FRESNO RESERVOIR
1999 RESERVOIR SURVEY

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed Fresno Reservoir in May 1999 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were used to calculate reservoir capacity lost due to sediment accumulation since dam closure in 1939. The underwater survey was conducted near reservoir elevation 2,564 feet (project datum). The underwater survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portions of the reservoir covered by the survey vessel. The above-water topography was determined by digitizing the developed contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. The new topographic map of Fresno Reservoir was developed from the combined 1999 underwater measured topography and the digitized USGS contours. The 1999 survey only measured the area change of the reservoir from elevation 2,565 and below.

As of May 1999, at spillway crest water surface elevation (feet) 2,575.0, the surface area was 4,878 acres with a total capacity of 92,880 acre-feet. Since initial filling in November of 1939, about 36,210 acre-feet of sediment have accumulated in Fresno Reservoir below elevation 2,575.0, resulting in a 28.0 percent loss in reservoir volume. Since November 1939, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 608.6 acre-feet.

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FRESNO RESERVOIR

1999 RESERVOIR SURVEY

by

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Technical Service Center
Denver, Colorado

September 2000

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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari and James Melena of the TSC conducted 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 final map development. Kent Collins of TSC performed the technical peer review of this documentation

Mission Statements

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

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

CONTENTS

TABLES

FIGURES

INTRODUCTION

Fresno Reservoir and dam are located in Hill County on the Milk River about 30 miles south of the Canadian boarder and 13 miles west of Havre in north central Montana (fig. 1). Fresno Reservoir is the principal storage component for suppling irrigation water for the Milk River Project and also furnishes flood control along with providing wildlife and recreation benefits.

Fresno Dam was constructed from 1937 through 1939 with first storage in November of 1939. The crest of the dam was raised two feet in 1943 due to excessive foundation settlement that occurred during and after construction. In 1950 the crest was again raised to elevation 2,596.1 (feet)[1], from elevation 2,594.5, and a concrete parapet and curb walls were constructed. The dam is a wide, homogeneous, rolled earth embankment whose dimensions are (fig. 2):

Hydraulic height[2]	57	feet	Structural height	110	feet
Top width	22	feet	Crest length	2,070	feet
Crest elevation	2,596.1	feet	Top of parapet wall	2,596.1	feet

The drainage area above Fresno Dam is 3,766 square miles with 3,096 square miles considered sediment contributing. The elevations range from 2,520.0, outlet sill elevation, to about 10,000 feet. Fresno Reservoir has an average width of 0.5 miles with a length of around 15.5 miles.

The Fresno Dam's spillway is near the left abutment and consists of a riprap-lined inlet channel, concrete overflow crest structure, concrete chute and stilling basin, and a riprap-lined outlet channel to the river. The uncontrolled spillway crest is at elevation 2,575.0 with a length of 210 feet. The spillway provides a maximum discharge of 62,000 cubic feet per second (cfs) at maximum reservoir water surface elevation 2,592.8.

The outlet works provide the only controlled discharge through the dam. They have an inlet elevation of 2,520.0 and consist of two 72-inch conduits located in the left abutment of the dam. The outlets have a total discharge capacity of 2,600 cfs at reservoir elevation 2,575.0.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1999 results of the survey of Fresno Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships

[1]Elevation levels are shown in feet. All elevations shown in this report are based on the original project datum established by U.S. Bureau of Reclamation which is 4.71 feet higher than National Geodetic Vertical Datum of 1929.

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

- estimate storage depletion caused by sediment deposition since dam closure and 1978 survey

Prior to the underwater survey in May of 1999, a contract static global positioning system (GPS) control survey was conducted to establish horizontal and vertical control points around the reservoir. The horizontal control was established in Montana State plane coordinates in the North American Datum of 1983 (NAD83). The vertical control for the established points was in the National Geodetic Vertical Datum of 1929 (NGVD29) and NGVD88. The survey found that for the established points the average elevations in NGVD29 were around 2.87 feet lower than in NGVD88. During the May 1999 underwater survey, the average reservoir water surface recorded by the Reclamation gauge was elevation 2664 which was around 4.7 feet higher than the NGVD29 GPS measured water surfaces at the same time. All computations in this report are based on the Reclamation project construction datum which was measured to be 4.71 feet higher then the NGVD29 datum.

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

Since a 1999 above water survey wasn't conducted for this study, the Fresno Reservoir contours were digitized from the U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps. This included contour elevations 2560, 2570, 2571, and 2587. To match the Reclamation project datum these NGVD29 measured contour elevations were increased by 4.7 feet. For developing the underwater contours the 2560 USGS labeled contour was used as a clip around the 1999 underwater collection data. This contour clip was assigned an elevation of 2,564.7 to match the Reclamation project datum. The new topographic map of Fresno Reservoir is a combination of the digitized and underwater-measured topography. The 1999 reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using this combined reservoir data. The 1999 area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 2 and 3 contain a summary of the 1999 Fresno Reservoir survey. The 1999 survey determined that the reservoir has a total storage capacity of 92,880 acre-feet and a surface area of 4,878 acres at reservoir spillway crest elevation 2,575.0. Since closure in November 1939, the reservoir has accumulated a volume of 36,210 acre-feet of sediment below elevation 2,575.0. This volume represents a 28.0 percent loss in total capacity and an average annual loss of 608.6 acre-feet.

RESERVOIR OPERATIONS

Fresno Reservoir operates in conjunction with several other reservoirs of the Milk River Project to provide irrigation water. The May 1999 area-capacity tables show 217,974 acre-feet of total storage below elevation 2,592.8. The 1999 survey measured a minimum elevation of 2,525. The dead storage below elevation 2,530.0 was measured as 448 acre-feet.

The Fresno Reservoir inflow and end-of-month stage records in table 2 are listed for the years since the last reservoir survey in 1978 (water years 1979 through May 1999). The estimated average inflow into the reservoir for this period was 247,620 acre-feet per year. The estimated average inflow for the total period of operation was 264,700 acre-feet per year. Since October 1978, the recorded storage fluctuations of Fresno Reservoir ranged from an end of month elevation 2536.6 in 1989 to a maximum end-of-month elevation 2,577.6 in 1996.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

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

The shore equipment included a second GPS receiver with an external radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. To obtain the maximum radio transmission range, known datum points with clear line-of-sight to the survey boat were selected. The power for the shore unit was provided by a 12-volt battery.

