LAKE ESTES
2001 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 Lake Estes 2001 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 Lake Estes in August of 2001 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were used to calculate reservoir capacity lost due to sediment accumulation since dam closure in November of 1948. The underwater survey was conducted between lake elevation 7,471.4 and 7,473.0 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 Lake Estes was developed from the combined digitized USGS quad contours and August 2001 underwater measured topography. This study assumed no change from elevation 7470.0 (feet) and above.

As of August 2001, at maximum water surface elevation 7,475.0, the surface area was 185 acres with a total capacity of 2,783 acre-feet. Since initial operation in November of 1948, about 284 acre-feet of sediment have accumulated in Lake Estes below elevation 7,470.0, resulting in a 12.8 percent loss in reservoir volume. Since 1948, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 5.4 acre-feet.

14. SUBJECT TERMS			15. NUMBER OF PAGES
reservoir area and capacity/ sedimentation/ reservoir surveys/ sonar/ sediment distribution/ contour area/ reservoir area/ sedimentation survey/ global positioning system/ lake			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

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Lake Estes

2001 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. Kent Collins and Ronald Ferrari of the TSC conducted the hydrographic survey. Ron Ferrari of the TSC 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 Indian Tribes and our commitments to island communities.

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.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Lake Estes, formed by Olympus Dam, is located in Larimer County on the Big Thompson River approximately 2 miles east of the city of Estes Park in Colorado (fig. 1). Colorado State Highway 36 divides the lake with the smaller portion to the south on the Fish Creek arm and the larger portion being north on the Big Thompson River arm. Six 5-foot diameter culverts located under the highway connect the two lakes. The dam and lake are features of the Colorado-Big Thompson Project that provides water from Colorado River diversions from the western slope of the Continental Divide to lands on the eastern slope. Lake Estes, located on the eastern slope, is used as an afterbay for the Estes Powerplant and provides water for irrigation, recreation and forebay storage for the Pole Hill Powerplant.

Olympus Dam, completed in 1948, is a composite structure consisting of a zoned earth embankment whose dimensions are (fig. 2):

Hydraulic height[1]	45	feet	Structural height	70	feet
Top width	30	feet	Crest length	1,951	feet
Crest elevation	7,481.0	feet[2]			

The spillway is located in the center of the concrete gravity section of the dam with a crest elevation of 7,460.0. The spillway flows are controlled by five 17– by 20-foot radial gates, with a top elevation of 7,475.0, over an ogee-shaped overflow into a 120-foot wide stilling basin. The spillway provides a maximum discharge of 21,200 cubic feet per second (cfs) at maximum reservoir elevation 7,475.0.

A river outlet with a crest elevation of 7,450.25 is located in the concrete dam left of the spillway. The release from the river outlet is about 60 cfs through an 18-inch diameter pipe controlled by a 2.5-foot square cast iron slidegate. A canal outlet work, with a crest elevation of 7,456.0, is located in the right side of the concrete dam. The canal outlet consists of a trashrack with a fish screen protection intake structure that discharges up to 575 cfs into the 10.75-foot diameter Olympus Siphon.

The drainage area above Olympus Dam is 158 square miles and for this study all is considered sediment contributing. The lake is around 1.2 miles in length and around 0.2 miles in width.

---

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

[2]Elevation levels are shown in feet. All elevations shown in this report are based on the original project datum established by U.S. Bureau of Reclamation that is tied to the National Geodetic Vertical Datum of 1929.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2001 results of the survey of Lake Estes. 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 used for this reservoir survey. The horizontal control was established in the Colorado 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 Geoldetic Survey (NGS) datum point "Collinson Az Mark" located near the lake. All elevations in this report are referenced to the Reclamation project datum that is assumed to be tied to the National Geodetic Vertical Datum of 1929 (NGVD29).

