

Streamflow and Sediment Data Collected to Determine the Effects of a Controlled Flood in March and April 1996 on the Colorado River between Lees Ferry and Diamond Creek, Arizona

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CONVERSION FACTORS

Multiply	By	To obtain
millimeter (mm)	0.0394	inch
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
liter (L)	0.2642	gallon
kilogram (kg)	2.205	pound

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the following equation:

$$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

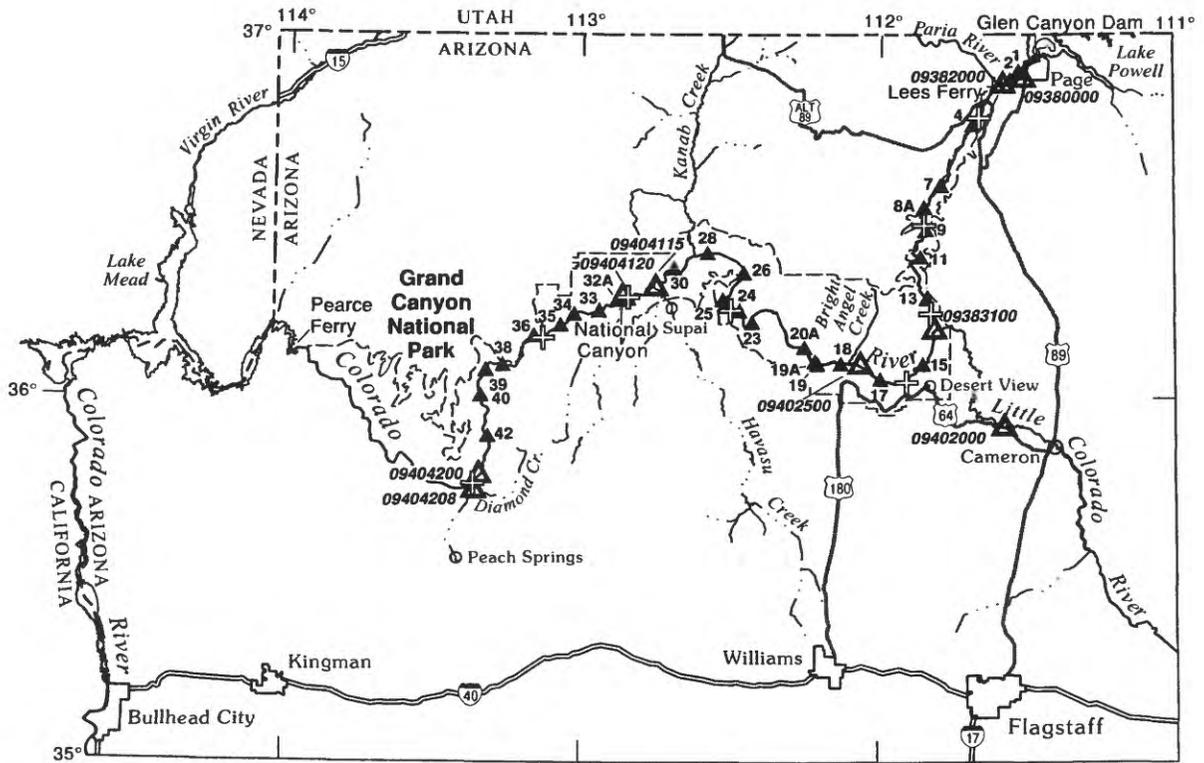
An 8-day period of planned release of water at 1,275 cubic meters per second from Glen Canyon Dam in March and April 1996 provided an opportunity to collect data on river stage, streamflow, water chemistry, and sediment transport at discharges above powerplant releases. The U.S. Geological Survey collected data at five streamflow-gaging stations on the mainstem of the Colorado River and four on tributaries during the controlled flood. River-stage data were collected at an additional 29 locations, and suspended-sediment data were collected at 4 of the 5 mainstem streamflow-gaging stations. In addition, measurements of reach-average flow velocity were made using a dye tracer, and water-surface slope was measured in reaches adjacent to three of the streamflow-gaging stations. Sand-storage changes caused by the controlled flood were documented by measuring bed elevation of the channel at cross sections before and after the controlled releases at the network of 120 monumented locations. This report presents selected data in tabular and graphical form. The data presented in the report are available in electronic form.

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 powerplant 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 releases of water through the dam 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 releases from the dam on the riparian and aquatic resources of the Colorado River downstream from Glen Canyon 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 from Glen Canyon Dam.

Because of growing concern of the effects from releases from the dam on riparian resources, restrictions were placed by Congress on releases under the Grand Canyon Protection Act of 1992. This Act requires the Secretary of the Interior to operate Glen Canyon Dam to protect and improve the uses for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. An Environmental Impact Statement (EIS) on operations of the dam was requested by the Secretary and was completed in March 1995. The EIS resulted in a preferred operating



Base from U.S. Geological Survey digital data, 1:100,000, 1980
 Lambert Conformal Conic projection
 Standard parallels 29°30' and 45°30', central meridian -96°00'

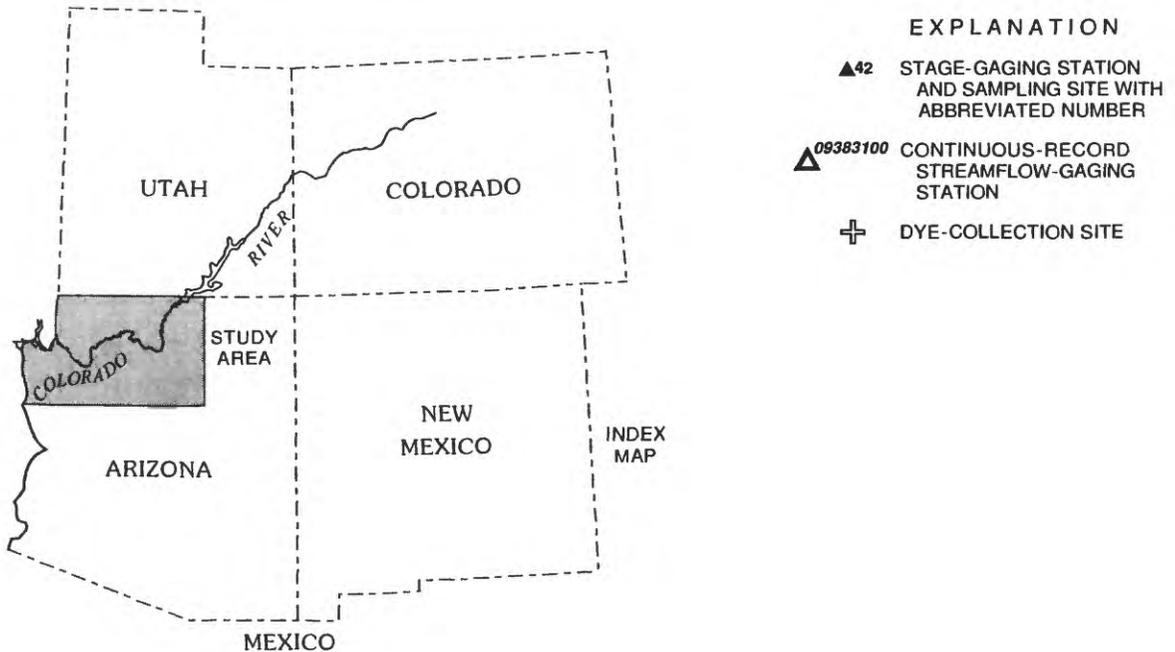
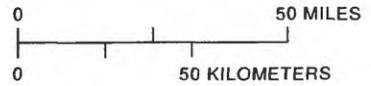


Figure 1. Study area and locations of gaging stations and sampling sites.

2 Data Collected to Determine the Effects of a Controlled Flood in March and April 1996 on the Colorado River

alternative for the dam that included scheduled short duration, high-flow releases from the dam to simulate some of the dynamics of a natural river and to accomplish specific management objectives for the riparian resources.

In March and April 1996, an experiment of a controlled high-flow release from Glen Canyon Dam was made to evaluate the feasibility of using such a release to meet the management objectives identified in the EIS. The experiment included an 8-day period of 1,275 m³/s high-flow release preceded and followed by a 3-day period of steady release of 227 m³/s. These releases were intended to simulate the type and approximate timing of the floods that occurred in response to snowmelt runoff before the dam was built. The high-flow release was more than double the maximum release of 566 m³/s allowed under the interim-flow criteria implemented in 1991 to protect the riparian system from extreme daily flow fluctuations. However, the high-flow release was only about half of the average annual peak discharge that the system experienced under natural conditions and much smaller in volume than the typical annual snowmelt hydrograph as shown by the annual hydrograph for the year 1942 (fig. 2).

Purpose and Scope

The U.S. Geological Survey (USGS) collected data on stage, discharge, water chemistry, flow velocity, water-surface slope, suspended-sediment transport, and sand storage associated with the controlled high-flow release from Glen Canyon Dam from March 26 to April 2, 1996. This report includes the data collected before, during, and after the experimental releases from the dam to document flow conditions and the response of sediment on the channel to the high-flow release.

Acknowledgments

Many individuals helped with the collection of data presented in this report. Scott C. Alexander, Bernice E. Cobb, Ernest D. Cobb, Wooddora Eisenhauer, Jamie Harding, Sally Haines, L. Rodney Larson, Joseph K. Lyons, Jeffrey L. Manning, Dr. Erich R. Marzolf, Travis McGrath, Dr. James M. Mitchell, Rodney H. Roeske, Orville Rosenberry, Rick Seidemann, Ron Teeters, Mark Thompson, and Brian Thompson helped collect data under the Volunteers For Science Program.

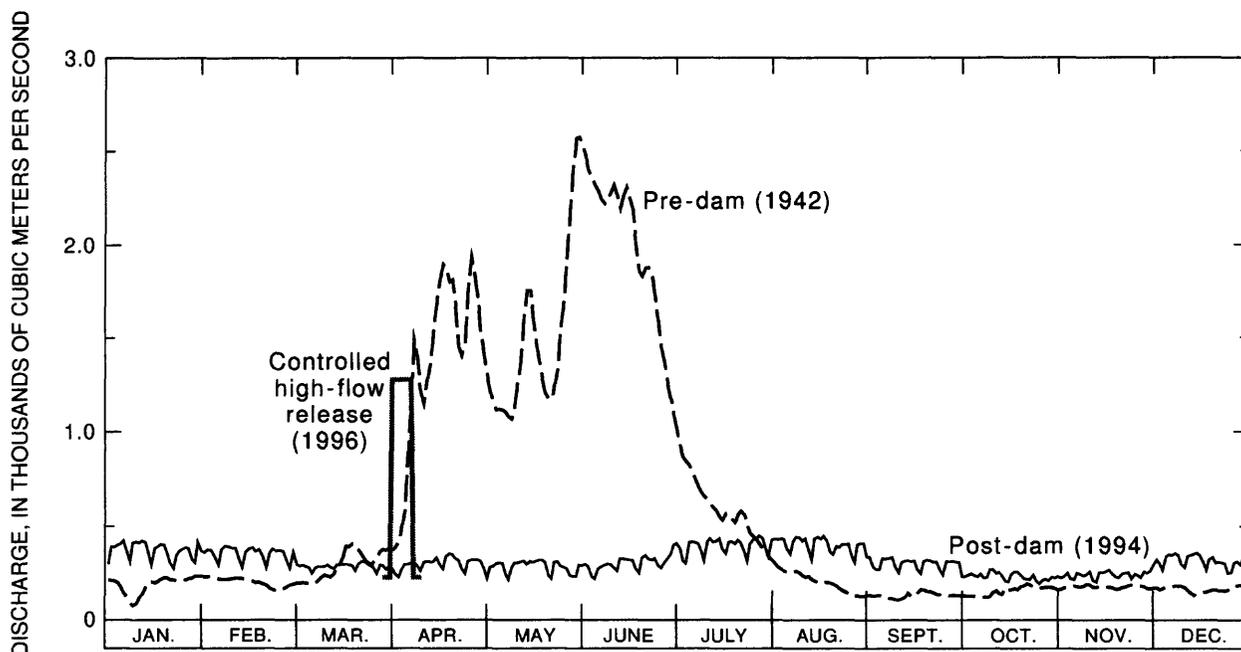


Figure 2. Relation of the controlled high-flow release of 1996 to a typical snowmelt-runoff hydrograph (1942) before dam construction and to typical powerplant releases (1994).

Dr. Erich R. Marzolf of the St. Johns River Water Management District and E. Calvin Alexander of the Geology and Geophysics Department, University of Minnesota, provided fluorimeters for the measurement of reach-average velocity.

STREAMFLOW-GAGING STATIONS

River stage was measured throughout the period at five mainstem streamflow-gaging stations and streamflow-gaging stations on four tributaries (fig. 1; table 1). Tributaries had no runoff during the period. Discharge was measured at the five mainstem streamflow-gaging stations to verify stage-discharge ratings at those sites (table 2). Discharge hydrographs at the five mainstem sites illustrate the passage of the controlled flood through the canyon (fig. 3).

Samples for analysis of suspended-sediment concentration were collected at four mainstem streamflow-gaging stations (table 3). Three of the samples collected at gaging station 09383100, Colorado River above the Little Colorado River, seven samples collected at 09402500, Colorado River near Grand Canyon, and all six samples collected at gaging station 09404120, Colorado River above National Canyon near Supai, were point samples collected to define the suspended-sediment transport field in the cross section (table 4). Samples of bed material in the gaged section were collected at the gaging station

near Grand Canyon once each day during March 26–April 3, 1996. Laboratory analyses of some samples from gaging station 09383100, Colorado River above the Little Colorado River; and 09402500, Colorado River near Grand Canyon, were not complete at the time of writing this report, and these data are not included.

Suspended-sediment samples were collected and point velocity was measured from a cableway at 10 or 11 locations in the cross section at gaging station 09404120, Colorado River above National Canyon near Supai. At each location, point suspended-sediment samples were collected with a P-61 suspended-sediment sampler (Edwards and Glysson, 1988) at seven points in the water column. Each sample, therefore, consisted of a suite of 70 or 77 samples. Measurements of flow velocity at similar points were made using a Price AA meter and standard rating (Rantz and others, 1982). A suite of suspended-sediment samples and point-velocity measurements was collected on each of 6 days during the passage of the controlled flood at the gaging station (fig. 4; table 5). Similar samples and measurements were made in 1991 during a period of releases from the dam designed to characterize the response of resources to various steady- and fluctuating-flow patterns within the operating range of the powerplant. Specific details of sample collection and velocity measurement are given by Christiansen (1993). The streamflow-gaging station at National Canyon was discon-

Table 1. Streamflow-gaging stations at which data were collected during the controlled releases of 1996

Station number	Station name	Data collected
09380000	Colorado River at Lees Ferry, Ariz.	Stage, discharge, water temperature, water-quality samples, sediment samples
09382000	Paria River at Lees Ferry, Ariz.	Stage; no runoff during the period
09383100	Colorado River above the Little Colorado River near Desert View, Ariz.	Stage, discharge, sediment samples
09402000	Little Colorado River near Cameron, Ariz.	Stage; no runoff during the period
09402500	Colorado River near Grand Canyon, Ariz.	Stage, discharge, sediment samples
09404115	Havasu Creek above mouth near Supai, Ariz.	Stage; no runoff during the period
09404120	Colorado River above National Canyon near Supai, Ariz.	Stage, discharge, sediment samples
09404200	Colorado River above Diamond Creek near Peach Springs, Ariz.	Stage, discharge
09404208	Diamond Creek near Peach Springs, Ariz.	Stage; no runoff during the period

Table 2. Discharge measured at streamflow-gaging stations during the controlled releases of 1996

Date	Time	Width, in meters	Area, in square meters	Mean velocity, in meters per second	Stage, in meters	Discharge, in cubic meters per second
09380000 Colorado River at Lees Ferry, Ariz.						
03-26-96	0800	125.9	782.5	1.08	3.66	824
03-26-96	1140	134.1	878.3	1.42	4.14	1,206
03-28-96	1120	131.1	881.0	1.49	4.24	1,311
04-02-96	1055	149.0	898.7	1.46	4.23	1,311
04-06-96	1505	123.7	627.3	.37	2.46	236
09383100 Colorado River above the Little Colorado River near Desert View, Ariz.						
03-26-96	0945	100.6	335.7	.71	8.40	237
03-27-96	1100	115.8	676.3	1.82	11.63	1,232
03-29-96	1000	108.2	642.8	2.00	11.66	1,286
03-31-96	1040	115.8	661.7	1.96	11.67	1,297
04-06-96	1500	101.2	331.1	.72	8.39	237
09402500 Colorado River near Grand Canyon, Ariz.						
03-26-96	1000	86.6	354.1	.67	2.09	238
03-27-96	1510	92.4	665.4	2.01	5.70	1,340
03-28-96	1510	91.4	614.3	2.08	5.70	1,280
03-29-96	1000	92.0	645.9	2.07	5.71	1,340
03-31-96	0920	92.0	616.2	2.15	5.65	1,328
04-02-96	1500	92.0	658.0	2.05	5.65	1,345
04-03-96	1525	90.2	538.1	1.48	4.26	787
09404120 Colorado River above National Canyon near Supai, Ariz.						
03-26-96	1005	81.1	341.1	.73	11.45	250
03-28-96	1630	96.6	756.5	1.76	15.61	1,334
03-29-96	1645	94.5	698.0	1.79	15.60	1,246
04-02-96	1610	97.2	687.9	1.90	15.62	1,311
09404200 Colorado River above Diamond Creek near Peach Springs, Ariz.						
03-29-96	1430	69.8	626.4	2.29	17.68	1,430
03-30-96	1100	70.1	573.7	2.43	17.70	1,393

tinued following the controlled releases, and all equipment at the site was removed.

Water samples were collected at the streamflow-gaging station 09380000, Colorado River at Lees Ferry, for chemical analysis as a part of the USGS National Stream Quality Accounting Network (NASQAN) (Horowitz, 1994; Leahy, 1993) program and periodic sampling in cooperation with the Arizona Department of

Environmental Quality. Samples were collected on March 25, at a discharge of 234 m³/s; on March 27, at a discharge of 1,277 m³/s; on April 1, at a discharge of 1,294 m³/s; and on April 6, at a discharge of 231 m³/s. The samples were analyzed at the USGS National Water-Quality Laboratory in Arvada, Colorado, for a broad range of constituents that included nutrients, major ions, metals, and bacteria (table 6).

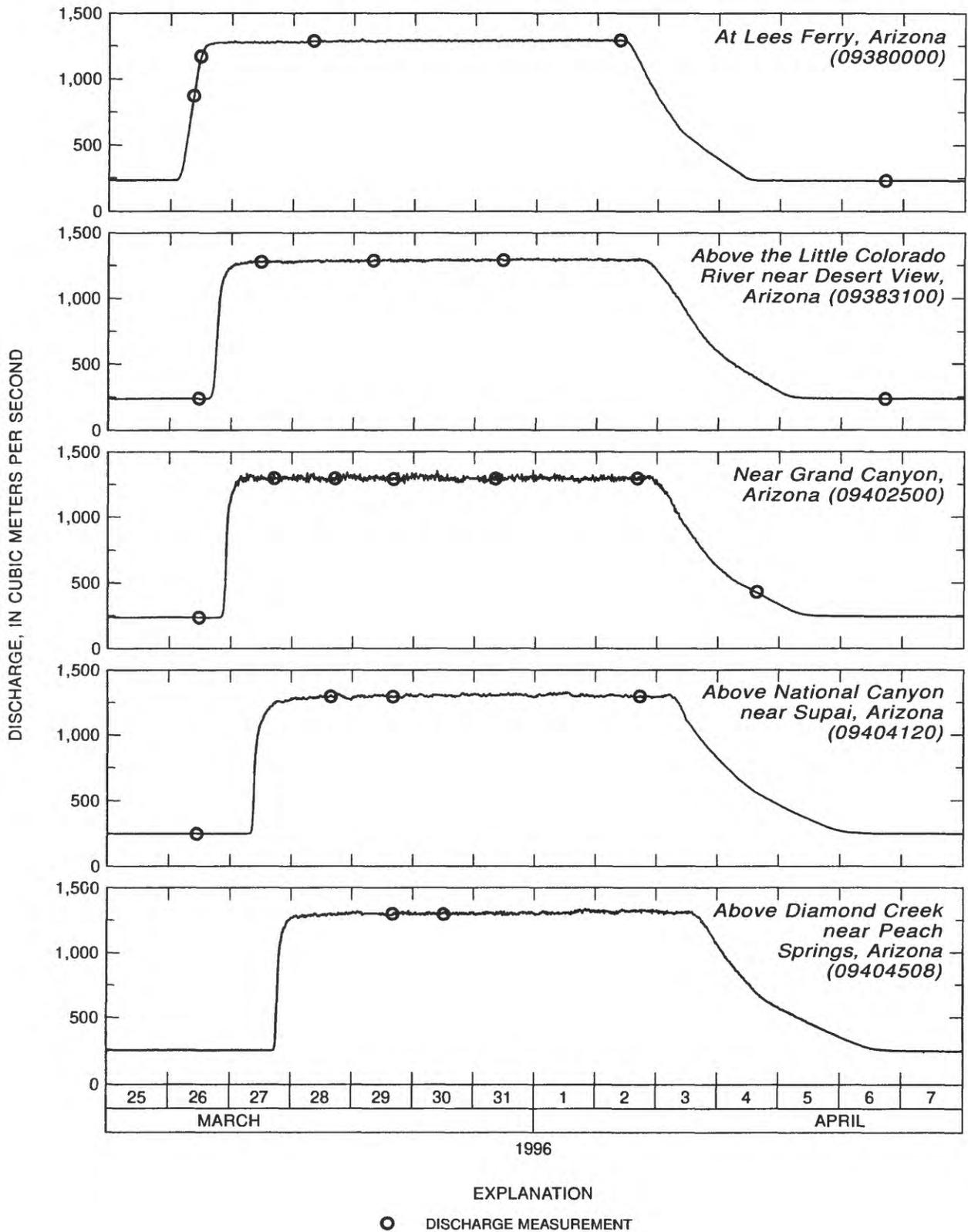


Figure 3. Discharge during the controlled releases of 1996 at streamflow-gaging stations on the Colorado River.

