
CLARK CANYON RESERVOIR 2000 RESERVOIR SURVEY



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| 13. ABSTRACT (Maximum 200 words) The Bureau of Reclamation (Reclamation) surveyed Clark Canyon Reservoir in June of 2000 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 August of 1964. The underwater survey was conducted in June of 2000 near reservoir elevation 5538 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 Clark Canyon Reservoir was developed from the combined digitized USGS quad contours and June 2000 underwater measured topography. This study assumed no change from elevation 5540 and above. As of June 2000, at top of joint use water surface elevation (feet) 5,546.1, the surface area was 5,151 acres with a total capacity of 174,367 acre-feet. Since initial filling in August of 1964, about 4,106 acre-feet of sediment have accumulated in Clark Canyon Reservoir below elevation 5,546.1, resulting in a 2.3 percent loss in reservoir volume. Since 1964, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 114.7 acre-feet. | | | | |
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CLARK CANYON RESERVOIR

2000 RESERVOIR SURVEY

by

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**Sedimentation and River Hydraulics Group
Water Resources Services
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Denver, Colorado**

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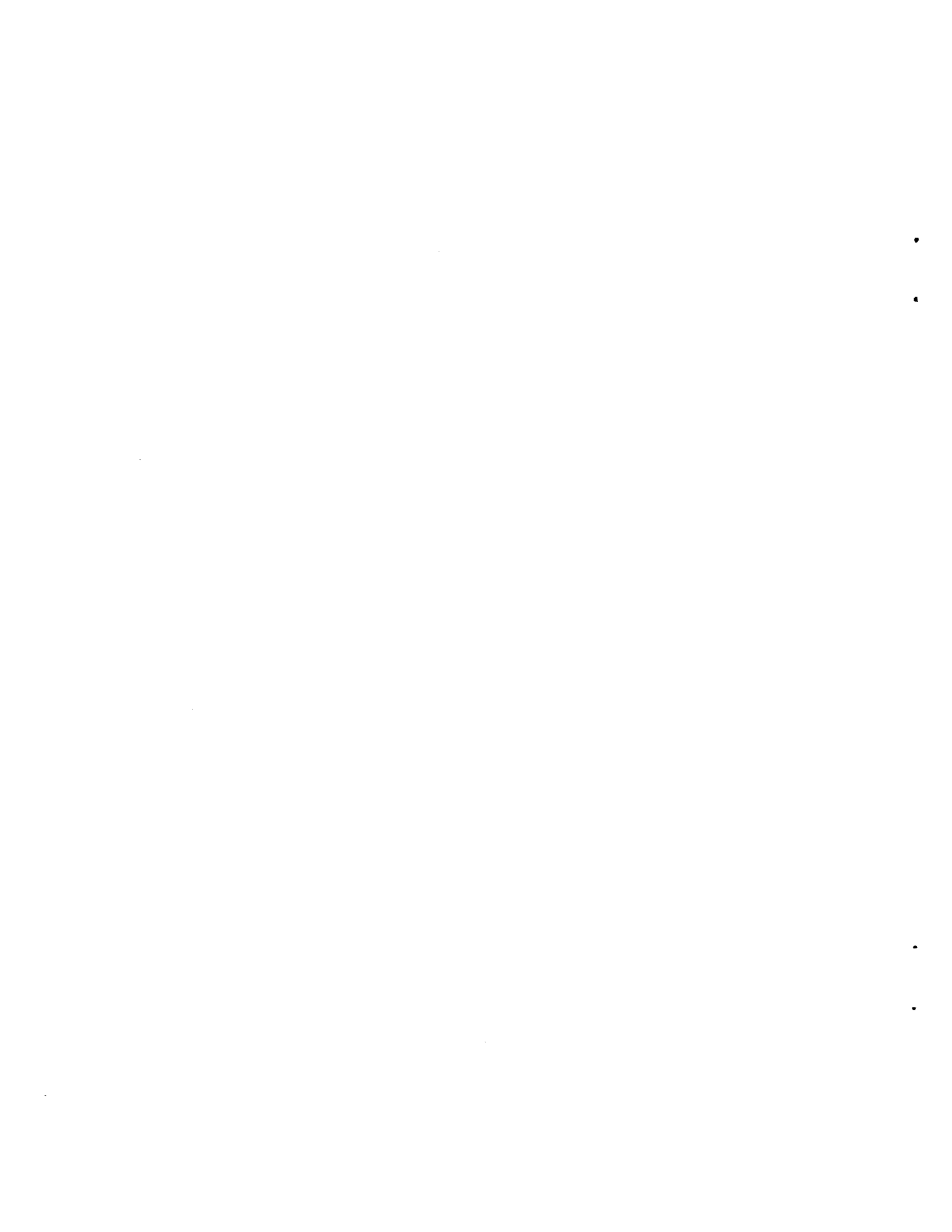
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INTRODUCTION

Clark Canyon Reservoir and dam are located in Beaverhead County at the head of the Beaverhead River about 20 miles southwest of Dillon, Montana (fig. 1). Clark Canyon Reservoir as part of the East Beach Unit provides irrigation, flood control, and recreation benefits. The dam and reservoir are operated and maintained by the East Bench Irrigation District.

Clark Canyon Dam was completed in 1964 and is a zoned earthfill structure whose dimensions are (fig. 2):

| | | | |
|-------------------------------|-------------------------|-------------------|------------|
| Hydraulic height ¹ | 113.9 feet ² | Structural height | 147.5 feet |
| Top width | 36 feet | Crest length | 2,950 feet |
| Crest elevation | 5,578.0 feet | | |

The spillway is located in the left abutment of the dam and consists of an inlet channel, a free overflow crest at elevation 5560.4, a chute with underlying drainage gallery, and a stilling basin. The spillway provides a discharge of 9,530 cubic feet per second (cfs) at reservoir elevation 5571.9

The outlet works, through the left abutment, consists of an approach channel, concrete intake structure, concrete conduit, a gate chamber with four high-pressure gates, an access shaft, shaft house and stilling basin. The discharge capacity of the outlet works is 2,325 cfs at reservoir elevation 5,547.

