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1986 LAKE POWELL SURVEY

December 1988

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16. ABSTRACT
The 1986 Lake Powell sediment survey documented the present storage-elevation relationship and loss of storage from sediment accumulation since the reservoir began filling in 1963. Sonic depth recording equipment mounted in a power boat was used to run the hydrographic survey. Sediment range-lines at 409 locations were established to determine the present capacity and for future monitoring of the sediment build-up. The reservoir capacity was computed based on surface areas determined by a range-line survey method.

As of September 1986, at reservoir elevation 3700, the capacity was 26,214,861 acre-feet with a surface area of 160,784 acres. Since March 1963, 868,231 acre-feet of sediment accumulation have resulted in 3.2-percent loss in reservoir storage.

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1986 LAKE POWELL SURVEY

by

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December 1988

Surface Water Branch
Earth Sciences Division
Denver Office
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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INTRODUCTION

Lake Powell, named in honor of Major John Wesley Powell and formed by Glen Canyon Dam, is one of the major storage features of the CRSP (Colorado River Storage Project). Under the 1922 Colorado River Compact, the CRSP provides regulatory storage for the States in the Upper Colorado River Basin and allows them to use their appropriated water and still meet flow obligations to water users in the Lower Colorado River Basin. Glen Canyon Dam is located on the Colorado River in north central Arizona, 2 miles northwest of Page, Arizona, about 15 river miles upstream from Lees Ferry, and 12 river miles downstream of the Arizona and Utah State line, see figure 1.

Construction of Glen Canyon Dam was authorized under Public Law 485, 84th Congress, 70 Statute 105, April 11, 1956. Construction began in 1957 and was completed in 1964. Closure of the diversion tunnels was made on March 13, 1963, commencing the regulation of flows in the Grand Canyon and reservoir filling. The reservoir reached its full capacity at reservoir elevation 3700 on June 22, 1980.

Glen Canyon Dam is a concrete structure with a structural height of 710 feet and a length of 1,560 feet. At the top of active conservation storage, elevation 3700, the reservoir had an initial calculated total storage capacity of 27 million acre-feet. An additional 10 million acre-feet is estimated to be stored in the banks of the reservoir. A surcharge capacity of 1.8 million acre-feet is provided between elevations 3700 and 3711 for storing and routing the inflow design flood by releasing water through the spillways. The maximum elevation to date is 3708.4 feet, attained on July 14, 1983. This elevation was attained during the first major use of the spillways. At elevation 3700, the reservoir extends 186 miles up the Colorado River and 75 miles up the San Juan River, and creates 1,960 miles of winding canyon shoreline.

Water can be released through Glen Canyon Dam by three different routes: (1) powerplant releases, (2) river outlet tubes bypassing the generators, and (3) through the spillways. The primary operating objectives of the dam are water storage and power generation; consequently, the majority of the water released is routed through the powerplant. Bypassing the generators or spilling the water is avoided if possible. The powerplant has eight generators, each fed by a 15-foot-diameter penstock tube drawing water from the upstream side of the dam, passing it through the generators, and discharging it downstream into the tailwater afterbay (fig. 2). The penstock intakes are at elevation 3470. A spillway on each abutment consists of an approach channel, intake structure, spillway tunnel, and deflector bucket. Spillway discharges are controlled by two 40- by 52.5-foot radial gates on each intake structure. The capacity of each spillway is 138,000 cubic feet per second at reservoir elevation 3711. The deflector buckets on the downstream end of the spillway direct the water away from the canyon walls to prevent undercutting. Four 96-inch-diameter, steel-lined river outlets are installed near the left abutment of the dam; the centerline inlet elevation to these outlets is 3374 feet. The maximum design capacity of all four outlet pipes is 15,000 cubic feet per second at reservoir elevation 3711. The maximum uprated capacity of the powerplant is 1.364 million kilowatts at a maximum release of 33,000 cubic feet per second.

SUMMARY AND CONCLUSIONS

This report presents the results of the 1986 Lake Powell Sedimentation Survey, the first extensive survey by the Bureau of Reclamation since the reservoir began filling. The primary objectives of this survey were to document the present water storage capacity by elevation, location of sediment deposits, loss of storage from sediment accumulation, and rate of sediment deposition. Other objectives included establishing a set of sedimentation range lines for future monitoring of sediment accumulation and for providing public information refuting claims that the reservoir will shortly fill with sediment.

An original sediment range-line system was established for the Colorado and San Juan River arms and all major tributaries of the entire reservoir. A total of 409 range line locations were surveyed. To take advantage of the nearly full reservoir and to avoid extensive land surveying, the majority of the sediment elevations were determined by a bathymetric survey using sonic depth recording equipment mounted in a power boat. In the wide-bay reservoir areas, the bathymetric survey was run using an electronic depth sounder interfaced with a line-of-sight microwave positioning system capable of determining locations of soundings. The positioning system provided information to the boat operator for maintaining course along each range-line alignment. For all other areas, the boat traversed the range line at a constant speed while depth soundings were being recorded. Water-surface elevations read at the dam were used as the datums in converting depth measurements to true bottom elevations. According to a previous study, the reservoir surface elevation varies no more than a few inches throughout the 150 miles upstream of the dam (Condit, et al.[1][1]). The back-water profile elevations

[1]Numbers in brackets refer to entries in the Bibliography.

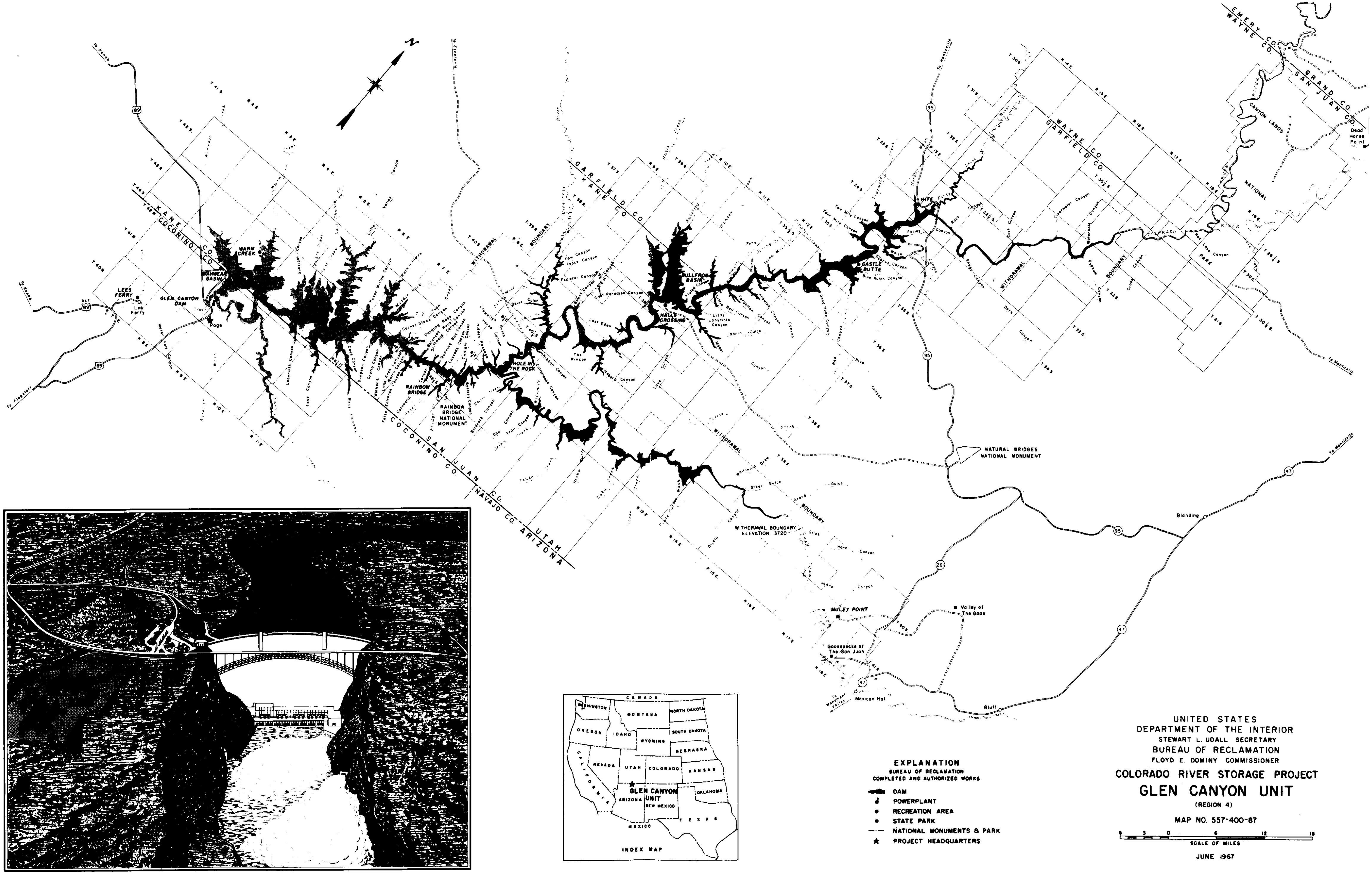

Figure 1. – Lake Powell location map.

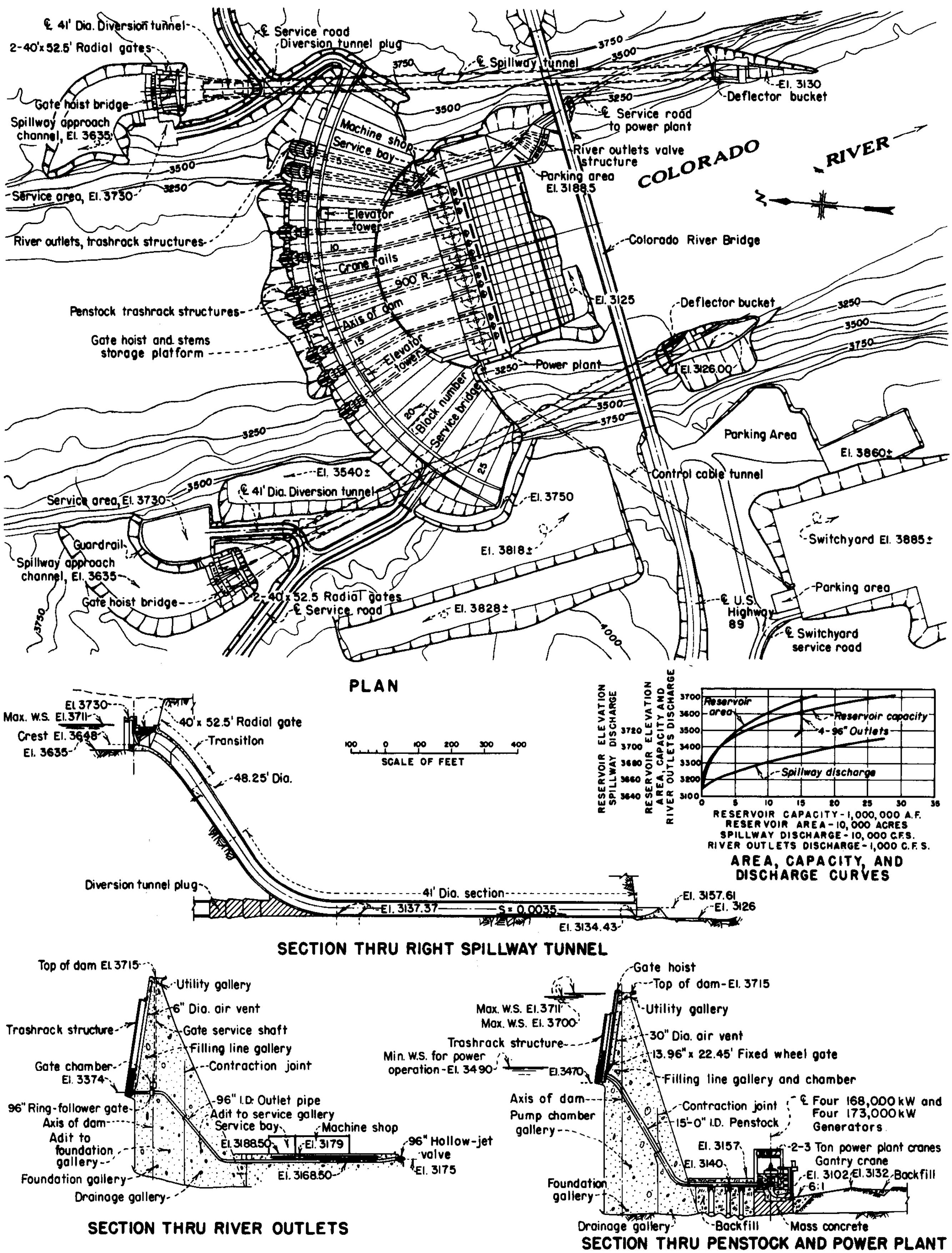

Figure 2. – Glen Canyon Dam and Powerplant, plan and sections.

were surveyed during this study for the extreme upper reaches of the Colorado and San Juan Rivers. These elevations were used as datums for determining the bottom elevation along the range lines in these areas.

The 1986 survey determined that the reservoir has a storage capacity of 26,214,861 acre-feet and a surface area of 160,784 acres at elevation 3700. A computer program determined the reservoir capacity and surface area by using contour surface areas and a curve-fitting technique to compute these values at predetermined elevations.

Since closure of the dam in 1963, the volume of sediment accumulated in the reservoir below elevation 3700 is 868,231 acre-feet. This total sediment volume represents a loss in storage of 3.2 percent. This total volume also includes 52,100 acre-feet of sediment estimated to have accumulated in the channels of the original Colorado and San Juan Rivers. These original river channel volumes were not included in the original storage capacity calculations. The reservoir sediment data and watershed characteristics for the 1986 survey are summarized in table 1.

An average annual sediment accumulation rate of 36,946 acre-feet occurred from March 1963 to September 1986. If this average rate was to continue, it would take more than 700 years for sediment to fill the reservoir to elevation 3700.

DESCRIPTION OF WATERSHED

Drainage Area

The major tributaries draining into Lake Powell are the Colorado, Green, and San Juan Rivers. The basin contains high mountains, some over 14,000 feet in elevation, and many plateaus that are 5,000 to 8,000 feet in elevation. The drainage area above Glen Canyon Dam, as shown in figure 3, is about 107,700 square miles. The current net sediment contributing area is about 82,100 square miles. This area excludes the surface area of Lake Powell; the reservoir surface areas and basins upstream of Crystal, Flaming Gorge, and Navajo Dams; and all other upstream reservoir surface areas and basins above these dams that have areas over 100 square miles. An effective sediment contributing area for the period of study was computed by a method of weighting the drainage basin area for each period between upstream reservoir closures, totaling all of these weighted values, and then dividing by the 23.5-year period of storage. Excluding the surface area of Lake Powell, the effective drainage basin was computed to be 83,150 square miles.

Geology

Glen Canyon Dam is situated in the Colorado Plateau Province, an area characterized by broad, cliff-edged mesas cut by narrow, steep-walled canyons. Lake Powell occupies a long, narrow canyon of the main stem of the Colorado River. Many long, slender arms extend out from the main canyon, where tributaries enter the Colorado River. The confining walls of the main body of the reservoir basin are the massive, smooth, steep, narrow, and straight-sided sandstone cliffs of the Glen Canyon Group made up of the Wingate, Kayenta, and Navajo formations. The San Juan River arm is predominately Triassic beds made up of the Moenkopi, Shinarump, and Chinle formations.

Rising water in Lake Powell caused some slumping of formerly stable cliffs and slopes. The effects of slumping are most noticeable along the Colorado River near Rincon and Good Hope Bays and along the San Juan River near Cha Canyon, Piute Canyon, and Clay Hills Crossing. The total volume of slumped material is impossible to measure, but it is estimated to be small compared to the volume of sediment carried by the major tributaries. The slumping of material below the 3,700-foot level has altered the geometry of the reservoir, but has not affected the capacity of the reservoir. To avoid affecting the sediment storage calculations, range lines were located to omit known slump areas.

Precipitation, Vegetation, and Erosion

The average climate of the Upper Colorado River Basin can be classified as semiarid, varying from wet in the high mountains surrounding the area, to dry-temperate in the higher northern areas, and to arid in the lower southern areas. Thousands of square miles in the lower part of the basin are sparsely vegetated because of inadequate rainfall and poor soil conditions. Rainfall averages from 6 to 8 inches in the lower basin area, mostly from cloudburst storms during the late summer and early fall. The greatest sediment concentrations recorded at gauging stations on the Colorado, Green, and San Juan Rivers have been a result of these storms. In the higher elevation drainage basins where vegetation cover is good, higher precipitation occurs but the streams remain relatively clear. Annual precipitation in the higher mountains occurs mostly as snow, which has resulted in as much as 60 inches of precipitation.

Runoff

The long-term average flow at the USGS (U.S. Geological Survey) gauging station at Lees Ferry for water years 1912-62 was 12.9 million acre-feet per year. The annual flow is extremely erratic, ranging from 4 to 22 million acre-feet annually, as shown on figure 4. In the 23.5 years since closure of the dam in 1963,

Table 1. – Reservoir sediment data summary.

RESERVOIR SEDIMENT DATA SUMMARY

Lake Powell (Glen Canyon Dam)
NAME OF RESERVOIR

1 of 3
DATA SHEET NO.

DAM

1. OWNER Dept of Int. – USBR	2. STREAM Colorado River	3. STATE Arizona & Utah
4. SEC 24 TWP. 41N RANGE 8E	5. NEAREST P O Page, Arizona	6. COUNTY Coconino
7. LAT 36 °56 ' 12 " LONG 111° 29' 00 "	8. TOP OF DAM ELEVATION 3715	9. SPILLWAY CREST ELEV. 3700

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	3711.0	169,790	1,821,000	28,821,000	3-13-63
b. MULTIPLE USE	3700.0	161,390	20,876,000	27,000,000	
c. POWER					
d. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
e. IRRIGATION					
f. CONSERVATION	3490.0	51,600	4,126,000	6,124,000	6-22-80
g. INACTIVE	3370.0	20,640	1,998,000	1,998,000	

17. LENGTH OF RESERVOIR 261[1] MILES	AV. WIDTH OF RESERVOIR 0.43[2] MILES

WATERSHED

18. TOTAL DRAINAGE AREA 107,700 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 5-60 INCHES
19. NET SEDIMENT CONTRIBUTING AREA 83,150 SQ. MI.	23. MEAN ANNUAL RUNOFF 2.25 INCHES
20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 12,923,000[3] AC.-F T.
21. MAX. ELEV. 14,000 (+) MIN. ELEV. 3136	25. ANNUAL TEMP MEAN 45 °F RANGE –60 °F –110 °F

SURVEY DATA

26. DATE OF SURVEY	27.[4] PERIOD YEARS	28.[4] 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.
3/13/63					161,389	27,083,092[5]	2.10
4/86–9/86	23.5	23.5	Range (R)	407	160,784	26,214,861	2.03

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE
3/13/63	5–60	11,550,000[6]	20,620,000[6]	271,424,000[6]		
4/86–9/86					11,550,000[6]	271,424,000[6]

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
3/13/63						
4/86–9/86	868,231	36,946	0.444	868,231	36,946	0.444

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
3/13/63							
4/86–9/86				0.128	3.01		

Table 1. – Reservoir sediment data summary.—Continued

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[8]

WATER YEAR	MAX. ELEV.[8]	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.
1963[7]	3409.7[8]	3233.4	3,218,000	1975	3674.8	3645.3	12,077,000
1964	3491.9	3397.7	6,933,000	1976	3672.2	3655.3	8,516,000
1965	3534.6	3490.9	13,565,000	1977	3654.3	3630.0	5,268,000
1966	3544.9	3521.4	8,688,000	1978	3652.3	3622.7	9,247,000
1967	3532.5	3507.3	7,940,000	1979	3684.3	3628.0	14,029,000
1968	3548.7	3514.0	9,761,000	1980	3700.5	3673.0	12,678,000
1969	3580.5	3540.2	11,332,000	1981	3680.6	3667.5	6,167,000
1970	3600.9	3566.6	11,637,000	1982	3687.3	3662.8	10,767,000
1971	3620.8	3600.8	11,030,000	1983	3707.1	3682.1	19,528,000
1972	3619.6	3603.4	8,526,000	1984	3702.7	3674.1	20,620,000
1973	3648.8	3590.6	14,848,000	1985	3700.1	3676.1	17,486,000
1974	3667.4	3647.1	10,047,000	1986	3699.7	3680.7	17,516,000

46. ELEVATION-AREA-CAPACITY DATA (Original)

ELEVATION	AREA	CAPACITY[9]	ELEVATION	AREA	CAPACITY[9]	ELEVATION	AREA	CAPACITY[9]
3136	0	0	3320	13,775	1,190,036	3520	61,747	7,885,201
3140	29	249	3340	15,986	1,488,663	3540	69,702	9,200,682
3160	1,047	15,513	3360	18,968	1,840,749	3560	78,805	10,686,422
3180	2,373	54,147	3380	22,479	2,256,798	3580	88,148	12,356,551
3200	4,103	123,652	3400	26,676	2,751,292	3600	98,468	14,223,177
3220	5,598	223,781	3420	30,649	3,326,181	3620	109,691	16,305,293
3240	6,962	351,650	3440	35,835	3,992,934	3640	121,511	18,617,762
3260	8,459	508,790	3460	42,113	4,774,505	3660	134,275	21,176,052
3280	10,485	702,070	3480	48,590	5,684,943	3680	147,492	23,994,098
3300	12,110	929,895	3500	54,790	6,719,409	3700	161,389	27,083,092
						3710	169,027	28,735,325

47. REMARKS AND REFERENCES

[1] Includes 186 miles on Colorado River and 75 miles on San Juan River.
[2] 252-mi^2 lake surface area divided by 580 miles which is total length of all tributaries surveyed by this study.
[3] Colorado River at Lees Ferry Arizona. 1912–62.
[4] 3/63–9/86
[5] Adjusted for volume within river channel below surface contours and to conform to current computational method.
[6] Colorado River near Cisco, Utah; Green River at Green River, Utah; and San Juan River near Bluff, Utah, (approximately 90 percent of all inflow).
[7] 3/13/63–9/30/63
[8] Maximum and minimums determined from end-of-month elevation table.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation

50. DATE ______

April 1966

Table 1. – Reservoir sediment data summary.—Continued

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

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
3172	0	0	3360	18,504	1,698,475	3560	75,981	10,215,568
3180	1,249	4,995	3380	22,102	2,104,540	3580	85,667	11,832,048
3200	3,381	51,290	3400	26,062	2,586,177	3600	95,387	13,642,587
3220	5,114	136,241	3420	30,045	3,147,240	3620	105,929	15,655,745
3240	6,752	254,905	3440	34,699	3,794,678	3640	118,054	17,895,574
3260	8,044	402,872	3460	40,361	4,545,281	3660	130,899	20,385,098
3280	10,299	586,303	3480	46,275	5,411,639	3680	145,647	23,150,551
3300	11,906	808,350	3500	52,386	6,398,246	3700	160,784	26,214,861
3320	13,603	1,063,436	3520	59,476	7,516,870	3710	169,027	27,863,919
3340	15,698	1,356,447	3540	67,206	8,783,697			

47. REMARKS AND REFERENCES

[9] Adjusted to include area within river channel below surface contours with sediment.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation

50. DATE ________________

April 1966

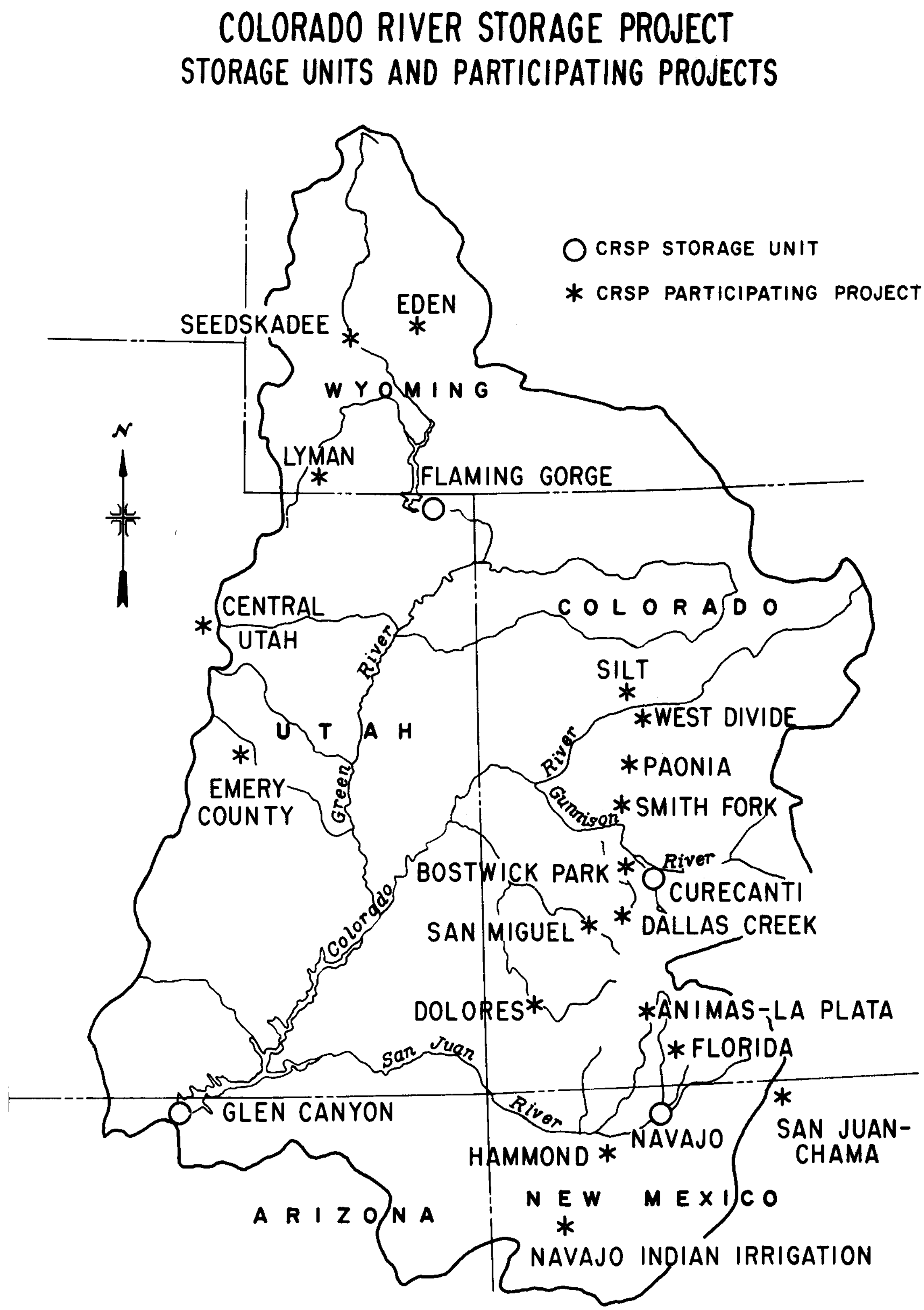

Figure 3. – Drainage area above Glen Canyon Dam.

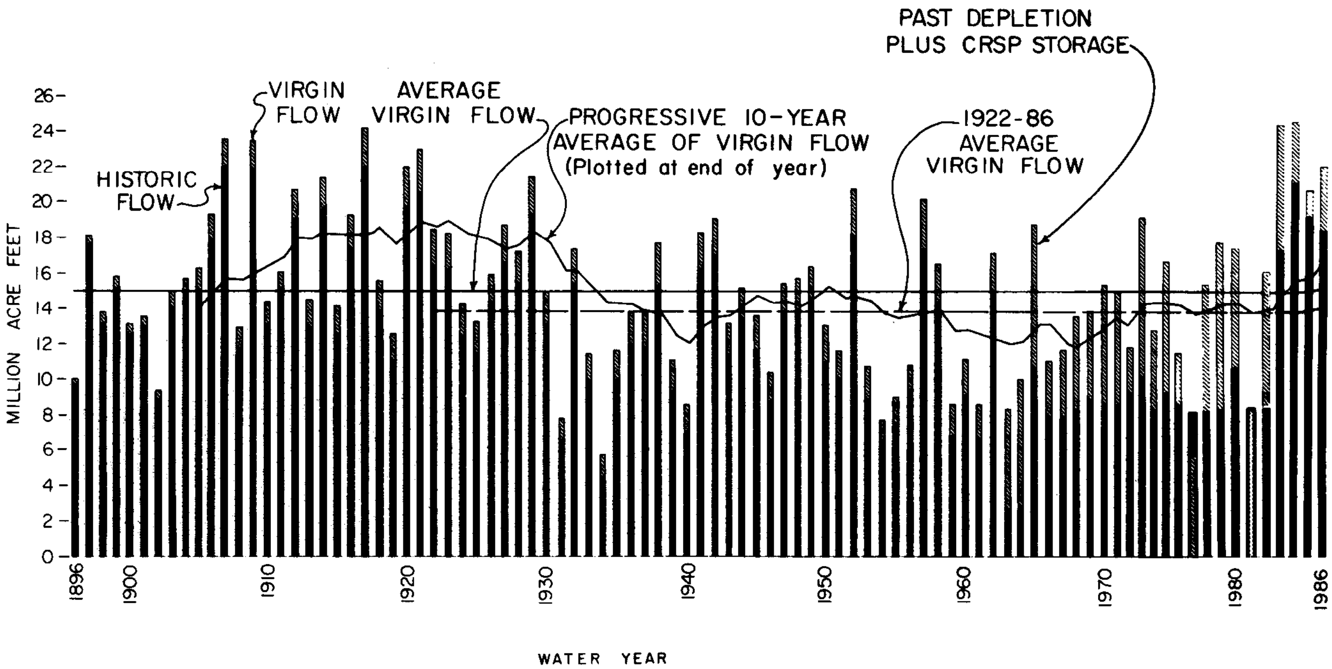

Figure 4. – Flow of the Colorado River at Lees Ferry.

an average of 10.46 million acre-feet has annually flowed past the Lees Ferry gauge.

Table 2 shows the annual inflow into Lake Powell from March 1963 through water year 1985-86. This inflow was measured at USGS gauges on the Colorado River near Cisco, Utah; Green River at Green River, Utah; and San Juan River near Bluff, Utah. These three gauges measure about 90 percent of all inflow into the reservoir. The measured average annual inflow during the period of storage was 11.55 million acre-feet, including the 1977 drought year and the flood years of 1983 and 1984.

RESERVOIR OPERATIONS

The reservoir is designed as a multiple-use facility with 1.821 million acre-feet of exclusive flood control between elevations 3700 and 3711, 20.876 million acre-feet of active conservation storage between elevations 3490 and 3700, 4.126 million acre-feet of inactive storage between elevations 3370 and 3490, and 1.998 million acre-feet of dead storage between elevations 3120 and 3370.

From 1963 to June 1980, Lake Powell was filling to elevation 3700 (shown numerically in table 3 and graphically on figure 5), and releases were made only to meet the conditions of the Colorado River Compact of 1922 and the operating criteria of 1970. During 1963-80, the reservoir was operated to provide storage replacement for upstream irrigation development under the compact, peaking and steady power production, flood control, and reservoir recreation. In addition, the controlled releases provided a trophy trout fishery downstream of the dam and year-round rafting opportunities in the Grand Canyon.

SURVEYS AND EQUIPMENT

Original Survey

The reservoir area topography, excluding the San Juan River arm, was developed from aerial photography flown in 1958 and 1959, and mapped at a scale of 1:4,800 with contour intervals of 10 feet. The San Juan River arm was mapped in 1947 at a scale of 1:12,000 with contour intervals of 20 feet. These topographic maps covered the area from the water surface of the rivers to elevation 3750. The original capacity of the reservoir was determined by the Division of River Control, Bureau of Reclamation, Salt Lake City, Utah, from 301 large-scale topographic maps. The surface areas of each 20-foot contour interval was determined by planimetering each map from elevation 3140 to elevation 3700, and at elevation 3710. A summation of these map areas gave the original surface area for each elevation. Because of insufficient data and capacity, the river channel volume was not included.

Table 2. – Annual inflow into Lake Powell[1]. Values shown are in million acre-feet, and do not include ungauged areas.

Water Year	Colorado River near Cisco, UT	Green River at Green River, UT	San Juan River near Bluff, UT	Total Inflow
1914-57*	5.141	4.067	2.028	12.710
1963†	1.716	1.136	0.366	3.218
1964	3.357	2.784	0.792	6.933
1965	6.403	5.134	2.028	13.565
1966	3.507	3.211	1.970	8.688
1967	3.022	3.999	0.919	7.940
1968	4.093	4.651	1.017	9.761
1969	4.759	4.920	1.653	11.332
1970	5.838	4.268	1.531	11.637
1971	5.633	4.057	1.340	11.030
1972	3.538	4.003	0.985	8.526
1973	6.436	5.388	3.024	14.848
1974	4.514	4.468	1.065	10.047
1975	5.220	4.947	1.910	12.077
1976	3.495	3.863	1.158	8.516
1977	1.905	2.752	0.611	5.268
1978	4.533	3.779	0.935	9.247
1979	6.591	4.373	3.065	14.029
1980	6.219	4.317	2.142	12.678
1981	2.670	2.501	0.996	6.167
1982	4.950	4.256	1.561	10.767
1983	9.192	8.043	2.293	19.528
1984	10.841	7.907	1.872	20.620
1985	8.761	5.928	2.797	17.486
1986	8.055	6.775	2.686	17.516
			Total	271.424
			Average (for 23.5 years)	11.550

[1]These inflow values represent about 90 percent of all inflow into Lake Powell.
*Average annual inflow.
†After closure on March 13, 1963.

Table 3. – Lake Powell end-of-month elevations for 1963–87.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1963	0.0	0.0	3233.4	3282.2	3342.5	3370.5	3372.2	3382.4	3393.6	3397.8	3404.7	3409.7
1964	3414.6	3414.8	3410.2	3397.7	3436.1	3472.5	3484.4	3490.3	3491.7	3491.7	3491.4	3491.9
1965	3491.4	3491.9	3491.9	3490.9	3491.8	3510.8	3530.9	3531.3	3530.1	3531.6	3532.6	3534.6
1966	3535.2	3534.4	3536.1	3539.0	3544.6	3544.9	3540.0	3534.0	3529.5	3527.1	3523.6	3521.4
1967	3517.4	3515.2	3512.5	3507.3	3509.1	3529.7	3532.5	3530.5	3528.5	3528.2	3528.3	3527.1
1968	3525.1	3526.0	3520.5	3514.0	3522.2	3547.0	3546.1	3548.7	3545.4	3543.4	3541.7	3539.3
1969	3540.2	3542.9	3543.6	3552.6	3571.5	3580.0	3580.5	3575.9	3573.3	3574.9	3574.2	3572.1
1970	3569.4	3570.1	3571.3	3566.6	3582.1	3599.1	3600.9	3597.9	3598.9	3599.8	3600.9	3599.8
1971	3600.8	3602.7	3602.9	3603.6	3608.7	3620.8	3620.8	3617.3	3614.2	3614.2	3612.4	3609.6
1972	3607.9	3609.5	3612.7	3610.6	3611.9	3619.6	3615.4	3609.1	3603.4	3609.1	3609.5	3606.2
1973	3601.0	3600.7	3598.1	3590.6	3616.5	3636.4	3644.0	3645.2	3646.0	3645.8	3646.8	3648.8
1974	3647.1	3648.5	3651.1	3652.3	3662.3	3667.4	3662.6	3655.8	3651.7	3650.7	3649.5	3648.3
1975	3645.8	3645.3	3646.1	3647.8	3655.7	3668.9	3674.8	3671.9	3668.1	3666.6	3667.2	3667.9
1976	3666.8	3665.4	3664.7	3664.2	3667.8	3672.2	3670.4	3667.4	3664.0	3661.2	3657.9	3655.3
1977	3651.8	3651.5	3651.2	3652.6	3654.3	3653.6	3649.4	3642.5	3636.7	3635.6	3634.6	3630.0
1978	3625.0	3622.7	3622.7	3626.8	3635.6	3649.6	3652.3	3645.8	3640.1	3637.3	3636.1	3632.8
1979	3628.8	3628.0	3635.0	3646.3	3663.8	3680.4	3684.3	3680.8	3678.1	3676.1	3673.5	3672.7
1980	3673.0	3674.3	3675.5	3677.6	3691.7	3700.5	3696.4	3690.5	3687.8	3685.5	3682.8	3681.3
1981	3679.6	3678.1	3677.8	3677.2	3677.8	3680.6	3677.8	3673.4	3672.0	3671.9	3670.7	3667.5
1982	3663.8	3662.8	3664.0	3665.6	3674.6	3684.9	3687.4	3686.6	3687.3	3687.6	3686.3	3684.7
1983	3683.3	3682.1	3684.6	3685.8	3695.1	3707.1	3707.4	3704.4	3698.7	3694.2	3689.8	3685.2
1984	3680.5	3677.0	3674.1	3674.2	3687.8	3701.3	3702.7	3700.4	3695.9	3693.3	3689.2	3684.8
1985	3680.5	3676.1	3676.5	3684.6	3695.6	3700.1	3697.1	3690.7	3685.7	3686.2	3686.5	3687.2
1986	3685.6	3683.6	3680.7	3682.1	3685.1	3695.0	3699.7	3694.7	3689.6	3689.2	3688.1	3684.4
1987	3679.1	3677.6	3679.4	3684.4	3694.6	3698.4	3696.1	—	—	—	—	—

*All elevations shown in feet.

