EFFECTS OF WILDFIRE ON THE HYDROLOGY OF CAPULIN AND RITO DE LOS FRIJOLES CANYONS, BANDELIER NATIONAL MONUMENT, NEW MEXICO

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

Water-Resources Investigations Report 02-4152

Prepared in cooperation with the

NATIONAL PARK SERVICE

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By Jack E. Veenhuis

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Albuquerque, New Mexico
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U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.004047	square kilometer
acre-inch	102.75	cubic meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per acre-inch	0.0002756	cubic meter per second per acre-inch
foot per mile	0.1894	meter per kilometer

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

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ABSTRACT

In June of 1977, the La Mesa wildfire burned 15,270 acres in and around Frijoles Canyon in Bandelier National Monument and the adjacent Santa Fe National Forest, New Mexico. The Dome wildfire in April of 1996 in Bandelier National Monument burned 16,516 acres in Capulin Canyon and the surrounding Dome Wilderness area. Both watersheds are characterized by abundant and extensive archeological sites that could be affected by increased runoff and accelerated rates of erosion, which typically occur after a wildfire. The U.S. Geological Survey in cooperation with the National Park Service monitored the wildfires' effects on streamflow in both canyons.

The magnitude of large stormflows increased dramatically after these wildfires; peak flows at the most downstream streamflow-gaging station in Frijoles and Capulin Canyons increased to about 160 times the maximum recorded flood prior to the fire. Maximum peak flow was 3,030 cubic feet per second at the gaging station in Frijoles Canyon (drainage area equals 18.1 square miles) and 3,630 cubic feet per second at the most downstream crest-stage gage in Capulin Canyon (drainage area equals 14.1 square miles). The pre-fire maximum peak flow recorded in these two canyons was 19 and an estimated 25 cubic feet per second, respectively. As vegetation reestablished itself during the second year, the post-fire annual maximum peak flow decreased to about 10 to 15 times the pre-fire annual maximum peak flow. During the third year, maximum annual peak flows decreased to about three to five times the pre-fire maximum peak flow. In the 22 years since the La Mesa wildfire, flood magnitudes have not completely returned to pre-fire size.

Post-fire flood magnitudes in Frijoles and Capulin Canyons do not exceed the maximum floods per drainage area for physiographic regions 5 and 6 in New Mexico. For a burned watershed, however, the peak flows that occur after a wildfire are several orders of magnitude larger than normal forested watershed peak flows.

The frequency of larger stormflows also increased in response to the effects of the wildfires in both canyons. In Frijoles Canyon, the number of peak stormflows greater than the pre-fire maximum flow of 19 cubic feet per second was 15 in 1977, 9 in 1978, and 5 in 1979, which is about the magnitude of the maximum pre-fire peak flow in both canyons. Again the hydrologic effects of a wildfire seem to be more pronounced for the 3 years following the date of the fire. Likewise, larger peakflows occurred more frequently in Capulin Canyon for the first 3 years after the 1996 wildfire.

Median suspended-sediment concentrations in samples collected in Frijoles Canyon in 1977 were 1,330 milligrams per liter; median concentrations were 16 milligrams per liter after the watershed stabilized in 1993-95. The annual load calculated from regression equations for load compared to flow for the first year after the wildfire was 220 times the annual load for the post-recovery period.

To convey the increased frequency and magnitude of average flows in Capulin Canyon after the 1996 Dome wildfire, the stream channel in Capulin Canyon increased in flow capacity by widening and downcutting. As Capulin Canyon peak flows have decreased in both magnitude and frequency with vegetative recovery, the stream channel also has slowly begun to readjust. The channel at the most downstream crest-stage gage, which has the shallowest initial valley slope, is showing the first signs of aggradation.

INTRODUCTION

In April of 1996, the Dome wildfire burned 16,516 acres in Bandelier National Monument and the adjacent Dome Wilderness part of the Santa Fe National Forest (fig. 1). Because of concern about destruction of the extensive archeological artifacts and resources within the monument from increased runoff and possible increased sedimentation after the wildfire, a rehabilitation plan was developed. The Dome Fire Burned Area Emergency Rehabilitation Plan (BAER

Plan, 1996) recommended hydrologic monitoring and a hydrologic hazards assessment. In response to this concern, the National Park Service (NPS), in cooperation with the U.S. Geological Survey (USGS), conducted a study to estimate and document the flooding hazard after the Dome wildfire that burned in and near Bandelier National Monument in 1996. The assessment of potential hydrologic hazards in Capulin Canyon was based, in part, on analysis of the streamflow-gaging station record for Frijoles Canyon and the effect of the 1977 La Mesa wildfire on the hydrology of that canyon. This summary report was funded by the Interagency Joint Fire Science Program with cooperative funding from the USGS. A comparison of the burn intensity for these two major wildfires in Bandelier National Monument is presented in table 1.

Historically, hydrologic changes after the Yellowstone National Park fires in 1992 and hydrologic changes in post-fire areas have been observed but never documented for wildfires in New Mexico, Wyoming, California, Idaho, Montana, and Arizona. In 1996, the Hondo fire in the Carson National Forest near Taos, New Mexico; the Buffalo Creek fire in the Pike National Forest near Denver, Colorado; a fire in the Jicarilla Apache Reservation, New Mexico; and a fire in Mesa Verde National Monument all caused large increases in the magnitude of peak flows. After each of these fires, the frequency of peak flows increased; sediment transport had substantial increases and channel geometry changed.

Purpose and Scope

This report summarizes the effects of the 1977 La Mesa wildfire on the hydrology of Frijoles Canyon and the 1996 Dome wildfire on the hydrology of Capulin Canyon in and near Bandelier National Monument for 2 1/2 years after the fire (July 1996 to November 1998). Pre- and post-hydrologic analyses for each canyon are compared and discussed.

Description of Study Area

The study area is located in and near Bandelier National Monument and includes parts of Frijoles Canyon and Capulin Canyon (fig. 1) in the north-central part of New Mexico. Streamflow for these two watersheds originates at higher elevations near the east rim of the Jemez Mountains and is in an easterly direction, eventually entering the Rio Grande.

Methods of Study

The USGS installed five tipping-bucket rain gages (WRD-1, WRD-2, WRD-3, GD-1, and GD-2) within the Capulin Canyon watershed in July and August of 1996 to record 5- or 15-minute rainfalls; the rain gages were monitored and operated until November and December 1998. The location of these rain gages is shown in figure 2, and the site names and numbers are listed in table 2. One rain gage (WRD-2) was located at the ranger cabin (Capulin Canyon at Ranger Cabin - 083133655), a second rain gage (WRD-3) was located at the Dome fire tower (Dome Fire Tower - 354527106221630) and was used as a rainfall alert gage, and the third rain gage (WRD-1) was located on a burned, east-facing western slope of upper Capulin Canyon (Capulin Canyon Upper Basin - 354700106244630) (fig. 2). As part of a geological hazard assessment conducted by the USGS, post-fire hazard researchers installed and operated two additional recording rain gages (GD-1 and GD-2) on

Table 1. Burn intensities for major recent wildfires in Bandelier National Monument

[--, no data]

Name of fire area (fig. 1)	Location of fire	Total acres burned	Burn intensities, in acres				
			High	Moderate	Low to moderate	Low	Low to unburned
La Mesa	Frijoles Canyon	15,270	5,209 (33 percent)	--	8,941 (57 percent)	--	1,570 (10 percent)
Dome	Capulin Canyon	16,516	114 (1 percent)	2,203 (13 percent)	--	1,725 (10 percent)	12,474 (76 percent)

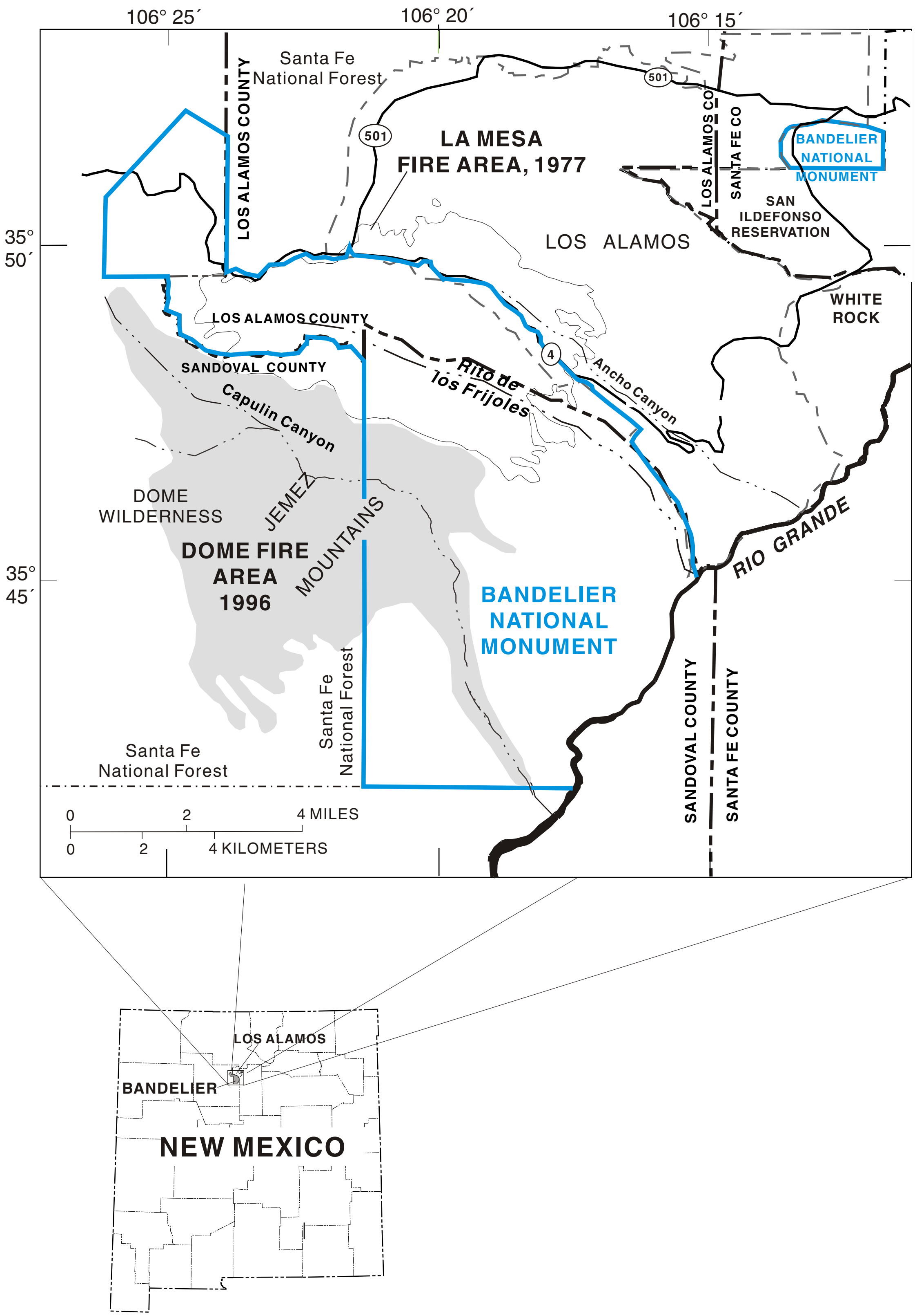


Figure 1. Location of Bandelier National Monument, extent of 1977 La Mesa fire, and extent of 1996 Dome fire.

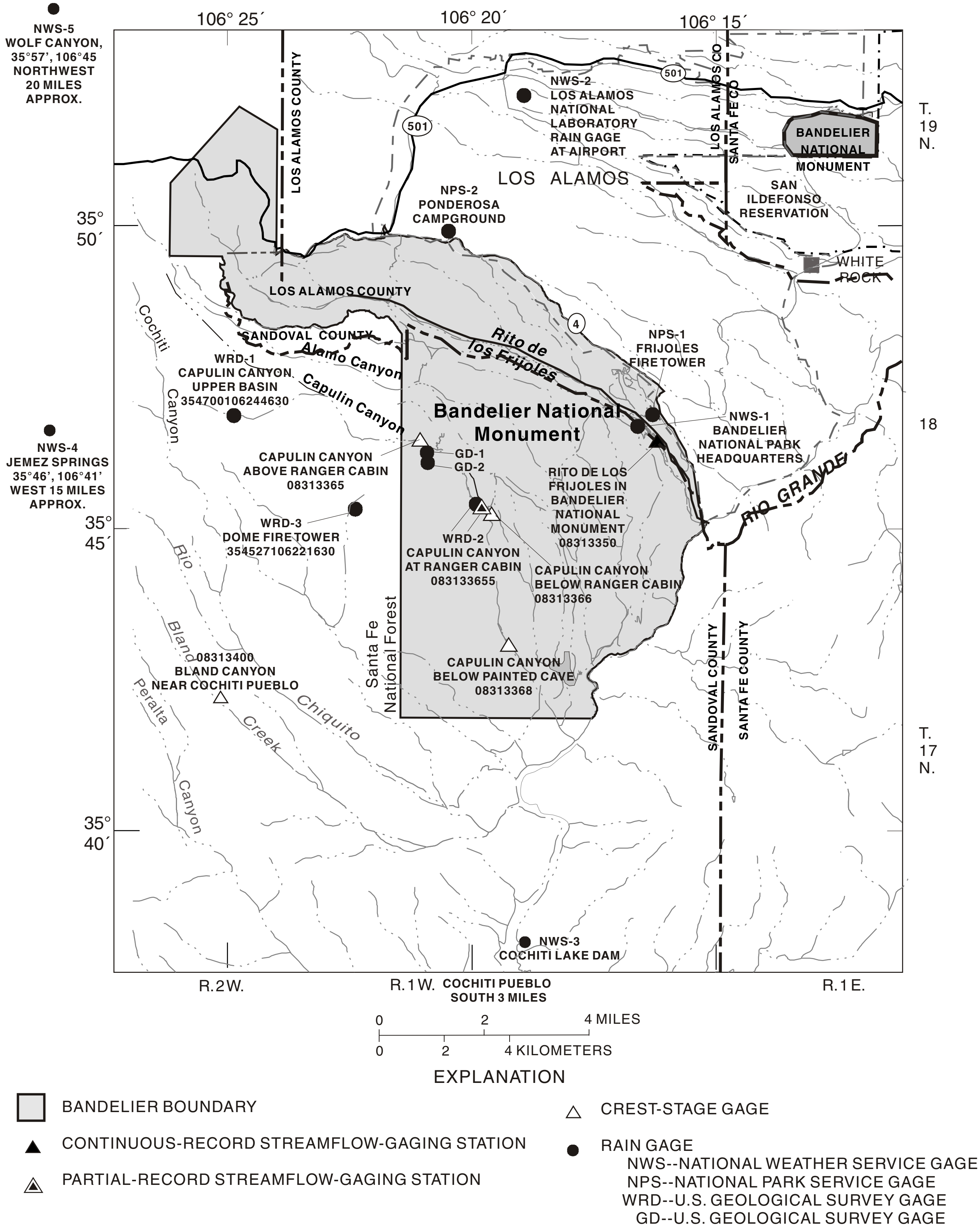


Figure 2. Capulin Canyon watershed and location of partial-record station, crest-stage gages, and rain gages. Names and numbers of stations and rain gages are listed in table 2.

the north-facing slope of Capulin Canyon from August 1996 to December 1998 (fig. 2) (William Ellis, U.S. Geological Survey, written commun., 1998). The rainfall data collected are available in daily totals and in shorter durations in USGS files. Daily rainfall data are available from the USGS Automated Data Processing System (ADAPS) database.

The NPS operates two daily rain gages: one on the south-facing slope of Frijoles Canyon at the Frijoles Fire Tower (NPS-1) and one at the Ponderosa Campground (NPS-2) (fig. 2). A National Weather Service (NWS) observer rain gage (NWS-1) collected rainfall at the National Park Headquarters in Bandelier National Monument from 1931 to 1976, and a rain gage at Los Alamos National Laboratory (NWS-2) has been in operation since 1931 (fig. 2). In addition, NWS observer rain gages are located at Jemez Springs, Wolf Canyon, and at Cochiti Lake Dam.

A continuous-record streamflow-gaging station (Rito de los Frijoles in Bandelier National Monument - 08313350, hereinafter referred to as Frijoles Canyon gaging station) was established and operated by the USGS from July 1963 to September 1969 and after the 1977 La Mesa wildfire from July 1977 until September 1982 (fig. 2; table 2). Since 1983 this gaging station has been operated as a crest-stage gage or a continuous-record gaging station by several different agencies.

An NPS gaging station in Capulin Canyon collected streamflow data from 1985 until the 1-foot concrete flume was destroyed by the first post-fire flood on June 26, 1996.

