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QUARTERMASTER RESEARCH & ENGINEERING COMMAND
U S ARMY

TECHNICAL REPORT
EP-108

DESERT FLOOD CONDITIONS IN THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

APRIL 1959

NATICK, MASSACHUSETTS

HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND, U.S. ARMY
OFFICE OF THE COMMANDING GENERAL
NATICK, MASSACHUSETTS

Major General Andrew T. McNamara
The Quartermaster General
Washington 25, D. C.

Dear General McNamara:

This report, "Desert Flood Conditions in the White Mountains of California and Nevada," contains the results of more than a year's intensive study of field conditions and historical records. Based upon this research, the authors have formulated some principles for evaluating the relative safety of sites for communication routes, storage, and bivouacs in the vicinity of a desert mountain range. Application of these principles during military operations in similar terrain could prevent recurrence of incidents that in the past have cost lives and materiel.

Sudden floods will always be a possibility in certain desert regions, but the research findings show that these floods are nearly always limited to only a few canyons or even to a single canyon, and that certain canyons are more likely to have destructive floods than others. By analyzing the shape and other characteristics of a given canyon, its degree of flooding hazard can be estimated. In addition, it is shown that the relative safety of different parts of the terrain below a canyon mouth varies considerably. These varying degrees of hazard on different sites, and the factors that determine them, should be considered especially in planning permanent or semipermanent installations at or near the base of a desert mountain.

Sincerely yours,

C. G. Calloway

C. G. CALLOWAY
Major General, USA
Commanding

1 Incl
EP-108

HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND, US ARMY
Quartermaster Research & Engineering Center
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
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DESERT FLOOD CONDITIONS IN THE WHITE MOUNTAINS OF CALIFORNIA AND NEVADA

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UNIVERSITY OF CALIFORNIA

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7-83-01-005
Contract No:
DA 19-129-QM-565

April 1959

FOREWORD

It has long been known that military operations in the vicinity of desert mountains are subject to hazards from sudden and unexpected floods. The records of World War II operations in North Africa contain instances of drowning, damage to material, and obstruction to operations as a result of such floods. Little has been known, however, concerning the relationship between degree of flooding hazard and the characteristics of the catchment area, or the relative safety of various parts of the alluvial fans at the base of a desert mountain range.

To answer some of the questions concerning desert flooding hazards, a research contract (DA19-129-QM-565) was negotiated with the University of California, with Dr. John E. Kesseli, Associate Professor of Geography, as Principal Investigator. The University maintains a high altitude research station in the White Mountains, a desert mountain range on the California-Nevada border, and makes meteorological observations at two stations near the crest of the range. The facilities of the White Mountain Research Station, the height of the range, and its location in a settled, arid region, made the White Mountains exceptionally suitable for a study of flooding conditions.

An assistant investigator, Mr. Chester B. Beaty, resided in the area for more than a year, studying the problem from the climatological, geomorphological, and historical aspects. The results of his research are presented in this report. All maps and photographs were made by Mr. Beaty.

AUSTIN HENSCHEL, Ph. D.
Chief
Environmental Protection
Research Division

Approved:

CARL L. WHITNEY, Lt. Col., QMC
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Acting Scientific Director
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ABSTRACT

A field study of flood conditions in the White Mountains, California and Nevada, was carried out during the period July 1956 to December 1957. No serious floods were observed, but snowmelt runoff during early June 1957 resulted in minor flooding in some of the drainages along the west flank of the range. The most recent major floods occurred in 1952, 1955, and 1956. Those of 1952 and 1955 developed debris flows in the affected drainages, while the floods of 1956 were of the high water type.

Three physiographic characteristics were found to influence flooding behavior in a desert stream system: (1) profile of the trunk canyon, (2) amount of debris on the floor of the canyon, and (3) width of the lower canyon and canyon mouth. It is concluded that the most dangerous canyons are essentially steep, narrow, bedrock flumes with 5 to 15 feet of unconsolidated debris on their floors. In contrast, the safest drainages have gentle gradients in their trunk canyons, are deeply alluviated over their entire length, and are characterized by wide lower canyons.

The area of greatest flooding danger on an alluvial fan was found to be that flanking and including the active channel. The upper and lower thirds of a fan are classified as moderately dangerous, while the middle third is subject only to slight flood danger.

The historical record, reaching back to 1872, indicates that nearly three-fourths of the floods in and adjacent to the White Mountains occurred during summer and were the result of thunderstorms. Less frequent floods result from prolonged frontal rains on a snow cover in winter. Snowmelt flooding is least frequent and occurs in late spring or early summer. From 1 to 3 major floods per decade, and a considerably larger number of minor floods, have been reported in the White Mountains.

DESERT FLOOD CONDITIONS IN THE WHITE MOUNTAINS, CALIFORNIA AND NEVADA

INTRODUCTION

1. Purpose of study

This investigation was conducted to achieve four major goals:

a. determine the intensity and amount of rainfall that will result in flooding in desert regions;

b. determine the frequency, duration, and areal extent of floods within a selected are·

c. determine the effect of floods upon the terrain and land utilization;

d. observe, at close range, the behavior of floods in desert streams and record their obstructive and destructive effects.

2. Choice of area

The four goals determined the choice of the area in which the research was carried out.

The White Mountains were chosen because the University of California maintains two laboratories on their crest at which year-round weather observations are made, and these would be of value in determining precipitation intensities and absolute totals resulting in flooding of a specific degree of seriousness.

The range is situated along the California-Nevada boundary line approximately half way between Lake Tahoe and Las Vegas (see Figure 1 and folded map at end of report). It lies on the western border of the desert region of the Great Basin, but it is a true desert range as the adjacent valleys, Fish Lake Valley to the east and Upper Owens Valley to the west, are true deserts (Cold Desert, BWk according to the Koeppen classification), while the crest of the range has a steppe climate (Cold Steppe, BSk). The area is taken to be representative of other desert ranges to the east and south; if there are notable differences in climatic characteristics they are of degree, not of type.

A preliminary survey of the White Mountains revealed signs of recent flooding on both flanks of the range, but they were more numerous as well as more conspicuous on the west side of the mountains. Although both sides of the range were kept under surveillance for possible floods, and

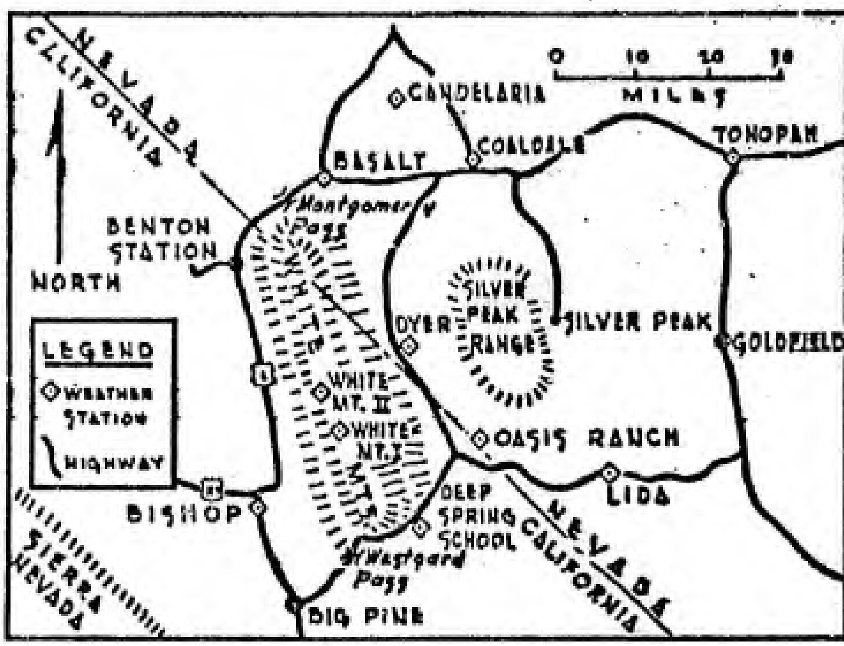

Figure 1. Location of the White Mountains, showing U.S. Weather Bureau stations within and near the study area.

studied for effects of former floods, the investigation of the western flank proved more rewarding; more attention was therefore given to that part of the mountains.

3. Methods of investigation

The assembly of published data consisted of the gathering of climatic records available for the White Mountains and the valleys flanking them and the collecting of reports of former floods. For the latter task, the files of the Inyo Register of Bishop, California, and the Inyo Independent, of Independence, California, at the offices of the Chalfant Press, Bishop, which combined reach back to 1872, were invaluable.

For gathering original data, varied means were chosen. In order to supplement precipitation data collected at climatic stations a number of rain gages were set out in selected locations (indicated on map at end of report) and visited after every rain or snowfall from September 1956 to October 1957. The record of these observations is assembled in the Appendix.

In order to observe floods first hand at close range, the Assistant lived in the study area from 3 August 1956 to 25 October 1957 and kept a constant watch on weather conditions in the mountains. In addition, he made arrangements with California and Nevada state and county road maintenance crews and other local residents to be informed whenever news of a flood reached them. Unfortunately, no major floods occurred in the area during the 15-month period of field work.

An attempt was also made to obtain eyewitness accounts of former floods. Several ranchers who had witnessed destructive floods during the last decade were located and interviewed. Although more concerned with saving their fields or irrigation systems from destruction than with an objective examination of the floods, they made observations which, coupled with other evidence, permitted a reasonable reconstruction of the events accompanying a major flood.

Most informative, however, was the morphologic evidence of former floods. Therefore, a thorough study was undertaken of the flood-producing canyons and of their alluvial fans. Recent flood deposits inside and outside the canyons were given particular attention, and some of them were carefully mapped. The morphologic investigation was greatly assisted by vertical aerial photographs of the White Mountains taken in 1954 for the U.S. Geological Survey at a scale of 1:37,400 and made available for this investigation by the Department of Geography, University of California, Berkeley.

The field investigation was carried out entirely by the Assistant. The final report was prepared by the Principal Investigator and the Assistant.

PART I

GENERAL GEOGRAPHIC SETTING

1. Morphology

a. The range in general

The White Mountains are the westernmost of the "basin ranges" in the latitude of southern Nevada. The northern limit of the range is well defined by Montgomery Pass, Nevada (7,200 feet). Westgard Pass (7,200 feet), east of Big Pine, California, is generally accepted as the southern limit of the White Mountains, and their extension beyond that point bears the name of Inyo Range. The length of the White Mountains between Montgomery Pass and Westgard Pass amounts to about 45 miles. Only the part north of Bishop, embracing 40 miles of this total, is considered in this report.

On the west the range is bounded by the northern extension of Owens Valley, for which no name has yet been generally accepted. It will be referred to as "Upper Owens Valley" in this report. Fish Lake Valley, Nevada, lies east of that part of the range of interest to this study. Between these valleys the range attains a width which increases from 10 miles in the north to approximately 20 miles in the south.

The White Mountains are no less imposing in height than the adjacent sector of the Sierra Nevada a few miles to the west. White Mountain Peak, culminating summit of the range, has an elevation of 14,246 feet, only 250 feet lower than Mt. Whitney. Average elevations of the crest vary from 10,000 feet to approximately 13,000 feet. Upper Owens Valley has elevations ranging from 4,100 feet near Bishop to roughly 6,500 feet at the west foot of Montgomery Pass. To the east, the floor of Fish Lake Valley has an average elevation of approximately 5,000 feet. Local relief is thus on the order of 6,000 to 8,000 feet in horizontal distances of four to eight miles, and stream gradients are correspondingly steep. As the crest of the range is everywhere close to its western margin, stream gradients are especially steep on the precipitous western flank of the mountains (Fig. 2).

The White Mountains are essentially a single, large, tilted block (Knopf, 1918; Anderson, 1937). Relative tilting has been toward the east, and parts of the western front of the range present many of the time-honored morphologic features generally associated with recent faulting (Fig. 3). The transition from mountain slope to valley fill is abrupt, producing a sharp and distinct boundary between the two. No large embayments, floored with alluvium, indent the general line of the mountain

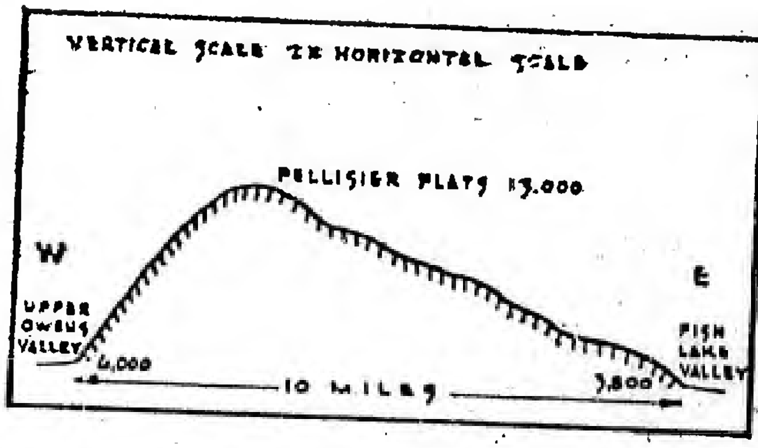

Figure 2. Diagrammatic cross-section of the northern White Mountains from mouth of Falls Creek on the west to mouth of Indian Creek on the east.

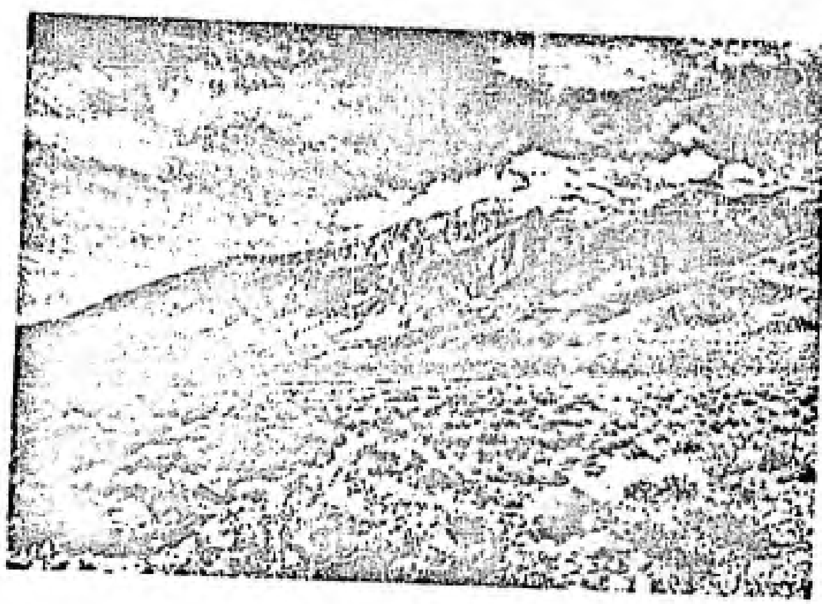

Figure 3. Western flank of northern White Mountains between Birch Creek and Marble Creek. Triangular facets, precipitous range front, and straight contact between mountain bedrock and valley alluvium are all indicative of recent faulting and are conspicuous along the range front in the left half of the picture.

boundary, which is remarkably straight, particularly in the northern third of the western flank.

Parts of the crest of the range are distinguished by the presence of so-called "flats," such as Pellisier Flats and Chiatovich Flat. These remnants of older topographic surfaces are not level but have a strongly rolling to hilly topography, which contrasts strikingly with the steeper slopes of either flank.

b. Canyons

Canyons are relatively closely spaced along both sides of the White Mountains. There are some 24 major drainage systems on the west flank from Silver Canyon in the south to Queen Canyon in the north. Average spacing of canyon mouths here is on the order of one to two miles. Major canyons are fewer and have larger catchment areas on the east flank of the White Mountains. North of White Mountain Peak, on this side of the range, there are only seven major drainage basins; average spacing of their canyon mouths is four to five miles.

Notable differences exist between profiles of east- and west-side drainage systems. Many of the west-side streams give the visual impression of extreme physiographic youth. The notches they have carved into the mountain mass are relatively shallow, their gradients are high, up to 2,000 feet per mile, and bedrock is exposed nearly everywhere in their courses. Major east-side drainages generally are distinguished by much gentler gradients, between 600 and 1,000 feet per mile, and larger catchment areas; physiographically speaking, they must be considerably older than their counterparts on the west.

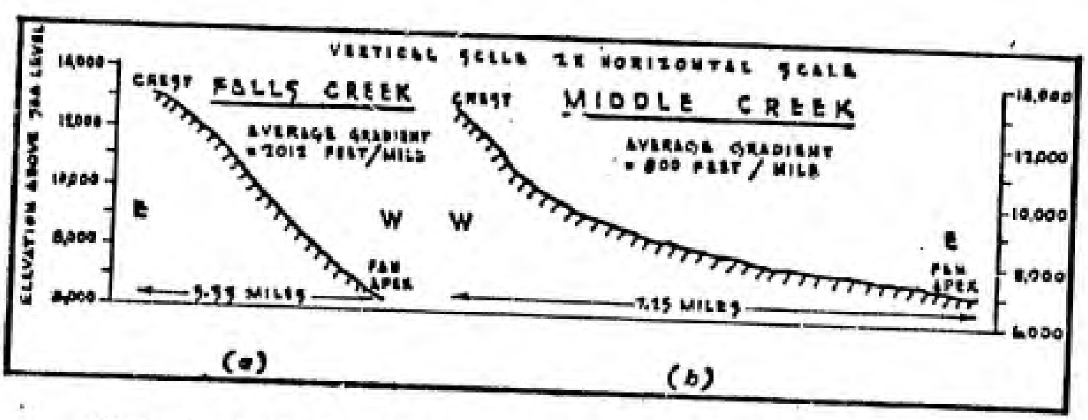

Figure 4. White Mountain trunk canyon profile types. (a) Falls Creek; (b) Middle Creek.

Profiles of trunk canyons of drainage systems in the White Mountains can be grouped into two contrasting types: (1) the Falls Creek type, steep to mouth of canyon; and (2) the Middle Creek type, steep in headwater area only and relatively gentle in lower main canyon (Figure 4). In the area, gradients of the Falls Creek profile type range from 1,200 to 2,000 feet per mile for main canyons, and the excessive steepness of the trunk canyon floor persists to the fan apex. Gradients of the Middle Creek type are high in the headwater area, up to 1,500 feet per mile, but lower main canyons are relatively gentle, with gradients ranging from 300 to 600 feet per mile.

Although gradations exist between the two types in the White Mountains, valid generalizations can be made concerning their areal distribution. From Milner Creek north to Morris Creek on the west side of the range, all canyon profiles are of the Falls Creek type. Queen Canyon in the north and drainages south of Milner Creek on the west flank have Middle Creek type profiles. On the east side of the range, all major drainage systems from McAfee Creek to Trail Canyon have the Middle Creek type of profile.

Depths of major canyons on both sides of the range are quite respectable. Elevation differences of 2,500 to 3,000 feet between canyon floors and adjoining interfluvial ridge crests are common. Relief is therefore large, not only between the main crest of the White Mountains and adjacent valleys, but on the dissected flanks of the mountain mass as well.

c. <u>Alluvial fans</u>

Alluvial fans along the west flank of the range are steep and sharply delimited in their upper portions. Their lower extensions coalesce to form an alluvial apron or piedmont alluvial plain. Some display excellent evidence of recent flooding. The belt of fans fringing the western front is two to three miles wide and has a height of 600 to 1,200 feet from fan perimeters to apexes.

Alluvial fans in northern Fish Lake Valley measure four to six miles in width and thus are larger than those of the west side. Although elevation differences between perimeters and apexes are similar to those of the west side, that is, from 800 to 1,200 feet, the greater radial extent of the east-side fans gives them in general much gentler slopes. Evidence of flooding on these fans is much less conspicuous than that on the smaller, steeper fans of the west flank of the range.

Although the transition from fan surface to bedrock mountain front generally is abrupt, narrow tongues or fingers of alluvium extend into the mountain mass above fan apexes at the lower ends of several drainage

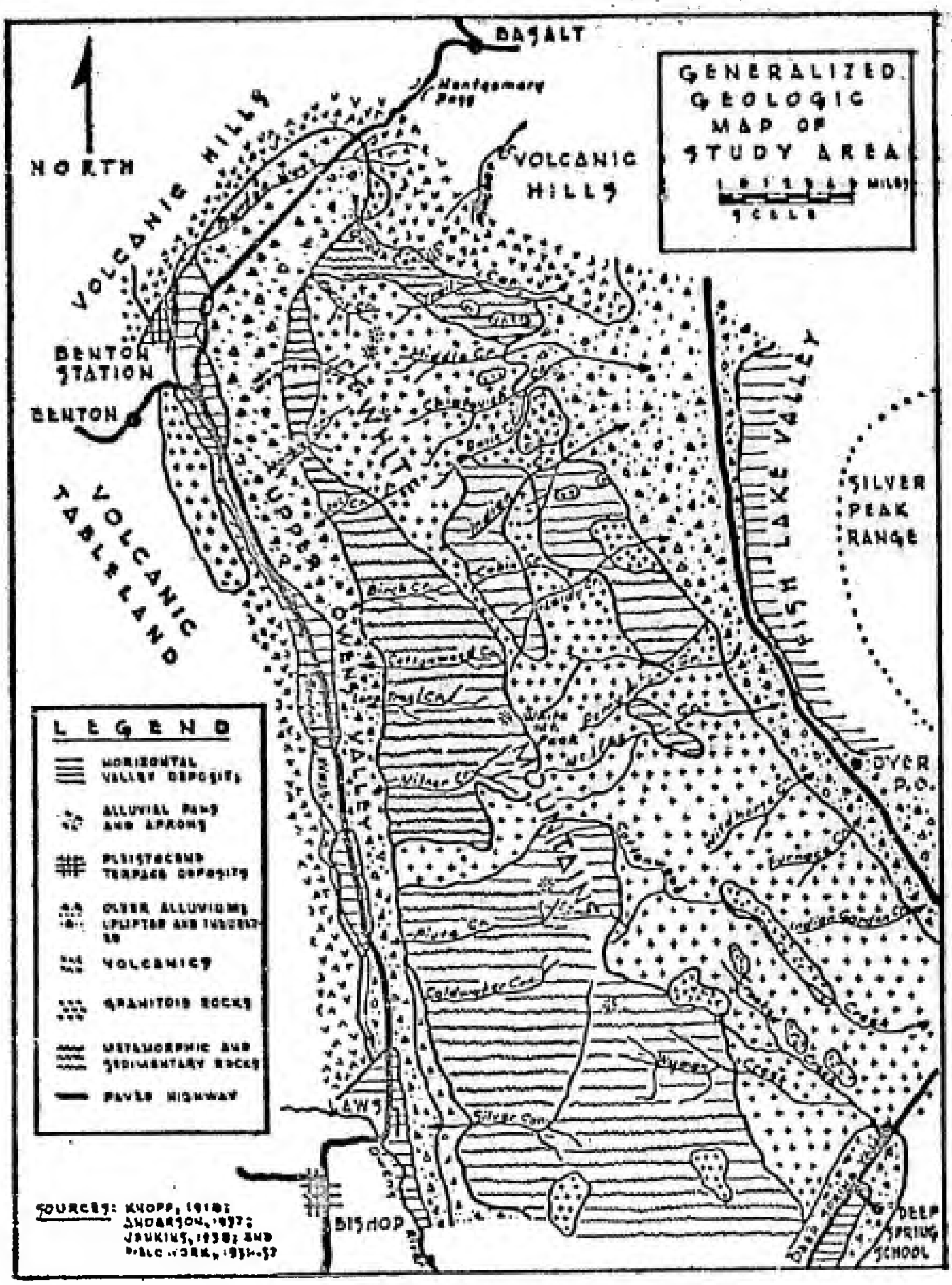

Figure 5. Generalized geologic map

systems on either side of the range. These extensions of alluvium are not true mountain-front embayments such as have been described for older, lower ranges in the Mohave Desert and elsewhere (Davis, 1938), since the contact between the White Mountains and their alluvial aprons is generally straight, not scalloped. The extensions of alluvium into the mountain block represent at best only the very beginning of the development of true embayments; they occupy only the slightly wider, lower portions of the canyons, and the transition from lower canyons to the fans proper is still abrupt.

Most White Mountain fans are characterized by a radial channel pattern, diverging outward from the well-defined apex region. Most channels are former flood channels. The active channel on virtually all of the fans is entrenched below the general fan surface for at least half of its course. Average depth of this incisement is on the order of 10 to 20 feet near fan apexes and decreases downslope. Surface morphology on the upper parts of most fans is characterized by vigorous micro-relief, brought about by the existence of alternate ridges and channels, extending radially from apexes to one-third to one-half of the way down the fan slope. Local relief on the upper parts of fans is on the order of 5 to 15 feet. Lower fan slopes are relatively smooth, although a few widely spaced dry channels create locally a micro-relief of 2 to 3 feet.

Slopes of the steepest fans along the west flank range from 10 to 12 degrees near apexes to 2 or 3 degrees in peripheral areas. Average overall slope of west-side fans amounts to 5 or 6 degrees. East-side fans generally are more gentle. The steepest fans here have slopes in apex regions of 7 to 9 degrees, while their perimeters often approach horizontality. Average slope of all east-side fans is only 3 to 4 degrees.

The steepness of the alluvial fans is in direct relation to the steepness of the mountain canyons providing the debris out of which they are constructed. Since fans fringing the western front of the range are being built by shorter, steeper, physiographically younger streams, they are accordingly steeper than those along the east flank.

2. Areal Geology

a. Major rock types

Essential features of the surface geology are indicated on Figure 5. Basically, the White Mountains consist of a granitic core flanked by a belt of sedimentary, metamorphic, and volcanic rocks. The granitic core underlies the crest in the northern third of the range, but trending more easterly than the crest it passes onto the eastern slope farther to the south, while the adjacent crest and the western flank are underlain by metamorphic and sedimentary rocks.

Of specific interest to this study is the bedrock exposure in each drainage basin. Major valleys in the northern third of the range are cut predominantly in granitoid rocks. Slopes within the mountains in these drainages tend to be steep, with considerable bedrock exposed. Weathering along joint planes and other zones of weakness within the granitoid masses produces an abundance of large, coherent blocks, some measuring many feet in length. In the southern two-thirds of the range, drainage basins are cut dominantly or exclusively in metamorphic and sedimentary rocks. In general, slopes in such terrain are less rugged, with fewer bedrock exposures and more gentle inclination. Weathering in this part of the study area produces many smaller pieces of rock, ranging up to fist-sized cobbles and only occasional blocks 1 or 2 feet in diameter, in marked contrast to the much larger number and size of blocks in the granitic areas to the north.

b. Effect on canyon profile

There is little evidence that bedrock differences alone within the study area account for the notable differences in canyon profile observed. Steep canyon profiles generally are associated with physiographically younger parts of the range. More gentle canyon profiles, of approximately similar shape, occur in both granitic and metamorphic-sedimentary terrains. It seems more likely that canyon profile variations should be attributed to different recent diastrophic activity in diverse parts of the range than to bedrock differences alone.

c. Effect on narrowness of canyon mouths

The mouths of three west-side drainage systems, Cottonwood Canyon, Lone Tree Creek, and Milner Creek, are cut in a steeply tilted stratum of particularly resistant quartzite. The inherent toughness of this rock has resulted in the creation of exceedingly narrow, gorge-like stretches of canyon at these points. These canyon "narrows" are not common in the White Mountains; other drainages on both sides of the range leave it in moderately broad lower canyons cut in other rock types. The three west-side streams are unique in this respect, and the particular morphology of their lower trunk canyons and canyon mouths has been a determining factor in the behavior of higher than normal runoff.

d. Effect on size of debris in fans

Marked differences exist in the size distribution of debris in fans built by streams coming from areas of different bedrock. Fans below granitic terrain consist of sand, cobbles, and numerous blocks of all sizes, averaging perhaps 4 to 6 feet across; there is little material in the gravel range, and little, if any, silt and clay. Surfaces of fans built of granitic debris usually are rough, and the presence of occasional blocks of extreme size far from canyon mouths (Fig. 6) invites much speculation.

