# HUGH BUTLER LAKE

# 1997 SEDIMENTATION SURVEY

U.S. Department of the Interior
Bureau of Reclamation

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188



**1. AGENCY USE ONLY** ***(Leave Blank)***

**2. REPORT DATE**
August 1998

**3. REPORT TYPE AND DATES COVERED**
Final

**4. TITLE AND SUBTITLE**
Hugh Butler Lake
1997 Sedimentation Survey

**5. FUNDING NUMBERS**
PR

**6. AUTHOR(S)**
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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Bureau of Reclamation, Technical Service Center, Denver CO 80225-0007

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Bureau of Reclamation, Denver Federal Center, PO Box 25007,
Denver CO 80225-0007

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
DIBR

**11. SUPPLEMENTARY NOTES**
Hard copy available at Bureau of Reclamation Technical Service Center, Denver, Colorado

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Available from the National Technical Information Service,
Operations Division, 5285 Port Royal Road, Springfield VA 22161

**12b. DISTRIBUTION CODE**

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

The Bureau of Reclamation (Reclamation) surveyed the underwater area of Hugh Butler Lake behind Red Willow Dam in May 1997 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were also used to calculate reservoir capacity lost due to sediment accumulation since dam closure on September 5, 1961. 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. Reservoir topography was developed by a computer program using collected underwater data along with above-water topography determined by digitized contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps. The USGS quads of the reservoir area were developed from aerial photography obtained in 1965. The new topographic map of Hugh Butler Lake is a combination of digitized contours and 1997 underwater measured topography.

As of May 1997, at top of active conservation elevation (feet) 2,581.8, the surface area was 1,629 acres, the total capacity was 36,224 acre-feet, and the active capacity was 27,303 acre-feet. Since initial filling in September 1961, about 1,616 acre-feet of sediment have accumulated in Hugh Butler Lake below elevation 2,581.8, resulting in a 0.99 percent loss in total reservoir volume. Since 1961, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 45.3 acre-feet.

**14. SUBJECT TERMS**
reservoir area and capacity/ sedimentation/ reservoir surveys/ sonar/ sediment distribution/ contour area/ reservoir area/ sedimentation survey/ global positioning system

**15. NUMBER OF PAGES**
21

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UL | UL | UL | UL |

# HUGH BUTLER 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. Ronald Ferrari conducted the hydrographic survey. Mr. Jerry Nelson, the Great Plains Regional Superintendent at Hugh Butler Lake, deserves special thanks for field assistance during the hydrographic survey. Ronald Ferrari completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC completed the USGS contour digitizing and was consulted during the map development. 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 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.

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# INTRODUCTION

Red Willow Dam and Hugh Butler Lake are principal features of the Frenchman-Cambridge Division of the Pick-Sloan Missouri Basin Program. Additional storage features are Harry Strunk Lake, Enders Reservoir, and Swanson Lake. Red Willow Dam is located on Red Willow Creek in Frontier County in southwestern Nebraska approximately 10 miles north of McCook (fig. 1). Hugh Butler Lake provides storage for irrigation, downstream flood control, and recreation.

Red Willow Dam was constructed between June 1960 and September 1961 with first storage on September 5, 1961. The dam is a rolled earthfill structure with riprap on the upstream face, whose dimensions are (figs. 2 and 3):

| | | |
|---|---|---|
| • Hydraulic height[1] | 123 | feet |
| • Structural height | 126 | feet |
| • Top width | 30 | feet |
| • Crest length | 3,159 | feet |
| • Crest elevation | 2,634.0 | feet |

Red Willow Dam's spillway inlet, located in the right abutment, is a glory hole type structure with an ungated crest having a diameter of 31.5-feet. The crest elevation is 2,604.9[2] which is the top of the flood control pool. The discharge flow is directed through a 13.5-foot-diameter conduit that transitions at the downstream face into a flaring chute that directs the flow into a stilling basin. The discharge capacity is 4,910 cubic feet per second ($ft^3/s$) at maximum reservoir elevation 2,628.0 (Bureau of Reclamation 1981).

The outlet is through the right side of dam, left of the spillway, with a sill elevation of 2,552.0. It consists of a trashracked intake structure, 5- by 6-foot high-pressure emergency gate, an 82-inch-diameter steel pipe accommodated by an 11.5-foot downstream conduit, a control house with two 3.5-foot square high-pressure regulating gates, a stilling basin, and an outlet channel. The outlet works has the same outflow channel as the spillway. The discharge capacity, at reservoir elevation 2,604.9, is 1,170 $ft^3/s$.

Hugh Butler Lake stores water from Red Willow and Spring Creeks with a drainage area above the dam of 730 square miles, ranging from elevation 2,558.0, top of inactive pool, to greater than elevation 3,205 at its headwaters. The reservoir length, at elevation 2,604.9, is around 12 miles that includes 7 miles of the Red Willow Arm and 5 miles of the Spring Creek Arm. The reservoir's average width is 0.35 mile.

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[1]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.

[2]Elevation levels are shown in feet.

## SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1997 results of the first extensive survey of Hugh Butler Lake. The primary objective of the survey was to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since Red Willow 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 Hugh Butler 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 1997 underwater surface areas at predetermined contour intervals were generated by a computer graphics program using the underwater collected data. The above-water reservoir contours were digitized from U.S. Geological Survey 7.5-minute quadrangle (USGS quad) maps of Hugh Butler Lake. The new topographic map of Hugh Butler Lake 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 1997 area and capacity tables were generated using the 1997 measured areas at elevation 2,576.0 and less and the original measured areas for elevation 2,580.0 and greater.

