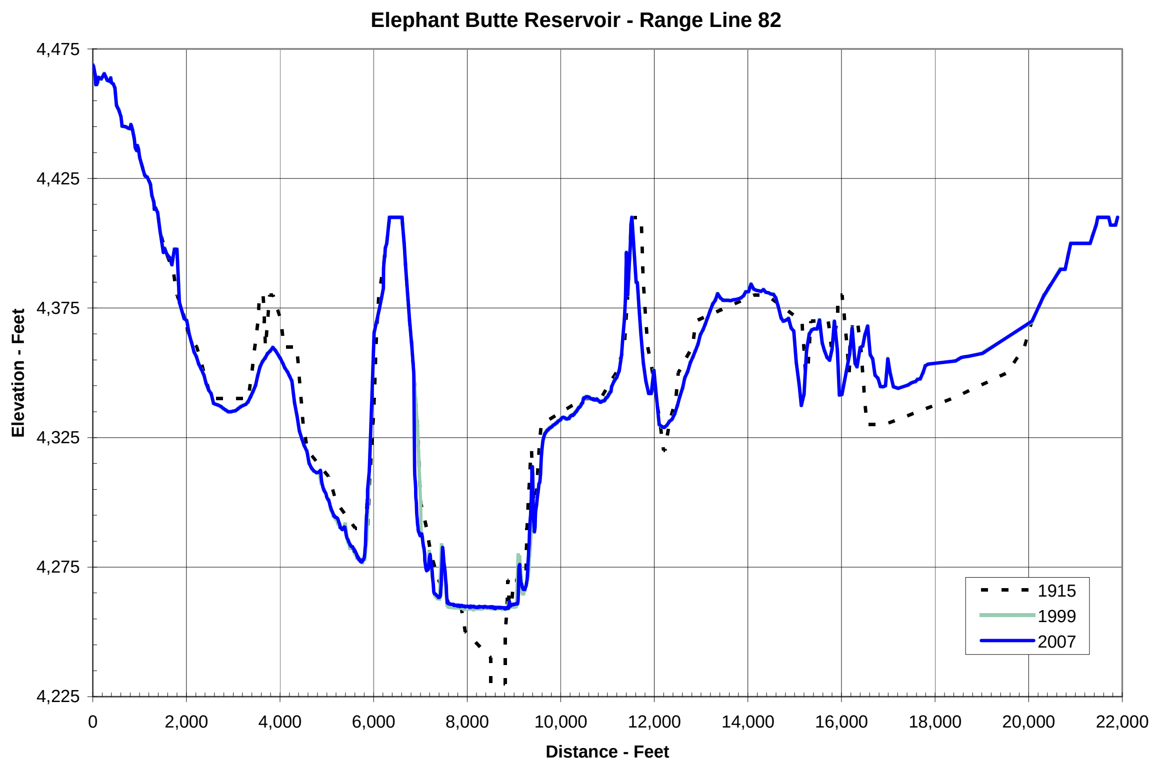

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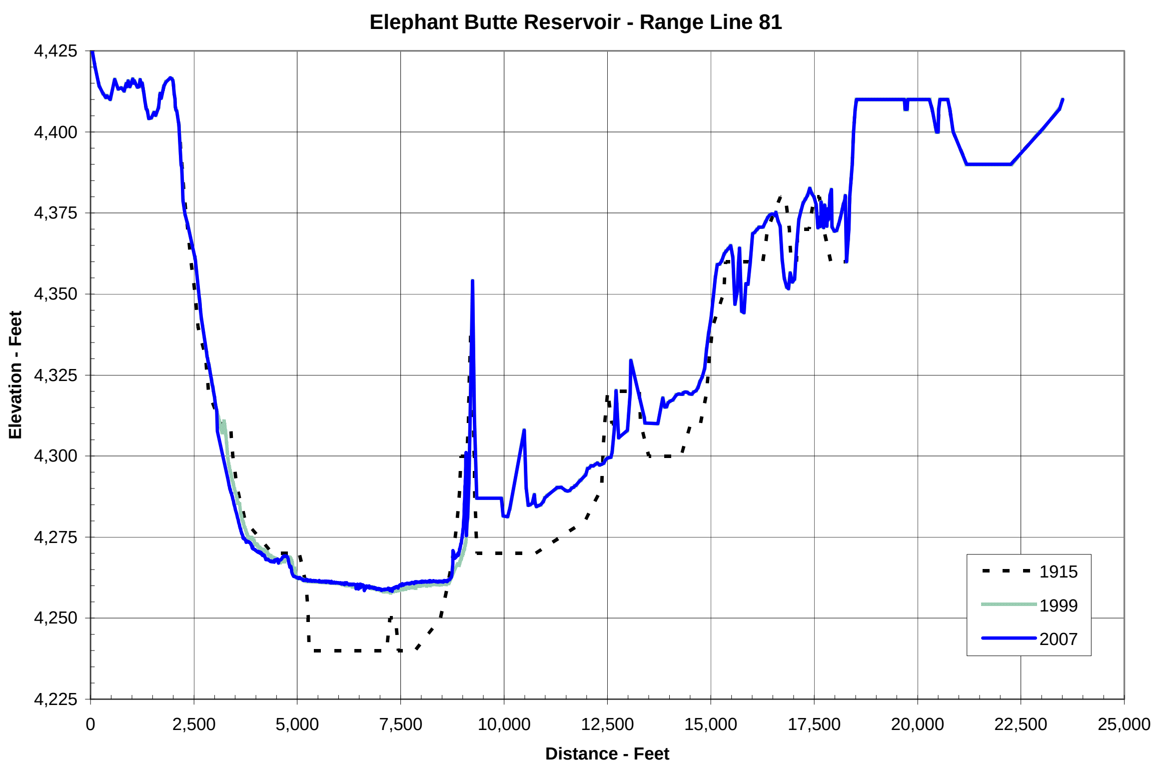

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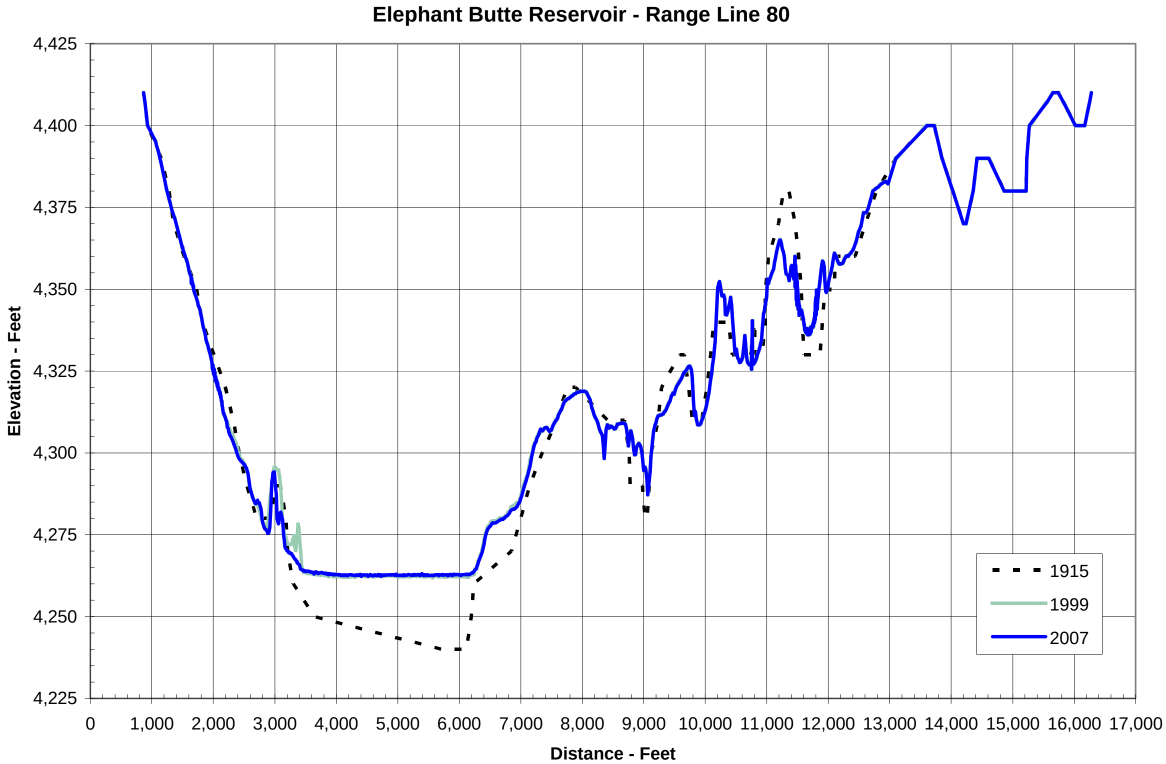

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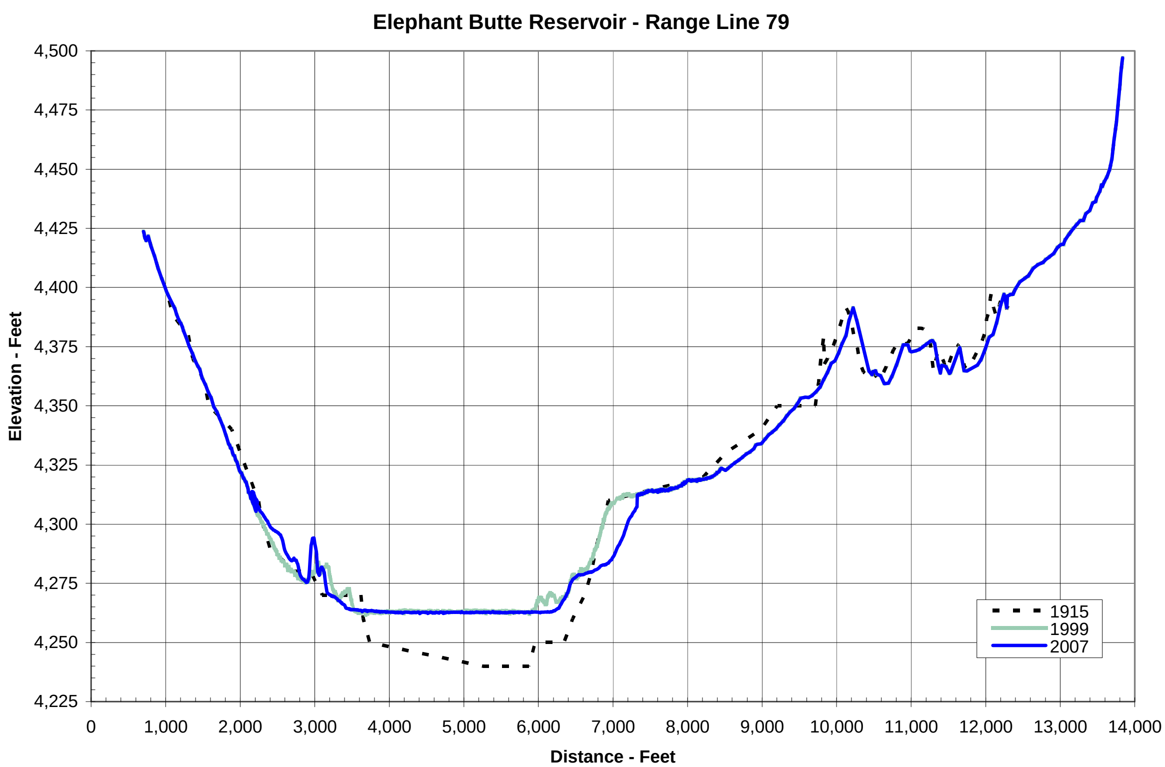

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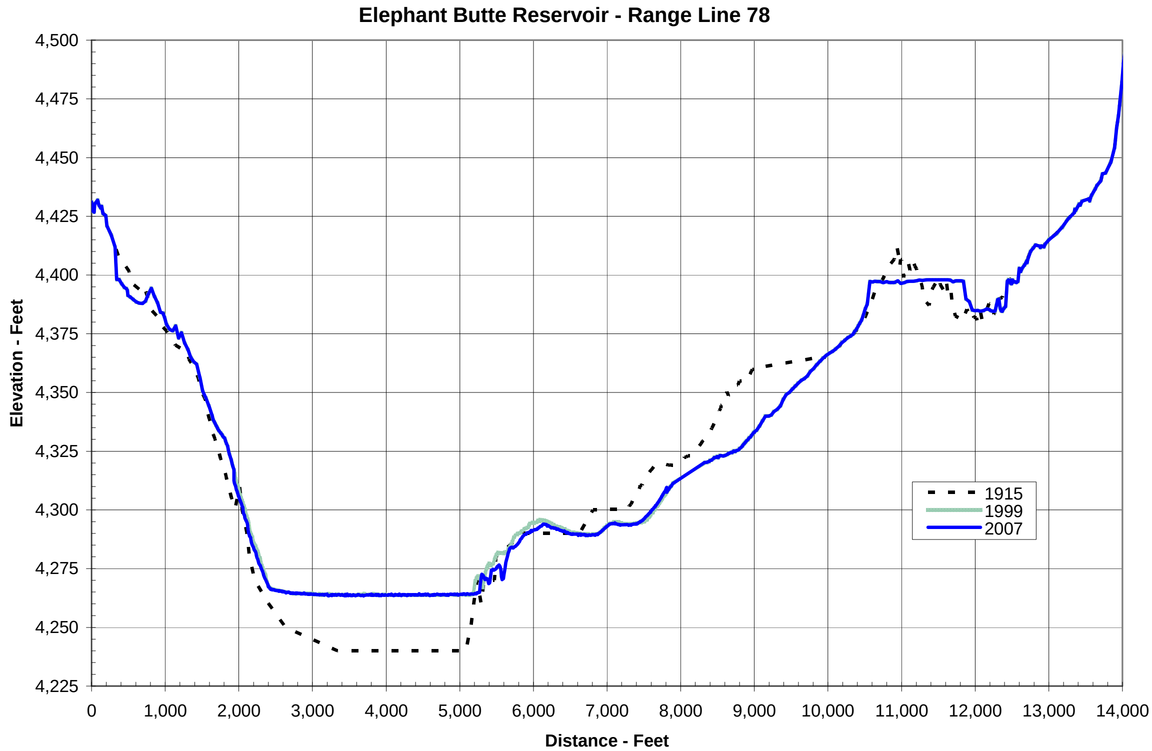

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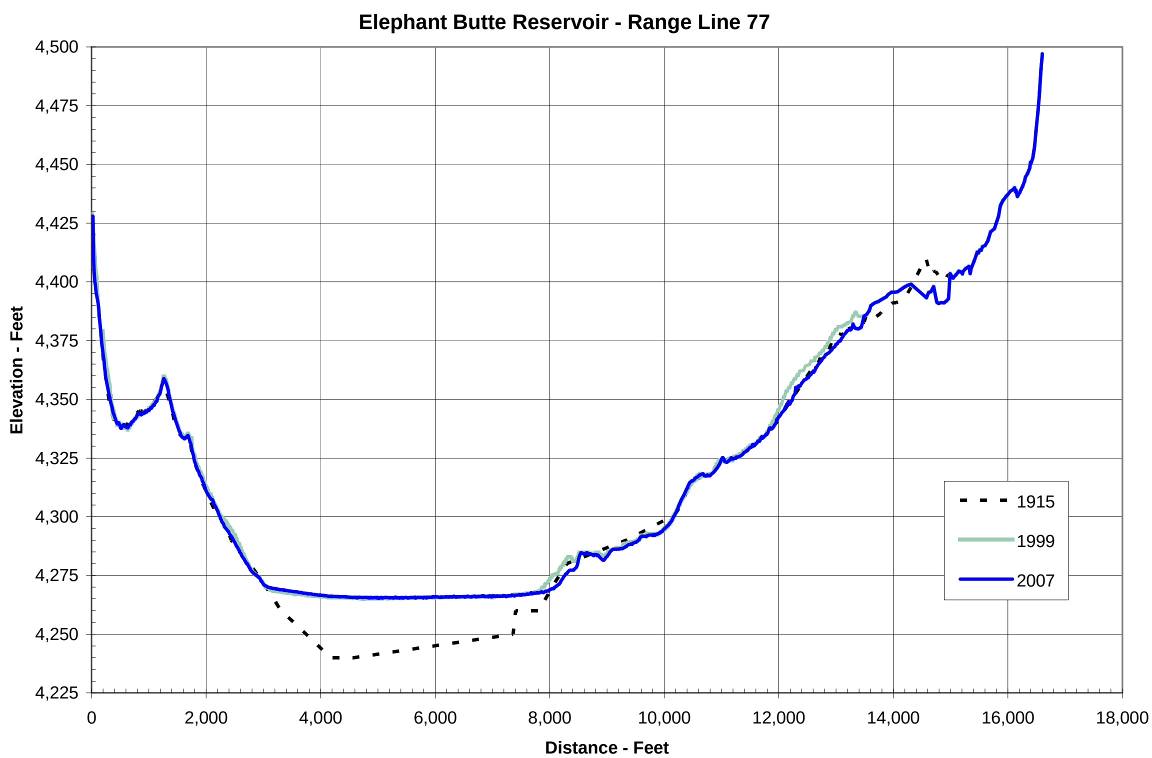

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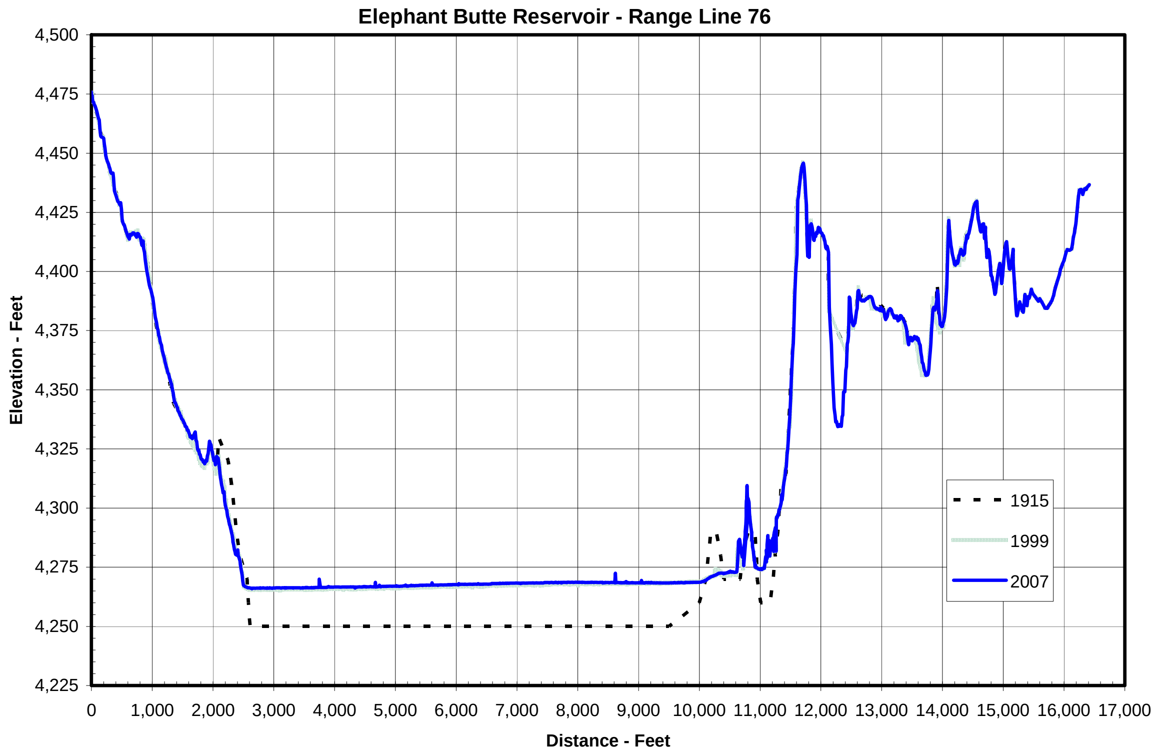

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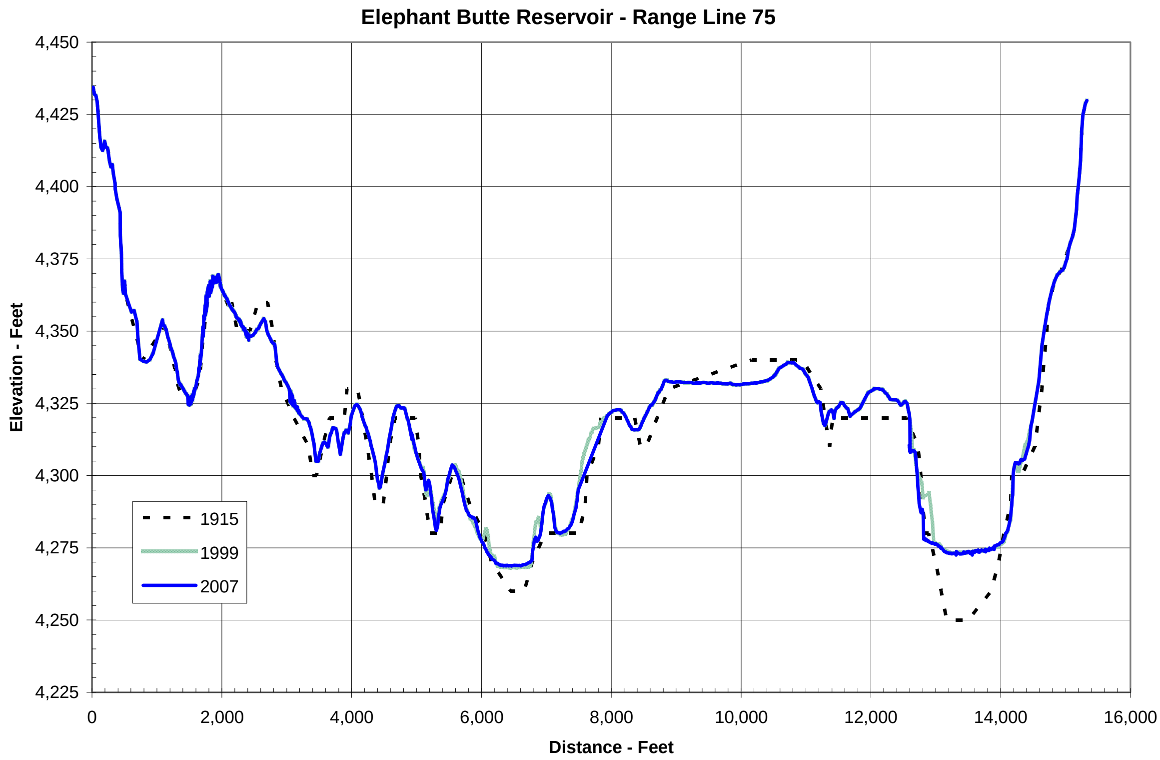

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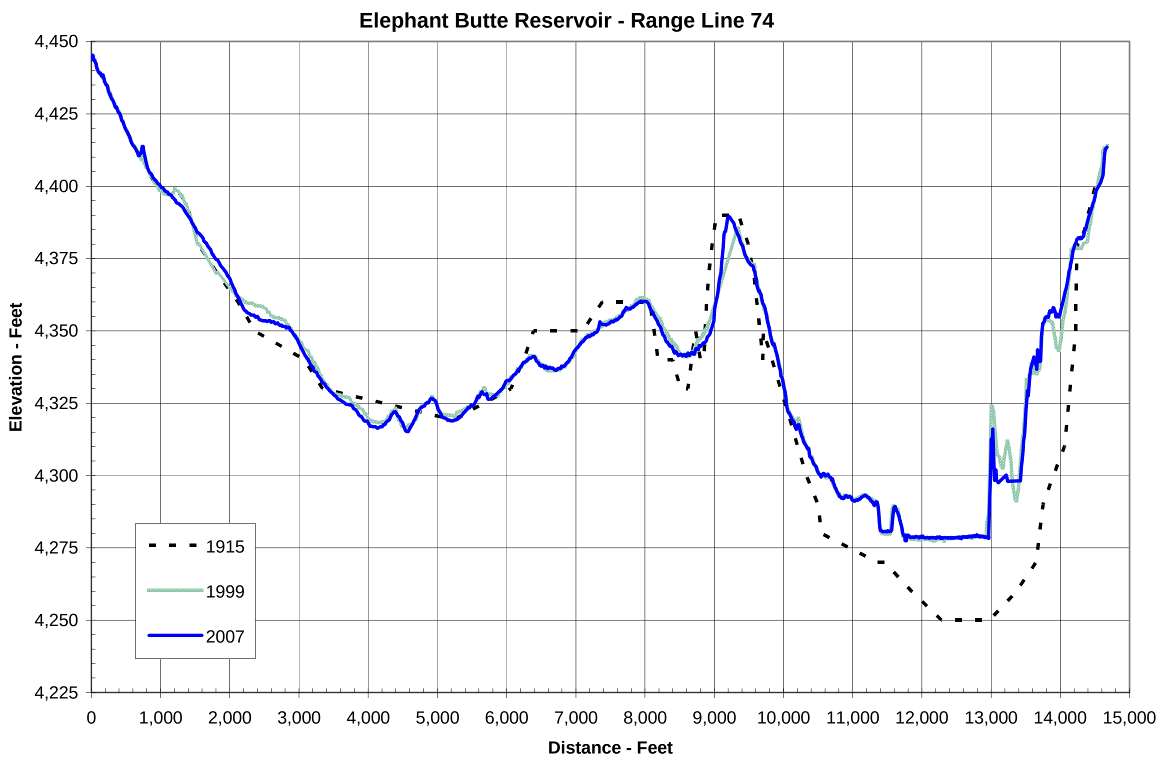

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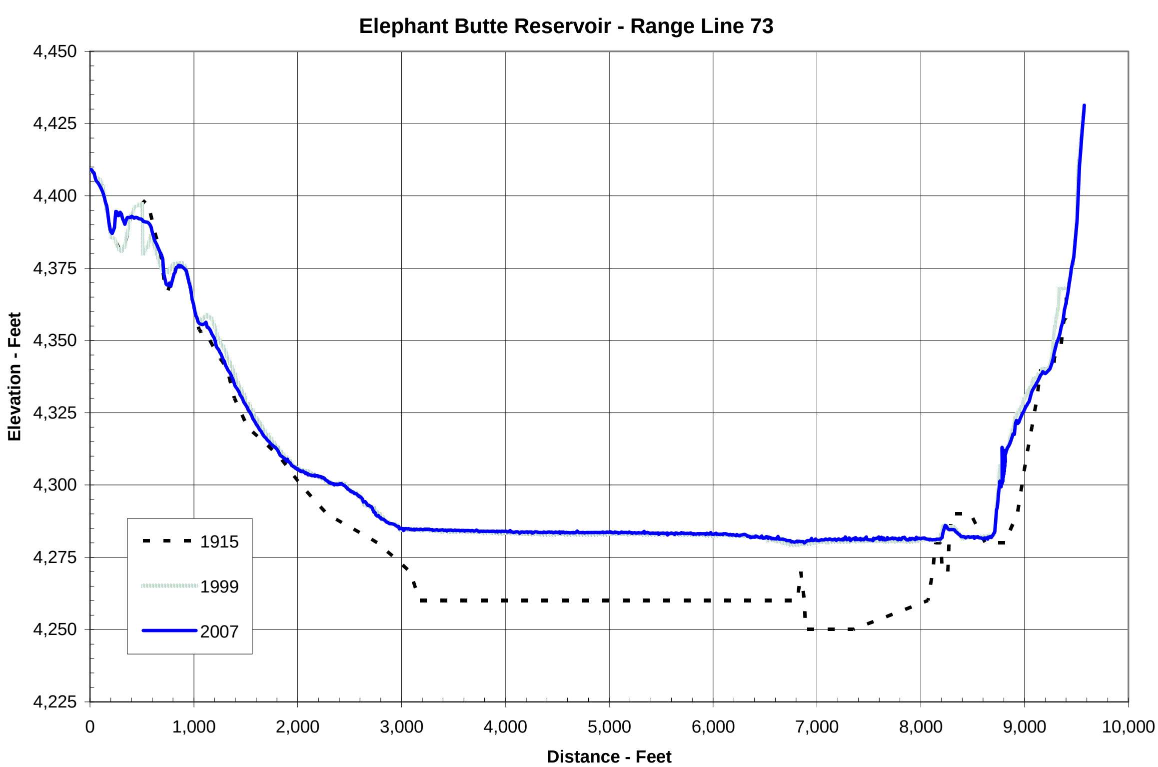

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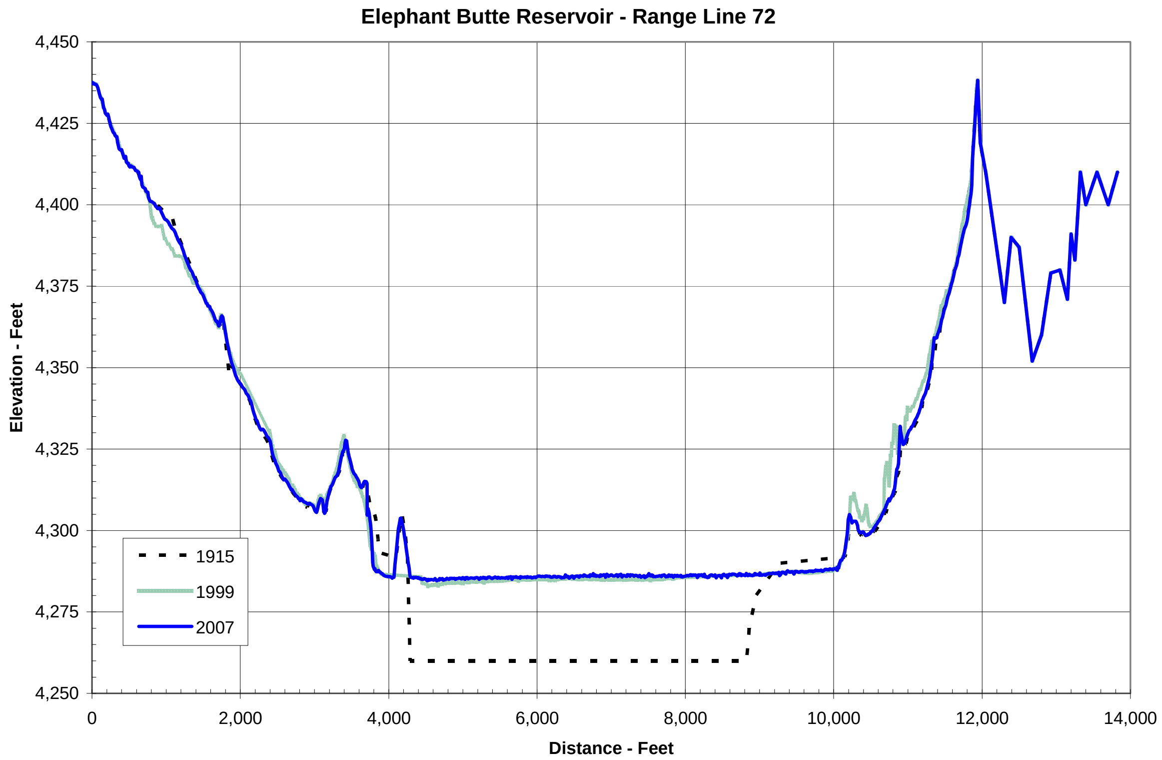

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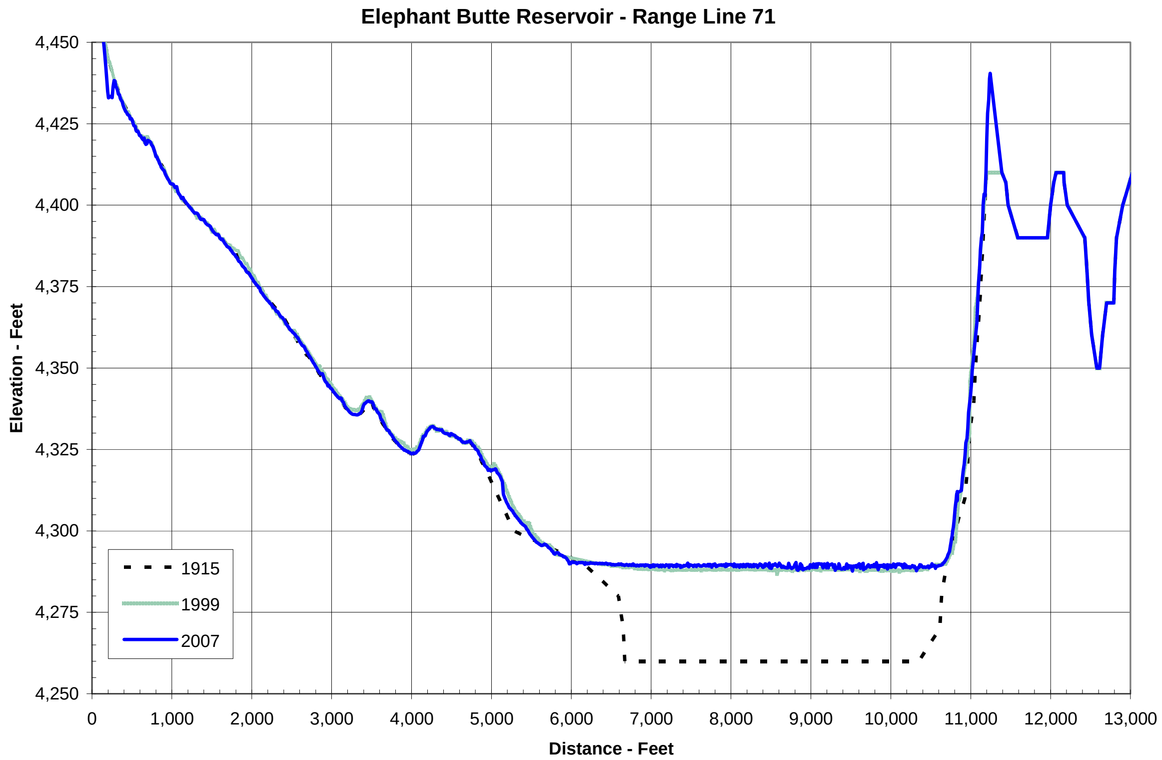

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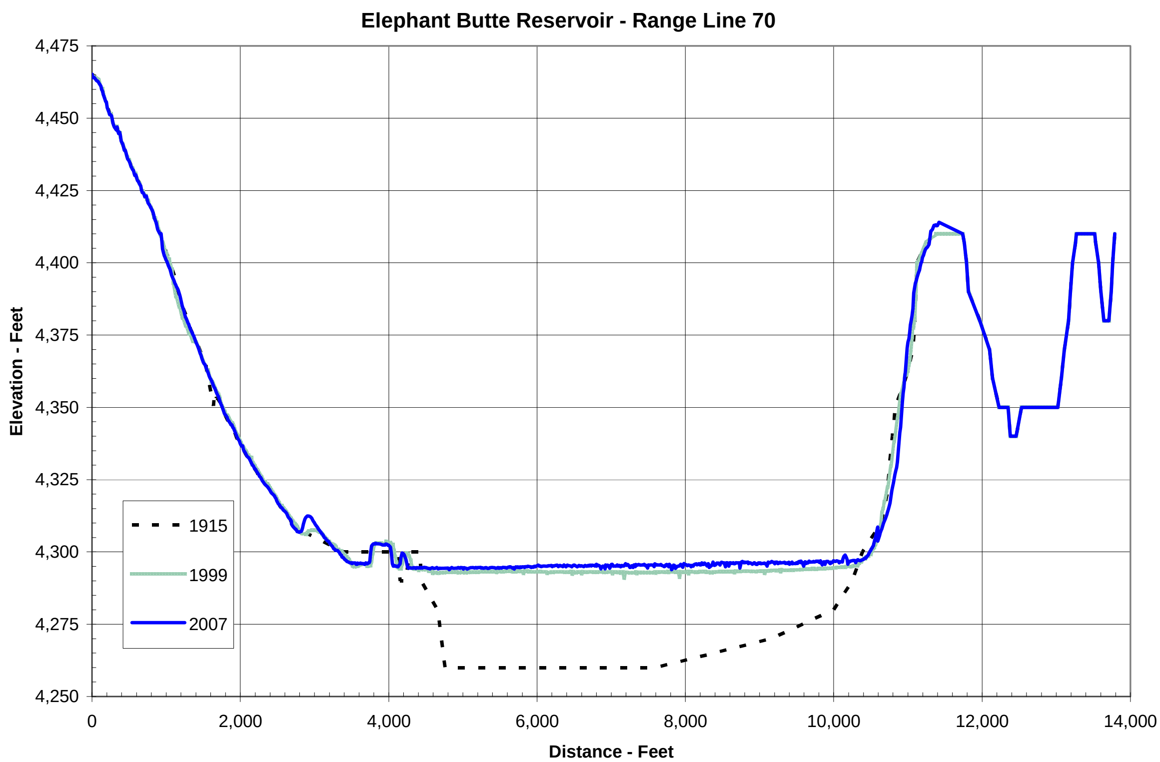

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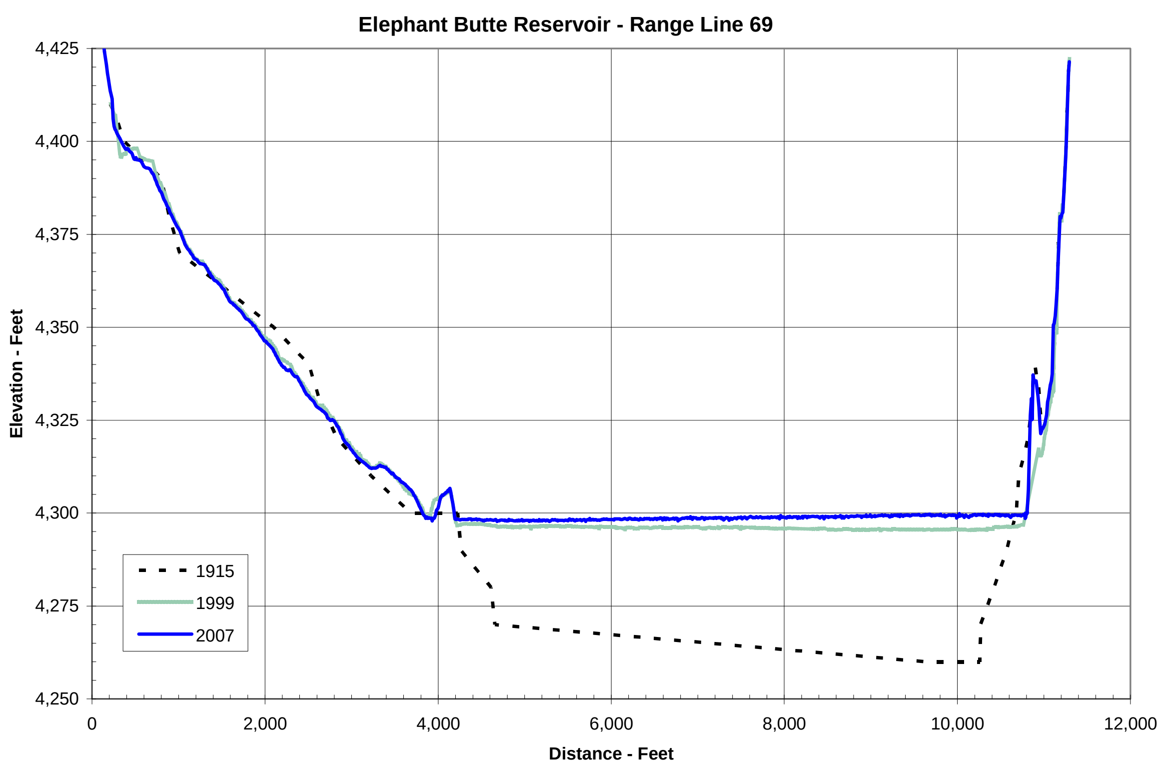

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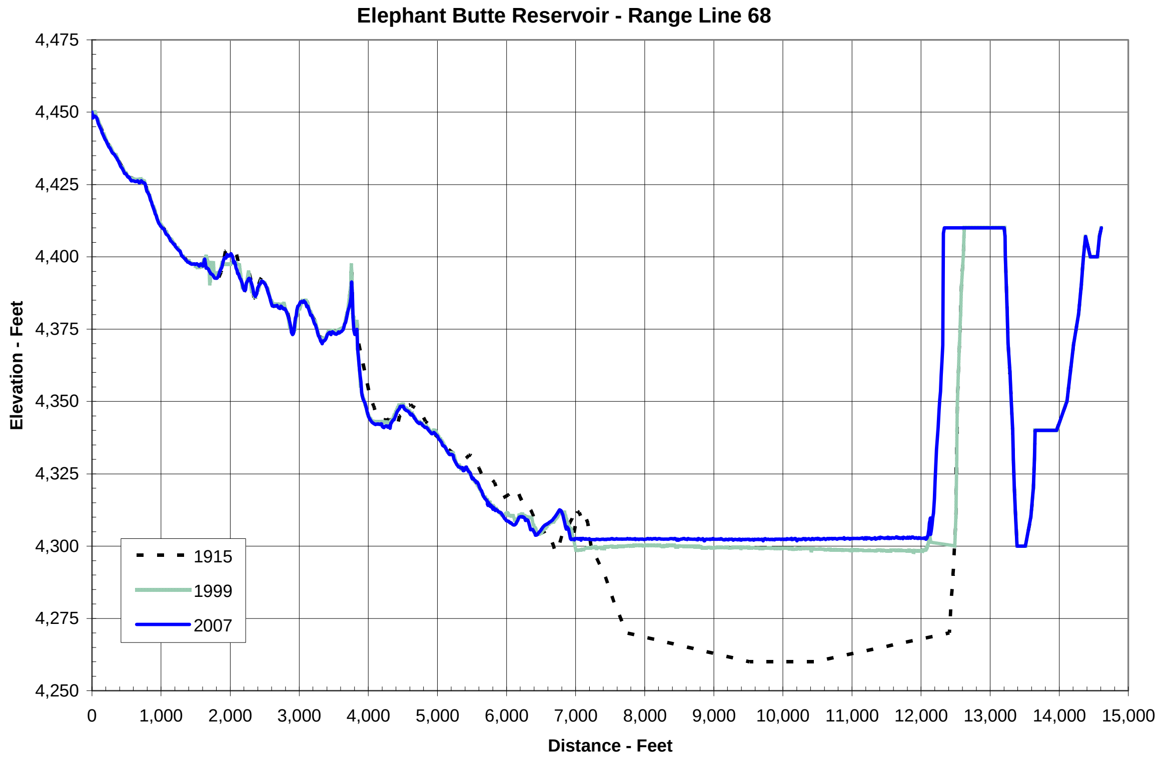

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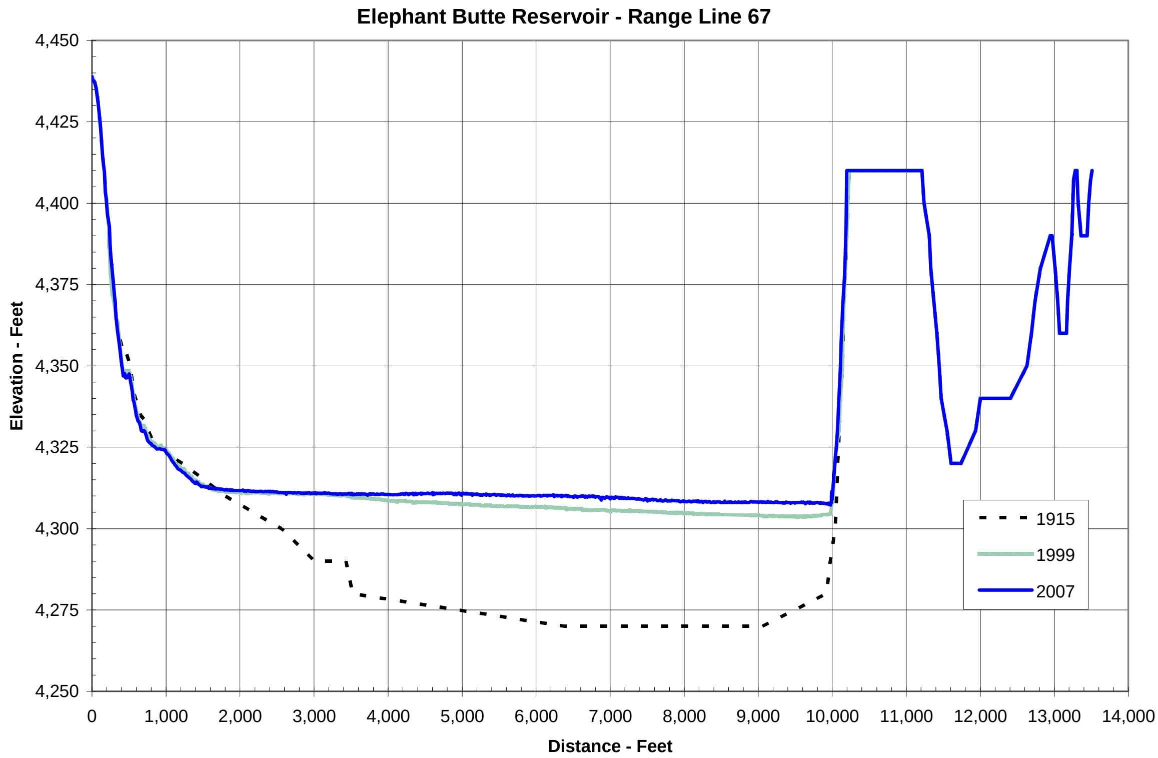

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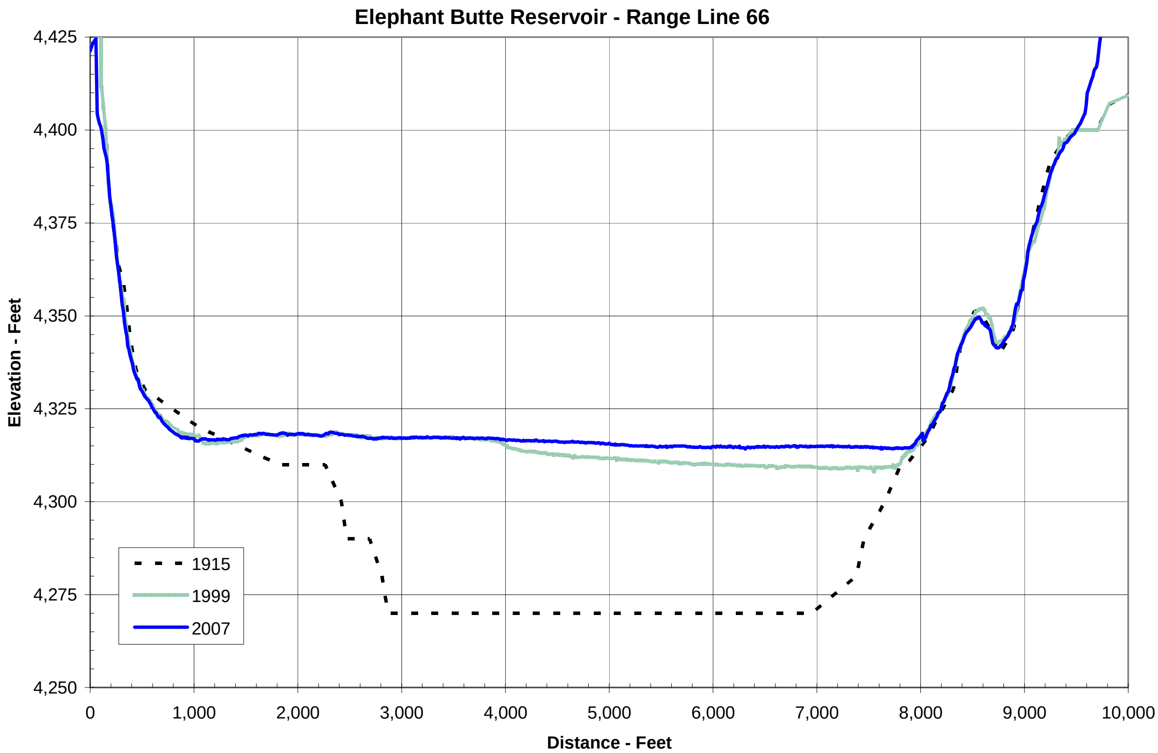

