WACONDA LAKE 2001
SEDIMENTATION SURVEY

U.S. Department of the Interior
Bureau of Reclamation

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE February 2003	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Waconda Lake 2001 Sedimentation Survey			5. FUNDING NUMBERS PR
6. AUTHOR(S) Ronald L. Ferrari			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Technical Service Center, Denver CO 80225-0007			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Denver Federal Center, PO Box 25007, Denver CO 80225-0007			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DIBR
11. SUPPLEMENTARY NOTES Hard copy available at Bureau of Reclamation Technical Service Center, Denver, Colorado			
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation (Reclamation) surveyed Waconda Lake in July 2001 to develop a topographic map and compute the present storage-elevation relationship (area-capacity tables). The data were used to calculate reservoir capacity lost due to sediment accumulation since dam closure in October of 1967. The underwater survey was conducted in July of 2001 near reservoir elevation 1,455 feet (project datum). The underwater survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portions of the reservoir covered by the survey vessel. The above-water topography was determined by digitizing the developed contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. The new topographic map of Waconda Lake was developed from the combined 2001 underwater measured topography and the digitized USGS contours. This study assumed no change above elevation 1,450.0 since no above water topography was collected in 2001.

As of July 2001, at top of conservation water surface elevation (feet) 1,455.6, the surface area was 12,602 acres with a total capacity of 219,420 acre-feet. Since initial filling in October of 1967, about 22,597 acre-feet of sediment have accumulated in Waconda Lake below elevation 1,455.6, resulting in a 9.34 percent loss in reservoir volume. Since 1967, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 668.6 acre-feet.

14. SUBJECT TERMS reservoir area and capacity/ sedimentation/ reservoir surveys/ sonar/ sediment distribution/ contour area/ reservoir area/ sedimentation survey/ global positioning system			15. NUMBER OF PAGES 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UL	18. SECURITY CLASSIFICATION OF THIS PAGE UL	19. SECURITY CLASSIFICATION OF ABSTRACT UL	20. LIMITATION OF ABSTRACT UL

Waconda Lake 2001

Sedimentation Survey

by

Ronald L. Ferrari

Sedimentation and River Hydraulics Group
Water Resources Services
Technical Service Center
Denver, Colorado

February 2003

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ty Mull and Ronald Ferrari of the TSC conducted the hydrographic survey. Ronald Ferrari completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC completed the final map development. Kent Collins of the TSC performed the technical peer review of this documentation.

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

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.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by Reclamation.

The information contained in this report was developed for the Bureau of Reclamation; no warranty as to the accuracy, usefulness, or completeness is expressed or implied.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Waconda Lake, formed by Glen Elder Dam, is located in Mitchell County on the Solomon River just southwest of Glen Elder, Kansas (fig. 1). Waconda Lake and Glen Elder Dam are part of the Glen Elder Unit of the Missouri Basin Program and were developed to provide flood control for the Kansas River Basin along with water storage for irrigation, municipal, recreation, and fish and wildlife needs. The dam and reservoir are operated and maintained by the Bureau of Reclamation.

Glen Elder Dam was completed in 1969 and is a zoned, rolled earthfill embankment structure whose dimensions are (fig. 2):

Hydraulic height[1]	108	feet[2]	Structural height	142	feet
Top width	30	feet	Crest length	15,275	feet
Crest elevation	1,500.0	feet			

The spillway structure is located on the right abutment of the dam and consists of a 644-foot-wide overflow crest controlled by twelve 50 by 21.76-foot radial gates with a crest elevation of 1,467.4. The capacity of the spillway is 263,000 cubic feet per second (cfs) at reservoir elevation 1,492.9. The outlet works is located near the left abutment adjacent to the original river channel. It is controlled by two 6.5 by 8.0-foot high-pressure slide gates with a discharge capacity of 4,000 cfs at reservoir elevation 1,455.6.

The total drainage area above Glen Elder Dam is 5,076 square miles as listed by the USGS Water Resources Data Book. Water and sediment inflow is partially regulated by Webster Reservoir with a drainage area of 1,150 square miles and Kirwin Reservoir with a drainage area of 1,367 square miles. Waconda Lake has an average width of 1.6 miles with a length of around 12.4 miles.

---

[1]The definition of such terms as hydraulic height, structural height, and etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*, or ASCE's *Nomenclature for Hydraulics*.

[2]Elevation levels are shown in feet. All elevations shown in this report are based on the original project datum established by U.S. Bureau of Reclamation that were found by this study to be around 1.2 feet greater then the NGVD29.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2001 results of the survey of Waconda Lake. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since dam closure

A Real-time Kinematic (RTK) GPS control survey was conducted to establish a temporary horizontal and vertical control point near the marina that was used for this reservoir survey. The horizontal control was established in the Kansas north state plane coordinate zone in the North American Datum of 1983 (NAD83). The RTK GPS control survey was conducted with the base set on the National Geodetic Survey (NGS) datum point "Downs" located in Downs, Kansas. All elevations in this report are reference to the Reclamation project datum that from this study was found to be around 1.2 feet greater than the National Geodetic Vertical Datum of 1929 (NGVD29).