To monitor streamflow after the 1996 Dome wildfire, the USGS established and operated three crest-stage gages in Capulin Canyon from July 1996 until November 1998. The three crest-stage gages are Capulin Canyon above Ranger Cabin - 08313365; Capulin Canyon below Ranger Cabin - 08313366; and Capulin Canyon below Painted Cave - 08313368 (fig. 2; table 2). On June 18, 1997, a high-flow, partial-record/continuous-record gaging station (Capulin Canyon at Ranger Cabin - 083133655) was installed by the USGS slightly upstream from the Capulin Canyon below Ranger Cabin crest-stage gage and near the discontinued NPS gaging station (fig. 2). Because of the short distance between these two sites, the record at the crest-stage gage and at the NPS gaging station are considered one record. The new gaging station was added to the network the second year of the study because of the need to determine peak flows associated with rainfall in Capulin Canyon. This gaging station recorded peak stages from June 1997 until November 1998. On July 15, 1997, the gaging station and rain gage were upgraded to a satellite data collection platform (DCP) uplink that transmits data at 4-hour intervals. With the addition of the DCP at this site, peak flows and rainfall could be monitored remotely and individual peaks could be related to maximum rainfall for selected durations for each of the three rain gages.

Slope-area and step-backwater indirect discharge measurements were surveyed at the three crest-stage gages and gaging station in Capulin Canyon. At each location, a cross section was monumented to provide a benchmark for possible channel changes during the subsequent post-fire runoff. Monumented cross sections were surveyed and referenced to cross-section end points of rebar and other surveyed benchmarks.

The Bland Canyon near Cochiti crest-stage gage has been operated by the USGS since 1962 as part of a New Mexico flood study in Bland Canyon (fig. 2; table 2), a parallel watershed south of Capulin Canyon. Los Alamos National Laboratory (LANL) also has been operating 19 gaging stations (not shown on map) on major canyons north of the Bandelier National Monument boundary since 1992-94.

In Frijoles Canyon, the USGS collected suspended-sediment samples of the 1977 La Mesa post-fire runoff from 1977 to 1981. From 1993 to 1995, as part of the USGS National Water-Quality Assessment (NAWQA) program, suspended-sediment samples from Frijoles Canyon were again collected and analyzed.

Acknowledgments

The author acknowledges Brian Jacobs (NPS) and Craig Allen (USGS) for their continued patience and support in this effort. Thanks are extended to the personnel of the USGS Albuquerque Field Headquarters for gage installation and to Todd Kelly (USGS) for his expertise in data collection and numerous arduous hikes into remote sites in Capulin Canyon with the author to document channel changes and record peak-flow stage. Also, thanks are extended to Lead Hydrologic Technician David Ortiz of the USGS Albuquerque Field Headquarters for his help with the interpretation of historical record charts in Capulin Canyon.

Table 2. Selected watershed characteristics of Capulin Canyon, Rito de los Frijoles Canyon, and Bland Canyon used in peak-flow estimation

[--, no data]

Station name and number (fig. 2)	Gage type	Drainage area (square miles)	Station elevation (feet above sea level)	Period of record
Capulin Canyon Upper Basin (WRD-1) 354700106244630	Rain gage	---	8,280	7/96-11/98
Capulin Canyon at Ranger Cabin (WRD-2)	Rain gage	---	6,225	7/96-11/98
Dome Fire Tower (WRD-3) 354527106221630	Rain gage	---	8,490	7/96-11/98
GD-1	Rain gage	--	--	8/76-11/98
GD-2	Rain gage	--	--	9/96-11/98
National Park Service	Discontinued continuous record	8.30	6,230	4/85-6/96
Rito de los Frijoles in Bandelier National Monument 08313350	Continuous record	18.1	6,035	7/63-9/69 7/77-9/82 5/93-present
Capulin Canyon at Ranger Cabin 083133655	Partial record	8.32	6,225	4/85-11/98
Capulin Canyon above Ranger Cabin 08313365	Crest stage	6.51	6,740	7/96-11/98
Capulin Canyon below Ranger Cabin 08313366	Crest stage	8.36	6,170	7/96-11/98
Capulin Canyon below Painted Cave 08313368	Crest stage	14.1	5,670	7/96-11/98
Bland Canyon near Cochiti Pueblo 08313400	Crest stage	7.57	6,210	1962-present

EFFECTS OF WILDFIRE ON HYDROLOGY

Pre-Fire Hydrologic Analysis

To determine the effects of the 1996 Dome wildfire on the hydrology of Capulin Canyon, a discussion of the rainfall and runoff characteristics prior to the fire is useful. By understanding the hydrologic conditions that exist in an unburned watershed, one can more easily understand the differences between pre-fire and post-fire channel flow and the reactions of channels to changes in flow conditions. As part of the pre-fire analysis, peak-flow records collected in Capulin Canyon from 1985 to 1996 at the NPS gaging station were analyzed.

Rainfall

Precipitation in and near Bandelier National Monument falls as snow during the winter season, as large-scale frontal storms with low-intensity rainfall during the spring and fall and as very localized, high-intensity thunderstorms from June through September. Precipitation data collected at a rain gage at Bandelier National Monument (NWS-1) and an LANL rain gage (NWS-2) (fig. 2) probably best indicate the magnitude and distribution of monthly rainfall in the study area from 1931 to 1976 (fig. 3). Variation in monthly precipitation at these two sites is similar. The difference in elevation between the two stations (Bandelier is 6,061 feet and LANL is 7,424 feet above sea level, respectively) is primarily responsible for the increased monthly precipitation at the LANL rain gage. Annual precipitation is about 18 inches per year at Los Alamos and 15 inches per year at Bandelier National Monument. More than 50 percent of this precipitation falls during June, July, August, and September. Most annual maximum peak flows in Frijoles and Capulin Canyons are a result of rainstorms during these 4 summer months.

Runoff

Recorded streamflows at the Frijoles Canyon gaging station prior to the 1977 La Mesa wildfire and at the Capulin Canyon at Ranger Cabin gaging station (hereinafter referred to as the Capulin Canyon gaging station) prior to the 1996 Dome wildfire are the best indicators of pre-fire historical streamflow and also provide estimates of annual flood magnitude. Pre-fire peak flows in Frijoles Canyon from 1964 through 1969 are presented in table 3 and shown in figure 4. Median annual peak flow during this pre-fire period was 5.7 ft^3/s (cubic feet per second). The maximum recorded peak flow during this time was 19 ft^3/s. Pre-fire peak flows in Capulin Canyon from 1985 through 1994 are listed in table 4 and shown in figure 5. The median pre-fire peak flow was 15.2 ft^3/s for these years. The peak flow on September 3, 1988 (table 4), was slightly greater than the maximum flow capacity of the concrete flume (22.4 ft^3/s); thus, flow was estimated to be about 25 ft^3/s. Peak flows that occurred prior to the 1996 Dome wildfire in Capulin Canyon are similar in magnitude to peak flows recorded prior to the 1977 La Mesa wildfire in Frijoles Canyon.

Another indicator of pre-fire historical streamflow in Bandelier National Monument is data collected at the crest-stage gage in Bland Canyon. Annual peak flows for this watershed are shown in figure 6. This watershed had a maximum peak flow of 300 ft^3/s and a median annual maximum flow of 35 ft^3/s from 1962 to 1998. The Bland Canyon drainage area is 7.57 square miles, less than half the drainage area of Frijoles Canyon (18.1 square miles). Despite the difference in drainage areas, length of records, and management of these two watersheds, data for both canyons give a consistent pre-fire estimate of flood magnitudes in Bandelier National Monument.

The magnitude, frequency, and distribution of pre-fire peak runoff can be estimated using several techniques. The USGS developed two sets of regression equations from annual peak-flow data collected for 219 sites in New Mexico (Waltemeyer, 1996). These equations can be used to estimate flood peak flows for ungaged streams. Selected watershed characteristics used in the two sets of equations are listed in table 2. The first equation, which applies to watersheds with less than 10 square miles of contributing drainage area, uses only drainage area to estimate peak flows for 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals (table 5; fig. 7). The second set of equations was developed for specific physiographic regions in New Mexico (figs. 8 and 9). For physiographic region 6, which includes Bandelier National Monument, drainage area, mean channel elevation, and the 10-year, 24-hour rainfall (Miller and others, 1973) were used to estimate peak flows for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals (table 5). The flood-frequency magnitudes

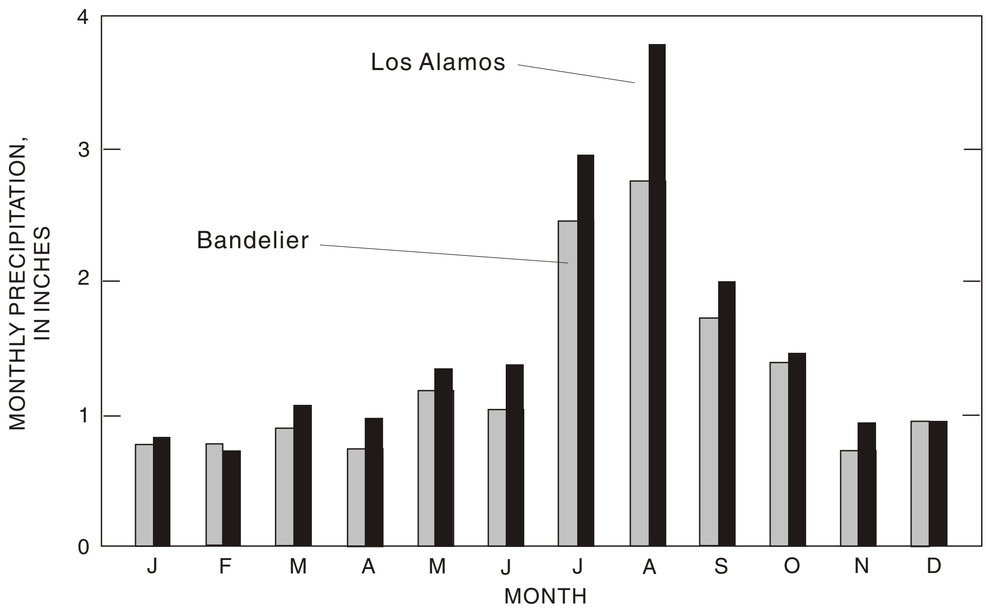


Figure 3. Average monthly precipitation at National Weather Service rain gages at Bandelier National Monument (NWS-1) and Los Alamos (NWS-2), 1931-76. See figure 2 for location of rain gages.

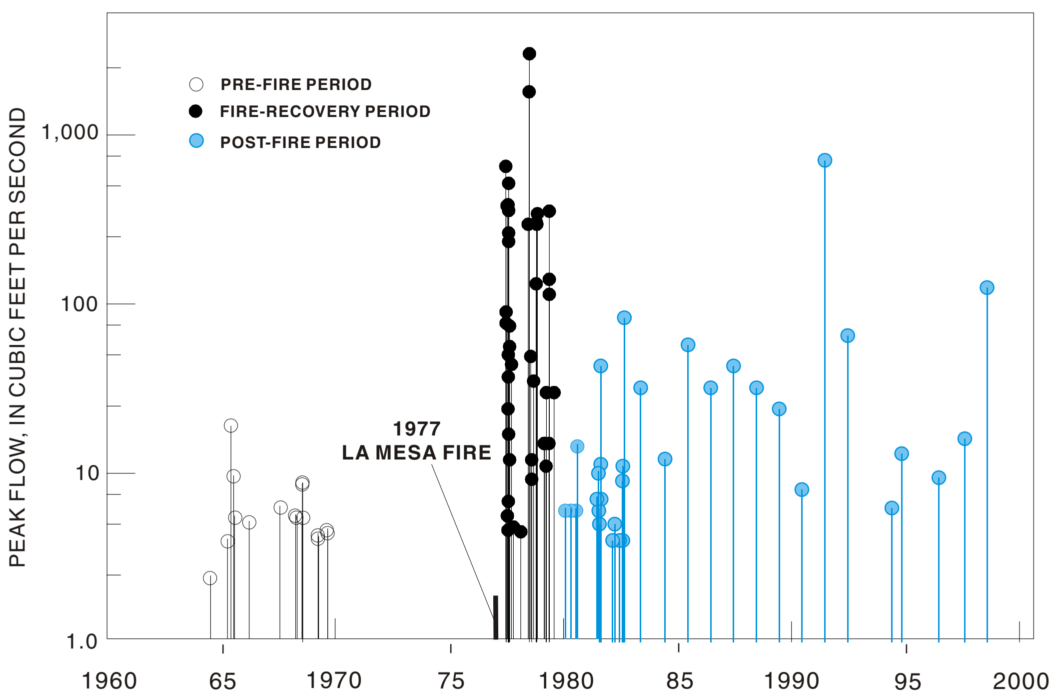


Figure 4. Peak flow for Rito de los Frijoles, 1964-69 and 1977-98.

Table 3. Peak flow at Rito de los Frijoles Canyon in Bandelier National Monument, 1964-98

[Streamflow-gaging station 08313350; ft^{3}s, cubic feet per second; --, no data]

Date	Stage (feet)	Peak flow (ft^3/s)
07-26-64	1.26	2.4
04-26-65	1.45	4.0
06-18-65	1.49	19
07-31-65	.97	9.6
08-14-65	.70	5.5
04-04-66	1.07	5.1
08-09-67	1.28	6.3
04-19-68	.76	5.6
05-12-68	.80	5.5
07-31-68	.68	5.1
08-04-68	.94	8.6
08-08-68	.71	5.5
08-11-68	.95	8.8
04-11-69	.67	4.3
04-24-69	.69	4.2
09-12-69	.65	4.6
09-15-69	.64	4.5
	La Mesa Fire - June 1977	
07-05-77	5.02	653
07-08-77	2.67	77
07-09-77	2.77	90
07-27-77	3.88	382
07-30-77	.73	5.6
08-11-77	.65	4.6
08-12-77	3.94	386
08-12-77	1.76	24
08-16-77	2.37	50
08-16-77	.80	6.8
08-17-77	2.14	37
08-18-77	1.43	17
08-19-77	3.45	234
08-20-77	4.33	519

Table 3. Peak flow at Rito de los Frijoles Canyon in Bandelier National Monument, 1964-98--Continued

Date	Stage (feet)	Peak flow (ft^3/s)
08-20-77	3.55	264
08-22-77	3.82	358
09-02-77	2.45	56
09-03-77	2.64	74
09-04-77	1.20	12
10-04-77	2.28	44
11-07-77	.94	4.8
03-01-78	.63	4.5
06-30-78	3.65	296
07-12-78	5.60	1,800
07-21-78	6.34	3,030
08-09-78	2.35	49
08-23-78	1.15	9.2
08-24-78	1.33	12
09-24-78	2.09	35
11-03-78	3.02	132
11-11-78	3.67	303
11-12-78	3.65	296
11-25-78	3.78	343
03-08-79	1.26	15
03-21-79	1.20	15
04-10-79	1.05	11
04-18-79	1.92	30
05-26-79	1.30	15
06-01-79	2.92	114
06-02-79	3.06	140
06-03-79	3.81	354
08-15-79	1.96	30
02-15-80	2.08	6.0
05-15-80	2.06	6.0
08-06-80	2.07	6.0
08-27-80	2.31	14.4
07-01-81	2.11	7.0

Table 3. Peak flow at Rito de los Frijoles Canyon in Bandelier National Monument, 1964-98--Continued

Date	Stage (feet)	Peak flow (ft^3/s)
07-27-81	2.20	10
08-05-81	2.08	6.0
08-16-81	2.03	5.0
09-01-81	2.24	11
09-05-81	2.67	43
09-07-81	2.10	7.0
03-13-82	2.01	4.0
04-18-82	2.03	5.0
07-02-82	1.98	4.0
08-18-82	2.18	9.0
08-21-82	2.23	11
08-25-82	1.96	4.0
09-16-82	2.93	83
05-03-83	2.56	32
1984	2.26	12
1985	2.68	57
1986	2.56	32
1987	2.67	43
1988	2.56	32
1989	2.46	24
1990	2.15	8.0
1991	4.15	710
1992	3.44	65
1993	--	--
05-03-94	2.05	6.2
11-12-94	2.29	13
06-29-96	2.19	9.4
08-17-97	2.35	16
08-13-98	3.12	125

Table 4. Peak flow at National Park Service gaging station in Capulin Canyon in Bandelier National Monument

[--, no data; >, greater than; peak flow in cubic feet per second]

Date	Time	Peak flow
08-12-85	23:50	14
08-13-85	22:00	21*
No data for 1986		
07-12-87	16:00	2.5
08-10-87	23:50	2.6*
07-05-88	13:00	7.3
09-03-88	--	> 22.4*
09-12-88	13:00	11
09-12-88	23:00	8.3
07-12-89	00:00	2.2
07-15-89	13:00	3.8*
07-22-89	23:30	2.6
07-24-89	1:00	2.6
11-02-89	10:15	1.3
11-02-89	24:00	1.3
08-15-90	4:00	1.1
09-17-90	3:00	1.3
09-28-90	23:45	1.7*
11-17-90	20:30	2.1
07-04-91	4:20	2.0
07-23-91	12:00	4.8
09-16-91	20:00	13
09-17-91	12:30	20*
09-20-91	16:00	9.4
09-22-91	18:00	13
04-14-92	24:00	17

Table 4. Peak flow at National Park Service gaging station in Capulin Canyon in Bandelier National Monument--Concluded

Date	Time	Peak flow
04-28-92	8:00	19*
05-23-92	2:00	1.6
05-26-92	17:00	1.9
05-30-92	12:00	2.0
07-26-92	9:00	1.4
08-15-92	10:30	2.2
08-20-93	9:00	2.4
08-26-93	12:00	1.9
08-28-93	2:00	2.5*
07-17-94	3:50	1.5
07-28-94	23:00	1.6
08-13-94	9:00	15*
No data for 1995	--	
	Dome Fire - April 1996	
06-26-96	20:30	2,700**
09-03-97		270***
08-11-98		75***

* Peak flow for water year.