Table 1 contains a summary of Hugh Butler Lake's watershed characteristics for the 1997 survey. The 1997 survey determined that the reservoir has a storage capacity of 36,224 acre-feet and a surface area of 1,629 acres at reservoir elevation 2,581.8. Since closure in 1961, the reservoir has accumulated a sediment volume of 1,616 acre-feet below reservoir elevation 2,581.8. This volume represents a 0.99 percent loss in total capacity at elevation 2,628.0 and an average annual loss of 45.3 acre-feet.

## RESERVOIR OPERATIONS

Hugh Butler Lake is primarily an irrigation and flood protection facility (the following values are from May 1997 area-capacity tables):

- 76,829 acre-feet of surcharge storage between elevations 2,604.9 and 2,628.0.
- 48,846 acre-feet of flood control between elevations 2,581.8 and 2,604.9.
- 27,303 acre-feet of active conservation storage between elevations 2,558.0 and 2,581.8.
- 3,736 acre-feet of inactive storage between elevations 2,552.0 and 2,558.0.
- 5,185 acre-feet of dead storage below elevation 2,552.0.

The Hugh Butler Lake inflow and end-of-month stage records in table 1 show the annual (January through December) inflow and fluctuation for the operation period September 1961 through May 1997. The average annual reservoir inflow for this operation period was 19,838 acre-feet. The records show the annual elevation fluctuation of the reservoir water surface with the maximum elevation of 2,583.0 occurring May 1973 and the minimum, since normal operation of the reservoir began, being elevation 2,565.4 occurring September 1978.

## 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 Hugh Butler 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, Hugh Butler Lake's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel. During the Hugh Butler 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 Hugh Butler 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 Hugh Butler 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 Hugh Butler 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 an 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 of collecting the data in 1927 or 1983 North American Datums (NAD) in the surveyed area's state plane coordinate system's zone. For Hugh Butler Lake, the data were collected in the Nebraska's 1927 NAD south state plane zone.

**Survey Method and Equipment**

The Hugh Butler Lake hydrographic survey was conducted from May 19 through May 21, 1997 at reservoir water surface elevation 2,582.4. 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 north-south direction. Data were also collected along the shore as the boat traversed to the next transect and as it maneuvered in the open areas between the vegetation. Figure 4 illustrates the reservoir area covered by the 1997 underwater survey versus the elevation 2,582.0 contour digitized from the USGS quad maps. 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 22,536 data points. 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 there were no known benchmarks or datums that overlooked the reservoir that had the needed control information. For the underwater collection, the hydrographic survey crew established a datum at a USBR unmarked brass cap 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. This method calculated Nebraska's 1927 NAD south state plane coordinates of North 252,421.9 and East 1,669,757.1 at this location. The shore-based master GPS unit, which transmits the correction information to the mobile GPS unit on the survey vessel, was stationed at this new datum site throughout the survey. This location was chosen because it was 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. During postprocessing 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 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 Hugh Butler Lake was developed from the 1997 collected underwater data and from the USGS quad maps. The upper contours of Hugh Butler Lake were developed by digitizing the contour lines of elevation 2,582.0 and 2,605.0, from the USGS quad maps that covered the Hugh Butler Lake area. The USGS quad maps were developed from aerial photography dated 1965. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Nebraska's NAD 1927 south state plane coordinates using the ARC/INFO PROJECT command.

The elevation 2,582.0 contour digitized from USGS quad maps was used to perform a clip of the Hugh Butler Lake triangular irregular network (TIN) such that interpolation was not allowed to occur outside the 2,582.0 contour. This complete contour was selected since it was the elevation that most nearly enclosed the 1997 underwater data collected at reservoir elevation 2,582.4. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and the digitized 2,582.0 contour from the USGS quad maps were plotted (fig. 4). The plot found that the majority of the underwater data occurred completely within the elevation 2,582.0 clip, but required adjustments to enclose all collected data along the shorelines.

The original 2,582.0 digitized contour from the USGS quad maps had a measured surface area of 1,642 acres which compared well with the original reservoir surface area of 1,637 acres at the same elevation. As illustrated on figure 4 there are shoreline areas on both the north and south sides of the main body of the reservoir that required adjusting to enclose the underwater collected area. There were existing small coves and land points that extended into the reservoir in 1965 that no longer exist since the survey boat in 1997 was able to pass over these digitized shorelines. A portion of this condition was caused by the scale of the digitized contours, 1 in = 2,000 ft, but it is assumed that the majority of this condition was due to shoreline erosion that has occurred since the aerial collection in 1965. The 2,582 clip was further adjusted in the very upstream portion of the reservoir where both the Red Willow and Spring Creeks enter the reservoir. This was accomplished by projecting where it would occur using the 1997 developed underwater contours. The resulting surface area of this enclosed clip was around the original area for the same elevation.

Contours for elevations 2,576.0 and below were computed from the developed underwater data using the 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, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great detail in the ARC/INFO V7.0.2 *ARC Command References* (ESRI 1992)

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Hugh Butler Lake TIN from elevation 2,576.0 and below. 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 Hugh Butler Lake. The contour topography at 5-foot intervals is presented on figure 5, drawing number 328-D-2340.

