RECLAMATION

Managing Water in the West

Keyhole Reservoir
2003 Sedimentation Survey

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

July 2005

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13. ABSTRACT *(Maximum 200 words)*

The Bureau of Reclamation surveyed Keyhole Reservoir in May 2003 to develop new reservoir topography and compute a present storage-elevation relationship (area-capacity tables). The underwater survey, conducted between reservoir elevation 4,091.7 (feet) and 4,091.8 (project datum), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was obtained by digitizing the developed reservoir contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. This study assumed no change, since the 1979 range line survey, from elevation 4,090 and above.

As of May 2003, at spillway crest elevation 4,099.3, the surface area was 9,411 acres with a total capacity of 188,671 acre-feet. Since dam closure on February 12, 1952, about 12,495 acre-feet of change have been estimated below elevation 4,099.3, resulting in a 6.2 percent loss in reservoir volume.

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Keyhole Reservoir 2003 Survey

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UNITED STATES DEPARTMENT OF THE INTERIOR

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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INTRODUCTION

Keyhole Dam and Reservoir, about 11 miles east of Moorcroft and 21 miles southwest of Sundance, is located in Crook County on the Belle Fourche River of northeast Wyoming (figure 1). The dam, reservoir, and facilities are part of the Keyhole Unit that provides storage for irrigation, municipal, and industrial water supplies, flood control, fish and wildlife conservation, recreation, and sediment control for the Pick-Sloan Missouri Basin Project.

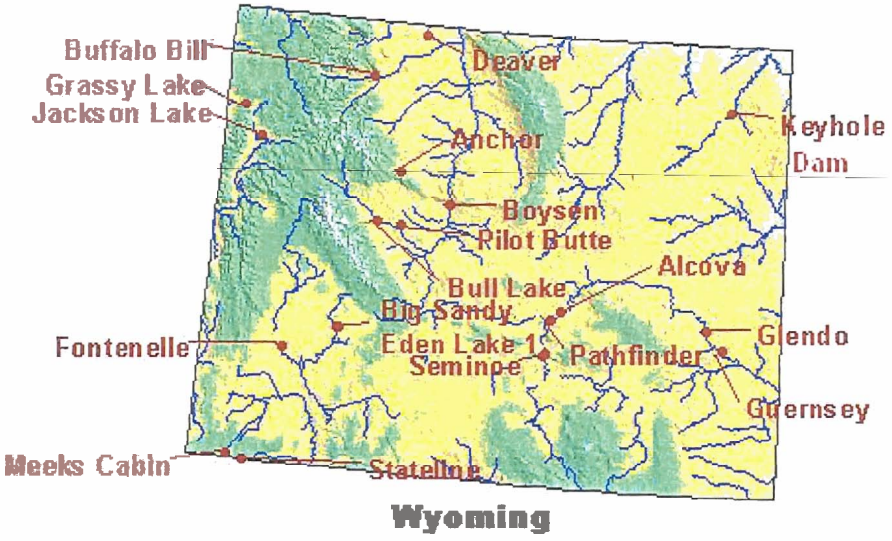

Figure 1 – Keyhole Reservoir Location Map.

The reservoir, formed by a zoned rolled earth embankment structure, was completed in 1952. The dam's dimensions are:

Hydraulic height[1]	113	feet	Structural height	168	feet
Top width	20	feet	Crest length	3,420	feet
Crest elevation	4,134.0	feet[2]			

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

[2]Elevations in feet. All elevations based on the original project datum established by U.S. Bureau of Reclamation that was reported to be the National Geodetic Vertical Datum of 1929 (NGVD29) and 2.1 feet lower than the North American Vertical Datum of 1988 (NAVD88).

The spillway is an open concrete channel that extends through the dike on the right abutment. The spillway consists of a concrete inlet structure, an uncontrolled concrete crest, and an open concrete-lined chute having a small flip bucket at the downstream end. The ogee crest is at elevation 4,099.3 and has a length of 19.25 feet. The discharge capacity is 10,850 cubic feet per second (cfs) at maximum reservoir elevation 4,128.7.

An outlet works is located near the left abutment and consists of a concrete intake tower, an upstream outlet tunnel, a gate chamber containing four 3.5 foot square high-pressure slide gates, a downstream horseshoe-shaped outlet tunnel, and an open concrete chute and stilling basin. The discharge capacity is 1,480 cfs at maximum reservoir elevation 4,128.7.

The drainage area above Keyhole Dam is approximately 1,953 square miles and all is considered sediment contributing. The reservoir length, at elevation 4,090, is about 13 miles (including all the contributing bays) with an average width of 0.75 miles.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2003 results of the survey of Keyhole Reservoir. The primary objective of the survey was to gather data to:

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

A real-time kinematic (RTK) global positioning system (GPS) control survey established a temporary horizontal and vertical control point near the reservoir for the hydrographic survey. The GPS base was set over the National Geodetic Survey (NGS) datum point "J 120" that was located several miles from the study area. The horizontal control was in the Wyoming state plane east coordinate zone in the North American Datum of 1983 (NAD83) and the vertical control was tied to the National American Vertical Datum of 1988 (NAVD88). All elevations in this report are in feet and referenced to the Reclamation project vertical datum that is reported to be the National Geodetic Vertical Datum of 1929 (NGVD29) and 2.1 feet lower than NAVD88.

The underwater survey was conducted in May 2003 between reservoir elevation 4,091.7 and 4,091.8. The bathymetric survey used sonic depth recording equipment interfaced with RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along grid lines covering Keyhole Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by the Reclamation's reservoir gauge during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations. The 2003 above-water area of Keyhole Reservoir was determined by digitizing previously developed contour lines from the USGS quad maps of the reservoir area. The 2003 survey assumed no change, since the 1978 survey, from elevation 4,090 and above.