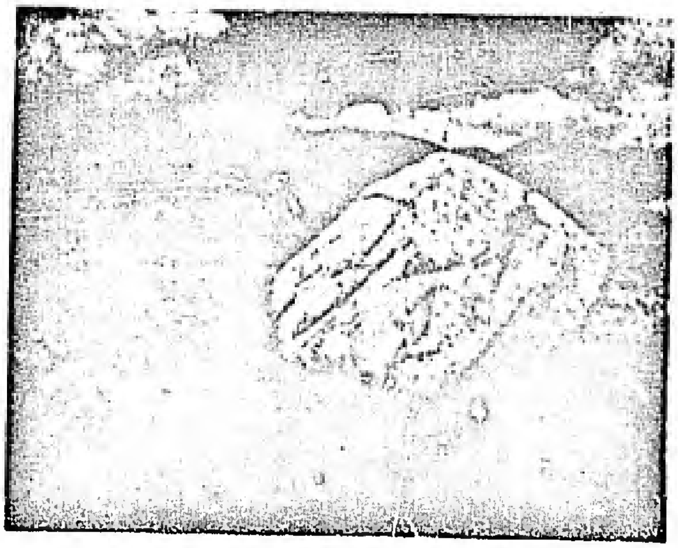

Figure 6. Granite boulder on Marble Creek alluvial fan three-quarters of a mile below apex. Note man standing at lower right of block. This is the largest of all boulders seen on fans and measures approximately 30 x 25 x 25 feet.

Fans built of material from metamorphic and sedimentary terrain contain a large proportion of debris in the sand, gravel, and cobble range, with a few medium-sized blocks of 2 to 3 feet diameter. Blocks 6 to 8 feet in diameter or larger are very rare in these fans.

e. Effect on depth of regolith

Regolith depth is a function both of rate of weathering and steepness of slope. In general, granitic terrain in the northern part of the study area is characterized by steep slopes; weathering here may be rapid, but the ready removal of fine debris by gullying and rillcutting prevents the accumulation of more than small patches of very shallow regolith. The more gentle slopes of the southern part of the range which are underlain by metamorphic and sedimentary bedrock have a nearly continuous and thicker cover of weathered material. The upper portion of the regolith in this part of the area moves downslope primarily in the form of small debris tongues or lobes, a type of mass movement which is influential in slope development and in the transportation of debris toward major valley floors.

Infiltration rates on more gentle slopes with thicker regolith are considerably higher than on the steeper, practically bare slopes. Thus, surface runoff from metamorphic and sedimentary terrain is likely to be less, for a given amount of rain, than that from drainages cut exclusively in granitic rock types.

3. Climate

a. Yearly weather summary

Generally, winters are wet and summers dry in the White Mountains. Winter precipitation is associated with the passage of cyclonic storms which, in their west to east course, release a large proportion of their moisture over the Sierra Nevada. As a result, depth of winter precipitation is normally only moderate in amount in the White Mountains, even at higher elevations.

During the summer months, May through October, occasional thunderstorms occur, especially over the higher parts of the region. Thunderstorm precipitation is sporadic, both in time and place, and reliable records of intensities and absolute totals are scarce.

Temperatures are relatively moderate during the year throughout the area. Wintertime minima are occasionally below zero and summertime maxima occasionally exceed 100°F. in the valleys during July and August, but equable sensible temperatures are the rule in all seasons.

Frequent strong northerly and southerly surface winds occur from time to time, and the area is internationally known for the development of the "Sierra Wave" in Owens Valley during winter months.

b. Climatic averages

In Table I the available record of average monthly and annual temperatures for U.S. Weather Bureau stations within and adjacent to the study area is assembled, and in Table II the corresponding record of precipitation is presented. Location of the weather stations is indicated in Figure 1. Station elevations and years of record are presented in Table III.

Average annual precipitation over the study area is depicted in Figure 7. Precipitation distribution is about what would be expected, that is, it is greater at the higher elevations. Precipitation distribution in the northern White Mountains had to be estimated, but it is felt that the map representation is reasonably accurate. Valley residents on both sides of the range are all but unanimous in their assurances that the part of the range between White Mountain Peak and Montgomery Peak receives the greatest amount of winter snow and the most frequent summer thunderstorms. Personal observations during the contract period tended to bear out at least the former part of this contention (see Fig. 8).

TABLE I. Average monthly and annual temperatures for stations within and adjacent to the study area.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bishop	37.9	41.3	47.4	54.7	62.6	69.4	75.5	73.5	67.3	57.1	46.2	39.1	56.0
Coaldale	32.5	39.2	43.5	54.3	62.1	70.4	79.2	77.0	69.6	56.0	42.3	34.9	55.1
Dyer	29.5	35.7	39.7	49.9	58.0	64.1	73.2	70.1	63.3	52.7	40.4	31.9	50.7
Oasis Ranch	29.4	34.3	41.3	49.6	55.3	64.1	69.6	67.9	60.3	49.0	37.9	25.6	48.9
Deep Spr. School	27.8	34.5	41.9	51.8	58.9	67.5	71.1	70.1	65.9	54.0	42.4	29.9	51.7
Lida	29.7	32.6	36.6	43.7	50.6	59.2	66.5	65.0	56.6	46.6	38.1	30.9	46.3
Tonopah	30.1	34.3	40.4	48.2	56.9	65.7	74.6	72.2	64.3	51.4	40.9	32.9	51.0
Candelaria	37.1	37.9	43.1	48.1	57.6	68.6	74.0	72.2	63.7	54.9	45.1	37.4	53.1
Basalt	29.1	33.3	38.2	47.8	54.2	61.2	70.5	68.5	61.8	50.4	38.6	31.3	48.6
White Mt. I	18.9	21.6	22.5	30.9	36.4	46.7	53.6	52.5	47.6	39.2	31.5	22.8	35.4
White Mt. II	14.3	15.0	16.0	20.5	26.6	38.2	45.6	44.1	39.9	31.8	25.0	18.2	28.0

TABLE II. Average monthly and annual precipitation for stations within and adjacent to the study area.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bishop	1.12	.91	.66	.26	.20	.10	.10	.14	.19	.34	[illegible]	.89	5.38
Coaldale	.22	.16	.23	.37	.34	.08	.52	.26	.09	.27	.31	.34	3.57
Dyer	.41	.33	.19	.78	.36	.11	.42	.09	.28	.14	.07	.36	3.22
Oasis Ranch	.66	.57	.35	.41	.47	.26	.40	.41	.28	.27	.27	.42	4.77
Deep Spr. School	.71	.29	.63	1.11	.43	.15	.36	.11	.26	.12	.26	.77	5.45
Lida	1.54	1.49	.71	1.09	1.17	.93	.70	.63	.17	.91	.46	.48	10.28
Tonopah	.48	.39	.50	.49	.40	.20	.38	.58	.35	.36	.32	.38	4.83
Candelaria	.47	.42	.37	.40	.66	.17	.28	.66	.35	.51	.17	.29	4.95
Basalt	.41	.58	.34	.66	.54	.21	.49	.26	.25	.55	.51	.83	5.39
White Mt. I	1.66	1.46	1.37	2.03	.88	.30	1.74	.33	.74	.31	.66	1.45	13.09
White Mt. II	1.96	1.22	.67	2.25	1.97	.50	2.26	.29	.83	.37	.82	2.02	15.72

TABLE III. Elevations and years of record of weather stations within and adjacent to the study area.

Station	Elevation	Total years of record	Years Operated
Bishop	4,108	49	1884-1918 1944-1957
Coaldale	4,636	16	1942-1957
Dyer	4,975	10	1948-1957
Oasis Ranch	5,106	16	1903-1919
Deep Spring School	5,225	10	1948-1957
Lida	6,037	7	1912-1918
Tonopah	6,090	50	1907-1957
Candelaria	6,180	17	1889-1905
Basalt	6,350	17	1941-1957
White Mt. I	10,150	10	1948-1957
White Mt. II	12,470	7	1951-1957

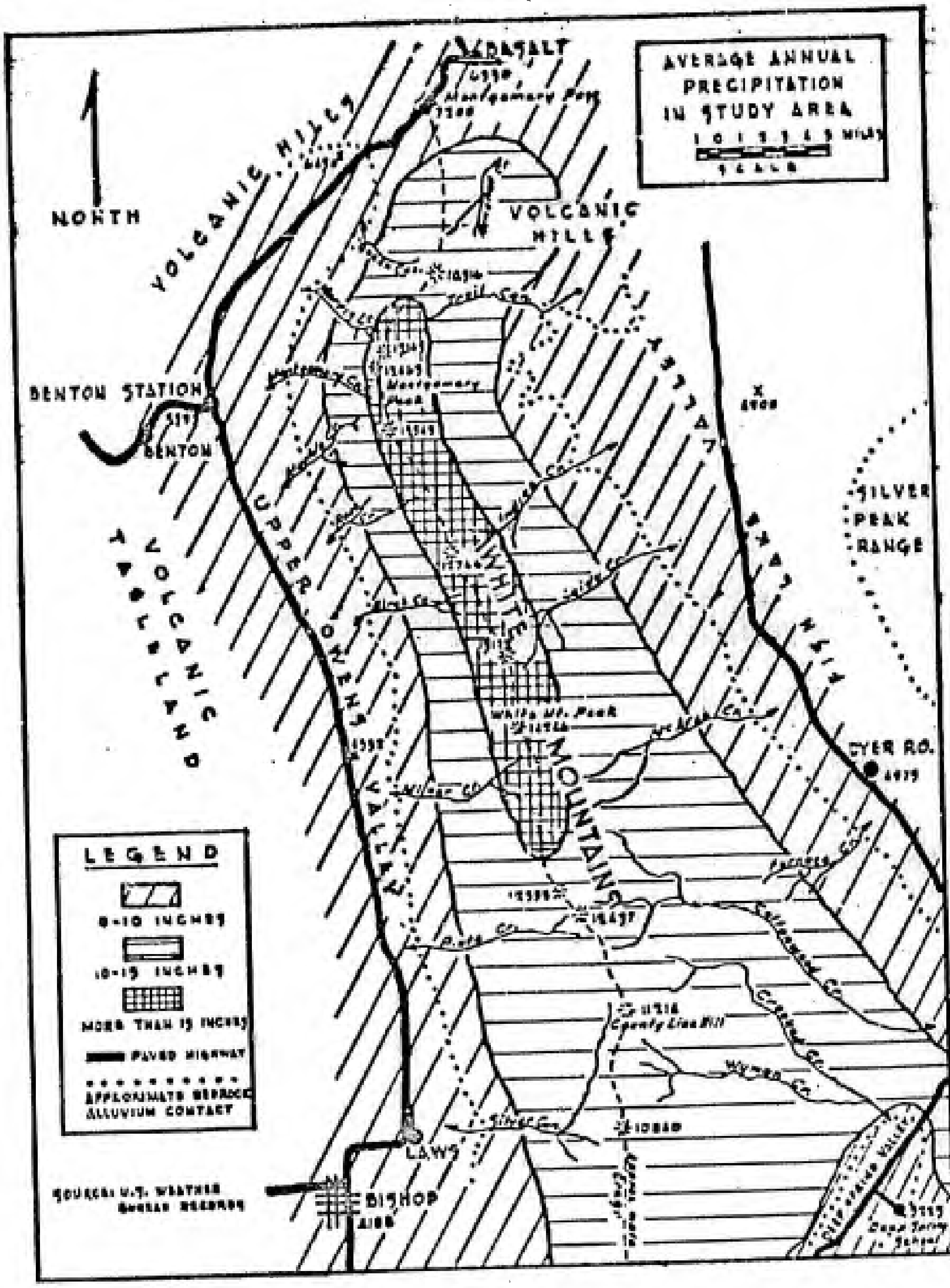

Figure 7. Average annual precipitation

c. Seasonal distribution of precipitation

Of some interest to this study is the distribution of precipitation through the year in various parts of the region. Apparently the White Mountains correspond to a definite boundary or transition zone between two areas with markedly different precipitation regimes. Figure 9 illustrates the rhythm of yearly precipitation for three stations, one on the west side of the range, two on the east side.

A notable difference evidently exists between the distribution at Bishop and that at the stations east of the mountains. Bishop has a typical California coastal regime with pronounced summer dryness. The other stations lack an obvious summer minimum, and summer and winter precipitation are close to equal. The following explanation is offered to account for this difference.

The area east of the White Mountains is invaded frequently during the summer months by moist air from the Gulf of Mexico. This potentially unstable air is at times a prolific source of thunderstorm activity, the frequency of which is reflected by the normal precipitation totals for the months May through October at Tonopah and Oasis Ranch. Evidently little of this warm, moist air normally gets across the high barrier of the White Mountains and into Owens Valley and areas beyond, to the west. Summertime thunderstorm activity in these regions is dependent upon the importation of moist Pacific air, and the general circulation of the atmosphere during the summer months is apparently such that this situation arises rather infrequently. East of the mountains, consequently, summer thunderstorms are likely to produce as much precipitation as weakened wintertime cyclonic storms, or even more.

d. Precipitation extremes

Of greater interest to this study than averages or normals are the extremes of precipitation. Table IV shows the maximum monthly total precipitation recorded at the various weather stations thus far. At all but one of the stations listed the maxima fall into the winter months, November to April. The exception, Candelaria, is not only remarkable for the period of its maximum, August, but also for the size of that maximum, which is exceeded at only three other stations.

Table V presents for some of the stations the maximum 24-hour precipitation totals for each month during an approximate decade. Maxima again fall predominantly into the winter half-year, but Tonopah and Coaldale show a clear summer maximum. Impressive values of 24-hour precipitation during the summer are also evident at Oasis Ranch, Basalt, and White Mountain II.

Figure 8. General view of east side of northern White Mountains between Montgomery Peak on the right and White Mountain Peak on the left, taken on 14 February 1957. The midwinter snow pack in this part of the range is conspicuous in this view, taken from near Coaldale, Nevada. Playa of Columbus Salt Marsh in middle.

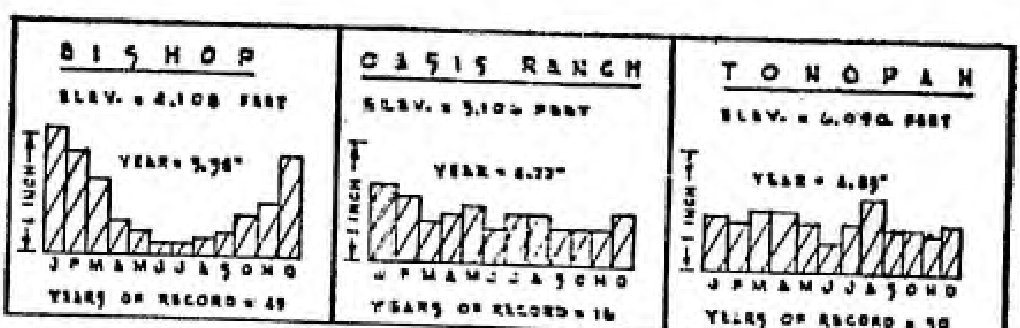

Figure 9. Distribution of precipitation throughout the year at selected stations

TABLE IV. Maximum monthly total precipitation for stations within and adjacent to the study area

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Bishop	2.67	5.50	3.92	2.25	2.90	1.54	1.05	.75	1.67	2.73	2.69	6.58
Goldfield	.82	.73	1.09	2.10	1.56	.48	1.45	1.20	.47	1.26	2.50	1.44
Dyer	1.66	1.30	.75	2.31	1.65	.57	.85	.55	1.06	1.04	.19	1.70
Oasis Ranch	3.20	2.00	1.10	1.75	1.83	.75	1.02	1.63	1.04	.81	1.65	2.00
Deep Springs School	2.07	.91	2.05	3.80	1.36	.47	.91	.28	1.46	.67	.55	1.93
Mina	4.33	2.06	2.57	2.79	2.53	2.58	1.45	2.20	.36	2.61	1.78	.70
Tonopah	2.72	1.79	1.47	3.26	2.50	1.29	1.47	1.74	2.07	1.60	2.67	1.63
Candelaria	2.04	1.20	1.19	1.28	2.33	.45	1.52	6.05	1.27	1.82	1.40	1.37
Basalt	2.92	1.64	1.05	2.26	1.46	.85	2.29	1.01	1.41	3.00	2.63	5.14
White Mt. I	3.92	5.42	3.41	6.70	2.74	.97	3.26	1.39	2.30	.76	1.65	6.03
White Mt. II	2.95	2.29	2.19	6.65	4.66	1.07	2.54	1.12	1.28	1.24	2.37	6.11

Note: Wettest month on record for each station is underlined thus: 3.80

TABLE V. Maximum 24-hour total precipitation for stations within and adjacent to the study area

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Period of record
Bishop	3.32	2.08	1.24	1.47	.95	.22	.20	.13	.39	.39	1.79	2.54	1946-57
Coaldale	.37	.73	.39	.62	.61	.18	.93	1.30	.19	.90	.72	.88	1946-57
Dyer	1.28	1.00	.45	.92	.45	.05	.64	.28	.58	.40	.12	1.46	1946-57
Oasis Ranch	1.94	2.00	.51	1.23	1.75	.60	1.02	1.24	1.04	.63	.60	1.50	1903-19
Deep Spr. School	1.07	.85	1.50	1.43	1.01	.21	.45	.15	1.17	.29	.39	1.18	1948-57
Tonopah	.54	.33	.76	.85	.88	.93	1.23	1.10	.91	.71	.67	.43	1946-57
Basalt	.59	.73	.38	1.23	.95	.39	1.40	.43	.71	.87	1.13	1.70	1946-57
White Mt. I	1.60	3.10	1.20	1.71	1.49	.41	.96	.51	.63	.33	.59	2.74	1951-57
White Mt. II	1.18	1.10	.39	2.70	1.95	.51	1.40	.40	70	.45	1.80	2.27	1952-57

Note: Absolute maximum for each station is underlined thus: 1.41

e. Dependability of record

As is the case in most of the mountainous West, weather stations within and adjacent to the study area, with two exceptions, are situated in valley locations. The White Mountains are unique in this respect in that the University of California maintains two laboratories on their crest at which year-round weather observations are made. During July and August observations of temperature and precipitation are also made at White Mountain Peak. Precipitation intensities are not recorded at these stations, only 24-hour totals.

Because of this distribution of stations it is not at all certain that maximum rainfalls, particularly in the summer months, have been caught in official rain gages. The sporadic occurrence of small cells of heavy rain during the summer months in this area is a well-known phenomenon. In the past, in the general White Mountain region, it has often happened that weather stations closest to areas of heavy, flood-producing precipitation have received little or no rain on days on which flooding has taken place. A few recent examples will serve as illustrations.

The most serious recent flooding in the study area occurred on 26 July 1952, when three west-side drainage systems, Lone Tree Creek, Cottonwood Canyon, and Milner Creek, and one east-side basin, Leidy Creek, flooded severely, pouring large quantities of debris onto their alluvial fans. The closest weather station in operation that year was White Mountain I. This station recorded a 24-hour total for that day of 0.33 inch, all rain. It lies about 13 airline miles from the headwater areas of the affected drainages, where presumably the heaviest rain fell. Whatever the total may have been, it must have exceeded by several times the amount caught in the official rain gage.

A small cloudburst flood occurred in August 1957 in the west end of Deep Spring Valley, in the southern White Mountains. The weather station at the Deep Spring School, about 6 airline miles from the flooded area, recorded only 0.02 inch of rain that afternoon; the rain in the mountains nearby must have been much more severe.

Again in August 1957, minor flooding took place along U. S. Federal Highway 6, east of Basalt, Nevada. Although the center of the flooded area was less than 2 airline miles from the weather station at Basalt, only 0.02 inch of rain was recorded there that day.

It can thus be realized that accurate catches of flood-producing rainfall are exceedingly rare in this area. Extreme precipitation values presented in Table V should be taken as minimum amounts to be expected from any given frontal storm or individual convective cell. Wintertime figures probably are much more representative of average or normal conditions than summertime values, but personal observations during the contract period indicated that the distribution of precipitation even in large cyclonic disturbances was far from uniform over the area. Under these conditions, chance catches of rainfall in various receptacles become of importance in a consideration of the possible precipitation intensities and totals that may be attained.

f. Accidental records of precipitation

Numerous estimates of extreme thunderstorm precipitation in areas contiguous to the White Mountains were obtained. They were based on catches in empty watering troughs, wheelbarrows, tubs, pails, and similar receptacles. They were encountered in newspaper reports describing floods in the Silver Peak Range, Nevada; near Lone Pine, California, in southern Owens Valley; the Bodie, California area, north of Mono Lake; and from near Laws, California, in the southern part of the study area. With but one exception, to be discussed below, no estimates for thunderstorm precipitation in the White Mountains proper could be found.

The figures stated indicate totals of 4 to 5 inches in a period of 2 to 3 hours for individual thunderstorms that happen to have centered over occupied areas. Short-time intensities during such heavy storms are difficult to estimate, but it seems probable that perhaps as much as 2 to 3 inches may have fallen in an hour on occasion, of which more than half fell in the first 25 to 30 minutes, corresponding to a rate of 4 or 5 inches per hour for that period.

These estimates are admittedly crude and subject to some degree of error. In particular, the shapes of the receptacles for these accidental catches varied considerably, and depths of water in the bottoms of these may well not have reflected accurately the total depth of precipitation that actually fell but may have exaggerated the amount somewhat. But until a heavy, flood-producing rain centers on one of the White Mountain stations it will not be possible to improve upon these estimates.

The heaviest precipitation accurately recorded anywhere within the general area occurred on 19 July 1955 when more than 8 inches of rain fell in slightly more than two hours on Chiatovich Flat, on the east flank of the northern White Mountains (Powell, D.,* Personal Communication, 1957). The catch was made in a portable rain gage. It was purely accidental; the observer happened to be in the area, happened to have a portable rain gage, and had carried it to the Flat on the chance that a heavy rain might fall.

* Mr. Powell was a graduate student in Geography, University of California.

Mr. Powell's measurement indicates that reported valley precipitation catches are obviously much smaller than amounts received in the mountains from most storms. Totals recorded at valley stations can be taken as minima, and in most cases they should be doubled or even tripled to correspond to the probable mountain rain.

4. Vegetation

There are three well-defined and easily recognizable vegetation associations within the study area, plus an Alpine zone of relatively bare regolith above timber line in the high White Mountains.

a. Valley shrubs

Covering all of the valley floors and alluvial fans and extending into the mountains themselves for a short distance is an association of Valley Shrubs. The total number of species is great, but the dominant plants make up a comparatively brief list. In the northern lowlands of the area, Great Basin sagebrush (*Artemisia tridentata*) is the predominant plant, with minor amounts of other shrubs, notably joint firs (*Ephedra* spp.), bitterbrush (*Purshia tridentata*), and various buckwheats (*Eriogonum* spp.). Farther south in the valleys, at lower elevations, sagebrush all but disappears; here, a rather extensive mixture of shrubs replaces it: rabbit brush (*Chrysothamnus* sp.), salt bush (*Atriplex* spp.), greasewood (*Sarcobatus vermiculatus*), hop sage (*Grayia spinosa*), dalea (*Parosela* sp.), cotton thorn (*Tetradymia spinosa*), and other lowland plants. This vegetal association blankets valley flats and alluvial fans and gives the impression of a rather continuous cover (Fig. 10). However, this impression is misleading. There is no development of a turf or sod, and bare ground between plants greatly exceeds the portion of surface actually covered or protected by vegetation.

b. Pinyon-Sagebrush

The Pinyon-Sagebrush association extends altitudinally from approximately 6,000 feet to about 9,000 feet. Most of the intermediate slopes of the White Mountains are covered by this association, but it should not be thought of as constituting a true forest. Pinyon pine (*Pinus monophylla*) and Great Basin sagebrush (*Artemisia tridentata*) are the dominant plants in this association, although along its upper border mountain mahogany (*Cercocarpus* sp.) and juniper (*Juniperus californica*) locally become prominent. Individual trees are not closely spaced in the Pinyon-Sagebrush zone, although here and there small patches of thick growth may occur. Sagebrush is rather uniformly interspersed among the pines, and a view from a distance provides an impression of more or less complete ground cover. This, however, is illusory; bare regolith covers perhaps 40 to 50 percent of the total area within this type, and slopes are by no means protected by vegetation.

Figure 10. Valley Shrub vegetation on alluvial fan of Marble Creek. Most of the bushes are Great Basin sagebrush, recognizable by its light color. The few darker plants in the fore- and middle-ground are bitterbrush. The density shown is typical for Valley Shrubs. The height of the largest bushes is about 4 to 5 feet.

Figure 11. Bristlecone pine on crest of White Mountains. Elevation here is about 10,500 feet. The trees have a height of 35 to 40 feet. Bedrock is dolomite, which the High-Altitude Pines seem to prefer.

c. High-Altitude Pines

Extending from about 9,000 feet to the upper timber line at 10,500 to 12,000 feet is the zone of High-Altitude Pines (Fig. 11). Bristlecone pine (Pinus aristata) is the dominant species, but here and there occur groves or individual specimens of limber pine (Pinus flexilis). Stunted sagebrush and other smaller plants survive at these higher elevations, but the ground cover generally is sparse. Soil is all but lacking here, although shallow patches of finer debris locally support areas of relatively thick lesser vegetation.

d. Alpine Zone

Above the High-Altitude Pines and extending to the very crest is an Alpine Zone of shattered rock and bedrock outcrops on which only a very few hardy plants manage to survive. The number of species is surprisingly large, but they exert no practical influence on landform development and are of greater interest to the botanist than to the geomorphologist.

In comparison with other desert regions, the study area is undoubtedly rather well vegetated. It is quite likely that vegetation exerts a general, overall control on surface runoff and infiltration rates in the White Mountains. However, its effect on rains of brief duration and high intensity is slight, and it is primarily precipitation of this type that is significant in a consideration of flooding in the range.

PART II

FLOODING IN THE WHITE MOUNTAINS

1. Recorded floods since 1872

a. Sources of information

Newspaper files at the office of the Chalfant Press, Bishop, California, were consulted for information concerning former floods. The newspaper record goes back to 1872, but a few years are missing during the early part of the period. It can hardly be expected that all floods taking place within the area were recorded by the journals of the time. Nevertheless, the record as here presented is believed to represent a satisfactory sample, and generalizations derived from it are considered to be valid.

