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Informal Report

Geohydrology of Bandelier National Monument, New Mexico

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GEOHYDROLOGY OF BANDELIER NATIONAL MONUMENT, NEW MEXICO

by

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ABSTRACT

Bandelier National Monument is located on the eastern slopes of the Sierra de los Valles and the Pajarito Plateau. The Pajarito Plateau was formed by a series of ashflow and ashfall of rhyolite tuff. Perennial and intermittent streams have cut the surface of the plateau into a number of narrow southeast-trending mesas separated by deep canyons. Perennial surface flow occurs in Cañon de los Frijoles and in the upper and middle reaches of Alamo, Capulin, Medio, and Sanchez Canyons. Of the five springs in and adjacent to the Monument, three discharge from perched aquifers and two from the main aquifer. Water in the deep main aquifer moves south to southeast in the Monument. Along the western edge of the Monument, the intrusion of volcanic rock of the San Miguel Mountains forms a barrier to the movement of water from the recharge area in the Valles Caldera. About 46.4 km^2 of the drainage area in the upper and middle reaches of Cañon de los Frijoles, Alamo, Lummis and Capulin Canyons were burned over by a wildfire (the La Mesa Fire) in June 1977. The geohydrology of the area was determined to assess the availability of surface and ground water in the Monument and to determine the impact of the wildfire on these water resources.

I. INTRODUCTION

Bandelier National Monument is located on the eastern slopes of the Sierra de los Valles and Pajarito Plateau, west of the Rio Grande, in north-central New Mexico (Fig. 1). The elevation ranges from 1620 m along the Rio Grande in the southeast corner of the Monument to 3109 m in the northwest corner on the crest of the Sierra de los Valles. The major part of the Monument is on the Pajarito Plateau. The plateau forms a broad apron around the flanks of the mountains, with its surface sloping gently from mountains toward the Rio Grande. The eastern edge of the plateau is terminated along the deep canyon of the Rio Grande. Southeast trending streams have cut the surface of the plateau into a series of long narrow mesas separated by deep canyons.

Near the western boundary of the Monument, extruded volcanic rocks form the San Miguel Mountains, which bifurcate the plateau into an east and west segment. The crest of the mountains (St. Peter's Dome) rises to an elevation of about 2580 m. North of the San Miguel Mountains near the Monument boundary, the western part of the plateau is uplifted about 100 m along a north-south trending fault scarp. South and east of the San Miguel Mountains the plateau slopes gently toward the canyon of the Rio Grande.

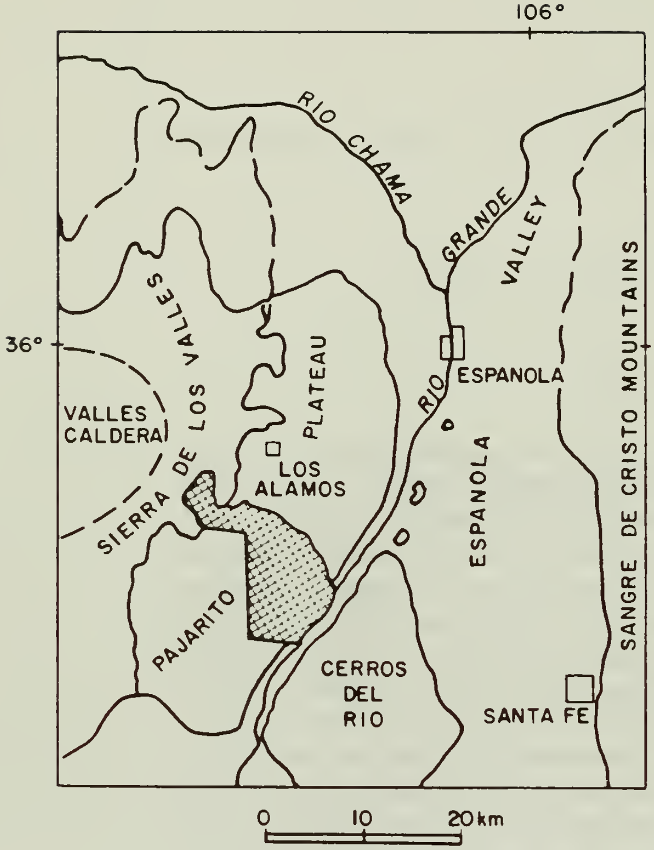

Fig. 1.
Physiographic features in the vicinity of Bandelier National Monument.

The wide range of elevations results in climate and vegetation changes from the Rio Grande to the crest of the Sierra de los Valles. Average precipitation increases from about 23 cm along the river to as much as 76 cm along the crest of the mountains. The average precipitation on the plateau is about 46 cm, with about 70% of the precipitation occurring in late June, July, and August during summer thunder showers.

The average July temperature at the lower elevations is about 23°C and on the plateau about 19°C, while average January temperatures along the river are −6°C and on the plateau −7°C. Juniper-grass lands with Russian Olive, some willow, cottonwood, and salt cedar are found along the river. The eastern two-thirds of the plateau is covered with pinon and juniper, while the western third and lower slopes of the mountains are covered with pine. Spruce, fir, and aspen intermingle with pine on the upper slopes of the mountains. Alpine meadows are found on the south-facing slopes of the mountains. In June 1977, the La Mesa Fire consumed about 61.9 km^2 of pinon, juniper, spruce, aspen and pine in and adjacent to the Monument.

The purpose of this report is to present the general geohydrology in and adjacent to the Monument in order to evaluate the effects of the wildfire on the water resources. The study was made in cooperation with the National Park Service at Bandelier National Monument. It is based on hydrologic data collected by the Monument and by the Los Alamos Scientific Laboratory (LASL). The report includes data through 1978.

The data are expressed in metric units. The following table, conversion from metric to English units, is included for the convenience of the reader.

To Convert From	To	Multiply By
cm	in	3.94×10^{-1}
m	ft	3.28
km	mi	6.22×10^{-1}
m^3	acre-ft	8.11×10^{-4}
km^2	mi^2	3.85×10^{-1}
ℓ/s	gal/min	15.85
m^3/s	ft^3/s	35.3
ℓ/s/m	gal/min/ft	4.82
m^2/day	ft^2/day	10.76
$m^3/s/km^2$	$ft^3/s/mi^2$	91.5
kg	ton	1.10×10^{-3}
kg/km^2	lb/mi^2	5.71

The generalized geology is presented as a basis for understanding the hydrology of the area. Detailed geology can be found in Ross et al. (1961), Smith et al. (1962), Griggs (1964), Bailey et al. (1969), and Smith et al. (1970).[1-5]

The Monument is located on the southeastern flank of the Valles Caldera, thus most of the rocks that outcrop are from volcanic cycles of eruption from the Caldera (Fig. 1). The generalized geologic map groups the outcrops in the area from oldest to youngest as the Galisteo Formation, Santa Fe Formation, basaltic rocks of the Rio Grande, volcanic rocks of the Valles Caldera, volcanic rocks of the Pajarito Plateau, and alluvium (Fig. 2 and Table I). The volcanic rocks of the Pajarito Plateau (Bandelier tuff) are a part of the eruption sequence of the Valles Caldera, but are shown separately on

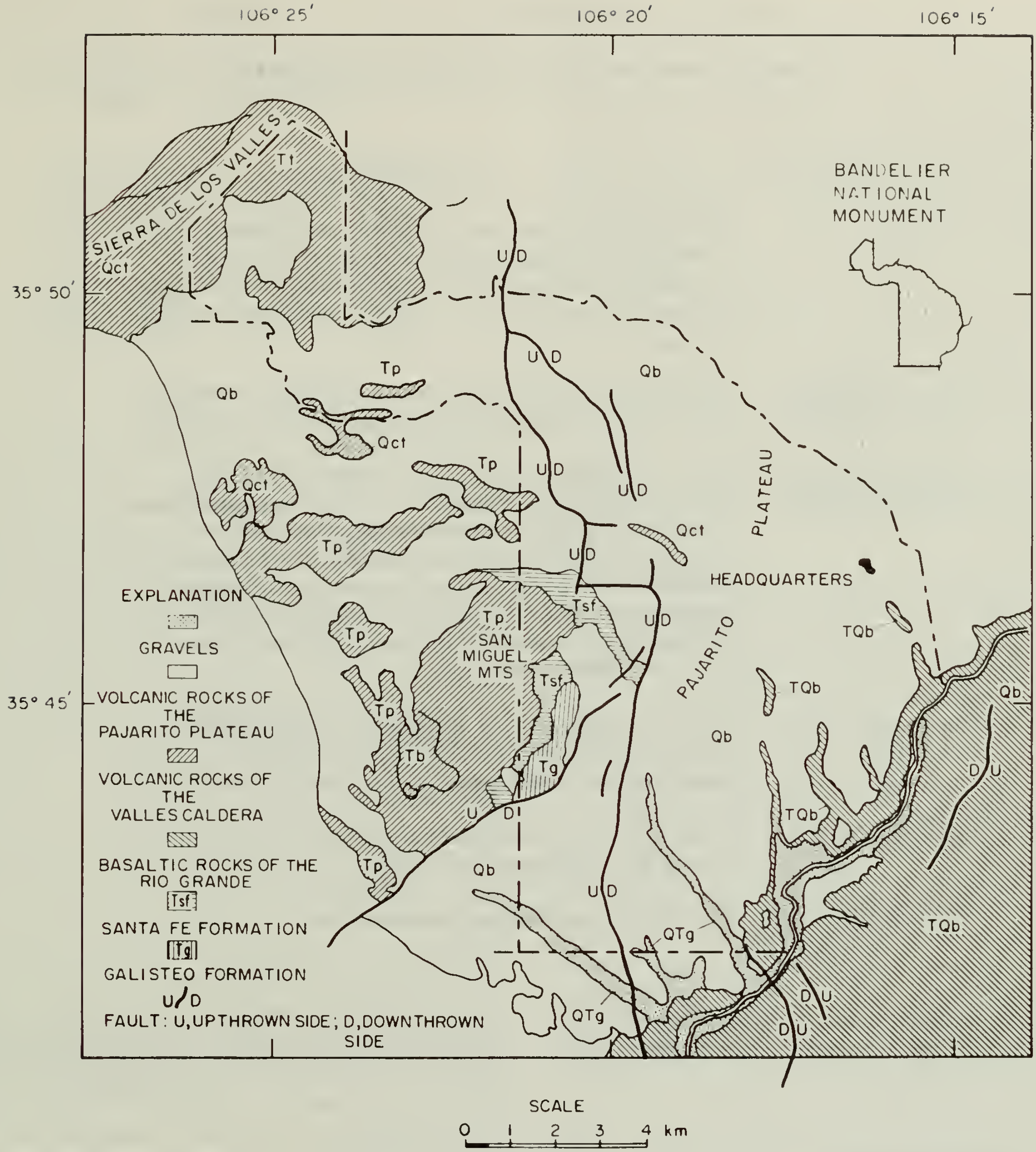

Fig. 2.

