RECLAMATION

Managing Water in the West

Technical Report No. SRH-2010-12

Bighorn Lake-Yellowtail Dam 2007 Sedimentation Survey

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

September 2010

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Reclamation Report

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

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Bighorn Lake - Yellowtail Dam 2007 Sedimentation Survey

prepared by

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

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14. ABSTRACT

Reclamation surveyed Bighorn Lake (impounded by Yellowtail Dam) in July 2007 to develop updated reservoir topography, present storage-elevation relationships (area-capacity tables), and sediment deposition estimates. The bathymetric survey, conducted between water surface elevations 3,635.7 and 3,637.4 (feet), 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 survey was conducted using a reconnaissance collection and analysis technique that utilizes streamline bathymetric collection procedures within the areas of the reservoir where the majority of the sediment was known to accumulate (Ferrari, R.L. 2006). Sediment deposition locations were determined during the 2007 field collection and from the 1982 sedimentation survey (Blanton, J. O., 1982). The reconnaissance method was employed due to the size of the reservoir and because no detailed above water data was collected. The 2007 survey data measured the change of the original surface areas due to sediment accumulation.

As of July 2007, at flood control reservoir pool elevation 3,657.0, the surface area was 17,279 acres with a total capacity of 1,278,896 acre-feet. Since November 1965 closure of Yellowtail Dam, the 2007 survey measured 103,415 acre-feet of sediment accumulation. This represents an annual sediment accumulation rate of 2,480 acre-feet or 0.242 acre-feet per square mile of contributing drainage area and a 7.48 percent loss in storage capacity.

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Bighorn Lake - Yellowtail Dam 2007 Sedimentation Survey

Pick-Sloan Missouri Basin Program, Montana
Fort Smith, Montana

11/22/10

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Introduction

Yellowtail Dam, located on the Bighorn River, impounds water to form Bighorn Lake. Both are principal features of the Yellowtail Unit of the Lower Bighorn Division and are integral parts of the Pick-Sloan Missouri Basin Program that includes other major water bodies such as Canyon Ferry and Tiber Reservoirs. Yellowtail Dam is within the Crow Indian Reservation, about 21 miles north of the Montana-Wyoming State line and 90 miles southwest of Billings, Montana (Figure 1).

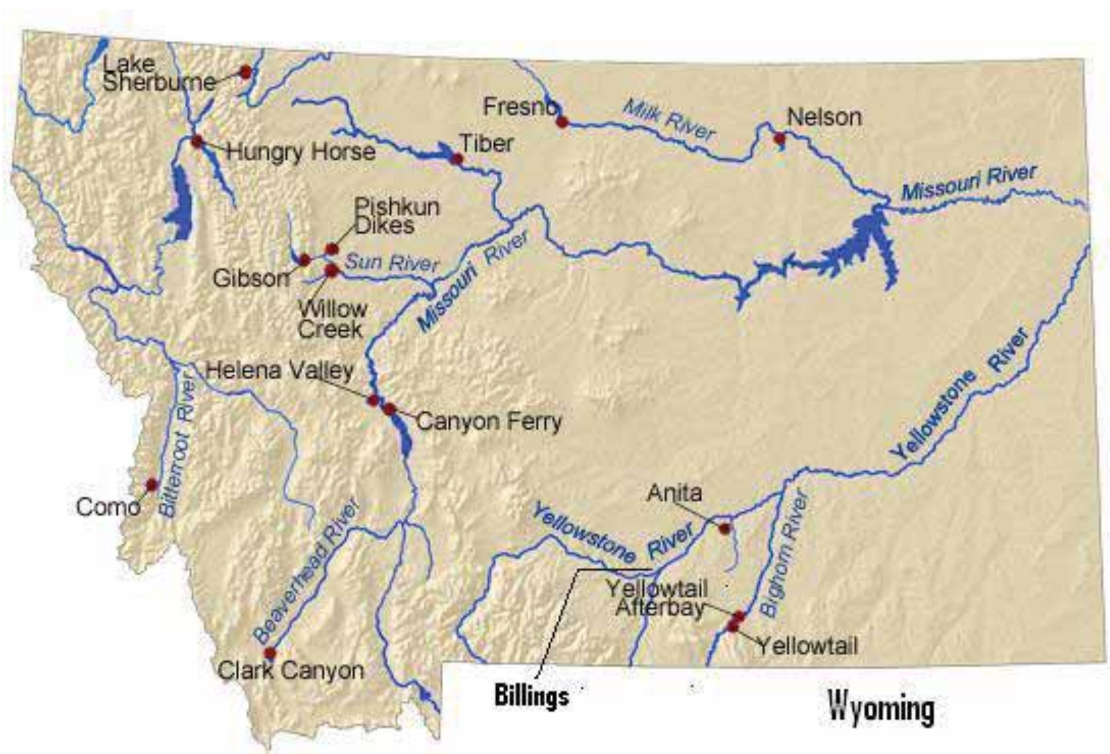

Figure 1 - Reclamation Reservoirs Located in Montana.

Yellowtail Dam is a concrete thin-arch dam that was constructed between 1961 and 1966 (Figure 2). The dam's dimensions are:

Hydraulic height[1]	494 feet	Dam crest elevation	3,660.0 feet[2]
Structural height	525 feet	Parapet crest elevation	3,664.0
Crest length	1,480.0 feet		

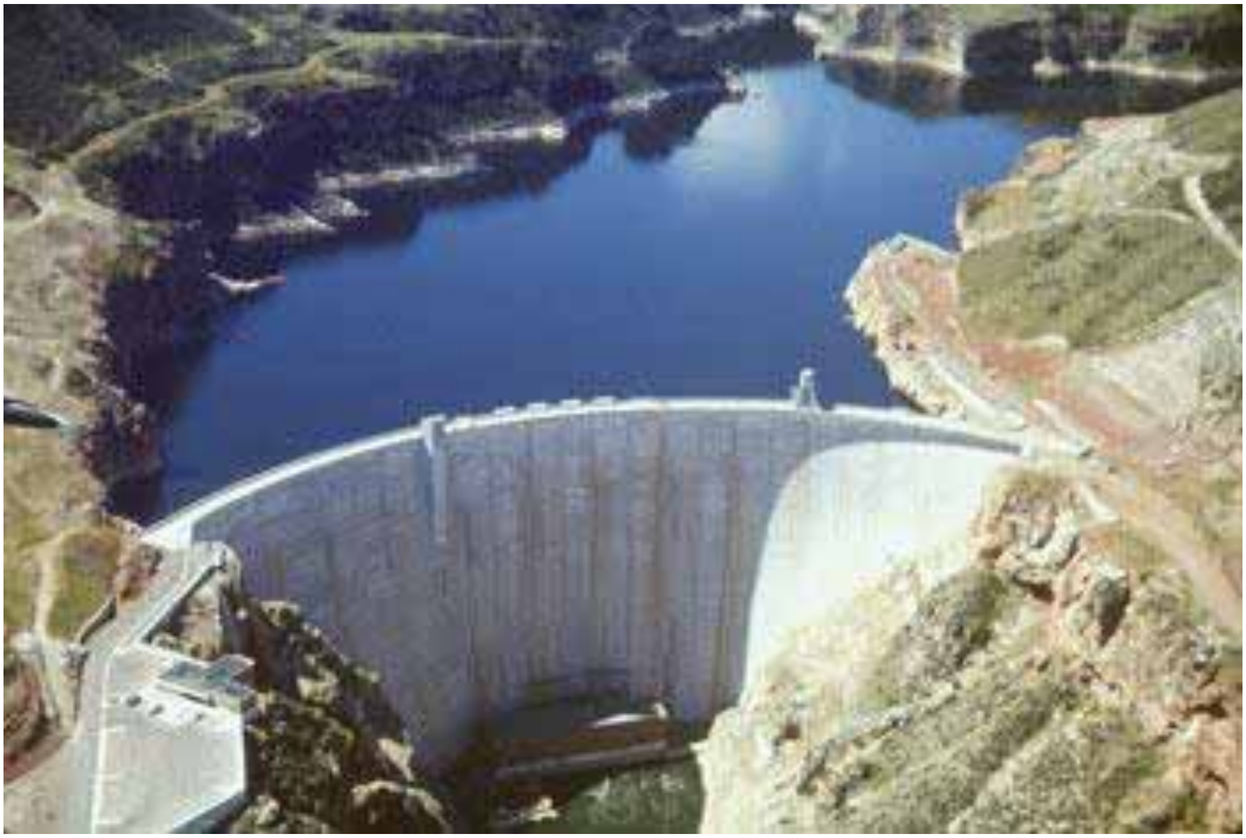

Figure 2 - Downstream Face of Yellowtail Dam.

The spillway is located in the left abutment of the dam and consists of an unlined inlet channel, an intake structure, a concrete-lined tunnel transition, a concrete-lined tunnel ranging in diameter from 32 to 40.5 feet, and a stilling basin. Discharge through the spillway is controlled by two 25-foot by 64.4 foot radial gates with a total discharge capacity of 92,000 cubic feet per seconds (cfs) at reservoir elevation 3,660.0. The spillway crest elevation is 3,593.0 and when closed, the top gate elevation is 3,657.0.

[1] The definition of such terms as "hydraulic height," "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and ASCE's *Nomenclature for Hydraulics.*

[2] Elevations in feet. Elevations based on original project datum established by Reclamation that is near National Geodetic Vertical Datum of 1929 (NGVD29) and approximately 2.6 feet lower than the North American Vertical Datum of 1988 (NAVD88).

The river outlet works near the right end of the dam consisting of an upper irrigation and lower evacuation outlets located one over the top of the other. Each has an 84-inch-diameter outlet pipe controlled by an 84-inch ring-follower gate. Both discharge into a stilling basin to the right of the powerplant at the toe of the dam. The outlets normally operate at equal releases with minimal releases of 500 cfs and maximum releases of 2,000 cfs at top of joint-used storage elevation 3,640.0. The lowest outlet invert elevation is 3,296.5.

The Yellowtail Powerplant structure, located at the toe of the dam, has four 12-foot-diameter penstocks through the dam that supply water to four hydraulic turbines. Normal water discharges from Bighorn Reservoir are released solely through the power waterways with releases generally ranging between 7,200 and 7,800 cfs, depending on the level of the reservoir.

The Yellowtail Project is operated and maintained to provide regulation of river flow for power generation, flood control, irrigation, municipal and industrial water supply, fish and wildlife enhancement, and recreational development. The dam, reservoir, and distribution system are operated by the Montana Area Office of the Bureau of Reclamation.

Bighorn Lake when filled to top of exclusive flood control elevation 3,657.0 extends a total of 61.8 river–miles through the entire length of Bighorn Canyon and onto the valley floor in the Bighorn Basin in Wyoming. The reservoir inundates an area of valley several miles wide and extends about 11 miles south of the head of Bighorn Canyon. The original surface area of the reservoir at elevation 3,657.0 was 17,298 acres. The reservoir had a total original capacity of 1,375,000 acre-feet of which 503,328 acre-feet was considered inactive below elevation 3,547.0. For the purpose of sedimentation computations, the 1982 survey study estimated the river channel capacity, resulting in a recomputed total original capacity of 1,382,311 acre-feet at elevation 3,657.0 and a inactive capacity of 509,686 acre-feet below elevation 3,547.0 (Blanton, J.O, 1986).

Drainage Area

The total drainage area for Bighorn River above Yellowtail Dam is 19,626 square miles (mi^2). The net sediment contributing area into Bighorn Lake is 10,270 mi^2 that excludes the reservoir area and contributing drainage basins above Anchor, Boysen, and Buffalo Bill Dams all located in the state of Wyoming, Figure 3.

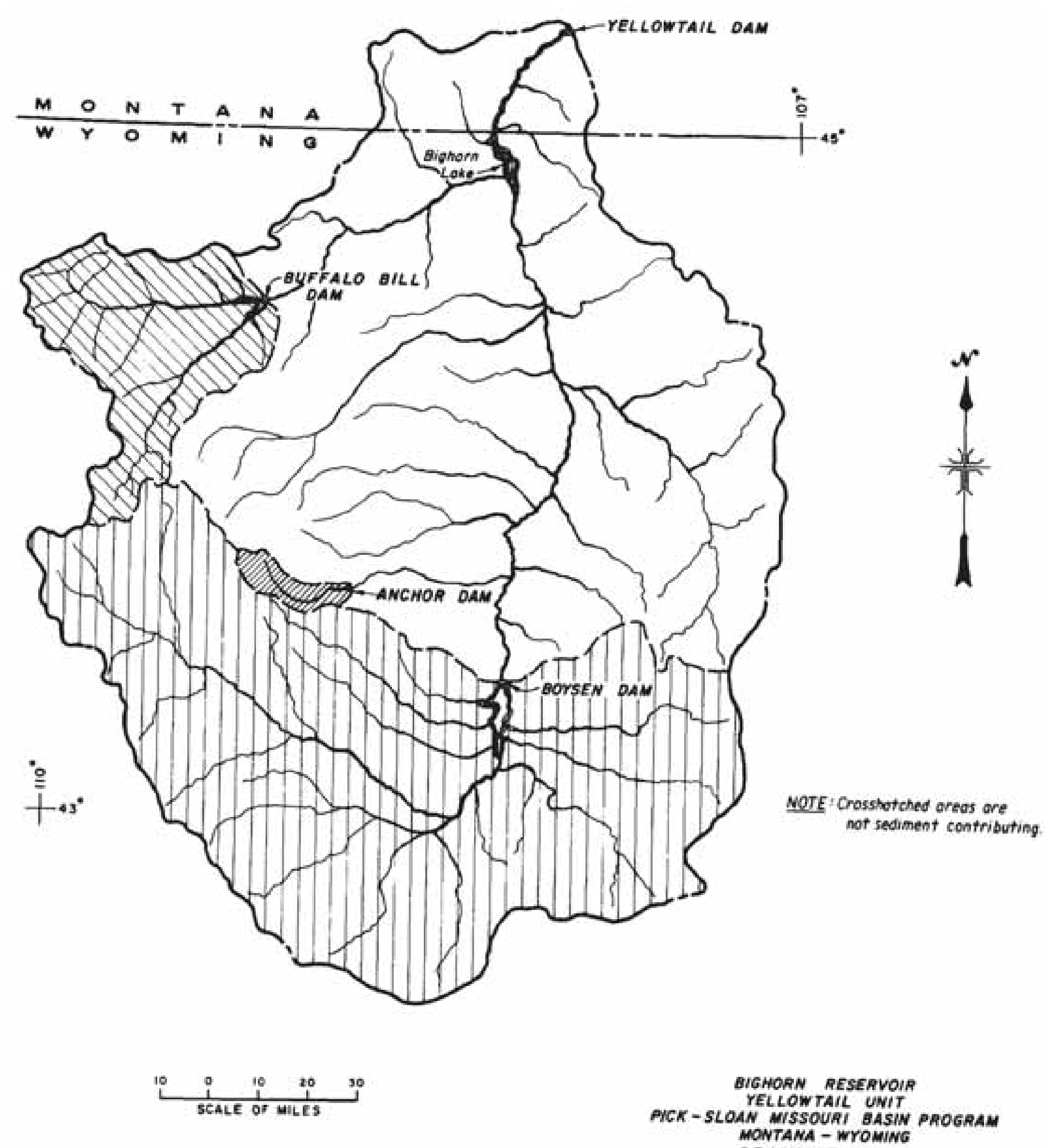

Figure 3 - Drainage Area Above Yellowtail Dam.

Summary and Conclusions

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

- $ develop reservoir topography
- $ compute current area-capacity relationships
- $ estimate storage depletion, by sediment deposition since dam closure in 1965 and since the 1982 sedimentation survey

Reclamation's Sedimentation Group has evaluated sedimentation on numerous reservoirs requiring extensive data collection and resources to complete. A complete hydrographic survey provides the most accurate reservoir topography and capacity. However, complete hydrographic of larger reservoirs can be cost prohibitive. Limited budgets affect survey frequency for updating reservoir information, resulting in limited knowledge of our nation's reservoir systems. For the 2007 Bighorn Lake survey, the reconnaissance technique was used with streamline collection procedures utilizing the latest equipment and analysis technology to produce a quality product in a cost-effective matter. Utilizing the reconnaissance technique, only reservoir areas where the majority of the sediment is known to accumulate are surveyed. For Bighorn Reservoir, areas of sediment accumulation were determined during the 2007 field collection and from the 1982 sedimentation survey results.

Bighorn Lake bathymetric survey was conducted in 2007 from July 6-17 between water surface elevation 3,635.7 and 3,637.4 (Reclamation project datum). The bathymetric survey was conducted using sonic depth recording equipment interfaced with a differential global positioning system (GPS) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along predetermine grid lines. Water surface elevations recorded by a Reclamation gage during the time of collection were used to convert sonic depth measurements to reservoir bottom elevations tied to the project's vertical datum. Due to the high vertical canyon walls of the lower portion of the reservoir, there were times no differential or adequate GPS information was received for collection purposes. The majority of these areas were eventually surveyed by returning during different times or days when the satellite coverage was better.

The initial above-water topography was determined by digitizing the elevation 3,660 contour line from the USGS quads of the reservoir area. During analysis the original USGS contours, inundated by the reservoir, were found in a digital format. These contours were not continuous around the reservoir and varied from 20- to 40-foot contour intervals. Orthographic aerial images for the years of 2004, 2006, and 2009; collected between water surface elevations 3,586 and 3,644; were downloaded from the internet and allowed reservoir contours to be digitized at the various water surface elevations (USDA, 2010). These aerial images were collected at high altitudes over the reservoir and in most cases; it was difficult to distinguish the reservoir water surface edge due to shadows from the canyon walls and poor images quality. However, the viewable water edges were the best means to accurately locate the shoreline changes due to erosion or sediment accumulation.

The 2007 reservoir topography was developed by combining the 2007 bathymetric data with previously collected data. This was accomplished by removing the areas of previously collected data where the 2007 bathymetric data overlapped. Even with multiple data sources, the 2007 developed contours were very crude in the upper elevation contours and small coves of the reservoir. This had little effect on the 2007 study results since this analysis measured change from the original topography due to sediment deposition which mainly occurred at elevation 3,630 and below.

The 1982 report indicated the original surface areas of the reservoir were measured from aerial developed topography flown in 1945. The developed contour intervals were 20-foot in the narrow canyon portion of the reservoir downstream of range line 13 and 5-foot upstream of range line 13, where the reservoir is more wide open. During the 1982 and 2007 analyses, the reservoir was divided into segments using the sediment range lines as upstream and downstream boundaries. The 1982 and 2007 analysis computations were at the 5 and 20-foot contour increments defined above, depending on reservoir location.

The 2007 method of analysis was similar to the 1982 method except the 2007 detailed bathymetric survey allowed new topography to be developed where the survey vessel had access. The 2007 area and capacity tables were produced using a computer program that utilized the measured contour surface areas and a curve-fitting technique to compute the area and capacity values at prescribed elevation increments (Bureau of Reclamation, 1985). Tables 1 and 2 contain summaries of Bighorn Lake analysis and watershed characteristics for the 2007 study. The 2007 survey determined the reservoir has a total storage capacity of 1,278,896 acre-feet with a surface area of 17,279 acres at top of the flood control pool elevation 3,657.0. Since November 1965 Yellowtail Dam closure, this survey measured 103,415 acre-feet of sediment accumulation at elevation 3,657.0 of which 39,776 acre-feet has deposited in the inactive and dead pool zones below elevation 3,547.0.

Survey Control Information

The 2007 bathymetric survey of Bighorn Lake was conducted with the horizontal control in feet, Montana state plane coordinates, in the North American Datum of 1983 (NAD83). Even though the upper portion of the reservoir lies within the state of Wyoming, for ease of analysis and since the dam is located in Montana, the Montana state plane horizontal coordinate system was used for all topography development presented in this report. All elevations were converted to the same elevation as the recorded water surface elevations at the dam. The water surface elevations are in Reclamation’s project vertical datum which was the vertical datum used during construction of the project. It was determined during this study that Reclamation’s project vertical datum is near NGVD29 and about 2.6 feet lower than NAVD88.

During the 2007 bathymetric collection 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. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files for processing with known point data to determine positions relative to the national control network. The GPS base was set over temporary marks in the upper end of the reservoir near the Lovell Causeway and in the lower end of the reservoir near the marina located upstream of the dam. The coordinates for these points were processed using OPUS, and from these bases additional points were measured such as the reservoir water surface and a sediment range line monument. Differential corrections from these base locations were used for only a small portion of the bathymetric survey.

The majority of the 2007 bathymetric survey used a commercial differential GPS (DGPS) positioning service. The leased system mounted on the survey boat over the transducer provided sub-meter accuracies that met the objectives of the 2007 study. Differential corrections were obtained via satellite and were available during the majority of the survey. However, at times corrected positions were not obtained due to blockage of the GPS satellites by the high vertical canyon walls that existed from the dam to the upper portion of the reservoir near range line 13. The majority of the reservoir was eventually surveyed by returning to these areas on different days or times of the day when satellite coverage improved. Since the 2007 survey was measuring changes from the original topography, issues with the 2007 positioning system did not adversely affect the study results.

Since the 2007 survey, there have been steady improvements in both the United States global positioning system (GPS) and the GLObal NAvigation Satellite System (GLONASS) that is managed for the Russian Federation Government. GLONASS is a counterpart to the United States GPS and both systems share the same principles in the data transmission and positioning methods. With the continuous improvements of these systems and possible launching of other systems, future surveys of Bighorn Lake will be able to obtain more reliable detailed data. Combined with above water data, new topography could be developed for the complete reservoir area.

During the bathymetric survey, topographic shots were collected on the water surface in the upper portion of the reservoir in Wyoming near the Lovell Causeway and lower portion of the reservoir in Montana at the public boat ramp near the dam. These readings, when compared to the Reclamation reservoir water surface gage readings, determined the gage readings were tied to NGVD29 or around 2.6 feet lower than NAVD88. A topographic shot was collected on a Reclamation sedimentation range line brass cap R30R located in the upper end of the reservoir in Wyoming. A sheet of survey data of the sediment range line end points listed the elevation as 3,700.04. The 2007 survey measured the elevation as 3,700.57 in NGVD29 (see Appendix). There was no history of how these end points were originally surveyed or if any other surveys have been conducted to confirm their original measurements. The 1982 survey report indicated that destroyed range end monuments were replaced, but did not list which ones.

The following is the 2007 measurement that was collected on brass cap R30R. Located in the appendix are the original position and elevation coordinate values for the sediment range end monuments. The 2007 survey for R30R also showed the horizontal coordinates were off about 4.4 feet. It is possible this monument was one replaced during the 1982 survey.

	Montana NAD83, (Feet)	Montana South, NAD27, (Feet)
North	226,430.41	317,494.43
East	2,311,616.88	2,343,271.15
Elevation	3,703.22 (NAVD88)	3,700.57 (NGVD29)

Hydrographic Survey, Equipment, and Methods

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 4). The hydrographic system included a GPS receiver with a built-in radio, depth sounders, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the equipment. The shore equipment that provided DGPS 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 power for the shore unit. The majority of the bathymetric survey was conducted with DGPS provided by a leased commercial service.

Figure 4 - Survey Vessel With Mounted Instrumentation on Jackson Lake in Wyoming.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights are 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 Montana's state plane coordinates, NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS. Due to the canyon topography there were no easily accessible locations for setting a base receiver throughout the reservoir so the 2007 survey was mainly conducted utilizing a commercial differential service that provided submeter corrections to the boat mounted GPS unit by satellite communications. Due to the vertical canyon walls of the lower portion of the reservoir below range line 13, there were times adequate satellites or corrections were not available to provide corrected positions to the collection vessels. The majority of these areas were eventually mapped when the survey vessels returned at different times or on different days when adequate coverage was available.

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 5 illustrates the swath of the reservoir floor that is about 3.5 times as wide as the water depth below the transducer.

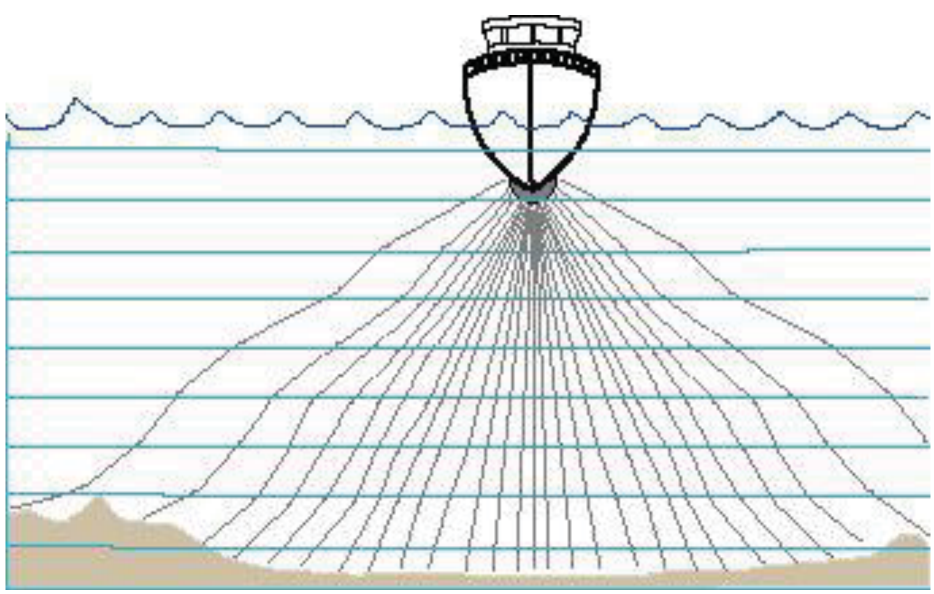

Figure 5 - Multibeam Collection System.

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.

A single beam depth sounder was also used and was calibrated by lowering a weighted marked cable and comparing the cable depths to digital depths. In the upper portion of the reservoir in the deeper portion of the channel, the sediment laden bottom was very soft allowing the weight to easily sink 1 to 2-feet below the reservoir bottom, making accurate calibration difficult. In the main part of the reservoir, downstream of range line 13, the bottom was found to be much more solid. The weighted cable was able to be lowered to a maximum depth of around 180 feet while the maximum depth of the velocity probe was nearly 100 meters. This limited the calibration of the single beam sounder to 180 feet with the weighted cable, but the measurements from the velocity probe can be applied to adjust the measured single beam depths beyond 180 feet. The sounders were calibrated independently and depths compared well up to 200 feet. For depths greater than 200 feet only the multibeam soundings were used.

The collected depth data were digitally transmitted to the computer collection system through a RS-232 port. For the single beam collection, the depth sounder 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 Reclamation project datum lake-bottom elevations. The single beam sounder was used to survey the sediment range lines collected in 2007 and map the reservoir from range line 13 upstream. Additional information on collection and analysis procedures is included in *Engineer and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

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 multibeam and single beam depth sounders. Most transects (grid lines) were run parallel to the upstream-downstream alignment of the reservoir below range line 13. For areas upstream of range line 13 the gridlines were run somewhat perpendicular to the river alignment. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining a course along the predetermined lines. During each run, the depth and position data were recorded on the laptop computer hard drive for subsequent processing.

Reservoir Surveys, Surface Area and Capacity, Sediment Distribution

Original Surveys

The original sedimentation range line survey was conducted during the construction period from November 1962 through September 1964 (see Appendix). Within the Bighorn Canyon, the underwater portion of each range line was surveyed and the river water surface elevation coincident with the survey was determined. Each range end was marked by a monument and surveyed to determine the horizontal and vertical positions. The layout of the reservoir sediment range system is shown on Figures 6 through 9.

The original topographic mapping of the reservoir was performed under contract by Fairchild Aerial Surveys, Inc. and was flown in 1945. The canyon portions of the maps had a scale of 1:6000 and a contour interval of 20 feet. The topographic map of the reservoir area upstream of range line 13 had a scale of 1:6000 and a contour interval of 5 feet. The river portion of the reservoir during the time of flight was not mapped.

1982 Resurvey

Fieldwork for the 1982 survey began in April 1981, ended on August 4, 1982, and was a range line survey where 51 of the sediment range lines were resurveyed (Blanton, J.O, 1986). The preliminary fieldwork consisted of searching for the range end markers, flagging the range ends and points on line near the water’s edge, replacing end markers that were destroyed, and running ground profiles on range lines in the delta area not inundated during the bathymetric survey. Within Bighorn Canyon, range line 13 and downstream, each range line was projected down to the reservoir level from the canyon rim where many of the original range monuments had been placed. All range lines between ranges 34 and 44 were profiled by standard land surveying procedures since they were located above the existing reservoir water surface.

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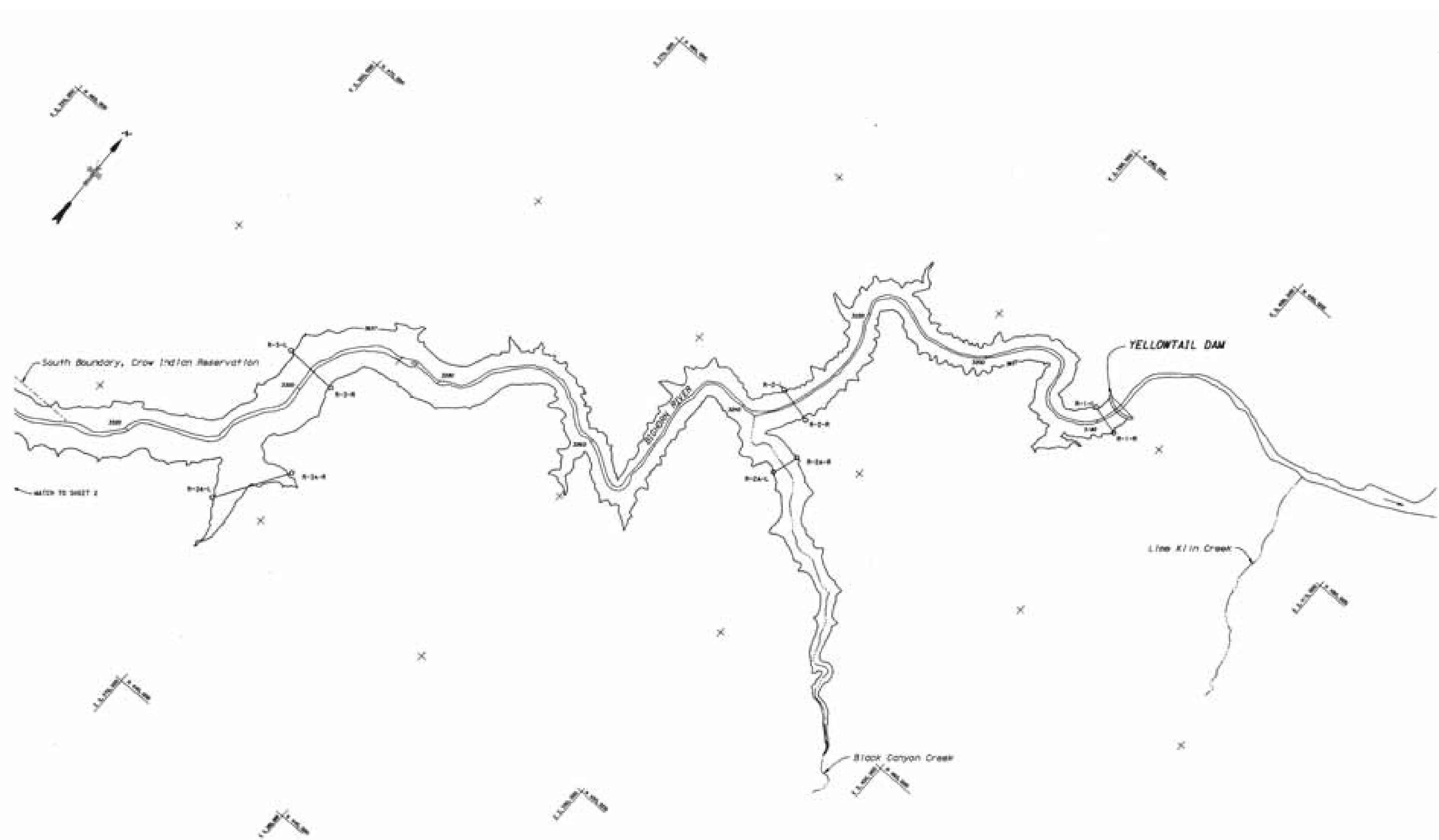


Figure 6 - Bighorn Lake Sediment Range Lines, Page 1 of 4.

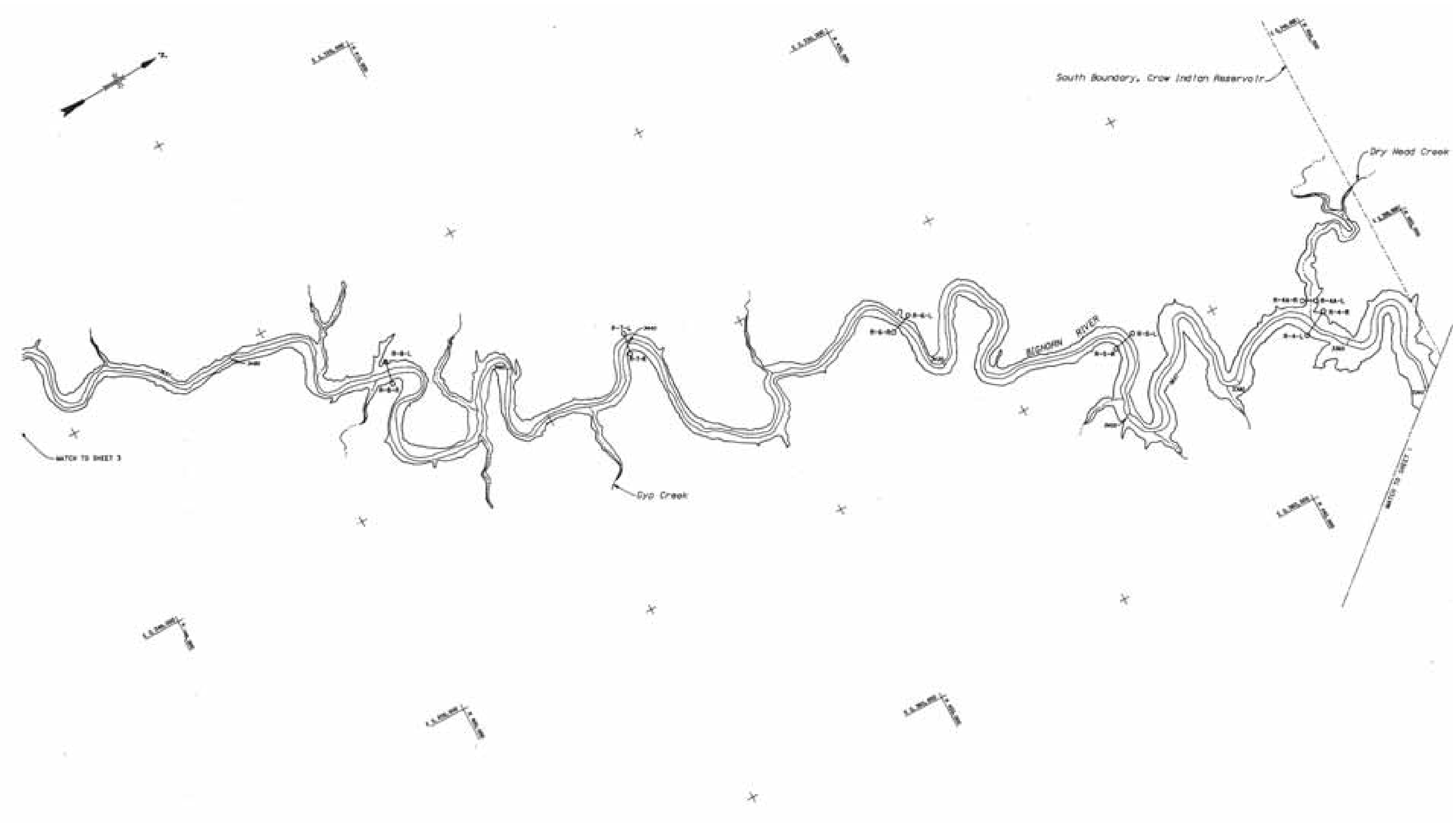


Figure 7 - Bighorn Lake Sediment Range Lines, Page 2 of 4.

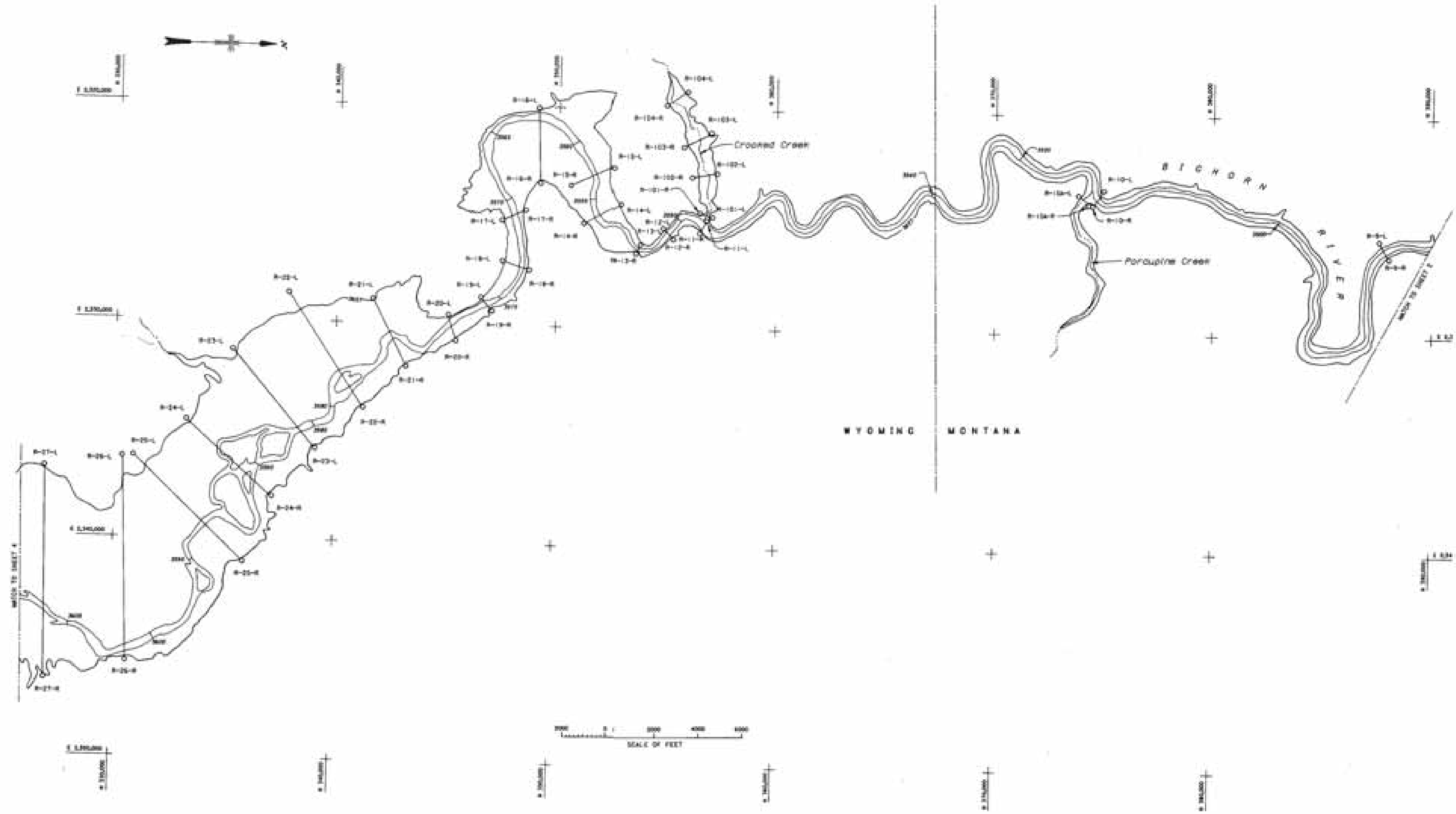


Figure 8 - Bighorn Lake Sediment Range Lines, Page 3 of 4.

