U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Determination of Channel Change for Selected Streams, Maricopa County, Arizona

Water-Resources Investigations Report 01–4209

Prepared in cooperation with the FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

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Tucson, Arizona
November, 2001

U.S. DEPARTMENT OF THE INTERIOR
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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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 of 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.

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD 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”. Elevation, as used in this report, refers to distance above or below sea level.

Determination of Channel Change for Selected Streams, Maricopa County, Arizona

By Joseph P. Capesius *and* Ted W. Lehman[1]

Abstract

In Maricopa County, Arizona, 10 sites on seven streams were studied to determine the lateral and vertical change of the channel. Channel change was studied over time scales ranging from individual floods to decades using cross-section surveys, discharge measurements, changes in the point of zero flow, and repeat photography. All of the channels showed some change in cross-section area or hydraulic radius over the time scales studied, but the direction and magnitude of change varied considerably from one flow, or series of flows, to another. The documentation of cross-section geometry for streams in Maricopa County for long-term monitoring was begun in this study.

INTRODUCTION

Stream channels in arid regions are subject to a wide range of hydrologic, hydraulic, and sedimentary conditions. Stream channels often are dry or have little streamflow most of the time. The few flows that do occur can cause substantial changes to the channel and flood plain (Burkham, 1970; Huckleberry, 1994). Floods in arid regions commonly can be four to five orders of magnitude larger than low flows and can mobilize most of the channel sediment for a period of time (Graf, 1988).

Determining channel conditions in arid regions during floods is difficult because of the dynamic nature of desert stream channels. Floods are often flashy, and many gaging stations are in remote areas; therefore, a variety of direct and indirect methods must be utilized to determine channel behavior during and between floods.

This study was done by the U.S. Geological Survey (USGS) in cooperation with the Flood Control District of Maricopa County (FCDMC).

Purpose and Scope

The purpose of this study is to determine channel change at or near 10 USGS streamflow-gaging stations in and near Maricopa County, Arizona. Channel changes were examined by repeated cross-section measurements, point-of-zero-flow changes, and repeat photography. An examination of channel changes helps to evaluate the accuracy of peak-discharge values determined from indirect measurements of discharge, such as slope area or slope conveyance.

Data from 10 sites that have 10 to 30 years of record were analyzed (**fig. 1**). Two sites are at USGS crest-stage gaging stations—Tiger Wash near Aguila and Waterman Wash near Buckeye. Five sites are at continuous USGS streamflow-gaging stations—Gila River at Estrella Parkway, near Goodyear; Hassayampa River near Morristown; Agua Fria River near Rock Springs; Hassayampa River near Arlington, and Verde River below Bartlett Dam. Two sites are at continuous gaging stations operated by the FCDMC—Hassayampa River at Box Canyon, near Wickenburg and Hassayampa River at U.S. Highway 60, at Wickenburg.

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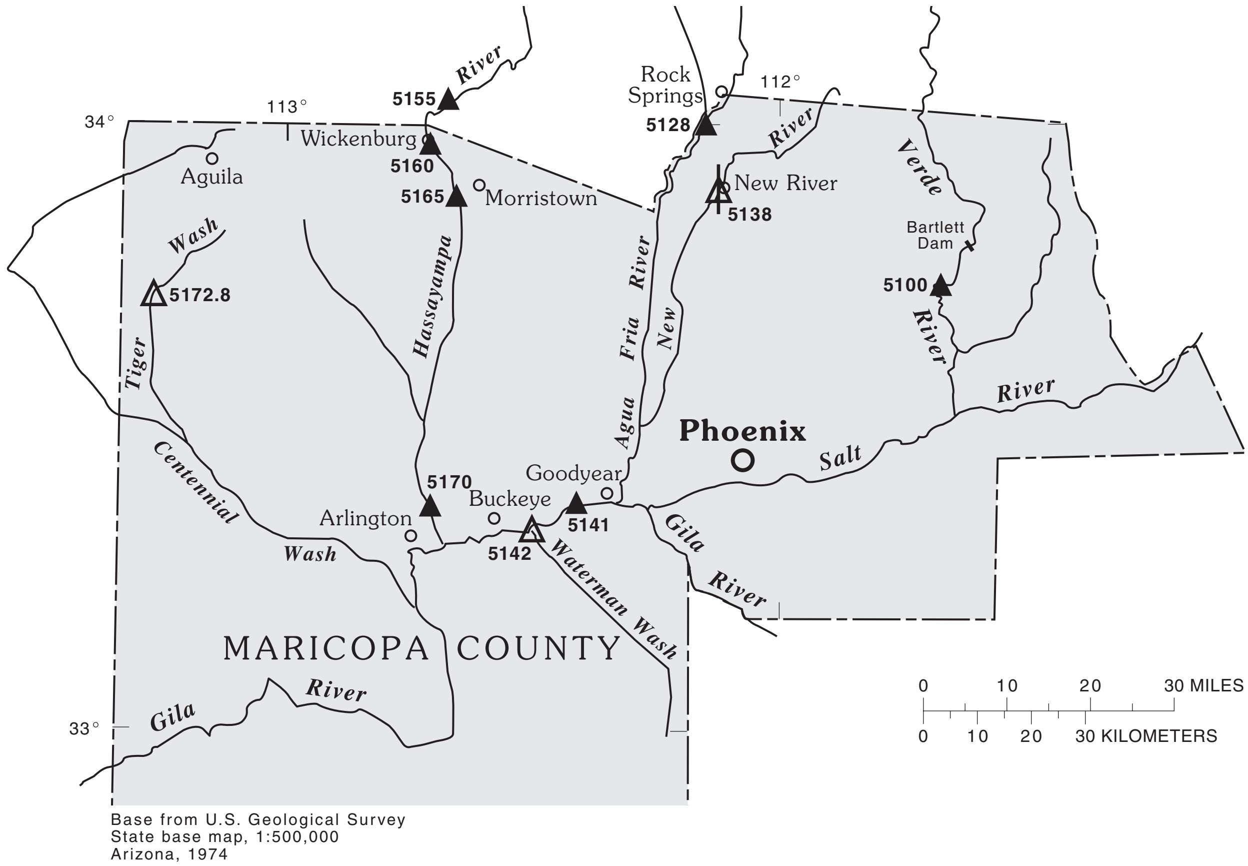


EXPLANATION

5170 ▲ STREAMFLOW-GAGING STATION AND ABBREVIATED NUMBER—Complete station number is 09517000

STATION NUMBER	STATION NAME
09510000	Verde River below Bartlett Dam, Arizona[1]
09512800	Agua Fria River near Rock Springs, Arizona[1]
09514100	Gila River at Estrella Parkway, near Goodyear, Arizona[1]
09515500	Hassayampa River at Box Canyon, near Wickenburg, Arizona[2]
09516000	Hassayampa River at U.S. Highway 60, at Wickenburg, Arizona[2]
09516500	Hassayampa River near Morristown, Arizona[1]
09517000	Hassayampa River near Arlington, Arizona[1]

5172.8 △ CREST-STAGE GAGING STATION AND ABBREVIATED NUMBER—Complete station number is 09517280

STATION NUMBER	STATION NAME
09514200	Waterman Wash near Buckeye, Arizona
09517280	Tiger Wash near Aguila, Arizona

5138 DISCONTINUED U.S. GEOLOGICAL SURVEY GAGING STATION AND ABBREVIATED NUMBER—Complete station number is 09513800

STATION NUMBER	STATION NAME
09513800	New River at New River, Arizona

[1] Operated by the U.S. Geological Survey.
[2] Operated by the Flood Control District of Maricopa County.

Figure 1. Location of study area and channel-change study sites, Maricopa County, Arizona. Study sites were at or near streamflow-gaging stations shown.

Both FCDMC sites are discontinued USGS streamflow-gaging stations. The final site, New River at New River, is a discontinued USGS gaging station.

Acknowledgments

Hjalmar W. Hjalmarson, USGS, retired, provided helpful discussions and review of drafts of the report. John Parker, USGS, provided photographs, fieldnotes, and guidance in resurveying the Hassayampa River near Arlington, and review of drafts of the report. Melissa Lawrance, Todd Ingersoll, Ann Tillery, Dawn McDoniel, and Leigh Hubbard, USGS, assisted with field work. Richard Helton and Sid Alwin, USGS, and Steve Acquafredda assisted with graphics. Jeff Phillips, Robert Jarrett, and William Emmett, retired, of the USGS participated in helpful discussions. Joseph Tram, FCDMC, and Russell Cruff, USGS, retired, also provided reviews of early drafts of this report.

MECHANISMS OF CHANNEL CHANGE

Channel change varies over time and space. In this study, channel change was investigated that occurred from one streamflow to another and that occurred over the course of several years or decades. Most channel change was studied on a reach scale. A brief description is presented here of the mechanisms of channel change that were relevant to this study.

Channel Scour and Fill

The beds of alluvial stream channels in nearly all physiographic and climatic environments are scoured during large flows (Emmett and Leopold, 1965). Leopold and others (1964) and Emmett and Leopold (1965) showed that depth of scour on perennial streams increases as discharge increases and that scour may occur continuously throughout a reach of stream. Theoretically, maximum scour should occur during maximum discharge because the shear stress and stream power on the streambed usually are greatest during peak discharge. Consequently, in indirect measurements of discharge, the common assumption that the postflood channel represents peak-discharge channel conditions is questionable.

The relation between changes in bed elevation and discharge at a particular cross section is complex. Andrews (1979) examined 11 cableway cross sections along the East Fork River in western Wyoming during a spring peak-runoff season and determined that sections that scour during high flow tended to fill during low flow, and those sections that fill during high flow tended to scour during low flow. The cross sections appeared to change from filling to scouring or scouring to filling at about bankfull discharge. The findings by Andrews (1979) support the hypothesis of a velocity or shear-stress reversal where flow competence in pools exceeds the flow competence over riffles above a certain discharge (Knighton, 1984).

Colby (1964) discussed many of the misconceptions of scour and fill of sand-bed channels and showed that scour at a single point in the stream is not necessarily continuous across the channel nor over long reaches of the channel. Also, most observations of channel-bed elevations are made at gaging stations where flow is typically restricted laterally, which results in large amounts of local vertical scour. Colby (1964) also stated that the total amount of sand transported by a flow may account for only a few hundredths of a foot of depth. Foley (1978) likewise showed that most of the scour and fill that occurs in ephemeral sand-bed channels in southern California was attributed to the passing of dune and antidune crests and troughs. The passing of these bedforms, which appear as scour and fill at a single cross section, is not considered scour or fill along the length of the channel.

Gaging stations in and near Maricopa County, Arizona, are in channel reaches where scour-and-fill processes are active. The extent to which these processes affect stage-discharge relations at these sites, especially at large discharges, is uncertain.

Aggradation and Degradation

Long-term processes also are at work in control reaches near gaging stations. Channel-bed elevations may increase, or aggrade, over time as more sediment is delivered to the reach than can be transported. Conversely, channel beds may erode or degrade over time as more sediment is transported from the reach than is being delivered. The causes of these changes may be natural as in the event of large-scale wildfires or climate change, or they may be anthropogenic causes such as deforestation, overgrazing, or mining activity. In the arid and semiarid southwestern United States, channels generally have incised their beds or degraded since the end of the 19th century (Graf, 1988).

Regardless of the cause, if aggradation or degradation occurs in the control reach for a gaging station, the effect is a change in the stage-discharge relation. Another effect is a change in the conveyance capacity of the stream in the affected reaches. Changes in conveyance can result in changes in water-surface elevations for floods of a given recurrence interval. Similarly, the performance of engineered structures, such as levees and bridges, is changed.

METHODS OF DETERMINATION OF CHANNEL CHANGES

The quantity of channel change was determined using three methods. The first method used remeasured cross sections. Changes in cross-section geometry were examined over a period of years and during individual floods. The second method examined historic trends in the point-of-zero-flow (PZF) elevation. The PZF is the elevation at which flow ceases to occur at a gaging station. Finally, the third method used was repeat photography. Repeat photographs were used to document qualitative changes in channel shape, vegetation, and sediment characteristics and to provide photographic evidence of channel changes.

Site Selection

For this study, 10 streamflow-gaging stations in and near Maricopa County, were selected. Criteria for site selection included known changes to channel geometry or characteristics, streamflow records that exceeded 10 years, several measurements of large discharge during the same flood, mobile channels, and previously monitored cross sections.

Site Survey

After site selection, existing cross-section data were examined including those from current-meter and indirect measurements of discharge. Current-meter measurements included wading, bridge, and cableway measurements. Cross-section geometry was determined from these measurements by subtracting the flow depth at locations along the cross section from the gage height at the time of the discharge measurement. At sites that had not been surveyed previously for indirect measurements of discharge, cross sections were surveyed for this study. On the Hassayampa River near Arlington, monumented cross sections surveyed by Parker (1995) were resurveyed.

The depth measurements from current-meter measurements were used to determine channel changes during individual floods. The widespread floods of January–March 1993 rank among the largest in the history of discharge measurements in Maricopa County. Channel change during this period was determined almost exclusively using data from current-meter measurements of discharge. A second period of smaller regional flooding occurred in 1995, and data from selected floods during this period also were used to determine channel change.

Long-term changes in channel geometry were determined using survey data from indirect measurements of discharge. Because the original purpose of these surveys was to determine discharge, rather than monitor channel change, cross-section locations often changed from one survey to another. The differences in location resulted in differences in elevation that needed to be taken into account before cross sections were compared for the purpose of measuring channel change. In these instances, the elevation data from one of the cross sections were adjusted by multiplying the distance of the cross section from a point common to both sections by the slope (in percent) of the stream in that reach. Because a key assumption of a slope-area computation is that the stream channel generally is uniform, these modifications to the original measurement data were considered reasonable for this study of channel changes.

Channel Geometry

The historic cross-section data and data from cross-section surveys done for this study were compiled into a single data set (table 1 and tables 2–12 in the section entitled "**Cross-Section Data**" at the back of the report). From this data set, cross-section plots were created to display cross-section changes. Graphical representations of cross sections in this report are oriented so that the view is downstream and the left bank appears on the left side of the graph.

To provide a datum for measuring channel geometry at a cross section, a reference elevation was established at each site for this study. The amount of change at a cross section was calculated relative to its reference elevation. The reference elevation for each cross section was high enough to include the area of the greatest scour and fill but low enough to eliminate large areas of the cross section that may experience no scour or fill, such as at the edges of the flood plain. Given that the deepest and fastest sections of any cross section usually convey the most flow, use of the reference elevation emphasizes channel change in the main channel only. This methodology allows for the comparison of the channel geometry determined from current-meter measurements with that from channel surveys. Because the reference elevation remains constant between measurements, changes in channel geometry are the result of channel scour and fill only, but only represent a small portion of the cross section during flood flows. Cross-section measurement date, reference elevation, hydraulic radius, width, and cross-sectional area are given for each site (**table 1**). The change and percent change in cross-sectional area were computed on the basis of data for the first measured cross section (table 1). A positive change in cross-sectional area represents scour or an increase in cross-sectional area, and a negative change represents fill or a decrease in cross-sectional area compared with the first measured cross section.

Point-of-Zero-Flow Method

As a part of routine discharge measurements and gaging-station inspections, hydrographers often determine the PZF. The PZF is the gage height at which flow begins. The PZF can be highly variable in sand channels because the control for the gaging station can shift as a result of low flows. In this study, the PZF was used to represent the channel elevation. Although the PZF is not an exact representation of a channel-bed elevation, it does show fluctuations in channel elevations through time and the relation of the channel-bed elevation to floods.

RESULTS

Data and analysis of channel change for streamflow-gaging stations are presented by site. The results for each site generally are organized as follows: (1) site information, (2) cross-section analysis, and (3) PZF analysis. Sites on the same stream are presented in downstream order.

09512800 Agua Fria River near Rock Springs, Arizona

The Agua Fria River near Rock Springs (**fig. 1**) has a drainage area of 1,111 mi^2 and usually has a small base flow. Channel alluvium generally is coarse gravel but ranges in size from boulders to silt. Outcrops of bedrock restrict lateral movement of the stream channel at the cableway and the gaging station. All current-meter measurements of discharge were made at the cableway about 500 ft upstream from the gaging station. The left bank of the cableway cross section is a bedrock cliff, and the right bank is on the inside of a bend in the channel, which is unconsolidated alluvium. The cableway cross section is much more constricted than the cross section at the control for the gaging station. The cableway cross section would have about one half the cross-sectional area of the gaging-station cross section for the same discharge.

Data for cross sections were reconstructed from cross-section surveys and current-meter measurements (figs. 2–5; table 1). The current-meter measurements were made from the cableway. The surveyed cross sections are 315 and 800 ft downstream from the gaging station, at the gaging station, and 390 ft upstream from the gaging station. Historical changes to the PZF were compiled and are presented (**fig.6**).

Cableway cross section.—The cross section at the cableway scoured during increasing discharge and filled as discharge decreased (**figs. 2** and **3**; table 1). During the discharge measurement of 5,530 ft^3/s on January 7, 1993, the cross section generally had a wide and shallow shape (fig. 3). The peak discharge of 52,500 ft^3/s occurred on January 8, 1993 (fig. 2). Following this peak, data from the next discharge measurement show that the right portion of the channel filled about 3 ft, probably during the recession of the flood peak (fig. 3). Maximum scour was measured on February 8 during a discharge of 16,900 ft^3/s. Between January 18 and February 8, the width increased slightly in relation to the reference elevation, and the hydraulic radius more than doubled. Most of the increase in cross-sectional area, therefore, was accounted for by the increase in depth.

Table 1. Channel properties at selected streams, Maricopa County, Arizona

[---, not applicable]

Cross-section number and (or) location	Date	Channel properties: Reference elevation, in feet	Width, in feet	Hydraulic radius, in feet	Area, in square feet	Change in area from initial survey, in square feet	Change in area, in percent
09512800 Agua Fria River near Rock Springs, Arizona							
1	01–14–79	17	234	4.9	1,154	---	---
1	03–12–93	17	244	6.9	1,709	555	48
2	10–29–75	11.6	139	6.1	860	---	---
2	01–14–79	11.6	124	3.6	454	-406	-47
2	03–12–93	11.6	147	5.4	804	-56	-7
2	02–03–97	11.6	123	5.6	705	-155	-18
3	01–14–79	19	308	6.5	2,041	---	---
3	03–12–93	19	275	9.5	2,674	633	31
4	01–14–79	15	202	7.8	1,594	---	---
4	03–12–93	15	217	8.6	1,899	305	19
Cableway	01–07–93	7.5	118	2.8	344	---	---
Cableway	01–13–93	7.5	57	5.5	336	-8	-2
Cableway	01–18–93	7.5	91	4.8	487	143	42
Cableway	02–08–93	7.5	106	11.7	1,501	1,157	337
Cableway	02–10–93	7.5	63	4.7	329	-15	-4
Cableway	02–20–93	7.5	86	4.8	461	117	34
Cableway	02–21–93	7.5	61	3.7	244	-100	-29
09514100 Gila River at Estrella Parkway, near Goodyear, Arizona							
	01–06–93	12	862	2.8	2,439	---	---
	01–09–93	12	1,202	4.2	5,006	2,567	105
	01–12–93	12	914	4.8	4,389	1,950	80
	01–26–93	12	829	5.4	4,495	2,056	84
	02–05–93	12	798	5.4	4,337	1,898	78
09515500 Hassayampa River at Box Canyon, near Wickenburg, Arizona							
1	05/17/95	99	84	3.3	281	---	---
1	08/08/96	99	79	3.0	264	-17	-6
1	03/04/97	99	83	2.8	249	-32	-11
2	05/17/95	99	95	3.6	352	---	---
2	08/08/96	99	95	2.9	288	-64	-18
2	03/04/97	99	97	3.5	360	8	2
3	05/25/46	100	93	1.5	142	---	---
3	05/17/95	100	89	4.2	395	253	178
3	08/08/96	100	107	3.8	434	292	206
3	03/04/97	100	104	4.4	485	343	242
4	05/17/95	97	98	2.6	395	---	---
4	08/08/96	97	98	1.9	187	-208	-53
4	03/04/97	97	95	2.4	234	-161	-41

Table 1. Channel properties at selected streams, Maricopa County, Arizona—Continued

Cross-section number and (or) location	Date	Channel properties: Reference elevation, in feet	Width, in feet	Hydraulic radius, in feet	Area, in square feet	Change in area from initial survey, in square feet	Change in area, in percent
09515500 Hassayampa River at Box Canyon, near Wickenburg, Arizona—Continued							
5	05/17/95	96	86	2.4	213	---	---
5	08/08/96	96	87	1.8	168	-45	-21
5	03/04/97	96	86	2	179	-34	-16
6	05/17/95	95	77	2.1	165	---	---
6	08/08/96	95	81	1.8	149	-16	-10
6	03/04/97	95	78	2	162	-3	-2
7	05/17/95	96	102	3.2	327	---	---
7	08/08/96	96	94	3	284	-43	-13
8	05/17/95	95	83	2.8	242	---	---
8	08/08/96	95	84	2.8	240	-2	-1
8	03/04/97	95	81	2.9	245	3	1
9	05/17/95	94	89	2.2	204	---	---
9	03/04/97	94	88	2.3	206	2	1
09516000 Hassayampa River at U.S. Highway 60, at Wickenburg, Arizona							
	03–18–88	3.7	420	2.8	1,192	---	---
	09–26–97	3.7	404	3.9	1,608	416	35
	09–29–97	3.7	404	3.5	1,438	246	21
09516500 Hassayampa River near Morristown, Arizona							
	01–19–93	9	160	1.0	165	---	---
	01–21–93	9	170	1.3	220	55	33
	02–05–93	9	163	1.4	222	57	35
	02–09–93	9	164	1.5	244	79	48
	02–20–93	9	157	1.3	208	43	26
	03–04–93	9	158	1.4	226	61	37
	03–31–93	9	173	1.6	282	117	71
	02–17–95	9	157	1.8	285	120	73
	11–30–96	9	172	1.7	286	121	73
09517000 Hassayampa River near Arlington, Arizona							
2	12–01–92	19	703	4.1	2,896	---	---
2	01–02–97	19	774	2.8	2,158	-738	-25
4	12–01–92	16	704	3.4	2,408	---	---
4	01–02–97	16	713	2.1	1,495	-913	-38

Table 1. Channel properties at selected streams, Maricopa County, Arizona—Continued

Cross-section number and (or) location	Date	Channel properties				Change in area from initial survey, in square feet	Change in area, in percent
		Reference elevation, in feet	Width, in feet	Hydraulic radius, in feet	Area, in square feet		
09517000 Hassayampa River near Arlington, Arizona—Continued							
5	12–01–92	15	671	3.9	2,616	---	---
5	01–02–97	15	660	1.9	1,280	-1,336	-51
6	12–01–92	15	698	4.6	3,195	---	---
6	01–02–97	15	694	2.5	1,729	-1,466	-46
7	12–01–92	14	723	4.4	3,226	---	---
7	01–02–97	14	712	2.8	2,009	-1,217	-38
8	12–01–92	12	665	4.5	3,015	---	---
8	01–02–97	12	691	2.1	1,429	-1,586	-53
09513800 New River at New River, Arizona							
	12–19–67	89	143	5.3	776	---	---
	09–05–70	89	159	5.5	891	115	15
	03–04–78	89	201	5.1	1,036	260	33
	01–15–97	89	231	4.0	974	198	26
09517280 Tiger Wash near Agulia, Arizona							
	08–18–65	8	113	3.0	338	---	---
	08–01–70	8	123	2.3	287	-51	-15
	09–19–72	8	120	2.2	270	-68	-20
	06–20–95	8	118	3.3	396	58	17
	08–10–97	8	120	3.3	401	63	19
	10–09–97	8	117	3.9	469	131	39
09510000 Verde River below Bartlett Dam, Arizona							
	01–04–93	7.5	195	4.9	965	---	---
	01–19–93	7.5	190	4.2	804	-161	-17
	01–21–93	7.5	175	4.5	749	-216	-22
	02–15–95	7.5	151	5.7	873	-92	-10
	04–28–95	7.5	140	4.4	617	-348	36
09514200 Waterman Wash near Buckeye, Arizona							
	09–16–64	5	192	2.3	448	---	---
	09–16–66	5	174	2.8	484	36	8
	11–11–71	5	190	1.7	330	-118	-26
	10–05–82	5	169	1.2	205	-243	-54
	11–30–96	5	162	1.7	283	-165	-37
	08–14–97	5	171	2.0	342	-106	-24

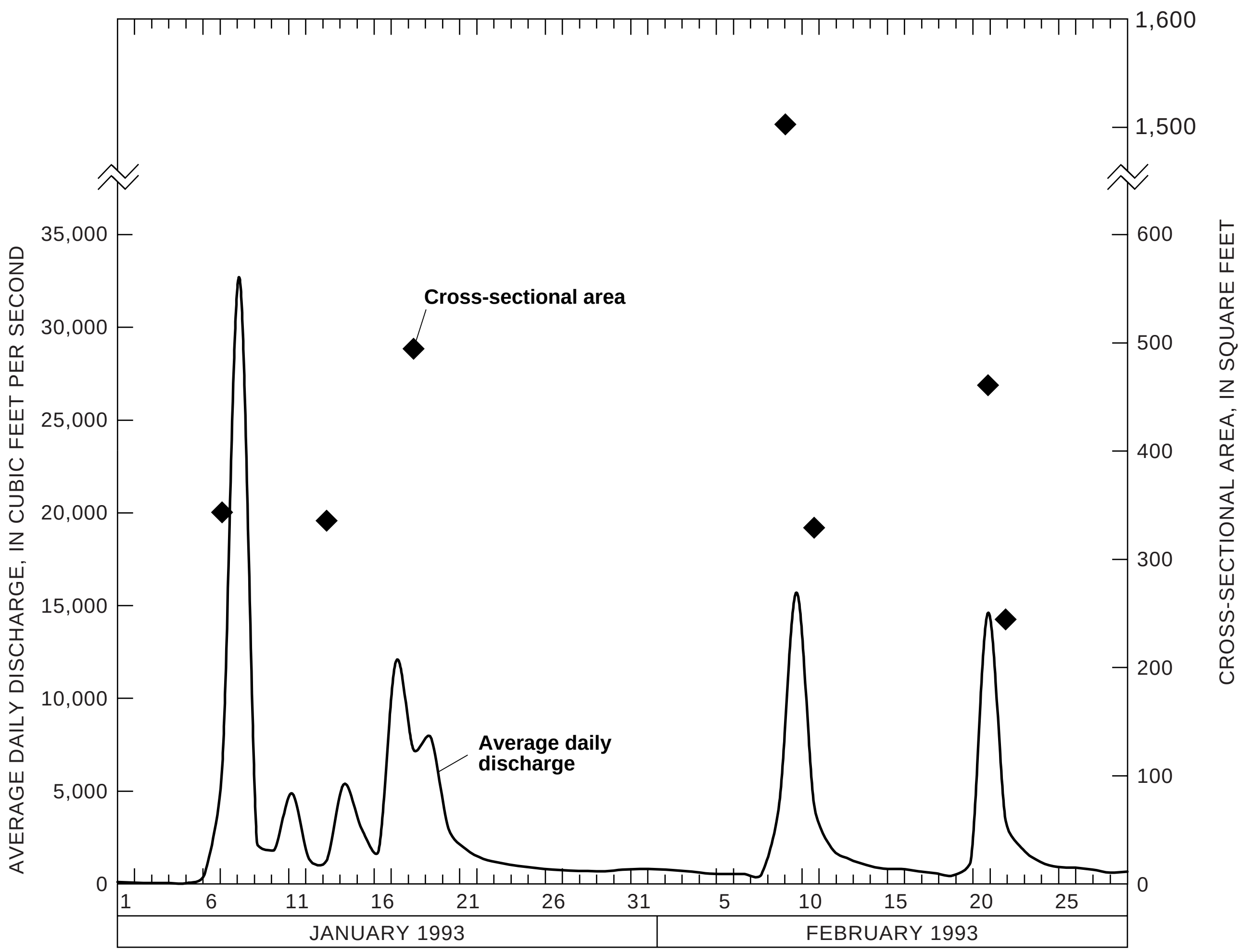


Figure 2. Average daily discharge and cross-sectional area, determined from current-meter measurements, at cable way, Agua Fria River near Rock Springs, Arizona, 1993.