** Peak flow from slope-area indirect discharge measurement at Capulin Canyon below Ranger Cabin crest-stage gage.

*** Peak flow at U.S Geological Survey streamflow-gaging station partial-record gage (Capulin Canyon at Ranger Cabin).

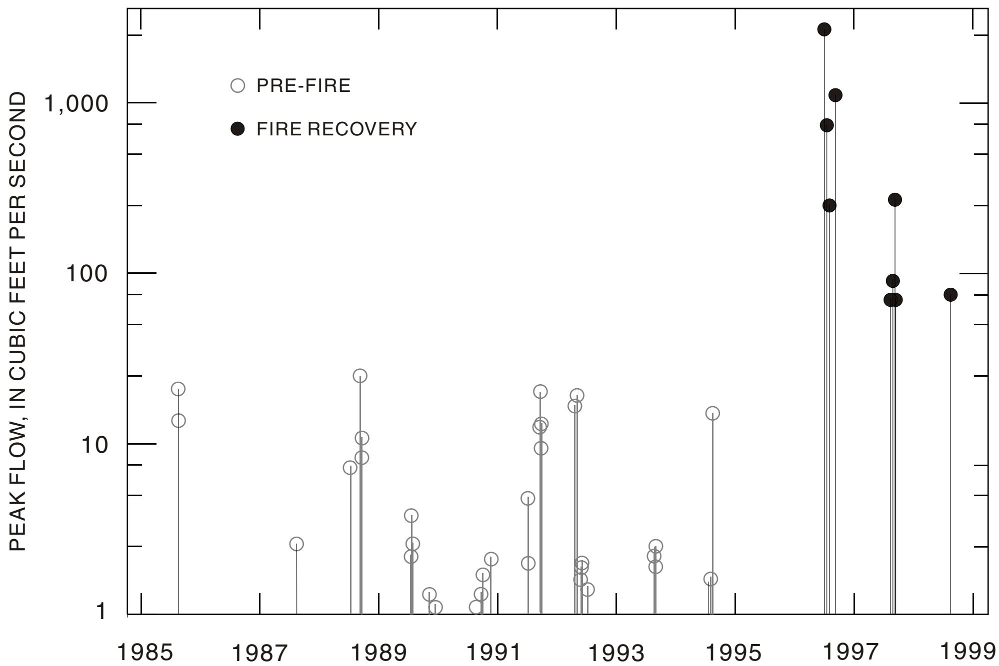


Figure 5. Peak flows recorded at the National Park Service streamflow-gaging station in Capulin Canyon, 1985 through 1995 (Brian Jacobs, National Park Service, written commun., 1997). See figure 2 for location of gaging station.

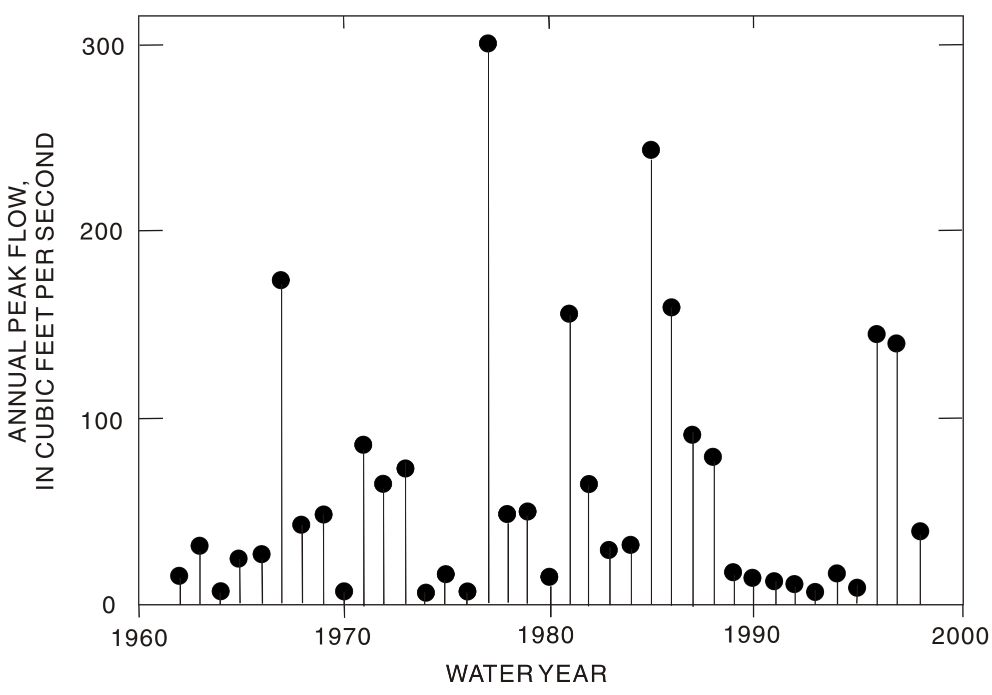


Figure 6. Annual peak flows at the Bland Canyon crest-stage gage near Cochiti Pueblo, 1962-98. See figure 2 for location of gage.

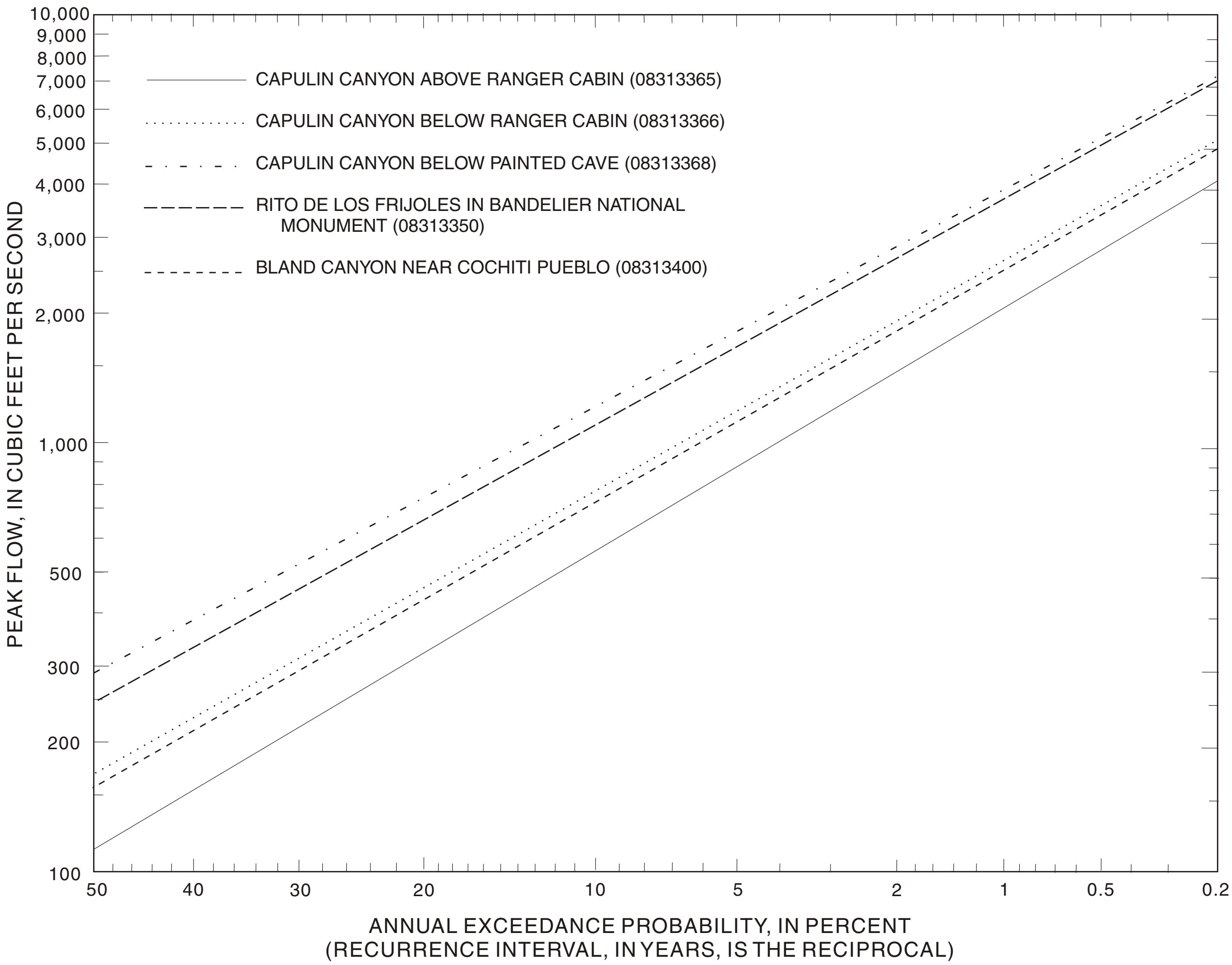
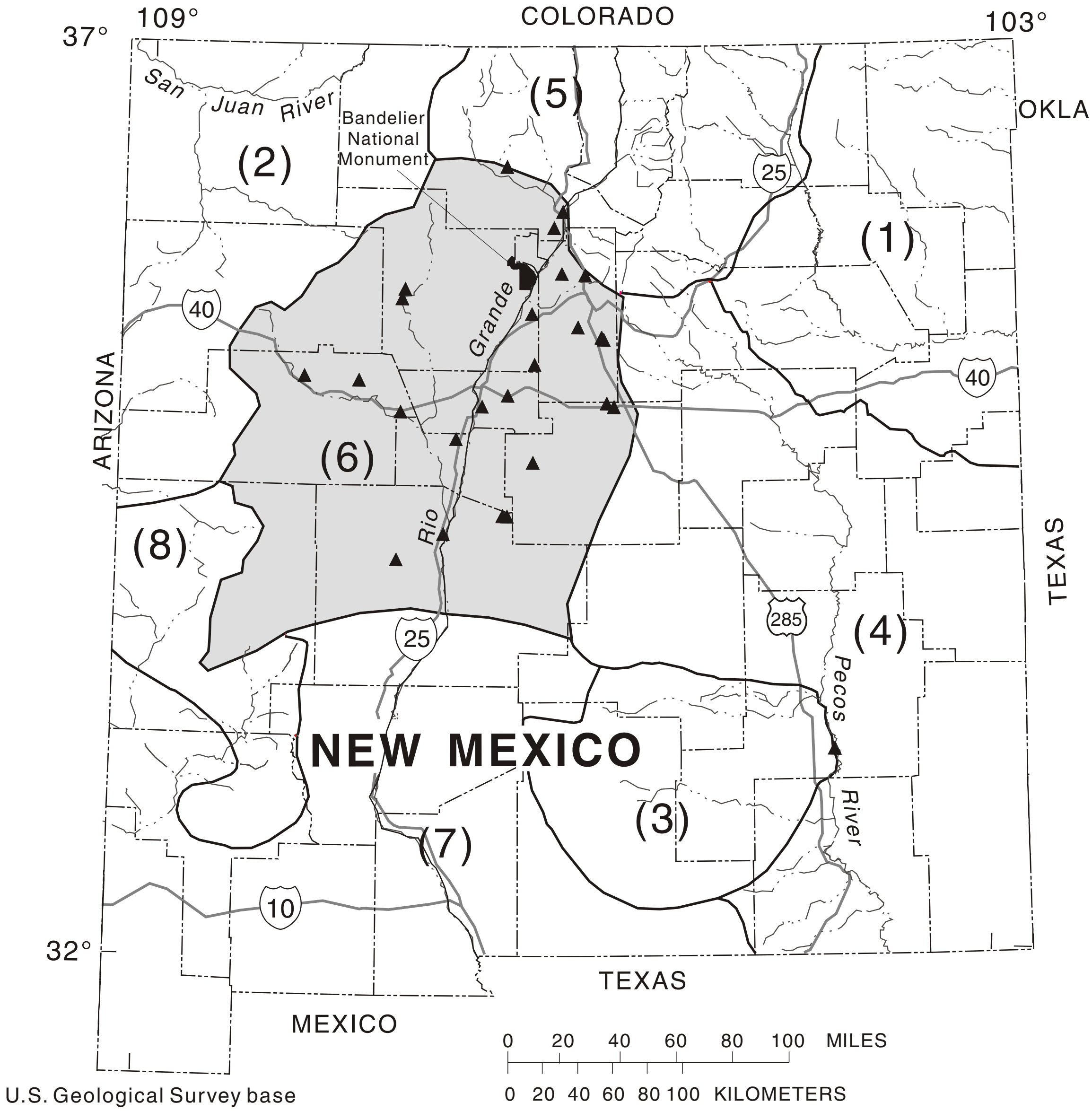


Figure 7. Estimated flood-frequency magnitudes using regression equations (Waltemeyer, 1996) that apply to drainage areas less than 10 square miles in Capulin Canyon and nearby watersheds. See figure 2 for location of stations.



EXPLANATION

— (3) PHYSIOGRAPHIC REGION BOUNDARY AND NUMBER

(1)-Northeast plains region
(2)-Northwest plateau region
(3)-Southeast mountain region
(4)-Southeast plains region
(5)-Northern mountain region
(6)-Central mountain valley region
(7)-Southwest desert region
(8)-Southwest mountain region

▲ STREAMFLOW-GAGING STATION (used in Waltemeyer analysis)

Figure 8. Physiographic regions used in flood-frequency analysis for New Mexico (from Waltemeyer, 1996).

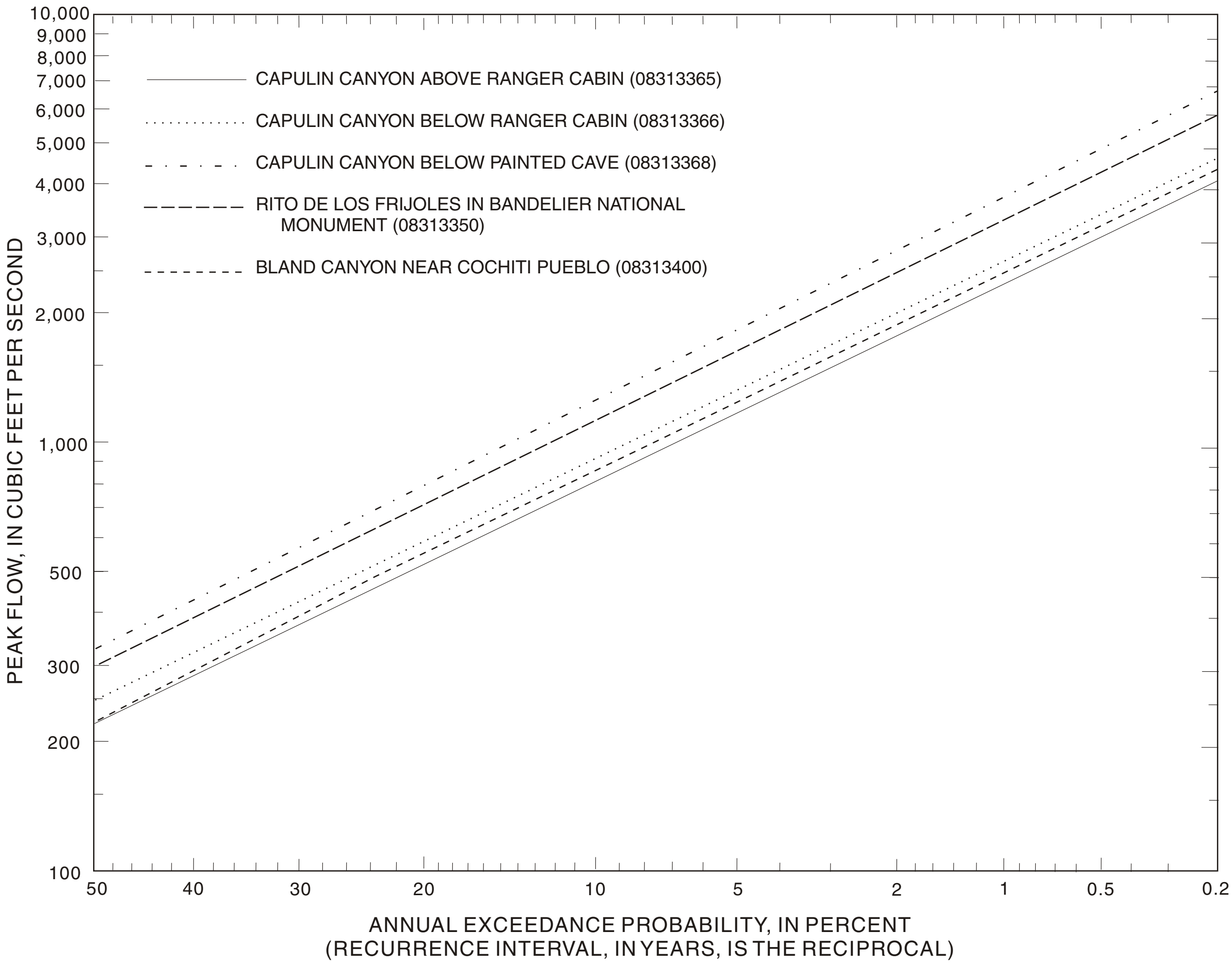


Figure 9. Estimated flood-frequency magnitudes using regression equations developed for physiographic region 6 (Waltemeyer, 1996) in Capulin Canyon and nearby watersheds. See figure 2 for location of stations.

