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BIGHORN LAKE —1982 SEDIMENTATION SURVEY

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16. ABSTRACT

Bighorn Lake was surveyed in 1982 to compile field data needed to compute reservoir storage capacity. The data were also used to compute the volume of sediment accumulated in the reservoir since the gates in the dam were closed in 1965, and to determine the sediment distribution characteristics. Sonic depth recording equipment interfaced with an automated survey system was used to run the bathymetric survey. Reservoir capacity was computed from revised contour surface areas determined by means of a width-adjustment method for the upstream portion of the reservoir and by determining loss of contour surface area by sedimentation in the downstream portion.

The reservoir capacity is 1,328,360 acre-feet and the surface area is 17,279 acres at El. 3657.0. Since November 1965, 53,950 acre-feet of sediment has accumulated, resulting in a loss in storage capacity of 3.9 percent. This represents an annual accumulation rate of 3,224 acre-feet or 0.314 acre-foot per square mile.

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BIGHORN LAKE
– 1982 SEDIMENTATION SURVEY

by

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April 1986

Hydrology Branch
Division of Planning Technical Services
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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Frontispiece. – Yellowtail Dam and Bighorn Lake.

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INTRODUCTION

Yellowtail Dam and Bighorn Lake are the major storage features of the Yellowtail Unit, Lower Bighorn Division, an integral part of the Pick-Sloan Missouri Basin Program. The dam is located near the mouth of Bighorn Canyon on the Bighorn River in sec. 18, T. 6 S., R. 31 E., Montana principal meridian, Big Horn County, Wyoming (fig. 1). The damsite is within the Crow Indian Reservation, about 21 miles north of the Montana-Wyoming State line and 45 miles by road southwest of Hardin, Montana.

Construction of Yellowtail Dam was authorized by the Flood Control Act of December 22, 1944. Construction of the dam and powerplant began in May 1961, and was completed in December 1967. Closure of the diversion tunnel was made on November 4, 1965, which marked the commencement of reservoir filling.

Yellowtail Dam (fig. 2) is a concrete, thin-arch structure with a structural height of 525 feet and a crest length of 1,480 feet. It impounds a reservoir of 1,375,000 acre-feet at El. 3657.0*. The spillway, located in the left abutment of the dam, consists of an unlined inlet channel, an intake structure controlled by two 25- by 64.4-foot radial gates, a concrete-lined tunnel transition, a concrete-lined tunnel ranging in diameter from 40.5 to 32 feet, and a stilling basin. The outlet works consists of an irrigation outlet and an evacuation outlet, each having 84-inch-diameter outlet pipes controlled by 84-inch ring-follower gates. Both outlets discharge into a stilling basin to the right of the powerplant at the toe of the dam.

The Yellowtail Powerplant structure is located at the toe of the dam. Four 12-foot-diameter penstocks through the dam supply water to four 87,500-horsepower, Francis-type hydraulic turbines, each driving a 62,500-kW generator.

Bighorn Lake, when filled to El. 3657.0, top of exclusive flood control, extends a total of 71 river-miles through the entire length of Bighorn Canyon and onto the valley floor in the Bighorn Basin of Wyoming. The reservoir inundates an area of valley several miles wide, extending about 11 miles south from the head of Bighorn Canyon. The original surface area of the reservoir at El. 3657.0 was 17,298 acres. The reservoir had a total original capacity of 1,375,000 acre-feet of which 503,328 acre-feet was dead or inactive capacity.

SUMMARY AND CONCLUSION

This report presents the results of the 1982 sedimentation survey of Bighorn Lake. The purposes of the survey were to determine the amount of reservoir storage depletion caused by sediment deposition and to define the current sediment distribution pattern in the reservoir.

Horizontal and vertical control points from the original (1962-64) sediment range survey were used for control in the 1982 survey. Range lines and portions of range lines above the current reservoir level and upstream of Bighorn Canyon were profiled by standard land surveying methods. The bathymetric survey within Bighorn Canyon was run using sonic depth recording equipment in conjunction with either a mechanical distance-measuring machine or the constant-speed method. In the reservoir area upstream of Bighorn Canyon, the bathymetric survey was run using sonic depth recording equipment interfaced with an automated survey system consisting of a line-of-sight microwave positioning unit capable of determining the locations of soundings. The total system continuously recorded reservoir depth and horizontal coordinates as the survey boat was steered across each sedimentation range line. Water surface elevations read from the reservoir gauge at the dam were used as references in converting sonic depth measurements to true bottom elevations and in delineating the cross-sectional profiles.

Twenty-one sediment samples were collected from the reservoir deposits with a gravity core sampler. The analyses for 20 of these samples were used to determine a unit weight of 53 lb/ft^3 and an average particle size that indicated 51 percent clay, 35 percent silt, and 14 percent sand. These results are considered biased toward the finer sediment and not representative of the average sediment being deposited because of the lack of adequate sampling from the coarser sediment deposits in the delta.

The reservoir, as determined from the 1982 survey, has a storage capacity of 1,328,360 acre-feet and a surface area of 17,279 acres at El. 3657.0 (the top of the spillway gates). The reservoir area and capacity tables were produced by a computer program that used measured contour surface areas and a curve-fitting technique to compute both area and capacity at prescribed increments of elevation.

A comprehensive summary of reservoir sediment data and watershed characteristics for the 1982 survey is shown in table 1. Since closure in 1965, the volume of sediment accumulated in the reservoir below El. 3657.0 is 53,950 acre-feet. This represents a loss in storage of 3.9 percent. An average annual sediment accumulation rate of 3,224 acre-feet occurred from November 1965 through July 1982. Sediment was deposited at the annual rate of 0.314 acre-feet per square mile during that period.

* All elevations in this report are in feet above mean sea level.

Table 1. – Reservoir sediment data summary (sheet 1 of 3).

RESERVOIR SEDIMENT
DATA SUMMARY

Bighorn Lake
NAME OF RESERVOIR

DATA SHEET NO.

DAM	1. OWNER Dept. of Int.–USBR	2. STREAM Bighorn River	3. STATE Montana & Wyoming
	4. SEC. TWP. RANGE	5. NEAREST P O. Hardin, MT	6. COUNTY Bighorn
	7. LAT ° ′ ″ LONG. ° ′ ″	8. TOP OF DAM ELEVATION 3660.0	9. SPILLWAY CREST ELEV. 3657

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
	a. FLOOD CONTROL	3657.0	17,298	259,000	1,375,000	November 1, 1965
	b. MULTIPLE USE [2]	3640.0	12,685	250,000	1,116,000	
	c. POWER					
	d. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
	e. IRRIGATION					
	f. CONSERVATION	3614.0	7,410	363,672	866,000	August 1, 1967
	g. INACTIVE	3547.0	4,192	483,361	502,328	
	17. LENGTH OF RESERVOIR 61.8 MILES			AV. WIDTH OF RESERVOIR 0.44 MILES		

WATERSHED	18. TOTAL DRAINAGE AREA 19,626 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 6-48 INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 10,270 SQ. MI.	23. MEAN ANNUAL RUNOFF 2.47 INCHES
	20. LENGTH 226 MILES; AV. WIDTH 168 MILES	24. MEAN ANNUAL RUNOFF 2,590,000 [3] AC.-F T.
	21. MAX. ELEV. 13,165; MIN. ELEV. 3166	25. ANNUAL TEMP. MEAN 44.2 RANGE – 60 °F + 110 °F

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I. RATIO, AC.-FT. PER AC.-FT.
Nov. 1, 1965			Contour (D)	20′ & 5′	17,298	1,382,310[4]	0.534
Aug. 1982	16.75	16.75	Range (D)	51	17,279	1,328,360	0.513

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	36. WATER INFL. TO DATE, AC.-FT. a. MEAN ANNUAL	b. TOTAL TO DATE
Nov. 1. 1965	6-48					
Aug. 1982		2,401,400[5]	3,363,000[5]	40,224,000[5]	2,401,400[5]	40,224,000[5]

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
Nov. 1, 1965						
Aug. 1982	53,950	3,221	0.314	53,950	3,221	0.314

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR. a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AV. ANN.	b. TOT. TO DATE	42. SED. INFLOW, PPM a. PERIOD	b. TOT. TO DATE
Nov. 1, 1965							
Aug. 1982	60*	410	410	0.234	3.92	1290	1290

Table 1. – Reservoir sediment data summary (sheet 2 of 3).

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION											
	491-445.8	445.8-397	397-357	357-317	317-277	277-237	237-157	157-107	107-64	64-27	27-CR	CR+3
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
Aug, 1982	2.8	2.8	2.4	3.6	6.1	4.9	3.2	4.2	29.4	42.3	4.5	0.1

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														
Aug, 1982					Not	available									

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.
1966	3573.10		1,395,570	1975	3646.81	3597.13	2,876,100
1967	3656.43	3573.30	3,363,000	1976	3635.61	3598.35	2,612,400
1968	3637.65	3585.68	2,391,000	1977	3636.37	3613.83	1,514,900
1969	3637.33	3588.93	2,263,200	1978	3648.60	3599.15	2,621,100
1970	3644.65	3584.45	2,215,100	1979	3637.95	3611.87	2,071,400
1971	3638.24	3591.16	2,878,400	1980	3639.16	3600.13	1,997,900
1972	3639.42	3592.38	3,017,900	1981	3641.07	3610.33	1,894,100
1973	3638.31	3618.03	2,465,000	1982	3640.17	3595.52	1,785,680
1974	3639.90	3600.61	2,861,200				

46. ELEVATION–AREA–CAPACITY DATA (Original)

ELEVATION	AREA [6]	CAPACITY [4]	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
3166	0	0	3460	2,367	220,891	3595	6,043	747,503
3180	3	30	3480	2,803	272,591	3600	6,474	778,796
3200	67	731	3500	3,311	333,731	3605	6,775	811,918
3220	79	2,191	3520	3,674	403,581	3610	7,088	846,576
3240	165	4,631	3540	4,048	480,801	3615	7,508	883,066
3260	220	8,481	3545	4,136	501,261	3620	8,152	922,216
3280	340	14,081	3550	4,289	522,323	3625	8,746	964,461
3300	421	21,687	3555	4,399	544,043	3630	9,882	1,011,031
3320	597	31,871	3560	4,515	566,328	3635	11,179	1,063,683
3340	722	45,061	3565	4,660	589,266	3640	12,685	1,123,343
3360	947	61,751	3570	4,797	612,908	3645	14,427	1,191,123
3380	1,134	82,561	3575	5,001	637,403	3650	15,768	1,266,611
3400	1,425	108,151	3580	5,280	663,106	3655	16,852	1,348,161
3420	1,696	139,361	3585	5,468	689,976	3657	17,298	1,382,311
3440	2,045	176,771	3590	5,750	718,021	3660	17,958	1,435,186

47. REMARKS AND REFERENCES

1 Elevation of top of gates.
2 Flood control, irrigation, power, and fish and wildlife.
3 Bighorn River near St. Xavier, Montana.
4 Original capacity adjusted for volume within river channel below surface contours and to conform to current computational method.
5 Bighorn River at Kane, Wyoming, and Shoshone River near Lovell, Wyoming.
6 Original area adjusted to include area within river channel below surface contours.

48. AGENCY MAKING SURVEY —Bureau of Reclamation

49. AGENCY SUPPLYING DATA —Bureau of Reclamation

50. DATE ______________

April 1966

Table 1. – Reservoir sediment data summary (sheet 3 of 3).

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST 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	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.

46. ELEVATION–AREA–CAPACITY DATA (1982)

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
3211.2	0	0	3480	2,795	259,424	3595	5,296	717,564
3220	51	224	3500	3,244	319,814	3600	5,511	744,582
3240	133	2,064	3520	3,631	388,564	3605	5,814	772,894
3260	208	5,474	3540	4,016	465,034	3610	6,317	803,222
3280	291	10,464	3545	4,103	485,332	3615	7065	836,677
3300	400	17,374	3550	4,218	506,134	3620	7,699	873,587
3320	531	26,684	3555	4,313	527,462	3625	8,532	914,164
3340	679	38,784	3560	4,392	549,224	3630	9,611	959,522
3360	850	54,074	3565	4,512	571,484	3635	10,997	1,011,042
3380	1,045	73,024	3570	4,624	594,324	3640	12,598	1,070,029
3400	1,350	96,974	3575	4,734	617,719	3645	14,396	1,137,514
3420	1,667	127,144	3580	4,873	641,737	3650	15,728	1,212,824
3440	2,032	164,134	3585	4,963	666,327	3655	16,839	1,294,242
3460	2,351	207,964	3590	5118	691,529	3657	17,279	1,328,360
						3660	17,940	1,381,189

47. REMARKS AND REFERENCES

48. AGENCY MAKING SURVEY –Bureau of Reclamation

49. AGENCY SUPPLYING DATA –Bureau of Reclamation

50. DATE ____________

Apri [illegible]

DESCRIPTION OF WATERSHED

Drainage Area

The drainage area (fig. 3) for the Bighorn River above Yellowtail Dam is 19,626 square miles. However, the net sediment contributing area, which essentially excludes the reservoir area and that part of the basin above Buffalo Bill, Boysen, and Anchor Dams, is 10,270 square miles.

Geology

The Bighorn Basin is a horseshoe-shaped structural depression almost surrounded by an unbroken mountain wall. The open end of the basin is on the north side, where the Clark Fork and Bighorn Rivers flow to join the Yellowstone River. The valley floor of the basin is underlain by essentially flay-lying, weak, young sedimentary rocks of the Tertiary Age. These rocks coexist with formations that lie to the north of the basin and underlie the Great Plains. On the margins the younger strata become inclined as the mountains are approached. Surrounding the younger strata is a border of hogbacks and cuestas of older Cretaceous sediments (often sharply folded and faulted) that, in general, compose the foothills.

Because of the differences in durability of the weaker formations underlying the valley, predominantly shales and friable sandstones, erosion has been quite effective in the dissection of the bedrock. Dissection has been more apparent in the southeastern portion of the basin where erosion has had much more effect, leaving barren wastelands, typical of badland topography.

Precipitation

Precipitation varies considerably in the Bighorn Basin. Annual precipitation in the higher mountains surrounding the basin measures as much as 48 inches. However, at Powell in the Shoshone River valley west of the reservoir, the annual precipitation is only about 6.0 inches. In general, the area confined within the foothill zone has a very low average annual precipitation, ranging from about 6.0 inches at Powell to about 9.5 inches at Cody. The mean annual precipitation within the basin has been estimated at 15.5 inches.

Runoff

The mean annual runoff from the basin is estimated to be 2.5 inches. Table 2 shows the inflow to Bighorn Lake from November 1965, to the date of the survey measured on the Bighorn River at Kane, Wyoming, and on the Shoshone River near Lovell, Wyoming. The average annual inflow during the period of storage was 2,401,400 acre-feet. The long-term average flow past the damsite measured at the USGS (U.S. Geological Survey) gauge near St. Xavier, Montana, from 1934 to 1958 was 2,590,000 acre-feet.

Table 2. – Annual inflow to Bighorn Lake (excluding ungauged areas).

Water year	Inflow, acre-feet		Total inflow, acre-feet
	Bighorn River at Kane, WY	Shoshone River near Lovell, WY	
1966*	965,900	429,700	1,395,600
1967	2,447,000	916,000	3,363,000
1968	1,812,000	579,000	2,391,000
1969	1,567,000	696,200	2,263,200
1970	1,440,000	775,100	2,215,100
1971	1,971,000	907,400	2,878,400
1972	2,199,000	818,900	3,017,900
1973	1,781,000	684,000	2,465,000
1974	1,777,000	884,200	2,861,200
1975	2,029,000	847,100	2,876,100
1976	1,659,000	953,400	2,612,400
1977	1,166,000	348,900	1,514,900
1978	1,826,000	795,100	2,621,100
1979	1,492,000	579,400	2,071,400
1980	1,461,000	536,900	1,997,900
1981	1,259,000	635,100	1,894,100
1982**	1,123,000	662,700	1,785,700
Total			40,224,000
Average (for 16.75 yr)			2,401,400

* After closure in November 1965.
** Excluding August and September 1982.

Vegetation

The vegetation indigenous to the valley part of the basin is typical of a desert environment. The barren shale slopes support only occasional salt sage plants. Along water courses in the basin, the improved water supply and soil cover support a better grass cover, and some cottonwoods and willows. The irrigated lands within the valley produce a variety of crops, including grains, alfalfa, beets, beans, and corn. The mountainous areas within the basin support a variety of pine and aspen trees.

Erosion

In the central valley area, the physiographic factors that control erosion favor high sediment production. These factors are the erodability of the underlying rock strata, the lack of ground cover to protect the ground surface and retard runoff, and the steepness of stream gradients in the area. The storm runoff in the valley portion of the basin, therefore, normally bears a high sediment concentration.

RESERVOIR OPERATIONS

The reservoir is designed as a multiuse facility with 259,000 acre-feet of exclusive flood control storage between El. 3657.0 and 3640.0, 250,000 acre-feet of joint-use storage between El. 3640.0 and 3614.0, and 363,672 acre-feet of conservation storage between elevations 3614.0 and 3547.0. The total dead and inactive storage is 502,328 acre-feet.

Since closure of the dam, the operation of Bighorn Lake (shown graphically on fig. 4) has been designed to provide flood control downstream of the reservoir, to enhance power production, and to satisfy recreational needs during the summer and early fall. To accomplish this, the reservoir is filled to approximately El. 3633.0 by mid-July and held near that elevation until the end of October. From late October through April, the reservoir is drawn down to meet power demands; it reaches a mean elevation in April of about 3606.0. According to the stage duration curve (fig. 5), the reservoir is operated in the joint-use pool above elevation 3614.0 about 70 percent of the time. At El. 3614.0, the 1982 reservoir pool extended upstream in the Bighorn Valley to about range 24. The 1982 reservoir pool at El. 3633.0 extended upstream to about range 34.

SURVEYS AND EQUIPMENT

Original Surveys

The original range survey was conducted during the construction period from November 1962, through September 1964. Within the Bighorn Canyon, the underwater portion of each range line was surveyed, and the river water surface elevation coincident with the survey was determined. Each range end was marked by a monument, and both the horizontal and vertical positions of these range ends were determined by survey. The control information for all range lines is available at the Missouri Basin Regional Office in Billings, Montana. A layout of the reservoir sediment range system is shown on figure 6.

The original topographic mapping of the reservoir was performed under contract by Fairchild Aerial Surveys, Inc., in 1945. The canyon portions of the maps had a scale of 1:6000 and a contour interval of 20 feet. The topographic map of the reservoir area upstream of Bighorn Canyon had a scale of 1:6000 and a contour interval of 5 feet.

1982 Resurvey

Fieldwork for the 1982 survey began in April 1981, and ended on August 4, 1982. The preliminary fieldwork consisted of searching for the range end markers, flagging the range ends and points on line near the water's edge, replacing end markers that were lost, and running ground profiles on range lines in the delta area not inundated during the hydrographic survey. Within Bighorn Canyon, each range line was projected down to the reservoir level from the canyon rim, where many of the range monuments had been placed. All range lines between ranges 34 and 44 were profiled by standard land surveying procedures and equipment.

Because of the variety of conditions encountered, several techniques were used to obtain profiles of the sediment ranges. Because of extreme depths along range 1 (nearest the dam), surveying that line consisted of determining the surface elevation of the deposited sediment by electronic depth sounding. This limited survey was possible because the sediment surface was approximately level in the transverse direction.

Because of the steep walls on most of the range lines and the nature of the sediment surfaces, one of two positioning methods were used for each of the other range lines within the Bighorn Canyon area. The selection of the positioning method depended on reservoir bank conditions and on the amount of recreational boating occurring at the time. One method was performed by releasing a fine piano wire, which was tethered to a pin on line near the water's edge, from a calibrated measuring wheel mounted on the deck of a flat-bottom survey boat (fig. 7). As the wire was released, floats were attached to hold the wire on or near the water surface. The boat operator maintained the line by heading toward a flag on the opposite canyon wall. As the survey (sounding) boat progressed, the distance along line was read from the wheel qauge and a mark was placed on the sounding chart along with measured distance to correlate distance with water depth. When this method was used, a second boat kept recreational boats away from the survey area. The other positioning method used in the canyon consisted of maintaining nearly constant speed and fixing position and measuring depth at constant time intervals. This method was adequate for most of the canyon because the survey was directed toward determining the approximate horizontal line marking the surface of the deposited sediments. Twenty-three main stem and tributary range lines were surveyed by these two methods. A precision electonic sounding device was used to obtain the reservoir depth on all lines.

Because of the width of the reservoir and the unevenness of its bottom, an automated survey system was used to profile the inundated portion of range lines within the Horseshoe Bend area (ranges 14 through 16) and within the Bighorn Valley south of the canyon (ranges 21 through 34). The underwater portion of 17 range lines were surveyed by that method. The system consisted of a sonic depth recorder that was interfaced with an automated positioning system (fig. 8) to continuously measure reservoir depth and sounding position as the survey boat traversed each range line. This positioning system transmitted line-of-sight microwave signals to fixed shore stations (fig. 9) and converted the reply time to range distances that were used by the system data logger to compute the coordinate position of the sounding boat.

The controls required for the automated survey system were the horizontal grid coordinates for all range ends and fixed shore stations, and the elevations of the reservoir and shore-station antennas. When the system was activated, the survey boat (fig. 10) was steered across the range line at about 8 feet per second. The system also gave directions for maintaining course to the boat operator. During each run, the depth and position data were recorded on magnetic tape for subsequent processing by computer. A graph plotter was used to track the boat and to provide an immediate plot of each range profile.

Sampling of Reservoir Deposits

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Core samples were not obtained between ranges 26 and 30 because of a large oil spill that occurred on a tributary of the Shoshone River. The oil from the spill reached the reservoir on the day when the other samples were taken. All access to the reservoir area from near range 26 upstream to the highway 14A bridge was restricted to facilitate oil removal operations. Because the samples that had been taken displayed little variation in the adjacent areas, further sampling in the closed area was considered unnecessary.

RESERVOIR AREA AND CAPACITY

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The 1982 contour surface areas for Bighorn Lake were developed by dividing the reservoir into two parts: the narrow canyon portion downstream from range 13 and the wider valley portion upstream from

Table 3. – Summary of sediment sample analyses for 1982 survey.

Sample, Lab No.	Identification, Sampling location	Sample length, in	Sampling depth, ft	Percent finer than size indicated, mm											Median diameter, mm	Unit weight, lb/ft³
				0.002	0.005	0.009	0.019	0.037	0.074	0.149	0.297	0.590	1.190	2.380		
1	Range-13	53	62	59.2	76.8	85.4	96.2	100.0	–	–	–	–	–	–	0.0014	35.2
2	Range-14	50	54	51.4	66.8	78.4	91.0	97.0	99.9	100.0	–	–	–		0.0019	39.8
3	Range-15-left	19	46	19.2	22.9	25.3	30.6	42.6	63.4	*96.3	*99.3	*99.6	*99.8	*99.9	0.049	54.3
4	Range-15-right	11	46	12.5	16.4	18.2	25.4	42.7	73.2	98.5	*99.8	99.9	100.0	–	0.043	63.1
5	Range-16	35	40	53.6	65.2	74.0	84.8	93.8	*98.2	*99.2	*99.8	99.9	100.0	–	0.0016	42.1
6	Range-17-right	24	35	33.0	44.0	50.6	65.6	87.6	*97.1	*99.6	*99.8	*99.9	100.0	–	0.0089	41.1
7	Range-17-left	53	41	66.0	78.0	88.6	90.6	98.6	*99.8	*99.9	100.0	–	–	–	0.0010	42.1
8	Range-18	45	34	52.4	68.4	79.8	87.8	94.8	99.0	*99.9	100.0	–	–	–	0.0018	48.1
9	Range-19	13	39	3.5	3.5	3.7	4.3	7.6	8.5	21.2	93.7	100.0	–	–	0.190	95.7
**10	Range-20 gray	17	31	49.0	61.4	69.0	74.8	79.8	87.5	93.7	96.1	97.5	98.8	99.8	0.050	69.9
**10	Range-20 red	17	31	17.6	24.1	27.2	33.1	42.9	54.3	71.7	80.2	87.3	94.1	98.4	0.002	-
11	Range-21-right	37	32	53.0	67.6	78.2	85.0	91.0	*98.7	*99.8	100.0	–	–	–	0.0018	48.0
12	Range-21-left	44	32	29.0	35.6	39.2	45.0	56.0	69.3	94.5	*99.0	*99.7	*99.9	100.0	0.0260	56.4
13	Range-22	51	31	54.2	65.8	74.4	85.2	97.2	*99.7	*99.9	100.0	–	–	–	0.0015	42.4
14	Range-23	24	29	54.8	72.2	78.8	89.6	95.6	99.8	*99.9	100.0	–	–	–	0.0016	44.8
15	Range-24	22	27	41.8	55.4	62.0	73.8	83.8	96.3	*99.3	99.9	100.0	–	–	0.0035	52.3
16	Range-25	29	26	50.4	66.0	71.6	84.4	96.4	*98.7	*99.9	100.0	–	–	–	0.0020	58.2
†17	Range-31; upstream of causeway bridge	16	–	43.6	52.2	59.5	75.2	89.1	95.7	*98.0	*98.6	*99.0	*99.1	99.2	0.0040	67.5
†18	Range-31; right 200 ft from R-31-R	13	–	54.6	67.0	77.0	86.0	94.0	*99.2	*99.7	*99.9	100.0	–	–	0.0015	59.0
†19	Range-32; 400 ft from R-32-R	14	–	56.4	71.8	81.4	90.2	94.0	*99.4	*99.9	100.0	–	–	–	0.0014	61.6
†20	Range-33; 300 ft from R-33-R	15	–	41.6	54.4	60.0	74.8	86.8	*98.0	*99.9	100.0	–	–	–	0.0036	71.1
‡21	Range-34; 10 ft from main channel bank to R-34-R	11	–	35.0	40.6	48.4	62.4	80.4	98.6	99.8	99.9	100.0	–	–	0.0098	61.7

* Contained organic material.

** Contained two different types of material, different in grain size, distribution, and coloration.

† 05-11-83

‡ 05-10-83

fixed shore stations (fig. 9) and converted the reply time to range distances that were used by the system data logger to compute the coordinate position of the sounding boat.

The controls required for the automated survey system were the horizontal grid coordinates for all range ends and fixed shore stations, and the elevations of the reservoir and shore-station antennas. When the system was activated, the survey boat (fig. 10) was steered across the range line at about 8 feet per second. The system also gave directions for maintaining course to the boat operator. During each run, the depth and position data were recorded on magnetic tape for subsequent processing by computer. A graph plotter was used to track the boat and to provide an immediate plot of each range profile.

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range 13. In the upstream part, all original 5-foot contours were digitized, and the surface area was computed for each contour. The original topographic map of the reservoir downstream from range 13 had 20-foot contour intervals. Therefore, the only valid surface area data for the downstream reach were at 20-foot contours. To develop a 5-foot contour table for the higher elevations in the downstream portion of the reservoir, the 5-foot contour areas for the downstream reach were determined by straight-line interpolation between measured areas. The 20-foot contour areas were obtained by subtracting the digitized contour areas representing the upstream part from the original, total contour surface area. The part of the downstream reservoir that was lower than the original thalweg at range 13 is represented by contour surface areas only at even 20-foot contour intervals.

The original contour suface areas for elevations below the channel thalweg at range 13 were reduced by the amount of the 1982 sediment surface area. These sediment surface areas were developed by plotting the 1982 average bottom profile versus the original thalweg profile, transferring the location of 1982 contour crossings to the original topography, and digitizing the resulting sediment surface areas. The steepness of the river channel and the relative shallow depth of sediment in that part of the reservoir simplified this step, but still produced satisfactory results.

For the upstream part of the reservoir, the 1982 contour surface areas were computed by means of the computer program RESSED. This program uses the original and revised sediment range profile data to devleop adjustment factors, which are then used to revise the original segmented surface areas. The method is called the width-adjustment method and is described in the USBR's Technical Guide, *Procedures for Monitoring Reservoir Sedimentation.*

A final 1982 area versus elevation table was developed by summing the upstream segmental contour areas and adding the contour areas derived for the downstream reach. The resulting data, presented in column 4 of table 4, has a maximum elevation of 3660.0 with derived surface areas at 5-foot intervals above and at 20-foot intervals below El. 3540.

Revised Storage Capacity

The storage-elevation relationship was determined using the USBR (Bureau of Reclamation) program ACAP. Both the surface area versus elevation and the storage (capacity) versus elevation relationships are shown graphically on figure 12.

Surface areas from the 1982 resurvey were used as the control parameters to compute reservoir capacity. The program was written to include computation of 0.01- to 1-foot area increments by linear interpolation between 5-foot contour intervals. The computational procedure is progressive; it begins by testing the initial capacity equation over successive intervals to check whether these intervals fit within an allowable error limit (set at 0.000001 for Bighorn Lake). This capacity equation is then used over the whole range of intervals that fit within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from the basic area curve over that interval) begins testing the fit until it, too, exceeds the error limit. Thus, the capacity curve is defined by a series of curves, or splines, each falling within a specific elevation interval as constrained by the limiting error. Final area equations are derived by differentiating the capacity equations. Capacity equations are of second order polynomial form:

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

where:

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

Results of the 1982 Bighorn Lake area and capacity computations are listed in table 4, columns (4) and (5). A separate set of 1982 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments [1]*.

The maximum 1982 reservoir capacity at El. 3660.0 is computed to be 1,381,189 acre-feet, which represents a loss in storage of 53,997 acre-feet since the beginning of storage. This storage loss is derived solely from a comparison of the adjusted original capacity versus the 1982 computed capacity at El. 3660.0.

The original capacity, which was developed during the project planning stage by planimetering the official reservoir topographic maps, does not include the part of the river channel that existed below the contour elevation shown on the topographic sheets. An analysis of the original sediment range profiles has shown that the omitted storage space is approximately 8,100 acre-feet in the downstream canyon area. Because the omitted storage space was not included in the original area-capacity determination, it was not used in developing the revised area-capacity tables. However, for the purpose of determining the volume of sediment storage in the reservoir and the basin yield characteristics, the omitted storage has been considered in the analyses. The original area and capacity given in table 4, columns

* Number in brackets refer to entries in the bibliography.

Table 4. – Summary of 1982 survey results

(1) Elevation, feet	(2) 1964 area, acres	(3) 1964 capacity, acre-feet	(4) 1982 area, acres	(5) 1982 capacity, acre- feet	(6) Measured sediment volume, acre-feet	(7) Percent of measured sediment	(8) Percent of reservoir depth
3660	17,958	1,435,186	17,940	1,381,189	53,997	100.0	100.0
3657	17,298	1,382,311	17,279	1,328,360	53,950	99.9	99.4
3655	16,852	1,348,161	16,839	1,294,242	53,919	99.9	99.0
3650	15,768	1,266,611	15,728	1,212,824	53,787	99.6	98.0
3645	14,427	1,191,123	14,396	1,137,514	53,609	99.3	97.0
3640	12,685	1,123,343	12,598	1,070,029	53,314	98.7	96.0
3635	11,179	1,063,683	10,997	1,011,042	52,641	97.5	94.9
3630	9,882	1,011,031	9,611	959,522	51,509	95.4	93.9
3625	8,746	964,461	8,532	914,164	50,297	93.1	92.9
3620	8,152	922,216	7,699	873,587	48,629	90.1	91.9
3615	7,508	883,066	7,065	836,677	46,389	85.9	90.0
3610	7,088	846,576	6,317	803,222	43,354	80.3	89.9
3605	6,775	811,918	5,814	772,894	39,024	72.3	88.9
3600	6,474	778,796	5,511	744,582	34,214	63.4	87.9
3595	6,043	747,503	5,296	717,564	29,939	55.4	86.8
3590	5,750	718,021	5,118	691,529	26,492	49.1	85.8
3585	5,468	689,976	4,963	666,327	23,649	43.8	84.8
3580	5,280	663,106	4,873	641,737	21,369	39.6	83.8
3575	5,001	637,403	4,734	617,719	19,564	36.2	82.8
3570	4,797	612,908	4,624	594,324	18,584	34.4	81.8
3565	4,660	589,266	4,512	571,484	17,782	32.9	80.8
3560	4,515	566,328	4,392	549,224	17,104	31.7	79.8
3555	4,399	544,043	4,313	527,462	16,576	30.7	78.7
3550	4,289	522,323	4,218	506,134	16,189	30.0	77.7
3545	4,136	501,261	4,103	485,332	15,929	29.5	76.7
3540	4,048	480,801	4,016	465,034	15,767	29.2	75.7
3520	3,674	403,581	3,631	388,564	15,017	27.8	71.7
3500	3,311	333,731	3,244	319,814	13,917	25.8	67.6
3480	2,803	272,591	2,795	259,424	13,167	24.4	63.6
3460	2,367	220,891	2,351	207,964	12,927	23.9	59.5
3440	2,045	176,771	2,032	164,134	12,637	23.4	55.5
3420	1,696	139,361	1,667	127,144	12,217	22.6	51.4
3400	1,425	108,151	1,350	96,974	11,177	20.7	47.4
3380	1,134	82,561	1,045	73,024	9,537	17.7	43.3
3360	947	61,751	850	54,074	7,677	14.2	39.3
3340	722	45,061	679	38,784	6,277	11.6	35.2
3320	597	31,871	531	26,684	5,187	9.6	31.2
3300	421	21,687	400	17,374	4,313	8.0	27.1
3280	340	14,081	291	10,464	3,617	6.7	23.1
3260	220	8,481	208	5,474	3,007	5.6	19.0
3240	165	4,631	133	2,064	2,567	4.8	15.0
3220	79	2,191	51	224	1,967	3.6	10.9
3211.2	73	1,515	0	0	1,515	2.8	9.1
3200	67	731	0	0	731	1.4	6.9
3180	3	30	0	0	30	0.1	2.8
3166	0	0	0	0	0	0	0

Explanation of columns:

(1) Elevation of reservoir water surface.
(2) Original reservoir water surface area adjusted to include area within river channel below surface contours.
(3) Original reservoir capacity adjusted for volume within river channel below surface contours.
(4) Reservoir surface area from 1982 survey.
(5) Reservoir capacity from 1982 survey.
(6) Measured sediment volume = column (3) - column (5).
(7) Measured sediment expressed in percentage of total sediment (53,997 acre-feet).
(8) Depth of the reservoir expressed in percentage of total depth (494 feet).

(2) and (3), respectively, have been adjusted to include that area and volume within the river channel below the original contours.

SEDIMENT ANALYSES

Sediment Accumulation

The 1982 resurvey results indicate the 53,997 acre-feet of sediment have deposited below El. 3660.0 since closure in November 1965. The average rate of sediment deposition in the 16.75-year period between closure and July 1982, was 3,224 acre-feet per year, or 0.314 acre-foot per square mile of contributing drainage area. The measured annual inflow rate is approximately 88 percent of the original estimate of 3,662 acre-feet.

The average annual inflow to the reservoir during the same period, which is measured at stream-qauging stations upstream on the Bighorn River and on the Shoshone River, was 2,401,000 acre-feet (see table 2). This represents approximately 92 percent of the recorded historical flow of the Bighorn River at the stream-gauging station near St. Xavier, Montana, for the period from 1926 through 1958. Disregarding some relatively small unmeasured tributary inflows, the annual inflow since closure was within about 7 percent of the predam mean annual inflow.

Particle Size and Unit Weight Analyses

Twenty-one samples from the reservoir sediment deposits were collected in 1982. A summary of the analyses results for each sample, which shows sampling location, sample length, sampling depth, size gradations, median diameter, and unit weight, is given in table 3. The particle size analyses for all of the samples are plotted on figures 13 through 29. The samples varied in length from 11 to 53 inches. In most instances, the depth of sediment penetration was greater than the sample length retrieved. It is assumed that where this occurred, there was some compaction within the sample casing and some penetration without intrusion within the casing, caused by a buildup of surface tension on the casing wall. Each sample was analyzed in the laboratory. After each whole sample was frozen, it was cut to appropriate lengths, and representative segments were selected for testing. Then individual specimens were weighed and measured to determine their densities; after which they were extruded for moisture content determinations. A representative (50- to 100-gram) sample of the oven-dry material was then used for the gradation analyses.

