GIBSON RESERVOIR
1996 SEDIMENTATION SURVEY

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

The Bureau of Reclamation (Reclamation) surveyed the underwater area of Gibson Reservoir in July 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 in 1929 and the last reservoir survey in 1973. 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 the 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 1955. The new topographic map of Gibson Reservoir is a combination of digitized contour and 1996 underwater measured topography.

As of July 9, 1996, at top of active conservation elevation (feet) 4,724.0, the surface area was 1,296 acres and the total capacity was 96,477 acre-feet. Since initial filling in 1929, about 8,383 acre-feet of capacity has been lost in Gibson Reservoir below elevation 4724.0 (top of radial gates), resulting in a 7.99-percent loss in reservoir volume. Since the last sediment survey in 1973, about 2,590 acre-feet of sediment has accumulated below elevation 4724.0. Since 1929, the estimated average annual rate of reservoir capacity lost is 125.7 acre-feet. Since 1973, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 113.1 acre-feet.

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GIBSON 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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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. Lee Carlbon, dam tender, Greenfields Irrigation District, for his support 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 contour digitizing and was consulted during the map development. James Melena of TSC performed the technical peer review of this documentation.

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INTRODUCTION

Gibson Dam and Reservoir, principal features of the Sun River Project, are located on the North Fork of the Sun River about 24 miles northwest of Augusta, 75 miles west of Great Falls, and within Teton, and Lewis and Clark Counties in Montana (fig. 1). Additional features are the Willow Creek Dam and Reservoir, Pishkun Dikes and Reservoir, Sun River Diversion Dam, and Fort Shaw Diversion Dam. The dam, operated by the Greenfields Irrigation District, releases water to supplement natural river flows used for irrigation of Sun River Project lands.

Gibson Dam was constructed between 1926 and 1929 with first storage in December 1929. The drainage area above the dam is 575 square miles, ranging from elevation (feet)[1] 4,557.5, top of dead pool, to greater than 8,800 at its head waters. The reservoir length, at elevation 4,724, is around 5.2 miles with an average width of 0.4 mile. The dam is a massive concrete arch structure, whose dimensions are (fig. 2):

• Hydraulic height[2]	195	feet	• Structural height	199	feet
• Top width	15	feet	• Crest length	960	feet
• Crest elevation	4,725.5	feet	• Top of parapet wall	4,729	feet

The design maximum controllable water surface (top of spillway radial gates) is elevation 4,724.0. The maximum historical water surface, elevation 4,732.23, occurred on June 8, 1964. A record inflow of 60,000 cubic feet per second (cfs) caused Gibson Dam to overtop where water flowed over the parapet wall for 20 hours without seriously damaging the dam. After this event, modification work was done to provide additional protection to the dam and foundation for safe overtopping of greater than 100-year frequency flood flows.

Gibson Dam's spillway, located through the left abutment, is a drop-type structure controlled by six 34-foot-wide by 12-foot-high radial gates. The radial gates were installed in 1938 to provide 15,000 acre-feet of storage. The spillway crest is at elevation 4,712.0, with top of the spillway radial gates at elevation 4,724.0. The spillway provides a discharge of 30,000 cfs at reservoir elevation 4,724, top of active conservation, and 50,000 cfs at reservoir elevation 4,729.0, top of the parapet. The discharge enters a 29.5-foot-diameter vertical shaft and turns into a horizontal tunnel before discharging into the river below.

The outlet works consist of a trashrack, two 72-inch-diameter steel-lined conduits through the base of the dam, and a 60-inch jet-flow gate in each conduit that controls flows. The jet-flow gates, installed in 1971-72, replaced two original installed needle valves. Five-foot-square, hydraulically operated high-pressure emergency slide gates are located upstream from the jet-flow gates. The discharge capacity is 3,050 cfs at reservoir elevation 4,724.0.

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[1]Elevation levels are shown in feet.

[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*.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1996 results of the survey of Gibson 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 dam closure
- estimate storage depletion caused by sediment deposition since last reservoir survey in 1973

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 Gibson 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.

1996 underwater surface areas at predetermined contour intervals were generated by a computer graphics program using the underwater collected data. Above-water reservoir contours were digitized from U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps of Gibson Reservoir. The new topographic map of Gibson 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 1996 areas at elevation 4,720.0 and below and 1973 areas for elevation 4,724.0 and greater.

Table 1 contains a summary of the Gibson Reservoir's watershed characteristics for the 1996 survey. The 1996 survey determined that the reservoir has a storage capacity of 96,477 acre-feet and a surface area of 1,296 acres at reservoir elevation 4,724.0 feet. Since closure in 1929, the reservoir has had a volume change of 8,383 acre-feet below reservoir elevation 4,724.0. This volume represents a 7.99 percent loss in capacity and an average annual loss of 125.7 acre-feet.

RESERVOIR OPERATIONS

Gibson Reservoir is primarily an irrigation facility. The July 1996 area-capacity tables show 96,477 acre-feet of active conservation storage below elevation 4,724.0. The 1996 survey measured a maximum depth of elevation 4,557.1, but there is no volume below the dead pool of elevation 4,557.5, bottom of outlet conduits.

