WEBSTER RESERVOIR
1996 SEDIMENTATION SURVEY

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed the underwater area of Webster Reservoir in May 1996 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were also used to calculate reservoir capacity lost due to sediment accumulation since dam closure on May 3, 1956. The survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir. Underwater topography was developed by a computer program using collected data. Above-water topography was determined by digitizing contour lines from the U. S.Geological Survey quadrangle (USGS quad) maps of the reservoir area developed from aerial photography obtained in 1951, 1967, and 1978. The new topographic map of Webster Reservoir is a combination of digitized contours and 1996 underwater measured topography.

As of May 19, 1996, at top of active conservation elevation (feet) 1,892.45, the surface area was 3,767 acres, the total capacity was 76,157 acre-feet, and the active capacity was 71,926 acre-feet. Since initial filling in May 1956, about 1,267 acre-feet of sediment have accumulated in Webster Reservoir below elevation 1884.6 (spillway crest), resulting in a 1.64 percent loss in reservoir volume. Since 1957, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 31.7 acre-feet.

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WEBSTER RESERVOIR

1996 SEDIMENTATION SURVEY

by

Ronald L. Ferrari

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

August 1997

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ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari and James Melena of the TSC conducted the hydrographic survey. Special thanks to Mr. Robert Schamel and Mr. David Grooms, of the Great Plains Region, for the field assistance during the hydrographic survey. Ronald Ferrari completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC completed the USGS contour digitizing and was consulted during the map development. James Melena of TSC performed the technical peer review of this documentation.

U.S. Department of the Interior
Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Tribes.

INTRODUCTION

Webster Dam and Reservoir are principal features of the Solomon Division-Webster Unit of the Pick-Sloan Missouri Basin Program. Additional unit features are the dike, four pumping plants, Woodson Diversion Dam, and Osborne Canal, laterals, and drains. Webster Dam and Reservoir are located in Rooks County of north-central Kansas about 8 miles west of Stockton. The reservoir is on South Fork Solomon River (fig. 1).

Webster Dam was constructed between 1952 through 1956 with first storage on May 3, 1956. The dam, a modified homogeneous earthfill embankment with a cutoff trench, has dimensions of (fig. 2):

• Hydraulic height[1]	86.7 feet
• Structural height	154 feet
• Top width	30 feet
• Crest length	10,720 feet
• Crest elevation	1,944 feet

A 2,640-feet long, rolled-earthfill dike, with a maximum height of 12 feet above the original ground surface, closes a low saddle to the northwest of the left abutment of Webster Dam and provides flood storage impoundment.

Webster Dam's spillway, located in the left abutment, consists of an inlet channel, two intake floatwells, an overflow crest, spillway bridge above the crest, gated structure controlled by three 33.3- by 39.5-foot counterweighted radial gates, chute, stilling basin, and outlet channel. The gates are designed for automatic and manual operation. The automatic float operation of the radial gates occurs when water flows into unvalved orifices of two floatwells where at reservoir elevation 1,923.7 (feet)[2] the radial gates begin to open. The gates can be manually opened to obtain greater releases then the automated system and to make releases when the storage level is above elevation 1,892.45, the allocated flood control space. The spillway crest is at elevation 1,884.6. The downstream safe river channel capacity is 2,400 cubic feet per second (cfs). The discharge capacity is 138,000 cfs at reservoir elevation 1,938.0 (Bureau of Reclamation, 1981).

The gated outlet works are near the right abutment through the base of the dam. The outlet works consist of an inlet channel with trashrack, gate chamber, 3.5- by 3.5-foot emergency slide gate, 48-inch-diameter steel outlet pipe, 3.5- by 3.5-foot regulating slide gate, control house, stilling basin, and an outlet channel to the downstream canal entrance The discharge capacity is 380 cubic feet per second at reservoir elevation 1,892.45.

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

[2]Elevation levels are shown in feet.

Webster Reservoir stores water from the South Fork Solomon River. The drainage area above the dam is 1,150 square miles ranging from elevation 1,860.0, top of inactive pool, to greater than elevation 3,450 at its headwaters. The reservoir length at elevation 1,890 is around 6 miles with an average width of 1 mile.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1996 results of the first extensive survey of Webster Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since Webster Dam closure

The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system (DGPS) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it was navigated along grid lines covering Webster 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 1996 underwater surface areas at predetermined contour intervals were generated by a computer graphics program using the underwater collected data. The above-water reservoir contours were digitized from U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps of Webster Reservoir. The new topographic map of Webster Reservoir is a combination of the digitized and underwater measured topography. 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. The 1996 area and capacity tables were generated using the 1996 measured areas at elevation 1880.0 and less and the original measured areas for elevation 1890.0 and greater.

Table 1 contains a summary of Webster Reservoir's watershed characteristics for the 1996 survey. The 1996 survey determined that the reservoir has a storage capacity of 76,157 acre-feet and a surface area of 3,767 acres at reservoir elevation 1,892.45 feet. Since closure in 1956, the reservoir has accumulated a sediment volume of 1,267 acre-feet below reservoir spillway crest elevation 1,884.6. This volume represents a 1.64 percent loss in capacity and an average annual loss of 31.7 acre-feet.

RESERVOIR OPERATIONS

Webster Reservoir is primarily an irrigation and flood protection facility (the following values are from May 1996 area-capacity tables):

- 140,912 acre-feet of surcharge storage between elevations 1,923.7 and 1,938.0.

- 183,353 acre-feet of flood control between elevations 1,892.45 and 1,923.7.
- 71,926 acre-feet of active conservation storage between elevations 1,860.0 and 1,892.45.
- 3,185 acre-feet of inactive storage between elevations 1,855.0 and 1,860.0.
- 1,046 acre-feet of dead storage below elevation 1,855.0.

The Webster Reservoir inflow and end-of-month stage records in table 1 show the inflow and annual fluctuation for the operation period May 1956 through May 1996. The average inflow into the reservoir for this operation period was 36,598 acre-feet per year. Figure 3 shows the extreme storage fluctuations of Webster Reservoir, ranging from elevation 1,855.2 to 1,899.6 in 1957 to the maximum elevation on record, elevation 1,907.0, on June 5, 1995. The records show the reservoir has operated in the inactive zones, below elevation 1860.0, during the years 1971, 1972, 1991, and 1992 and at low reservoir content, below elevation 1870, between the years 1967 through 1978, 1980 through 1987, and 1989 through 1993.

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 global positioning system (GPS) receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a plotter, a computer, and hydrographic system software for collecting underwater data. Power to the equipment was supplied by an on-board generator.

The shore equipment included 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 unit was provided by a 12-volt battery.

GPS Technology and Equipment

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

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in precise orbit 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, and the data are then retransmitted to the user segment.

- The user segment includes 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 (called L1 and L2) for the distance measurement signal. 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, Webster's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel; during the Webster Reservoir survey, the best 6 available satellites were used for position calculations).

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and the 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 of the ionosphere. Geometric dilution of precision (GDOP) describes the geometrical 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: position dilution of precision (x,y,z) (PDOP) and horizontal dilution of precision (x,y) (HDOP). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored during the Webster 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 (Corps of Engineers, 1991).

An additional and larger error source in GPS collection is caused by false signal projection, called selective availability (S/A). 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 differential GPS (DGPS). DGPS was used during the Webster 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 Webster Reservoir, position corrections were determined by the master receiver and transmitted via a ultra-high frequency (UHF) 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 Technical Service Center (TSC) mobile and reference GPS units are identical in construction and consist of a 6-channel L1 coarse acquisition (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 Radio Technical Commission for Maritime Services (RCTM) 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 to collect the data in 1927 or 1983 North American Datums (NAD) in the surveyed area's state plane coordinate system's zone. For Webster Reservoir, the data were collected in the Kansas's 1927 NAD north state plane zone.

Survey Method and Equipment

The Webster Reservoir hydrographic survey collection was conducted on May 17 through May 19, 1996, between water surface elevations 1,894.76 and 1,894.80. The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run primarily in a north-south direction. Data were also collected along the shore as the boat traversed to the next transect and as it maneuvered in the open areas between the trees. Thick tree growth prevented the boat from reaching some areas of the reservoir, such as those near the shoreline or in shallow water areas in the main body of the reservoir. In some areas the growth was so thick the survey vessel ended the collection in 16 feet of water, at approximately bottom elevation 1878. This included areas of the reservoir in the upper north shore and some portions of the lower south shore. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing by TSC personnel. The underwater data set includes 24,477 data points. A graph plotter was used in the field to track the boat and ensure adequate coverage during the collection process. The water surface elevation recorded by a Reclamation gage during the time of collection was used to convert the sonic depth measurements to true lake bottom elevations.

