BOYSEN RESERVOIR

1994 SEDIMENTATION SURVEY

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13. ABSTRACT ***(Maximum 200 words)***

Bureau of Reclamation (Reclamation) surveyed the underwater area of Boysen Reservoir in July 1994 to develop topographic maps and compute storage-elevation relationship (area-capacity tables). The data were also used to calculate reservoir capacity lost to sediment accumulation since dam closure in October 1951. The bathymetric survey used sonic depth recording equipment interfaced with a GPS (global positioning system) that gave continuous sounding positions. This survey was the first conducted by Reclamation using newly acquired GPS equipment. Underwater topography was developed by computer program using 1994 collected data. The above-water reservoir area was measured from the USGS quad (United States Geological Survey quadrangle) maps developed from aerial photography and Reclamation resurvey data. The new reservoir contour map and surface areas are a combination of hydrographic survey data and USGS aerial topography.

As of July 1994, at reservoir spillway crest elevation (feet) 4725.0, surface area was 19,602.5 acres, total capacity was 741,594 acre-feet, and active capacity was 522,414 acre-feet. Since initial filling in October 1951, about 78,171 acre-feet of Boysen Reservoir capacity has been lost below elevation 4725.0—a 9.54-percent loss in reservoir volume. Since 1951, average rate of reservoir capacity lost below elevation 4725.0 is 1,826.4 acre-feet per year.

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BOYSEN RESERVOIR

1994 SEDIMENTATION SURVEY

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September 1996

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U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Boysen Dam, Reservoir, and Powerplant are features of the Boysen Unit of the Pick-Sloan Missouri Basin Program. The dam, located in Fremont County, Wyoming, on the Wind River, is located about 20 miles upstream from Thermopolis, Wyoming (fig. 1). The reservoir created by the dam is used for irrigation storage, power generation, flood and silt control, recreation, and fish and wildlife conservation. The Bureau of Reclamation (Reclamation) and the Corps of Engineers (Corps) cooperated in establishing the regulations for the control of the reservoir. The Corps prescribes the regulations when storage is in the flood-control zone, and Reclamation prescribes regulations when the storage is below the flood zone.

Investigations of this area were made by Reclamation in 1904 and again in 1916-17. In 1908, a concrete dam (Old Boysen Dam) was constructed across the Wind River about 1.5 miles downstream from the present dam location, primarily for power generation. A 1923 flood raised the reservoir water surface, inundating several miles of railroad tracks and resulting in a portion of the dam being blasted away to reduce future flooding. Repairs to the dam were never undertaken and power generation ceased in the 1930s. The dam was removed in 1948 to improve the tail-water conditions for the present Boysen Powerplant.

A 1939 Corps study of the Bighorn River recommended construction of a dam at the Old Boysen Dam site. In 1941, Reclamation resumed study investigations and recommended construction of a dam 1.5 miles upstream from the old site where relocation costs would be more reasonable. The project was authorized by the United States 78th Congress with the Flood Control Act of December 22, 1944. Construction began on Boysen Dam and Powerplant along with relocation of the CB&Q Railroad on September 19, 1947, and was completed December 11, 1952. Closure of the dam and first reservoir storage began on October 11, 1951.

Boysen Dam is an zoned earth and rockfill structure (fig. 2) with:

- a structural height* of 220 feet
- a hydraulic height of 117 feet
- a crest elevation of 4758.0 feet
- a top crest width of 30 feet
- a crest length of 1,143 feet

Boysen Dam spillway has a crest elevation of 4725.0 at the top of the control gates with a maximum capacity of 25,000 cubic feet per second. The spillway is located on the right abutment of the dam and consists of:

- an unlined approach channel
- a gate structure with an ogee-type overflow weir with crest elevation 4700.0
- a hoist bridge
- a highway bridge
- two 30-foot-wide by 25-foot-high radial gates
- a concrete control house, chute, and stilling basin
- a riprap-lined inlet channel

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

The river outlet works is located on the right abutment, has a capacity of 1,300 ft^3/s at elevation 4725.0, and consists of:

- an intake trashrack
- a 57-inch branch outlet pipe from the 15-foot-diameter penstock
- a 66-inch-diameter outlet pipe
- a 48-inch ring-follower gate
- a 48-inch hollow-jet valve in each of the two outlet pipes
- a stilling basin
- a downstream river channel

The powerplant is located on the right bank of the river, adjacent to the spillway, and at the downstream toe of the embankment. The capacity is 15,000 kilowatts developed by two 7,500-kilowatt units operating at an average head of 99 feet. Each unit is served by a 10-foot-diameter steel penstock joined to a common 15-foot-diameter steel penstock immediately upstream from the powerplant.

The original reservoir survey measured a surface area of 19,660 acres at reservoir spillway crest elevation 4725.0. The original calculated total capacity at reservoir elevation 4725.0 was 819,132 acre-feet, of which 146,652 acre-feet was joint use, 413,241 acre-feet was active conservation space, and 259,239 acre-feet was inactive and dead storage. An additional surcharge storage capacity of about 671,000 acre-feet is available between spillway crest elevation 4725.0 and the design maximum water surface of 4752.0. At elevation 4725.0, the reservoir length is around 18 miles and has an average width of 1.7 miles.

SUMMARY AND CONCLUSIONS

This Reclamation (Bureau of Reclamation) report presents the 1994 results of the second extensive survey of Boysen Reservoir. The primary objectives of the survey were to gather data needed to:

- develop underwater topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since closure of Boysen Dam

The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS (differential global positioning system) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates as the survey boat was navigated along grid lines covering Boysen Reservoir. The positioning system provided information to allow the boat operator to maintain course along these grid lines. Water surface elevations recorded by a Reclamation gage during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations.

The above-water Boysen Reservoir areas were measured from digitized USGS quad maps of the reservoir along with resurvey data from several of the original sedimentation range lines located above the 1994 reservoir water surface. The new topographic map of Boysen Reservoir is a combination of underwater measured topography, digitized map contours, and range line survey data. The 1994 underwater surface areas at predetermined 5-foot contour intervals were generated by a computer graphics program using the collected data. The area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments.

Tables 1 and 2 contain a summary of the Boysen Reservoir sedimentation and watershed characteristics for the 1994 survey. The 1994 survey determined that the reservoir has a total storage capacity of 741,594 acre-feet and a surface area of 19,602.5 acres at water surface elevation 4725.0. Since closure in October 1951, the reservoir has accumulated an estimated volume of 78,171 acre-feet of sediment below elevation 4725.0. This volume represents an 9.54-percent loss in total capacity and an average loss of 1,826.4 acre-feet per year.

RESERVOIR OPERATIONS

The reservoir is a multi-use facility having (following values are from July 1994 area-capacity tables):

- 525,110 acre-feet of surcharge storage between elevations 4,732.0 and 4,752.0.
- 146,201 acre-feet of flood control storage between elevations 4,725.0 and 4,732.0.
- 144,229 acre-feet of joint storage between elevations 4,717.0 and 4,725.0.
- 378,184 acre-feet of conservation storage between elevations 4,685.0 and 4,717.0.
- 219,181 acre-feet of inactive and dead storage below elevation 4,685.0.

Boysen Reservoir receives the majority of its inflow from the Wind River. Available records for years 1952 through 1994 show that the average unregulated inflow into the reservoir was 1,018,293 acre-feet per year. This average would compute to a mean annual runoff of 2.48 inches for the 7,700 square mile basin. The inflow and end-of-month stage records in table 1 show the annual fluctuation of the reservoir. After initial filling to spillway crest elevation 4725.0 in 1954, available records show Boysen Reservoir operation ranging from elevation 4,684.2 in 1956 to elevation 4,730.8 in 1967.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment was mounted in the cabin of a 24-foot tri-hull aluminum vessel equipped with twin in-board motors. The hydrographic system contained on the survey vessel consisted of a GPS (global positioning system) receiver with a built-in radio and omnidirectional antenna, a dual frequency depth sounder, a helmsman display for navigation, a plotter, a computer, and hydrographic system software for collecting the underwater data. Power to the equipment was supplied by an on-board generator.

The shore equipment included a second GPS receiver with a built-in radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. The power for the shore units was provided by a 12-volt battery. To obtain the maximum radio transmission range, known datum points high above the water surface were selected.

GPS Technology and Equipment

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

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in precise orbits, about 10,900 nautical miles above the earth, each completing an orbit every 12 hours.

- The ground control segment tracks the satellites, determining their precise orbits. Periodically, the ground control segment transmits correction and other system data to all the satellites, which are then retransmitted to the user segment.

- The user segment is the GPS receivers, which measure the broadcasts from the satellites and calculate the position of the receivers.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. To calculate the receiver's position on earth, the satellite distance and the satellite's position in space are needed. The satellites transmit signals to the GPS receivers for distance measurements along with the data messages about their exact orbital location and operational status. The satellites transmit two "L" band frequencies for the distance measurement signal called L1 and L2. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time). The time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers. For hydrographic surveying the altitude, Boysen Reservoir's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel. During the Boysen Reservoir survey, a minimum of five satellites were used for position calculations; most of the time the best six available satellites were used.

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and geometric position of the satellites. Precision is affected by several factors—time, because of the clock differences, and atmospheric delays caused by the effect on the radio signal by the ionosphere. GDOP (geometric dilution of precision) describes the geometric uncertainty and is a function of the relative geometry of the satellites and the user. Generally, the closer together in angle two satellites are from the receiver, the greater the GDOP. GDOP is broken into components: PDOP is position dilution of precision (x,y,z), and HDOP is horizontal dilution of precision (x,y). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored during the Boysen Reservoir Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys.

An additional and larger error source of GPS collection is caused by false signal projection, called S/A (selective availability). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters.

A method of collection to resolve or cancel the inherent errors of GPS (satellite position or S/A, clock differences, atmospheric delay, etc.) is called DGPS (differential GPS). DGPS was used during the Boysen Reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over the geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel. For the Boysen Reservoir survey, position corrections were determined by the master receiver and transmitted via a UHF (ultra-high frequency) radio link every 3 seconds to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS resulted in positional accuracies of 1 to 2 meters for the moving vessel compared to positional accuracies of 100 meters with a single receiver.

The TSC (Technical Service Center) mobile and reference GPS units are identical in construction and consist of a 6-channel L1 C/A code continuous parallel tracking receiver, an internal modem, and a UHF radio transceiver. The differential corrections from the reference station to the mobile station are transmitted using the industry standard RTCM (Radio Technical Commission for Maritime Services) message protocol via the UHF radio link. The programming to the mobile or reference GPS unit is accomplished by entering necessary information via a notebook computer. The TSC's GPS system has the capability of establishing or confirming the land base control points by using notebook computers for logging data and post-processing software. The GPS collection system has the capability of collecting the data in 1927 or 1983 NAD (North American Datums) in the surveyed area's state plane coordinate system zone, which for the 1994 Boysen Reservoir sedimentation survey was Wyoming's 1927 NAD west central state plane zone.

Survey Method and Equipment

History.—The original Boysen Reservoir strip topography was obtained by a 1944 planetable survey. The original 5-foot surface areas were measured from the reservoir topography, mapped at a scale of one inch equals two thousand feet. A sedimentation network of 75 range lines were established from 1949 through 1952 by transit, chain, and level techniques. For the 1964 sedimentation survey, the original 75 range lines were resurveyed by land and bathymetric survey methods. To better define the sedimentation in the main reservoir area, seven additional range lines were established in 1964. The 1964 volume of accumulated sediment in Boysen

Reservoir was computed from the surveyed 82 range lines using the constant-factor method. A detailed description of the collection and analysis methods is outlined in a previous Reclamation (1965) report.

1994 Survey.—The Boysen Reservoir hydrographic survey was completed using the contour method as outlined by Blanton (1982). The procedure involved collecting adequate coordinate data for developing a reliable contour map by bathymetric survey methods. The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS capable of determining sounding locations throughout the reservoir. This reservoir survey was the first conducted by Reclamation's Sedimentation Group using the newly acquired DGPS equipment.