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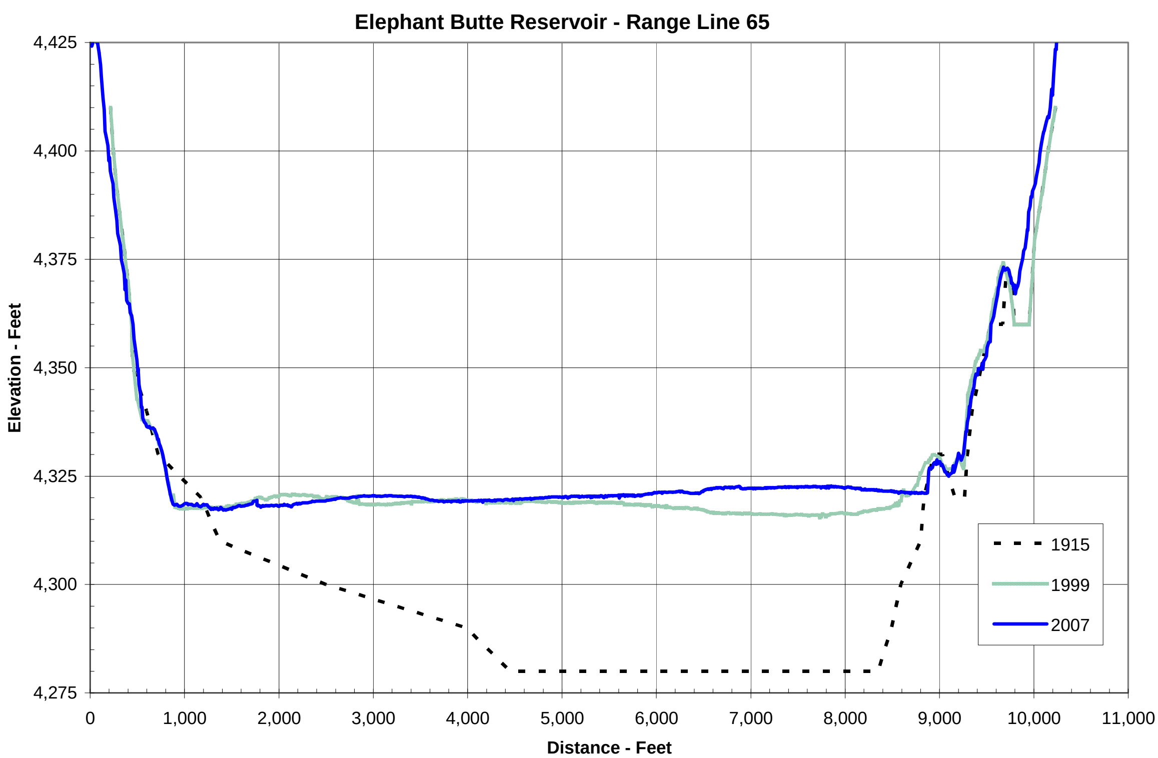

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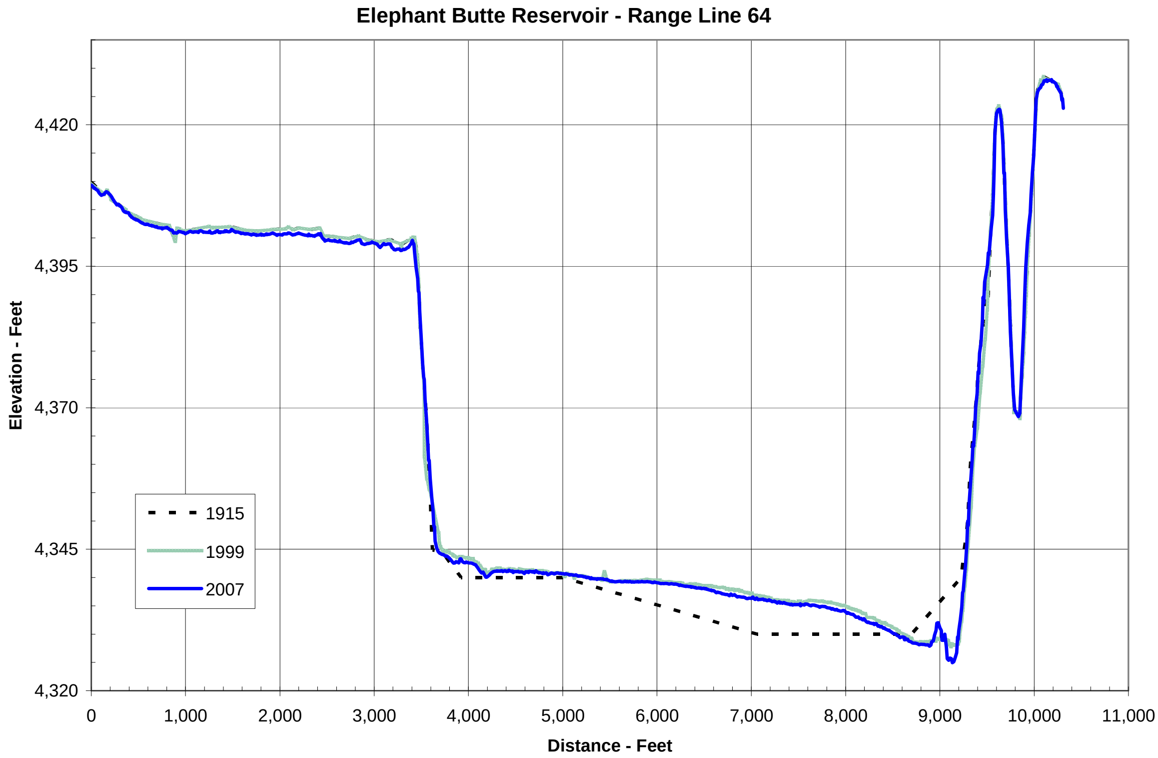

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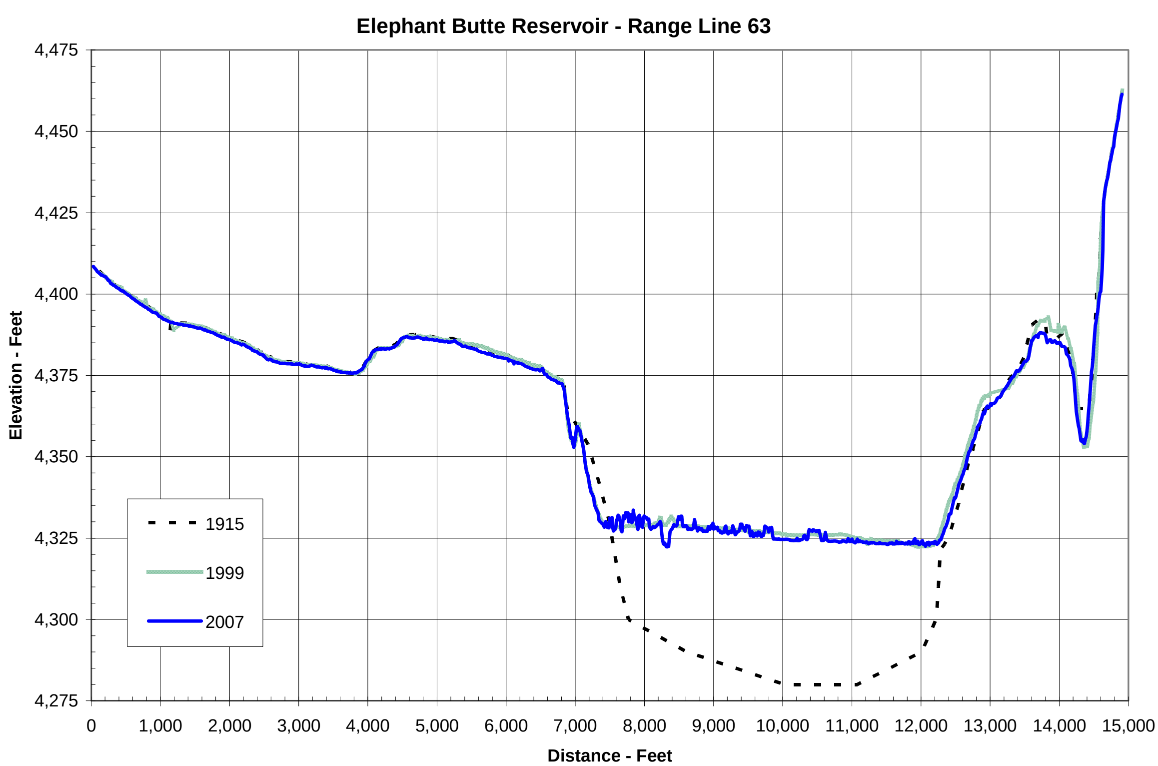

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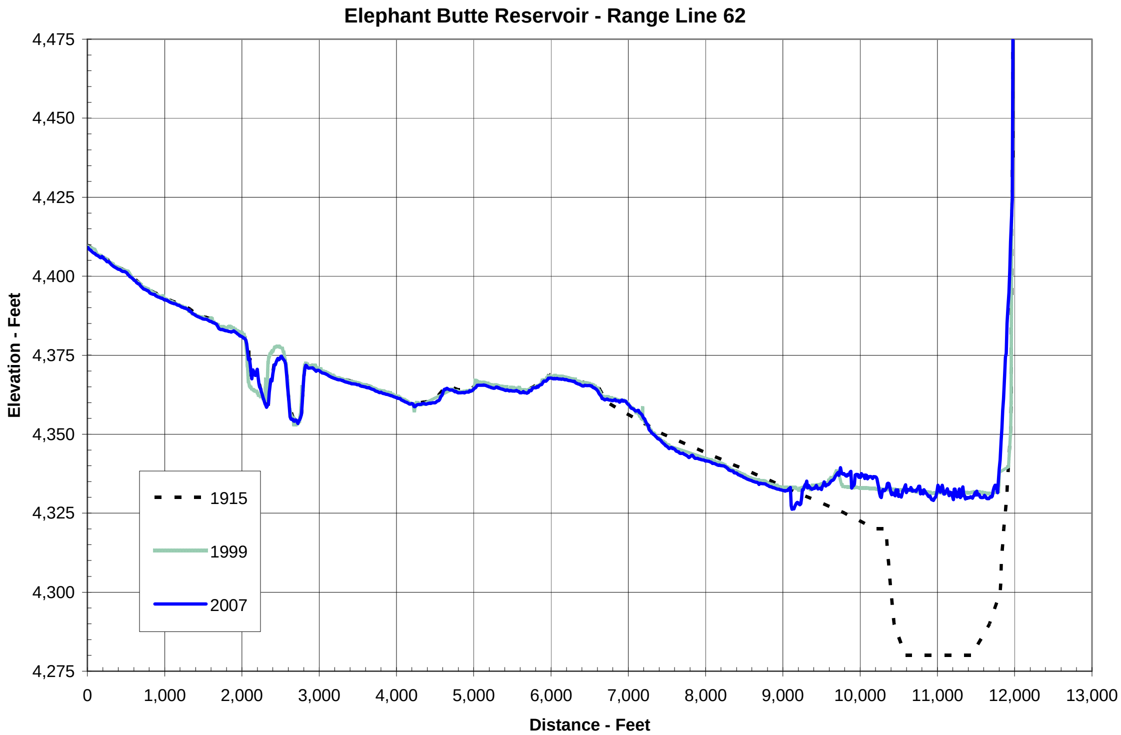

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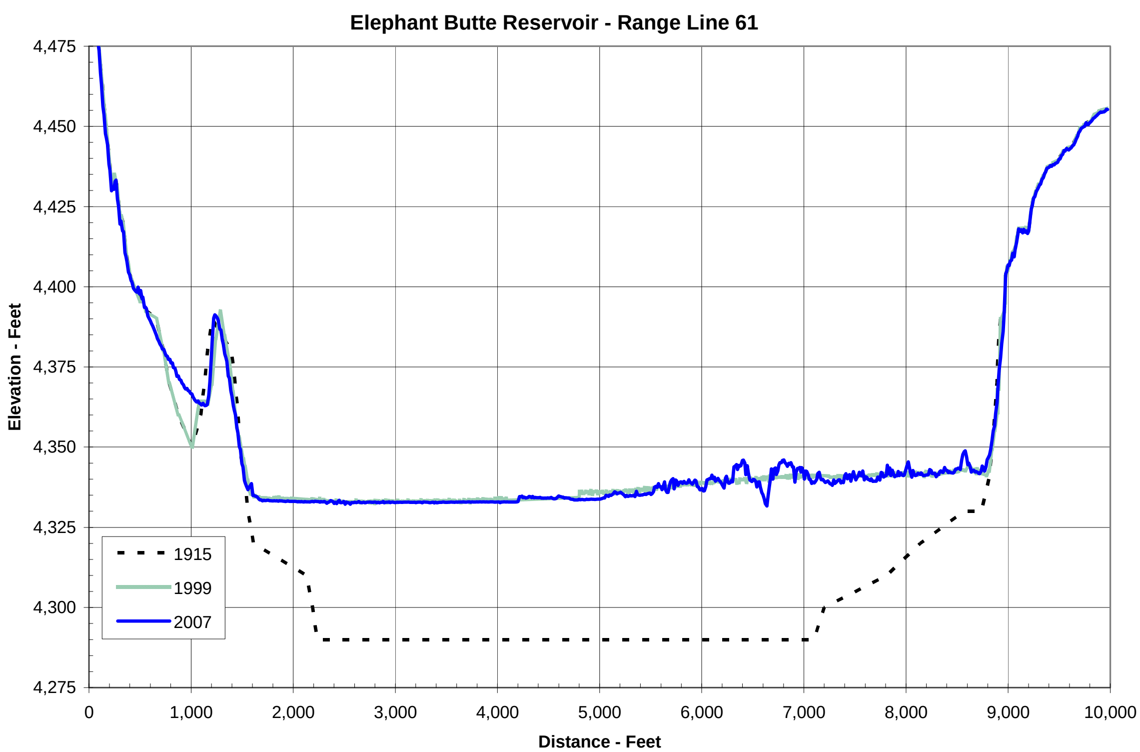

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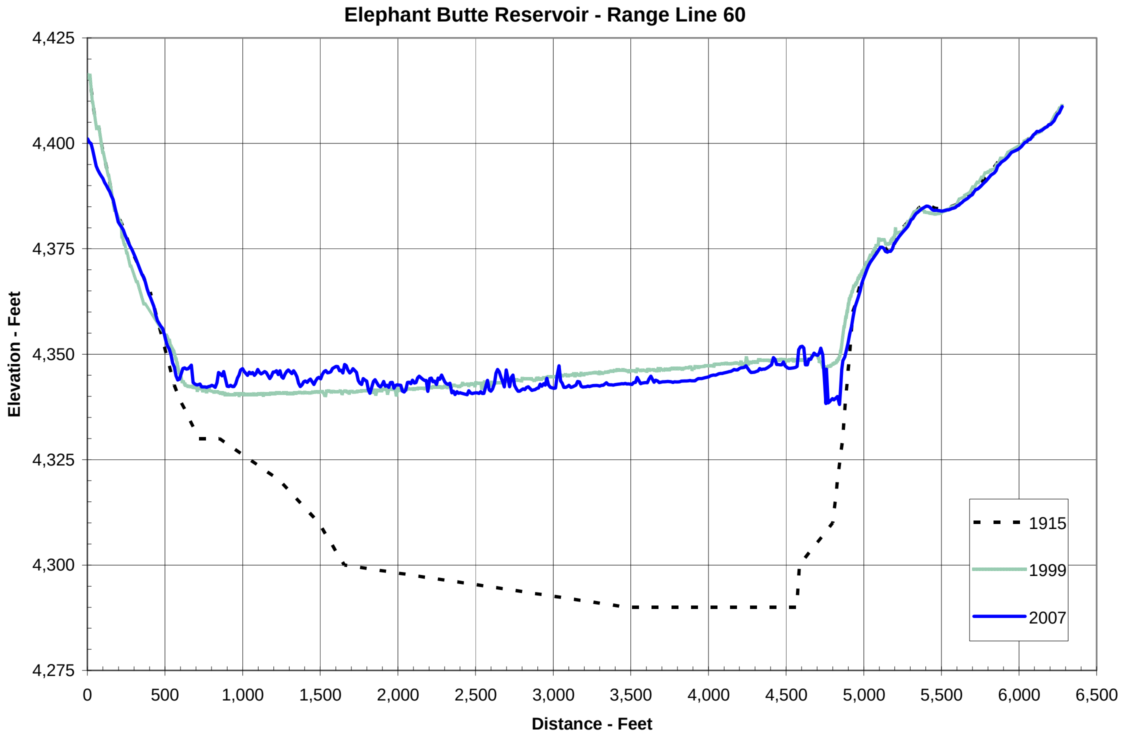

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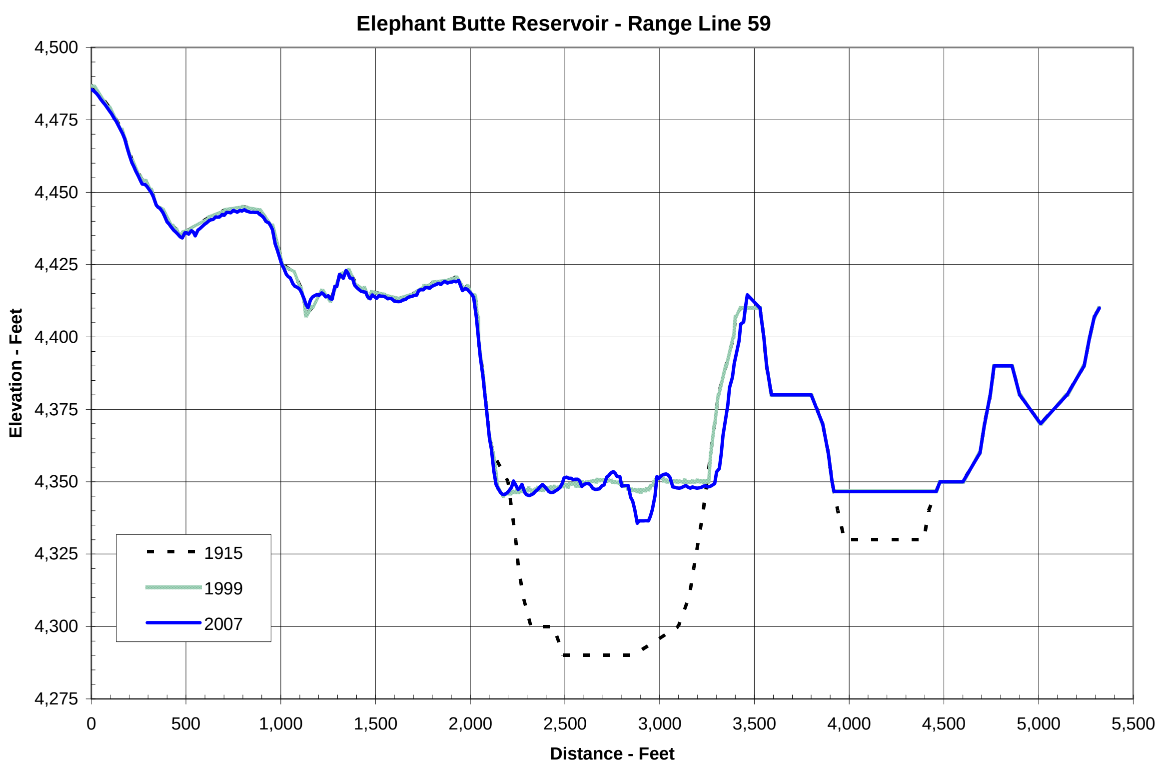

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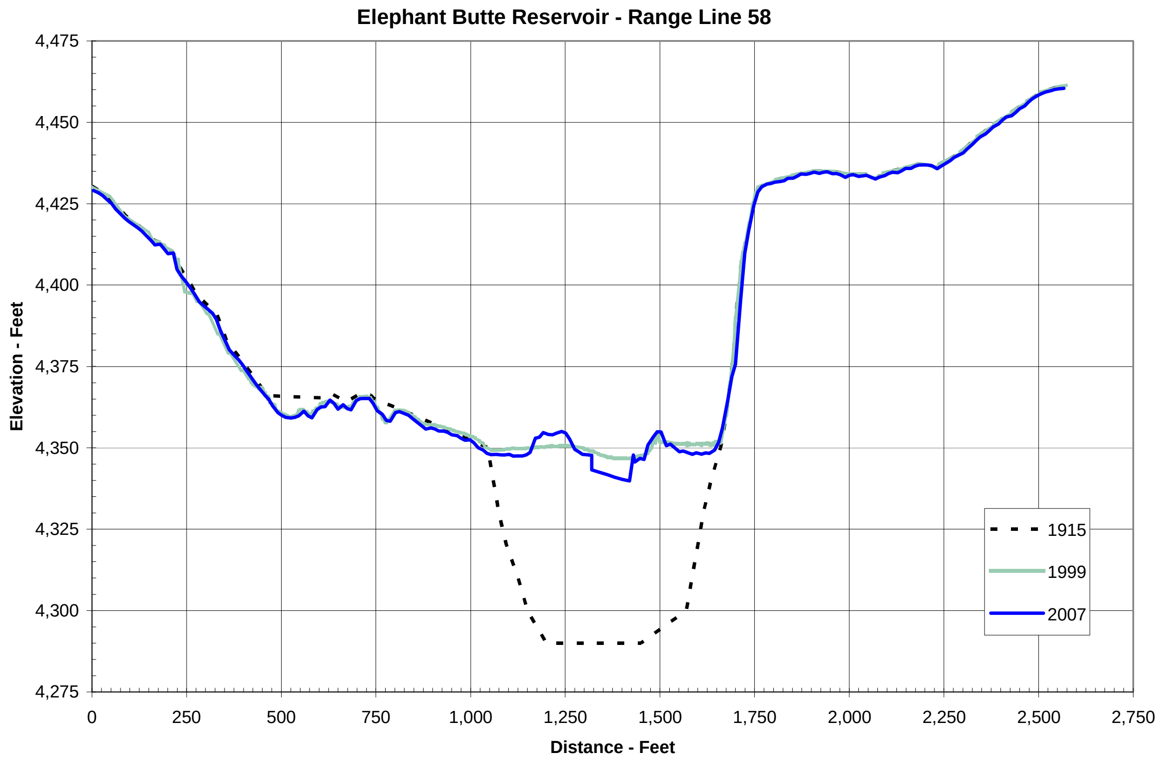

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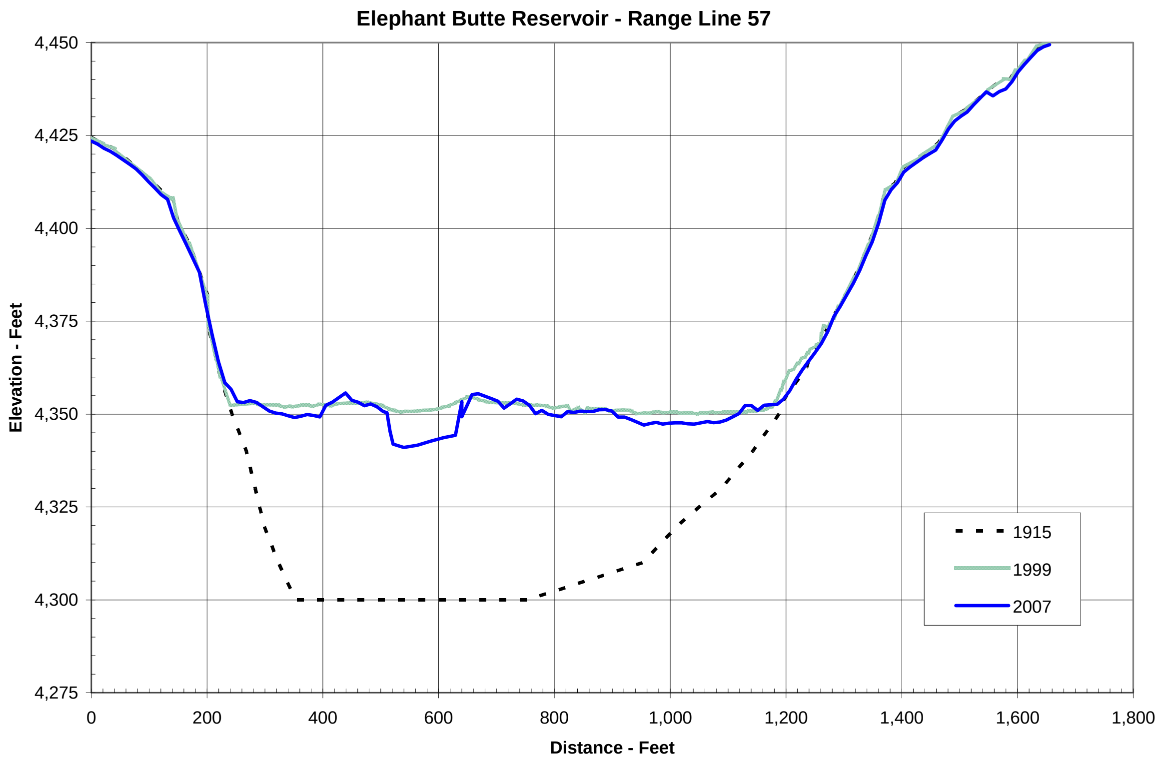

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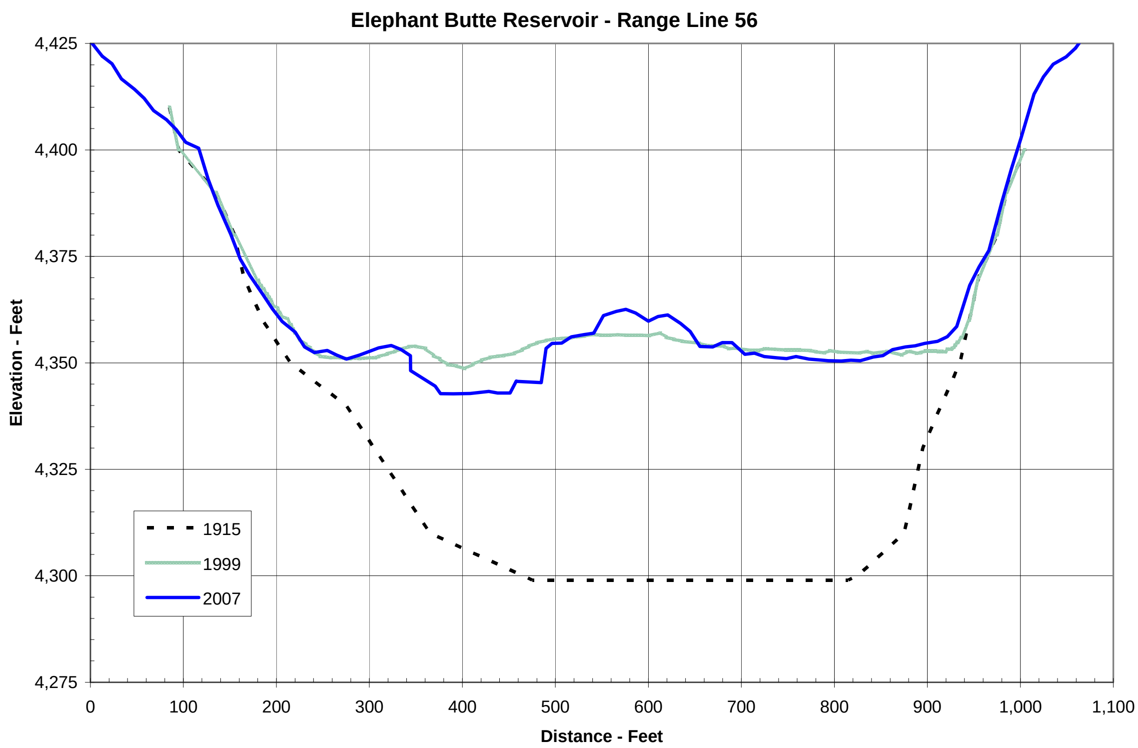

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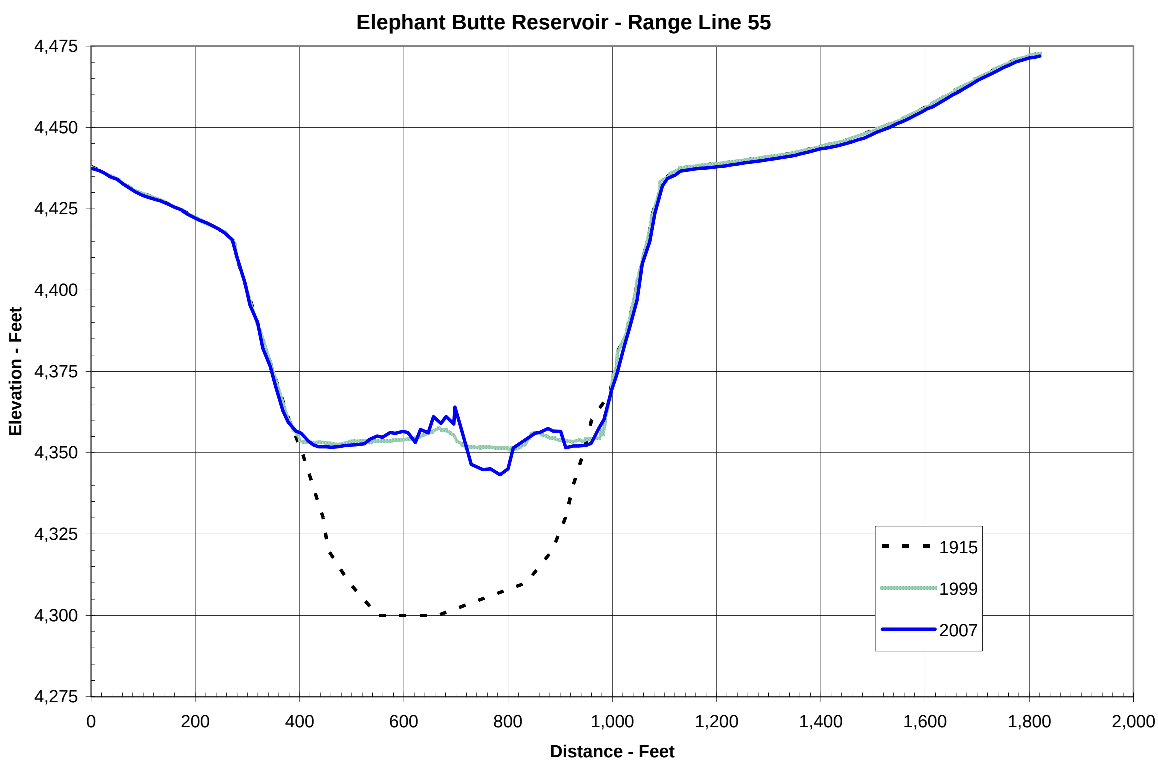

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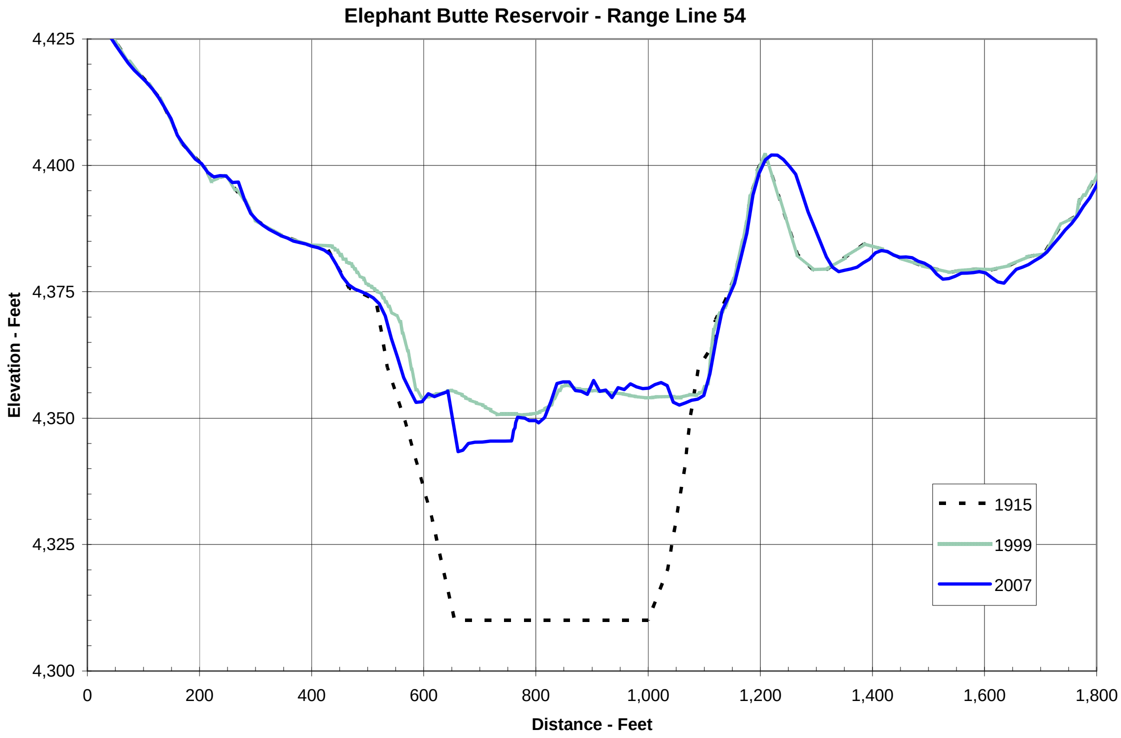

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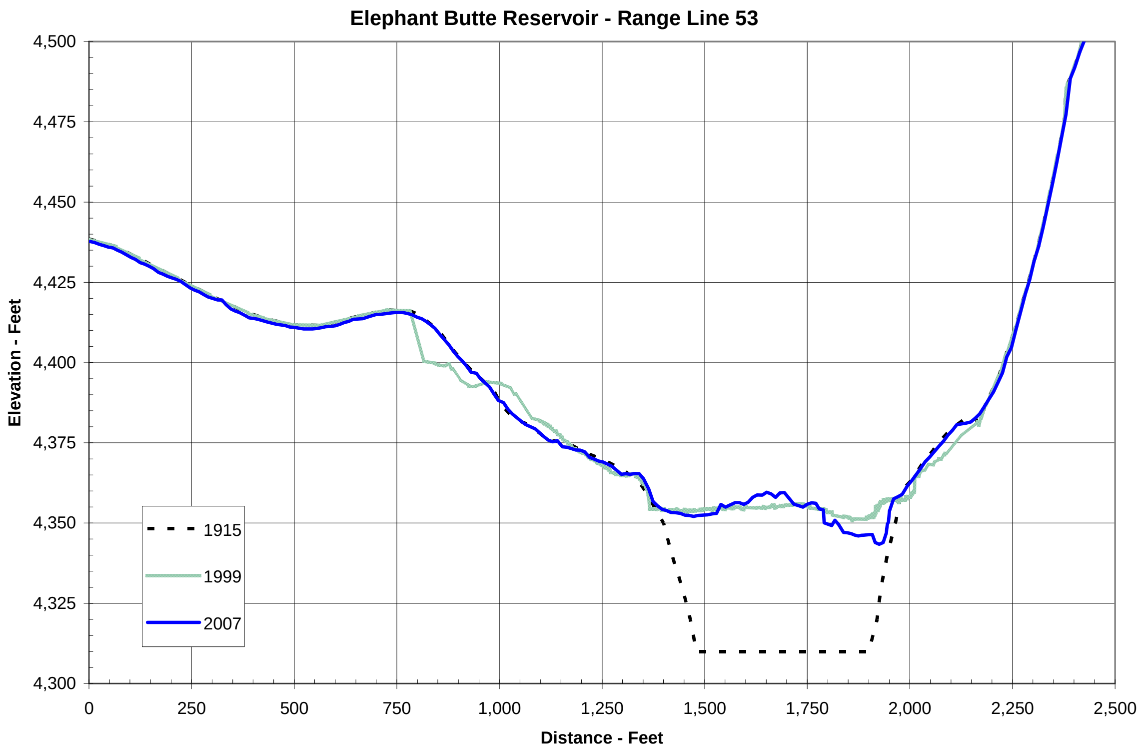

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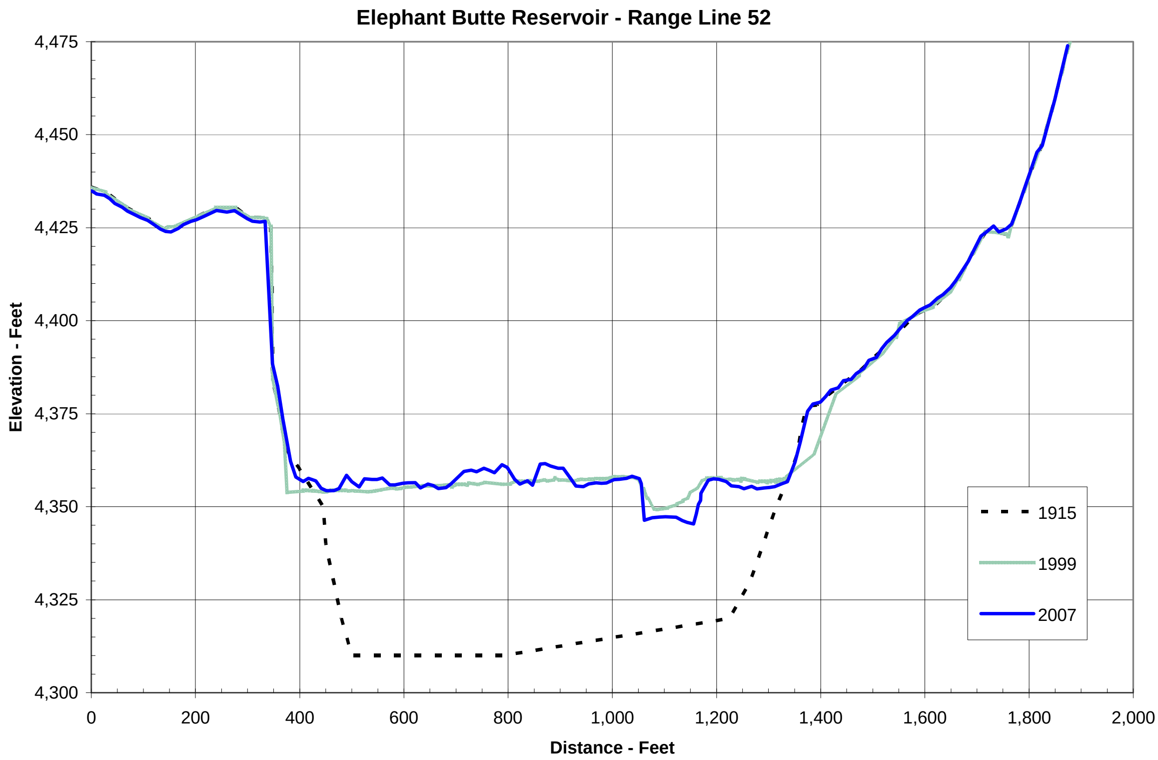

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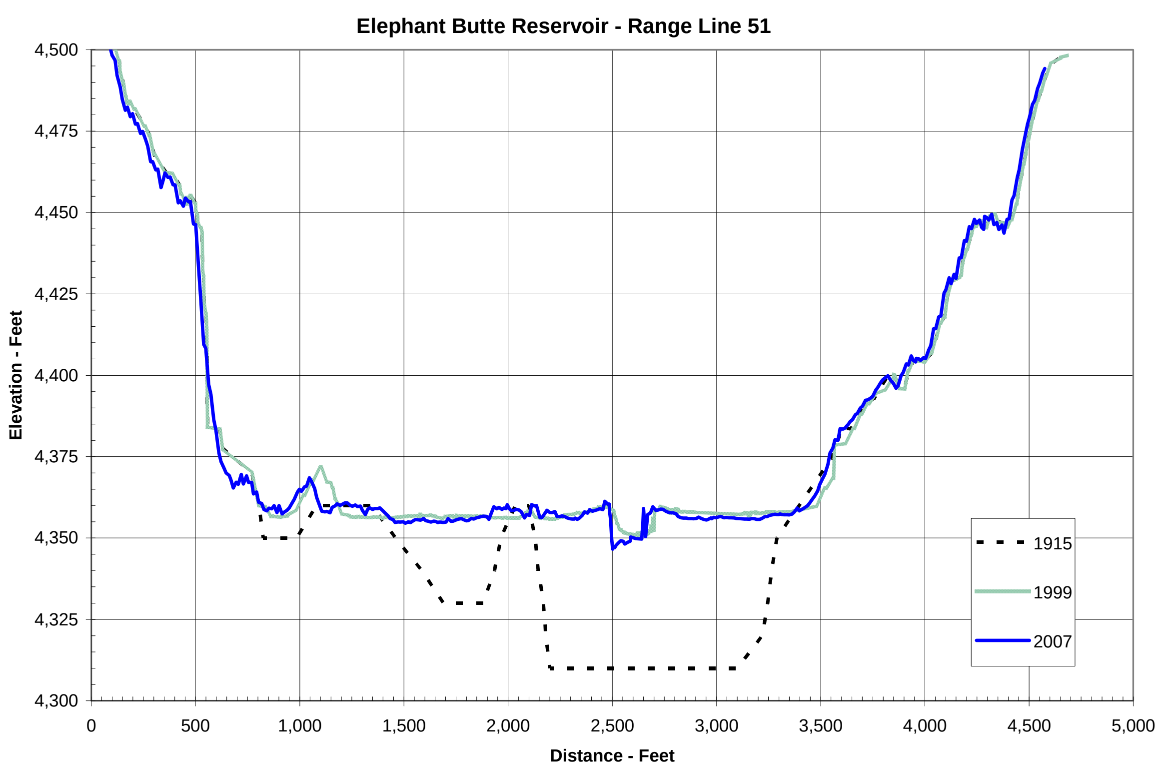
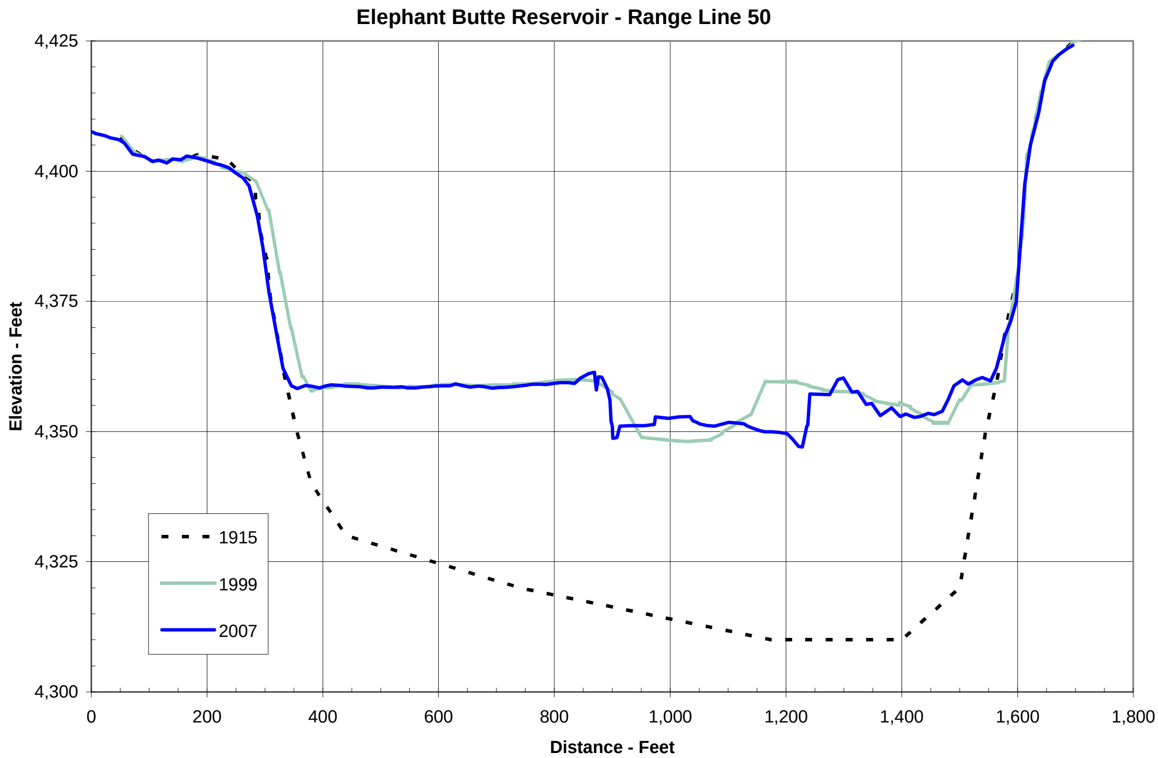


Figure 51 - Range Line 51.