The underwater survey was conducted in July of 2001 between reservoir water surface elevations 1,455.0 to 1,455.3. The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system (DGPS) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it was navigated along grid lines covering Waconda Lake. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by the reservoir gauge (tied to the Reclamation vertical datum) during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations. The above-water topography was determined by digitizing the developed contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. No above water data was collected during the 2001 survey, therefore no change was assumed since the original survey from elevation 1,455.0 and above.

The 2001 Waconda Lake topographic map is a combination of the USGS quad contours and the 2001 underwater survey data. The 2001 reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using the collected reservoir data. The 2001 area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of the Waconda Lake sedimentation and watershed characteristics for the 2001 survey. The 2001 survey determined that the reservoir has a total storage capacity of 1,107,489 acre-feet and a surface area of 38,178 acres at maximum reservoir elevation 1,492.9. Since closure in October of 1967, the reservoir had an estimated volume change of 22,597 acre-feet below reservoir elevation 1,455.6. This volume represents a 9.34 percent loss in total capacity and an average annual loss of 668.6 acre-feet per year.

RESERVOIR OPERATIONS

Glen Elder Dam operates to provide flood control and supply water for irrigation, municipal, recreation, and fish and wildlife needs. The July 2001 area-capacity tables show 1,107,489 acre-feet of total storage below the maximum water surface elevation 1,492.9. The 2001 survey measured a minimum bottom elevation of 1,395.0. The following values are from the July 2001 area-capacity tables:

- 165,081 acre-feet of surcharge between elevation 1,488.3 and 1,492.9.
- 722,988 acre-feet of flood control storage between elevation 1,455.6 and 1,488.3.
- 193,183 acre-feet of conservation use between elevation 1,428.0 and 1,455.6.
- 25,989 acre-feet of inactive storage between elevation 1,407.8 and 1,428.0.
- 248 acre-feet of dead storage below elevation 1,407.8.

The Waconda Lake inflow and end-of-month stage records in table 1 for operation period of water years 1967 through 2001 show the computed inflow and annual fluctuation since dam closure. The estimated average inflow into the reservoir for this operation period was 209,200 acre-feet per year. Since initial filling in 1973, the extreme storage fluctuations of Waconda Lake ranged from an end of month elevation of 1,449.0 in 1984 to the maximum-recorded elevation of 1,487.0 in 1993.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors. The hydrographic system contained on the survey vessel consisted of a GPS receiver with a built-in radio and an omnidirectional antenna, depth sounders, a helmsman display for navigation, computers, and hydrographic system software for collecting underwater data. An on-board generator supplied power to the equipment.

The shore equipment included a second GPS receiver with an external radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. To obtain the maximum radio transmission range, known datum points with clear line-of-sight to the survey boat were selected. A 12-volt battery provided the power for the shore unit.

GPS Technology and Equipment

The hydrographic positioning system used at Waconda Lake was Navigation Satellite Timing and Ranging (NAVSTAR) GPS, an all-weather, radio-based, satellite navigation system that enables users to accurately determine three-dimensional position. The NAVSTAR system's primary mission is to provide passive global positioning and navigation for land-, air-, and sea-based strategic and tactical forces and is operated and maintained by the Department of Defense (DOD). The GPS receiver measures the distances between the satellites and itself and determines the receiver's position from intersections of the multiple-range vectors. Distances are determined by accurately measuring the time a signal pulse takes to travel from the satellite to the receiver.

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in a precise orbit about 10,900 nautical miles above the earth, each completing an orbit every 12 hours.

- The ground control segment tracks the satellites, determining their precise orbits. Periodically, the ground control segment transmits correction and other system data to all the satellites, and the data are then retransmitted to the user segment.

- The user segment includes the GPS receivers which measure the broadcasts from the satellites and calculate the position of the receivers.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. To calculate the receiver's position on earth, the satellite distance and the satellite's position in space are needed. The satellites transmit signals to the GPS receivers for distance measurements along with the data messages about their exact orbital location and operational status. The satellites transmit two "L" band frequencies (called L1 and L2) for the distance measurement signal. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time); the time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers.

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and the geometric position of the satellites. Precision is affected by several factors--time, because of the clock differences, and atmospheric delays caused by the effect of the ionosphere on the radio signal. Geometric dilution of precision (GDOP) describes the geometrical uncertainty and is a function of the relative geometry of the satellites and the user. Generally, the closer together in angle two satellites are from the receiver, the greater the GDOP. GDOP is broken into components: position dilution of precision (x,y,z) (PDOP), and horizontal dilution of precision (x,y) (HDOP). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored at the survey vessel's GPS receiver during the Waconda Lake Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys (Corps of Engineers, 2002).