When possible, local residents were consulted to corroborate newspaper accounts of specific floods within their memories. A few floods not reported in the press were recalled by long-time local residents of the area, and four of these that could be cross-checked by verification from two or more people were added to the newspaper record.

b. Distribution in time during period 1872-1957

The number of floods per year mentioned in the newspapers during this period is shown graphically in Figures 12 and 13. Figure 12 is based on all recorded floods, a total of 179, which occurred in an area bounded by lines joining Mono Lake, California; Tonopah, Nevada; Baker, California; and Mohave, California. In addition to the White Mountains, it thus includes the eastern slope of the high Sierra Nevada south of Mono Lake and the Death Valley region, as well as part of the Mohave Desert.

The number of floods per year during the historical period in the White Mountains alone is presented in Figure 13, and covers a total of 63 floods.

Flooding occurrences in the larger area were investigated to see if the pattern established for the White Mountains was comparable to that prevailing in adjacent desert regions In general, the distribution in the historical period as well as the seasonal distribution for both the larger and smaller regions display marked similarities.

The two graphs (Figs. 12 and 13) show similar trends in flooding occurrence; the most notable feature is the remarkable increase in reported floods during the last two or three decades. This increase coincides with a general increase in population in the affected area, in

Figure 12. Distribution of number of reported floods per year during period 1872-1957 in the area bounded by lines joining Mono Lake, California; Tonopah, Nevada; Baker, California; and Mohave, California. This graph includes floods in the White Mountains.

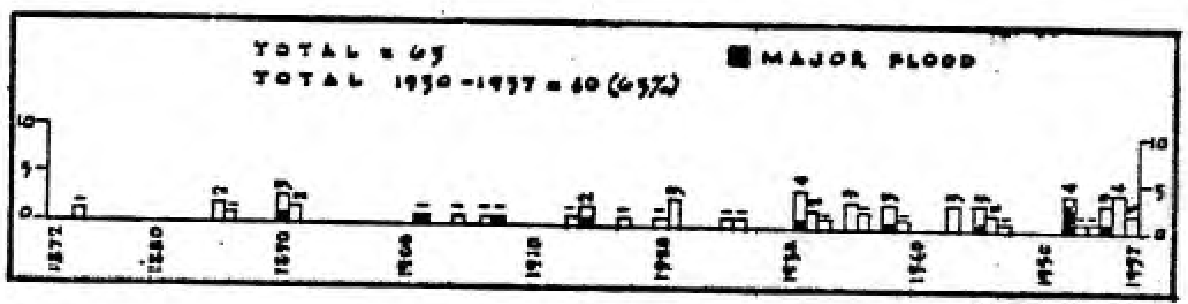

Figure 13. Distribution of number of reported floods per year during period 1872-1957 in the White Mountains alone.

extension of the highway network, and a pronounced increase in the number of cars using the road system. More people, more roads, and more automobiles in an area subject to flooding lead to one inevitable result: more floods will interfere with human activity and will thus be reported in the press. There is no evidence in the available weather records to indicate that climatic factors account for the increase in the number of reported floods during the last 20 to 30 years. Other investigators of flooding in arid America have noted similar trends in other areas (see, in particular, Woolley, 1946).

c Seasonal distribution

The distribution of floods throughout the year (Fig. 14) is of considerable interest. About three-fifths, or 60 percent, of the recorded floods in the White Mountains and in the larger area have taken place during the two summer months, July and August. All of these have been the result of cloudbursts, or thunderstorms, which are also predominantly responsible for the less frequent September floods.

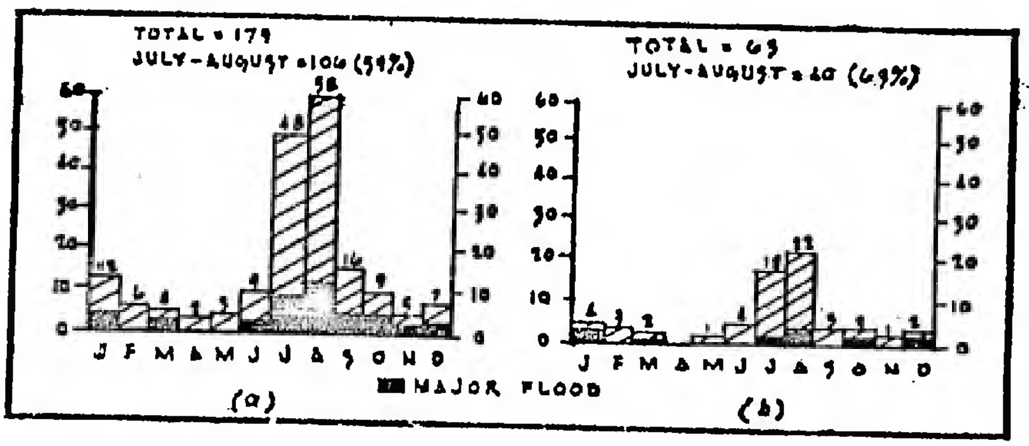

Figure 14. Flooding occurrence for each month during the period 1872-1957 in (a) the larger area; and (b) the White Mountains alone.

However, some of the more damaging floods, from the standpoint of property loss and highway washouts, have come during the winter months, particularly in December and January. Almost invariably these wintertime floods have been the result of warm rain on a snow cover, or of very heavy valley rains accompanying snowfall at higher elevations.

Flooding from snowmelt normally has come in late spring and early summer, that is, May and June, and often has been augmented by thunderstorm rainfall.

Relative scarcity of floods during the spring months, February to April, is the result of a combination of circumstances. Frontal activity is weakening then; average daytime temperatures are too low for copious snowmelt; and meteorologic conditions are not conducive to thunderstorm activity.

Moderately heavy rains, of frontal origin, are not uncommon during the fall months, October and November, but usually they are accompanied by snow at higher elevations, and since the infiltration capacity of the mountain soils is high at this season relatively few floods have occurred.

In general, then, floods in the area can be arranged into three groups:

(1) The true Cloudburst Flood, occurring almost invariably in summer.

(2) The Snowmelt Flood, taking place in late spring and early summer; sometimes augmented by thunderstorm rainfall.

(3) The Wintertime Flood, occurring as a result of warm rain on snow, rain on frozen ground, or heavy rain in the lowlands accompanied by snow at higher elevations.

Virtually all of the historic floods within and adjacent to the White Mountains can be assigned to one of these three classifications.

d. Areal distribution in White Mountains

The areal distribution of recorded and observed floods in and immediately adjacent to the White Mountains during the period 1872-1957 is shown on Figure 15. A concentration of reported floods along the west front of the range is conspicuous. Meteorologic factors may account for this concentration, but it seems likely that other factors should be considered primarily responsible. Today, a major highway, U.S. 6, leads north from Bishop along the mountains and over Montgomery Pass; during the period 1882-1941, a narrow-gage railroad traversed this portion of the area; and during the whole period, mining activities and settlement have been concentrated along the west flank of the range. Most of the floods reported in the local press or remembered by long-time valley residents occurred along the highway or railroad, or in or near towns, mines, and other settled localities.

Long-time valley residents have expressed the opinion that more severe thunderstorms have occurred in the vicinity of White Mountain Peak than along other parts of the crest (Minneberry, P., Personal Communication, 1957; Robinson, D., Personal Communication, 1957). Personnel of the U.S. Weather Bureau station at Bishop noted that the White

Mountain Peak sector of the range may well be a thunderstorm "breeding ground" (Pyle, E., Personal Communication, 1956). It is certainly true that in recent years there has been an apparent concentration of thunderstorm activity in this part of the White Mountains. However, Figure 15 shows a rather regular distribution of floods along the west side of the range with only a slight concentration below the White Mountain Peak sector. It is believed that over the years the distribution of observed floods will show concentration and lack of concentration in direct relation to the density of settlement and the frequency of travel on the major roads of an area.

e. Major floods

The seriousness of a given flood is a purely subjective matter. A flood is serious if one's house is swept away, or one's fields are covered with coarse debris; a flood is serious if major lines of communication are cut, or if human lives are lost. But morphologically significant floods may occur in unoccupied areas and will thus be ignored or mentioned only very briefly in the local press. Consequently, the seriousness of a given flood frequently is difficult to determine, especially many years after the event.

Major floods are indicated in the graphs of Figures 12, 13, and 14. These were considered to be major because in each case serious damage was done to human habitation, other structures, or main lines of communications; or human lives were lost. The seriousness of the great majority of the reported floods could not be determined satisfactorily from a reading of the newspaper accounts, and it is possible that more major floods have occurred than are shown in the graphs.

The distribution of major floods in time and throughout the year is of interest. In general, the number of reported major floods shows an increase in the second half of the historical period, corresponding, as might be expected, to the increase in population in the area. In the White Mountains alone, however, major floods appear to have been more or less evenly spaced in time during the historical period.

A concentration of major floods in the summer months is very evident, particularly for the larger area for which data are available. Thus, not only are cloudburst floods numerically most important in and adjacent to the White Mountains, but often they have been quite destructive. This has been notably true along the southern part of the eastern Sierra Nevada slope, along which are located a federal highway, a railroad, and the Los Angeles aqueduct, but the general trend prevails over the entire area.

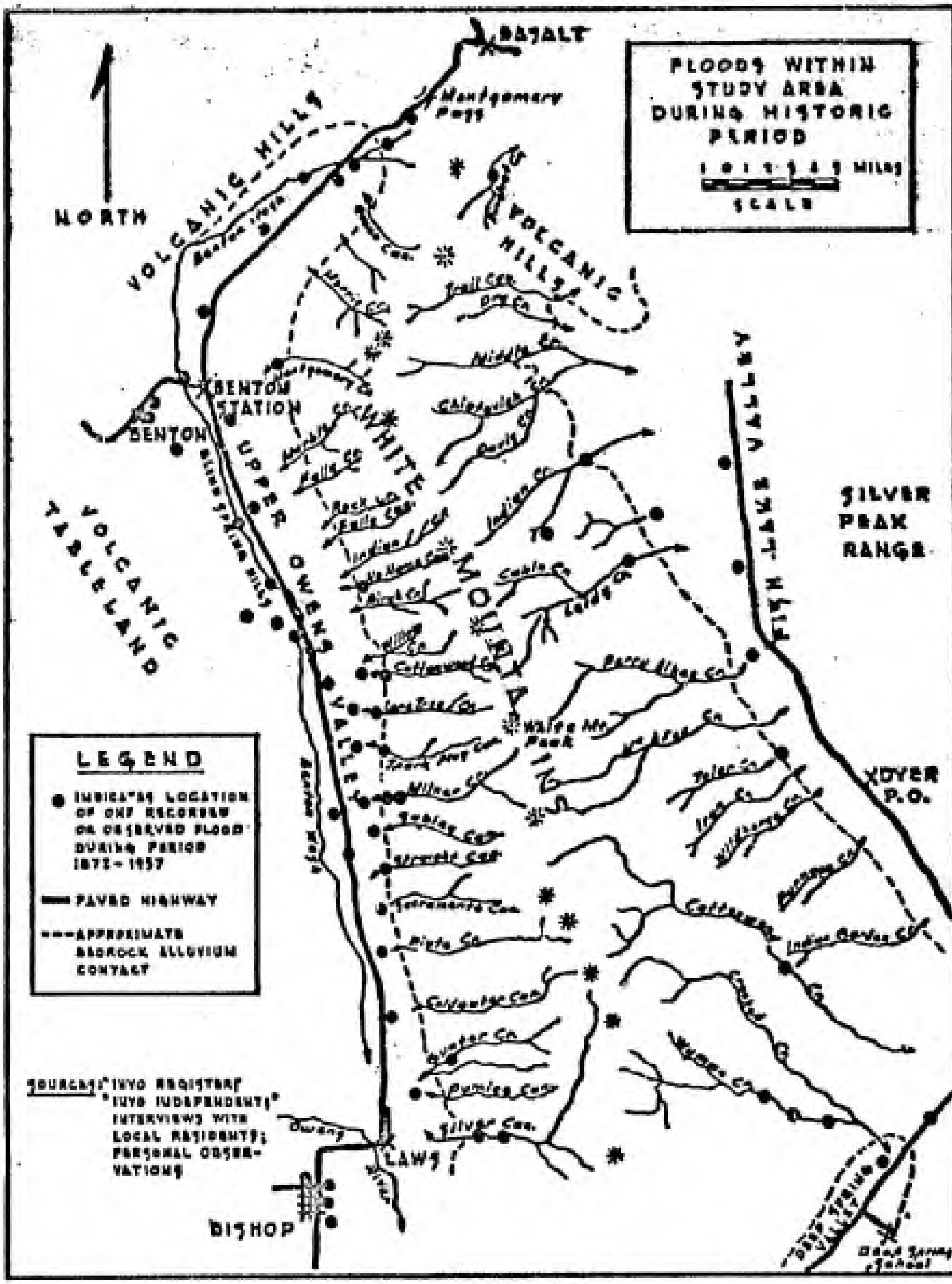

Figure 15. Floods within study area during historic period

f. Flood damage

By far the most frequent type of damage reported in the newspapers has been debris across or washing out of highways. Major roads within the region have been built on alluvial fans fringing mountain masses, and secondary roads leading into the ranges almost invariably are in canyon-floor locations over at least part of their length. In both cases flooding has caused damage. Often the reported damage has been no more than a thin film of cobbles and finer material covering short stretches of roadway crossing normally dry channels. Railroad washouts have sometimes been more serious in that several hundred feet of raised roadbed on fan surfaces has been carried away. Secondary canyon-floor roads within the mountains have often suffered damage and occasionally have been destroyed for thousands of feet.

Damage to structures and cultivated land within the area has been relatively limited. Most of the farm land is not on alluvial fans but on flatter areas at their lower margins, and only infrequently have cultivated acres been damaged severely by floods issuing from the mountains. Secondary damages to farms and ranches have come about as a result of the destruction of canyon-mouth intakes for irrigation systems, and it has thus occasionally happened that ranches have been without water for a week or more during critical periods of the growing season.

Small-scale mining has been carried out in the past in most of the White Mountain drainages; occasionally cabins and out-buildings on canyon floors have been swept away by a flood. But very few miners or residents have been so foolish as to put buildings in locations of such obvious flooding danger.

g. Duration of floods

Normally, flooding as a result of summertime cloudbursts is a comparatively brief phenomenon. Thunderstorm rain of flood-producing intensity rarely has lasted more than two or three hours; usually the heaviest precipitation has been of little more than an hour's duration. Actual flooding may take place in no more than 40 or 50 minutes, that is, as a typical flash flood. The high water crest with its mobile debris surges down the main channel within the mountains and out onto the fan surface relatively shortly after the heavy rain has fallen. After such an outburst, higher than normal water flow may continue in the affected drainage for 24 to 48 hours Thunderstorms can deliver water to catchment areas at rates greatly exceeding infiltration capacities of watersheds; overland flow then quickly develops and runoff may be rapidly concentrated into the main canyon of the drainage basin.

Flooding from snowmelt runoff is usually of longer duration and of correspondingly lesser intensity It commonly may last for about a week or ten days. Flood danger is stated to be particularly great in late afternoon or evening. Observations of a snowmelt flood period, made in June 1957, are discussed in a later section of this report. Rate of snowmelt runoff is affected directly by maximum daily temperatures, and great daily variations of snowmelt discharge have been experienced whenever temperature fluctuations from day to day were large.

Wintertime flooding as a result of prolonged frontal rains usually has been a lowland phenomenon, and crests normally have been reached only after a period of days of heavy precipitation. High discharge in the creeks has usually lasted for two to four days. Minor crests in smaller individual streams within the mountains may occur as a result of temporary landslide damming. It has only been during periods of prolonged cyclonic rainfall that saturation of soils has been sufficiently deep to promote landsliding as an additional cause of severe flooding.

h. Frequency of flooding

A subjective estimate of flooding frequency within the White Mountains alone, based upon the newspaper record, gives six to eight floods per decade, of which one to three can be classified as serious major floods. These estimates are undoubtedly low, as all floods very probably have not been recorded. The same frequencies seem to hold true for areas of similar size in the general desert region of southeastern California and southwestern Nevada. For the area as a whole, the flood frequencies are greater since they are the result of the summation of the floods in the smaller areas.

Little evidence of the cyclical occurrence of floods is to be found in the historical record. As noted, the marked increase in the number of reported floods in the last three decades can probably be traced directly to an increase in population in the area and not to identifiable meteorologic factors. Wet years follow dry years in the study area, but flooding occurrence remains sporadic and unpredictable.

2. Floods of the last decade

More definite information concerning floods in the White Mountains is available for the last decade. A few eyewitnesses were located who remembered three major flood years quite vividly. In one of these the floods were of such intensity that they left prominent morphologic evidence which, in conjunction with the eyewitness accounts, permits a satisfactory reconstruction of the events. Morphologic evidence from the more recent floods is less satisfactory, but it is sufficient to allow a reasonable reconstruction to be made.

a. The floods of 26 July 1952

Heavy thunderstorm rain on that date caused flooding in four canyons of the White Mountains, of which three, Milner Creek, Lone

Tree Creek, and Cottonwood Canyon, are on the west flank of the range, while the fourth, Leidy Creek, drains the eastern flank. All four head in the highest part of the range near White Mountain Peak, and, according to testimony of local residents, flooded severely at approximately the same time on that day.

(1) Precipitation

Exceedingly heavy rains fell along the crest of the range on the afternoon of 26 July 1952, and were obviously concentrated in the vicinity of White Mountain Peak. The weather station closest to the flooded areas in operation that year was White Mountain I, approximately 13 airline miles from the headwater areas of the affected drainages. This station recorded a 24-hour total of 0.33 inch of rain on that date.

Ranchers in Upper Owens Valley who observed the heavy rains in the mountains state that the most intense rain fell between approximately 1400 and 1600 hrs. Ranchers in Fish Lake Valley noticed the heavy rain from their side of the range at about the same time. Valley residents have little information to offer regarding absolute totals or short-time intensities. The rain was heavy enough "so that we couldn't see the bulk of the mountains for an hour or so" (Symons, W., Jr., Personal Communication, 1956), but no estimates of actual totals are available. Whatever the total during the two-hour period of maximum precipitation, it must have been many times the 0.33 inch received at White Mountain I. The heavy rain was restricted to the range itself, and no rain fell on the ranches in the valleys.

(2) Flooding in Milner Creek, Lone Tree Creek, and Cottonwood Canyon

The flooding of these drainages can be considered together as it was of the same type in all three streams. The similarities in basin morphology and geology of the three systems are in all probability responsible for the similarities in resulting floods.

(a) Eyewitness accounts

Four eyewitnesses of the floods from Milner Creek, Lone Tree Creek, and Cottonwood Canyon were located. Two of these provided relatively valuable information concerning flooding on the Cottonwood Canyon and Lone Tree Creek alluvial fans; the other two had less informative evidence regarding Milner Creek and its fan.

The witnesses of the Cottonwood Canyon and Lone Tree Creek floods (William Symons, Jr., for the former and Robert Cashbaugh for the latter) were stockmen whose ranches are located on fan margins two to three miles from the canyon mouths (see Figures 16 and 17). From these

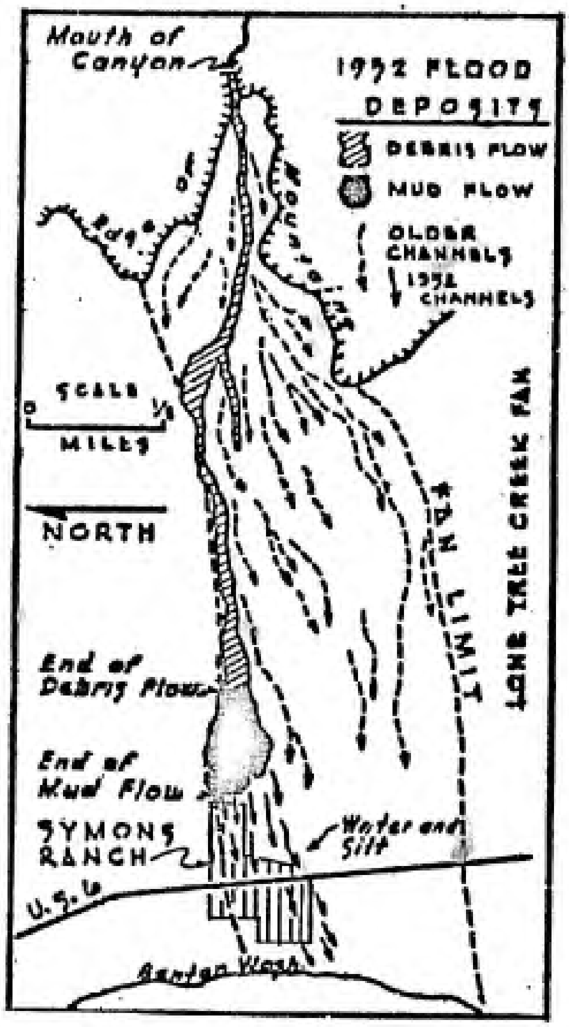

Figure 16. Map of Cottonwood Canyon fan showing deposits of 1952 flood and location of Symons ranch. Traced from an aerial photograph taken in 1954.

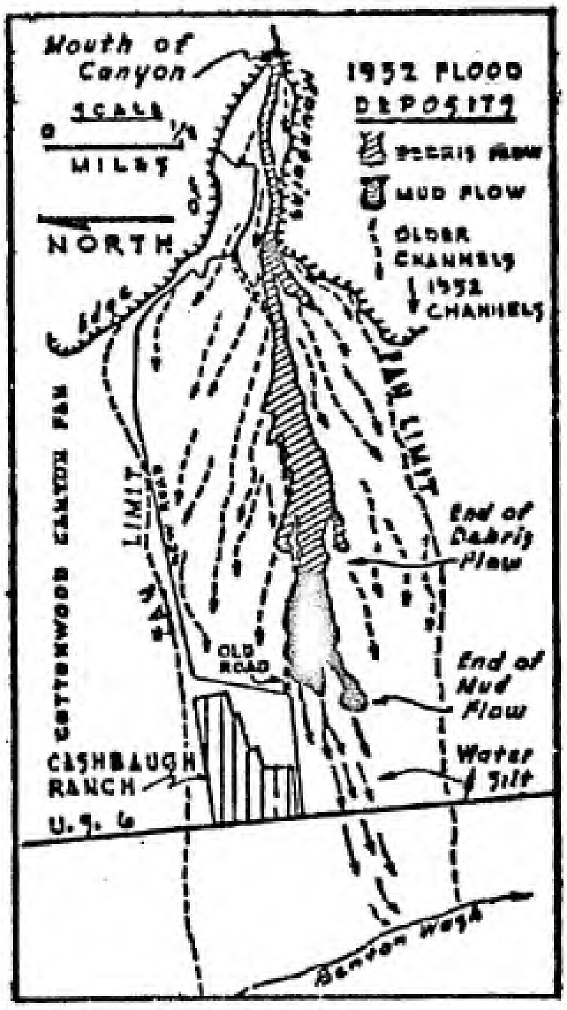

Figure 17. Map of Lone Tree Creek fan showing deposits of 1952 flood and location of Cashbaugh ranch. Traced from an aerial photograph taken in 1954.

ranches almost the whole extent of the nearby fans is visible. On the Cottonwood Canyon fan the flood passed over Mr. Symons' ranch and on the Lone Tree Creek fan it passed within half a mile of Mr. Cashbaugh's ranch.

The witnesses of the Milner Creek flood were on a ranch from which the mouth of Milner Creek canyon is not visible and from which only part of the fan can be seen. Consequently, their observations serve only to corroborate parts of the evidence given by the better-situated observers.

The combined testimony of all of the witnesses leads to the following reconstruction of events on the fans:

1 Approximately two hours after the heaviest rain in the mountains, that is, at about 1800 hours, loud rumbling and roaring noises were heard apparently emanating from the lower canyons of the affected drainages. It was agreed by all observers that these noises were not thunder since the storm had already abated by that time.

2 About one-half hour after the rumbling noises in the canyons were heard, tongues of debris were seen advancing downslope on the upper parts of the fans of Cottonwood Canyon and Lone Tree Creek. The debris from a distance of about one mile had the appearance of a moving rampart or wall of boulders and mud a few feet high, without visible water (W. Symons).

3 The moving debris was preceded and accompanied by a low, rolling, transluscent cloud of dust, which presumably was thrown up from the dry fan surface as the viscous material advanced downslope (R. Cashbaugh).

4 The material moved downslope in a series of waves, or surges, each succeeding wave apparently overtaking the preceding one and advancing farther down the fan surface (W. Symons). The advancing tongues of debris tended to follow the stream channels until these shallowed on the lower parts of the fans. Here, the debris spread out and assumed the form of broad, thin, discontinuous sheets of mud (W. Symons and R. Cashbaugh).

5 The debris flows on the fans were accompanied by noises likened by one of the observers to "the sound of a thousand freight cars bumping together simultaneously" (R. Cashbaugh). Presumably the noise came from the pounding together of boulders in the flows.

6 The material was moving over the lower, more gentle part of the Cottonwood Canyon fan at a speed estimated to have been "about as fast as a man could dog-trot," perhaps 400 to 600 feet per minute. On this part of the fan the moving mass was about 1 to 2 feet thick and seemed to have greater fluidity than it possessed when first observed on the upper part of the fan (W. Symons; by this time the flow

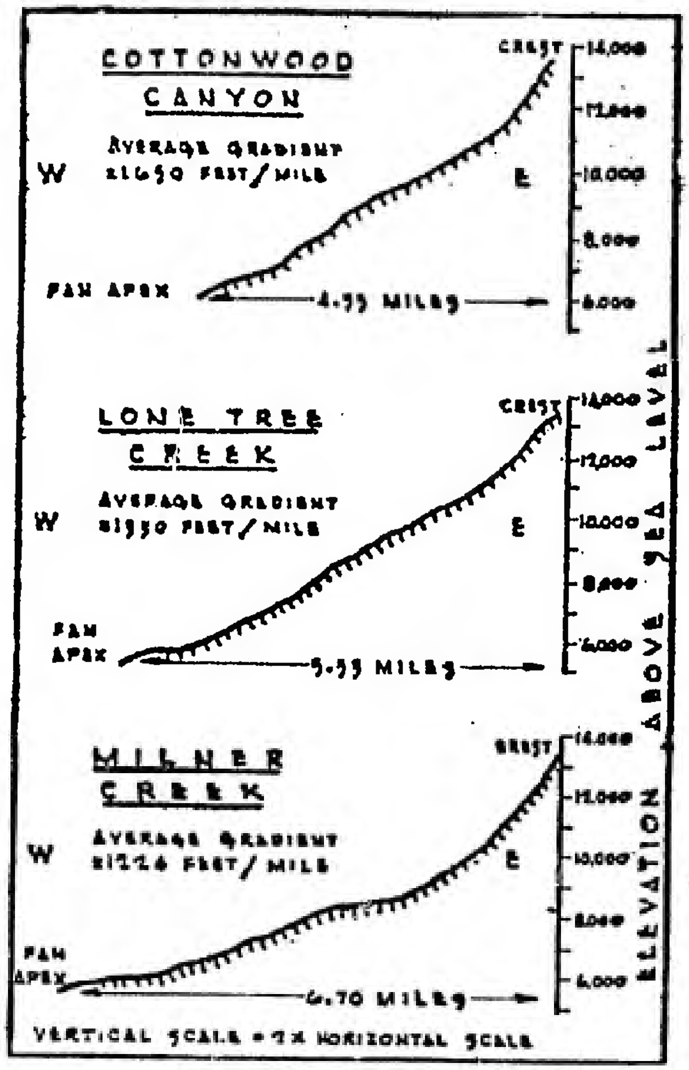

Figure 18. Profiles of trunk canyons of Cottonwood Canyon, Lone Tree Creek, and Milner Creek.

had reached the edge of his ranch yard so that he was in an excellent position to make this close-range observation).