The underwater survey was conducted in August of 2001 between reservoir water surface elevations 7,471.4 to 7,473.0. 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 Lake Estes. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by the reservoir gauge (tied to the Reclamation vertical datum) during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations. The above-water topography was determined by digitizing the developed contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. The RTK GPS was used to collect water surface data during the underwater collection along with a limited amount of above water topography points. Due to the limited amount of above water data collected, the 2001 study assumed no change since the original survey from elevation 7,470.0 and above.

The 2001 Lake Estes topographic map is a combination of the USGS quad contours and the underwater and above water 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 Lake Estes sedimentation and watershed characteristics for the 2001 survey. The 2001 survey determined that the reservoir has a total storage capacity of 2,783 acre-feet and a surface area of 185 acres at maximum reservoir elevation 7,475.0. Since closure in November of 1948, the reservoir had an estimated volume change of 284 acre-feet below reservoir elevation 7,470.0. This volume represents a 12.8 percent loss in total capacity and an average annual loss of 5.4 acre-feet per year.

RESERVOIR OPERATIONS

Lake Estes is part of the Colorado-Big Thompson Project and operates as an afterbay for the Estes Powerplant, along with providing water for irrigation, recreation, and forebay storage for the Pole Hill Powerplant. The August 2001 capacity table shows 2,783 acre-feet of total storage below the maximum water surface elevation 7,475.0. The 2001 survey measured a minimum lake bottom elevation of 7,432.0. The following values are from the August 2001 capacity table:

- 2,470 acre-feet of conservation use between elevation 7,450.25 and 7,475.0.
- 313 acre-feet of inactive storage between elevation 7,432.0 and 7,450.25.

The Lake Estes inflow and end-of-month stage records in table 1, operation period 1977 through 2001, show the inflow and annual fluctuation for several readily available years of operation. The estimated historical average inflow into the reservoir from the natural drainage basin was 92,480 acre-feet per year. For recreational purposes the normal operation of Lake Estes has annual fluctuations between 7,469.5 and 7,474, but lower operations do occur as needed. The maximum-recorded elevation was 7,474.6 on June 19, 1965.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment, mounted on an 18-foot pontoon raft with an outboard motor, consisted of a GPS receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting underwater data. On-board batteries 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 Lake Estes 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 that 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 Lake Estes Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys (Corps of Engineers, 1994).

An additional and larger error source in GPS collection is caused by false signal projection called selective availability (S/A). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters. In May of 2000 the use of S/A was discontinued, but the errors of a single receiver are still around $\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 Lake Estes survey, position corrections were determined by the master receiver and transmitted via an ultra-high frequency (UHF) radio link every second to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS can result in sub-meter positional accuracies for the survey vessel.

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

Survey Method and Equipment

The Lake Estes hydrographic survey collection was conducted from August 9 through August 12 of 2001 between water surface elevations 7,471.4 and 7,473.0 (Reclamation project datum). The bathymetric survey was run using sonic depth recording equipment, interfaced with an RTK GPS, capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across closely-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat in a north or south direction of the reservoir at a 100-foot spacing or less. 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 2001 underwater data were 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 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.

Lake Estes Datum

Prior to the underwater survey, a RTK GPS survey was conducted to establish a horizontal and vertical control point near the marina of Lake Estes. The NGS control point "Collinson Az Mk" located south of the dam was used as the base station for the control survey. This datum was readily available and provided a first order horizontal accuracy that was needed for the boat survey. There was no stated vertical accuracy on this NGS datum, but all vertical information for this study is referenced to the reservoir water surface gauge measurements. The gauge is referenced to the Reclamation project datum that is reported as tied to NGVD29. The RTK GPS survey equipment was also used to collect a limited amount of above water data along the shore of the lake, along the highway, and on top of the dam.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Lake Estes was developed from the 2001 collected underwater and above water data combined with digitized contours from the USGS quad maps. The digitized USGS contour lines included the Lake Estes water surface labeled elevation 7468 and 7475 along with contour lines 7480 and 7520 that surrounded the reservoir area. The USGS quad maps were developed from aerial photography dated 1958 and photorevised from aerial photographs taken in 1978. This study found several areas that had to be adjusted to enclose the 2001 underwater data. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Colorado's NAD 1983 state plane north zone coordinates using the ARC/INFO PROJECT command.

