Sand-Storage Changes in the Colorado River Downstream from the Paria and Little Colorado Rivers, June 1992 to February 1994

U.S. GEOLOGICAL SURVEY
Open-File Report 95—446

Prepared in cooperation with the
BUREAU OF RECLAMATION

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Tucson, Arizona
1995

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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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

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By Julia B. Graf, Jonathan E. Marlow, Gregory G. Fisk, *and* Samuel M.D. Jansen

Abstract

Sixty-six cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers were monitored from June 1992 to February 1994 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 and remeasured four times between then and January-February 1994. 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. This report presents the data from the five measurements made during the reporting period in graphical form and describes the electronic form of the data. Bed-elevation differences and the computed p value from the Wilcoxon rank-sum test are included in electronic form, and the format of the electronic files is described in the report.

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 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. Interim flow criteria were followed during the period of measurements presented in this report, and the daily mean discharge at Lees Ferry, Arizona, was between about 200 and 500 m^3/s

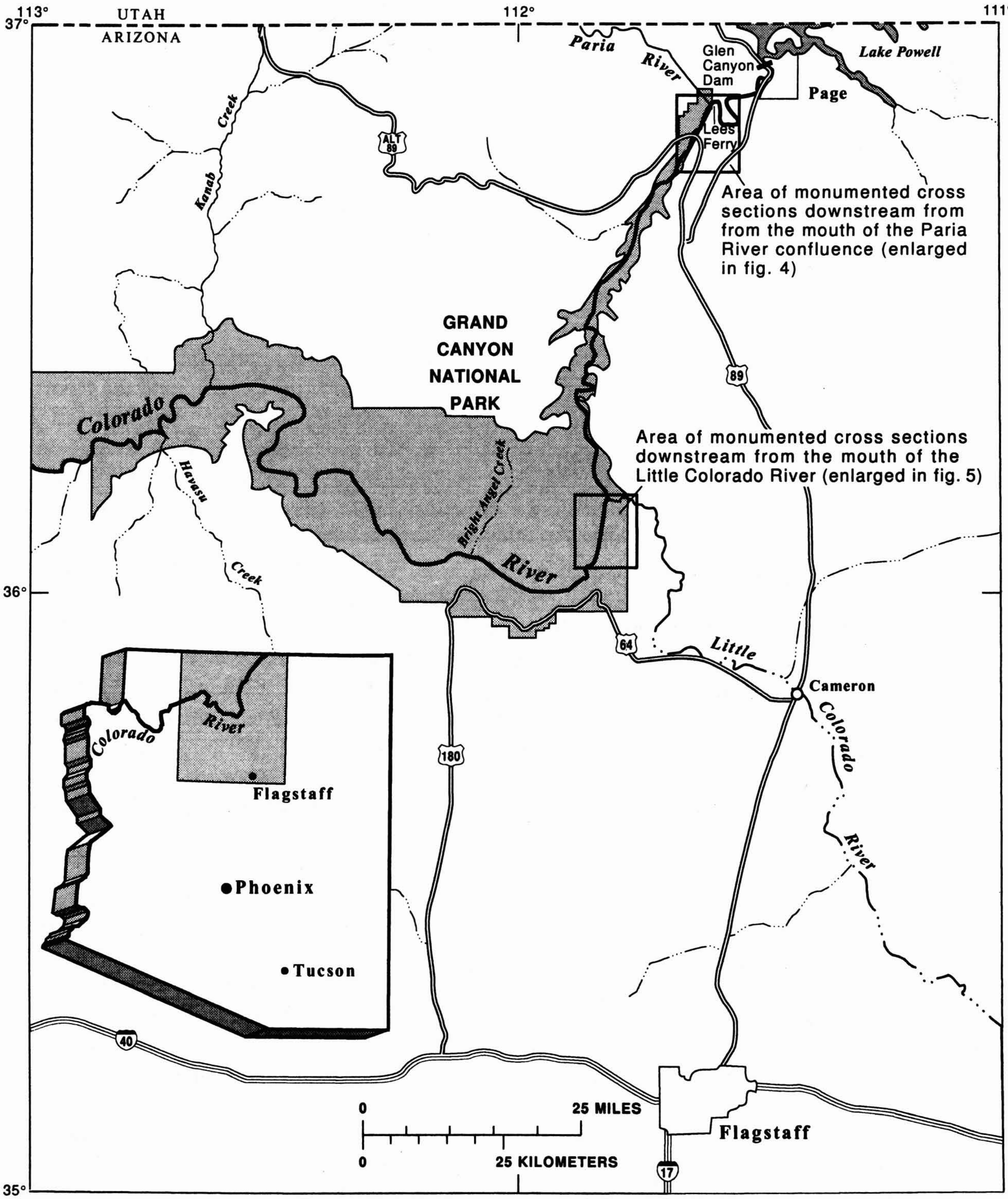

Figure 1. Location of the two monitored reaches.

(fig. 2) with the range in discharge during a given day commonly between about 100 and 200 m^3/s (fig. 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). Monitoring 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 are in the 11-kilometer reach from the mouth of the Little Colorado River to Tanner Rapids (fig. 5). Measurements are made at each section downstream from the Paria and Little Colorado Rivers at three key times during the year—in the winter before the spring floods in tributaries; in late spring or early summer after the floods; and in the fall after summer rains. The time of each measurement is shown in relation to flow and sediment load in these two tributaries (figs. 6 and 7).

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 will be used with multidimensional sediment-transport models under development (S.M. Wiele, J.B. Graf, and J.D. Smith, hydrologists, U.S. Geological Survey, written commun., 1995) 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 June 1992 to February 1994. Data are presented graphically and summarized in tables. Data are available electronically as ASCII files. Contents and format of the files are described in tables in the report. In addition, differences in bed elevation and changes in area of cross sections between measurement dates are presented.

Acknowledgments

Kenton Grua operated the boat during the cross-section measurements. His patience and skill made it possible to collect the high-quality data required for the study. Trine Christiansen, Mikkel Christiansen, and James J. Duncker volunteered their time to help collect the bathymetric and cross-section data. Franklin R. Protiva, Fidel M. (Mark) Gonzales, and Robert C. (Chris) Brod did the surveys required to tie the cross-section end points to the GCES control network.

METHODS OF DATA COLLECTION AND ANALYSIS

Data Collection

Channel geometry, character of bank and visible bed materials, 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-July 1992, when the 15 sections at the upstream end were installed and first measured (table 1). The remaining 16 sections were installed and first measured in January-February 1993 (table 1). All 34 sections downstream from the Paria River were installed and first measured in August 1992 (table 1). Sections were remeasured four times between January 1993 and February 1993 (table 1). 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 2) are documented in the Arizona State Plane coordinate system, in meters, used for all other GCES geographic data (Werth and others, 1993).

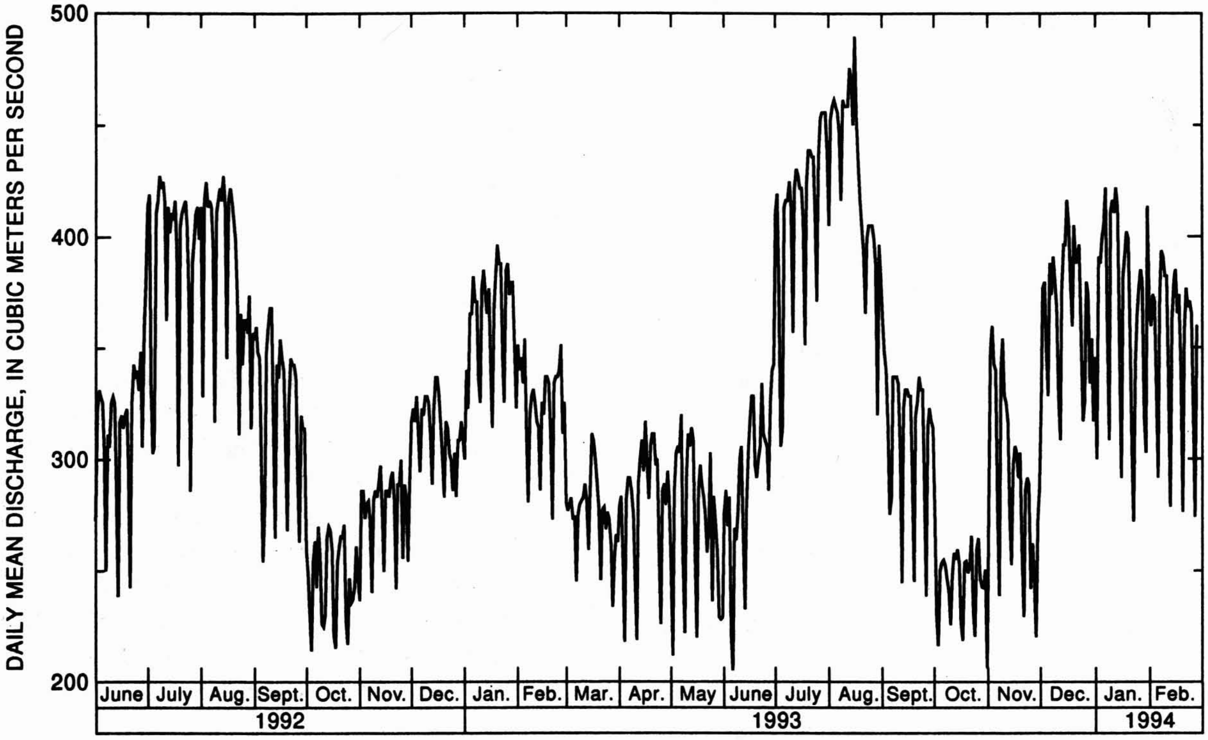

Figure 2. Daily mean discharge at the streamflow-gaging station, Colorado River at Lees Ferry, Arizona, June 1992 to February 1994.

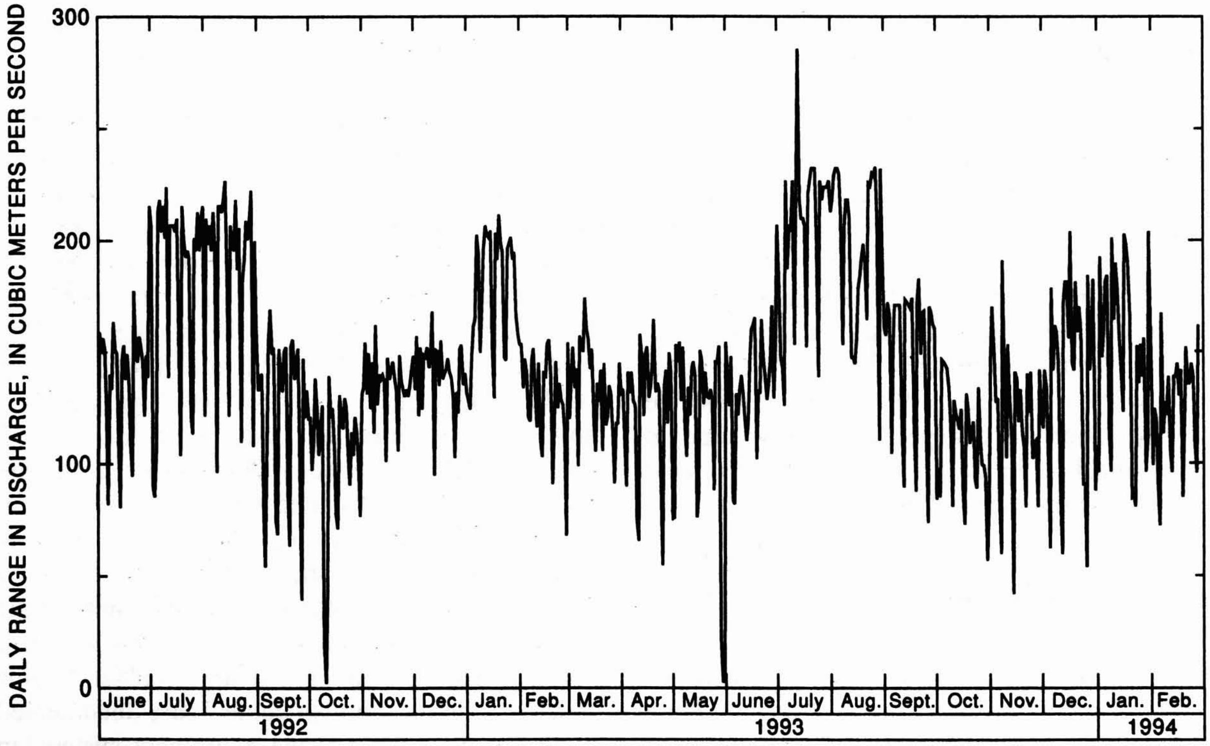

Figure 3. Daily range in discharge at the streamflow-gaging station, Colorado River at Lees Ferry, Arizona, June 1992 to February 1994.

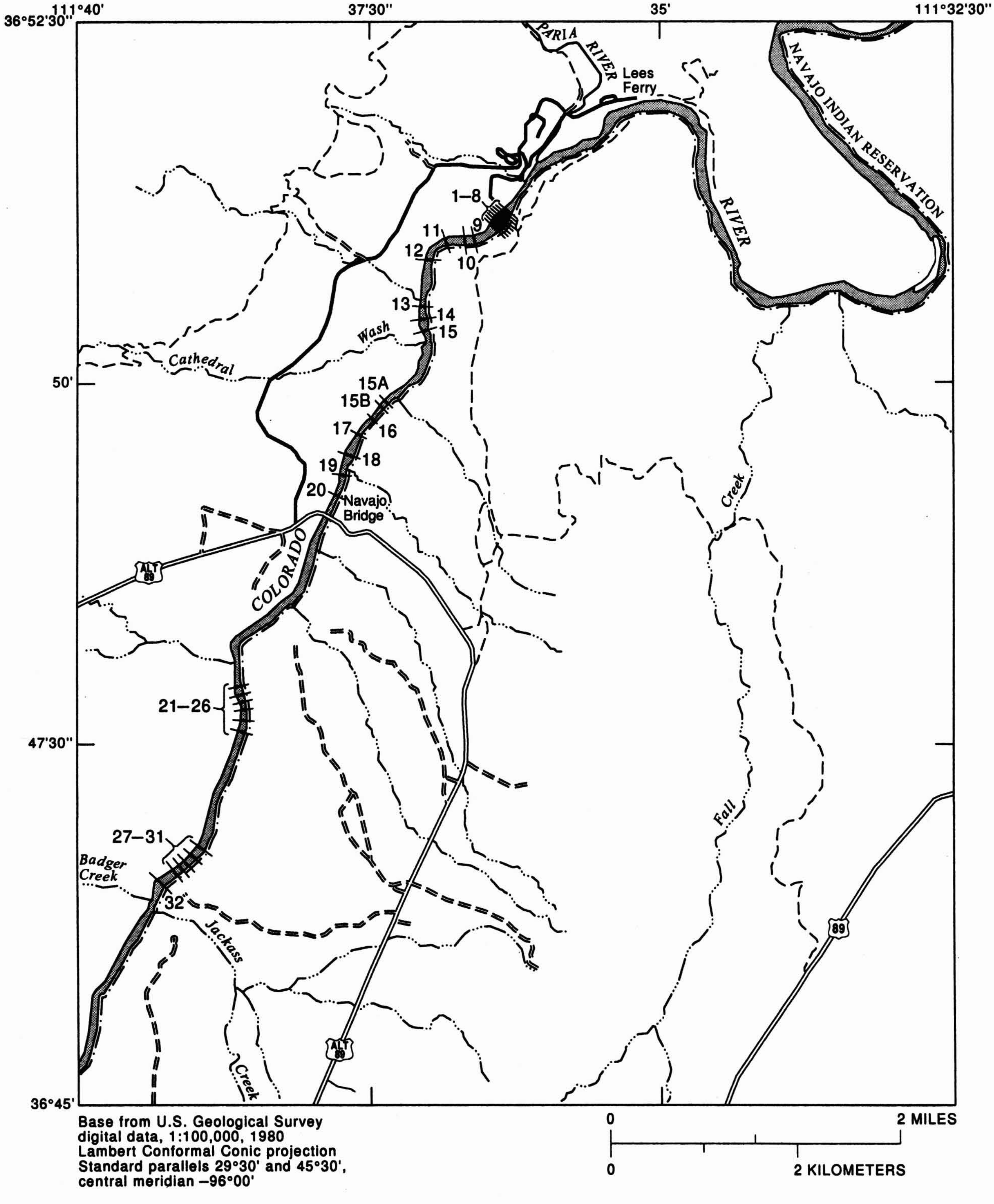

Figure 4. Location of monumented cross sections on the Colorado River downstream from the mouth of the Paria River.

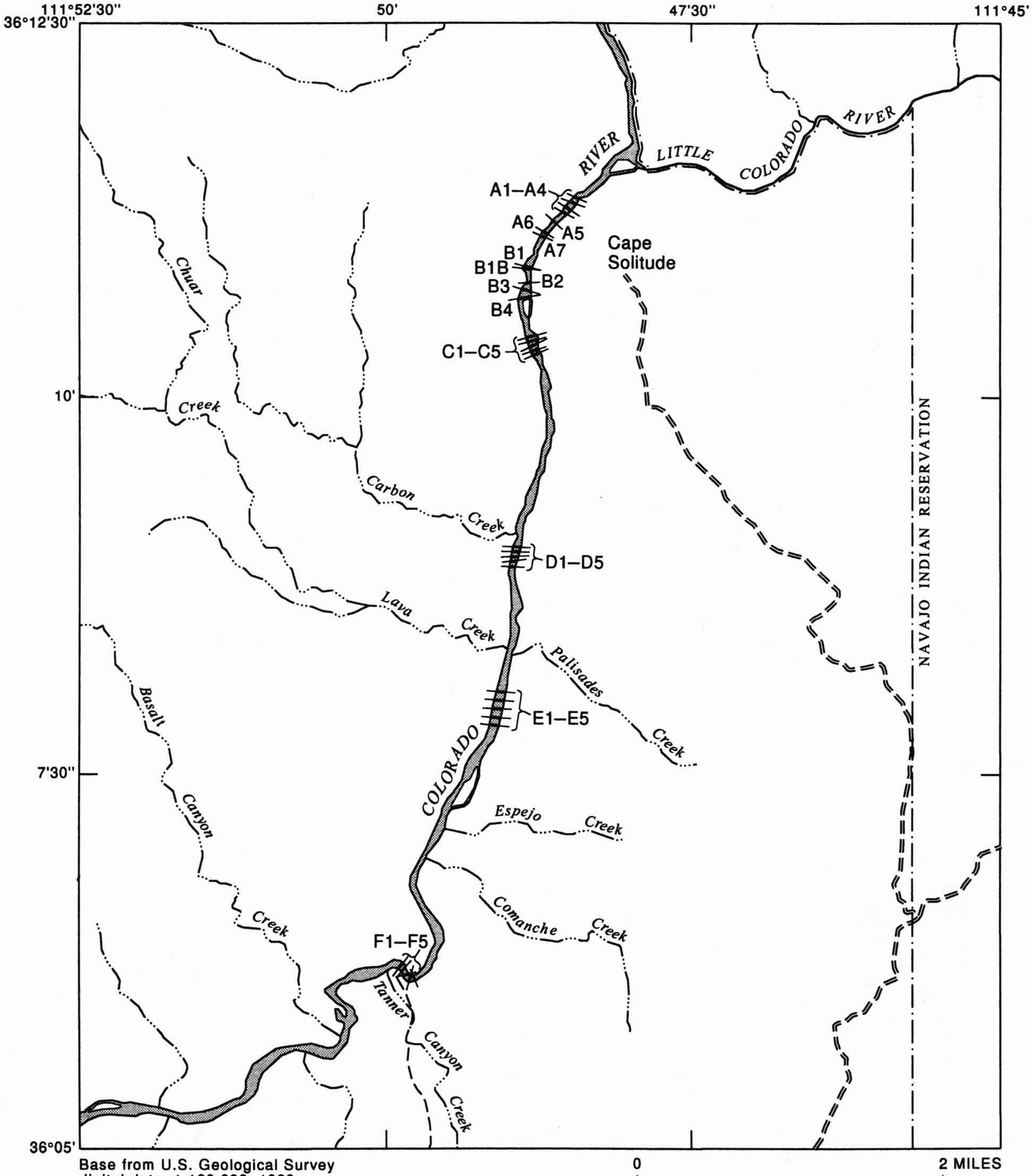

Figure 5. Location of monumented cross sections on the Colorado River downstream from the mouth of the Little Colorado River.

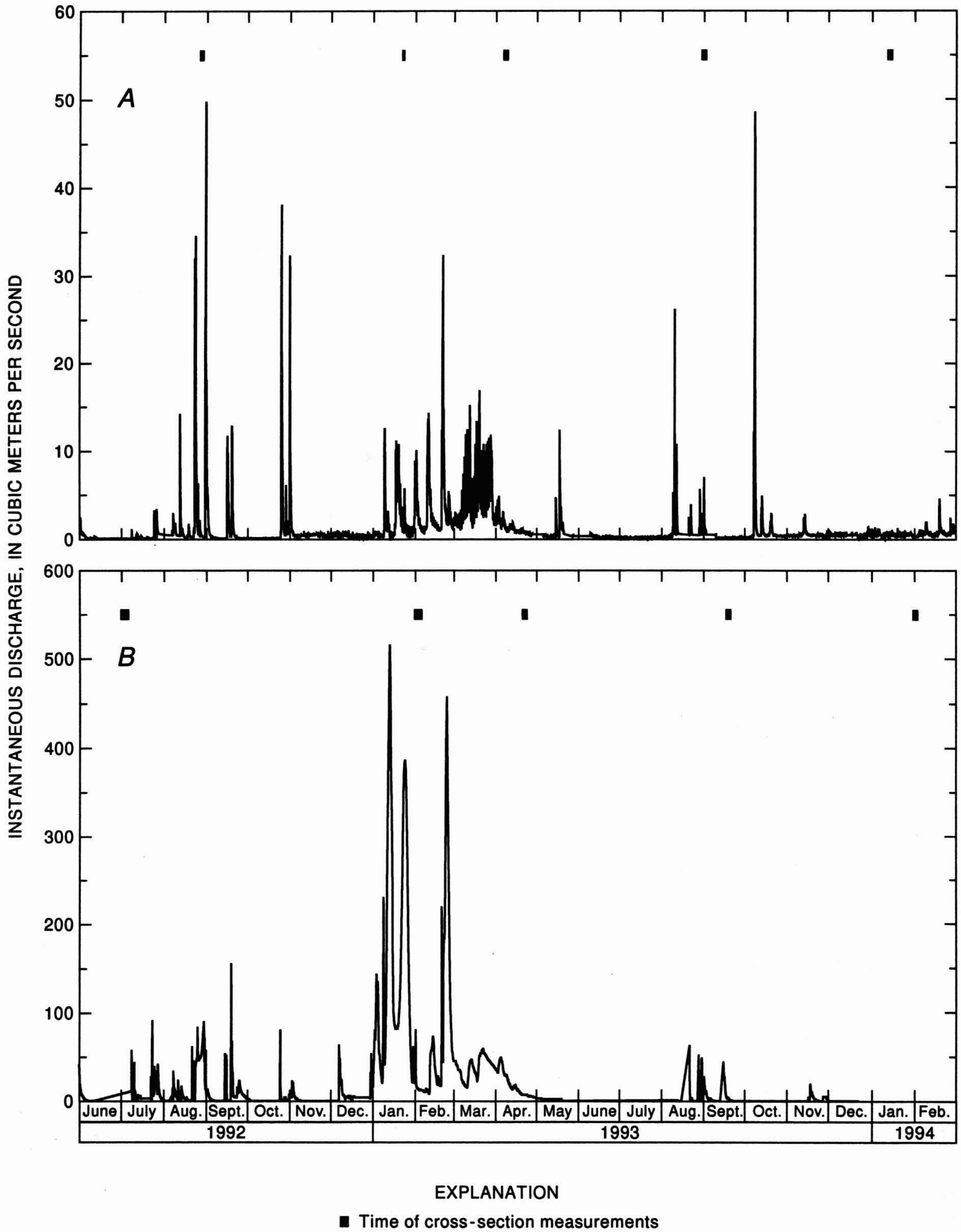

Figure 6. Instantaneous discharge at streamflow-gaging stations on tributaries, June 1992 to February 1994. *A*, Paria River at Lees Ferry, Arizona. *B*, Little Colorado River near Cameron, Arizona.

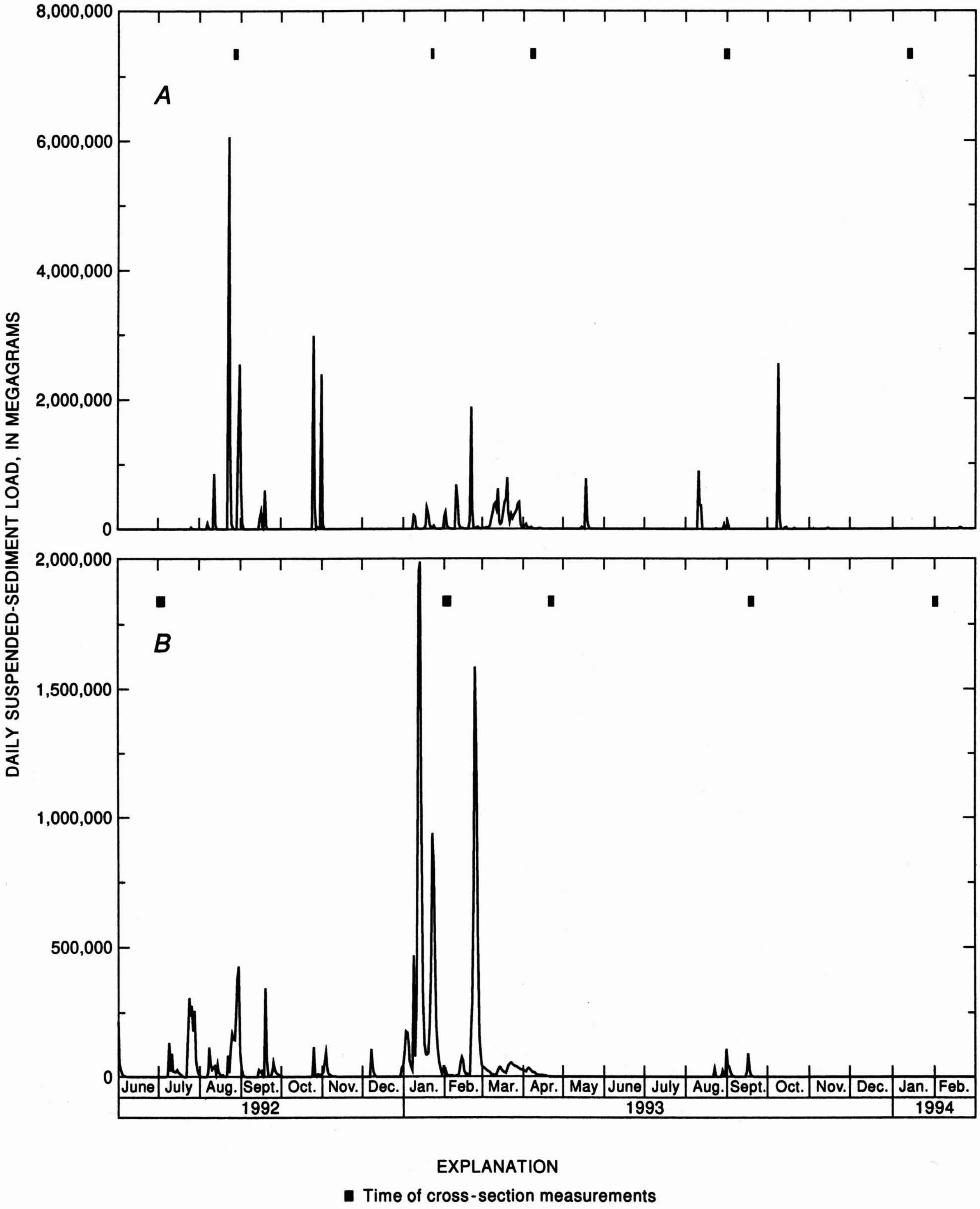

Figure 7. Daily suspended-sediment load at streamflow-gaging stations on tributaries, June 1992 to February 1994. *A*, Paria River at Lees Ferry, Arizona. *B*, Little Colorado River near Cameron, Arizona.