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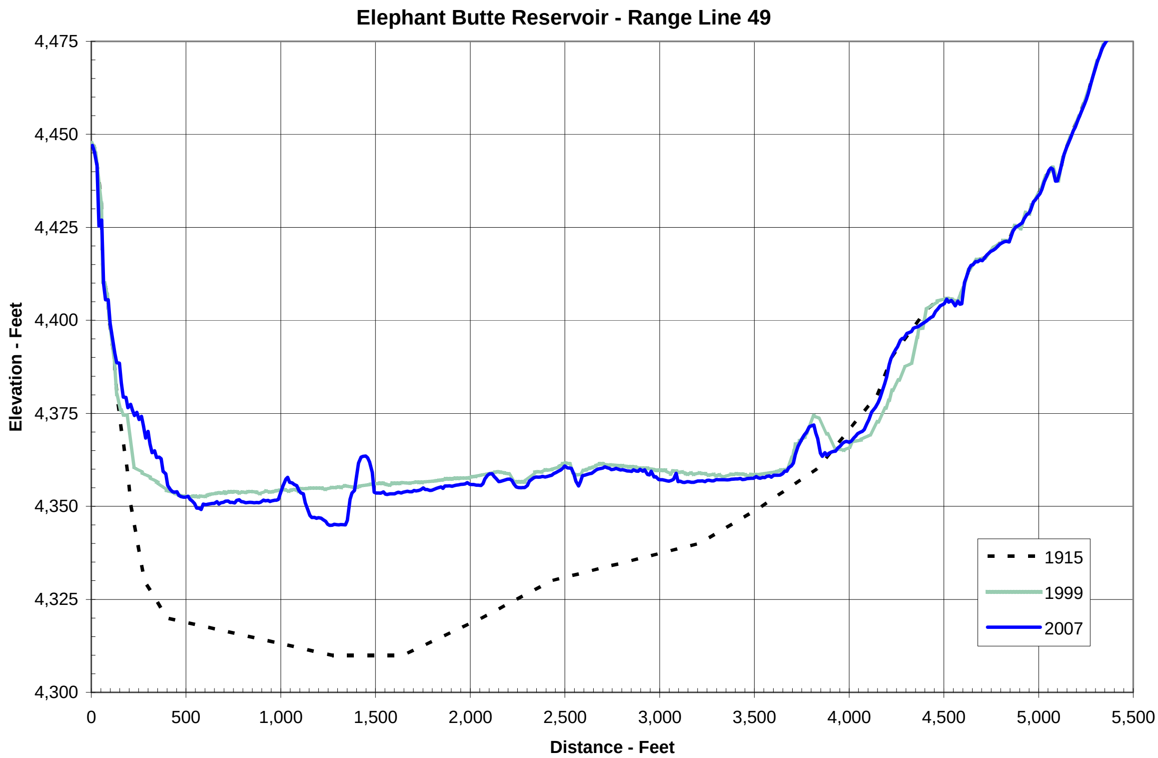

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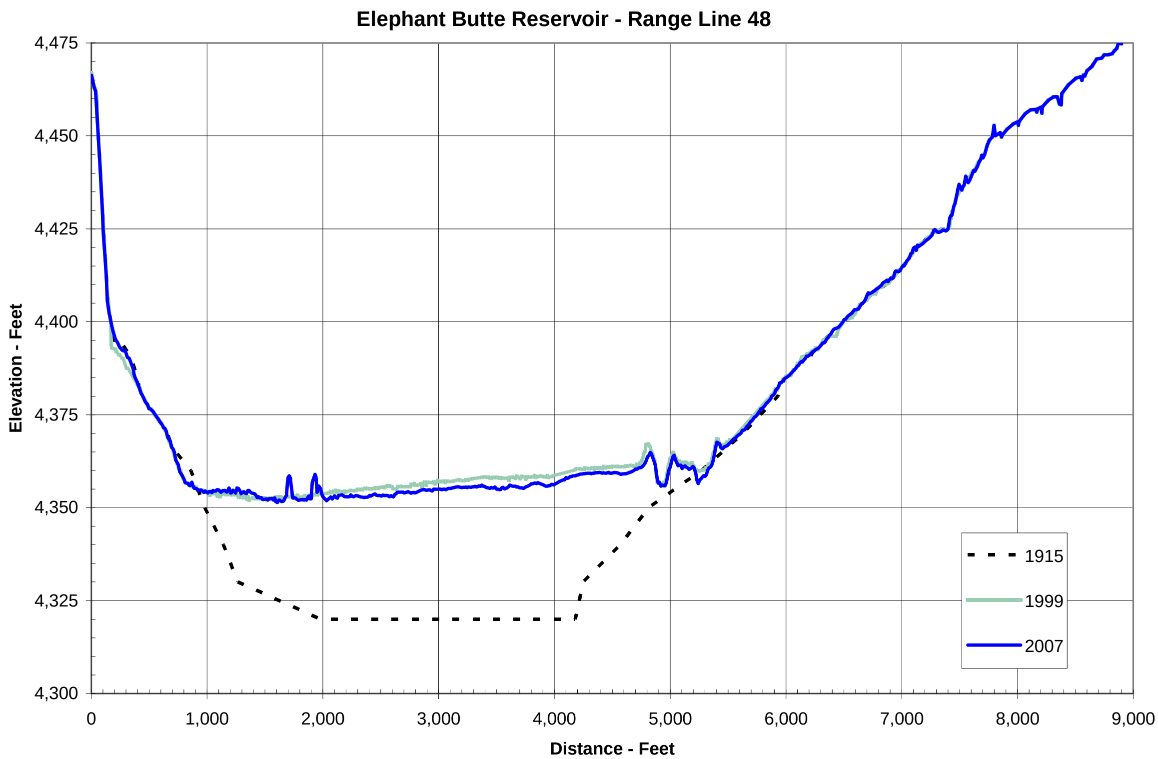

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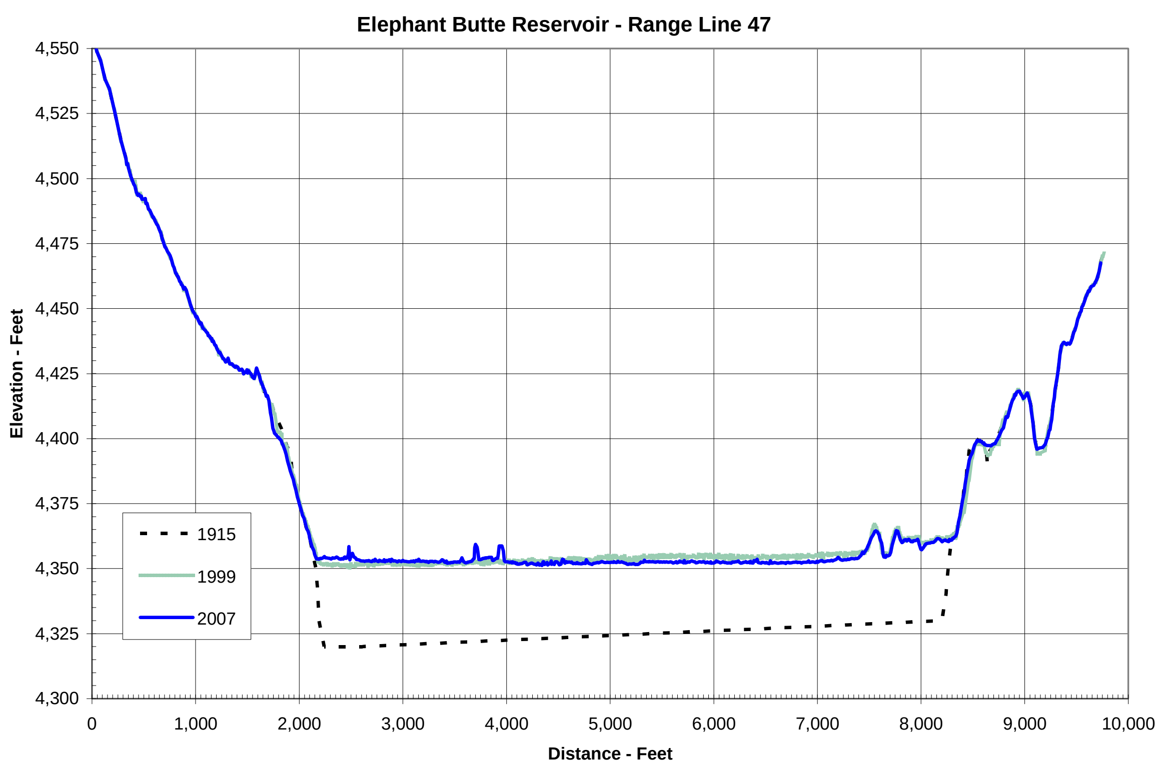

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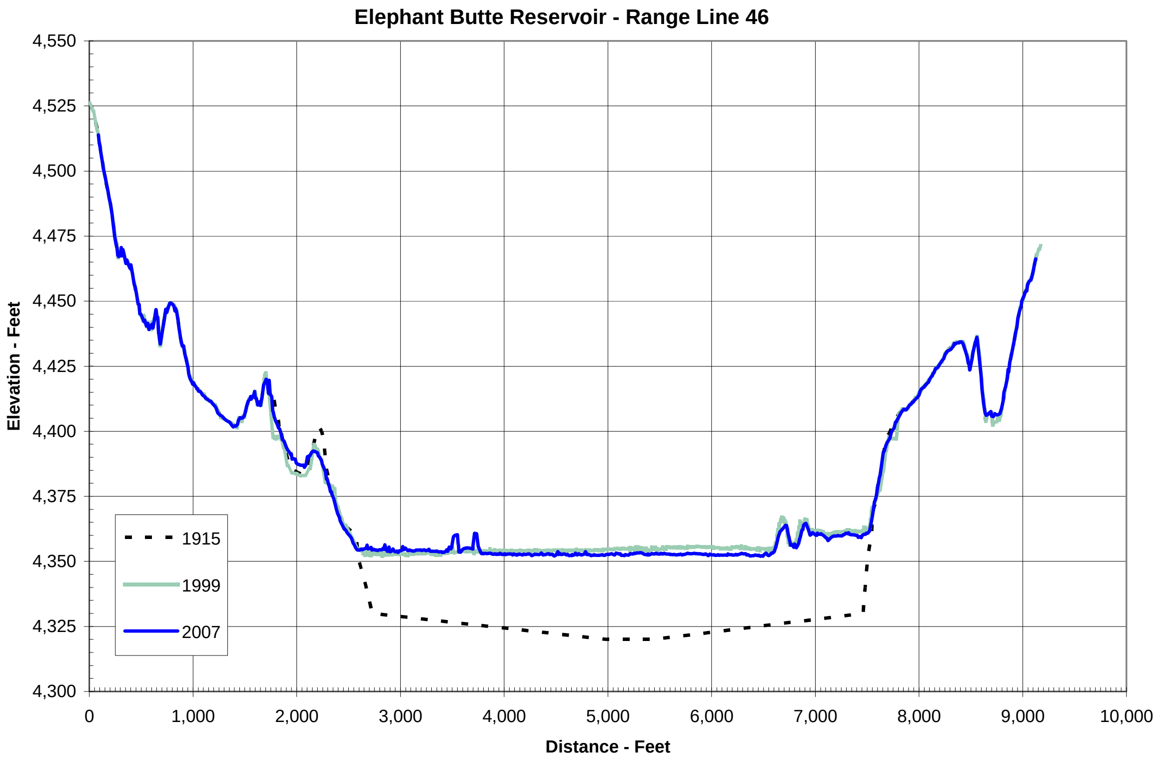

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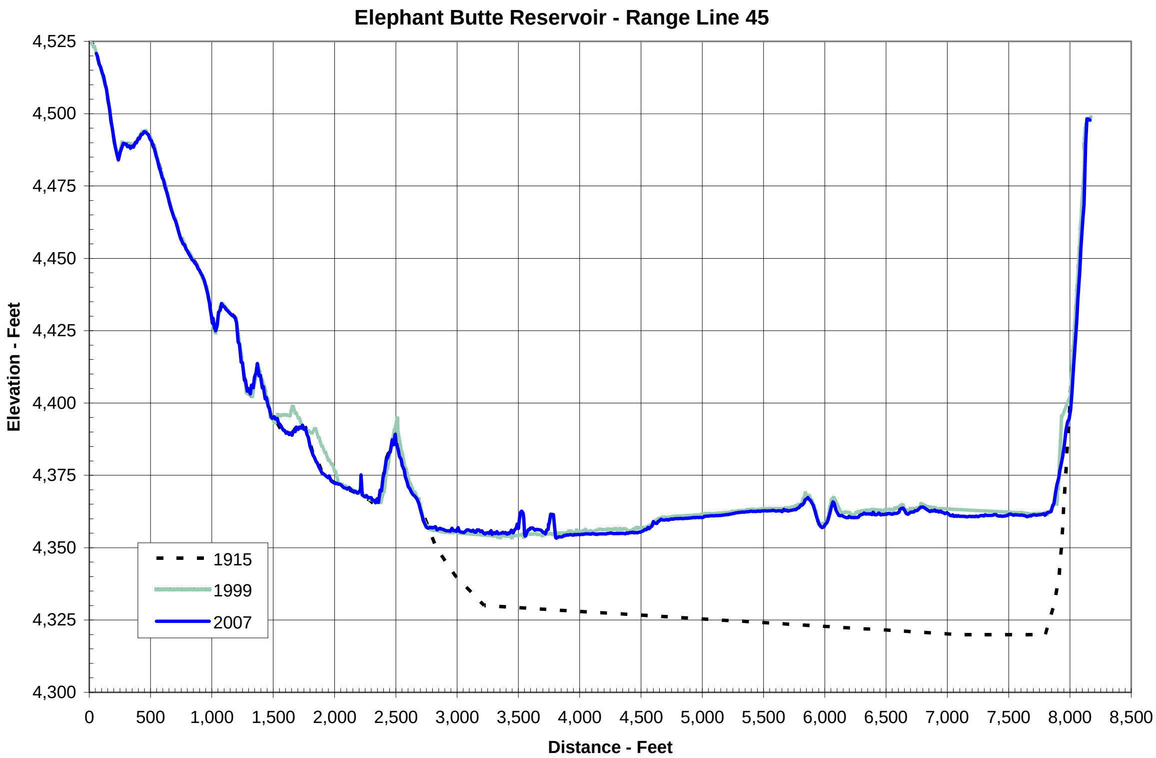

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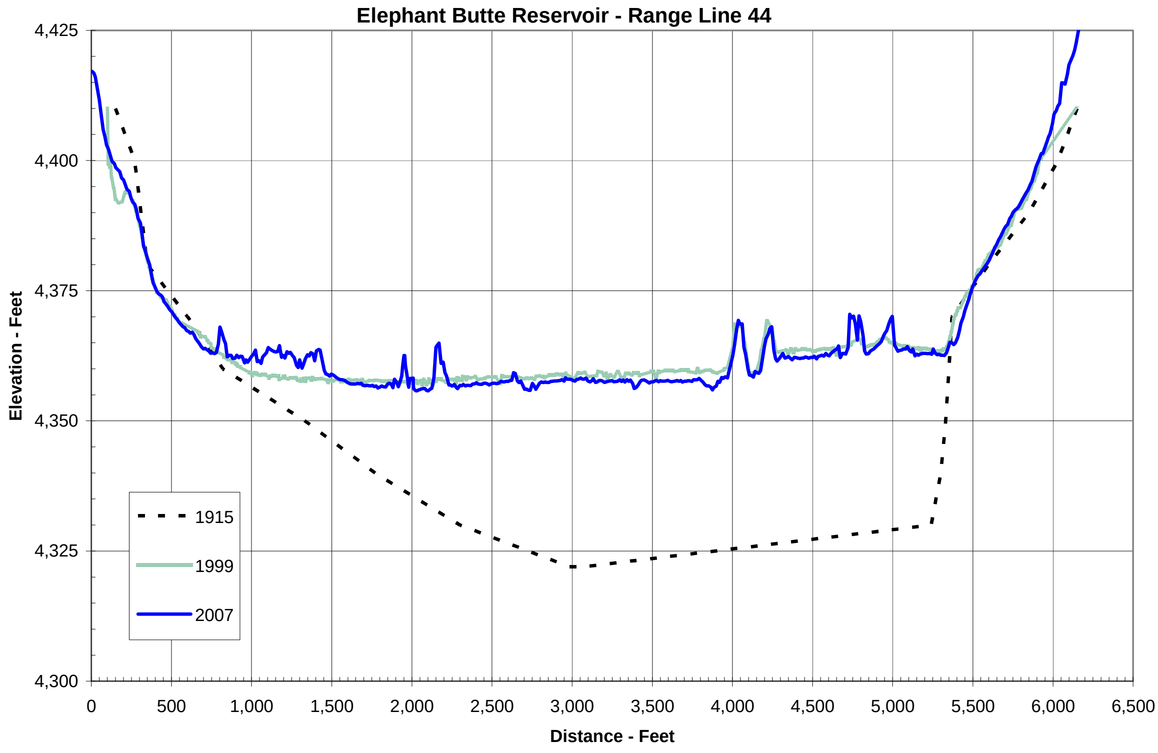

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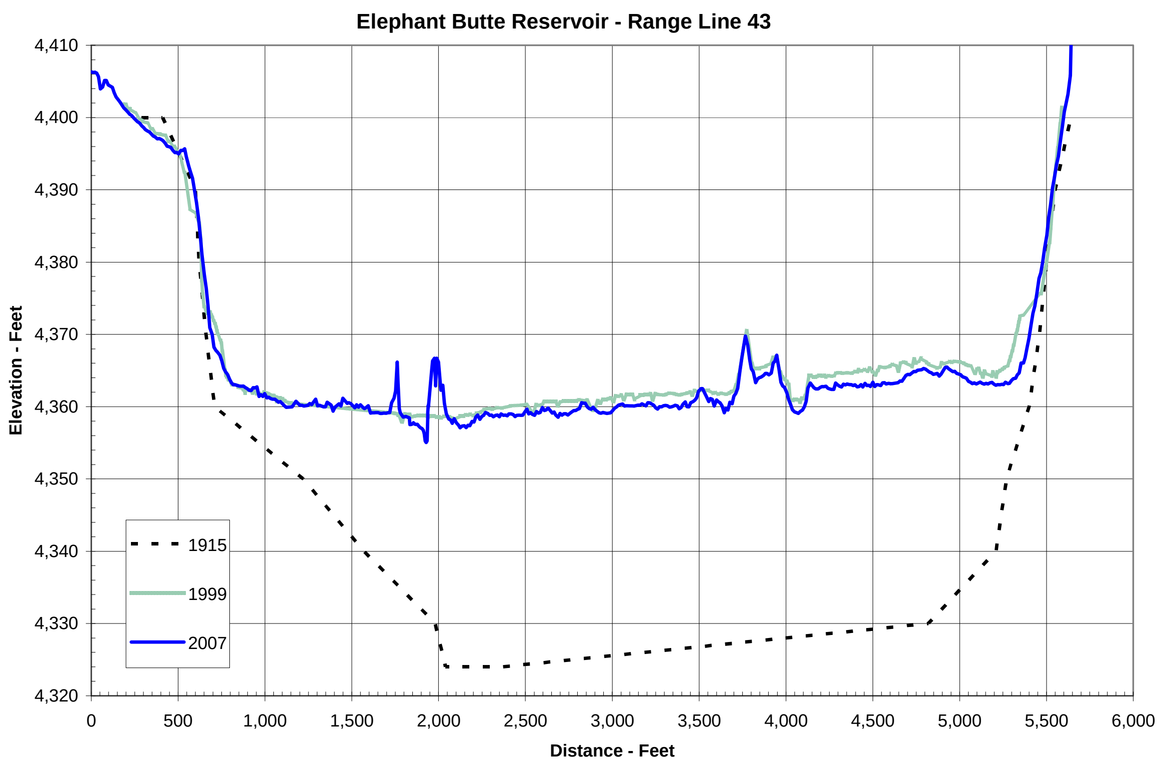

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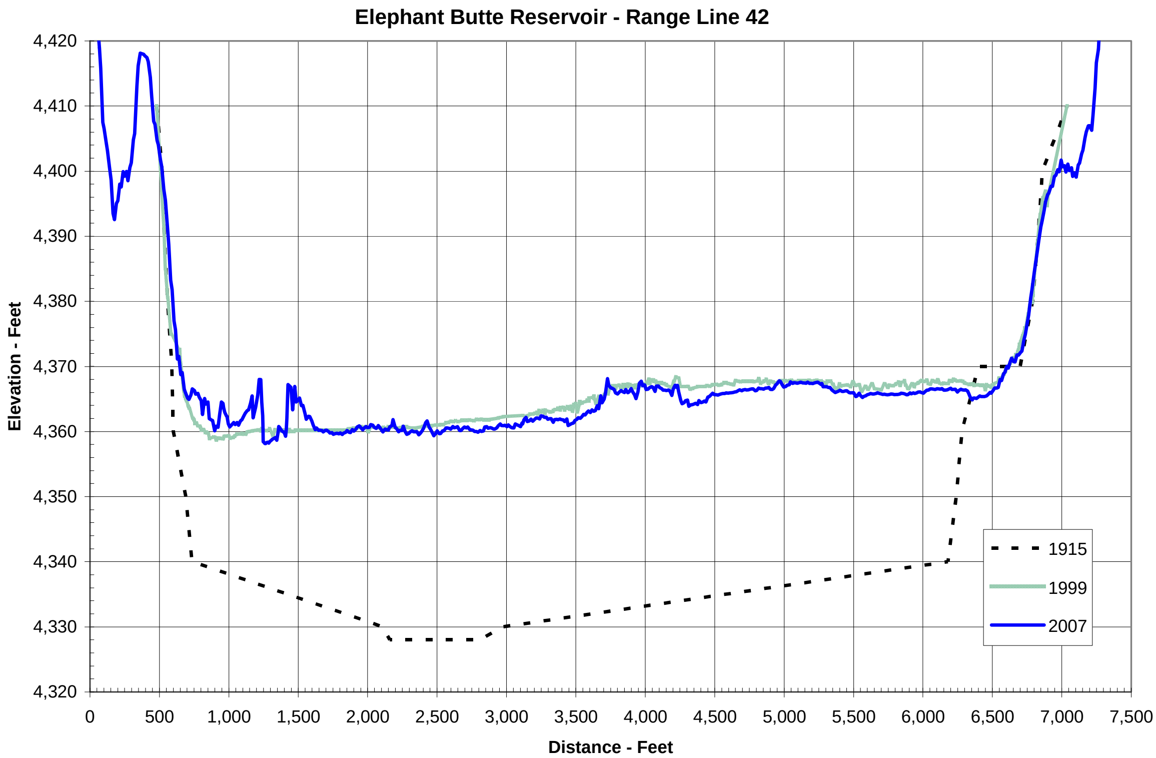

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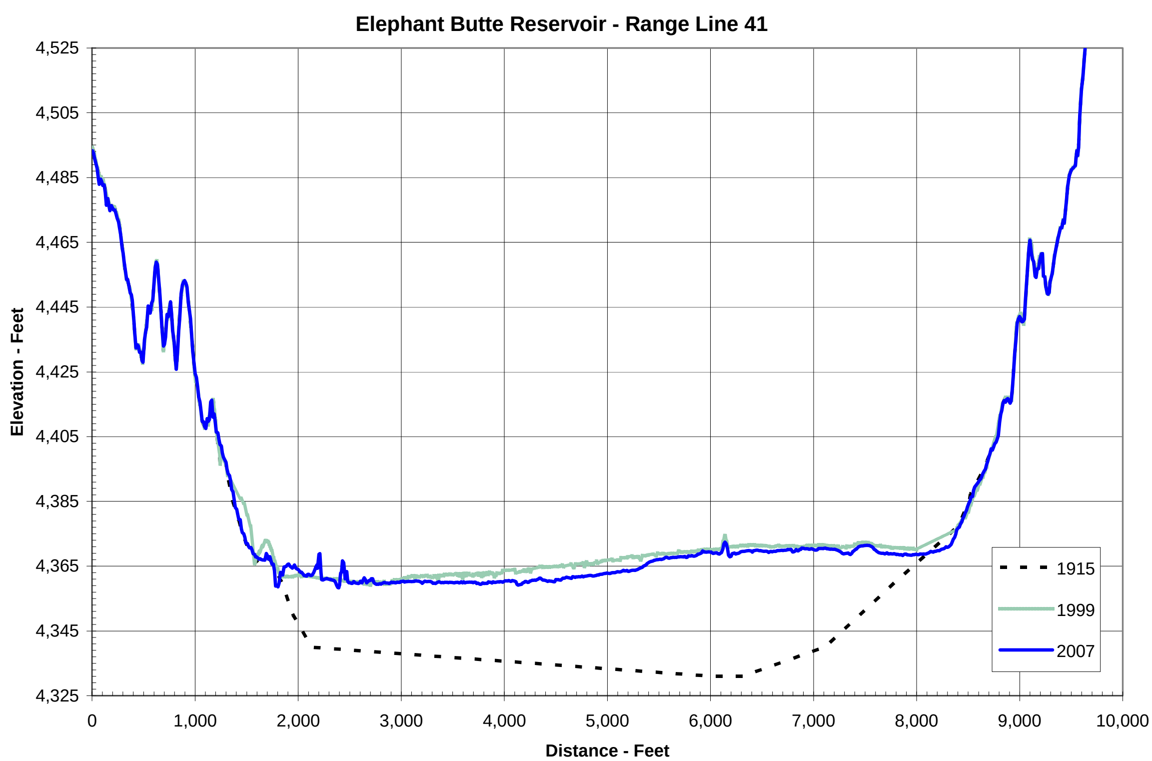

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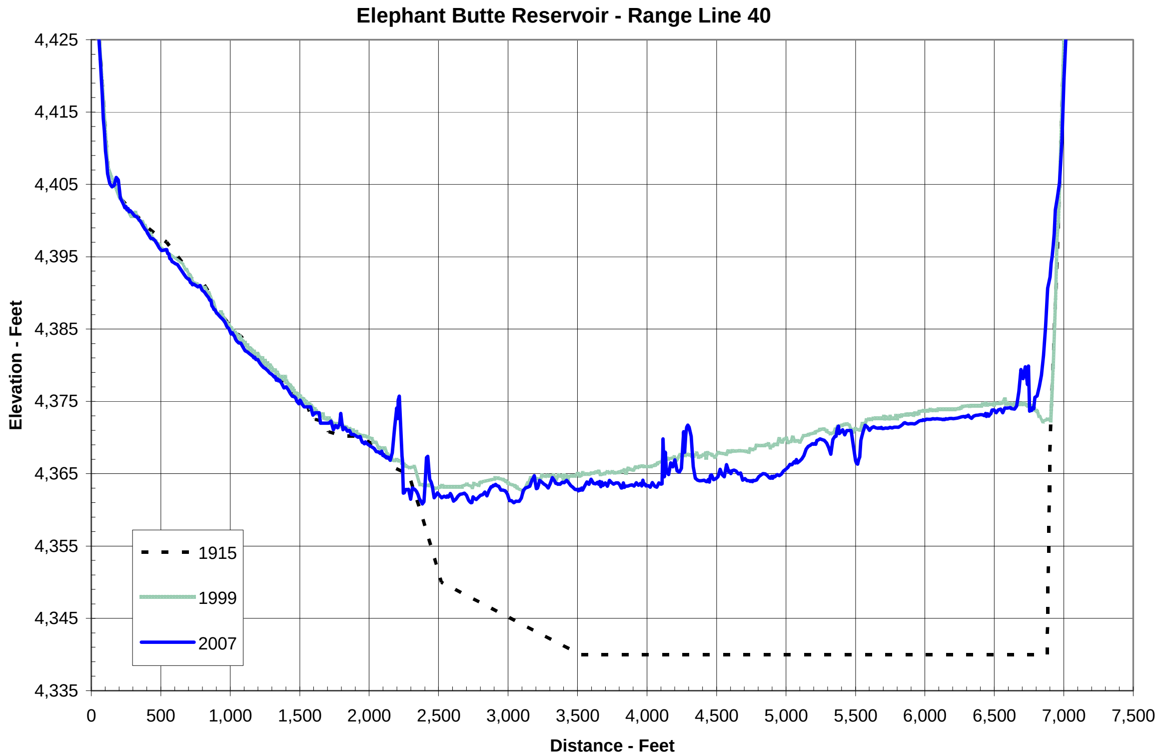

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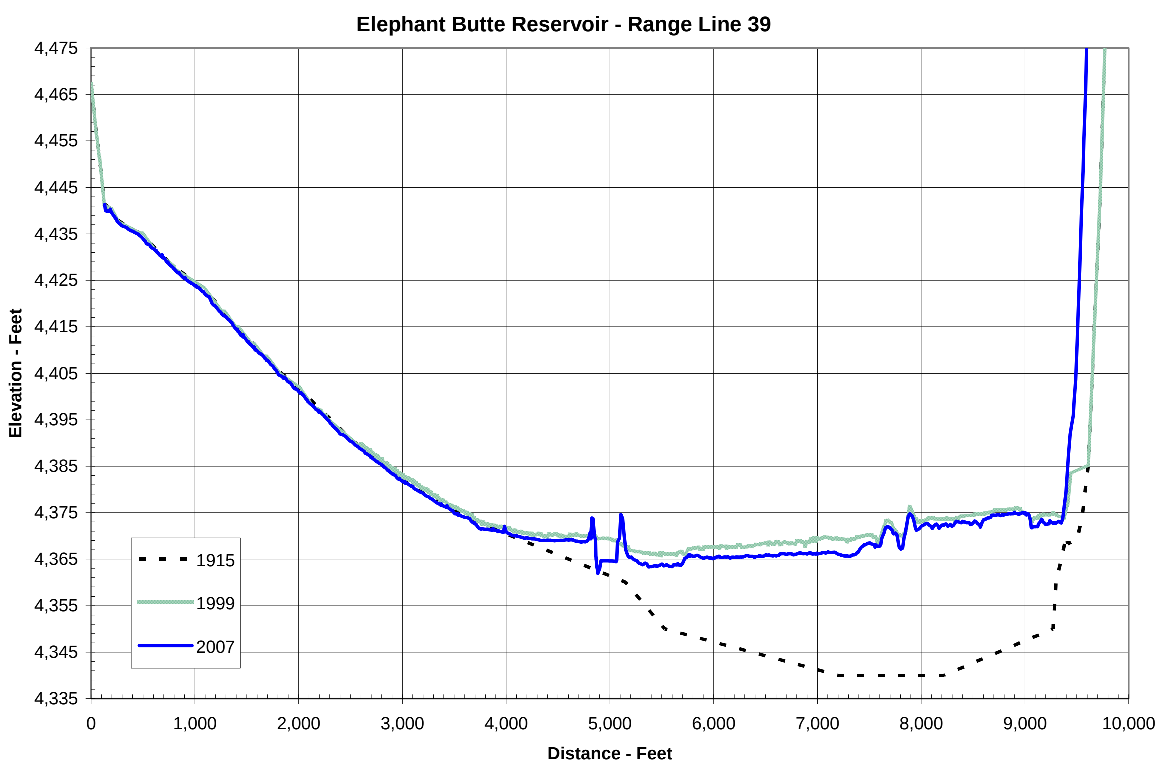
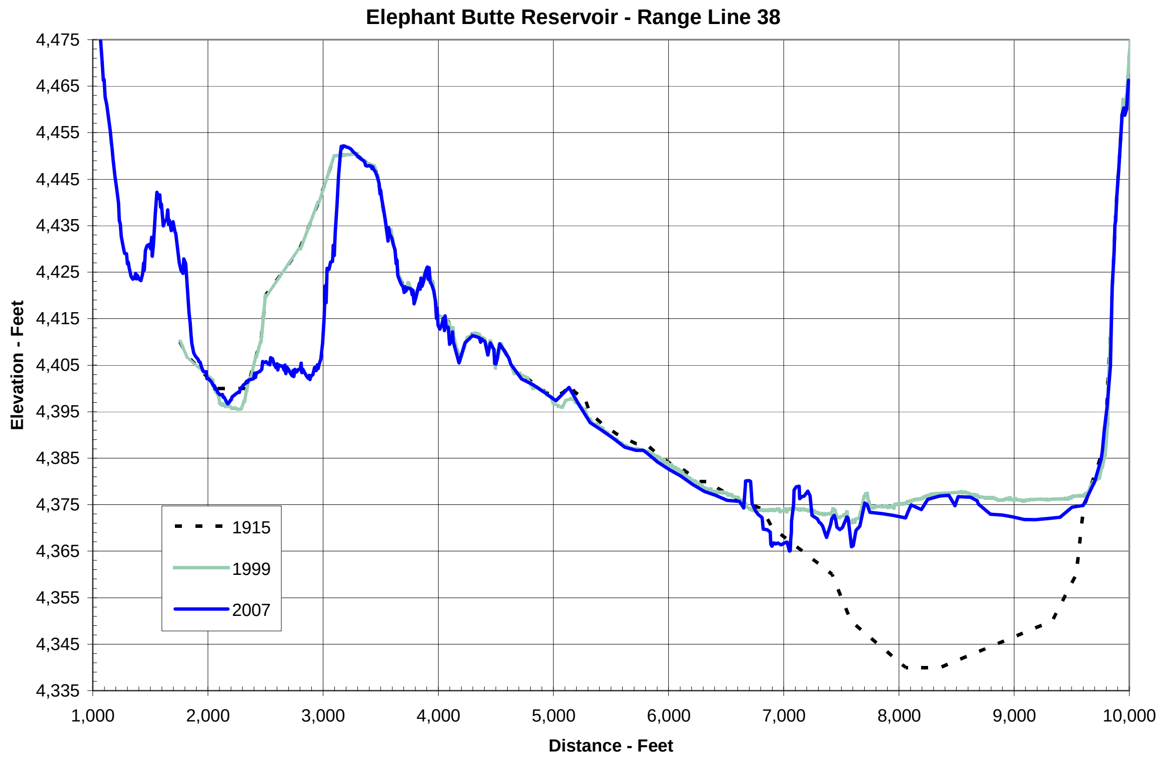


Figure 63 - Range Line 39.



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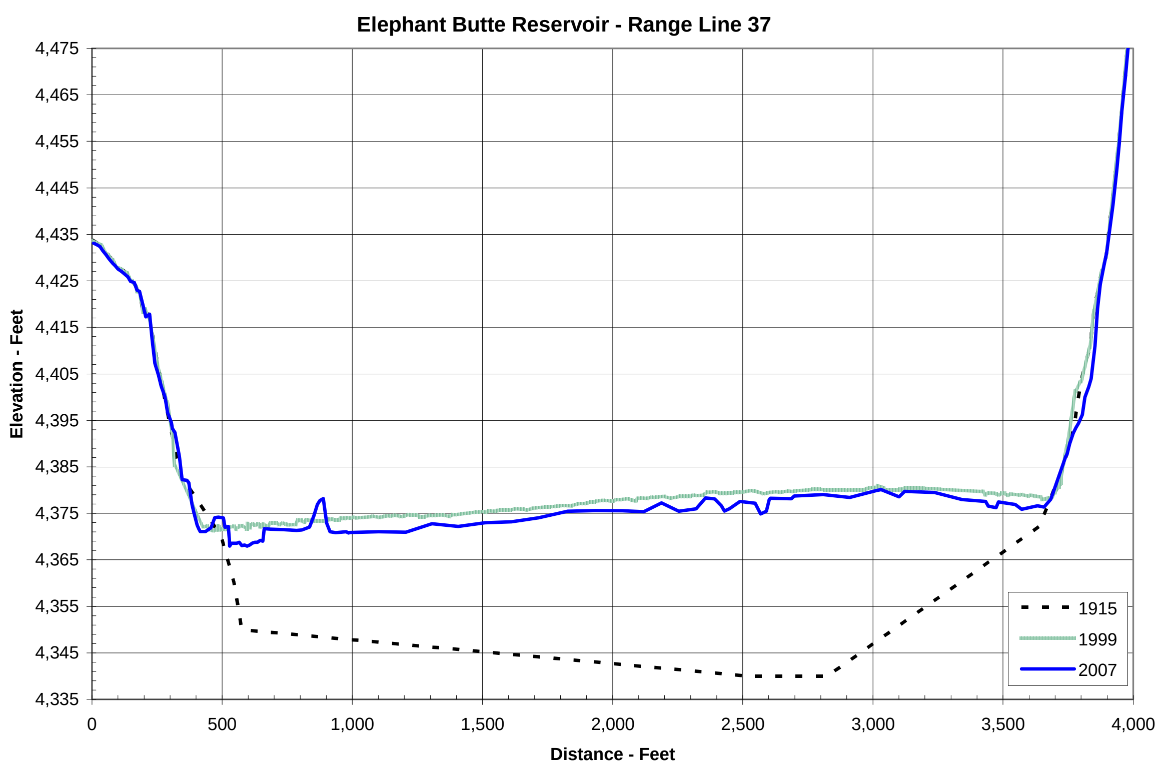

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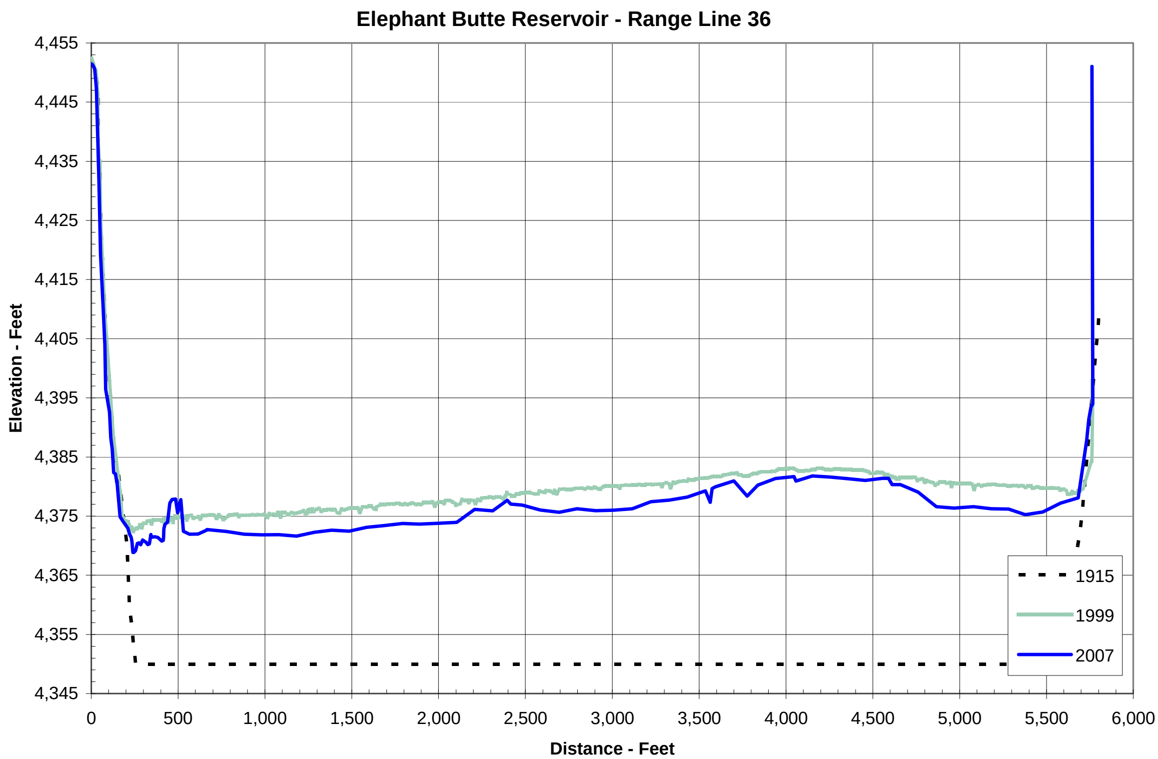

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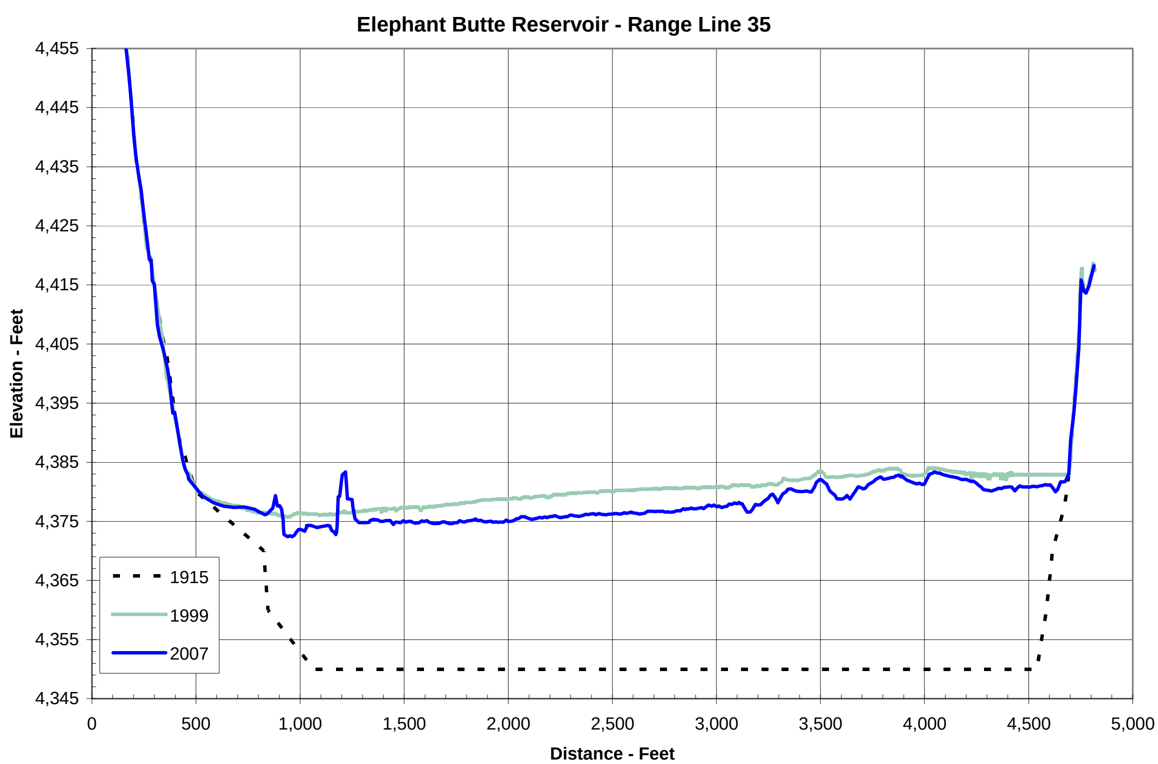

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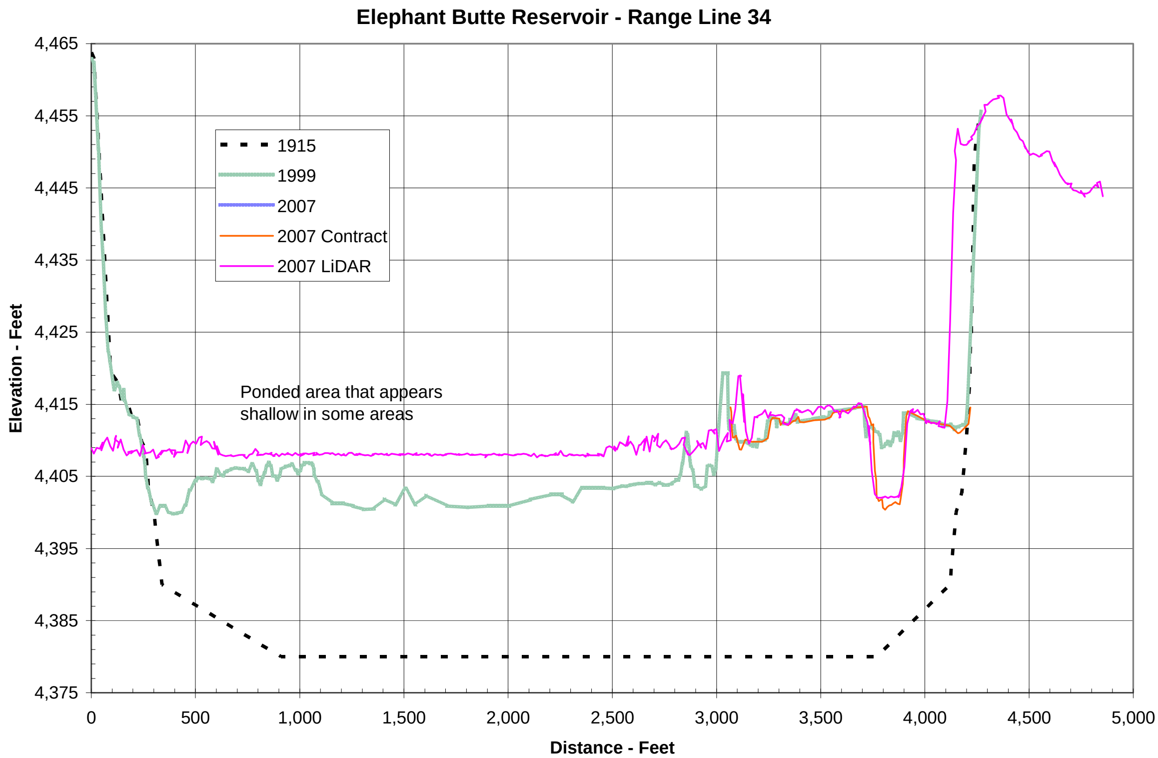

Figure 68 - Range Line 34 with notes.

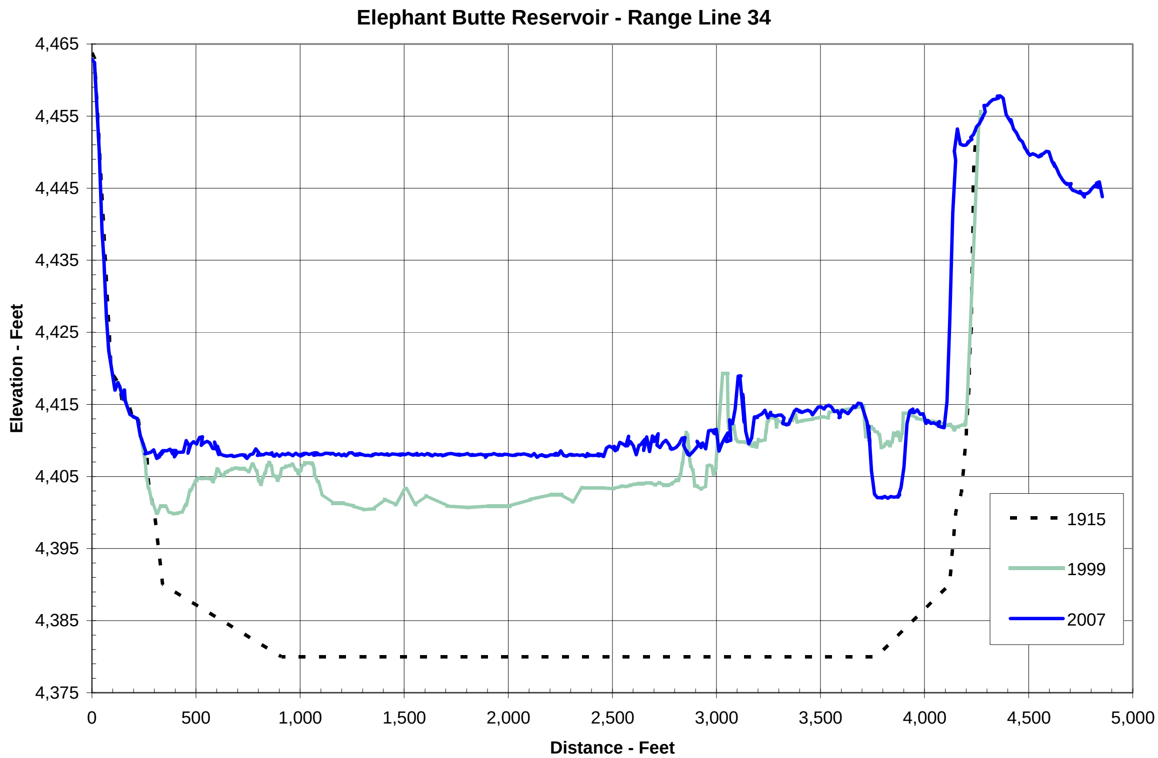

Figure 69 - Range Line 34.

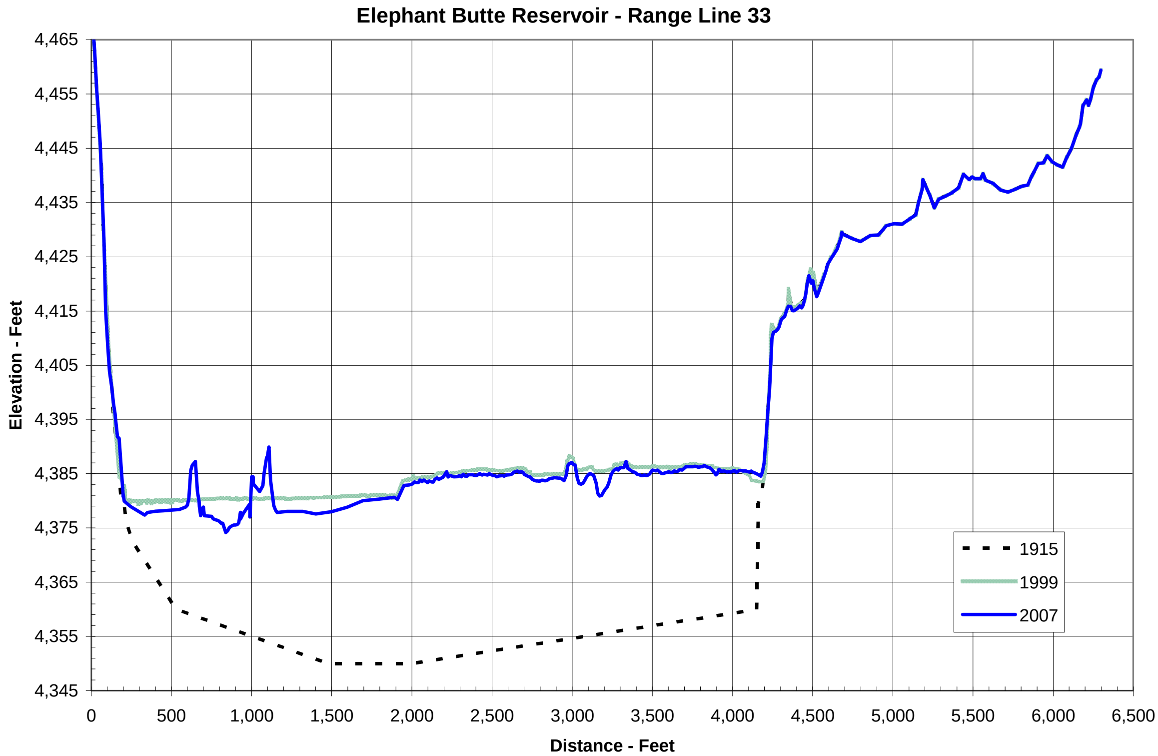

Figure 70 - Range Line 33.

