RECLAMATION

Managing Water in the West

Angostura Reservoir
2004 Sedimentation Survey

U.S. Department of the Interior
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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed Angostura Reservoir in May 2004 and winter of 2005 to develop new reservoir topography and compute a present storage-elevation relationship (area-capacity tables). The 2004 underwater survey, conducted between reservoir elevation 3,178.5 (feet) and 3,179.0 (project datum), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. In 2005, a RTK GPS land survey on a small portion of the upper reach of the reservoir was completed. Above-water topography was determined by digitizing reservoir contours from U.S. Geological Survey quadrangle (USGS quad) and Reclamation's original topographic maps of the reservoir area. These digitized contours were adjusted in the upper reservoir area using the 2005 survey data. Due to the lack of detailed above water data this study assumed no change since the 1979 range line survey from elevation 3,187.2 and above.

As of May 2004, at conservation pool elevation 3,187.2, the surface area was 4,612 acres with a total capacity of 123,048 acre-feet. Since dam closure on October 3, 1949, about 36,871 acre-feet of sediment has accumulated below elevation 3,187.2, resulting in a 23.0 percent loss in reservoir volume.

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Angostura Reservoir
2004 Sedimentation Survey

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BUREAU OF RECLAMATION

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

Angostura Dam and Reservoir in Fall River County on the Cheyenne River is located about nine miles southeast of Hot Springs in southwest South Dakota (figure 1). The dam, reservoir, and facilities are part of the Angostura Unit that provides storage for irrigation water, flood control, fish and wildlife conservation, recreation, and sediment control for the Pick-Sloan Missouri Basin Project.

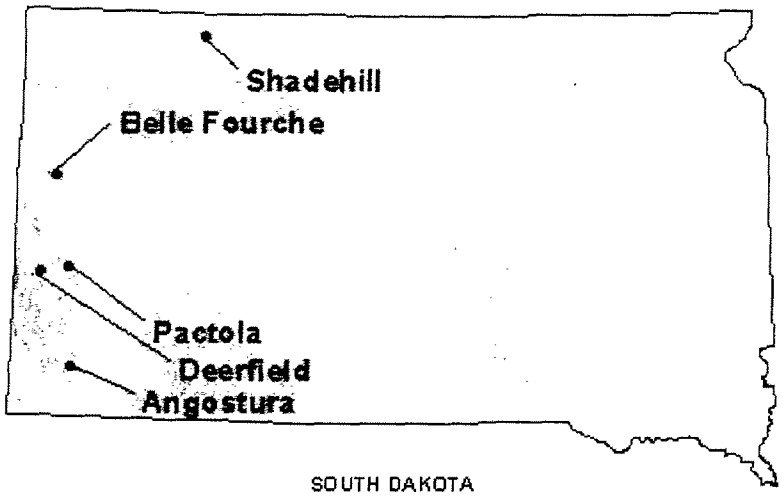

Figure 1 - Angostura Reservoir location map.

The reservoir, formed by a concrete gravity and earth embankment structure, was completed in December of 1949. The dam's dimensions are:

Hydraulic height[1]	136	feet	Structural height	193	feet
Top width	10	feet	Crest length	2,030	feet
Crest elevation	3,199.0	feet[2]			

[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]Elevations in feet. All elevations based on the original project datum established by U.S. Bureau of Reclamation that was reported to be the National Geodetic Vertical Datum of 1929 (NGVD29) and around two feet lower than the North American Vertical Datum of 1988 (NAVD88).

The spillway, crest elevation 3,157.2, is an overflow section in the concrete portion of the dam controlled by five 50- by 30-foot radial gates (Bureau of Reclamation, 1967). The discharge capacity is 247,000 cubic feet per second (cfs) at maximum reservoir elevation 3,198.1.

A river outlet works, location in the concrete portion of the dam, consists of a 4.5-foot diameter steel conduit controlled by a 48-inch jet-flow gate in the gatehouse to the right of the spillway. The discharge capacity is 590 cfs at maximum reservoir elevation 3,198.1. The main canal outlet works for irrigation water delivery consists of a 6-foot-diameter steel conduit through the concrete dam section with a discharge capacity of 720 cfs at active capacity elevation 3,187.2.

The drainage area above Angostura Dam is approximately 9,100 square miles and all is considered sediment contributing. The reservoir extends 17 miles in length along the Cheyenne River and 7.6 miles in length along Horsehead Creek. The average reservoir widths are 0.44 mile on the Cheyenne River and 0.32 mile on Horsehead Creek (Bureau of Reclamation, 1983).

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2004 results of the survey of Angostura Reservoir. The primary objective of the survey was to gather data to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion due to sediment deposition

A real-time kinematic (RTK) global positioning system (GPS) control survey established a temporary horizontal and vertical control point near the reservoir for the hydrographic survey. The GPS base was set over the National Geodetic Survey (NGS) datum point "HSR A" that is located at the Hot Springs Airport. The horizontal control was in the South Dakota state plane south coordinate zone in the North American Datum of 1983 (NAD83) and the vertical control was tied to the National American Vertical Datum of 1988 (NAVD88) and the Reclamation project vertical datum. All elevations in this report are referenced to Reclamation's project or construction vertical datum. Reclamation's vertical datums for this study are assumed tied to the National Geodetic Vertical Datum of 1929 (NGVD29) that is around two feet lower than NAVD88.

The May 2004 underwater survey was conducted between reservoir elevation 3,178.5 and 3,179.0. The bathymetric survey used sonic depth recording equipment interfaced with RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along grid lines covering Angostura 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 Reclamation's reservoir gauge during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations. The above-water topography was determined by digitizing the developed contour lines from the USGS quad and Reclamation's original mapped contours of the

reservoir area. In winter of 2005, a RTK GPS land survey in the upper reach of the reservoir on the Cheyenne River was conducted and was used to adjust the digitized contours to represent the 2005 conditions.

The Angostura Reservoir topographic map is a combination of the adjusted digitized contours and the 2004 underwater survey data. A computer graphics program generated the 2004 reservoir surface areas at predetermined contour intervals from the collected reservoir area. The 2004 area and capacity tables were produced by a computer program that used measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of the Angostura Reservoir and watershed characteristics for the 2004 survey. The 2004 survey determined that the reservoir has a total storage capacity of 123,048 acre-feet and a surface area of 4,612 acres at top of conservation pool elevation 3,187.2. Since closure on October 3 of 1949, the reservoir has an estimated volume change of 36,871 acre-feet below reservoir elevation 3,187.2. This volume represents a 23.0 percent loss in total original capacity at this elevation.

RESERVOIR OPERATIONS

Angostura Reservoir is part of the Angostura Unit of the Pick-Sloan Missouri Basin Project that provides storage for irrigation, flood control, fish and wildlife conservation, recreation and sediment control. The May 2004 capacity table shows 180,356 acre-feet of total storage below the maximum water surface elevation 3,198.1. The 2004 survey measured a minimum lake bottom elevation of 3,119.6. The following values are from the May 2004 capacity table:

- 57,308 acre-feet of surcharge between elevation 3,187.2 and 3,198.1
- 80,843 acre-feet of conservation use between elevation 3,163.0 and 3,187.2
- 36,547 acre-foot of inactive storage between elevation 3,139.75 and 3,163.0
- 5,658 acre-foot of dead storage below 3,139.75

Angostura Reservoir available inflow and end-of-month stage records listed on table 1, operation period 1952 through 2004, show the calculated inflow and annual fluctuation for these years of operation. The computed average inflow into the reservoir for these years was 81,500 acre-feet per year. The maximum-recorded elevation was 3,189.4 in May of 1978 with a minimum elevation of 3,162.9 in September of 1960. The mean elevation of the reservoir for the period of record is near elevation 3,180.

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 (figure 2). The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the equipment. The shore equipment included a second GPS receiver with an external radio powered by a 12-volt battery. The GPS receiver and antenna were mounted on a survey tripod over a known datum point.

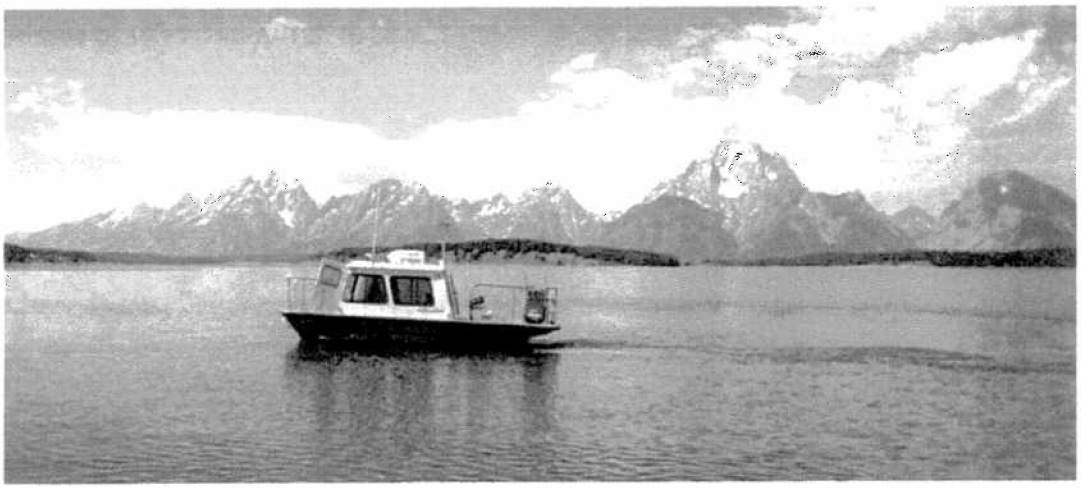

Figure 2 - Survey vessel with mounted hydrographic equipment on Jackson Lake in Wyoming

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefits being precise heights measured in real time to monitor water surface elevation changes and the ability to conduct land topographic surveys with minimal post-processing of data. The basic outputs from an RTK receiver are precise 3D coordinates in latitude, longitude, and height with accuracies on the order of two centimeters horizontally and three centimeters vertically. The output is on the GPS datum of WGS-84 that the hydrographic collection software converted into South Dakota's NAD83 state plane south coordinate zone. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

Angostura Reservoir hydrographic survey was conducted in May of 2004 between reservoir elevation 3,178.5 and 3,179.0 (Reclamation project datum). The bathymetric survey was conducted using sonic depth recording equipment, interfaced with a 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 along closely spaced grid lines covering the reservoir area. Most transects (grid lines) were run somewhat in a perpendicular alignment to the reservoir at around 300-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 2004 underwater data was collected by a depth sounder that was calibrated by lowering a weighted cable below the boat with beads marking known depths. 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 produced an analog hard-copy chart of the measured depths. These graphed analog charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the computer recorded 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.