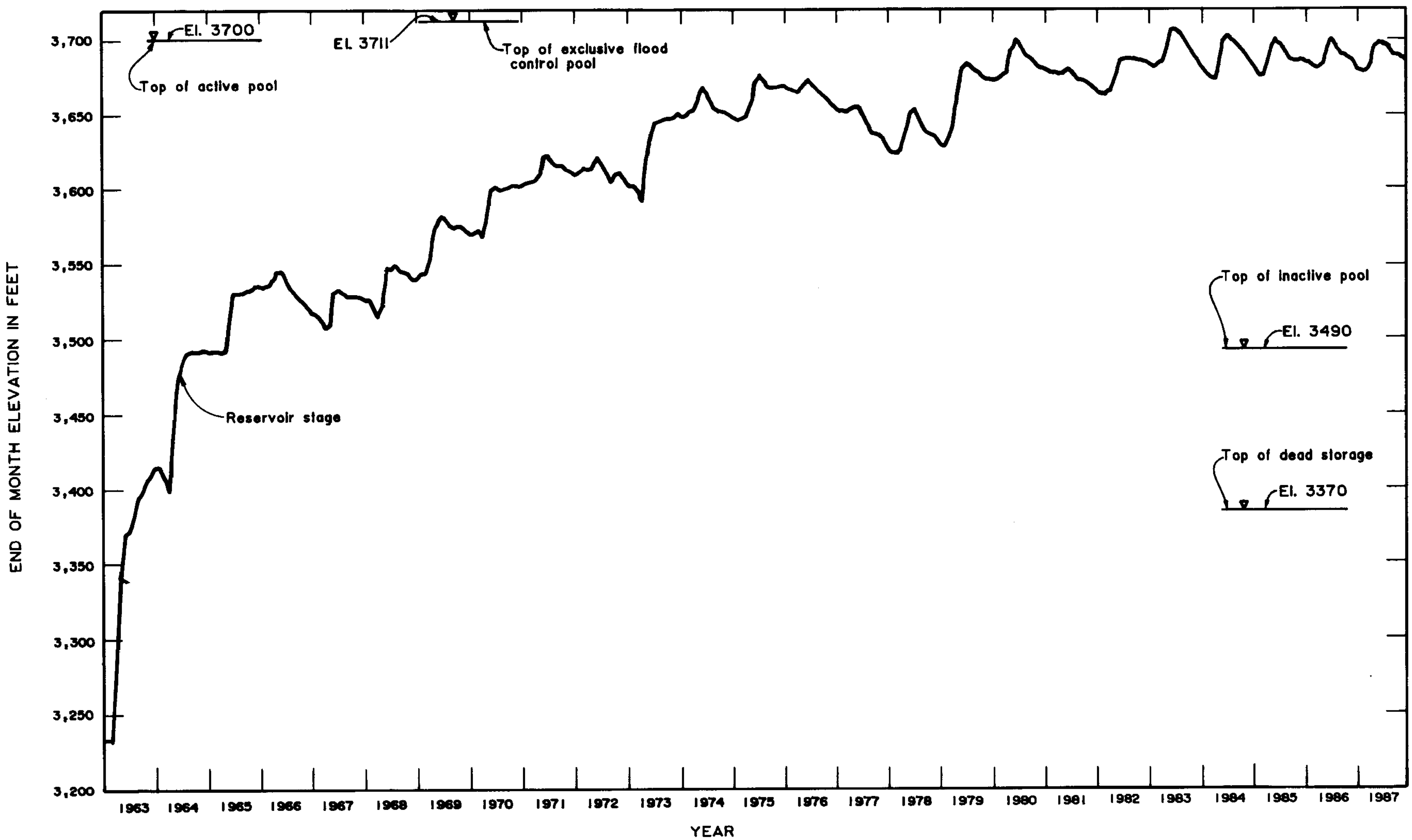

Figure 5. – Reservoir end-of-month elevations for 1963-87.

The original computer program for determining intermediate areas and the storage-elevation relationship was based on power function equations using a curve-fitting method. Capacities were determined by integration of the area curve for 1-foot intervals. Straight-line interpolation was used to obtain capacities at 0.01-foot intervals. Area and capacity tables were published by the Bureau in 1963 [2].

Previous Work

A pre-project study, completed by the Bureau in 1962, concluded the average long-term sediment accumutation rate would be 85,400 acre-feet annually. This estimate considered the effects of the upstream development of reservoirs on the Green, San Juan, and Gunnison Rivers; however, only the sediment load data collected prior to completion of any development were available for reference.

In 1978, a report was issued summarizing the activities and findings of the Lake Powell Research Project, which was a consortium of universities doing interdiciplinary research in the Lake Powell area with funding from the National Science Foundation [1]. This report concluded that 400,000 acre-feet of sediment had accumulated between the 1963 dam closure and the 1977 survey. Assuming the same sediment inflow of 27,000 acre-feet per year, this report estimated it would take 1,000 years for Lake Powell to fill with sediment to the 3,700-foot level.

In 1968, 1970, 1973, and 1976, Bureau personnel conducted underwater surveys of temporary sediment range lines located primarily in the upper reaches of the Colorado and San Juan River arms of the reservoir [3]. Centerline profiles were also obtained for these areas and for several other main tributaries. These surveys were not comprehensive enough to provide an estimate of volumetric changes from sediment deposits.

A 10-year monitoring program was initiated in 1974 to monitor the effects of Lake Powell's intrusion into Rainbow Bridge National Monument [4]. To determine the rate and delineate the pattern of sediment deposition in that portion of Bridge Canyon flowing through Rainbow Bridge Natural Monument, 22 sedimentation sections were established. These data were used in the 1986 sediment study analysis to determine the volume loss.

A set of color aerial photographs of Lake Powell, scaled at about 1:12,000, was obtained during July 1980 when the reservoir was nearly full. These photographs, in combination with the original topographic sheets, were used to locate and identify range lines. They will also serve as a permanent record for locating established range lines.

Bureau personnel examined the major delta areas of the reservoir by helicopter on April 9-10, 1985. The purpose of this examination was to evaluate the survey methods that could define both the underwater and exposed portions of the delta areas and to determine if range-line locations could be found using aerial photographs and topographic maps. Figures 6 through 9 show some of the delta areas formed in the reservoir at about or above elevation 3677.

1986 Survey

Field work for the survey began in April and ended in September of 1986. To complete the analysis, a few additional lines were surveyed in late June and early July of 1987. A total of 409 range lines were surveyed, their locations are shown on figure 10. The first week of field work consisted of testing the electronic sonar depth-measuring equipment and surveying a grid system to be used with the automated positioning system.

The 1986 survey used the range-line method, described in the Bureau's *Procedures for Monitoring Reservoir Sedimentation* [5]. This method consists of measuring existing sediment profiles and comparing them to section profiles taken from original topographic maps. Sedimentation range lines were not established prior to the initial reservoir filling, therefore, this study had to compare the existing sediment profile with the land surface and river water surface elevations obtained from the pre-inundation topographic maps.

The initial step prior to collection of field data was to establish a range-line system. Sediment range-line locations proposed by the Bureau in 1968 were used as a guide; however, many locations were adjusted to provide more sediment range lines in tributary canyons and fewer lines in the steep canyon areas of the main reservoir.

Because of the variety of conditions encountered, several positioning techniques were used to determine the position of the boat as it traversed the sediment range lines. Bay areas—such as Wahweap, Bullfrog Bay, Halls Creek Bay, Warm Creek, Padre Bay, Last Chance, and Rock Creek—required ground surveys to establish coordinates as a control for the automated survey system. The control system required horizontal grid coordinates for all range-line ends and fixed shore stations, and elevations of all the grid points. The bay areas were of such large widths that the automated system was needed to keep the sounding boat on line. A sonic depth recorder interacting with an automated positioning system continuously measured reservoir depth and sounding position as the survey boat traversed each range line (figs. 11 and 12). To compute the location,

Figure 6. – San Juan arm delta located just upstream of Piute Farms. P801–D–81395

Figure 7. – Upper delta of Escalante Canyon. P801–D–81396

the positioning system transmitted line-of-sight microwave signals to fixed shore stations. The system on the boat then converted the reply into time-to-range distances for the data logger. The system transmitted signals to the boat operator to maintain course while the depth and position data were recorded on a computer printout and plotted by the depth recorder.

The majority of the profile lines were measured using the constant-speed positioning method. This method requires a constant boat speed and maintaining a straight line between two fixed points, and it was selected because of the relatively narrow width and steep wall canyons of the reservoir and the nature of the sediment surfaces. By using the topographic maps and aerial photographs, the proposed range-line alignments were located in the field to be as perpendicular to the natural stream channel as possible. Once the markers for each end of the range lines were set, a crew member equipped with field glasses and a two-way radio would guide the survey

Figure 8. – Colorado River near Gypsum Canyon. P801–D–81397

Figure 9. – Upper delta area of Navajo Canyon. P801–D–81398

boat along the range-line alignment. This method provided accurate results because of the horizontal deposition of the sediment at the majority of the range lines. Profiles with channel cuts through the deposited sediments occurred during lower reservoir elevations, and were found in the upper ends of the reservoir. The constant-speed method was also used in these upper delta areas. Good results were obtained because of the short distances traversed at these range lines.

A permanent marker (a 2-inch-diameter aluminum cap) was placed for future reference at each end of the majority of the range lines surveyed. If an erodable bank or distinct feature marked the end of a line, a permanent marker was not placed. Attempts were made to place all markers at an elevation of 3,700 feet or higher. The range-line end locations were marked on the topographic maps and aerial photographs. Ground photographs and a written description also documented each range-line end.

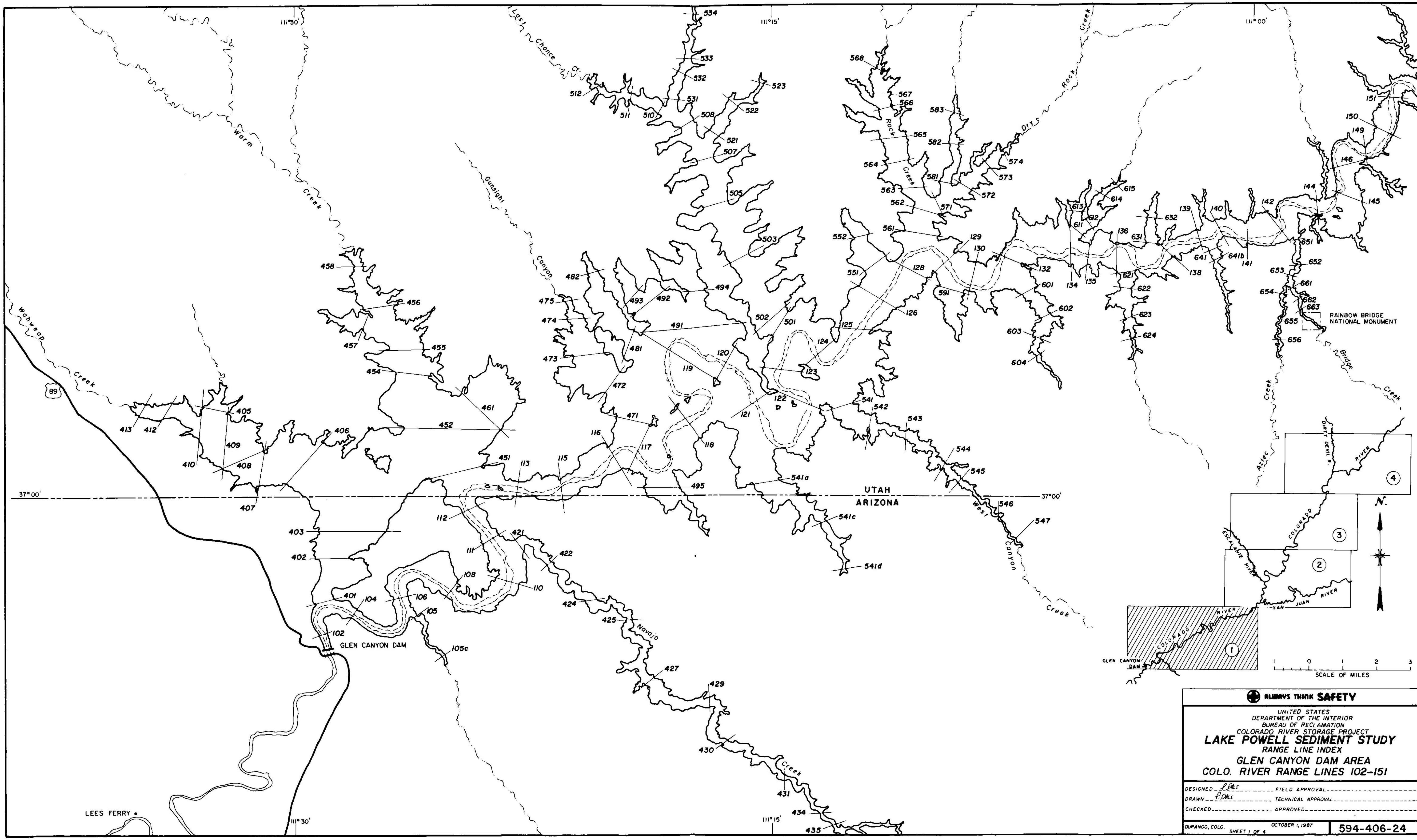

Figure 10. – Locations of sediment range lines (sheet 1 of 4).

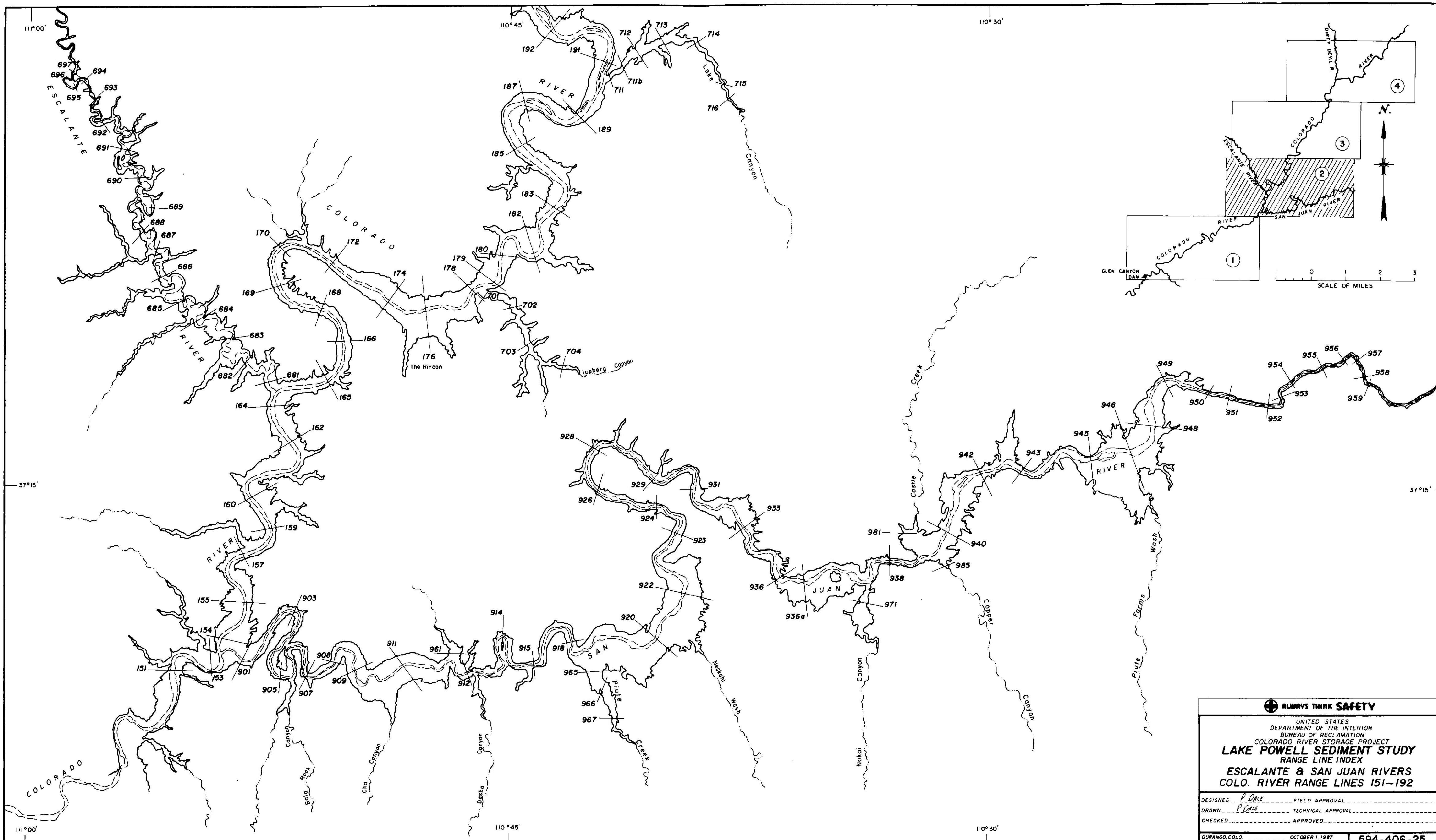

Figure 10. – Locations of sediment range lines (sheet 2 of 4).

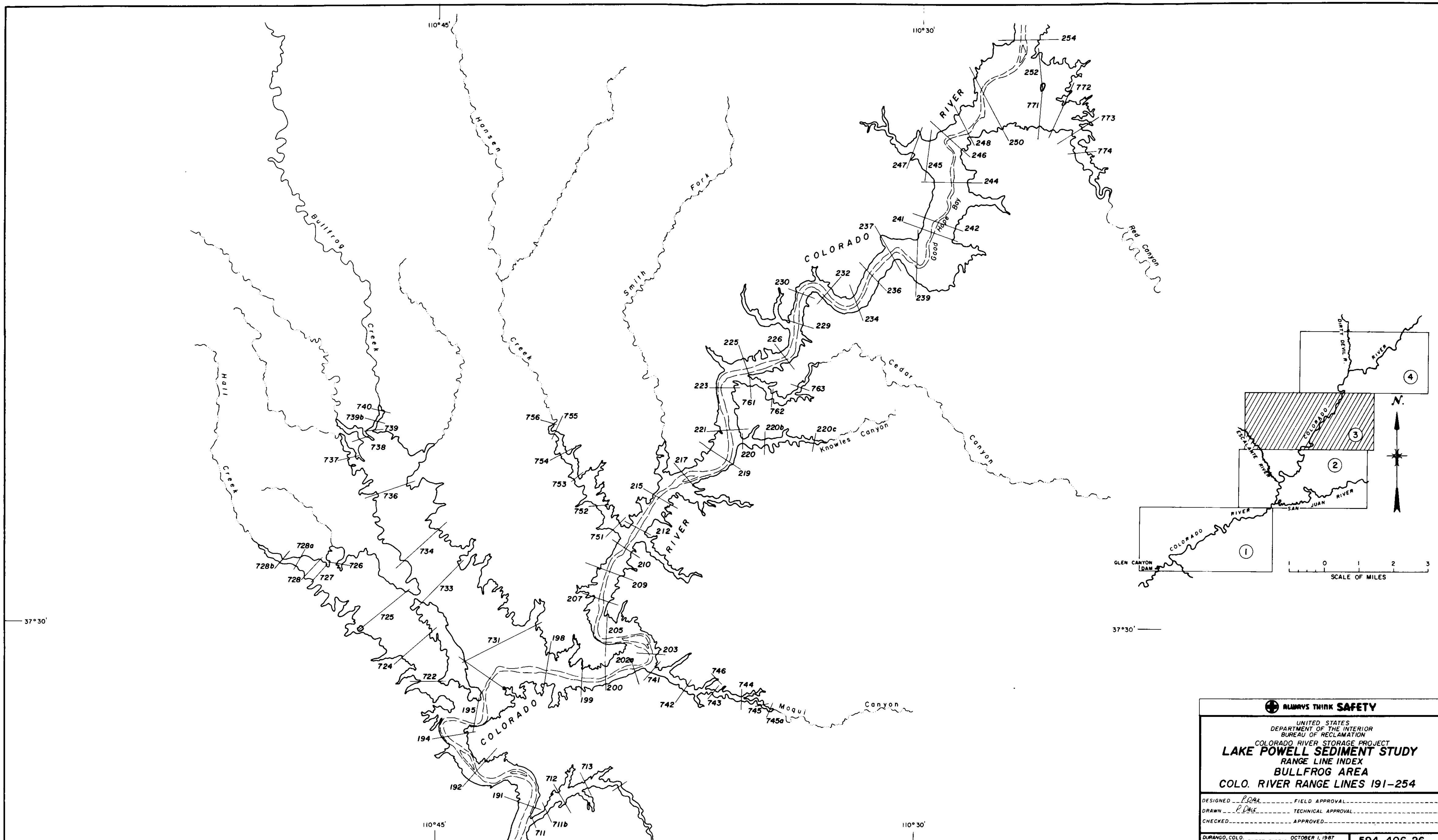

Figure 10. – Locations of sediment range lines (sheet 3 of 4).

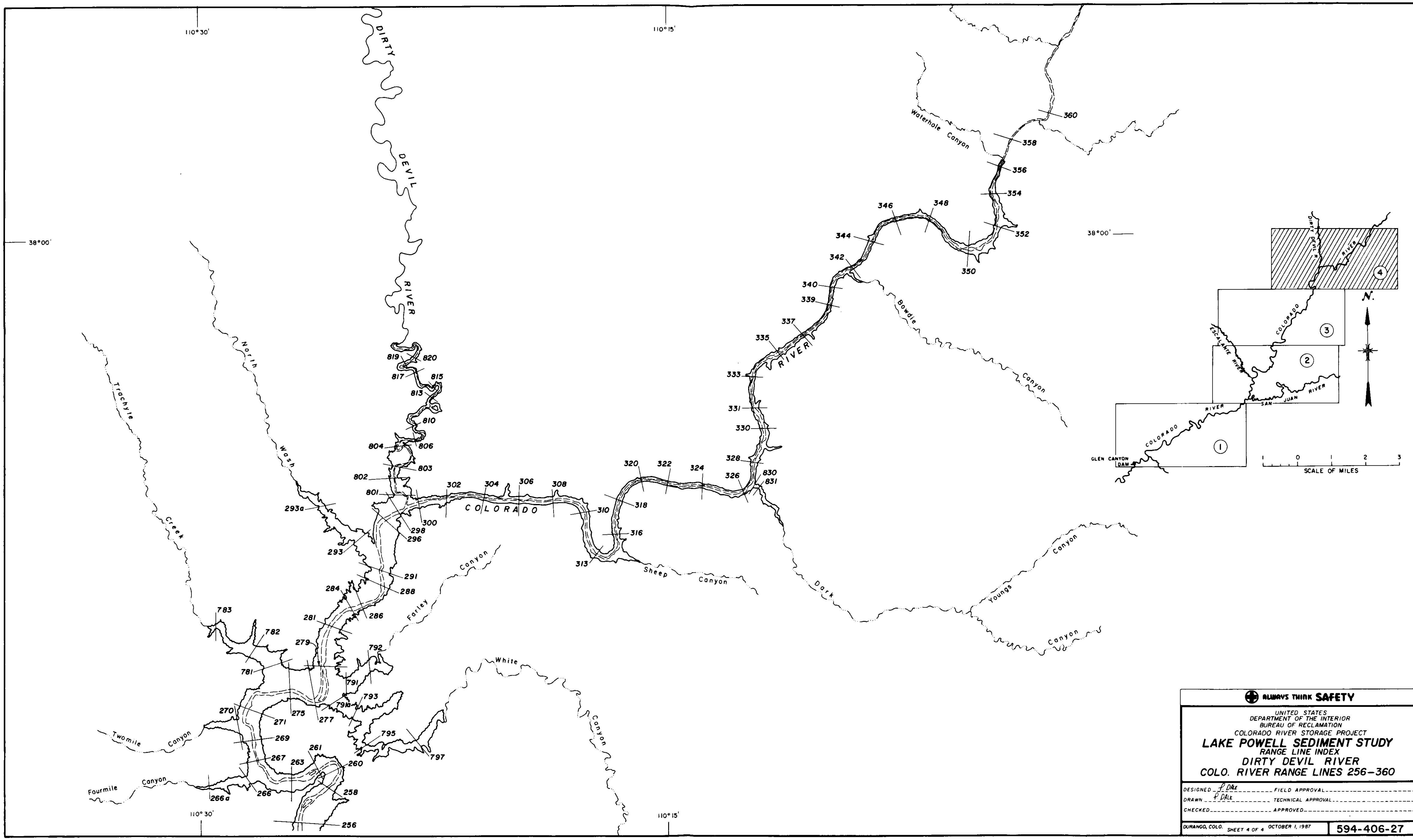

Figure 10. – Locations of sediment range lines (sheet 4 of 4).

Figure 11. – Microwave receiver-transmitter at shore station. P801–D–81399

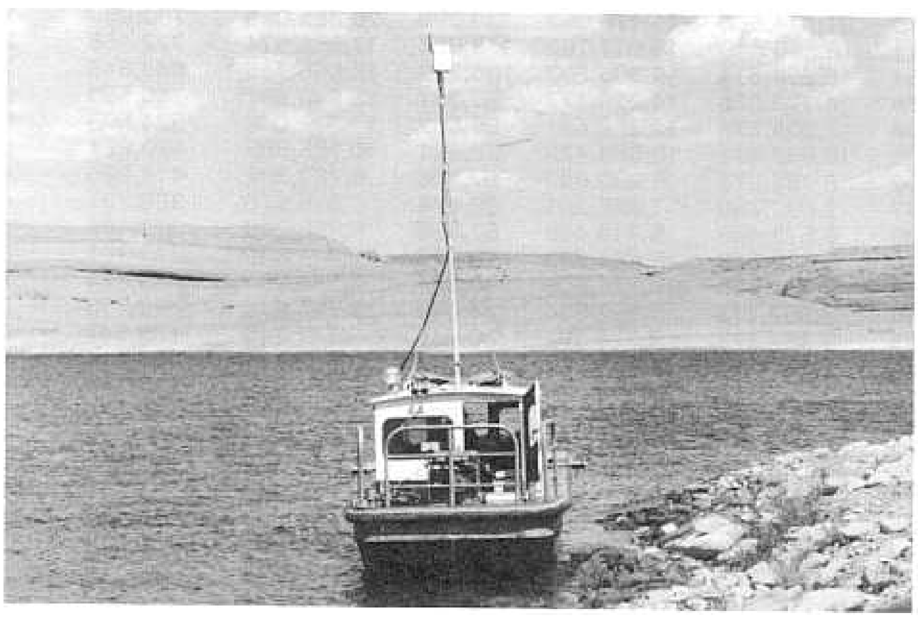

Figure 12. – Survey boat with automated survey system. P801–D–81400

RESERVOIR AREA AND CAPACITY

Development of 1986 Contour Areas

New Lake Powell surface areas were developed in 1986 for each 20-foot contour interval from elevation 3140 to elevation 3700. The main channel from the dam to the upstream end of the reservoir in Cataract Canyon and the different tributaries from their confluence to their upper ends were analyzed separately.

The areas occupied by sediment were developed by plotting the 1986 average bottom profile versus the original river profile, and determining the new horizontal location of each 20-foot contour interval on the profile. These locations were then transferred to the original topographic maps. Digitizing surface areas between the new and original contours described the areas filled with sediment. The 20-foot contour interval surface areas were calculated by subtracting these measured sediment-filled areas from the original surface areas. The final 20-foot elevation interval areas are presented in column (5) of table 4.

The maximum elevation that the reservoir has reached is 3708.4 feet, therefore, this study assumed no surface area changes from the 1963 totals at reservoir elevation 3710. Sediment does exist above elevation 3700 and there are some negligible amounts above elevation 3710; however, this sediment was deposited in the upper deltas of the San Juan and Colorado Rivers through the backwater effect when the reservoir was at its highest elevation of 3708.4 feet. Since then, undercutting and erosion by the rivers have caused much of this delta deposit to either slump below elevation 3710 or be transported downstream to lower elevations.

Revised Storage Capacity

The storage-elevation relationships based on the 1986 survey data were developed using the Bureau's computer program ACAP (Area-Capacity Computation Program) [6]. For determining change in reservoir storage, the original storage-elevation relationship was recomputed using ACAP. The "surface area versus elevation" and "storage capacity versus elevation" relationships are graphically shown on figure 13.

Table 4. – Summary of 1986 survey results.

(1) Elevation (feet)	(2) 1963 area (acres)	(3) 1963 capacity (acre-feet)	(4) Adjusted 1963 capacity (acre-feet)	(5) 1986 area (acres)	(6) 1986 capacity (acre-feet)	(7) Measured sediment volume (acre-feet)	(8) Percent of measured sediment	(9) Percent of reservoir depth
3700	161,389	27,030,992	27,083,092	160,784	26,214,861	868,231	100.0	100.0
3680	147,492	23,942,178	23,994,098	145,647	23,150,551	843,547	97.2	96.4
3660	134,275	21,124,505	21,176,052	130,899	20,385,098	790,954	91.1	92.9
3640	121,511	18,566,640	18,617,762	118,054	17,895,574	722,188	83.2	89.4
3620	109,691	16,254,614	16,305,293	105,929	15,655,745	649,548	74.8	85.8
3600	98,468	14,173,026	14,223,177	95,387	13,642,587	580,590	66.9	82.3
3580	88,148	12,306,875	12,356,551	85,667	11,832,048	524,503	60.4	78.7
3560	78,805	10,637,346	10,686,422	75,981	10,215,568	470,854	54.2	75.2
3540	69,702	9,152,272	9,200,682	67,206	8,783,697	416,985	48.0	71.6
3520	61,747	7,837,780	7,885,201	59,476	7,516,870	368,331	42.4	68.1
3500	54,790	6,672,409	6,719,409	52,386	6,398,246	321,163	37.0	64.5
3480	48,590	5,638,609	5,684,943	46,275	5,411,639	273,304	31.5	61.0
3460	42,113	4,731,586	4,774,505	40,361	4,545,281	229,224	26.4	57.4
3440	35,835	3,952,113	3,992,934	34,699	3,794,678	198,256	22.8	53.9
3420	30,649	3,287,273	3,326,181	30,045	3,147,240	178,941	20.6	50.4
3400	26,676	2,714,017	2,751,292	26,062	2,586,177	165,115	19.0	46.8
3380	22,479	2,222,461	2,256,798	22,102	2,104,540	152,258	17.5	43.3
3360	18,968	1,807,989	1,840,749	18,504	1,698,475	142,274	16.4	39.7
3340	15,986	1,458,455	1,488,663	15,698	1,356,447	132,216	15.2	36.2
3320	13,775	1,160,848	1,190,036	13,603	1,063,436	126,600	14.6	32.6
3300	12,110	901,997	929,895	11,906	808,350	121,545	14.0	29.1
3280	10,485	676,043	702,076	10,299	586,303	115,773	13.3	25.5
3260	8,459	486,600	508,790	8,044	402,872	105,918	12.2	22.0
3240	6,962	322,388	351,650	6,752	254,905	96,745	11.1	18.4
3220	5,598	206,786	223,781	5,114	136,241	87,540	10.1	14.9
3200	4,103	109,775	123,652	3,381	51,290	72,362	8.3	11.3
3180	2,373	45,010	54,147	1,249	4,995	49,152	5.7	7.8
3172	1,843	28,146	38,693	0	0	38,693	4.4	6.4
3160	1,047	10,809	15,513	0	0	15,513	1.8	4.3
3140	29	57	249	0	0	249	0	0.7
3136	0	0	0	0	0	0	0	0

Explanation of columns:
(1) Elevation of reservoir water surface.
(2) Original reservoir water surface area.
(3) Original reservoir capacity computed in 1986 using ACAP computer program.
(4) Original reservoir capacity adjusted for 1986 sediment volume within river channel below surface contours.
(5) Reservoir surface area from 1986 survey.
(6) Reservoir capacity from 1986 survey.
(7) Measured sediment volume = column (4) - column (6).
(8) Measured sediment expressed in percentage of total sediment (868,231 acre-feet).
(9) Depth of reservoir expressed in percentage of total depth (564 feet).

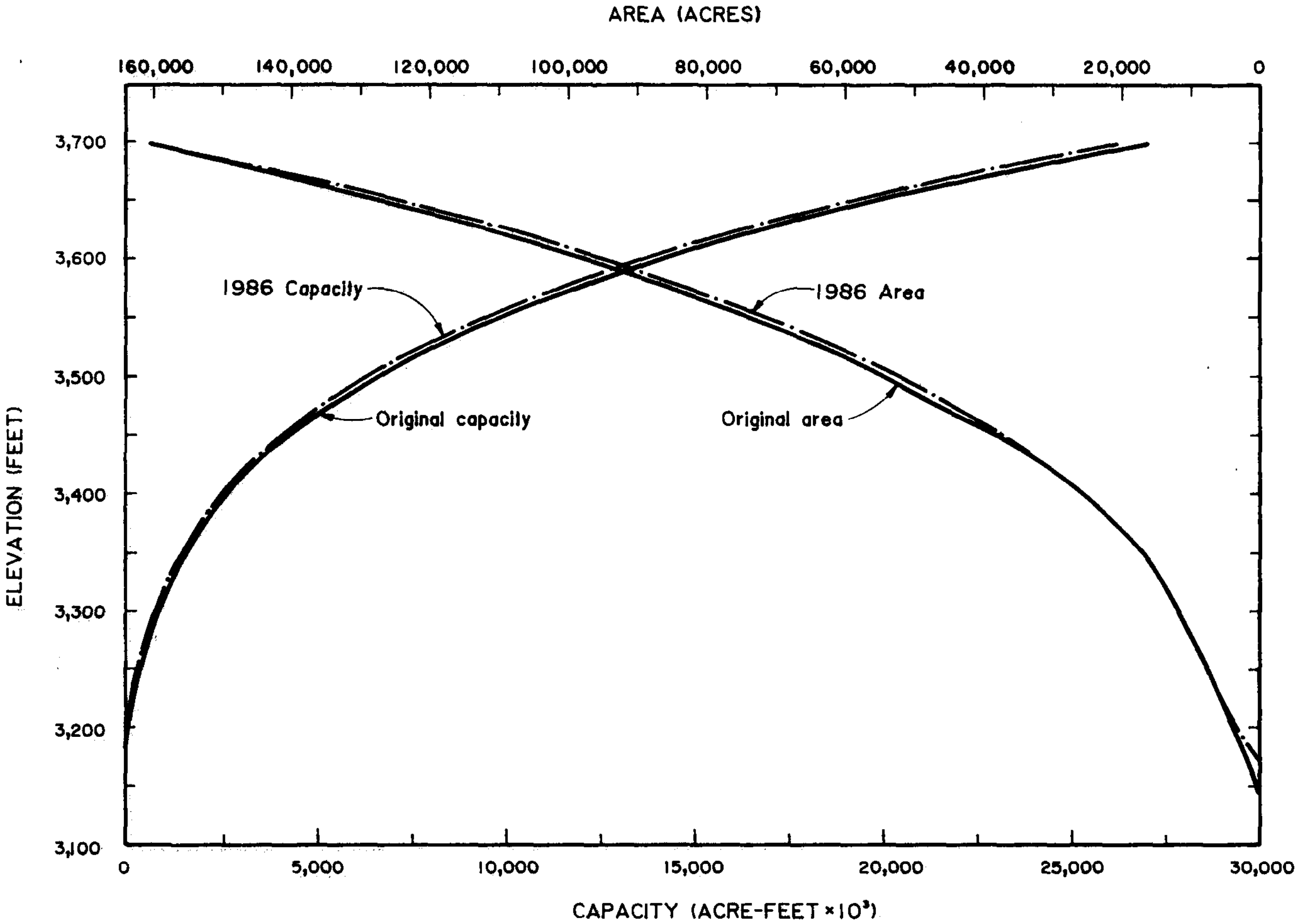

Figure 13. – Area and capacity curves.

