RECLAMATION
Managing Water in the West

Millerton Lake
2004 Survey

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

March 2007

Millerton Lake 2004 Survey

prepared by

Ronald L. Ferrari
Sharon Nuanes

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water Resources Services
Sedimentation and River Hydraulics Group
Water Supply, Use, and Conservation Group
Denver, Colorado

March 2007

ACKNOWLEDGMENTS

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group and the Water Supply, Use and Conservation Group of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari of TSC and Robert Keller of the Mid-Pacific Regional Office conducted the underwater data collection. Ron Ferrari and Sharon Nuanes of the TSC completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes developed the final topographic maps presented in this report. 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.

Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68540), PO Box 25007, Denver, Colorado 80225-0007. **http://www.usbr.gov/pmts/sediment/**

Disclaimer

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**			
1. REPORT DATE *(DD-MM-YYYY)* March 2007	**2. REPORT TYPE**		**3. DATES COVERED** *(From – To)*
4. TITLE AND SUBTITLE Millerton Lake 2004 Survey			**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Ronald L. Ferrari Sharon Nuanes			**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Technical Service Center, Denver, CO 80225			**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. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
12. DISTRIBUTION/AVAILABILITY STATEMENT			
13. SUPPLEMENTARY NOTES			

14. ABSTRACT

The Bureau of Reclamation surveyed Millerton Lake in July 2004 to develop new reservoir topography and compute a present storage-elevation relationship (area-capacity tables). The underwater survey, conducted between reservoir water surface elevation 528.7 (feet) and 536.2, 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. The above-water topography was obtained from aerial photography flown on August 28, 2001, at water surface elevation 496.2. This study assumed no change since the 2001 aerial survey from elevation 496.2 and above.

As of July 2004, at conservation elevation 578.0, the surface area was 4,810 acres with a total capacity of 521,482 acre-feet. At maximum reservoir elevation 585.0, the surface area was 5,010 acres with a total capacity of 555,763 acre-feet.

15. SUBJECT TERMS

reservoir area and capacity/ sedimentation/ reservoir surveys/ global positioning system/ multibeam sounders/ contour area/

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Table of Contents

Index of Figures

Index of Tables

Millerton Lake 2004 Survey

Introduction

Friant Dam and Millerton Lake, on the San Joaquin River, are located in Fresno County about 25 miles northeast of Fresno, California (figure 1). The dam and reservoir are major features of the Friant Division of the Central Valley Project that also includes the Friant-Kern and Madera Canals. The dam and lake control San Joaquin River flows, providing flood control, recreation, and a conservation storage. Friant Dam provides diversion flows into the Madera and Friant-Kern Canals and downstream releases meet requirements above Mendota Pool, prevent salt water from destroying thousands of acres in the Sacramento-San Joaquin Delta, and deliver water to a million acres of agricultural land in Fresno, Kern, Madera, and Tulare Counties in the San Joaquin Valley. Millerton Lake storage began on February 21, 1944 and is approximately 15 miles long with an average width of 0.5 miles. The drainage area above the dam is around 1,638 square miles of which 526 square miles is considered sediment contributing.

Figure 1 - Friant Dam location map, California.

Completed in 1942, the dam (figure 2) is a concrete gravity structure with dimensions of:

Hydraulic height[1]	293 feet	Structural height	319 feet
Top width	20 feet	Crest length	3,488 feet
Crest elevation[2]	581.3 feet		

Figure 2 - Friant Dam downstream face.

The spillway consists of an overflow section at the center of the dam controlled by three 18-by-100-ft drum gates. The elevation at the top of the gates is 578.0. The discharge capacity of the spillway is 83,000 cubic feet per second (cfs) at dam crest elevation 578.0.

The outlet works to the San Joaquin River consists of four 110-in diameter steel pipes through the dam controlled by four 96-in hollow jet valves at the downstream end with two18-in needle valves branching from two of the 110-in valves. The Friant–Kern Canal outlet consists of four 110-in diameter steel pipes

[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. Unless otherwise noted, all elevations based on the original project datum established by U.S. Bureau of Reclamation that was reported to be 2.582 feet lower than the North American Vertical Datum of 1988 (NAVD88).

through the dam controlled by four 96-in hollow-jet valves. The Madera Canal outlet consists of two 91-in diameter steel pipes through the dam controlled by two 86-in valves. The total discharge capacity of the combined outlets is 16,400 cfs at reservoir elevation 578.0.

Summary and Conclusions

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

- develop reservoir topography
- compute area-capacity relationships

There was a control network established for the 2001 aerial survey of Millerton Lake, but no control markers near the dam were easily accessible. The hydrographic survey crew conducted a real-time kinematic (RTK) global positioning system (GPS) survey utilizing horizontal and vertical control established by the National Geodetic Survey (NGS) to tie the 2004 underwater data collection to the NGS network. The survey was conducted on July 6, 2004 with the base set at NGS datum "HPGN D CA 06 RG." This point was tied to a brass cap marked "604.16" that was located near the dam's left abutment. The horizontal control was in California state plane Zone 4 in the North American Datum of 1983 (NAD83) and the vertical control was tied to the Reclamation project datum elevation that was 604.16 at the brass cap. The National American Vertical Datum of 1988 (NAVD88) elevation of this brass cap was 606.742. All elevations in this report are in feet and referenced to the Reclamation project vertical datum that is reported to be 2.582 feet lower than NAVD88.

The underwater survey, July 7-12, 2004, was conducted between reservoir elevation 528.7 and 536.2. The bathymetric survey used sonic depth recording equipment interfaced with a real-time kinematic (RTK) and global positioning system (GPS) capable of 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 Millerton Lake. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. The reservoir's water surface elevations, recorded by the Reclamation reservoir gauge during the time of collection, were used to convert the sonic depth measurements to reservoir bottom elevations. These gauge elevations were tied to the Reclamation project datum. The contours of Millerton Lake were generated with elevations tied to NAVD88 by adding 2.582 feet to the Reclamation reservoir gauge elevations. All area and capacity computations within this report were tied to the Reclamation datum by reducing the elevations of the Millerton Lake surface area results by 2.582 feet.

The 2004 above-water area of Millerton Lake was developed from aerial data flown August 28, 2001, near reservoir elevation 496.2. The 2001 Millerton Lake aerial data was on tied the NAVD88 and the horizontal coordinates were California state plane Zone 4 in NAD83. This aerial survey covered an extensive portion of the drainage area above Millerton Lake and a small portion just downstream of Friant Dam. The aerial survey x, y, and z coordinates below elevation 600 feet where merged with the underwater x, y, and z coordinates to develop the new reservoir topography.