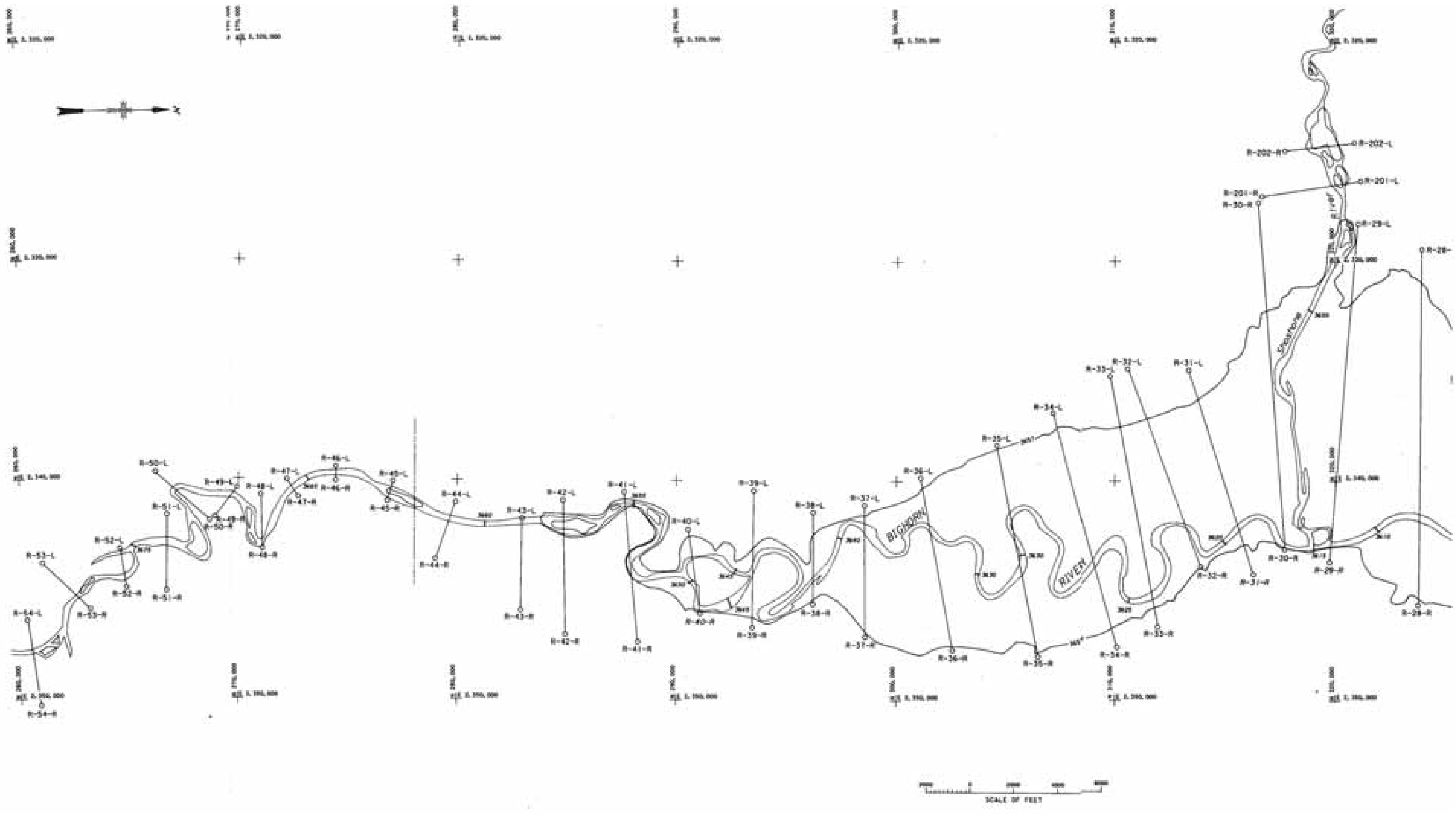


Figure 9 - Bighorn Lake Sediment Range Lines, Page 4 of 4.

Development of 1982 Contour Areas

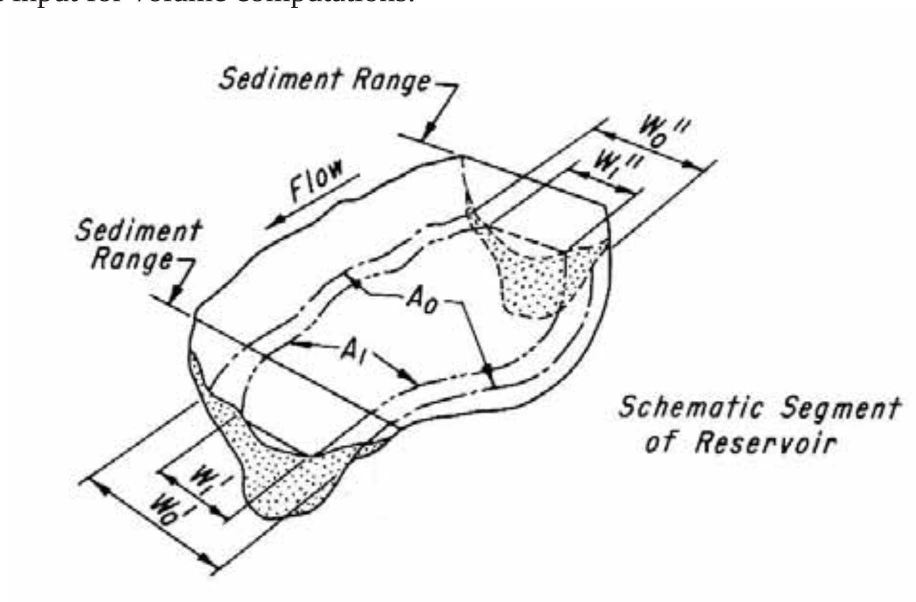
The original capacity, which was developed during the project planning stage by planimeter on the official reservoir topographic maps, did not include the river channel that existed below the contour elevation shown on the topographic sheets. An analysis of the original sediment range line profiles estimated the omitted river channel capacity as approximately 8,100 acre-feet in the downstream canyon area. For the purpose of determining the volume of sediment storage in the reservoir and the basin yield characteristics, this omitted storage was considered during the 1982 analyses. The original area and capacity listed in Table 2, columns 2 and 3, respectively, was adjusted to include the river channel area and volume at the listed elevations.

The 1982 contour surface areas for Bighorn Lake were developed by dividing the reservoir into two parts with range line 13 separating the downstream narrow Bighorn Canyon portion from the upstream wider valley topography. The original topographic map of the reservoir had 20-foot contour intervals downstream from range 13. The 1982 developed surface area data for this downstream reach were also at 20-foot contour intervals. In the upstream area, all original 5-foot contours were digitized and the surface areas computed for each contour for each segment of the reservoir.

The reservoir was divided into segments using the range lines as the upstream and downstream boundaries. For the lower reach downstream of range line 13, the 20-foot 1982 contour areas were obtained by subtracting the areas of the upstream portion of the original contour area lost due to sediment deposition. These sediment surface areas were developed by plotting the 1982 average bottom profile versus the original average bed elevation profile and transferring the location of 1982 contour crossings to the original topography. The contour area upstream, where the 1982 contours crossed, represented the surface area lost due to sediment deposition.

For the reservoir area upstream of range line 13, the 1982 contour surface areas were computed by means of a computer program that used the original and revised sediment range line data to develop adjustment factors, which were then used to revise the original segmented surface areas. The method, called width-adjustment, is described in chapter 9 of the USBR's Erosion and Sedimentation Manual (Ferrari and Collins, 2006).

For the width adjustment method, illustrated in Figure 10, 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.



	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*

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

Figure 10 - Width Adjustment Method for Revising Contour Areas.

The final 1982 surface area versus elevation tables were developed by summing the upstream segmental 5-foot contour areas, computed by width adjustment method, and adding the contour areas derived for the reach downstream of range line 13. When required, 5-foot contour areas for the downstream reach were determined by straight-line interpolation between the measured 20-foot contours. The resulting data had surface areas at 20-foot intervals below elevation 3,540.0 and surface areas at 5-foot intervals from elevation 3,540.0 to the maximum reservoir elevation of 3,660.0.

2007 Resurvey

The 1982 study resurveyed the original sediment range lines while the 2007 study resurveyed the sediment range lines along with the segmented areas between these range lines that were accessible by the vessel. The 2007 survey and analysis was a combination range line and contour method using single and multibeam depth sounders. The survey was the second sediment survey since dam closure and collected more detail than the 1982 resurvey, allowing new topographic map development.

The multibeam sounder was primarily used in the main channel areas from just upstream of range line 1 to range line 13, Figures 8 and 9. The multibeam collection concentrated on the deeper portions of the reservoir along the original river alignment and provided detailed data from toe to toe of each vertical bank. Due to security buoys, the boat was not able to proceed downstream to range line 1 or further to the face of the dam. Little change was measured at range line 2 since the 1982 survey, so for this study, it was assumed the missing data downstream did not affect the 2007 area and capacity development and resulting sediment computations. The single beam collection system was used to collect the 2007 underwater data along sediment range lines 2 through 31 and range lines 101 through 103. For mapping purposes, single beam data was also collected along the shoreline and parallel gridlines in the wide portion of the reservoir from range line 13 upstream to range line 28 before the water became too shallow and vegetated for larger boat access.

An arrangement was made to survey areas not accessible by the Reclamation survey boat using a smaller shallow draft boat, but due to vegetation the boat was only able to operate a short period of time. Even so, there was adequate data to project the sediment accumulations up to range line 31, located at the Lovell Causeway. Changes since the 1982 survey are show in the plotted results of the upper sediment range lines of 29 through 31, Figures 61 through 63. It was determined that a complete survey of these range lines, along with the ones located upstream of the causeway, was not necessary. Limited sediment was measured in 1982 and the projected changes since the 1982 survey would have a minimal affect on the overall sediment deposition change and resulting capacity computations. The changes in the upper reservoir were computed at 5-foot increments and the 2007 average deposition thickness at the upper range lines was less than that. The multibeam and single beam soundings, combined with available above water data provided detailed data sets to represent the majority of the reservoir where sediment has deposited. These data sets were used to generate reservoir topography from range line 28 downstream towards the dam.

The underwater collected data were 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 in 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 Bighorn Lake topographic development. These data were filtered further by removing points in the flat bottom portions of the reservoir that were not necessary to produce accurate detail 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).

2007 Analysis

The 2007 analysis was conducted similarly to the 1982 study. Initially the 2007 analysis developed detailed topography from the dam upstream to the causeway and computed area and capacity values, but comparison of the 2007 survey area computations with the original and 1982 values revealed some inconsistencies. Even though the 2007 developed contours crossed the reservoir downstream of the original and 1982 contours for the same elevation, indicating a storage loss due to sediment deposition, there were times the 2007 computed surface areas were greater than both the original and 1982 measured areas. Differences in detail and accuracy between the 2007 survey and the previous surveys are likely the primary reason for the variation in surface areas. The use of the multibeam system in 2007 allowed areas to be mapped that were not previously accounted for. However, the 2007 survey was a reconnaissance method survey with no detailed above water aerial collection and the only means to develop updated surface areas was by measuring change, due to sediment deposition, from the original developed topography and surface areas. The multibeam system did provide more detail than the previous collection methods, but there were areas not covered by this system, including the reservoir area from just upstream of range line 1 downstream towards the dam. Also, since the reconnaissance method mainly concentrated on the reservoir bottom between the toes of each vertical bank; there were sections in the lower deeper portion of the reservoir where the upper elevation contours were not measured. As a result, the 2007 contour development had to rely on other sources of previously collected digital data. These factors introduced uncertainty and affected the accuracy of the 2007 developed surface areas.

The upstream location of the 2007 developed contours is not in question. The 2007 method of analysis was similar to the 1982 analysis and provided the best means for developing the 2007 area and capacity tables by measuring change to the original capacity due to sediment inflow. A literature search of the 1982 survey study located the original 5-foot surface areas of the upper reservoir that were measured for each segment from range line 13 upstream. This allowed a modification of the 1982 analysis to be used for the 2007 analysis.

The 2007 contour surface areas for Bighorn Lake were developed by dividing the reservoir into two parts with range line 13 separating the downstream narrow Bighorn Canyon from the upstream wider valley topography. The original topographic map of the reservoir downstream of range 13 had 20-foot contour intervals and the 2007 developed surface area data for this downstream reach were developed at the same 20-foot contour intervals. Due to the size and detail of the 2007 multibeam data, the contour topography was developed by reservoir segments using the range lines as the upstream and downstream boundaries of each segment. The 20-foot 2007 contour areas were obtained by subtracting the areas of the upstream portion of the original contour area lost due to sediment deposition. These sediment surface areas were developed by overlaying the 2007 developed contours over the original contours. The contour area upstream of where the 2007 contours crossed the reservoir to where the original contour of the same elevation crossed the reservoir represented the surface area lost due to sediment deposition, Figure 11. The computed areas of these polygons were removed from the original 20-foot surface areas to compute the 2007 surface areas.

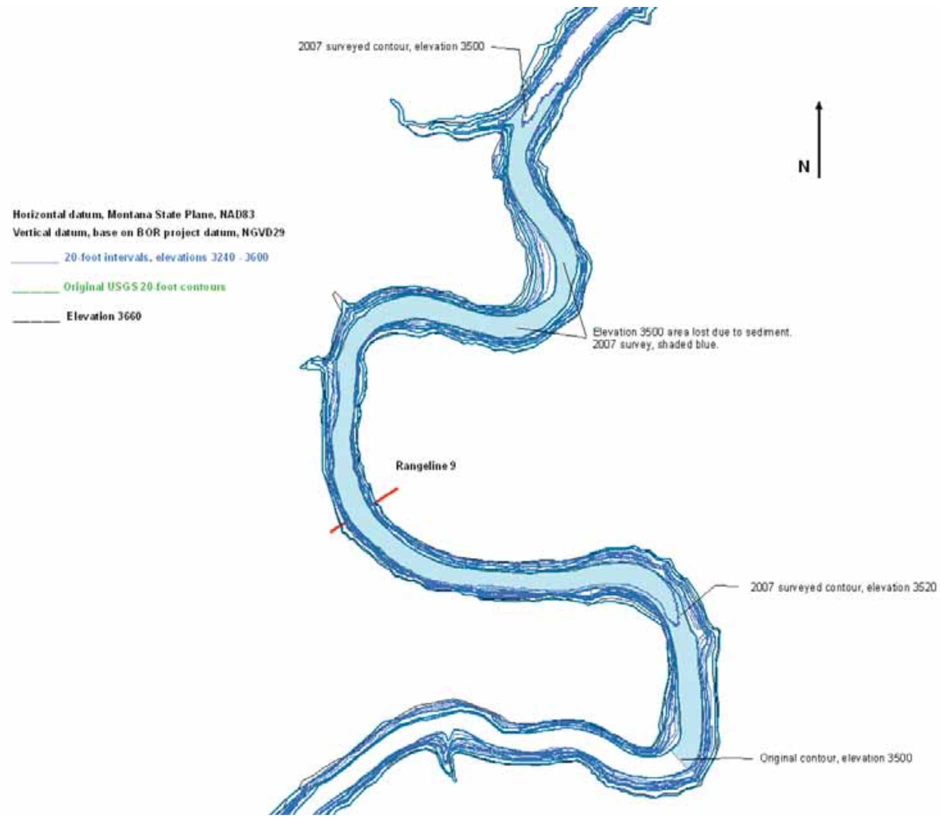


Figure 11 - Bighorn Lake Areas Lost Due to Sediment Deposition.

The original 5-foot segmented areas of the reservoir area above range line 13 were computed for the 1982 study. The 1982 adjustments due to sediment accumulation within these 5-foot surface areas for each segment were calculated using the width adjustment method as previously described. The 2007 study used a similar approach in that the upstream reservoir was divided into segments, but the added detail of the 2007 data allowed contour development and surface area computations for each segment mapped. For each segment the upstream and downstream range line plots for the 2007 and original surveys were compared. As with the width adjustment method, where the 2007 range lines indicated no change since the original survey from a selected elevation and above, no change from the original surface areas was computed. For the 5-foot contour increments below the elevation of no change, the computed surface areas from the 2007 developed segment topography were used. Some 5-foot increments had values of zero since the areas were totally lost due to sediment deposition. The final 2007 surface areas are a summary of each segment from range line 13 upstream added to the computed surface areas from range line 13 downstream.

For the reservoir areas not surveyed in 2007 (Lovell Causeway upstream) the 1982 study results were used. The 1982 survey measured little change at these range lines since the original survey and based on examination of the 2007 downstream data and reservoir operations since 1982, it was assumed little change has occurred in this reservoir area since the 1982 survey.

2007 Topography Development

The topography of Bighorn Lake was developed from the combined 2007 bathymetric survey data, digitized reservoir water surface from several sets of USDA aerial photographs, digital USGS original contours, and the digitized elevation 3,660 contour from USGS quad maps. The elevation 3,660 digitized contour was used as the reservoir boundary during the 2007 field collection and as the upper elevation polygon during topography development.

Contours for the reservoir from elevation 3,660.0 and below were developed from TINs (triangular irregular networks) generated within ARCGIS (ESRI, 2010). 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 and all the collected data points are preserved.

The linear interpolation option of the ARCGIS TIN and CONTOUR commands was used to interpolate contours from the Bighorn Lake TINs. The areas of the enclosed contour polygons at 5- and 20-foot increments were computed from the survey data for elevations 3,220.0 through 3,660.0. Due to the narrow steep canyon area downstream of range line 13, the contours are at 20-foot increments matching the original contour increments in that same area. There was adequate 2007 bottom data to develop 5-foot contours, but for presentation purposes, only the 20-foot contours were drawn. The reservoir contour topography at 5- and 20-foot intervals are presented on Figures 12 through 25. The contours were developed within ARCGIS directly from the TINs using all the enclosed data points resulting in somewhat jagged contours. For presentation purposes the contours were modified by removing some shorter line segments from the developed contours. Other mapping packages can be used to generate smoother contours, but for this study the TIN approach included all data points to produce the most accurate surface area and resulting volume from the 2007 collected data. The best means to develop the upper contours and resulting above water reservoir areas would be to conduct a detailed aerial survey when the reservoir is drawn down.

The 2007 surface areas for Bighorn Lake were computed at 5- and 20-foot increments directly from the reservoir TINs from elevation 3,220 through 3,660. Surface area calculations were performed using ARCGIS commands that compute areas at user-specified elevations directly from the TIN. For the purpose of this study, the measured survey areas at 5- and 20-foot increments were used in computing the surface areas for each reservoir segment as previously described. This study assumed no change in surface area, since the 1982 survey, at elevation 3,645 and above.

Table 1 provides a summary of the 2007 survey conducted on Bighorn Lake. The area and capacity curves for the original, 1982 and 2007 surveys are plotted on Figure 69.

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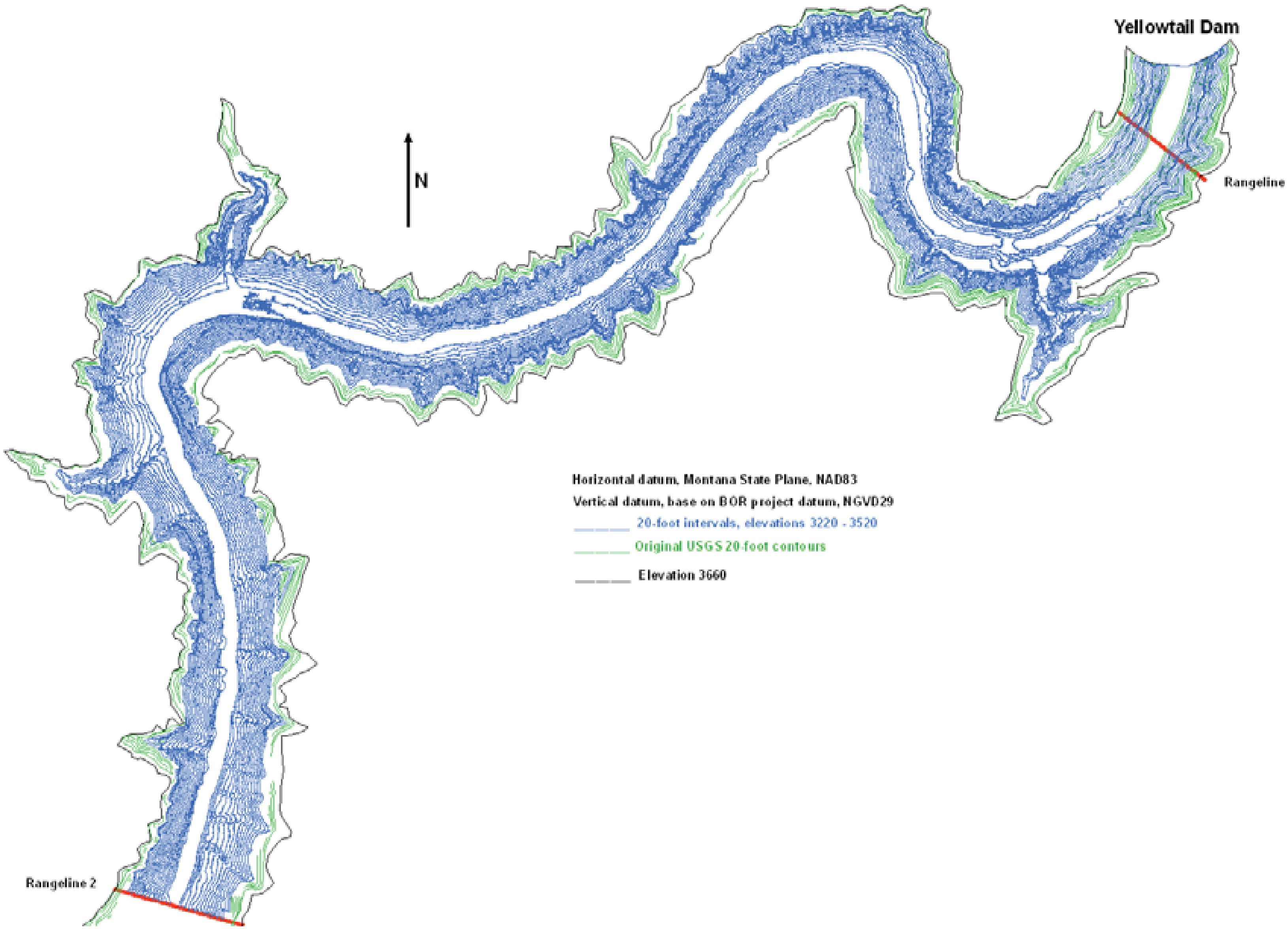


Figure 12 - Bighorn Lake Topographic Image, Page 1 of 14.

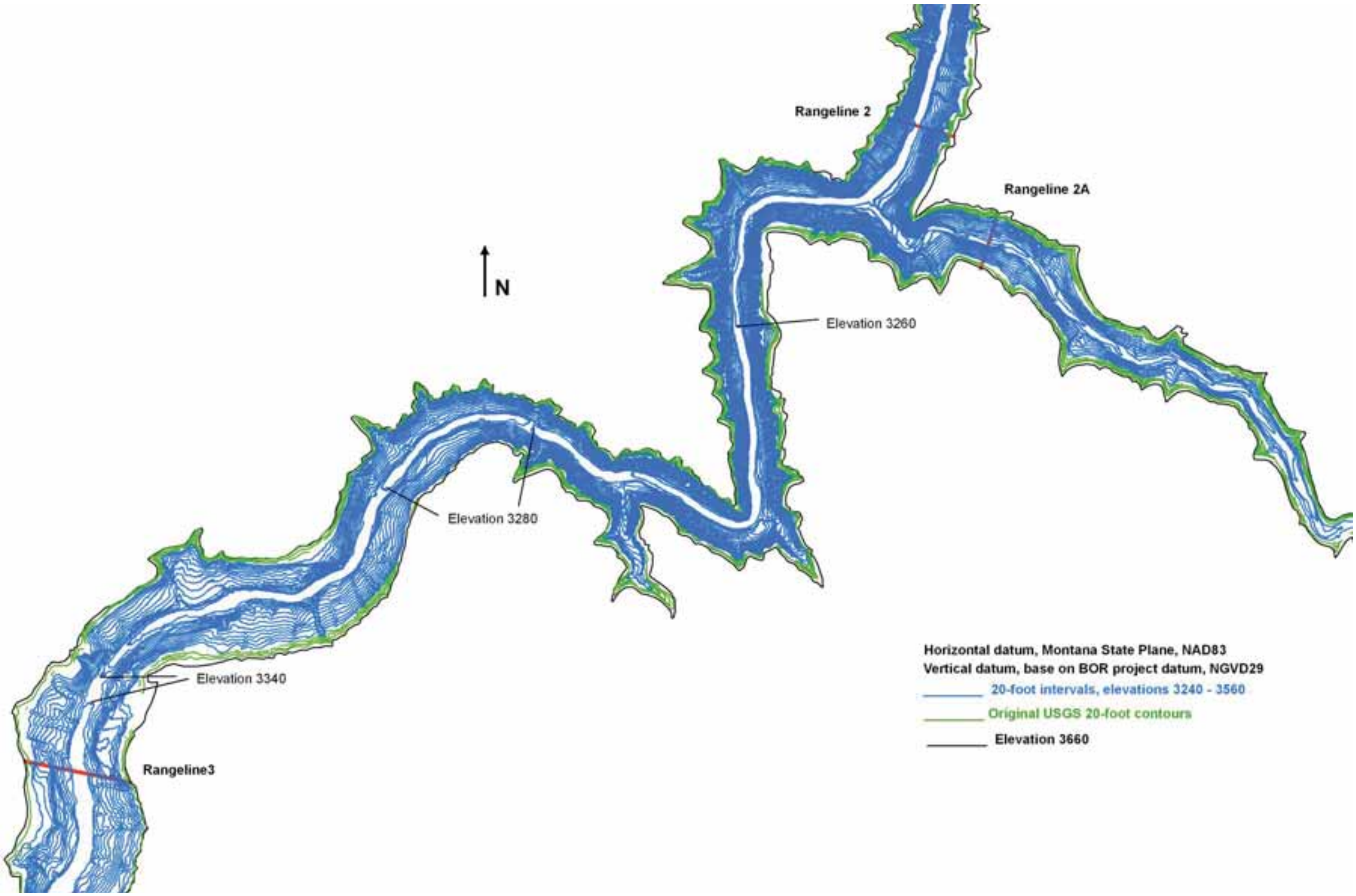


Figure 13 - Bighorn Lake Topographic Image, Page 2 of 14.

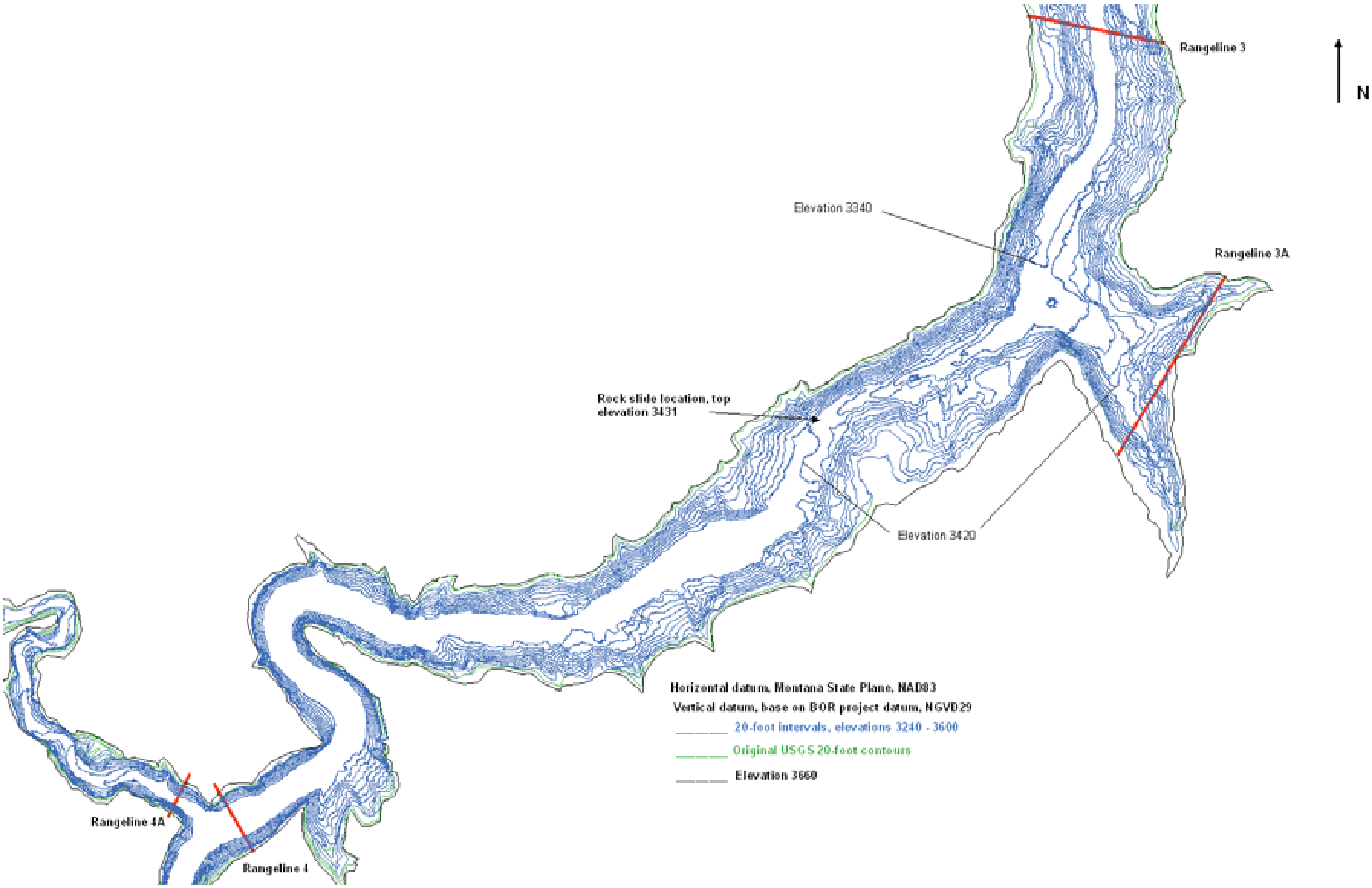


Figure 14 - Bighorn Lake Topographic Image, Page 3 of 14.

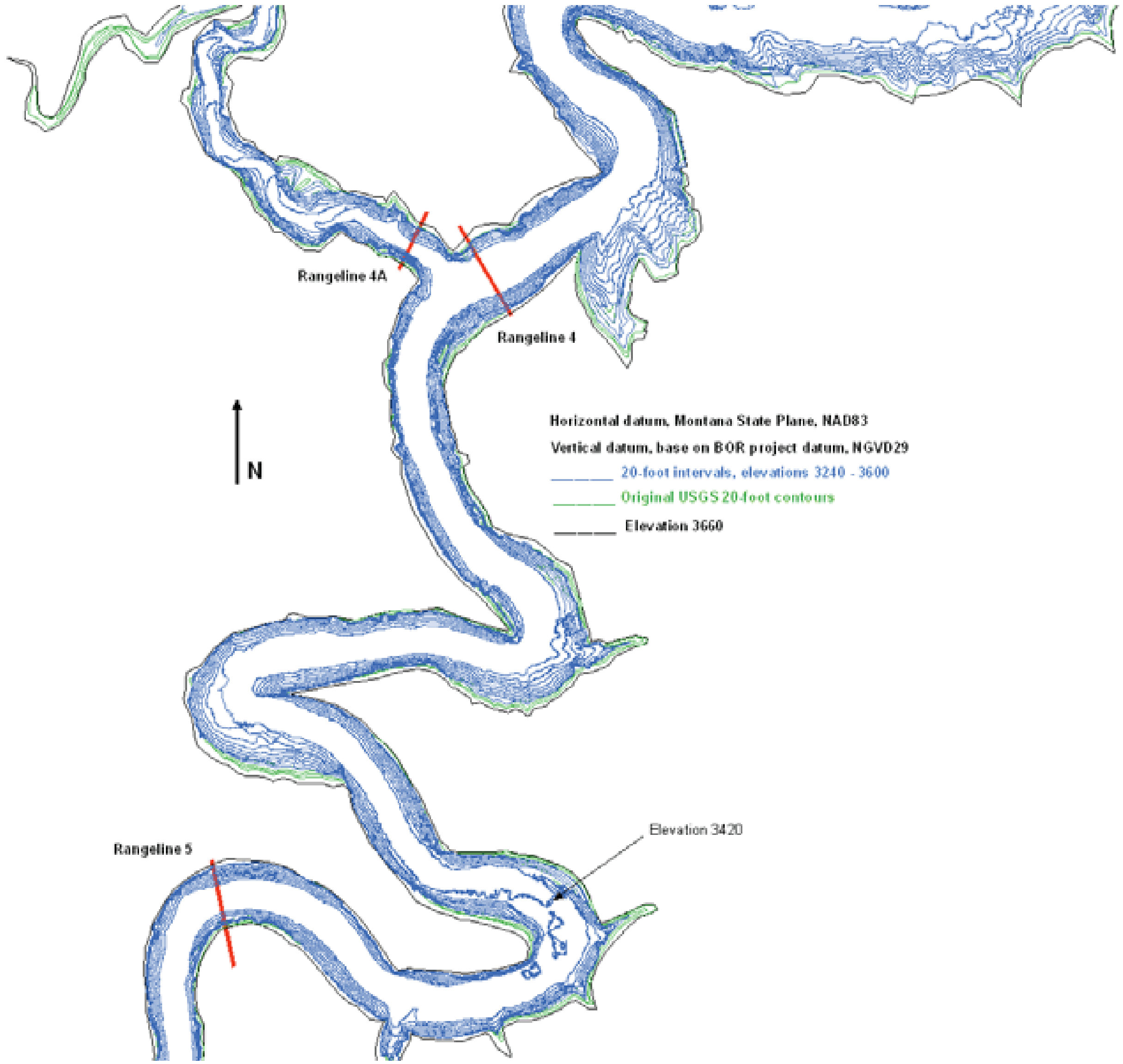


Figure 15 - Bighorn Lake Topographic Image, Page 4 of 14.

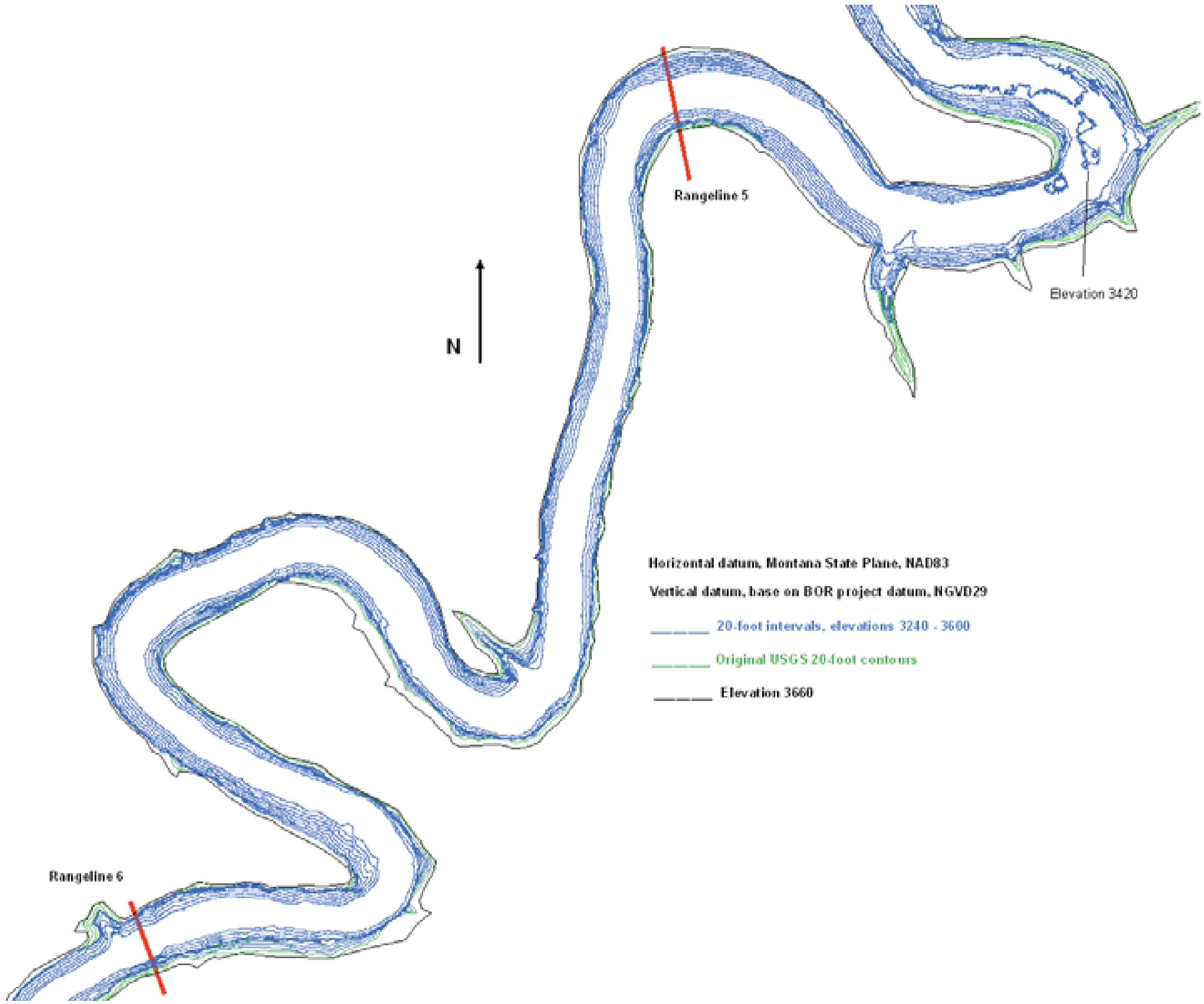


Figure 16 - Bighorn Lake Topographic Image, Page 5 of 14.