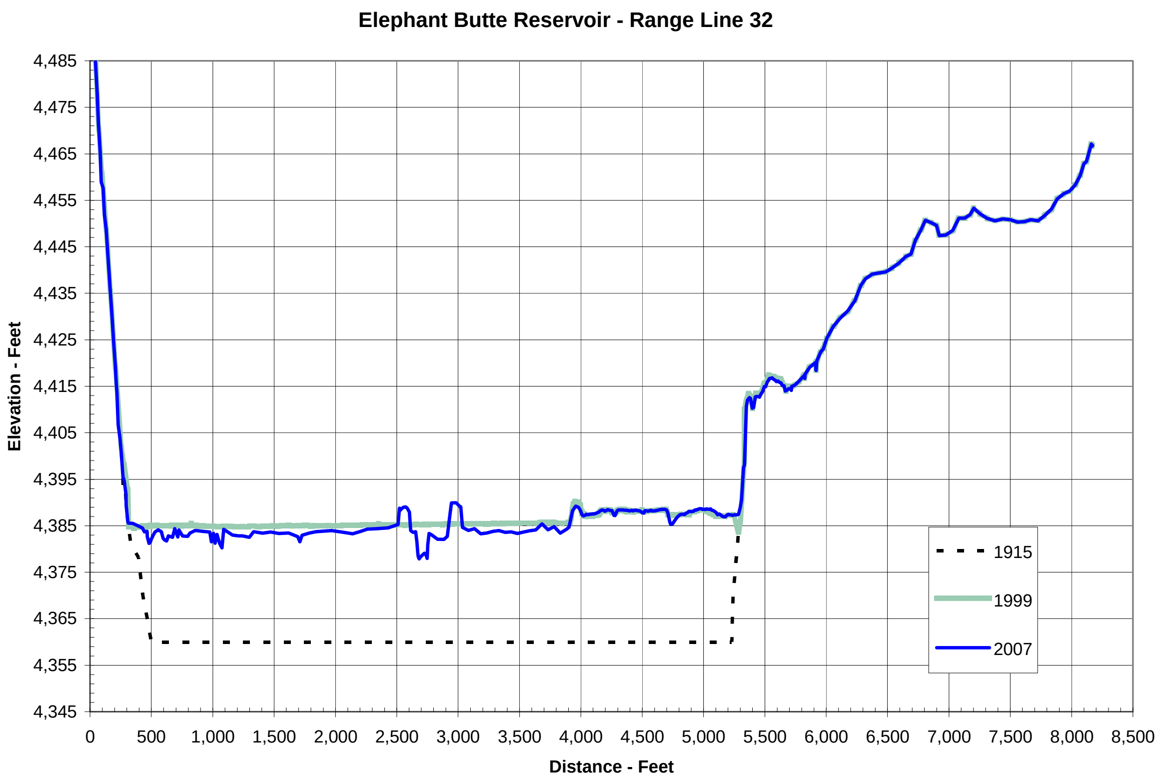

Figure 71 - Range Line 32.

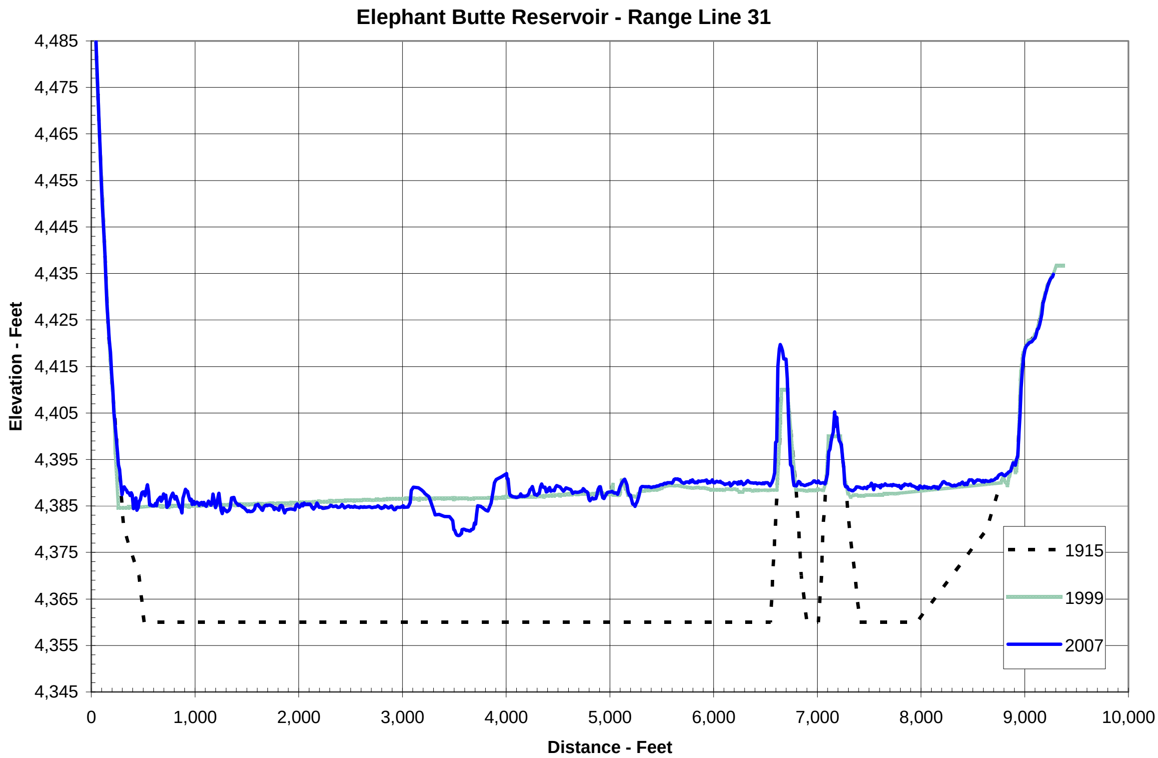

Figure 72 - Range Line 31.

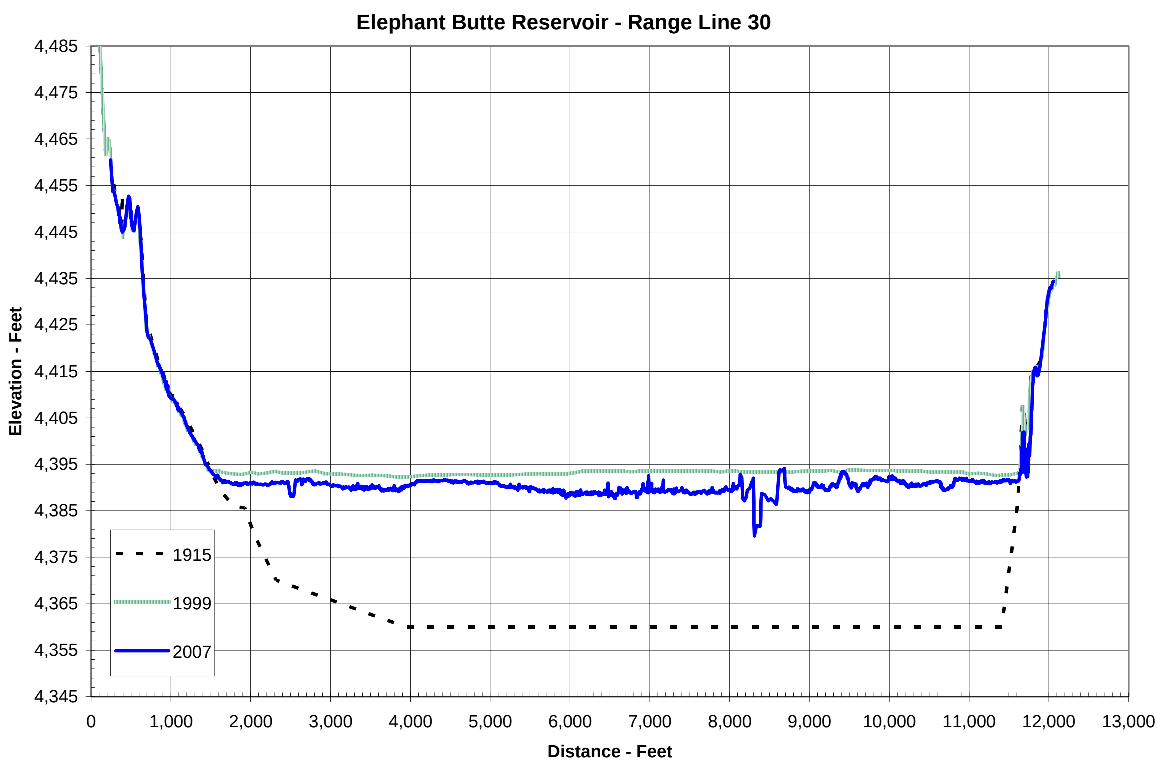

Figure 73 - Range Line 30.

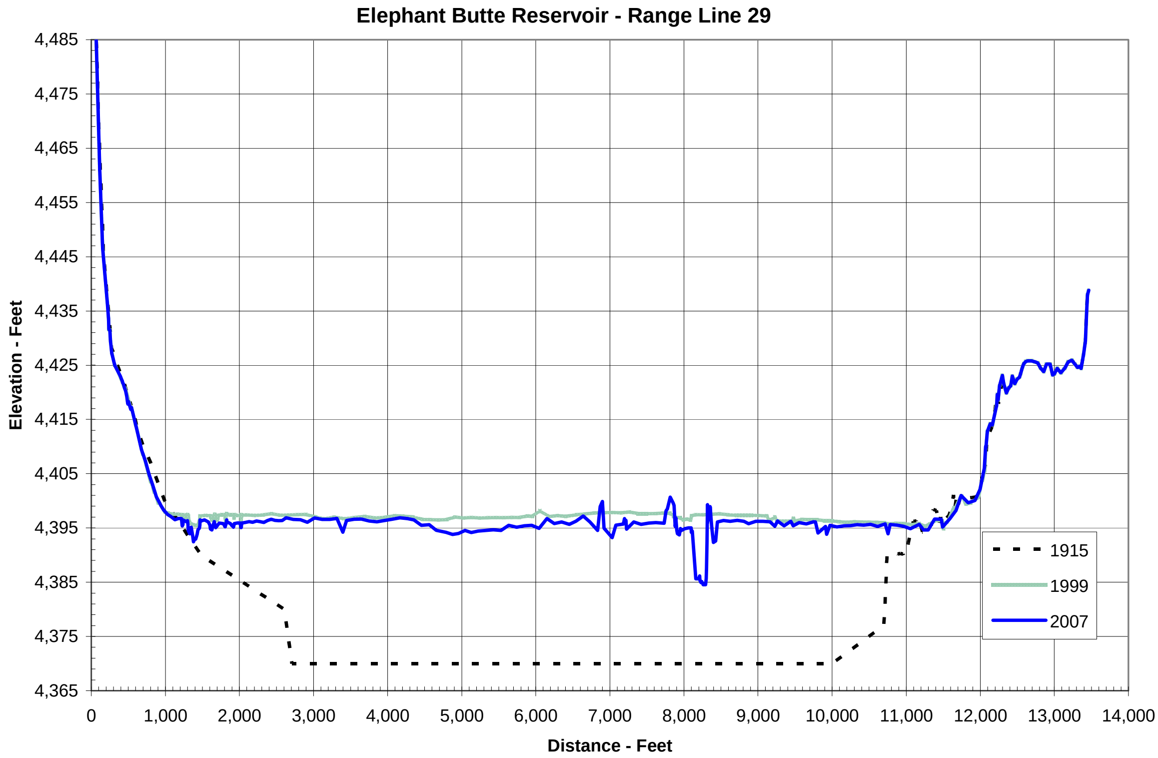

Figure 74 - Range Line 29.

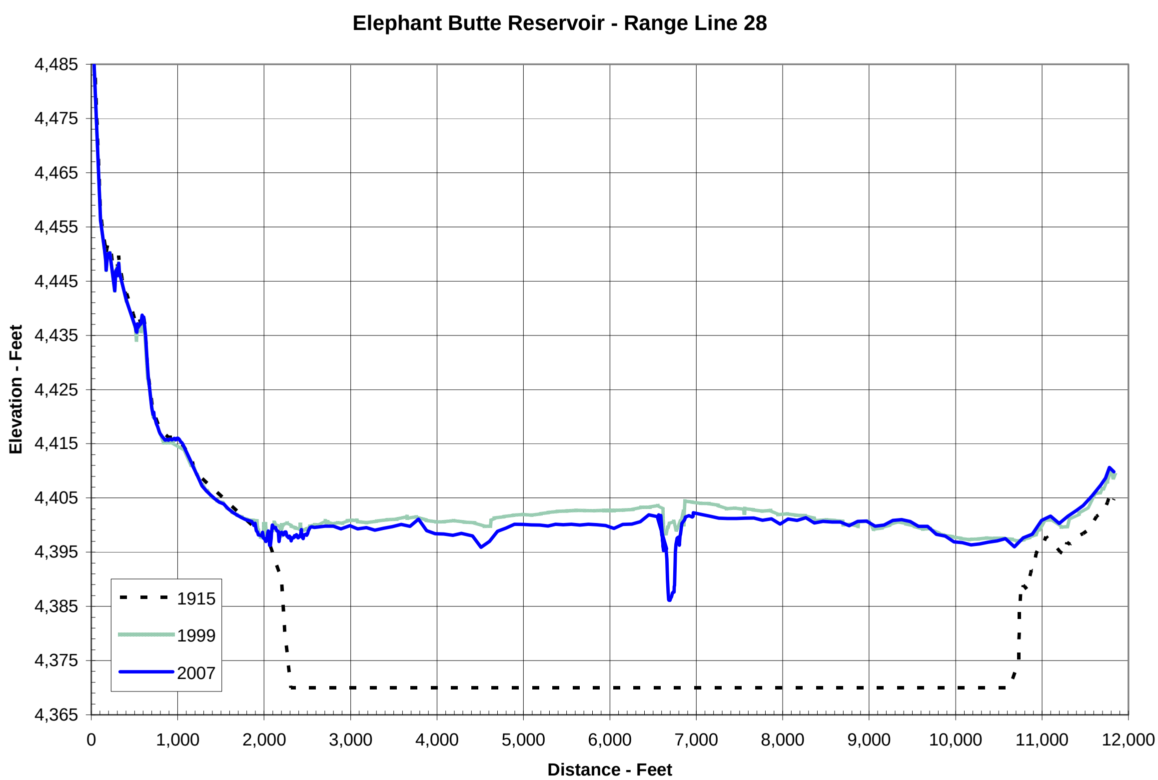

Figure 75 - Range Line 28.

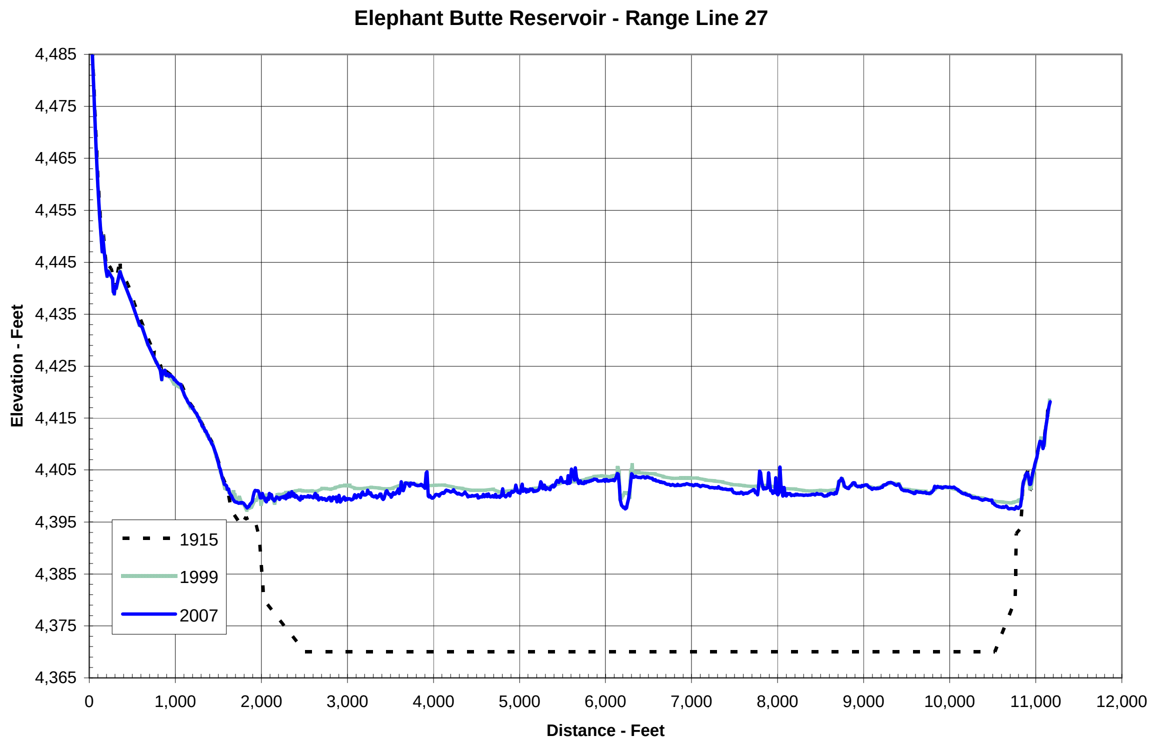

Figure 76 - Range Line 27.

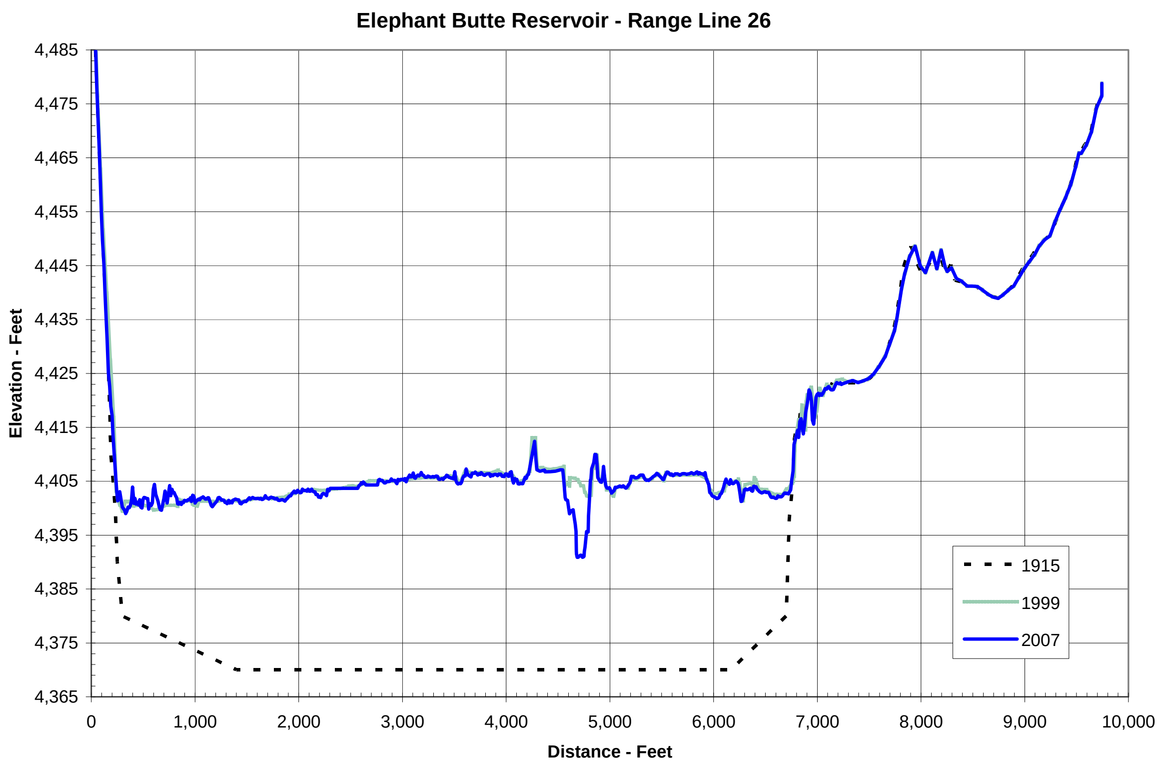

Figure 77 - Range Line 26.

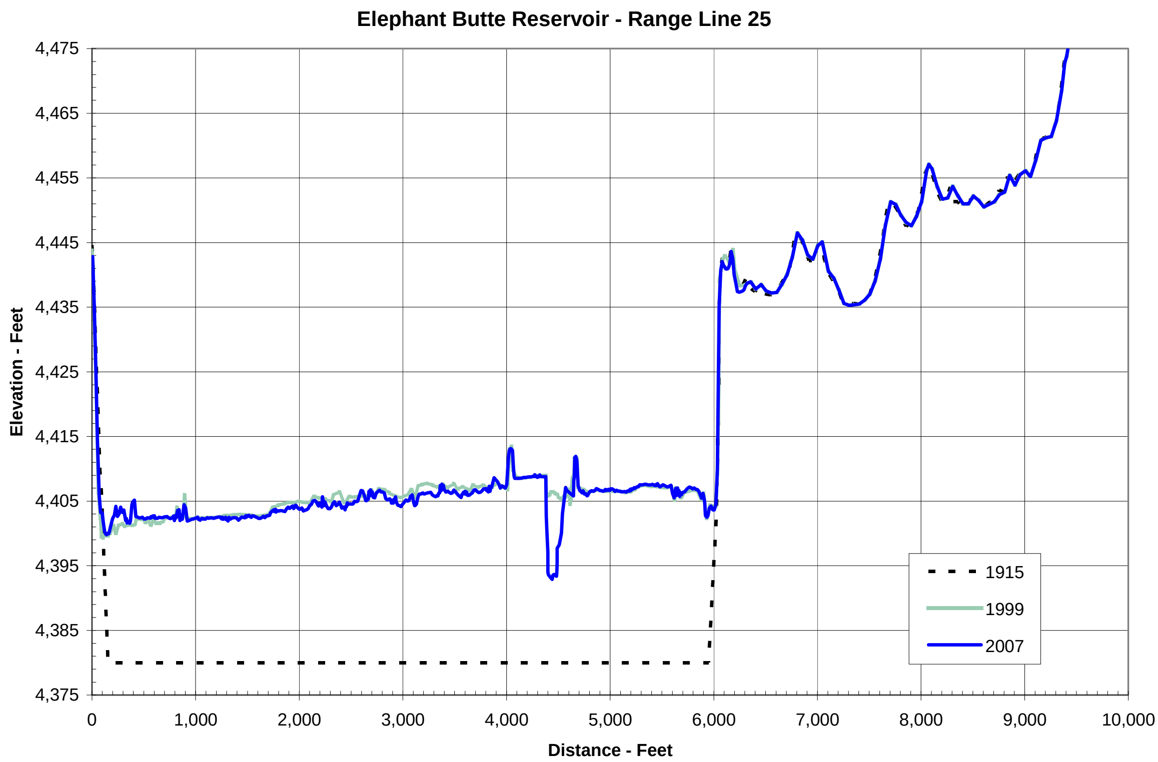

Figure 78 - Range Line 25.

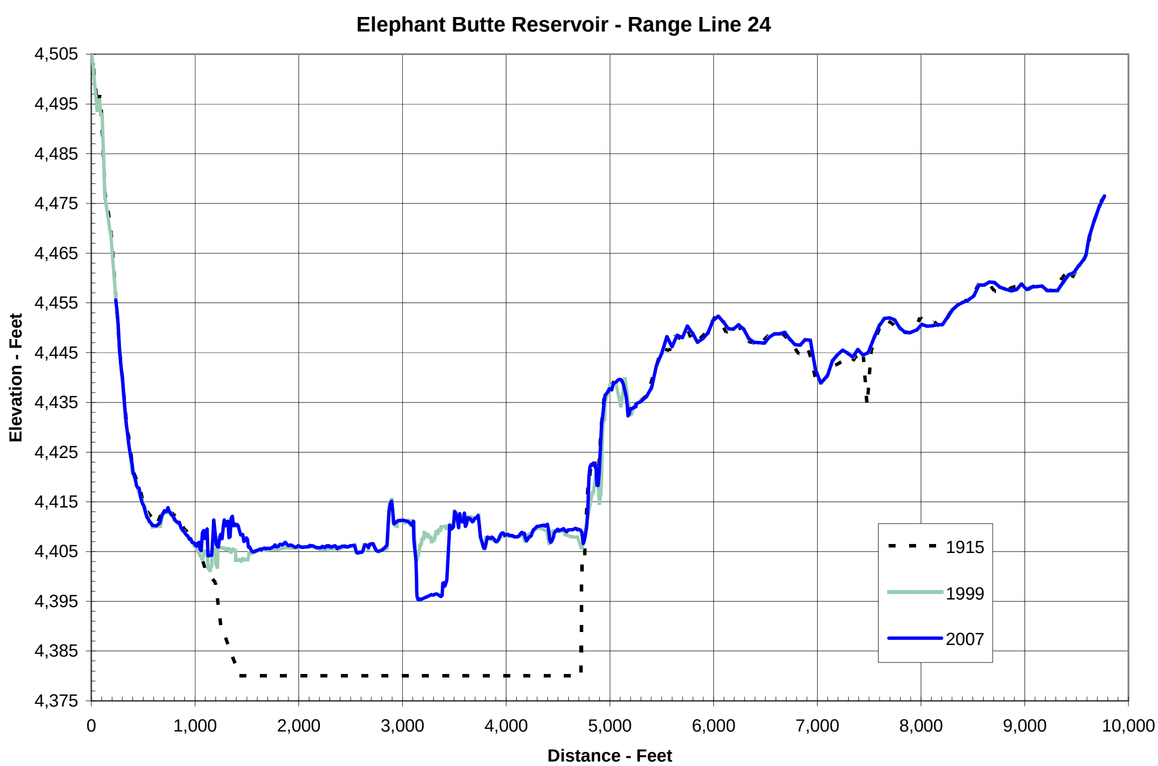

Figure 79 - Range Line 24.

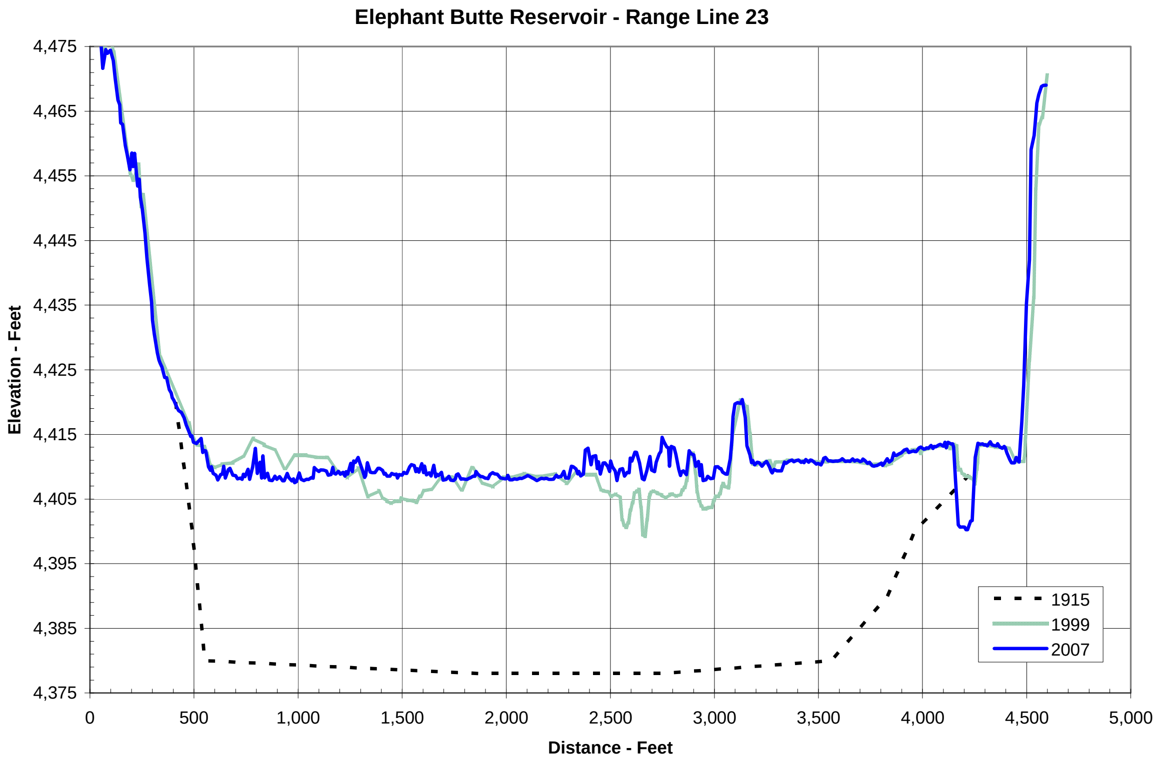

Figure 80 - Range Line 23.

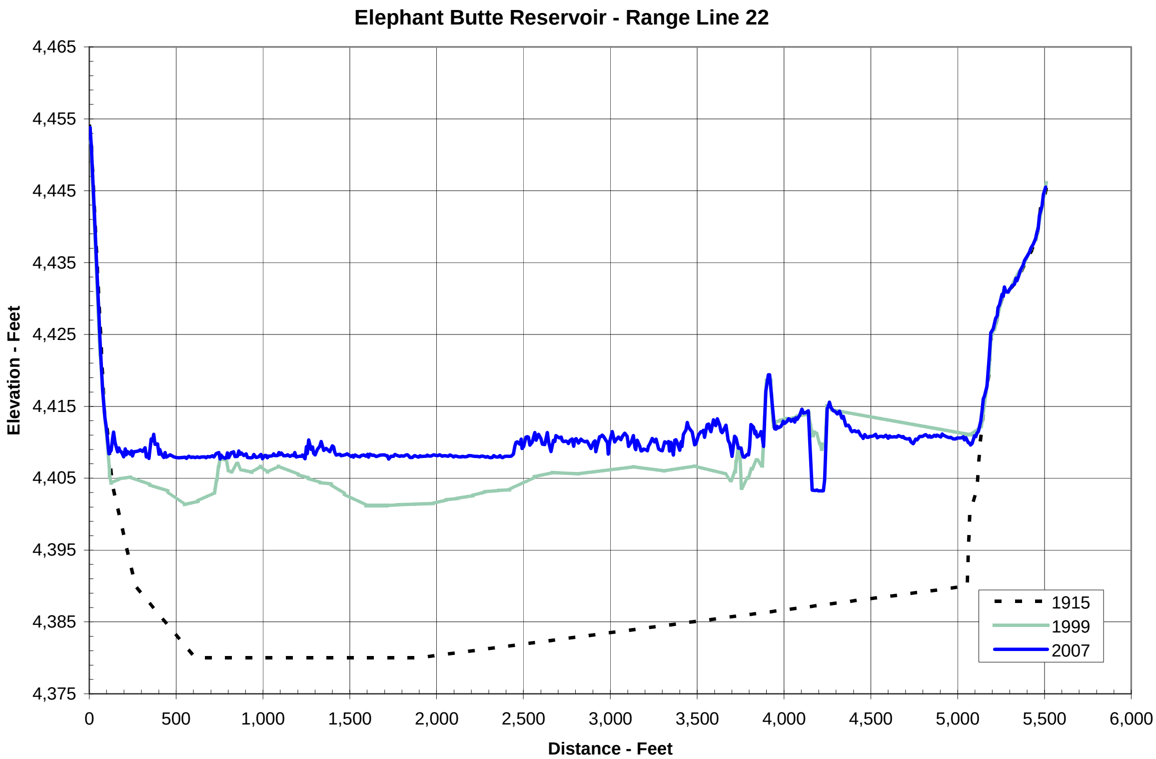

Figure 81 - Range Line 22.

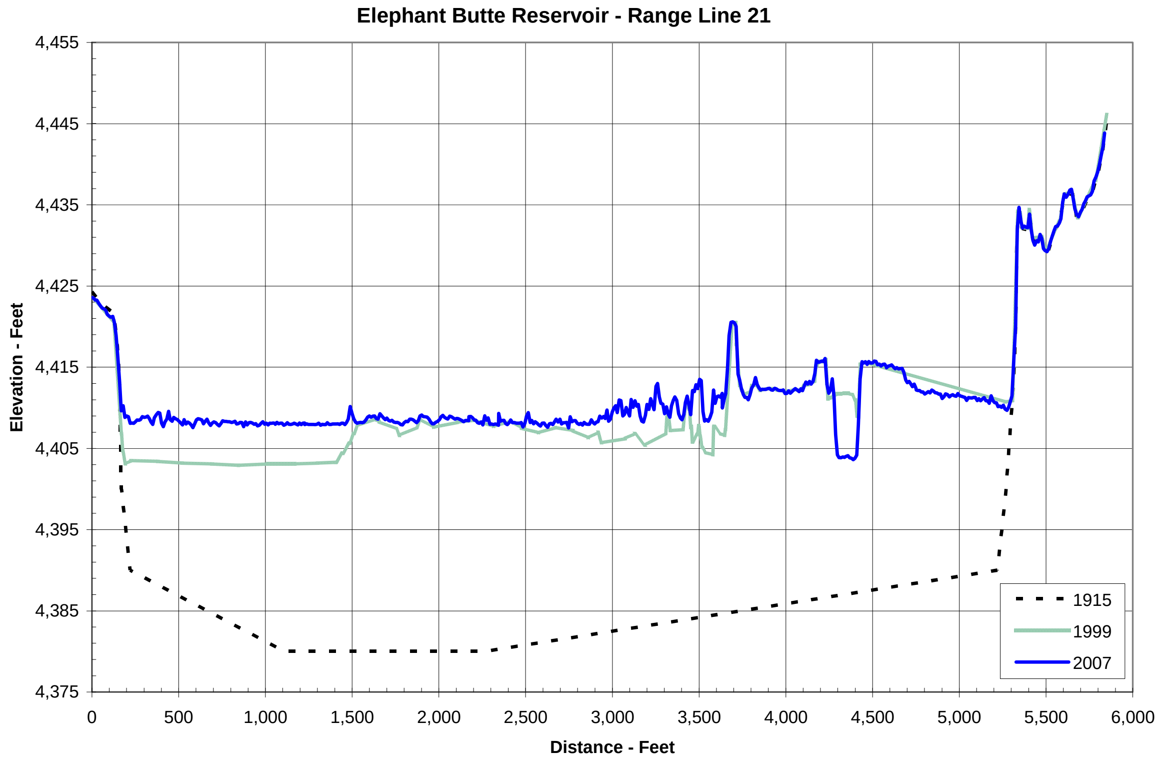

Figure 82 - Range Line 21.

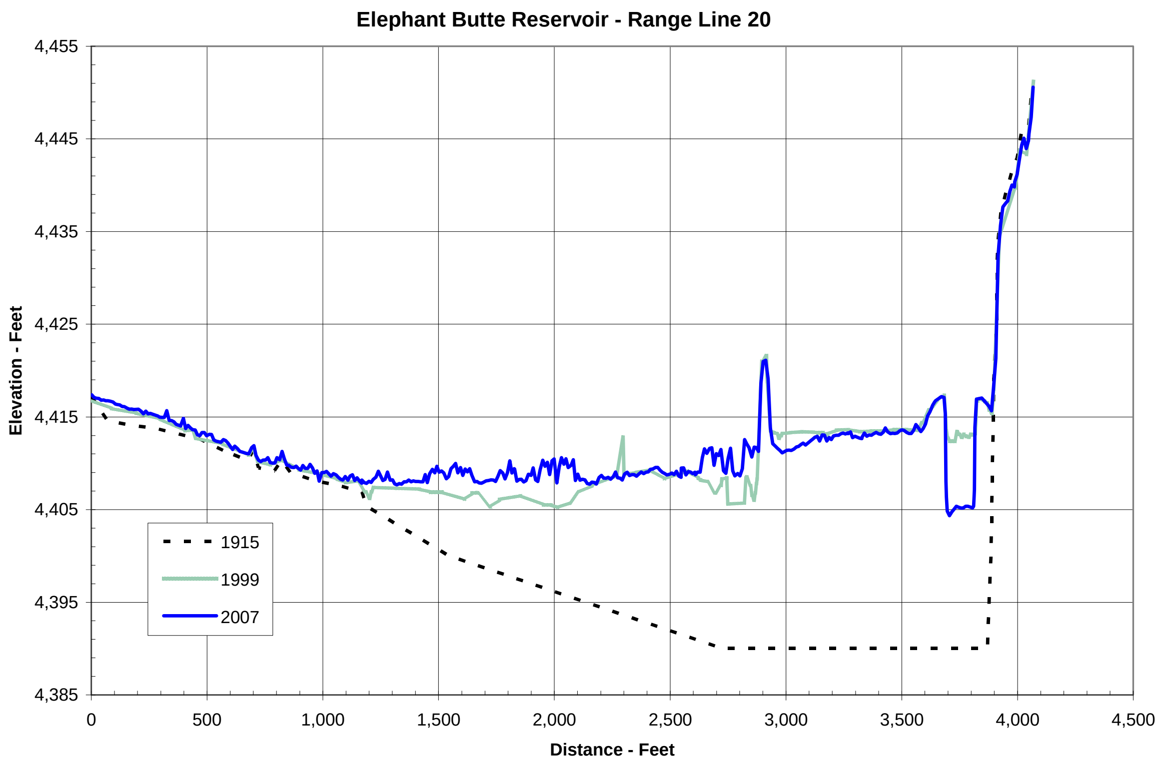

Figure 83 - Range Line 20.

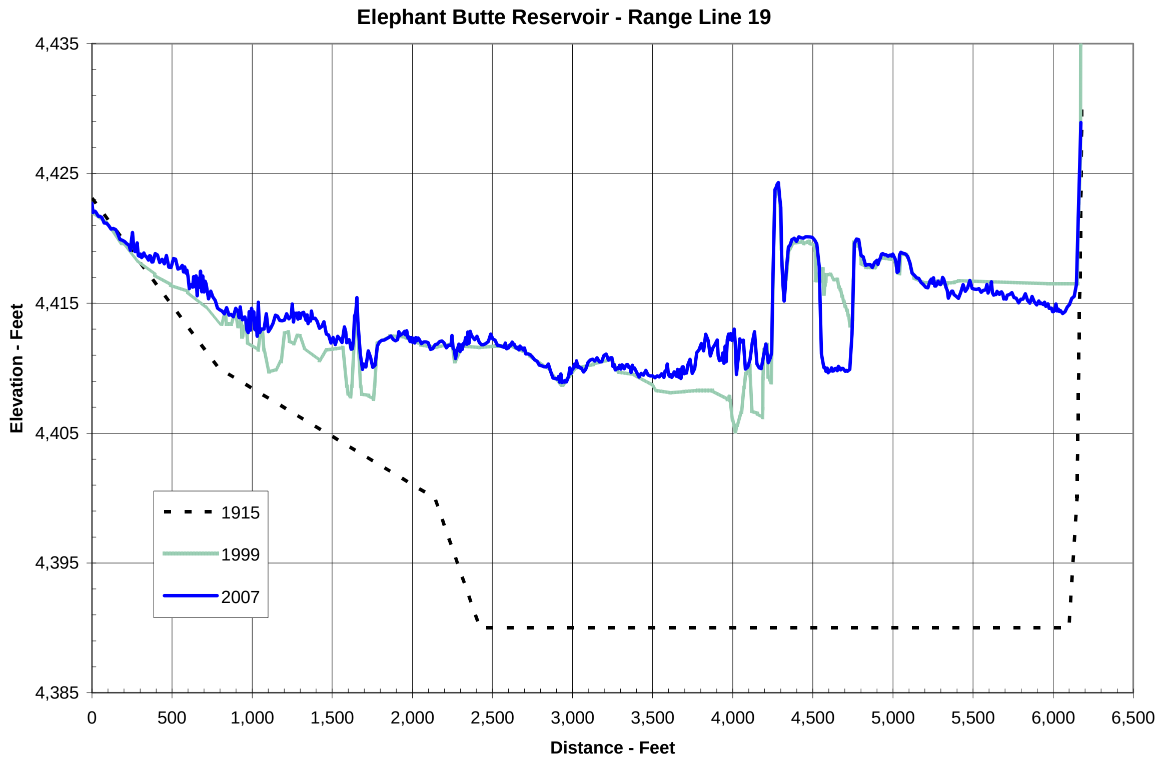

Figure 84 - Range Line 19.

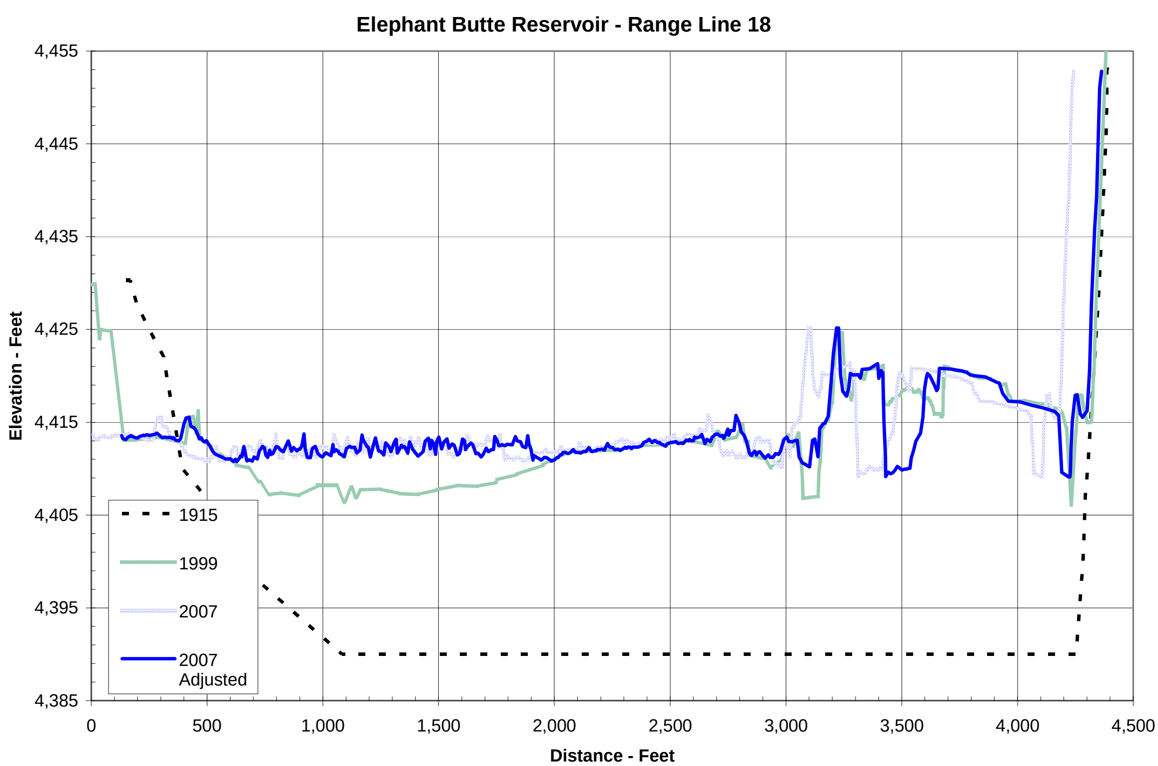

Figure 85 - Range Line 18.

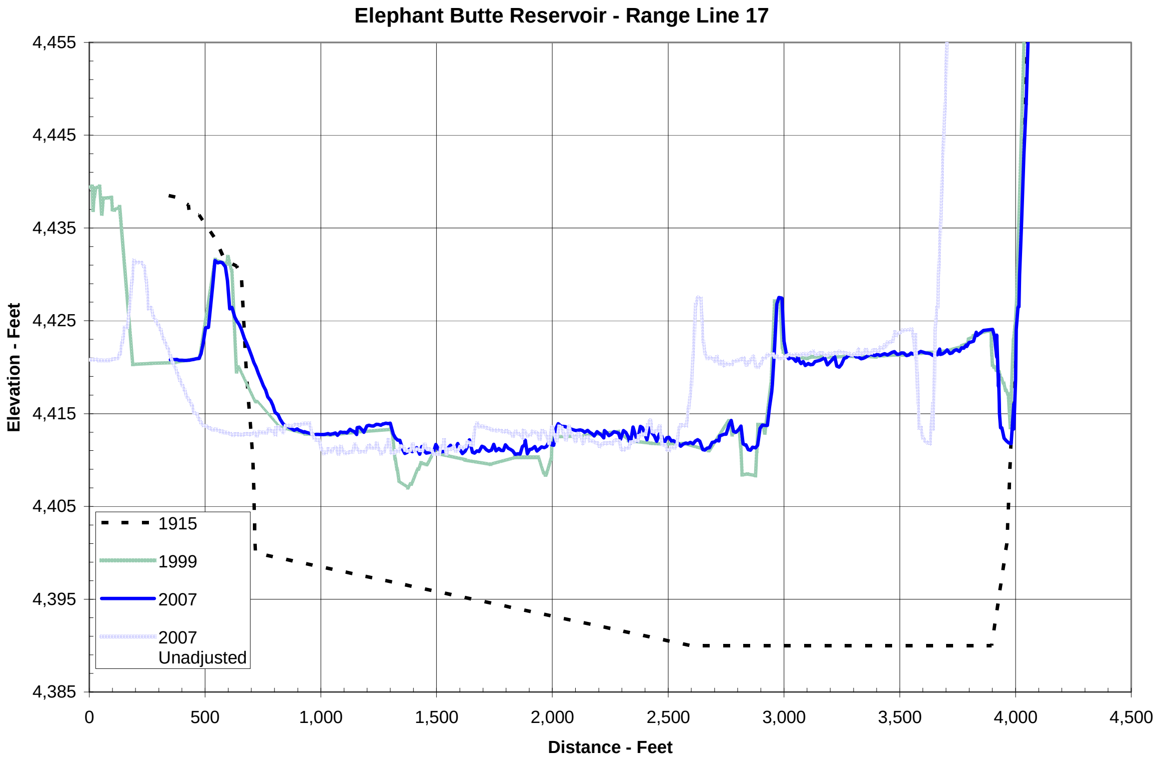

Figure 86 - Range Line 17.

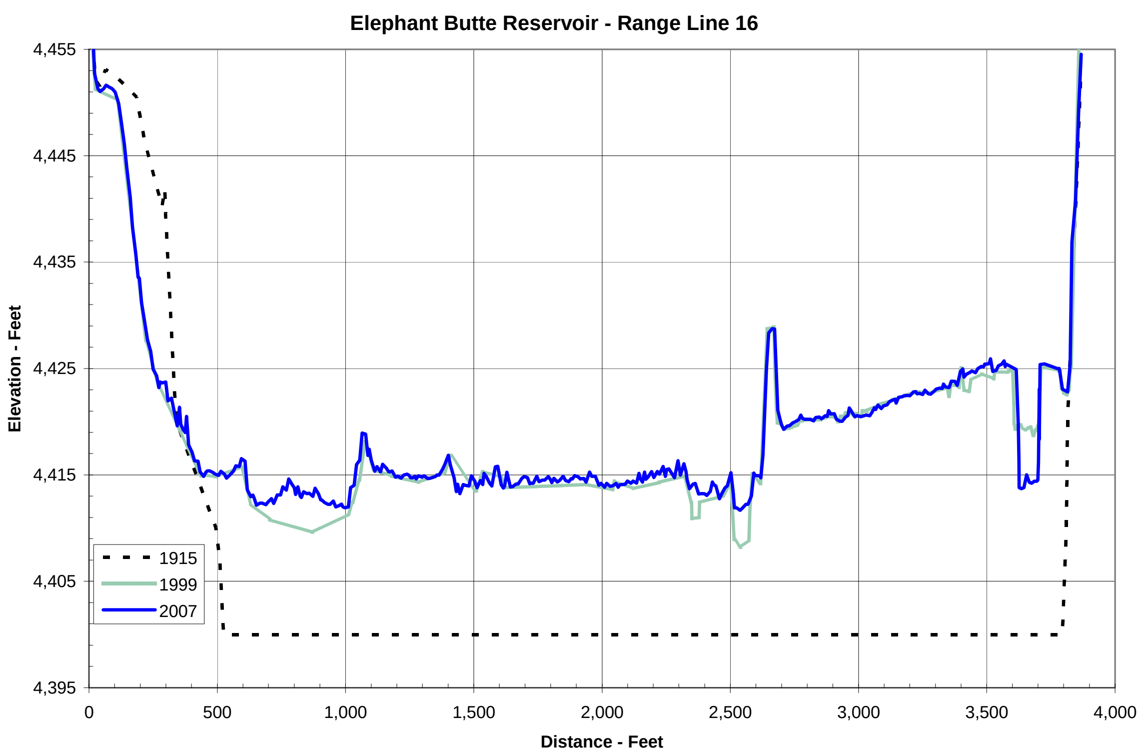

Figure 87 - Range Line 16.