An additional and larger error source in GPS collection is caused by false signal projection, called selective availability (S/A). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters. In May of 2000 the use of S/A was discontinued, but the errors of a single receiver are still around $\pm$10 meters.

A method of collection to resolve or cancel the inherent errors of GPS is called differential GPS (DGPS). DGPS is used during the reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over the geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel.

For the Waconda Lake survey, position corrections were determined by the master receiver and transmitted via an ultra-high frequency (UHF) radio link every second to the survey vessel's mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS can result in sub-meter positional accuracies for the survey vessel.

The Sedimentation and River Hydraulics Group conducts their bathymetric surveys using Real-time Kinematic (RTK) GPS. The major benefit of RTK versus DGPS are precise heights can be measured in real time for monitoring water surface elevation changes. The basic outputs from an RTK receiver are precise 3D coordinates in latitude, longitude, and height with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS datum of WGS-84 that the hydrographic collection software converted into the Kansas's NAD83 state plane north coordinate system. The system employs two receivers, like with DGPS, and collects additional satellite data that allows on-the-fly centimeter accuracy measurements.

Survey Method and Equipment

The Waconda Lake hydrographic survey collection was conducted from July 26 through July 30 of 2001 between water surface elevation 1454.34 and 1454.95 (Reclamation project datum). The bathymetric survey was run using sonic depth recording equipment, interfaced with an RTK GPS, capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat in a north or south direction of the reservoir at around a 400-foot spacing. Data was also collected along the shore as the boat traversed between transects. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing.

The underwater data was collected by a depth sounder that was calibrated by lowering a deflector plate below the boat by cables 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 produces an analog hard-copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gauge were used to convert the sonic depth measurements to true lake-bottom elevations.

In 2001 the Sedimentation and River Hydraulics Group began using a multibeam depth sounder that is capable of collecting 80 depths at a time in a 120 degree swath. For the Waconda Lake survey this system was used for one day of collection that included along the face of the dam and along portions of the original river channel alignment. The weather and rough water conditions only allowed one day of collection with the multibeam depth sounder system, but the additional data supplemented the single beam data and provided more detail of the reservoir bottom. The additional data didn't have a significant impact on the area computations when compared to the area results of the single beam only data.

Waconda Lake Datums

Prior to the underwater survey in July 2001, a RTK GPS survey was conducted to establish a temporary horizontal and vertical control point that overlooked Waconda Lake. The horizontal control was established in Kansas state plane north coordinates in the North American Datum of 1983 (NAD83). The GPS control was conducted with the base set on the NGS datum point "Downs" located about 9 miles from the lake. All vertical information in this report is tied to the reservoir water surface gauge measurements at the time of this survey that are referenced to the Reclamation project or construction datum. The RTK GPS survey determined that the Reclamation project datum is around 1.2 feet greater than the NGVD29. This difference must be used with caution since it was measured using only one NGS control point located several miles away and was tied only to the reservoir water surface. No additional measurements were taken on Reclamation structures or survey monuments during this survey that may have assisted in more accurately determining the difference.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Waconda Lake was developed from the 2001 collected underwater data and the USGS quad maps. Digitizing the contour lines of elevation 1,450; 1,456; and 1,460 from the USGS quad maps that covered the Waconda Lake area developed the upper contours of Waconda Lake. The USGS quad maps were developed from aerial photography dated1960 and photorivised in 1978. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Kansas's NAD 1983 north state plane coordinates using the ARC/INFO PROJECT command.

Following are the ARC/INFO resulting digitized reservoir surface areas from the USGS quads versus the original 1967 reported surface areas:

(1) USGS digitized 1,450 contour area was 9,469 acres, or 92.8% of the original 10,205 acres
(2) USGS digitized 1,456.6 contour area was 11,452 acres, or 90.8% of the original 12,602 acres
(3) USGS digitized 1,460 contour area was 13,998 acres, or 96.8% of the original 14,456 acres

It is assumed that the area differences are due to the quad scale, different methods of digitizing the contour areas, and the 1.2-foot difference between Reclamation and the NGS datums. The digitized measured surface areas from the USGS quads were not used to develop the 2001 area and capacity tables, but were presented to provide information used during the analysis. The digitized contour, elevation 1,450, was used for map development by providing a clip around the underwater collected data.

The elevation 1,450 contour, digitized from USGS quad maps, was used to perform a clip of the Waconda Lake TIN such that interpolation was not allowed to occur outside of this contour. This complete contour was selected since it was the closest elevation to enclose the July 2001 underwater data that was collected near reservoir elevation 1,455. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and the digitized contours from the USGS quad maps were plotted. The plot showed that the majority of the underwater data lie completely within this clip. The upstream end of the 1,450 clip was adjusted to account for changes due to sediment deposition. This was completed using the underwater survey data to interpolate where the upstream end of the elevation 1,450 contour line would occur due to the sediment delta formation. The contour was also slightly adjusted to enclose all the underwater data points. Elevation points were added to represent the island areas within the reservoir area of the elevation 1,450 contour lines.