## Development of 1997 Contour Areas

The 1997 contour surface areas for Hugh Butler Lake were computed at 2-foot increments, from elevations 2,528.0 to 2,576.0, using the Hugh Butler Lake TIN discussed above. The 1997 survey measured the minimum reservoir bottom elevation at 2,526.1 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. Due to the draft of the survey boat, the 1997 collected survey data were limited above elevation 2,576 causing the final 1997 area computations to assume no change in surface area from elevation 2,580.0 and above.

## 1997 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation 1985). Surface areas at 2-foot contour intervals from minimum reservoir elevation 2,526.1 to elevation 2,576.0 and the original surface areas at 5-foot contour intervals from elevations 2,580.0 to 2,635.0 were used as the control parameters for computing Hugh Butler Lake's 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. The error limit was set at 0.000001 for Hugh Butler 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 Hugh Butler 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. 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 ACAP program is included with these tables. Both the original and 1997 area-capacity curves are plotted on figure 6. As of May 1997, at elevation 2,581.8, the surface area was 1,629.0 acres with a total capacity of 36,224 acre-feet and an active capacity of 27,303 acre-feet.

## SEDIMENT ANALYSES

Sediments have accumulated in Hugh Butler Lake to a total volume of 1,616 acre-feet since dam closure in September 1961. This volume was calculated at reservoir water surface elevation 2,581.8. It must be noted that the 1997 underwater survey was conducted at water surface elevation 2,582.4, and the final product relied on the original measured surface areas at elevation 2,580.0 and greater for computing the 1997 reservoir area and capacity tables. Column 6 of table 2 gives the measured sediment volume by elevation, and the area curve on figure 6 illustrates the resulting measured surface areas and calculated capacities. The table and figure illustrate that the majority of the sediment deposited in the lower elevations of the reservoir with 97.4 percent accumulating below the inactive elevation of 2,558.0. The average annual rate of sediment deposition between closure and May 1997 (35.7 years) was 45.3 acre-feet per year. The storage loss in terms of percent of original storage capacity below elevation 2,628.0 was 0.99 percent and below elevation 2,581.8 was 4.27 percent. Tables 1 and 2 contain the Hugh Butler Lake sediment accumulation and water storage data based on the 1997 resurvey.

The 1997 study determined that significant shoreline erosion has occurred as discussed in the topography development section. This is illustrated on figure 4 where the 1997 underwater collected data crossed over the USGS digitized 2,582 contour. The area curves on figure 6 illustrates that the bank erosion affect was between elevations 2,570 and 2,580. The only means to measure the extent of this erosion would be to conduct an above-water survey. For this study it was assumed that there was no surface area change at elevation 2,580 and above. This assumption was made due to the lack of 1997 collected data above elevation 2,576. The bank erosion does not affect the overall area-capacity of the reservoir, but redistributes the elevation zones where the reservoir volumes exist.

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RESERVOIR SEDIMENT
DATA SUMMARY

Hugh Butler Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

| | | | |
|---|---|---|---|
| DAM | 1. OWNER Bureau of Reclamation | 2. STREAM Red Willow Creek | 3. STATE Nebraska |
| | 4. SEC. 31 TWP. 5N RANGE 29W | 5. NEAREST P.O. McCook | 6. COUNTY Frontier |
| | 7. LAT 40° 21' 35" LONG 100° 39' 55" | 8. TOP OF DAM ELEVATION 2,634.0 | 9. SPILLWAY CREST EL. 2,604.9[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 | 2,628.0 | 4,084 | 76,790 | 163,420 | |
| | b. FLOOD CONTROL | 2,604.9 | 2,682 | 48,850 | 86,630 | 9/5/61 |
| | c. POWER | | | | | |
| | d. WATER SUPPLY | 2,581.8 | 1,629 | 27,330 | 37,776 | 16. DATE NORMAL OPERATION BEGAN |
| | e. IRRIGATION | | | | | |
| | f. INACTIVE | 2,558.0 | 787 | 4,140 | 10,450 | |
| | g. DEAD | 2,552.0 | 596 | 6,310 | 6,310 | 9/61 |
| | 17. LENGTH OF RESERVOIR 12[2] MILES | | | AVG. WIDTH OF RESERVOIR 0.35 MILES | | |

| | | | |
|---|---|---|---|
| BASIN | 18. TOTAL DRAINAGE AREA 730 SQUARE MILES | | 22. MEAN ANNUAL PRECIPITATION 20[3] INCHES |
| | 19. NET SEDIMENT CONTRIBUTING AREA 730 SQUARE MILES | | 23. MEAN ANNUAL RUNOFF 0.57[4] INCHES |
| | 20. LENGTH MILES | AV. WIDTH MILES | 24. MEAN ANNUAL RUNOFF 19,838[5] ACRE-FEET |
| | 21. MAX. ELEVATION 3205 | MIN. ELEVATION 2558.0 | 25. ANNUAL TEMP. MEAN 52°F RANGE -22°F to 110°F[6] |