7 The debris flows on the Cottonwood Canyon and Lone Tree Creek fans lasted about 45 minutes to one hour (W. Symons and R. Cashbaugh).

8 After the debris flows had come to rest, high water flow continued in all three drainage systems for 24 to 48 hours (W. Symons and R. Cashbaugh).

9 Deposition of 8 to 10 inches of silt on parts of the Symons ranch resulted from this high water from Cottonwood Canyon (W. Symons).

The witnesses of the Milner Creek flood heard loud rumbling noises in lower Milner Canyon. Some time afterward they drove to the mouth of the canyon to check a pipeline, but by the time they reached that locality debris deposition on the upper part of the Milner Creek fan had come to an end, and masses of primarily muddy water were then rushing out of the canyon. High water flow here continued for approximately 36 hours after the occurrence of the debris flow. This testimony thus reinforces that of Mr. Cashbaugh and Mr. Symons.

Unfortunately, no witnesses could be located who had observed events taking place within the mountain canyons. Consequently, the behavior of flood waters and debris in major canyons can only be inferred from the available morphologic evidence.

(b) Observed morphologic effects

Morphologies of the drainage basins. The three creeks head in the highest part of the range, the area adjacent to White Mountain Peak. Their average gradients are among the steepest in the range, amounting to 1,200 to 1,600 feet per mile (Fig. 18). All are cut primarily in metamorphic terrain which provides abundant debris of easily transportable sizes. All three exhibit an extreme narrowing of the lower trunk canyon at or above the canyon mouth (Fig. 19), which is cut into a particularly resistant red quartzite. At their narrowest, these canyons are no more than 20 or 30 feet across on their floors. These constrictions exerted a decided influence on the behavior of the floods of 1952.

Morphologic evidence and effects in canyons. Since no witnesses of the floods in the canyons could be found, a reconstruction of events taking place therein must be based primarily upon the available morphologic evidence.

Figure 19. Milner Creek bedrock narrows and dam at foot of lower falls. Men on dam give scale.

Some idea of the depth of mobile debris in the various canyons during the floods was gained from an examination of lower canyon walls. Patches of mud and cobbles were found 40 to 60 feet above present canyon floors in all three drainage systems, indicating that depths of debris and water of at least 40 to 50 feet were attained at several locations. Only at particularly narrow parts of the canyons and at canyon mouths, however, did such depths of material accumulate, and it is certainly not implied that at the height of the floods there were continuous masses of viscous debris of this thickness flowing through lower canyons.

Evidently temporary dams were formed at the canyon constrictions, building up behind piles of larger boulders and tree trunks. Temporary damming at canyon narrows has been noted elsewhere, particularly in drainages along the Wasatch front in Utah (Pack, 1923), on the southern flank of the San Gabriel Mountains in southern California (Taylor, 1934; Krumbein, 1942), and on the northern side of the San Gabriel Mountains (Sharp and Nobles, 1953). It is logical to assume that damming of some sort during flooding would take place in any drainage system characterized by extreme constrictions in its trunk canyon.

Collapse of the dams from below or downcutting from the top presumably released surges of debris and water intermittently, and the movement of material down-canyon and onto fan surfaces must have been far from uniform. Testimony of ranchers in Upper Owens Valley indicates that debris movement on fans was apparently conditioned by its intermittent release from canyon mouths, and the presence of mud patches high on the walls of the canyons at and immediately above the canyon mouths argues strongly for the postulated sequence of events, that is, the formation and collapse of temporary dams, at least at the narrowest sites.

Depths of mobile debris in stretches of canyon between constrictions were evidently much more moderate. Judging from traces of mud and cobbles along these sections of the canyons, they averaged perhaps 8 to 10 feet in the lower sectors of all three streams.

The consistency of the material during the floods is problematical, but the debris remnants are now well solidified and resemble concrete, with gravel, cobbles, and smaller boulders set in a well-cemented matrix of sand and finer material. The heterogeneous distribution of debris of all sizes in these remnants indicates lack of sorting by running water and suggests that the material moved in the form of a well-wetted, coherent mass of mixed debris, that is, a mixture of mud and boulders. The flowing debris must have had the appearance of the material of the Wrightwood, California, mud flow, which was described as resembling "freshly mixed concrete" (Sharp and Nobles, 1953).

The source areas for the debris which left its marks scores of feet above canyon floors at constrictions are somewhat conjectural. All three creeks are today flowing on or very close to bedrock for most of the length of their trunk canyons. Also, in each drainage system one of the headwater branches is characterized by flow on or near bedrock, while adjacent headwater branches are alluvium-floored and display clumps of smaller vegetation which must pre-date the heavy rains of 1952 since they in no way differ from the shrubs on adjoining canyon walls. Obviously the bare rock branches must have been cleared of debris relatively recently and appear to have been the sources of the debris flows of 1952.

In the headwater areas there is no evidence of landsliding as a source of debris during these floods; there are no fresh landslide scars on slopes, nor are there remnants of debris tongues or lobes on tributary or trunk canyon floors.

There is no morphologic evidence at the junction of tributary canyons with their trunk canyons to indicate that tributary canyons contributed any notable amounts of debris to the floors of the main canyons during the floods. The floors of the tributary canyons still have a continuous alluvial cover and support patches of vegetation similar to that growing on adjacent slopes.

Thus the conclusion is all but inescapable that the bulk of the debris involved in these floods came from the floors of the trunk canyons and from one of the upper branches of each system.

There is excellent evidence of the removal of debris from the floor of the lower canyon of one of the drainage systems, Cottonwood Canyon. Today, a stand of dead cottonwood trees occupies matched narrow terraces of alluvial fill about 15 to 20 feet above the creek bottom in the lower half-mile of canyon (Fig. 20). Prior to 1952, these trees were green and were growing on a flat extending completely across the lower canyon; the creek then occupied a shallow channel in the approximate center of the flat (Springer, R., Personal Communication, 1957). During the flood of 1952, a body of material roughly 20 to 30 feet wide, 20 feet deep, and about 1,500 to 2,000 feet long was removed and added to that brought down from higher in the basin. The lowering of the

Figure 20. View looking downstream just above mouth of Cottonwood Canyon showing dead trees on terraces formed by 1952 flood. Depth of cut at this point is about 15 feet.

creek bed has subsequently caused the death of the trees on the terraces, as their root systems no longer can tap ground water or water from the stream itself.

In the other two drainages, Milner Creek and Lone Tree Creek, narrow terrace remnants are present for more than a mile above the mouths of the canyons, but their formation cannot be dated by eye-witness accounts. They stand 5 to 10 feet above the creek bottoms and indicate a recent removal of debris to this depth. In analogy with the well-dated removal of debris in lower Cottonwood Canyon, it is postulated that all or the major part of the removal in Milner Creek and Lone Tree Creek was accomplished by the floods of 1952.

Following movement of debris on trunk canyon floors, high water flow continued for some time. Presumably this high water removed some of the material remaining on canyon floors after the debris flows had passed, but it is impossible to determine how much alluvium may have been shifted onto the fans in this manner.

In summary, then, the major morphologic effect of the floods in these drainage systems, as inferred from the available morphologic evidence, was the removal of five to ten and in places 20 feet of alluvial and colluvial fill from the floors of the trunk canyons, leaving the streams today flowing in bedrock channels over much of their course.

<u>Morphologic evidence and effects on fans</u>. Two major morphologic effects were brought about on the fans by the floods of 1952, the addition of debris to fan surfaces and the deepening of active channels. Evidence of the former is much more conspicuous, and the present surface morphology of all of the fans is characterized by the still-recognizable deposits of the floods (Figs. 21 and 22). Evidence of channel deepening is much less obvious, but estimates by local residents and field examinations indicate that some lowering of channel floors took place during the floods.

Debris deposition on each of the fans was in the form of a long, relatively narrow strip of material extending radially from the apex to near the margin (Figs. 16, 17, and 23). The flowing debris masses followed the pre-existent active channel on each fan.

On the upper thirds of the fans the debris was generally confined within the pre-existent active channels, which had a depth of 10 to 15 feet. The average width of the debris flows here was about 100 to 150 feet. In a few places, however, debris overtopped channel walls, and short tongues or fingers of material spread diagonally away from the main debris masses. The largest of these tongues spilled out of the active channel near the apex of the Lone Tree Creek fan (see Fig. 17),

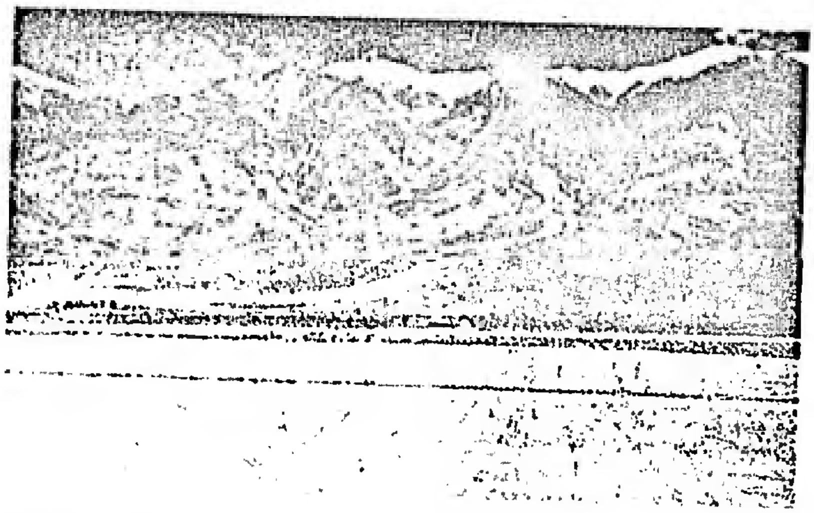

Figure 21. General view of Cottonwood Canyon fan showing 1952 flood deposits, which are conspicuous by their lighter color. The clump of trees at the left side of the picture marks the location of Symons ranch. Corn field on floor of Upper Owens Valley in foreground.

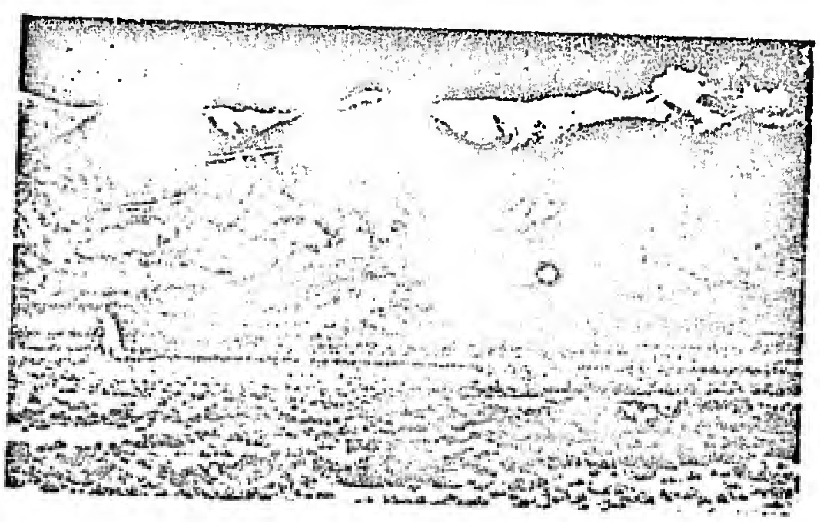

Figure 22. General view of Lone Tree Creek fan showing 1952 flood deposits, which stand out because of their lighter color. Floor of Upper Owens Valley in foreground.

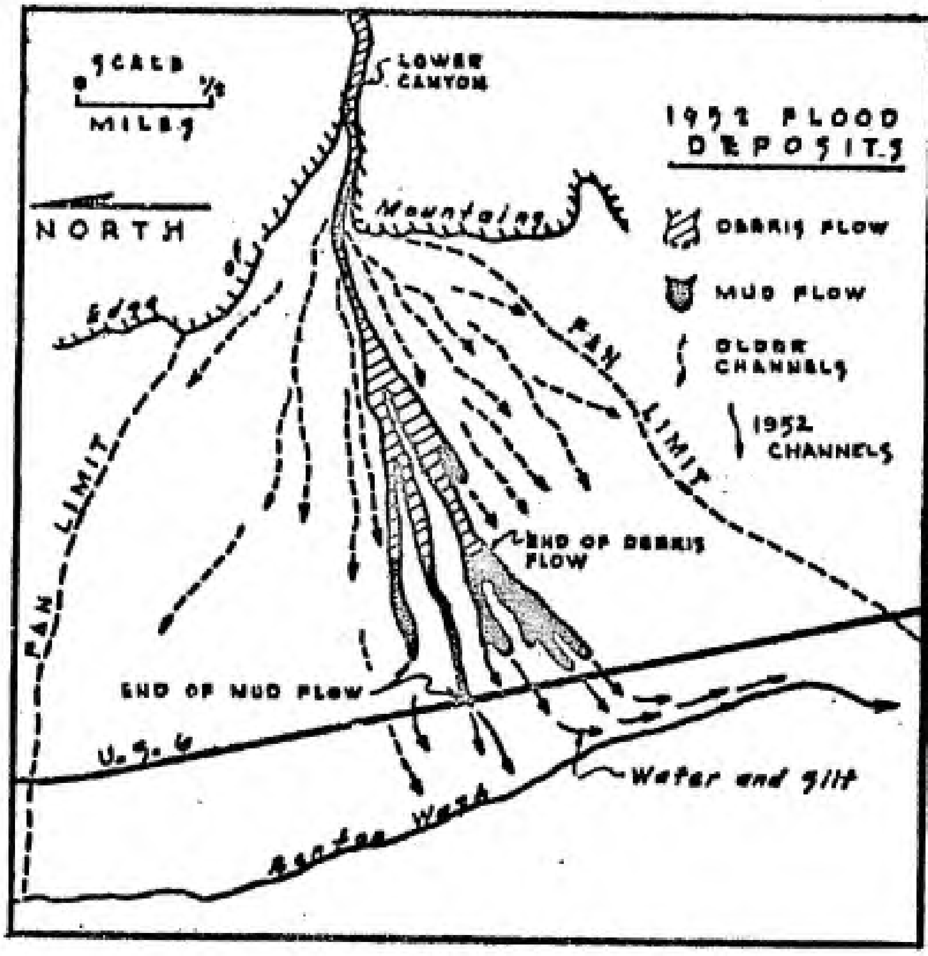

Figure 23. Map of Milner Creek fan showing deposits of 1952 flood. Traced from an aerial photograph taken in 1954.

and, maintaining a width of 200 feet, advanced 700 feet downslope. Its deposits attain thicknesses of 2 to 4 feet. A somewhat narrower and longer tongue branched off from the debris flow of Cottonwood Canyon in this sector of its fan.

In the middle third of the fans, where the incised channels shallowed to around 5 feet, the debris masses increased their width by overtopping channel walls and spreading or dividing laterally. On the Cottonwood Canyon fan (Fig. 16) the increase in width was gradual, except for a momentary widening at a major bend of the active channel. Here, the flow assumed a width of 400 feet, but immediately below, it narrowed to 100 feet and in the next mile gradually widened to 400 feet. On the Lone Tree Creek fan (Fig. 17) the widening of the flow in this sector was rather abrupt, changing from a width of 200 feet to one of 500 feet within less than a quarter of a mile. This greater width was maintained for half a mile. Half a dozen short and two longer lobes branched off from the main flow in this sector. On the Milner Creek fan (Fig. 23) the shallowing of the active channel caused a sudden widening which induced a division into first two, then three arms, which combined, cover an area nearly a mile in length and attain a greatest width of close to half a mile.

On all three fans the blocky debris flows ended about two-thirds of the way down the slopes. Beyond these points the blocks become scarce and the deposits indicate that the material assumed the consistency of viscous mud with a liberal admixture of small rubble. In this form the flows advanced in numerous narrow tongues (Milner Creek) or in two broad lobes (Lone Tree Creek and Cottonwood Canyon) another quarter of a mile or half a mile down slope.

The change from debris flow to mud flow was gradual and thus less abrupt than indicated in Figures 16, 17, and 23.

The depth of deposited debris tends to decrease down slope from the fan apexes. On the upper third of the fans the deposits attain thicknesses of 6 to 8 feet. Isolated patches of debris above the main deposits, as well as the height of the channel sides where overtopping took place, indicate that the debris flows assumed a greater volume during passage and attained thicknesses of 15 to 20 feet during the occurrence of some of the surges described by eyewitnesses.

The depth of the blocky debris in the middle third of the fans, where spreading could take place, is only 2 to 3 feet, and the material left in the mud flow deposits is thinner still, a foot or less on an average.

The depth of the pre-existent active channel on all of the fans was sufficient to confine the greater bulk of the fluid debris to these channels for between one-third and two-thirds of the radial length of the fans. Thus, the effect of a relatively deeply incised active channel on the upper fan surface is to prevent flooding there and to extend downslope the confined flow of water and debris until shallowing of the channel permits spreading of the two.

The length of the deposits on the fans greatly exceeds the width. The comparatively narrow strips of debris extend two to three miles downslope on the alluvial surfaces, in contrast to maximum widths of individual arms at fan margins of 400 to 500 feet and an overall width of the affected area of 1,000 to 3,000 feet.

Water content of the moving debris masses on the fans is highly speculative. According to eyewitness accounts, the masses gave an impression of high fluidity, yet where small tongues of debris spilled out of main channels during the floods they did not continue to flow for any great distance, despite the steepness of the fans. There is no clear evidence that water drained from the masses that spilled out of main channels after they had come to rest. At present, all of the debris on fan surfaces is well-solidified and looks like concrete, suggesting a rather pasty consistency at the time of movement. Water content of the Wrightwood, California, mud flow was measured during the occurrence of the flow and found to be from 15 to 30 percent by weight (Sharp and Nobles, 1953). It is reasonable to assume that similar percentages prevailed in the White Mountain flows of 1952, since in both cases the behavior of the material during the floods and its later appearance were similar.

In their courses down the fans the flows adhered closely to the underlying topography. The main masses were guided by the pre-existent channels and followed all of their bends. The tongues of debris which formed when material topped channel walls, and the different branches of the Milner Creek flow, followed old flood channels in their courses down the fans. This close adherence to rather shallow depressions suggests that the mobile debris was moving at such slow rates that its momentum was not sufficient to overcome even minor surface irregularities.

The appearance of the debris flows today, several years after the event, is quite distinctive. In cross section they are concave upward, with well-defined lateral ridges 3 to 6 feet wide and 2 to 4 feet high along parts of their margins (Fig. 24). Evidently the central part of these debris flows had greater fluidity than the margins, and material gradually was left stranded along the edges. Subsequent water runoff followed the centers of the flows and removed a certain amount of material, tending to accentuate the ridge-like characteristics of the margins.

Figure 24. Lateral ridges along edge of 1952 debris flow near apex of Cottonwood Canyon fan. One ridge extends diagonally across picture from lower left corner and is about 3 feet high and 5 feet wide at the base. A second ridge can be seen on opposite side of fresh deposits. Cultivated fields in background are Symons ranch, near which the lower end of the debris flow is visible.

Lateral ridges along Alaskan mud flows have been termed "mudflow levees" (Sharp, 1942), and the term "moraine" has also been used to describe similar features on mud flows in Turkestan (Rickmers, 1913). The lateral ridges along the margins of the White Mountain debris flows of 1952 resemble both natural levees and glacial moraines, the former in that they are represented in plan by a pair of closely spaced, winding, linear ridgelets, the latter in the steepness of their sides and their composition, which is characterized by a heterogeneous mixture of debris of all sizes. Along margins of the White Mountain flows there is a gradation from a moraine-like shape and composition of the ridges on upper fan surfaces to levee-like silt deposits near fan perimeters.

After deposition of the main debris masses had taken place, flows of muddy water came from the canyons and followed down approximately the center of the flood deposits. The effect was to dissect the fresh debris and to excavate material from the floors of the older, pre-flood channels underlying the new deposits, at least on the upper third of the fans. Water floods have typically followed debris deposition in other parts of western America (Pack, 1923; Blackwelder, 1928).

The amount of channel deepening on the fans is difficult to determine accurately. It is possible that some high water flooding preceded the debris flows and accomplished a certain amount of cutting on the floors of the pre-flood active channels. However, the eyewitnesses were not in a position to observe this, and from their fan-margin locations they saw only moving debris at the outset of the floods.

It is definitely established by eyewitness accounts and field examinations that the high water flows which followed debris deposition dissected the fresh material in the channels and cut down into the alluvium of the pre-flood channel floors. Estimates by local residents of the amount of this channel cutting vary. An average of the various estimates gives a figure of 4 to 5 feet in the immediate apex region of the three fans, and a field determination of the positions of the pre-flood channel floors established roughly the same depth of channel incision on upper parts of the Milner Creek and Lone Tree Creek fans (Fig. 25).

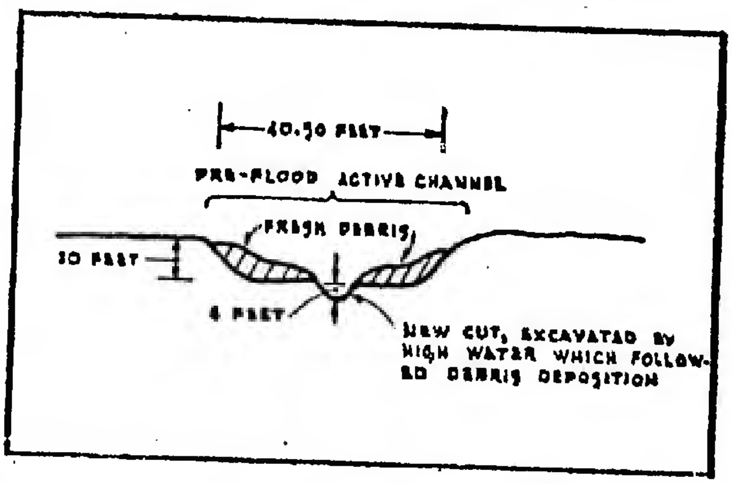

Figure 25. Diagrammatic cross-section of active channel on Milner Creek fan about 100 yards below canyon mouth showing debris deposition and channel cutting brought about by the 1952 flood.

Channel deepening took place over approximately the upper third to half of each fan, and the material thus excavated was transported beyond the lower end of the debris and mud flows where it was deposited as sand and silt in a braiding system of flood channels on the lower fan and in broad, thin masses of fine material on the flatter land beyond.

Property damage resulting from these floods was moderate. Intakes to irrigation pipelines at the mouths of the three canyons were destroyed, and the ranches dependent upon these streams were without water for approximately ten days. Water and fine debris from the drainage basins streamed across the valley highway (U.S. 6) at several locations, but the pavement itself was not seriously damaged, and at no time was traffic halted for more than a few minutes. An unsurfaced road to a pyrophyllite mine on Lone Tree Creek, which had been routed along the edge of the stream channel on the fan, was covered by the fresh debris for most of its length (see Fig. 17). In relocating this road, it was shifted to the northern margin of the fan, a position of much greater safety. Luckily, there were no structures or other man-made installations directly in the path of the main masses of debris.

(3) <u>Flooding in Leidy Creek</u>

(a) <u>Eyewitness account</u>

Only one bona fide eyewitness of this flood was located. This man, an employee of one of the larger ranches on the floor of Fish Lake Valley, observed the heavy rains in the mountains during the early afternoon, and later, about 1700 hours, heard a heavy roaring and rumbling in the Leidy Creek drainage (Johnson, G., Personal Communication, 1957). He immediately drove to the mouth of the canyon and walked one-third of a mile up-canyon to inspect the irrigation intake for the ranch. When he reached it he noticed a broad tongue of fresh debris a short distance up-canyon in which he could detect slight movement along the lower margin. He had the impression that the creeping movement of the debris tongue was just coming to a halt. He noticed that the creek had a much higher than normal discharge at this time and stated that the high water continued for 24 to 36 hours thereafter. This description tallies well with eyewitness accounts of the floods on the other side of the range.

(b) <u>Observed morphologic effects</u>

<u>Morphology of the drainage basin</u>. Leidy Creek is one of the larger and more important east-side drainages and can be considered typical in morphology of the big drainage systems on that side of the northern White Mountains. The profile of the main canyon is characterized by a relatively steep upper portion and a long, moderately gentle lower segment (Fig. 26). It is cut in both granitic and metamorphic terrain; because of these bedrock differences it is possible to check source

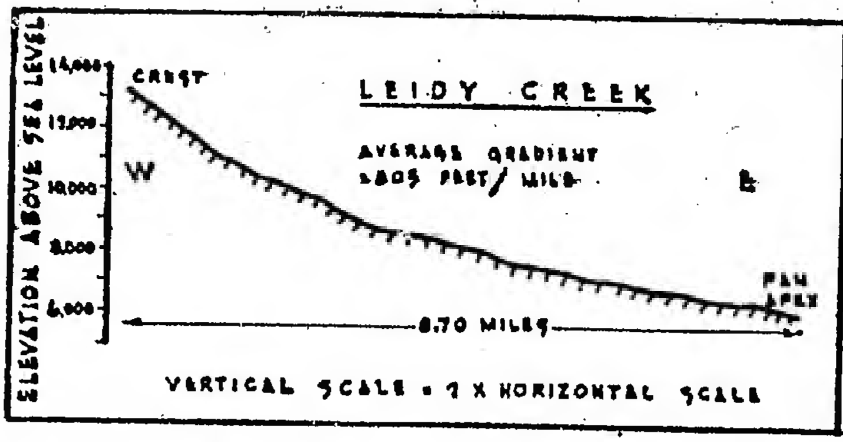

Figure 26. Profile of trunk canyon of Leidy Creek.

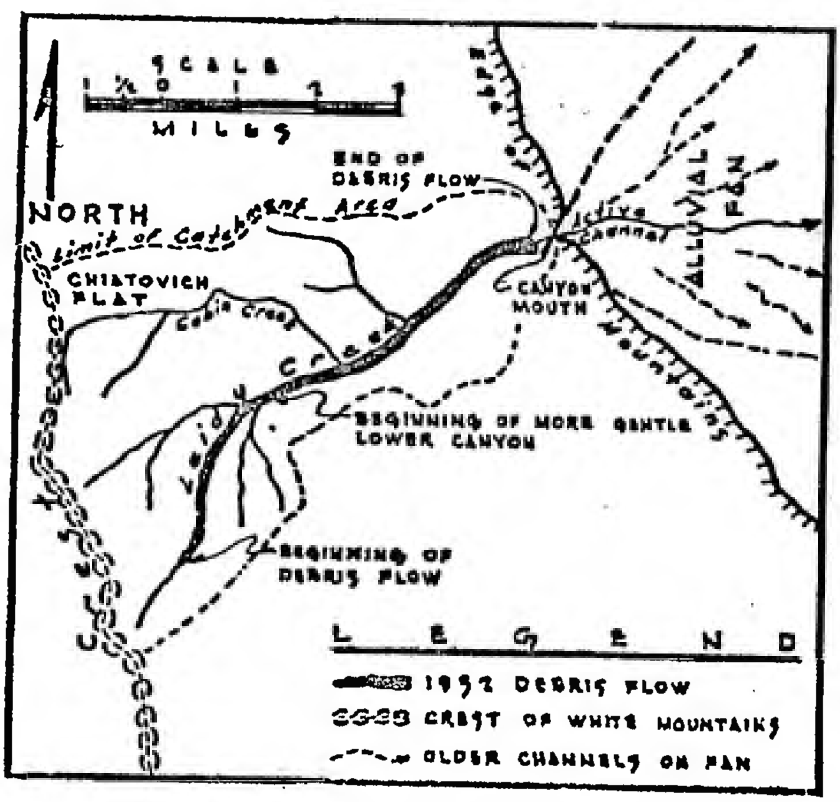

Figure 27. Plan of Leidy Creek drainage basin showing location of 1952 debris flow. Base from U.S.G.S. White Mountain Peak topographic quadrangle.

areas for specific debris deposits. The upper portions of the main forks, heading a short distance north of White Mountain Peak in the highest part of the range, were glaciated during the Pleistocene; the most recent glaciers, although small, left morainal deposits of exceedingly fresh appearance. The lower main canyon is deeply alluviated and contains well-preserved segments of matched terraces 50 to 75 feet above the valley floor along its entire length.