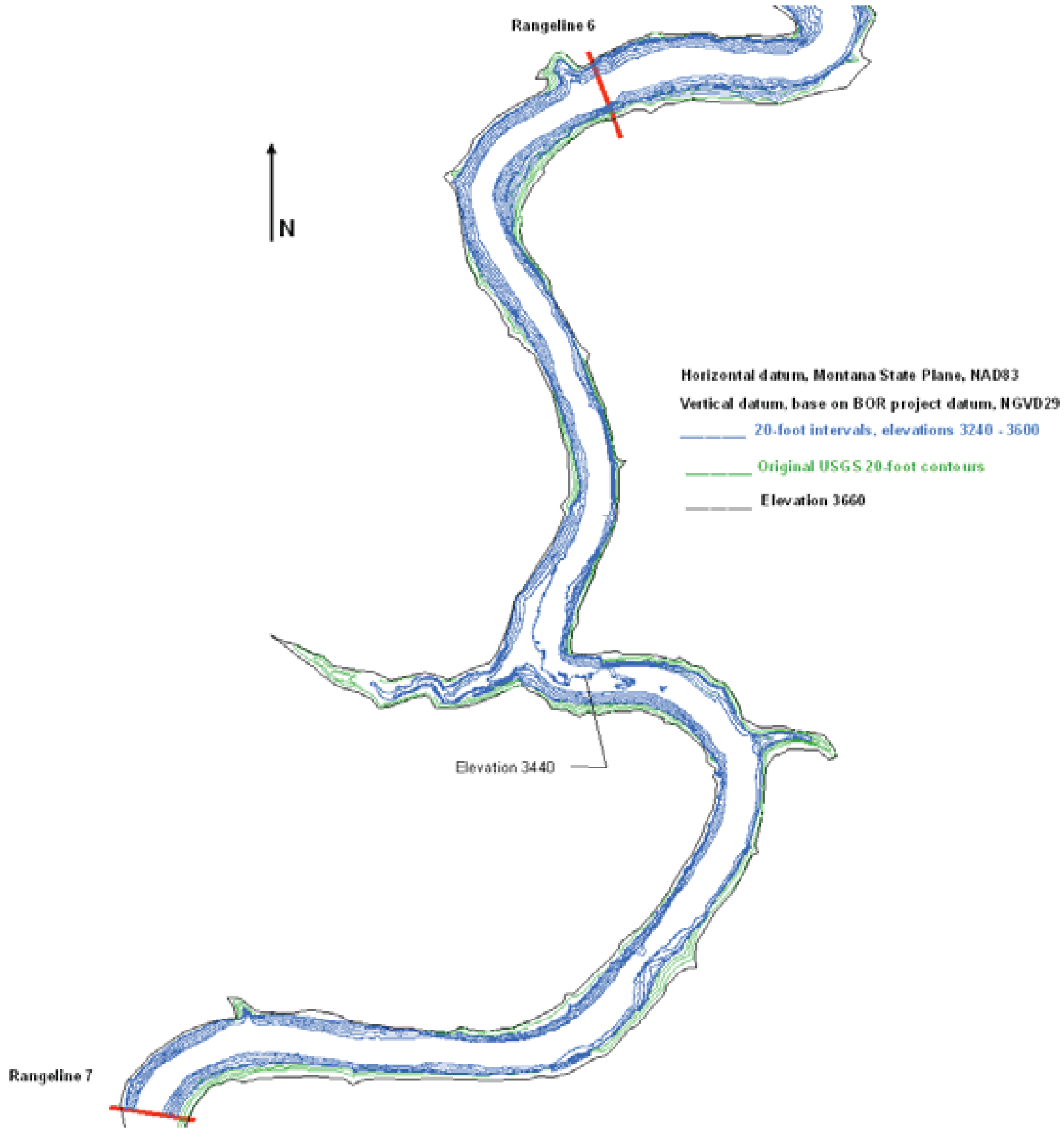


Figure 17 - Bighorn Lake Topographic Image, Page 6 of 14.

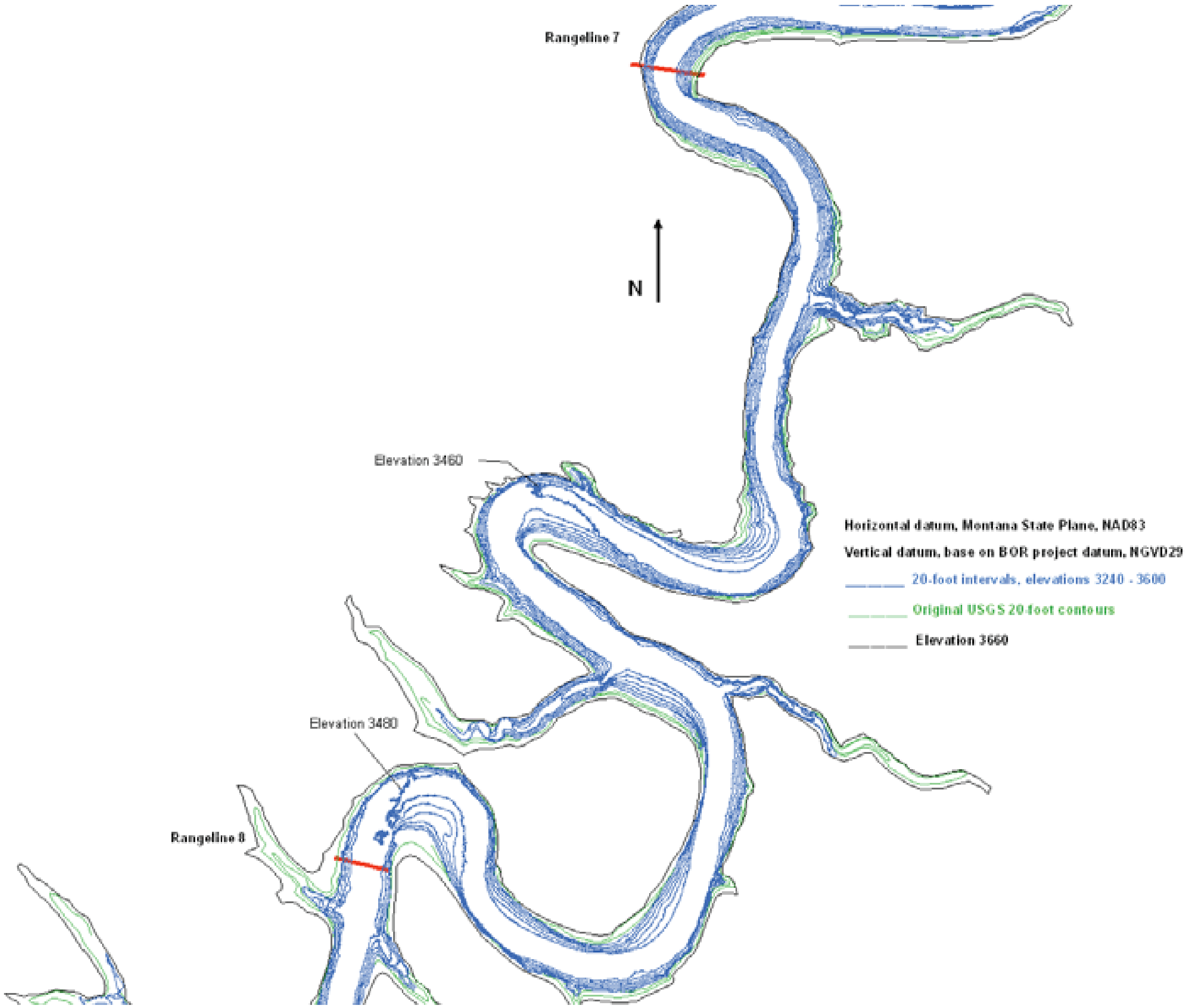


Figure 18 - Bighorn Lake Topographic Image, Page 7 of 14.

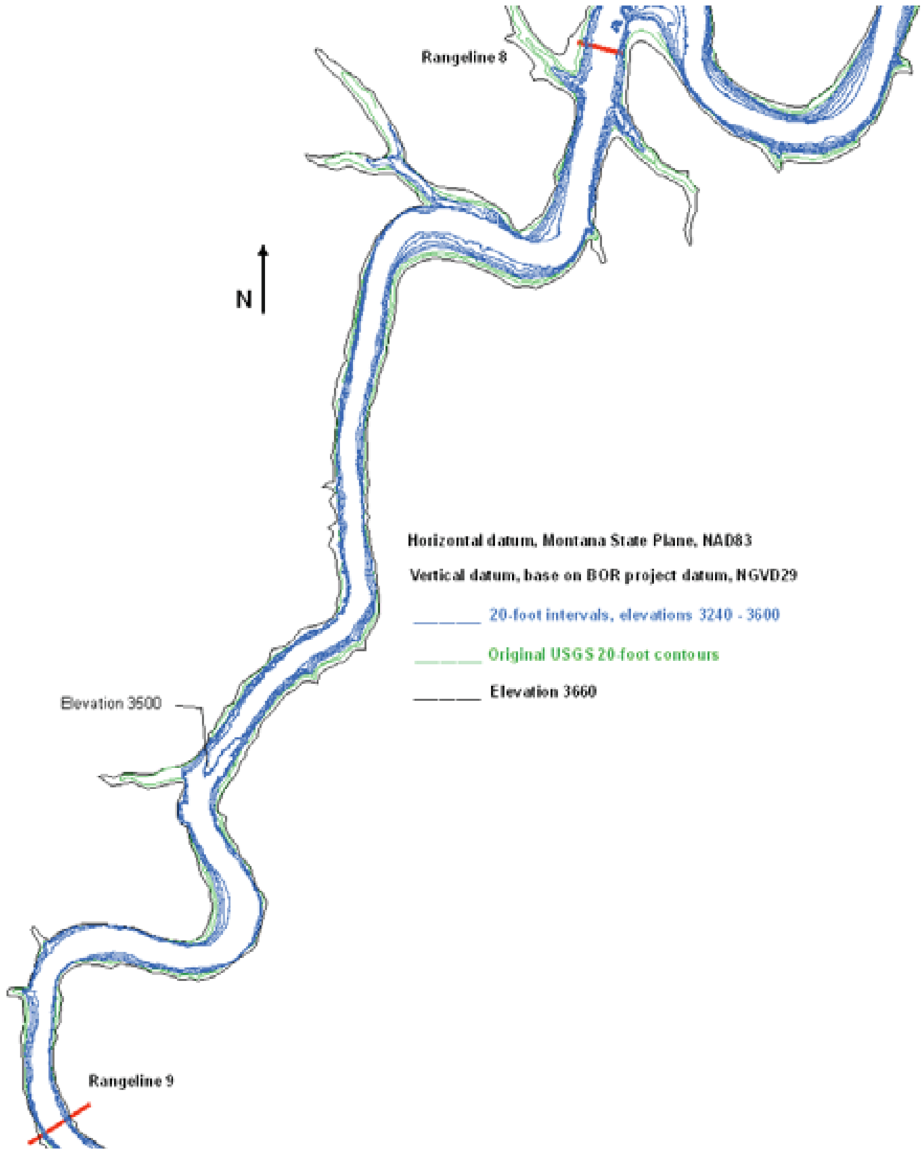


Figure 19 - Bighorn Lake Topographic Image, Page 8 of 14.

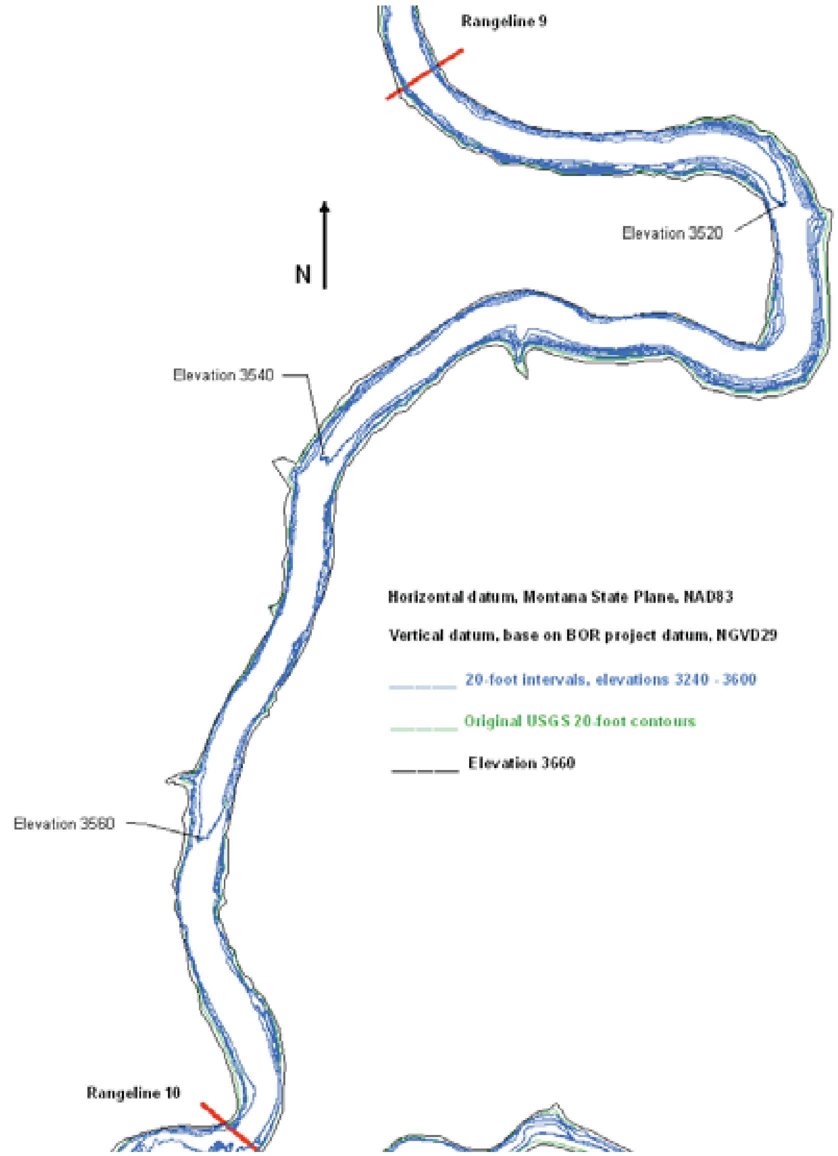


Figure 20 - Bighorn Lake Topographic Image, Page 9 of 14.

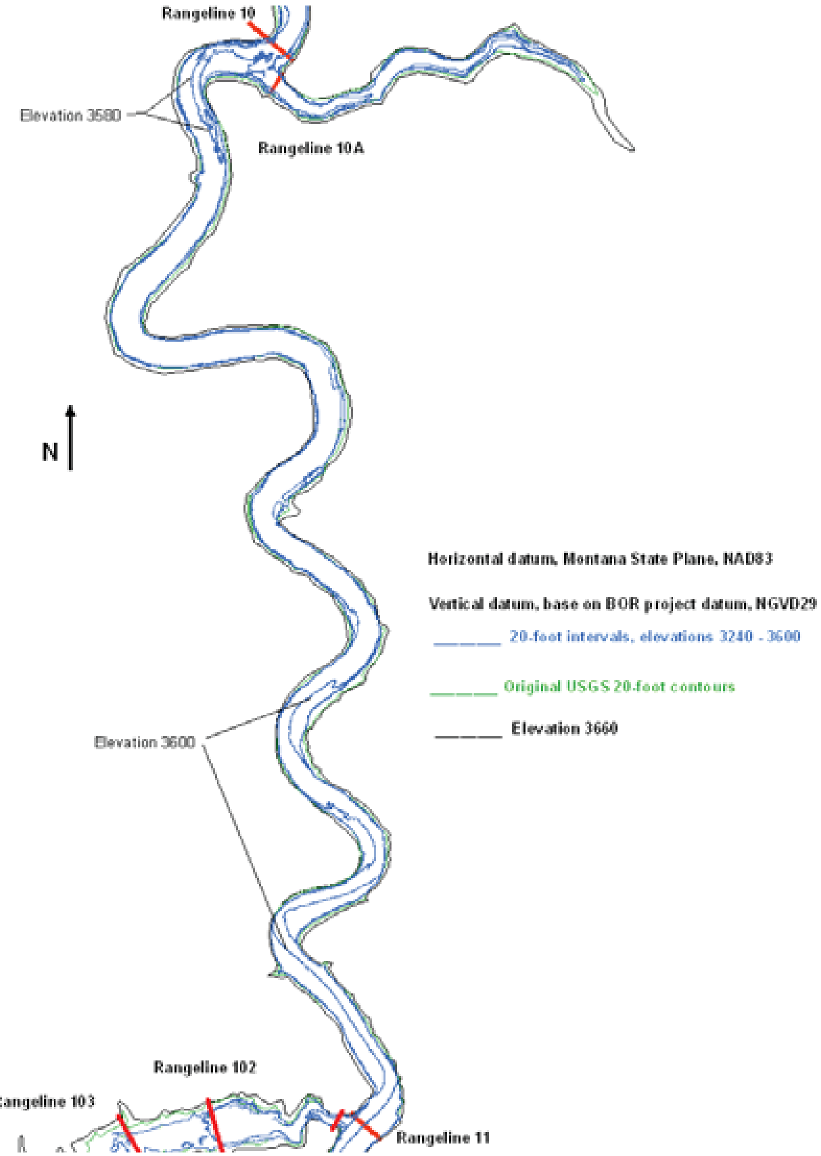


Figure 21 - Bighorn Lake Topographic Image, Page 10 of 14.

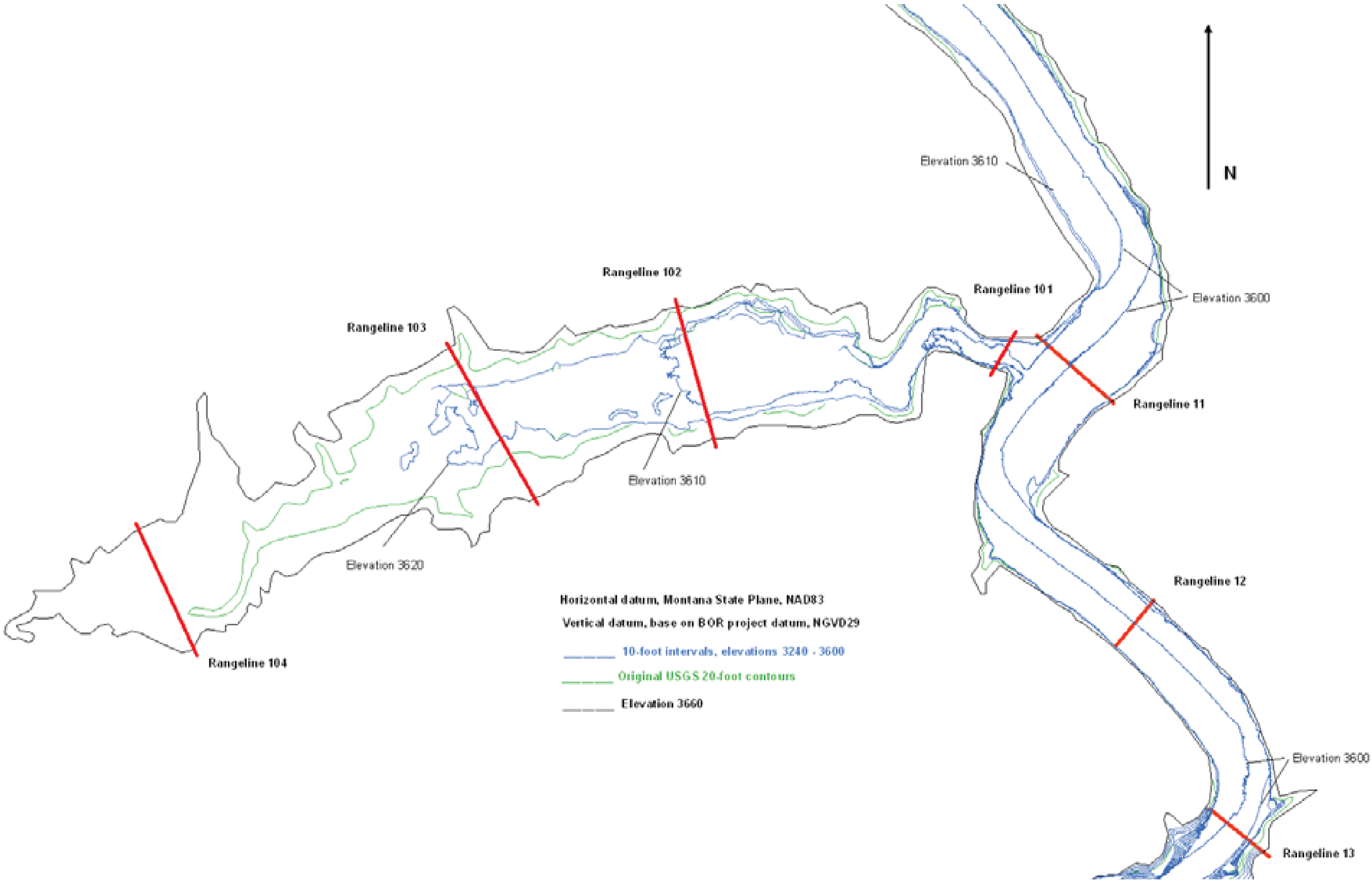


Figure 22 - Bighorn Lake Topographic Image, Page 11 of 14.

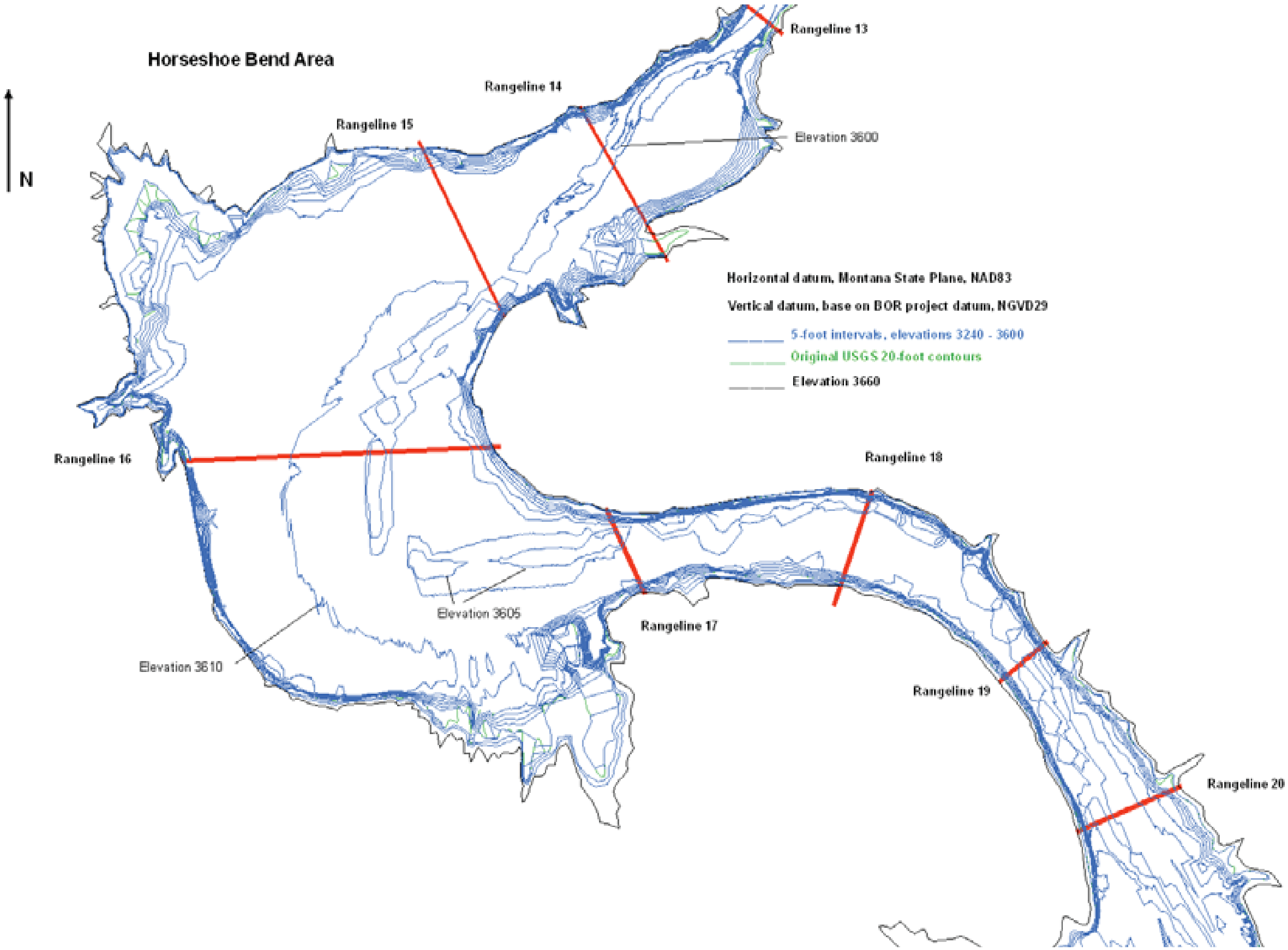


Figure 23 - Bighorn Lake Topographic Image, Page 12 of 14.

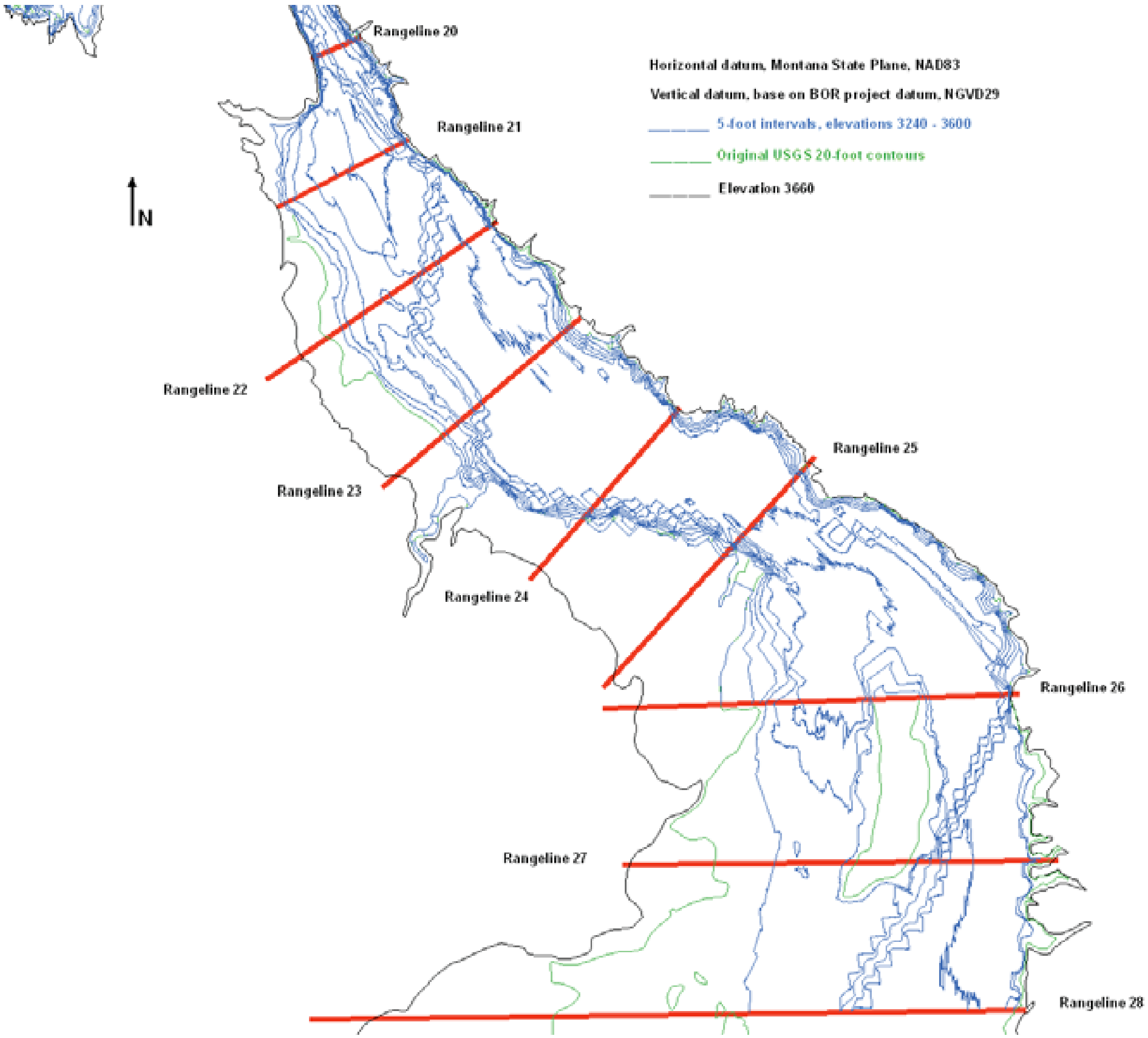


Figure 24 - Bighorn Lake Topographic Image, Page 13 of 14.

Figure 25 - Bighorn Lake Topographic Image, Page 14 of 14.

Lateral Distribution

Ground profiles of the reservoir sedimentation range lines are shown on Figures 29 through 66. These profiles illustrate the general lateral distribution of sediments in the reservoir for the range lines surveyed in 2007. The plots illustrate the survey results from the original, 1982, and 2007 surveys along with results for the range lines surveyed in 2000 by the Sedimentation Group. Range line 31 (located near the causeway) was the most upstream line surveyed in 2007. Range line 1 was not resurveyed in 2007 due to no access, but since no change in 2007 was measured at range line 2 since 1982 it is expected little change would be measured at range line 1. Also the limited 2007 data between range line 1 and range line 2 verified little change since 1982. The presented range lines were surveyed using the single beam depth sounder. Range lines 2 through 13 were surveyed by both the single beam and multibeam sounders. The single and multibeam soundings compared well up to around 200 foot depths. Since the single beam sounder was only calibrated up to 180 feet, range lines 2 through 7 were developed using the multibeam soundings.

The range line plot comparisons illustrate some interesting results when comparing the original, 1982, 2000 and 2007 surveys. The plots indicate minimal to no change at range line 2 and 2A since the 1982 survey. From the multibeam bottom images a high point or rock slide was located upstream of range line 3A and about 1.7 miles upstream of range line 3, Figures 26 through 28. The slide created a 20-foot high point, measured in 2007, that hindered the density currents from carrying the bottom depositing sediments downstream towards the dam. Changes measured at range line 3 indicate that some sediment has crept over the barrier and deposited downstream with the toe of the deposit about 3,500 feet downstream of range line 3.

Figure 26 - Bighorn Lake Landslide Area Upstream of Range Line 3A.

The plots from range line 8 through 28 show varied results with the 2007 sediment level plotting below the 2000 survey level from range line 11 upstream. This is likely due to compaction or consolidation of the previously deposited sediments caused by long exposure and drying out during the low reservoir content and drought period from 2001 through 2004. The average consolidation across the range lines was around 2 to 3 feet.

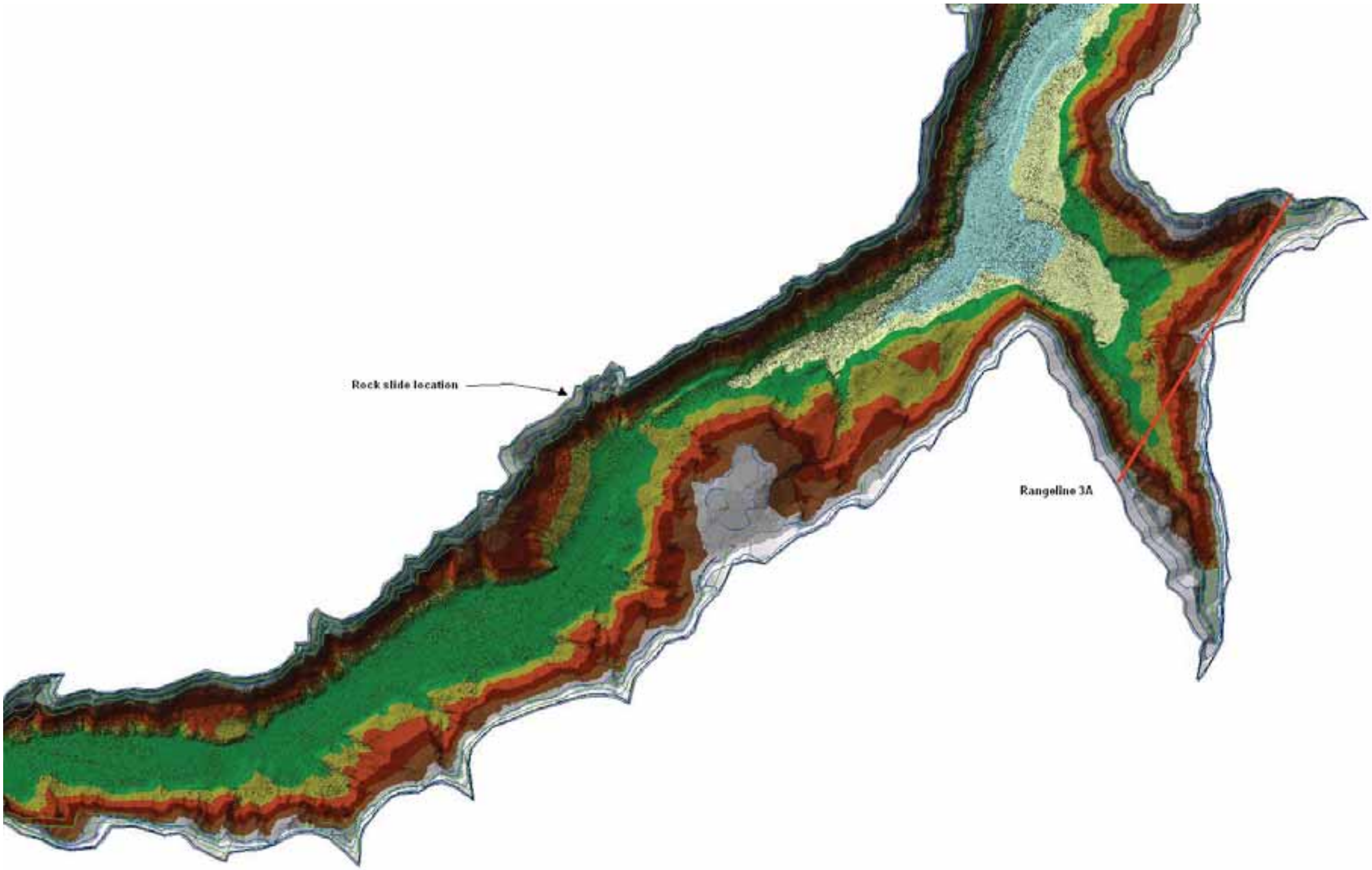


Figure 27 - Bighorn Lake Rock Slide Area, TIN Image.

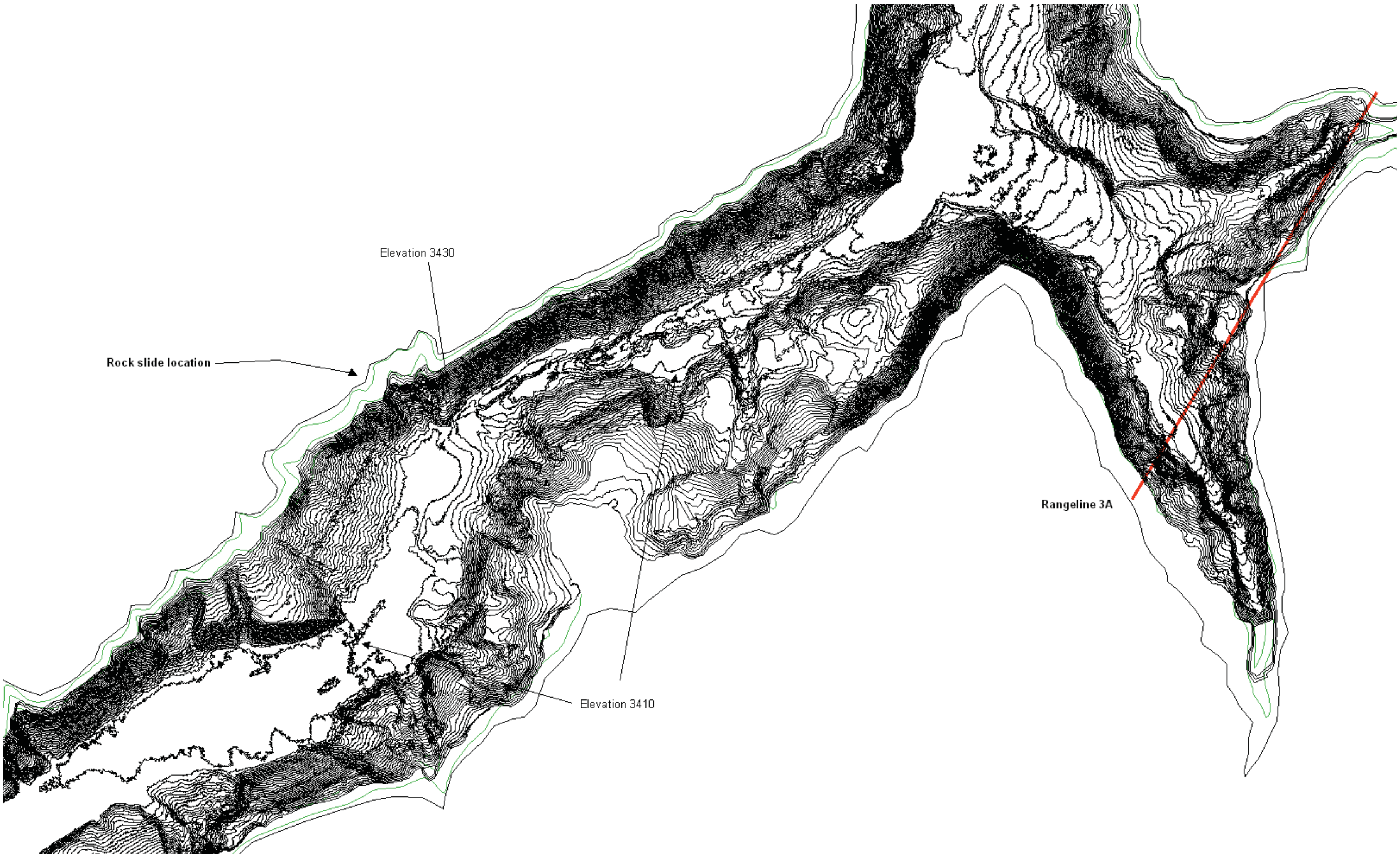


Figure 28 - Bighorn Lake Landslide Area, Contours.

