CANYON FERRY LAKE

1997 SEDIMENTATION SURVEY

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed the above-water area in October 1996 and the underwater area of Canyon Ferry Lake in July and August of 1997 with the purpose 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 in March 1953. The bathymetric 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. The above-water reservoir area was measured from aerial photography obtained on October 7, 1996 near reservoir water surface elevation 3,787.7. Reservoir topography was developed by a computer program using the collected data. Project features were determined by digitizing the U.S. Geological Survey quadrangle (USGS quad) maps. The new topographic map of Canyon Ferry Lake is a combination of the above information.

As of August 1997, at top of spillway gate elevation (feet) 3,800.0, the surface area was 34,048 acres with a total capacity of 1,992,977 acre-feet. Since initial filling in March 1953, about 59,746 acre-feet of sediment have accumulated in Canyon Ferry Lake below elevation 3,800.0, resulting in a 2.91 percent loss in reservoir volume. Since 1953, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 1,345.6 acre-feet.

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CANYON FERRY LAKE

1997 SEDIMENTATION SURVEY

by

Ronald L. Ferrari

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

August 1998

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ron Ferrari of the TSC conducted the hydrographic survey. Stephen Hughes and Kent Collins of the TSC, who assisted during the hydrographic survey, deserve special thanks. Facilities Manager James Lynes and staff at Canyon Ferry Field Branch Office deserve very special thanks for their assistance during the hydrographic survey. Larry Edwards and staff at Aero-Metric also deserve special thanks for providing the aerial data in the needed format. Ronald Ferrari completed the data processing and generated 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. Kent Collins of the 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.

CONTENTS

Page

TABLES

Table

FIGURES

Figure

INTRODUCTION

Canyon Ferry Dam, Lake, and Powerplant of the Canyon Ferry Unit are located on the Missouri River in Broadwater and Lewis and Clark Counties approximately 17 miles northeast of Helena, Montana (fig. 1). The dam was constructed in a narrow constriction of the Missouri River Valley about 1.5 miles downstream from the old Canyon Ferry Dam that formed Lake Sewell in 1898. The formation of Canyon Ferry Lake, located about 50 miles downstream from where the Gallatin, Madison, and Jefferson Rivers join to form the Missouri River, inundated the old Canyon Ferry Dam, powerplant buildings, and Lake Sewell.

The Canyon Ferry Unit is a multiple-purpose project that contributes power supply, flood control, irrigation, and recreation in the upper Missouri Basin. The drainage area above the dam is 15,904 square miles of which 11,248 square miles contributes sediment inflow. The reservoir length at elevation 3,800[1] is around 24 miles with an average width of about 2.2 miles.

Canyon Ferry Dam construction began May 24, 1949 and was completed June 23, 1954 with first storage in March 1953. The dam is a concrete gravity structure, whose dimensions are (figs. 2 and 3):

- Hydraulic height[2] 225 feet
- Structural height 172 feet
- Top width 20 feet
- Crest length 1,000 feet
- Crest elevation[3] 3,808.5 feet

Canyon Ferry Dam's spillway consists of an overflow section in the central portion of the dam with a crest elevation of 3,766.0. The spillway is controlled by four 51- by 34.5-foot radial gates with a top of gate elevation of 3,800.0. The spillway capacity is 150,000 cubic feet per second (ft^3/s) at reservoir elevation 3,800.0, (Bureau of Reclamation 1981).

Four river outlets are provided in the spillway section of the dam. Each is 84 inches in diameter and controlled by 77-inch regulating gates. The discharge capacity, at reservoir elevation 3,800.0, is 9,500 ft^3/s. One 156-inch-diameter intake pipe is embedded in the concrete of the dam near the left abutment for Helena Valley Pumping Plant. Three 162-inch-diameter penstock pipes for the power-generating units are embedded in the dam near the right abutment. The powerplant is a reinforced concrete structure located at the downstream toe of the dam on the right abutment adjacent to the spillway apron.

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[1]Elevation levels are shown in feet.

[2]The definitions 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.*

[3]Parapet walls located on the upstream and downstream sides of the dam raised the maximum concrete elevation to 3,810.7.

Wind-blown fine-grained material from exposed flats in the upper end of Canyon Ferry Lake became a major contributor to air pollution upon initial filling and normal reservoir operation. The Montana Department of Health reported the average deposition of material in the Townsend area to be 301 tons per square mile per month compared to the acceptable limit of 15 to 20 tons per month. In 1968 a cooperative program between Reclamation and the Montana Fish and Game Department planned and constructed a dike system in the upper end of the lake for dust abatement that also included waterfowl-development features. The construction of the dikes began in 1972 and finished in 1978 with the creation of four separate enclosed ponds. The original reservoir area was affected by the dredging and diking between elevation 3,780 and the top of dikes, elevation 3,800. These enclosed areas were essentially removed from the original reservoir area, which is reflected in this report. The original reservoir area-capacity, with these dike areas removed, was reported as 2,051,519 acre-feet with a surface area of 33,535 acres at top of spillway gate elevation 3,800.0.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1997 results of the first extensive survey of Canyon Ferry Lake. 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 Canyon Ferry 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 Canyon Ferry Lake. The positioning system provided information to allow the boat operator to maintain 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.

The above-water area of Canyon Ferry was measured from aerial photography obtained in October of 1996 by Reclamation contract with Aero-Metric in Fort Collins, Colorado. Photo interpretation produced 45 detailed drawings of the development around the reservoir with 5-foot contour topography of the above-water reservoir area that was around elevation 3,788.4 at time of flight. For the purpose of this study, the 737,402 aerial data points used to develop these 5-foot contours were merged with the underwater data set to produce the 1997 reservoir topography. The aerial data set completely saturated the reservoir area above elevation 3,788.4 and provided detailed information for the contour development.

The 1997 reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using the merged aerial and underwater collected data. The 1997 topographic map of Canyon Ferry Lake is a combination of the underwater and aerial topography along with the digitized features of the U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps of Canyon Ferry Lake. Using the digitized underwater contours from the USGS quad maps, a few data points were interpolated when needed. This included the area near the dam and small coves not covered by the underwater survey. The 1997 reservoir surface areas at predetermined 5-foot contour intervals were generated by a computer graphics program using all the collected data. The area and capacity tables were produced by a computer program that used measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments.

Tables 1 and 2 contain a summary of Canyon Ferry Lake sedimentation and watershed characteristics for the 1997 survey. The 1997 survey determined that the reservoir has a storage capacity of 1,992,977 acre-feet and a surface area of 34,048 acres at reservoir elevation 3,800.0. Since closure in 1953, the reservoir has accumulated a sediment volume of 59,746 acre-feet below reservoir elevation 3,800.0. This volume represents a 2.91 percent loss in capacity and an average annual loss of 1,345.6 acre-feet.

RESERVOIR OPERATIONS

Canyon Ferry Lake is a multiple purpose project which operates for power production, flood protection, irrigation, and recreation (the following values are from August 1997 area-capacity tables):

- 101,089 acre-feet of flood control storage between elevations 3,797.0 and 3,800.0.
- 794,289 acre-feet of joint use between elevations 3,770.0 and 3,797.0.
- 701,568 acre-feet of active conservation storage between elevations 3,728.0 and 3,770.0.
- 394,971 acre-feet of inactive storage between elevations 3,650.0 and 3,728.0.
- 1,060 acre-feet of dead storage below elevation 3,650.0.