From the laboratory gradation analyses of the 21 samples, an average particle size was computed that indicated 51 percent clay, 35 percent silt, and 14 percent sand. Applying the average size gradation determined, an initial unit weight of 44.7 lbs/ft^3 was computed by an empirical method [2]. Correcting for compaction, a unit weight of 49.8 lb/ft^3 was computed for the 16.75-year period since closure. This compares well with the 52.9 lb/ft^3 computed for the nonweighted average of the 20 samples (omitting sample No. 9, assumed to include nondeposited material) listed in table 3. The unit weights determined by either the empirical method or by averaging the results of the laboratory analyses should be considered only approximations. Both average size gradations and the unit weight from analysis of the core samples are biased toward the finer sediments and are therefore not representative of the total range of sediment sizes deposited in the reservoir. A more comprehensive core sampling program covering the whole reservoir and using equipment capable of sampling the full depth of sediment deposits would be necessary to produce statistically reliable results.

Sedimentation Summary

The Bighorn Lake sediment data for the 1982 resurvey are summarized in table 1. The data include a tabulation of the incremental sediment inflow volume and the sediment accumulation rate computed for the period between the original (1964) survey and the 1982 resurvey. These data and other information on the watershed and reservoir are listed in table 1 for the purpose of ongoing sediment investigations and research.

RESERVOIR SEDIMENT DISTRIBUTION

Longitudinal Distribution

The distribution of sediment throughout the length of the reservoir is described by three sets of plots, each chosen to display a distinct characteristic of the sediment distribution.

The longitudinal profiles for the original and the 1982 channel thalweg are plotted on figure 30. The thalweg is the lowest elevation point on each range line. The distance shown on the plots is the channel distance measured along the centerline of the channel on the original topographic maps. These profiles indicate two delta-like formations in the reservoir, one quite low, forming with a pivot point about range 4; the other, which is more typical, forming with a pivot point about range 16. Most of the deposits in the lower portions of the reservoir entered during initial filling and from tributary inflow during the life of the reservoir. The apparent delta shape of the deposits is probably accidental. The delta forming in the upper end of the reservoir reflects the long-term operations and prevailing reservoir elevation during periods of high sediment inflow. The elevation of the pivot point is about 3600 feet mean sea level. The pivot point usually occurs near the mean operating pool elevation. However, for Bighorn Lake, it is about 25 feet lower than mean pool level. This difference is due in part to the timing of the reservoir filling and the periods of highest sediment inflow, some of which occur early in the filling period. The high mean pool level is also influenced by how the reservoir is operated in the summer and fall at high levels to enhance recreational use.

A set of longitudinal plots that are more representative of the sediment distribution than the longitudinal thalweg plots (fig. 30) are the plots of average bottom elevation shown on figure 31. The average depth was determined by selecting a reference elevation for each range line above the level of any sediment deposition and dividing the total section area for that elevation by the hydraulic width. The average depth was then used to compute average bottom elevation for the range. Because the average bottom elevation plots display a sediment surface much closer to the actual sediment surface of the range line subject to deposition, they provide better information on the progressive growth of the delta in the reservoir.

The longitudinal profiles are shown in dimensionless form on figure 32, which shows plots of percent depth versus percent distance. Percent depth is the ratio of thalweg depth to total depth. Because of the incised channel through the sediment deposits in the upstream portion of the reservoir above range 13, the average bottom elevation has been used instead of the thalweg elevation throughout the reservoir. The depth was computed as the difference between the thalweg (or average bottom) elevation at each sedimentation range and the low point on the original profile (El. 3166.0). The total depth is 491.0 feet; which represents the total difference between the top of the spillway gates (El. 3657.0) and the original low point in the reservoir profile. The percent distance was computed as the ratio of the channel distance between the dam and a given range to the total distance (368,230 ft) between the dam and the upstream point in the river where the 3657.0 contour crosses between ranges 42 and 43.

Depth Distribution

The measured distribution of sediment in the reservoir is plotted on figure 33 as percent reservoir depth versus percent sediment deposited. The sediment volumes supporting the plotted curve are given on table 4. The design curves for type I, type II, and type III [3] reservoirs are also plotted against the measured curve. Plotting the depth-capacity relationship (fig. 34) using the original data indicated a type II reservoir. Although the reservoir, throughout most of its depth, most closely resembles type II, the reservoir area upstream of Bighorn Canyon is better characterized as type I. In the Bighorn Canyon area, if reservoir shape were the only criterion, that portion of the reservoir would be better classified as type III. As shown on figure 33, the measured sediment distribution is not well represented by any of the type curves.

The nature of the measured distribution is due to reservoir operation, the shape of the reservoir area above Bighorn Canyon, and the timing of major sediment inflow. The reservoir pool fluctuates as shown on figure 4, between (approx.) El. 3600.0 and 3640.0. Filling usually begins in late April, and the reservoir reaches its maximum elevation for the year about mid-June. As the reservoir approaches maximum reservoir level, it also experiences its highest annual inflow rates and, consequently, its largest sediment inflow rates. From May through October when the reservoir level is high, about 80 percent of the annual sediment load enters the reservoir. About 55 percent of the annual load enters during May and June. Because of the very low flow velocity in the downstream direction at high reservoir levels, most of the sediment entering the reservoir from May to October is deposited within the Bighorn Valley from the Horseshoe Bend area (between ranges 13 and 17) and farther upstream.

The original space allocations for sediment were made before construction and assumed a different type reservoir operation. Of the 75,000 acre-feet allocated for sediment within the active and joint-use pools, 45,000 acre-feet (60 percent) have already been lost to sedimentation. However, of the 240,000 acre-feet allocated to sediment below El. 3547.0, only 7,960 acre-feet (3.3 percent) have been lost to sedimentation. Before construction, minimum reservoir levels during winter operations were estimated to be as low as El. 3547.0. By operating the reservoir lower at the beginning of the spring and summer runoff season, a much larger percentage of the high sediment inflow in May and June would have reached the lower depths of the reservoir farther downstream.

The reservoir stage duration plot (fig. 5) shows that only 10 percent of the time has the reservoir been below El. 3595.0; whereas, over 50 percent of the time it has been above El. 3625.0. As a result, more than 70 percent of the total sediment deposited in the reservoir area is above El. 3560.0. The area of the reservoir receiving most of that deposition is upstream of range 13. Any substantial change in the present depositional pattern can only be accomplished by a change in current reservoir operations in the direction of the original operation plan.

Lateral Distribution

Ground surface profiles of 44 sedimentation ranges and 7 tributary ranges are shown on figures 35 through 85. These profiles show how the sediment is distributed laterally across the reservoir. There was no resurvey run on ranges 104, 201, 202, and 45, based on judgment that no reservoir deposition had occurred there. Plots of these lines are therefore not included. Sediments are shown to have been deposited to depths ranging from about 1.1 feet in the channel at range 43 to about 43 feet at range 15 in the Horseshoe Bend area.

The channel, which has cut through the deposited sediments when the reservoir was lowered, varies in width from about 320 feet at range 27 to 175 feet at range 17. The average channel width is 198 feet between ranges 16 and 20, and 264 feet between ranges 21 and 34. The channel width increases rather abruptly between ranges 20 and 21, then remains relatively constant until reaching a point upstream near range 33, above which only minor deposition, caused by reservoir backwater, has occurred.

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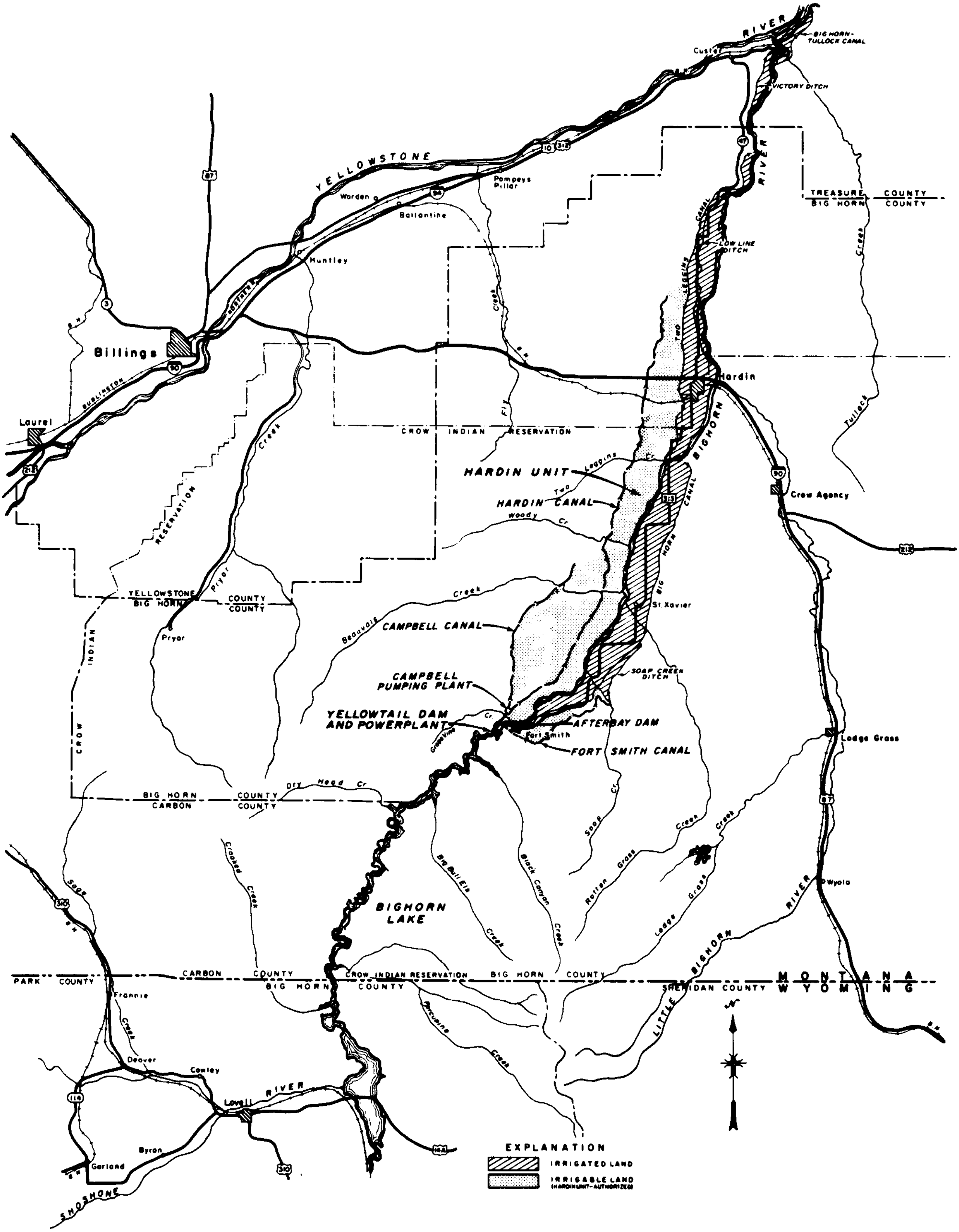

Figure 1. – Vicinity map.

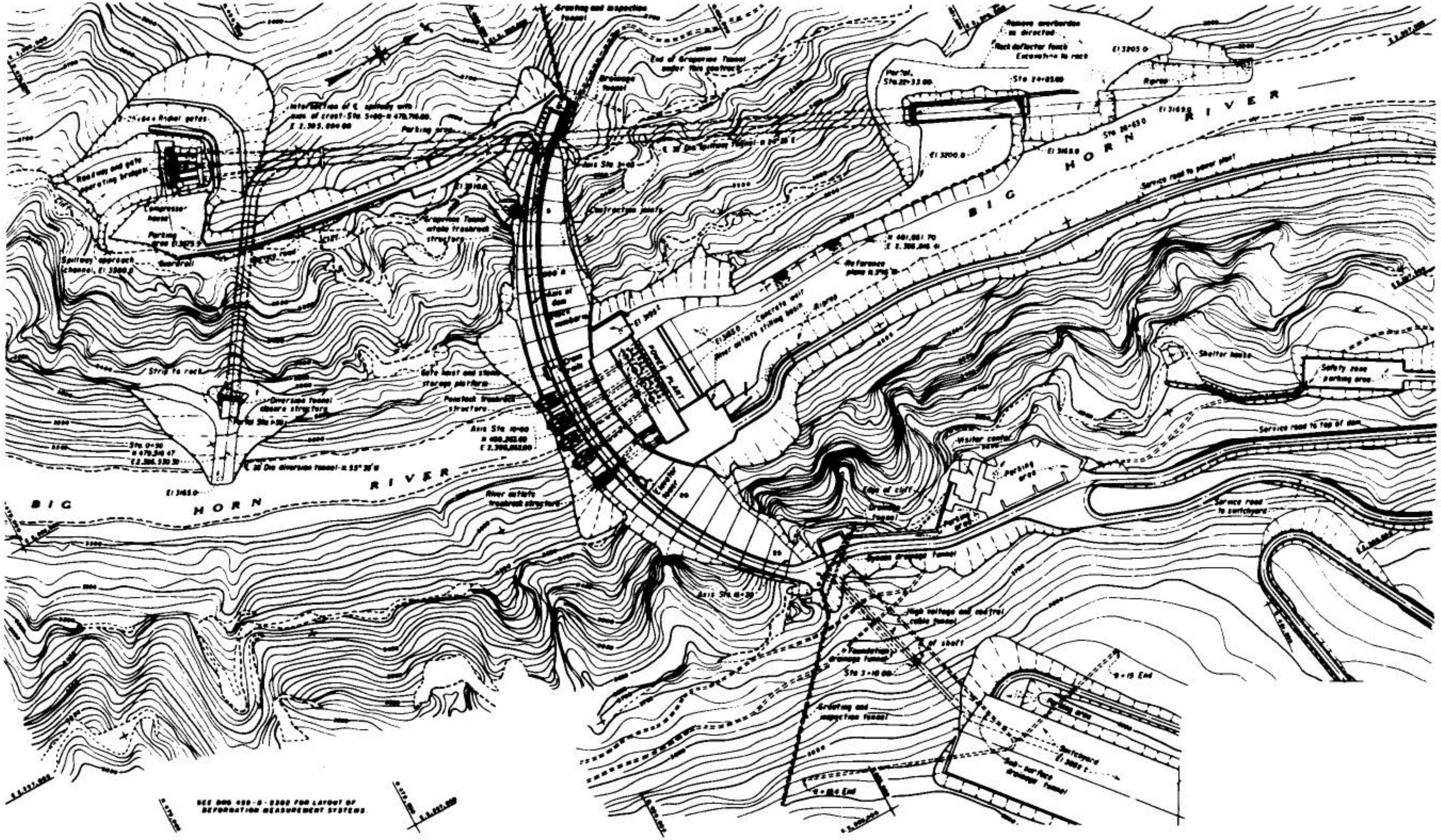

Figure 2. – Plan and sections of Yellowtail Dam. (sheet 1 of 2)

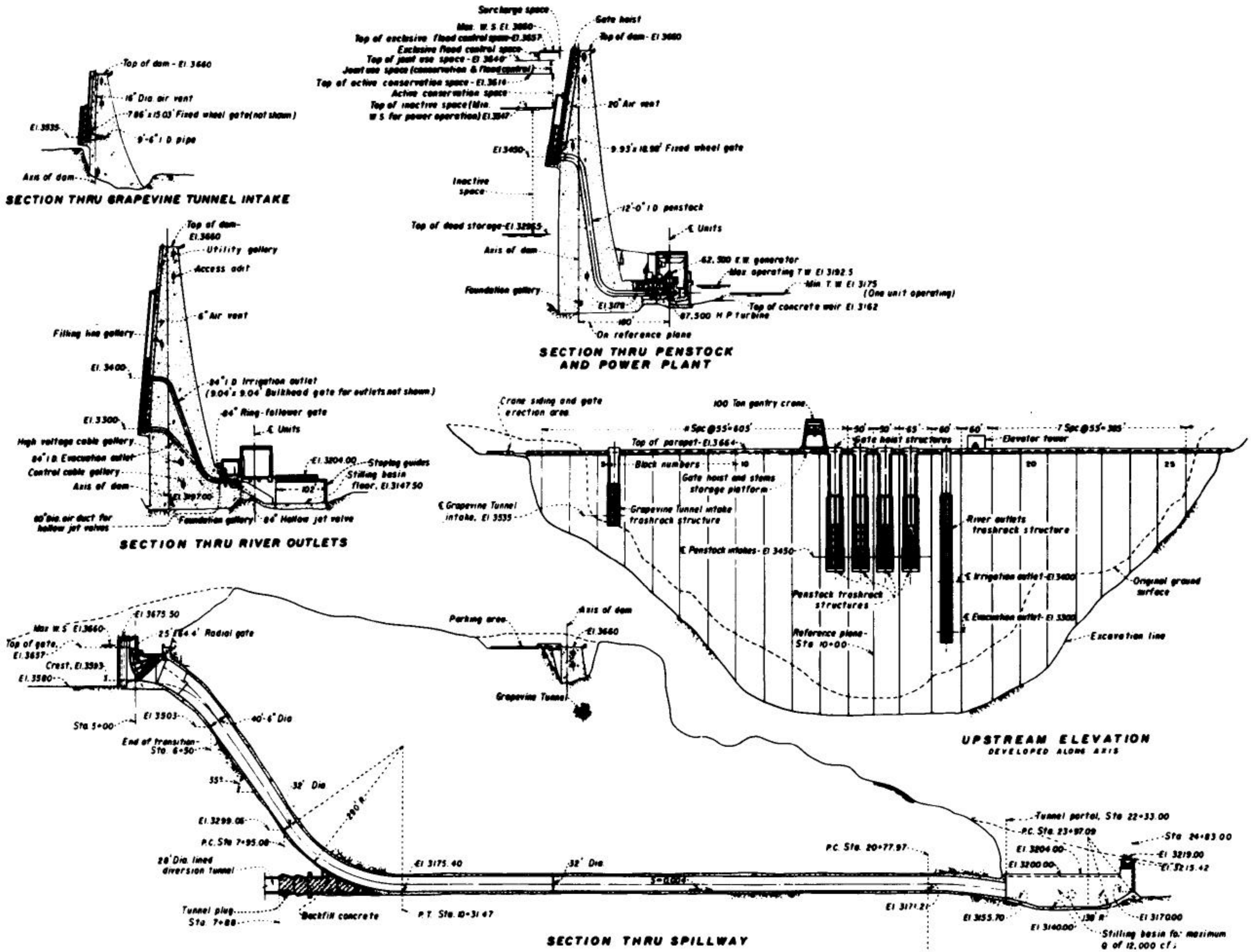

Figure 2. – Plan and sections of Yellowtail Dam. (sheet 2 of 2)

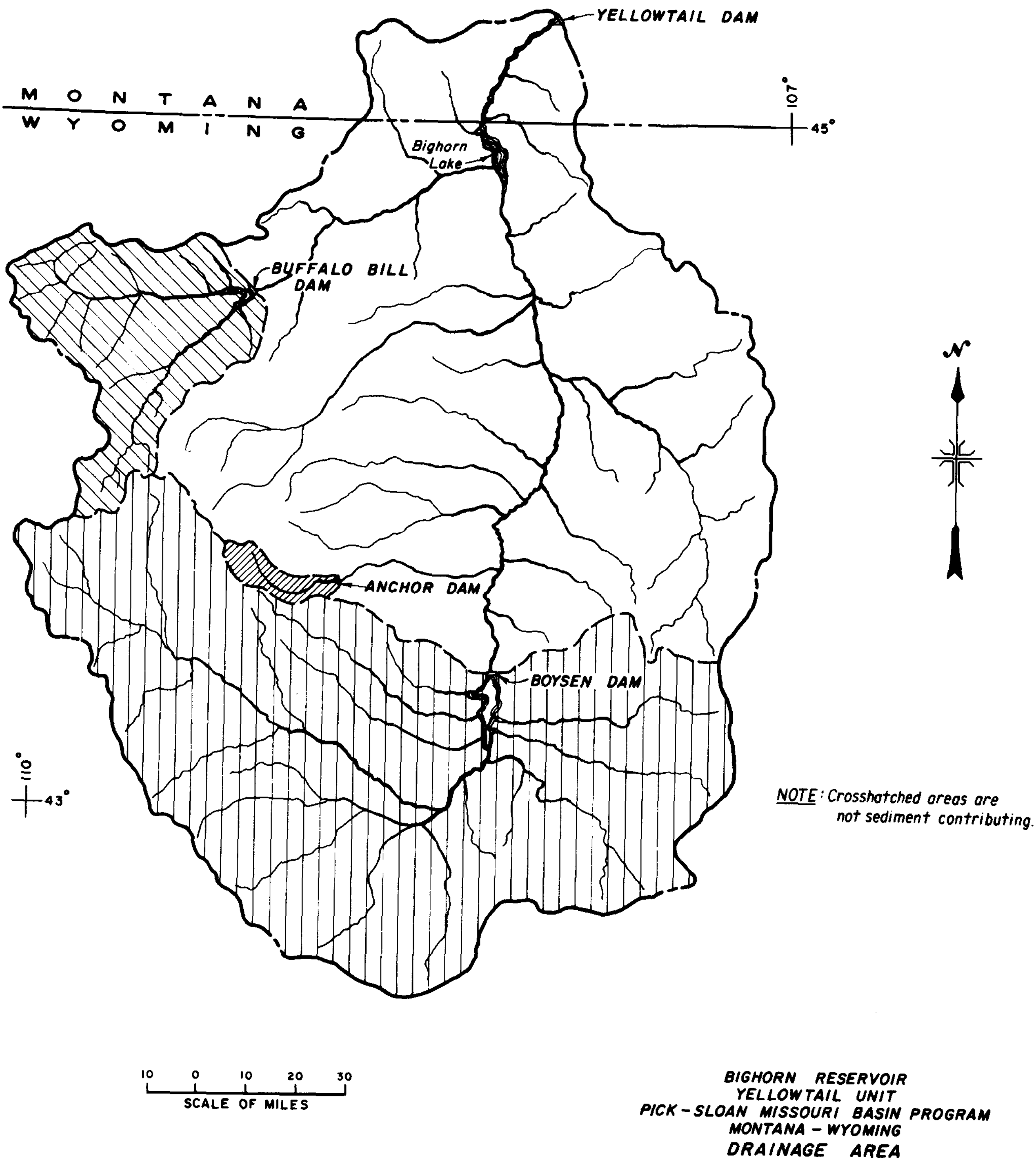

Figure 3. – Drainage area for Bighorn River above Yellowtail Dam.

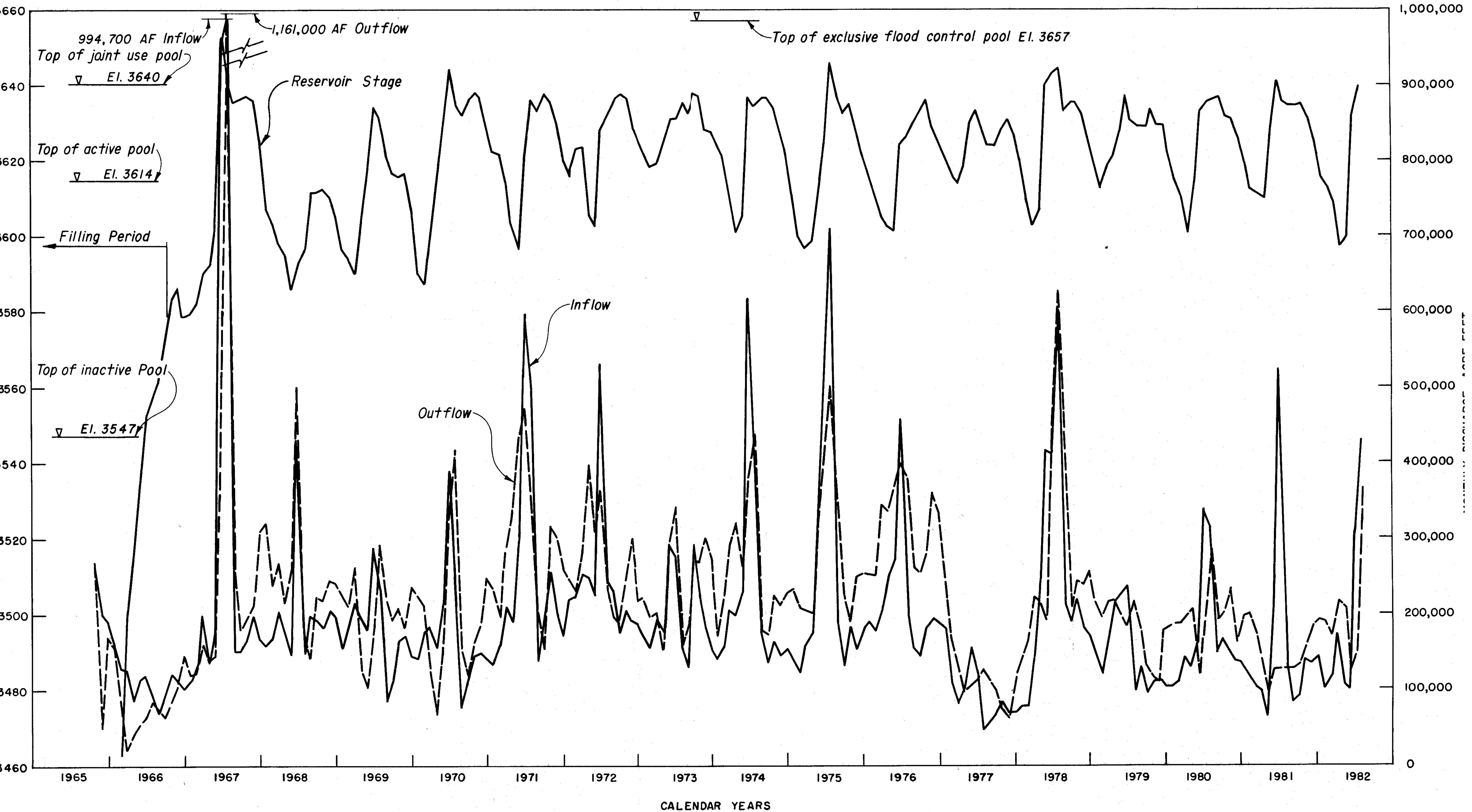

Figure 4. – Reservoir operation, 1965-1982.

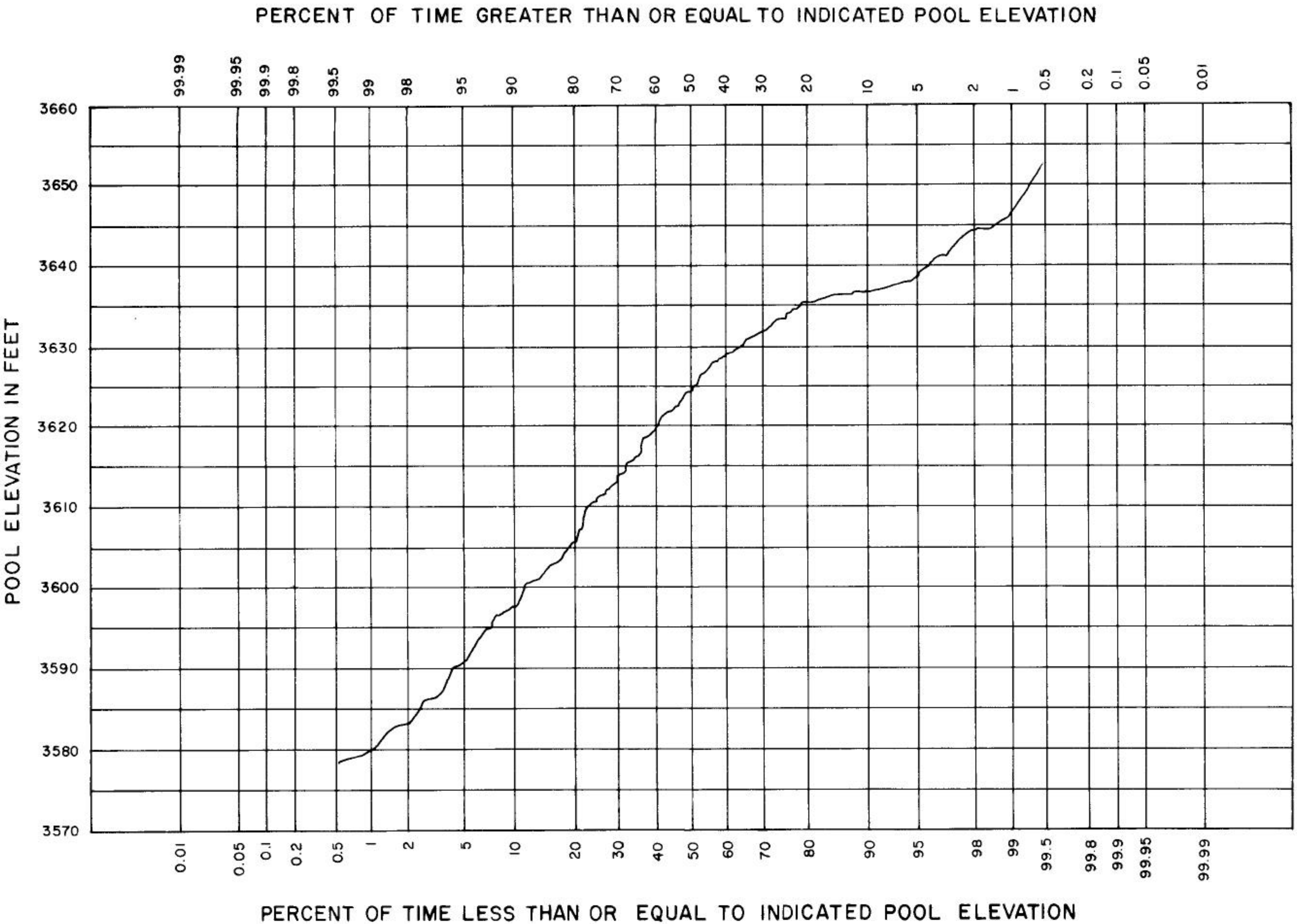

Figure 5. – Reservoir stage duration curve.

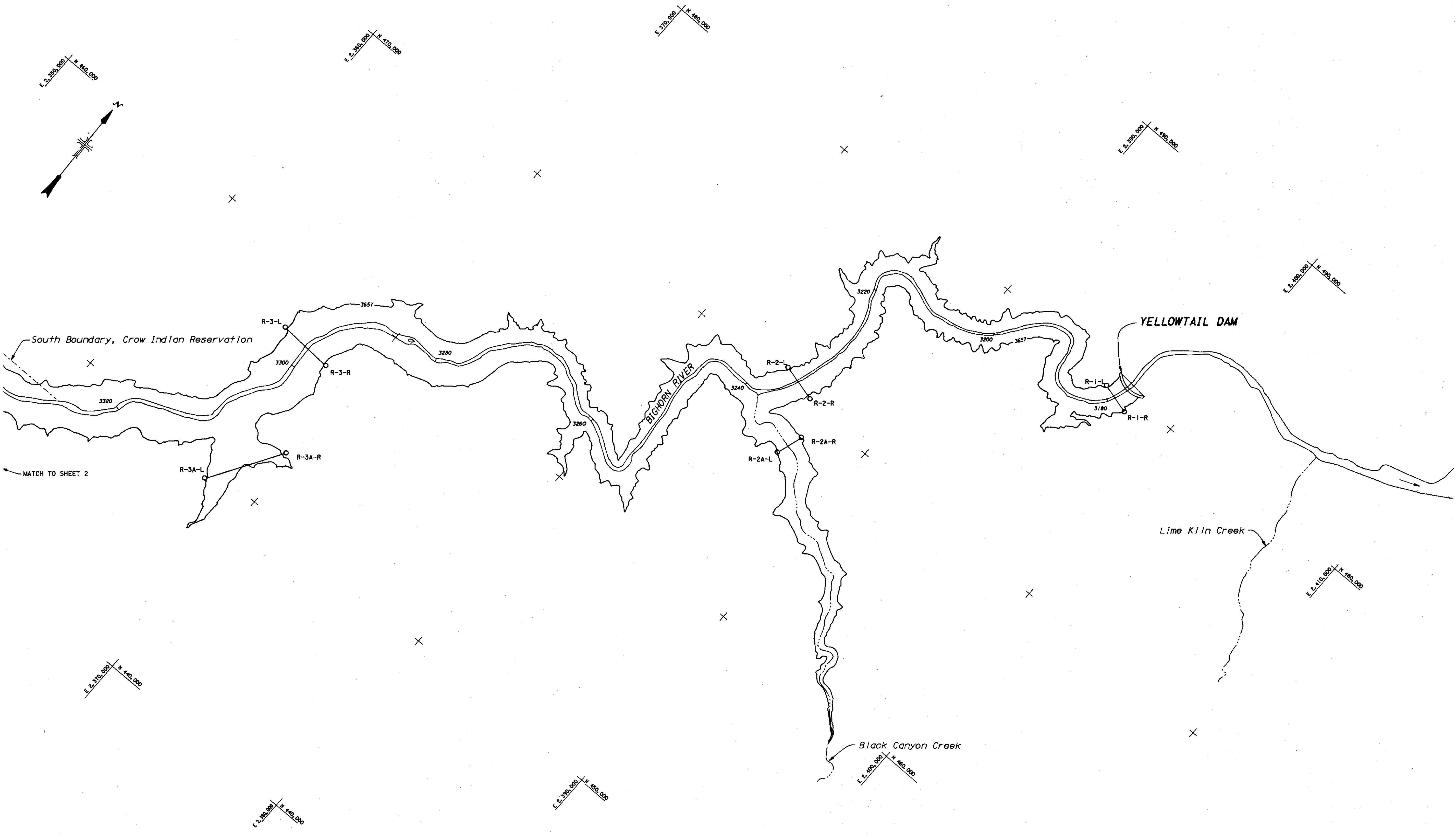

Figure 6. – Sediment range location map. (sheet 1 of 4)

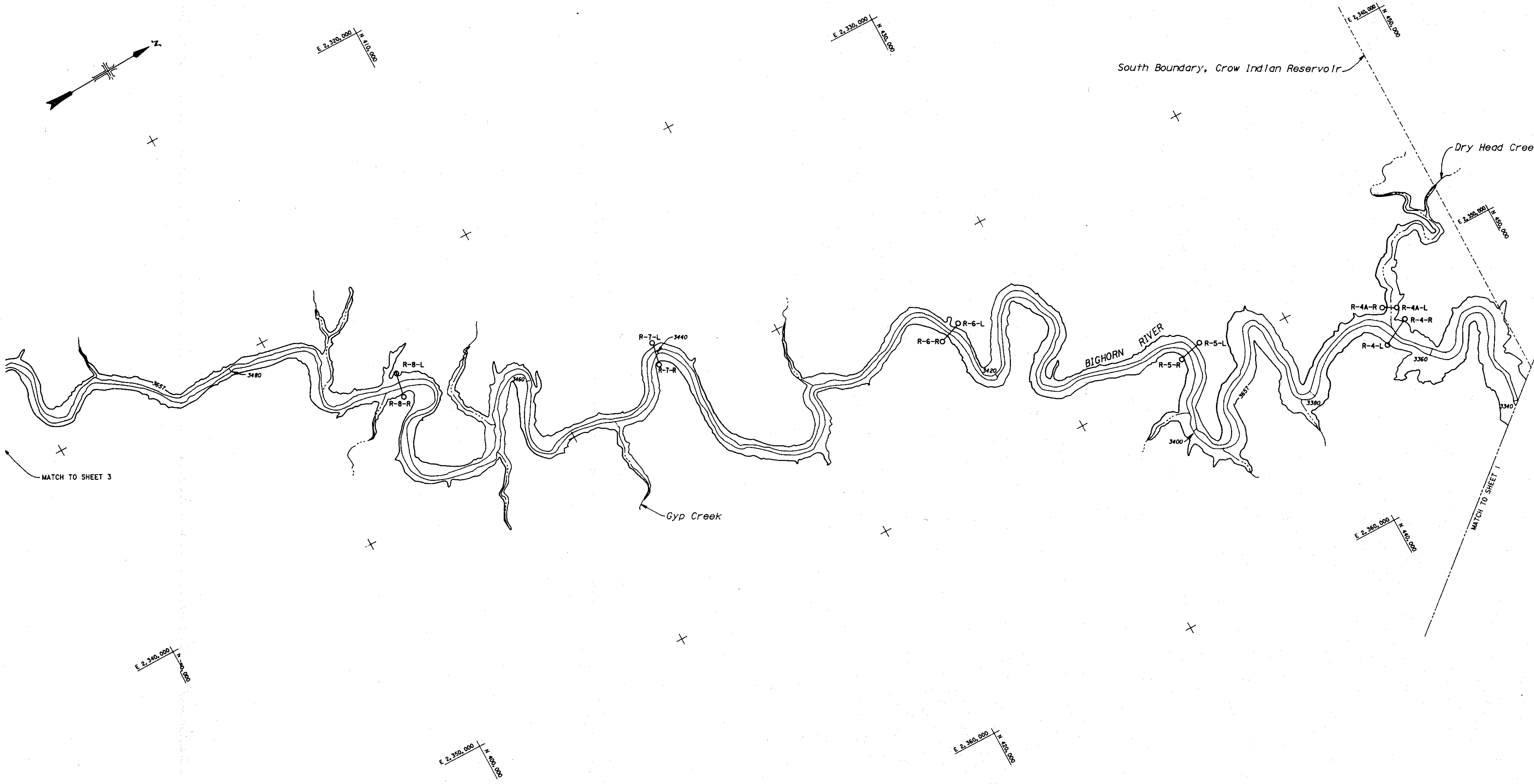

Figure 6. – Sediment range location map. (sheet 2 of 4)

