(8)9-AA-40-07910

Sand-Storage Changes in the Colorado River Downstream from the Paria and Little Colorado Rivers, April 1994 to August 1995

U.S. GEOLOGICAL SURVEY
Open-File Report 97—206

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By Julia B. Graf, Jonathan E. Marlow, Patricia D. Rigas, and Samuel M.D. Jansen

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CONVERSION FACTORS

Multiply	By	To obtain
meter (m)	3.281	foot
square meter (m^2)	10.76	square foot
kilometer (km)	0.6214	mile
cubic meter per second (m^3/s)	35.31	cubic foot per second
megagram	1.102	ton, short

Sand-Storage Changes in the Colorado River Downstream from the Paria and Little Colorado Rivers, April 1994 to August 1995

By Julia B. Graf, Jonathan E. Marlow, Patricia D. Rigas, *and* Samuel M.D. Jansen

Abstract

Sixty-six cross sections on the Colorado River in 11-kilometer reaches downstream from the Paria and Little Colorado Rivers were monitored from June 1992 to August 1995 to provide data to evaluate the effect of releases from Glen Canyon Dam on channel-sand storage and for development of multidimensional flow and sediment-transport models. Most of the network of monumented cross sections was established and first measured June–September 1992. Data collected from June 1992 through February 1994 were published in a previous report. Cross sections downstream from the Paria River were remeasured six times between April 1994 and August 1995. Most sections downstream from the Little Colorado River were remeasured four times in the same time period. Each measurement consisted of 10 passes across the section, and data presented are the mean section and the standard deviation from the mean. Measured depths were converted to bed elevations using water-surface elevations measured or estimated for each reach. A line marked at regular intervals was strung across the river between the section end points and used to provide horizontal-position control. A Wilcoxon rank-sum test was applied to the data, and bed-elevation differences between successive measurements that were statistically significant at the 5-percent significance level were identified and used to compute the difference in cross-sectional area from measurement to measurement. Changes in sand storage computed for selected cross sections are presented. Changes in area at most of the selected cross sections during the period presented in this report were smaller than those measured during the period covered by the previous report. The largest changes over the monitoring period presented in this report were measured at section p22 (+115 square meters) downstream from the Paria River and at sections lb1 (+209 square meters) and lc2 (–156 square meters) downstream from the Little Colorado River. This report presents selected data from the measurements made from April 1994 through August 1995 in graphical form and describes the electronic form of the entire data set.

INTRODUCTION

In the early 1980's, agencies charged with management of the Colorado River in Grand Canyon, white-water rafters, and anglers became concerned that flow releases from Glen Canyon Dam were eroding sandbars that are critical to the riparian system in Grand Canyon National Park (fig. 1). Concern about sandbars has focused on potential degradation by unsteady dam releases for power generation. Since 1982, the Bureau of Reclamation has coordinated a comprehensive program of investigations—the Glen Canyon Environmental Studies (GCES)—to determine the effects of dam releases on the riparian and aquatic resources of the Colorado River downstream from

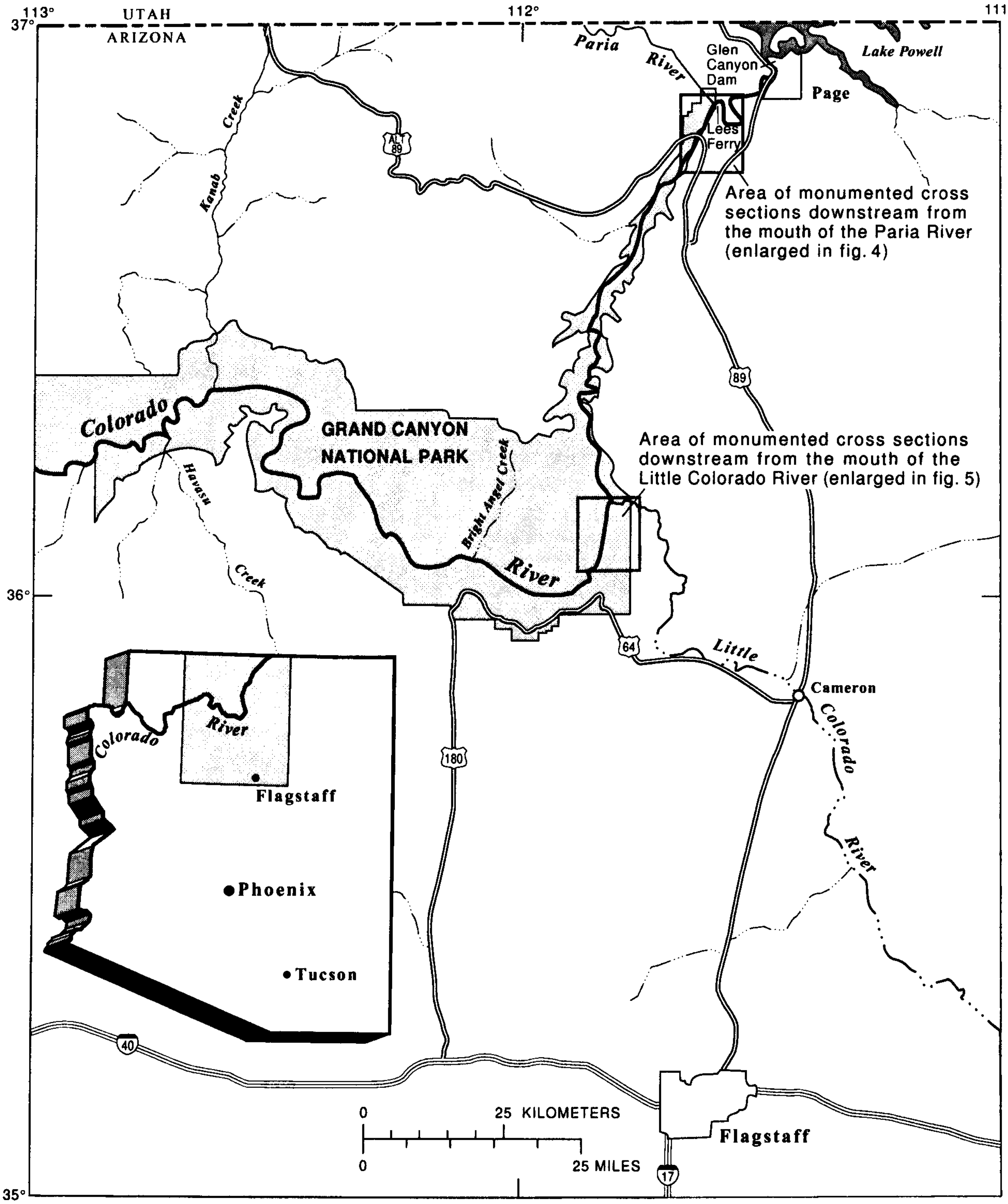

Figure 1. Location of the two monitored reaches.

the dam. In 1989, as a part of the GCES, the U.S. Geological Survey (USGS) began a program of field-data collection and model development aimed at the production of a suite of flow- and sediment-transport models to monitor sand movement and to predict sediment response to releases.

Because of growing concern over the effects of dam releases on riparian resources, restrictions were placed on releases by Congress under the Grand Canyon Protection Act in 1992. The restrictions, called Interim Flow Criteria, set limits on maximum and minimum daily releases and on the rate of increase and decrease of releases and were in effect from 1992 to 1996. During the period of measurements presented in this report, the daily mean discharge at Lees Ferry, Arizona, was between 194 and 558 m^3/s (fig. 2) and the range in discharge—maximum instantaneous discharge minus the minimum instantaneous discharge—during a given day was between 0 and 331 m^3/s (fig. 3). About two-thirds of the days in the period had daily mean discharges between 230 and 380 m^3/s and ranged in instantaneous discharges between 80 and 160 m^3/s. The increased daily mean discharge and decreased daily range in discharge that began in June 1995 reflects increased dam releases necessitated by runoff of the exceptionally heavy snowpack in the upper part of the drainage basin in the winter of 1994–95. These higher releases continued to the end of the monitoring period covered in this report (figs. 2 and 3).

A monitoring program was begun in 1992 to provide information on the state of the riparian system under the restricted operating rules. As a part of the interim-flow monitoring and model-development programs, the USGS established networks of monumented cross sections downstream from the two largest tributaries—the Paria and Little Colorado Rivers—to monitor the deposition and subsequent movement of sand supplied by these major sources (fig. 1). Cross sections were established at locations judged to be favorable for sand storage. Thirty-four monitoring sections are in the 11-kilometer reach from just downstream from the mouth of the Paria River to the pool above Badger Creek Rapid (fig. 4), and 32 sections are in the 11-kilometer reach from the mouth of the Little Colorado River to Tanner Rapids (fig. 5). Measurements were planned for three key times during the year—in the winter before the spring snowmelt runoff in tributaries; in late spring or early summer after the snowmelt runoff; and in the fall after summer rains. Flow and suspended-sediment load in these two tributaries during the monitoring presented in this report are shown in figures 6 and 7.

Although bed sediment is not routinely sampled as a part of the channel monitoring, several lines of indirect evidence show that bed-elevation changes are a reliable indicator of sand-storage changes. Samples of bed material at gaging stations and in other selected pools and eddies, the presence of sand waves on the bed, and direct observation of the bed with underwater video (Wilson, 1986; Anima and others, 1996) show that very little material outside the sand-size range occurs in bed material that moves under flow conditions that prevailed during the monitoring period.

Measurements at the monumented cross sections provide accurate and precise information on sand-storage changes at selected cross sections in reaches of importance to river management. These precise measurements of bed change are being used with multidimensional sediment-transport models under development (Wiele and others, 1996) to make possible the computation of changes in sand volume in selected reaches in response to tributary sand inflow and main-channel flows.

Purpose and Scope

This report documents the location of the 66 monumented sections downstream from the Paria and Little Colorado Rivers, dates and times of measurements, methods of data collection and processing, and the measurements made at each section from April 1994 to August 1995. Selected data are presented graphically and summarized in tables. In addition, changes in area of cross section between measurement dates are presented for selected cross sections. The entire data set is available electronically as ASCII files. Contents and format of the files are described in tables in the report.

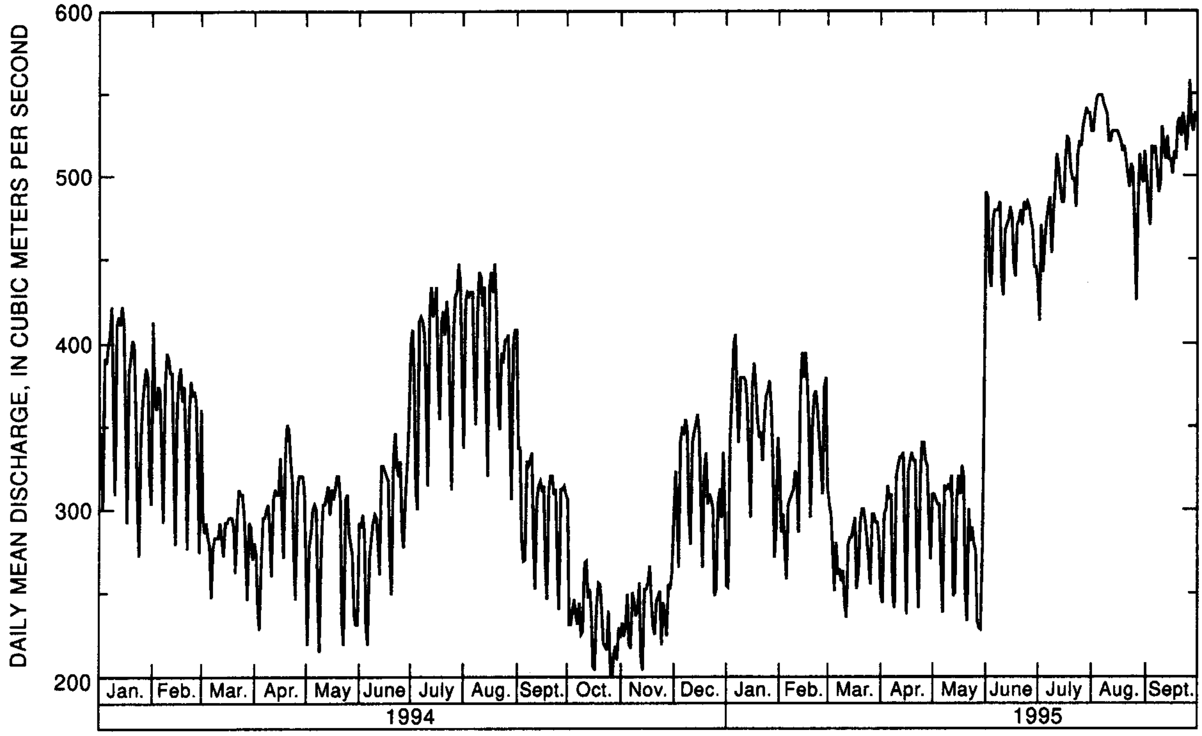

Figure 2. Daily mean discharge at the streamflow-gaging station, Colorado River at Lees Ferry, Arizona, January 1994 to September 1995.

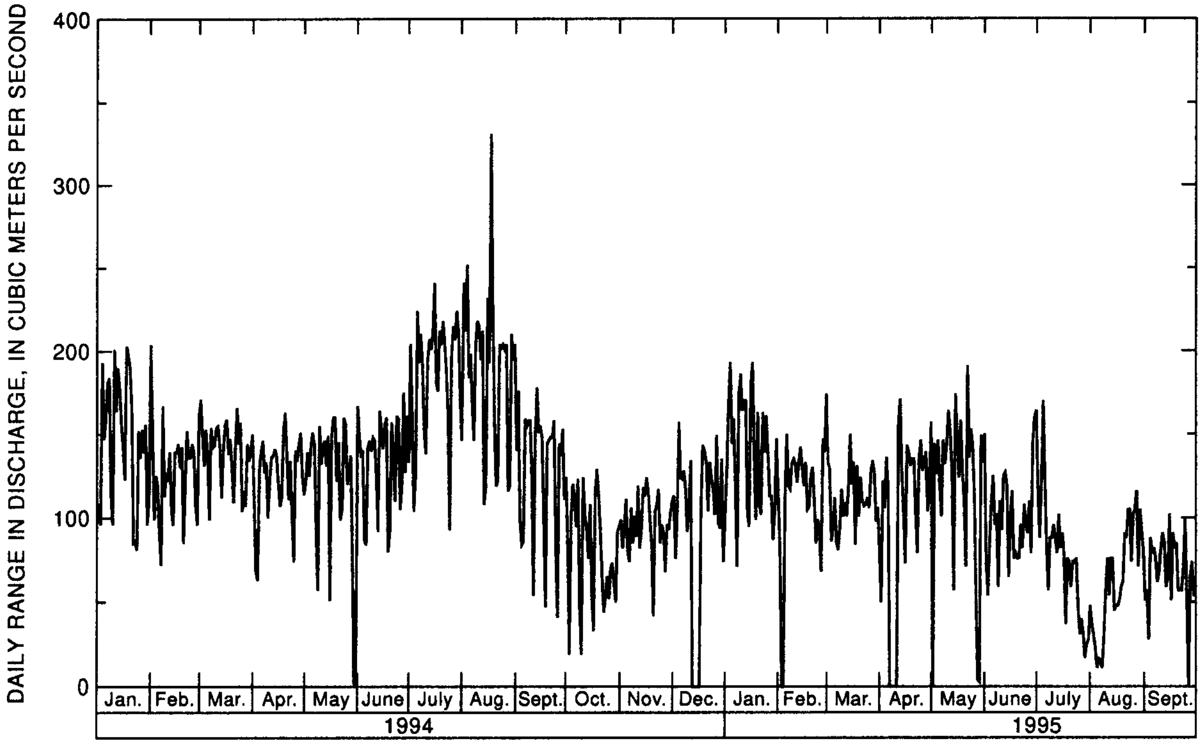

Figure 3. Daily range in discharge at the streamflow-gaging station, Colorado River at Lees Ferry, Arizona, January 1994 to September 1995. Range is difference between maximum instantaneous discharge and minimum instantaneous discharge during a given day.