For stationing the master GPS unit there were no known benchmarks or datums that overlooked the reservoir. For the underwater collection the hydrographic survey crew established a datum using the hydrographic GPS units and software. In establishing the control for the reference datum, the second-order National Geodetic Survey's benchmark Alcona, located several miles from the reservoir, was used. The control was brought in from the Alcona benchmark to a pipe near the basketball court at a church campground located west of the dam. This method calculated 1927 NAD state plane coordinates of North 391,080.156 and East 1,586,802.053 at this location. The shore-based master GPS unit, which transmits the correction information to the mobile GPS unit on the survey vessel, was stationed at this site throughout the survey. This location was chosen because it was accessible, near the reservoir, and overlooked the reservoir. The location allowed for good radio transmission of the differential corrections to the mobile survey vessel throughout the reservoir survey. During post-processing of the collected data, the few collected points without differential correction were removed.

The underwater data was collected by a depth sounder which was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. The collected data were digitally transmitted to the computer collection system via a RS-232 port. The depth sounder also produces an analog hard copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data was 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.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Webster Reservoir was developed from the 1996-collected underwater data and from the USGS quad maps. The upper contours of Webster Reservoir were developed by digitizing the contour lines of elevation 1,880.0, 1890.0, 1892.0, 1900.0, 1910.0, and 1,924.0, from the USGS quad maps that covered the Webster Reservoir area. The USGS quad maps were developed from aerial photography dated 1951, 1967 and 1978. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Kansas' NAD 1927 north state plane coordinates using the ARC/INFO PROJECT command.

Following are the resulting ARC/INFO digitized areas from the USGS quad contours compared to the original contour areas reported in May 1956:

(1) USGS 1880 contour area was 2,474 acres, or 99.5% of the original area of 2,486 acres
(2) USGS 1890 contour area was 3,269 acres, or 94% of the original area of 3,487 acres
(3) USGS 1892 contour did not exist on all quads

(4) USGS 1910 contour area was 5,916 acres, or 98.5% of the original area of 6,010 acres
(5) USGS 1924 contour area was 8,337 acres, or 97.6% of the original area of 8,540 acres

Except for elevation 1890, all digitized areas were close to original computed areas. Except for elevation 1890, it is assumed that the difference was due to the quad map scale (one inch equals two thousand feet) and the different methods of digitizing the areas.

The elevation 1,890.0 contour that was digitized from USGS quad maps was used to perform a clip of the Webster Reservoir triangular irregular network (TIN) such that interpolation was not allowed to occur outside the 1,890.0 contour. This complete contour was selected since it was the closest complete elevation to represent the reservoir at the time of the survey. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and digitized contours from the quad maps were plotted. The plot found that the underwater data did not completely lie within this clip, which would require some modifications to include the entire underwater data set. These areas included the north and south shores of the reservoir downstream of the state park and at the left abutment of the dam where the spillway inlet channel exists. Conversations with the reservoir superintendent confirmed that there has been some shoreline erosion since the reservoir fill in 1993, which accounts for the north and south shore areas. Using select and move commands within ARCEDIT, the vertices of the 1890.0 clip were shifted to fit all the collected underwater data. The underwater data and the contour topography are presented on figure 4.

Contours for elevations below 1,890.0 were computed from collected underwater data using the TIN surface modeling package within ARC/INFO. The underwater survey data were collected in the Kansas north zone state plane coordinates in NAD 1927 (a TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values). TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation. 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, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data. 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.*

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 and helped create more continuous contours in the lower elevations of the reservoir.

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Webster 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 little bearing on the computation of surface areas and volumes for Webster Reservoir. The contour topography at 4-foot intervals, from elevation 1852 to 1890 is presented on figure 5, drawing number 468-D-457. Contour elevations 1910 and 1924 are the digitized results for the USGS quad maps.

Development of 1996 Contour Areas

The 1996 contour surface areas for Webster Reservoir were computed at 1-foot increments, from elevation 1,849.4 to 1,880.0, using the Webster Reservoir TIN discussed above. The 1996 survey measured the minimum reservoir elevation at 1,849.4 feet. 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. As discussed in the survey method and equipment section, large areas of the underwater portion of the reservoir were not surveyed due to the thick tree growth. This accounts for the fact that the 1996 areas were only computed for elevation 1,880.0 and below. Several variations of the TIN were developed using different clip options, including larger clips and assigning no elevation to the clip. The resulting computed areas from all these options were virtually the same for elevation 1880 and below due to the lack of collected data in the thick vegetated areas. The final 1996 area computations assumed no change from the original surface area from elevation 1890 and above.

1996 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). Surface areas at 2-foot contour intervals from minimum reservoir elevation 1,849.4 to elevation 1,880.0 and the original surface areas at 2-foot contour intervals from elevation 1,890.0 and 1,938.0 were used as the control parameters for computing Webster Reservoir capacity. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit, which was set at 0.0000001 for Webster 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 1996 Webster Reservoir area and capacity computations are listed in table 1 and columns (4) and (5) of table 2. Listed in columns (2) and (3) of table 2 are the original surface areas and recomputed capacity values. A separate set of 1996 area and capacity tables has been 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 ACAP85 program is included with these tables. Both the original and 1996 area-capacity curves are plotted on figure 6. As of May 1996, at elevation 1,892.45, the surface area was 3,767 acres with a total capacity of 76,157 acre-feet and an active capacity of 71,926 acre-feet.

SEDIMENT ANALYSES

Sediments have accumulated in Webster Reservoir to a total volume of 1,267 acre-feet since dam closure in May 1956. This volume was calculated at reservoir spillway crest elevation 1,884.6. It must be noted that the 1996 underwater survey was conducted at around water surface elevation 1894.8 and that the final product relied on the original measured surface areas at elevation 1890.0 and greater for computing the 1996 reservoir area and capacity tables. Column 6 of table 2 gives the measured sediment volume by elevation and illustrates that the majority of the deposit is in the lower elevations of the reservoir. Of the total measured deposited sediment of 1,267 acre-feet, 1,069 acre-feet were deposited in the inactive pool storage areas and 198 acre-feet in the active pool storage areas. The average annual rate of sediment deposition between closure and May 1996 (40.0 years) was 31.7 acre-feet per year. The storage loss in terms of percent of original storage capacity was 1.64 percent. Table 1 and 2 contain the Webster Reservoir sediment accumulation and water storage data based on the 1996 resurvey.

Reclamation's original 50-year sediment deposition prediction was 9,300 acre-feet, of which 6,697 acre-feet were projected to settle above elevation 1860.0. The 1996 study found very little sediment accumulation within Webster Reservoir considering the size of the drainage basin. Prior to reservoir impoundment, a sediment range line network was established for monitoring sediment inflow (figure 7). Figures 8, 9, and 10 show plotted results of several range line surveys for range line 2, 3, and 4. Range line 2, surveyed in January of 1985, showed no change except in the original channel area. The original channel bottom was around elevation 1848 and the 1985 survey measured the bottom at approximately elevation 1856. Range line 3, surveyed in September 1968 and February 1979, showed little change between surveys except at the left bank above elevation 1885, indicating bank erosion and the sediment accumulated in the original channel area.. The original channel bottom was approximately elevation 1854, with the 1968 survey measuring the bottom at around elevation 1859 and the 1979 survey measuring the bottom at around elevation 1861. Range line 4, surveyed in September 1968 and February 1979, also showed little change between surveys except for channel sediment accumulation and right bank erosion. The original channel bottom was around elevation 1868 and the 1968 and 1979 surveys measured the bottom at around elevation 1873. Visually locating the range lines on the resulting 1996 contour map also indicated that there has been little bottom change in the lower original channel portions of the reservoir.

Table 1 may give some clues as to why the sediment accumulation is lower than original projections. Item 23 shows that the mean annual runoff of the basin for the 40-year period of record was only 0.6 inches. Lovewell Reservoir, located on White Rock Creek around 85 miles northeast of Webster Reservoir, had a calculated mean annual runoff of 3.4 inches. Webster Reservoir drainage basin has a much lower runoff, reflecting the lower sediment contribution. Additional factors are illustrated in item 45 of table 1 and on figure 3, which depicts the range of reservoir operation. The reservoir has operated at near full conditions (above elevation 1890) in a few years, but in many years the reservoir has operated at low reservoir content, below elevation 1870, and in a few years it has operated even in the inactive zone, below elevation 1860. These low reservoir operating conditions probably have moved some of the upper reservoir accumulated sediments toward the dam so that they are eventually flushed downstream through the outlet works.