Surface areas at 20-foot contour intervals computed from the 1986 survey data were used as the control parameters for computing reservoir capacity. The computer program was written to include computation of 0.01- to 1.0-foot area increments by linear interpolation between the 20-foot contour intervals. The computer program begins by testing the initial capacity equation over successive intervals to check whether it fits within an allowable error limit, which was set at 0.000001 for Lake Powell. This 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) begins testing the fit until it also exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

$$y = a + bx + cx^2 \qquad (1)$$

where:

y = capacity,
x = elevation above a reference base,
a = intercept, and
b and c = coefficients.

Results of the 1986 Lake Powell area and capacity computations are listed in table 4, columns (5) and (6). The maximum 1986 reservoir capacity at elevation 3700 was computed to be 26,214,861 acre-feet, representing a loss in storage of 868,231 acre-feet since reservoir filling began. This storage loss is derived solely from a comparison of the adjusted original capacity with the 1986 computed capacity at elevation 3700.

To determine this storage loss, the original capacity was adjusted to determine a more accurate volume of sediment storage. Since the original capacity came from a computer program no longer used, it was recomputed using ACAP. The result using ACAP was an additional 30,992 acre-feet of storage at reservoir elevation 3700, as shown in column (3) of table 4. The original capacity developed by planimetering the reservoir topographic maps did not include the old river channel volumes of the Colorado and San Juan Rivers. An analysis of this omitted volume, calculated from elevation 3140 to 3700, resulted in 57,800 acre-feet of additional storage.

The 1986 survey found that only 90 percent (or 52,100 acre-feet) of the old river channel has filled with sediment. The unfilled areas occurred in the Colorado River channel in areas between elevation 3270 and 3400 and in the upper end above elevation 3660. This omitted storage area was not used in developing the revised area-capacity tables because this area was not included in the original area-capacity determination. However, for determining the volume of sediment storage in the reservoir and the basin yield characteristics, this omitted storage that is now filled with sediment and the additional calculated storage using the ACAP program have been considered in the analyses. As shown in column (4) of table 4, the original capacity determined from the ACAP program was adjusted to include the original channel volume, now consisting of 52,100 acre-feet of sediment, for the respective reservoir elevations.

Sediment Accumulation

The 1986 survey results indicate that 868,231 acre-feet of sediment have been deposited below elevation 3700 since dam closure in March 1963. The average rate of sediment deposition between closure and September 1986 (23.5 years) was 36,946 acre-feet per year, or 0.444 acre-feet per square mile per year for the sediment contributing area. This measured annual rate is about 43 percent of the original estimate of 85,400 acre-feet per year [7]. As shown in table 2, the average annual inflow measured at the three stream-gauging stations was 11.55 million acre-feet for the 23.5-year period of study. This total is about 91 percent of the 1914-57 average measured at these gauges.

The annual suspended sediment was measured at the stream gauging stations upstream of the reservoir on the Colorado and Green Rivers during 1914-84, and on the San Juan River during 1914-80, as shown in table 5. The average of the annual suspended sediment collected at these gauges from 1963 until their discontinuance showed a marked decrease from the 1914-57 average. The reduction in sediment deposition over that originally estimated may reflect land-use controls such as grazing restrictions and seeding programs, changes in climatic conditions, and the major upstream storage facilities at Blue Mesa (1965), Flaming Gorge (1962), and Navajo (1962). The records show most of the decrease in the measured annual suspended-sediment occurred before 1963, an indication of the impact of rangeland management practices on decreasing erosion rates [8].

Of the 868,231 acre-feet of measured volume lost due to sediment, it was determined that 54 percent (or 472,000 acre-feet) occurred in the Colorado River area; 32 percent (or 281,000 acre-feet) occurred in the San Juan River area; and 14 percent (or 115,000 acre-feet) occurred in the remaining tributaries. These are the measured volume losses due to sediment deposits, and are not indicative of the sediment that each of these areas contributes. Deltas of several of the reservoir tributaries, such as the San Juan and Dirty Devil Rivers, have intruded into the main channel storage area.

RESERVOIR SEDIMENT DISTRIBUTION

Longitudinal Distribution

Two sets of plots describe the distribution of sediment for the two main tributaries of the reservoir, the Colorado and San Juan Rivers. The longitudinal profiles for the original river surface and the 1986 average bottom elevation are plotted on figure 14 for the Colorado River and on figure 15 for the San Juan River. The profile lines on figure 14 start at the dam and proceed upstream to the headwaters of Cataract Canyon, while the profile lines on figure 15 start at the San Juan River confluence and proceed upstream to the headwaters 25 river miles above Piute Farms Wash. The average bottom 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. These average depths were used to compute the average bottom elevation for each range line. The progressive growth of deltas in the reservoir is best illustrated using the average bottom elevation plots because they display a sediment surface closely approximating the actual sediment surface of the range line. The river channel length is measured along the centerline of the original channel on the topographic maps.

The Colorado and San Juan River profiles indicate several delta-like formations in the reservoir. The main channel indicates deposits occurring in the lower portions upstream to Good Hope Bay (mile 0 to 135) and a typical delta forming upstream of this area. Since the original profile is of the old river's water surface and not the river channel bottom, some areas have little to no sediment from elevation 3269 to 3393, causing the 1986 profile to plot below the original profile of the main channel. The sediment deposits in the lower portions of the reservoir, measured from elevation 3140 to 3270, are sediments that entered during construction and from fine-grain sediment inflow during the life of the reservoir. The cofferdam used during construction, February 1959 through March 1963, had a top elevation of 3,300 feet and seasonally backed water upstream, allowing sediment to settle in the channel. During low river flows, the back waters receded, causing channeling

Table 5. – Annual suspended sediment inflow into Lake Powell[1].

Water Year	Colorado River near Cisco, UT	Green River at Green River, UT	San Juan River near Bluff, UT
1914-57*	14.350	20.800	37.100
1963	4.830	5.730	12.880
1964	10.000	12.090	16.340
1965	17.410	17.880	34.830
1966	5.490	6.450	13.130
1967	8.460	11.740	17.070
1968	11.610	7.970	20.770
1969	9.390	8.980	31.670
1970	9.240	7.400	23.620
1971	5.460	5.370	15.000
1972	3.540	5.160	13.530
1973	14.550	15.070	72.080
1974	4.140	10.620	3.380
1975	7.380	10.890	16.100
1976	2.610	4.430	3.890
1977	2.960	2.750	3.520
1978	13.280	7.690	3.230
1979	10.900	8.430	27.820
1980	8.510	10.280	11.780
1981	2.040	2.380	Discontinued
1982	8.170	9.140	—
1983	19.070	19.960	—
1984	22.980	17.880	—
1985	Discontinued	Discontinued	—
Totals	202.020	208.290	340.640
Average	9.183	9.468	18.924

[1] Values shown are in million tons.
* Average

through previously deposited sediment and the transport of a portion of this sediment downstream toward the dam. This study did not distinguish between the pre- and post-dam sediment volumes. Consequently, to determine annual rates, the use of 23.5 years in the calculations ignored any volumes of sediment accumulated during construction.

The delta in the upper end of the Colorado River arm of the reservoir, above river mile 135, starts forming around elevation 3400 and reflects the prevailing reservoir elevations over the last 23.5 years. The average sediment thickness above Hite, river mile 154 to 182, was 127 feet. The elevation of the pivot point, where the sediment profile starts to flatten out, is about 3,670 feet. The pivot point will usually occur near the mean operating pool level, which has been about elevation 3685 since Lake Powell filled in June 1980. The reservoir has not been as low as elevation 3670 since 1982. The pivot point is at this lower elevation because the high velocity and sediment bearing flows enter the narrow canyon of the Colorado arm and move the sediment farther downstream.

The San Juan River profile (fig. 15) shows a small sediment deposit at the mouth, with the depth of the delta progressively increasing in the upstream direction. The small deposits at the mouth, elevation 3300 and below, were probably deposited during construction, the initial filling, and as a result of the settling of fine-grain suspended sediment as it moved downstream. The delta forming upstream of elevation 3300 reflects the reservoir elevations since filling began in 1963. The average thickness of the sediment layer at the upper end is 56 feet, or 71 feet less than the average thickness of sediment in the Colorado River channel. The elevation of the pivot point at the upper end of the San Juan is about 3,690 feet, near Lake Powell's mean operating pool elevation over the last several years and 20 feet higher than the pivot point on the Colorado River. This 20-foot difference results from the lower river velocities and higher sediment concentration occurring on the San Juan River at the upper delta area. Unlike the Colorado arm, this part of the reservoir widens to a large bay near the pivot point in the Piute Farms area.

The longitudinal profiles for the Colorado River channel are shown in dimensionless form on figure 16, a plot of percent depth versus percent distance. This plot permits the comparison of the deposition profile versus original river surface profile without scale interference. The percent depth of the original survey

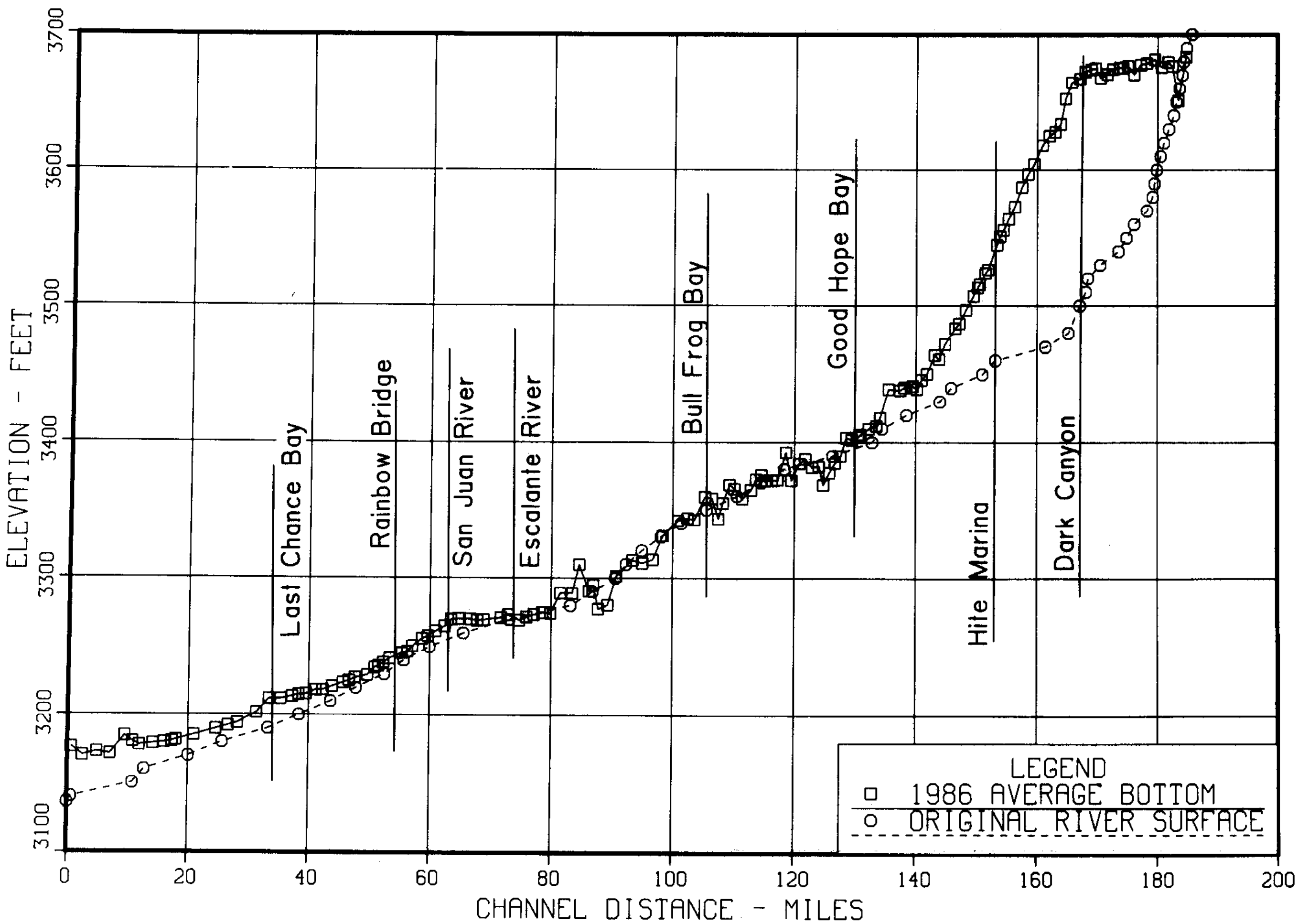

Figure 14. – Profile of Colorado River showing original river surface and 1986 average bottom profile.

is the ratio of the river water surface depth at each range-line location to the total depth. In comparison, the percent depth of the 1986 survey is the ratio of the average bottom depth at each range-line location to the total depth. The total depth of 564 feet represents the difference between the top of the spillway gates, elevation 3700, and the original low point in the reservoir profile, elevation 3136. The percent distance was computed as the ratio of the channel distance between the dam and a given range line to the total distance of 185.7 miles from the dam to the upstream point in the river where the 3,700-foot contour crosses.

Bottom surface data were collected to develop profiles for most of the smaller tributaries, with Dirty Devil Canyon being the only one having any significant amount of sediment deposition. The build-up is significant for this small canyon; however, it is only a small percentage of the total reservoir sediment volume. The smaller tributaries store only an estimated 14 percent of the total reservoir sediment volume. Profiles along Dirty Devil and Escalante Canyons are shown on figures 17 and 18. These profiles illustrate the original river surface elevation compared to the 1986 average bottom elevation. The profiles begin at the mouth and proceed upstream to the crossing of the 3,700-foot contour and above. To illustrate the average sediment bottom in the upper portion of the channel, a line was drawn between the most upstream measured bottom elevation and the original 3,708-foot contour location. Since the maximum reservoir elevation has been about 3,708 feet, sediment deposition was assumed to extend up to that elevation. Additional tributary profiles are shown at the end of this report.

Depth Distribution

The measured distribution of sediment in the reservoir is plotted on figure 19 as the percent reservoir depth versus percent sediment deposited. The sediment volumes and depth data are from columns (8) and (9) of table 4. Design curves for Type I and Type II reservoirs are also plotted against this measured curve. The curve indicates that, during the first period

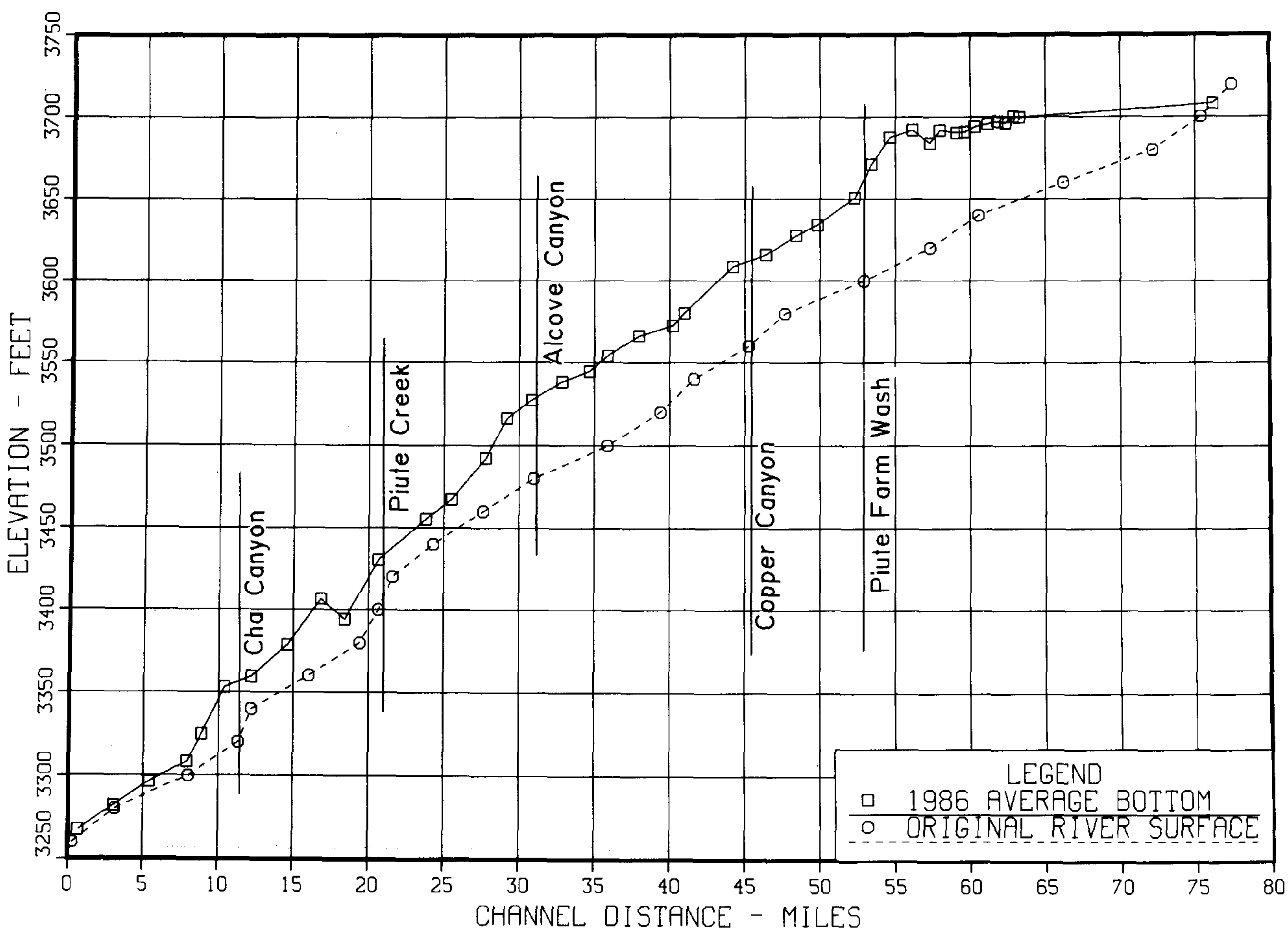

Figure 15. – Profile of San Juan River showing original river surface and 1986 average bottom profile.

of reservoir operation, the measured sediment distribution is best described by a Type I design curve, although a Type II curve was used during the planning studies. The Type I curve describes a reservoir with sediment always or nearly always submerged, while the Type II curve describes a reservoir with sediment exposed by normally moderate to considerable reservoir drawdown.

The curve shows that 80 percent of the volume of the total sediment deposit is stored in the reservoir area above elevation 3420, 50 percent stored above elevation 3550, and 30 percent above elevation 3600. The nature of this distribution is due to reservoir operation, shape of reservoir, and timing of major sediment inflows. Figures 5 and 20 show that reservoir elevations have fluctuated; but have been above elevation 3550 about 80 percent of the time, above elevation 3600 about 73 percent of the time, and above elevation 3650 about 48 percent of the time. The highest annual inflow normally occurs when the reservoir is approaching maximum annual elevation, with the sediment depositing in the lower velocity portion of the reach. Because of the narrow shape of the reservoir at the upper end of the Colorado and San Juan River channels, the inflow velocity is high enough to transport the majority of the sediment downstream. Also, the space in the most upper portion of the reservoir area capable of storing sediment is nearly full. Operation of the reservoir results in the water surface fluctuating 25 or more feet per year, with the fluctuation during the last 10 years occurring in the upper portion of the reservoir's active pool. During any future drawdown of the reservoir, a considerable amount of the sediment currently stored in the upper reach will be transported to lower reservoir elevations by the velocity of the river inflows.

Lateral Distribution

Table 6 summarizes the data for the 409 sedimentation range lines. The locations of these lines were shown on figure 10. The sediment is shown to have been deposited to average depths ranging from about 1 foot in several channels to about 182 feet

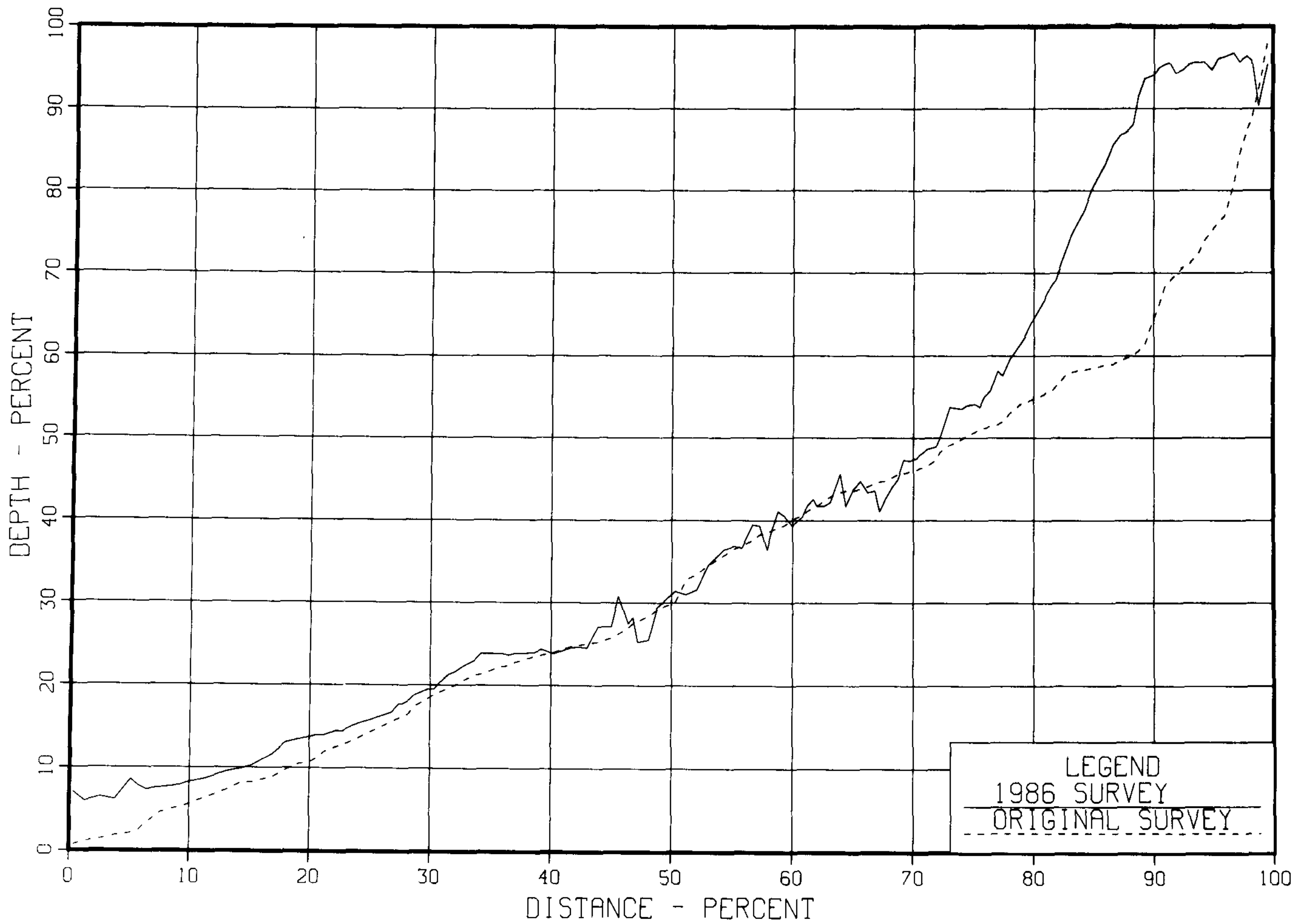

Figure 16. – Percent depth versus percent distance for Lake Powell above Glen Canyon Dam.

at range-line 324 in the Cataract Canyon area. These average sediment depth calculations, shown in last column of table 6, were determined by taking the average bottom elevation and subtracting the original river surface elevation determined from the topographic maps. Since the pre-dam cross sections begin at the old river surface and not at the channel bottom, a few range lines in areas having little or no sediment show negative numbers.

Plots of several of the measured sediment elevations versus the original river surface elevations are shown on figures 21 through 44. These range-line plots show how the sediment has distributed itself laterally across the reservoir. The majority of the plots depict the average sediment depth measured at each range-line location. Although a few of the plots show channels cut through the deposited sediments, the majority show the sediment lying horizontal. The plots with channel cuts were in the upper ends of the reservoir. The channel cuts were made when the reservoir surface was below elevation 3700. A computer program using a digitizer determined the elevation versus distance coordinates for the plots from the original topographic maps. The data were collected and plotted from the left to right bank, looking downstream. To enhance the original river channel location on the plots, an additional 10 feet were subtracted from the river water surface elevations outlining the channel on the topographic maps. The dashed line represents the original channel, and the solid line represents the new channel bottom, as shown on figures 21 through 44. Figures 45 through 67 show additional tributary profiles.

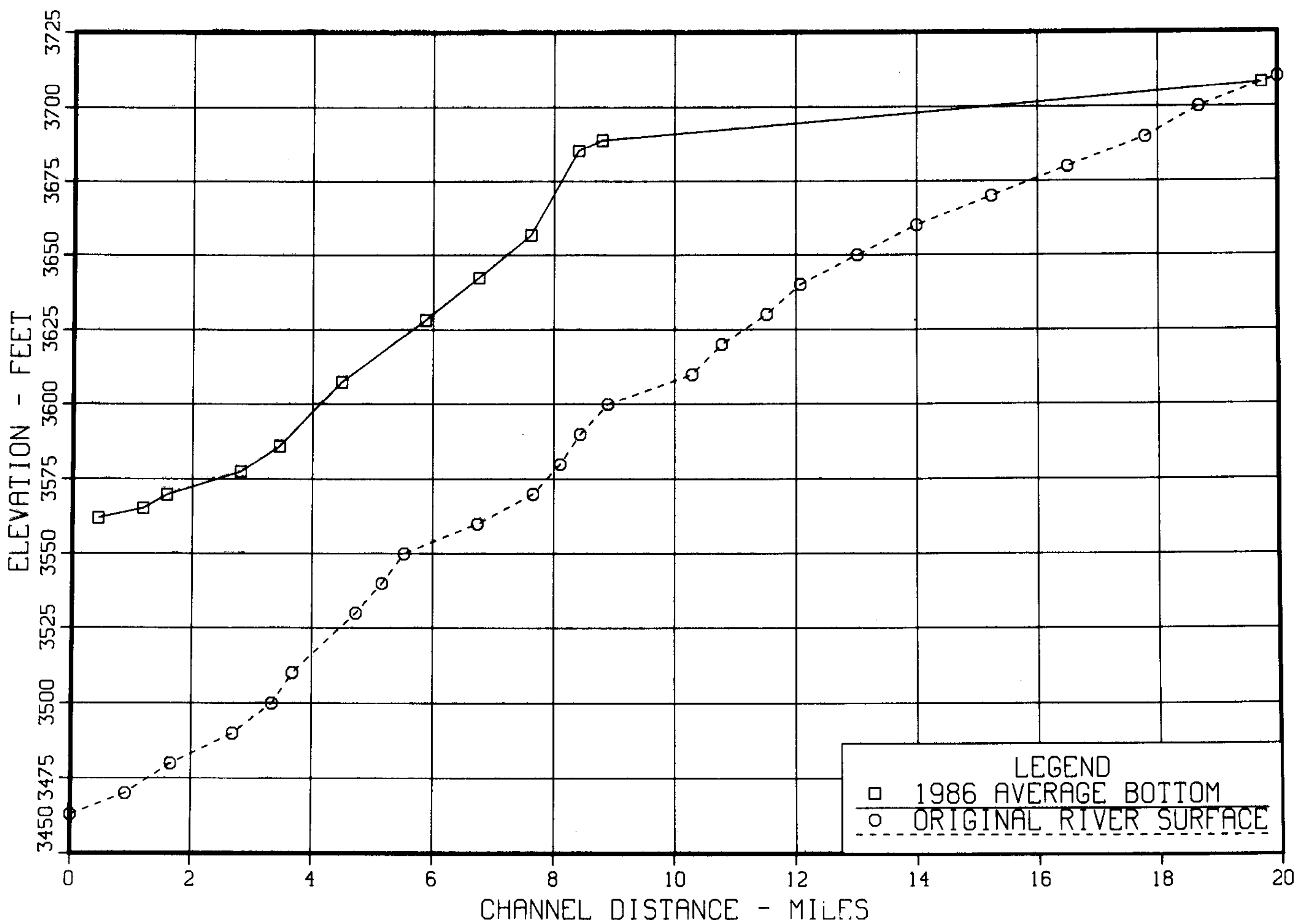

Figure 17. – Profile along Dirty Devil Canyon showing original river surface and 1986 average bottom profile.

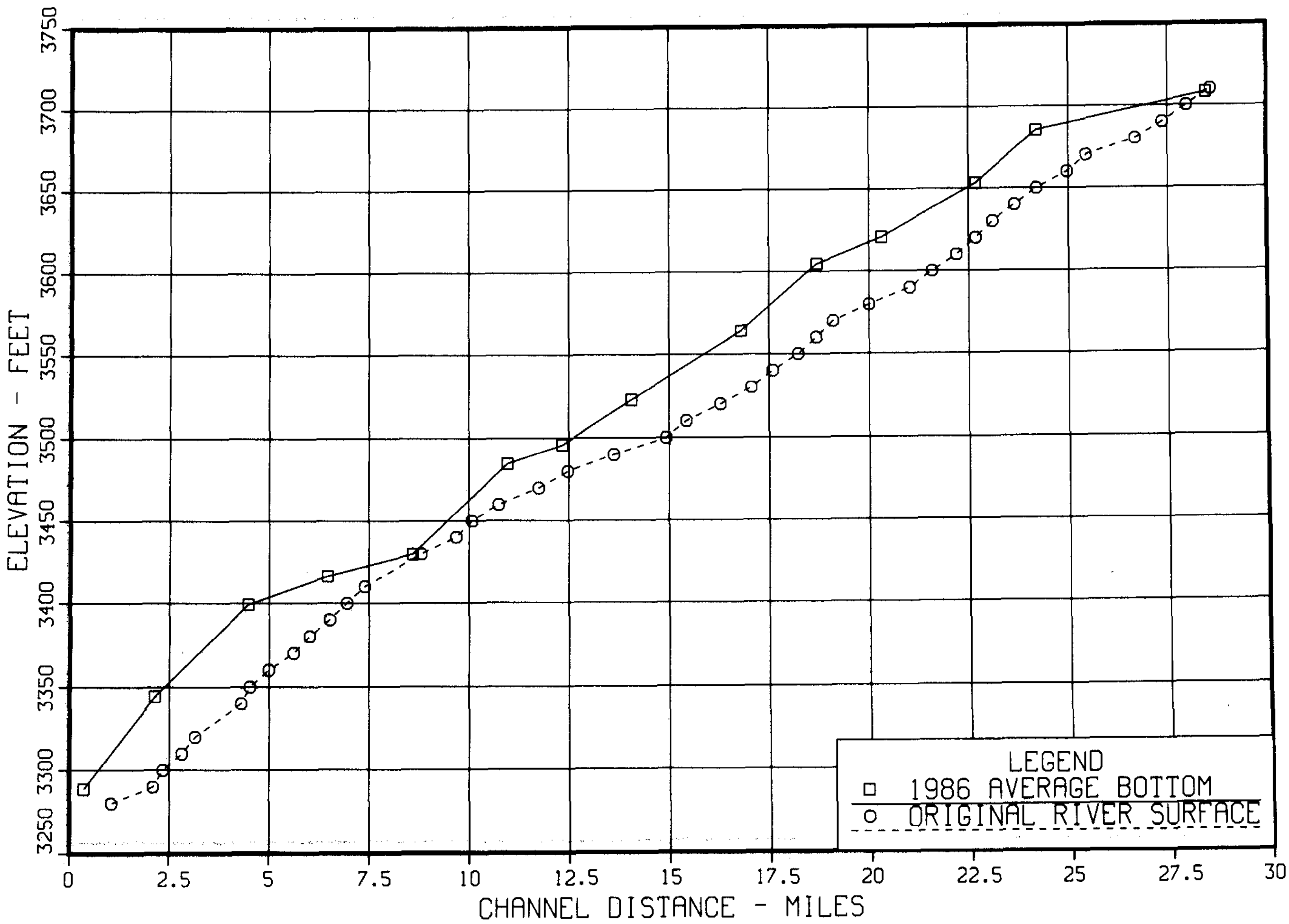

Figure 18. – Profile along Escalante Canyon showing original river surface and 1986 average bottom profile.

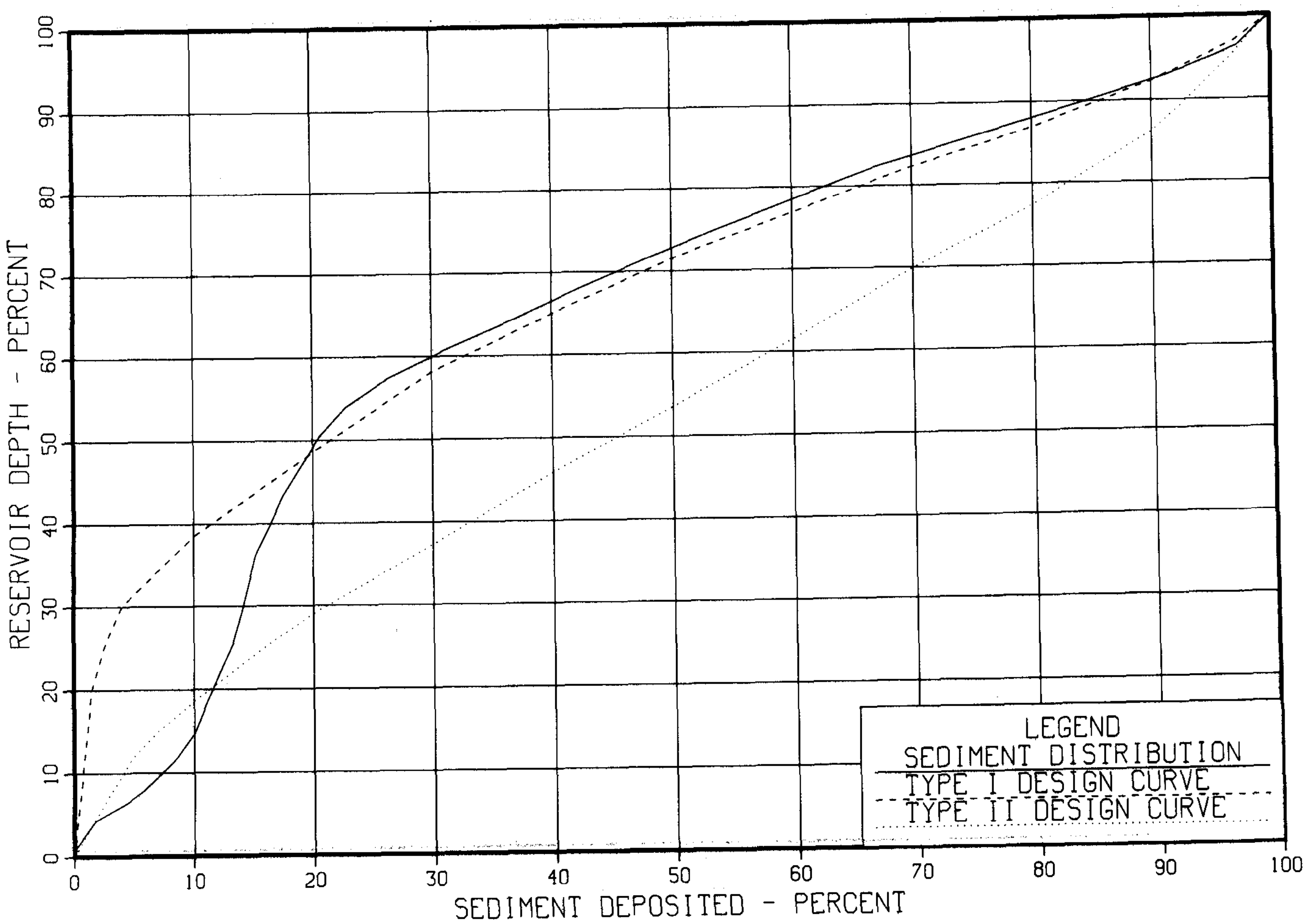

Figure 19. – Measured sediment distribution shown as percent depth versus percent deposited.