The Canyon Ferry Lake inflow and end-of-month stage records are listed by water year in table 1 for the operation period of October 1953 through September 1997. The average annual reservoir inflow for this operation period was 3,908,214 acre-feet. After initial filling to spillway gate elevation 3,800.0 in 1956, records show that Canyon Ferry Lake fills to near full conditions the majority of the years. The minimum water surface, since filling, was elevation 3,764.7 that occurred in April of 1967.

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 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 attached 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 Canyon Ferry 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 of the altitude, Canyon Ferry's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel. During the Canyon Ferry Lake survey, the best six 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 Canyon Ferry Lake 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 Canyon Ferry Lake 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 that 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 Canyon Ferry Lake survey, position corrections were determined by the master receiver and transmitted via an 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 (RTCM) 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 postprocessing software. The GPS collection system has the capability of collecting the data in 1927 or 1983 North American Datums (NAD) in the surveyed area's state plane coordinate system's zone. For Canyon Ferry Lake, the data were collected in the Montana's 1927 NAD south state plane zone to match the data collected for the 1996 aerial survey.

Survey Method and Equipment

The Canyon Ferry Lake hydrographic survey was conducted from July 11 through July 22, and August 19, and August 20 of 1997 between reservoir water surface elevations 3,796.4 and 3,798.3. At the time the lower reservoir area was being mapped the dam was spilling due to the higher than average inflow. In anticipation of the high runoff the reservoir was lowered to elevation 3,769.2 in April of 1997. 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 along closely spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run primarily in a east-west direction. The spacing of the gridlines varied depending on the reservoir bottom conditions. The spacing was set at 400 feet for the area downstream of Cemetery Hill island and the old Canyon Ferry dam due to the varied bottom and vertical walls. Upstream of this location the spacing was set at 500 feet due to the bottom being very flat with a gradual slope from bank to bank. In the very upper reservoir areas the spacing was set at 600 feet due to the very flat bottom conditions. Data were also collected along the shore as the boat traversed to the next transect.

The survey vessel's guidance system gave directions to the boat operator to assist in maintaining course along these predetermined 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 139,785 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 gauge during the time of collection was used to convert the sonic depth measurements to true lake bottom elevations.

For stationing the master GPS unit, known benchmarks (datums) that overlooked the reservoir were established and or confirmed by the hydrographic survey crew prior to underwater collection. This was accomplished using the hydrographic GPS units and software. In establishing the control, previously established datums for a detailed aerial survey of several of the reservoir campsites were used. The control for the 1996 aerial survey was set as temporary control points marked with wooden stakes that in most cases could not be located. Temporary control points for the hydrographic survey were established at Goon Hill near the dam, an old USBR brass elevation datum overlooking White Earth campground, and near Canyon Ferry airport at the Silos campground. At Goon Hill, a wood survey stake, #710, that was established for the 1996 aerial survey, was located. As a check, the hydrographic units and software measured the location within 1 foot of what was established for the 1996 aerial survey. The shore-based master GPS unit, which transmits the correction information to the mobile GPS unit on the survey vessel, was stationed at one of these three datum sites throughout the survey. These locations were chosen because they were accessible and overlooked the reservoir. The location allowed for good radio transmission of the differential corrections to the mobile survey vessel throughout the reservoir survey.

The underwater data were 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 an 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 postprocessing, 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 Canyon Ferry Lake was developed from the merged 1996 aerial and 1997 underwater data, points. All of the data were in the Montana's south zone state plane coordinates in NAD 1927. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours and other features such as roads and rivers along with a boundary or polygon that enclosed all the collected data. The underwater contours of the USGS quad maps were used as a guide to interpolate around 160 data points near the dam and in a few coves not surveyed in 1997. The USGS quad maps were developed from aerial photography dated 1970 and 1980. The digitized contours were transformed to Montana's NAD 1927 south state plane coordinates using the ARC/INFO PROJECT command.

Contours from the collected data were computed using the triangular irregular network (TIN) surface modeling package within ARC/INFO. A TIN is a set of adjacent, nonoverlapping 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. This requirement means that sample points are connected to their nearest neighbors to form triangles using all collected data. Using the hardclip option of the ARC/INFO CREATETIN command, a clip or polygon boundary around the data was developed. The digitized polygon enclosing the collected data was assigned an elevation of no data and was used to perform the clip of the data set such that interpolation was not allowed to occur outside the boundary. The elevation contours are then interpolated along the triangle elements. The TIN method is discussed in detail in the ARC/INFO V7.0.2 *ARC Command References* (ESRI 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Canyon Ferry Lake TIN. In addition, the contours were generalized by eliminating select 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 Canyon Ferry Lake. The contour topography at 5-foot intervals is presented on figures 4 through 10 (map Nos. 296-D-1158 though 296-D-1164).

Development of 1997 Contour Areas

The interpolated contours from the Canyon Ferry Lake TIN confirmed that the tops of the dust abatement dikes are around elevation 3,800. For the 1997 Canyon Ferry Lake contour surface areas, 1-foot increments were computed from elevations 3,630.0 to 3,800.0 using a TIN that removed the dike areas of the dust abatement ponds from the data set. The 1997 survey measured the minimum reservoir bottom elevation at 3,625.3 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.

1997 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 5-foot contour intervals from minimum reservoir elevation 3,625.3 to elevation 3,800.0 were used as the control parameters for computing the Canyon Ferry Lake capacity. The program can compute an area and capacity at elevation increments of 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit (set at 0.000001 for Canyon Ferry Lake). 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 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 of the 1997 Canyon Ferry Lake 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. These original values listed were adjusted for the reservoir areas and capacity removed due to the constructed dust abatement ponds. A separate set of 1997 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1997). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1997 area-capacity curves are plotted on figure 5 . As of August 1997, at elevation 3,800.0, the surface area was 34,048 acres with a total capacity of 1,992,977 acre-feet.

SEDIMENT ANALYSES

The 1997 study found that since storage of Canyon Ferry Lake began in March of 1953, sediments have accumulated to a total volume of 59,746 acre-feet. This volume was calculated at top of spillway gate elevation 3,800.0. Column 6 of table 2 gives the measured sediment volume by elevation, and the area curve on figure 11 illustrates the resulting measured surface areas and calculated capacities. This table and figure illustrate that the majority of the sediment deposit is in the lower elevations of the reservoir. The average annual rate of sediment deposition between closure and August 1997 (44.4 years) was 1,345.6 acre-feet or 0.12 acre-foot per square mile from the sediment-contributing drainage area of 11,248 square miles. The storage loss in terms of percent of original storage capacity was 2.91 percent. This compares to Reclamation's original 100-year sediment deposition estimate of 7.8 percent and a sediment yield of 0.1 acre-foot per square mile from the contributing drainage area.