The Gibson Reservoir inflow and end-of-month stage records in table 1, operation period October 1973 through July 1996, show the inflow and annual fluctuation since the last reservoir survey in 1973. The average inflow into the reservoir for this operation period was 590,210 acre-feet per year. Also shown for this operation period are the extreme storage fluctuations of Gibson Reservoir, ranging from elevation 4,575.7 in 1988 to elevation 4,724.2 in 1976. The records show that in more than 50 percent of the years, the reservoir fills to the near-full reservoir condition of elevation 4724.0, maximum conservation level, and in some years, while supplying irrigation water downstream, drops more than 100 feet in elevation. The maximum reservoir water surface on record, elevation 4,732.23, occurred on June 8, 1964 when a major inflow caused overtopping flows of Gibson Dam.

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 Gibson 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, Gibson's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel; during the Gibson 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 Gibson 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 Gibson 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 Gibson 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 (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 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 Gibson Reservoir, the data were collected in Montana's 1927 NAD central state plane zone.

Survey Method and Equipment

The Gibson Reservoir hydrographic survey collection was conducted on July 8 through July 9, 1996, at water surface elevations 4,723.1 and 4,723.3, respectively. 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 perpendicular direction to the original river thalweg. 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 22,038 data points. A graph plotter was used in the field to track the boat and ensure adequate coverage during the collection process.

For stationing the master GPS unit there were no initial, known benchmarks or datums that overlooked the reservoir. For the underwater collection, the hydrographic survey crew established an initial datum near the center of the dam using a precision lightweight GPS receiver (PLGR). The PLGR unit utilizes the precise positioning service of the DOD GPS that is available to federal users only and has a horizontal accuracy of ±4 meters. At the time the datum coordinates were collected, the position accuracy was ±4.5 meters. 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 at the start of 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 for the lower portion of the reservoir survey. Additional datums were established when the radio-transmitted differential corrections were blocked by the reservoir terrain. This was accomplished by using the hydrographic GPS units and software with a horizontal accuracy of ±1 to 2 meters. The initial datum, at the center of the dam, was used as the reference for establishing the land-based network of datums that were used for locating the shore-based master GPS units during the survey of the reservoir. During-post processing of the collected data, the few collected points without differential correction were removed.

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 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 elevation recorded by a Reclamation gage during the time of collection was used to convert the sonic depth measurements to true lake-bottom elevations.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Gibson Reservoir was developed from 1996-collected underwater data and USGS quad maps. The upper contours of Gibson Reservoir were developed by digitizing the contour line, marked spillway elevation 4,725.0, from the USGS quad maps that covered the Gibson Reservoir area. For the purpose of this study, this contour was assume to be elevation

4,724.0, top of movable radial gates. The USGS quad maps were developed from aerial photography dated 1955. ARC/INFO V7.0.2 geographic information system (GIS) software was used to digitize the USGS quad contours. The digitized contours were transformed to Montana's NAD 1927 central state plane coordinates using the ARC/INFO PROJECT command. The resulting digitized area from the USGS quads was 1,312 acres, or 101.2% of the 1,296 acres reported in the 1973 survey of Gibson Reservoir at elevation 4,724.0.

As part of the 1996 sediment analysis of Gibson Reservoir, the elevation 4,725.0 contour of the 1973 aerial maps was also digitized. The 1973 reservoir survey completed an aerial analysis on September 22, 1973 of Gibson Reservoir at water surface elevation 4,597.8. A total of seven Reclamation maps, drawing numbers 28-600-58 through 64, were developed at intervals of 1 inch equals 200 feet, with 5-foot contour. The resulting digitized area of the 4,725.0 contour, from the seven maps, was 1,317 acres, or 101.2% of the 1,302 acres reported in the 1973 survey of Gibson Reservoir at elevation 4,725.0. This is a very small difference that can be attributed to the different methods of measuring the areas. To match the northeast tick marks of the 1973 aerial contour maps with the USGS quad northeast tick marks and the 1996 underwater data required a slight rotation along with a shift of around 6,200 feet to the north and 4,430 feet to the west. It appears the coordinate system for the 1973 aerial control was a local system established by Reclamation. Using the local control system had no bearing on the 1973 results, but it did not allow the digitized contour to be used as the clip for the 1996 study.

The Gibson Reservoir contour outline that was digitized from USGS quad maps was used to perform a clip of the Gibson Reservoir triangular irregular network (TIN) such that interpolation was not allowed to occur outside of this contour that was assigned an elevation of 4724.0. This 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 required slight modification in order to incorporate the entire underwater data set. Modifications were also made to the clip so the 1996 computed area at elevation 4,724.0 matched the 1,296 acres computed by the 1973 survey. Using select and move commands within ARCEDIT, the vertices of the 4724.0 clip were shifted to enclose all the collected underwater data and to reduce the area to match the 1973 study. The 1996 underwater data are presented on figure 3.