The original range line horizontal grid system was established in a local coordinate system. The original triangulation range line network was tied to a known USGS bench mark, labeled BigHorn, with assumed coordinates of 100,000 North and 50,000 East. To use the hydrographic GPS collection system the range line coordinate network and benchmarks for the shore base GPS unit needed to be in state plane coordinates. Using the known state plane coordinates for BigHorn benchmark and the original triangulation information, the Reclamation Cody Office computed the state plane coordinates for the range line network in Wyoming's 1927 NAD west central zone. The resulting computations are listed in table 3. Additional verification of the computations was obtained by the hydrographic survey crew by performing a static survey using the GPS receivers. During the hydrographic collection four master GPS shore station locations were used for relaying correction information to the survey vessel, with the BigHorn benchmark being one of them.

The Boysen Reservoir bathymetric survey took a total of 10 days starting on July 19, 1994, and concluding on July 28, 1994. During this time the water surface of the reservoir ranged from elevation 4711.9 to 4712.8. The survey system software was capable of recording depths and horizontal coordinates at 1-second increments as the survey boat moved along predetermined grid lines covering the reservoir. To produce adequate data for developing contours of Boysen Reservoir, the original range lines accessible by the survey boat were collected along with parallel grid lines at a spacing of 400 feet. The data were collected at 2-second intervals, and additional data were collected along the shore as the boat traversed to the next transect. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining course along these predetermined grid lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing by TSC personnel. A graph plotter was used in the field to track the boat and ensure adequate coverage during the collection process. The underwater data set includes 113,000 data points and is illustrated on figure 3. Water surface elevations recorded by a Reclamation gage at the dam were used to convert the sonic depth measurements to true lake bottom elevations.

The TSC's depth sounder has a 208-kilohertz transducer that reflects the first bottom surface, which is used for sediment surveys. The bottom is determined by measuring elapsed time between the transmission of the sound pulse from the transducer to the waterway bottom and the reception of its echo back to the transducer. Prior to data collection and periodically through the survey the depth sounder was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound which can vary due to water density, salinity, temperature, turbidity, and other conditions. The accuracy of an instantaneous reading from the depth finder is estimated to be ± 0.5 feet, but these errors are minimized over the entire survey. The estimated accuracy takes into consideration calibration error and the collection of depth data when the boat is moving.

The collected data were digitally transmitted to the computer collection system via an RS232 port. The depth sounder also produces an analog hard copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during post processing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified.

In September 1994, the range lines located above water—10, 10A, 10B, 11, 12, 12A, 13, 14, 22, 23, 31, 32, 41, 42, 43, 51, 52, 61, 62, 63, 70, and 71—were surveyed by the Great Plains Region using standard surveying procedures. The range lines are located on the main river and tributaries in the delta areas of the upper portion of the reservoir. The survey found the delta areas to be fairly flat, which was also observed by the hydrographic crew during the underwater collection. The collected data were converted into state plane coordinates using the known end point values. The state plane coordinates for the end points of range lines 10A, 10B, and 12A that were established during the 1964 survey were projected from plotted locations of the range lines on the USGS quad maps. The state plane data points were part of the data set used to produce the topographic contours.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Boysen Reservoir was developed from the 1994 collected data and from the USGS quads (7.5-minute quadrangle maps). The upper contours of Boysen Reservoir were developed by digitizing the elevation 4725.0 and 4740.0 contour lines from the USGS quad maps that cover the reservoir area. These USGS quad maps were dated 1956 and photorevised in 1978 and 1980. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to state plane coordinates using the ARC/INFO PROJECT command.

The digitized area of the USGS contour, elevation 4740.0, that encloses the reservoir area was around 25,210 acres or 99.0 percent of the original measured area of 25,450 acres. Removing the island areas within this enclosed contour gave a surface area of around 24,500 acres or around 96 percent of the original area. The difference can be attributed to several factors, such as surface area measuring methods or different methods used to develop the topography—original method by planetable survey with 5-foot contours and USGS method by aerial photography with 20-foot contours. For the purpose of the 1994 sedimentation study, the original areas above elevation 4725.0 were used as the base for surface area development. The 1994 land survey of the range lines located above elevation 4725.0 found minor differences from the original and 1964 survey results indicating little change. For the purpose of computing the 1994 capacity above elevation 4725.0, the 1964 resulting surface areas for elevations 4730.0, 4735.0, 4740.0, 4745.0 and 4752.0 were used.

The digitized area of contour elevation 4725.0, shaded blue on the USGS quad maps, was around 19,730 acres, or 100.4 percent of the original measured area of 19,660 acres. For the 1994 study, the original 4725.0 contour, as presented on the USGS quad maps, was adjusted on the Wind River and several of the tributaries using the 1994 above water range line survey data. Removing the island areas within the adjusted elevation 4725.0 clip found an area of 19,602.5 acres or around 99.7 percent of the original area. This computed area was used for the 1994 study results.

Contours for elevations below 4,725.0 were computed from collected underwater data using the TIN (triangular irregular network) surface modeling package within ARC/INFO. The underwater survey data were collected in the Wyoming west central zone state plane coordinates in NAD 1927. The collected underwater data ranged in elevation from around 4622.0 to 4710.0. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with *x,y* coordinates and *z* values. TIN was designed to deal with continuous data such as elevations.

The TIN software uses a method know as Delaunay's criteria for triangulation. Triangles are formed between all data points, including all boundary points. This method preserves all collected survey points. The method requires that a circle drawn through the three nodes of a triangle will contain no other point. This requirement means that sample points are connected to their nearest neighbors to form triangles. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great detail in the ARC/INFO V7.0.2 users documentation.

The adjusted elevation 4,725.0-foot contour that was digitized from USGS quad maps was used to perform the clip of the Boysen Reservoir TIN such that interpolation was not allowed to occur outside of the 4,725.0-foot contour. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. In creating the TIN, points that fell within a set distance of each other were weeded out to eliminate flat triangular elements. Flat triangles occur where all three points making up a triangle have the same elevation. Elimination of redundant points helped to improve the performance of the contouring process as well as helped to create more continuous contours in the lower elevations of the reservoir.

Incomplete upper contour development occurred because of the limited data between the underwater data (that ended around elevation 4710.0) and the 1994 above water range line data and the digitized 4725.0 clip. The 1994 above water range line data caused islands to develop, not the continuous contours that actually existed. This development was caused by the large distances between the range lines. To correct this problem, additional elevation points, interpreted from the 1994 range line data and the USGS 4725.0 contour clip, were added using the ARCEDIT commands. This method required the engineer to interpret elevations between the range lines, but inherit errors caused by this method were greatly reduced because of the flat sediment delta conditions that existed in the upper reservoir areas.

Island contours also occurred in the lower reservoir area from the dam upstream through the narrow canyon portion of the reservoir. This condition occurred because the stream meandered from canyon wall to canyon wall. The contour program could have completed the meandering channel contours for the affected contour elevations 4730.0 and 4735.0 if the area had been saturated with additional data. Computed island areas for these elevations are assumed to be only slightly less than if additional data were collected. Also, these areas are a small percentage of the overall reservoir area and have little effect on the overall sediment computations.

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Boysen Reservoir TIN. In addition, the contours were generalized by weeding out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had no bearing on the computation of surface areas and volumes for Boysen Reservoir. The contour topography at 5-foot intervals is presented on figures 4 through 8 (map numbers 285-D-1362 through 285-D-1366).

Development of 1994 Contour Areas

The 1994 contour surface areas for Boysen Reservoir were computed in 0.1-foot intervals from elevation 4622.0 to 4725.0 using the Boysen Reservoir TIN discussed above. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user specified elevations directly from the TIN and takes into consideration all regions of equal elevation.

1994 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The 1994 surface areas at 5-foot contour intervals from elevation 4622.0 to 4725.0 and the 1964 survey results for the 5-foot contour interval from elevation 4730.0 to 4745.0 and elevation 4752.0 were used as the control parameters for computing the Boysen Reservoir capacity. The program can compute an area and capacity at elevation increments of 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, which was set at 0.000001 for Boysen Reservoir. This capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) tests the fit until it also exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

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

where:

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

Results of the 1994 Boysen Reservoir area and capacity computations are listed in tables 1 and 2 and plotted on figure 9. A separate set of 1994 area and capacity tables was published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation, 1996). A description of the computations and coefficients output from the ACAP program is included with these tables. Computation results are listed in columns (5) and (6) of table 2. Column (2) in the table gives the original measured contour areas used in the original area and capacity computation, and column (3) gives the original capacity recomputed using ACAP. Both the original and 1994 area and capacity curves are plotted on figure 9. As of July 1994, at spillway crest elevation 4725.0 feet, the surface area was 19,602.5 acres with a total capacity of 741,594 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Sediment Longitudinal Distribution

The distribution of sediment throughout the length of the reservoir is illustrated by plots of the thalweg profile representing the original (1951), 1964, and 1994 resurveyed profiles for Badwater, Cottonwood, Five Mile, Muddy, Poison, and Tuff Creeks and for the Wind River (figs. 10 through 16). Thalweg elevations representing the original and 1964 profiles and the river channel distances of the range line locations were scaled from the thalweg profiles presented in the 1964 sedimentation report (Bureau of Reclamation, 1965). The average thalweg elevation for the 1994 resurvey profile was measured from the above water range line collected data and from the developed ARC/INFO developed TIN. For the range lines collected during the underwater collection, the STACKPROFILE option within ARC/INFO was used to develop cross sections of the range line location. This option required the state plane end points of the range lines and displayed on screen the cross sections where the average elevation could be interpreted. Except for some minor inaccuracies, these plots closely represent the channel bottom conditions at the time of the survey. The channel distances for the Wind River start at the dam and for each creek start at the river and creek confluence.

Sedimentation Accumulation

Since storage began in October 1951, sediments have accumulated in Boysen Reservoir to an estimated volume of 78,171 acre-feet below spillway crest elevation 4725.0. The average annual rate of deposition was 1,826.4 acre-feet per year, or 0.24 acre-foot per square mile from the sediment contributing drainage area. The storage loss in terms of percent of original storage capacity was 9.54 percent.

Tables 1 and 2 contain the Boysen Reservoir sediment accumulation and water storage data based on the 1994 resurvey. The 1994 study based its sediment calculations on the difference between the original and 1994 measured reservoir capacities and accounts for the sediment accumulation during the 42.8 years of reservoir operation.