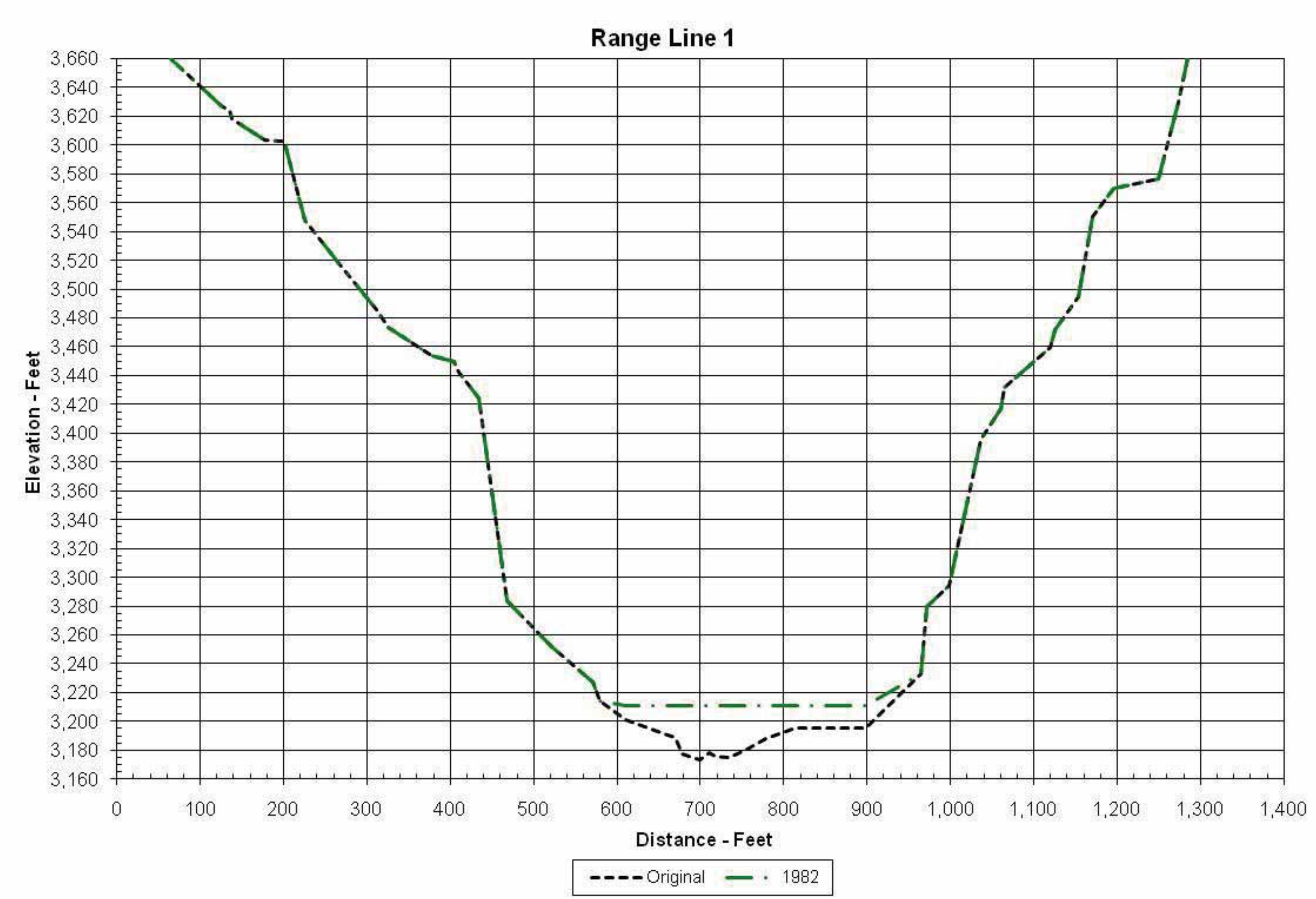


Figure 29 - Bighorn Lake, Range Line 1.

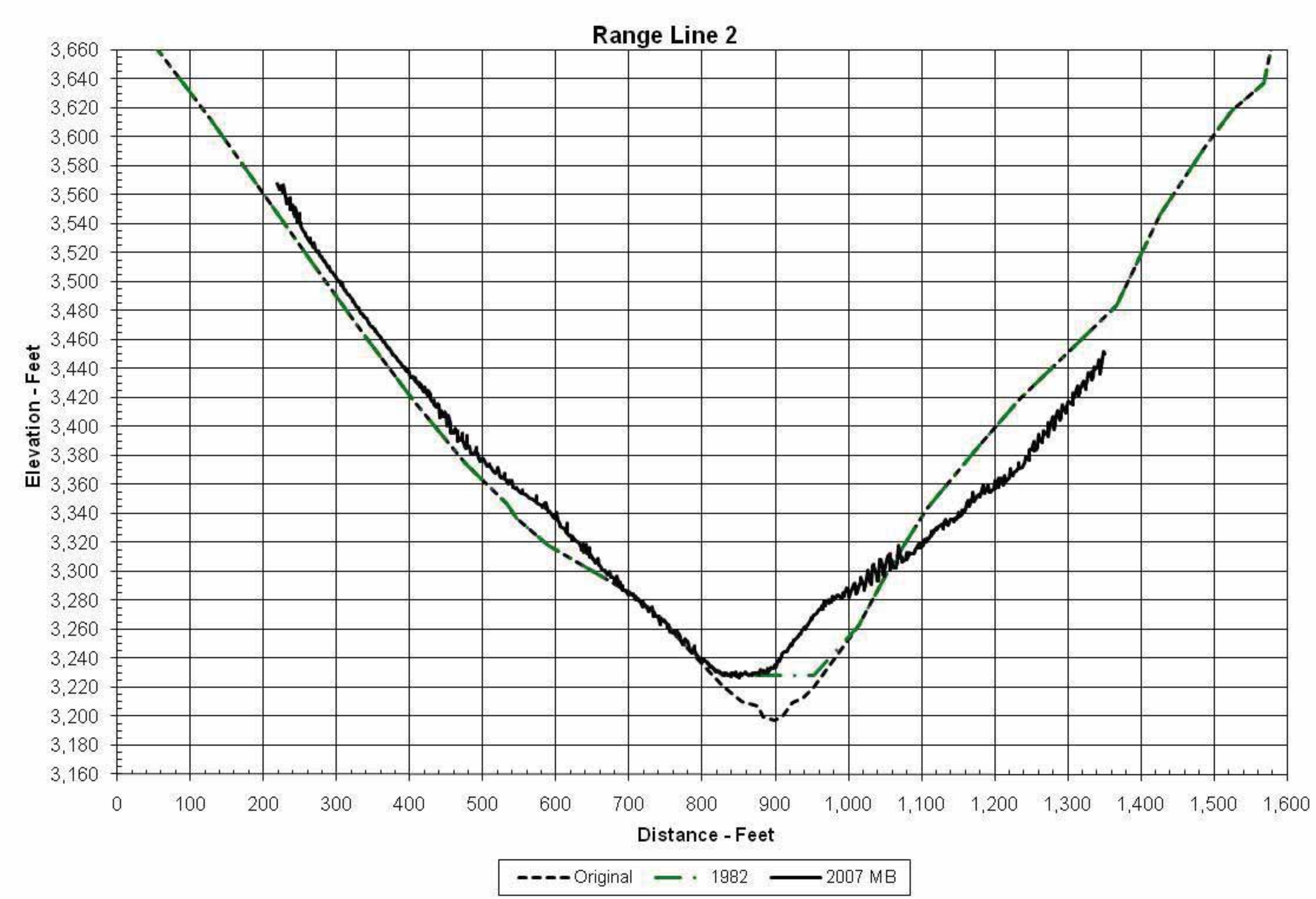


Figure 30 - Bighorn Lake, Range Line 2, Multibeam Data.

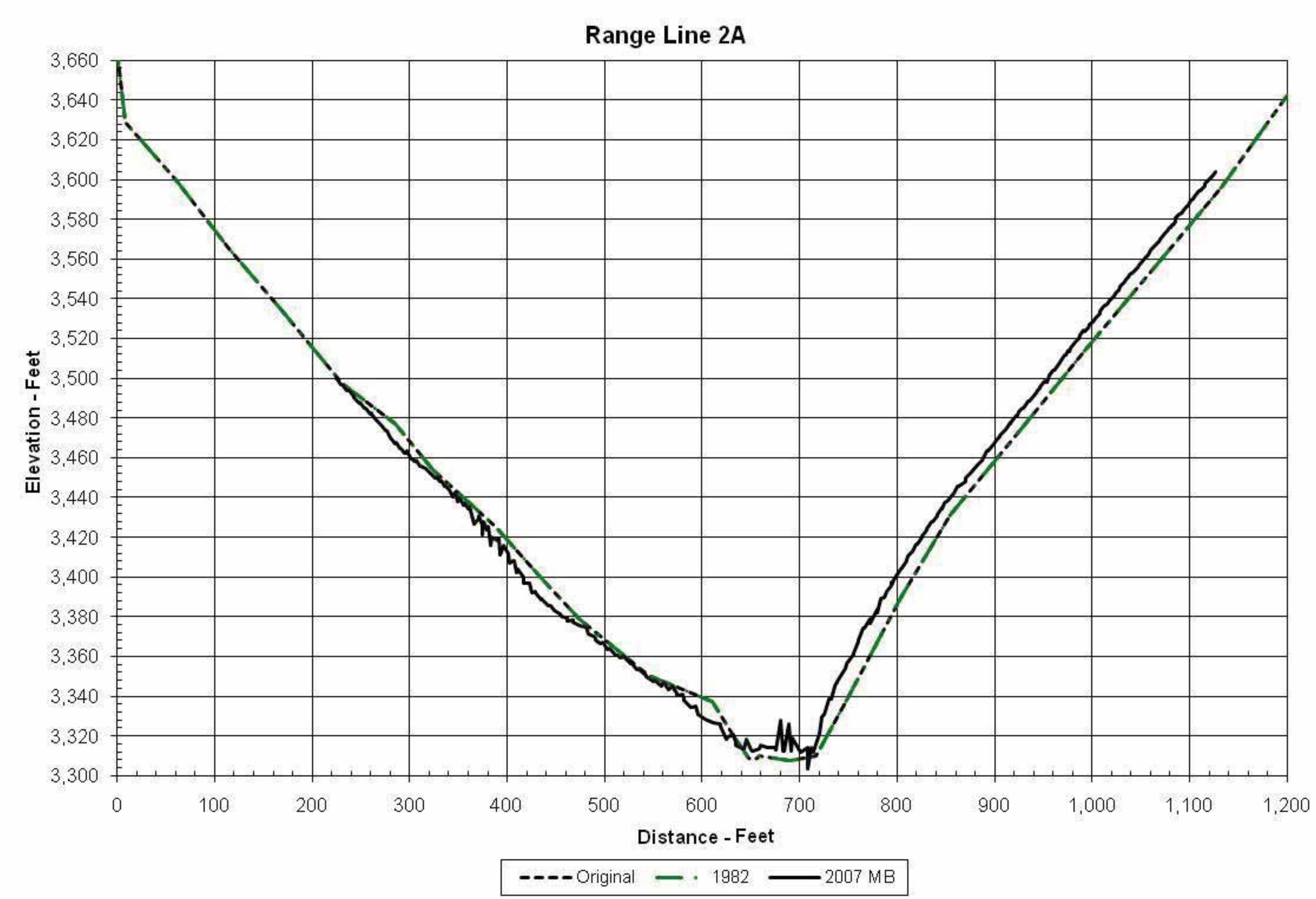


Figure 31 - Bighorn Lake, Range Line 2A, Multibeam Data.

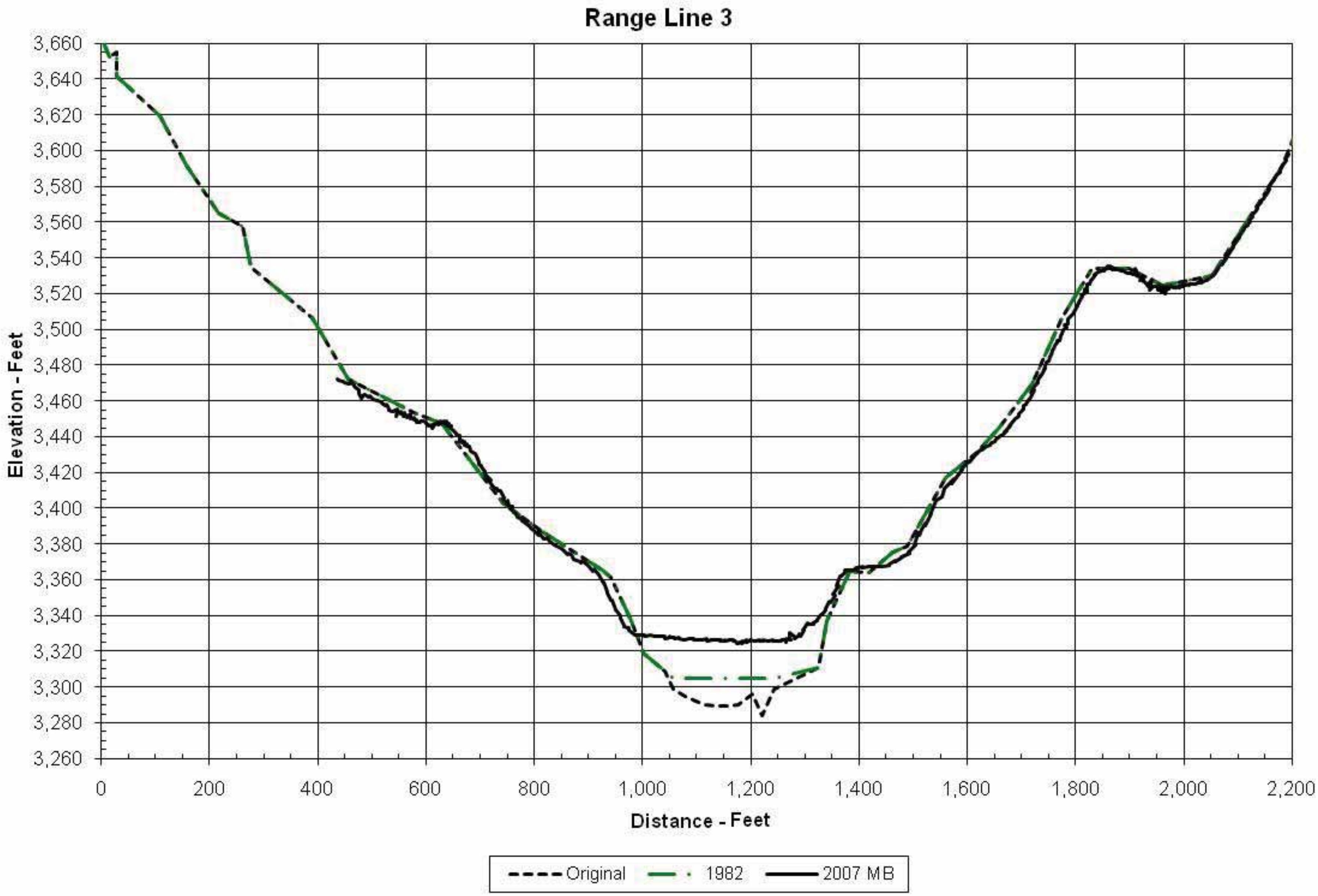


Figure 32 - Bighorn Lake, Range Line 3, Multibeam Data.

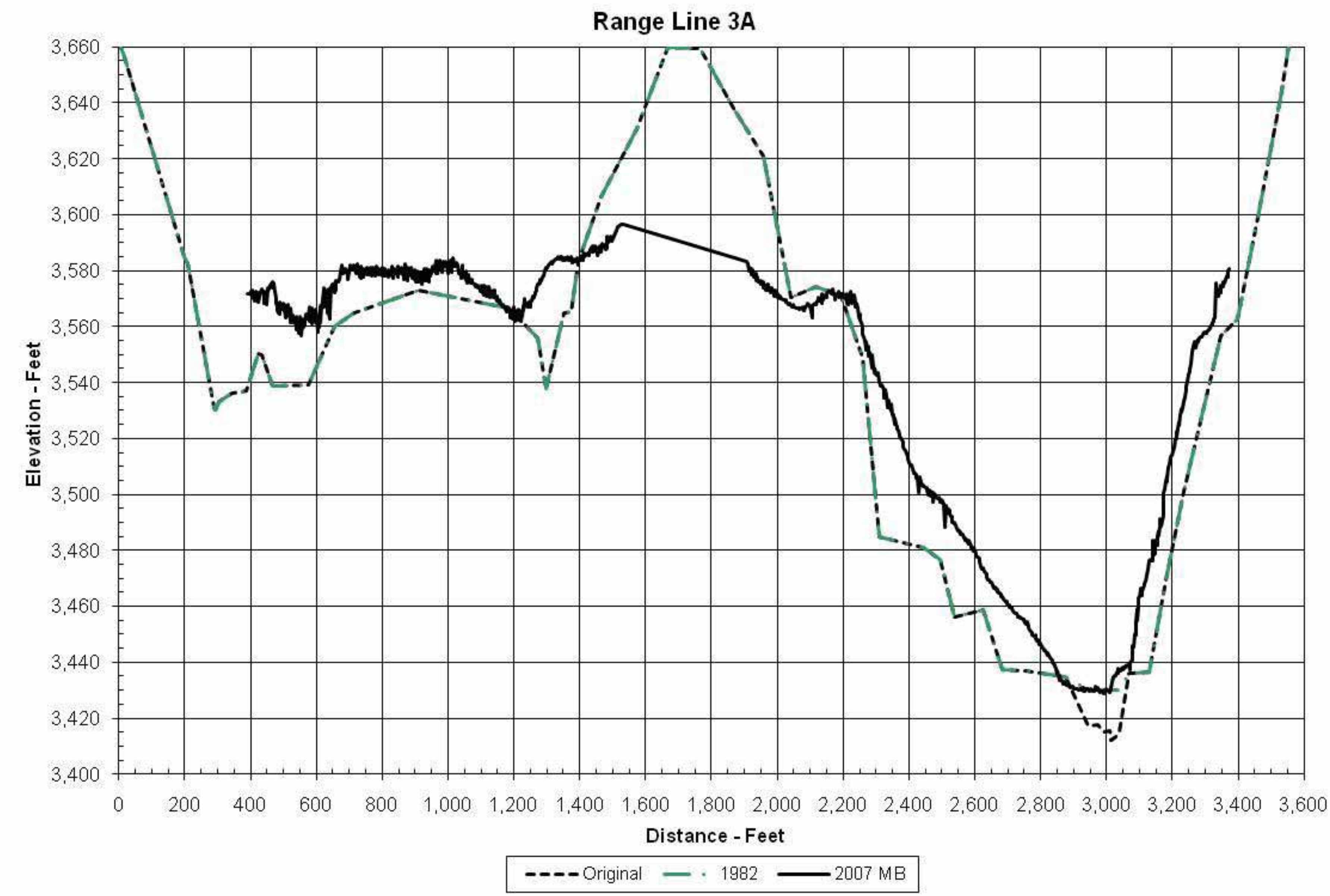


Figure 33 - Bighorn Lake, Range Line 3A, Multibeam Data.

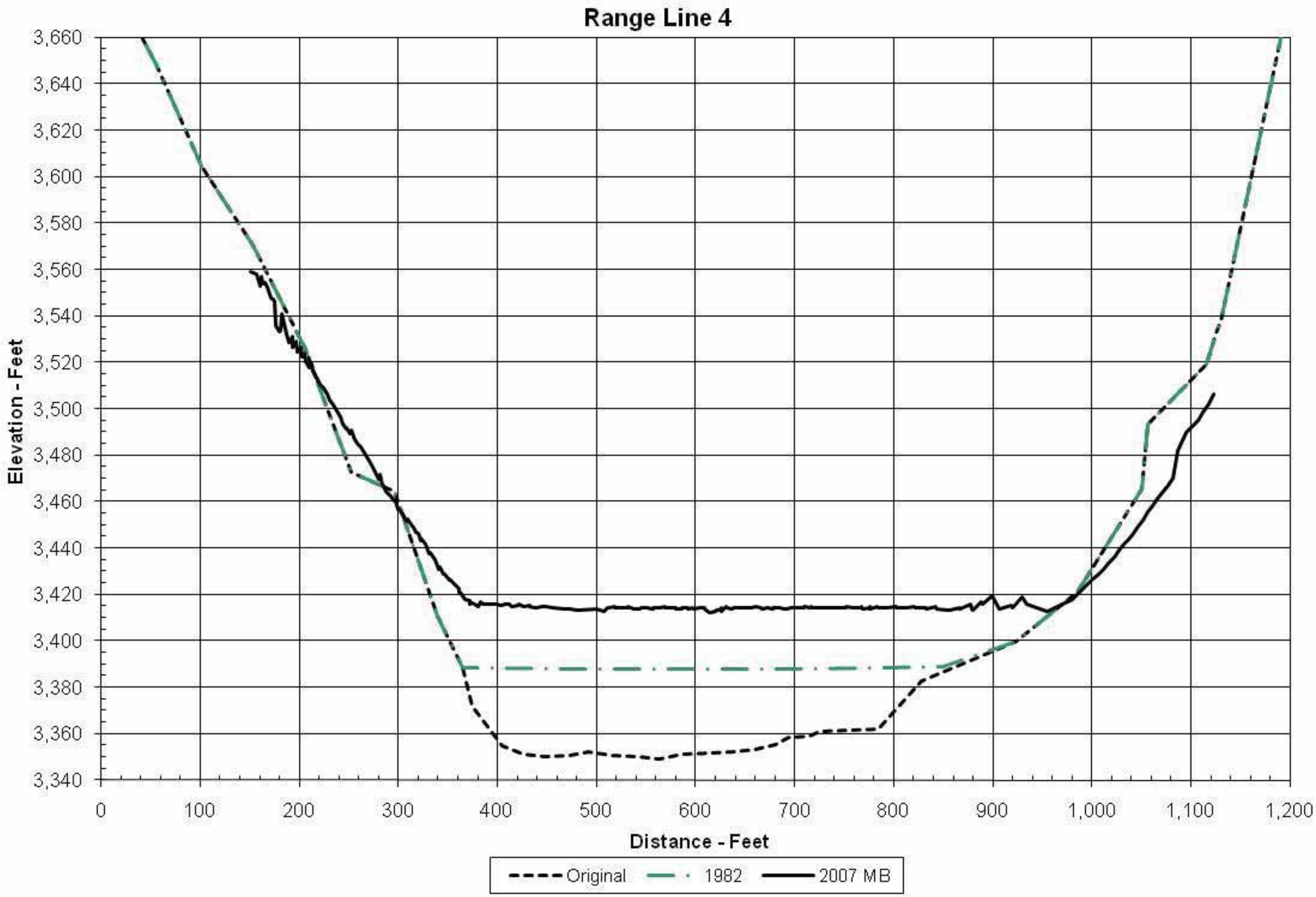


Figure 34 - Bighorn Lake, Range Line 4, Multibeam Data.

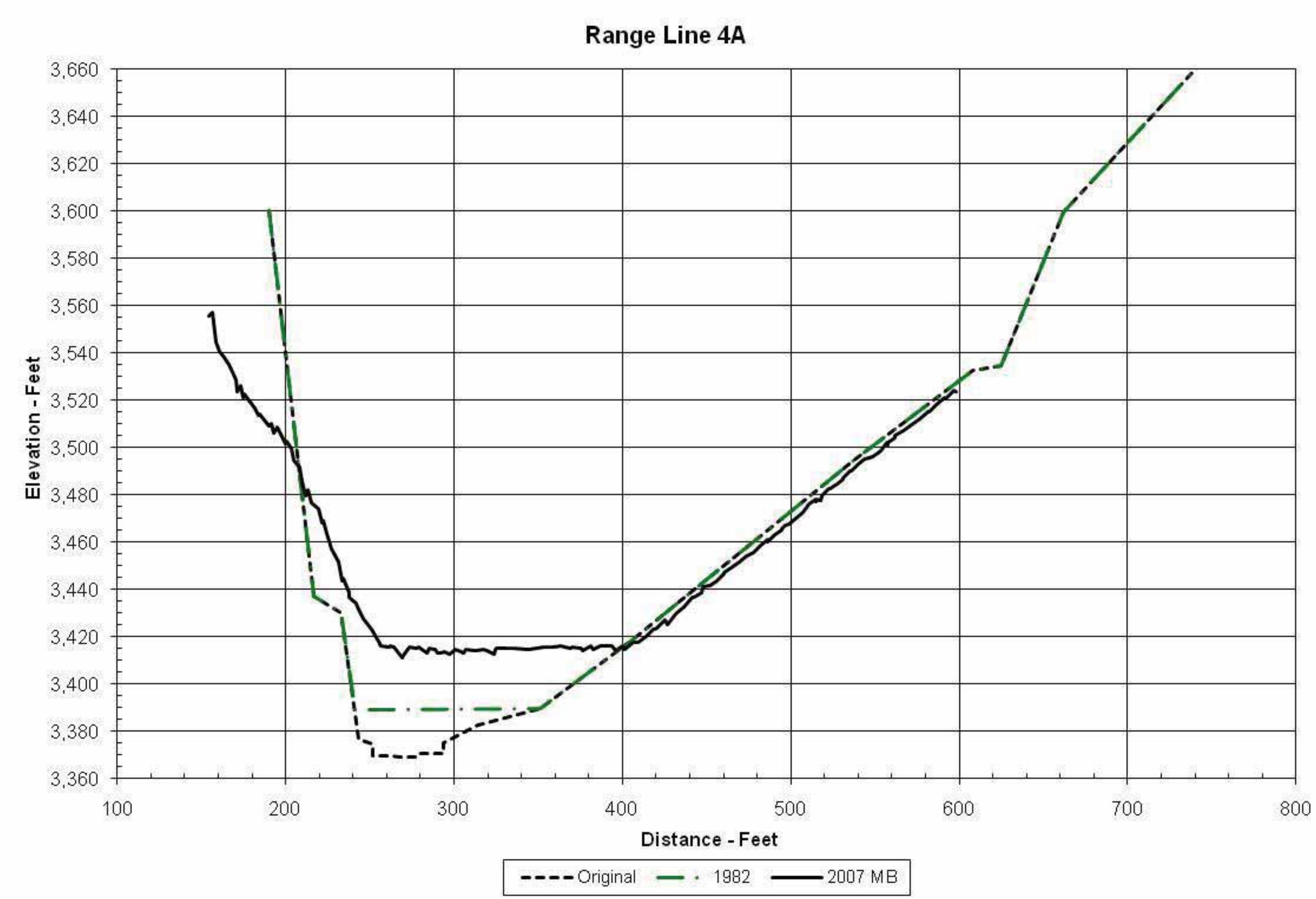


Figure 35 - Bighorn Lake, Range Line 4A, Multibeam Data.

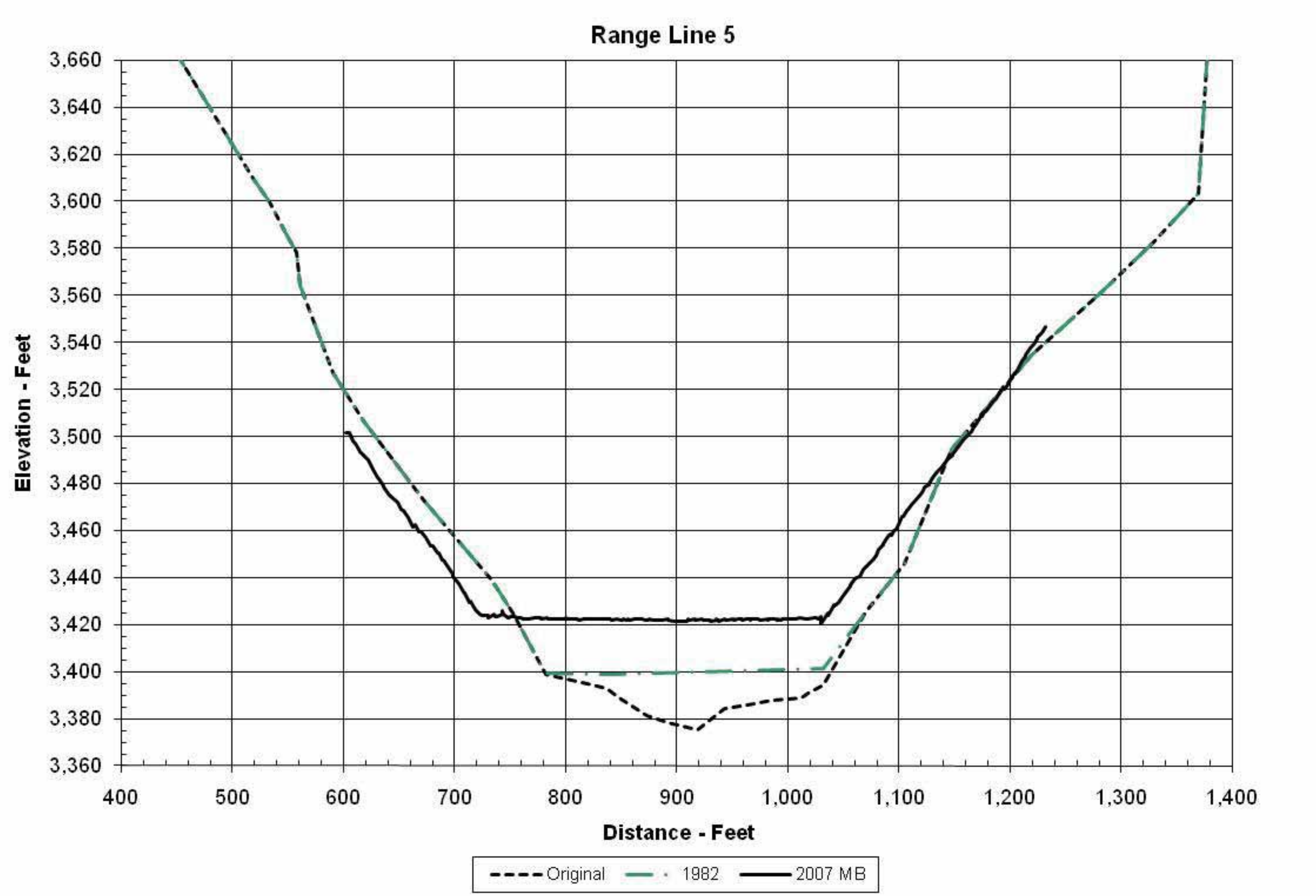


Figure 36 - Bighorn Lake, Range Line 5, Multibeam Data.

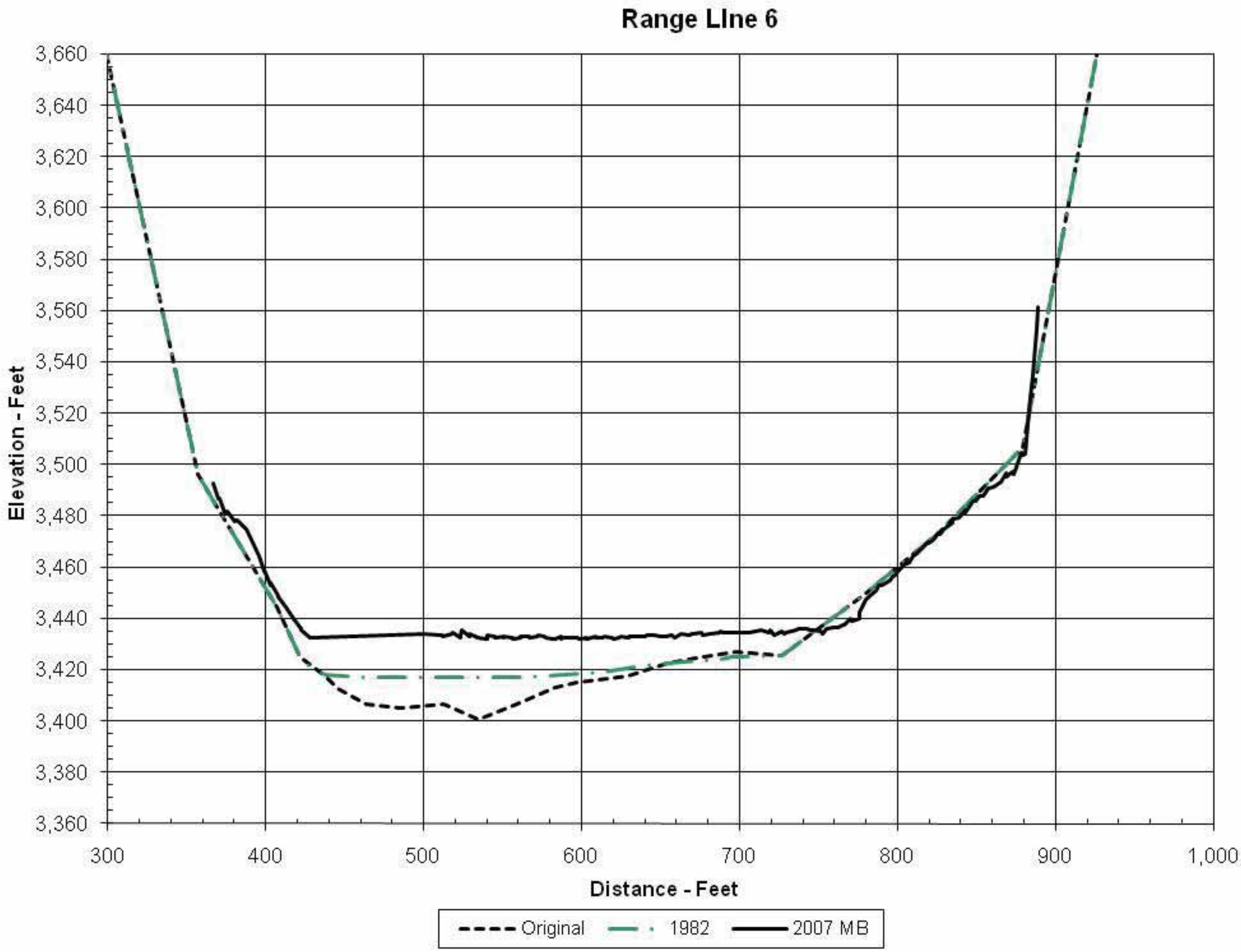


Figure 37 - Bighorn Lake, Range Line 6, Multibeam Data.

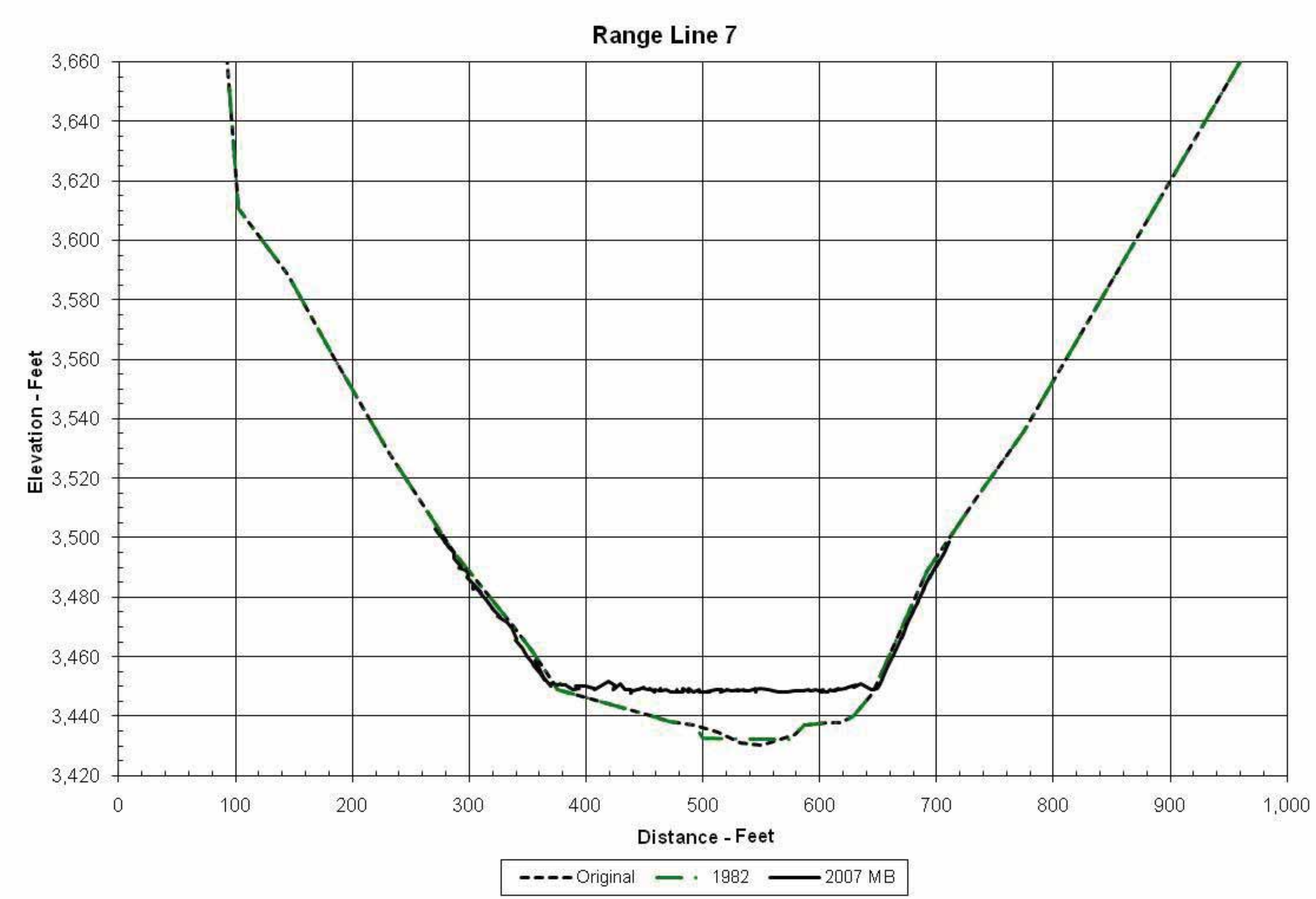


Figure 38 - Bighorn Lake, Range Line 7, Multibeam Data.