The final 2004 Millerton Lake topography below elevation 590 is a combination of the 2001 aerial data and the 2004 underwater collected data. A computer graphics program generated the 2004 reservoir surface areas at predetermined contour intervals from these combined data sets. The 2004 area and capacity tables were generated by a computer program using the 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 Millerton Lake and watershed characteristics for the 2004 survey. The 2004 survey determined that the reservoir has a total storage capacity of 555,763 acre-feet and a surface area of 5,010 acres at maximum reservoir water surface elevation 585.0 (table 2).

Reservoir Operations

Friant Dam operates to provide regulated diversion and downstream flows from the San Joaquin River. The July 2004 capacity table shows 555,763 acre-feet of total storage below the maximum water surface elevation 585.0 feet (table 2). The 2004 survey measured a minimum lake bottom elevation of 287.4 feet. The following values are from the July 2004 capacity table:

- 34,281 acre-feet of surcharge between elevation 578.0 and 585.0 feet.
- 390,262 acre-feet of joint use between elevation 466.3 and 578.0 feet.
- 43,944 acre-foot of active storage between elevation 442.2 and 466.3 feet.
- 69,889 acre-foot of inactive storage between elevation 375.4 and 442.2 feet.
- 17,387 acre-foot of dead storage below 375.4 feet.

Millerton Lake computed annual inflow and reservoir stage available records are listed by water year on table 1 for the operation period 1944 through 2004. The inflow values were computed by the Mid-Pacific Regional office and show annual fluctuation with a computed average inflow of 1,756,500 acre-feet per year. Table 1 also lists the maximum and minimum end-of-month elevation by water year. The maximum reservoir elevation was 580.0 recorded on January 3, 1997 with a minimum elevation of 467.8 recorded on April 11, 1969 (USGS, 2003).

RESERVOIR SEDIMENT
DATA SUMMARY

Millerton Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: San Joaquin River	3. STATE: California
A	4. SEC 5 TWP. 11 S RANGE 21 E	5. NEAREST P.O. Friant	6. COUNTY: Fresno
M	7. LAT 37° 00' 00" LONG 119° 42' 13"	8. TOP OF DAM ELEVATION: 581.25 [1]	9. SPILLWAY CREST EL. 560.0 [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC-FT	13. ORIGINAL CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN / 16 DATE NORMAL OPERATIONS BEGAN
	a. SURCHARGE	585.0 [3]	5,110	35,000	555,500	15: 2/1944
	b. FLOOD CONTROL					
	c. POWER					
	d. JOINT USE	578.0	4,900	390,000	520,500	16: 2/1944
	e. CONSERVATION	466.3	2,125	43,800	130,500	
	f. INACTIVE	442.2	1,580	69,300	86,700	
	g. DEAD	375.4	636	17,400	17,400	
	17. LENGTH OF RESERVOIR 13.6 [4] MILES		AVG. WIDTH OF RESERVOIR 0.55 MILES			

BASIN		
	18. TOTAL DRAINAGE AREA 1,638 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 8.9 [6] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 526 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 20.1 [7] INCHES
	20. LENGTH MILES; AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 1,756,500 [7] ACRE-FEET
	21. MAX. ELEVATION 14,000; MIN. ELEVATION 560	25. ANNUAL TEMP, MEAN 64 °F RANGE 17 °F to 116 °F [6]

26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/ RATIO AF/AF
2/44			Contour (D)	5-ft	4,900 [8]	520,500 [8]	0.30
7/04			Contour (D)	3-ft	4,810 [9]	521,482 [9]	0.30

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36 WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
7/04		1,756,500 [7]	4,704,000	107,144,600	1,756,500	107,144,600

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
7/04	[10]					

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR		41. STORAGE LOSS, PCT.		42 SEDIMENT INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AVG. ANNUAL	b. TOTAL TO DATE	a. PER.	b. TOT.
7/04				[10]	[10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	50-60	60-70	70-80	80-90	90-100	100-105	105-111	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

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

45. RANGE IN RESERVOIR OPERATION [7]								
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF		YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1944	526.6	379.6	1,264,600		1945	561.0	453.5	2,109,200
1946	561.2	492.6	1,740,200		1947	552.7	451.0	1,177,900
1948	568.1	442.5	1,139,800		1949	562.1	434.6	1,209,200
1950	560.0	406.6	1,314,800		1951	563.2	428.5	1,817,800
1952	562.0	471.2	2,789,800		1953	570.5	472.4	1,275,600
1954	577.3	469.8	1,300,200		1955	576.8	470.1	1,148,100
1956	567.4	468.0	2,834,400		1957	578.5	478.9	1,371,800
1958	579.0	477.9	2,568,200		1959	565.2	471.5	1,132,100
1960	535.2	467.8	863,000		1961	543.8	471.0	647,100
1962	561.4	468.3	1,725,000		1963	579.5	477.3	1,944,900
1964	555.1	469.4	1,121,300		1965	562.1	475.7	2,028,900
1966	569.7	479.3	1,370,700		1967	578.7	483.8	3,128,500
1968	522.8	460.3	1,135,100		1969	577.9	467.8	3,798,300
1970	566.4	476.8	1,515,300		1971	575.3	473.4	1,417,100
1972	539.6	473.6	1,043,400		1973	579.7	472.3	2,003,300
1974	576.0	470.0	2,200,000		1975	571.3	469.4	1,797,900
1976	547.2	474.3	828,000		1977	511.8	489.9	377,700
1978	570.1	475.0	3,041,500		1979	577.2	481.0	1,975,800
1980	578.7	478.3	2,925,500		1981	559.1	480.8	1,140,000
1982	579.2	481.8	3,140,300		1983	579.0	468.2	4,704,000
1984	573.7	480.2	2,096,100		1985	557.9	475.4	1,215,500
1986	576.8	477.9	2,922,400		1987	532.7	471.0	1,000,200
1988	539.9	473.0	825,500		1989	547.2	469.7	927,100
1990	539.8	469.5	766,500		1991	554.5	477.9	925,200
1992	565.2	480.3	890,600		1993	577.9	475.3	2,456,300
1994	560.1	476.0	1,011,700		1995	577.2	488.5	3,584,000
1996	576.6	507.1	2,337,200		1997	579.4	493.8	2,832,100
1998	579.7	479.7	3,072,400		1999	578.7	503.9	1,636,800
2000	578.1	498.0	1,707,900		2001	575.6	486.3	1,120,400
2002	576.3	481.0	1,164,800		2003	574.1	499.8	1,413,400
2004	567.4	498.4	1,145,200					