The total drainage area above Clark Canyon Dam is 2,321 square miles of which 1,751 square miles are considered sediment contributing. Sediments from the remaining drainage area are trapped by Lima Reservoir that has a drainage area of 570 square miles. Clark Canyon Reservoir has an average width of 2.0 miles with a length of around 4.5 miles.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2000 results of the survey of Clark Canyon 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

¹The 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*.

²Elevation 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 tied to the National Geodetic Vertical Datum of 1929.

A Real-time Kinematic (RTK) GPS control survey was conducted to establish a temporary horizontal and vertical control point for the reservoir survey. The horizontal control was established in Montana state plane coordinates in the North American Datum of 1983 (NAD83). The RTK GPS control was conducted with the base set on the NGS datum point "Dillon" located in the town of Dillon, Montana. All elevations in this report are reference to the Reclamation project datum that is tied to the NGVD29

The underwater survey was conducted in June of 2000 near reservoir water surface elevation 5,538. 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 Clark Canyon Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by the reservoir gauge (tied to the Reclamation vertical datum) during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations. 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 Clark Canyon Reservoir topographic maps are a combination of the USGS quad contours and underwater survey data. The 2000 reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using the collected reservoir data. The 2000 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 1 and 2 contain a summary of the Clark Canyon Reservoir sedimentation and watershed characteristics for the 2000 survey. The 2000 survey determined that the reservoir has a total storage capacity of 174,367 acre-feet and a surface area of 5,151 acres at reservoir elevation 5,546.1. Since closure in August of 1964, the reservoir had an estimated volume change of 4,106 acre-feet below reservoir elevation 5,546.1. This volume represents a 2.3 percent loss in total capacity and an average annual loss of 114.7 acre-feet per year.

RESERVOIR OPERATIONS

Clark Canyon Dam operates as part of the East Bench Unit to provide flood control, irrigation water, and recreational use. The June 2000 area-capacity tables show 325,324 acre-feet of total storage below the maximum water surface elevation 5,571.9. The 2000 survey measured a minimum elevation of 5,449.0. The following values are from the June 2000 area-capacity tables:

- 71,882 acre-feet of surcharge between elevation 5,560.4 and 5,571.9.
- 79,075 acre-feet of flood control storage between elevation 5,546.1 and 5,560.4.
- 50,207 acre-feet of joint use storage below elevation 5,535.7 and 5,546.1.
- 123,099 acre-feet of conservation use between elevation 5,470.6 and 5,535.7.
- 1,057 acre-feet of inactive storage between elevation 5,455.0 and 5,470.6.
- 4 acre-feet of dead storage below elevation 5,455.0.

The Clark Canyon Reservoir inflow and end-of-month stage records in table 1 , operation period August 1964 through June 2000, show the inflow and annual fluctuation since dam closure. The estimated average inflow into the reservoir for this operation period was 288,963 acre-feet per year. Since 1966, the extreme storage fluctuations of Clark Canyon Reservoir ranged from an elevation of 5,508.7 in 1989 to the maximum recorded elevation of 5,564.7 in 1984.

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 Clark Canyon 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.

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 Clark Canyon 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 ± 10 meters.

A method of collection to resolve or cancel the inherent errors of GPS is called differential GPS (DGPS). DGPS is 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 Clark Canyon 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.

The Sedimentation and River Hydraulics Group conducts their bathymetric surveys using Real-time Kinematic (RTK) GPS. The major benefit of RTK versus DGPS is 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 on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS datum of WGS-84 which the hydrographic collection software converted into Montana's NAD83 state plane coordinate system. The system employs two receivers, like with DGPS, that collect additional satellite data that allows on-the-fly centimeter accuracy measurements.

Survey Method and Equipment

The Clark Canyon Reservoir hydrographic survey collection was conducted June 7 through June 10 of 2000 between water surface elevations 5,537.0 and 5537.9 (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 closely-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat in a north or south direction of the reservoir at a 400-foot spacing. Data was also collected along the shore as the boat traversed between 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 2000 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 gauge, were used to convert the sonic depth measurements to true lake-bottom elevations.

Clark Canyon Reservoir Datums

Prior to the underwater survey in June 2000, a RTK GPS survey was conducted to establish a horizontal and vertical control point that overlooked Clark Canyon Reservoir. The National Geodetic Survey control point "Dillon" in the town of Dillon, Montana was used as the base station for the control survey. The radio link between Dillon and Clark Canyon Reservoir was intermittent, but control information appeared to be good for the horizontal and close for the vertical measurements. All vertical information in this report was referenced to the reservoir water surface gauge measurements during the time of this survey. The gauge is referenced to the Reclamation project datum that is reported as NGVD29.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Clark Canyon Reservoir was developed from the 2000-collected underwater data and from the USGS quad maps. The upper contours of Clark Canyon Reservoir were developed by digitizing the contour lines of elevation 5,542 and 5,560 from the USGS quad maps that covered the reservoir area. The USGS quad maps were developed from aerial photography dated 1964. There was a small area of the dam and reservoir not covered by the 1964 aerial that did not appear on the Dalys, Montana quad map. For this study, this area was interpolated using available original information. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Montana's NAD 1983 state plane coordinates using the ARC/INFO PROJECT command. The resulting digitized areas from the USGS quad contours compared well with the original contour areas. The original computed surface area for elevation 5542.0 was 4,929 acres compared to the digitized computed area of 4,930.5 acres. The original area for elevation 5560.0 was measured as 5,880 acres compared to the digitized computed area of 5,879 acres.