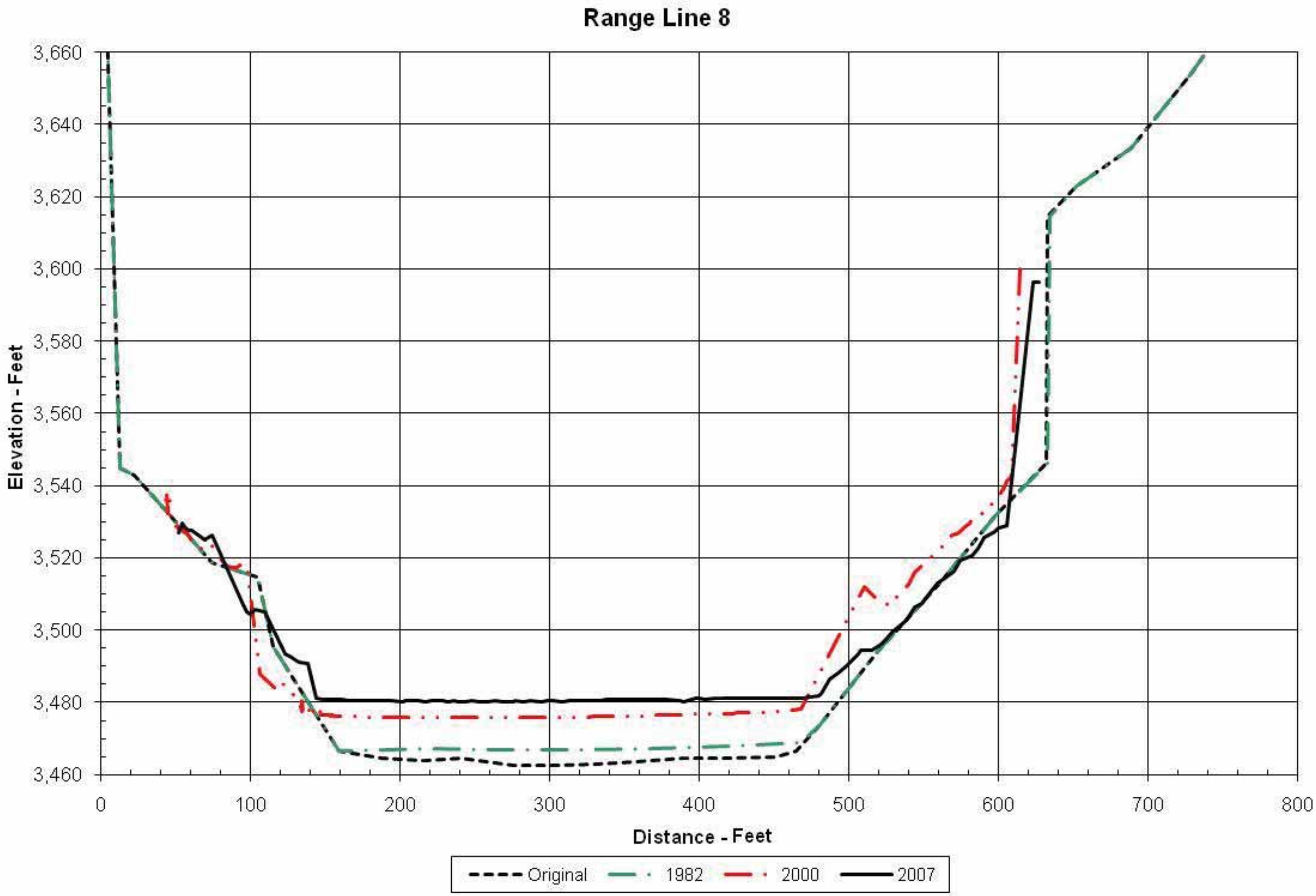


Figure 39 - Bighorn Lake, Range Line 8.

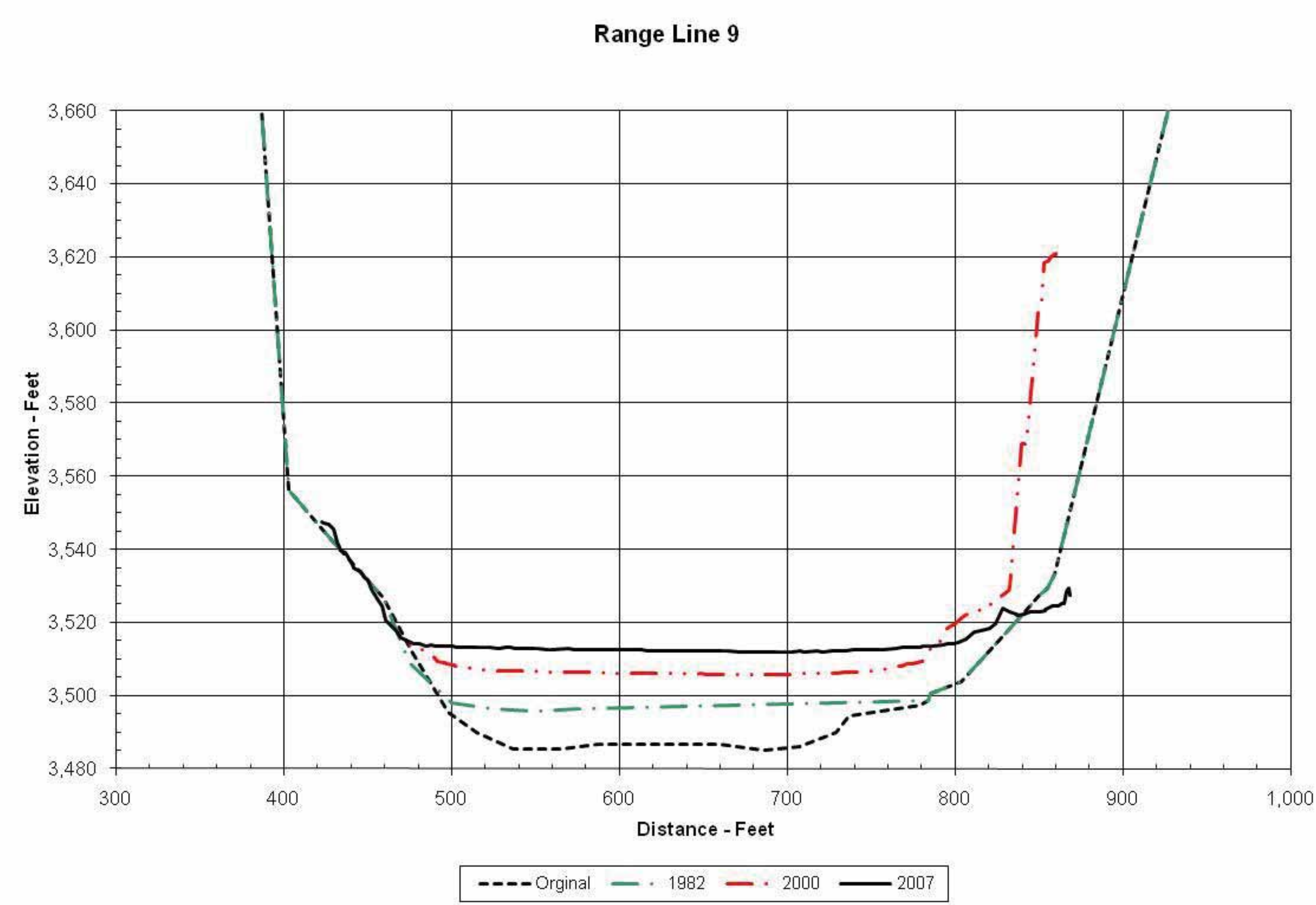


Figure 40 - Bighorn Lake, Range Line 9.

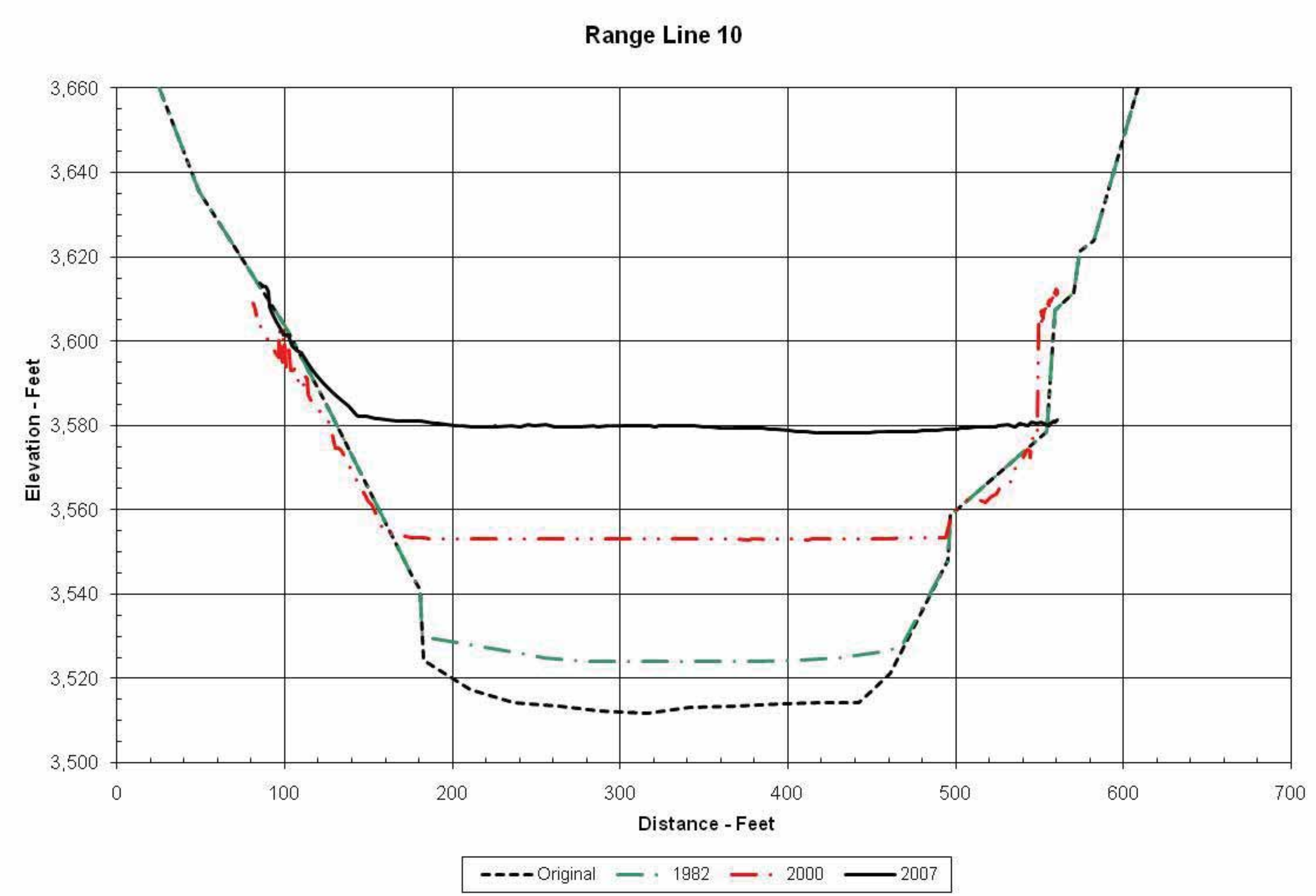


Figure 41 - Bighorn Lake, Range Line 10.

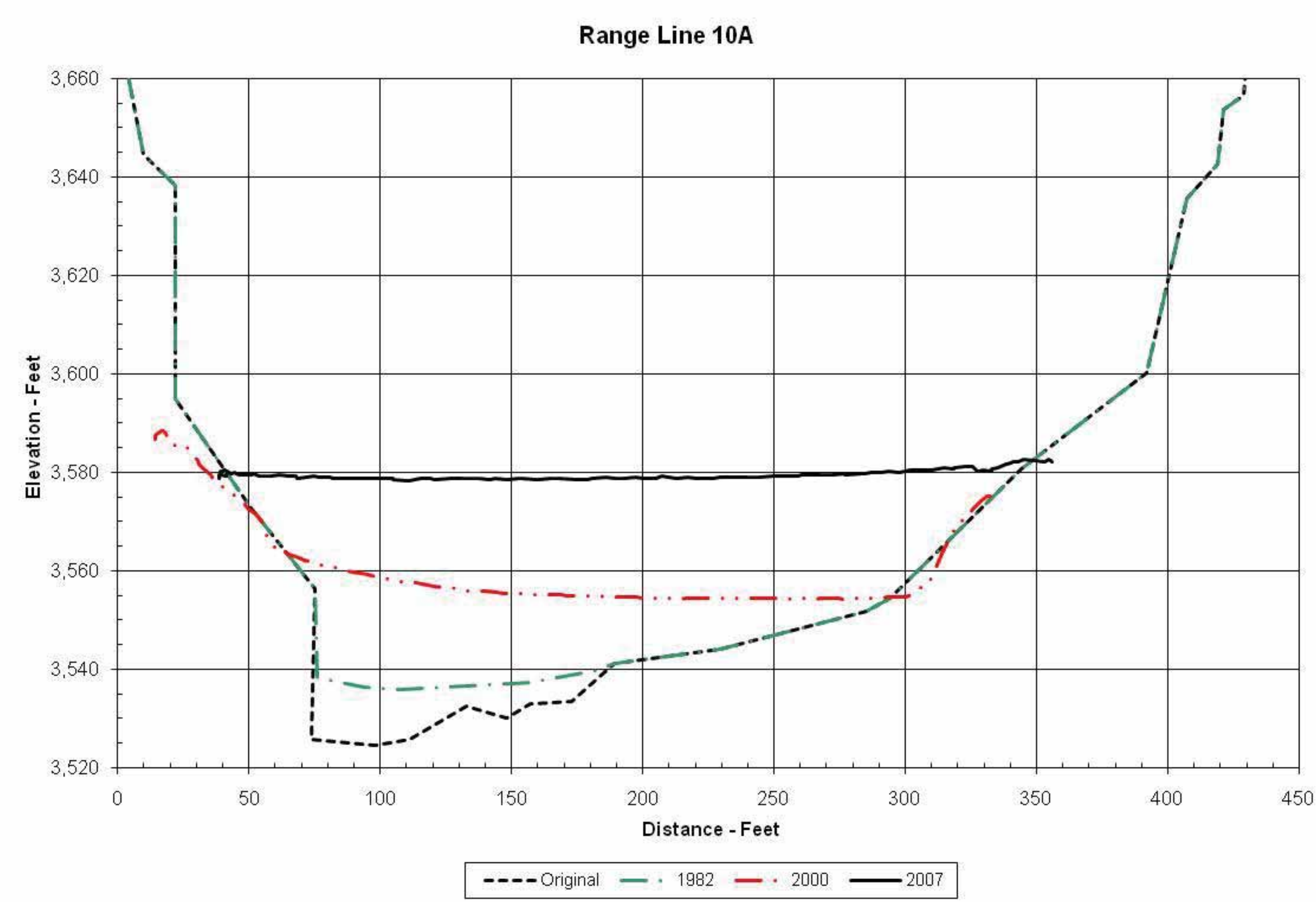


Figure 42 - Bighorn Lake, Range Line 10A.

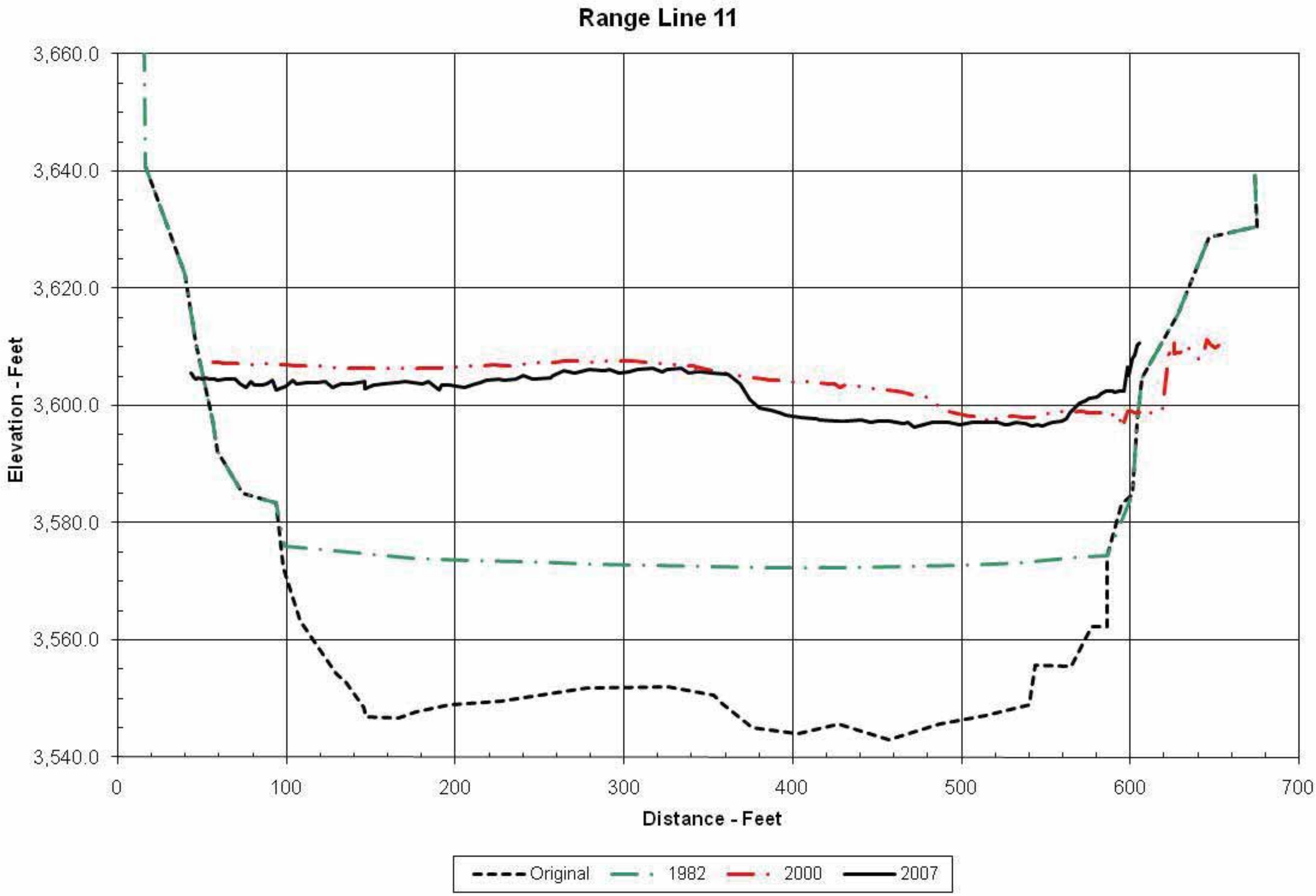


Figure 43 - Bighorn Lake, Range Line 11.

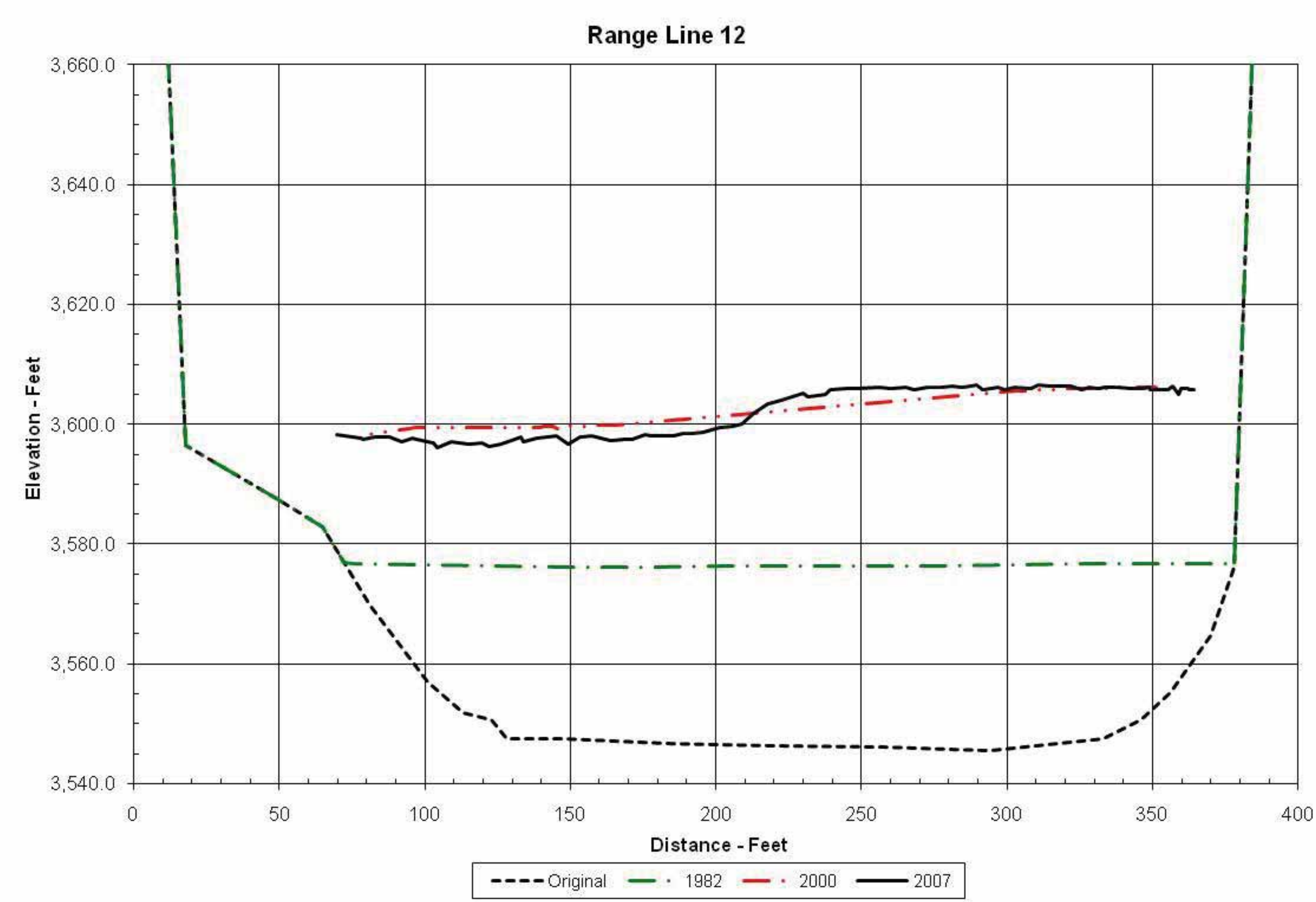


Figure 44 - Bighorn Lake, Range Line 12.

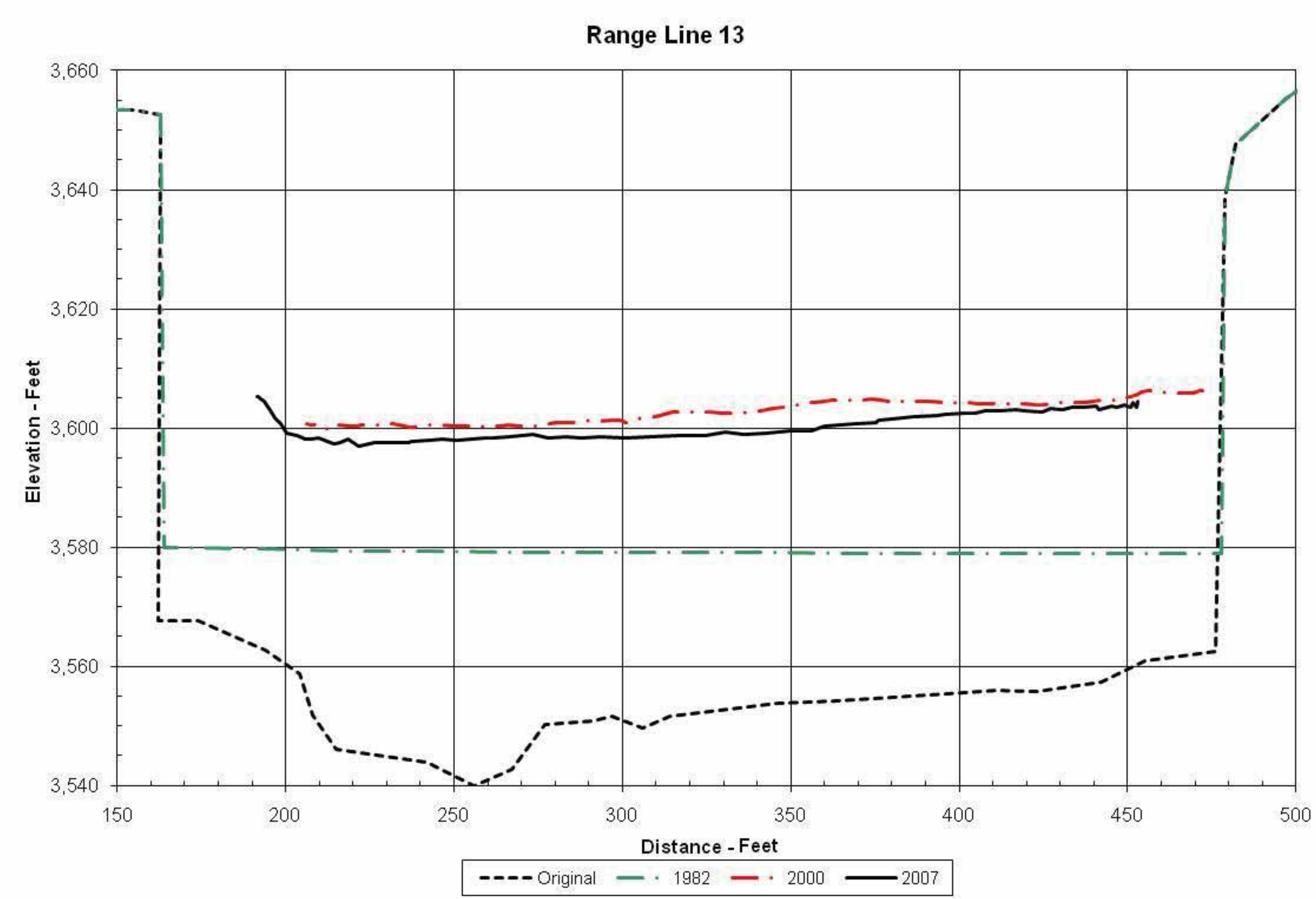


Figure 45 - Bighorn Lake, Range Line 13.

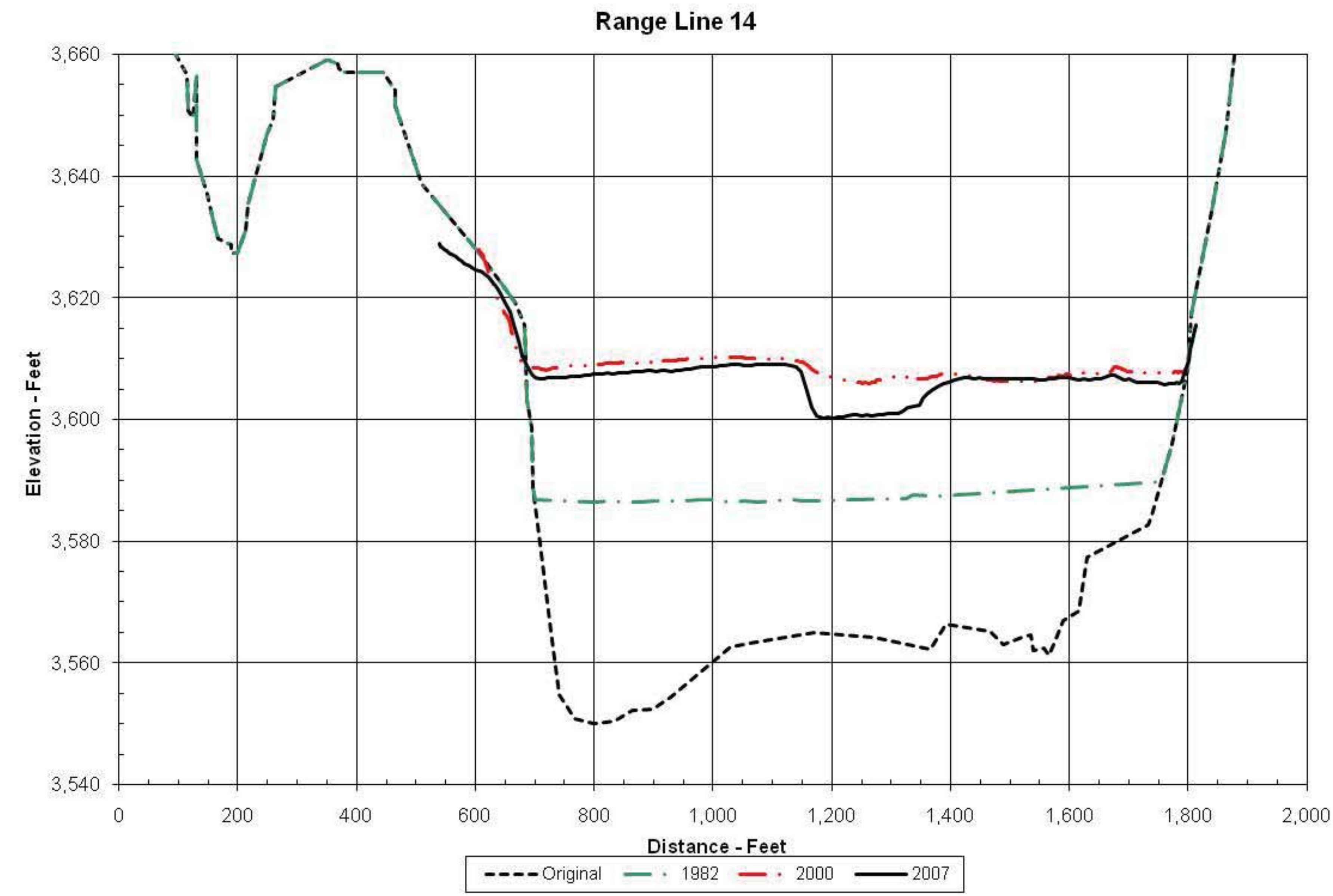


Figure 46 - Bighorn Lake, Range Line 14.

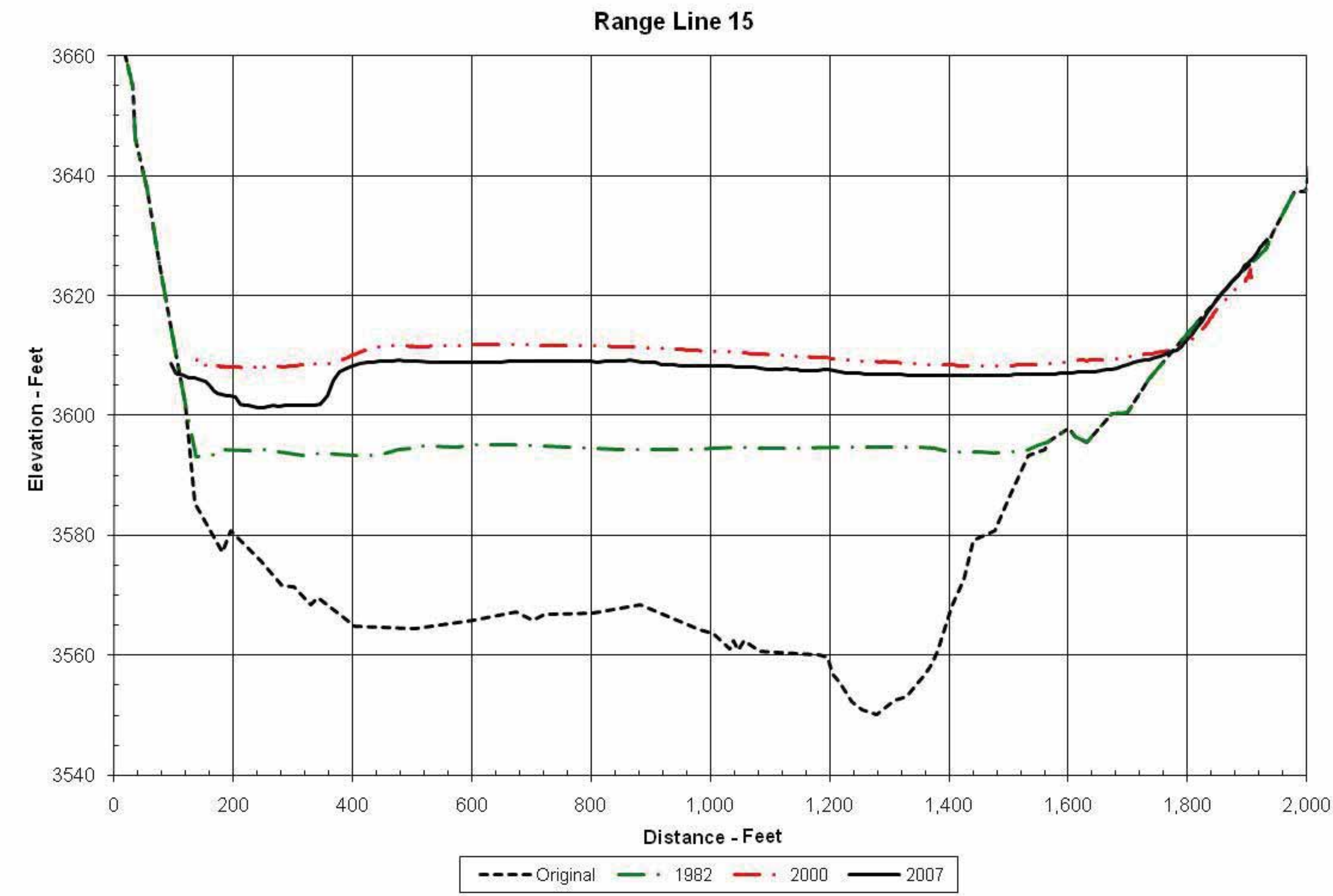


Figure 47 - Bighorn Lake, Range Line 15.

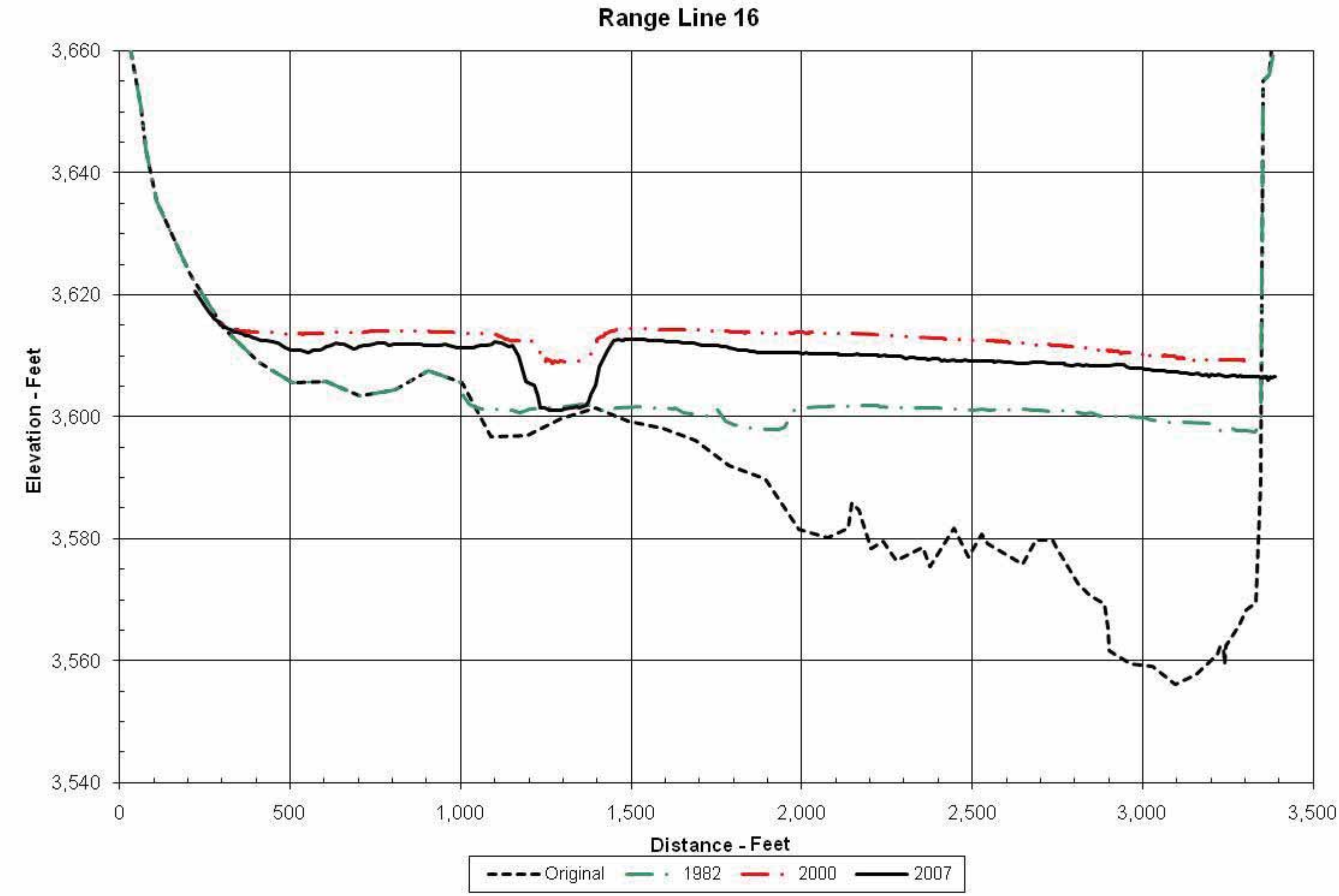


Figure 48 - Bighorn Lake, Range Line 16.