In the winter of 2005, a RTK GPS land topographic survey on a small portion of the upper reach of the Cheyenne River arm of the reservoir was completed. The survey was on the formed sediment delta around range lines 7A, 7, and 8 that were inaccessible during the 2004 boat survey (figure 3). The above water data was limited, but the area covered provided adequate information for developing updated contours for elevations 3,175 and 3,180. The 2005 surveyed data determined changes in the digitized original contours and at several of the range lines. The 2005-surveyed elevation data were collected in NAVD88 and was shifted to match the project vertical datum during processing. The results of the 2005 land survey showed little change, since 1979, at range lines 7, 7A and 8. Following is a summary of a visual interpretation of the average bottom elevation from the 1979 range line plots and the 2005 elevation data collected near the range line alignment.

Range Line	1979	2005
7	3,175	3,178
7A	3,175	3,179
8	3,183	3,184

A land survey cannot account for the full extent of change that has occurred on Angostura Reservoir. As documented in the 1965 survey report, there was extensive measured shoreline erosion on many of the range lines. For this study, a complete aerial survey of the reservoir would have been required to accuracy measure the surface area from elevation 3,175 and above.

Figure 3- Layout of reservoir sedimentation range lines.

Angostura Reservoir Datum

Prior to the reservoir underwater survey, the hydrographic survey crew conducted a RTK GPS survey from the NGS control point "HSR A" to tie horizontal and vertical control to a temporary point used for this study and to the reservoir water surface. All vertical information for this study is referenced to the Reclamation reservoir water surface gauge measurements that were found to be near the NGVD29 and around two feet lower than NAVD88. The horizontal control was in the South Dakota state plane south coordinate zone in NAD83.

History of Surveys

In 1940-41, Reclamation conducted a detailed topographic survey of the Angostura dam site and a 5-foot contour topographic survey of the reservoir area. The original sedimentation range lines were established to be used to monitor sediment inflow. The original area and capacity tables for the reservoir were determined from the 5-foot topographic survey.

The first Reclamation resurvey of Angostura Reservoir sedimentation range lines was conducted in the summer and fall of 1965. A total of 39 range lines were surveyed. The volume of sediment accumulation was computed by a constant-factor method that is based on the principle of the average end area procedure to compute volumes. Using a gravity core sampler eighteen samples were collected throughout the reservoir. The samples were analyzed for particle-size distribution throughout the reservoir (Bureau of Reclamation, January 1967).

A second Reclamation resurvey of Angostura Reservoir was conducted in the spring of 1979 when 44 reservoir sedimentation ranges were surveyed. The volume of sediment accumulation was computed by the width adjustment method (Pemberton, 1980). This method is a variation of the average end area procedure. Using a gravity core sampler sixteen samples were collected throughout the reservoir. The samples were analyzed for particle size and unit weight (Bureau of Reclamation, August 1983). The 1979 area and capacity results were modified using 1986 aerial data. The new tables were generated using the 1979 surface area results from elevation 3,115 through 3,190 and the 1986 aerial data from elevation 3,198 through 3,230. The 1986 computed area at elevation 3,198.1 was about 100 acres larger than the original computed surface area at the same elevation.

2004 SEDIMENTATION SAMPLING AND SOIL ANALYSIS

The previous Angostura sedimentation surveys in 1965 and 1979 collected sediment samples for particle size and unit weight values. In 2004, samples were collected at three locations to establish baseline soil analysis data of the sediment deposited in Angostura Reservoir. The 2004 samples were analyzed for chemical composition not covered by previous studies. The three locations were in the bay where Horsehead Creek flows into the reservoir, in the upper reservoir where the Cheyenne River flows into the reservoir, and approximately 300-feet directly upstream from the radial gates of the dam.

The 2004 samples were collected to record base line sediment analysis information on the reservoir that might be helpful in future investigations. One of the current activities that might be of future concern is the coal bed methane (CBM) development that is located upstream of the reservoir in Wyoming. This activity has the potential for increasing salt loads into the drainages upstream of the reservoir. In addition, the "Upper Cheyenne Watershed Assessment" is being conducted by the State of South Dakota in Pennington, Custer, and Fall River Counties. The long-term goal of the assessment is to locate and document non-point source pollution in the watershed and produce feasible restoration recommendations.

From the survey vessel, a gravity core sampler was used to collect the 2004 Angostura Reservoir sediment samples near the dam. A soil core sampler collected the other samples since the reservoir was low due to several years of dry weather. Duplicate samples were taken at each site for a total of six samples.

The samples were shipped in coolers to the Reclamation Water & Soil Laboratory in Bismarck, North Dakota. The plastic core sleeves were cut away from the soil cores, that varied in length from 9 to 26 inches, and were set out to air dry. After drying, the first 4 inches of each core, and the remaining soil in each core, were treated as individual samples. They were ground, homogeneously mixed, and a 1 to 4- water digestion and extract was performed. Most of the analyses were performed on a diluted sample of this extract. The exceptions were for Total Phosphate, Total Kjeldahl Nitrogen, and Mercury that had analyses run directly off the dried sediment. The results from the analyses are listed on tables 3 through 6.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Angostura Reservoir was developed from the 2004 collected underwater data, 2005 land survey data, and the digitized contours from the USGS quad and Reclamation maps. The digitized contour lines of Angostura Reservoir were elevations 3,175 and 3,187. The USGS quad maps were developed from aerial photography dated 1948 and the Reclamation contour, elevation 3,175, was from original developed topography of the reservoir. The developed digital Reclamation map contours were somewhat blurry. ARC/INFO geographic information system (GIS) software was used to transform the digital contours to South Dakota's NAD 1983 state plane coordinates, south zone, to match the USGS quad and 2004-05 data. This study found the enclosed digitized contour area, with the island surfaces removed, to be within a few percent of the original surface area at the same elevation. The 2005 survey data was used to adjust the 3,175 contour and to project the surface area loss due to the above water sediment delta that had formed from the Cheyenne River's sediment inflow.

The adjusted contour, elevation 3,175, was used to perform a hardclip around the 2004-05 data of Angostura Reservoir. This hardclip was used during the triangular irregular network (TIN) development so interpolation did not occur outside the enclosed polygon. This contour was selected since it was the closest data available to represent the water surface during the 2004 survey. Using ARCEDIT, the 2004 underwater and 2005 land data along with the 3,175 and 3,187 contours were plotted. The plot showed that the underwater data did not lie completely within the 3,175 clip, which required modifications to include the entire underwater data set within this enclosed polygon. Using select and move commands within ARCEDIT, the vertices of the clip were shifted to contain the 2004 underwater data. Using the 2005 land survey data the clip was further modified in the upper end where a significant loss of area due to sedimentation accumulation had occurred on the Cheyenne River arm of the reservoir. This adjusted clip was assigned an elevation of 3,175.0.

Contours for the reservoir below elevation 3,175.0 were computed from the 2004-05 data sets 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 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 Angostura 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 Angostura Reservoir since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the survey data for elevations 3,120.0 through 3,175.0.

A 2005 land survey was performed on the Cheyenne River reach in the upper reservoir to measure the sediment delta formation. This area was not accessible during the 2004 underwater survey due to shallow water or dry conditions. The data from the 2005 survey was used to adjust the Reclamation 3,175 contour and to project the surface area loss since the original areas were measured for contours 3,180. Since no complete reservoir aerial data was collected, this study assumed no change in reservoir surface area since the 1979 survey for elevation 3,187.2 and above. The reservoir contour topography at 2-foot intervals is presented on figures 4 through 8.

Development of 2004 Surface Areas

The 2004 TIN generated surface areas for Angostura Reservoir were computed at 1-foot increments from elevation 3,120.0 to 3,175.0. The 2004 underwater survey measured a minimum reservoir bottom elevation of 3,119.6. 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. For the purpose of this study, the measured 2004 survey areas at 2-foot and 5-foot increments from elevation 3,120.0 through 3,175.0 were used to compute the new area and capacity tables. Using ARC/INFO edit tools, the 3,175 contour was adjusted in the upper end of the reach, within some of the reservoir coves and along the shores, using the Reclamation and USGS quad contours, the 2004 bathymetry, and the 2005 land survey data as a guide. This study assumed no change in surface area, since the 1979-86 survey, from elevation 3,187.2 and above. The surface area at elevation 3,180 was interpolated using the limited 2005 land survey data that provided adequate information for developing this contour in the upper end of the reservoir. There was not enough data for computer development of the 3,175 and 3,180 contours in the lower reservoir. As noted previously, the 2005 surface area elevations for range lines 7, 7A, and 8 did not differ significantly since the 1979 survey. The only accurate means to develop contours and resulting surface areas at elevation 3,175 and above would be by an aerial survey. The 2005 data did allow projection of contours 3,175 and 3,180 in the upper reservoir area by assuming no change of these contours for the rest of the reservoir.