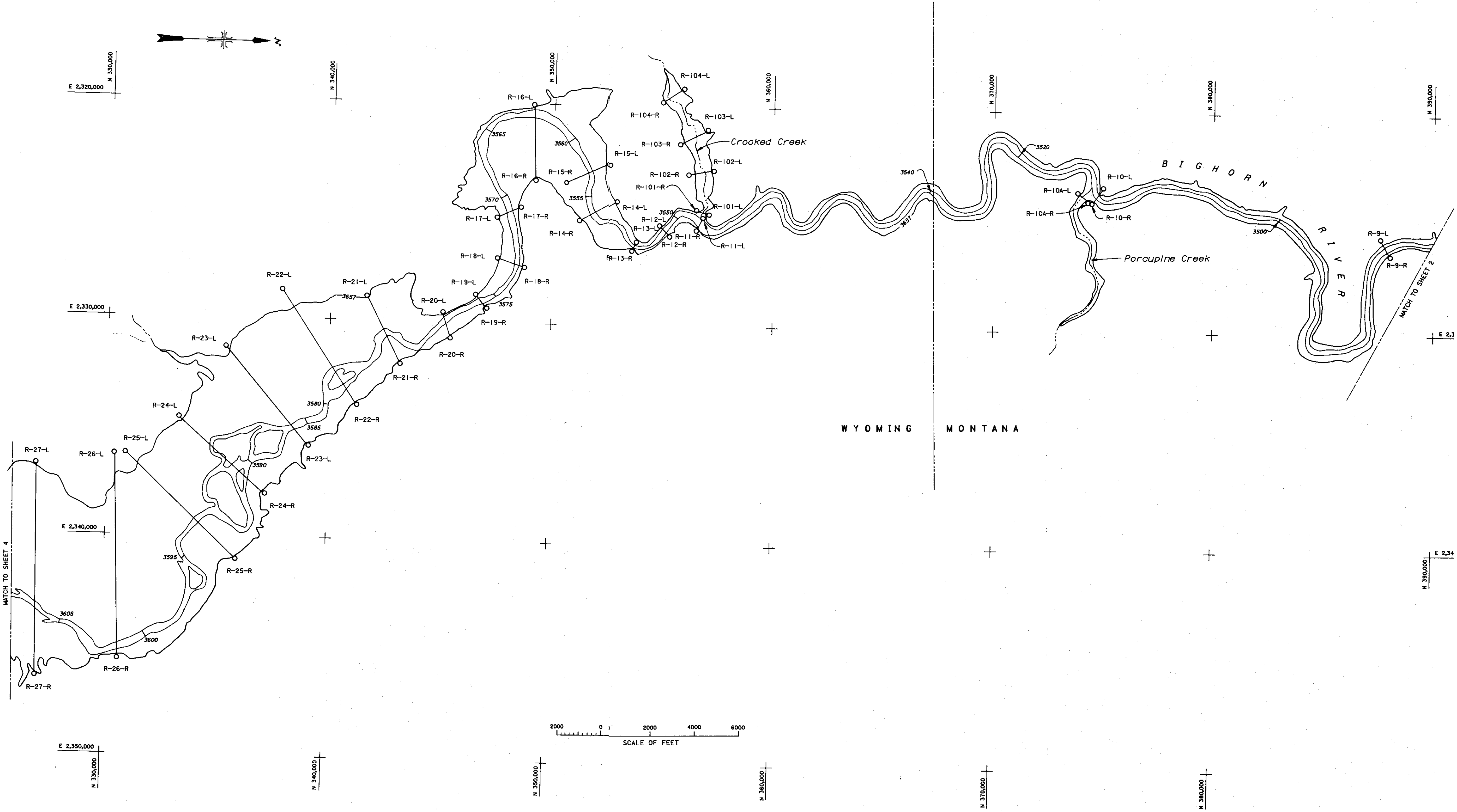

Figure 6. – Sediment range location map. (sheet 3 of 4)

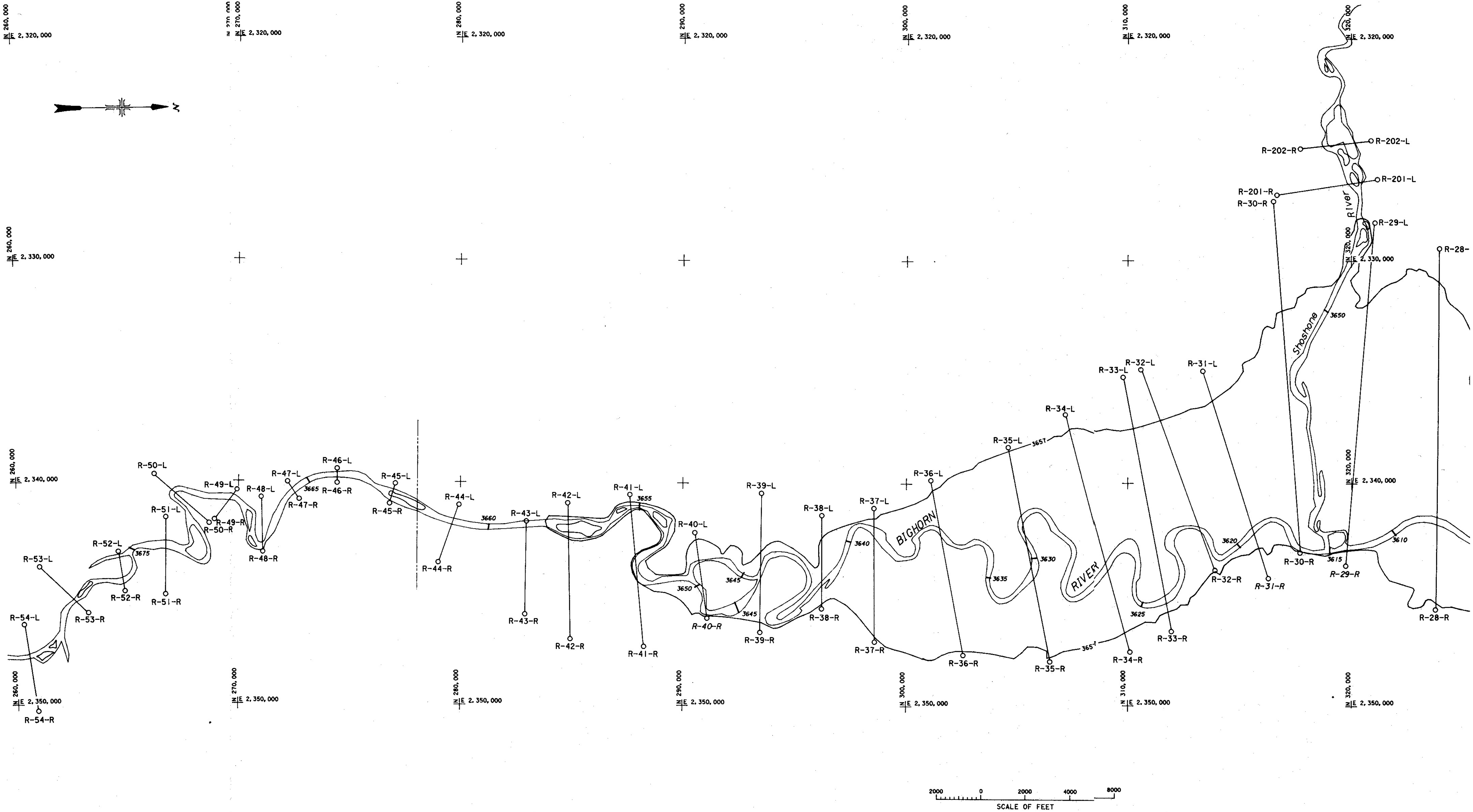

Figure 6. – Sediment range location map. (sheet 4 of 4)

Figure 7. – Surveying a range line in Bighorn Canyon. P801-D-80965

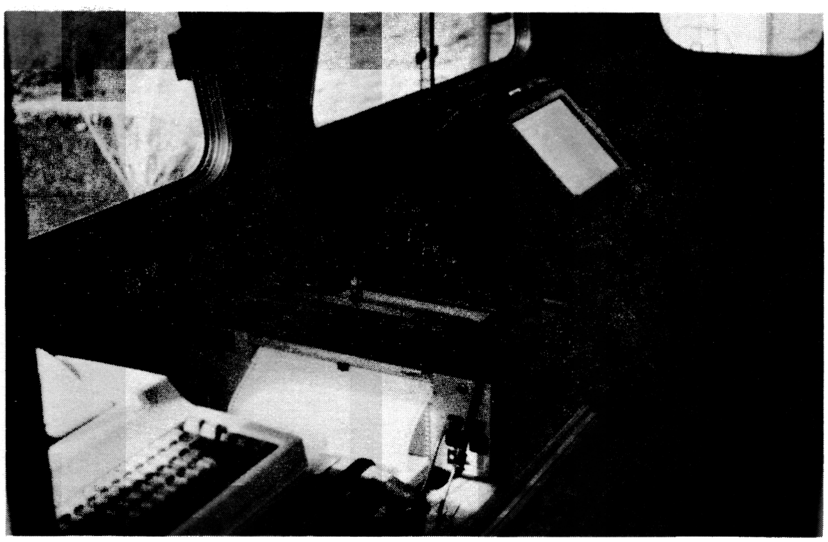

Figure 8. – Sonic depth recorder interfaced with automated positioning system. P801-D-80966

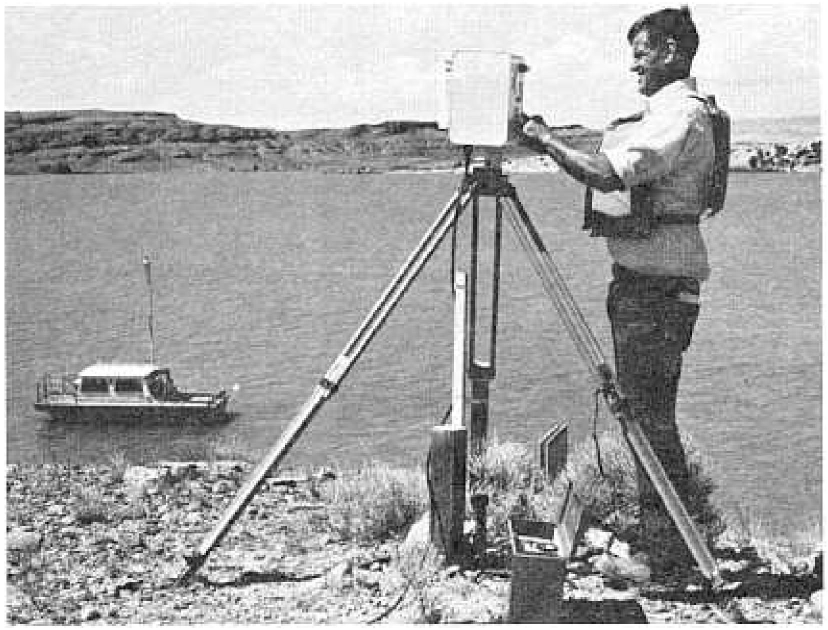

Figure 9. – Microwave receiver-transmitter at shore station. P801-D-80967

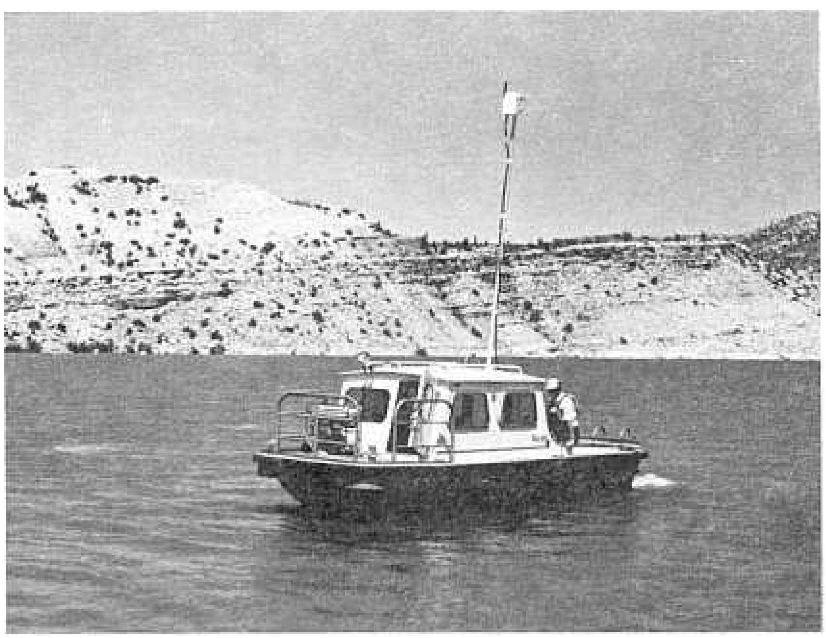

Figure 10. – Survey boat with automated survey system. P801-D-80968

Figure 11. – Gravity core sampler and retrieval system.

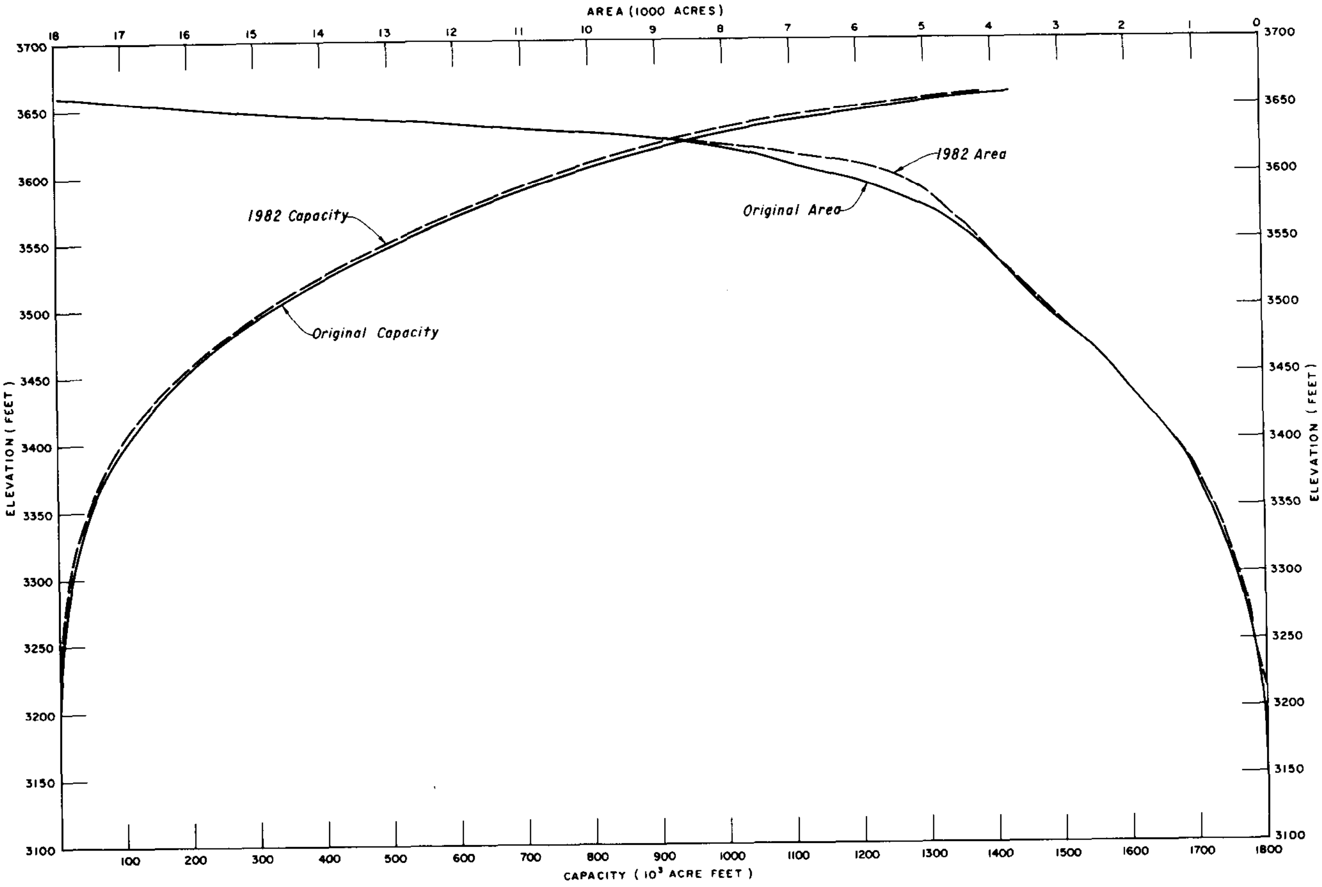

Figure 12. – Area-capacity curve.

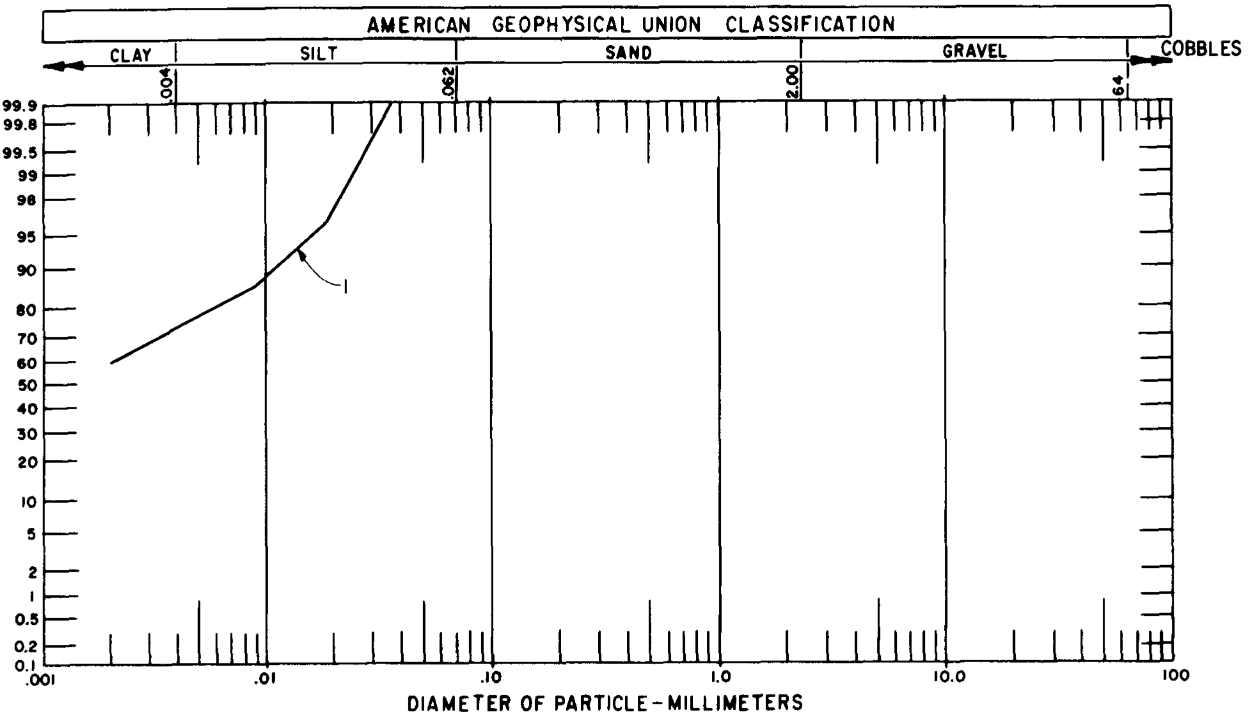

Figure 13. – Particle size analysis curve, range 13.

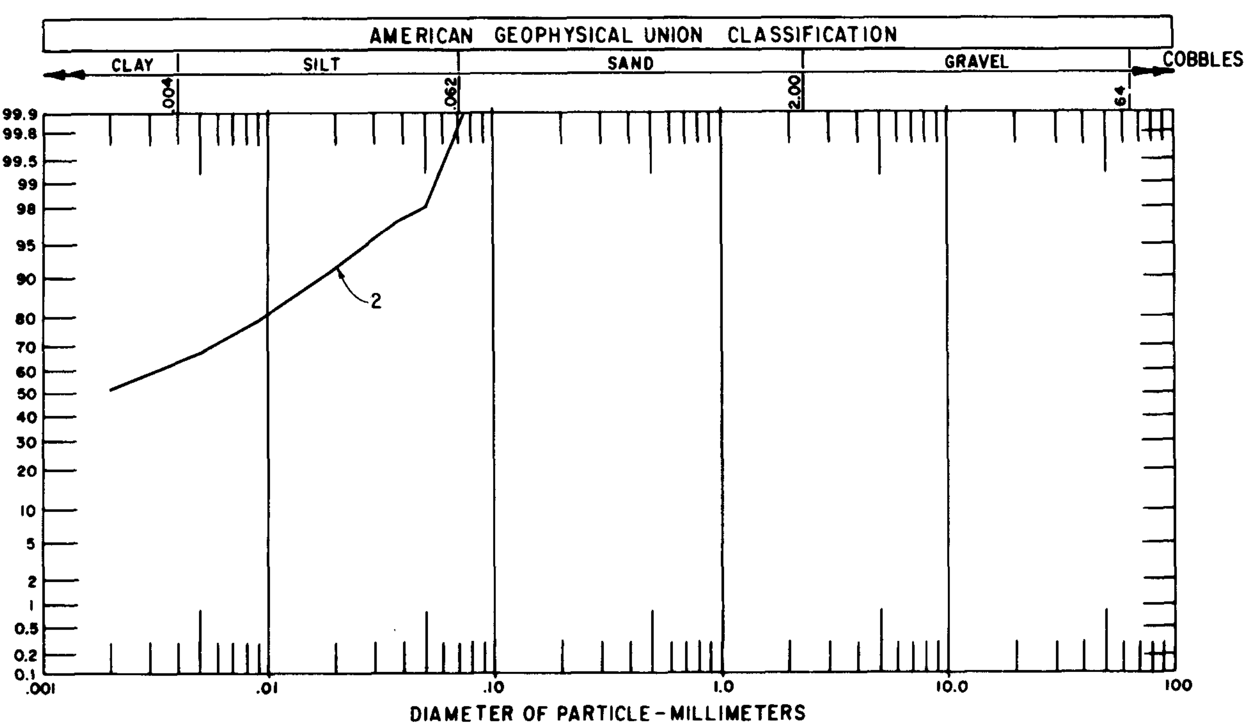

Figure 14. – Particle size analysis curve, range 14.

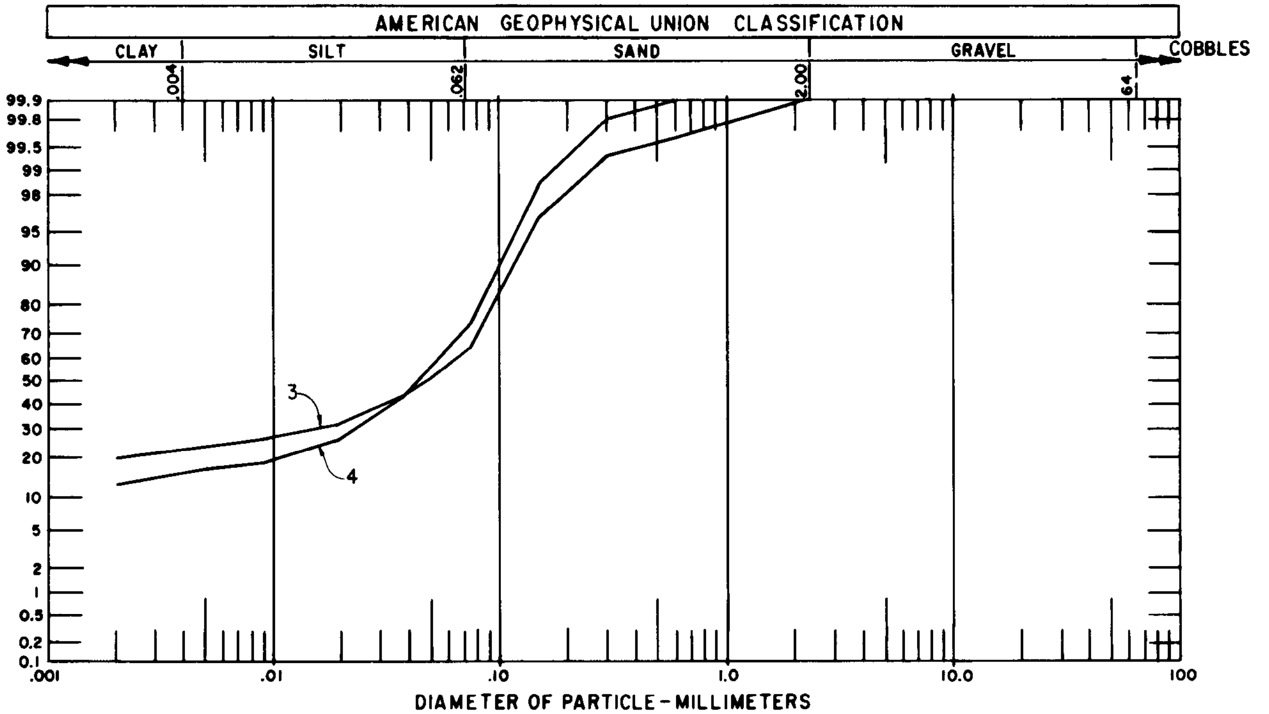

Figure 15. – Particle size analysis curves, range 15.

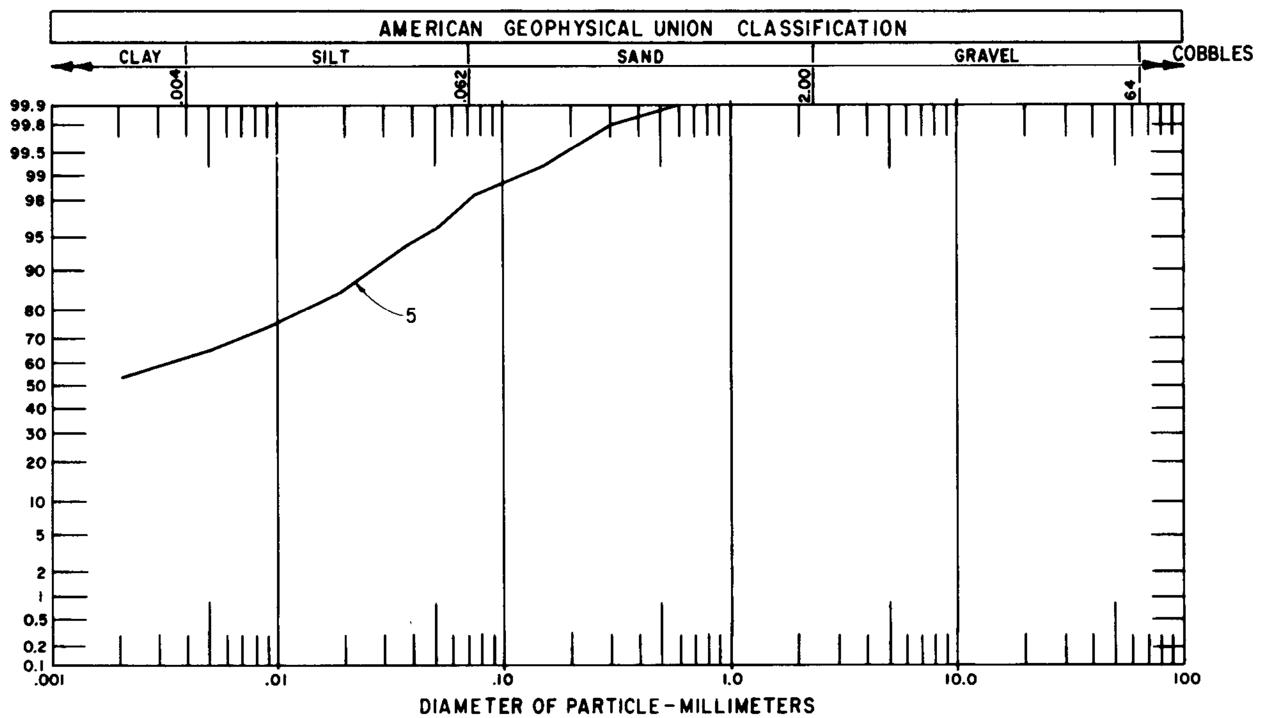

Figure 16. – Particle size analysis curve, range 16.

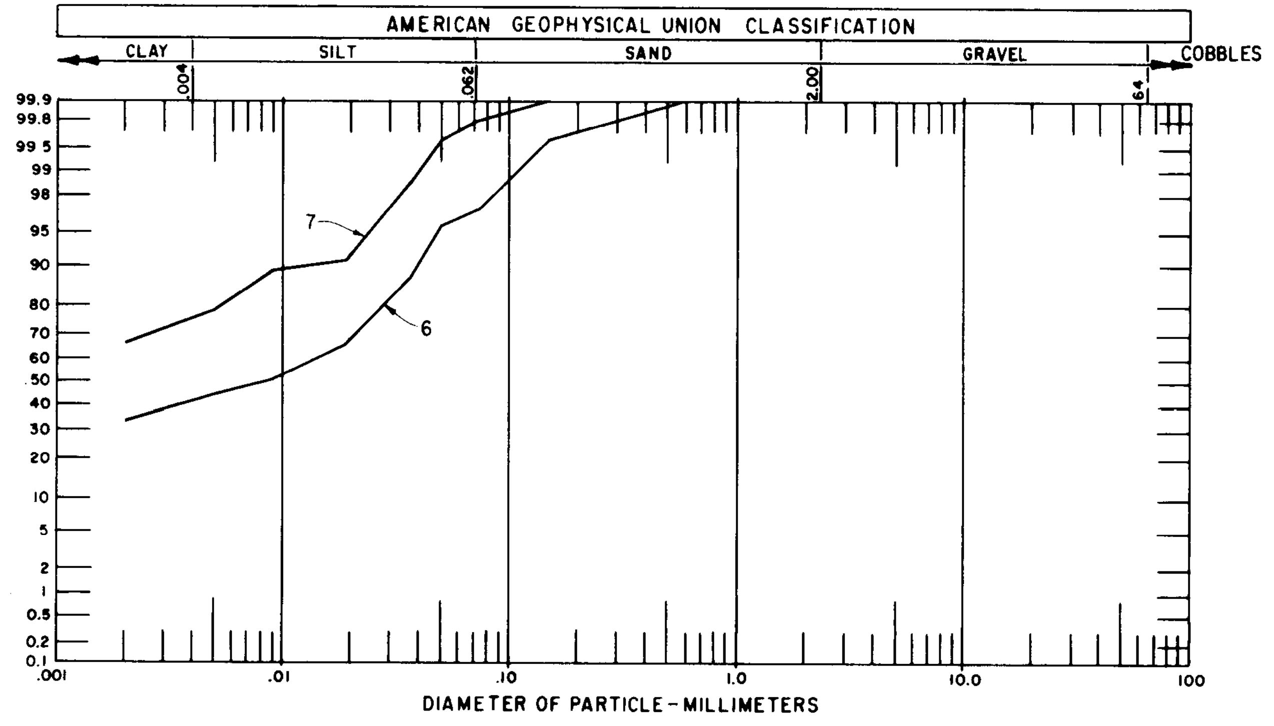

Figure 17. – Particle size analysis curves, range 17.

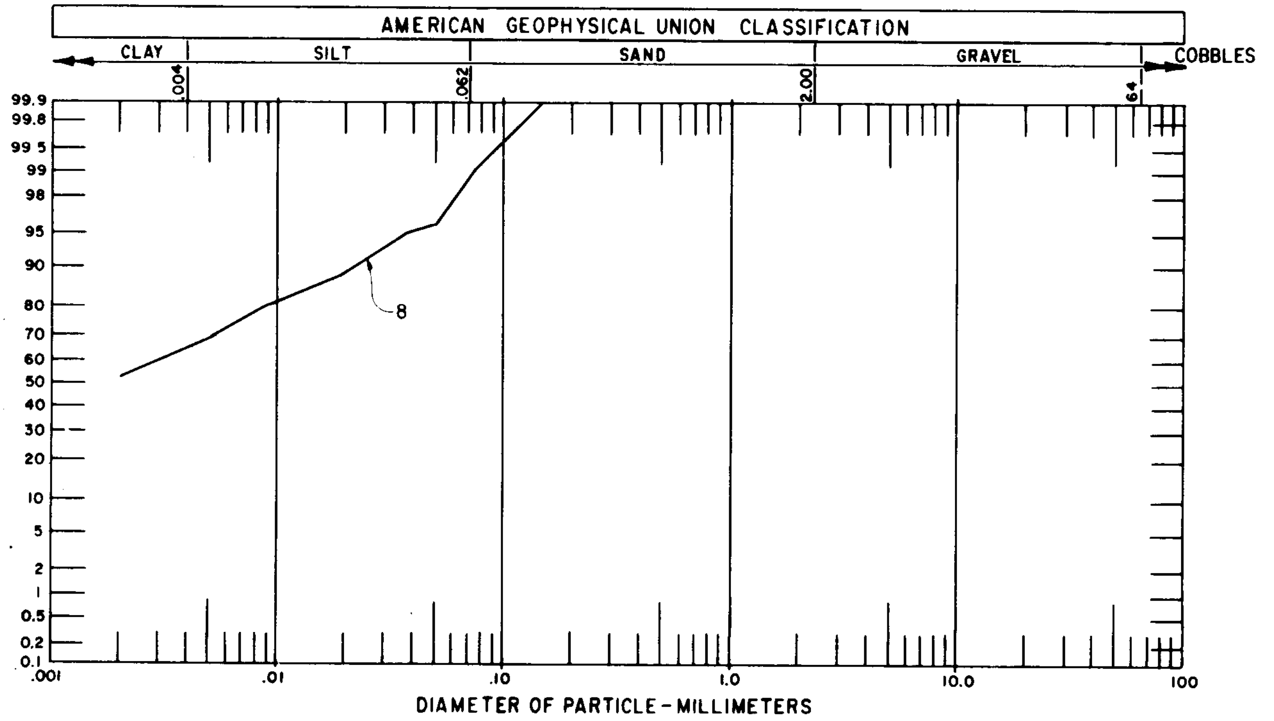

Figure 18. – Particle size analysis curve, range 18.

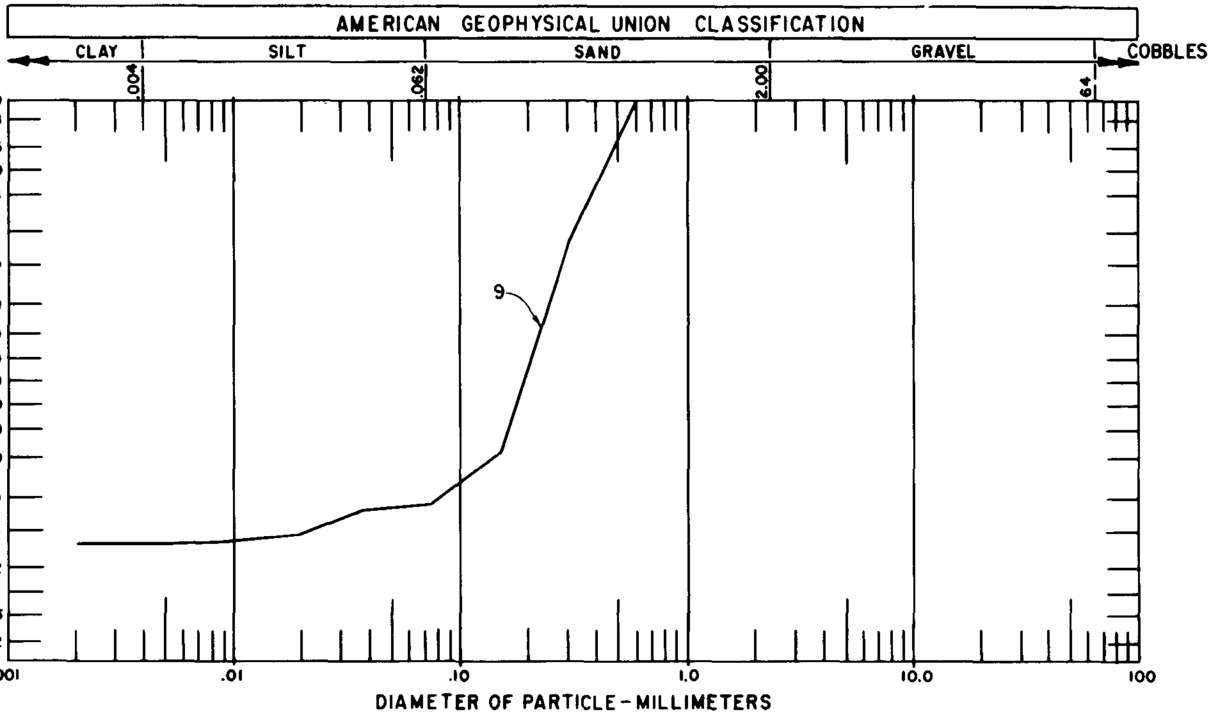

Figure 19. – Particle size analysis curve, range 19.