Contours for elevations below 4,724.0 were computed from the 1996 collected underwater data using the 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. 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 greater detail in the ARC/INFO V7.0.2 *Users Documentation.*

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Gibson 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 Gibson Reservoir. The contour topography at 25-foot intervals is presented on figure 4, drawing number 28-D-873. Contour topography at 5-foot intervals with a scale of 1 inch = 200 feet is also available from Reclamation.

Development of 1996 Contour Areas

The 1996 contour surface areas for Gibson Reservoir were computed at 5-foot increments, from elevation 4,560.0 to 4,724.0, using the Gibson Reservoir TIN discussed above. The 1996 survey measured the minimum reservoir elevation at 4,557.1 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.

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 5-foot contour intervals from minimum reservoir elevation 4,557.1 to elevation 4,724.0 and the 1973 surface areas at contour elevation 4,730.0 and 4,740.0 were used as the control parameters for computing the Gibson 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 0.000001 for Gibson 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 Gibson Reservoir area and capacity computations are listed in table 1 and columns (8) and (9) of table 2. On table 2, columns (2) and (3) list the original surface areas and recomputed capacity values and columns (4) and (5) list the 1973 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, 1973, and 1996 area-capacity curves are plotted on figure 5. As of July 1996, at elevation 4,724.0, the surface area was 1,296 acres with a total capacity of 96,477 acre-feet.

SEDIMENT ANALYSES

Since dam closure in December 1929 the measured total volume change at reservoir elevation 4,724.0 was 8,383 acre-feet. The average annual rate of capacity lost between closure and July 1996 (66.7 years) was 125.7 acre-feet per year. The storage loss in terms of percent of original storage capacity was 7.99 percent. Tables 1 and 2 contain the Gibson Reservoir sediment accumulation and water storage data based on the 1996 resurvey. Column 10 of table 2 gives the measured volume change by elevation. This column is labeled "1996 measured sediment volume," but it is assumed that a portion of this change is due to the accuracy of the original surface areas that were projected from an area curve developed in the 1930's. Figure 5, a plot of the original area data versus the 1973 and 1996 measured areas, shows the plots/areas in a near-mirror image of each other, possibly indicating an elevation datum difference between the original survey and the resurveys of Gibson Reservoir.

The geology of Gibson Dam and Reservoir area is described as a steep ridge of erosion-resistant limestone and dolomite with a low probability of landslides (Goodson, 1981). During the 1996 survey, and noted in the 1973 resurvey report, no delta deposit of coarser-size sediments in the upper reach of the reservoir was observed. The 1996 survey, at elevation 4,724.0, measured a 61-acre difference in surface area since the original survey. One suspects an elevation datum difference between the original survey and the resurveys of Gibson Reservoir because of the low probability of landslides and because no large landslides and upper reservoir deposits of coarser-size sediments were observed. The reservoir is located in a forest drainage usually conducive to low sediment contribution except after major events within the drainage, such as forest fires. Records for the period between 1929 and 1973 list a 1945 fire near the Bench Mark Area in the South Fork drainage that burned approximately 2,270 acres. Since the 1973 survey, records show two fires in 1988 with one burning 466 acres and the second burning 50,408 acres.

The purpose of the 1996 survey was to measure the reservoir volume lost due to sediment contribution from the major 1988 forest fire that occurred in the drainage since the 1973 survey. Column 12 of table 2 gives the 1996 measured sediment volume, since the 1973 reservoir sedimentation surveys, which was 2,590 acre-feet at elevation 4,724.0. The average annual rate of sediment deposition since 1973 (22.9 years) was 113.1 acre-feet per year. It is assumed that the majority of this sediment contribution came after the drainage fire. Field observation from the dam tender during low reservoir elevation indicated that large sediment deposits existed in the upper reservoir area. With the first few years after the fire, the inflow definitely had large amounts of burn material, lessening each year.

A resurvey of Gibson Reservoir should be considered in the future if major sediment inflow events are observed, such as those occurring after a major drainage fire, or if the average annual rate of sediment accumulation requires further clarification.

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RESERVOIR SEDIMENT
DATA SUMMARY

Gibson Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Sun River	3. STATE Montana
	4. SEC. 4 TWP. 21 N RANGE 9 W	5. NEAREST P.O. Augusta	6. COUNTY Teton/Lewis-Clark
	7. LAT 47° 36' 09" LONG 112° 45' 39"	8. TOP OF DAM ELEVATION 4725.5[1]	9. SPILLWAY CREST EL 4712.0[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					
	c. POWER					12/29
	d. WATER SUPPLY					16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. CONSERVATION	4724.0	1357	104,768	104,784	
	g. DEAD	4557.5	18	16	16	12/29
	17. LENGTH OF RESERVOIR 5.2 MILES			AVG. WIDTH OF RESERVOIR 0.4 MILES		

BASIN	18. TOTAL DRAINAGE AREA 575 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 19[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 575 SQUARE MILES		23. MEAN ANNUAL RUNOFF 20.1[4] INCHES
	20. LENGTH 45 MILES	AV. WIDTH 13 MILES	24. MEAN ANNUAL RUNOFF 615,480[5] ACRE-FEET
	21. MAX. ELEVATION 8800	MIN. ELEVATION 4557.5	25. ANNUAL TEMP. MEAN 45°F RANGE -49°F to 106°F[3]