The elevation 5,542.0 contour that was digitized from USGS quad maps was used to perform a clip of the Clark Canyon Reservoir triangular irregular network (TIN) such that interpolation was not allowed to occur outside the 5,542.0 contour. This complete contour was selected since it was the closest complete elevation to represent the reservoir at the time of the survey which was conducted near reservoir elevation 5,537. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and digitized contours from the quad maps were plotted. The plot found that the underwater data did not completely lie within this clip, which would require some modifications to include the entire underwater data set. These areas included the north and some on the south shores of the reservoir. It is assumed that most of this occurred due to shoreline erosion caused by the high winds that occur on this reservoir. Using select and move commands within ARCEDIT, the vertices of the 5,542.0 clip were shifted to fit all the collected underwater data.

Contours for the reservoir below elevation 5,542.0 were computed from the 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 among all data points within the polygon clip. 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. This method preserves all collected survey points. 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*, (ESRI, 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Clark Canyon Reservoir TIN. In addition, the contours were generalized by filtering out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had no bearing on the computation of surface areas and volumes for Clark Canyon Reservoir since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons developed from the survey data were completed for elevations 5,449.0 through elevation 5,542.0. The contour topography at 5-foot intervals is presented on figures 3 and 4, drawing numbers 699-D-569 and 699-D-570.

Development of 2000 Contour Areas

The 2000 contour surface areas for Clark Canyon Reservoir were computed at 1-foot increments from elevation 5,449.0 to 5,542.0. The 2000 underwater survey measured the minimum reservoir elevation at 5,449.0. 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. As indicated above, the underwater data was collected near reservoir elevation 5,537 and no above water data was collected during the 2000 survey. For the purpose of this study the measured 2000 survey areas at 5-foot increments from elevation 5,450 through 5,530 were used to compute the new area and capacity tables. Due to the lack of above water data this study assumed no area change from elevation 5,540 and above. The areas between elevation 5,530 and 5,540 were computed by the area and capacity program which assumed a straight line interpolation.

2000 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 reservoir elevation 5,450.0 to elevation 5,530.0 were used as the control parameters for computing the Clark Canyon Reservoir capacity. Since this study did not collect any above water data, the original areas from elevation 5,540 and above were used to complete the table. 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 Clark Canyon 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 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
 a₁ = intercept
 a₂ and a₃ = coefficients

Results of the 2000 Clark Canyon Reservoir area and capacity computations are listed in table 1 and columns 4 and 5 of table 2. On table 2, columns 2 and 3 list the original surface areas and recomputed capacities. A separate set of 2000 area and capacity tables has been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2000). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 2000 area-capacity curves are plotted on figure 5. As of June 2000, at elevation 5,571.9, the surface area was 6,606.2 acres with a total capacity of 325,324 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Figure 5 is a plot of Clark Canyon Reservoir's original area data versus the 2000 measured areas. This illustrates the difference between the original and the 2000 measured surface areas. Since Clark Canyon Dam closure in August 1964, the measured total volume change at reservoir elevation 5,546.1 was estimated to be 4,106 acre-feet. The estimated average annual rate of capacity lost for this time period (35.8 years) was 114.7 acre-feet per year. The storage loss in terms of percent of original storage capacity was 2.3 percent. Tables 1 and 2 contain the Clark Canyon Reservoir sediment accumulation and water storage data based on the 2000 resurvey.

The original 100 year sediment inflow estimate used during the design of Clark Canyon Reservoir was 10,000 acre-feet for an average annual rate of capacity loss of 100 acre-feet which is near the 2000 survey computed result of 114.7 acre-feet per year. It must be noted that the 2000 area and capacity table were generated using measured surface areas from elevation 5,530 and below. The original surface areas from elevation 5,540 and above were used to complete the new area and capacity table. This assumed no surface area change from elevation 5,540 and above which in all probability is not the case. The ACAP program computed a straight line interpolation to compute the surface areas between elevation 5,530 and 5,540. Overlaying the 2000 collected data with the digitized USGS quad contours appears to indicate there has been shoreline erosion since the original survey at elevation 5,542, but the only way to confirm this would be to conduct a shoreline survey. A resurvey of Clark Canyon Reservoir should be considered in the future if major sediment inflow events are observed, or if the average annual rate of sediment accumulation requires further clarification.

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, 1987(b). *Design of Small Dams*, U.S. Government Printing Office, Denver CO.
- Bureau of Reclamation, May 2000. Denver Office, *Clark Canyon Reservoir Area and Capacity Tables, East Bench Unit*, Great Plains Region, Billings, MT.
- 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