The 1997 sediment calculations were based on the differences between the original and 1997 measured reservoir capacities and are only as accurate as the two surveys. The measured surface areas, columns 2 and 4 of table 2, the calculated sediment volume, column 6 of table 2, and the area curves of figure 11 show some interesting results. The table shows the 1997 surface areas are greater than the original areas from elevation 3,790 and above. These are the reservoir areas mapped by the detailed aerial data. At elevation 3,790.0 the 1997 surface area was measured around 1 percent larger than the original area. At elevations 3,795.0 and greater the 1997 surface areas were measured around 1.5 percent larger than the original areas. A portion of this difference can be attributed to the accuracy difference between the original and the 1996 aerial survey. A comparison plot of the 3,797.0 contour developed from the 1997 study and the digitized 3,797.0 contour from the USGS quad maps show a near mirror image of each other. There are some small differences in some of the cove areas for which the 1996 aerial data provided greater detail and the larger resulting areas.

A comparison plot of the 3,760.0 contour developed from the 1997 study and the digitized 3,760.0 contour from the USGS quad maps also show a near mirror image of each other. There are some small differences in some of the cove areas, but in the upper portion of the reservoir there is very little difference. This is reflected in the sediment calculations where only 2 percent of the computed sediment volume is above elevation 3,760. In anticipation of the 1997 high spring runoff the reservoir was lowered to elevation 3,769.2 in April of that year. With these conditions it is possible that a portion of any delta that may have existed prior to the 1997 spring runoff was flushed into the lower elevations of the reservoir.

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RESERVOIR SEDIMENT
DATA SUMMARY

Canyon Ferry Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

D A M	1. OWNER Bureau of Reclamation	2. STREAM Missouri River	3. STATE Montana
	4. SEC. 4 TWP. 10N RANGE 1W	5. NEAREST P.O. Helena	6. COUNTY Lewis & Clark
	7. LAT 46° 38' 57" LONG 111° 43' 39"	8. TOP OF DAM ELEVATION 3808.5	9. SPILLWAY CREST EL. 3766.0[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					
	b. FLOOD CONTROL	3,800.0	33,535	99,460	2,051,519[2]	
	c. JOINT USE	3,797.0	32,866	795,135	1,952,059	3/53
	d. CONSERVATION	3,770.0	24,126	411,462	1,156,924	16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. INACTIVE	3,728.0	11,479	437,996	445,462	
	g. DEAD	3,650.0	1,000	7,466	7,466	3/53
	17. LENGTH OF RESERVOIR 24.0 MILES			AVG. WIDTH OF RESERVOIR 2.2 MILES		

BASIN	18. TOTAL DRAINAGE AREA 15,904 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 11,248[4] SQUARE MILES		23. MEAN ANNUAL RUNOFF 4.6[5] INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 3,908,214[6] ACRE-FEET
	21. MAX. ELEVATION	MIN. ELEVATION	25. ANNUAL TEMP. MEAN °F RANGE -°F to °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
3/53			Contour (D)	5-ft	33,535[7]	2,052,723[7]	.52
8/97		44.4	Contour (D)	5-ft	34,048[8]	1,992,977[8]	.51

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
8/97		3,908,214[6]	5,785,673	171,961,416	3,908,214	171,961,416

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AV. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AV. ANNUAL	c. /MI.^{2}-YR.
8/97	59,746[9]	1,345.6	.12	59,746	1,345.6	.12

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR. a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AV. ANNUAL	b. TOTAL TO DATE	42. SEDIMENT INFLOW, PPM a. PER.	b. TOT
8/97				.0656	2.91		

26. DATE OF SURVEY 8/97	43. DEPTH DESIGNATION RANGE IN FEET BELOW ELEVATION										
	3650-3625.3	3675-3650	3700-3675	3725-3700	3750-3725	3775-3750	3800-3775				
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
	10.8	41.9	15.9	12.0	13.9	5.5	0.0				

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

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

45. RANGE IN RESERVOIR OPERATION[10]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1953				1954	3,780.3	3,754.0	3,011,836
1955	3,000.0	3,771.2	2,961,658	1956	3,800.0	3,782.4	3,821,747
1957	3,799.2	3,781.2	3,525,877	1958	3,798.9	3,784.0	3,460,498
1959	3,799.9	3,789.1	3,379,898	1960	3,799.9	3,788.5	3,906,155
1961	3,788.4	3,774.6	2,200,078	1962	3,800.0	3,772.8	3,692,882
1963	3,799.7	3,793.4	3,791,881	1964	3,800.0	3,790.2	4,207,875
1965	3,799.9	3,785.6	4,991,376	1966	3,798.6	3,777.5	2,957,394
1967	3,798.3	3,764.7	4,210,664	1968	3,797.1	3,777.8	4,342,009
1969	3,791.1	3,797.6	4,830,498	1970	3,797.1	3,778.2	4,748,646
1971	3,797.5	3,777.0	5,031,866	1972	3,797.3	3,781.9	4,514,152
1973	3,796.6	3,780.6	3,364,578	1974	3,798.6	3,781.8	4,356,349
1975	3,799.9	3,774.8	5,184,447	1976	3,798.2	3,781.0	5,661,328
1977	3,797.1	3,789.8	2,953,637	1978	3,797.9	3,780.7	4,288,383
1979	3,796.2	3,779.2	3,488,449	1980	3,799.2	3,781.8	3,904,306
1981	3,799.7	3,784.2	4,368,406	1982	3,798.8	3,779.7	4,975,431
1983	3,798.3	3,785.1	4,658,448	1984	3,799.1	3,785.0	5,769,112
1985	3,791.7	3,778.0	3,425,320	1986	3,797.2	3,781.4	3,889,138
1987	3,792.9	3,784.4	2,702,506	1988	3,791.9	3,779.8	2,399,306
1989	3,785.9	3,773.8	2,623,247	1990	3,794.4	3,777.8	2,749,861
1991	3,798.0	3,780.5	3,014,350	1992	3,786.8	3,780.1	2,423,802
1993	3,797.9	3,778.8	4,186,638	1994	3,794.7	3,781.8	2,736,253
1995	3,798.8	3,781.4	4,536,841	1996	3,797.8	3,778.8	4,928,562
1997	3,798.5	3,769.2	5,785,673				

46. ELEVATION - AREA - CAPACITY DATA FOR **1997 CAPACITY**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
3625.3	0.0	0	3630	3.3	8	3635	13.7	51
3640	32.0	165	3645	91.1	473	3650	143.7	1,060
3655	226.6	1,986	3660	581.4	4,006	3665	1,443.4	9,068
3670	2,102.8	17,934	3675	2,628.1	29,761	3680	3,572.3	45,262
3685	4,657.4	65,836	3690	5,382.6	90,936	3695	5,872.7	119,074
3700	6,705.2	150,519	3705	7,558.6	186,179	3710	8,353.9	225,960
3715	8,811.9	268,874	3720	9,498.5	314,650	3725	10,292.0	364,126
3730	11,435.1	418,444	3735	12,534.3	478,368	3740	13,643.4	543,812
3745	14,937.1	615,263	3750	16,442.0	693,711	3755	18,226.1	780,381
3760	20,227.8	876,516	3765	22,120.8	982,388	3770	23,963.7	1,097,599
3775	26,064.2	1,222,669	3780	28,457.4	1,358,973	3785	30,656.5	1,506,757
3790	31,942.6	1,663,620	3795	32,876.2	1,825,667	3797	33,345.0	1,891,888
3800	34,047.9	1,992,977						

47. REMARKS AND REFERENCES

1 Top of spillway gates, elevation 3800.0.

2 Original reservoir areas and volumes adjusted for area and volume removed due to construction of dust abatement dikes.

3 Represents loss of contributing areas behind dams at Lima (570 mi^2), Ruby (596 mi^2), and Ennis (2,181 mi^2) reservoirs. Clark Canyon Reservoir closed June of 1964 (2,321 mi^2). Contributing area adjusted by time.

