SHADEHILL RESERVOIR
1993 SEDIMENTATION SURVEY

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

The Bureau of Reclamation surveyed the underwater area of Shadehill Reservoir in July 1993 to compile field data for developing a reservoir topographic map and computing a present storage-elevation relationship. The data were also used to calculate volume of reservoir capacity lost since dam closure in July 1950. The volume lost is attributed to sediment accumulation and significant reservoir shoreline erosion. The 1993 bathymetric survey used sonic depth recording equipment interfaced with an automated microwave positioning system that gave continuous depth and sounding positions throughout the reservoir. The underwater topography was developed by a computer graphics program using collected data. The above-water reservoir area was measured from USGS (U.S. Geological Survey) topography maps developed from aerial photography obtained in 1978. The new reservoir contour map and surface areas are a combination of 1993 underwater data and 1978 USGS aerial topography.

As of July 1993, at reservoir spillway crest elevation 2272.0 (feet), the surface area was 5019.0 acres with a total capacity of 120,172 acre-feet. Since initial filling in July 1950, an estimated 15,241 acre-feet of Shadehill Reservoir capacity have been lost below elevation 2272.0, resulting in an 11.2-percent loss in reservoir volume. Since 1950, the average annual rate of reservoir capacity lost below elevation 2272.0 is 354.4 acre-feet.

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SHADEHILL RESERVOIR

1993 SEDIMENTATION SURVEY

by

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Denver, Colorado

September 1995

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The Bureau of Reclamation (Reclamation) prepared and published this report under the supervision of the Sedimentation and River Hydraulics Group. The reservoir survey is part of the Shadehill Lake Protection Project, which is under the direction of Bob Drown, SCS (Soils Conservation Service) Project Coordinator. The reservoir survey was performed under the direction of J. Craig Kjar, Chief, O&M Division of Reclamation's Newell Office of the Great Plains Region. Ronald Ferrari of the TSC (Technical Service Center) conducted the hydrographic survey. Personnel from the Newell Office performed the required land survey and assisted during the hydrographic data collection. Special thanks to John Strachan, Douglas Bandy, and Robert Reedy, who performed the land survey; and Walt Zell, Dave Lucas, and Curt Anderson, who assisted during the hydrographic data collection. Personnel from SCS participated during the hydrographic data collection and surveyed several sediment range lines located in the upper end of the reservoir area. Special thanks to Tom VerHelst, Cindy Steele, Carol Reed, Michelle Lauritzen, and Sharon Huber for their field assistance. Ronald Ferrari completed the data processing and generated the new reservoir topographic map and area-capacity tables. James Melena of the TSC performed the peer review of the study.

U.S. Department of the Interior
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INTRODUCTION

Shadehill Dam and Reservoir, major features of the Pick-Sloan Missouri Basin Program, are located on the Grand River in northwestern South Dakota. The dam, located in Perkins County, South Dakota, is 12 miles south of Lemmon, South Dakota, and immediately downstream from the confluence of the North and South Fork of the Grand River (fig. 1).

The Shadehill Unit investigations began in 1931. The Corps of Engineers conducted a topographic survey of a reservoir site immediately downstream from the confluence of the North and South Forks of the Grand River. Reclamation followed with a reconnaissance survey in 1938-39 to determine the quality of available water. The Shadehill Unit was authorized by the United States 78th Congress with the Flood Control Act of December 22, 1944. Detailed studies of the dam and reservoir were conducted from 1945 through 1948. Construction of Shadehill Dam and Reservoir began April 19, 1949 and was completed August 15, 1951.

Closure of the dam and first reservoir storage began on July 1, 1950. At elevation 2772.0 (feet), the reservoir extends around 10.2 miles up the South Fork and 8.0 miles up the North Fork of the Grand River. The reservoir has an average width of 0.42 mile.

Shadehill Dam and two dikes that form the reservoir are modified, homogeneous, rolled earthfill structures. The two dikes, located in saddles south of the right abutment, have structural heights of 83 and 18 feet and respective crest lengths of 1,090 and 264 feet. Shadehill Dam (figs. 2 and 3), at a crest elevation of 2318.0, has:

- a structural height* of 145 feet
- a hydraulic height of 102 feet
- a top crest width of 30 feet
- a crest length of 12,843 feet

Shadehill Dam has two spillways. The service spillway has a crest elevation of 2272.0 with a maximum capacity of 5,700 cubic feet per second at reservoir water surface elevation 2312.0. The service spillway is located near the left abutment of the dam and consists of:

- an uncontrolled morning-glory type inlet structure
- a 13.5-foot-diameter reinforced concrete conduit
- a chute
- a common stilling basin with the outlet works
- a downstream channel

The emergency spillway, located immediately upstream from the left abutment, consists of an open-cut, unlined channel with a bottom width of 1,500 feet and an earthen crest at elevation 2302.0. The maximum discharge capacity is 127,000 cubic feet per second at reservoir elevation 2312.0. The discharge flows downstream from the dam into Flat Creek, a tributary of the Grand River.

* The definition of terms such as "structural height," "hydraulic 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*.

The river outlet works is located adjacent to the left side of the service spillway and consists of:

- three steel 10-foot-square intake trashracks
- 84-inch-diameter steel-lined upstream pressure conduit
- hoist house and access shaft
- a gate chamber housing a 6-foot-square emergency slide gate and a 6-foot-square top seal radial gate to regulate flows
- a 7.25-foot horseshoe-shaped discharge conduit leading to a stilling basin
- a 6-foot-diameter steel pipe
- a common stilling basin with the service spillway

The rated discharge capacity of the outlet works is 600 cubic feet per second at reservoir elevation 2272.0. No releases are made from the outlet works above elevation 2274.0 because of restrictions on maximum flow when the reservoir is using the service spillway.

Shadehill Reservoir is a multi-purpose reservoir with primarily a flood control function. The original calculated total capacity at reservoir elevation 2302.0 was 357,382 acre-feet, of which 217,708 acre-feet was exclusive flood control, 81,443 acre-feet was conservation space, and 58,231 acre-feet was dead storage. An additional 111,203 acre-feet of surcharge storage capacity exists between the emergency spillway crest elevation 2302.0 and the design maximum water surface of 2312.0. The original reservoir survey measured a total storage capacity of 139,674 acre-feet and a surface area of 4,868 acres at reservoir spillway crest elevation 2272.0.

The Bureau of Reclamation (Reclamation) operates Shadehill Dam and Reservoir. The Corps of Engineers reservoir regulations for flood control have been canceled. Reclamation administers the flood control component of the project. Because the reservoir is on a tributary of the Missouri River, the Corps of Engineers is notified of flood control decisions at the reservoir. Recreation areas and lands around the reservoir are administered by the South Dakota Department of Game, Fish, and Parks under an agreement with Reclamation.

SUMMARY AND CONCLUSIONS

This report presents the 1993 results of the first extensive sedimentation survey of Shadehill Reservoir since construction of Shadehill Dam. The primary objectives of the survey were to:

- establish accurate baseline data for future monitoring of storage depletion
- gather data needed for developing new reservoir topography
- compute area-capacity relationships
- estimate storage depletion since closure of the dam

The reservoir survey is part of the Shadehill Lake Protection Project, which is sponsored by the Perkins County Conservation District. The project provides technical and financial assistance from various Federal, State, and local agencies. The project is a 3-year effort consisting of planning and implementing a voluntary program of Best Management Practices with users of lands that drain into Shadehill Reservoir. The project's primary objectives, to be met by 1996, are to:

- reduce 20,000 acres of cropland erosion to tolerable levels
- improve 60,000 acres of pastured rangeland that is currently in poor to fair condition and upgrade to fair to good condition
- maintain water quality in the reservoir
- improve the beneficial use of the Grand River

Standard land surveying methods were used to establish horizontal and vertical control points for the hydrographic survey. A horizontal grid system was established using monumented control points located in the reservoir area. The bathymetric survey was run using sonic depth recording equipment interfaced with an automated survey system consisting of a line-of-sight microwave positioning unit capable of determining sounding locations within the reservoir. The system continuously recorded reservoir depth and horizontal coordinates as the survey boat was navigated along close-spaced gridlines covering the reservoir area. The positioning system provided information to allow the boat operator to maintain course along these gridlines. Water surface elevations measured at the time of data collection were used to convert the sonic depth measurements to true lake bottom elevations.