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RESERVOIR SEDIMENT
DATA SUMMARY

Webster Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM South Fork Solomon River	3. STATE Kansas
	4. SEC. 3 TWP. 8S RANGE 19W	5. NEAREST P.O. Stockton	6. COUNTY Rocks
	7. LAT 39° 23' 29" LONG 99° 25' 33"	8. TOP OF DAM ELEVATION 1,944.0	9. SPILLWAY CREST EL. 1884.6[1]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN
	a. SURCHARGE	1,938.0	11,270	140,910	401,650	
	b. FLOOD CONTROL	1,923.7	8,480	183,370	260,740	5/03/56
	c. POWER					
	d. WATER SUPPLY	1,892.45	3,767	72,070	77,370	16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. INACTIVE	1,860.0	906	3,116	5,300	
	g. DEAD	1,855.5	473	2,184	2,184	5/58
	17. LENGTH OF RESERVOIR	6[2] MILES		AVG. WIDTH OF RESERVOIR	1.0 MILES	

BASIN			
	18. TOTAL DRAINAGE AREA 1,150 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 23.7[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 1,150 SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.6[4] INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 36,598[5] ACRE-FEET
	21. MAX. ELEVATION 3,460	MIN. ELEVATION 1,860	25. ANNUAL TEMP. MEAN 54°F RANGE -22°F to 112°F[6]

SURVEY DATA	26. DATE OF SURVEY	27. PER.	28. ACCL.	29. TYPE OF SURVEY	30. NO. OF RANGES OR	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
	5/03/56			Contour (D)	2-ft	3,767[7]	77,370[7]	2.11
	5/19/96	40.0	40.0	Contour (D)	2-ft	3,767[8]	76,157[8]	2.08

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
5/19/96	23.7[3]	36,598[5]	157,300	1,463,900	36,598	1,463,900

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.
5/19/96	1,267[9]	31.7	.03	1,267	31.7	.03

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
5/19/96				.041[9]	1.64[9]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW ELEVATION										
		34.6-45.6	24.6-34.6	14.6-24.6	4.6-14.6	Crest -4.6					
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
5/96		47.4	37.0	-17.5	32.4	0.7					

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 1 of 2).

45. RANGE IN RESERVOIR OPERATION[10]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1956	1,857.6	1,839.9	6,300
1957	1,899.6	1,855.2	128,500	1958	1,895.6	1,886.1	67,000
1959	1,894.6	1,888.0	24,100	1960	1,896.1	1,888.2	69,400
1961	1,899.7	1,884.2	87,700	1962	1,898.0	1,886.8	127,500
1963	1,890.4	1,886.0	43,700	1964	1,889.9	1,879.1	20,300
1965	1,890.4	1,879.0	64,700	1966	1,891.0	1,876.0	17,700
1967	1,877.9	1,869.7	11,300	1968	1,872.0	1,861.6	18,000
1969	1,879.0	1,866.8	38,400	1970	1,877.1	1,863.7	12,800
1971	1,868.8	1,857.4	12,100	1972	1,863.4	1,857.4	9,700
1973	1,873.6	1,863.1	34,100	1974	1,879.6	1,868.5	22,400
1975	1,886.3	1,868.6	52,500	1976	1,882.8	1,867.9	11,300
1977	1,871.7	1,861.4	14,900	1978	1,873.0	1,865.3	21,600
1979	1,879.6	1,871.7	21,600	1980	1,875.2	1,864.0	11,200
1981	1,867.8	1,863.8	7,500	1982	1,870.9	1,864.6	10,900
1983	1,872.7	1,860.9	8,800	1984	1,868.8	1,860.8	12,700
1985	1,868.7	1,866.4	6,400	1986	1,873.0	1,866.6	15,200
1987	1,880.1	1,867.4	31,600	1988	1,880.1	1,871.5	6,900
1989	1,871.5	1,864.8	10,700	1990	1,872.4	1,866.0	12,100
1991	1,867.3	1,858.7	4,500	1992	1,864.0	1,859.2	8,000
1993	1,904.3	1,864.0	143,700	1994	1,897.0	1,892.8	61,800
1995	1,907.0	1,892.0	157,300	1996	1,894.8	1,893.7	17,000

46. ELEVATION - AREA - CAPACITY DATA FOR **1996 CAPACITY**[11]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
1849.4	0	0	1850	2.0	1	1852	188.0	166
1854	326.9	681	1856	477.7	1,486	1858	682.0	2,645
1860	904.1	4,231	1862	1,087.9	6,223	1864	1,250.7	8,562
1866	1,390.0	11,203	1868	1,507.4	14,100	1870	1,648.0	17,255
1872	1,780.2	20,684	1874	1,929.0	24,393	1876	2,099.5	28,421
1878	2,274.6	32,795	1880	2,460.7	37,531	1890	3,487	67,269
1892.45	3,767	76,157	1894	3,939	82,129	1898	4,425	98,843
1902	4,832	117,380	1906	5,400	137,742	1910	6,010	160,532
1914	6,730	185,932	1918	7,425	214,267	1923.7	8,478	259,510
1928	9,315	297,797	1932	10,045	336,557	1938	11,270	400,422

47. REMARKS AND REFERENCES

1 Top of spillway radial gates is elevation 1923.7.

2 Length at reservoir elevation 1890.0 from USGS quad maps of reservoir.

3 Average precipitation at Webster Dam, 1955-1996, measured at Bureau of Reclamation gage.

4 Calculated using mean annual runoff value of 36,598 AF, item 24.

5 Computed inflows from the South Fork Solomon River, 5/56 through 5/96.

6 Bureau of Reclamation Project Data Book, 1981.

7 Original surface area and capacity at elevation 1,892.45, top of water supply. Original capacity recomputed by Reclamation's ACAP program using original surface areas.

8 Surface area and capacity at elevation 1892.45 computed by ACAP program using 1996 and original surface areas. 1996 surveyed only underwater portion of reservoir below elevation 1890.0, but heavy vegetation restricted adequate data collected to elevation 1880 and below. Elevation 1890.0 and above from original measured areas.

9 Total capacity loss calculated by comparing original recomputed capacity and 1996 capacity at reservoir elevation 1884.6, spillway crest elevation.

10 Maximum and minimum elevations and inflow values in acre-feet by calendar year, from 5/56 through 5/96.

11 Capacities computed by ACAP computer program. Areas at elevation 1890 and above from original survey.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE August 1997

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

Table 2 - Summary of 1996 survey results.

(1) Elevation (feet)	(2) Original Area (acres)	(3) Original Capacity (acre-feet)	(4) 1996 Area (acres)	(5) 1996 Capacity (acre-feet)	(6) Measured Sediment Volume (acre-feet)	(7) Percent Measured Sediment	(8) Percent Reservoir Depth
1938.0	11,270	401,636	11,270	400,422	-	-	100.0
1930.0	9,700	318,026	9,700	316,812	-	-	91.9
1923.7	8,478	260,723	8,478	259,510	-	-	85.6
1920.0	7,790	230,696	7,790	229,482	-	-	81.8
1910.0	6,010	161,746	6,010	160,532	-	-	71.7
1900.0	4,640	109,122	4,640	107,908	-	-	61.6
1892.45	3,467	77,370	3,767	76,157	-	-	54.0
1890.0	3,487	68,483	3,487	67,269	-	-	51.5
1884.6	2,922	51,203	2,933	49,936	1,267	100.0	46.1
1878.0	2,311	33,991	2,275	32,795	1,196	94.4	39.4
1874.0	1,967	25,407	1,929	24,393	1,014	80.0	35.4
1870.0	1,678	18,102	1,648	17,255	847	66.9	31.3
1866.0	1,368	12,014	1,390	11,203	811	64.0	27.3
1862.0	1,048	7,254	1,088	6,223	1,031	81.4	23.2
1858.0	723	3,671	682	2,645	1,026	81.0	19.2
1855.5	473	2,183	440	1,256	927	73.2	16.7
1850.0	154	602	2	1	601	47.4	11.1
1846.0	72	140	0	0	140	11.0	7.1
1842.0	8	10	0	0	10	0.8	3.0
1839.0	0	0	0	0	0	0	0.0

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area.
(3) Original calculated reservoir capacity computed using ACAP from original measured surface areas.
(4) Reservoir surface area from 1996 survey for elevations 1880 and below. Areas for elevation 1890 and greater are original measured areas.
(5) 1996 calculated reservoir capacity computed using ACAP, from 1996 surface areas.
(6) Measured sediment volume = column (3) - column (5).
(7) Measured sediment expressed in percentage of total sediment 1,267 acre-feet at elevation 1884.6.
(8) Depth of reservoir expressed in percentage of total depth (99 feet).

