UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

POTENTIAL HAZARDS FROM FLOODFLOWS AND DEBRIS MOVEMENT IN THE FURNACE CREEK AREA, DEATH VALLEY NATIONAL MONUMENT CALIFORNIA-NEVADA

By John R. Crippen

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UNITED STATES DEPARTMENT OF THE INTERIOR

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TABLES

CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer the International System of units (SI), the conversion factors for the terms used in the report are listed below:

Multiply inch-pound unit	By	To obtain SI (metric) unit
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
ft (feet)	0.3048	m (meters)
ft/mi (feet per mile)	0.1894	m/km (meters per kilometer)
ft/s (feet per second)	0.3048	m/s (meters per second)
ft^3/s (cubic feet per second)	0.02832	m^3/s (cubic meters per second)
inches	25.4	mm (millimeters)

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ABSTRACT

Death Valley is known as the driest and hottest region in the United States. Despite the aridity of the valley itself, however, very heavy rainfall sometimes occurs in the nearby mountains. Such violent rainstorms are likely to be of relatively short duration and to occur over rather small areas; nevertheless, they sometimes produce large floodflows that in turn cause severe erosion and flows of debris. The debris-laden flows may be hazardous to life and property. Given sufficient knowledge of the hydrologic and hydraulic environment, the degree of hazard can be estimated. Potential hazards are defined for areas in the vicinity of the Furnace Creek fan and the Park Service residential area.

INTRODUCTION

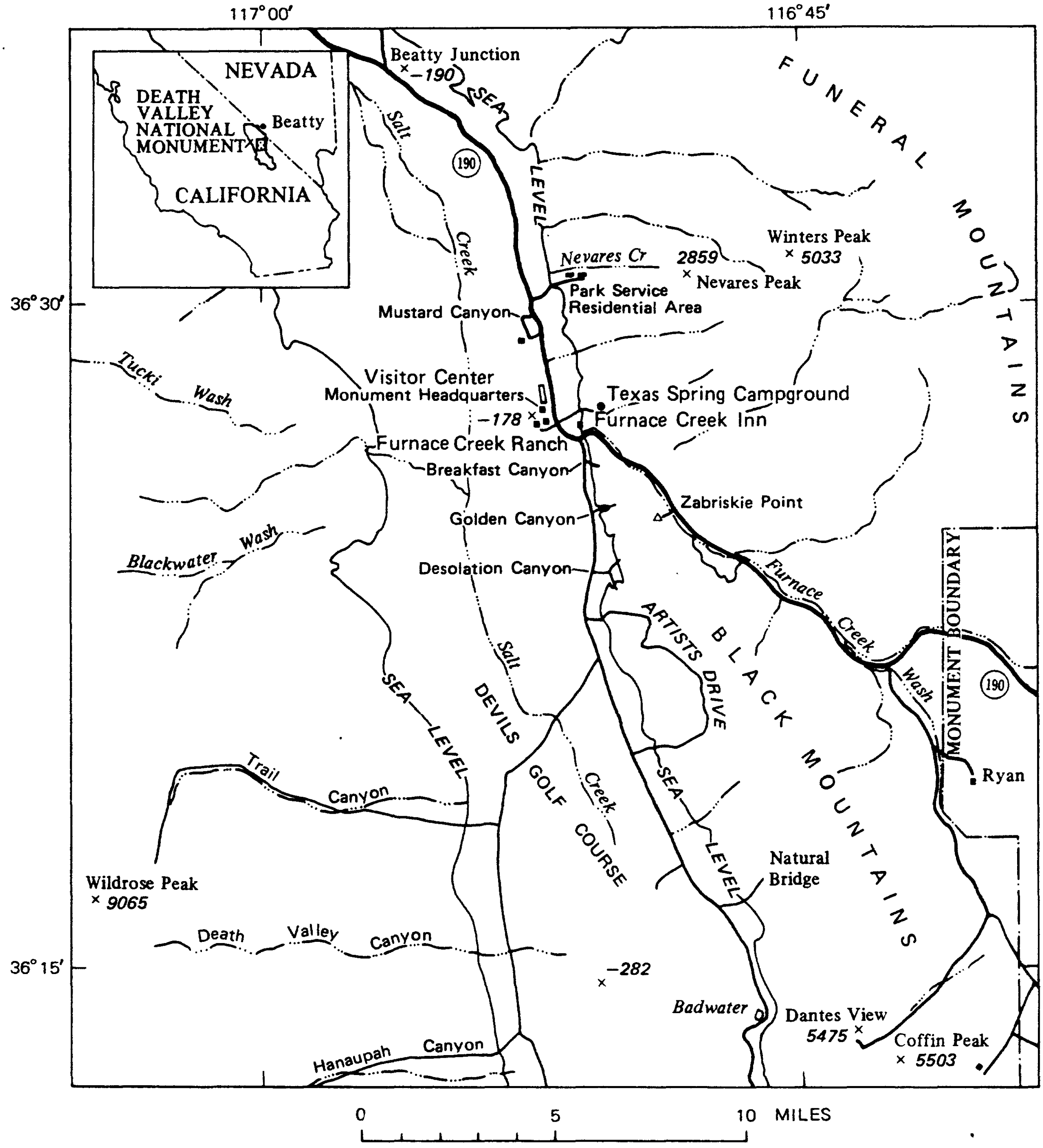
Death Valley is commonly perceived as a waterless wasteland, but despite the scanty rainfall of its desert environment Death Valley is occasionally visited by intense storms. The heavy precipitation accompanying these storms is likely to cause flash flooding in the unstable, normally dry stream channels, debris flows over the steep, easily eroded slopes of the alluvial fans, and shallow inundation of the relatively flat low areas. Roads and other works of man in these areas of potential hazard may be severely damaged.

Many of the roads and facilities in Death Valley National Monument are located in areas that may be subject to flood damage. Transmountain roads often occupy stream channels, and roads that follow the valley alinement often cross the upper parts of alluvial fan deposits. The most dramatic views and many of the most interesting geologic exposures are near canyon mouths; hence, visitor activity centers have been developed at or near these areas, and the centers may be exposed to considerable hazard in the event of flash flooding. Frequent visitors to the area can readily observe the many locations where roads have been damaged by washouts and where debris flows have been cleared. Because of these conditions the Water Resources Division of the Western Regional Office, National Park Service, requested and funded a study by the Geological Survey of the flood-hazard potential in the Furnace Creek area and Nevares Creek area of Death Valley National Monument.

The study presents a general evaluation of flood-hazard potential in the entire area and specific evaluations of the degree of hazard in three regions where human activity is concentrated: (1) the mouth of Furnace Creek Wash near Furnace Creek Inn (at the apex of Furnace Creek fan); (2) Furnace Creek fan itself in the vicinity of Furnace Creek Ranch, the Visitor Center, and Monument Headquarters; and (3) the Park Service residential area located about 3 mi north of the Monument Headquarters and east of Highway 190. The summary of extent and severity of flood hazards is intended to assist the National Park Service by providing a basis for planning visitor activities and selecting structure sites.