Clark Canyon Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

| | | | | | | | | | | | | | | |
|--|--|--------------------------------------|---------------------------|--|-------------------------------|---|--|--|------------------------------|------------------------|---|---------------------------|--------------------------------|---------------------|
| D A M R E S E R V O I R | 1. OWNER Bureau of Reclamation | | | 2. STREAM Beaverhead River | | | 3. STATE Montana | | | | | | | |
| | 4. SEC. 32 TWP. 9 S RANGE 10 W | | | 5. NEAREST P.O. Grant | | | 6. COUNTY Beaverhead | | | | | | | |
| | 7. LAT 45° 00' 06" LONG 112° 51' 27" | | | 8. TOP OF DAM ELEVATION 5578.0 | | | 9. SPILLWAY CREST EL 5560.4 ¹ | | | | | | | |
| | 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 8/64 | | | |
| | a. SURCHARGE | | 5571.9 | | 6,600 | | 71,827 | | 328,979 | | | | | |
| | b. FLOOD CONTROL | | 5560.4 | | 5,903 | | 79,090 | | 257,152 | | | | | |
| | c. POWER | | | | | | | | | | | | | |
| | d. JOINT USE | | 5546.1 | | 5,160 | | 50,436 | | 178,062 | | | | | |
| | e. CONSERVATION | | 5535.7 | | 4,496 | | 126,117 | | 127,626 | | | | | |
| | f. INACTIVE | | 5470.6 | | 367 | | 1,448 | | 1,509 | | | | | |
| | g. DEAD | | 5455.0 | | 23 | | 61 | | 61 | | 16. DATE NORMAL OPERATION BEGAN 8/64 | | | |
| | 17. LENGTH OF RESERVOIR | | | 4.5 MILES | | | AVG. WIDTH OF RESERVOIR | | | 2.0 MILES | | | | |
| | B A S I N | 18. TOTAL DRAINAGE AREA | | | 2,321 SQUARE MILES | | | 22. MEAN ANNUAL PRECIPITATION | | | 11.5 ² INCHES | | | |
| | | 19. NET SEDIMENT CONTRIBUTING AREA | | | 1,751 SQUARE MILES | | | 23. MEAN ANNUAL RUNOFF | | | 2.33 ³ INCHES | | | |
| | | 20. LENGTH | | MILES | | AV. WIDTH | | MILES | | 24. MEAN ANNUAL RUNOFF | | | 288,963 ⁴ ACRE-FEET | |
| | | 21. MAX. ELEVATION | | | MIN. ELEVATION | | | 25. ANNUAL TEMP. MEAN 43°F RANGE -40°F to 100°F ² | | | | | | |
| | S U R V E Y D A T A | 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 |
| 8/64 | | | | Contour (D) | | 10-ft | | 5,151 ⁵ | | 178,473 ⁵ | | .62 | | |
| 6/00 | | 35.8 | | Contour (D) | | 5-ft | | 5,151 ⁶ | | 174,367 ⁶ | | .60 | | |
| 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 | | |
| 6/00 | | | | 288,963 ⁷ | | 718,116 | | 10,344,871 | | 288,963 | | 10,344,871 | | |
| 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. | | |
| 6/00 | | 4106 ⁸ | | 114.7 | | 0.066 | | 4106 | | 114.7 | | 0.066 | | |
| 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. | | |
| 6/00 | | | | | | | | 0.064 ⁹ | | 2.3 ⁹ | | | | |

| | | | | | | | | | | | | | | |
|--|---|-------------|-------------|-----------|-----------|-----------|-----------|-----------|-------------|---------------|---------|---------|---------|---------|
| 26. DATE OF SURVEY | 43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION | | | | | | | | | | | | | |
| | 5460-5465 | 5460-5470.6 | 5470.6-5480 | 5480-5495 | 5495-5505 | 5505-5515 | 5515-5525 | 5525-5530 | 5530-5535.7 | 5535.7-5546.1 | | | | |
| PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION | | | | | | | | | | | | | | |
| 6/00 | 4.0 | 9.2 | 12.9 | 12.8 | 7.3 | 5.4 | 15.8 | 15.5 | 13.9 | 3.2 | | | | |
| 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 |
| PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION | | | | | | | | | | | | | | |

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

| 45. RANGE IN RESERVOIR OPERATION ¹ | | | | | | | |
|---|------------|------------|------------|------|------------|------------|------------|
| YEAR | MAX. ELEV. | MIN. ELEV. | INFLOW, AF | YEAR | MAX. ELEV. | MIN. ELEV. | INFLOW, AF |
| 1964 | 5,493.3 | | 19,671 | 1965 | 5,547.0 | 5,493.6 | 336,701 |
| 1966 | 5,542.4 | 5,521.2 | 199,264 | 1967 | 5,543.6 | 5,521.3 | 194,348 |
| 1968 | 5,543.2 | 5,536.1 | 252,984 | 1969 | 5,543.7 | 5,535.7 | 348,496 |
| 1970 | 5,545.6 | 5,535.7 | 314,767 | 1971 | 5,547.4 | 5,537.3 | 428,853 |
| 1972 | 5,542.8 | 5,535.7 | 393,999 | 1973 | 5,545.5 | 5,525.3 | 277,711 |
| 1974 | 5,543.4 | 5,517.9 | 266,131 | 1975 | 5,556.9 | 5,516.8 | 410,178 |
| 1976 | 5,554.5 | 5,540.5 | 408,233 | 1977 | 5,546.4 | 5,531.5 | 211,457 |
| 1978 | 5,547.5 | 5,533.1 | 263,965 | 1979 | 5,548.3 | 5,531.0 | 237,730 |
| 1980 | 5,548.2 | 5,532.2 | 250,648 | 1981 | 5,550.8 | 5,534.6 | 298,216 |
| 1982 | 5,549.6 | 5,534.6 | 333,406 | 1983 | 5,547.9 | 5,541.5 | 386,884 |
| 1984 | 5,564.7 | 5,542.2 | 718,116 | 1985 | 5,544.9 | 5,524.4 | 317,466 |
| 1986 | 5,545.8 | 5,536.8 | 250,958 | 1987 | 5,544.6 | 5,536.5 | 223,408 |
| 1988 | 5,546.6 | 5,522.1 | 140,224 | 1989 | 5,534.6 | 5,508.7 | 109,182 |
| 1990 | 5,531.9 | 5,511.0 | 131,346 | 1991 | 5,534.1 | 5,513.9 | 153,305 |
| 1992 | 5,537.7 | 5,509.8 | 133,115 | 1993 | 5,532.3 | 5,509.9 | 185,765 |
| 1994 | 5,546.7 | 5,523.1 | 175,003 | 1995 | 5,553.7 | 5,523.2 | 371,093 |
| 1996 | 5,544.0 | 5,532.0 | 346,664 | 1997 | 5,545.6 | 5,532.7 | 322,898 |
| 1998 | 5,551.1 | 5,539.7 | 402,243 | 1999 | 5,546.5 | 5,534.7 | 367,303 |
| 2000 | 5,532.2 | | 163,150 | | | | |