4 Calculated using mean annual runoff value of 3,908,214 AF, item 24.

5 Computed annual inflows from 10/53 through 9/97.

6 Adjusted original surface area and capacity at elevation 3,800.0. Original areas adjusted for reservoir area removed due to construction of dikes. Capacity recomputed by Reclamation's ACAP program using adjusted original surface areas.

7 Surface area and capacity at elevation 3800.0 computed by ACAP program using 1997 reservoir surface areas. Surface areas and capacity do not include areas of reservoir removed due to constructed dikes. The 1997 survey computed a larger surface area then the original, at elevation 3800.0, for both with and without dike areas conditions.

8 Total capacity loss calculated by comparing original capacity and 1997 capacity at reservoir elevation 3800.0.

9 Maximum and minimum elevations and inflow values in acre-feet by water year.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE March 1998

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

1	2	3	4	5	6	7	8
Elevations	Original Survey	Original Capacity (acre-feet)	1997 Survey (area)	1997 Capacity (acre-feet)	Computed Sediment Volume (acre-feet)	Percent of Computed Sediment	Percent of Reservoir Depth
3800	33535	2052723	34048	1992977	59746	100.0	100.0
3797	32866	1953121	33345	1891888	61233	102.5	98.3
3795	32420	1887835	32876	1825667	62168	104.1	97.1
3790	31634	1727700	31943	1663620	64080	107.3	94.3
3785	30730	1571790	30656	1506757	65033	108.8	91.4
3780	29125	1422153	28457	1358973	63180	105.7	88.6
3775	26279	1283643	26064	1222669	60974	102.1	85.7
3770	24126	1157630	23964	1097599	60031	100.5	82.9
3765	22241	1041713	22121	982388	59325	99.3	80.0
3760	20418	935065	20228	876516	58549	98.0	77.1
3755	18458	837875	18226	780381	57494	96.2	74.3
3750	16622	750175	16442	693711	56464	94.5	71.4
3745	15150	670745	14937	615263	55482	92.9	68.6
3740	13905	598108	13643	543812	54296	90.9	65.7
3735	12878	531150	12534	478368	52782	88.3	62.9
3730	11925	469142	11435	418444	50698	84.9	60.0
3725	10816	412290	10292	364126	48164	80.6	57.1
3720	9798	360755	9499	314650	46105	77.2	54.3
3715	9133	313428	8812	268874	44554	74.6	51.4
3710	8541	269243	8354	225960	43283	72.4	48.6
3705	7778	228445	7559	186179	42266	70.7	45.7
3700	6995	191513	6705	150519	40994	68.6	42.9
3695	6278	158330	5873	119074	39256	65.7	40.0
3690	5573	128703	5383	90936	37767	63.2	37.1
3685	4843	102663	4657	65836	36827	61.6	34.3
3680	4123	80248	3572	45262	34986	58.6	31.4
3675	3481	61238	2628	29761	31477	52.7	28.6
3670	2891	45308	2103	17934	27374	45.8	25.7
3665	2351	32203	1443	9068	23135	38.7	22.9
3660	1857	21683	581	4006	17677	29.6	20.0
3655	1408	13520	227	1986	11534	19.3	17.1
3650	1000	7500	144	1060	6440	10.8	14.3
3645	667	3333	91	473	2860	4.8	11.4
3640	333	833	32	165	668	1.1	8.6
3635	0	0	14	51	-51	-0.1	5.7
3630	0	0	3	8	-8	0.0	2.9
3625.3	0	0	0	0	0	0.0	0.0

1 Elevation of reservoir water surface in feet.
2 Original reservoir surface areas adjusted for constructed dikes.
3 Original reservoir capacity recomputed using ACAP from column 2 areas.
4 1997 reservoir surface areas.
5 1997 reservoir capacity computed using ACAP and column 4 areas.
6 Measured sediment volume = column 3 minus column 5.
7 Measured sediment expressed in percentage of total sediment of 59,746.
8 Depth of reservoir expressed in percentage of total depth (175 feet).