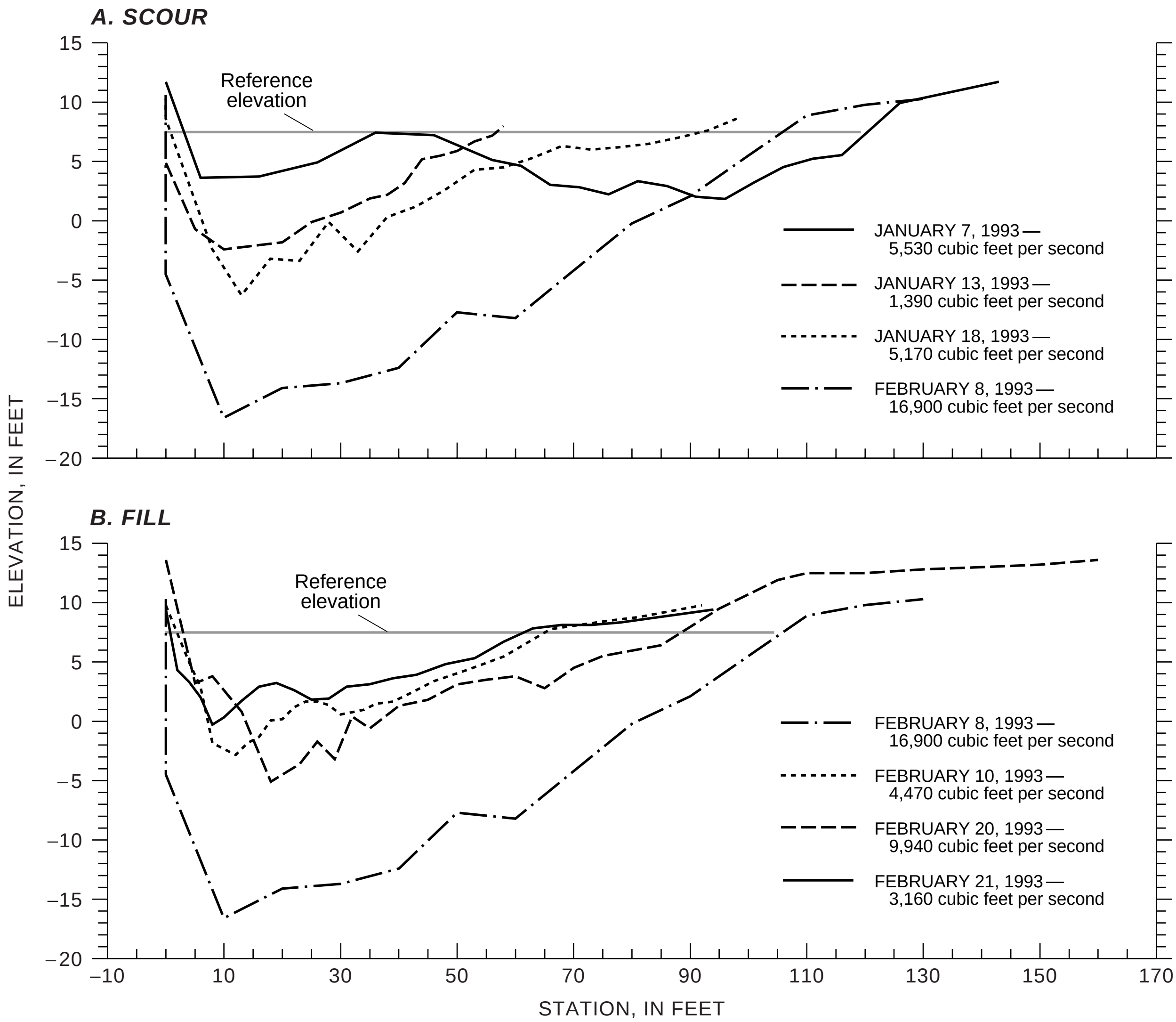


Figure 3. Cross section from discharge measurements at cable way, Agua Fria River near Rock Springs, Arizona, 1993. *A*, Scour, January 7 through February 8, 1993. *B*, Fill, February 8–24, 1993.

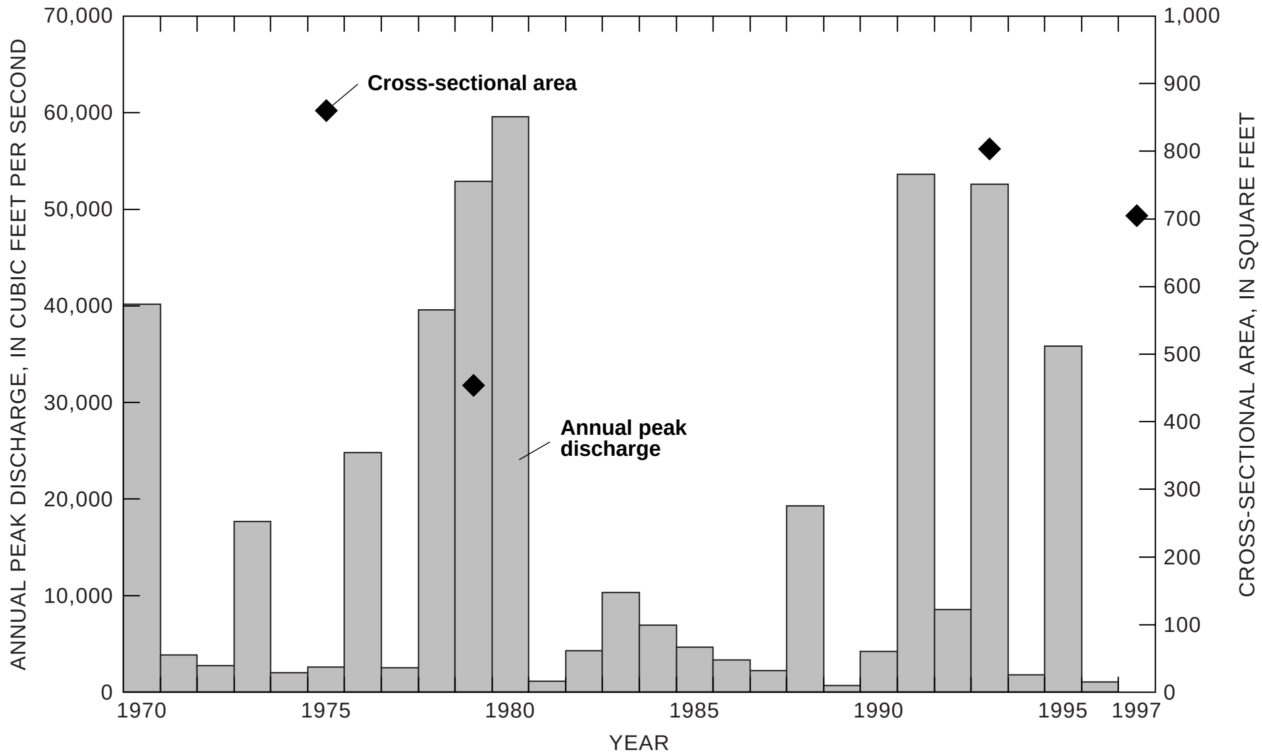


Figure 4. Annual peak discharge and cross-sectional area from surveys during indirect measurements of discharge at cross-section 2, Agua Fria River near Rock Springs, Arizona, 1970–97.

After February 8, increases in discharge caused an increase in channel scour, and decreases in discharge caused the channel to fill (fig. 3). Data from the discharge measurement made on February 10 at 4,470 ft^3/s show the cableway cross section filled with as much as 15 ft of sediment compared to the cross section of February 8. The final 1993 flood peak of 30,400 ft^3/s occurred on February 20. A discharge of 9,940 ft^3/s was measured using a current-meter on February 20, before the peak discharge. This cross section shows that some scour was occurring again in the channel. On February 21, 3,160 ft^3/s was measured on the re-cession of the flow. At that time, the channel had filled to a level higher than the level measured on February 10.

Surveyed cross sections.—When the gaging station was established at its present location in 1975, one cross section at the gaging station (cross-section 2) was surveyed for rating-curve development. In January 1979 after the large flood on December 18, 1978, four cross sections (1–4) were surveyed as part of an indirect measurement of discharge (fig. 5). Cross-section 1 was 390 ft upstream from the gaging station, and cross-sections 3 and 4 were 315 and 800 ft, respectively, downstream from the gaging station. Cross-section 2 showed substantial fill in the channel at the streamflow-gaging station after resurvey of the cross section in 1979.

Following the large floods of 1993, cross-sections 1–4 were resurveyed for another discharge computation (fig. 5). The 1993 survey showed that the channel incised by as much as 4 ft and by varying amounts in the overbank area at all four cross sections. In 1997, cross-section 2 was resurveyed. Since 1993, the only substantial change to cross-section 2 occurred along the low-flow channel where some fill occurred. Channel change is common along the reach near the gaging station. Figure 4 shows the annual peak discharge and the cross-sectional area relative to the reference elevation at cross-section 2.

PZF analysis.—The PZF at the Agua Fria gaging station changed by several feet over a period of a few decades. A correlation, however, could not be determined between PZF and annual peak discharge at this site (fig. 6). The highest PZF of 5.6 ft was measured in July 1979 when the channel filled with sediment after a large flood on December 18, 1978.

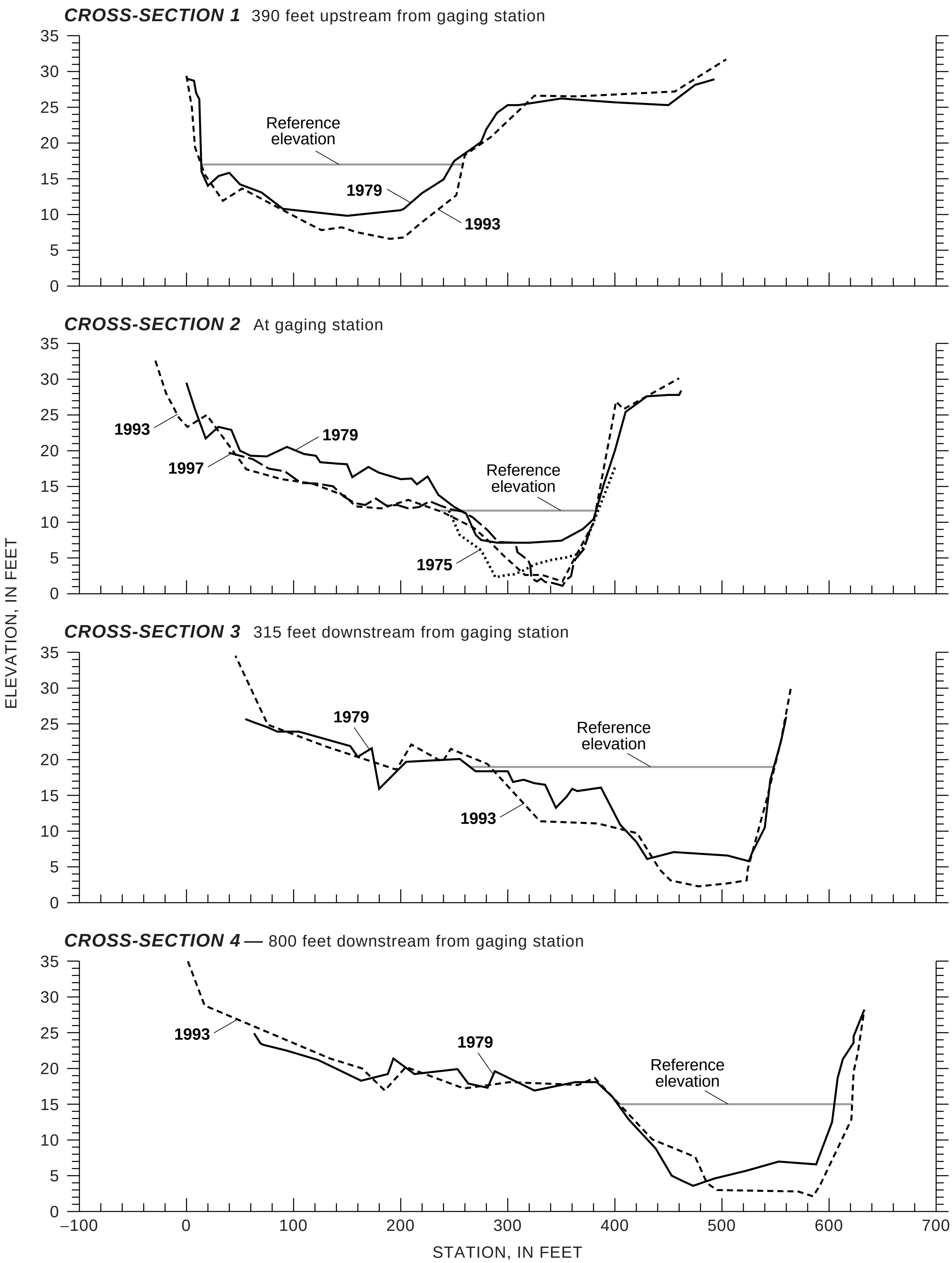


Figure 5. Cross sections from surveys during indirect measurements of discharge, Agua Fria River near Rock Springs, Arizona, 1975–96.

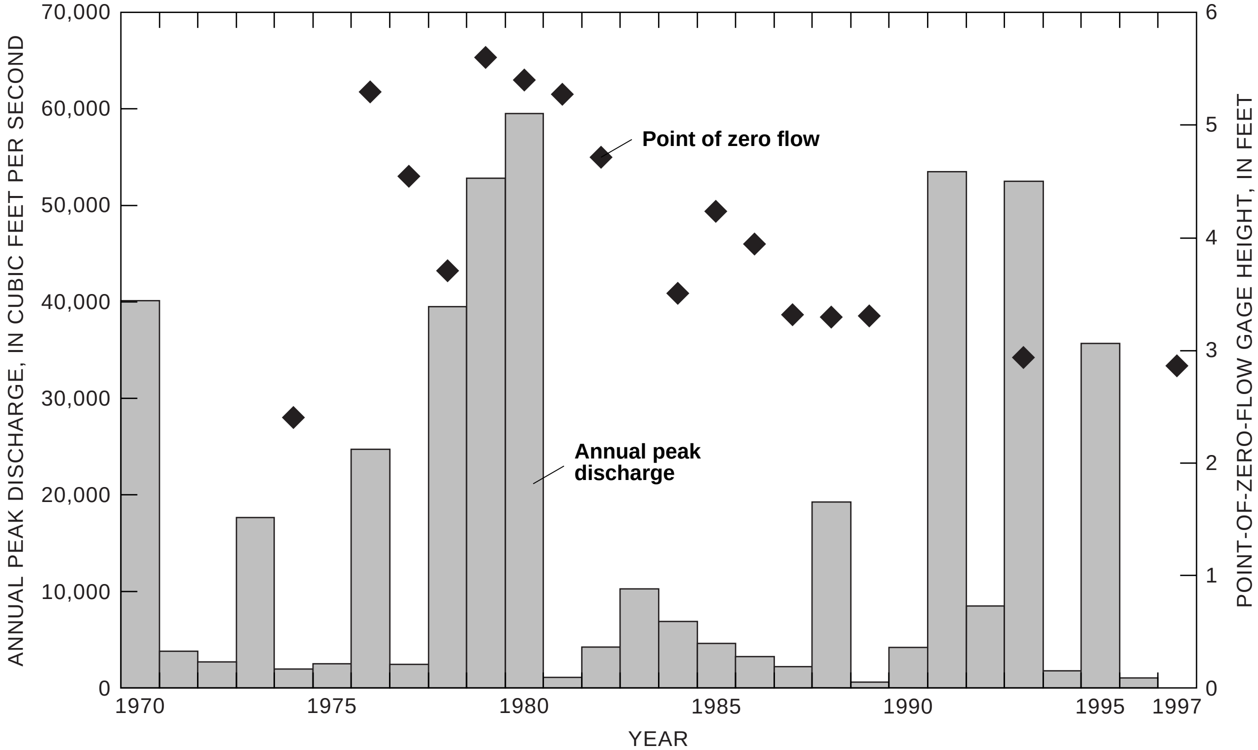


Figure 6. Point-of-zero-flow gage height and annual peak dischrge, Agua Fria River near Rock Springs, Arizona, 1970–97.

The large floods that occurred in 1978–80 were followed by 10 years of low flow in which no flood exceeded the 10-year recurrence interval, and only two floods exceeded the 2-year recurrence interval. By 1988, the PZF had decreased in elevation to 3.29 ft. Since 1989, only a slight additional decrease in the PZF has occurred despite three floods with peak instantaneous discharges greater than the 10-year recurrence interval. The PZF was 2.93 ft in 1993 and 2.86 ft in 1996. This small decrease appears inconsistent with the large amount of scour measured at the cableway cross section (**fig. 3**); however, the channel filled following the high flows of January and February 1993, and the PZF is measured at the control of the gaging station upstream from the cableway primarily during low-flow conditions and may not reflect channel conditions at the cableway.

Repeat photography.—Two sets of repeat photographs were taken. The first (**7**A–B) is of a downstream view taken from the bedrock cliff at the left end of the cableway cross section shown in figure 3. After the large flood on December 18, 1978, the channel is wide, flat, and sandy (fig. 7A). From the cross-section surveys of the reach, the channel had aggraded as a result of the flood. Figure 7B shows the channel on June 18, 1998, from about the same perspective. Note that figure 7B shows the reach several years after the large floods that occurred in 1993. The riparian vegetation to the right of the truck in figure 7B borders a narrow, well-defined low-flow channel.

A view of the right bank of cross-section 3 is shown in **figures 8**A–B. Figure 8*A* shows a wide, flat, sandy channel in January 1979. Figure 8B shows about the same location and perspective on June 18, 1998. The growth of riparian trees along the low-flow channel obscures the view of the channel itself. The photograph, however, was taken from about the same elevation as that of figure 8A. The area with riparian tree growth indicates where several feet of channel incision has occurred since 1978.

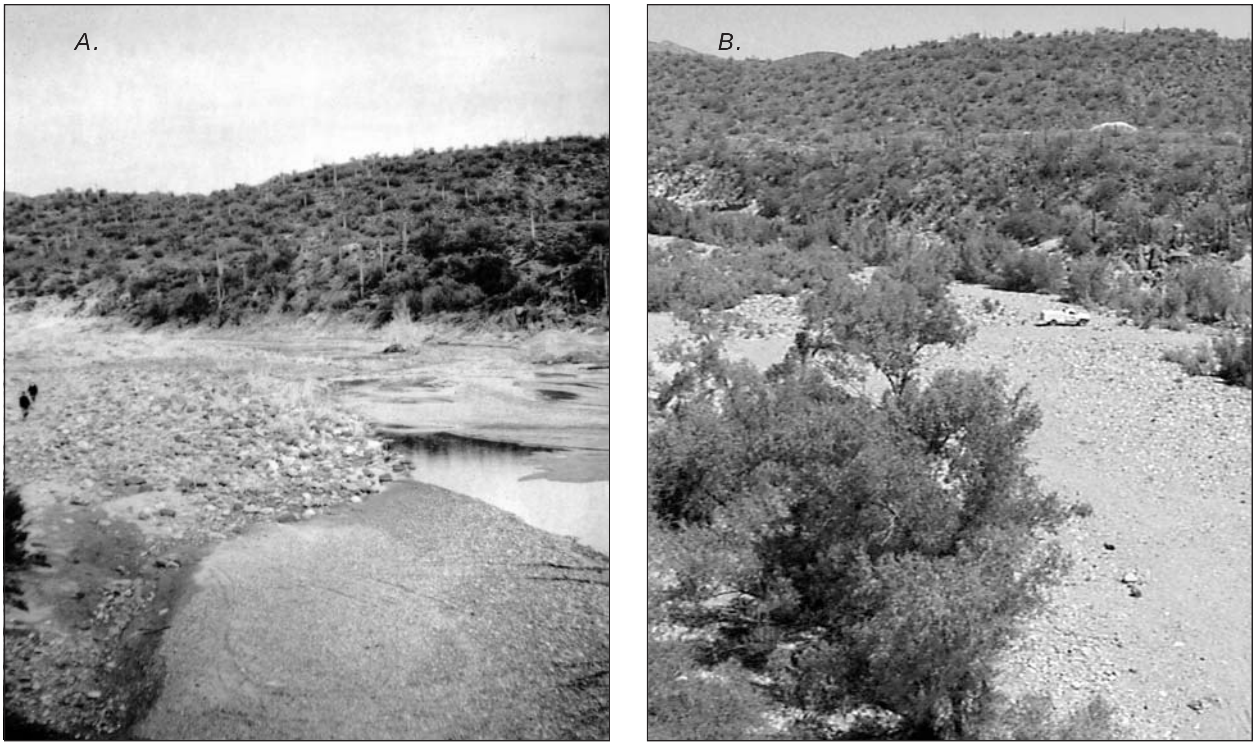


Figure 7. View downstream from cableway, Agua Fria River near Rock Springs, Arizona. *A*, January 1979 after the flood of December 18, 1978. *B*, June 18, 1998.

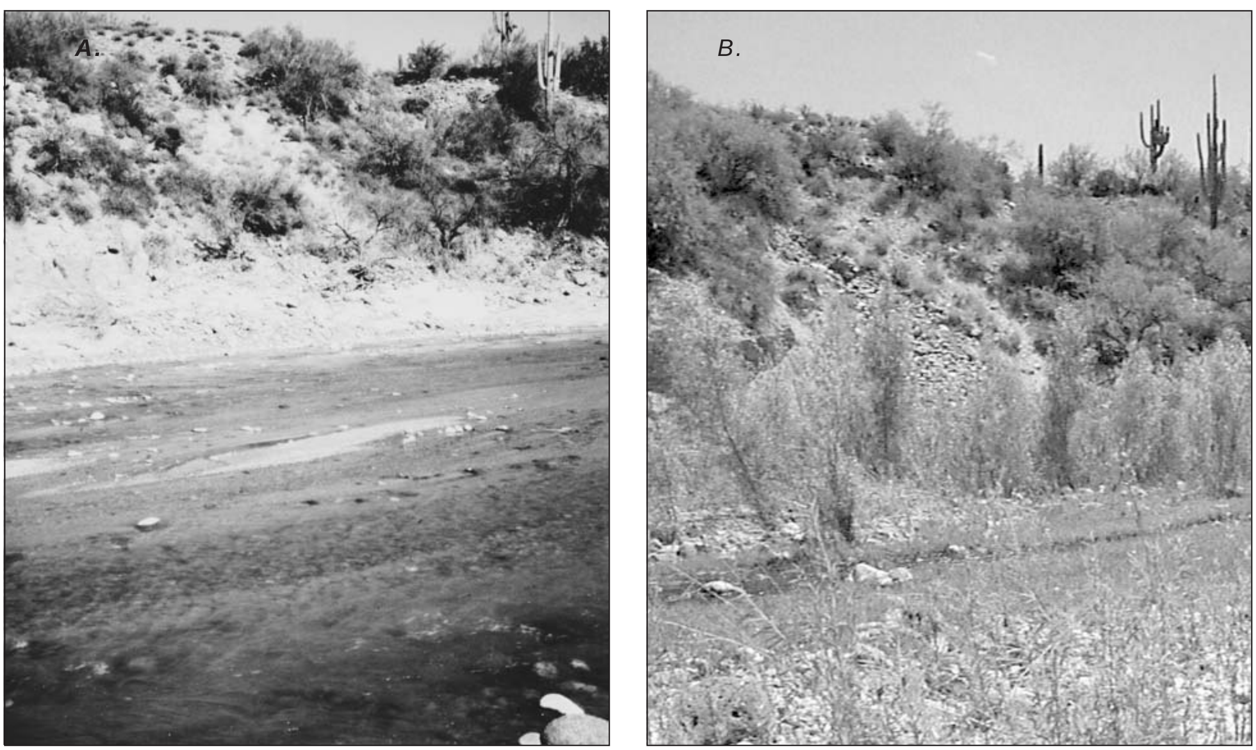


Figure 8. View of right bank near cross-section 3, Agua Fria River near Rock Springs, Arizona. *A*, January, 1979 after the flood of December 18, 1978. *B*, June 18, 1998. Flow is from right to left in photographs.