The 2003 Keyhole Reservoir topographic map is a combination of the USGS quad contours and the underwater survey data. A computer graphics program using the collected reservoir data generated the 2003 reservoir surface areas at predetermined contour intervals. The 2003 area and capacity tables were produced by a computer program that used measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of the Keyhole Reservoir and watershed characteristics for the 2003 survey. The 2003 survey determined that the reservoir has a total storage capacity of 188,671 acre-feet and a surface area of 9,411 acres at spillway crest elevation 4,099.3. Since closure in February of 1952, the reservoir has an estimated volume change of 12,495 acre-feet below reservoir elevation 4,099.3. This volume represents a 6.2 percent loss in total original capacity at this elevation.

RESERVOIR OPERATIONS

Keyhole Reservoir is part of the Pick-Sloan Missouri Basin Project that provides storage for irrigation, municipal and industrial water supplies, flood control, fish and wildlife conservation, recreation, and sediment control. The May 2003 capacity table shows 623,321 acre-feet of total storage below the maximum water surface elevation 4,128.7. The 2003 survey measured a minimum lake bottom elevation of 4,024.9. The following values are from the May 2003 capacity table:

- 294,187 acre-feet of surcharge between elevation 4,111.5 and 4,128.7.
- 140,463 acre-feet of flood control between elevation 4,099.3 and 4,111.5.
- 182,079 acre-feet of joint use between elevation 4,051.0 and 4,099.3.
- 6,305 acre-foot of inactive storage between elevation 4,036.0 and 4,051.0.
- 287 acre-foot of dead storage below 4,036.0.

Keyhole Reservoir inflow and end-of-month stage records are listed by water year on table 1 for operation period 1952 through 2003. The inflow values are computed by the Bureau of Reclamation's Great Plains regional office and for some years show negative inflow. The average computed inflow, for water years 1952 through 2003, was 16,918 acre-feet per year. The table also lists the maximum and minimum reservoir elevations by water year. The extremes for the period of record were maximum elevation 4,100.4 in 1978 and minimum elevation 4,046.4 in 1955.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (figure 2). The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. An on-board generator

supplied power to all the equipment. The shore equipment included a second GPS receiver with an external radio. 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.

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

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor 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 Wyoming's NAD83 state plane east zone coordinate system. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

Keyhole Reservoir hydrographic survey was conducted in May of 2003 between reservoir elevation 4,091.7 and 4,091.8 (Reclamation project datum). The bathymetric survey was conducted 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 along closely spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat perpendicular to the downstream alignment of the reservoir at around a 300-foot spacing. Data was also collected along the shore as the boat traversed between transects. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing. The underwater data set includes about 130,700 data points.

The 2003 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 produced an analog hard-copy chart of the measured depths. The 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 computer recorded bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gauge, were used to convert the sonic depth measurements to true lake-bottom elevations.

Keyhole Reservoir Datum

Prior to the reservoir underwater survey, the hydrographic survey crew conducted a RTK GPS survey from the NGS control point "J 120" to tie horizontal and vertical control to a temporary point used for this study and the reservoir water surface. All vertical information for this study is referenced to the Reclamation reservoir water surface gauge measurements that were found to be near the NGVD29 and 2.1 feet lower than NAVD88. The horizontal control was in the Wyoming state plane east coordinate zone in NAD83.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Keyhole Reservoir was developed from the 2003 collected underwater data and the digitized contours from the USGS quad maps. The digitized USGS contour lines of Keyhole Reservoir were elevations 4,086 and 4,100 along with a partial contour labeled 4,090. ARC/INFO geographic information system (GIS) software was used to transform the digital aerial contours to Wyoming's NAD 1983 state plane coordinates, east zone. The digitized contour elevation 4,086 was used to performed a hardclip around the 2003 underwater data of Keyhole Reservoir. This hardclip was used during the triangular irregular network (TIN) development so interpolation did not occur outside the enclosed polygon. This contour was selected since it was the closest data available to represent the upper elevations of the 2003 surveyed reservoir bottom. Using ARCEDIT, the 2003 underwater data and the 4,086 contour were plotted. The plot found that some of the 2003 bottom data plotted slightly outside of this contour. Using select and move commands within ARCEDIT, the vertices of the clip were shifted to contain the 2003 underwater data. This clip was assigned an elevation of 4,086.5 to reflect the upper elevation bottom data collected in 2003.

Contours for the reservoir below elevation 4,086.5 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 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 Keyhole Reservoir TIN. In addition, the contours were generalized by filtering out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had no bearing on the computation of surface areas and volumes for Keyhole Reservoir since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the survey data for elevations 4,025.0 through elevation 4,080.0. Due to no above water data collection, the 2003 study assumed no change in area, since the 1978 survey, for elevation 4,090.0 and above. Also due to limited data near elevation 4,085, this final contour and resulting surface area was interpolated as explained below. The 2003 contour topography is presented on figures 3 through 6.

Development of 2003 Surface Areas

The 2003 TIN generated surface areas for Keyhole Reservoir were computed at 1-foot increments from elevation 4,025.0 to 4,085.0. The 2003 underwater survey measured a minimum reservoir bottom elevation of 4,024.9. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user-specified elevations directly from the TIN and takes into consideration all regions of equal elevation. For the purpose of this study, the measured 2003 survey areas at 2-foot and 5-foot increments from elevation 4,025.0 through 4,080.0 were used to compute the new area and capacity tables. This study assumed no change in surface area, since the 1978 survey, from elevation 4,090.0.0 and above. As noted previously, the surface area at elevation 4,080 was interpolated using the limited 2003 data in this range and the digitized USGS contours. Using ARC/INFO edit tools, the 4,085 contour was adjusted in the upper end of each reach, within some of the reservoir coves, and along some of the shores using the USGS quad contours and 2003 bathymetry as a guide. There was enough data for computer development of this contour, but it was decided that there was insufficient data along some of the reservoir bays and upstream reaches to reflect the actual location of this contour. It was determined that the resulting surface area from the computer generated 4,085 contour indicated a much greater loss than actually occurred. With no above water collection, the only means to develop this contour was to interpolate its location.