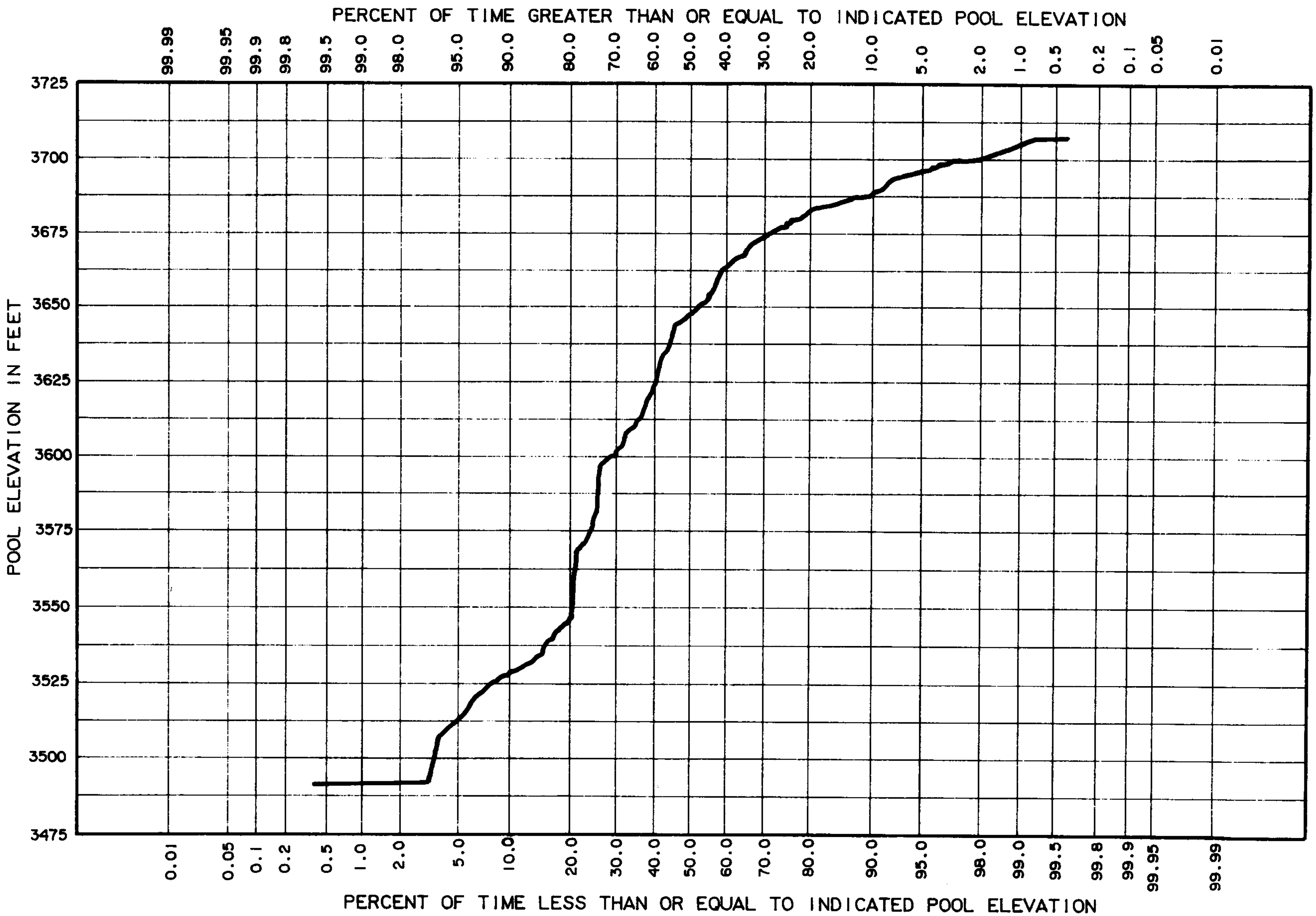

Figure 20. – Reservoir stage duration curve.

Table 6. – Summary of range-line data.[1]

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
102	8-12-86	3698.3	522.2	3176.1	3176.3	3140	36
104	8-12-86	3698.3	528.8	3169.5	3170.1	3142	28
105	6-23-87	3698.5	401	3297.5	3297.5	3290	8
105B	6-23-87	3698.5	158	3540.5	3540.5	3520	2
105C	6-23-87	3698.5	9.5	3689.0	3689.0	3648	41
106	8-12-86	3698.3	526.4	3171.9	3172.8	3144	29
108	8-12-86	3698.3	527.2	3171.1	3171.3	3146	25
110	8-12-86	3698.3	514	3184.3	3184.5	3148	36
111	8-12-86	3698.3	518.5	3179.8	3180.3	3150	30
112	8-12-86	3698.3	521.9	3176.4	3177.8	3155	23
113	8-12-86	3698.3	520.5	3177.8	3178.9	3162	17
115	8-12-86	3698.3	519.5	3178.8	3179.8	3165	15
116	8-13-86	3698.1	520	3178.1	3180.7	3166	15
117	8-13-86	3698.1	519	3179.1	3181.6	3167	15
118	8-12-86	3698.3	514	3184.3	3185.1	3172	13
119	8-13-86	3698.1	510	3188.1	3189.6	3178	12
120	8-13-86	3698.1	509	3189.1	3192.1	3182	10
121	8-13-86	3698.1	505.5	3192.6	3194.1	3183	11
122	8-13-86	3698.1	497	3201.1	3201.6	3186	16
123	7-30-86	3699.9	490	3209.9	3209.9	3191	19
124	7-30-86	3699.9	489	3210.9	3211.9	3195	17
125	8-14-86	3697.9	485	3212.9	3213.7	3197	17
126	8-21-86	3696.5	482	3214.5	3215.0	3199	16
128	8-21-86	3696.5	482.5	3214.0	3215.0	3204	11
129	8-21-86	3696.5	478.6	3217.9	3218.5	3207	12
130	7-28-86	3700.0	482	3218.0	3218.5	3208	10
132	7-28-86	3700.0	480	3220.0	3221.0	3211	10
134	7-26-86	3699.9	476	3223.9	3223.9	3215	9
135	7-26-86	3699.9	475	3224.9	3225.4	3217	8
136	7-26-86	3699.9	473	3226.9	3227.4	3219	8
138	7-15-86	3698.5	469.5	3229.0	3229.5	3224	6
139	7-25-86	3700.0	465.4	3234.5	3235.5	3226	10
140	7-25-86	3700.0	464.4	3235.6	3236.0	3228	8
141	7-25-86	3700.0	461.7	3238.3	3238.5	3229	10
142	7-25-86	3700.0	459	3241.0	3241.5	3234	8
144	7-15-86	3698.5	453.8	3244.7	3245.5	3239	6
145	7-15-86	3698.5	452.9	3245.6	3246.5	3242	4
146	7-15-86	3698.5	450.5	3248.0	3250.5	3244	6
149	7-15-86	3698.5	443.5	3255.0	3256.0	3247	9
150	7-15-86	3698.5	441.6	3256.9	3258.0	3249	9
151	7-15-86	3698.5	438.1	3260.4	3261.5	3252	10
153	7-15-86	3698.5	434.5	3264.0	3265.0	3255	10
154	7-15-86	3698.5	429	3269.5	3270.0	3256	14
155	7-15-86	3698.5	428.6	3269.9	3270.5	3258	12
157	7-15-86	3698.5	428.8	3269.7	3270.3	3261	9
159	7-14-86	3698.3	430.2	3268.1	3269.3	3262	7
160	7-14-86	3698.3	430.5	3267.8	3269.8	3264	6
162	7-14-86	3698.3	427.9	3270.4	3271.3	3268	3
164	7-14-86	3698.3	426.0	3272.3	3273.3	3269	4
165	7-13-86	3698.0	429.7	3268.3	3269.5	3271	−2
166	7-13-86	3698.0	427.1	3270.9	3271.8	3273	−1
168	7-13-86	3698.0	425.3	3272.7	3273.5	3275	−2
169	7-13-86	3698.0	424.2	3273.8	3275.0	3276	−1
170	7-13-86	3698.0	424.5	3273.5	3274.5	3277	−3
172	7-13-86	3698.0	410.3	3287.7	3289.0	3278	11
174	7-13-86	3698.0	409.4	3288.6	3289.0	3281	8
176	7-13-86	3698.0	390.4	3307.6	3309.8	3284	26
178	4-21-86	3681.6	392.1	3289.5	3290.6	3288	3
179	4-22-86	3681.5	387.5	3294.0	3295.0	3291	4

Table 6. - Summary of range-lilne data.[1]—Continued

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
180	4-22-86	3681.5	406	3275.5	3277.5	3293	−16
182	4-22-86	3681.5	403	3278.5	3280.5	3296	−16
183	4-30-86	3682.0	382	3300.0	3301.5	3301	0
185	4-30-86	3682.0	370	3312.0	3313.0	3305	8
187	4-30-86	3682.0	372	3310.0	3311.0	3321	−10
189	4-30-86	3682.0	368.5	3313.5	3313.5	3325	−12
191	4-04-86	3681.0	351.0	3330.0	3330.8	3331	0
192	4-04-86	3681.0	340.0	3341.0	3342.0	3338	4
194	4-05-86	3681.1	338.0	3343.1	3343.6	3342	2
195	4-05-86	3681.1	339.0	3342.1	3342.6	3345	−2
197	7-11-86	3697.4	339.5	3357.9	3359.4	3348	11
198	7-11-86	3697.4	339.5	3357.9	3358.4	3352	6
199	7-12-86	3692.8	350.5	3342.3	3342.3	3354	11
200	4-07-86	3681.4	327.0	3354.4	3354.9	3355	0
202	4-07-86	3681.4	315.5	3365.9	3368.4	3357	11
203	4-07-86	3681.4	317	3364.4	3365.4	3358	7
205	4-19-86	3681.5	324.4	3357.1	3358.0	3362	−4
207	4-19-86	3681.5	317	3364.5	3364.5	3365	0
209	4-20-86	3681.5	309.8	3371.7	3372.3	3368	4
210	4-20-86	3681.5	306.0	3375.5	3375.5	3370	6
212	5-01-86	3682.1	311.0	3371.1	3371.6	3372	0
215	5-01-86	3682.1	311.5	3370.6	3371.6	3375	−3
217	5-01-86	3682.1	311.5	3370.6	3373.9	3378	−4
219	5-01-86	3682.1	291	3391.1	3392.6	3381	12
220	6-27-87	3698.4	233.5	3464.9	3464.9	3435	30
220B	6-27-87	3698.4	114.0	3584.4	3584.4	3592	−8
220C	6-27-87	3698.4	15.0	3683.4	3683.4	3710	−27
221	5-01-86	3682.1	311.5	3370.6	3371.6	3382	−10
223	5-02-86	3682.2	299.5	3382.7	3383.2	3382	1
225	5-02-86	3682.2	296.2	3386.0	3387.7	3383	5
226	5-02-86	3682.2	302.0	3380.2	3380.7	3385	−4
229	5-02-86	3682.2	300	3382.2	3382.2	3387	−5
230	5-02-86	3682.2	315	3367.2	3368.2	3388	−20
232	5-02-86	3682.2	306.4	3375.8	3377.2	3389	−12
234	5-03-86	3682.4	298.2	3384.2	3384.4	3391	−7
236	5-03-86	3682.4	294	3388.4	3389.9	3393	−4
237	5-03-86	3682.4	279.5	3402.9	3403.4	3394	9
239	5-20-86	3684.1	283.8	3400.3	3401.8	3395	7
241	5-20-86	3684.1	280.5	3403.6	3403.9	3396	8
242	5-20-86	3684.1	279	3405.1	3405.6	3397	9
244	5-20-86	3684.1	274.5	3409.6	3409.9	3399	11
245	5-21-86	3684.1	226	3458.1	3458.1	3455	3
246	5-20-86	3684.1	273	3411.1	3412.1	3403	9
247	5-21-86	3684.1	186.2	3497.9	3498.1	3495	3
248	5-20-86	3684.1	266	3418.1	3418.1	3408	10
250	5-20-86	3684.1	246.0	3438.1	3439.1	3413	26
252	5-05-86	3682.8	117.5	3565.3	3565.8	3551	15
254	5-05-86	3682.8	245	3437.8	3438.3	3417	21
256	5-05-86	3682.8	243	3440.8	3440.3	3419	21
258	5-05-86	3682.8	242	3440.8	3441.3	3422	19
260	5-05-86	3682.2	243.5	3438.7	3439.2	3424	15
261	5-05-86	3682.8	237.5	3445.3	3445.8	3425	21
263	5-05-86	3682.8	233	3449.8	3450.3	3426	24
266	5-16-86	3684.4	159.5	3524.9	3526.4	3509	17
266	5-16-86	3684.4	8.2	3676.2	3676.9	3665	12
267	5-16-86	3684.4	221	3463.4	3463.9	3427	37
269	5-16-86	3684.4	224	3460.4	3460.9	3429	32
270	5-17-86	3684.3	201	3483.3	3484.8	3455	30
271	5-17-86	3684.3	214	3470.3	3471.8	3435	37

Table 6. – Summary of range-line data.[1]—Continued

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
275	5-17-86	3684.3	202	3482.3	3483.3	3441	42
277	5-17-86	3684.3	198	3486.3	3486.8	3442	45
279	5-18-86	3684.2	188.5	3495.7	3496.7	3444	53
281	5-19-86	3684.2	178	3506.2	3507.0	3446	61
284	5-19-86	3684.2	171.6	3512.6	3513.2	3448	65
286	5-19-86	3684.2	169	3515.2	3515.7	3449	67
288	5-19-86	3684.2	160.6	3523.6	3524.0	3451	73
291	5-19-86	3684.2	158.4	3525.8	3526.4	3453	73
293	5-19-86	3684.2	142	3542.2	3543.0	3531	12
293	5-19-86	3684.2	24.8	—	3659.4	—	—
296	5-19-86	3684.2	140.4	3543.8	3544.7	3461	84
298	5-19-86	3684.2	133.8	3550.4	3551.0	3462	89
300	5-19-86	3684.2	129.8	3554.4	3555.7	3463	93
302	9-09-86	3693.2	129.6	3563.6	3564.0	3464	100
304	9-09-86	3693.2	120.8	3572.4	3573.0	3465	108
306	9-09-86	3693.2	107.5	3585.7	3587.2	3466	121
308	9-12-86	3692.7	96.2	3596.5	3596.7	3467	130
310	9-12-86	3692.7	89.6	3603.1	3604.2	3468	136
313	9-12-86	3692.7	76	3616.7	3618.2	3469	149
316	9-12-86	3692.7	71	3621.7	3625.2	3471	154
318	9-12-86	3692.7	65.8	3626.9	3628.0	3473	155
320	9-12-86	3692.7	60.5	3632.2	3633.2	3475	158
322	9-12-86	3692.7	43.1	3649.6	3652.5	3478	174
324	9-12-86	3692.7	36.4	3656.3	3664.5	3482	182
326	9-10-86	3693.0	38.2	3654.8	3667.2	3500	167
328	9-10-86	3693.0	29.4	3663.6	3672.5	3509	164
330	9-10-86	3693.0	39.9	3653.1	3674.2	3522	152
331	9-10-86	3693.0	37.5	3655.5	3675.0	3525	150
333	9-10-86	3693.0	40.0	3553.0	3668.0	3530	138
335	9-10-86	3693.0	33	3660	3670.5	3534	136
337	9-10-86	3693.0	21.9	3671.1	3674.5	3536	138
339	9-10-86	3693.0	24.9	3668.1	3675.5	3542	134
340	9-10-86	3693.0	38.2	3654.8	3675.2	3545	130
342	9-10-86	3693.0	26.8	3666.2	3676.8	3552	125
344	9-11-86	3692.8	28.2	3664.6	3670.3	3559	111
346	9-11-86	3692.8	16	3676.8	3677.6	3565	113
348	9-11-86	3692.8	20.2	3672.6	3678.8	3569	110
350	9-11-86	3692.8	18.8	3674.0	3681.6	3590	92
352	9-11-86	3692.8	32.8	3660.0	3676.0	3612	64
354	9-11-86	3692.8	18	3674.8	3679.6	3628	52
356	9-11-86	3692.8	20.9	3671.9	3676.6	3636	41
358	9-11-86	3692.8	47	3645.8	3645.8	3658	−12
360	9-11-86	3692.8	18.4	3674.4	3674.4	3688	−14
401	8-12-86	3698.3	524.3	3173.8	3174.8	3145	30
402	8-12-86	3698.3	440	3258.3	3258.3	3256	3*
403	8-08-86	3699.0	327.5	3371.5	3372.5	3350	22
405	8-09-86	3698.9	137.8	3561.1	3562.1	3560	2
406	8-09-86	3698.9	272	3426.9	3428.9	3408	21
407	8-08-86	3699.0	252	3447.0	3447.5	3450	−2
408	8-08-86	3699.0	205.7	3493.3	3494.0	3505	−11
409	8-08-86	3699.0	167.5	3531.5	3532.0	3528	4
410	8-09-86	3698.9	137	3561.9	3563.4	3555	8
412	8-09-86	3698.9	67.5	3631.4	3632.2	3622	10
413	8-09-86	3698.9	30.2	3668.7	3674.9	3650	25
421	8-12-86	3698.3	510.3	3188.0	3188.3	3154	34
422	8-12-86	3698.3	490	3208.3	3208.3	3189	19
424	8-10-86	3698.7	413.5	3285.2	3286.2	3263	23
425	8-10-86	3698.7	360	3338.7	3340.7	3338	3
427	8-10-86	3698.7	277	3421.7	3423.2	3405	18

Table 6. – Summary of range-line data.[1]—Continued

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
429	8-10-86	3698.7	221.5	3477.2	3477.7	3451	27
430	8-09-86	3698.9	184	3514.7	3514.9	3490	25
431	8-10-86	3698.7	93.2	3605.5	3605.7	3570	36
434	8-10-86	3698.7	30.1	3668.6	3669.2	3619	50
435	8-10-86	3698.7	15	3683.7	3689.2	3635	54
451	8-07-86	3699.0	—	—	3198	3198	0*
452	8-07-86	3699.0	320	3379.0	3379.5	3365	14
454	8-07-86	3699.0	192	3507.0	3507.0	3508	−1
455	8-07-86	3699.0	155.0	3544.0	3544.5	3532	12
456	8-07-86	3699.0	81.7	3617.3	3619.0	3602	17
457	8-07-86	3699.0	56.2	3642.8	3643.0	3635	8
458	8-07-86	3699.0	25	3674.0	3674.5	3651	24
461	8-07-86	3699.0	229.4	3469.6	3470.0	3469	1
471	8-12-86	3698.3	438	3260.3	3260.3	3222	38*
472	8-13-86	3698.1	273.0	3425.1	3426.1	3404	22
473	8-13-86	3698.1	161	3537.1	3538.1	3521	17
474	8-11-86	3698.5	53.5	3645.0	3645.0	3627	18
475	8-11-86	3698.5	21	3677.5	3678.0	3670	8
481	8-11-86	3698.5	348	3350.5	3350.5	3345	6
482	8-11-86	3698.5	132.4	3566.1	3566.1	3548	18
483	8-11-86	3698.5	57.0	3641.5	3641.5	3631	10
491	8-13-86	3698.1	444	3254.1	3256.1	3220	36
492	8-13-86	3698.1	197	3501.1	3503.1	3477	26
493	8-11-86	3698.5	161	3537.5	3539.5	3536	4
494	8-11-86	3698.5	244.5	3454.0	3454.3	3453	1
495	8-12-86	3698.3	481.8	3216.5	3217.3	3217	0
501	7-29-86	3700.0	476	3224.0	3224.0	3204	34
502	7-29-86	3700.0	476	3224.0	3224.0	3216	8
503	7-29-86	3700.0	379.8	3320.2	3321.0	3305	16
505	7-29-86	3700.0	315.8	3384.2	3385.5	3372	14
507	7-29-86	3700.0	250	3450.0	3451.0	3438	13
508	7-29-86	3700.0	193.8	3506.2	3508.5	3481	28
510	7-29-86	3700.0	152.3	3547.7	3547.7	3529	19
511	7-29-86	3700.0	106	3594.0	3596.8	3581	16
512	7-29-86	3700.0	45	3655.0	3657.0	3628	29
521	7-29-86	3700.0	224	3476.0	3476.5	3465	12
522	7-29-86	3700.0	153.7	3546.3	3546.5	3524	22
523	7-29-86	3700.0	82	3618.0	3619.0	3609	10
531	7-29-86	3700.0	155.3	3544.7	3546.0	3527	19
532	7-29-86	3700.0	108	3592.0	3596.2	3575	21
533	7-29-86	3700.0	92.6	3607.4	3608.0	3598	10
534	7-29-86	3700.0	24.5	3675.5	3678.0	3657	21
541A	6-23-87	3698.5	410+	3288.5	3288.5	3286	2
541C	6-23-87	3698.5	289.0	3409.5	3409.5	3403	6
541D	6-23-87	3698.5	14.5	3684	3684	3682	2
541	7-30-86	3699.9	448	3251.9	3255.9	3254	2
542	6-23-87	3698.5	406.5	3292.0	3292.0	3295	−3
543	6-23-87	3698.5	351.5	3347.0	3347.0	3345	2
544	6-23-87	3698.5	246	3452.5	3452.5	3441	12
545	6-23-87	3698.5	200.0	3498.5	3498.5	3480	18
546	6-23-87	3698.5	123.8	3574.7	3574.7	3565	10
547	6-23-87	3698.5	7.0	3691.5	3692.0	3688	4
551	7-27-86	3700.0	252.5	3447.5	3448	3448	0
552	7-27-86	3700.0	152.5	3547.5	3547.9	3555	−7
561	8-21-86	3700.0	456	3244.0	3244.0	3238	6
562	7-28-86	3700.0	404	3296.0	3296.0	3295	1
563	7-28-86	3700.0	358	3342.0	3342.0	3342	0
564	7-28-86	3700.0	292.4	3407.6	3408.0	3395	13
565	7-28-86	3700.0	236	3464.0	3464.5	3445	20

Table 6. – Summary of range-line data.[1]—Continued

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
566	7-28-86	3700.0	172.5	3527.5	3528.0	3504	24
567	7-28-86	3700.0	123.5	3576.5	3579.0	3555	24
568	7-28-86	3700.0	60.7	3639.3	3639.8	3611	28
571	7-28-86	3700.0	358	3342.0	3342.0	3322	20
572	7-27-86	3700.0	271	3429.0	3429.0	3423	6
573	7-27-86	3700.0	155	3545.0	3545.0	3535	10
574	7-27-86	3700.0	78.2	3621.8	3622.2	3596	26
581	7-27-86	3700.0	307	3393.0	3393.0	3405	−12
582	7-27-86	3700.0	187	3513.0	3513.5	3508	6
583	7-27-86	3700.0	61	3639.0	3640.5	3635	6
591	7-28-86	3700.0	253	3447	3447	3445	2†
601	6-24-87	3698.4	384	3314.4	3314.4	3320	−6†
602	6-24-87	3698.4	302.2	3396.2	3396.2	3410	−6
603	6-24-87	3698.4	228	3470.4	3470.4	3475	−5
604	6-24-87	3698.4	146	3552.4	3552.4	3545	7
611	6-24-87	3698.4	404+‡	3294.4	3294.4	3320	0†
612	6-24-87	3698.4	330	3368.4	3368.4	3370	−1
613	6-24-87	3698.4	326	3372.4	3372.4	3393	−21
614	6-24-87	3698.4	179.5	3518.9	3518.9	3490	29
615	6-24-87	3698.4	107.5	3590.9	3590.9	3567	24
621	7-26-86	3699.9	465	—	3234.9	3239	−4†
622	6-24-87	3698.4	404	3294.4	3294.4	3375	−†
623	6-24-87	3698.4	280	3418.4	3418.4	3415	3†
624	6-24-87	3698.4	132	3566.4	3566.4	3570	−4
631	6-25-87	3698.4	398	3300.4	3300.4	3335	−35
632	7-25-86	3698.4	264	3434.4	3434.4	3465	−31
641	6-25-87	3698.4	412+	3286	3286	3275	0†
641B	6-25-87	3698.4	304†	—	—	—	—
651	6-25-87	3698.4	410	3288.4	3288.4	3289	0
652	7-24-86	3699.9	319.8	3380.1	3380.9	3369	12
653	7-24-86	3699.9	261.5	3438.4	3439.4	3439	0
654	7-25-86	3700.0	176.9	3523.1	3523.5	3512	12
655	7-25-86	3700.0	77.3	3622.7	3623.8	3590	34
656	6-25-87	3698.4	16.2	3682.2	3682.2	3645	37
661	7-24-86	3699.9	217.6	3482.3	3482.9	3472	11
662	7-24-86	3699.9	176	3523.9	3525.9	3525	−1
663	7-24-86	3699.9	121.8	3578.1	3578.4	3568	10
681	7-16-86	3698.7	410.6	3288.1	3288.7	3275	14
682	7-16-86	3698.7	354.5	3344.2	3344.5	3292	52
683	7-16-86	3698.7	300.2	3398.5	3399.2	3348	51
684	7-16-86	3698.7	282.9	3415.8	3416.5	3389	28
685	8-25-86	3695.7	266	3429.7	3429.9	3428	2
686	8-25-86	3695.7	212.2	3483.5	3484.7	3466	19
687	8-25-86	3695.7	201	3494.7	3495.9	3478	18
688	8-25-86	3695.7	174	3521.7	3522.2	3494	28
689	8-25-86	3695.7	132	3563.7	3564.2	3525	39
690	8-25-86	3695.7	92	3603.7	3604.2	3560	44
691	8-25-86	3695.7	78.2	3617.5	3617.7	3582	36
692	8-25-86	3695.7	43.1	3652.6	3652.9	3620	33
693	8-25-86	3695.7	10.2	3685.5	3685.5	3650	36
694	7-04-87	3698.3	13.2	3685.1	3688.8	3657	32
695	7-04-87	3698.2	8.0	3690.3	3692.8	3667	26
696	7-04-87	3698.3	6.0	3692.3	3694.8	3673	22
697	7-04-87	3698.3	2.8	3695.5	3695.8	3676	20
701	4-21-86	3681.6	396.0	3285.6	3286.6	3297	−10
702	7-05-87	3698.3	246.2	3451.2	3452.1	3455	−3
703	4-21-86	3681.6	166	3515.6	3515.6	3524	−8
704	4-21-86	3681.6	48.4	3633.2	3633.6	3645	−13
711	4-04-86	3681.0	340	3341.0	3341.0	3337	4
711B	6-26-87	3698.5	296.0	3402.5	3402.5	3412	−10

Table 6. – Summary of range-line data.[1]—Continued

Range No.	Date	Lake Eleva-tion	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
712	4-04-86	3681.0	218	3463.0	3464.0	3472	−8
713	4-04-86	3681.0	158	3523.0	3523.5	3520	4
714	4-04-86	3681.0	56.2	3624.8	3625.5	3592	34
715	4-04-86	3681.0	6.2	3674.8	3675.5	3640	36
716	6-26-87	3698.5	5.4	3693.1	3693.1	3661	32
722	7-10-86	3697.2	271	3426.2	3426.2	3415	11
724	7-09-86	3697.1	187.8	3509.3	3509.6	3502	8
725	7-09-86	3697.1	138.2	3558.9	3559.1	3552	7
726	4-05-86	3681.1	44.5	3636.6	3636.6	3630	7
727	4-05-86	3681.1	50	3632.1	3631.6	3614	18
728	4-05-86	3681.1	36.2	3644.9	3645.1	3635	10
728A	7-05-87	3698.3	18.5	3679.8	3679.5	3649	30
728B	7-05-87	3698.3	9.5	3688.8	3688.5	3669	20
731	7-11-86	3697.4	305	3392.4	3392.9	3382	11
733	7-11-86	3697.4	219.3	3478.1	3478.4	3455	23
734	7-11-86	3697.4	149	3548.4	3548.9	3534	15
736	7-11-86	3697.4	107	3590.4	3594.5	3586	8§
737	7-10-86	3697.2	53	3644.2	3644.2	3635	9
738	7-10-86	3697.2	57	3640.2	3640.2	3615	25
739	7-10-86	3697.2	11.4	—	3685.8	3672	14
739B	7-10-86	3697.2	9	8.0	3689.2	3678	11
740	7-10-86	3697.2	**	**	3698	3683	15
741	4-07-86	3681.4	294.2	3387.2	3387.2	3375	12
742	4-07-86	3681.4	224	3457.4	3457.4	3449	8
743	4-07-86	3681.4	148.2	3533.2	3533.4	3525	8
744	4-07-86	3681.4	70.4	3611.0	3611.4	3572	39
745	4-07-86	3681.4	11	3670.4	3672.5	3652	20
745A	7-05-87	3698.3	7.0	3691.3	3691.3	3670	21
746	4-07-86	3681.4	35.2	3646.2	3646.2	3648	−2
747	4-07-86	3681.4	22	3659.4	3659.4	3661	−2
748	7-05-87	3698.3	13.0	3685.3	3685.3	3688	−3
751	4-06-86	3681.3	266.0	3415.3	3415.5	3405	10
752	4-06-86	3681.3	208	3473.3	3473.8	3465	9
753	4-06-86	3681.3	86.2	3595.1	3595.1	3568	27
754	4-06-86	3681.3	34	3647.3	3647.3	3635	12
755	4-06-86	3681.3	10.2	3671.1	3673.8	3655	19
756	7-05-87	3698.3	7.2	3691.1	3691.8	3688	4
761	5-14-86	3684.5	217	3467.5	3468.0	3448	20
762	5-06-86	3683.2	132	3551.2	3551.2	3510	41
763	5-06-86	3683.2	34.5	3648.7	3649.2	3635	14
771	5-04-86	3682.6	156.8	3525.8	3526.1	3491	35
772	5-03-86	3682.4	116.5	3565.9	3567.8	3524	44§
773	5-03-86	3682.4	63.8	3618.6	3618.6	3596	23
774	5-03-86	3682.4	27.2	3655.2	3655.4	3647	8
781	5-17-86	3684.3	162.5	3521.8	3523.0	3509	14
782	5-17-86	3684.3	~~99.6~~	3584.7	3584.9	3575	10
783	5-17-86	3684.3	—	3684.5	3689.5	3670	20
791	5-18-86	3684.2	204.5	3479.7	3480.2	3478	2
791A	5-18-86	3684.2	192.8	3491.4	3491.7	3451	41
792	5-18-86	3684.2	104.5	3579.7	3580.2	3577	3
793	5-18-86	3684.2	182.8	3501.7	3501.7	3488	14
795	5-18-86	3684.2	118.5	3565.7	3565.7	3561	5
797	5-18-86	3684.2	36	3648.2	3648.5	3642	6
801	9-13-86	3692.5	130.8	3561.7	3562.1	3465	97
802	9-13-86	3692.5	127.4	3565.1	3565.3	3475	90
803	9-13-86	3692.5	122.9	3569.6	3569.8	3479	91
804	9-13-86	3692.5	115.3	3577.2	3577.5	3492	86
806	9-13-86	3692.5	107.2	3585.3	3586.0	3504	82
810	9-13-86	3692.5	86.2	3606.3	3607.5	3526	82
813	9-13-86	3692.5	66	3626.5	3628.2	3553	75

Table 6. – Summary of range-line data.[1]—Continued

Range No.	Date	Lake Elevation	Measured Maximum Depth	Maximum Bottom Elevation	Average Bottom Elevation	Original River Elevation	Average Sediment Height
815	9-13-86	3692.5	52.2	3640.3	3642.4	3561	81
817	9-13-86	3692.5	36.2	3656.3	3656.7	3569	88
819	9-13-86	3692.5	7.1	3685.4	3685.5	3589	96
820	9-13-86	3692.5	4.5	3688.0	3689.0	3598	91
830	9-10-86	3693.0	37.5	3655.5	3666.1	3518	148
831	9-10-86	3693.0	18.5	3674.5	3675.0	3550	125
901	7-24-86	3699.9	433.2	3266.7	3267.4	3265	2
903	7-24-86	3699.9	418.4	3281.5	3281.9	3275	7
905	7-24-86	3699.9	403.7	3296.2	3296.4	3285	11
907	7-24-86	3699.9	391.7	3308.2	3308.4	3298	10
908	7-24-86	3699.9	375.2	3324.7	3324.9	3310	15
909	7-24-86	3699.9	347.8	3352.1	3352.9	3315	38
911	7-23-86	3699.8	341.0	3358.8	3359.3	3340	19
912	7-23-86	3699.8	321.4	3378.4	3378.8	3350	29
914	8-22-86	3696.4	290.5	3405.9	3406.4	3365	41
915	8-22-86	3696.4	303	3393.4	3394.2	3375	19
918	8-22-86	3696.4	267	3429.4	3430.4	3399	31
920	8-22-86	3696.4	242	3454.4	3455.4	3435	20
922	8-22-86	3696.4	229	3467.0	3467.4	3450	17
923	8-22-86	3696.4	205	3491.4	3492.4	3462	30
924	8-23-86	3696.2	182	3514.2	3516.2	3470	46
926	8-23-86	3696.2	165	3527.2	3527.4	3478	49
928	8-23-86	3696.2	159	3537.2	3538.4	3485	53
929	8-23-86	3696.2	151.8	3544.4	3544.7	3490	55
931	8-23-86	3696.2	142	3554.2	3554.2	3500	54
933	8-23-86	3696.2	130.5	3565.7	3566.4	3510	56
936	6-26-86	3694.1	122	3572.1	3572.6	3525	48
936A	8-23-86	3696.2	117	3579.2	3580.2	3535	45
938	6-26-86	3694.1	86	3608.1	3608.6	3555	54
940	6-26-86	3694.1	78.5	3615.6	3615.9	3570	46
942	8-23-86	3696.2	69	3627.2	3627.7	3585	43
943	8-23-86	3696.2	62	3634.2	3634.2	3590	44
945	8-23-86	3696.2	46	3650.2	3650.7	3598	53
946	8-23-86	3696.2	36	3660.2	3671.1	3602	69
948	8-23-86	3696.2	11	3685.2	3687.5	3605	82
949	4-10-87	—	—	—	3692.0	3615	77††
950	6-27-86	3694.0	12	3682.0	3684.0	3620	64
951	7-02-87	3698.3	6.5	3691.8	3691.8	3624	68
952	7-02-87	3698.4	16	3682.4	3690.4	3631	59
953	7-02-87	3698.8	11	3687.8	3690.8	3634	57
954	7-02-87	3700.0	8	3692.0	3694.0	3638	56
955	7-02-87	3701.2	7	3694.2	3695.7	3642	54
956	7-02-87	3702.6	7.5	3695.1	3697.1	3644	53
957	7-02-87	3703.9	12	3691.1	3696.4	3646	50
958	7-02-87	3704.6	8	3696.6	3700.1	3648	52
959	7-02-87	3705.2	8	3697.2	3699.7	3650	50
961	7-23-86	3699.8	270.1	—	3429.7	3390	40*
965	8-22-86	3696.4	202	3494.4	3494.9	3475	20
966	8-22-86	3696.4	153.5	3542.9	3542.9	3515	28
967	8-22-86	3696.4	19.5	3676.9	3680.0	3620	60
971	6-26-86	3694.1	63	3631.1	3631.6	3555	77
981	6-26-86	3694.1	62.8	3631.3	3631.3	3635	−4
985	6-26-86	3694.1	76	3618.1	3620.1	3575	45

[1] All elevations, depths, and heights are shown in feet.
* No clear maximum depth reading.
† No clear maximum depth signal.
‡ Dangling Rope Creek Channel was 410+, second channel was 404.
§ Average of two channels.
** Too shallow to survey from boat.
†† Land survey.