Table 3. Sediment samples collected at streamflow-gaging stations during the controlled releases of 1996

[EDI, equal discharge increment; DI, depth integrated; dashes indicate no data]

Date	Time	Discharge, in cubic meters per second	Sampling method	Sampler	Point velocity measured	Comments
09380000 Colorado River at Lees Ferry, Ariz.						
03-25-96	1620	238	EDI	D77	No	
03-27-96	0905	1,279	EDI	D77	No	
04-01-96	1100	1,312	EDI	D77	No	NASQAN protocol followed for all samples
04-06-96	0945	246	EDI	D77	No	
09383100 Colorado River above the Little Colorado River near Desert View, Ariz.						
03-27-96	--	1,294	EDI	D77	No	
03-28-96	1146	1,278	Point	P61	Yes	Three verticals, 7 points sampled in each
03-29-96	1540	1,280	EDI	D77	No	
03-30-96	1340	1,293	Point	P61	Yes	Three verticals, 7 points sampled in each
04-01-96	1049	1,292	Point	P61	Yes	Three verticals, 7 points sampled in each
04-02-96	1221	1,296	EDI	D77	No	
09402500 Colorado River near Grand Canyon, Ariz.						
03-26-96	1325	238	EDI	D77	No	Percent sand
03-26-96	1705	236	Dip	---	No	River center; no size
03-27-96	1001	1,290	DI	P61	No	Cable station 190; sand size
03-27-96	1011	1,276	DI	P61	No	Cable station 190; sand size
03-27-96	1244	1,290	DI	P61	No	Cable station 190; sand size
03-27-96	1249	1,290	DI	P61	No	Cable station 190; sand size
03-27-96	1257	1,301	DI	P61	No	Cable station 290; sand size
03-27-96	1302	1,301	DI	P61	No	Cable station 290; sand size
03-27-96	1507	1,290	DI	P61	No	Cable station 290; sand size
03-27-96	1510	1,295	DI	P61	No	Cable station 290; sand size
03-28-96	1100	1,271	Point	P61	No	Eighteen samples at cable station 190; various depths; sand size
03-28-96	1136	1,301	DI	P61	No	Cable station 190; sand size
03-28-96	1145	1,305	DI	P61	No	Cable station 290; sand size
03-28-96	1220	1,299	Point	P61	No	Eighteen samples at cable station 290; various depths; sand size
03-28-96	1251	1,286	DI	P61	No	Cable station 290; sand size
03-28-96	1745	1,301	EDI	D77	No	Sand size
03-29-96	1507	1,288	DI	P61	No	Cable station 190; sand size
03-29-96	1511	1,288	DI	P61	No	Cable station 190; sand size
03-29-96	1629	1,294	DI	P61	No	Cable station 190; sand size
03-29-96	1632	1,294	DI	P61	No	Cable station 190; sand size
03-29-96	1638	1,288	DI	P61	No	Cable station 290; sand size
03-29-96	1640	1,288	DI	P61	No	Cable station 290; sand size
03-29-96	1745	1,338	DI	P61	No	Cable station 290; sand size
03-29-96	1747	1,338	DI	P61	No	Cable station 290; sand size
03-30-96	0947	1,324	DI	P61	No	Cable station 190; sand size
03-30-96	1006	1,276	Point	P61	No	Twelve samples at cable station 190; various depths; sand size
03-30-96	1242	1,288	Point	P61	No	Six samples at cable station 190; various depths; sand size

Table 3. Sediment samples collected at streamflow-gaging stations during the controlled releases of 1996—Continued

Date	Time	Discharge, in cubic meters per second	Sampling method	Sampler	Point velocity	Comments
09402500 Colorado River near Grand Canyon, Ariz.—Continued						
03-30-96	1328	1,282	Point	P61	No	Twenty samples at cable station 290; various depths; sand size
03-30-96	1403	1,284	DI	P61	No	Cable station 290; sand size
03-30-96	1500	1,287	EDI	D77	No	Sand size
03-31-96	1411	1,305	DI	P61	No	Cable station 190; sand size
03-31-96	1414	1,305	DI	P61	No	Cable station 190; sand size
03-31-96	1528	1,275	DI	P61	No	Cable station 190; sand size
03-31-96	1531	1,275	DI	P61	No	Cable station 190; sand size
03-31-96	1536	1,275	DI	P61	No	Cable station 290; sand size
03-31-96	1539	1,283	DI	P61	No	Cable station 290; sand size
03-31-96	1645	1,324	DI	P61	No	Cable station 290; sand size
03-31-96	1648	1,324	DI	P61	No	Cable station 290; sand size
04-01-96	0953	1,301	DI	P61	No	Cable station 190; sand size
04-01-96	0956	1,309	DI	P61	No	Cable station 190; sand size
04-01-96	1132	1,290	DI	P61	No	Cable station 190; sand size
04-01-96	1135	1,290	DI	P61	No	Cable station 190; sand size
04-01-96	1140	1,298	DI	P61	No	Cable station 290; sand size
04-01-96	1144	1,298	DI	P61	No	Cable station 290; sand size
04-01-96	1259	1,292	DI	P61	No	Cable station 290; sand size
04-01-96	1305	1,292	DI	P61	No	Cable station 290; sand size
04-01-96	1430	1,314	EDI	D77	No	Sand size
04-02-96	1021	1,303	DI	P61	No	Cable station 190; sand size
04-02-96	1100	1,291	Point	P61	No	Nineteen samples at cable station 190; various depths; sand size
04-02-96	1136	1,302	DI	P61	No	Cable station 190; sand size
04-02-96	1142	1,305	DI	P61	No	Cable station 290; sand size
04-02-96	1215	1,297	Point	P61	No	Eighteen samples at cable station 290; various depths; sand size
04-02-96	1253	1,291	DI	P61	No	Cable station 290; sand size
04-02-96	1415	1,291	EDI	D77	No	Sand size
04-03-96	1049	939	DI	P61	No	Cable station 190; sand size
04-03-96	1054	930	DI	P61	No	Cable station 190; sand size
04-03-96	1100	930	DI	P61	No	Cable station 190; sand size
04-03-96	1211	900	DI	P61	No	Cable station 190; sand size
04-03-96	1215	900	DI	P61	No	Cable station 190; sand size
04-03-96	1221	900	DI	P61	No	Cable station 290; sand size
04-03-96	1224	898	DI	P61	No	Cable station 290; sand size
04-03-96	1334	898	DI	P61	No	Cable station 290; sand size
04-03-96	1338	898	DI	P61	No	Cable station 290; sand size
09404120 Colorado River above National Canyon near Supai, Ariz.						
03-28-96	1200	1,296	Point	P61	Yes	For each date sampled: Seven points sampled in each of 10 verticals; each sample analyzed for percent sand; sand fraction retained for later analysis of size dis- tribution
03-29-96	1201	1,310	Point	P61	Yes	
03-30-96	1400	1,307	Point	P61	Yes	
03-31-96	1630	1,318	Point	P61	Yes	
04-01-96	1307	1,323	Point	P61	Yes	
04-02-96	1400	1,299	Point	P61	Yes	

Table 4. Concentration and percent of sample finer than 0.062 millimeter for suspended-sediment samples collected at streamflow-gaging stations during the controlled releases of 1996

[Dashes indicate no data. DI, depth integrated; EDI, equal discharge increment]

Date	Time	Suspended sediment concentration, in milligrams per liter	Percent grain size finer than 0.062 millimeter	Sampling method
09380000 Colorado River at Lees Ferry, Ariz.				
03-28-96	1425	19	--	DI
09383100 Colorado River above the Little Colorado River near Desert View, Ariz.				
03-27-96	--	1,850	16.5	EDI
03-29-96	1540	1,240	16.6	EDI
04-02-96	1221	774	9.2	EDI
09402500 Colorado River near Grand Canyon, Ariz.				
03-26-96	1330	17	42	EDI
03-26-96	1705	44	--	DI
03-28-96	1745	2,680	8.8	EDI
03-30-96	1500	1,760	8.0	EDI
04-01-96	1430	1,250	8.1	EDI
04-02-96	1415	1,430	7.1	EDI

STAGE-GAGING STATIONS

Stage data were collected at 29 locations along the mainstem of the Colorado River (table 7) in addition to those collected at the streamflow-gaging stations. Stage was recorded at 15-minute intervals at each site. Data were retrieved from the gaging-stations recorders in April after the controlled releases, and the stage-gaging network was removed at that time. The stage data from the network from 1990 to 1994 and the details of the equipment and techniques used to measure river stage at these stations are presented by Gauger (1996). Change in stage between the steady release of 227 m³/s and the high-flow release of 1,275 m³/s ranged from about 2 to about 5 m. At all but a few sites, the change in stage was between 3 and 5 m (figs. 5–11). The stage data from several of the sites appear to be abnormal and may be the result of malfunctioning recorders.

REACH-AVERAGE FLOW VELOCITY

Flow velocity and longitudinal dispersion in eight subreaches of the river were measured using rhodamine WT, a red fluorescent dye developed for water tracing. About 1,000 kg of 20-percent stock solution of dye were mixed with river water and injected into the river at Lees Ferry at noon on March 27, 1996, which was about 24 hours after the discharge at the injection site had reached the planned peak discharge of the controlled flood. The dye was injected into the downstream current from a point near the right bank using a high-velocity pump and fire hose. Crews located at eight sites downstream (table 8) documented the passage of the dye and collected water samples for quantitative analysis of dye concentration. Samples were remeasured under controlled laboratory conditions after retrieval from the field, and velocity of the centroid of the time-concentration curve at each site was computed (table 8). Sampling methods, data-analysis procedures, and the results of a measurement made in 1991 at a

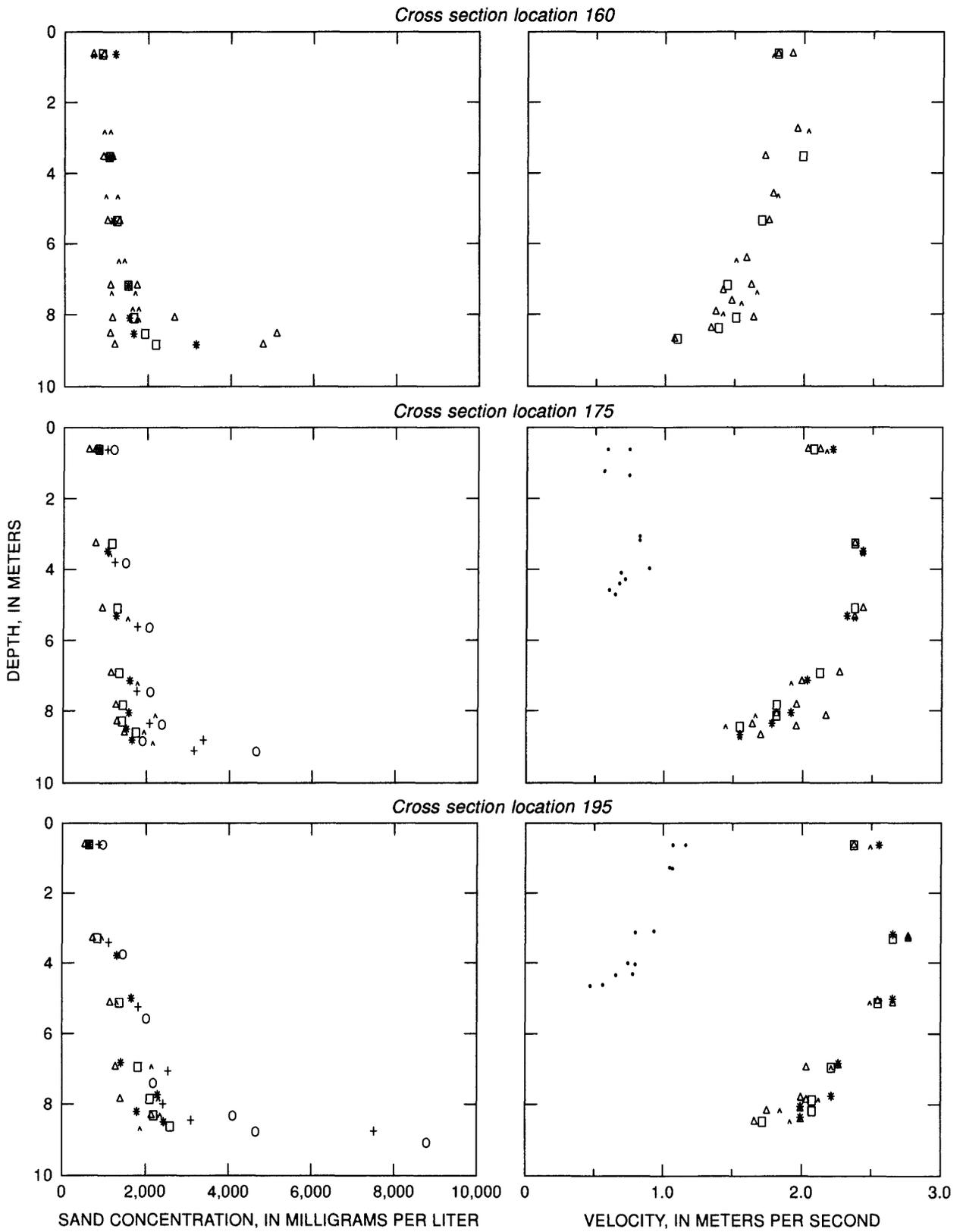


Figure 4. Relation of measured sand concentration and velocity to depth at 11 locations in the cross section at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona. See p. 13 for explanation.

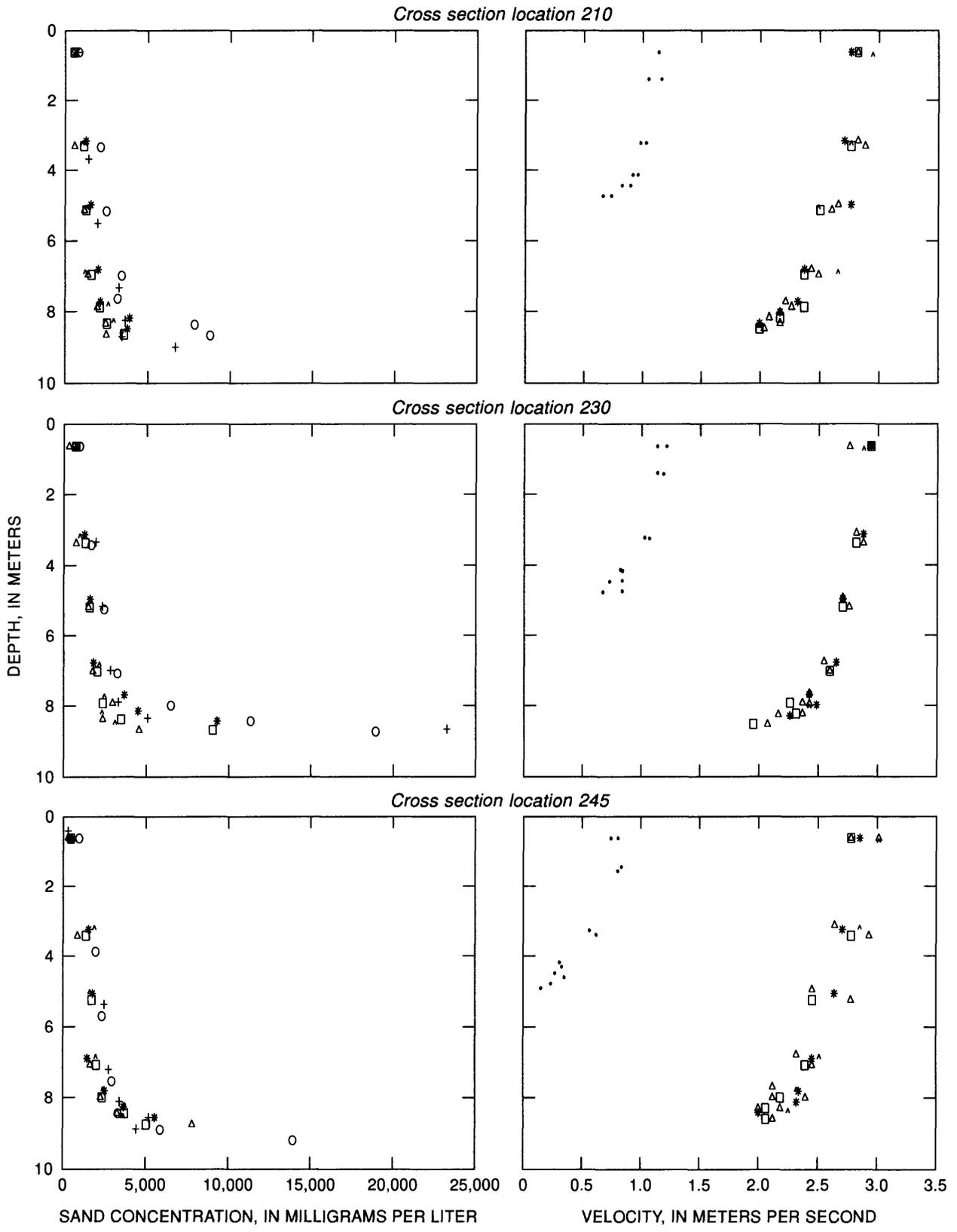


Figure 4. Continued.

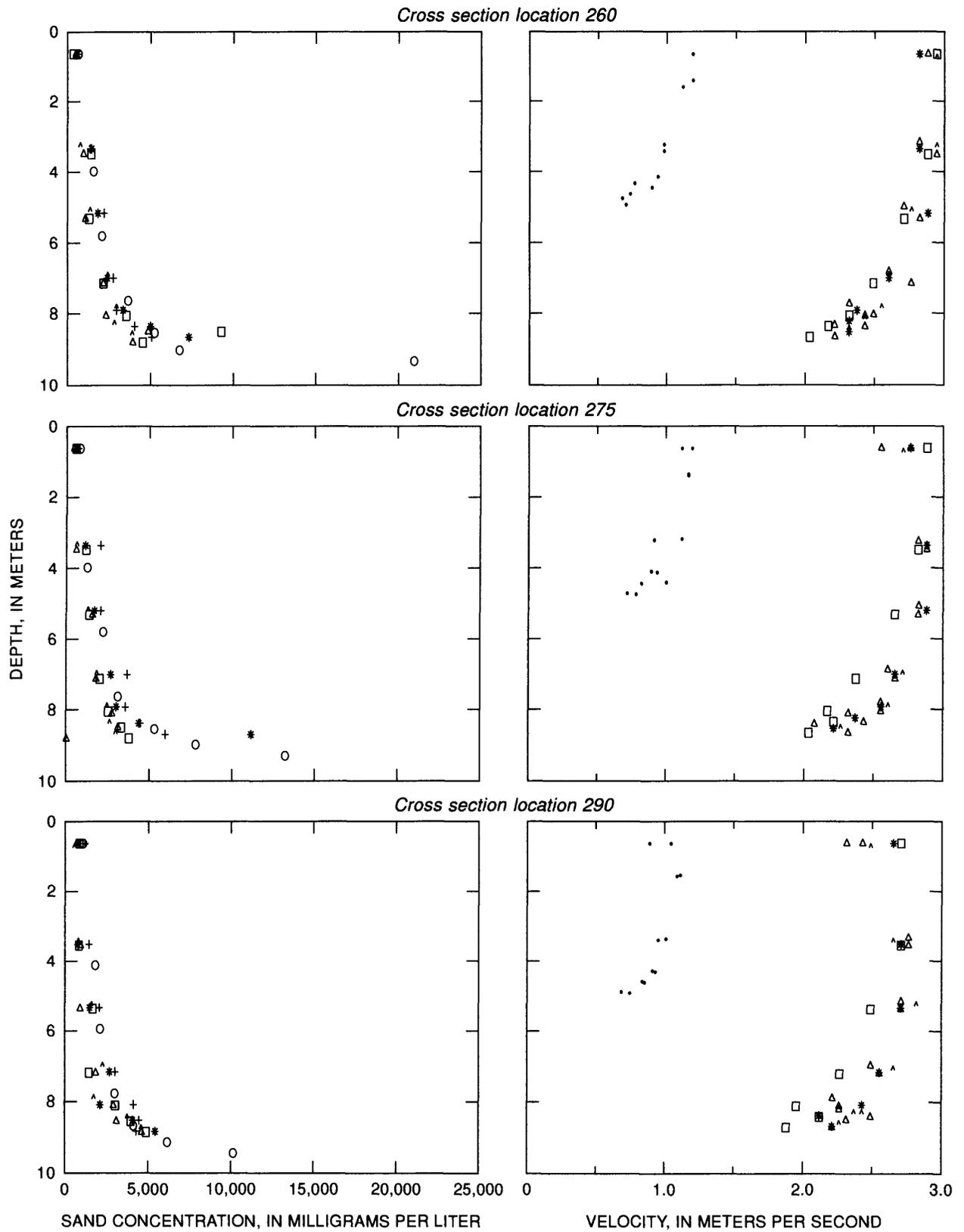
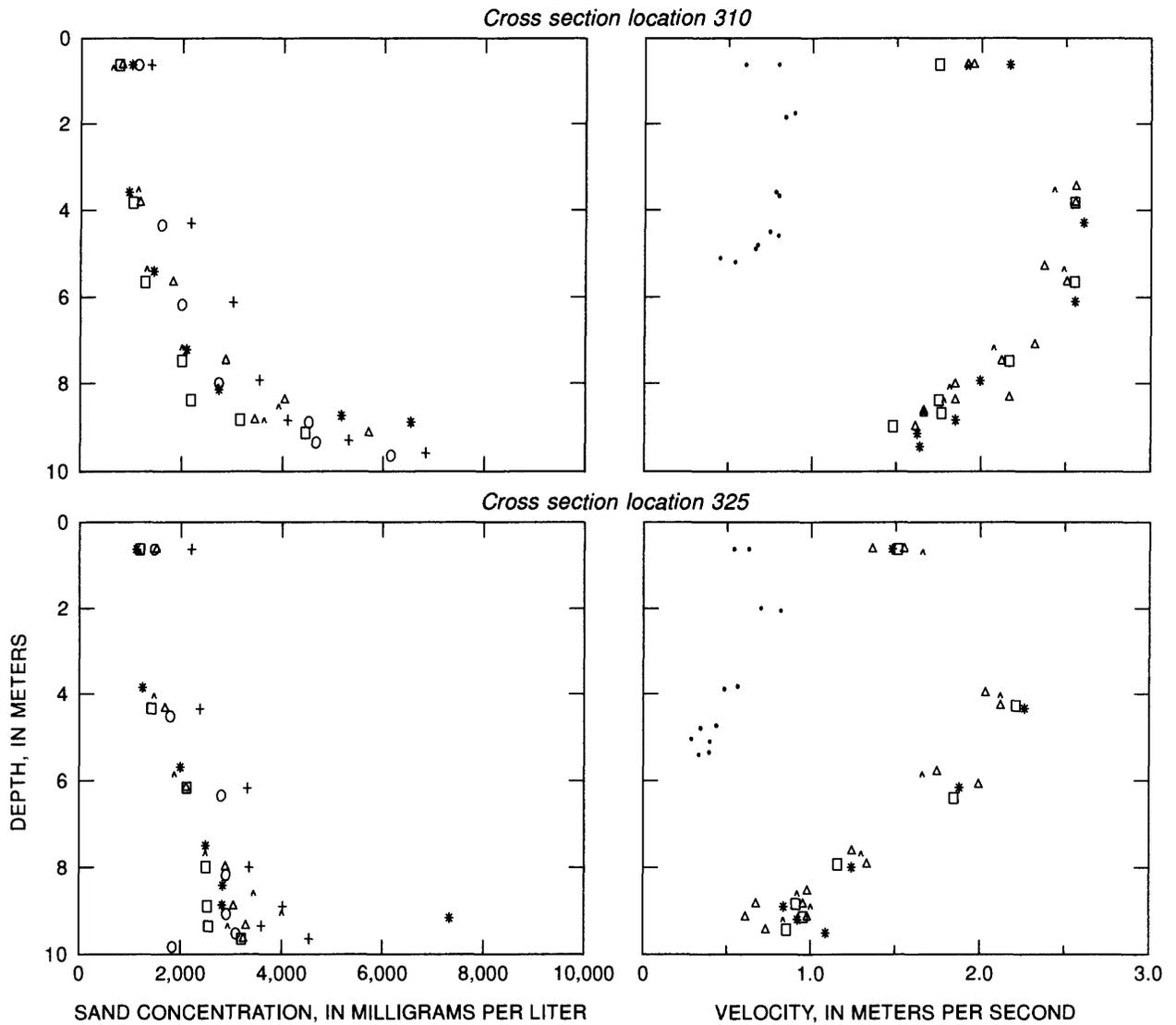


Figure 4. Continued.