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
	12/29					1,357[6]	104,860[6]	.17
	8/73	43.8	43.8	Contour (D)	10-ft	1,296[6]	99,067[6]	.16
	7/09/96	22.9	66.7	Contour (D)	5-ft	1,296[7]	96,477[7]	.16

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
8/73	17.62	628,690	984,500	27,536,700[8]	628,690	27,536,700[8]
7/09/96	19[3]	590,210	918,300	13,515,800	615,480	41,052,500

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.²-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.²-YR.
8/73	5,793[9]	132.3[9]	.23	5,793	132.3	.23
7/09/96	2,590[10]	113.1	.20	8,383[11]	125.7	.22

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.
8/73				.126	5.52		
7/09/96				.120	7.99		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
		4580-4550	4600-4580	4620-4600	4640-4620	4660-4640	4680-4660	4700-4680	4720-4700	4724-4720		
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
7/96		3.3	13.2	7.5	8.4	9.1	12.2	22.9	19.7	3.7		

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[12]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1974	4,723.9	4,595.1	709,600	1975	4,720.4	4,672.7	902,600
1976	4,724.2	4,673.4	824,000	1977	4,715.4	4,595.5	285,500
1978	4,724.0	4,596.8	739,600	1979	4,724.0	4,609.4	570,200
1980	4,724.0	4,618.1	596,000	1981	4,724.0	4,625.8	600,400
1982	4,723.5	4,637.8	677,500	1983	4,724.0	4,656.9	442,800
1984	4,723.9	4,626.3	419,000	1985	4,723.9	4,637.0	503,200
1986	4,716.3	4,610.2	657,600	1987	4,724.1	4,641.8	429,900
1988	4,722.0	4,575.7	357,000	1989	4,723.8	4,605.7	663,400
1990	4,724.0	4,653.0	737,100	1991	4,723.7	4,651.0	918,300
1992	4,720.9	4,621.8	416,000	1993	4,724.0	4,622.0	530,800
1994	4,720.0	4,607.5	435,400	1995	4,724.0	4,610.0	483,800
1996	4,724.0	4,677.0	616,100[12]				

46. ELEVATION - AREA - CAPACITY DATA FOR **1996 CAPACITY**[13]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4557	0	0	4560	1.0	2	4565	5.2	17
4570	12.6	62	4575	26.9	160	4580	59.5	376
4585	89.0	748	4590	125.2	1,283	4595	147.2	1,964
4600	200.3	2,833	4605	240.9	3,936	4610	312.3	5,319
4615	374.9	7,037	4620	415.7	9,013	4625	456.7	11,194
4630	494.1	13,571	4635	525.2	16,120	4640	554.2	18,818
4645	580.4	21,655	4650	610.3	24,631	4655	651.2	27,785
4660	691.4	31,142	4665	733.4	34,704	4670	784.3	38,498
4675	853.2	42,592	4680	916.5	47,016	4685	967.6	51,726
4690	1,009.2	56,668	4695	1,048.7	61,813	4700	1,105.5	67,198
4705	1,160.2	72,862	4710	1,217.4	78,806	4715	1,255.0	84,987
4720	1,280.2	91,325	4724	1,296.2	96,477	4730	1,333	104,364
4740	1,394	117,999						

47. REMARKS AND REFERENCES

[1] Parapet elevation 4729.0.

[2] Top of movable radial gates = 4724.0.

[3] Bureau of Reclamation Project Data Book, 1981.

[4] Calculated using mean annual runoff value of 615,480 AF, item 24, 1973-1996.

[5] Computed annual inflows from 1929 through 7/96.

[6] Original surface area and capacity at elevation 4,724.0. Original and 1973 capacity recomputed by Reclamation's ACAP program using measured surface areas. Original areas projected from 1931 area curve. 1973 areas measured from aerial photography.

[7] Surface area and capacity at elevation 4724.0 computed by ACAP program using 1996 and 1973 surface areas. 1996 surveyed only underwater portion of reservoir below elevation 4724.0. Elevation 4724.0 and above from 1973 study.

[8] Values from May 7, 1976 reservoir sedimentation data summary table.

[9] Capacity loss calculated by comparing original recomputed capacity and 1973 capacity at reservoir elevation 4724.0, top of conservation elevation. Portion of capacity difference due to accuracy of two surveys, original areas projected from area curve and 1973 areas measured from aerial survey.

[10] Capacity loss calculated by comparing 1973 recomputed capacity and 1996 capacity at reservoir elevation 4724.0.

[11] Total capacity loss calculated by comparing original recomputed capacity and 1996 capacity at reservoir elevation 4724.0. Portion of capacity difference due to accuracy of two surveys. Original areas projected from area curve.

[12] Maximum and minimum elevations and inflow values in acre-feet by water year, from October 1973 through July 1996.

[13] Capacities computed by ACAP computer program. Areas at elevation 4724 and above from 1973 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).