The 1993 underwater surface areas at predetermined 5-foot contour intervals were generated by a computer graphics program using the collected data. The above-water reservoir areas were measured from USGS 7.5-degree quadrangle maps with 5-meter contour intervals developed from aerial photography obtained in 1978. The new reservoir contour map is a combination of the 1993 generated underwater and the USGS above water topography (figs. 4, 5, and 6). The area and capacity tables were produced by a computer program that uses the measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments.

Table 1 contains a summary of reservoir watershed characteristics and sediment data for the 1993 survey. The 1993 survey determined that the reservoir has a storage capacity of 120,172 acre-feet and a surface area of 5,019 acres at reservoir spillway crest elevation 2272.0. Since closure in 1950, the reservoir has accumulated an estimated volume of 15,241 acre-feet of sediment and reservoir shoreline erosion material below elevation 2272.0. This volume represents an 11.2-percent loss in total capacity and an average annual loss of 354.4 acre-feet. For the purpose of calculating reservoir depletion, the difference between the original and 1993 capacity was used, but questions exist regarding:

- accuracy of the original reservoir area-capacity values
- amount of shoreline erosion material versus accumulated sediment
- amount of shoreline erosion since development of the USGS topography maps.

The original 25-foot contour topography maps of the Shadehill Reservoir area were generated by a plane table survey prior to dam construction. The 1993 sedimentation study found the proposed axis of the dam's left bank levee on these original topography maps in a slight northwest direction. The USGS maps had the final axis in a northeast direction. For determining reservoir volume change, the original capacity was recomputed taking into account the additional surface areas between the proposed and actual levee axis. An aerial survey of the above water portion of the reservoir would resolve issues of present shoreline topography and amount of shoreline erosion versus sediment inflow.

DESCRIPTION OF WATERSHED

Shadehill Reservoir watershed has a drainage area of 3,120 square miles; elevations range from 2250.8 feet at the outlet works to around 4000 feet on top of the higher buttes. The calculated net sediment contributing area is 2,841 square miles. This area represents the loss of drainage area since closure of Bowman-Harley Reservoir in August 1966. The North Fork of the Grand River drains about 900 square miles of the southwestern corner of North Dakota before flowing southeastward into South Dakota. The North Fork joins the South Fork of the Grand River about 2 miles upstream from Shadehill Dam. The South Fork of the Grand River is formed by six large tributaries with several intermittent streams. The drainage basin has a maximum width of 60 miles and a west to east length of 90 miles. The topography is characterized by tablelands and buttes typical of the Great Plains Region. Pockets of typical badland topography occur throughout the basin. The general geology is characterized by resistant sandstone alternating with soft sands and shales forming broad terraces and flat-topped buttes. The higher elevations of the tops of buttes are generally 500 to 600 feet higher than the tableland elevation. The majority of the soils are well drained and are developed from silty and clayey shales. A small portion of the drainage area of the North Fork of the Grand River contains sandy loams. Rangeland used for livestock production is the major land use in the watershed; less than 25 percent of the watershed is cultivated.

RESERVOIR OPERATIONS

The reservoir is a multi-use facility having (following values are from July 1993 area-capacity tables):

- 119,560 acre-feet of surcharge flood storage between elevations 2302.0 and 2312.0
- 230,004 acre-feet of exclusive flood control storage between elevations 2272.0 and 2302.0
- 76,303 acre-feet of exclusive conservation storage between elevations 2250.8 and 2272.0
- 43,869 acre-feet of dead storage below elevation 2250.8

Records for Shadehill Reservoir show an average unregulated inflow of 63,607 acre-feet per year. The estimated mean annual runoff from the basin is 0.38 inch. Since the initial filling, Shadehill Reservoir operations have ranged from elevation 2258.6 in November 1981 to a maximum elevation of 2297.9 in April 1952. The inflow and end-of-month stage records in table 1 show the annual fluctuation of the reservoir. Except for water year 1952, the records show that the normal reservoir operation does not include extreme reservoir water surface fluctuations.

SURVEY METHOD AND EQUIPMENT

The original Shadehill Reservoir surface areas were measured from 25-foot contour topography developed in the 1940s by a plane table survey. During the fall of 1949 through 1951, 51 range lines were established, 42 within the reservoir area, for the purpose of monitoring sediment accumulation. Reclamation's method of calculating sediment accumulation by resurveying the range lines depends on the accuracy of the original surface areas. For the 1993 study, the original reservoir topography of 25-foot contour intervals were determined to be insufficiently accurate to use the range line method. To meet the objectives of the Shadehill Lake Protection

Project, a new 1993 topography map of the reservoir area was recommended and therefore developed.

The 1993 Shadehill Reservoir hydrographic survey was completed using the contour method as outlined by Blanton (1982). The procedure involves collecting adequate coordinate data for developing a reliable contour map by photogrammetric and bathymetric survey methods. Because of the cost of photogrammetric mapping, the above water data were obtained from the USGS 5-meter contour topography of the area above the reservoir shoreline. Standard land surveying methods were used by the Newell Office personnel to establish horizontal and vertical control points for the 1993 bathymetric survey. A horizontal grid system was established using monumented points, with state plane coordinates, located in the reservoir area. The field survey involved establishing a triangulation network around the reservoir to provide horizontal and vertical control for all required grid lines and shore stations for the bathymetric survey. To a large extent, the previously established sediment range lines and their monuments were used for this survey.

The hydrographic survey was run on July 6 through 13, 1993, with the reservoir water surface between elevations 2272.97 and 2273.17. The bathymetric survey was run using sonic depth recording equipment interfaced with an automated survey system consisting of a line-of-sight microwave positioning unit capable of determining sounding locations within the reservoir. This positioning system transmitted line-of-sight microwave signals to fixed shore stations and converted the reply time to range distances, which were used by the system data logger to compute the coordinate position of the sounding boat. The survey system continuously recorded reservoir depth and horizontal coordinates as the survey boat moved across close-spaced gridlines covering the reservoir area. To produce adequate data for developing contours of Shadehill Reservoir, an average grid spacing of 300 feet was used. The system gave directions to the boat operator to assist in maintaining course along these close-spaced gridlines. During each run, the depth and position data were recorded on a hard drive disk at 1-second intervals for subsequent processing by Reclamation personnel. A graph plotter was used in the field to track the boat and ensure adequate coverage during the collection process. Water surface elevations measured at the time of collection were used to convert the sonic depth measurements to true lake bottom elevations.

Personnel from the Belle Fourche and Bison SCS Offices collected data for several range lines located in the upper reservoir area. Standard land survey methods were used to collect data for range lines 9 through 13 and 25 through 28. SCS processed the data and provided hard copy comparison plots of the 1950 versus 1993 data for the range lines surveyed. The comparison plots found about 4 feet of sediment buildup at range line 9; the other surveyed range lines measured little to minimal bottom change. Water in the reservoir was too deep to collect channel bottom data for range line 25. Several of the ranges measured some bank erosion. Results from these comparisons were used to finalize the upper contours of the reservoir topography map. Copies of these plots can be obtained from the SCS Belle Fourche and Bison Offices or Reclamation's Newell Office.

Meetings on the Shadehill Lake Protection Project revealed that the U.S. Forest Service had a contract for the collection of aerial photography in the reservoir study area. The final product was non-rectified, 60 percent overlapping photos at a scale of 1:24,000. The aerial photography of the reservoir was obtained on September 23, 1993, at water surface elevation 2270.79. A few known points were marked with panels by the Newell Office. It was hoped that the aerial photos could be used by developing a contour of the reservoir water surface elevation at the time of collection. Funding was not available for the aerial contractor to complete a map of the above water portion of the reservoir area or to have the aerial photos rectified. The 1993 analysis determined that the use of the non-rectified photos would introduce an error that could not be reliably corrected with the equipment and software presently available at Reclamation's TSC (Technical Service Center).