GEOGRAPHIC SETTING

Death Valley National Monument includes 3,231 mi^2 in southeastern California and southwestern Nevada. The valley floor, which is the central part of the monument, extends about 140 mi in a generally northwest-southeast direction. The monument is in the Basin and Range physiographic province and is the terminus for surface- and ground-water movement from an area of about 8,700 mi^2 in Nevada and California. The largest tributary drainage system is that of the Amargosa River, with its headwaters north of Beatty, Nev. The Amargosa River enters Death Valley from the southeast. Death Valley Wash, which has a drainage area of more than 2,000 mi^2, is the principal tributary from the northwest. Both streams at times contribute flow to the saltpan in the lowest, almost level, part of the valley floor, which is about 280 ft below sea level. The valley is bounded on the east by mountain ranges with crest elevations that are generally higher than 4,000 ft and with peaks higher than 8,000 ft. On the west side of the valley is a series of somewhat higher ranges, with the highest peak rising to more than 11,000 ft. The average slope of the mountain fronts is steeper on the east side of the valley than on the west side. The area of specific interest in this study is shown in figure 1.



EXPLANATION

× *5503* **SPOT ELEVATION—Number is elevation of land surface, in feet above or below (−) mean sea level**

FIGURE 1.--Furnace Creek area and principal features, Death Valley National Monument.

PRECIPITATION

Annual precipitation on the valley floor has averaged less than 2 inches for more than 50 years. About 60 percent of the annual precipitation falls during the five winter months, November to March; rainfall is rare during the month of June. Precipitation in the neighboring mountains is considerably greater than on the valley floor. According to Hunt (Hunt and others, 1966, p. 36), mean annual precipitation increases about two-thirds of an inch for each 1,000 ft increase of elevation, up to about 5000 ft. Relatively short, intense, and small-area bursts of rainfall in the nearby mountains are the cause of most floods in Death Valley. Although the greatest part of the annual precipitation comes during the winter months, summer or early autumn storms produce most of the flash flooding. Localized convective precipitation associated with summer hurricane-type storms in coastal regions to the south or southwest of Death Valley has caused several recent outstanding floods in the valley (Miller, 1977, p. 19).

The rate of evaporation in Death Valley is very high; therefore, the accumulation of water that sometimes occurs on the lowest part of the saltpan is shallow and generally short-lived. However, a recent "lake" thus formed (1969) was 2 to 3 ft deep, and standing water endured for several months. Most of this water was contributed in late February and early March by the Amargosa River as a result of sustained storms over a large area.

FLOODFLOWS

Many equations have been derived that relate floodflows of specified probabilities to various characteristics of climate and topography. Although the dearth of information from desert regions prevents such relations from being as accurate as those for more humid areas, the relations can provide estimates useful in planning and design. Equations that were used in this study include:

$$Q_{25} = 410\ A^{0.63} \quad (1)$$
$$Q_{50} = 700\ A^{0.68} \quad (2)$$
$$Q_{100} = 1,080\ A^{0.71} \quad (3)$$

(Waananen and Crippen, 1977)

with Q_{25} being the flood discharge in cubic feet per second with a 4 percent probability of being exceeded in any given year; Q_{50} the 2-percent flood, Q_{100} the 1-percent flood, and A the drainage area, in square miles. Equation 4, below, describes an envelope curve which includes the maximum floods experienced in the desert regions of the Basin and Range province:

$$Q_{me} = 98,900A^{1.029}\ Z^{-1.341} \quad (4)$$

with Q_{me} being the maximum flood discharge in cubic feet per second, A the drainage area in square miles, and Z having a value $(A^{0.5} + 5)$

(Crippen, 1978)

Although floodflows of the magnitude described by equation 4 are extremely rare, they are possible at many desert locations. For example, the peak flow of Eldorado Canyon, which is 120 mi southeast of Death Valley and drains 22.9 mi^2, was estimated to be 76,000 ft^3/s on September 14, 1974 (Glancy and Harmsen, 1975). For a basin of that size, Q_{100} calculated from equation 3 is 9,970 ft^3/s. Equation 4 indicates a practical upper limit of 117,000 ft^3/s. Matthai (1969) proposed a limiting equation, based on maximum floods observed throughout the nation through 1965, of $Q = 11,000\ A^{0.61}$. The Eldorado peak flow exceeded Matthai's limit (74,300 ft^3/s) slightly.

The estimated values of Q_{me} represent flows that would in many places exceed the capacity of the channels as they now exist. When such extreme flows occur they defy hydraulic analysis for two principal reasons: The channels themselves are altered by erosion and deposition; and backwater effects cause water to leave the normal channels. Some of the overflow may return to the original channel at downstream points, but if topography and erosion permit, new channels may be formed which in some cases may not rejoin the original channel within the area of study. Therefore, the estimates of quantities and mean velocities for extreme flows have little practical value. They represent potential hydrologic input to the point of interest, but the physical bounds of the channel are overwhelmed, and new, unpredictable, situations are created. Even though magnitudes of estimated maximum flows are shown and theoretical elevations reached at the cross sections are indicated, it is not possible to show the potential hazard areas that correspond. Conditions leading to the occurrence of Q_{me} would be so severe that landslips, extreme erosion, and sheet flow of water and debris would be widespread, even where distinct channels do not now exist. There is bountiful evidence of the past occurrence of such randomly widespread flood activity throughout desert areas.

Studies by Hedman (1970) and others have shown that annual runoff in ephemeral streams can be related to certain measurements of channel traces. Further investigations by M. W. Busby (U.S. Geological Survey, written commun., 1978) show a possible relation between floodflows of selected probabilities and traces that preserve a record of the active width of channels in ephemeral streams in southern California. Field measurements made of channels in Death Valley were interpreted on the basis of the southern California investigations. The results were generally similar in magnitude to the flows determined by use of equations 1, 2, and 3 (table 1); however, they were somewhat inconsistent, and, therefore, the equations are regarded as more reliable.

Table 1 shows discharges computed by equations for basins of 1, 10, and 100 mi^2.

TABLE 1.--Computed peak discharges for basins of selected size

Equation number	Discharge (Q), in cubic feet per second, for indicated basin size, in square miles			Probability of flow being exceeded in any given year
	1	10	100	
1	410	1,750	7,460	0.04
2	700	3,350	16,000	.02
3	1,080	5,540	28,400	.01
4	8,950	63,000	299,000	Unidentified, but extremely rare

DEBRIS MOVEMENT

Floodflows in arid regions are often accompanied by movement of large amounts of debris. The generally steep slopes, together with the deep, loose, and poorly sorted materials in which most channels are located, contribute to the ready movement of debris. As flow descends toward valley bottoms there is generally a flattening of slope, and the coarser material tends to drop out first as velocity slows. If the debris contains enough fine-grained material in proportion to the amount of water, the flow may be thickened to form a slurry of mud. Frequently such mudflows may follow behind a leading wave of water; evidence of slight mudflows is often found after even minor rains, but the mud is usually so shallow that it causes no problems. At times, however, debris flows leave accumulations up to several feet in depth and require substantial clearing efforts. In Death Valley almost all noteworthy floods are accompanied by debris movement and, where roads follow stream courses, by washouts; together they may stop all wheeled vehicles.

While a leading wave of water will frequently outdistance the contained debris, the opposite situation may arise: Coarse debris pushed up by a water wave may act as a moving dam and cause a buildup of water behind the leading debris. When this occurs in a poorly incised channel or on the surface of an alluvial fan, the flow of water may be redirected. Such action may in part explain the pattern of interweaving flow traces common to many planar but inclined alluvial surfaces that are north of the residential area, along the eastern foot of the Funeral Mountains.