Contours for the reservoir below elevation 1,450.0 were computed from the underwater data set using the triangular irregular network (TIN) surface-modeling package within ARC/INFO. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation where triangles are formed among all data points within the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data. This method preserves all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in greater detail in the ARC/INFO V7.0.2 *Users Documentation,* (ESRI, 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Waconda Lake TIN. In addition, the contours were generalized by filtering 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 Waconda Lake since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons developed from the survey data were completed for elevations 1,395.0 through elevation 1,448.0. The contour topography at 2-foot and 5-foot intervals is presented on figures 3.

Development of 2001 Contour Areas

The 2001 contour surface areas for Waconda Lake were computed at 1-foot increments, from elevation 1,395.0 to 1,448.0, using the Waconda Lake TIN discussed above. The 2001 survey measured a minimum reservoir bottom elevation of 1,395.0. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user specified elevations directly from the TIN and takes into consideration all regions of equal elevation. As discussed before, there were no 2001 above water data collected for this study. This accounts for the fact that the 2001 areas were only computed for elevation 1,448.0 and below. Due to the lack of 2001 above water data, the final 2001 area computations assumed no change in the original measured surface area from elevation 1,455.0 and above and allowed the computation program to compute the areas between elevations 1,448 and 1,455.

2001 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). Computed surface areas from the developed TIN, at 2-foot and 5-foot contour intervals, from reservoir elevation 1,400.0 to elevation 1,448.0 were used as the control parameters for computing the Waconda Lake capacity. The surface areas for elevations 1450.0 and above were computed using the original surface areas and assuming no change since dam closure for this portion of the reservoir since this study did not collect any above water data. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Waconda Lake. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

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

where:

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

Results of the 2001 Waconda Lake area and capacity computations are listed in table 1 and columns 4 and 5 of table 2. On table 2, columns 2 and 3 list the original surface areas and recomputed capacities. A separate set of 2001 area and capacity tables has been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2001). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 2001 area-capacity curves are plotted on figure 4. As of July 2001, at maximum reservoir water surface elevation 1,492.9, the surface area was 38,178 acres with a total capacity of 1,107,489 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Figure 4 is a plot of Waconda Lake's original area and capacity data versus the 2001 measured area and capacity to illustrate the difference and change since Glen Elder Dam closure in October of 1967. Since closure, the measured total volume change at reservoir elevation 1,455.6 was estimated to be 22,597 acre-feet. The estimated average annual rate of capacity lost for this time period (33.8 years) was 668.6 acre-feet per year. The storage loss in terms of percent of original storage capacity was 9.34 percent. Tables 1 and 2 contain the Waconda Lake sediment accumulation and water storage data based on the 2001 resurvey.

The original 100 year sediment inflow estimate used during the design of Waconda Lake was 47,500 acre-feet for an average annual rate of capacity loss of 475 acre-feet. This is compared to the 2001 survey results of 668.6 acre-feet. It must be noted that the 2001 area and capacity table were generated using measured surface areas from elevation 1,448 and below. The original surface areas from elevation 1,455 and above were used to complete the new area and capacity table. This assumed no surface area change from elevation 1,455 and above, which in all probability is not the case. The only means to measure this would be to conduct an aerial survey. Since the maximum-recorded water surface elevation was 1,487 in July of 1993, it is assumed that there has been some change. A resurvey of Waconda Lake should be considered in the future if major sediment inflow events are observed or if the average annual rate of sediment accumulation requires further clarification.

REFERENCES

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

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

Bureau of Reclamation, 1985. Surface Water Branch, ***ACAP85 User's Manual***, Technical Service Center, Denver CO.

Bureau of Reclamation, 1987(a). ***Guide for Preparation of Standing Operating Procedures for Bureau of Reclamation Dams and Reservoirs***, U.S. Government Printing Office, Denver, CO.

Bureau of Reclamation, 1987(b). ***Design of Small Dams***, U.S. Government Printing Office, Denver CO.

Bureau of Reclamation, July 2001. Denver Office, ***Waconda Lake Area and Capacity Tables, Missouri River 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***.

RESERVOIR SEDIMENT
DATA SUMMARY

Waconda Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Solomon River	3. STATE Kansas
	4. SEC. 27 TWP. 6 S RANGE 9 W	5. NEAREST P.O. Glen Elder	6. COUNTY Mitchell
	7. LAT 39° 29' 46" LONG 98° 18' 48"	8. TOP OF DAM ELEVATION 1500.0	9. SPILLWAY CREST EL 1,467.4[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 / 16. DATE NORMAL OPERATION BEGAN
	a. SURCHARGE	1492.9	38,178	164,966	1,128,741	15. 10/67
	b. FLOOD CONTROL	1488.3	33,682	722,315	963,775	
	c. POWER					
	d. JOINT USE					16. 07/68
	e. CONSERVATION	1455.6	12,602	204,789	241,460	
	f. INACTIVE	1428.0	3,341	35,435	36,671	
	g. DEAD	1407.8	350	1,236	1,236	
	17. LENGTH OF RESERVOIR 12.4 MILES			AVG. WIDTH OF RESERVOIR 1.6 MILES		