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 |
|---|---|---|---|---|---|---|---|
| 09/61 | | | Contour (D) | 5-ft | 4,079[6] | 163,515[6] | 8.24 |
| 5/97 | 35.7 | 35.7 | Contour (D) | 2-ft | 4,079[7] | 161,899[7] | 8.16 |

| 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 |
| 5/97 | 20[3] | 19,838[5] | 30,100 | 708,200 | 19,838 | 708,200 |

| 26. DATE OF SURVEY | 37. PERIOD CAPACITY LOSS, ACRE-FEET | | | 38. TOTAL SEDIMENT DEPOSITS TO DATE, AF | | |
|---|---|---|---|---|---|---|
| | a. TOTAL | b. AV. ANN. | c. /MI.$^2$-YR. | a. TOTAL | b. AV. ANNUAL | c. /MI.$^2$-YR. |
| 5/97 | 1,616[8] | 45.3 | .06 | 1,616 | 45.3 | .06 |

| 26. DATE OF SURVEY | 39. AV. DRY WT. (#/FT$^3$) | 40. SED. DEP. TONS/MI.$^2$-YR. | | 41. STORAGE LOSS, PCT. | | 42. SEDIMENT INFLOW, PPM | |
|---|---|---|---|---|---|---|---|
| | | a. PERIOD | b. TOTAL TO DATE | a. AV. ANNUAL | b. TOTAL TO DATE | a. PER. | b. TOT. |
| 5/97 | | | | .0277[9] | .988[9] | | |

| 26. DATE OF SURVEY | 43. DEPTH DESIGNATION RANGE BETWEEN INDICATED ELEVATIONS. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2511-2520 | 2520-2530 | 2530-2535 | 2535-2540 | 2540-2545 | 2545-2550 | 2550-2552 | 2552-2558 | 2558-2581.8 | | |
| | PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION | | | | | | | | | | |
| 5/97 | | 1.2 | 8.8 | 15.2 | 11.6 | 13.4 | 15.3 | 7.3 | 24.6 | 2.6 | | |

| 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 2 of 2).

45. RANGE IN RESERVOIR OPERATION[10]

| YEAR | MAX. ELEV. | MIN. ELEV. | INFLOW, AF | YEAR | MAX. ELEV. | MIN. ELEV. | INFLOW, AF |
|---|---|---|---|---|---|---|---|
| 1961 | | | 1,400[10] | 1962 | 2,570.6 | 2,550.5 | 24,300 |
| 1963 | 2,574.3 | 2,570.3 | 16,100 | 1964 | 2,578.0 | 2,572.2 | 15,600 |
| 1965 | 2,578.4 | 2,574.1 | 22,100 | 1966 | 2,581.4 | 2,578.4 | 19,100 |
| 1967 | 2,582.3 | 2,580.4 | 30,100 | 1968 | 2,582.6 | 2,576.6 | 21,700 |
| 1969 | 2,582.9 | 2,579.0 | 28,600 | 1970 | 2,582.0 | 2,576.0 | 17,900 |
| 1971 | 2,582.0 | 2,574.9 | 22,100 | 1972 | 2,581.3 | 2,575.6 | 23,200 |
| 1973 | 2,583.0 | 2,575.0 | 27,800 | 1974 | 2,582.4 | 2,574.3 | 20,800 |
| 1975 | 2,582.2 | 2,574.8 | 24,300 | 1976 | 2,581.1 | 2,571.5 | 18,600 |
| 1977 | 2,580.4 | 2,574.1 | 21,700 | 1978 | 2,581.7 | 2,565.4 | 22,900 |
| 1979 | 2,575.4 | 2,569.4 | 21,300 | 1980 | 2,578.3 | 2,568.3 | 18,200 |
| 1981 | 2,575.9 | 2,570.9 | 19,200 | 1982 | 2,579.0 | 2,573.3 | 16,700 |
| 1983 | 2,581.6 | 2,573.6 | 19,100 | 1984 | 2,581.4 | 2,574.8 | 20,400 |
| 1985 | 2,580.6 | 2,573.6 | 16,500 | 1986 | 2,578.8 | 2,571.9 | 16,000 |
| 1987 | 2,578.1 | 2,571.4 | 16,900 | 1988 | 2,578.2 | 2,573.4 | 18,800 |
| 1989 | 2,577.5 | 2,572.8 | 16,900 | 1990 | 2,577.5 | 2,568.3 | 14,100 |
| 1991 | 2,575.0 | 2,567.5 | 16,200 | 1992 | 2,573.6 | 2,570.7 | 17,600 |
| 1993 | 2,581.4 | 2,574.2 | 24,300 | 1994 | 2,582.8 | 2,577.3 | 16,000 |
| 1995 | 2,582.6 | 2,576.6 | 16,800 | 1996 | 2,581.3 | 2,577.9 | 18,900 |
| 1997 | 2,582.5 | 2,581.0 | 6,000[10] | | | | |