Generalized geologic map of Bandelier National Monument (see Table II for description of units).

the map as they form the upper surface of the Pajarito Plateau (Fig. 2). The volcanic rocks of the Valles Caldera form the Sierra de los Valles and San Miguel Mountains, while the basaltic rock of the Rio Grande outcrops along the Rio Grande. A large area of basalts occur east of the river. Alluvium is found along the Rio Grande and in the canyons cut into the plateau in the southern part of the area (Fig. 2).

The Monument is located on the western side of the Rio Grande depression, a structural basin that extends from southern Colorado through central New Mexico into northern Mexico.[6] Major faults

TABLE I

GENERALIZED STRATIGRAPHY OF MAP UNITS

Map Unit	Description
Alluvium	River gravels of recent age in Capulin and Sanchez Canyons; Old alluvium and pediment gravels of late Pliocene or early Pleistocene age in lower Capulin and Medio Canyon and midreach of Sanchez Canyon. All are shown as QTg in Figure 2.
Volcanic Rocks of the Pajarito Plateau	Bandelier Tuff (Qb) composed of ashflow and ashfalls of rhyolite tuff in units ranging from nonwelded to welded.
Volcanic Rocks of the Valles Caldera	Cerro Toledo Rhyolite (Qct) of rhyolite tuff and tuff breccias; Tschicoma Formation (Tt) of dacite and quartz latite forming thick massive flows and domes of the Sierra de Valles; Bearshead Rhyolite (Tb) of rhyolitic volcanic flows, domes, and intrusions; and the Paliza Canyon Formation (Tp) olivine-augite basalt, andesite-olivine basaltic andesite, and dacite and quartz latite in massive flows and domes.
Basaltic Rocks of the Rio Grande	Basaltic andesites of the Tank Nineteen basalts and basaltic lavas and tuff of Cerro del Rio (TQb) and including interbedded sediments containing basaltic debris.
Santa Fe Formation	Arkosic siltstone and sandstone with lenses of clay and pebbly conglomerate (Tsf).
Galisteo Formation	Shales, siltstone and conglomerate (Tg).

along the western boundary of the Monument are part of the faulting associated with the Rio Grande depression (Fig. 2).

II. SURFACE WATER

Major canyons that originate in or cross the Monument are Cañon de los Frijoles, Lummis, Alamo, Capulin, Medio and Sanchez. All are tributaries to the Rio Grande.

A. Rio Grande and Cochiti Reservoir

The Rio Grande is the master stream in north central New Mexico. The drainage area above Otowi (U.S. Geol. Survey Gaging Station), about 18 km upstream from the mouth of Cañon de los Frijoles, is about 37×10^3 km^2 in southern Colorado and northern New Mexico.

The discharge at Otowi for 78 years of record to 1978 has ranged from 1.7 m^3/s in 1902 to 691 m^3/s in 1920. During 1977 the discharge ranged from 4.8 m^3/s to 74 m^3/s, with 5.3×10^8 m^3 of water passing through the station. The daily sediment concentrations in 1977 ranged from 53 to 17 500 mg/ℓ, with about 8.1×10^8 kg of sediments carried by the station.[7]

During 1978 the discharge at Otowi ranged from 6.8 m^3/s to 114 m^3/s with 8.6×10^8 m^3 of water passing through the station. The daily sediment concentrations ranged from 76 to 6000 mg/ℓ with about

TABLE II

CAPACITY OF COCHITI RESERVOIR BASED ON ELEVATION

Elevation		Storage	
(m)	(ft)	(m^3)	(Ac-ft)
1621.5	5,320	56.7×10^6	46,010
1624.6	5,330	72.4×10^6	58,730
1627.7	5,340	90.5×10^6	73,410

1.1×10^9 kg of sediments carried through the station.[8]

Since 1973 a part of the flow of the Rio Grande has been impounded at Cochiti reservoir, about 9.6 km south of the Monument. Water impounded by the reservoir extends up the canyon into the Monument. In 1977, the maximum impoundment was at an elevation of 1622.4 m or near the mouth of Alamo Canyon (Fig. 3).[7] In 1978, the maximum impoundment reached an elevation of 1625 m. The capacity of the reservoir, based on elevations, is shown in Table II.

Based on surface water records at Otowi and Cochiti before construction of the reservoir, it was estimated that the Rio Grande gained about 0.71 m^3/s of ground water inflow in a 41.6 km reach of the river from Otowi to Cochiti.[9] Seepage investigations of the river in 1963 and 1964 indicated that 0.42 m^3/s were discharged to the river in the reach between Otowi and the mouth of Cañon de Frijoles. In the reach from Cañon de los Frijoles to Cochiti the river was losing water to the sediments and volcanics underlying the river channel.[10]

B. Chaquihui Canyon

Chaquihui Canyon heads on the eastern edge of the Pajarito Plateau and has a drainage area of 4.7 km^2 above the Rio Grande (Table III). Only a small part of the drainage area is within the Monument (Fig. 3). The channel is cut into tuff, basalts, and volcanic sediments, and has a steep gradient of about 9%. The middle reach of the canyon has perennial flow for a short distance from springs and seeps (Doe Spring) in the volcanic sediments.

C. Cañon de los Frijoles

Cañon de los Frijoles heads on the eastern slopes of the Sierra de los Valles and has a drainage area of 51.5 km^2 above the junction with the Rio Grande (Fig. 3). Almost all of the drainage area lies within the Monument. The canyon in the upper reach west of the Upper Crossing (Site No. D) is underlain by some andesite and latite, but is mainly cut into the tuff. East of the upper crossing and across the Pajarito Plateau the channel is cut into the tuff to near the Rio Grande where basalts and volcanic sediments underlie the channel. The basalts have limited downcutting of the canyon to the west. The gradient of the channel in the upper reach is about 7%, while to the east across the plateau the slope decreases to about 3%. Near the Rio Grande where the channel is cut into basalts the gradient increases to about 7%.

The surface flow in the canyon is perennial and generally extends to the Rio Grande except for short periods during the summer. The base flow is from springs that emerge from a densely welded tuff at an elevation of about 2570 km in the north and the west forks of the canyon as it cuts into the slopes of the Sierra de los Valles (Fig. 3).

The U.S. Geological Survey made a series of low-flow measurements in the canyon from 1958 through 1960 in order to determine increases or decreases in discharge in the various reaches of the canyon (Fig. 3).[11,12] Stream discharge increased slightly from the springs in the upper canyon downstream to the Site No. D, Upper Crossing (Table IV). The Upper Crossing is near the major fault that crosses the canyon (Fig. 2). The flow increase in this reach of the canyon is probably due to thinning of the alluvium west of the fault (return flow from alluvium), to seepage from coalluvium on the canyon walls, and in part to the fault zone as water from higher elevations moves downward through the brecciated zone. The canyon walls west of Upper Crossing range from 120 to 250 m in height. Surface flow decreases across the plateau by evapotranspiration with some loss of water into the alluvium and underlying tuff. The alluvium in the canyon appears to be thin, probably less than 6 m. East of the Monument Headquarters the alluvium thins further and the channel is cut onto basalts and volcanic sediments.

A surface water gaging station was operated near the Upper Crossing during 1960-62 (Table V). The

Fig. 3.
Drainage area and location of hydrologic stations.

drainage area above the station was 23.1 km². The annual runoff (i.e., drainage area to volume of runoff) ranged from 6.4 to 7.1 cm. This station was moved in 1963 into a reach of the canyon above the Monument Headquarters (Fig. 3). The drainage area above the relocated station was about 45.3 km². Runoff at the lower station ranged from 1.5 to 3.3 cm as the result of surface waters loss across the plateau (Table V).

The gaging station above the headquarters was activated in July 1977 after the wildfire. The fire burned about 26.2 km² or about 58% of the drainage area above the station. Runoff in 1978, after the

TABLE III

DRAINAGE AND BURN AREAS OF CANYONS

Canyon	Drainage Area[a] km²	Drainage Area[a] mi²	Burn Area km²	Burn Area mi²
Chaquihui	4.7	1.8	---	---
Slope 1 to Rio Grande	0.8	0.3	---	---
Canon de Frijoles	51.5	19.9	26.2	10.1
Slope 2 to Rio Grande	1.3	0.5	---	---
Canyon 3 to Rio Grande	2.3	0.9	---	---
Slope 4 to Rio Grande	1.3	0.5	---	---
Lummis[b]	19.7	7.6	6.0	2.3
Alamo	49.7	19.2	11.1	4.3
Slope 5 to Rio Grande	1.0	0.4	---	---
Capulin	51.0	19.7	3.1	1.2
Slope 6 to Rio Grande	0.8	0.3	---	---
Medio	17.1	6.6	---	---
Sanchez	19.9	7.7	---	---
Total			46.4	17.9

[a]At Rio Grande.

[b]Tributary to Capulin.

burn, was 128.2×10^4 m³ or about the same as occurred at the station (1964-69) before the fire (Table V). Though it appears that the volume of runoff has not changed, the time of collection and retention of precipitation in the drainage area has decreased. This resulted in larger discharge from runoff events.