The 1993 study concluded that the most accurate information of the upper reservoir contour area was the USGS topography maps. The problem with the USGS topography was the development from aerial photography obtained in 1978, which would not account for the reservoir shoreline erosion that occurred from 1978 through July 1993. Digitizing programs were used to measure the surface areas and develop state plane coordinates of the following USGS topographic Shadehill Reservoir contours: elevation 2272.0 (692.5 meters), elevation 2280.2 (695.0 meters), elevation 2296.6 (700.0 meters), and elevation 2313.0 (705 meters).

RESERVOIR AREA AND CAPACITY

Original Area and Capacity

Detailed information on development of original surface areas of Shadehill Reservoir was not located, but they appear to have been measured from four topography maps (dated December 4, 1946), Reclamation drawing numbers 276-626-214 through 276-626-217. Available copies of original topography maps were of fair to poor quality, but they appear to have been developed by a plane table survey method with contour elevations of 2225.0, 2250.0, 2275.0, 2300.0, and 2312.0. The 1993 study measured the surface area of contour elevation 2300.0 to verify use of these maps for determining original surface area. Contour 2300.0 was chosen because it was the easiest to distinguish on the maps. The measured value was within 1 percent of the surface area projected from a curve of Shadehill Reservoir surface areas.

The original 5-foot surface area values for reservoir elevation 2200.0 through 2310.0 were projected from a July 30, 1948, Reclamation elevation versus area curve (drawing 276-D-28). The area for reservoir elevation 2312.0 was projected from a June 26, 1963 revised Reclamation area curve (drawing 276-602-465). The projected surface area values from the curves are listed in column 2 of table 2.

A comparison of the projected original area curve values with the 1993 areas, listed in column 5 of table 2, found large differences at the higher contours (elevations 2275.0 through 2312.0). Major shoreline erosion was expected, but the measured differences seemed too great to attribute to shoreline erosion only. A major surface area difference was found when the original topography maps were overlaid with the USGS topography maps. The original topography map had the proposed axis of the dam's left bank levee in a slight northwest direction; the USGS maps had the actual levee axis in a northeast direction. From the overlay and the measurement of the 2300.0 contour, the difference in levee axis alignment was assumed to have affected the original reservoir surface areas above contour elevation 2275.0. To account for the difference, the surface areas between the two alignments for contour elevations 2296.6 and 2313.0 were measured from the USGS topography. These measured surface areas were used for calculating the adjusted original areas as listed on column 3 of table 2. The adjusted original capacity, listed in column 4 of table 2, was recomputed using the area-capacity computer program ACAP85 (Reclamation, 1985) with the adjusted original areas in column 3.

Development of 1993 Contour Areas

The 1993 contour surface areas for Shadehill Reservoir were measured from the 1993 reservoir topography and existing USGS topography maps. The 1993 contour map was generated from the 1993 collected underwater coordinate data and state plane coordinate points of the USGS above water reservoir contours. The state plane coordinate points were determined for contour elevations 2272.0 (692.5 meters), 2280.2 (695.0 meters), 2296.6 (700.0 meters), and 2313.0 (705 meters). The USGS state plane coordinate points were used as boundary information for developing the reservoir contours from the underwater data. The problem with using the USGS topography was that it was developed from 1978 aerial photography that does not account for the reservoir shoreline erosion that has occurred from 1978 through July 1993. An overlay of the 1993 collected underwater data with the USGS maps illustrated large areas of shoreline erosion. Because of the overlapping data, the coordinate points from the USGS topography for contour elevation 2272.0 were not used for developing the final contour map.

Five-foot contour intervals of the underwater reservoir data, from elevation 2215.0 through elevation 2265.0, were created by the computer graphics software program SURFACE II (Kansas Geological Survey, 1978). The program developed closed 5-foot contours for reservoir elevations 2215.0 through 2260.0 and calculated the closed contour surface areas of the generated map. SURFACE II did not completely close the elevation 2265.0 contour. The final 2265.0 contour was developed by overlaying computer generated portions of the contour with the USGS topography maps and a plot of the 1993 underwater data. With the available information, the 2265.0 contour was finalized using engineering judgement to determine the location. The 2272.0 contour on the final reservoir topography was projected from the USGS maps. The USGS 2272.0 contour was adjusted to avoid crossing of the developed lower elevation contours. The 1993 surface area for contour elevation 2272.0 was measured from the USGS topography maps, not the modified 2272.0 contour on the 1993 reservoir maps. The final reservoir maps shown on figures 4, 5, and 6 were prepared by the TSC Visual Presentations Group. The map has a scale of 1 inch equals 1000 feet with a 5-foot contour interval.

1993 Revised Storage Capacity

The storage-elevation relationships based on the aerial and underwater survey data were developed using the area-capacity computer program ACAP85 (Reclamation, 1985). Surface areas at 5-foot contour intervals, computed from the underwater survey data and the measured reservoir surface areas from USGS topography, were used as the control parameters for computing reservoir capacity. The program computes an area at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour intervals. 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 Shadehill 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:

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

where:

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

Results of the 1993 Shadehill Reservoir area and capacity computations are listed in table 1 and columns 5 and 6 of table 2. Listed in columns 3 and 4 of table 2 are the original adjusted surface areas and recomputed capacity values. A separate set of 1993 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Reclamation, 1993). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1993 area-capacity curves are plotted on figure 7. As of July 1993, at reservoir elevation 2272.0, the surface area was 5,019.0 acres with a total capacity of 120,172 acre-feet.

SEDIMENT ANALYSES

Tables 1 and 2 contain the Shadehill Reservoir sediment accumulation and water storage data based on the 1993 resurvey. The 1993 study based its sediment calculations on the difference between the original and 1993 measured reservoir capacities. This method accounts for the sediment accumulation during the 43.0 years of reservoir operation, but is only as accurate as the original and 1993 reservoir areas. For sediment calculation purposes, the difference between the original and 1993 capacity was used, but as previously noted, a question exists as to the accuracy of the original area-capacity. Also, there is the problem of determining the portions of measured reservoir lost to sediment inflow and shoreline erosion. Future monitoring of the reservoir will continue to have this problem. During the 1993 high reservoir period, additional bank erosion was observed, and it is assumed that this erosion will continue throughout the life of the reservoir. To assist in measuring the difference between the inflow sediments and bank erosion, an aerial reservoir area survey should be completed in the future. Results could be compared with the original and 1978 USGS topography along with the 1993 aerial photography for measuring the changes in reservoir shoreline.

Prior to construction, the sediment inflow for Shadehill Reservoir was estimated to be 270 acre-feet per year for a 100-year total of 27,000 acre-feet. It was expected that 77 percent of the total sediment would deposit in the dead storage pool. The 1993 reservoir survey computed a total volume lost of 15,241 acre-feet for the first 43 years of reservoir operation, July 1950 through July 1993. The survey measured 73.3 percent of the total deposit in the dead storage area, below elevation 2250.8. The average annual rate of deposition was 354.4 acre-feet per year, or 0.12 acre-foot per square mile from the sediment contributing drainage area. The storage loss in terms of percent of original storage capacity was 11.2 percent.

SEDIMENT SAMPLING

Underwater sediment samples were collected with a gravity core sampler for the purpose of characterizing the type and distribution of the sediment in the reservoir. Eight sample point locations were chosen to represent the sediment entering from the main tributaries (North and South Forks of the Grand River) and the sediment deposited within the reservoir pool area located downstream from the confluence of the Grand River North and South Forks. The sampler was suspended over the bow of the survey vessel from a cable reeled off a power-operated winch. The sampler was allowed to fall free into the sediment deposits to obtain maximum possible penetration. The sampler was then retrieved, and the plastic liner containing the sediment sample was withdrawn from the coring pipe. The samples were sealed with plastic caps on each end of the liner and labeled. SCS personnel transported the samples to a laboratory for analysis.