GPS Technology and Equipment

The hydrographic positioning system used at Fresno 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 a 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 (Fresno's water surface elevation parameter) was known, which in theory meant only three satellite observations were needed to track the survey vessel. During the Fresno Reservoir survey, the best available satellites were used for position calculations which usually consisted of 5 or more.

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 of the ionosphere on the radio signal. 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 at the survey vessel's GPS receiver during the Fresno 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, 1994).

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. In May of 2000 the use of S/A was discontinued, but the errors of a single receiver are still around $\pm$10 meters.

A method of collection to resolve or cancel the inherent errors of GPS is called differential GPS (DGPS). DGPS are used during the 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 Fresno Reservoir survey, position corrections were determined by the master receiver and transmitted via an ultra-high frequency (UHF) radio link every second to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS can result in sub-meter positional accuracies for the survey vessel compared to positional accuracies of $\pm$100 meters with a single receiver.

The Sedimentation and River Hydraulics Group started using Real-time Kinematic (RTK) GPS in the spring of 1999. The major benefits of RTK versus DGPS are that precise heights can be measured in real time for monitoring water surface elevation changes. The basic outputs from an RTK receiver are precise 3D coordinates in latitude, longitude, and height with accuracies in the order of 2 centimeters horizontally and 3 centimeters vertically. This output was on the GPS datum of WGS-84 which the hydrographic collection software converted into Montana's NAD83 state plane coordinate system. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with DGPS. The receivers track the L1 C/A code and full cycle L1 and L2 carrier phases. The additional data logged from the second frequency allows the on-the-fly centimeter accuracy measurements.

Survey Method and Equipment

The Fresno Reservoir hydrographic survey collection was conducted from May 2 through May 6, 1999 at around water surface elevation 2,564 (Reclamation project datum). The bathymetric survey was run using sonic depth recording equipment interfaced with an RTK GPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat in a perpendicular direction to the center line of the reservoir at 300-foot spacing. Data was also collected along the shore as the boat traversed to the next transects. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing.

The 1999 underwater data were collected by a depth sounder that was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. The collected data were digitally transmitted to the computer collection system via a RS-232 port. The depth sounder also 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. The water surface elevations at the dam, recorded by a

Reclamation gage at 15-minute intervals, were used to convert the sonic depth measurements to true lake-bottom elevations.

Fresno Reservoir Datums

Prior to the underwater survey in May of 1999, a contract static global positioning system (GPS) control survey was conducted to establish horizontal and vertical control points around the reservoir. The horizontal control was established in Montana State plane coordinates in the North American Datum of 1983 (NAD83). The vertical controls for the established points were in the NGVD29 and NGVD88. The survey found that for the established points the average elevations in NGVD29 were around 2.87 feet lower than in NGVD88. The results from the survey are listed on table 1.

This control network was used during the May 1999 underwater survey for measuring horizontal and vertical data using RTK GPS measuring techniques. This included periodic water surface measurements. A comparison of the reservoir water surface recorded by the Reclamation gauge on a 15-minute interval found it to be around 4.7 feet higher than the NGVD29 RTK GPS measured water surfaces that were collected by the hydrographic survey crew at the same time. It must be noted that all computations in this report are based on the original Reclamation project datum that was established during construction. An additional static survey determined that the Reclamation project datum was 4.71 feet higher that the datum of NGVD29.

RESERVOIR AREA AND CAPACITY

Topography Development

Using ARC/INFO the topography of Fresno Reservoir was developed from the 1999 collected underwater data and the USGS quad maps. ARC/INFO is a software package for development and analysis of geographic information system (GIS) layers and development of interactive GIS applications (ESRI, 1992). GIS technology provides a means of organizing and interpreting large data sets.

The upper contours of Fresno Reservoir were developed by digitizing the water surface contour lines from the USGS quad maps that covered the Fresno Reservoir area. These USGS quad maps were developed from aerial data collected in the late 1960's. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed into Montana's NAD 1983 state plane coordinates using the ARC/INFO PROJECT command. The quad's contours digitized were labeled elevation 2560, 2570, 2571, and 2587 in NGVD29. For map development these digitized contours were assigned vertical elevations of 2564.7, 2574.7, 2575.7, and 2,591.7 respectfully. As noted previously the 1999 GPS survey determined that the Fresno Reservoir Reclamation project datum was around 4.7 feet higher than NGVD29.

Table 1. - GPS control survey

U.S. BUREAU OF RECLAMANTION									
FRESNO RESEVIOR									
1999 STATIC GPS CONTROL SURVEY									
CONTRACT #1425-98-CA-60-00090									
					Montana State Plane				
Point #	Latitude	Longitude	Ellipsoid		NAD83(1992)		NAVD 88		NGVD 29
	NAD83(1992)	NAD83(1992)	Height		Northing	Easting	Elevation		Elevation
			Meters		Meters	Meters	Meters		Meters
FRESNO 1	48°° 35' 47.54518" N	109°° 56' 54.08306" W	779.730		483100.3077	566936.3382	795.878		795.002
FRESNO 2	48°° 36' 3.90468" N	109°° 56' 27.36946" W	780.700		483602.4167	567486.3909	796.858		795.982
FRES-3	48°° 36' 37.89651" N	109°° 57' 40.01141" W	779.937		484660.7272	566004.6846	796.096		795.221
FRES-4	48°° 39' 18.81695" N	109°° 58' 17.30154" W	797.761		489634.9366	565270.9452	813.962		813.095
FRES-5	48°° 40' 51.93928" N	110°° 0' 19.08169" W	800.732		492526.4071	562797.7478	816.933		816.070
FRES-6	48°° 42' 12.39244" N	110°° 3' 44.19820" W	805.626		495039.6903	558620.7916	821.805		820.945
FRES-7	48°° 43' 42.13424" N	110°° 6' 23.03320" W	798.011		497835.5109	555395.3641	814.174		813.317
FRES-8	48°° 46' 41.94877" N	110°° 9' 14.46069" W	781.679		503417.2286	551939.1379	797.849		797.000
HAVRE GPS	48°° 32' 47.07068" N	109°° 46' 22.74926" W	769.742		477467.3708	579849.3927	785.858		784.976
T369	48°° 33' 29.31648" N	110°° 25' 28.11461" W	909.290		479139.5013	531776.1105	924.992		924.098
2744 HAVRE	48°° 44' 25.07521" N	110°° 13' 34.41896" W	821.495		499236.6873	546593.6405	837.555		836.697
31 WCA	48°° 44' 24.92945" N	110°° 17' 30.50433" W	851.093		499278.9197	541771.0900	867.079		866.220
CHAIN	48°° 38' 42.93800" N	110°° 0' 52.42722" W	817.565		488546.8662	562089.6311	833.731		832.861
F513	48°° 34' 10.92497" N	110°° 0' 56.72294" W	823.920		480147.1110	561946.4045	839.983		839.100