The largest runoff event (1964-69) was 0.53 m³/s in June 1965. During the post-fire period, July 1977 through September 1978, 20 runoff events exceeded the discharge of 0.53 m³/s in 1965 (Table VI). The largest events, 51 m³/s and 88.5 m³/s were in July 1978.[7,8]

The burn removed most of the vegetation in the drainage area, thus reducing the holding capacity of precipitation. This has resulted in larger discharge yields from summer storms. The maximum yield prior to the burn was 0.012 m³/s/km². In a smaller canyon to the north the yield for a season of summer runoff events in 1967 averaged 0.024 m³/s/km².[13] The discharge yield since the fire for the 20 events in Cañon de los Frijoles has ranged from 0.015 to 1.95 m³/s/km². The discharge yield is highly variable as the precipitation from summer storms is highly localized and rainfall intensity varies in a long narrow drainage area such as Cañon de los Frijoles.

TABLE IV

LOW-FLOW MEASUREMENTS OF RITO DE LOS FRIJOLES (m³/s)

	1958	1959					1960		
Site No.[a]	10-20	4-16	4-29	6-3	9-3	10-12	5-16	6-20	Av
A	---	---	0.025	0.014	0.008	0.003	0.025	0.014	0.015
B	---	---	0.040	0.025	0.017	0.017	0.040	0.025	0.027
C	---	---	0.059	0.042	0.034	0.034	0.045	0.034	0.041
D	0.054	0.076	---	0.045	---	0.040	0.059	0.034	0.051
E	0.034	0.074	---	0.042	0.034	0.028	0.042	0.023	0.040
F	0.042	0.068	---	0.031	0.034	0.031	---	0.025	0.038
G	0.034	0.062	---	0.037	0.034	0.028	0.048	0.028	0.038
H	0.037	0.074	---	0.031	0.031	0.028	0.042	0.023	0.038
I	0.034	0.045	---	0.031	0.034	0.023	0.040	0.023	0.032
J	---	---	---	---	0.020	0.014	0.034	0.008	0.019

[a]For location, see Fig. 3.

TABLE V

ANNUAL RUNOFF AT GAGING STATIONS

Water Year	Volume		Runoff	
	10^4 m^3	Acre-feet	cm	in.
1960	164.3	1332	7.11	2.8
1961	145.5	1180	6.35	2.5
1962	152.9	1240	6.60	2.6
1963	---	---	---	---
1964	71.5	580	1.52	0.6
1965	102.3	830	2.03	0.8
1966	90.6	735	2.03	0.8
1967	83.0	673	1.78	0.7
1968	155.4	1260	3.30	1.3
1969	128.2	1040	2.78	1.1
1978[a]	128.2	1040	2.78	1.1

[a]After burn.

Note: 1960-62 drainage area 23.1 km^2 (8.9 mi^2); 1964-69 and 1978 drainage area 45.3 km^2 (17.5 mi^2).

D. Lummis Canyon

Lummis Canyon heads on the Pajarito Plateau and has a drainage area of 19.7 km^2 above the Rio Grande (Fig. 3). About 6.0 km^2 or 30% of the drainage area was burned over in the 1977 fire. The canyon is cut into the tuff in the upper and middle reaches and into the basalts and sediments along the Rio Grande. The gradient of the channel is about 4%.

Stream flow in the canyon is a result of snowmelt runoff or summer type storms. On July 5, 1977, after the burn, precipitation in the drainage area produced a runoff event, with a discharge estimated at 6.5 m^3/s. The drainage area discharge yield for the event was 0.33 $m^3/s/km^2$, or slightly less than the 0.41 $m^3/s/km^2$ that occurred in Cañon de los Frijoles on the same day (Table VI).

E. Alamo Canyon

Alamo Canyon heads on the flanks of the Sierra de los Valles and has a drainage area of 49.7 km^2 above the Rio Grande (Table II). About 11.1 km^2 or 22% of the drainage area was burned over in 1977. The upper and middle reach of the canyon cuts mainly into the tuff and small segments of other volcanic rocks, while the lower reach above the Rio Grande is cut into basalts and sediments (Fig. 2). The gradient of the channel in the upper reach west of the Monument boundary is about 7%, while in the middle and lower reach of the canyon the gradient is about 4%.

Stream flow in the upper, middle, and part of the lower reach is perennial. The base flow is from springs and seeps in the upper reach of the channel. Flow decreases eastward in the canyon as water is lost to evapotranspiration and infiltration into the underlying alluvium and volcanic rocks. Base flow in July 1977 was 0.002 m^3/s at Station K, 0.001 m^3/s at Station L, and 0.0006 m^3/s at station O (Fig. 3).

On July 5, 1977, precipitation produced a runoff event similar to that in Cañon de los Frijoles and Lummis Canyon. The discharge was estimated at 7.6 m^3/s. The drainage area yielded about 0.15 $m^3/s/km^2$ or less than occurred from the same storm in Cañon de los Frijoles and Lummis Canyon. The percent of burn in the drainage area decreased from 42% in Cañon de los Frijoles to 30% in Lummis and 22% in Alamo, with runoff yield of 0.41 $m^3/s/km^2$, 0.33 $m^3/s/km^2$, and 0.15 $m^3/s/km^2$, respectively for the same storm.

F. Capulin Canyon

Capulin Canyon heads on the Pajarito Plateau but also receives part of the drainage from the San Miguel Mountains. The drainage area is about 51.0 km^2 above the Rio Grande. About 3.1 km^2 or 6% of the drainage area was burned over in 1977. The channel is cut into tuff and volcanics in the upper reach west of the Monument boundary. East of the boundary on the Pajarito Plateau the middle reach is cut into the tuff and older sediments of the Santa Fe Formation. The lower reach is underlain by gravels, some recent and some older sediments. The gradient of the channel in the upper reach is about 6% and in the middle and lower reaches is about 4%.

Stream flow in the upper, middle, and part of the lower reaches of the canyon is perennial. The base flow is from springs and seep in the upper reach of the canyon. Base flow in July 1977 was 0.02 m^3/s at

TABLE VI

MAXIMUM DISCHARGES ABOVE 0.54 m^3/s (19 cfs) AND RUNOFF JULY—SEPTEMBER 1977-78

Date	Time	Discharge m^3/s	Discharge ft^3/s	Runoff $m^3/s/km^2$	Runoff $ft^3/s/mi^2$
July 5, 1977	(Unknown)	18.5	653	0.408	37.3
July 8, 1977	(18:00)	2.18	77	0.048	4.4
July 9, 1977	(19:30)	2.55	90	0.056	5.1
July 27, 1977	(15:30)	10.8	382	0.238	21.8
Aug. 12, 1977	(08:45)	10.9	386	0.241	22.1
Aug. 12, 1977	(15:15)	0.68	24	0.015	1.4
Aug. 16, 1977	(01:30)	1.42	50	0.031	2.8
Aug. 17, 1977	(20:15)	1.05	37	0.023	2.1
Aug. 19, 1977	(20:30)	6.63	234	0.146	13.4
Aug. 20, 1977	(15:15)	14.7	519	0.325	29.7
Aug. 20, 1977	(21:30)	7.48	264	0.165	15.1
Aug. 22, 1977	(16:30)	10.1	358	0.223	20.5
Sept. 2, 1977	(15:45)	1.59	56	0.035	3.2
Sept. 3, 1977	(14:30)	2.10	74	0.046	4.3
Oct. 4, 1977	(17:00)	1.25	44	0.028	2.5
June 30, 1978	(13:00)	8.38	296	0.185	16.9
July 12, 1978	(15:00)	51.0	1800	1.13	103
July 21, 1978	(13:45)	88.5	3030	1.95	173
Aug. 9, 1978	(20:30)	1.39	49	0.031	2.8
Sept. 24, 1978	(06:00)	0.99	35	0.22	2.0

Stations N and O (Fig. 3). Stream flow east of Station O (Base Camp) decreases with evapotranspiration and infiltration into gravels that make up the stream channel.

G. Medio Canyon

Medio Canyon heads on the southern flanks of the San Miguel Mountains and has a drainage area of about 17.1 km^2 above the Rio Grande. Only the middle reach of the canyon is within the Monument. The upper reach of the channel west of the Monument boundary is cut into the volcanic rocks associated with the Valles Caldera. The middle reach is cut into the tuff while the lower reach above the Rio Grande is underlain by older gravels, basalts and associated sediments. The gradient of the upper reach is about 13%, while in the middle and lower reaches the gradient is about 4%. The stream flow in the upper reach of the canyon is perennial, fed by springs and seeps in the volcanic rocks.

H. Sanchez Canyon

Sanchez Canyon heads on the western flanks of the San Miguel Mountains and has a drainage area of about 19.9 km^2. Only a small part of the canyon is within the Monument (Fig. 3). The channel is cut into the tuff and other volcanic rocks west of the Monument boundary and into gravels and sediments both recent and older as it extends eastward across the Monument to the Rio Grande. The gradient of the channel west of the boundary is 8% and east of the boundary to the Rio Grande is about 4%. The middle reach of the canyon contains perennial flow from small springs and seeps (Fig. 3).

I. Other Drainage Areas

Six smaller drainage areas are located near the Monument boundary adjacent to the Rio Grande (Fig. 3). All, except one described below, are steep slopes at the end of the mesas between major canyons. The slopes contain no well defined stream channels. Runoff from the slopes is intermittent and occurs in many small channels during excessive precipitation. Slope 1 contains a small seep area high on the canyon wall. The seep is in sediments associated with basalts and is covered by an area of vegetation.

The one exception is Canyon 3 below Cañon de los Frijoles with a drainage area of 2.3 km² (Fig. 3). The upper reach of the canyon is cut into the tuff and near the Rio Grande it is cut into basalts and sediments. The gradient of the channel is about 8%.