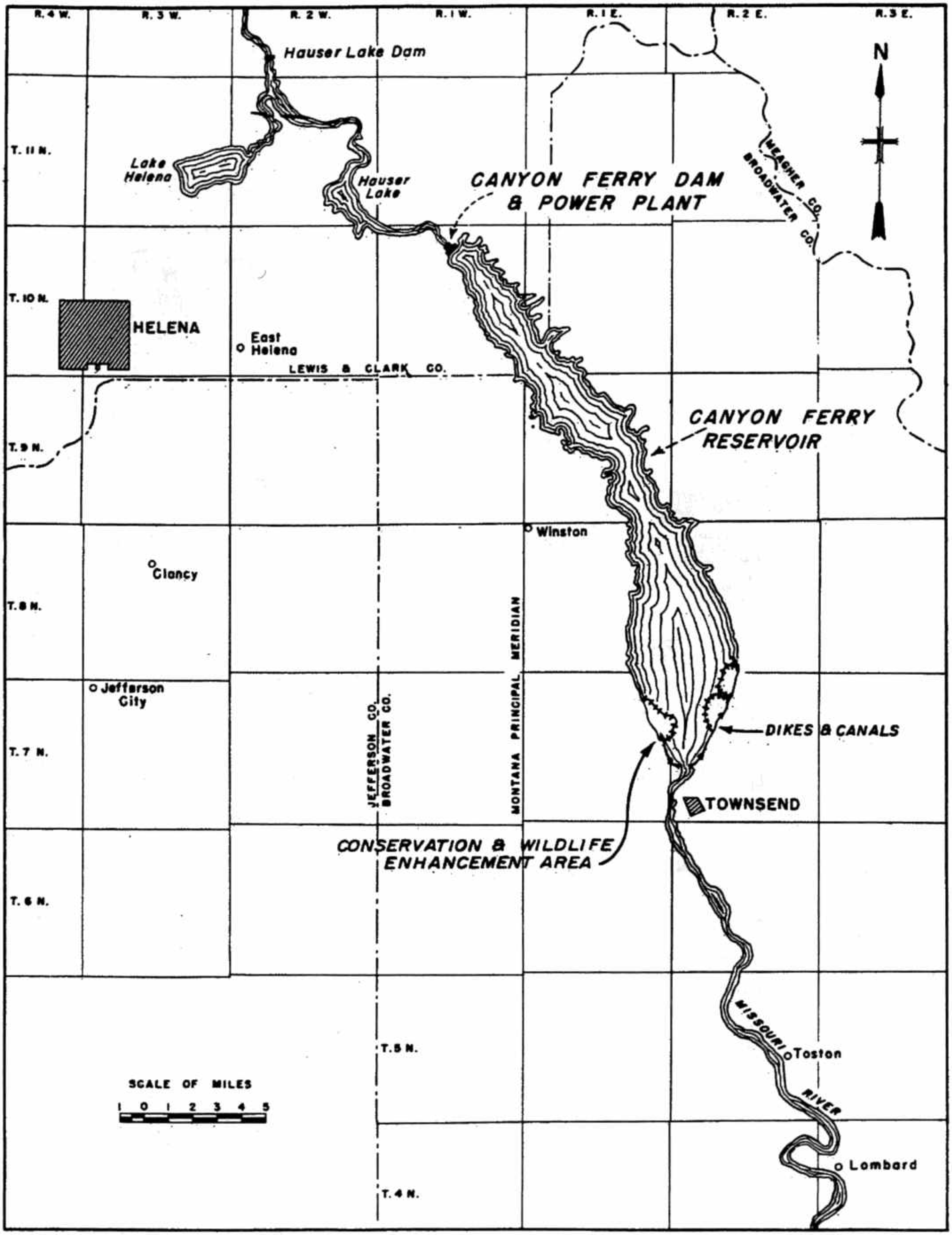

Figure 1. - Canyon Ferry Lake location map

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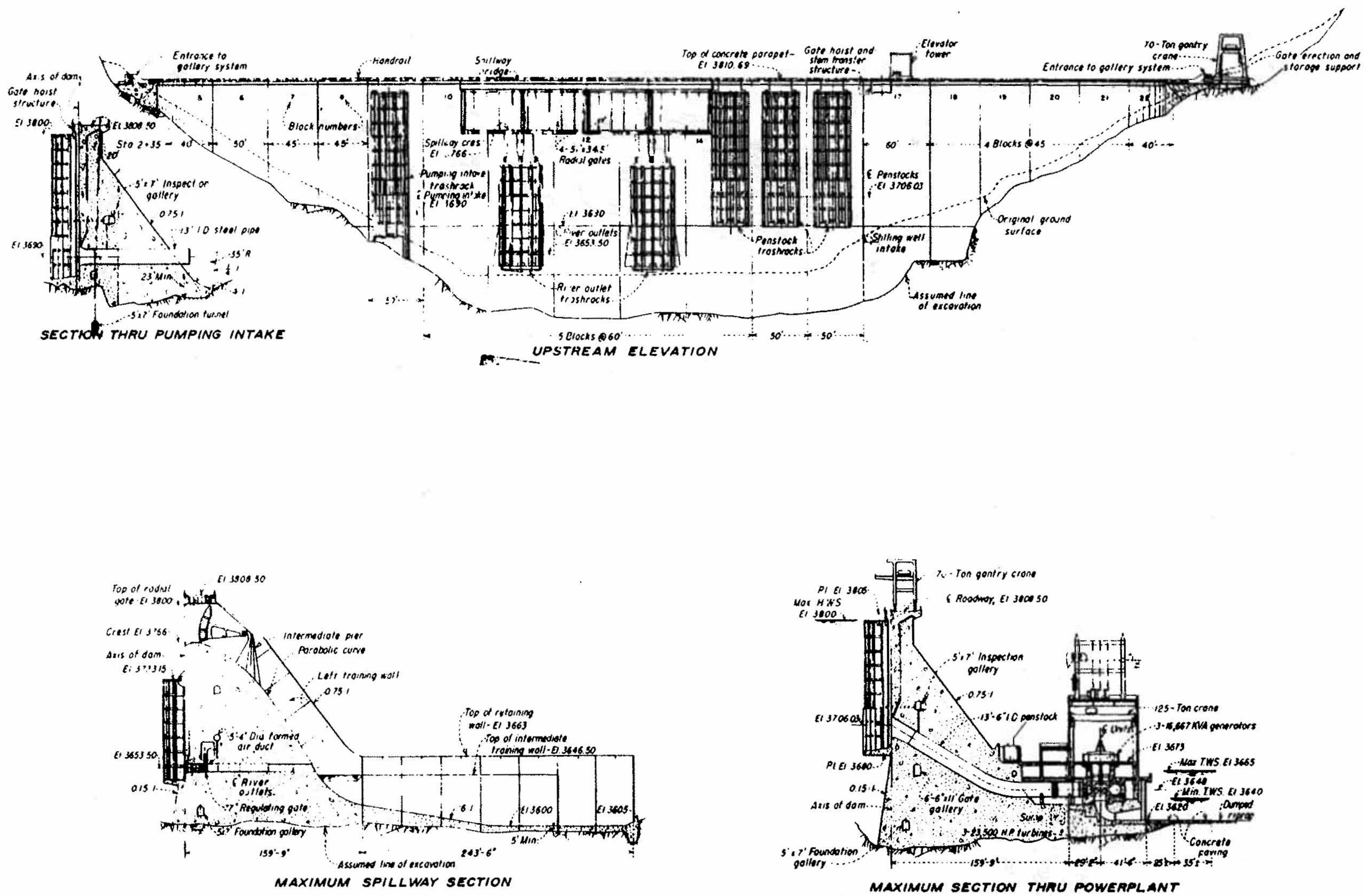