(1) Elevation (feet)	(2) Original Area (acres)	(3) Original Capacity (acre-feet)	(4) 1973 Area (acres)	(5) 1973 Capacity (acre-feet)	(6) 1973 Measured Sediment Volume (acre-feet)	(7) 1973 Percent of Computed Sediment	(8) 1996 Survey Area	(9) 1996 Survey Capacity	(10) 1996 Measured Sediment Volume (acre-feet)	(11) 1996 Percent of Computed Sediment	(12) 1973-1996 Measured Sediment Volume (acre-feet)	(13) 1973-1996 Percent of Computed Sediment	(14) Percent Reservoir Depth
4724.0	1,357	104,860	1,296	99,067	5,793	100.0	1,296	96,477	8,383	100.0	2,590	100.0	100.0
4720.0	1,319	99,508	1,272	99,930	5,578	96.3	1,280	91,325	8,183	97.6	2,605	100.6	97.7
4710.0	1,263	86,598	1,214	81,500	5,098	88.0	1,217	78,806	7,792	93.0	2,694	104.0	92.0
4700.0	1,192	74,323	1,109	69,885	4,438	76.6	1,105	67,198	7,125	85.0	2,687	103.7	86.2
4690.0	1,091	62,908	1,016	59,260	3,648	63.0	1,009	56,668	6,240	74.4	2,592	100.1	80.5
4680.0	972	52,593	939	49,485	3,108	53.7	917	47,016	5,577	66.5	2,469	95.3	74.7
4670.0	870	43,383	825	40,665	2,718	46.9	784	38,498	4,885	58.3	2,167	83.7	69.0
4660.0	728	35,393	710	32,990	2,403	41.5	691	31,142	4,251	50.7	1,848	71.4	63.2
4650.0	666	28,423	636	26,260	2,163	37.3	610	24,631	3,792	45.2	1,629	62.9	57.5
4640.0	597	22,108	570	20,230	1,878	32.4	554	18,818	3,290	39.2	1,412	54.5	51.7
4630.0	534	16,453	510	14,830	1,623	28.0	494	13,571	2,882	34.4	1,259	48.6	46.0
4620.0	461	11,478	438	10,090	1,388	24.0	416	9,013	2,465	29.4	1,077	41.6	40.2
4610.0	385	7,248	377	6,015	1,233	21.3	312	5,319	1,929	23.0	696	26.9	34.5
4600.0	262	4,013	215	3,055	958	16.5	200	2,833	1,180	14.1	222	8.6	28.7
4590.0	168	1,863	126	1,350	513	8.9	125	1,283	580	6.9	67	2.6	23.0
4580.0	72	663	50	407	193	3.3	60	376	287	3.4	94	3.6	17.2
4570.0	24	183	18	130	53	0.9	13	62	121	1.4	68	2.6	11.5
4560.0	5	38	4	20	18	0.3	1	2	36	0.4	18	0.7	5.7
4557.0	4	24	3	10	14	0.2	0	0	24	0.3	10	0.4	4.0
4550.0	0	0	0	0	0	0.0	0	0	0	0.0	0	0.0	0.0

Table 2

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area.
(3) Original calculated reservoir capacity computed using ACAP from original measured surface areas projected by area curves.
(4) Reservoir surface area from 1973 survey.
(5) 1973 calculated reservoir capacity computed using ACAP, from 1973 surface areas.
(6) Measured sediment volume = column (3) - column (5).
(7) Measured sediment expressed in percentage of total sediment 5,793 acre-feet at elevation 4724.0.
(8) Reservoir surface area from 1996 survey for elevations 4720.0 and below. Areas for elevation 4724 and above from 1973 survey.
(9) 1996 calculated reservoir capacity computed using ACAP, from 1996 surface areas.
(10) 1996 measured sediment volume = column (3) - column (9).
(11) Measured sediment expressed in percentage of total sediment 8,383 acre-feet at elevation 4724.0.
(12) Measured sediment volume from 1973 to 1996 = column (5) - column (9).
(13) Measured sediment expressed in percentage from 1973 to 1996, sediment volume of 2,590 acre-feet at elevation 4724.0.
(14) Depth of reservoir expressed in percentage of total depth (174 feet).