III. GROUND WATER

Ground water occurs as springs in or adjacent to the Monument. Some of these springs form base flow in several of the canyons. Five springs, two adjacent to and three within the Monument are described. There are no wells or test holes within the Monument. Hydrology of the Main Aquifer of the Los Alamos area (deep ground water body) is described from data collected adjacent to the Monument.[3,14-18]

A. Springs

Springs adjacent to the Monument are Doe and Turkey Springs (Fig. 4). Doe Spring discharges from sediments below a basalt flow in Chaquihui Canyon. The spring is a large seep area on the north wall of the canyon. The seep area forms several deep pools in a short reach of the canyon. Turkey Spring discharges from volcanic rocks associated with the Valles Caldera. The spring discharge is about 1.4 ℓ/s. This spring maintains surface flow in the upper reach of the canyon tributary to Capulin Canyon (Fig. 4).

Springs in the Monument are located in the North Fork of Cañon de los Frijoles (Station 3), Apache Spring (Station 7), and near the mouth of Cañon de los Frijoles (Station 10).

The spring at Station 3, North Fork of Cañon de los Frijoles, discharges from volcanics associated with the Valles Caldera. The source, perched aquifer in fractured, densely welded latites, is rather large as the discharge from this aquifer in both the north and west fork of the canyon forms the base flow in Cañon de los Frijoles (Fig. 4). Base flow in the canyon below the junction is about 0.015 m³/s. Recharge to the aquifer is probably from a shallow water bearing zone in the Valles Caldera.

The spring at Station 7 (Apache Spring) discharges from a welded unit of tuff on the north side of Cañon de los Frijoles (Fig. 3). The water body, perched in the tuff, is small as flow from the collection tank (built by Civil Conservation Corps in the 1930s) is <0.06 ℓ/s.

The spring near the mouth of Cañon de los Frijoles (Station 10) discharges from volcanic sediments associated with basalts. The discharge is about 0.1 ℓ/s and is from the main aquifer.

About 20 springs and seeps discharge from the main aquifer along the Rio Grande north of Cañon de los Frijoles. There are no springs and seeps south of Cañon de los Frijoles along the Rio Grande.[10]

B. Main Aquifer of the Los Alamos Area

The surface of the main aquifer rises westward from the Rio Grande from basalts and associated sediments into a fanglomerate which lies below the tuff. North of the Monument along the western edge of the Pajarito Plateau the surface of the aquifer lies at a depth of 300 to 375 m; the surface slopes gently eastward at about 10 m/km. The water in the aquifer moves from the major recharge area in the Valles Caldera eastward to the Rio Grande, where a part is discharged through seeps and springs north of the mouth of Cañon de los Frijoles.

Tests of the main aquifer (in two test holes) on the plateau north of the Monument indicated a transmissivity of 450 m³/day with 72 m of penetration of the aquifer and 750 m³/day with 152 m of penetration. The test, at a pumping rate of 5 ℓ/s, indicated specific capacity of 3.3 ℓ/s/m and 4.6 ℓ/s/m of drawdown for a 24-hr test. Based on the gradient of the potentiometric surface of the aquifer and hydrologic characteristics of the aquifer, the rate of movement in the aquifer was calculated to be about 120 m/yr.

Fig. 4.
Burn area and location of water sampling stations.

Generalized contours of the potentiometric surface of the main aquifer were extrapolated from the Los Alamos area to the north into the eastern part of the Monument using the additional control of a well in Cochiti Canyon southwest of the Monument and wells and test holes east of the Rio Grande.[19] The Rio Grande above the mouth of Cañon de los Frijoles is a gaining stream (ground water discharge to the river) while below the mouth of the canyon the river is a losing stream (river recharging the aquifer). Thus the surface of the aquifer north of Cañon de los Frijoles along the Rio Grande is at or slightly above the river level while the surface of the aquifer to the south is at an elevation below the river level (Fig. 5).

The movement of water in the southern part of the Monument trends more to the south than southeast in the Los Alamos area. A small ground water depression forms west of the river south of the Monument.[20] This depression, offset west of the river, extends into the Bernalillo-Albuquerque area to the south.[21] The major faults along the western edge of the Monument and the intrusion of volcanic rocks of the Valles Caldera that form the San Miquel Mountains apparently restrict the movement of water in the western part of the Monument and west of the Monument boundary from the main recharge area in the Valles Caldera. Depth to the top of the main aquifer at Monument Headquarters is estimated to be 108 m, and at Base Camp in Capulin Canyon at 185 m (Fig. 5).

IV. QUALITY OF WATER

Water quality data were obtained from samples of surface water in the Rio Grande and Cañon de los Frijoles and several springs prior to the wildfire in 1977 (Table VII). After the fire, two sets of samples, 1977 and 1978, were collected in and adjacent to the Monument of surface water in major canyons and at springs (Table VIII). Routine analyses of these samples included calcium, magnesium, sodium, carbonate, bicarbonate, chloride, fluoride, nitrate, total dissolved solids (TDS), total hardness, specific conductance and pH.

Samples of base flow and runoff events were collected in Cañon de los Frijoles and Alamo and Capulin Canyons by Monument personnel. These samples were analyzed by Environmental Consultants Inc. (Clarksville, Indiana). The analyses included a number of different constituents. Those showing the largest change were barium, calcium, bicarbonate, manganese, magnesium, lead, phenol, and zinc, as shown in Table IX.

A. Surface Water

Water samples are routinely collected from the Rio Grande at Otowi north of the Monument and from the Rio Grande below Cochiti Dam south of the Monument. Water in the river contains principal ions of calcium and bicarbonate (Tables VII, VIII). The chemical quality of the water in the Rio Grande will vary at a given station during the year because of dilution of base flow with storm runoff from various parts of the drainage area (Fig. 6).

Water samples have been collected from Cañon de los Frijoles at the Monument Headquarters since 1957. The principal ions in the stream water are calcium and bicarbonate. The water is typical of mountain streams in the area with TDS ranging from 84 to 168 mg/ℓ for samples collected prior to the fire in 1977. Variations in constituent concentrations occurs as the result of increase discharge due to storm runoff resulting in dilution of base flow (Table VII). Debris washed into the stream after the fire caused a slight increase in some chemical constituents (Table VIII).

During the 1958-60 low-flow investigations, water samples were collected at various stations and analyzed for calcium-carbonate, sodium, and chloride (Table X). The average calcium-carbonate and sodium concentration increased only slightly downgradient; chloride varied considerably but also generally increased downgradient.[22] The slight increase in constituent concentrations is caused by minerals taken into solution from the alluvium.

In July 1977 after the fire, water samples were collected from six stations above and below the burn (Fig. 4). These stations and one additional station were sampled a year later in June and July 1978. A graphic comparison by station of calcium, sodium, chloride, TDS, and bicarbonate of samples taken in 1977 shows a general increase in these constituents downgradient in the canyon. The largest increase occurs between stations 5 and 6 where the stream enters the burn area (Fig. 7). Chemicals leached from the fire debris in the burn area enter the stream increasing certain chemical concentrations. In 1978,

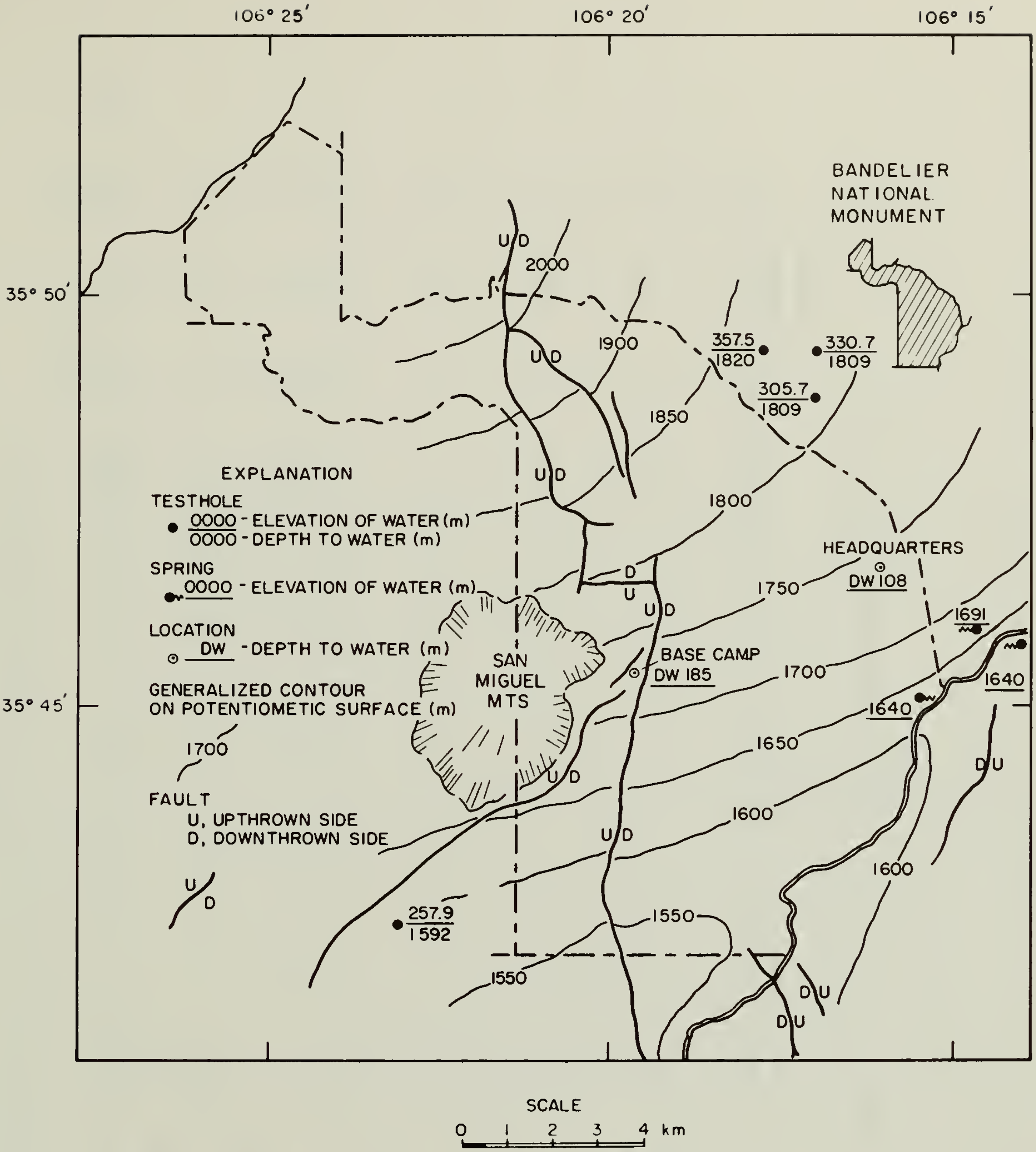

Fig. 5.
Generalized contours on the potentiometric surface of the main aquifer.

the constituents increased at station 6 (near Monument Headquarters), then decreased slightly at the Rio Grande. A comparison of the constituents in 1977 to those in 1978 show considerable variation but below station 6 a general decrease in most concentrations is indicated.