Hazards posed by debris movement cannot be dissociated from the hazards of floodflows. They are greatest, of course, where flow is deep and fast and, therefore, are likely to occur along deeply incised and steep washes. Discussion of debris hazards is of necessity quite generalized in the following sections.

The size of material eroded or deposited by any given floodflow, and the depth of cut or deposit, cannot be predicted. However, inspection of cutbanks in recently eroded channels and fans provides evidence that the great bulk of material is of sand and pebble size (0.1- to 64-mm diameter). Some layers include cobbles (64 to 256 mm), but very few boulders are found in the graded deposits; they seem unlikely to move far from the areas of the rock formations where they originate. Most fan material and debris from road-clearing operations are of pebble size or smaller. Larger material predominates near the apex regions of the fans, and gravel and sand are deposited successively down the fan as water velocities and depths diminish. Depths of deposits are greatest at the bases of steep slopes, and for an extreme flood they may be on the order of 3 to 5 ft.

POTENTIAL HAZARDS

Hazards from floodflows can be defined by various criteria, such as combinations of depth and velocity, amount of debris carried and deposited by the flood, and location and areal extent of inundation and debris movement. The hazards themselves may cause only temporary inconvenience such as short travel delays, more serious property damage or loss, or even personal danger and loss of life. Minor losses and disruption can be tolerated, but unusual floods must be met by awareness of their capacity to harm and, insofar as possible, by precautions to alleviate their effects. To that end, several levels of probability have been selected for computing peak flow and preparing maps of relative hazard. These levels are described as slight, moderate, and extreme. The choice of categorical names rather than precise numerical descriptions of degree of risk reflects the fact that both hydrologic probability and hydraulic behavior of floodflows are imperfectly known in the desert environment. Despite this inability to assign a specific value of probability, the relative degree of risk is obvious; the greater the depth and velocity of flow, the greater the risk.

Hazards from debris movement, however, are brought about by a more complex interaction of unknown and unpredictable circumstances. The estimation of such hazards must therefore be more general; in this report hazards from debris movement will be broadly defined in areas where debris movement of a harmful nature may be expected to occur during floods.

The three categorical degrees of risk--extreme, moderate, and slight--correspond to the levels of probability that were specified, that is, 4 percent, 2 percent, and 1 percent. For example, areas where the 4-percent (or 25-year) flood will cause inundation, debris movement, or hazardous erosion are classified as extreme flood-hazard areas because the event is of relatively frequent occurrence. These areas will experience flows of even greater depths and velocities during 2-percent or 1-percent floods. The 2-percent flood will include the 4-percent area and also may endanger a fringe area that was not affected by the 4-percent flood; this fringe area is classified as an area of moderate hazard. Similarly, the 1-percent flood will cover the moderate-hazard area and an additional fringe area; this additional area is classified as a region of slight hazard.

To determine flow patterns and risk categories, the investigator must analyze data with respect to hydrologic and hydraulic behavior, then assign probabilities on the basis of observed experience. Flow over the surface of alluvial fans, however, is subject to many random influences that do not lend themselves to such deterministic treatment. Many variables that cannot be adequately described or measured act upon the water and the detritus over which it moves. Events that occur on a microscale, such as the behavior of a very small obstacle in directing flow in one direction or another, can initiate a "chain reaction" of subsequent events that is important in determining the location and magnitude of flow down the fan.

SUMMARY OF HAZARDS

Apex of Furnace Creek Fan

Discussion of the flooding potential at the apex of Furnace Creek fan and at Furnace Creek Ranch requires a brief description of the geography of Furnace Creek Wash as it descends into the valley.

California Highway 190 parallels Furnace Creek Wash downstream (northwest) for 10½ mi, from the junction of Highway 190 and the road to Ryan (fig. 1) to the apex of Furnace Creek fan. The highway then turns north and traverses the upper part of the fan for 2½ mi. The elevation at the junction with the road to Ryan, 2 mi west of the monument boundary, is about 2,000 ft, and the elevation at the apex of the fan is about 20 ft. The slope of the wash and the highway is therefore about 190 ft/mi; it is fairly constant with no markedly steep stretches.

The wash itself is fairly broad throughout this reach. In much of the reach, flow usually occurs in a narrower channel that is incised 2 to 6 ft into the loose alluvium. However, as it approaches the apex near the entrance to Furnace Creek Inn, the wash narrows substantially from its upstream width.

Estimation of peak flows at the apex is complicated by the presence of a manmade diversion work near Zabriskie Point, 3.5 mi upstream (southeast) from Furnace Creek Inn at an elevation of 670 ft (fig. 2). At this point the head of a small westward-draining basin, Gower Gulch, had eroded by 1941 almost to the bed of Furnace Creek Wash, an example of stream piracy nearly being accomplished by natural processes. In 1941 an artificial cut was made to connect the two channels so that all Furnace Creek flow from the 169 mi^2 basin above that point was diverted into the 2-square mile basin of Gower Gulch (Troxel, 1974; Dzurisin, 1975). Thus, by man's efforts, stream piracy was accomplished when Furnace Creek Wash was beheaded by Gower Gulch. Because the bed of Gower Gulch is lower than the bed of Furnace Creek Wash, the manmade notch has eroded further by natural processes. It is now (1979) a channel of irregular shape and slope, cutting through the southwest bank of the Wash. The incised channel in the bottom of Furnace Creek Wash itself has now deepened to the level of the bottom of the notch, probably through both natural and artificial means. As flow moves downstream in Furnace Creek Wash, it is diverted to the notch by a headwall 8 to 10 ft high cut into the original channel deposits that compose the bottom of the wash. The diverted flow does not return to Furnace Creek Wash nor does it reach Furnace Creek fan.

On the basis of peak flows expected from the 169-square mile area of Furnace Creek drainage above the diversion and estimates of the amount of flow likely to be diverted, the following can be expected: For peaks having an annual probability greater than 0.03 (floods less than Q_{33}), all flow from the upper part of Furnace Creek will be diverted into Gower Gulch; for peaks at the 0.01 probability level, slightly more than half the flow will be diverted; during more rare floods, most flow will discharge over the headwall and continue down Furnace Creek Wash. These estimates of flow are made by assuming conditions as they existed in January 1978.