BASIN	18. TOTAL DRAINAGE AREA 5,076 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 25.5[2] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 2,559[3] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.72[4] INCHES
	20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 209,200[5] ACRE-FEET
	21. MAX. ELEVATION MIN. ELEVATION	25. ANNUAL TEMP. MEAN 54°F RANGE -27°F to 113°F[2]

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
10/67			Contour (D)	5-ft	12,602[6]	242,017[6]	1.16
7/01	33.8	33.8	Contour (D)	2-ft	12,602[7]	219,420[7]	1.05

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
7/01		209,200[4]	1,334,500[8]	7,070,260	209,200	7,070,260

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.
7/01	22,597[9]	668.6	0.26	22,597	668.6	0.26

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
7/01				0.28[10]	9.34[10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
		1386-1400	1400-1420	1420-1428	1428-1440	1440-1450	1450-1455.6				
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
		1.4	34.3	11.5	21.1	26.6	5.1				

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

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

45. RANGE IN RESERVOIR OPERATION[8]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1967			130,800	1968	1,417.8	1,407.7	87,100
1969	1,435.0	1,419.7	169,100	1970	1,439.6	1,435.5	55,200
1971	1,441.5	1,437.7	62,200	1972	1,442.9	1,441.1	54,400
1973	1,460.8	1,442.5	275,700	1974	1,462.1	1,454.4	349,900
1975	1,458.9	1,454.5	169,500	1976	1,456.0	1,452.1	83,000
1977	1,454.4	1,451.8	88,400	1978	1,455.3	1,453.8	84,100
1979	1,460.6	1,453.4	191,600	1980	1,455.5	1,451.8	106,700
1981	1,453.7	1,451.4	73,100	1982	1,461.3	1,453.2	264,000
1983	1,454.8	1,452.4	92,000	1984	1,456.8	1,449.0	146,000
1985	1,453.5	1,449.0	93,300	1986	1,454.2	1,452.3	82,700
1987	1,471.2	1,454.2	527,000	1988	1,454.5	1,450.4	109,900
1989	1,457.1	1,449.9	156,300	1990	1,456.9	1,455.3	102,100
1991	1,455.7	1,450.7	44,100	1992	1,457.0	1,450.1	147,100
1993	1,487.0	1,454.9	1,334,500	1994	1,480.6	1,453.6	474,100
1995	1,467.1	1,453.4	480,900	1996	1,455.7	1,451.5	200,000[8]
1997	1,458.9	1,452.0	237,900	1998	1,454.9	1,453.7	225,260
1999	1,458.4	1,453.6	199,100	2000	1,455.2	1,451.9	45,300
2001	1,458.0	1,451.6	127,400				

46. ELEVATION - AREA - CAPACITY DATA FOR **2001 CAPACITY**[11]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
1,395	0	0	1,400	13.7	34	1,405	26	133
1,407.8	63	248	1,410	174.9	502	1,415	772.7	2,814
1,420	1,580.9	8,802	1,425	2,297.4	18,309	1,428	3,020.5	26,237
1,430	3,516	32,773	1,435	4,503.3	52,853	1,440	6,121.2	79,016
1,445	7,722.1	113,615	1,450	9,747	156,655	1,455	12,363	211,931
1,455.6	12,602	219,420	1,460	14,456	278,948	1,465	17,204	358,098
1,470	20,287	451,693	1,475	23,864	562,071	1,480	27,375	690,168
1,485	30,898	835,851	1,488.3	33,682	942,408	1,490	35,258	1,001,007
1,492.9	38,178	1,107,489	1,495	40,443	1,190,041	1,500	46,155	1,406,536

47. REMARKS AND REFERENCES

1 Controlled by twelve 50- by 21.76-foot radial gates.
2 Bureau of Reclamation Project Data Book, 1981.
3 Natural drainage area above the dam is 5,076 square miles. Upstream sediment inflow controlled by Kirwin Dam (1,367 square miles) and Webster Dam (1,150 square miles).
4 Calculated using mean annual runoff value of 195,000 AF, item 24, 1967-2001. Estimated inflow for water year 1996.
5 Estimated inflow for water years 1996.
6 Original surface area and capacity at elevation 1455.6. For sediment computation purposes the original capacity was recomputed by the Reclamation ACAP program using the original surface areas.
7 Surface area & capacity at elevation 1,455.6 computed by ACAP program.
8 Inflow values in acre-feet and maximum and minimum elevations in feet by water year for readily available years. Inflow value estimated for 1996.
9 Computed sediment volume at elevation 1455.6. 2001 study assumed no change from elevation 1,455.6 and above due to lack of above water survey data.
10 Storage losses at elevation 1,455.6.
11 Capacities computed by Reclamation's ACAP computer program. Input data from 2001 survey only for elevation 1448.0 and below. Original areas were used for elevation 1455.0 and above assume no change due to lack of above water data.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE January 2003