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

RESERVOIR SEDIMENT DATA SUMMARY

Boysen Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Wind River	3. STATE Wyoming
	4. SEC. 16 TWP. 5N RANGE 6E	5. NEAREST P.O. Thermopolis	6. COUNTY Fremont
	7. LAT 43° 25' 00" LONG 108° 10' 37"	8. TOP OF DAM ELEVATION 4,758	9. SPILLWAY CREST EL. 4,725[2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, Ac	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN / 16. DATE NORMAL OPERATION BEGAN
	a. SURCHARGE	4,752	30,856	520,686	1,490,246	15: 10/11/51
	b. FLOOD CONTROL	4,732	22,100	150,428	969,560	
	c. POWER	4,725[2]	19,660	146,652	819,132	
	d. WATER SUPPLY					16:
	e. IRRIGATION					
	f. CONSERVATION	4,717	17,079	413,241	672,480	
	g. INACTIVE	4,685[3]	9,444	259,239	259,239[3]	
	17. LENGTH OF RESERVOIR 18 MILES			AVG. WIDTH OF RESERVOIR 1.7 MILES		

BASIN	18. TOTAL DRAINAGE AREA 7,700 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 9.5[4] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 7,670 SQUARE MILES		23. MEAN ANNUAL RUNOFF 2.48[5] INCHES
	20. LENGTH 150 MILES	AV. WIDTH 51 MILES	24. MEAN ANNUAL RUNOFF 1,018,293[6] ACRE-FEET
	21. MAX. ELEVATION 13,785	MIN. ELEVATION 4,607	25. ANNUAL TEMP. MEAN 47°F[4] RANGE 108°F to -37°F[4]

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS.	28. ACCL. YRS.	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVAL	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
10/11/51			Contour (D)	5-ft	19,660	819,765[7]	.80
8/1/64	12.8	12.8	Range (D)	82	19,560	802,000[7]	.79
7/28/94	30.0	42.8	Contour (D)	5-ft	19,602.5	741,594[7]	.73

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
8/1/64	8-48	972,505[6]	1,505,681[6]	12,448,069[6]	972,505[6]	12,448,069[6]
7/28/94	9.5[4]	1,055,547[6]	1,676,565[6]	31,666,400[6]	1,018,293[6]	43,582,940[6]

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.^{2}-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.^{2}-YR.
8/1/64	17,129	1,338	0.17	17,129	1,338.0	0.17
7/28/94	60,406	3,512	0.46	78,171	1,826.4	0.24

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANNUAL	b. TOTAL TO DATE	a. PER.	b. TOT.
8/1/64	83.0	307	307	0.163	2.09	1,830	1,83
7/28/94	-	-	-	0.223	9.54	-	-

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION										
	110-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-	CREST	
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
7/94	14.6	10.5	7.8	8.2	10.5	8.9	15.4	18.3	5.8	0.0	

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

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

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1952	4,721.4	4,680.0	914,958
1953	4,720.2	4,705.6	811,209	1954	4,725.2	4,712.0	889,855
1955	4,721.4	4,703.3	600,735	1956	4,724.7	4,684.2	1,161,817
1957	4,729.8	4,702.5	1,480,525	1958	4,723.2	4,701.7	988,470
1959	4,716.6	4,692.6	732,703	1960	4,702.8	4,686.4	505,436
1961	4,708.3	4,686.6	639,073	1962	4,725.0	4,696.7	1,196,952
1963	4,727.6	4,711.8	1,072,100	1964	4,725.1	4,703.6	983,913
1965	4,727.3	4,704.4	1,534,473	1966	4,724.3	4,711.3	675,187
1967	4,730.8	4,706.9	1,676,565	1968	4,724.9	4,704.9	1,088,719
1969	4,724.6	4,707.8	1,065,882	1970	4,721.3	4,700.9	840,425
1971	4,727.1	4,695.7	1,498,884	1972	4,725.3	4,707.0	1,409,535
1973	4,725.4	4,706.7	1,221,488	1974	4,725.2	4,708.8	1,317,685
1975	4.726.4	4,706.5	1,224,011	1976	4,721.7	4,697.7	1,077,724
1977	4,722.1	4,705.0	485,002	1978	4,726.2	4,701.5	1,207,560
1979	4,721.8	4,706.5	882,266	1980	4,726.9	4,708.4	1,129,341
1981	4,722.1	4,711.1	822,569	1982	4,725.4	4,702.2	1,077,651
1983	4,727.9	4,707.1	1,632,122	1984	4,725.0	4,709.5	1,265,023
1985	4,722.6	4,709.8	760,921	1986	4,725.6	4,704.8	1,461,928
1987	4,723.1	4,711.0	980,236	1988	4,721.8	4,703.8	523,304
1989	4,719.3	4,703.7	681,730	1990	4,717.6	4,710.0	681,252
1991	4,729.2	4,712.7	1,279,569	1992	4,719.9	4,709.4	620,178
1993	4,725.3	4,712.0	996,047	1994[8]	4,720.1	4,711.9	487,917

46. ELEVATION - AREA - CAPACITY DATA FOR **1994 CAPACITY**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4622	0.0	0	4665	5,542.5	78,903	4710	13,820.1	492,696
4625	4.0	6	4670	6,231.7	108,338	4715	15,376.0	565,686
4630	43.6	125	4675	6,923.3	141,226	4720	17,692.4	648,357
4635	144.7	596	4680	7,774.9	177,971	4725	19,602.5	741,594
4640	392.0	1,938	4685	8,708.8	219,181	4730	21,449[9]	844,223
4645	1,273.2	6,101	4690	9,480.3	264,653	4735	23,133[9]	955,678
4650	2,743.5	16,142	4695	10,364.1	314,264	4740	25,456[9]	1,077,151
4655	3,708.0	32,271	4700	11,240.3	368,275	4745	27,353[9]	1,209,173
4660	4,701.1	53,294	4705	12,353.9	427,261	4752	30,856[9]	1,412,905

47. REMARKS AND REFERENCES

[1] Top of movable spillway gates.

[2] Joint Use--Flood control and conservation.

[3] Includes dead storage below elevation 4,657.0.

[4] USBR *Project Data Book*, 1981.

[5] Calculated from mean annual runoff value, 1,018,293 acre-ft, Item 24.

[6] Unregulated monthly inflow records from March 1952 through July 1994. 1964 values from 1964 sedimentation survey.

[7] Capacity at elevation 4725.0, spillway crest. Area and capacity calculated by Bureau of Reclamation program ACAP using original surface area values.

[8] For October 1993 through July 1994.

[9] Computed areas from 1964 survey.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE August 1996

Table 2. - Summary of 1994 survey results.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Elevation (ft)	1951 Area (acres)	1951 Capacity (acre-ft)	1964 Area (acres)	1964 Capacity (acre-ft)	1994 Area (acres)	1994 Capacity (acre-ft)	Sediment Volume (acre-ft)	Percent Sediment	Percent Depth
4752.0	30,894	1,491,924	30,856	1,473,204	30,856*	1,412,905	79,019	-	100.0
4745.0	27,380	1,287,965	27,353	1,269,473	27,353*	1,209,173	78,792	-	94.9
4740.0	25,450	1,155,890	25,456	1,137,450	25,456*	1,077,151	78,739	-	91.2
4735.0	23,210	1,034,240	23,133	1,015,978	23,133*	955,678	78,562	-	87.6
4730.0	21,460	922,565	21,449	904,522	21,449*	844,223	78,342	-	83.9
4725.0	19,660	819,765	19,560	802,000	19,602.5	741,594	78,171	100.0	80.3
4720.0	17,990	725,640	17,951	708,222	17,692.4	648,357	77,283	98.9	76.6
4715.0	16,510	639,390	16,303	622,588	15,376.0	565,686	73,704	94.2	73.0
4710.0	15,220	560,065	14,807	544,812	13,820.1	492,696	67,369	86.2	69.3
4705.0	14,160	486,615	13,727	473,478	12,353.9	427,261	59,354	75.9	65.7
4700.0	12,410	420,190	12,363	408,252	11,240.3	368,275	51,915	66.4	62.0
4695.0	11,040	361,565	10,693	350,612	10,364.1	314,264	47,301	60.5	58.4
4690.0	10,170	308,540	9,650	299,755	9,480.3	264,653	43,887	56.1	54.7
4685.0	9,444	259,505	9,277	252,438	8,708.8	219,181	40,324	51.6	51.1
4680.0	8,605	214,383	8,523	207,938	7,774.9	177,971	36,412	46.6	47.4
4675.0	7,816	173,330	7,488	167,910	6,923.3	141,226	32,104	41.1	43.8
4670.0	6,821	136,738	6,535	132,852	6,231.7	108,338	28,400	36.3	40.1
4665.0	6,011	104,658	5,882	101,810	5,542.5	78,903	25,755	32.9	36.5
4660.0	5,317	76,338	5,087	74,388	4,701.1	53,294	23,044	29.5	32.8
4655.0	4,469	51,873	4,280	50,970	3,708.0	32,271	19,602	25.1	29.2
4650.0	3,351	32,323	3,418	31,725	2,743.5	16,142	16,181	20.7	25.5
4645.0	2,588	17,475	2,422	17,125	1,273.2	6,101	11,374	14.6	21.9
4640.0	1,099	8,258	1,263	7,912	392.0	1,938	6,320	8.1	18.2
4635.0	641	3,908	577	3,312	144.7	596	3,312	4.2	14.6
4630.0	293	1,573	265	1,208	43.6	125	1,448	1.8	10.9
4625.0	135	503	83	338	4.0	6	497	0.6	7.3
4622.0	74	189	-	140	0.0	0	189	0.2	5.1
4620.0	33	83	26	65	0.0	0	83	0.1	3.6
4615.0	0	0	0	0	0.0	0	0	0.0	0.0

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area measured in 1951.
(3) Original (1951) calculated reservoir capacity computed using ACAP from original measured surface areas.
(4) Reservoir surface area from 1964 survey.
(5) 1964 calculated reservoir capacity computed using ACAP from 1964 measured surface areas.
(6) Reservoir surface area from 1994 survey.
(7) 1994 calculated reservoir capacity computed using ACAP from 1994 surface areas
(8) 1994 measured sediment volume = column (3) - column (7).
(9) 1994 measured sediment expressed in percentage of total sediment of 78,171 acre-feet at elevation 4725.0.
(10) Depth of reservoir expressed in percentage of total depth (137 ft).

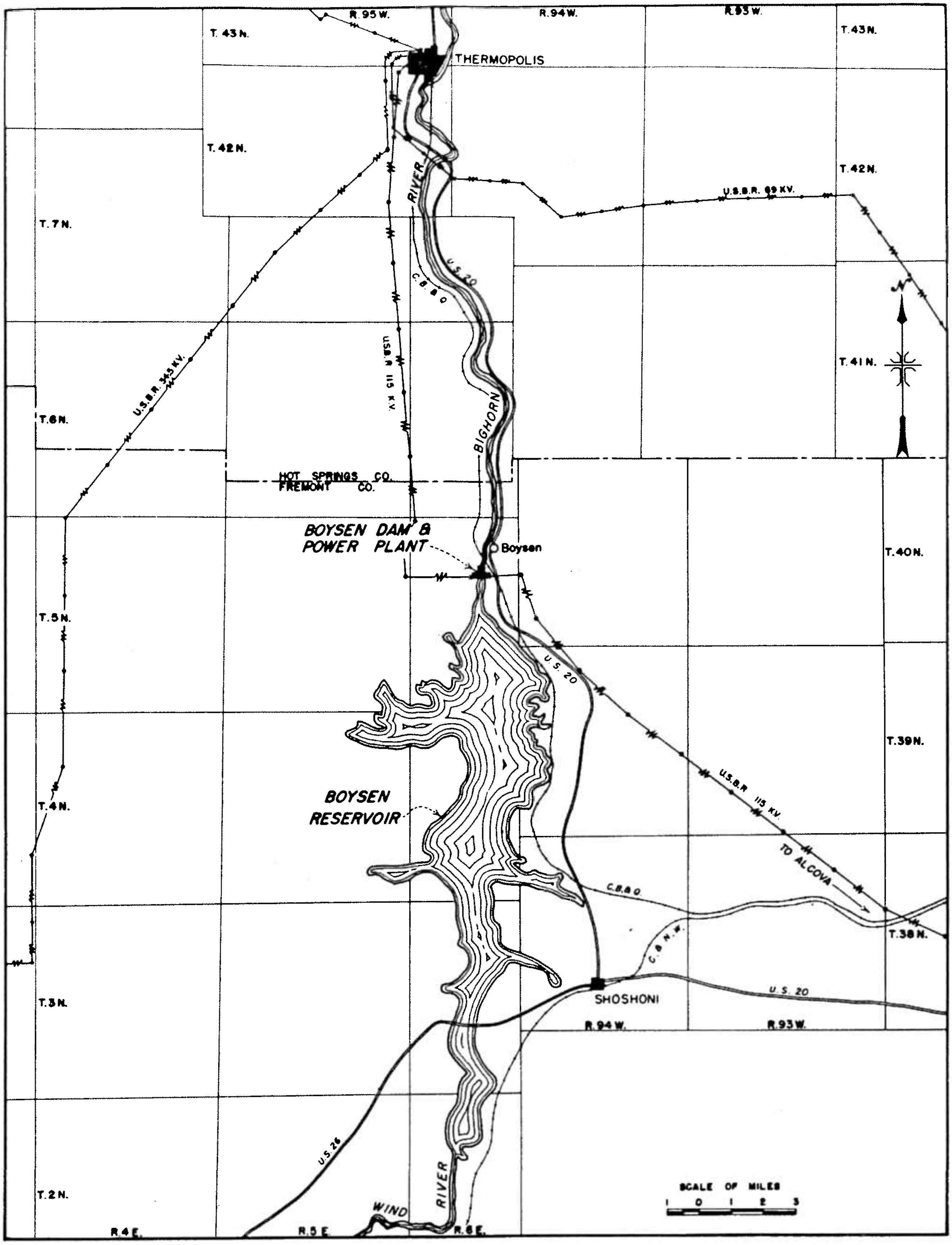
* From 1964 survey results.