The burn brought about a slight increase in calcium, bicarbonate, chloride, fluoride, and TDS in base flow at the Monument Headquarters (Fig. 8). TDS concentrations increased after the fire from 110 mg/ℓ in March 1977 to 214 mg/ℓ in July 1977. After July, the TDS concentrations declined slightly (Fig.

TABLE VII

CHEMICAL QUALITY OF SURFACE AND GROUND WATER, AUGUST 1957-MARCH 1977

Station	Location	Date	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	CO_3 (mg/ℓ)	HCO_3 (mg/ℓ)	Cℓ (mg/ℓ)	F (mg/ℓ)	NO_2 (mg/ℓ)	TDS (mg/ℓ)	Total Hard	Specific Conductance (μmho)	pH
Adjacent to Monument														
---	Rio Grande at Otowi	3-8-77	44	7	23	0	124	8	0.4	0.8	316	138	390	8.0
---	Rio Grande at Cochiti	3-8-77	44	8	22	0	136	2	0.4	0.4	308	142	390	8.2
---	Doe Spring	10-27-74	13	2	13	0	66	4	0.5	0.8	138	42	130	7.1
---	Test Well-Plateau	3-11-77	9	1	11	0	56	3	0.2	0.3	106	28	130	7.7
5	Frijoles, Upper Crossing	5-13-66	6	3	13	0	34	1	0.2	0.4	111	28	80	7.4
Inside Monument														
7	Apache Spring	6-7-61	---	---	5	0	67	1	0.1	0.1	---	44	120	7.1
8	Frijoles, Mon. Hdq													
		1957-1976												
	No. of Analyses		13	13	23	23	23	23	22	22	13	23	23	23
	Minimum		6	2	5	0	34	<1	<0.1	0.1	84	28	70	7.1
	Maximum		11	11	15	0	82	8	0.9	1.6	168	68	145	8.4
	Average		9	5	10	0	56	3	0.3	0.4	137	39	106	7.6
	Standard Deviation		1	2	3	0	11	2	0.2	0.3	25	9	17	0.3
		3-8-77	8	2	10	0	48	2	0.2	<0.4	110	30	120	7.9
9	Frijoles at Rio Grande	9-12-73	13	3	11	0	56	4	<0.1	0.4	174	44	120	7.8
10	Spring	9-1-73	11	4	9	0	68	6	0.2	0.8	206	44	120	7.4
		10-3-74	13	2	13	0	66	4	0.5	0.8	138	42	130	7.1

TABLE VIII

CHEMICAL QUALITY OF SURFACE AND GROUND WATER, JUNE 1977-SEPTEMBER 1978

Station	Location	Date	mg/ℓ SiO$_2$	Ca	Mg	K	Na	CO$_3$	HCO$_3$	SO$_4$	Cℓ	F	NO$_3$	TDS	Total Hard	Specific Conductance (μmho)	pH	Total Uranium (μg/ℓ)	Temp (°C)
Adjacent to Monument																			
---	Rio Grande at Otowi	3-6-78	---	38	9	---	24	0	139	---	6	0.5	<0.4	394	131	350	8.5	---	---
---	Rio Grande at Cochiti	3-7-78	---	36	8	---	25	0	156	---	2	0.5	<0.4	410	123	350	8.3	---	---
---	Doe Spring	9-20-78	---	8	3	---	11	0	78	---	2	0.5	0.4	160	33	140	---	---	---
---	Test Well—Plateau	10-27-77	---	8	4	---	17	0	58	---	2	0.2	0.2	149	36	130	7.6	---	---
---	Turkey Spring	7-10-77	---	24	5	2.5	11	0	104	---	3	0.2	<0.1	166	80	250	7.8	2.0 ± 0.3	19
---		7-10-78	69	23	7	---	11	0	100	<1	4	0.3	<0.1	188	87	215	8.4	---	---
Inside Monument																			
01	Frijoles, North Fork	7-8-77	---	13	3	3.2	5	0	48	---	12	0.1	0.1	154	44	130	7.3	1.9 ± 0.6	10
01		6-27-78	63	7	4	---	9	0	46	5	4	0.2	0.1	158	32	120	7.8	---	---
02	Frijoles, West Fork	7-8-77	---	10	2	0.7	9	0	48	---	5	0.2	0.1	164	34	130	7.8	2.5 ± 0.6	16
02		6-27-78	70	4	2	---	11	0	40	9	2	0.3	<0.1	168	19	90	7.7	---	---
03	Spring, North Fork	7-8-77	---	12	3	2.3	8	0	66	---	2	0.1	0.1	150	44	130	7.8	2.5 ± 0.6	10
03		6-27-78	79	6	2	---	15	0	54	6	1	0.3	0.1	174	23	120	7.9	---	---
04	Frijoles, Confluence	6-27-78	60	6	6	9	9	0	48	4	4	0.2	0.1	158	38	120	7.9	---	---
05	Frijoles above Burn	7-8-77	---	10	<1	0.2	9	0	62	---	5	0.1	0.1	140	26	100	7.7	2.8 ± 0.6	15
05		6-27-78	66	6	4	---	15	0	46	6	<1	0.2	<0.1	162	31	110	7.9	---	---
06	Frijoles, Upper Crossing	7-8-77	---	17	3	1.1	9	0	84	---	6	0.1	0.2	166	56	170	7.6	3.4 ± 0.8	17
06		6-27-78	69	9	4	---	10	0	56	4	4	0.2	0.1	164	39	130	8.0	---	---
07	Apache Spring	7-8-77	---	13	5	3.5	14	0	60	---	22	0.1	0.1	222	54	200	7.5	2.0 ± 0.6	7
07		7-10-78	55	10	6	---	10	0	56	5	5	0.3	0.1	110	50	160	7.7	---	---
08	Frijoles. Mon. Hdq	7-10-77	---	32	4	1.9	10	0	120	---	7	0.2	0.3	214	96	220	7.6	5.5 ± 0.8	13
08		11-1-77	---	13	<1	---	22	0	78	---	7	0.3	1.6	190	32	180	7.9	---	---
08		3-8-78	48	5	3	---	10	0	185	18	9	0.6	7.0	162	27	120	8.2	0.2 ± 0.1	---
08		6-26-78	63	11	4	---	11	0	66	<1	2	0.3	0.1	120	44	150	8.0	---	---
08		3-12-79	26	6	3	2.5	10	0	56	11	3	0.2	<0.1	162	25	130	8.3	0.2 ± 0.4	---
09	Frijoles at Rio Grande	7-10-77	---	34	4	4.5	13	0	124	---	2	<0.1	0.5	246	102	260	7.5	6.8 ± 1.0	17
09		9-14-77	---	22	4	---	17	0	102	---	6	0.2	0.4	182	72	210	8.5	---	17
09		6-26-78	65	13	5	---	11	0	74	<1	2	0.3	<0.1	126	52	180	7.8	---	---
10	Spring 10	9-14-77	---	13	2	---	11	0	62	---	4	0.5	0.3	138	41	140	7.8	---	18
10		6-26-78	67	10	5	---	11	0	66	<1	1	0.4	0.2	118	47	150	8.0	---	---
10		9-20-78	62	8	3	---	11	0	78	2	2	0.5	0.4	160	70	140	---		

TABLE VIII (cont)

CHEMICAL QUALITY OF SURFACE AND GROUND WATER, JUNE 1977-SEPTEMBER 1978

			mg/ℓ												Total Hard	Specific Conductance (μmho)	pH	Total Uranium (μg/ℓ)	Temp (°C)
Station	Location	Date	SiO_2	Ca	Mg	K	Na	CO_3	HCO_3	SO_4	Cℓ	F	NO_3	TDS					
11	Alamo Canyon	7-10-77	---	13	3	4.1	3	0	50	---	2	0.2	0.2	148	44	140	7.2	2.5 ± 0.6	11
11		7-10-78	20	6	3	---	4	0	34	<1	1	0.2	<0.1	68	29	100	7.0	---	---
12	Alamo Canyon	7-10-77	---	29	4	6.3	8	0	98	---	1	0.1	0.1	176	90	260	7.6	2.4 ± 0.6	15
12		7-10-78	51	19	6	---	9	0	80	11	2	0.3	<0.1	114	71	200	8.1	---	---
13	Alamo Canyon	7-10-77	---	33	5	4.0	11	0	122	---	3	0.1	0.3	232	104	240	7.7	3.7 ± 0.8	22
13		7-10-78	43	24	6	---	9	0	82	6	3	0.6	<0.1	178	83	210	8.2	---	---
14	Capulin Canyon	7-10-77	---	15	3	2.3	10	0	72	---	3	0.1	0.1	148	51	170	7.7	1.9 ± 0.6	17
14		7-10-78	69	12	5	---	10	0	66	<1	3	0.5	<0.1	162	51	145	8.5	---	---
15	Capulin Canyon	7-9-77		21	4	4.5	8	0	92	---	2	0.2	0.1	178	70	220	7.8	2.4 ± 0.6	18
15		7-10-78	61	14	4	---	10	0	72	<1	3	0.4	<0.1	162	54	160	8.3	---	---