46. ELEVATION - AREA - CAPACITY - DATA FOR **2004 CAPACITY**										
ELEVATION	AREA	CAPACITY		ELEVATION	AREA	CAPACITY		ELEVATION	AREA	CAPACITY
2004	**SURVEY**			287.4	0	0		290.0	0	0
295.0	0	0		300.0	0	1		305.0	1	3
310.0	2	8		315.0	7	27		320.0	24	102
325.0	51	285		330.0	103	649		335.0	160	1,307
340.0	222	2,257		345.0	278	3,517		350.0	339	5,054
355.0	397	6,899		360.0	452	9,020		365.0	514	11,431
370.0	569	14,141		375.0	629	17,134		375.4	633	17,387
380.0	678	20,404		385.0	727	23,916		390.0	791	27,700
395.0	854	31,816		400.0	913	36,234		405.0	971	40,944
410.0	1,036	45,962		415.0	1,103	51,305		420.0	1,174	56,994
425.0	1,253	63,060		430.0	1,339	69,535		435.0	1,430	76,456
440.0	1,531	83,863		442.2	1,571	87,276		445.0	1,622	91,744
450.0	1,721	100,096		455.0	1,831	108,971		460.0	1,952	118,423
465.0	2,078	128,494		466.3	2,115	131,220		470.0	2,216	139,233
475.0	2,349	150,646		480.0	2,475	162,711		485.0	2,596	175,388
490.0	2,718	188,676		495.0	2,841	202,567		500.0	2,970	217,105
505.0	3,090	232,254		510.0	3,213	248,013		515.0	3,335	264,381
520.0	3,458	281,364		525.0	3,586	298,973		530.0	3,703	317,199
535.0	3,820	336,007		540.0	3,935	355,397		545.0	4,051	375,365
550.0	4,163	395,901		555.0	4,276	416,999		560.0	4,391	438,665
565.0	4,507	460,913		570.0	4,622	483,737		575.0	4,763	507,151
578.0	4,810	521,482		580.0	4,854	531,146		585.0	5,010	555,763

47. REMARKS AND REFERENCES

[1] All elevations are in feet based on the original project datum that is 2.582 feet lower than NAVD88. Top of parapet wall elevation 585.0.

[2] Spillway crest elevation 560.0. Located in center of dam, controlled by drum gates with top elevation 578.0.

[3] Values from Reservoir Capacity Allocation table dated 5/69.

[4] Reservoir length at elevation 578.

[5] Total drainage area from USGS water year records. Upstream reservoirs capture some of the sediment runoff. Florence Lake (173 mi^2), Thomas A. Edison Lake (92 mi^2), Huntington Lake (81 mi^2), Bass Lake (49 mi^2), Shaver Lake (30 mi^2), and Mammoth Pool Reservoir (81 mi^2).

[6] Bureau of Reclamation Project Data Book, 1981. Values for Central Valley Project.

[7] Mean annual runoff of 1,756,500 AF, item 24, from 1944 through 2004 from Reclamation's Mid Pacific Region's computed inflows. Values account for additional inflow from diversion flows. End of month maximum and minimum elevations from USGS annual reports.

[8] Surface area and capacity at elevation 578.0, spillway crest elevation.

[9] All 2004 capacities computed by Reclamation's ACAP computer program.

[10] Due to difference of detail between original and 2004 surveys, computing capacity loss due to sediment deposition by comparing differences is not possible.

48. AGENCY MAKING SURVEY Bureau of Reclamation

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

Table 1 – Reservoir sediment data summary (2 of 2).

1	2	3	4	5	6	7	8
					2004	**2004**	**Percent of**
Elevations	**Original**	**Original**	**2004**	**2004**	**Area**	**Volume**	**Reservoir**
	Survey	**Capacity**	**Survey**	**Survey**	**Difference**	**Difference**	**Depth**
(feet)	**(acres)**	**(acre-feet)**	**(acres)**	**(acre-feet)**	**(acres)**	**(acre-feet)**	
585.0	5110	555500	5010	555763	100	-263	100.0
580.0	4951	530402	4854	531146	97	-744	98.3
578.0	4900	520528	4810	521482	90	-954	97.7
570.0	4699	482151	4622	483737	77	-1586	95.0
560.0	4433	436485	4391	438665	42	-2180	91.7
550.0	4176	393446	4163	395901	13	-2455	88.3
540.0	3922	352956	3935	355397	-13	-2441	85.0
530.0	3682	314940	3703	317199	-21	-2259	81.7
520.0	3432	279364	3458	281364	-26	-2000	78.3
510.0	3185	246285	3213	248013	-28	-1728	75.0
500.0	2943	215645	2970	217105	-27	-1460	71.7
490.0	2695	187455	2718	188676	-23	-1221	68.3
480.0	2454	161720	2475	162711	-21	-991	65.0
470.0	2211	138389	2216	139233	-5	-844	61.7
466.3	2125	130437	2115	131220	10	-783	60.4
460.0	1957	117539	1952	118423	5	-884	58.3
450.0	1700	99274	1721	100096	-21	-822	55.0
442.2	1580	86707	1571	87276	9	-569	52.4
440.0	1493	83337	1531	83863	-38	-526	51.7
430.0	1311	69339	1339	69535	-28	-196	48.3
420.0	1160	57000	1174	56994	-14	6	45.0
410.0	1025	46087	1036	45962	-11	125	41.7
400.0	910	36432	913	36234	-3	198	38.3
390.0	797	27885	791	27700	6	185	35.0
380.0	689	20457	678	20404	11	53	31.7
375.4	636	17412	633	17387	3	25	30.1
370.0	574	14134	569	14141	5	-7	28.3
360.0	452	8960	452	9020	0	-60	25.0
350.0	329	4977	339	5054	-10	-77	21.7
340.0	216	2282	222	2257	-6	25	18.3
330.0	103	675	103	649	0	26	15.0
320.0	23	93	24	102	-1	-9	11.7
310.0	2	4	2	8	0	-4	8.3
287.4	0	0	0	0	0	0	0.8
285.0	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 2004 survey.**						
5	**Reservoir capacity computed using ACAP.**						
6	**Area difference between original and 2004 survey = column (3) - column (5).**						
7	**Volume difference between original and 2004 survey = column (4) - column (5).**						
8	**Depth of reservoir expressed in percentage of total depth of 300.0 feet.**						

Table 2 - Summary of 2004 survey results.

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 3). 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. The GPS receiver and antenna were mounted on a survey tripod over a known datum point and a 12-volt battery provided the power for the shore unit.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The basic output from a RTK receiver are precise 3D coordinates in latitude, longitude, and height with accuracies in 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 California's state plane Zone 4 coordinates in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

Figure 3 - Survey vessel with mounted instrumentation on Jackson Lake in Wyoming.