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

1	2	3	4	5	6	7	8
					2001	2001	Percent of
Elevations	Original	Original	2001	2001	Sediment	Percent of	Reservoir
	Survey	Capacity	Survey	Survey	Volume	Sediment	Depth
(feet)	(acres)	(acre-feet)	(acres)	(acre-feet)	(acre-feet)		
1,500.0	46155	1429133	46155	1406536	22597		100.0
1,495.0	40443	1212638	40443	1190041	22597		95.6
1492.9*	38178	1130086	38178	1107489	22597		#VALUE!
1,490.0	35258	1023604	35258	1001007	22597		91.2
1,488.3	33682	965005	33682	942408	22597		89.7
1,485.0	30898	858448	30898	835851	22597		86.8
1,480.0	27375	712765	27375	690168	22597		82.5
1,475.0	23864	584668	23864	562071	22597		78.1
1,470.0	20287	474290	20287	451693	22597		73.7
1,465.0	17204	380695	17204	358098	22597		69.3
1,460.0	14456	301545	14456	278948	22597		64.9
1,455.6	12602	242017	12602	219420	22597	100.0	61.1
1,455.0	12363	234528	12363	211931	22597	100.0	60.5
1,450.0	10205	178108	9747	156655	21453	94.9	56.1
1,445.0	8429	131523	7722.1	113615	17908	79.2	51.8
1,440.0	6402	94445	6121.2	79016	15429	68.3	47.4
1,435.0	4895	66203	4503.3	52853	13350	59.1	43.0
1,430.0	3923	44158	3516.0	32773	11385	50.4	38.6
1,428.0	3341	36894	3020.5	26237	10657	47.2	36.8
1,425.0	2520	28102	2297.4	18309	9793	43.3	34.2
1,420.0	1970	16877	1580.9	8802	8075	35.7	29.8
1,415.0	1554	8067	772.7	2814	5253	23.2	25.4
1,410.0	693	2450	174.9	502	1948	8.6	21.1
1,407.8	350	1303	63.0	248	1055	4.7	19.1
1,405.0	89	688	26.0	133	555	2.5	16.7
1,400.0	49	343	13.7	34	309	1.4	12.3
1,395.0	32	142	0.0	0	142	0.6	7.9
1,386.0	0	0	0.0	0	0	0.0	0.0
1	Elevation of reservoir water surface.						
2	Original reservoir surface area.						
3	Original reservoir capacity recomputed using ACAP.						
4	Reservoir surface area from 2001 survey.						
5	Reservoir capacity computed using ACAP.						
6	Measured sediment volume = column (3) - column (5).						
7	Measured sediment expressed in percentage of total sediment 22,597.						
8	Depth of reservoir expressed in percentage of total depth of 114 feet.						
*	Design maximum reservoir elevation.						