<u>Morphologic evidence and effects in canyon</u>. The heavy rains of July 1952 produced considerable debris movement on the floor of the trunk canyon within the mountains; the large debris flow came to a halt about one-quarter of a mile above the canyon mouth (Fig. 27). The lower portion of the main canyon floor, which widens markedly about one mile above the canyon mouth, was covered with coarse, blocky debris to a depth of 2 to 3 feet (Fig. 28).

Figure 28. Looking downstream in lower Leidy Canyon from a point about one-half mile above mouth. The row of trees to the right of the stream cut marks the approximate margin of the 1952 debris flow, which spread to cover most of the canyon floor in the middle-ground of the photograph. Note well-defined, sloping terrace at left of stream channel, which supports a thrifty growth of pinyon pine.

A clear superposition of three or more sheets of blocky debris is recognizable in the deposits, which suggests that the material came down in surges. Here and there an overlapping of the debris sheets is noticeable, indicating that the later surges advanced a bit farther than the earlier ones. A similar overlapping of flood deposits was also reported by Blackwelder (1928). The bulk of the debris consists of metamorphic material. Since outcrops of metamorphic rock in this drainage basin are found primarily in the crestal area, the debris must have originated well up in the catchment area. One branch in the headwaters of the trunk canyon is again completely cleared of debris, while neighboring branches are still alluviated. The debris thus originated in one headwater branch and the main canyon, as was the case in west-sid drainages.

Following debris deposition in the lower trunk canyon, high water dissected the deposits and shifted finer material out of the mountain mass and onto the fan surface.

Morphologic evidence and effects on fan. Since the debris flow did not reach the apex of the fan, no material was added to its upper half, and the major agent of morphologic change was running water. The high water which followed debris deposition in the lower trunk canyon deepened the active channel in the upper third of the fan approximately 3 to 4 feet (G. Johnson). The material thus removed was spread on the lower third of the fan in a series of relatively thin deposits in and adjacent to half a dozen shallow channels which functioned as distributaries to the main channel on the fan margin.

The total morphologic effect of this flood on the fan was thus very slight. Flood water simply flowed across the fan surface in existing channels and eventually reached the low point in Fish Lake Valley by following a series of man-made ditches across the valley floor.

(4) Comparison of floods in the four canyons

It is evident that considerable differences existed between the behavior of flood waters in Leidy Creek and in the three west-side drainages discussed above. In particular, movement of significant volumes of coarse debris in the Leidy Creek drainage system was confined to the trunk canyon floor within the mountains and did not reach the fan surface.

It is believed that the most important physiographic factor responsible for the different behavior of the flood in Leidy Creek was the relatively gentle gradient of the lower main canyon. Evidently a considerable proportion of the potential and actual energy of the flood was expended in this length of canyon; velocity of the moving debris dropped rapidly as the gradient lessened, and whatever inertia it may have had in the steeper, headwater area was quickly dissipated. Additionally, the floor of lower Leidy Creek is relatively broad and permitted ready spreading of the debris, causing a further loss of momentum. In short, as the gradient lessened, the bulk of the coarser debris load was dropped, and only muddy water emerged from the canyon mouth, causing little damage on the fan.

In contrast, the steep gradient of the west-side streams allowed debris movement to continue beyond canyon mouths, and as it spread onto the fan surfaces it could cause greater damage.

b. The flood of 19 July 1955

This flood affected only Indian Creek, on the east side of the White Mountains.

(1) Precipitation

This flood is the only one for which moderately accurate precipitation estimates are available. A portable rain gage had been carried to Chiatovich Flat on the afternoon of this date, and 8.25 inches of rain were there received in approximately two and one-half hours (Powell, D., Personal Communication, 1957). According to Mr. Powell, the heaviest rain was concentrated on Chiatovich Flat and in the south fork of Indian Creek; adjacent drainages showed no evidence of high water after the passage of the storm. Thus, the areal extent of the intensive precipitation was limited perhaps to no more than 1 or 2 square miles. White Mountain II, 10 miles south of Chiatovich Flat, recorded only 0.13 inch of rain on that day, and White Mountain I, 16 miles south, had only 0.03 inch.

(2) Flooding in Indian Creek

(a) Eyewitness accounts

The observer on Chiatovich Flat had little opportunity to see the effects of the heavy rain in the lower trunk canyon of Indian Creek proper. Fresh gullies and small tongues of debris were noticed on the steeper slopes of the headwater area of the south fork of the stream after the rains had passed.

Fish Lake Valley residents reported hearing the usual rumbling and roaring sounds in the Indian Creek drainage, although much of this noise may have been thunder in the storm from which the heavy rain came.

High water emerged from the mouth of the canyon approximately one hour after the period of heaviest rain.

(b) Observed morphologic effects

Morphology of the drainage basin. The south fork of Indian Creek heads near the east end of Chiatovich Flat at an elevation of approximately 10,000 feet (Fig. 29). The profile of the canyon is similar to that of Leidy Creek in that it has a steep headwaters portion and a much gentler lower segment. The lower main canyon is terraced and floored with alluvium. Slopes in the upper portion of the basin are steep and have a shallow regolith; bedrock outcrops are common here. Canyon narrows are absent in the lower main canyon.

Morphologic evidence and effects in canyon. Slopes within the headwater area of the south fork of the drainage were severely gullied in places by the heavy rain. Trains of debris lead downward from

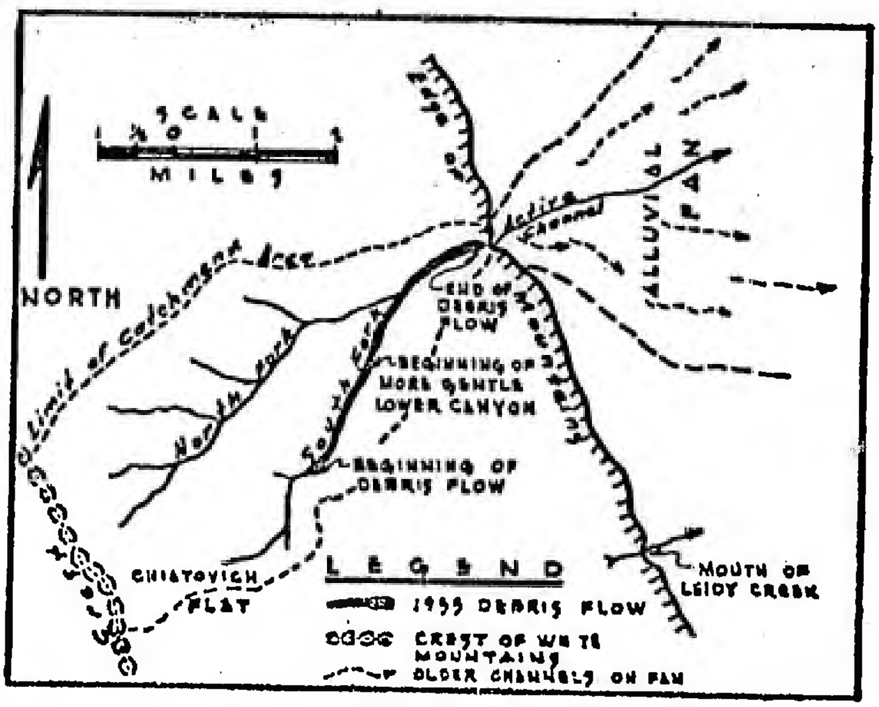

Figure 29. Plan of Indian Creek drainage basin showing location of 1955 debris flow. Base from U.S.G.S. White Mountain Peak topographic quadrangle.

the gullies, indicating that material was thus shifted toward and onto the floor of the canyon. Tributary canyons on the southeastern side of the south fork contributed debris to the floor of the main canyon, as evidenced by remnants of small debris flows extending from their mouths to the main canyon floor.

A larger debris flow developed on the floor of the south fork and continued downstream past the junction with the north fork, reaching almost to the canyon mouth (Fig.29). Debris deposited on the trunk canyon floor below the junction reached a thickness of three to four feet, as measured in the stream cut. Following debris deposition here, high water flow developed and a certain amount of channel scouring took place.

The Indian Creek flood of 1955 in the canyon was remarkably similar to that in Leidy Creek in 1952 in many respects. The notable difference was that in Indian Creek a large proportion of the debris which flowed along the floor of the lower trunk canyon came not from the floor of the upper canyon itself, but rather from adjacent slopes and floors of tributary canyons.

Morphologic evidence and effects on fan. Primarily dirty water issued from the canyon mouth onto the Indian Creek alluvial fan following the heavy rain within the mountains. Accordingly, the major morphologic effects were similar to those produced on the Leidy Creek fan by the flood of 1952. That is to say, there was channel deepening on the upper third of the fan, judged to be about 3 to 4 feet in places, and re-deposition of the finer debris thus removed on the lower, peripheral parts of the fan. Excess water from the fan followed indistinct natural channels and man-made ditches across the floor of Fish Lake Valley to the low point, collecting there in a temporary playa lake. Morphologically the effect of the flood on the fan was slight.

The total morphologic effect of this flood both within the mountains and on the fan appears small, considering the probable intensity and absolute total of the rain responsible for it. It is possible, however, that rain falling in the catchment area of the south fork of Indian Creek was not as intense as that measured on Chiatovich Flat.

(c) The floods of 25 July 1956

These floods occurred in the same three west-side drainage basins in which large floods took place in 1952, that is, Milner Creek, Lone Tree Creek, and Cottonwood Canyon. Although these floods happened in the beginning of the contract period, neither the Principal Investigator nor the Assistant was in the study area at that time, and an invaluable opportunity to observe flooding at first-hand was thus lost.

(1) Precipitation

Heavy rains again fell in the headwater areas of the three drainage basins on 25 July 1956. Absolute amounts and intensities could not be determined. The weather stations closest to the area, White Mountain I and White Mountain II, recorded 24-hour totals for that day of, respectively, 0.56 inch and 0.26 inch of rain. Residents of Upper Owens Valley reported that the rains of July 1956 appeared to be at least as heavy as those of July 1952 when serious flooding and debris flowing took place, but the floods of 1956 were comparatively mild in their effects. The comparison made by the local ranchers is admittedly subjective, but it is given for completeness of record.

(2) Flooding in Milner Creek, Lone Tree Creek, and Cottonwood Canyon

(a) Eyewitness accounts

Local valley residents were particularly cognizant of the heavy cumulus buildup over the White Mountains on this date because of the relative recency of the serious floods of 1952. But their fears were not realized; no debris flows came from the canyons, only high water. The heaviest rains fell during the early afternoon, from about 1300 to 1500 hours, and high water developed in the drainages within less than an hour after the period of maximum precipitation. The high water built up to crests of maximum discharge in about 45 minutes and subsided to somewhat higher than normal flow in a slightly longer period. Irrigation system intakes were once again destroyed by the high water, but little debris was carried out of the canyons by the flood waters. Although at time of highest water there was evidently considerable noise in the lower trunk canyons, none of the ranchers who paid attention to these floods reported hearing exceedingly loud rumbling and roaring noises such as occurred in 1952.

(b) Observed morphologic effects

Morphologic evidence and effects in canyons. When visited ten days after the event, these canyons showed surprisingly little morphologic evidence of these recent floods. There was no evidence of the shifting of large volumes of debris in the main canyons, either in the form of stranded remnants of debris on the sides of trunk canyons or in the form of patches of material on their floors. The only evidence consisted of marks left by muddy water on canyon walls and occasional small piles of fresh sand and silt on the creek banks. These indicated that depths of 8 to 10 feet were attained at the narrowest parts of the canyons.

Morphologic evidence and effects on fans. The major morphologic effect on the fans was the deepening of active channels in apex regions and re-deposition of finer material on fan perimeters. During the relatively brief period of high water, channel scouring took place on the upper portions of alluvial fans of all three stream systems. As is usually the case, it is impossible to get more than a very rough estimate of just how much deepening actually occurred; estimates based on testimony of the most reliable local residents vary from 2 to 4 feet.

Material removed from channel floors in the upper third of fans was carried downslope and redeposited in peripheral portions of the fans. Floodwaters charged with this finer debris remained in main channels about two-thirds of the way down the fans; only on the lower third was there any spreading of water into numerous branches and sheets. No important channel course changes occurred during these floods.

Comparison of the 1956 and 1952 floods. The floods of 1952 in these three drainage systems produced extensive morphologic changes in lower trunk canyons within the mountains and on the alluvial fans. The floods of 1956 consisted primarily of water in all three drainages; a minor amount of debris was moved from canyons to fan surfaces, but the major effect was to deepen principal channels on the fans, particularly near apexes. The differences between the two years are remarkable and demand an explanation.

The much shorter duration of high water flow suggests that the rains of 1956 were in all probability less intense than those of 1952, despite the tendency of the valley ranchers to ascribe the more recent floods to equal or heavier precipitation.

It seems very probable that difference in behavior of floodwaters in the two years was at least in part due to differences in the availability of debris in the canyons. One of the major morphologic effects of the 1952 floods was the flushing out of debris from the trunk canyons, leaving essentially bedrock channels over their greater length. Although similar amounts of rain may have fallen in 1956, lack of significant amounts of debris in main canyons prevented the development of debris flows and allowed relatively rapid runoff. Streams quickly reached a high water stage and receded from it just as rapidly. Minor volumes of material probably were moved into main canyons from tributary valleys during the period of intensive rain, but the total amounts brought in were small and were easily carried off by normal stream processes.

Assuming this reconstruction of events to be accurate, a fundamental relation emerges: Given sufficiently excessive water in a drainage basin, its flooding behavior in the trunk canyon and on the fan will largely be controlled by the amount of debris on the floor of the trunk canyon. Large amounts of debris in the main channel within the range should result in floods producing debris flows and mud flows which may travel a considerable distance down the fans, with high water following debris deposition. Bedrock valley floors, in contrast, will promote rapid runoff of muddy water; the most important effect on fans will be deepening of the active channels. Once most of the accumulated loose alluvium is flushed from the floor of a major canyon by a large flood, it would be expected that the canyon would produce nothing but high water floods until normal movement of debris from tributary canyons and slope retreat had resulted in the accumulation of sufficient alluvium and colluvium on the canyon floor for the development of another large debris flow.

Thus, close examination of the condition of the floor of the trunk canyon of a mountain drainage system ought to provide one guide to a determination of the flooding potentialities and possible destructive effect of high water in that drainage basin.

3. Minor flooding during contract period

No serious flooding took place in the study area while the Assistant was in the field. Floods and flood effects actually observed first-hand were thus minor in both volumes of water involved and physiographic changes produced. Nevertheless, it was possible to make close-range observations during one period of snowmelt flooding and of two small cloudburst floods. However, no wintertime flooding occurred during the contract period.

a. Snowmelt flooding in west-side drainages, 28 May to 7 June 1957

(1) Weather prior to flooding

Snow pack in the White Mountains was considerably below normal until May 1957. A prolonged series of frontal storms crossed the area during the period 7 - 25 May, resulting in relatively heavy rains at lower elevations and much snow in the mountains above 9,000 feet. This was the wettest May for most of California for 25 to 30 years. Cool weather, with broken to overcast skies, persisted in the area until about 26 May at which time the last cloudiness of the frontal systems moved out of the region and warm, dry air moved in. During the next two weeks, days were hot in the valleys, reaching continuously to over 95°F in Bishop, and warm in the mountains. Nighttime temperatures were relatively high, even at higher elevations. White Mountain II, elevation 12,470 feet, had average daily minima of 34°F during the period, and White Mountain I, elevation 10,150 feet, experienced daily minima of around 38°F.

(2) Snowmelt runoff

The persistent high temperatures brought rapid melting of the accumulated snow pack and caused a rise in discharge in all creeks. This increase in runoff was especially evident in Cottonwood Canyon, Lone Tree Creek, and Milner Creek, the same three streams that flooded seriously in July 1952, and again less seriously in July 1956.

During the period of high water in 1957, both Cottonwood Canyon and Lone Tree Creek were delivering relatively clear water to their canyon mouths at the time of maximum flow. The two ranches using water from these drainages have arrangements for diverting it to pipelines so that most of the increased discharge was used, leaving relatively little to flow in old channels across the fans, and no marked flooding developed here.

The Milner Creek pipeline intake box, however, is so constructed that it is easily filled with debris during periods of high discharge, and diversion is thus ineffective. This happened in late May and early June 1957, and the full discharge followed the creek channel across the fan, creating minor flooding and an opportunity to observe the event.

(3) High water in Milner Creek

Lower Milner Creek canyon is characterized by an extreme narrowing about one and one-half miles above the canyon mouth. At this narrows there are two waterfalls with an aggregate drop of approximately 70 feet; the floor of the valley is here only 20 to 30 feet wide. The pipeline intake is situated at the very foot of the lower falls in a concrete box which extends all the way across the canyon floor at this point (see Figure 19). A grill of 5-inch "I" beams on top of the box prevents large boulders from lodging in it but permits cobbles, gravel, and sand to settle in it. The snowmelt runoff brought sufficient debris that the box became filled, and the full flow of Milner Creek surged down the rest of the lower canyon and out onto the fan.

Discharge during the week of snowmelt was characterized by marked daily periods of maximum and minimum flow. In terms of estimated volumes obtained by very rough measurements of surface velocity and channel cross-section, minimum discharge was on the order of 25 to 40 cubic feet per second (cfs) immediately below the narrows, and maximum discharge was 400 to 500 cfs for short periods of time Normal discharge at this time of year is on the order of 10 to 15 cfs. Maximum flow occurred at about 0200 hours and minimum flow at about 1400 hours. This suggests that it took approximately 10 to 12 hours for one afternoon's snowmelt to reach the canyon mouth in the form of the day's crest. The horizontal distance from headwater area to the narrows is about seven miles.

(a) Behavior of runoff in lower canyon

The short section of lower Milner Creek canyon below the narrows widens gradually downstream to 200 feet and is apparently rather deeply alluviated. The present main channel in this stretch of canyon is incised partly in the deposits of the 1952 flood and partly in the older alluvium.

During the first day or two of excess snowmelt runoff, the channel in the lower canyon was evidently deepened about 2 feet. During this period primarily muddy water, with little or no bed load larger than cobbles, was coming out of the mountains. Following the initial period, however, little if any deepening took place; the dominant process at work in this reach of channel was transportation of the bed and suspended loads downstream toward the fan apex.

Observations at the waterfalls in the narrows indicated that large quantities of coarse debris were being delivered to the upper end of the lower canyon. Observations between the narrows and the canyon mouth indicated that the channel at any given place was constantly changing shape, both in plan and cross-section. But evidence of channel deepening after the initial period, other than local and temporary, was not discernible to an observer on the banks.

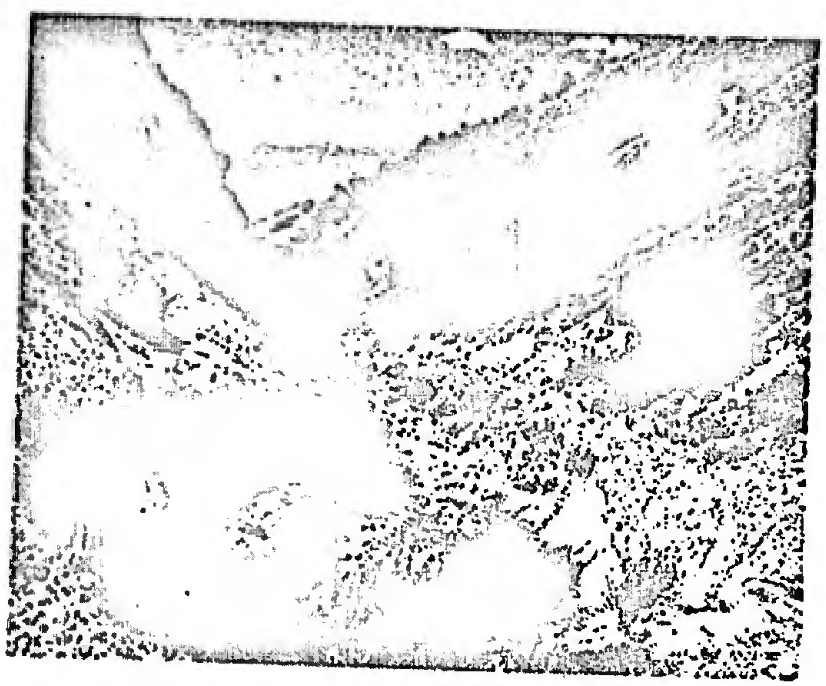

Figure 30. Floor of Milner Creek canyon about one-quarter mile above the narrows. To the right of the cut, attributable to the 1952 flood, is a narrow ridge of debris left by the debris flow of that year. Undercutting of similar narrow terraces or ridges and movement of material on the creek bottom shifted rubble down the canyon to the falls in the narrows during the period of snowmelt runoff of 1957.

Large quantities of debris very obviously were coming from some place upstream; the major source was found to be narrow terraces of fresh material left stranded on lower canyon walls by the flood of 1952 (Fig. 30). Undercutting of these terraces was observed to occur more or less continuously at some place during periods of high water, caving much coarse material and considerable fines into the channel. The flow coming over the dam at the lower falls in the narrows was extremely dirty (Fig. 31), and boulders up to three or four feet in diameter were being moved. A certain amount of undercutting and caving went on in the lower canyon, but the amount of material added to the total load of the stream in this manner was not great.

Observations in the lower canyon at fixed points indicated that constant change in channel shape may take place without appreciable deepening of the channel itself. The main strand of current swings back and forth across the width of the channel within remarkably short periods, and gravel and cobble bars are quickly built and just as quickly washed away (Fig. 32). Relatively fixed obstacles in the channel, such as large boulders and partially buried logs, control the course of the main strand of current to a certain extent, but temporary masses of cobbles and gravel, built and torn apart by the stream itself, seem to be more important in bringing about shifts in the position of the main strand.

From time to time logs would become stranded on shallow bars at an angle to the main current. It was but a matter of minutes before debris accumulated upstream from the logs, creating new, temporary obstacles and thus bringing about further course changes. Bank cave-ins deflected the main strand of current from one side of the channel to the other but occurred less frequently.

These course changes of the main strand of current were observed to take place so rapidly that any given part of the channel in the lower canyon would hardly be recognizable 5 or 10 minutes after first sight of it. Yet throughout the process of ever-changing channel shape, channel depth remained essentially constant. Material moved downstream discontinuously, perhaps 10 or 20 feet at a spurt. It would be incorporated into temporary midstream or side-channel bars which might persist for 10 or 15 minutes. As they were washed away, cobbles and gravel would be shifted downstream another few feet, again to be lodged in a temporary resting place. In this manner, material from above the narrows was transported through the lower canyon and onto the fan.

(b) Behavior of runoff on fan

On the Milner Creek alluvial fan, high water followed the creek channel on the upper two-thirds of the surface, after which it divided into half a dozen branches which followed old channels downslope to the highway. Here, man-made dikes diverted it into ditches leading to

Figure 31. Flow over Milner Creek intake box during the period of snowmelt flooding of June 1957. Compare with Figure 19.

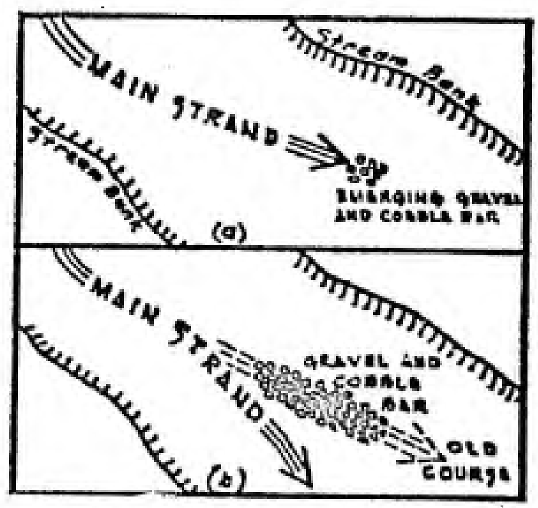

Figure 32. Bar construction and change in course of main strand of current in lower Milner Creek canyon. (a) Initial position of main strand of current; (b) changed shape four minutes later. The newly emerged bar persisted for eight minutes and was then washed away.

culverts. Below the highway, the flow followed an anastomosing channel pattern, reuniting into a single strand near the southwestern edge of the fan, from where a single channel, cut in finer material, led the dwindling water onto the valley flat south of the fan. Here sheet deposition of silt and fine sand took place.

The main channel on the fan is entrenched, and runoff during this period never got out of this trench. Only during the first couple of days of high water did it ever cover all of the channel floor, which is here 15 to 20 feet wide. However, during the course of a day's high water, the smaller, shallower channels within the major cut were undergoing constant change, similar to that observed in the lower canyon, but generally much less rapidly. The major work of the water over the upper two-thirds of the fan consisted of debris transportation; the channel in any given section was constantly changing shape (Fig. 33), but no deepening could be detected despite prolonged observation.

Shifts in the position of the main strand of current took place in essentially the same manner as in the lower canyon and were caused by the same processes: buildups of debris behind stranded logs, construction of temporary gravel and cobble bars at the foot of straight reaches, deflection by minor bank cave-ins.

There was obviously a considerable loss of volume of the stream by infiltration between the bedrock narrows and the lower part of the fan. The result was a loss in velocity and carrying power. Deposition, as a dominant process of the stream, began about one-half mile above the

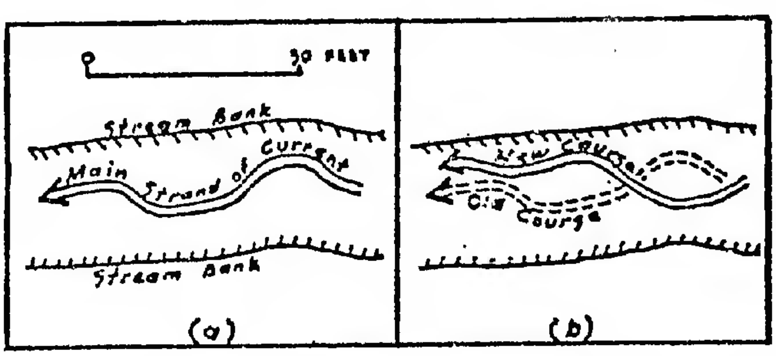

Figure 33. Changing channel location on Milner Creek fan. (a) Initial shape and position of main strand of current. (b) Position and shape 15 minutes later. No discernible deepening occurred during this interval.

highway, where changes in channel shape took place especially frequently and rapidly. Milner Creek, just below the narrows at the head of the lower canyon, was moving boulders up to 3 or 4 feet in diameter during the daily period of maximum high waters; at the highway the maximum size moved at highest water was 6 to 8 inches. Below the highway fine gravel was rolled in shallow channels, and sand and silt were carried in suspension, but very little coarser material was moved.