In 2001, the Sedimentation and River Hydraulics Group began utilizing an integrated multibeam hydrographic survey system. The system consists of a single transducer mounted on the center bow or forward portion of the boat. From the single transducer a fan array of narrow beams generate a detailed cross section of bottom geometry as the survey vessel passes over the areas to be mapped. The system transmits 80 separate 1-1/2 degree slant beams resulting in a 120-degree swath from the transducer. The 200 kHz high-resolution multibeam echosounder system measured the relative water depth across the wide swath perpendicular to the vessel's track. Figure 4 illuminates the swath of the sea floor that is about 3.5 times the water depth below the transducer.

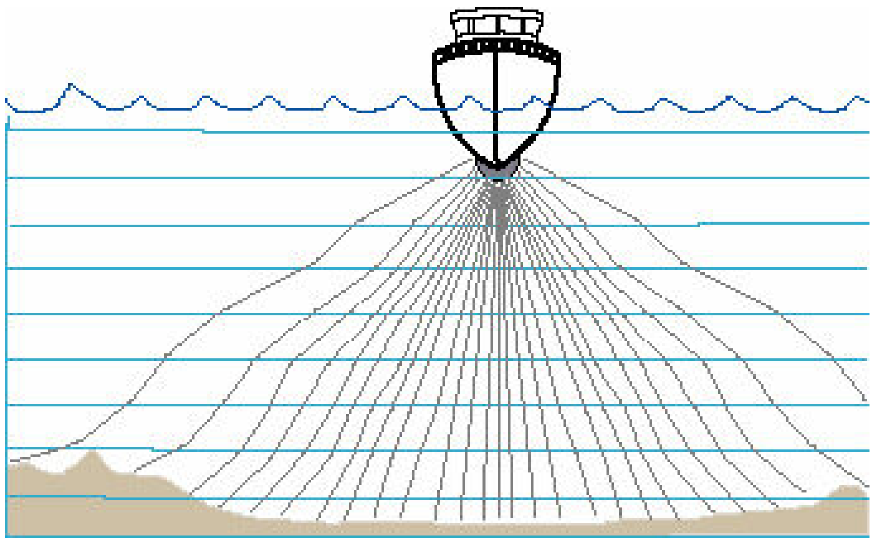

Figure 4 - Multibeam collection system.

The multibeam system is composed of several instruments that are all in constant communication with a central on-board notebook computer. The components include the RTK GPS for positioning; a motion reference unit to measures the heave, pitch, and roll of the survey vessel; a gyro to measures the yaw or vessel attitude; and a velocity meter to measure the speed of sound of the reservoir water column. With the proper calibration, the data processing software utilizes all the incoming information to provide an accurate detailed x, y, z data set of the lake bottom.

The Millerton Lake bathymetric survey collection was conducted from July 7 through July 12 of 2004 between water surface elevation 528.7 and 536.1 (Reclamation project datum). The survey was run using the multibeam instrumentation described above where the survey system software continuously recorded reservoir depths and horizontal coordinates as the survey vessel moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run along the original river alignment of the reservoir where the multibeam swaths overlapped each other. The multibeam system could have provided full bottom coverage of the area not covered by the aerial collection, but time, budget, and access did not allow this to occur in all the shallow portions of the reservoir. The loss of these additional data points did not have a significant impact on the area computations since it only occurred in a few areas of the reservoir.

The data analysis began with the processing of all the collected raw profile files of the bottom. This included applying all necessary correction information that was collected, such as vessel location, and the roll, pitch, and yaw effects on the survey vessel. Other corrections included applying the field measured sound velocity of the reservoir water column and then converting all corrected depth data to elevations. All elevations in the final analysis were tied to the Reclamation measured water surface elevation at the time of collection. These water surface elevations were converted to NAVD88 datum by adding 2.582 feet. Due to the massive amount of data, the data was filtered utilizing built-in procedures within the collection and analysis software that logically filtered data points without adversely affecting the results. Quality control and assurance of the data were accomplished by conducting field calibration as required by the multibeam system and collecting velocity profile data for the areas being surveyed.

Reservoir Area and Capacity

Topography Development

The topography of Millerton Lake was developed from the 2004 underwater and the 2001 aerial data. The 2001 aerial data was in an x, y, and z format, California state plane Zone 4 in NAD83, from around elevation 496.2 and above. The 2001 aerial data elevations were tied to NAVD88 for the survey of Millerton Lake. Due to the large data set, all elevations below elevation 496 and above elevation 600 were removed. Additionally, all aerial data downstream of the dam was also removed. Using the aerial data a hardclip was developed to enclose all of the reservoir data. This hardclip was used during the triangular irregular network (TIN) development so interpolation did not occur outside the enclosed polygon. This clip was not assigned an elevation and was strictly used to enclose the 2001 and 2004 data sets.

Contours for the reservoir within this hardclip were computed from the combined aerial and underwater 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 Millerton Lake 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 Millerton Lake since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the combined survey data sets. The 2004 contour topography is presented on figures 5 through figure 9. The contour data presented on these maps are tied to the vertical datum of NAVD88. All computations within this report are tied to the Millerton Lake project datum that is 2.582 feet lower than NAVD88.

Development of the 2004 Contours

The 2004 contours of Millerton Lake were developed by combining the 2001 aerial and 2004 underwater data. The reservoir contours are presented on the included maps (figures 5 through 9) at 10-foot increments from elevation 290.0 through elevation 590.0. As stated previously the contours presented on these maps are tied to NAVD88 which is 2.582 feet higher than the project datum and the horizontal coordinates were on the California State Plane, Zone 4, in NAD83.

Development of the 2004 Surface Areas

The 2004 contour surface areas for Millerton Lake were computed at 1-foot increments from Millerton Lake TIN. Since the TIN was developed from elevations tied to NAVD88, the resultant elevation versus surface area table was shifted down 2.582 feet to match the project datum elevations. The final table had measured results from project elevation 288.0 through elevation 585.0. The 2004 underwater survey measured a minimum reservoir bottom elevation of 287.4. Surface area calculations were performed using the ARC/INFO VOLUME command that computes areas at user-specified elevations directly from the TIN and takes into consideration all regions of equal elevation.