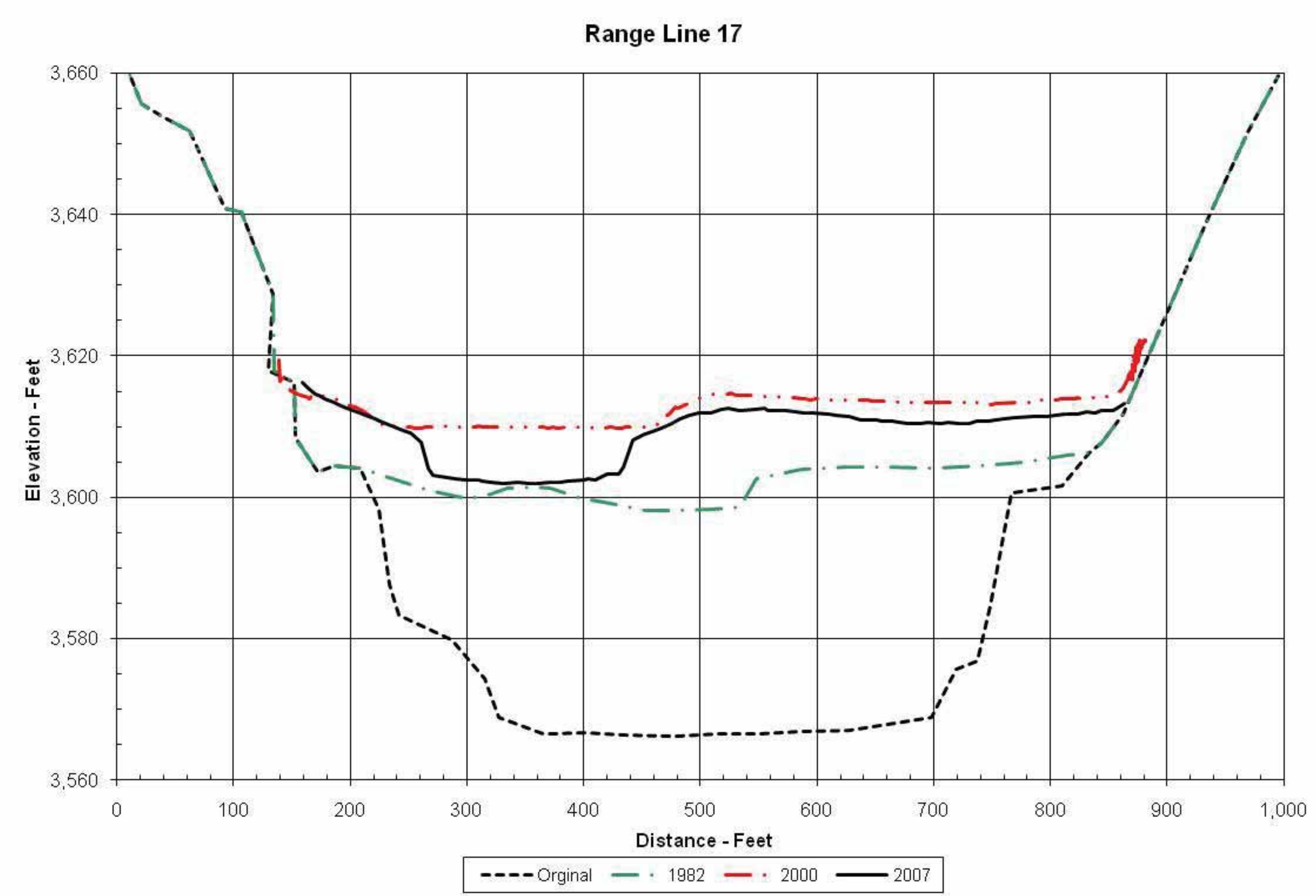


Figure 49 - Bighorn Lake, Range Line 17.

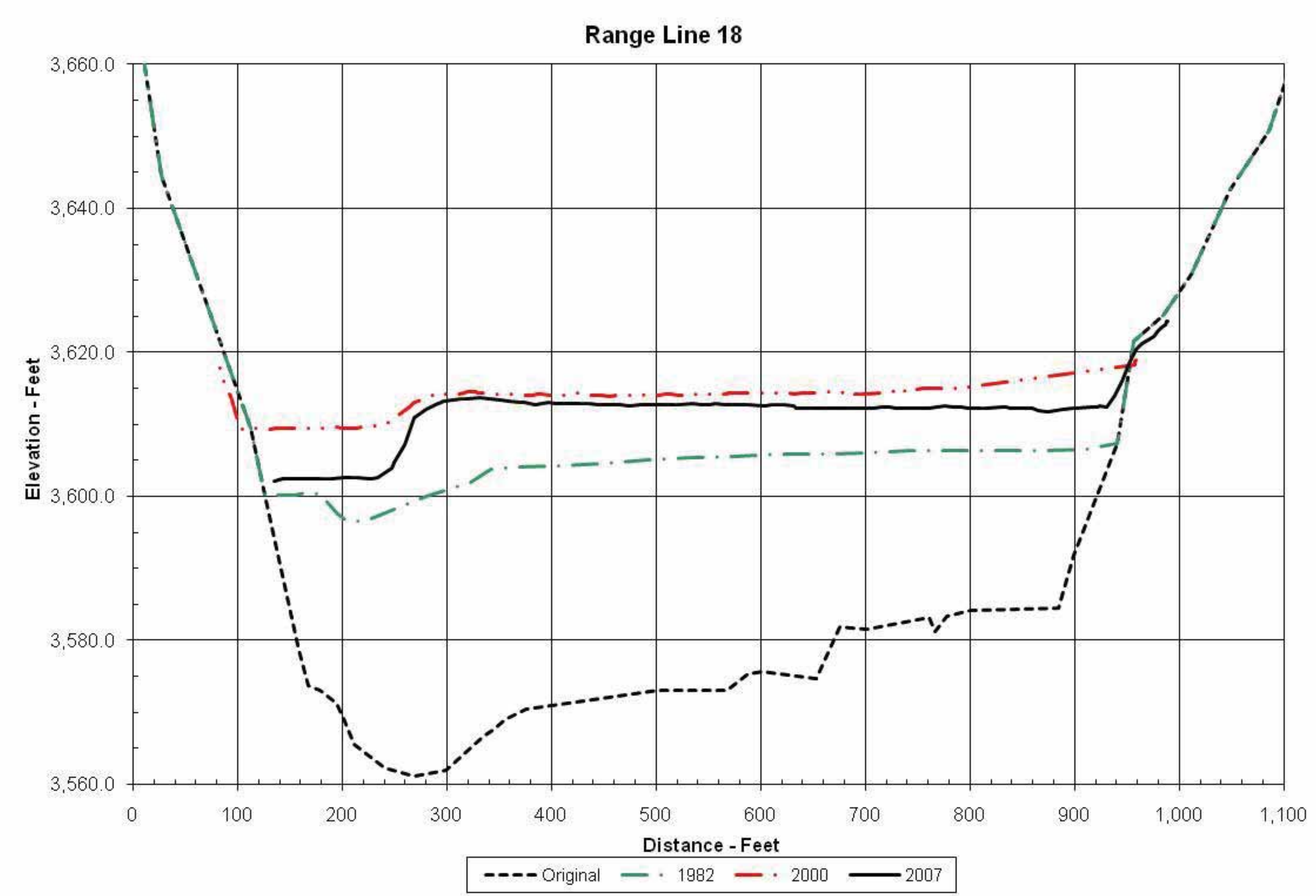


Figure 50 - Bighorn Lake, Range Line 18.

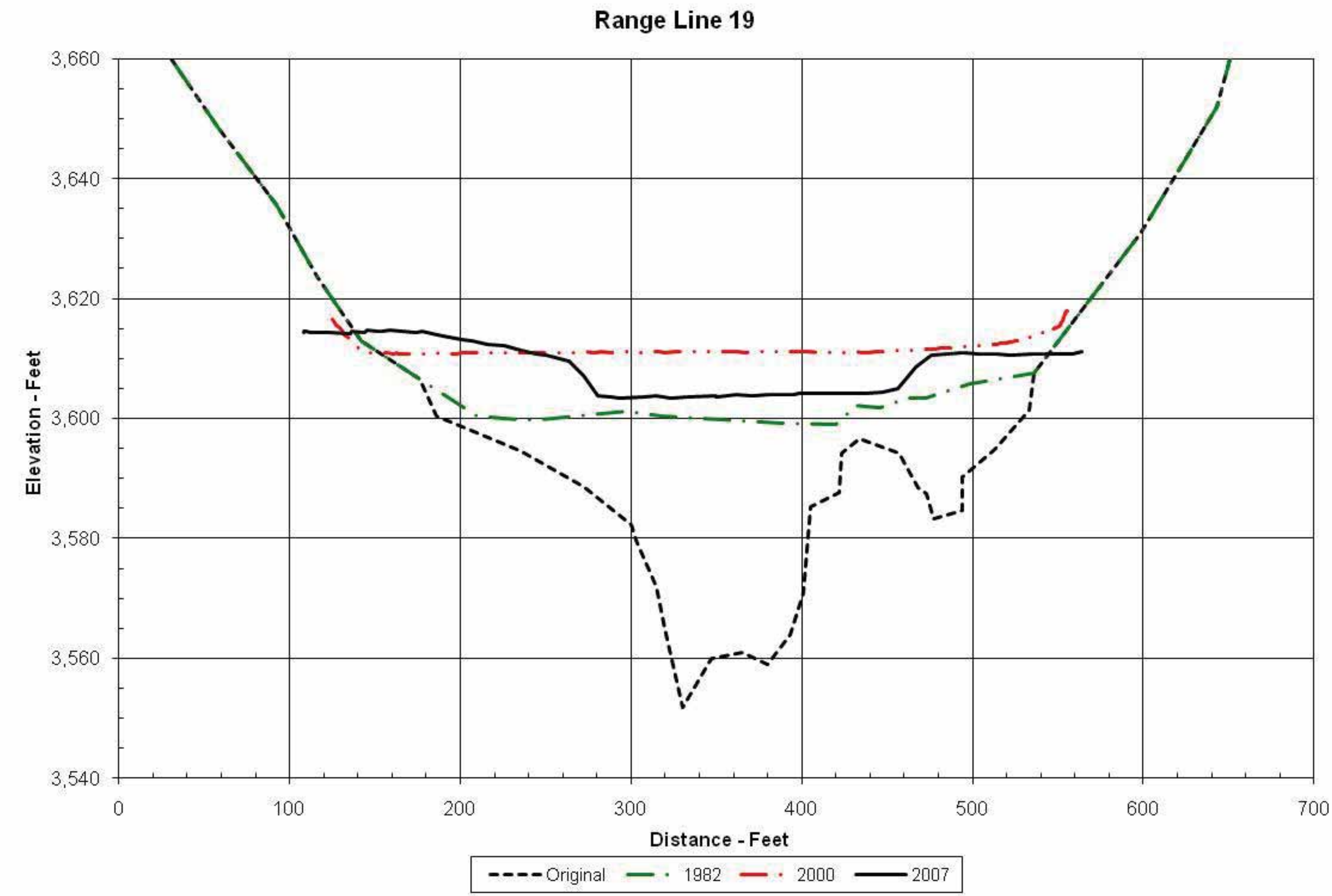
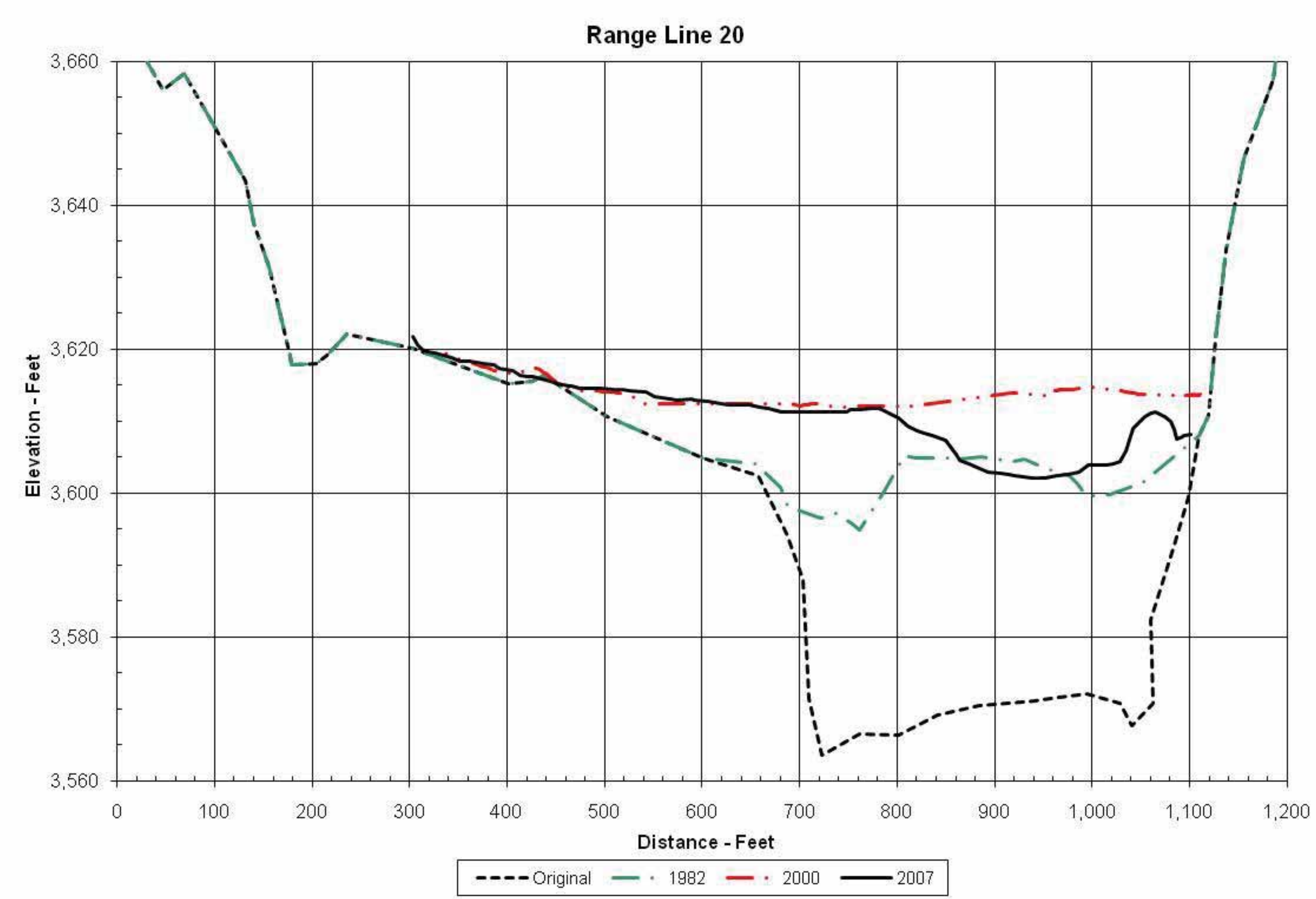


Figure 51 - Bighorn Lake, Range Line 19.



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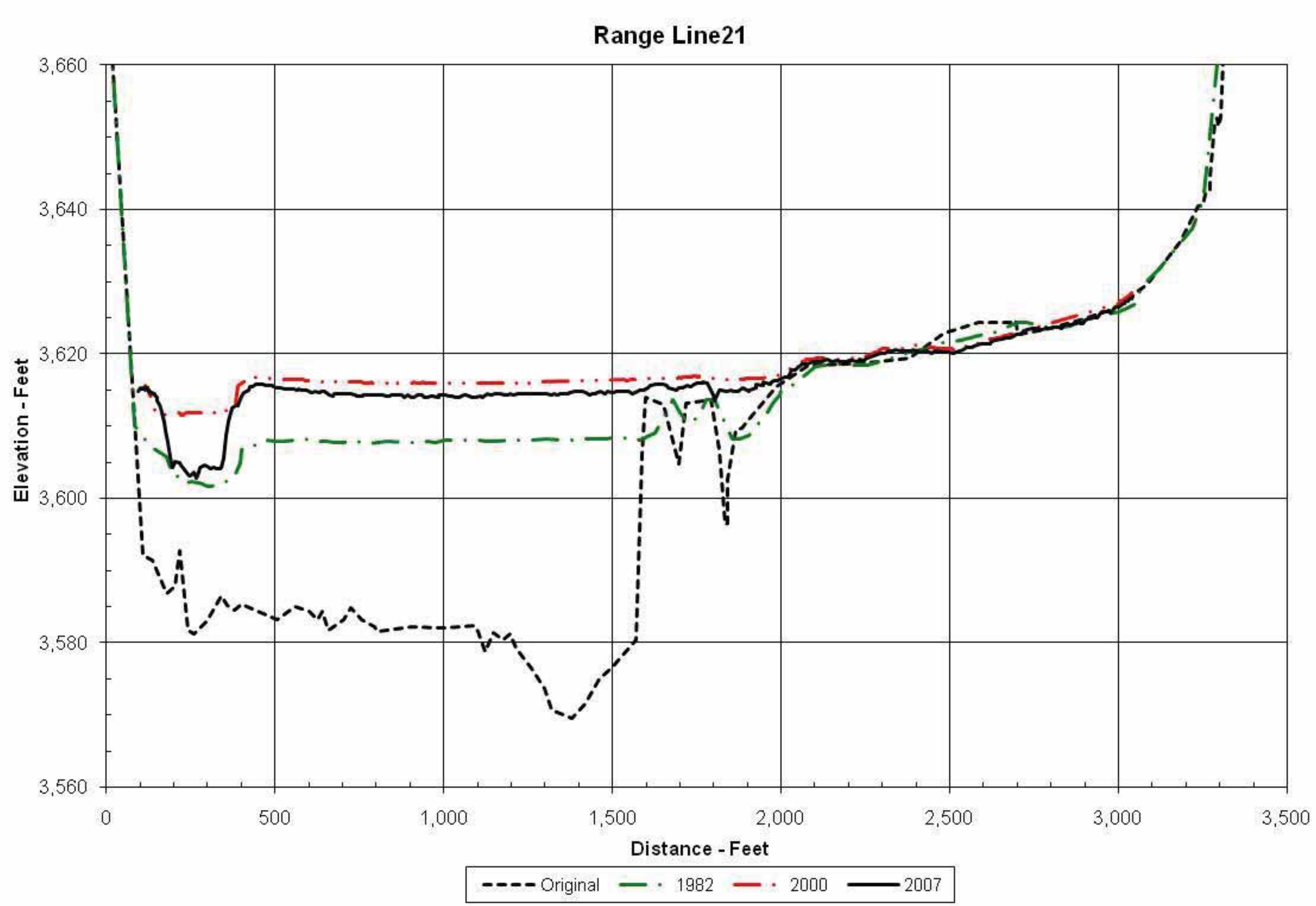

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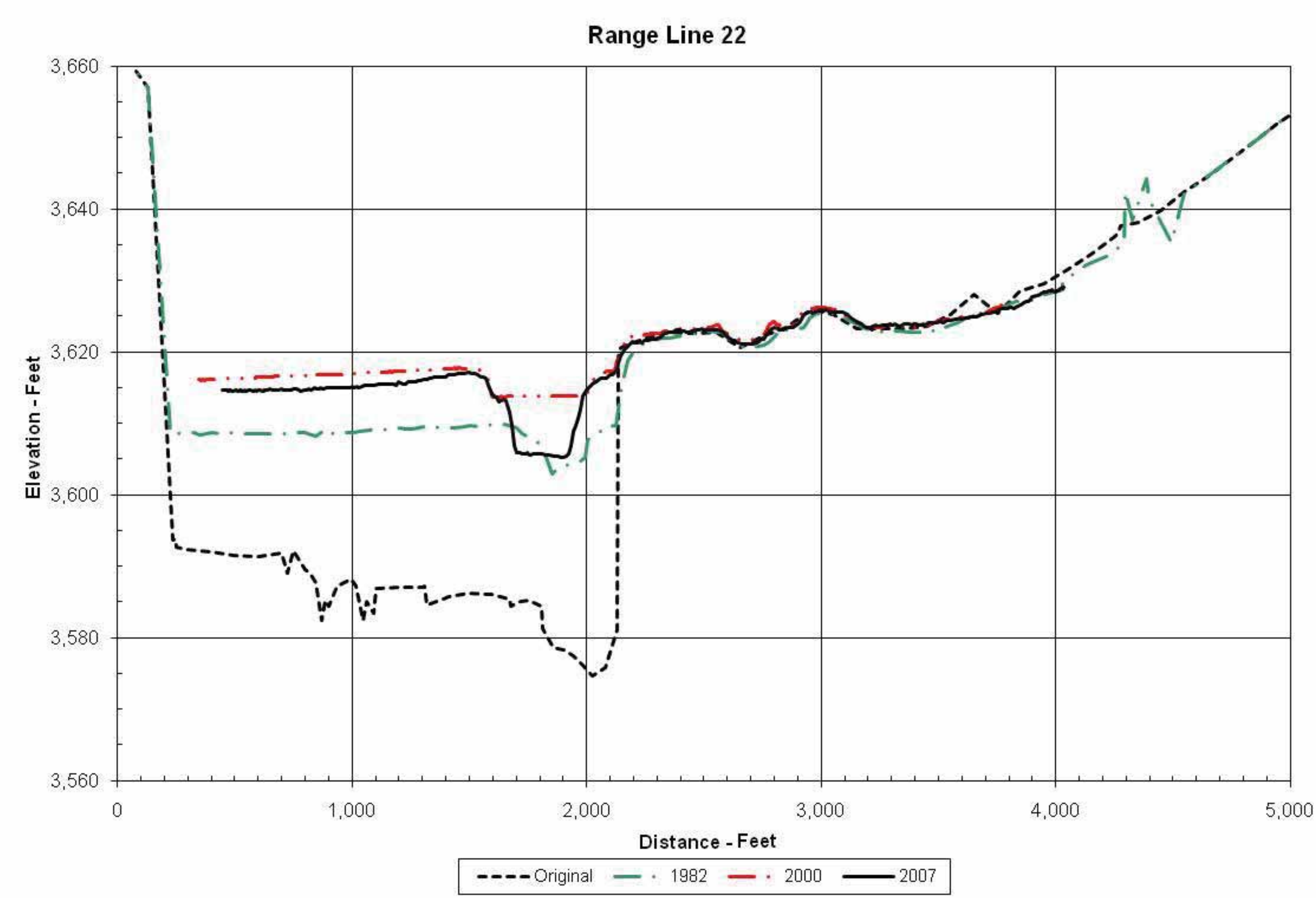

Figure 54 - Bighorn Lake, Range Line 22.

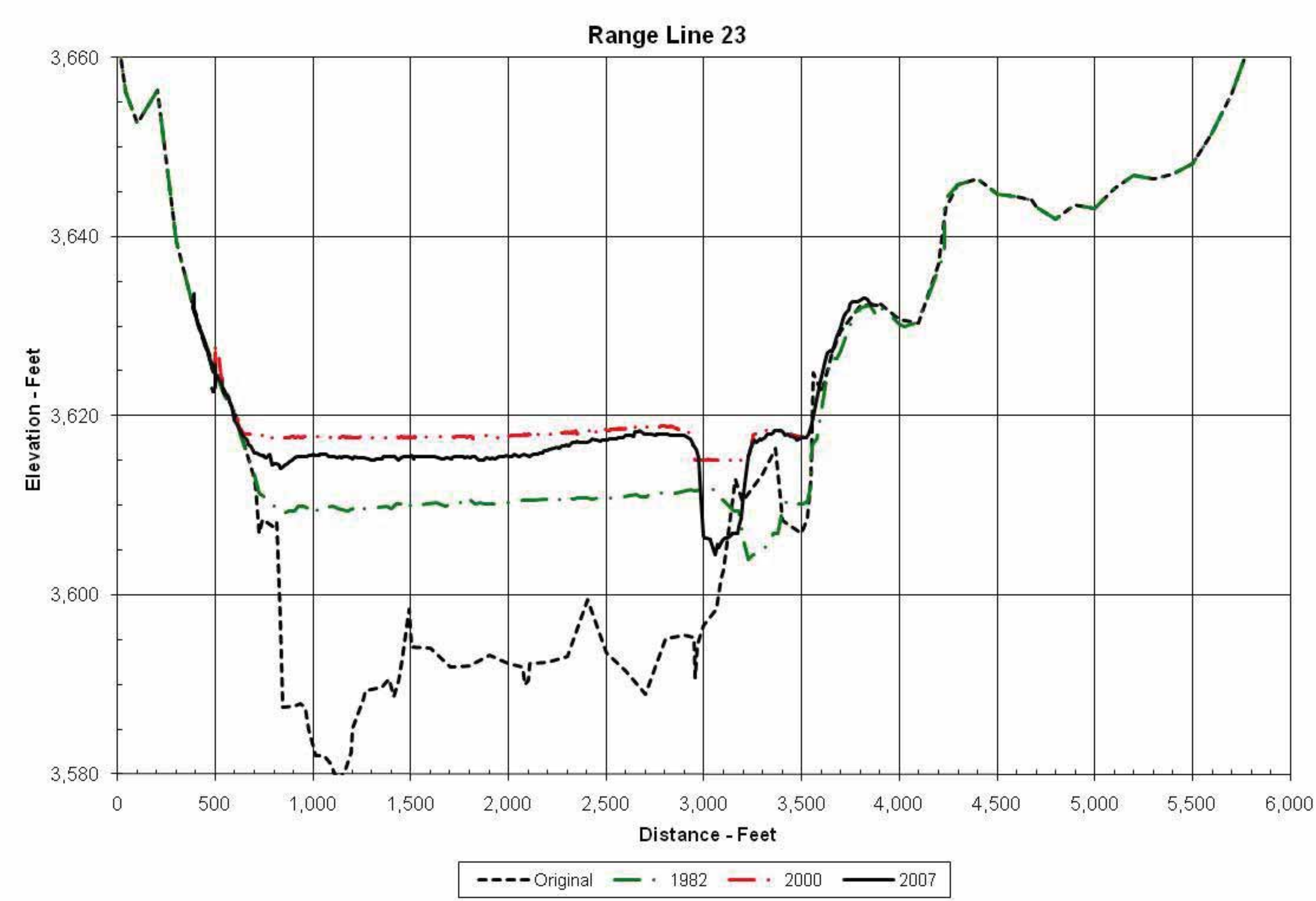

Figure 55 - Bighorn Lake, Range Line 23.

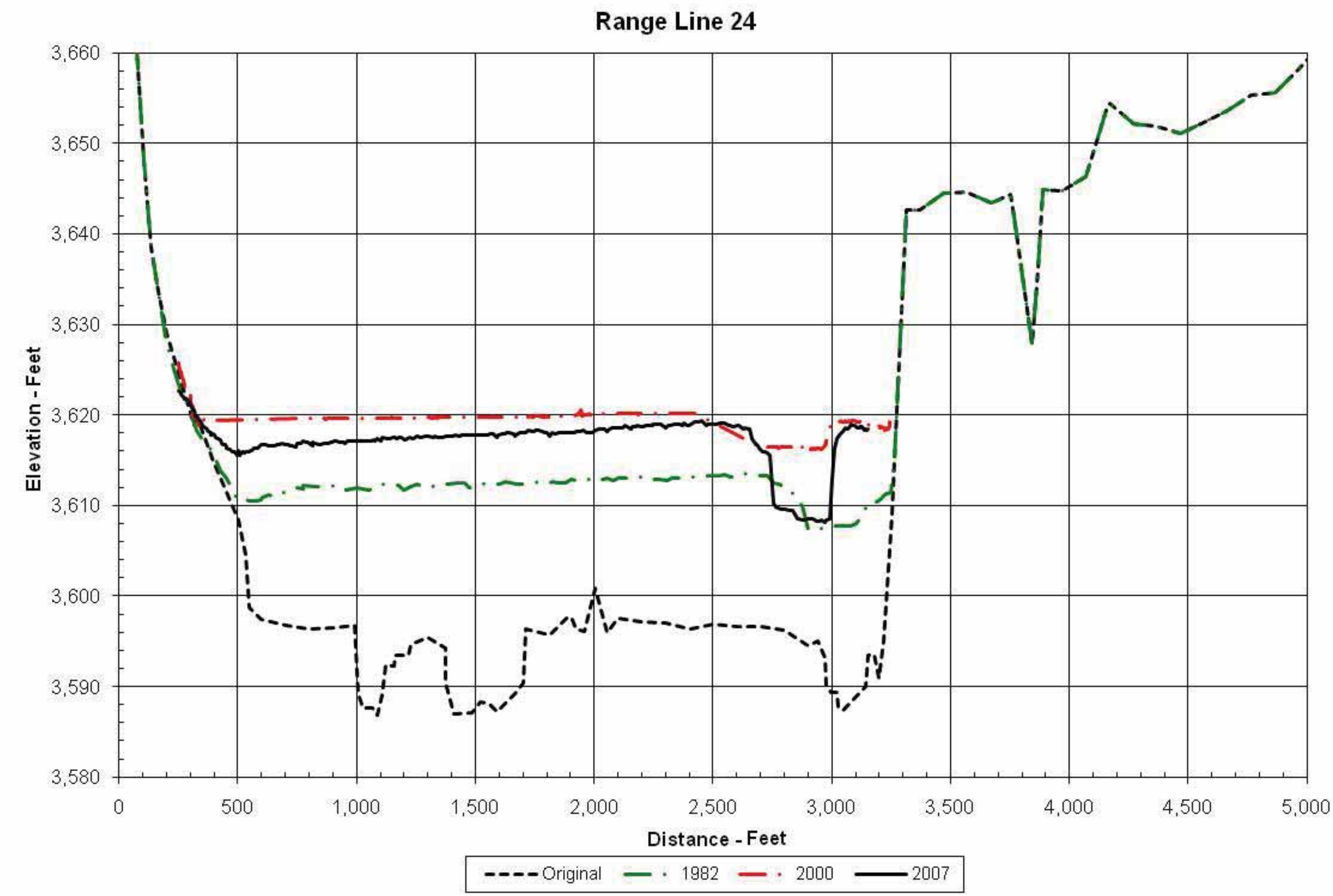

Figure 56 - Bighorn Lake, Range Line 24.

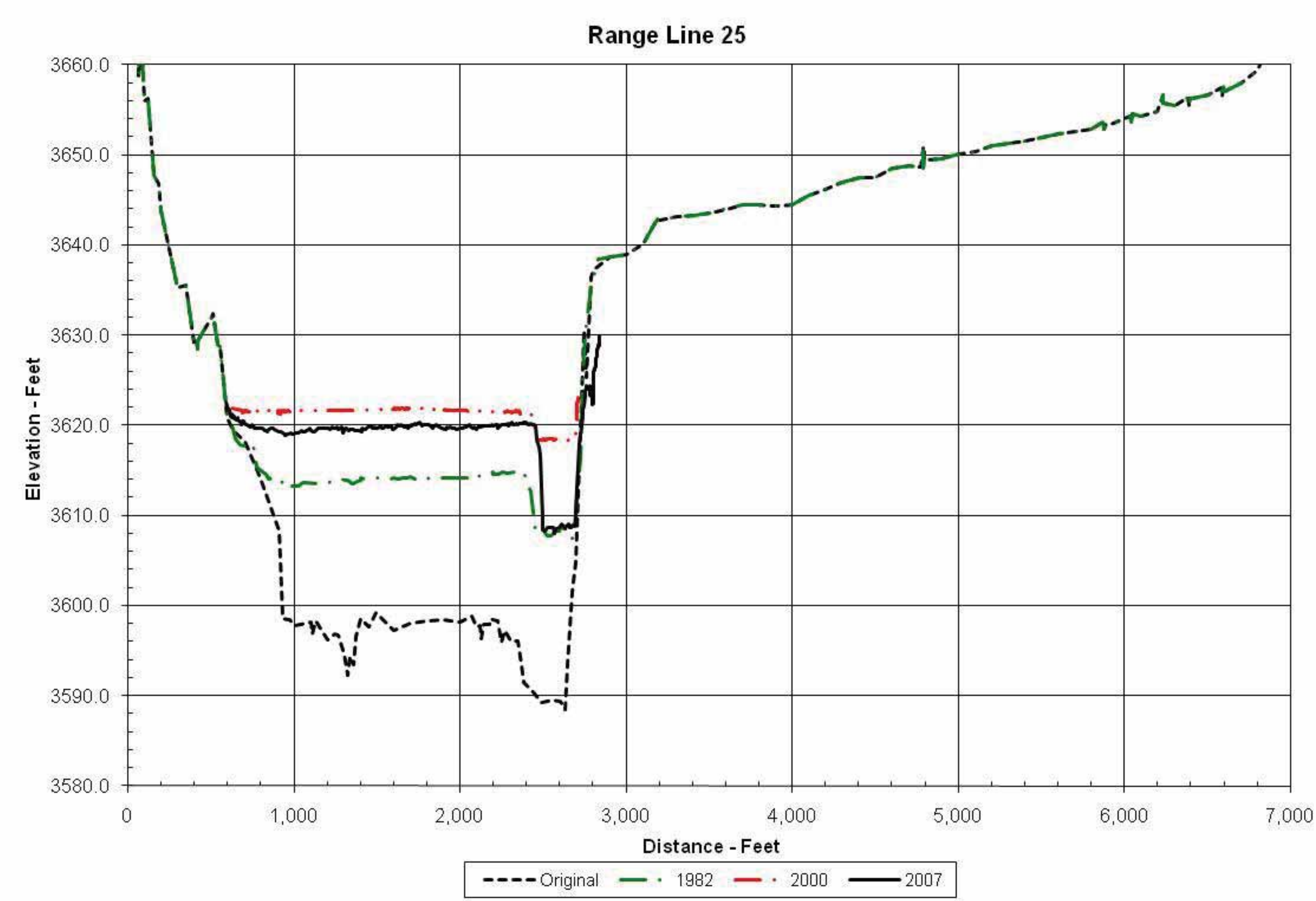

Figure 57 - Bighorn Lake, Range Line 25.

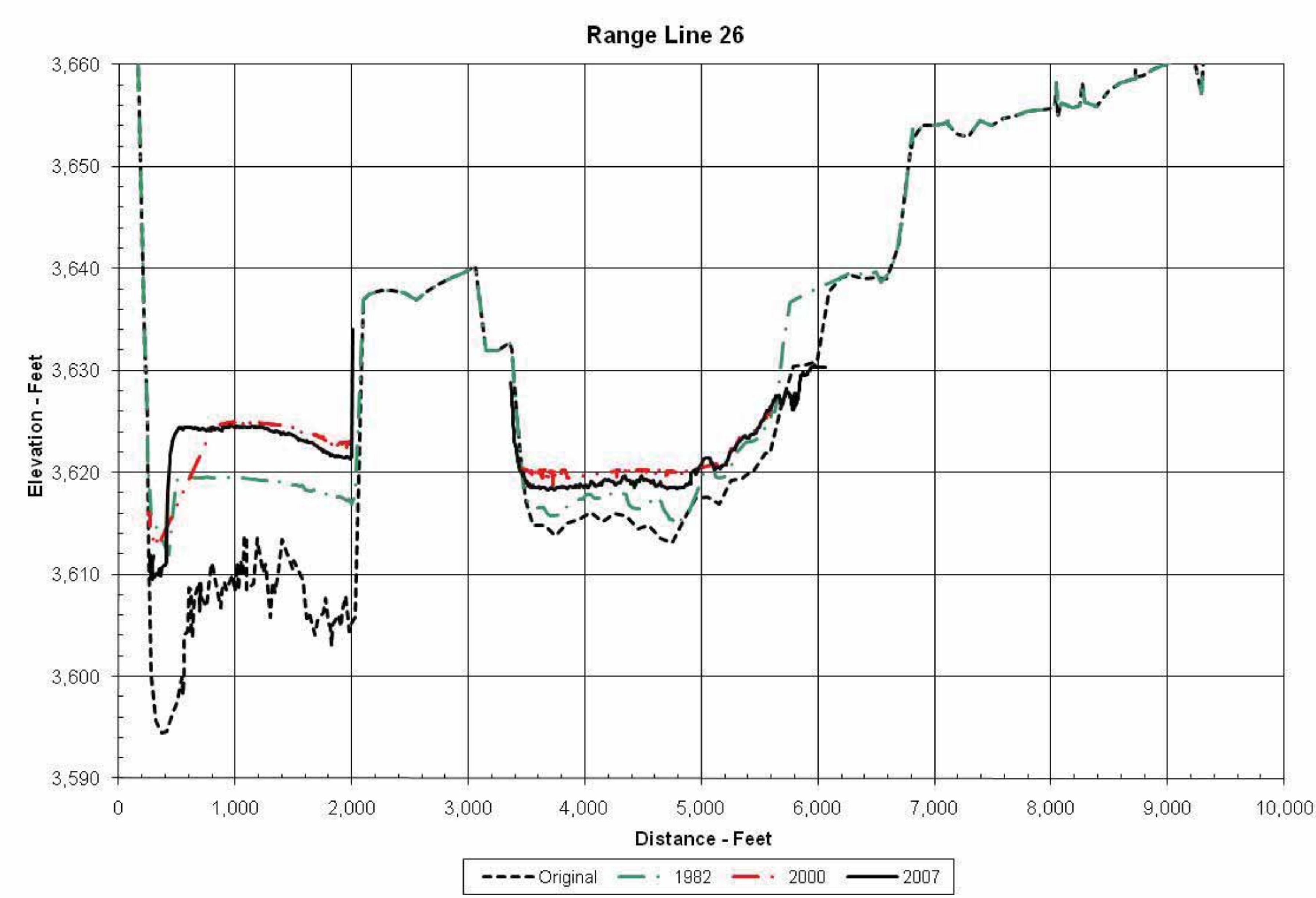

Figure 58 - Bighorn Lake, Range Line 26.