2004 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). The 2004 surveyed surface areas at 2- and 5-foot contour intervals from reservoir elevation 3,120.0 to elevation 3,175.0 were used as the control parameters for computing the 2004 Angostura Reservoir capacity. Since this study collected only limited above water data, the interpolated survey area at elevation 3,180 and the 1979-86 surface area at elevation 3,187.2 and at 5-foot increments for elevation 3,190.0 and above were used to complete the area and capacity tables.

The ACAP 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 Angostura 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 a 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. By differentiating the capacity equations, which are of second order polynomial form, the final area equations are derived:

$$y = a_1 + a_2x + a_3x^2$$

where:
- y = capacity
- x = elevation above a reference base
- a_1 = intercept
- a_2 and a_3 = coefficients

Results of the Angostura Reservoir area and capacity computations are listed in table 1 and columns 12 and 13 of table 2. On table 2, columns 2 and 3 list the original area and capacity values. Columns 4 and 5 list the 1965 surface areas and capacity values. Column 8 and 9 list the 1979-86 surface area and capacity values. A separate set of 2004 area and capacity tables has been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2004). A description of the computations and coefficients output from the ACAP program is included with those tables. The original, 1965, 1979-86, and 2004 area-capacity curves are plotted on figure 9. As of May 2004, at conservation pool elevation 3,187.2, the surface area was 4,612 acres with a total capacity of 123,048 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Figure 9 is a plot of Angostura Reservoir surface area and capacity for the original, 1965, 1979-86, and 2004 computed values. The plots illustrate the differences between the surveys. Since Angostura Dam closure in October of 1949, the measured total volume change at reservoir elevation 3,187.2 was estimated to be 36,871 acre-feet. The estimated average annual rate of

capacity lost for this period (54.6 years) was 675.3 acre-feet per year. The storage loss in terms of percent of original storage capacity was 23.0 percent at elevation 3,187.2. From table 1 and 2, the 2004 study shows that of the total computed sediment, 49.0 percent or 18,062 acre-feet, has accumulated in dead storage zone below elevation 3,139.75 with the rest accumulating in the active storage areas of the reservoir.

It must be noted that the 2004 area and capacity tables were generated assuming no change since the 1979-86 surveyed area and capacity from elevation 3,187.2 and above which in all probability is not the case. It is assumed any loss due to sediment deposition above elevation 3,187.2 would not be significant, but the only means to measure this would be by an aerial survey. As noted previously, the 2005 land survey did not measure significant changes in average bottom elevation at range lines 7A, 7, and 8. Similar results were found during the 1979 range line survey for the range lines located upstream of range line 7 and 8. As illustrated on figure 10 this is a typical reservoir sediment deposition profile where a pivot point of the depositing delta is near the normal water surface of the reservoir that for Angostura Reservoir is near elevation 3,180 (Bureau of Reclamation, 1982). The 1979 study developed a longitudinal profile of the Cheyenne River that further illustrates this, figure 11. The 1965 and 1979 profile comparison shows the face of the upper sediment delta pushing further downstream towards the dam. The 2005 data did not measure a significant change in average bottom elevation at range line 7 and 8 since 1979, but the 2004 developed contours show the measure sediment delta moving further downstream towards the dam.

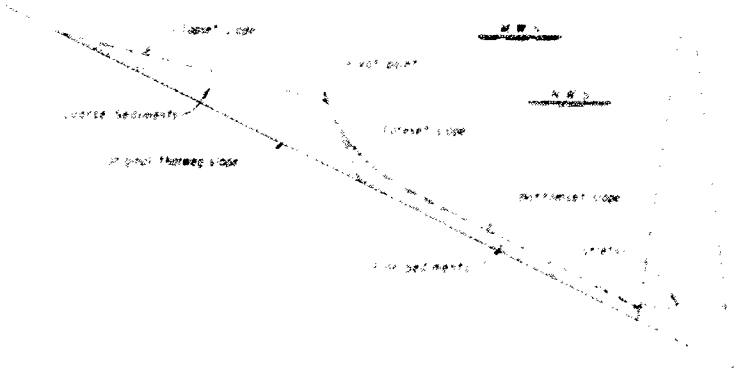

Figure 10 - Typical sediment deposition profile.

The estimated 100 years of sediment accumulation for Angostura Reservoir was 170,000 acre-feet that computed to an annual loss of 1,700 acre-feet. The 170,000 acre-feet of estimated sediment accumulation is greater than the original measured volume at conservation elevation 3,187.2, meaning a total loss of the original reservoir volume was projected. The 1965 study measured a total sediment volume of 21,158 acre-feet that computed to an annual loss of 1,322 acre-feet. The measured volume of sediment accumulation from 1965 to 1979 was 7,993 acre-feet that computed to an average annual rate of 588 acre-feet. This was a significant reduction in the average annual loss since the 1965 survey. This reduction in sediment yield from the

drainage basin was supported by a study made by the Wyoming District of the USGS on Lance Creek that is a major tributary to Cheyenne River. The study compared the average discharge and suspended sediment for two periods. The study attributed the reduced sediment discharge from Lance Creek to a change in land use in the basin. The study concluded that due to fewer domestic livestock grazing the basin, vegetation cover improved resulting in less sediment runoff. The 2004 study measured a further reduction in the annual loss rate of 308.8 acre-feet.

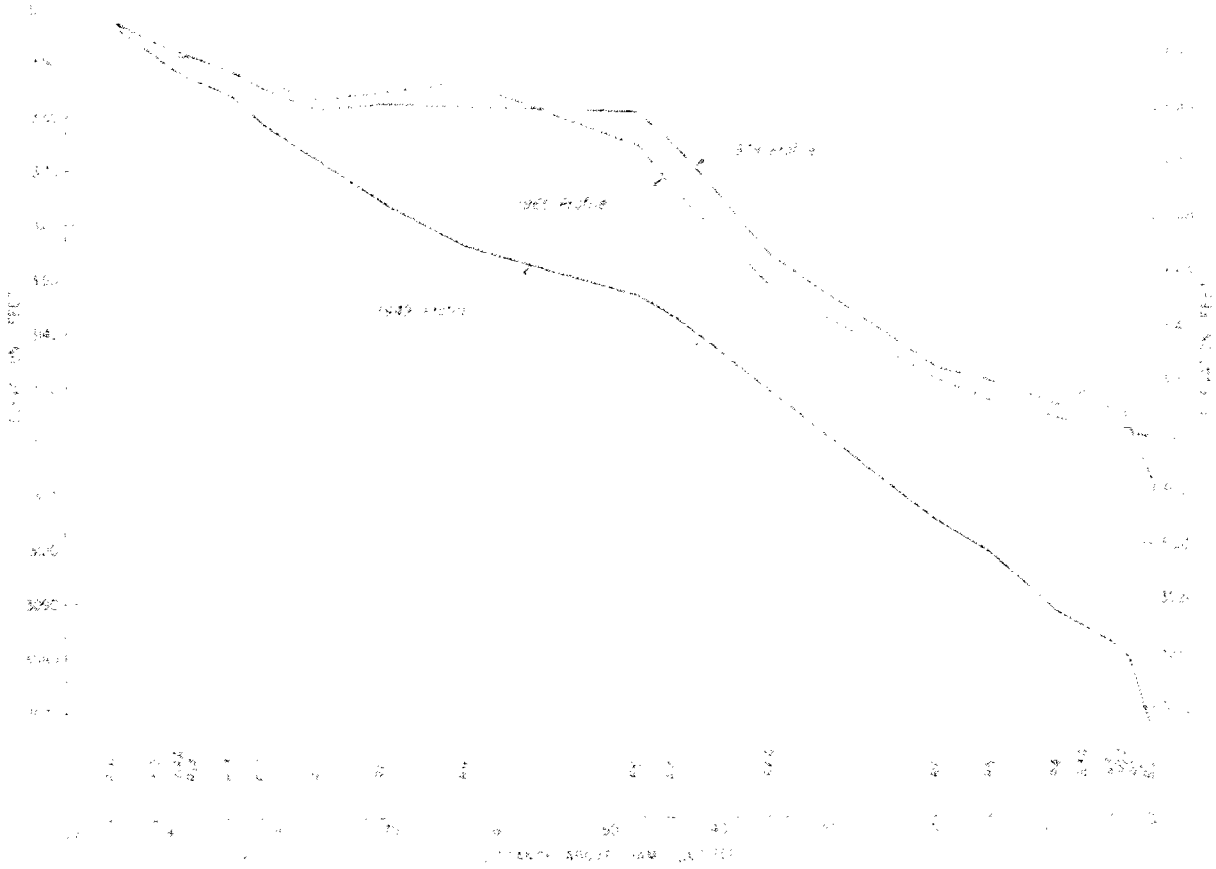

Figure 11 - Longitudinal profiles of the Cheyenne River for the 1949, 65, and 79 surveys.

REFERENCES

American Society of Civil Engineers, 1962. ***Nomenclature for Hydraulics***, ASCE Headquarters, New York.

Bureau of Reclamation, January 1967. Sedimentation Section of Denver Office, ***The 1965 Sedimentation Survey of Angostura Reservoir, South Dakota,*** Denver, Colorado.

Bureau of Reclamation, 1981. ***Project Data,*** Denver Office, Denver CO.