46. ELEVATION - AREA - CAPACITY DATA FOR 1997 **CAPACITY**[11]

| ELEVATION | AREA | CAPACITY | ELEVATION | AREA | CAPACITY | ELEVATION | AREA | CAPACITY |
|---|---|---|---|---|---|---|---|---|
| 2526.1 | 0 | 0 | 2528 | 1.0 | 1 | 2530 | 2.5 | 5 |
| 2532 | 6.0 | 13 | 2533 | 43.3 | 38 | 2534 | 65.2 | 92 |
| 2536 | 101.8 | 259 | 2538 | 139.9 | 501 | 2540 | 188.2 | 829 |
| 2542 | 245.1 | 1,262 | 2544 | 295.3 | 1,802 | 2546 | 367.4 | 2,465 |
| 2548 | 428.2 | 3,261 | 2550 | 479.8 | 4,169 | 2552 | 536.2 | 5,185 |
| 2554 | 594.6 | 6,316 | 2556 | 648.1 | 7,558 | 2558 | 715.0 | 8,921 |
| 2560 | 780.0 | 10,416 | 2562 | 844.3 | 12,041 | 2564 | 912.9 | 13,798 |
| 2566 | 974.0 | 15,685 | 2568 | 1,055.4 | 17,714 | 2570 | 1,131.1 | 19,901 |
| 2572 | 1,210.8 | 22,243 | 2574 | 1,303.9 | 24,757 | 2576 | 1,398.2 | 27,459 |
| 2580 | 1,555 | 33,366 | 2581.8 | 1,621 | 36,224 | 2585 | 1,738 | 41,598 |
| 2590 | 1,948 | 50,813 | 2595 | 2,144 | 61,043 | 2600 | 2,444 | 72,513 |
| 2604.9 | 2,681 | 85,070 | 2605 | 2,686 | 85,338 | 2610 | 2,928 | 99,373 |
| 2615 | 3,211 | 114,721 | 2620 | 3,501 | 131,501 | 2625 | 3,882 | 149,958 |
| 2628 | 4,079 | 161,899 | | | | | | |

47. REMARKS AND REFERENCES

1 Spillway inlet structure is glory hole type with ungated crest.

2 Total of 12 miles at elevation 2605, includes 7 miles Red Willow Arm & 5 miles Spring Creek Arm.

3 Bureau of Reclamation Project Data Book, 1981.

4 Calculated using mean annual runoff value of 19,838 AF, item 24.

5 Computed annual inflows from 9/61 through 5/97 by calendar year.

6 Original surface area and capacity at elevation 2,628.0. Original capacity recomputed by Reclamation's ACAP program using original surface areas.

7 Surface area and capacity at elevation 2,628.0 computed by ACAP program using 1997 and original surface areas. 1997 surveyed only underwater portion of reservoir below elevation 2,580.0. Elevation 2,580.0 and above from original measured areas.

8 Computed sediment volume at reservoir elevation 2,581.8.

9 Capacity loss by comparing original recomputed capacity and 1997 capacity at reservoir elevation 2,628.0.

10 Maximum and minimum elevations and inflow values in acre-feet by calendar year, from 9/61 through 5/97.

11 Capacities computed by ACAP computer program. Areas at elevation 2,580.0 and above from original survey.

48. AGENCY MAKING SURVEY Bureau of Reclamation

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

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

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Elevation (feet) | Original Area (acres) | Original Capacity (acre-feet) | 1997 Area (acres) | 1997 Capacity (acre-feet) | Computed Sediment Volume (acre-feet) | Percent of Computed Sediment | Percent of Reservoir Depth |
| 2634.0 | 4508 | 189239 | 4508 | 187623 | | | 100.0 |
| 2630.0 | 4210 | 171804 | 4210 | 170188 | | | 96.7 |
| 2628.0 | 4079 | 163515 | 4079 | 161899 | | | 95.1 |
| 2625.0 | 3882 | 151574 | 3882 | 149958 | | | 92.7 |
| 2620.0 | 3501 | 133117 | 3501 | 131501 | | | 88.6 |
| 2615.0 | 3211 | 116337 | 3211 | 114721 | | | 84.6 |
| 2610.0 | 2928 | 100989 | 2928 | 99373 | | | 80.5 |
| 2605.0 | 2686 | 86954 | 2686 | 85338 | | | 76.4 |
| 2604.9 | 2681 | 86686 | 2681 | 85070 | | | 76.3 |
| 2600.0 | 2444 | 74129 | 2444 | 72513 | | | 72.4 |
| 2595.0 | 2144 | 62659 | 2144 | 61043 | | | 68.3 |
| 2590.0 | 1948 | 52429 | 1948 | 50813 | | | 64.2 |
| 2585.0 | 1738 | 43214 | 1738 | 41598 | | | 60.2 |
| 2581.8 | 1629 | 37840 | 1629 | 36224 | 1616 | 100.0 | 57.6 |
| 2580.0 | 1555 | 34982 | 1555 | 33366 | 1616 | 100.0 | 56.1 |
| 2575.0 | 1291 | 27867 | 1351 | 26085 | 1782 | 110.3 | 52.0 |
| 2570.0 | 1115 | 21852 | 1131 | 19901 | 1951 | 120.7 | 48.0 |
| 2565.0 | 961 | 16662 | 943 | 14726 | 1936 | 119.8 | 43.9 |
| 2560.0 | 851 | 12132 | 780 | 10416 | 1716 | 106.2 | 39.8 |
| 2558.0 | 785 | 10495 | 715 | 8921 | 1574 | 97.4 | 38.2 |
| 2555.0 | 687 | 8287 | 621 | 6923 | 1364 | 84.4 | 35.8 |
| 2552.0 | 597 | 6361 | 536 | 5185 | 1176 | 72.8 | 33.3 |
| 2550.0 | 537 | 5227 | 480 | 4169 | 1058 | 65.5 | 31.7 |
| 2545.0 | 383 | 2927 | 331 | 2116 | 811 | 50.2 | 27.6 |
| 2540.0 | 218 | 1424 | 188 | 829 | 595 | 36.8 | 23.6 |
| 2535.0 | 122 | 574 | 84 | 166 | 408 | 25.2 | 19.5 |
| 2530.0 | 41 | 167 | 3 | 5 | 162 | 10.0 | 15.4 |
| 2526.0 | 14 | 57 | 0 | 0 | 57 | 3.5 | 12.2 |
| 2525.0 | 7 | 47 | 0 | 0 | 47 | 2.9 | 11.4 |
| 2520.0 | 4 | 19 | 0 | 0 | 19 | 1.2 | 7.3 |
| 2515.0 | 2 | 4 | 0 | 0 | 4 | 0.2 | 3.3 |
| 2511.0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 |