2003 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The 2003 surveyed surface areas at 2- and 5-foot contour intervals from reservoir elevation 4,025.0 to elevation

4,080.0 were used as the control parameters for computing the 2003 Keyhole Reservoir capacity. Since this study did not collect above water data, the interpolated survey area of elevation 4,085 and the 1978 surface areas at 5-foot increments for elevation 4,090.0 and above were used to complete the area and capacity table development. 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 Keyhole Reservoir. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. By differentiating the capacity equations, which are of second order polynomial form, the final area equations are derived:

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

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

Results of the Keyhole Reservoir area and capacity computations are listed in table 1 and columns 8 and 9 of table 2. On table 2, columns 2 and 3 list the original area and capacity values. Columns 4 and 5 list the 1978 surface areas and capacity values. A separate set of 2003 area and capacity tables has been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2003). A description of the computations and coefficients output from the ACAP program is included with these tables. The original, 1978, and 2003 area-capacity curves are plotted on figure 7. As of May 2003, at spillway crest elevation 4,099.3, the surface area was 9,411 acres with a total capacity of 188,671 acre-feet.

RESERVOIR SEDIMENT ANALYSES

Figure 7 is a plot of Keyhole Reservoir surface area and capacity for the original, 1978, and 2003 computed values. The plots illustrate the differences between the surveys. Since Keyhole Dam closure in February of 1952, the measured total volume change at reservoir elevation 4,099.3 was estimated to be 12,495 acre-feet. The estimated average annual rate of capacity lost for this period (51.3 years) was 243.6 acre-feet per year. The storage loss in terms of percent of original storage capacity was 6.2 percent at spillway crest elevation 4,099.3. From table 1 and 2, the 2003 study shows that of the total computed sediment 7.5 percent, or 940 acre-feet, has accumulated below dead storage elevation 4,036.0 with the rest accumulating in the active storage areas of the reservoir.

It must be noted that the 2003 area and capacity tables were generated assuming no change since the 1978 surveyed area and capacity from elevation 4,090.0 and above which in all probability is not the case. The 1978 survey measured about 12 percent of the total measured sediment above

elevation 4,090 with the majority of this depositing between elevation 4,090 and 4,095. The reservoir has operated above elevation 4,090 during many years of its operation. The 1978 survey reflected the first 26.3 years of operation when the majority of the upper reservoir sediment deltas are usually formed. Since 1978, it is assumed additional sediments have deposited in the upper reservoir elevation, but more than likely not to the extent of what was measured in 1978. The usual case is for the upper reservoir delta to begin to extend further downstream and deposit in lower elevations of the reservoir. The 2003 underwater survey measured the deposition below elevation 4,085, but an above water survey would be needed to accurately measure the deposition above this elevation.

The original 74 years of estimated sediment accumulation for Keyhole Reservoir was 63,900 acre-feet below elevation 4,099.3 of which 55,900 acre-feet was projected to deposit above elevation 4,051.0. The original estimated annual inflow would have been 863.5 acre-feet per year. The 2003 study calculated an annual inflow of sediment of 243.6 acre-feet per year that would extrapolate to a total sediment accumulation of 18,026 acre-feet in the first 74 years of operation. The 1978 survey measured an annual inflow of 281.9 acre-feet per year. Both surveys results only calculated about thirty percent of the original estimate. Further analysis would be necessary to determine why the original estimate is so much greater than what the two surveys have reflected.

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, May 2003. Denver Office, ***Keyhole Reservoir Area and Capacity Tables, Pick-Sloan Missouri Basin Project***, Great Plains Region, Billings, MT.

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

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

RESERVOIR SEDIMENT
DATA SUMMARY

Keyhole Reservoir

NAME OF RESERVOIR

1

DATA SHEET NO.

DAM

1. OWNER Bureau of Reclamation	2. STREAM Belle Fourche River	3. STATE Wyoming
4. SEC. 27 TWP. 51 N RANGE 66 W	5. NEAREST P.O. Moorcroft	6. COUNTY Crook
7. LAT 44° 22' 55" LONG 104° 46' 45"	8. TOP OF DAM ELEVATION 4,134.0	9. SPILLWAY CREST EL 4,099.3[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	4,128.7[2]	20,721	294,195	635,920	
b. FLOOD CONTROL	4,111.5	15,273	140,559	341,725	2/12/52
c. POWER					
d. JOINT USE					16. DATE NORMAL OPERATION
e. CONSERVATION	4,099.3	9,417	191,453	201,166	
f. INACTIVE	4,051.0	920	8,486	9,713	
g. DEAD	4,036.0	239	1,227	1,227	10/25/52

BASIN

17. LENGTH OF RESERVOIR 13[3] MILES		AVG. WIDTH OF RESERVOIR 0.75	MILES
18. TOTAL DRAINAGE AREA 1,953[4] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 15.5[5]	INCHES
19. NET SEDIMENT CONTRIBUTING AREA 1,953[4] SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.16[6]	INCHES
20. LENGTH MILES	AV. WIDTH	24. MEAN ANNUAL RUNOFF 16,918[7]	ACRE-FEET
21. MAX. ELEVATION	MIN. ELEVATION	25. ANNUAL TEMP. MEAN 45°F RANGE -38°F to 110°F[5]	

SURVEY DATA

26. DATE OF SURVEY	27. PER.	28. ACCL	29. TYPE OF SURVEY	30. NO. OF RANGES OR	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO
2/52	26.3	26.3	Contour (D)	5-ft	9,417[8]	201,166[8]	11.9
1978			Range (D)	30	9,411	193,753	11.4
5/03	25.0	51.3	Contour (D)	2-ft	9,411[9]	188,671[9]	11.2

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
1978		20,028	100,318	526,736	20,028	526,736
5/03		13,560[9]	52,832	339,000	16,918	865,736

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.
1978	7,413	281.9	0.144	7,413	281.9	0.144
5/03	5,082[10]	203.3	0.104	12,495	243.6	0.125

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR.		41. STORAGE LOSS, PCT.		42.	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
1978				0.14	3.7		
5/03				0.12[10]	6.2[10]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
		4016-4040	4040-4051	4051-4060	4060-4070	4070-4080	4080-4090	4090-crest			
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
5/03		12.2	12.8	20.4	18.5	13.7	16.1	6.3			