Table 5. Estimated pre-fire peak flows in Capulin Canyon

[See figure 2 for location of sites]

Regression equation number	[1]Capulin Canyon above Ranger Cabin (08313365)		[1]Capulin Canyon below Ranger Cabin (08313366)		[2]Capulin Canyon below Painted Cave (08313368)		[2]Rito de los Frijoles in Bandelier National Monument (08313350)		[1]Bland Canyon near Cochiti Pueblo (08313400)	
	1	2	1	2	1	2	1	2	1	2
2 year	222	112	245	168	300	289	331	248	222	157
5 year	534	318	593	456	738	736	820	655	569	424
10 year	837	559	932	783	1,167	1,232	1,299	1,116	893	732
25 year	1,348	1,002	1,504	1,365	1,893	2,080	2,113	1,917	1,440	1,281
50 year	1,840	1,464	2,059	1,956	2,605	2,920	2,926	2,726	1,969	1,840
100 year	2,438	2,090	2,736	2,744	3,479	4,014	3,903	3,795	2,613	2,588
500 year	4,173	4,195	4,693	5,290	6,000	7,407	6,748	7,205	4,479	5,017

[1]Drainage area less than 10 square miles.
[2]Drainage area greater than 10 square miles.

estimated using the first set of equations (contributing drainage area less than 10 square miles) for Capulin Canyon, Frijoles Canyon, and Bland Canyon are shown in figure 7. Pre-fire floods estimated using the equations for physiographic region 6 for the three Capulin Canyon crest-stage gages and the Frijoles Canyon and Bland Canyon gaging stations are shown in figure 9.

Waltemeyer (1996) used maximum floods that occurred in all nearby watersheds to estimate peak flows for ungaged watersheds for a given drainage area (Waltemeyer, 1996). As part of that study, maximum known floods were compared to drainage area for each watershed. Upper envelope curves were developed for the same regions of New Mexico for which the regression equations apply (fig. 10). A frequently referenced graphical estimate of maximum floods developed by Crippen and Bue (1977) is also presented. Both envelope curves show projections that represent the maximum observed flood for the drainage areas of the monitoring sites in Capulin Canyon.

Annual flow records for Capulin, Frijoles, and Bland Canyons also provide a good indication of the magnitude of pre-fire peak flows, as well as the months during which flood hazards are most likely. Annual peak flows recorded at the Frijoles Canyon gaging station for 1963-69 and 1977-98 and peak flows at 21 Los Alamos gaging stations for 1994-98 (Shaull and others, 1998, 1999**)** indicate about 75 percent of annual peak flows occurring during June, July, August, and September. The increased flood hazard attests to the high rainfall intensity frequently occurring this time of year. Thirty-three percent of annual peak flows recorded at the Frijoles Canyon and Los Alamos gaging stations occurred in August when about 19 percent of total annual rain typically falls. This pattern is highlighted when a watershed is affected by fire, and intense rainfall on exposed soil can generate larger peak flows. For the 25 percent of the years when large thunderstorms do not occur in an individual canyon, the annual peaks result from snowmelt in March, April, and (or) May and an occasional storm that passes over New Mexico from a remnant hurricane in the Gulf of Mexico.

Suspended Sediment

Suspended-sediment samples were not collected in Frijoles Canyon prior to the La Mesa wildfire in 1977. The distribution of suspended-sediment concentrations in 22 samples collected during the NAWQA study are represented by boxplots in figure 11. During 1993-95, concentrations ranged from 6 to 44 mg/L (milligrams per liter) with a median of 16 mg/L. The NAWQA study was considered to have been conducted long enough after the 1977 La Mesa wildfire to be representative of suspended-sediment concentrations from a stable, unburned watershed in this type of geologic setting. Streamflow during sample collection ranged from 0.26 to 8.4 ft^3/s, with a median flow of 1.4 ft^3/s.

Post-Fire Hydrologic Analysis

Wildfire affects the magnitude of floodflows, the frequency of large flows, and the sediment transport of an affected watershed. Wildfire may also affect local rainfall patterns; however, this study makes no attempt to investigate pre- and post-fire rainfall patterns because rainfall in burned areas was collected only after the fire. Rainfall near Bandelier is extremely variable and may not show significant differences between pre-fire and post-fire conditions.

Rainfall

Monthly summaries of precipitation data collected at USGS gages and average monthly precipitation (1931-76) collected at NWS rain gages in and near Capulin Canyon during 1996-98 are listed in table 6. Monthly precipitation data collected at the Upper Basin rain gage (WRD-1) compared with monthly average precipitation data collected at the LANL rain gage (NWS-2) are shown in figure 12. Precipitation data collected at the ranger cabin (WRD-2) compared with monthly average precipitation data collected at the National Park Headquarters (NWS-1) are shown in figure 13. Monthly precipitation was greater at WRD-1 than the monthly average at NWS-2 for 18 of 27 months (table 6). During the first year after the 1996 Dome wildfire, monthly precipitation at WRD-1 was greater than the long-term average; most precipitation was rainfall during the fall and spring, which aided in revegetation of the burned Capulin watershed (fig. 12). The rain gage at WRD-2 recorded greater monthly precipitation than the average monthly precipitation at NWS-1 at Bandelier National Monument for 11 of 27 months (no data are available for 7 months at this rain gage) of data collection (table 6; fig. 13).

A maximum 24-hour rainfall of 2.89 inches was recorded at the WRD-1 rain gage on September 2, 1996 (table 7). The rain gage at WRD-2 recorded a maximum daily rainfall of 1.53 inches on July 31, 1996. A maximum daily rainfall can occur almost anytime during the year, but because fall and spring storms typically have less intense rainfall, these storms rarely cause the annual peak flow in a watershed. Rainfall in the spring and fall usually infiltrates into the ground, thus producing less runoff. Infiltration helps accelerate the process of revegetation and subsequently speed up the runoff abatement process in a burned watershed.

The maximum 15-, 30-, 60-, 180-, and 1,440-minute (24-hour) rainfall for days with greater than 0.25 inch from 1996 to 1998, the date of occurrence, and an estimate of the recurrence interval are listed in table 7 for the WRD-1, WRD-2, and WRD-3 rain gages. Because of the localized nature of rainfall, the limited number of rain gages within the Capulin watershed, and correlation between maximum rainfall for the listed durations and the resultant crest-stage gage, flood peaks are difficult to interpret. Rain gages outside the Capulin Canyon boundaries had such minimal correlation to summer peak flows that the data are of little or no use in interpreting rainfall/peak-flow relations.

The peak runoff recorded at the three crest-stage gages in Capulin Canyon was most highly correlated to the 60-minute maximum rainfall, particularly at the WRD-1 rain gage. The maximum 60-minute rainfall for the 27 months of data collection at this rain gage and the WRD-2 rain gage for all storms with greater than 0.25 inch of rain is shown in figure 14.

Next Generation Radar Rainfall

Next Generation Radar (Nexrad) rainfall images in and near Bandelier National Monument recorded at the Albuquerque area NWS site (on the west mesa of Albuquerque; not shown on map) were used to estimate total rainfall and maximum rainfall intensity for the first large storm (June 26, 1996) after the wildfire (fig. 15). Maximum 24-hour rainfall for this storm was 2.00 inches, whereas the 60-minute maximum rainfall was about 1.75 inches. The NWS-2 rain gage recorded 1.55 inches of rain for this storm (National Oceanic and Atmospheric Administration, 1996a,b); Nexrad estimated about 1.52 inches at this rain gage.

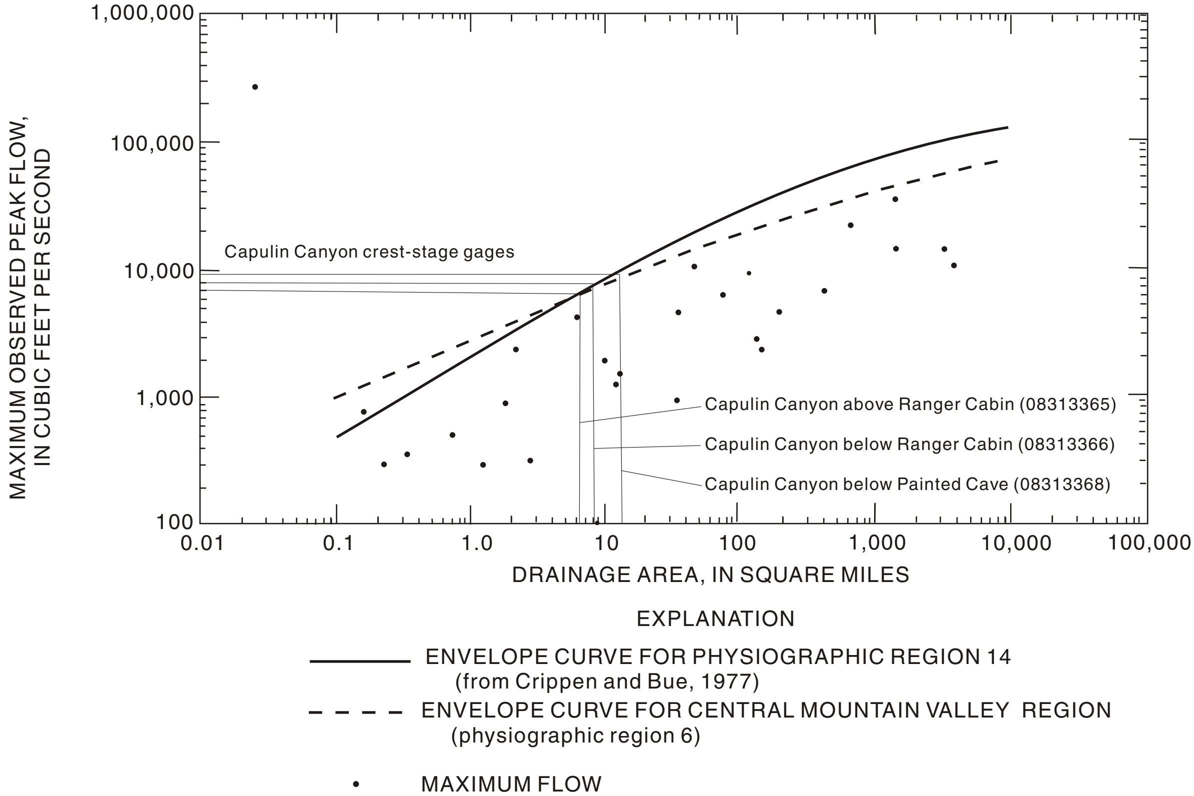


Figure 10. Maximum observed peak flow in relation to drainage area for physiographic region 6 in Capulin Canyon (modified from Waltemeyer, 1996). See figure 2 for location of crest-stage gages.

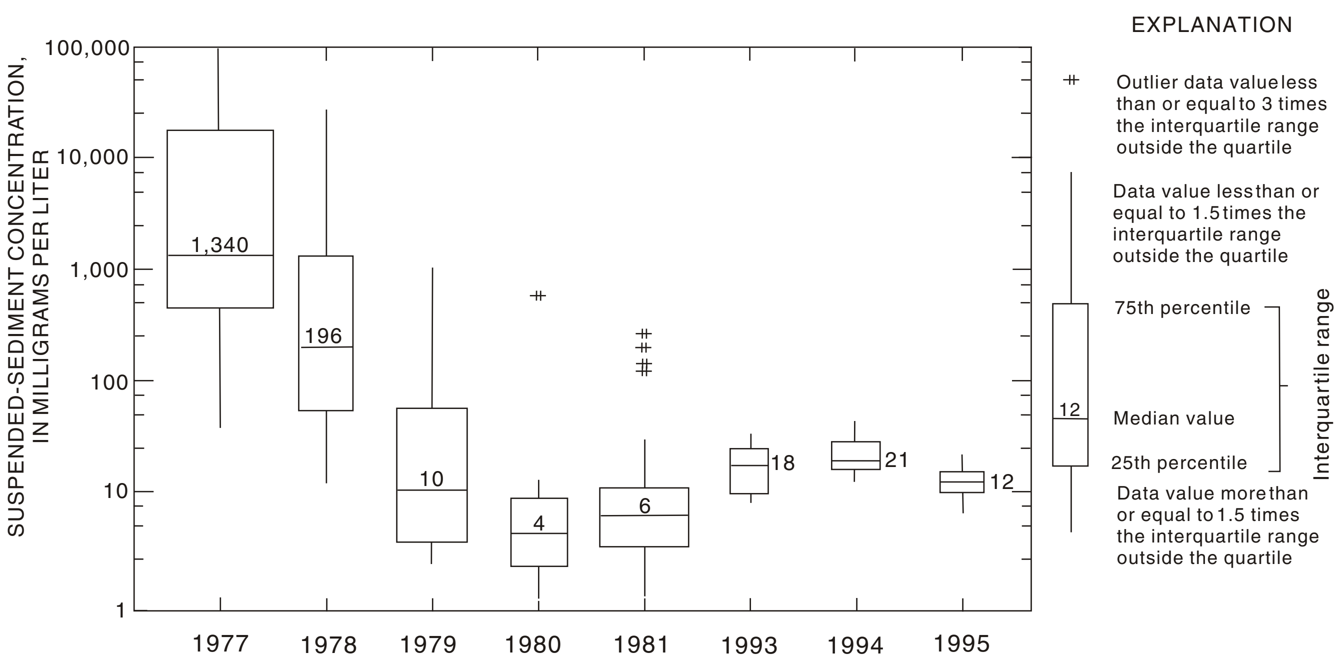


Figure 11. Suspended-sediment concentrations in samples collected in Rito de los Frijoles Canyon by calendar year.

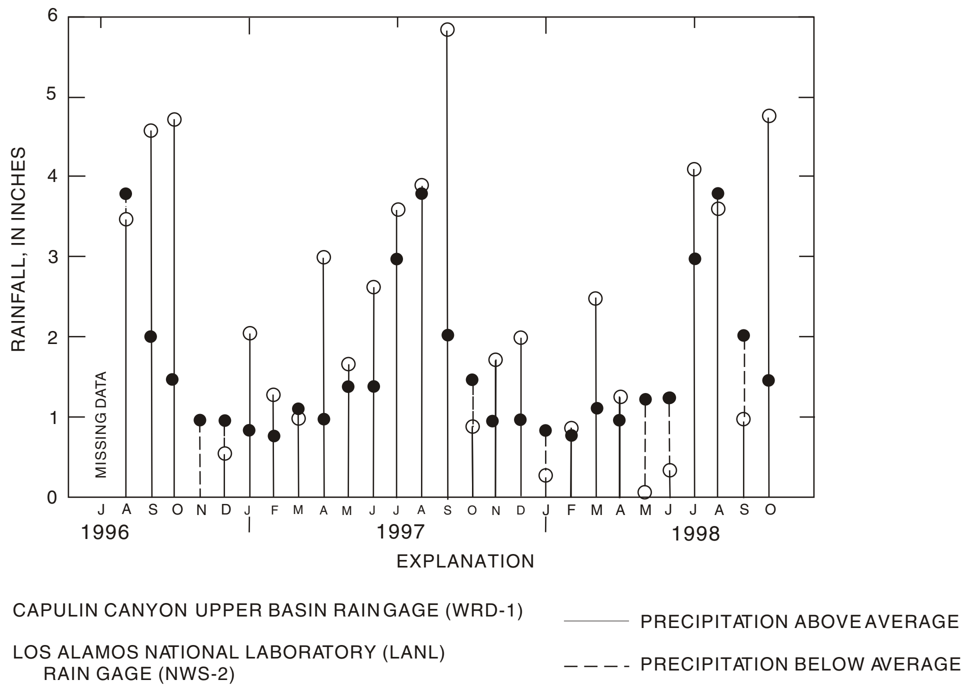


Figure 12. Monthly precipitation at the Capulin Canyon Upper Basin rain gage, 1996-98, compared with average monthly precipitation at the NWS Los Alamos National Laboratory rain gage, 1931-76 (National Weather Service data). See figure 2 for location of rain gages.