1 Elevation of reservoir water surface.
2 Original reservoir surface area.
3 Original calculated reservoir capacity computed using ACAP.
4 Reservoir surface area from 1997 survey for elevations 2576 and below. Areas for elevation 2580 and greater are original measured areas.
5 1997 calculated reservoir capacity computed using ACAP from 1997 surface areas.
6 Measured sediment volume = column (3) - column (5).
7 Measured sediment expressed in percentage of total sediment 1616 acre-feet at elevation 2581.8.
8 Depth of reservoir expressed in percentage of total depth (123.0 feet).

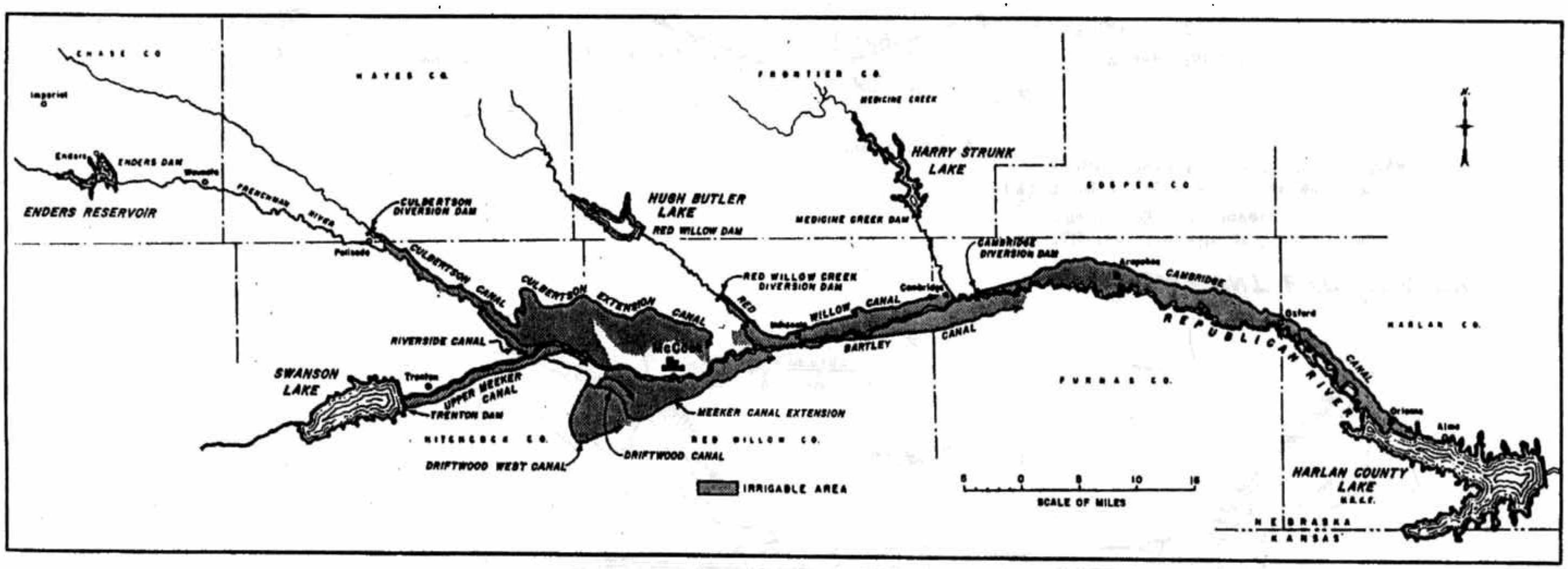


Figure 1. - Hugh Butler Lake location map.