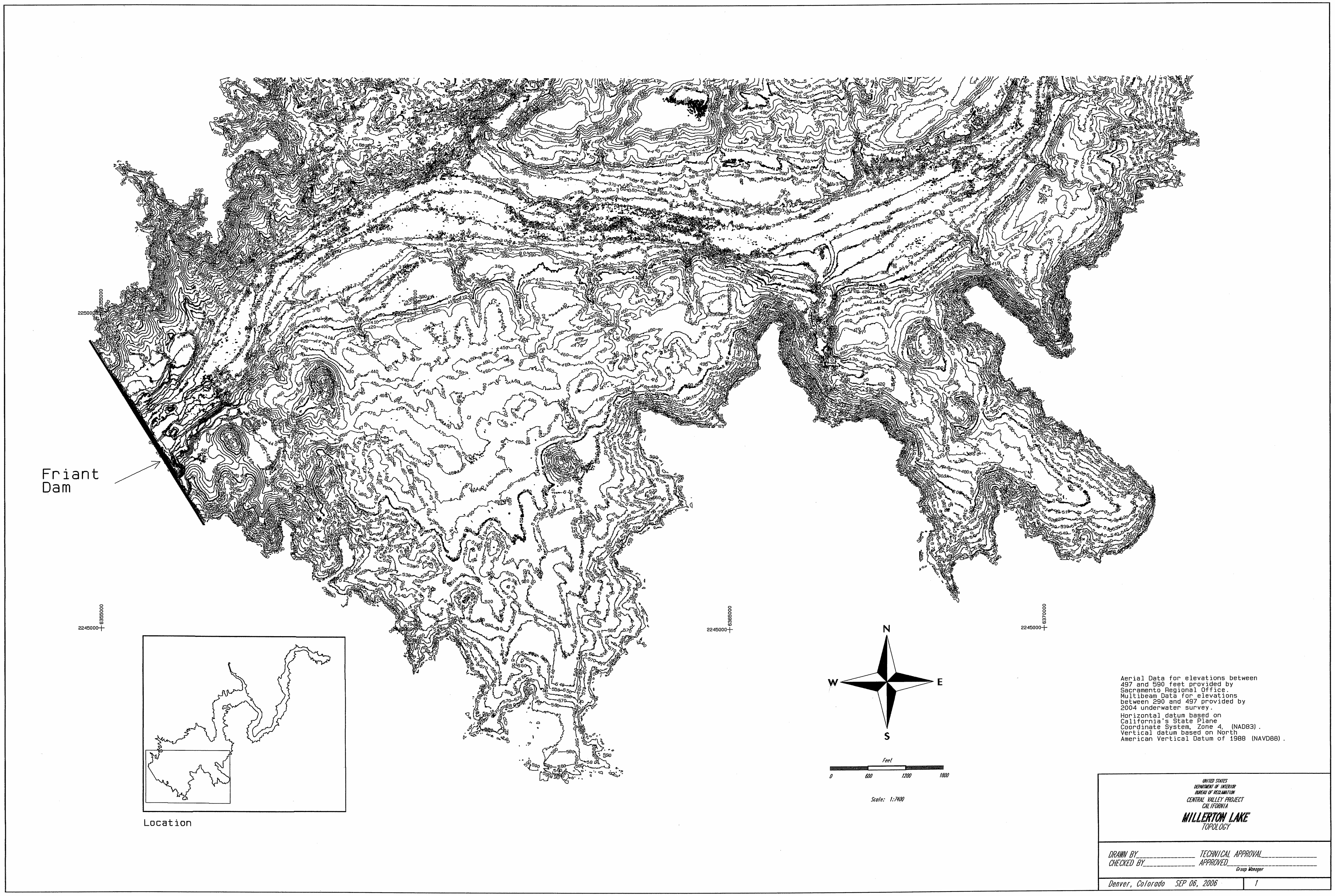

Figure 5 - Millerton Lake topographic map 1.

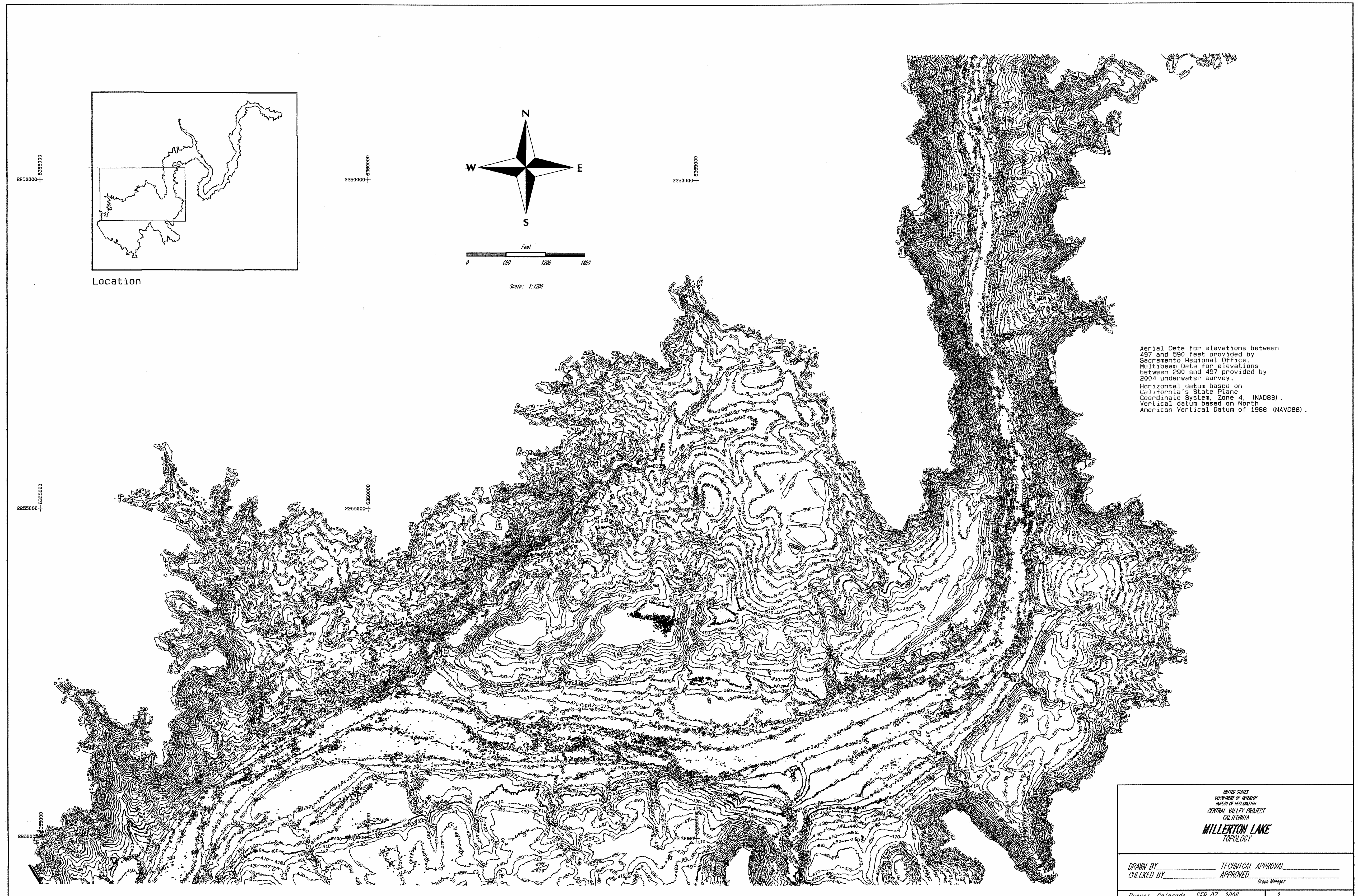

Figure 6 – Millerton Lake topographic map 2.