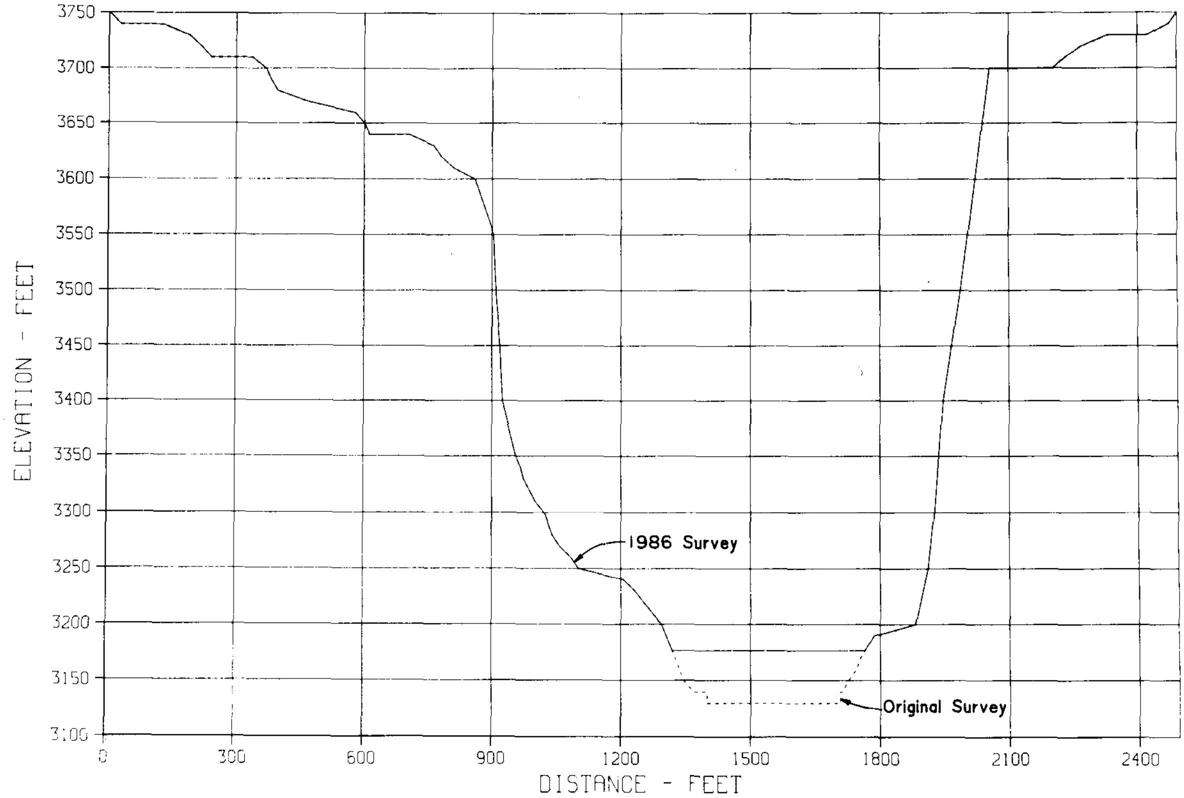

Figure 21. – Original and 1986 sedimentation range profiles, range 102, Colorado River.

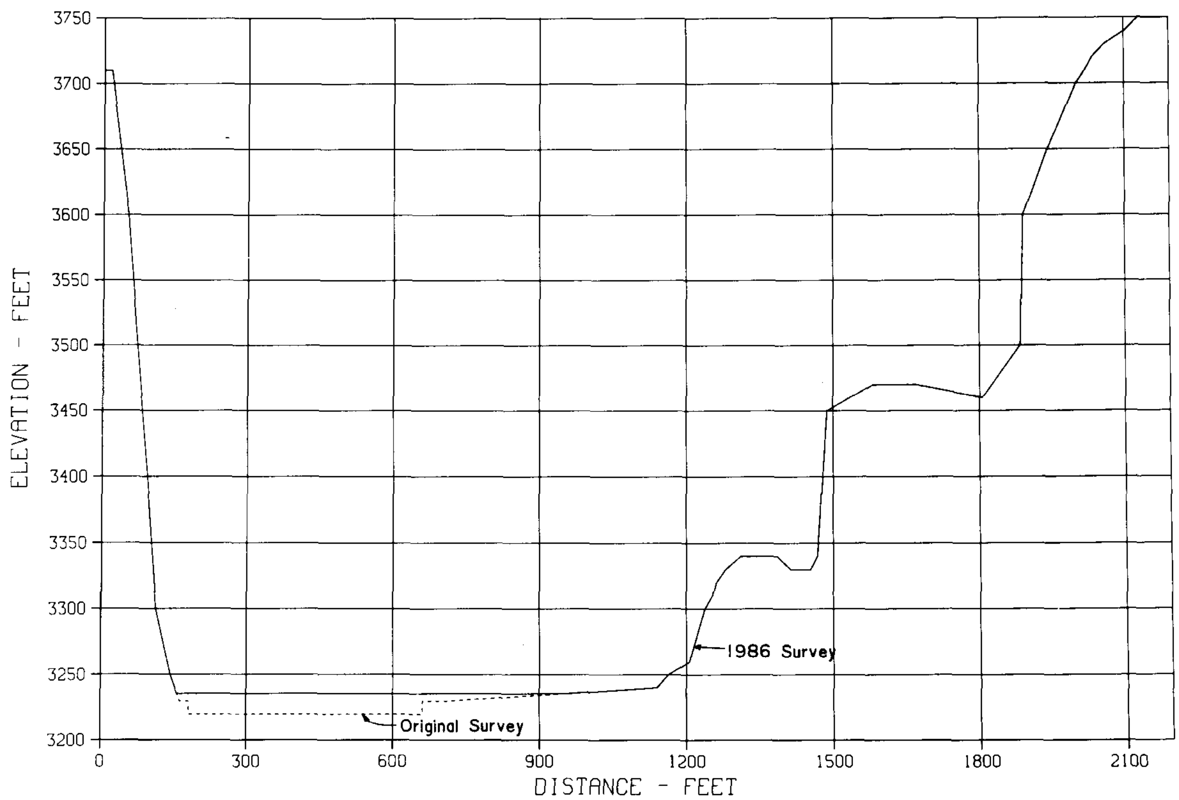

Figure 22. – Original and 1986 sedimentation range profiles, range 139, Colorado River.

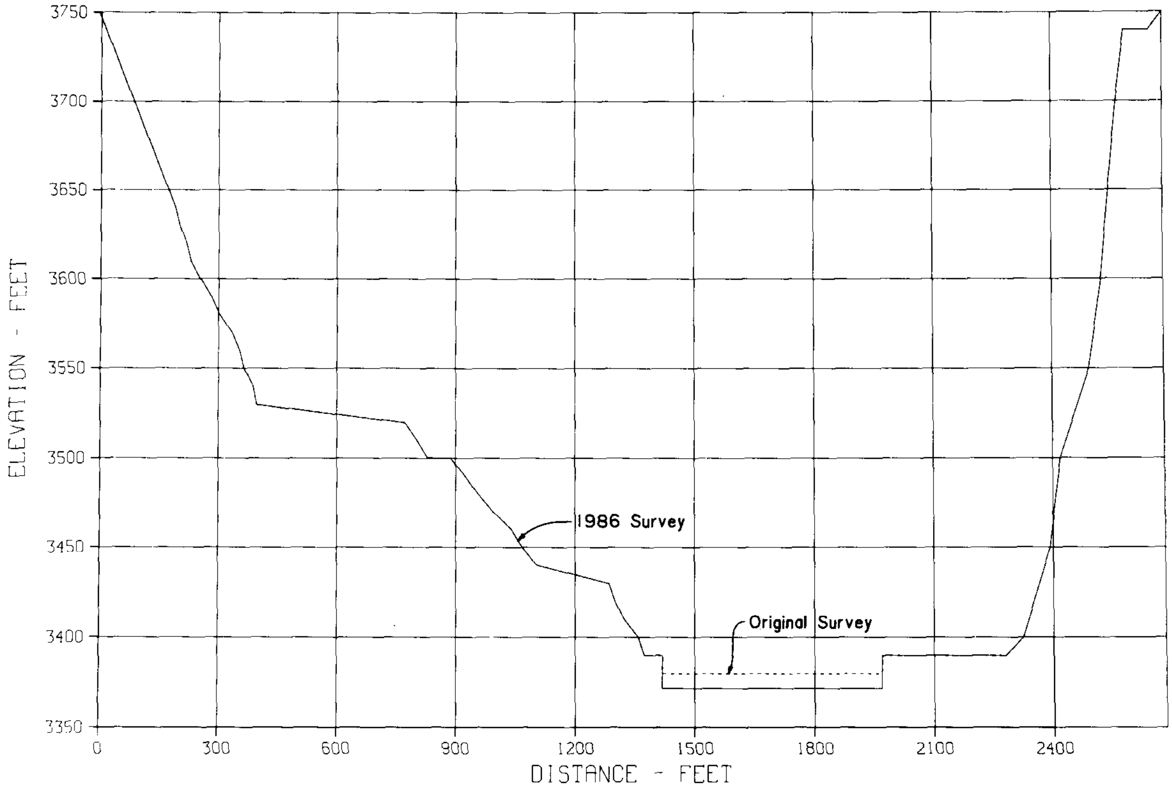

Figure 23. – Original and 1986 sedimentation range profiles, range 221, Colorado River.

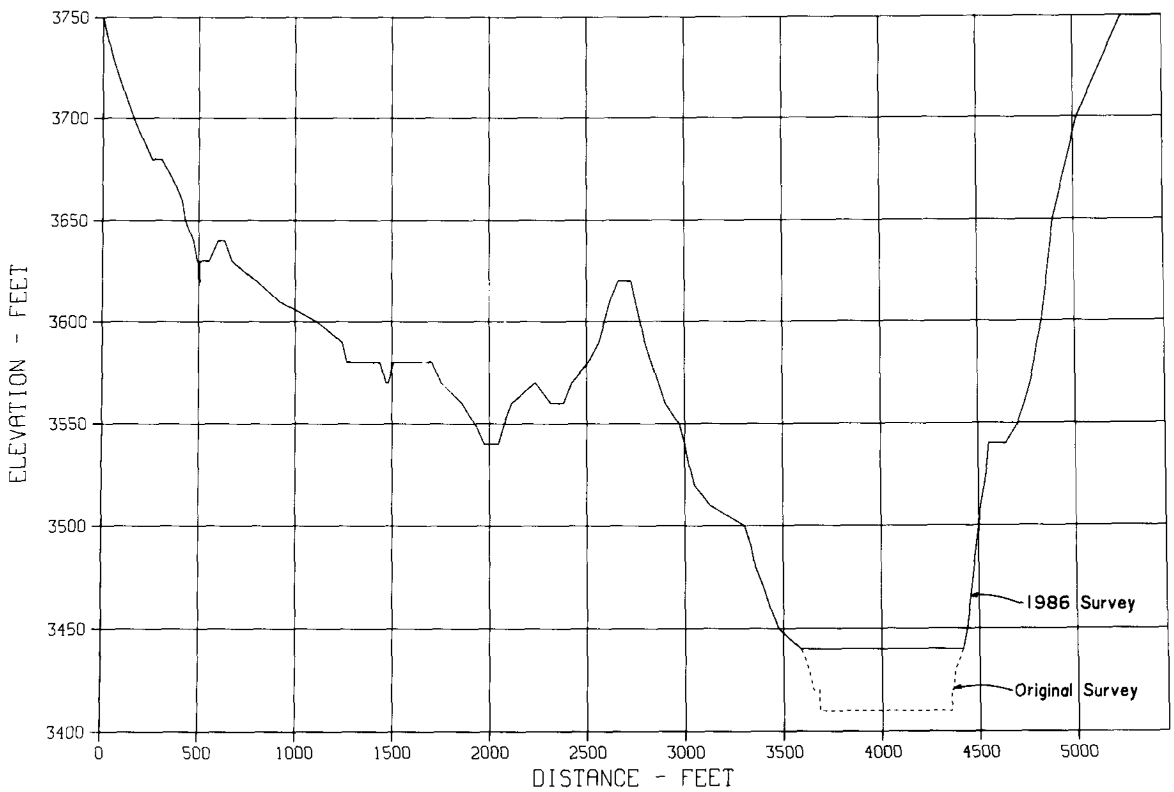

Figure 24. – Original and 1986 sedimentation range profiles, range 256, Colorado River.

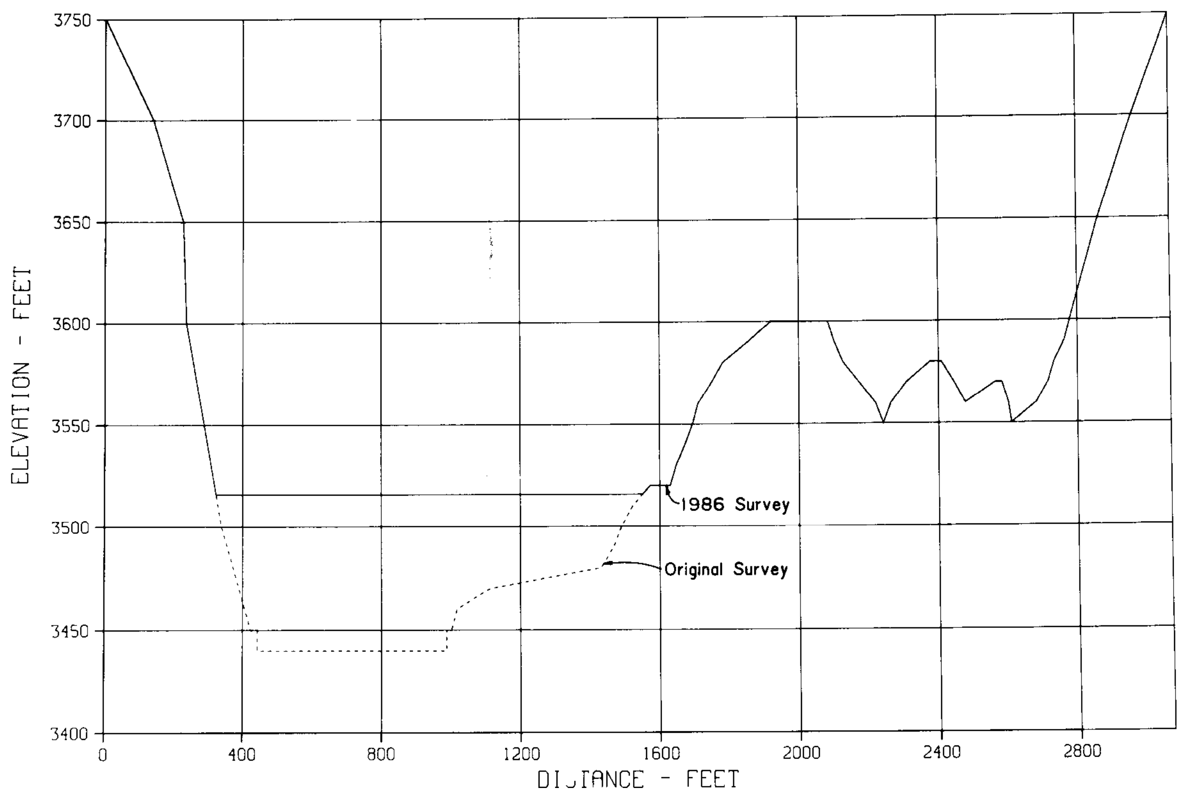

Figure 25. – Original and 1986 sedimentation range profiles, range 286, Colorado River.

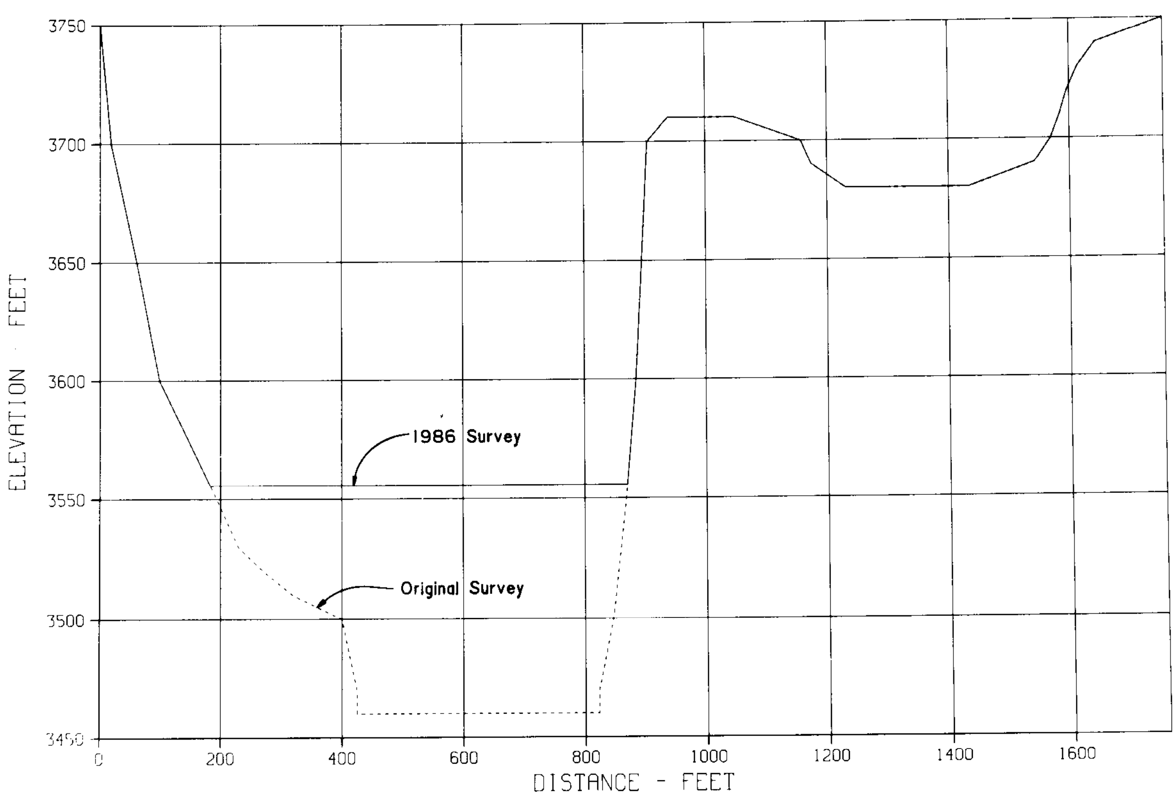

Figure 26. – Original and 1986 sedimentation range profiles, range 300, Colorado River.

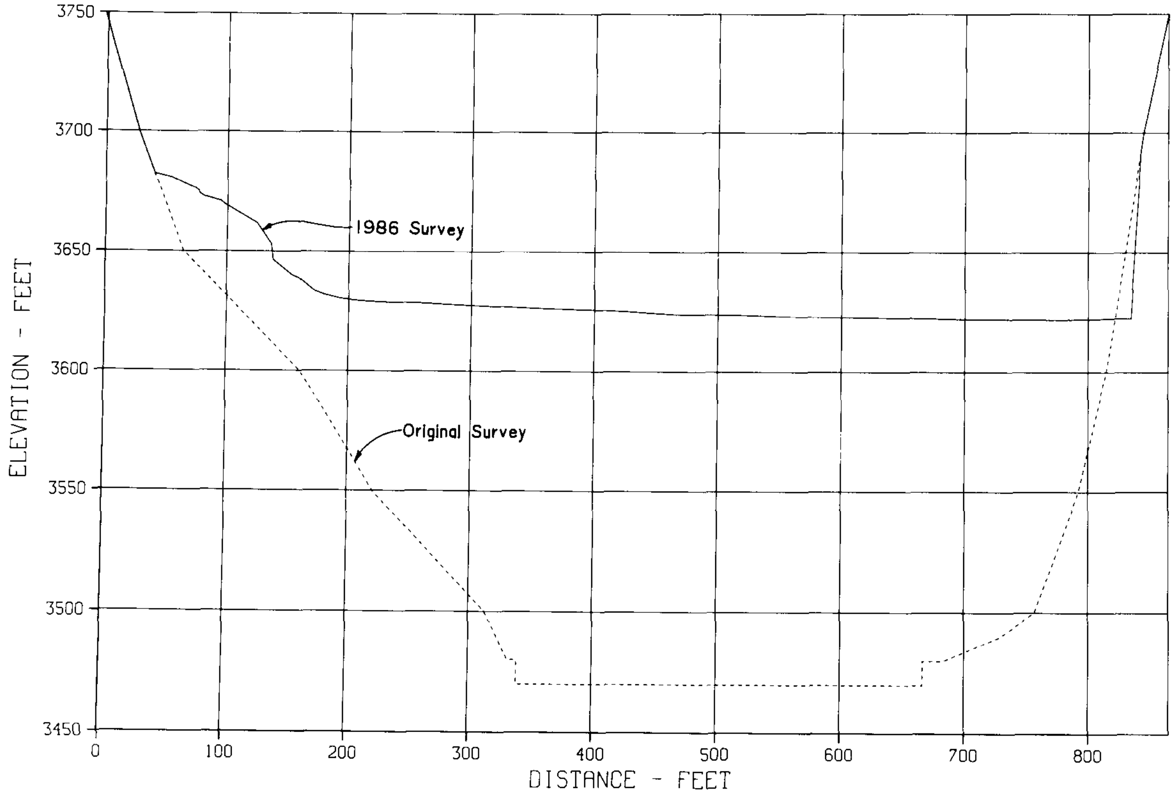

Figure 27. – Original and 1986 sedimentation range profiles, range 316, Colorado River.

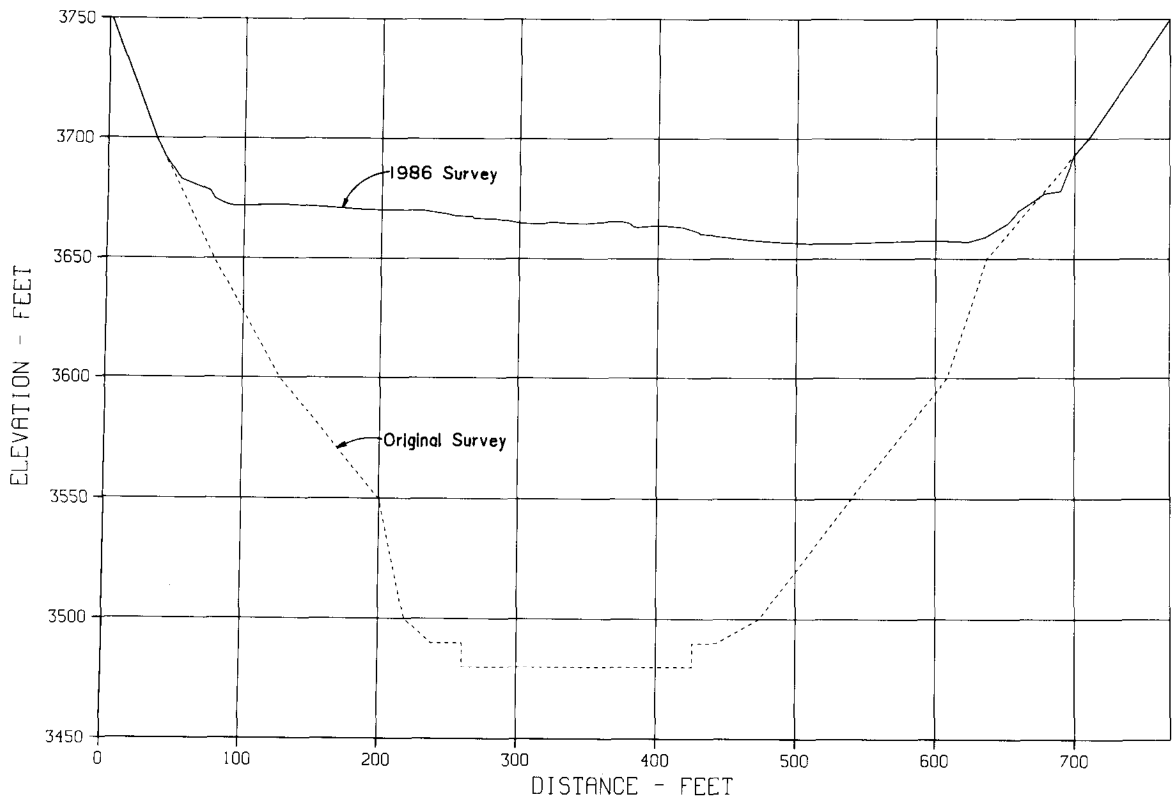

Figure 28. – Original and 1986 sedimentation range profiles, range 324, Colorado River.

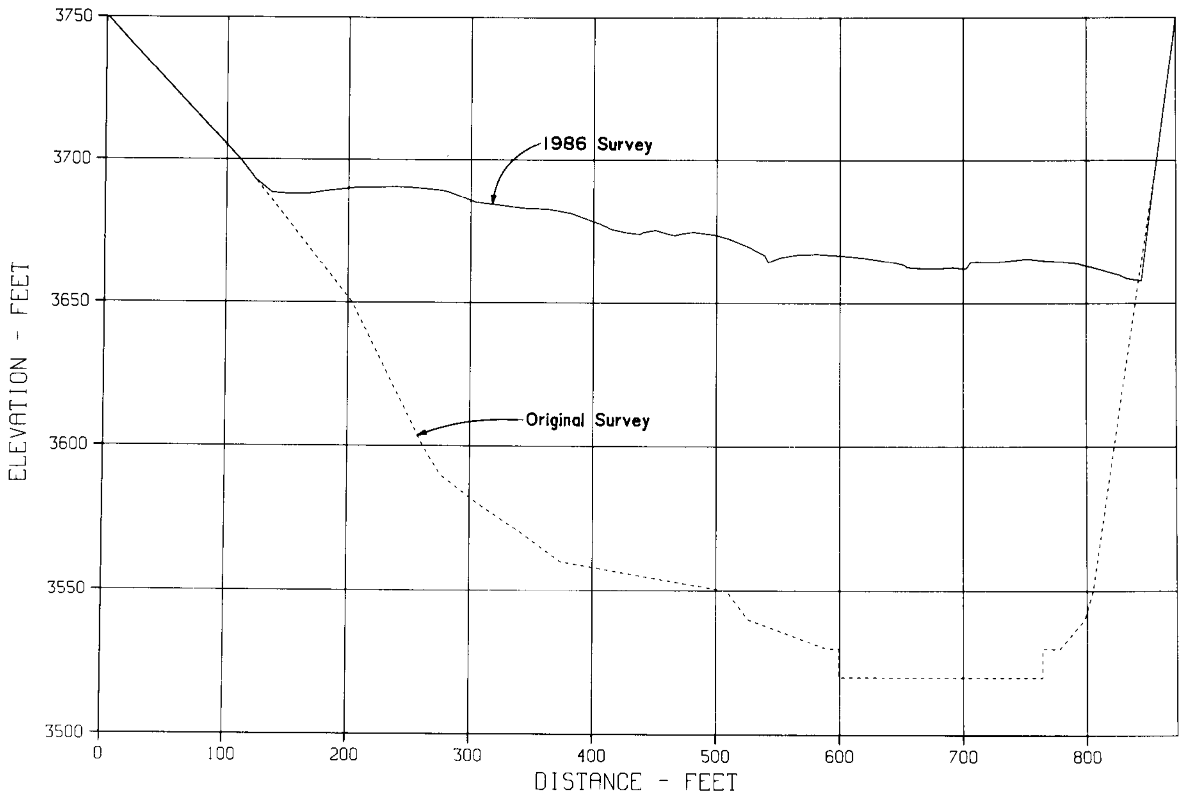

Figure 29. – Original and 1986 sedimentation range profiles, range 331, Colorado River.

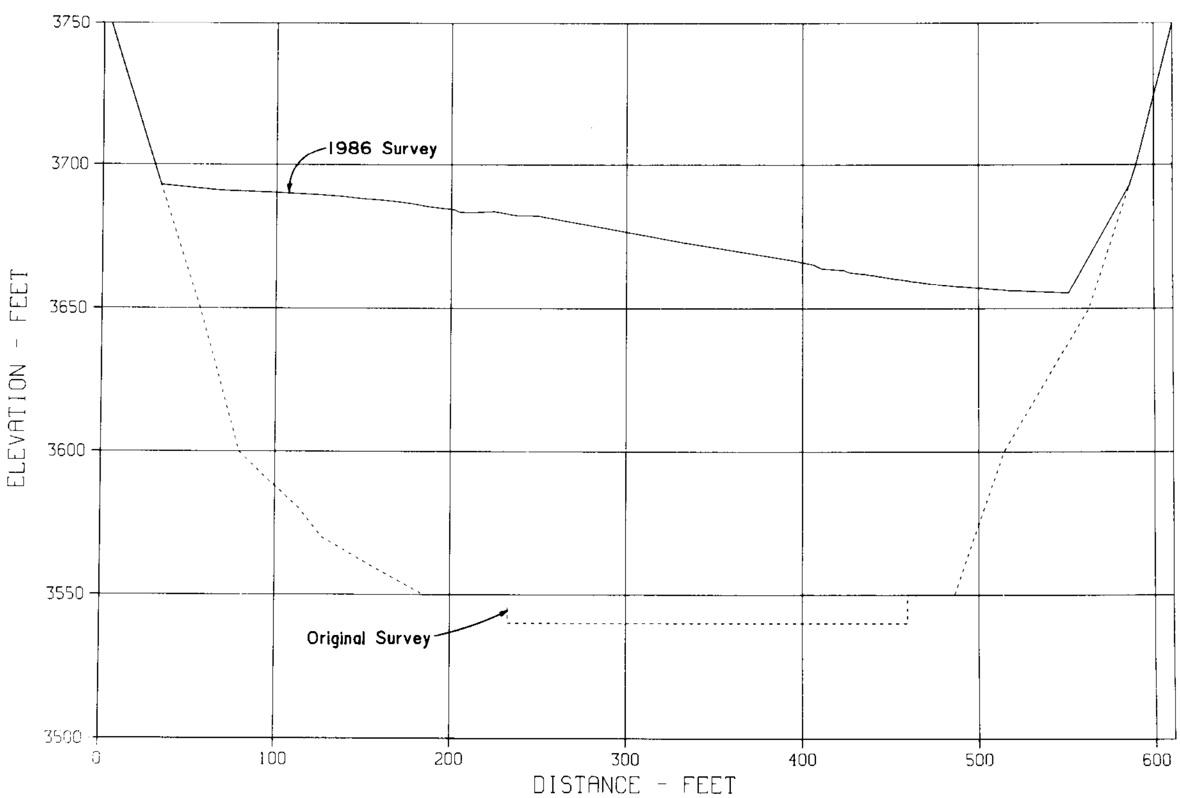

Figure 30. – Original and 1986 sedimentation range profiles, range 340, Colorado River.

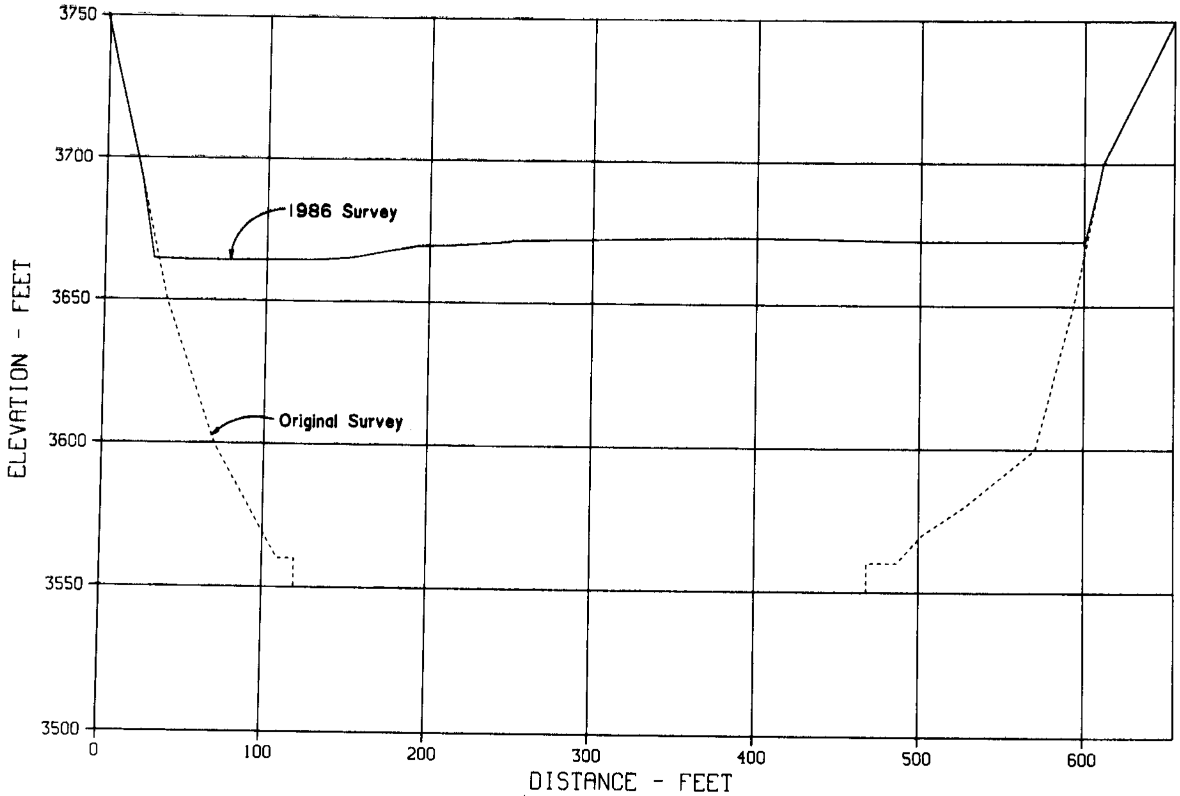

Figure 31. – Original and 1986 sedimentation range profiles, range 344, Colorado River.