09514100 Gila River at Estrella Parkway, near Goodyear, Arizona

The gaging station, Gila River at Estrella Parkway, near Goodyear, was put into operation in 1991 (**fig. 1**). Only limited historical cross-section data, therefore, were available for this study, and only one rating curve has been computed for this site. Several current-meter measurements of discharge were made from the bridge, and these measurements provide information about scour and fill during high flows.

Gila River at Estrella Parkway, near Goodyear, has a drainage area of 45,585 mi^2. Only large regional storms cause the river to flow naturally because the river and most of its large tributaries are regulated by dams. Sediment size in the channel ranges from sand to cobbles. The overbank area is an assortment of sand and gravel deposits. Prolonged low flows are common at this site because of wastewater-effluent discharge upstream.

Bridge-measuring section.— Five current-meter measurements of discharge were made between January 6 and February 5, 1993. The measurements ranged from 12,500 to 122,000 ft^3/s and were made during floodflow that reached a peak discharge of 162,000 ft^3/s at the gaging station on January 9. Daily mean discharge and cross-sectional area at the gaging station during this period are shown in **figure 9**.

Using the cross section of January 6, 1993, as a basis of comparison, the cross section measured on January 9 shows several feet of scour mostly in the deepest part of the channel (**fig. 10**). The cross-sectional area doubled in relation to the reference elevation of 12 ft (figs. 9 and 10). The measurement made after the peak shows a 12 percent decrease in cross-sectional area. Subsequent cross sections that were measured at lower discharges show little additional change.

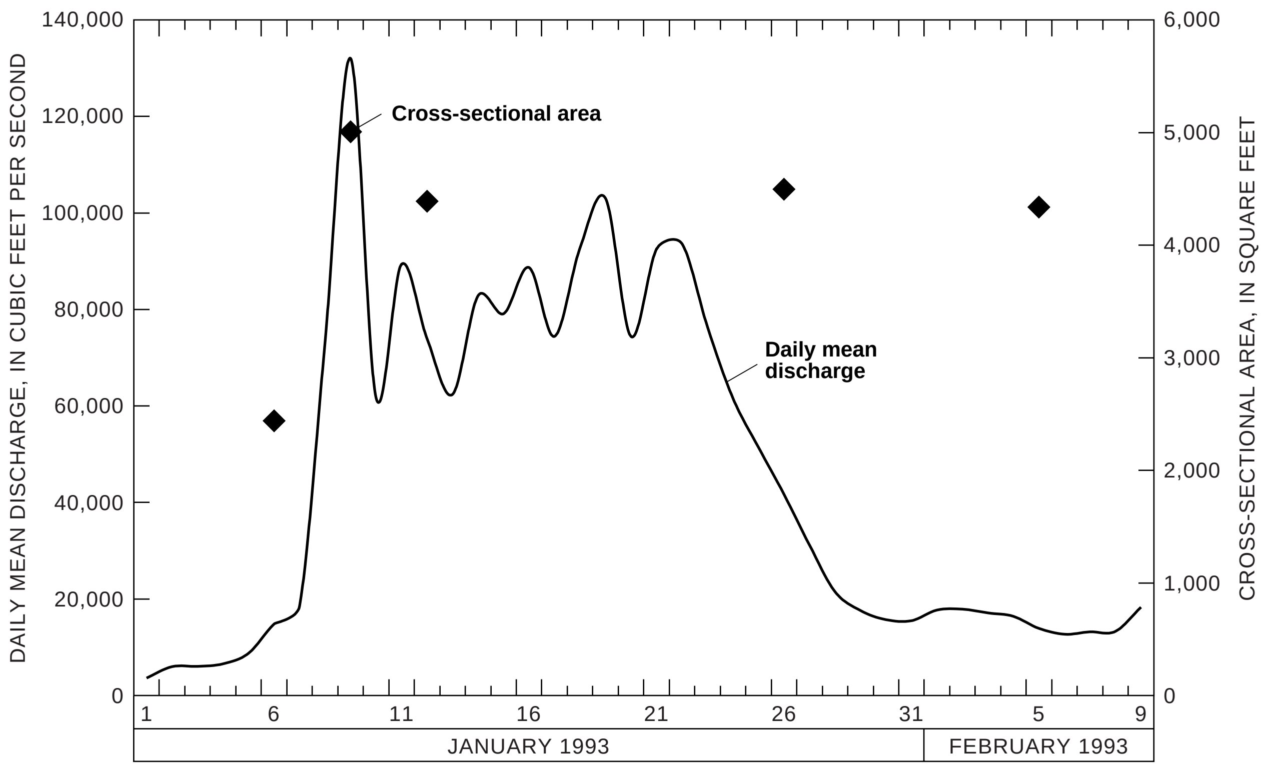


Figure 9. Daily mean discharge and cross-sectional area, Gila River at Estrella Parkway, near Goodyear, Arizona, 1993.

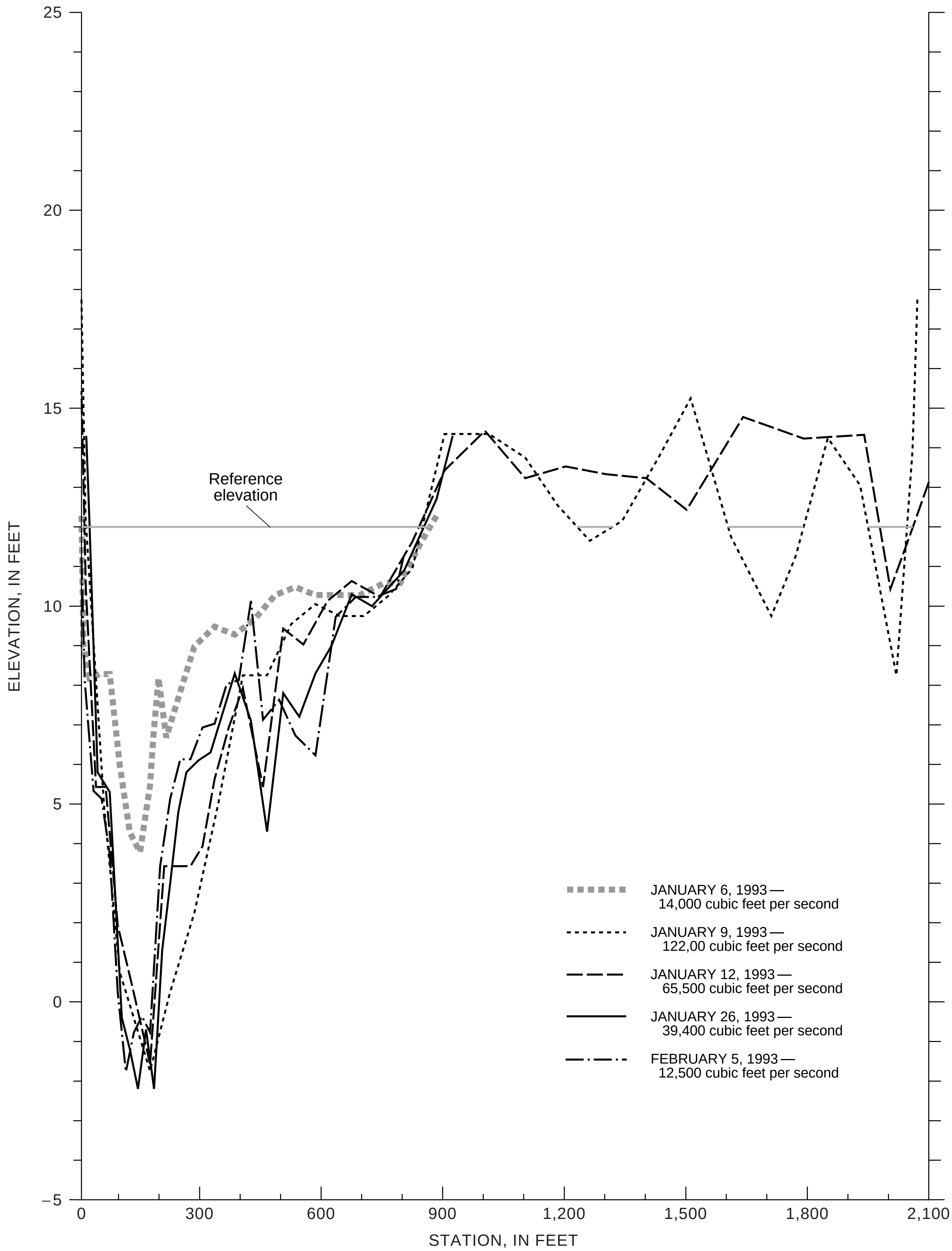


Figure 10. Cross section from discharge measurements and cross-section survey, Gila River at Estrella Parkway, near Goodyear, Arizona, 1993.

Hassayampa River

The Hassayampa River drains an area of about 1,500 mi^2 from near Prescott in the north through Wickenburg and south to the Gila River near Goodyear (fig. 1). Downstream from the gaging station, Hassayampa River near Morristown, the river becomes entrenched in the alluvium of the Hassayampa Plain, a large alluvial basin between the White Tank Mountains on the east and the lower Belmont Mountains on the west. The upper reaches of the Hassayampa River are characterized by steep, high-energy channels that have gravel beds. Farther downstream near Wickenburg, the Hassayampa River enters the Sonoran Desert where the channel is wider, has more sand, and is less steep. Apart from runoff, the Hassayampa River is dry most of the year except for a short reach in Box Canyon, a reach downstream from Wickenburg, and a reach with irrigation return flow near Arlington. The flow in these three areas occurs for only a few miles before the water infiltrates into the sandy streambed or, near Arlington, enters the Gila River. Floods generally are short in duration, although smaller flows (in the hundreds of cubic feet per second) can be sustained for several weeks after winter and spring floods in the watershed upstream from Morristown. This sustained flow, however, normally does not reach the gaging station, Hassayampa River near Arlington, because the flow infiltrates the sandy bed downstream from Morristown.

09515500 Hassayampa River at Box Canyon, near Wickenburg, Arizona

The gaging station at Box Canyon, near Wickenburg (sometimes referred to as Box dam site), is about 8 mi upstream from Wickenburg (fig. 1). The USGS operated the gaging station at the present location from May 1, 1946, to September 30, 1982, and the FCDMC began operating the station in 1993. Drainage area at the gaging station is 417 mi^2. The channel width past the gaging station is confined to 80 ft by nearly vertical rock cliffs that are about 50 ft high. The reach generally is straight from 1,800 ft upstream from the gaging station to 2,700 ft downstream. The channel is about 40 ft wide upstream from the gaging station and widens to 100 ft immediately downstream from the gaging station. The streambed is sand and gravel, and bed-sediment size varies in response to flooding. When the bed elevation is low, often following an extreme flood or prolonged moderate flow, the bed appears as predominantly coarse gravel. At higher bed elevations, the bed sediments are composed primarily of medium to coarse sand.

Cross sections.—Nine cross sections were surveyed in Box Canyon. Cross-section 1 is at the streamflow-gaging station and cross-section 3 is under the cableway about 200 ft downstream. The first measured cross section—cross-section 3—was measured in 1946 (fig. 11). The other eight cross sections— 1, 2, and 4–9—were established in 1995 and resurveyed in 1996 and 1997.

The channel of the Hassayampa River at Box Canyon generally has lowered through time, and the left half of the channel is about 4 ft lower on average than it was 50 years ago (fig. 11). Between May 1995 and August 1996, the central and deepest part of the channel filled 2 to 3 ft although the left and right margins did not change significantly. Other cross sections throughout the reach show similar responses over short periods (fig. 11).

PZF analysis.—The PZF elevation changed significantly at the Hassayampa River at Box Canyon, near Wickenburg, as shown by PZF measurements and annual peak discharge (fig. 12). The PZF elevation ranged from 0.85 ft in October 1951 to 7.2 ft in July 1966. The greatest changes in the PZF occurred in relation to large floods, such as in 1951 and 1970 (fig. 12), although the direction of change was not consistent. For example, following a large flood in 1951, the PZF increased over 4 ft; however, following the peak of record in 1970, the PZF decreased more than 4.5 ft.

In addition to the large, single-event changes in the PZF, there seem to be longer-term patterns of change at this site. For example, the PZF generally decreased from the highest PZF measured in 1966 until the peak flood of record in 1970 (fig. 12). Following several years of low PZF measurements immediately following the large flood, the channel filled, and by 1974 the PZF increased to within 0.5 ft of the PZF before the flood of 1970. After 1975, the PZF again decreased at about the same rate as before the flood of 1970.

Longitudinal profile.—Four longitudinal profiles were made of the reach near the gaging station (fig. 13). The three profiles measured between May 1995 and March 1997 generally show parallel slopes and vertical shift of about 0.5 ft. An examination of historic photographs and field observations revealed a distinct white line along the canyon walls in Box Canyon especially upstream from the gaging station.

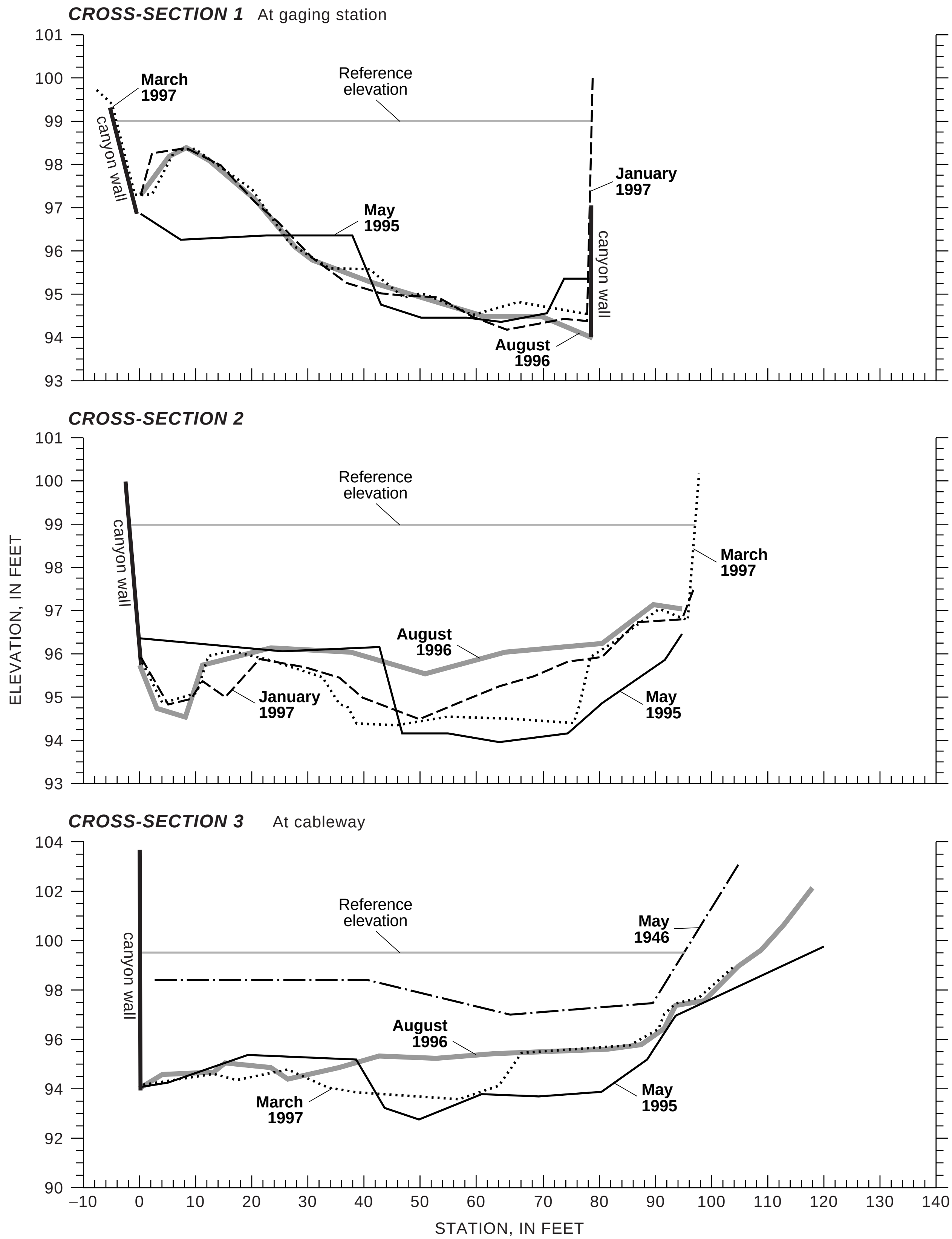


Figure 11. Cross sections from surveys, Hassayampa River at Box Canyon, near Wickenburg, Arizona, 1946–97.

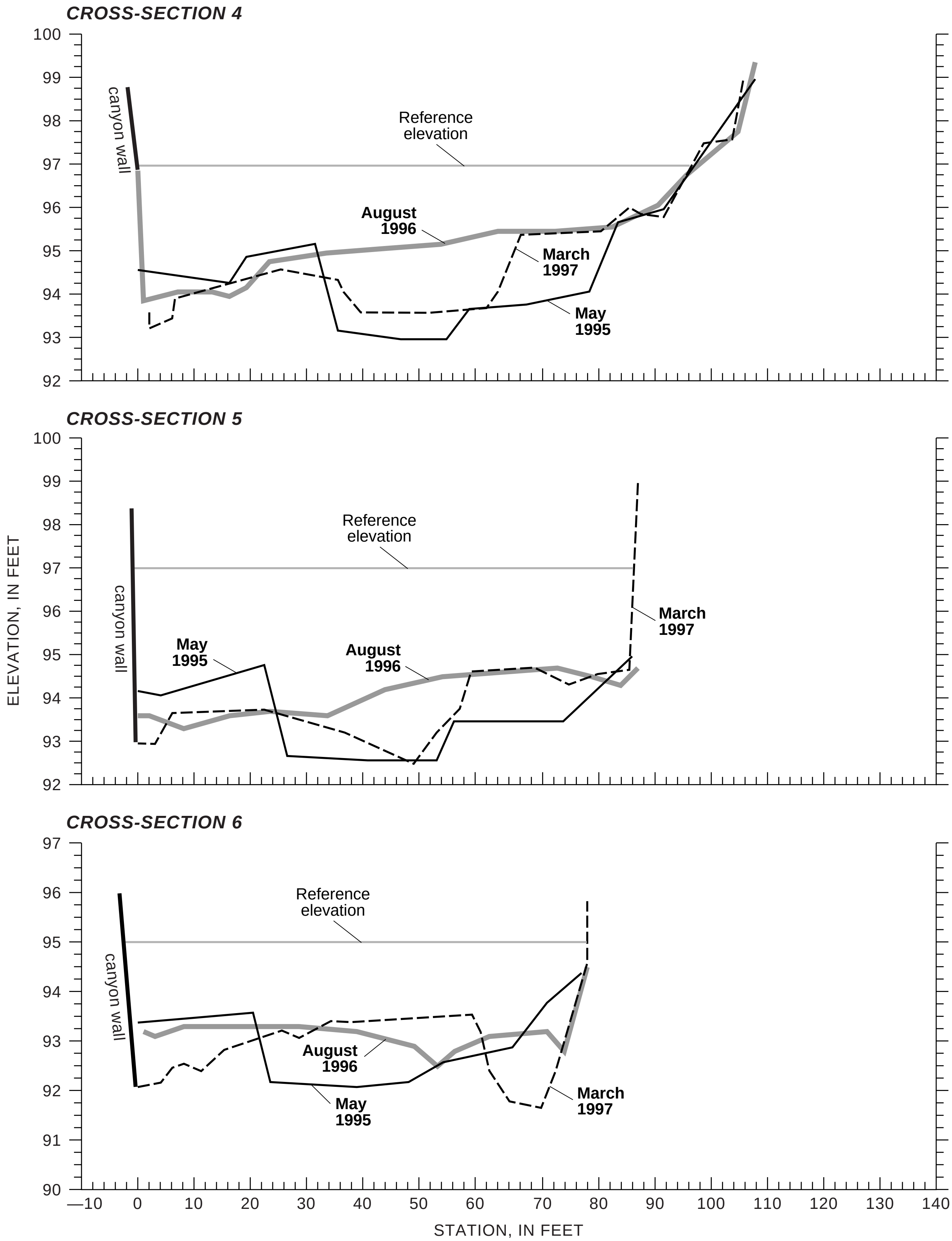
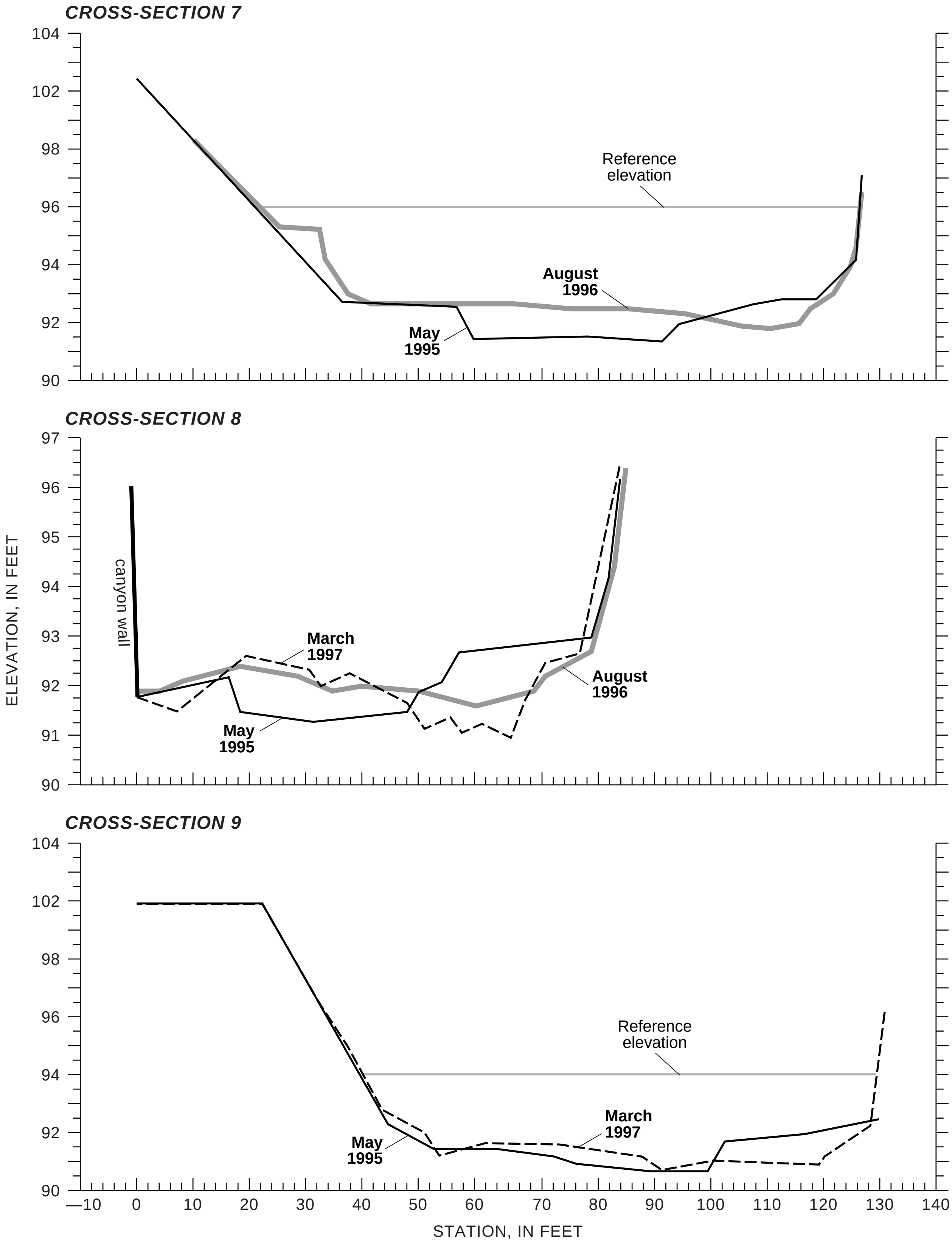


Figure 11. Continued.