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

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

45. RANGE IN RESERVOIR OPERATION[9]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1952	4,056.0	-	2,702	1953	4,059.4	4,048.7	20,486
1954	4,052.8	4,049.0	1,258	1955	4,067.5	4,046.4	47,579
1956	4,062.4	4,054.2	9,631	1957	4,057.0	4,052.5	14,240
1958	4,055.7	4,050.3	8,944	1959	4,057.9	4,049.9	12,335
1960	4,062.0	4,051.0	13,498	1961	4,055.5	4,049.4	(-) 732
1962	4,079.7	4,049.1	98,349	1963	4,085.0	4,078.6	17,385
1964	4,091.8	4,081.2	47,364	1965	4,092.8	4,089.2	14,094
1966	4,092.0	4,088.8	(-) 7,981	1967	4,092.9	4,088.5	18,520
1968	4,090.8	4,088.9	149	1969	4,091.8	4,088.4	12,194
1970	4,092.0	4,088.8	6,057	1971	4,096.3	4,088.5	43,693
1972	4,098.8	4,093.8	48,406	1973	4,096.4	4,094.3	(-) 5,295
1974	4,095.7	4,091.9	(-) 2,945	1975	4,094.5	4,091.4	(-) 7,014
1976	4,093.7	4,091.1	9,346	1977	4,092.6	4,087.9	4,149
1978	4,100.4	4,087.6	100,318	1979	4,096.1	4,093.1	2,702
1980	4,093.3	4,086.6	(-) 8,908	1981	4,086.6	4,071.9	(-) 846
1982	4,078.2	4,071.5	24,018	1983	4,079.7	4,074.4	7,769
1984	4,084.8	4,074.6	33,345	1985	4,083.0	4,076.3	(-) 4,093
1986	4,081.3	4,076.0	17,535	1987	4,085.1	4,078.5	26,024
1988	4,083.3	4,075.5	(-) 756	1989	4,077.9	4,070.7	5,927
1990	4,075.5	4,067.3	9,407	1991	4,074.0	4,066.7	14,198
1992	4,066.9	4,060.6	2,043	1993	4,080.4	4,060.3	52,832
1994	4,087.6	4,079.5	31,415	1995	4,088.6	4,083.6	20,539
1996	4,094.7	4,087.5	36,163	1997	4,098.6	4,093.0	41,316
1998	4,098.3	4,096.9	8,793	1999	4,099.1	4,097.2	29,851
2000	4,097.4	4,095.4	(-) 13,507	2001	4,097.0	4,095.1	1,818
2002	4,095.2	4,089.4	(-) 9,414	2003	4,092.3	4,088.4	10,823

46. ELEVATION - AREA - CAPACITY DATA FOR **2003 CAPACITY**[11]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4,024.9	0	0	4,025	0.2	0	4,026	1.5	0
4,028	2.6	4	4,030	10.2	17	4,032	18.5	45
4,034	54.2	118	4,035	84.0	187	4,036	115.2	287
4,038	172.0	574	4,040	259.4	1,005	4,042	344.2	1,609
4,044	438.2	2,391	4,045	485.7	2,853	4,046	539.1	3,366
4,048	631.2	4,536	4,050	703.7	5,871	4,051	737.7	6,592
4,052	773.7	7,348	4,054	849.0	8,971	4,055	899.5	9,845
4,056	976.0	10,783	4,058	1,141.0	12,900	4,060	1,344.0	15,385
4,062	1,529.4	18,258	4,064	1,740.2	21,528	4,065	1,825.8	23,311
4,066	1,920.1	25,184	4,068	2,114.9	29,219	4,070	2,363.2	33,697
4,072	2,692.5	38,753	4,074	3,008.8	44,454	4,075	3,174.1	47,546
4,076	3,327.7	50,796	4,078	3,650.6	57,775	4,080	3,958.0	65,383
4,085	4,949.0	87,651	4,090	6,267	115,691	4,095	7,974	151,293
4,099.3	9,411	188,671	4,100	9,645	195,341	4,105	11,329	247,776
4,110	13,150	308,973	4,111.5	13,730	329,134	4,115	15,085	379,561
4,120	16,965	459,686	4,125	19,055	549,736	4,128.7	20,721	623,321
4,129	20,856	629,558						

47. REMARKS AND REFERENCES

1 Uncontrolled spillway. All elevations in feet. Based on original project datum reported as NGVD29.

2 Original values computed from 5-foot contours.

3 Total of main stream, 8.3 miles and two smaller arms that make up the reservoir at elevation 4,090.

4 From USGS water year records.

5 Bureau of Reclamation Project Data Book, 1981.

6 Calculated using mean annual computed inflow value of 16,918 AF, item 24, 1952 through 2003.

7 Annual computed inflows by Reclamation GP Regional Office. Water years from 1952 through 2003.

8 Surface area & capacity at elevation 4,099.3, top of active conservation, by indicated year. The capacities were computed by BOR program ACAP.

9 Maximum and minimum elevations and annual computed inflows by water year from 1952 through 2003 (Reclamation computed values and records).

10 All sediment computations are computed by comparing the 1978 and 2003 survey results with the original results at spillway crest elevation 4,099.3. This assumed the original data is of a reliable accuracy. The 2003 survey assumed no change since the 1978 survey from elevation 4,090 and above. Computed storage loss is due to accuracy differences between original and 2003 surveys and due to accumulation of sediment.