Notes:

The horizontal coordinates were established by GPS observation and were adjusted to NGS "B" order stations HAVRE GPS and T369.

Elevation values are based upon GPS observation.

NAVD 88 Elevations are based upon NGS Published values which were held at stations 31 WCA, F513, and T369.

NGVD 29 Elevations are based upon NGS "SUPERSEDED SURVEY CONTROL" values which were held at stations 31 WCA, F513, and T369.

The elevation 2,564.7 contour digitized from USGS quad maps (labeled 2560) was used to perform a clip or boundary around the edge of the underwater data set such that interpolation was not allowed to occur outside of this boundary. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. This clip was selected because it was close to the elevation of the reservoir water surface during the underwater collection.

Contours for elevations 2,564.7 and below were computed from the 1999 underwater data set using the triangular irregular network (TIN) surface modeling package within ARC/INFO. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation where triangles are formed between all data points within a polygon or the boundary clip. This method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data preserving all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great detail in the ARC/INFO V7.0.2 *Users Documentation, (ESRI, 1992).*

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Fresno 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 Fresno Reservoir since the areas were calculated from the developed TIN. The contour topography at 5-foot intervals is presented on figures 3 through 5, drawing numbers 15-D-279 through 15-D-281.

Development of 1999 Contour Areas

The 1999 contour surface areas for Fresno Reservoir were computed at 5-foot increments, from elevation 2,525.0 to 2,560.0, using the Fresno Reservoir TIN discussed above. The 1999 survey measured the minimum reservoir elevation at 2,525.0. 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.

Due to the limited amount of 1999 underwater data points between elevation 2560 and the clip elevation 2,564.7, the computed areas from the TIN model were judged to not be reliable. Using the lower developed contours as a guide engineering judgement was used to project where the elevation 2,564.7 clip would be located in the upper end of the reservoir. The surface area from this adjusted clip was used to compute the 1999 reservoir area and capacity tables.

Since there was no data collected in 1999 above water surface elevation 2,565, this study assumed there were no changes in surface area since the 1978 survey from elevation 2575 and above. Since 1978, the maximum reservoir water surface has been around elevation 2578. Since the upper reservoir is a narrow canyon, this allows inflowing sediments to be flushed further downstream into the reservoir. The 1978 measured surface areas were used since it is the most accurate documented data available.

1999 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). The 1999 measured surface areas at 5-foot contour intervals from minimum reservoir elevation 2,525.0 to elevation 2,565.0 and 5-foot contour intervals from elevation 2,575.0 to elevation 2,595.0 from the 1978 measured surface areas were used as the control parameters for computing the Fresno Reservoir capacity. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Fresno Reservoir. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from a basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

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

where:

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

Results o the 1999 Fresno Reservoir area and capacity computations are listed in table 2 and columns (8) and (9) of table 3. Listed in columns (2) and (3) of table 3 are the original surface areas and recomputed capacity values. A separate set of 1999 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1999). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1999 area-capacity curves are plotted on figure 6. As of May 1999, at spillway crest elevation 2,575.0, the surface area was 4,878 acres with a total capacity of 92,880 acre-feet and an active capacity of 92,432 acre-feet.

Analysis of Results

The Fresno Reservoir original, 1978, and 1999 area and capacity values are illustrated on the figure 6 plot and table 2 and 3 results. These presentations illustrate the large capacity change that has occurred during the 59.5 years of reservoir operations. The original capacity in column 3 and 1978 capacities in column 6 of table 3 were recomputed by the ACAP program for comparisons purposes using the original and 1978 measured area values. The area and capacity comparison plots of figure 6 illustrate the large change in surface areas and capacity for the original, 1978, and 1999 studies. This illustrates the large change of the reservoir geometry due to sediment accumulation. The sediment accumulation values and developed plot were obtained from comparisons with the original data. As stated in the 1978 sediment survey report, the original area-capacity tables for Fresno Reservoir, dated 1953, were based on preconstruction 1934 data that could not be located. The accuracy of the original data is unknown and this must be noted when making sediment calculations.

The 1978 study was the first resurvey of the reservoir and illustrated an extensive loss of capacity due to sediment accumulation, but the large measured change in the upper reservoir area appears to be more due to the accuracy difference between the surveys than sediment accumulation. The maximum recorded reservoir water surface since dam closure is elevation 2,579.3 (April 3, 1952) so no major changes of surface area due to sediment accumulation would be expected at elevation 2585 and above as was found during the 1978 survey. One could argue the difference is due to a datum shift problem, but the lower elevation measured values appear reasonable for the reservoir conditions. With the limited information available on the original data, no scientific basis can be used to adjust the original values.

As stated previously, the USGS quad contours of the Fresno Reservoir area were digitized for this study. These quad contours were developed from aerial data collected in 1968-69 and the underwater contours were provided by the Bureau of Reclamation. The resulting computed surface areas from these contours produced some interesting results. The digitized surface area for the quad contour labeled 2570 was around 4,608 acres which corresponds with elevation 2573.9 surface area from the 1978 survey. For the quad contour labeled elevation 2571 the digitized area was around 5,216 acres which corresponds with elevation 2576.5 surface area from the 1978 study. For the quad contour labeled elevation 2587 the digitized surface area was around 8950 acres which corresponds with elevation 2,592.5 surface area from the 1978 survey. On average the vertical difference is around 5 feet which corresponds with the measured datum shift of 4.7 feet as measured from the 1999 GPS static survey. Since the 1978 survey was conducted by a detailed aerial analysis, along with underwater collection, it was reasonable to use the 1978 upper reservoir values to supplement the 1999 survey.