| 46. ELEVATION - AREA - CAPACITY DATA FOR 2000 CAPACITY ¹⁰ | | | | | | | | |
|--|---------|----------|-----------|---------|----------|-----------|---------|----------|
| ELEVATION | AREA | CAPACITY | ELEVATION | AREA | CAPACITY | ELEVATION | AREA | CAPACITY |
| 5449.0 | 0 | 0 | 5455 | 1.2 | 4 | 5460 | 21.4 | 60 |
| 5465 | 82.9 | 321 | 5470 | 170.6 | 955 | 5470.6 | 184 | 1,061 |
| 5475 | 284.8 | 2,093 | 5480 | 454.9 | 3,942 | 5485 | 661.8 | 6,734 |
| 5490 | 929.2 | 10,712 | 5495 | 1,207.5 | 16,053 | 5500 | 1,503.5 | 22,831 |
| 5505 | 1,824.4 | 31,151 | 5510 | 2,151.3 | 41,090 | 5515 | 2,508.5 | 52,739 |
| 5520 | 2,966.4 | 66,427 | 5525 | 3,399.6 | 82,342 | 5530 | 3,880.1 | 100,541 |
| 5535 | 4,343 | 121,098 | 5535.7 | 4,407 | 124,160 | 5540 | 4,805.3 | 143,968 |
| 5546.1 | 5,151 | 174,367 | 5550.0 | 5,363.0 | 194,870 | 5560 | 5,880.1 | 251,086 |
| 5560.4 | 5,904 | 253,442 | 5570 | 6,481.0 | 312,891 | 5571.9 | 6,606.2 | 325,324 |

47. REMARKS AND REFERENCES

- 1 Top of uncontrolled concrete spillway crest.
- 2 Bureau of Reclamation Project Data Book, 1981.
- 3 Calculated using mean annual runoff value of 718,116 AF, item 24, 8/64-6/00.
- 4 Computed annual inflows from 8/64 through 6/00.
- 5 Original recomputed surface area and capacity at el. 5,546.1. For sediment computation purposes the original area and capacity was recomputed by the Reclamation ACAP program using the original 5-foot increment surface areas.
- 6 Surface area & capacity at el. 5,546.1 computed by ACAP program.
- 7 Inflow values in acre-feet and maximum and minimum elevations in feet by water year from 8/64 through 6/00.
- 8 Computed sediment volume at elevation 5,546.1.
- 9 Storage losses at elevation 5,546.1.
- 10 Capacities computed by Reclamation's ACAP computer program.

48. AGENCY MAKING SURVEY Bureau of Reclamation

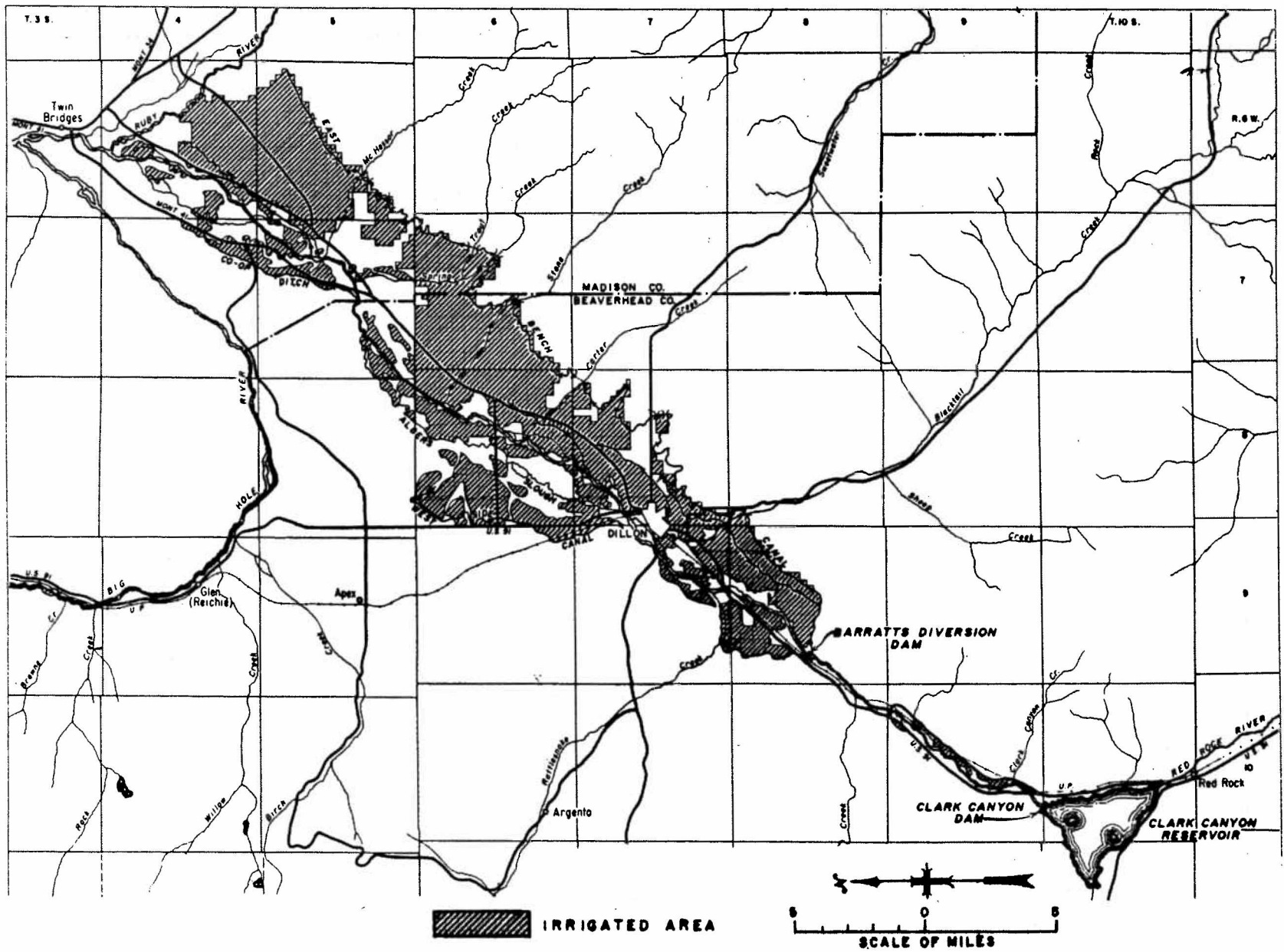
49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE March 2001