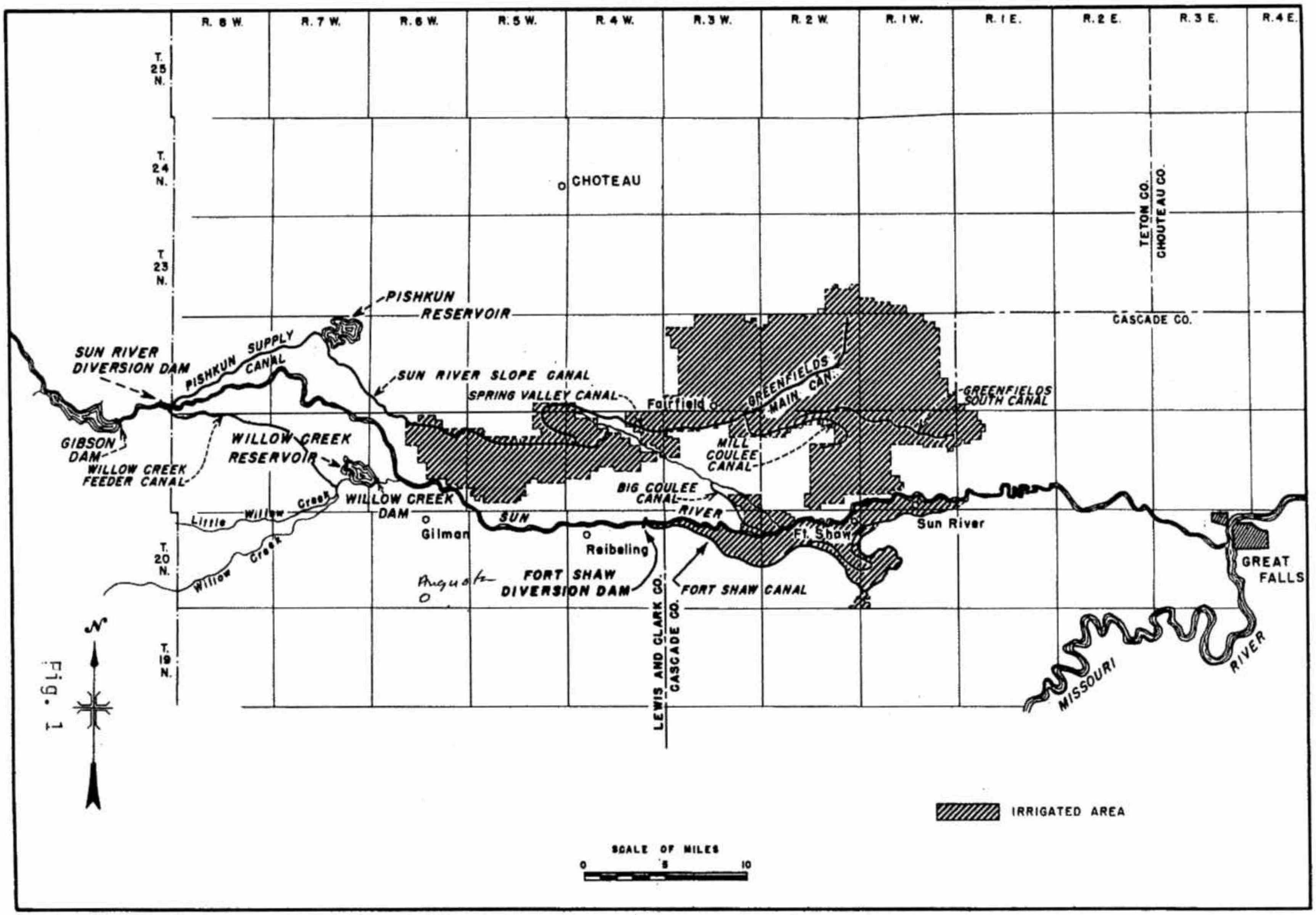

Fig. 1

Sun River Project

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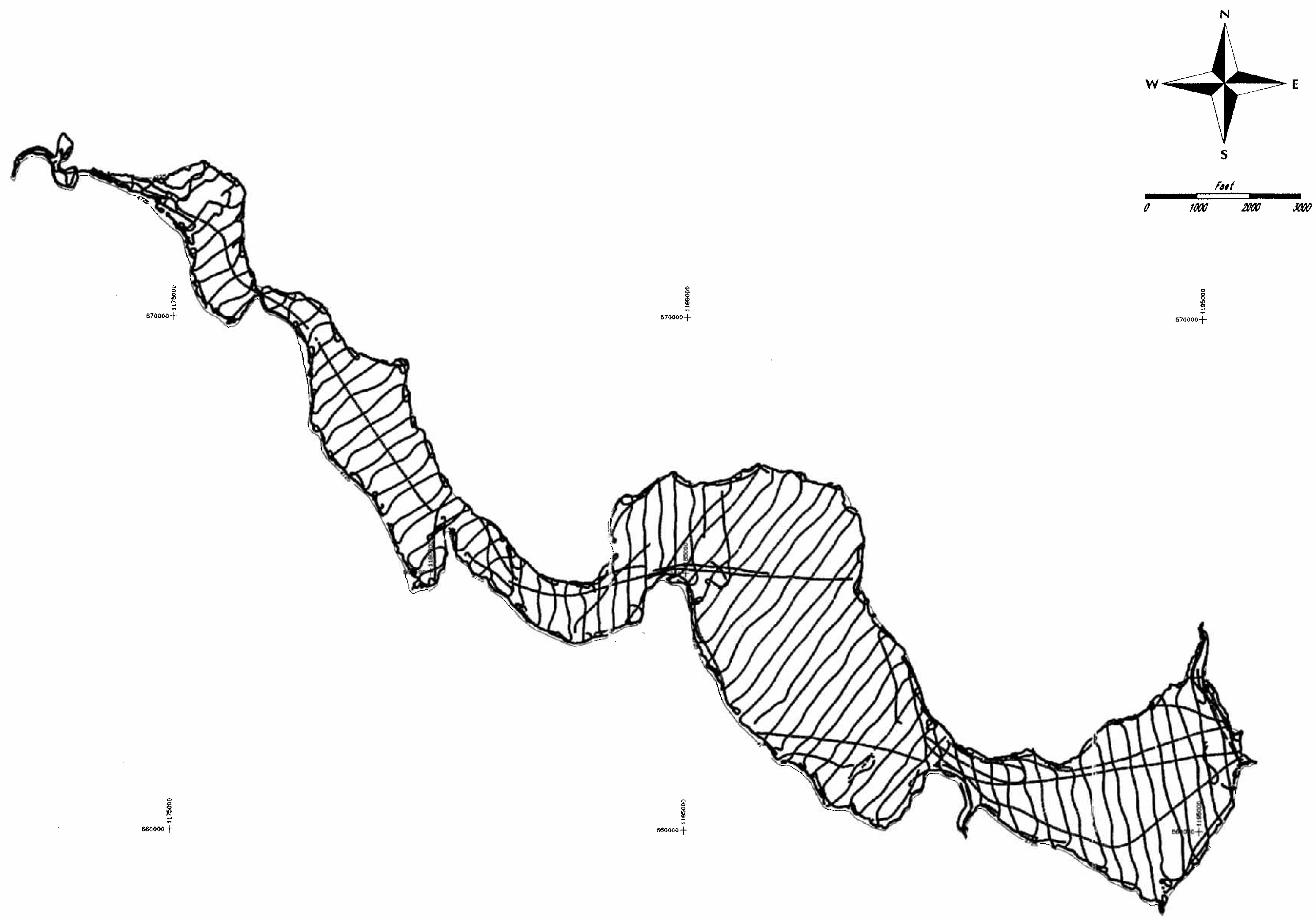