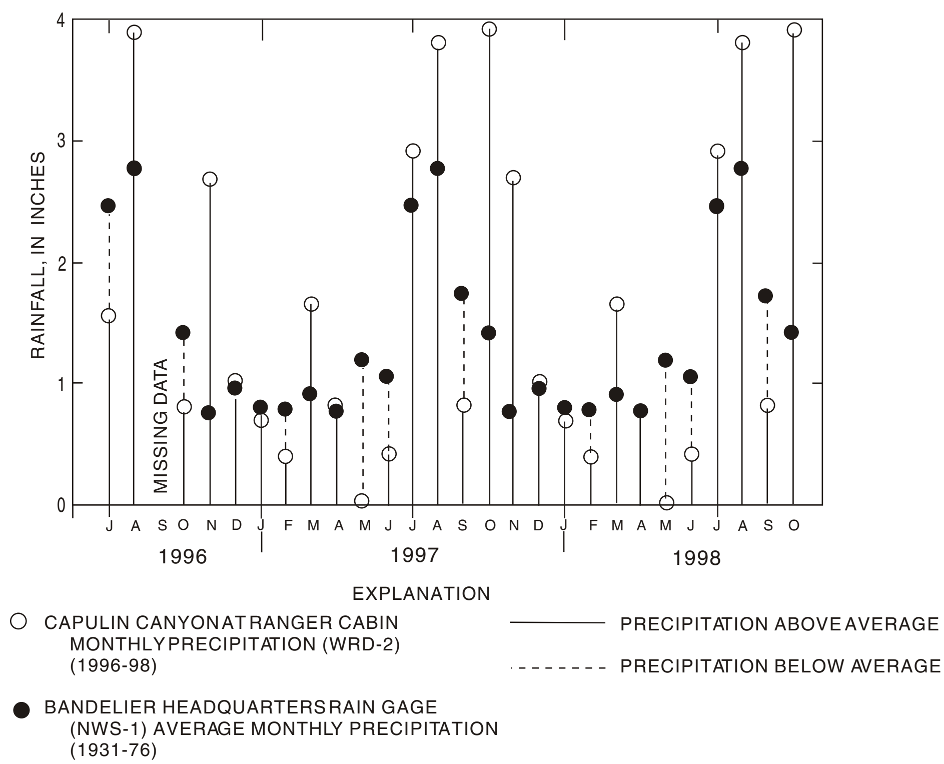


Figure 13. Monthly precipitation at the Capulin Canyon Ranger Cabin rain gage, 1996-98, compared with average monthly precipitation at the NWS Bandelier National Monument rain gage, 1931-76 (National Weather Service data). See figure 2 for location of rain gages.

Table 6. Summary of monthly precipitation data collected at rain gages in and near Capulin Canyon, 1996-98

[Rainfall in inches. NWS, National Weather Service; LANL, Los Alamos National Laboratory; see figure 2 for location of rain gages; --, no data]

Date (month and year)	Average precipitation		Monthly precipitation				
	Bandelier Park Head-quarters average (NWS-1)	**LANL average (NWS-2)**	**Capulin Canyon at Ranger Cabin (WRD-2)**	**Capulin Canyon Upper Basin (WRD-1)**	**Dome Fire Tower (WRD-3)**	**GD-1**	**GD-2**
08-1996	2.76	3.78	2.01	3.47	--	--	--
09-1996	1.73	2.00	1.76	4.58	--	1.97	--
10-1996	1.41	1.46	4.08	4.72	--	4.32	4.32
11-1996	.74	.93	.37	.95	0.22	.27	--
12-1996	.95	.95	--	.54	--	.23	--
01-1997	.79	.83	--	2.05	.26	.19	--
02-1997	.78	.74	--	1.27	.31	.51	--
03-1997	.91	1.07	.82	.97	.74	1.08	.59
04-1997	.76	.96	2.35	2.98	1.12	2.18	2.20
05-1997	1.18	1.35	--	1.65	.80	1.37	1.52
06-1997	1.04	1.37	--	2.60	2.14	3.01	3.06
07-1997	2.46	2.96	1.56	3.59	1.31	--	1.67
08-1997	2.76	3.78	3.89	3.88	4.80	4.92	--
09-1997	1.73	2.00	--	5.85	5.03	4.57	--
10-1997	1.41	1.46	--	.87	--	.70	--
11-1997	.74	.93	2.69	1.70	--	1.46	--
12-1997	.95	.95	1.02	1.98	--	.08	--
01-1998	.79	.83	.69	.26	--	.11	--
02-1998	.78	.74	.39	.84	--	.30	--
03-1998	.91	1.07	1.65	2.48	--	1.52	--
04-1998	.76	.96	.81	1.25	--	.55	--
05-1998	1.18	1.35	.00	.06	--	.01	--
06-1998	1.04	1.37	.42	.33	--	.43	--
07-1998	2.46	2.96	2.92	4.10	4.44	2.86	--
08-1998	2.76	3.78	3.81	3.59	3.37	3.41	--
09-1998	1.73	2.00	.79	.96	.74	.70	--
10-1998	1.41	1.46	3.92	4.74	2.60	4.22	--

Table 7. Maximum rainfall recorded in Capulin Canyon, 1996-98

[Rainfall in inches. <, less than; --, no data]

Rainfall duration	1996		1997		1998	
Capulin Canyon Upper Basin rain gage (WRD-1)						
15 minute	0.72 7-27-96	10 year	0.78 8-6-97	10 year	0.60 8-11-98	5 year
30 minute	.75 7-27-96	2 year	.91 8-6-97	5 year	1.05 8-11-98	10 year
60 minute	1.43 9-2-96	25 year	.94 8-6-97	2 year	1.09 8-11-98	5 year
180 minute	2.22 9-2-96	25 year	1.13 9-7-97	2 year	1.09 8-11-98	2 year
1,440 minute (24 hour)	2.89 9-2-96		1.30 9-7-97		1.19 8-11-98	
Capulin Canyon at Ranger Cabin rain gage (WRD-2)						
15 minute	0.33 7-31-96	<2 year	0.49 8-2-97	2 year	0.51 8-13-98	2 year
30 minute	.44 7-31-96	<2 year	.60 8-2-97	2 year	.72 8-13-98	2 year
60 minute	.81 7-31-96	2 year	.68 8-2-97	<2 year	.89 8-13-98	2 year
180 minute	1.07 7-31-96	2 year	.68 8-2-97	<2 year	.96 8-13-98	2 year
1,440 minute (24 hour)	1.53 7-31-96		.69 8-2-97		1.33 10-31-98	
Dome Fire Tower rain gage (WRD-3)						
15 minute	--	--	0.79 8-6-97	10 year	0.69 7-27-98	5 year
30 minute	--	--	.90 8-6-97	5 year	1.03 7-27-98	10 year
60 minute	--	--	.91 8-6-97	2 year	1.25 7-27-98	10 year
180 minute	--	--	1.12 9-7-97	2 year	1.41 7-27-98	5 year
1,440 minute (24 hour)	--	--	1.12 9-7-97		1.48 7-27-98	

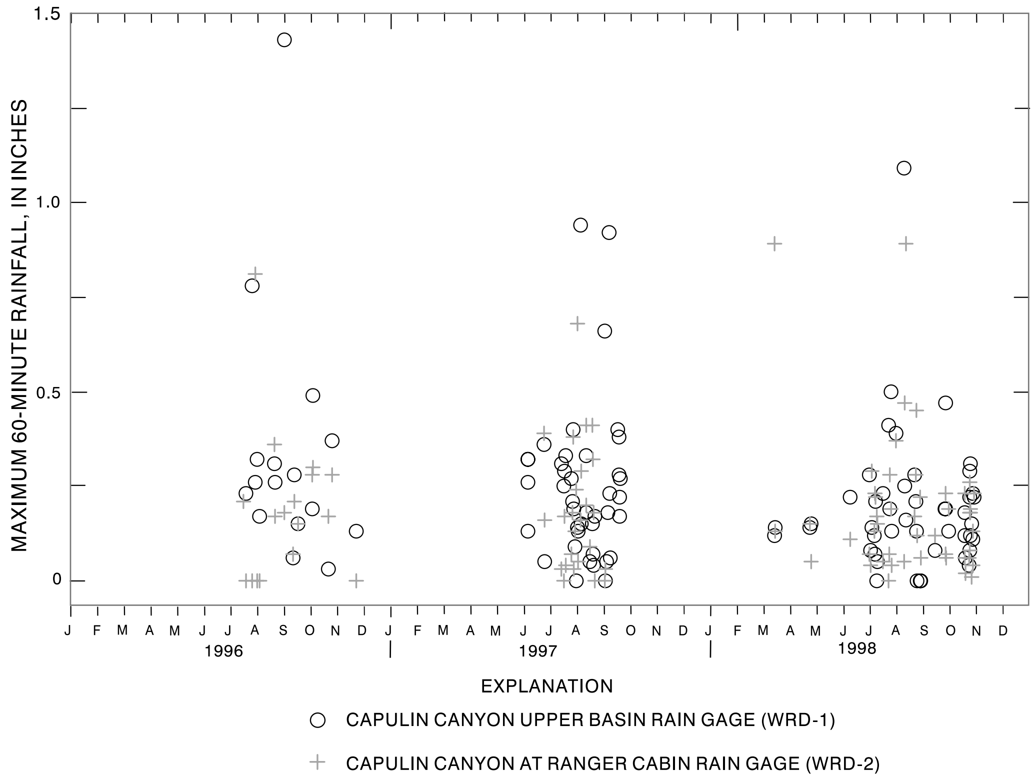


Figure 14. Maximum 60-minute rainfall at the Capulin Canyon at Upper Basin rain gage and the Capulin Canyon at Ranger Cabin rain gage, 1997-98. See figure 2 for location of rain gages.

Nexrad-estimated rainfall for the West Mesa is fairly close to the measured amount. Nexrad represents spatially distributed rainfall cells; the three Capulin Canyon rain gages represent point rainfall. For this reason, the intensity of the June 26, 1996, storm was probably less than the 1.43-inch, 60-minute rainfall that was recorded at WRD-1 on September 2, 1996 (table 7). The estimated 60-minute maximum rainfall of about 1.35 inches would translate into the 2,820-, 2,700-, and 3,630-ft^3/s peak flows recorded in Capulin Canyon for June 26, 1996.

Runoff—Historical Data

Continuous streamflow data recorded at the Frijoles Canyon gaging station after the La Mesa wildfire in 1977 shows the effects of the wildfire on the watershed. Peak flows increased as well as the magnitude and frequency of larger peak flows. Peak flow in Frijoles Canyon increased from a maximum of 19 ft^3/s for 6 years of record (1964-69) prior to the La Mesa wildfire to 3,030 ft^3/s in July 1978, the second summer season and about 1 year after the fire (table 3). Two years after the wildfire, peak flows were less than 354 ft^3/s. Flood magnitudes decreased substantially from July 1977 to June 1979. Even after 1979, however, plant evapotranspiration and interception of rainfall by vegetation were still less than during pre-fire conditions, which effectively doubled the magnitude of post-fire mean annual flows. In the 22 years since the La Mesa wildfire, flood magnitudes have not completely returned to pre-fire magnitudes.

As discussed previously, a particular storm may affect only a small part of a watershed because rainfall for most summer thunderstorms is localized. Seventy-five peak flows recorded from 1963 to 1998 in Frijoles Canyon showed no correlation to daily rainfall collected from four NWS rain gages in the surrounding Jemez Mountains (fig. 2). Seventeen peak flows in Frijoles Canyon, however, did significantly correlate (0.875) to rainfall collected at the NWS-1 rain gage, which was located in Frijoles Canyon in Bandelier National Monument when the gaging station was in operation from 1964 to 1969. Again, rainfall data are useful for peak-flow estimation only if the data are collected in the same canyon that recorded the flow data. For example, data collected from a rain gage located in the next canyon are of little or no use for estimating the magnitude or the date of the peak flow.

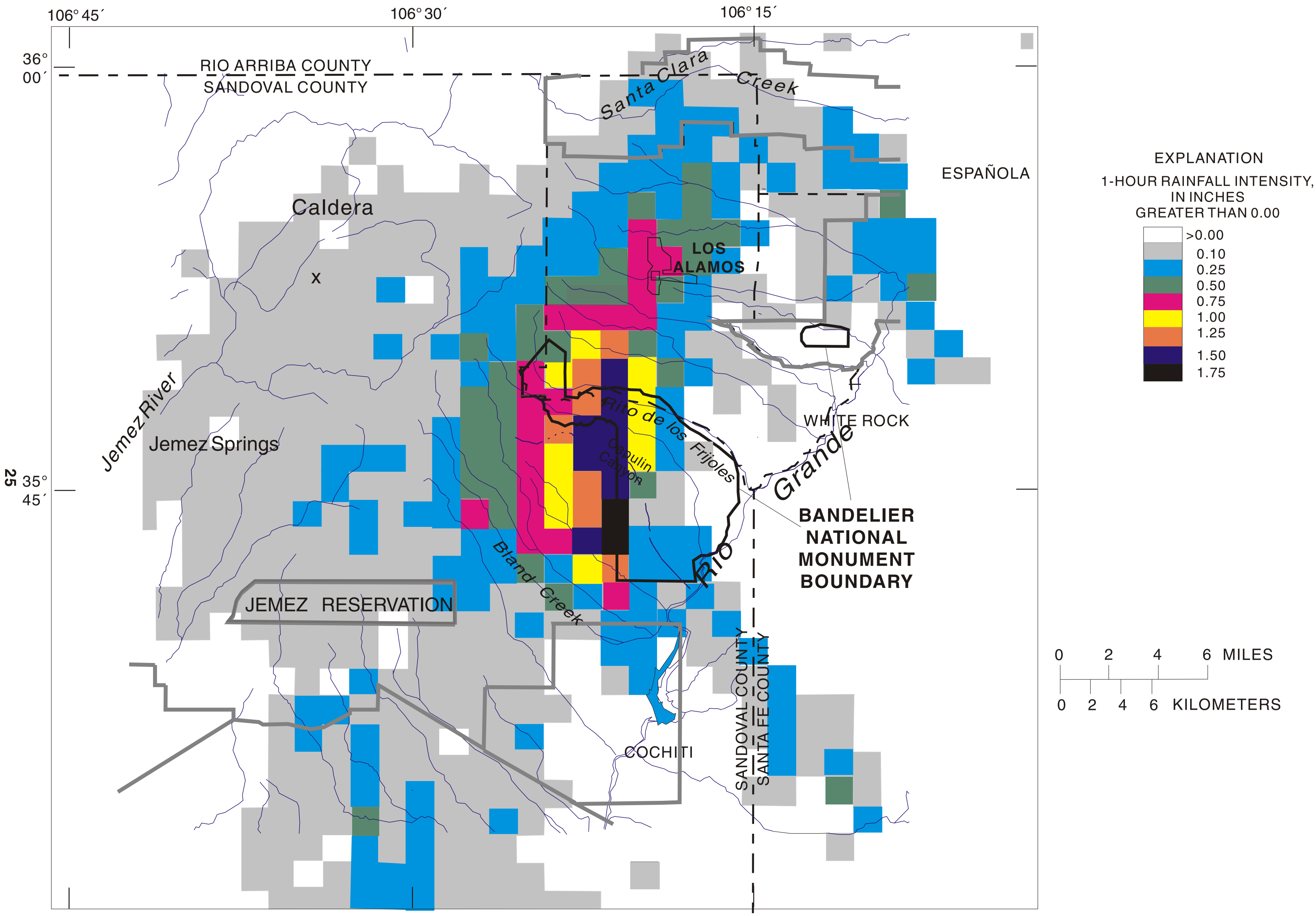


Figure 15. Nexrad radar 1-hour rainfall intensity for storm of June 26, 1996 (from the National Weather Service, June 26, 1996).

This inability to estimate is a result of localized thunderstorms and long, narrow canyons in which storm runoff is divided between two or more canyons. Annual peak flow from 1962 to 1998 at the Bland Canyon crest-stage gage was not correlated to rainfall data collected at any surrounding rain gages.

A paleoflood survey of Capulin Canyon in July 1996 suggests that large peak flows occurred in the past. Depending on the elevation of the base level of the flood channel at the time of the flood, this analysis estimated a paleoflood magnitude of 9,000 to 10,500 ft^3/s for Capulin Canyon (Joseph P. Capesius and Robert D. Jarrett, U.S. Geological Survey, written commun., 1996). This estimation closely agrees with the maximum observed flood for a watershed of this drainage area in physiographic region 6 in Waltemeyer (1996). The analysis also indicates that peak flows of significantly greater magnitude occurred in Capulin Canyon prior to 1996; whether these large peak flows were a result of historical wildfires or other catastrophic events is unknown.

The number of peak flows in Frijoles Canyon greater than a pre-fire peak flow of 19 ft^3/s was 15 in 1977, 9 in 1978, and 5 in 1979 (fig. 16; table 3). Of these recorded peak flows, seven were greater than 100 ft^3/s in 1977 and again in 1978 and three were greater than 100 ft^3/s in 1979 (table 3). Similar to pre-fire peak flows, most of the larger peak flows occurred during July, August, and September; however, four peak flows greater than 100 ft^3/s occurred in November 1978 that were associated with remnants of a Gulf of Mexico hurricane. The number of larger than normal peak flows seems to be most pronounced for 3 years after the fire.

Runoff—Current Data

Peak-flow data recorded in 1996 at the three Capulin Canyon crest-stage gages (fig. 2; table 7) show more than a 100-fold increase in annual peak flow. As happened in Frijoles Canyon after the La Mesa wildfire in 1977, the magnitude and frequency of flooding increased in Capulin Canyon during the post-fire period and did not stabilize until watershed vegetation was reestablished.