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

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|----------------------|---|-------------------------------------|---------------------------|-------------------------------|---|--------------------------------|----------------------------------|
| Elevations (feet) | Original Survey (acres) | Original Capacity (acre-feet) | 2000 Survey (acres) | 2000 Survey (acre-feet) | 2000 Sediment Volume (acre-feet) | 2000 Percent of Sediment | Percent of Reservoir Depth |
| 5,571.9 | 6606.2 | 329430 | 6606.2 | 325324 | | | 100.0 |
| 5,570.0 | 6481.0 | 316997 | 6481.0 | 312891 | | | 98.5 |
| 5,565.0 | 6181.0 | 285343 | 6181.0 | 281237 | | | 94.5 |
| 5,560.4 | 5904.0 | 257548 | 5904.0 | 253442 | | | 90.8 |
| 5,560.0 | 5880.1 | 255191 | 5880.1 | 251086 | | | 90.5 |
| 5,555.0 | 5622.0 | 226437 | 5622.0 | 222332 | | | 86.5 |
| 5,550.0 | 5363.0 | 198976 | 5363.0 | 194870 | | | 82.5 |
| 5,546.1 | 5151.0 | 178473 | 5151.0 | 174367 | 4106 | 100.0 | 79.4 |
| 5,542.0 | 4929.0 | 157808 | 4929.0 | 153702 | 4106 | 100.0 | 76.2 |
| 5,540.0 | 4805.3 | 148074 | 4805.3 | 143968 | 4106 | 100.0 | 74.6 |
| 5,535.7 | 4468.0 | 128136 | 4407.0 | 124160 | 3976 | 96.8 | 71.1 |
| 5,535.0 | 4413.0 | 125028 | 4343.0 | 121098 | 3930 | 95.7 | 70.6 |
| 5,530.0 | 4020.6 | 103944 | 3880.1 | 100541 | 3403 | 82.9 | 66.6 |
| 5,525.0 | 3513.0 | 85110 | 3399.6 | 82342 | 2768 | 67.4 | 62.6 |
| 5,520.0 | 3005.2 | 68815 | 2966.4 | 66427 | 2388 | 58.2 | 58.6 |
| 5,515.0 | 2578.0 | 54857 | 2508.5 | 52739 | 2118 | 51.6 | 54.6 |
| 5,510.0 | 2150.6 | 43036 | 2151.3 | 41090 | 1946 | 47.4 | 50.6 |
| 5,505.0 | 1845.0 | 33048 | 1824.4 | 31151 | 1897 | 46.2 | 46.7 |
| 5,500.0 | 1538.6 | 24590 | 1503.5 | 22831 | 1759 | 42.8 | 42.7 |
| 5,495.0 | 1238.0 | 17649 | 1207.5 | 16053 | 1596 | 38.9 | 38.7 |
| 5,490.0 | 937.1 | 12212 | 929.2 | 10712 | 1500 | 36.5 | 34.7 |
| 5,485.0 | 720.0 | 8069 | 661.8 | 6734 | 1335 | 32.5 | 30.7 |
| 5,480.0 | 503.0 | 5013 | 454.9 | 3942 | 1071 | 26.1 | 26.7 |
| 5,475.0 | 354.0 | 2871 | 284.8 | 2093 | 778 | 18.9 | 22.7 |
| 5,470.6 | 223.0 | 1601 | 184.0 | 1061 | 540 | 13.2 | 19.2 |
| 5,470.0 | 205.2 | 1473 | 170.6 | 955 | 518 | 12.6 | 18.7 |
| 5,465.0 | 125.0 | 648 | 82.9 | 321 | 327 | 8.0 | 14.8 |
| 5,460.0 | 44.7 | 224 | 21.4 | 60 | 164 | 4.0 | 10.8 |
| 5,455.0 | 22.0 | 56 | 1.2 | 4 | 52 | 1.3 | 6.8 |
| 5,450.0 | 1.0 | 1 | 0.0 | 0 | 1 | 0.0 | 2.8 |
| 5,449.0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 2.0 |
| 5,446.5 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0.0 |
| 1 | Elevation of reservoir water surface. | | | | | | |
| 2 | Original reservoir surface area. | | | | | | |
| 3 | Original reservoir capacity recomputed using ACAP. | | | | | | |
| 4 | Reservoir surface area from 2000 survey. Assume no change from elevation 5,540.0. | | | | | | |
| 5 | Reservoir capacity computed using ACAP using surface areas from column 4. | | | | | | |
| 6 | Measured sediment volume = column (3) - column (5). | | | | | | |
| 7 | Measured sediment expressed in percentage of total sediment 4,106. | | | | | | |
| 8 | Depth of reservoir expressed in percentage of total depth of 125.4 feet. | | | | | | |

Table 2. - Summary of 2000 survey results

Figure 1 - Clark Canyon Reservoir location map.