As stated in the 1978 sedimentation report, a 1968 memorandum from the Chief, Sedimentation Section in Denver estimated 0.20 to 0.35 acre-feet per square mile annually or 550 to 1,000 acre-feet per year of sediment inflow for Fresno Reservoir. The results as presented in tables 2 and 3 from the 1978 and 1999 reservoir surveys are near these expected values making all results reasonable.

The 1999 study found that since storage of Fresno Reservoir began in November of 1939, sediments have accumulated to a total volume of 36,210 acre-feet below spillway crest elevation 2575.0. The average annual rate of sediment deposition since closure was 608.6 acre-feet or 0.20 acre-feet per square mile from the sediment contributing drainage area of 3,096 square miles. The storage loss in terms of percent of original storage capacity was 28.0 percent.

REFERENCES

American Society of Civil Engineers, 1962. ***Nomenclature for Hydraulics***, ASCE Headquarters, New York.

Bureau of Reclamation, 1981. ***Project Data,*** Denver Office, Denver CO.

Bureau of Reclamation, 1985. Surface Water Branch, ***ACAP85 User's Manual***, Technical Service Center, Denver CO.

Bureau of Reclamation, 1987(a). ***Guide for Preparation of Standing Operating Procedures for Bureau of Reclamation Dams and Reservoirs***, U.S. Government Printing Office, Denver, CO.

Bureau of Reclamation, 1984. Hydrology Branch, ***Fresno Reservoir 1978 Sedimentation Survey***, Division of Planning, Billings MT.

Bureau of Reclamation, 1987(b). ***Design of Small Dams***, U.S. Government Printing Office, Denver CO.

Bureau of Reclamation, May 1999. Denver Office, ***Fresno Reservoir Area and Capacity Tables, Boise Project***, Pacific Northwest Region, Denver CO.

Corps of Engineers, October 1994. Engineer and Design - ***Hydrographic Surveying***, EM 1110-2-1003 (FR), Department of the Army, Washington DC (www.usace.army.mil/inet/usace.docs/eng-manuals/em.htm).

Environmental Systems Research Institute , Inc. (ESRI), 1992. ***ARC Command References***.

RESERVOIR SEDIMENT
DATA SUMMARY

Fresno Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D A M	1. OWNER Bureau of Reclamation	2. STREAM Milk River	3. STATE Montana
	4. SEC. 19 TWP. 33 N RANGE 14 E	5. NEAREST P.O. Havre	6. COUNTY Hill
	7. LAT 48° 36' 30" LONG 109° 56' 50"	8. TOP OF DAM ELEVATION 2596.1[1]	9. SPILLWAY CREST EL 2575.0[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
	a. SURCHARGE					
	b. FLOOD CONTROL					Nov. 1939
	c. MULTIPLE USE	2575.0	5757	40,430	129,062	
	d. WATER SUPPLY					16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. CONSERVATION	2567.0	4,374	86,770	88,632	
	g. INACTIVE	2530.0	505	1,862	1,862	April 1943
	17. LENGTH OF RESERVOIR	15		AVG. WIDTH OF RESERVOIR	0.5	MILES

BASIN		
	18. TOTAL DRAINAGE AREA 3,766 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 13[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 3,096 SQUARE MILES	23. MEAN ANNUAL RUNOFF 1.60[4] INCHES
	20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 264,700[5] ACRE-FEET
	21. MAX. ELEVATION 6,000 MIN. ELEVATION 2,500	25. ANNUAL TEMP. MEAN 42°F RANGE -56°F to 109°F[3]

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
11/39			Contour	5-ft	5,757[6]	129,090[6]	0.49
6/78	38.7	38.7	Range	223	4,878	103,980[6]	0.39
5/99	20.9	59.5	Contour (D)	5-ft	4,878[7]	92,880[7]	0.35

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
6/78	11.7	271,160	389,100	10,575,256	271,160	10,575,300
5/99	13[3]	247,620[8]	362,000	5,175,200	264,700	15,750,300

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.
6/78	25,110	648.8	0.21	25,110	648.8	0.21
5/99	11,100[9]	531.1	0.17	36,210	608.6	0.20

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	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.
6/78				0.50	19.4		
5/99				0.47[9]	28.0		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION.											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
5/99												

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 2. - 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
1978				1979	2,576.6	2,558.6	262,900
1980	2,572.0	2,547.5	250,400	1981	2,568.8	2,552.0	285,400
1982	2,575.5	2,543.9	227,500	1983	2,564.0	2,541.4	184,700
1984	2,563.8	2,537.2	151,300	1985	2,561.3	2,536.5	231,800
1986	2,575.8	2,556.5	241,300	1987	2,575.5	2,563.7	198,000
1988	2,573.7	2,540.2	164,600	1989	2,568.6	2,536.6	296,400
1990	2,575.6	2,556.3	321,400	1991	2,575.8	2,557.9	325,000
1992	2,572.4	2,551.8	161,300	1993	2,575.1	2,549.0	319,000
1994	2,577.4	2,557.8	305,400	1995	2,575.6	2,559.7	245,000
1996	2,577.6	2,556.6	362,000	1997	2,576.6	2,561.5	320,800
1998	2,572.7	2,557.8	247,400	1999	2,564.5	2,557.9	73,600

46. ELEVATION - AREA - CAPACITY DATA FOR **1999 CAPACITY**[11]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2525	0	0	2530	179	448	2535	705	2,658
2540	1,096	7,160	2545	1,399	13,398	2550	1,701	21,148
2555	2,001	30,403	2560	2,342	41,260	2565	2,850	54,240
2567	3,256	60,346	2570	3,864	71,025	2575	4,878	92,880
2580	6,130	120,400	2585	7,397	154,218	2590	8,369	193,633
2592.8	9,017	217,974						

47. REMARKS AND REFERENCES

1 Design elevation of dam, documents note settlement may have occurred. All elevations tied to Reclamation project datum which is 4.71 feet higher than NGVD29.