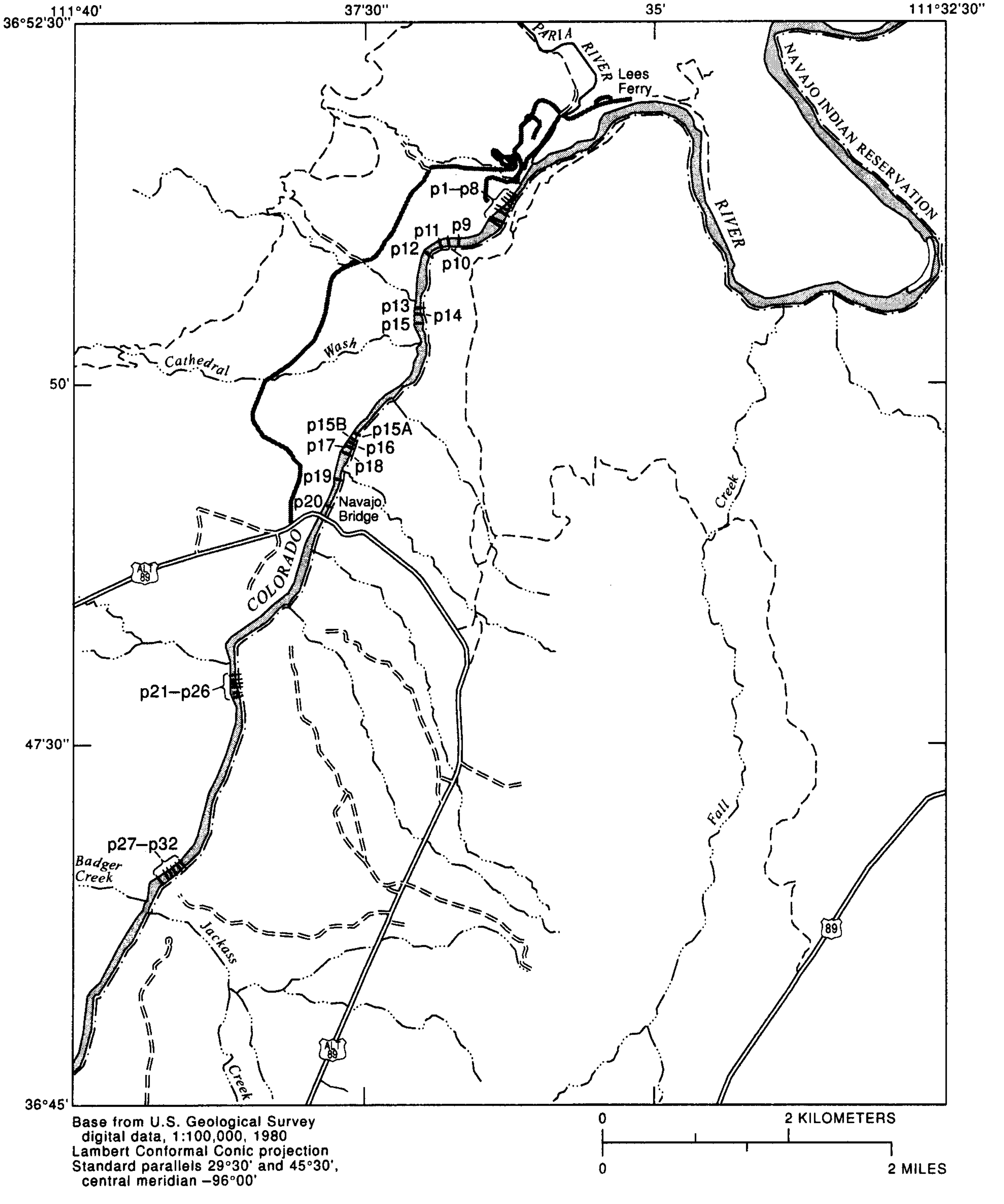

Figure 4. Location of monumented cross sections on the Colorado River downstream from the mouth of the Paria River.

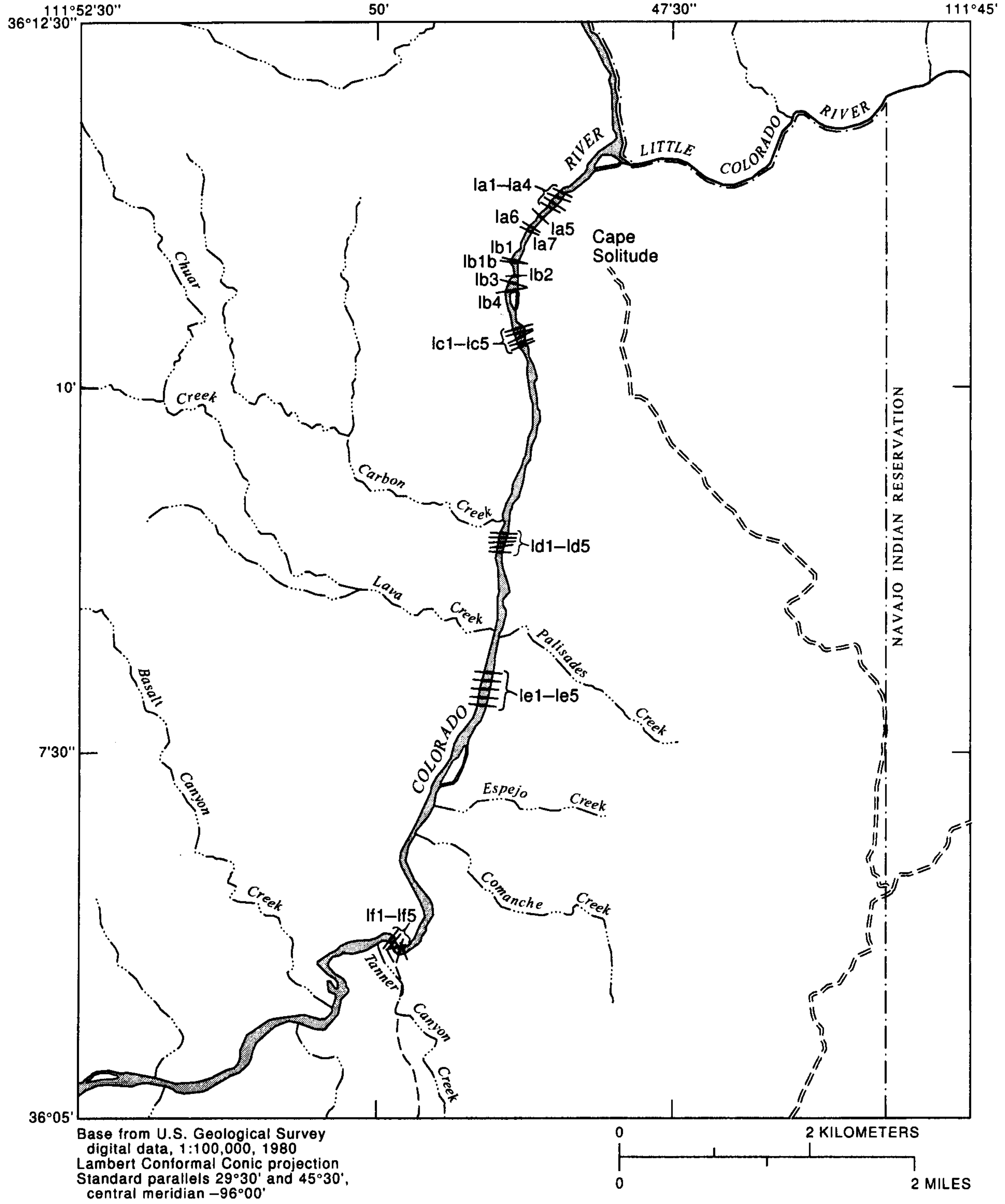

Figure 5. Location of monumented cross sections on the Colorado River downstream from the mouth of the Little Colorado River.

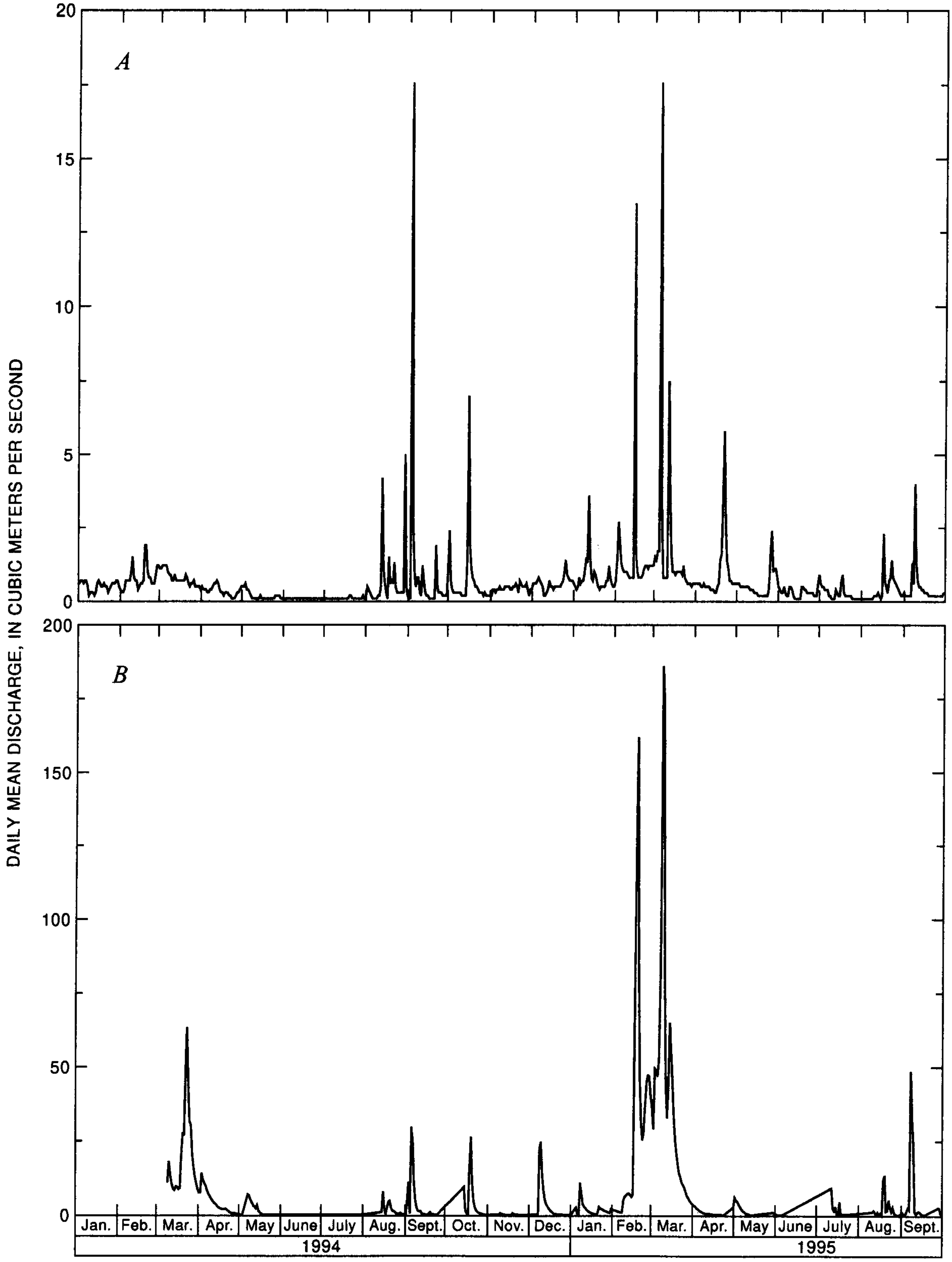

Figure 6. Daily mean discharge at streamflow-gaging stations on tributaries, January 1994 to September 1995. *A*, Paria River at Lees Ferry, Arizona. *B*, Little Colorado River near Cameron, Arizona.

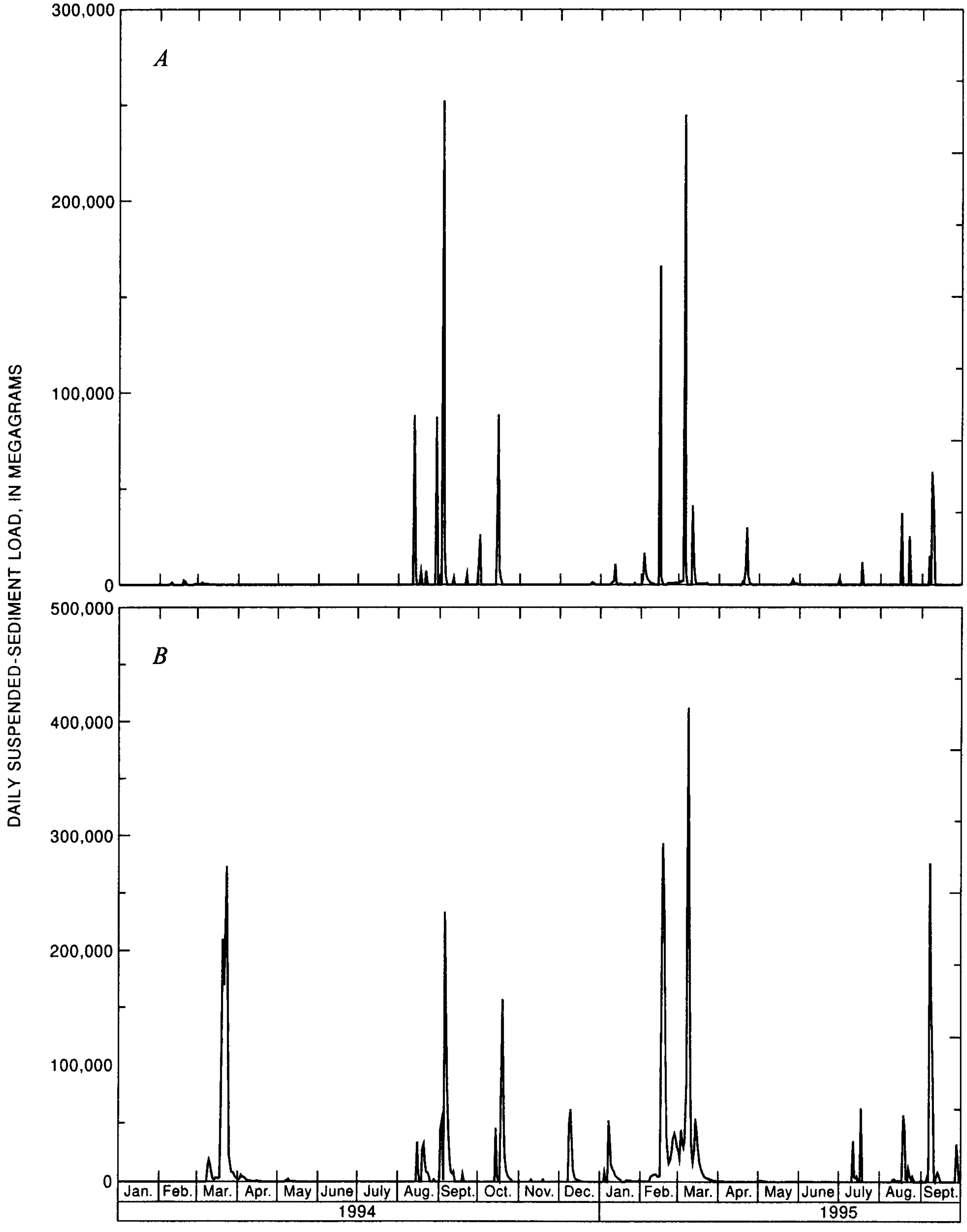

Figure 7. Daily suspended-sediment load at streamflow-gaging stations on tributaries, January 1994 to September 1995. *A*, Paria River at Lees Ferry, Arizona, for days when daily mean discharge exceeded 0.85 cubic meter per second. *B*, Little Colorado River near Cameron, Arizona, for days when daily mean discharge exceeded 0.57 cubic meter per second.

Acknowledgments

Brian Dierker, Kenton Grua, Lars Nimi, Stuart Reeder, and Greg Williams, OARS, Inc., operated the boat during the cross-section measurements. Their patience and skill made it possible to collect the high-quality data required for the study. Franklin R. Protiva, Fidel M. (Mark) Gonzales, and Robert C. (Chris) Brod (contracted employees, BOR) did the surveys required to tie the cross-section end points to the GCES control network. Rob Pankow volunteered his time to assist in several data-collection trips. Additional assistance in data collection was provided by Norbert R. Duet, Gregory G. Fisk, Eleanor R. Griffin, Greg Kisiel, and Jeff V. Phillips of the USGS.

METHODS OF DATA COLLECTION AND ANALYSIS

Data Collection

Channel geometry, the presence of sand on the bank and or visible on the bed, and the presence of sand waves on depth-sounder charts were used to select locations of probable sand storage for location of the cross sections. Monitoring downstream from the Little Colorado River was established in June and July 1992, when the 15 sections at the upstream end were installed and first measured. The remaining 16 sections were installed and first measured in January and February 1993. All 34 sections downstream from the Paria River were installed and first measured in August 1992. In most cases, the end points of the cross sections are identified by a carriage bolt embedded in the bedrock or a large boulder or talus block. Section end points (table 1) are documented in the Arizona State Plane Coordinate System Central Zone format, in meters, and were used for all other GCES geographic data (Werth and others, 1993).

The sections downstream from the Paria River were remeasured six times between April 1994 and August 1995 (table 2). Most sections downstream from the Little Colorado River were remeasured three times during the same period, and a few sections also were measured in July 1995 (table 2).

For each measurement, a line with flags at about 20-foot (6-meter) intervals was strung across the river between the section end points. Where feasible, the zero point on the line was positioned on the left bank. The position of each monument and the edge of the water on each bank was noted as distance along the line from the zero point. A boat equipped with a sonic-depth sounder and a pole that extended 2–3 m above the water was driven back and forth under the line. The pole, mounted directly over the depth-sounder transducer, was used to locate the transducer under the line and flags as precisely as possible. One person in the boat watched the line and pole and used a switch attached to the depth sounder to activate a fix mark on the graphical depth-sounder record when the pole passed under a flag. A second person in the boat made notes on the graphical record. Date, time, distance of end points and edges of water, and distance along the line of each fix mark were noted on the paper charts.