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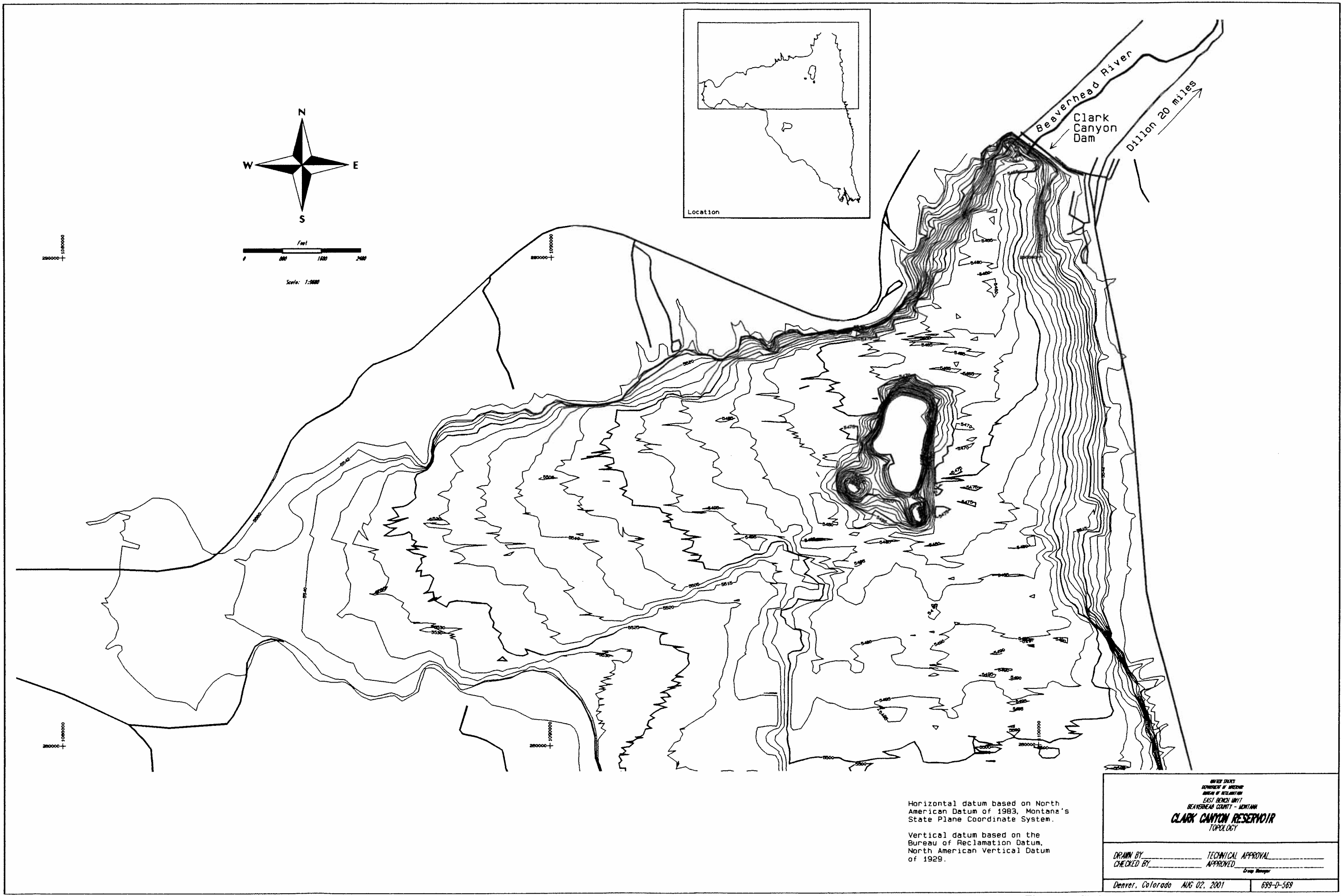
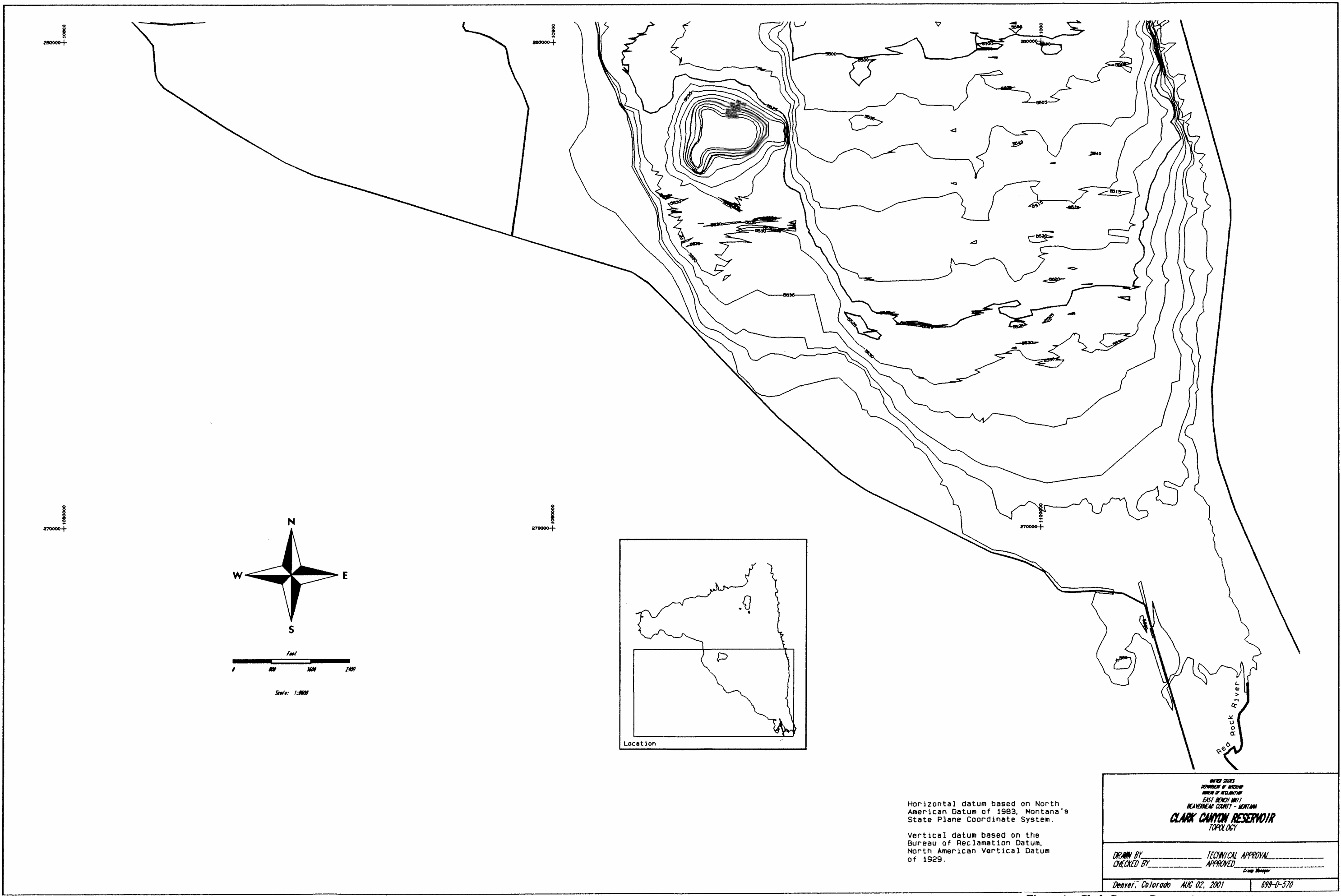