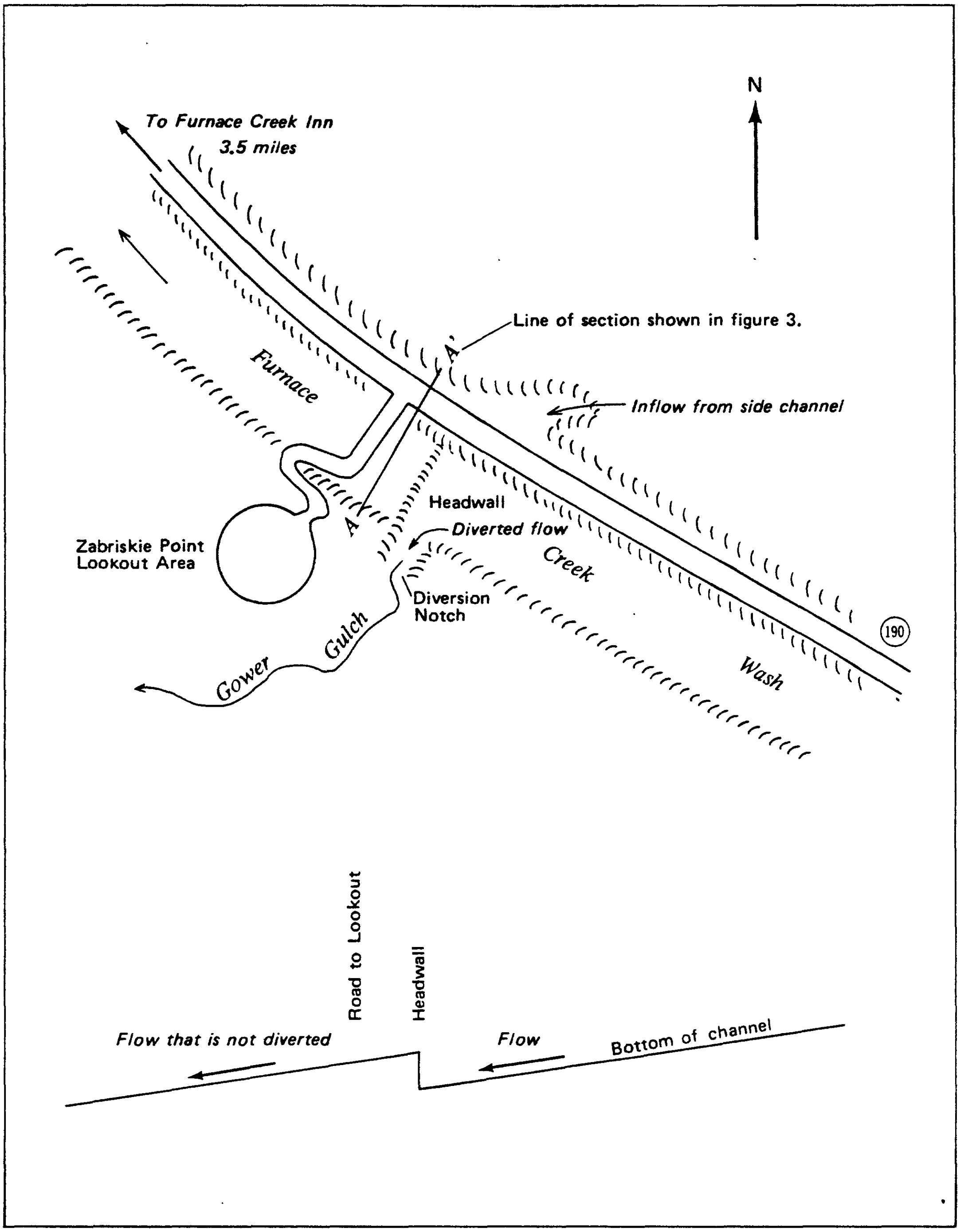


FIGURE 2.--Schematic profile of Furnace Creek Wash at Gower Gulch diversion.

It is unlikely that events of equal probability would occur simultaneously in the 169-square mile upper basin and the 36-square mile lower basin. Therefore, peak flows from the entire 205-square mile drainage basin have been computed as the amount of flow for a given probability that will bypass the diversion plus the flow at double that probability from the lower 36 mi^2. As an example, of a 100-year flood flow in the basin above Zabriskie Point (the upper 169 mi^2), not quite half would continue down Furnace Creek Wash. That flow would be augmented by flow from a 50-year flood from the lower basin. Similar computations would be made for an upper basin peak of 0.02 probability and lower basin peak of 0.04. For upper basin peaks of 0.04 probability, there would be no contribution to the lower basin from the upper basin and the only flow at the apex would be that from the lower 36 mi^2.

A cross section of Furnace Creek Wash, as surveyed in January 1978 just upstream from the side road leading to the Zabriskie Point outlet and downstream from the headwall, is shown in figure 3. Estimates of flows and mean velocities are shown below. These estimates are highly problematical, as they are based upon channel conditions that would probably be unstable and likely to be changed by the flows themselves.

Probability	Peak flow (ft^3/s)	Recurrence interval, years	Mean velocity (ft/s)
0.04	0	---	---
.02	4,500	50	13
.01	18,000	100	19
Q_{me}	221,000	---	45

Estimated maximum flow (Q_{me}) for the study area has been computed by using equation 4, modified on the basis of the Eldorado Canyon experience to include an additional multiplier of two-thirds. To adjust Q_{me} at the apex of Furnace Creek fan for the split-basin effect of the Zabriskie Point diversion, the 0.01 probability flow from the lower basin will be added to that part of Q_{me} that will bypass the diversion. The modifications of probabilities between the upper and lower parts of the basin represent judgment decisions, because both data and knowledge are lacking to justify a formal mathematical analysis.