Uncertainty in the depth measurements is caused by precision and accuracy of the instrument, uncertainty in boat position, and actual changes in bed and (or) water-surface elevation during a measurement. Of these, the uncertainty in boat position is by far the largest contributor to depth uncertainty. The precision of the depth sounder used was 0.03 m and the accuracy was 0.5 percent of the measured depth, or about 0.075 m at a depth of 15 m. Measurements were made over periods of 10–20 minutes, and changes in water-surface elevations during the measurements were very small. The uncertainty in boat position is caused by the difficulty in keeping the boat under the flagged line in the strong and variable currents of this river. Because the bed is very irregular, small changes in boat position can yield large differences in measured depth. The method devised to minimize the uncertainty in depth caused by boat position was to measure the section 10 times in rapid succession and compute the mean of the 10 passes. The number of passes (10) was selected to provide enough data for statistical analysis and to keep the measurement time short so that the changes in bed and water-surface elevation during the measurement would be insignificant.

Table 1. Locations of end points of cross sections in the monitoring network

[Coordinate system for all locations in Arizona State Plane Central Zone format, in meters]

Cross section	Left-bank monument		Right-bank monument		Cross section	Left-bank monument		Right-bank monument	
	Northing	Easting	Northing	Easting		Northing	Easting	Northing	Easting
Downstream from the Paria River									
p1	649421.71	241309.53	649493.209	241204.481	p17	646187.415	239219.802	646230.424	239120.081
p2	649380.591	241280.119	649466.589	241168.705	p18	646104.244	239188.589	646154.399	239074.442
p3	649335.301	241261.843	649425.257	241133.542	p19	645780.835	239089.840	645814.987	238986.426
p4	649283.886	241234.175	649402.747	241100.635	p20	645431.964	238958.288	645461.709	238875.696
p5	649237.488	241215.875	649321.906	241036.078	p21	643296.485	237790.557	643277.102	237632.151
p6	649179.977	241192.434	649277.348	241016.707	p22	643234.794	237806.510	643215.286	237643.602
p7	649080.790	241152.666	649171.155	240954.877	p23	643182.991	237813.392	643175.770	237660.987
p8	649027.167	241106.726	649137.219	240946.046	p24	643135.520	237808.735	643127.566	237670.792
p9	648774.323	240555.163	648942.263	240553.839	p25	643063.316	237804.450	643052.034	237681.605
p10	648763.725	240432.510	648927.457	240410.277	p26	643017.958	237814.630	642999.995	237696.974
p11	648743.239	240342.126	648893.279	240293.536	p27	640799.854	237102.781	640923.283	236997.332
p12	648634.525	240230.339	648719.642	240114.490	p28	640755.612	237051.097	640887.678	236952.326
p13	647985.852	240131.880	647989.415	239990.736	p29	640716.580	236987.571	640840.631	236893.609
p14	647902.425	240115.357	647911.291	239987.528	p30	640689.096	236933.789	640816.181	236845.330
p15	647789.331	240107.709	647789.067	239993.697	p31	640654.765	236885.466	640788.941	236798.253
p15a	646350.036	239301.019	646402.223	239208.870	p32	640591.105	236811.021	640723.202	236711.593
p15b	646288.099	239267.437	646329.925	239179.359					
p16	646230.628	239253.002	646284.032	239153.261					
Downstream from the Little Colorado River									
la1	575489.052	223110.238	575413.247	223226.890	ld1	571165.292	222357.384	571133.453	222504.873
la2	575431.436	223070.898	575356.797	223186.744	ld2	571114.650	222361.320	571092.277	222491.986
la3	575386.219	223023.247	575315.021	223117.898	ld3	571071.349	222365.034	571050.825	222479.385
la4	575334.984	222988.594	575265.874	223078.956	ld4	570999.956	222353.105	570972.711	222457.824
la5	575257.394	222899.836	575175.859	222978.077	ld5	570903.067	222331.361	570912.548	222445.903
la6	575000.000	222850.000	575072.719	222755.582	le1	569628.213	222234.312	569614.854	222387.155
la7	575013.292	222728.468	574949.054	222828.679	le2	569576.077	222234.258	569542.172	222372.521
lb1	574643.169	222518.501	574376.429	222651.019	le3	569521.855	222203.010	569488.478	222358.993
lb2	574376.429	222518.345	574352.997	222640.523	le4	569453.335	222195.857	569423.131	222343.513
lb3	574333.196	222467.612	574314.227	222659.991	le5	569394.322	222177.593	569368.722	222336.154
lb4	574251.976	222452.202	574270.963	222656.615	lf1	565963.358	221181.066	565854.179	221189.694
lc1	573716.585	222584.749	573759.474	222754.260	lf2	565968.694	221167.530	565847.291	221091.968
lc2	573646.924	222572.011	573685.284	222769.399	lf3	565996.554	221166.167	565928.158	221039.382
lc3	573583.307	222594.767	573649.772	222779.721	lf4	566045.500	221125.054	565957.922	221020.148
lc4	573535.706	222614.292	573587.353	222799.046	lf5	566075.216	221095.960	565993.211	221006.899
lc5	573487.698	222639.238	573547.034	222804.374					

Table 2. Date, time, and water-surface elevations for measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers

[Numbers that begin with a p are stations downstream from the Paria River; numbers that begin with the letters la–lf are stations downstream from the Little Colorado River; yymmdd, year, month, and day; N/A, not available]

Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters	Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters
p1	940406	1041	944.08	p7	940406	1538	944.34
p1	940829	1614	945.05	p7	940830	1351	944.96
p1	950214	1032	944.57	p7	950214	1532	944.76
p1	950217	0939	944.26	p7	950510	1532	944.29
p1	950511	0752	943.67	p7	950704	1116	944.52
p1	950703	1510	945.00	p7	950829	1716	945.26
p1	950831	0847	944.89	p8	940406	1610	944.36
p2	940406	1119	944.18	p8	940830	1436	945.01
p2	940829	1577	945.07	p8	950214	1606	944.76
p2	950214	1117	944.64	p8	950510	1607	944.32
p2	950217	1014	944.30	p8	950704	1205	945.19
p2	950511	0820	943.70	p8	950829	1642	945.24
p2	950703	1611	945.07	p8	950831	N/A	N/A
p3	940406	1151	944.23	p9	940407	0801	943.69
p3	940829	1733	945.07	p9	940830	1539	945.05
p3	950214	1151	944.68	p9	950214	1644	944.75
p3	950217	1042	944.34	p9	950510	1456	944.26
p3	950511	0843	943.75	p9	950704	1358	948.89
p3	950703	1651	944.40	p9	950829	1602	945.21
p3	950831	0924	944.92	p10	940407	0837	943.74
p4	940406	1332	944.31	p10	940830	1615	945.05
p4	940830	0959	944.42	p10	950215	0850	944.29
p4	950214	1307	944.72	p10	950510	1422	944.24
p4	950511	0926	943.85	p10	950704	1436	945.13
p4	950703	1801	944.72	p10	950829	1531	945.21
p4	950831	1014	944.95	p11	940407	0916	943.86
p5	940406	1406	944.32	p11	940830	1654	945.06
p5	940830	1044	944.54	p11	950215	0929	944.40
p5	950214	1345	944.71	p11	950510	1347	944.21
p5	950511	0958	943.94	p11	950704	1532	945.69
p5	950704	0922	944.50	p11	950829	1456	945.20
p5	950831	1107	944.98	p12	940407	0952	943.97
p6	940406	1445	944.34	p12	940830	1736	945.05
p6	940830	1131	944.68	p12	950215	1006	944.49
p6	950214	1436	944.73	p12	950510	1317	944.19
p6	950511	1030	944.01	p12	950704	1608	945.38
p6	950704	1020	944.70	p12	950829	1420	945.19
p6	950831	1141	945.00	p13	940407	1136	944.24

See footnote at end of table.

Table 2. Date, time, and water-surface elevations for measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters	Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters
p13	940831	0846	944.30	p17	950829	0910	943.65
p13	950215	1044	944.61	p18	940406	0818	942.04
p13	950510	1245	944.15	p18	940831	1425	943.55
p13	950704	1653	945.49	p18	950215	1530	943.14
p13	950829	1342	945.18	p18	950510	0842	942.26
p14	940407	1105	944.19	p18	950705	1210	945.42
p14	940831	0933	944.47	p18	950828	1723	943.85
p14	950215	1116	944.67	p19	940406	0855	942.12
p14	950510	1217	944.11	p19	940831	1503	943.57
p14	950704	1724	945.59	p19	950215	1604	943.12
p14	950829	1217	945.18	p19	950510	0811	942.24
p15	940407	1035	944.11	p19	950705	1249	944.20
p15	940831	1013	944.58	p19	950828	1648	943.85
p15	950215	1156	944.69	p20	940406	0935	942.22
p15	950510	1150	944.07	p20	940831	1534	943.59
p15	950704	1754	946.04	p20	950215	1636	943.10
p15	950829	1144	945.16	p20	950510	0743	942.23
p15a	940405	1615	942.75	p20	950705	1324	944.61
p15a	940831	1124	943.15	p20	950828	1613	943.85
p15a	950215	1321	943.17	p21	940405	0945	940.44
p15a	950510	1033	942.41	p21	940901	0906	940.65
p15a	950705	0825	943.90	p21	950216	1025	941.00
p15a	950829	1056	943.72	p21	950509	1355	940.92
p15b	940405	1640	942.76	p21	950705	1502	942.05
p15b	940831	1158	943.27	p21	950830	1413	941.66
p15b	950215	1354	943.17	p22	940405	0903	940.38
p15b	950510	1007	942.35	p22	940901	0947	940.67
p15b	950705	0856	942.22	p22	950216	1105	941.06
p15b	950829	1023	943.70	p22	950509	1426	940.94
p16	940405	1703	942.76	p22	950705	1552	941.28
p16	940831	1224	943.34	p22	950830	1446	941.68
p16	950215	1427	943.18	p23	940404	1638	940.79
p16	950510	0941	942.31	p23	940901	1024	940.71
p16	950705	0936	942.98	p23	950216	1141	941.11
p16	950829	0945	943.67	p23	950509	1455	940.96
p17	940405	1723	942.75	p23	950705	1637	941.95
p17	940831	1344	943.51	p23	950830	1516	941.70
p17	950215	1457	943.16	p24	940404	1608	940.77
p17	950510	0911	942.28	p24	940901	1059	940.76
p17	950705	1128	943.29	p24	950216	1251	941.20

See footnote at end of table.

Table 2. Date, time, and water-surface elevations for measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters
p24	950509	1520	940.98
p24	950705	1717	940.98
p24	950830	1543	941.71
p25	940404	1540	940.74
p25	940901	1133	940.82
p25	950216	1318	941.24
p25	950509	1551	940.99
p25	950706	0809	940.83
p25	950830	1610	941.72
p26	940404	1510	940.69
p26	940901	1210	940.87
p26	950216	1346	941.26
p26	950509	1617	941.01
p26	950706	[1]0840	940.98
p26	950830	1635	941.74
p27	940405	1500	940.70
p27	940901	1658	940.89
p27	950216	1719	941.13
p27	950509	0912	940.36
p27	950706	1102	941.22
p27	950830	1223	941.24
p28	940405	1424	940.69
p28	940901	1624	940.89
p28	950216	1649	941.13
p28	950509	0957	940.41
p28	950706	N/A	941.17
p28	950830	1148	941.19
p29	940405	1219	940.57
p29	940901	1544	940.88
p29	950216	1617	941.13
p29	950509	1307	940.67
p29	950706	1257	941.12
p29	950830	1106	941.15
p30	940405	1148	940.51
p30	940901	1513	940.86
p30	950216	1546	941.13
p30	950509	1034	940.45
p30	950706	1343	941.22
p30	950830	1030	941.15
p31	940405	1115	940.44
p31	940901	1440	940.83
p31	950216	1515	941.12
p31	950509	1110	940.50
p31	950706	1440	941.00
p31	950830	0954	941.15
p32	940405	1041	940.38
p32	940901	1401	940.80
p32	950216	1437	941.11
p32	950509	1156	940.58
p32	950830	0859	941.14
la1	940430	1618	824.72
la1	940914	1329	824.98
la1	950422	1433	824.96
la1	950630	1824	826.15
la2	940430	1700	824.65
la2	940914	1313	824.92
la2	950422	1511	824.91
la2	950630	1900	826.15
la3	940430	1741	824.60
la3	940914	1453	824.89
la3	950422	1539	824.87
la4	940914	1536	824.84
la4	950422	1633	824.80
la5	940914	1621	824.78
la5	950422	1700	824.77
la6	940501	1551	824.63
la6	940915	0826	825.18
la6	950424	0931	824.47
la6	950701	0814	825.81
la7	940501	1628	824.61
la7	940915	0904	825.17
la7	950424	1002	824.48
la7	950701	0855	825.75
lb1	940502	1153	822.77
lb1	940915	1309	823.37
lb1	950424	1042	822.89
lb1b	940502	1235	822.78
lb1b	940915	0707	823.57

See footnote at end of table.

Table 2. Date, time, and water-surface elevations for measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters	Cross-section number	Date [yymmdd]	Mean time	Water-surface elevation, in meters
1b1b	950424	1120	822.91	1d3	940916	1115	819.12
1b2	940502	1315	822.78	1d3	950425	0928	819.31
1b2	940915	0957	823.50	1d4	940503	1410	818.90
1b2	950424	1333	822.95	1d4	940916	1134	819.07
1b3	940502	1358	822.77	1d4	950425	0952	819.31
1b3	940915	1041	823.48	1d5	940503	1508	818.88
1b3	950424	1313	822.96	1d5	940916	1302	819.02
1b3	950701	1114	824.13	1d5	950425	1024	819.31
1b4	940502	1445	822.77	1e1	940503	1634	816.57
1b4	940915	1133	823.41	1e1	940917	0924	816.82
1b4	950424	1148	822.92	1e1	950426	0810	816.25
1b4	950701	1027	824.17	1e2	940503	1719	816.51
1c1	940502	1559	822.44	1e2	940917	0851	816.81
1c1	940915	1446	822.93	1e2	950426	0849	816.36
1c1	950424	1411	822.71	1e3	940504	0847	816.65
1c1	950701	1242	823.70	1e3	940917	0821	816.81
1c2	940502	1648	822.44	1e3	950426	0919	816.45
1c2	940915	1535	822.85	1e4	940504	0929	816.65
1c2	950424	1451	822.70	1e4	940916	1531	816.60
1c2	950701	1537	823.48	1e4	950426	0950	816.54
1c3	940502	1726	822.42	1e5	940504	1019	816.65
1c3	940915	1624	822.80	1e5	940916	1459	816.61
1c3	950424	1520	822.70	1e5	950426	1019	816.62
1c4	940503	0901	822.96	1f1	940504	1208	809.73
1c4	940915	1705	822.74	1f1	940917	1016	809.91
1c4	950424	1548	822.70	1f1	950426	1149	809.89
1c5	940503	0945	822.96	1f2	940504	1353	809.72
1c5	940916	0901	823.26	1f2	940917	1055	809.89
1c5	950424	1613	822.70	1f2	950426	1217	809.88
1d1	940503	1132	818.96	1f3	940504	1445	809.72
1d1	940916	1004	819.18	1f3	940917	1129	809.87
1d1	950425	0840	819.30	1f3	950426	1312	809.86
1d2	940503	1303	818.94	1f4	940504	[1]1640	809.61
1d2	940916	1037	819.16	1f4	940917	1205	809.81
1d2	950425	0905	819.30	1f4	950426	1348	809.85
1d3	940503	1335	818.93	1f5	940504	1705	809.57

[1]Start time; end time not recorded.

A bias in the marking of flag position was detected during data processing that depended on the direction of the measurement of the cross section—the observer would tend to mark the chart in a consistent way, either slightly before or slightly after the flag. This bias was eliminated by collecting data on an even number of passes and by alternating the direction used in crossing the river.

River stage was documented by measuring the vertical distance from a reference point, typically an "x" chiselled into bedrock or a large boulder, to the water surface periodically during the measurement at the cross sections. Four reference points were established and used for the entire measurement period for sections below the mouth of the Paria River (table 3). Six reference points were established in the reach downstream from the mouth of the Little Colorado River in September 1994 (table 3). For some measurements, a portable stage gage and datalogger were installed at each reference point to automatically record stage at 5-minute intervals during some measurement periods. The distance between the water surface and the reference point was measured periodically with a measuring tape to check the accuracy of the stage record. The location and elevation of the reference points in the Arizona State Plane Coordinate System Central Zone format were determined by field surveys.