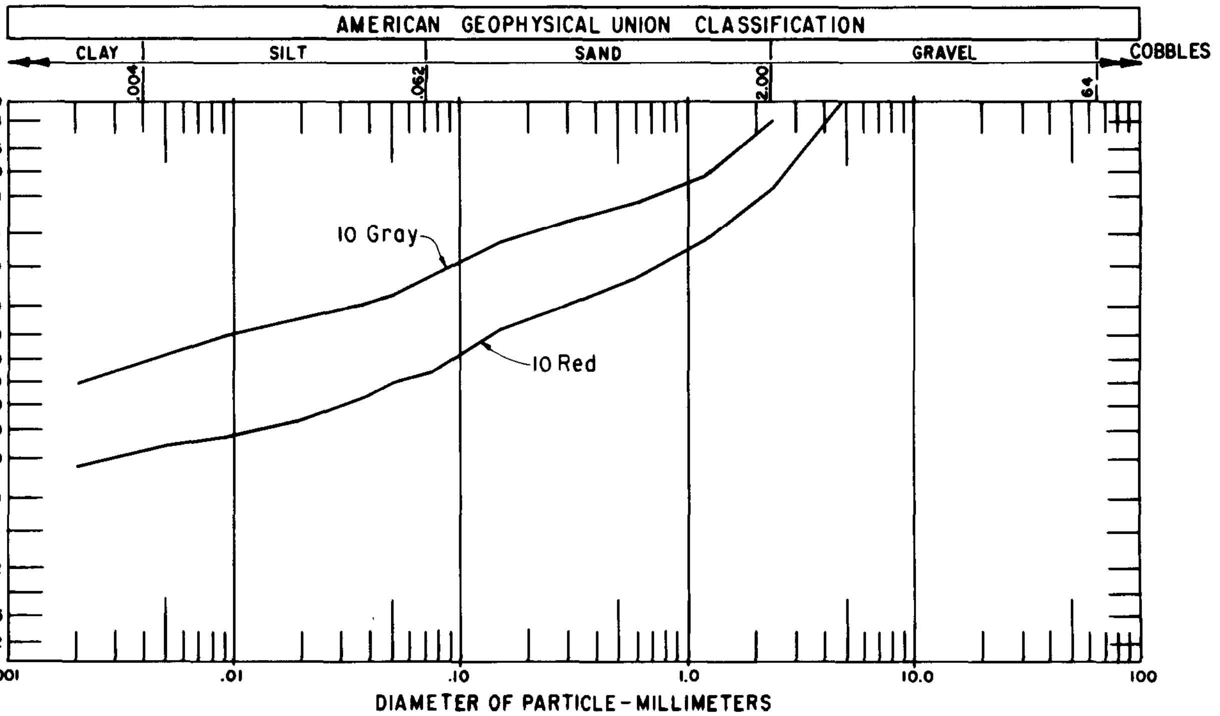

Figure 20. – Particle size analysis curves, range 20.

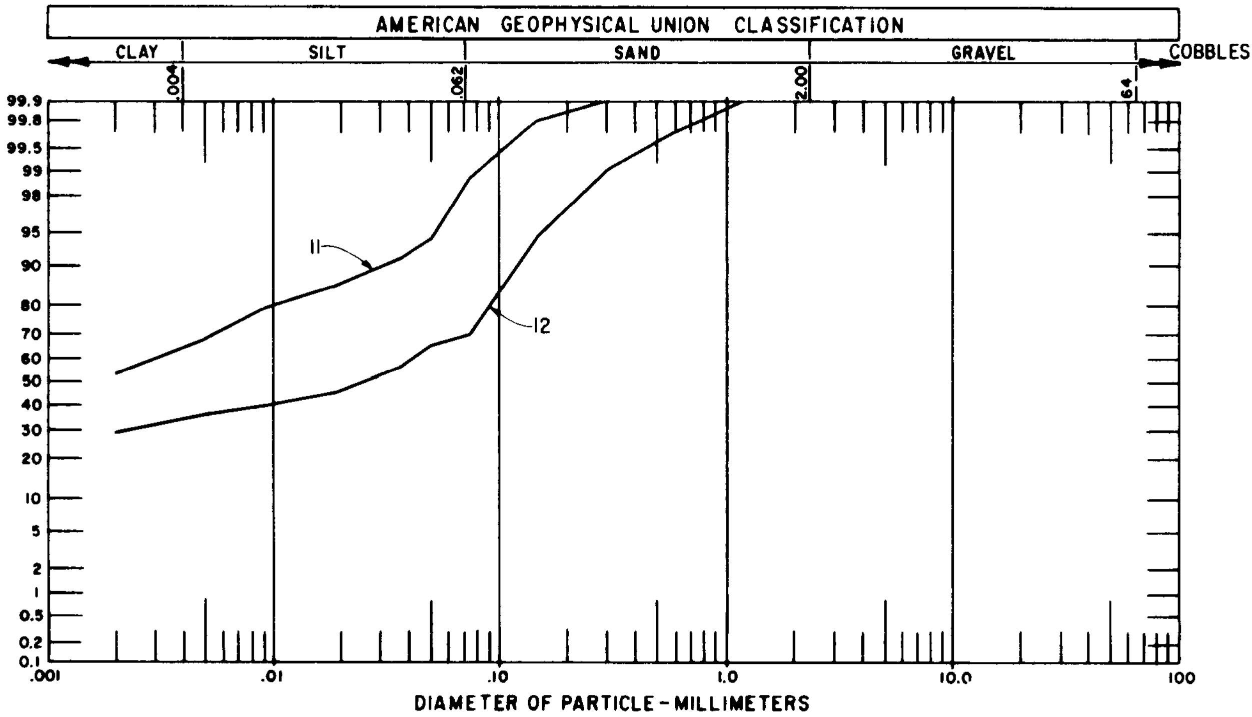

Figure 21. – Particle size analysis curves, range 21.

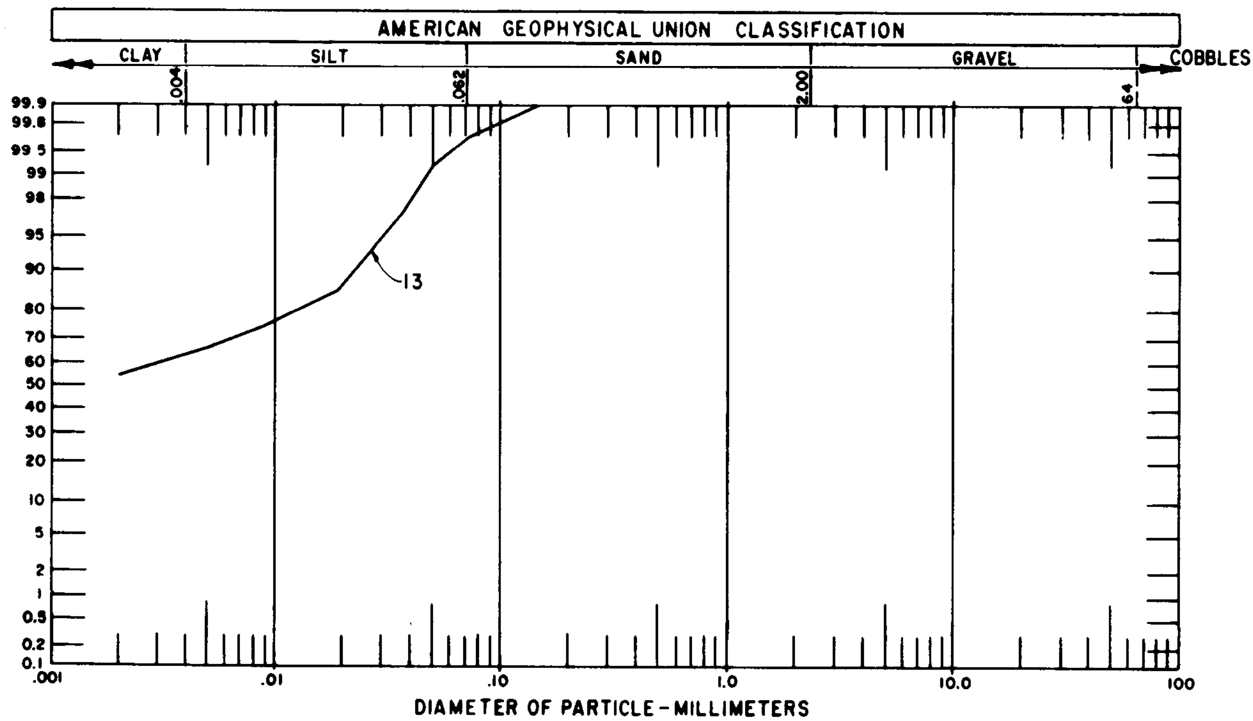

Figure 22. – Particle size analysis curve, range 22.

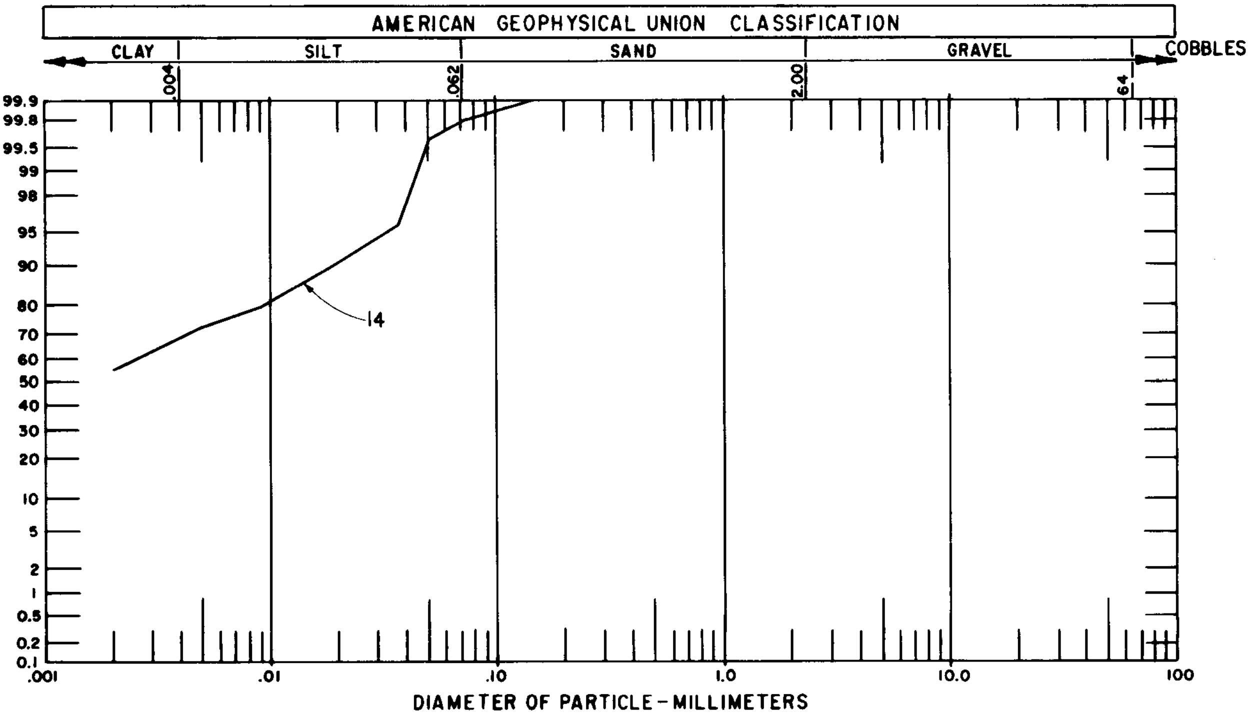

Figure 23. – Particle size analysis curve, range 23.

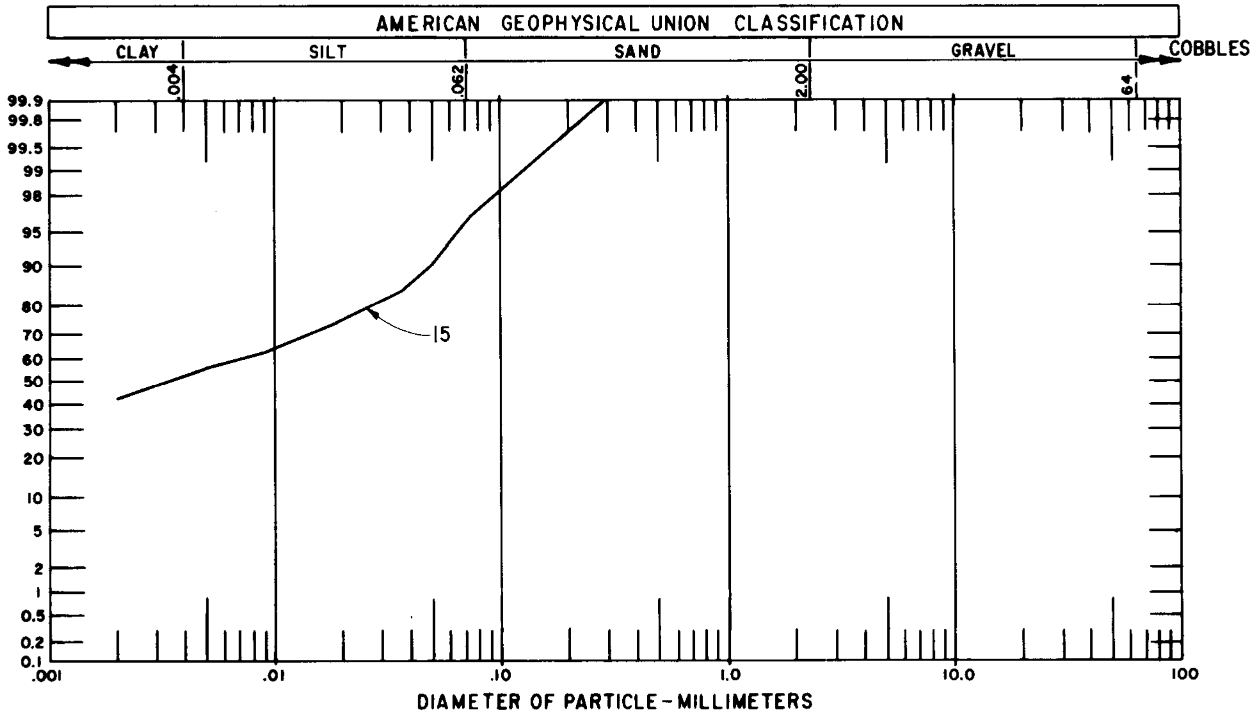

Figure 24. – Particle size analysis curve, range 24.

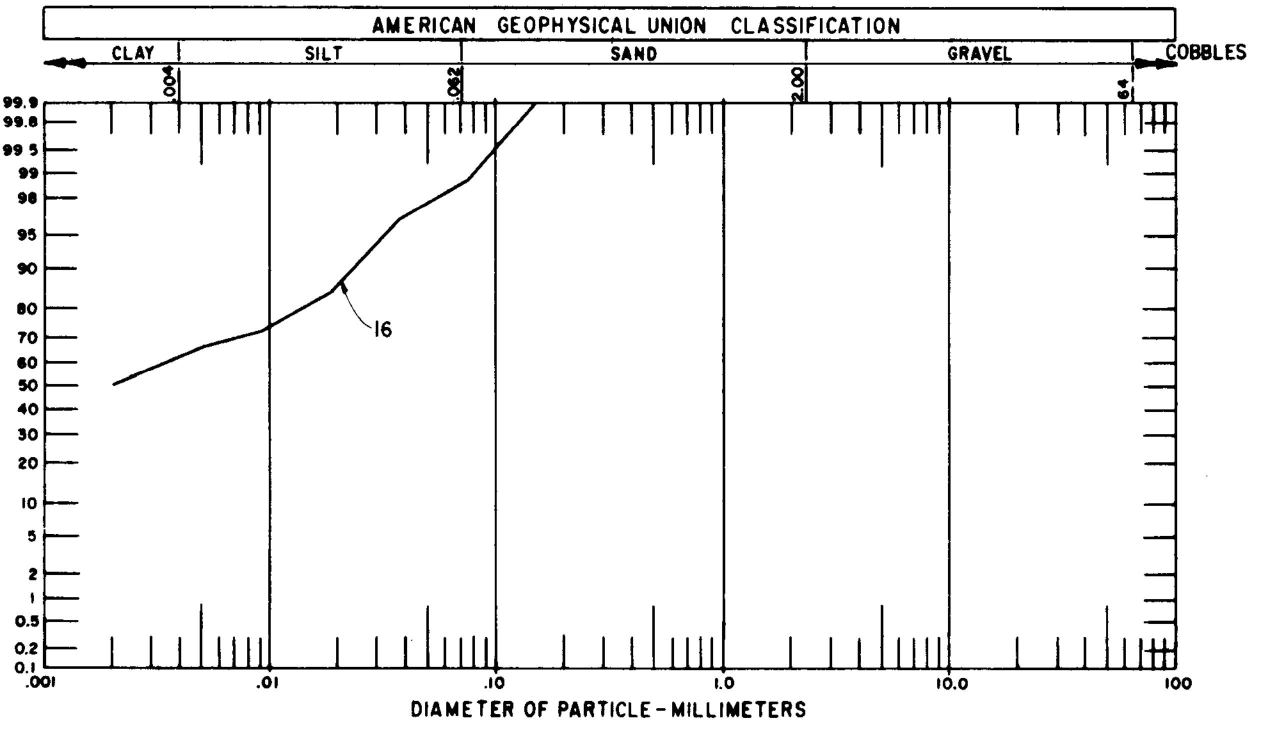

Figure 25. – Particle size analysis curve, range 25.

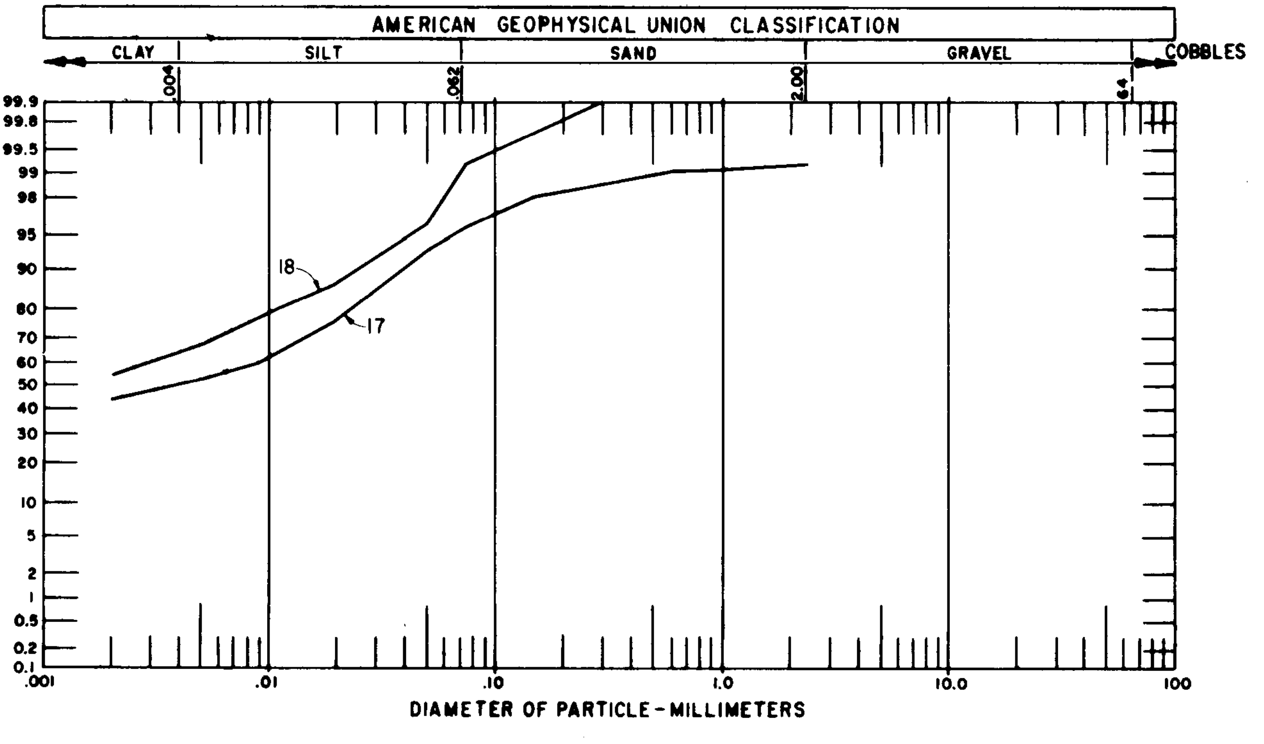

Figure 26. – Particle size analysis curves, range 31.

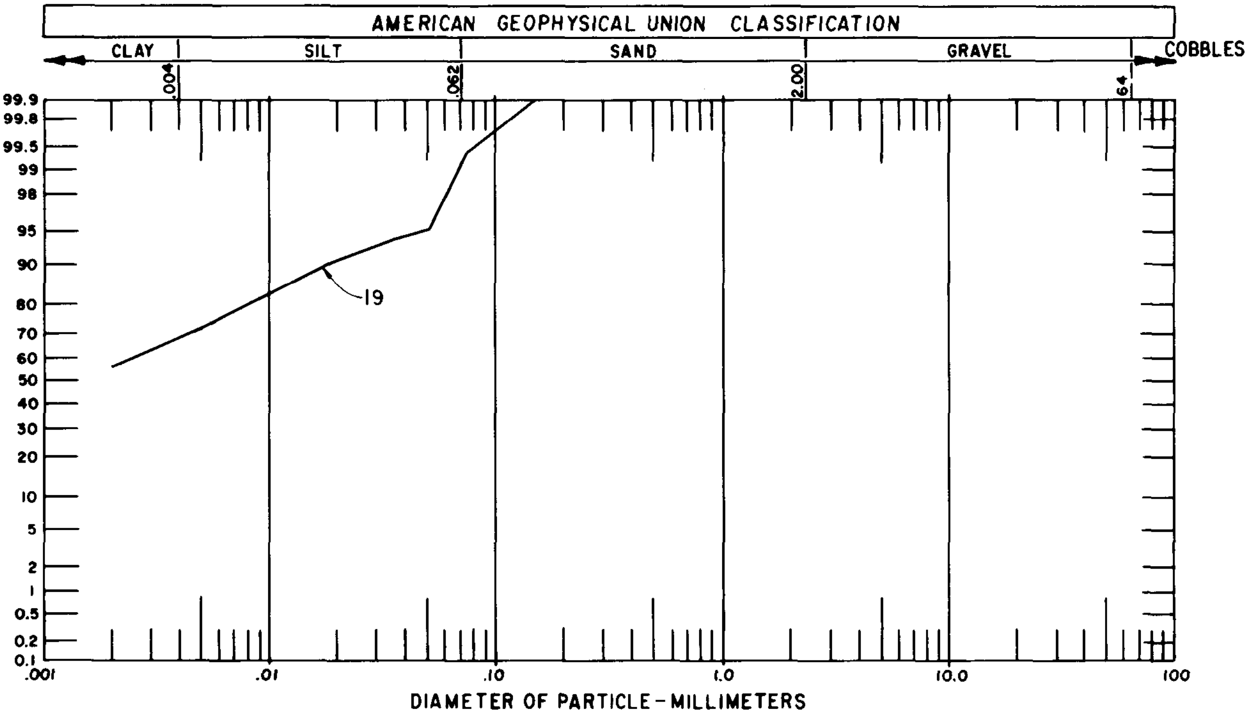

Figure 27. – Particle size analysis curve, range 32.

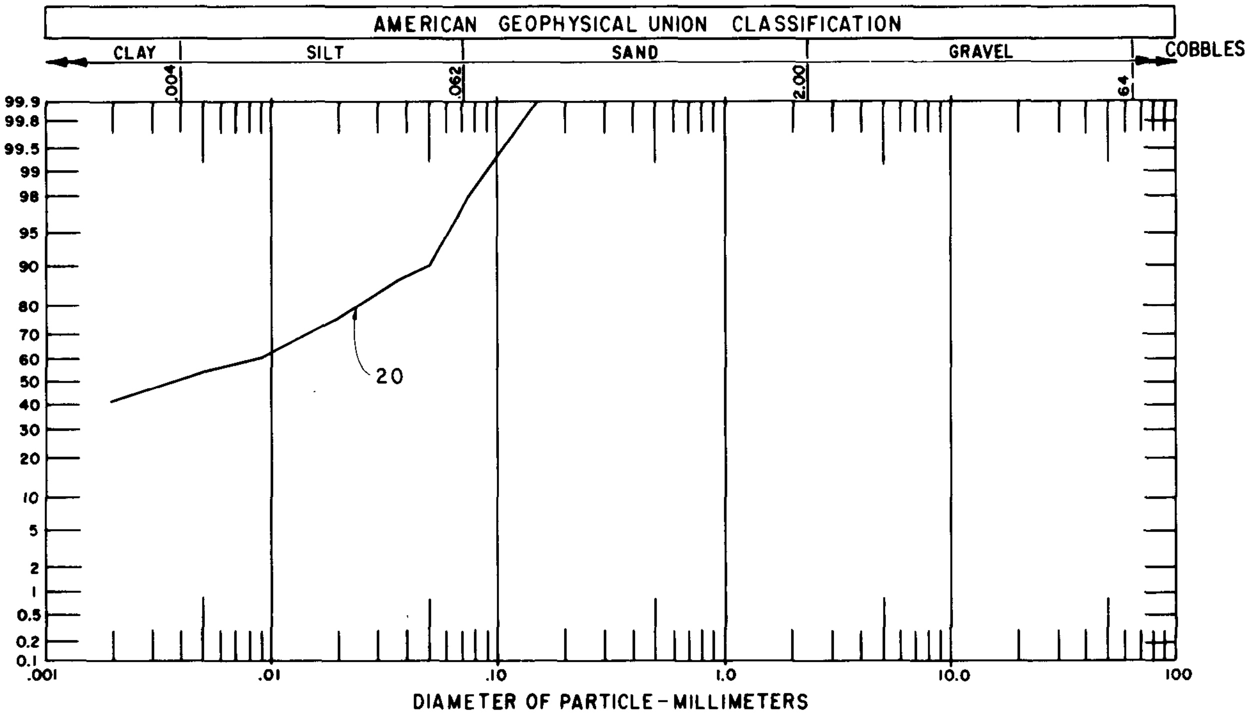

Figure 28. – Particle size analysis curve, range 33.

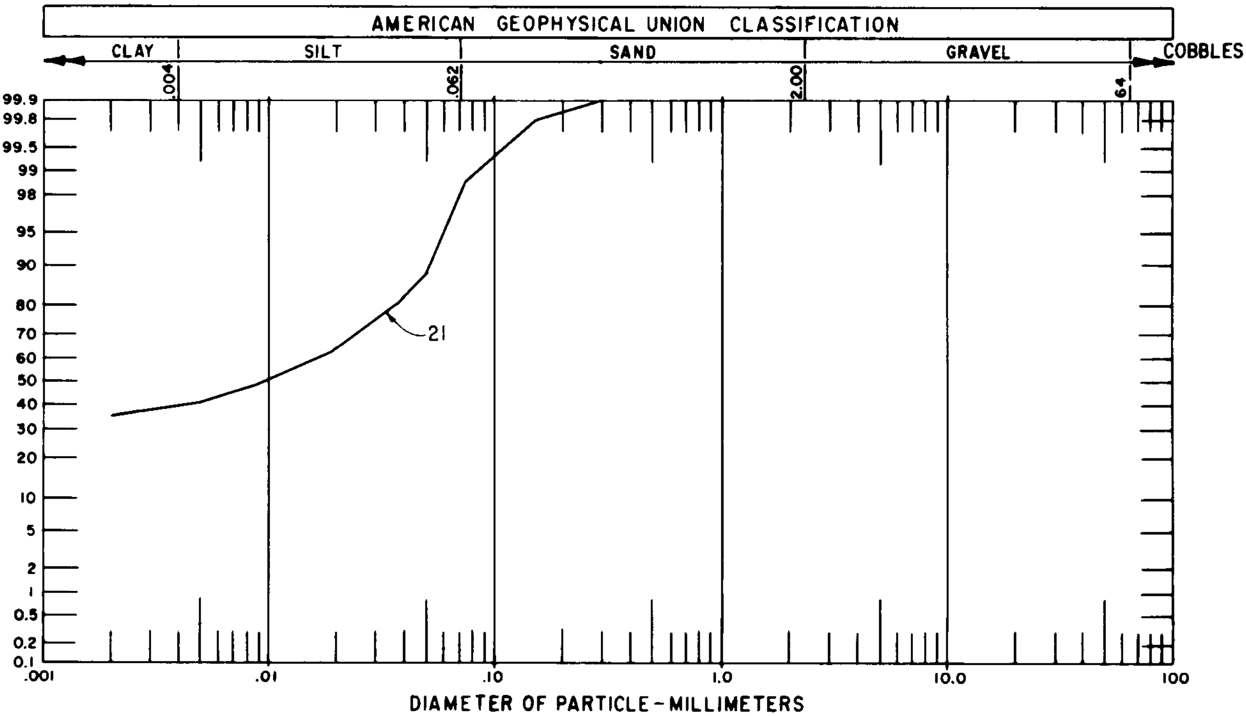

Figure 29. – Particle size analysis curve, range 34.

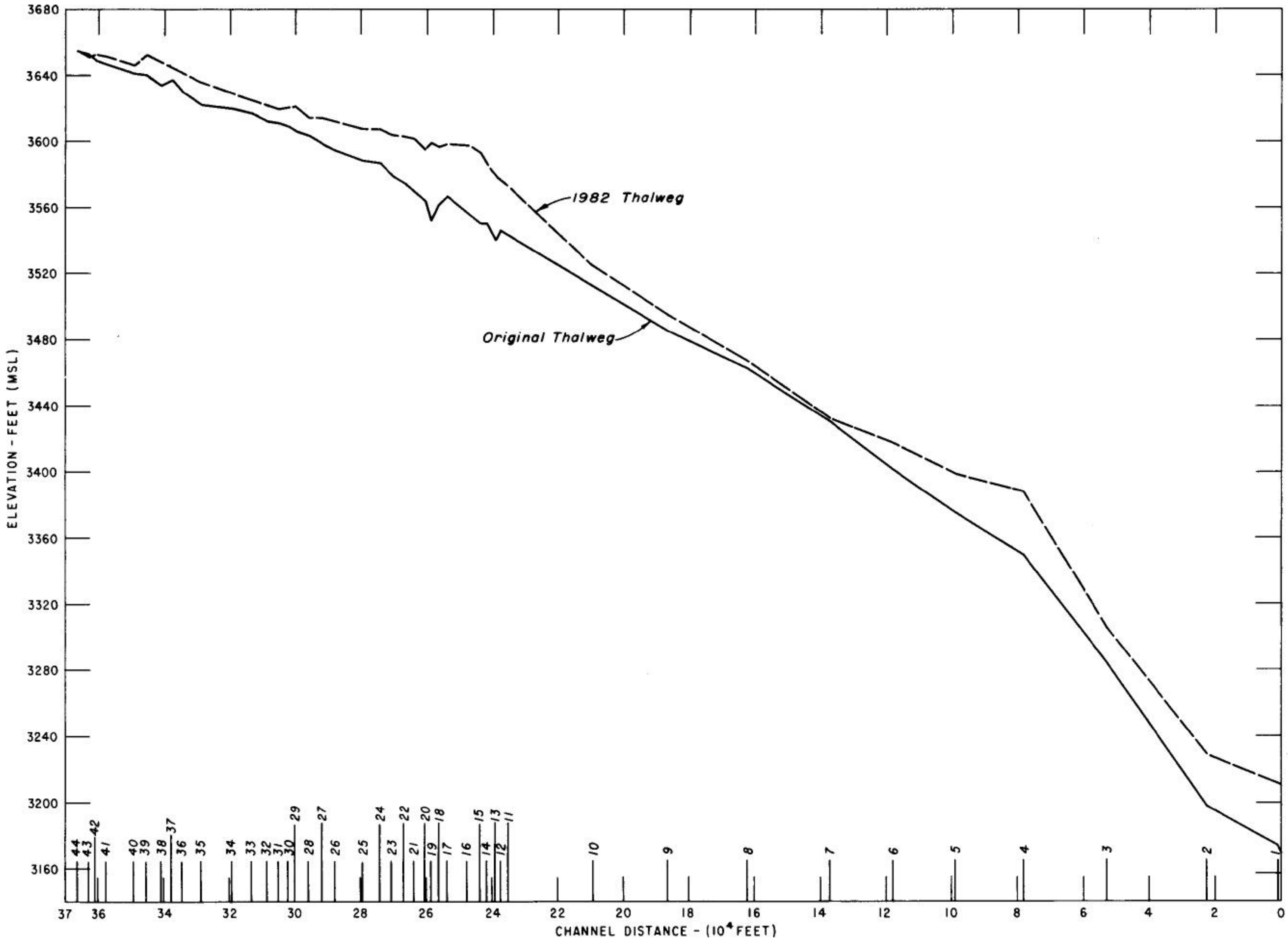

Figure 30. – Longitudinal thalweg profiles for Bighorn Lake.

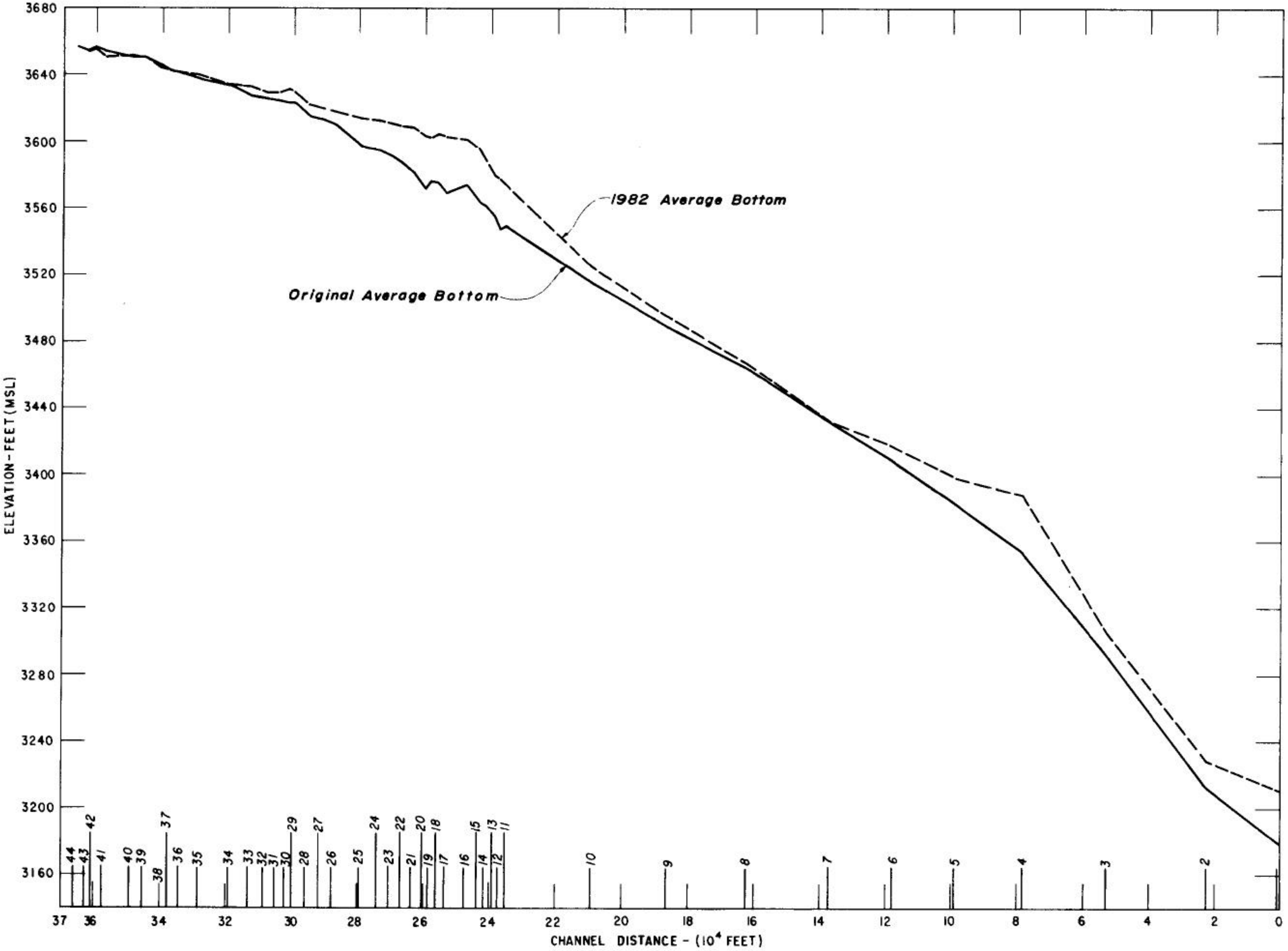

Figure 31. – Average bottom profiles for Bighorn Lake.