11 Capacities computed by Reclamation's ACAP computer program.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE December 2004

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

Table 2. - Summary of 2003 survey results

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Elev.	Original Survey	Original Capacity	1978 Survey	1978 Survey	1978 Sediment Volume	1978 Computed Sediment	2003 Survey	2003 Survey	2003 Sediment Volume	2003 Computed Sediment	Sediment Volume 1978-03	Percent Sediment 1978-03	Percent Reservoir Depth
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft		Acres	Ac-Ft	Ac-Ft		Ac-Ft		
4,128.7	20,721	635,920	20,721	628,403	7,517	100.0	20,721	623,321					100.0
4,125.0	19,056	562,333	19,055	554,817	7,516	100.0	19,055	549,736					96.7
4,120.0	16,965	472,280	16,965	464,767	7,513	99.9	16,965	459,686					92.3
4,115.0	15,085	392,155	15,085	384,642	7,513	99.9	15,085	379,561					87.8
4,111.5	13,732	341,725	13,730	334,215	7,510	99.9	13,730	329,134					84.7
4,110.0	13,152	321,563	13,150	314,055	7,508	99.9	13,150	308,973					83.4
4,105.0	11,347	260,315	11,329	252,857	7,458	99.2	11,329	247,776					79.0
4,100.0	9,644	207,838	9,645	200,422	7,416	98.7	9,645	195,341					74.5
4,099.3	9,417	201,166	9,411	193,753	7,413	98.6	9,411	188,671	12,495	100.0	5,082	100.0	73.9
4,095.0	8,023	163,670	7,974	156,375	7,295	97.0	7,974	151,293	12,377	99.1	5,082	100.0	70.1
4,090.0	6,486	127,398	6,267	120,772	6,626	88.1	6,267	115,691	11,707	93.7	5,081	100.0	65.7
4,085.0	5,170	98,258	5,062	92,450	5,808	77.3	4949.0	87,651	10,607	84.9	4,799	94.4	61.2
4,080.0	4,103	75,075	3,982	69,840	5,235	69.6	3958.0	65,383	9,692	77.6	4,457	87.7	56.8
4,075.0	3,359	56,420	3,227	51,817	4,603	61.2	3174.1	47,546	8,874	71.0	4,271	84.0	52.4
4,070.0	2,536	41,683	2,406	37,735	3,948	52.5	2363.2	33,697	7,986	63.9	4,038	79.5	47.9
4,065.0	2,035	30,255	1,953	26,837	3,418	45.5	1825.8	23,311	6,944	55.6	3,526	69.4	43.5
4,060.0	1,643	21,060	1,552	18,075	2,985	39.7	1344.0	15,385	5,675	45.4	2,690	52.9	39.0
4,055.0	1,200	13,953	1,025	11,632	2,321	30.9	899.5	9,845	4,108	32.9	1,787	35.2	34.6
4,051.0	920	9,713	815	7,952	1,761	23.4	739.0	6,592	3,121	25.0	1,360	26.8	31.1
4,050.0	850	8,828	763	7,162	1,666	22.2	703.7	5,871	2,957	23.7	1,291	25.4	30.2
4,045.0	626	5,138	536	3,915	1,223	16.3	485.7	2,853	2,285	18.3	1,062	20.9	25.7
4,040.0	415	2,535	331	1,747	788	10.5	259.4	1,005	1,530	12.2	742	14.6	21.3
4,036.0	239	1,227	180	726	501	6.7	115.2	287	940	7.5	439	8.6	17.7
4,030.0	75	335	41	107	228	3.0	10.2	17	318	2.5	90	1.8	12.4
4,024.9	25	83	1	2	81	1.1	0.0	0	83	0.7	2	0.0	7.9
4,020.0	5	10	0	0	10	0.1	0.0	0	10	0.1	0	0.0	3.5
4,016.0	0	0	0	0	0	0.0	0.0	0	0	0.0	0	0.0	0.0

1 Elevation of reservoir water surface.
2 Original reservoir surface areas.
3 Original reservoir capacity computed using ACAP.
4 1978 measured reservoir surface area.
5 1978 reservoir capacity computed using ACAP.
6 1978 computed sediment volume, column (3) - column (5).
7 Measured sediment in percentage of total sediment, 7,517 acre-feet, by elevation.
8 2003 measured reservoir surface area. Areas for elevation 4,090 and above from 1978 survey.
9 2003 reservoir capacity computed using ACAP.
10 2003 measured sediment volume = column (3) - column (9).
11 Measured sediment in percentage of total sediment, 12,495 acre-feet, by elevation.
12 Measured sediment volume from 1978 to 2003, column (5) - column (9).
13 Measured sediment in percentage my elevation from 1978 to 2003. Total sediment volume of 5,082 acre-feet.
14 Depth of reservoir expressed in percentage of total depth (112.7), from maximum water surface.