Table 1. Date and time of measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers

[Dashes indicate no data. N/A, not applicable]

Cross-section number	June-August 1992		January-February 1993		April-May 1993		August-September 1993		January-February 1994	
	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time
Downstream from Paria River										
P1	August 23, 1992	1300	January 23, 1993	1500	April 8, 1993	1650	September 1, 1993	1415	January 13, 1994	855
	August 24, 1992	0930								
P2	August 23, 1992	1355	January 23, 1993	1420	April 8, 1993	1615	September 1, 1993	1500	January 13, 1994	930
	August 24, 1992	1025								
P3	August 23, 1992	1435	January 23, 1993	1350	April 8, 1993	1540	September 1, 1993	1530	January 13, 1994	900
	August 24, 1992	1055								
P4	August 23, 1992	1510	January 23, 1993	1235	April 8, 1993	1445	September 1, 1993	1610	January 13, 1994	1035
	August 24, 1992	1120								
P5	August 24, 1992	1200	January 23, 1993	1200	April 8, 1993	0905	September 1, 1993	1650	January 13, 1994	1110
P6	August 24, 1992	1300	January 23, 1993	1120	April 7, 1993	1625	September 2, 1993	1105	January 13, 1994	1245
P7	August 24, 1992	1615	January 23, 1993	1030	April 7, 1993	1540	September 2, 1993	1150	January 13, 1994	1325
P8	August 24, 1992	1710	January 23, 1993	0935	April 7, 1993	1450	September 2, 1993	1240	January 13, 1994	1410
P9	August 25, 1992	0840	January 22, 1993	1735	April 7, 1993	1410	September 2, 1993	1010	January 13, 1994	1455
P10	August 25, 1992	0930	January 22, 1993	1700	April 7, 1993	1150	September 2, 1993	0930	January 12, 1994	1640
P11	August 25, 1992	1015	January 22, 1993	1625	April 7, 1993	1110	September 2, 1993	0900	January 12, 1994	1605
P12	August 25, 1992	1105	January 22, 1993	1545	April 7, 1993	1045	September 2, 1993	0830	January 12, 1994	1530
P13	August 25, 1992	1320	January 22, 1993	1455	April 7, 1993	1010	September 1, 1993	1225	January 12, 1994	1500
P14	August 25, 1992	1405	January 22, 1993	1415	April 7, 1993	0935	September 1, 1993	1150	January 12, 1994	1420
P15	August 25, 1992	1435	January 22, 1993	1340	April 7, 1993	0900	September 1, 1993	1120	January 12, 1994	1350
P15a	August 25, 1992	1555	January 22, 1993	1130	April 6, 1993	1645	September 1, 1993	1025	January 12, 1994	915

Table 1. Date and time of measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	June-August 1992		January-February 1993		April-May 1993		August-September 1993		January-February 1994	
	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time
Downstream from Paria River—Continued										
P15b	August 25, 1992	1620	January 22, 1993	1050	April 6, 1993	1615	September 1, 1993	0955	January 12, 1994	940
P16	August 25, 1992	1650	January 22, 1993	1020	April 6, 1993	1550	September 1, 1993	0930	January 12, 1994	1005
P17	August 25, 1992	1720	January 22, 1993	0940	April 6, 1993	1525	September 1, 1993	0900	January 12, 1994	1030
P18	August 26, 1992	0810	January 21, 1993	1645	April 6, 1993	1450	September 1, 1993	0820	January 12, 1994	1105
P19	August 26, 1992	0855	January 21, 1993	1610	April 6, 1993	1420	August 30, 1993	1740	January 12, 1994	1130
P20	August 26, 1992	0920	January 21, 1993	1540	April 6, 1993	1330	August 30, 1993	1710	January 12, 1994	1200
P21	August 26, 1992	1035	January 21, 1993	1440	April 6, 1993	1205	August 31, 1993	1715	January 11, 1994	1120
P22	August 26, 1992	1115	January 21, 1993	1400	April 6, 1993	1130	August 31, 1993	1640	January 11, 1994	1045
P23	August 26, 1992	1155	January 21, 1993	1230	April 6, 1993	1015	August 31, 1993	1605	January 11, 1994	1010
P24	August 26, 1992	1320	January 21, 1993	1155	April 6, 1993	0945	August 31, 1993	1530	January 11, 1994	935
P25	August 26, 1992	1405	January 21, 1993	1115	April 6, 1993	0910	August 31, 1993	1450	January 10, 1994	1645
P26	August 26, 1992	1440	January 21, 1993	1015	April 6, 1993	0840	August 31, 1993	1415	January 10, 1994	1605
P27	August 26, 1992	1540	January 20, 1993	1700	April 6, 1993	1800	August 31, 1993	1235	January 11, 1994	1550
P28	August 26, 1992	1620	January 20, 1993	1615	April 6, 1993	1730	August 31, 1993	1200	January 11, 1994	1515
P29	August 26, 1992	1655	January 20, 1993	1530	April 6, 1993	1650	August 31, 1993	1125	January 11, 1994	1445
P30	August 26, 1992	1730	January 20, 1993	1450	April 6, 1993	1625	August 31, 1993	1045	January 11, 1994	1415
P31	August 26, 1992	1800	January 20, 1993	1225	April 6, 1993	1555	August 31, 1993	1015	January 11, 1994	1345
P32	August 26, 1992	1850	January 20, 1993	1320	April 6, 1993	1500	August 31, 1993	0915	January 11, 1994	1305

Table 1. Date and time of measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	June-August 1992		January-February 1993		April-May 1993		August-September 1993		January-February 1994	
	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time
Downstream from Little Colorado River										
A1	June 30, 1992	1010	January 29, 1993	1100	April 22, 1993	1530	September 15, 1993	1535	January 30, 1994	1550
A2	June 30, 1992	1205	January 29, 1993	1340	April 22, 1993	1655	September 15, 1993	1615	January 30, 1994	1615
A3	June 30, 1992	0746	January 29, 1993	1435	April 23, 1993	0950	September 15, 1993	1655	January 30, 1994	1645
A4	June 30, 1992	1545	January 29, 1993	1510	April 23, 1993	1025	September 15, 1993	1730	January 30, 1994	1710
A5	July 1, 1992	0730	January 29, 1993	1620	April 23, 1993	1100	September 15, 1993	1800	January 31, 1994	0915
A6	July 1, 1992	N/A	January 31, 1993	1050	April 23, 1993	1140	September 16, 1993	1115	January 31, 1994	0955
A7	July 1, 1992	0930	January 31, 1993	1115	April 23, 1993	1210	September 16, 1993	1210	January 31, 1994	1015
B1	---	---	January 31, 1993	1150	April 23, 1993	1355	September 16, 1993	1415	January 31, 1994	1125
B1b	---	---	January 31, 1993	1225	April 23, 1993	1430	September 16, 1993	1455	January 31, 1994	1200
B2	July 5, 1992	1930	January 31, 1993	1425	April 23, 1993	1500	September 16, 1993	1535	January 31, 1994	1355
B3	July 5, 1992	N/A	January 31, 1993	1455	April 23, 1993	1555	September 16, 1993	1610	January 31, 1994	1430
B4	July 5, 1992	N/A	January 31, 1993	1530	April 23, 1993	1635	September 16, 1993	0850	January 31, 1994	1505
C1	July 6, 1992	1210	January 31, 1993	1650	April 24, 1993	0910	September 17, 1993	0830	January 31, 1994	1555
C2	July 6, 1992	N/A	January 31, 1993	1640	April 24, 1993	1000	September 17, 1993	0910	January 31, 1994	1630
C3	July 6, 1992	0950	February 1, 1993	0940	April 24, 1993	1040	September 17, 1993	1000	February 1, 1994	0950
C4	July 6, 1992	0830	February 1, 1993	1030	April 24, 1993	1130	September 17, 1993	1040	February 1, 1994	1035
C5	July 6, 1992	0720	February 1, 1993	1110	April 24, 1993	1210	September 17, 1993	1130	February 1, 1994	1110
D1	---	---	February 1, 1993	1435	April 24, 1993	1425	September 17, 1993	1635	February 1, 1994	1455
D2	---	---	February 1, 1993	1630	April 24, 1993	1510	September 17, 1993	1610	February 1, 1994	1530

Table 1. Date and time of measurements of cross sections on the Colorado River downstream from the Paria and Little Colorado Rivers—Continued

Cross-section number	June-August 1992		January-February 1993		April-May 1993		August-September 1993		January-February 1994	
	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time	Measurement date	Mean time
Downstream from Little Colorado River—Continued										
D3	---	---	February 1, 1993	1525	April 24, 1993	1535	September 17, 1993	1540	February 1, 1994	1555
D4	---	---	February 1, 1993	1545	April 24, 1993	1600	September 17, 1993	1505	February 2, 1994	1015
D5	---	---	February 1, 1993	1605	April 24, 1993	1625	September 17, 1993	0715	February 2, 1994	1045
E1	---	---	February 2, 1993	1255	April 25, 1993	0945	September 18, 1993	0910	February 2, 1994	1135
E2	---	---	February 2, 1993	1350	April 25, 1993	1015	September 18, 1993	1000	February 2, 1994	1200
E3	---	---	February 2, 1993	1340	April 25, 1993	1040	September 18, 1993	1030	February 2, 1994	1310
E4	---	---	February 2, 1993	1500	April 25, 1993	1110	September 18, 1993	1100	February 2, 1994	1335
E5	---	---	February 2, 1993	1425	April 25, 1993	1140	September 18, 1993	1130	February 2, 1994	1405
F1	---	---	February 5, 1993	1010	April 25, 1993	1335	September 18, 1993	1305	February 2, 1994	1520
F2	---	---	February 5, 1993	1035	April 25, 1993	1410	September 18, 1993	1330	February 2, 1994	1600
F3	---	---	February 5, 1993	1100	April 25, 1993	1450	September 18, 1993	0700	February 3, 1994	0930
F4	---	---	February 5, 1993	1120	April 25, 1993	1520	September 18, 1993	1445	February 3, 1994	1005
F5	---	---	February 5, 1993	1145	April 25, 1993	1550	September 18, 1993	1530	February 3, 1994	1040

Table 2. Locations of end points of cross sections in the monitoring network

[Locations are given in Arizona State Plane coordinates, in meters. N/A, not applicable]

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 Paria River									
P1	649421.71	241309.53	649493.209	241204.481	P16	646230.628	239253.002	646284.032	239153.261
P2	649380.591	241280.119	649466.589	241168.705	P17	646187.415	239219.802	646230.424	239120.081
P3	649335.301	241261.843	649425.257	241133.542	P18	646104.244	239188.589	646154.399	239074.442
P4	649283.886	241234.175	649402.747	241100.635	P19	645780.835	239089.840	645814.987	238986.426
P5	649237.488	241215.875	649321.906	241036.078	P20	645431.964	238958.288	645461.709	238875.696
P6	649179.977	241192.434	649277.348	241016.707	P21	643296.485	237790.557	643277.102	237632.151
P7	649080.790	241152.666	649171.155	240954.877	P22	643234.794	237806.510	643215.286	237643.602
P8	649027.167	241106.726	649137.219	240946.046	P23	643182.991	237813.392	643175.770	237660.987
P9	648774.323	240555.163	648942.263	240553.839	P24	643135.520	237808.735	643127.566	237670.792
P10	648763.725	240432.510	648927.457	240410.277	P25	643063.316	237804.450	643052.034	237681.605
P11	648743.239	240342.126	648893.279	240293.536	P26	643017.958	237814.630	642999.995	237696.974
P12	648634.525	240230.339	648719.642	240114.490	P27	640799.854	237102.781	640923.283	236997.332
P13	647985.852	240131.880	647989.415	239990.736	P28	640755.612	237051.097	640887.678	236952.326
P14	647902.425	240115.357	647911.291	239987.528	P29	640716.580	236987.571	640840.631	236893.609
P15	647789.331	240107.709	647789.067	239993.697	P30	640689.096	236933.789	640816.181	236845.330
P15a	646350.036	239301.019	646402.223	239208.870	P31	640654.765	236885.466	640788.941	236798.253
P15b	646288.099	239267.437	646329.925	239179.359	P32	640591.105	236811.021	640723.202	236711.593
Downstream from Little Colorado River									
A1	575489.052	223110.238	575413.247	223226.890	D1	571165.292	222357.384	571133.453	222504.873
A2	575431.436	223070.898	575356.797	223186.744	D2	571114.650	222361.320	571092.277	222491.986
A3	575386.219	223023.247	575315.021	223117.898	D3	571071.349	222365.034	571050.825	222479.385
A4	575334.984	222988.594	575265.874	223078.956	D4	570999.956	222353.105	570972.711	222457.824
A5	575257.394	222899.836	575175.859	222978.077	D5	570903.067	222331.361	570912.548	222445.903
A6	575000.000	222850.000	575072.719	222755.582	E1	569628.213	222234.312	569614.854	222387.155
A7	575013.292	222728.468	574949.054	222828.679	E2	569576.077	222234.258	569542.172	222372.521
B1	574643.169	222518.501	574376.429	222651.019	E3	569521.855	222203.010	569488.478	222358.993
B2	574376.429	222518.345	574352.997	222640.523	E4	569453.335	222195.857	569423.131	222343.513
B3	574333.196	222467.612	574314.227	222659.991	E5	569394.322	222177.593	569368.722	222336.154
B4	574251.976	222452.202	574270.963	222656.615	F1	565963.358	221181.066	565854.179	221189.694
C1	573716.585	222584.749	573759.474	222754.260	F2	565968.694	221167.530	565847.291	221091.968
C2	573646.924	222572.011	573685.284	222769.399	F3	565996.554	221166.167	565928.158	221039.382
C3	573583.307	222594.767	573649.772	222779.721	F4	566045.500	221125.054	565957.922	221020.148
C4	573535.706	222614.292	573587.353	222799.046	F5	566075.216	221095.960	565993.211	221006.899
C5	573487.698	222639.238	573547.034	222804.374					

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.

A measurement consists of 10 consecutive passes across the river under the line. Because depth differences over short distances are typically large, a significant variation in measured depth at any position along the line was observed even with the use of a fixed line and with every effort to keep the boat under the line. The 10 passes were made to characterize the variability and define the mean section as precisely as possible. 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. Measurement of one cross section typically took from 10 to 30 minutes depending on the length of the section.

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 before and after each series of 10 passes that make up a measurement or series of measurements in the same pool. 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). A portable stage gage was installed at each reference point to automatically record stage during most 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 GCES coordinate system were determined by field surveys.

Data Processing

The graphical record of each pass was digitized using a digitizer mode that recorded a point at a preset distance of cursor movement across the paper. The interval between digitized points per unit of paper was kept constant and was

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				
A5, right bank	575257.394	222899.836	829.54	A1–A7
B2, left bank	574352.997	222640.523	828.41	B1–B4
C3, right bank	574105.914	222186.177	827.91	C1–C5
D5, left bank	570912.548	222445.903	822.16	D1–D5
E3, right bank	569521.855	222203.010	820.32	E1–E5
F1, left bank	565854.179	221189.694	813.63	F1–F5

selected to give about 2 digitized points for each ground foot of distance. The ground distance between the digitized points varied with the ground distance covered per unit of paper. The speed of movement of the paper chart during recording was held constant at the fastest possible rate; therefore, the ground distance covered by a unit of chart paper varied with boat speed. Once the data were digitized, the distance of each point from the left bank end point 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, points were selected or interpolated at 0.25-meter intervals across the channel.

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 or estimated for the time and location of the cross-section measurement (table 4). The method of determining the water-surface elevation depended on the type of data available.

Measurements of water-surface elevation were used to convert the depth data for those survey dates on which water-surface elevation was directly obtained by measuring the distance from the reference point to the water surface. Water-surface elevation typically was measured before and after all 10 passes at a section. The water-surface elevation measured at the reference point was applied to all sections within the same reach (table 3).

For some survey dates, data from the portable stage gage were used to give water-surface elevation for the time of each cross-section measurement. In these cases, a measured distance from the reference point to the water surface and the measured depth of water over the transducer were used to determine the elevation of the transducer, and the water-surface elevation for the time of the survey was computed by adding the measured depth of water over the transducer measured by the gage to the elevation of the transducer.

For the measurements of June 1992 downstream from the Little Colorado River, water-surface elevation for each cross section was determined from data from a bathymetric survey made at the same time. Elevations for the bathymetric survey were computed by matching bathymetric data points to points of known elevation from GCES topographic surveys. The water-surface elevation for each measured cross section was adjusted until a best fit by eye was achieved between the measured cross-section profile and a cross-section profile determined for the same section from the bathymetry.

Stage record is available for the measurements made downstream from the Little Colorado River in January 1993 and for sections F1–F5 in April 1993, and downstream from the Paria River in August 1992 and January 1993; however, no direct measurements of water-surface elevation were made. For those measurements, a relation between water-surface elevation and discharge was developed at each reference point using water-surface elevation data from other dates and a discharge computed using a one-dimensional discharge-routing model developed for the river (S.M. Wiele and J.D. Smith, hydrologists, U.S. Geological Survey, written commun., 1995).

For the reaches downstream from the Little Colorado River in which the A, C, and E series of cross sections are located, the relation that was developed exhibited a pronounced hysteresis that was related to the rising and falling limbs of the daily hydrograph. The hysteresis was not observed for the F reach, perhaps because the data available to define the relation were sparse. For reaches A, C, and E, a second-order polynomial was fit to each limb of the relation, and the equation for the appropriate limb was used to compute a water-surface elevation for the discharge computed by the model for the time of the cross-section measurement. The hysteresis was less pronounced for the D and F series cross sections downstream from the Little Colorado River and for all locations downstream from the Paria River. For these sections, least-squares linear regression was used to determine the relation between water-surface elevation and discharge. Water-surface elevation computed from the relation for the model-computed discharge for the time of each

Table 4. Water-surface elevations used to convert measured depths to bed elevations

[Water-surface elevations are in meters. Computed by direct measurement except as noted. Water-surface elevations computed for June 1992 and January 1993, and sections F1–F5 measured in April 1993 are considered to be less precise than the others and therefore are shown with fewer significant figures. N/A, not applicable]

Sections	Measurement date				
	June 1992	January 1993	April 1993	September 1993	January 1994
Sections downstream from Paria River					
P1–P15	[1,2]943.79	[1,2]944.80	943.31	943.27	944.23
P15a–P21..............	[2]943.15	[2]942.72	941.53	941.59	942.09
P22–P26	[2]941.06	[2]941.21	939.26	939.79	940.24
P27–P32	[2]941.11	[2]941.11	939.95	939.86	940.04
Sections downstream from Little Colorado River					
A1–A7	[3]825.0	[2]825.1	824.54	825.03	824.94
B1–B4	[3]822.8	[4]823.7	[4]823.43	823.95	823.48
C1–C5	[3]821.8	[2]823.5	823.16	822.84	823.04
D1–D5	N/A	[2]819.6	818.82	819.25	819.41
E1–E5	N/A	[2]816.9	816.38	816.62	816.89
F1–F5	N/A	[2]810.1	[2]809.7	810.03	810.07

[1]Stage gage located at section P9. For other dates it was located at P5.
[2]Water-surface elevation adjustment computed from water-surface elevation-discharge relations.
[3]Water-surface elevation adjustment computed by matching cross section to bathymetric data.
[4]Water-surface elevation adjustment computed from the average-elevation value for given discharge.

measurement was used to adjust the data. The water-surface elevation data for the reach downstream from the Little Colorado River that contains sections B1–B4 had a less systematic relation to discharge than the other reaches. Water-surface elevation for a given discharge was computed as the average of the lowest and highest measured water-surface elevations for that discharge for those sections.

Statistical Analysis

The number of values; the mean, median, and maximum and minimum bed elevation; and standard deviation from the mean bed elevation were computed for each distance from the left-bank end point from the 10 passes that define a measurement. The results are the measurement made at the mean time of all 10 passes (fig. 8). Because the entire cross section was not always recorded, not all distances 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

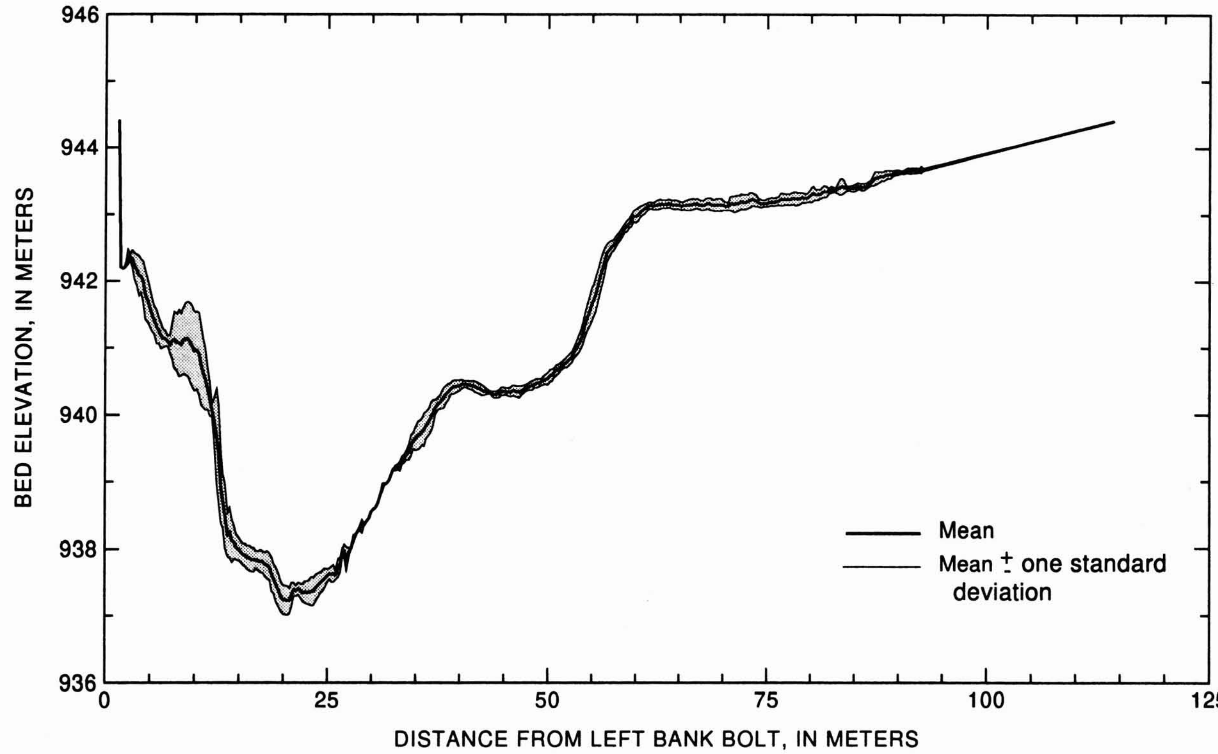

Figure 8. Example of a mean cross section and standard deviation from the mean computed from the 10 passes that define a measurement.

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 number of values in 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 one or more of the sample numbers was 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 samples for which the number of values for either sample in the tested pair was equal to or less than two. 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. For example, if the *p* value is 0.01, the null hypothesis is rejected with a 1-percent probability of its being true. *P* values varied considerably within a given cross section (fig. 9) and from section to section.

PRESENTATION OF THE DATA

Data are presented graphically in figures 10–74 and are available as two types of tab-delimited ASCII electronic files. The first file type, the data files, contains the 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 (table 2) 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 5). The second file type, statistical files, are named for

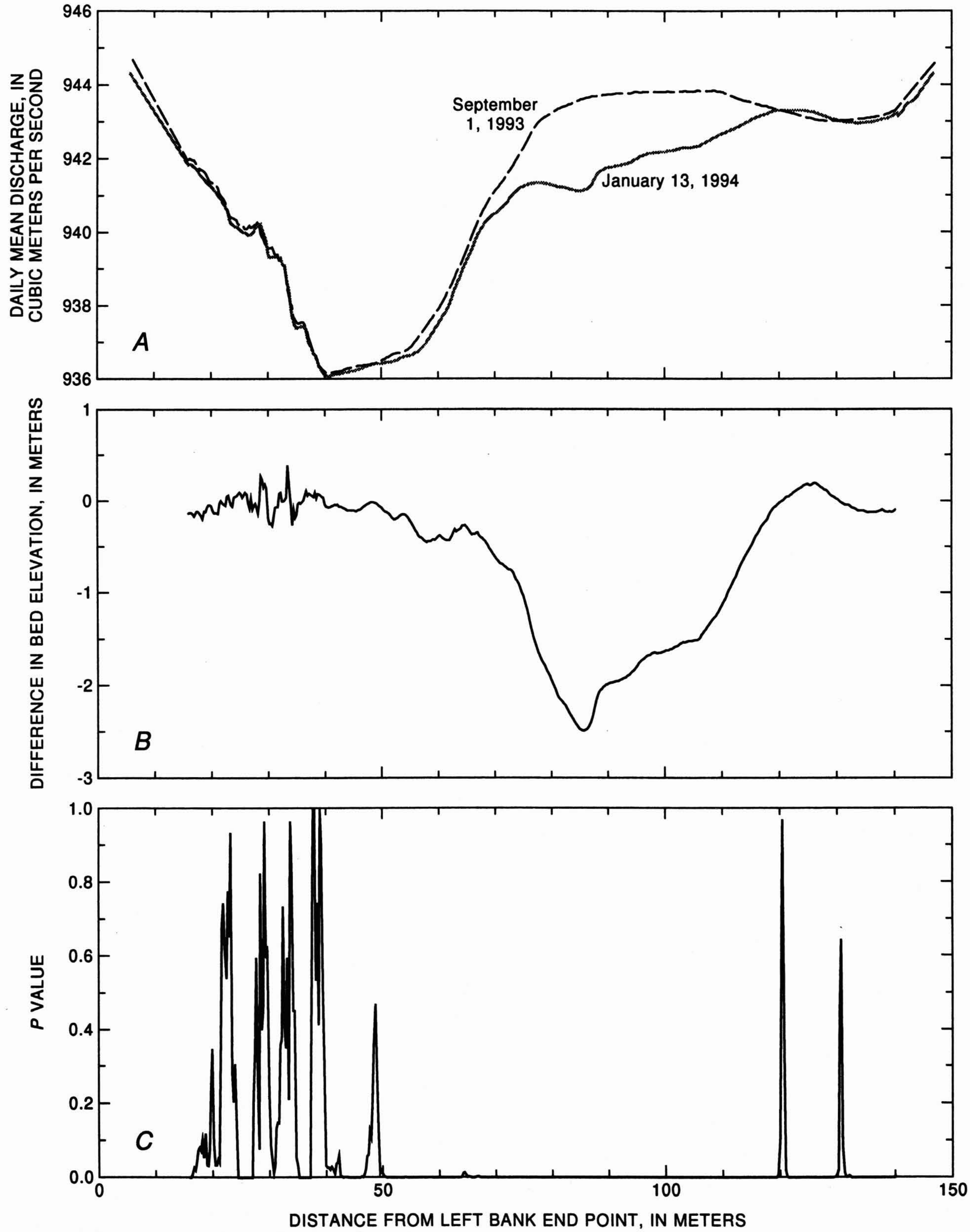

Figure 9. Example of the comparison of two successive cross-section measurements using cross section P3, September 1, 1993, and January 13, 1994. *A*, Measured bed elevations for the two dates. *B*, Difference between the measured bed elevations on the two dates. *C*, *P* value computed from the Wilcoxon rank-sum test.

Table 5. 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 reference 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

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 6). Readers who would like to obtain the electronic data should contact the District Chief, U.S. Geological Survey, WRD, 375 S. Euclid Avenue, Tucson, AZ 85719-6644. The mean cross section for each measurement date is shown graphically in figures 10–43 for the cross sections downstream from the Paria River and in figures 44–74 for cross sections downstream from the Little Colorado River and are presented at the back of this report.

SAND-STORAGE CHANGES

Changes in area between successive measurements at each cross section were computed to illustrate the changes in cross sections documented by the measurements (tables 7 and 8). 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. 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 was then computed by summing the area differences for the incremental distances. 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 these 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 7 and 8.

Sections were first measured downstream from the Paria River in August 1992. A flood of moderate size—recurrence interval of the peak discharge of about 2 years—occurred on the Paria River on August 23, 1992 (fig. 6), after measurement of the first four sections. The measurements on these sections were repeated the following day to document changes caused by sand contributed by this flood. A flood of moderate peak discharge but of long duration occurred on the Little Colorado River in late January and early February 1993 (fig. 7). A flood of the volume of that flood has a recurrence interval of about 50 years. Measurements made at cross sections A1–C5 in late January and early February 1993 document changes caused largely by sand contributed by that flood.

Sand was deposited as a result of the Paria River flood of August 23, 1992, at all four cross sections measured before and after the flood (table 8 and figs. 10–13). All four sections, however, contained less sediment when measured in January 1993 than before the August flood (figs. 10–13). From August 24, 1992, to January 1994, 24 of the 34 cross sections downstream from the Paria River had a net loss of sand (table 8). All sections downstream from the Little Colorado River measured before and after the flood of January 1993 showed deposition (table 8 and figs. 44–59). Unlike the sections downstream from the Paria River, however, 14 of the 15 sections downstream from the Little Colorado River that were first measured in the summer of 1992 contained more sand in the winter of 1994 than they had when they were first measured (table 8 and figs. 44–59).

Table 6 Example of a statistical file

[Data from cross section 1a1. 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—				

Table 7. Changes in area at monumented cross section, June 1992 to February 1994

[Area changes were computed using a p value of 0.05 to select significant differences in bed elevation. Positive differences indicate deposition during the indicated period. The periods are defined by successive dates at each section (table 1). For sections P1–P4, period 1 begins on August 24, 1992, and net-change values do not include the material deposited during the flood of August 23. Net change is not given for sections D1–D5, E1–E5, and F1–F5 downstream from the Little Colorado River because these sections were not measured in the summer of 1992. The fraction of section tested is given by number of distance values for which the test was applied divided by the number of distance values for which at least one depth was measured. The fraction of tested section with significant changes is given by the number of distance values passing the test divided by the number of distance values tested. Dashes indicate no data]

Cross-section number	Period 1 Summer 1992 to winter 1992			Period 2 Winter 1992 to spring 1993			Period 3 Spring 1993 to fall 1993			Period 4 Fall 1993 to winter 1994			Period 1 to period 4
	Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Net-area change, in square meters
		Significant	Tested		Significant	Tested		Significant	Tested		Significant	Tested	
Downstream from Paria River													
P1	–22.2	1.00	0.64	36.6	0.93	0.82	–47.2	0.97	0.83	4.6	0.98	0.83	–28.2
P2	–39.6	.99	.79	49.5	.99	.88	–42.4	.99	.92	–2.3	.92	.94	–34.8
P3	–117.6	1.00	.80	52.0	.99	.71	–58.9	.94	.82	–79.3	.97	.96	–203.8
P4	–257.4	1.00	.90	63.8	.97	.97	2.8	.99	.95	–35.3	.99	.95	–208.1
P5	–417.0	1.00	.94	137.6	.95	.93	–66.2	.88	.92	62.1	.90	.97	–283.5
P6	–161.6	1.00	.99	241.4	1.00	.96	–136.8	.99	.97	6.7	.93	.96	3.7
P7	–263.0	1.00	.78	95.4	1.00	.93	–39.9	1.00	.95	–33.0	1.00	.80	–24.5
P8	–161.6	1.00	.99	3.8	.98	.90	3.7	1.00	.89	–19.5	.73	.98	–146.6
P9	–64.3	1.00	.91	33.4	1.00	.94	–18.5	.92	.96	–23.3	.87	.89	–72.7
P10	–12.6	1.00	.92	33.4	.92	.94	–28.8	.88	.96	–23.8	.92	.97	–139.8
P11	–123.6	.97	.88	45.1	.83	.88	–49.0	.94	.97	–11.1	.79	.91	–138.6
P12	–39.8	.97	.91	43.2	1.00	.85	–38.0	.92	.95	9.9	.13	.86	–24.7
P13	134.9	.87	.96	35.2	.92	.93	–185.7	.96	.92	–5.9	.81	.93	–21.5
P14	51.2	.96	.87	33.7	.98	.84	–113.1	.99	.91	45.4	.96	.91	17.2
P15	8.0	.99	.97	39.8	.97	.95	–95.9	1.00	.94	31.3	.99	.98	–16.8
P15a	7.8	.81	.95	68.6	.99	.88	–51.9	.97	.90	16.4	.85	.96	4.9
P15b	–64.1	1.00	.90	78.2	.99	.93	–42.5	1.00	.87	–5.2	.94	.95	–33.6
P16	–13.9	.95	.87	78.5	1.00	.90	–48.2	.96	.93	–24.5	.99	.90	–8.1

Table 7. Changes in area at monumented cross section, June 1992 to February 1994—Continued

Cross-section number	Period 1 Summer 1992 to winter 1992			Period 2 Winter 1992 to spring 1993			Period 3 Spring 1993 to fall 1993			Period 4 Fall 1993 to winter 1994			Period 1 to period 4
	Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Net area change, in square meters
		Significant	Tested		Significant	Tested		Significant	Tested		Significant	Tested	
Downstream from Paria River—Continued													
P17	–2.6	0.98	0.84	–6.1	1.00	0.98	–1.5	0.98	0.97	33.8	0.78	0.95	5.6
P18	–5.1	.98	.92	76.5	1.00	.98	–41.5	.98	.99	7.5	.9	.98	37.4
P19	–62.4	1.00	.95	57.9	.82	.95	–111.8	.96	.93	85.8	.73	.95	–3.5
P20	–108.4	.80	.94	68.3	.99	.94	–113.7	.99	.96	7.0	.94	.98	–146.8
P21	–63.2	.97	.98	–16.0	.81	.97	75.3	.90	.97	32.3	.86	.98	28.4
P22	–75.0	.94	.77	–48.7	.84	.87	104.9	.85	.68	–3.6	.96	.68	–22.4
P23	15.0	1.00	.94	–51.9	1.00	.93	18.1	1.00	.88	3.2	1.00	.96	11.4
P24	2.6	.97	.91	–37.0	1.00	.99	13.8	.97	.96	37.5	.99	.97	16.9
P25	32.9	.99	.84	–3.8	.70	.94	–27.0	.87	.93	2.6	.87	.95	4.7
P26	9.6	.91	.95	–.1	.67	.97	–17.3	.96	.99	–3.2	.58	.96	–11
P27	5.7	.70	.95	9.2	.65	.97	–15.1	.78	.99	–2.1	.66	.93	–2.3
P28	2.3	.95	.92	3.8	.45	.97	–24.7	.85	.96	–1.3	.58	.93	–19.9
P29	–18.7	.93	.92	18.9	.83	.92	–25.0	.82	.94	6.1	.80	.94	–18.7
P30	–21.7	1.00	.87	28.9	.95	.85	–25.2	.87	.96	18.2	.92	.91	.2
P31	–22.2	1.00	.64	36.6	.93	.82	–47.2	.97	.83	4.6	.98	.83	–28.2
P32	–39.6	.99	.79	49.5	.99	.88	–42.4	.99	.92	–2.3	.92	.94	–34.8
Downstream from Little Colorado River													
A1	578.6	1.00	.75	–46.3	.98	.82	–33.4	.98	.74	–12.5	.73	.94	486.4
A2	135.4	1.00	.78	73.2	1.00	.71	11.7	.92	.78	–4.8	.75	.98	215.5
A3	3.2	1.00	.96	–47.0	.98	.91	73.7	1.00	.91	–18.4	.98	.98	11.5
A4	41.2	.82	.96	–25.7	.97	.95	55.6	1.00	.98	–3.5	.66	.94	67.6
A5	43.2	1.00	.89	–46.3	1.00	.89	48.3	1.00	.89	–14.1	.93	.94	31.1
A6	432.5	1.00	.85	–3.3	.99	.42	–19.5	.98	.73	–.3	.89	.65	382.4
A7	328.6	1.00	.54	–41.6	.96	.93	32.1	1.00	.94	1.3	.91	.92	32.4

Table 7. Changes in area at monumented cross section, June 1992 to February 1994—Continued

Cross-section number	Period 1 Summer 1992 to winter 1992			Period 2 Winter 1992 to spring 1993			Period 3 Spring 1993 to fall 1993			Period 4 Fall 1993 to winter 1994			Period 1 to period 4
	Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Area change, in square meters	Fraction		Net area change, in square meters
		Significant	Tested		Significant	Tested		Significant	Tested		Significant	Tested	
Downstream from Little Colorado River—Continued													
B1	---	---	---	134.3	1.00	0.37	–216.4	1.00	0.51	–134.3	0.99	0.97	–216.4
B2	56.6	.94	.64	–2.5	.86	.78	–2.9	.98	.84	–53.3	.99	.79	–2.1
B3	237.7	1.00	.68	–68.7	1.00	.90	–37.3	.96	.91	–56.5	.95	.94	75.2
B4	242.9	1.00	.88	–25.1	.97	.92	74.0	.96	.92	–87.6	1.00	.96	204.2
C1	561.9	1.00	.44	–5.4	.98	.90	–263.6	1.00	.62	79.1	.95	.97	327
C2	787.3	1.00	.51	–1.6	.99	.89	–261.1	1.00	.77	21.8	.94	.91	537.4
C3	51.8	1.00	.67	–1.2	.93	.89	–8.7	1.00	.88	–28.1	.94	.95	391.8
C4	294.0	1.00	.65	–16.9	.94	.93	–85.4	1.00	.91	–33.1	.99	.98	158.6
C5	247.5	1.00	.89	–36.9	.90	.93	–7.3	1.00	.91	–43.1	1.00	.93	97.2
D1	---	---	---	4.6	.94	.67	2.1	.93	.82	–32.3	.94	.88	---
D2	---	---	---	1.0	.75	.56	3.4	.55	.89	–15.2	.93	.90	---
D3	---	---	---	–19.4	.47	.74	–27.4	.64	.88	–18.9	.97	.96	---
D4	---	---	---	–27.5	.96	.95	–16.5	.94	.97	–18.2	.93	.92	---
D5	---	---	---	–45.4	.85	.95	–31.2	.97	.95	–28.6	.99	.95	---
E1	---	---	---	9.5	.95	.78	–22.5	.53	.53	14.0	.95	.96	---
E2	---	---	---	33.2	.98	.94	–8.9	.92	.80	8.6	.80	.88	---
E3	---	---	---	–9.5	.97	.96	–16.7	.94	.93	17.2	.95	.95	---
E4	---	---	---	–2.6	.92	.94	–15.1	.88	.98	21.7	1.00	.94	---
E5	---	---	---	–3.4	.98	.94	–12.4	.99	.94	23.0	.98	.97	---
F1	---	---	---	89.6	.99	.94	–71.3	1.00	.90	24.7	.98	.96	---
F2	---	---	---	55.7	.99	.93	–76.3	.98	.92	37.0	.98	.96	---
F3	---	---	---	46.2	.99	.86	–73.0	1.00	.75	28.0	.87	.77	---
F4	---	---	---	17.0	.95	.90	–53.5	.99	.73	–15.7	.99	.76	---
F5	---	---	---	–5.5	.87	.80	–57.8	1.00	.87	22.3	.92	.91	---

Table 8. Changes in area at cross sections P—P4 as a result of the flood of August 23, 1992, Paria River

[A *p* value of 0.05 was used to determine significant changes in bed elevation. All tested values had significant changes. Positive area changes indicate deposition between August 23 and August 24]

Cross-section number	Area change, in square meters	Fraction of section tested	Cross-section number	Area change, in square meters	Fraction of section tested
P1	23.9	0.72	P3	139	0.92
P2	53.5	.90	P4	187	.88

REFERENCES CITED

Devore, J.L., 1991, Probability and statistics for engineering and the sciences, 3rd ed.: Pacific Grove, California, Brooks/Cole Publishing Company, 716 p.