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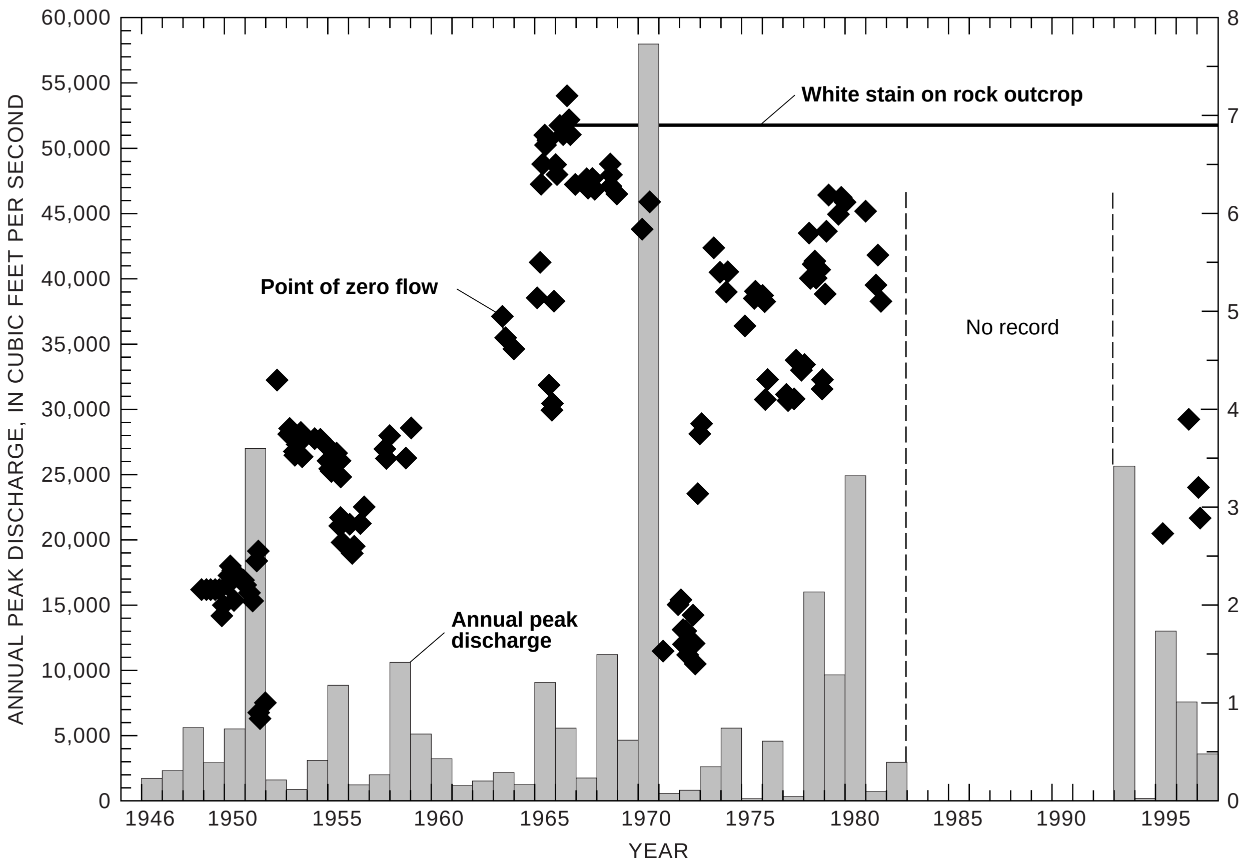


Figure 12. Point-of-zero-flow gage height and annual peak discharge, Hassayampa River at Box Canyon near Wickenburg, Arizona, 1946–97. Data for 1993–97 from Flood Control District of Maricopa County.

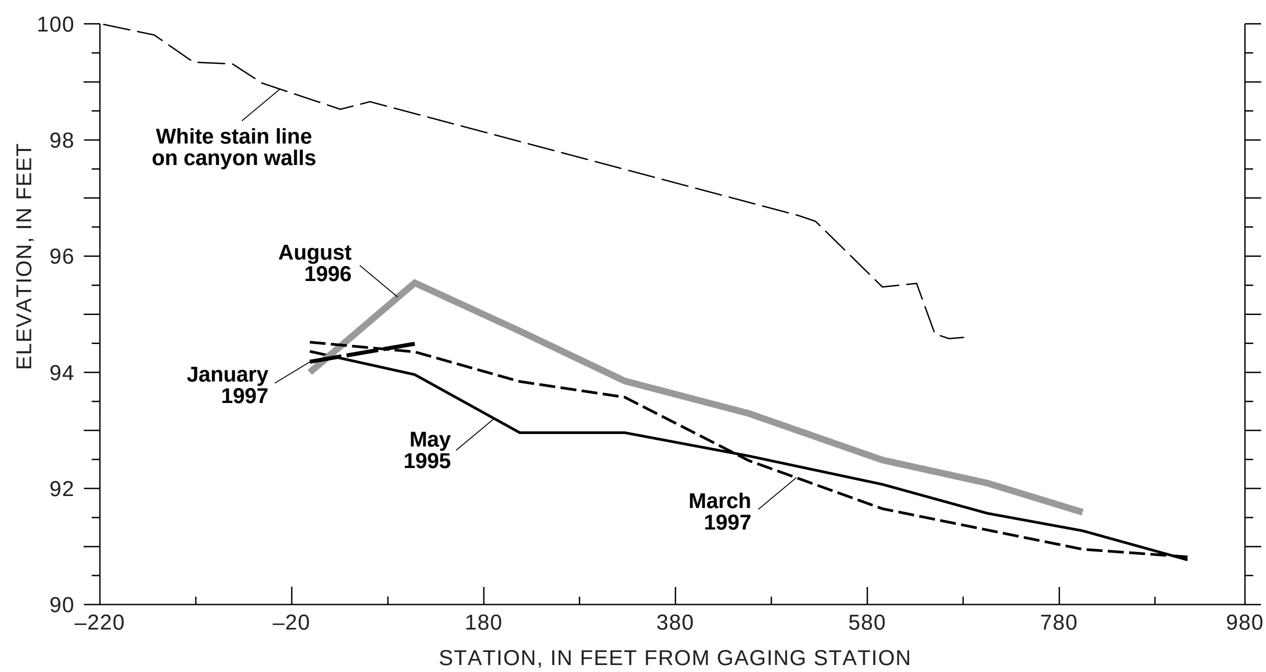


Figure 13. Longitudinal-profile changes, Hassayampa River at Box Canyon, near Wickenburg, Arizona, 1995–97.

The fourth plotted profile, therefore, is that of a white stain line that generally parallels the surveyed channel profiles (as plotted in relation to the reference elevation on fig. 13). This white line appears in the same position on the canyon walls in 1998 as it did in photographs of the gaging station taken in 1970. The white line is found at a gage height of 6.9 ft at the gaging station (**fig. 12**). The PZF elevation of 7.2 ft on July 20, 1966, and the elevations of 6.9 ft or above from March 15, 1966, to August 23, 1966, indicate that the channel bed was at roughly the same elevation as the white line for at least 5 months in 1966. Therefore, the line probably represents a former channel elevation.

Repeat photography.—Comparison of photographs taken before and after the flood of September 1970 show significant channel change at this site (figs.14A–C). On January 9, 1964 (**fig. 14**A), there was a stand of riparian trees along the right bank of the stream channel. At that time, the PZF was 4.62 ft. Figure 14B shows the channel in 1970 (exact date unknown) before a large flood that occurred on September 5, 1970. Note the absence of the riparian trees along the right bank and the flatness of the channel in comparison to figure 14*A*. The two PZF measurements made in 1970 were 5.84 ft on March 11 and 6.12 ft on July 29; these are about 1 ft higher than the PZF at the time of the 1964 photograph. Also note the location of the top of the white stain on the rock in relation to the channel (fig. 14B), and compare this to the location of the white stain to the channel in figure 14C. These two photographs show that the channel has lowered about 4 ft in elevation from before and after the flood on September 5, 1970. This change in channel relative to the white stain is similar to the changes in the PZF from 6.12 ft on July 29, 1970, to 1.53 ft on March 18, 1971, and is a change of 4.59 ft. Thus, it seems that the large flood on September 5, 1970, caused the channel bottom to incise about 4 ft along this reach.

The second set of repeat photographs were taken 2 days before and 4 days after the flood on September 26, 1997 (**figs. 15**A–15B*)*. The photographs show the coarsening of the channel sediment immediately following prolonged flows, which occurred after the flood on September 26, 1997. This coarsening of channel sediment has been observed on several occasions at this site.

09516000 Hassayampa River at U.S. Highway 60, at Wickenburg, Arizona

The Hassayampa River has a drainage area of about 711 mi^2 at the crossing of U.S. Highway 60 in Wickenburg, Arizona (**fig. 1**). The channel is about 400 ft wide under the highway bridge. The channel sediment is primarily sand and is highly mobile. Flow velocities during large discharges are high, and standing waves are common. The USGS operated a crest-stage gaging station on the bridge in the 1960s and 1970s. Only maximum stage values were reported from this station. In 1994, the FCDMC installed a continuous streamflow-gaging station on the bridge.

Cross sections.—The earliest cross-section measurement (**fig. 16**) was taken from the Flood Insurance Study HEC-2 model of 1988 (Cella-Barr Associates, written commun., 1989). A second cross-section measurement was constructed from a current-meter measurement of discharge made from the bridge on September 26, 1997, at 3,800 ft^3/s on the recession limb of a flood. The peak discharge earlier that morning was estimated at 15,400 ft^3/s at this site. A third cross section was surveyed on September 29, 1997.

A comparison of the dry riverbed in 1988 with the riverbed on September 29, 1997, shows that the cross-sectional area increased by 21 percent relative to the reference elevation. The cross-sectional area measured during the flood on September 26, 1997, was 12 percent greater than the cross section of the post-flood channel.

09516500 Hassayampa River near Morristown, Arizona

The gaging station, Hassayampa River near Morristown, has a drainage area of 796 mi^2 and is at an elevation of 1,831 ft (fig. 1). The gaging station, which is attached to a bedrock cliff that overlooks the channel on the left bank, is about 15 mi downstream from the gaging station, Hassayampa River at Box Canyon, and 8 mi downstream from the gaging station, Hassayampa River at U.S. Highway 60. Bedrock cliffs also are immediately downstream from the gaging station. Beyond these bedrock controls, the river enters the alluvial fill of the valley called the Hassayampa Plain. The river channel is flat, and narrows as it approaches the gaging station. Bed material is primarily sand.

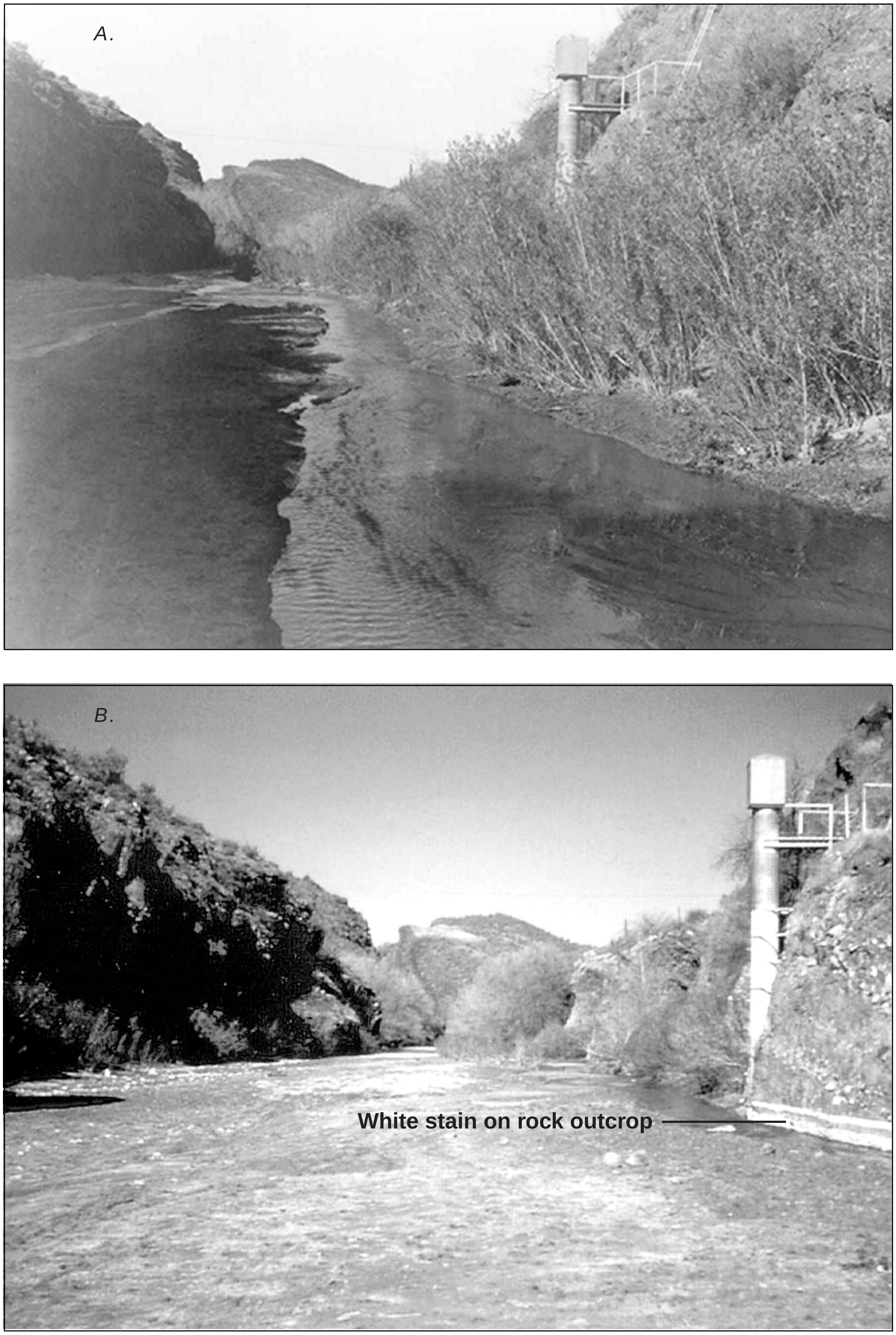


Figure 14. View downstream past stilling well, Hassayampa River at Box Canyon, near Wickenburg, Arizona. *A*, January 9, 1964. *B*, 1970, exact data unknown. *C*, After flood of September 5, 1970.

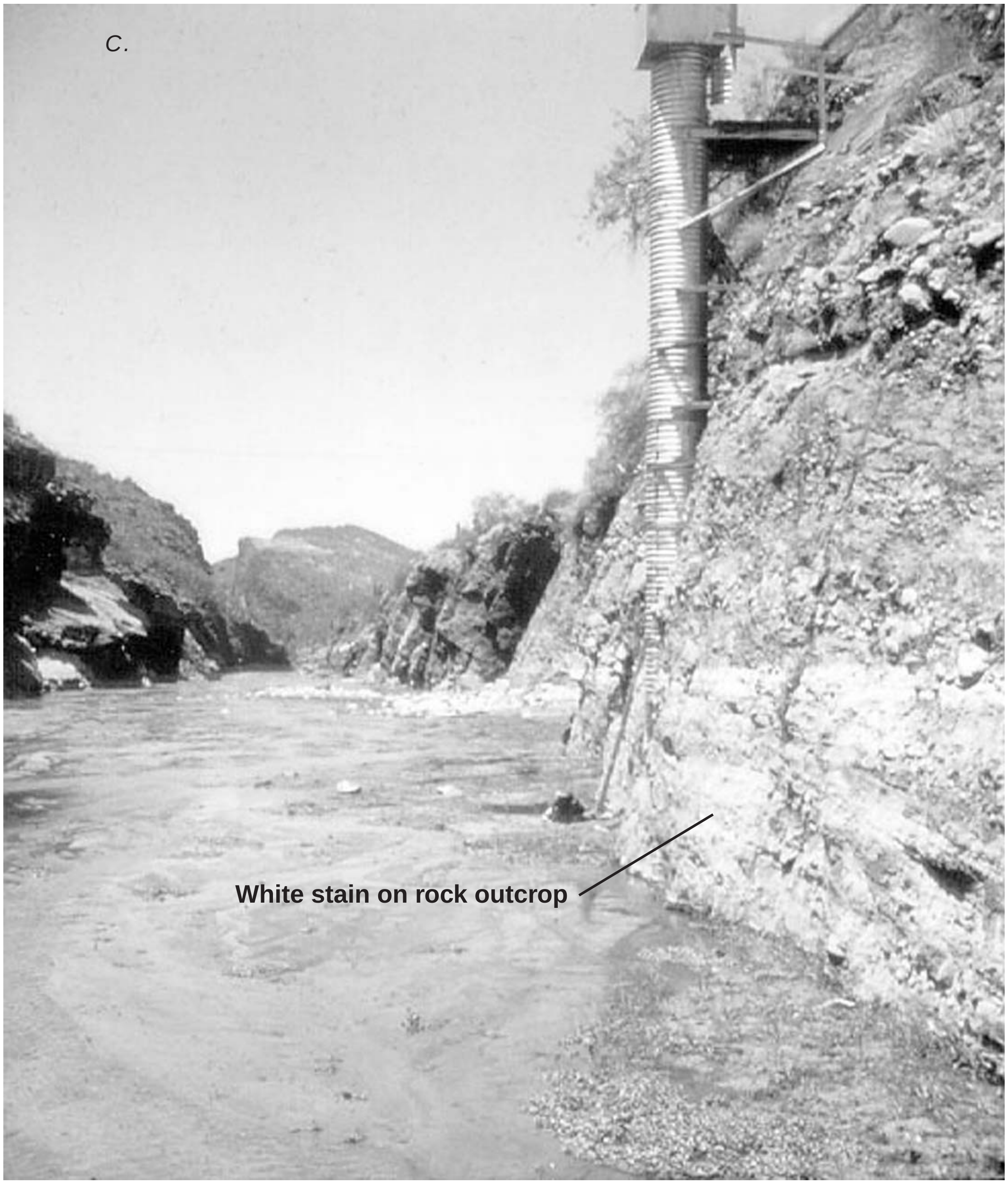


Figure 14. Continued.

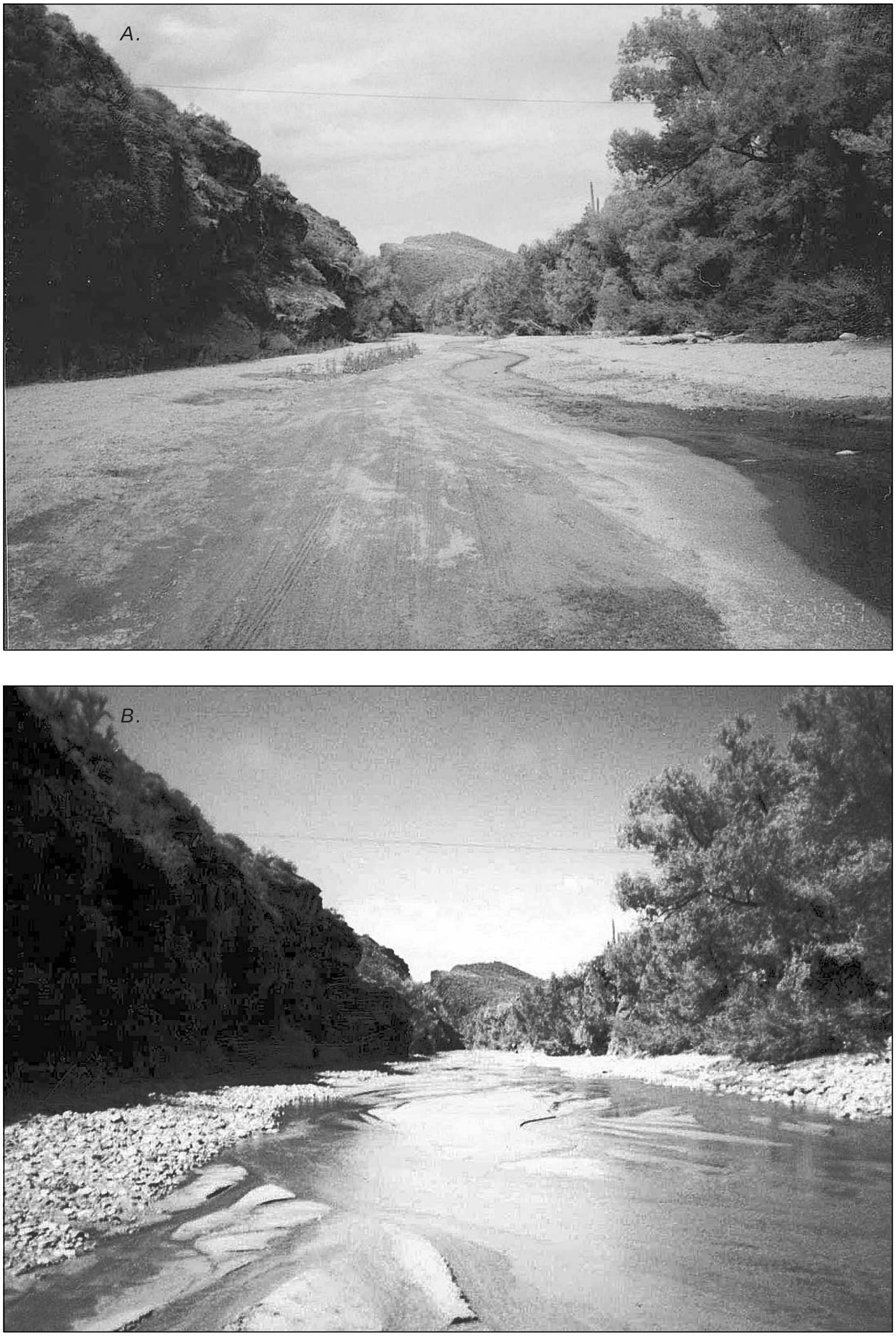


Figure 15. View downstream from gaging station. *A*, September 24, 1997. *B*, September 30, 1997.

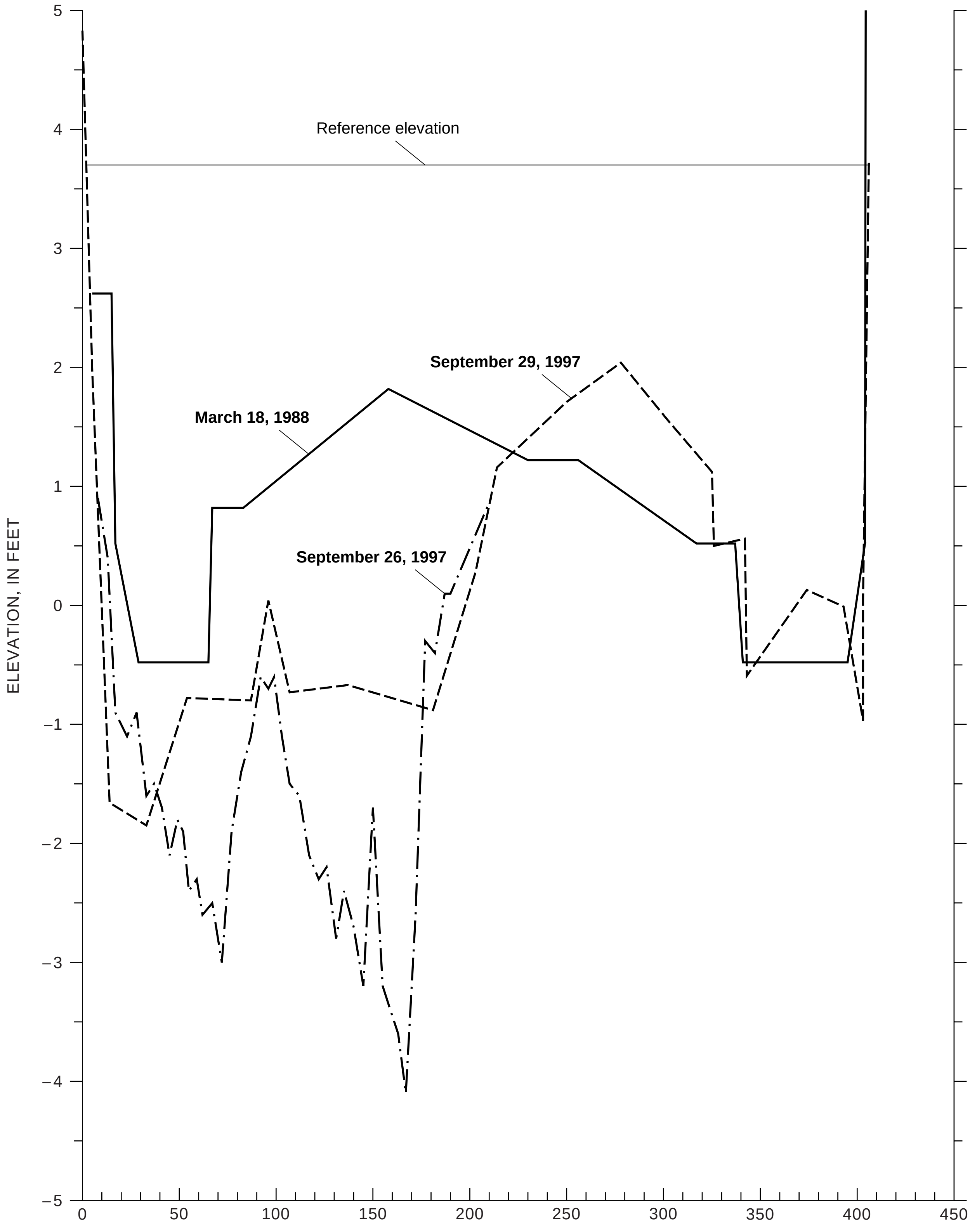


Figure 16. Cross section from current-meter measurement of discharge and from cross-section surveys on downstream side of the bridge, Hassayampa River at U.S. Highway 60, at Wickenburg, Arizona, 1988–97. Data for cross section of March 18, 1998, from Cella Barr Associates, (written commun., 1989).

The narrowing increases stream velocity past the gaging station, and most high flows are near or at critical depth. The cross section was measured nine times at the site during and after the flood of 1993—seven measurements were made from cableway-discharge measurements and two measurements were made from cross-section surveys at the cableway, which is at the gaging station (fig.17).

Cross sections.—Examination of the cross-section data shows that changes to the cross section were limited to a range of about 2 ft vertically for the entire cableway cross section (figs. 17 and 18; table 1). Although the low-flow channel moves across the cross section, it changes little in shape and size. The cross sections for February 9, 1993, and February 20, 1993, indicate that the bed becomes more irregular at higher flows. The cross sections for March 4 and 31, 1993, show that the channel smoothed out at lower flows. The cross-section for March 31, 1993, shows the channel scoured after the measurement on March 4 (figs. 17 and 18). The scour probably was a result of prolonged low flow between 100 and 200 ft^3/s during the period between measurements. The cross sections of 1995 and 1996 show little change in cross-sectional area from the survey on March 31, 1993. Since the initial cross-sectional measurement on January 19, 1993, channel changes range from 26 to 73 percent of the cross-sectional area relative to the reference elevation.