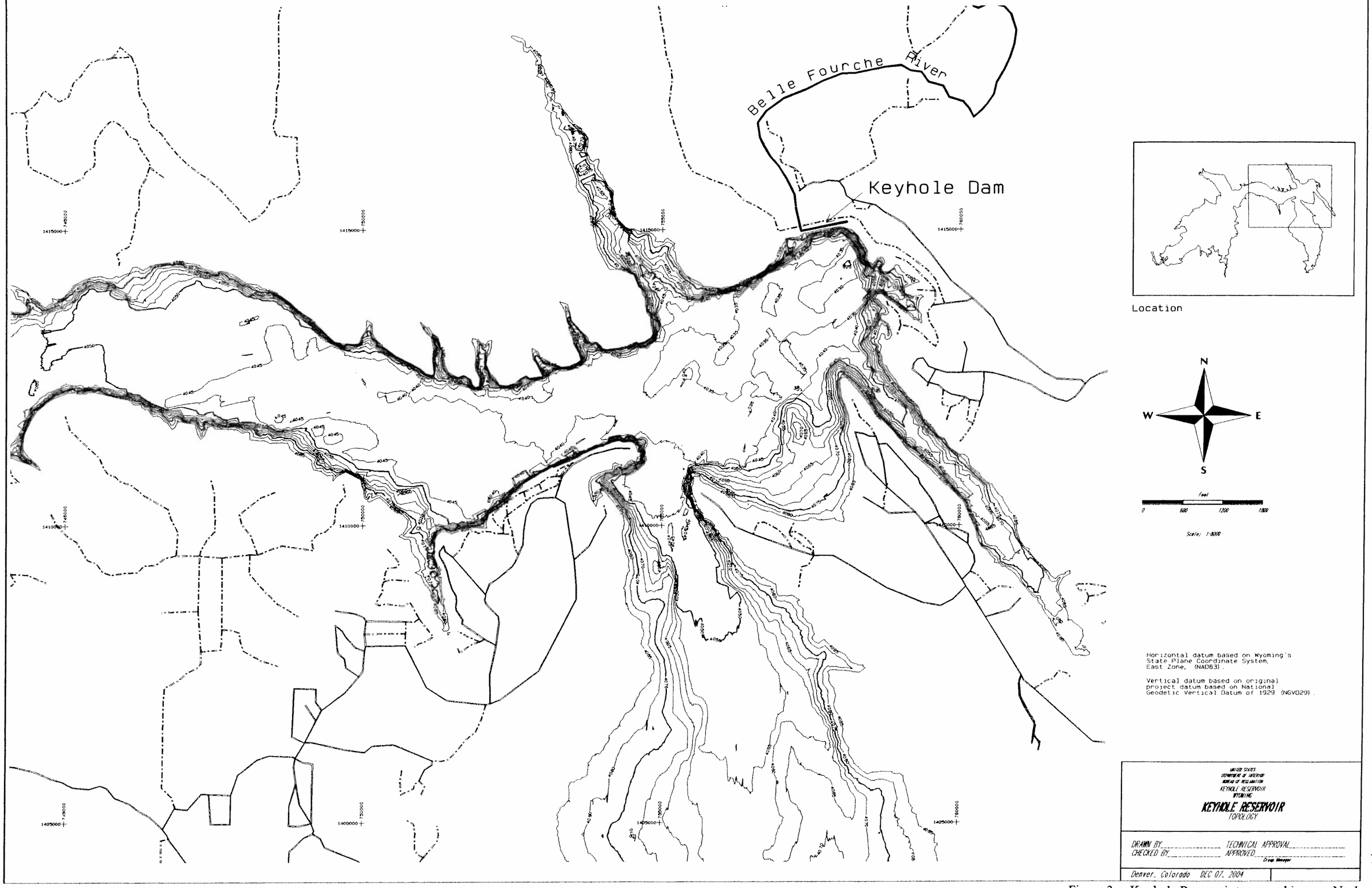

Figure 3. – Keyhole Reservoir topographic map, No 1.

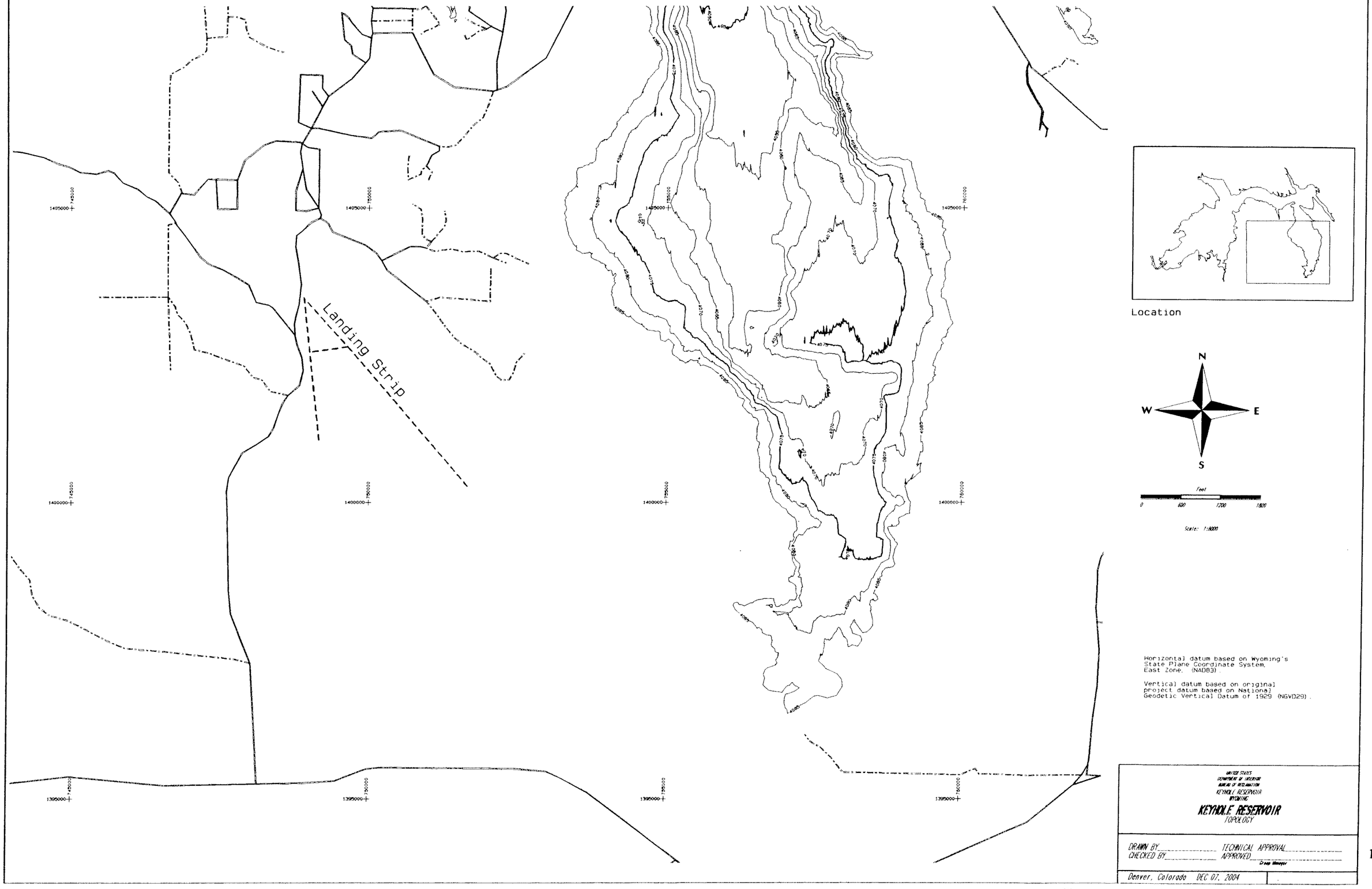

Figure 4. – Keyhole Reservoir topographic map, No. 2.