The four samples collected below the confluence of the Grand River North and South Forks were composed of fine silty clay with some organic matter and about 2 percent fines. These samples did not vary significantly in type and texture of sediment. The dry weight of the samples ranged from 53 lb/ft^3 (pounds per cubic feet) to 56 lb/ft^3. Two samples collected from the South Fork of the Grand River varied in the amount of fine sands that were present. The sample collected 200 feet from the south bank was about 5 to 10 percent fines. These fines were composed of fine sand, silt, and clay with a dry weight of 64 lb/ft^3. The second sample, located north of the first, had about 20 percent fines and a dry weight of 69 lb/ft^3. The two sediment samples collected from the North Fork of the Grand River had a wide variation in type and texture. The sample nearer the southern bank had a dry weight of 79 lb/ft^3 and was comprised of about 60 percent fines with a mixture of silt and clay with coarse and fine sands. The second sample closer to the northern bank was silty sand with about 30 to 35 percent fines and a dry weight of 72 lb/ft^3. As expected, the samples with a higher percentage of fines were collected from the North Fork of the Grand River.

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RESERVOIR SEDIMENT
DATA SUMMARY

SHADEHILL RESERVOIR
NAME OF RESERVOIR

1
DATA SHEET NO.

D A M	1. OWNER Bureau of Reclamation	2. STREAM Grand River	3. STATE South Dakota
	4. SEC. 25 TWP. 21N RANGE 15E	5. NEAREST P.O. Shadehill	6. COUNTY Perkins
	7. LAT 45° 45' 12" LONG 102° 12' 12"	8. TOP OF DAM ELEVATION 2318.0	

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, Ac	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	
	a. SURCHARGE	2312.0	12,150	111,203	468,585	15. DATE STORAGE BEGAN 7/1/50
	b. FLOOD CONTROL	2302.0	9,926	217,708	357,382	
	c. POWER					
	d. WATER SUPPLY					16. DATE NORMAL OPERATION BEGAN 8/51
	e. IRRIGATION					
	f. CONSERVATION	2272.0	4,868	81,443	139,674	
	g. INACTIVE	2250.8	2,789	58,231	58,231	
	17. LENGTH OF RESERVOIR 18.2[2] MILES			AVG. WIDTH OF RESERVOIR 0.42 MILES		

BASIN			
	18. TOTAL DRAINAGE AREA 3,120 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 15.7[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 2,841[4] SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.38[5] INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 63,607[6] ACRE-FEET
	21. MAX. ELEVATION 4000	MIN. ELEVATION 2250.8	25. ANNUAL TEMP. MEAN 43°F RANGE -45°F to 115°F[3]

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS.	28. ACCL. YRS.	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVAL	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
7/1/50			Contour(R)	25-ft	4,868[7]	135,413[8]	2.13
7/93	43.0	43.0	Contour(D)	5-ft	5,019.0	120,172	1.89

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
7/93	15.7"	63,607[6]	388,200[6]	2,607,887	63,607	2,607,887

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AV. ANN.	c. /MI.²-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AV. ANNUAL	c. /MI.²-YR.
7/93	15,241[9]	354.4	0.12	15,241	354.4	.12

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR. a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AV. ANNUAL	b. TOTAL TO DATE	42. SEDIMENT INFLOW, PPM a. PER.	b. TOT.
7/93				0.262[10]	11.2[10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, SPILLWAY CREST ELEVATION									
				72.0-	62.0-	52.0-	42.0-	32.0-	22.0-	12.0-	
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION									
7/93				8.2	22.9	15.1	9.6	15.8	24.4	4.0	

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

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

45. RANGE IN RESERVOIR OPERATION [6,11]

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1950	-	-	388,200[6]	1951	-	-	400[6]
1952	2297.9	2248.7	-	1953	2276.2	2270.9	-
1954	2272.9	2271.2	14,044	1955	2271.9	2270.6	5,426
1956	2272.6	2269.6	42,768	1957	2273.4	2270.7	22,295
1958	2272.6	2270.7	8,650	1959	2273.1	2269.8	16,337
1960	2273.3	2269.3	27,775	1961	2271.0	2261.5	-1,491
1962	2268.2	2258.9	36,185	1963	2270.3	2263.1	42,598
1964	2268.2	2259.3	35,663	1965	2274.2	2261.0	106,313
1966	2272.2	2262.0	63,077	1967	2274.3	2266.1	74,424
1968	2266.6	2261.7	15,064	1969	2274.1	2260.8	109,761
1970	2272.1	2264.7	41,594	1971	2275.0	2264.8	182,035
1972	2276.4	2264.6	170,636	1973	2272.8	2265.9	73,172
1974	2268.7	2262.8	20,020	1975	2273.4	2261.8	75,442
1976	2271.6	2266.9	27,793	1977	2269.7	2267.5	16,773
1978	2282.4	2266.8	227,841	1979	2273.1	2265.4	62,903
1980	2268.3	2260.9	326	1981	2260.9	2259.2	7,433
1982	2275.7	2258.6	166,483	1983	2271.9	2267.8	68,200
1984	2271.8	2266.5	35,083	1985	2271.6	2265.2	43,943
1986	2273.8	2267.8	103,588	1987	2273.9	2267.6	78,879
1988	2268.9	2264.4	11,987	1989	2267.9	2262.7	28,852
1990	2269.5	2266.1	19,856	1991	2267.3	2265.2	8,860
1992	2265.7	2264.0	11,216	1993	2275.3	2264.1	117,483

46. ELEVATION - AREA - CAPACITY DATA FOR **1993 TOTAL CAPACITY** [12]

ELEV.	AREA	CAP.	ELEV.	AREA	CAP.	ELEV.	AREA	CAP.
2212.1	0	0	2215	33.5	49	2220	302.2	888
2225	655.3	3,282	2230	1,010.0	7,445	2235	1,413.4	13,503
2240	1,720.9	21,339	2245	2,061.6	30,795	2250	2,393.0	41,932
2255	2,748.4	54,785	2260	3,297.6	69,900	2265	4,076.9	88,337
2270	4,750	110,403	2272	5,019.0	120,172	2275	5,489	135,934
2280	6,272	165,335	2280.2	6,303.0	166,592	2285	7,221	199,050
2290	8,177	237,544	2295	9,133	280,819	2296.6	9,439.0	295,677
2300	10,262	329,168	2305	11,472	383,503	2310	12,682	443,888
2312	13,166	469,736						

47. REMARKS AND REFERENCES

1 Two spillways. Service spillway, crest elevation 2272.0, is an uncontrolled concrete morning-glory inlet, with a concrete conduit through dam located left side of original river channel, with capacity of 5,700 ft/s^3 at reservoir elevation 2312.0. Emergency spillway, crest elevation 2302.0, is unlined open cut structure located at north end of dam with capacity of 127,000 ft/s^3 at elevation 2312.0.

2 Includes 10.2 miles from dam to upper end of the South Fork of the Grand River and 8.0 miles from the North and South Fork confluence to the upper end of the North Fork of the Grand River.

3 Bureau of Reclamation *Project Data Book* on Shadehill Unit, 1966 - 80.

4 Represents loss of contributing area since closure of Bowman-Harley Reservoir in August 1966.

5 Calculated using mean annual runoff value of 63,607 acre-feet (item 24).

6 Calculated unregulated monthly inflows for reservoir operation period July 1950 through July 1993. No calculated records for water years 1952 and 1953. Inflow for 1950-51 from Reclamation *Project Data Book*.

7 Surface area at reservoir elevation 2272.0. Original areas projected from area curve drawing 276-D-28, for elevations 2275.0 and below only.

8 Capacity at elevation 2272.0. Recomputed by Reclamation's ACAP program using original surface areas. Some question as to the accuracy of the original surface areas because of projecting from area curve.

9 Total capacity loss calculated by comparing recomputed capacity (see remarks No. 7 and 8) and 1993 capacity at reservoir elevation 2272.0. Reservoir experienced significant shoreline erosion.