The elevation 7468 and 7475 contour lines that were digitized from USGS quad maps were used to perform a clip of the Lake Estes triangular irregular network (TIN) such that interpolation was not allowed to occur outside the enclosed polygon. The complete 7475 contour was selected since it was the closest complete elevation to represent the reservoir water surface at the time the survey was conducted, which was near reservoir elevation 7473. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and digitized contours from the quad maps were plotted. The plot showed that the underwater data did not lie completely within this clip, which required modifications to include the entire underwater data set. Modified areas included the shoreline near the marina towards the dam and the majority of the shoreline of the reservoir located south of the highway. It is assumed these changes were due to construction around the marina and boat launch area and from shoreline erosion that has occurred since the 1950's. Using select and move commands within ARCEDIT, the vertices of the clip were shifted to fit all the collected underwater data. The clip was assigned an elevation of 7,471.0 to reflect the original area of the developed polygons.

Contours for the reservoir below elevation 7,471.0 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 Lake Estes 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 Lake Estes 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 elevations 7,432.0 through elevation 7,468.0. The 2001 study assumed no change in area since the original survey for elevation 7,470.0 and above. The contour topography at 1-foot intervals is presented on figure 3.

Development of 2001 Contour Areas

The 2001 contour surface areas for Lake Estes were computed at 1-foot increments from elevation 7,432.0 to 7,468.0. The 2001 underwater survey measured a minimum reservoir bottom elevation of 7,432.0. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user-specified elevations directly from the TIN and takes into consideration all regions of equal elevation. As indicated above, the 2001 underwater survey data was collected near reservoir elevation 7,473 and included limited amount of above water data points. For the purpose of this study the measured 2001 survey areas at 1-foot increments from elevation 7,432.0 through 7,468.0 were used to compute the new area and capacity tables. Due to the limited amount of above water data, this study assumed no change in original area from elevation 7,470.0 and above. The area and capacity program computed the areas between elevation 7,468.0 and 7,470.0 by assuming a straight-line interpolation.

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). The 2001 surveyed surface areas at 1-foot contour intervals from reservoir elevation 7,432.0 to elevation

7,468.0 were used as the control parameters for computing the 2001 Lake Estes capacity. Since this study did not collect adequate above water data, the original 1-foot surface areas from elevation 7,470.0 to 7,475.0 were used to complete the area and capacity table. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Lake Estes. 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. Differentiating the capacity equations, which are of second order polynomial form, derives final area equations:

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

where:

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

Results of the 2001 Lake Estes 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 original 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 August 2001, at elevation 7,475.0, the surface area was 185 acres with a total capacity of 2,783 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Figure 4 is a plot of Lake Estes original surface area and capacity versus the 2001 measured surface area and capacity that illustrates the differences between the two. Since Olympus Dam closure in 1948, the measured total volume change at reservoir elevation 7,470.0 was estimated to be 284 acre-feet. The estimated average annual rate of capacity lost for this time period (52.8 years) was 5.4 acre-feet per year. The storage loss in terms of percent of original storage capacity was 12.8 percent at elevation 7,470.0. All sediment computations are based on elevation 7,470.0 due to the lack of 2001 survey data above this elevation. Tables 1 and 2 contain the Lake Estes sediment accumulation and water storage data based on the 2001 resurvey. Section 26 of table 1 shows that 66.2 percent of the measured sediment has deposited between the conservation storage elevations of 7,450.25 to 7,470.0 and 33.8 percent has deposited in the inactive zone below elevation 7,450.25.