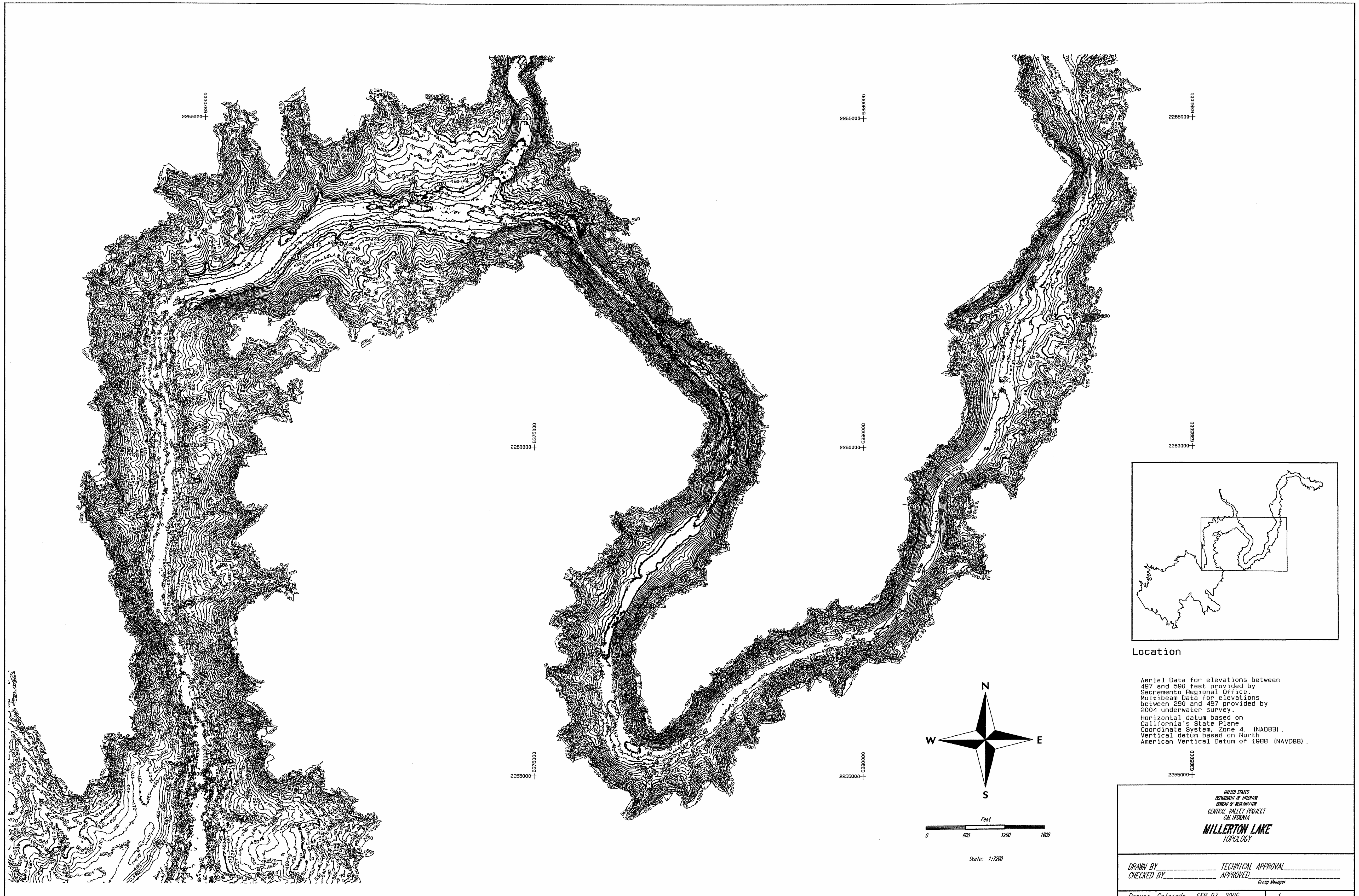

Figure 7 - Millerton Lake topographic map 3.