Of considerable interest were the observable effects on the fan brought about by the rise of water; slow at first, but quite rapid as the daily maximum flow was attained. During the first hour of the rise the existing channel appeared to be deepening by a few inches, and an apparent stability of channel shape and location was maintained. But when a certain critical volume and velocity were attained, the construction of gravel and cobble bars began; it was then only a matter of minutes until the main strand of current was thrown against one bank or the other and undercutting and concomitant bar construction below the cave-in points assured that deflections of the current would continue. Pieces of driftwood large enough to alter channel shape began to move after the first hour of rise.

(c) Flood damage

Plugging of the pipeline intake at the Milner Creek narrows deprived the ranch using this stream of irrigation water and hydroelectric power for more than a week. The intake box was not destroyed but simply filled with fist-sized and smaller debris, and flow of the stream thereafter went over it and into the lower canyon.

Damage to the highway crossing the fan was limited to a certain amount of undercutting of the downhill side at four places where culverts became plugged and the full flow of the stream went across the paved surface. At these points, small waterfalls were formed, the plunge pools of which effectively ate away the weaker fill beneath the pavement. At no time was water crossing the road more than 8 or 10 inches deep; most of the time it was no more than 4 or 5 inches (Fig. 34). Traffic on the highway was slowed down over a five-hundred foot stretch, but at no time was it halted.

(4) High water in Lone Tree Creek and Cottonwood Canyon

Lone Tree Creek and Cottonwood Canyon were also delivering considerably greater than normal volumes of water to their canyon mouths during the period of snowmelt runoff. Daily maximum discharge in these drainages was on the order of eight to ten times the volume of minimum flow; the ratio was thus somewhat lower than that of Milner Creek.

However, because of the absence of easily erodable fresh debris on or near the floors of these canyons, their water was relatively clear, even at maximum discharge. Also, the arrangements for diverting these

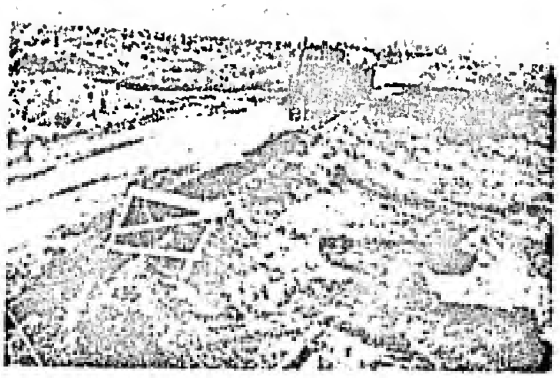

Figure 34. Runoff from Milner Creek crossing U.S. 6 on fan during period of snowmelt flooding in June 1957. Four such sites in a five-hundred-foot stretch of highway, at which culvert plugging occurred, experienced flooding of this sort.

streams into irrigation pipelines were such that most of the flow could be utilized to fill reservoirs on the ranches. Consequently, only small volumes of water were left to flow down the main channel on each fan. Most of this water was absorbed in the upper parts of the permeable channels on the fan, and relatively little reached fan perimeters and eventually found its way to the valley highway. Thus, the high water in these drainage systems produced insignificant morphologic effects on the fans and no damage to the highway.

(5) High water in other west-side stream systems

Drainage systems north of Cottonwood Canyon which were also being fed by snowmelt at this time displayed remarkably different regimes of flow. Most of these are relatively well-alluviated in their lower trunk canyons, with a vigorous growth of riparian vegetation, indicating that serious flooding has not occurred in them for some time. Discharge in these canyons increased gradually at the onset of the warm period, but rather than exhibiting notable daily fluctuations it tended to remain somewhat higher than normal throughout the entire period, cresting over a four to five day interval and receding to normal flow in a like time.

It is postulated that alluvium on trunk canyon floors here acted as a very efficient reservoir for snowmelt water, releasing it gradually and thus equalizing discharge throughout the day. Presumably there is a limit to this "sponge" effect, but it was not reached in these drainages during the period under discussion. These stream systems might well behave differently under the application of brief, torrential rains such as those which fell in Milner Creek, Lone Tree Creek, and Cottonwood Canyon in 1952. But it is of interest to note the decided difference in the behavior of snowmelt runoff in drainages with deeply alluviated trunk canyons compared with that in creeks which have been flooded recently and therefore have comparatively clean trunk canyon floors.

b. Cloudburst flooding in Deep Spring Valley, 20 August 1957

(1) Precipitation

During the period 18 - 22 August 1957 warm, moist, unstable air from desert regions to the southeast moved into western Nevada. Thunderstorm activity was pronounced east of the White Mountains, and minor flooding was reported to have occurred at isolated places over much of western Nevada. Afternoon cumulus buildups over the White Mountains during this period were impressive but heavy, flood-producing rains did not fall in the highest part of the range. Minor flooding did occur in the west end of Deep Spring Valley, located in the southern part of the study area. This flood was not observed first-hand; the site was visited 24 hours after the event.

A heavy rain fell in the mountains north of the highway traversing Deep Spring Valley on the afternoon of 20 August 1957, but the weather station at the Deep Spring School, about six airline miles from these mountains, recorded only 0.02 inch of rain that afternoon. Obviously, the rain in the highlands must have been much more severe. One small, unnamed drainage, about 4 square miles in area, seemed to have received the bulk of the heaviest precipitation; adjacent drainage systems showed no indication of excessive runoff.

(2) Morphologic effects and damage

Morphologic effects of this flood were limited. Traces of mud on lower canyon walls indicated that flood waters were 3 to 4 feet deep at the mouth of the normally dry canyon. The water was approximately one foot deep in channels just above the highway. Cobbles and boulders up to a foot and one-half in diameter at and just below the canyon mouth appeared to have been recently moved, but only fine sand, silt, and minor

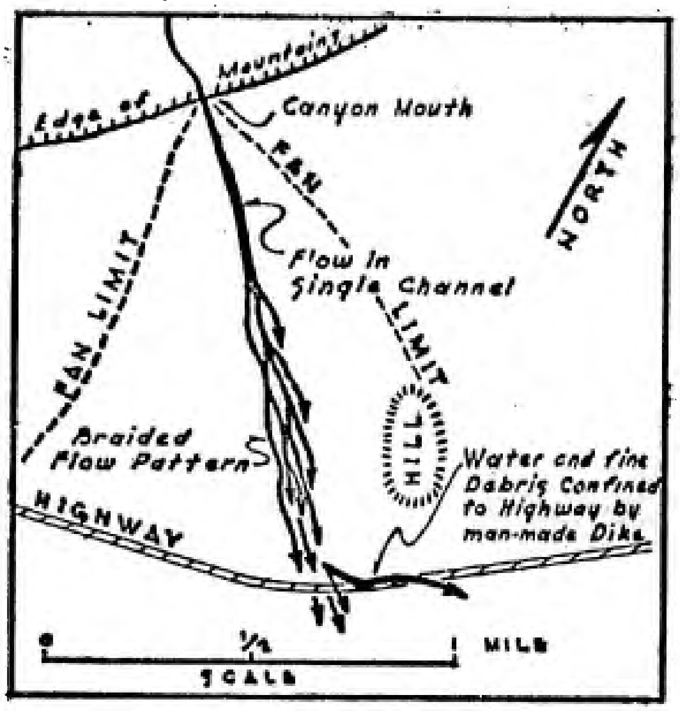

Figure 35. Diagrammatic sketch map of minor cloudburst flooding in Deep Spring Valley, 20 August 1957. Traffic was held up for about one hour while highway was cleared of debris.

amounts of fine gravel had been shifted at the highway where the slope of the fan surface is less than one degree. Water stayed in the single main channel on the fan about one-third of the way down, then developed a braided pattern in intermeshing channels (Fig. 35). A shallow stream of water was held in the highway right-of-way for a few hundred feet by man-made dikes and raised shoulders on either side of the road.

It was impossible to determine to what extent the main channel within the mountains and on the fan had been altered. Material deposited on the highway was predominantly in the sand and silt range, with minor amounts of gravel, and it is quite probable that it came from channel floors close to the highway. Presumably some channel deepening on the upper part of the fan must have taken place, but in the absence of an accurate knowledge of the pre-flood morphology no reliable estimate can be made.

c. Cloudburst flooding of U.S. 6 in western Nevada, 21 August 1957

(1) Precipitation

Heavy rains fell late in the afternoon of 21 August 1957 in a triangle roughly delimited by the weather stations of Basalt, Coaldale, and Dyer, Nevada (see Fig. 6). The three stations had 24-hour totals for that day of 0.02, 0.04 and 0.01 inch of rain respectively. The heaviest precipitation, which lasted about 45 minutes, was concentrated along U.S. Highway 6 between Basalt and Coaldale. What the absolute total here may have been is a matter of conjecture. The area was visited approximately one hour after the intensive rain had fallen, and virtually no surface runoff was then in evidence. It is postulated that perhaps as much as 2 or 3 inches may have fallen in an area of about one square mile, with amounts dropping off rapidly away from the center of the storm. The figures are offered because, in the past, similar amounts, as measured by catches in watering troughs, wheelbarrows, and other receptacles, have produced approximately similar morphologic effects in comparable terrain, as judged from newspaper accounts of historic floods.

(2) Morphologic effects and damage

When visited an hour after flooding, U.S. Highway 6 had debris across it in a number of places, as did state and county roads in the general area. In all cases the flooding of the roads was the result of the same processes: (1) plugging of culverts and subsequent flow across roadways; and (2) flow of water and debris through highway "dips".

Systems of man-made dikes and ditches upslope from the highway direct natural runoff on alluvial surfaces to culverts and dips (Fig. 36). Diffuse surface runoff is thereby collected into a few large channels. On 21 August the few culverts plugged up rapidly and debris and water then overflowed the pavement, or the concentrated runoff moved debris into and through the infrequent dips.

On slopes above the dike and ditch systems it was difficult to find much evidence of these floods. Surfaces above the highways in the area are usually alluvial aprons or bajadas, rather than series of individual fans. Large drainage systems in the low mountains above the bajadas are rare. Natural flow takes place in a series of numerous, small, shallow, interconnecting channels, any one of which is incapable of carrying a great volume of water. All of these smaller channels had water in them during the period of heavy rain, but it is doubtful if much damage would have been done had runoff not been concentrated by the dike and ditch systems above the highways. There was little visible evidence of debris movement above the V-shaped ditch systems. Most of the material moved onto and across the highways seemed to have come from the floors of the ditches which flank

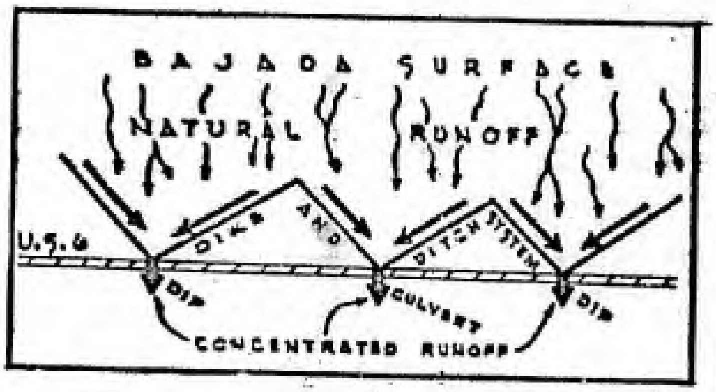

Figure 36. Diagram of flooding of U.S. 6 between Basalt and Coaldale, Nevada, on 21 August 1957. The effect of the ditch and dike system on flood runoff was to concentrate surface flow and direct it across the highway at the few indicated sites.

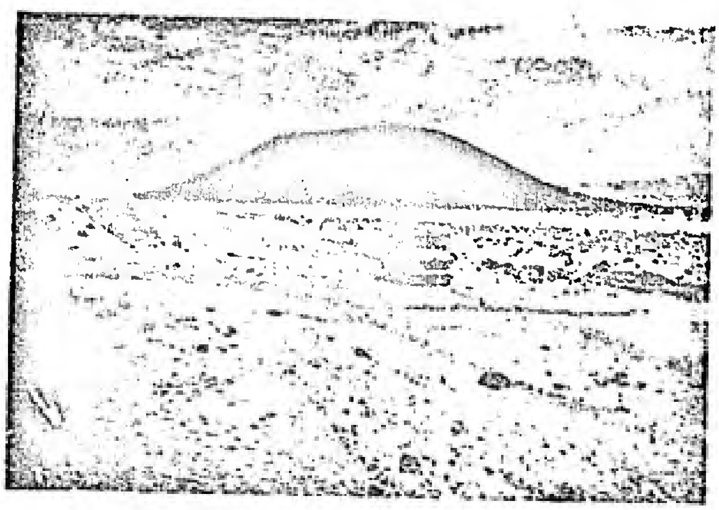

Figure 37. Thin film of debris across highway north of Silver Peak, Nevada. The flooding was brought about by the heavy rain of 21 August 1957. The truck marks the center of the sheet of debris which crosses the road from left to right.

the dikes on the upslope side. Their floors were seen to have been deepened by the flood, the amount of incision increasing toward the highway where it reached as much as 2 feet.

Damage to highways resulting from these floods was quite limited. Debris piled up to depths of 1 or 2 feet in a few places, but most of the accumulations of material across roadways were much thinner (Fig. 37). The plugging of one large culvert near the west end of the Columbus Salt Marsh, between Basalt and Coaldale, resulted in the formation of a temporary waterfall that cut away almost half of the width of the highway (Fig. 38). In most places, however, highway crews quickly removed debris with mechanical equipment. Traffic on the highway was interrupted for only half an hour, a clear indication of the suddenness of appearance and disappearance of the flood water.

These instances of "flooding" illustrate nicely a point about desert flooding that should be stressed: large floods with high crests which move major amounts of debris take place usually in areas that contain large drainage systems in which most of the runoff from major storms can quickly

Figure 38. Damage to U.S. 6 at west end of Columbus Salt Marsh, Nevada. This was caused by the cloudburst flooding of 21 August 1957. The amount of uncovered culvert, about 15 feet, indicates the width of road and shoulder removed by the overflow.

be concentrated into a single channel. Most of the White Mountain drainages are of this type; that is, all of their surface runoff must leave the mountain front by way of the single, large channel on the floor of their trunk canyon. This physiographic arrangement means simply that large amounts of water will be delivered to fan apexes in single channels; such floods will thus have a great deal of potential energy and have the ability to do a significant amount of morphologic work on the fans.

In contrast, runoff from a broad, gentle alluvial surface, such as a bajada or alluvial apron fringing a low, physiographically old desert range, may be spread over a great horizontal distance; in this type of terrain there is evidently less tendency for large volumes of water to accumulate in a single, large channel.

This discussion refers, of course, to natural conditions. Any interference by man through construction of roads, dike and ditch systems, or structures of similar type, will frequently result in an unnatural concentration of runoff. And it is concentrated runoff that provides the greatest potential flooding danger.

4. Morphologic evidence of former floods

The most recent floods in the White Mountains which have left very conspicuous evidence have been discussed in preceding sections. However, morphologic evidence on the fans and in the canyons indicates that flooding has occurred not only in the drainage basins already enumerated, but in others as well.

a. Evidence of former debris flows

(1) Deposits on fans

The best evidence of the occurrence of former major floods is provided by deposits left by debris flows. These take the form of closely spaced pairs of parallel ridges, radiating from fan apexes toward margins. They give the upper part of some fans a corrugated surface, the local relief of which may be 5 to 15 feet. Between the radiating pairs of ridges of debris the former flood channels are often still recognizable. Some are now used by surface runoff resulting from heavy rains or snowmelt on the fans. The fact that ridges and channels diverge from canyon mouths is probably the best piece of morphologic evidence suggesting channel change as a normal process in the construction of a desert alluvial fan. Potential future channel changes thus present a real danger to be reckoned with.

Deposits of former debris flows are conspicuous on the steep fans along the northern third of the west flank of the White Mountains from Willow Creek in the south to Morris Creek in the north (Fig. 39). These fans are dominantly of granitic debris. Former debris flows also left readily recognizable deposits on the fans of Sabies and Straight Canyons, which adjoin Milner Creek on the south. Of the two, Sabies Canyon heads in metamorphic terrain, while Straight Canyon drains a granitic area.

All but two of the fans with clear evidence of former debris flows are associated with steep canyons of the Falls Creek profile type (see Figure 3a). Straight and Sabies Canyons are the only exceptions to this rule. The morphologic evidence thus suggests that flooding in the past has been more frequent in the steeper drainages.

Figure 39. Looking down on apex of Rock Creek fan, showing deeply incised active channel. Deposits of former debris flows are recognizable in the area with scattered pinyon pine. Farther down the slope, former flood channels radiate toward the fan perimeter. The ruggedness of this surface is typical of the steeper granitic fans along the northern third of the western flank of the White Mountains.

Deposits of the more recent debris flows differ from the underlying, older alluvial surfaces in a number of respects. Most conspicuous is their lighter color (see Figs. 21 and 22), presumably resulting from lesser weathering, or less advanced development of desert varnish. Vegetation differences on surfaces of different ages can also be noticed. The deposits of the 1952 debris flows along the west flank of the mountains, for example, are rapidly being invaded by tumbleweed or Russian thistle (Salsola kali tenuifolia) and various buckwheats (Eriogonum spp), which contrast markedly with different plants on the adjacent, older surfaces. But vegetation differences as well as color variations tend to become less distinct with the passage of time, and most of the former debris flows are recognizable today only by their very distinctive morphologic features.

Few of the former debris flows on White Mountain fans can definitely be dated, but two of them, one each on the Sabies and Straight Canyon fans, are known to have occurred in the summer of 1918 (Buckley, E., Personal Communication, 1957). From a distance these flows are still recognizable by their slightly lighter color. This characteristic makes them stand out even better on aerial photographs, but at close range they are harder to distinguish; weathering has erased their originally sharp marginal contact with the darker alluvium, and the formerly abrupt change in color has become rather gradational. The vegetation on these flows today differs in no way from that on adjacent parts of the fans.

Other identifiable former debris flows cannot be dated. At present they do not differ from their surroundings by either color or vegetation. Although their age is uncertain, it appears reasonable to assume that they occurred at least half a century ago.

The topographic features of the surfaces of these White Mountain alluvial fans indicate that they have been built essentially by the superposition of a series of individual debris flows. A study in Arizona by Blissenbach (1954) indicated that there was a probable correlation between average annual rainfall and type of deposition on alluvial fans. He concluded that small annual precipitation, 10 to 12 inches or less, was usually associated with an increase in the volume of material in a fan contributed by debris and mud flows as opposed to that laid down by normal erosion processes and minor stream floods. It certainly is true that a large proportion of the volume of the typical fan of the west flank of the White Mountains has probably been supplied by debris flow deposition rather than by normal stream processes, and it is here concluded that the debris flow in this area is a normal agent in fan development.

(2) Deposits in canyons

Evidence of former debris flows in the form of deposits in canyons is rare in the White Mountains. It seems probable that the major morphologic effect of most of the floods which produced debris flows has been the flushing out of unconsolidated material from canyon floors. Thus, positively identifiable flood deposits are scarce.

An exception is provided by Straight Canyon. The lower part of its canyon has a moderately gentle gradient and is floored with deep alluvium. The debris flow of 1918 in this drainage system left well-defined lateral ridges along the edges of the active channel in the lower trunk canyon (Fig. 40), and these definitely can be correlated with the deposits on the fan, as the latter are a direct extension of the canyon-floor deposits. Thus, in this case at least, a pair of well-preserved lateral ridges in the lower canyon provides corroborating evidence of a former debris flow.

Figure 40. Lateral ridges along active channel in lower Straight Canyon deposited by flood of 1918. The channel is about 10 feet deep and 20 feet wide. Despite its artificial appearance, it is a natural feature. One lateral debris ridge appears in the right foreground near the right edge of the photograph and can be followed upstream beyond the prominent terrace in the middle distance. The lateral ridge in the left half of the picture is on the upper edge of the channel and appears especially clearly at the first upstream bend. The lateral ridges are about three to four feet high and four to eight feet wide at their bases.

Further evidence of a former debris flow would be represented by a bedrock canyon floor from which accumulated material had been swept away. However, only in the canyons of the three westside systems which flooded severely in 1952, that is, Milner Creek, Lone Tree Creek, and Cottonwood Canyon, is such evidence available. No other White Mountain canyons, on either side of the range, have such relatively clean floors. Even Straight and Sabies Canyons, which can be assumed to have been completely or partially cleared during the floods of 1918, now have a nearly continuous cover of debris on their trunk canyon floors. It thus seems possible that half a century may suffice to allow for the accumulation of material adequate for the development of another large debris flow.

It is seen, then, that the most prominent evidence of former debris flows consists of deposits on fan surfaces. They indicate that debris-flow deposition is a normal part of the construction of these fans and, as such, is to be expected in the future.

b. Evidence of high water flooding

Morphologic evidence of former high water floods is less conspicuous. It consists of channels on the fans and of associated deposits of silts and sands.

(1) Channels on fans

Generally, the deepest, best-defined channel on the upper part of a fan is the active one, the channel leading directly out of the canyon mouth above the apex and onto the fan surface proper (Fig. 39). But other channels exist on upper fan surfaces, usually radiating away from apexes (Fig. 41). Most of these can be attributed to former floods because they are flanked by lateral ridges of former debris flows, at least in their upper sections.

It is quite apparent that the deeply incised active channels on fan surfaces are not only the result of extreme discharge associated with major floods but owe part of their depth to normal discharge, including the light floods caused by snowmelt. Evidence from the most recent serious floods in the White Mountains indicates that active channels were deepened by them, at least near fan apexes, however, the amount of downcutting was limited to a few feet. Active channels on fans which have had no major floods for at least half a century often attain depths of 10 to 20 feet, and, in the case of Rock Creek (Fig. 39), of even 30 feet. These figures suggest considerable downcutting since the occurrence of the last major flood, a deepening which must have been achieved by normal runoff and minor flooding.

It can thus be realized that incised channels on upper fan surfaces are not, by themselves, a positive indication that major flooding has taken place.

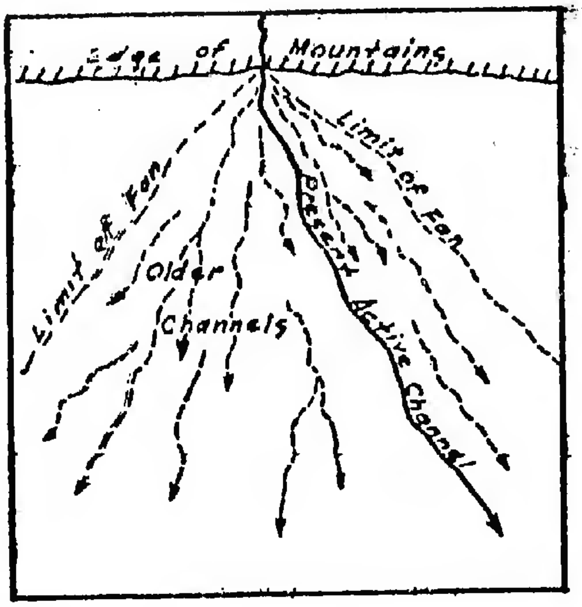

Figure 41. Diagrammatic sketch of the channel pattern on a typical White Mountain fan. The active channel may be anywhere on the fan; it is not necessarily in a medial position.

Along fan margins the evidence of former flooding consists of shallow, incised channels. They generally occur in groups. Their location indicates the sections of the fans most subject to flooding. The shape of the channels often permits conclusions to be drawn concerning the recency of flooding. Fresh channels have perpendicular sides and flat bottoms and are generally free of bushes or shrubs. Older channels assume rounded outlines in cross-section and may have become invaded by vegetation.

(2) Deposits of silt on fan margins

Deepening of the active channel on the upper fan surface by flood discharge is accompanied by redeposition of the material on its periphery. Hence, fresh, sheet-like deposits or thin ribbons of silt on fan perimeters can be considered evidence of high water flooding.

Such deposits are not particularly conspicuous and may be laid down without disturbing the vegetation. Where the deposits are thicker, as in areas adjoining the lower end of large debris flows, they may kill off the vegetation, but their bare surfaces are soon re-invaded by plant pioneers, and the distinctive appearance of the fresh material is rapidly subdued.

5. Drainage basins lacking evidence of serious flooding within the last century

Some White Mountain drainage systems appear not to have been flooded seriously for at least 100 years. Their fans lack well-defined pairs of lateral ridges attributable to former debris flows. Instead, their fan apexes have a gently undulating surface on which a faint radial pattern of swells and depressions is recognizable. These undulations are obviously associated with former debris flows, but their very subdued forms indicate a long lapse of time since their deposition. Since the present forms of the 1918 flows in Sabies and Straight Canyons indicate that half a century is barely sufficient to eliminate color differences among deposits but insufficient to mar the fresh appearance of the debris ridges, these very subdued forms justify an estimate that 100 to 200 years may have passed since their deposition. Most of these fans have a deeply incised active channel. Older flood channels are very indistinct and thus hard to identify in the field, although a faint radial pattern on aerial photographs indicates their presence. Cottonwoods, willows, and birches growing on canyon floors and parts of the active channels on the fans further indicate a prolonged absence of major flooding.

The canyons above these fans have certain common morphologic characteristics which could furnish a guide to the estimation of relative security from major flooding danger.

a. Location of canyons

On the west side of the White Mountains all of the canyons between Sacramento Canyon and Silver Canyon in the southern third of the range, and Queen Canyon in the north, lack evidence of serious flooding within the last century.

On the east side of the range, all of the larger drainages, with the exception of Leidy and Indian Creeks, are also of this type. This includes the drainage systems between McAfee Creek in the south and Trail Canyon in the north, inclusively. South of McAfee Creek the drainages are small and short, and they were not studied during the contract period.

b. Common morphologic characteristics

(1) Profile of trunk canyon

All of the drainage systems with extremely subdued forms of former debris flows on their fans are characterized by a Middle Creek type profile in their trunk canyons (see Fig. 3b), that is, they have relatively steep gradients in their upper branches and trunk canyon, but the gradient of the lower main canyon is comparatively gentle. Those canyons which seem to have been free of major floods for a century or more have a relatively long section of gentle gradient, measuring 1 to 3 miles in length and corresponding to between one-fourth and one half of their over-all length.

Figure 42. Floor of Silver Canyon about 5 miles above canyon mouth. Width of bottom of canyon here is about 150 to 200 feet. Compare with Figure 30.