The original estimated sediment inflow used during the design of Lake Estes was an annual contribution of 15.5 acre-feet that would result in around 50 percent of reservoir storage space being depleted after the first 100 years of operation. The 2001 study determined an annual rate of 5.4 acre-feet or a total capacity lost of 284 acre-feet after the first 52.8 years of reservoir operation. It must be noted that the 2001 area and capacity tables were generated assuming no change in original area and capacity from elevation 7,470.0 and above which in all probability is not the case. It must also be noted that the original estimate was generated with the best information available at the time of the design with a reservoir survey being the best means to determine actual sediment inflow.

Since the closure of Olympus Dam in November of 1948 there have been several events that have affected the sediment inflows into Lake Estes. On May 25 of 1951 the Lily Lake dike broke which was located on the headwaters of Fish Creek about 5.5 miles upstream of Lake Estes. The dike was only around 5 to 6 feet high, but from investigation memorandums it appears a large amount of debris was carried downstream that eventually emptied into Lake Estes. During the Big Thompson Flood of 1976 no major sediment inflow into the lake was noted since the majority of the rain fell downstream in Big Thompson Canyon between Estes Park and Loveland. During this 1976 flood event there was a large amount of debris, cobbles, and boulders deposited in the spillway-stilling basin below the dam as a result of a large flood flow from Dry Creek. On July 15, 1982 Lawn Lake and Cascade Lake Dams, located on the Falls River, failed causing extensive damage as the flood flowed through Estes Park and eventually into Lake Estes (USGS 1986). There were no accurate measurements of the sediment and debris deposited in Lake Estes from this flood, but following the flood Reclamation did conduct debris and sediment removal operations from the Lake Estes area. It was also reported that a large volume of sediment was deposited the following year during a 1983 high spring snowmelt flood with the main source of the sediment material being exposed riverbanks from the 1982 flood.

A resurvey of Lake Estes 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. An above water survey should be conducted if better information is needed for elevation 7,470.0 and above.

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, August 2001. Denver Office, ***Lake Estes Area and Capacity Tables, Colorado – Big Thompson 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.***

U.S. Geological Survey, 1986, Professional Paper 1,369, ***Hydrology, Geomorphology, and Dam-Break Modeling of the July 15, 1982 Lawn Lake Dam and Cascade Lake Dam Failures***, Larimer County, Colorado, U.S. Government Printing Office, Washington.

RESERVOIR SEDIMENT
DATA SUMMARY

Lake Estes
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Big Thompson River	3. STATE Colorado
	4. SEC. 29 TWP. 5 N RANGE 72 W	5. NEAREST P.O. Estes	6. COUNTY Larimer
	7. LAT 40° 22' 31" LONG 105° 29' 19"	8. TOP OF DAM ELEVATION 7481.0	9. SPILLWAY CREST EL 7,460.0[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					
	b. FLOOD CONTROL					11/48
	c. POWER					
	d. JOINT USE					16. DATE NORMAL OPERATION BEGAN
	e. CONSERVATION	7475.0	185	2,659	3,068	
	f. INACTIVE	7450.25		409	409	
	g. DEAD					11/48
	17. LENGTH OF RESERVOIR 1.2 MILES			AVG. WIDTH OF RESERVOIR 0.2 MILES		

BASIN	18. TOTAL DRAINAGE AREA 158 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 15[2] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 158[3] SQUARE		23. MEAN ANNUAL RUNOFF 11.0[4] INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 92,480[5] ACRE-FEET
	21. MAX. ELEVATION	MIN. ELEVATION	25. ANNUAL TEMP. MEAN 48°F RANGE -41°F to 102°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
11/48			Contour (D)	5-ft	185[6]	3,068[6]	.02
8/01	52.8	52.8	Contour (D)	1-ft	185[7]	2,783[7]	.02

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
8/01		92,480	136,300[8]		92,480	

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.
8/01	284[9]	5.4	0.034	284	5.4	0.034

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	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.
8/01				0.24[10]	12.8[10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION											
		7525-7435	7435-7445	7445-7450.2	7450.2-7455	7455-7460	7460-7465	7465-7470				
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
		11.3	10.9	11.6	11.6	18.3	19.8	16.5				