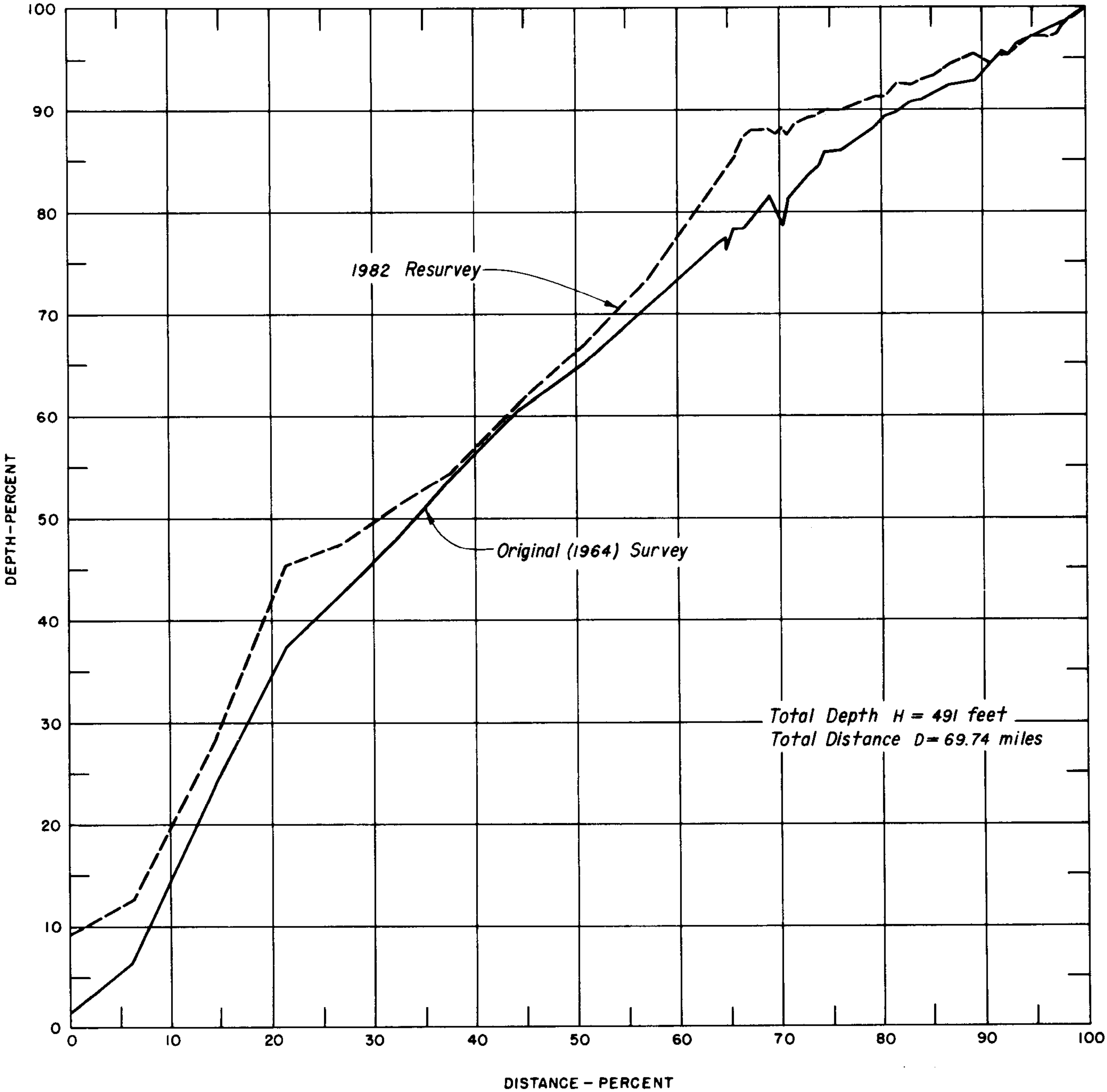

Figure 32. – Percent depth vs. percent distance for Bighorn Lake above Yellowtail Dam.

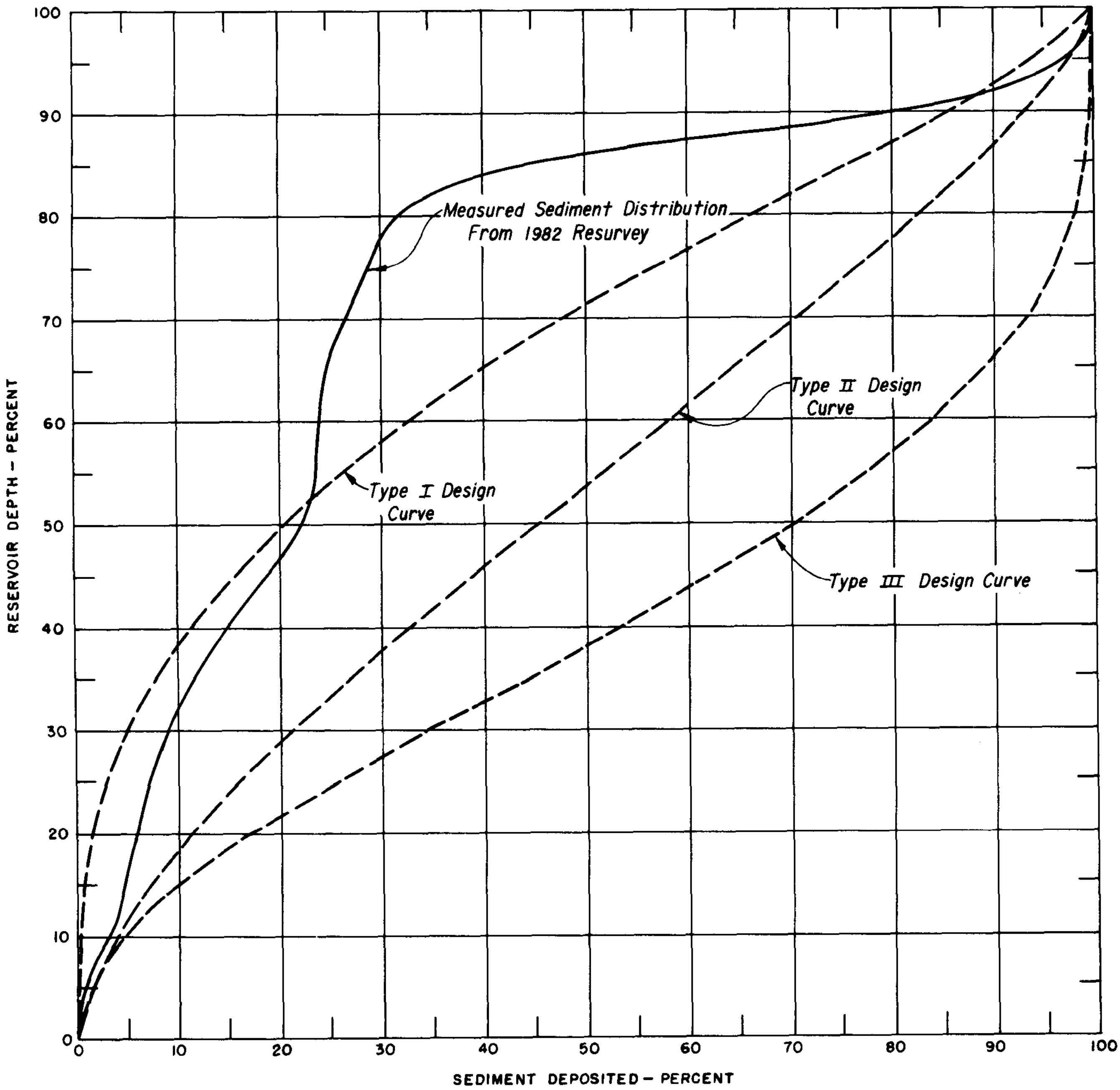

Figure 33. – Percent depth vs. percent sediment deposited.

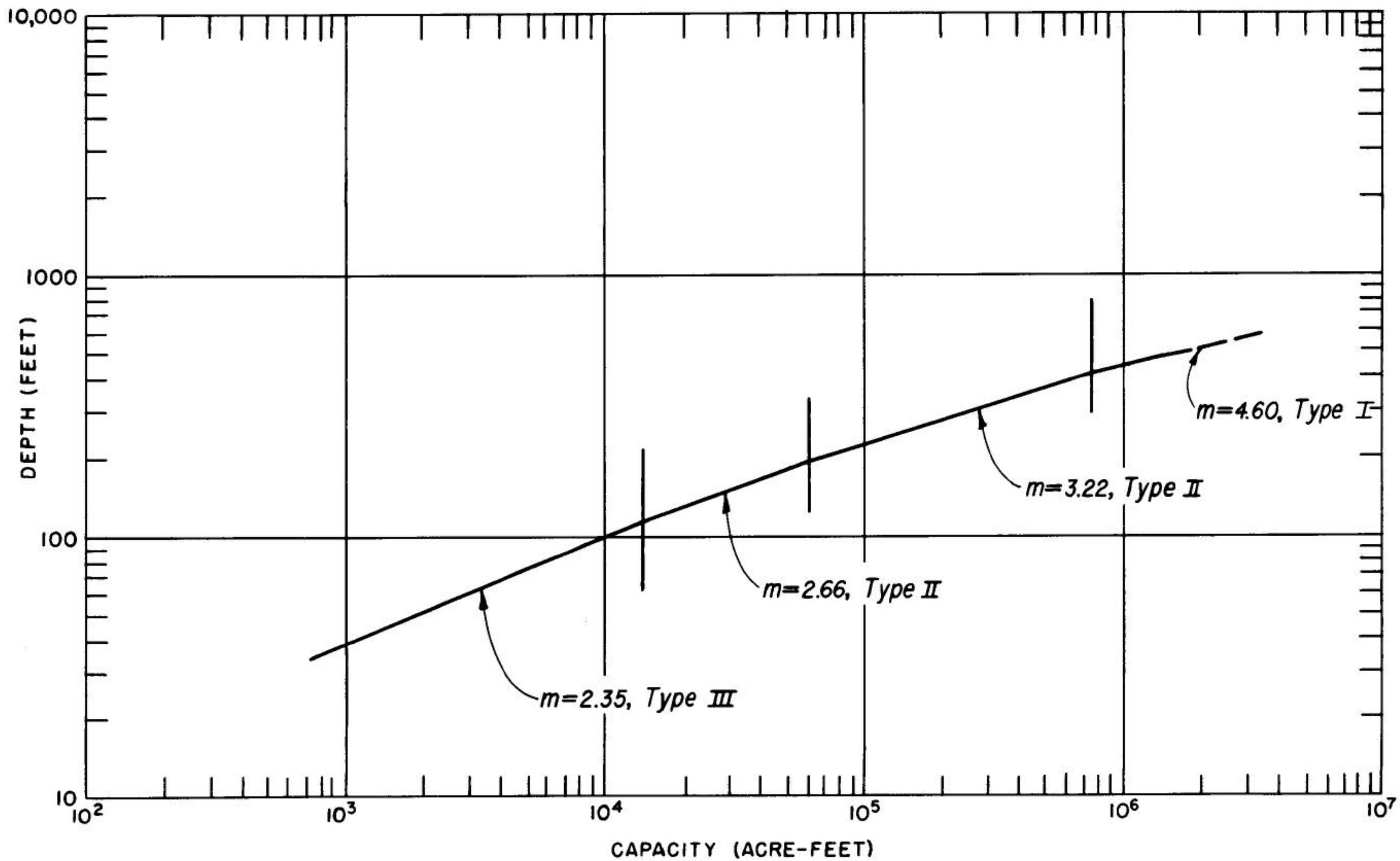

Figure 34. – Depth-capacity relationship.

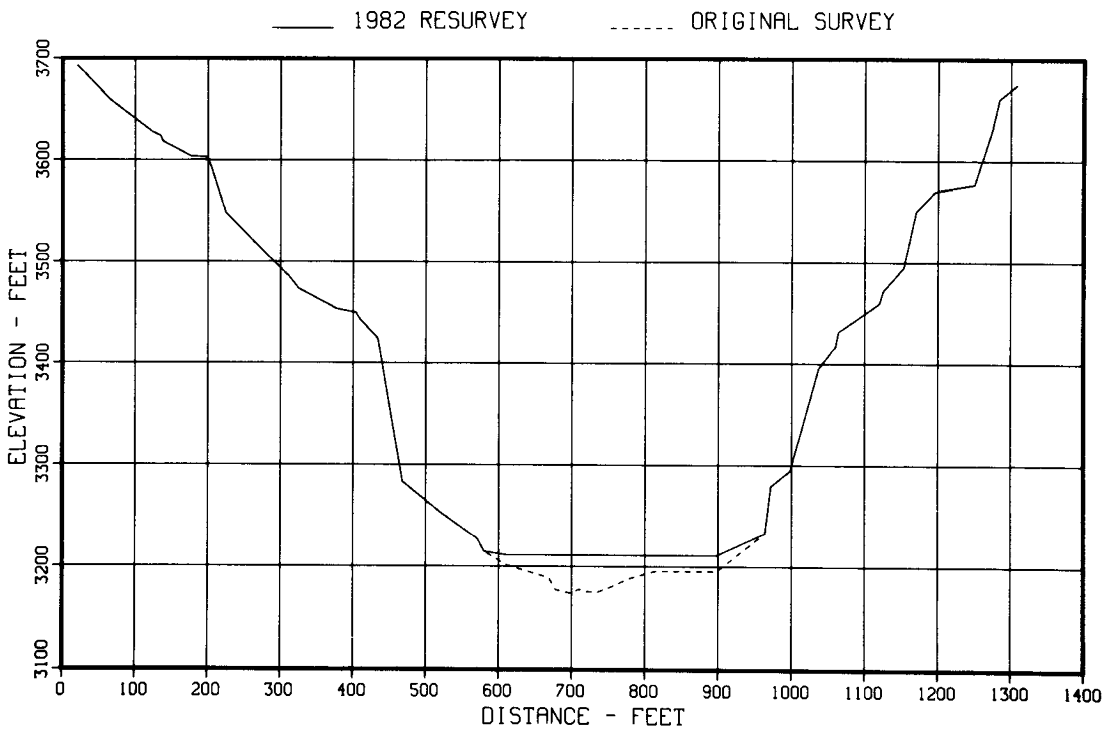

Figure 35. – Original and 1982 sedimentation range profiles, range 1.

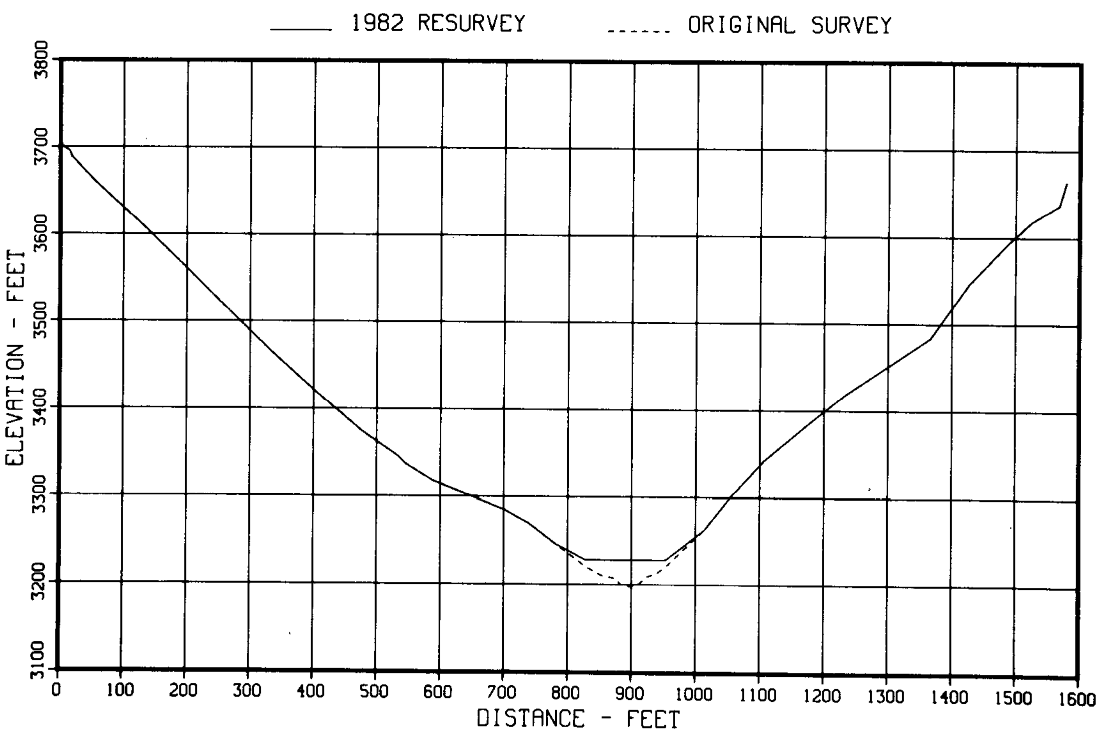

Figure 36. – Original and 1982 sedimentation range profiles, range 2.

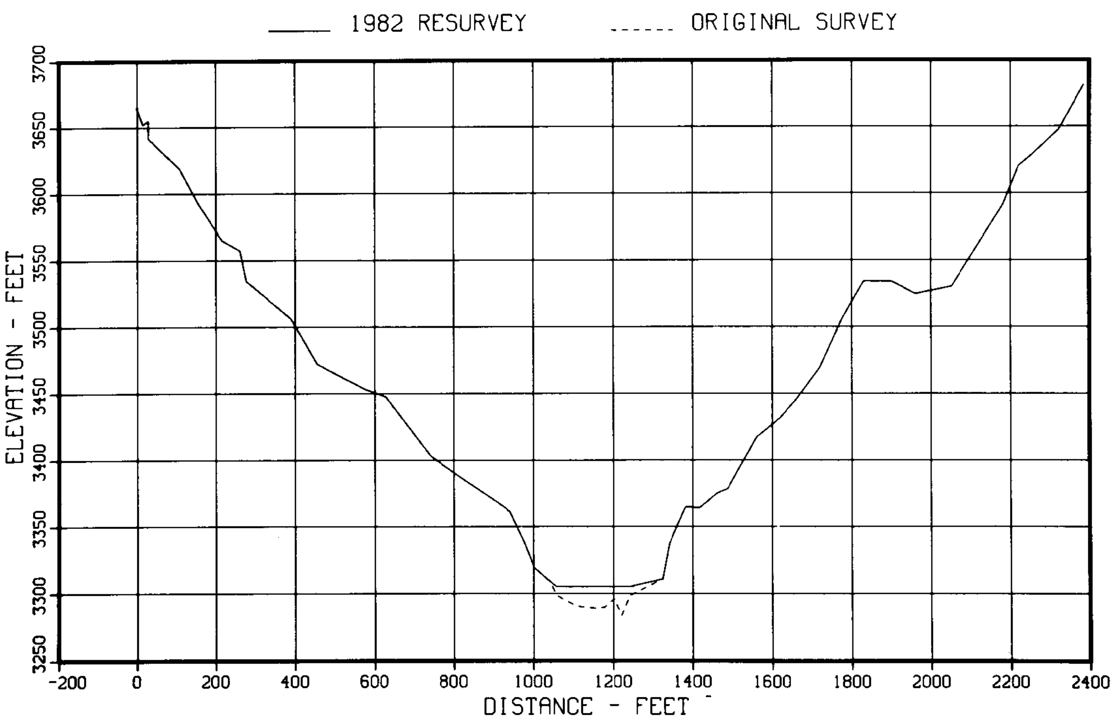

Figure 37. – Original and 1982 sedimentation range profiles, range 3.

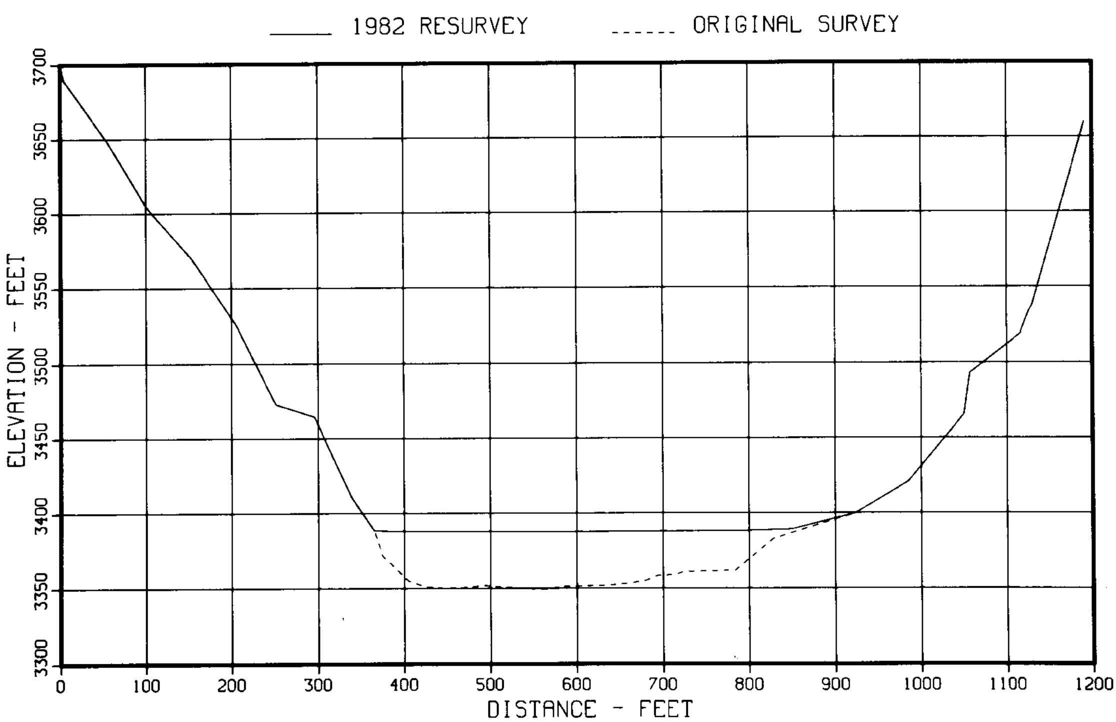

Figure 38. – Original and 1982 sedimentation range profiles, range 4.

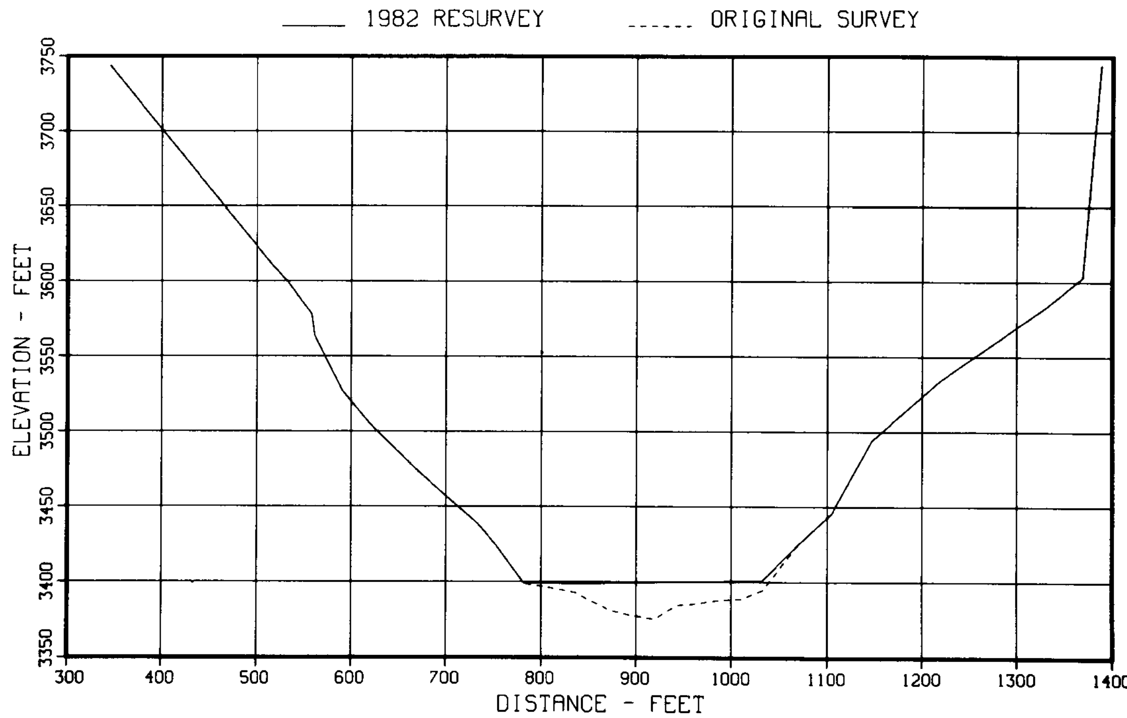

Figure 39. – Original and 1982 sedimentation range profiles, range 5.

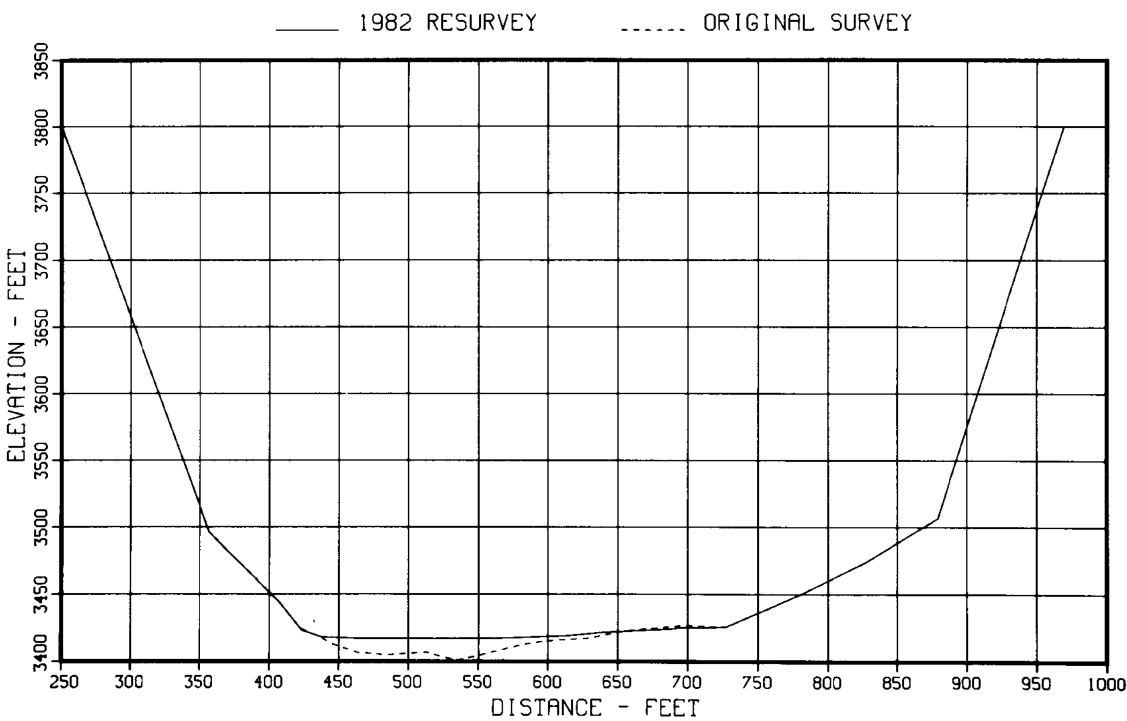

Figure 40. – Original and 1982 sedimentation range profiles, range 6.

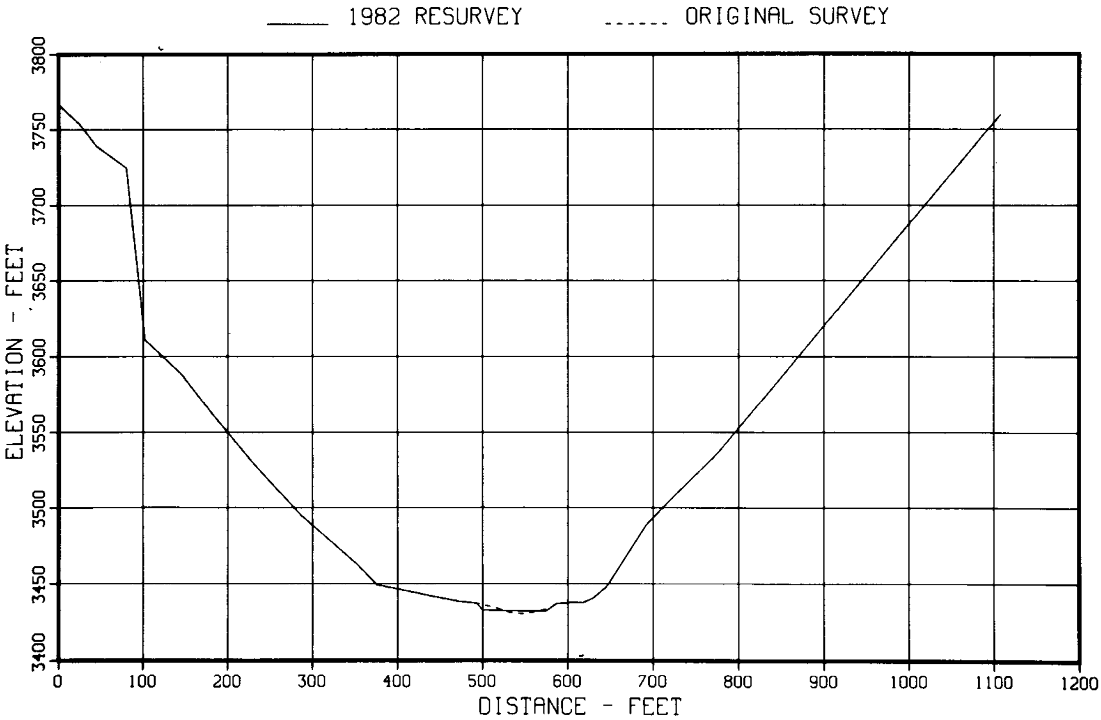

Figure 41. – Original and 1982 sedimentation range profiles, range 7.

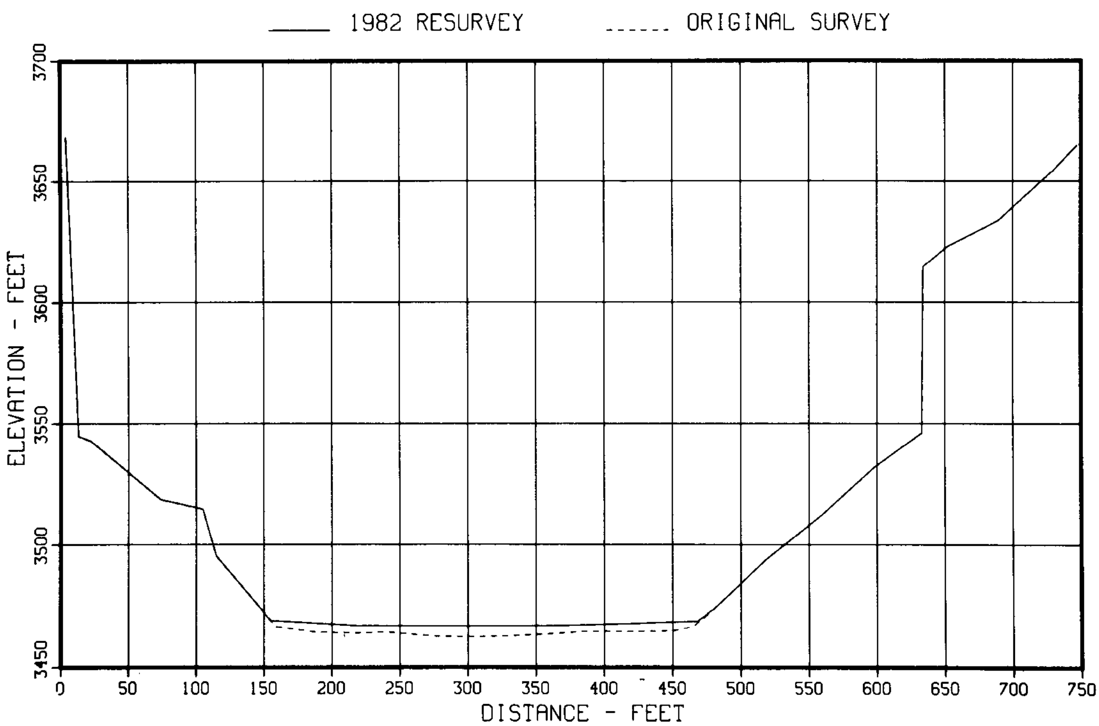

Figure 42. – Original and 1982 sedimentation range profiles, range 8.

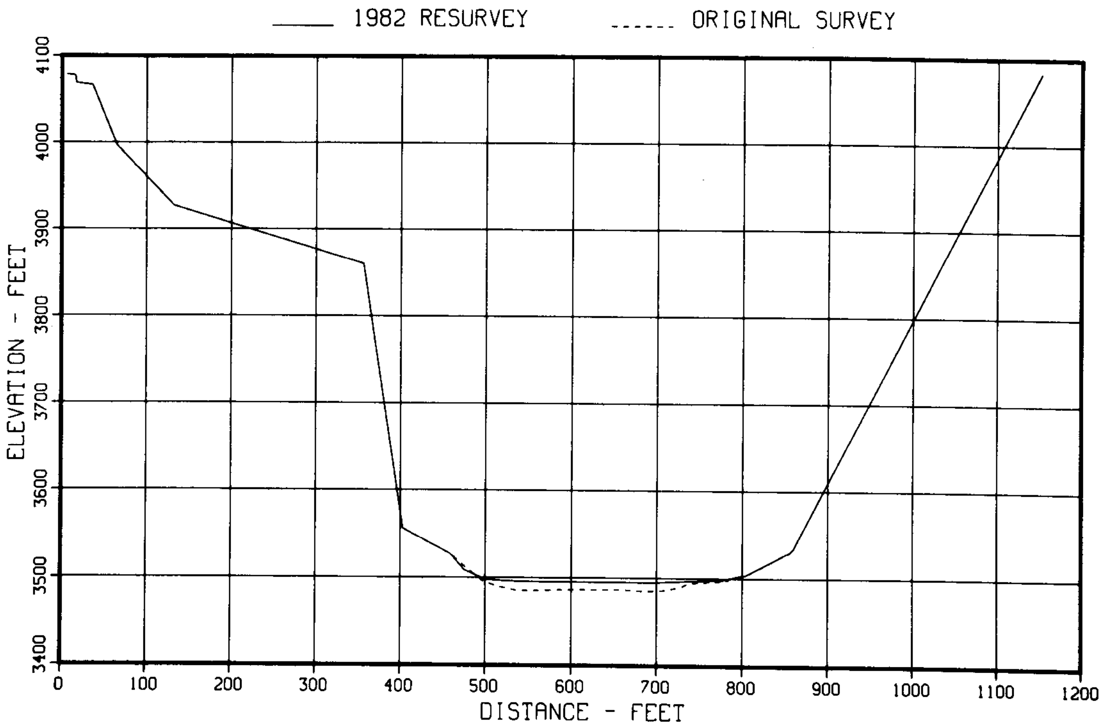

Figure 43. – Original and 1982 sedimentation range profiles, range 9.