Data Processing

The graphical record of each pass was digitized by recording a point at a preset distance of horizontal cursor movement across the paper. The interval between digitized points per unit of paper was kept constant and was selected to give about two digitized points for each foot of distance along the bed. Once the data were digitized, the distance of each point from the left-bank end point—the left-bank monument—in inches of graph paper was converted to ground distance in meters using the known locations of the fix marks on the graphical record and assuming constant boat speed between marks. To provide depths at equal distances from the end point for the statistical analysis of the data, points were selected or interpolated at 0.25-meter intervals across the section.

Conversion from Depth to Bed Elevation

The sonic-depth sounder recorded depths of the bed below the water surface. Depth data were converted to bed elevation by subtracting the measured depth from a water-surface elevation measured at fixed reference points (table 3). Water-surface elevation typically was measured before and after all passes at two cross-section locations. The water-surface elevation measured at

Table 3. Location of reference points used for measurement of water-surface elevation

[Coordinate system for locations in Arizona State Plane Central Zone format]

Location of the reference point				Sections for which reference point was used
Description	Northing, in meters	Easting, in meters	Elevation, in meters	
Sections downstream from Paria River				
p5, left bank	649237.488	241215.875	949.55	p1–p15
p15b, right bank	646329.925	239179.359	946.64	p15a–p21
p23, left bank	643182.991	237813.392	944.70	p22–p26
p30, left bank	640689.096	236993.789	944.57	p27–p32
Sections downstream from Little Colorado River				
la5, right bank	575257.394	222899.836	829.54	la1–la7
Sections downstream from Little Colorado River—Continued				
lb2, left bank	574352.997	222640.523	828.41	lb1–lb4
lc3, right bank	574105.914	222186.177	827.91	lc1–lc5
ld5, left bank	570912.548	222445.903	822.16	ld1–ld5
le3, right bank	569521.855	222203.010	820.32	le1–le5
lf1, left bank	565854.179	221189.684	813.63	lf1–lf5

the reference point was applied to all sections within the same reach.

Statistical Analysis

The number of values; the mean, median, maximum, and minimum bed elevation; and standard deviation from the mean-bed elevation were computed for each distance from the left-bank end point for the 10 passes that define a measurement (fig. 8). The mean time for measurement of all 10 passes was computed and used to define the time of the measurement. The entire section was not always recorded for all 10 passes. Shallow water, strong turbulence or air bubbles in the water column, or abrupt changes in depth can interfere with the sonic signal and prevent the recording of correct depth data. These conditions occur most commonly near the banks, and the parts of the sections near the banks were typically recorded on fewer than 10 passes. Also, the boat operator was not always able to follow the line for the entire section. Because the entire cross section was not always recorded, not all locations in the cross section have data for all 10 passes.

The standard deviation from the mean of the passes is typically less than 0.1 m but can be a meter or more. Standard deviation varies considerably along most cross sections and tends to be largest near the edges and in areas of abrupt change in bed elevation (fig. 8). Relatively large standard deviation at the ends of the measurement are caused by the greater bed slope in those areas and the fact that the boat position is more variable at the beginning of a pass than it is elsewhere in the section.

A Wilcoxon rank-sum test was used to test for differences in bed elevation from measurement to measurement at each distance from the left-bank end point (Devore, 1991, p. 609–615), and a two-sided p value was computed for each distance for pairs of subsequent dates. For tests in which the size of both samples equaled or exceeded eight, the normal approximation for the distribution of the test statistic (W) was used to compute the p value. For tests in which either or both sample size was

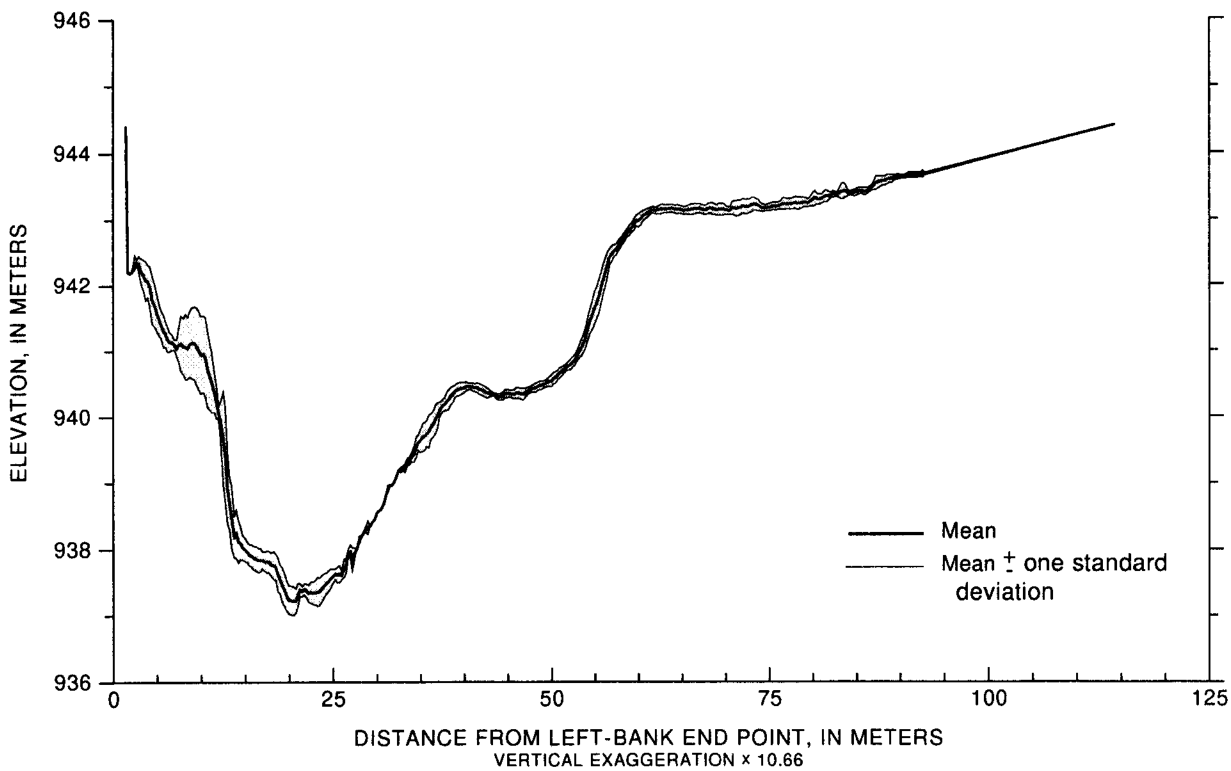

Figure 8. Example of a cross section computed from the 10 passes that comprise a measurement and standard deviation from the mean.

less than eight and greater than two, the *p* value associated with the computed value of W was determined from the discrete distribution of the W statistic. The test was not applied to distances at which either sample size in the tested pair was equal to or less than two. In the statistical tables described in the next section, the fraction tested gives the fraction of the total number of distance values in the section to which this test was applied, or the number of values in which both dates had a sample size greater than two divided by the total number of distance values.

For all tests, the null hypothesis tested was that the mean bed elevation for one measurement (date) was equal to the mean bed elevation for the next measurement. The *p* value is the lowest level of significance for which the null hypothesis would be rejected (Iman and Conover, 1983, p. 217). For example, if the *p* value is 0.05, the null hypothesis is rejected with a 5-percent probability of its being true. *P* values varied considerably within a given cross section (fig. 9) and from section to section. A *p* value of 0.05 was used to determine differences in depth that were statistically significant for computation of changes in cross-sectional area presented in this report. The method for computing area changes is described in a later section.

PRESENTATION OF THE DATA

Selected data are presented graphically in figures 10–23 at the back of this report, and all data are available as two types of tab-delimited ASCII electronic files. The first file type, the data files, contains the averaged data for each measurement. Files are named for the cross-section number and date of the measurement in year-month-day (yymmdd) format. For example, the file containing the data for the measurement of cross-section p1 made on August 23, 1992, is called p1.920823. Files contain the distance from the left-bank end point, in meters; the number of bed-elevation measurements for that distance; the mean, median, minimum, and maximum bed elevations for that distance, in meters; and the standard deviation from the mean bed elevation, in meters (table 4). The second file type, statistical files, are named for each cross section. For example, the file called "p1" contains the statistical data for the first cross section downstream from the Paria River. These files contain the difference in mean bed elevation from measurement to measurement and the *p* value computed from the Wilcoxon rank-sum test. In all cases, the differences were computed by subtracting the earlier measurement from the later measurement; and positive values indicate deposition between the two tested dates. These files contain the distance from the left-bank end point followed by groups of values for the difference in bed elevation at that distance between two successive measurements and the two-sided *p* value from the rank sum test on the bed-elevation data from those measurements (table 5). Readers who would like to obtain the electronic data should contact the District Chief, U.S. Geological Survey, WRD, 520 North Park Avenue, Suite 221, Tucson, AZ 85719-5035.

SAND-STORAGE CHANGES

Graphs of selected cross sections are presented in figures 10–23 to illustrate the range and style of changes that occurred during the monitoring period. In the reach between the Paria River and Badger Rapids, sections p1–p6 showed the most dramatic changes (fig. 10). These sections cross a pool, a zone of recirculating flow (eddy), and sandbar just downstream from the mouth of the Paria River (figs. 1 and 4). In each case shown in the figure, the first measurement of the period, in April 1994, showed the channel to be very much as it was in January 1994 at the end of the previous period (Graf and others, 1995). In section p1, at the upstream end of the eddy, the sandbar in the eddy on the right bank had eroded between April and August 1994, and some sand had been deposited in the channel bottom (fig. 10*A*). By August 1995, after about 3 months of the higher, steadier dam releases described in the introduction, the channel side of the bar had been eroded, and the upper surface of the bar had aggraded slightly. When measured in May 1995 and July 1995, the bed had a configuration similar to that measured in April 1994.

At section p4, crossing the middle part of the sandbar, sand had been deposited in the channel by August 1994 (fig. 10*B*). By May 1995, the channel

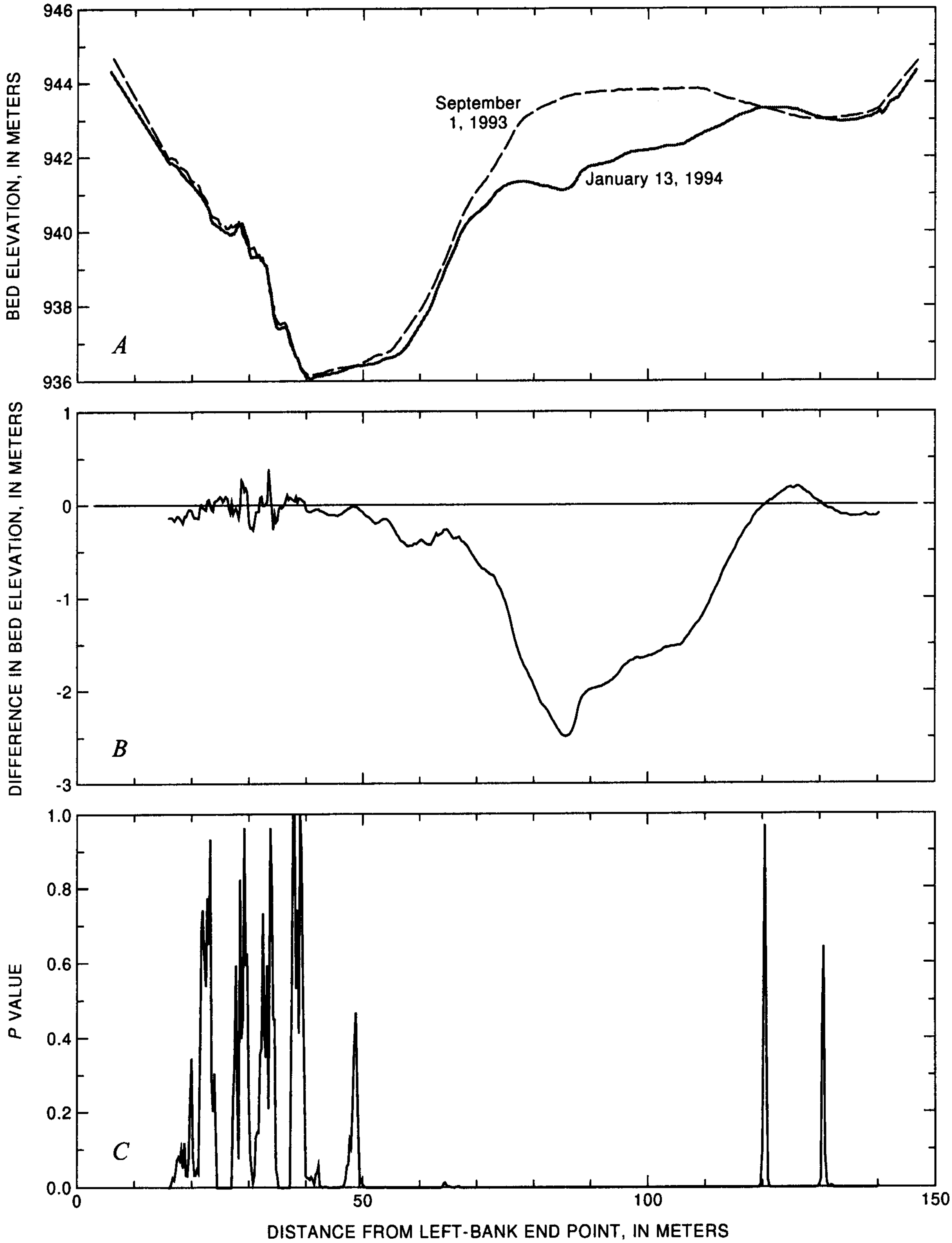

Figure 9. Example of the comparison of two successive cross-section measurements using cross-section p3, September 1, 1993, and January 13, 1994. *A*, Measured bed elevations for the two dates. *B*, Difference between the measured bed elevations on the two dates. *C*, *P* value computed from the Wilcoxon rank-sum test.

Table 4. Example of a data file

[Data are from the file la1_930129. Only a few lines from the beginning, middle, and end of the file are shown. x is distance from the left-bank end point; cases is number of depth measurements at that distance; mean, median, mindp, and maxdp are the mean, median, minimum, and maximum bed elevation, respectively; std is the standard deviation from the mean-bed elevation; the second line, 12n and following, gives the number of spaces allocated to the variable in the data files. All distances and elevations are in meters]

x	cases	mean	median	mindp	maxdp	std
12n	9n	12n	12n	12n	12n	12n
45.75	1	825.1	825.1	825.1	825.1	0
51.75	5	824.23	824.22	824.33	824.17	0.06
52	8	824.17	824.16	824.33	824.04	0.09
52.25	8	824.15	824.13	824.33	824.02	0.09
52.5	8	824.13	824.11	824.32	824	0.1
52.75	8	824.11	824.1	824.32	823.96	0.1
53	8	824.09	824.09	824.31	823.89	0.12
53.25	8	824.06	824.07	824.31	823.84	0.13
53.5	7	823.96	824	824.07	823.71	0.13
53.75	8	823.95	823.98	824.28	823.57	0.2
54	7	823.85	823.93	824.04	823.47	0.19
			—data not shown—			
83	10	821.23	821.24	821.4	821.08	0.1
83.25	10	821.21	821.22	821.37	821.1	0.09
83.5	10	821.19	821.2	821.35	821.08	0.09
83.75	10	821.17	821.17	821.32	821.05	0.09
84	10	821.15	821.15	821.27	821.04	0.08
84.25	10	821.13	821.13	821.24	820.99	0.08
84.5	10	821.11	821.13	821.22	820.98	0.07
84.75	10	821.09	821.11	821.19	820.99	0.07
85	10	821.07	821.1	821.18	820.96	0.06
			—data not shown—			
129.25	8	820.74	820.75	821.09	820.47	0.2
129.5	8	820.83	820.83	821.18	820.57	0.19
129.75	8	820.91	820.9	821.24	820.63	0.19
130	6	821	820.97	821.31	820.69	0.21
130.25	6	821.09	821.06	821.37	820.74	0.22
130.5	6	821.21	821.18	821.47	820.92	0.21
130.75	4	821.25	821.28	821.46	820.98	0.2
134	1	825.1	825.1	825.1	825.1	0