TABLE IX

CHEMICAL QUALITY OF BASE FLOW AND STORM RUNOFF
(Analyses in mg/ℓ)

Station	Location	Type of Flow	Date	Ba	Ca	Fe	HCO_3	Mg	Mn	Pb	Phenol	Zn
8	Frijoles, Mon. Hdq.	Storm	8-12-77	1.5	164	42	262	9	9.3	0.58	0.068	0.6
		Base	8-27-77	<0.5	100	2.4	92	14	0.4	<0.03	<0.005	<0.5
		Base	9-15-77	<0.5	101	0.8	88	13	<0.1	<0.03	<0.001	<0.5
		Base	10-1-77	<0.5	19	0.9	89	6	<0.1	<0.03	<0.001	0.6
		Base	2-8-78	<0.5	3	<0.5	67	1	<0.1	<0.03	0.003	<0.5
		Storm	6-19-78	1.3	58	240	112	28	14	1.0	0.023	1.2
13	Alamo Canyon	Base	9-1-77	<0.5	87	0.6	80	11	<0.1	<0.3	<0.001	<0.5
		Base	10-6-77	<0.5	20	<0.5	85	5	0.1	<0.3	0.002	<0.5
		Base	6-2-77	<0.5	6	<0.5	95	1	<0.1	<0.3	<0.001	<0.5
15	Capulin Canyon	Storm	8-17-77	0.8	112	3.7	52	20	1.2	<0.3	<0.001	<0.5
		Base	9-9-77	<0.5	65	<0.5	72	13	<0.1	<0.3	<0.001	<0.5
		Base	4-30-78	<0.5	5	<0.5	81	1	<0.1	<0.3	<0.001	<0.5
		Base	11-30-78	<0.5	6	<0.5	56	7	<0.1	<0.3	<0.001	<0.5

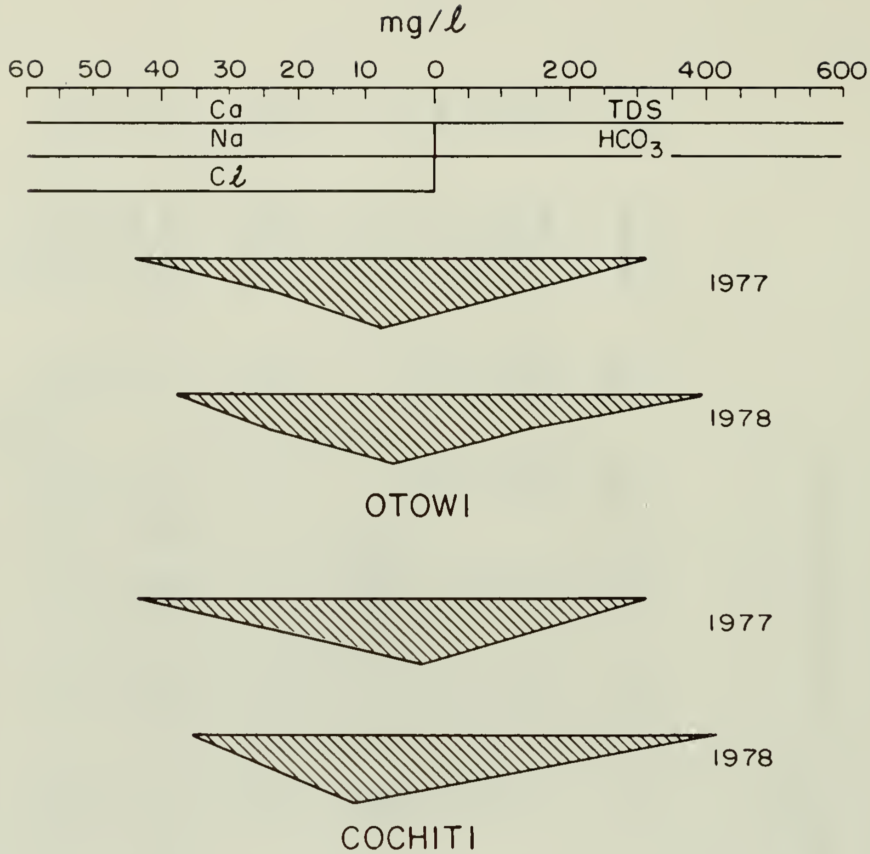

Fig. 6.
Calcium, sodium, chloride, total dissolved solids, and bicarbonates at Otowi and Cochiti on the Rio Grande.

8). Sodium and fluoride varied slightly but showed no significant trend (Table VIII). These constituents in base flow have shown a general decline in concentration as the fire debris and ash are removed from the channel by continued runoff.

Samples of base flow and storm runoff were collected in Cañon de los Frijoles, indicating barium, calcium, iron, bicarbonate, manganese, lead, phenol, and zinc concentrations were elevated in storm runoff when compared to base flow (Table IX). Phenol is attributed to decay of vegetation. Other constituents, with the exception of lead, can be attributed to the runoff from the burn area. Lead could be from automobile emissions, as it was not reported in a similar runoff event in Capulin Canyon, which is remote from vehicle traffic (Fig. 9).

Three surface water samples were collected in Alamo Canyon in July 1977 and 1978 above, within, and downgradient from the burn (Fig. 4). The water

TABLE X

AVERAGE CALCIUM BICARBONATE, SODIUM, AND CHLORIDE AT LOW-FLOW STATIONS, 1958-60

Low-Flow Stations	mg/ℓ		
	$CaCO_3$	Na	Cℓ
C	30	8.2	2.0
D	30	8.8	1.6
E	31	8.8	1.8
F	32	9.0	1.9
G	32	8.6	1.8
H	32	9.2	1.8
I	33	9.3	1.7
J	34	10.5	2.5

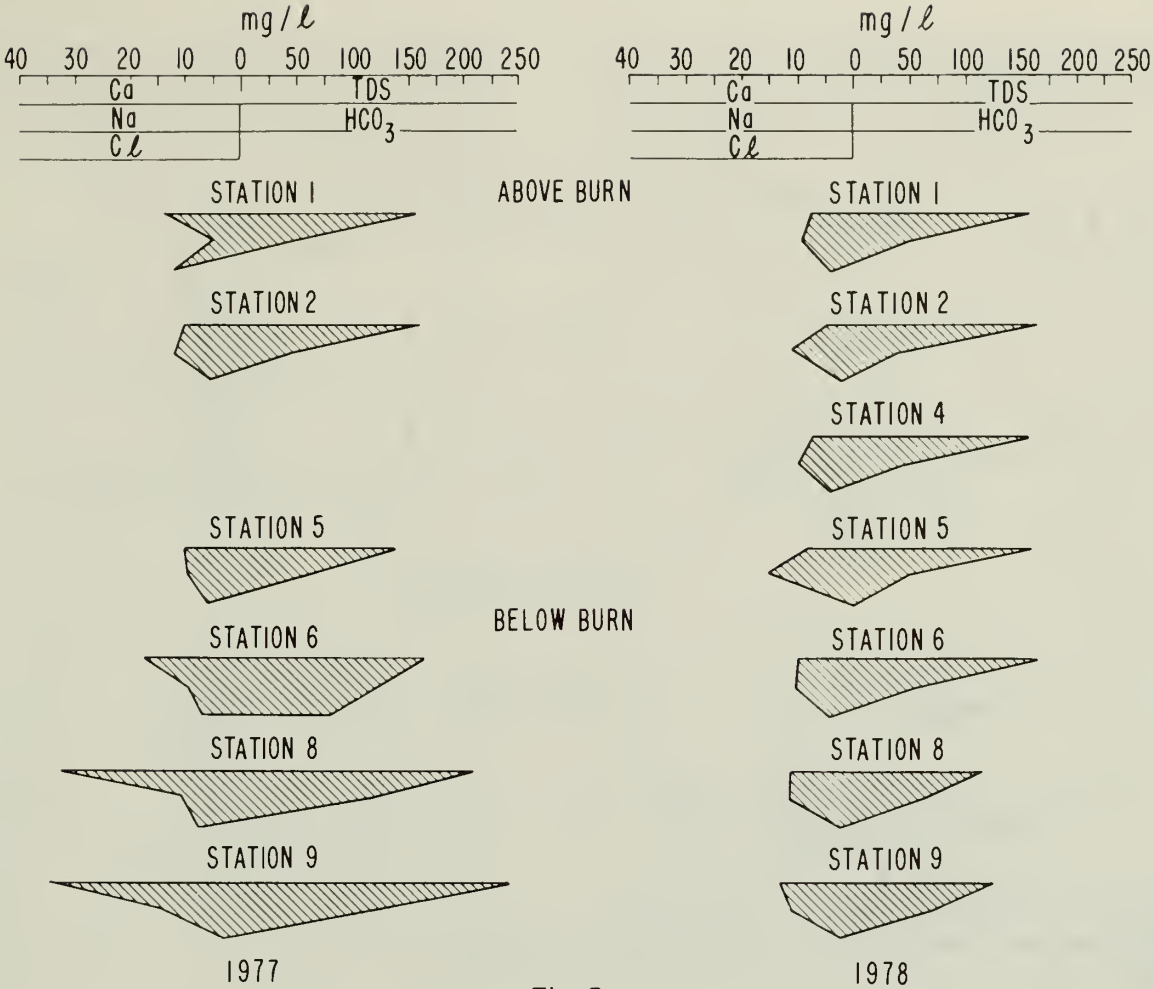

Fig. 7.

Calcium, sodium, chloride, total dissolved solids, and bicarbonate in surface water from Cañon de los Frijoles.

contains principal ions of calcium and bicarbonate (Table VIII). A comparison of the water quality at the three stations in 1977 shows the effect of the burn, with a slight increase of calcium, sodium, bicarbonate, and TDS (Fig. 10). Analyses of samples collected in 1978 indicated a decrease in most of these constituents,. Three analyses of base flow for barium, calcium, iron, bicarbonate, magnesium, manganese, lead, phenol, and zinc are shown in Table IX. Only calcium and magnesium decreased during the year. The remaining constituents varied but showed no significant trends.