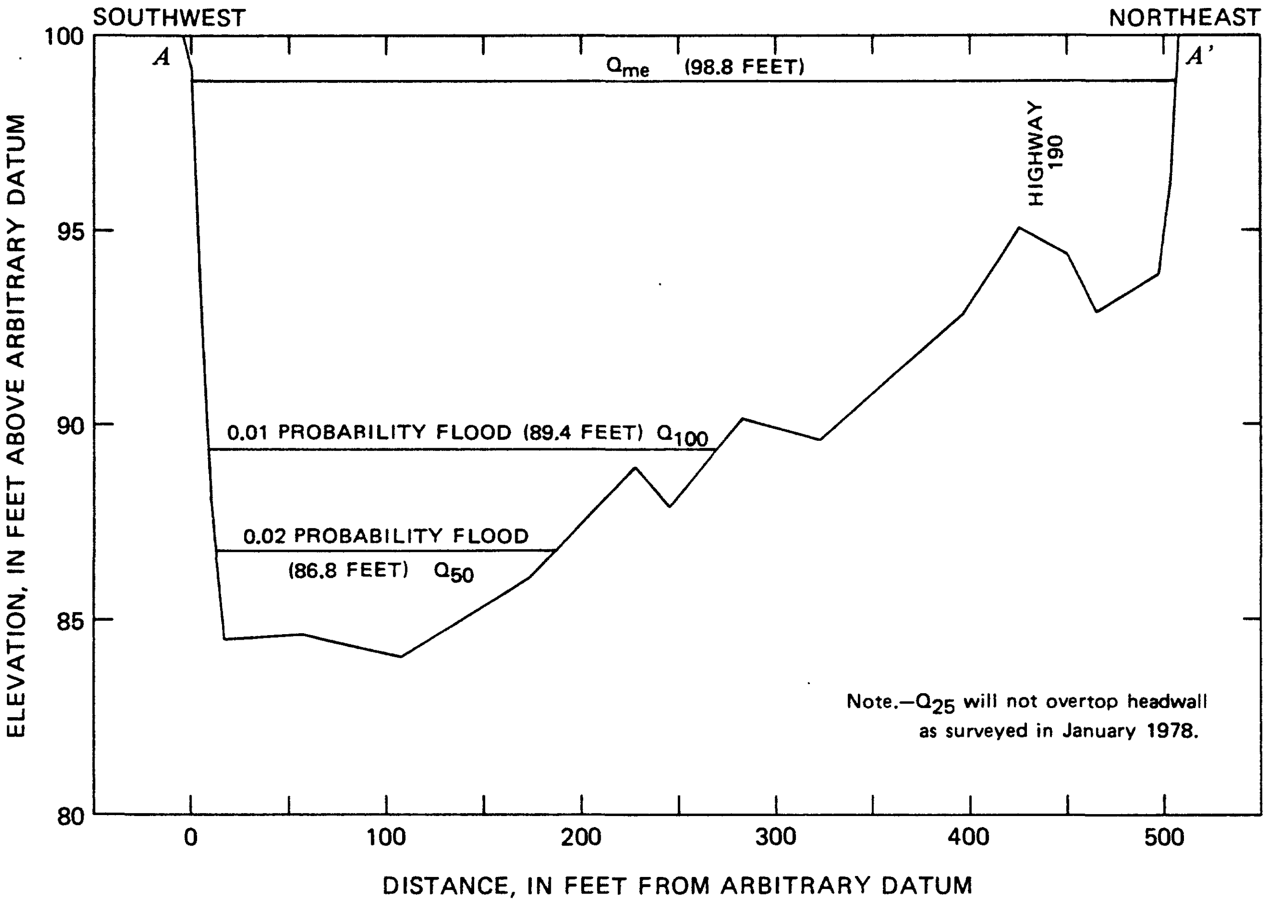


FIGURE 3.--Cross section and estimated flood levels of Furnace Creek below the diversion to Gower Gulch, at Zabriskie Point. Location of section shown in figure 2.

From the foregoing considerations, these quantities of peak flow are estimated for the apex of Furnace Creek fan, with the indicated probability for each being exceeded in any given year:

Probability	Peak flow (ft^3/s)	Recurrence interval, years	Mean velocity* (ft/s)
0.04	3,900	25	13
.02	8,400	50	18
.01	26,000	100	22
Q_{me}	235,000	---	47

*The velocities shown here and elsewhere apply only to the cross section surveyed, with conditions at the time of survey.

Figure 4 shows the areas that will be inundated by flows with probabilities of 0.04, 0.02, and 0.01. Flows of the Q_{me} level are so rare, and of such uncertain magnitude, that they do not lend themselves to meaningful assignment of degree of risk. Figure 5 shows the levels of selected floodflows, at a cross section surveyed in January 1978, about 150 ft downstream (southwest) from the drive leading from Highway 190 to Furnace Creek Inn.

It is possible that any substantial flow over the headwall in Furnace Creek Wash at Zabriskie Point would lower the channel at the headwall by erosion, thus increasing the proportion of flow that continues down the wash to the apex of the fan and decreasing the amount of diversion to Gower Gulch. Estimates of the likelihood of such a change and of the magnitude of resulting flow shifts would require a detailed study of erosion characteristics of the material in the vicinity of the headwall; the deposition that would be likely to occur in the vicinity of the headwall; the simultaneous erosion of the diversion notch; and assumptions as to magnitude, velocity, and duration of flow reaching the headwall area from the upstream basin. All these details are beyond the scope of this study.

Furnace Creek Fan near Furnace Creek Ranch and Visitor Center

Furnace Creek Ranch and the Visitor Center are on the Furnace Creek fan to the west or downslope side of Highway 190 (fig. 6). The fan is typically arcuate in form, centered about a line running due west from the apex. To the north the arcuate contours are intersected by the contours of a smaller fan formed by accumulation of detritus from a much smaller basin (about 5 mi^2) on the west-sloping front of the Funeral Mountains. The slopes of the fan surface vary somewhat; in general they range from 4 percent near the apex, at sea level, to 3 percent at the entrance of Furnace Creek Ranch. Slope diminishes as the fan descends to the saltpan in the flat valley floor, here about 265 ft below sea level.

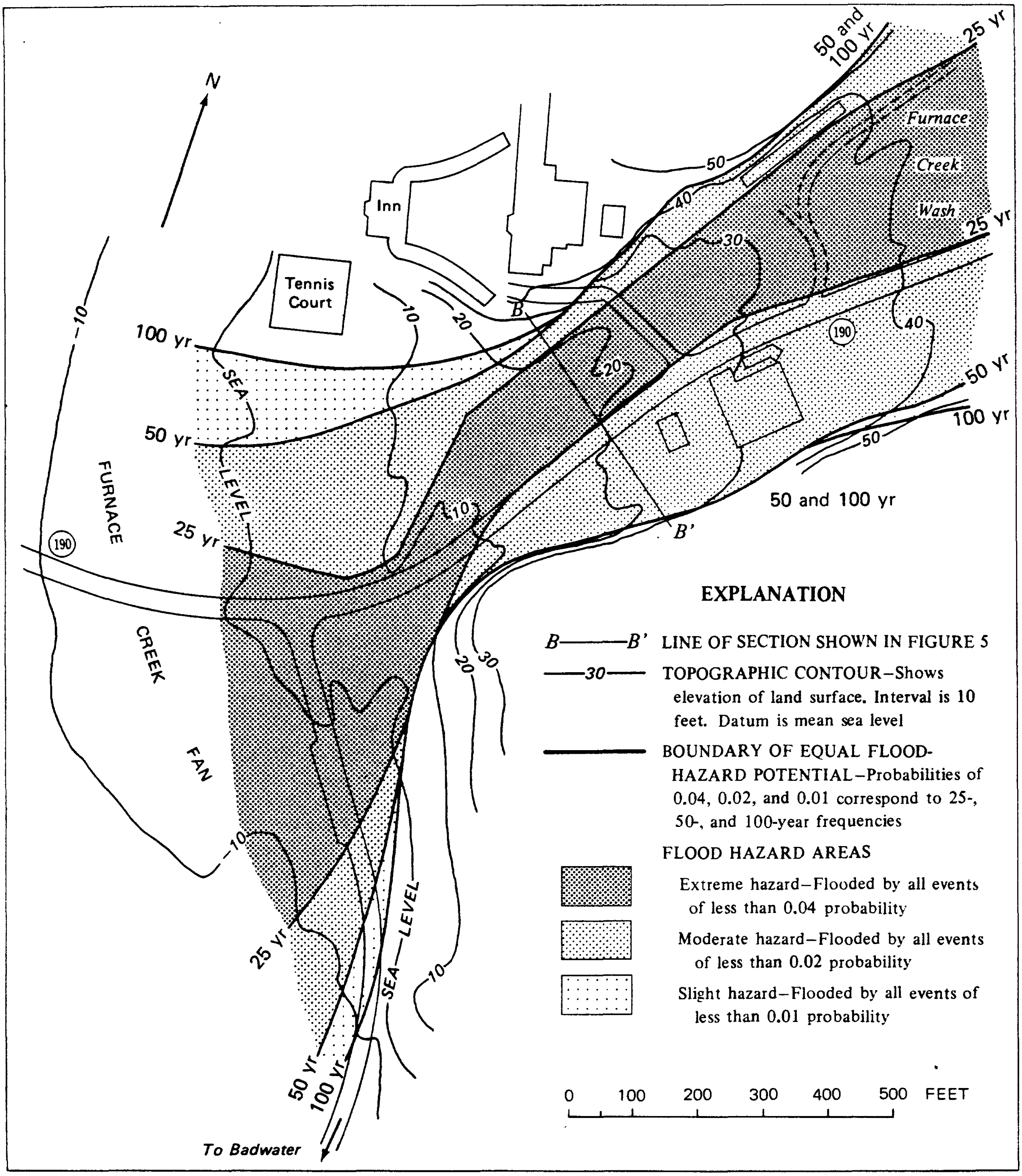


FIGURE 4.--Flood-hazard areas in Furnace Creek Wash at apex of Furnace Creek fan.