EXPLANATION

DATE OF SAND SAMPLE:

- March 28
- + March 29
- * March 30
- March 31
- △ April 1
- ^ April 2

DATE OF VELOCITY MEASUREMENT:

- March 26
- * March 30
- March 31
- △ April 1
- ^ April 2

Figure 4. Continued.

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona

[*, single vertical sample collected; ---, no data]

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-27-96	1700	230	70	0.6	1,667	36
03-28-96	1200	175	53	.6	1,736	31
03-28-96	1200	175	53	3.8	2,010	26
03-28-96	1200	175	53	5.6	2,601	21
03-28-96	1200	175	53	7.5	2,609	20
03-28-96	1200	175	53	8.4	2,929	19
03-28-96	1200	175	53	8.8	2,414	21
03-28-96	1200	175	53	9.1	5,215	11
03-28-96	1200	195	59	.6	1,466	35
03-28-96	1200	195	59	3.7	1,951	26
03-28-96	1200	195	59	5.6	2,527	21
03-28-96	1200	195	59	7.4	2,684	19
03-28-96	1200	195	59	8.3	4,654	12
03-28-96	1200	195	59	8.8	5,214	11
03-28-96	1200	195	59	9.1	9,347	6
03-28-96	1200	210	64	.6	1,297	39
03-28-96	1200	210	64	3.3	2,637	20
03-28-96	1200	210	64	5.2	2,995	18
03-28-96	1200	210	64	7.0	3,949	14
03-28-96	1200	210	64	7.6	3,648	14
03-28-96	1200	210	64	8.4	8,403	7
03-28-96	1200	210	64	8.7	9,418	7
03-28-96	1200	230	70	.6	1,422	34
03-28-96	1200	230	70	3.4	2,167	24
03-28-96	1200	230	70	5.2	2,966	18
03-28-96	1200	230	70	7.1	3,777	14
03-28-96	1200	230	70	8.0	7,036	8
03-28-96	1200	230	70	8.4	11,894	5
03-28-96	1200	230	70	8.7	19,485	3
03-28-96	1200	245	75	.6	1,418	35
03-28-96	1200	245	75	3.9	2,445	21
03-28-96	1200	245	75	5.7	2,826	18
03-28-96	1200	245	75	7.5	3,431	15
03-28-96	1200	245	75	8.4	3,824	14
03-28-96	1200	245	75	8.9	6,436	9
03-28-96	1200	245	75	9.2	14,472	4
03-28-96	1200	260	79	.6	1,151	43
03-28-96	1200	260	79	4.0	2,021	23
03-28-96	1200	260	79	5.8	2,862	28
03-28-96	1200	260	79	7.6	4,136	12
03-28-96	1200	260	79	8.5	5,757	9
03-28-96	1200	260	79	9.0	7,318	8

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-28-96	1200	260	79	9.3	24,086	13
03-28-96	1200	275	84	.6	1,231	35
03-28-96	1200	275	84	4.0	1,663	25
03-28-96	1200	275	84	5.8	2,660	17
03-28-96	1200	275	84	7.6	3,560	13
03-28-96	1200	275	84	8.5	5,838	9
03-28-96	1200	275	84	9.0	8,289	6
03-28-96	1200	275	84	9.3	13,758	4
03-28-96	1200	290	88	.6	1,473	28
03-28-96	1200	290	88	4.1	2,204	19
03-28-96	1200	290	88	5.9	2,533	17
03-28-96	1200	290	88	7.8	3,420	13
03-28-96	1200	290	88	8.7	4,513	9
03-28-96	1200	290	88	9.1	6,601	7
03-28-96	1200	290	88	9.4	10,652	5
03-28-96	1200	310	94	.6	1,646	32
03-28-96	1200	310	94	4.3	2,115	25
03-28-96	1200	310	94	6.2	2,519	21
03-28-96	1200	310	94	8.0	3,283	17
03-28-96	1200	310	94	8.9	4,947	9
03-28-96	1200	310	94	9.4	5,104	9
03-28-96	1200	310	94	9.7	6,608	7
03-28-96	1200	325	99	.6	2,019	27
03-28-96	1200	325	99	4.5	2,325	23
03-28-96	1200	325	99	6.3	3,373	17
03-28-96	1200	325	99	8.2	3,448	16
03-28-96	1200	325	99	9.1	3,458	16
03-28-96	1200	325	99	9.5	3,638	15
03-28-96	1200	325	99	9.8	2,296	20
03-29-96	1201	60	18	*	2,432	11
03-29-96	1201	340	104	*	2,682	10
03-29-96	1201	175	53	.6	1,287	19
03-29-96	1201	175	53	3.8	1,459	16
03-29-96	1201	175	53	5.6	2,009	12
03-29-96	1201	175	53	7.4	1,997	12
03-29-96	1201	175	53	8.4	2,304	10
03-29-96	1201	175	53	8.8	3,620	7
03-29-96	1201	175	53	9.1	3,420	8
03-29-96	1201	195	59	.6	1,080	21
03-29-96	1201	195	59	3.4	1,325	17
03-29-96	1201	195	59	5.2	2,054	12
03-29-96	1201	195	59	7.1	2,783	9

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-29-96	1201	195	59	8.0	2,686	10
03-29-96	1201	195	59	8.4	3,318	7
03-29-96	1201	195	59	8.7	7,747	3
03-29-96	1201	210	64	.6	933	23
03-29-96	1201	210	64	3.7	1,614	15
03-29-96	1201	210	64	5.5	2,170	11
03-29-96	1201	210	64	7.3	3,464	7
03-29-96	1201	210	64	8.2	3,880	7
03-29-96	1201	210	64	8.7	3,667	7
03-29-96	1201	210	64	9.0	6,917	4
03-29-96	1201	230	70	.6	887	25
03-29-96	1201	230	70	3.3	2,163	11
03-29-96	1201	230	70	5.2	2,599	10
03-29-96	1201	230	70	7.0	3,067	8
03-29-96	1201	230	70	7.9	3,550	7
03-29-96	1201	230	70	8.4	5,326	5
03-29-96	1201	230	70	8.7	23,497	1
03-29-96	1201	245	75	.6	701	31
03-29-96	1201	245	75	3.5	1,770	14
03-29-96	1201	245	75	5.4	2,688	9
03-29-96	1201	245	75	7.2	2,985	9
03-29-96	1201	245	75	8.1	3,632	7
03-29-96	1201	245	75	8.6	5,423	5
03-29-96	1201	245	75	8.9	4,679	6
03-29-96	1201	260	79	.6	876	30
03-29-96	1201	260	79	3.3	1,658	18
03-29-96	1201	260	79	5.2	2,453	11
03-29-96	1201	260	79	7.0	3,046	10
03-29-96	1201	260	79	7.9	3,227	9
03-29-96	1201	260	79	8.4	4,345	7
03-29-96	1201	260	79	8.7	5,378	6
03-29-96	1201	275	84	.6	957	28
03-29-96	1201	275	84	3.4	2,342	13
03-29-96	1201	275	84	5.2	2,360	13
03-29-96	1201	275	84	7.0	3,959	8
03-29-96	1201	275	84	7.9	3,862	8
03-29-96	1201	275	84	8.4	4,780	7
03-29-96	1201	275	84	8.7	6,279	5
03-29-96	1201	290	88	.6	1,461	20
03-29-96	1201	290	88	3.5	1,716	17
03-29-96	1201	290	88	5.3	2,370	13
03-29-96	1201	290	88	7.2	3,331	10

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-29-96	1201	290	88	8.1	4,433	7
03-29-96	1201	290	88	8.5	4,782	7
03-29-96	1201	290	88	8.8	4,598	7
03-29-96	1201	310	94	.6	1,648	17
03-29-96	1201	310	94	4.3	2,452	12
03-29-96	1201	310	94	6.1	3,290	9
03-29-96	1201	310	94	7.9	3,840	8
03-29-96	1201	310	94	8.8	4,396	7
03-29-96	1201	310	94	9.3	5,633	6
03-29-96	1201	310	94	9.6	7,189	5
03-29-96	1201	325	99	.6	2,500	12
03-29-96	1201	325	99	4.3	2,641	10
03-29-96	1201	325	99	6.2	3,609	8
03-29-96	1201	325	99	8.0	3,647	8
03-29-96	1201	325	99	8.9	4,326	7
03-29-96	1201	325	99	9.4	3,919	8
03-29-96	1201	325	99	9.7	4,830	6
03-30-96	1400	145	44	*	1,299	15
03-30-96	1400	340	104	*	1,661	12
03-30-96	1400	160	49	.6	1,392	13
03-30-96	1400	160	49	3.5	1,236	14
03-30-96	1400	160	49	5.3	1,332	13
03-30-96	1400	160	49	7.2	1,686	10
03-30-96	1400	160	49	8.1	1,724	10
03-30-96	1400	160	49	8.5	1,836	10
03-30-96	1400	160	49	8.8	3,322	5
03-30-96	1400	175	53	.6	1,005	16
03-30-96	1400	175	53	3.5	1,218	14
03-30-96	1400	175	53	5.3	1,433	12
03-30-96	1400	175	53	7.1	1,779	10
03-30-96	1400	175	53	8.0	1,754	10
03-30-96	1400	175	53	8.5	1,686	10
03-30-96	1400	175	53	8.8	1,835	10
03-30-96	1400	195	59	.6	781	21
03-30-96	1400	195	59	3.8	1,473	12
03-30-96	1400	195	59	5.0	1,822	10
03-30-96	1400	195	59	6.8	1,569	11
03-30-96	1400	195	59	7.7	2,445	7
03-30-96	1400	195	59	8.2	1,959	9
03-30-96	1400	195	59	8.5	2,609	7
03-30-96	1400	210	64	.6	821	21
03-30-96	1400	210	64	3.1	1,410	13

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-30-96	1400	210	64	5.0	1,695	11
03-30-96	1400	210	64	6.8	2,168	9
03-30-96	1400	210	64	7.7	2,297	8
03-30-96	1400	210	64	8.2	4,086	5
03-30-96	1400	210	64	8.5	3,939	5
03-30-96	1400	230	70	.6	952	24
03-30-96	1400	230	70	3.1	1,428	13
03-30-96	1400	230	70	4.9	1,787	11
03-30-96	1400	230	70	6.8	1,990	10
03-30-96	1400	230	70	7.7	3,862	5
03-30-96	1400	230	70	8.1	4,700	4
03-30-96	1400	230	70	8.4	9,455	2
03-30-96	1400	245	75	.6	679	25
03-30-96	1400	245	75	3.2	1,686	11
03-30-96	1400	245	75	5.1	1,947	10
03-30-96	1400	245	75	6.9	1,611	11
03-30-96	1400	245	75	7.8	2,666	7
03-30-96	1400	245	75	8.3	3,817	5
03-30-96	1400	245	75	8.6	5,676	3
03-30-96	1400	260	79	.6	744	24
03-30-96	1400	260	79	3.3	1,641	12
03-30-96	1400	260	79	5.2	2,015	10
03-30-96	1400	260	79	7.0	2,593	8
03-30-96	1400	260	79	7.9	3,534	6
03-30-96	1400	260	79	8.4	5,209	4
03-30-96	1400	260	79	8.7	7,534	3
03-30-96	1400	275	84	.6	741	26
03-30-96	1400	275	84	3.4	1,311	14
03-30-96	1400	275	84	5.2	1,881	11
03-30-96	1400	275	84	7.0	2,876	7
03-30-96	1400	275	84	7.9	3,182	6
03-30-96	1400	275	84	8.4	4,601	5
03-30-96	1400	275	84	8.7	11,374	2
03-30-96	1400	290	88	.6	989	20
03-30-96	1400	290	88	3.5	949	21
03-30-96	1400	290	88	5.3	1,674	12
03-30-96	1400	290	88	7.2	2,860	7
03-30-96	1400	290	88	8.1	2,305	9
03-30-96	1400	290	88	8.5	4,272	5
03-30-96	1400	290	88	8.8	5,653	4
03-30-96	1400	310	94	.6	1,182	16
03-30-96	1400	310	94	3.6	1,132	17

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-30-96	1400	310	94	5.4	1,636	12
03-30-96	1400	310	94	7.2	2,298	9
03-30-96	1400	310	94	8.1	2,930	7
03-30-96	1400	310	94	8.7	5,366	4
03-30-96	1400	310	94	8.9	6,735	3
03-30-96	1400	325	99	.6	1,314	15
03-30-96	1400	325	99	3.8	1,435	13
03-30-96	1400	325	99	5.7	2,188	9
03-30-96	1400	325	99	7.5	2,678	7
03-30-96	1400	325	99	8.4	3,050	7
03-30-96	1400	325	99	8.9	3,038	7
03-30-96	1400	325	99	9.2	7,555	3
03-31-96	1800	45	14	*	1,108	12
03-31-96	1800	340	104	*	1,981	7
03-31-96	1630	160	49	.6	1,040	14
03-31-96	1630	160	49	3.5	1,209	12
03-31-96	1630	160	49	5.3	1,390	10
03-31-96	1630	160	49	7.2	1,665	9
03-31-96	1630	160	49	8.1	1,842	10
03-31-96	1630	160	49	8.5	2,067	7
03-31-96	1630	160	49	8.8	2,327	6
03-31-96	1630	175	53	.6	972	14
03-31-96	1630	175	53	3.3	1,290	11
03-31-96	1630	175	53	5.1	1,428	10
03-31-96	1630	175	53	6.9	1,487	10
03-31-96	1630	175	53	7.8	1,569	9
03-31-96	1630	175	53	8.3	1,555	9
03-31-96	1630	175	53	8.6	1,898	8
03-31-96	1630	195	59	.6	749	17
03-31-96	1630	195	59	3.3	958	14
03-31-96	1630	195	59	5.1	1,490	9
03-31-96	1630	195	59	6.9	1,937	7
03-31-96	1630	195	59	7.9	2,228	6
03-31-96	1630	195	59	8.3	2,322	6
03-31-96	1630	195	59	8.6	2,718	5
03-31-96	1630	210	64	.6	638	21
03-31-96	1630	210	64	3.3	1,225	11
03-31-96	1630	210	64	5.1	1,386	10
03-31-96	1630	210	64	6.9	1,685	8
03-31-96	1630	210	64	7.9	2,248	7
03-31-96	1630	210	64	8.3	2,665	6
03-31-96	1630	210	64	8.6	3,684	4

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-31-96	1630	230	70	0.6	839	16
03-31-96	1630	230	70	3.4	1,436	10
03-31-96	1630	230	70	5.2	1,705	9
03-31-96	1630	230	70	7.0	2,188	7
03-31-96	1630	230	70	8.7	9,189	2
03-31-96	1630	230	70	7.9	2,517	6
03-31-96	1630	230	70	8.4	3,610	4
03-31-96	1630	245	75	.6	550	24
03-31-96	1630	245	75	3.4	1,490	10
03-31-96	1630	245	75	5.2	1,869	9
03-31-96	1630	245	75	7.1	2,129	7
03-31-96	1630	245	75	8.0	2,482	6
03-31-96	1630	245	75	8.4	3,834	4
03-31-96	1630	245	75	8.7	5,142	3
03-31-96	1630	260	79	.6	460	27
03-31-96	1630	260	79	3.5	1,567	9
03-31-96	1630	260	79	5.3	1,403	8
03-31-96	1630	260	79	7.1	2,286	6
03-31-96	1630	260	79	8.0	3,664	4
03-31-96	1630	260	79	8.5	9,460	2
03-31-96	1630	260	79	8.8	4,665	3
03-31-96	1630	275	84	.6	665	19
03-31-96	1630	275	84	3.5	1,304	11
03-31-96	1630	275	84	5.3	1,514	9
03-31-96	1630	275	84	7.1	2,151	7
03-31-96	1630	275	84	8.0	2,646	5
03-31-96	1630	275	84	8.5	3,453	4
03-31-96	1630	275	84	8.8	3,926	4
03-31-96	1630	290	88	.6	970	14
03-31-96	1630	290	88	3.5	939	14
03-31-96	1630	290	88	5.4	1,792	8
03-31-96	1630	290	88	7.2	1,556	9
03-31-96	1630	290	88	8.1	3,183	5
03-31-96	1630	290	88	8.6	4,110	4
03-31-96	1630	290	88	8.9	5,022	3
03-31-96	1630	310	94	.6	876	15
03-31-96	1630	310	94	3.8	1,157	12
03-31-96	1630	310	94	5.6	1,395	9
03-31-96	1630	310	94	7.5	2,143	7
03-31-96	1630	310	94	8.4	2,307	6
03-31-96	1630	310	94	8.8	3,272	4
03-31-96	1630	310	94	9.1	4,571	3

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
03-31-96	1630	325	99	0.6	1,319	10
03-31-96	1630	325	99	4.3	1,563	9
03-31-96	1630	325	99	6.2	2,254	6
03-31-96	1630	325	99	8.0	2,653	6
03-31-96	1630	325	99	8.9	2,670	5
03-31-96	1630	325	99	9.4	2,682	5
03-31-96	1630	325	99	9.7	3,339	4
04-01-96	1310	340	104	*	2,040	8
04-01-96	1310	145	44	*	1,371	10
04-01-96	1600	145	44	*	1,309	11
04-01-96	1600	160	49	.6	1,056	12
04-01-96	1600	160	49	3.5	1,271	10
04-01-96	1600	160	49	5.3	1,453	10
04-01-96	1600	160	49	7.2	1,856	7
04-01-96	1600	160	49	8.1	2,767	5
04-01-96	1600	160	49	8.5	5,253	3
04-01-96	1600	160	49	8.8	4,911	3
04-01-96	1310	160	49	.6	789	14
04-01-96	1310	160	49	3.5	1,037	11
04-01-96	1310	160	49	5.3	1,134	10
04-01-96	1310	160	49	7.2	1,198	9
04-01-96	1310	160	49	8.1	1,264	10
04-01-96	1310	160	49	8.5	1,209	10
04-01-96	1310	160	49	8.8	1,314	9
04-01-96	1310	175	53	.6	712	16
04-01-96	1310	175	53	3.3	870	13
04-01-96	1310	175	53	5.1	1,031	11
04-01-96	1310	175	53	6.9	1,259	9
04-01-96	1310	175	53	7.8	1,371	8
04-01-96	1310	175	53	8.3	1,406	8
04-01-96	1310	175	53	8.6	1,599	8
04-01-96	1310	195	59	.6	629	18
04-01-96	1310	195	59	3.3	826	14
04-01-96	1310	195	59	5.1	1,247	9
04-01-96	1310	195	59	6.9	1,385	9
04-01-96	1310	195	59	7.9	1,495	8
04-01-96	1310	195	59	8.3	2,247	5
04-01-96	1310	195	59	8.6	1,985	6
04-01-96	1310	210	64	.6	582	20
04-01-96	1310	210	64	3.3	644	17
04-01-96	1310	210	64	5.1	1,269	10
04-01-96	1310	210	64	6.9	1,463	8

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
04-01-96	1310	210	64	7.9	2,054	6
04-01-96	1310	210	64	8.3	2,564	5
04-01-96	1310	210	64	8.6	2,590	5
04-01-96	1310	230	70	.6	402	28
04-01-96	1310	230	70	3.4	864	14
04-01-96	1310	230	70	5.2	1,614	8
04-01-96	1310	230	70	7.0	1,897	7
04-01-96	1310	230	70	7.9	3,074	4
04-01-96	1310	230	70	8.4	2,479	5
04-01-96	1310	230	70	8.7	4,677	3
04-01-96	1310	245	75	.6	522	23
04-01-96	1310	245	75	3.4	959	13
04-01-96	1310	245	75	5.2	1,776	7
04-01-96	1310	245	75	7.1	1,738	7
04-01-96	1310	245	75	8.0	2,363	5
04-01-96	1310	245	75	8.4	3,387	4
04-01-96	1310	245	75	8.7	7,944	2
04-01-96	1310	260	79	.6	591	18
04-01-96	1310	260	79	3.5	1,081	11
04-01-96	1310	260	79	5.3	1,176	10
04-01-96	1310	260	79	7.1	2,282	6
04-01-96	1310	260	79	8.0	2,425	5
04-01-96	1310	260	79	8.5	4,999	3
04-01-96	1310	260	79	8.8	4,037	3
04-01-96	1310	275	84	.6	530	22
04-01-96	1310	275	84	3.5	696	18
04-01-96	1310	275	84	5.3	1,686	7
04-01-96	1310	275	84	7.1	1,909	7
04-01-96	1310	275	84	8.1	2,898	5
04-01-96	1310	275	84	8.5	3,243	4
04-01-96	1310	275	84	8.8	5,984	*
04-01-96	1310	290	88	.6	759	15
04-01-96	1310	290	88	3.5	1,036	12
04-01-96	1310	290	88	5.4	1,033	12
04-01-96	1310	290	88	7.2	1,968	7
04-01-96	1310	290	88	8.1	3,033	4
04-01-96	1310	290	88	8.6	3,215	4
04-01-96	1310	290	88	8.9	4,745	3
04-01-96	1310	310	94	.6	915	13
04-01-96	1310	310	94	3.8	1,299	11
04-01-96	1310	310	94	5.6	1,948	7
04-01-96	1310	310	94	7.5	3,012	5

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
04-01-96	1310	310	94	8.4	4,154	3
04-01-96	1310	310	94	8.8	3,574	4
04-01-96	1310	310	94	9.1	5,806	2
04-01-96	1310	325	99	.6	1,647	8
04-01-96	1310	325	99	4.3	1,854	9
04-01-96	1310	325	99	6.2	2,267	7
04-01-96	1310	325	99	8.0	3,031	5
04-01-96	1310	325	99	8.9	3,210	5
04-01-96	1310	325	99	9.4	3,465	5
04-01-96	1310	325	99	9.7	3,413	5
04-02-96	1300	340	104	*	2,029	6
04-02-96	1300	145	44	*	1,066	10
04-02-96	1400	160	49	.6	951	11
04-02-96	1400	160	49	2.7	1,201	9
04-02-96	1400	160	49	4.6	1,368	8
04-02-96	1400	160	49	6.4	1,537	7
04-02-96	1400	160	49	7.3	1,793	6
04-02-96	1400	160	49	7.8	1,897	7
04-02-96	1400	160	49	8.1	1,837	6
04-02-96	1400	160	49	.6	777	13
04-02-96	1400	160	49	2.7	1,047	10
04-02-96	1400	160	49	4.6	1,092	10
04-02-96	1400	160	49	6.4	1,402	8
04-02-96	1400	160	49	7.3	1,223	9
04-02-96	1400	160	49	7.8	1,722	6
04-02-96	1400	160	49	8.1	1,890	6
04-02-96	1400	175	53	.6	855	12
04-02-96	1400	175	53	3.5	1,217	9
04-02-96	1400	175	53	5.3	1,655	7
04-02-96	1400	175	53	7.2	1,892	6
04-02-96	1400	175	53	8.1	2,330	5
04-02-96	1400	175	53	8.5	2,040	5
04-02-96	1400	175	53	8.8	2,265	5
04-02-96	1400	195	59	.6	697	15
04-02-96	1400	195	59	3.2	1,036	10
04-02-96	1400	195	59	5.1	1,402	8
04-02-96	1400	195	59	6.9	2,245	5
04-02-96	1400	195	59	7.8	2,417	5
04-02-96	1400	195	59	8.3	2,466	5
04-02-96	1400	195	59	8.6	3,111	4
04-02-96	1400	210	64	.6	623	16
04-02-96	1400	210	64	3.1	1,125	10