Table 5. Example of a statistical file

[Data from cross section la1. x is distance from the left-bank end point, d1_2 is the bed elevation from measurement 2 minus the elevation from measurement 1; p1_2 is the two-sided *p* value computed from the Wilcoxon rank-sum test on the data from the first two measurements; d2_3 is the bed elevation from measurement 3 minus the elevation from measurement 2; p2_3 is the two-sided *p* value computed from data from measurements 2 and 3, etc. The difference is calculated so that positive differences indicate deposition in the section and negative differences indicate erosion. Missing values are indicated by double tabs in the files and represent the case of no data collected. The value, 999.000, is used to indicate those cases for which data were collected but the number of data points was insufficient to apply the statistical test]

x	d1_2	p1_2	d2_3	p2_3	d3_4	p3_4	d4_5	p4_5
				—data not shown—				
44.500	999.000	0.000	0.391	0.000	999.000	0.000	-0.014	0.743
44.750	999.000	0.000	0.398	0.000	999.000	0.000	-0.044	0.190
45.000	999.000	0.000	0.409	0.000	999.000	0.000	-0.082	0.049
45.250	999.000	0.000	0.412	0.000	999.000	0.000	-0.105	0.011
45.500	999.000	0.000	0.416	0.000	999.000	0.000	-0.127	0.004
45.750	999.000	0.000	0.422	0.000	999.000	0.000	-0.139	0.002
46.000	999.000	0.000	0.433	0.000	999.000	0.000	-0.154	0.001
				—data not shown—				
80.750	6.215	0.000	-1.522	0.000	0.233	0.000	-0.042	0.087
81.000	6.246	0.000	-1.540	0.000	0.288	0.000	-0.003	0.790
81.250	6.791	0.000	-1.556	0.000	0.309	0.000	0.013	0.254
81.500	6.827	0.000	-1.586	0.000	0.335	0.000	0.033	0.075
81.750	6.854	0.000	-1.599	0.000	0.351	0.000	0.039	0.088
82.000	6.873	0.000	-1.609	0.000	0.354	0.000	0.038	0.075
82.250	6.894	0.000	-1.612	0.000	0.359	0.000	0.029	0.240
82.500	6.928	0.000	-1.633	0.000	0.353	0.000	0.019	0.361
82.750	6.951	0.000	-1.639	0.000	0.339	0.000	-0.004	0.594
83.000	6.982	0.000	-1.650	0.000	0.321	0.000	-0.027	0.139
				—data not shown—				
99.000	11.232	0.000	-2.918	0.000	0.077	0.011	-0.370	0.000
99.250	11.314	0.000	-2.995	0.000	0.059	0.025	-0.380	0.000
99.500	11.413	0.000	-2.136	0.002	0.027	0.138	-0.389	0.000
99.750	11.493	0.000	-1.311	0.018	0.015	0.305	-0.403	0.000
100.000	11.574	0.000	-1.307	0.018	0.024	0.172	-0.411	0.000
100.250	11.637	0.000	-1.830	0.024	0.016	0.344	-0.414	0.000
100.500	11.717	0.000	-1.820	0.024	-0.003	0.910	-0.420	0.000
100.750	11.765	0.000	-1.860	0.024	-0.024	0.362	-0.418	0.000
101.000	11.816	0.000	-3.128	0.014	-0.030	0.345	-0.421	0.000
101.250	11.851	0.000	999.000	0.000	-0.039	0.289	-0.429	0.000
101.500	11.890	0.000	999.000	0.000	-0.051	0.161	-0.436	0.000
101.750	11.945	0.000	999.000	0.000	-0.062	0.121	-0.438	0.000
102.000	11.968	0.000	999.000	0.000	-0.054	0.130	-0.439	0.000
102.250	12.012	0.000	999.000	0.000	-0.042	0.363	-0.442	0.000
102.500	12.053	0.000	999.000	0.000	-0.041	0.325	-0.442	0.000
102.750	12.115	0.000	999.000	0.000	-0.043	0.342	-0.440	0.000
103.000	12.127	0.000	999.000	0.000	-0.034	0.647	-0.447	0.000
				—data not shown—				

had eroded back to about the level of April 1994, and the channel side of the sandbar had eroded. In August 1995, the sandbar was higher than at any other time during the period, and had a very steep face on the channel side perhaps in response to 3 months of dam releases that were higher and steadier than any experienced previously.

At the downstream end of the pool and eddy, section p6 is the deepest and widest section in the set (fig. 10*C*). The August 1994 measurement shows increased sand over the measurement in April 1994 for this section as for all the sections in this pool. By May 1995, the sandbar had been eroded somewhat, and the channel on the bank side of the bar had filled in (fig. 10*C*). This is a return-flow channel in the terminology of Schmidt and Graf (1990). The measurement in August 1995 shows the channel bed and channel side of the sandbar had lost sand, and the top and side of the bar toward the bank had aggraded.

Cross sections p10, p13, p15a, p22, and p32 are shown to illustrate changes in the remainder of the reach between the Paria River and Badger Rapids (figs. 11–16). Section p10 is at the upstream end of a broad curve in the channel, p13 is just downstream from a channel constriction caused by a small debris fan formed by an unnamed tributary on the left bank, and p15a is at a slight constriction in a relatively straight section of channel upstream from a debris fan formed by a small tributary called Four-Mile Wash. Cross-section p22 crosses a pool downstream from a channel constriction at the debris fan formed on the right bank by Six-Mile Wash, and p32 crosses the pool just upstream from Badger Rapids (fig. 4).

Cross sections la1, lb1, lb3, lc2, ld5, le2, and lf4 are shown to illustrate the changes in channel sand storage in the reach downstream from the Little Colorado River (figs. 5, 17–23; tables 6 and 7). Section la1 crosses the upstream end of the first pool downstream from the Little Colorado River. The entire section including the zone of downstream flow and left-bank eddy, accumulated sand during the 1993 flood on the Little Colorado River (Graf and others, 1995, fig. 44). The section has been relatively stable since that time (fig. 17; Graf and others, 1995, fig. 44). The last measurement in the reporting period, made on June 30, 1995, showed the highest bed elevation since the January 1993 flood.

Cross-section lb1 crosses a small channel expansion between two debris fans downstream from the pool with the sections labeled la1–la7, and cross-section lb3 crosses a channel expansion just upstream from a large mid-channel gravel bar (fig. 5). A large right-bank eddy is formed by the channel expansion crossed by lb1 and lb1b. Both the eddy and the channel areas have the highest measured bed elevation in January 1993, just after the flood on the Little Colorado River (Graf and others, 1995, fig. 51). The last measurement of the current reporting period on April 26, 1995, shows that this section had accumulated sand but remained lower in elevation than it was just after the flood on the Little Colorado River (fig. 18).

Cross-section lb3, just upstream from the gravel bar, also aggraded during the 1993 flood on the Little Colorado River. The section had lost sand by January 1995, the end of the previous reporting period (Graf and others, 1995, fig. 53) and remained relatively stable during the current reporting period (fig. 19).

The sections represented by lc2 cross a large, wide pool downstream from the mid-channel gravel bar (fig. 5). This pool accumulated the largest amount of sand during the 1993 flood on the Little Colorado River—an estimated $23 \times 10^4 m^3$ (Weile and others, 1996; Graf and others, 1995). The pool had lost sand by the last measurement of the previous reporting period in January 1994, especially the upstream part crossed by sections lc1–lc3 (Graf and others, 1995, fig. 55–59). Section lc2 continued to erode through September 1994 but had aggraded slightly when measured in April 1995 (fig. 20). By the last measurement of the reporting period, the section had lost the sand that had been deposited between September 1994 and April 1995; however, the bed remained higher in elevation than when first measured in July 1992 before the flood on the Little Colorado River (Graf and others, 1995, fig. 56; this report, fig. 20).

Cross sections downstream from Carbon Creek (fig. 5) were not measured before the 1993 flood on the Little Colorado River (Graf and others, 1995). Changes in area at these downstream cross sections were typically smaller than the sections upstream during the current monitoring period (table 7).

Changes in area between successive measurements at the cross sections shown in figures 10–23 were computed to illustrate the

Table 6. Changes in area at selected monumented cross sections for the monitoring period

[yymmdd, year, month, and day. Sections selected are those shown in figures 10–23]

Cross-section number	Period evaluated (yymmdd)	Difference in area, in square meters	Fraction of tested section with differences significant at p=0.05	Fraction of section where rank-sum test was applied
Downstream from Paria River				
p1	940113–940406	–4	0.98	0.93
p1	940406–940829	5	1.00	.67
p1	940829–950831	14	1.00	.82
p4	940113–940406	–9	.86	.93
p4	940406–940830	53	.99	.95
p4	940830–950511	–113	1.00	.90
p4	950511–950831	84	.98	.94
p6	940113–940406	–66	.87	.97
p6	940406–940829	50	.99	.97
p6	940829–950511	–59	.99	.97
p6	950511–950831	89	.97	.96
p10	940112–940407	–19	.73	.95
p10	940407–940830	29	.97	.97
p10	940830–950215	40	1.00	.97
p10	950215–950510	–51	1.00	.99
p10	950510–950704	32	1.00	.97
p10	950704–950829	–12	.91	.93
p13	940112–940407	35	.78	.98
p13	940407–940831	–100	.96	.96
p13	940831–950215	95	1.00	.91
p13	950215–950510	–56	.96	.95
p13	950510–950704	18	.99	.68
p13	950704–950829	–4	1.00	.68
p15a	940112–940405	–20	.73	.97
p15a	940405–940831	–43	.90	.71
p15a	940831–950215	134	.99	.96
p15a	950215–950510	–36	.93	.65
p15a	950510–950705	35	1.00	.65
p15a	950705–950829	–67	.99	.94
p22	940111–940405	148	.98	.95
p22	940405–940901	–169	.94	.95

Table 6. Changes in area at selected monumented cross sections for the monitoring period—Continued

Cross-section number	Period evaluated (yymmdd)	Difference in area, in square meters	Fraction of tested section with differences significant at p=0.05	Fraction of section where rank-sum test was applied
Downstream from Little Colorado River				
p22	940901–950216	214	0.99	0.97
p22	950216–950509	–69	.95	.97
p22	950509–950705	–110	.92	.95
p22	950705–950830	190	1.00	.94
p32	940111–940405	–2	.84	.92
p32	940405–940901	–18	.95	.99
p32	940901–950216	89	1.00	.92
p32	950216–950509	–20	.97	.94
p32	950509–950830	37	1.00	.95
la1	940130–940430	–21	1.00	.95
la1	940430–940914	–9	.91	.94
la1	940914–950422	21	.68	.88
la1	950422–950630	76	1.00	.83
lb1	940131–940502	–40	.99	.95
lb1	940502–940915	–47	1.00	.97
lb1	940915–950424	292	1.00	.96
lb3	940131–940502	–27	.98	.86
lb3	940502–940915	–7	.94	.79
lb3	940915–950424	46	.87	.88
lb3	950424–950701	40	.96	.84
lc2	940131–940502	–7	.78	.91
lc2	940502–940915	–148	1.00	.80
lc2	940915–950424	191	1.00	.71
lc2	950424–950701	–188	1.00	.57
ld5	940202–940503	18	.98	.89
ld5	940503–940916	–33	1.00	.93
ld5	940916–950425	54	.92	.91
le2	940202–940503	5	.47	.95
le2	940503–940917	–13	.96	.85
le2	940917–950426	–8	.80	.89
lf4	940203–940504	8	1.00	.75
lf4	940504–940917	31	1.00	.71
lf4	940917–950426	–18	.77	.84

Table 7. Total changes in area at selected monumented cross sections for the monitoring period

[yymmdd, year, month, and day. Sections selected are those shown in figures 10–23]

Cross-section number	Period evaluated (yymmdd)	Difference in area, in square meters	Fraction of tested section with differences significant at p=0.05	Fraction of section where rank-sum test was applied
Downstream from Paria River				
p1	940113–950831	17	0.99	0.79
p4	940113–950831	2	.98	.94
p6	940113–950831	-2	.96	.95
p10	940112–950829	8	1.00	.95
p13	940112–950829	–27	.85	.96
p15a	940112–950829	–13	.99	.73
p22	940111–950830	115	1.00	.98
p32	940111–950830	82	1.00	.93
Downstream from Little Colorado River				
la1	940130–950630	63	1.00	.85
lb1	940131–950424	209	.99	.97
lb3	940131–950424	35	.98	.79
lc2	940131–950701	–156	1.00	.69
ld5	940202–950425	36	1.00	.88
le2	940202–950426	–13	.92	.85
lf4	940203–950426	7	.91	.92

changes in cross sections documented by the measurements (tables 6 and 7). For pairs of successive measurements for each cross section, the area difference for each incremental distance was computed as difference in mean-bed elevations multiplied by 0.25 m—half the distance to the next data point on either side. The difference in area for the entire cross section then was computed by summing the subsection areas. Some parts of the section may not have been measured each time because of differences in water level or in cross-section geometry or because interference by material in the water column caused loss of depth-sounder signal. For some distances, not enough values were measured to apply the rank-sum test. To aid the user of area-change data, the fraction of the total section to which the rank-sum test was applied and the fraction of the section tested for which bed-elevation differences were significant are given in tables 6 and 7. Data from the statistical files were used to make these computations. Area differences were computed from differences in mean-bed elevation from measurement to measurement for which the p value was less than or equal to 0.05.

All of the changes observed during the reporting period in the group of sections represented by figure 10 are small relative to the deposition that resulted from a flood in the Paria River in August 1992 and subsequent scour that was found during the previous reporting period (Graf and others, 1995). Changes from January 1994 through August 1995 at the three sections selected to illustrate changes in this pool ranged from –2 to +17 m^2 (tables 6 and 7). Changes at section p4 ranged from –257 to +187 m^2 during the previous reporting period (Graf and others, 1995).

Most of the sections downstream from that upstreammost pool experienced alternating scour and fill and a small net change during the reporting period (figs. 11–16; tables 6 and 7). At section p10, for example, the maximum change during any period between successive measurements was a loss of 52 m^2 between February and May 1995, and the net change between January 1994 and August 1995 was a gain of 8 m^2. During the previous reporting period, the section experienced a net loss of about 140 m^2. Sections toward the downstream end of the monitored reach experienced larger changes than those at the upstream end, and the largest changes measured in the subset selected for illustration occurred at section p22. At that section, a net gain of 115 m^2 was measured during the period from January 1994 through August 1995, and large gains and losses were measured between each survey (fig. 15; tables 6 and 7).

Changes in cross-sectional area at measured sections in the reach downstream from the Little Colorado River were largest in the pools crossed by lb1–lb4 and lc1–lc5 (fig. 5; tables 6 and 7). Changes during the individual monitoring periods ranged from –188 to +292 m^2 (table 6), and net changes over the entire monitoring period ranged from –156 to +209 m^2. As for the sections downstream from the Paria River, changes measured during the monitoring period presented in this report were small compared to those measured during the previous reporting period (Graf and others, 1995). All but two of the sections in the first three pools downstream from the Little Colorado River—the la, lb, and lc sections on figure 5—gained sand between the summer of 1992 and the winter of 1994 (Graf and others, 1995, table 7). Much of the gain occurred during the large flood on the Little Colorado River in January 1993. Measurements during the period presented in this report show that much of the sand deposited in the channel by that flood remained in the channel in the spring of 1995. For example, section la1 had gained 486 m^2 of sand during the previous reporting period and lost only 63 m^2 during the current reporting period. Section lc2 gained 537 m^2 during the previous period and lost only 156 m^2 during the current one (Graf and others, 1995, table 7; this report, table 7).