PZF analysis.— The gaging station has a long PZF record (fig.19), and the stage-discharge relation generally is under channel control. Typically, the PZF is recorded when low-flow discharge measurements are made. The number of PZF measurements at this site, however, is limited because frequently there is no flow during site visits. The first record of PZF is 6.0 ft on December 12, 1965 (fig. 19). The PZF increased to 6.6 ft on April 22, 1966, and then decreased to 5.12 ft on August 19, 1970, before the flood of record on September 5, 1970. The next measured PZF after the flood of 1970 was 4.6 ft on December 5, 1972. After December 25, 1972, the PZF generally increased until it reached 8.0 ft on April 3, 1984. Since 1984, the PZF slowly decreased.

09517000 Hassayampa River near Arlington, Arizona

The site is about 3,000 ft upstream from the continuous streamflow-gaging station, Hassayampa River near Arlington, and is immediately downstream from the Southern Pacific Railroad bridge (fig. 1). Monumented cross sections emplaced and surveyed by Parker (1995) were resurveyed for the current study. The site has a drainage area of about 1,471 mi^2 at the gaging station. The river has entrenched into the surrounding alluvial valley fill. The main flow path is wide and shallow and is composed primarily of sand, silt, and occasional deposits of gravel. Within the main channel, there is an unvegetated low-flow channel. The areas above the low-flow channel, which probably represents the flood plain, are covered with scattered saltcedar, palo verde, and other assorted bushes and shrubs.

Surveyed cross sections.—Although Parker (1995) originally surveyed 11 cross sections, only 6 of these cross sections were found and resurveyed. The resurveyed cross sections are cross-sections 2 and 4–8 as numbered in Parker (1995; fig. 20, this report). Since 1992, the cross sections generally filled with sediment (fig. 20). Cross sections surveyed in 1991 (Parker, 1995) have been omitted from the graphs because the changes from 1991 to 1992 were minor compared with the large changes between the surveys of 1992 and 1997. Relative to the reference elevation, the cross sections lost between 737 and 1,586 ft^2 of cross-sectional area to deposition of sediment. The greatest depths of fill occurred in the deepest sections of the cross sections of 1992. The channel probably filled during the floods in 1993 or 1995 (fig. 21).

09513800 New River at New River, Arizona

The discontinued USGS gaging station, New River at New River, used in this study is 1,000 ft upstream from the bridge on Interstate 17 (fig. 1). The New River drainage basin is bounded by the New River Mountains to the north and west and the New River Mesa to the south and east. The drainage area at the gaging station (elevation of 1,800 ft) is 83.3 mi^2. The channel at the gaging station has a bedrock control on the right bank and sand and gravel-size sediments in the channel and overbank area.

Surveyed cross sections.—Three cross-section measurements used for this site were from indirect measurements of discharge in 1967, 1970, and 1978 (fig. 22). The cross section also was surveyed in 1997 as part of this study (fig. 22). From 1967 to 1997, the channel increased in width by more than 40 percent, the bed was scoured along both banks, and a large midchannel bar developed (fig. 22; table 1). Along the right bank, the alluvial channel was scoured to

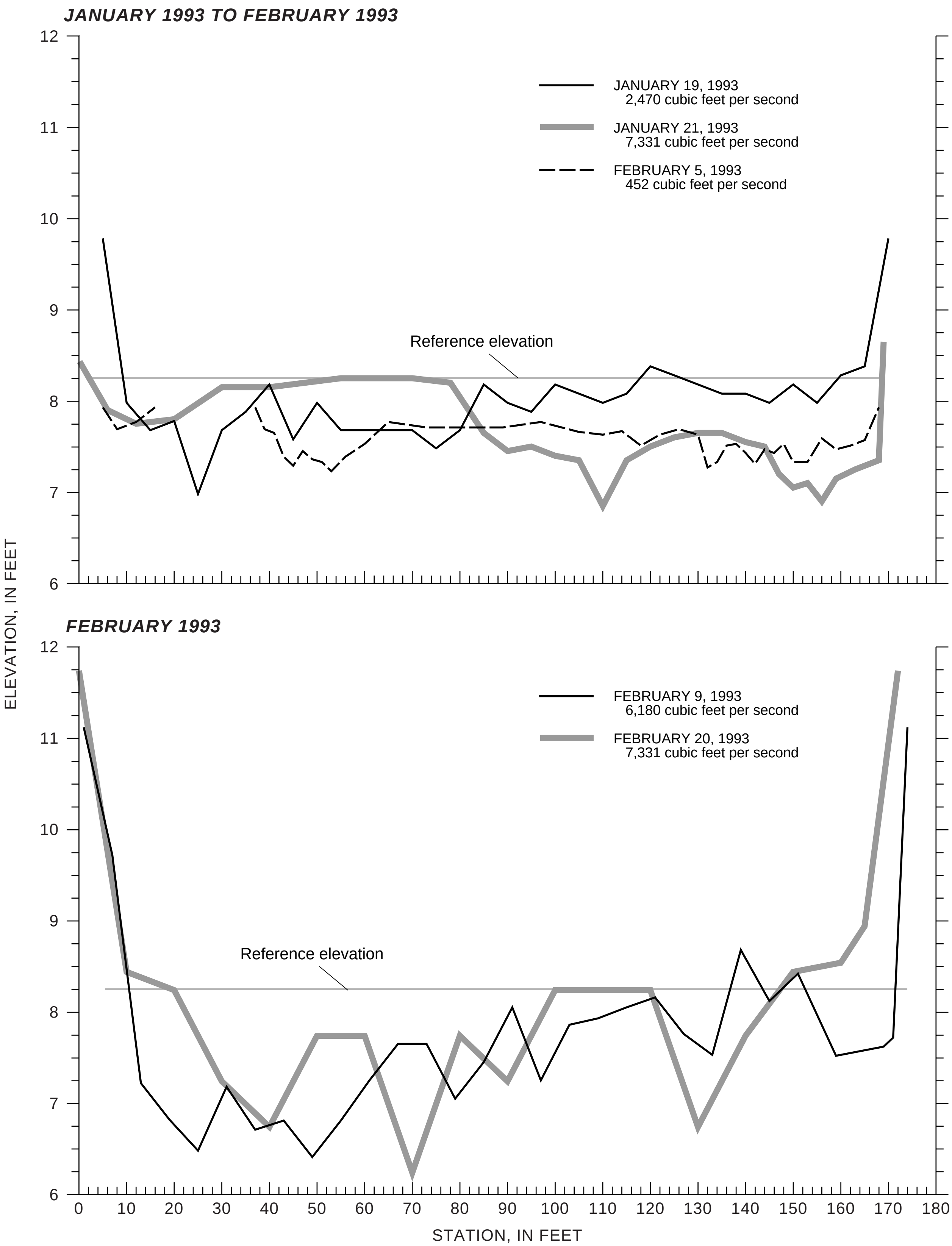
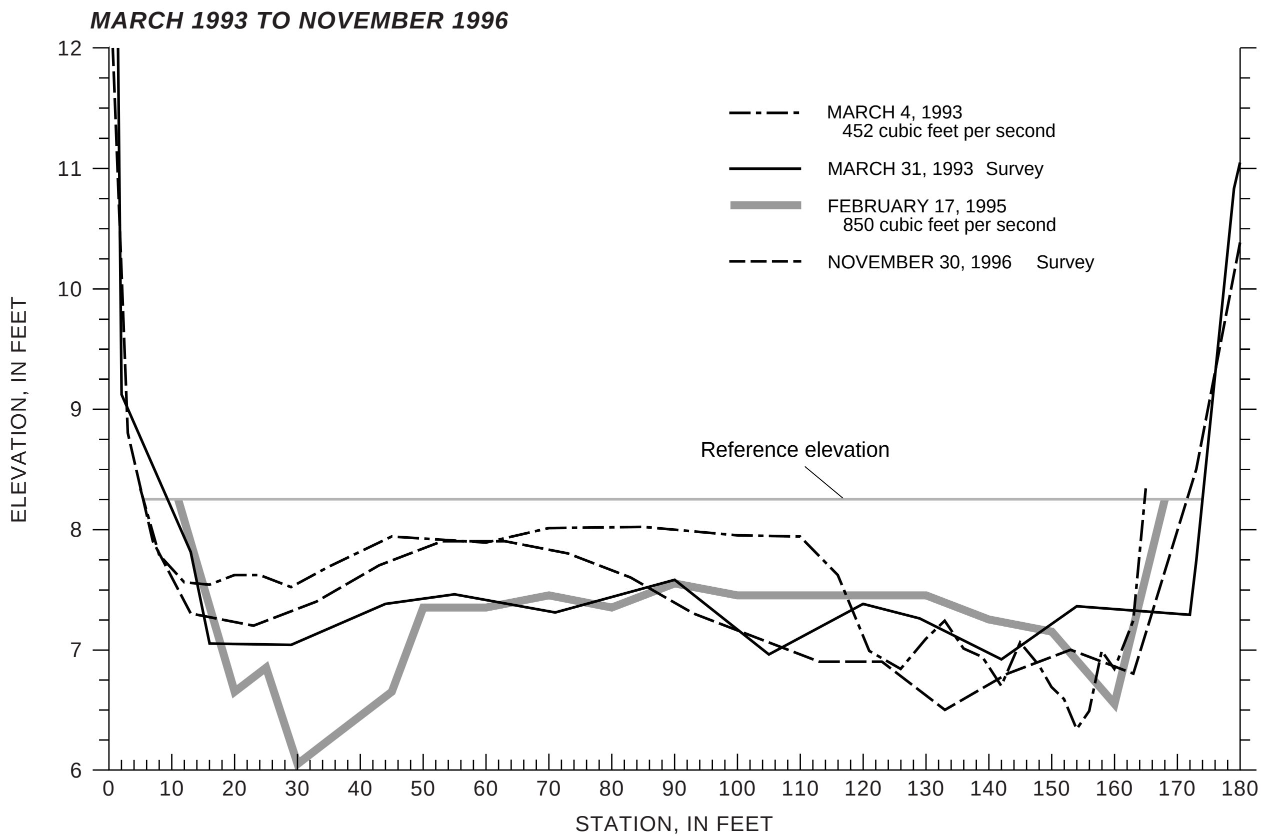


Figure 17. Cross section at cableway from discharge measurements and cross-section surveys, Hassayampa River near Morristown, Arizona, 1993–96.



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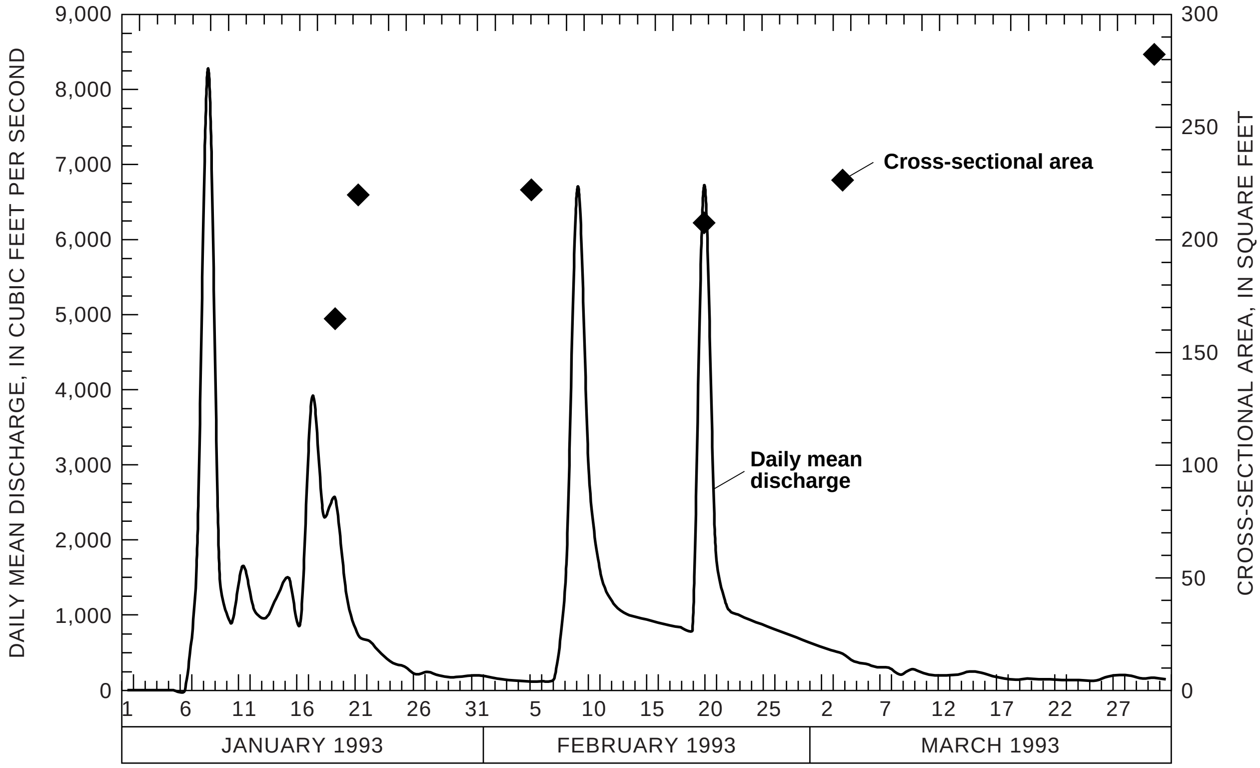


Figure 18. Daily mean discharge and cross-sectional area, Hassayampa River near Morristown, Arizona, 1993.

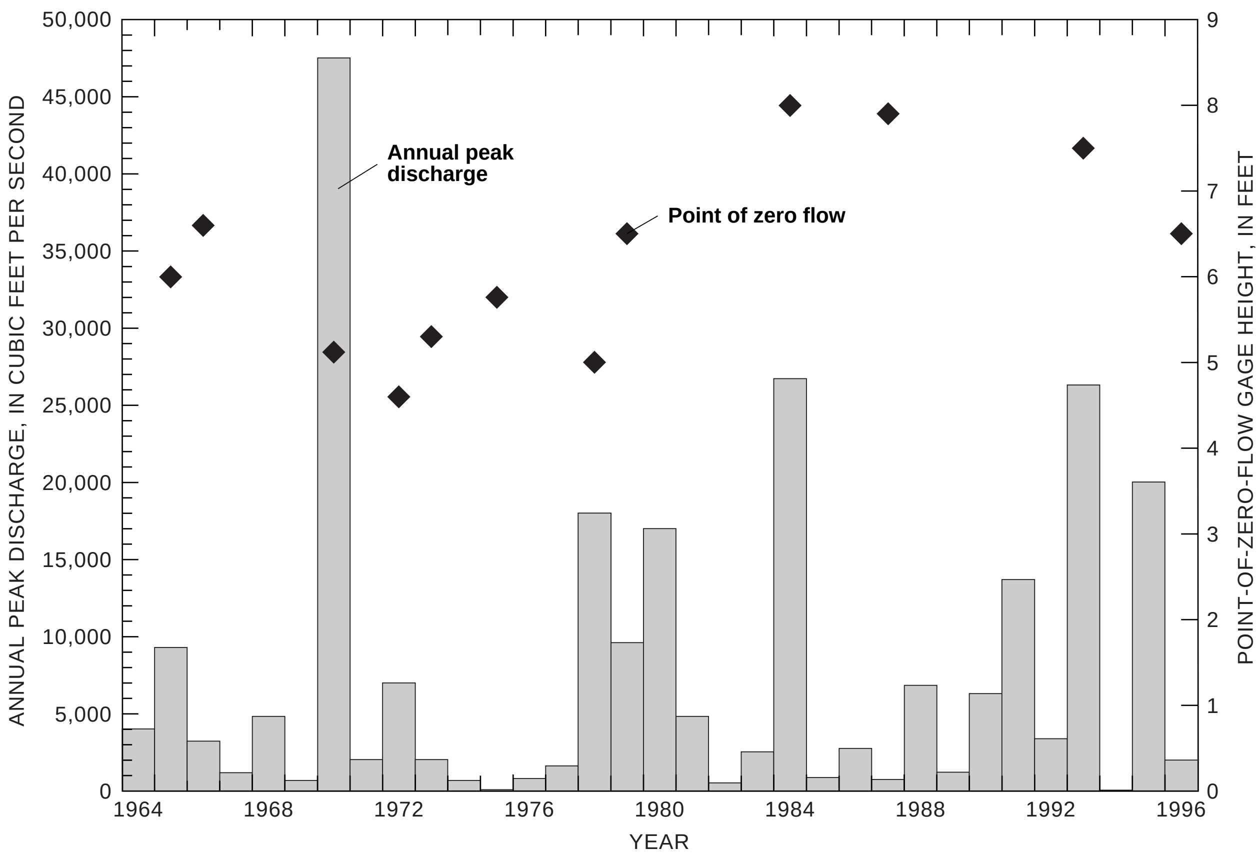


Figure 19. Point-of-zero-flow gage height and annual peak discharge, Hassayampa River near Morristown, Arizona, 1964–96.

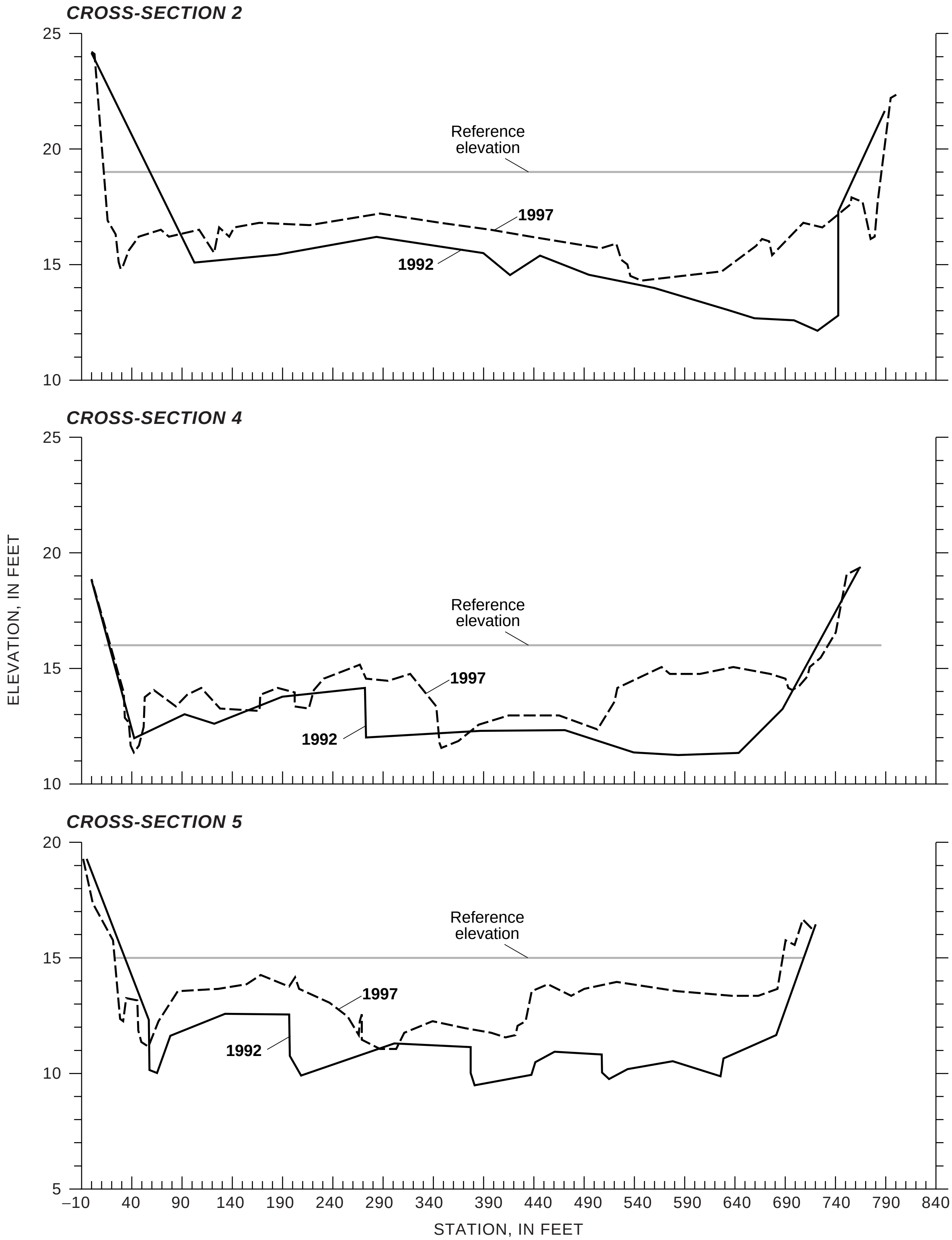
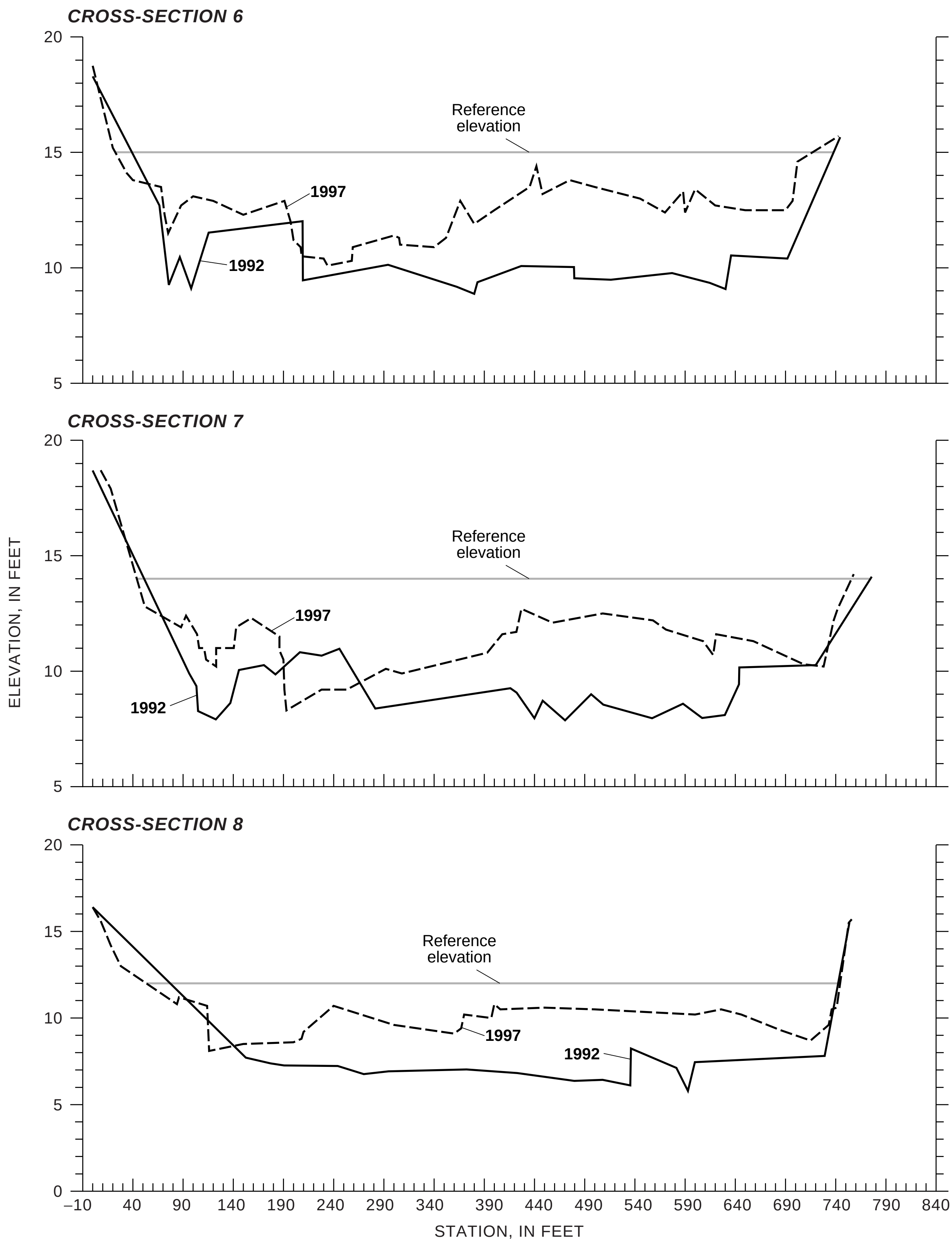


Figure 20. Cross sections from surveys, Hassayampa River near Arlington, Arizona, 1992 and 1997. Cross sections for 1992 and cross-section numbers are from Parker (1995).