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
04-02-96	1400	210	64	5.0	1,381	8
04-02-96	1400	210	64	6.8	1,289	8
04-02-96	1400	210	64	7.7	2,698	4
04-02-96	1400	210	64	8.2	3,032	4
04-02-96	1400	210	64	8.5	3,496	3
04-02-96	1400	230	70	.6	662	16
04-02-96	1400	230	70	3.1	1,067	10
04-02-96	1400	230	70	4.9	1,716	6
04-02-96	1400	230	70	6.7	2,253	5
04-02-96	1400	230	70	7.7	2,559	4
04-02-96	1400	230	70	8.1	2,441	5
04-02-96	1400	230	70	8.4	5,844	47
04-02-96	1400	245	75	.6	545	20
04-02-96	1400	245	75	3.1	1,969	6
04-02-96	1400	245	75	4.9	1,706	7
04-02-96	1400	245	75	6.8	2,088	6
04-02-96	1400	245	75	7.7	2,532	5
04-02-96	1400	245	75	8.1	3,809	3
04-02-96	1400	245	75	8.4	3,716	3
04-02-96	1400	260	79	.6	509	20
04-02-96	1400	260	79	3.1	871	12
04-02-96	1400	260	79	5.0	1,434	7
04-02-96	1400	260	79	6.8	2,503	4
04-02-96	1400	260	79	7.7	3,050	4
04-02-96	1400	260	79	8.2	2,950	4
04-02-96	1400	260	79	8.5	4,013	3
04-02-96	1400	275	84	.6	540	18
04-02-96	1400	275	84	3.2	705	14
04-02-96	1400	275	84	5.1	1,399	8
04-02-96	1400	275	84	6.9	1,937	6
04-02-96	1400	275	84	7.8	2,541	4
04-02-96	1400	275	84	8.3	2,731	4
04-02-96	1400	275	84	8.6	3,101	4
04-02-96	1400	290	88	.6	611	16
04-02-96	1400	290	88	3.3	875	11
04-02-96	1400	290	88	5.2	1,693	7
04-02-96	1400	290	88	6.9	2,362	5
04-02-96	1400	290	88	7.8	1,805	6
04-02-96	1400	290	88	8.4	3,856	3
04-02-96	1400	290	88	8.7	4,679	2
04-02-96	1400	310	94	.6	711	14
04-02-96	1400	310	94	3.4	1,229	9

Table 5. Suspended-sediment concentration and percent of sample finer than 0.062 millimeter for samples collected during the controlled releases of 1996 at the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona—Continued

Date	Mean time	Cable station location, in feet	Cable station location, in meters	Sample depth, in meters	Concentration, in milligrams per liter	Percent sample finer than 0.062 millimeter
04-02-96	1400	310	94	5.3	1,409	8
04-02-96	1400	310	94	7.1	2,103	5
04-02-96	1400	310	94	8.0	2,815	4
04-02-96	1400	310	94	8.5	4,031	3
04-02-96	1400	310	94	8.8	3,732	3
04-02-96	1400	325	99	.6	1,285	8
04-02-96	1400	325	99	4.0	1,589	7
04-02-96	1400	325	99	5.8	1,998	6
04-02-96	1400	325	99	7.6	2,615	5
04-02-96	1400	325	99	8.5	3,552	3
04-02-96	1400	325	99	9.0	4,128	3
04-02-96	1400	325	99	9.3	3,055	4

steady discharge of 425 m³/s are described by Graf (1995).

Less than 80 hours after the injection, the dye concentration returned to background levels near the mouth of Diamond Creek about 362 km downstream (fig. 12). From Lees Ferry to Diamond Creek, flow velocity was 1.8 m/s during the controlled flood, and velocity ranged from about 1.5 to 2.1 m/s in the subreaches between sampling sites. Time-concentration curves are nearly symmetrical and closely approach a normal distribution (fig. 12). Water particles traced by the dye dispersed very little—the dye cloud took only about 7.8 hours to pass the sampling site at Diamond Creek.

Data from the 1991 measurement made during a release from the dam of 425 m³/s showed that at that discharge, peak concentration decreased and the dye-cloud variance increased at about the rate predicted by one-dimensional mixing theory (Graf, 1995). The strongly skewed distributions and long tails typical of time-concentration curves measured on natural streams were not present. Time-concentration curves and attenuation of peak concentration for the measurement made during the controlled high-flow release from the dam in 1996 are shown in figures 12 and 13. Reach-average velocity varied from reach to reach in both 1991 (Graf, 1995) and 1996 measurements

(table 8) and was lowest in the reaches upstream from the mouth of the Little Colorado River in both cases (fig. 14).

WATER-SURFACE SLOPE

Water-surface slope was measured during the controlled releases in subreaches between the Paria River and Badger Rapids, downstream from the streamflow-gaging station 09402500, Colorado River near Grand Canyon, and upstream from the streamflow-gaging station 09404120, Colorado River above National Canyon near Supai (table 9). Water-surface slopes between the Paria River and Badger Rapids were measured in four different subreaches on March 31 and ranged from 0.00020 to 0.00072. Five surface-water slopes were measured above Bright Angel Creek below the streamflow-gaging station at Colorado River near Grand Canyon from March 26 to April 1. The smallest slope, 0.00021, was measured during the steady release, before the arrival of the high flow. The slopes ranged from 0.00073 to 0.00094 during the high-flow release. Slope measurements were made in four subreaches extending upstream from the cableway at National Canyon. Slopes measured in each reach on March 26, before the high flow

Table 6. Physical and chemical characteristics of water samples collected at the streamflow-gaging station 09380000, Colorado River at Lees Ferry, Arizona, during the controlled releases of 1996

[m³/s, cubic meters per second; μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mm, millimeters; <, actual values is known to be less than the value shown; mg/L, milligrams per liter; IT, incremental titration; dis, dissolved; μm-mf, 0.7 micrometer membrane filter; cols./100 mL, colonies per 100 milliliters; K, based on non-ideal colony count; T/ac-ft, tons per acre feet; μg/L, micrograms per liter; ---, no data]

Field measurements

Date	Time	Dis-charge instantaneous (m ³ /s)	Specific conductance (μS/cm)	pH (standard units)	Temperature, air (°C)	Temperature, water (°C)	Barometric pressure (mm of mercury)	Oxygen, dissolved (mg/L)	Oxygen demand, chemical (high level) (mg/L)
03-25-96	1620	234	778	8.2	17.0	10.0	678	10.2	10
03-27-96	0905	1,277	800	8.1	17.0	9.0	685	11.2	--
04-01-96	1100	1,294	800	8.2	20.0	9.5	680	11.3	<10
04-06-96	0945	231	747	8.2	18.5	10.0	688	9.1	--

Field measurements and laboratory measurements

Date	Turbidity (NTU)	Alkalinity, water dissolved, total IT, field (mg/L as CaCO ₃)	Bicarbonate, water, dissolved, IT field (mg/L as HCO ₃)	Carbonate, water, dissolved, IT field (mg/L as CO ₃)	Carbon, inorganic, total (mg/L as C)	Carbon, inorganic, dissolved (mg/L as C)	Hardness, noncarbonate, dissolved, field (mg/L as CaCO ₃)	Coliform, fecal, μm-mf (cols./100 mL)	Streptococci, fecal, kf agar (cols./100 mL)
03-25-96	0.20	122	149	0	0.20	3.0	250	K2	K1
03-27-96	.60	130	159	0	.20	3.1	260	--	--
04-01-96	.40	136	166	0	.30	2.7	240	<1	K3
04-06-96	.20	132	161	0	.20	2.8	240	--	--

Laboratory measurements

Date	Residue solids, residue at 180°C, dissolved (mg/L)	Residue, dissolved (T/ac-ft)	Residue, total at 105°C, suspended (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO ₄)	Chloride, dissolved (mg/L as Cl)
03-25-96	494	0.67	1	62	22	64	2.9	190	45
03-27-96	518	.70	--	65	23	70	2.7	200	52
04-01-96	522	.71	4	62	21	63	2.9	200	47
04-06-96	478	.65	--	63	21	59	2.9	180	44

Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO ₂)	Sodium adsorption ratio	Aluminum, dissolved (μg/L as Al)	Antimony, total (μg/L as Sb)	Antimony, dissolved (μg/L as Sb)	Arsenic, total (μg/L as As)	Arsenic, dissolved (μg/L as As)
03-25-96	0.30	7.9	2	<1.0	1	<1.0	1	1
03-27-96	.40	8.6	2	2.0	--	<1.0	--	1
04-01-96	.30	7.9	2	<1.0	<1	<1.0	1	1
04-06-96	.30	8.4	2	3.0	--	<1.0	--	1

Table 6. Physical and chemical characteristics of water samples collected at the streamflow-gaging station 09380000, Colorado River at Lees Ferry, Arizona, during the controlled releases of 1996—Continued

Laboratory Measurements—Continued

Date	Barium, dissolved (µg/L as Ba)	Beryllium, total (µg/L as Be)	Beryllium, dissolved (µg/L as Be)	Boron, total (µg/L as B)	Boron, dissolved (µg/L as B)	Cadmium, total (µg/L as Cd)	Cadmium, dissolved (µg/L as Cd)	Chromium, total (µg/L as Cr)	Chromium, dissolved (µg/L as Cr)
03-25-96	79	<10	<10	--	90	<1	<1.0	<1	<5.0
03-27-96	86	--	<1.0	--	100	--	<1.0	--	1.0
04-01-96	83	<10	<10	80	80	<1	<1.0	<1	<5.0
04-06-96	79	--	<1.0	--	80	--	<1.0	--	2.0

Date	Cobalt, dissolved (µg/L as Co)	Copper, total (µg/L as Cu)	Copper, dissolved (µg/L as Cu)	Iron, total (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Lead, total (µg/L as Pb)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)
03-25-96	<1.0	<1	<10	10	<3.0	<1	<30	26
03-27-96	<1.0	--	2.0	--	6.0	--	<1.0	28
04-01-96	<1.0	<1	<10	50	<3.0	<1	<10	26
04-06-96	<1.0	--	2.0	--	<3.0	--	<1.0	24

Date	Manganese, total (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)	Mercury, total (µg/L as Hg)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, total (mg/L as Ni)	Nickel, dissolved (mg/L as Ni)	Selenium, total (µg/L as Se)	Selenium, dissolved (µg/L as Se)
03-25-96	<10	<1.0	<0.10	<0.1	4.0	<100	2.0	2	2
03-27-96	--	2.0	--	--	4.0	--	2.0	--	2
04-01-96	<10	<1.0	<.10	<.1	4.0	<100	2.0	2	2
04-06-96	--	1.0	--	--	4.0	--	2.0	--	2

Date	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, total (µg/L as Zn)	Zinc, dissolved (µg/L as Zn)	Uranium, natural (µg/L as U)	Nitrogen, nitrite, total (mg/L as N)
03-25-96	<1.0	720	<6	<10	12	4.0	<0.010
03-27-96	<1.0	750	<6	--	2.0	4.0	<.010
04-01-96	<1.0	720	<6	<10	4.0	4.0	.020
04-06-96	<1.0	670	<6	--	2.0	3.0	<.010

Date	Nitrogen, NO ₂ and NO ₃ , total (mg/L as N)	Nitrogen, NO ₂ and NO ₃ , dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia and organic, total (mg/L as N)	Nitrogen, ammonia and organic, dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, total (mg/L as P)
03-25-96	0.240	0.240	0.020	<0.015	<0.20	<0.20	0.010	<0.010	0.003
03-27-96	.310	.310	--	<.015	<.20	<.20	.020	.010	.007
04-01-96	.320	.320	.020	.030	<.20	<.20	.020	.020	.007
04-06-96	.240	.240	--	<.015	<.20	<.20	<.010	<.010	.005

Table 7. Stage-gaging stations at which data were collected during the controlled releases of 1996

[RM, river mile. All stations are in Grand Canyon National Park except stations 09379950 and 09379965, which are in Glen Canyon National Recreation Area]

Station number	Latitude	Longitude	Site name	Site description
09379950	36°53'50"	111°31'26"	R200-01	11 miles above Lees Ferry
09379965	36°52'26"	111°33'07"	R200-02	6.5 miles above Lees Ferry
09383006	36°44'56"	111°40'53"	R200-04	At RM 10 below 10 Mile Rock
09383040	36°35'03"	111°47'02"	R200-07	At RM 25 below 24 Mile Rapid
09383055	36°29'55"	111°51'10"	R200-8A	At RM 32 at Vasey's Paradise
09383060	36°27'42"	111°50'14"	R200-09	At RM 35 below Nautiloid Canyon
09383075	36°23'06"	111°51'24"	R200-11	At RM 45 below President Harding Rapid
09383090	36°16'20"	111°50'10"	R200-13	At RM 55 above Kwagunt Rapid
09402390	36°05'42"	111°50'51"	R200-15	At RM 70 below Basalt Canyon
09402460	36°03'14"	111°59'30"	R200-17	At RM 80 above Grapevine Rapid
09403020	36°05'46"	112°07'26"	R200-18	At RM 90 above Horn Creek Rapid
09403040	36°05'55"	112°12'19"	R200-19	At RM 95 above Hermit Rapid
09403045	36°06'03"	112°12'48"	R200-19A	At RM 95.5 below Hermit Rapid
09403065	36°08'20"	112°14'52"	R200-20A	At RM 98.5 below Crystal Rapid
09403170	36°12'31"	112°25'25"	R200-23	At RM 115 below Garnet Canyon
09403200	36°14'20"	112°28'07"	R200-24	At RM 120 above Blacktail Rapid
09403250	36°16'09"	112°31'33"	R200-25	At RM 125 above Fossil Rapid
09403300	36°20'33"	112°27'15"	R200-26	At RM 131 above Deubendorff Rapid (record incomplete)
09403400	36°23'48"	112°34'40"	R200-28	At RM 140 below 140 Mile Canyon (record incomplete)
09403870	36°21'14"	112°41'24"	R200-30	At RM 150 above Upset Rapid
09404119	36°16'07"	112°52'47"	R200-32A	At RM 165.5 above National Canyon
09404130	36°14'25"	112°56'42"	R200-33	At RM 170 above Stairway Canyon
09404135	36°13'54"	113°01'43"	R200-34	At RM 175 below Cove Canyon
09404140	36°12'02"	113°04'29"	R200-35	At RM 179 above Lava Falls Rapid
09404145	36°10'17"	113°09'48"	R200-36	At RM 185 above 185 Mile Rapid
09404155	36°05'34"	113°16'12"	R200-38	At RM 195 below 194 Mile Canyon
09404165	36°04'42"	113°19'30"	R200-39	At RM 200 below Parashant Wash
09404170	36°00'30"	113°20'34"	R200-40	At RM 205 above 205 Mile Rapid
09404185	35°53'46"	113°19'03"	R200-42	At RM 215 above Three Springs Canyon

reached the site, were lower than the slopes measured during the high flow (table 9).

SAND-STORAGE CHANGES

Sand-storage changes caused by the high-flow release were documented by measuring bed elevation of the channel at cross sections before

and after the controlled releases at the network of 120 monumented locations established for interim-flow and transition monitoring programs (fig. 15; table 10). Samples, the presence of sand waves, and direct observation by underwater video (Anima and others, 1996) have shown that changes in elevation of the channel bed are caused by movement of bed material in the sand-size range. Changes in area between measurements at each

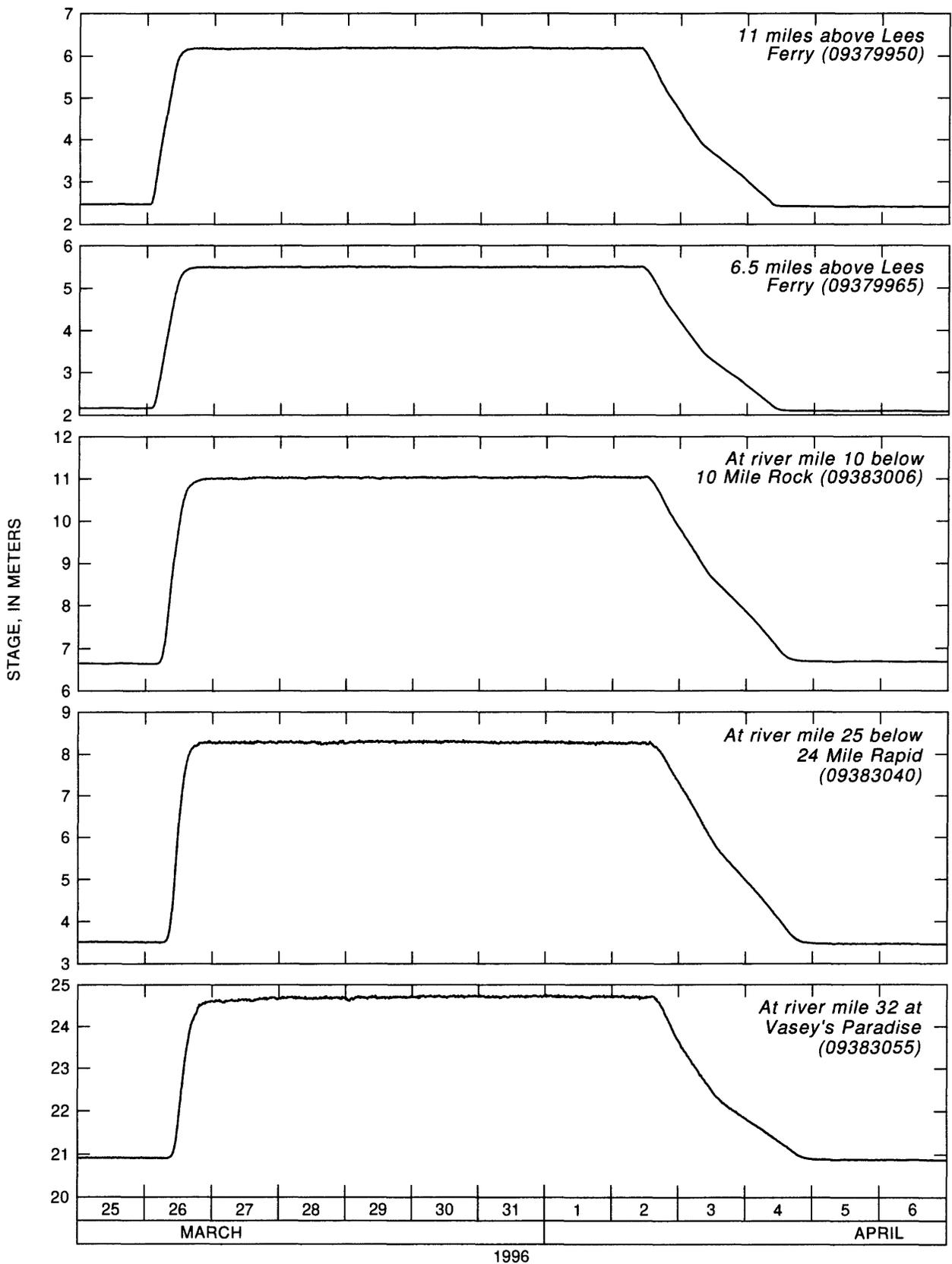


Figure 5. Stage measured during the controlled releases of 1996 at stage-gaging stations 09379950, 09379965, 09383006, 09383040, and 09383055.

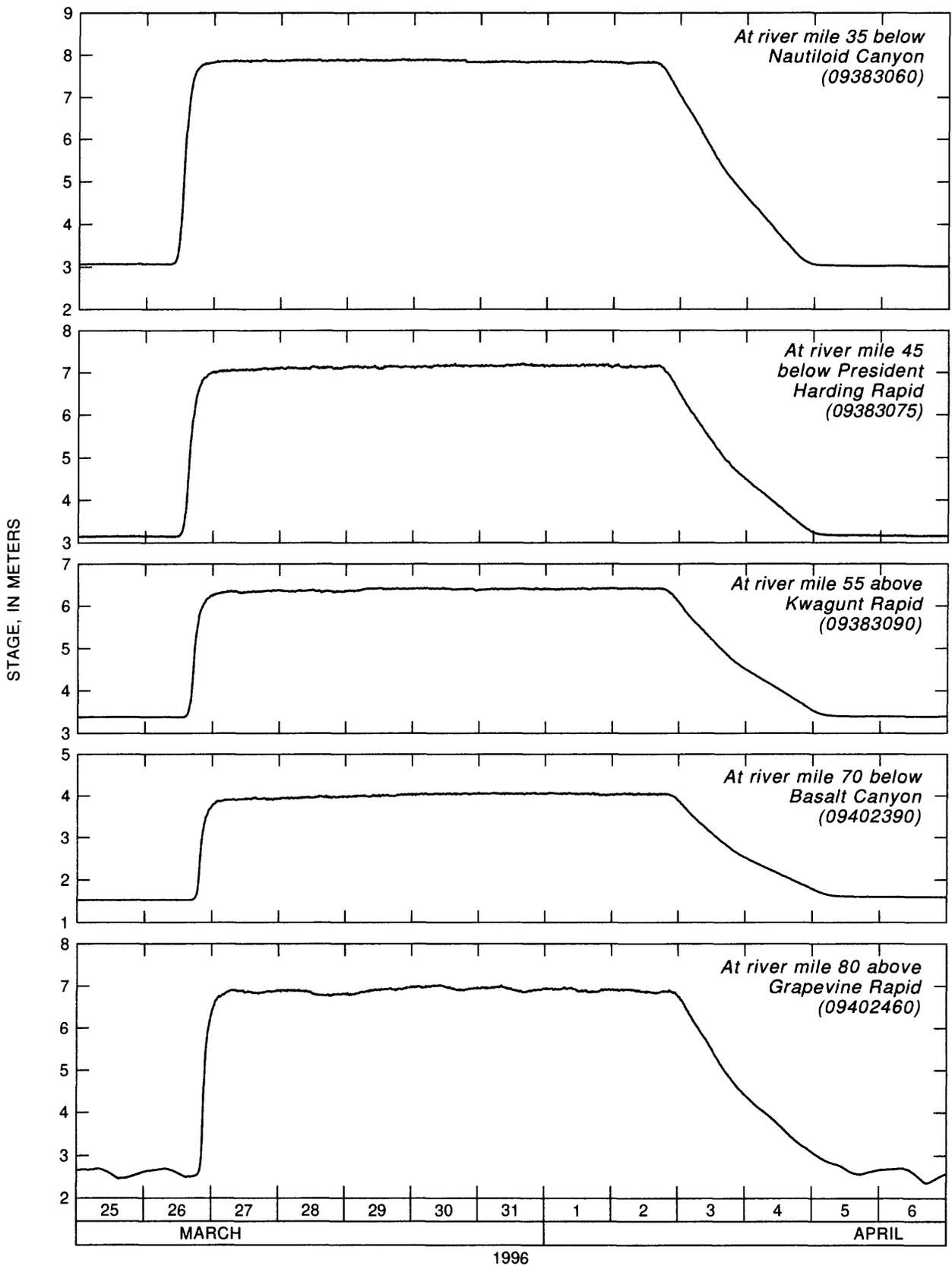


Figure 6. Stage measured during the controlled releases of 1996 at stage-gaging stations 09383060, 09383075, 09383090, 09402390, and 09402460.