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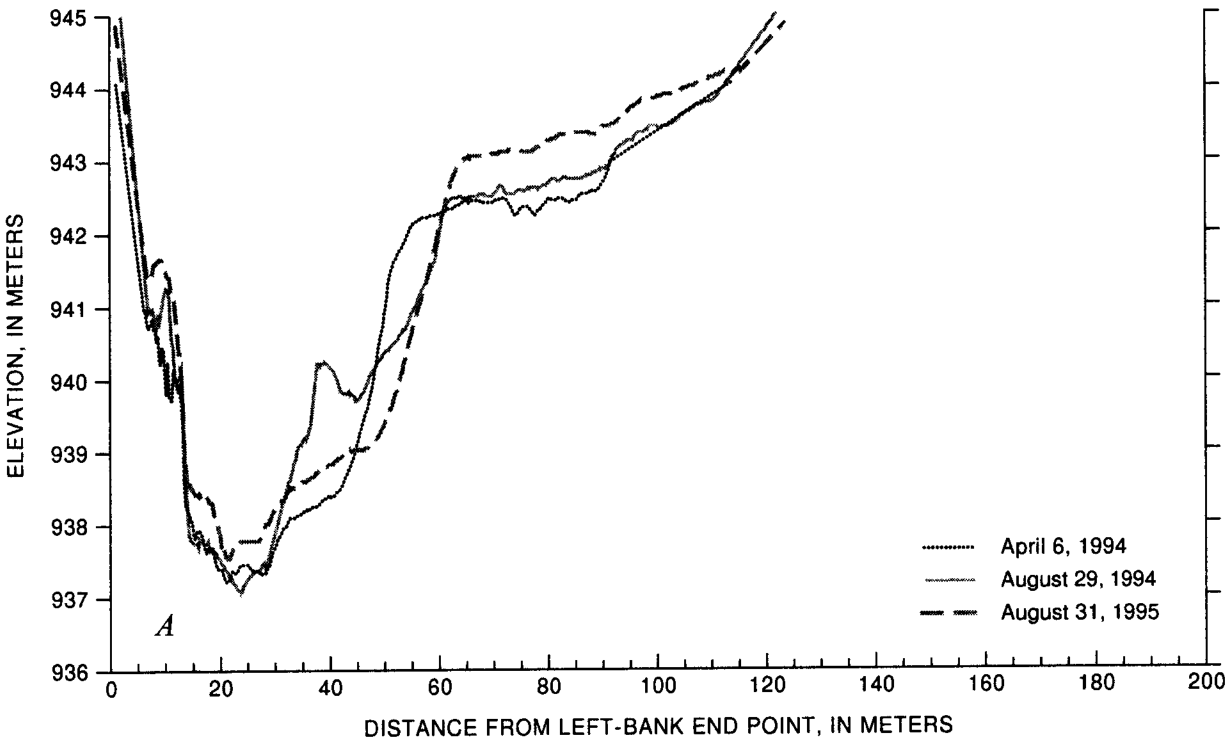
BASIC DATA

Figures 10–23



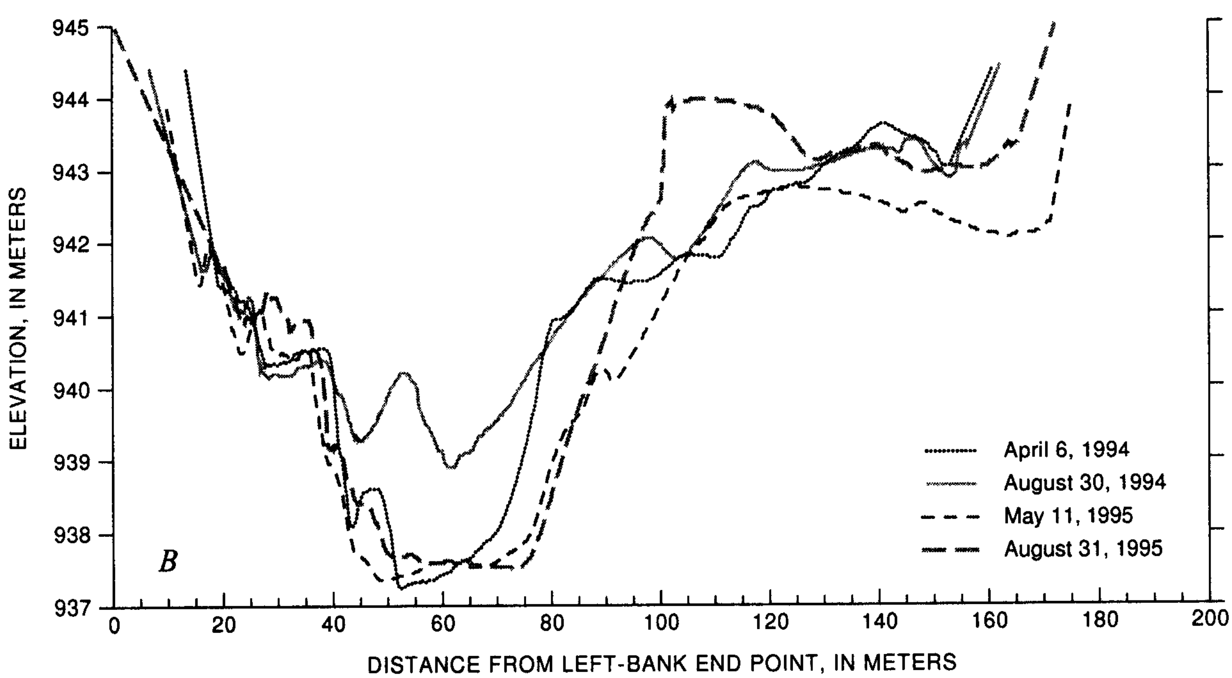


Figure 10. Cross sections measured downstream from the Paria River at monumented sections. *A*, p1. *B*, p4. *C*, p6.

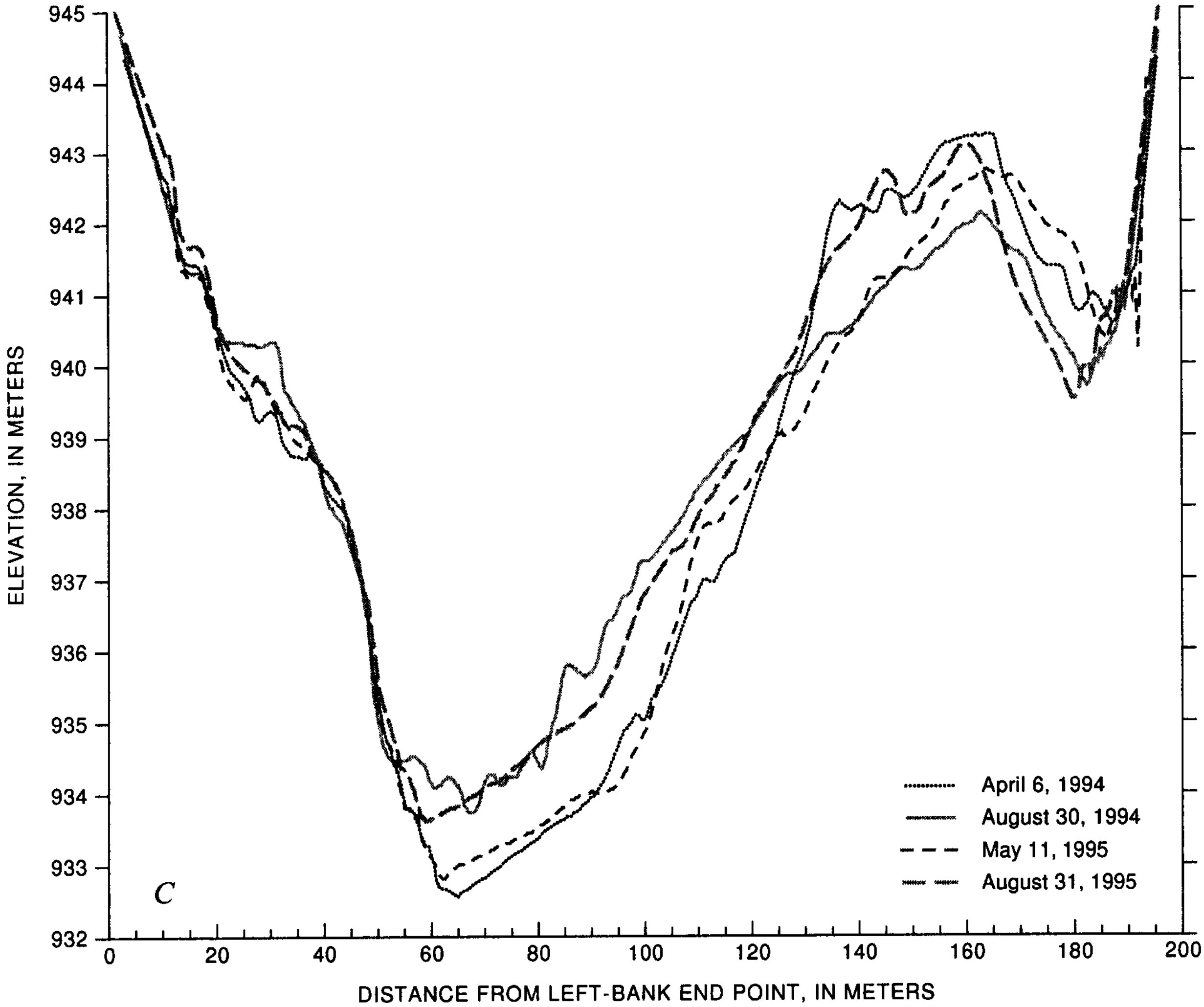


Figure 10. Continued.

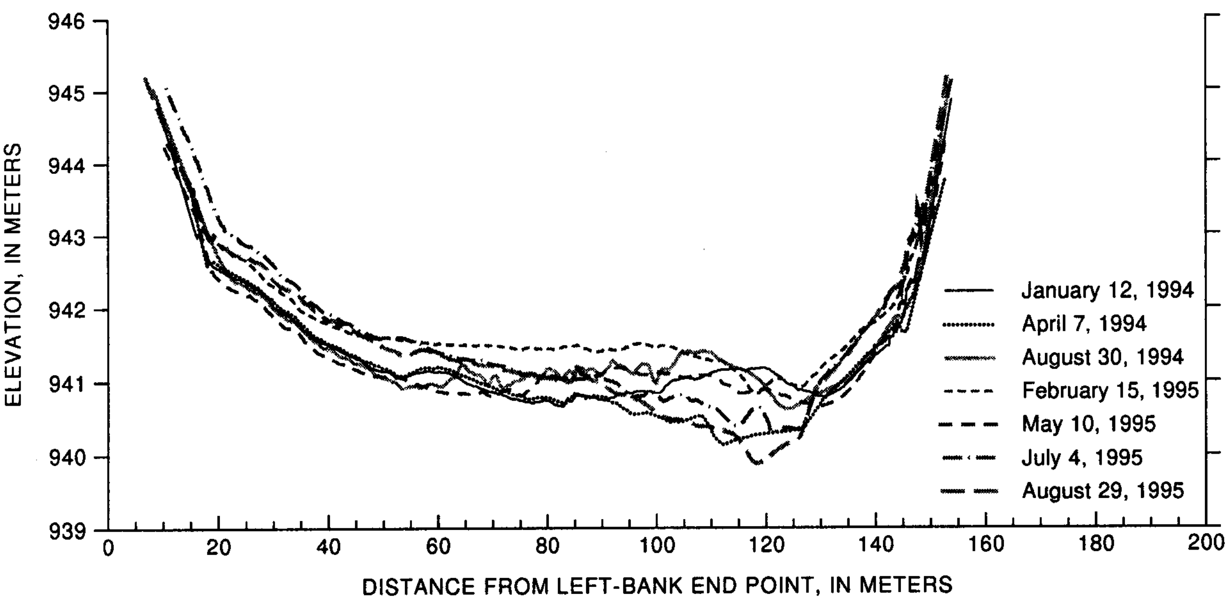


Figure 11. Cross section measured downstream from the Paria River at monumented section p10.

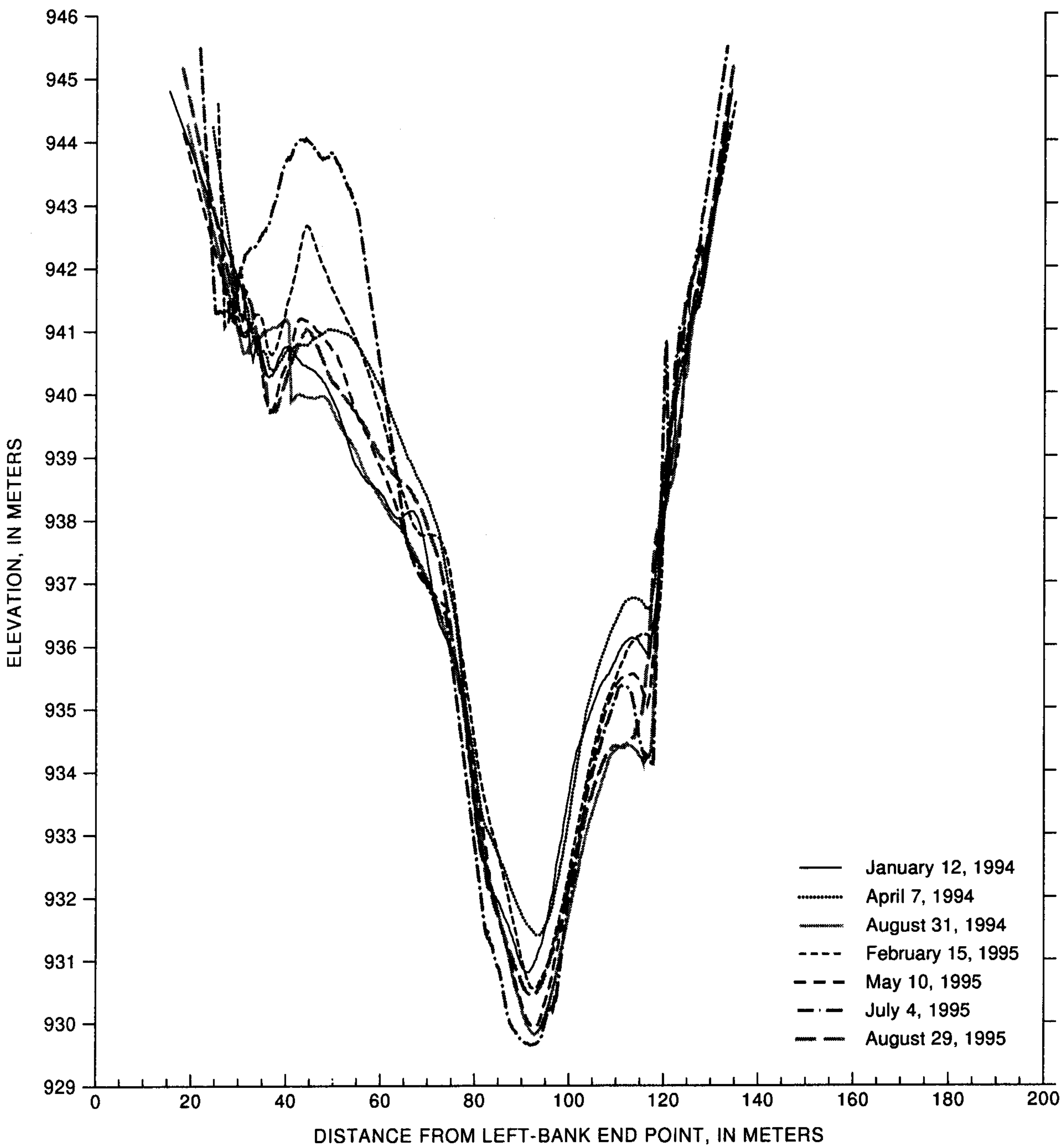


Figure 12. Cross section measured downstream from the Paria River at monumented section p13.

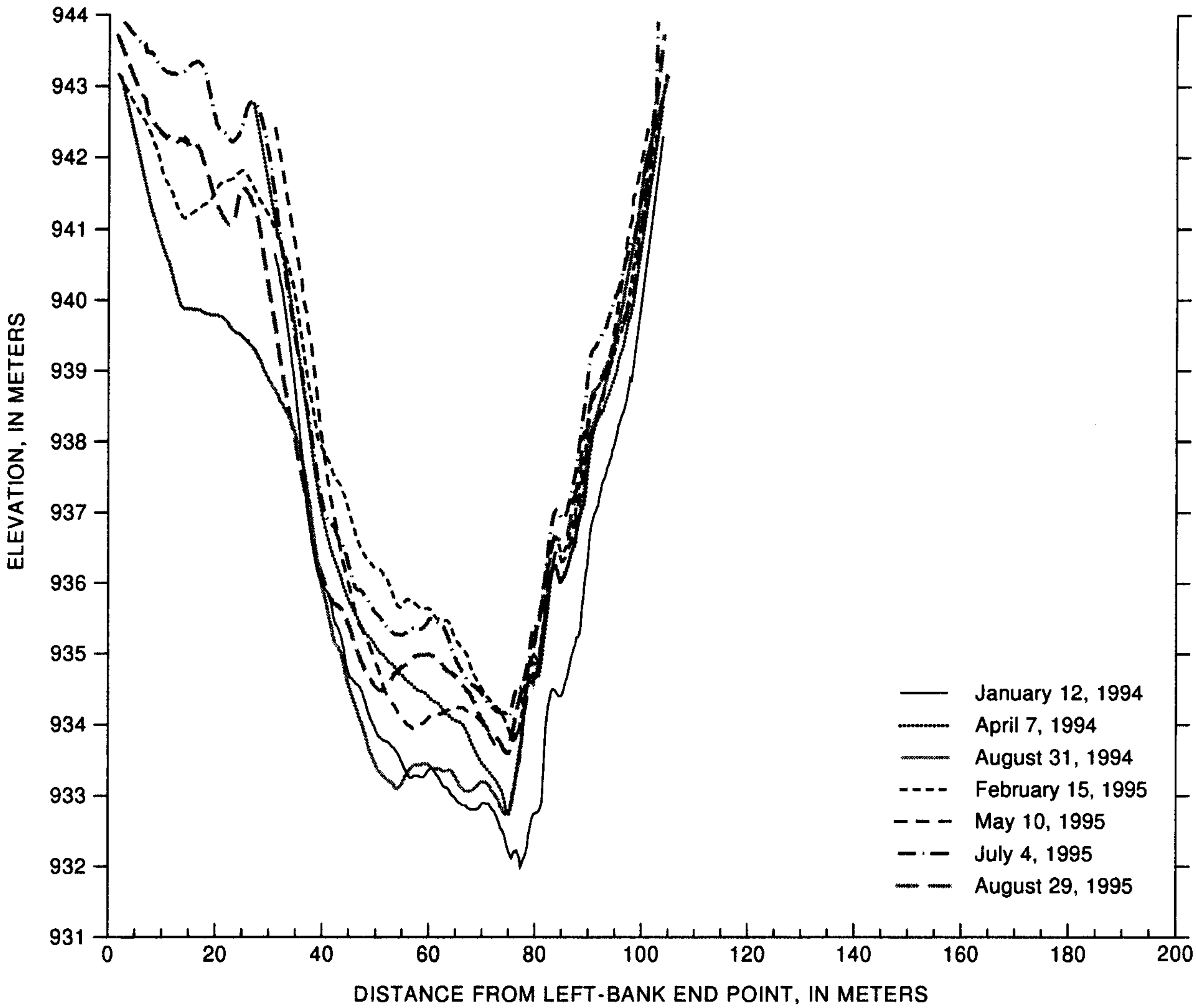


Figure 13. Cross section measured downstream from the Paria River at monumented section p15a.