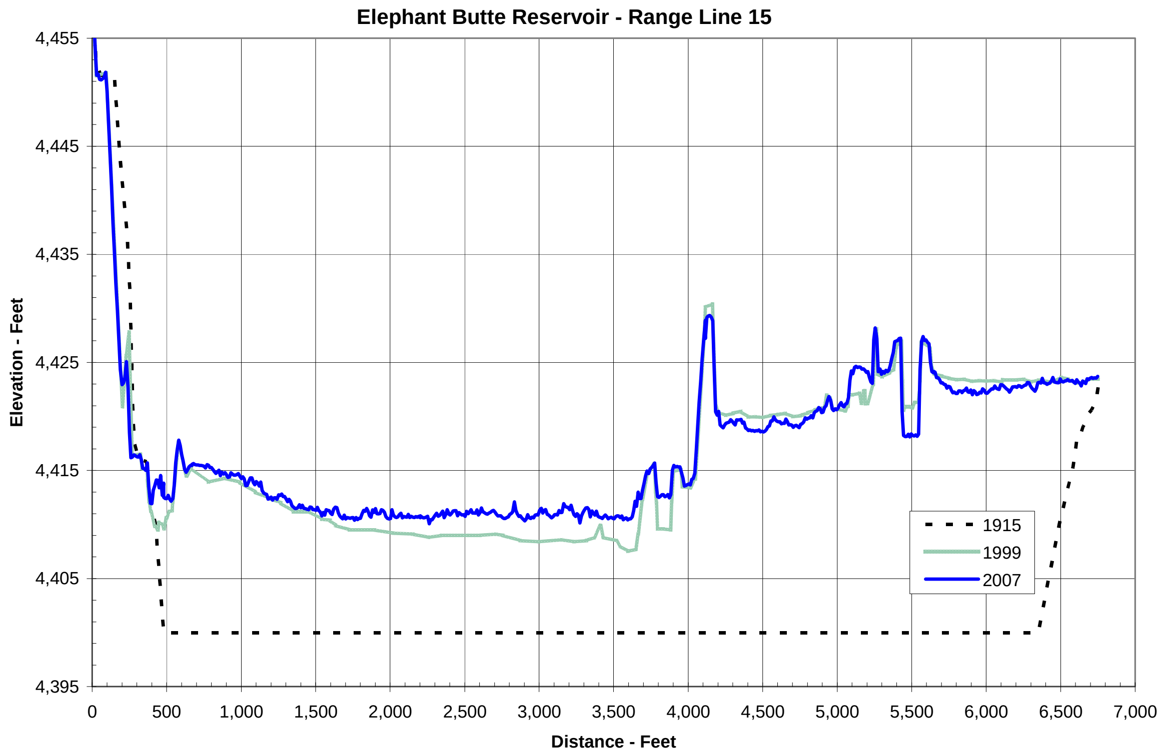

Figure 88 - Range Line 15.

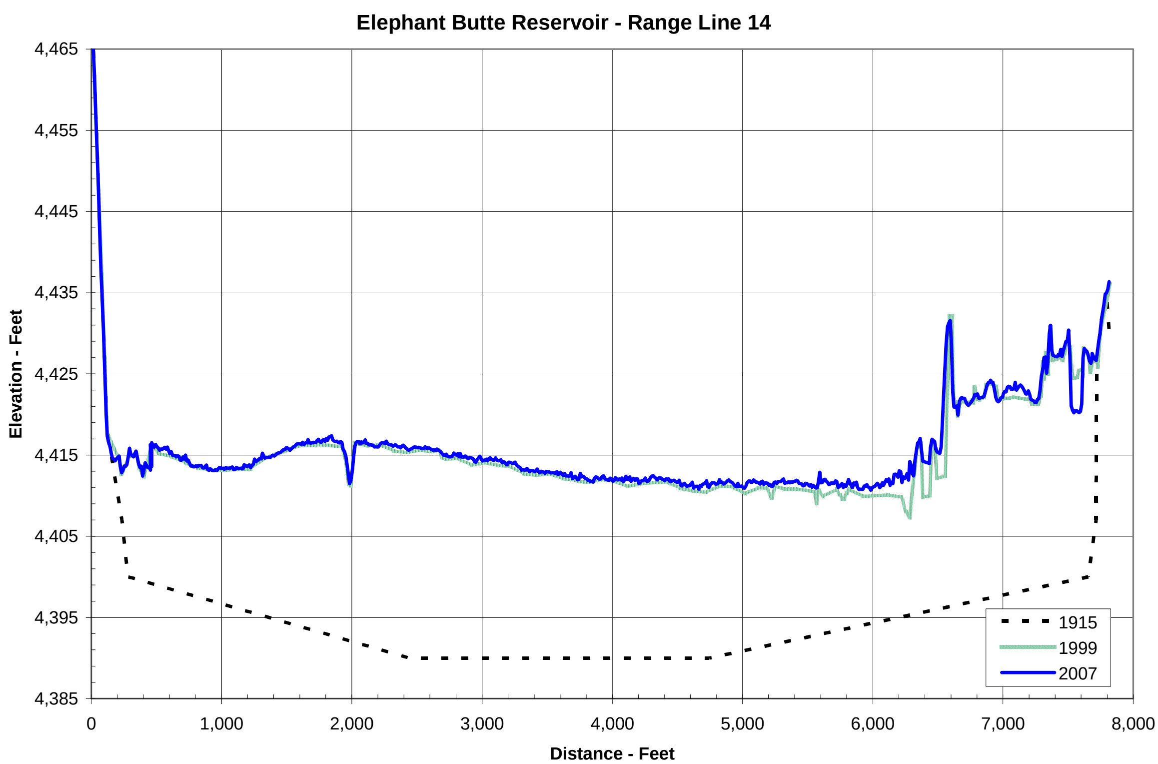

Figure 89 - Range Line 14.

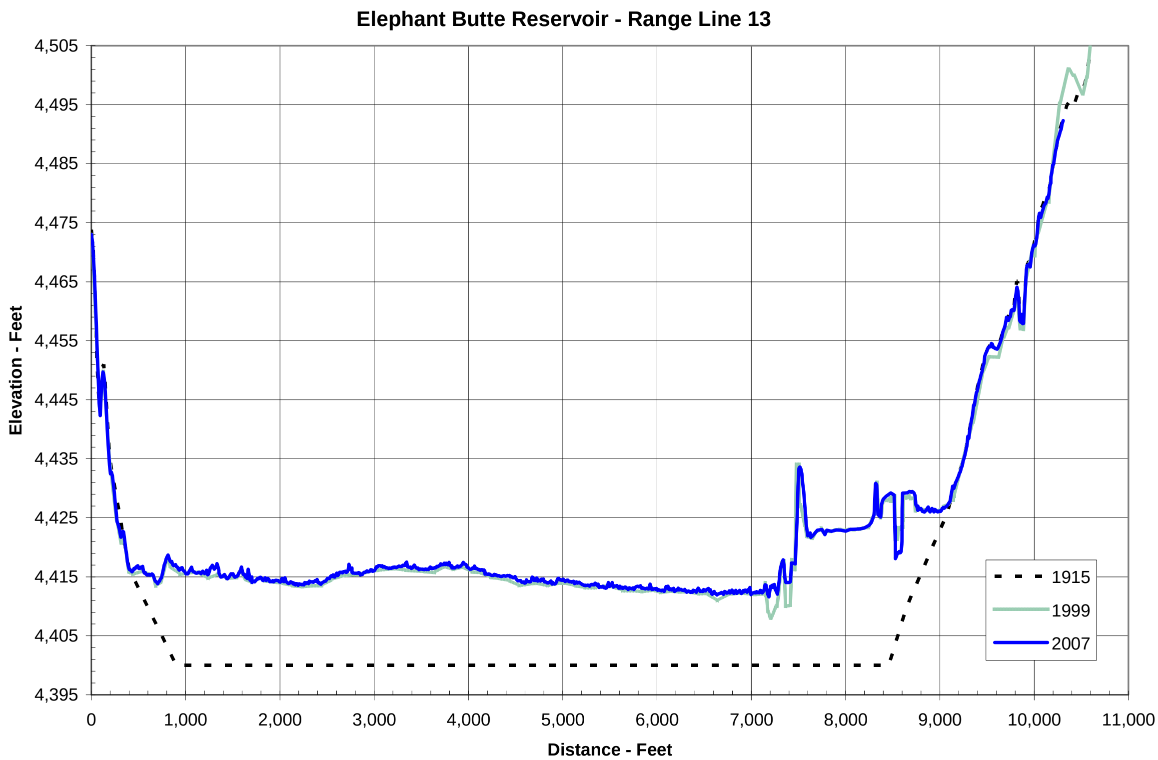

Figure 90 - Range Line 13.

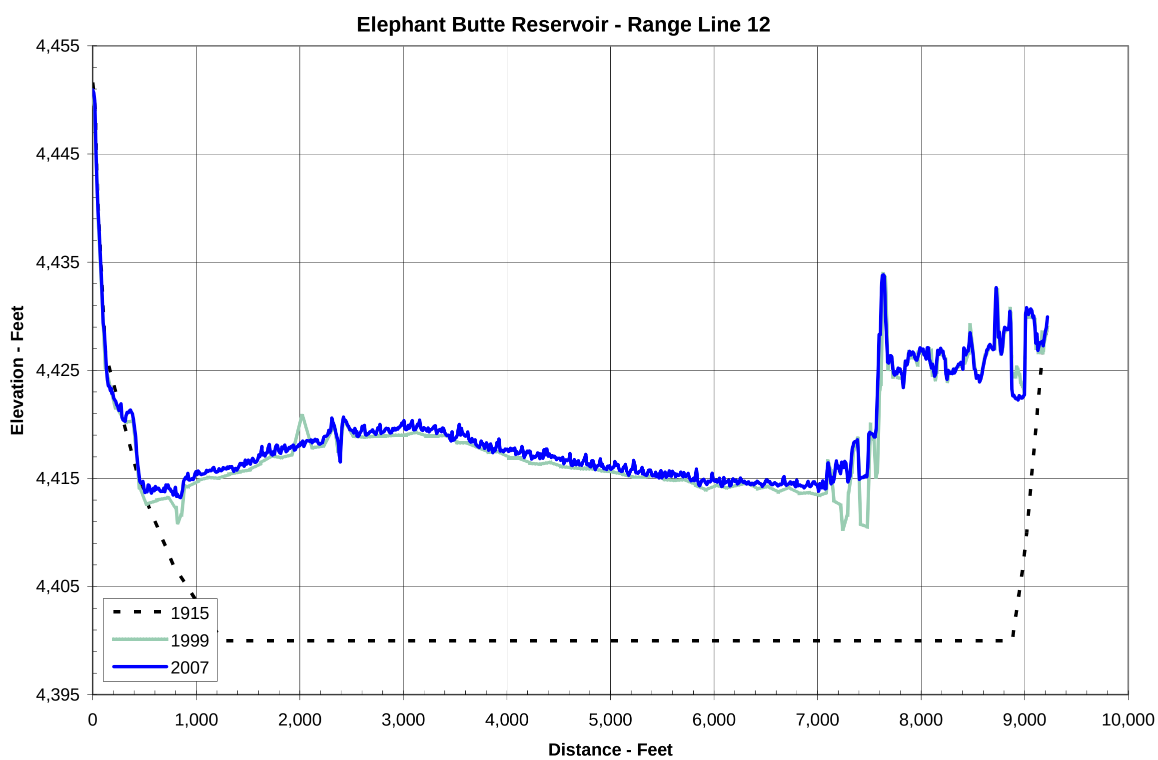

Figure 91 - Range Line 12.

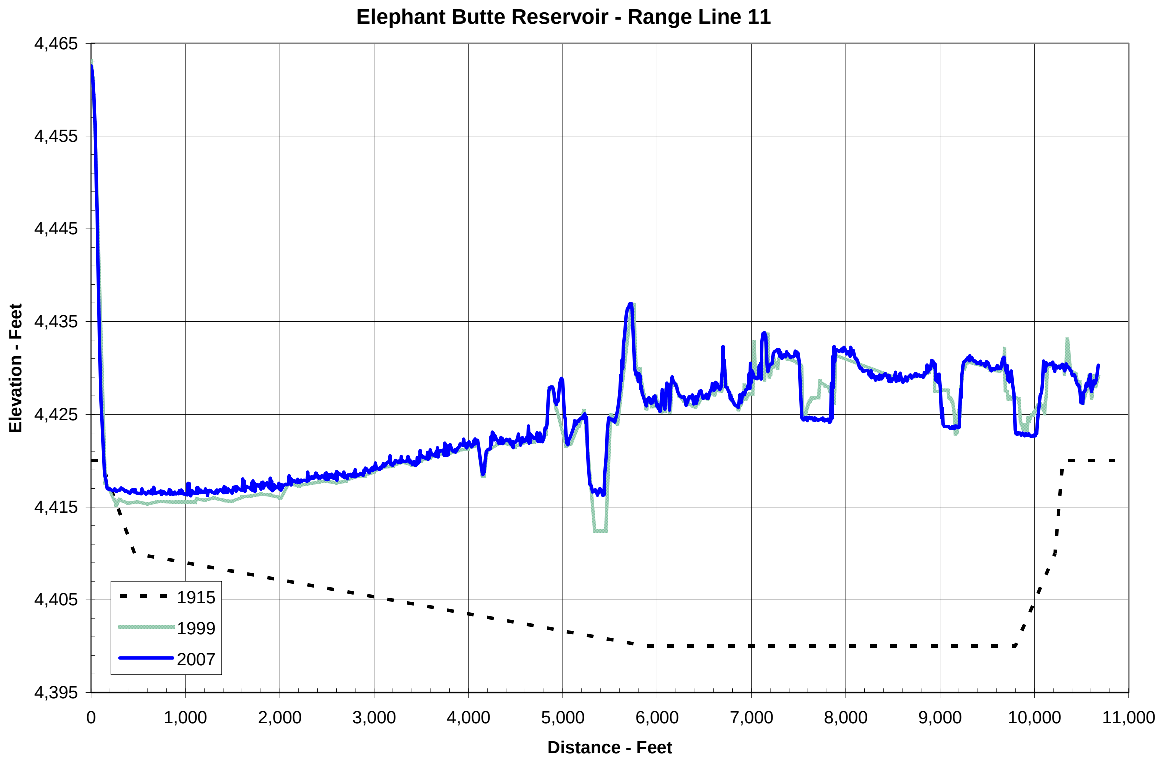

Figure 92 - Range Line 11.

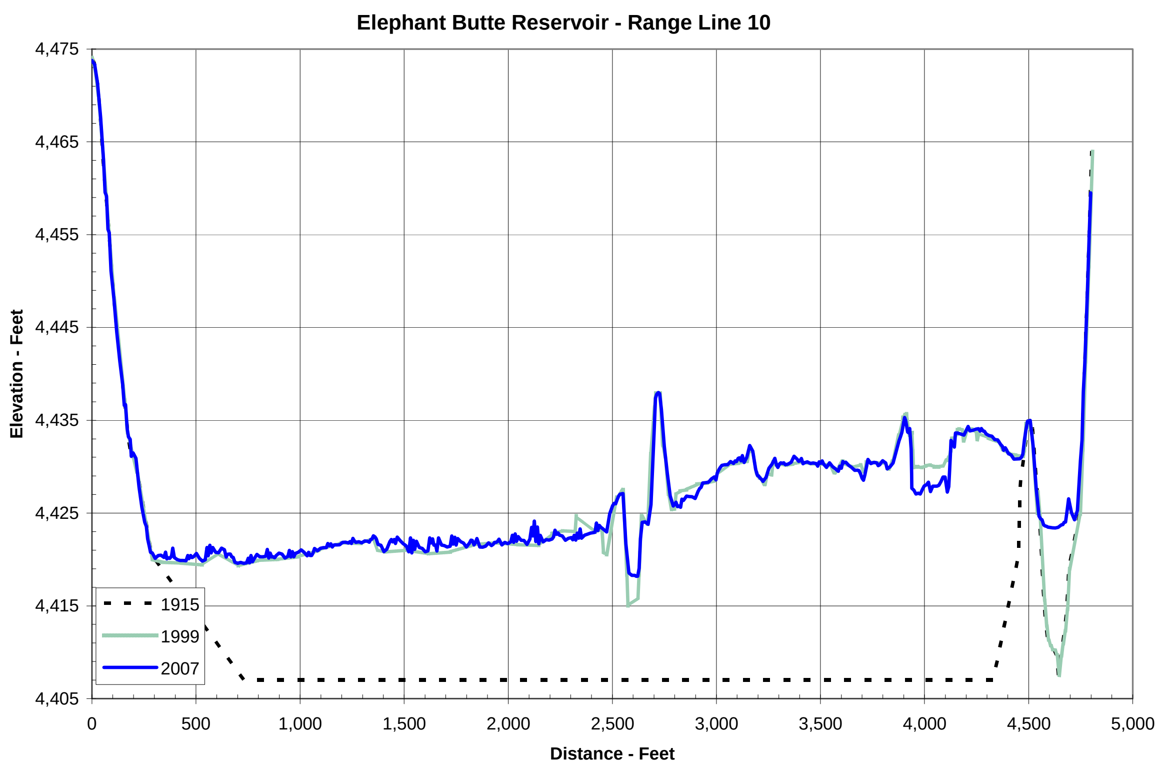

Figure 93 - Range Line 10.

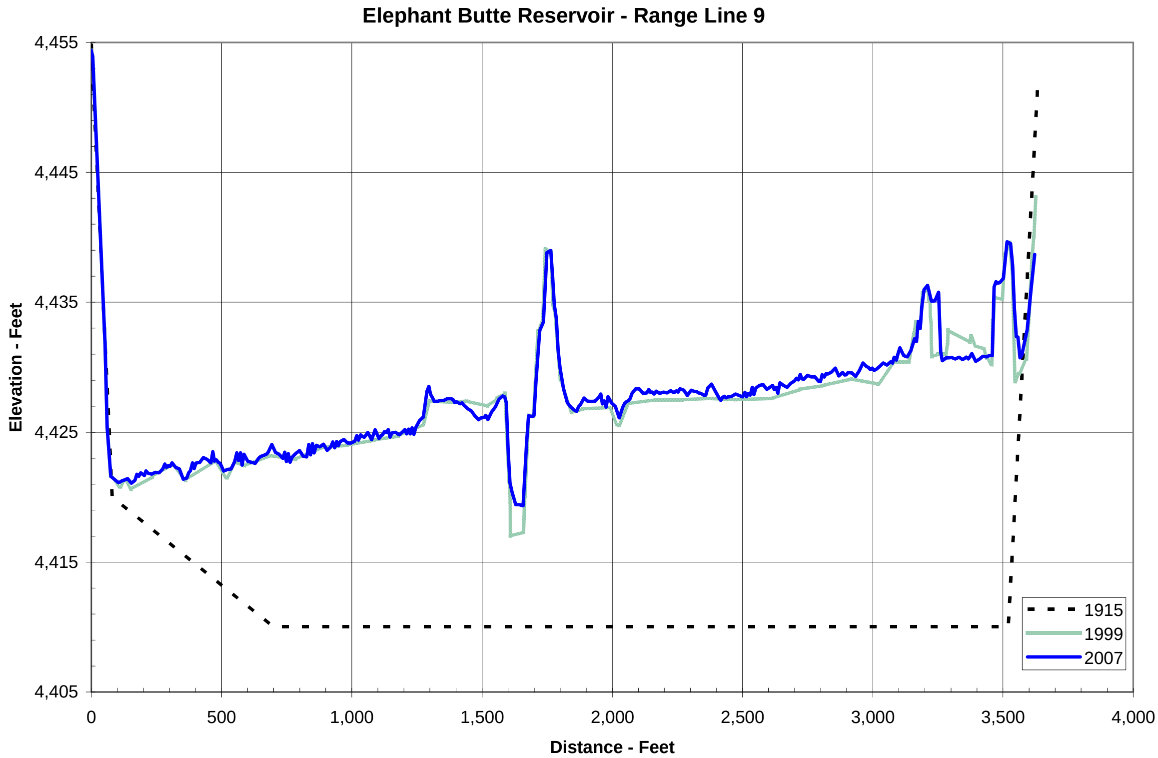

Figure 94 - Range Line 9.

Longitudinal Distribution

To illustrate the sediment distribution throughout the reservoir, a longitudinal profile was plotted for the original, 1988, 1999, and 2007 reservoir conditions (Figure 95). The difference between the original thalweg and the 1988, 1999, and 2007 thalweg represents the sediment encroachment into the reservoir since the dam closed in 1915. The plot shows the greatest depths of longitudinal sediment deposits since 1915 occurring in 1988 and 1999 between 14 to 16 miles upstream of the dam. The deposit pattern in this region was influenced by the "Narrows" area located between 15 and 20 miles above the dam when the reservoir pool extends upstream.

For this same reach the 2007 longitudinal plot is lower than the 1988 and 1999 plots. Looking at the lateral distribution plots of the range lines in this area, range line 50 through 60, one can see this is a reach of the reservoir where the inflow channel has cut through the previously deposited sediments. The 2007 plot shows sediment deposition since 1999 occurring around mile 6 upstream to around mile 13. When the reservoir is full, the "Narrows" divide the reservoir into 2 large water bodies. The "Narrows" have 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. From 1950 through 1968 there was a severe drought in the region where the reservoir was held at a much lower stage, allowing the inflowing sediment to be deposited in the lower reaches of the reservoir. Another severe regional drought began in 1999 and the lateral and longitudinal plots show the affect of the sediment deposition more downstream towards the dam. The plot of the 1999 and 2007 thalweg illustrates where the majority of sediments have deposited over the last 8 years: in the upper reservoir area above mile 34 and the reach downstream of the narrows where the reservoir water surface has fluctuated since the 1999 drawdown.

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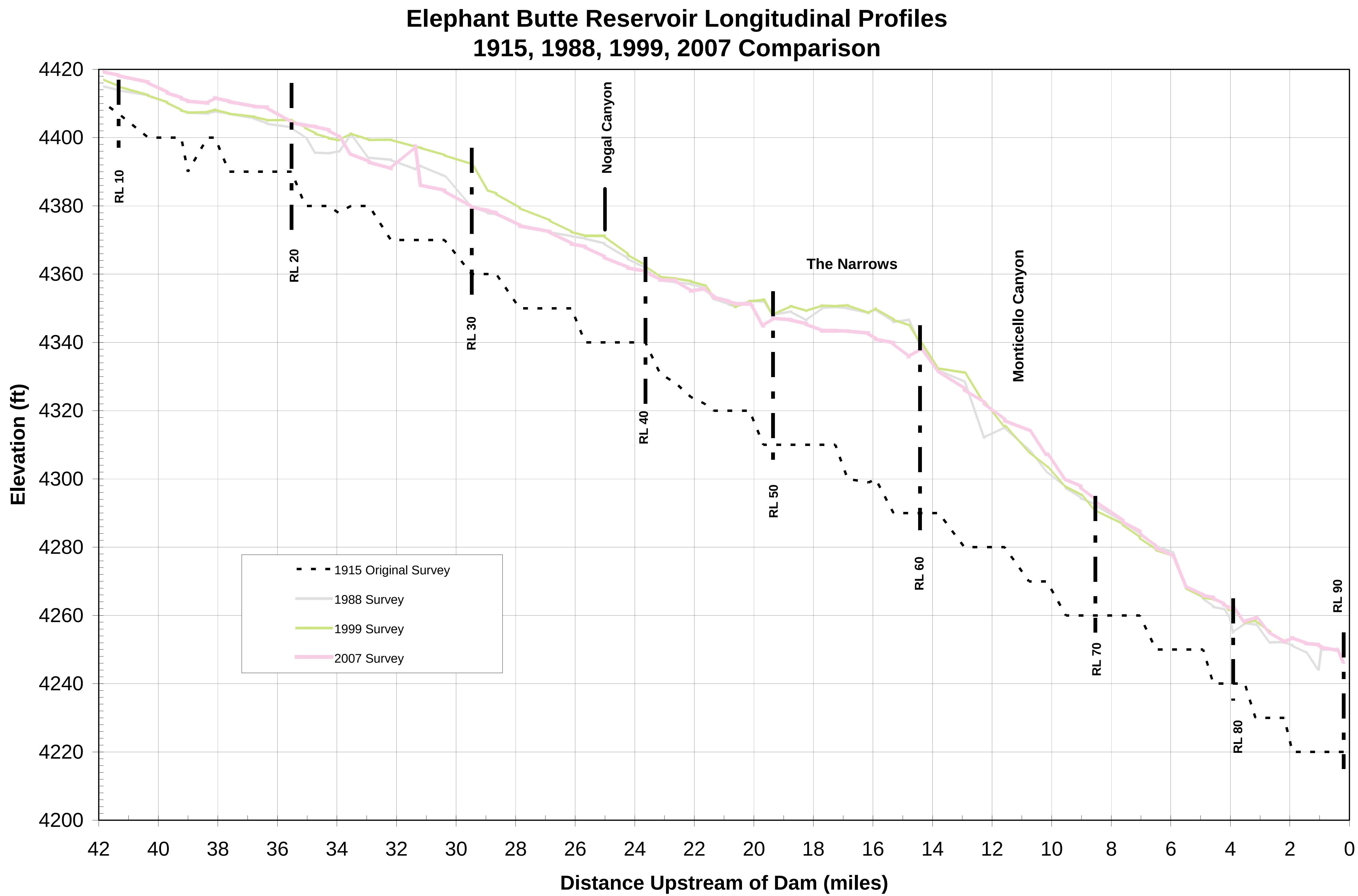

Figure 95 - Elephant Butte Reservoir Longitudinal Profiles.

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Reservoir Area and Capacity

2007 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program can compute the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.00001 for Elephant Butte Reservoir. The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Through differentiation of the capacity equations, which are of second order polynomial form, final area equations are derived:

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

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

Results of the Elephant Butte Reservoir area and capacity computations are listed in a separate set of 2007 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2008). A description of the computations and coefficients output from the ACAP program is included with these tables. The original (1915) and 2007 results are listed on table 1. The original, 1988, 1999, and 2007 area-capacity relationships are listed on Table 2. The curves for these surveys are plotted on Figure 96. As of October 2007, at elevation 4,407.0, the surface area was 35,825 acres with a total capacity of 2,024,586 acre-feet.

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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	3. STATE New Mexico
	4. SEC 30 TWP. 13 S RANGE 3 W	5. NEAREST P.O. Truth or Consequences	6. COUNTY Sierra
	7. LAT 33 ° 09 ' 1 5 " LONG 107 ° 11 ' 28 "	8. TOP OF DAM ELEVATION 4414.0 [1]	9. SPILLWAY CREST EL 4407.0

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC-FT	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN
	a. SURCHARGE					
	b. FLOOD CONTROL					
	c. MULTIPLE USE	4,407.0 [2]	40,064	2,631,585	2,634,800	1/6/15
	d. JOINT USE					16 DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION					
	f. INACTIVE	4,231.5	420	3,215	3,215	
	g. DEAD					2/1/15
	17. LENGTH OF RESERVOIR 41 MILES		AVG. WIDTH OF RESERVOIR 1.39 MILES			

BASIN			
	18. TOTAL DRAINAGE AREA 25923 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 8.29 [3]	INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 11996 [4] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.62 [5]	INCHES
	20. LENGTH 305 MILES AVG. WIDTH 85 MILES	24. MEAN ANNUAL INFLOW 853,600 [6]	ACRE-FEET
	21. MAX. ELEVATION 10000 MIN. ELEVATION 4100.5	25. ANNUAL TEMP, MEAN 64 °F RANGE -16 °F to 111 °F [7]	

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/ RATIO AF/AF
1/6/1915 [7]			Contour (D)	10-ft (CI)	40,064	2,634,800	3.09
4/28/47 [7]	32.3	32.3	Range (D)	90 Feet	36,772	2,197,600	2.57
2/12/57 [7]	9.8	42.1	Contour (D)	10-ft	36,584	2,206,780	2.59
4/1999 [7]	42.2	84.3	Range (D)	82 (RL)	35,984	2,023,358	2.37
10/2007 [8]	8.5	92.8	Range (D)	82 (RL)	35,825	2,024,586	2.37

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	35. b. MAX. ANN.	35. c. TOTAL	36 WATER INFLOW TO DATE, AF a. MEAN ANN.	36. b. TOTAL
2/28/47 [7]		1,154,862	2,440,000	7,506,600	1,077,623	34,807,230
2/12/57 [7]		441,776	1,036,000	4,307,318	930,191	39,114,548
4/14/1999 [7]		991,354	1,776,999	11,103,200	892,281	75,219,280
10/2007 [8]		504,200	944,365	4,285,400	853,600	79,210,000

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	37. b. AVG. ANN.	37. c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	38. b. AVG. ANN.	38. c. /MI.^{2}-YR.
2/28/47	437,200	13,535.6	0.522	437,000	13,535.6	0.522
2/12/57 [9]	-9,180 [9]			428,020	10,166.7	0.392
4/14/1999	183,422	4,346.5	0.362	611,442	7,253.2	0.605
10/2007 [10]	-1,228 [9]			610,214	6,575.6	0.548

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	40. b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	41. b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	42. b. TOT.
2/28/47		182	751	0.514	16.59	3,010	13,300
2/12/57	60			0.386	16.24	673	673
4/14/1999				0.275	23.21		
10/2007				0.250	23.16		

26. DATE OF SURVEY	43. DEPTH DESIGNATION ELEVATION RANGE IN FEET									
		137-197	117-137	97-117	77-97	57-77	37-57	27-37	17-27	7-17	crest-7.0
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
4/1999		2.6	12.2	15.6	8.5	11.9	16.0	9.6	9.3	8.9	5.4
10/2007		9.9	10.9	10.6	9.5	12.1	15.5	9.1	8.7	8.4	5.3

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

Table 1 - Reservoir Sediment Summary Sheets (1 of 3).

45. RANGE IN RESERVOIR OPERATION [6]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1915	4,321.8		1,302,250	1916	4,346.8	4,306.6	1,421,000
1917	4,353.8	4,331.8	1,305,000	1918	4,337.0	4,290.3	379,100
1919	4,358.8	4,285.5	1,527,000	1920	4,393.9	4,350.9	1,970,000
1921	4,392.5	4,377.5	1,470,000	1922	4,389.5	4,370.7	1,044,000
1923	4,377.4	4,366.5	964,000	1924	4,395.8	4,368.9	1,662,000
1925	4,382.1	4,354.7	321,000	1926	4,378.1	4,354.6	1,120,000
1927	4,374.0	4,363.0	1,180,000	1928	4,379.1	4,359.7	773,000
1929	4,374.8	4,353.7	1,240,000	1930	4,384.5	4,372.3	930,000
1931	4,374.2	4,349.7	418,000	1932	4,384.5	4,351.8	1,440,000
1933	4,377.9	4,365.0	717,000	1934	4,367.8	4,325.0	298,300
1935	4,342.2	4,322.8	917,600	1936	4,354.9	4,331.8	872,900
1937	4,380.7	4,333.9	1,597,000	1938	4,377.1	4,365.6	1,004,000
1939	4,378.4	4,351.2	615,700	1940	4,357.0	4,323.2	333,100
1941	4,399.2	4,324.3	2,440,000	1942	4,409.2	4,397.0	2,322,000
1943	4,399.0	4,380.8	441,600	1944	4,385.7	4,369.2	982,500
1945	4,385.6	4,372.3	851,500	1946	4,375.7	4,339.5	224,900
1947	4,339.4	4,311.9	419,200	1948	4,349.2	4,313.1	1,036,000
1949	4,351.3	4,329.7	1,031,000	1950	4,346.1	4,315.5	364,100
1951	4,315.8	4,262.3	132,900	1952	4,324.6	4,261.6	967,000
1953	4,220.5	4,283.2	286,800	1954	4,297.3	4,258.0	198,500
1955	4,295.5	4,276.6	257,900	1956	4,304.4	4,268.4	174,800
1957	4,337.1	4,267.1	972,300	1958	4,373.3	4,336.2	1,391,000
1959	4,362.8	4,334.5	341,900	1960	4,339.0	4,322.4	563,400
1961	4,329.1	4,302.0	437,700	1962	4,329.8	4,304.4	748,100
1963	4,327.5	4,282.1	405,500	1964	4,299.2	4,275.5	164,200
1965	4,323.0	4,277.5	821,700	1966	4,338.3	4,311.0	725,340
1967	4,321.8	4,293.0	391,600	1968	4,319.7	4,295.1	646,230
1969	4,335.0	4,308.8	787,600	1970	4,339.4	4,303.0	729,200
1971	4,326.4	4,271.2	413,100	1972	4,319.0	4,297.7	427,900
1973	4,355.5	4,319.2	1,309,000	1974	4,360.9	4,312.2	451,400
1975	4,345.9	4,326.1	875,900	1976	4,353.0	4,318.0	580,900
1977	4,325.2	4,295.8	243,200	1978	4,314.7	4,290.2	385,100
1979	4,365.0	4,305.9	1,427,000	1980	4,380.5	4,363.8	1,280,000
1981	4,378.1	4,354.3	341,700	1982	4,364.7	4,354.3	824,300
1983	4,383.6	4,364.8	1,262,000	1984	4,392.3	4,381.0	1,052,000
1985	4,404.4	4,392.0	1,542,000	1986	4,407.2	4,402.8	1,576,000
1987	4,406.6	4,402.7	1,732,000	1988	4,406.7	4,401.4	930,300
1989	4,405.1	4,393.4	478,200	1990	4,397.5	4,380.3	347,100
1991	4,392.4	4,380.6	1,043,000	1992	4,405.7	4,391.4	1,167,000
1993	4,405.7	4,398.4	1,254,000	1994	4,406.0	4,401.1	1,776,000
1995	4,406.6	4,403.9	1,385,000	1996	4,406.5	4,394.2	525,700
1997	4,401.5	4,395.2	943,200	1998	4,404.5	4,393.1	919,200
1999	4,398.1	4,392.4	870,500	2000	4,397.6	4,377.6	361,100
2001	4,383.2	4,361.9	452,300	2002	4,365.9	4,320.1	273,100
2003	4,331.9	4,303.3	244,600	2004	4,324.2	4,294.0	365,700
2005	4,344.2	4,309.9	944,400	2006	4,340.7	4,308.5	515,000
2007	4,347.8	4,324.4	612,800				

46. ELEVATION - AREA - CAPACITY - DATA FOR								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
1915	**SURVEY**							
4,210.0	0	0	4,220.0	98	490	4,230.0	376	2,960
4,240.0	671	4,660	4,250.0	1,684	15,800	4,260.0	3,157	39,700
4,270.0	4,691	78,600	4,280.0	6,145	132,800	4,290.0	7,715	202,100
4,300.0	8,923	285,400	4,310.0	10,202	380,800	4,320.0	11,894	490,800
4,330.0	14,240	621,400	4,340.0	16,595	775,600	4,350.0	19,194	954,400
4,360.0	22,563	1,162,100	4,370.0	26,620	1,408,000	4,380.0	30,191	1,692,800
4,390.0	33,451	2,010,300	4,400.0	37,328	2,363,900	4,407.0	40,060	2,634,800
4,410.0	41,283	2,756,600						

Table 1 – Reservoir Sediment Summary Sheets (2 of 3).

46.	ELEVATION - AREA - CAPACITY - DATA FOR							
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2007	**SURVEY**							
4,245.0	0.0	0	4,250.0	56.5	141	4,255.0	402.4	1,288
4,260.0	748.2	4,165	4,265.0	1,402.9	9,542	4,270.0	2,057.6	18,194
4,275.0	2,298.6	29,084	4,280.0	2,539.5	41,179	4,285.0	3,378.2	55,974
4,290.0	4,216.9	74,961	4,295.0	5,001.6	98,008	4,300.0	5,786.4	124,978
4,305.0	6,442.1	155,549	4,310.0	7,097.8	189,399	4,315.0	8,190.2	227,619
4,320.0	9,282.7	271,301	4,325.0	10,072.6	319,690	4,330.0	10,862.6	372,028
4,335.0	11,929.5	429,008	4,340.0	12,996.5	491,323	4,345.0	13,948.0	558,684
4,350.0	14,899.4	630,803	4,355.0	16,383.9	709,011	4,360.0	17,868.4	794,642
4,365.0	19,499.7	888,062	4,370.0	21,130.9	989,638	4,375.0	22,928.9	1,099,788
4,380.0	24,726.9	1,218,927	4,385.0	26,453.1	1,346,877	4,390.0	28,179.2	1,483,458
4,395.0	30,256.8	1,629,548	4,400.0	32,334.5	1,786,026	4,407.0	35,825.5	2,024,586
4,410.0	37,321.6	2,134,307						

47. REMARKS AND REFERENCES

[1] All elevations are project datum which is 43.3 feet less than National Geodetic Vertical Datum of 1929 and 45.5 feet less than North American Vertical Datum of 1988. There is a parapet wall on upstream and downstream sides of the dam crest with top elevation 4,419.0.

[2] Irrigation and power water supply, except the top 50,000 acre-feet in the summer (April 1- September 30) and the top 25,000 acre-feet in the winter (October 1 - March 31), which is used for prudent flood control space. Surface area at elevation 4231.5 estimated.

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

[4] Previous studies report total drainage area as 25,923 mi^2 while USGS gage data at dam indicated 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 mi2). Galisteo Dam in 1970 (596 mi2), Cochiti in 1973 (11,960 mi2), noncontributing area (310 mi2), and reservoir area (57 mi2.

[5] Calculated using mean annual runoff value of 853,600 acre-feet (item 24).

[6] Computed annual inflow from 1/1915 through 10/2008. Annual inflow records from different sources, used published values in 1999 Elephant Butte Sediment Survey report from 1915 through 1998.

[7] Values for 1915, 1947, 1957, and 1999 survey results from previous published results of Elephant Butte surveys. (www.usbr.gov/pmts/sediment)

[8] 2007 survey results.

[9] Measured total storage measured a gain of 9,180 acre-feet since 1947 survey. Attributable to compaction of previous measured sediments located in the upper reservoir area that had long term exposure and dewatering due to low reservoir content.

[10] Measured total storage measured a gain of 1,228 acre-feet since 1999 survey. Attributable to compaction of previous measured sediments located in the upper reservoir area that had long term exposure and dewatering due to low reservoir content.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE August 2008

Table 1 – Reservoir Sediment Summary Sheets (3 of 3).

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1915	1915			1988	1988			1999	1999			2007	2007	
	Original	Original	1988	1988	Sediment	Percent	1999	1999	Sediment	Percent	2007	2007	Sediment	Percent	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Computed	Area	Capacity	Volume	Computed	Area	Capacity	Volume	Computed	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Depth
4,407.0	40,060	2,634,800	36,643	2,065,010	569,790	100.0	35,984	2,023,358	611,442	100.0	35,826	2,024,586	610,214	100.0	100.0
4,400.0	37,328	2,363,900	33,433	1,819,744	544,156	95.5	32,051	1,785,235	578,665	94.6	32,335	1,786,026	577,874	94.7	96.4
4,390.0	33,451	2,010,300	28,697	1,509,096	501,204	88.0	27,788	1,486,042	524,258	85.7	28,179	1,483,458	526,842	86.3	91.4
4,380.0	30,191	1,692,800	24,890	1,241,164	451,636	79.3	24,323	1,225,489	467,311	76.4	24,727	1,218,927	473,873	77.7	86.3
4,370.0	26,620	1,408,000	20,994	1,011,742	396,258	69.5	20,856	999,593	408,407	66.8	21,131	989,638	418,362	68.6	81.2
4,360.0	22,563	1,162,100	18,011	816,715	345,385	60.6	17,765	806,489	355,611	58.2	17,868	794,642	367,458	60.2	76.1
4,350.0	19,194	954,400	14,872	652,300	302,100	53.0	14,784	643,744	310,656	50.8	14,899	630,803	323,597	53.0	71.1
4,340.0	16,595	775,600	13,210	511,890	263,710	46.3	13,046	504,591	271,009	44.3	12,997	491,323	284,277	46.6	66.0
4,330.0	14,240	621,400	11,260	389,537	231,863	40.7	11,169	383,516	237,884	38.9	10,863	372,028	249,372	40.9	60.9
4,320.0	11,894	490,800	9,535	285,562	205,238	36.0	9,563	279,857	210,943	34.5	9,283	271,301	219,499	36.0	55.8
4,310.0	10,202	380,800	7,503	200,374	180,426	31.7	7,434	194,872	185,928	30.4	7,098	189,399	191,401	31.4	50.8
4,300.0	8,923	285,400	6,205	131,833	153,567	27.0	6,063	127,388	158,012	25.8	5,786	124,978	160,422	26.3	45.7
4,290.0	7,715	202,100	4,263	79,490	122,610	21.5	4,171	76,222	125,878	20.6	4,217	74,961	127,139	20.8	40.6
4,280.0	6,145	132,800	2,660	44,873	87,927	15.4	2,562	42,561	90,239	14.8	2,539	41,179	91,621	15.0	35.5
4,270.0	4,691	78,600	2,142	20,861	57,739	10.1	2,107	19,220	59,380	9.7	2,058	18,194	60,406	9.9	30.5
4,260.3	3,302	40,717	1,007	5,590	35,127	6.2	860	4,831	35,886	5.9	1,141	6,999	33,718	5.5	25.5
4,260.0	3,157	39,700	971	5,293	34,407	6.0	822	4,579	35,121	5.7	748	4,165	35,535	5.8	25.4
4,250.0	1,684	15,800	55	160	15,640	2.7	63	157	15,643	2.6	57	141	15,659	2.6	20.3
4,245.0	1,178	10,230	8	3	10,227	1.8	0	0	10,230	1.7	0	0	10,230	1.7	17.8
4,244.2	1,096	9,339	0	0	9,339	1.6	0	0	9,339	1.5	0	0	9,339	1.5	17.4
4,240.0	671	4,660	0	0	4,660	0.8	0	0	4,660	0.8	0	0	4,660	0.8	15.2
4,230.0	376	2,960	0	0	2,960	0.5	0	0	2,960	0.5	0	0	2,960	0.5	10.2
4,220.0	98	490	0	0	490	0.1	0	0	490	0.1	0	0	490	0.1	5.1
4,210.0	0	0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	0.0

1 Reservoir water surface elevation. Elevations tied to project datum that is 43.3 feet less than NGVD29 and 45.5 feet less than NAVD88.
2 Original, 1915 reservoir surface area.
3 Original, 1915 reservoir capacity.
4 1988 reservoir surface area.
5 1988 reservoir capacity.
6 1988 computed sediment volume, column (3) - column (5).
7 1988 measured sediment in percentage of total sediment of 569,790 acre-feet.
8 1999 reservoir surface area.
9 1999 reservoir capacity.
10 1999 computed sediment volume, column (3) - column (9).
11 1999 measured sediment in percentage of total sediment of 611,442 acre-feet.
12 2007 measured reservoir surface area.
13 2007 reservoir capacity computed using ACAP.
14 2007 measured sediment volume, column (3) - column (13).
15 2007 measured sediment in percentage of total sediment of 610,214 acre-feet.
16 Depth of reservoir expressed in percentage of total depth, 197 feet, from maximum water surface 4,407.0.

Table 2 - 2007 Elephant Butte Reservoir Survey Summaries.

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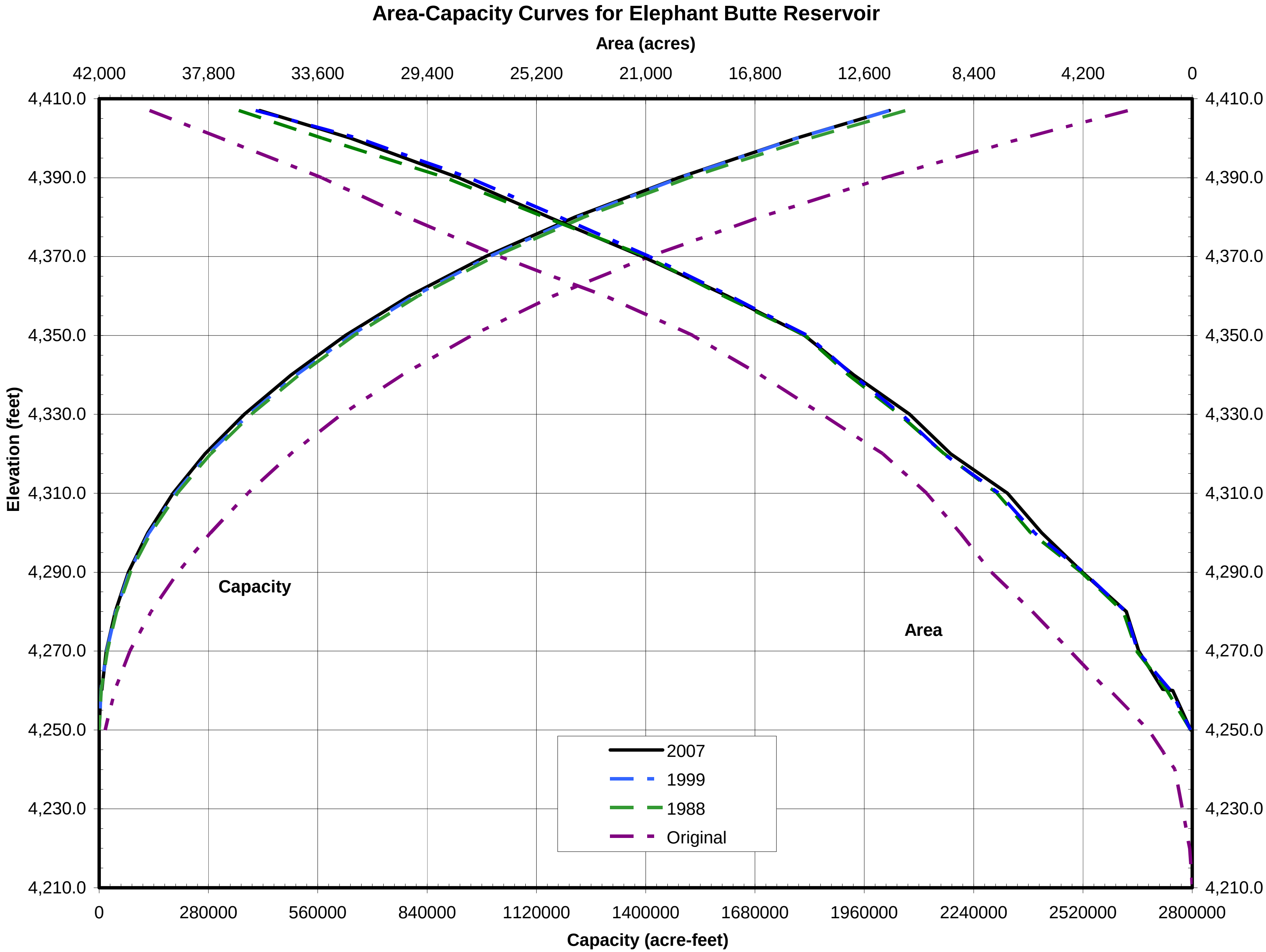

Figure 96 - Elephant Butte Reservoir Area and Capacity Plots

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2007 Analyses of Results

The Elephant Butte Reservoir original, 1988, 1999, and 2007 area and capacity values are illustrated on Figure 96 and the results are listed on Tables 1 and 2. These presentations illustrate the capacity change that has occurred during the 92.8 years of reservoir operations. This study found that as of October 2007, at reservoir water surface elevation (feet) 4,407.0, the surface area was 35,825 acres with a total capacity of 2,024,586 acre-feet. Since the reservoir's 1915 initial filling, 610,214 acre-feet of sediment have accumulated in Elephant Butte Reservoir. The average annual rate of sediment accumulation since 1915 is 6,576 acre-feet. These results were computed using the range line width area adjustment method. The range line method has been used been used in one form or another for all past surveys. Using like analysis methods for the 2007 survey was the best means to show change over time.