Figure 3. - Clark Canyon Reservoir topographic map, No. 699-D-569



Horizontal datum based on North American Datum of 1983, Montana's State Plane Coordinate System.

Vertical datum based on the Bureau of Reclamation Datum, North American Vertical Datum of 1929.

| | |
|---|---|
| <small>UNITED STATES DEPARTMENT OF AGRICULTURE BUREAU OF RECLAMATION EAST BENCH UNIT BEAVERHEAD COUNTY - MONTANA</small> CLARK CANYON RESERVOIR TOPOLOGY | |
| DRAWN BY _____ CHECKED BY _____ | TECHNICAL APPROVAL _____ APPROVED _____ <small>Chief Engineer</small> |
| Denver, Colorado AUG 02, 2001 | 699-D-570 |

Figure 4. - Clark Canyon Reservoir topographic map, No. 699-D-570

Area-Capacity Curves for Clark Canyon Reservoir

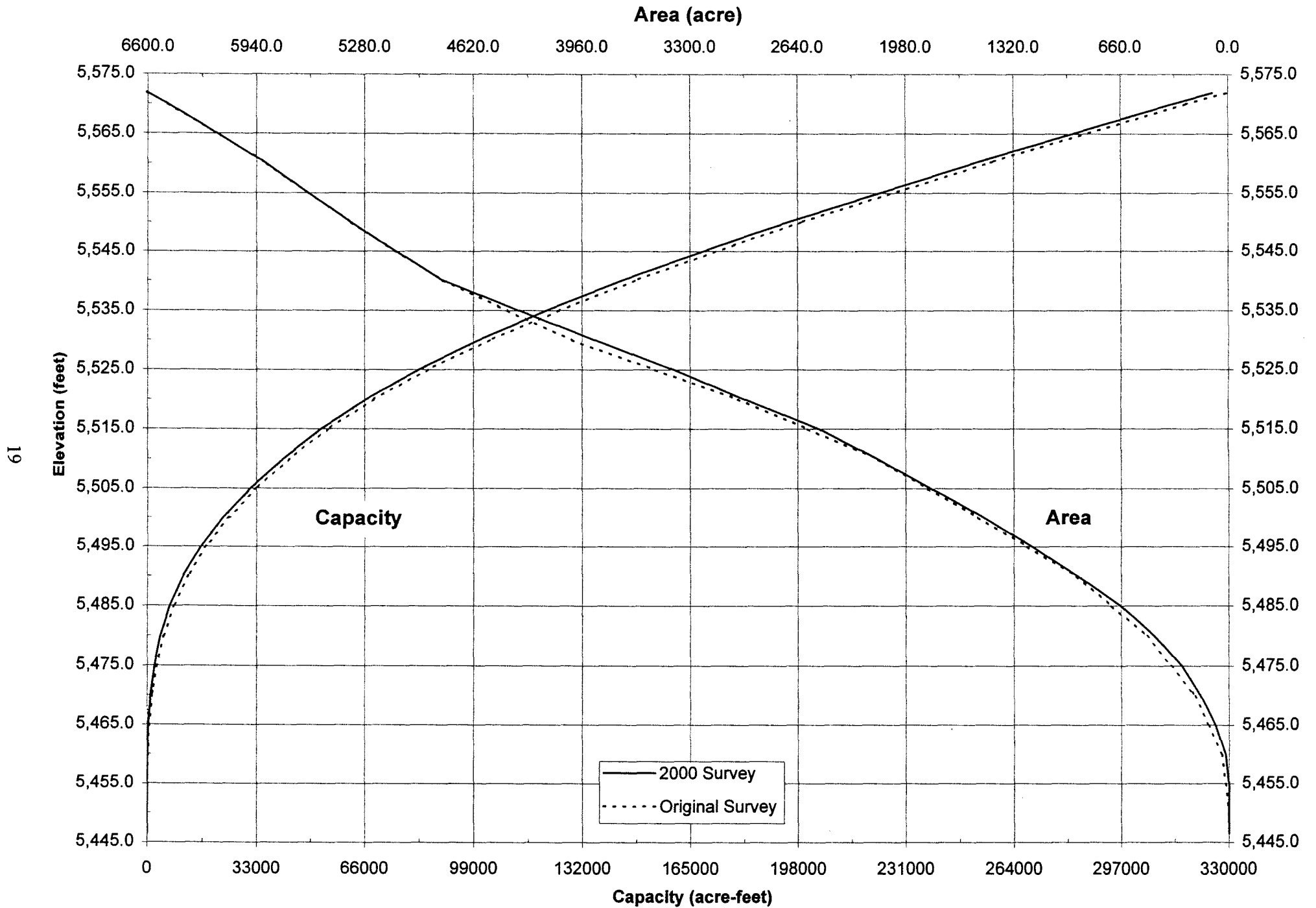


Figure 5. - 2000 area and capacity curves