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
				1977	7,473.8	7,467.9	
1978	7,474.1	7,468.2	114,200	1979	7,474.1	7,468.0	114,100
1980	7,474.0	7,469.4	121,900	1981	7,474.0	7,469.7	56,000
1982	7,473.9	7,464.9	89,900	1983	7,473.9	7,469.7	133,600
1984	7,474.1	7,468.4	112,600	1985	7,474.2	7,470.6	87,700
1986	7,474.4	7,469.8	113,200	1987	7,473.9	7,469.7	73,100
1988	7,473.9	7,470.3	72,300	1989	7,474.0	7,470.1	61,400
1990	7,473.9	7,459.8	88,700	1991	7,474.0	7,470.2	80,700
1992	7,473.8	7,463.3	71,600	1993	7,474.0	7,469.5	101,500
1994	7,474.2	7,469.9	76,400	1995	7,473.7	7,469.7	133,300
1996	7,473.6	7,470.0	108,200	1997	7,473.4	7,460.1	136,300
1998	7,473.8	7,460.1	107,400	1999	7,473.5	7,461.2	120,100
2000			77,200	2001			75,000

46. ELEVATION - AREA - CAPACITY DATA FOR **2001 CAPACITY**[11]								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
7,432	0	0	7,435	7	11	7,440	14	65
7,445	22	155	7,450	38	304	7,450.25	39	313
7,455	58	546	7,460	73	874	7,465	102	1,313
7,470	156	1,936	7,475	185	2,783			

47. REMARKS AND REFERENCES

1 Controlled by five radial gates with top elevation of 7,475.0.
2 Bureau of Reclamation Project Data Book, 1981. Values for Colorado Big Thompson Project.
3 Natural drainage area above the dam is 158 square miles. Value does not include diversions from Colorado River and sediment control by upstream dams.
4 Calculated using mean annual runoff value of 92,480 AF, item 24, 1936-2001.
5 Historical annual average for natural drainage above dam for water years 1936 through 20001. Does not include Colorado River diverted flows.
6 Original surface area and capacity at elevation 7,475.0. 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 7,475.0 computed by ACAP program.
8 Inflow values in acre-feet and maximum and minimum elevations in feet by water year for readily available years, 1978 through 2001. The historical inflow average for water years 1936 through 2001 is 92,480 AF. Normal operation of the reservoir is between elevation 7469.5 through 7474. Maximum pool elevation was 7,474.6 on June 19, 1965. Inflow values does not include diverted Colorado River flows.
9 Computed sediment volume at elevation 7,470.0. 2001 study assumed no change from elevation 7,470.0 and above due to lack of above water survey data.
10 Storage losses at elevation 7,470.0.
11 Capacities computed by Reclamation's ACAP computer program.

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)		
7,475.0	185	3068	185	2783			100.0
7,474.0	177	2887	177	2602			98.0
7,473.0	172	2712	172	2428			96.0
7,472.0	166	2543	166	2259			94.0
7,471.0	162	2379	162	2095			92.0
7,470.0	156	2220	156	1936	284	100.0	90.0
7,465.0	112	1550	102	1313	237	83.5	80.0
7,460.0	86	1055	73	874	181	63.7	70.0
7,455.0	66	675	58	546	129	45.4	60.0
7,450.25	46	409	39	313	96	33.8	50.5
7,450.0	45	398	38	304	94	33.1	50.0
7,445.0	27	218	22	155	63	22.2	40.0
7,440.0	16	110	14	65	45	15.8	30.0
7,435.0	11	43	7	11	32	11.3	20.0
7,432.0	6	17	0	0	17	6.0	14.0
7,430.0	3	8	0	0	8	2.8	10.0
7,425.0	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 284.						
8	Depth of reservoir expressed in percentage of total depth of 50 feet.						