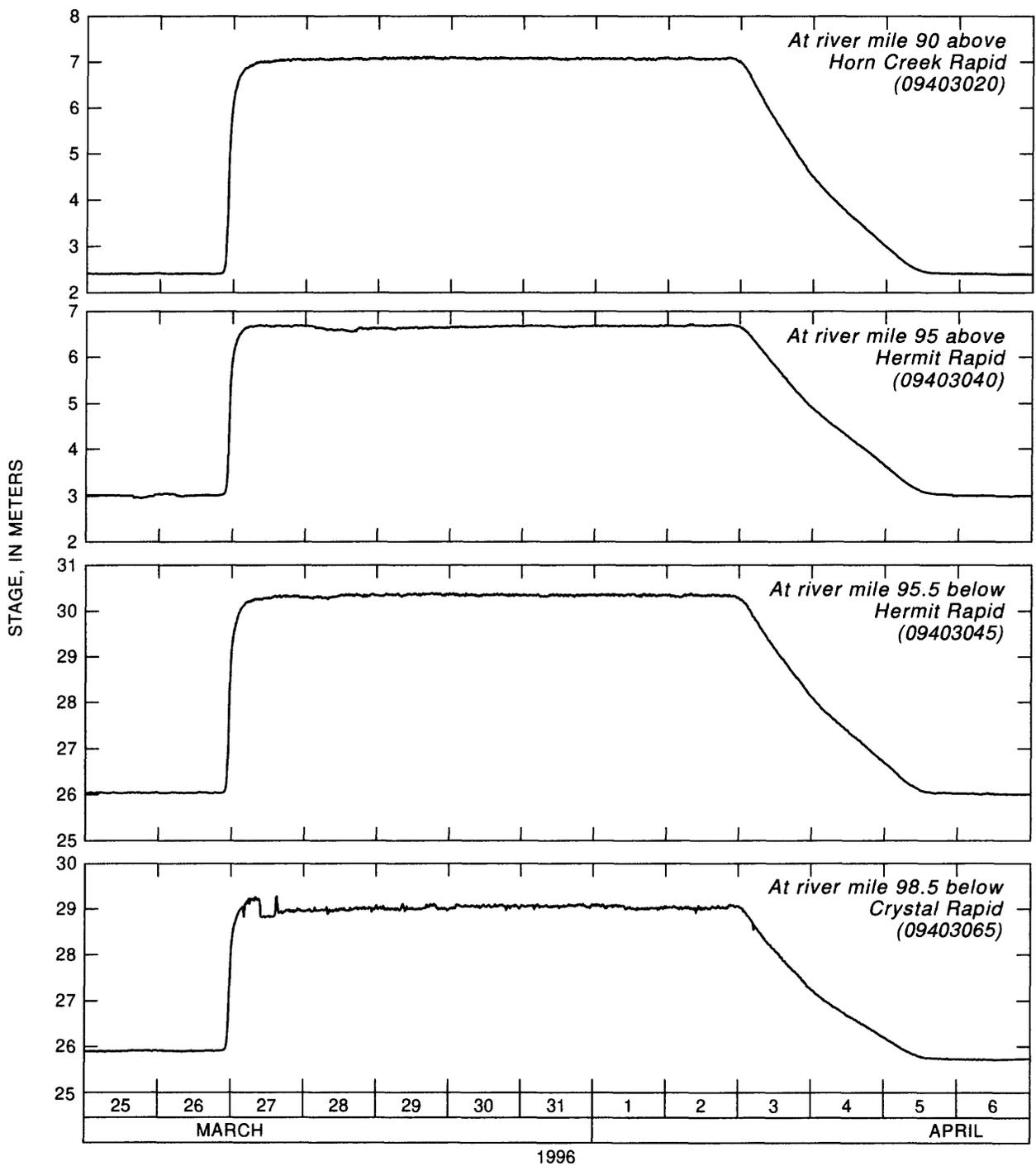


Figure 7. Stage measured during the controlled releases of 1996 at stage-gaging stations 09403020, 09403040, 09403045, and 09403065.

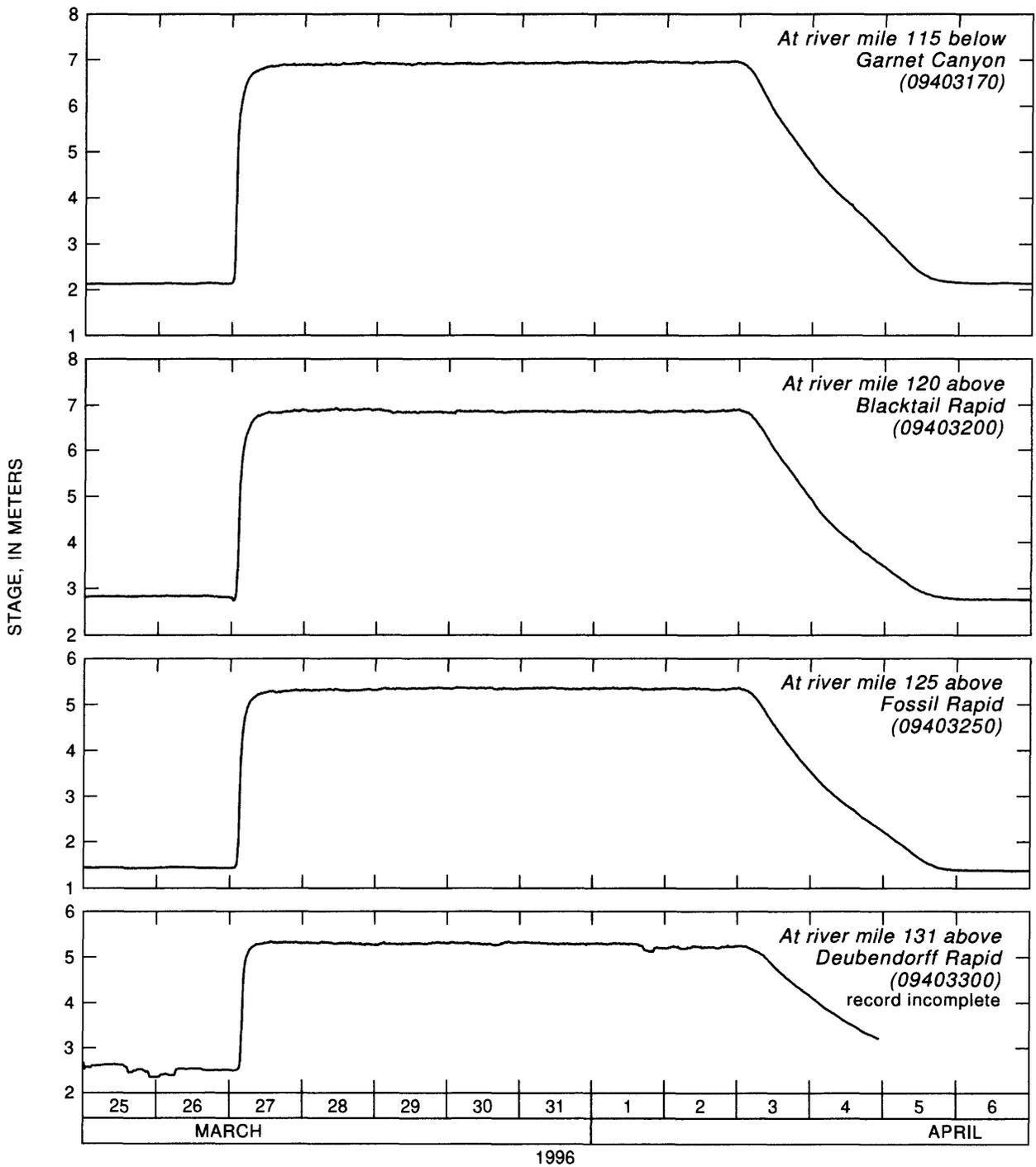


Figure 8. Stage measured during the controlled releases of 1996 at stage-gaging stations 09403170, 09403200, 09403250, and 09403300.

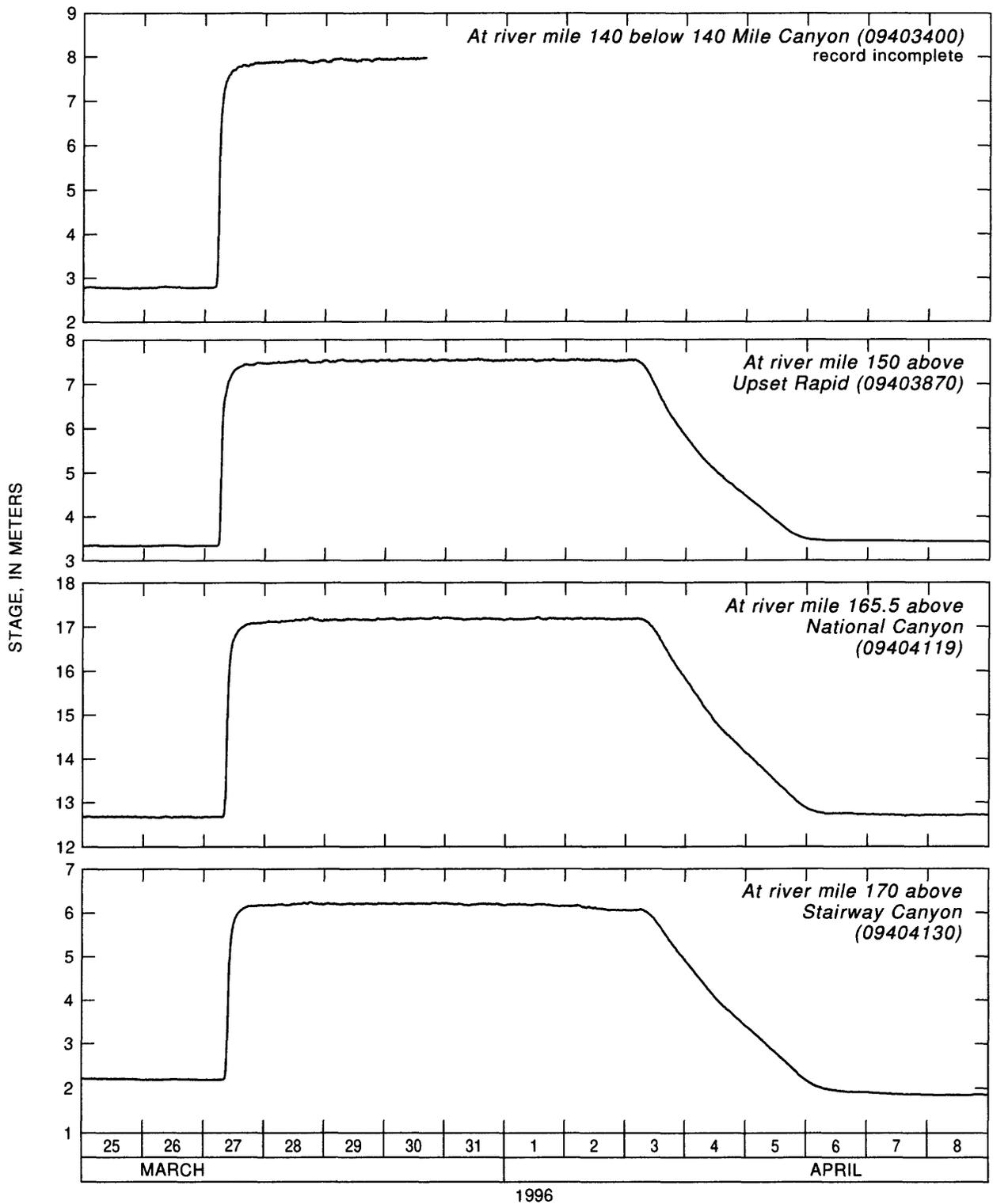


Figure 9. Stage measured during the controlled releases of 1996 at stage-gaging stations 09403400, 09403870, 09404119, and 09404130.

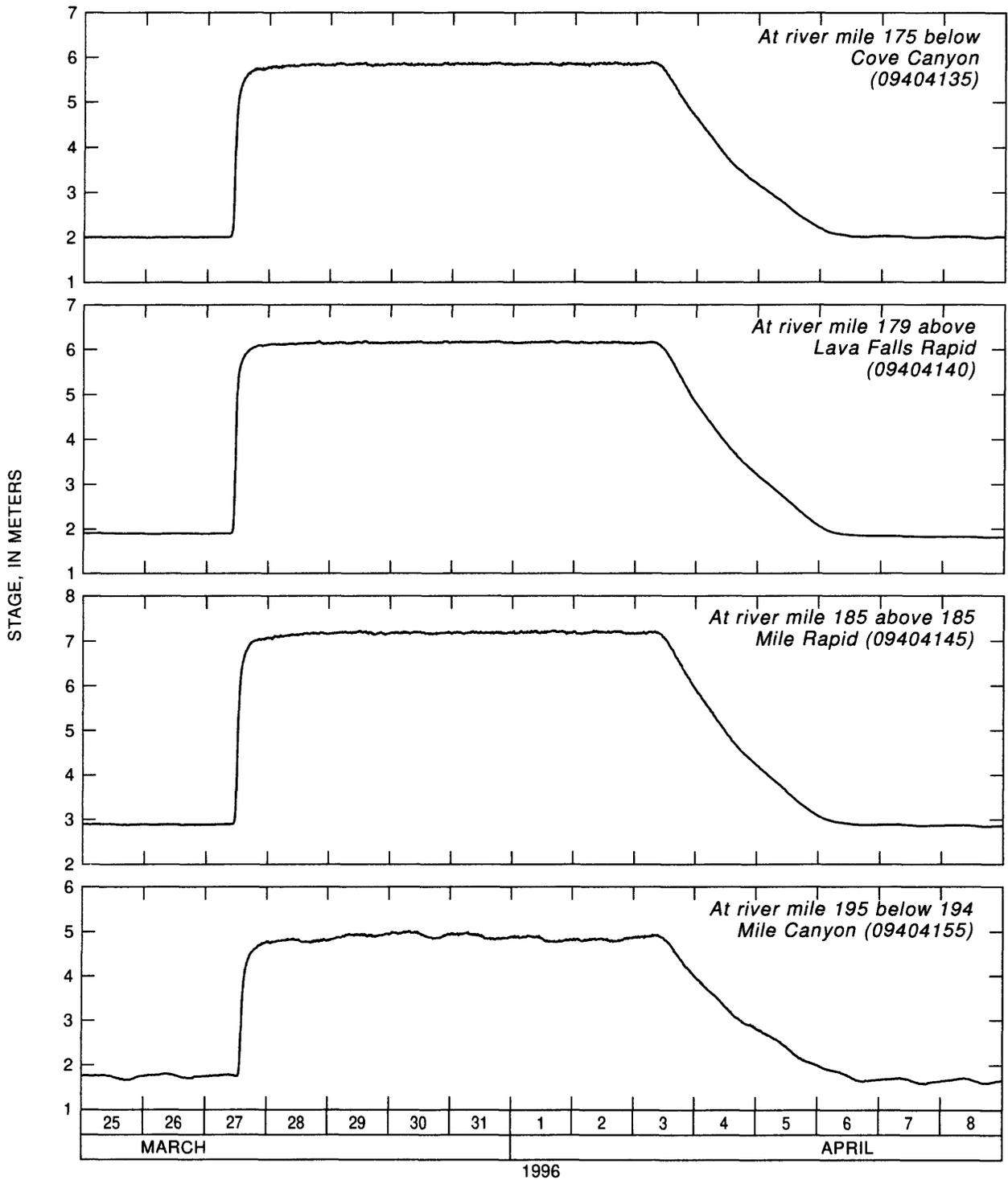


Figure 10. Stage measured during the controlled releases of 1996 at stage-gaging stations 09404135, 09404140, 09404145, and 09404155.

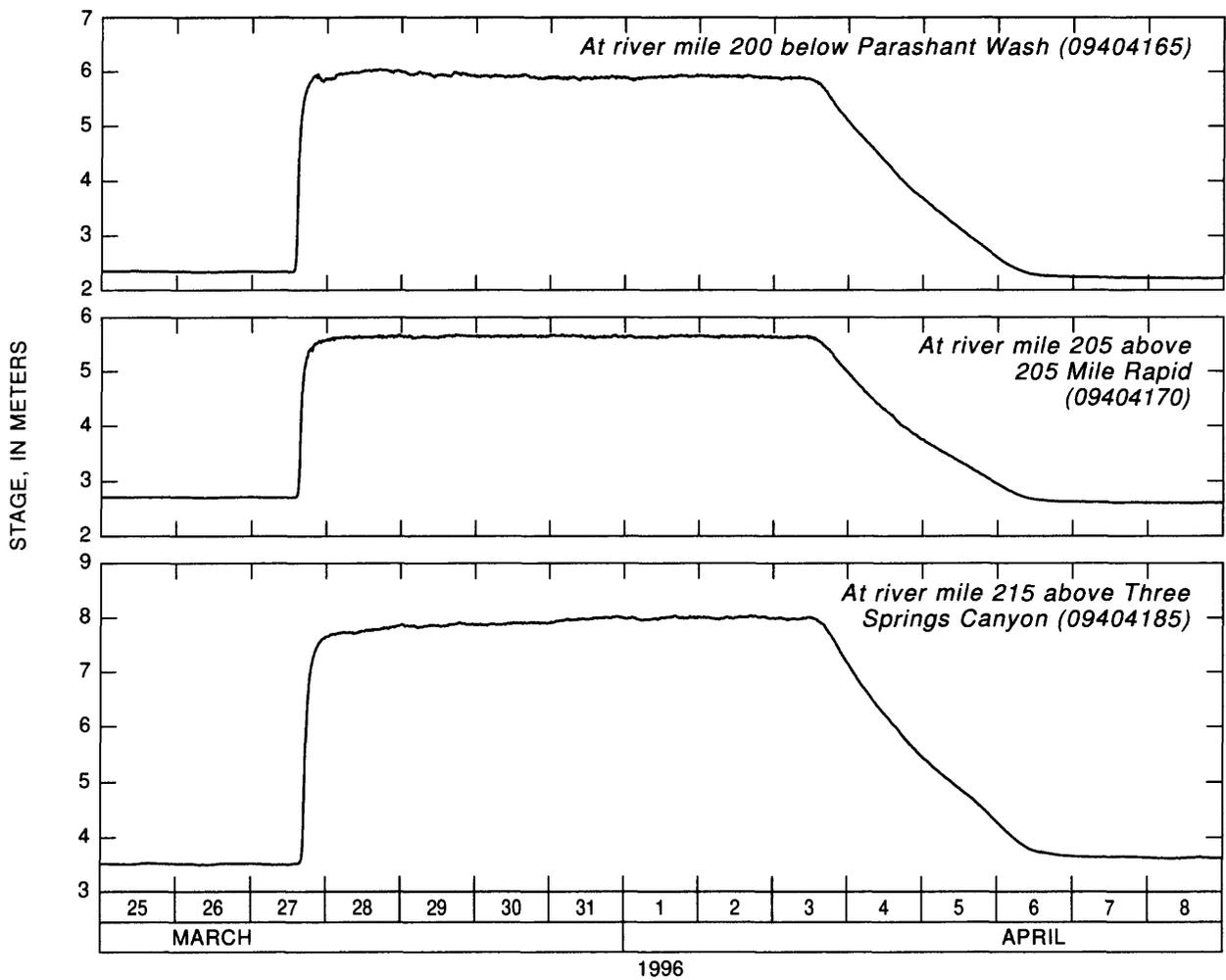


Figure 11. Stage measured during the controlled releases of 1996 at stage-gaging stations 09404165, 09404170, and 09404185.

Table 8. Reach-average flow velocity determined from the dye-tracer measurement made during the controlled flood of 1996

[Dye was injected at Lees Ferry at noon on March 27, 1996]

Location of site	Location of sampling site, in river miles downstream from Lees Ferry, Ariz.	Peak dye concentration, in micrograms per liter	Time from injection to peak, in hours	Velocity in the reach upstream from the sampling site		Cumulative reach velocity, in meters per second
				Miles per hour	Meters per second	
Above Badger Creek Rapid.....	7.9	36.0	2.33	3.39	1.51	1.51
At Nautiloid Canyon	35.9	22.2	9.75	3.77	1.69	1.65
Above mouth of the Little Colorado River	61.1	13.8	17.33	3.32	1.49	1.57
Above Hance Rapid	76.7	11.5	21.00	4.25	1.90	1.63
At 122 Mile Creek.....	122.0	10.1	31.5	4.31	1.93	1.73
At National Canyon.....	166.5	9.3	42.0	4.23	1.89	1.77
At river mile 183	183.0	9.15	45.5	4.71	2.11	1.80
At Diamond Creek	225.0	8.10	55.75	4.10	1.83	1.80

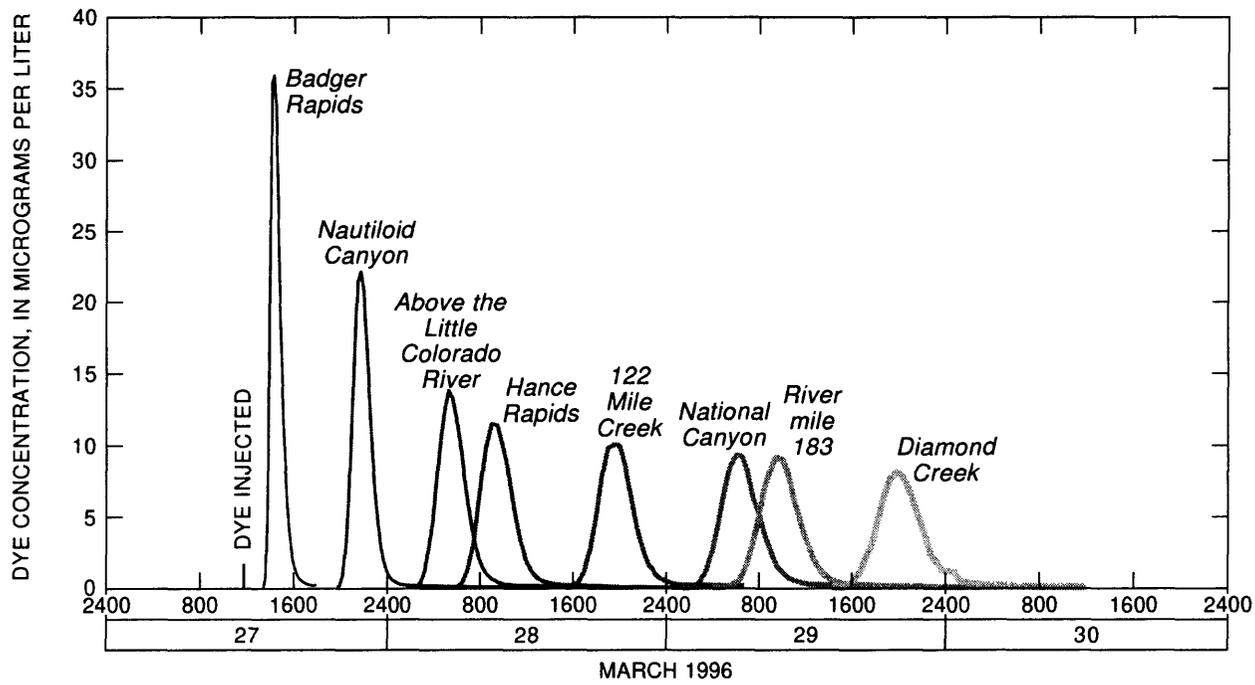


Figure 12. Variation of dye concentration with time at sampling sites, March 27–30, 1996.