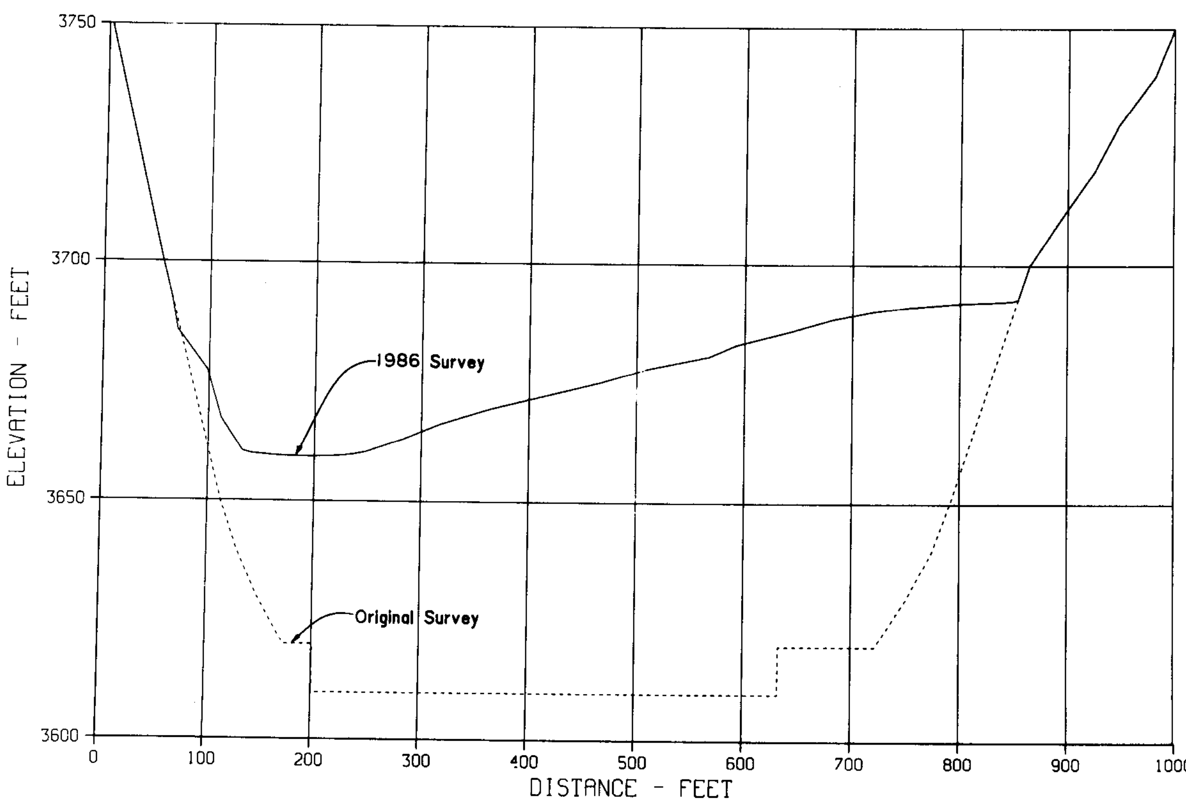

Figure 32. – Original and 1986 sedimentation range profiles, range 352, Colorado River.

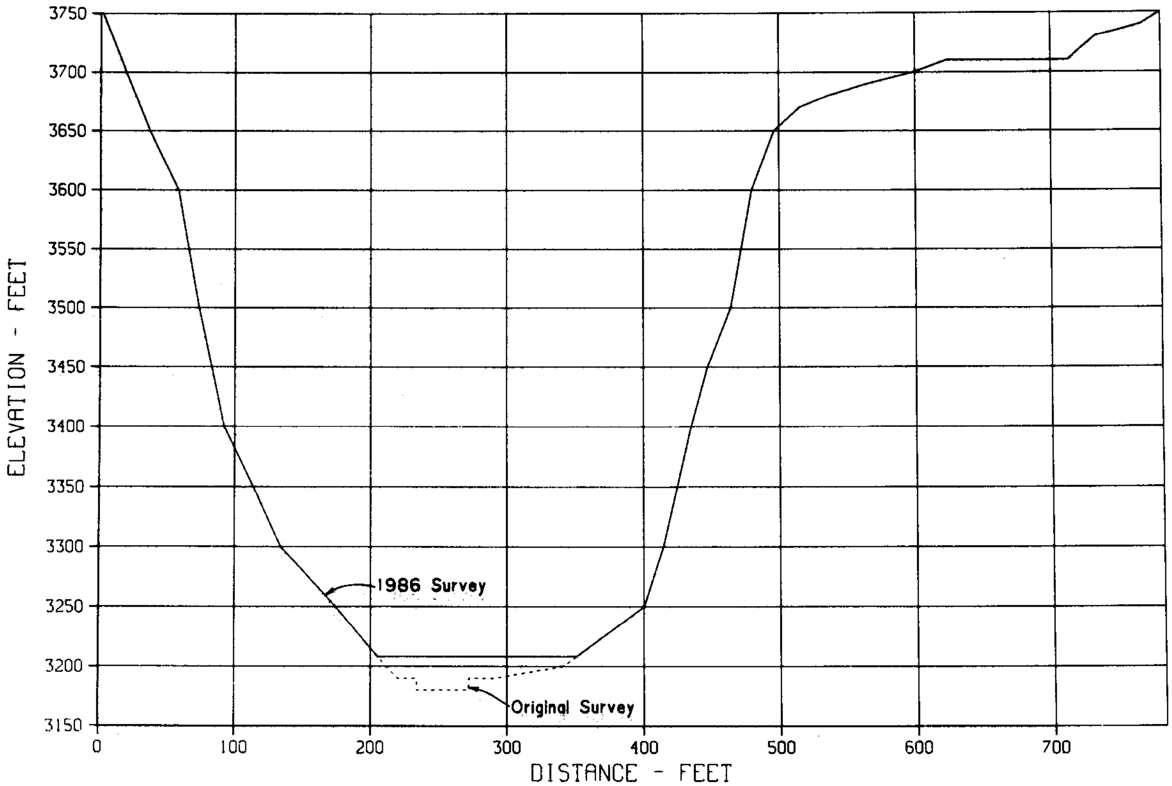

Figure 33. – Original and 1986 sedimentation range profiles, range 422, Navajo Creek.

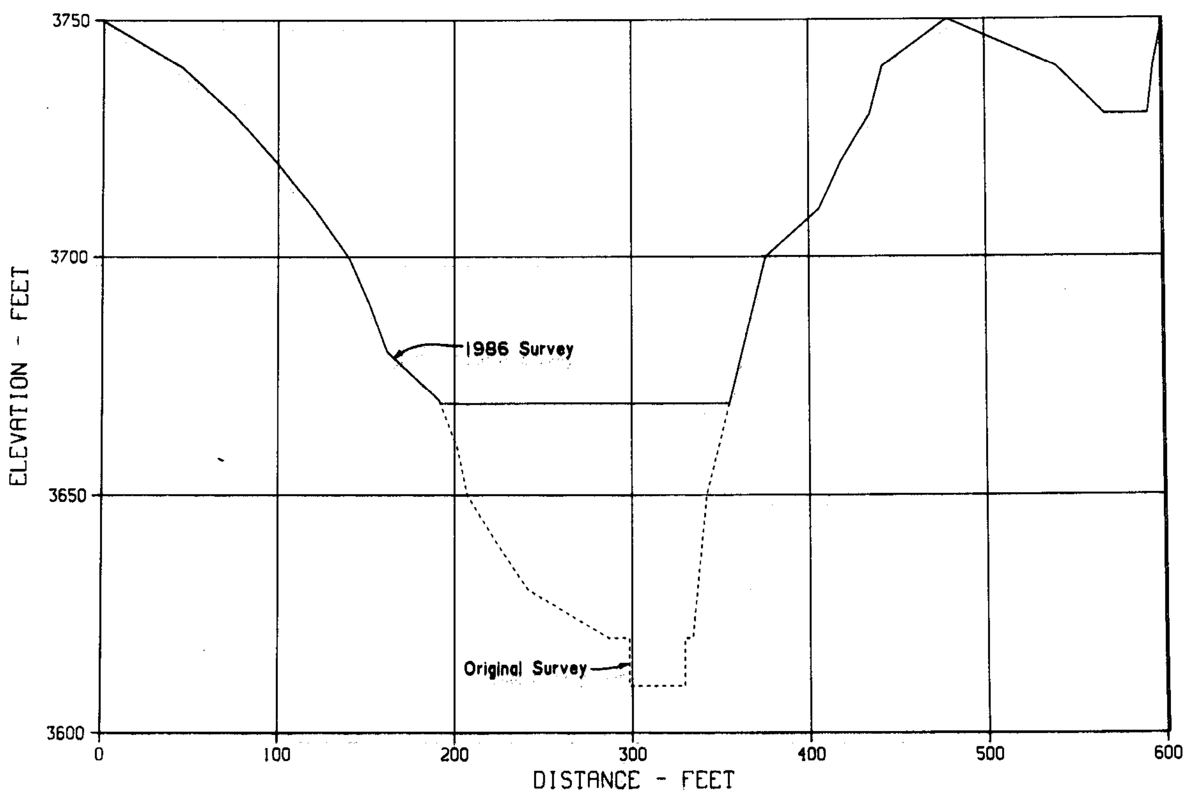

Figure 34. – Original and 1986 sedimentation range profiles, range 434, Navajo Creek.

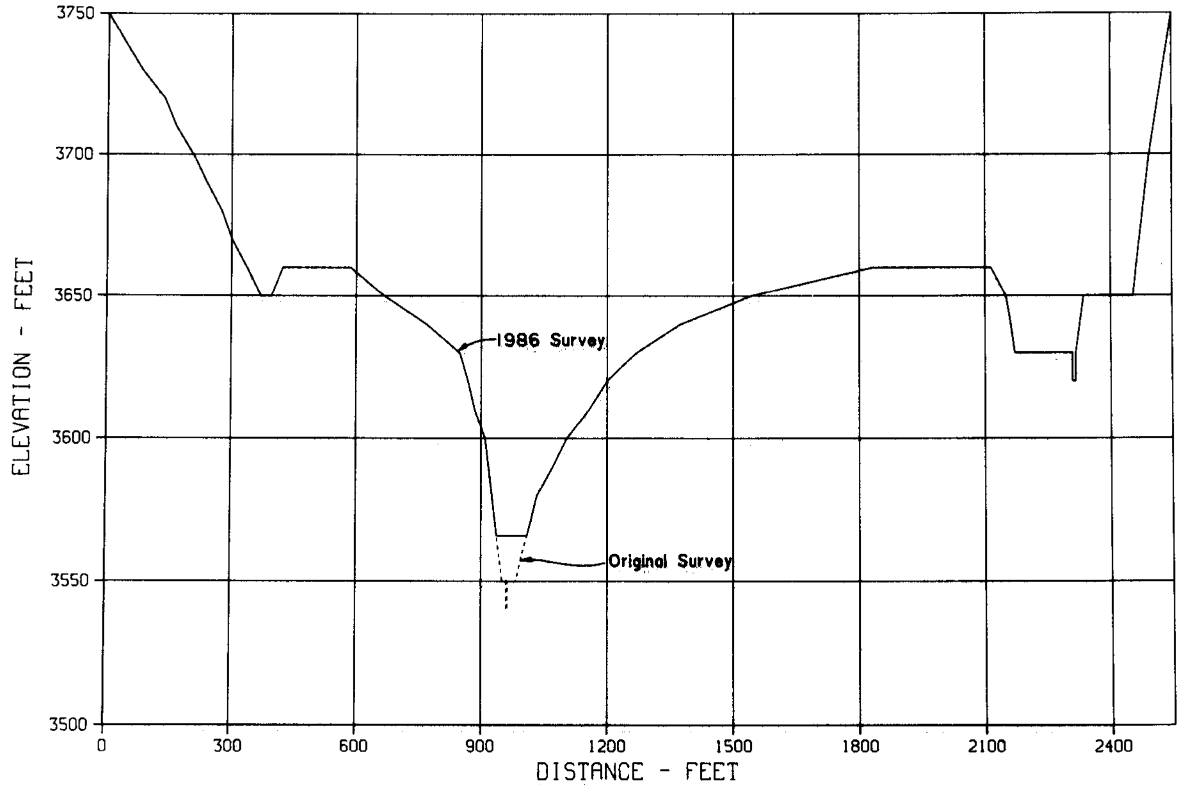

Figure 35. – Original and 1986 sedimentation range profiles, range 482, Padre Canyon.

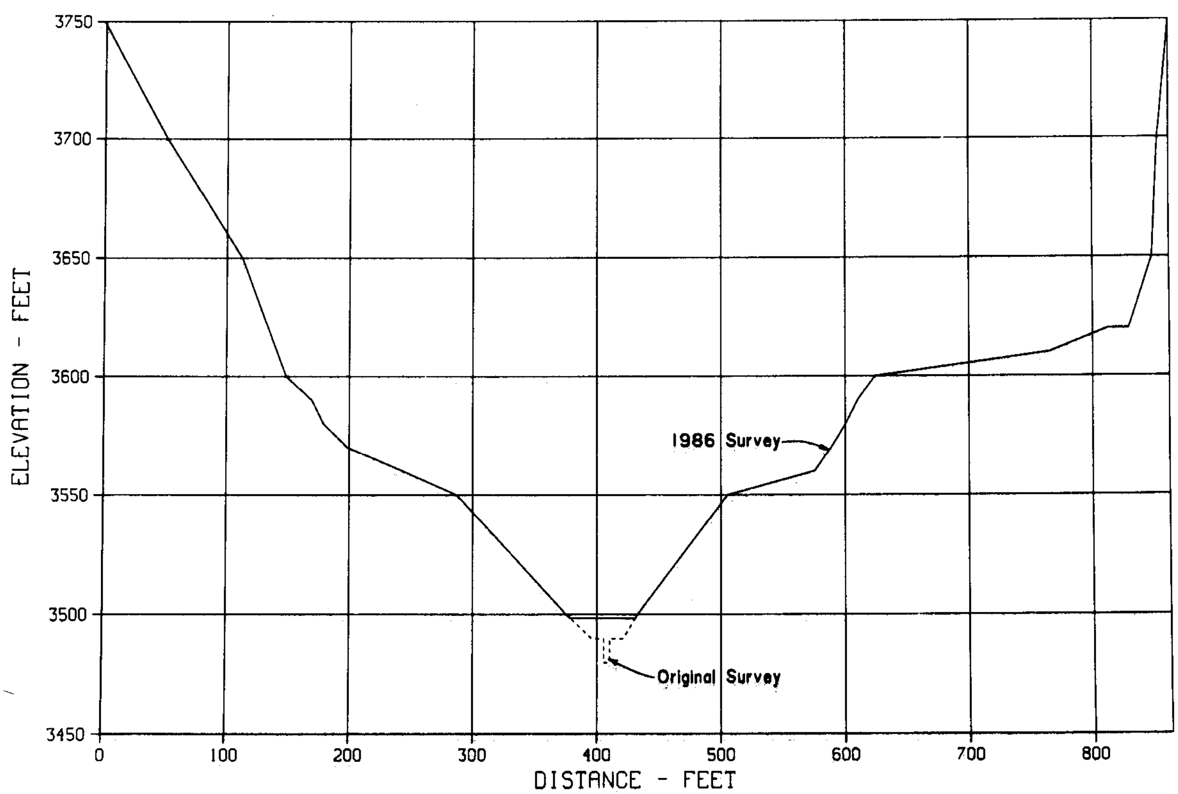

Figure 36. – Original and 1986 sedimentation range profiles, range 545, West Canyon Creek.

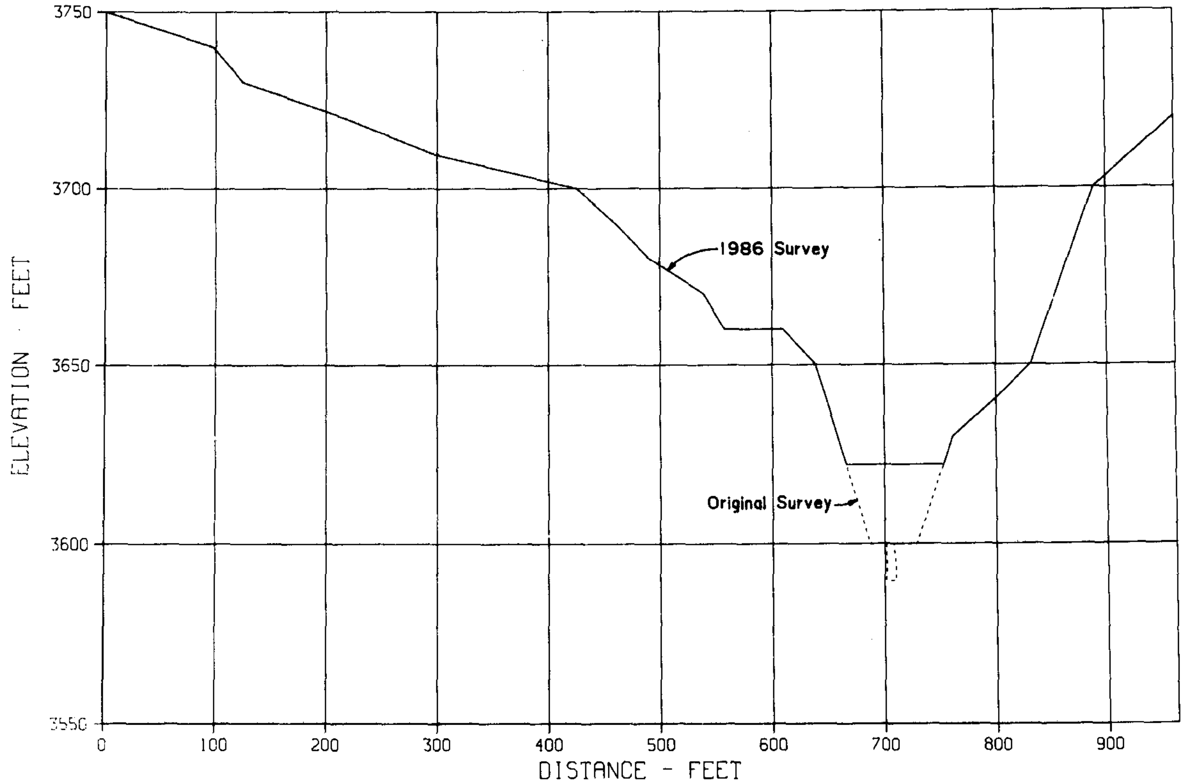

Figure 37. – Original and 1986 sedimentation range profiles, range 574, Dry Rock Creek.

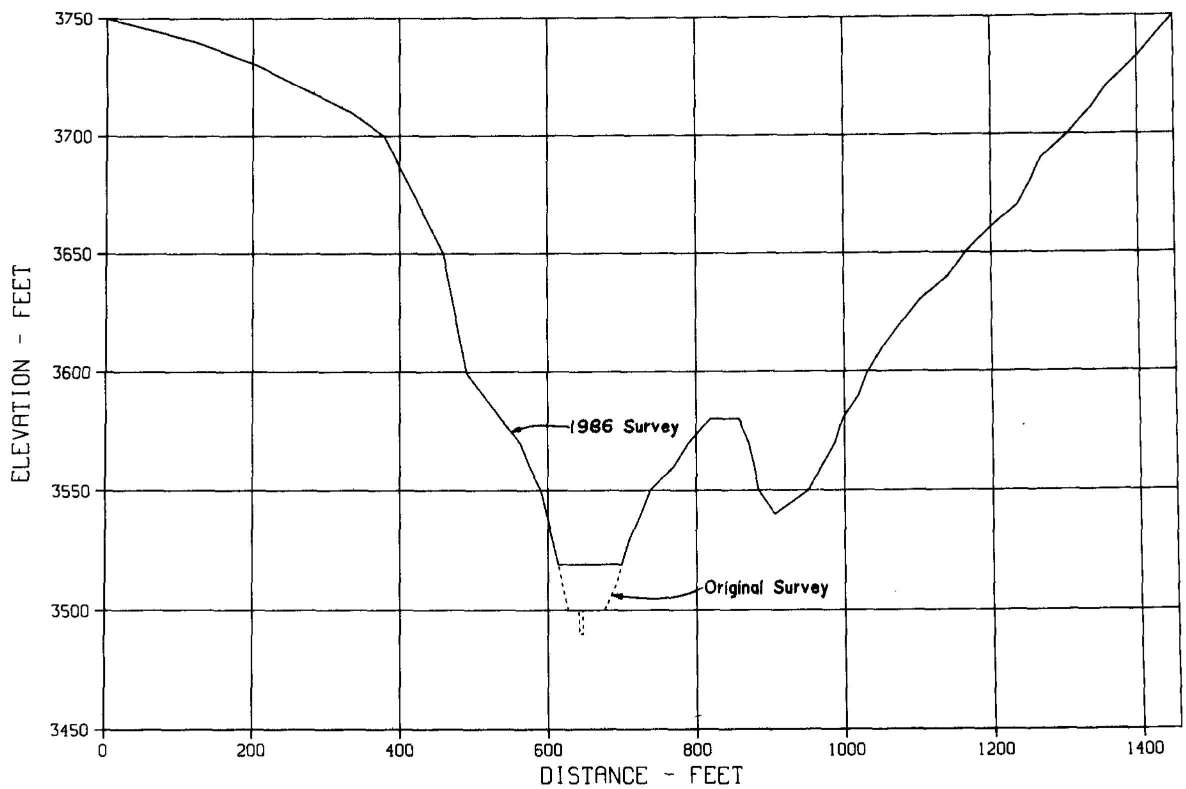

Figure 38. – Original and 1986 sedimentation range profiles, range 614, Dangling Rope Canyon.

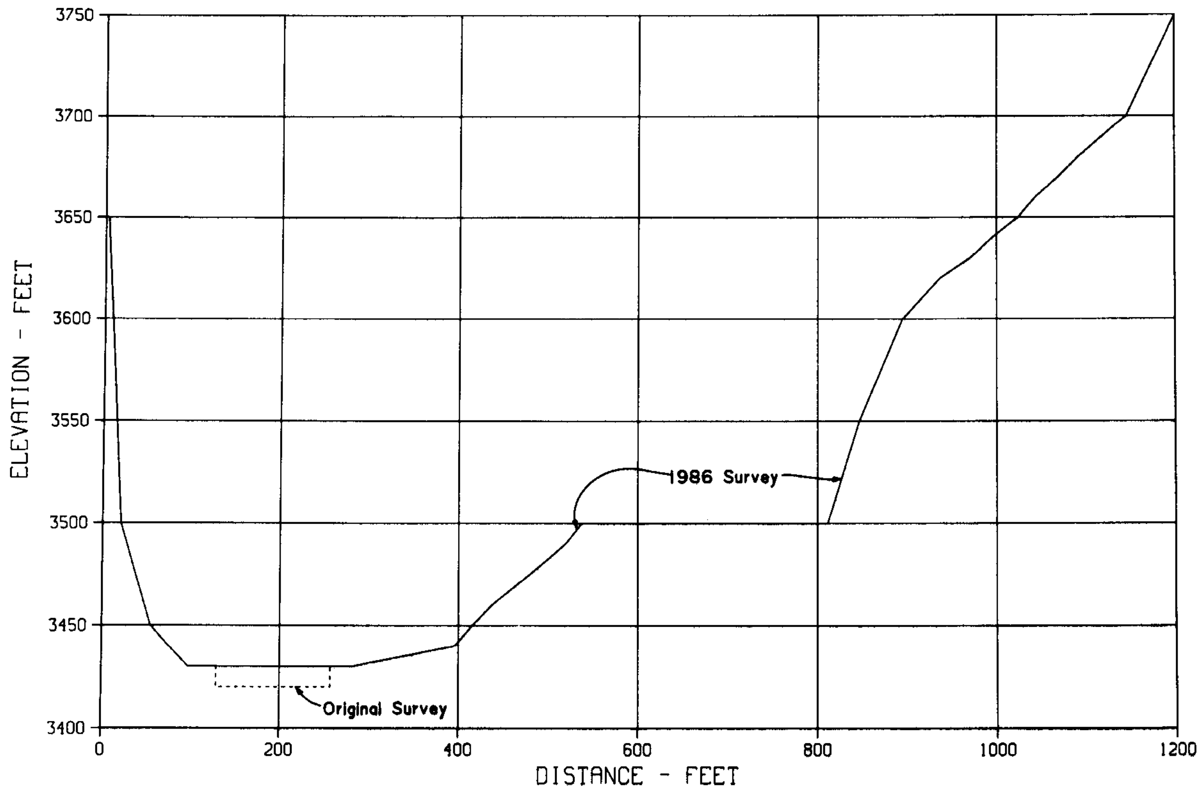

Figure 39. – Original and 1986 sedimentation range profiles, range 685, Escalante River.

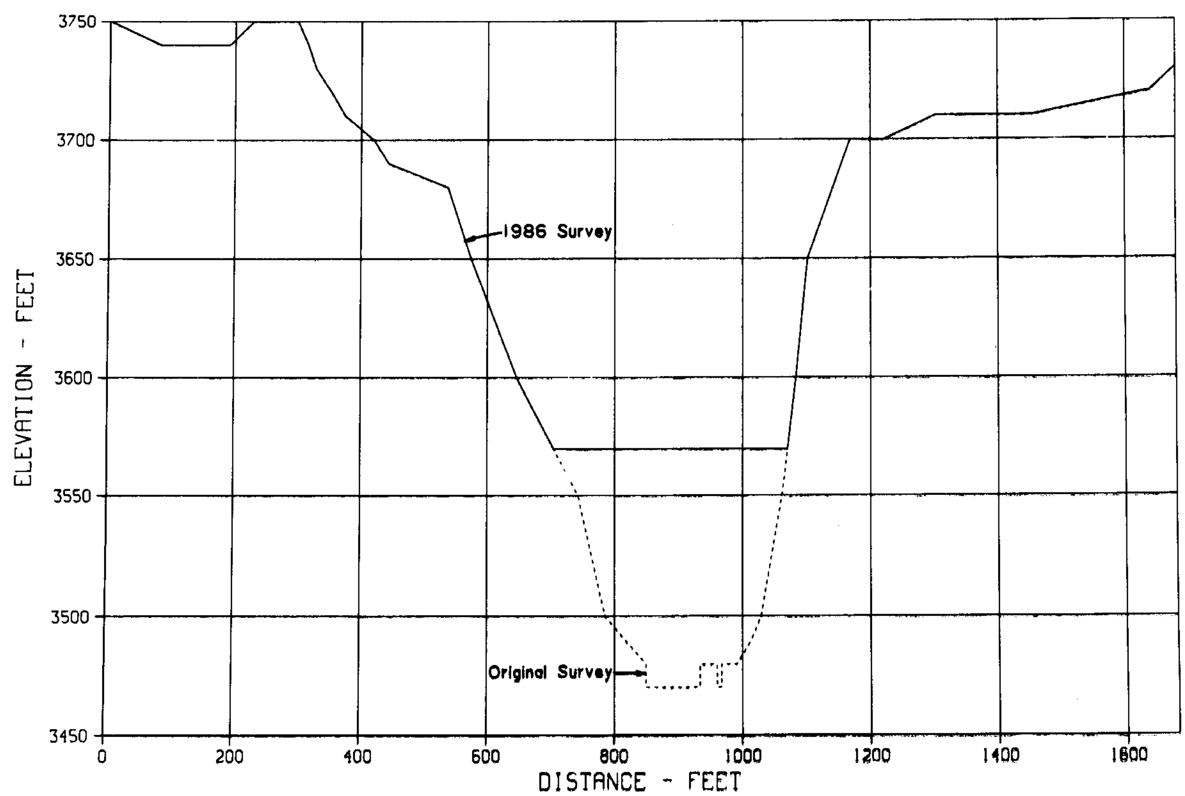

Figure 40. – Original and 1986 sedimentation range profiles, range 803, Dirty Devil River.

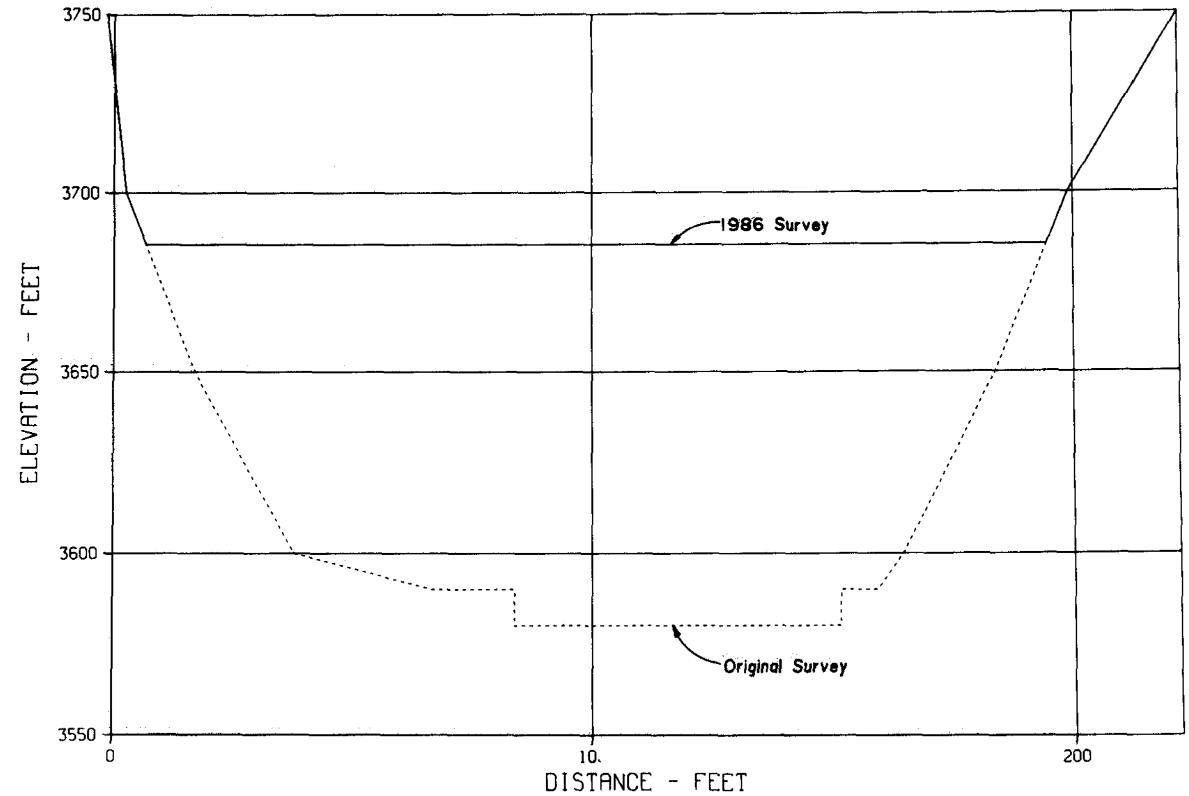

Figure 41. – Original and 1986 sedimentation range profiles, range 819, Dirty Devil River.

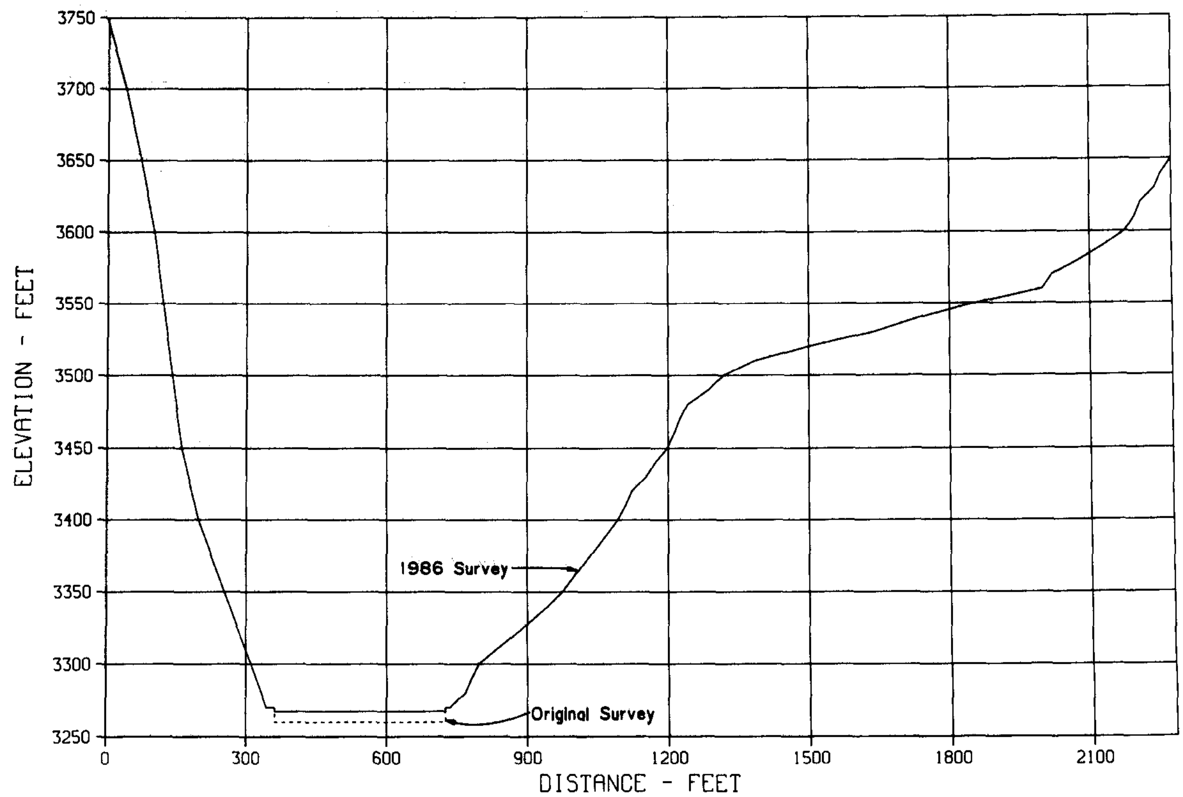

Figure 42. – Original and 1986 sedimentation range profiles, range 901, San Juan River.

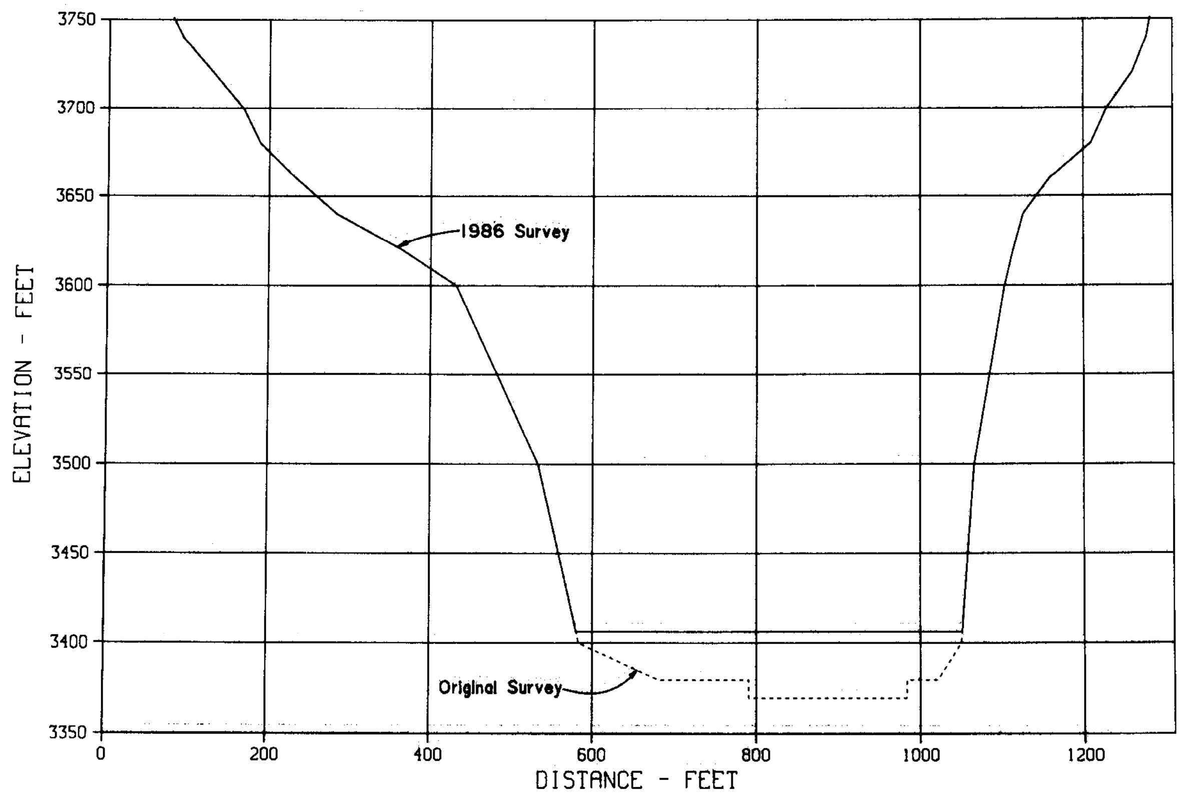

Figure 43. – Original and 1986 sedimentation range profiles, range 914, San Juan River.