Table 2. - Summary of 2001 survey results

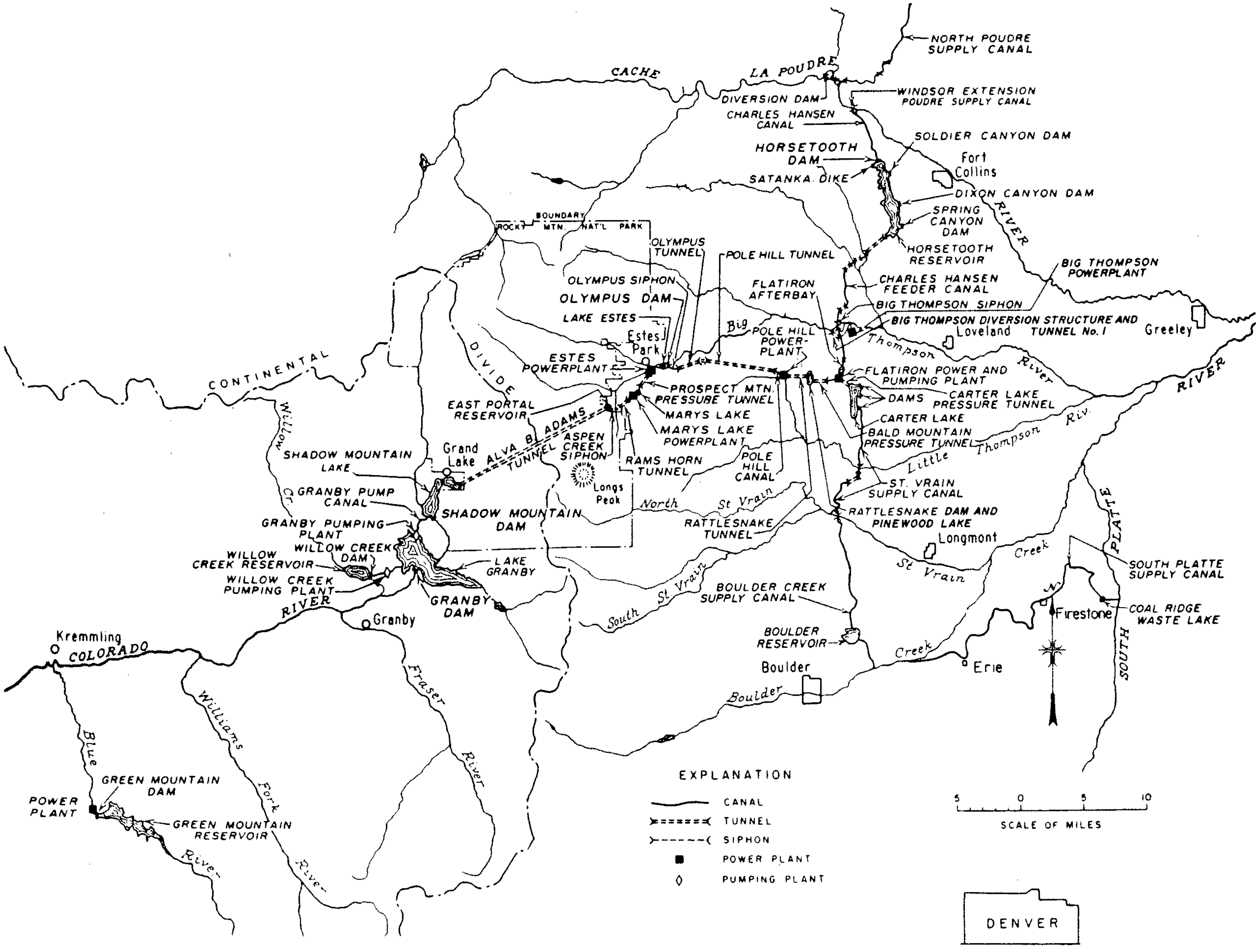

Figure 1. – Lake Estes location map.