Werth, L.F., Wright, P.J., Pucherelli, M.J., Wegner, D.L., and Kimberling, D.N., 1993, Developing a geographic information system for resources monitoring on the Colorado River in the Grand Canyon: Denver Colorado, Bureau of Reclamation Report R–93–20, 46 p.

BASIC DATA

Figures 10-74

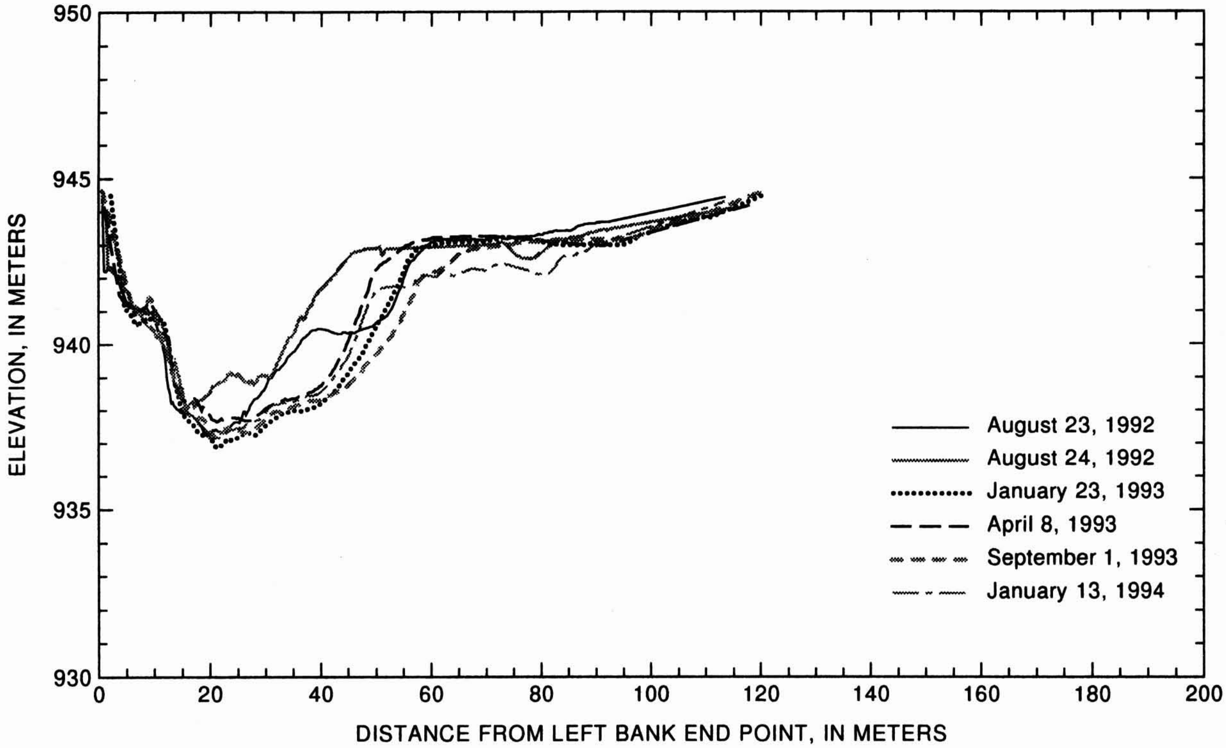

Figure 10. Cross sections measured downstream from the Paria River at monumented section P1.

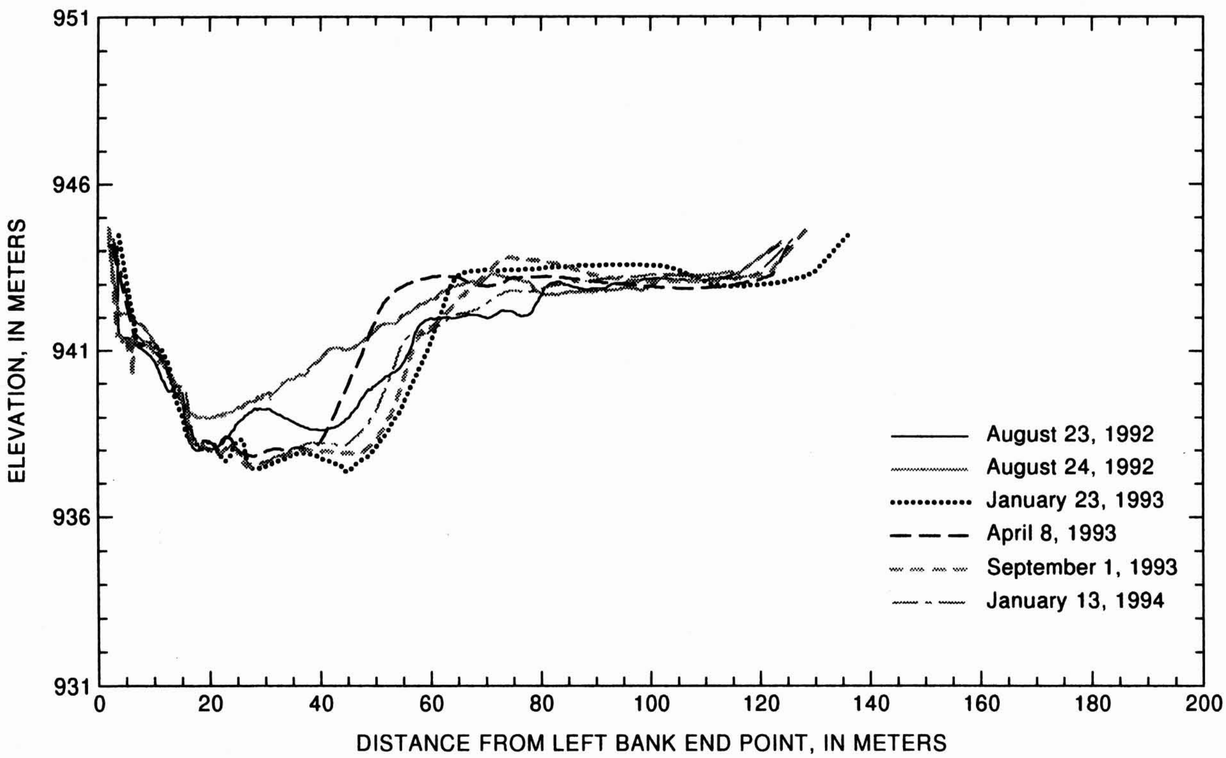

Figure 11. Cross sections measured downstream from the Paria River at monumented section P2.

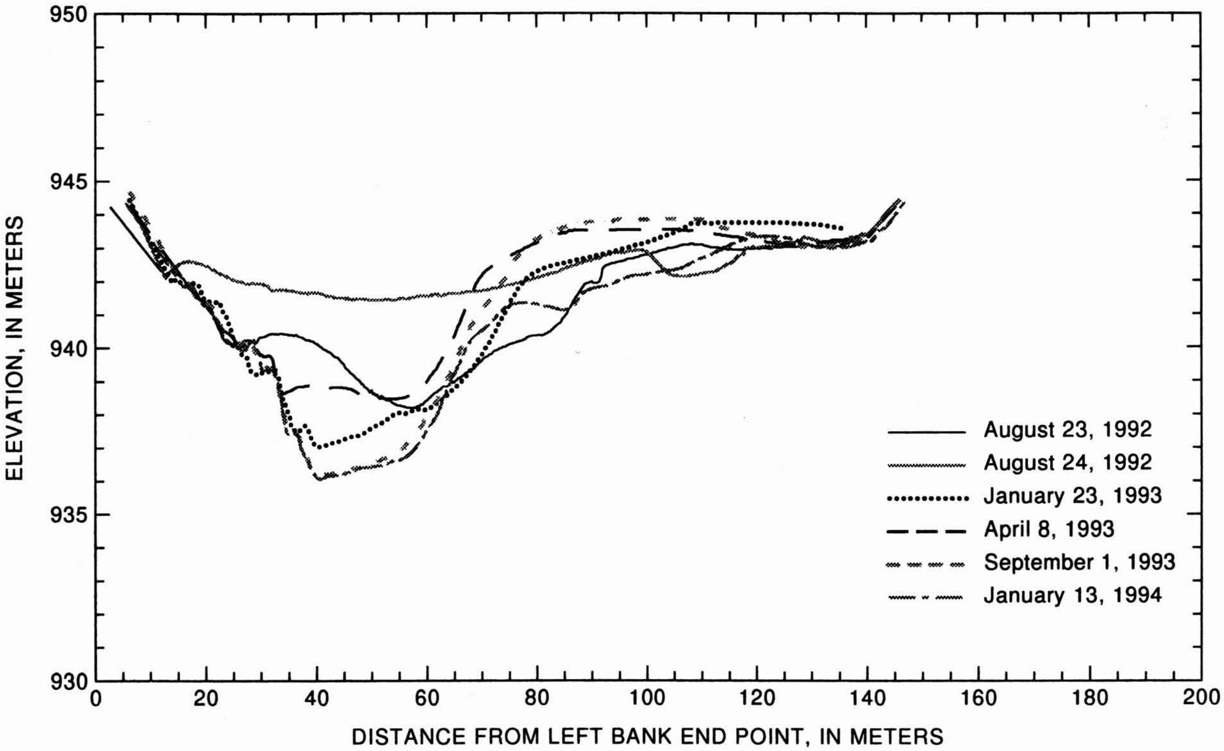

Figure 12. Cross sections measured downstream from the Paria River at monumented section P3.

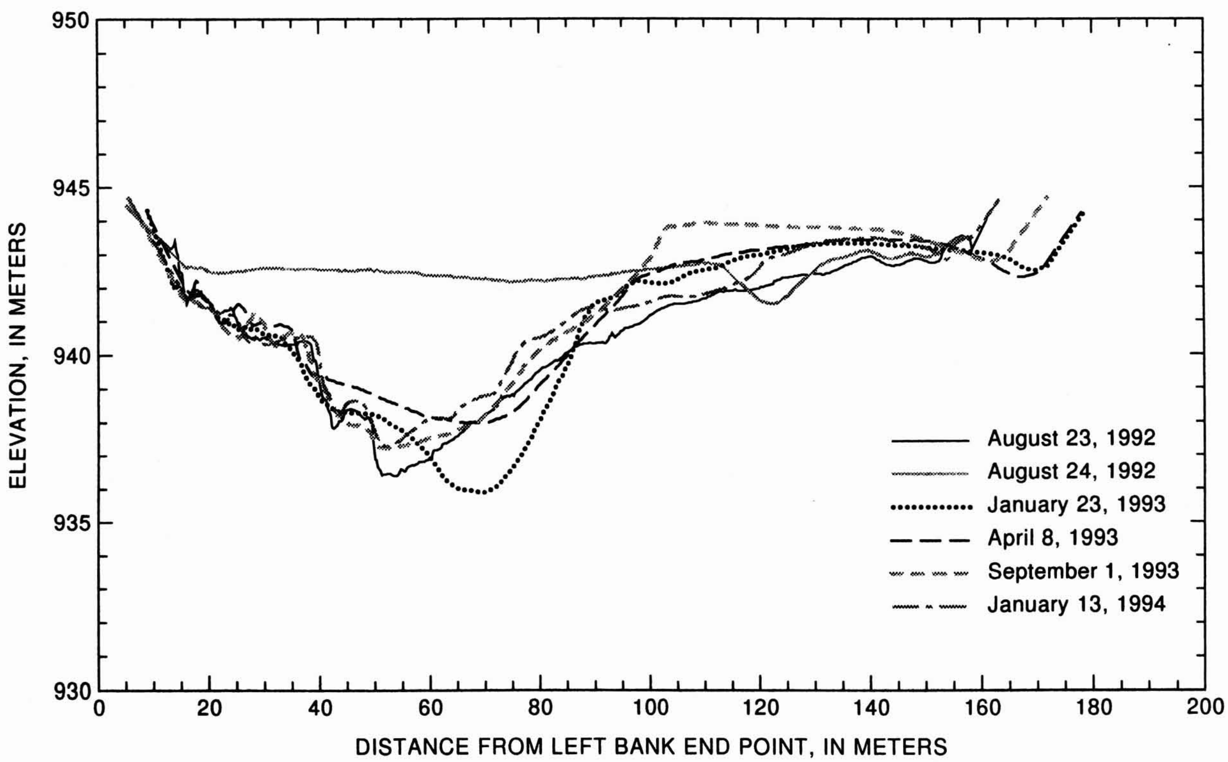

Figure 13. Cross sections measured downstream from the Paria River at monumented section P4.

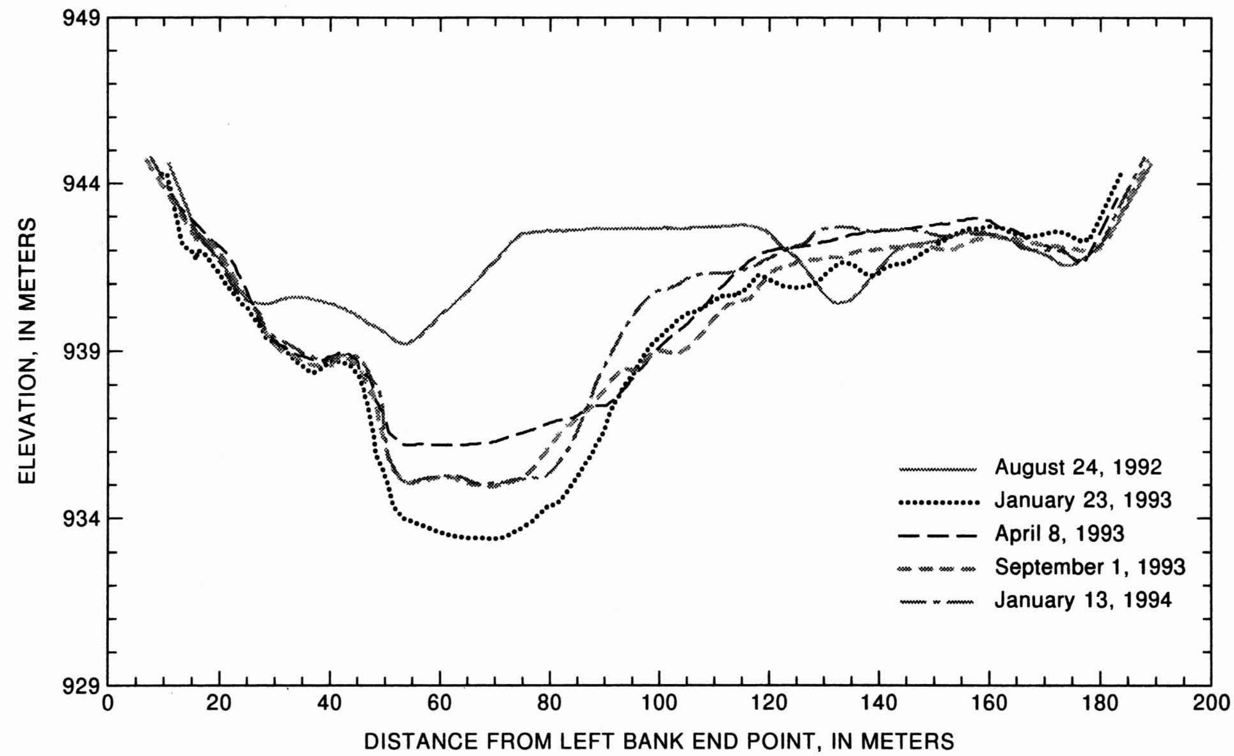

Figure 14. Cross sections measured downstream from the Paria River at monumented section P5.

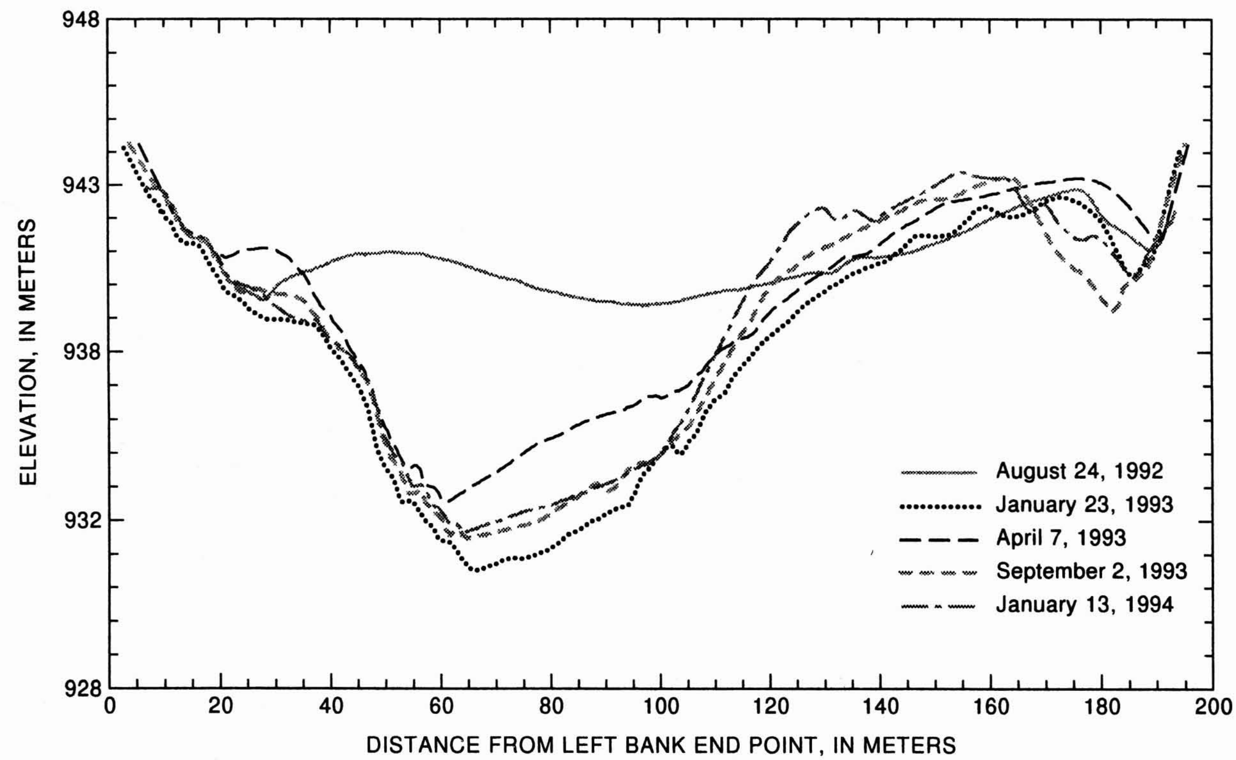

Figure 15. Cross sections measured downstream from the Paria River at monumented section P6.

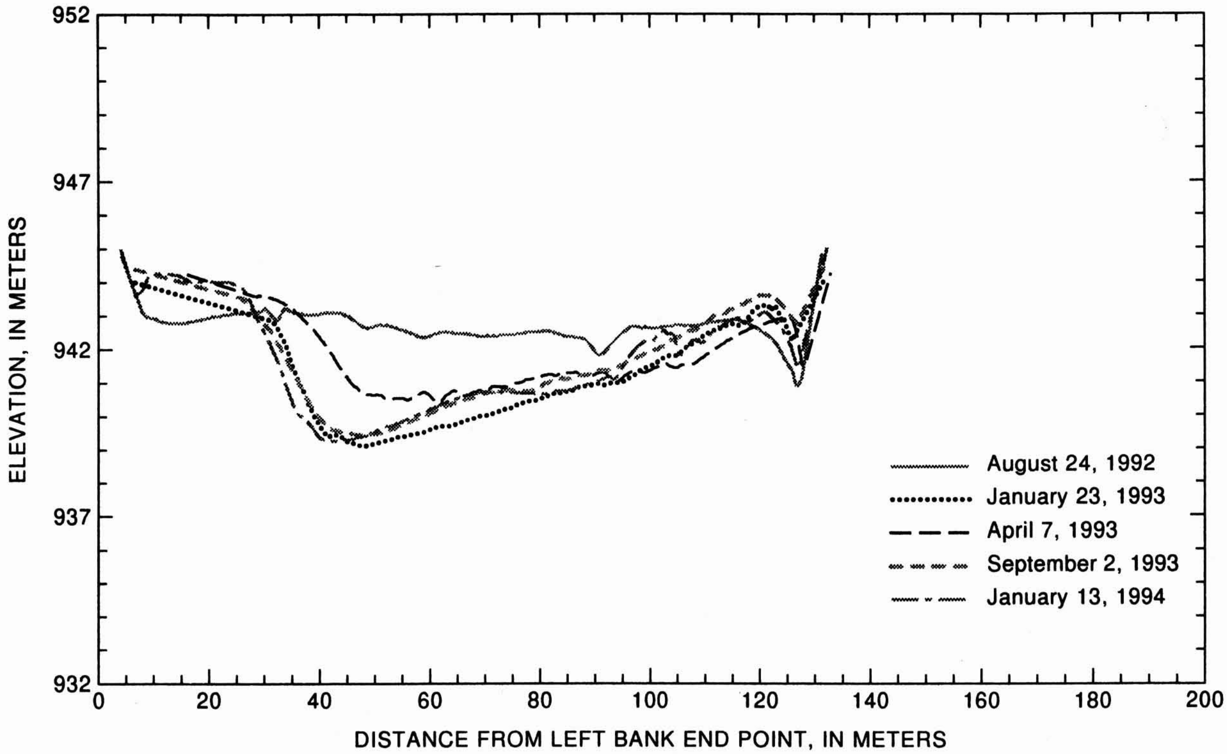

Figure 16. Cross sections measured downstream from the Paria River at monumented section P7.

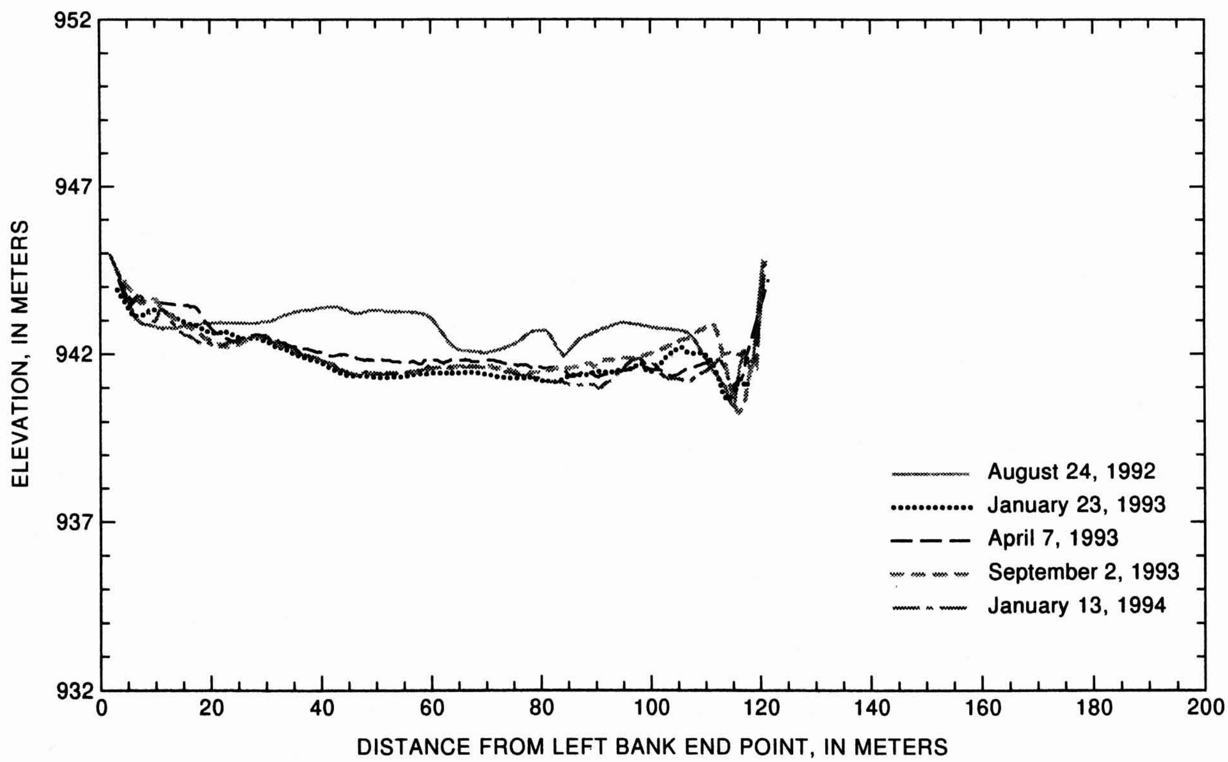

Figure 17. Cross sections measured downstream from the Paria River at monumented section P8.

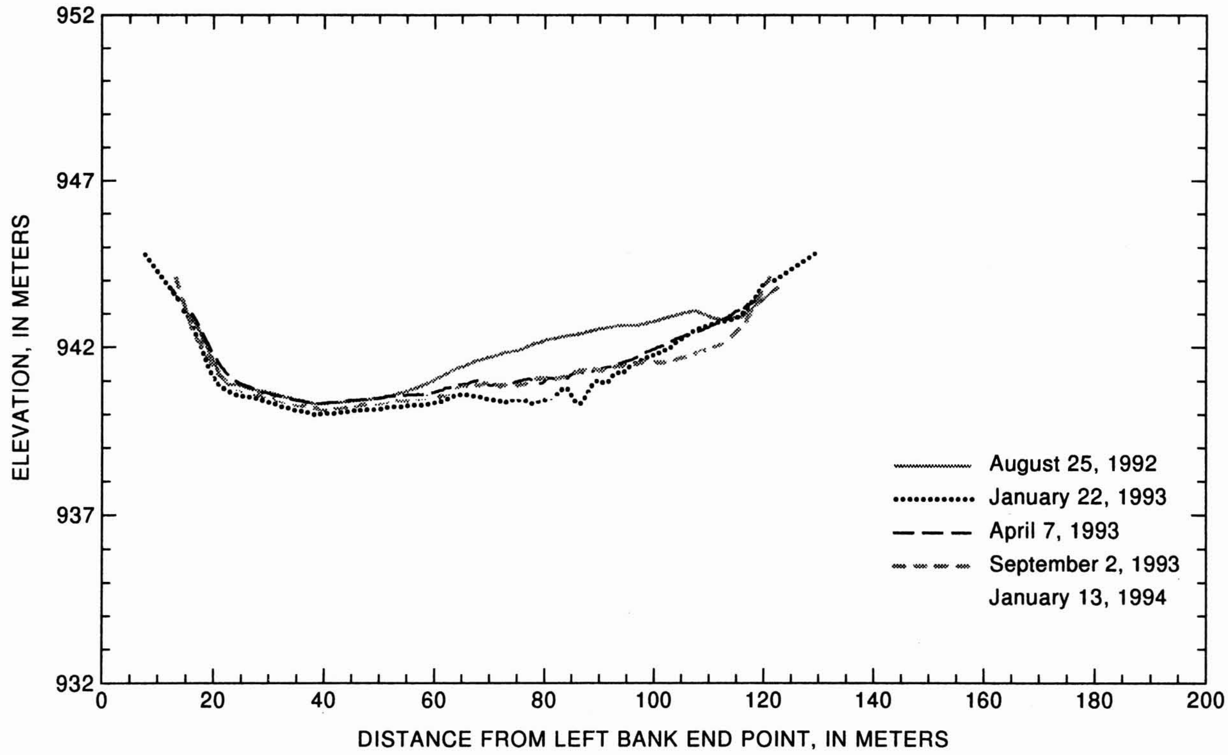

Figure 18. Cross sections measured downstream from the Paria River at monumented section P9.

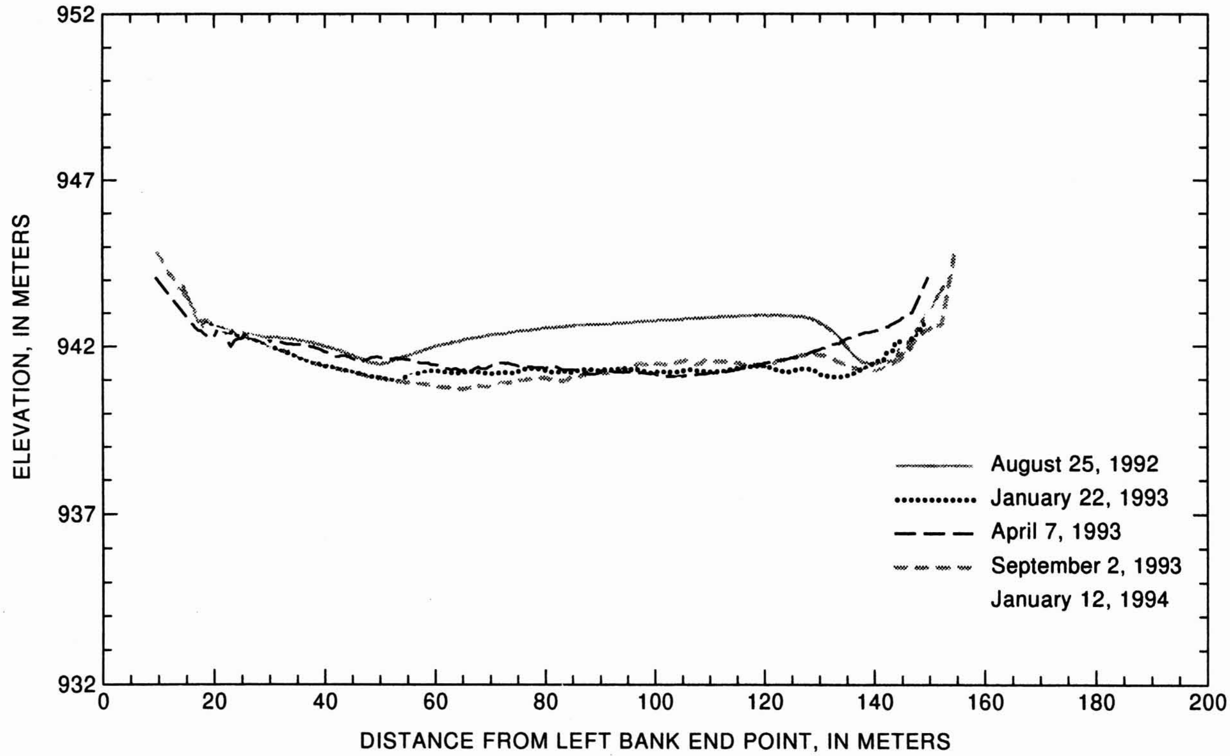

Figure 19. Cross sections measured downstream from the Paria River at monumented section P10.