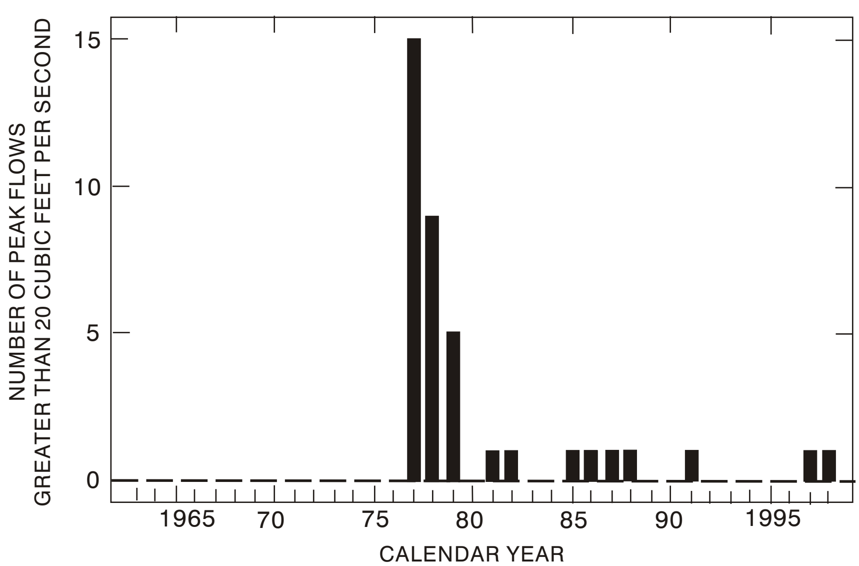


Figure 16. Number of peak flows greater than 19 cubic feet per second in Rito de los Frijoles by calendar year, 1977-98.

On June 26, 1996, less than 2 months after the Dome wildfire, the first large flood occurred in Capulin Canyon. A step-backwater analysis and slope-area of flood magnitude determined peak flows of 2,820 ft^3/s at the Capulin Canyon above Ranger Cabin, 2,700 ft^3/s at the Capulin Canyon below Ranger Cabin, and 3,630 ft^3/s at Capulin Canyon below Painted Cave crest-stage gages. Large peak flows continued to occur during July, August, and September 1996. Peak flows in Capulin Canyon during the second summer of monitoring (1997) substantially decreased in comparison with peak flows in 1996. The peak flood stages and associated peak flows recorded by the three crest-stage gages for 1996-98 and by the Capulin Canyon gaging station for 1997-98 are listed in table 8.

The peak flow recorded at the Capulin Canyon above Ranger Cabin crest-stage gage between August 22 and September 30, 1996 (3,020 ft^3/s), was larger than the peak recorded June 26 (2,820 ft^3/s) at this site (table 8). The larger peak flow was probably a result of the September 2, 1996, storm that was localized in the upper part of Capulin Canyon. The flow was attenuated by extreme channel roughness, debris, and fallen trees, which substantially reduced the peak at the two downstream crest-stage gages. The June 26, 1996, peak flow also decreased from 2,820 ft^3/s at Capulin Canyon above Ranger Cabin to 2,700 ft^3/s at Capulin Canyon below Ranger Cabin because of the decrease in channel slope and the channel roughness. During the June 26, 1996, flood a tributary channel near the ranger cabin had no substantial runoff, indicating that this storm was centered near the upper part of the canyon. The increase in flow from 2,700 ft^3/s to 3,630 ft^3/s suggests that the upper parts of two smaller tributary watersheds in the lower part of Capulin Canyon also had substantial rainfall that supplemented the main channel flow and resulted in the increased peak. Rainfall data were not collected for the first large flood in June 1996. The Frijoles Canyon gaging station recorded a peak less than 1.5 ft^3/s on June 26, 1996; an LANL gaging station in nearby Ancho Canyon recorded no flow (Shaull and others, 1996b); and the Bland Canyon crest-stage gage recorded a peak flow less than the annual peak flow of 175 ft^3/s in 1996. The differences in peak flows among these local drainages demonstrate the areal variation of thunderstorms over parallel watersheds.

At all four crest-stage gages in Capulin, 1997 peak flows decreased to less than 400 ft^3/s (table 8) despite some fairly large rainfalls within the watershed. The reestablishment of vegetation in the Capulin Canyon watershed during the first year after the Dome wildfire is probably responsible for much of the decrease in peak flow. In 1997, Capulin Canyon above Ranger Cabin had an annual peak of 310 ft^3/s (Ortiz and others, 1998), about 20 times the average annual peak flow but still a substantial decrease from the 3,020 ft^3/s in 1996 (table 7). Capulin Canyon below Ranger Cabin had no high-water marks that year, which confirmed that the annual flood peak at this site was less than 300 ft^3/s. A high-water mark at Capulin Canyon below Painted Cave indicated an annual peak flow of 380 ft^3/s, which is about 10 percent of the peak flow of the 1996 monitoring season.

The gaging station at Ranger Cabin provided the opportunity to remotely monitor the rainfall and peak runoff subsequent to June 18, 1997, using a satellite link. A peak flow of 70 ft^3/s was recorded on August 6; 90 ft^3/s on August 22; 270 ft^3/s on September 3; and 70 ft^3/s on September 7, 1997. Three of these dates (August 6 and September 3 and 7) coincided with the maximum rainfall for the 1-hour-duration rainfalls recorded at the upper basin rain gage. The rain gage at the ranger cabin did not record high-intensity rainfall on August 22, 1997; however, rain gages GD-1 and GD-2 each recorded about one-half inch of rainfall on 3 successive days, August 21-23, 1997 (William Ellis, written commun., 1998). Even though the ranger cabin rainfall gage did not record high-intensity rainfall for that period, the high-water mark for the 1977 calendar year (7.07 feet), based on a debris line, closely agreed with the peak stage marks on the recorder (7.20 feet). The annual maximum peak flow at the ranger cabin site was less than 300 ft^3/s, and the data for Capulin Canyon below Ranger Cabin crest-stage gage corroborated this flow. The smallest peak flow that the gaging station at the ranger cabin could detect was 40 ft^3/s on June 18, 1997, at the time of installation. This occurred because the orifice needed to be mounted above the channel bottom in such a way to protect it from heavy debris during flow events. Minimum recordable flow increased to about 100 ft^3/s after the channel cross section was downcut after summer stormflow. The Frijoles Canyon gaging station recorded an annual peak flow of 16.0 ft^3/s on August 17, 1997, and the Bland Canyon crest-stage gage had an annual peak flow of 139 ft^3/s on April 24, 1997, further demonstrating the areal variation in rainfall (Ortiz and others, 1998) and resultant annual maximum peak flow.

Table 8. Peak flood-stage data and associated peak flows in Capulin Canyon, 1996-98

[ft^3/s, cubic feet per second; <, less than; * indicates the maximum rainfall for the same period of record that peak flow was recorded]

Crest-stage gage and partial-record gaging station	Period of record	Stage recorded (feet)	Associated peak flow (ft^3/s)
Capulin Canyon above Ranger Cabin (08313365)	06-26-1996	14.69 15.24	2,820
	07-10-1996	13.33	1,440
	07-11-1996 to 07-18-1996	12.20	630
	07-18-1996 to 08-22-1996	<11.21	<250
	08-22-1996 to 09-30-1996	13.66 12.28	*3,020 *1,640
	09-30-1996 to 12-20-1996	<11.21	*<860
	12-20-1996 to 05-27-1997	<9.85	<300
	05-27-1996 to 08-26-1997	8.96	160
	08-26-1997 to 10-01-1997	9.52	310
	10-01-1997 to 11-20-1998	8.30	100
Capulin Canyon at Ranger Cabin (083133655)	08-06-1997	6.56	70
	08-22-1997	6.59	90
	09-03-1997	7.20	270
	09-07-1997	6.56	70
	10-01-1997 to 07-01-1998	<6.56	<70
	07-01-1998 to 08-19-1998	6.075	100
	08-19-1998 to 11-20-1998	<6.56	<70

Table 8. Peak flood-stage data and associated peak flows in Capulin Canyon, 1996-98--Concluded

Crest-stage gage and partial-record gaging station	Period of record	Stage recorded (feet)	Associated peak flow (ft^3/s)
Capulin Canyon below Ranger Cabin (08313366)	06-26-1996	8.80 9.30	2,700
	07-10-1996 to 07-18-1996	6.614	740
	07-18-1996 to 08-22-1996	4.625	250
	08-22-1996 to 09-30-1996	7.080	*1,110
	09-30-1996 to 12-20-1996	<4.625	*<350
	12-20-1996 to 05-27-1997	<4.625	<300
	05-27-1997 to 07-29-1997	<4.625	<300
	07-29-1997 to 10-01-1997	<4.625	<300
Capulin Canyon below Painted Cave (08313368)	06-26-1996	7.80 7.90	3,630
	07-09-1996 to 07-18-1996	5.34	540
	07-18-1996 to 08-22-1996	<4.46	<310
	08-22-1996 to 10-07-1996	5.24	*860
	10-08-1996 to 12-20-1996	--	--
	10-07-1996 to 10-09-1997	4.21	380
	10-09-1997 to 11-20-1998	2.29	150

*Peak flow estimated from rating 2, which was created after partial resurvey on 09-30-1996 and 12-20-1996 (monumented section only) for the upper two sites and on 10-07-1996 for the lower site.

By 1998, annual peak flow in Capulin Canyon had decreased to less than 160 ft^3/s (fig. 17). The peak flow in relation to the maximum 60-minute rainfall intensity is shown in figure 18. Although rainfall is only from the upper basin rain gage, peak flows substantially decreased from storms of similar intensity as the watershed recovered from 1996 to 1998.

Annual peak flows for Frijoles Canyon after the 1977 La Mesa wildfire and for Capulin Canyon after the 1996 Dome wildfire were larger in magnitude and frequency for about 30 months after the fire (fig. 19). The magnitude of peak flows for both canyons, in comparison to the number of years before and after the date of the wildfires, is shown in figure 20. The magnitude of large stormflows increased dramatically after the wildfire; peak flows at the most downstream gage in each of these two watersheds increased to about 160 times the maximum-recorded flood prior to the fire. As vegetation reestablished itself during the second year, the annual maximum peak flow was reduced to about 10 to 15 times the pre-fire annual maximum peak flow. During the third year, maximum annual peak flows were reduced to about three to five times the pre-fire maximum peak flow. Annual peak flows in response to the 1977 La Mesa and 1996 Dome wildfires appear quite similar.

Maximum flood magnitudes plotted against drainage area for regions 5 and 6 (Waltemeyer, 1996) are shown in figure 21. The maximum post-fire floods for Frijoles and the three Capulin crest-stage gages are also plotted for comparison. Even though maximum post-fire floods in these two canyons are several orders of magnitude larger than pre-fire flows, they do not appear to be larger than what previously has been measured for similar drainage areas in these two regions. When these large floods occur in watersheds that lack effective vegetative cover, the size of the flood for a given drainage area is more a function of maximum rainfall intensity. Whether any of the maximum floods listed in Waltemeyer (1996) are due to post-fire watershed conditions is unknown.

Suspended Sediment

Suspended-sediment concentrations in samples collected after the 1977 La Mesa wildfire in relation to discharge are shown in figure 22. The annual distribution of suspended-sediment concentrations are represented by the boxplots in figure 10. Median suspended-sediment concentrations were about 1,330 mg/L in samples collected in 1977 compared to 16 mg/L in samples collected in 1993-95 (concentrations in 1977 samples were about 80 times those in 1993-95 samples). The substantial increase in discharge the first year after a wildfire and the gradual decrease in discharge for about 3 years after the fire cause a similar response in suspended-sediment concentrations. The suspended-sediment samples collected in 1993-95 averaged about 10 times the concentrations in samples collected in 1980 and 1981. This increase in concentrations in the 16 to 18 years after the wildfire from the concentrations 3 and 4 years after the fire is probably due to the channel returning to a pre-fire, sediment-supply equilibrium.

Table 9. Regression equations relating suspended-sediment load to flow for Rito de los Frijoles Canyon, 1977 and 1993-95

[S, standard error, Adj R^2, adjusted regression; Q, range of flow; ≤, less than or equal to]

Sampling period	Regression equation		
1977	Instantaneous suspended-sediment load = 0.597 $Q^{2.11}$ for suspended-sediment samples		
	S = 0.345	Adj R^2 = 95.8	$0.70 \leq Q \leq 433.0$
1993-95	Instantaneous suspended-sediment load = 0.041 $Q^{1.12}$ for suspended-sediment samples		
	S = 0.204	Adj R^2 = 75.6	$0.26 \leq Q \leq 8.40$

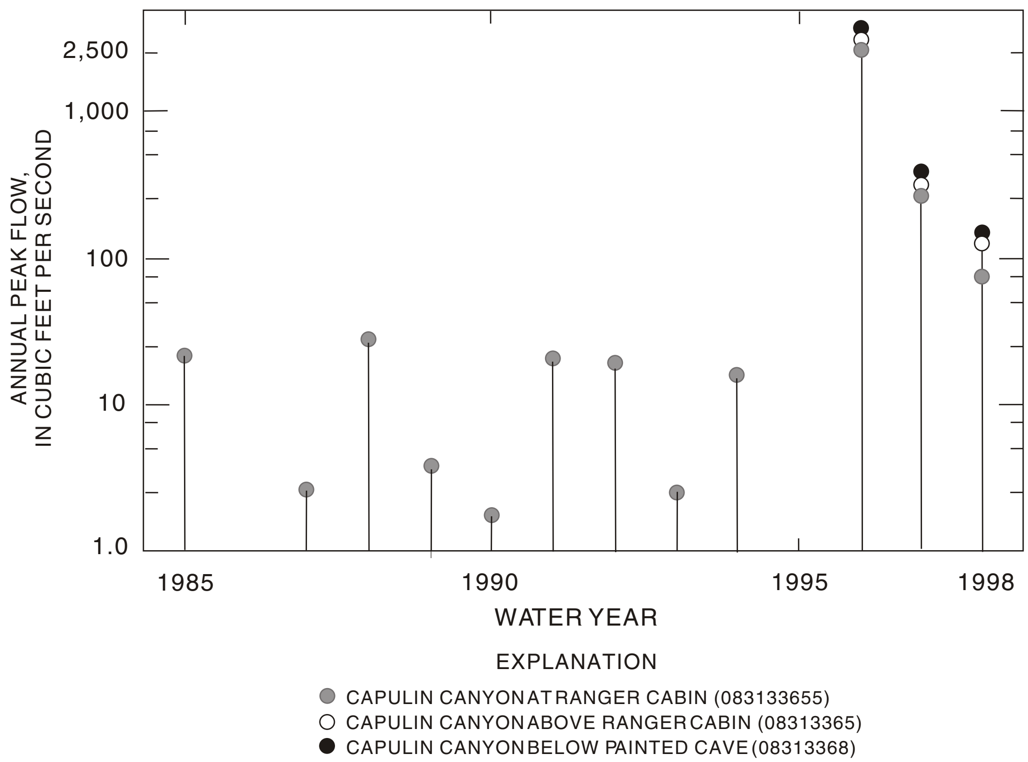


Figure 17. Annual peak flow for Capulin Canyon in Bandelier National Monument. See figure 2 for location of stations.