2 Uncontrolled spillway crest.

3 Bureau of Reclamation Project Data Book, 1981.

4 Calculated using mean annual runoff value of AF, item 24, water years 1979-1999.

5 Computed annual inflows from 10/79 through 5/99. Some inflow diverted through St. Mary's canal.

6 Original and 1978 surface area and capacity at elevation 2575. Original and 1978 capacity recomputed by Reclamation's ACAP program using original and 1978 measured surface areas.

7 Surface area and capacity at elevation 2575 computed by ACAP program using 1999 surface areas. 1999 surveyed only underwater portion of reservoir below elevation 2565. Elevation 2566 and above from 1978 survey.

8 Values from water years 1979 through 5/99 (20.9 years).

9 Capacity loss calculated by comparing 1978 recomputed capacity and 1999 capacity at reservoir elevation 2575, spillway crest elevation. Portion of capacity difference due to accuracy of surveys.

10 Maximum and minimum elevations and inflow values in acre-feet by water year, from October 1978 through May 1999.

11 Capacities computed by ACAP computer program. Areas from elevation 2565 and below from 1999 survey. Areas at elevation 2575 and above from original survey. The ACAP program calculated the areas between elevation 2565 to 2575.

48. AGENCY MAKING SURVEY Bureau of Reclamation

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

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

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					1978	1978			1999	1999	Sediment	Percent of	
					Computed	Percent of			Computed	Percent of	Volume	Computed	Percent of
Elevations	Original	Original	1978	1978	Sediment	Computed	1999	1999	Sediment	Computed	1978-1999	Sediment	Reservoir
	Survey	Capacity	Survey	Survey	Volume	Sediment	Survey	Survey	Volume	Sediment		1978-1999	Depth
FT	AC	AC-FT	AC	AC-FT	AC-FT		AC	AC-FT	AC-FT		AC-FT		
2,592.8			9,017	229,074			9,017	217,974					
2,590.0			8,369	204,733			8,369	193,633					
2,585.0	8,250	195,962	7,397	165,318			7,397	154,218					
2,580.0	6,674	160,144	6,130	131,500	28,644	100.0	6,130	120,400					
2,575.0	5,757	129,090	4,878	103,980	25,110	87.7	4,878	92,880	36,210	100.0	11,100	100.0	100.0
2,570.0	4,882	102,502	3,904	82,025	20,477	71.5	3,864	71,025	31,477	86.9	11,000	99.1	91.2
2,567.0	4,374	88,632	3,504	70,913	17,719	61.9	3,256	60,346	28,286	78.1	10,567	95.2	86.0
2,565.0	4,043	80,220	3,237	64,173	16,047	56.0	2,850	54,240	25,980	71.7	9,933	89.5	82.5
2,560.0	3,398	61,768	2,752	49,200	12,568	43.9	2,342	41,260	20,508	56.6	7,940	71.5	73.7
2,555.0	2,930	45,963	2,357	36,428	9,535	33.3	2,001	30,403	15,560	43.0	6,025	54.3	64.9
2,550.0	2,523	32,389	2,040	25,435	6,954	24.3	1,701	21,148	11,241	31.0	4,287	38.6	56.1
2,545.0	2,088	20,761	1,753	15,953	4,808	16.8	1,399	13,398	7,363	20.3	2,555	23.0	47.4
2,540.0	1,511	11,775	1,254	8,435	3,340	11.7	1,096	7,160	4,615	12.7	1,275	11.5	38.6
2,535.0	983	5,561	784	3,340	2,221	7.8	705	2,658	2,903	8.0	682	6.1	29.8
2,530.0	505	1,862	275	693	1,169	4.1	179	448	1,414	3.9	245	2.2	21.1
2,525.0	115	377	1	0	377	1.3	0	0	377	1.0	0	0.0	12.3
2,520.0	36	0	0	0	0	0.0	0	0	0	0.0	0	0.0	3.5
2,518.0	0	0	0	0	0	0.0	0	0	0	0.0	0	0.0	0.0

1	Elevation of reservoir water surface.
2	Original reservoir surface area.
3	Original calculated reservoir capacity computed using ACAP from original measured surface areas.
4	Reservoir surface area from 1978 survey.
5	Recomputed reservoir capacity computed using ACAP, from 1978 measured surface areas.
6	Measured sediment volume = column (3) - column (5).
7	Measured sediment expressed in percentage of total sediment 28,644 at elevation 2,580.0.
8	Reservoir surface area from 1999 survey for elevations 2,565 and below. Areas for elevation 2,575 and above from 1978 survey.
9	1999 calculated reservoir capacity computed using ACAP, from 1999 measured surface areas.
10	1999 measured sediment volume = column (3) - column (9).
11	Measured sediment expressed in percentage from 1978 to 1999, sedimet volume of 11,1000 acre-feet at elevation 2,575.0.
12	Measured sediment volume from 1978 to 1999 = column (5) - column (9).
13	Measured sediment expressed in percentage from 1978 to 1999, sediment volume of 11,100 acre-feet at elevation 2,575.0
14	Depth of reservoir expressed in percentage of total depth (57), below spillway crest.