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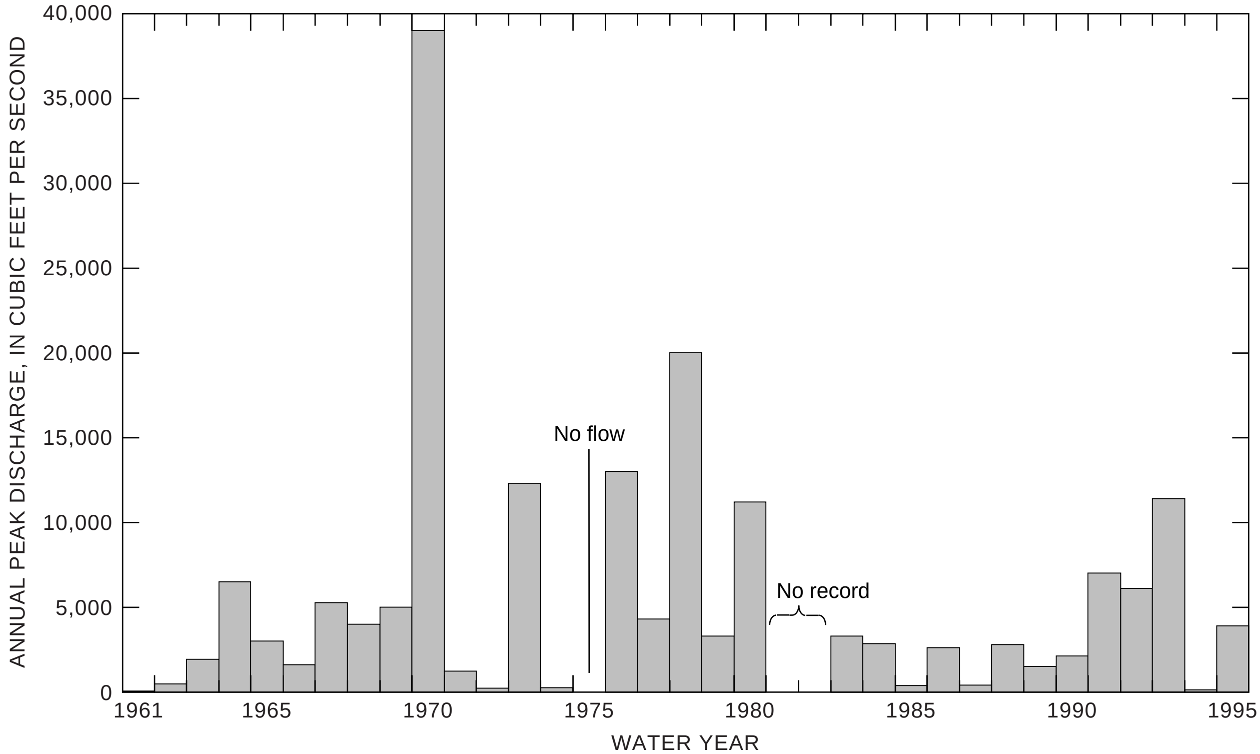

Figure 21. Annual peak discharge, Hassayampa River near Arlington, Arizona, 1961–95.

bedrock. In 30 years, the left bank of the channel appears to have eroded during each large flood. A midchannel bar first appeared in the cross section in 1978, and by 1997, the bar had grown 2 ft in height and 60 ft in width.

Cross-sectional area of the channel decreased about 6 percent from 1,036 ft^2 in 1978 to 974 ft^2 in 1997. Hydraulic radius decreased by 22 percent from 5.1 ft in 1978 to 4.0 ft in 1997 (**fig. 23**; table 1).

09517280 Tiger Wash near Aguila, Arizona

Tiger Wash near Aguila is an ephemeral stream in western Maricopa County and has a drainage area of 85.2 mi^2 and an elevation of 1,870 ft at the gaging station (**fig. 1**). Runoff in Tiger Wash is often rapid, of short duration, and usually occurs no more than a few times each year. Bed material is primarily sand and gravel.

Surveyed cross sections.—The surveys used to document channel change at this site were all at the crest-stage gaging station. The channel was measured in 1965, 1970, and 1972 (**fig. 24**). Little channel change was measured for these three surveys. The crest-stage gaging station was not operated from 1979 to 1991 except for a miscellaneous discharge measurement of 3,170 ft^3/s in 1983. Streamflow-data collection was resumed in 1991. In 1995, a slope-area measurement showed that the main channel had incised about 1.5 ft since 1972 (fig. 24). The gravel bar on the right bank appeared to have eroded as well. In 1997, surveys of the channel showed that the cross section changed little after moderate flows on August 3 and August 8, but considerable erosion occurred following the flood of record at the site on September 26, 1997. During this flood, the right half of the main channel eroded about 1 ft, and several feet of the heavily vegetated right bank was removed.

The channel at the gaging station has changed by as much as 57 percent over time. The cross-sectional area relative to the reference elevation and the annual peak discharge are shown in **figure 25**. Although the large gap in the stream-flow data exists, the stream channel appears to have filled during the 1960s and incised during the 1990s, especially following the peak flood of record in 1997.

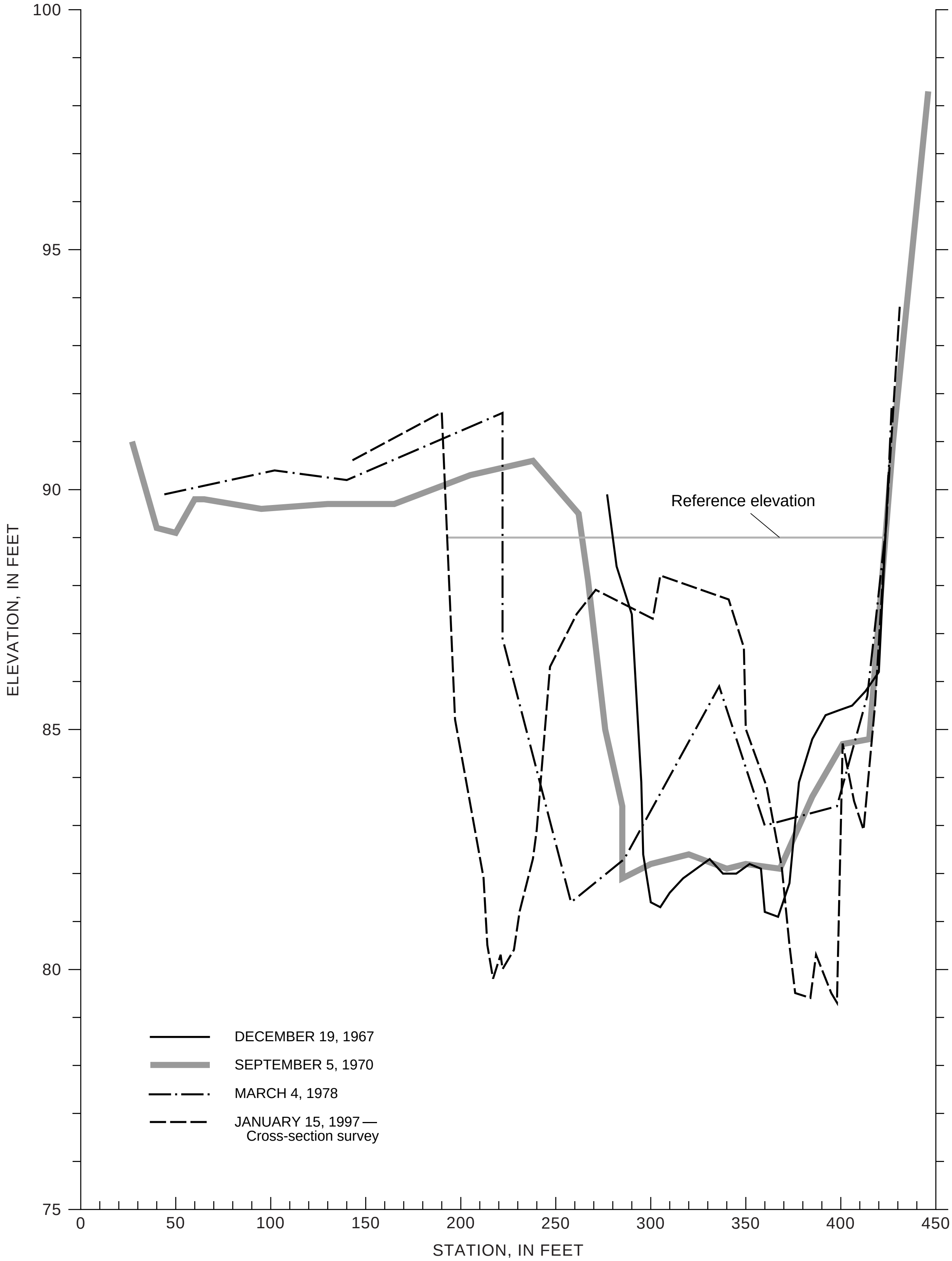

Figure 22. Cross section from surveys during indirect measurements of discharge and from cross-section survey, New River at New River, Arizona, 1967–97.

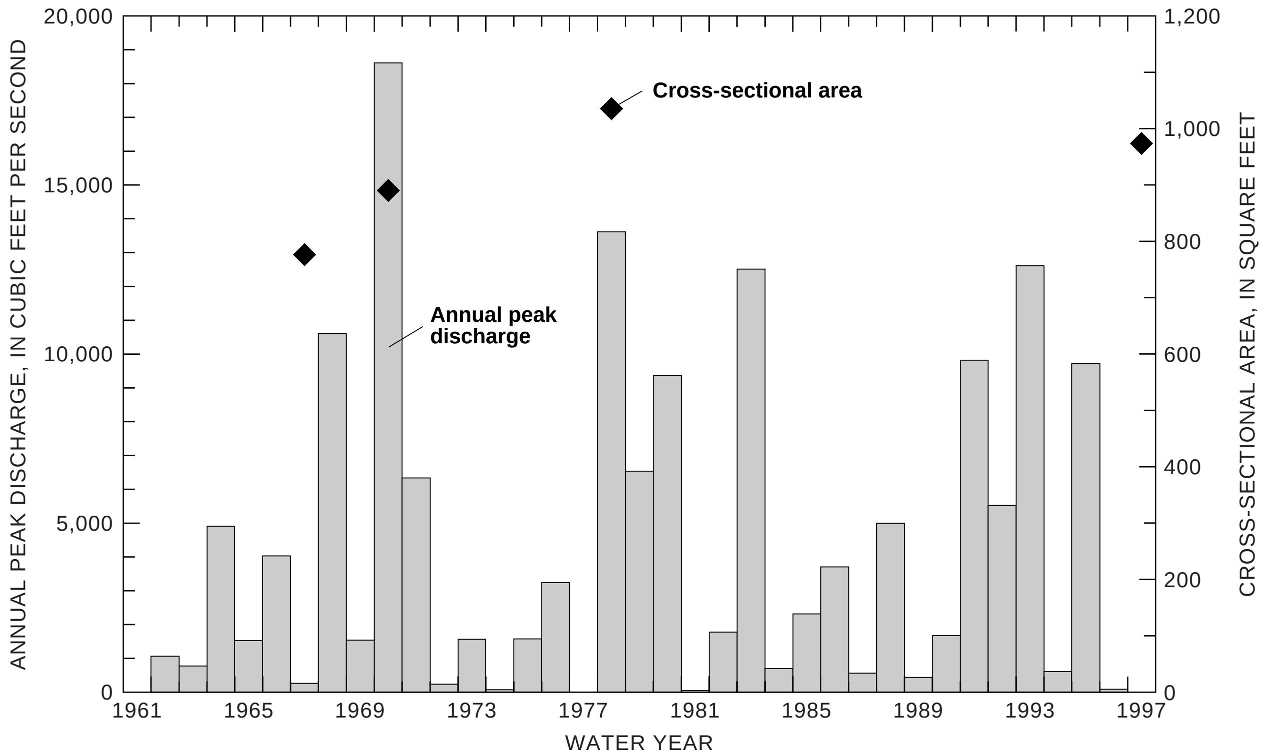

Figure 23. Annual peak discharge and cross-sectional area relative to reference elevation, New River at New River, Arizona, 1961–97.

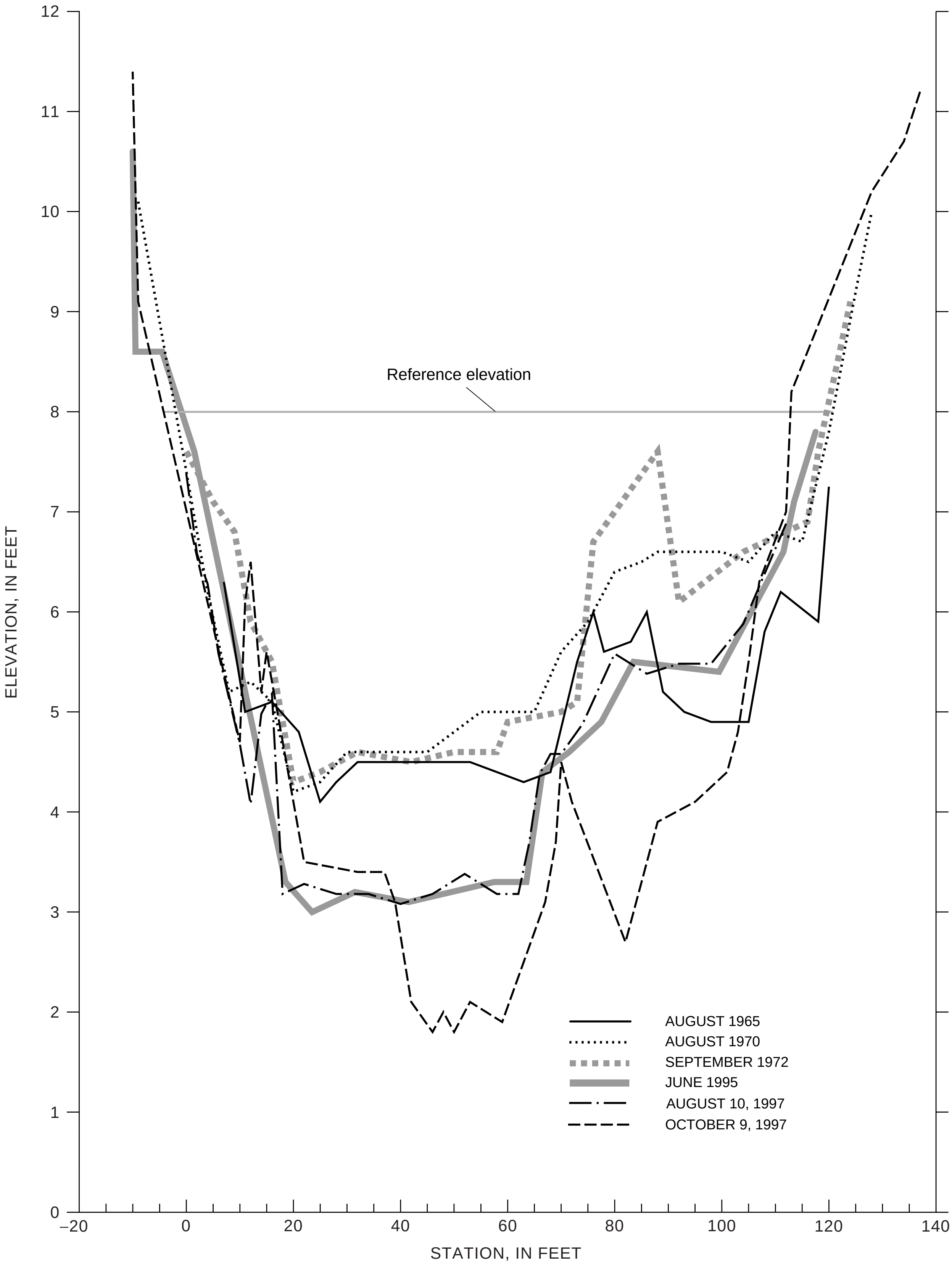

Figure 24. Cross section from surveys during indirect measurement of discharge and from cross-section surveys, Tiger Wash near Aguila, Arizona, 1965–97.

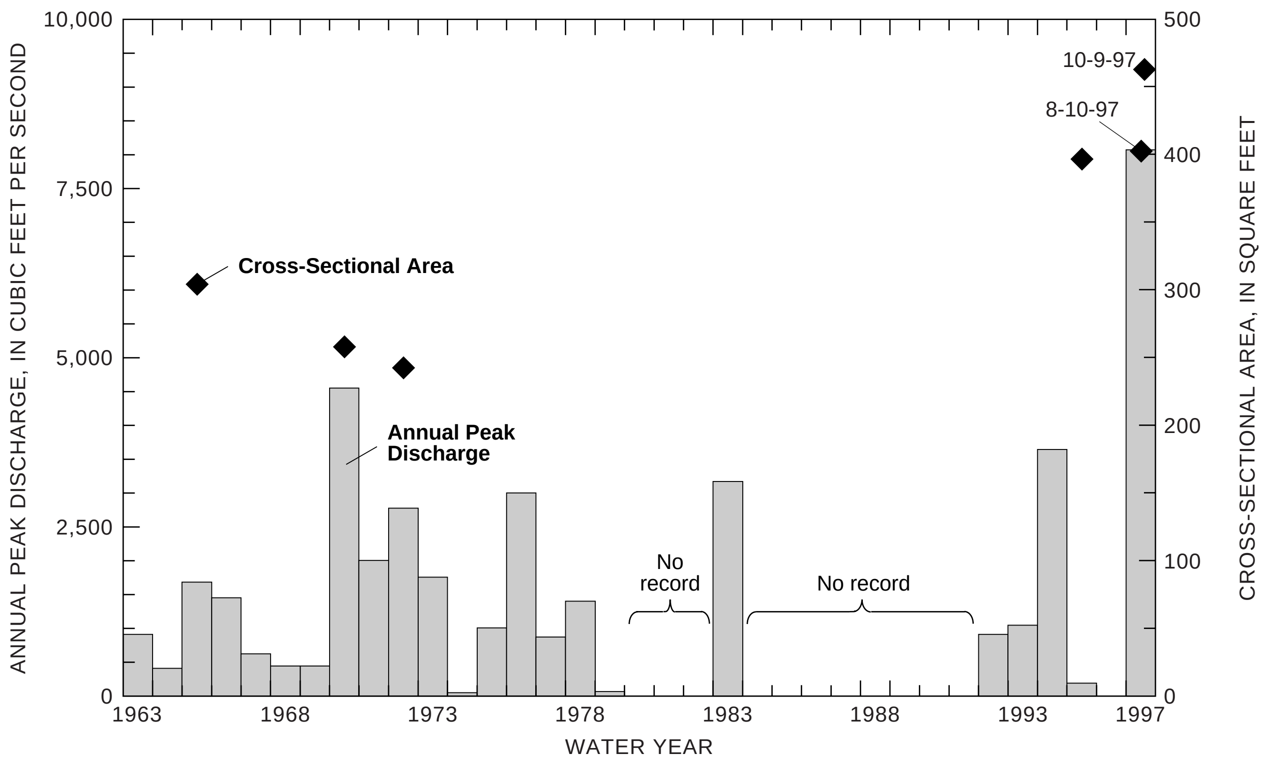

Figure 25. Annual peak discharge and cross-sectional area, Tiger Wash near Aguila, Arizona, 1963–97.

09510000 Verde River below Bartlett Dam, Arizona

The Verde River below Bartlett Dam has a drainage area of 6,161 mi^2 and an elevation of 1,570 ft at the gaging station (fig. 1). Bartlett Dam regulates flow at the site. Channel sediment ranges in size from boulders to fine sand. The gaging station is on the upstream edge of a bend in the channel. The channel is straight from 500 ft upstream to 1,000 ft downstream from the gaging station; the right bank is bedrock, and the left bank is coarse alluvium. The two largest discharges measured at this gaging station occurred in 1993 and 1995; therefore, cableway discharge measurements from 1993 and 1995 were used to show channel change during increases and decreases in discharge.

Cableway cross sections.—The cross section is at the cableway, which is about 200 ft upstream from the gaging station. The first cross section was measured on January 4, 1993, during a discharge of 3,750 ft^3/s (fig. 26). This measurement was made before the peak of record of 110,000 ft^3/s that occurred on January 8, 1993 (fig. 27). The second discharge measurement of 36,400 ft^3/s was made on January 19, 1993, at 36,400 ft^3/s. Between these two measurements, the cross section filled with sediment. The third discharge measurement was made on January 21, 1993, at 7,160 ft^3/s. The cross section narrowed and deepened as compared to the previous measurement. Sediment was scoured from the channel bottom and deposited on the left bank (fig. 26).

A second large flood occurred in 1995, and the discharge was measured at 78,200 ft^3/s on February 15 (fig. 26). The cross section during this flow shows several feet of scour on the channel bed. The discharge measurement on April 28, 1995, shows that the channel filled to a level comparable with the level before the 1993 flows.

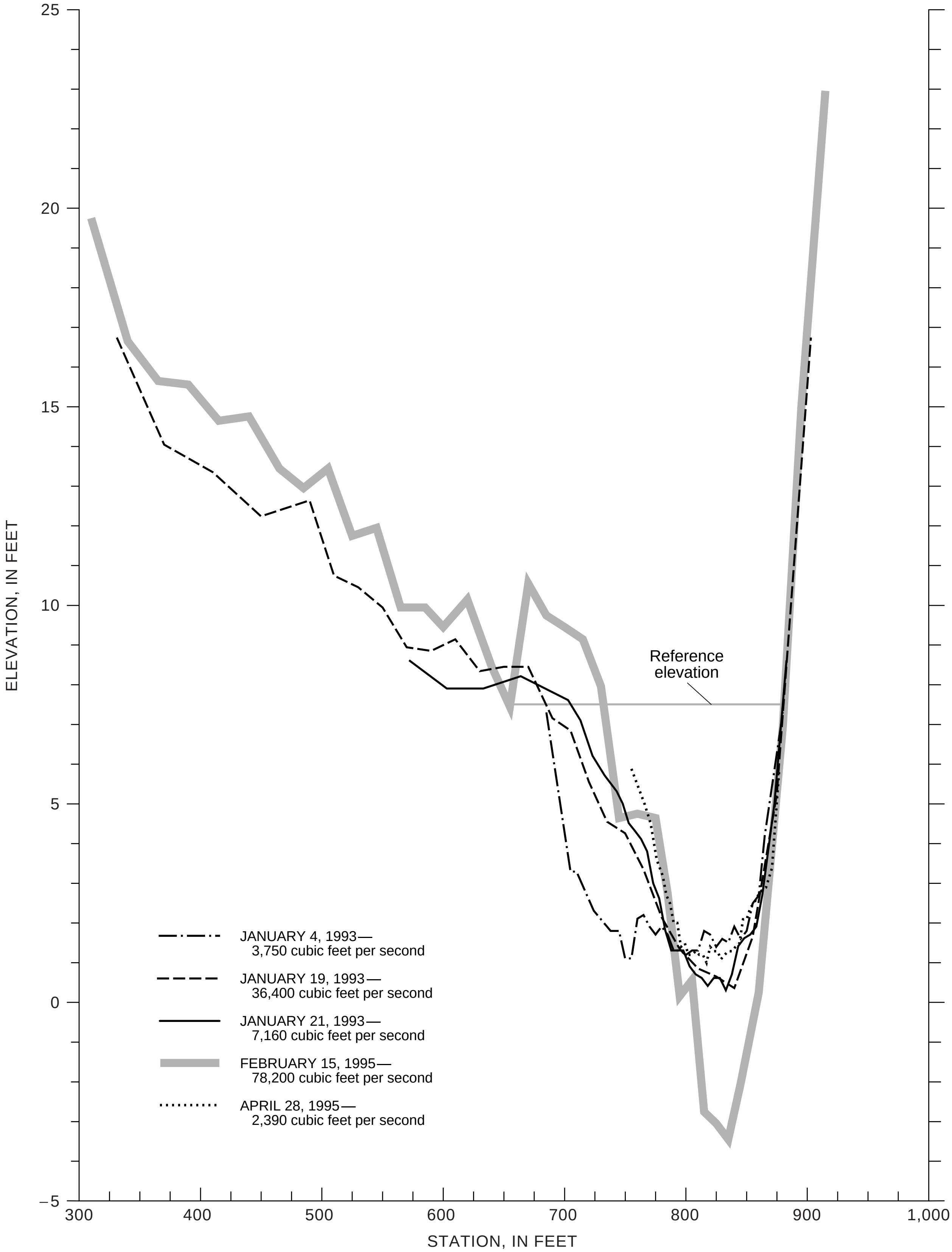

Figure 26. Cross section from cableway discharge measurements, Verde River below Bartlett Dam, Arizona, 1993–95.

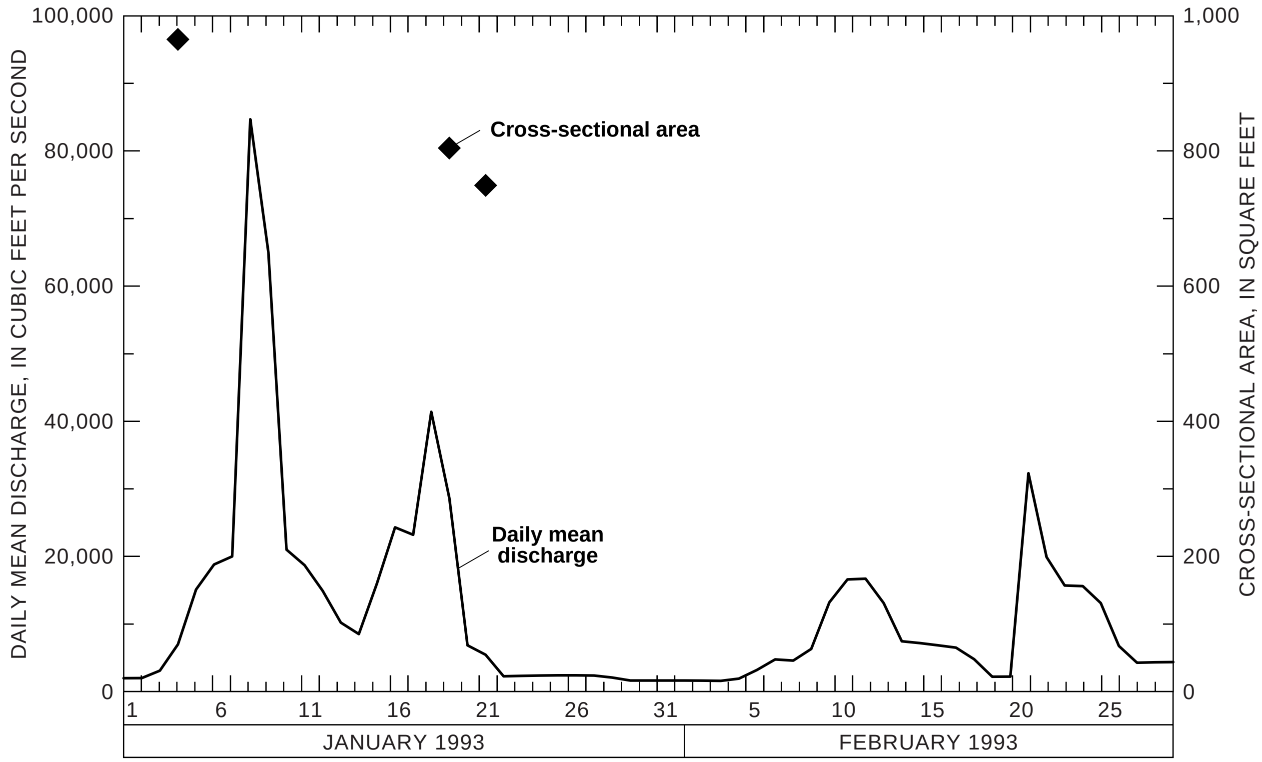

Figure 27. Daily mean discharge and cross-sectional area, Verde River below Bartlett Dam, Arizona, January and February 1993.