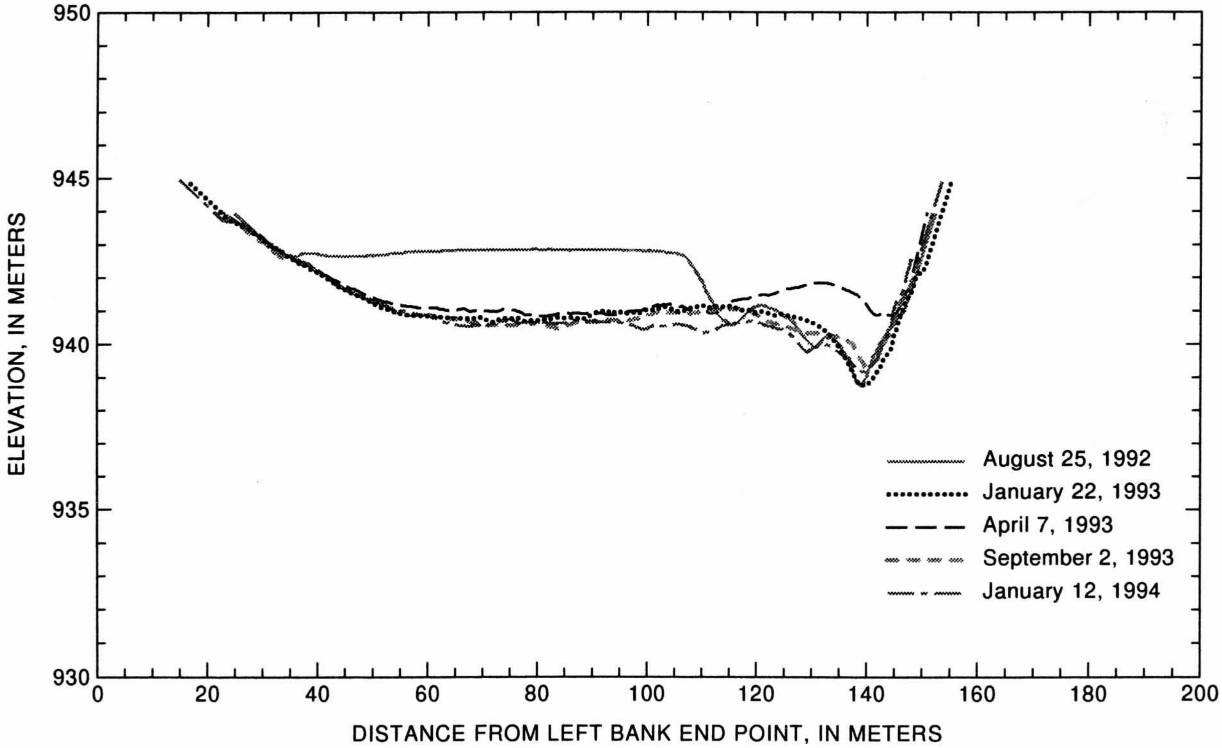

Figure 20. Cross sections measured downstream from the Paria River at monumented section P11.

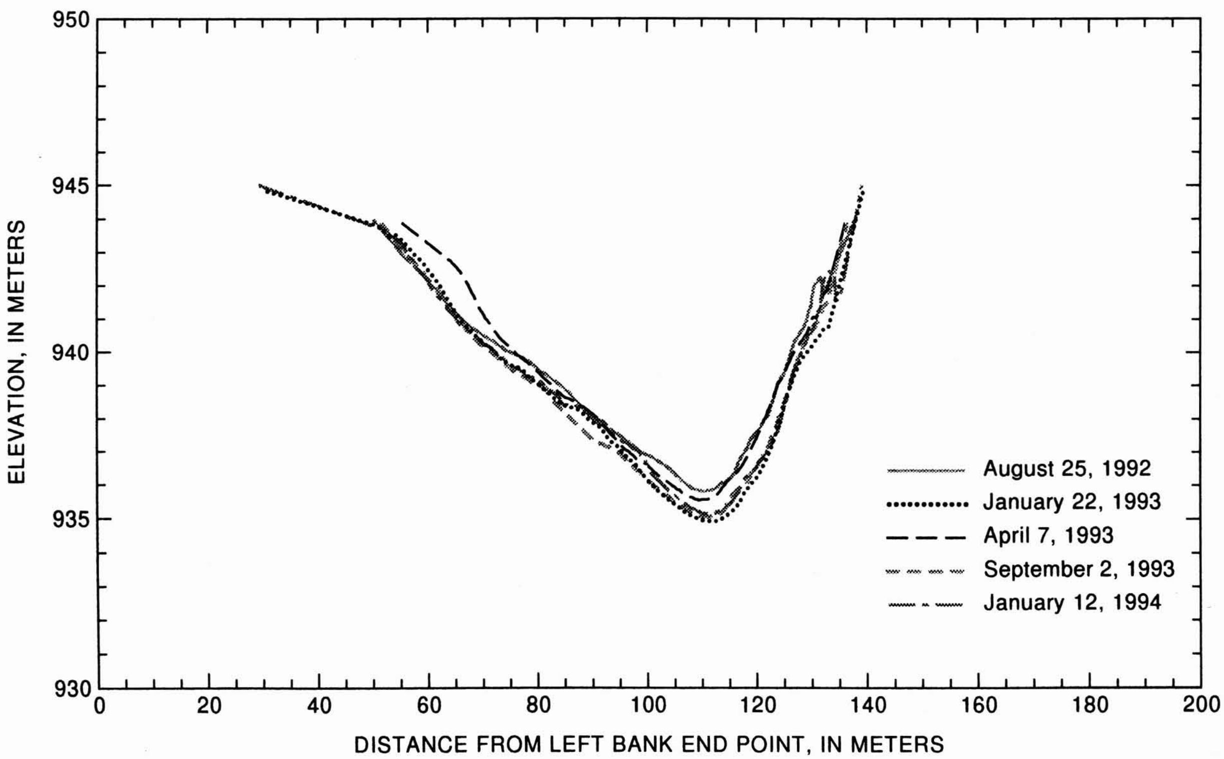

Figure 21. Cross sections measured downstream from the Paria River at monumented section P12.

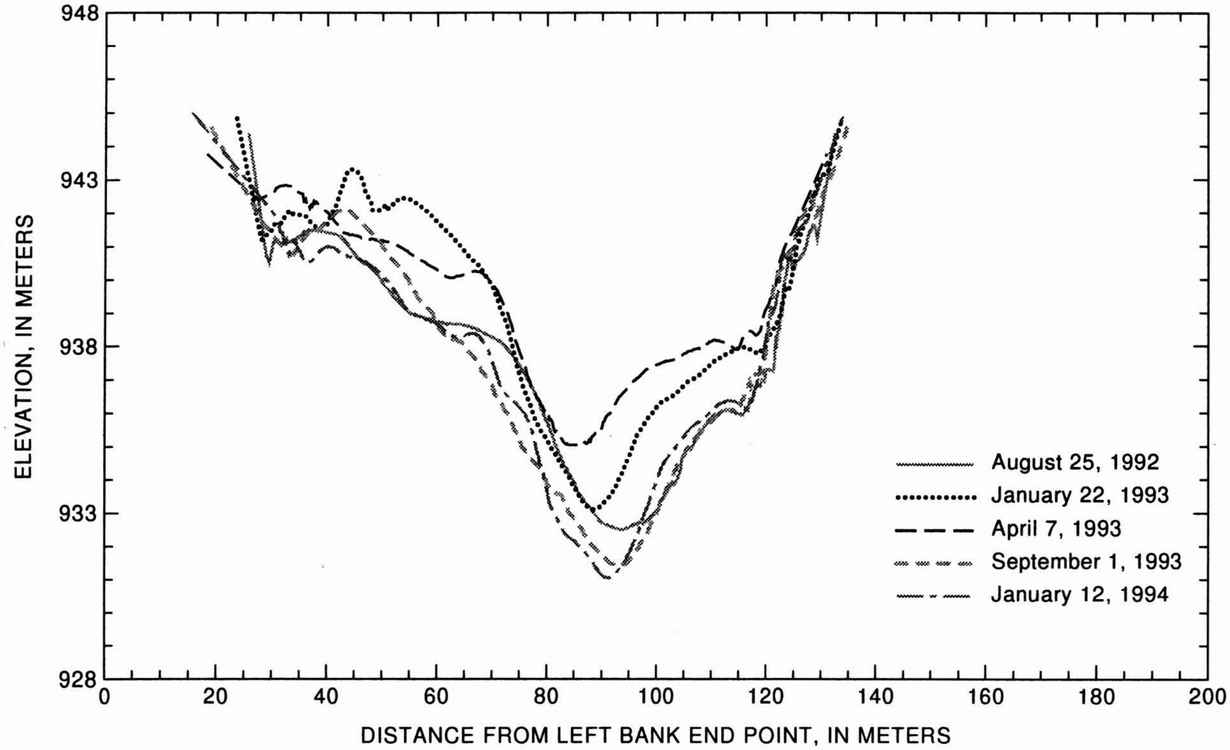

Figure 22. Cross sections measured downstream from the Paria River at monumented section P13.

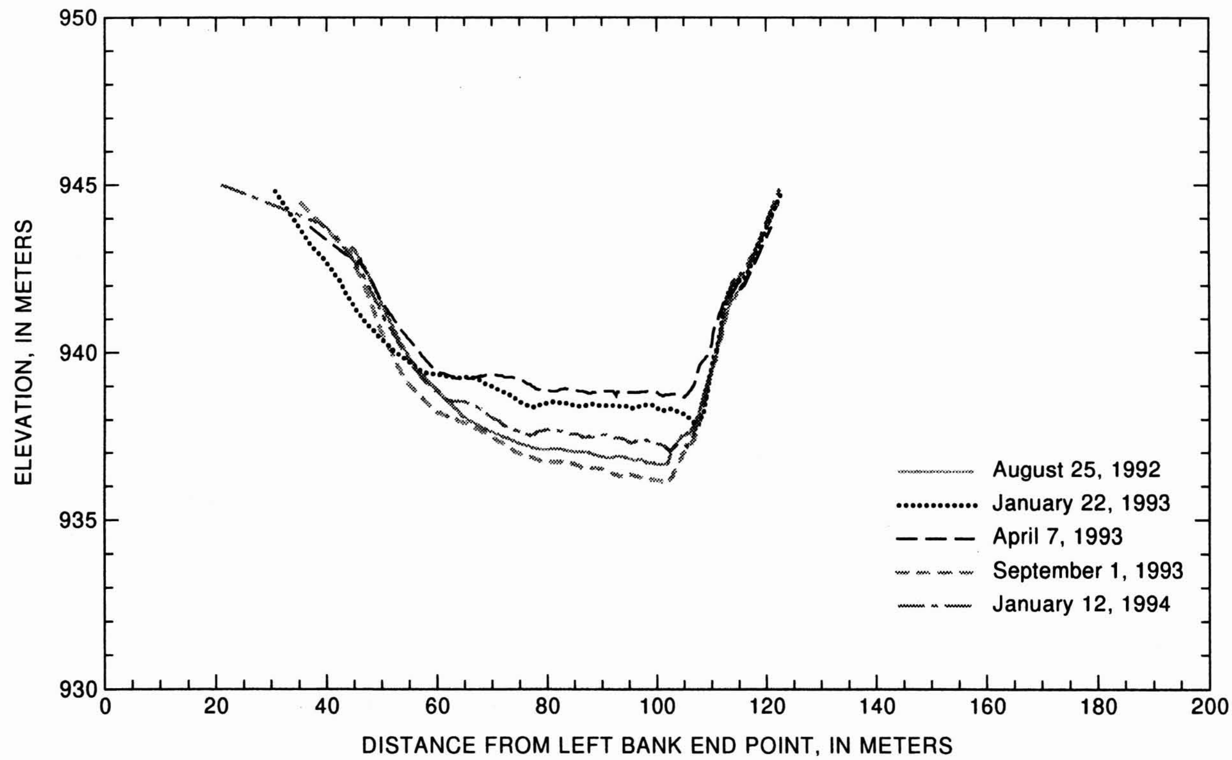

Figure 23. Cross sections measured downstream from the Paria River at monumented section P14.

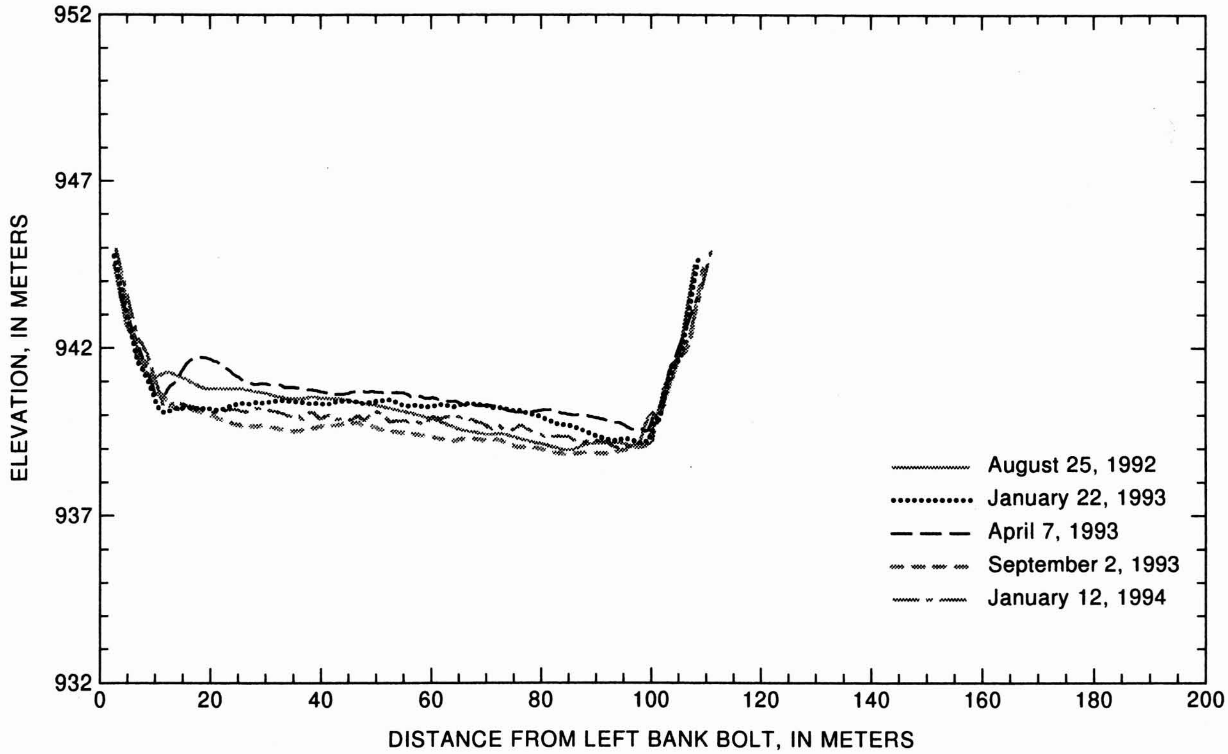

Figure 24. Cross sections measured downstream from the Paria River at monumented section P15.

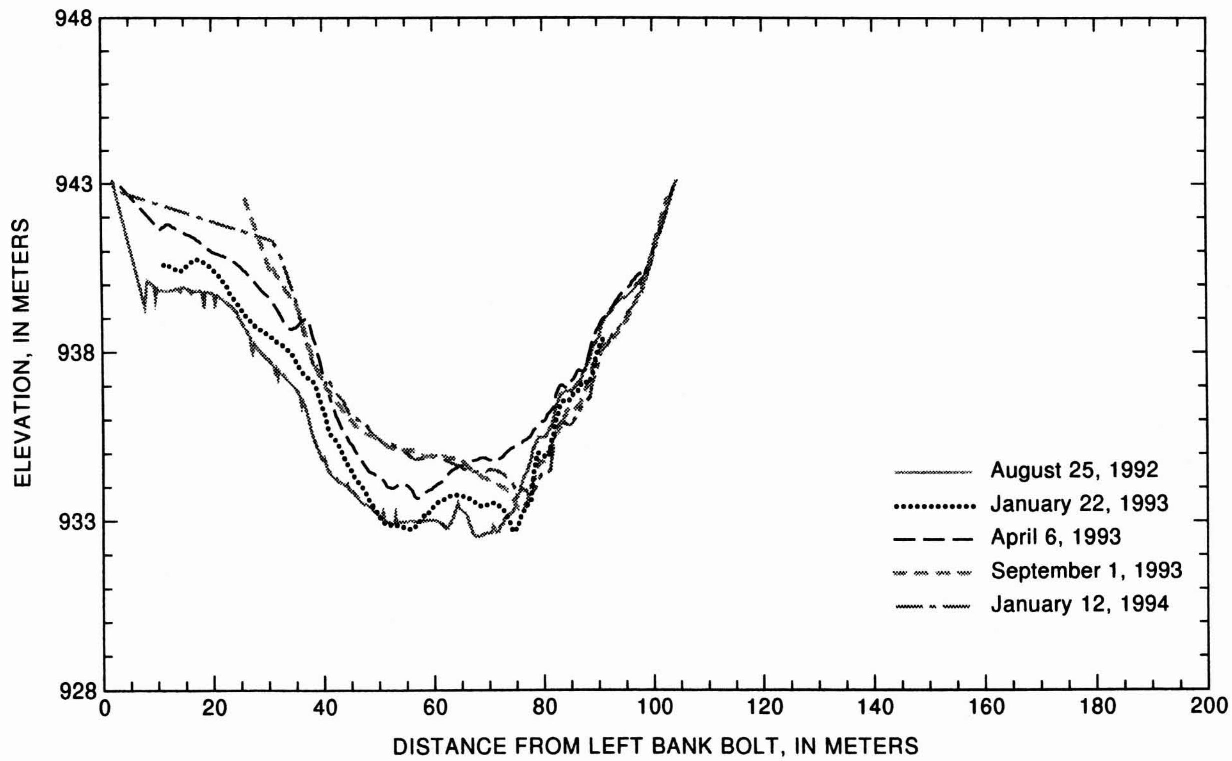

Figure 25. Cross sections measured downstream from the Paria River at monumented section P15a.

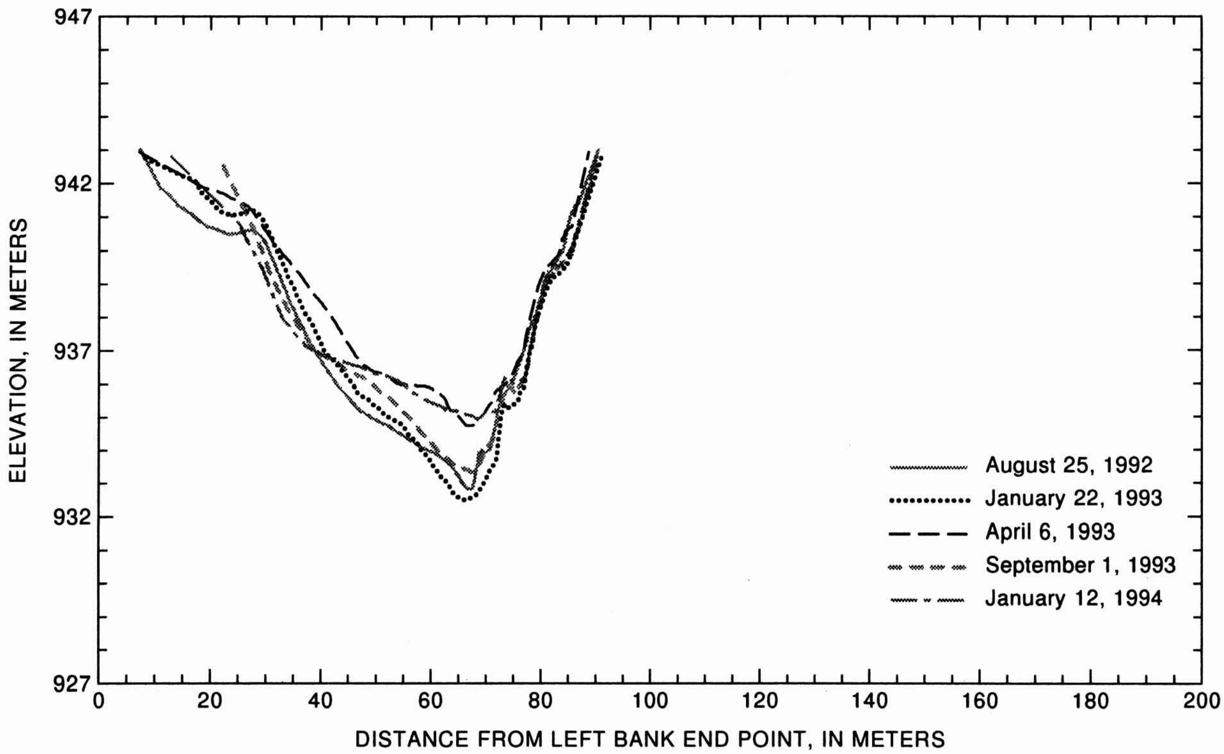

Figure 26. Cross sections measured downstream from the Paria River at monumented section P15b.

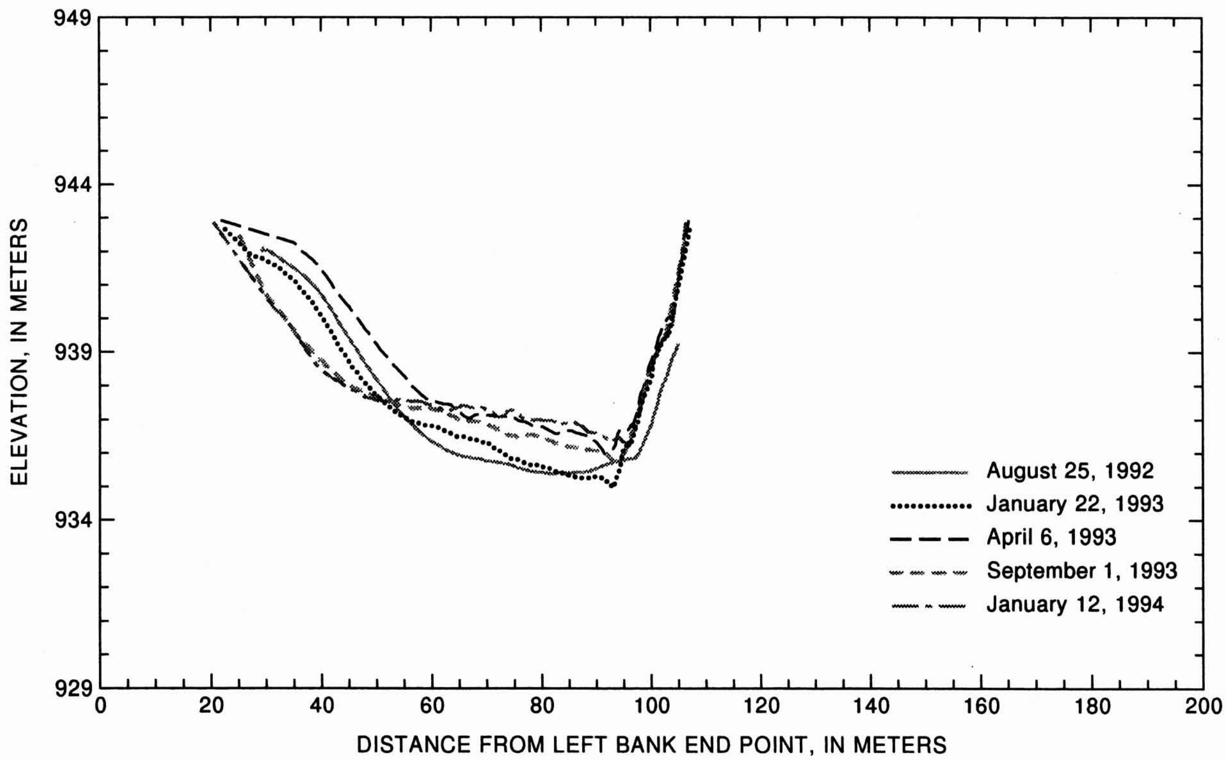

Figure 27. Cross sections measured downstream from the Paria River at monumented section P16.

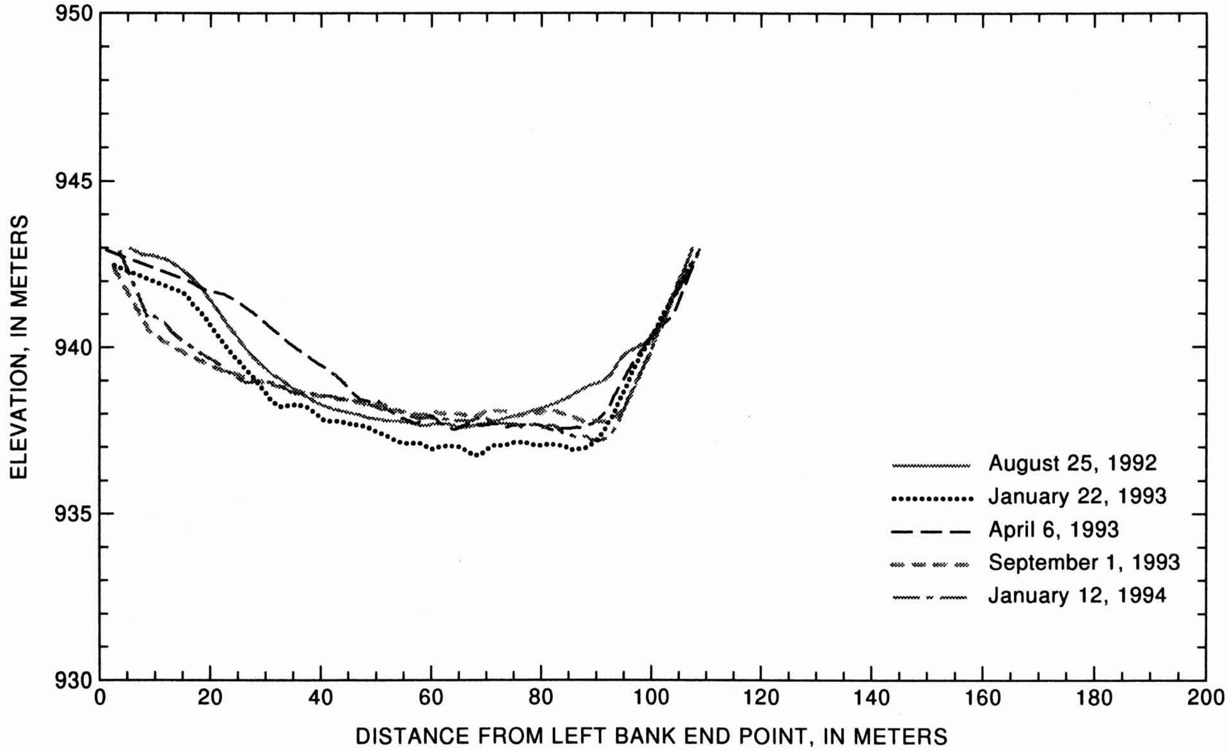

Figure 28. Cross sections measured downstream from the Paria River at monumented section P17.

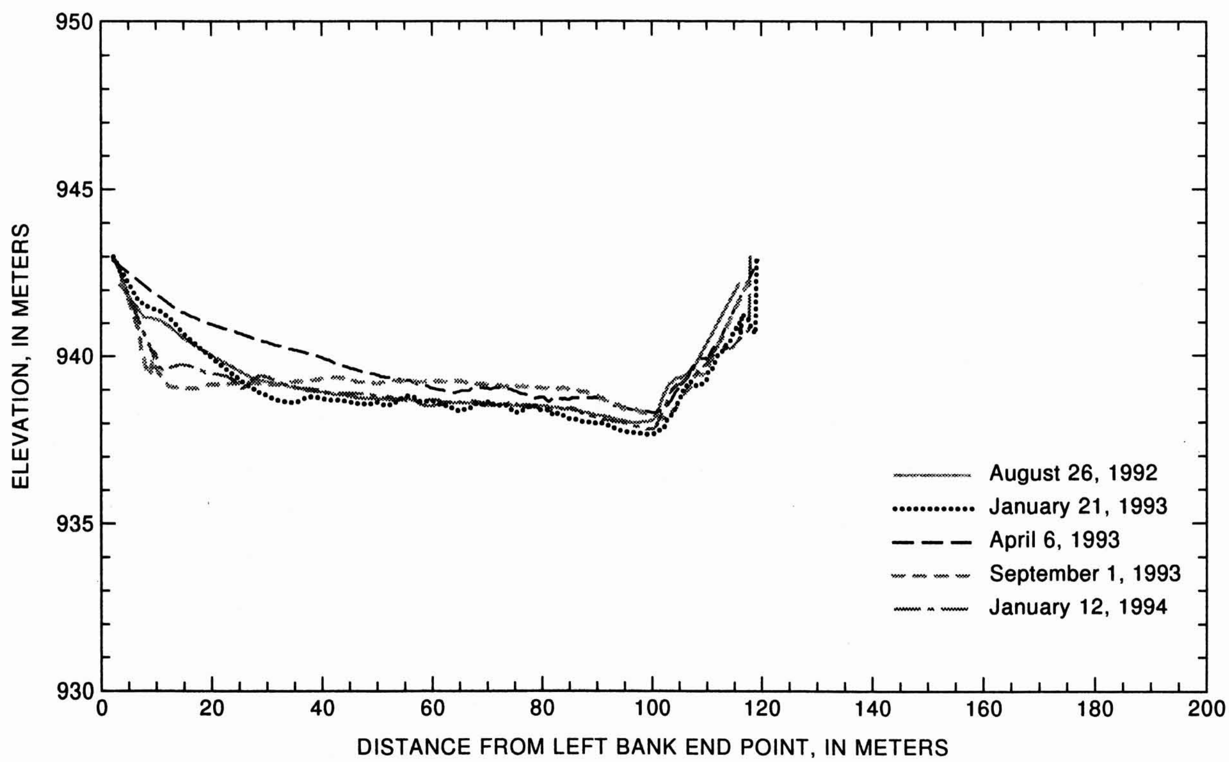

Figure 29. Cross sections measured downstream from the Paria River at monumented section P18.

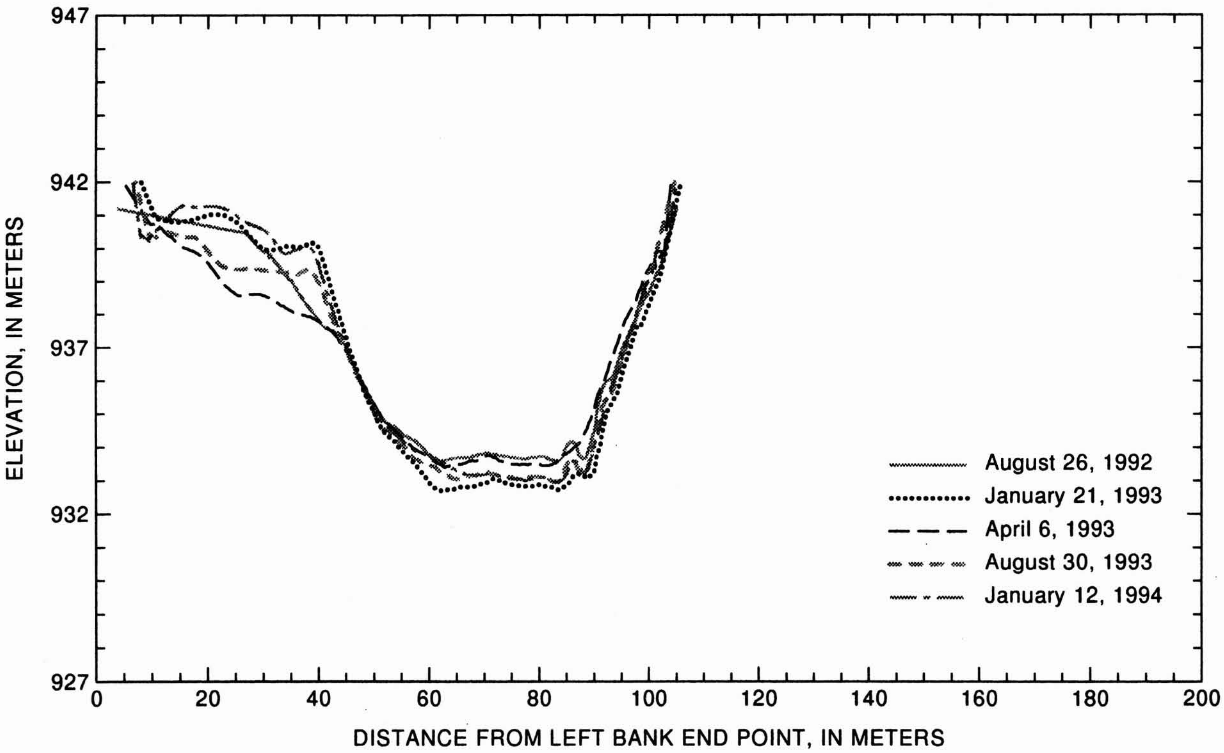

Figure 30. Cross sections measured downstream from the Paria River at monumented section P19.