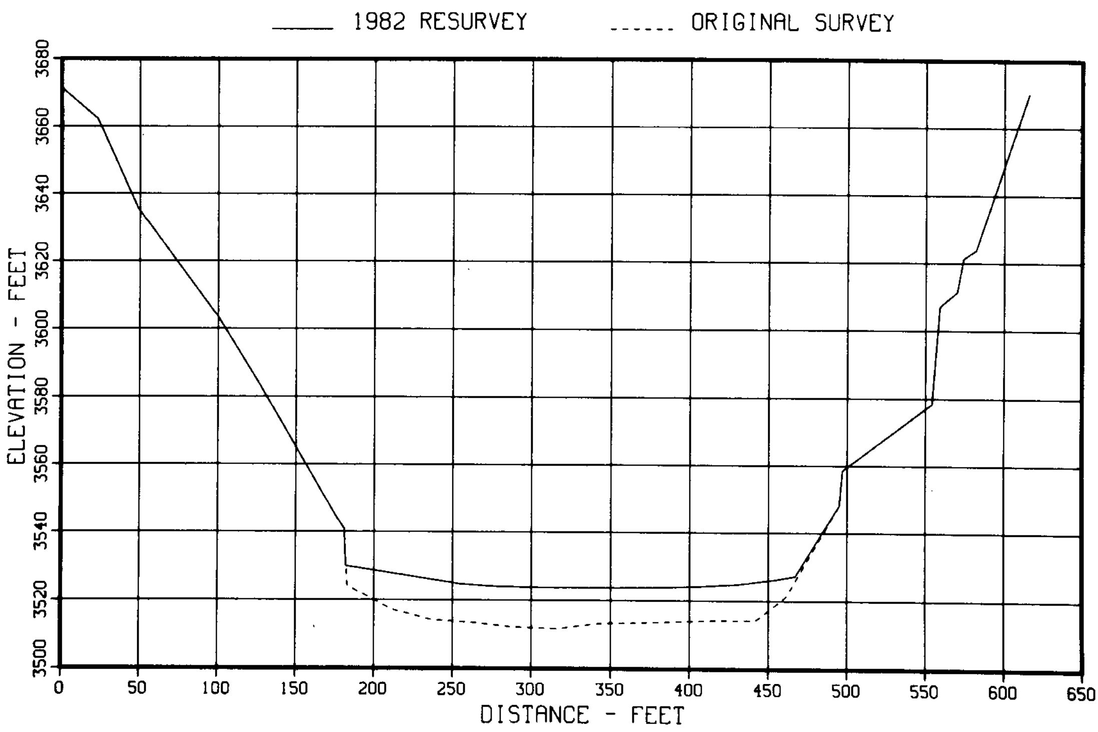

Figure 44. – Original and 1982 sedimentation range profiles, range 10.

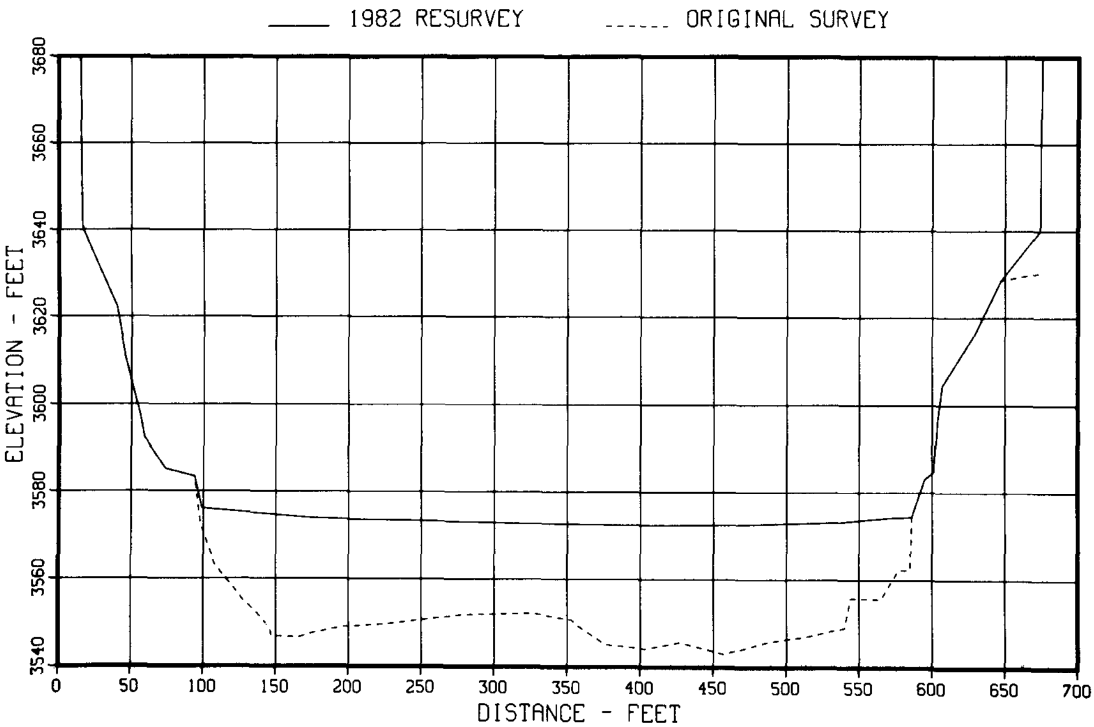

Figure 45. – Original and 1982 sedimentation range profiles, range 11.

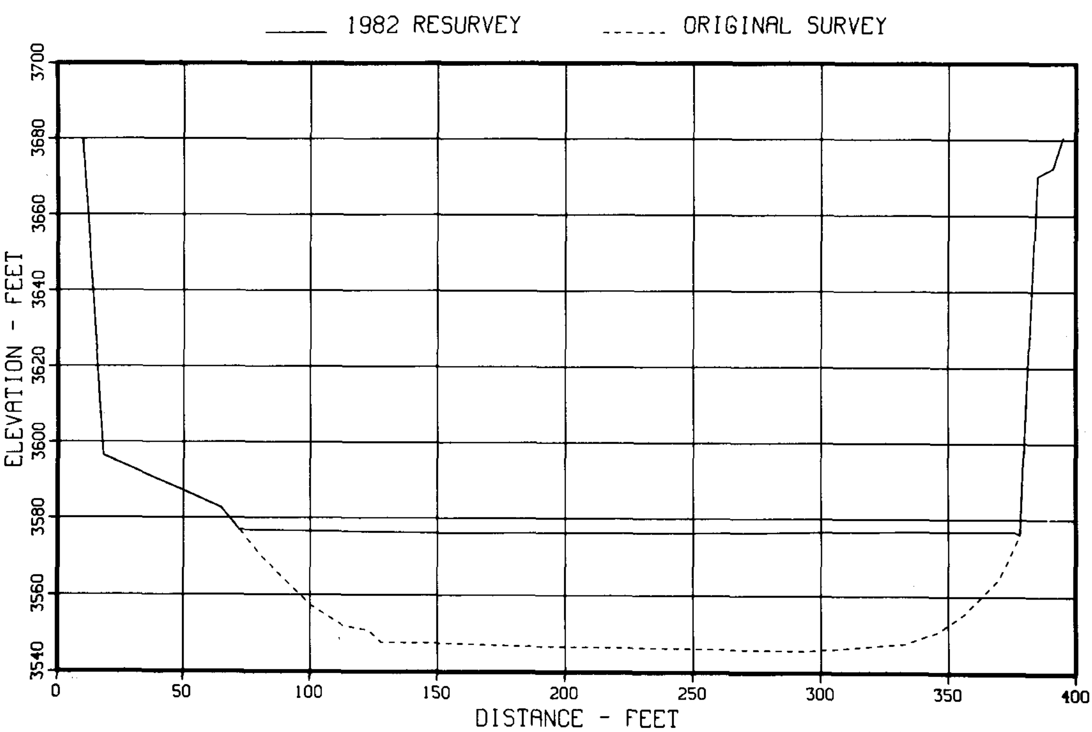

Figure 46. – Original and 1982 sedimentation range profiles, range 12.

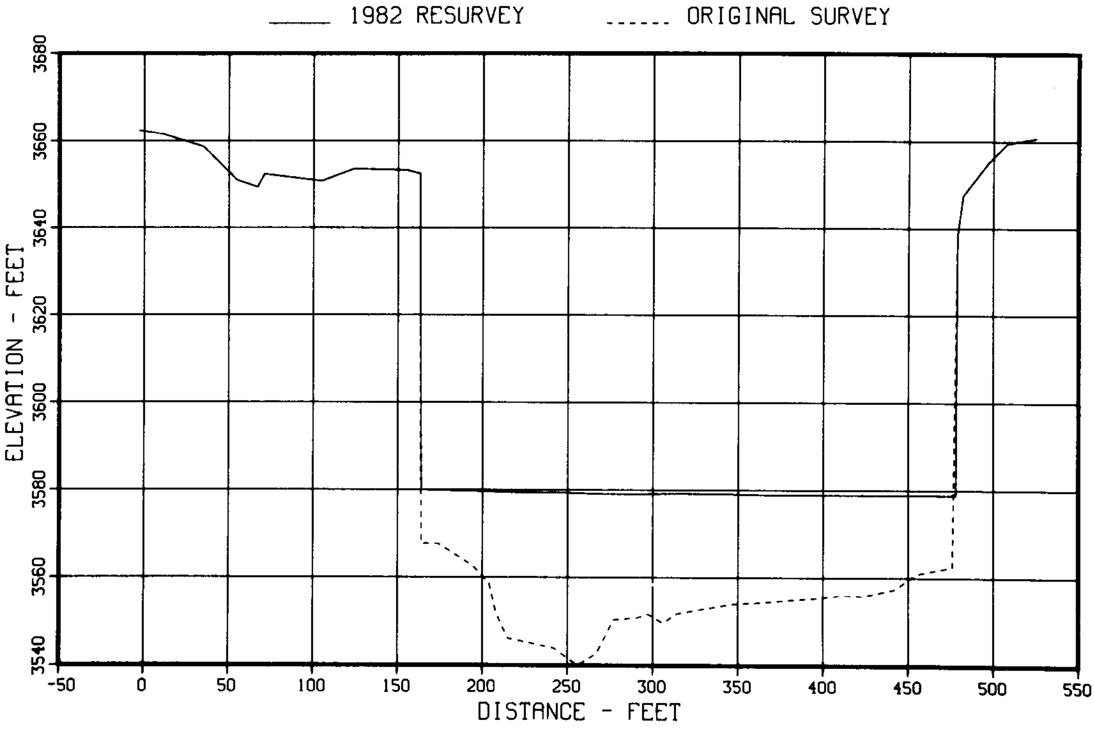

Figure 47. – Original and 1982 sedimentation range profiles, range 13.

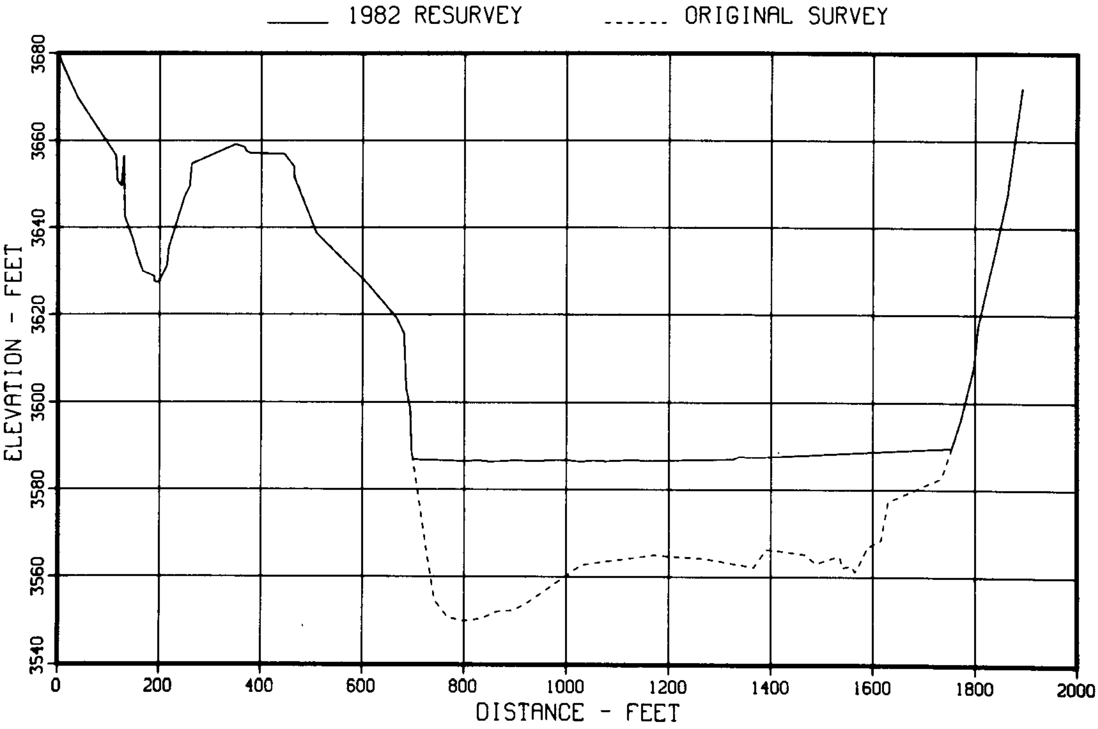

Figure 48. – Original and 1982 sedimentation range profiles, range 14.

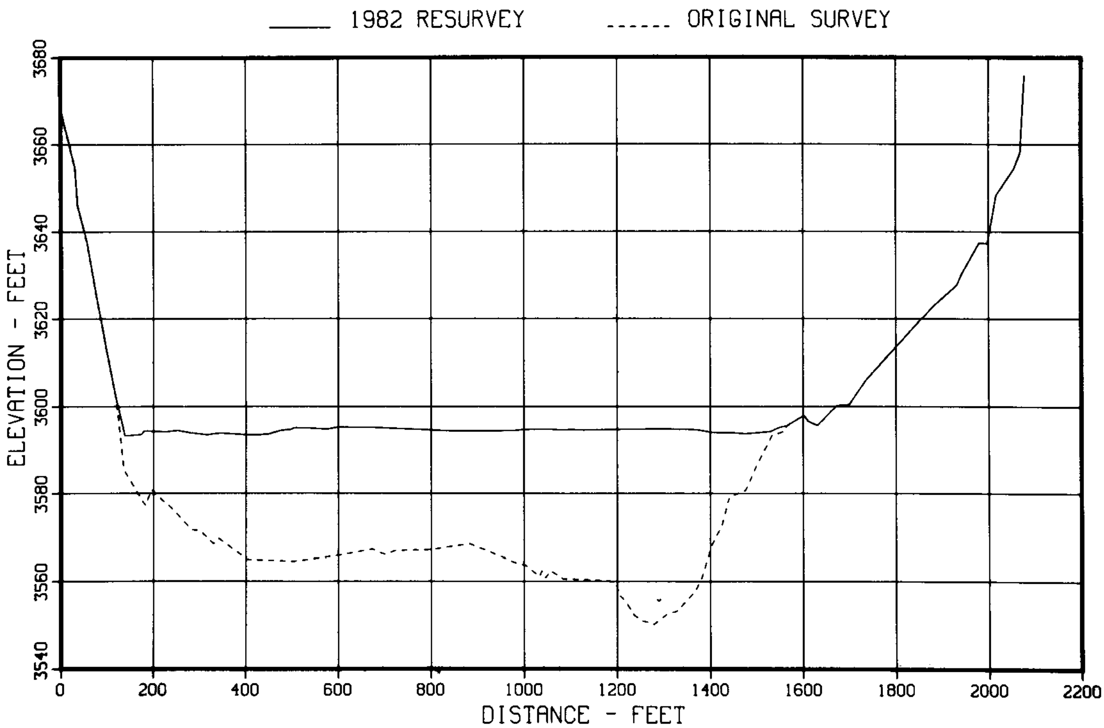

Figure 49. – Original and 1982 sedimentation range profiles, range 15.

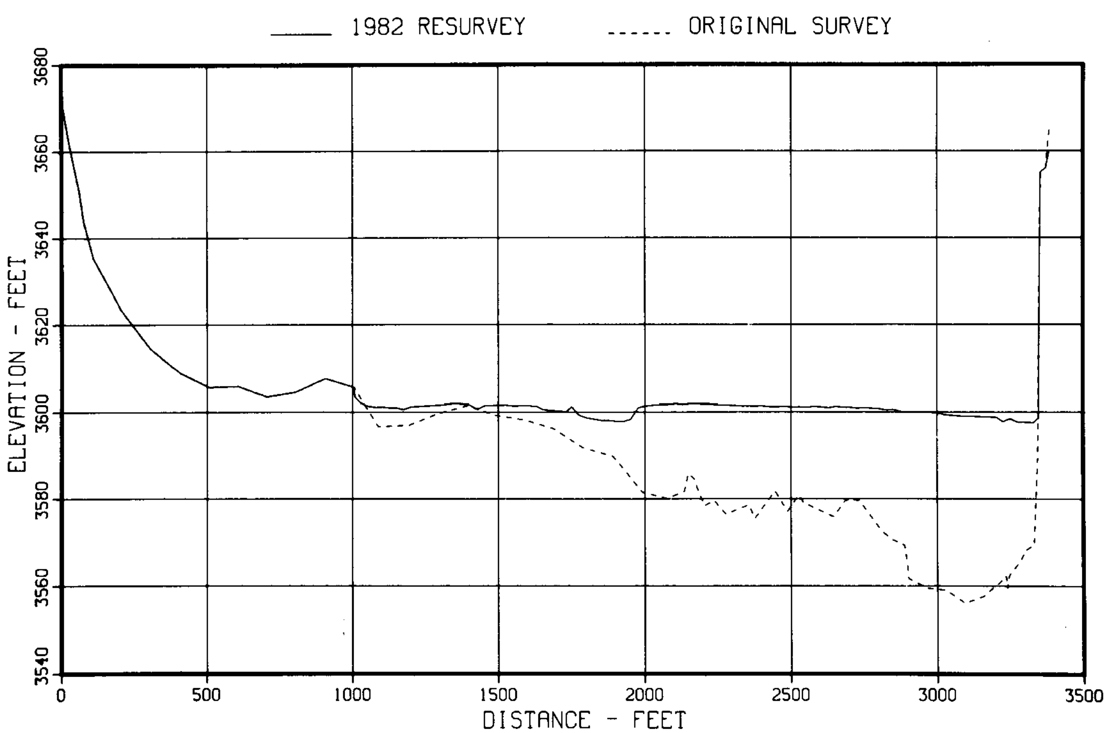

Figure 50. – Original and 1982 sedimentation range profiles, range 16.

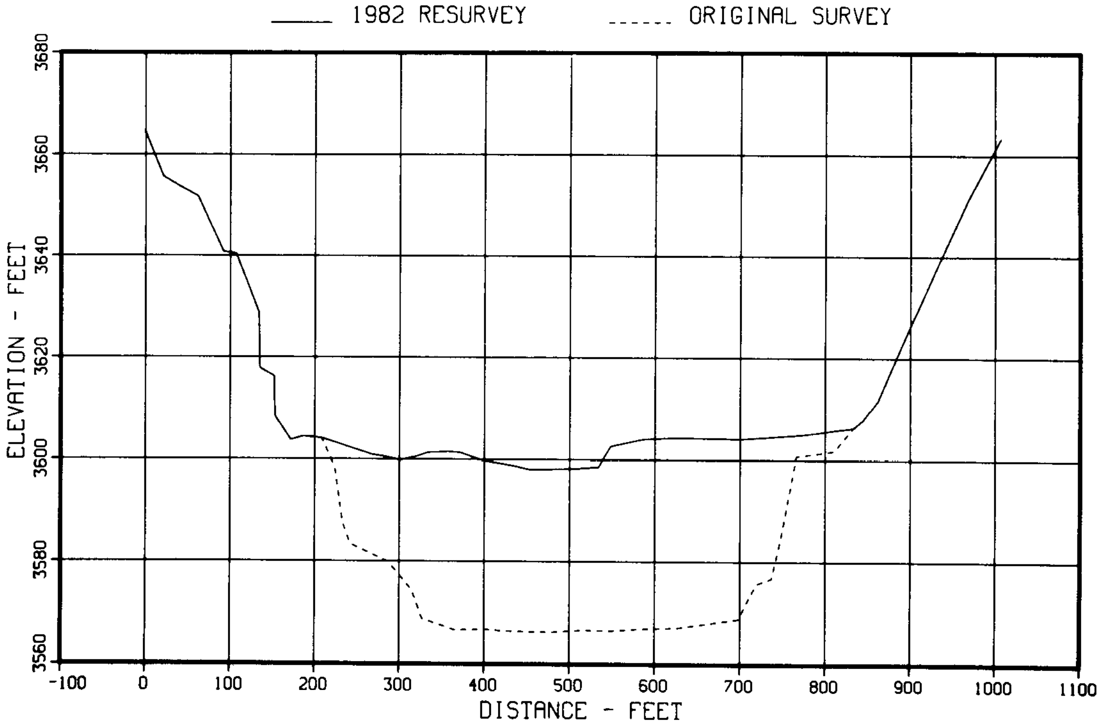

Figure 51. – Original and 1982 sedimentation range profiles, range 17.

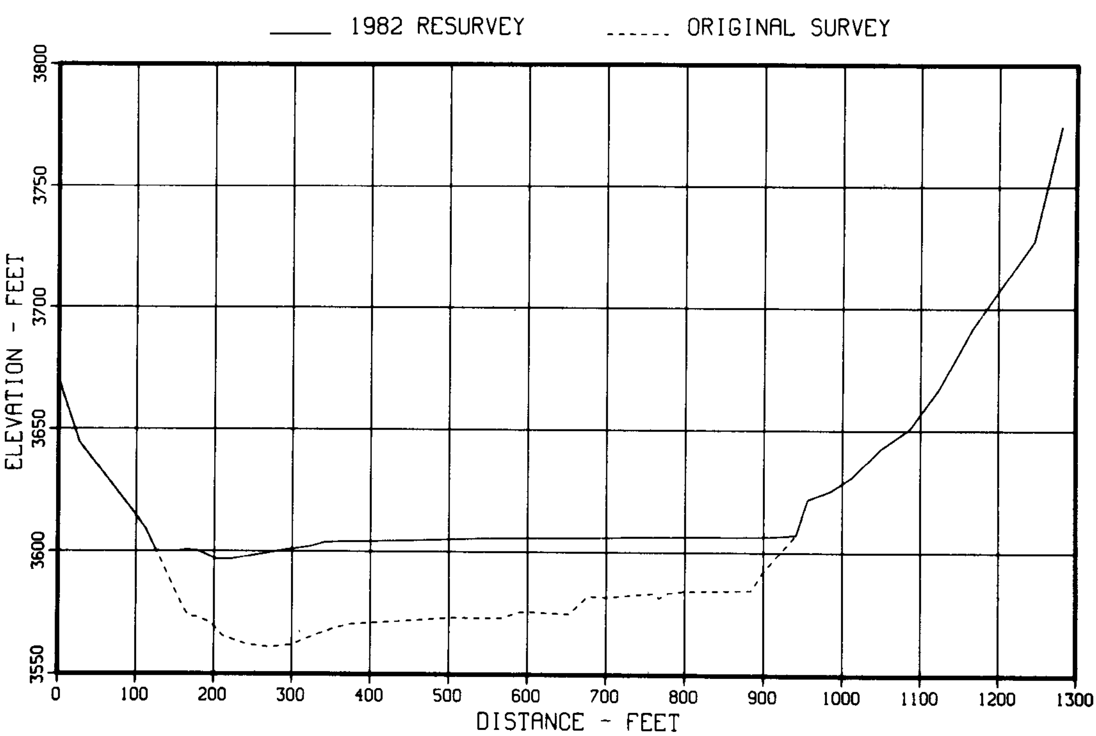

Figure 52. – Original and 1982 sedimentation range profiles, range 18.

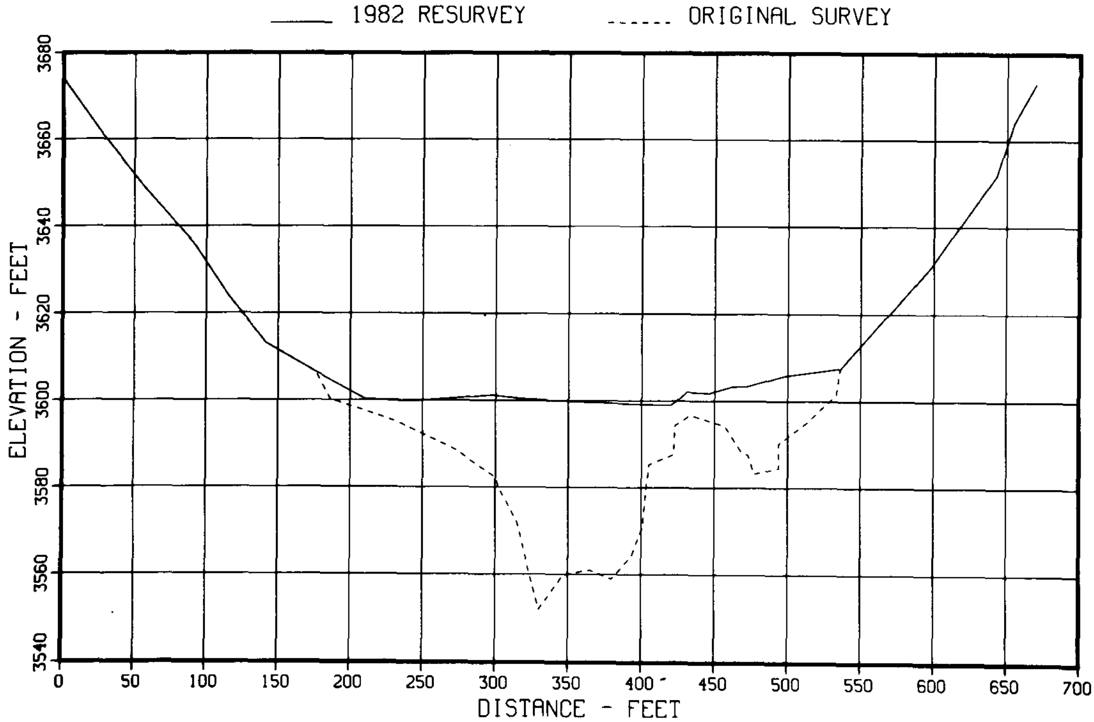

Figure 53. – Original and 1982 sedimentation range profiles, range 19.

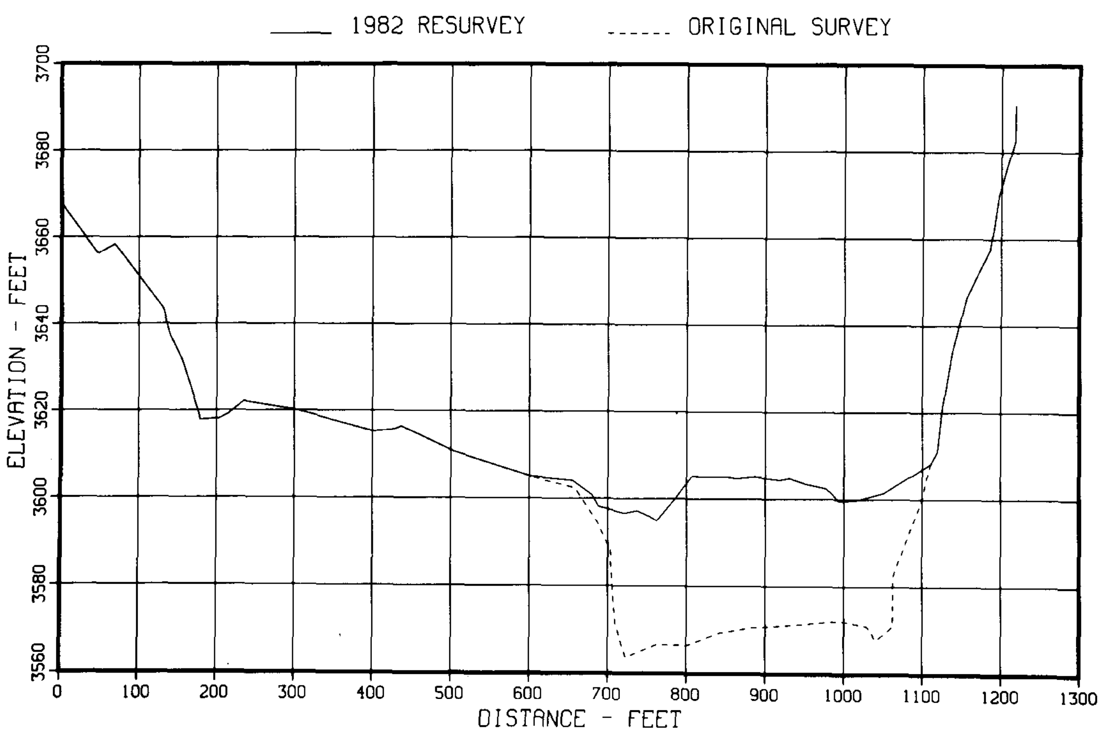

Figure 54. – Original and 1982 sedimentation range profiles, range 20.

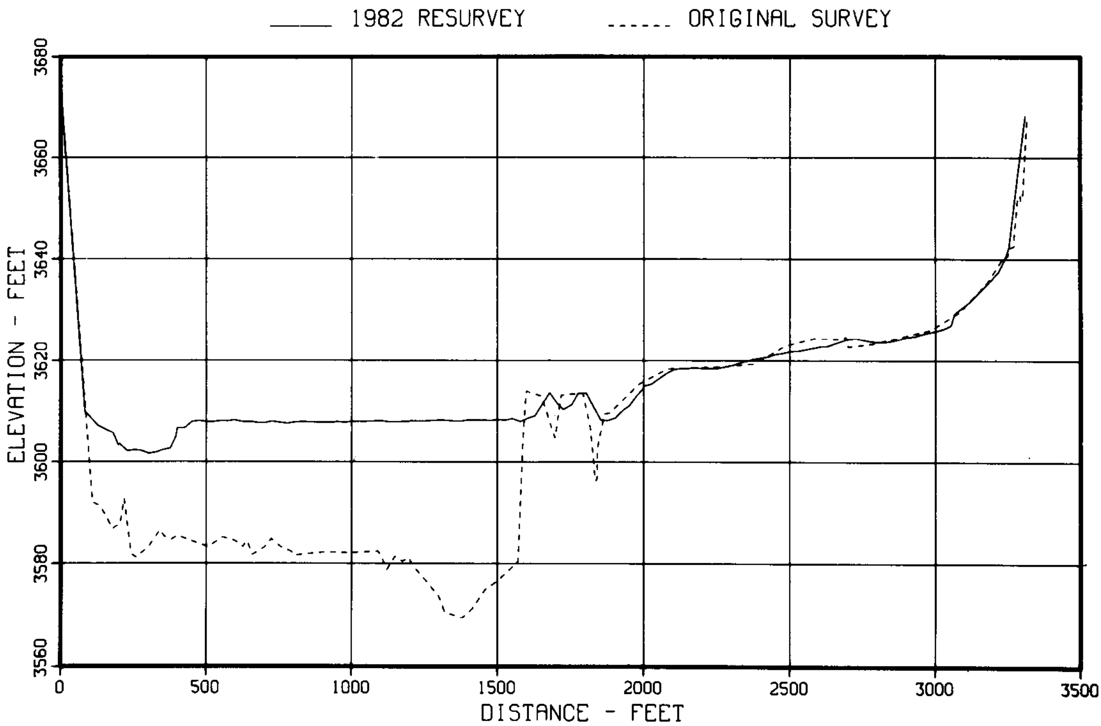

Figure 55. – Original and 1982 sedimentation range profiles, range 21.

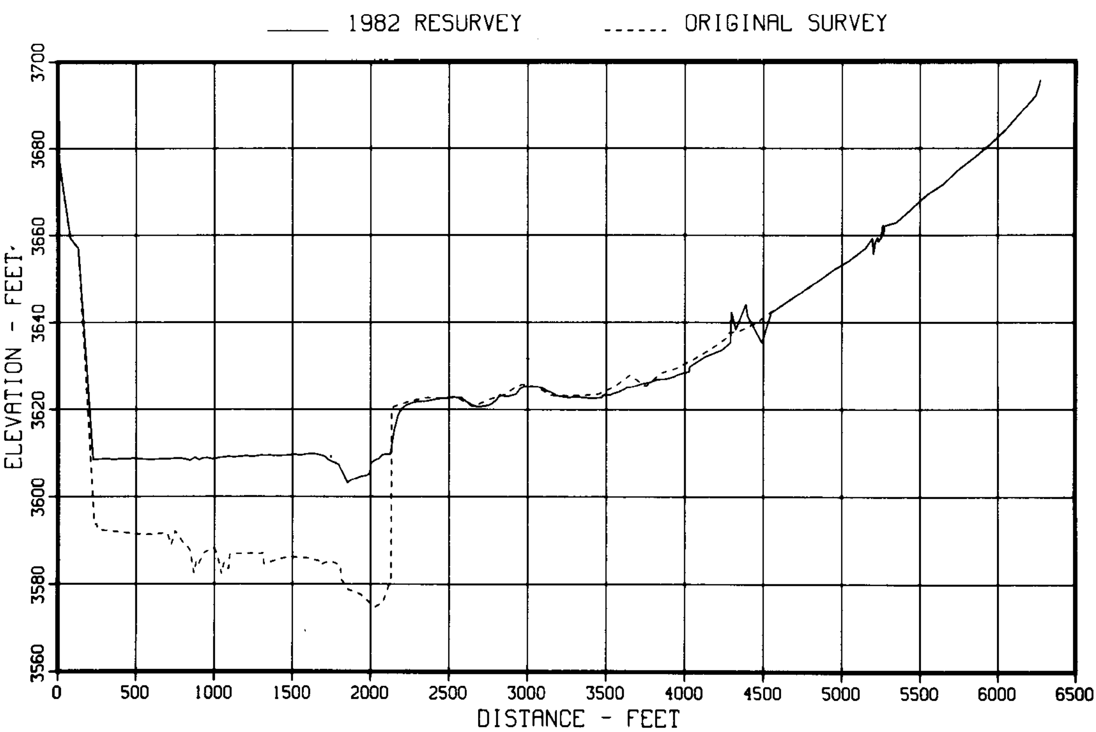

Figure 56. – Original and 1982 sedimentation range profiles, range 22.

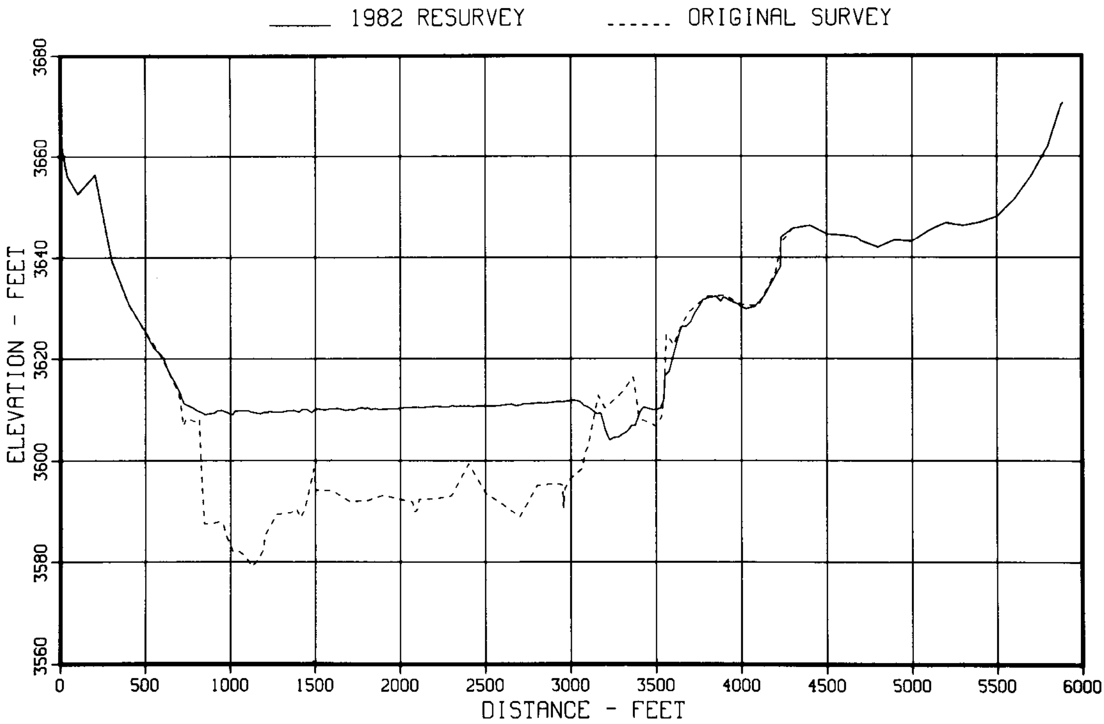

Figure 57. – Original and 1982 sedimentation range profiles, range 23.