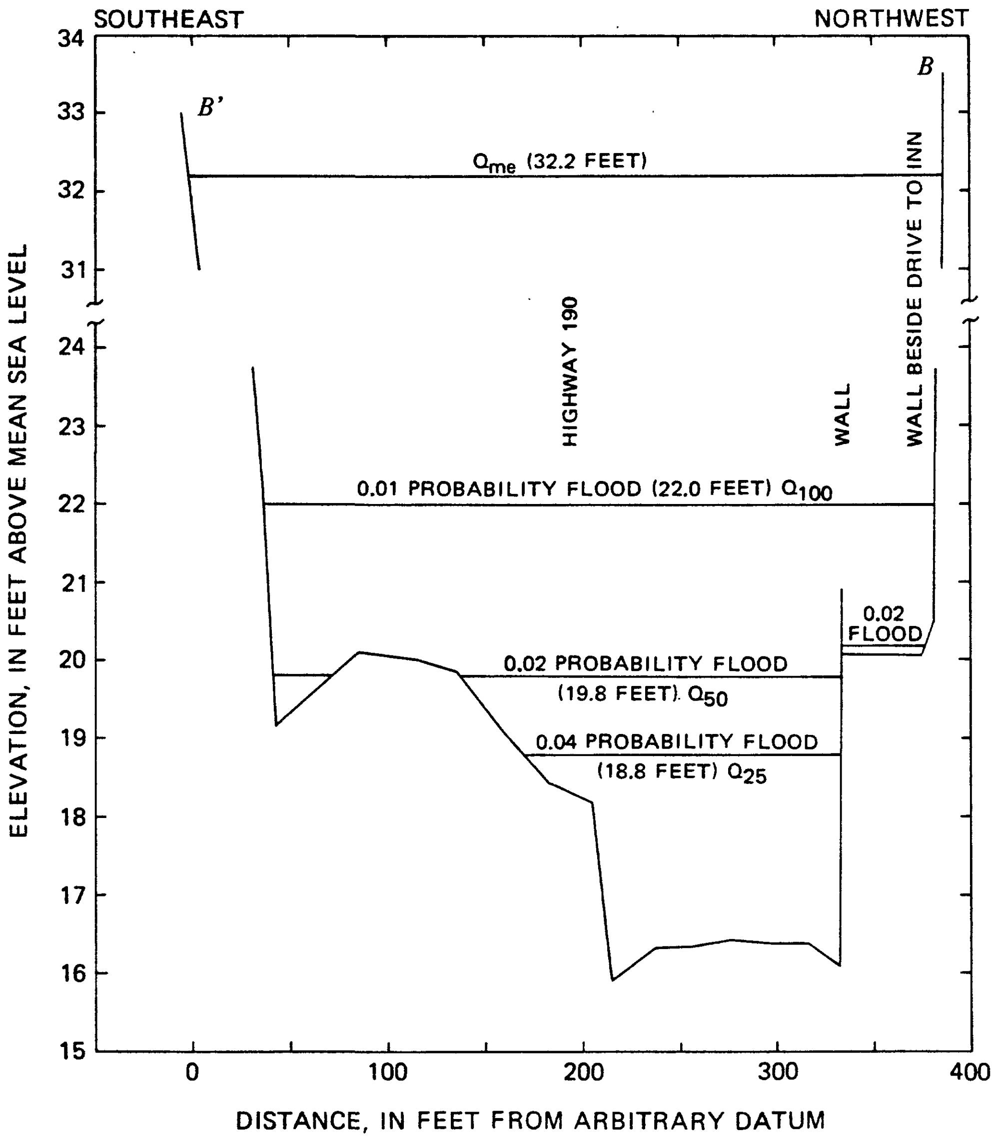


FIGURE 5.--Cross section and estimated flood levels of Furnace Creek Wash near Furnace Creek Inn. Location of section shown in figure 4.

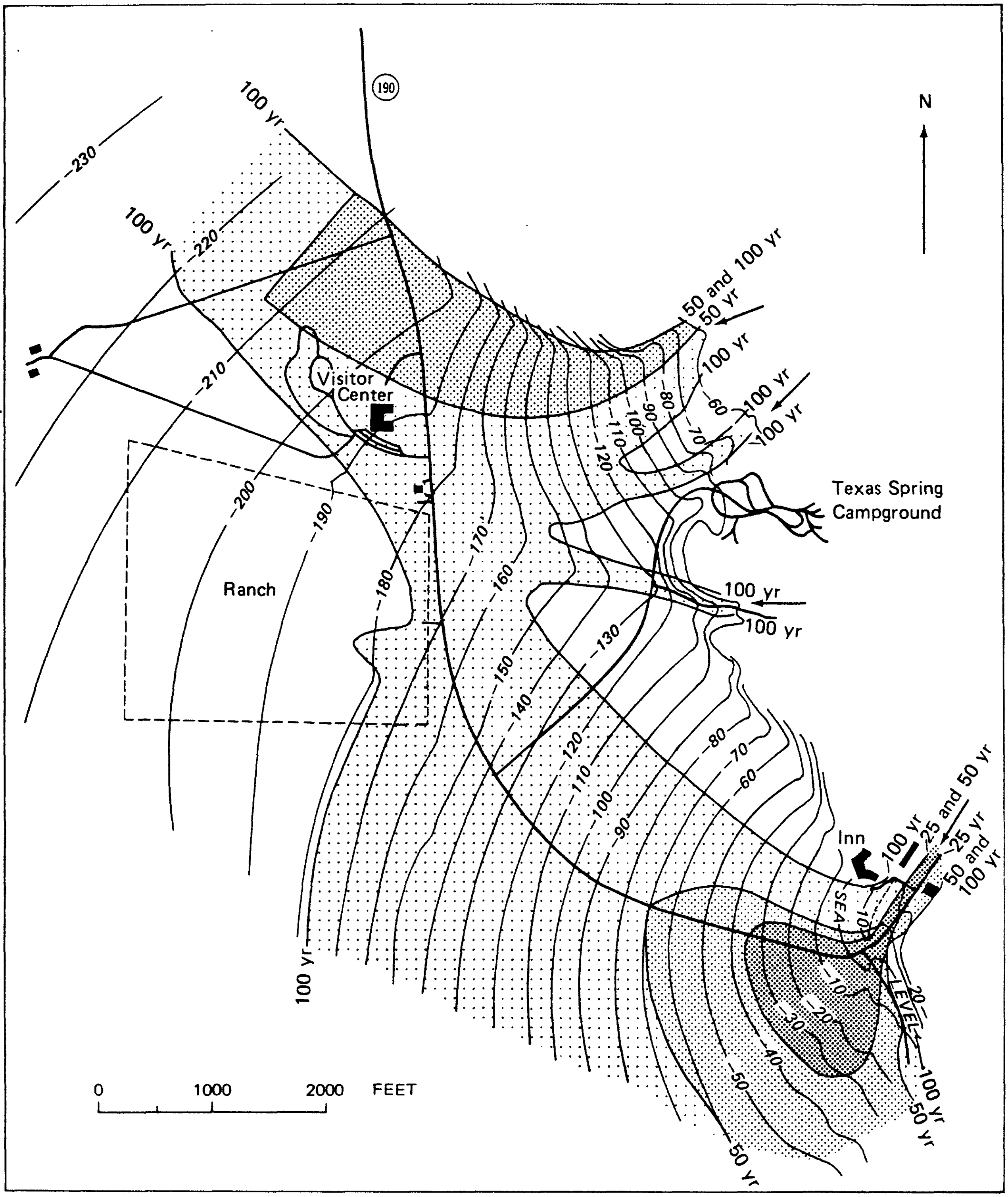


FIGURE 6.--Flood-hazard areas on Furnace Creek fan.