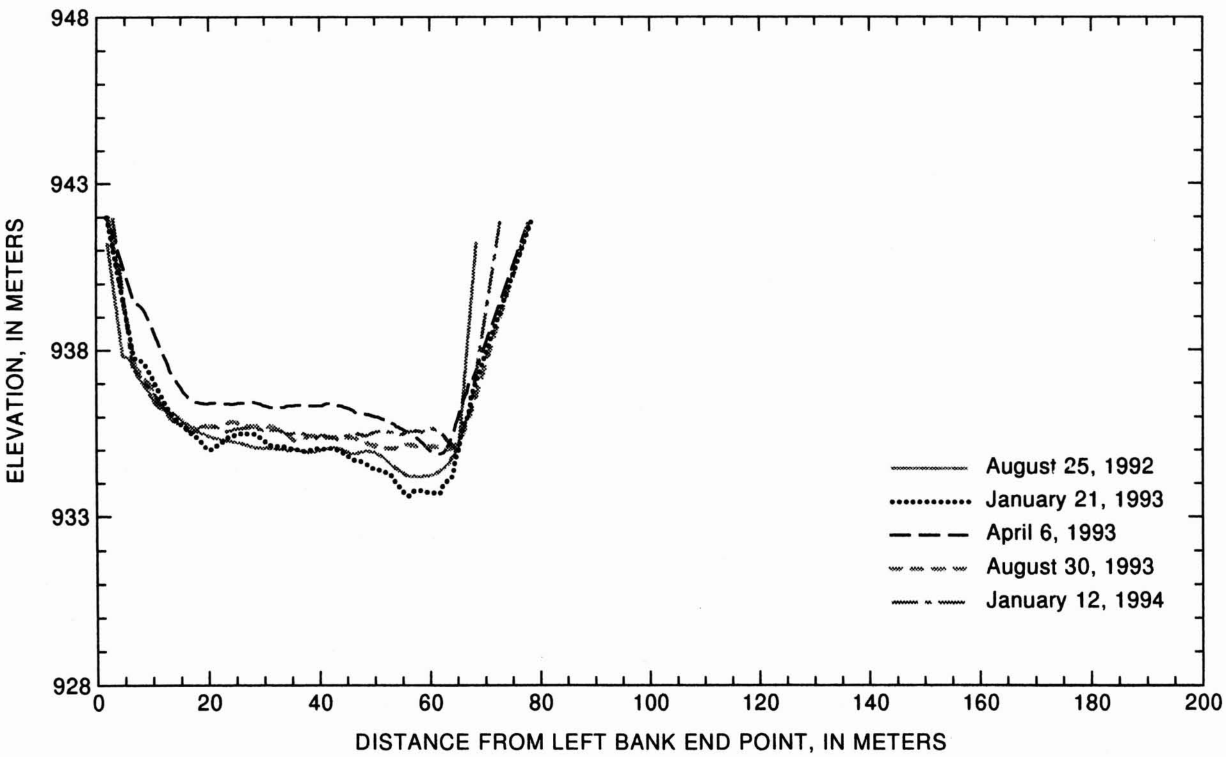

Figure 31. Cross sections measured downstream from the Paria River at monumented section P20.

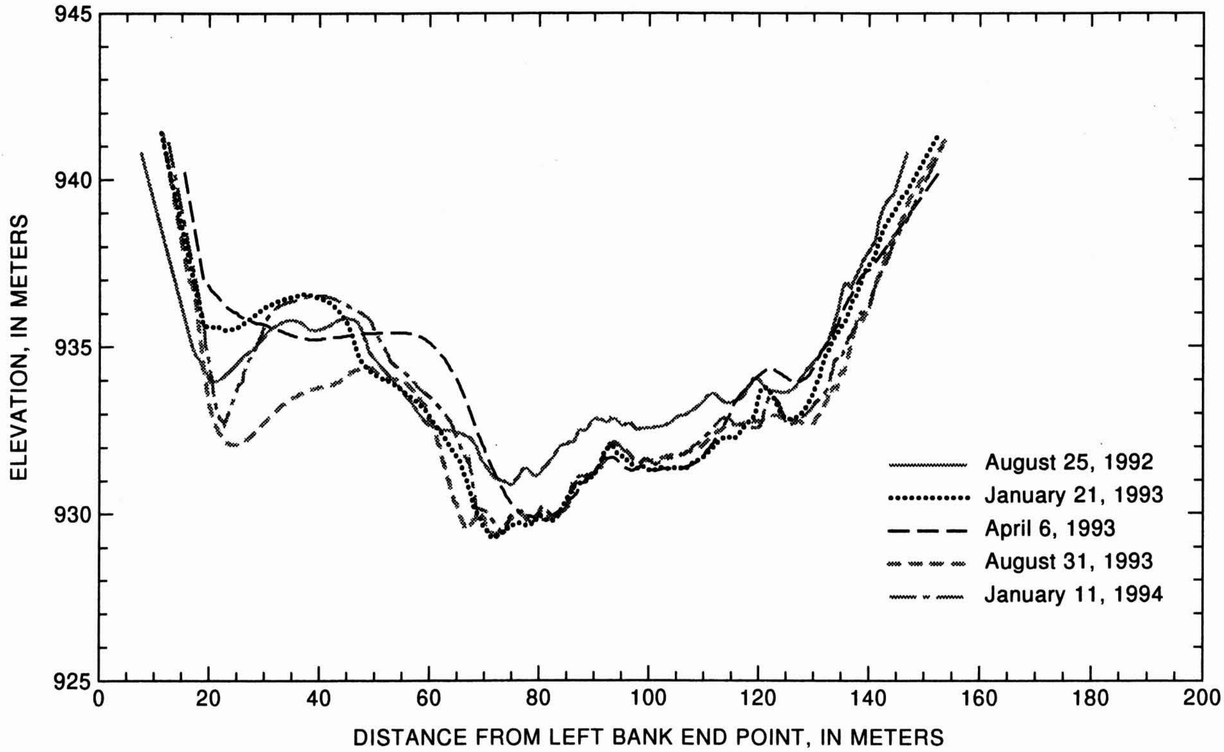

Figure 32. Cross sections measured downstream from the Paria River at monumented section P21.

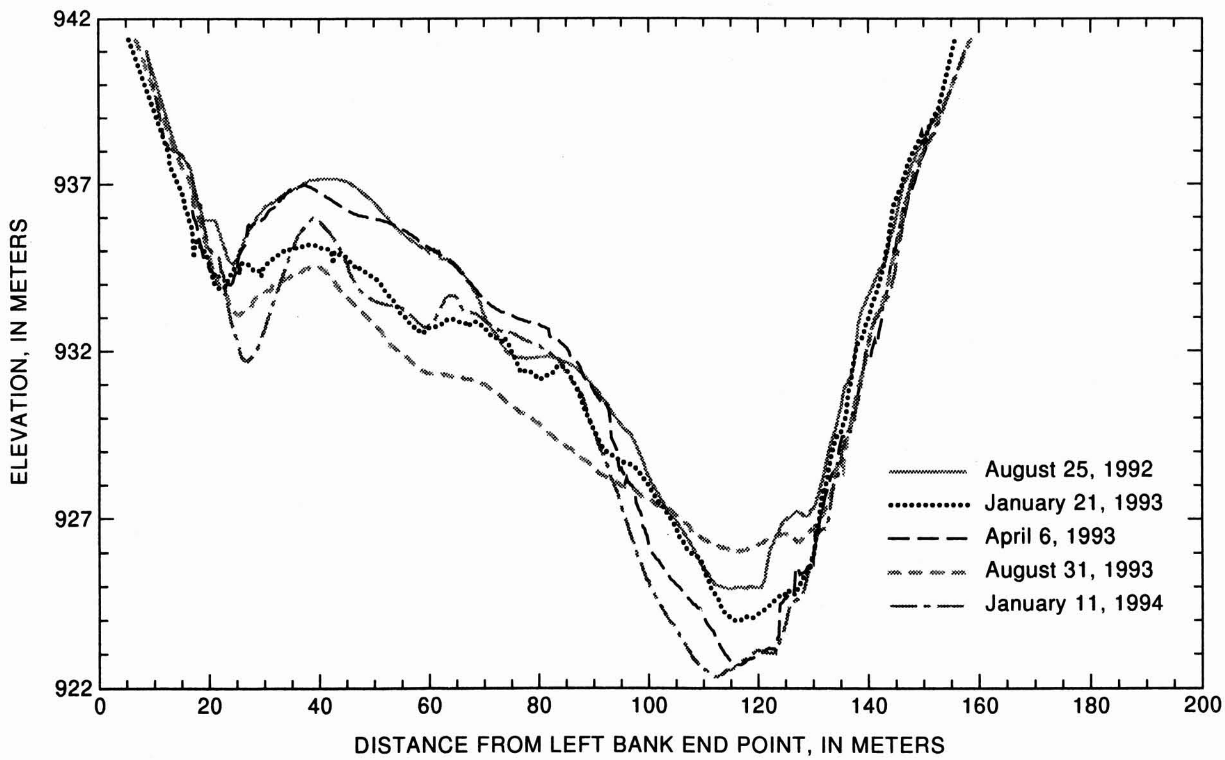

Figure 33. Cross sections measured downstream from the Paria River at monumented section P22.

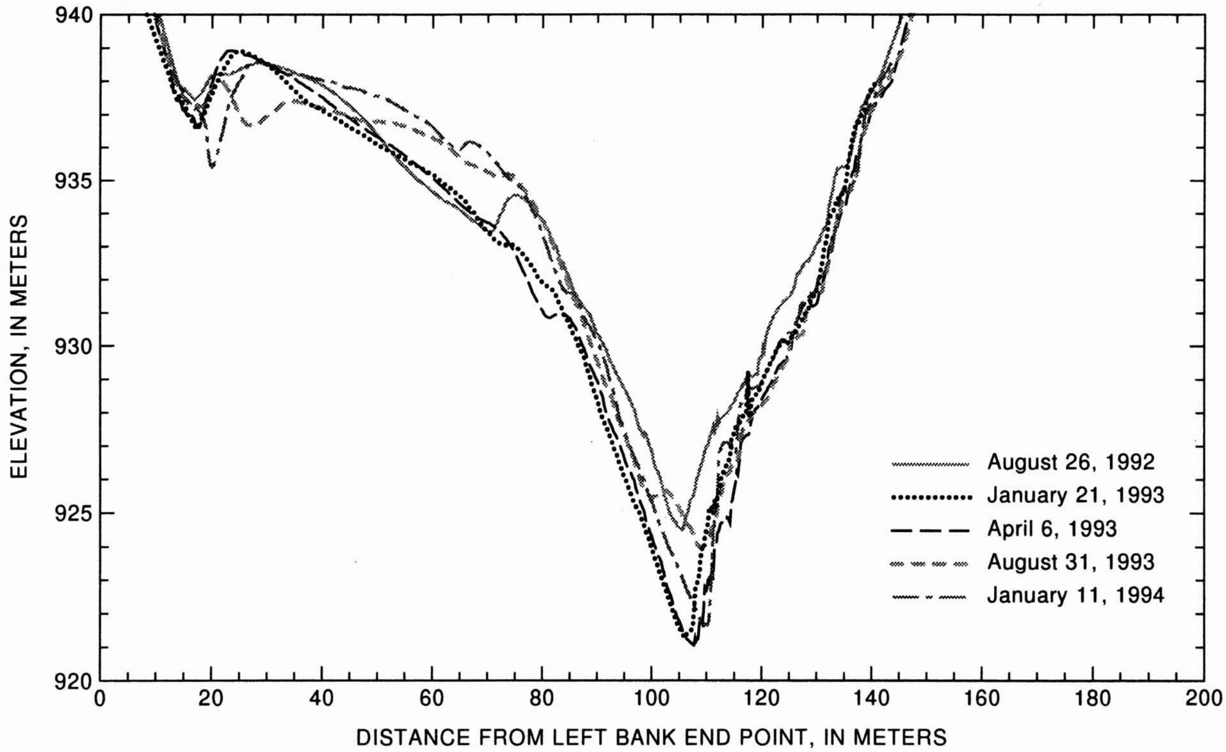

Figure 34. Cross sections measured downstream from the Paria River at monumented section P23.

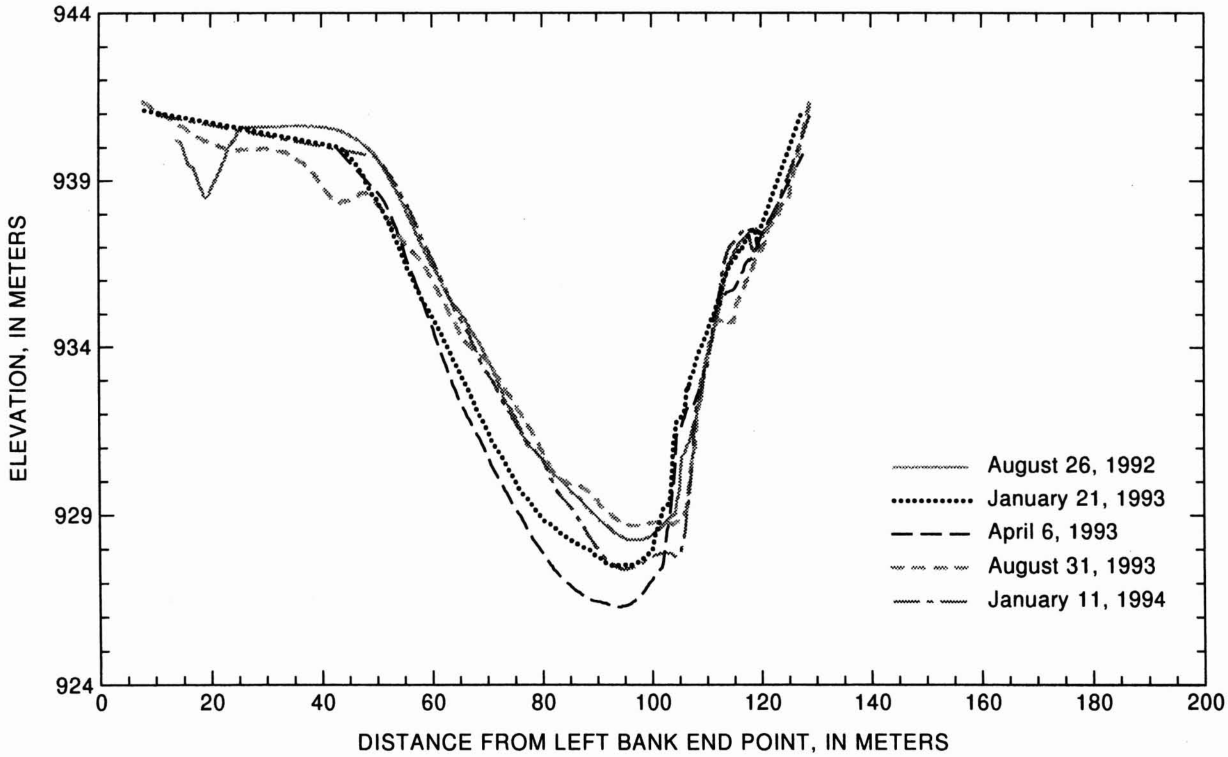

Figure 35. Cross sections measured downstream from the Paria River at monumented section P24.

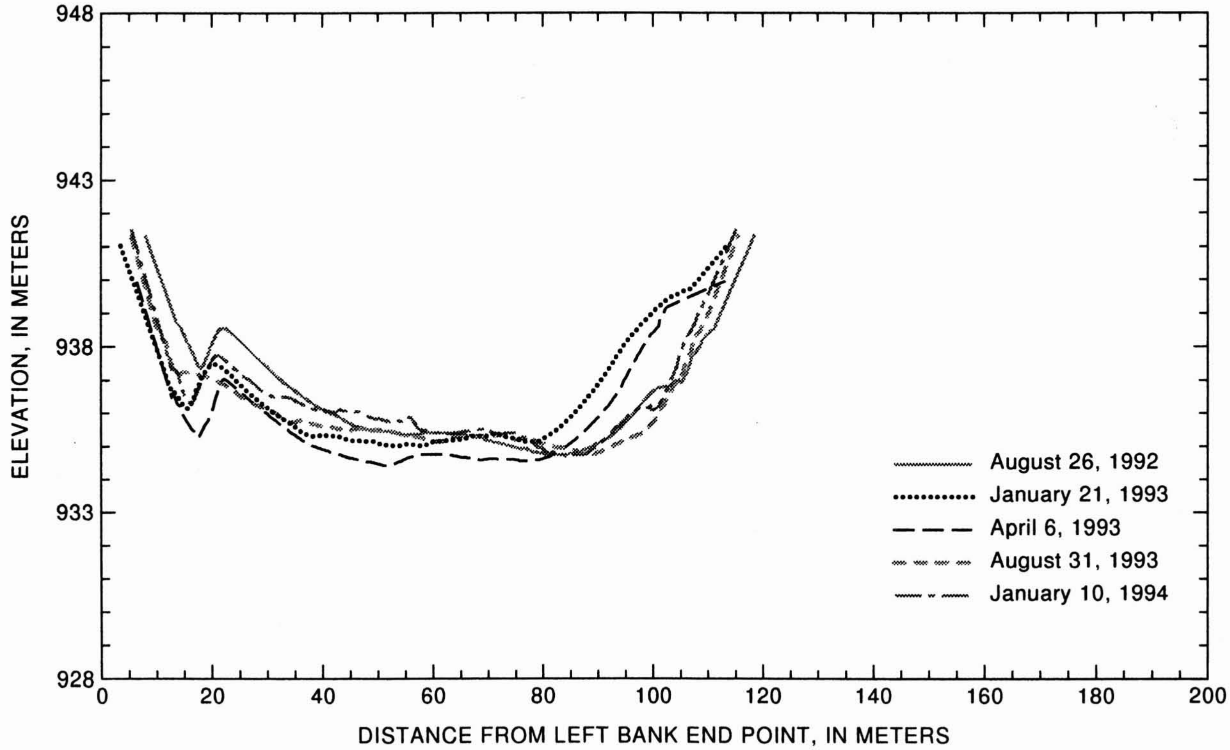

Figure 36. Cross sections measured downstream from the Paria River at monumented section P25.

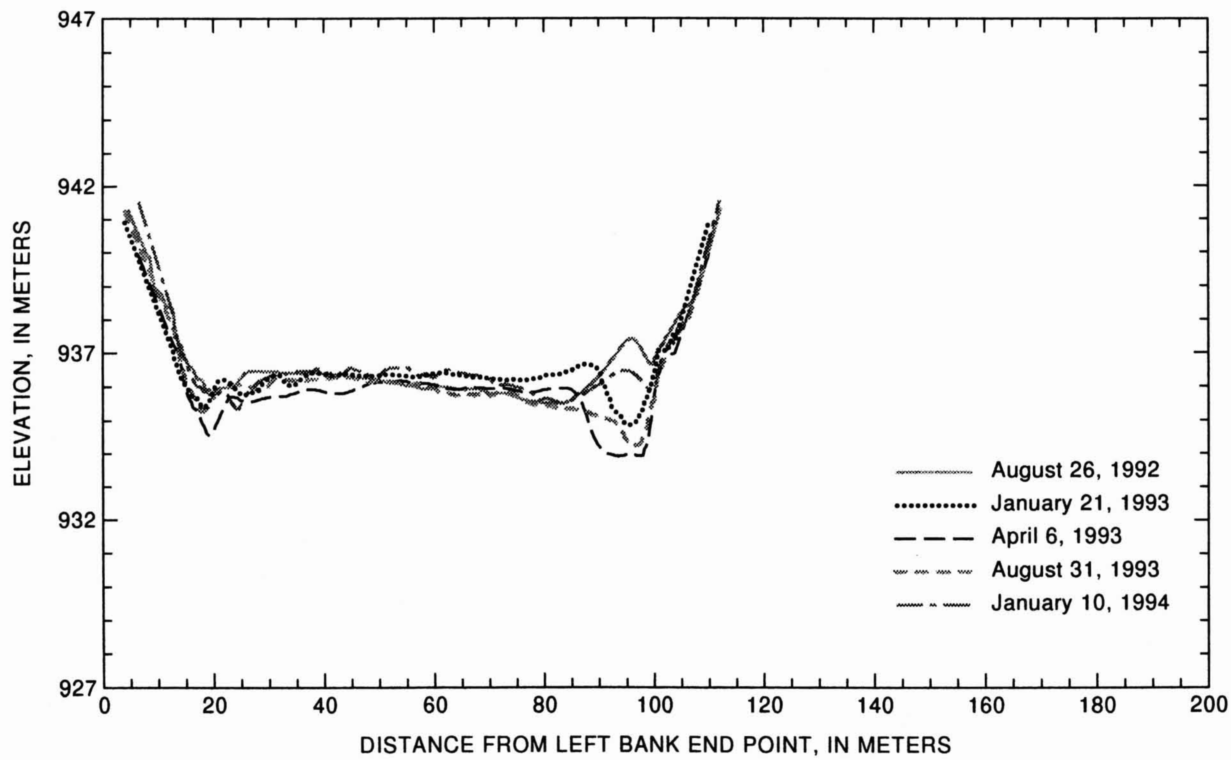

Figure 37. Cross sections measured downstream from the Paria River at monumented section P26.

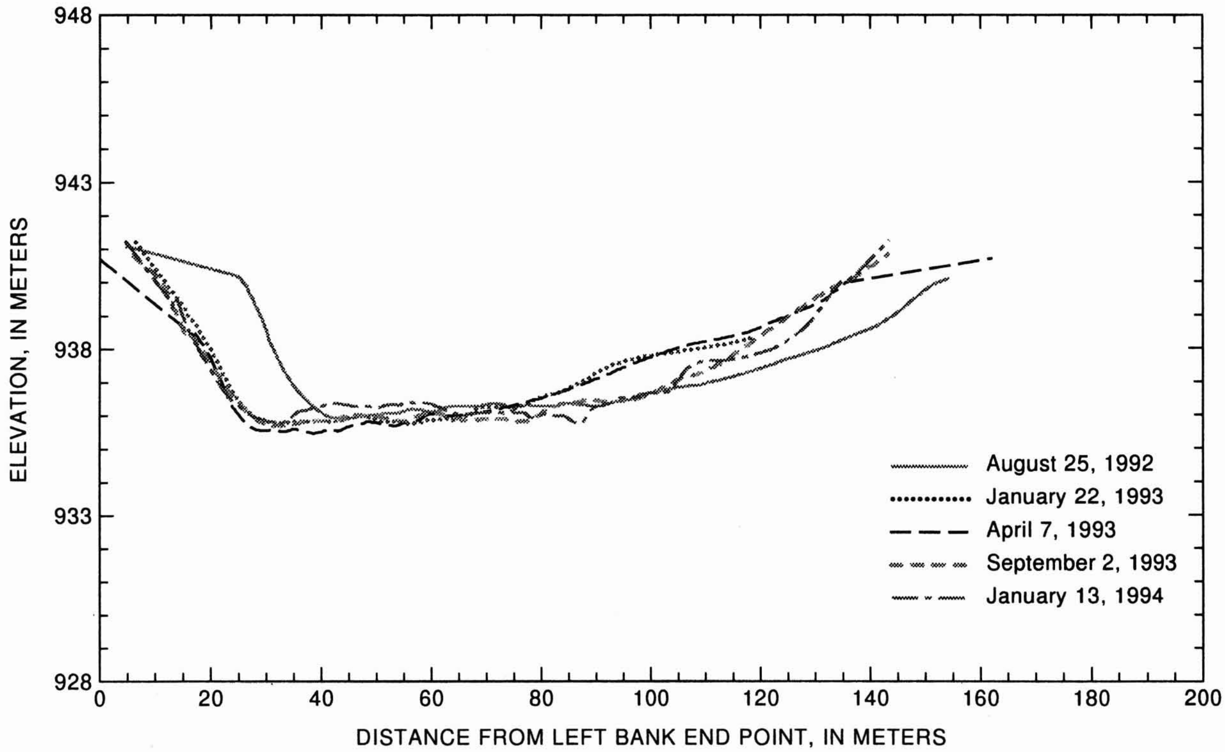

Figure 38. Cross sections measured downstream from the Paria River at monumented section P27.

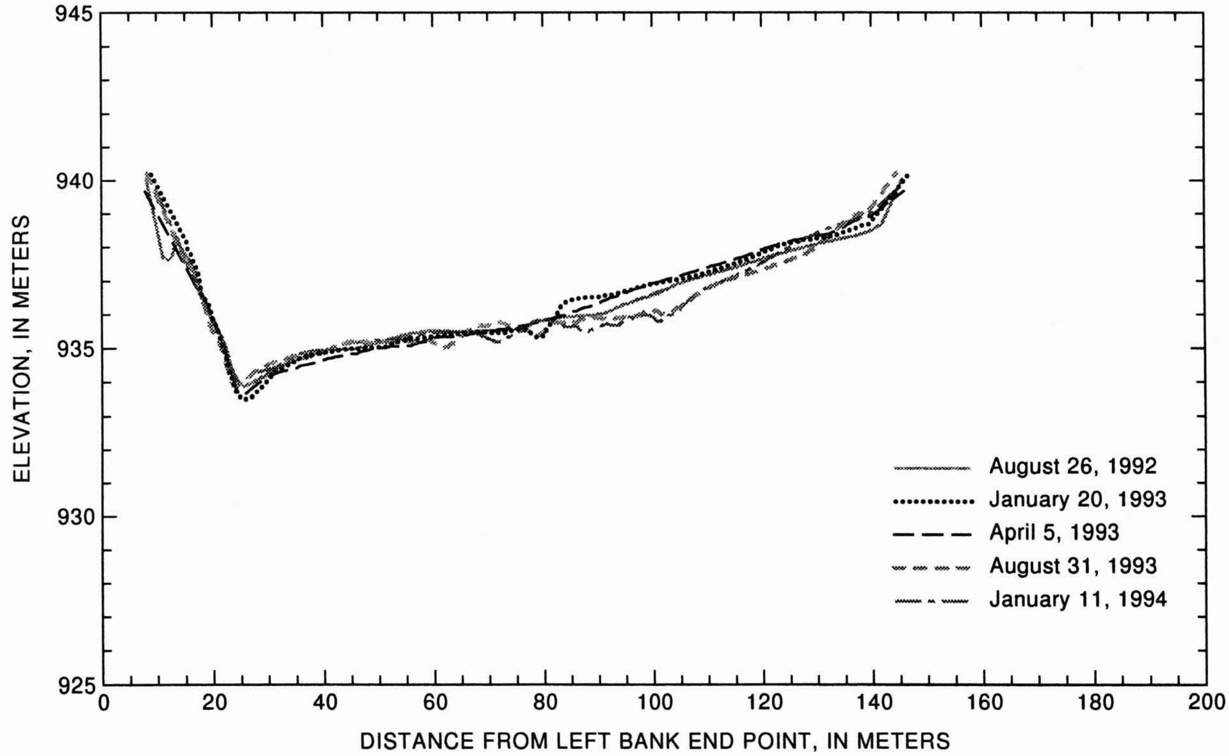

Figure 39. Cross sections measured downstream from the Paria River at monumented section P28.

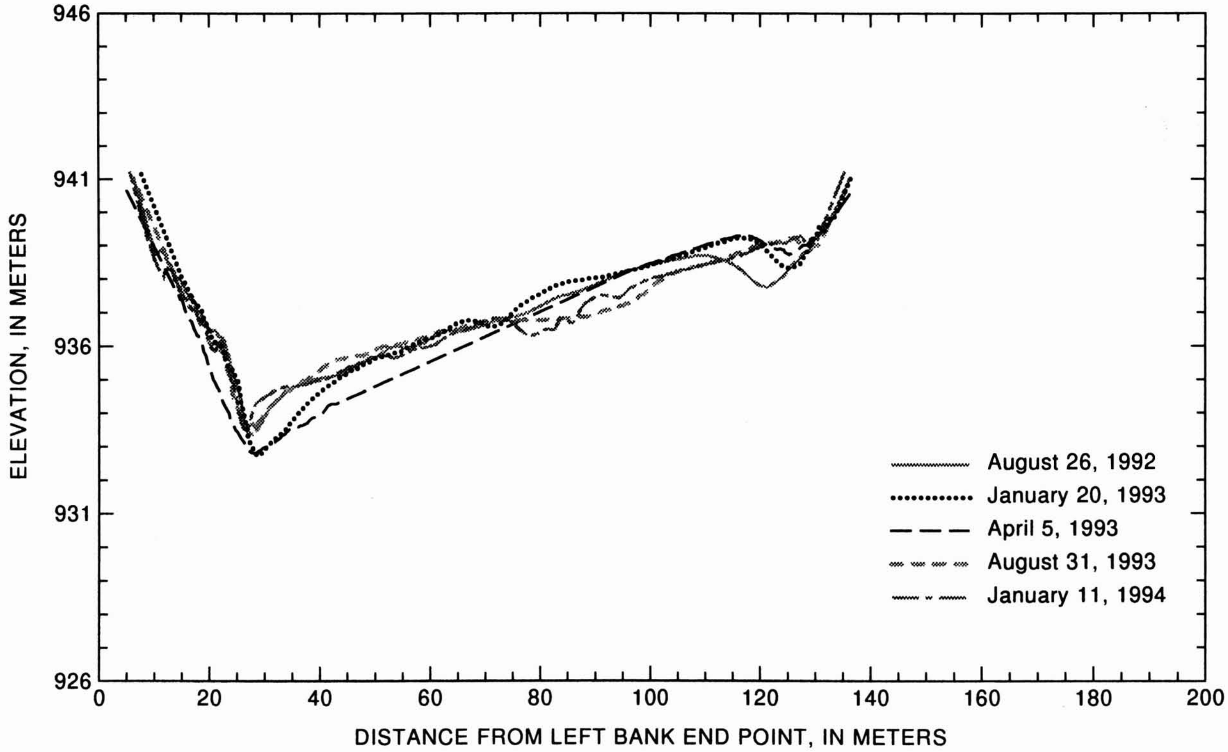

Figure 40. Cross sections measured downstream from the Paria River at monumented section P29.

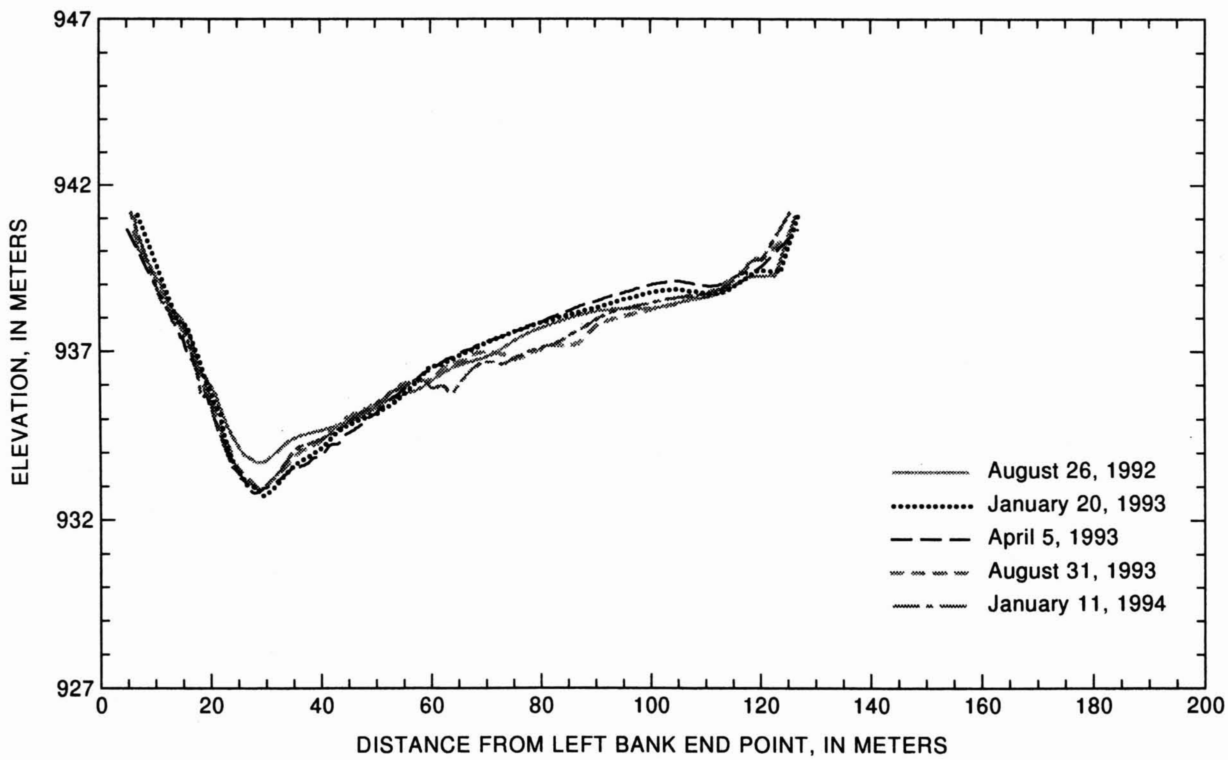

Figure 41. Cross sections measured downstream from the Paria River at monumented section P30.