09514200 Waterman Wash near Buckeye, Arizona

Waterman Wash near Buckeye (**fig. 1**) is an ephemeral sand channel that flows through Rainbow Valley, which is filled with alluvial sediments that originate from the Estrella and Maricopa Mountains to the northeast and southwest, respectively. Waterman Wash has a drainage area of 420 mi^2 and an elevation of about 1,000 ft at the gaging station. Bed material at the gaging station is mainly sand with some gravel. The channel is incised into the valley alluvium.

Surveyed cross sections.—The cross section was measured near the gaging station. Resurveys were reconstructed from five indirect measurements of discharge and one cross-section survey (**fig. 28**). The first measurement was made in 1964. Subsequent cross sections were surveyed in 1966, 1971, 1982, 1996, and 1997. Nearly all channel change was vertical (fig. 28). Vertical change in the streambed elevations has been as much as 2 ft between surveys and as much as 3.5 ft overall between 1966 and 1982. The channel filled almost 60 percent of the cross-sectional area relative to the reference elevation between 1964 and 1982. A survey following the flood of August 8, 1997, showed a 13-percent increase in cross-sectional area. The flow of August 8, 1997, of 9,400 ft^3/s was the peak discharge of record at this site (**fig. 29**).

SUMMARY

This report has presented channel cross-section changes over short and long periods of time. Most of the sites show changes in channel geometry spanning both time scales. Point-of-zero-flow data also suggest changes in channel geometry over time.

Short-Term Channel Change

Alluvial stream channels in arid regions are dynamic, and channel changes can occur over short time periods ranging from hours to weeks. A channel that scours during increasing discharge and fills during

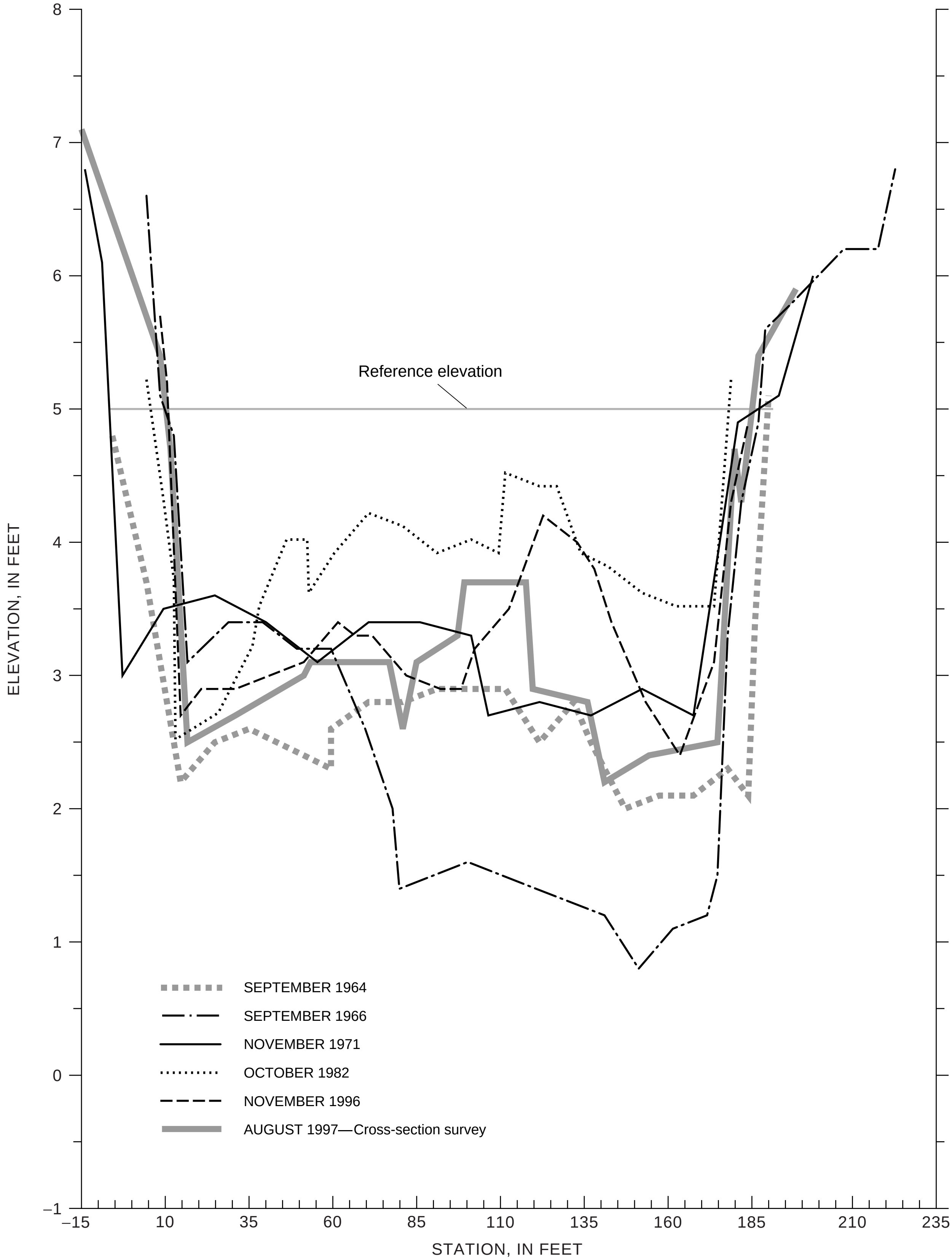

Figure 28. Cross section from surveys during indirect measurements of discharge and from cross-section survey, Waterman Wash near Buckeye, Arizona, 1964–97.

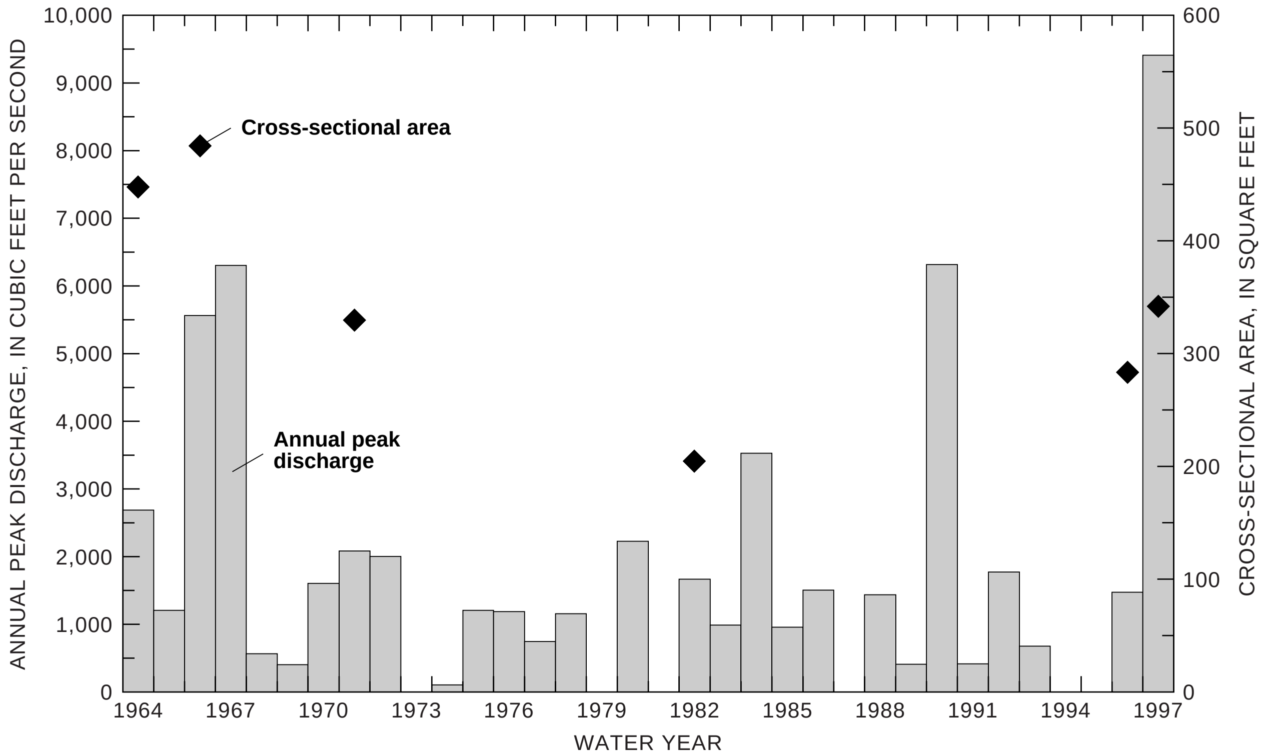

Figure 29. Annual peak discharge and cross-sectional area, Waterman Wash near Buckeye, Arizona, 1964–97.

decreasing discharge is an example of a site experiencing short-term channel change. Results of the examination of short-term channel change from current-meter measurements indicate that some reaches are more dynamic than others. Several gaging stations that are in dynamic reaches include the Agua Fria River near Rock Springs; Hassayampa River at U.S Highway 60, at Wickenburg; Gila River at Estrella Parkway, near Goodyear; and Verde River below Bartlett Dam.

Current-meter measurements made at the Agua Fria River near Rock Springs from January to February of 1993 show that several feet of scour and fill can occur during changes in discharge. Channel changes were observed at two sites on larger rivers, Gila River at Estrella Parkway, near Goodyear, and Verde River below Bartlett Dam. Most of the short-term channel change at these two sites occurred in the low-flow channel area. The cross-sectional area and hydraulic radius at the Gila River site increased between flows.

Long-Term Channel Change

Long-term channel change was measured in time scales ranging from years to decades. These channel changes were determined by cross-section surveys and usually represent general scour and fill of the stream channel reach. Short-term change is the type that occurs during an individual flood. Long-term channel change represents lasting changes that would have more of an effect on flood-hazard regulation. Most sites in this study had substantial long-term channel change.

Three sites appeared to have substantial long-term channel change. For example, Hassayampa River at Box Canyon, near Wickenburg, scoured as much as 6 ft at the gaging station during the peak-of-record flood in 1970. This scour extended for a reach several hundred feet upstream and downstream from the gaging station, and the streambed at the gaging station did not recover to within 1 ft of the preflood elevation for 3 years.

Conversely, a large flood in 1979 at Agua Fria River near Rock Springs caused several feet of aggradation at the control reach of the gaging station.

The cross sections measured at the Hassayampa River near Arlington also show several feet of fill from 1992 to 1996, during which only two flows occurred at this site.

At Waterman Wash near Buckeye, as much as 2 ft of vertical change occurred between surveys and 3.5 ft occurred from 1964 to 1982. Because base flow does not occur at this site, this change and changes observed over the period of record can be attributed to individual floods.

The final site that showed long-term channel change was Tiger Wash near Aguila. Like stream-flow at the Waterman Wash gaging station, streamflow at Tiger Wash at Aguila is ephemeral, and all channel change is caused by the few floods that occur at this site. Between 1972 and 1996, the bed elevation decreased by about 1 ft. Further incision into the channel followed the peak-of-record flood in 1997.

Point-of-Zero-Flow Method

The PZF method, which is the examination of the changes in the PZF through time and in relation to annual peak discharge, was developed for this study. Although the PZF method has limitations for examining channel change, this method may provide useful information under certain circumstances.

The PZF method is most useful for streams in which channel control exists throughout most of the range in discharge. The gaging stations Hassayampa River at Box Canyon, near Wickenburg, and Hassayampa River near Morristown are two examples where channel control exists for nearly all flows.

An examination of the change in the PZF elevation through time indicates long-term channel change. For example, the PZF at the Hassayampa River at Box Canyon, near Wickenburg, changed by as much as 6 ft from 1945 to 1996. The PZF data at this site also show that the channel can change dramatically in response to a single large flood, such as the peak-of-record flood in 1970.

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CROSS-SECTION DATA

Table 2. Data from cableway cross section, Agua Fria River near Rock Springs, Arizona

[All values are in feet]

01–07–93[1]		01–13–93[1]		01–18–93[1]		02–08–93[1]		02–10–93[1]		02–20–93[1]		02–21–93[1]	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
0	[2]11.76	0	4.91	0	[2]10.62	0	[2]10.3	0	[2]9.77	0	[2]13.6	0	[2]9.42
6	3.66	5	-.69	0	8.62	0	-4.5	4	4.97	5	3.2	2	4.32
16	3.76	10	-2.39	8	-2.38	10	-16.6	6	2.87	8	3.8	4	3.32
26	4.96	20	-1.79	13	-6.28	20	-14.1	8	-1.83	13	.8	6	2.02
36	7.46	25	-.09	18	-3.18	30	-13.7	10	-2.33	28	-5.1	8	-.28
46	7.26	30	.71	23	-3.38	40	-12.4	12	-2.83	23	-3.6	10	.32
56	5.16	35	1.91	28	-.08	50	-7.7	14	-1.83	26	-1.7	13	1.72
61	4.66	38	2.21	33	-2.58	60	-8.2	16	-1.33	29	-3.2	16	2.92
66	3.06	41	3.21	38	.32	70	-4.2	18	.07	32	.4	19	3.22
71	2.86	44	5.21	43	1.22	80	-.2	20	.17	35	-.6	22	2.62
76	2.26	47	5.51	48	2.62	90	2.1	22	1.17	40	1.3	25	1.82
81	3.36	50	5.91	53	4.32	100	5.5	24	1.67	45	1.8	28	1.92
86	2.96	53	6.71	58	4.52	110	8.9	26	1.67	50	3.1	31	2.92
91	2.06	56	7.21	63	5.32	120	9.8	28	1.37	55	3.5	35	3.12
96	1.86	58	[2]8.01	68	6.32	130	10.3	30	.57	60	3.8	39	3.62
101	3.26			73	6.02			32	.77	65	2.8	43	3.92
106	4.56			78	6.22			34	.97	70	4.5	48	4.82
111	5.26			83	6.52			36	1.47	75	5.5	53	5.32
116	5.56			88	7.02			39	1.67	85	6.4	58	6.72
126	9.96			93	7.62			42	2.37	95	9.5	63	7.82
143	11.76			98	8.62			46	3.37	105	11.9	68	8.12
								52	4.37	110	12.5	73	8.12
								58	5.47	120	12.5	78	8.32
								66	7.77	130	12.8	94	9.42
								76	8.47	140	13		
								81	8.77	150	13.2		
								92	9.77	160	13.6		

[1]Measured discharges: 01-07-93, 5,530 ft^3/s; 01-13-93, 1,390 ft^3/s; 01-18-93, 5,170 ft^3/s; 02-08-93, 16,900 ft^3/s; 02-10-93, 4,470 ft^3/s; 02-20-93, 9,940 ft^3/s; 02-21-93, 3,160 ft^3/s.

[2]Highest gage height.

Table 3. Data from indirect measurements of discharge at cross sections, Agua Fria River near Rock Springs, Arizona

[All values are in feet]

10–29–75		01–14–79		03–12–93		2–3–97	
Station	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**
Cross-section 1							
		0	29	0	29.4		
		7	28.7	5	25		
		9	27	8	19.4		
		12	26.1	17	15.6		
		14	16	34	11.9		
		20	14	52	13.6		
		30	15.4	113	8.8		
		40	15.8	126	7.8		
		50	14.2	145	8.2		
		70	13.1	159	7.5		
		90	10.8	190	6.6		
		150	9.8	203	6.8		
		200	10.6	218	8.7		
		203	10.8	252	12.7		
		220	13	260	18.3		
		240	14.9	284	20.8		
		250	17.5	325	26.6		
		275	20.1	365	26.5		
		280	21.9	456	27.2		
		290	24.2	504	31.7		
		300	25.3				
		310	25.3				
		350	26.2				
		400	25.7				
		450	25.3				
		475	28.1				
		493	28.9				
Cross-section 2							
245	11.6	0	29.5	-29	32.6	377	9
255	8.2	8	25.8	-19	28	371	6.2
275	6.1	18	21.7	-7	24.6	363	4.8
287	2.7	30	23.3	1	23.3	361	3.9
288.4	2.3	42	22.9	19	25	359	2.4
299	2.6	50	20	56	17.4	355	2
306	2.7	60	19.3	89	16	351	1.1
315	3.3	75	19.2	118	15.4	347	1.3
325	4.1	94	20.5	148	13.7	341	1.5
340	4.7	110	19.5	158	12.2	335	1.6
355	5.1	121	19.3	182	11.9	331	2.1
367	5.6	125	18.4	207	13.1	327	1.7
372	6.9	140	18.2	239	11.4	322	2.2
388	13	150	18.1	268	9.2	321	3.9
401	18	155	16.3	284	7.1	319	4.7
		170	17.7	296	5.3	317	4.9
		180	16.9	316	2.6	309	5.8
		200	16	332	2.6	307	7.1
		210	16.1	351	1.7	291	7.2

Table 3. Data from indirect measurements of discharge at cross sections, Agua Fria River near Rock Springs, Arizona—Continued

[All values are in feet]

10–29–75		01–14–79		03–12–93		2–3–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 2—Continued							
		215	15.3	364	5.4	281	8.9
		225	16.4	380	9.9	267	10.7
		235	13.8	398	24.2	257	11.5
		250	12.1	401	26.9	247	11.8
		261	11.2	408	25.8	237	12.3
		270	8.2	460	30.1	227	12.9
		275	7.5			217	12.1
		290	7.1			207	11.9
		320	7.1			197	12.4
		350	7.4			187	12.3
		370	9			177	13.3
		380	10.4			167	12.4
		390	15.5			157	12.7
		400	20			147	13.6
		410	25.4			137	15
		430	27.6			122	15.4
		450	27.8			107	15.5
		460	27.8			92	17.1
		462	28.4			77	17.5
						62	18.8
						37	19.8
Cross-section 3							
		55	25.7	0	49.1		
		65	25.1	76	24.9		
		75	24.6	131	21.8		
		85	23.9	196	18.6		
		105	23.9	210	22.1		
		153	21.9	239	19.7		
		160	20.4	247	21.5		
		173	21.6	281	19.4		
		180	15.9	330	11.4		
		205	19.7	384	11.1		
		255	20.1	421	9.7		
		270	18.4	442	4.6		
		300	18.4	452	3.1		
		305	16.9	478	2.3		
		315	17.2	504	2.7		
		325	16.7	523	3.1		
		335	16.5	524	4.7		
		345	13.3	542	14.6		
		355	14.8	555	22.7		
		360	15.9	564	29.9		
		365	15.6				
		387	16.1				
		405	10.9				
		420	8.5				
		430	6.1				

Table 3. Data from indirect measurements of discharge at cross sections, Agua Fria River near Rock Springs, Arizona—Continued

[All values are in feet]

10–29–75		01–14–79		03–12–93		2–3–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 3—Continued							
		455	7.1				
		505	6.6				
		525	5.8				
		528	6.9				
		540	10.5				
		545	17.2				
		555	22.6				
		560	26				
Cross-section 4							
		63	24.9	0	35.5		
		69	23.5	17	28.8		
		72	23.3	134	21.4		
		93	22.5	164	20		
		123	21.2	185	16.9		
		163	18.3	205	20.2		
		188	19.2	259	17.2		
		193	21.4	302	18.1		
		213	19.2	366	17.7		
		253	19.9	381	18.7		
		263	17.9	435	10.1		
		281	17.3	475	7.6		
		288	19.6	486	4		
		313	17.8	495	3		
		325	16.9	571	2.8		
		363	18.1	585	2.1		
		383	18.1	592	3.8		
		398	16	621	12.9		
		413	12.9	623	19.5		
		438	8.8	627	22.2		
		453	5	633	28.2		
		463	4.3				
		473	3.6				
		493	4.6				
		523	5.7				
		553	7				
		588	6.6				
		603	12.5				
		608	18.7				
		613	21.3				
		623	23.6				
		623	24.5				
		633	28.2				

Table 4. Data from cross section at bridge, Gila River at Estrella Parkway, near Goodyear, Arizona

[All values are in feet]

01–06–93[1]		01–09–93[1]		01–12–93[1]		02–05–93[1]	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
0	12.28	0	17.75	0	15.43	0	11.23
5	8.98	10	12.25	11	10.43	8	8.13
20	8.18	56	4.95	36	5.43	30	5.33
45	8.28	95	.75	60	5.43	50	5.13
70	8.28	170	-1.75	90	1.93	70	3.73
95	5.98	220	.25	125	.43	90	.23
120	4.28	280	2.25	170	-1.57	110	-1.77
145	3.78	340	5.05	205	3.43	130	-.77
170	5.48	400	8.25	240	3.43	150	-.37
178	6.68	460	8.25	270	3.43	170	-.77
191	8.18	520	9.55	300	3.93	195	3.43
210	6.68	580	10.05	330	5.63	220	5.13
240	7.68	640	9.75	365	6.93	245	6.13
280	8.98	700	9.75	400	7.93	270	6.13
330	9.48	760	10.25	450	5.43	300	6.93
380	9.28	820	10.95	500	9.43	330	7.03
430	9.68	900	14.35	550	9.03	360	8.03
480	10.28	1,010	14.35	610	10.13	390	8.13
530	10.48	1,100	13.75	670	10.63	420	10.13
580	10.28	1,180	12.55	740	10.23	450	7.13
630	10.28	1,260	11.65	820	11.63	490	7.63
690	10.28	1,340	12.15	900	13.43	530	6.73
750	10.58	1,430	13.75	1,000	14.43	580	6.23
790	10.58	1,510	15.25	1,100	13.23	630	9.73
840	11.58	1,610	11.75	1,200	13.53	680	10.23
880	12.28	1,710	9.75	1,300	13.33	730	10.23
		1,770	11.25	1,400	13.23	780	10.43
		1,850	14.25	1,500	12.43	798	11.23
		1,930	13.05	1,640	14.78		
		2,020	8.25	1,790	14.23		
		2,060	13.95	1,940	14.33		
		2,072	17.75	2,005	10.43		
				2,055	11.83		
				2,180	15.43		

[1]Measured discharges: 01-06-93, 14,000 ft^3/s; 01-09-93, 122,000 ft^3/s; 01-12-93, 65,500 ft^3/s.