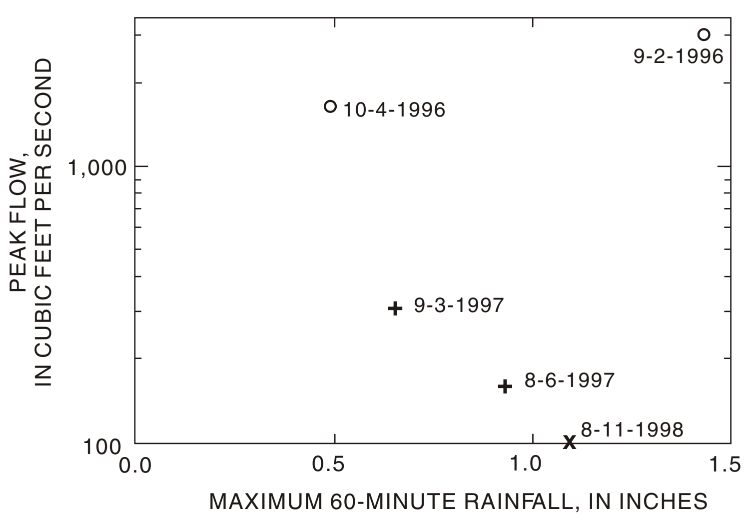
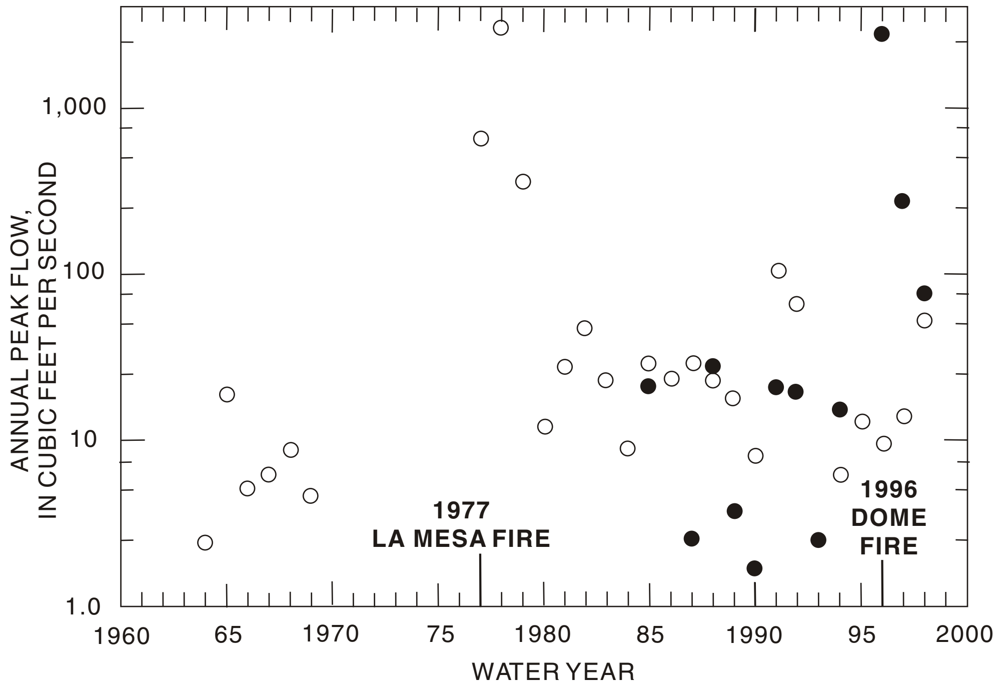


Figure 18. Peak flows at Capulin Canyon above Ranger Cabin (08313365) compared to maximum 60-minute rainfall recorded at Capulin Canyon Upper Basin rain gage (WRD-1), Bandelier National Monument, 1996-98. See figure 2 for location of rain gage.



EXPLANATION

○ FRIJOLES CANYON, 1977 La Mesa wildfire in Frijoles Canyon, Rito de los Frijoles in Bandelier National Monument streamflow-gaging station (08313350)

● CAPULIN CANYON, 1966 Dome wildfire in Capulin Canyon, Capulin Canyon at Ranger Cabin streamflow-gaging station (083133655)

Figure 19. Annual peak flows in Frijoles Canyon and Capulin Canyon. Water year is from October 1 to September 30 of the next calendar year. See figure 2 for location of stations.

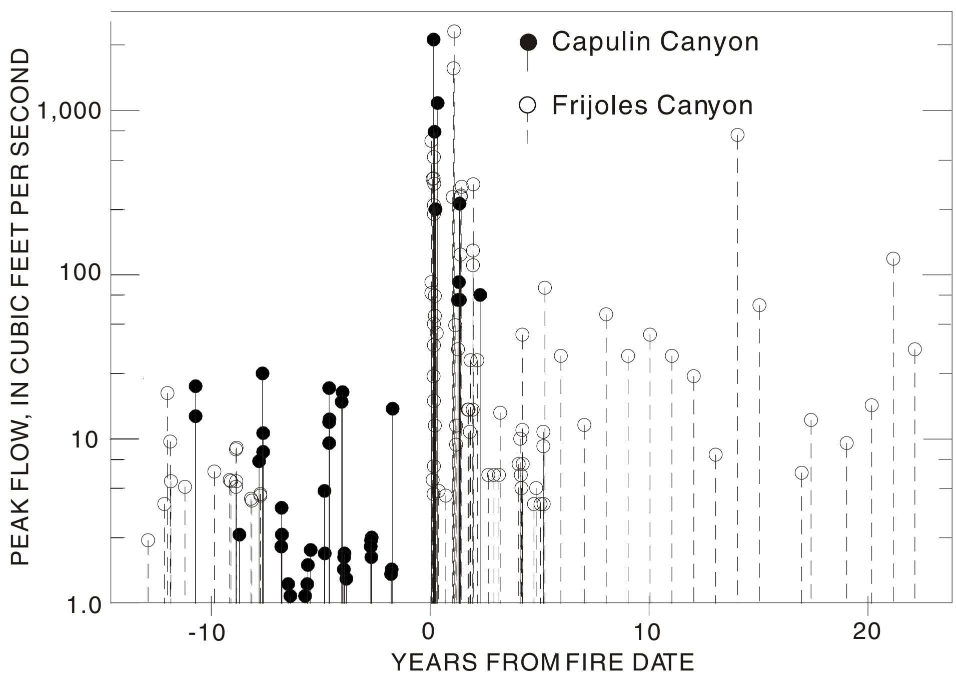


Figure 20. Peak flows in Frijoles Canyon after the 1977 La Mesa wildfire and in Capulin Canyon after the 1996 Dome wildfire.

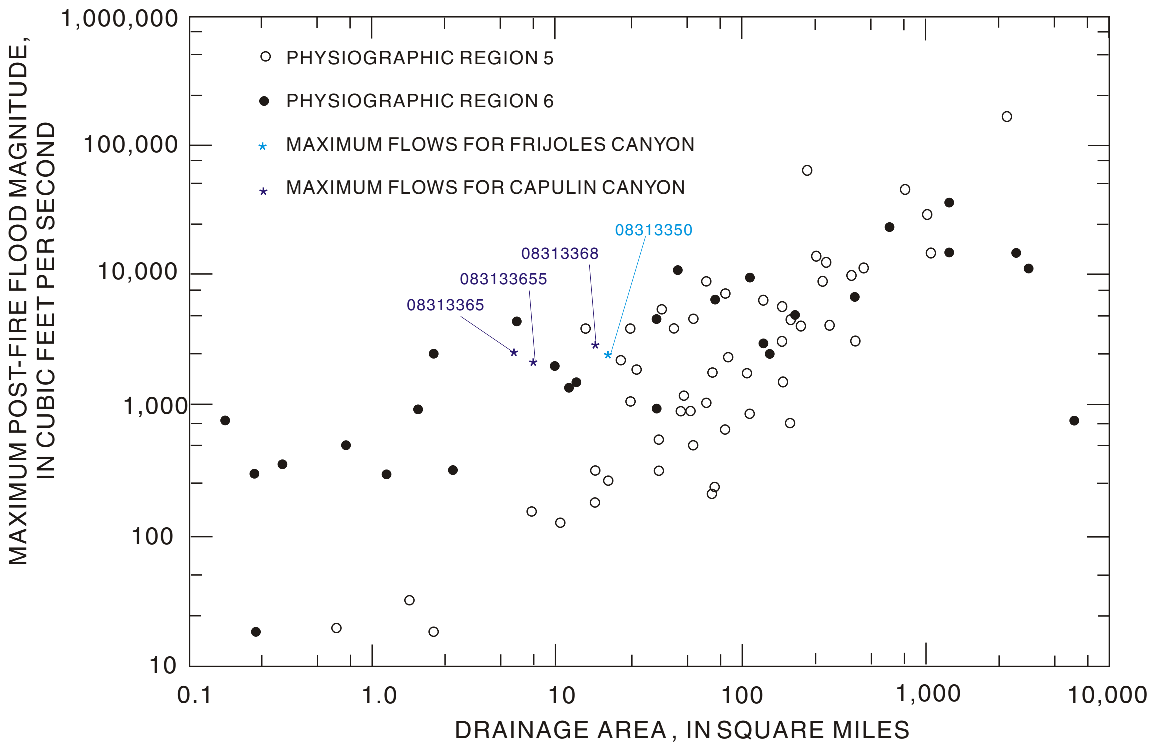


Figure 21. Maximum post-fire flood magnitudes for Frijoles and Capulin Canyons and flood magnitudes for physiographic regions 5 and 6 in New Mexico compared to drainage area (data for regions 5 and 6 from Waltemeyer, 1996). See figure 2 for location of gaging stations and crest-stage gages and figure 8 for location of physiographic regions 5 and 6.

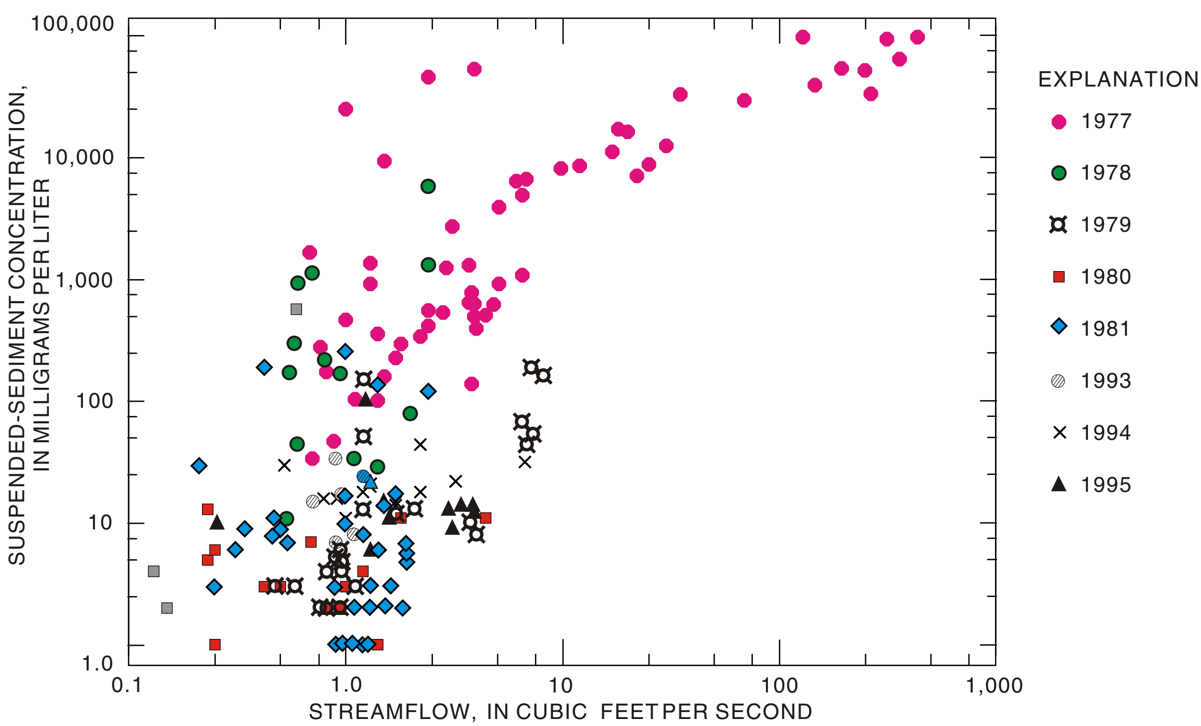


Figure 22. Instantaneous suspended-sediment concentration compared to flow in Rito de los Frijoles, 1977-95, after the 1977 La Mesa wildfire.

Suspended-sediment load in relation to discharge is shown in figures 23 and 24. The regression equations determined for the 1977 sampling year and for the 1993-95 La Mesa post-fire recovery period in Frijoles Canyon are listed in table 9. The relation between suspended-sediment load and discharge was used with mean daily discharge to calculate annual suspended-sediment load. Using these regression equations, 20 tons per year of suspended sediment was transported past the Frijoles Canyon gaging station during the post-fire recovery period in 1993-95. The first year after the wildfire, about 4,400 tons of suspended sediment were transported past the Frijoles Canyon gaging station by the increased magnitude and frequency of flows. Thus, the first year after the wildfire, sediment transport was about 220 times annual suspended-sediment load for a recovered watershed.

Channel Cross Sections and Stream Gradient

Because of the increased magnitude, frequency, and duration of flow and the resultant substantial increase in suspended-sediment loads during the 1996 summer months, the main flow channel of Capulin Creek in Capulin Canyon adjusted to the increase in runoff by increasing in size both laterally and by downcutting. The mean channel width provides a better estimate of mean annual flow and floods of all recurrence intervals than does drainage area, mean channel slope, and precipitation as used in the Waltemeyer (1996) regression equations (Scott and Kunkler, 1976).

Cross sections at the three crest-stage gages and the partial-record gage were resurveyed six times during the 2 1/2-year study. The final survey measurements of the cross sections were superimposed over the initial survey measurements (figs. 25-27). The differences between measurements in the cross sections were then translated upstream and downstream from the crest-stage gage, and the stage-discharge ratings were recalculated for each site.

The Capulin Canyon above Ranger Cabin cross section was surveyed just after the initial flood on July 11, 1996. A resurvey on August 19, 1998, is plotted at the same scale in figure 25 to observe channel changes over about a 2-year period. The cross sections at Capulin Canyon below Ranger Cabin are plotted in figure 26 for the July 10, 1996, and November 20, 1998, surveys, detailing changes for the duration of the study. Initial cross sections on July 9, 1996, at Capulin Canyon below Painted Cave and a resurvey on November 20, 1998, are plotted in figure 27 showing changes over the study period. For all three crest-stage-gage cross sections, the water level of the initial post-fire (June 26, 1996) flood is shown.

The changes in stream channel cross-section surveys after the Dome wildfire, between 1996 and 1997 at the three crest-stage gages, were a good indicator of initial recovery in the Capulin watershed. At Capulin Canyon above Ranger Cabin, the stream channel continued to downcut in 1997, but at a much reduced rate as compared immediately after the wildfire in 1996 (fig. 24). Measurements of the channel in 1997 at Capulin Canyon below Ranger Cabin did not change enough to warrant a recalculation of the rating from the initial survey in 1996. The stream channel at Capulin Canyon below Painted Cave initially downcut and then began to aggrade as sediment transported from upstream settled out in channel reaches where the slope and discharge lessened. The decrease in downcutting in the upper reach and the deposition in the lower reach in 1997 are indicative of a stream channel that is readjusting to smaller magnitude and less frequent peak flows.

Downcutting of the channel at Capulin Canyon at Ranger Cabin was also observed. An accumulation of sediment from June to July 1996 had reduced the channel capacity at Capulin Canyon at Ranger Cabin, and the first large flows in August 1996 transported the accumulated sediment downstream. The change in the original channel profile at the gaging station is shown in figure 28.

As the Capulin Canyon peak flows reduced both in magnitude and frequency in response to vegetative recovery, the stream channels have slowly begun to recover as well. The channel at the most downstream gage, which has the shallowest initial valley slope, is showing the first signs of aggradation.

SUMMARY

In June of 1977, the La Mesa wildfire burned 15,270 acres in and around Frijoles Canyon in Bandelier National Monument and the adjacent Santa Fe National Forest, New Mexico. The Dome wildfire in April of 1996 in Bandelier National Monument burned 16,516 acres in Capulin Canyon and the surrounding Dome Wilderness area. Both canyons are characterized by extensive archeological resources that could be affected by increased runoff and accelerated rates of sedimentation after a wildfire. The USGS in cooperation with the NPS monitored the wildfires' effects on streamflow in both canyons.

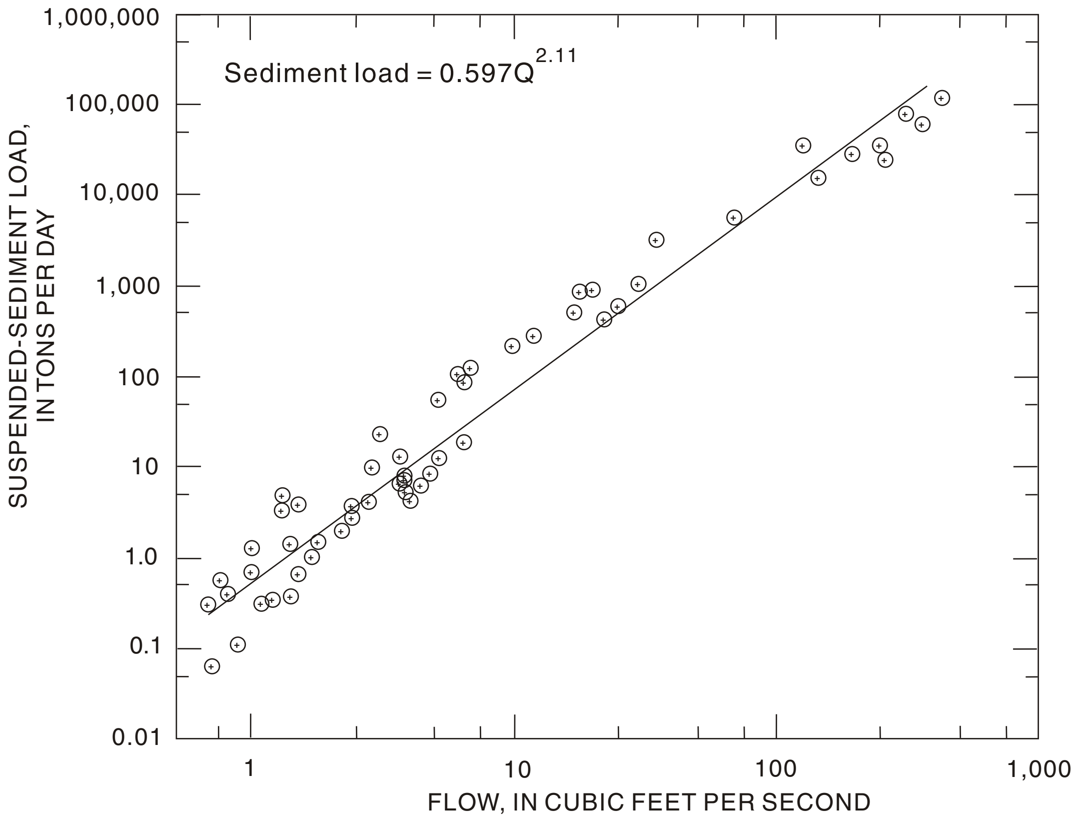


Figure 23. Instantaneous suspended-sediment load compared to flow for 1977, Rito de los Frijoles.