Figure 2. - Canyon Ferry Dam, plan and section

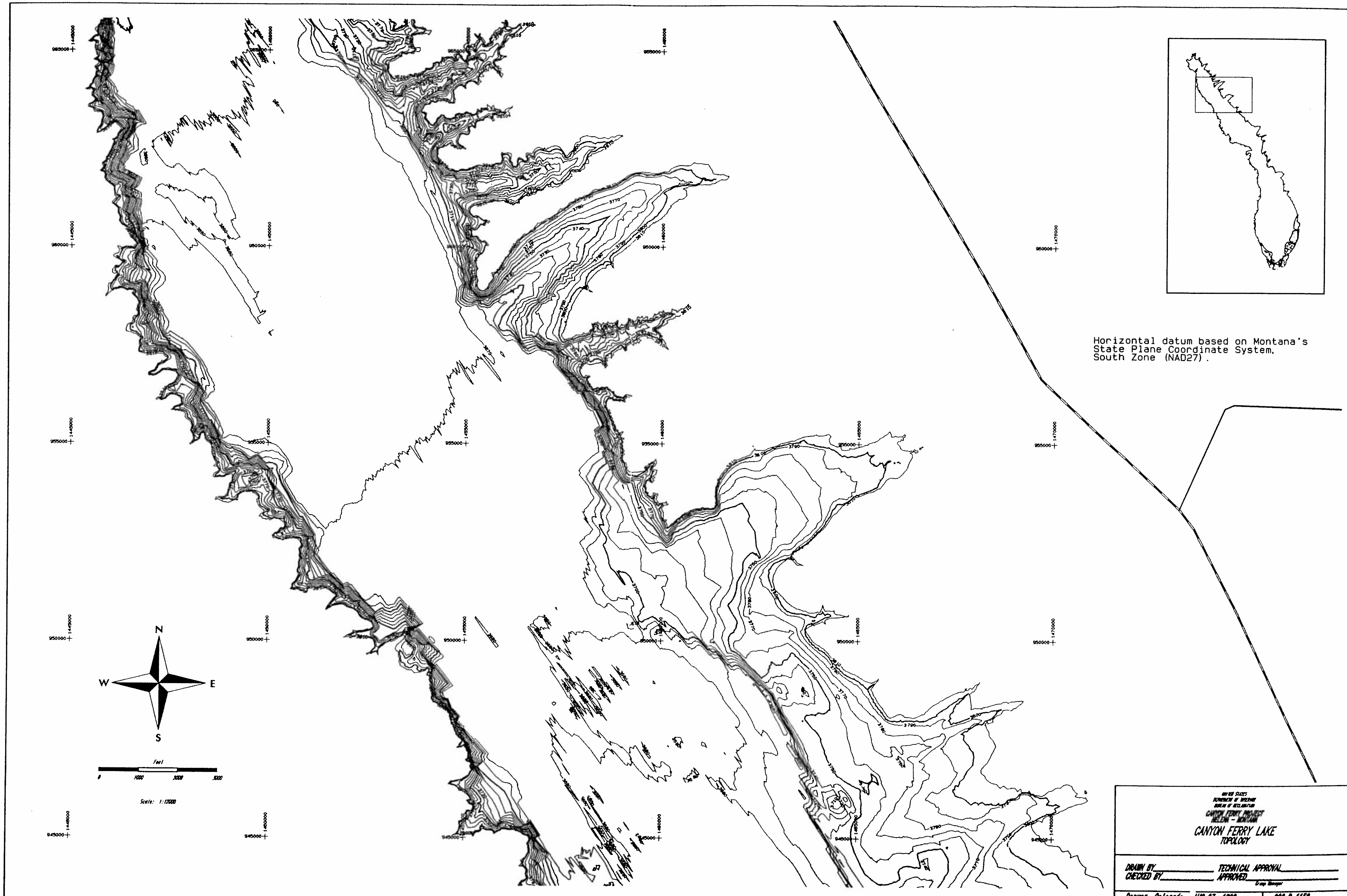

Figure 5. - Canyon Ferry Lake topographic map, No. 296-D-1159

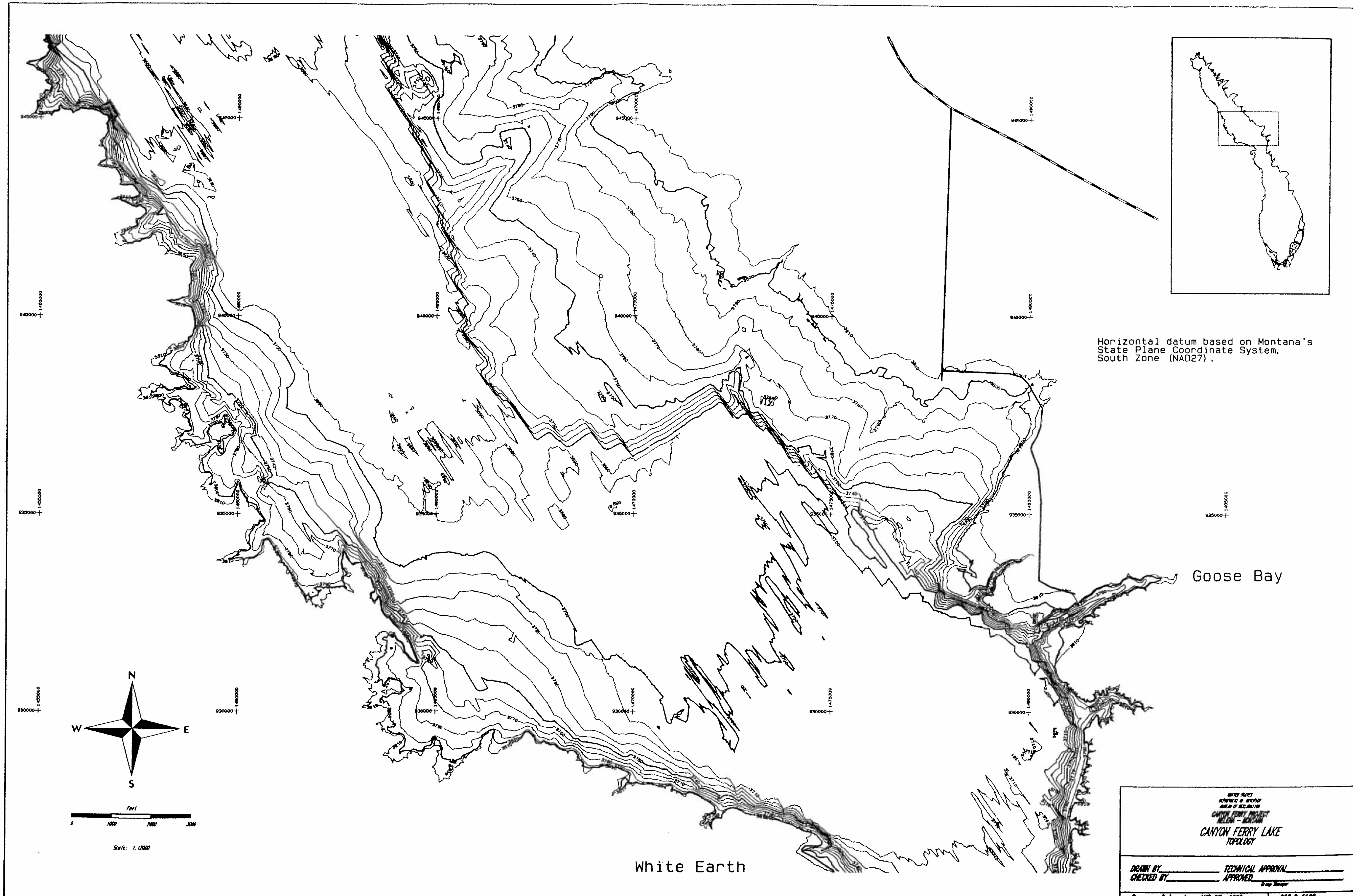

Figure 6. - Canyon Ferry Lake topographic map, No. 296-D-1160