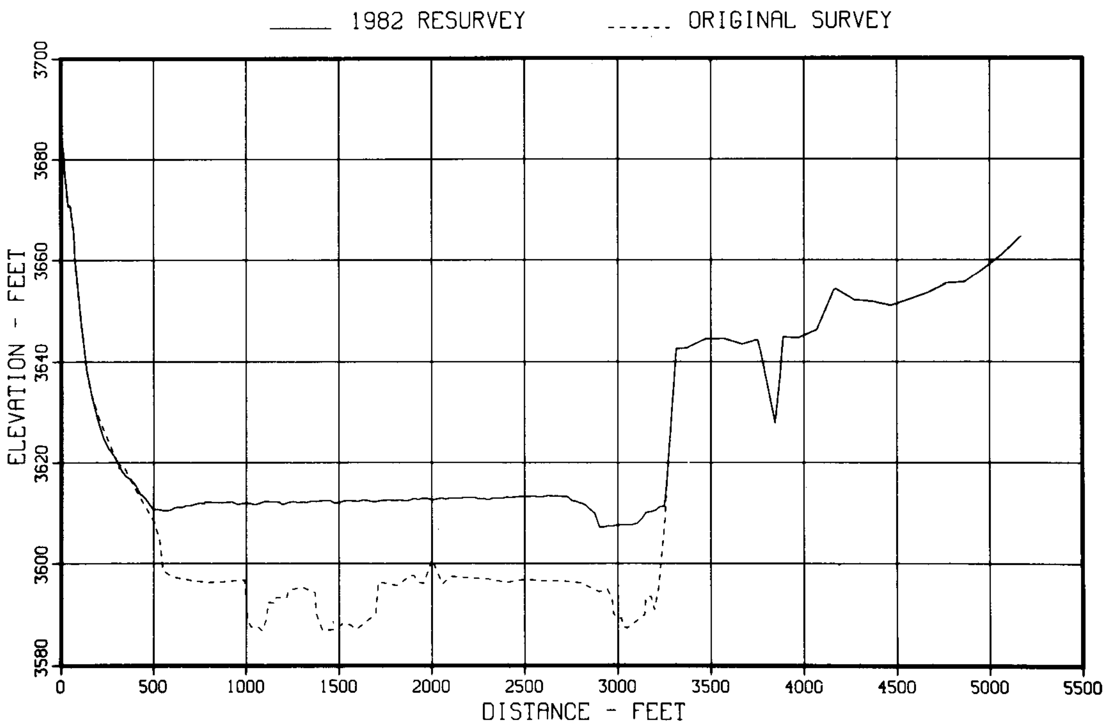

Figure 58. – Original and 1982 sedimentation range profiles, range 24.

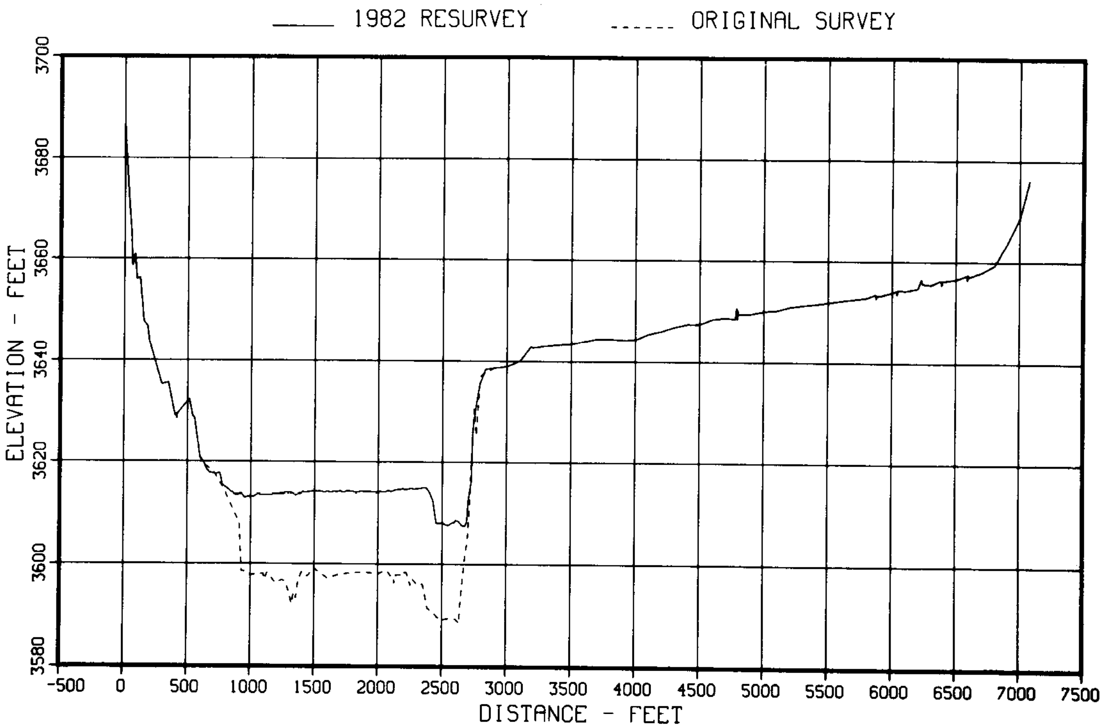

Figure 59. – Original and 1982 sedimentation range profiles, range 25.

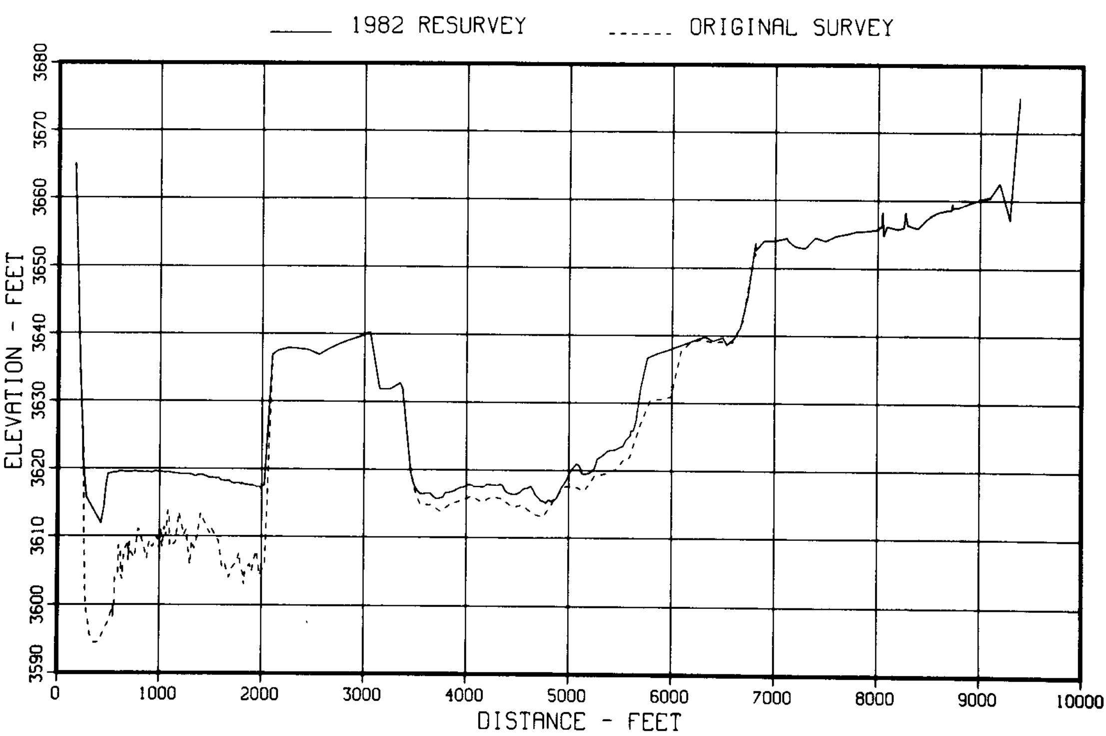

Figure 60. – Original and 1982 sedimentation range profiles, range 26.

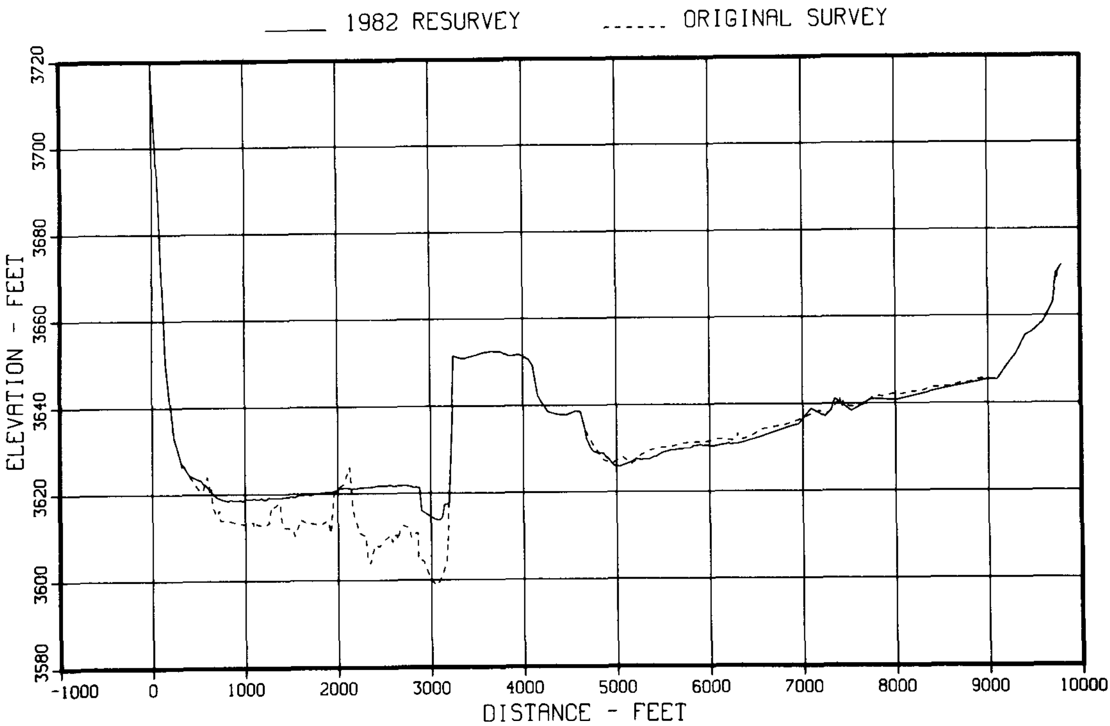

Figure 61. – Original and 1982 sedimentation range profiles, range 27.

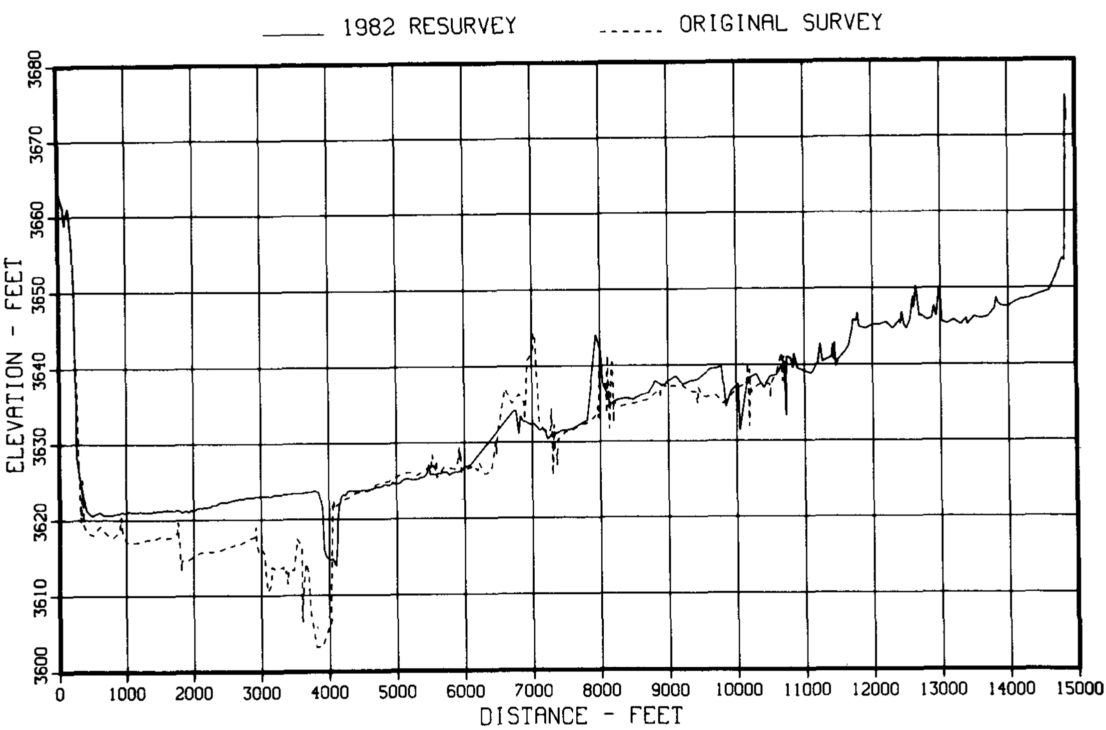

Figure 62. – Original and 1982 sedimentation range profiles, range 28.

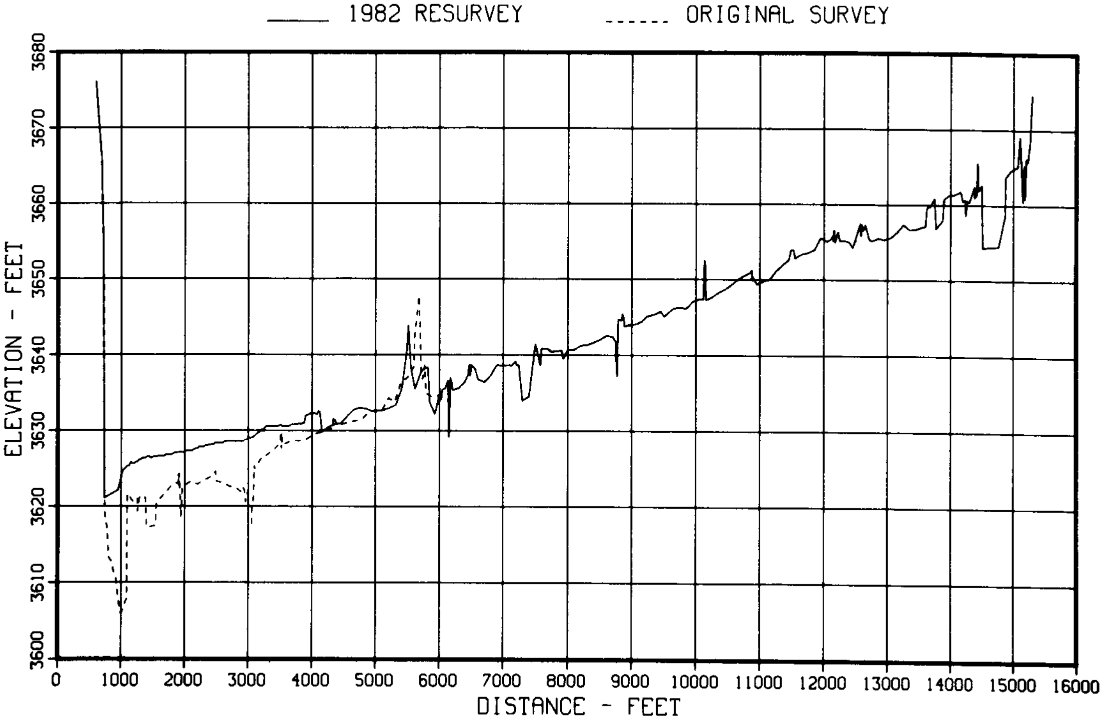

Figure 63. – Original and 1982 sedimentation range profiles, range 29.

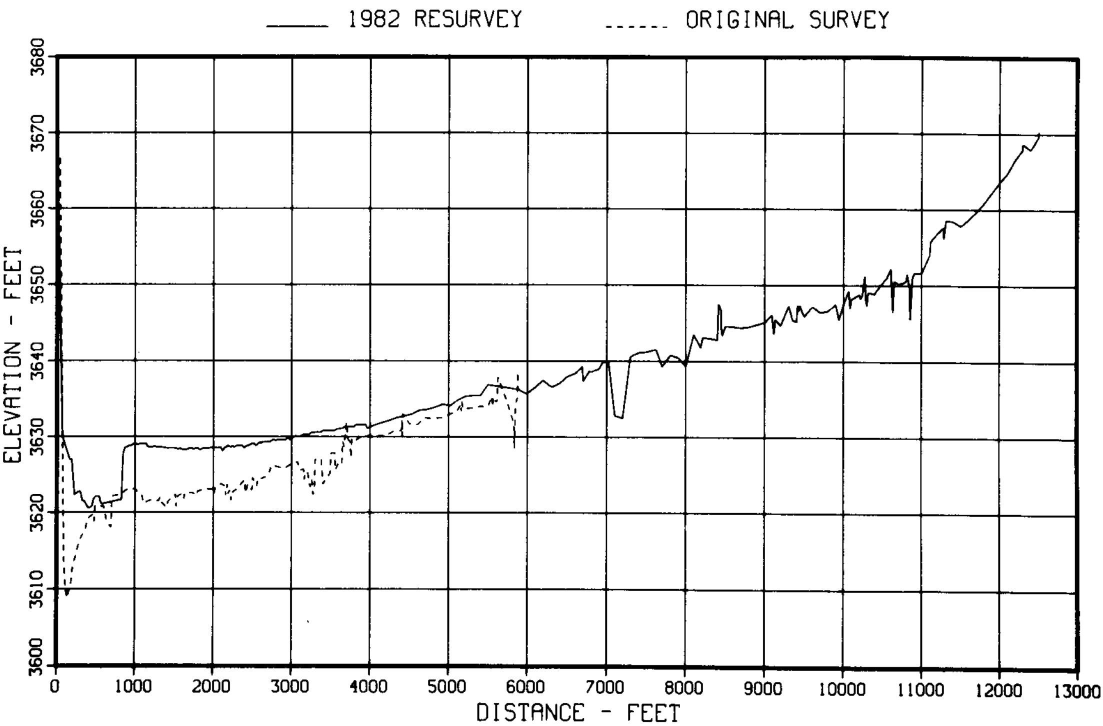

Figure 64. – Original and 1982 sedimentation range profiles, range 30.

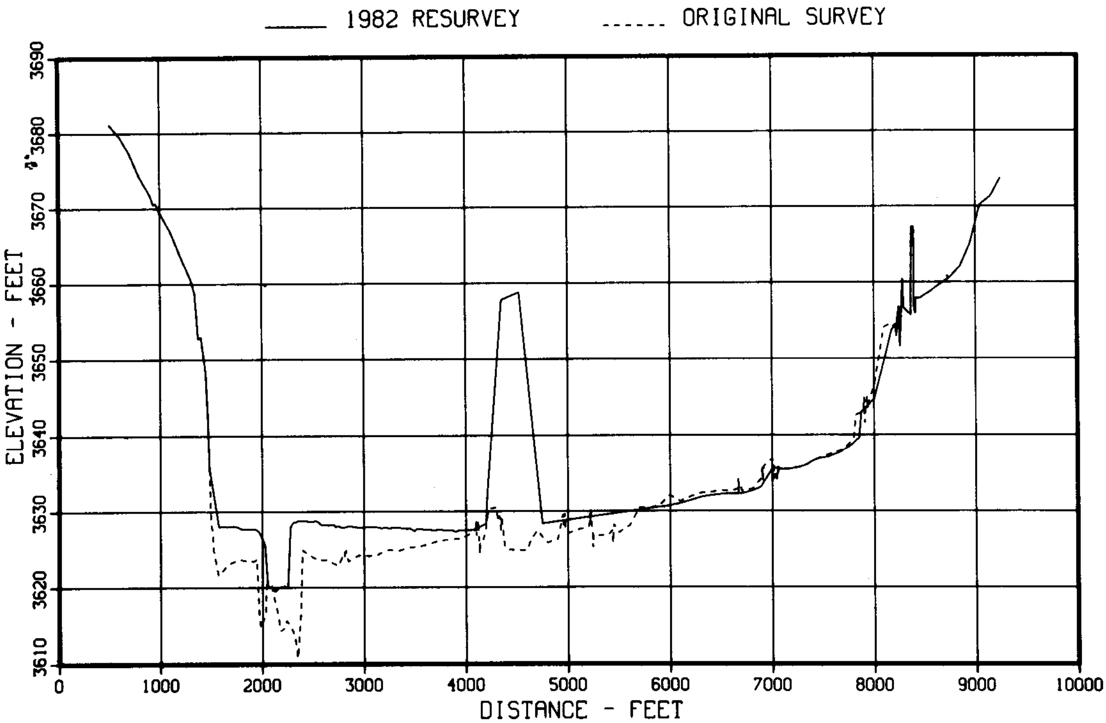

Figure 65. – Original and 1982 sedimentation range profiles, range 31.

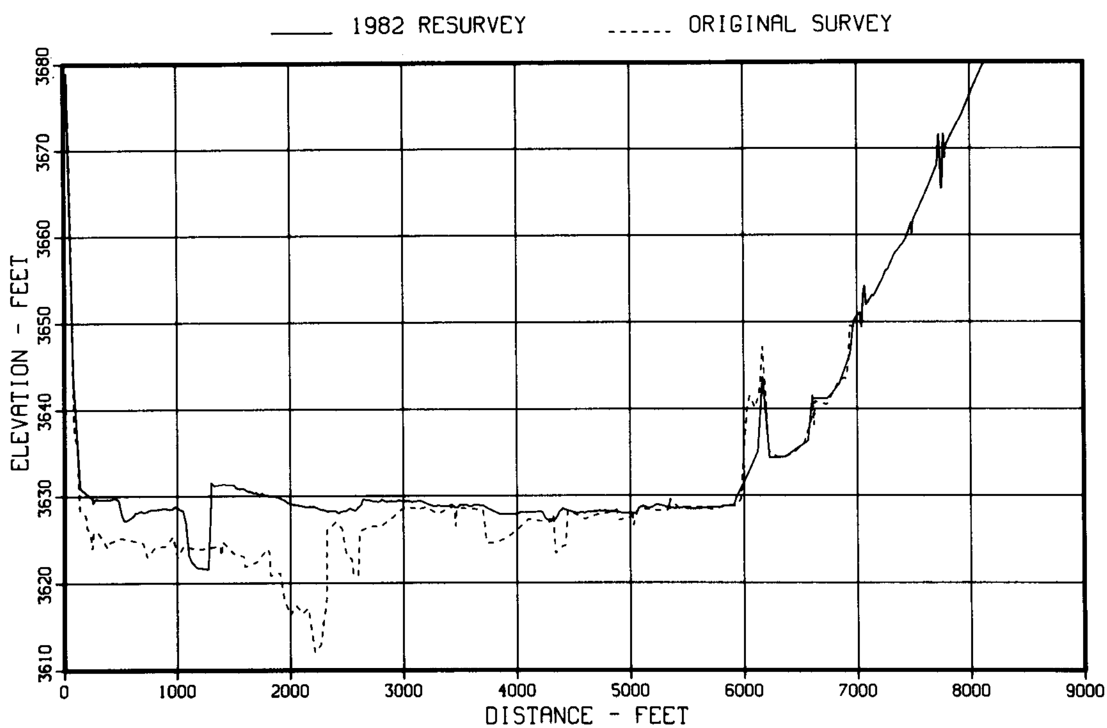

Figure 66. – Original and 1982 sedimentation range profiles, range 32.

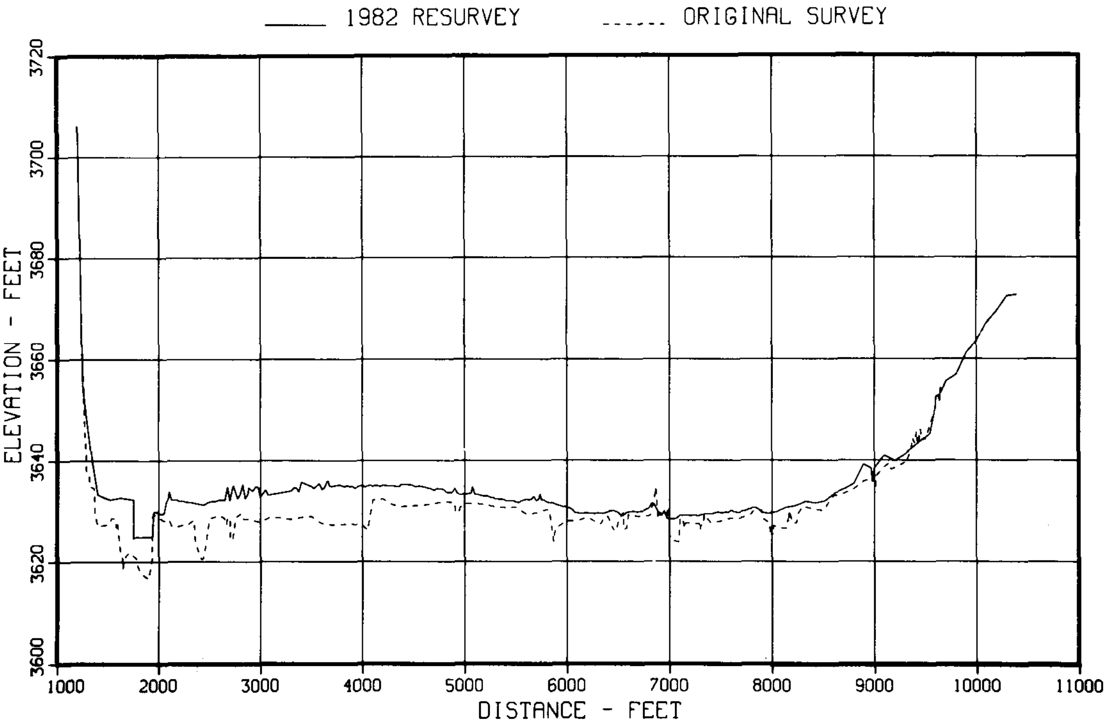

Figure 67. – Original and 1982 sedimentation range profiles, range 33.

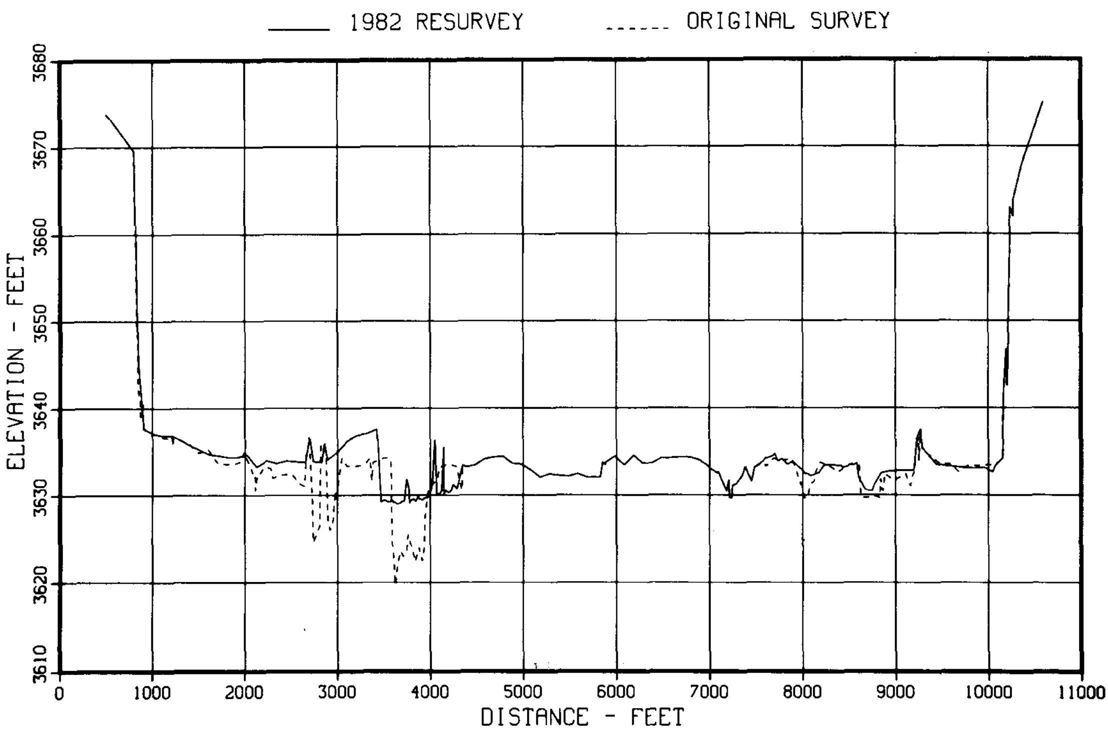

Figure 68. – Original and 1982 sedimentation range profiles, range 34.

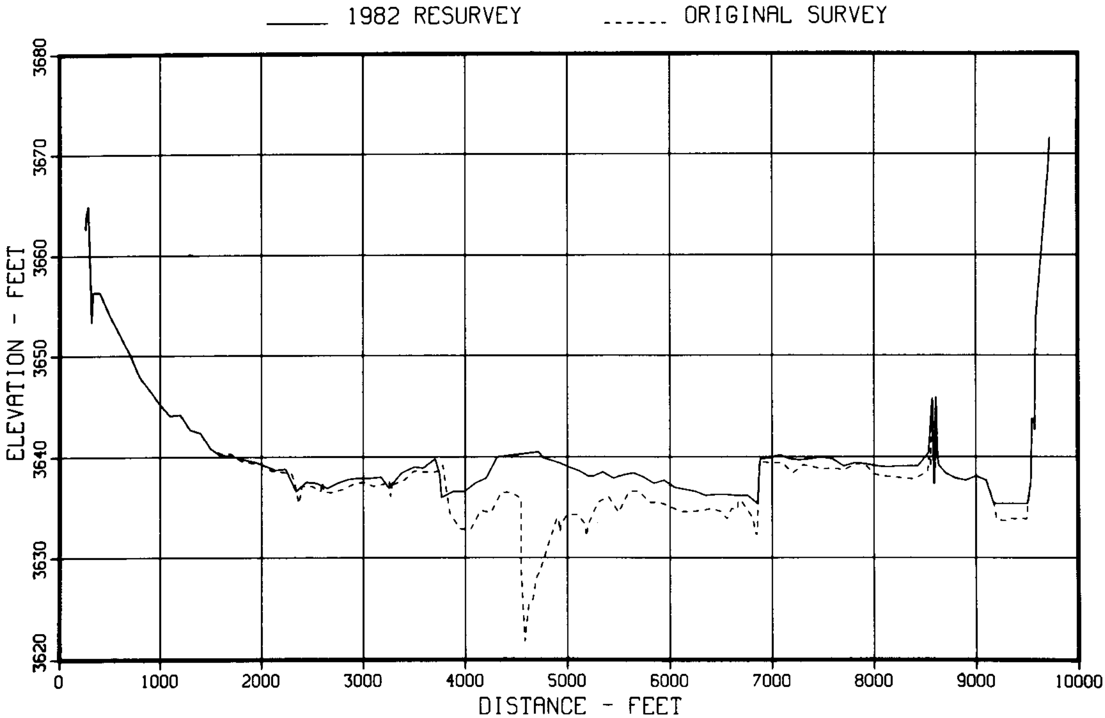

Figure 69. – Original and 1982 sedimentation range profiles, range 35.

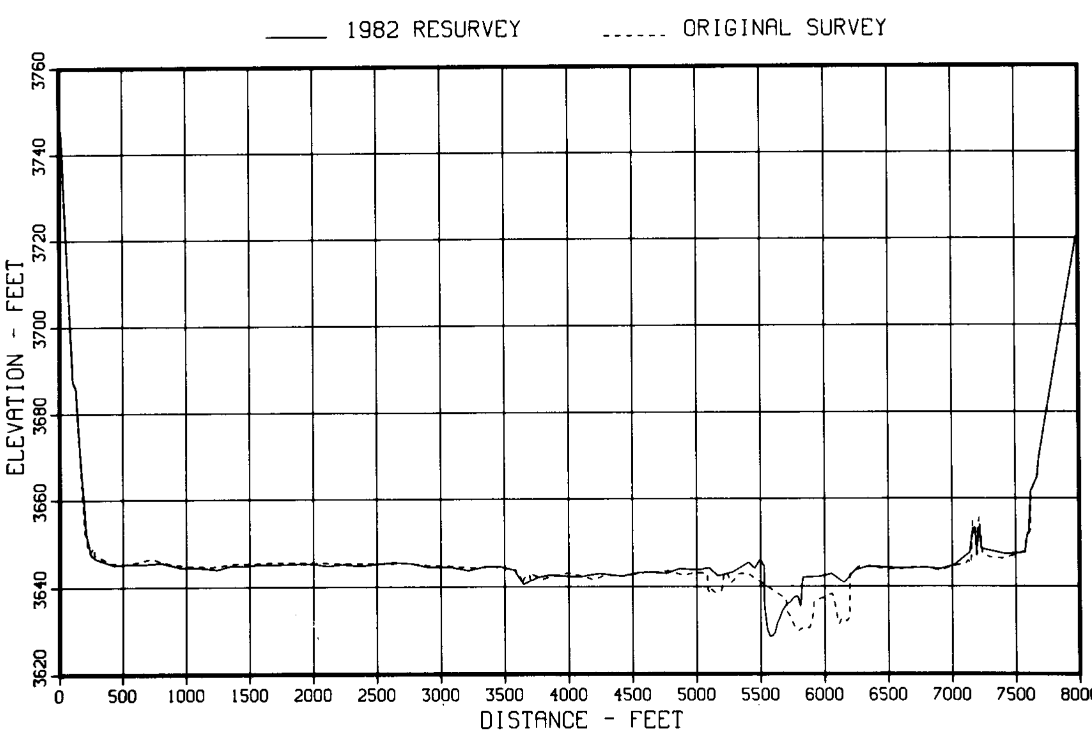

Figure 70. – Original and 1982 sedimentation range profiles, range 36.

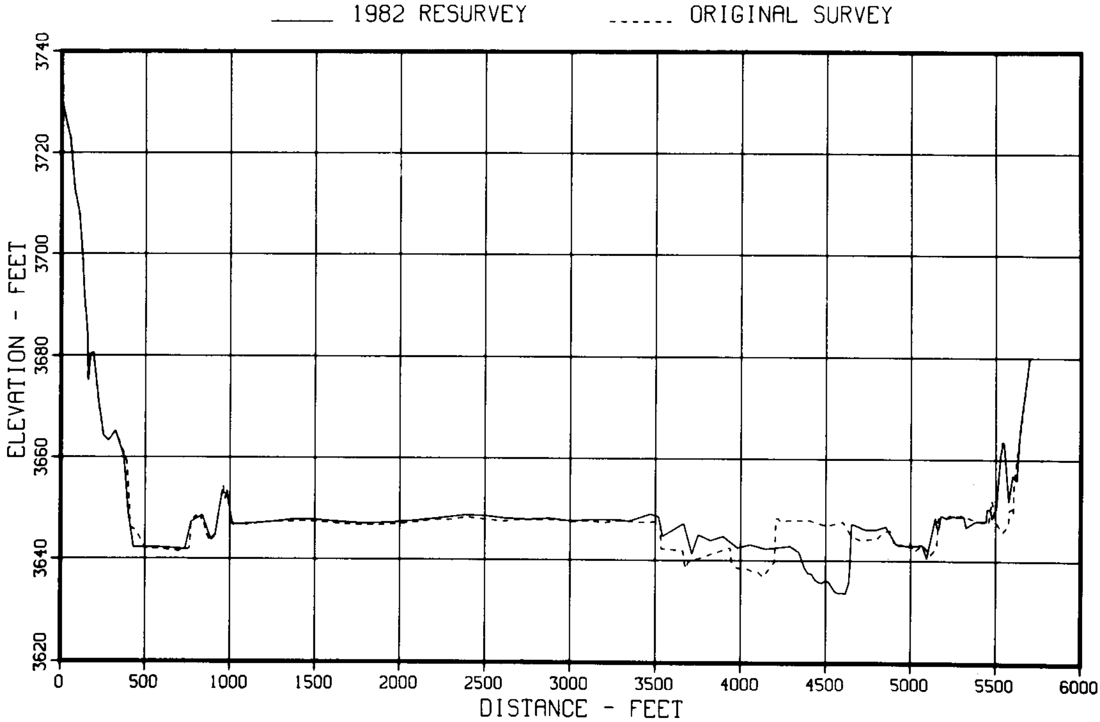

Figure 71. – Original and 1982 sedimentation range profiles, range 37.