Table 3. - Summary of 1999 survey results

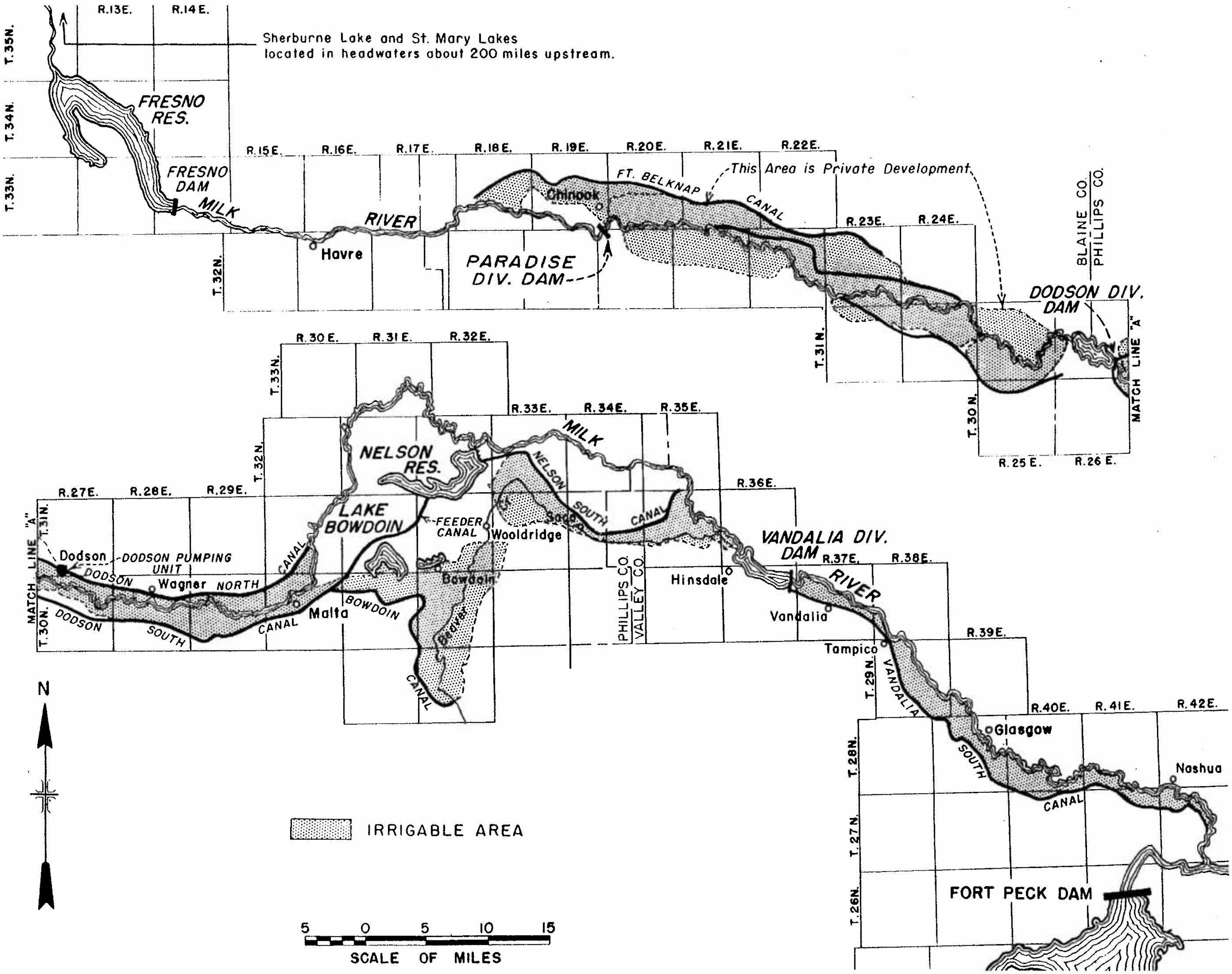

Figure 1. - Fresno Reservoir location map.