10 Average annual and total sediment deposits of 354.4 and 15,241 acre-ft, respectively, divided by original capacity of 135,413 acre-ft. Original capacity at El. 2272.0 computed by ACAP using projected original surface area data.

11 Maximum and minimum reservoir elevations for indicated water year.

12 1993 total capacity computed by ACAP using 1993 measured areas. Areas for elevation 2265.0 and below measured from July 1993 hydrographic survey data. Areas at elevation 2272.0 and above measured from USGS topography maps developed from aerial photography obtained in 1978.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE August 1994

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

(1) Elevation (feet)	(2) Original Area (acres)	(3) Adjusted Original Area (acres)	(4) Adjusted Original Capacity (acre-feet)	(5) 1993 Area (acres)	(6) 1993 Capacity (acre-feet)	(7) Measured Sediment Volume (acre-feet)	(8) Percent Measured Sediment	(9) Percent Reservoir Depth
2312	12,150	12,773	474,056	(13,166)	469,736	4,320	-	100.0
2310	11,829	12,421	448,862	(12,682)	443,888	4,974	-	98.2
2305	10,600	11,116	390,020	(11,472)	383,503	6,517	-	93.8
2302	-	(10,397)	357,751	(10,746)	350,176	7,575	-	91.1
2300	9,477	9,917	337,437	(10,262)	329,168	8,269	-	89.3
2296.6	-	9,133	305,052	9,439.0	295,677	9,375	-	86.2
2295	8,400	8,840	290,674	(9,133)	280,819	9,855	-	84.8
2290	7,490	7,925	248,761	(8,177)	237,544	11,217	-	80.4
2285	6,500	7,010	211,425	(7,221)	199,050	12,375	-	75.9
2280.2	-	(6,131)	179,888	6,303.0	166,592	13,296	-	71.6
2280	5,790	6,094	178,666	(6,272)	165,335	13,331	-	71.4
2275	5,179	5,179	150,482	(5,489)	135,934	14,548	-	67.0
2272	-	(4,868)	135,413	5,019.0	120,172	15,241	100.0	64.3
2270	4,660	4,660	125,885	(4,750)	110,403	15,482	100.0	62.5
2265	4,120	4,120	103,935	4,076.9	88,337	15,598	100.0	58.0
2260	3,640	3,640	84,535	3,297.6	69,900	14,635	96.0	53.6
2255	3,160	3,160	67,535	2,748.4	54,785	12,750	83.6	49.1
2250.8	-	(2,789)	55,043	(2,450)	43,869	11,174	73.3	45.4
2250	2,718	2,718	52,840	2,393.0	41,932	10,908	71.6	44.6
2245	2,290	2,290	40,320	2,061.6	30,795	9,525	62.5	40.2
2240	1,900	1,900	29,845	1,720.9	21,339	8,506	55.8	35.7
2235	1,540	1,540	21,245	1,413.4	13,503	7,742	50.8	31.2
2230	1,160	1,160	14,495	1,010.0	7,445	7,050	46.2	26.8
2225	874	874	9,410	655.3	3,282	6,128	40.2	22.3
2220	640	640	5,625	302.2	888	4,737	31.1	17.8
2215	430	430	2,950	33.5	49	2,901	19.0	13.4
2212.1	-	(326)	1,854	0	0	1,854	12.2	10.8
2210	250	250	1,250	0	0	1,250	8.2	8.9
2200	0	0	0	0	0	0	0.0	0.0

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area values projected from area curve drawing 276-D-28. Area for reservoir elevation 2312.0 is from area curve drawing 276-602-465.
(3) Original reservoir surface area values projected from area curve drawing 276-D-28. The original surface areas above elevation 2275.0 were adjusted for final dam axis alignment projected from USGS topography maps. Areas in parentheses computed by ACAP85.
(4) Original reservoir capacity recomputed using ACAP85 from original surface areas from column two.
(5) Reservoir surface area from 1993 hydrographic surveys. Areas in parentheses computed by ACAP85. Areas above elevation 2265.0 were measured from USGS topography maps. The maximum area measured at elevation 2313.0 (705 meters), was 13,408 acres.
(6) 1993 reservoir capacity computed by ACAP85 using areas from column 4.
(7) Measured sediment volume = column 4 - column 6.
(8) Measured sediment expressed in percentage of total sediment 15,241 acre-feet at spillway crest elevation 2272.0.
(9) Depth of reservoir in percentage of total depth of 112 feet, from maximum reservoir water surface elevation 2312.0 and original river channel elevation 2200.0.

Table 2. - Summary of 1993 survey results.

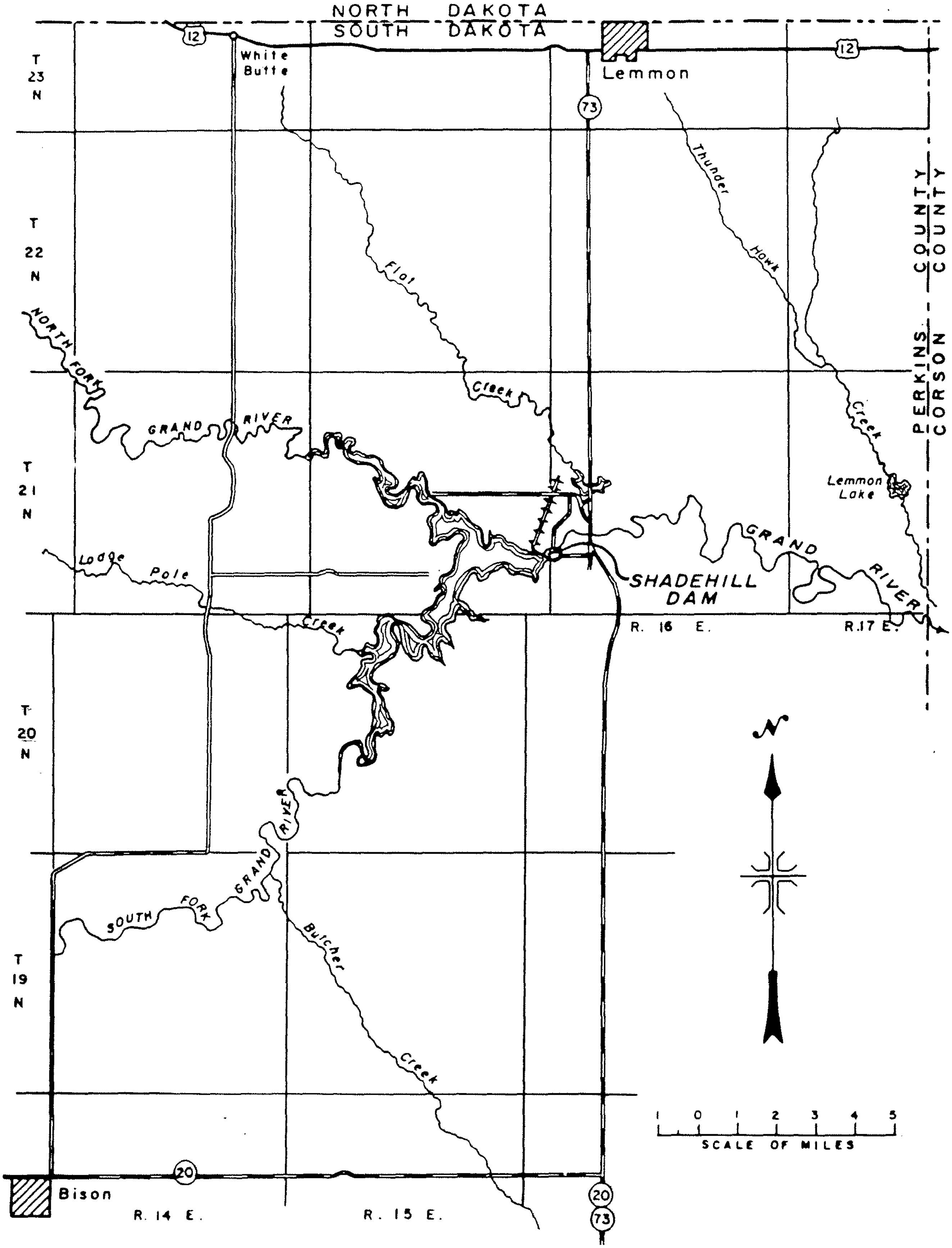

Figure 1. - Shadehill Reservoir location map.