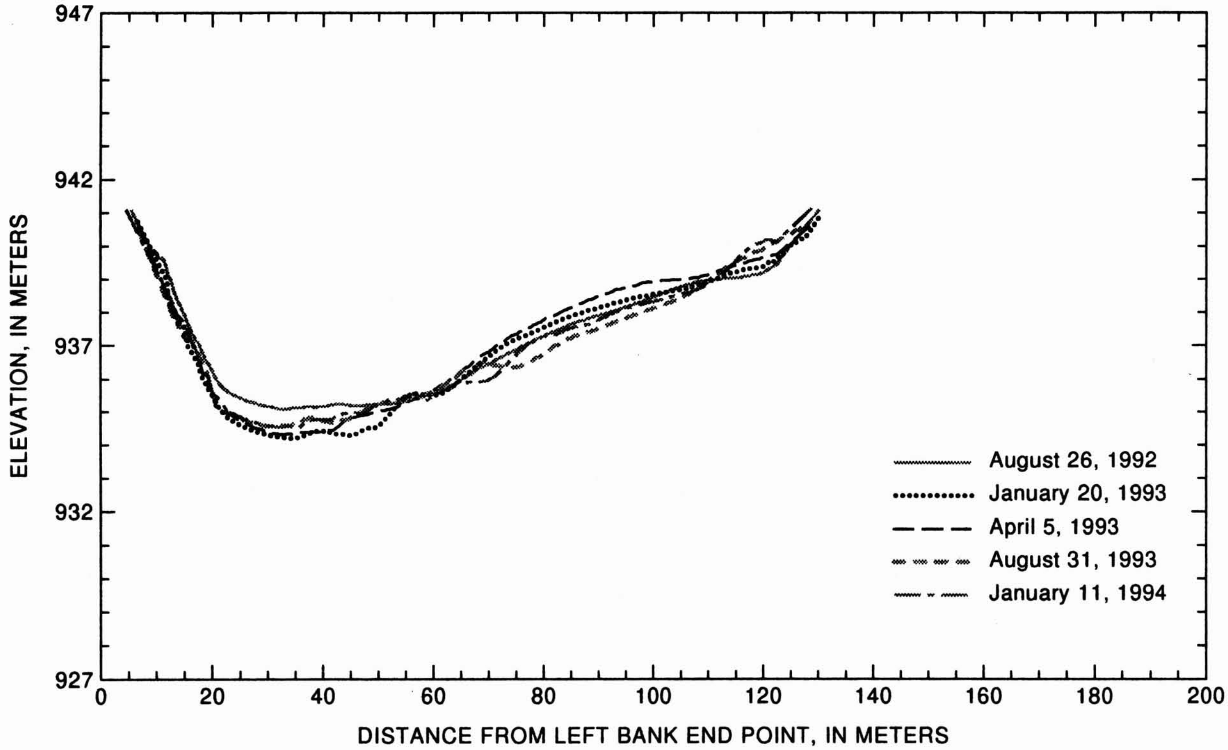

Figure 42. Cross sections measured downstream from the Paria River at monumented section P31.

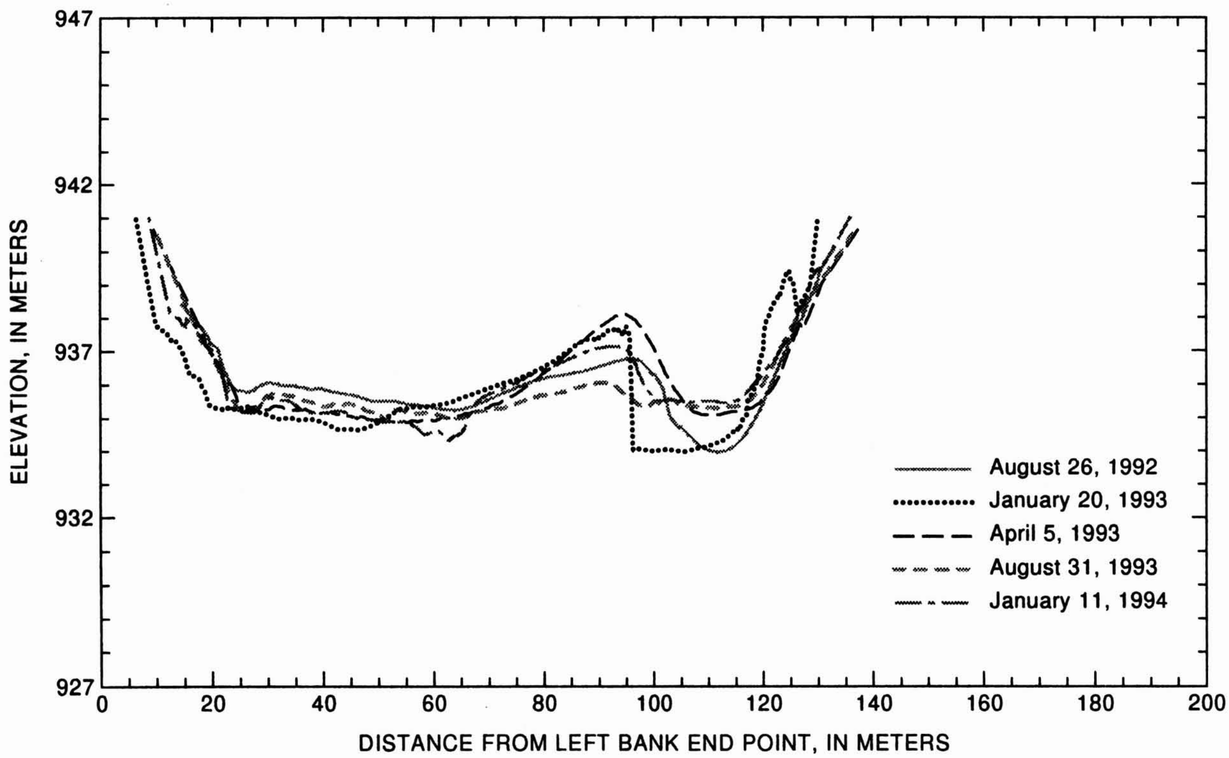

Figure 43. Cross sections measured downstream from the Paria River at monumented section P32.

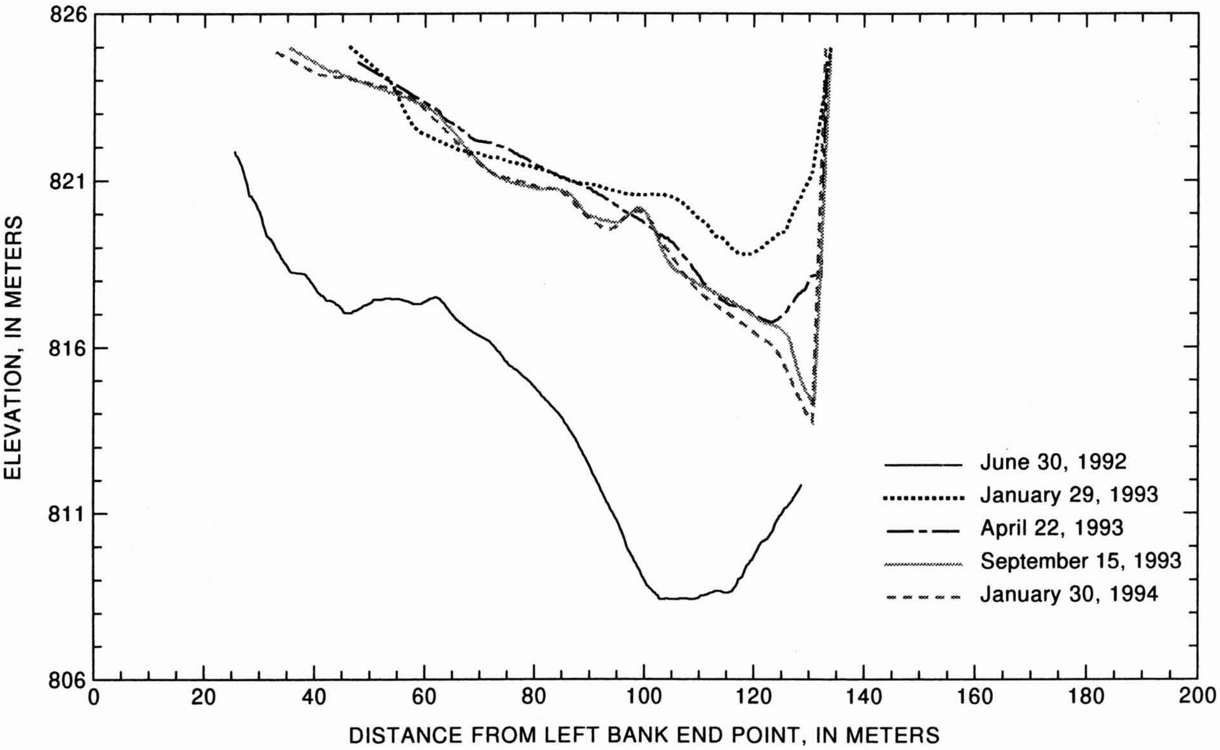

Figure 44. Cross sections measured downstream from the Little Colorado River at monumented section A1.

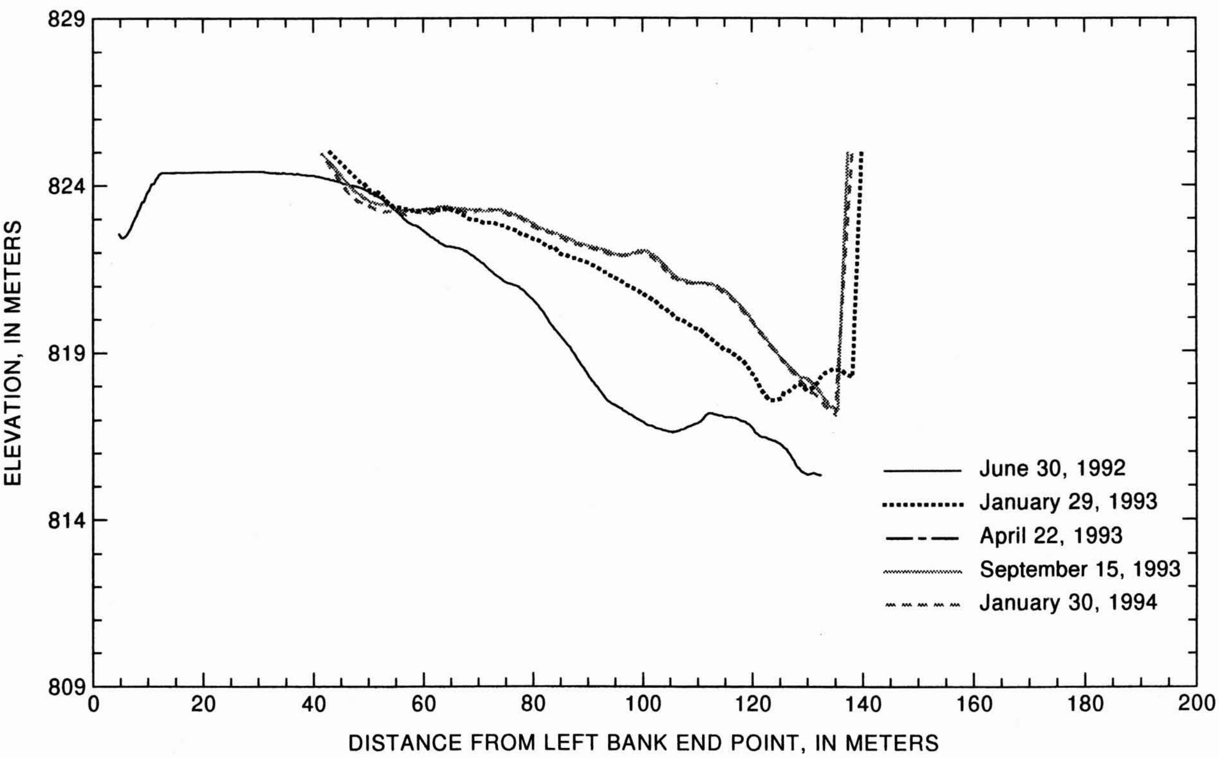

Figure 45. Cross sections measured downstream from the Little Colorado River at monumented section A2.

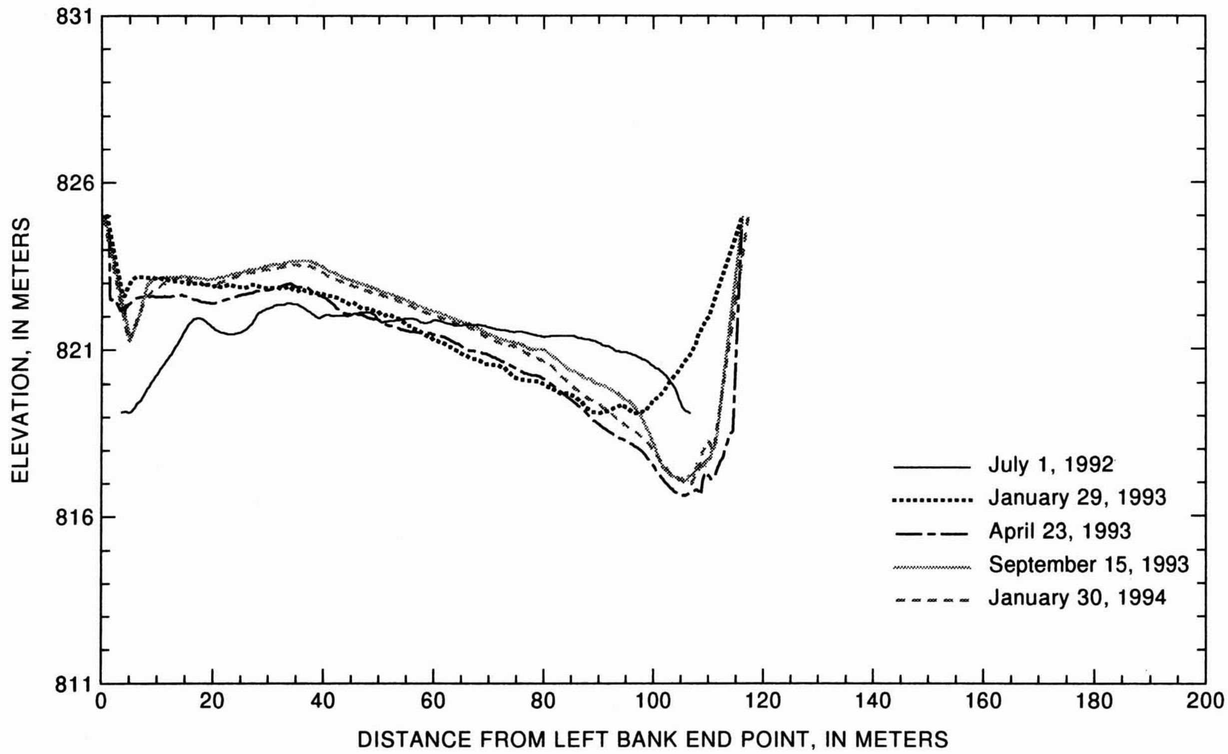

Figure 46. Cross sections measured downstream from the Little Colorado River at monumented section A3.

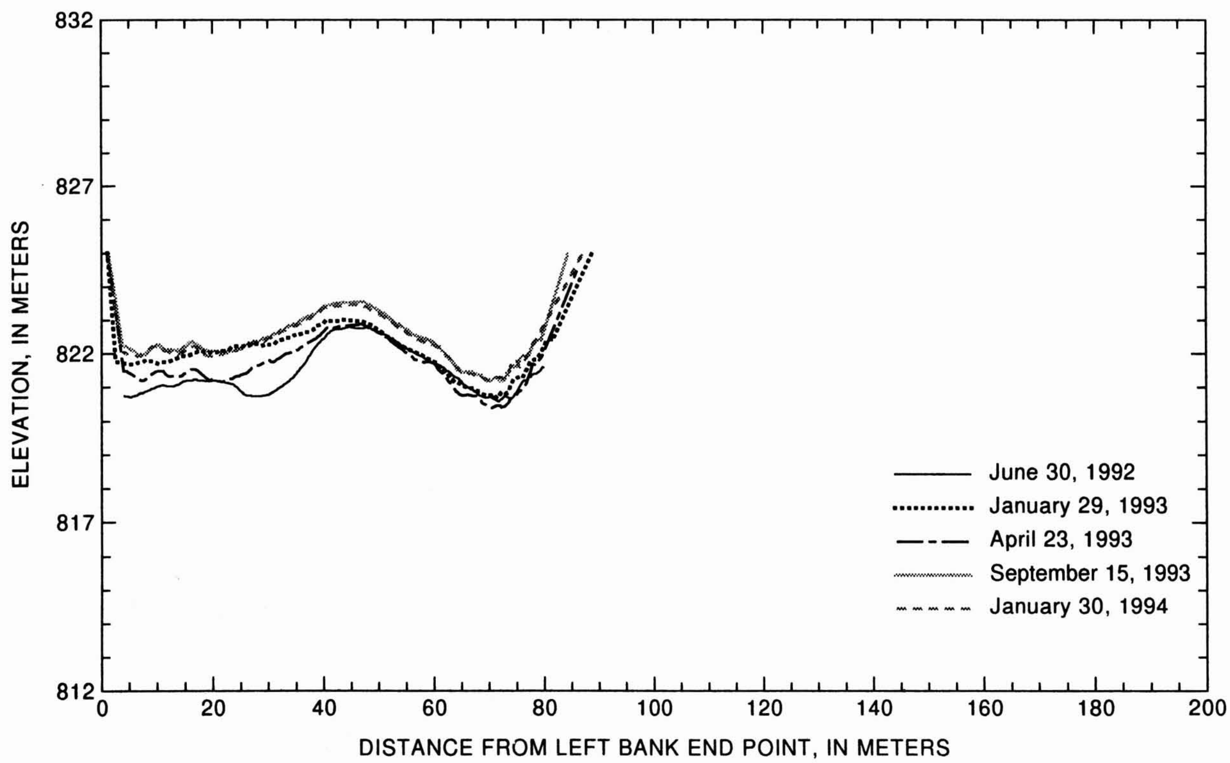

Figure 47. Cross sections measured downstream from the Little Colorado River at monumented section A4.

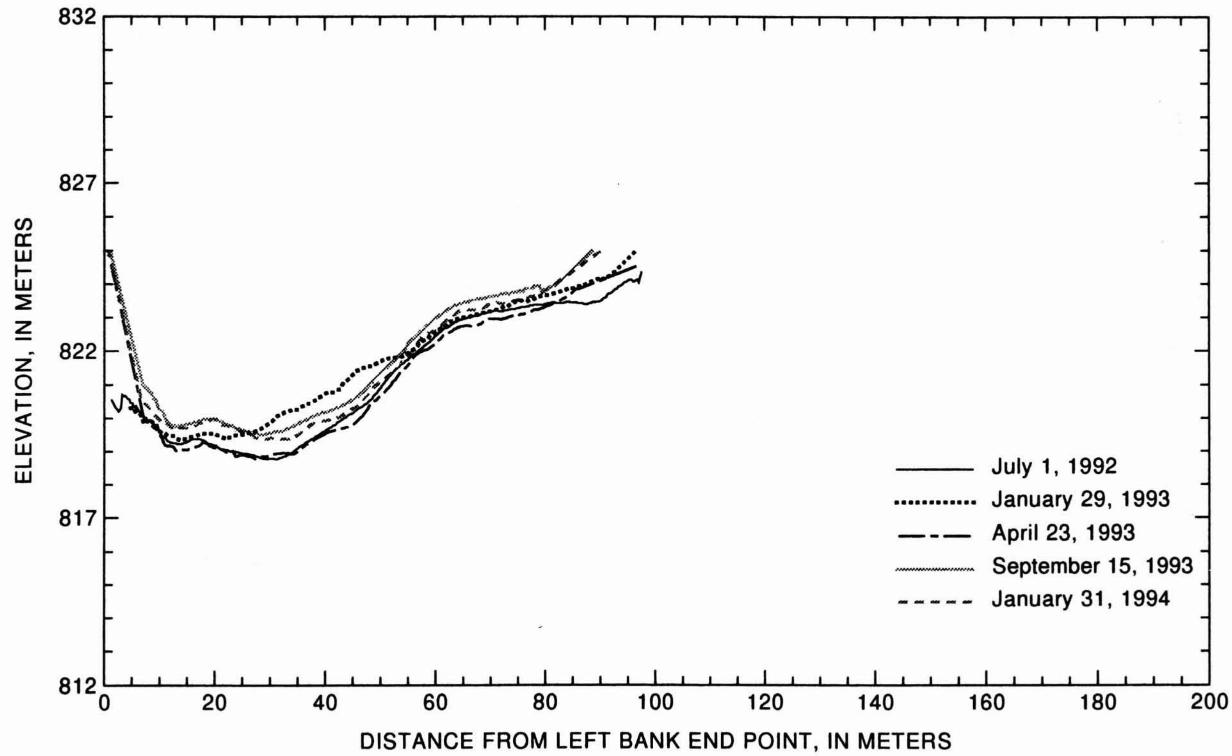

Figure 48. Cross sections measured downstream from the Little Colorado River at monumented section A5.

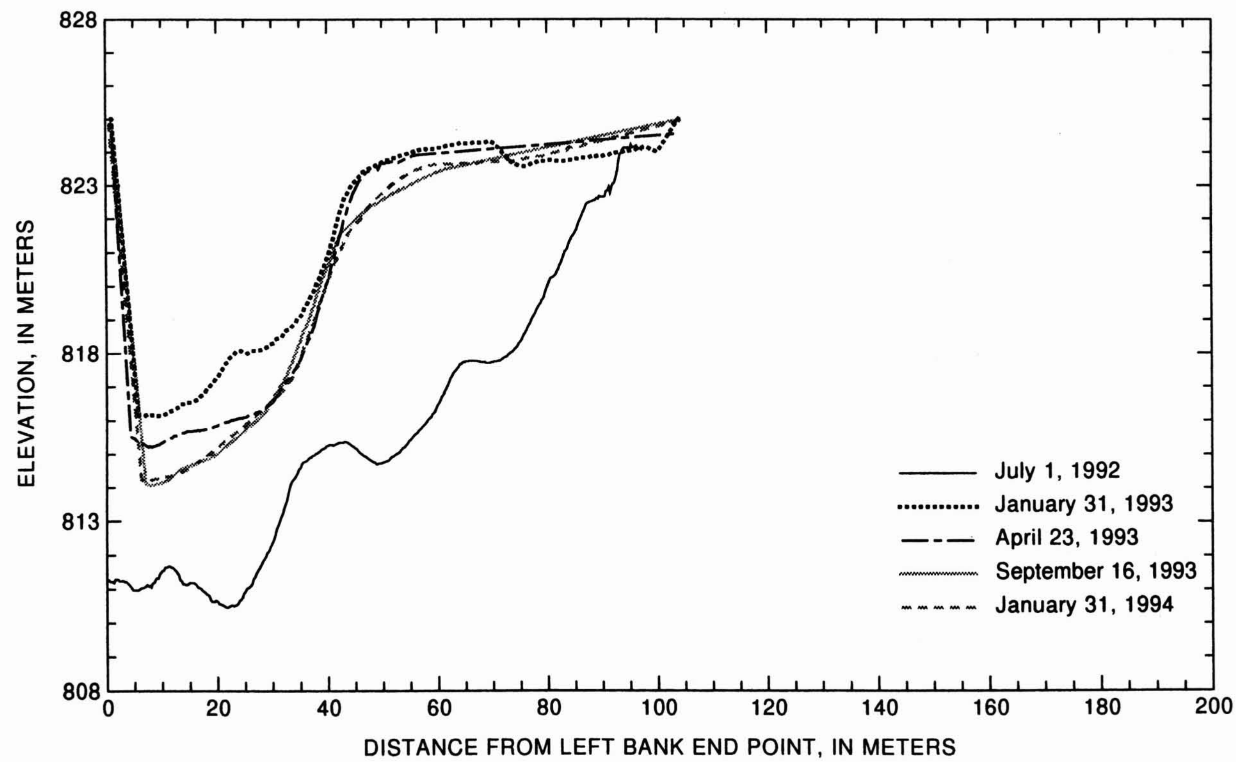

Figure 49. Cross sections measured downstream from the Little Colorado River at monumented section A6.

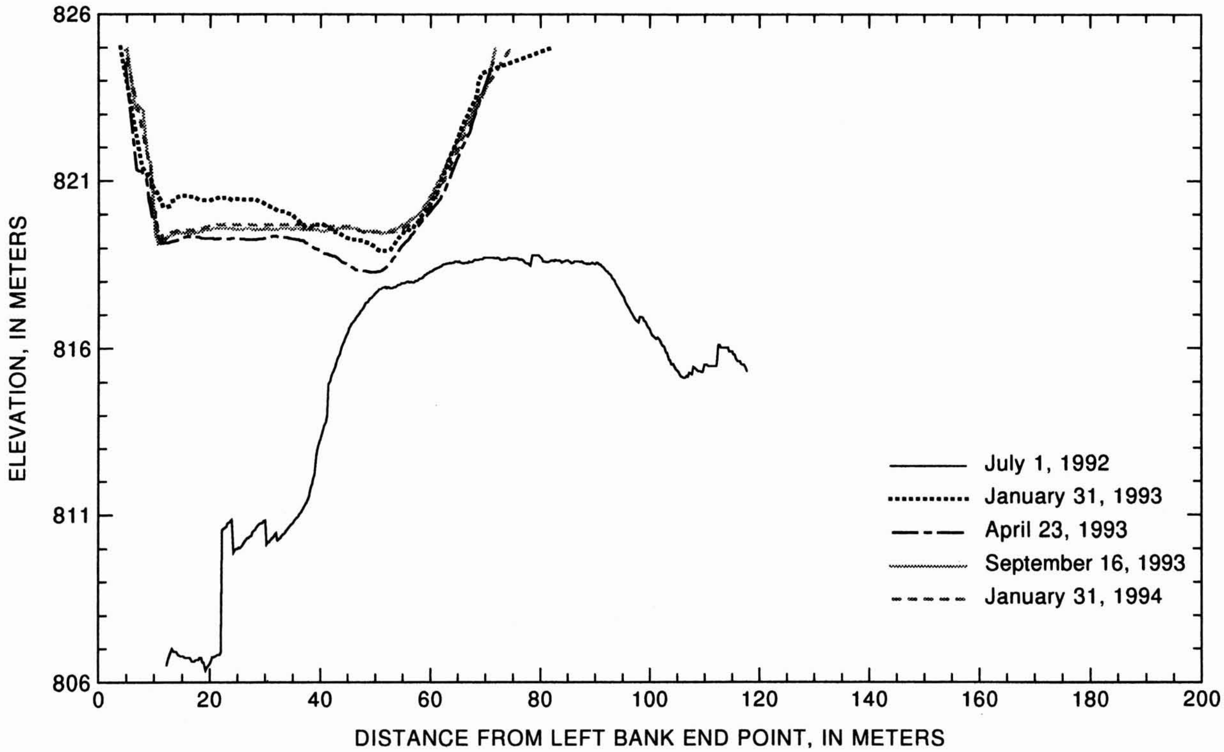

Figure 50. Cross sections measured downstream from the Little Colorado River at monumented section A7.

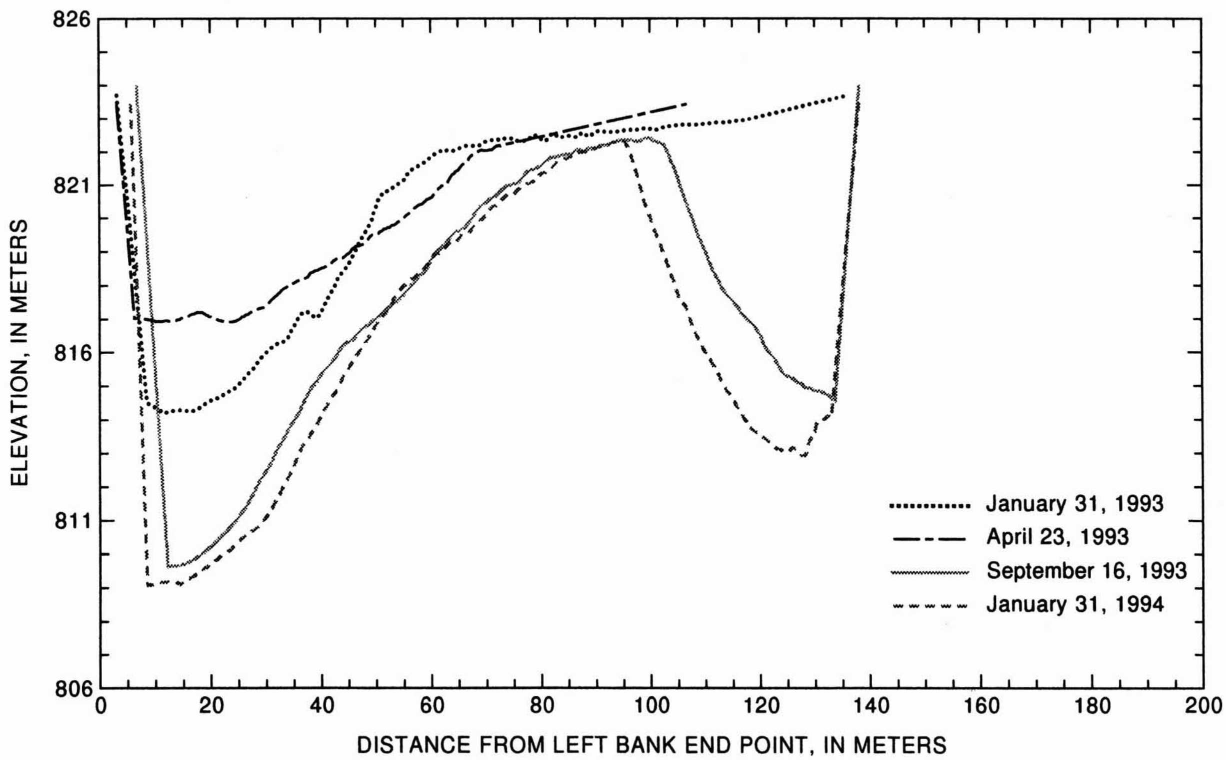

Figure 51. Cross sections measured downstream from the Little Colorado River at monumented section B1.

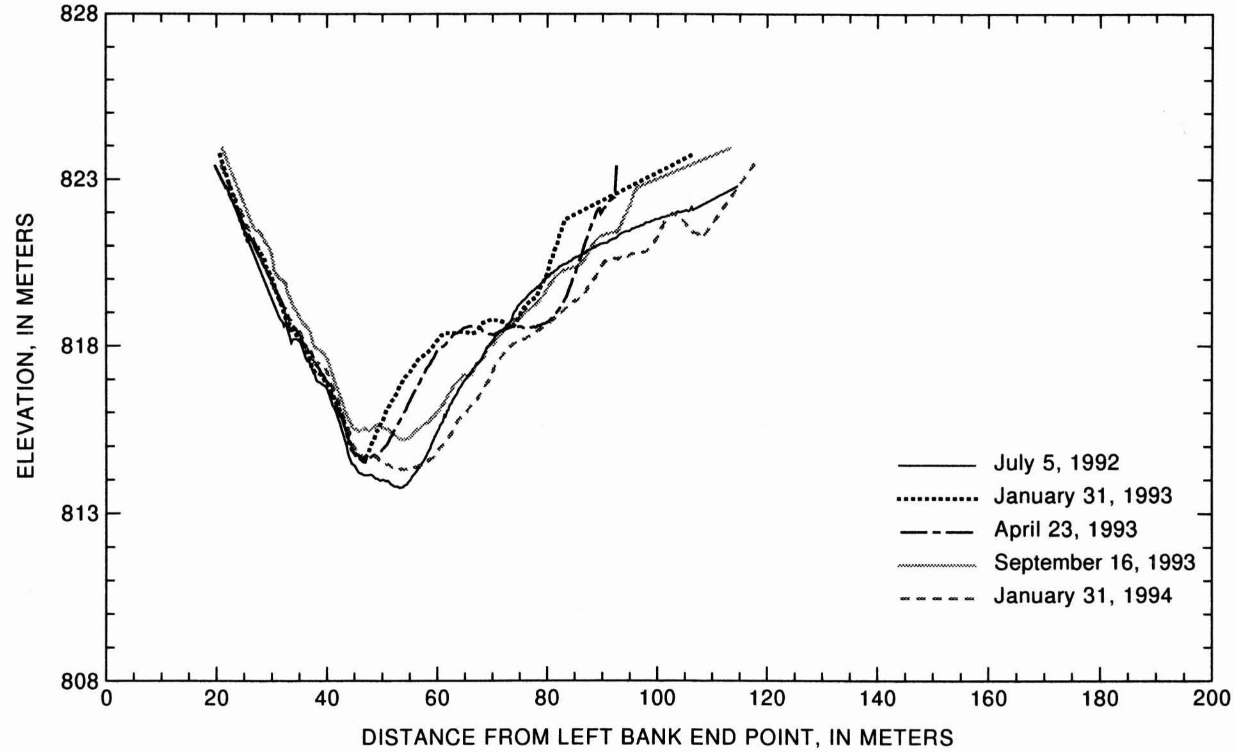

Figure 52. Cross sections measured downstream from the Little Colorado River at monumented section B2.