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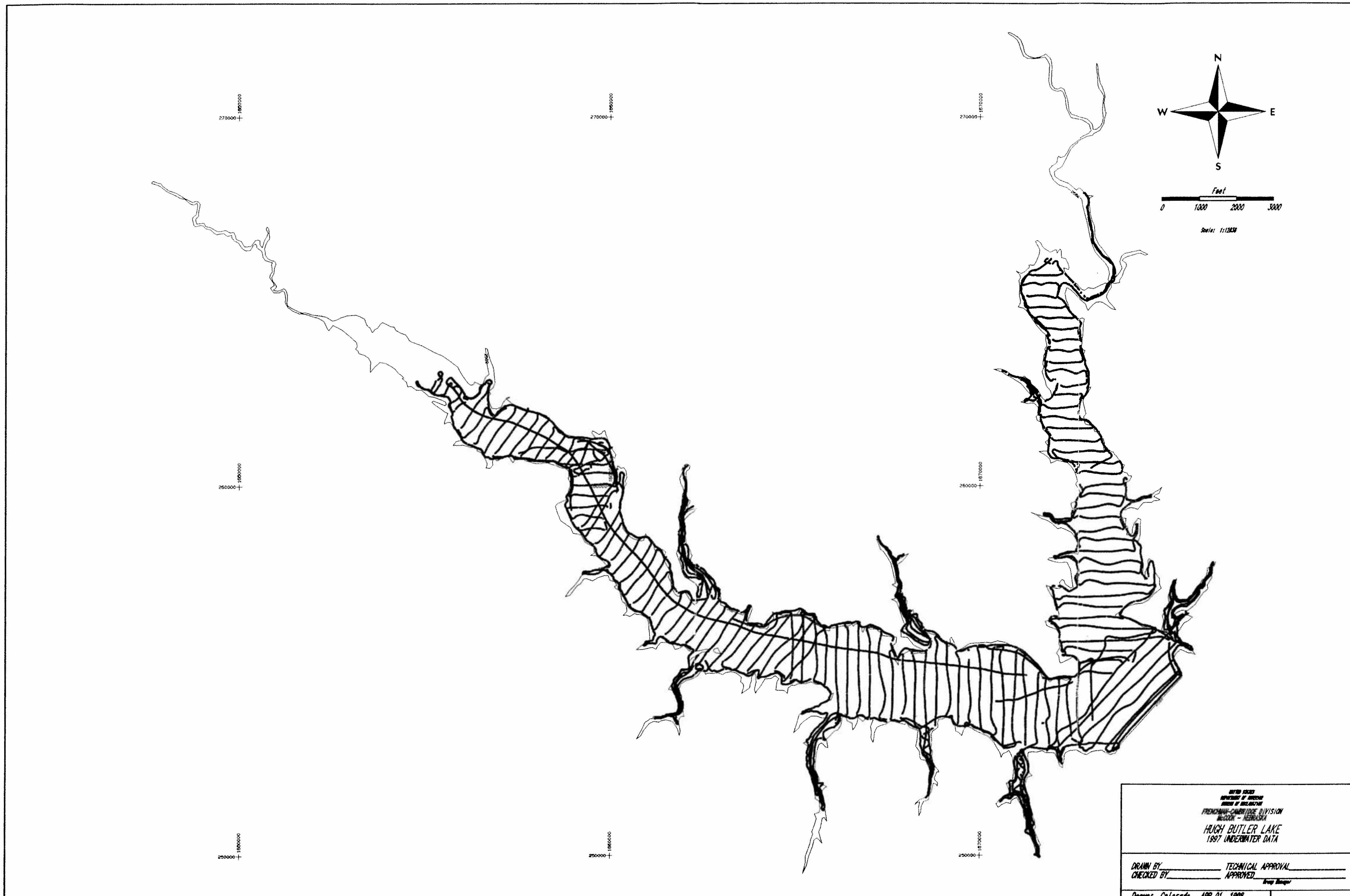


Figure 4. - Hugh Butler Lake 1997 underwater data.