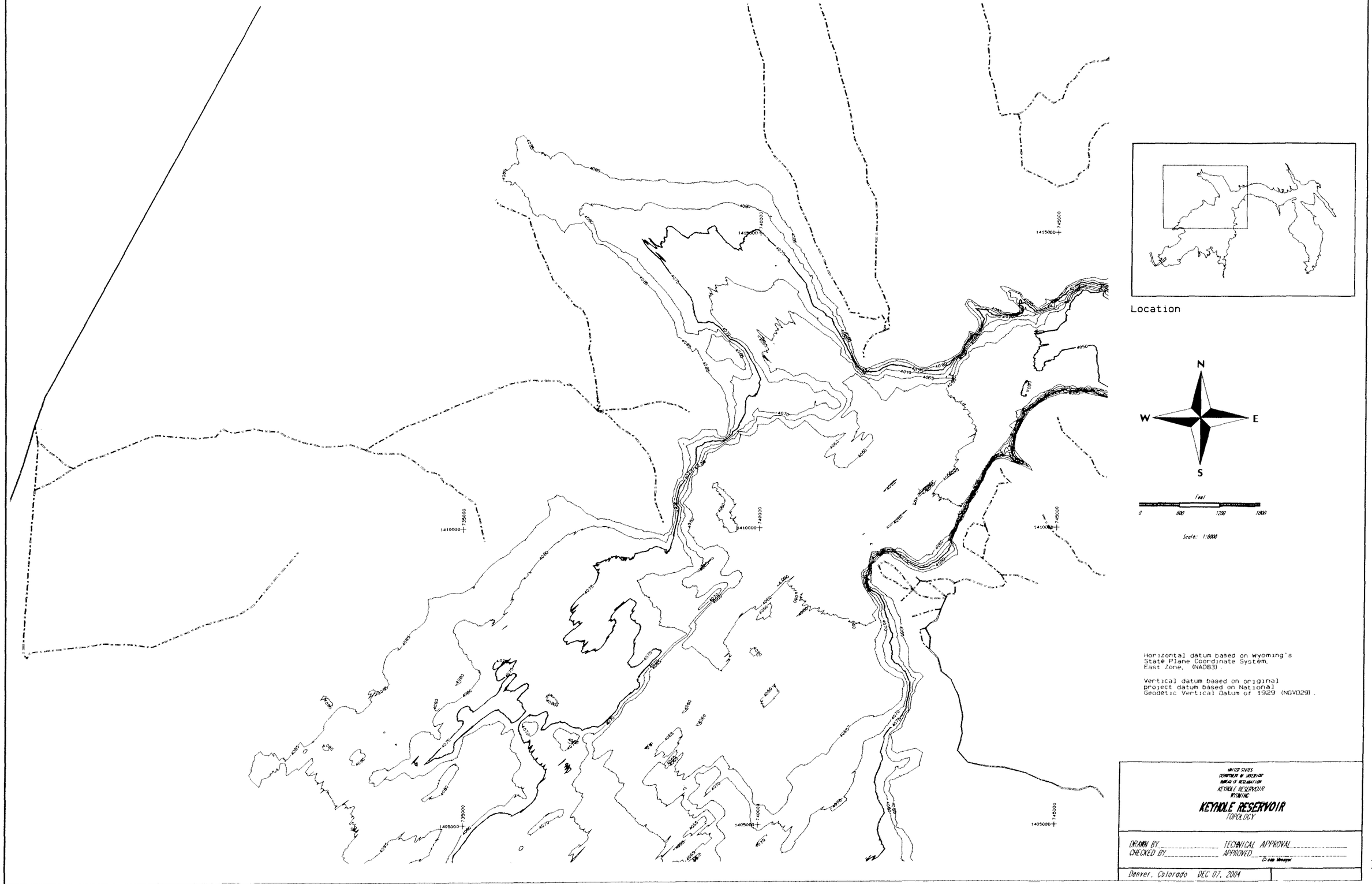

Figure 5. – Keyhole Reservoir topographic map, No. 3.