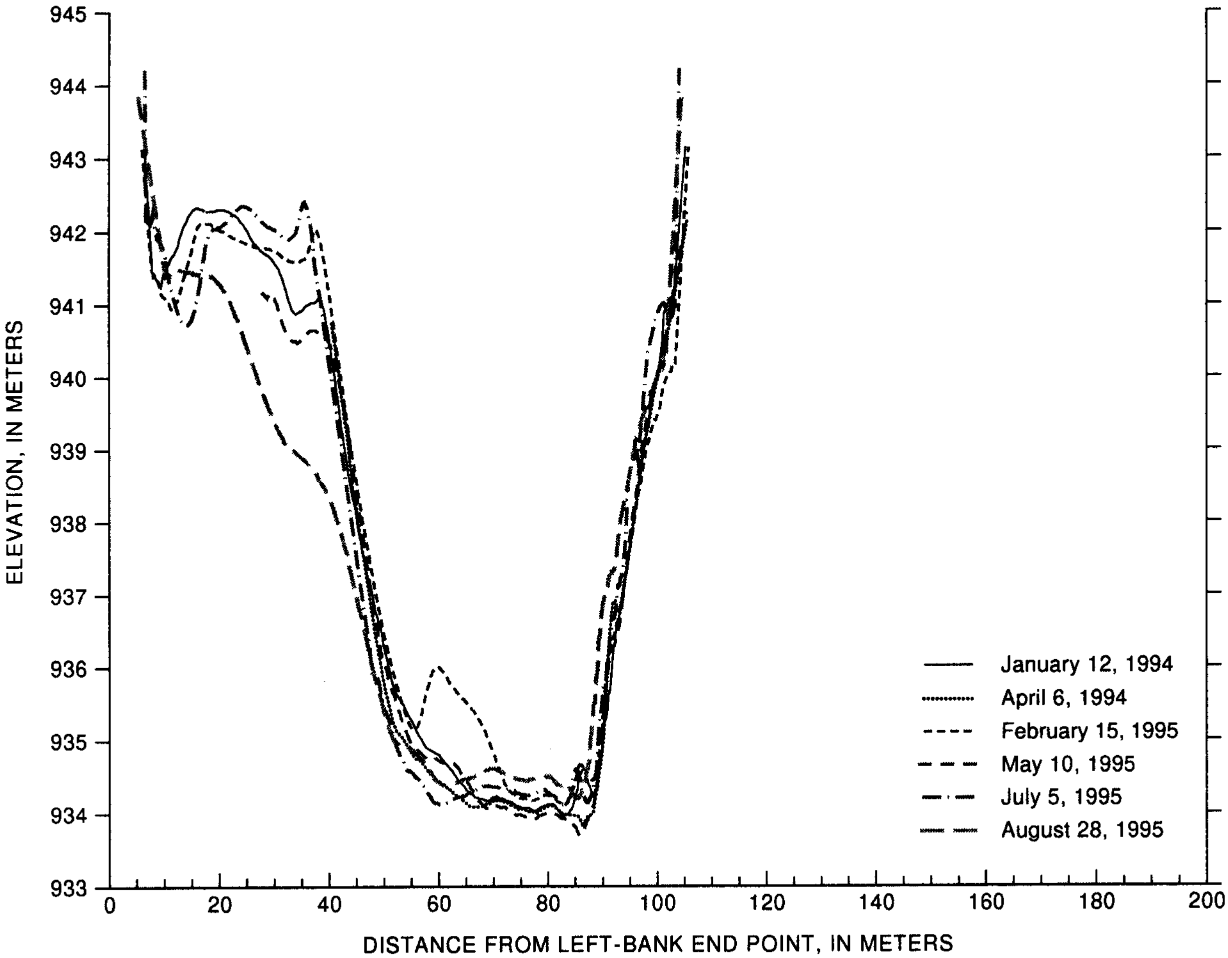


Figure 14. Cross section measured downstream from the Paria River at monumented section p19.

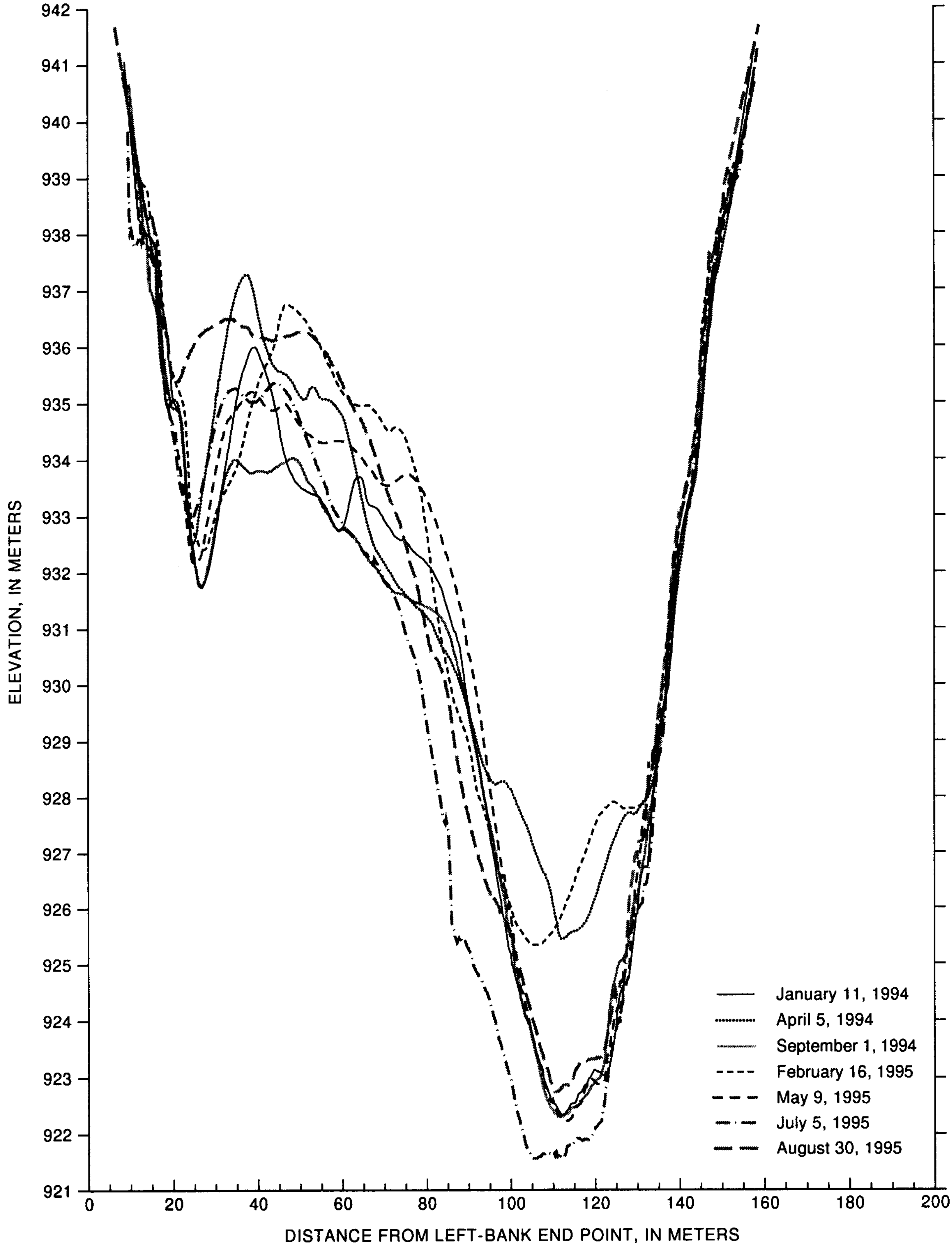


Figure 15. Cross section measured downstream from the Paria River at monumented section p22.

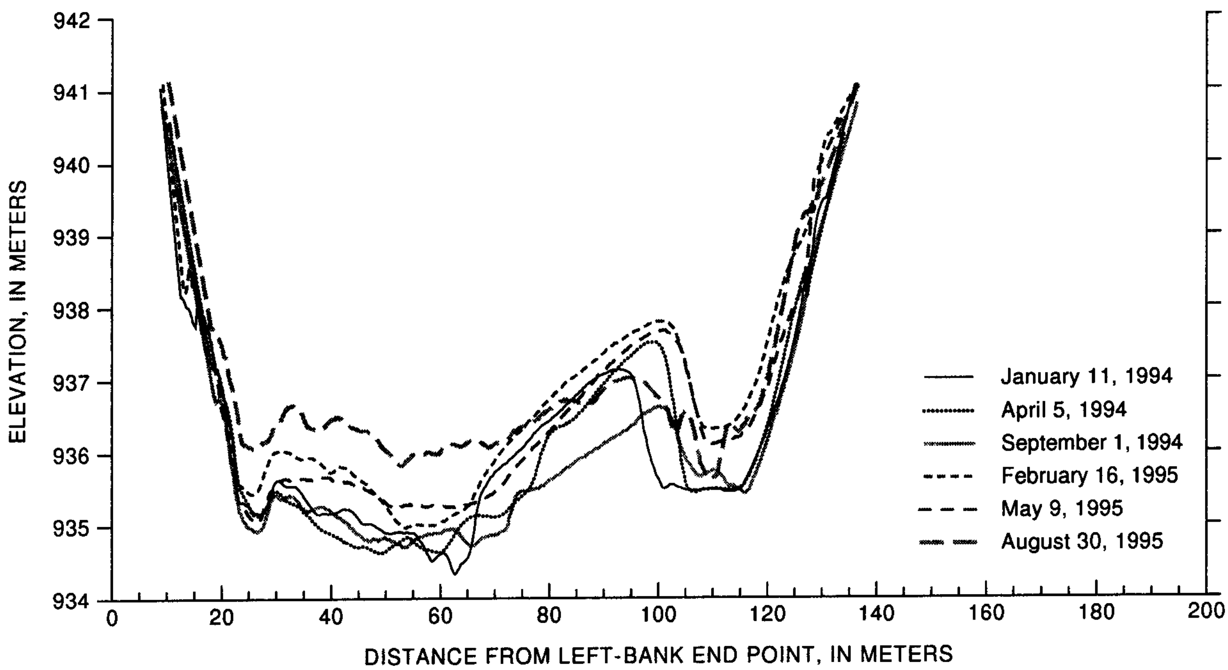


Figure 16. Cross section measured downstream from the Paria River at monumented section p32.

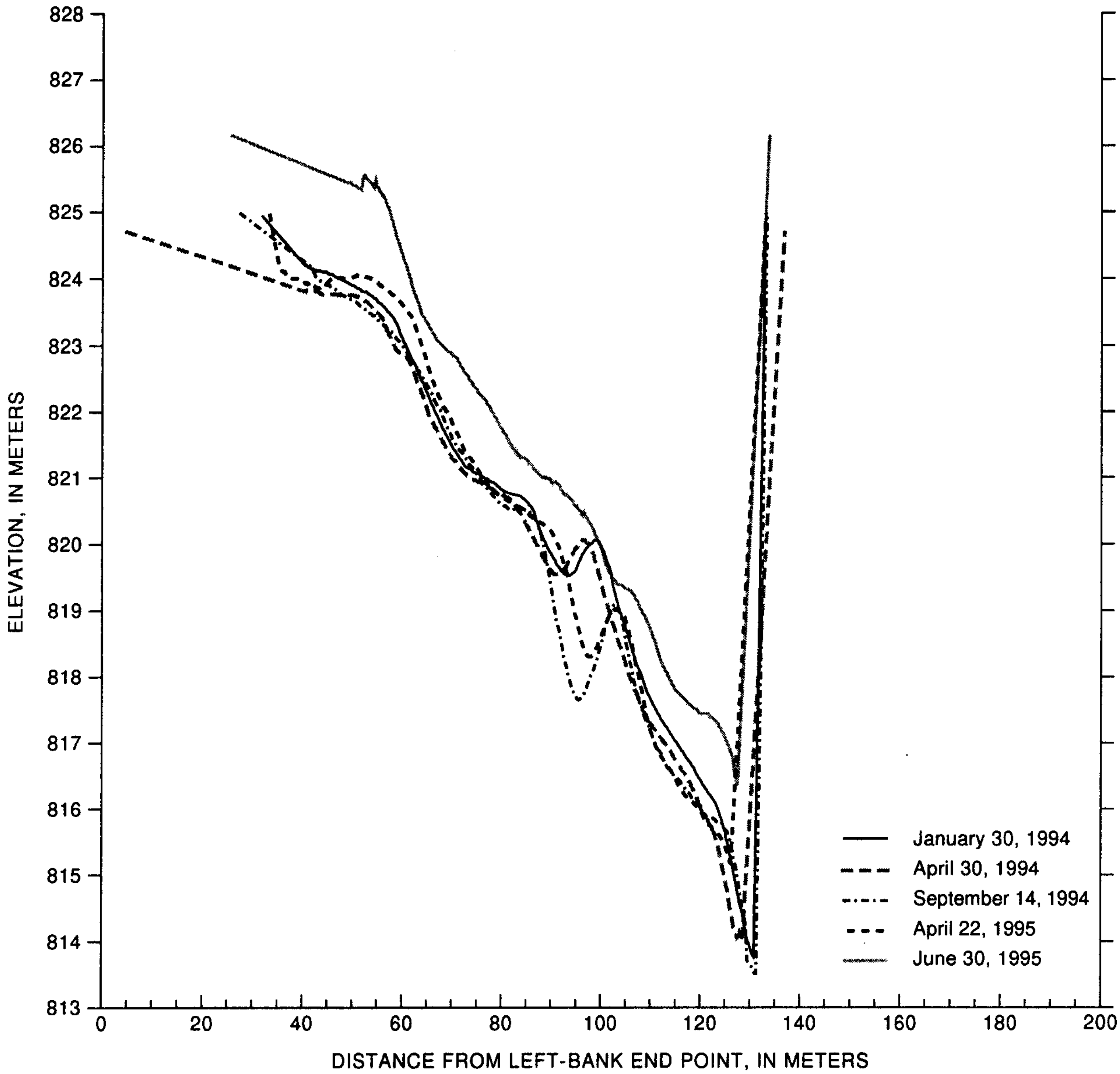


Figure 17. Cross section measured downstream from the Little Colorado River at monumented section la1.

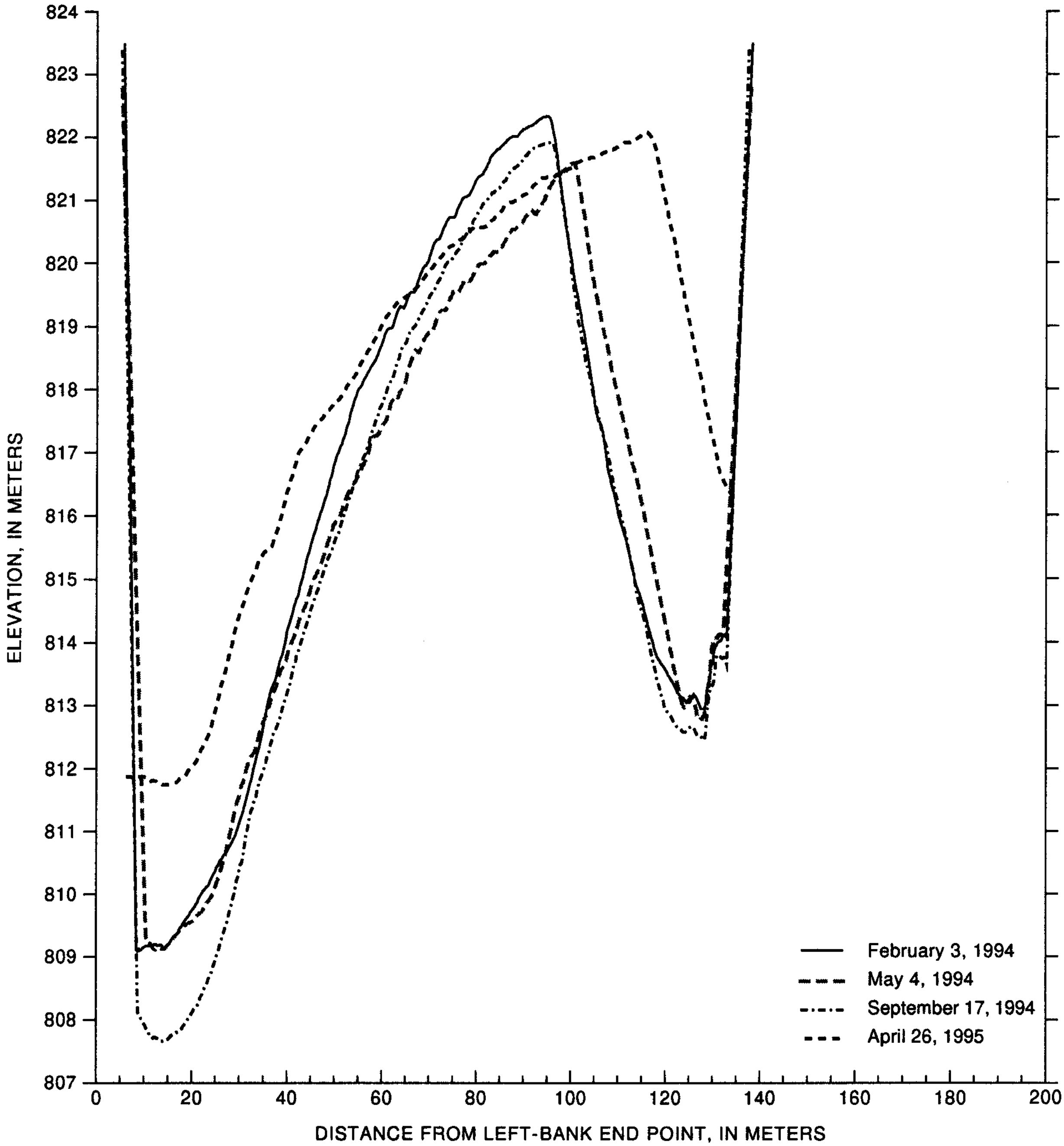


Figure 18. Cross section measured downstream from the Little Colorado River at monumented section lb1.