Note: The 1996 survey developed updated underwater reservoir topography from elevation 1880.0 and below. Surface areas at elevation 1890 and above are original measured areas.

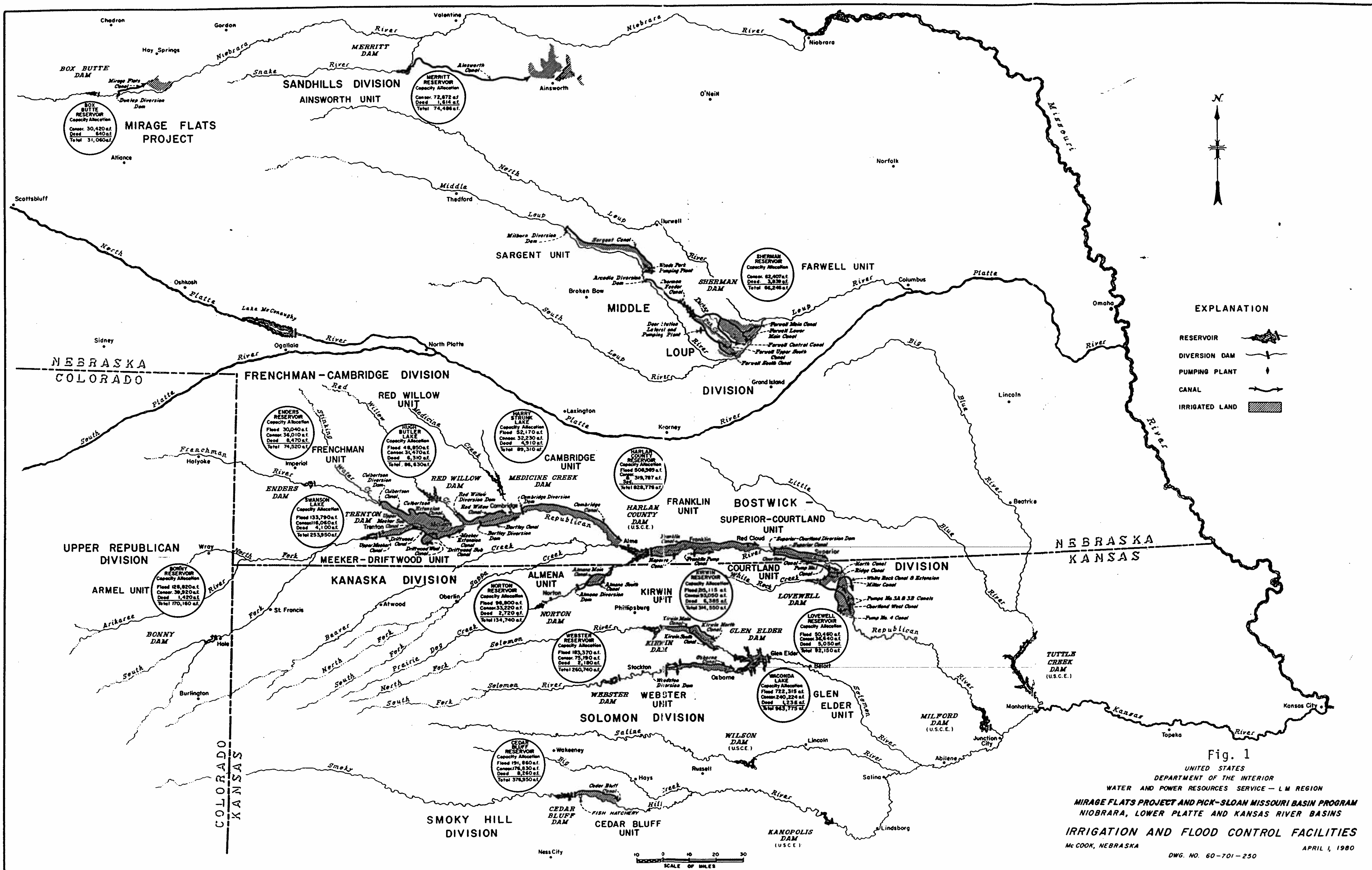

Fig. 1

UNITED STATES
DEPARTMENT OF THE INTERIOR
WATER AND POWER RESOURCES SERVICE — L M REGION