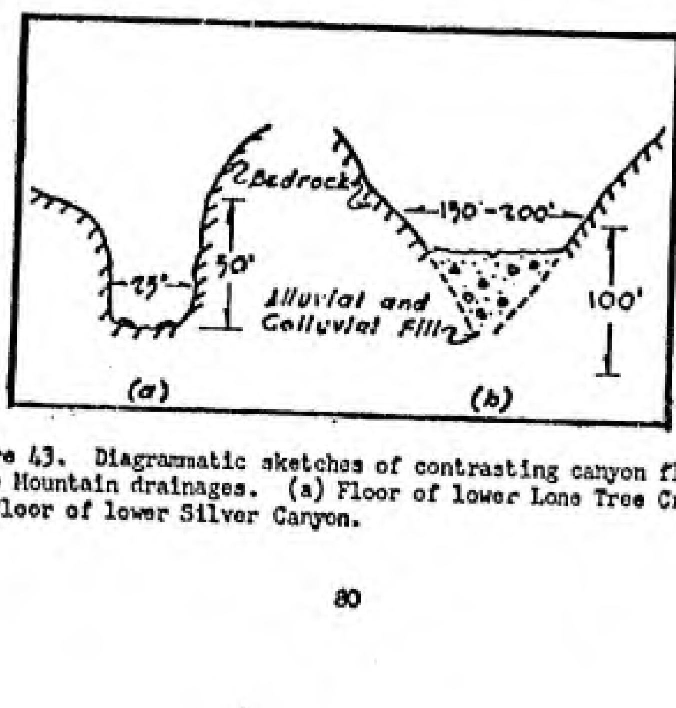

Figure 43. Diagrammatic sketches of contrasting canyon floors of White Mountain drainages. (a) Floor of lower Lone Tree Creek; (b) Floor of lower Silver Canyon.

The gradient of these lower sections is among the gentler of the Middle Creek types, amounting to between 200 and 400 feet per mile. The effect of a gentle lower canyon section upon a major debris flow was illustrated by the 1952 flood in Leidy Creek. The marked decrease in canyon gradient caused a decrease in velocity and loss of momentum of the debris flow and prevented it from reaching the apex of the fan.

(2) Width of lower trunk canyon

Trunk canyons of the drainages lacking evidence of flooding within the last 100 to 200 years are relatively broad. At the canyon mouth they attain a width of about 200 to 300 feet. Some maintain this width for most of the length of the section of gentle gradient (Fig. 42), although most show a gradual tapering to about 50 to 100 feet at the upper end of this section. Bedrock narrows are absent in all east-side canyons of this type but occur in Silver and Coldwater Canyons on the west side of the range.

(3) Alluviated trunk canyons

All of the canyons of this type not only are relatively broad in their lower portions, but they are also comparatively deeply alluviated. In most canyons, bedrock is nowhere exposed on their floors. In Silver and Coldwater Canyons it appears only for a short stretch in the above-mentioned narrows. Stream banks show a depth of alluviation of 10 to 20 feet. Downward projection of the canyon walls suggests a possible depth of 50 to 100 feet in some of the canyons (Fig. 43b).

A relatively luxurious growth of trees and shrubs, notably willows, birches, and cottonwoods, further attests to a considerable depth of alluviation in some of the drainages.

In none of these canyons were the very subdued forms of former debris flows seen, an indication that even their lower sectors have not been subject to major floods for a long time.

(4) Gently sloping, smooth alluvial fans

There is a general correlation between the slope of alluvial fans and the gradient of the adjoining canyon sections in White Mountain drainage systems. The alluvial fans fronting canyons which seem to have escaped serious floods for over a century are therefore the most gently sloping fans in the area. Their slope amounts to only 150 to 200 feet per mile, or about 2 degrees, in opposition to slopes of fans of such drainages as Milner Creek or Cottonwood Canyon which reach inclinations of 7 or 8 degrees.

All of the fans below the canyons free of floods for over a century have smooth or smoothly rolling surfaces which contrast markedly with the more irregular appearance of other fans. The smoothness of surface of some of these fans has been slightly marred by recent faulting, by which scarplets or piedmont scarps (Gilbert, 1928) break the otherwise smooth profile of lines drawn radially from apex to fan margin. A certain amount of channel incision on upper fan surfaces probably has been induced by this faulting. But even the faulted fans remain much smoother in appearance than those built by streams which suffered floods either recently or half a century to a century ago.

e. Diverse conditions

(1) Bedrock differences

Drainages which have not flooded for over a century show no correlation with the type of bedrock into which they are cut. The six systems from Silver to Sacramento Canyons in the southern part of the western side of the mountains are cut dominantly or exclusively in metamorphic and sedimentary bedrock. Queen and Trail Canyons, at the northern end of the range, lie in granitic, metamorphic, and volcanic terrain. The east-side drainages between Middle Creek and Davis Creek traverse granitic and metamorphic rocks, in which the former dominates areally.

Lithologic character of the drainage basins thus apparently has little to do with their flooding propensities.

(2) Climatic differences

It is probable that depth of precipitation, including snowfall, is greater in the highest part of the range and that thunderstorms are more frequent and more severe in that section. Drainage systems heading in the highest part of the White Mountains thus should be more prone to flooding. Yet the canyons in which no major floods occurred within a century or two head at all elevations of the range, in its highest central sector as well as in the lower southern and northern parts. Apparent difference in thunderstorm frequency and intensity thus does not seem to have had any influence on flood occurrence in these drainages.

Minor climatic differences among drainage systems thus appear to be of lesser importance than their morphologic characteristics in determining flooding frequencies.

PART III

CONCLUSIONS

1. Relative flooding probability

The relative flooding probability of any desert stream system depends upon two factors: (1) the morphologic characteristics of the drainage basin and its fan; and (2) the climatic characteristics of the area in which the drainage is located.

The morphologic characteristics of a drainage basin can readily be determined by a field and/or map study. The determination of climatic characteristics has to rely on available weather records which are often quite unsatisfactory, either because weather stations are too few and/or too far from the area under consideration or because climatic records are available for too short a time.

It is therefore believed that the most productive approach to a determination of the flooding potential of a given drainage system should consist of a careful study and evaluation of the physiographic features of the drainage basin; that is, the morphology of its canyon and fan.

a. Characteristics of canyon morphology

(1) Location

Although the available evidence is not conclusive, it is generally true that canyons heading in the highest part of the White Mountains show more indications of recent flooding than do canyons which head in lower crestal sections. Most major floods of the last decade occurred in canyons heading in the vicinity of White Mountain Peak. Sparkplug Canyon, located between Lone Tree Creek and Milner Creek, well illustrates the effect of elevation of the valley head. Although situated close to White Mountain Peak, it heads 2 miles to the west of it and about 3,000 feet below the crest. While its neighbors suffered severe floods in 1952, Sparkplug Canyon did not flood to any extent. The valley ranchers did not notice any unduly high discharge, and an investigation of its fan and canyon did not reveal any signs of very recent debris flows.

It seems logical to associate greater flooding frequency with the highest part of the crest, because it is just there that the orographic effect of the range on thunderstorm intensity should be greatest. This relation has been noticed by long-time valley residents of the area who assert that the White Mountain Peak sector of the range has experienced more severe thunderstorms within their memories than any other lower parts of the crest. It was not possible to confirm this assertion through measurements during the few, mild thunderstorms which occurred while the Assistant was in the field, but the premise is probably valid.

It is thus very likely that location of the headwater area of a stream system in the higher part of the range is an important factor contributing to the possibility of flooding.

(2) Long profile

The shape of the long profile of a given stream system is judged to be one of the most important morphologic factors affecting flooding.

Canyons with the Falls Creek type of profile (see Fig. 3a), which are exceedingly steep for their entire length, appear to be much more likely to suffer serious floods, including debris flows, than canyons with the Middle Creek type of profile (see Fig. 4b), in which only the upper half or third of the trunk canyon is extremely steep. As noted, all of the canyons which appear not to have flooded severely in a century or more are of the Middle Creek type. In Leidy Creek, which has the same profile, the long, relatively gentle lower sector effectively brought to a halt the debris flow of 1952 before it reachedthe fan apex.

The effect of the Falls Creek type of profile upon flooding is well illustrated by Milner and Lone Tree Creeks and Cottonwood Canyon, which flooded severely in 1952 and again less seriously in 1956.

The relation, then, is relatively simple: steep canyons are more apt to produce serious floods, including debris flows, that advance far out upon the fans, than are canyons with gently sloping lower sections.

(3) Width of canyon and depth of alluviation

White Mountain drainage systems are characterized by trunk canyons both wide and narrow in cross section. In general, wide canyon floors are associated with canyon profiles of the Middle Creek type. The lower sectors of these canyons thus have both a gentle gradient and a broad floor, and the ameliorating effect on flooding is marked. The Leidy Creek flood of 1952 and the Indian Creek flood of 1955 clearly illustrate the effec' f these two factors. The debris flows descending from the headwater areas did not only suffer a loss of momentum brought about by the more gentle gradient of the lower canyons but were also induded to spread on the broad floors of the canyons and thus experienced a further loss of potential energy which brought them to a halt some distance above the canyon mouths so that only high water reached fan surfaces.

In contrast, the canyons with the Falls Creek type of profile are not only steep but their floors are at the same time narrow. They thus assume the shape of flumes in which runoff and debris flows can acquire great velocity (see Figure 43a). Debris flows from such canyons are thus able to advance far down the associated fan surfaces. The 1952 floods in the west-side canyons illustrate this combined effect of steepness and narrowness of the canyons upon debris flows.

There is a general correlation between width of canyon floor and amount of debris present thereon in White Mountain drainages. The floors of narrow canyons often exhibit bedrock over most of their length, and debris occurs mainly in separate, relatively shallow patches. The wider canyons are usually continuously and often deeply alluviated, and some even have well-defined pairs of matched alluvial terraces near their mouths. The mild snowmelt flooding of June 1957 showed that discharge from alluviated trunk canyons was rather steady despite the daily variation in melting. The alluvium thus acted as a temporary reservoir. Deep alluvium apparently serves as a sponge and hence has the capacity to absorb considerable amounts of precipitation or snowmelt, thereby reducing flood danger.

Lack of debris on trunk canyon floors, on the other hand, permits rapid runoff of water originating through snowmelt, cloudbursts, or prolonged frontal rains.

(4) Type of bedrock

The effect of the type of bedrock in the drainage basin on flooding frequency and behavior appears to be quite limited. Canyons which have not been flooded for a hundred years or more show no relation to bedrock. The 1918 floods in Sabies and Straight Canyons produced identical effects in both canyons although they differ greatly in lithologic character. However, bedrock exposures in a drainage basin do determine the size of the debris released by weathering to be incorporated into a flood or debris flow. Granitic terrain yields large blocks of rock, some of which are coherent enough to maintain their size and shape during transportation to the fans (see Fig. 6). Metamorphic and sedimentary outcrops in the study area, in contrast, weather to relatively small-sized pieces of rock.

b. Characteristics of fan morphology

If a flood, either in the form of a debris flow or a high water crest, reaches the mouth of a canyon, the morphologic features of the fan below determine what course it may follow and potentially how dangerous it may be.

(1) Slope

Fans around the White Mountains can be classified as (1) steep, with slopes of 8 to 12 degrees (750 to 1,000 feet per mile); (2) moderate, with slopes of 5 to 8 degrees (450 to 750 feet per mile); and (3) gentle, with slopes of 2 to 5 degrees (150 to 450 feet per mile).

Obviously, the steepness of a fan surface affects the momentum of a moving mass of debris or water, and it is to be expected that debris flows on steep and moderate fans will tend to move faster and farther down their surfaces than on gentle fan slopes. Also, the velocity of high water in channels will be greater on the steeper fans, and the potential erosive energy thus will be much greater.

Since the slope of a fan is in direct relation to the slope of the lower end of the associated canyon, it is quite apparent that steep fan slopes are characteristic of canyons with the Falls Creek type of profile and that moderate and gentle fan slopes are associated with canyons having the Middle Creek type of profile. The slope of a fan is thus an easily established first indicator of the probability and expectable severity of floods which issue from the associated canyon.

(2) Channel pattern

The channel pattern of the typical White Mountain fan is radial (see Figure 41), with a well-defined active channel and less distinct former flood channels diverging from the apex. Former debris flows and high water crests on west-side fans have tended to stay in the active channel for one-third or two-thirds of their courses across the fans. Where a shallowing of the channel caused debris and water to spill out, the tendency has been for the fluid material to follow one or more of the older channels. This behavior has been noted particularly on the Milner Creek fan (see Fig. 23). Older channels are thus a guide indicating the probable courses debris flows and succeeding high water might follow after leaving the active channels.

(3) Marginal channels

Channels on the lower periphery of White Mountain fans are a key to the location of that part of the fan most subject to recent flooding. Although they are found on all parts of the perimeter, they tend to be most numerous and have the freshest appearance in that part of the fan margin on which the latest flooding has occurred. This sector of the fan is usually a strip or wedge of terrain flanking the present active channel and attaining a greatest width of 1 to 2 miles. Unless a recent channel change has occurred near the apex of the fan, this zone will continue to be the most dangerous part of the fan periphery from the standpoint of potential flooding.

(4) Depth of active channel

The practical effect of a deeply entrenched active channel is to extend downslope the confined flow of fluid debris and high water floods. The area of the fan in which spreading of debris and flood waters may take place is thus shifted to the zone below the point of shallowing of the active channel, and this zone becomes the most dangerous part of the fan in the event of a large flood (Troxell and Peterson, 1937). On the White Mountain fans this spreading has generally occurred one-half to two-thirds of the way down the fan slope. Evidently the transportation of coarser debris to lower fan slopes, including blocks up to several feet in length, is made possible by the greatly increased carrying capacity of confined flow in entrenched channels (Buwalda, 1951), and on fans with such features the possibility is thus increased that blocky debris will be encountered far down on the slope.

Course changes on upper fan surfaces may occur if the depth of the active channel is shallow, that is, only 5 feet or less. Temporary damming or plugging of shallow active channels, with overflow to one side or the other, could occur if larger blocks became stranded on channel floors during debris flows. It is possible that such course changes may be more frequent on fans built of granitic debris, which generally includes a limited number of large boulders, than on fans constructed of the smaller material weathered from metamorphic and sedimentary bedrock areas. There is a suggestion of this effect on the steeper, rougher, granitic fans along the northern third of the west flank of the White Mountains, where the great number of radially oriented debris ridges and former channels indicates rather frequent course changes (see Fig. 39).

The depth of the active channel thus will indicate if debris flows and high water floods issuing from the associated canyon will stay within the channel or will spread over the adjoining area.

c. Climatic factors

(1) Precipitation intensity and amount

It is axiomatic that flooding cannot occur without sufficiently heavy precipitation, but the accurate determination of what may become a flood-producing rain is difficult. As stated in Part I, accidental and unofficial catches of some rains associated with severe flooding have indicated totals of 4 to 5 inches in 2 to 3 hours, and in one case a fall of over 8 inches in $2\frac{1}{2}$ hours was measured.

It has sometimes been contended that light to moderate rains can also produce desert flooding (Russell, 1936; 1956). This may happen in almost completely barren desert terrain, but it is questionable that the same result can be achieved in the White Mountains. Several moderate rains totalling between one-half and one inch in 1 to 3 hours were observed and measured in the White Mountains during the contract period, but their effects on stream flow in the affected catchment areas were negligible. The larger figures quoted above thus appear more trustworthy for the region.

A very rough rule of thumb for determining potential flood-producing rainfall by observation was suggested by Leopold and Miller in their study of ephemeral flow in arroyos in New Mexico (1956). They concluded that for flash flow to occur the rain as viewed from a distance must be so dense that one cannot see through it. This rule seems also to apply to the White Mountains; valley residents who observed the rains preceding the debris flows of 1952 in Upper Owens Valley reported that the precipitation was so heavy that the mountains were obscured for some time.

(2) Flood seasons.

There are three periods in the year during which flooding probability is greatest in the White Mountains. These seasons are:

(a) Winter, especially December and January, when flooding may happen as a result of rain on snow.

(b) Late spring and early summer, that is, May and June, when snowmelt flooding may take place.

(c) Summer, particularly July and August, when cloudburst floods occur.

In the past, the season of greatest flooding frequency has been summer, in which approximately three-fourths of all recorded floods have occurred (see Fig. 14). Additionally, the majority of the serious floods of the past have taken place in this season. Major floods have also occasionally occurred during the winter months. Snowmelt flooding has been relatively infrequent in the past and has usually been more of a nuisance than a cause of extensive damage, since, although daily crests are not exceedingly high, they may continue for a week or more.

(3) Periodicity of flooding

The record of the past, as revealed by a study of newspaper files, indicates a frequency of floods for the White Mountains as a whole of perhaps 6 to 8 per decade, of which 1 to 3 can be classified as major floods. The same frequency is indicated by newspaper records, for areas of similar size in adjacent regions of southwestern Nevada and southeastern California. Probably more dependable is the record of the last decade during which increased mobility of a growing population has caused more floods to come to the attention of the public. For this period there also remain eyewitnesses who can attest to the severity of the floods, as well as morphologic evidence supporting their contentions. The experience of this period in the White Mountains indicates a flooding possibility of as many as 12 to 15 floods per decade, of which five may be of major proportions.

Flooding frequency within individual drainage basins is much more difficult to estimate. It depends primarily upon the profile type of drainage in question.

Severe flooding in drainage systems with Falls Creek type profiles may occur as often as twice in a decade, as indicated by the flooding histories of Milner and Lone Tree Creeks and Cottonwood Canyon. However, morphologic evidence on fans of other canyons with the same profile type, that is the ten west-side canyons between Willow Creek and Morris Creek, inclusively, indicates less frequent flooding. The state of preservation of deposits of former debris flows suggests that these fans have not suffered a serious flood for at least 50 years.

The frequency of severe flooding in canyons with the Middle Creek profile type is lower, but also seems subject to great variations. In Sabies and Straight Canyons the last serious floods occurred 40 years ago, that is, in 1918. In Leidy Creek and Indian Creek the state of preservation of deposits underlying the most recent debris flows, of 1952 and 1955, respectively, indicates an interval of 50 to 100 years since the preceding serious floods. For the majority of the canyons of the Middle Creek type it has been established that they have not suffered major flooding for about 100 to 200 years.

The great variations in frequency of severe flooding even among drainages with the same profile type reflect the influence of other factors, such as location relative to the highest part of the range and chance localization of extremely concentrated thunderstorm rain.

Minor flooding, particularly of the snowmelt variety, is of much greater frequency in all of the stream systems, regardless of profile type. The occurrence of reported minor floods in the last three decades has been rather frequent (see Figures 12 and 13), and it is possible that one small flood may occur every year in those drainages heading in that part of the range which receives the heaviest snowfall.

2. Danger of debris flows

The potentially most damaging floods are associated with debris flows, such as occurred in the west-side drainages, Milner Creek, Lone Tree Creek, and Cottonwood Canyon, in 1952. Former debris flows have left unmistakable morphologic evidence on alluvial fans and in canyons around the White Mountains. The amount and state of preservation of the deposits furnish a guide for an estimation of the probability of future occurrence of debris or mud flows.

The evidence of former debris flows is most common and clearest on fans of drainage basins which have certain common morphologic characteristics, which seem to have induced the development of debris flows when heavy rains have fallen. These characteristics relate to: (1) canyon profile; (2) amount of debris on floor of trunk canyon; and (3) width of lower trunk canyon and mouth.

a. Effect of canyon profile

The effect of canyon profile on the development and course of a major debris flow has been evaluated in a comparison of the July 1952 floods in Leidy Creek and in the three west-side drainages.

Alluvial fans of drainage basins with the Falls Creek profile type in their trunk canyons are in danger of suffering serious debris flows at least in their upper sectors. The exceedingly steep gradient of the floor of canyons of this profile type permits a debris flow to maintain its velocity and momentum to the canyon mouth and beyond, and serious damage may thus be brought about on the fan surface.

On the other hand, in canyons with the Middle Creek profile type, debris flows may come to an end in the gentler, lower section, where a loss in velocity and momentum occurs as the fluid material encounters the lesser gradient of the lower canyon floor.

Some of the White Mountain drainages which appear not to have flooded seriously for at least a century, notably Silver Canyon in the southern part of the western flank of the range, have exceedingly gentle canyons with broad, smooth floors even several miles within the mountains (see Fig. 42). It is obvious that a debris flow generated in the short upper section of the trunk canyon of such a drainage would be relatively small. On reaching the valley floor, the low gradient of the latter would quickly rob it of velocity and momentum and force it to spread, causing it to stop a considerable distance above the canyon mouth.

b. Effect of debris on floor of trunk canyon

Very obviously the material involved in a large debris flow must have a source area. Evidence from the 1952 floods in Milner Creek, Lone Tree Creek, and Cottonwood Canyon on the west side of the range, and from Leidy Creek on the east flank, indicated that most of the material in these flows came from the floor of the trunk canyons. In contrast, the 1956 floods in the same west-side canyons, although probably of similar intensity, did not result in debris flows, as the canyons had been cleared of alluvium by the preceding floods. Consequently, the degree of alluviation of the trunk canyon becomes of importance in a determination of the probability of the occurrence of a large debris flow.

Three possibilities exist: (1) "optimum" degree of alluviation for debris flowage: (2) little or no alluvium on the canyon floor: (3) too deeply alluviated canyon floor.

It is difficult to say with precision what depth the so-called optimum amount of alluvium should attain, but a figure of 5 to 15 feet is suggested by the evidence from the White Mountains. This amount of unconsolidated material on the floor of a steep, narrow, slot-like canyon should result in the development of a debris flow in the drainage and possibly on its fan if a sufficiently heavy rain falls.

If little or no debris is present on the floor of the trunk canyon, as was the case in the three west-side drainages in July 1956, primarily high water will flow out of the canyon and onto the fan following heavy rains. High water flows after excessive precipitation would be expected until the canyon floor again fills up with loose debris. This process may take at least 50 to 60 years; this time lapse is suggested by the present condition of the floors of Sabies and Straight Canyons, which were presumably flushed out by the floods of 1918 and today have a nearly continuous cover of alluvium.

If trunk canyon floors are wide and deeply alluviated, a great part of the runoff from the steep upper canyon and side slopes may simply be absorbed and released gradually. This sponge effect is significant in alleviating the possible dangers of flooding resulting from snowmelt even in lightly alluviated steep canyons. It is held to be even more efficient in deeply alluviated canyons of gentle gradient and is considered a major factor preventing serious floods for a century or more in some of the White Mountain canyons.

c. Effect of width of lower trunk canyon and mouth

The most serious recent debris flows in the White Mountains have come from canyons with exceedingly narrow floors which, in addition, have bedrock constrictions at or near their mouths.

Debris flows are most likely to develop in the most narrow canyons. Constrictions in such canyons have caused temporary damming and an increase in mass, with consequently greater momentum below the narrows after the temporary dams have given way. This temporary damming at the narrows was repeated at short intervals during the 1952 floods, causing repeated surges in the debris flows, each surge associated with [illegible]able increase in thickness of the debris flow and a consequent advance.

In contrast, a drainage basin without conspicuous bedrock constrictions should at time of flood release excess water and rubble to the fan surface at a more continuous rate.

If a debris flow is developed high in a drainage basin it is much more likely to be stopped by a broad lower canyon, where spreading and loss of momentum may occur, than in a narrow, bedrock channel in which the coherence of the tumbling, surging fluid mass can be maintained to the canyon mouth.

d. Most dangerous canyons

From a consideration of the morphologic characteristics discussed above, it is concluded that the canyons most likely to produce damaging debris flows in their lower sectors and on their fans are distinguished by the following physiographic features:

(1) They have the Falls Creek profile type in their trunk canyons; that is, their gradient is excessively steep to the very canyon mouth.

(2) They are narrow throughout their entire length, and they have bedrock constrictions in their lower sections and at their mouths.

(3) They have perhaps 5 to 15 feet of unconsolidated alluvium on the floor of their trunk canyon.

They are, in short, narrow bedrock flumes of steep gradient, on the floors of which is found 5 to 15 feet of loose debris. They and their fans are to be avoided if possible when land utilization of any sort is contemplated.

e. Safest canyons

Conversely, the potentially safest canyons have Middle Creek type profiles, broad, deeply alluviated lower canyons reaching far into the mountains, and usually support a relatively thick growth of riparian vegetation on their floors. They have all of the characteristics of those canyons in the White Mountains in which evidence of flooding within the last hundred years or more is absent.

3. Danger of high water flooding

High water flooding is associated with all debris flows and commonly follows them. Theoretically, high water flooding without a debris flow could occur at almost any time and place, provided, of course, that sufficiently heavy precipitation falls. But high water flooding alone seems to be more likely to happen under certain definite conditions.

a. Heavy precipitation in streams with clean trunk canyon floors

The heavy rains of July 1956 produced high water flooding in Milner Creek, Lone Tree Creek, and Cottonwood Canyon on the west flank of the White Mountains, all of which have clean trunk canyon floors, and it seems likely that excessive precipitation in any drainage basin, the floor of which is essentially a bedrock channel, would result in high runoff, possibly of flood dimensions. It thus follows that drainages which have recently undergone a serious debris flow by which accumulated material was swept out of their main canyons should be regarded as probable high water flood producers in the event of heavy rain in their catchment areas.

b. Snowmelt

In the White Mountains and adjacent regions, snowmelt flooding in the past has been of the high water type. Copious snowmelt can release large volumes of water during the period of an afternoon's high temperatures, but the amount thus delivered each day to the floor of the trunk canyon is limited and is delivered gradually. Although higher than normal, snowmelt runoff has not been sufficiently large to initiate substantial debris movement. It has been primarily in lowland areas that the united runoff of a number of individual mountain drainage systems has been great enough to cause damage or interfere with communications.

Snowmelt runoff in Milner Creek in June 1957 did move debris out of the mountains and onto the fan, but the amount was limited.

c. Wintertime rains

Wintertime rains on a snow cover have occasionally produced high water flooding in the White Mountains area. The most recent occurrence was in December 1955, when rains totaling 10 inches in two days at Benton Station (Reichert, F., Personal Communication, 1957) resulted in the flow of much water and fine debris across nearby valley-floor highways. The estimated total seems rather high, but in any event a lot of rain must have fallen over an extended period, and considerable overland flow took place.

Prolonged frontal rains during the winter months may drop several inches of water on a snow cover which the latter is able to retain (Foster, 1948). Further rains or sudden warm spells may bring the mixture to a state at which quick melting takes place, causing a sudden release of the accumulated precipitation. Usually floods resulting from this combination of meteorologic conditions have been restricted to lowland areas, such as the floor of Upper Owens Valley, Owens Valley proper, and floors of adjacent closed desert basins, in which temporary playa lakes have been formed. Little debris movement within the mountain canyons and on the fans has been noted in flooding of this sort, and morphologic effects have been negligible.

d. Effect of rains on fans

The effect of a heavy rain on an alluvial fan is determined primarily by the channel pattern thereon. White Mountain fans have a radial channel pattern, and any surface runoff that may result from a heavy rain is quickly dispersed and prevented from uniting into a single, large flow by the diverging channels.

Fans with dendritic channel patterns are absent in the study area but are found in other parts of the Great Basin desert region, notably in and around Death Valley. Heavy rains on Death Valley fans have produced significant high water flooding on their margins, as surface flow in smaller channels has been united near fan perimeters into relatively large channels (Hunt, C.B., Personal Communication, 1957).

Heavy rains on fans are comparatively rare, of course, both in the study area and elsewhere, but the possibility definitely exists that dangerous high water flow can develop on fans with dendritic rather than radial channel patterns.