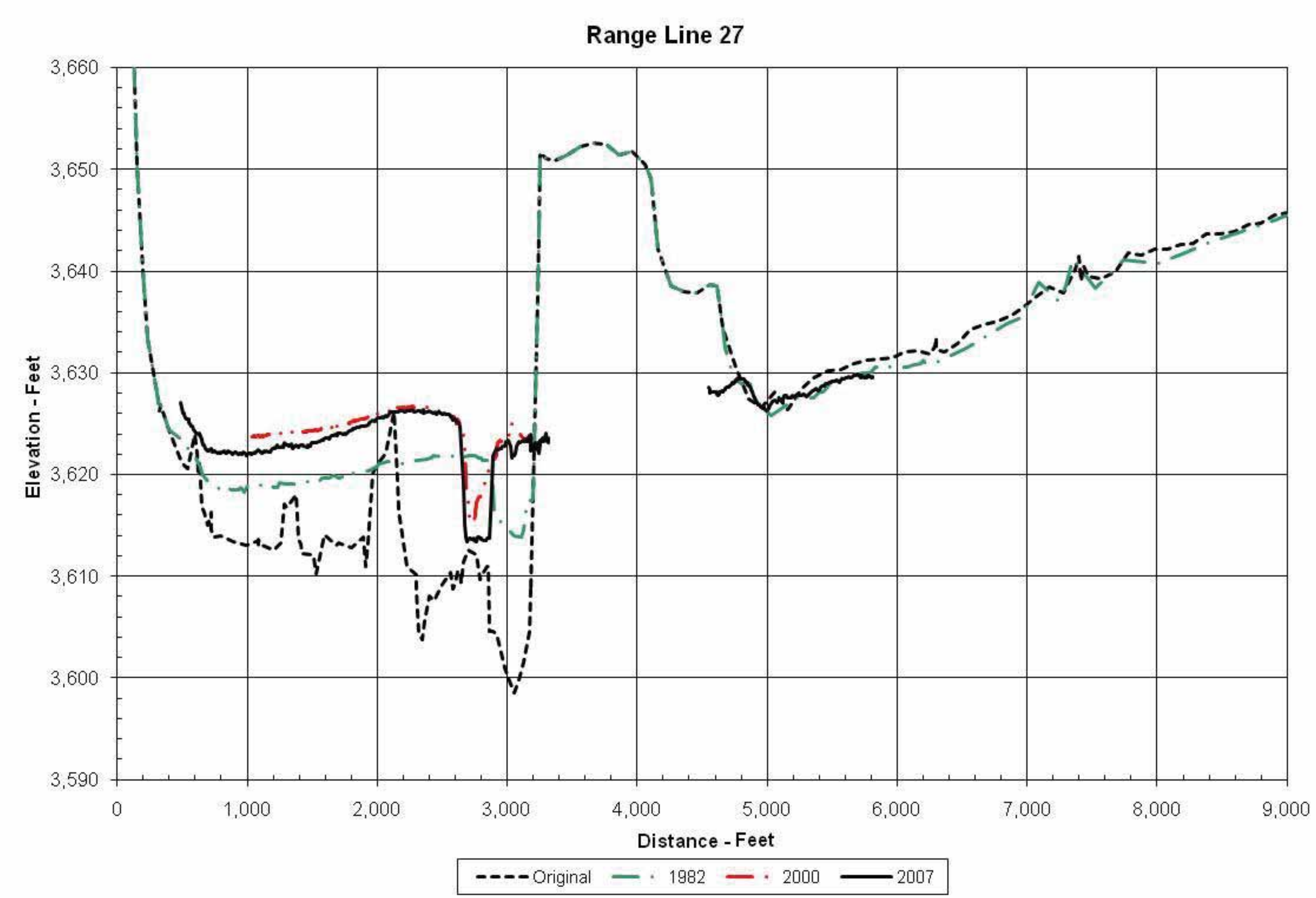

Figure 59 - Bighorn Lake, Range Line 27.

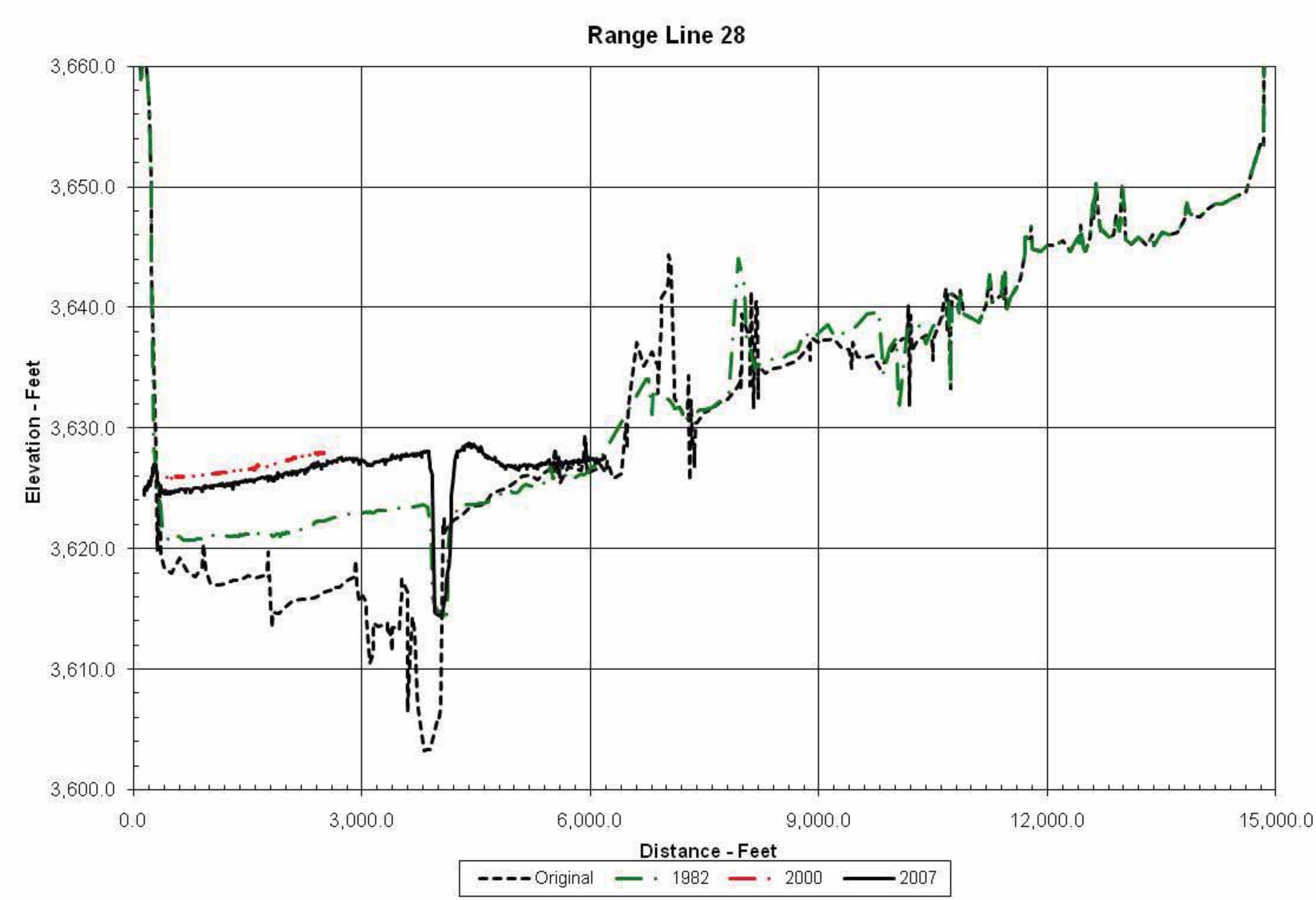

Figure 60 - Bighorn Lake, Range Line 28.

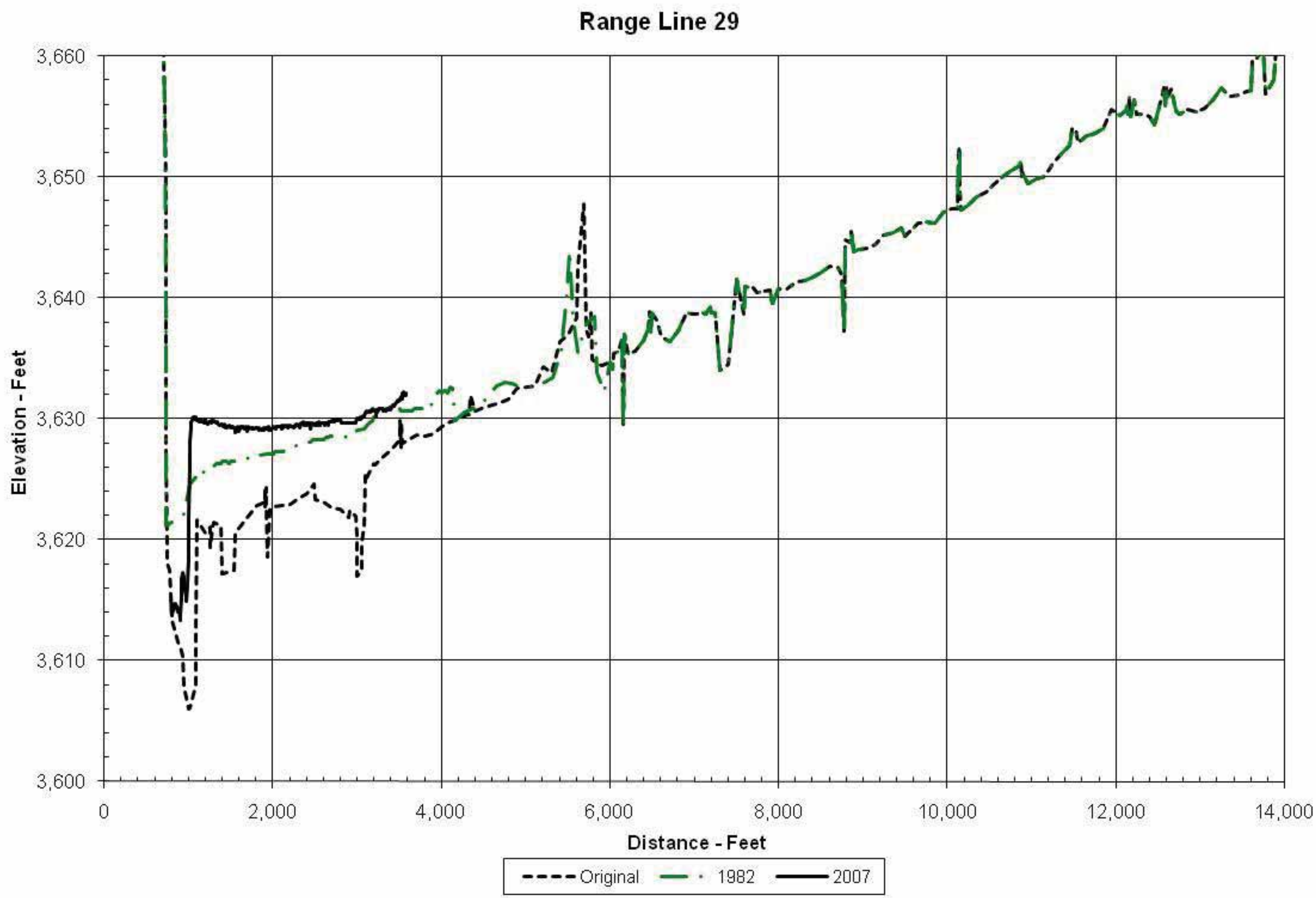

Figure 61 - Bighorn Lake, Range Line 29.

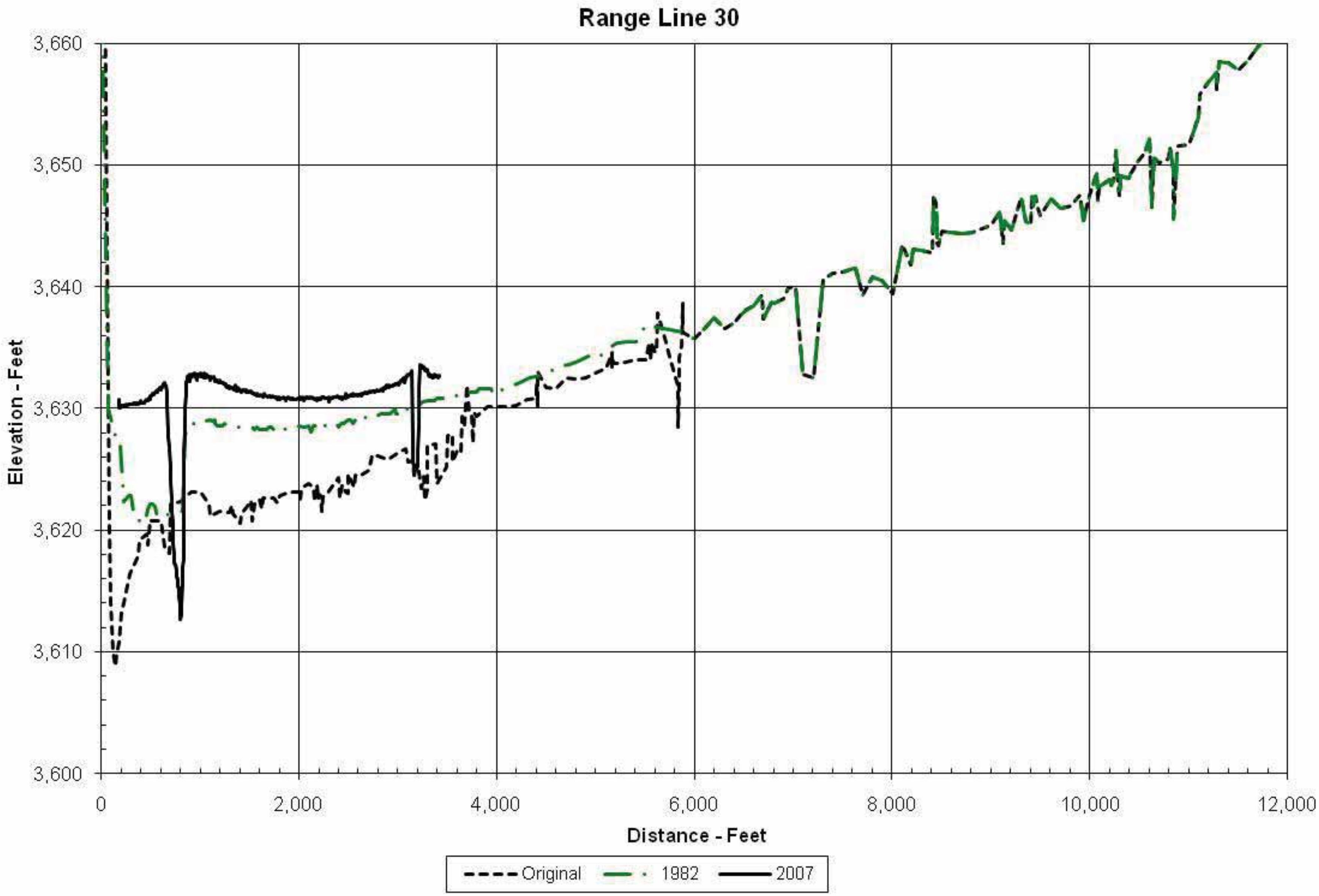

Figure 62 - Bighorn Lake, Range Line 30.

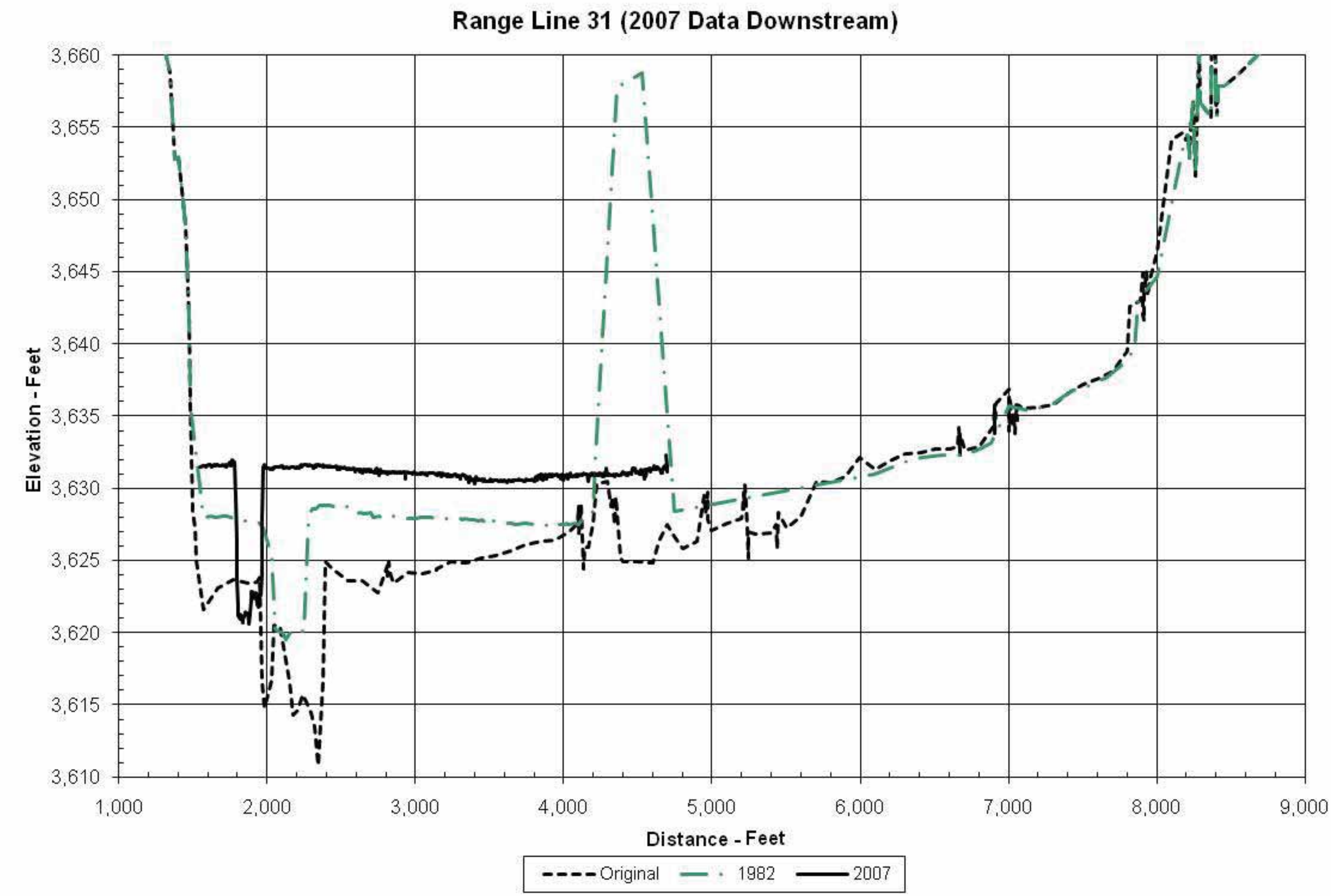

Figure 63 - Bighorn Lake, Range Line 31.

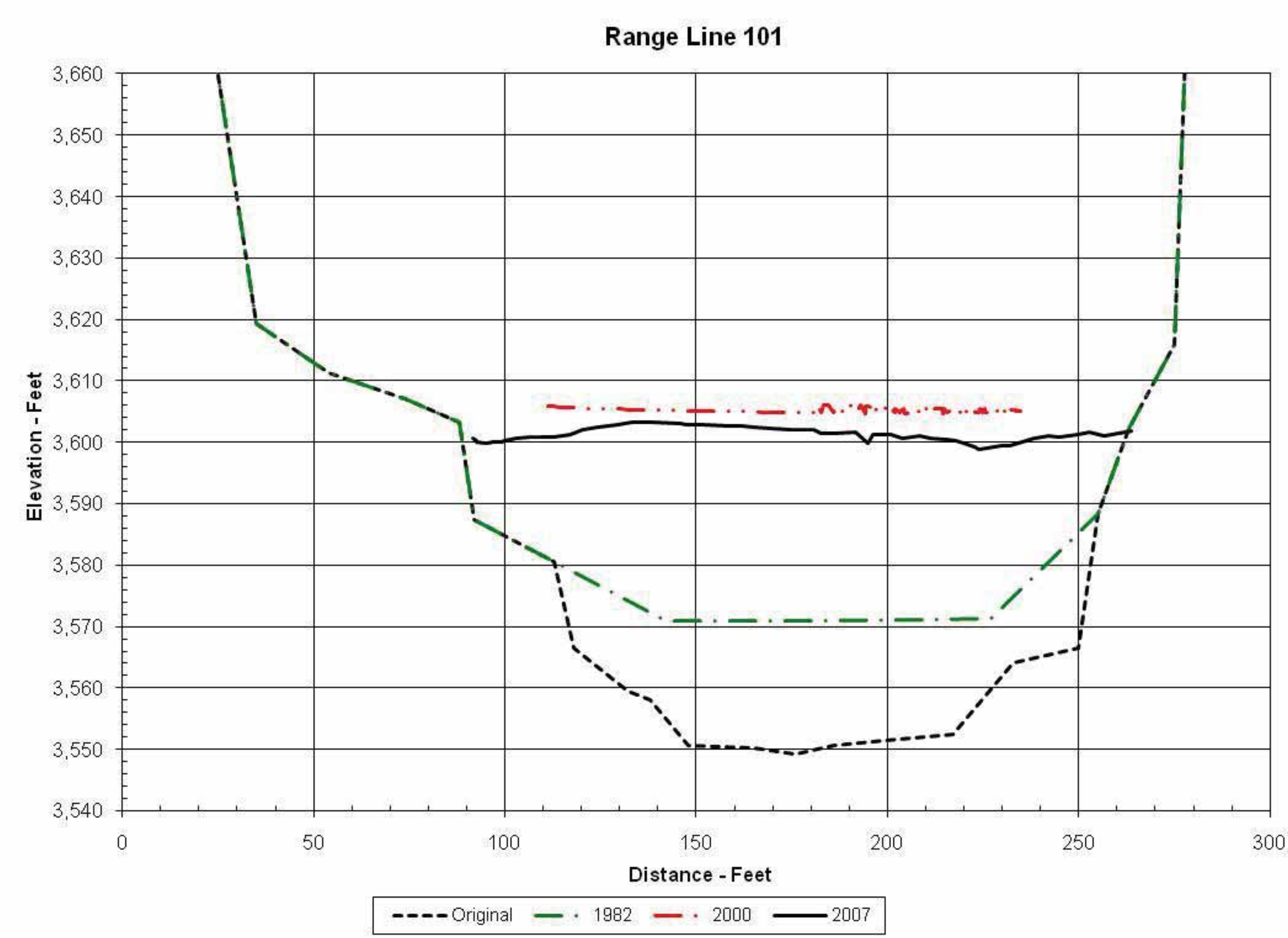

Figure 64 - Bighorn Lake, Range Line 101.

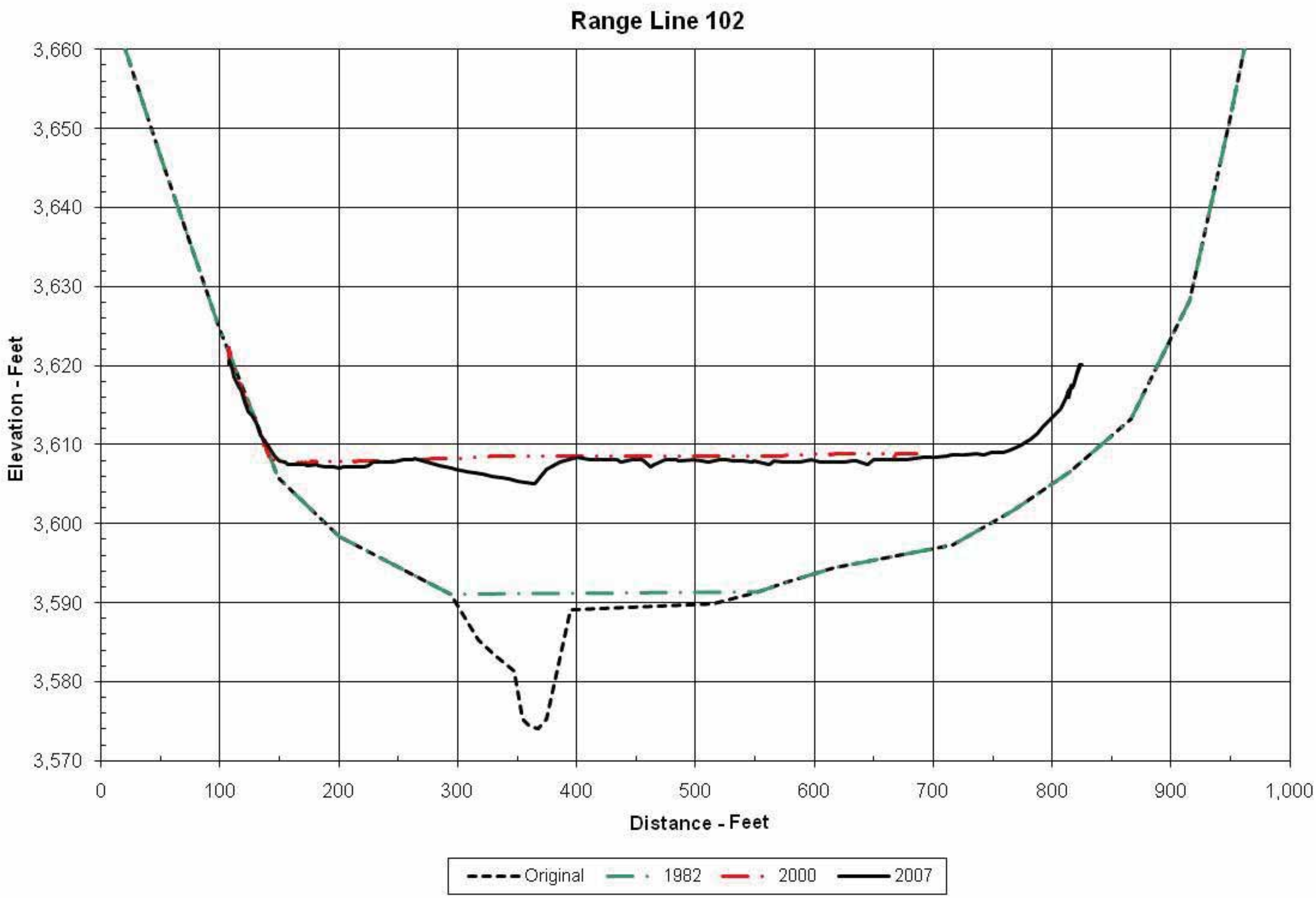

Figure 65 - Bighorn Lake, Range Line 102.

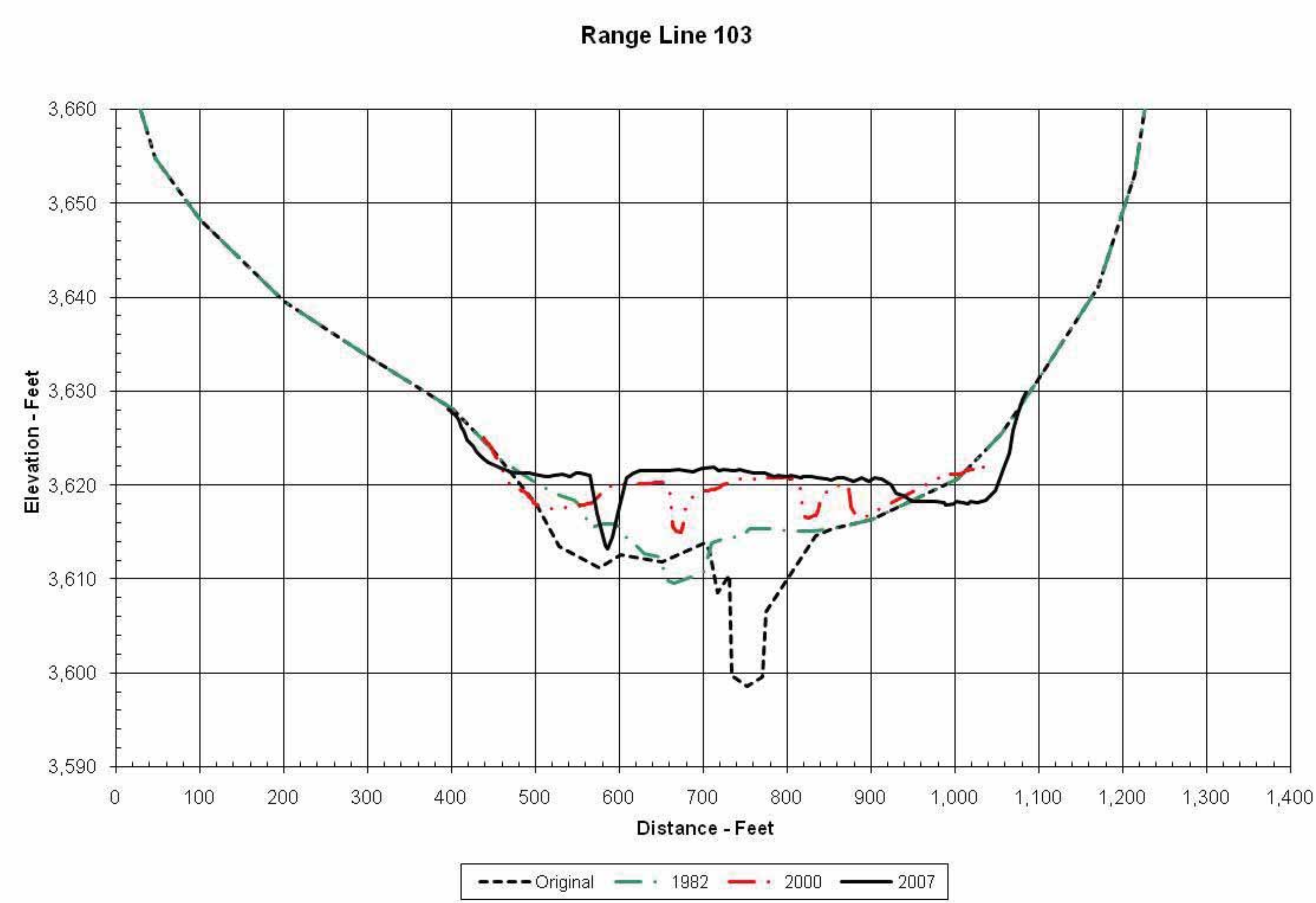

Figure 66 **- Bighorn Lake, Range Line 103.**

Longitudinal Distribution

To illustrate the sediment distribution throughout the reservoir, a longitudinal profile was plotted for the original, 1982, 2000, and 2007 reservoir conditions (Figure 68). The difference between the original average bed elevation and the resurveyed average bed elevations represents the sediment encroachment into the reservoir since the dam closed in 1965. Reservoir size, shape, and operation affect the location and nature of the sediment deposition. Sedimentation is an ongoing depositional process that can remain invisible for a significant portion of the life of a reservoir (Figure 67). The lack of visual evidence does not reduce the potential impacts of reservoir sedimentation on functional operations of a reservoir such as the use of outlets. For Bighorn Lake the drawdown exposed the significant delta that has developed in the Horseshoe Bend area while a bottom survey was required to show the buildup of sediment in the deep portions the reservoir as it nears the dam.

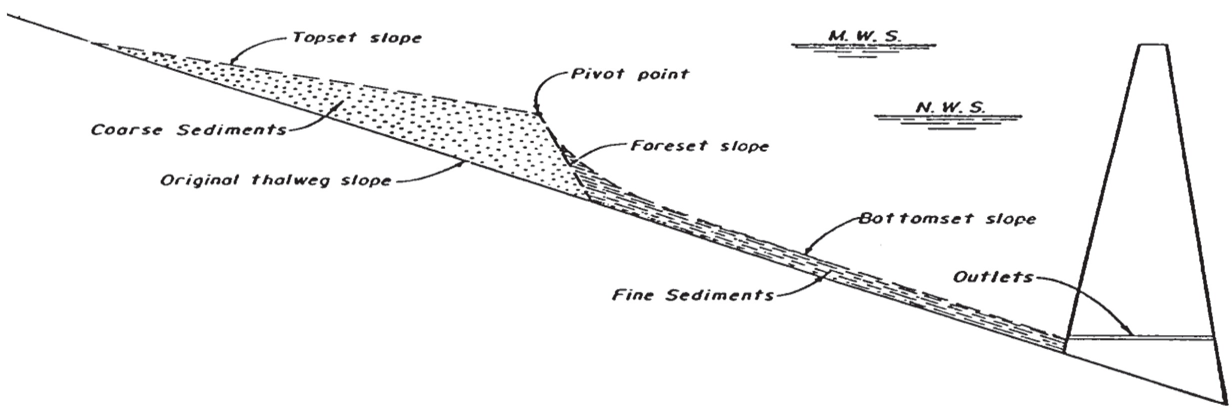

Figure 67 - Profile of Reservoir Delta Formation.

As rivers and streams enter a reservoir, the flow depth increases, decreasing inflow velocity and causing a loss in the sediment transport capacity of the inflow. The loss of sediment transport capacity and the damming effect of the reservoir may cause deposition of sediment in the upper reservoir area and in the river channels upstream. The sediment deposition process in reservoirs generally follows the same basic pattern, with coarser sediments settling first in the upper reservoir area as the river inflow velocities decrease, forming a delta. Deposition progresses from upstream to downstream towards the dam, with the sediment gradation becoming finer in the downstream direction, until the inflowing sediment is deposited throughout the length of the reservoir, Some of the inflowing fine sediments (silts and clays) typically stay in suspension and settle much further downstream and eventually discharge through the dam outlets and spillways.

The Bighorn Lake longitudinal plot shows the greatest depths of sediment deposits since 1965 occurring by 1982 at river miles 15 and 47, and by 2007 at river miles 15 and 39 (Figure 68). It appears the depositional pattern in the lower region at mile 15 was influenced by the “rock slide” area located upstream of range line 3A on the same bank (Figures 26, 27, and 28). Since the 1982 study showed a similar pattern at river mile 15, it appears the rock slide was present in 1982 and possibly occurred during the filling of the reservoir. In 1982, at reservoir pool elevation 3,633 the reservoir extended upstream to about range line 34. The 2007 survey found the reservoir at elevation 3,633 still extended to near range line 34, but due to sediment deposition the depths of the reservoir have decreased downstream of this location. The 2007 topography found at elevation 3,605, the reservoir extended to range line 13 while in 1982 the reservoir extended to range line 18 at the same elevation. This shows the significant loss in reservoir length since 1982 due to sediment deposition.

For the upper delta, the inflowing sediments first deposit in the Horseshoe Bend area when the flow velocities greatly decrease due to the damming effects of the reservoir and narrow restricted topography as flow enters Bighorn Canyon at range line 13. The significant decrease of storage capacity in the Horseshoe Bend area due to sediment deposition allows more inflowing sediment to enter Bighorn Canyon. A major factor influencing the longitudinal pattern is also the average or normal operation water surface which has varied since the 1982 and 2000 surveys. The extensive drought in the region after 2000 resulted in the reservoir being held at a lower stage for several years, allowing previously deposited upper elevation sediments along with the inflowing sediments to be transported further downstream and deposited in the lower elevation reaches of the reservoir. A lower pivot point elevation formed in 2007 compared to the 1982 and 2000 surveys due to this lower normal operation water surface. The profiles in Figure 68 also show that the longitudinal location of the pivot points did not change much from 1982 to 2000, but the drawdown resulted in the formation of a 2007 pivot point nearly 7 miles downstream. The normal water surface elevation has risen since the drought. The elevation of the delta pivot point would be expected to rise with the water surface, but once the newly available upstream reservoir area fills with sediment, the delta face will proceed downstream towards the dam.

During the period of drought and low reservoir content from 2001 through 2004, the river scoured some of the previously deposited sediments from the upper range lines. Along with inflowing sediment from tributaries in the area, much of the eroded material deposited in the wider Horseshoe Bend area downstream to the narrow Bighorn Canyon entrance. Cross section plots (Figures 41 and 42) and longitudinal profiles (Figure 68) show significant deposits at range lines 10 and 10A which experienced over 25 feet of deposition since 2000 and around 55 feet since 1982. The 2000 and 2007 surveys measured significant sediment deposition beginning to enter the narrow Bighorn Canyon area from range line 10 upstream to range line 13.

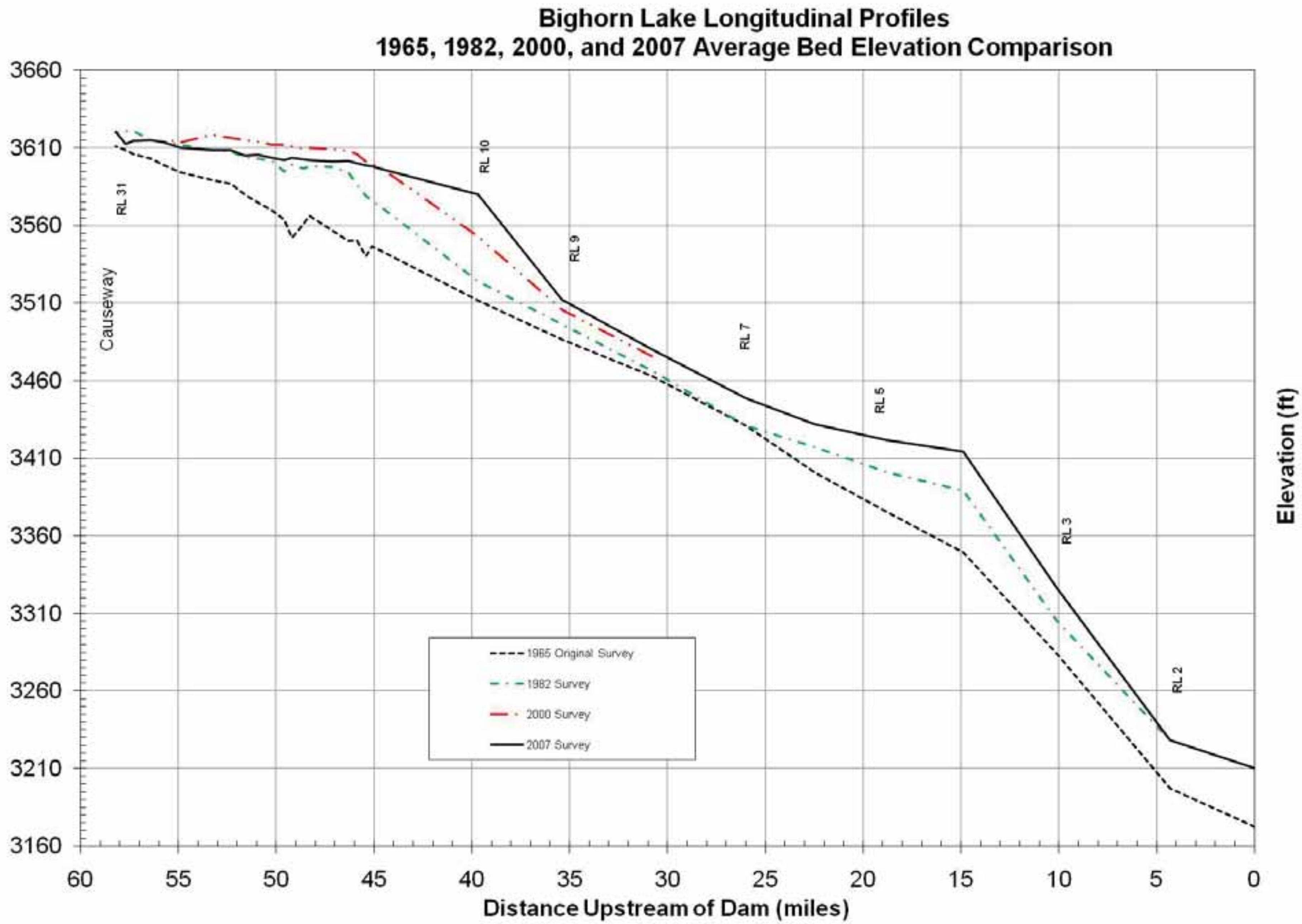

Figure 68 - Bighorn Lake Longitudinal Profiles.