Bureau of Reclamation, 1982. ***Reservoir Sedimentation,*** Sedimentation and River Hydraulics Section by Robert I. Strand and Ernest L. Pemberton, Denver CO.

Bureau of Reclamation, August 1983. Hydrology Branch of Denver Office by Joe M. Lara. ***Angostura Reservoir 1979 Sedimentation Survey,*** Denver, Colorado.

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 2004. Denver Office, ***Angostura Reservoir Area and Capacity Tables, Pick-Sloan Missouri Basin Project***, Great Plains Region, Billings, MT.

Corps of Engineers, January 2002. *Engineer and Design* - ***Hydrographic Surveying,*** EM 1110-2-1003, Department of the Army, Washington DC, (www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1003/toc.htm).

Environmental Systems Research Institute, Inc. (ESRI), 1992. ***ARC Command References.***

Pemberton, E. L., **Survey and Prediction of Sedimentation in Reservoirs,** Application of Stochastic Processes in Sediment Transport, Water Resources Publications, Denver, Colorado, 1980.

RESERVOIR SEDIMENT
DATA SUMMARY

Angostura Reservoir

NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation		2. STREAM Cheyenne River		3. STATE South Dakota	
	4. SEC. 20 TWP. 8S RANGE 6 E		5. NEAREST P.O. Hot Springs		6. COUNTY Fall River	
	7. LAT 43° 20' 35" LONG 103° 26' 16"		8. TOP OF DAM ELEVATION 3,199.0		9. SPILLWAY CREST EL 3,157.2[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	3,198.1[2]	5,797	57,785	217,700	
	b. FLOOD CONTROL					
	c. POWER					10/03/49
	d. JOINT USE					16. DATE NORMAL OPERATION
	e. CONSERVATION	3,187.2	4,841	90,655	159,919	
	f. INACTIVE	3,163.0	2,722	45,544	69,264	
	g. DEAD	3,139.75	1,251	23,720	23,720	1949
	17. LENGTH OF RESERVOIR 17[3] MILES			AVG. WIDTH OF RESERVOIR 0.44 MILES		
BASIN	18. TOTAL DRAINAGE AREA 9,100[4] SQUARE MILES			22. MEAN ANNUAL PRECIPITATION 17.5[5] INCHES		
	19. NET SEDIMENT CONTRIBUTING AREA 9,100 SQUARE MILES			23. MEAN ANNUAL RUNOFF 0.17[6] INCHES		
	20. LENGTH 184 MILES	AV. WIDTH 49.5 MILES		24. MEAN ANNUAL RUNOFF 81,500[7] ACRE-FEET		
	21. MAX. ELEVATION 7165	MIN. ELEVATION 3065		25. ANNUAL TEMP. MEAN °48F RANGE -41°F to 112°F[5]		

SURVEY DATA

26. DATE OF SURVEY	27. PER.	28. ACCL	29. TYPE OF SURVEY	30. NO. OF RANGES OR	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO
10/3/49			Contour (D)	5-ft	4,841[8]	159,919[8]	0.87
9/22/65	16.0	16.0	Range (D)	39	4,706	138,761	0.75
5/4/79	13.6	29.6	Range (D)	45	4,612	130,768	0.67
5/04	25.0	54.6	Contour (D)	2-ft	4,612	123,048	0.66

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
9/22/65	6-19	96,500	328,300	1,544,020	96,500	1,544,020
5/4/79	6-19	91,270[9]	282,218	1,185,689	94,128	2,729,709
5/04		74,000	234,300	1,850,000	81,500	4,579,700

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.
9/22/65	21,158	1,322.4	0.14	21,158	1,322.4	0.14
5/4/79	7,993	587.7	0.06	29,151	984.8	0.11
5/04	7,720[10]	308.8	0.034	36,871	675.3	0.074

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR.		41. STORAGE LOSS, PCT.		42.	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
9/22/65	56.4	178	178	0.827[10]	13.2[10]		
5/4/79				0.616	18.2		
5/04				0.422	23.0		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
		3065-3120	3120-3130	3130-3140	3140-3150	3150-3160	3160-3170	3170-3180	3180-3187.		
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
5/04		19.4	15.5	14.4	10.4	10.5	11.2	12.3	6.3		

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

Table 1. - Reservoir sediment data summary (page 1 of 3).

45. RANGE IN RESERVOIR OPERATION[9]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1952	3,187.1	-	72,800	1953	3,182.5	3,173.8	55,800
1954	3,177.8	3,172.8	34,600	1955	3,187.4	3,172.5	143,600
1956	3,187.1	3,171.4	36,500	1957	3,187.9	3,170.1	145,600
1958	3,187.4	3,179.5	93,100	1959	3,180.7	3,167.4	28,100
1960	3,173.1	3,162.9	21,600	1961	3,166.4	3,162.9	14,000
1962	3,189.0	3,163.6	399,400	1963	3,187.4	3,182.0	86,500
1964	3,187.3	3,178.7	38,800	1965	3,187.9	3,178.3	117,500
1966	3,187.3	3,182.6	58,100	1967	3,188.0	3,181.5	170,300
1968	3,187.6	3,180.8	61,100	1969	3,187.6	3,181.5	85,400
1970	3,187.2	3,176.9	24,000	1971	3,188.4	3,176.8	181,200
1972	3,187.3	3,178.5	44,300	1973	3,187.3	3,179.0	66,900
1974	3,187.3	3,174.8	37,600	1975	3,184.2	3,174.6	42,100
1976	3,182.1	3,174.6	38,400	1977	3,179.2	3,169.2	25,600
1978	3,189.4	3,170.3	282,100	1979	3,187.2	3,184.4	62,500
1980	3,187.2	3,176.8	35,800	1981	3,179.7	3,171.7	34,900
1982	3,187.2	3,171.7	94,800	1983	3,187.1	3,179.6	48,800
1984	3,187.2	3,178.3	97,600	1985	3,182.9	3,169.9	21,600
1986	3,187.6	3,170.1	125,100	1987	3,187.3	3,178.1	83,400
1988	3,181.1	3,169.2	17,300	1989	3,173.9	3,165.8	21,300
1990	3,175.0	3,167.7	29,900	1991	3,187.6	3,167.9	201,900
1992	3,183.2	3,174.9	18,500	1993	3,187.1	3,174.9	104,400
1994	3,187.0	3,175.9	58,000	1995	3,187.1	3,175.9	67,300
1996	3,187.2	3,177.9	75,000	1997	3,187.2	3,177.9	178,100
1998	3,187.1	3,183.6	61,000	1999	3,187.2	3,181.9	234,300
2000	3,187.3	3,176.7	109,500	2001	3,186.6	3,176.7	57,200
2002	3,184.6	3,173.7	16,600	2003	3,179.1	3,165.3	42,800
2004	3,176.3	3,165.5	16,100				

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

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
Orignal								
3,065	0	0	3,070	16	42	3,075	18	128
3,080	22	230	3,085	38	373	3,090	77	659
3,095	99	1,097	3,100	152	1,723	3,105	193	2,583
3,110	266	3,725	3,115	340	5,236	3,120	441	7,167
3,125	630	9,825	3,130	835	13,482	3,135	1,065	18,235
3,139.75	1,251	23,720	3,145	1,580	31,118	3,150	1,840	39,669
3,155	2,170	49,677	3,160	2,520	61,401	3,163	2,722	69,264
3,170	3,245	90,082	3,175	3,720	107,474	3,180	4,210	127,307
3,185	4,650	149,471	3,187.2	4,841	159,919	3,190	5,080	173,804
3,195	5,490	200,213	3,198.1	5,797	217,700			
1965	**Survey**							
3,110	0	0	3,115	5	12	3,120	30	39
3,125	110	449	3,130	610	2,253	3,135	980	6,275
3,139.75	1,094	11,203	3,145	1,380	17,640	3,150	1,700	25,310
3,155	2,000	34,672	3,160	2,350	45,431	3,163	2,485	52,601
3,170	3,170	72,309	3,175	3,450	88,718	3,180	4,050	107,552
3,185	4,420	128,563	3,187.2	4,706	138,761	3,190	5,080	152,478
3,195	5,490	178,888	3,198.1	5,700	196,221			
1979-86	**Survey**							
3,115	0	0	3,120	3	7	3,125	69	187
3,130	275	1,047	3,135	889	3,957	3,139.75	1,065	8,601
3,145	1,275	14,737	3,150	1,517	21,717	3,155	1,998	30,505
3,160	2,288	41,220	3,163	2,449	48,325	3,170	2,892	66,950
3,175	3,317	82,472	3,180	3,861	100,417	3,185	4,340	130,920
3,187.2	4,612	130,768	3,190	4,959	144,167	3,195	5,529	170,386
3,198.1	5,883	188,072	3,199	6,002	193,421	3,200	6,135	199,489
2004	**Survey**							
3,119.6	0	0	3,125	37.3	47	3,130	196.0	613
3,135	515.7	2,329	3,139.75	838.4	5,658	3,145	1,198.4	10,940
3,150	1,474.4	17,642	3,155	1,775.0	25,736	3,160	2,136.9	35,528
3,163	2,314	42,205	3,170	2,789.9	60,058	3,175	3,262.9	75,126
3,180	3,797.0	92,775	3,185	4,363.0	113,175	3,187.2	4,612	123,048
3,190	4,959	136,447	3,195	5,529	162,667	3,198.1	5,883	180,356

Table 1. - Reservoir sediment data summary (page 2 of 3).

47. REMARKS AND REFERENCES

1 Spillway crest elevation. Top of gates elevation 3,187.2. All elevations in feet. Based on original project datum reported as NGVD29.