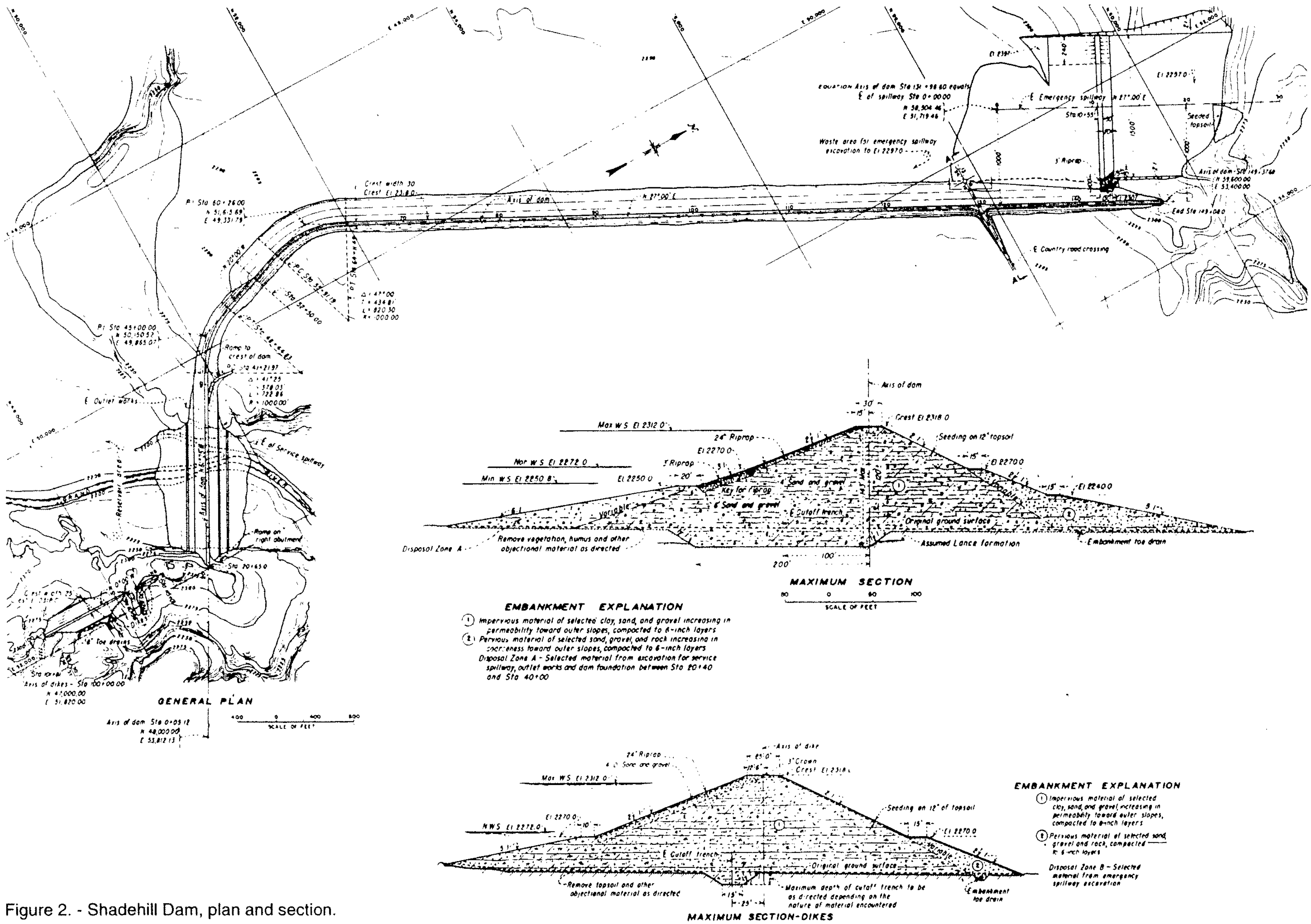

Figure 2. - Shadehill Dam, plan and section.

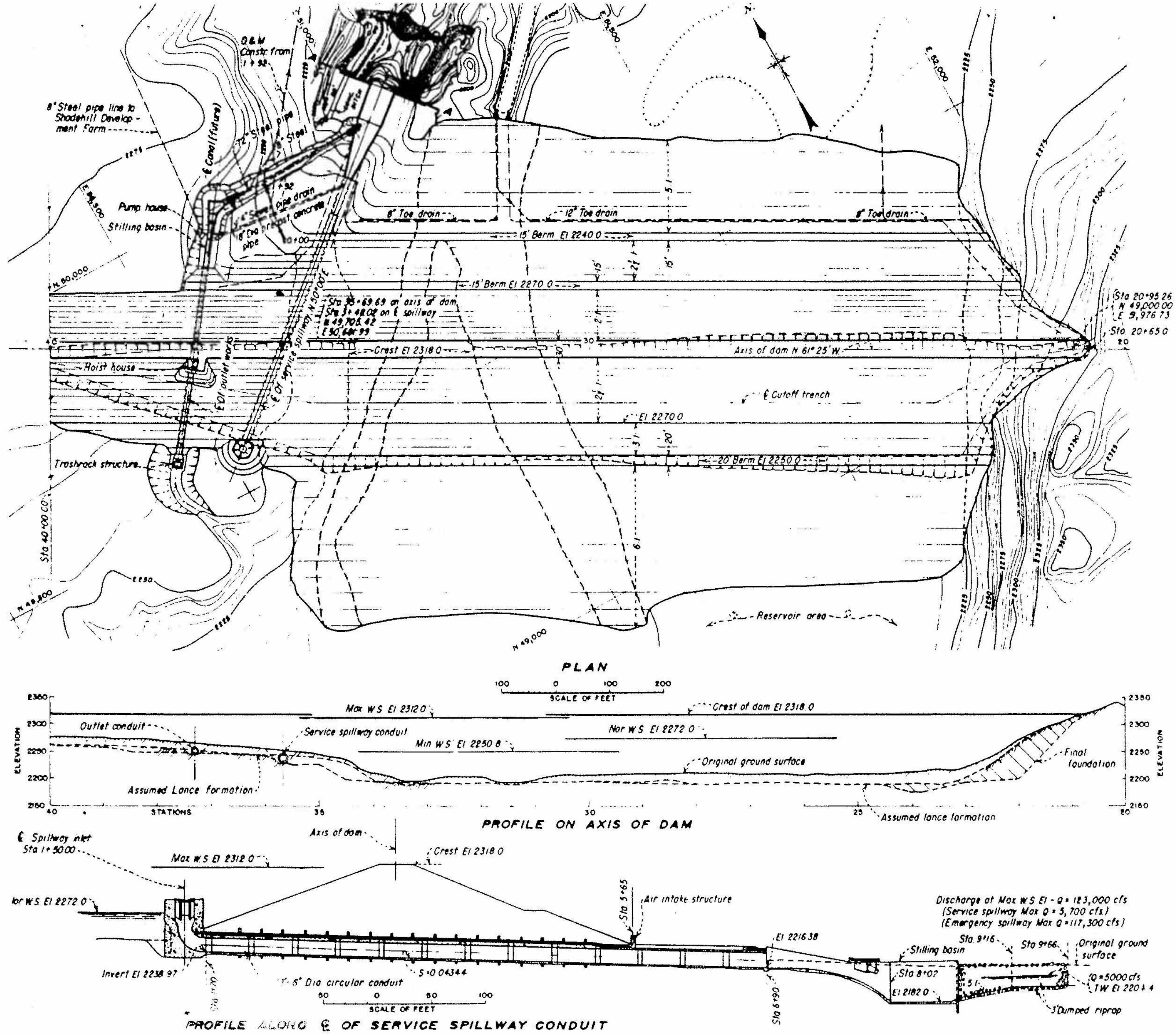

Figure 3. - Shadehill Dam, plan and profiles.