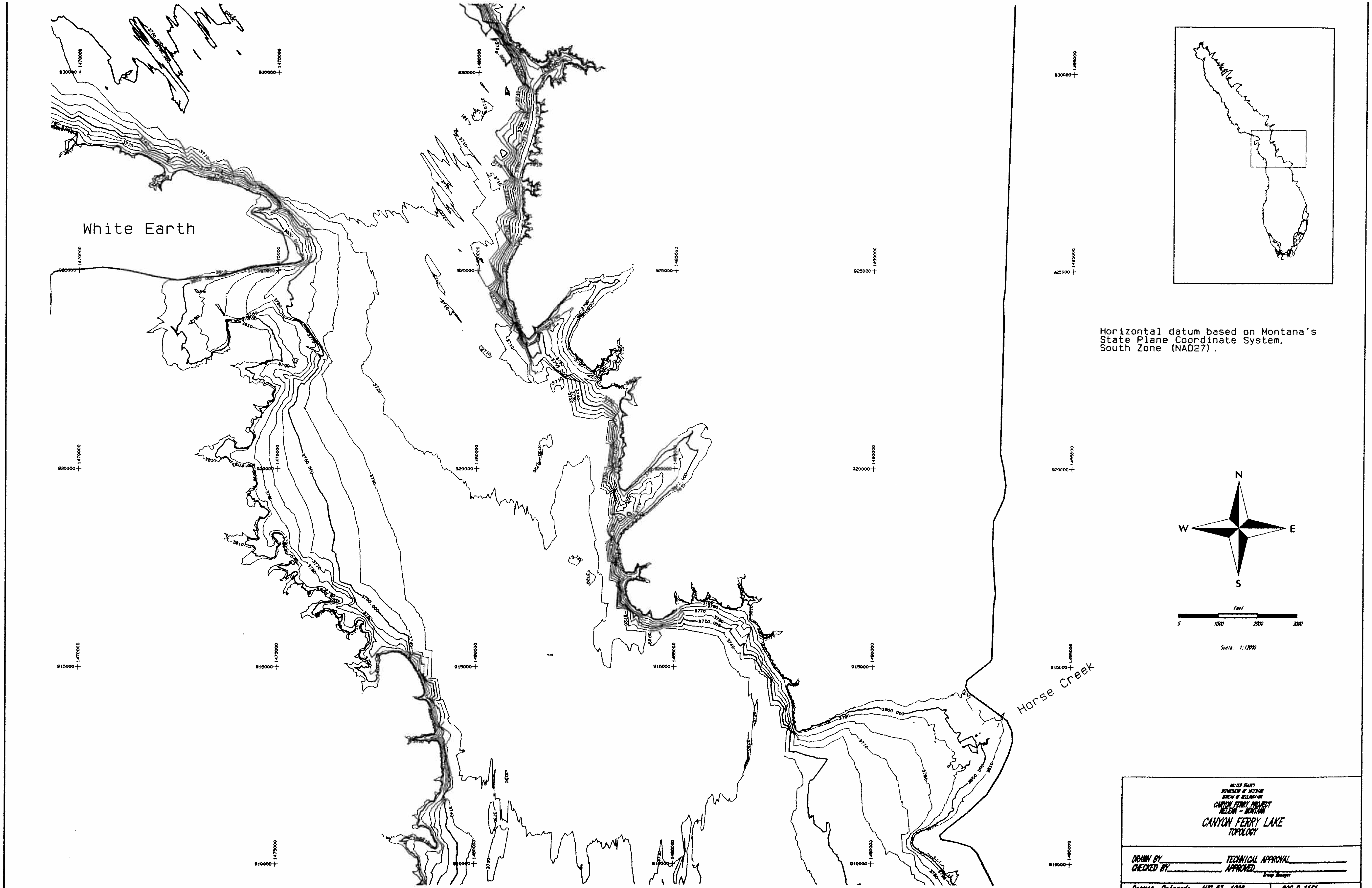

Figure 7. - Canyon Ferry Lake topographic map, No. 296-D-1161

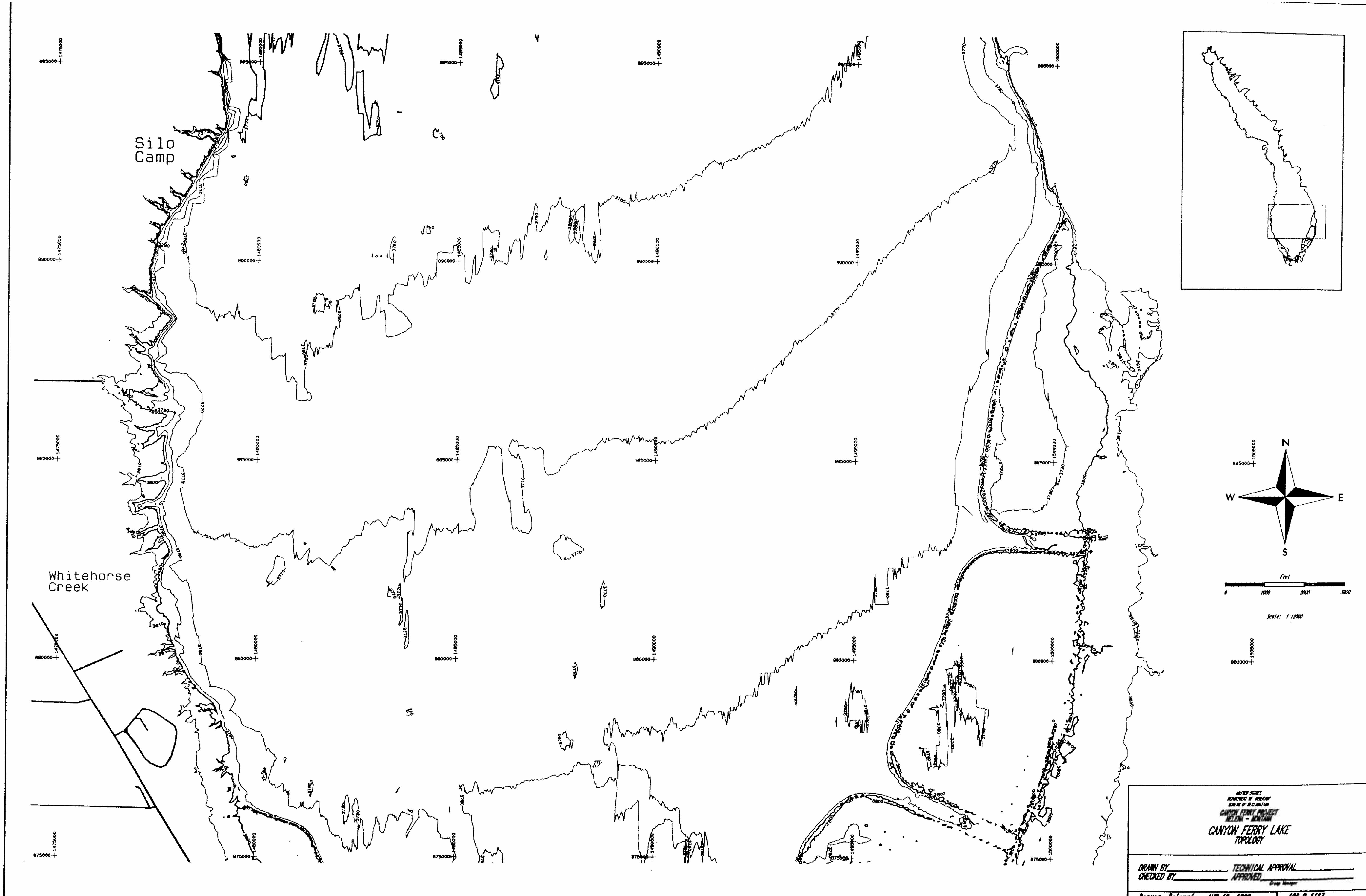

Figure 9. - Canyon Ferry Lake topographic map, No. 296-D-1163