Table 2. - Summary of 2001 survey results

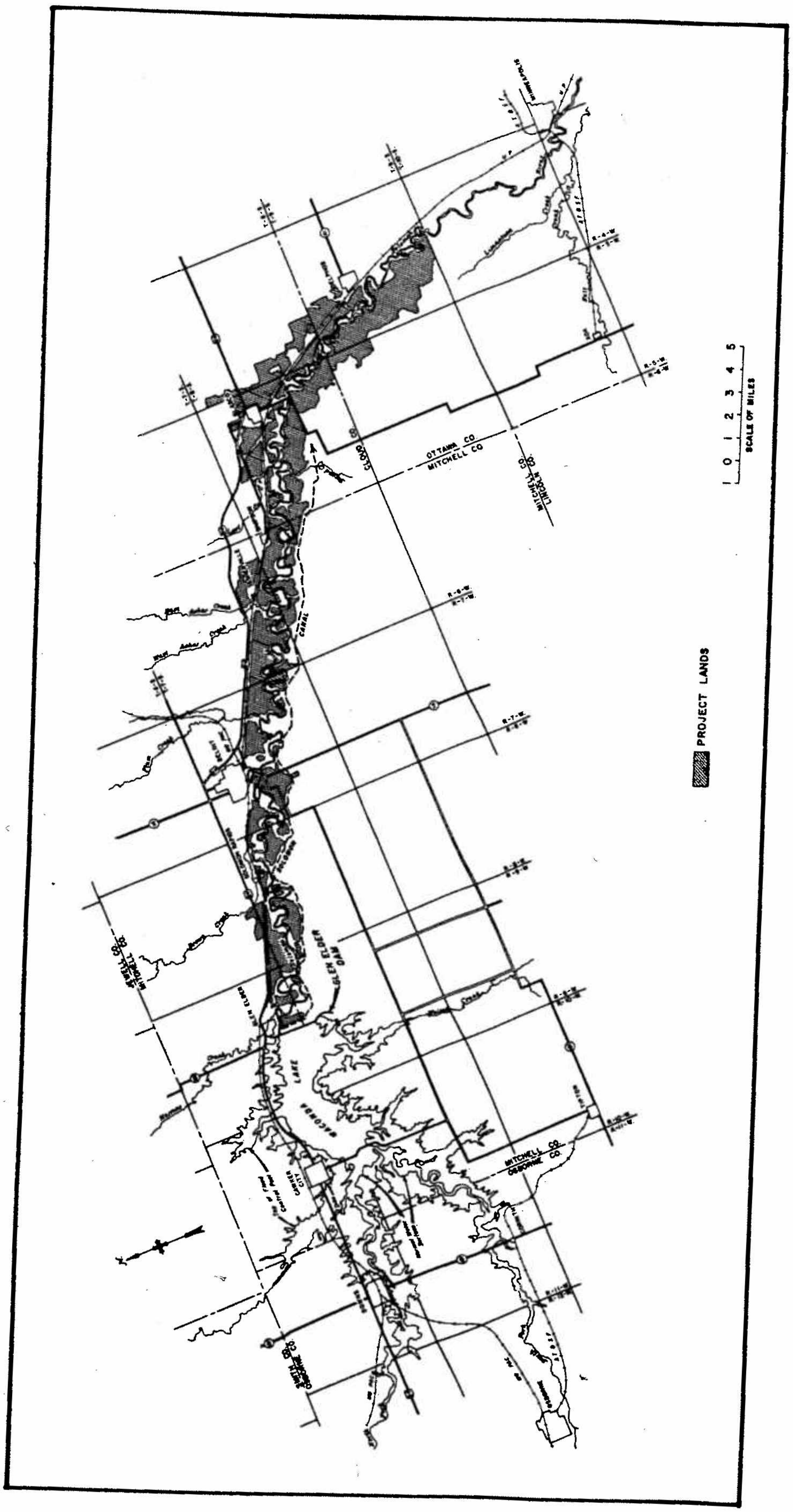

Figure 1. - Waconda Lake location map.