EXPLANATION

← POINTS WHERE FLOODFLOWS MAY ENTER FAN

—110— TOPOGRAPHIC CONTOUR–Shows elevation of land surface. Interval 10 feet. Datum is mean sea level

——— BOUNDARY OF EQUAL FLOOD-HAZARD POTENTIAL–Probabilities of 0.04, 0.02, and 0.01 correspond to 25-, 50-, and 100-year frequencies

FLOOD HAZARD AREAS

- Extreme hazard–Flooded by all events of less than 0.04 probability
- Moderate hazard–Flooded by all events of less than 0.02 probability
- Slight hazard–Flooded by all events of less than 0.01 probability

Inspection of the fan surface, both from the ground and from the air, indicates that low or moderate flow debouching from Furnace Creek Wash passes southward across Highway 190 just east of the junction with the road to Badwater, then crosses the Badwater road mainly over a concrete apron some 250 ft south of the junction. It is evident that at times of high discharge part of the flow may continue north of the junction and move down the fan toward the ranch area.

Flow from the 5-square-mile basin passes a few hundred feet north of the Texas Spring campground in an incised wash and therefore does not pose a threat to the campground itself. The incised wash loses its distinctive character as it enters the upper end of its fan about half a mile east of and 130 ft higher than the Visitor Center. Inspection of this smaller fan indicates, and discussion with Park Service personnel confirms, that floodflows wander in unpredictable paths before crossing Highway 190 and continuing down the fan. Topography and flow traces indicate a tendency for flow to move downslope along the north edge of the fan and to cross Highway 190 near the junction of a side road to the west, 0.6 mi north of the ranch entrance. In passing down the fan, the flow from other very small basins may combine with larger flows to form a fairly broad area of slight hazard with shallow depths but rather high velocities. Figure 6 shows the estimated extent of these hazard areas and the relative degree of hazard.

The pattern of risk areas shown in figure 6 is based upon inspection of aerial photographs that provide visual evidence of historical patterns of flow, together with oral recounting of details of recent floodflows and observation of past diking and road-clearing activities that have resulted. The sum of these experiential data is probably more dependable in estimating the relative location and magnitude of risk than would be the results of computations based upon numbers of uncertain value applied to a set of arbitrary and uncertain relations.

Residential Area

The residential area shown on topographic maps as Park Village is 3.5 mi north of the Visitor Center. It lies beside Nevares Creek (fig. 7) at 150 to 300 ft above sea level and is reached by a paved road that leads about 2 mi east from Highway 190 (fig. 1).

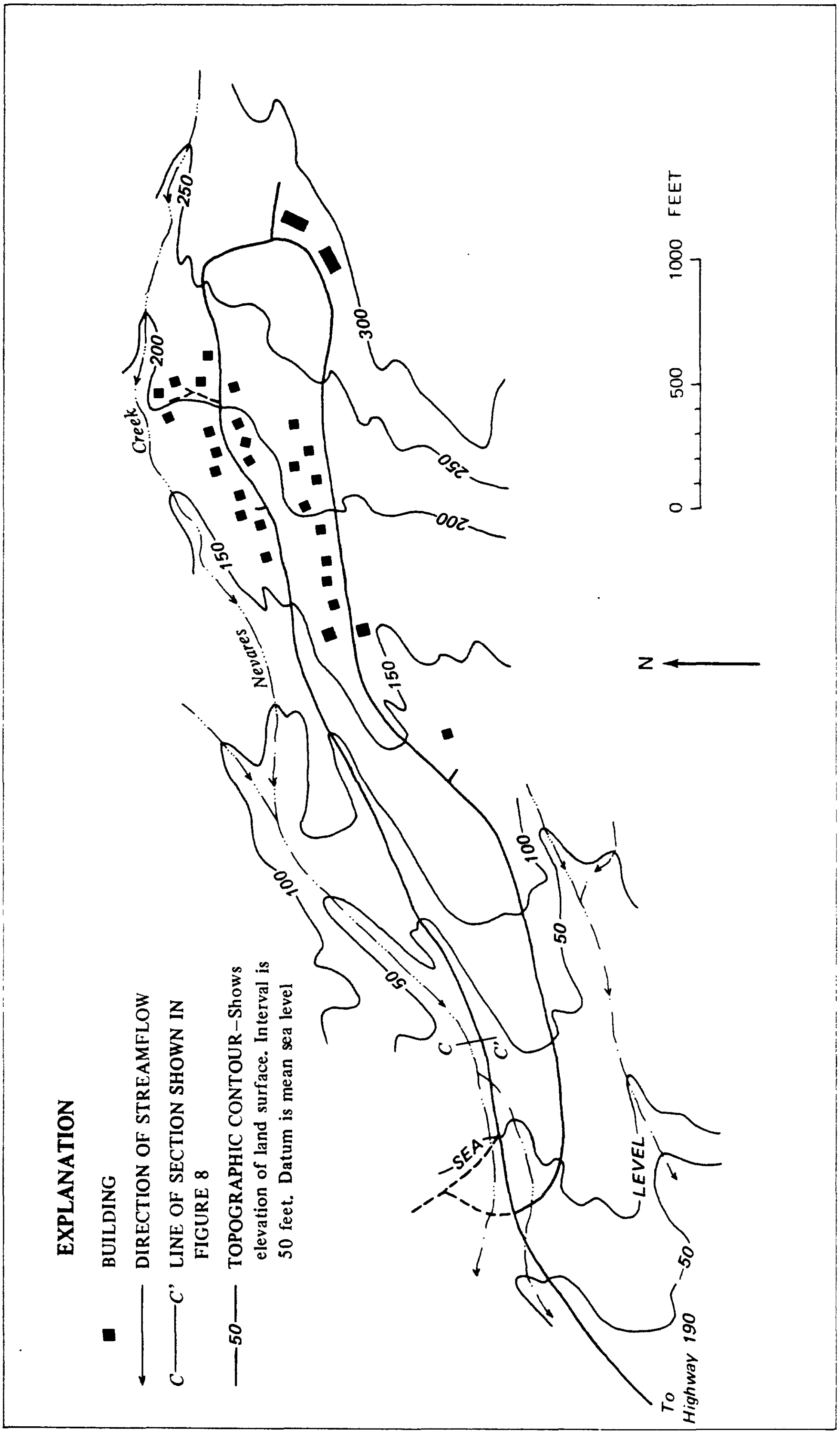


FIGURE 7.--Residential area and vicinity.