Space intentionally left blank due to security concerns

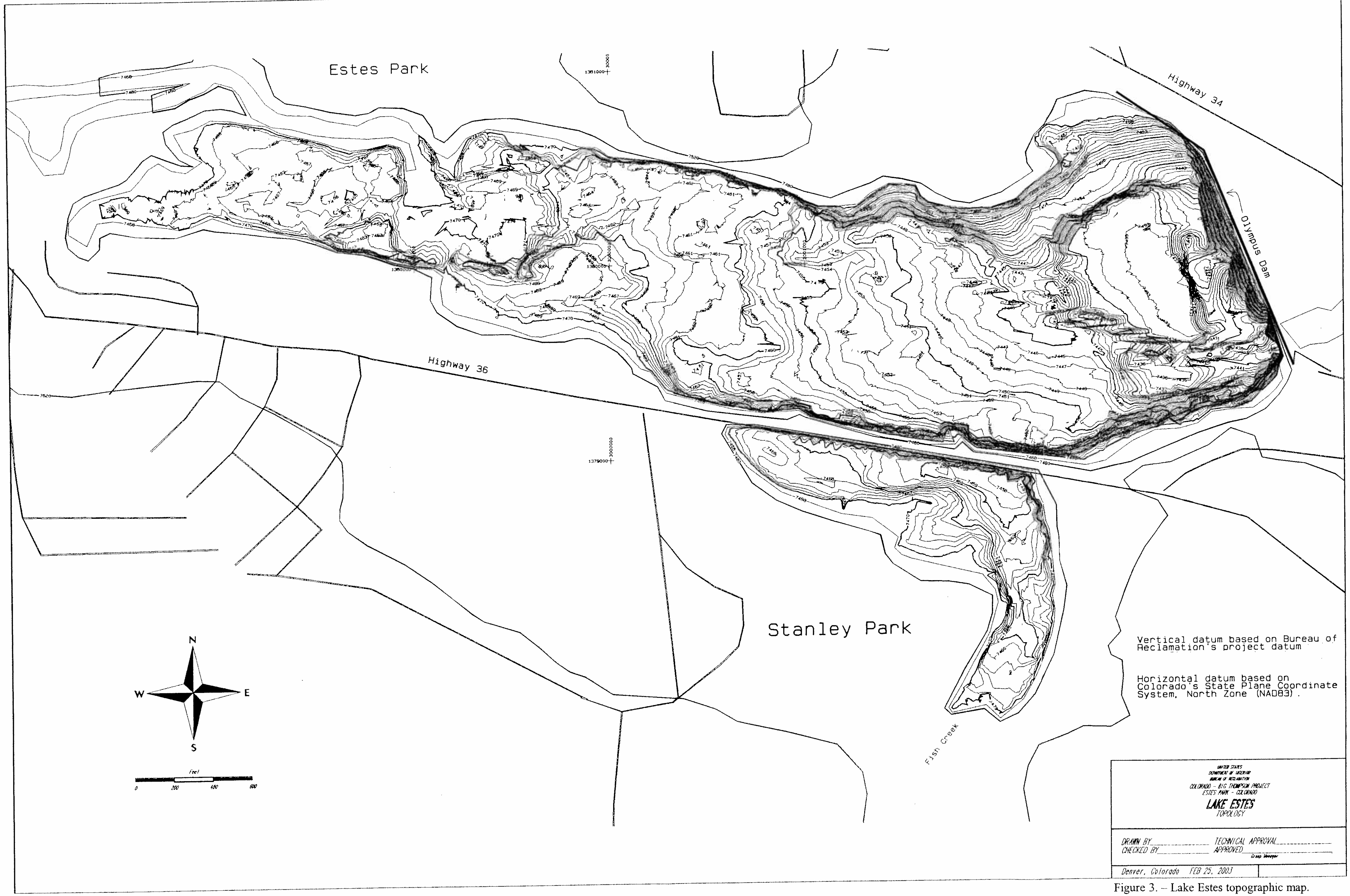

Figure 3. – Lake Estes topographic map.