Table 3. - State plane coordinates (page 1 of 2).

Range	North	East	Elevation
Big Horn	960,448.065	654,659.097	
R-1L	1,002,498.051	650,651.849	4766.38
R-1R	1,001,664.530	653,397.156	4807.76
R-2L	996,735.520	650,070.206	4804.91
R-2R	997,068.213	654,039.517	4904.87
R-3L	989,436.939	645,660.609	4805.39
R-3R	990,042.132	659,189.311	4760.16
R-4L/R-20L	983,195.450	643,515.657	4754.92
R-4R	982,590.044	660,944.399	4759.12
R-5L	976,865.175	647,705.165	4765.56
R-5R/R-30R	977,094.093	661,181.054	4778.83
R-6L	967,899.358	647,824.402	4949.40
R-6R/R-30L	966,577.199	657,357.533	4780.28
R-7L/R-40L	960,874.821	642,515.138	4758.96
R-7R/R-50R	960,335.172	657,862.719	4764.89
R-8L	951,955.594	647,446.563	4784.88
R-8R/R-50L	952,168.215	654,475.617	4881.29
R-9L	941,722.248	646,728.752	4756.71
R-9R	941,871.175	655,466.391	4785.06
R-10L	934,276.731	648,742.650	4751.41
R-10R	934,144.117	654,030.225	4782.37
R-11L	926,203.210	646,831.329	4782.79
R-11R	927,218.466	652,831.962	4759.48
R-12L	921,407.207	647,078.150	4761.23
R-12R	920,682.482	656,221.798	4796.00
R-13L	915,283.115	648,423.840	4667.09
R-13R	914,896.883	654,688.289	4773.32
R-14L	909,465.273	645,633.926	4798.63
R-14R	909,877.651	654,022.871	4755.19
R-15L	903,948.444	646,902.636	4793.95
R-15R	902,868.061	651,424.530	4747.68
R-16L	898,058.392	645,550.245	4769.66
R-16R	897,271.163	650,003.779	4784.95
R-16AL	895,370.000	646,246.880	4769.66
R-17L	897,157.180	643,582.420	4773.13
R-17R	896,515.569	643,620.738	4766.24
R-20R	975,400.723	645,731.232	4775.32
R-21L	987,239.303	637,374.261	4770.47
R-21R	975,037.956	638,998.447	4755.98
R-22L	979,904.860	631,390.426	4771.12
R-22R	976,179.971	632,239.000	4753.78
R-23L	981,913.110	625,794.831	4790.92
R-23R	979,317.634	626,268.741	4790.74

Table 3. - State plane coordinates (page 2 of 2).

Range	North	East	Elevation
R-24L	980,252.814	621,464.348	4809.29
R-24R	978,051.412	621,451.574	4814.92
R-31L	975,524.307	664,462.457	4801.60
R-31R	975,524.307	664,462.457	4775.74
R-32L	969,703.289	666,301.987	
R-32R			4764.93
R-40L	960,874.821	642,515.138	
R-40R	954,201.938	645,240.109	
R-41L	956,411.324	639,942.764	4750.86
R-41R	951,497.915	640,800.866	4766.21
R-42L	956,424.244	635,893.915	4767.65
R-42R	954,352.848	636,260.486	4761.22
R-43L	955,315.031	631,199.362	
R-43R	954,143.276	631,612.573	4758.46
R-44L	954,479.926	628,217.615	
R-44R	952,738.013	629,090.750	4773.79
R-51L	951,583.800	661,902.785	4766.29
R-51R	954,307.503	662,967.398	4766.29
R-52L	949,976.703	665,197.252	4766.11
R-53L	949,368.109	669,235.066	4785.52
R-54L	950,433.939	672,476.968	4804.93
R-54R	952,117.695	671,738.345	4819.08
R-60L	940,112.768	656,010.064	4743.14
R-60R			4785.06
R-61L	940,371.000	658,631.858	4778.43
R-61R	941,489.308	659,667.137	4766.29
R-62L	938,135.511	660,530.086	4811.17
R-62R	939,109.061	661,678.859	4781.46
R-63L	936,442.292	662,920.267	4757.43
R-63R	936,952.551	663,409.032	4754.99
R-70L	937,952.687	648,150.024	
R-70R	934,276.730	648,742.650	4757.41
R-71L	935,224.945	642,863.509	
R-71R	934,037.284	644,144.437	4768.2
R-72L	932,476.689	641,516.087	
R-80L	905,497.525	651,567.359	
R-80R	906,499.174	652,287.412	
R-81L	904,161.148	654,637.825	
R-81R	905,439.292	655,352.556	



Boysen Unit

Figure 1. - Boysen Reservoir location map.

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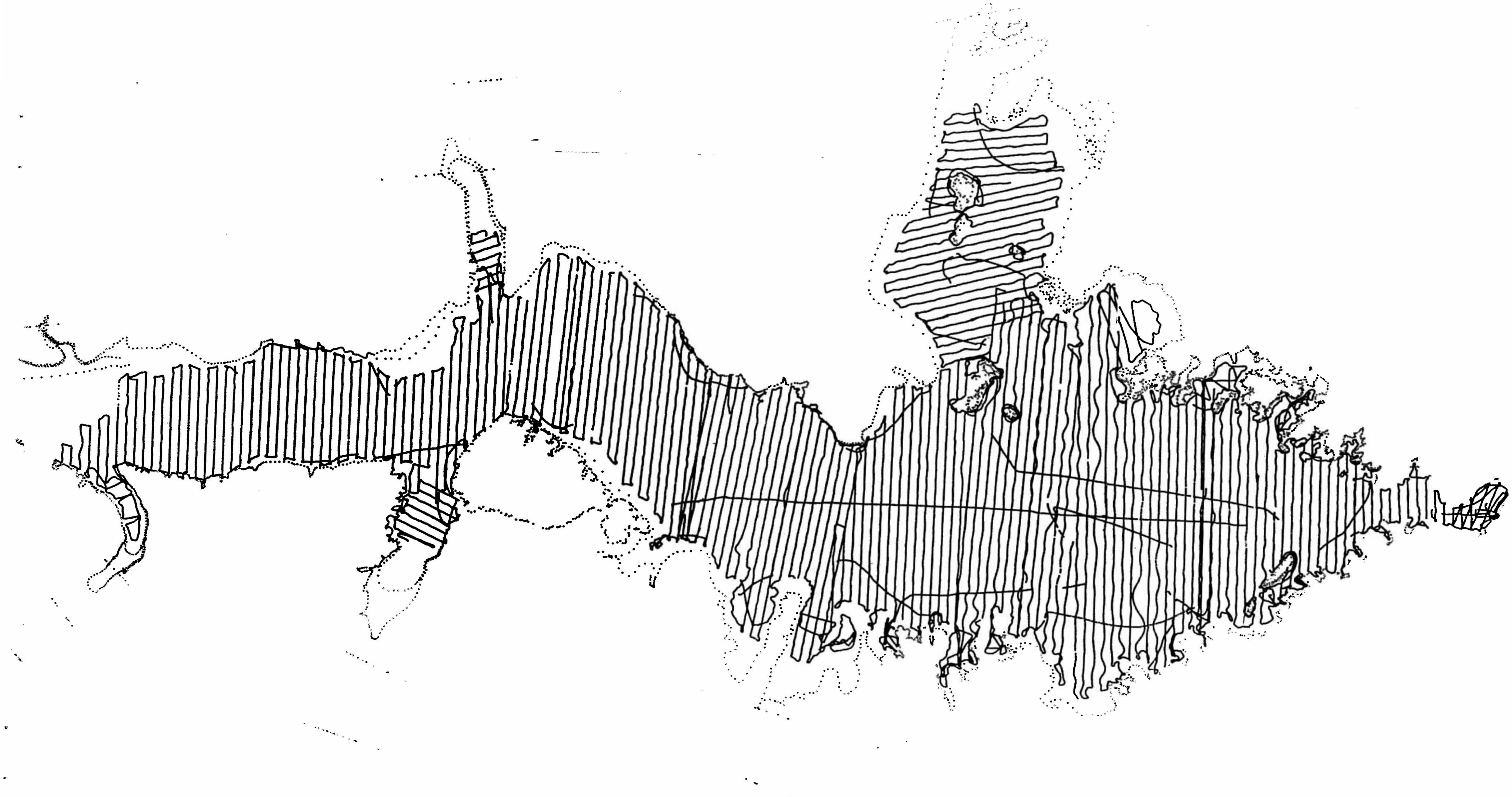

Figure 3. - Boysen Reservoir survey data.

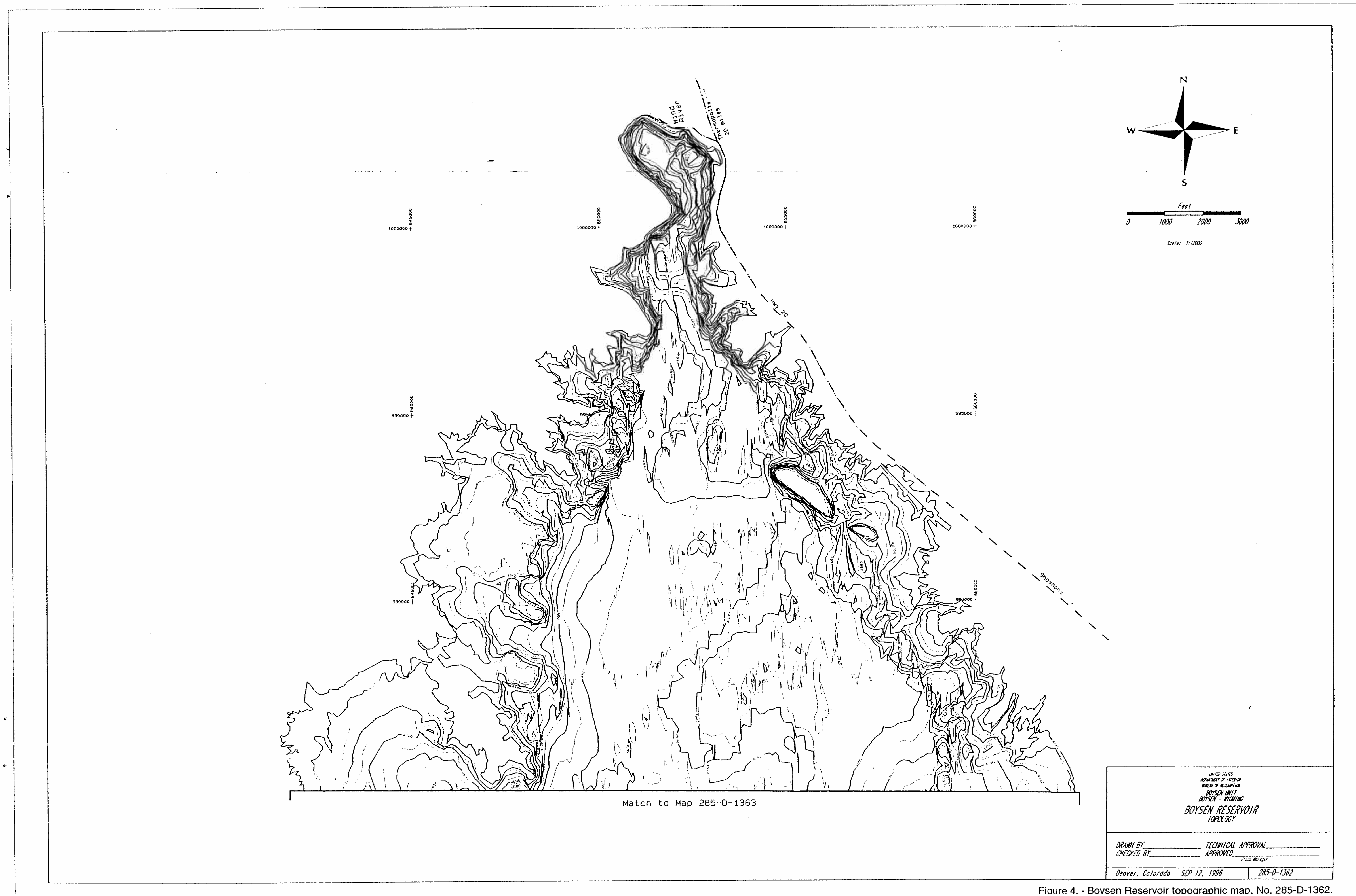

Figure 4. - Boysen Reservoir topographic map, No. 285-D-1362.