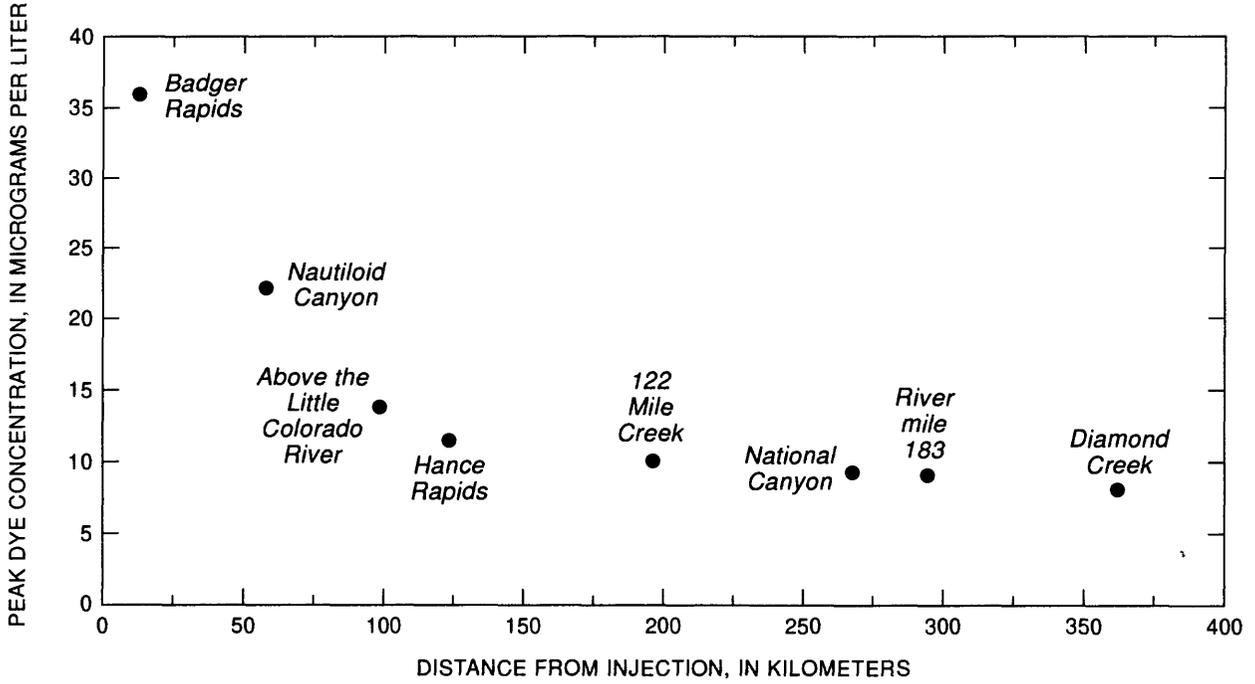
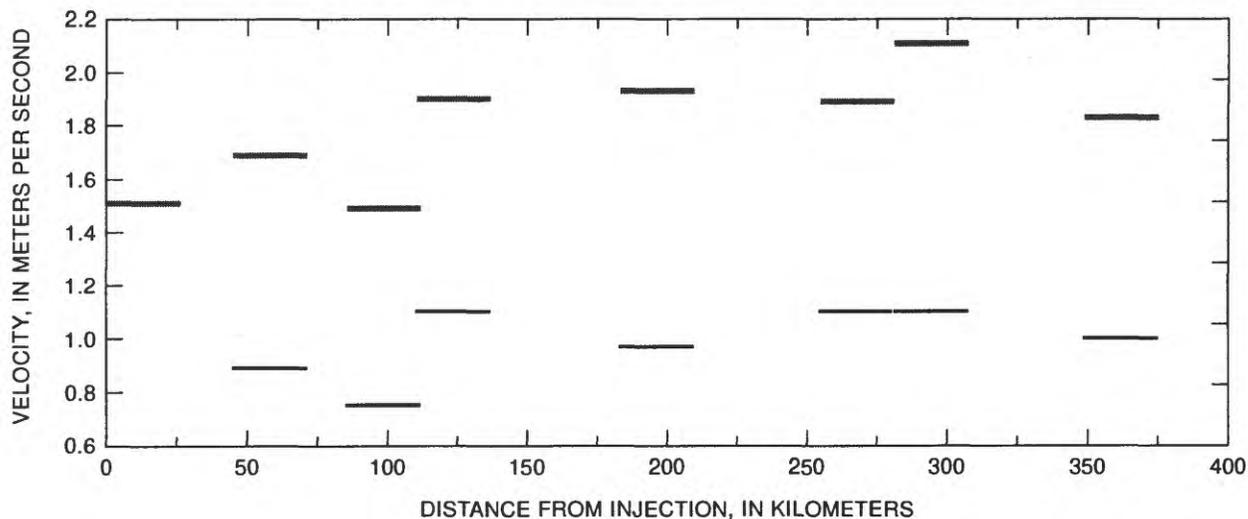


Figure 13. The relation of peak concentration of dye to distance traveled during the March 1996 measurement.



EXPLANATION

425 CUBIC METERS PER SECOND (15,000 CUBIC FEET PER SECOND)
 1,275 CUBIC METERS PER SECOND (45,000 CUBIC FEET PER SECOND)

Figure 14. Reach-average flow velocity determined from dye transport at steady releases from the dam of 425 and 1,275 cubic meters per second.

Table 9. Water-surface slopes measured during the controlled releases of 1996

[Reach number at streamflow-gaging station 09404120, Colorado River above National Canyon near Supai, Arizona: Reach 1, from cableway to 366 m upstream from cableway; Reach 2, from 122 m to 244 m upstream from cableway; Reach 3, from 122 m to 366 m upstream from cableway; Reach 4, from 244 m to 366 m upstream from cableway]

Date	Reach number	Slope	Date	Reach number	Slope
Colorado River from Paria River to Badger Rapids			09404120, Colorado River above National Canyon near Supai, Ariz.—Continued		
03-31-96	1	0.00026	03-31-96	2	0.00012
03-31-96	2	.00041	03-31-96	2	.00020
03-31-96	4	.00072	03-31-96	3	.00055
03-31-96	5	.00020	03-31-96	4	.00090
Downstream from streamflow-gaging station 09402500, Colorado River near Grand Canyon, Ariz.			03-31-96	4	.00070
03-26-96	1	.00021	04-01-96	1	.00039
03-27-96	1	.00073	04-01-96	1	.00038
03-28-96	1	.00094	04-01-96	1	.00052
03-30-96	1	.00088	04-01-96	1	.00058
04-01-96	1	.00073	04-01-96	2	.00052
09404120, Colorado River above National Canyon near Supai, Ariz.			04-01-96	2	.00058
03-26-96	1	.00019	04-01-96	3	.00052
03-26-96	2	.00010	04-01-96	3	.00058
03-26-96	3	.00012	04-01-96	4	.00045
03-26-96	4	.00015	04-01-96	4	.00022
03-31-96	1	.00058	04-01-96	4	.00052
03-31-96	1	.00045	04-01-96	4	.00058

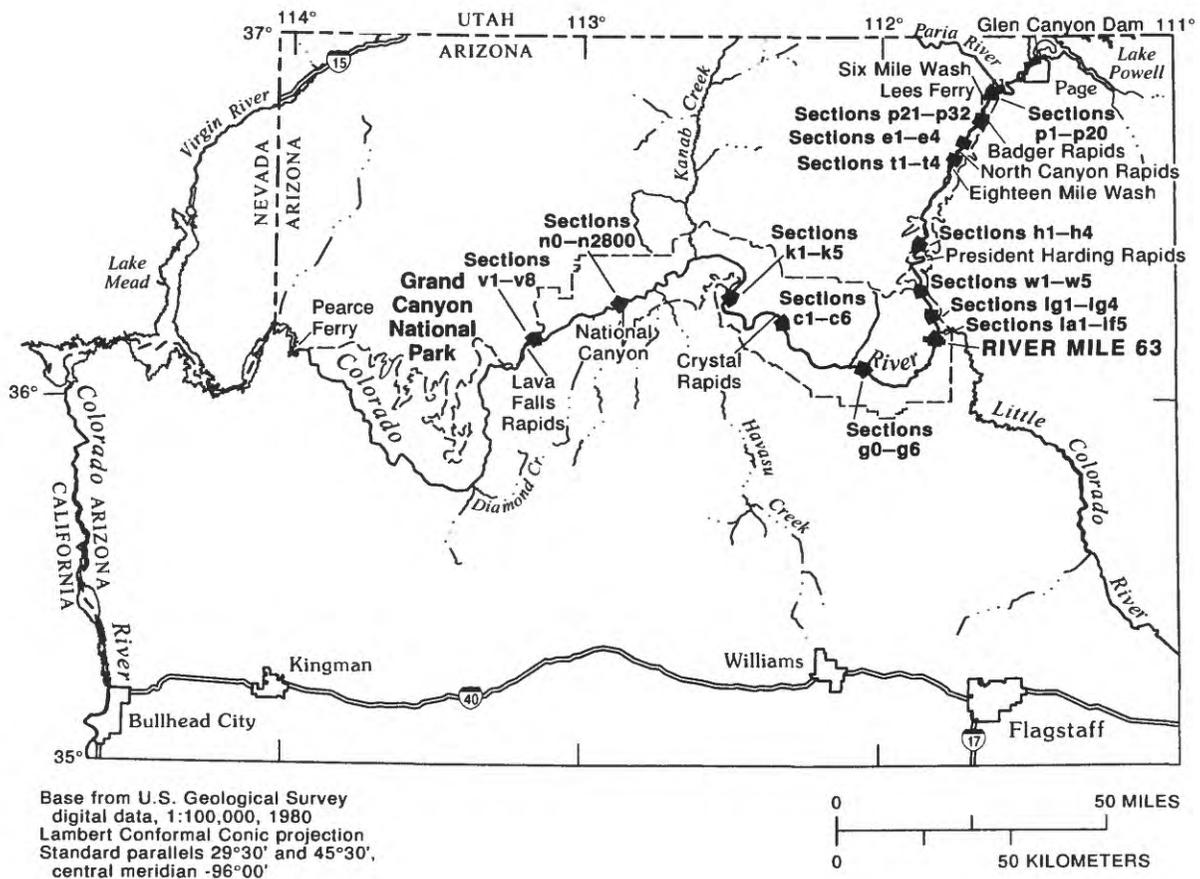


Figure 15. Locations of monumented cross sections on the Colorado River measured before, during, and after the controlled releases of 1996.

cross section were computed to show the changes in cross sections documented by the measurements. Techniques of measurement and data analysis are detailed by Graf and others (1995). In addition, about 40 cross sections were measured at least once during the high-flow release to better establish the rate at which changes took place (table 10). Sand-storage changes in the channel between surveys made in February–March 1996, before the controlled releases, and in April–May 1996, after the controlled releases, ranged from a gain of 118 m² at section p11, just downstream from the mouth of the Paria River, to a loss of 637 m² at section lc2, downstream from the mouth of the Little Colorado River (table 11). In the reach between the Paria River mouth and Badger Rapids, losses of sand from bed storage were greatest in the first pool downstream from the Paria River mouth and in the pool just downstream from Six-Mile Wash (table 11; fig. 16). Sections in

narrow reaches of Marble Canyon, represented by sections e1–e4 and t1–t4 upstream from Eighteen-Mile Wash and North Canyon Rapids, changed little as a result of the high-flow release. Wider reaches in Marble Canyon, such as that upstream from President Harding Rapids, sections h1 and h3, lost 194 and 737 m² of sand, respectively (table 11; fig. 16). Loss of sand from the bed in the three pools just downstream from the mouth of the Little Colorado River, monitored by sections la1–la7, lb1–lb4, lb1b, and lc1–lc5, ranged from -3 to -637 m² (table 11; fig. 16). These pools had aggraded significantly as a result of a large flood on the Little Colorado River in January 1993 and had retained much of that sand (Graf and others, 1995). Bed-elevation changes in section lc2 from 1993 to after the 1996 high-flow release are shown in figure 16. After the controlled releases, the channel bed was lower at its deepest point than before the 1993 Little Colorado River flood, but

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996

[yyymmdd, year, month, day; dashes indicate no data]

Section	Date (yyymmdd)	Start time	End time	Mean time	Section	Date (yyymmdd)	Start time	End time	Mean time
Between Paria River and Badger Rapids					Between Paria River and Badger Rapids—Continued				
p1	960212	1658	1719	1710	p13	960330	1320	1342	1331
p1	960506	1905	1920	1912	p13	960331	1500	1516	1508
p2	960213	0850	0910	0900	p13	960402	0908	0925	0916
p2	960507	0825	0837	0831	p13	960509	0720	0740	0730
p3	960213	0932	0950	0941	p14	960214	1153	1208	1200
p3	960507	0905	0923	0914	p14	960327	1512	1532	1522
p4	960213	1035	1053	1044	p14	960329	1356	1415	1410
p4	960507	0950	1013	1003	p14	960331	1530	1547	1538
p5	960213	1128	1152	1140	p14	960402	0940	0955	0948
p5	960327	1105	1124	1114	p14	960509	0800	0815	0808
p5	960328	1641	1706	1653	p15	960214	1317	1331	1324
p5	960330	1420	1449	1434	p15	960327	1600	1620	1610
p5	960401	1522	1555	1538	p15	960329	1428	1442	1435
p5	960507	1045	1114	1059	p15	960331	1605	1620	1612
p6	960213	1231	1254	1242	p15	960401	1010	1025	1018
p6	960326	1427	1523	1455	p15	960509	0844	0902	0852
p6	960329	0850	0916	0903	p15a	960214	1356	1409	1403
p6	960330	1510	1536	1523	p15a	960509	0935	0955	0945
p6	960401	0850	0914	0902	p15b	960214	1423	1437	1430
p6	960507	1435	1457	1446	p15b	960509	1009	1023	1016
p7	960213	1527	1557	1542	p16	960214	1456	1510	1503
p7	960327	1307	1340	1324	p16	960327	1654	1713	1704
p7	960329	0947	1017	1002	p16	960329	1515	1538	1526
p7	960507	1241	1305	1253	p16	960331	1335	1348	1342
p8	960213	--	1710	--	p16	960401	1355	1410	1402
p8	960507	1335	1400	1347	p16	960509	1040	1052	1046
p9	960214	0823	0843	0833	p17	960214	1526	1542	1534
p9	960507	1535	1555	1545	p17	960328	0940	0959	0950
p10	960214	0905	0924	0914	p17	960329	1600	1620	1610
p10	960507	1620	1643	1632	p17	960331	1410	1436	1423
p11	960214	0959	1013	1008	p17	960401	1435	1450	1442
p11	960507	1710	1729	1720	p17	960509	1205	1229	1217
p12	960214	1042	1055	1048	p18	960214	1610	1630	1620
p12	960507	1750	1802	1756	p18	960509	1245	1303	1254
p13	960214	1122	1137	1130	p19	960214	1650	1708	1659
p13	960327	1413	1440	1426	p19	960509	1322	1335	1328
p13	960329	1044	1106	1055	p20	960215	0828	0838	0833

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996—Continued

Section	Date (yymmdd)	Start time	End time	Mean time	Section	Date (yymmdd)	Start time	End time	Mean time
Between Paria River and Badger Rapids—Continued					Upstream from Eighteen-Mile Wash				
p20	960509	1347	1408	1358	e1	960221	1529	1540	1534
p21	960215	0920	0938	0929	e1	960322	1505	1527	1516
p21	960508	1435	1455	1445	e1	960405	1435	1450	1442
p22	960215	1023	1041	1032	e1	960415	1035	1049	1042
p22	960328	1040	1105	1052	e2	960221	1552	1605	1558
p22	960508	1520	1545	1532	e2	960322	1540	1554	1547
p23	960215	1102	1121	1112	e2	960405	--	--	--
p23	960508	1610	1632	1621	e2	960415	1003	1022	1012
p24	960215	1311	1325	1318	e3	960221	1635	1643	1639
p24	960508	1650	1710	1700	e3	960322	1706	1714	1710
p25	960215	1350	1405	1357	e3	960405	1151	1202	1157
p25	960328	1233	1250	1242	e3	960415	0932	0946	0939
p25	960330	--	0942	--	e4	960221	1703	1714	1708
p25	960401	1045	1105	1055	e4	960322	1617	1629	1623
p25	960508	1724	1740	1732	e4	960405	1112	1135	1124
p26	960215	1424	1439	1432	e4	960415	0855	0915	0905
p26	960328	1406	1420	1413	Upstream from North Canyon Rapids				
p26	960330	1001	1017	1009	t1	960222	1123	1135	1129
p26	960401	1008	1023	1016	t1	960415	1140	1206	1153
p26	960508	1754	1811	1802	t2	960222	1047	1100	1053
p27	960216	1119	1136	1128	t2	960415	1246	1302	1254
p27	960508	0715	0759	0737	t3	960222	1012	1027	1020
p28	960216	1026	1045	1036	t3	960415	1314	1331	1322
p28	960330	1040	1100	1050	t4	960222	0945	0957	0951
p28	960401	1050	1110	1100	t4	960415	1345	1358	1352
p28	960401	1125	1145	1135	Upstream from President Harding Rapids				
p28	960508	--	0902	--	h1	960222	1551	1612	1601
p29	960216	0931	0949	0940	h1	960415	1714	1729	1722
p29	960508	0935	1006	0951	h2	960222	1635	1650	1642
p30	960216	0852	0905	0858	h2	960415	1759	1814	1807
p30	960508	--	1104	--	h3	960222	1716	1735	1726
p31	960215	1623	1638	1630	h3	960415	1832	1852	1842
p31	960508	1217	1237	1227	h4	960223	0952	1012	1002
p32	960215	1515	--	--	h4	960416	0850	0915	0902
p32	960328	1515	1530	1522	h5	960223	1030	1044	1037
p32	960330	--	1144	--	h5	960416	0934	1000	0947
p32	960401	1251	1310	1300	Upstream from Nankoweap Rapids				
p32	960508	1335	1355	1345	w1	960223	1635	1648	1642

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996—Continued

Section	Date (yymmdd)	Start time	End time	Mean time	Section	Date (yymmdd)	Start time	End time	Mean time
Upstream from Nankoweap Rapids—Continued					Between Little Colorado River and Tanner Rapids—Continued				
w1	960416	1142	1210	1156	lb1b	960226	1540	1601	1550
w2	960223	1519	1530	1524	lb1b	960418	1310	1343	1326
w2	960416	1235	1249	1242	lb2	960226	1633	1645	1639
w3	960223	1444	1457	1450	lb2	960418	1440	1455	1448
w3	960416	1306	1321	1314	lb3	960226	1705	1727	1716
w4	960223	1410	1425	1418	lb3	960405	1154	1209	1202
w4	960416	1335	1350	1342	lb3	960418	1522	1546	1534
w5	960223	1347	1358	1352	lb4	960226	1749	1808	1758
w5	960416	1417	1433	1425	lb4	960418	1605	1643	1624
Upstream from the Little Colorado River					lc1	960226	0929	0952	0940
lg1	960224	1234	1246	1240	lc1	960405	1036	1054	1045
lg1	960417	0933	0945	0939	lc1	960407	1037	1055	1046
lg2	960224	1304	1317	1310	lc1	960419	0852	0916	0904
lg2	960417	0858	0917	0907	lc2	960226	1025	1048	1036
lg3	960224	1444	1504	1454	lc2	960405	0940	1020	1000
lg3	960416	1720	1734	1727	lc2	960407	0942	1005	1053
lg4	960224	1601	1614	1608	lc2	960419	0932	0957	0944
lg4	960416	1648	1705	1656	lc3	960226	1138	1159	1148
Between Little Colorado River and Tanner Rapids					lc3	960405	0820	0840	0830
la1	960225	0935	0955	0945	lc3	960407	0909	0927	0918
la1	960405	1433	1458	1446	lc3	960419	1022	1045	1034
la1	960417	1235	1256	1246	lc4	960226	1245	1309	1257
la2	960225	1016	1037	1026	lc4	960419	1101	1122	1112
la2	960405	1536	1554	1545	lc5	960226	1437	1504	1450
la2	960417	1310	1329	1320	lc5	960419	1140	1200	1150
la3	960225	1101	1127	1114	ld1	960227	0910	0932	0921
la3	960417	1340	1357	1348	ld1	960326	1201	1214	1208
la4	960225	1155	1209	1202	ld1	960407	1408	1419	1414
la4	960417	1410	1423	1416	ld1	960419	1342	1403	1353
la5	960225	1345	1359	1352	ld2	960227	0947	1004	0956
la5	960417	1440	1452	1446	ld2	960419	1418	--	--
la6	960225	1416	1428	1422	ld3	960227	1033	1048	1040
la6	960417	1512	1525	1518	ld3	960419	1455	1502	1459
la7	960225	1502	1513	1508	ld4	960227	1104	1117	1110
la7	960405	1624	1636	1630	ld4	960326	1116	1130	1123
la7	960417	1535	1548	1542	ld4	960407	1433	1450	1442
lb1	960225	1546	1608	1557	ld4	960419	1519	1530	1524
lb1	960418	1059	1115	1107	ld5	960227	1145	1202	1154