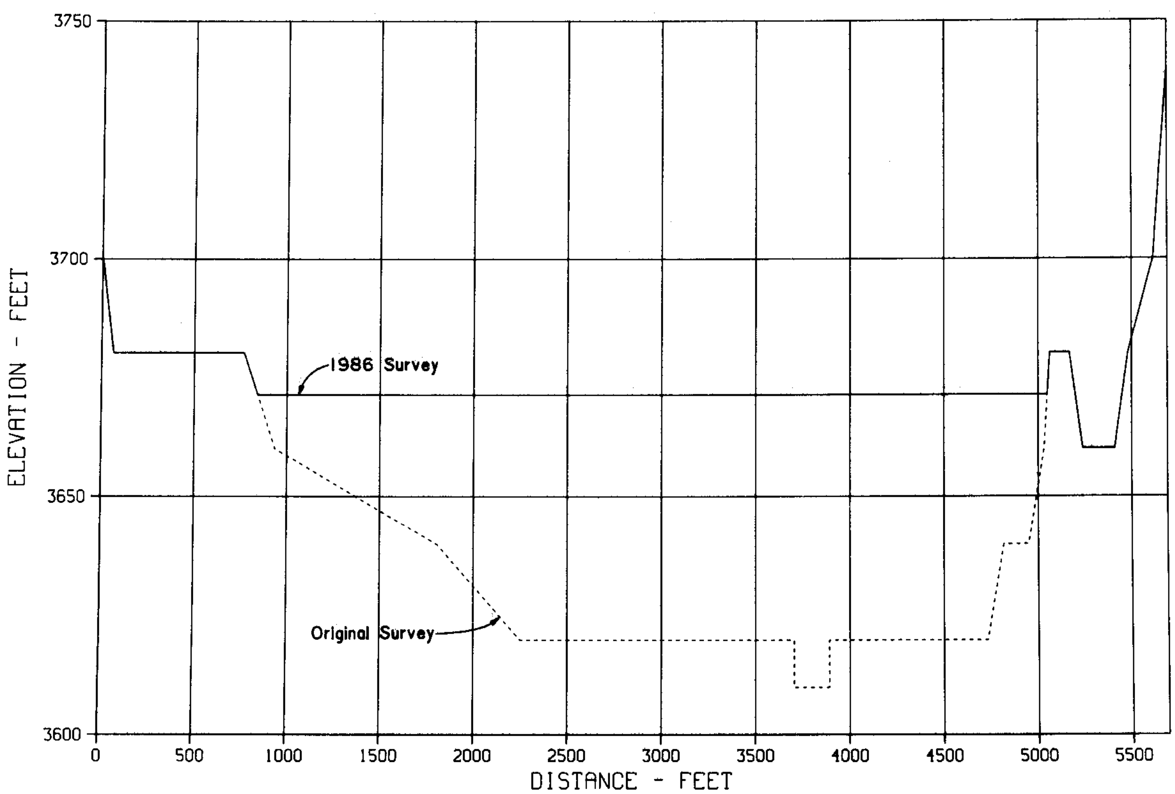

Figure 44. – Original and 1986 sedimentation range profiles, range 946, San Juan River.

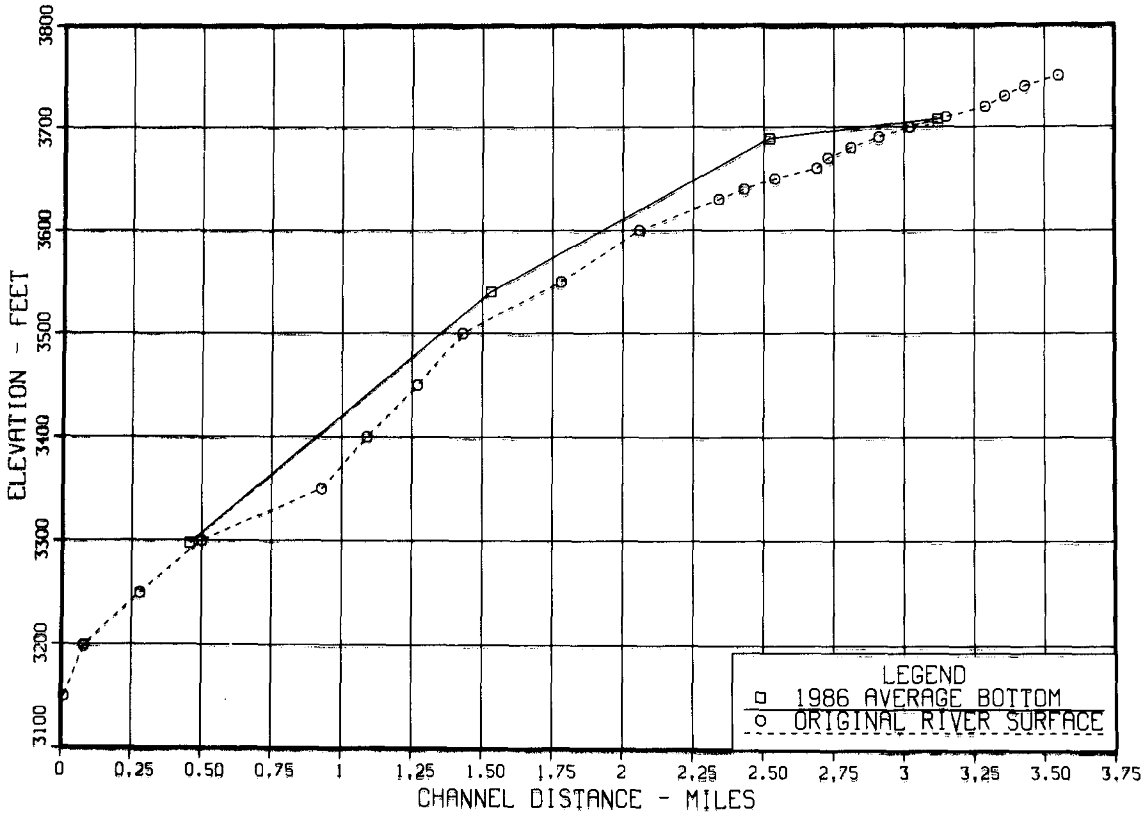

Figure 45. – Antelope Canyon profiles.

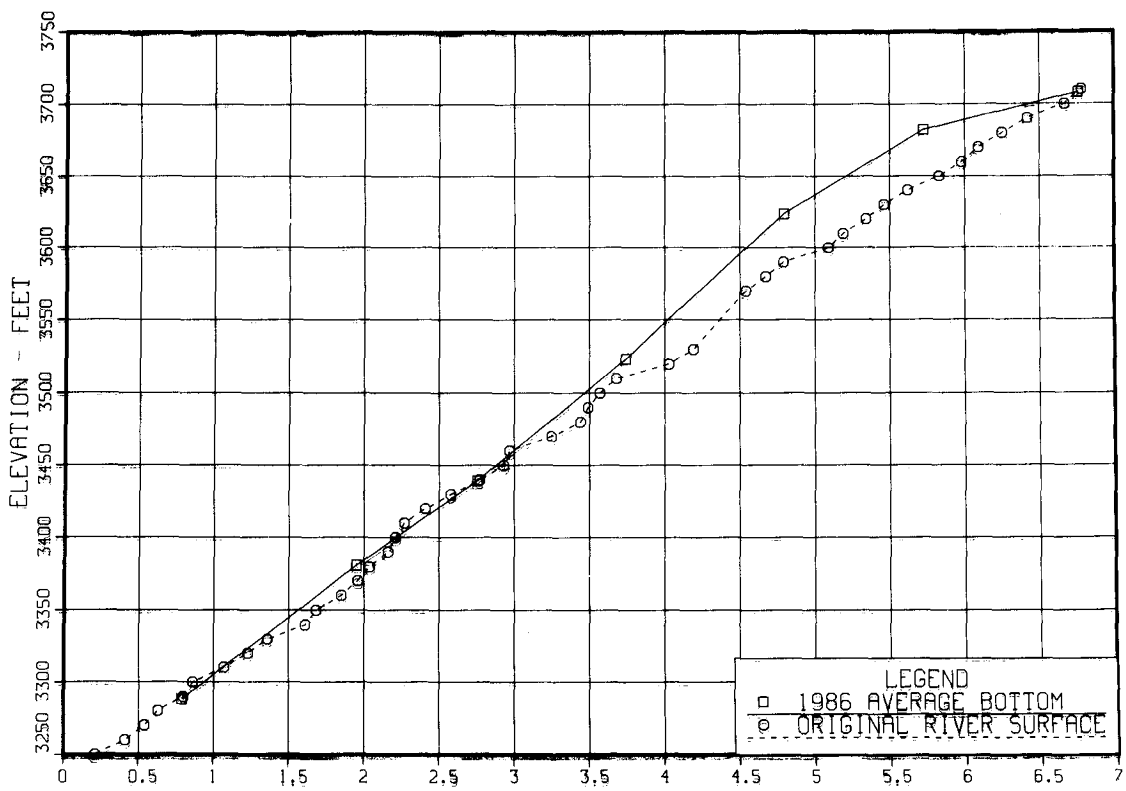

Figure 46. – Aztec Creek profiles.

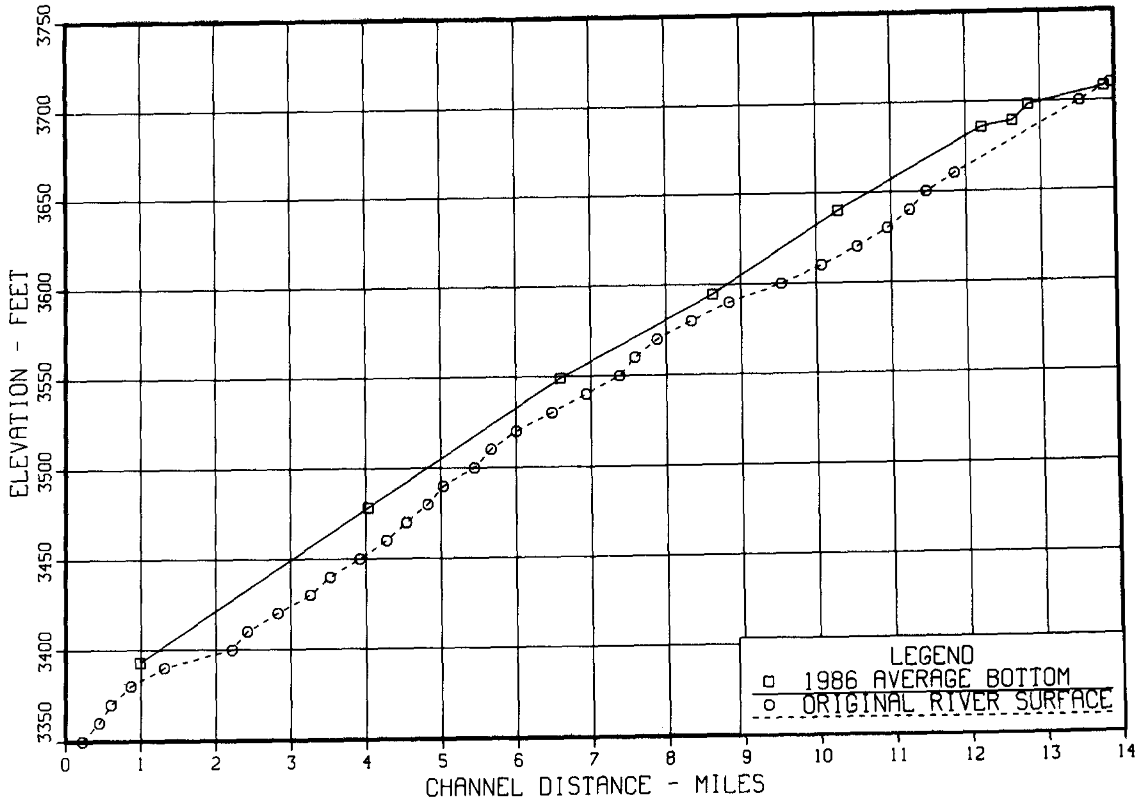

Figure 47. – Bullfrog Creek profiles.

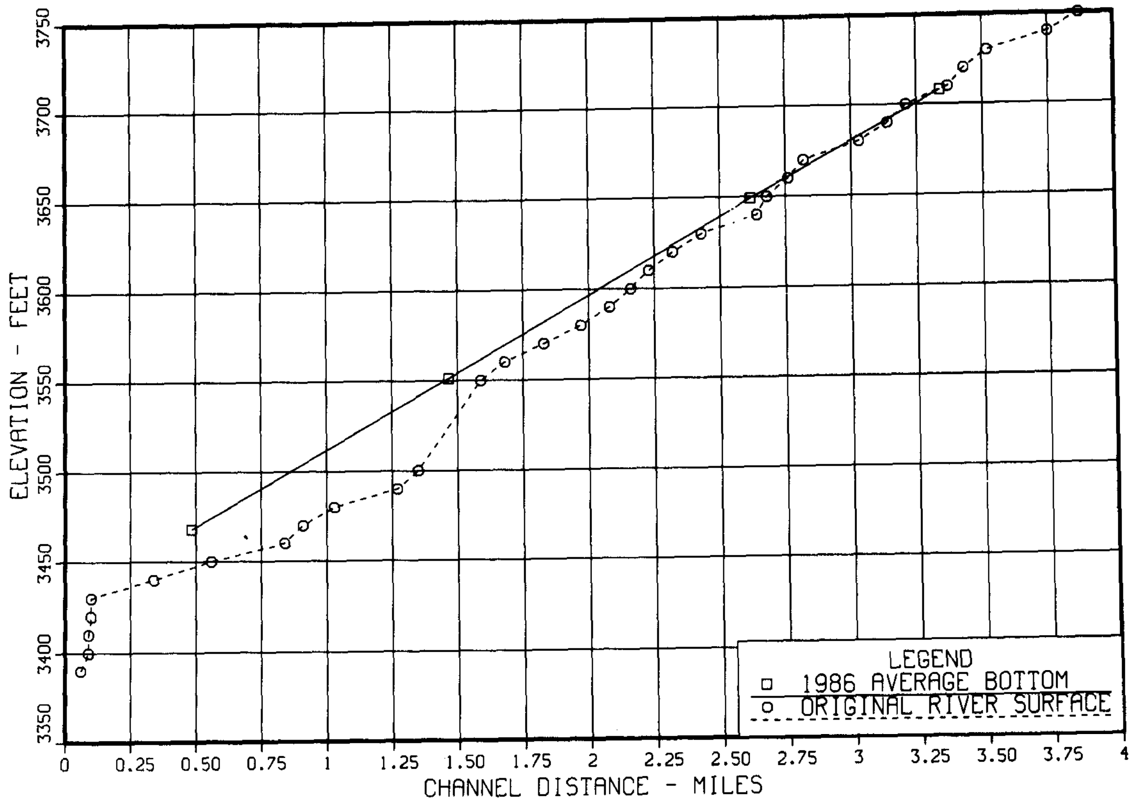

Figure 48. – Cedar Canyon profiles.

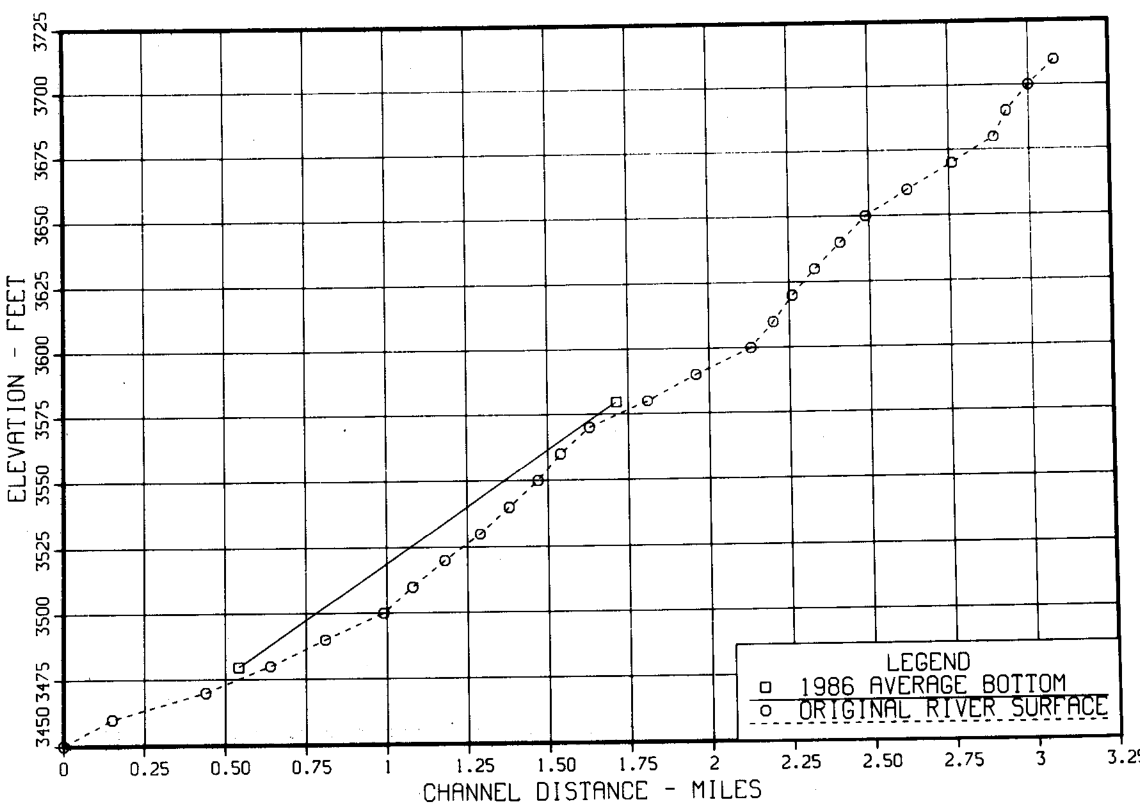

Figure 49. – Farley Canyon Profiles.

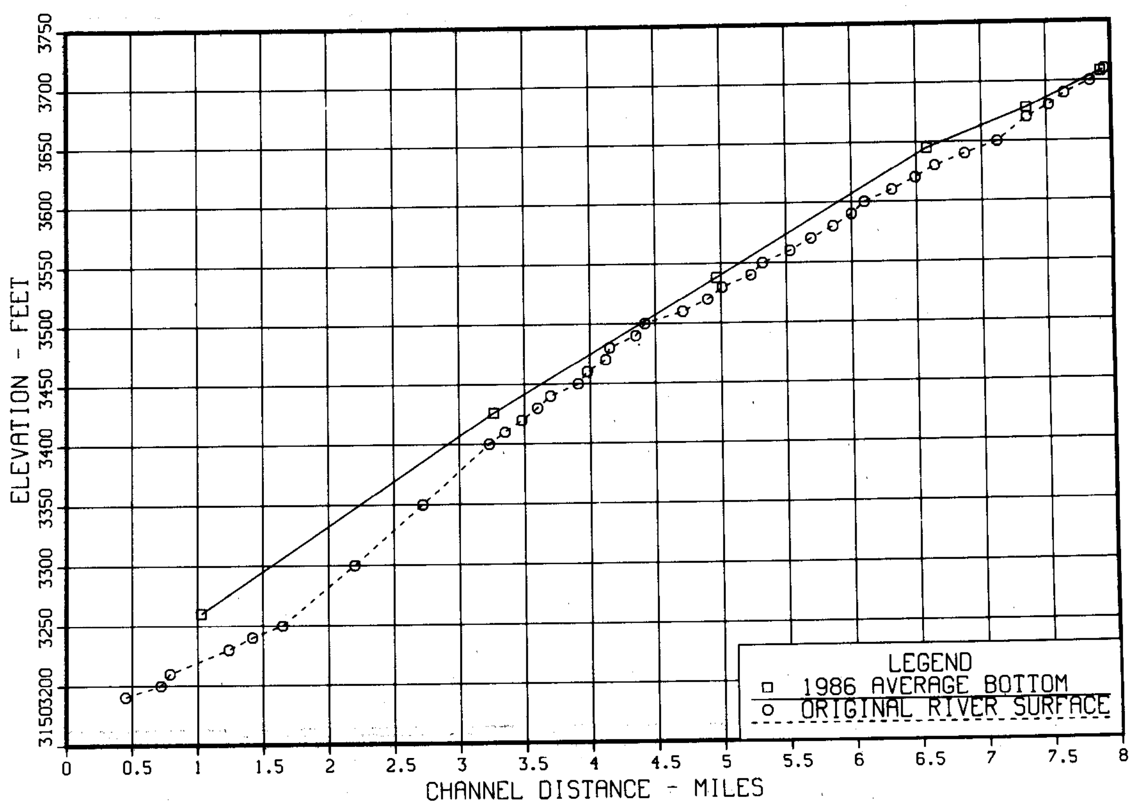

Figure 50. – Gunsight Canyon profiles.

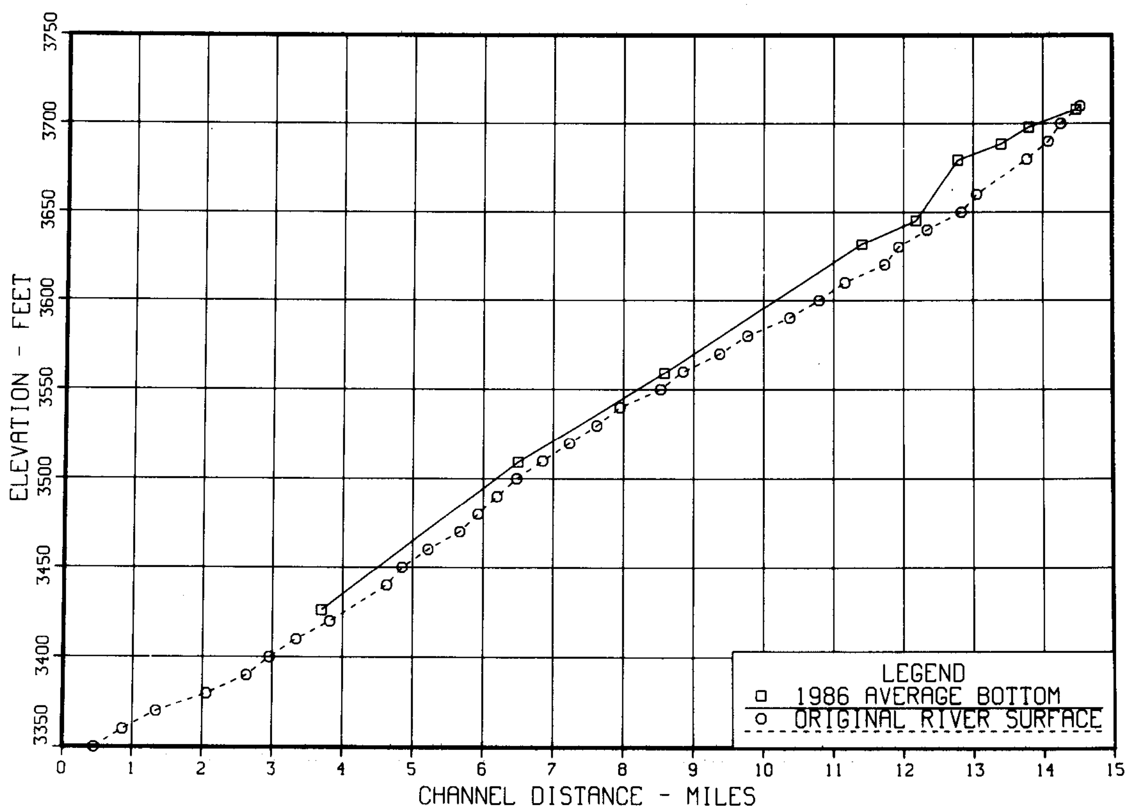

Figure 51. – Halls Creek profiles.

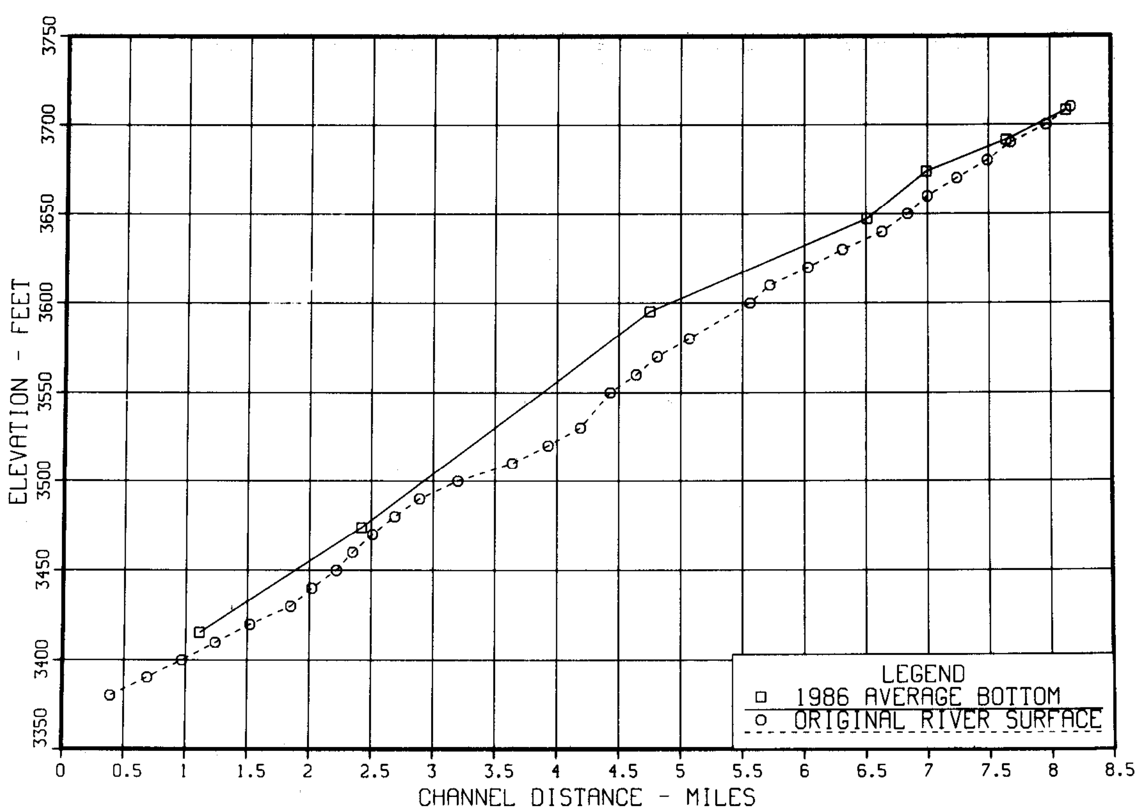

Figure 52. – Hansen Creek profiles.

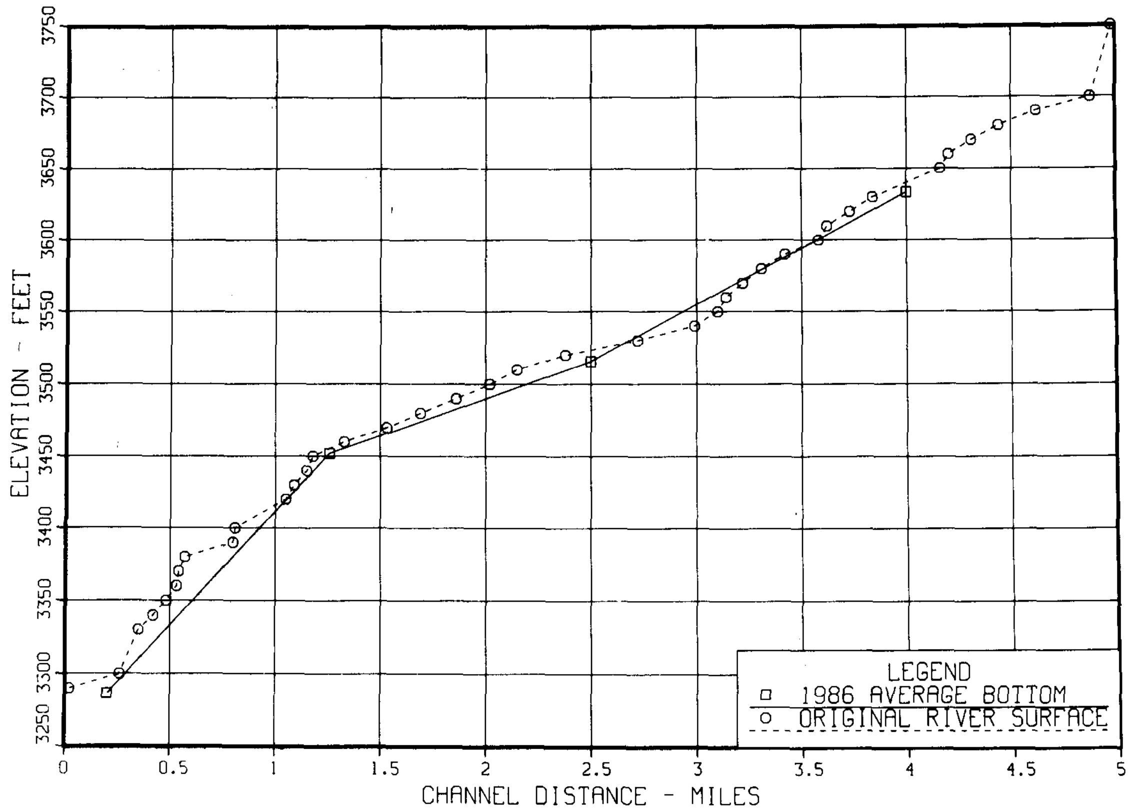

Figure 53. – Iceberg Canyon profiles.

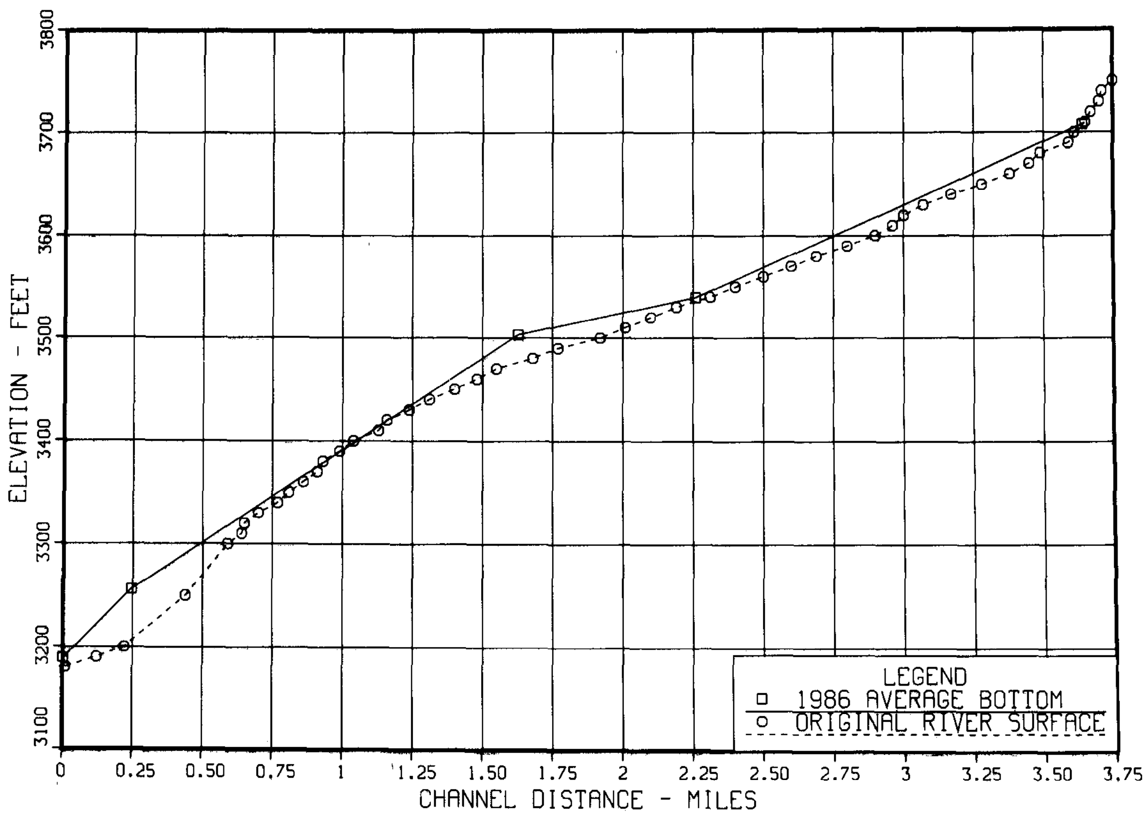

Figure 54. – Kane Creek profiles.

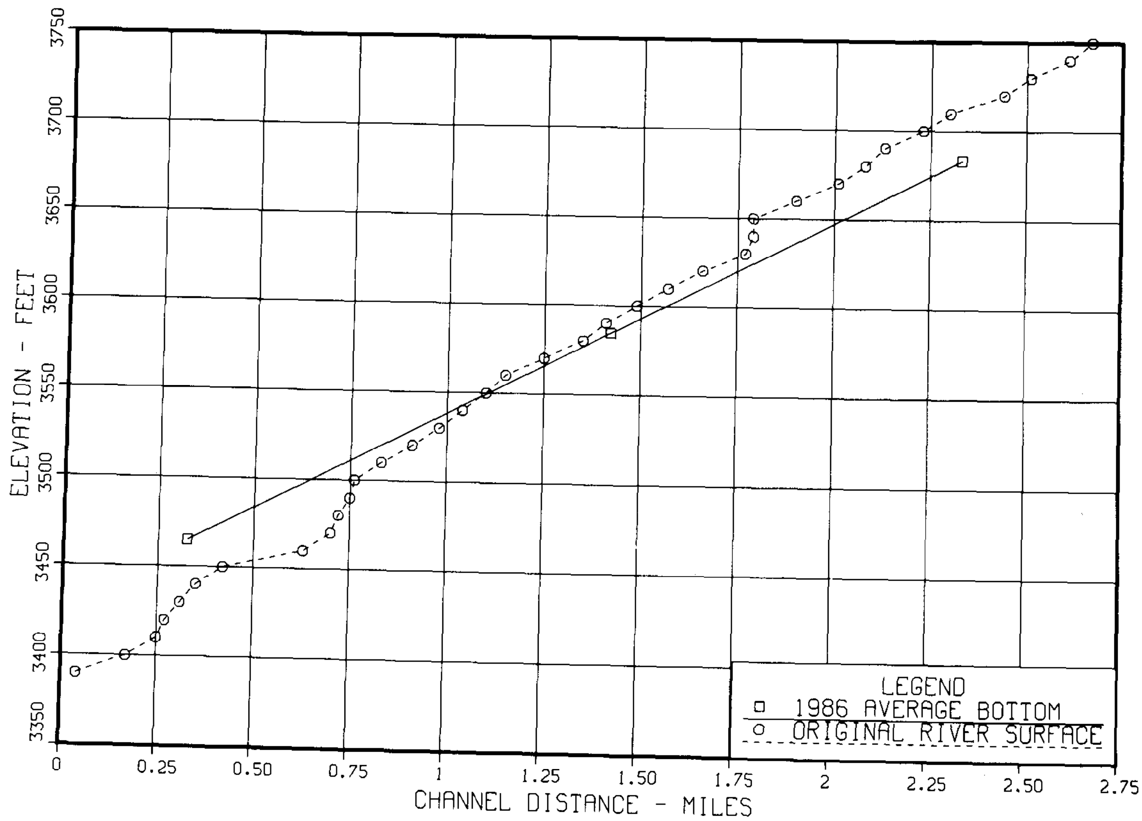

Figure 55. – Knowles Canyon profiles.