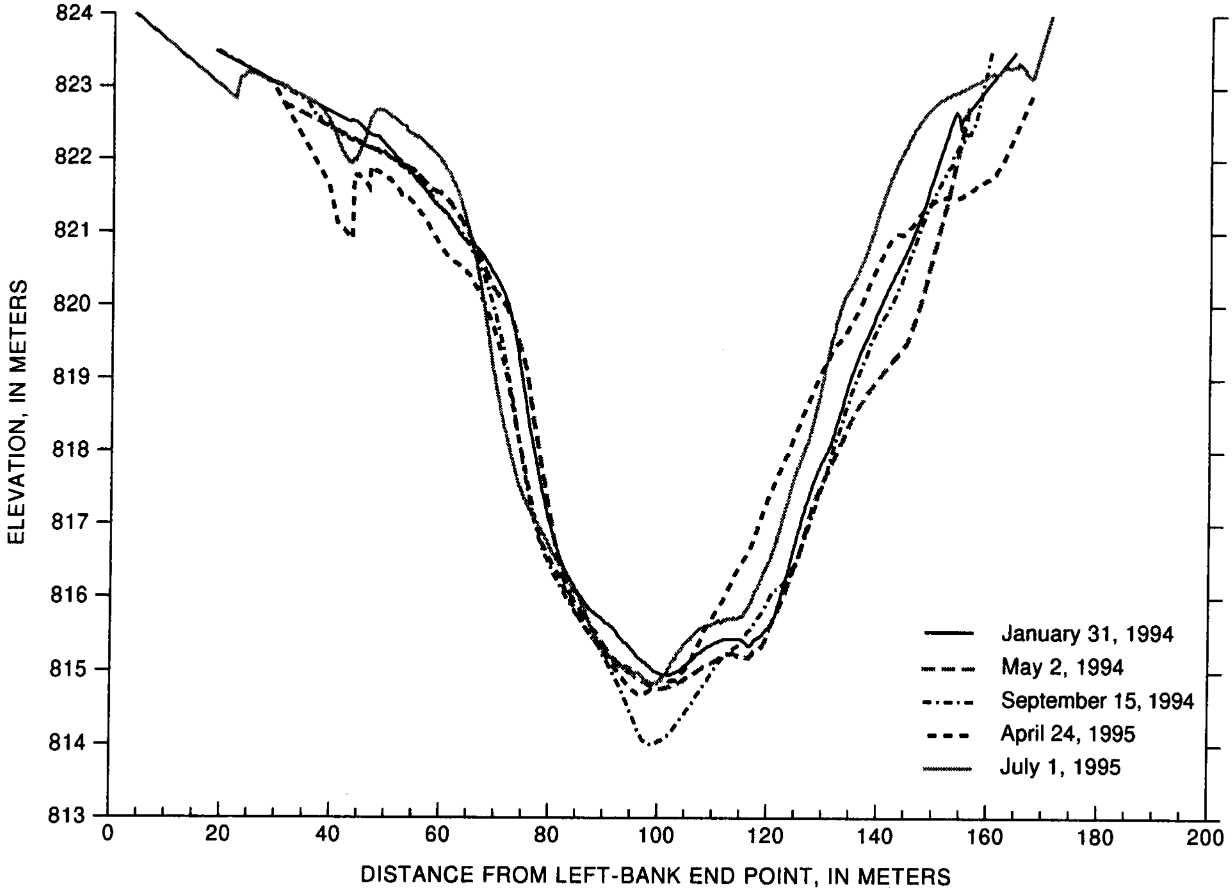


Figure 19. Cross section measured downstream from the Little Colorado River at monumented section lb3.

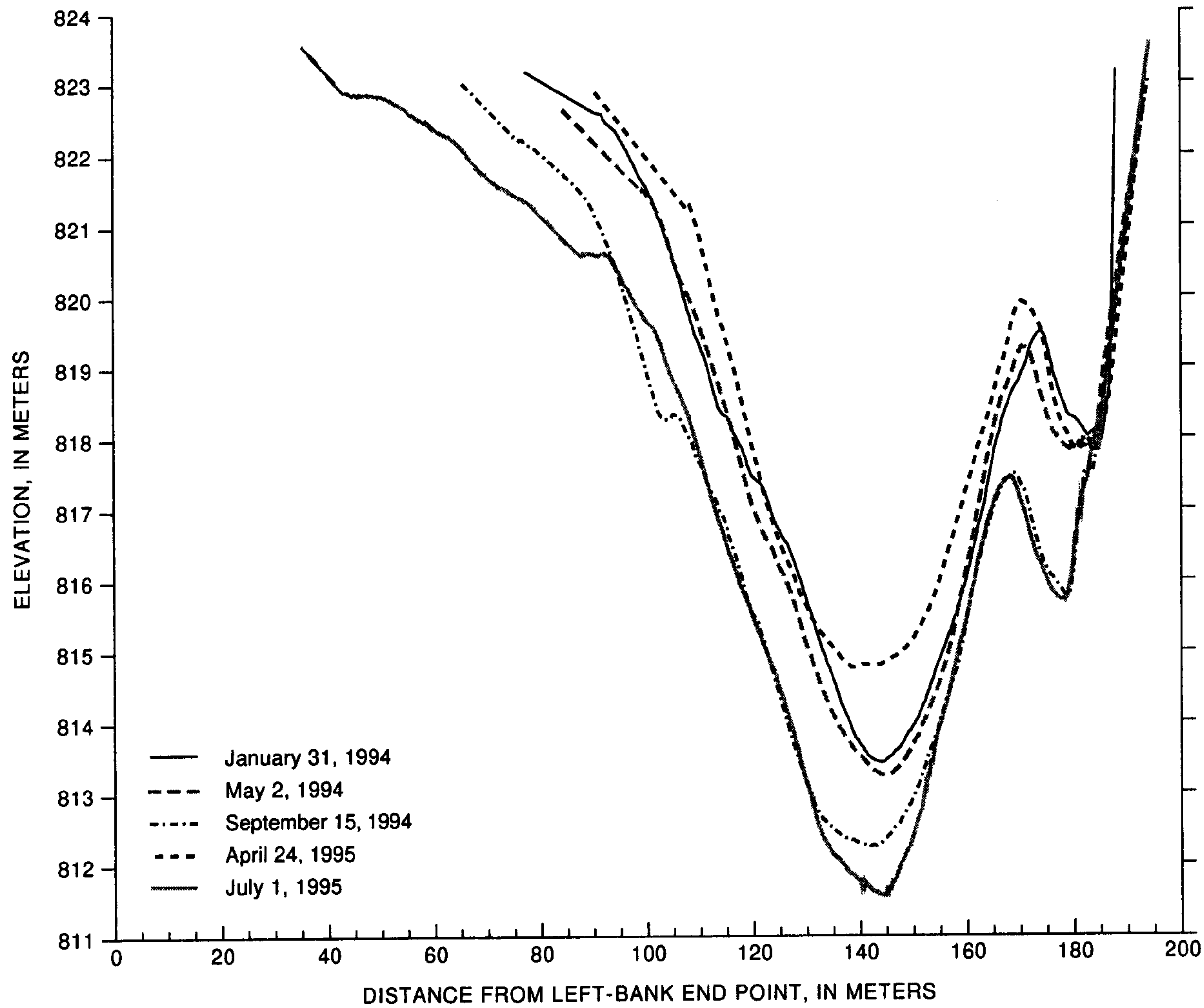


Figure 20. Cross section measured downstream from the Little Colorado River at monumented section lc2.

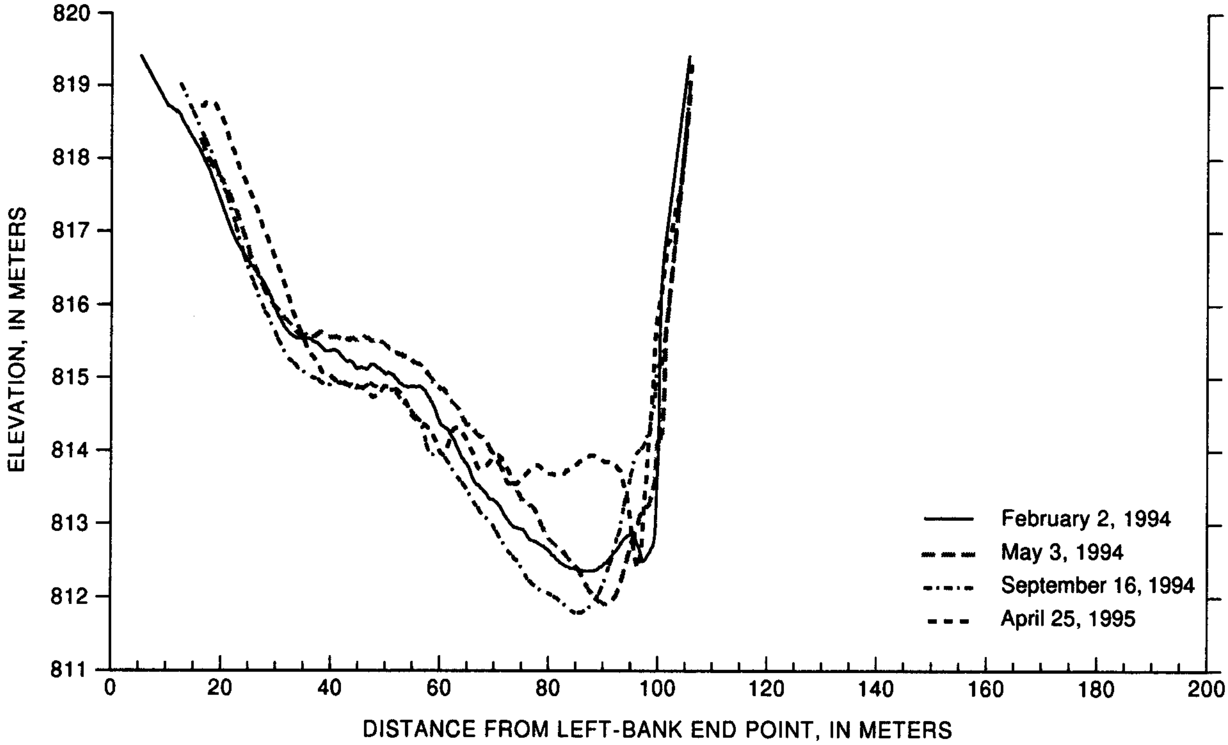


Figure 21. Cross section measured downstream from the Little Colorado River at monumented section ld5.

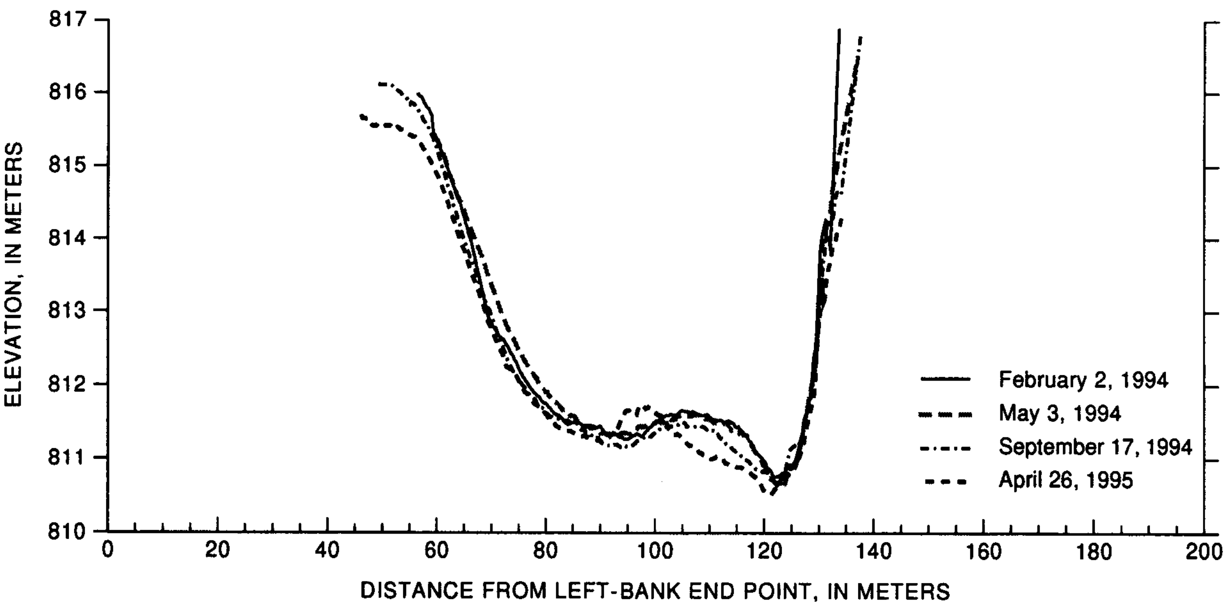


Figure 22. Cross section measured downstream from the Little Colorado River at monumented section le2.

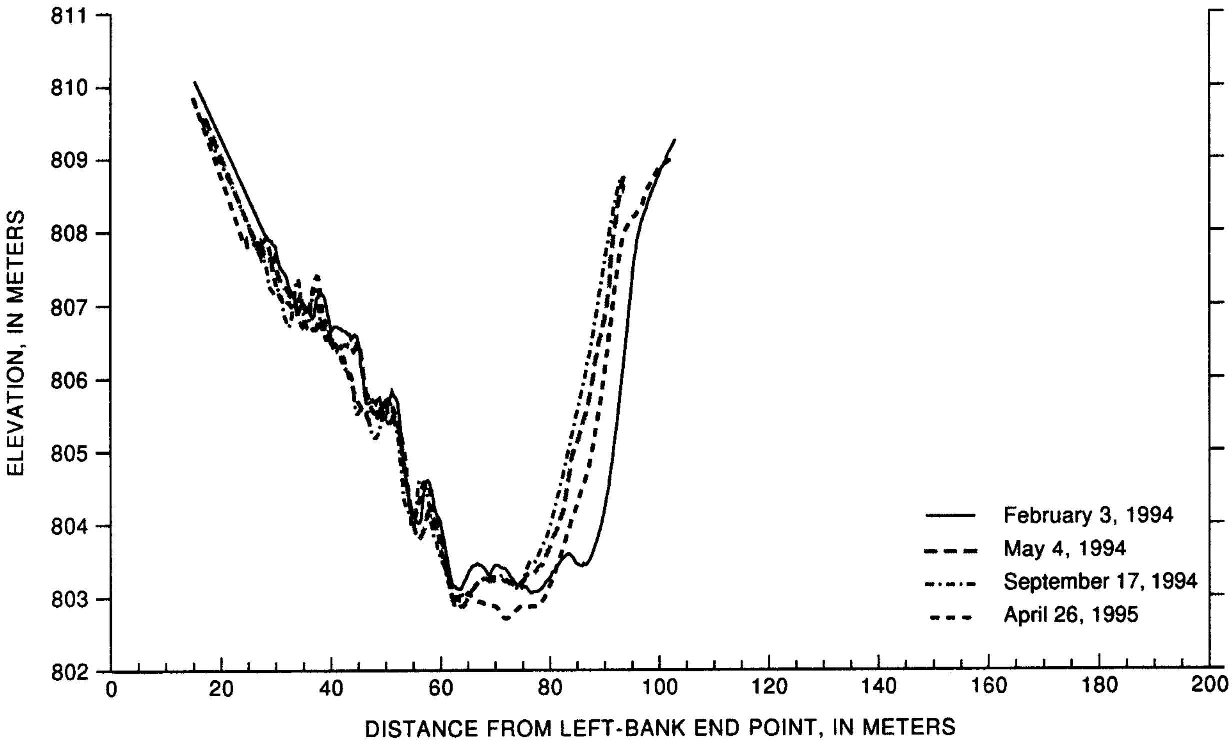


Figure 23. Cross section measured downstream from the Little Colorado River at monumented section lf4.

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