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996—Continued

Section	Date (yymmdd)	Start time	End time	Mean time	Section	Date (yymmdd)	Start time	End time	Mean time
Between Little Colorado River and Tanner Rapids—Continued					Between Little Colorado River and Tanner Rapids—Continued				
ld5	960419	1545	1559	1552	lf2	960402	1019	1040	1030
le1	960227	1416	1435	1426	lf2	960406	1047	1100	1054
le1	960406	1430	1442	1436	lf2	960420	1030	1047	1038
le1	960419	1158	1208	1203	lf3	960228	1530	--	--
le2	960227	1449	1505	1457	lf3	960328	1532	1541	1536
le2	960406	1508	1526	1517	lf3	960330	0910	0928	0919
le2	960420	1415	1429	1422	lf3	960402	0948	1002	0955
le3	960227	1530	1550	1540	lf3	960406	1116	1125	1120
le3	960420	1455	1507	1501	lf3	960420	1105	1138	1122
le4	960227	1605	1620	1612	lf4	960228	1650	1715	1702
le4	960420	1520	1542	1531	lf4	960420	1158	1208	1203
le5	960227	1648	1709	1658	lf5	960229	1058	1107	1103
le5	960420	1558	1619	1609	lf5	960420	1158	1202	1200
lf1	960228	1300	1315	1308	Upstream from streamflow-gaging station 09402500, Colorado River near Grand Canyon				
lf1	960326	0936	0952	0944	g0	960303	0934	0947	0940
lf1	960326	1940	2003	1952	g0	960326	0956	1016	1006
lf1	960327	0800	0815	0808	g0	960327	0914	1017	0932
lf1	960327	--	1727	--	g0	960328	1000	1012	1006
lf1	960328	1350	1402	1356	g0	960329	0945	0958	0952
lf1	960329	0830	0840	0835	g0	960330	0904	0914	0909
lf1	960329	1749	1805	1755	g0	960331	1312	1322	1317
lf1	960330	0834	0844	0839	g0	960401	1048	1101	1054
lf1	960330	1636	1651	1644	g0	960402	0946	1003	0954
lf1	960401	1352	1403	1357	g0	960403	0914	0923	0918
lf1	960402	1049	1101	1055	g0	960422	1030	1040	1035
lf1	960406	1014	1024	1019	g1	960302	1013	1031	1022
lf1	960327	--	1727	--	g1	960326	1037	1055	1046
lf1	960420	1000	1015	1008	g1	960327	1124	1143	1134
lf2	960228	1358	--	--	g1	960328	1025	1107	1046
lf2	960326	1010	1025	1018	g1	960329	1014	1024	1019
lf2	960326	2037	--	--	g1	960330	0924	0935	0930
lf2	960327	0830	0844	0837	g1	960331	1346	1351	1348
lf2	960327	1741	--	--	g1	960401	1114	1124	1119
lf2	960328	1414	1427	1420	g1	960402	1018	1033	1026
lf2	960329	0854	0907	0900	g1	960403	0936	0946	0941
lf2	960330	0940	1000	0950	g1	960422	1100	1115	1108
lf2	960401	1416	1430	1423	g2	960302	1053	1108	1100

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996—Continued

Section	Date (yyymmdd)	Start time	End time	Mean time	Section	Date (yyymmdd)	Start time	End time	Mean time
Upstream from streamflow-gaging station 09402500, Colorado River near Grand Canyon—Continued					Upstream from Crystal Rapids				
g2	960326	1114	1129	1122	c1	960303	1420	1434	1427
g2	960327	1200	1219	1210	c1	960423	1533	1545	1539
g2	960328	1120	1140	1130	c2	960303	1459	1514	1508
g2	960329	1109	1122	1116	c2	960423	1505	1518	1512
g2	960330	0945	0956	0950	c3	960303	1540	1556	1548
g2	960331	1401	1411	1406	c3	960423	1430	1449	1440
g2	960401	1226	1235	1230	c4	960303	1609	1622	1616
g2	960402	1050	1058	1054	c4	960423	1400	1411	1406
g2	960403	1000	1013	1006	c5	960303	1636	1645	1640
g2	960422	1130	1145	1138	c5	960423	1312	1323	1318
g3	960302	1140	1200	1150	c6	960303	1702	1710	1706
g3	960326	1234	1252	1243	c6	960423	1250	1300	1255
g3	960327	1234	1255	1244	Upstream from 127-Mile Rapids				
g3	960328	1152	1208	1200	k1	960304	1340	1351	1346
g3	960329	1236	1257	1246	k1	960424	1020	1050	1035
g3	960330	1006	1019	1012	k2	960304	1403	1410	1406
g3	960331	1441	1454	1448	k2	960424	1105	1115	1110
g3	960401	1246	1302	1254	k3	960304	1428	1446	1437
g3	960402	1107	1121	1114	k3	960424	1125	1135	1130
g3	960403	1023	1034	1028	k4	960304	1502	--	--
g3	960422	1350	1403	1356	k4	960424	1150	1200	1155
g4	960302	1240	1254	1247	k5	960304	1534	1550	1542
g4	960326	1312	1332	1322	k5	960424	1210	1223	1216
g4	960327	1319	1338	1328	Upstream from streamflow-gaging station 09404120, Colorado River above National Canyon near Supai				
g4	960328	1223	1239	1231	n0	960305	--	1843	--
g4	960329	1305	1315	1310	n0	960327	1548	--	--
g4	960330	1006	1019	1012	n0	960329	1215	1300	1238
g4	960331	1545	1615	1600	n0	960331	1028	1051	1040
g4	960401	1312	1337	1324	n0	960401	--	1538	--
g4	960402	1130	1140	1135	n0	960402	1051	1129	1110
g4	960403	1047	1101	1054	n0	960425	1650	1720	1705
g4	960422	1415	1430	1422	n400	960305	1804	1812	1808
g5	960302	1640	1652	1646	n400	960327	1716	1757	1737
g5	960422	1440	1455	1448	n400	960328	1045	1102	1054
g6	960302	--	1750	--	n400	960328	1701	1720	1710
g6	960422	1510	1530	1520	n400	960329	1450	1530	1510

Table 10. Monumented cross sections measured before, during, and after the controlled releases of 1996—Continued

Section	Date (yymmdd)	Start time	End time	Mean time	Section	Date (yymmdd)	Start time	End time	Mean time
Upstream from streamflow-gaging station 09404120, Colorado River above National Canyon near Supai—Continued					Upstream from streamflow-gaging station 09404120, Colorado River above National Canyon near Supai—Continued				
n400	960330	1413	1434	1424	n2400	960401	0948	1002	0955
n400	960331	--	1720	--	n2800	960305	1652	1700	1656
n400	960401	1607	1630	1618	n2800	960328	1435	1454	1444
n400	960402	0855	--	--	n2800	960330	1132	1144	1138
n400	960425	1620	1640	1630	n2800	960401	0911	0924	0918
n800	960305	1452	1518	1505	n2800	960425	1418	1430	1424
n800	960328	1045	1102	1054	Upstream from Lava Falls Rapids				
n800	960330	0857	0919	0908	v1	960306	1704	1722	1713
n800	960401	1146	1203	1154	v1	960426	1810	1830	1820
n800	960402	0958	1035	1016	v2	960306	1623	1632	1628
n800	960425	1545	1600	1552	v2	960426	1740	1752	1746
n1200	960305	1545	1556	1550	v3	960306	1547	1600	1553
n1200	960328	1130	1144	1137	v3	960426	1700	1718	1709
n1200	960330	--	1036	--	v4	960306	1500	1516	1508
n1200	960401	1119	1131	1125	v4	960426	1633	1645	1639
n1200	960425	1515	1525	1520	v5	960306	1425	1435	1430
n1600	960305	1612	1622	1617	v5	960426	1425	1440	1432
n1600	960328	1205	1218	1212	v6	960306	1353	1404	1359
n1600	960330	1051	1105	1058	v6	960426	1505	1515	1510
n1600	960401	1053	1105	1059	v7	960306	--	1338	--
n1600	960425	1450	1500	1455	v7	960426	1530	1540	1535
n2000	960328	1606	1621	1614	v8	960306	--	1310	--
n2000	960401	1016	1039	1028	v8	960426	1550	1602	1556
n2400	960328	1525	1540	1532					

the sandbar in the left-bank eddy was higher in elevation. Many of the sections, such as those above the Little Colorado River and those upstream from Crystal and Lava Falls Rapids, showed sand-storage changes less than 50 m² between the surveys made before and after the controlled releases (table 11; fig. 16).

In this report, cross sections between the Little Colorado River and Tanner Rapids have been identified with a leading l to distinguish them from the cross sections downstream from Tanner Rapids. In Graf and others (1995), those cross sections did not have the leading l.

Changes in sand stored in a sandbar downstream from the mouth of the Little Colorado River were monitored with load-cell scour sensors at five locations in cross section lc2 during the controlled releases (fig. 17). Description and operation of the load-cell scour sensor are detailed by Carpenter and others (1995) and Carpenter (1996). Sensors were buried across the sandbar at locations 1.5, 6.1, 12.2, 24.4, and 36.6 m from the reference point near the left-bank wall. The greatest change was recorded at the sensor at 12.2 m, where 0.8 m of deposition and 4 m of scour occurred (fig. 18).

Table 11. Changes in sand storage between measurements made at monumented cross sections before and after the controlled releases of 1996

[yyymmdd, year, month, day; *, a plot of the cross section is shown in figure 19]

Cross-section number	Period evaluated (yyymmdd)	Area difference, in square meters	Fraction	
			Significant	Tested
Between Paria River and Badger Rapids				
p1	960212-960506*	-3	0.99	0.85
p2	960213-960507	-15	1.00	.96
p3	960213-960507	-35	.99	.95
p4	960213-960507*	-71	1.00	.93
p5	960213-960507	-104	.96	.98
p6	960213-960507*	-257	.98	.98
p7	960213-960507	-163	.99	.96
p8	960213-960507	37	.98	.96
p9	960214-960507	30	.76	.92
p10	960214-960507*	66	.98	.97
p11	960214-960507	118	1.00	.93
p12	960214-960507	9	.75	.84
p13	960214-960509*	64	.97	.91
p14	960214-960509	5	.99	.92
p15	960214-960509	-23	1.00	.96
p15a	960214-960509*	-84	.95	.96
p16	960214-960509	-48	1.00	.95
p17	960214-960509	-46	1.00	.96
p18	960214-960509	-5	.96	.95
p19	960214-960509	-1	.96	.97
p20	960215-960509	-78	1.00	.92
p21	960215-960508*	89	.99	.93
p22	960215-960508*	-146	.99	.98
p23	960215-960508*	-273	1.00	.96
p24	960215-960508*	-233	.97	.97
p25	960215-960508	-68	1.00	.96
p26	960215-960508	-58	.99	.98
p27	960216-960508	-18	.93	.97
p28	960216-960508	-10	.98	.97
p29	960216-960508	-11	.96	.97
p30	960216-960508*	-21	.94	.98
p31	960215-960508	-1	.94	.96
p32	960215-960508*	18	.99	.98
Upstream from Eighteen-Mile Wash				
e1	960221-960415	5	.55	.93
e2	960221-960415	14	.67	.94
e3	960221-960415	17	.77	.87
e4	960221-960415*	21	.77	.96
Upstream from North Canyon Rapids				
t1	960222-960415	-13	.83	.92
t2	960222-960415	6	.69	.89
t3	960222-960415*	-11	.93	.92
t4	960222-960415	22	.87	.94

Table 11. Changes in sand storage between measurements made at monumented cross sections before and after the controlled releases of 1996—Continued

Cross-section number	Period evaluated (yymmdd)	Area difference, in square meters	Fraction	
			Significant	Tested
Upstream from President Harding Rapids				
h1	960222–960415*	-194	0.99	0.89
h2	960222–960415*	-88	.96	.98
h3	960222–960415	-737	1.00	.94
h4	960223–960416	6	.77	.98
h5	960223–960416	13	.75	.97
Upstream from Nankoweap Rapids				
w2	960223–960416*	-64	1.00	.91
w3	960223–960416*	41	.99	.90
w4	960223–960416	8	.95	.90
w5	960223–960416	-56	.96	.96
Upstream from the Little Colorado River				
lg1	960224–960417	2	.67	.92
lg2	960224–960417	29	1.00	.65
lg3	960224–960416	0	.08	.94
lg4	960224–960416	1	.08	.97
Between the Little Colorado River and Tanner Rapids				
la1	960225–960417*	-567	1.00	.94
la2	960225–960417	-148	.99	.74
la3	960225–960417	-37	.99	.98
la4	960225–960417	-62	1.00	.94
la5	960225–960417	26	1.00	.89
la6	960225–960417	-188	1.00	.70
la7	960225–960417*	-377	1.00	.64
lb1	960225–960418*	-332	1.00	.97
lb1b	960226–960418	-32	.97	.97
lb2	960226–960418	34	.80	.76
lb3	960226–960418*	-102	1.00	.86
lb4	960226–960418	-3	1.00	.90
lc1	960226–960419	-138	1.00	1.00
lc2	960226–960419*	-637	1.00	1.00
lc3	960226–960419*	-473	1.00	1.00
lc4	960226–960419	16	1.00	1.00
lc5	960226–960419	63	1.00	1.00
ld1	960227–960419	6	.98	.98
ld2	960227–960419	-2	.66	.58
ld3	960227–960419	5	.48	.79
ld4	960227–960419*	3	.64	.95
ld5	960227–960419*	-17	1.00	.84
le1	960227–960419	-10	.92	.74
le2	960227–960420*	-74	.99	.69
le3	960227–960420	-47	.98	.79
le4	960227–960420	38	.96	.96
le5	960227–960420*	45	.99	.95

Table 11. Changes in sand storage between measurements made at monumented cross sections before and after the controlled releases of 1996—Continued

Cross-section number	Period evaluated (yymmdd)	Area difference, in square meters	Fraction	
			Significant	Tested
Between the Little Colorado River and Tanner Rapids—Continued				
lf1	960228–960420	6	0.99	0.90
lf2	960228–960420	36	1.0	.96
lf3	960228–960420*	28	.99	.88
lf4	960228–960420*	81	.99	.84
lf5	960229–960420	62	.99	.86
Upstream from streamflow-gaging station 09402500, Colorado River near Grand Canyon				
g0	960303–960422*	-34	1.00	.97
g1	960302–960422	-31	1.00	.85
g2	960302–960422*	-67	.99	.93
g3	960302–960422	-152	.96	.90
g4	960302–960422	-189	1.00	.92
g5	960302–960422	-87	.95	.94
g6	960302–960422	53	.97	.98
Upstream from Crystal Rapids				
c1	960303–960423	22	.75	.93
c2	960303–960423*	18	.99	.97
c3	960303–960423	22	.95	.98
c4	960303–960423	10	.97	.96
c5	960303–960423	20	.96	.91
c6	960303–960423	26	.91	.89
Upstream from 127-Mile Rapids				
k1	960304–960424*	22	.88	.96
k2	960304–960424	-11	1.00	.90
k3	960304–960424	31	.62	.94
k4	960304–960424	34	.92	.88
k5	960304–960424	-12	.75	.93
Upstream from streamflow-gaging station 09404120, Colorado River above National Canyon near Supai				
n2800	960305–960425	-12	.99	.92
n1600	960305–960425	1	.68	.96
n1200	960305–960425	-26	.62	.96
n800	960305–960425	-4	.69	.94
n400	960305–960425	10	.98	.96
n0	960305–960425	10	.76	.96
Upstream from Lava Falls Rapids				
v1	960306–960426	7	.58	.90
v2	960306–960426	3	.80	.92
v3	960306–960426	3	.61	.89
v4	960306–960426	9	.94	.91
v5	960306–960426	-8	.63	.95
v6	960306–960426	1	.73	.97
v7	960306–960426*	-11	.92	.94
v8	960306–960426*	-50	1.00	.94

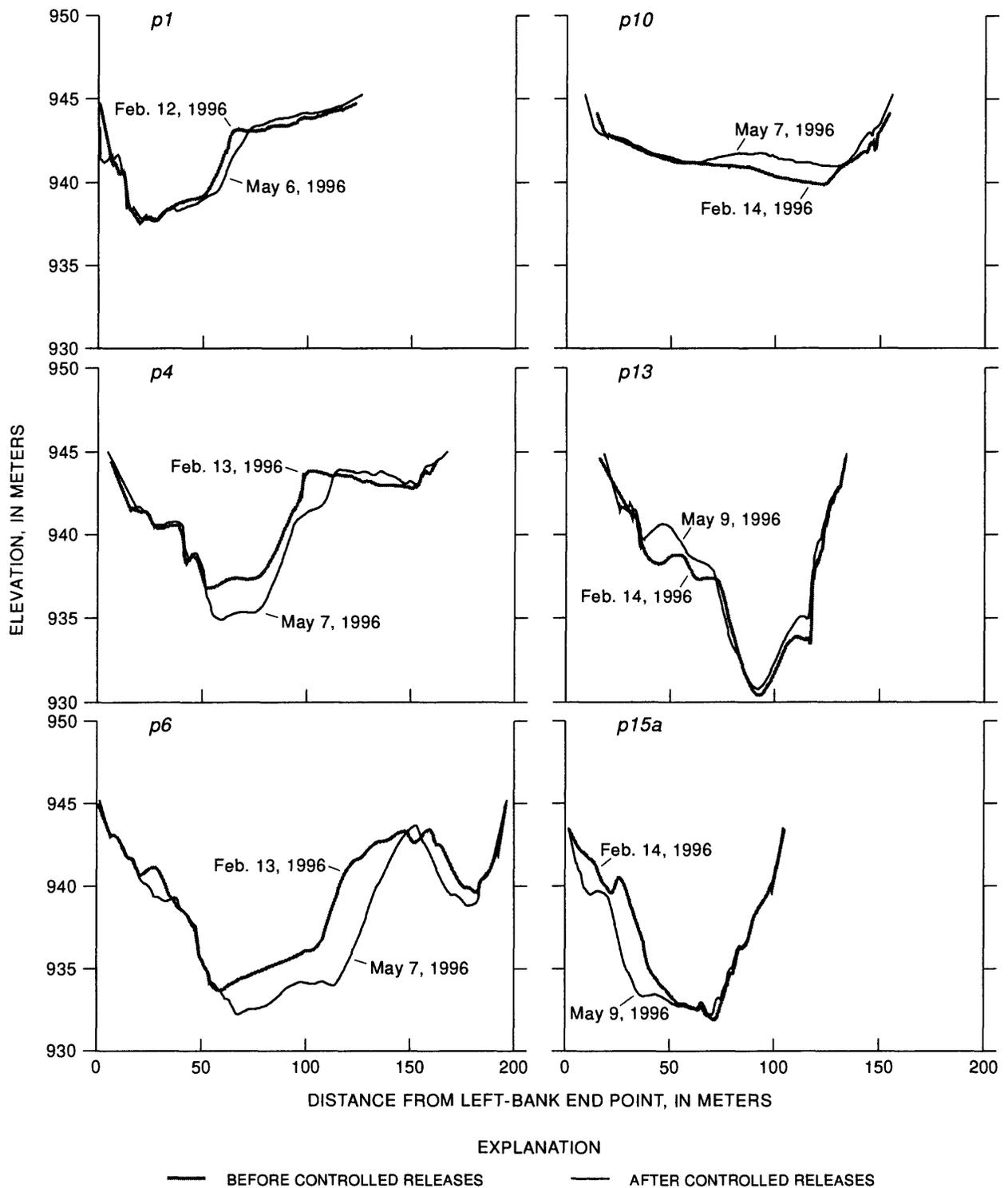


Figure 16. Elevation of the channel bed at selected monumented sections before and after the controlled releases of 1996.

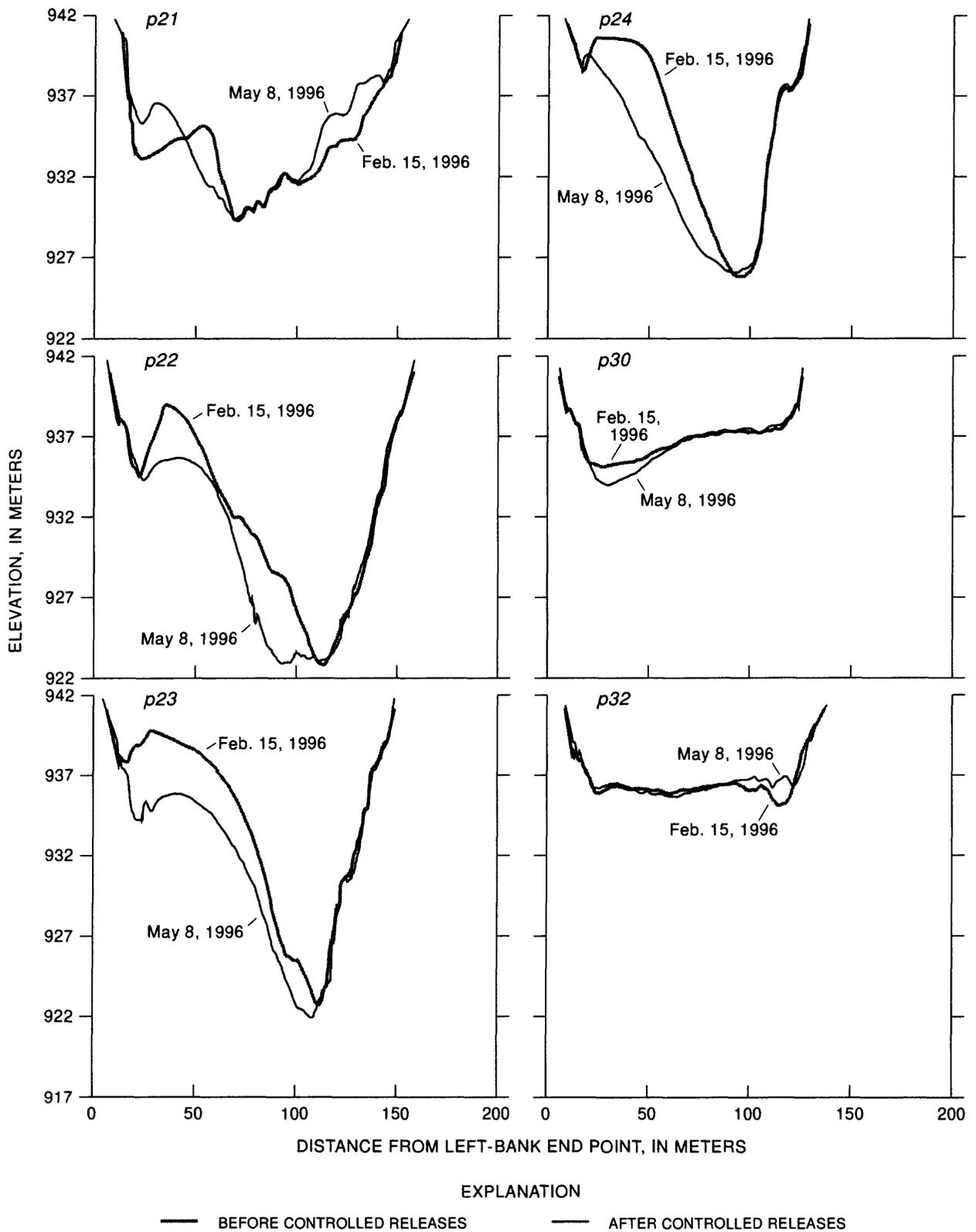


Figure 16. Continued.