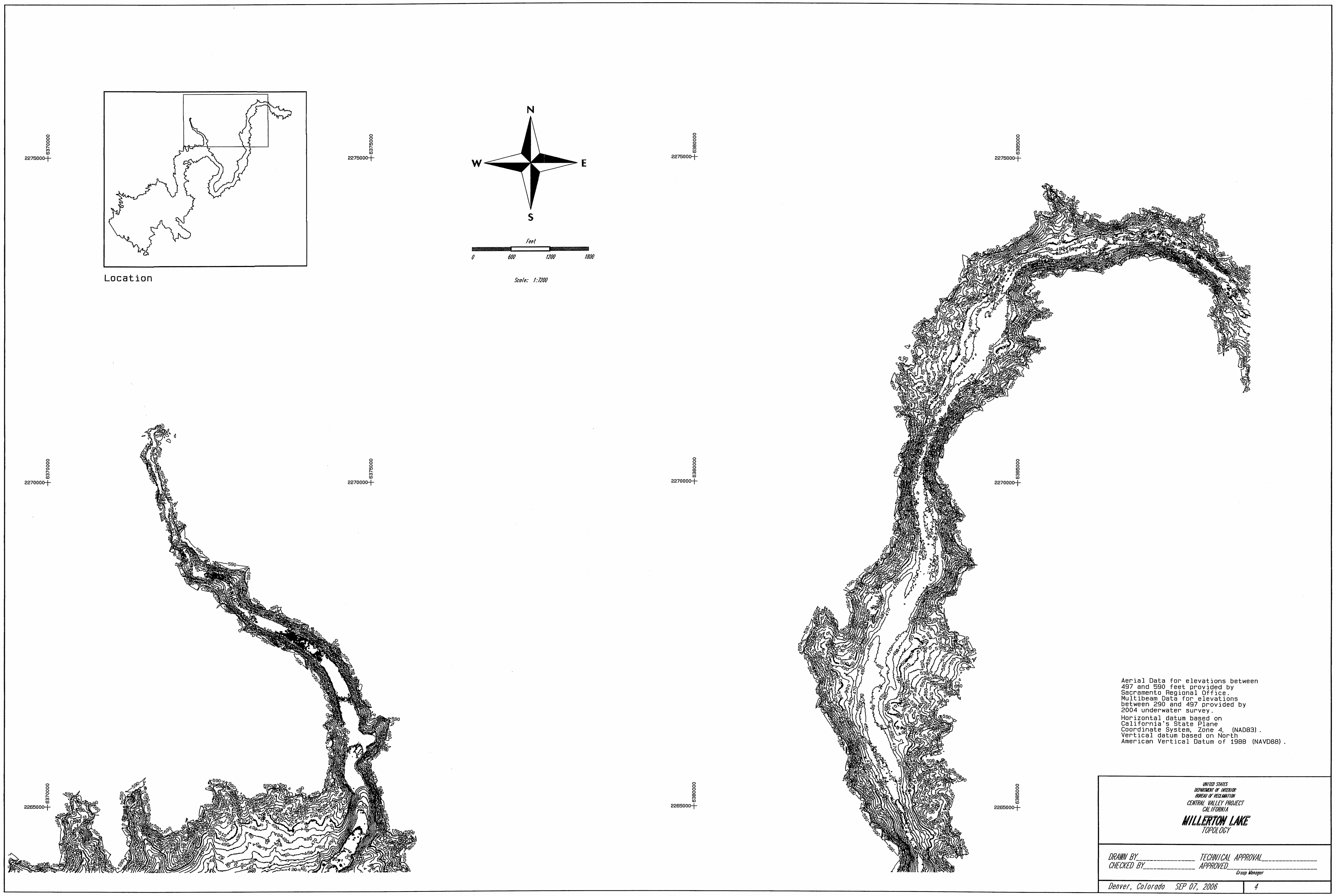

Figure 8 - Millerton Lake topographic map 4.

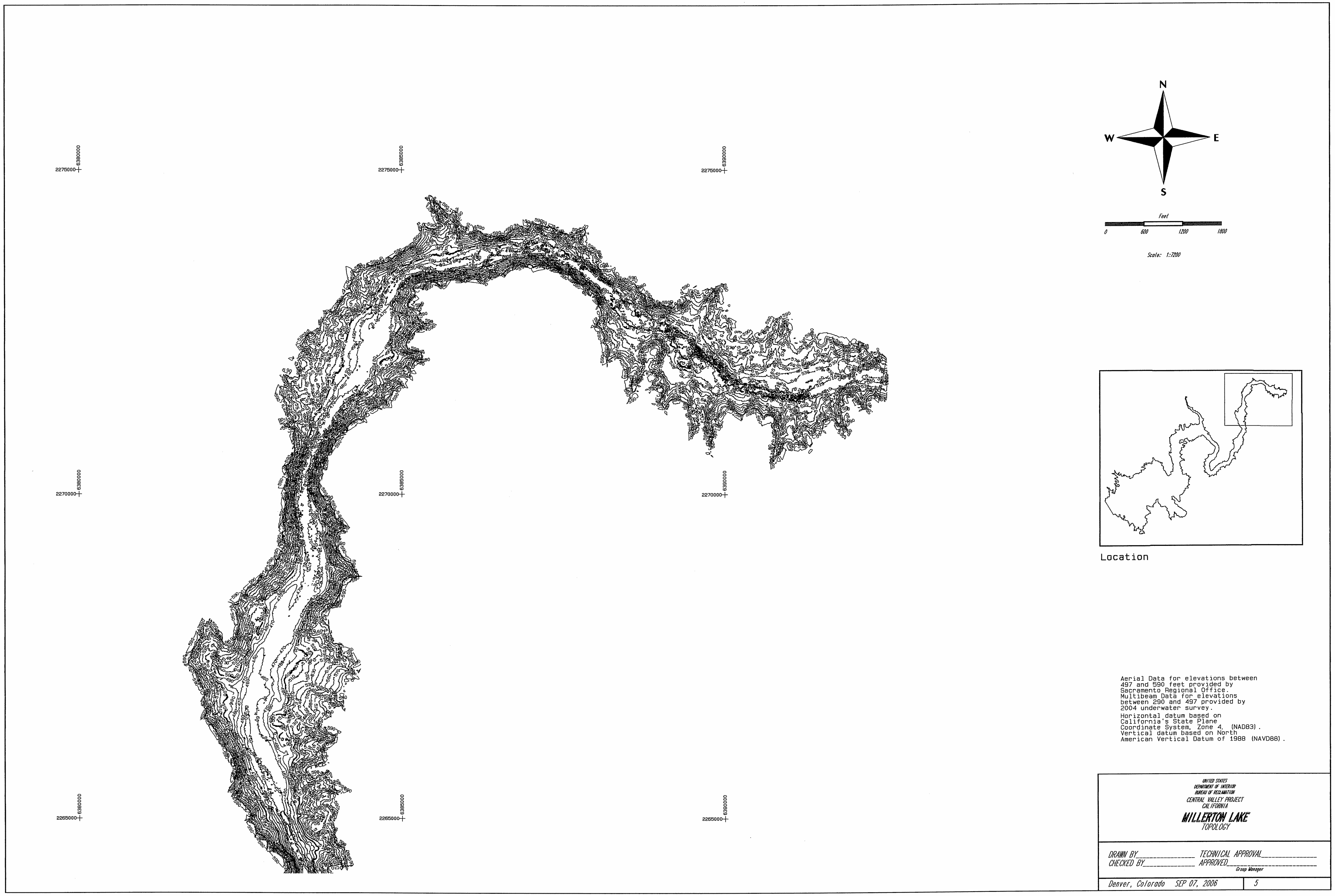

Figure 9 - Millerton Lake topographic map 5.

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). For the purpose of this study, the measured 2004 survey areas at 3-foot increments from elevation 290.0.0 through 590.0 were used to compute the new area and capacity tables and were used as the control parameters for computing the 2004 Millerton Lake capacity. 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 the Millerton Lake data analysis. 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 shorter 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 Millerton Lake area and capacity computations are listed in a separate set of 2004 area and capacity tables that have 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 these tables. The 1945 and 2004 area-capacity curves are listed on table 2 and plotted on figure 10. As of July 2004, at spillway top of gate elevation 578.0, the surface area was 4,810 acres with a total capacity of 521,482 acre-feet.