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2007 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Reclamation, 1985). The ACAP program computes the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Bighorn Lake. 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 equations, 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 Bighorn Lake area and capacity computations are listed in a separate set of 2007 area and capacity tables published at 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2007). A description of the computations and coefficients output from the ACAP program is included with these tables. The original and 2007 area-capacity relationships are listed on Table 2 and the curves are plotted on Figure 69. As of July 2007, at flood control elevation 3,657.0, the surface area was 17,279 acres with a total capacity of 1,278,896 acre-feet.

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RESERVOIR SEDIMENT
DATA SUMMARY

Bighorn Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER: Bureau of Reclamation	2. STREAM: Bighorn River	3. STATE: Montana - Wyoming
	4. SEC TWP. RANGE	5. NEAREST P.O. Hardin, MT	6. COUNTY Bighorn
	7. LAT 45 ° 18 ' 26 " LONG 107 ° 57 ' 25 "	8. TOP OF DAM ELEVATION: 3,660.0 [1]	9. SPILLWAY CREST EL. 3,593.0 [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
	a. SURCHARGE	3,660.0 [3]				
	b. FLOOD CONTROL	3,657.0	17,298	259,000	1,375,000	11/1/65
	c. POWER					
						16. DATE NORMAL OPERATIONS BEGAN
	d. JOINT USE	3,640.0	12,685	250,000	1,116,000	
	e. CONSERVATION	3,614.0	7,410	363,672	866,000	
	f. INACTIVE	3,547.0	4,192	483,361	502,328	
	g. DEAD	3,296.5	407	16,008	16,008	8/1/67
	17. LENGTH OF RESERVOIR 61.8 [4] MILES		AVG. WIDTH OF RESERVOIR 0.44 MILES			

BASIN			
	18. TOTAL DRAINAGE AREA 19,650 [5] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 20.5 [6] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 10,270 [5] SQUARE MILES		23. MEAN ANNUAL RUNOFF 2.24 [7] INCHES
	20. LENGTH 226 MILES	AVG. WIDTH 168 MILES	24. MEAN ANNUAL RUNOFF [7] 2,339,500 ACRE-FEET
	21. MAX. ELEVATION 13,165	MIN. ELEVATION 3,166	25. ANNUAL TEMP, MEAN 50 °F RANGE -27 °F to 106 °F [6]

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/I RATIO AF/AF
	11/1/1965			Contour (D)	5 and 20-ft	17,298 [8]	1,382,310 [8]	0.59
	08/1982	16.8	16.8	Range (D)	51	17,279	1,328,360	
	7/2007	24.9	41.7	Contour (D)	5-ft	17,279	1,278,896	0.55

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	36. WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
11/1/1965	20.5					
8/1982		2,690,800 [7]	3,458,707	45,205,500	2,690,800	45,205,500
7/2007		2,102,400	3,443,795	52,350,300	2,339,500	97,555,800

26. DATE OF SURVEY	37 PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
11/1/1965						
08/1982	53,950 [9]	3,221	0.314	53,950	3,221	0.314
7/2007	49,464	1,986	0.193	103,414	2,480	0.242

26. DATE OF SURVEY	39 AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	b. TOT.
08/1982	60*	410	410	0.233 [10]	3.90	[10]	1,290
07/2007				0.179	7.480		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION									
	3166-3260	3260-3296.5	3296.5-3360	3360-3420	3420-3480	3480-3520	3520-3560	3560-3600	3600-3640	3640-3657	3657-3660
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
7/2007	1.7	0.8	7.0	15.8	4.5	4.2	7.5	25.1	32.7	0.7	0.0

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	50-60	60-70	70-80	80-90	90-100	100-105	105-111	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

Table 1 – Reservoir Sediment Data Summary (page 1 of 3).

45. **RANGE IN RESERVOIR OPERATION** [9]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1966	3,573.1	3,166.0	1,480,881	1987	3,637.7	3,609.0	2,064,115
1967	3,656.4	3,573.3	3,458,701	1988	3,633.2	3,610.8	1,619,255
1968	3,637.6	3,585.7	2,805,526	1989	3,621.2	3,583.3	1,367,537
1969	3,637.3	3,588.9	2,538,976	1990	3,635.6	3,593.4	1,942,053
1970	3,644.5	3,584.4	2,536,718	1991	3,647.1	3,594.8	2,639,746
1971	3,638.2	3,591.2	3,215,821	1992	3,641.9	3,612.5	1,925,227
1972	3,639.4	3,592.5	3,320,210	1993	3,643.5	3,612.0	2,092,195
1973	3,638.2	3,618.0	2,738,186	1994	3,640.1	3,603.4	1,657,115
1974	3,639.9	3,600.7	3,094,673	1995	3,646.3	3,608.1	2,718,942
1975	3,646.8	3,597.2	3,221,723	1996	3,637.0	3,605.4	2,842,569
1976	3,635.6	3,598.4	2,966,926	1997	3,651.7	3,593.2	3,516,452
1977	3,636.4	3,613.8	1,740,632	1998	3,642.6	3,614.5	2,787,870
1978	3,648.6	3,599.2	2,887,245	1999	3,649.3	3,605.1	3,443,795
1979	3,637.8	3,611.9	2,370,933	2000	3,638.6	3,619.4	1,776,762
1980	3,639.0	3,600.1	2,226,961	2001	3,625.2	3,601.9	1,347,516
1981	3,641.1	3,610.3	2,143,235	2002	3,605.0	3,576.2	1,029,612
1982	3,640.2	3,595.5	2,458,122	2003	3,616.0	3,572.8	1,208,318
1983	3,647.0	3,612.0	3,259,036	2004	3,611.8	3,581.8	1,041,572
1984	3,640.8	3,608.4	2,887,520	2005	3,642.8	3,583.3	1,847,984
1985	3,637.8	3,611.3	1,883,586	2006	3,636.2	3,598.4	1,432,634
1986	3,640.6	3,588.9	2,852,666	2007	3,638.2	3,603.1	1,166,216
				TOTAL			

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

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
Original	**SURVEY**		3,460.0	2,367	220,891	3,595.0	6,043	747,503
3,166.0	0	0	3,480.0	2,803	272,591	3,600.0	6,474	778,796
3,180.0	3	30	3,500.0	3,311	333,731	3,605.0	6,775	811,918
3,200.0	67	731	3,520.0	3,674	403,581	3,610.0	7,088	846,576
3,220.0	79	2,191	3,540.0	4,048	480,801	3,615.0	7,508	883,066
3,240.0	165	4,631	3,545.0	4,136	501,261	3,620.0	8,152	922,216
3,260.0	220	8,481	3,550.0	4,289	522,323	3,625.0	8,746	964,461
3,280.0	340	14,081	3,555.0	4,399	544,043	3,630.0	9,882	1,011,031
3,300.0	421	21,687	3,560.0	4,515	566,328	3,635.0	11,179	1,063,683
3,320.0	597	31,871	3,565.0	4,660	589,266	3,640.0	12,685	1,123,343
3,340.0	722	45,061	3,570.0	4,797	612,908	3,645.0	14,427	1,191,123
3,360.0	947	61,751	3,575.0	5,001	637,403	3,650.0	15,768	1,266,611
3,380.0	1,134	82,561	3,580.0	5,280	663,106	3,655.0	16,852	1,348,161
3,400.0	1,425	108,151	3,585.0	5,468	689,976	3,657.0	17,298	1,382,311
3,420.0	1,696	139,361	3,590.0	5,750	718,021	3,660.0	17,958	1,435,186
3,440.0	2,045	176,771	3,595.0	6,043	747,503			
1982	**SURVEY**		3,480.0	2,795	259,424	3,595.0	5,296	717,564
3,211.2	0	0	3,500.0	3,244	319,814	3,600.0	5,511	744,582
3,220.0	51	224	3,520.0	3,631	388,564	3,605.0	5,814	772,894
3,240.0	133	2,064	3,540.0	4,016	465,034	3,610.0	6,317	803,222
3,260.0	208	5,474	3,545.0	4,103	485,332	3,615.0	7,065	836,677
3,280.0	291	10,464	3,550.0	4,218	506,134	3,620.0	7,699	873,587
3,300.0	400	17,374	3,555.0	4,313	527,462	3,625.0	8,532	914,164
3,320.0	531	26,684	3,560.0	4,392	549,224	3,630.0	9,611	959,522
3,340.0	679	38,784	3,565.0	4,512	571,484	3,635.0	10,997	1,011,042
3,360.0	850	54,074	3,570.0	4,624	594,324	3,640.0	12,598	1,070,029
3,380.0	1,045	73,024	3,575.0	4,734	617,719	3,645.0	14,396	1,137,514
3,400.0	1,350	96,974	3,580.0	4,873	641,737	3,650.0	15,728	1,212,824
3,420.0	1,667	127,144	3,585.0	4,963	666,327	3,655.0	16,839	1,294,242
3,440.0	2,032	164,134	3,590.0	5,118	691,529	3,657.0	17,279	1,328,360
3,460.0	2,351	207,964	3,595.0	5,296	717,564	3,660.0	17,940	1,381,189
2007	**SURVEY**		3,480.0	2,728	241,774	3,595.0	5,051	684,231
3,200.0	0	0	3,500.0	3,204	301,098	3,600.0	5,212	709,888
3,220.0	67	670	3,520.0	3,528	368,420	3,605.0	5,321	736,221
3,240.0	158	2,922	3,540.0	3,868	442,383	3,610.0	5,781	763,976
3,260.0	220	6,704	3,545.0	3,960	461,954	3,614.0	6,335	788,208
3,280.0	317	12,077	3,547.0	3,996	469,910	3,620.0	7,374	829,234
3,300.0	378	19,027	3,550.0	4,051	481,981	3,625.0	8,166	868,085
3,320.0	487	27,676	3,555.0	4,142	502,465	3,630.0	9,131	911,329
3,340.0	582	38,367	3,560.0	4,218	523,366	3,635.0	10,986	961,621
3,360.0	772	51,903	3,565.0	4,316	544,702	3,640.0	12,595	1,020,573
3,380.0	876	68,380	3,570.0	4,405	566,505	3,645.0	14,396	1,088,050
3,400.0	1,039	87,532	3,575.0	4,508	588,787	3,650.0	15,728	1,163,360
3,420.0	1,524	113,160	3,580.0	4,632	611,638	3,655.0	16,839	1,244,777
3,440.0	1,990	148,291	3,585.0	4,764	635,128	3,657.0	17,279	1,278,896
3,460.0	2,315	191,340	3,590.0	4,913	659,321	3,660.0	17,940	1,331,725

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

47. REMARKS AND REFERENCES		
[1] Elevations in feet based on original project datum reported as NGVD29; around 2.6 feet lower than NAVD88.		
[2] Spillway crest elevation, top of spillway gate elevation 3,657.0.		
[3] Elevations and basic values from Reservoir Capacity Allocation in SOP, dated 1/2000.		
[4] Reservoir lengths from 1982 study.		
[5] Total drainage area at dam. The net sediment contributing areas excludes the reservoir area and basins above Buffalo Bill, Boysen, and and Anchor Dams.		
[6] Bureau of Reclamation Project Data Book, 1981.		
[7] Mean annual runoff by water years, from 1966 through 2007, from Reclamation's Regional computations.		
[8] Original capacity adjusted for volume within river channel during 1982 study.		
[9] End of month maximum and minimum elevations along with inflow computations by water year.		
48. AGENCY MAKING SURVEY	Bureau of Reclamation	
49. AGENCY SUPPLYING DATA	Bureau of Reclamation	DATE September 2010

Table 1 – Reservoir Sediment Data Summary (page 3 of 3).

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1	2	3	4	5	6	7	8	9	10	11	12
					1982	1982			2007	2007	
	Original	Original	1982	1982	Sediment	Percent	2007	2007	Sediment	Percent	Percent
Elevation	Area	Capacity	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	Depth
3,660.0	17,958	1,435,186	17,940	1,381,189	53,997	100.0	17,940	1,331,725	103,461	100.0	100.0
3,657.0	17,298	1,382,311	17,279	1,328,360	53,951	99.9	17,279	1,278,896	103,415	100.0	99.4
3,655.0	16,852	1,348,161	16,839	1,294,242	53,919	99.9	16,839	1,244,777	103,384	99.9	99.0
3,650.0	15,768	1,266,611	15,728	1,212,824	53,787	99.6	15,728	1,163,360	103,251	99.8	98.0
3,645.0	14,427	1,191,123	14,396	1,137,514	53,609	99.3	14,396	1,088,050	103,073	99.6	97.0
3,640.0	12,685	1,123,343	12,598	1,070,029	53,314	98.7	12,595	1,020,573	102,770	99.3	96.0
3,635.0	11,179	1,063,683	10,997	1,011,042	52,641	97.5	10,986	961,621	102,062	98.6	94.9
3,630.0	9,882	1,011,031	9,611	959,522	51,509	95.4	9,131	911,329	99,702	96.4	93.9
3,625.0	8,746	964,461	8,532	914,164	50,297	93.1	8,166	868,085	96,376	93.2	92.9
3,620.0	8,152	922,216	7,699	873,587	48,629	90.1	7,374	829,234	92,982	89.9	91.9
3,615.0	7,508	883,066	7,065	836,677	46,389	85.9	6,474	794,613	88,453	85.5	90.9
3,614.0	7,424	875,768	6,915	829,687	46,081	85.3	6,335	788,208	87,560	84.6	90.7
3,610.0	7,088	846,576	6,317	803,222	43,354	80.3	5,781	763,976	82,600	79.8	89.9
3,605.0	6,775	811,918	5,814	772,894	39,024	72.3	5,321	736,221	75,697	73.2	88.9
3,600.0	6,475	778,796	5,511	744,582	34,214	63.4	5,212	709,888	68,908	66.6	87.9
3,595.0	6,043	747,503	5,296	717,564	29,939	55.4	5,051	684,231	63,272	61.2	86.8
3,590.0	5,750	718,021	5,118	691,529	26,492	49.1	4,913	659,321	58,700	56.7	85.8
3,585.0	5,468	689,976	4,963	666,327	23,649	43.8	4,764	635,128	54,848	53.0	84.8
3,580.0	5,280	663,106	4,873	641,737	21,369	39.6	4,632	611,638	51,468	49.7	83.8
3,575.0	5,001	637,403	4,734	617,719	19,684	36.5	4,508	588,787	48,616	47.0	82.8
3,570.0	4,797	612,908	4,624	594,324	18,584	34.4	4,405	566,505	46,403	44.9	81.8
3,565.0	4,660	589,266	4,512	571,484	17,782	32.9	4,316	544,702	44,564	43.1	80.8
3,560.0	4,515	566,328	4,392	549,224	17,104	31.7	4,218	523,366	42,962	41.5	79.8
3,555.0	4,399	544,043	4,313	527,462	16,581	30.7	4,142	502,465	41,578	40.2	78.7
3,550.0	4,289	522,323	4,218	506,134	16,189	30.0	4,051	481,981	40,342	39.0	77.7
3,547.0	4,197	509,686	4,149	493,584	16,102	29.8	3,996	469,910	39,776	38.4	77.1
3,545.0	4,136	501,261	4,103	485,332	15,929	29.5	3,960	461,954	39,307	38.0	76.7
3,540.0	4,048	480,801	4,016	465,034	15,767	29.2	3,868	442,383	38,418	37.1	75.7
3,520.0	3,674	403,581	3,631	388,564	15,017	27.8	3,528	368,420	35,161	34.0	71.7
3,500.0	3,311	333,731	3,244	319,814	13,917	25.8	3,204	301,098	32,633	31.5	67.6
3,480.0	2,803	272,591	2,795	259,424	13,167	24.4	2,728	241,774	30,817	29.8	63.6
3,460.0	2,367	220,891	2,351	207,964	12,927	23.9	2,315	191,340	29,551	28.6	59.5
3,440.0	2,045	176,771	2,032	164,134	12,637	23.4	1,990	148,291	28,480	27.5	55.5
3,420.0	1,696	139,361	1,667	127,144	12,217	22.6	1,524	113,160	26,201	25.3	51.4
3,400.0	1,425	108,151	1,350	96,974	11,177	20.7	1,039	87,532	20,619	19.9	47.4
3,380.0	1,134	82,561	1,045	73,024	9,537	17.7	876	68,380	14,181	13.7	43.3
3,360.0	947	61,751	850	54,074	7,677	14.2	772	51,903	9,848	9.5	39.3
3,340.0	722	45,061	679	38,784	6,277	11.6	582	38,367	6,694	6.5	35.2
3,320.0	597	31,871	531	26,684	5,187	9.6	487	27,676	4,195	4.1	31.2
3,300.0	421	21,687	400	17,374	4,313	8.0	378	19,027	2,660	2.6	27.1
3,296.5	407	20,236	381	16,008	4,228	7.8	367	17,724	2,512	2.4	26.4
3,280.0	340	14,081	291	10,464	3,617	6.7	317	12,077	2,004	1.9	23.1
3,260.0	220	8,481	208	5,474	3,007	5.6	220	6,704	1,777	1.7	19.0
3,240.0	165	4,631	133	2,064	2,567	4.8	158	2,922	1,709	1.7	15.0
3,220.0	79	2,191	51	224	1,967	3.6	67	670	1,521	1.5	10.9
3,200.0	67	731	0	0	731	1.4	0	0	731	0.7	6.9
3,180.0	3	30	0	0	30	0.1	0	0	30	0.0	2.8
3,166.0	0	0	0	0	0	0.0	0	0	0	0.0	0.0

1 Reservoir water surface elevation.
2 Original, 1965 reservoir surface area.
3 Original, 1965 reservoir capacity.
4 1982 reservoir surface area.
5 1982 reservoir capacity.
6 1982 computed sediment volume, column (3) - column (5).
7 1982 measured sediment in percentage of total sediment of 53,997 acre-feet.
8 2007 reservoir surface area.
9 2007 reservoir capacity.
10 2007 computed sediment volume, column (3) - column (9).
11 2007 measured sediment in percentage of total sediment of 103,461 acre-feet.
12 Depth of reservoir expressed in percentage of total depth, 494 feet, from maximum water surface 3,660.0.

Table 2 - Bighorn Lake survey results.

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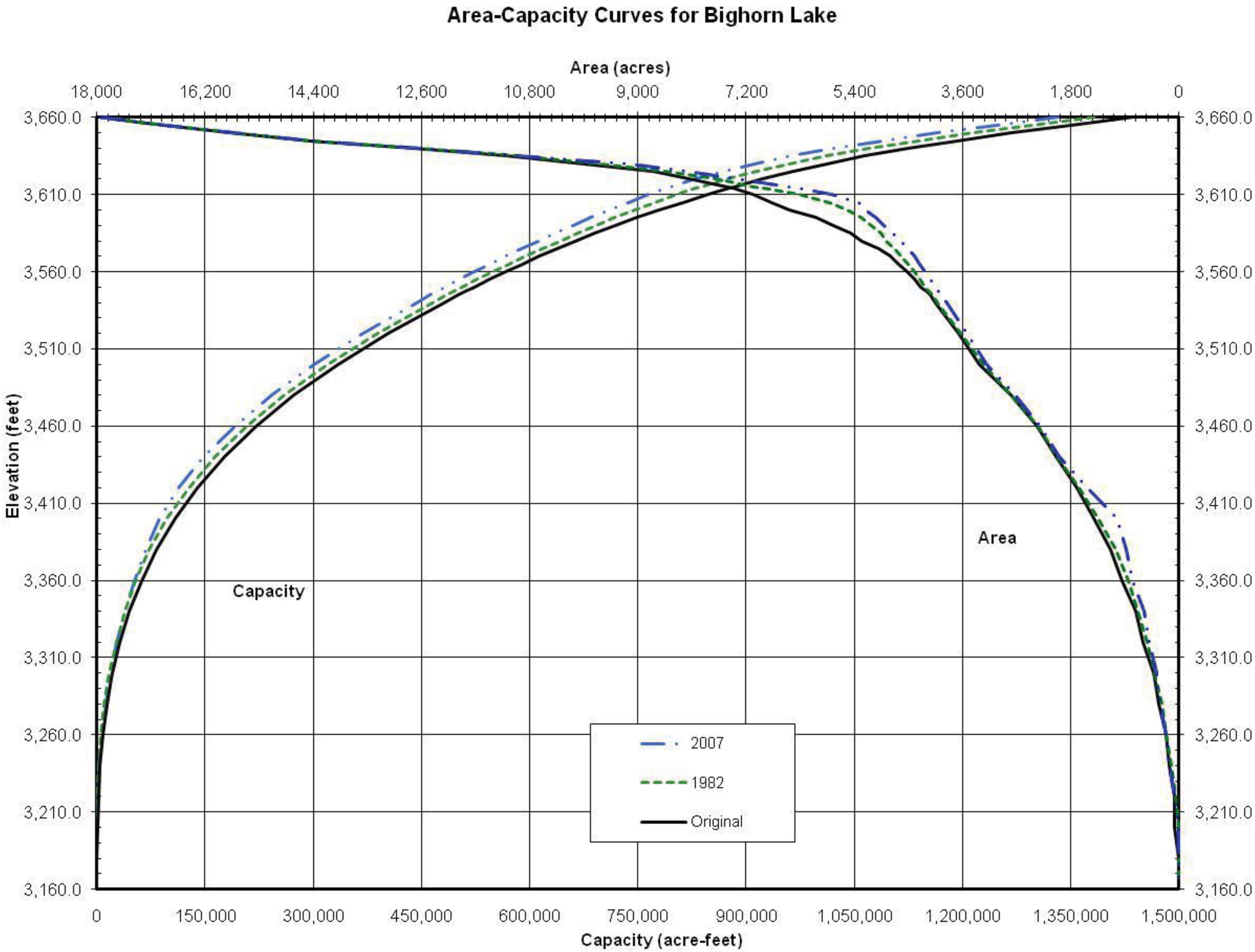

Figure 69 - Bighorn Lake Area and Capacity Plots

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Reservoir Allocations and Operations

The Yellowtail Project is operated and maintained to provide regulation of river flow for power generation, flood control, irrigation, municipal and industrial water supply, fish and wildlife enhancement, and recreational development. The July 2007 capacity table computed 1,331,725 acre-feet of total storage below the maximum water surface elevation 3,660.0 (Table 1). The following values are from the July 2007 capacity table:

- 52,829 acre-feet of surcharge storage, elevation 3,657.0 through 3,660.0.
- 258,323 acre-feet of exclusive flood control storage, elevation 3,640.0 through 3,657.0.
- 232,365 acre-feet of joint use pool storage, elevation 3,614.0 through 3,640.0.
- 318,298 acre-feet of active conservation pool storage, elevation 3,547.0 through 3,614.0.
- 452,186 acre-feet of inactive pool storage, elevation 3,296.5 through 3,547.0.
- 17,724 acre-feet of dead pool storage below elevation 3,296.5.

The computed annual inflow and reservoir stage records for Bighorn Lake are listed by water year in Table 1 for the 1966 through 2007 period. The inflow values, computed by Reclamation, show the annual fluctuation with a computed average annual inflow of 2,339,500 acre-feet. The maximum end of month reservoir elevation of 3,656.4 was recorded during water year 1967. Since this high water event, a minimum end of month reservoir elevation of 3,572.8 was recorded during water year 2003. The data shows that from 2001 through 2004 the reservoir operated below normal water levels due to severe drought conditions. During the drought years of 2001 through 2004 the maximum reservoir elevation was less than 3,626 and only reached elevation 3,605.0 during water year 2002.

2007 Analyses of Results

The Bighorn Lake original, 1982, and 2007 area and capacity values are illustrated on Figure 69 and the results are listed on Tables 1 and 2. These presentations illustrate the capacity change that has occurred during the 41.7 years of reservoir operations. This study found that as of July 2007, at reservoir water surface elevation (feet) 3,657.0, the surface area was 17,279 acres with a total capacity of 1,278,896 acre-feet. Since the reservoir’s 1965 initial filling 103,415 acre-feet of sediment have accumulated in Bighorn Lake with an average annual rate of 2,480 acre-feet. These results were computed using a modified contour, range line, and width area adjustment methods similar to the 1982 sedimentation study. These were the best means to show change, over time, due to sediment deposition. The results of the 2007 Bighorn Lake study provide up-to-date surface area and capacity information for the reservoir. This study had adequate information to develop the 2007 surface areas and resulting capacity as presented in this report. Aerial collection combined with total detailed bathymetry would be required for total reservoir topography development.

Since the 1982 reservoir survey, the 2007 survey measured a net capacity loss of 49,464 acre-feet and an average annual rate of 1,986 acre-feet compared to the 1982 average rate of 3,221 acre-feet. This was around a 38 percent reduction in sediment inflow, but during this same period the average water inflow was 22 percent less, resulting in less sediment inflow. The 2007 survey measured little change at range line 2 where it appears a 20-foot barrier from a land slide located upstream of range line 3 has restricted the sediment flow downstream towards the dam. From 1982 to 2007 the sediment level upstream of this barrier increased about 25-feet or about a foot per year. At this rate the barrier could be buried by 2030 allowing a free flow of the bottom sediments toward the dam. As this occurs, and if the same deposition rate continues, the bottom sediments could reach the lowest outlet elevation of 3,296.5 by the year 2110.

During the planning phase, the original estimated 100 year sediment accumulation for Bighorn Lake was 315,000 acre-feet from elevation 3,660.0 and below. Of this amount, it was estimated that 75,000 acre-feet would deposit above pool elevation 3,547.0, meaning the remainder would be deposited below the inactive pool elevation 3,547.0. From Table 2, a comparison of the original estimate and 2007 results show that for the first 41.7 years of reservoir operations 39,776 acre-feet of sediment has deposited below elevation 3,547.0 and 63,685 acre-feet has already deposited in the active pool above elevation 3,547.0.

The 2007 study measured a minimum bottom elevation of 3,210 upstream of range line 1 with little to no change since the 1982 survey. When compared to the original minimum bottom elevation of 3,174, there is nearly 47 feet of sediment accumulation upstream of range line 1 and the dam. It is assumed much of this build-up was behind the cofferdam during construction and during initial filling. Future collection will be required to better monitor and project the sediment build-up at the dam and throughout the reservoir.

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Appendix

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Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates

Range	Elevation	North	East	Distance (feet)	Bearing
R-1-L	3674.23	479,715.86	2,396,128.40		
R-1-R	3799.44	478,910.07	2,397,152.93		
R-1				1,303.44	S. 51°48'54" E.
R-2-L	3664.65	470,698.87	2,384,422.42		
R-2-R	3701.32	470,267.40	2,385,936.81		
R-2				1,574.66	N. 74°05'49" W.
R-2A-L	3688.65	467,397.20	2,386,474.86		
R-2A-R	3670.50	468,608.75	2,386,852.20		
R-2A				1,268.95	N. 17°17'57" E.
R-3-L	3681.04	456,907.66	2,365,954.89		
R-3-R	3665.29	456,440.16	2,368,295.08		
R-3				2,386.42	S. 78°42'10" E.
R-3A-L	3676.78	449,457.09	2,367,481.31		
R-3A-R	3662.37	452,512.62	2,369,330.53		
R-3A				3,571.54	N. 31°10'57" E.
R-4-L	4129.09	443,898.73	2,352,157.15		
R-4-R	3699.46	442,728.78	2,352,843.75		
R-4				1,356.54	N. 30°24'26" W.
R-4A-L	4133.06	444,069.40	2,351,748.28		
R-4A-R	4097.11	443,329.97	2,351,388.24		
R-4A				822.43	N. 25°57'44" E.
R-5-L	4154.35	435,698.14	2,348,958.61		
R-5-R	4144.64	434,302.13	2,349,243.63		
R-5				1,424.81	N. 11°32'22" W.
R-6-L	4149.86	426,737.43	2,343,372.10		
R-6-R	4142.73	425,764.40	2,343,732.05		
R-6				1,037.34	N. 20°18'13" W.
R-7-L	4086.578	414,976.87	2,338,027.83		
R-7-R	3766.0	414,830.39	2,338,985.42		
R-7				968.73	S. 81°18'12" E.
R-8-L	3665.02	404,686.85	2,334,165.20		
R-8-R	3669.71	404,507.74	2,334,891.12		
R-8				747.69	S. 76°08'23" E.
R-9-L	4083.51	387,458.21	2,325,574.83		
R-9-R	4078.94	388,082.58	2,326,530.52		
R-9				1,141.57	N. 56°50'34" E.

Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates - Continued

Range	Elevation	North	East	Distance (feet)	Bearing
R-10-L	4534.19	374,962.63	2,323,260.09		
R-10-R	3671.62	374,325.99	2,324,000.89		
R-10				976.78	S. 49°19'28" E.
R-10A-L	3670.96	373,771.80	2,323,601.73		
R-10A-R	3671.76	374,130.38	2,323,837.43		
R-10A				429.11	S. 33°19'02" E.
R-11-L	3752.71	356,897.75	2,324,952.58		
R-11-R	3753.44	356,445.21	2,325,467.43		
R-11				685.49	S. 48°41'01" E.
R-12-L	3681.26	354,846.92	2,325,472.28		
R-12-R	3732.91	355,165.12	2,325,730.20		
R-12				409.59	S. 39°01'40" W.
R-13-L	3660.95	353,793.08	2,326,080.62		
R-13-R	3662.76	353,465.49	2,326,492.45		
R-13				526.22	S. 51°29'55" E.
R-14-L	3672.16	352,705.52	2,324,335.57		
R-14-R	3682.66	351,060.66	2,325,269.08		
R-14				1,891.28	N. 29°34'35" W.
R-15-L	3675.91	352,337.45	2,322,631.73		
R-15-R	3667.31	350,466.38	2,323,534.40		
R-15				2,077.42	N. 25°45'15" W.
R-16-L	3665.56	348,945.23	2,320,112.07		
R-16-R	3671.73	349,088.98	2,323,496.47		
R-16				3,387.46	S. 87°34'04" W.
R-17-L	3663.29	347,526.77	2,325,024.15		
R-17-R	3664.74	348,444.82	2,324,603.77		
R-17				1,009.72	N. 66°58'21" W.
R-18-L	3774.96	347,414.08	2,327,028.80		
R-18-R	3669.38	348,633.80	2,327,434.76		
R-18				1,285.50	N. 65°20'02" E.
R-19-L	3672.99	346,596.44	2,328,778.94		
R-19-R	3674.12	347,020.02	2,329,299.98		
R-19				671.50	S. 50°53'26" W.
R-20-L	3690.79	345,012.73	2,329,606.70		
R-20-R	3667.95	345,493.36	2,330,726.16		
R-20				1,218.28	N. 66°45'54" E.

Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates - Continued

Range	Elevation	North	East	Distance (feet)	Bearing
R-21-L	3668.27	341,666.37	2,328,831.42		
R-21-R	3672.25	343,185.33	2,331,773.01		
R-21				3,310.62	N. 62°41'22" E.
R-22-L	3696.54	337,802.66	2,328,581.76		
R-22-R	3679.05	341,362.99	2,333,753.31		
R-22				6,278.65	N. 55°27'14" E.
R-23-L	3670.95	335,376.61	2,331,182.20		
R-23-R	3662.99	339,215.54	2,335,652.29		
R-23				5,892.29	N. 49°20'38" E.
R-24-L	3665.11	333,293.83	2,334,492.82		
R-24-R	3684.79	337,190.02	2,337,892.52		
R-24				5,170.9	N. 41°06'25" E.
R-25-L	3676.72	330,874.86	2,336,134.35		
R-25-R	3686.02	336,088.10	2,340,912.13		
R-25				7,071.44	N. 42°30'16" E.
R-26-L	3675.27	330,436.57	2,336,126.27		
R-26-R	3788.77	330,756.61	2,345,501.48		
R-26				9,380.67	N. 88°02'42" E.
R-27-L	3671.90	326,920.40	2,336,564.81		
R-27-R	3718.40	327,009.85	2,346,370.66		
R-27				9,725.26	S. 66°46'04" W.
R-28-L	3700.50	323,452.53	2,329,572.33		
R-28-R	3663.85	323,632.60	2,345,625.92		
R-28				16,054.55	S. 89°21'26" W.
R-29-L	3687.21	320,578.59	2,328,477.92		
R-29-R	3704.36	319,509.64	2,343,782.18		
R-29				15,341.55	
R-30-L	3731.49	316,064.29	2,327,573.47		
R-30-R	3700.04	317,498.38	2,343,273.14		
R-30				15,765.03	S. 84°46'51" W.
R-31-L	3698.99	312,994.55	2,335,108.00		
R-31-R	3699.85	316,092.74	2,344,408.55		
R-31				9,803.01	
R-32-L	3749.94	310,278.73	2,335,114.71		
R-32-R	3678.96	313,695.77	2,344,085.06		
R-32				9,599.13	S. 69°08'49" W.

Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates - Continued

Range	Elevation	North	East	Distance (feet)	Bearing
R-33-L	3743.18	309,485.73	2,335,522.60		
R-33-R	3706.29	311,791.68	2,347,142.48		
R-33				11,846.48	S. 78°46'33" W.
R-34-L	3739.73	306,774.16	2,337,120.70		
R-34-R	3711.28	309,907.22	2,347,774.75		
R-34				11,076.43	S. 73°34'08" W.
R-35-L	3706.51	304,240.65	2,338,609.21		
R-35-R	3729.52	306,317.63	2,348,183.38		
R-35				9,796.86	S. 77°45'37.5" W.
R-36-L	3720.33	300,786.78	2,340,215.26		
R-36-R	3747.44	302,324.18	2,348,048.58		
R-36				7,982.76	S. 78°73'46" W.
R-37-L	3827.99	298,246.02	2,341,540.33		
R-37-R	3730.10	298,350.46	2,347,422.82		
R-37				5,883.42	S. 88°58'58" W.
R-38-L	3700.57	295,892.32	2,341,892.56		
R-38-R	3704.77	295,984.23	2,346,047.12		
R-38				4,155.55	S. 88°43'55" W.
R-39-L	3699.06	293,198.66	2,340,946.30		
R-39-R	3732.15	293,259.04	2,347,191.12		
R-39				6,244.93	S. 89°26'45" W.
R-40-L	3665.12	290,247.20	2,342,742.80		
R-40-R	3705.47	290,878.17	2,346,551.52		
R-40				3,860.63	S. 80°35'33" W.
R-41-L	3696.41	287,299.13	2,341,189.89		
R-41-R	3722.74	288,065.68	2,347,836.94		
R-41				6,691.10	S. 83°25'20" W.
R-42-L	3698.32	284,460.88	2,341,578.58		
R-42-R	3733.05	284,713.00	2,347,616.11		
R-42				6,042.84	S. 87°36'30" W.
R-43-L	3714.66	282,621.42	2,342,342.11		
R-43-R	3704.45	282,664.65	2,346,508.68		
R-43				4,166.79	S. 89°24'20" W.

Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates - Continued

Range	Elevation	North	East	Distance (feet)	Bearing
R-44-L	3734.16	279,490.04	2,341,694.81		
R-44-R	3707.56	278,706.49	2,344,278.42		
R-44				2,699.81	N. 73°07'43" W.
R-45-L	3731.5	276,786.50	2,340,974.19		
R-45-R	3832.5	276,526.62	2,341,672.84		
R-45				745.43	N. 69°35'49" W.
R-46-L	3702.37	274,115.45	2,340,182.48		
R-46-R	3743.01	274,121.14	2,340,794.66		
R-46				612.20	S. 89°28'04" W.
R-47-L	3753.59	271,912.52	2,340,840.72		
R-47-R	3713.25	272,484.60	2,341,583.26		
R-47				937.36	S. 52°23'17" W.
R-48-L	3710.08	270,748.64	2,341,502.64		
R-48-R	3730.02	270,859.95	2,344,005.64		
R-48				2,505.47	N. 87°27'13" W.
R-49-L	3826.99	269,633.01	2,341,244.20		
R-49-R	3718.27	263,601.62	2,342,572.58		
R-49				1,681.80	N. 52°11'10" W.
R-50-L	3791.96	265,832.13	2,340,614.60		
R-50-R	3714.52	268,375.51	2,342,708.41		
R-50				3,294.38	S. 39°27'42" W.
R-51-L	3698.89	266,415.22	2,342,539.64		
R-51-R	3740.36	266,433.81	2,345,993.17		
R-51				3,453.58	N. 89°41'30" E.
R-52-L	3719.26	264,287.98	2,344,107.49		
R-52-R	3742.39	264,575.24	2,345,841.15		
R-52				1,757.34	S. 80°35'38" W.
R-53-L	3792.36	260,819.03	2,344,818.08		
R-53-R	3744.25	262,983.65	2,346,824.44		
R-53				2,951.45	N. 56°44'33" W.
R-54-L	3719.60	260,145.48	2,347,434.02		
R-54-R	3754.53	260,773.28	2,351,205.10		
R-54				3,823.03	S. 80°32'37" W.
R-55-L	3731.08	258,512.33	2,348,397.77		
R-55-R	3699.11	258,316.13	2,350,677.10		
R-55				2,287.75	N. 85°04'56.3" W.

Yellowtail Unit - Bighorn Lake
Sediment Range End Coordinates - Continued

Range	Elevation	North	East	Distance (feet)	Bearing
R-56-L	3807.63	254,188.50	2,351,223.16		
R-56-R	3700.93	257,584.52	2,350,881.44		
R-56				3,413.09	S. 05°44'37.7" E.
R-57-L	3743.85	254,646.90	2,353,039.88		
R-57-R	3756.27	258,237.73	2,353,338.11		
R-57				3,603.19	S. 04°44'50" W.
R-58-L	3736.31	254,619.68 ·	2,353,527.08		
R-58-R	3745.46	256,504.60	2,355,277.75		
R-58				2,572.61	S. 42°51'55" W.
R-101-L	3718.04	356,896.51	2,324,692.21		
R-101-R	3733.93	356,641.19	2,324,839.33		
R-101				294.67	
R-102-L	3668.09	357,157.37	2,322,837.71		
R-102-R	3688.63	356,186.73	2,323,006.08		
R-102				985.13	
R-103-L	3670.07	356,834.55	2,321,049.15		
R-103-R	3671.50	355,709.68	2,321,570.04		
R-103				1,239.62	
R-104-L	3662.33	355,775.22	2,319,139.94		
R-104-R	3666.56	354,957.28	2,319,633.03		
R-104				955.07	