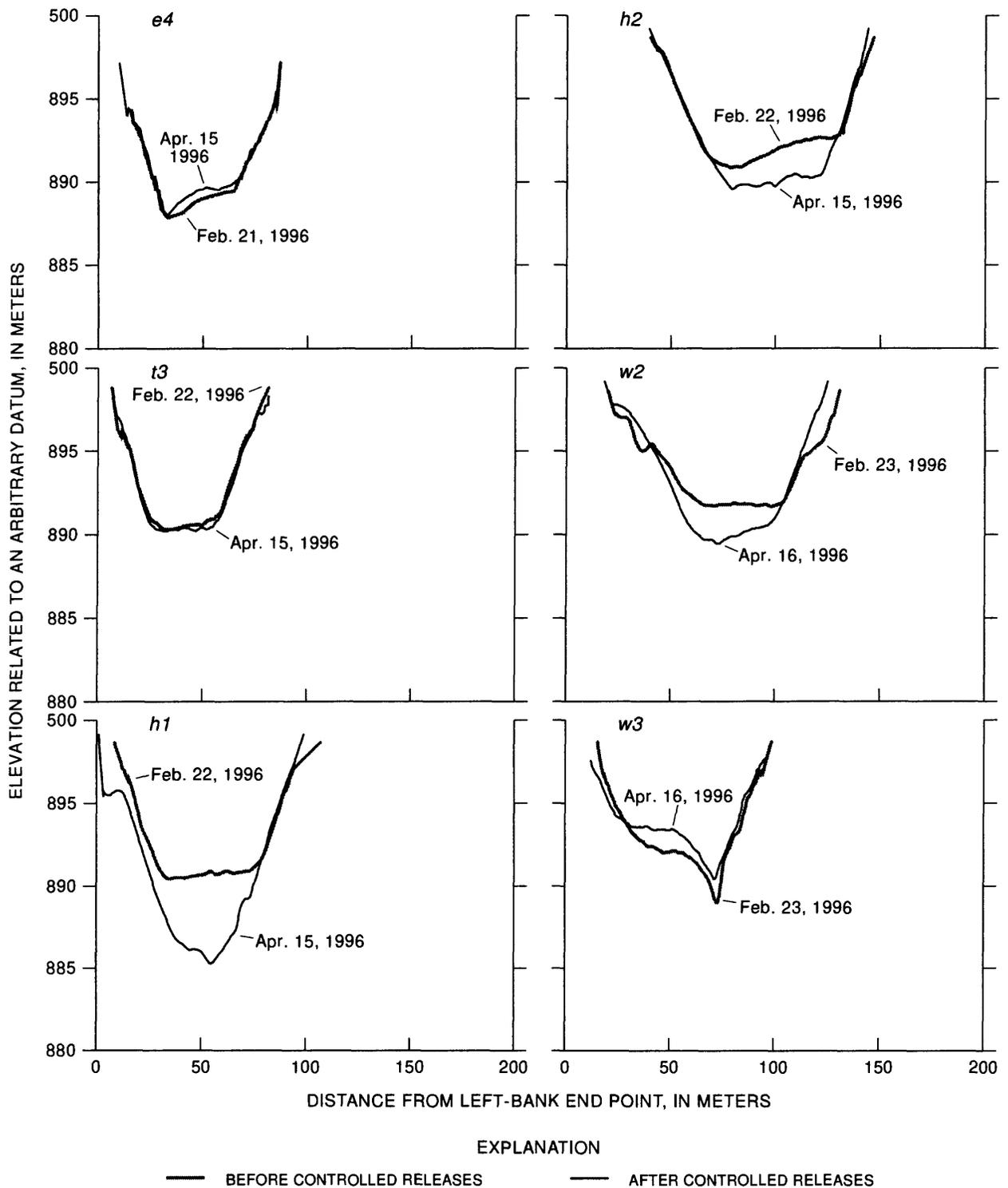


Figure 16. Continued.

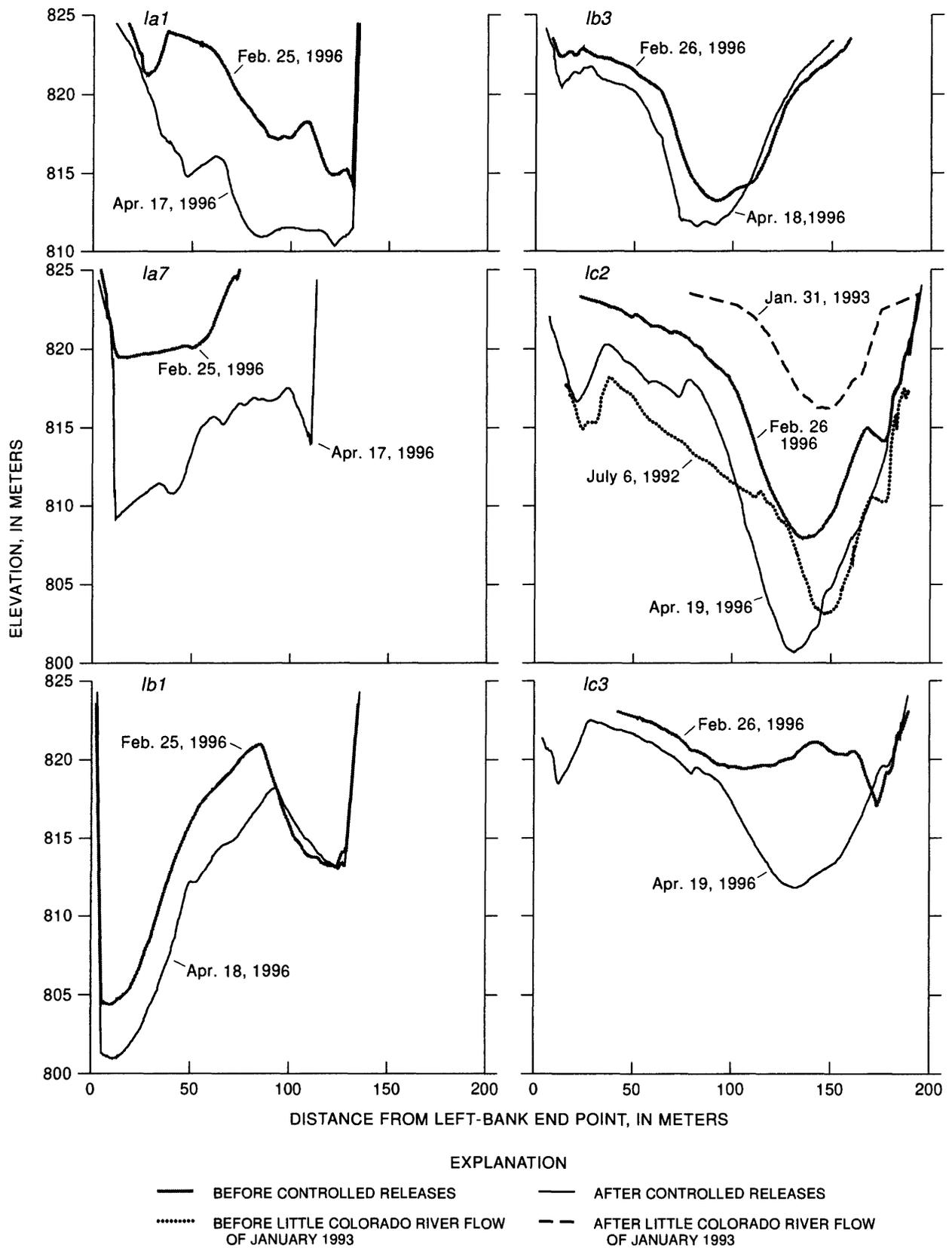


Figure 16. Continued.

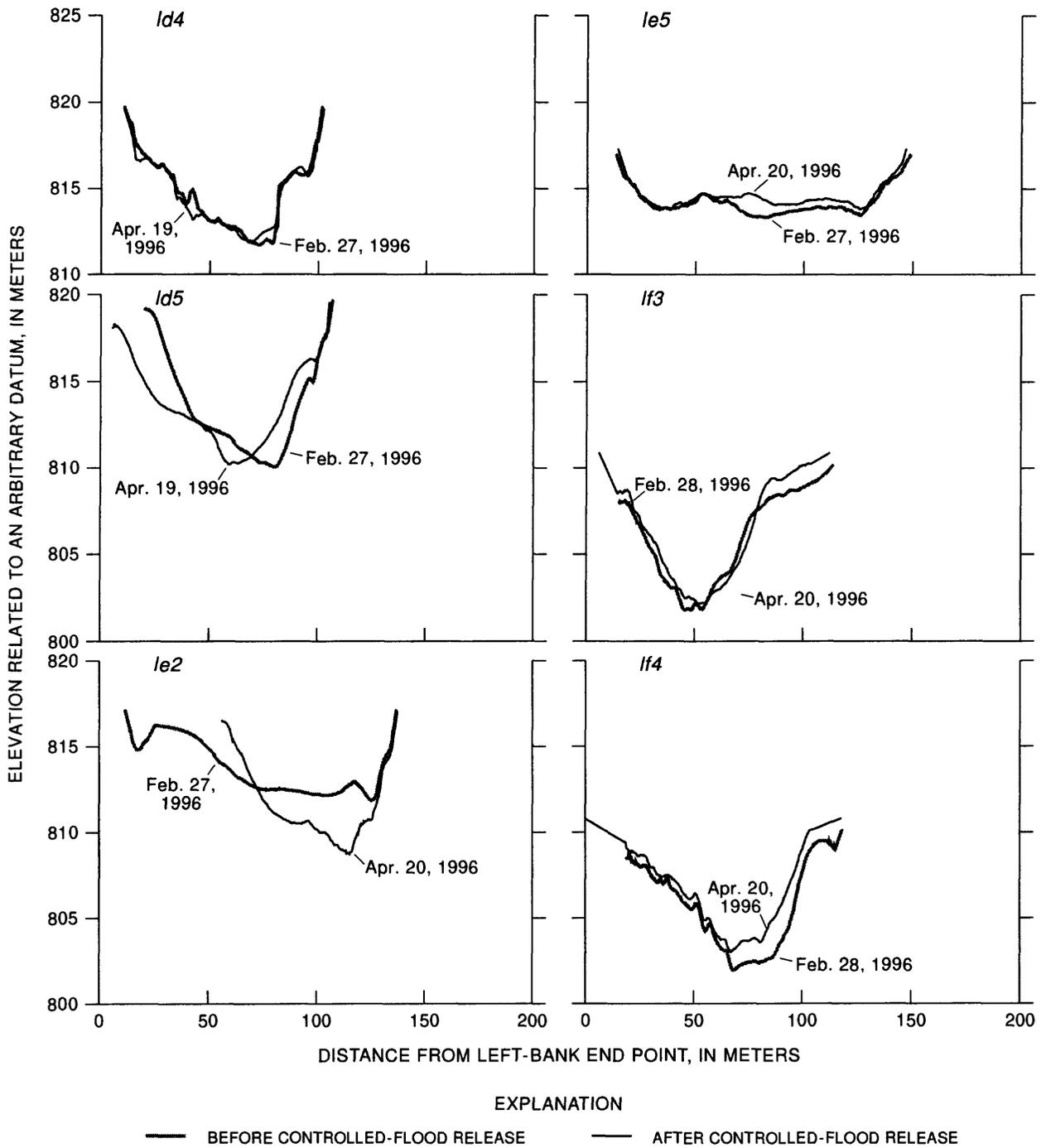


Figure 16. Continued.

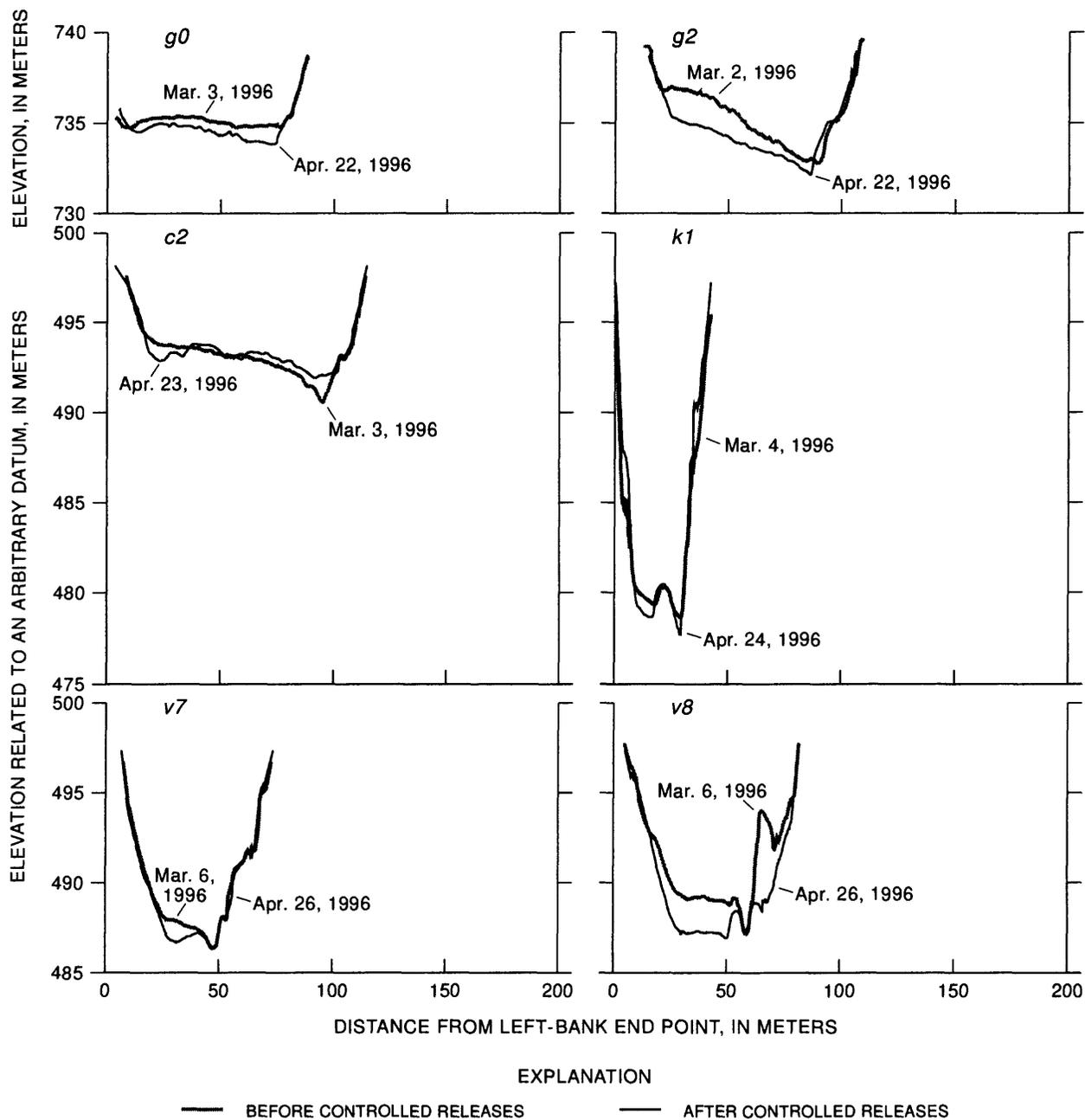


Figure 16. Continued.

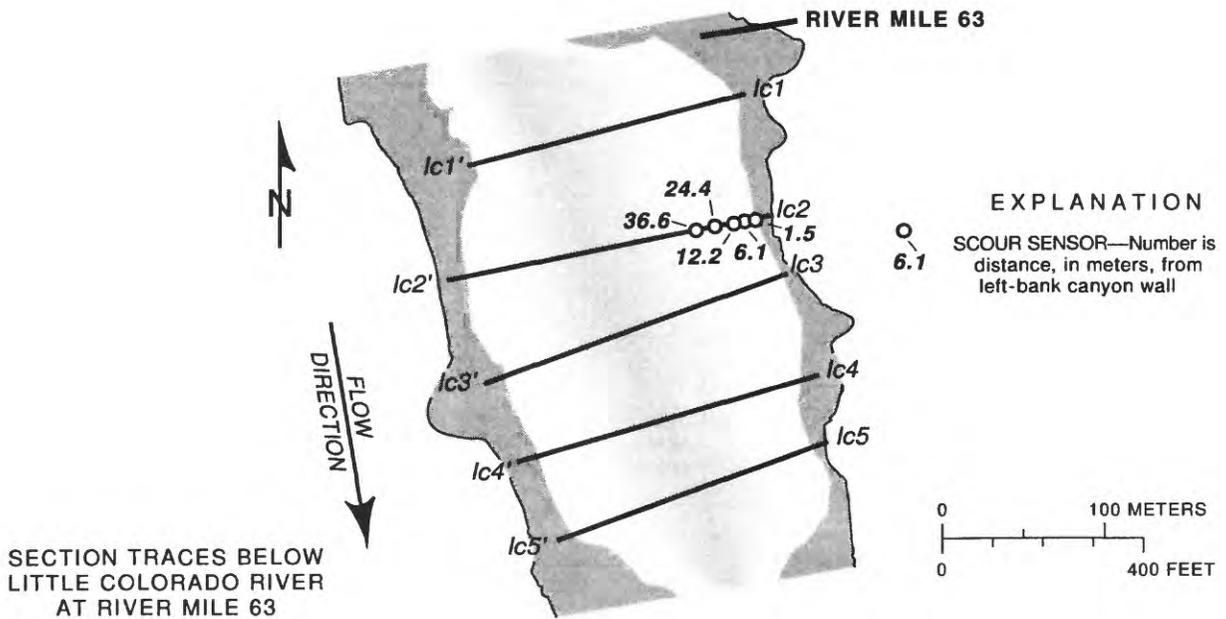


Figure 17. Locations of load-cell scour sensors on cross-section lc2.

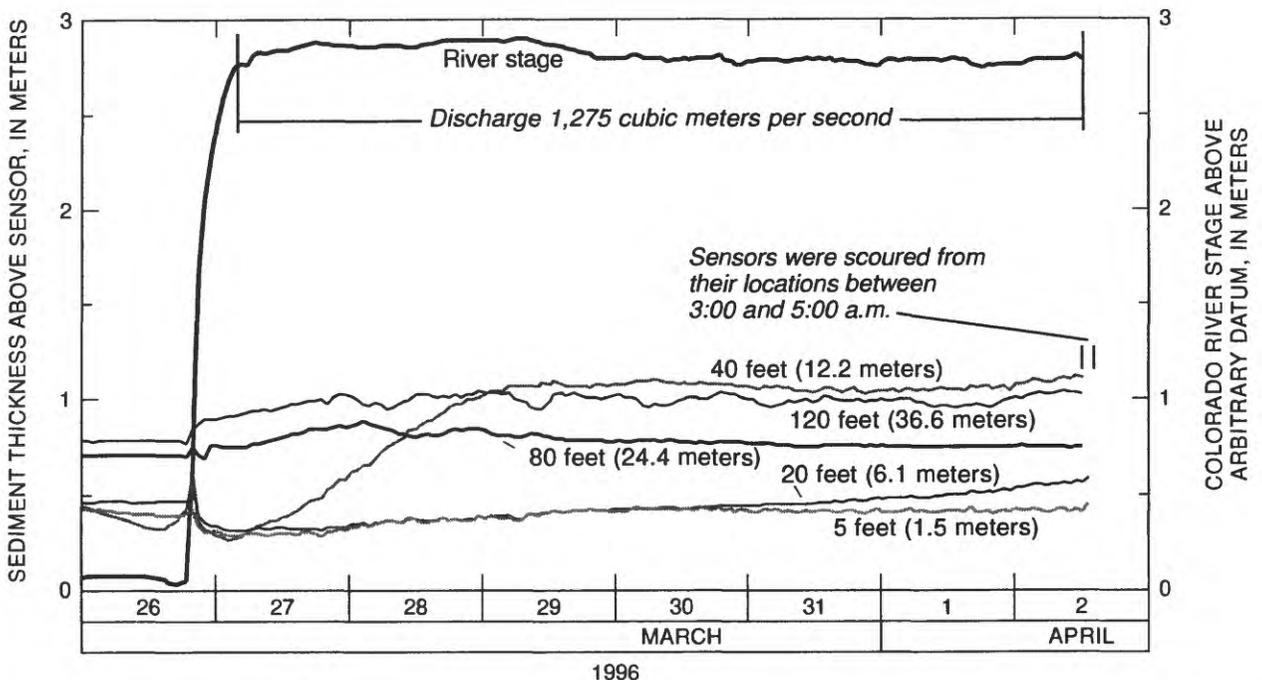


Figure 18. The relation of sediment thickness above scour sensors to the time during the controlled releases of 1996 at five locations along cross-section line lc2 at river mile 63, downstream from the mouth of the Little Colorado River, Grand Canyon, Arizona.

From March 26 to April 1, during the rising limb and first few days of the controlled flood, small amounts of erosion and deposition were measured by the sensors (fig. 18). Most of the change in section lc2 (fig. 16) occurred in a few hours on April 2 (Carpenter, 1996). Between 3:00 and 5:00 a.m. on April 2, while flow was still at a constant 1,275 m³/s, the sandbar was scoured to an average depth of about 4 m. The sensor at 36.6 m on lc2 was scoured 4.9 m between 3:00 and 4:00 a.m. The sensor at 24.4 was scoured 3 m between 3:00 and 5:00 a.m. The sensor at 12.2 m was scoured 4 m between 4:00 and 5:00 a.m.

The data collected to determine the effects of the controlled flood on the Colorado River indicate that changes in measured cross-sectional areas varied throughout the study reach before and after the controlled flood. The large amount of data collected will be used for future analysis.

DATA AVAILABILITY

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.

Additional information is available from the World Wide Web at: <http://www.daztcn.wr.usgs.gov/flood.html>

REFERENCES CITED

- Anima, R.J., Marlow, M.S., Rubin, D.M., Hogg, David, Graf, Julia, and O'Day, Christie, 1996, Comparison of pre-flood and post-flood sand distributions in pools along six reaches downstream from the Little Colorado River, Colorado River, Grand Canyon, Arizona: EOS, Transactions, American Geophysical Union, 1996 Fall Meeting Supplement, v. 77, no. 46, p. F273.
- Christiansen, Trine, 1993, Suspended sediment transport in the Colorado River: Seattle, University of Washington, M.S. thesis, 113 p.
- Carpenter, M.C., Crosswhite, J.A., and Marie, J.R., 1995, A load-cell scour sensor to measure erosion and deposition in the regulated Colorado River in the Grand Canyon, Arizona: EOS, Transactions, American Geophysical Union, 1995 Fall Meeting Supplement, v. 76, no. 46, p. F271.
- Carpenter, M.C., 1996, Monitoring erosion and deposition using an array of load-cell scour sensors during the spring 1996 controlled-flood experiment on the Colorado River in the Grand Canyon, Arizona: EOS, Transactions, American Geophysical Union, 1996 Fall Meeting Supplement, v. 77, no. 46, p. F271.
- Edwards, Thomas, and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.
- Gauger, R.W., 1996, River-stage data, Colorado River, Glen Canyon Dam to Upper Lake Mead, Arizona, 1990-94: U.S. Geological Survey Open-File Report 96-626, 20 p.
- Horowitz, A.J., Demas, C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94-539, 57 p.
- Leahy, P.P., 1993, QA/QC objectives and procedures for NAWQA SW basic fixed sites, unpublished memorandum, August 17, 1993.
- Graf, J.B., 1995, Measured and predicted velocity and longitudinal dispersion at steady and unsteady flow, Colorado River, Glen Canyon Dam to Lake Mead: Water Resources Bulletin, v. 31, no. 2, p. 265-281.
- Graf, J.B., Marlow, J.E., Fisk, G.G., and Jansen, S.M.D., 1995, 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, 61 p.
- Rantz, S.E., and others, 1992, Measurement and computation of streamflow: Volume 1. Measurement of Stage and Discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.