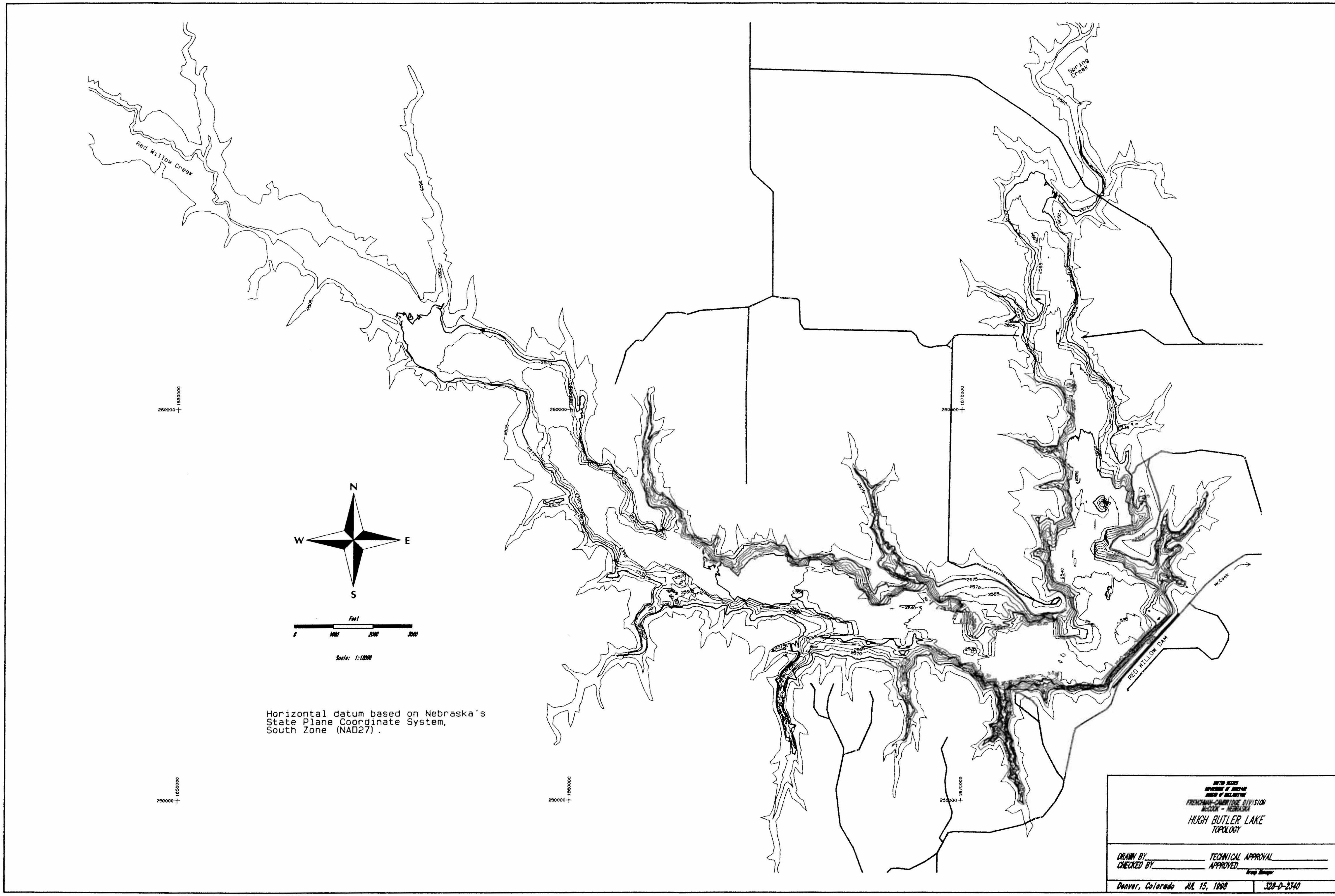


Figure 5. - Hugh Butler Lake topography.

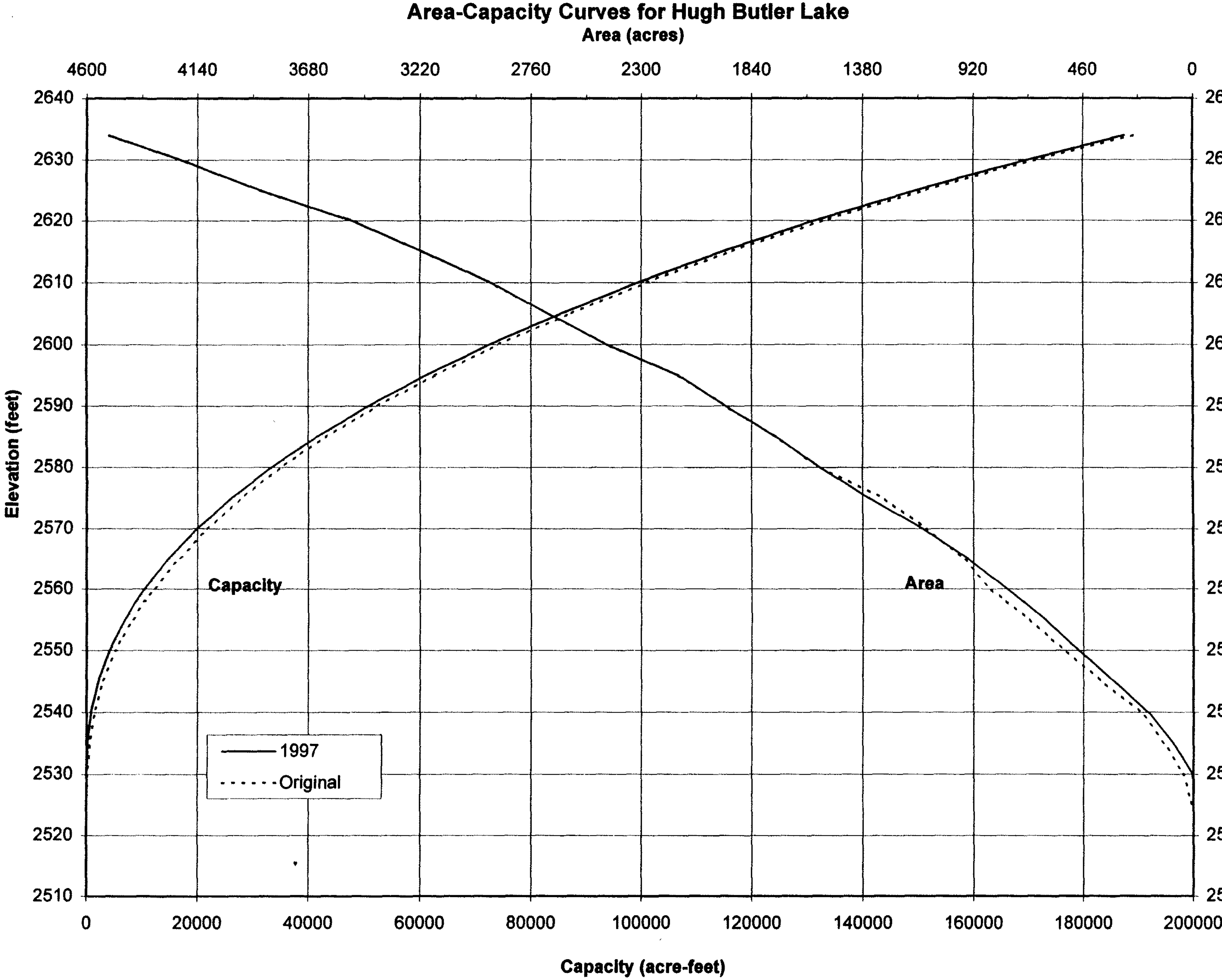


Figure 6. - 1997 area and capacity curves.

## 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.