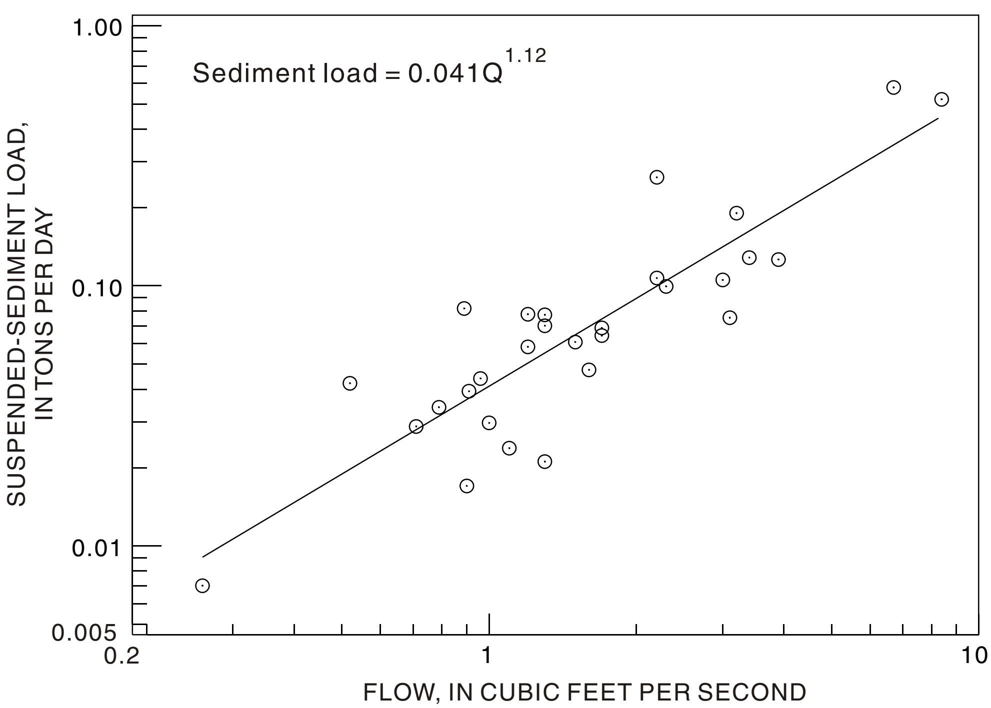


Figure 24. Instantaneous suspended-sediment load compared to flow for 1993-95, Rito de los Frijoles.

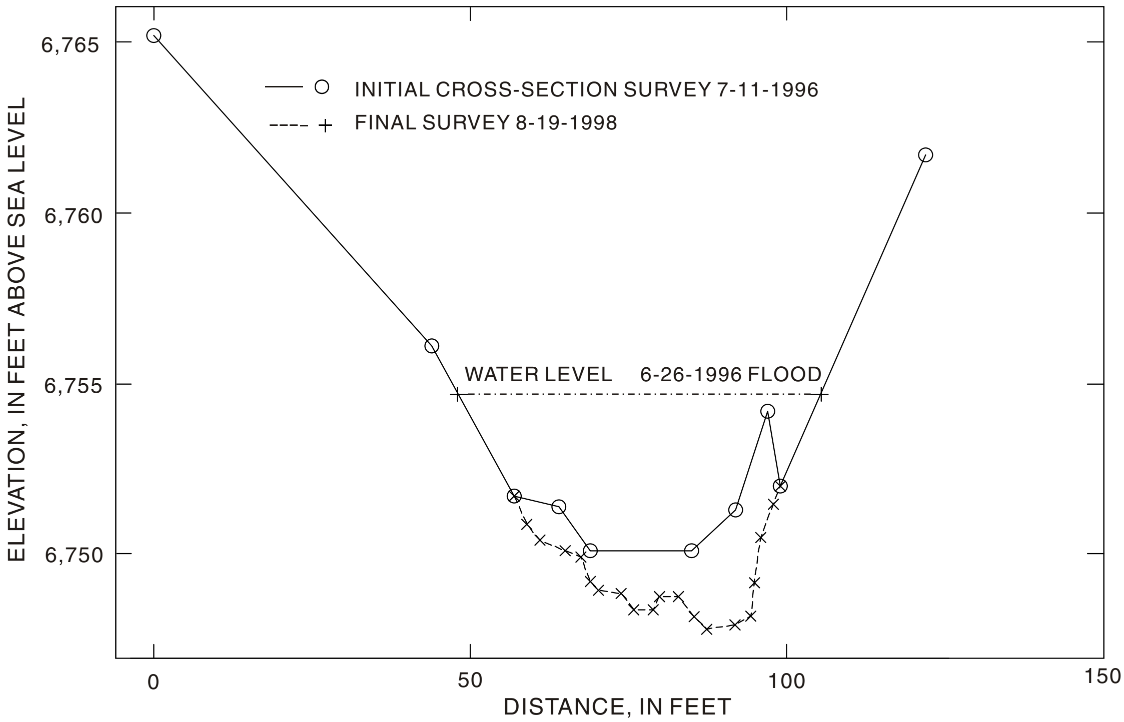


Figure 25. Changes in monumented cross section at Capulin Canyon above Ranger Cabin crest-stage gage (08313365), July 11, 1996, to August 19, 1998. See figure 2 for location of gage.

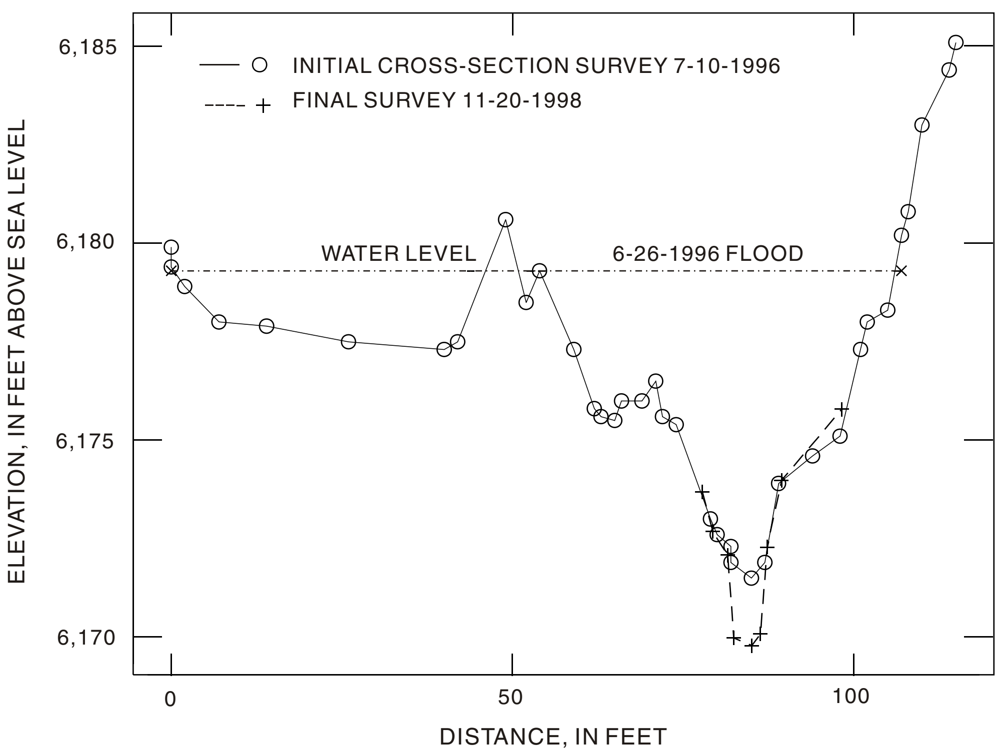


Figure 26. Changes in monumented cross section at Capulin Canyon below Ranger Cabin crest-stage gage (08313366), July 10, 1996, to November 20, 1998. See figure 2 for location of gage.

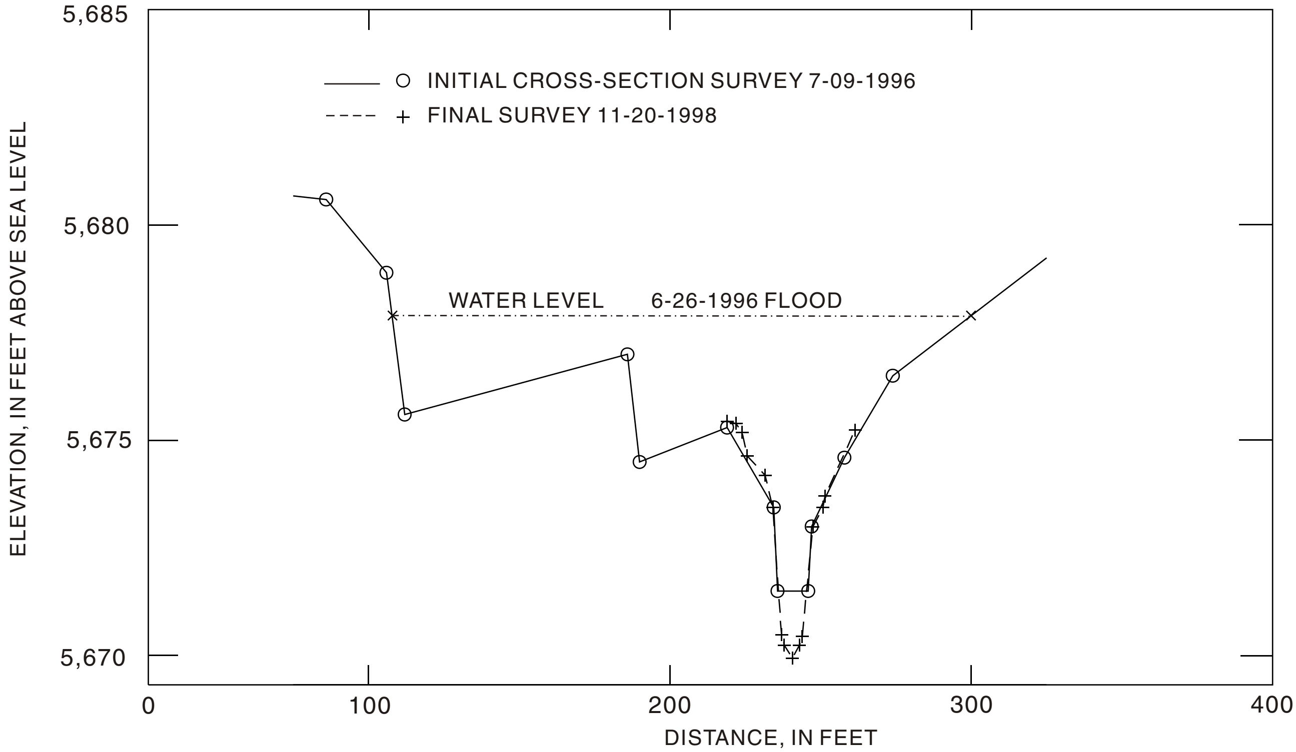


Figure 27. Changes in monumented cross section at Capulin Canyon below Painted Cave crest-stage gage (08313368), July 9, 1996, to November 20, 1998. See figure 2 for location of gage.

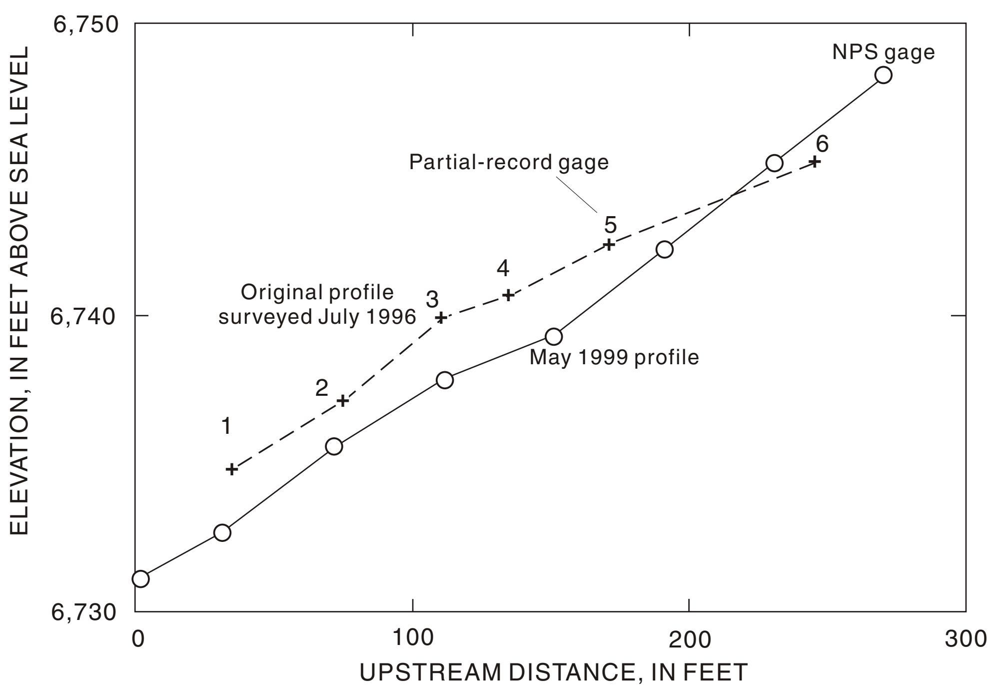


Figure 28. Stream profile and valley slope at partial-record gage Capulin Canyon at Ranger Cabin (083133655). See figure 2 for location of station.

A continuous-record gaging station was operated by the USGS in Frijoles Canyon from July 1963 to September 1969 and again from July 1977 until September 1982. Since 1983, that gage has been operated by several different agencies. The USGS operated three crest-stage gages in Capulin Canyon from July 1996 until November 1998. A partial-record gage was installed in June 1997, which recorded peak stages until November 1998 and transmitted that data by satellite for flood documentation. The NPS operated a streamflow-recording gage just upstream from the site of the partial-record gage from 1985 until 1996. This gage was destroyed by post-fire runoff events.

The magnitude of large stormflows increased dramatically after the wildfire; peak flows at the most downstream gage in each of these two watersheds increased to about 160 times the maximum-recorded flood prior to the fire. Maximum peak flow was 3,030 ft^3/s at the Frijoles Canyon gage (drainage area equals 18.1 square miles) and 3,630 ft^3/s at the most downstream crest-stage gage in Capulin Canyon (drainage area equals 14.1 square miles). The pre-fire maximum peak flow recorded at these two sites was 19 and an estimated 25 ft^3/s, respectively. As vegetation reestablished itself in the second year, the annual maximum peak flow was reduced to about 10 to 15 times the pre-fire annual maximum peak flow. During the third year, maximum annual peak flows were reduced to about three to five times the pre-fire maximum peak flow. In the 22 years since the La Mesa wildfire, flood magnitudes have not completely returned to pre-fire magnitudes.

Post-fire flood magnitudes in Frijoles and Capulin Canyons do not exceed the maximum floods per drainage area for physiographic regions 5 and 6 (two of the northern flood regions of New Mexico). This suggests that although post-fire flood magnitudes can be much larger than normal flood magnitudes for a given watershed, the Bandelier post-fire floods still do not exceed maximum floods per drainage area envelope curves for these regions.

The frequency of larger stormflows also increased in response to the effects of the wildfires in both canyons. In Frijoles Canyon, the number of peak stormflows greater than the pre-fire maximum flow of 19 ft^3/s is 15, 9, and 5 for the 3 post-fire runoff years (1977-79). Again, the hydrologic effects of the wildfire seem to be most pronounced for the 3 water years following the fire. Likewise, larger stormflows were more frequent in Capulin Canyon for the first 3 years after the 1996 wildfire.

Median suspended-sediment concentrations collected at Frijoles Canyon the year of the 1977 wildfire were about 80 times those collected after the watershed had stabilized in 1993-95. The annual load calculated from a regression of load against flow for the year after the wildfire was 220 times the annual load for the post-fire recovery period.

To convey the increased frequency and magnitude of average flows in Capulin Canyon, the stream channel in Capulin Canyon increased in flow capacity by lateral widening and downcutting. As the Capulin Canyon peak flows reduced both in magnitude and frequency in response to vegetative recovery, the stream channels have slowly begun to recover as well. The channel at the most downstream gage, which has the shallowest initial valley slope, is showing the first signs of aggradation.

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