MIRAGE FLATS PROJECT AND PICK-SLOAN MISSOURI BASIN PROGRAM
NIOBRARA, LOWER PLATTE AND KANSAS RIVER BASINS
IRRIGATION AND FLOOD CONTROL FACILITIES
Mc COOK, NEBRASKA APRIL 1, 1980
DWG. NO. 60-701-250

GPO 855-627

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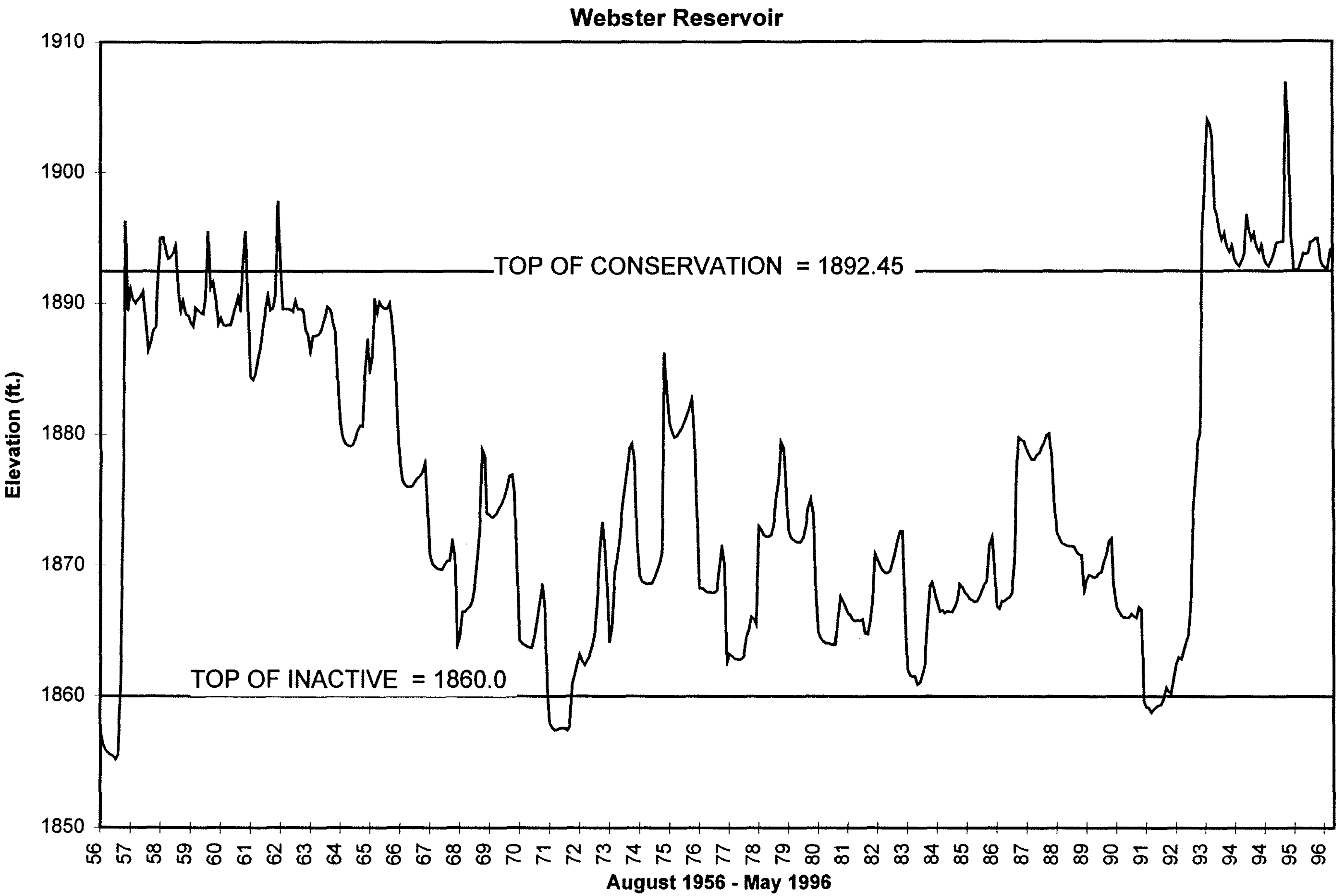
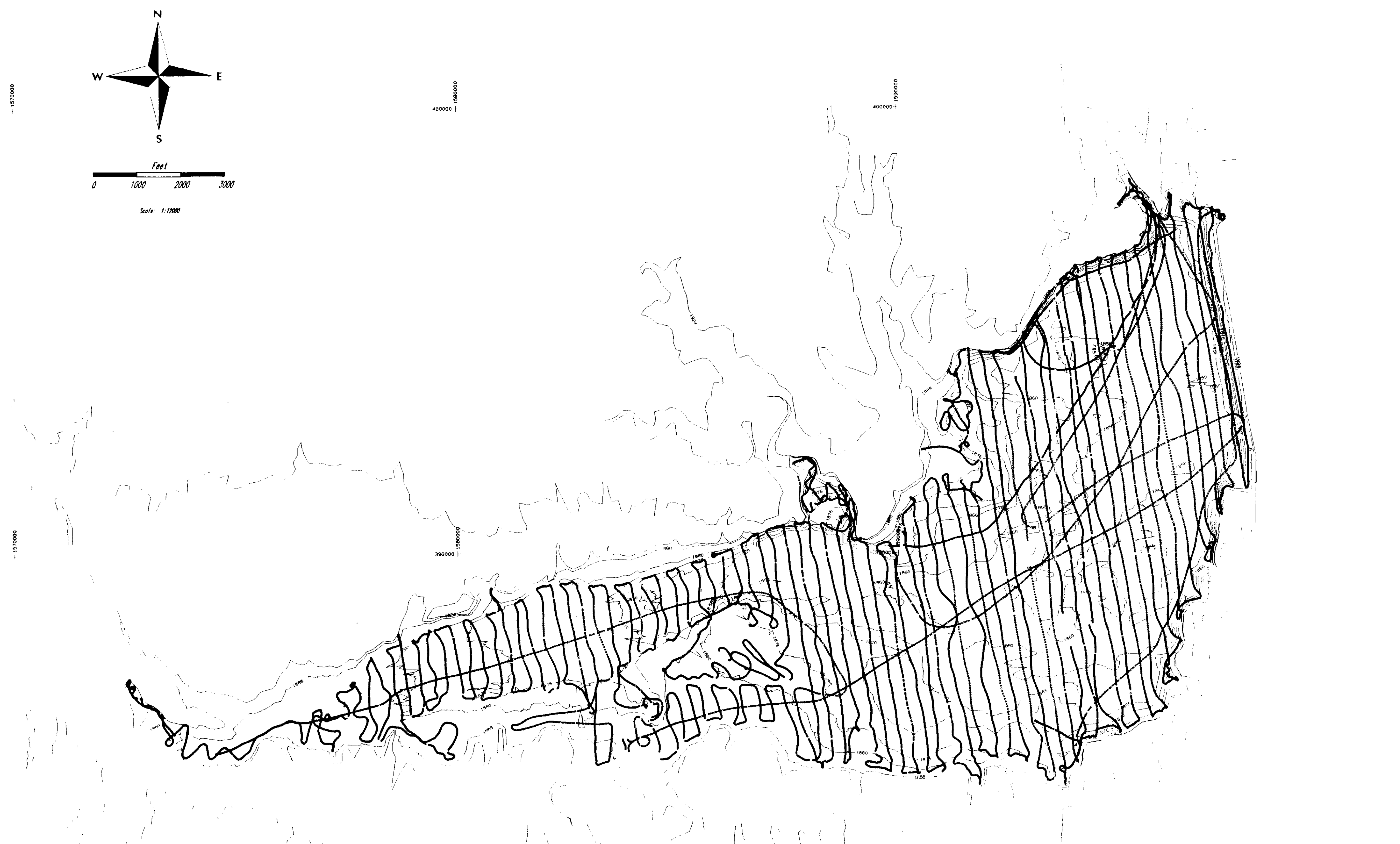