2 Original values computed from 5-foot contours as listed in 1979 survey report.

3 Total of main streams at elevation 3,087.2.

4 From USGS water year records.

5 Bureau of Reclamation Project Data Book, 1981 and 1979 survey study report.

6 Calculated using mean annual computed inflow value of 81,500 AF, item 24, 1952 through 2004.

7 Annual computed inflows by Reclamation GP Regional Office. Water years from 1952 through 2004.

8 Surface area & capacity at elevation 3,187.2, top of active conservation, by indicated year.

9 Maximum and minimum elevations and annual computed inflows by water year from 1952 through 2004 (Reclamation computed values and records).

10 All sediment computations are computed by comparing survey results with the original results at elevation 3,187.2. This assumed the original data is of a reliable accuracy. The 2004 survey assumed no change since the 1979 survey from elevation 3,187.2 and above. Computed storage loss is due to accuracy differences between original and 2004 surveys and due to accumulation of sediment.

11 Capacities computed by Reclamation's ACAP computer program.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE August 2005

Table 1. - Reservoir sediment data summary (page 3 of 3).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
					1965				1979-86						
					Computed	1965			Total	1979-86			Sediment	Percent	
	Original	Original	1965	1965	Sediment	Percent	1979-86	1979-86	Sediment	Percent	2004	2004	Volume	Computed	Percent
Elevation	Survey	Capacity	Survey	Survey	Volume	Computed	Survey	Survey	Volume	Computed	Survey	Survey	Original	Sediment	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Sediment	Acres	Ac-Ft	Ac-Ft	Total	Depth
3198.1	5797	217700	5790	196221	21479		5883	188072	29628		5883.0	180356	37344		100.0
3195	5490	200213	5490	178888	21325		5529	170386	29827		5529.0	162667	37546		97.7
3190	5080	173804	5080	152478	21326		4959	144167	29637		4959.0	136447	37357		93.9
3187.2	4841	159919	4706	138761	21158	100.0	4612	130768	29151	100.0	4612.0	123048	36871	100.0	91.8
3185	4650	149471	4420	128563	20908	98.8	4340	120920	28551	97.9	4363.0	113175	36296	98.4	90.2
3180	4210	127307	4050	107552	19755	93.4	3861	100417	26890	92.2	3797.0	92775	34532	93.7	86.4
3175	3720	107474	3450	88718	18756	88.6	3317	82472	25002	85.8	3262.9	75126	32348	87.7	82.6
3170	3245	90082	3170	72309	17773	84.0	2892	66950	23132	79.4	2789.9	60058	30024	81.4	78.9
3165	2860	74854	2600	57765	17089	80.8	2556	53330	21524	73.8	2442.8	46955	27899	75.7	75.1
3163	2722	69264	2485	52601	16663	78.8	2449	48325	20939	71.8	2314.0	42205	27059	73.4	73.6
3160	2520	61401	2350	45431	15970	75.5	2288	41220	20181	69.2	2136.9	35528	25873	70.2	71.4
3155	2170	49677	2000	34672	15005	70.9	1998	30505	19172	65.8	1775.0	25736	23941	64.9	67.6
3150	1840	39669	1700	25310	14359	67.9	1517	21717	17952	61.6	1474.4	17642	22027	59.7	63.9
3145	1580	31118	1380	17640	13478	63.7	1275	14737	16381	56.2	1198.4	10940	20178	54.7	60.1
3140	1260	24030	1100	11484	12546	59.3	1074	8865	15165	52.0	855.4	5871	18159	49.3	56.3
3139.75	1251	23720	1094	11203	12517	59.2	1065	8598	15122	51.9	838.4	5658	18062	49.0	56.2
3135	1065	18235	980	6275	11960	56.5	889	3957	14278	49.0	515.7	2329	15906	43.1	52.6
3130	835	13482	610	2253	11229	53.1	275	1047	12435	42.7	196.0	613	12869	34.9	48.8
3125	630	9825	110	488	9337	44.1	69	187	9638	33.1	37.3	47	9778	26.5	45.1
3120	441	7167	30	39	7128	33.7	3	7	7160	24.6	0.2	0	7167	19.4	41.3
3115	340	5236	5	12	5224	24.7	0	0	5236	18.0	0.0	0	5236	14.2	37.6
3110	266	3725	0	0	3725	17.6	0	0	3725	12.8	0.0	0	3725	10.1	33.8
3105	193	2583	0	0	2583	12.2	0	0	2583	8.9	0.0	0	2583	7.0	30.1
3100	152	1723	0	0	1723	8.1	0	0	1723	5.9	0.0	0	1723	4.7	26.3
3095	99	1097	0	0	1097	5.2	0	0	1097	3.8	0.0	0	1097	3.0	22.5
3090	77	659	0	0	659	3.1	0	0	659	2.3	0.0	0	659	1.8	18.8
3085	38	373	0	0	373	1.8	0	0	373	1.3	0.0	0	373	1.0	15.0
3080	22	230	0	0	230	1.1	0	0	230	0.8	0.0	0	230	0.6	11.3
3075	18	128	0	0	128	0.6	0	0	128	0.4	0.0	0	128	0.3	7.5
3070	16	42	0	0	42	0.2	0	0	42	0.1	0.0	0	42	0.1	3.8
3065	0	0	0	0	0	0.0	0	0	0	0.0	0.0	0	0	0.0	0.0

1	Elevation of reservoir water surface.
2	Original reservoir surface areas.
3	Original reservoir capacity computed using ACAP.
4	1965 measured reservoir surface area.
5	1965 reservoir capacity.
6	1965 computed sediment volume, column (3) - column (5).
7	1965 measured sediment in percentage of total sediment, 21,158 acre-feet, by elevation.
8	1979-86 measured reservoir surface area. Areas for elevation 3,198 and above from 1986 aerial survey.
9	1979-86 reservoir capacity.
10	1979-86 measured sediment volume = column (3) - column (9).
11	1979-86 measured sediment in percentage of total sediment, 29,151 acre-feet, by elevation.
12	2004 measured reservoir surface area. Study assume no change since 1979 from elevation 3,187.2 and above.
13	2004 reservoir capacity computed using ACAP.
14	2004 computed sediment volume, column (3) - column (13).
15	Measured sediment in percentage my elevation from original to 2004. Total sediment volume of 36,871 acre-feet.
16	Depth of reservoir expressed in percentage of total depth (131.1), from maximum water surface.

Table 2. - Summary of 2004 survey results

Report of Water Analysis
U.S. Bureau of Reclamation
Dakotas Area Office
Water & Soil Laboratory
Bismarck, North Dakota

3/9/2005

Study Area: Angostura Reservoir / Cheyenne River, SD
Project: Angostura Reservoir / Cheyenne River, SD

Laboratory Number:		2400641	2400642	2400643	2400644	2400645	2400646	2400647	2400648	2400649	2400650
Site ID:		CR1 Top	CR1 Bot	CR2 Top	CR2 Bot	HHR1 Top	HHR1 Bot	HHR2 Top	HHR2 Bot	Dam 1 Top	Dam 1 Bot
Quality Control											
Date Collected:		5/12/2004	5/12/2004	5/12/2004	5/12/2004	5/12/2004	5/12/2004	5/12/2004	5/12/2004	5/10/2004	5/10/2004
Time Collected:											
Field Data											
Water Temperture	(C)										
EC @ 25C	(mmhos/cm)										
pH											
Dissolved Oxygen	(mg/l)										
% Dissolved Oxygen	(Sat)										
Salinity	(PSS)										
ORP	(MV)										
Turbidity	(FTU)										
Secchi Disk Reading	(meters)										
Sample Depth	(inches)	1 - 4	4 - 13 1/4	1 - 4	4 - 13 1/2	1 - 4	4 - 11 1/2	1 - 4	4 - 9	1 - 4	4 - 26 1/4
1 to 4 Soil / Water Digest Data											
Major Cations											
Calcium	(mg/l)	142.2	110.6	91.8	57.8	43.2	49.8	23.6	23.2	296.0	150.8
Magnesium	(mg/l)	33.6	28.4	25.8	20.6	12.6	9.2	6.2	5.8	69.4	42.6
Potassium	(mg/l)	12.2	12.6	14.4	12.2	8.6	12.4	9.8	13.0	19.2	16.0
Sodium	(mg/l)	67.2	62.6	69.8	74.4	60.2	47.8	50.8	42.8	113.6	91.0
Major Anions											
Alkalinity (as CaCO3)	(mg/l)	123.1	99.9	110.1	118.0	34.5	26.9	21.9	16.4	131.1	90.4
Chloride	(mg/l)	32.8	31.0	43.1	59.8	23.7	19.2	16.4	13.4	75.0	67.4
Sulfate	(mg/l)	486.6	418.9	361.5	247.4	248.3	229.1	169.1	157.7	1015.0	546.6
Nutrients											
Ammonia (NH3-N)	(mg/l)	2.47	3.20	5.53	5.52	0.12	<0.1	0.63	1.62	2.12	5.50
Nitrate+Nitrite(NO3-N)	(mg/l)	0.28	0.35	0.32	0.25	0.28	0.32	1.00	0.37	0.25	0.12
Nitrite (NO2-N)	(mg/l)	0.25	0.19	0.18	0.15	0.05	0.14	0.11	0.12	0.15	0.04
Ortho-Phosphate (P)	(mg/l)	0.02	<.01	<.01	0.02	<.01	<.01	<.01	<.01	0.03	0.04
Calculated Values											
Total Dissolved Solids (mg/l)		851.3	727.5	678.3	548.8	417.7	384.0	290.6	267.8	1669.2	974.2
Sodium Adsorption Ratio		1.3	1.4	1.7	2.1	2.1	1.6	2.4	2.1	1.5	1.7
Hardness as mg CaCO3/l		493.4	393.1	335.5	229.2	159.8	162.2	84.5	81.8	1024.9	552.0
Cation/Anion Balance (%)		-1.0	-2.1	-2.2	-3.9	-4.0	-2.0	-3.4	-0.9	0.3	2.2
Direct Soil Digest Values											
Total Phosphate (P) (method SM4500-P-F)	(ug/g)	564	547	645	588	744	918	780	778	647	513
TKN (N) (method SM4500-N-B/NH3-E)	(ug/g)	1111	1087	1241	1118	1978	1749	1429	1039	1919	1124
Mercury (EPA Method 7471)	(ug/g) (RL = .04)	0.062	0.052	0.040	0.042	0.119	0.073	0.069	0.040	0.041	0.063

Table 3. - Summary of sediment sample analyses for 2004 survey (1 of 4).