Space intentionally left blank due to security concerns

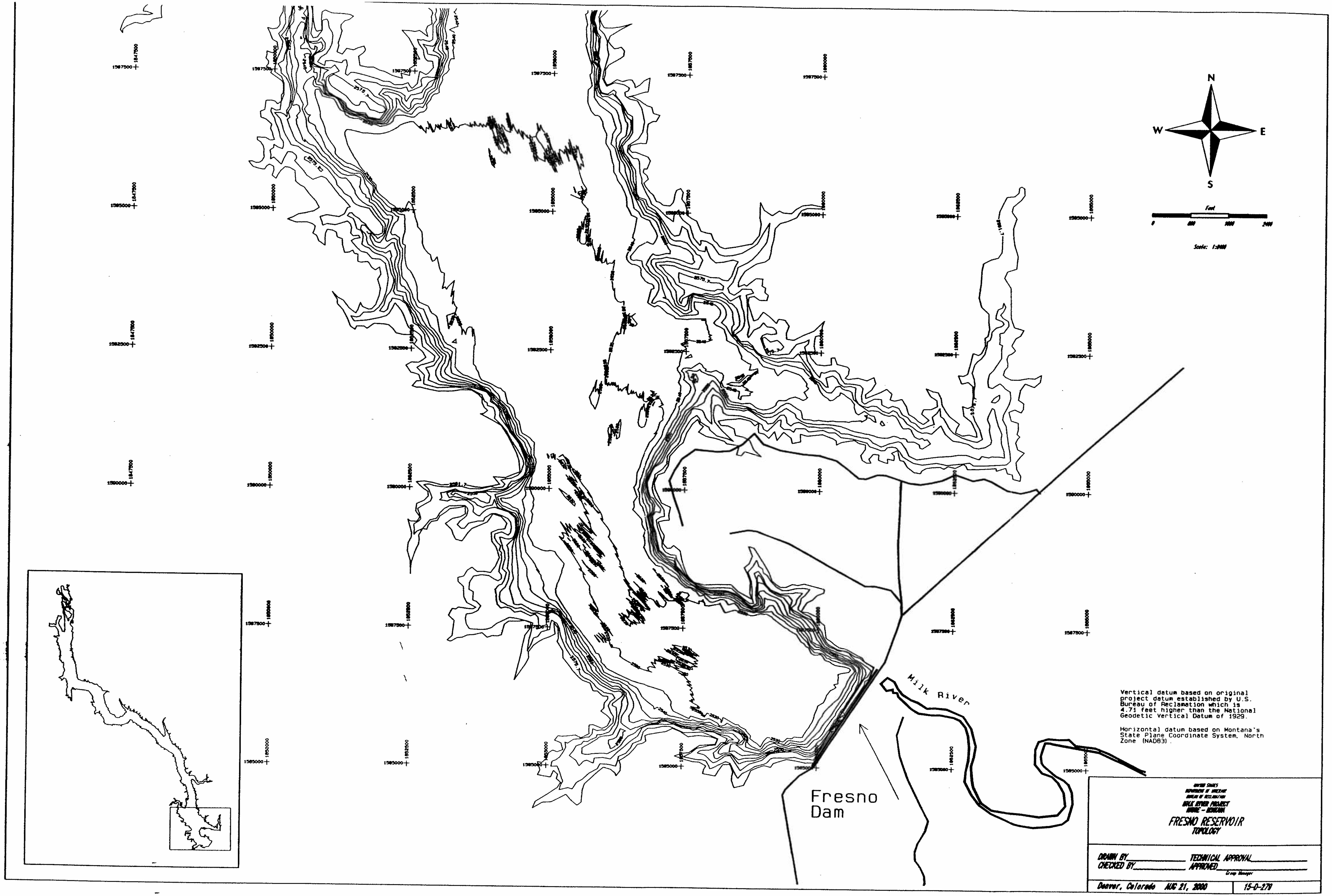

Figure 3. - Fresno Reservoir topographic map, No. 15-D-279

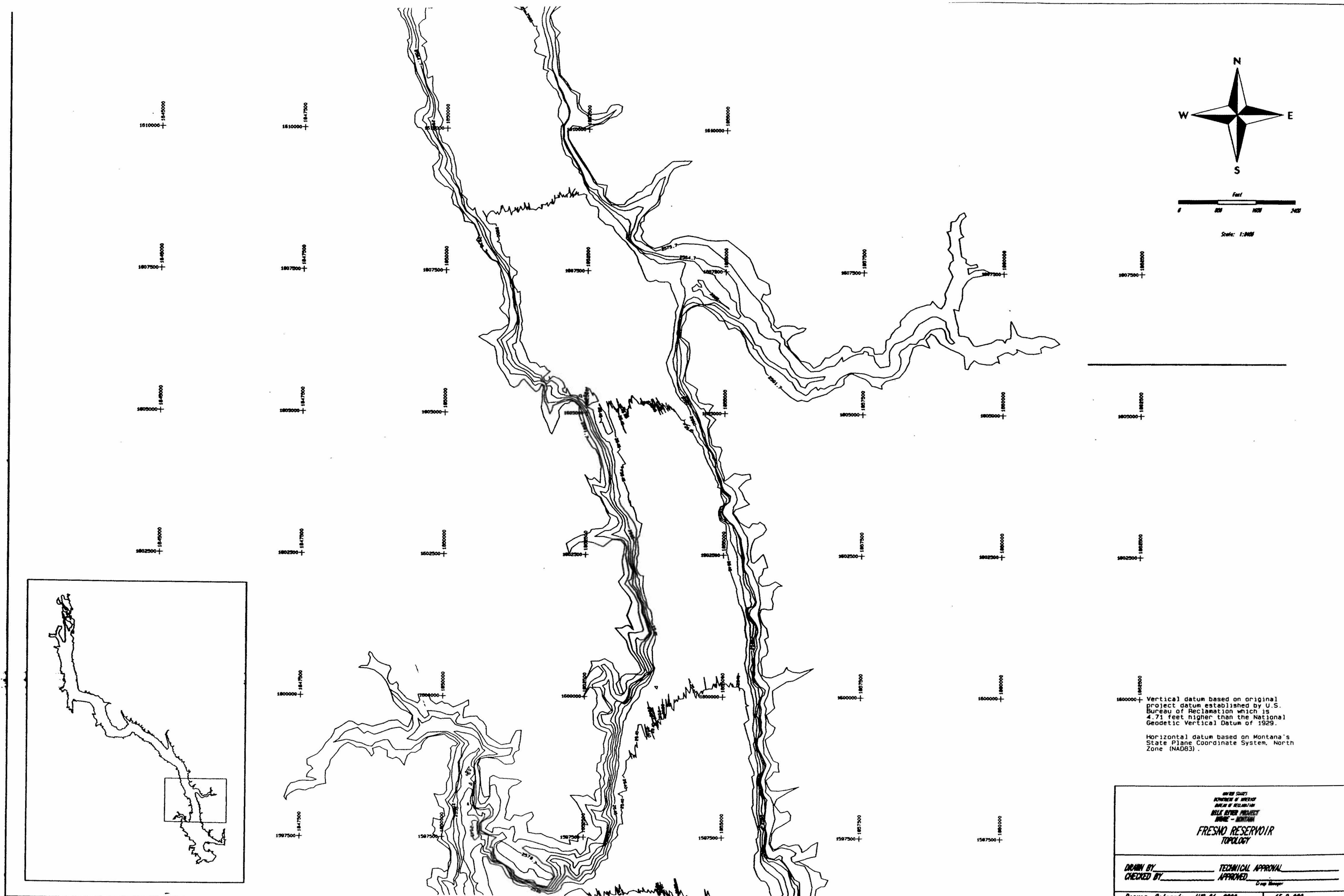