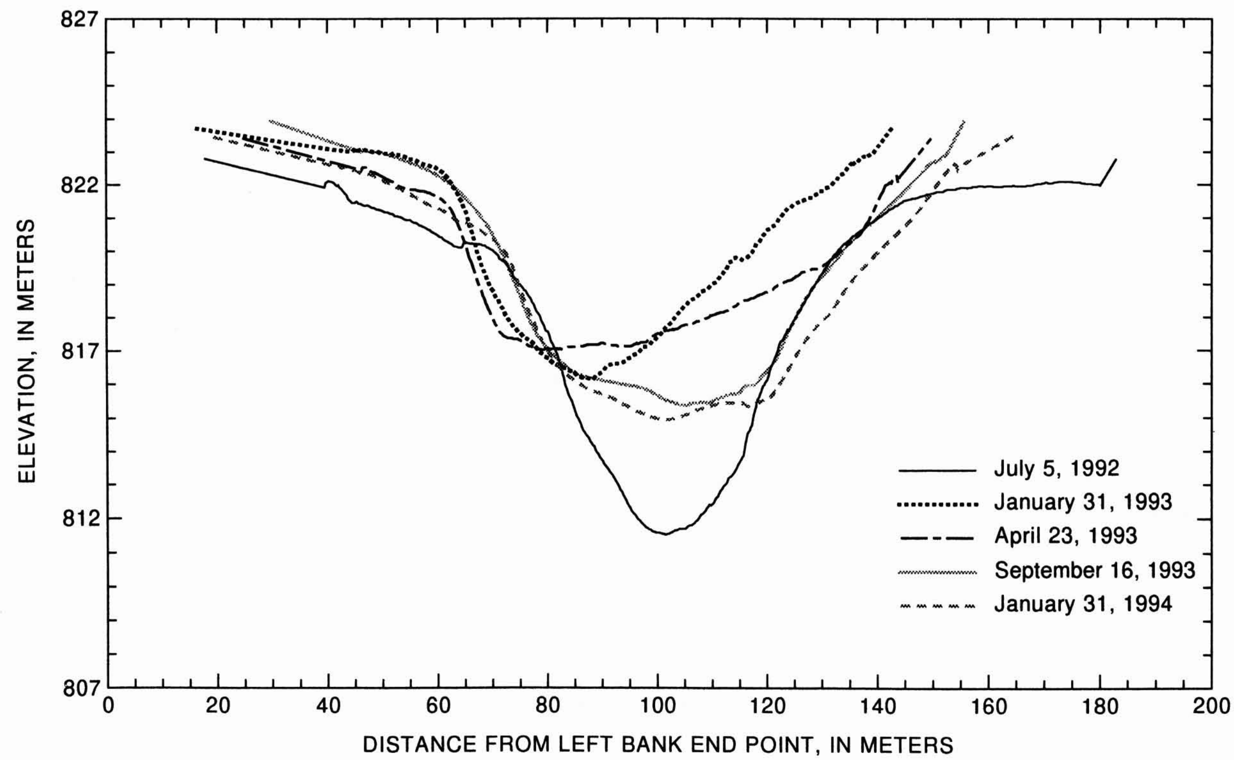

Figure 53. Cross sections measured downstream from the Little Colorado River at monumented section B3.

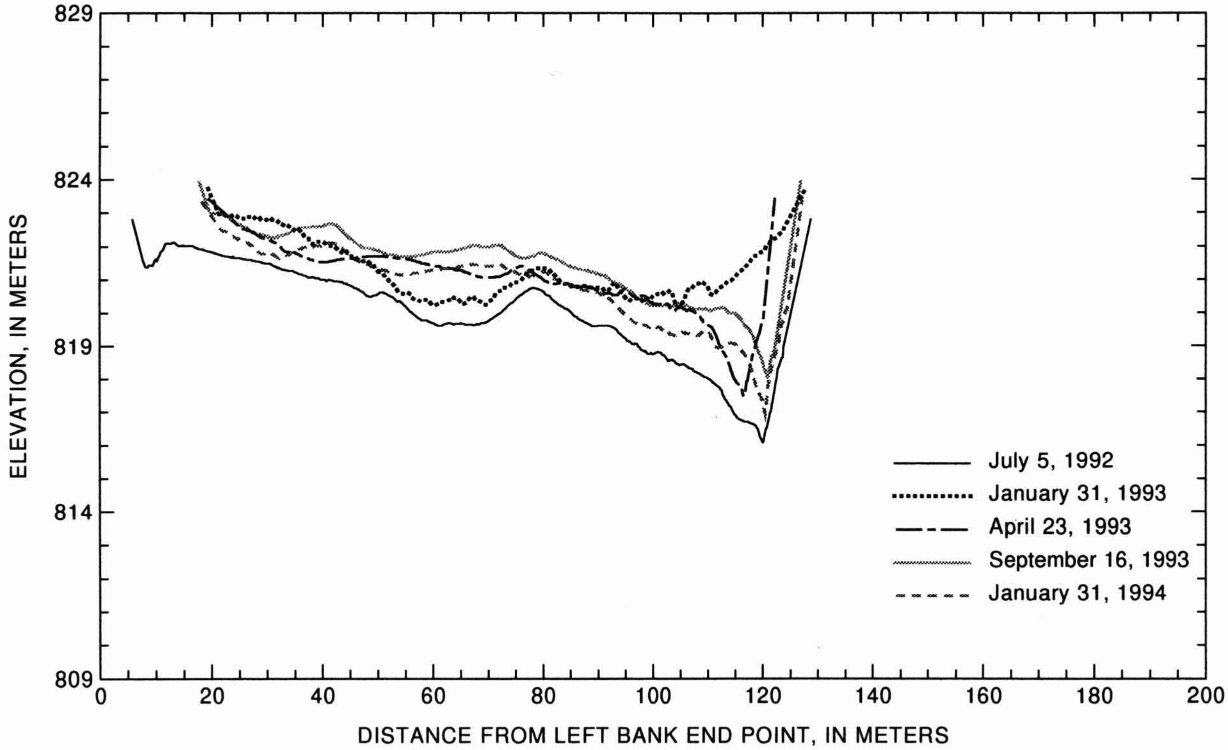

Figure 54. Cross sections measured downstream from the Little Colorado River at monumented section B4.

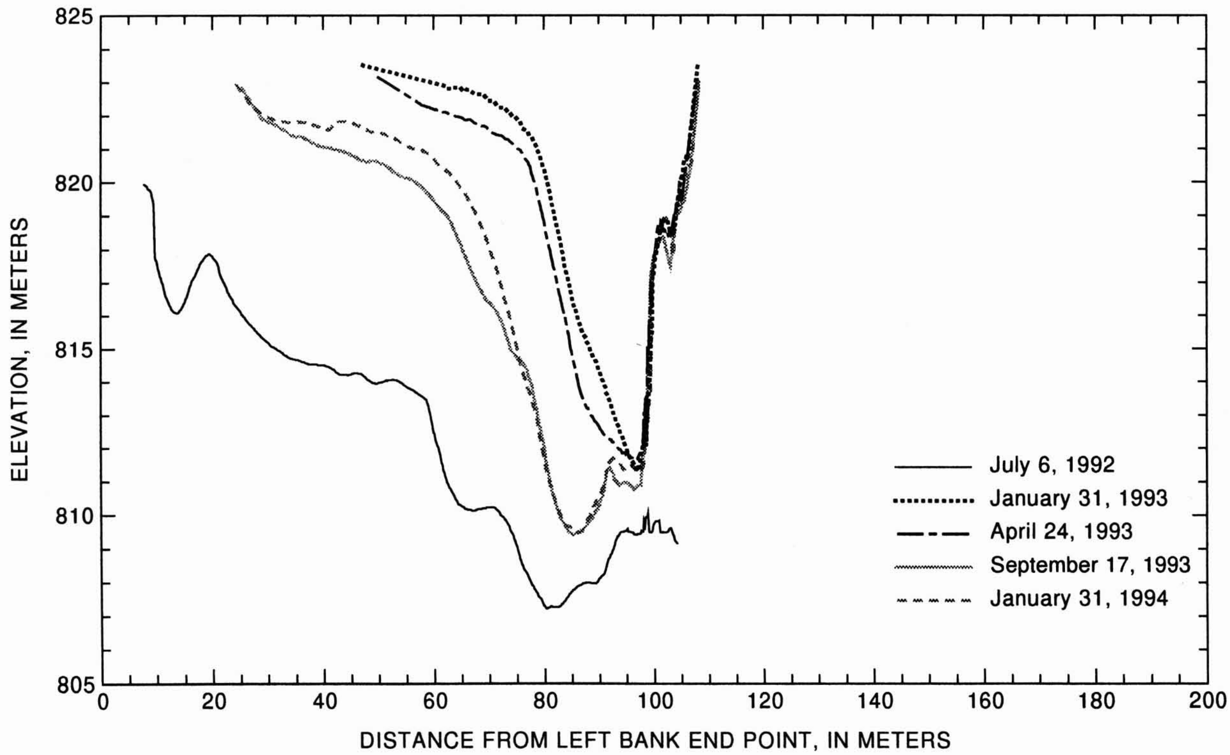

Figure 55. Cross sections measured downstream from the Little Colorado River at monumented section C1.

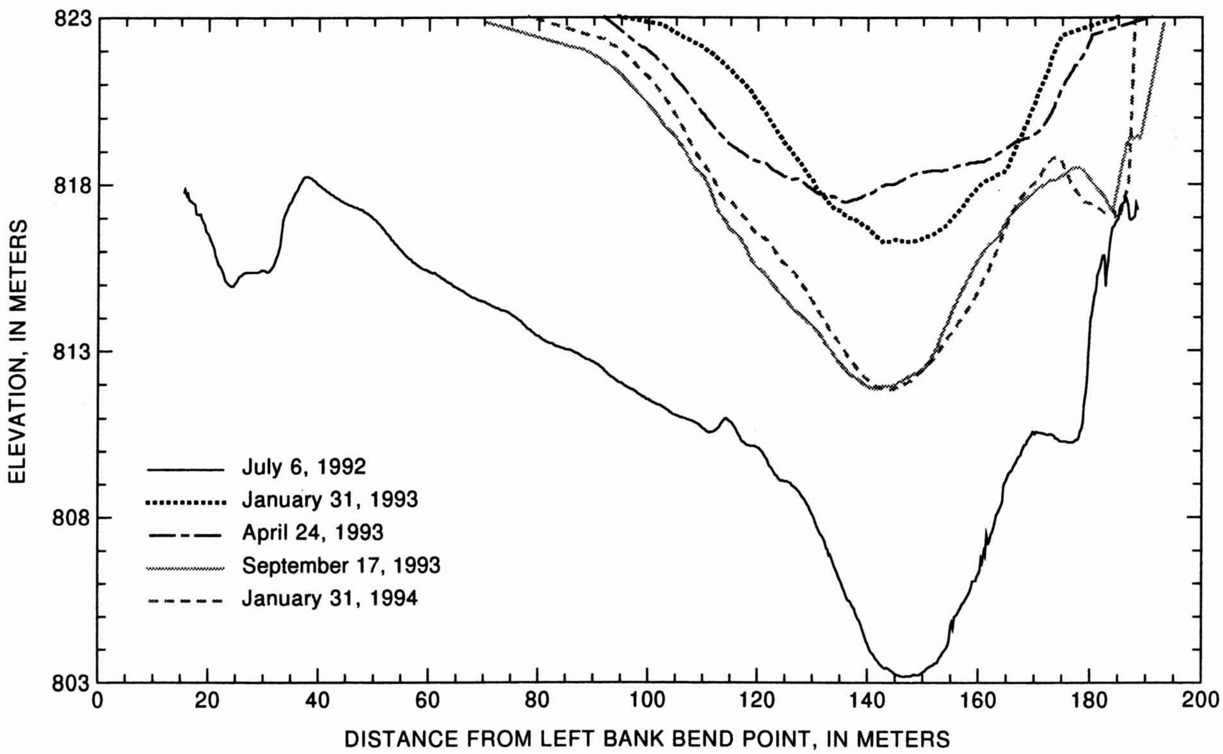

Figure 56. Cross sections measured downstream from the Little Colorado River at monumented section C2.

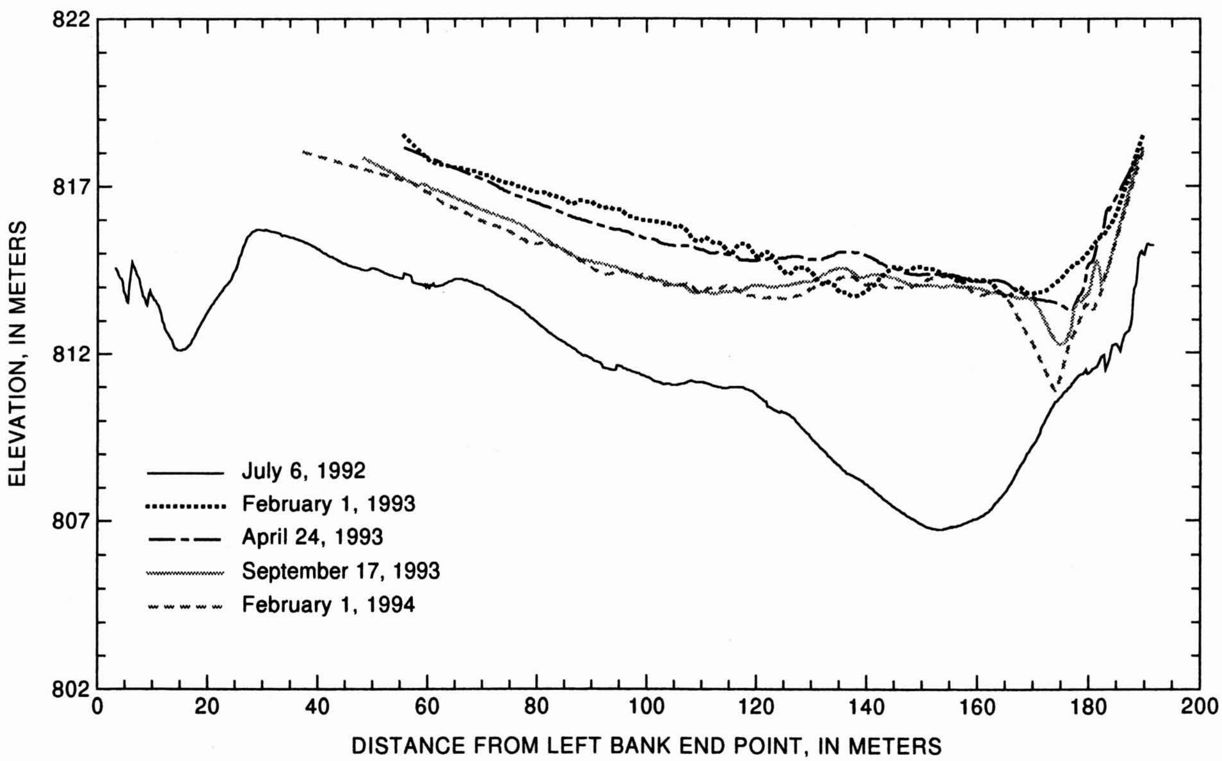

Figure 57. Cross sections measured downstream from the Little Colorado River at monumented section C3.

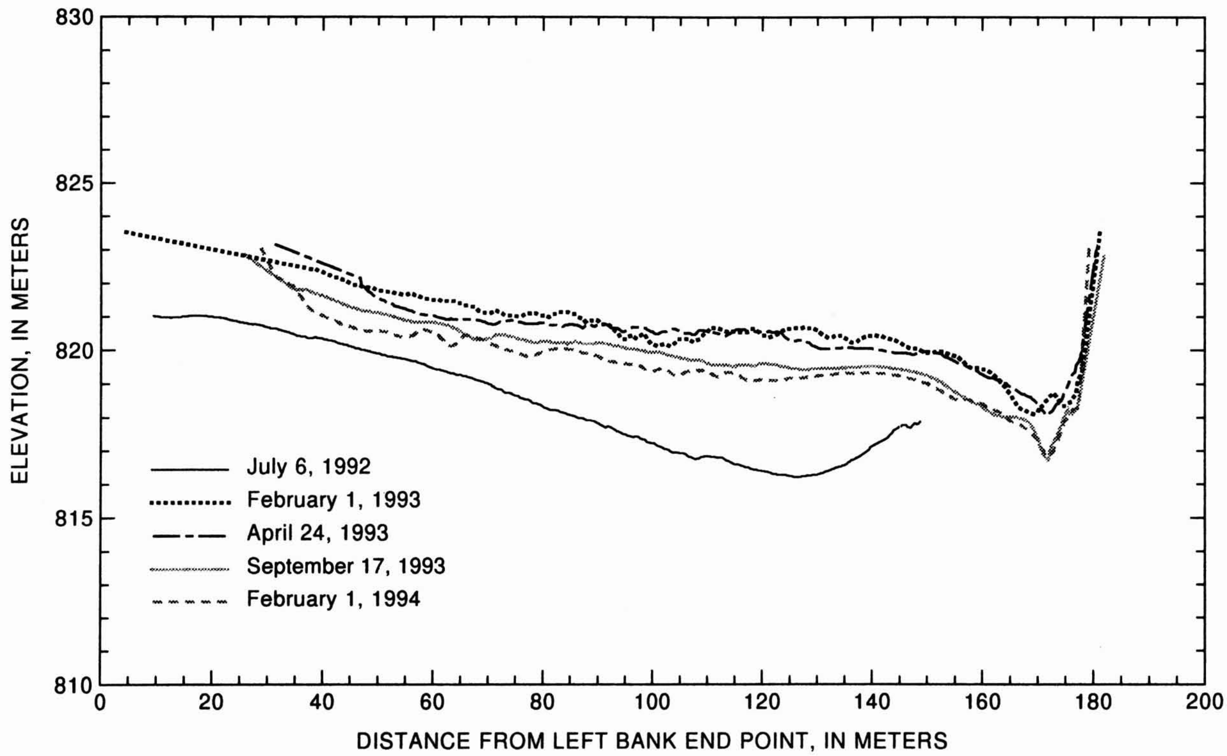

Figure 58. Cross sections measured downstream from the Little Colorado River at monumented section C4.

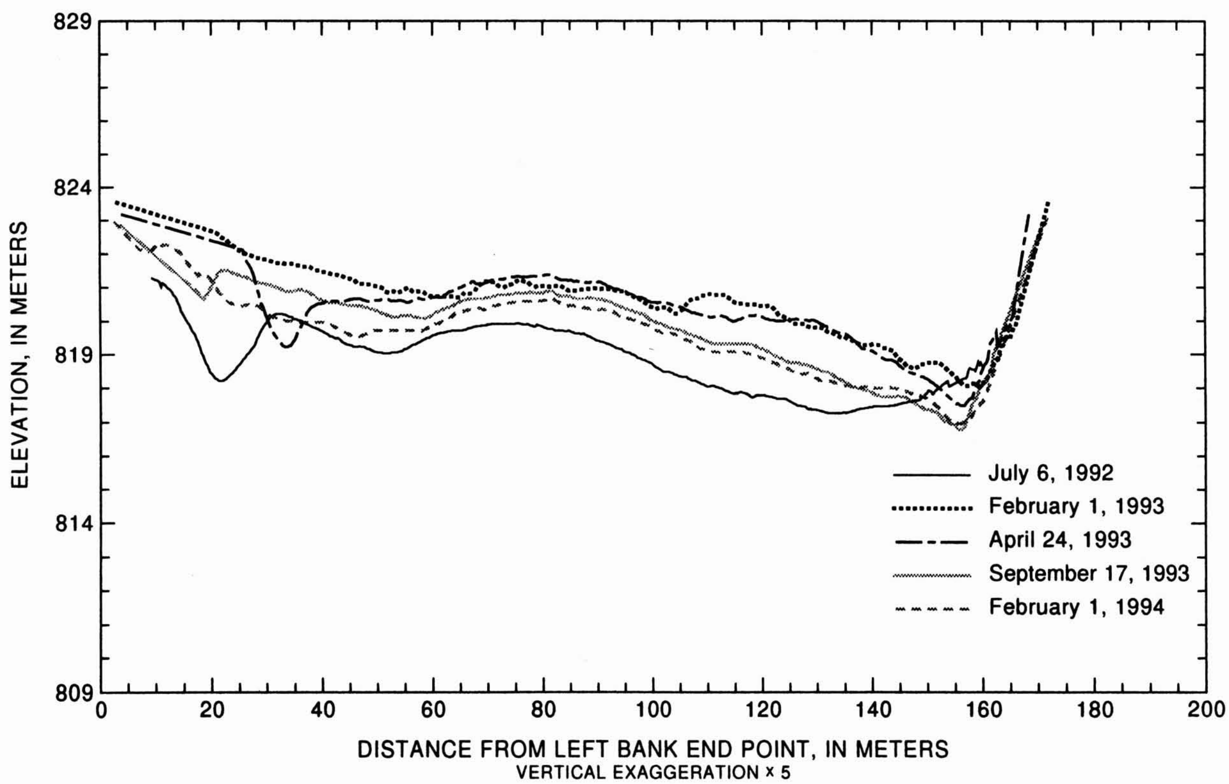

Figure 59. Cross sections measured downstream from the Little Colorado River at monumented section C5.

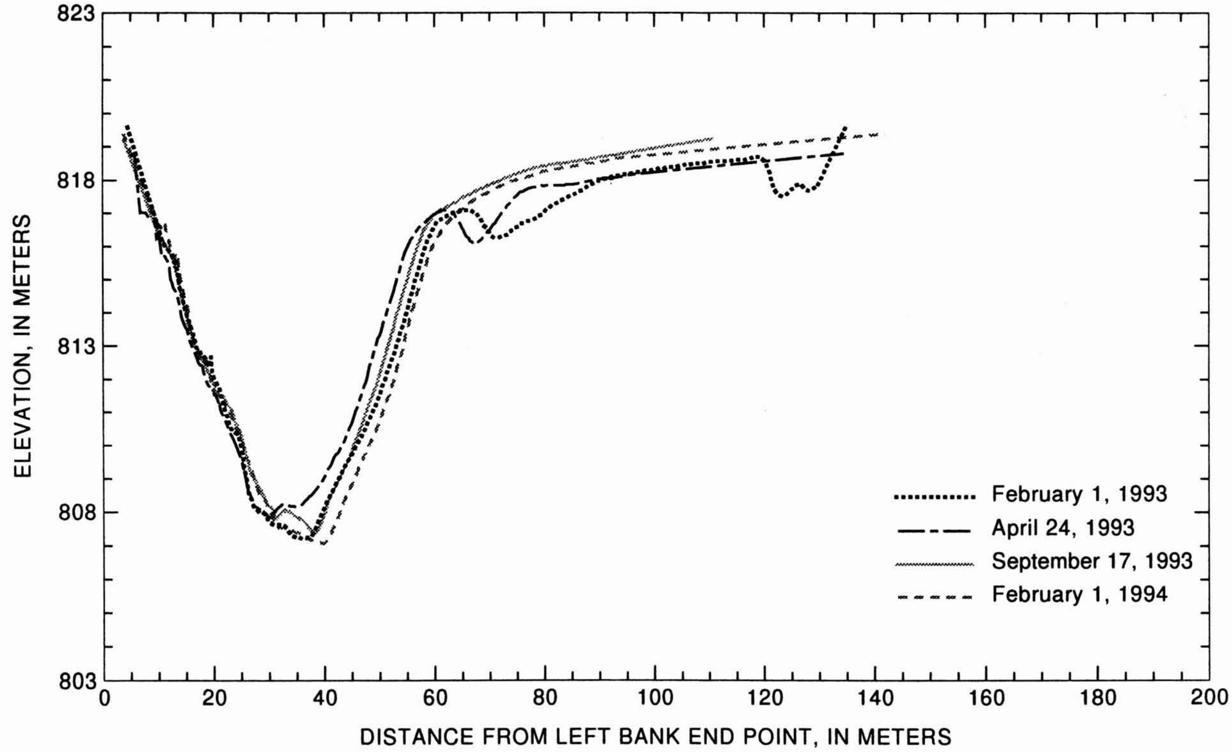

Figure 60. Cross sections measured downstream from the Little Colorado River at monumented section D1.

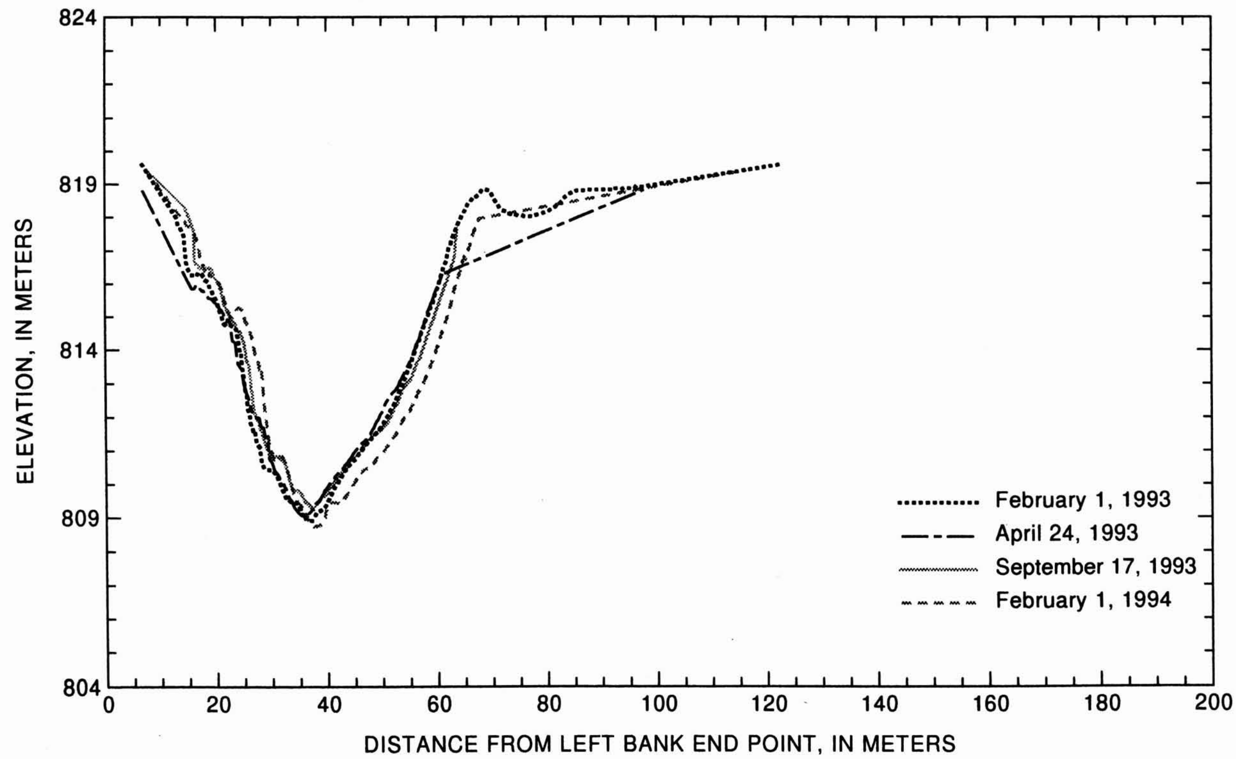

Figure 61. Cross sections measured downstream from the Little Colorado River at monumented section D2.

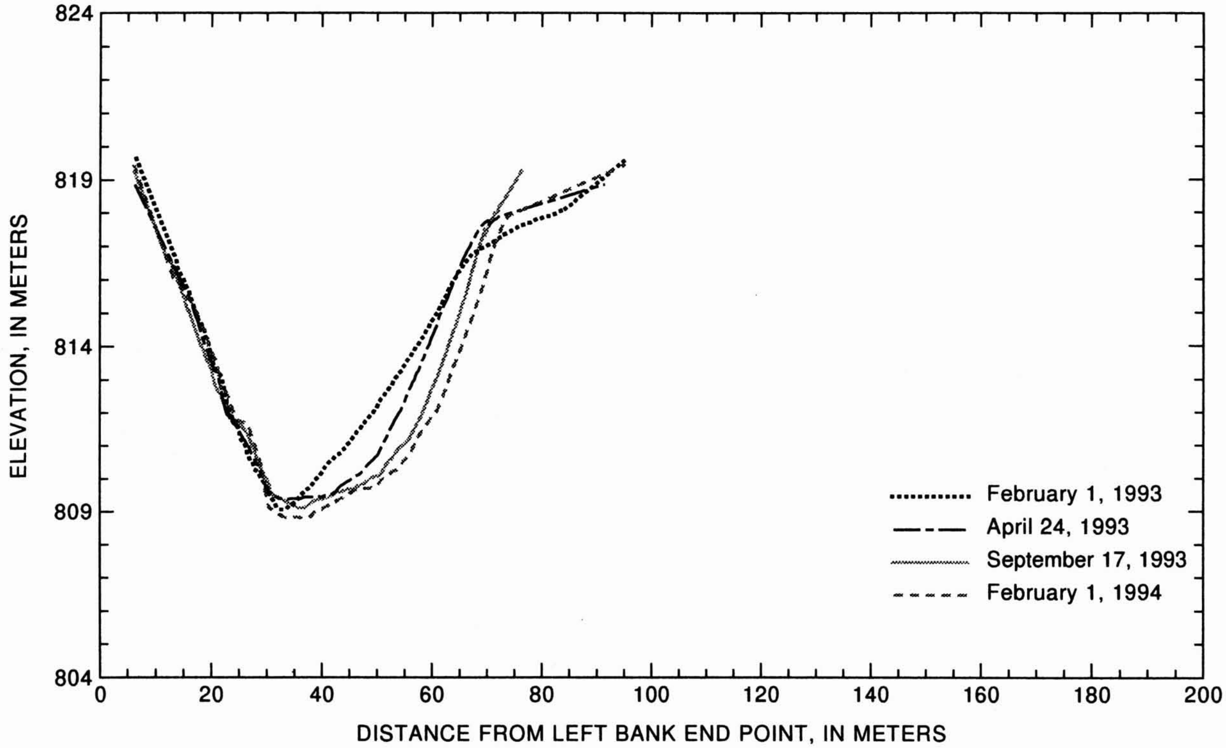

Figure 62. Cross sections measured downstream from the Little Colorado River at monumented section D3.

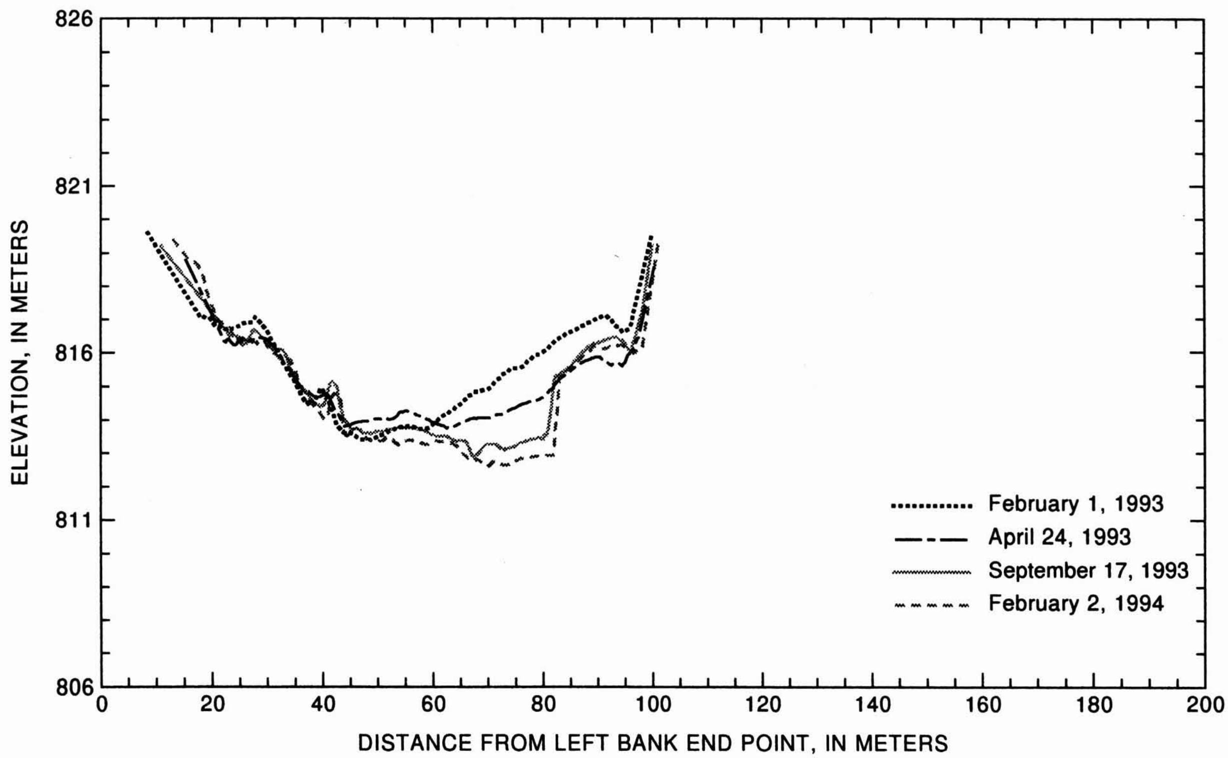

Figure 63. Cross sections measured downstream from the Little Colorado River at monumented section D4.