2004 Reservoir Analyses

Results of the Millerton Lake area and capacity computations are listed in table 1 and columns 4 and 5 of table 2. As stated previously, unless otherwise noted, all elevations in this report are based on the original project datum established by Reclamation that is reported to be 2.582 feet lower than NAVD88. Columns 2 and 3 of table 2 list the 1945 or original area and capacity values for Millerton Lake. Columns 6 and 7 list the surface area and capacity differences between the original and 2004 computations. Figure 10 is a plot of the Millerton Lake surface area and capacity values for the two surveys and illustrates the small differences. The comparison show the reservoir capacity in 2004 is slightly greater than the original capacity from around reservoir elevation 430 and higher.

Research into the original values found that the surface areas were calculated by the Division of Water Resources in January 1936 based on topographic maps of the reservoir prepared by the Madera Irrigation District from a survey conducted in 1921. The contour interval was 10 feet and maps were at a scale of one-inch equals two hundred feet. Information on how this survey was conducted was not located, but it is assumed it was a plane table type collection requiring many staff days to traverse the rugged terrain and resulting in less detail than the 2004 survey.

During the original planning of Millerton Lake, the estimated loss of total reservoir capacity over the first 100 years of operation was 7.9 percent or around 41,000 acre-feet. There is no information on how this sediment inflow value was determined and what factors were utilized. This investigation found that the total drainage area into Millerton Lake is around 1,638 square miles and if it assumed all the upstream reservoirs capture sediment inflow, then only around 526 square miles of the drainage area contributes sediment inflow directly into Millerton Lake. It is unknown if the original planning process took into account these upstream reservoirs even though most existed prior to Friant Dam closure. Due to all of these unknowns, there are no means from the 2004 survey results to estimate reservoir sediment deposition since dam closure.

It is the general conclusion the small capacity difference between the original and 2004 surveys is due to the differences in detail of the surveys. The 2004 detailed survey resulted in a more accurate representation of the reservoir volume as of July 2004. Even though the sediment contributing area is only about 32 percent of the total drainage basin, one would still anticipate annual capacity loss due to sediment inflow. If sediment inflow is a concern, then collection of reservoir bottom samples along with depth profiles from a low frequency sounder could possibly measure the thickness of any existing reservoir bottom sediments.

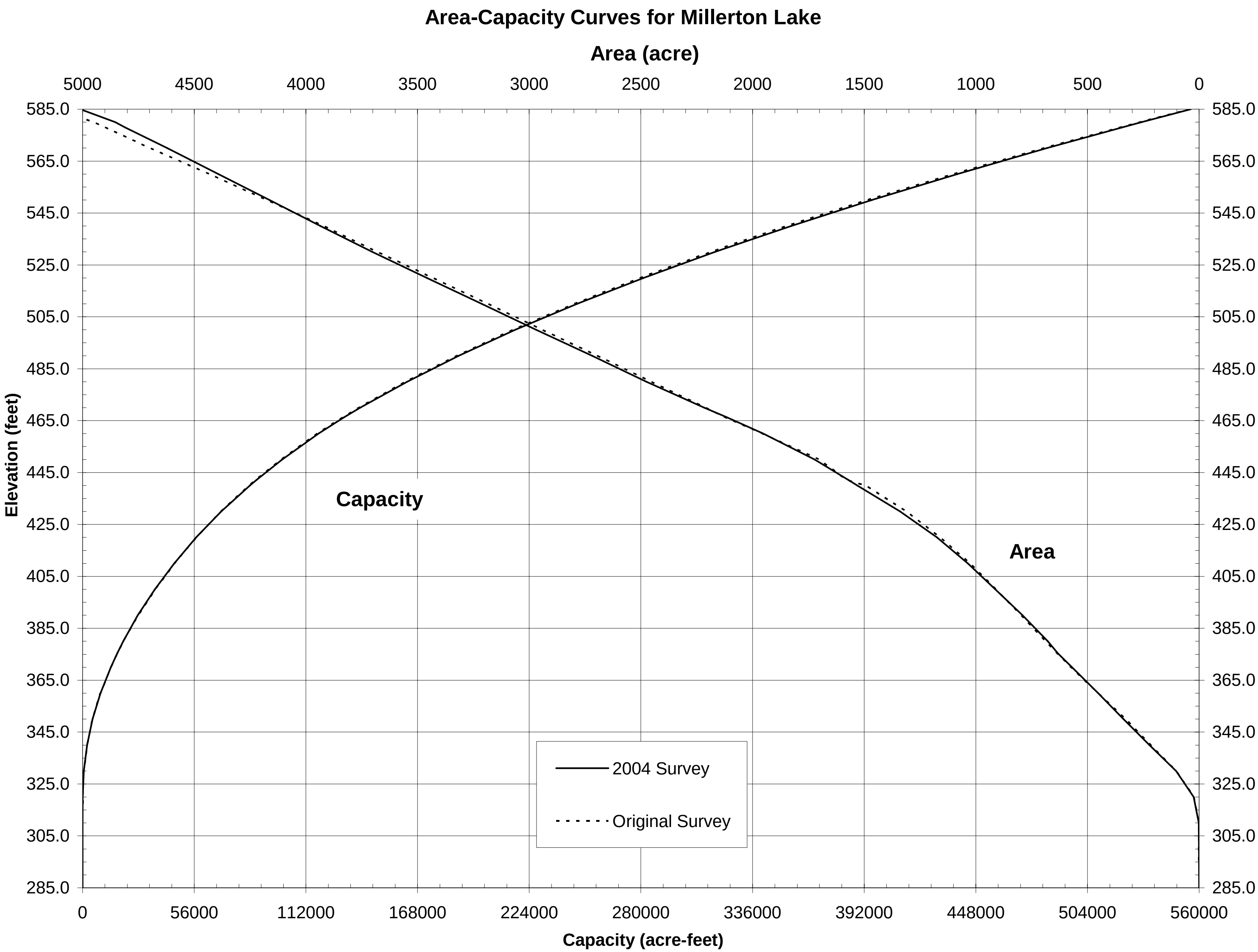

Figure 10 - 2004 area and capacity curves.

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 2004. Denver Office, ***Millerton Lake Area and Capacity Tables, Central Valley Project***, Mid-Pacific Region, Sacramento, CA.

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***.

United States Geological Survey (USGS), 2003. ***Water Resources Data Nevada Water Year 2003***, Water-Data Report NV-03-1, U.S. Geological Survey, Carson City, NV.