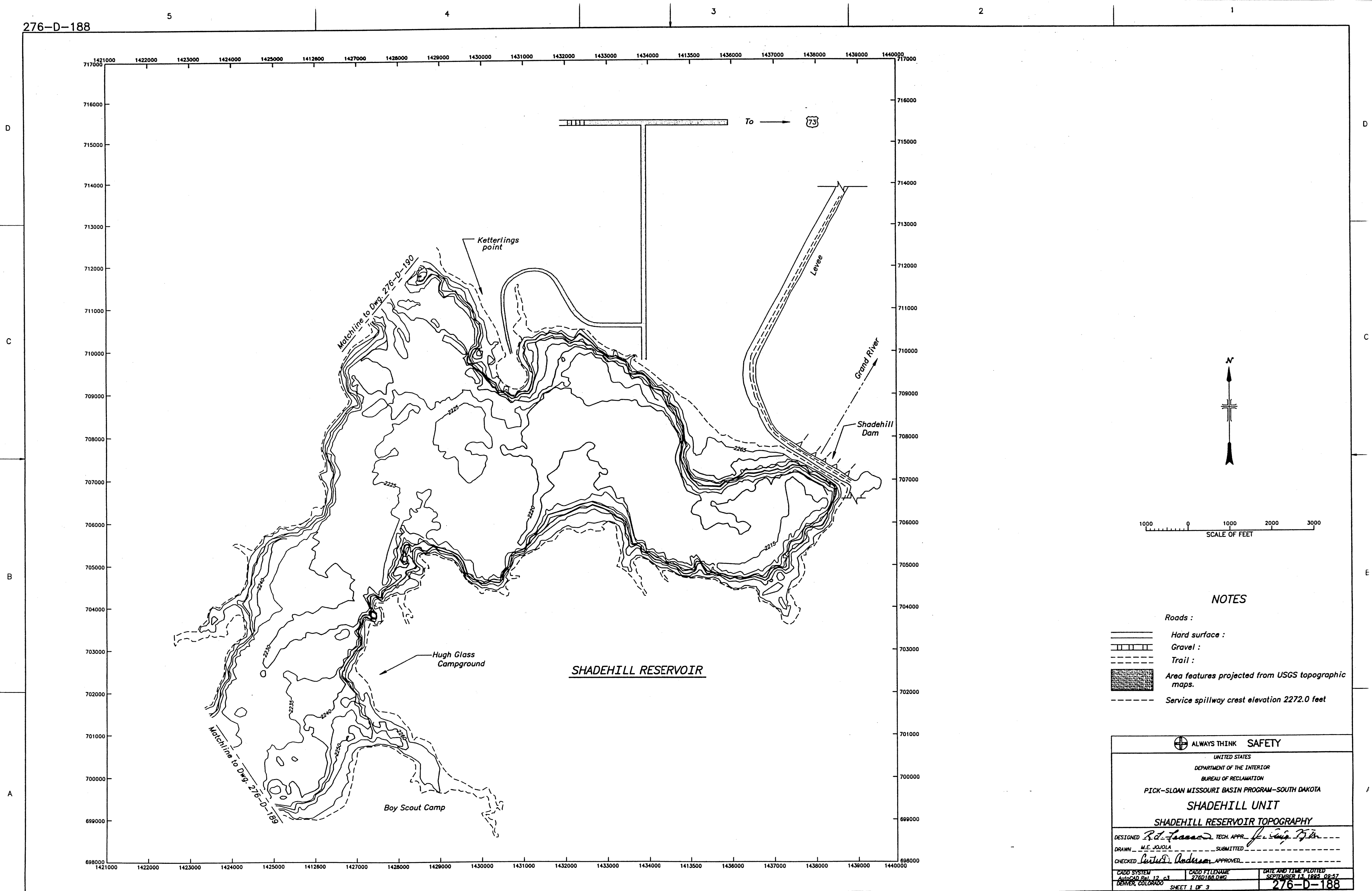

Figure 4. - Shadehill Reservoir topographic map (1 of 3).

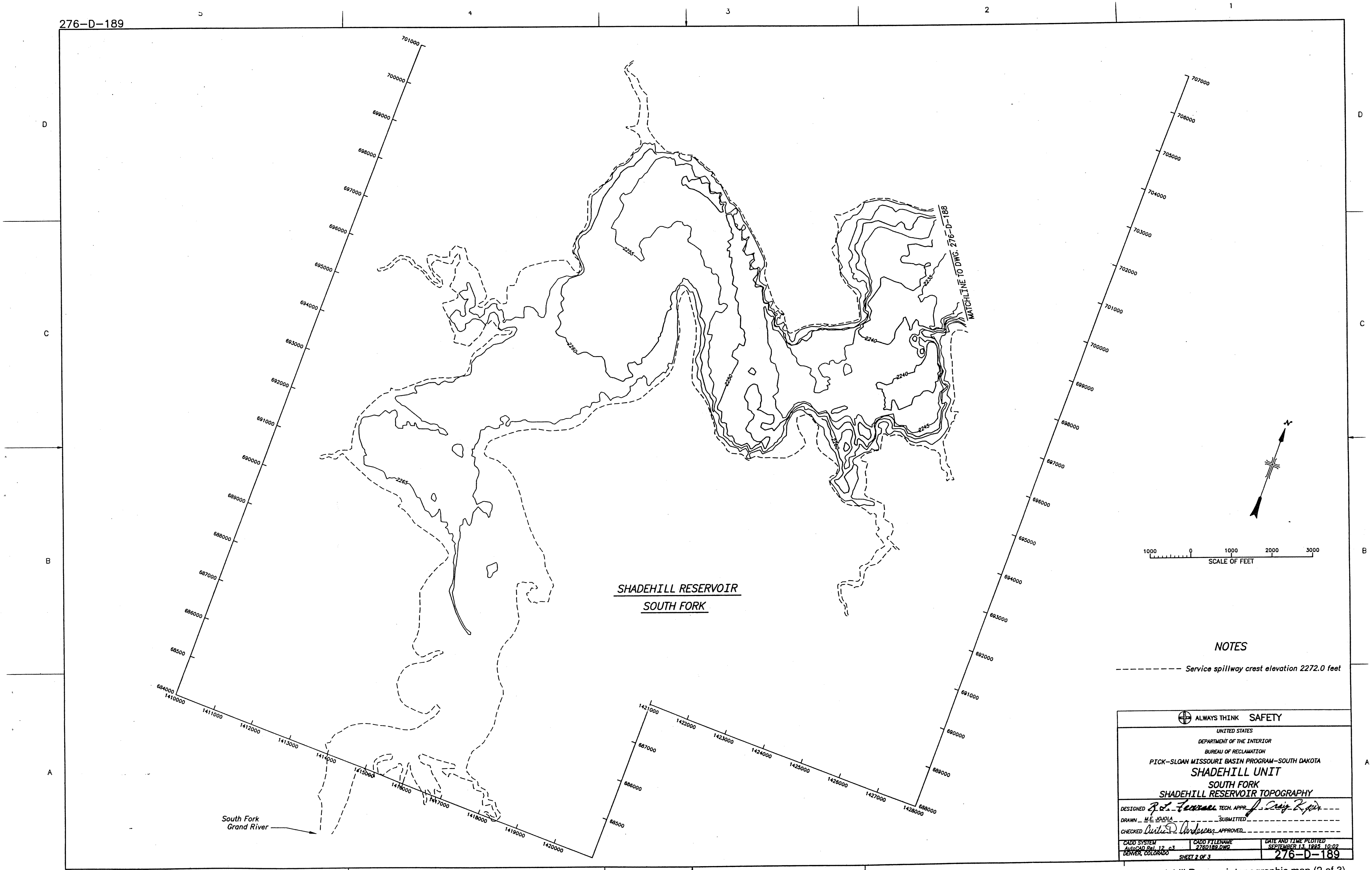

Figure 5. - Shadehill Reservoir topographic map (2 of 3).