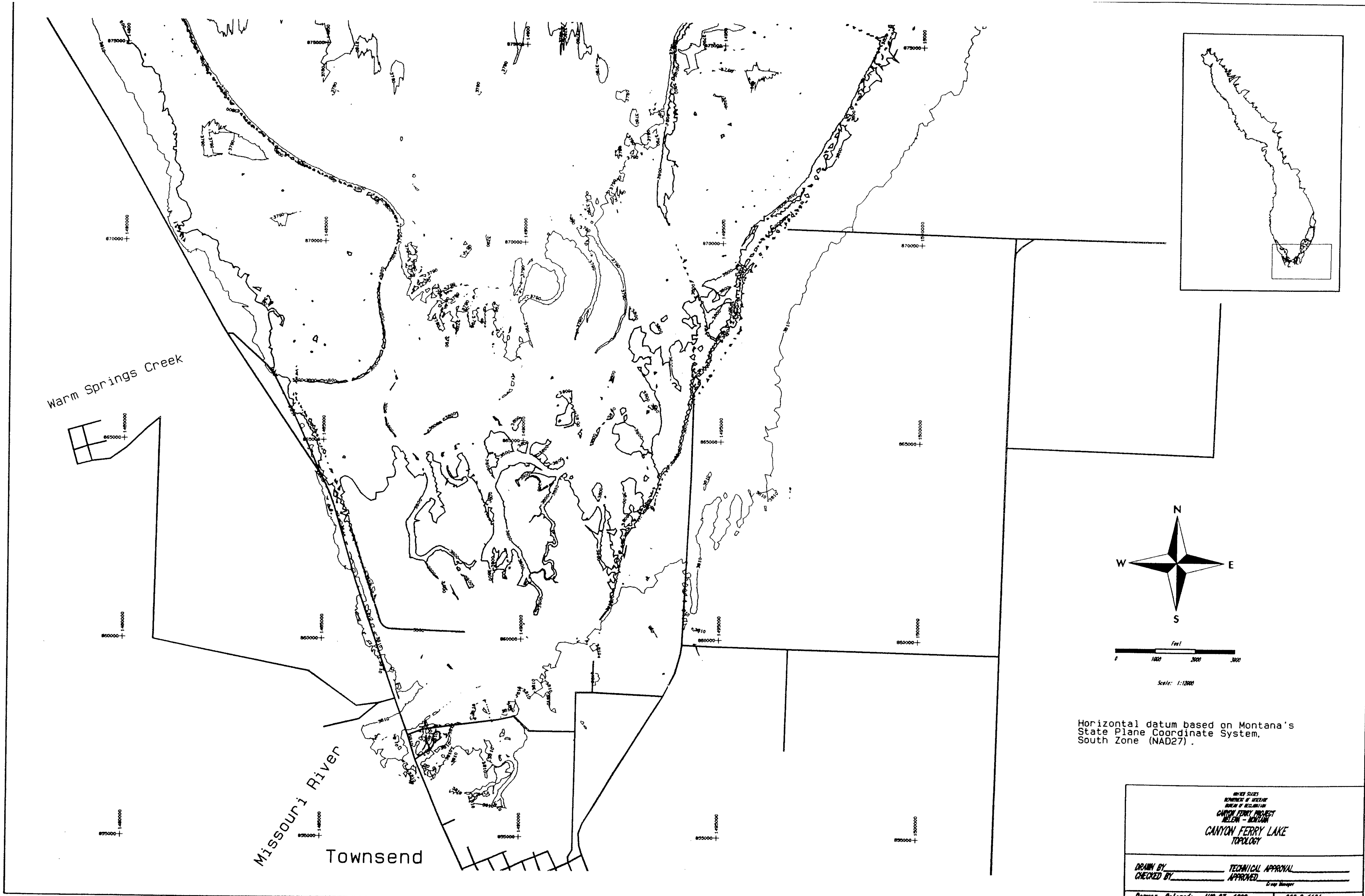

Figure 10. - Canyon Ferry Lake topographic map, No. 296-D-1164

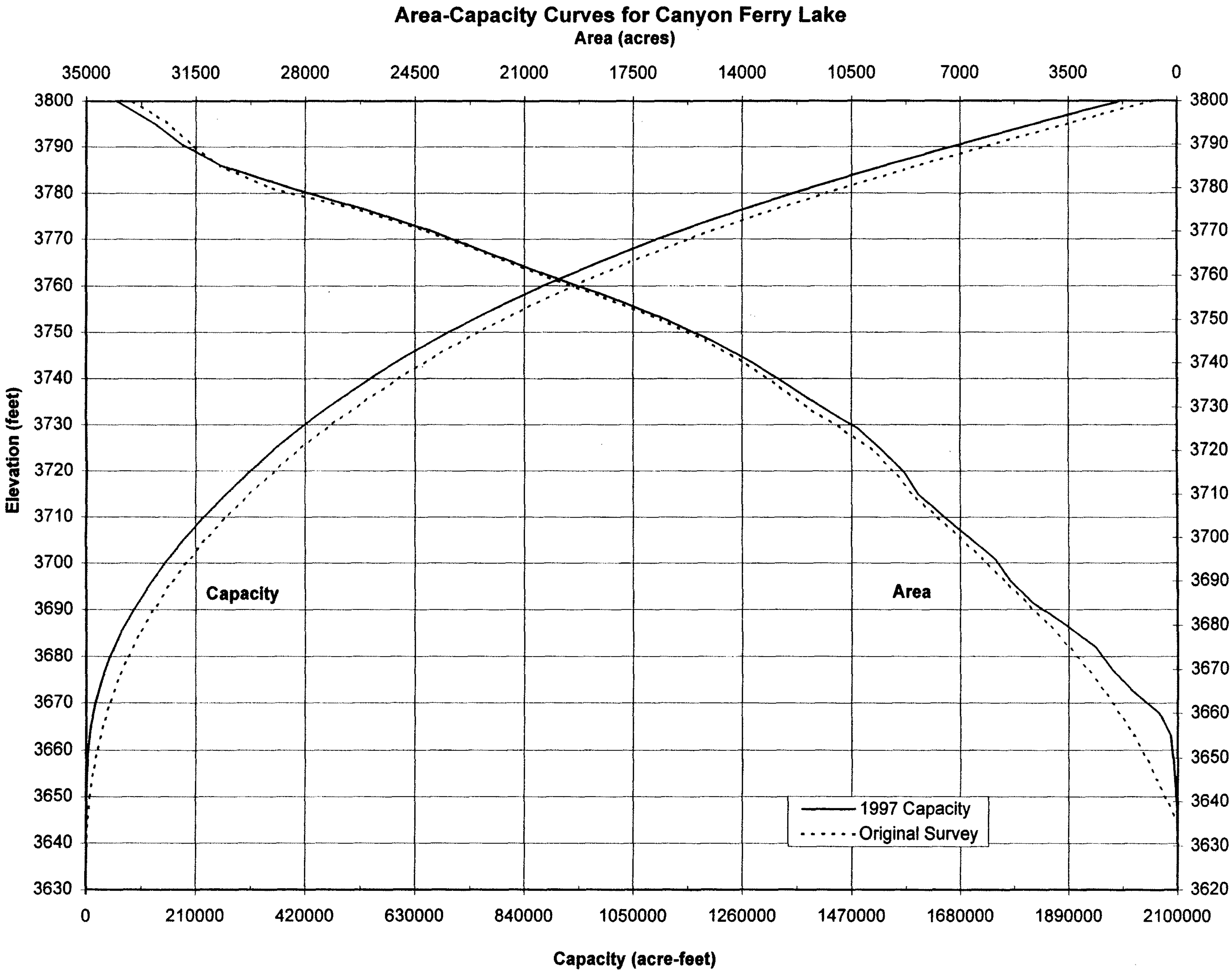

Figure 11. - 1997 area and capacity curves

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.