Surface water below the burn in Capulin Canyon was sampled in 1977 and 1978 (Fig. 4). The base flow contains principal ions of calcium and bicarbonate (Table VIII). The concentrations of calcium, bicarbonate, and TDS generally increase downgradient in the canyon. The concentrations of these constituents decreased from 1977 to 1978 when compared at individual stations.

Samples of base flow and storm runoff at Station 15 (Base Camp) were analyzed for barium, calcium, iron, bicarbonate, magnesium, manganese, lead, phenol, and zinc (Table IX). Barium, calcium, iron, and manganese concentrations were elevated during runoff events. Bicarbonate varied but showed no significant trend. Phenols and lead were below analytical limits.

B. Ground Water

Ground water from springs in and adjacent to the Monument has been analyzed for routine chemical constituents. Included in ground water data are one

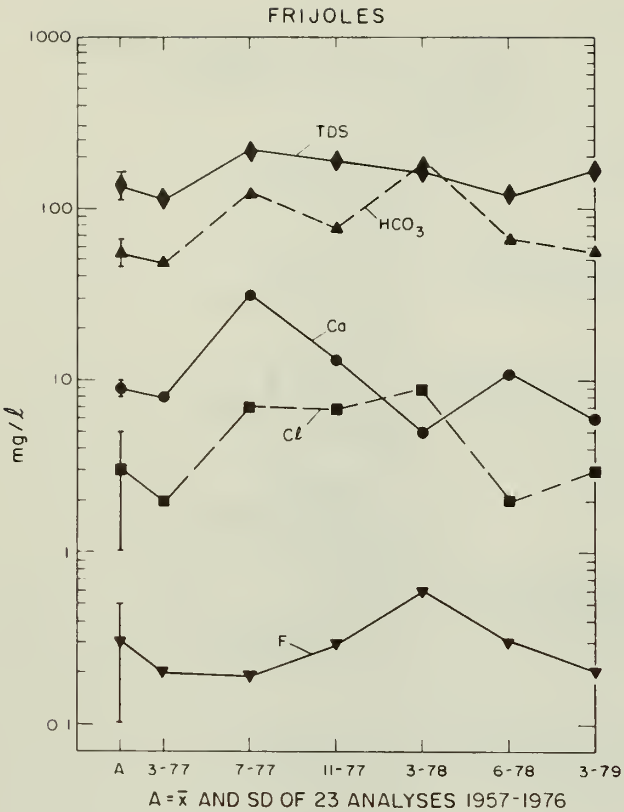

Fig. 8.
Base flow chemical constituent variation in Cañon de los Frijoles before and after the La Mesa Fire.

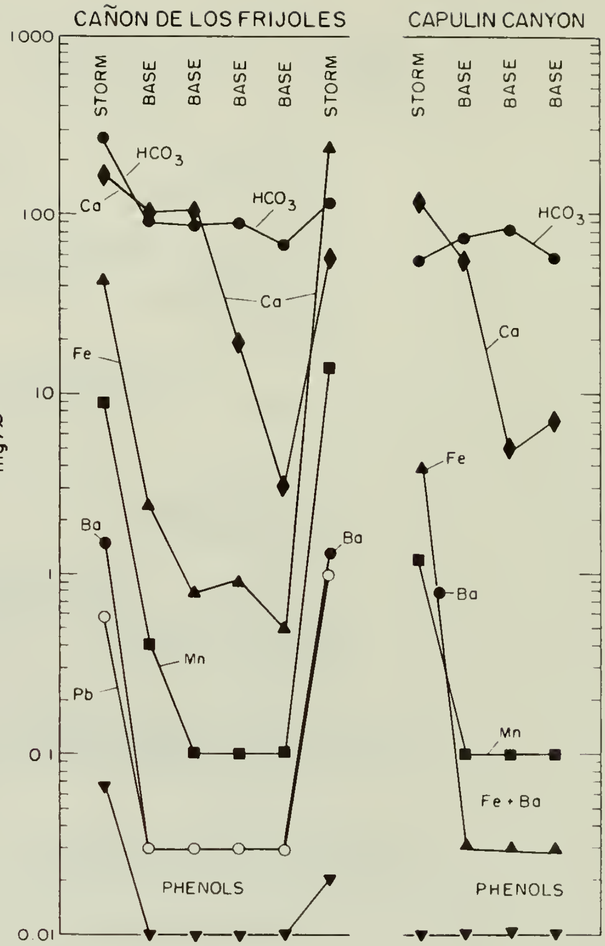

Fig. 9.
Base flow and storm runoff chemical constituent variations in Cañon de los Frijoles and Capulin Canyon after the La Mesa Fire.

chemical analysis from a test hole completed in the main aquifer on the plateau north of the Monument.

Doe and Turkey Springs are located adjacent to the Monument (Fig. 4). The principal ions in water from Doe Spring are sodium and bicarbonate (Fig. 11). The TDS is low, below 200 mg/ℓ with a water temperature of 18°C (Tables VII, VIII). The principal ions in water from Turkey Spring are calcium and bicarbonate (Fig. 11). TDS is under 250 mg/ℓ with water temperature of 19°C.

Three springs in the Monument are at Station 3 (North Fork of Cañon de los Frijoles), Station 7 (Apache Spring), and Station 10 (near mouth of Canon de los Frijoles). The discharge of the spring at Station 3 forms a part of the base flow in Cañon de los Frijoles. The water contains principal ions of calcium and bicarbonate (Tables VII, VIII). TDS are less than 175 mg/ℓ with a water temperature of about 10°C. Station 7 is a small seep with principal ions of calcium-sodium and bicarbonate (Fig. 11). TDS are low, less than 150 mg/ℓ, with a water temperature of 9°C. Water from the spring at Station 10 contains principal ions of sodium and bicarbonate with a water temperature of about 19°C. TDS are less than 200 mg/ℓ (Tables VII, VIII).

The chemical quality of water from the seep at Station 7 (Apache Spring) has shown some effect of recharge from the burn area. In July 1977, after the fire, the TDS were 222 mg/ℓ, while in 1978 they had decreased to 110 mg/ℓ. It is apparent that recharge to the small perched aquifer is rapid, usually within a month. Between the fire in early June and samples collected in early July there were only three periods of precipitation. The chemical quality of water from the other springs (outside the burn area; Doe,

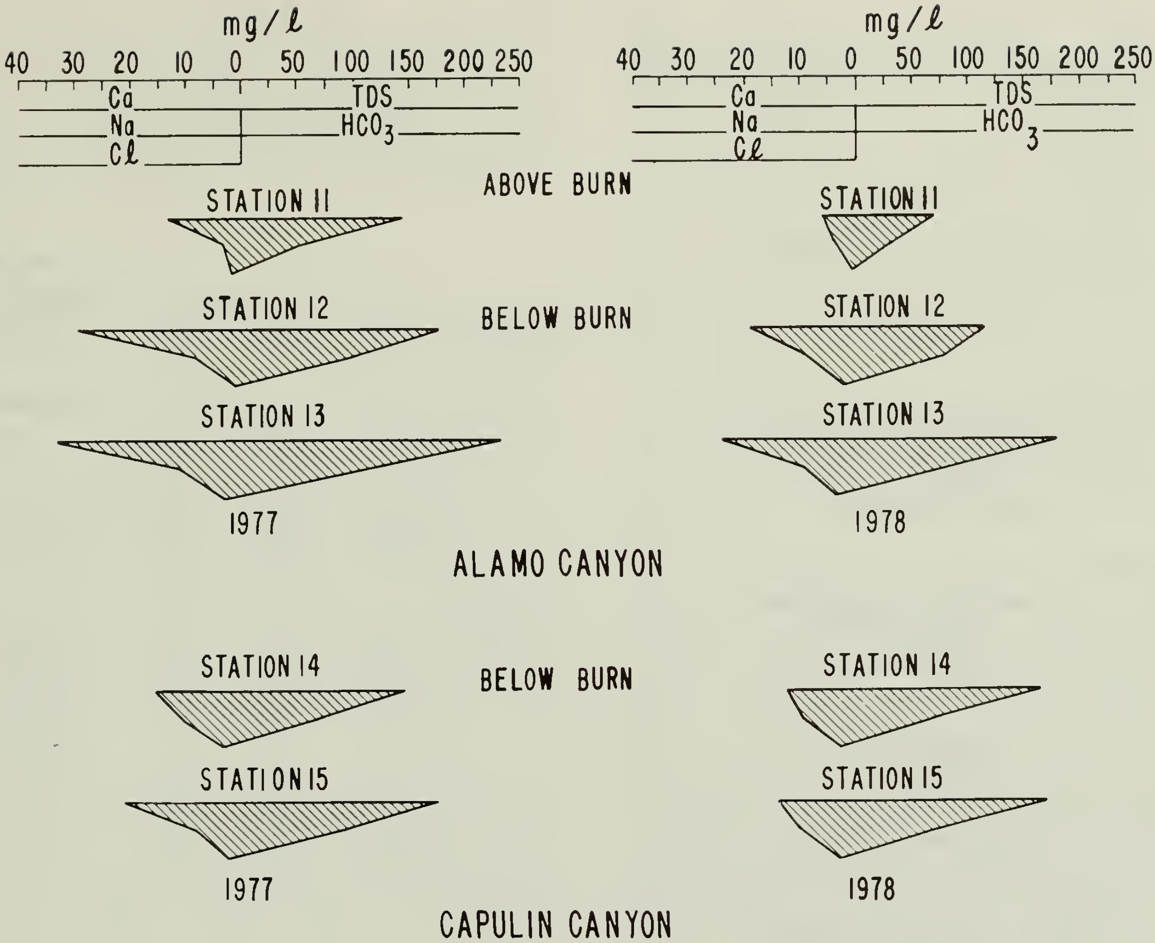

Fig. 10.
Calcium, sodium, chloride, total dissolved solids, and bicarbonate in surface water in Alamo and Capulin Canyons.

Turkey, Stations 3 and 10) have shown no significant changes between sampling periods.