Webster Reservoir
TOP OF CONSERVATION = 1892.45
TOP OF INACTIVE = 1860.0
Elevation (ft.)
1910
1900
1890
1880
1870
1860
1850
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 94 95 95 96
August 1956 - May 1996

Fig. 3



UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
SOLOMON DIVISION
WEBSTER - KANSAS

Fig. 4

WEBSTER RESERVOIR
1996 UNDERWATER COLLECTED DATA

DRAWN BY________ TECHNICAL APPROVAL________
CHECKED BY________ APPROVED________
Group Manager

Denver, Colorado FEB 01, 1997

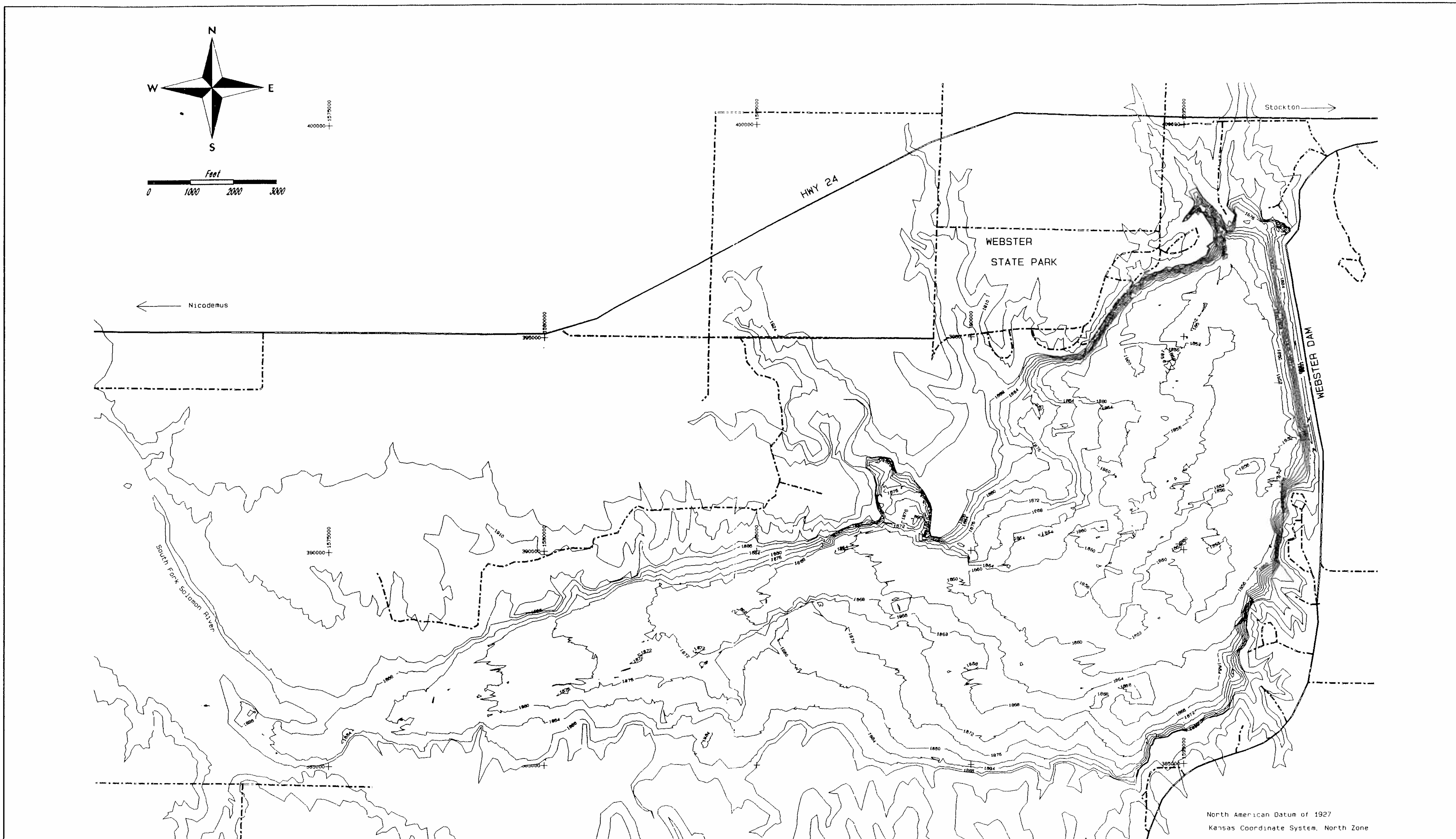


Fig. 5

UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
SOLOMON DIVISION
WEBSTER - KANSAS
WEBSTER RESERVOIR
TOPOLOGY

DRAWN BY________ TECHNICAL APPROVAL________
CHECKED BY________ APPROVED________
Group Manager

Denver, Colorado JUL 28, 1997 | 468-D-457

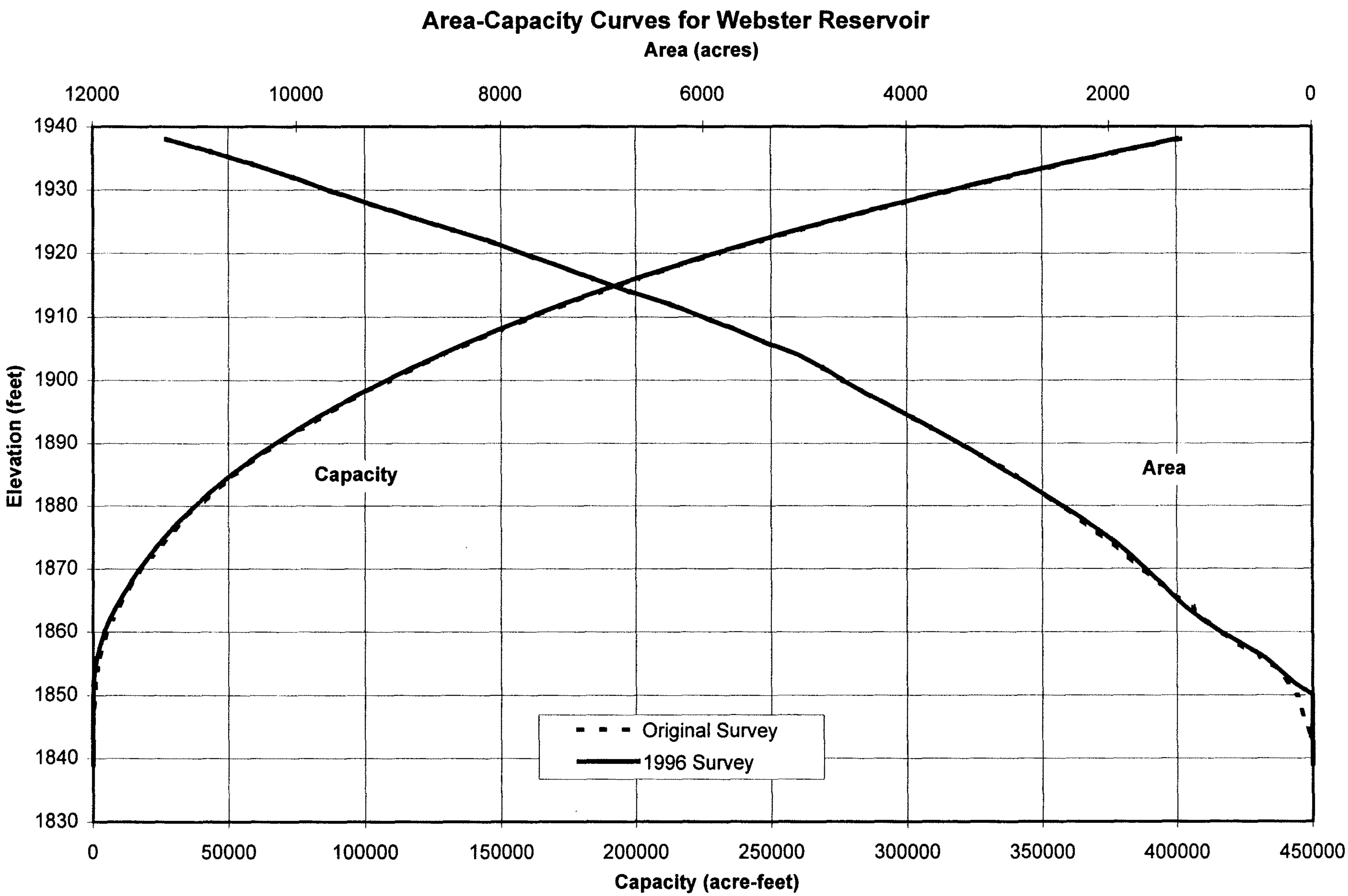

Area-Capacity Curves for Webster Reservoir
Area (acres)
12000
10000
8000
6000
4000
2000
0
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
1830
Elevation (feet)
Capacity
Area
Original Survey
1996 Survey
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
Capacity (acre-feet)

Fig. 6

LOCATION OF BRASS CAP MONUMENTS

B.C. monument 3.5 ft. north of east and west fence, 35.0 ft. north of east and west road, 12.0 ft. east of gate into field, 240.0 ft. west of fence corner, 550.0 ft. east of southwest corner of section 22, T 7S. R 19W.

B.C. monument on top of hill in pasture, 37.0 ft. north of east and west fence line, appr. 1283.0 ft. south and 104.0 ft. west of 1/4 corner sec. 34 & sec. 3 T 8S. R 19W.

• R 20L B.C. monument on top of hill in cultivated field, 70.0 ft north of sec. line 28 & 33, 1575.0 ft. east of southwest corner of sec. 28, T 7S. R 19W. 1.25 miles west of dam.

B.C. monument on top of hill in pasture, 10.5 ft. east of north and south fence line, 42.0 ft. east of north and south road, 62.0 ft. northwest of concrete block grainery, 862.0 ft northeast of 1/4 corner 9 & 10. T 8S. R 19W. Magnetic Bearing from 1/4 corner 9 & 10 to R 2R is north 7° east.

B.C. monument 2.0 ft. south of fence post in fence line, 35.0 ft. west of north and south road, 46.0 ft. south of east and west road, 85.8 ft. southwest of northeast corner of sec. 32, T 7S. R 19W.

B.C. monument set in east & west 1/4 line sec. 32, 426.0 ft. west of 1/4 corner sec. 32 & 33 T 7S. R 19W.

B.C. monument in north and south fence line, 15.0 ft. east of north and south trail, 378.0 ft. south of northwest corner of section 9, T 8S. R 19W.

B.C. monument in pasture, 1350.0 ft. southeast of c1/4 corner sec. 31, 712.0 ft. east of north and south fence southeast 1/4 of sec. 31, T 7S. R 19W. Magnetic Bearing from c1/4 corner sec. 31 to R 4L is south 42° 30′ east.

• R 30L = ▲42 B.C. monument on top of hill in pasture, appr. 725.0 ft. east of north and south fence, appr. 1700.0 ft. northeast of c1/4 corner sec. 7, T 8S. R 19W. Magnetic Bearing from c1/4 corner sec. 7 to R 4L = R 30L = ▲42, is north 22° 30′ east.

B.C. monument c1/4 corner sec. 8 in pasture, 3.5 ft. north of east and west fence line, 2.0 ft. east of north and south fence line of c 1/4 corner sec. 8, T 8S. R 19W.

B.C. monument c1/4 corner of sec. 36 in pasture, 3.2 ft. south of east and west fence line, 5.8 ft. west of north and south fence line, T 7S. R 20W.

B.C. monument in east and west fence line, 29.0 ft. north of east and west road, 46.1 ft. northeast of 1/4 corner sec. 1 & sec. 12, T 8S. R 19W.

B.C. monument on top rock knoll, east of north and south trail, about 1.5 ft. west of north and south fence, about 1570.0 ft. south of northeast corner of sec. 35, T 7S. R 19W.

• R 7R B.C. monument 1/4 corner sec. 3 & 2 west edge of trail, 56.0 ft. east of fence corner, T 8S. R 20W.

B.C. monument 8.0 ft. east of north and south fence in pasture, about 1300.0 ft. south of 1/4 corner between sec. 33 & 34, T 7S. R 20W