SUN RIVER PROJECT
GIBSON - MONTANA

GIBSON RESERVOIR
1996 UNDERWATER DATA

Fig. 3

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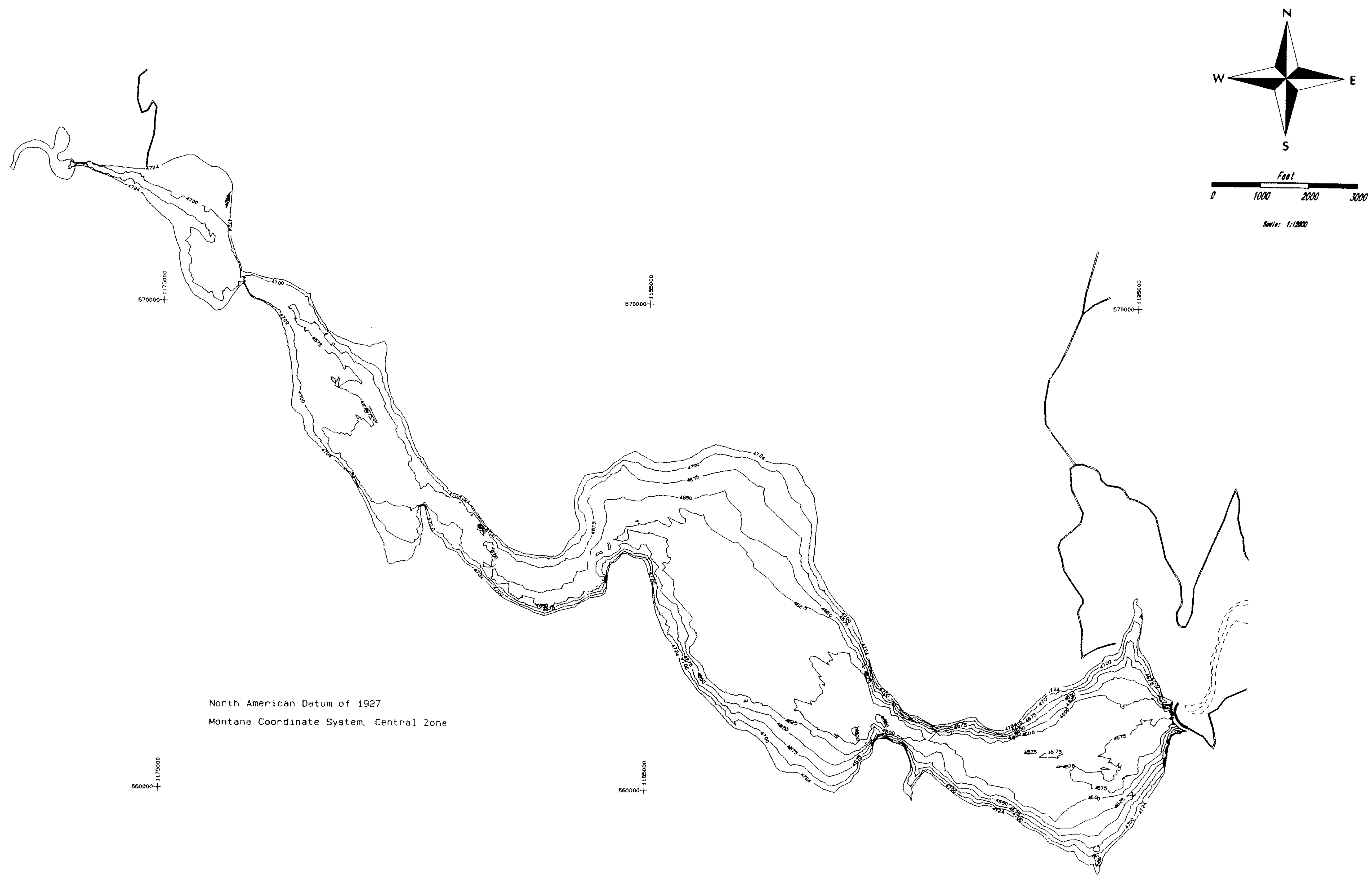
Denver, Colorado APR 12, 1997