Figure 4. - Fresno Reservoir topographic map, No. 15-D-280

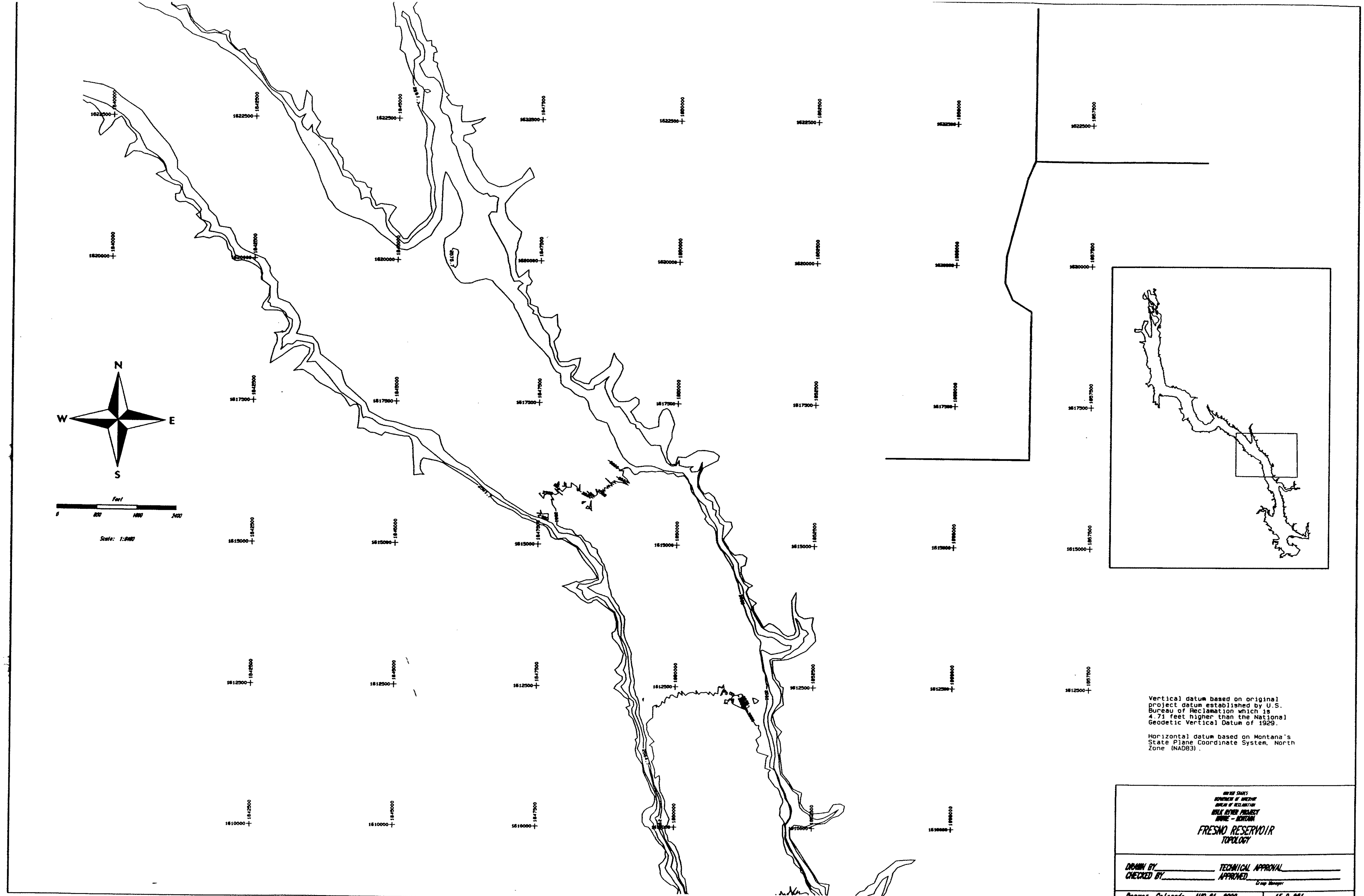

Figure 5. - Fresno Reservoir topographic map, No. 15-D-281

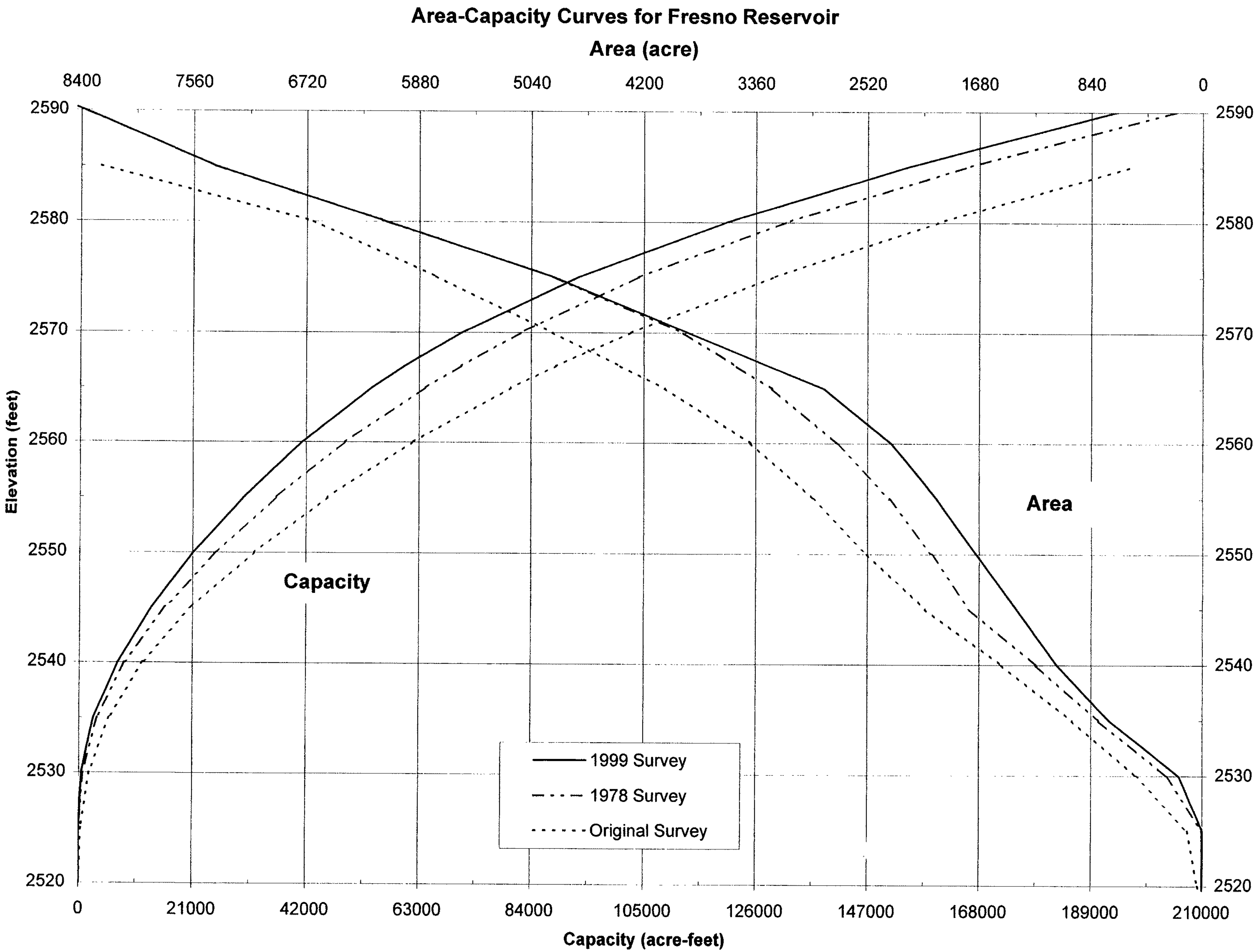

Figure 6. - 1999 area and capacity curves