Space intentionally left blank due to security concerns

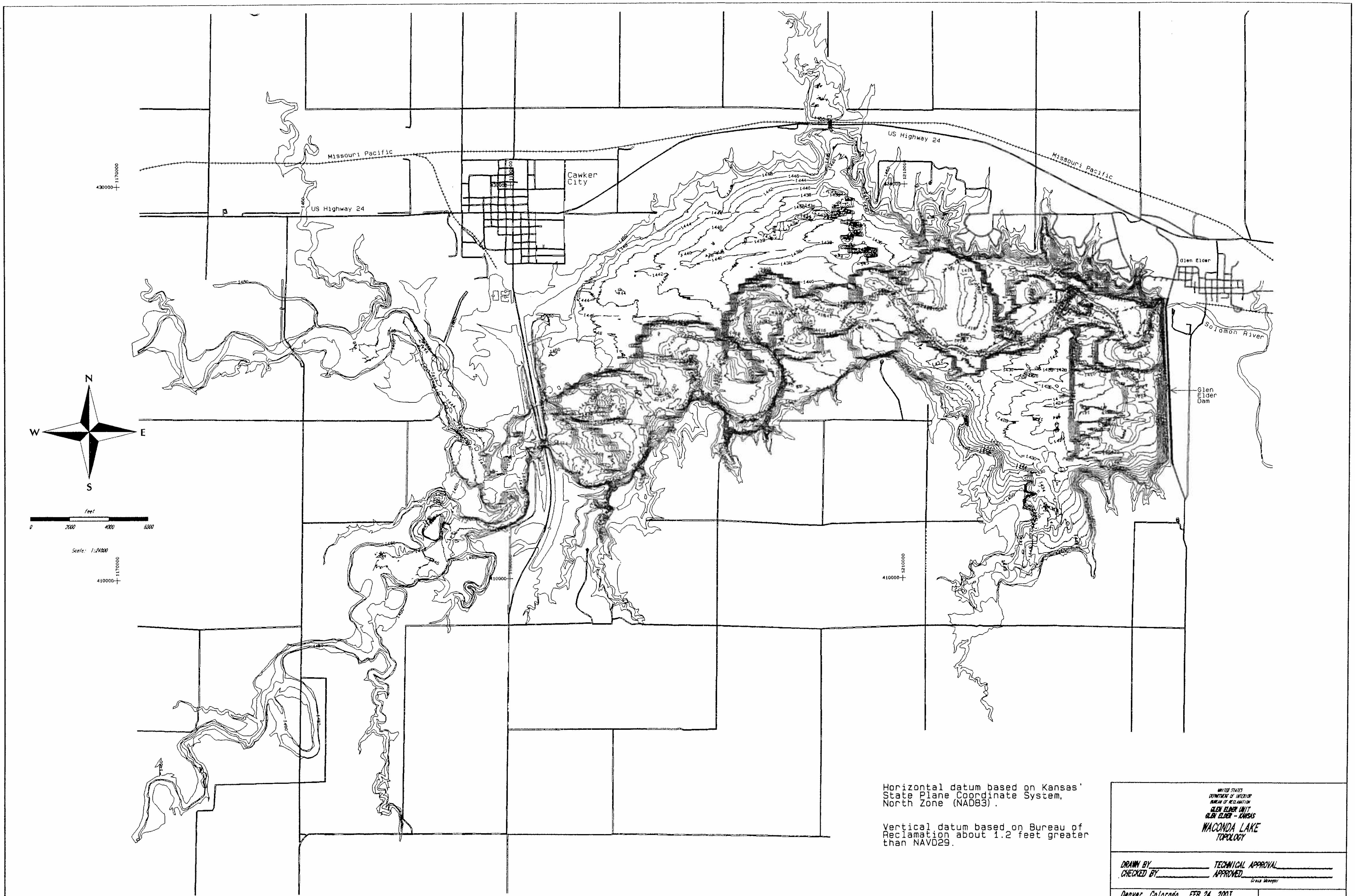

Figure 3. - Waconda Lake topographic map.

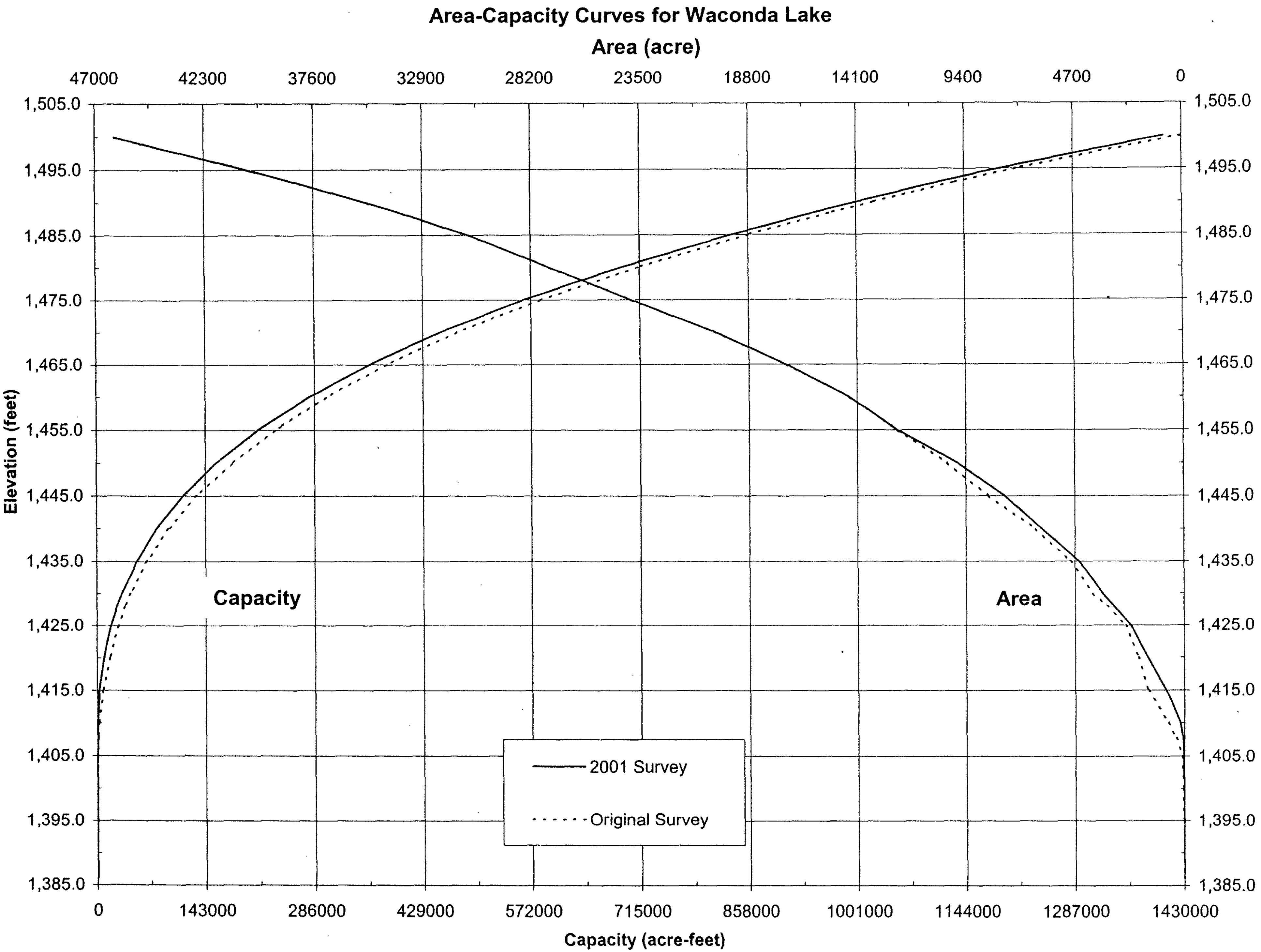

Figure 4. - 2001 area and capacity curves