Since the last reservoir survey in 1999, the 2007 survey measured a net capacity gain of 1,228 acre-feet. Comparing the results of the 1999 and 2007 surveys showed a greater sediment deposit downstream of the "Narrows" and in the very upper reach near range lines 9 through 20. Over the last 8.5 years since the 1999 survey, the reservoir has been at very low stages, operating below the "Narrows." The areas from the "Narrows" upstream seldom saw the river overflow its banks and the bulk of the incoming sediment was conveyed to the lower reservoir. These types of results were also seen during the 1957 survey that was conducted after a 10 year drought cycle (Bureau of Reclamation, 1960). During these periods the continual draw-down of the reservoir had a significant effect on the compaction of reservoir sediments. The deposits were exposed to the sun for prolonged periods where they dried, compacted, and increased the initial unit weight, resulting in an increase of the volume computations. Since the 1999 survey, similar conditions have occurred, resulting in an increase volume due to consolidation of previous deposited sediments.

The results presented on Table 1 and Table 2 were computed using the range line collection and the width area adjustment analysis method. These same methods were previously used for the 1980, 1988, and 1999 surveys. These methods were the best means to measure and illustrate changes that have occurred over these time frames. The following sections are the results of the contour analysis that compared very well with the 2007 overall results.

2007 Topography Development

Elephant Butte Data Sets and TIN Development

The topography of Elephant Butte Reservoir was developed from 2007 bathymetric survey data, digitized contours from the USGS quad maps, and the 2004 and 2007 LiDAR data sets. All elevations presented on the following drawings are tied to the NAVD88 vertical datum that is 45.5 feet higher than Elephant Butte Dam project datum. This means the top of the dam at project elevation 4,414.0 would be elevation 4,459.5 feet in vertical datum NAVD88. The USGS 10-foot quad contours represent elevations in NGVD29 and were shifted to NAVD88 by adding 2.2 feet to their assigned elevation. The USGS quad contours do not provide the detail of the LiDAR data sets, but were the only means to map the areas not covered. There were also small coves upstream of range line 78 that the LiDAR data sets did not cover. In these reaches the USGS quad contours were used to interpolate data points to force contour closure. Even though there are areas that were not covered by the TIN data sets, an estimated 85 percent of the reservoir was covered. The LiDAR provided the most recent data to map the actual reservoir geometry above the 2007 bathymetry. The LiDAR takes into account the bank changes that have occurred over the years not represented by the range line survey and analysis.

The LiDAR data was processed as bare earth, but at times the water surface and top of vegetation were mapped where the LiDAR couldn’t penetrate. In the areas of the data sets where the 2007 bathymetry overlaid the LiDAR, the overlapping LiDAR data points where removed. This method removed all of the LiDAR water surface data points, plus provided the most up to date reservoir volume since the lower reservoir LiDAR data set was flown in 2004. To force contour development within the reservoir area, a hardclip contour was developed that ran along the dam and dike alignments in the downstream reservoir areas. This clip was assigned an elevation of 4,480.0 (NAVD88) and was used as a hard boundary for the 2007 developed contours. This boundary allowed contour mapping within the reservoir area as outlined by the hardclip contour. The hardclip was used during the triangular irregular network (TIN) development to prevent interpolation outside the enclosed polygon. Figures 97 through 104 are illustrations of the developed TIN of the reservoir. Figure 97 shows the USGS quad contours that were imported into the processed data sets to develop the 2007 Elephant Butte topographic maps from the dam upstream to where the LiDAR began.

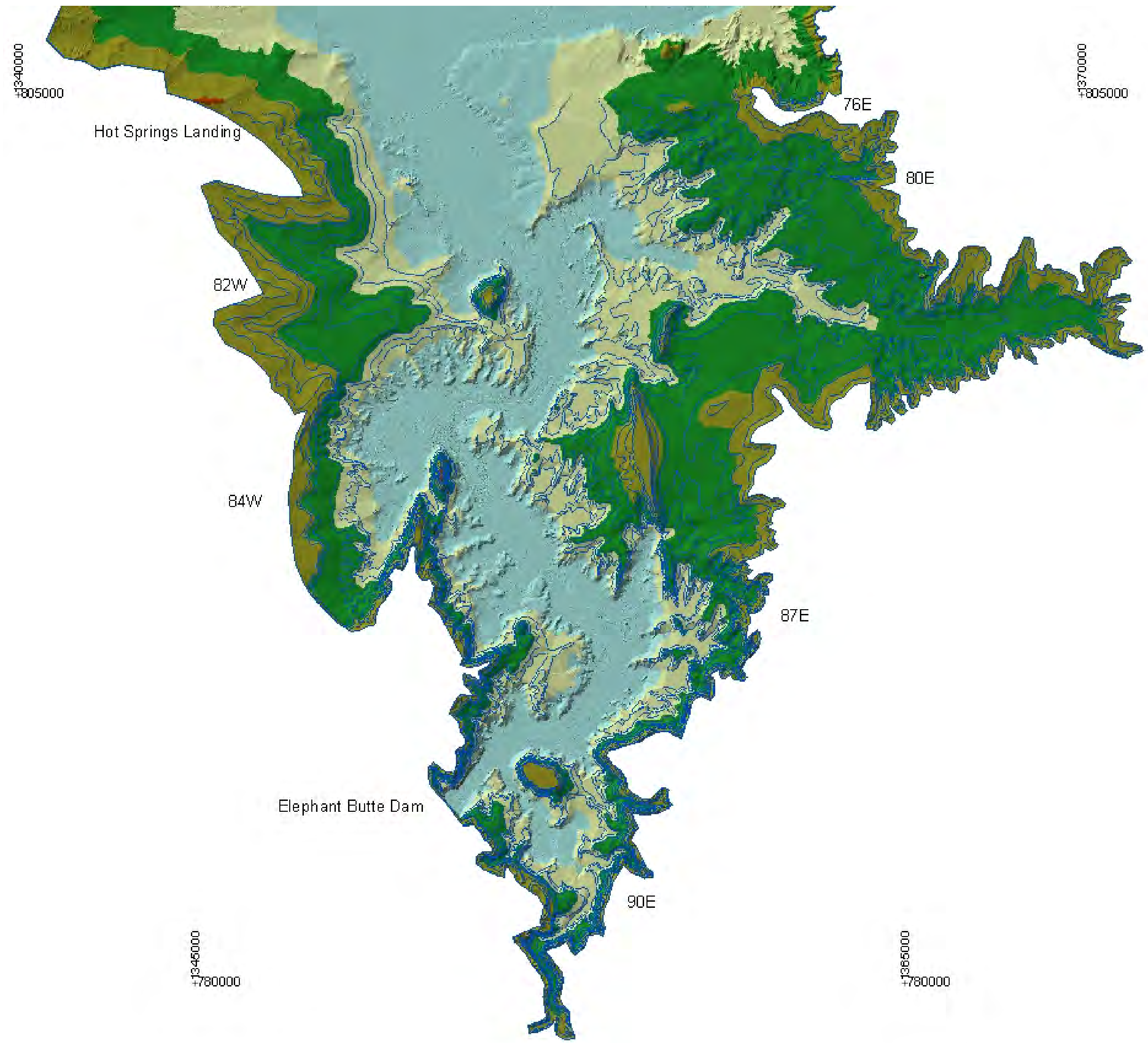

Figure 97 - Elephant Butte Reservoir TIN, 1 of 8.

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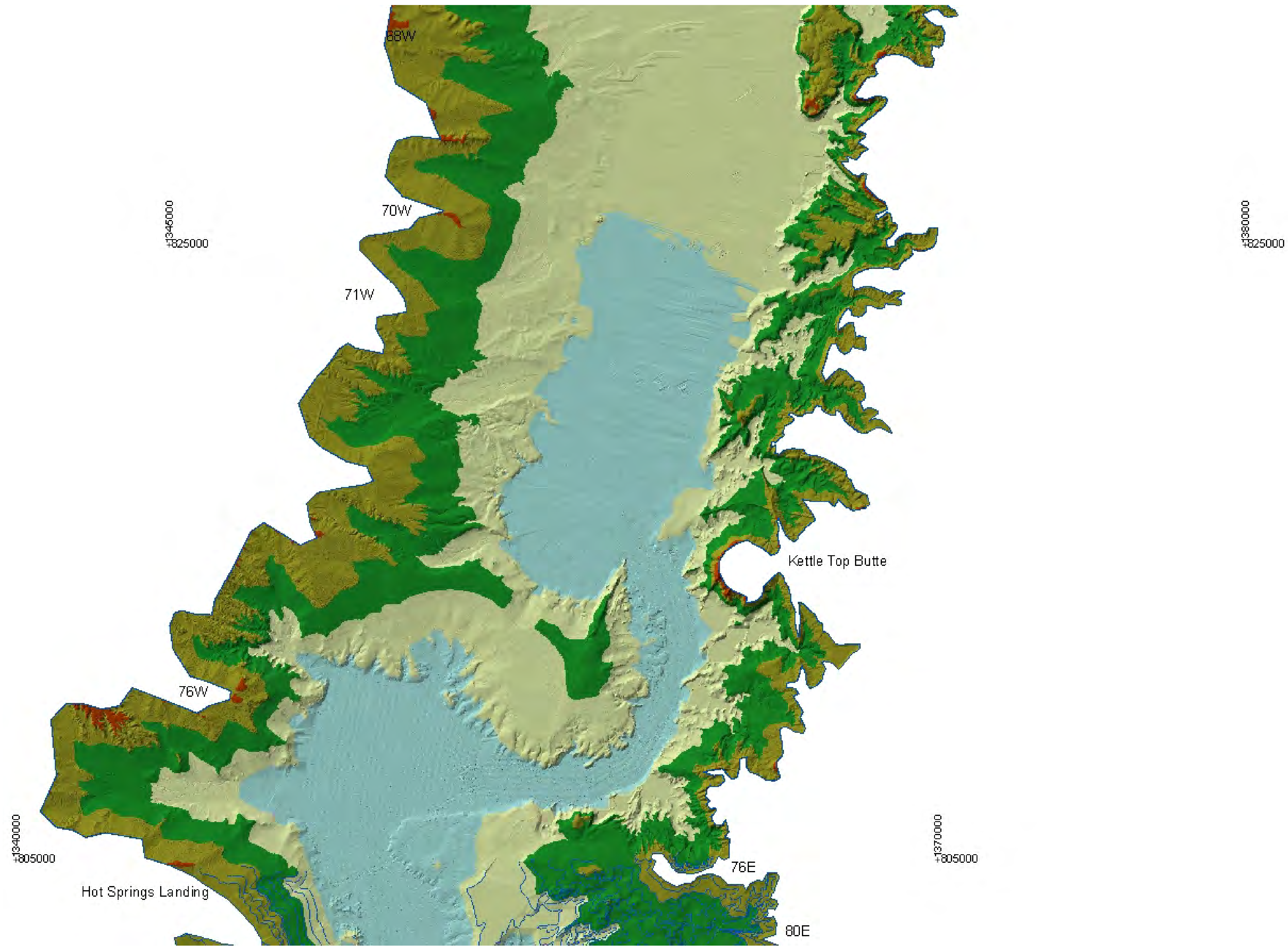

Figure 98 - Elephant Butte Reservoir TIN, 2 of 8.

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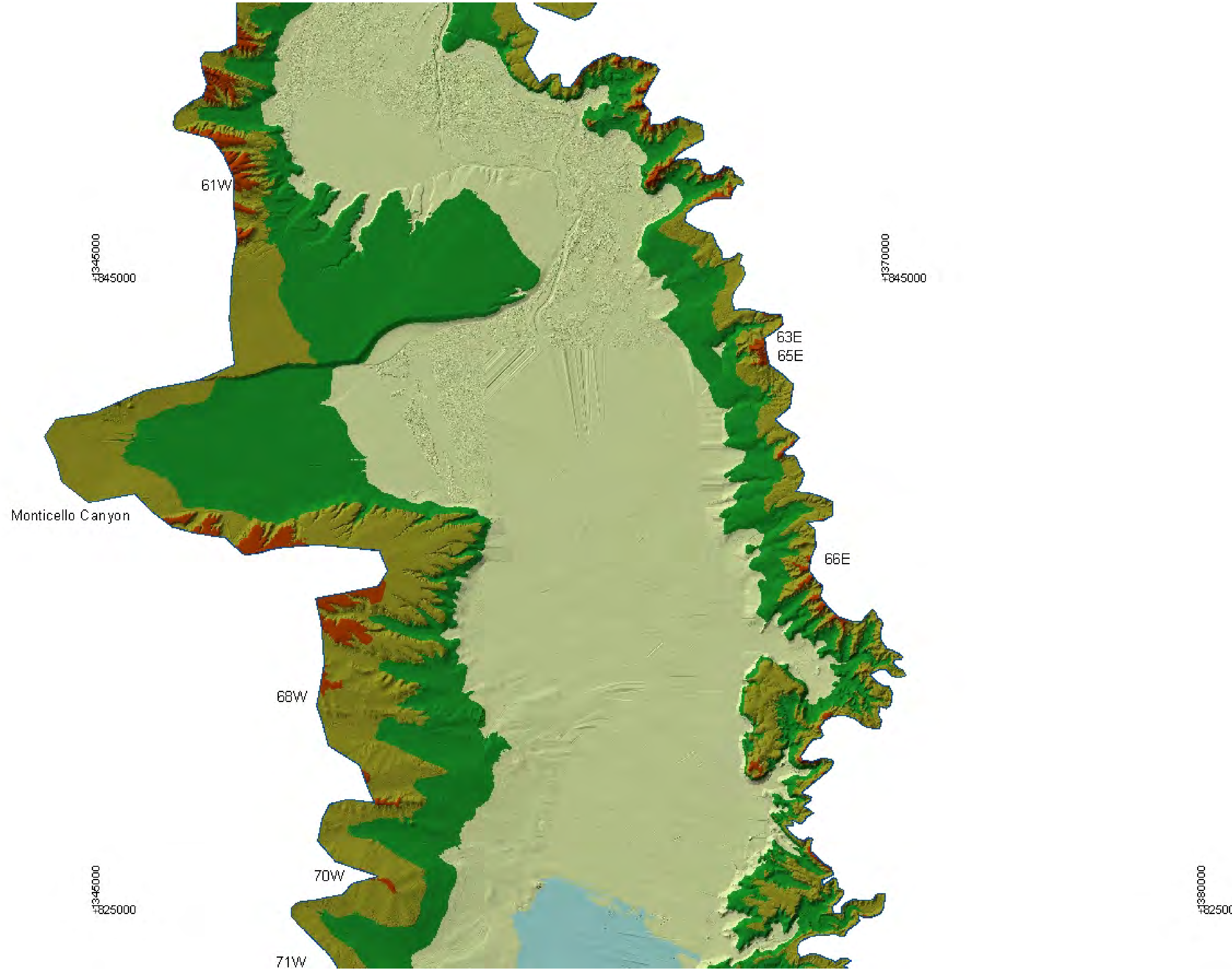

Figure 99 - Elephant Butte Reservoir TIN, 3 of 8.

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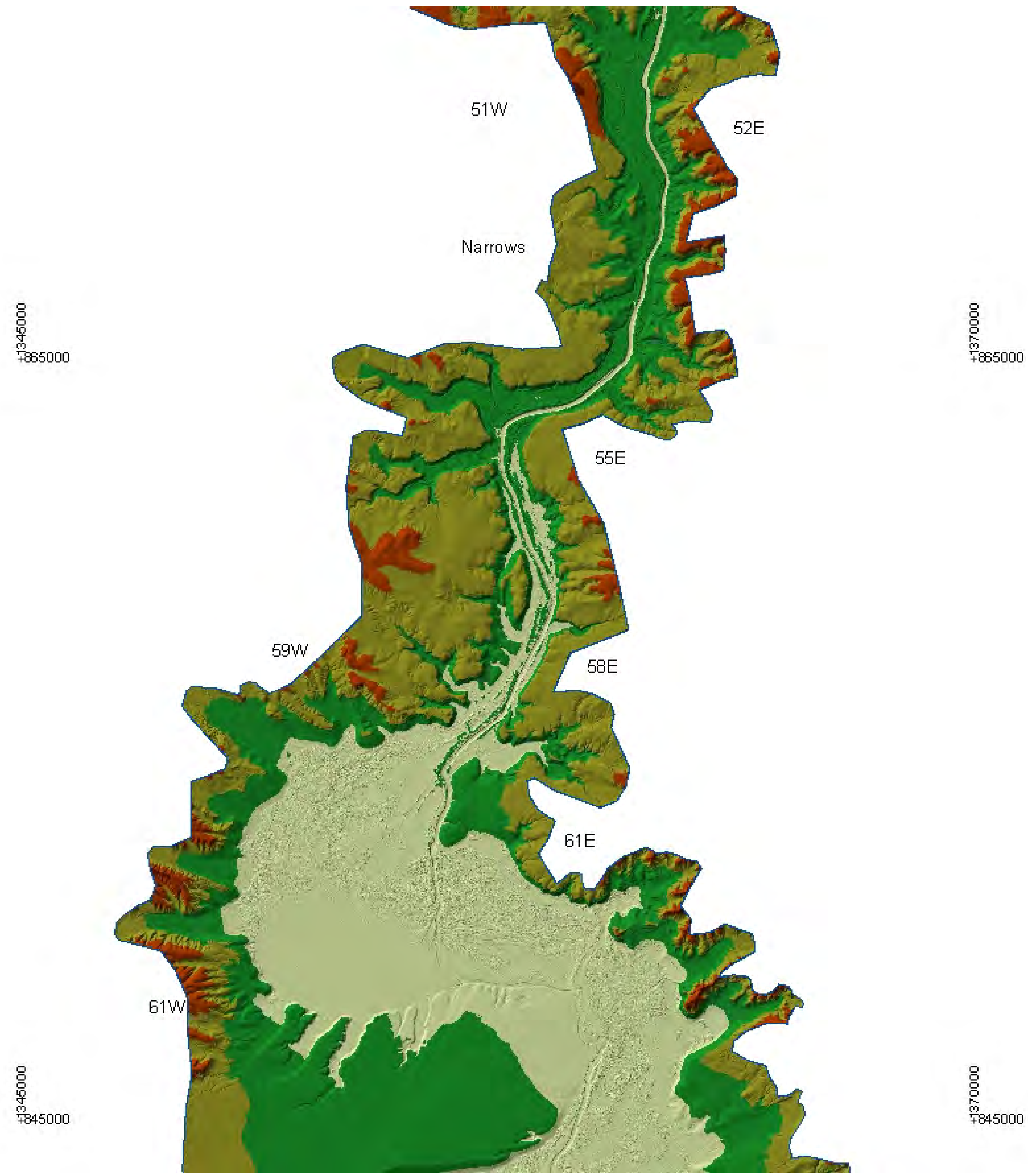

Figure 100 - Elephant Butte Reservoir TIN, 4 of 8.

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Figure 101 - Elephant Butte Reservoir TIN, 5 of 8.

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Figure 102 - Elephant Butte Reservoir TIN, 6 of 8.

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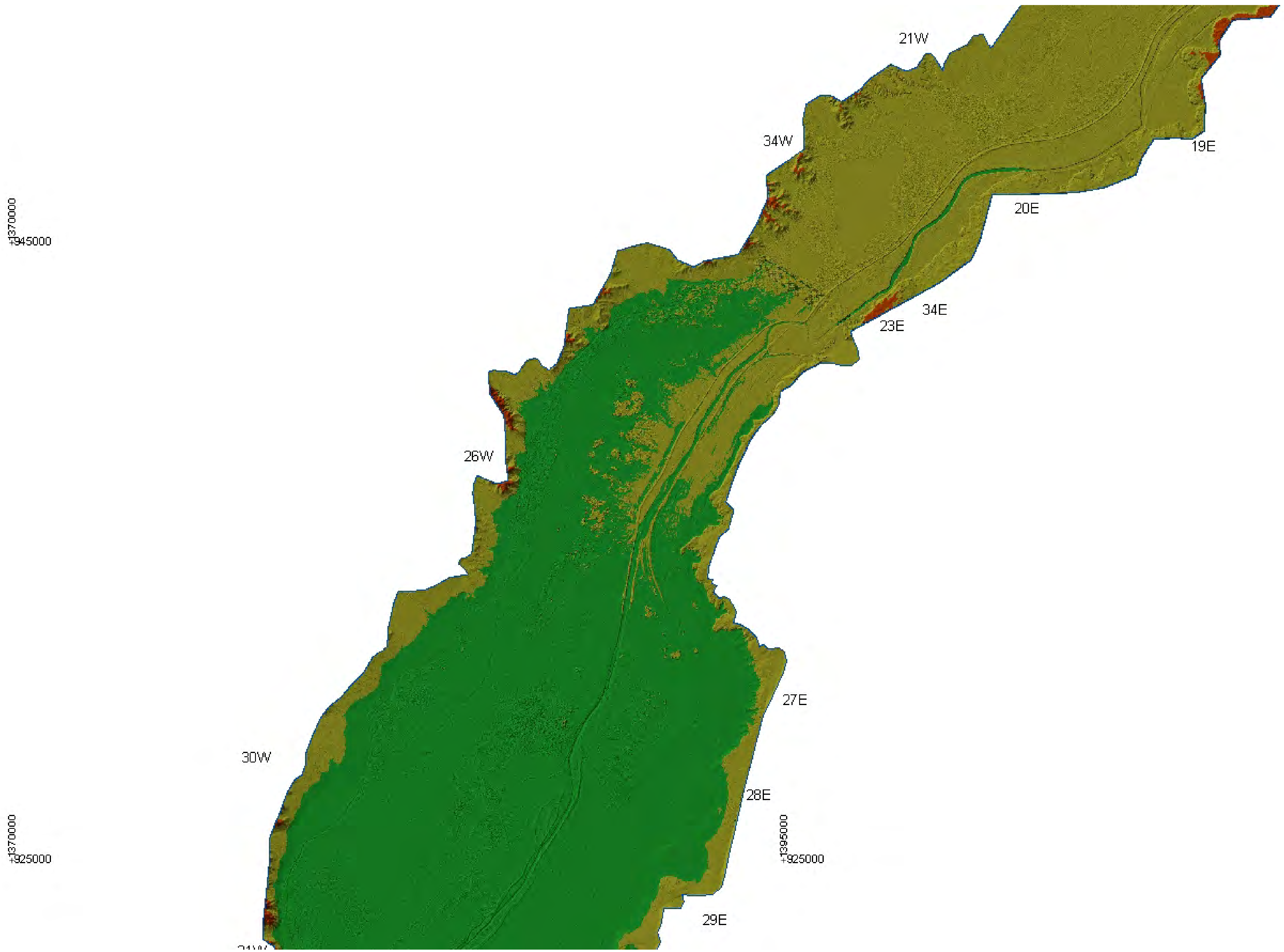

Figure 103 - Elephant Butte Reservoir TIN, 7 of 8.

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Figure 104 - Elephant Butte Reservoir TIN, 8 of 8.

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Elephant Butte Contour Development

Contours at reservoir elevation 4,470 (NAVD88) and below were developed from the TIN generated within ARCGIS. A TIN is a set of adjacent non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. A TIN is designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation where triangles are formed among all data points within the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that all the data points are connected to their nearest neighbors to form triangles. This method preserves all the collected data points. The TIN method is described in more detail in the ARCGIS user's documentation, (ESRI, 2007). The linear interpolation option of the ARCGIS TIN and CONTOUR commands were used to interpolate contours from the Elephant Butte Reservoir TIN. The contours were developed from the TIN at ten-foot increments from elevations 4,390 (NAVD88) through 4,470.0 and are presented in Figures 105 through 112. The ARCGIS software developed contours directly from the TIN using all the enclosed data points, resulting in some jagged representations of the contours. For presentation purposes the contour lines were smoothed by removing the smaller developed contour lines. The contours can be further smoothed using a smooth line option within ARCMAP, but overall the following maps are a good representation of the reservoir topography. The smoothing processes did not affect the reported surface areas of the topography since they were computed directly from the TIN using all the data points. The following figures present the developed 10-foot contours from elevation 4,470 (NAVD88) and below. The horizontal control is in New Mexico central state plane coordinates in NAD83. The contours are presented from the dam upstream in a north to south alignment.

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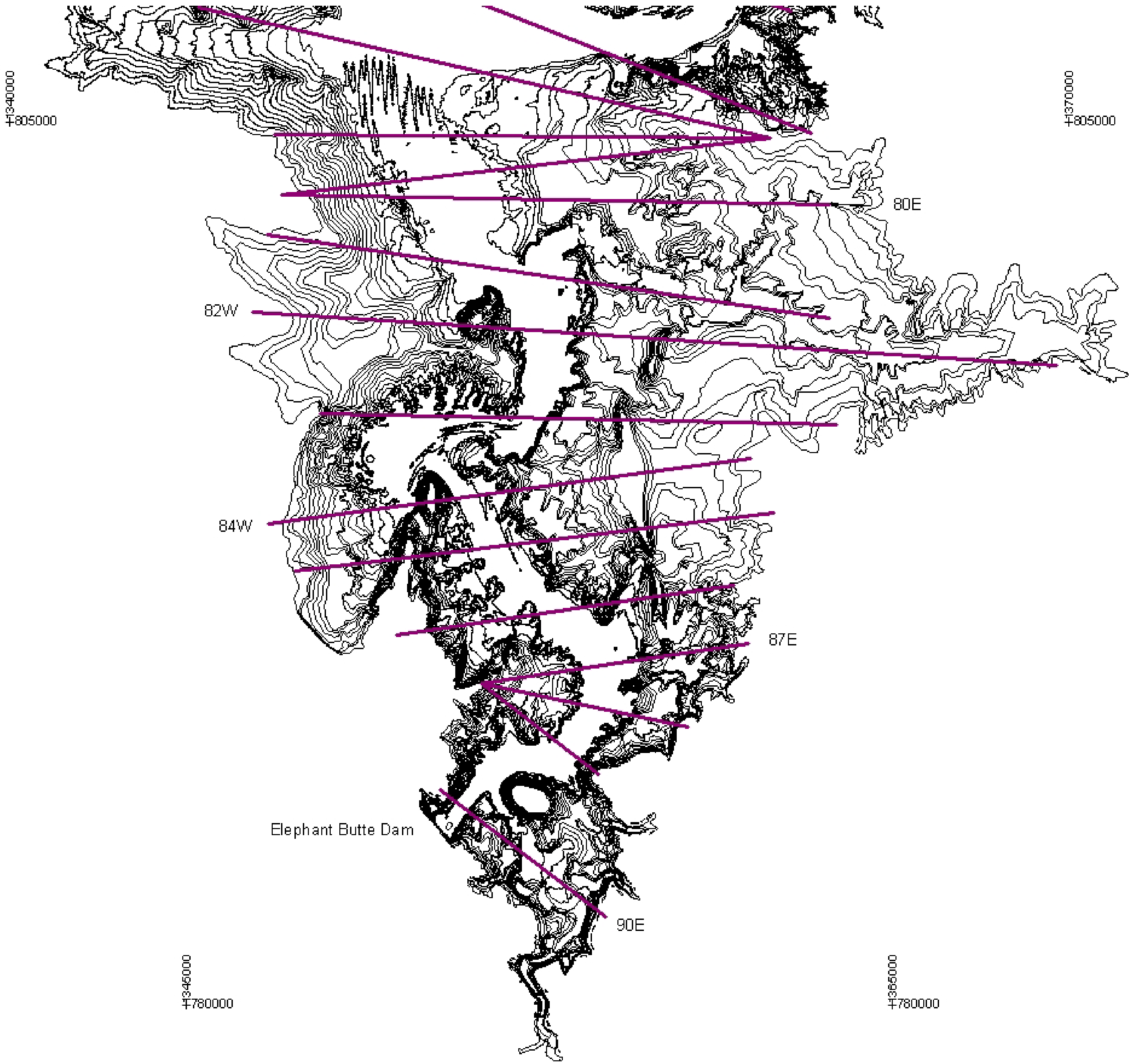

Figure 105 - Elephant Butte 2007 Reservoir Topography, 1 of 8.

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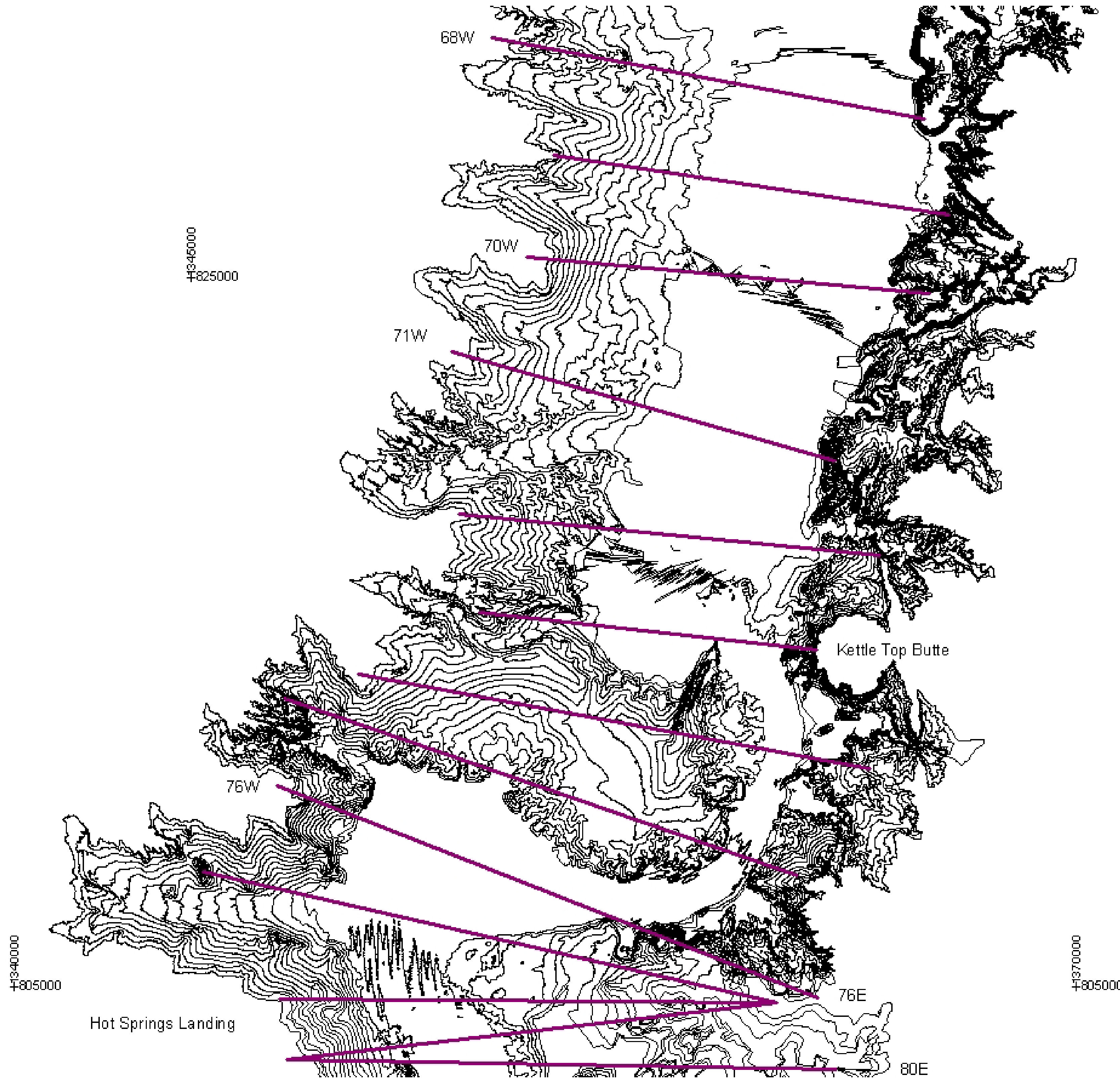

Figure 106 - Elephant Butte 2007 Reservoir Topography, 2 of 8.

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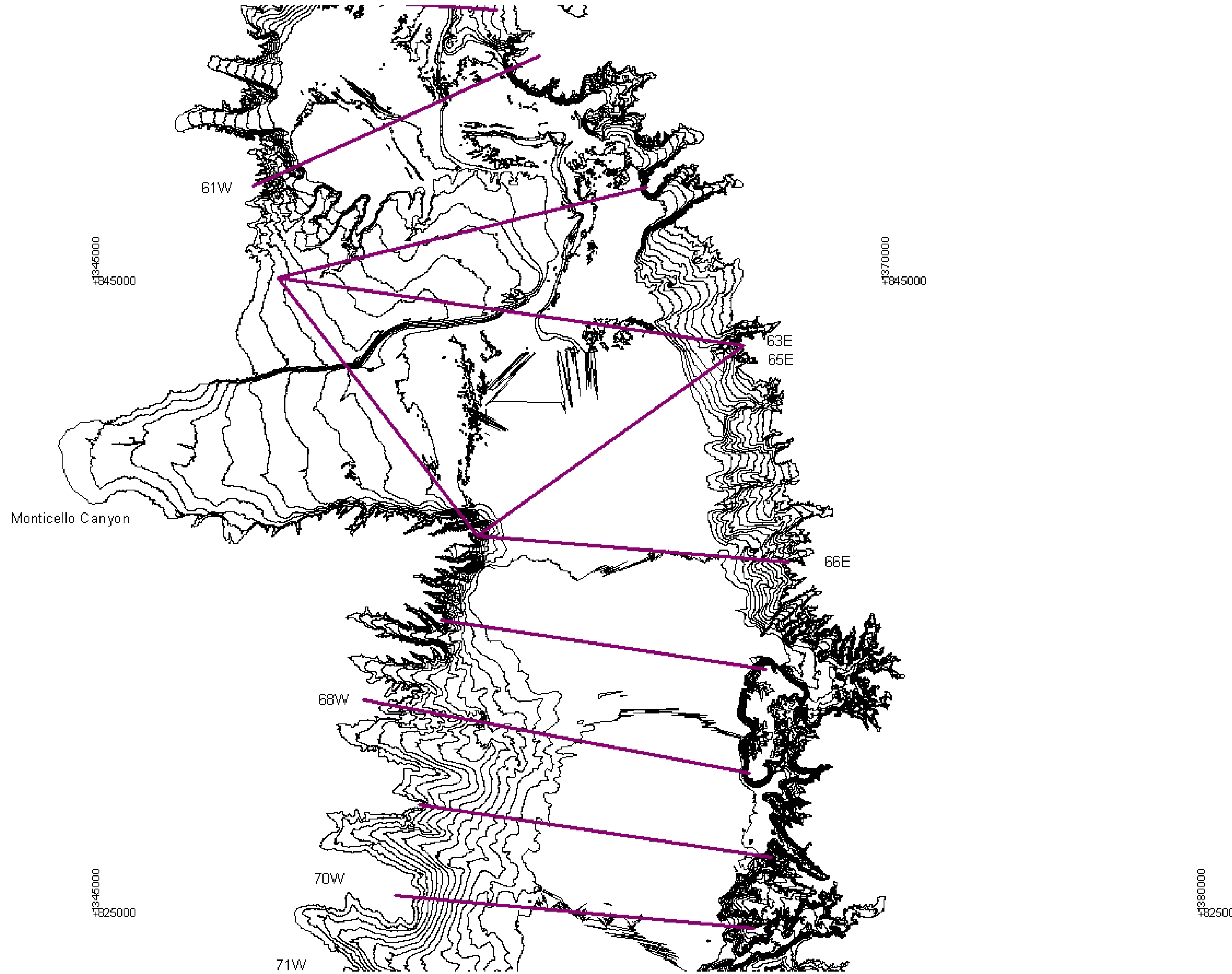

Figure 107 - Elephant Butte 2007 Reservoir Topography, 3 of 8.

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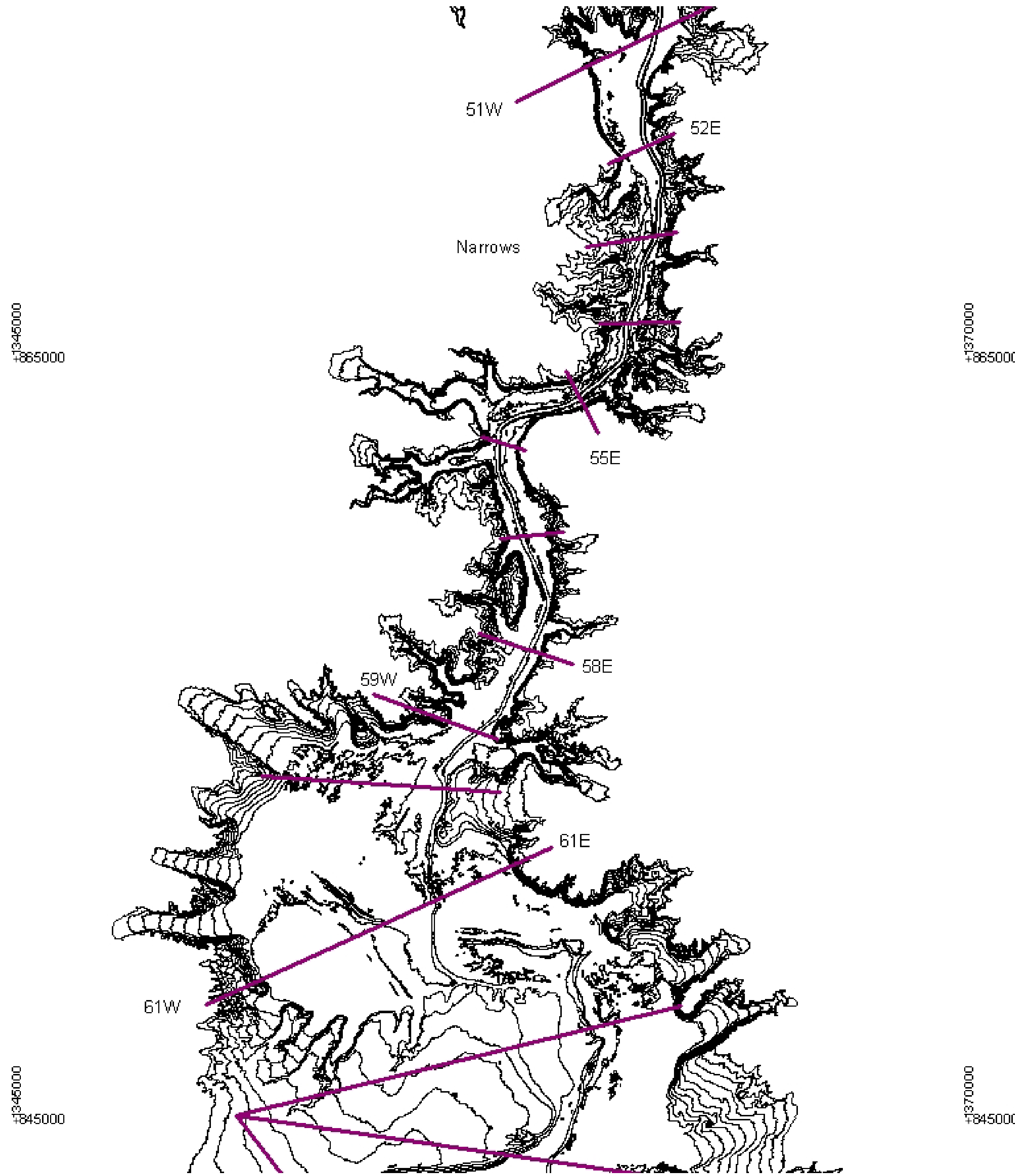

Figure 108 - Elephant Butte 2007 Reservoir Topography, 4 of 8.

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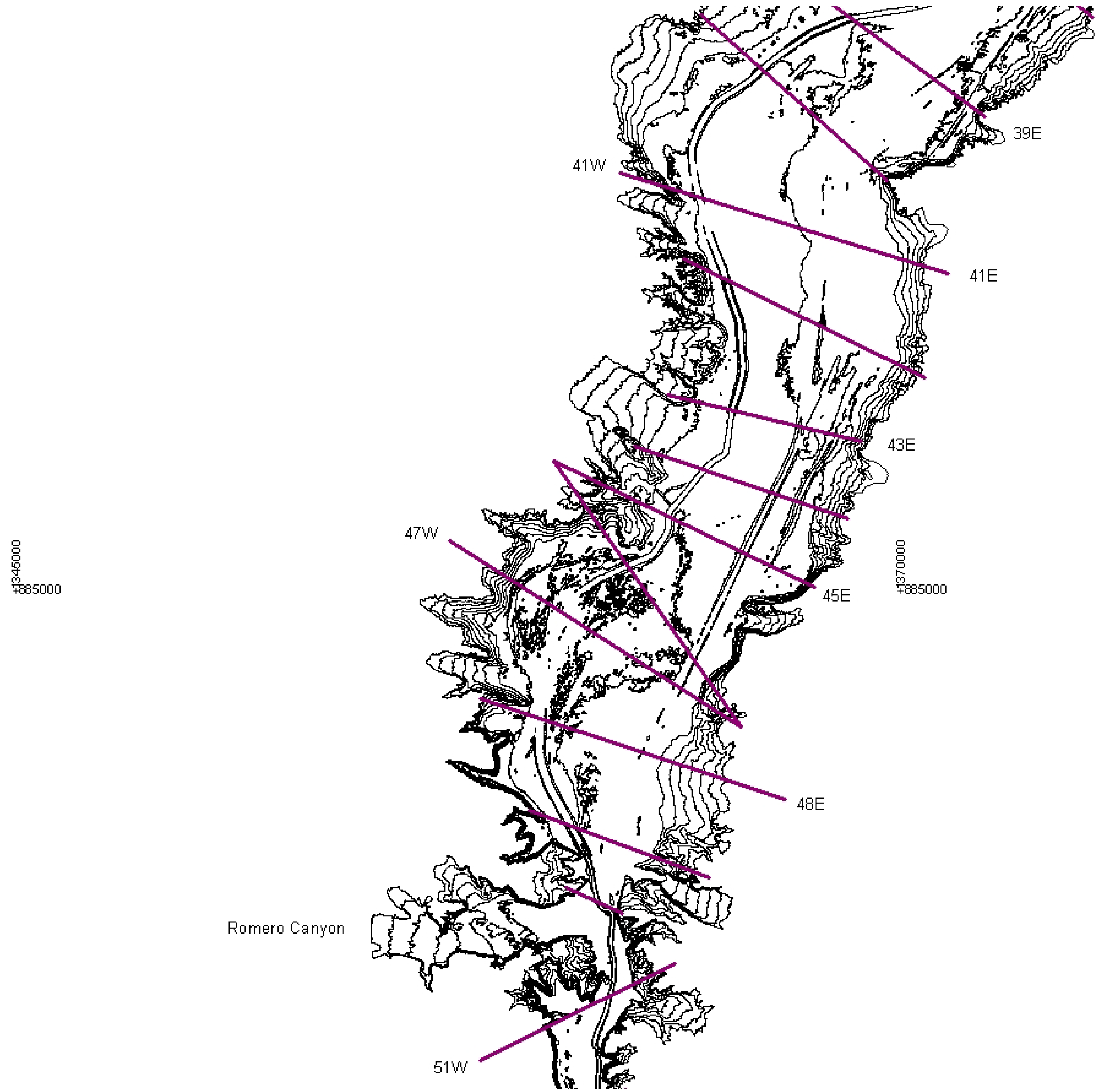

Figure 109 - Elephant Butte 2007 Reservoir Topography, 5 of 8.

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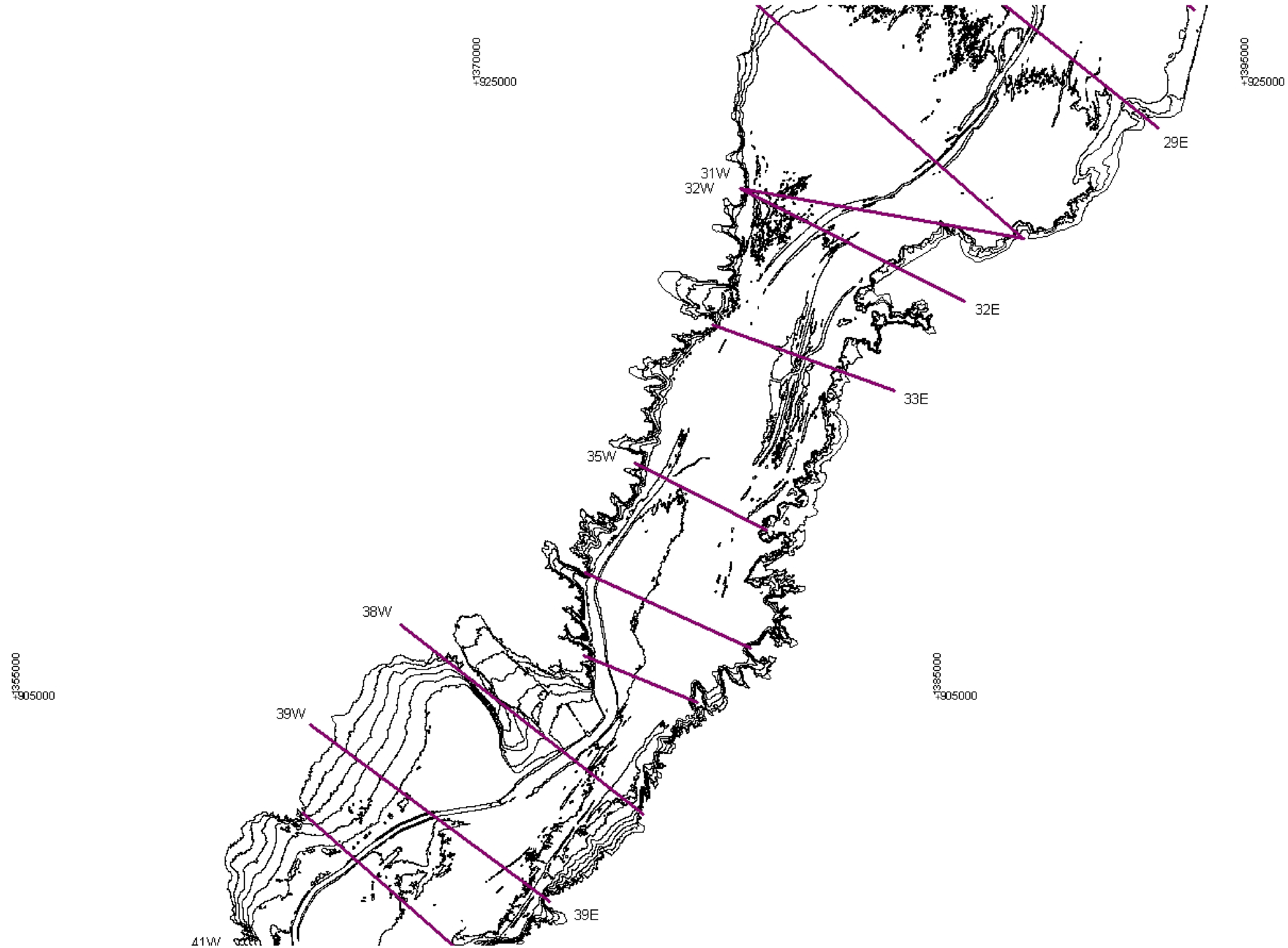

Figure 110 - Elephant Butte 2007 Reservoir Topography, 6 of 8.