SUN RIVER PROJECT
GIBSON - MONTANA

GIBSON RESERVOIR
TOPOLOGY

Fig. 4

DRAWN BY______________ TECHNICAL APPROVAL______________
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Area-Capacity Curves for Gibson Reservoir

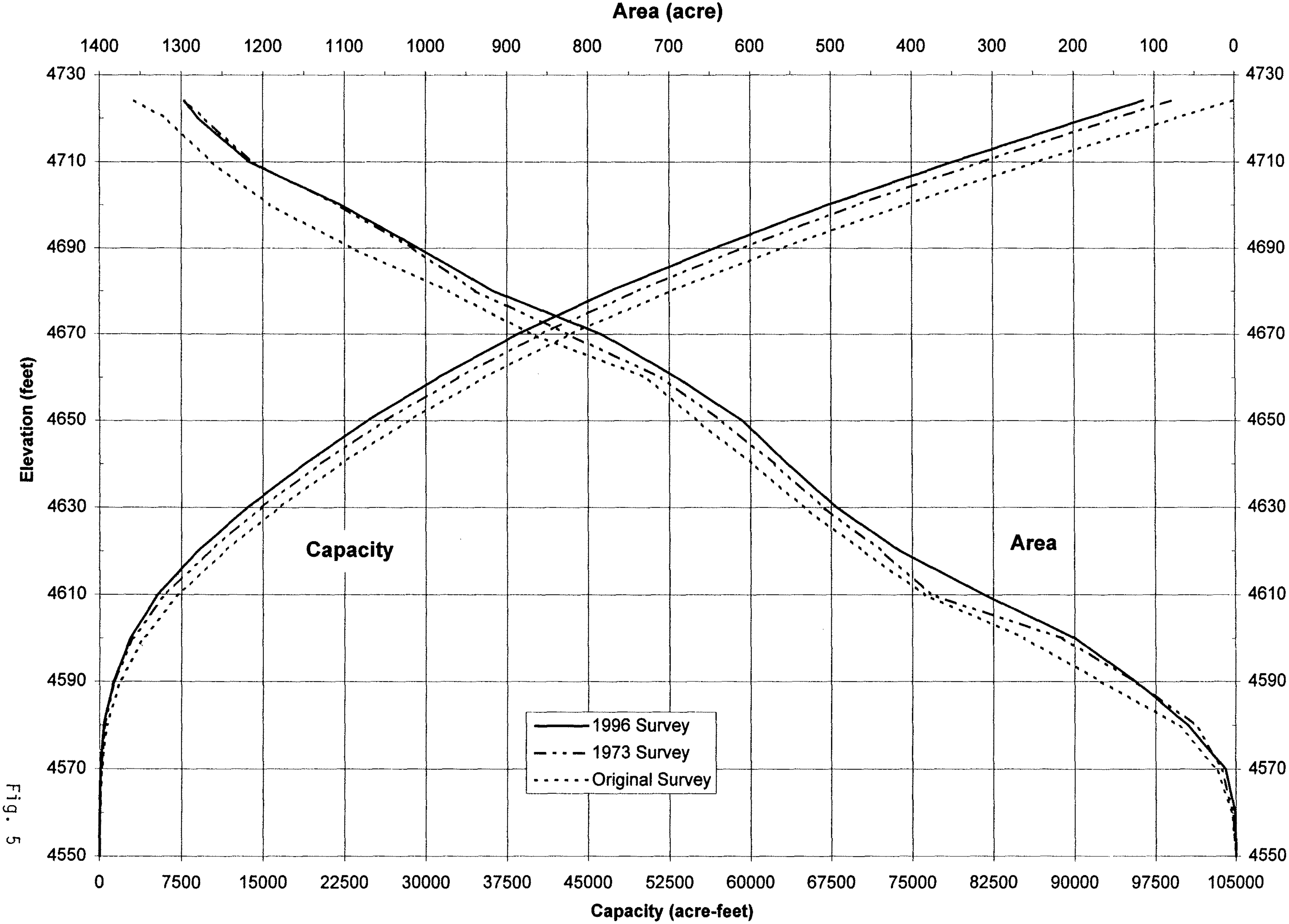

Fig. 5

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.