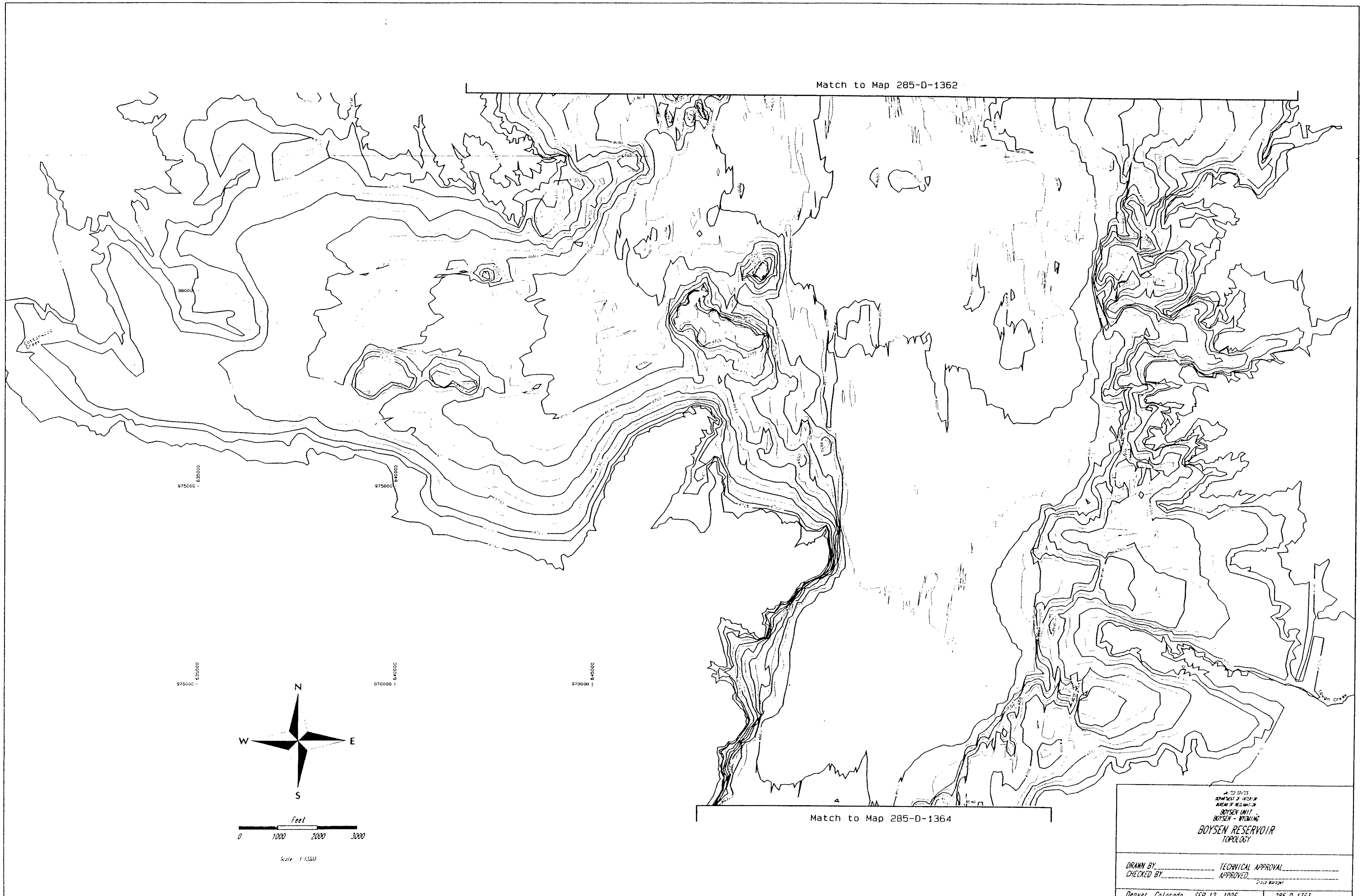

Figure 5. - Boysen Reservoir topographic map, No. 285-D-1363

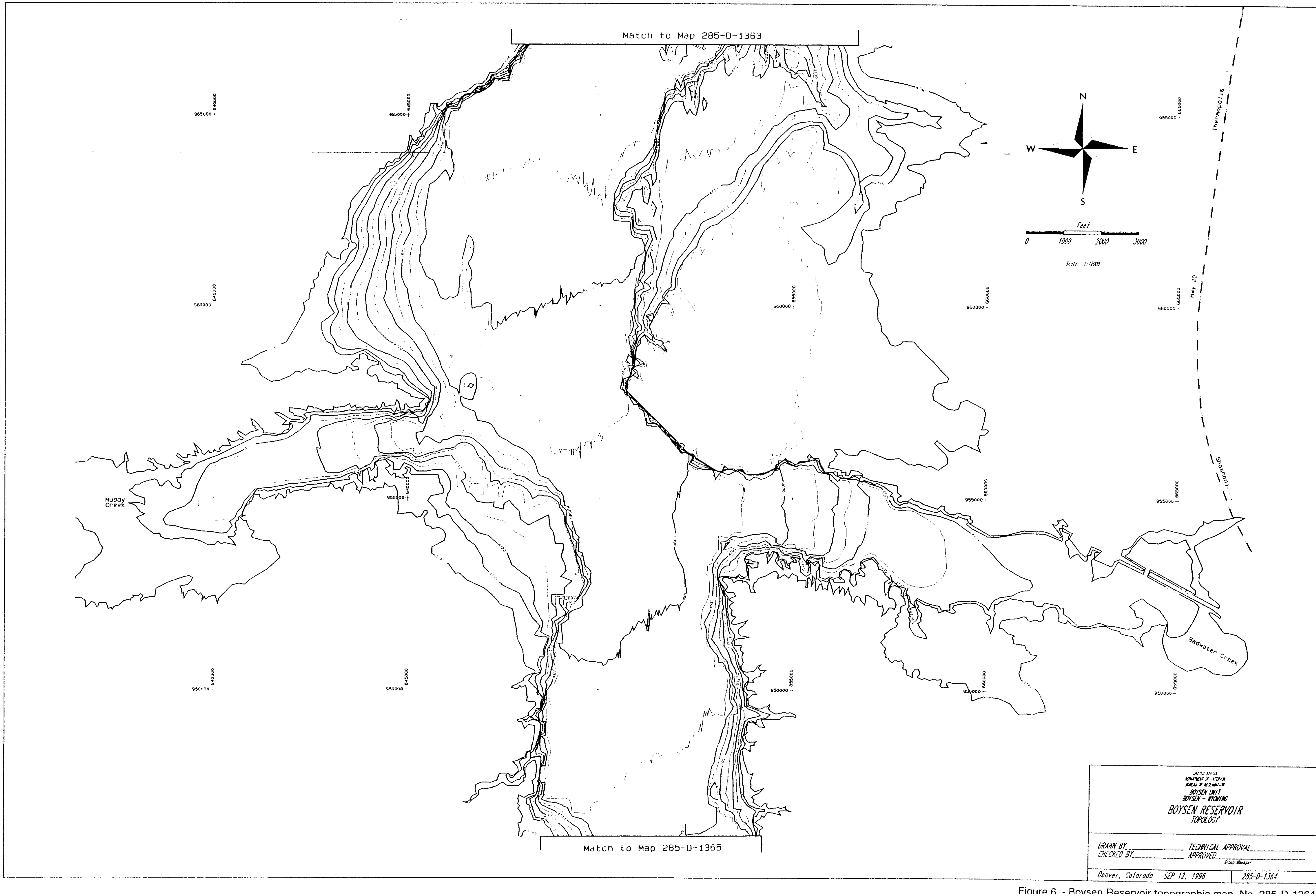

Figure 6 - Boysen Reservoir topographic map No. 285-D-1364

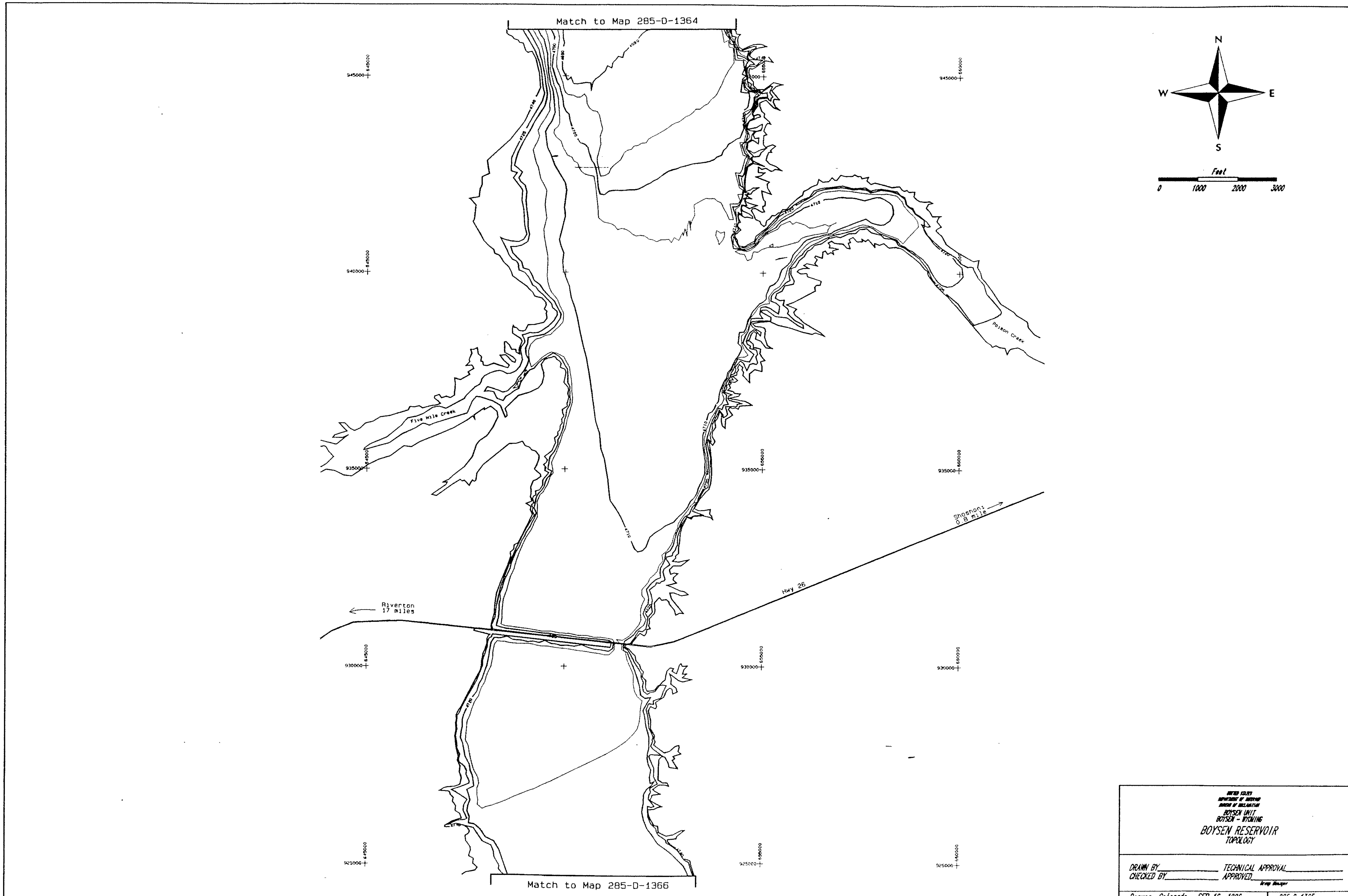

Figure 7. - Boysen Reservoir topographic map, No. 285-D-1365.