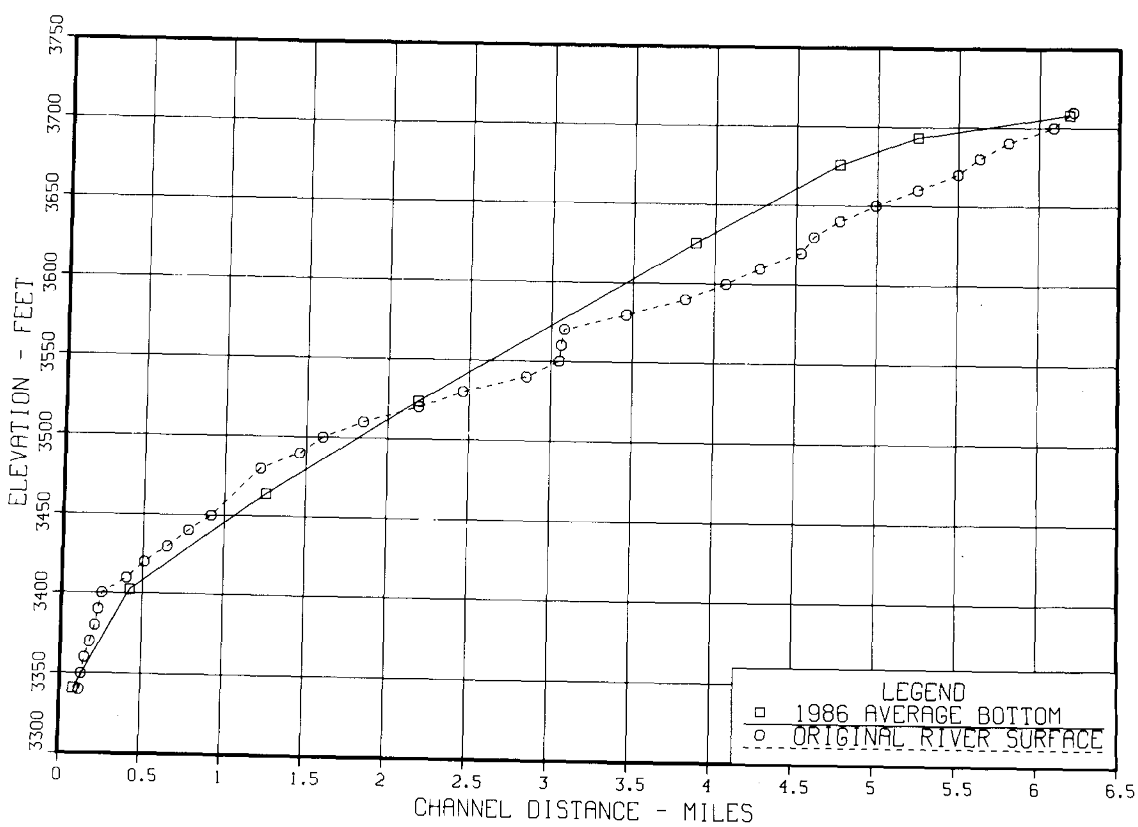

Figure 56. – Lake Canyon profiles.

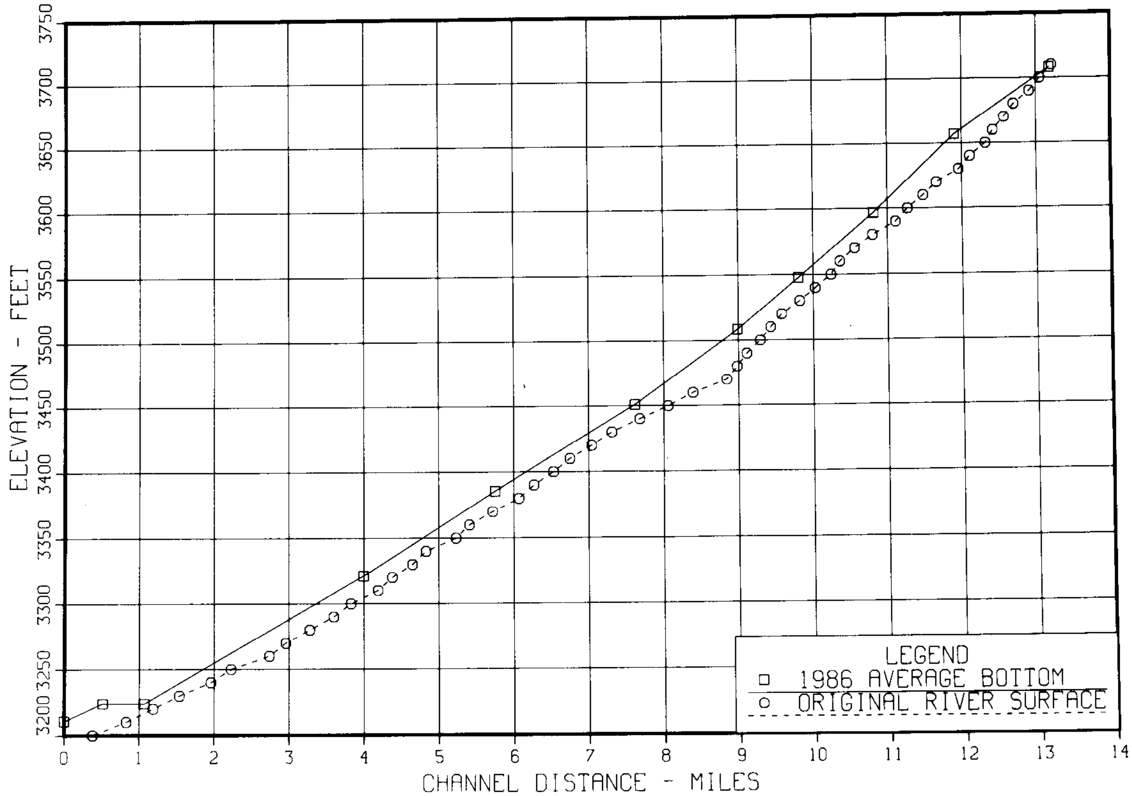

Figure 57. – Last Chance Canyon profiles.

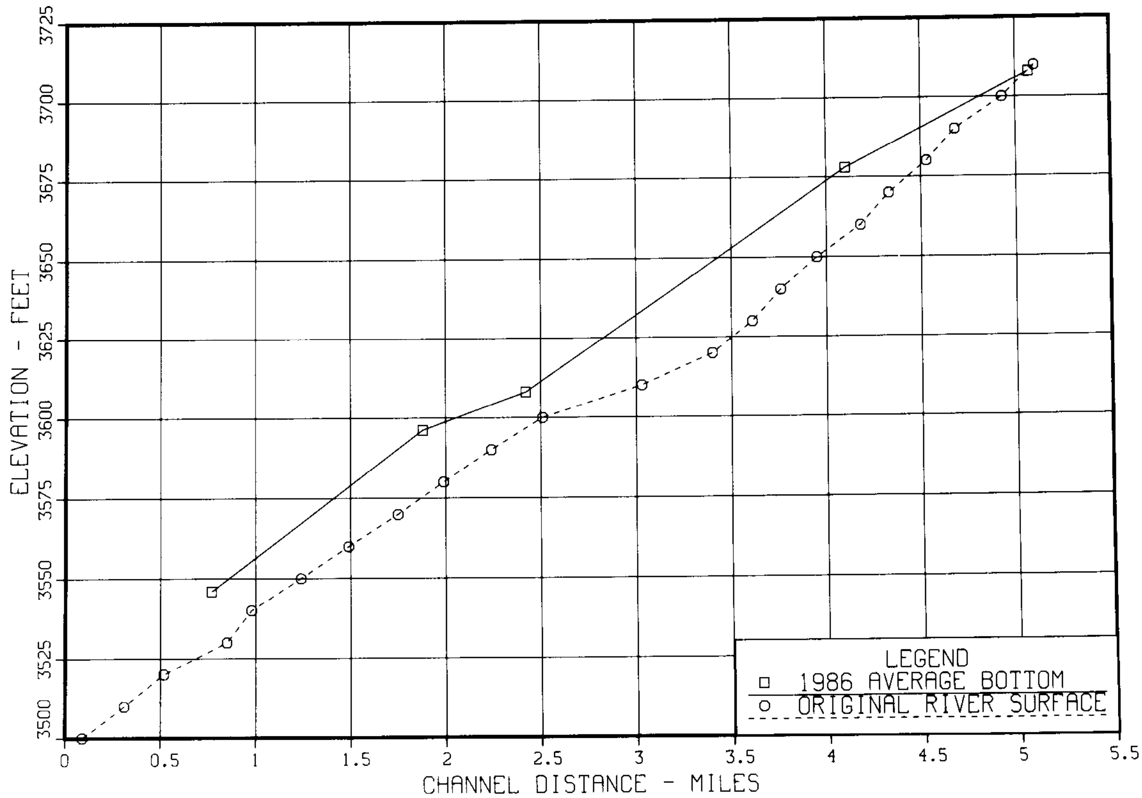

Figure 58. – Little Valley Canyon profiles.

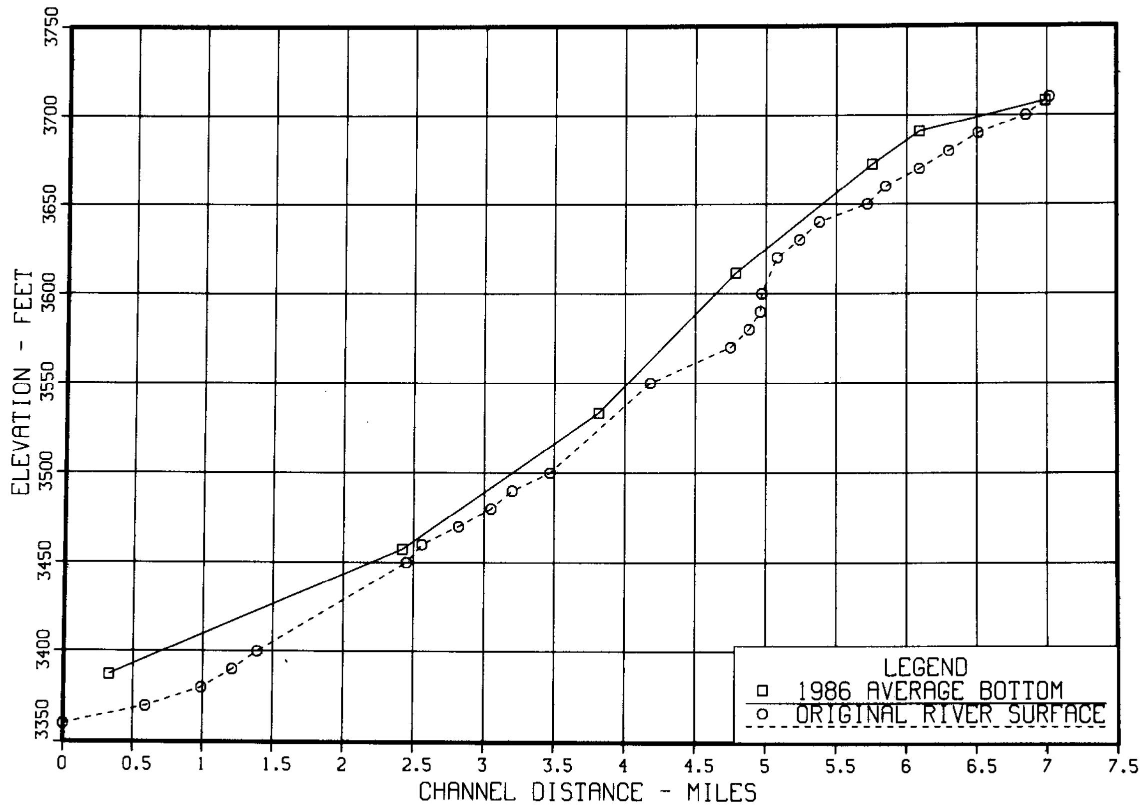

Figure 59. – Moki Canyon profiles.

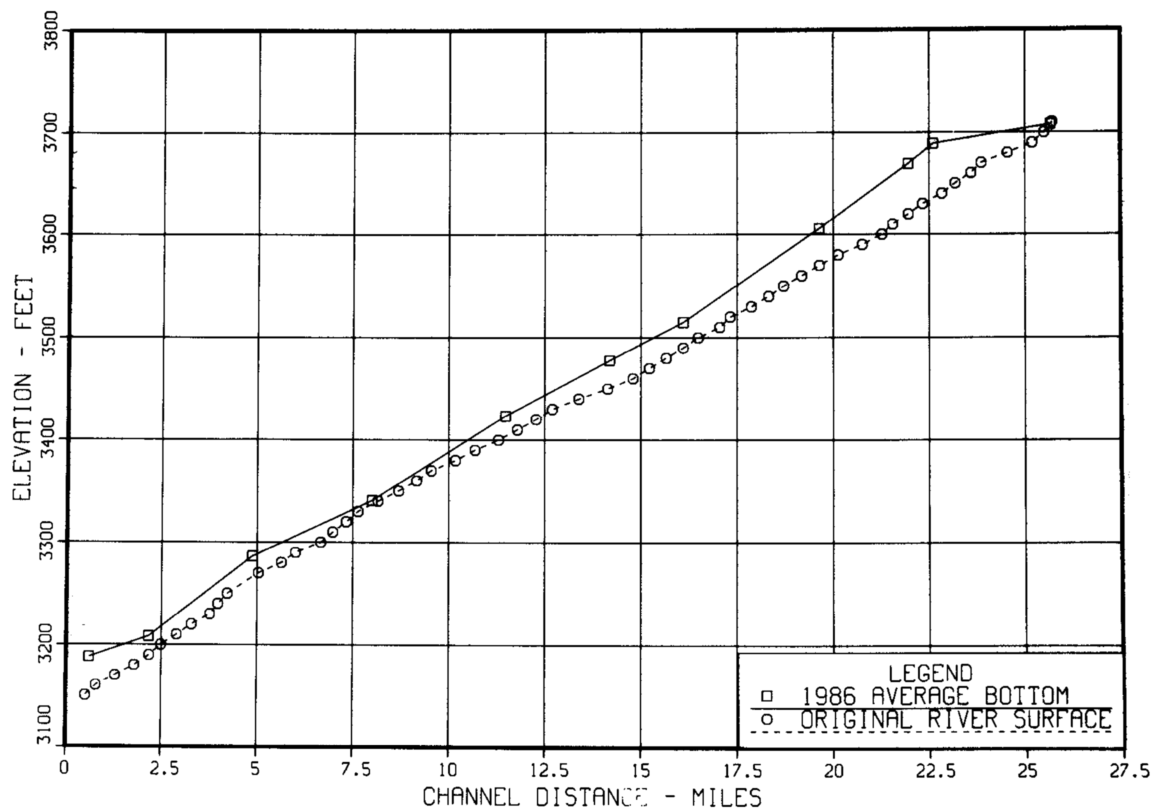

Figure 60. – Navajo Canyon profiles.

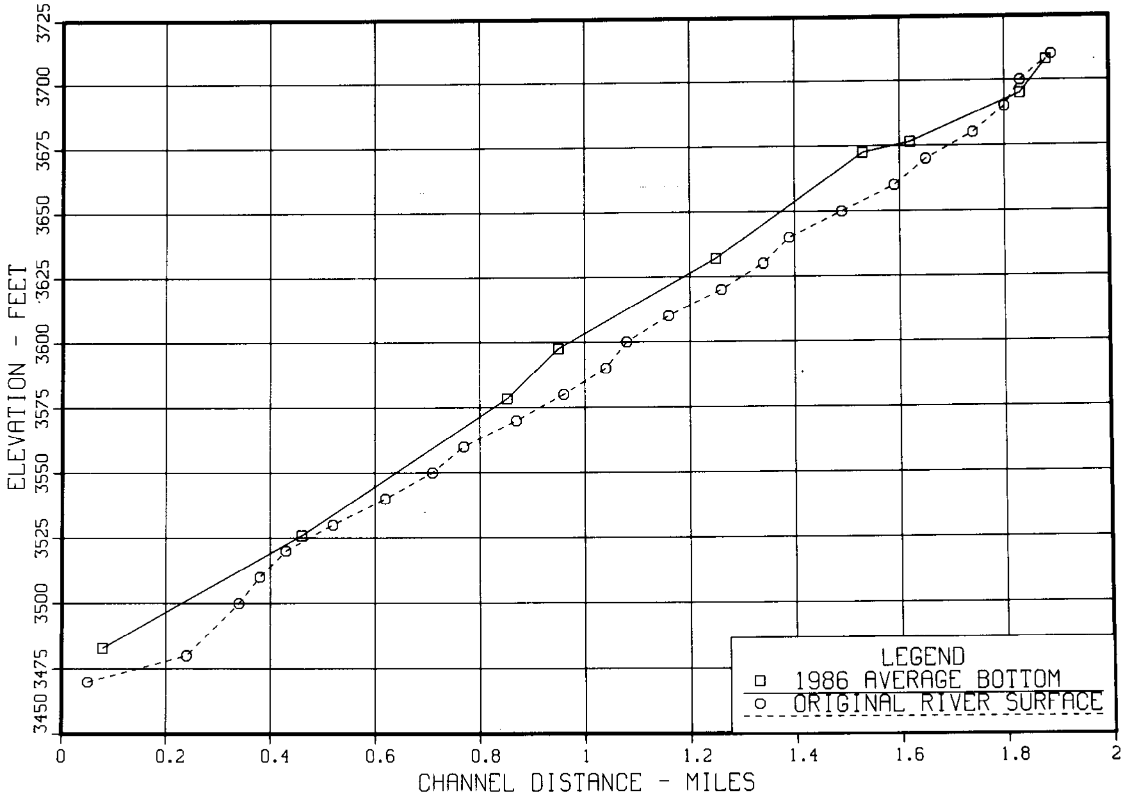

Figure 61. – Rainbow Bridge profiles.

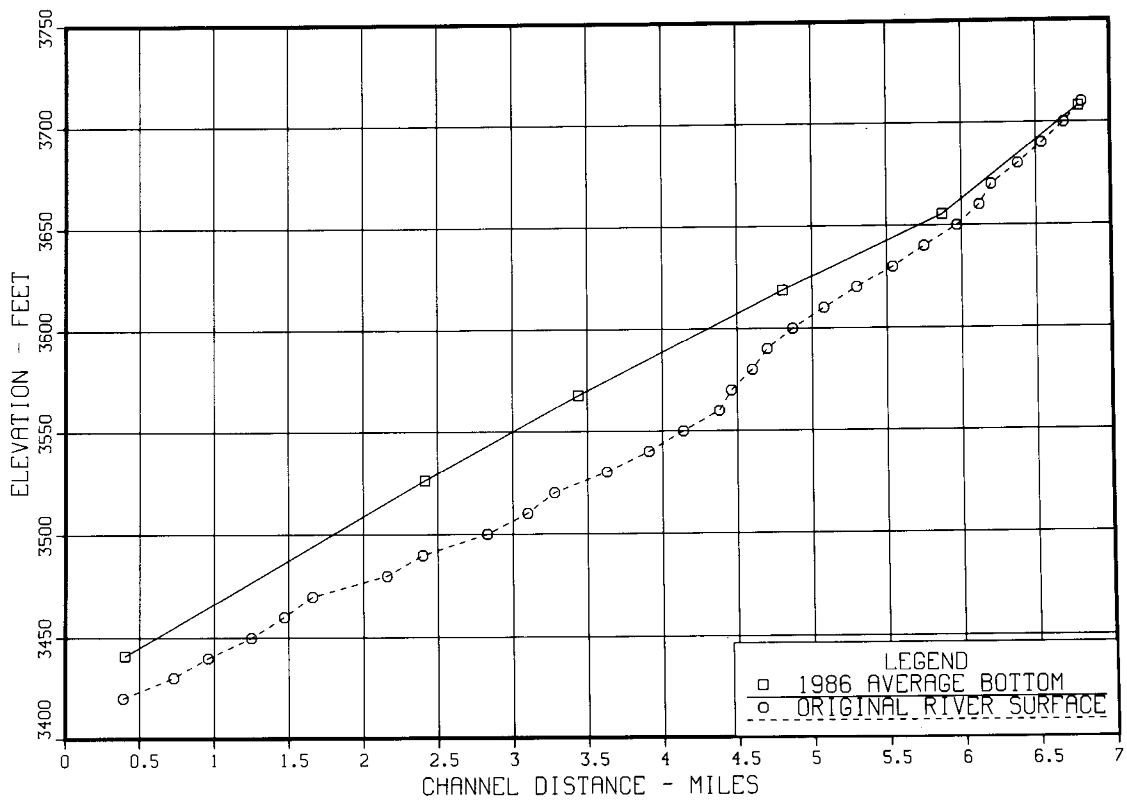

Figure 62. – Red Canyon profiles.

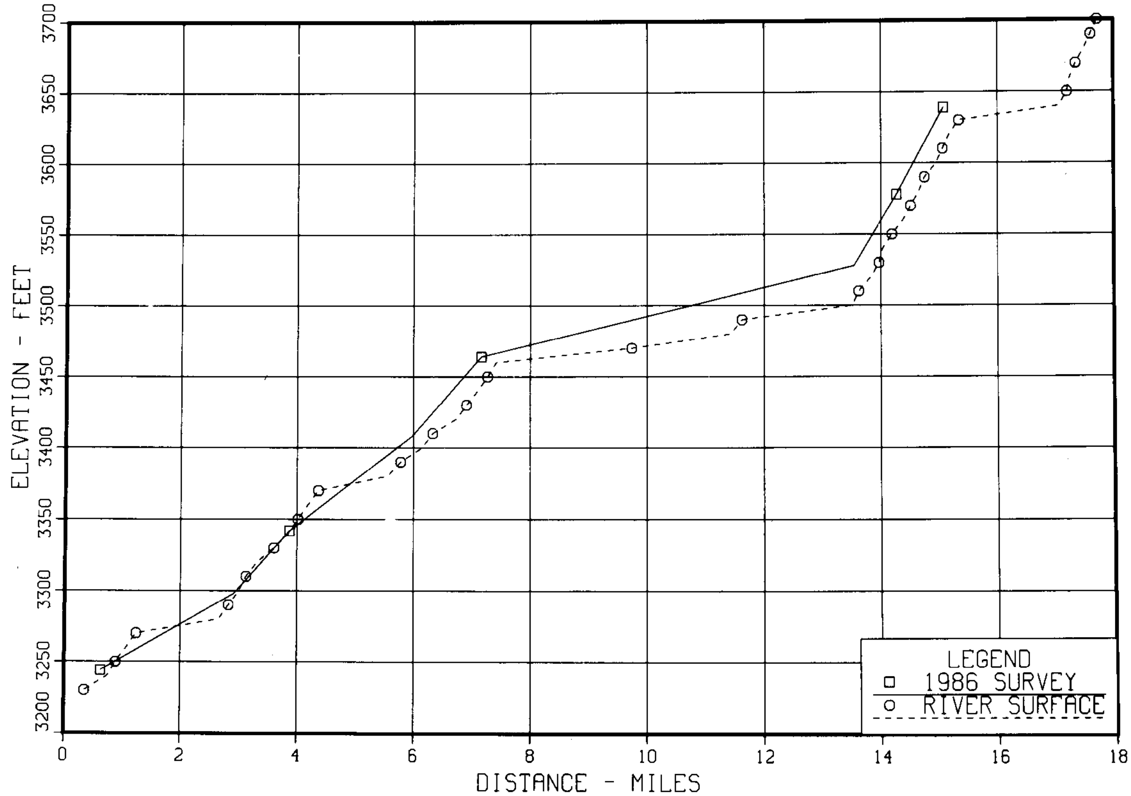

Figure 63. – Rock Creek profiles.

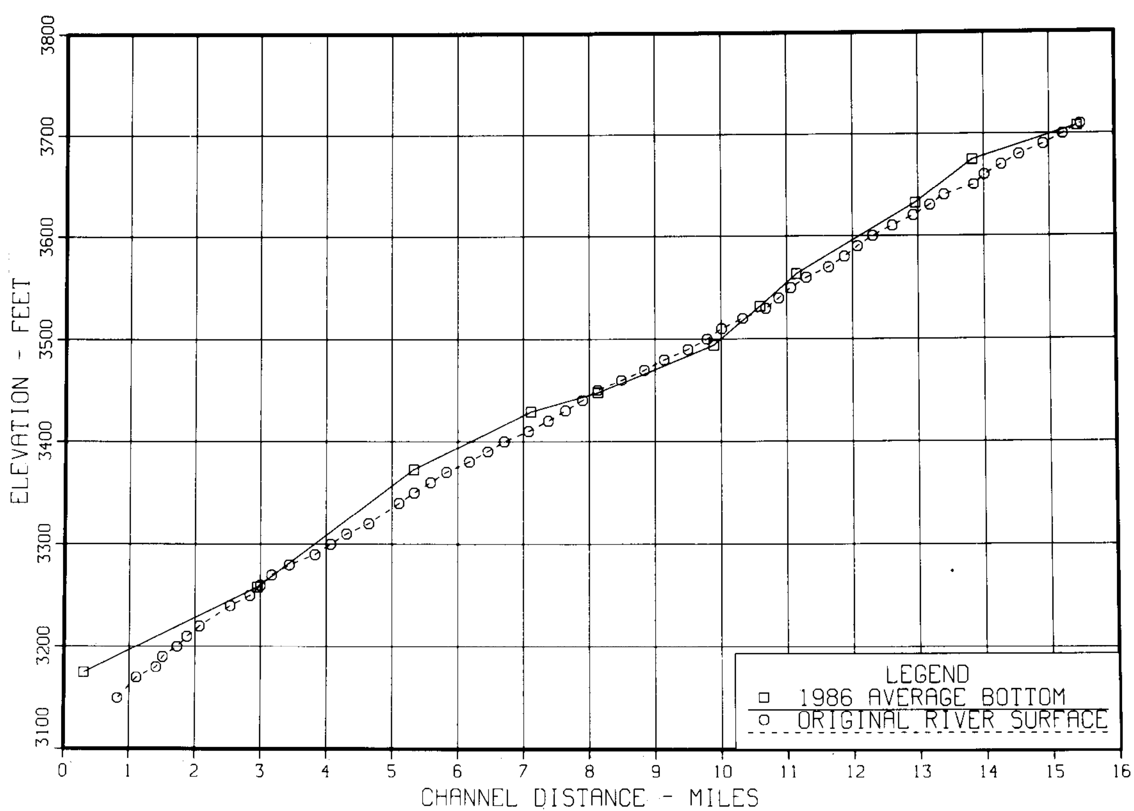

Figure 64. – Wahweap Canyon profiles.

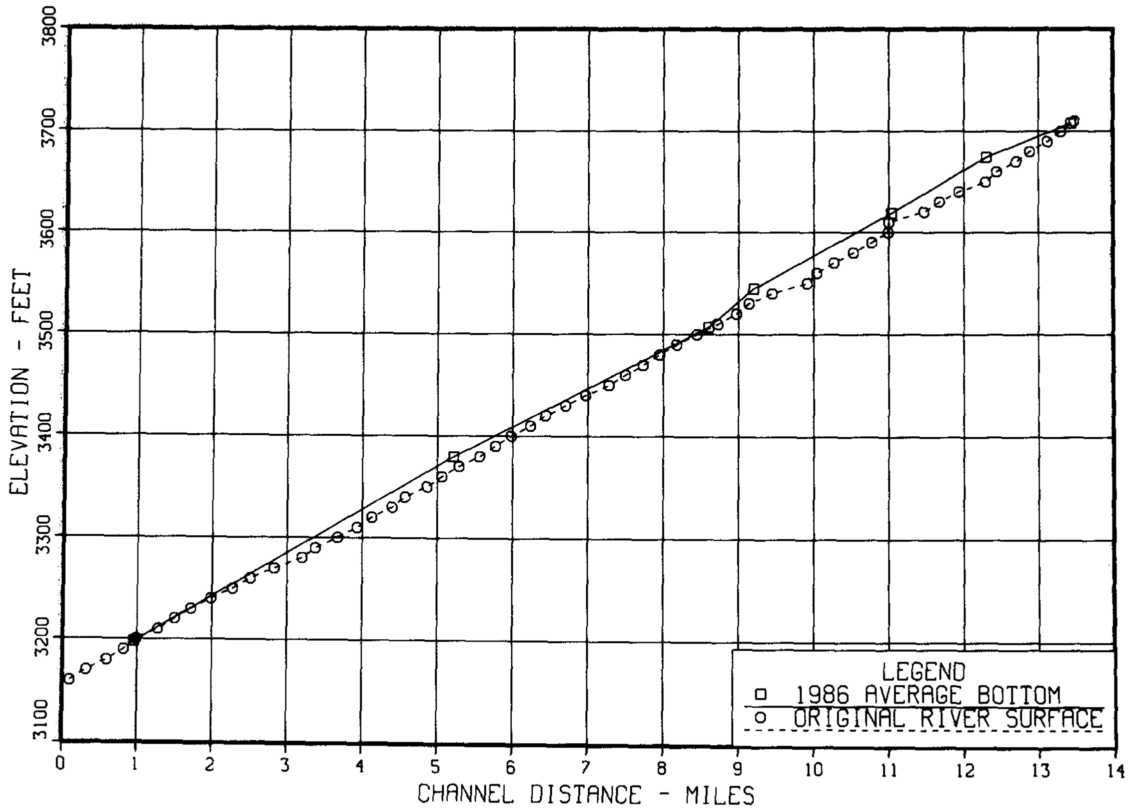

Figure 65. – Warm Creek profiles.

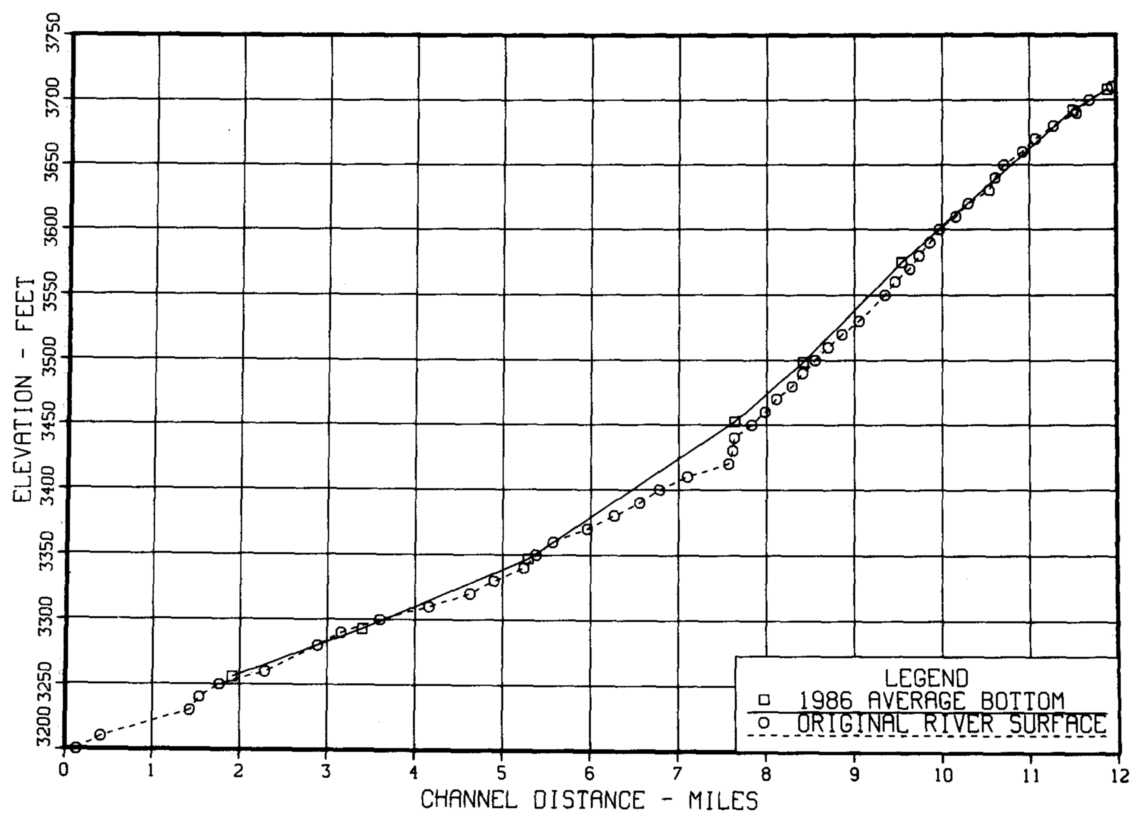

Figure 66. – West Canyon profiles.

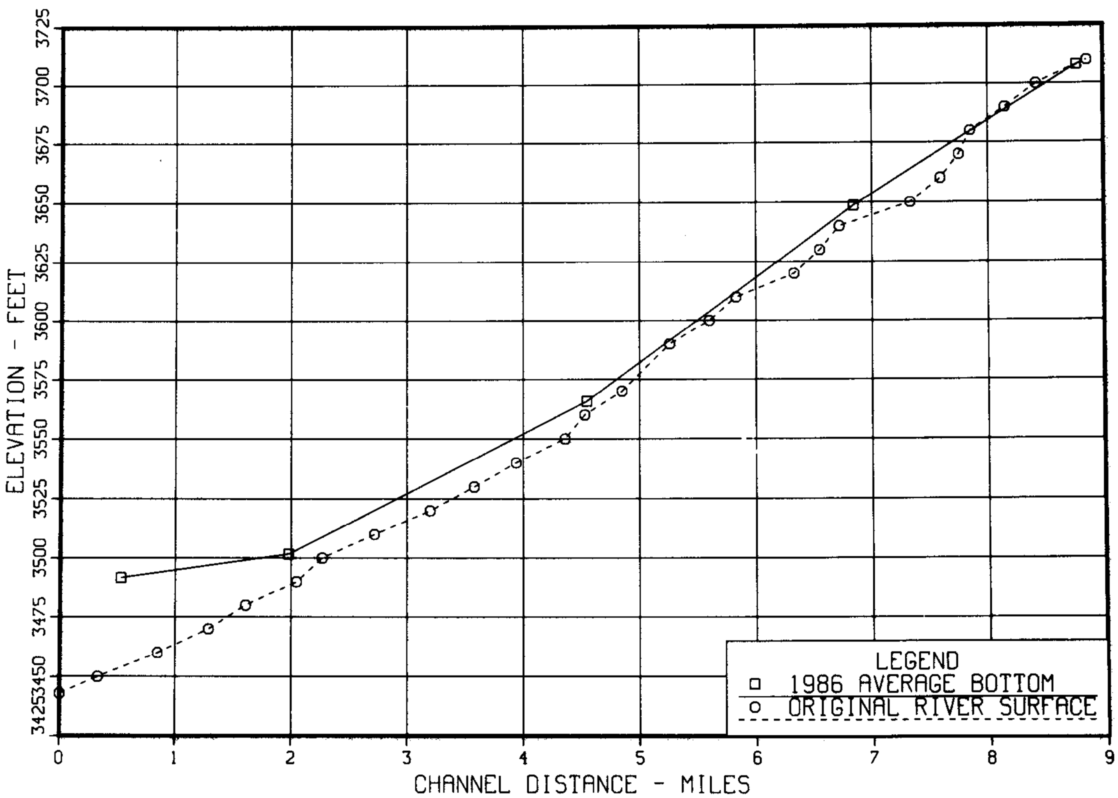

Figure 67. – White Canyon profiles.

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[3] *Lake Powell Sedimentation Surveys,* Colorado River Storage Project, Glen Canyon Unit, Bureau of Reclamation, Salt Lake City, UT, September 1976.

[4] *Rainbow Bridge National Monument,* Bureau of Reclamation Report G-395, June 1985.

[5] *Procedures for Monitoring Reservoir Sedimentation,* Bureau of Reclamation Technical Guideline, 52 p., Denver Office, Denver, CO, October 1982.

[6] *ACAP85 User's Manual,* Bureau of Reclamation, Denver Office, Denver, CO, 1985.

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GPO 858-896

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-7923A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.