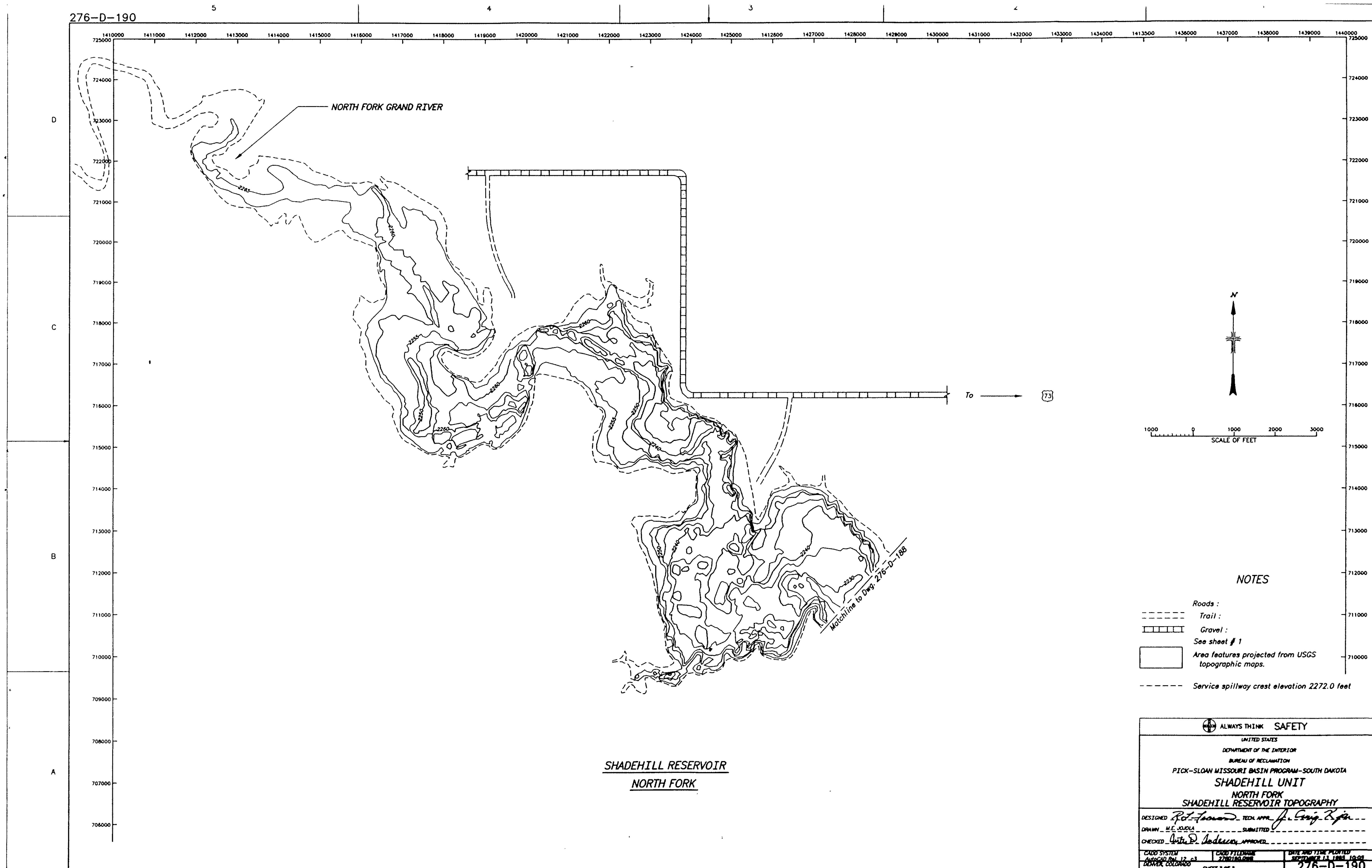

Figure 6. - Shadehill Reservoir topographic map (3 of 3)

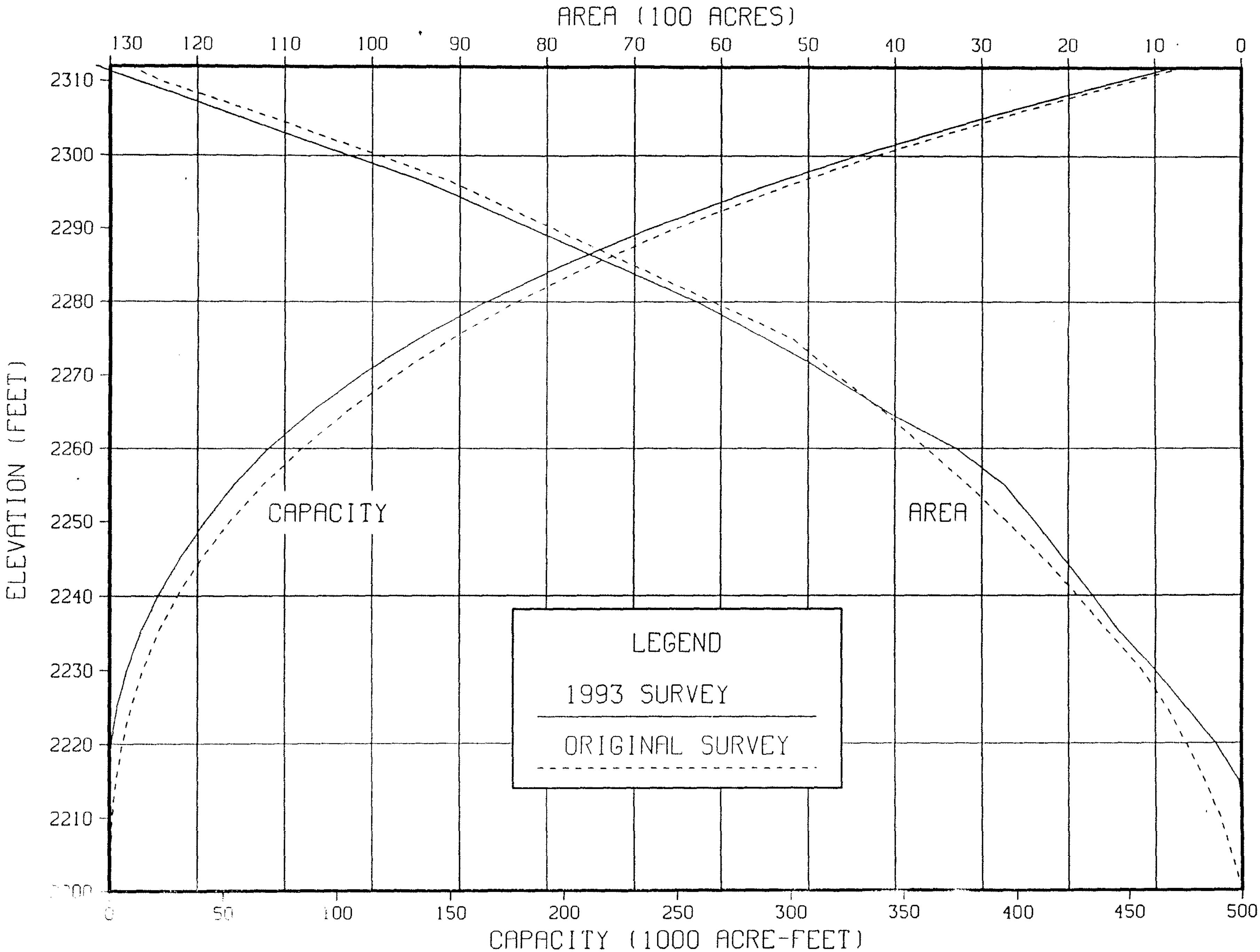

Figure 7. - 1993 area and capacity curves—Shadehill Reservoir.

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.