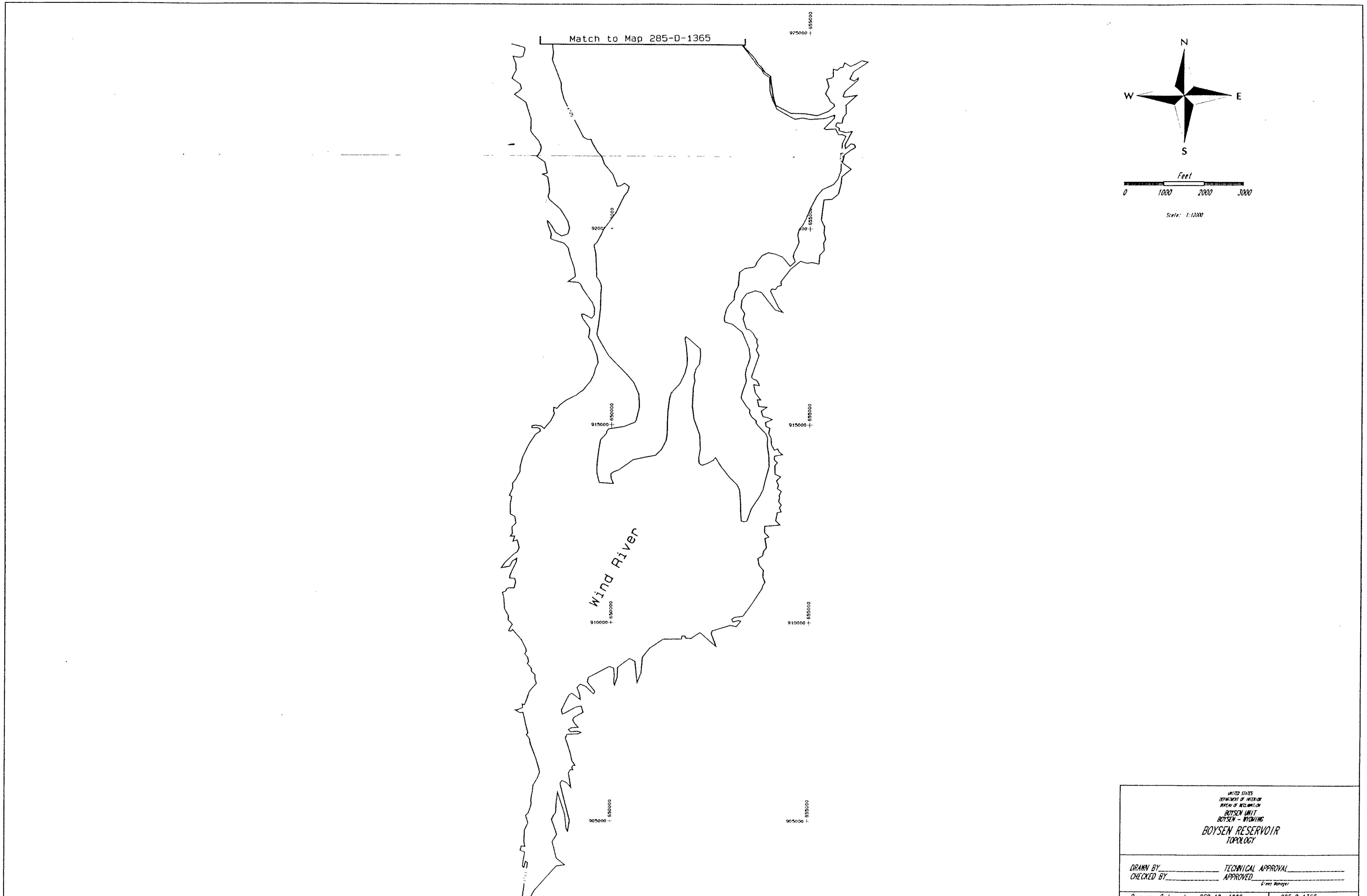

Figure 8. - Boysen Reservoir topographic map, No. 285-D-1366.

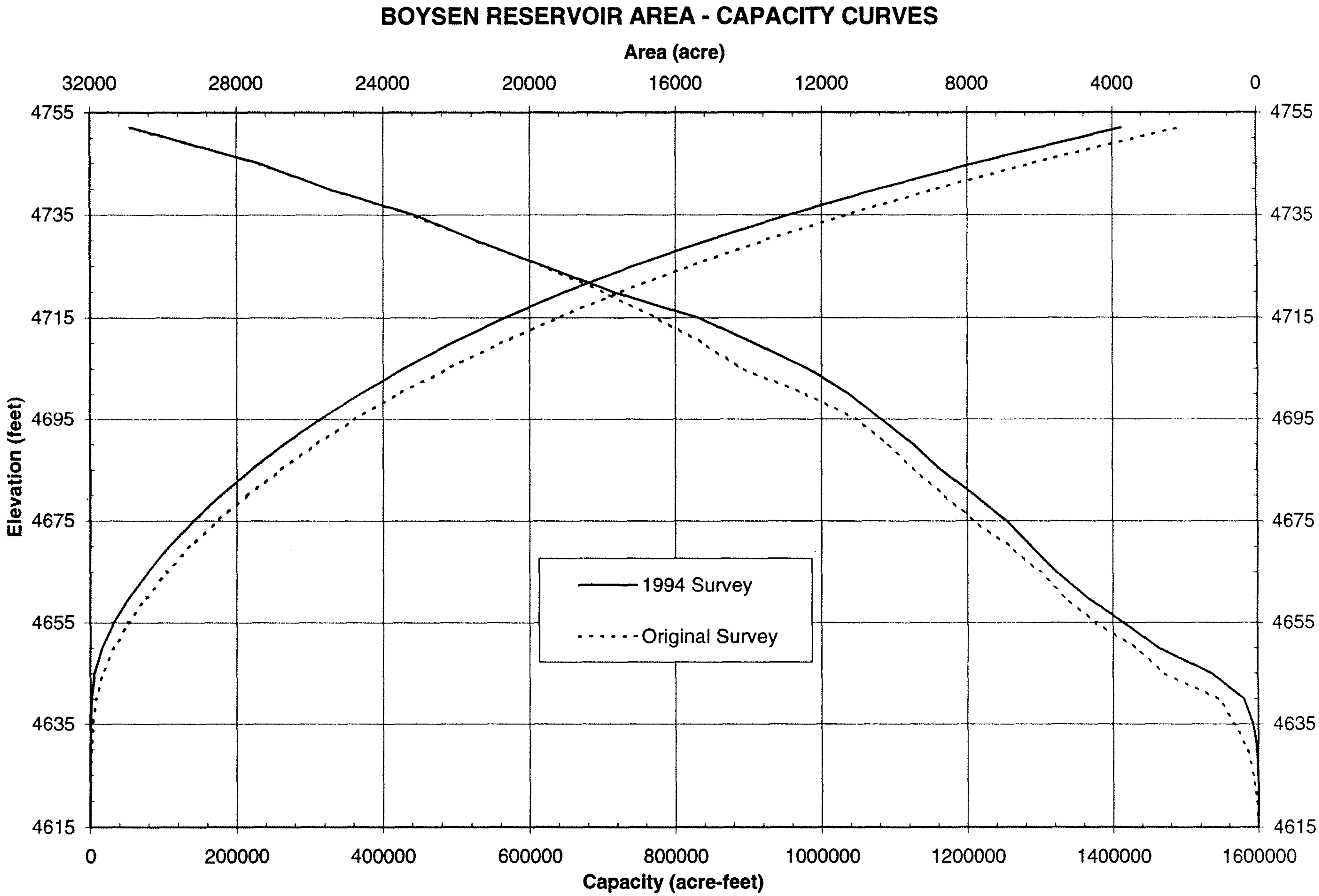

Figure 9. - 1994 area and capacity curves.

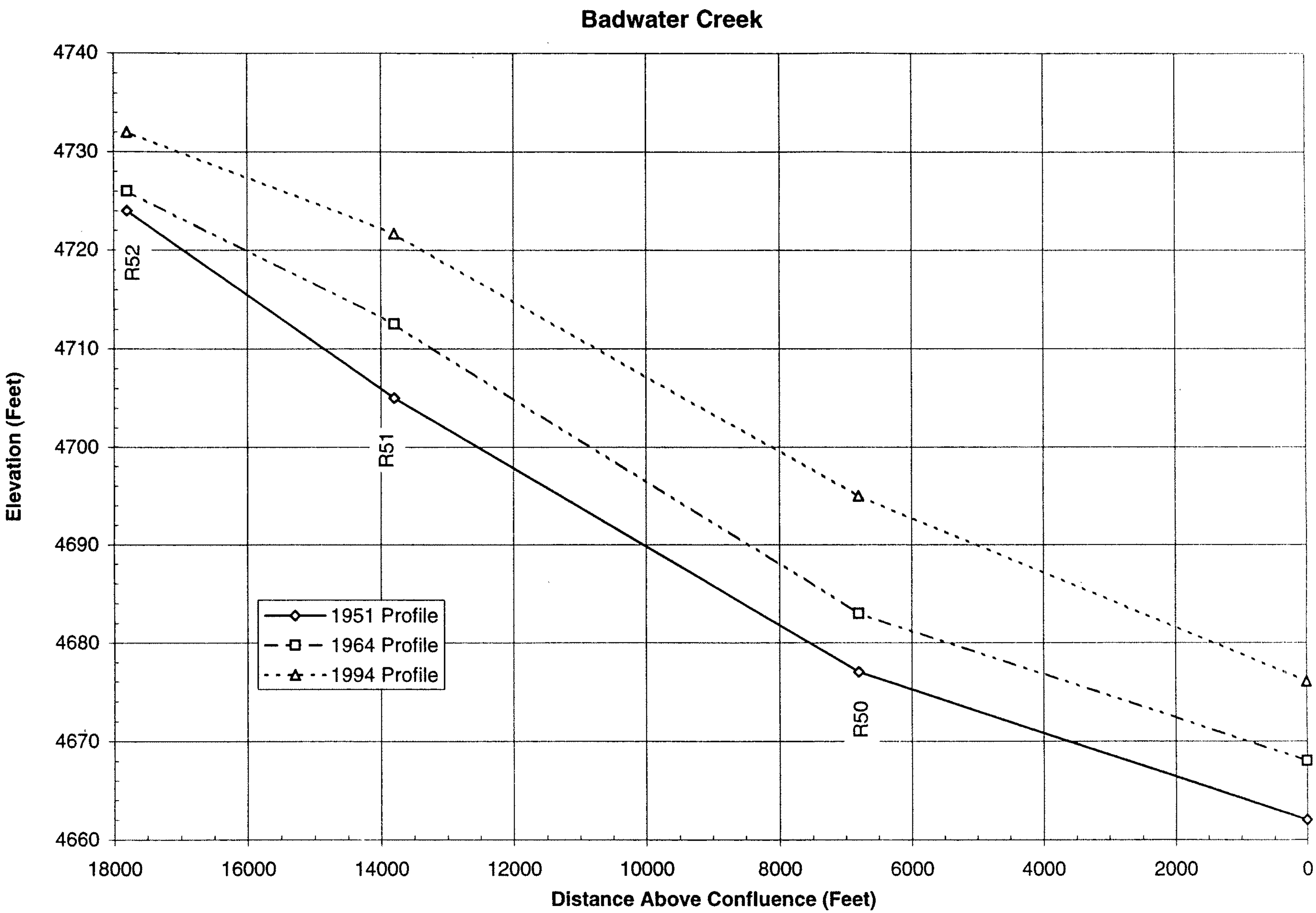

Figure 10. - Longitudinal profile—Badwater Creek.