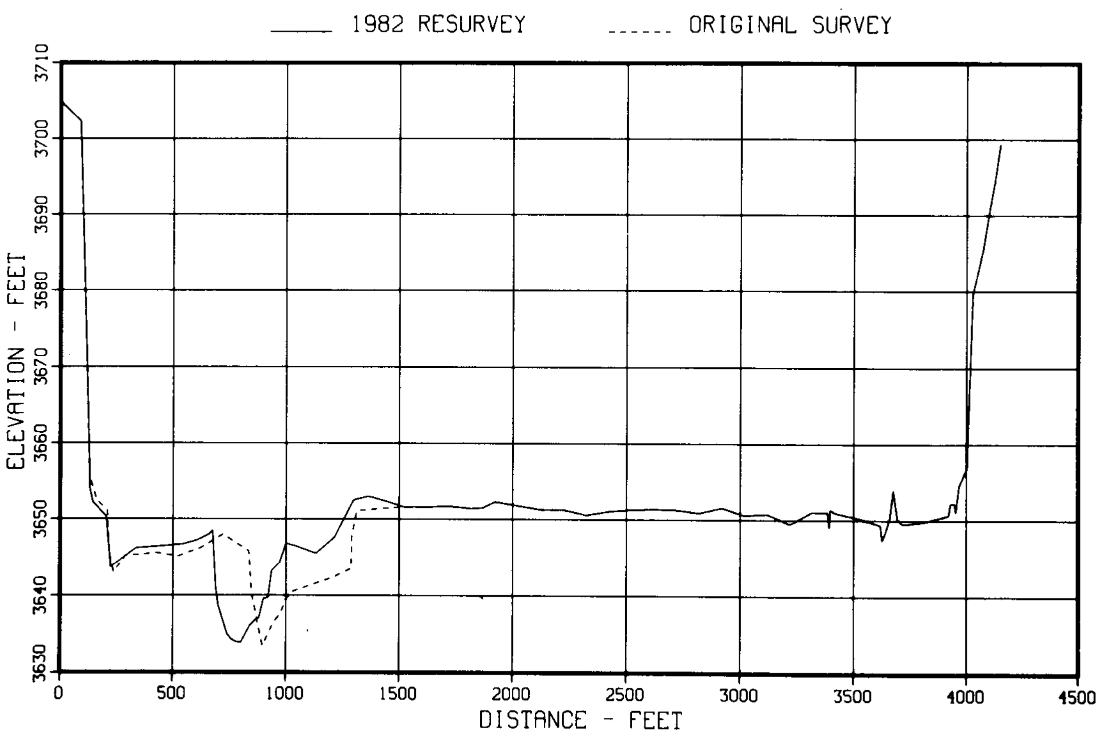

Figure 72. – Original and 1982 sedimentation range profiles, range 38.

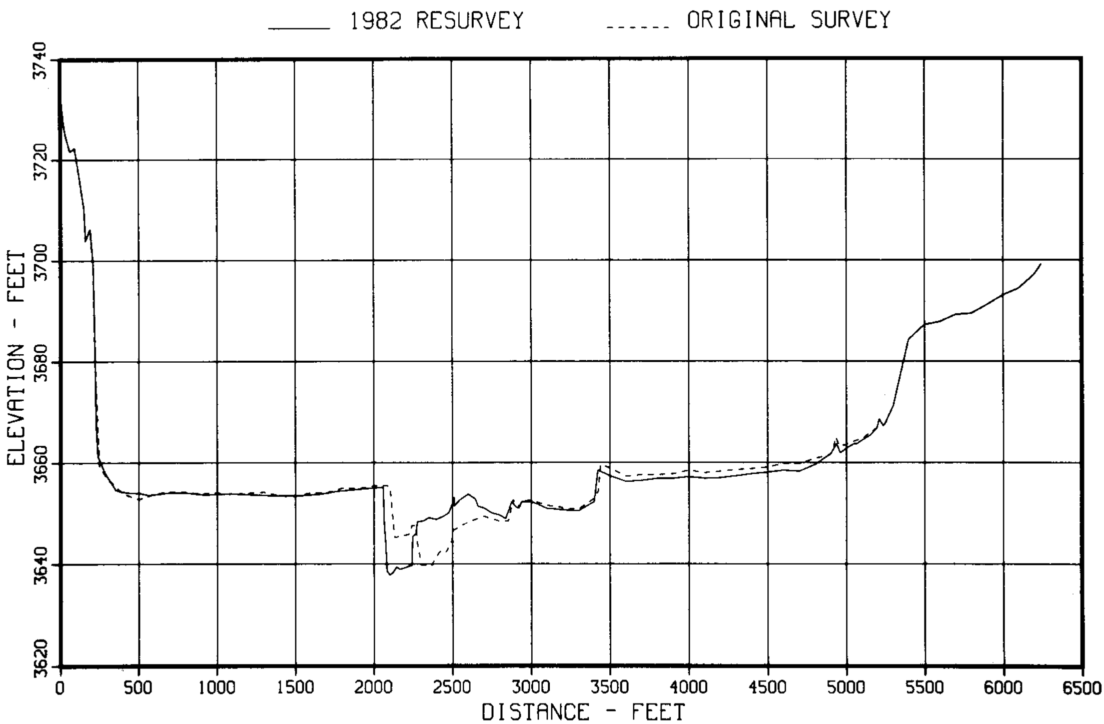

Figure 73. – Original and 1982 sedimentation range profiles, range 39.

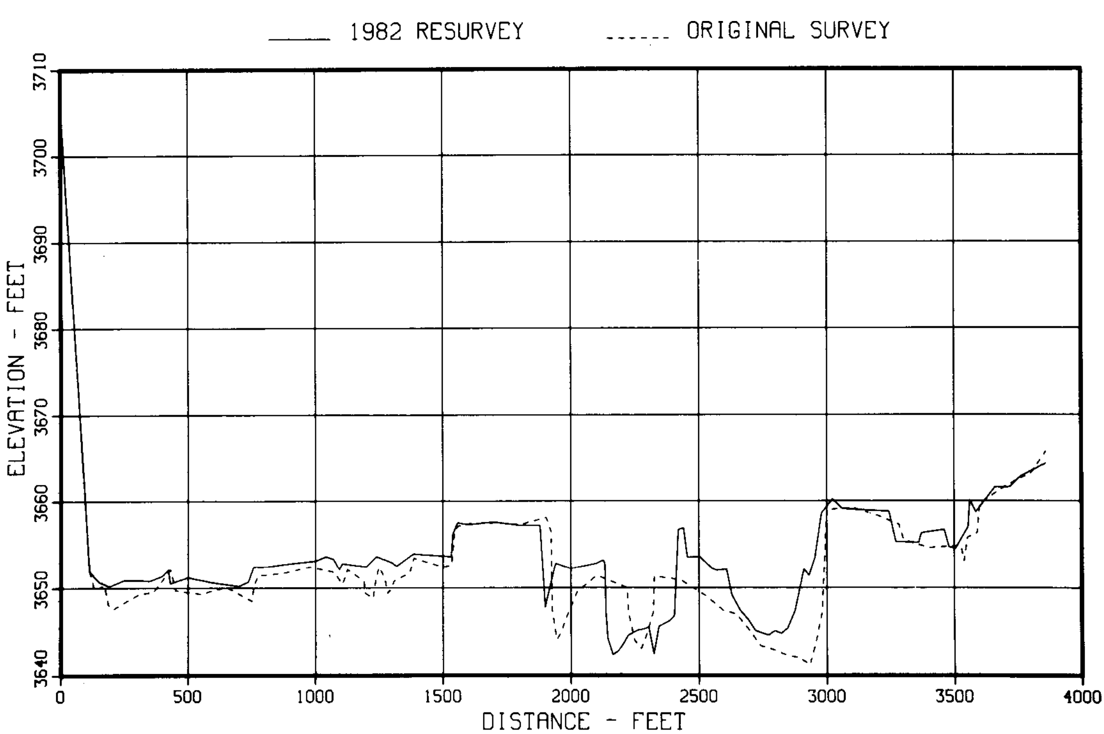

Figure 74. – Original and 1982 sedimentation range profiles, range 40.

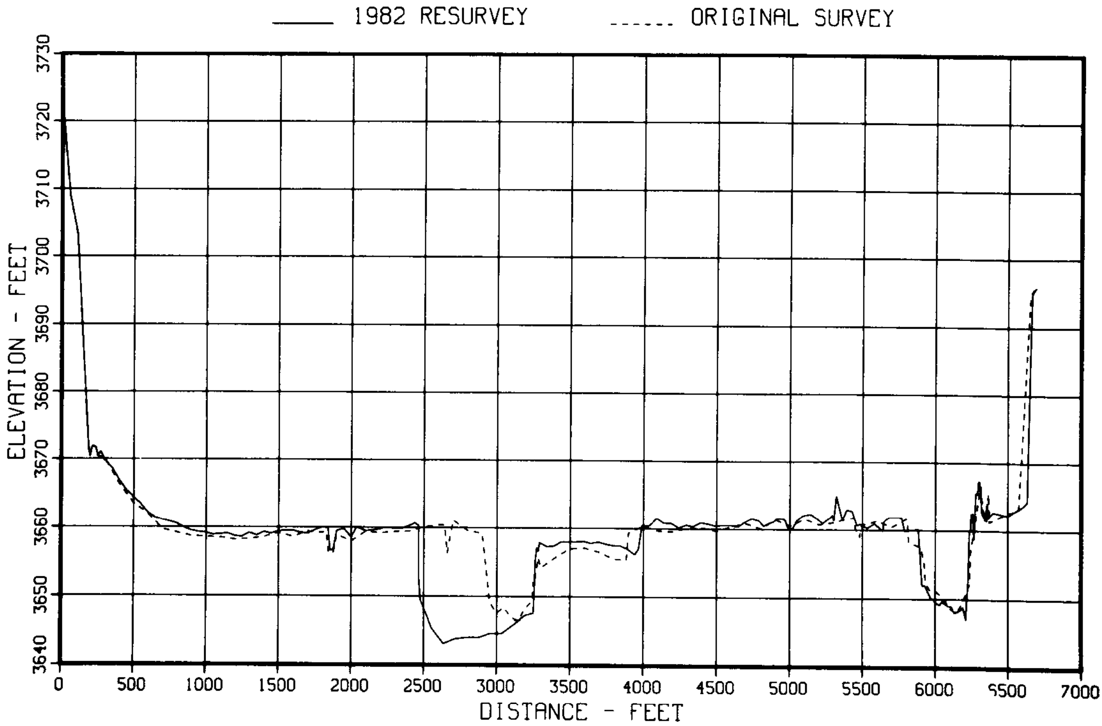

Figure 75. – Original and 1982 sedimentation range profiles, range 41.

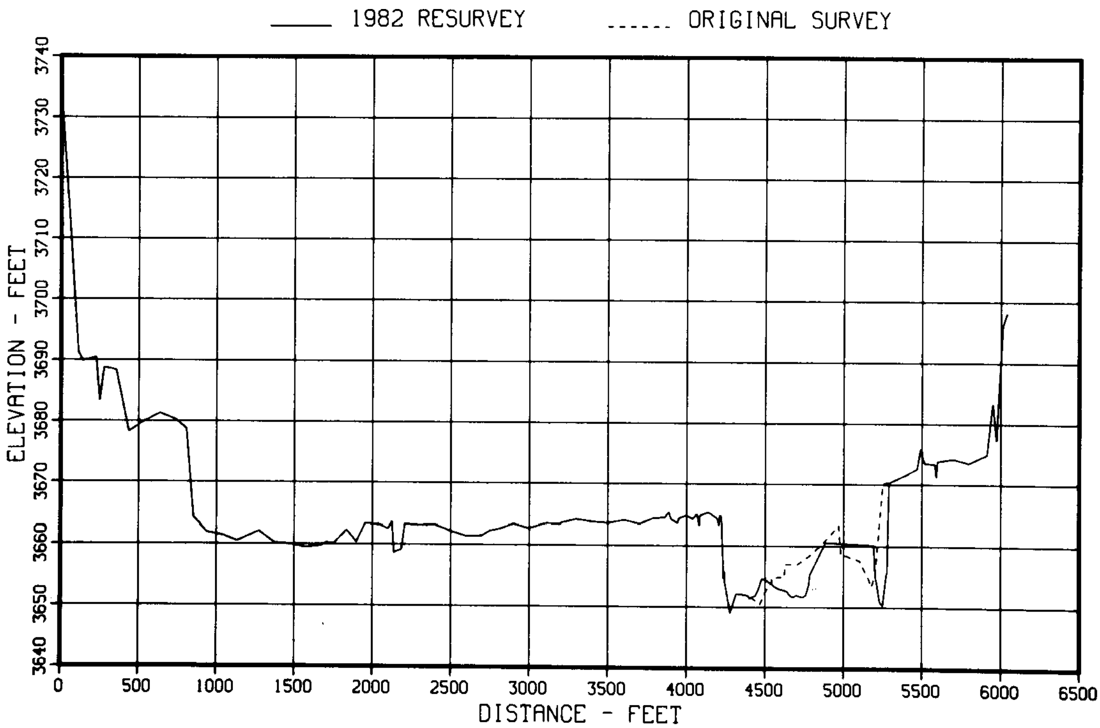

Figure 76. – Original and 1982 sedimentation range profiles, range 42.

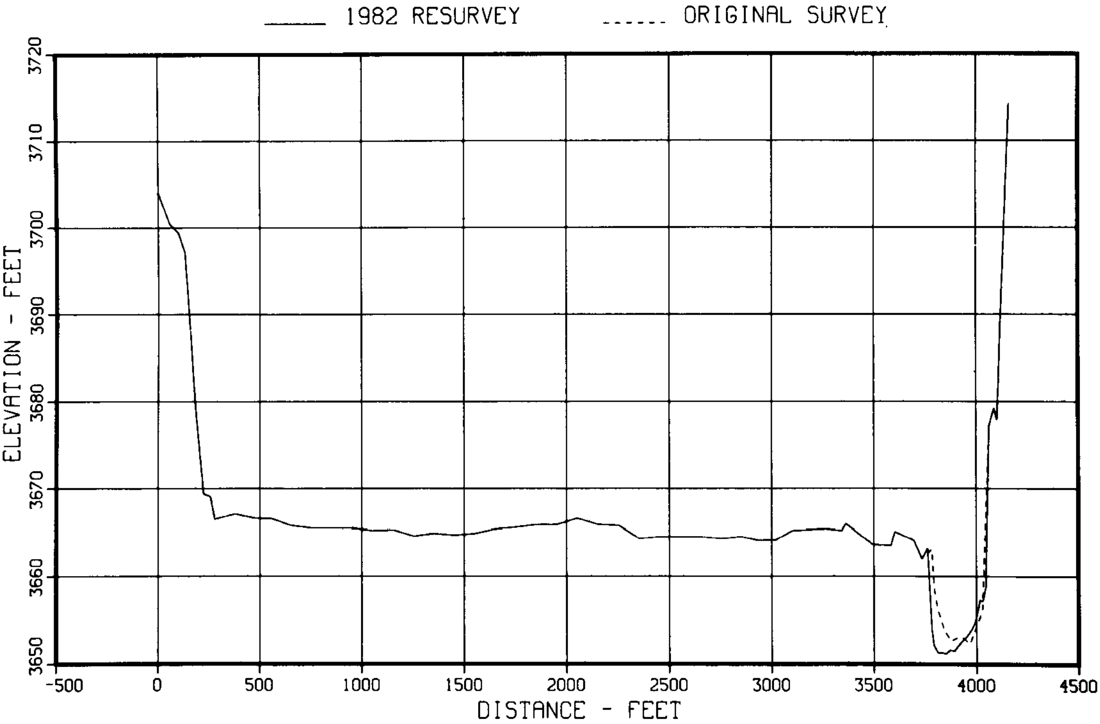

Figure 77. – Original and 1982 sedimentation range profiles, range 43.

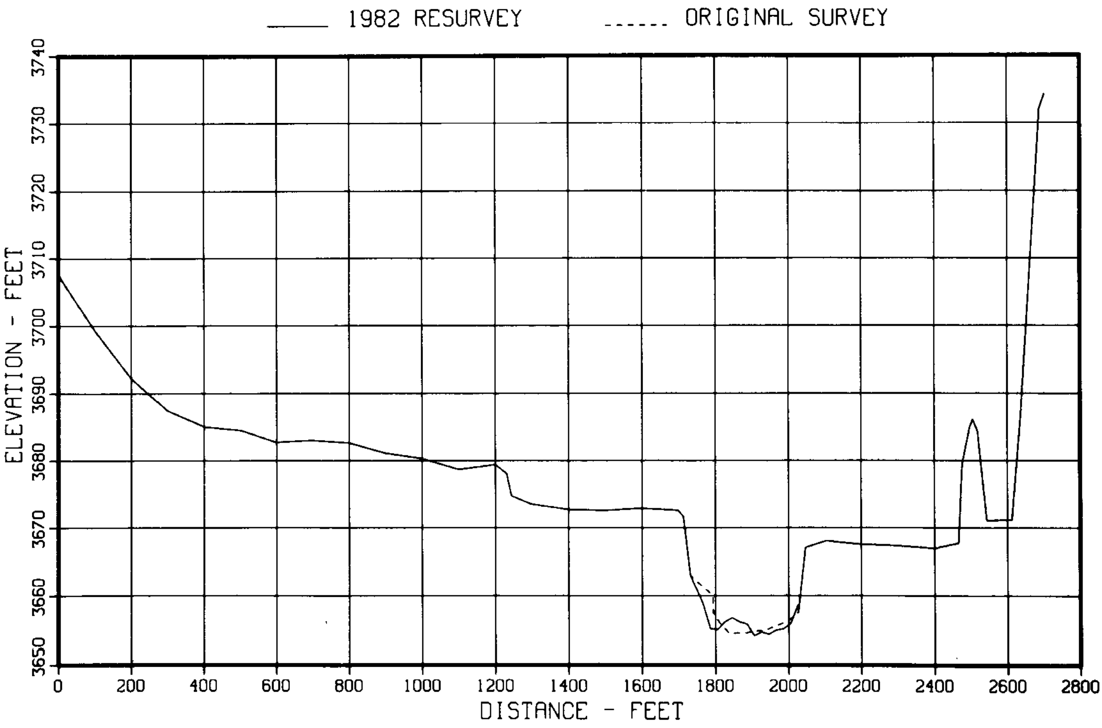

Figure 78. – Original and 1982 sedimentation range profiles, range 44.

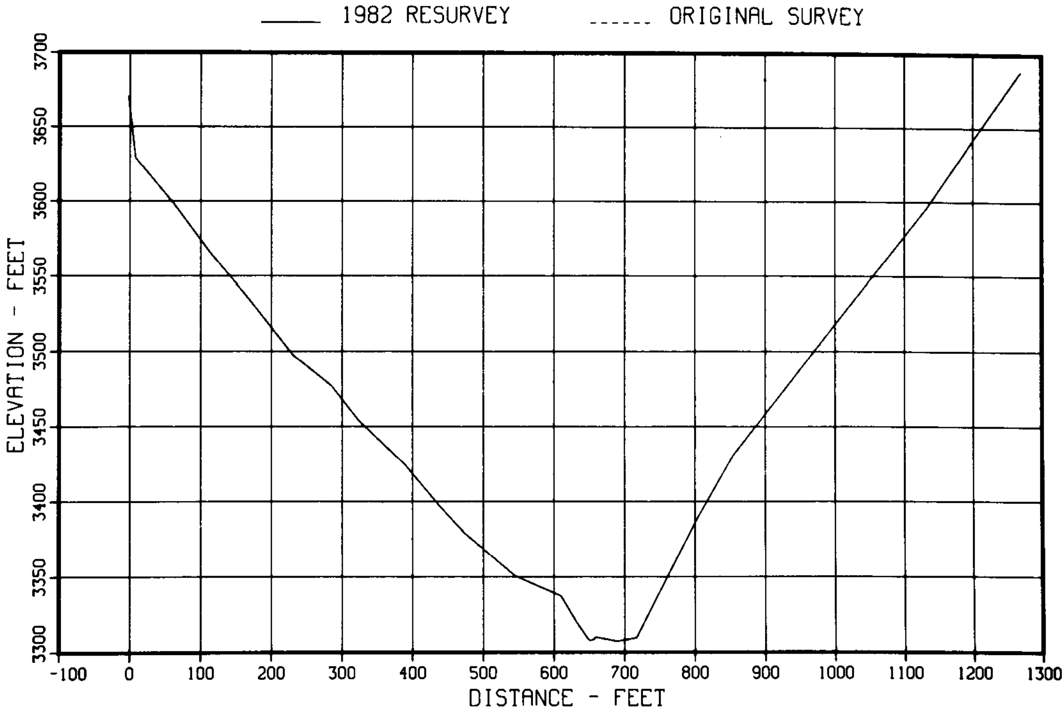

Figure 79. – Original and 1982 sedimentation range profiles, range 2A.

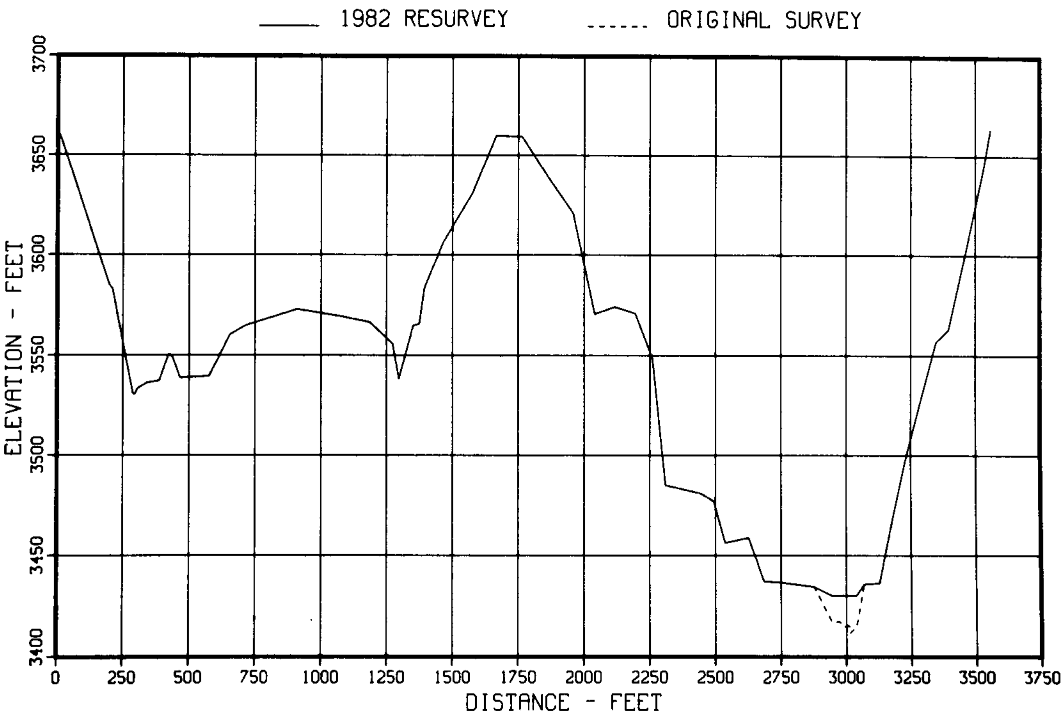

Figure 80. – Original and 1982 sedimentation range profiles, range 3A.

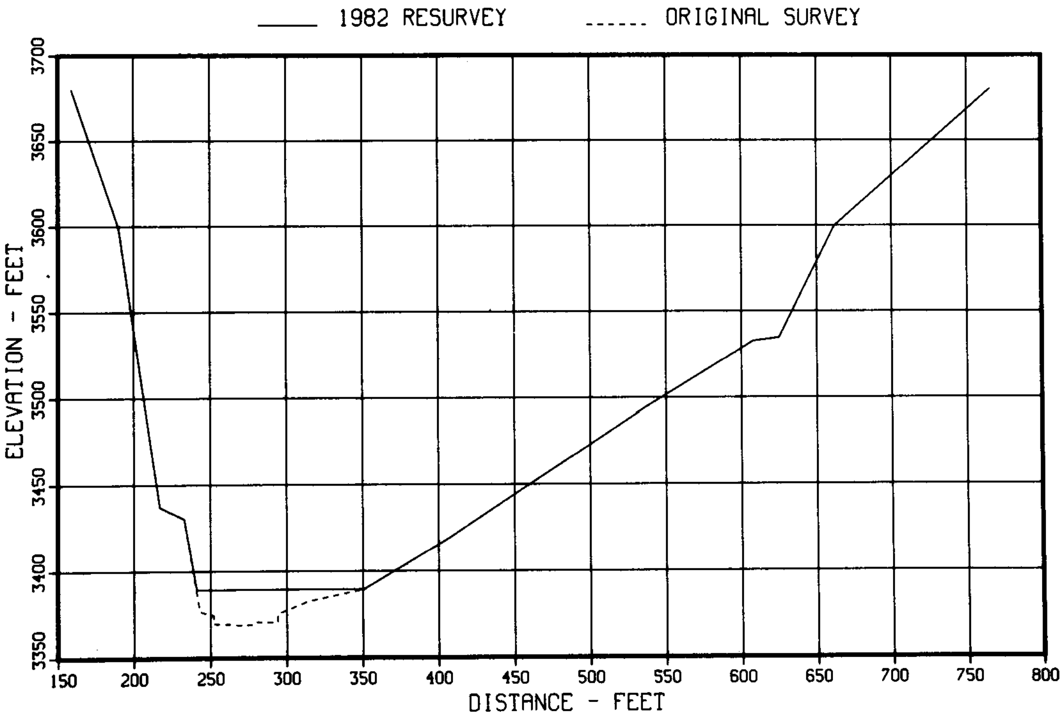

Figure 81. – Original and 1982 sedimentation range profiles, range 4A.

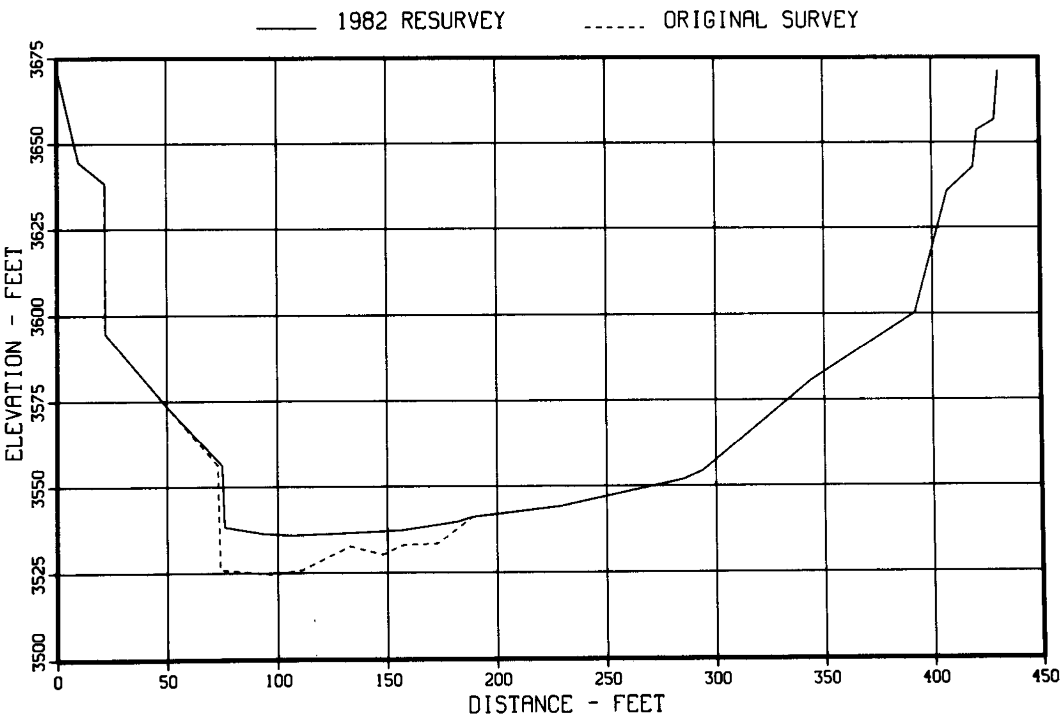

Figure 82. – Original and 1982 sedimentation range profiles, range 10A.

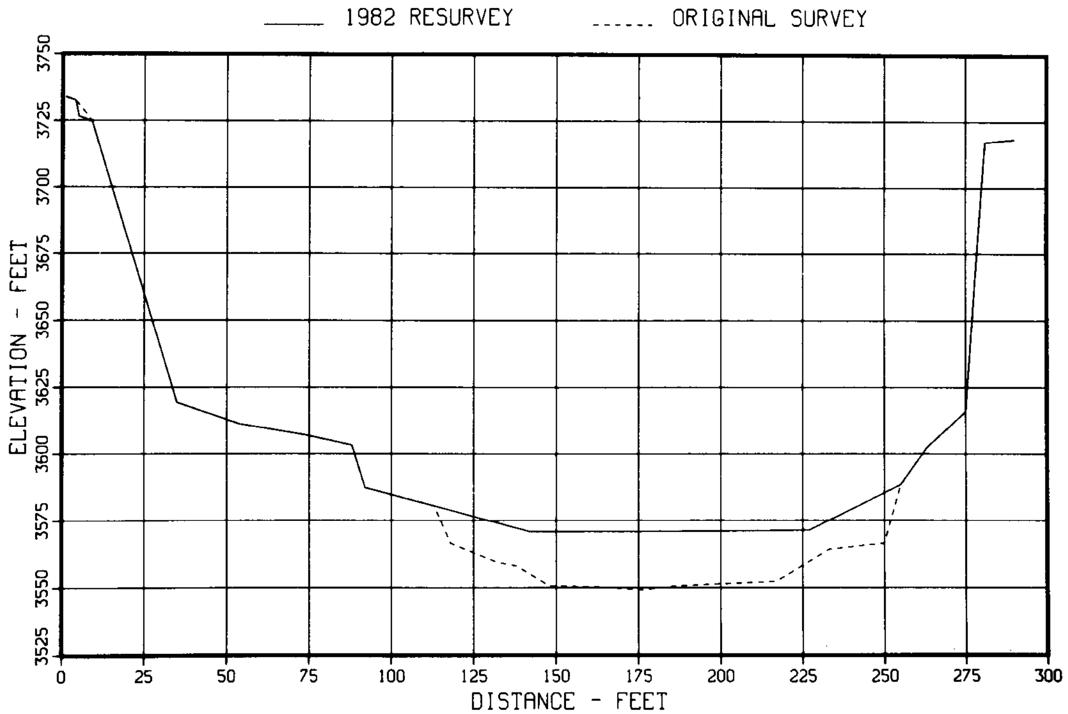

Figure 83. – Original and 1982 sedimentation range profiles, range 101.

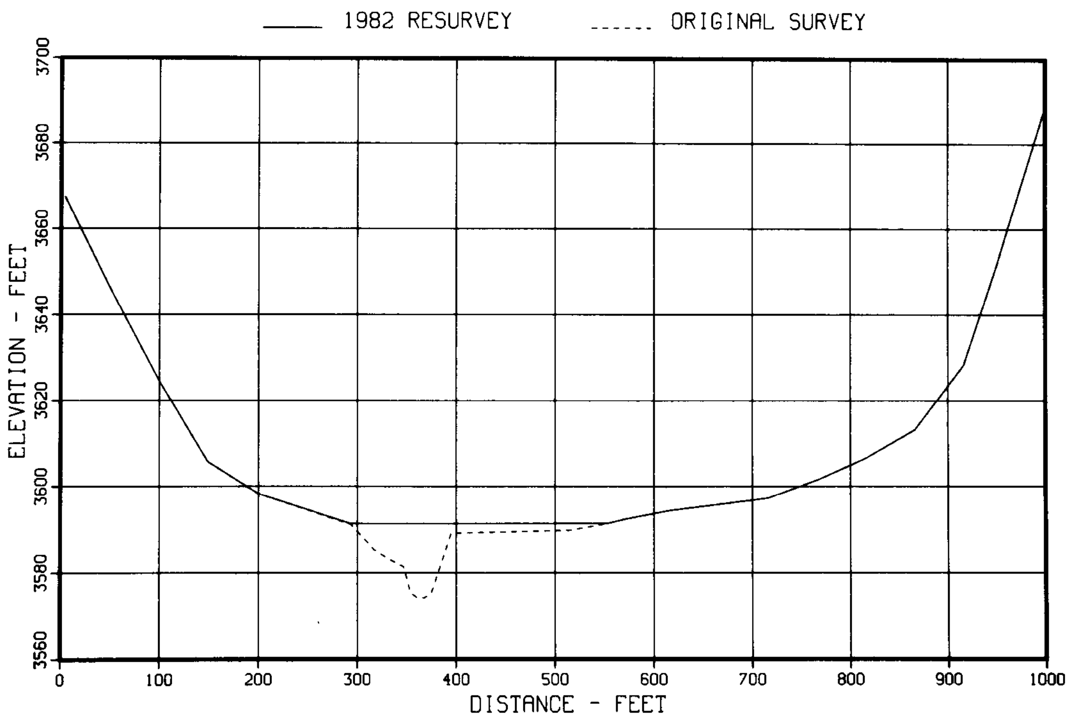

Figure 84. – Original and 1982 sedimentation range profiles, range 102.

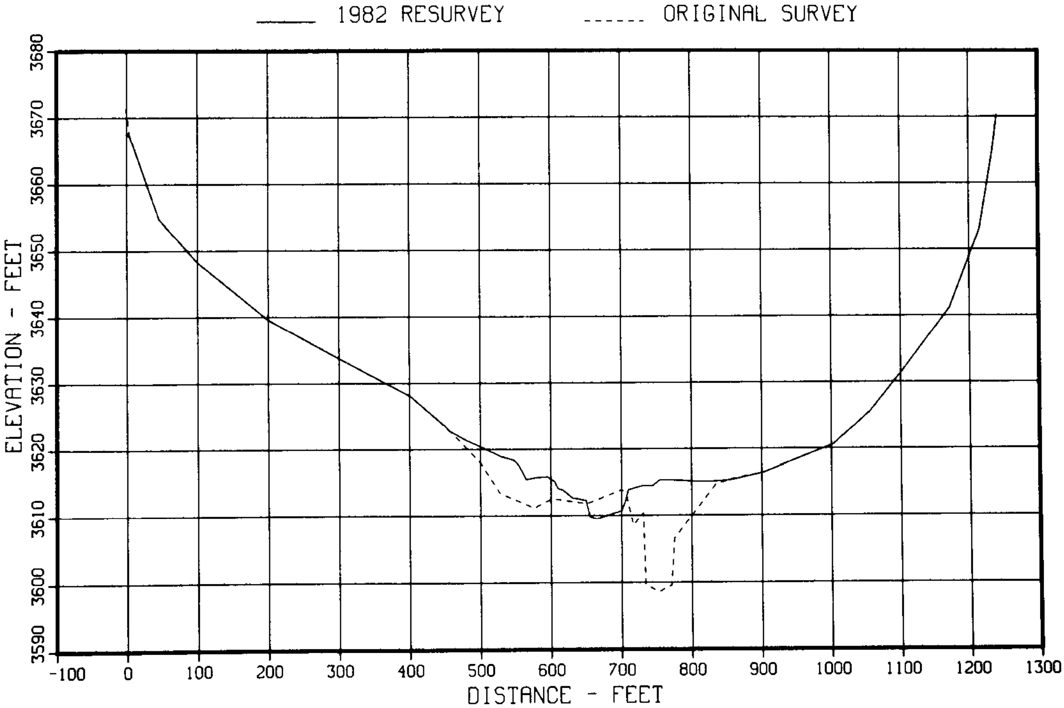

Figure 85. – Original and 1982 sedimentation range profiles, range 103.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.