Report of Water Analysis
U.S. Bureau of Reclamation
Dakotas Area Office
Water & Soil Laboratory
Bismarck, North Dakota

3/9/2005

Study Area: Angostura Reservoir / Cheyenne River, SD
Project: Angostura Reservoir / Cheyenne River, SD

Laboratory Number:		2400651	2400652	2400653	2400654						
Site ID:		Dam 2 Top	Dam 2 Bot	Dam 1 Bot	Blank						
Quality Control				DUP	Blank						
Date Collected:		5/10/2004	5/10/2004	5/10/2004							
Time Collected:											
Field Data											
Water Temperture	(C)										
EC @ 25C	(mmhos/cm)										
pH											
Dissolved Oxygen	(mg/l)										
% Dissolved Oxygen	(Sat)										
Salinity	(PSS)										
ORP	(MV)										
Turbidity	(FTU)										
Secchi Disk Reading	(meters)										
Sample Depth	(inches)	1 - 4	4 - 21 1/4	4 - 26 1/4							
1 to 4 Soil / Water Digest Data											
Major Cations											
Calcium	(mg/l)	318.0	141.0	142.2	0.6						
Magnesium	(mg/l)	82.8	38.8	39.8	< 0.1						
Potassium	(mg/l)	21.4	17.4	15.4	< 0.2						
Sodium	(mg/l)	132.0	103.4	90.6	0.4						
Major Anions											
Alkalinity (as CaCO3)	(mg/l)	116.1	95.5	84.6	12.6						
Chloride	(mg/l)	113.8	88.0	63.8	0.6						
Sulfate	(mg/l)	1124.5	508.8	522.7	<.5						
Nutrients											
Ammonia (NH3-N)	(mg/l)	4.06	5.95	5.49	0.13						
Nitrate+Nitrite(NO3-N)	(mg/l)	0.15	0.15	0.12	<0.1						
Nitrite (NO2-N)	(mg/l)	0.03	0.03	0.03	<.02						
Ortho-Phosphate (P)	(mg/l)	0.04	0.03	0.02	<.01						
Calculated Values											
Total Dissolved Solids	(mg/l)	1866.4	960.8	930.9							
Sodium Adsorption Ratio		1.7	2.0	1.7							
Hardness as mg CaCO3/l		1135.0	511.9	519.0							
Cation/Anion Balance	(%)	0.5	2.0	2.4							
Direct Soil Digest Values											
Total Phosphate (P)	(ug/g)	766	547	541							
(method SM4500-P-F)											
TKN (N)	(ug/g)	2404	1429	1106							
(method SM4500-N-B/NH3-E)											
Mercury	(ug/g)	0.041	0.057	0.063							
(EPA Method 7471)	(RL = .04)										

Table 4. - Summary of sediment sample analyses for 2004 survey (2 of 4).

Report of Water Analysis
U.S. Bureau of Reclamation
Dakotas Area Office
Water & Soil Laboratory
Bismarck, North Dakota

3/9/2005

Study Area: Angostura Reservoir / Cheyenne River, SD
Project Classification: Angostura Reservoir / Cheyenne River, SD
Sampling Dates: 5/12/2004

Trace Metal Report (1 to 4 Soil / Water Digest)

All values in Parts Per Billion (ug/l)

Lab #	Site ID	Ag	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	S	Sb	Se	Sl	Tl	V	Zn
2400641	CR1 Top	<.4	63.8	<4	200.0	220.0	<.4	0.7	<4	<4	10.4	<50	<50	620.0	33.8	12.8	<4	176000	<4	11.6	4880	<4	<4	40.8
2400642	CR1 Bot	<.4	77.0	<4	134.0	240.0	<.4	0.4	<4	<4	6.4	<50	<50	360.0	33.2	6.8	<4	148000	<4	6.6	3080	<4	<4	47.6
2400643	CR2 Top	<.4	45.0	<4	260.0	260.0	<.4	0.5	<4	<4	10.0	<50	<50	360.0	67.2	11.4	<4	137000	<4	<4	2860	<4	<4	30.0
2400644	CR2 Bot	<.4	75.8	<4	240.0	240.0	<.4	0.5	<4	<4	8.6	<50	<50	180.0	64.4	7.6	<4	99200	<4	<4	3100	<4	<4	31.8
2400645	HHR1 Top	<.4	332.4	<4	260.0	<200	<.4	0.7	<4	<4	13.0	300.0	<50	100.0	6.2	6.6	<4	85000	<4	5.4	9540	<4	<4	42.2
2400646	HHR1 Bot	<.4	99.0	<4	260.0	<200	<.4	2.6	<4	<4	8.6	<50	<50	540.0	<4	10.6	<4	74400	<4	<4	8140	<4	<4	76.2
2400647	HHR2 Top	<.4	156.6	<4	260.0	<200	<.4	3.7	<4	<4	10.0	200.0	<50	360.0	<4	19.6	<4	55000	<4	<4	9500	<4	<4	120.0
2400648	HHR2 Bot	<.4	102.6	<4	200.0	<200	<.4	20.6	15.8	<4	9.0	<50	50.0	980.0	<4	61.2	<4	57200	<4	<4	7420	<4	<4	240.0
2400649	Dam 1 Top	<.4	<20	<4	260.0	300.0	<.4	1.8	5.4	<4	18.0	<50	72.0	4060.0	59.6	26.4	<4	392000	<4	8.8	6340	<4	<4	39.6
2400650	Dam 1 Bot	<.4	22.2	<4	74.0	360.0	<.4	2.4	<4	<4	8.6	<50	<50	440.0	42.0	9.4	<4	236000	<4	5.6	1840	<4	<4	32.4
2400651	Dam 2 Top	<.4	24.2	<4	132.0	300.0	<.4	2.3	5.2	4.0	20.2	<50	82.0	4220.0	61.8	31.2	<4	456000	<4	8.4	6000	<4	<4	50.8
2400652	Dam 2 Bot	<.4	<20	<4	86.0	400.0	<.4	1.5	<4	<4	15.0	<50	<50	900.0	64.2	13.2	<4	252000	<4	5.6	2560	<4	<4	35.2
2400653	Dam 1 Bot	<.4	31.4	<4	90.0	360.0	<.4	0.6	<4	<4	9.2	<50	<50	380.0	43.6	9.6	<4	230000	<4	5.8	1860	<4	<4	34.6
2400654	Blank	<.4	<20	<4	<50	<200	<.4	<.4	<4	<4	<4	<50	<50	<100	<4	<4	<4	<2000	<4	<4	<1000	<4	<4	9.6
Reporting Limit:		0.4	20	4	50	200	0.4	0.4	4	4	4	50	50	100.0	4	4	4	2000	4	4	1000	4	4	4

Table 5. - Summary of sediment sample analyses for 2004 survey (3 of 4).

Report of Water Analysis
U.S. Bureau of Reclamation
Dakotas Area Office
Water & Soil Laboratory
Bismarck, North Dakota

3/9/2005

Study Area: Angostura Reservoir / Cheyenne River, SD
Project Classification: Angostura Reservoir / Cheyenne River, SD
Sampling Dates: 5/12/2004 Trace Metal Report (1 to 4 Soil / Water Digest; Reported on Dry Weight Basis)

All values in Parts Per Million (ug/g or mg/kg)