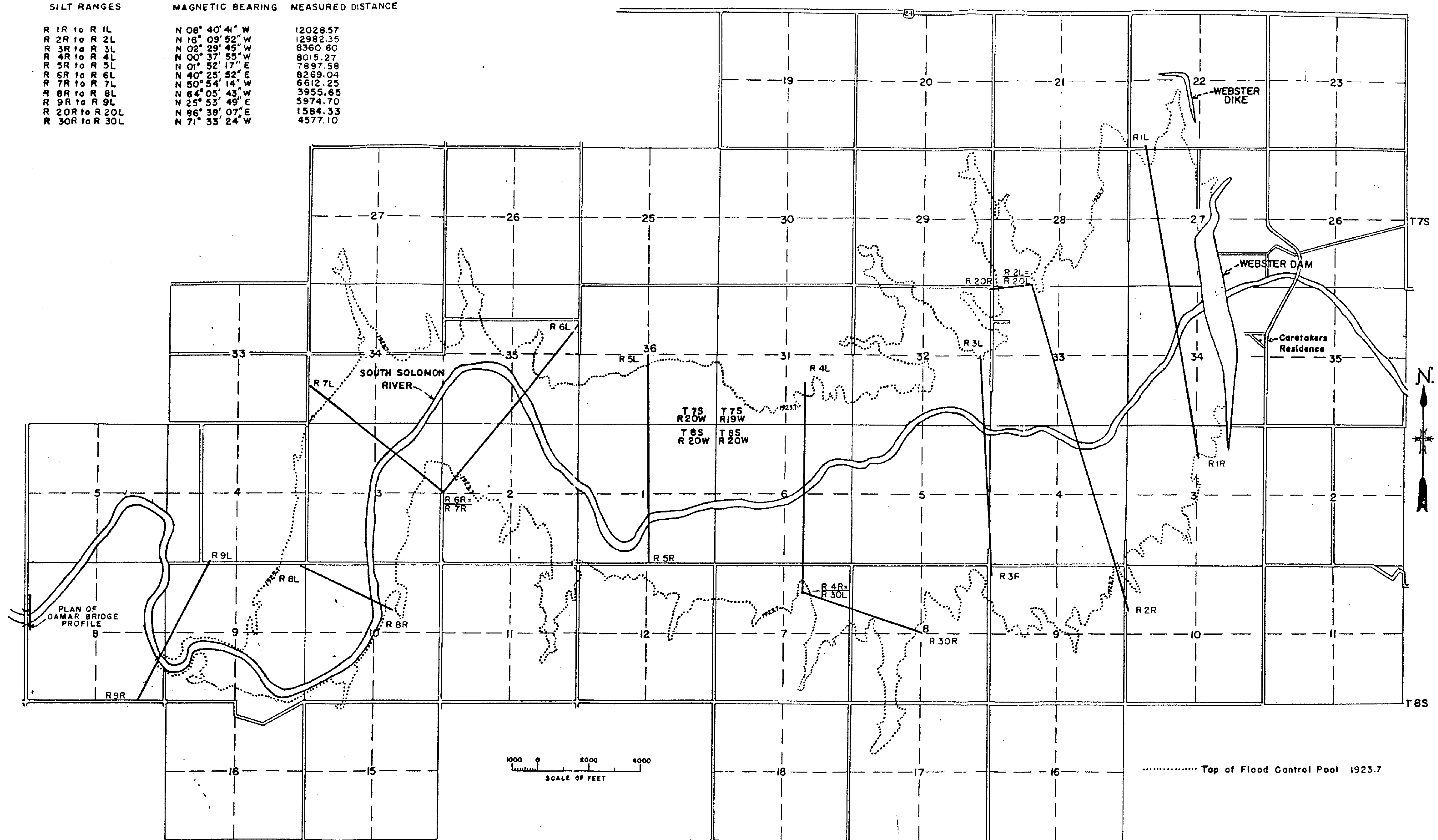
B.C. monument appr. 200.0 ft. west southwest of northeast corner of sec. 9, 18.0 ft. south of east and west fence line. T 8S. R 20W.

B.C. monument in pasture, about 1000.0 ft. south southwest of silo, about 80.0 ft. west of steep bank of drain, about 500.0 ft. east of river bank, appr. 2500.0 ft. southwest of northeast corner of sec. 10, T 8S. R 20W.

B.C. monument on top of sand hill 1000.0 ft. northwest of north 1/4 corner sec. 9, T 8S. R 20W.

• ▲81 B.C. monument in pasture on top of hill on north side of east and west road, about 13.0 ft. north of east and west fence, about a 1000.0 ft. west of southeast corner of sec. 8, T 8S. R 19W.

SILT RANGES	MAGNETIC BEARING	MEASURED DISTANCE
R 1R to R 1L	N 08° 40′ 41″ W	12028.57
R 2R to R 2L	N 16° 09′ 52″ W	12982.35
R 3R to R 3L	N 02° 29′ 45″ W	8360.60
R 4R to R 4L	N 00° 37′ 55″ W	8015.27
R 5R to R 5L	N 01° 52′ 17″ E	7897.58
R 6R to R 6L	N 40° 25′ 52″ E	8269.04
R 7R to R 7L	N 50° 54′ 14″ W	6612.25
R 8R to R 8L	N 64° 05′ 43″ W	3955.65
R 9R to R 9L	N 25° 53′ 49″ E	5974.70
R 20R to R 20L	N 86° 38′ 07″ E	1584.33
R 30R to R 30L	N 71° 33′ 24″ W	4577.10



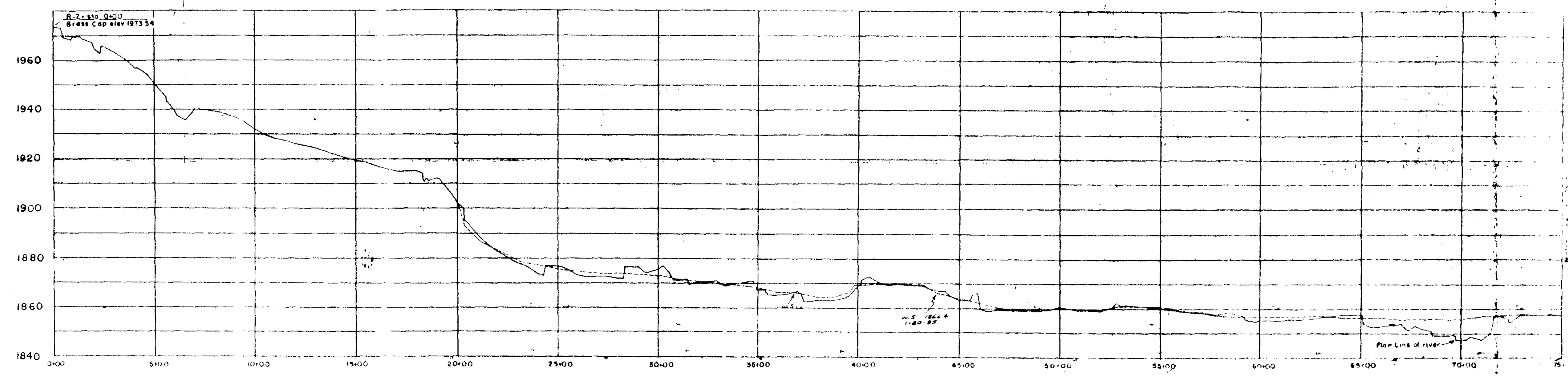
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
SOLOMON DIVISION KANSAS
WEBSTER DAM

Fig. 7

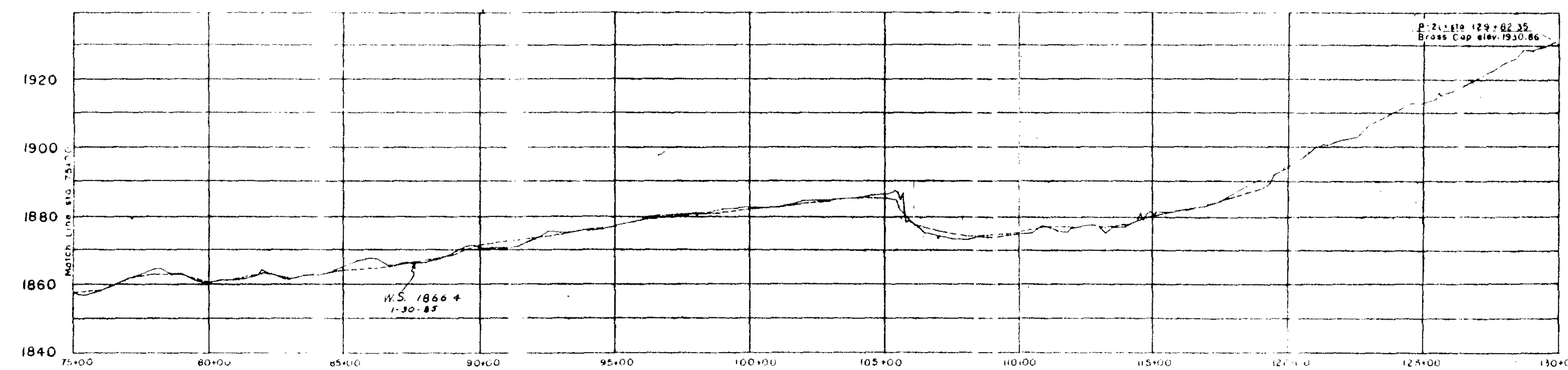
PLAN OF SILT RANGES IN RESERVOIR

DRAWN W.C.P. SUBMITTED Clifford S. Scribner
TRACED W.C.P. RECOMMENDED
CHECKED APPROVED