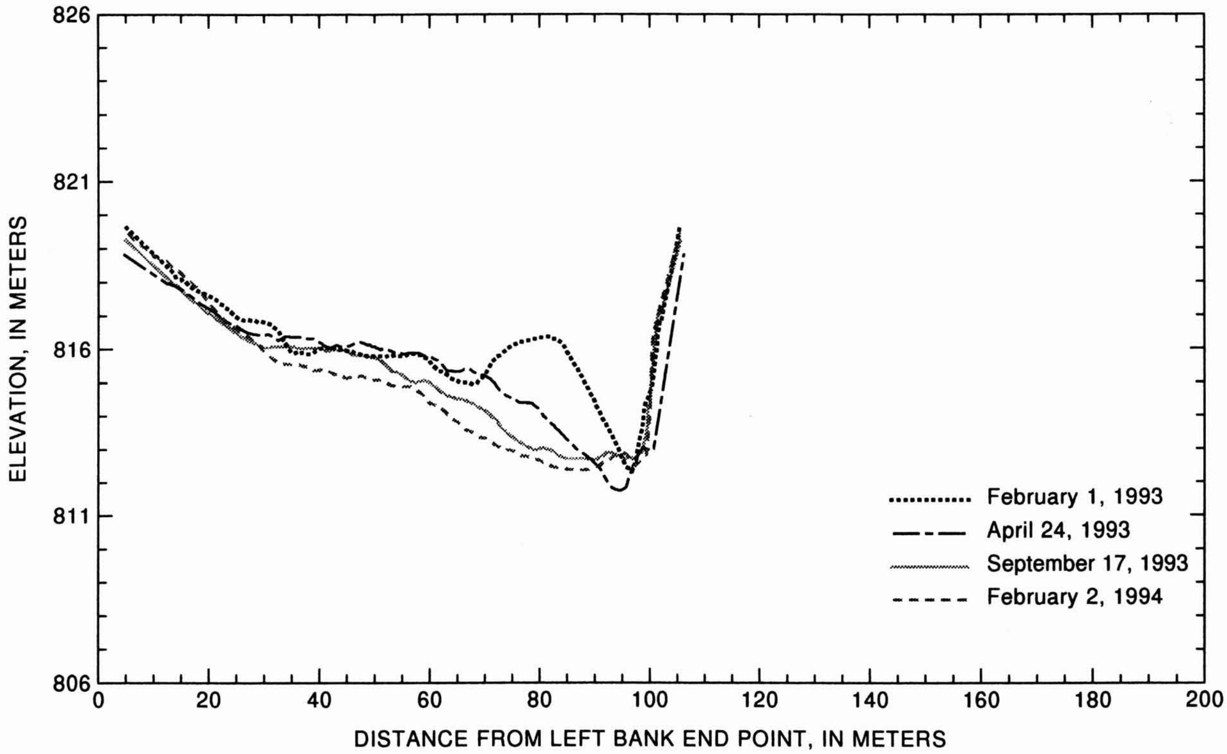

Figure 64. Cross sections measured downstream from the Little Colorado River at monumented section D5.

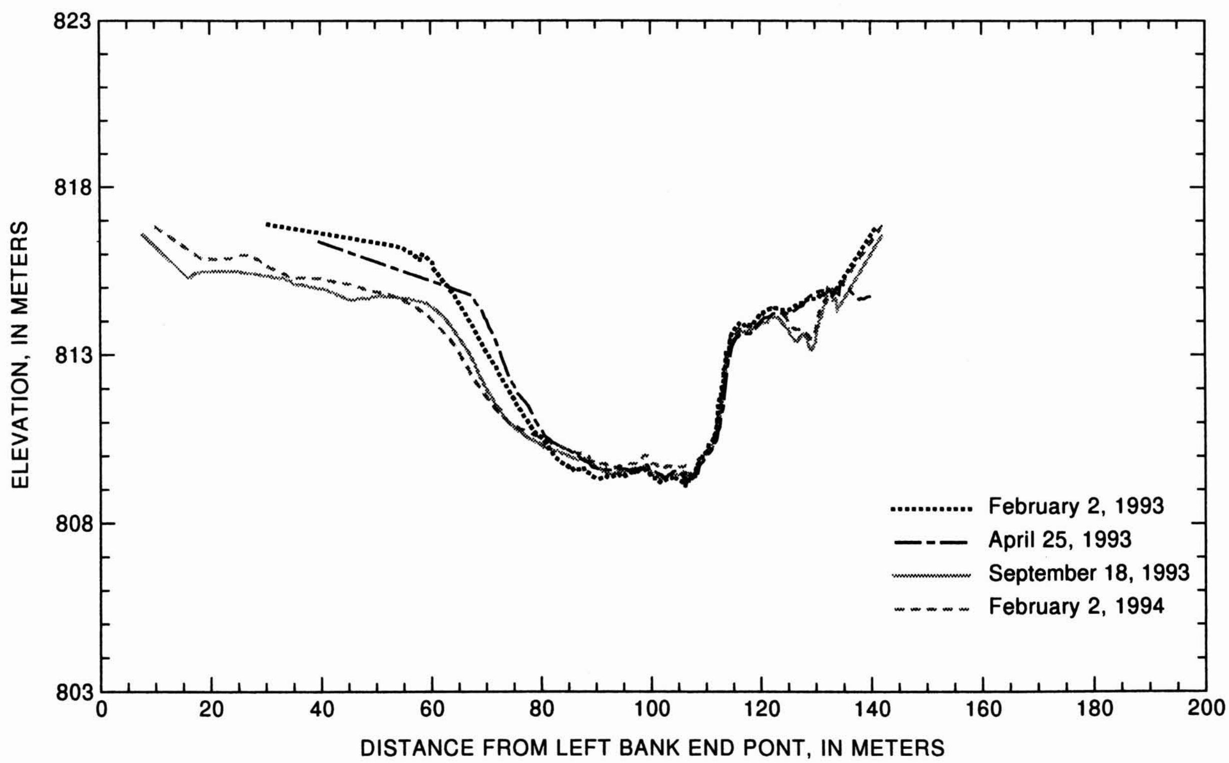

Figure 65. Cross sections measured downstream from the Little Colorado River at monumented section E1.

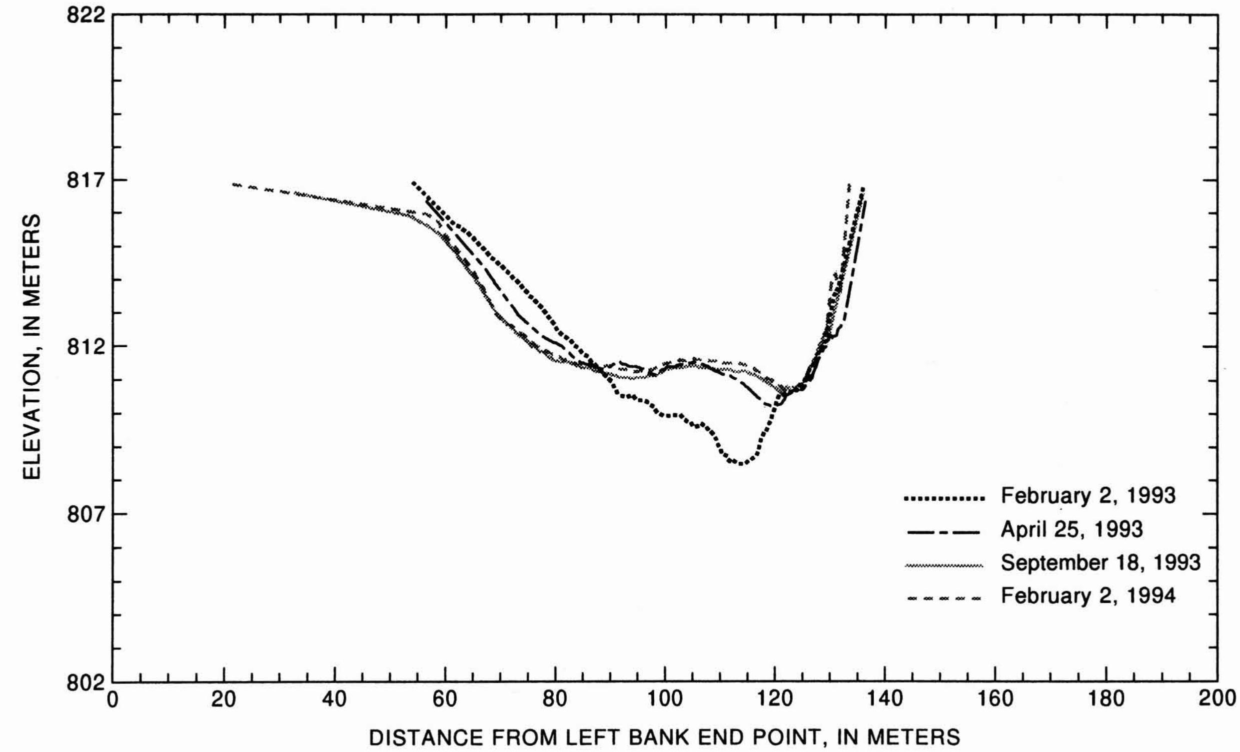

Figure 66. Cross sections measured downstream from the Little Colorado River at monumented section E2.

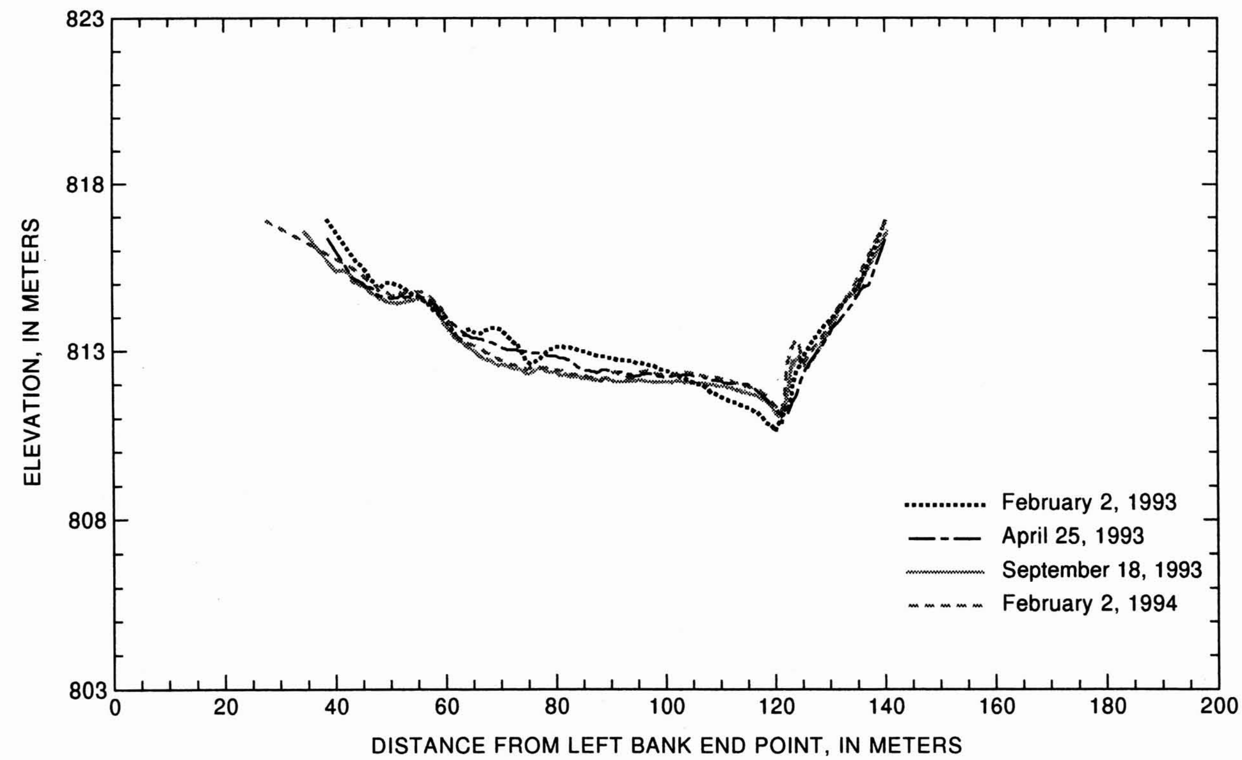

Figure 67. Cross sections measured downstream from the Little Colorado River at monumented section E3.

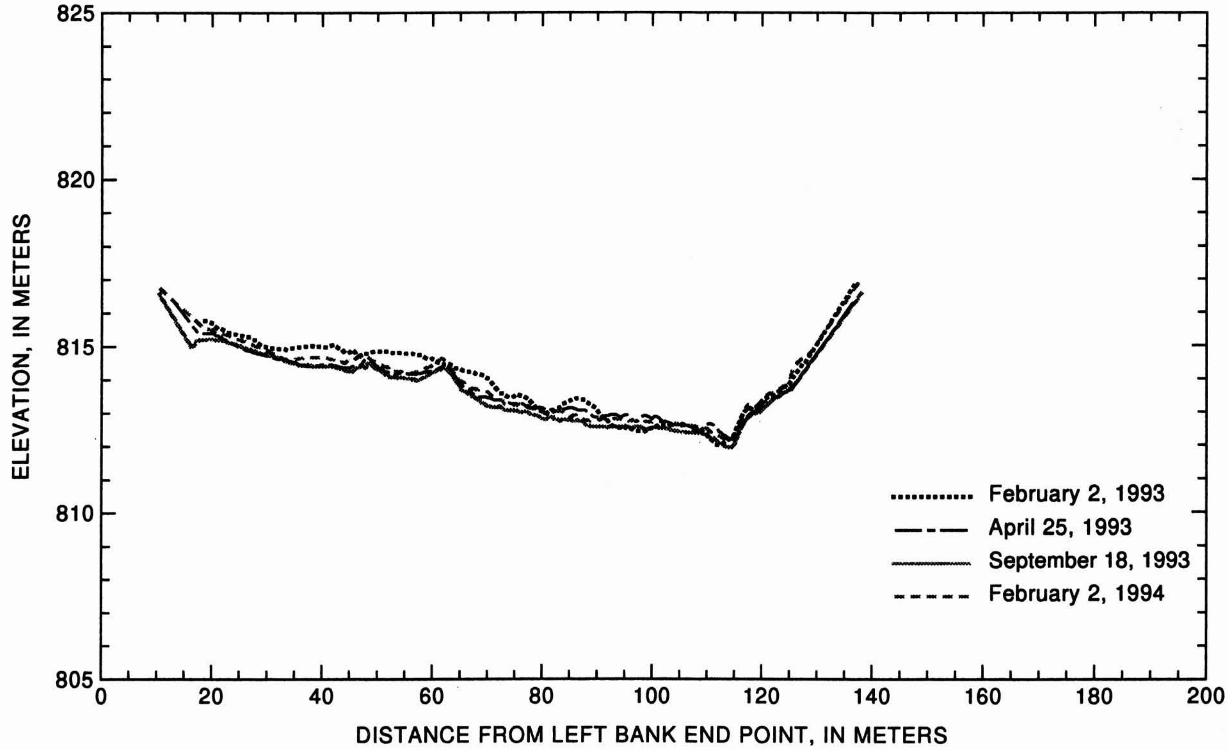

Figure 68. Cross sections measured downstream from the Little Colorado River at monumented section E4.

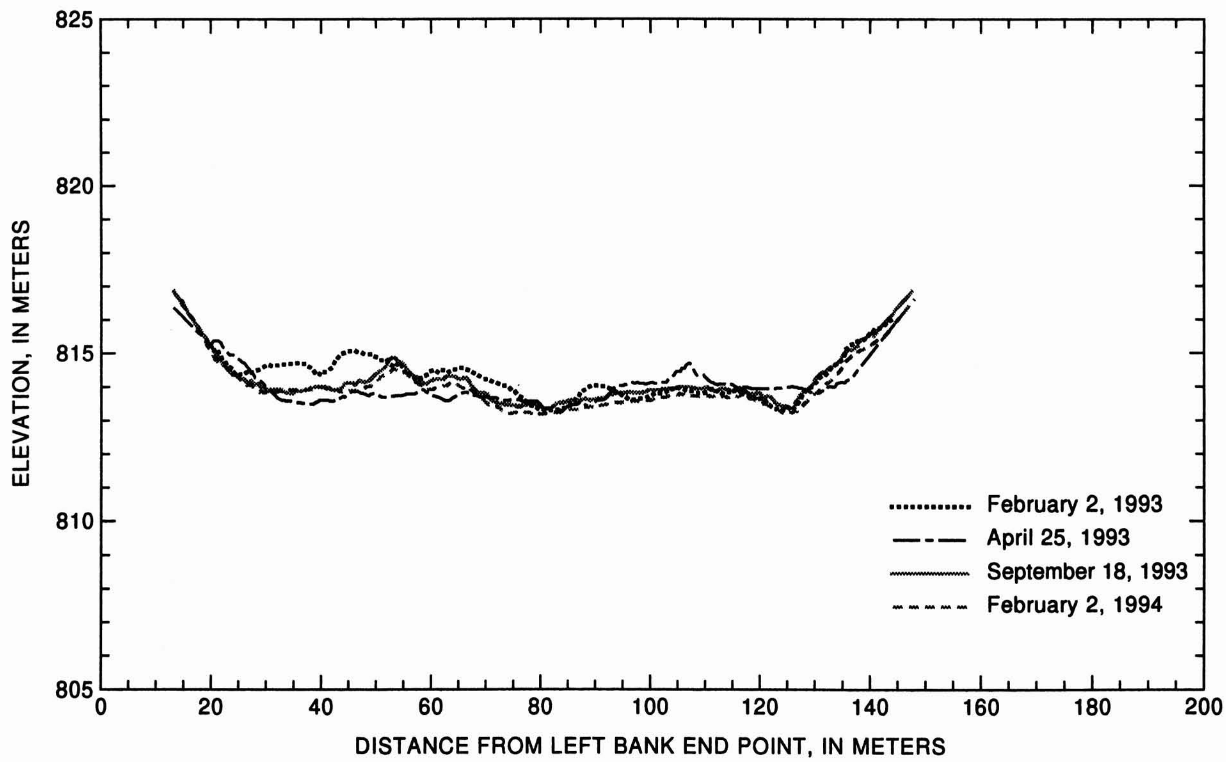

Figure 69. Cross sections measured downstream from the Little Colorado River at monumented section E5.

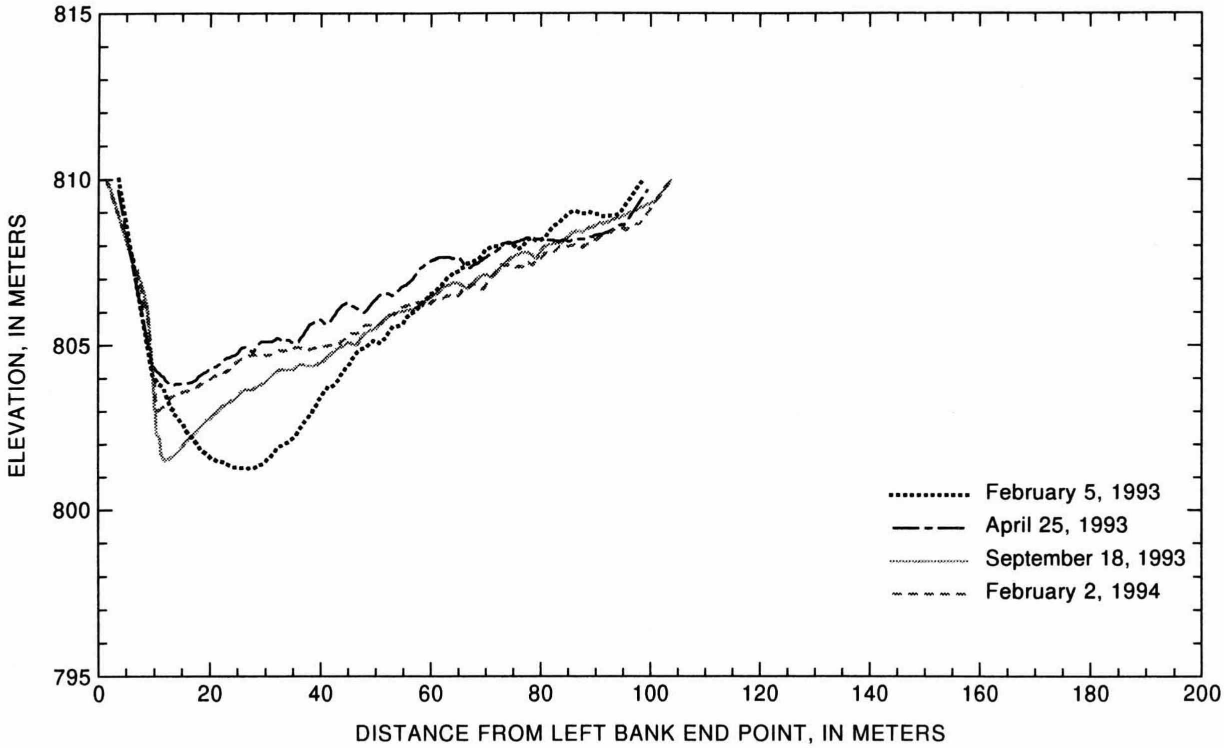

Figure 70. Cross sections measured downstream from the Little Colorado River at monumented section F1.

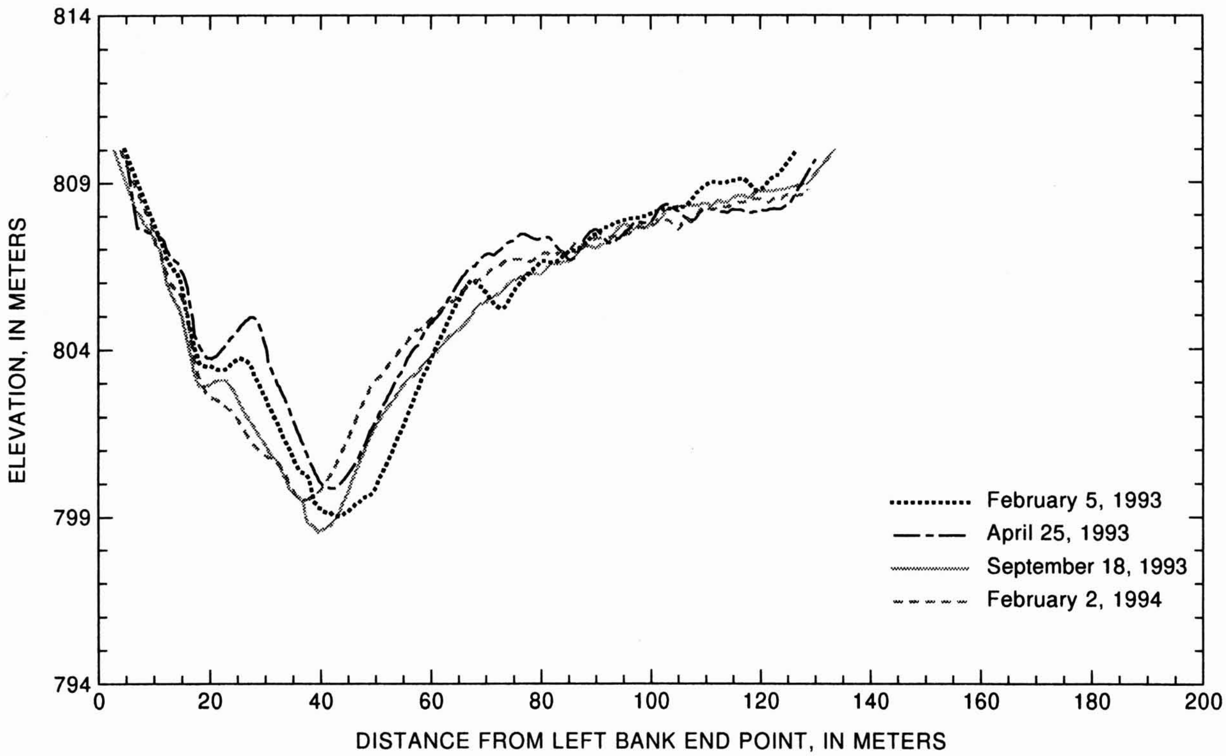

Figure 71. Cross sections measured downstream from the Little Colorado River at monumented section F2.

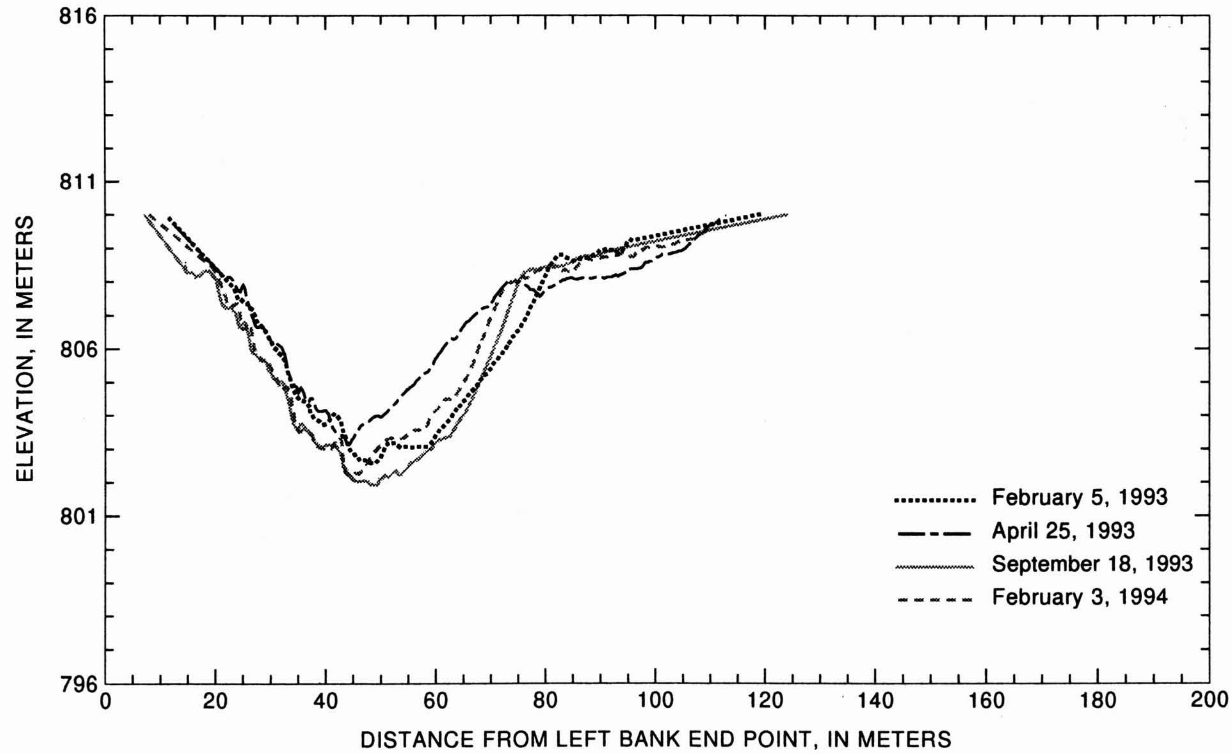

Figure 72. Cross sections measured downstream from the Little Colorado River at monumented section F3.

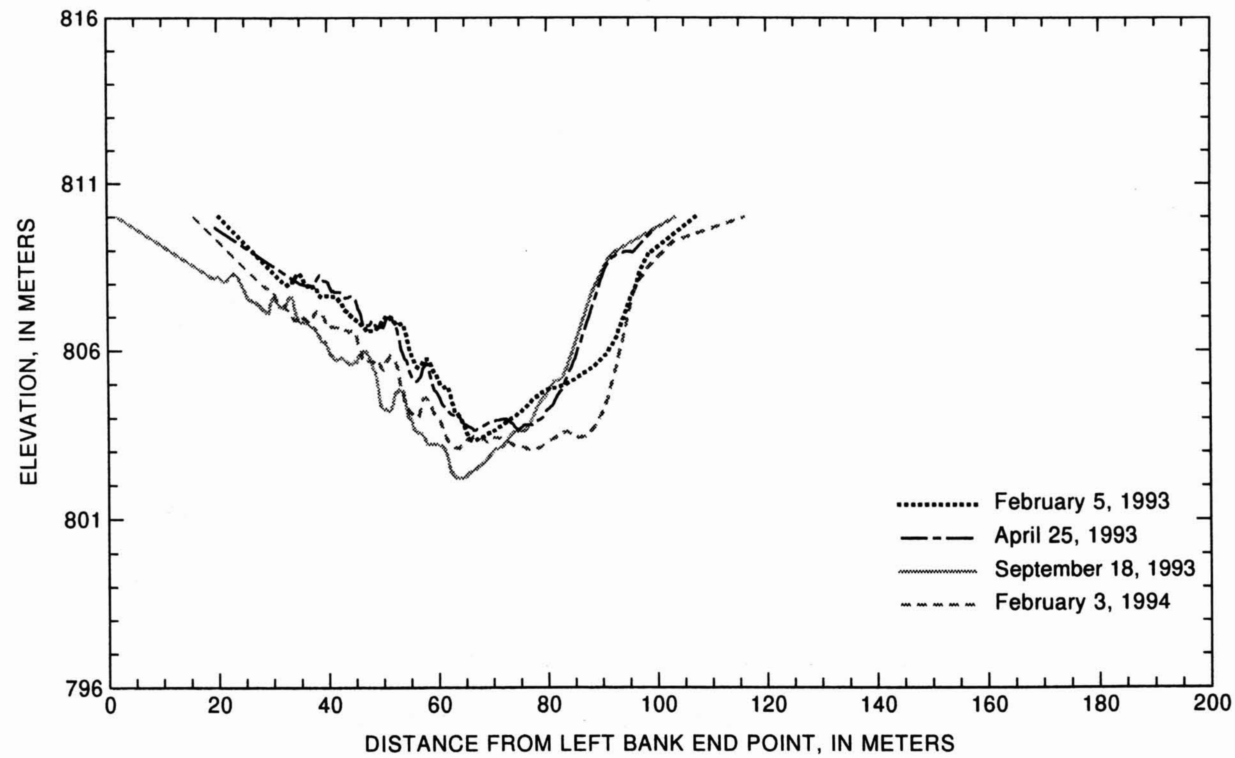

Figure 73. Cross sections measured downstream from the Little Colorado River at monumented section F4.

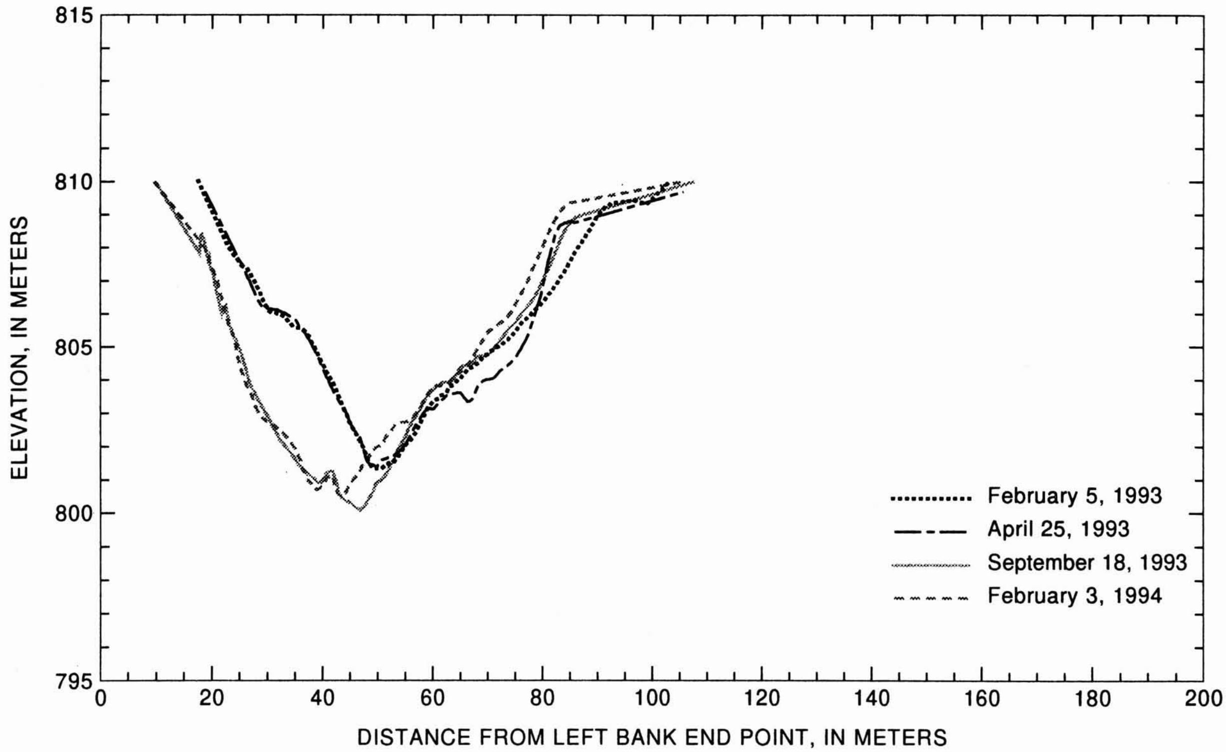

Figure 74. Cross sections measured downstream from the Little Colorado River at monumented section F5.