Lab #	Site ID	Ag	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	S	Sb	Se	Si	Tl	V	Zn	Ca	Mg	Na	K
2400641	CR1 Top	<.002	0.255	<.016	0.800	0.880	<.002	0.003	<.016	<.016	0.042	<.2	<.2	2.480	0.135	0.051	<.016	704.0	<.016	0.046	19.52	<.016	<.016	0.163	568.8	134.4	268.8	48.8
2400642	CR1 Bot	<.002	0.308	<.016	0.536	0.960	<.002	0.002	<.016	<.016	0.026	<.2	<.2	1.440	0.133	0.027	<.016	592.0	<.016	0.026	12.32	<.016	<.016	0.190	442.4	113.6	250.4	50.4
2400643	CR2 Top	<.002	0.180	<.016	1.040	1.040	<.002	0.002	<.016	<.016	0.040	<.2	<.2	1.440	0.269	0.046	<.016	548.0	<.016	<.016	11.44	<.016	<.016	0.120	367.2	103.2	279.2	57.6
2400644	CR2 Bot	<.002	0.303	<.016	0.960	0.960	<.002	0.002	<.016	<.016	0.034	<.2	<.2	0.720	0.258	0.030	<.016	396.8	<.016	<.016	12.40	<.016	<.016	0.127	231.2	82.4	297.6	48.8
2400645	HHR1 Top	<.002	1.330	<.016	1.120	<.8	<.002	0.003	<.016	<.016	0.052	1.200	<.2	0.400	0.025	0.026	<.016	340.0	<.016	0.022	38.16	<.016	<.016	0.169	172.8	50.4	240.8	34.4
2400646	HHR1 Bot	<.002	0.396	<.016	1.040	<.8	<.002	0.010	<.016	<.016	0.034	<.2	<.2	2.160	<.016	0.042	<.016	297.6	<.016	<.016	32.56	<.016	<.016	0.305	177.6	36.8	185.6	44.8
2400647	HHR2 Top	<.002	0.626	<.016	1.040	<.8	<.002	0.015	<.016	<.016	0.040	0.800	<.2	1.440	<.016	0.078	<.016	220.0	<.016	<.016	38.00	<.016	<.016	0.480	86.4	24.8	198.4	35.2
2400648	HHR2 Bot	<.002	0.410	<.016	0.800	<.8	<.002	0.083	0.063	<.016	0.036	<.2	0.200	3.920	<.016	0.245	<.016	228.8	<.016	<.016	29.68	<.016	<.016	0.960	92.8	23.2	171.2	52.0
2400649	Dam 1 Top	<.002	<.08	<.016	1.040	1.200	<.002	0.007	0.022	<.016	0.072	<.2	0.288	16.240	0.238	0.106	<.016	1568.0	<.016	0.035	25.36	<.016	<.016	0.158	<.4	277.6	454.4	779.2
2400650	Dam 1 Bot	<.002	0.089	<.016	0.296	1.440	<.002	0.010	<.016	<.016	0.034	<.2	<.2	1.760	0.168	0.038	<.016	944.0	<.016	0.022	7.36	<.016	<.016	0.130	603.2	170.4	364.0	64.0
2400651	Dam 2 Top	<.002	0.097	<.016	0.528	1.200	<.002	0.009	0.021	0.016	0.081	<.2	0.328	16.880	0.247	0.125	<.016	1824.0	<.016	0.034	24.00	<.016	<.016	0.203	1272.0	331.2	528.0	85.6
2400652	Dam 2 Bot	<.002	<.08	<.016	0.344	1.600	<.002	0.006	<.016	<.016	0.060	<.2	<.2	3.600	0.257	0.053	<.016	1008.0	<.016	0.022	10.24	<.016	<.016	0.141	<.4	155.2	413.6	69.6
2400653	Dam 1 Bot	<.002	0.126	<.016	0.360	1.440	<.002	0.002	<.016	<.016	0.037	<.2	<.2	1.520	0.174	0.038	<.016	920.0	<.016	0.023	7.44	<.016	<.016	0.138	568.8	159.2	362.4	61.6
2400654	Blank	<.002	<.08	<.016	<.2	<.8	<.002	<.002	<.016	<.016	<.016	<.2	<.2	<.4	<.016	<.016	<.016	<8	<.016	<.016	<4	<.016	<.016	0.038	<.4	<.4	1.6	<.8
Reporting Limit:		0.002	0.080	0.008	0.200	0.800	0.002	0.002	0.016	0.016	0.016	0.200	0.200	0.400	0.016	0.016	0.016	8.0	0.016	0.016	4.00	0.016	0.016	0.016	0.4	0.4	0.4	0.8

Table 6. - Summary of sediment sample analyses for 2004 survey (4 of 4).

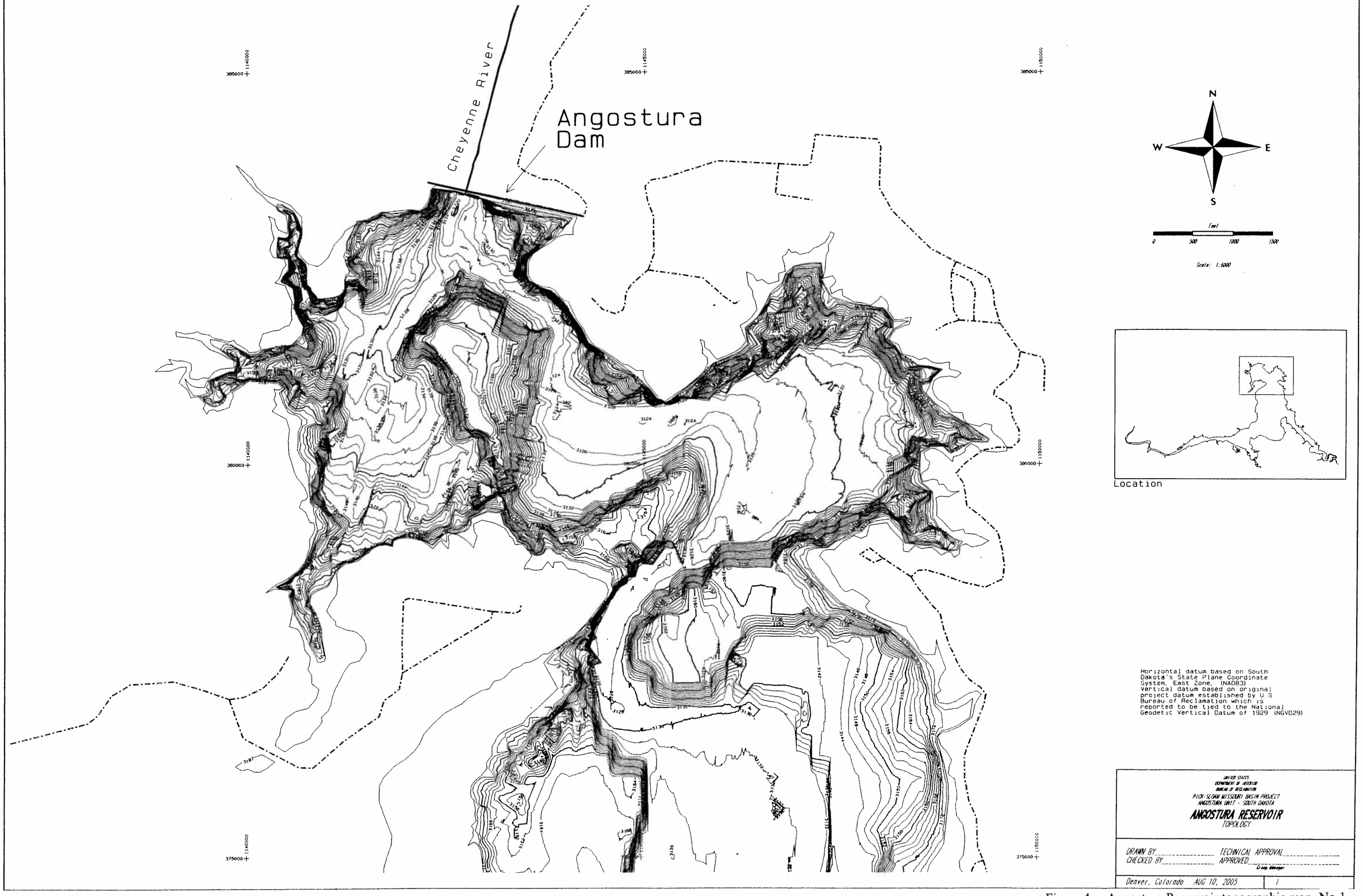

Figure 4. – Angostura Reservoir topographic map, No 1.