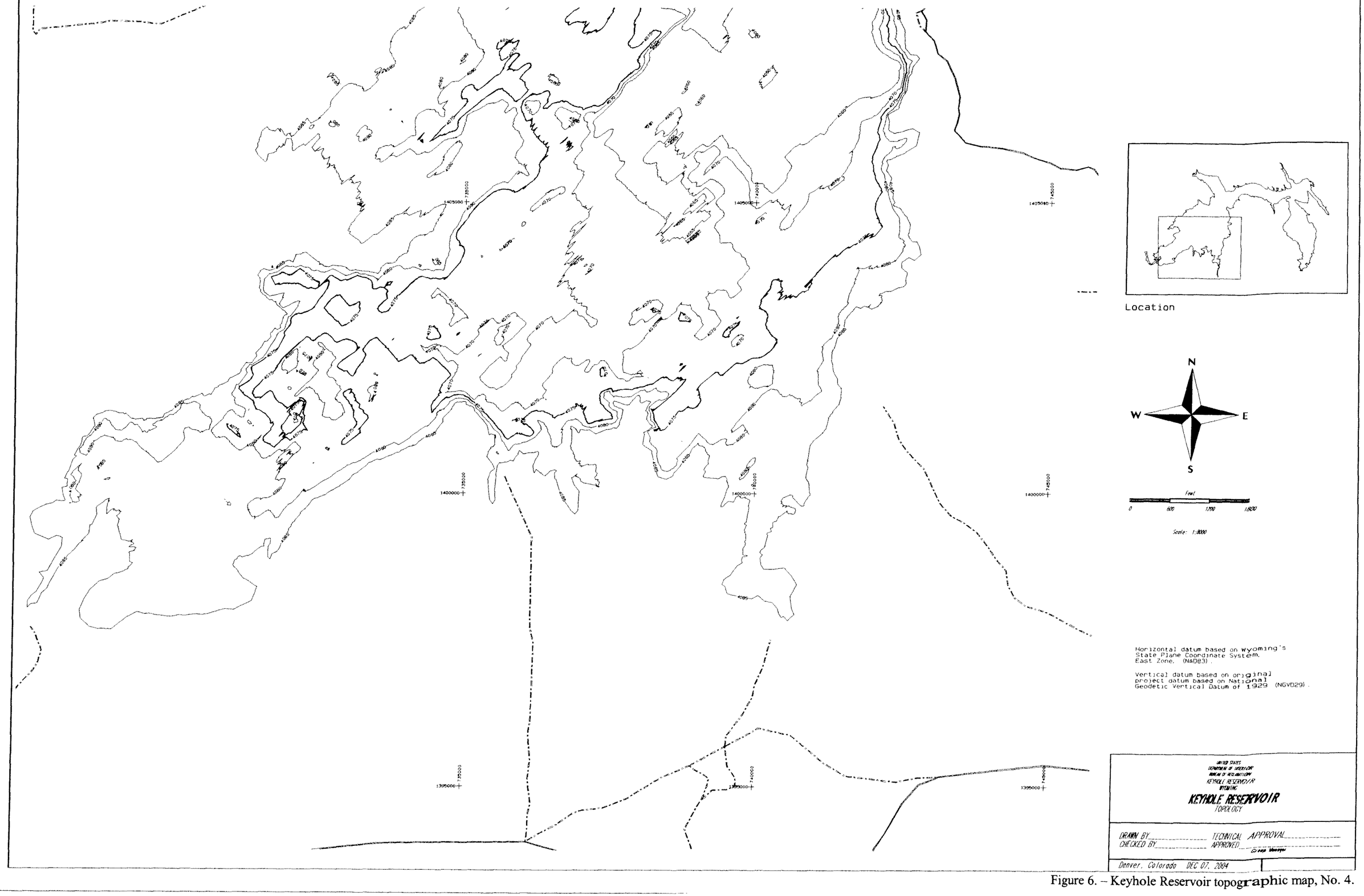

Figure 6. – Keyhole Reservoir topographic map, No. 4.

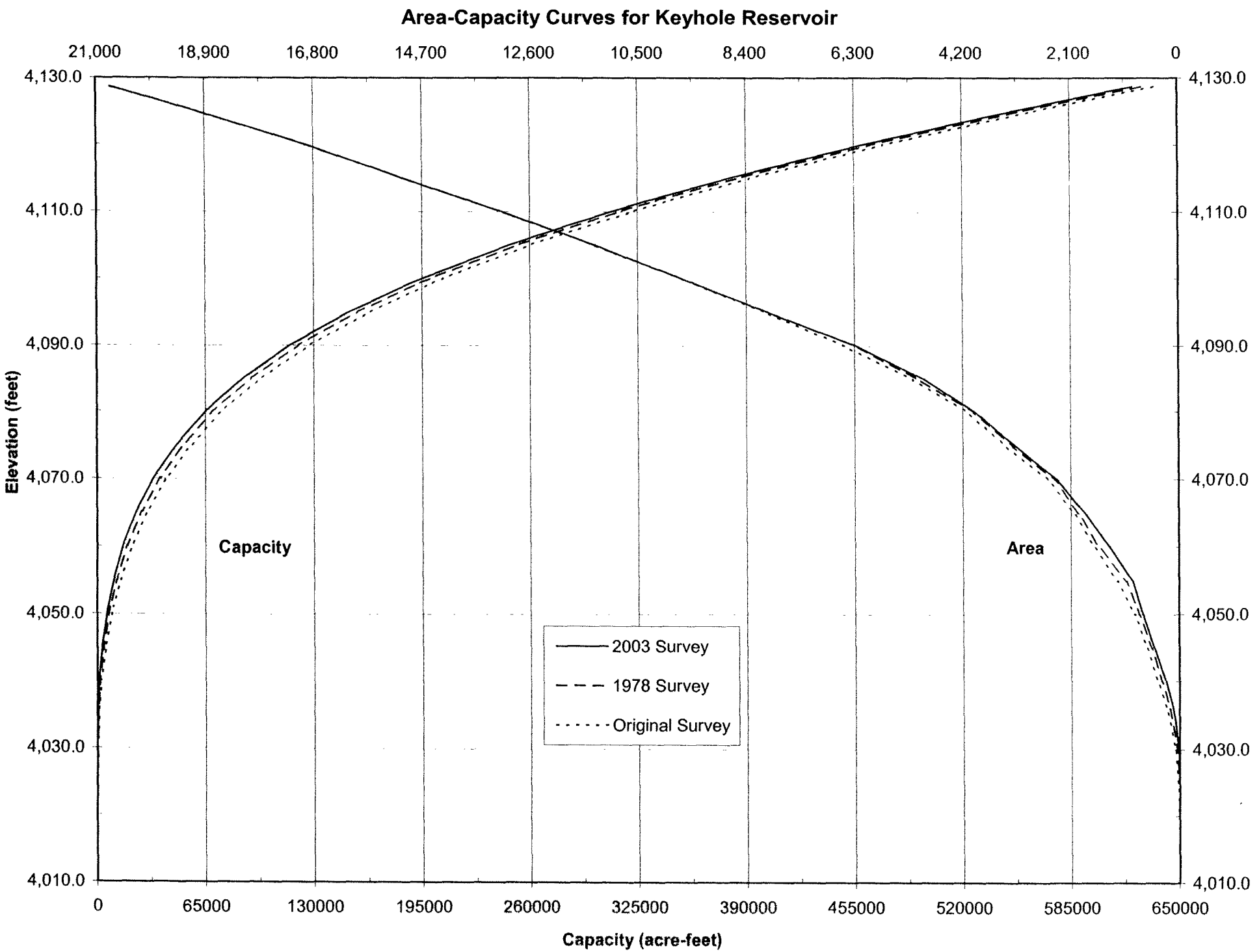

Figure 7. - 2003 area and capacity curves.