Table 5. Data from cross sections, Hassayampa River at Box Canyon, near Wickenburg, Arizona

[All values are in feet]

05–25–46		05–17–95		08–08–96		03–04–97	
Station	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**
Cross-section 1							
		79	95.36	79	94.0	79	94.52
		74	95.36	70	94.5	66	94.82
		71	94.56	60	94.5	58	94.52
		63	94.36	50	94.9	51	94.93
		57	94.46	40	95.3	49	95.02
		49	94.46	30	95.8	46	94.92
		42	94.76	27	96.1	40	95.58
		37	96.36	20	97.2	33	95.60
		22	96.36	12	96.1	26	96.18
		7	96.26	8	98.4	19.5	97.42
		0	96.86	5	98.2	9.5	98.36
				0	97.3	6	98.33
						2	97.31
						-1	97.30
						-5	99.40
						-8	99.76
Cross-section 2							
		95	96.46	95	97.04	98	100.17
		92	95.86	90	97.14	96	96.78
		81	94.86	81	96.24	91	97.04
		75	94.16	64	96.04	83	96.27
		63	93.96	50	95.54	79	95.93
		54	94.16	37	96.04	77	94.8
		46	94.16	23	96.14	76	94.4
		42	96.16	11	95.74	65	94.5
		25	96.06	8	94.54	54	94.55
		0	96.36	3	94.74	45	94.35
				0	95.74	38	94.39
						36.5	94.76
						35	94.84
						32	95.46
						23	95.85
						16	96.07
						12	95.95
						10	95.1
						4	94.86
						0	95.92

Table 5. Data from cross sections, Hassayampa River at Box Canyon, near Wickenburg, Arizona—Continued

05–25–46		05–17–95		08–08–96		03–04–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 3							
125	130.51	120	100.46	118	103.01	104	99.55
124	130.51	94	97.46	113	101.41	98	98.23
120	126.51	89	95.56	109	100.31	94	97.99
119	109.51	81	94.16	105	99.61	92	97.53
105	104.01	70	93.96	99	98.11	91	96.88
90	98.01	60	94.06	94	97.91	86	96.18
65	97.51	49	92.96	92	96.91	67	95.85
40	99.01	43	93.46	88	96.21	63	94.42
2	99.01	38	95.56	82	96.01	56	93.84
0	122.51	19	95.76	72	95.91	38	94.14
-4	125.51	5	94.56	62	95.81	33	94.35
-5	135.01	0	94.36	52	95.61	26	95.13
				42	95.71	17	94.67
				35	95.21	13	94.94
				26	94.71	.2	94.45
				23	95.21	0	94.65
				15	95.41		
				13	95.01		
				4	94.91		
				0	94.31		
Cross-section 4							
		108	98.96	108	99.35	2	93.58
		92	95.96	105	97.75	2	93.21
		84	95.66	96	96.75	6	93.44
		79	94.06	91	96.05	6.5	93.9
		68	93.76	83	95.55	25	94.57
		58	93.66	73	95.45	35	94.33
		54	92.96	63	95.45	36	94.05
		46	92.96	53	95.15	39	93.58
		35	93.16	43	95.05	51	93.57
		31	95.16	33	94.95	61	93.68
		19	94.86	23	94.75	63	94.06
		16	94.26	19	94.15	67	95.37
		0	94.56	16	93.95	81	95.45
				13	94.05	86	96
				7	94.05	88	95.85
				1	93.85	92	95.78
				0	96.85	99	97.48
						104	97.57
						106	99

Table 5. Data from cross sections, Hassayampa River at Box Canyon, near Wickenburg, Arizona—Continued

05–25–46		05–17–95		08–08–96		03–04–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 5							
		86	94.96	87	94.69	87	96.96
		74	93.46	87	94.29	85.5	94.65
		55	93.46	79	94.49	80	94.55
		52	92.56	73	94.69	75	94.31
		40	92.56	63	94.59	69	94.7
		26	92.66	53	94.49	58	94.61
		22	94.76	43	94.19	56	93.75
		4	94.06	33	93.59	52	93.2
		0	94.16	23	93.69	48	92.48
				16	93.59	36	93.2
				8	93.29	22	93.73
				2	93.59	6	93.65
				0	93.59	3	92.94
						0	92.95
Cross-section 6							
		77	94.37	78	94.49	78	95.82
		71	93.77	74	92.79	78	94.57
		65	92.87	71	93.19	72.5	92.39
		53	92.57	61	93.09	70	91.65
		47	92.17	55	92.79	64.5	91.78
		38	92.07	52	92.49	61	92.4
		23	92.17	49	92.79	59.5	93.18
		20	93.57	48	92.89	58	93.53
		10	93.47	38	93.19	37	93.38
		0	93.37	28	93.29	33.5	93.4
				18	93.29	28	93.06
				8	93.29	25	93.21
				3	93.09	15	92.82
				1	93.19	11	92.39
				-3	93.59	8	92.54
						6	92.46
						4	92.16
						0	92.07
Cross-section 7							
		127	98.27	117	97.59		
		126	94.87	116	95.39		
		119	93.27	115	94.59		
		113	93.27	112	93.49		
		108	93.07	108	92.89		
		95	92.27	106	92.29		

Table 5. Data from cross sections, Hassayampa River at Box Canyon, near Wickenburg, Arizona—Continued

05–25–46		05–17–95		08–08–96		03–04–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 7—Continued							
		92	91.57	101	92.09		
		79	91.77	96	92.19		
		59	91.67	86	92.69		
		56	92.97	76	92.89		
		36	93.17	66	92.89		
		0	102.17	56	93.09		
				46	93.09		
				36	93.09		
				31	93.09		
				27	93.49		
				23	94.89		
				22	96.09		
				15	96.19		
				0	99.69		
Cross-section 8							
		84	96.17	85	96.39	84	96.47
		82	94.17	83	94.39	77	92.65
		79	92.97	79	92.69	71	92.46
		56	92.67	71	92.19	67.5	91.71
		53	92.07	69	91.89	64	90.95
		49	91.87	59	91.59	60	91.23
		47	91.47	49	91.89	56.5	91.05
		30.7	91.27	39	91.99	54.5	91.36
		18	91.47	34	91.89	50	91.13
		16	92.17	28	92.19	47	91.65
		0	91.77	18	92.39	37	92.25
				8	92.09	32	91.99
				4	91.89	30	92.32
				0	91.89	19	92.6
						7	91.48
						0	91.77
Cross-section 9							
		130	92.87			131	97.2
		117	92.27			128.5	92.61
		103	91.97			120.5	91.37
		100	90.77			119.5	91.04

Table 5. Data from cross sections, Hassayampa River at Box Canyon, near Wickenburg, Arizona—Continued

05–25–46		05–17–95		08–08–96		03–04–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 9—Continued							
		90	90.77			112	91.1
		77	91.07			101	91.2
		73	91.37			92	90.82
		63	91.67			88.5	91.36
		52	91.67			74	91.85
		44	92.67			61	91.9
		22	101.57			53	91.4
		0	101.57			50.4	92.33
						43	93.25
						37	95.79
						32	97.55
						22	101.55
						0	101.55
						22	101.55
						0	101.55

Table 6. Data from cross section at bridge, Hassayampa River at U.S. Highway 60, at Wickenburg, Arizona

[All values are in feet]

03–18–88[1]		09–26–97[2]		09–29–97[3]	
Station	Gage height	Station	Gage height	Station	Gage height
-593	19.92	8	0.9	406	3.72
-411.7	20.92	13	.4	403	.05
-301.2	20.92	17	-.9	403	-.97
-218	20.52	23	-1.1	393	-.01
-59.3	20.52	28	-.9	374	.13
-50	10.52	33	-1.6	343	-.59
-49	5.42	37	-1.5	342	.56
5	2.62	41	-1.7	326	.5
15	2.62	45	-2.1	325	1.12
17	.52	49	-1.8	302	1.56
29	-.48	52	-1.9	278	2.04
65	-.48	55	-2.4	250	1.71
67	.82	59	-2.3	214	1.16
83	.82	62	-2.6	203	.28
158	1.82	67	-2.5	181	-.88
230	1.22	72	-3	137	-.67
256	1.22	77	-1.9	107	-.73
317	.52	82	-1.4	96	.04
337	.52	87	-1.1	87	-.8
341	-.48	92	-.6	54	-.78
395	-.48	96	-.7	33	-1.85
404	.52	99	-.6	14	-1.66
405.7	20.52	103	-1.1	5	1.98
712	19.62	107	-1.5	0	4.83
1,007	15.92	112	-1.6		
1,302	19.92	117	-2.1		
1,372	20.42	122	-2.3		
		126	-2.2		
		131	-2.8		
		135	-2.4		
		140	-2.7		
		145	-3.2		
		150	-1.7		
		155	-3.2		
		159	-3.4		
		163	-3.6		
		167	-4.1		
		172	-2.6		
		177	-.3		
		182	-.4		
		187	.1		
		190	.1		
		211	.9		

[1]Flood-Insurance Study HEC-2 (Cella Barr Associates, written commun., 1989).
[2]Measured discharge, 3,800 ft^3/s.
[3]Survey.

Table 7. Data from cableway cross section, Hassayampa River near Morristown, Arizona

[All values are in feet]

01–19–93[1]		01–21–93[1]		02–05–93[1]		02–09–93[1]		02–20–93[1]		03–04–93[1]	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
5	9.78	-1	8.65	5	7.93	1	11.12	0	11.74	5	8.34
10	7.98	1	8.35	8	7.69	7	9.72	10	8.44	8	7.79
15	7.68	6	7.9	12	7.77	13	7.22	20	8.24	12	7.56
20	7.78	12	7.75	16	7.93	19	6.82	30	7.24	16	7.54
25	6.98	20	7.8	---	---	25	6.48	40	6.74	20	7.62
30	7.68	30	8.15	37	7.93	31	7.18	50	7.74	24	7.62
35	7.88	40	8.15	39	7.69	37	6.71	60	7.74	29	7.52
40	8.18	55	8.25	41	7.65	43	6.81	70	6.24	35	7.69
45	7.58	70	8.25	43	7.39	49	6.41	80	7.74	45	7.94
50	7.96	78	8.2	45	7.29	55	6.81	90	7.24	60	7.89
55	7.68	85	7.65	47	7.45	61	7.25	100	8.24	70	8.01
60	7.68	90	7.45	49	7.36	67	7.65	110	8.24	85	8.02
65	7.68	95	7.5	51	7.33	73	7.65	120	8.24	100	7.95
70	7.68	100	7.4	53	7.23	79	7.05	130	6.74	110	7.94
75	7.48	105	7.35	56	7.39	85	7.45	140	7.74	116	7.62
80	7.68	110	6.85	60	7.53	91	8.05	150	8.44	121	6.99
85	8.18	115	7.35	65	7.77	97	7.25	160	8.54	126	6.84
90	7.98	120	7.5	73	7.71	103	7.86	165	8.94	130	7.09
95	7.88	125	7.6	81	7.71	109	7.93	172	11.74	133	7.27
100	8.18	130	7.65	89	7.71	115	8.05			136	7.01
105	8.08	135	7.65	97	7.77	121	8.16			139	6.94
110	7.98	140	7.55	105	7.66	127	7.76			142	6.7
115	8.08	144	7.5	110	7.63	133	7.53			145	7.06
120	8.38	147	7.2	114	7.67	139	8.68			148	6.87
125	8.28	150	7.05	118	7.51	145	8.12			150	6.69
130	8.18	153	7.1	122	7.63	151	8.42			152	6.59
135	8.08	156	6.9	126	7.69	159	7.52			154	6.34
140	8.08	159	7.15	130	7.63	169	7.62			156	6.49
145	7.98	163	7.25	132	7.27	171	7.72			158	6.99
150	8.18	168	7.35	134	7.33	174	11.12			160	6.84
155	7.98	169	8.65	136	7.51					163	7.24
160	8.28			138	7.53					165	8.34
165	8.38			140	7.43						
170	9.78			142	7.31						
				144	7.47						
				146	7.43						
				148	7.53						
				150	7.33						
				153	7.33						
				156	7.59						
				159	7.47						
				162	7.51						
				165	7.57						
				168	7.93						

See footnotes at end of table.

Table 7. Data from cross sections, Hassayampa River near Morristown, Arizona—Continued

03–31–93[2]		02–17–95[1]		11–30–96[2]	
Station	Gage height	Station	Gage height	Station	Gage height
1	16.1	11	8.25	0	12.8
1	14.36	20	6.65	1	11.5
2	9.12	25	6.85	3	8.8
13	7.81	30	6.05	7	7.9
16	7.05	35	6.25	13	7.3
29	7.04	40	6.45	23	7.2
44	7.38	45	6.65	33	7.4
55	7.46	50	7.35	43	7.7
71	7.31	60	7.35	53	7.9
90	7.58	70	7.45	63	7.9
105	6.96	80	7.35	73	7.8
120	7.38	90	7.55	83	7.6
129	7.26	100	7.45	93	7.3
142	6.92	110	7.45	103	7.1
154	7.36	120	7.45	113	6.9
172	7.29	130	7.45	123	6.9
173	7.74	140	7.25	133	6.5
179	10.83	150	7.15	143	6.8
185	12.18	160	6.55	153	7
189	12.16	168	8.25	163	6.8
190	16.1			173	8.5
				183	11.2
				189	12.7

[1]Measured discharges: 01-19-93, 2,470 ft^3/s; 01-21-93, 787 ft^3/s; 02-05-93, 103 ft^3/s; 02-09-93, 6,180 ft^3/s; 02-20-93, 7,331 ft^3/s; 03-04-93, 452 ft^3/s; 02-17-95, 850 ft^3/s.

[2]Survey.

Table 8. Data from cross sections, Hassayampa River near Arlington, Arizona

[All values are in feet]

12–01–92		01–02–97		12–01–92		01–02–97	
Station	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**
Cross-section 2				**Cross-section 4**			
0	24.2	0	24.2	0	18.82	0	18.86
102	15.1	3	24.1	43	11.98	32	13.96
185	15.4	16	16.9	93	13.02	33	12.86
283	16.2	24	16.3	122	12.61	37	12.66
390	15.5	27	15.1	190	13.78	39	11.66
416	14.5	29	14.8	272	14.15	42	11.36
446	15.4	31	14.9	273	12.01	47	11.66
495	14.6	37	15.6	387	12.30	52	12.46
560	14.0	47	16.2	471	12.33	53	13.76
633	13.0	69	16.5	539	11.36	62	14.06
659	12.7	77	16.2	583	11.25	84	13.36
699	12.6	107	16.5	643	11.34	95	13.86
722	12.1	122	15.5	687	13.24	109	14.16
743	12.8	127	16.6	763	19.30	128	13.26
743	17.3	137	16.2			167	13.16
789	21.6	142	16.6			168	13.86
		167	16.8			185	14.16
		217	16.7			202	13.36
		287	17.2			216	13.26
		347	16.8			221	14.06
		397	16.5			231	14.56
		437	16.2			267	15.16
		507	15.7			273	14.56
		522	15.9			295	14.46
		527	15.2			317	14.76
		533	15			343	13.36
		536	14.5			346	11.76
		547	14.3			348	11.46
		627	14.7			365	11.86
		661	15.8			385	12.56
		667	16.1			415	12.96
		674	16			465	12.96
		677	15.4			503	12.36
		708	16.8			520	13.56
		727	16.6			523	14.16
		755	17.6			567	15.06
		756	17.9			575	14.76
		767	17.7			605	14.76
		775	16.1			638	15.06
		779	16.2			675	14.76
		782	17.7			690	14.56
		795	22.2			693	14.16
		800.5	22.34			697	14.06
						704	14.26
						712	14.66
						714	15.06

Table 8. Data from cross sections, Hassayampa River near Arlington, Arizona—Continued

12–01–92		01–02–97		12–01–92		01–02–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 2—Continued				Cross-section 4—Continued			
						725	15.46
						740	16.56
						751	19.06
						765	19.38
Cross-section 5				Cross-section 6			
0	19.3	-3.5	19.28	0	18.3	0	18.75
61	12.3	6	17.36	67	12.7	20	15.2
62	10.2	26	15.76	76	9.3	34	14.1
70	10.0	33	12.36	87	10.5	40	13.8
83	11.6	36	12.26	98	9.1	68	13.5
137	12.6	39	13.26	115	11.5	71.5	12.3
200	12.6	50	13.16	209	12.0	75	11.5
201	10.8	51	11.86	209	9.5	88	12.7
212	9.9	54	11.36	294	10.1	100	13.1
304	11.3	61	11.16	363	9.2	120	12.9
380	11.1	71	12.26	380	8.9	150	12.3
380	10.0	90	13.46	383	9.4	191	12.9
384	9.5	130	13.66	427	10.1	197	12
440	9.9	158	13.86	479	10.0	200	11.2
444	10.5	172	14.26	480	9.6	207	10.9
463	10.9	200	13.76	516	9.5	208	10.5
509	10.8	206	14.16	577	9.8	230	10.4
510	10.0	210	13.66	615	9.4	234	10.1
516	9.8	240	13.06	630	9.1	258	10.3
535	10.2	258	12.46	636	10.5	259	10.9
579	10.5	269	11.66	692	10.4	300	11.4
627	9.9	270	12.26	744	15.7	305	11.3
630	10.7	272	12.56			306	11
682	11.7	272	11.47			340	10.9
721	16.5	290	11.06			352	11.3
		306	11.06			366	12.9
		314	11.76			380	11.9
		342	12.26			400	12.5
		374	11.96			435	13.5
		400	11.76			442	14.4
		414	11.56			448	13.2
		424	11.66			475	13.8
		426	12.06			500	13.5
		434	12.26			545	13
		440	13.56			570	12.4
		456	13.86			588	13.3
		479	13.36			590	12.4
		492	13.66			600	13.4
		524	13.96			620	12.7
		584	13.56			650	12.5
		638	13.36			690	12.5
		664	13.36			697	12.9
		683	13.66			702	14.6

Table 8. Data from cross sections, Hassayampa River near Arlington, Arizona—Continued

12–01–92		01–02–97		12–01–92		01–02–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
Cross-section 5—Continued				**Cross-section 6—Continued**			
		691	15.76			703	15.7
		700	15.56				
		708	16.66				
		717	16.26				
Cross-section 7				**Cross-section 8**			
0	18.7	8	18.7	0	16.4	0	16.4
96	9.9	18	17.9	153	7.7	8	15.6
103	9.4	52	12.8	177	7.4	18	14.2
105	8.3	88	11.9	191	7.3	28	13
123	7.9	93	12.4	244	7.22	84	10.8
137	8.6	104	11.6	270	6.8	86	11.2
146	10.1	106	11	295	6.9	114	10.7
171	10.3	111	11	372	7.0	116	8.1
182	9.9	113	10.5	423	6.8	150	8.5
206	10.8	123	10.2	480	6.4	200	8.6
228	10.7	123	11	508	6.4	208	8.8
246	11.0	140.5	11	535	6.1	210	9.2
282	8.4	143	11.9	536	8.2	240	10.7
416	9.3	158	12.3	581	7.1	300	9.6
422	9.1	186	11.5	593	5.8	360	9.1
440	8.0	186	10.9	600	7.5	367	9.4
448	8.7	190	10.5	729	7.8	370	10.2
470	7.9	191	9.2	754	15.5	397	10
496	9.0	193	8.3			400	10.8
509	8.6	228	9.2			406	10.5
557	8.0	253	9.2			450	10.6
588	8.6	292	10.1			500	10.5
607	8.0	308	9.9			600	10.2
630	8.1	393	10.8			626	10.5
644	9.4	408	11.6			646	10.2
644	10.2	422	11.7			685	9.3
720	10.3	427	12.7			715	8.7
776	14.1	458	12.1			733	9.6
		508	12.5			736	10.5
		558	12.2			741	10.6
		571	11.8			753	15.5
		608	11.3			756	15.7
		618	10.7				
		621	11.6				
		658	11.3				
		708	10.3				
		728	10.2				
		738	12.2				
		742	12.7				
		758	14.2				

Table 9. Data from cross section, New River at New River, Arizona

[All values are in feet]

12–19–67		09–05–70		03–04–78		01–15–97	
Station	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**
277	89.9	27	91	44	89.9	143	90.6
282	88.4	40	89.2	102	90.4	190	91.6
290	87.4	50	89.1	140	90.2	197	85.2
295	83.9	60	89.8	222	91.6	212	81.9
296	82.4	65	89.8	222	86.9	214	80.5
300	81.4	95	89.6	258	81.4	217	79.8‘
305	81.3	130	89.7	286	82.3	221	80.3
310	81.6	165	89.7	336	85.9	222	80.0
317	81.9	205	90.3	360	83	228	80.4
324	82.1	238	90.6	398	83.4	231	81.2
331	82.3	262	89.5	414	85.7	238	82.3
338	82	267	88.1	424	89.3	240	82.9
345	82	276	85	426.7	91.7	247	86.3
352	82.2	285	83.4			261	87.4
358	82.1	285	81.9			271	87.9
360	81.2	300	82.2			301	87.3
367	81.1	320	82.4			305	88.2
373	81.8	340	82.1			341	87.7
378	83.9	350	82.2			349	86.7
385	84.8	368	82.1			350	85.0
392	85.3	385	83.6			361	83.8
399	85.4	401	84.7			369	82.1
406	85.5	415	84.8			373	80.5
413	85.8	427.5	91			376	79.5
420	86.2	446	98.3			384	79.4
425	90.3					387	80.3
						395	79.5
						398	79.3
						401	84.7
						407	83.5
						412	82.9
						418	85.5
						424	89.4
						431	93.8

Table 10. Data from cross section, Tiger Wash near Aguila, Arizona

[All values are in feet]

08–16–65		08–01–70		09–19–72		08–10–97		10–09–97	
Station	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**	**Station**	**Gage height**
7	6.3	-9	10.1	0	7.6	0	7.38	-10	11.4
11	5	0	7.4	5	7.1	2	6.58	-9	9.1
16	5.1	4	6.2	9	6.8	4	6.28	10	4.7
21	4.8	8	5.2	12	5.9	6	5.58	11	6.1
25	4.1	12	5.3	16	5.5	10	4.68	12	6.5
28	4.3	16	5.1	20	4.3	12	4.08	14	5.2
32	4.5	20	4.2	25	4.4	14	4.98	15	5.6
38	4.5	25	4.3	32	4.6	16	5.18	22	3.5
43	4.5	30	4.6	42	4.5	18	3.18	32	3.4
53	4.5	35	4.6	50	4.6	22	3.28	37	3.4
63	4.3	40	4.6	58	4.6	28	3.18	39	3.1
68	4.4	45	4.6	60	4.9	34	3.18	42	2.1
73	5.5	50	4.8	70	5	40	3.08	46	1.8
76	6	55	5	73	5.1	46	3.18	48	2
78	5.6	60	5	76	6.7	52	3.38	50	1.8
83	5.7	65	5	88	7.6	58	3.18	53	2.1
86	6	70	5.6	92	6.1	62	3.18	59	1.9
89	5.2	75	5.9	104	6.6	64	3.68	67	3.1
93	5	80	6.4	116	6.9	66	4.38	69	3.7
98	4.9	85	6.5	118	7.6	68	4.58	70	4.5
105	4.9	88	6.6	124	9.1	70	4.58	72	4.1
108	5.8	90	6.6			74	4.88	82	2.7
111	6.2	95	6.6			80	5.58	88	3.9
118	5.9	100	6.6			86	5.38	95	4.1
120	7.25	105	6.5			92	5.48	101	4.4
		110	6.8			98	5.48	103	4.8
		115	6.7			104	5.88	105	5.5
		120	7.8			108	6.38	107	6.3
		125	9.2			112	6.88	112	7
		128	10					113	8.2
								128	10.2
								134	10.7
								137	11.2

Table 11. Data from cableway cross section, Verde River below Bartlett Dam, Arizona

[All values are in feet]

01–04–93[1]		01–19–93[1]		01–21–93[1]		02–15–95[1]		04–28–95[1]	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
685	7.3	331	16.75	572	8.61	260	22.95	755	5.89
695	5.3	370	14.05	603	7.91	310	19.75	766	4.99
705	3.3	410	13.35	633	7.91	340	16.65	771	4.49
710	3.3	450	12.25	664	8.21	365	15.65	776	3.59
724	2.3	490	12.65	703	7.61	390	15.55	781	3.19
738	1.8	510	10.75	713	7.11	415	14.65	784	2.69
745	1.8	530	10.45	723	6.21	440	14.75	787	2.49
750	1.1	550	9.95	733	5.71	465	13.45	790	1.99
755	1.1	570	8.95	738	5.51	485	12.95	793	1.99
760	2.1	590	8.85	743	5.31	505	13.45	796	1.39
765	2.2	610	9.15	748	5.01	525	11.75	799	1.49
770	1.9	630	8.35	753	4.51	545	11.95	802	1.19
775	1.7	650	8.45	758	4.31	565	9.95	805	1.19
780	1.9	670	8.45	763	4.11	585	9.95	808	1.29
785	1.7	690	7.15	768	3.81	600	9.45	811	1.19
790	1.3	705	6.85	773	3.01	620	10.15	814	1.19
795	1.3	720	5.55	778	2.61	640	8.45	817	.99
800	1.2	735	4.55	783	1.81	655	7.45	820	1.39
805	1.3	750	4.25	788	1.31	670	10.55	823	1.29
810	1.3	765	3.35	793	1.31	685	9.75	826	1.29
815	1.8	780	2.15	798	1.31	700	9.45	829	1.09
820	1.7	795	1.35	803	.91	715	9.15	832	1.19
825	1.4	810	.85	808	.71	730	7.95	835	1.29
830	1.6	825	.65	813	.61	745	4.65	838	1.29
835	1.5	840	.35	818	.41	760	4.75	841	1.39
840	1.9	855	1.65	823	.61	775	4.65	844	1.49
845	1.6	875	5.25	828	.61	785	2.75	847	2.09
850	1.8	903	16.75	833	.31	795	.15	850	2.09
855	2.5			838	.71	805	.55	853	2.39
860	2.7			843	1.41	815	-2.75	856	2.49
865	4.2			848	1.61	825	-3.05	861	2.79
880	7.3			853	1.71	835	-3.45	866	2.89
				858	1.91	845	-2.05	871	3.39
				863	2.71	860	.25	877	5.89
				873	5.01	880	6.95		
				883	8.61	895	14.95		
						915	22.95		

[1]Measured discharges: 04–04–93, 3,750 ft^3/s; 01–19–93, 36,400 ft^3/s; 01–21–93, 7,160 ft^3/s;02–15–95, 78,200 ft^3/s; 04–28–95, 2,390 ft^3/s.

Table 12. Data from cross section, Waterman Wash near Buckeye, Arizona

[All values are in feet]

09–16–64		09–16–66		11–11–71		10–05–82		11–30–96		08–14–97	
Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height	Station	Gage height
-6	4.8	4	6.6	-14	6.8	4	5.22	8	5.7	-15	7.1
4	3.7	8	5.1	-9	6.1	9	4.32	10	5.2	8	5.4
14	2.2	12	4.8	-3	3	12	3.72	14	2.7	11	4.7
24	2.5	16	3.1	9	3.5	12.5	2.52	20	2.9	16	2.5
34	2.6	28	3.4	24	3.6	25	2.72	30	2.9	30	2.7
50	2.4	38	3.4	39	3.4	35	3.22	40	3	50	3
58	2.3	48	3.2	54	3.1	37	3.52	50	3.1	52	3.1
58	2.6	58	3.2	69	3.4	45	4.02	60	3.4	75	3.1
69	2.8	68	2.6	84	3.4	51	4.02	65	3.3	79	2.6
79	2.8	76	2	99	3.3	51.5	3.62	70	3.3	83	3.1
89	2.9	78	1.4	104	2.7	59	3.92	80	3	95	3.3
109	2.9	88	1.5	119	2.8	69	4.22	90	2.9	97	3.7
119	2.5	98	1.6	134	2.7	79	4.12	96	2.9	115	3.7
129	2.8	118	1.4	149	2.9	89	3.92	100	3.2	117	2.9
134	2.5	138	1.2	164	2.7	99	4.02	110	3.5	133	2.8
144	2	148	.8	177	4.9	107	3.92	120	4.2	138	2.2
154	2.1	158	1.1	189	5.1	109	4.52	130	4	151	2.4
164	2.1	168	1.2	199	6	119	4.42	135	3.8	171	2.5
174	2.3	171	1.5			124	4.42	140	3.4	176	4.7
180	2.1	174	3.3			131	3.92	l50	2.8	178	4.3
182	3.4	178	4.3			139	3.82	160	2.4	183	5.4
186	5.1	183	4.9			149	3.62	170	3.1	194	5.9
		185	5.6			159	3.52	175	4.3		
		193	5.8			170	3.52	180	4.9		
		208	6.2			175	5.22				
		218	6.2								
		223	6.8								