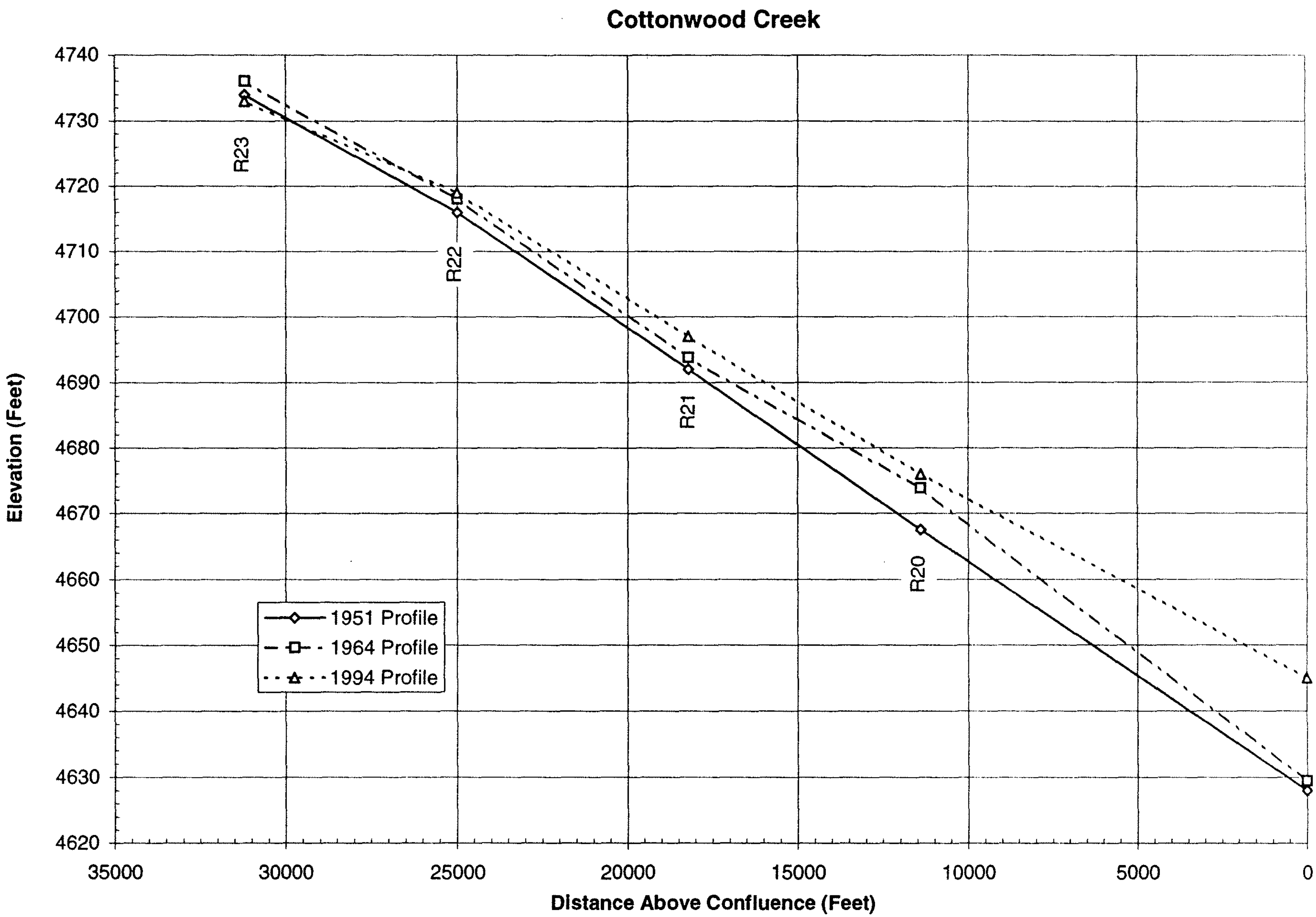

Figure 11. -Longitudinal profile—Cottonwood Creek.

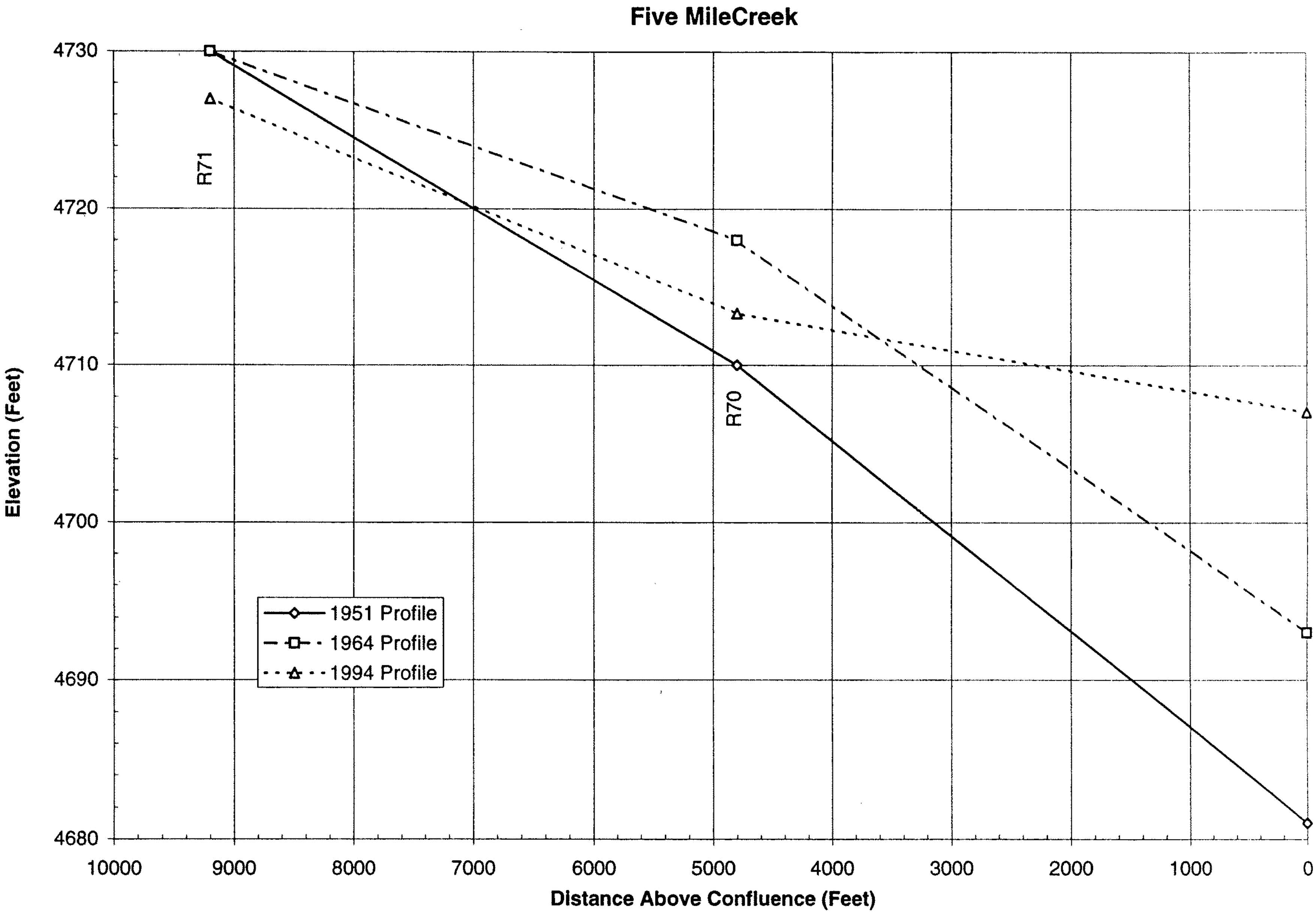

Figure 12. - Longitudinal profile—Five Mile Creek.

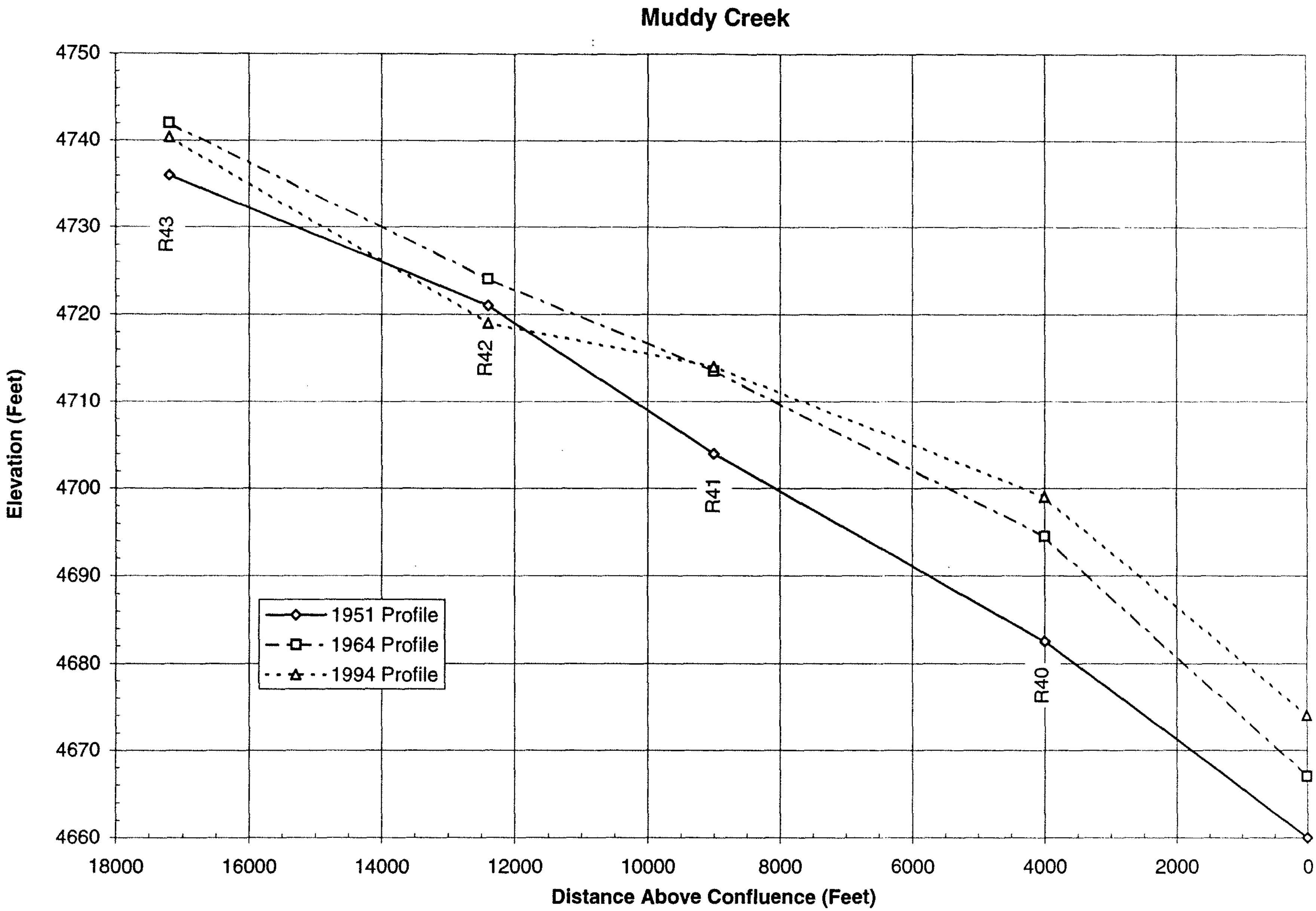

Figure 13. -Longitudinal profile—Muddy Creek.