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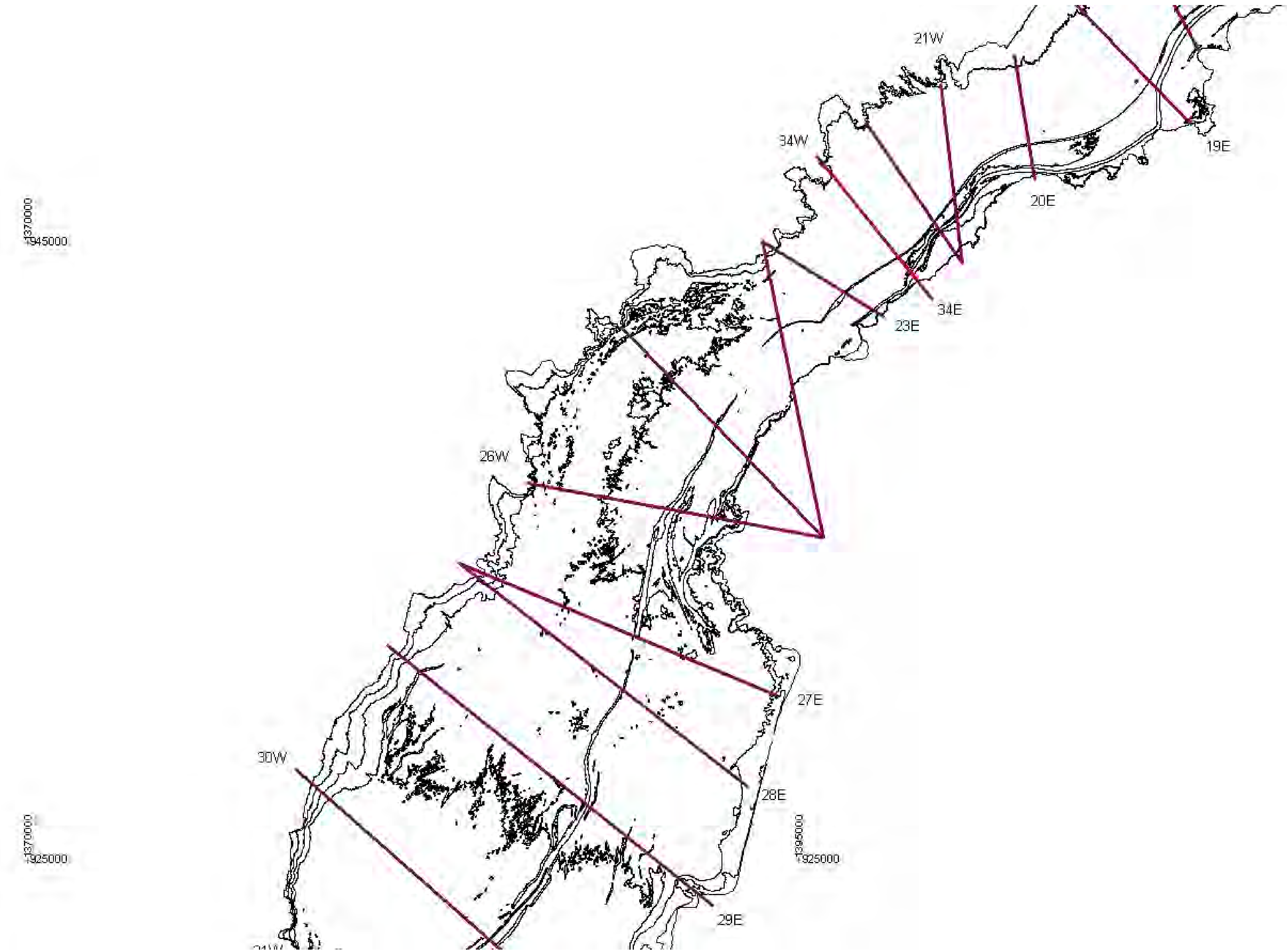

Figure 111 - Elephant Butte 2007 Reservoir Topography, 7 of 8.

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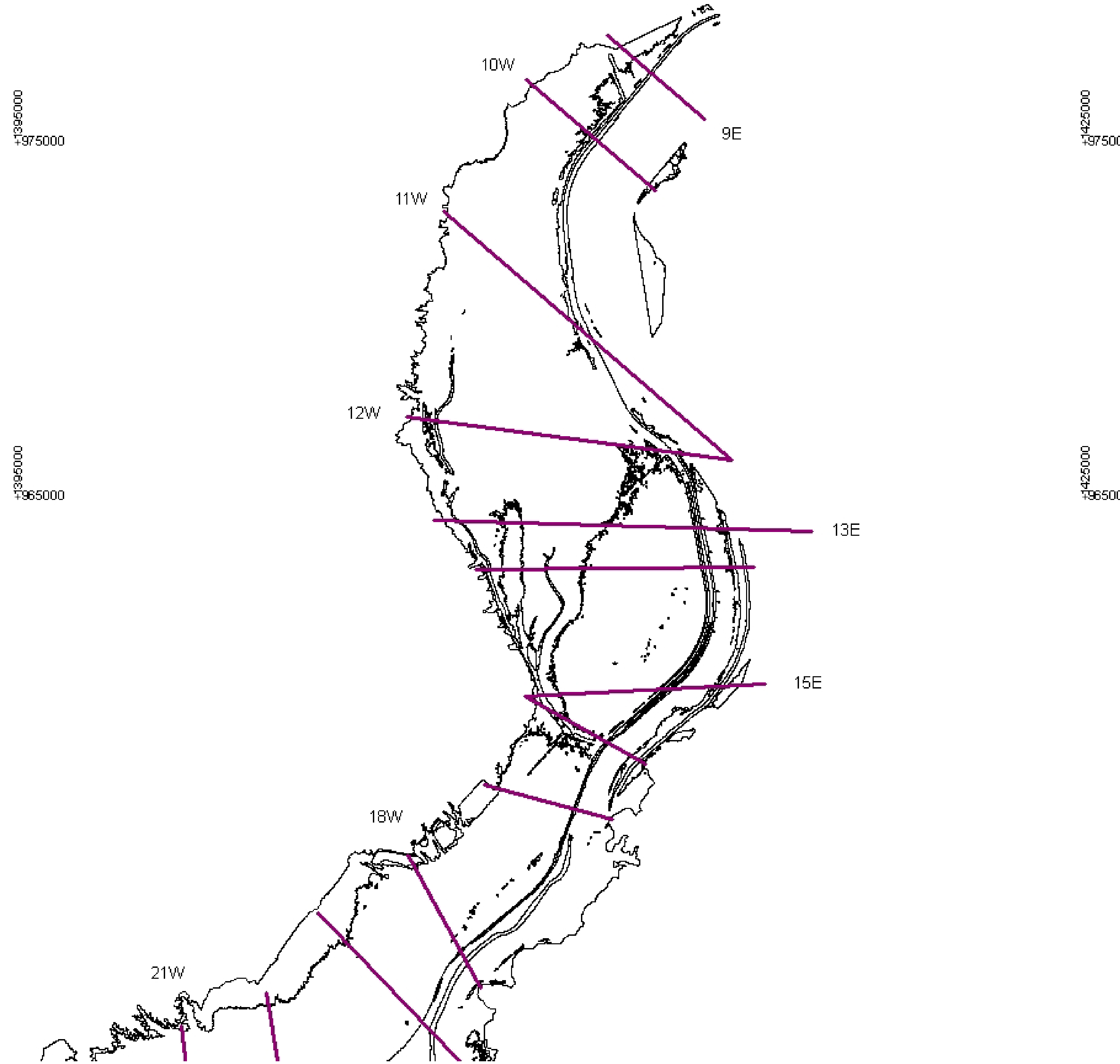

Figure 112 - Elephant Butte 2007 Reservoir Topography, 8 of 8.

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Elephant Butte 2007 Topography Surface Areas and Capacity Computations and Comparisons

The 2007 surface areas for Elephant Butte Reservoir were computed at 5-foot increments directly from the reservoir developed TIN from elevation 4,385 (NAVD88) through 4,470 (NAVD88). The TIN was developed from collected and interpolated data sets within the hard clip polygon created from the previously described TIN and resulting contour maps. Surface area calculations were performed using ARCGIS commands that compute areas at user-specified elevations directly from the TIN using all the data points. For the purpose of this study, the computed survey areas at 5-foot increments were shifted to the project vertical datum by reducing the elevations by 45.5 feet. The resulting surface areas versus elevation were input into the ACAP program for computing the resulting Elephant Butte 2007 capacity using the contour method. ACAP was also used to compute the 2007 range line analysis results. The volume differences are due to measured surface area difference only.

Table 3 and Figure 113 list and illustrate a comparison between the range line and contour methods. Comparison of the results of the two methods was favorable. The contour method computed a reservoir capacity of 2,008,244 acre-feet at elevation 4,407 compared to the range line method of 2,024,586 acre-feet. The difference is 16,342 acre-feet or less than 1 percent between the two analysis methods. The contour method was affected in the lower end of the reservoir where LiDAR coverage was not available, but overall the results are very good. It is recommended that future aerial surveys should cover the lower portion of the reservoir to the dam. Ideally the whole reservoir should be flown at one time, but budgets usually prevent such extensive coverage for larger reservoirs. Obtaining LiDAR type collection from the dam upstream to where the 2004 LiDAR coverage began will allow upper contours to be developed with more confidence.

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1	2	3	4	5	6	7	8	9	10	11	12	13
			TOPOGRAPHIC	**CONTOUR**	**METHOD**		**WIDTH**	**ADJUSTMENT**	**METHOD**			
	1915	1915	2007	2007	2007 TOPO	2007 TOPO			2007	2007	Difference	
	Original	Original	TOPOGRAPHIC	TOPOGRAPHIC	Sediment	Percent	2007	2007	Sediment	Percent	Range Method	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Computed	Area	Capacity	Volume	Computed	Contour Method	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Ac-Ft	Depth
4,407.0	40,060	2,634,800	35,629	2,008,244	626,556	100.0	35,826	2,024,586	610,214	100.0	16342.0	100.0
4,400.0	37,328	2,363,900	32,270	1,770,350	593,550	94.7	32,335	1,786,026	577,874	94.7	15676.0	96.4
4,390.0	33,451	2,010,300	27,860	1,470,855	539,445	86.1	28,176	1,483,458	526,842	86.3	12603.0	91.4
4,380.0	30,191	1,692,800	24,585	1,209,347	483,453	77.2	24,727	1,218,927	473,873	77.7	9580.0	86.3
4,370.0	26,620	1,408,000	21,012	981,920	426,080	68.0	21,131	989,638	418,362	68.6	7718.0	81.2
4,360.0	22,563	1,162,100	17,810	787,407	374,693	59.8	17,868	794,642	367,458	60.2	7235.0	76.1
4,350.0	19,194	954,400	14,912	625,406	328,994	52.5	14,899	630,803	323,597	53.0	5397.0	71.1
4,340.0	16,595	775,600	13,205	484,635	290,965	46.4	12,997	491,323	284,277	46.6	6688.0	66.0
4,330.0	14,240	621,400	11,034	363,744	257,656	41.1	10,863	372,028	249,372	40.9	8284.0	60.9
4,320.0	11,894	490,800	9,084	262,751	228,049	36.4	9,283	271,301	219,499	36.0	8550.0	55.8
4,310.0	10,202	380,800	7,032	182,694	198,106	31.6	7,098	189,399	191,401	31.4	6704.8	50.8
4,300.0	8,923	285,400	5,502	119,613	165,787	26.5	5,786	124,978	160,422	26.3	5364.8	45.7
4,290.0	7,715	202,100	3,891	72,824	129,276	20.6	4,217	74,961	127,139	20.8	2137.2	40.6
4,280.0	6,145	132,800	2,556	41,019	91,781	14.6	2,539	41,179	91,621	15.0	160.2	35.5
4,270.0	4,691	78,600	1,998	18,332	60,268	9.6	2,058	18,194	60,406	9.9	-138.2	30.5
4,260.3	3,302	40,717	781	5,356	35,361	5.6	1,141	6,999	33,718	5.5	1643.0	25.5
4,260.0	3,157	39,700	753	5,126	34,574	5.5	748	4,165	35,535	5.8	-961.2	25.4
4,250.0	1,684	15,800	221	663	15,137	2.4	57	141	15,659	2.6	-521.8	20.3
4,245.0	1,178	10,230	37	18	10,212	1.6	0	0	10,230	1.7	-18.0	17.8
4,244.2	1,096	9,339	0	1	9,338	1.5	0	0	9,339	1.5	-1.0	17.4
4,240.0	671	4,660	0	0	4,660	0.7	0	0	4,660	0.8	0.0	15.2
4,230.0	376	2,960	0	0	2,960	0.5	0	0	2,960	0.5	0.0	10.2
4,220.0	98	490	0	0	490	0.1	0	0	490	0.1	0.0	5.1
4,210.0	0	0	0	0	0	0.0	0	0	0	0.0	0.0	0.0
1	Reservoir water surface elevation. Elevations tied to project datum that is 43.3 feet less than NGVD29 and 45.5 feet less than NAVD88.											
2	Original, 1915 reservoir surface area.											
3	Original, 1915 reservoir capacity.											
4	2007 reservoir surface area by contour method.											
5	2007 reservoir capacity by contour method using ACAP.											
6	2007 contour computed sediment volume, column (3) - column (6).											
7	2007 contour measured sediment in percentage of total sediment of 626,556 acre-feet.											
8	2007 measured reservoir surface area by range line method.											
9	2007 reservoir capacity by range line method using ACAP.											
10	2007 measured sediment volume, column (3) - column (10).											
11	2007 measured sediment in percentage of total sediment of 610,214 acre-feet.											
12	Computed difference between the 2007 range line method and 2007 contour method.											
13	Depth of reservoir expressed in percentage of total depth, 197 feet, from maximum water surface 4,407.0.											

Table 3 - Elephant Butte Reservoir Contour and Range Line Comparisons

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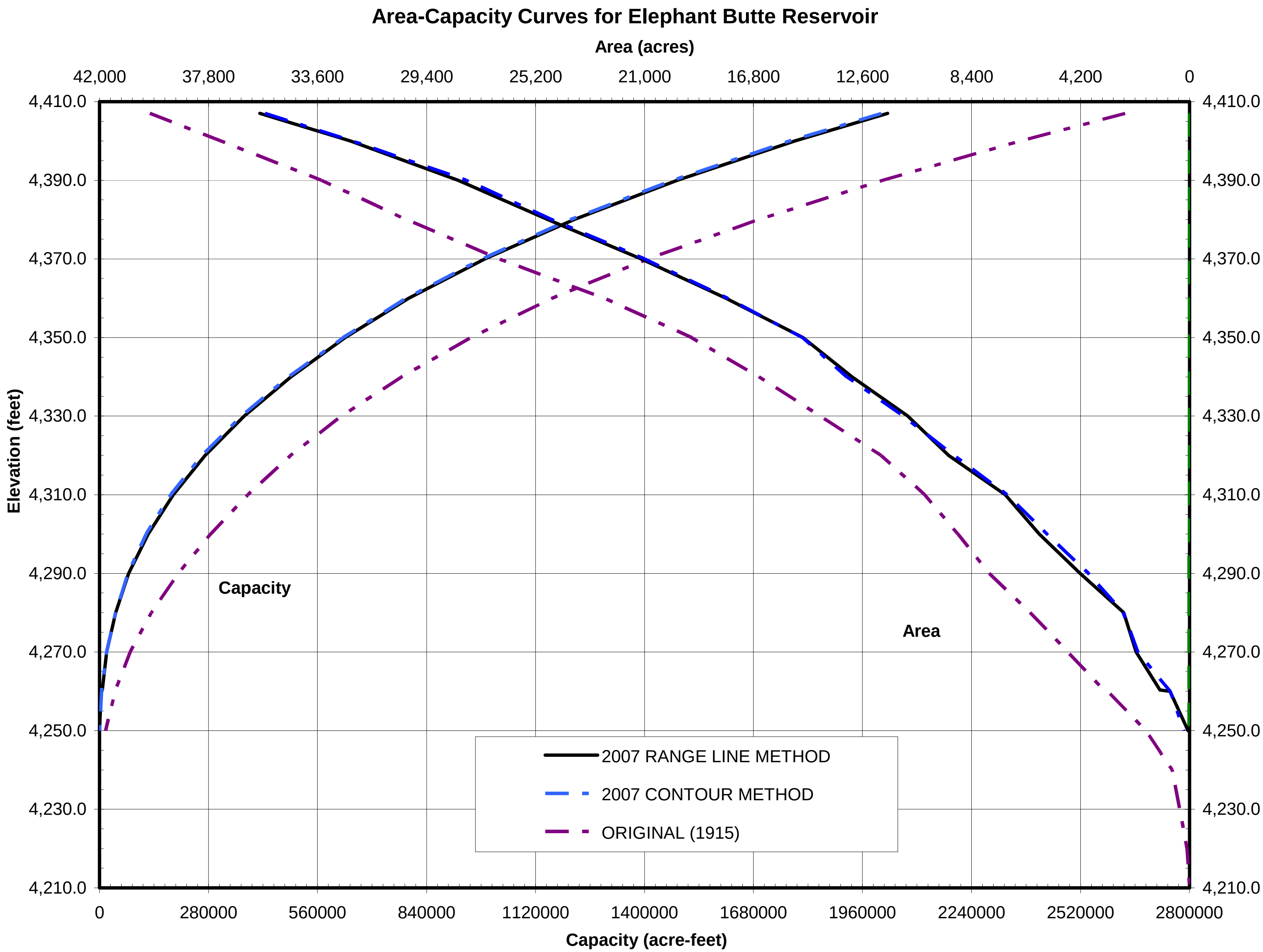

Figure 113 - Elephant Butte Reservoir Contour and Range Line Comparison Plots.

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Ferrari, R.L. and Collins, K. (2006). ***Reservoir Survey and Data Analysis,*** Chapter 9, Erosion and Sedimentation Manual, Bureau of Reclamation, Sedimentation and River Hydraulics Group. Denver, Colorado. www.usbr.gov/pmts/sediment

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Appendix I

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RECLAMATION
Managing Water in the West

Albuquerque Area Office
Technical Services Division
June 21, 2005

Elephant Butte LIDAR Data

Description of Data

In the fall of 2004, LIDAR data was collected in the Elephant Butte Area for the U.S. Bureau of Reclamation (Reclamation) by Aero-Metric. The LIDAR data was collected over an area extending from about a ¼ mile upstream of station 1800 south to Range Line 75. Field surveys on the EB range lines (northern portion of collected LIDAR data) were being done for Reclamation at about the same time. The spatial and temporal overlap of the field survey data with the LIDAR data (specifically points along Range Lines EB-24 to EB-50) was used to verify the vertical accuracy of the LIDAR data. A map of the LIDAR coverage area and the range lines used for comparison is shown in Figure A.

Analysis Method

Aero-Metric delivered filtered data (points spaced approx. 10 ft apart) to Reclamation around the end of March 2005. These points were brought into ESRI's ArcGIS software and used to create a Triangulated Irregular Network (TIN) surface. ArcGIS's 3D-Analyst tool was used to assign elevations from the LIDAR TIN to a point shapefile containing the 2004 field survey points (EB-24 to EB-50). This process captures the LIDAR elevations at the exact point that the field survey was conducted, allowing the comparison of the field survey data to the LIDAR data.

Because ArcGIS does not have a convenient means of extracting the x, y, and z data to a spreadsheet program such as Excel, the point shapefile with the LIDAR surface elevations was brought into AutoCAD's Land Desktop (LDD) software and converted to LDD points. These points were then exported to a text file and brought into Excel. In Excel, the percentage of LIDAR points within 0.5 and 1.0 foot of the field survey elevations was calculated and graphs were prepared showing each of the range lines (Figures E-S). The percentages listed on each graph are specific for those points on a given range line. The graphs show the field survey cross section across each range line compared with the cross section based on the LIDAR elevations. The LIDAR elevation is shown with an error line of plus/minus 0.5 feet.

Calculations involving the percent of all the LIDAR elevation points within the 0.5 and 1.0 foot errors of the field survey elevations were also computed. Similar percentages were calculated for scenarios where some of the LIDAR elevation points were eliminated because of possible inaccuracies due to water, dense vegetation, or time lapse. These inaccuracies are defined as follows:

- Water - Areas containing water during the field survey were marked out in ArcGIS and points falling within delineated polygons were not used in calculating percentages.

- Dense Vegetation- Areas containing brush that obscured the bare earth were marked out in ArcGIS (as delineated by Aero-Metric) and points falling within delineated polygons were not used in calculating percentages.
- Time Lapse- Areas defined as an active channel region (areas potentially affected by maintenance activities during the time interval when the LIDAR data was flown and the field survey was conducted) were marked out in ArcGIS and points falling within delineated polygons were not used in calculating percentages.

Maps delineating the dense vegetation and time lapse areas are shown in Figures B-D.

Results

Reclamation requested two-foot contour accuracy. The National Map Accuracy Standards requires that 90% of the points be accurate to within ½ of the contour interval (Falkner, p.86) or 1.0 foot for two foot contours. The metadata received from Aero-Metric for the LIDAR data lists the vertical accuracy at 6 inches or 0.5 feet. Table 1 summarizes the results for all analyzed scenarios. The table lists the number of points compared and the percent of the LIDAR elevation points within 0.5 and 1.0 foot of the field surveyed elevations. For all scenarios, 90% of the points are accurate to within 1 foot.

Table 1: Comparison Results of LIDAR Data to Field Surveyed Data

Description	Number of Points	% < 0.5 ft error	% < 1.0 ft error
All Points	2,408	63%	93%
Points with water not included	1,918	68%	92%
Points with water and dense vegetation not included	1,845	69%	91%
Points with water, dense vegetation, and time lapse not included	1,499	74%	90%

References

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RECLAMATION
Managing Water in the West

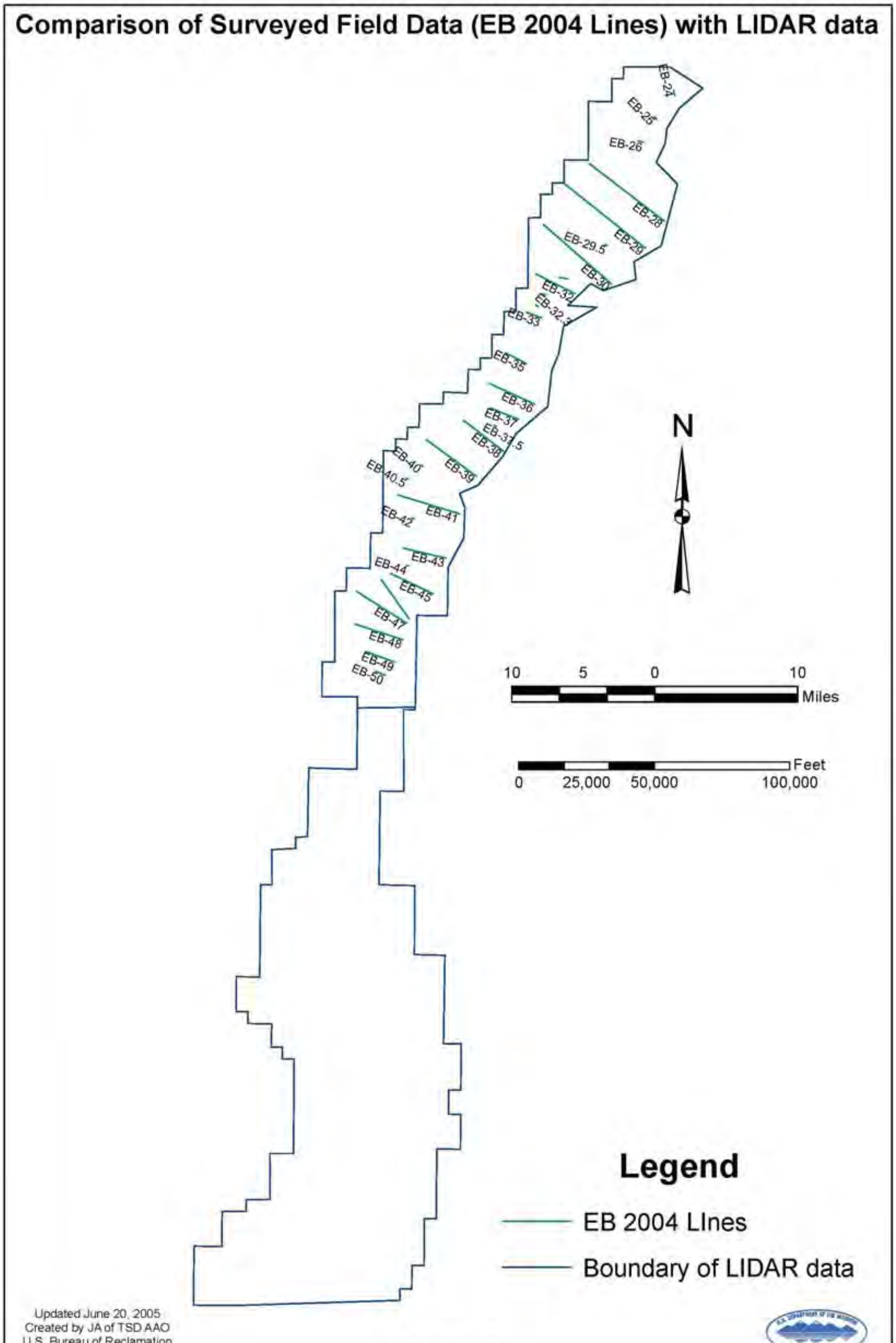

Figure A

Sampled Areas of Lidar Data

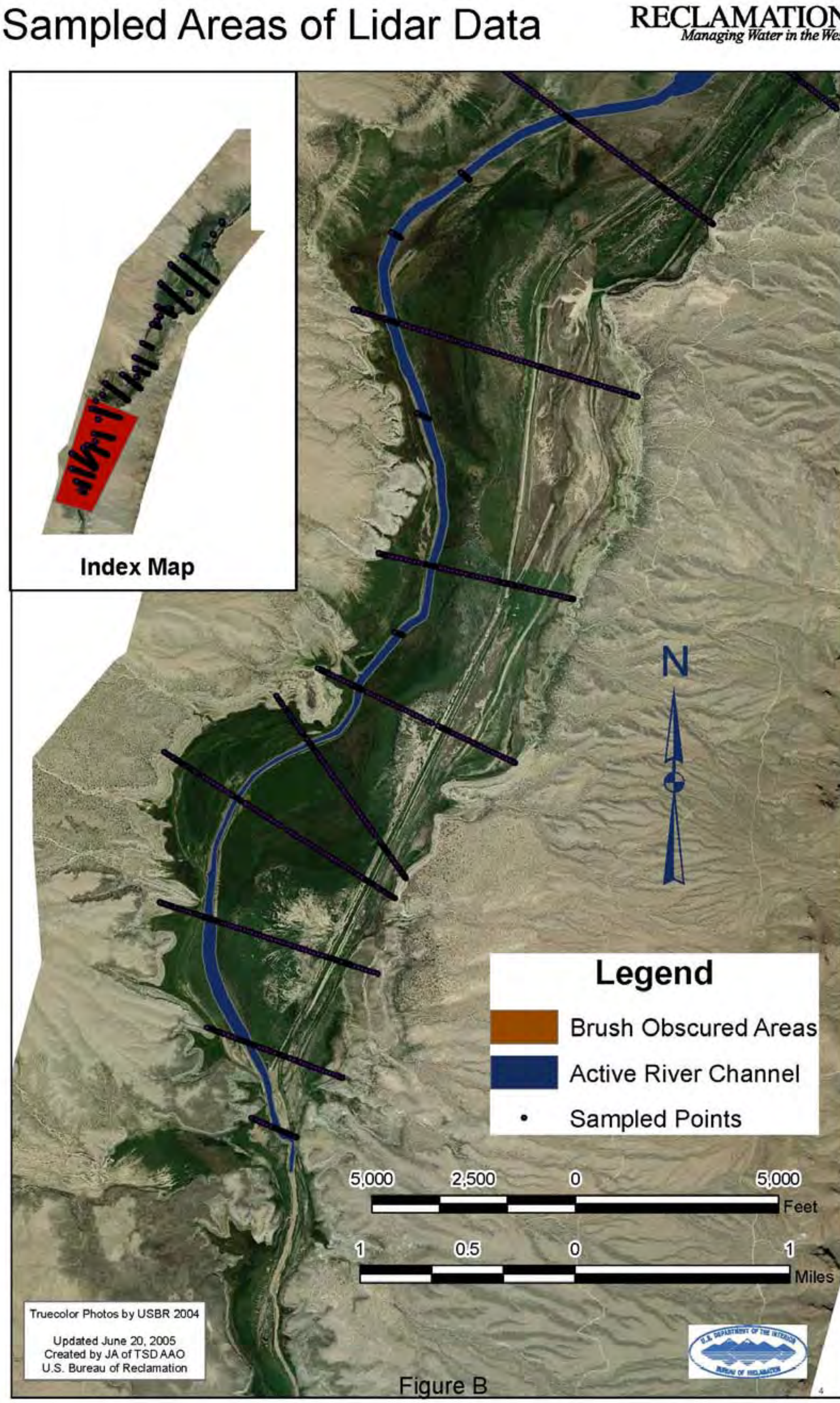

Figure B

Sampled Areas of Lidar Data

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Managing Water in the West

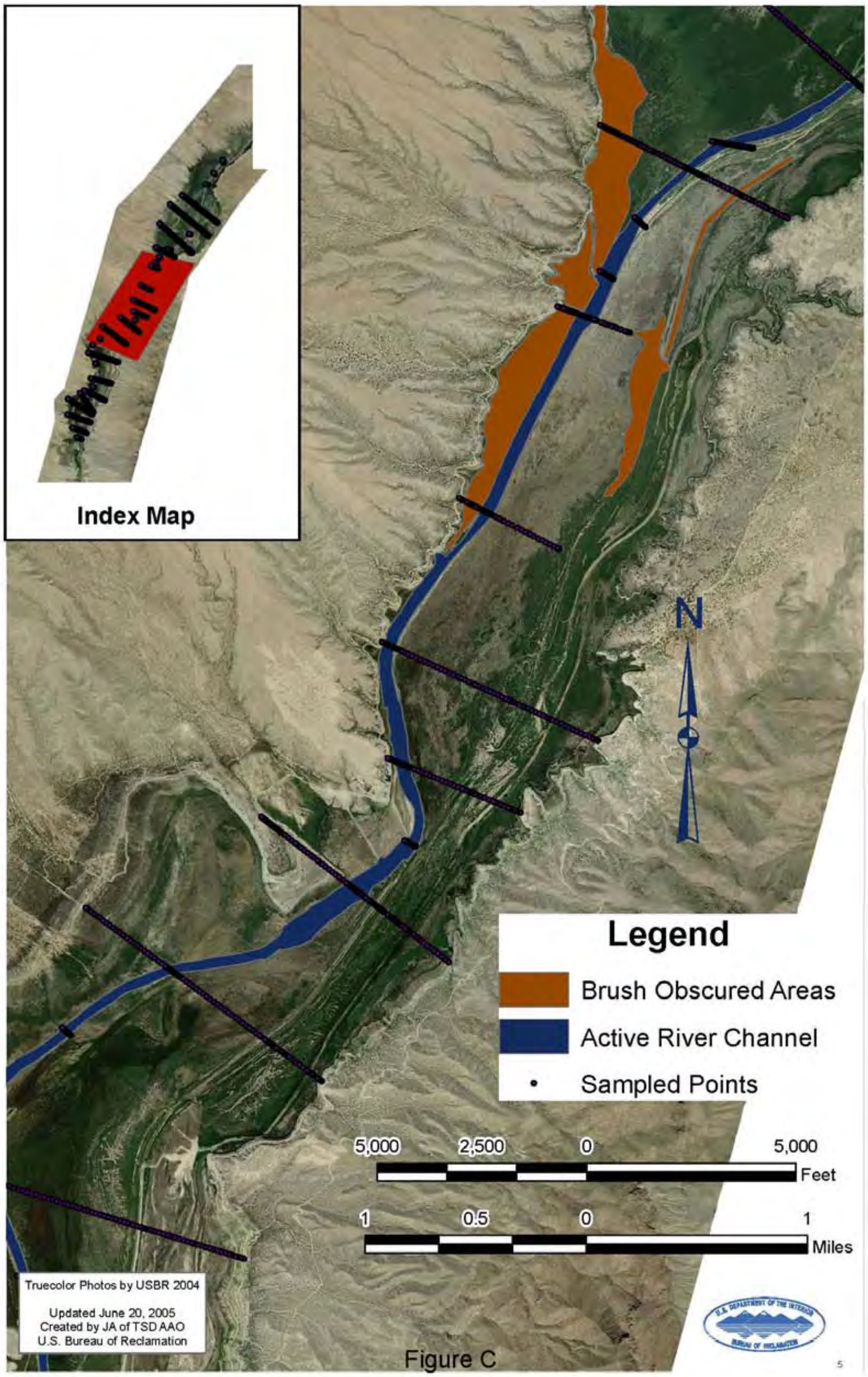


Figure C

Sampled Areas of Lidar Data

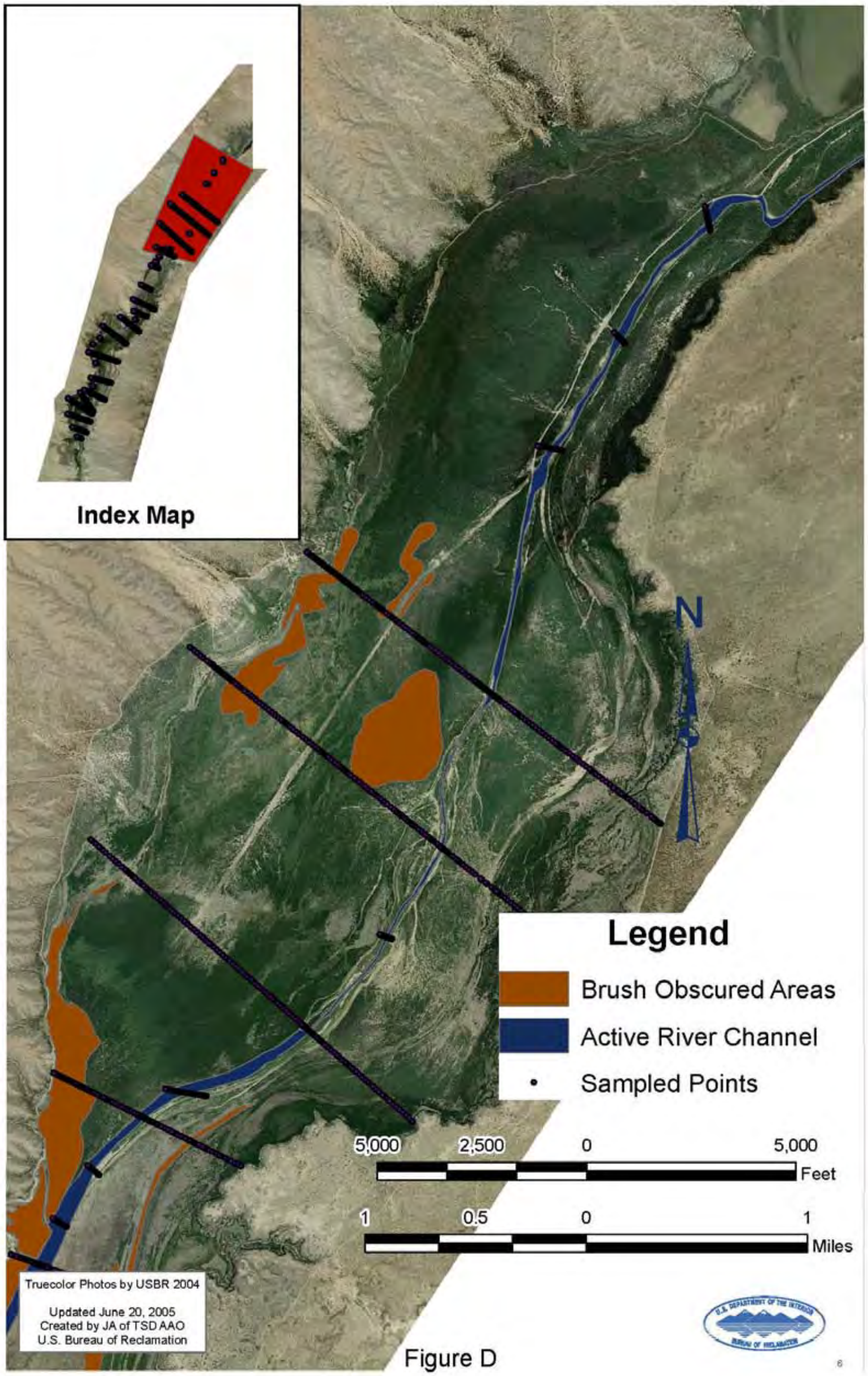


Figure D

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data

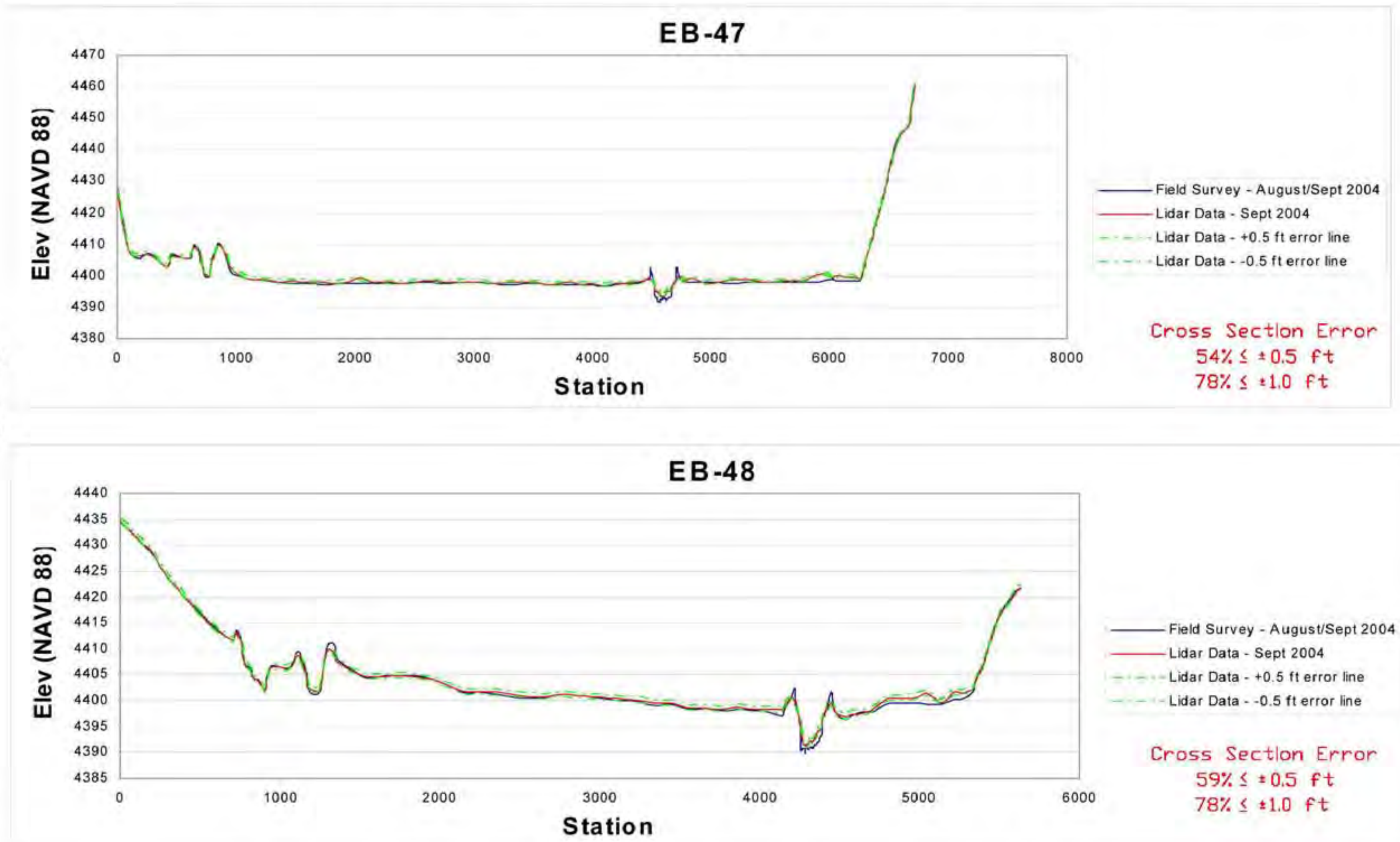


Figure E

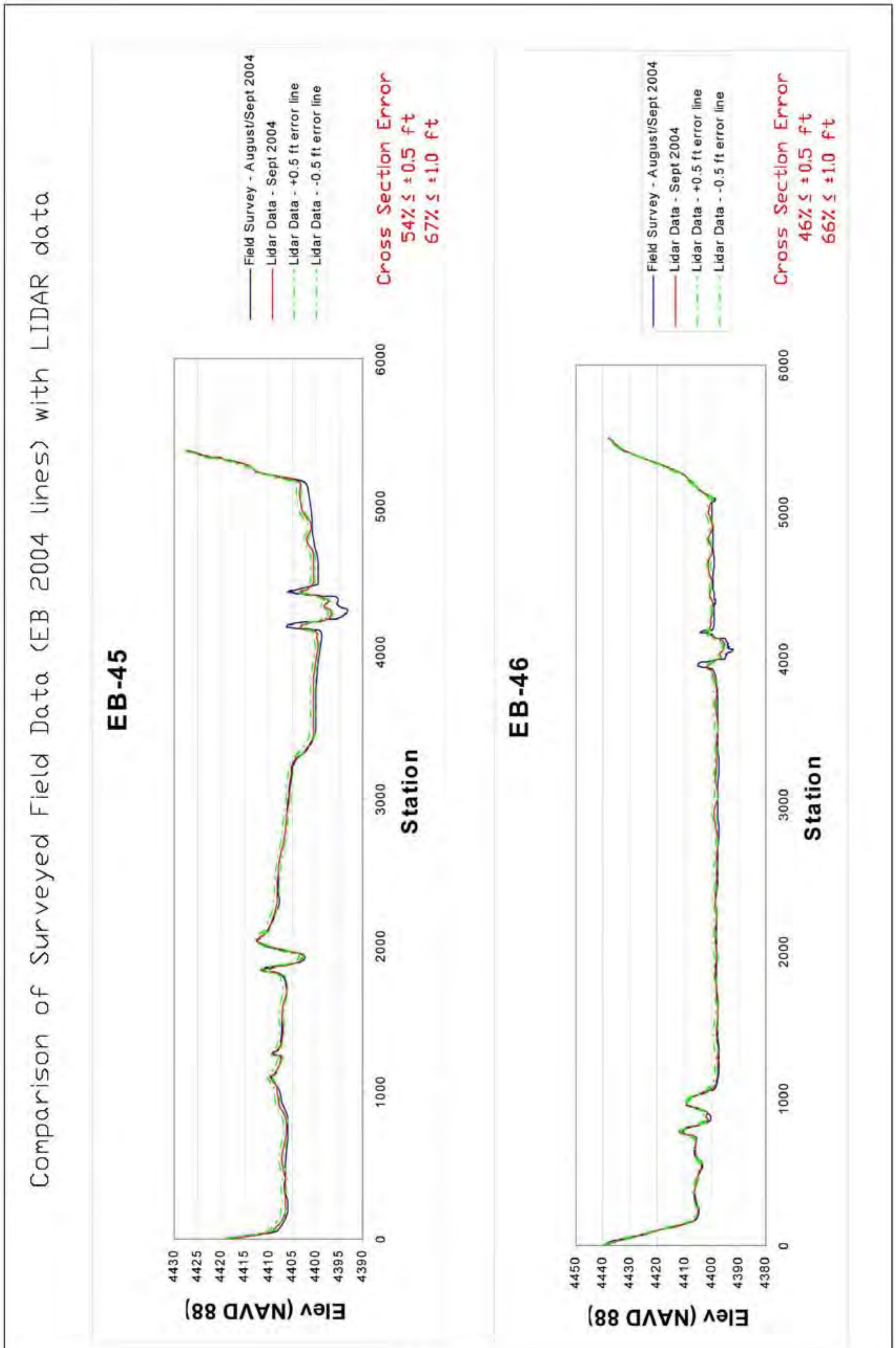

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-45
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
54% ≤ ±0.5 ft
67% ≤ ±1.0 ft
EB-46
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
46% ≤ ±0.5 ft
66% ≤ ±1.0 ft

Figure F

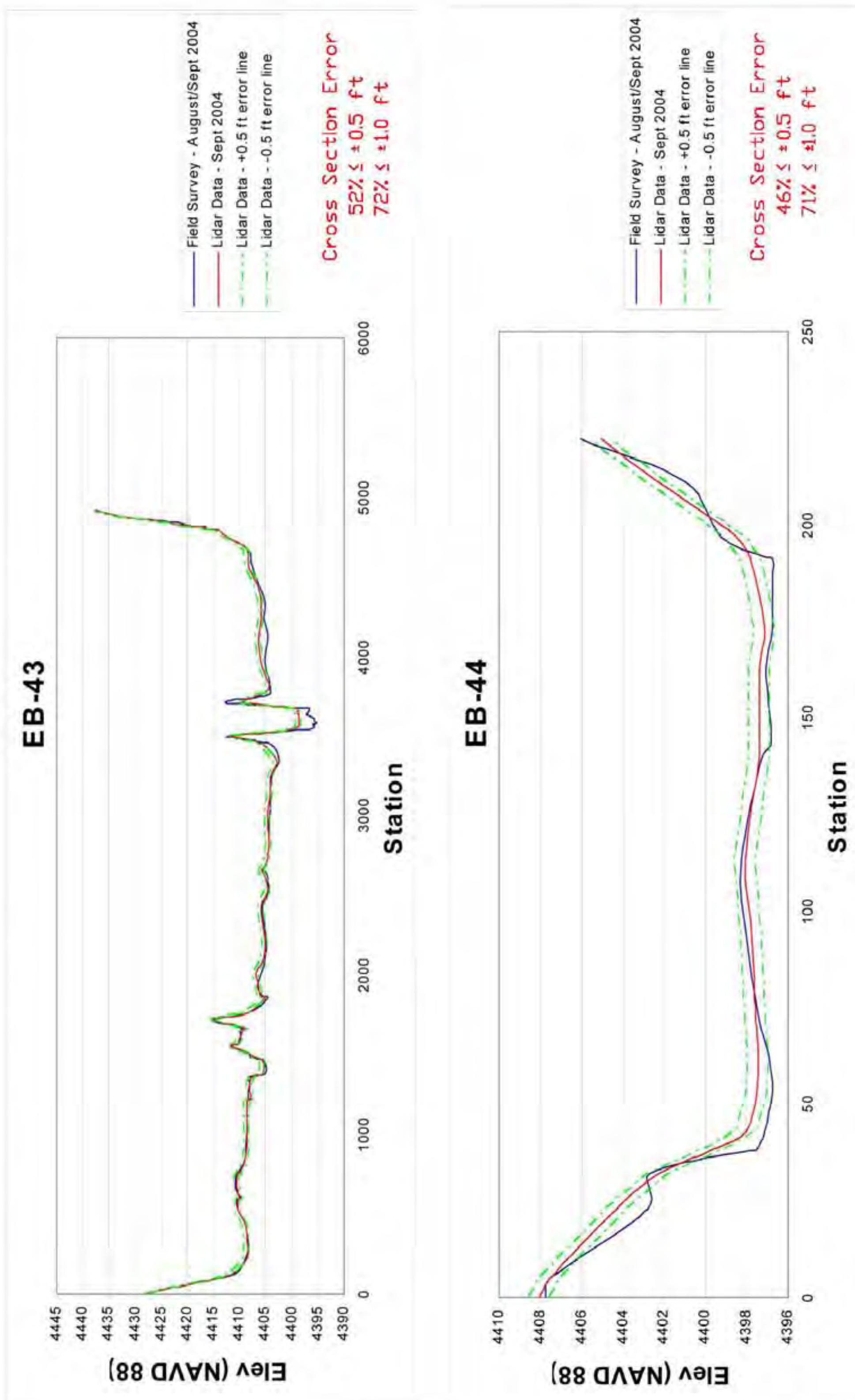

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-43
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
52% ≤ ±0.5 ft
72% ≤ ±1.0 ft
EB-44
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
46% ≤ ±0.5 ft
71% ≤ ±1.0 ft