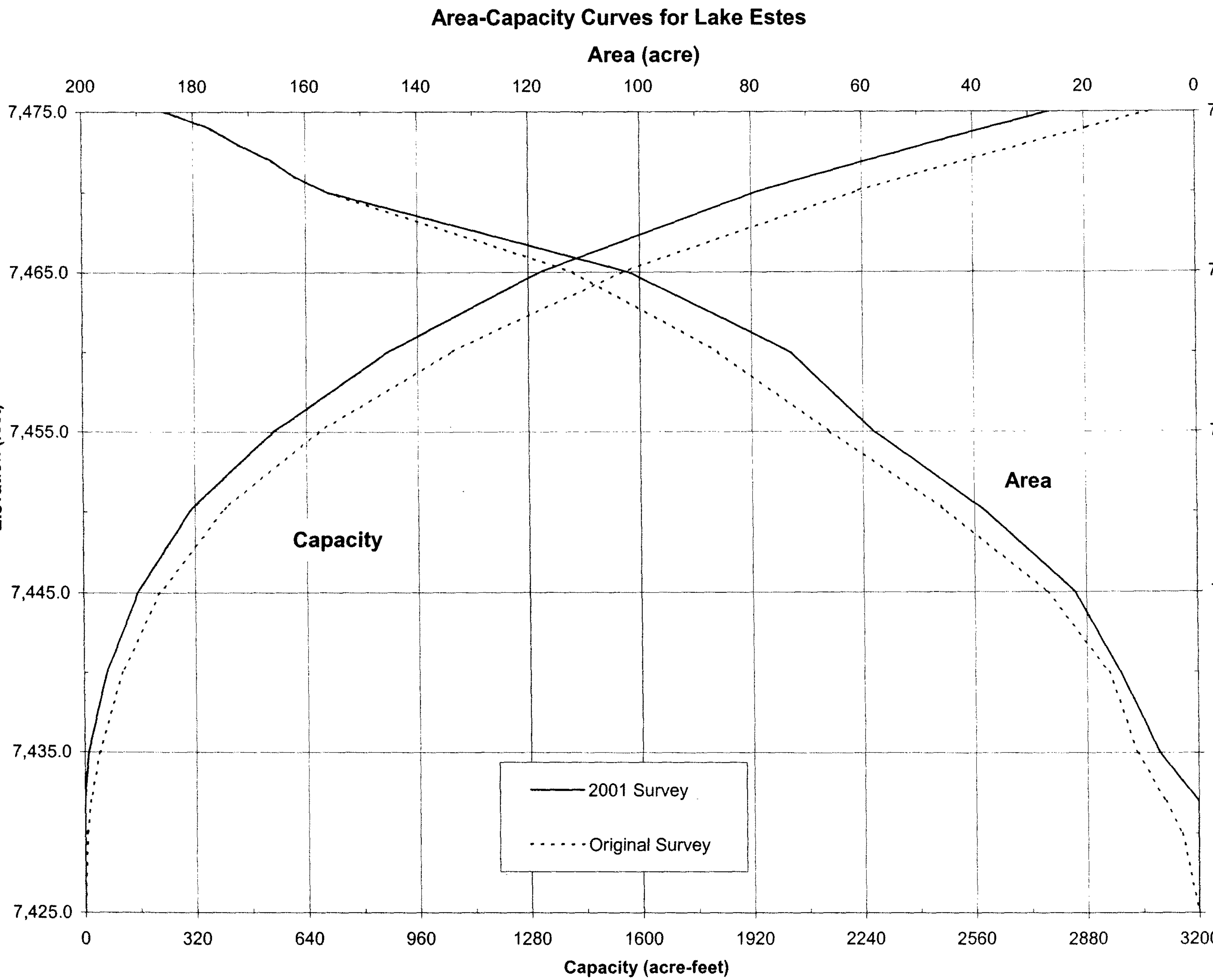

Figure 4. - 2001 area and capacity curves