STOCKTON, KANSAS April 3, 1956
SHEET 1 OF 7
468-701-490



SILT RANGE 2



SILT RANGE 2

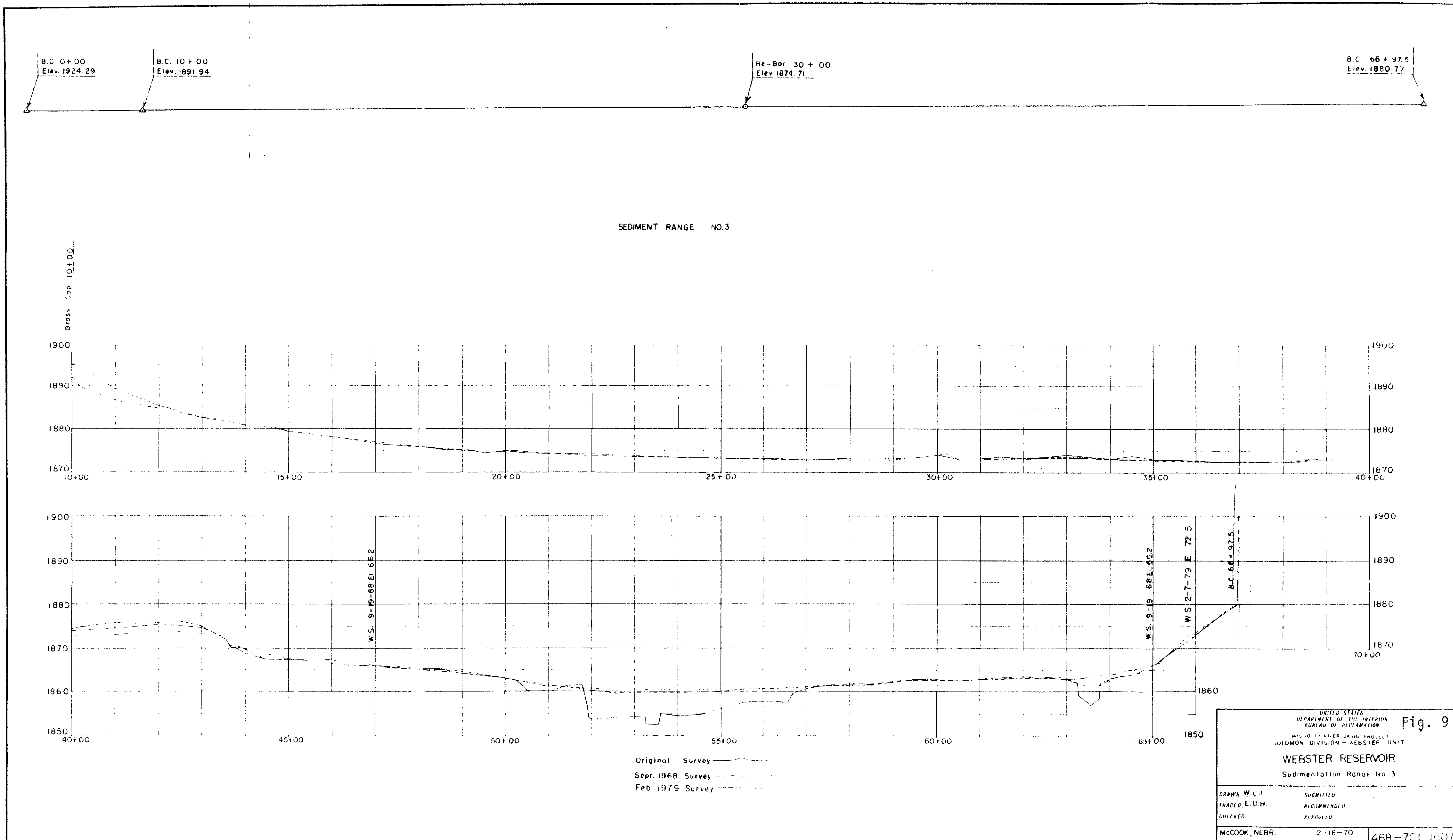
Original Survey
Jan 1985 Survey

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
SOLOMON DIVISION KANSAS
WEBSTER DAM

Fig. 8

PROFILE OF SILT RANGES IN RESERVOIR

DRAWN RWM SUBMITTED
TRACED WCP RECOMMENDED
CHECKED APPROVED
STOCKTON, KANSAS
461-701-492


B.C. 0+00
Elev. 1924.29
B.C. 10+00
Elev. 1891.94
Re-Bar 30+00
Elev. 1874.71
B.C. 66+97.5
Elev. 1880.77
SEDIMENT RANGE NO. 3
Brass Cap 10+00
W.S. 9-19-68 El. 65.2
W.S. 2-7-79 E. 72.5
B.C. 66+97.5
Original Survey
Sept. 1968 Survey
Feb 1979 Survey
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SOLOMON DIVISION - WEBSTER UNIT
WEBSTER RESERVOIR
Sedimentation Range No. 3
DRAWN W.L.J.
TRACED E.O.H.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
McCOOK, NEBR.
2-16-70
Fig. 9

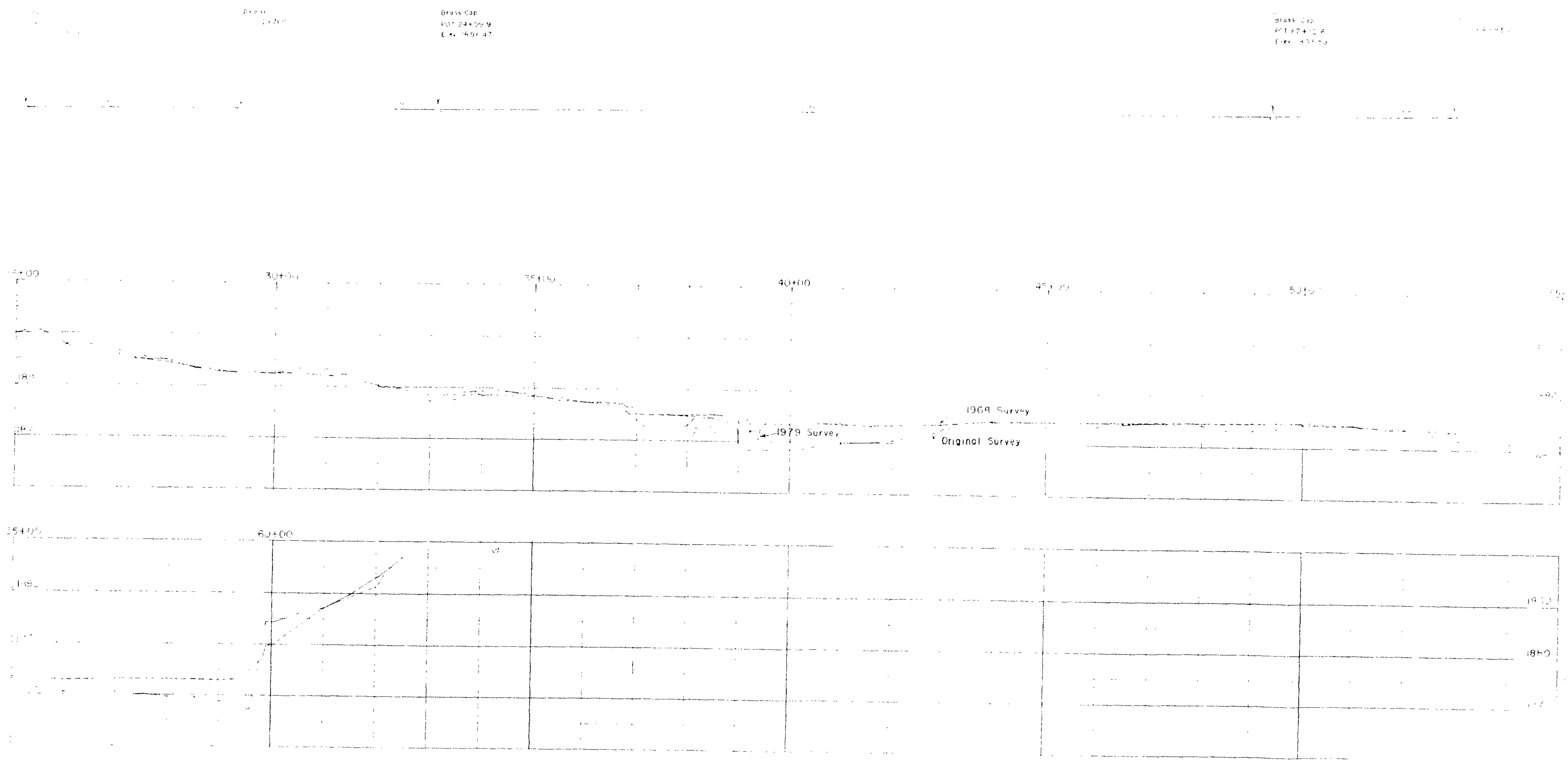


Fig. 10

WEBSTER RESERVOIR

RECLAMATION'S 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.