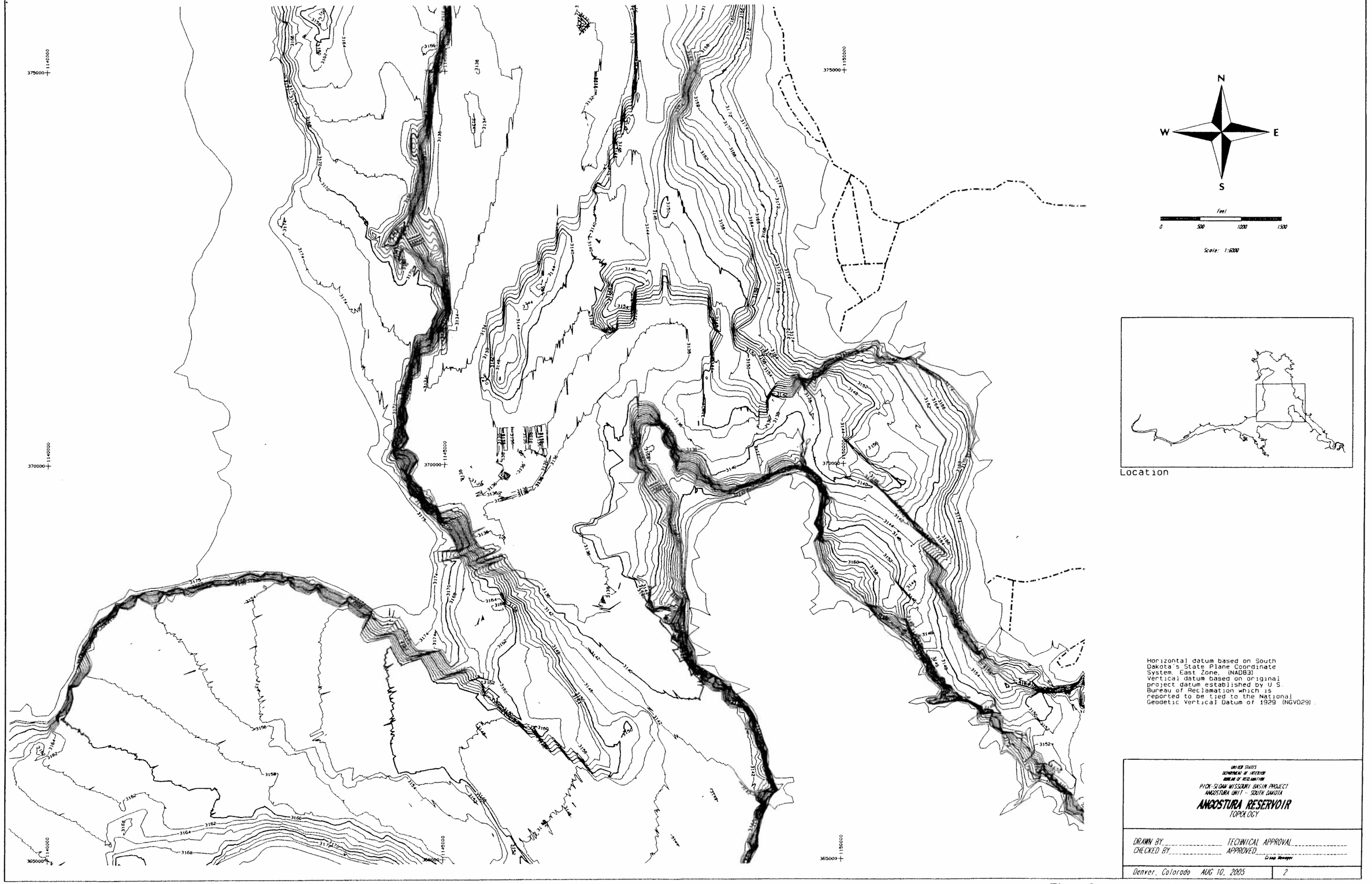

Figure 5. – Angostura Reservoir topographic map, No. 2.

Figure 6. – Angostura Reservoir topographic map, No. 3.

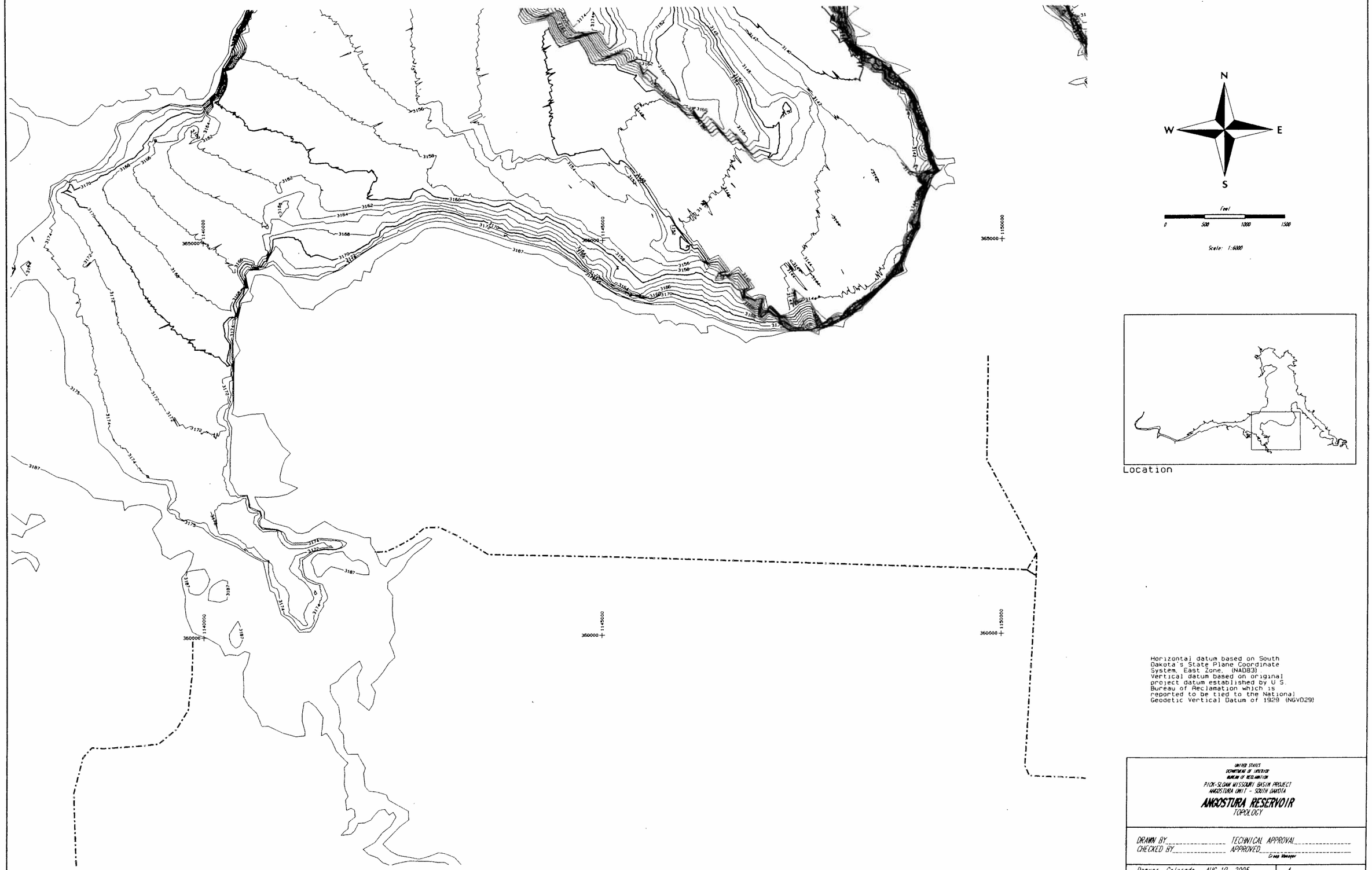

Figure 7. – Angostura Reservoir topographic map, No. 4.

Figure 8. – Angostura Reservoir topographic map, No. 5.

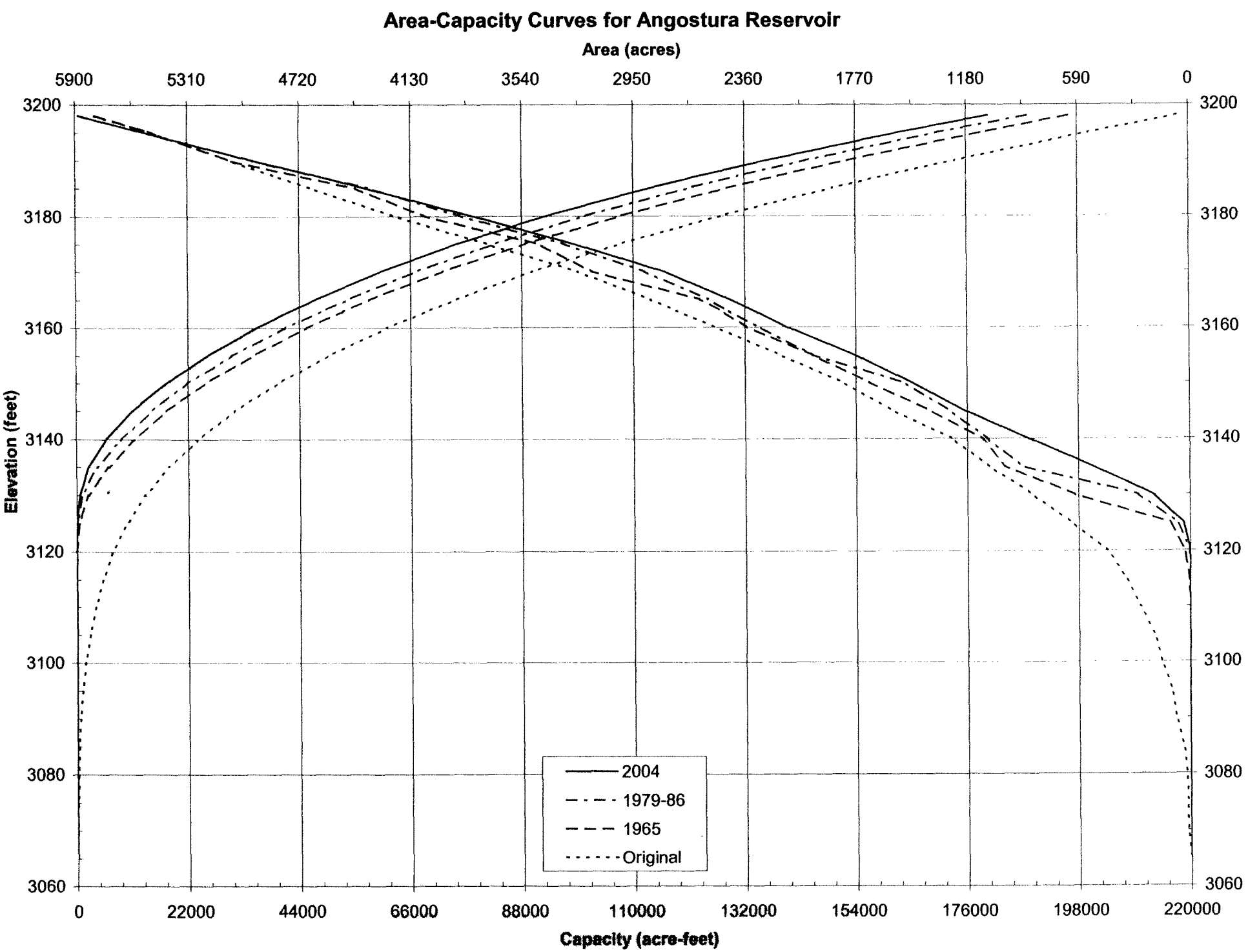

Figure 9. - 2004 area and capacity curves.