Figure G

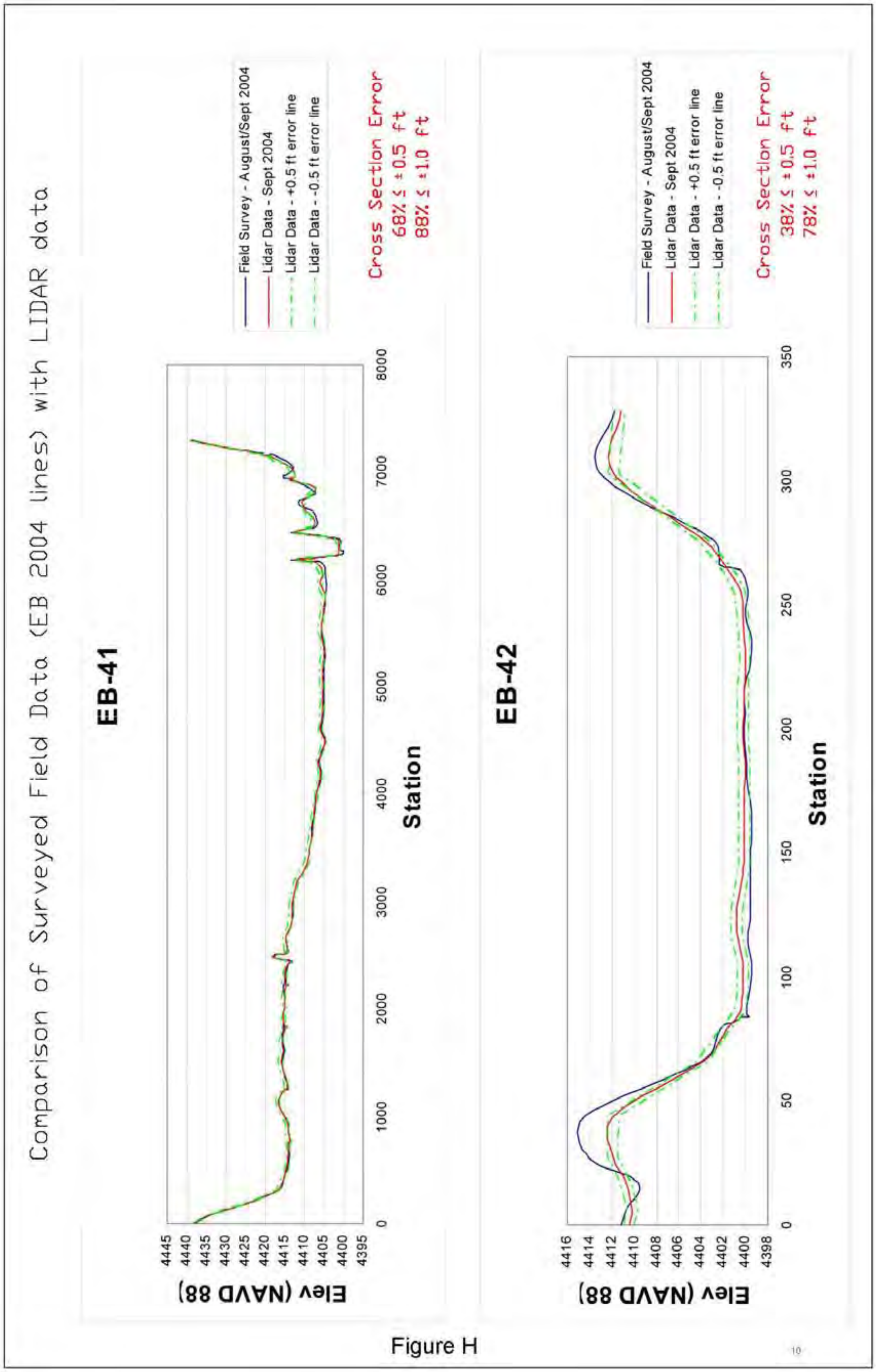
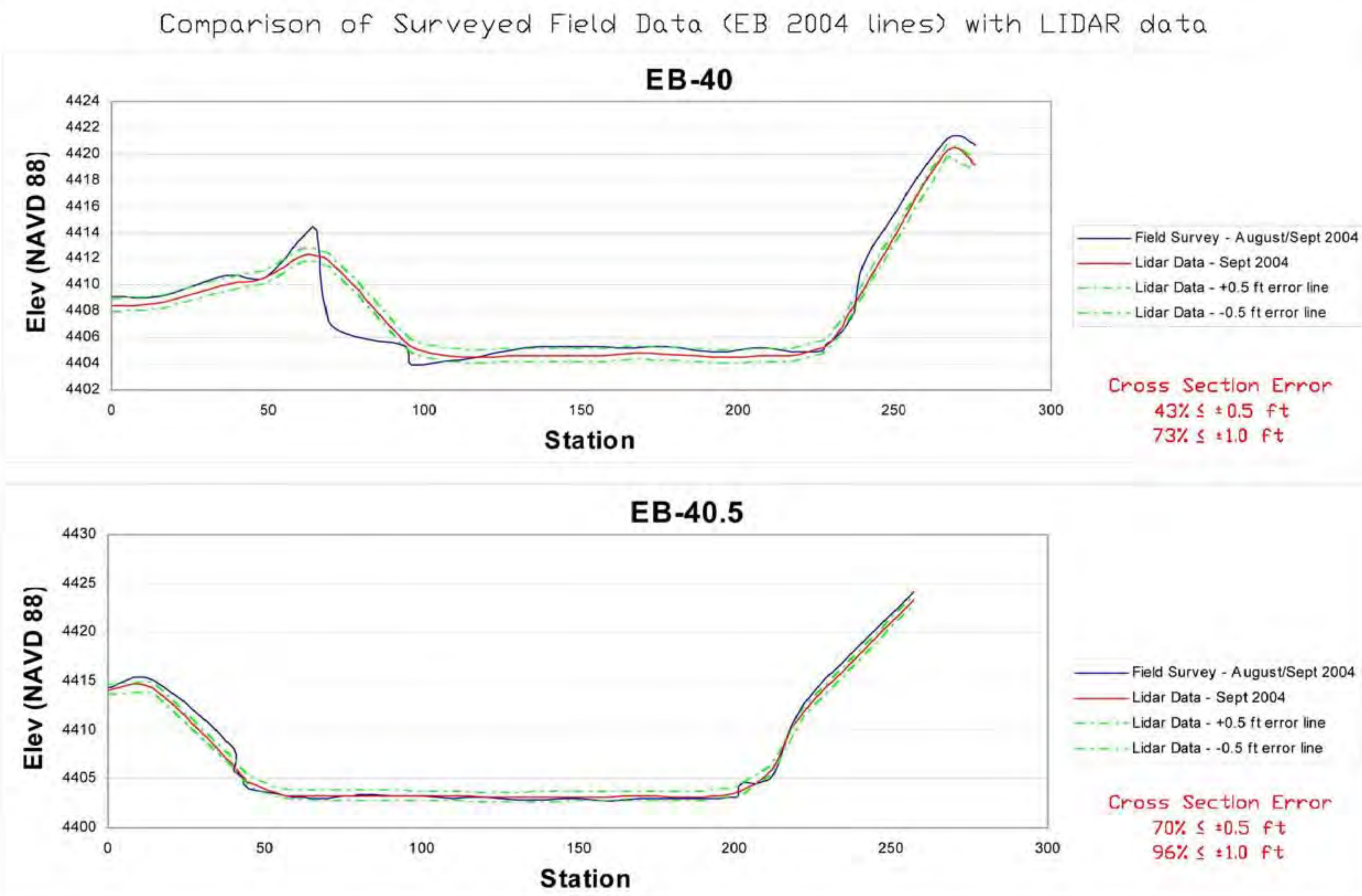

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-41
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
68% ≤ ±0.5 ft
88% ≤ ±1.0 ft
EB-42
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
38% ≤ ±0.5 ft
78% ≤ ±1.0 ft

Figure H



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-40
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
43% ≤ ±0.5 ft
73% ≤ ±1.0 ft
EB-40.5
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
70% ≤ ±0.5 ft
96% ≤ ±1.0 ft

Figure I

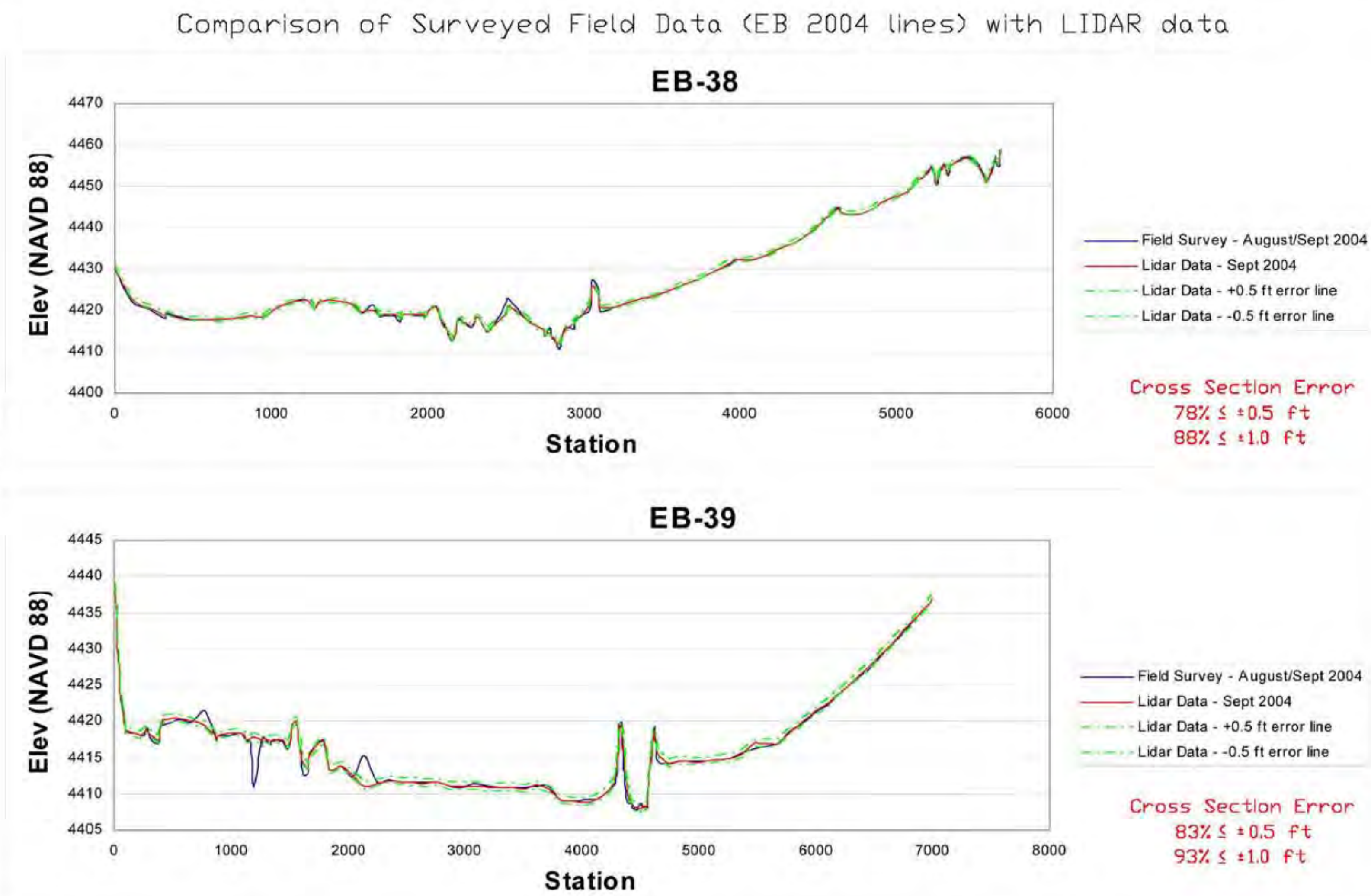
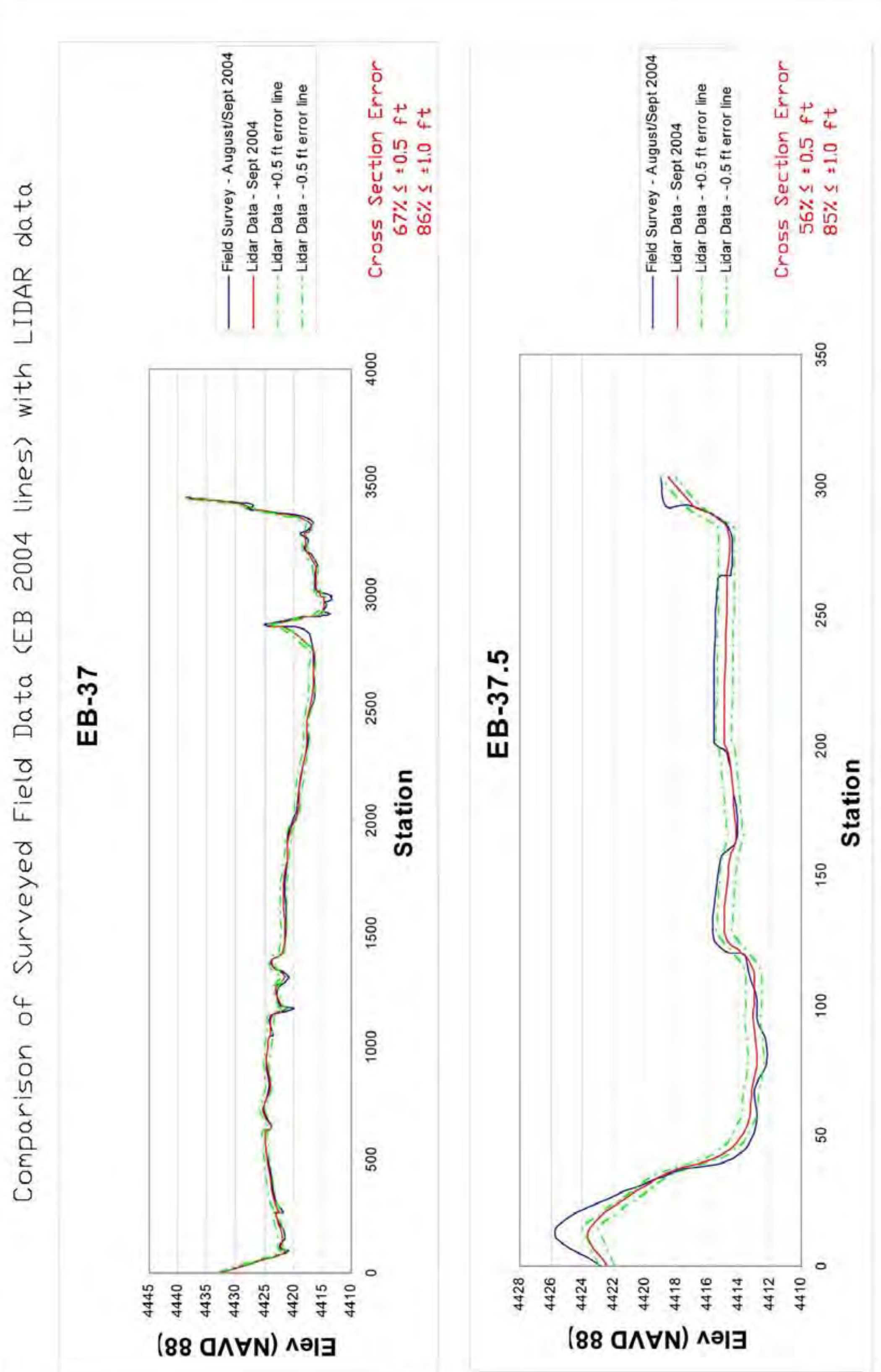

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-38
Elev (NAVD 88)
4470
4460
4450
4440
4430
4420
4410
4400
0
1000
2000
3000
4000
5000
6000
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
78% ≤ ±0.5 ft
88% ≤ ±1.0 ft
EB-39
Elev (NAVD 88)
4445
4440
4435
4430
4425
4420
4415
4410
4405
0
1000
2000
3000
4000
5000
6000
7000
8000
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
83% ≤ ±0.5 ft
93% ≤ ±1.0 ft
12

Figure J



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-37
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
67% ≤ ±0.5 ft
86% ≤ ±1.0 ft
EB-37.5
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
56% ≤ ±0.5 ft
85% ≤ ±1.0 ft

Figure K

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data

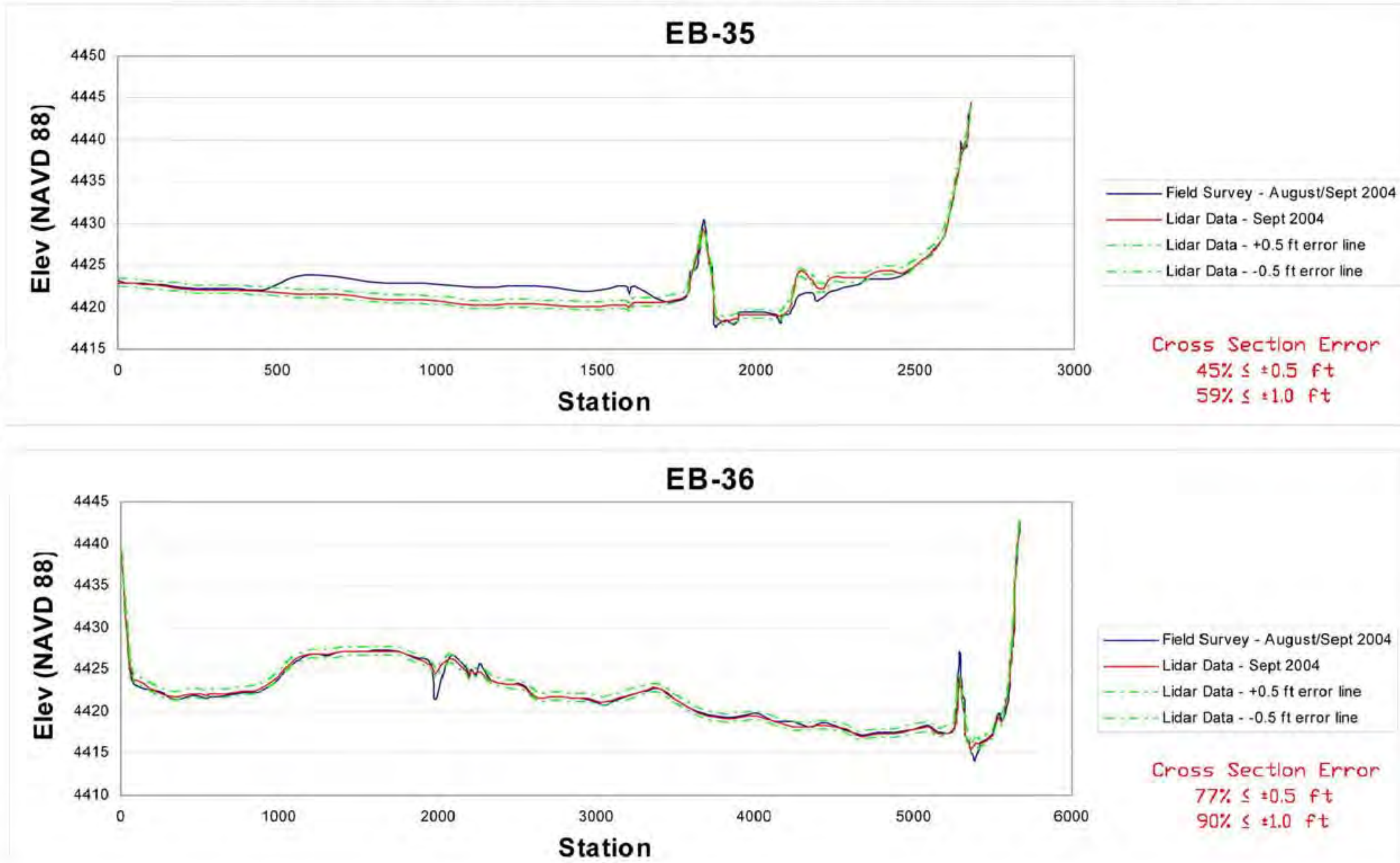
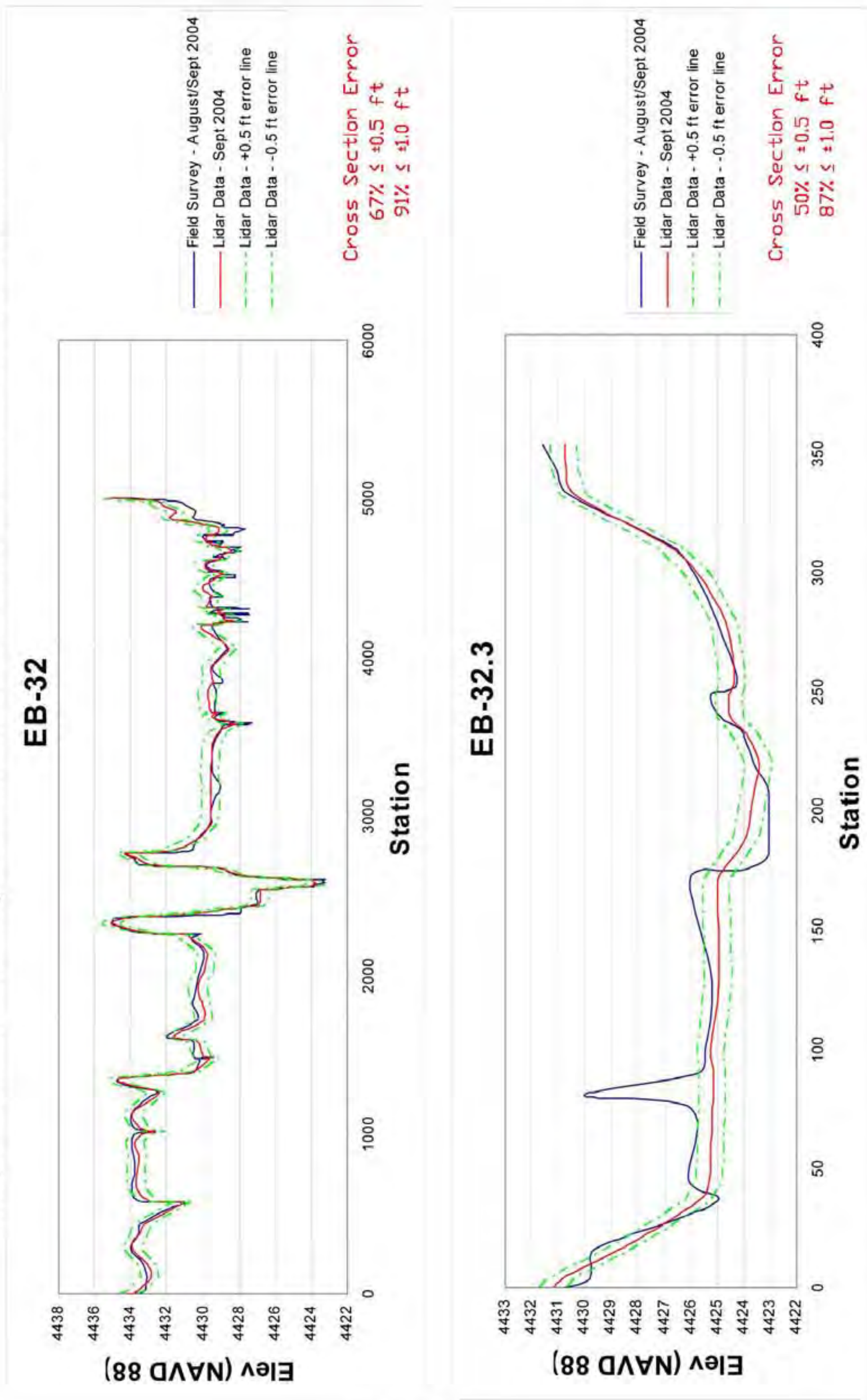


Figure L

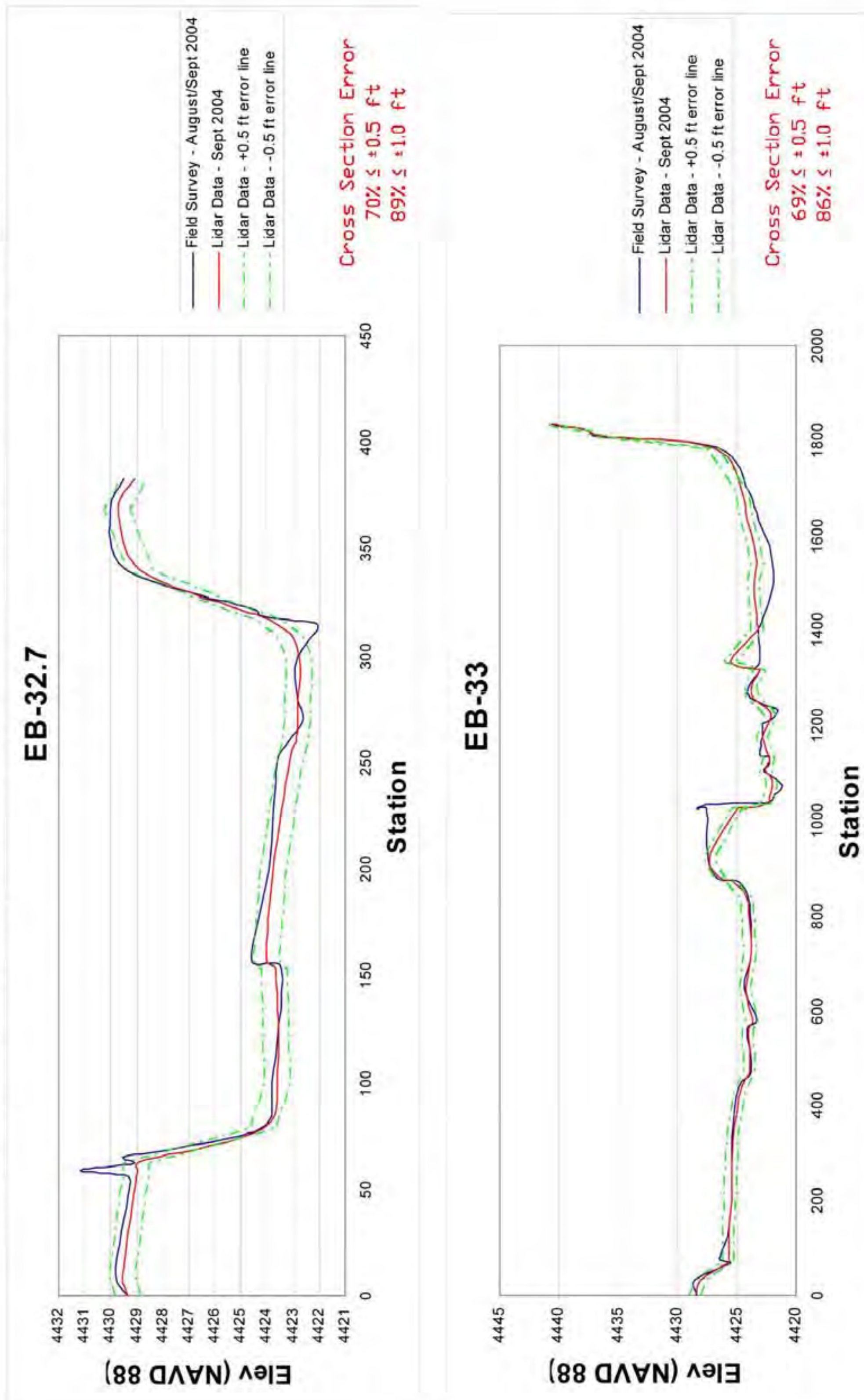
14



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-32
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
67% ≤ ±0.5 ft
91% ≤ ±1.0 ft
EB-32.3
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
50% ≤ ±0.5 ft
87% ≤ ±1.0 ft

Figure M

15



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-32.7
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
70% ≤ ±0.5 ft
89% ≤ ±1.0 ft
Elev (NAVD 88)
Station
EB-33
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
69% ≤ ±0.5 ft
86% ≤ ±1.0 ft
Elev (NAVD 88)
Station

Figure N

16

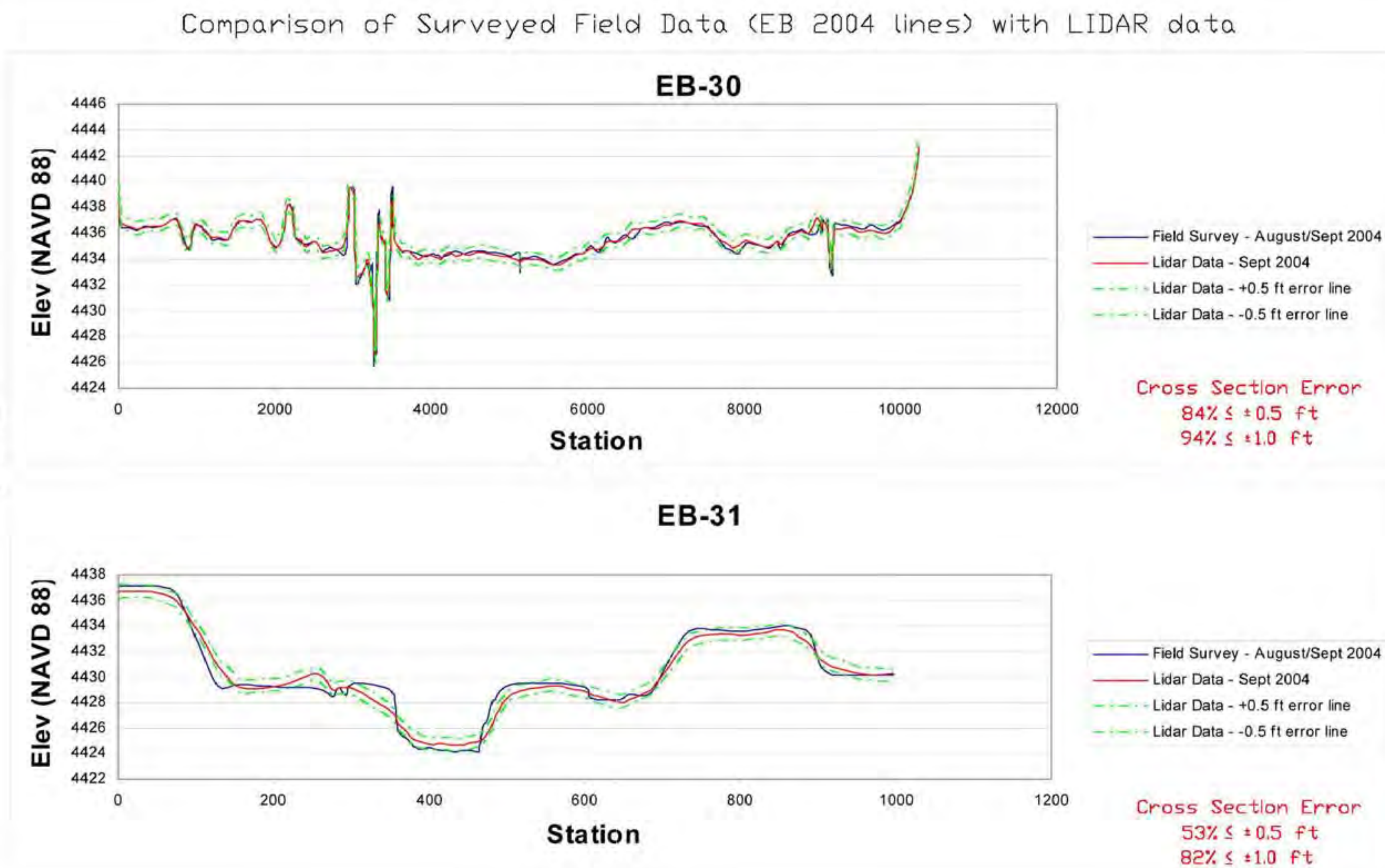
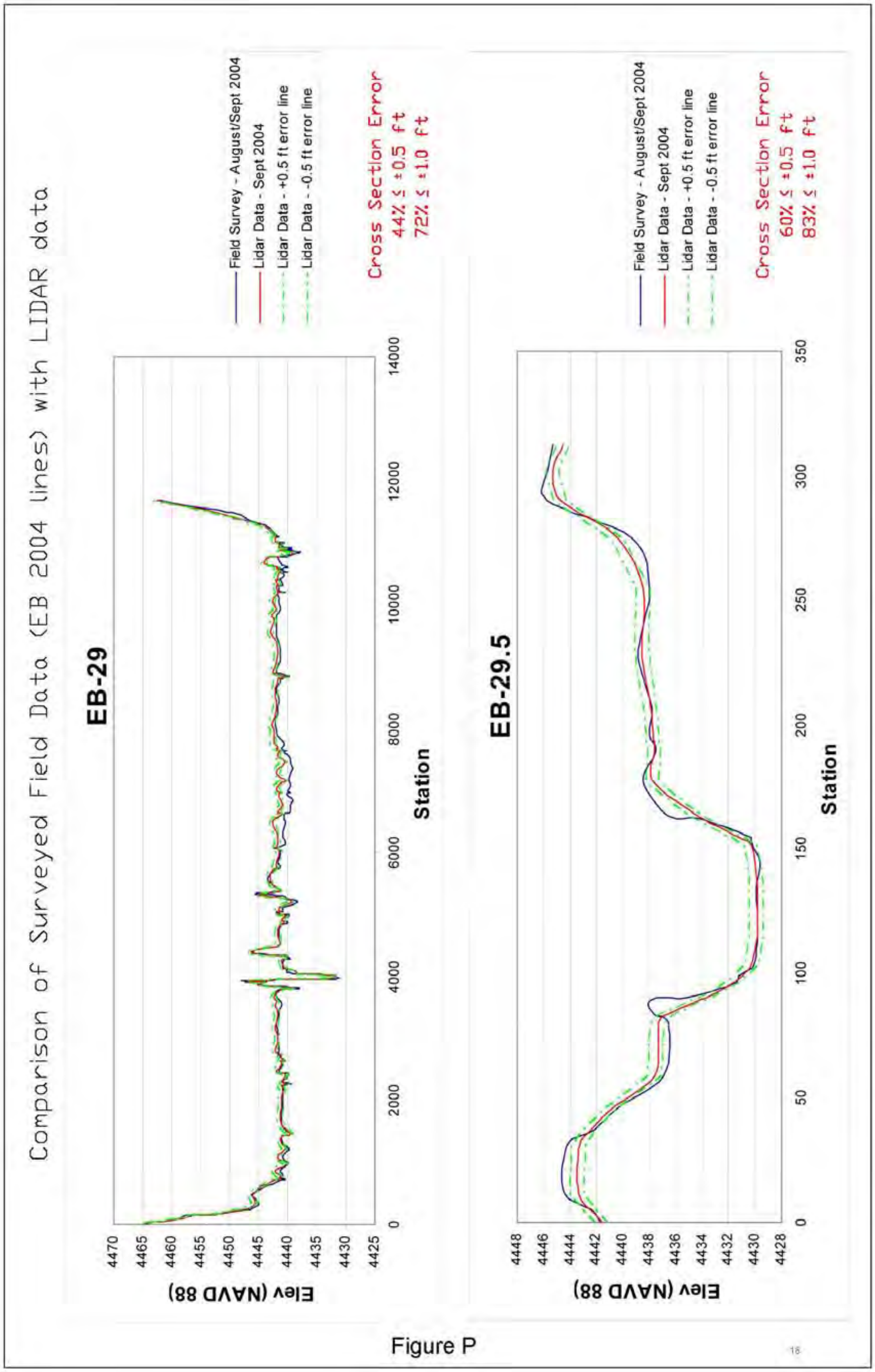
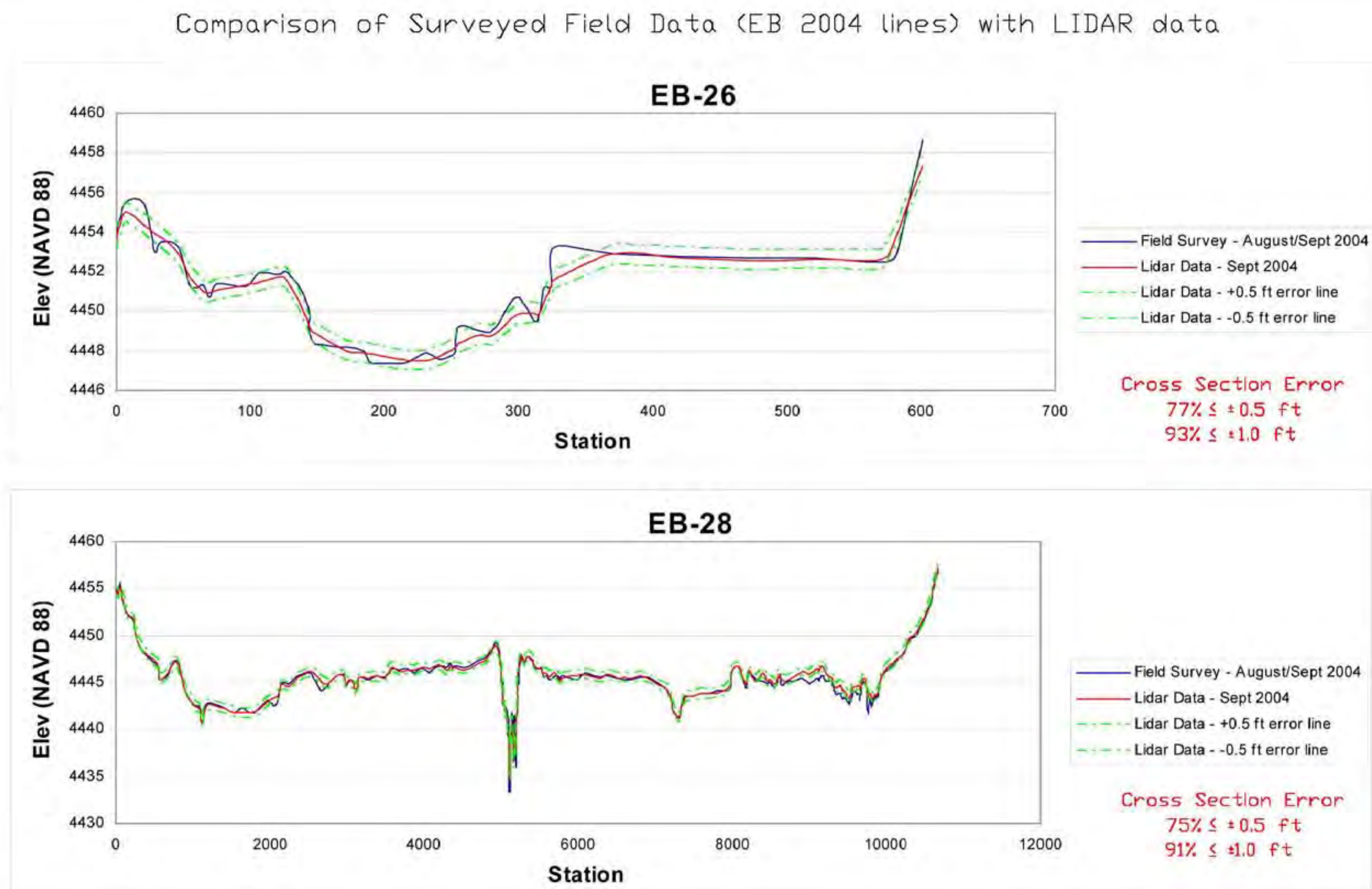

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-30
Elev (NAVD 88)
4446
4444
4442
4440
4438
4436
4434
4432
4430
4428
4426
4424
0
2000
4000
6000
8000
10000
12000
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
84% ≤ ±0.5 ft
94% ≤ ±1.0 ft
EB-31
Elev (NAVD 88)
4438
4436
4434
4432
4430
4428
4426
4424
4422
0
200
400
600
800
1000
1200
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
53% ≤ ±0.5 ft
82% ≤ ±1.0 ft

Figure O



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-29
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
44% ≤ ±0.5 ft
72% ≤ ±1.0 ft
EB-29.5
Elev (NAVD 88)
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
60% ≤ ±0.5 ft
83% ≤ ±1.0 ft

Figure P



Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-26
Elev (NAVD 88)
4460
4458
4456
4454
4452
4450
4448
4446
0
100
200
300
400
500
600
700
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
77% ≤ ±0.5 ft
93% ≤ ±1.0 ft
EB-28
Elev (NAVD 88)
4460
4455
4450
4445
4440
4435
4430
0
2000
4000
6000
8000
10000
12000
Station
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
75% ≤ ±0.5 ft
91% ≤ ±1.0 ft

Figure Q

19

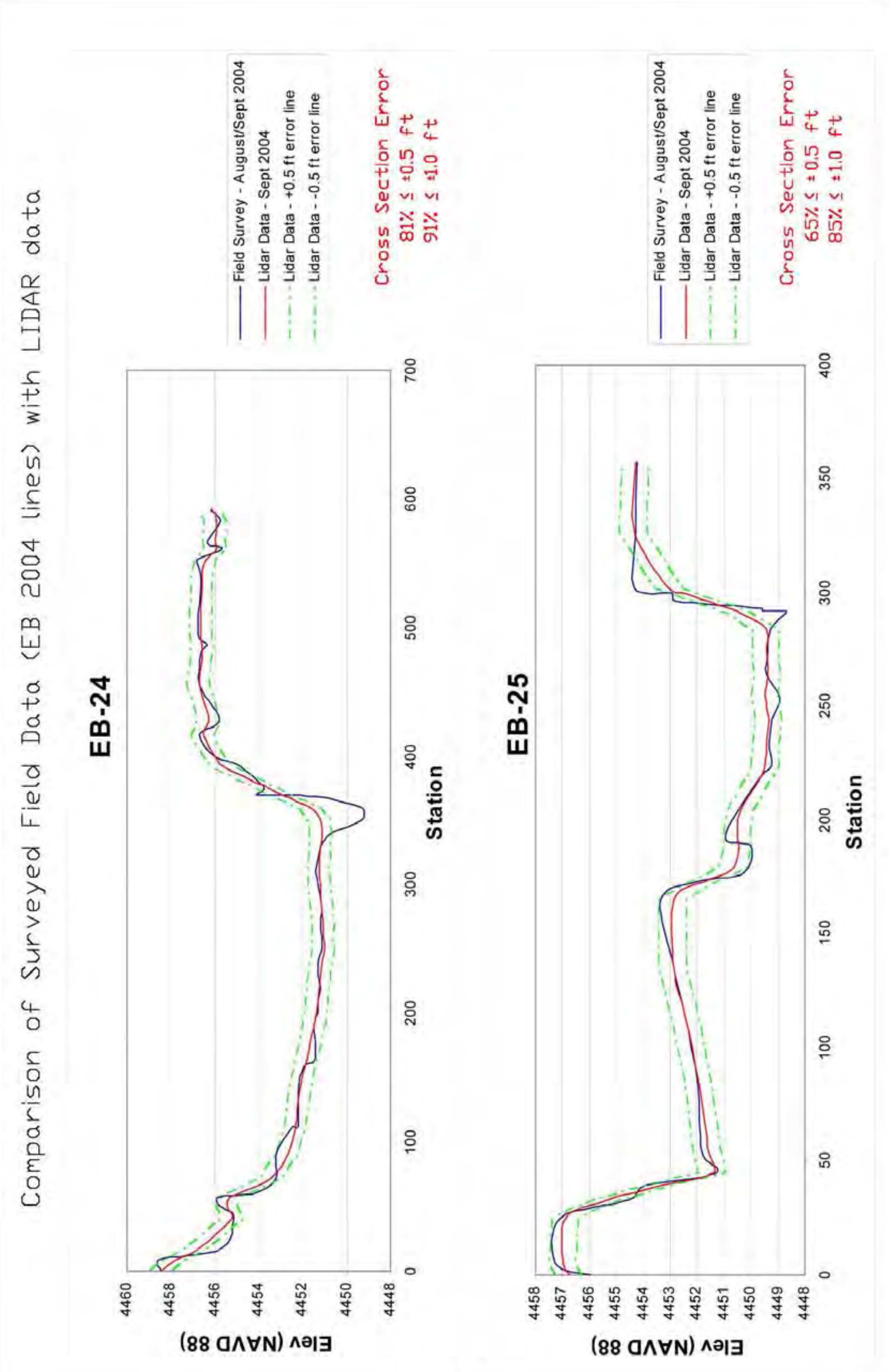

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-24
EB-25
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
81% ≤ ±0.5 ft
91% ≤ ±1.0 ft
Cross Section Error
65% ≤ ±0.5 ft
85% ≤ ±1.0 ft
Elev (NAVD 88)
Station

Figure R

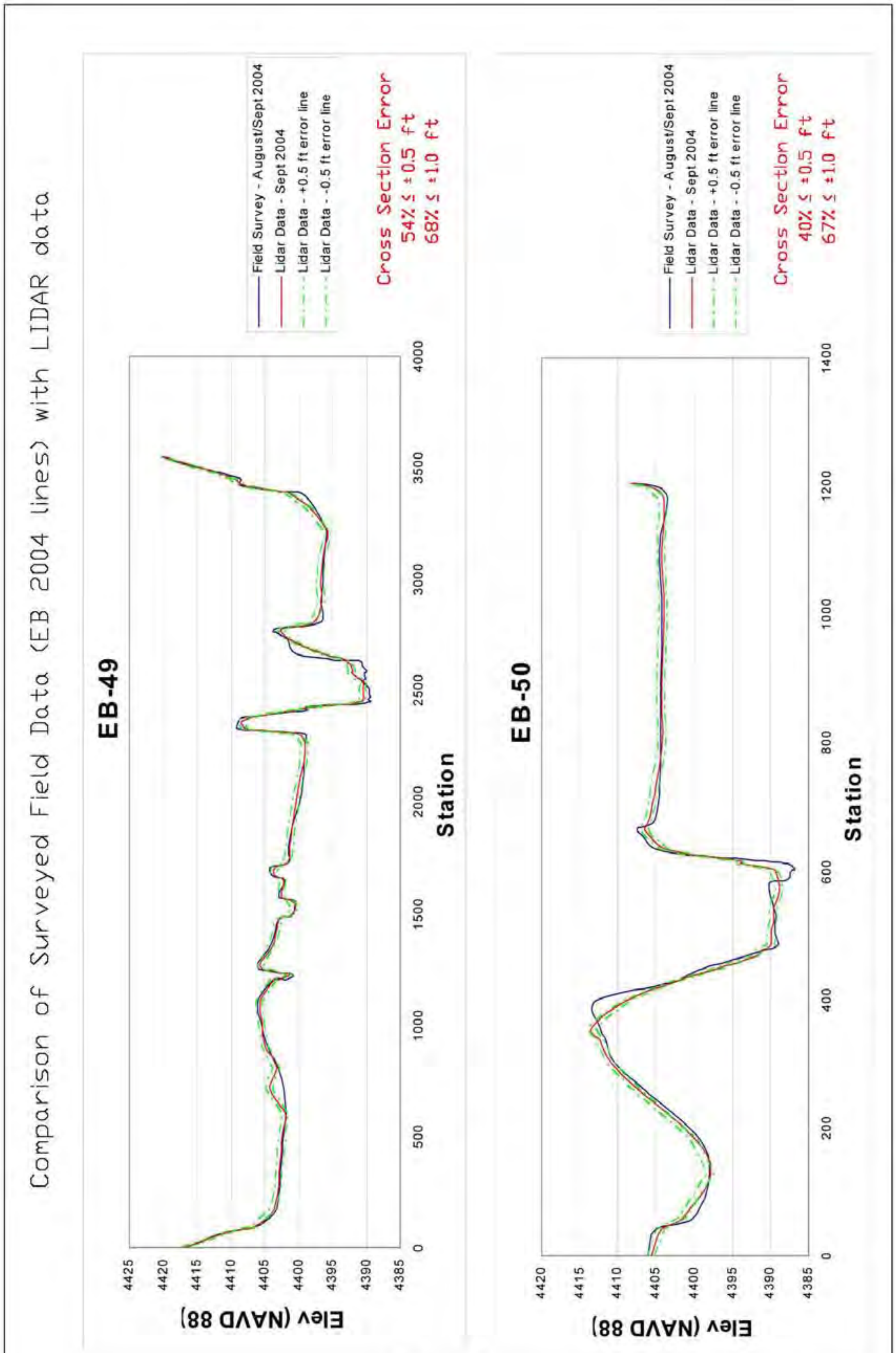

Comparison of Surveyed Field Data (EB 2004 lines) with LIDAR data
EB-49
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
54% ≤ ±0.5 ft
68% ≤ ±1.0 ft
Elev (NAVD 88)
Station
EB-50
Field Survey - August/Sept 2004
Lidar Data - Sept 2004
Lidar Data - +0.5 ft error line
Lidar Data - -0.5 ft error line
Cross Section Error
40% ≤ ±0.5 ft
67% ≤ ±1.0 ft
Elev (NAVD 88)
Station

Figure S