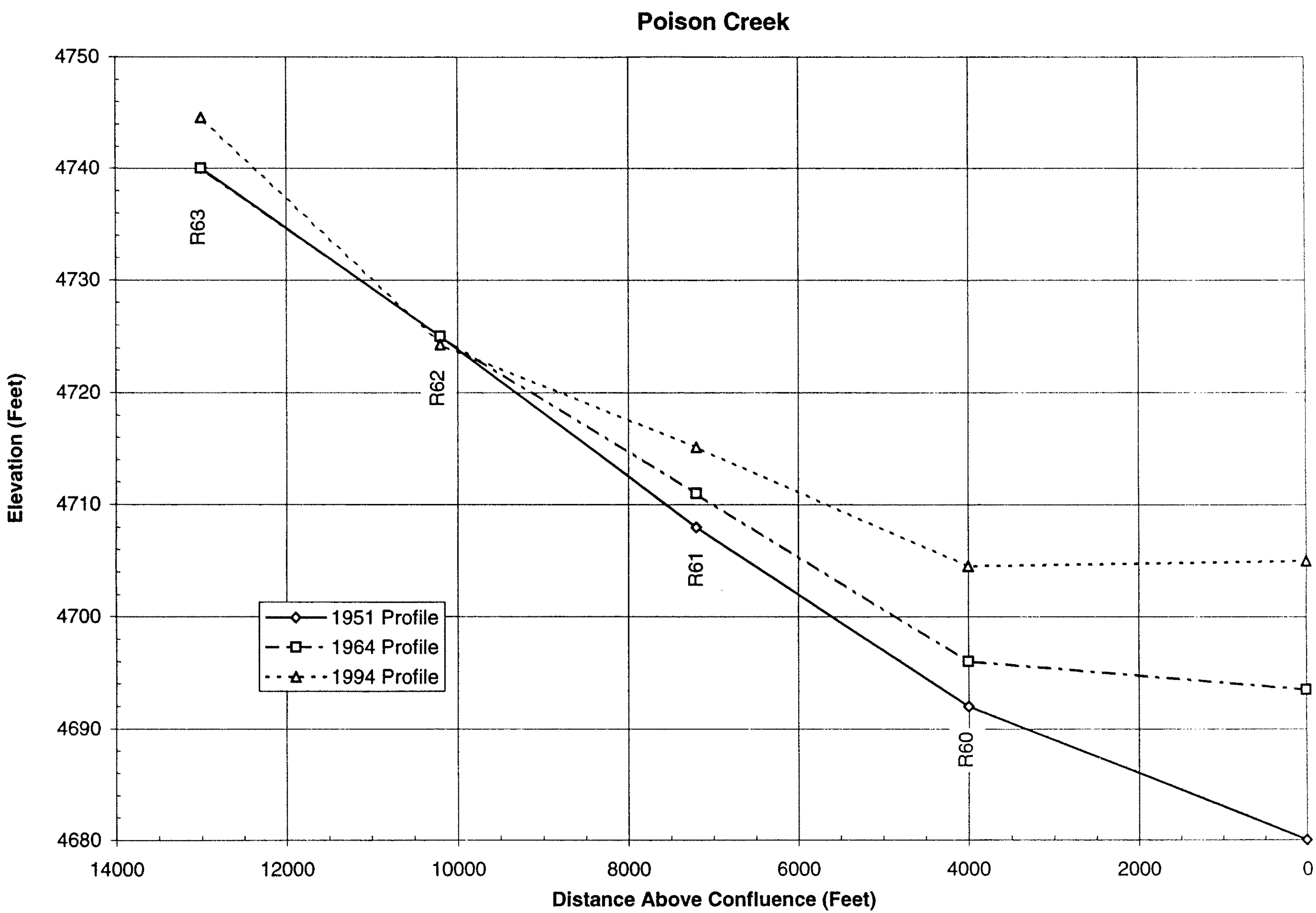

Figure 14. - Longitudinal profile—Poison Creek.

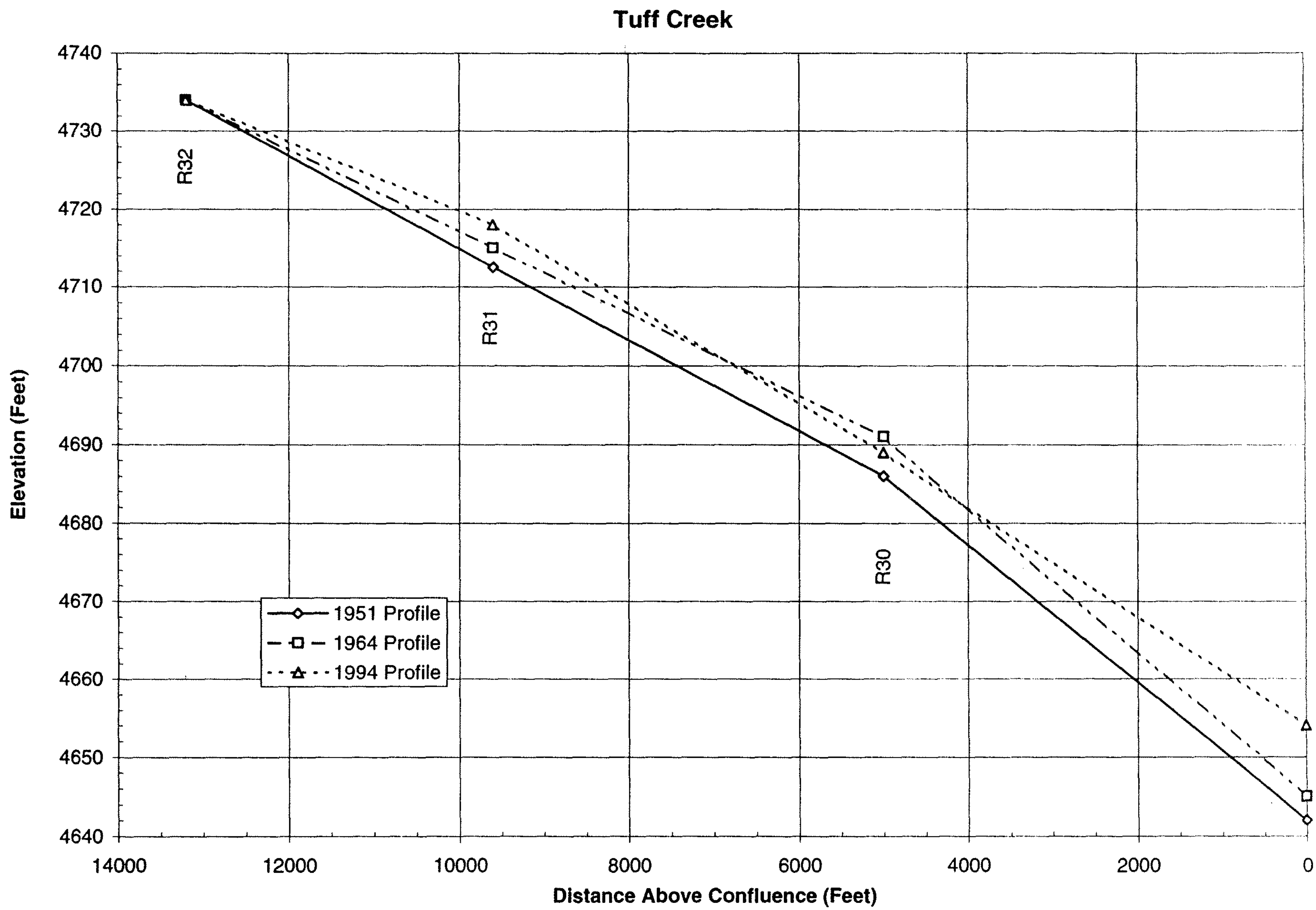

Figure 15. -Longitudinal profile—Tuff Creek.

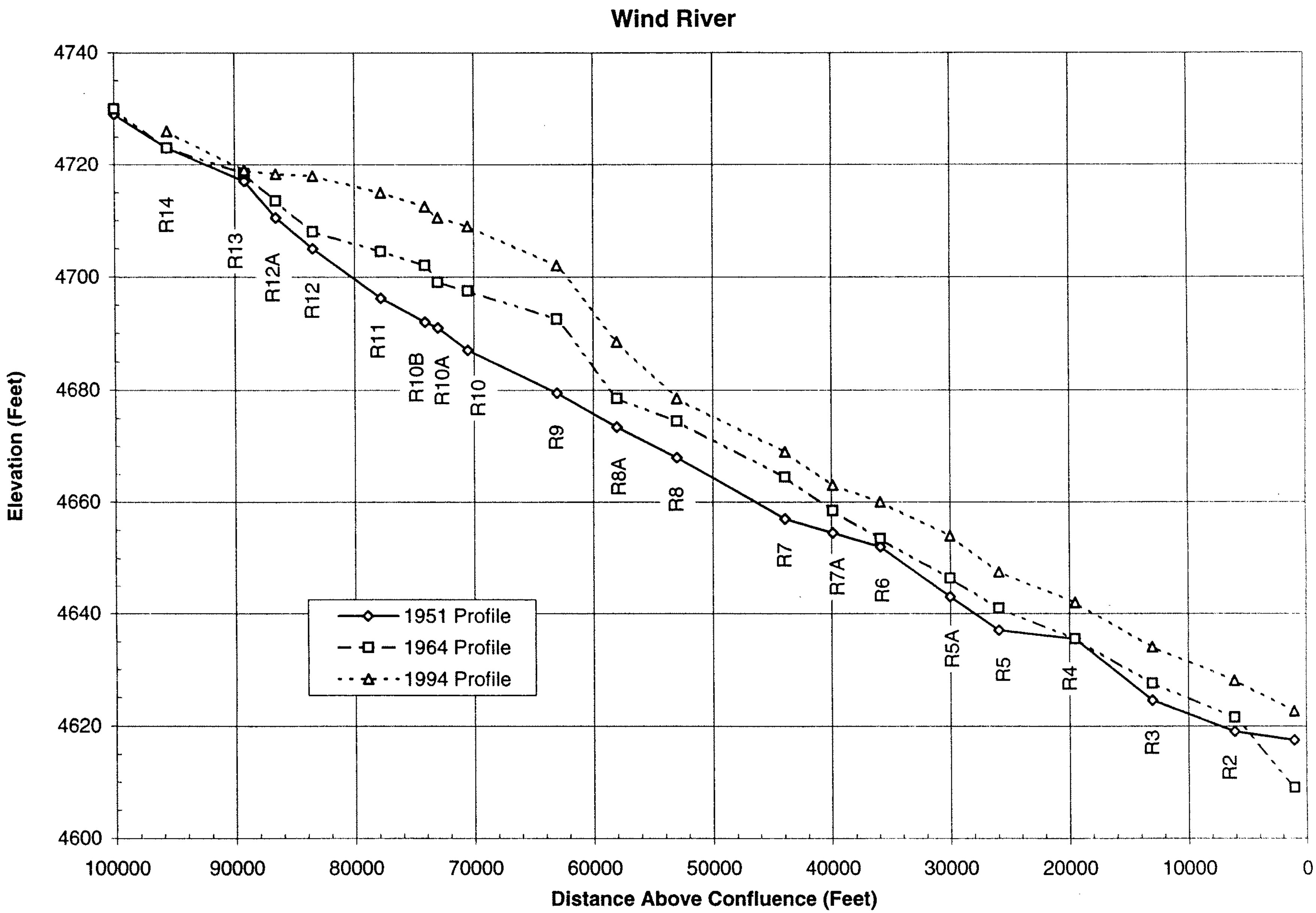

Figure 14. - Longitudinal profile—Wind River.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.