4. Evaluation of safe sites

Any evaluation of the safety of a given site on a fan or in a canyon must be relative only. Morphologic features vary from drainage basin to drainage basin, and no two flood-producing storms are alike. Nevertheless, some general principles of site safety can be established.

a. Narrow canyons

Obviously the utilization of narrow canyons must be limited. Roads on or near their floors, and intakes for water supply or hydroelectric power pipelines, are about the only installations that can be made. Although construction may be easier on the canyon floor itself, any important, permanent roads should be located at least 20 to 40 feet above the floor of the canyon in order to be free of the danger of flooding.

Any installation or construction put on the canyon floor must be considered only temporary, for in a narrow canyon it is possible that even slightly higher than normal discharge can be destructive, and the loss of canyon-floor structures or roadways must be considered inevitable in time.

b. Wide canyons

Wide canyon floors offer somewhat greater possibilities for utilization than do narrow valley bottoms.

Most of the drainages on the east side of the White Mountains are characterized by well-defined, matching terraces of alluvium in their lower canyons, standing 15 to 75 feet above creek bottoms (see Fig. 28). Most of the terraces are too narrow for any other use than road construction, but some of them, particularly those in Leidy Creek and Middle Creek, are wide enough (up to 75 to 100 feet) for more extensive installations. These terraces can be considered safe locations, since they are out of reach of any conceivable flood in the canyons.

If terraces are not present in the wider canyons, then the whole width of the floor must be considered potentially dangerous. It has been stressed that wide canyons usually are associated with Middle Creek type profiles, and these canyons seem less likely to experience severe debris flowing or high water flooding. However, in the flood of 1952 debris spread to cover most of the floor of lower Leidy Creek Canyon, other than the terraces, and it seems reasonable and prudent to assume that similar spreading could take place in other drainages with morphologically comparable lower canyons if and when debris flows occur.

Consequently, in the absence of terraces in wide canyons, permanent roads or other installations should be located above the canyon floor proper, that is, at least 20 to 30 feet up on the walls of the canyon.

c. Alluvial fans

(1) Upper third

The upper part of most alluvial fans can be considered moderately safe from the dangers of serious flooding, as the active channel is generally incised. The relative security increases if the active channel is deeply incised, that is, to 15 to 20 feet or more. The active channel itself, of course, is to be avoided and, if it must be bridged, single span construction should be used when possible.

If the active channel is only shallowly entrenched, that is, 5 feet or less, the possibility of course changes of major debris flows cannot be overlooked. The heterogeneous distribution of large boulders on the upper surfaces of some fans and the radiating pattern of deposits of former debris flows indicate that channel changes have occurred in the past and are ever a potential danger.

The major zone of danger, then, is in the active channel itself and a narrow strip flanking it on either side.

(2) Middle third

Most of the area of the middle section of a fan is relatively free from danger of serious flooding. Particularly is this true so long as the active channel remains moderately incised, that is, up to 10 feet. Some spreading of debris flows may occur as depth of entrenchment decreases, but the general course of most flows in the White Mountains has adhered to the active channel. Should course changes occur on this part of a fan, much of the initial momentum of a debris flow will already have been lost, and it should therefore be moving at a lower velocity and thus have decreased potential destructive energy.

Certain of the west-side fans along the southern part of the White Mountains, in particular the four between Straight and Coldwater Canyons, have had parts of their surfaces uplifted by recent faulting. The uplifted areas are for all practical purposes removed from the effects of any conceivable flood that might occur on the fans (Fig. 44). Parts of fan surfaces in southern California have been analogously isolated from the effects of flooding by deep channels excavated on their upslope sides, leaving them standing as "fan mesas" (Eckis, 1928), or "islands" of higher ground standing above the general fan surface.

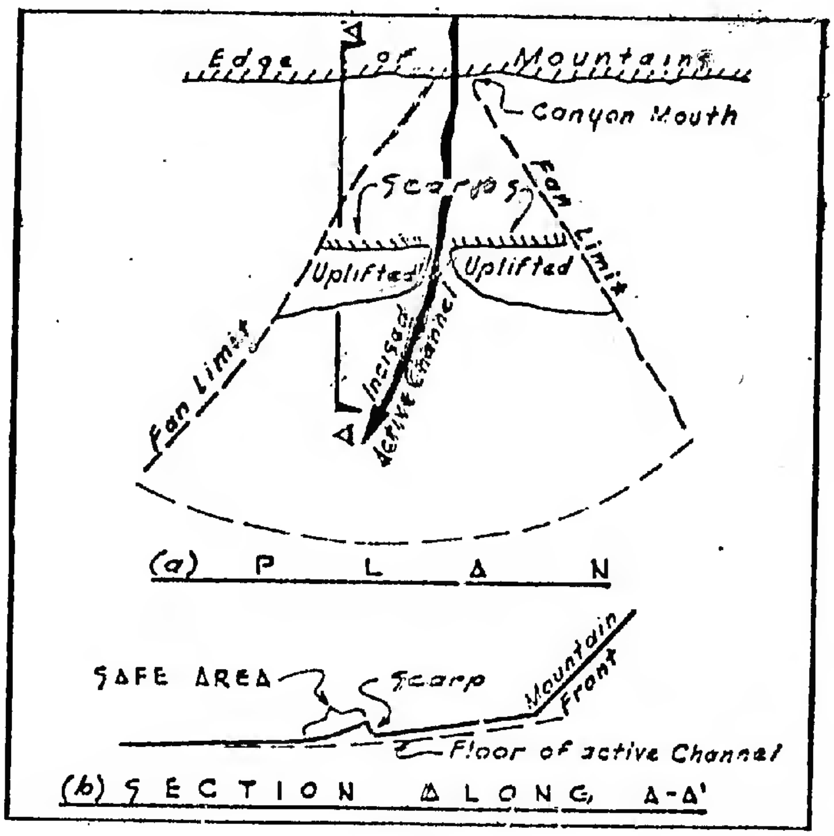

Figure 44. Diagrammatic sketch map of Coldwater Canyon fan showing upfaulted areas free from danger of flooding.

Flooding danger is thus classified as slight in middle fan sections, except for the strip including and flanking the active channel.

(3) Lower third

Below the point at which the active channel shallows decisively, that is, to less than 5 feet, the danger of spreading of debris flows and high water floods is greatest. On most White Mountain fans this takes place usually on the lower part of their surface. The spreading water establishes an extensive system of intermeshing channels. Here and there the junction of some of the channels leads to local sheet flooding, especially on the more gently sloping lower fan margins. The area subject to such flooding extends laterally for a mile or so on either side of the lower end of the active channel.

Flooding danger on lower fan surfaces is hence classified as moderate. It is extreme just below the point at which the active channel becomes shallow enough so that confinement of flowing water and debris no longer takes place.

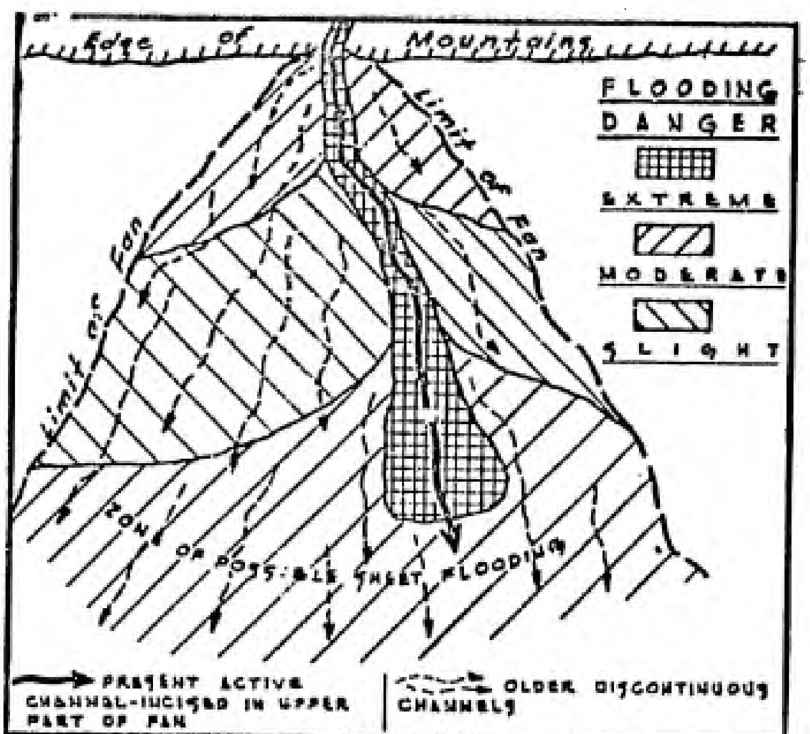

Figure 45. Diagrammatic sketch map showing areas of comparative flooding danger on a typical White Mountain alluvial fan.

(4) Resumé

Areas of comparative flooding danger on a typical White Mountain fan are indicated diagrammatically on Figure 45. As this sketch map shows, the most dangerous part of a fan is a radial strip or wedge including and flaring the active channel, which widens to a blunt-nosed bulge below the site at which channel shallowing occurs. The upper and lower thirds of a fan are classified as moderately dangerous, while the middle third of the fan is subject only to slight flood danger.

(5) Road location on fans

So far as highway location on fans is concerned, it is probable that any road trending perpendicularly to radial channels will have at least muddy water across it during a flood, regardless of where it may be situated on the fan. Design engineers at the California Division of Highways regional office in Bishop consider that the only relatively safe place on a desert alluvial fan for a highway trending parallel to the mountain front is the uppermost p..t of the apex, where a single-span bridge can be built across the active channel just below the canyon mouth (Creed, T., Personal Communication, 1957). If this plan of location cannot be followed, and if the fan cannot be avoided, then some flooding seems to be inevitable.

Roads leading up a fan toward the mountains are best located as far from the active channel as possible, since the neighborhood of this channel is decidedly unsafe.

(6) Effect of dikes

The effect of a V-shaped dike and ditch system on unorganized surface runoff on alluvial surfaces has been discussed in connection with the flooding of U.S. Highway 6 between Basalt and Coaldale, Nevada, in August 1957. The ditch and dike system in this instance concentrated the surface runoff from a myriad of shallow, sinuous, natural channels into only a few, deep, straight, man-made channels, in which increased volume and velocity gave it the ability to scour material from the floors of the ditches and carry it to and across the highway at numerous points.

It seems probable that whenever surface runoff is diverted from natural channels and concentrated into straight, smoothly floored, man-made ditches, the inevitably increased erosive power is going to cause trouble, unless the man-made channels are concrete-lined and thus immune to scouring.

A useful rule to remember, then, is that in any sort of land utilization on alluvial surfaces it is undoubtedly wise to allow natural runoff to follow channels of its own making insofar as this may be possible. Any interference with natural conditions will in all probability bring about increased flooding danger.

5. Summary and recommendations

In the preceding sections the morphologic characteristics of drainage basins which can be associated with greatest and least flooding danger have been described. It is not maintained that the indicated guides to an assessment of flooding potential are unequivocal, but it is believed that they can be of practical value if judiciously employed.

It is concluded that an estimation of the potential flooding danger of any site in mountainous desert terrain should be based upon the following steps:

a. An examination should be made of each drainage basin above the area contemplated for use to determine:

(1) Its profile type.

(2) The width of its trunk canyon.

(3) The depth of alluviation of its trunk canyon.

A consideration of these three morphologic factors should lead to an estimate of the flood hazard, as well as the type of flooding to be expected in the event of heavy rain or excessive snowmelt, that is, if they would cause debris flows or only result in high water flows.

b. An examination should be made of the alluvial fan or bajada to determine:

(1) The location of the active channel(s).

(2) The depth of incisement of the active channel(s).

(3) The zone of most recent flooding on the surface as indicated by freshness of deposits or channel cuts, and therefore the area of most probable future flooding.

(4) The channel pattern on the fan or bajada surface.

With these facts in hand, selection of the safest site on the fan or bajada will be facilitated.

It cannot be stressed too strongly that a careful field examination of the area for which utilization is planned should be made. There is no adequate substitute for such an investigation if the wisest land use is to be achieved.

6. Application of study to other areas

The White Mountains are a high desert range with very distinct geologic, morphologic, and climatologic characteristics. Consequently, the principles of desert flooding determined for this range should be directly applicable to other desert ranges only if they are similar in all three characteristics. The high mountain systems of the Great Basin region, and particularly those situated in the vicinity of the California-Nevada boundary line, such as the Panamint and Amargosa ranges, resemble the White Mountains sufficiently that all or most of the principles enumerated appear applicable to them. In other parts of the world, it appears that the south flank of the western high Atlas and Anti-Atlas mountains in Morocco and the western flank of the Pamirs in Russian Turkestan also resemble the White Mountains in geology, morphology, and climate, and thus should produce floods and flood effects very much like those observed in them.

Although other arid districts of the earth differ in morphology and climate from the White Mountains and their flanking valleys, some general principles of flooding established by this study should be valid also in these desert terrains. They are:

a. The relative safety of different parts of an alluvial fan should be approximately the same on fans fringing any desert mountain range. The most dangerous part of any fan is a strip flanking and including the active channel which extends downslope below the point at which shallowing of the active channel occurs.

b. The profile, width, and depth of alluviation of the trunk canyon of a desert stream system are important morphologic characteristics determining the flood hazard and probable type of flooding. The more nearly the trunk canyon resembles a steep, narrow, bedrock flume in form, the greater will be the flooding hazard; in addition, if such a canyon has unconsolidated alluvium on its floor, the possibility of the development of serious debris flow will definitely be increased.

c. A general correlation exists between steepness of fan slope and danger of major floods from the canyon above the fan; thus, steep fans are a first, easily recognizable indicator of the possibility of serious floods, while more gentle fans suggest a lower flooding hazard.

d. The radial channel pattern on White Mountain alluvial fans insures that debris and water spilling out of active channels during floods will follow divergent paths and thus lose part of their momentum and potential destructive energy. A similar result can be anticipated in other areas with fans on which a radial pattern of channels is evident.

e. The thunderstorm season, summer, is the period of greatest flooding danger in the White Mountains. Presumably the relation would hold true elsewhere; that is, greatest flooding frequency would prevail during that part of the year in which thunderstorms normally occur. For most deserts of the world these occur in the summer season.

f. The influence of man-made dikes and ditches on alluvial surfaces has been shown to be significant in bringing about a concentration of runoff into larger channels, in which it acquires increased volume and velocity and thus increased potential destructive energy. This influence should be active on any alluvial surface on which natural runoff is diverted to artificial channels by a system of dikes and ditches.

7. Suggested future research

It would be highly desirable for a follow-up study to be made in the White Mountains. Since no serious flooding was observed during the contract period, many of the ideas developed in this report had to be based solely on an examination of the morphologic evidence of former floods, and no verification by firsthand observation of a flood in action was possible. It is believed that the guides to an estimation of flooding potential and hazard are valid, but confirmation by close-range examination of one or more floods would be useful. If possible, one or more observers might well spend the summer months in the area on the chance that flooding in action could be seen.

Research in other desert regions might well be centered in an area of greater known thunderstorm frequency. Also, a study of past and future flooding in other desert regions could be of use in evaluating the guides to site safety and flooding hazard discussed in this report. Should these guides be proved to have a wider application, then a most valuable aid to safe land use in desert terrain would be available.

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APPENDIX

Precipitation in study area during contract period

Assembled in this Appendix are monthly records of precipitation for the six U.S. Weather Bureau stations in and immediately adjacent to the study area, and for the sites at which rain gages were installed during the investigation. Rain gage locations are shown on fold-in map at end of the report.

During the contract period rain gages were shifted as changes in the weather made some locations inaccessible, especially during the winter months. Thus, not all of the sites for rain gages shown on the map were maintained at the same time. For stations at which a continuous record of at least 1 year was maintained, totals for the 12-month period from 1 October 1956 to 30 September 1957 are given. For comparison, annual normals at the Weather Bureau stations are also given. Monthly normals are shown in Table II.

In general, the contract period was one of exceptional dryness in the study area. The following table indicates for the period July 1956 to October 1957, a total of 16 months, the number of months at each Weather Bureau station in which the precipitation received was above or below the established normal.

Station	Above	Below
Basalt	7	9
Bishop	5	11
Deep Spring School	6	10
Dyer	7	9
White Mountain I	5	11
White Mountain II	5	11

The winter of 1956-57 was relatively dry; only a few sizable frontal storms passed over the area during the period October 1956 to April 1957, and the snow pack in the mountains was considerably below normal during the cold months of the year. The month of May 1957 was the wettest in 25 or 30 years, but the summer months of 1957 were unusually dry. Ranchers grazing cattle on the crest of the White Mountains were forced to bring them down about a month and a half earlier than usual, since the higher meadows and normally dependable springs in these meadows dried up in early August.

The first 20 days of October 1957 were considerably wetter than normal, but as a result of the prolonged dryness preceding this wet spell the infiltration capacity of the mountain soils was so high that no discernible rise in stream discharge was noted.

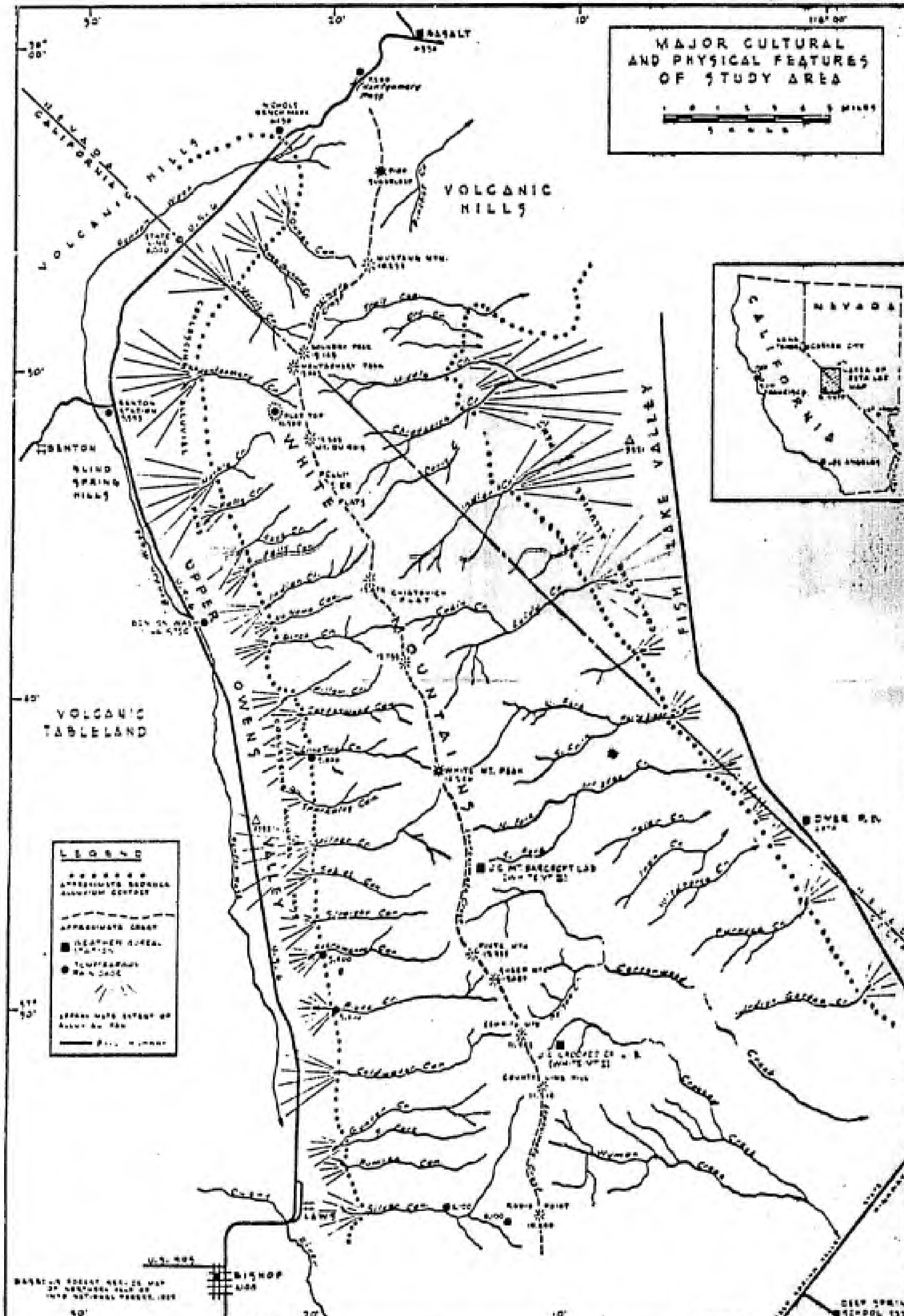
The Assistant left the study area on 25 October 1957, but a close check was kept on weather conditions in the area during November and December. No unusually severe storms occurred in these months, and no flooding of any sort was reported.

Precipitation During Contract Period

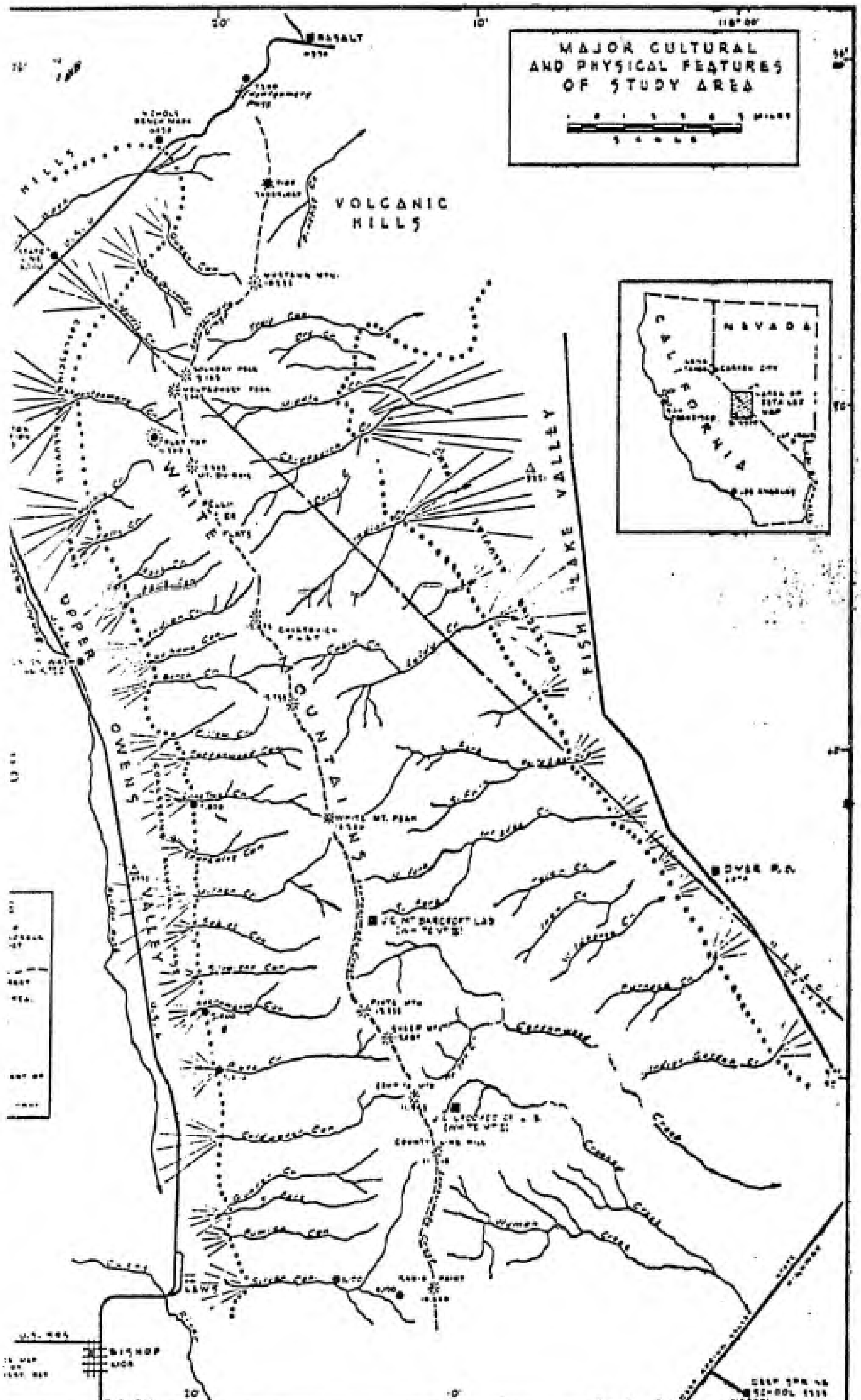
	1956 Jul	Aug	Sep	Oct	Nov	Dec	1957 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct 1-20	Period Oct 56 - Sep 57 Total	Normal
*Basalt	.99	0	.16	.58	0	T	.22	.76	.06	.84	1.48	.42	0	.06	.13	1.50	4.55	5.39
Benton Station		0	.24	.13	0	0	1.31	1.20	.01	.69	1.17	.12	.07	0	.07	.53	4.77	
Benton Wash Hill					0	0	1.16	.58	.02	.61	.61	.04						
*Bishop	.05	0	T	.46	0	.05	1.61	.57	07	.41	.49	T	.01	0	.05	1.33	3.72	5.38
*Deep Spring School	.66	0	0	.42	0	0	(.67)	.31	.02	.66	1.45	.02	.06	.12	.20	.57	(3.94)	5.45
*Dyer	.31	0	.05	37	T	T	.80	.01	.60	.53	1.85	.22	.23	.12	.16	1.94	4.89	3.22
Flat Top													.25	0	.66	3.55		
Lone Tree Creek			.15	.31	0	0	.71	.71	.05	1.02	1.64	.02	.13	0	.13	1.15	4.80	
Montgomery Pass			.25	.53	0	0	.85	.96	.14	1.20	2.15	.40	.02	.26	.66	1.94	7.20	
Nichols Bench Mark					0	0	.97	.69	.04	.59	1.67	.31						
Piute Creek			.07	.20	0	0	.58	.20	.03	.33	.94							
Sacramento Canyon												.03	.05	0	.08	1.00		
Silver Canyon 8100			03	.87	0	.02	1.30	1.31	.53	.96	2.26	.05	.14	0	.38	1.88	7.82	
Silver Canyon 6100				(T)	0	0	.59	.26	.12	.51	1.62	.01						
Stateline															.33	.85		
Sugarloaf			.27	(.32)									.04	(.14)				
*White Mountain I	3.26	.03	T	.73	T	.07	2.03	1.25	.86	1.90	2.74	T	.06	0	T	.91	9.67	13.09
*White Mountain II	2.94	.26	.03	1.24	.08	.31	1.85	.92	2.41	1.51	4.66	.26	.10	0	.15	1.78	13.49	15.72
White Mountain Peak	(.24)												(0)	0				

* For monthly normals see Table II

Values in parentheses are incomplete



MAJOR CULTURAL AND PHYSICAL FEATURES OF STUDY AREA
VOLCANIC HILLS
VOLCANIC HILLS
VOLCANIC TABLELAND
BLIND SPRING HILLS
UPPER OWENS VALLEY
WHITE MOUNTAINS
FISH LAKE VALLEY
BASALT
BENTON
BISHOP
LAWS
WHITE MT. PEAK
NEVADA
CALIFORNIA
LEGEND


MAJOR CULTURAL
AND PHYSICAL FEATURES
OF STUDY AREA
VOLCANIC
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NEVADA
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OWENS
VALLEY
FISH LAKE VALLEY
WHITE MT. PEAK
BISHOP