Water from the main aquifer at a test well north of the Monument on the plateau contains principal ions of sodium and bicarbonate (Fig. 11). The TDS are less than 150 mg/ℓ at a water temperature of 21°C.

The quality of water from Doe Spring and Station 10 is quite similar in chemical constituents, both have the same chemical concentrations and principal ions of sodium and bicarbonate (Fig. 11). The spring discharges from the main aquifer near the Rio Grande. The water quality of these springs is comparable to the water from the test well on the plateau.

C. Suspended Sediments

Soils in the drainage area of Cañon de los Frijoles above the gaging station near the Monument Headquarters are derived from the weathering of tuff and volcanic rocks of the Valles Caldera. Overland runoff moves loose, erodible particles from the land surface into the stream channel. Once in the channel the sediment particles are transported by the stream either as suspended or bed sediments. The suspended sediments are classified as having a mean diameter <6 mm (6 mm is the intake size of the DH-48 samples used in the study). Only the suspended sediment loads were determined for base flow and two small runoff events.

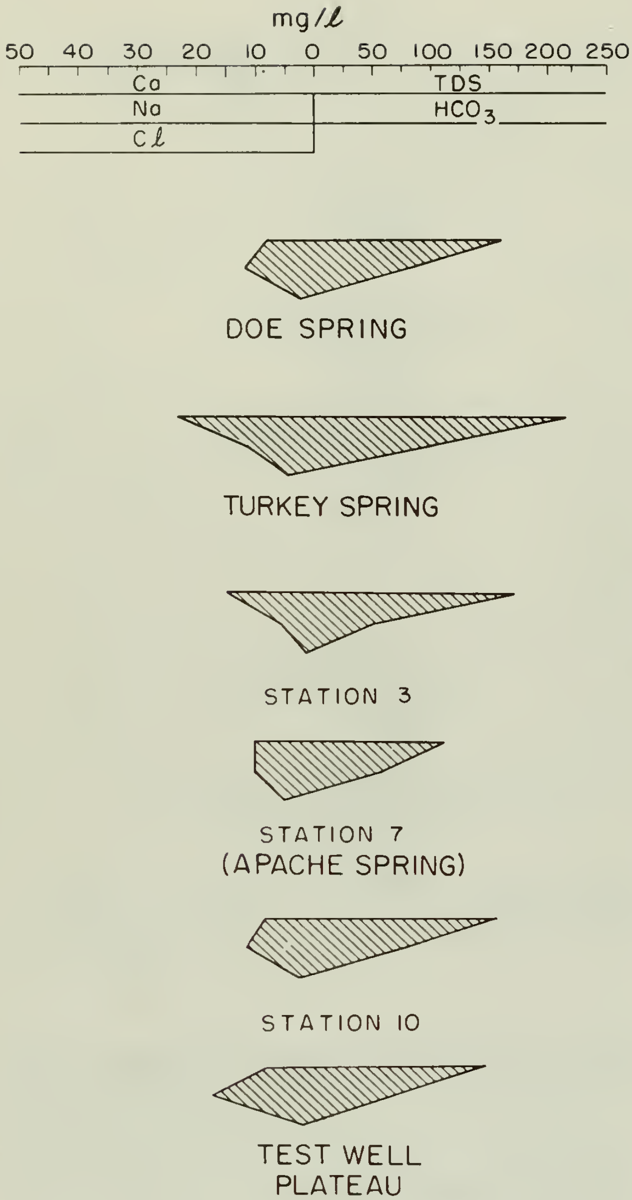

Fig. 11.
Calcium, sodium, chloride, total dissolved solids, and bicarbonate in ground water from springs and a test hole.

The base flow in Cañon de los Frijoles, about 0.03 m^3/ℓ, carries a small amount of suspended sediment. The average suspended sediment concentration in base flow for a 15-day period in July 1977 was about 140 mg/ℓ at the Monument Headquarters. During a 24-h period the stream carried about 381 kg of suspended sediments in 2.7×10^3 m^3 of water through the station. The suspended sediments yield of the base flow is about 8.4 kg/km^2.

TABLE XI

DISCHARGE AND SEDIMENT CONCENTRATION OF TWO STORM RUNOFF EVENTS, 1977

Date and Time		Discharge (m^3/s)	Discharge (ft^3/s)	Suspended Sediments (mg/ℓ)
Aug. 12	7:45	4.13	146	39,600
	11:15	0.48	17	11,200
	16:10	0.18	6.5	4,930
	17:20	0.10	3.7	1,310
	18:05	0.08	2.9	1,250
	20:15	0.07	2.5	560
Aug. 20	14:20	0.11	3.8	785
	15:20	12.3	433	98,800
	15:50	8.86	313	94,600
	16:25	5.49	194	54,100
	17:30	1.95	69	29,600
	19:00	0.85	30	12,600
	19:30	0.71	25	8,820
	20:00	0.62	22	7,120

The suspended sediment load in storm runoff increased as the vegetation cover holding the soil in place was destroyed in the fire. Also, the burned area is in the upper reaches of the canyon where channel gradients are steep. The resulting high flow velocities increase the transport of suspended sediments. Two runoff events were used to illustrate the amount of sediment transported through the gaging station near Monument Headquarters after the fire.

The maximum discharge on August 12, 1977 was 4.1 m^3/s with a maximum suspended sediment concentration of 39.6×10^3 mg/ℓ (Table XI). The mean discharge for the 15.2 h event was 0.14 m^3/s with a mean suspended sediment concentration of 2.1×10^3 mg/ℓ. About 16.6×10^3 kg of suspended sediments were carried through the gaging station in 7.9×10^3 m^3 of runoff. The suspended sediment yield for the event was 3.7×10^2 kg/km^2.

The maximum discharge of the second event, August 20, 1977, was 12.3 m^3/s with a maximum suspended sediment concentration of 98.8×10^3 mg/ℓ (Table XI). The mean discharge for the 5.7 h event was 0.57 m^3/s with a mean suspended sediment concentration of 5.8×10^3 mg/ℓ. About 6.7×10^4 kg of suspended sediments were carried through the gaging station in 11.6×10^3 m^3 of runoff. The suspended sediment yield for the event was 1.5×10^3 kg/km^2.

V. SUMMARY AND CONCLUSIONS

Cañon de los Frijoles contains a perennial stream from the mountains across the plateau to the Rio Grande. Four other canyons (Alamo, Capulin, Medio and Sanchez) contain perennial streams in short reaches from the flanks of the mountains on to part of the plateau. The base flow in these canyons is from springs and seeps along the base of the mountains. Low-flow investigations in Cañon de los Frijoles indicate decreased flow across the plateau where water is lost to evapotranspiration and infiltration into the underlying volcanic rocks and sediments.

Gradients in the stream channels are greater on the flanks of the mountains, decreasing across the plateau. The gradient increases in lower Cañon de los Frijoles because the basalt in the channel has limited the downcutting of the canyon to the west. The 1977 wildfire occurred mainly in the upper reaches of the canyons in areas of the greater channel gradients. This results in increased flow velocities during summer storms and increased transport of suspended sediments from erosion.

Available data on runoff from summer storms indicates the discharge yield increased from 0.012 $m^3/s/km^2$ to a maximum of 1.95 $m^3/s/km^2$ in Cañon de los Frijoles in a 15 month period after the burn. The discharge yield of a single runoff event in Lummis and Alamo Canyons was 0.33 $m^3/s/km^2$ and 0.15 $m^3/s/km^2$, respectively. The loss of the vegetative cover by burn has resulted in decreased collection and retention time for runoff resulting in larger discharge from runoff events. As the vegetation cover increases in the drainage area through seeding and natural growth, the discharge yield and suspended sediment yield will decrease.

The chemical quality of surface water in Cañon de los Frijoles changed slightly after the burn. The most noticeable change was an increase in calcium, chloride, bicarbonate, and TDS. Analyses taken over a 21-month period after the burn indicated a general decline in most of these constituents. Similar analyses of surface water in Alamo and Capulin Canyon indicate similar results over a 12-month period.

Analyses of samples collected of summer storm runoff compared with base flow in Cañon de los Frijoles indicated that higher concentrations of barium, calcium, iron, bicarbonate, manganese, lead, phenols, and zinc occurred in storm runoff than in the base flow.

Precipitation and runoff from the burn area will remove the fire debris allowing the quality of water of the streams to return to normal. The past two years data indicates the water quality of the base flow should return to normal three to five years after the fire.

Ground water occurs as springs and seeps in and adjacent to the Monument. There are no wells or test holes in the Monument. Two springs in Upper Cañon de los Frijoles discharge from a perched aquifer. The spring in the north fork of Cañon de los Frijoles (Station 3) discharges from a perched aquifer which is probably recharged from the upper water bearing zone in the Valles Caldera to the west. The spring contributes a part of the base flow for the stream in the canyon. Station 7 (Apache Spring) is a small spring on the north wall of Cañon de los Frijoles which discharges from a perched aquifer of limited extent. The TDS in the water from Apache Spring increased shortly after the burn, indicating rapid recharge. Turkey Spring, west of the Monument boundary, contributes a part of the base flow in a tributary to Capulin Canyon. This spring lies outside the burn area and was unaffected by the fire.

Two springs, Doe Spring in Chaquihui Canyon north of the Monument and the spring at Station 10 in lower Cañon de los Frijoles, discharge from the main aquifer. The main aquifer lies at a depth of 300 to 375 m along the western edge of the plateau north of the Monument. The surface slopes gently toward the Rio Grande where a part of the water is discharged into the river. North of the Monument the Rio Grande is a gaining stream with ground water discharged to the river, while to the south along the eastern boundary of the Monument, water from the river is lost into the underlying rocks. Contours on the potentiometric surface of the aquifer north of the Monument indicate water in the aquifer moves to the southeast. In the Monument the movement changes to a more southernly direction. Major recharge to the main aquifer is from the Valles Caldera. In the eastern part of the Monument, the intrusion of volcanic rocks which form the San Miguel Mountains have restricted the movement of water in the aquifer causing a ground water depression to form west of the Rio Grande and south of the Monument.

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