Drainage patterns of Nevares Creek and Cow Creek, its neighbor to the south, are difficult to define and may not be the same for major floodflows. Drainage patterns could not be defined conclusively by inspection on the ground or from the air or from study of aerial photographs taken several years apart. The streams cross a west-sloping alluvial surface that lies along the western base of the Funeral Mountains (fig. 1). Throughout the length of this sloping terrain (about 14 mi, from Texas Spring Campground northward), there is a similar pattern of indistinct flow traces, connecting with intermittent reaches of incised channel. Debris paths interweave, coalesce, and disperse in a random way, seemingly demonstrating the vagary of past flows as seen on the surface of many alluvial fans. For any given storm the location of rainfall, its areal extent, intensity, and duration, together with hydraulic action as determined by flow velocity and the nature of debris movement, probably combine to direct the downslope paths of flow. The lack of continuous clearly defined restrictive channels and of topographic separation may cause the contributing drainage area to change from one flood to another. For this study, the extent of the drainage basin of Nevares Creek was determined from inspection of topographic maps and aerial photographs together with on-the-ground observation.

There seems to be little direct flood hazard to the residential area. However, two or three buildings are very close to the steep southern side of an incised reach of Nevares Creek and might be threatened by bank erosion associated with extremely high flows in the creek. The condition does not lend itself to analysis of probability or degree of hazard and is therefore mentioned here only as a possibility. The road leading to the residential area, however, runs for some distance along the bank of the creek in locations that are more directly subject to damage from washout and overflow. A survey was made in January 1978 of a reach about 1 mi east of Highway 190 which showed evidence of substantial damage from a moderately high flow in September 1976. The estimated peak flows associated with selected probabilities at the site of the survey where drainage area is about 3.4 mi^2 are:

Probability	Peak flow (ft^3/s)	Recurrence interval, years	Mean velocity (ft/s)
0.04	900	25	13
.02	1,600	50	11
.01	2,600	100	12
Q_{me}	18,000	-	18

The location of cross section C-C' is shown in figure 7, and figure 8 is a plot of the cross section, which shows the estimated water-surface elevations associated with the three risk categories. Because of the steepness of the channel, the great variation in shape of the cross section from point to point along the stream, and the easily erodible nature of the channel material, no attempt has been made to map the boundaries of the hazard areas at this location. No development other than the road is subject to damage at this site; however, the pattern of flow during an extreme flood would probably result in severe damage to all access routes from Highway 190 to the residential area.

The school building, located near the maintenance area and 0.25 mi east of Highway 190, is at the bottom of a small but wide wash that is unlikely to experience heavy flow. However, the recreation field may be subject to shallow inundation and debris flow following extremely heavy precipitation, and water would probably find its way into the school building. The school and other structures in the wash should be considered to be within the 100-year flood area, subject to shallow flooding and debris flow.

ADDITIONAL STUDIES

From the foregoing discussion it is evident that terrain and weather conditions create a potential for flood hazard throughout much of Death Valley National Monument. The hazard areas are particularly concentrated in the channels and washes that carry flow towards the valley bottom and at the upper parts of the alluvial fans. Although heavy flows are rare, they must be expected whenever weather conditions exist that may lead to severe convective storms, a situation most probable during the summer and early autumn months. Winter storms are likely to bring rainfall over the entire region and, while they may bring a larger part of total precipitation than do the convective storms, they are less likely to bring the intense rainfall that causes floodflows.

Studies to evaluate flood hazard can be conducted for specific sites other than those in this report. For example: Artists Drive, Natural Bridge, Grapevine Canyon in the vicinity of Scotty's Castle, Titus Canyon Road, Wildrose Canyon, and Mosaic Canyon are also areas of potential flooding and debris movement. Other areas of less intensive use but accessible and likely to be subject to flash flooding include the Jubilee Pass Road, Warm Spring Canyon, Trail Canyon, Emigrant Wash, Twenty Mule Team Canyon, and the narrows near the mouth of Cottonwood Canyon.

Studies can be made on a reconnaissance level along the most heavily traveled routes throughout the monument to define those stretches that are most likely to be affected by floodflows of water or debris.

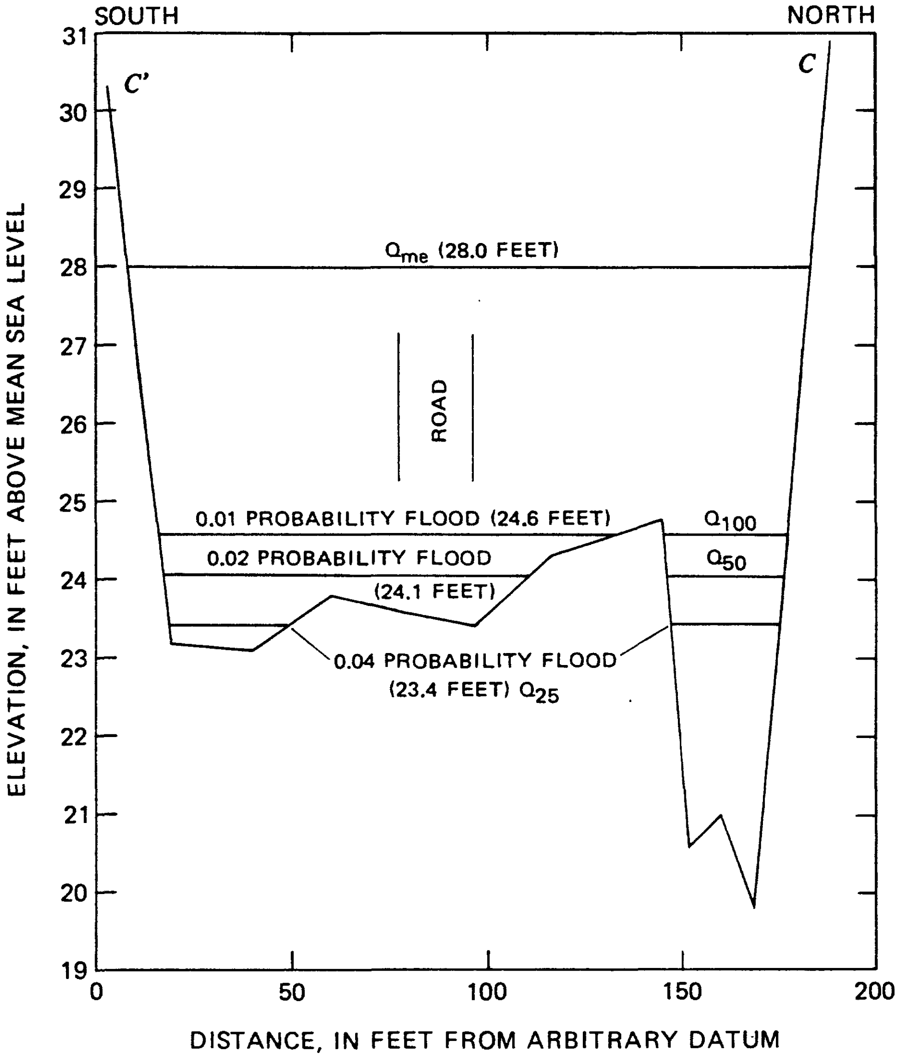


FIGURE 8.--Cross section of Nevares Creek showing estimated flood levels at a site on access road to residential area. Location of section shown in figure 7.

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PICTORIAL DATA

The photographs that follow were made from 35-millimeter transparencies that were selected from a larger group on file in the District Office, Water Resources Division, U.S. Geological Survey, Menlo Park, Calif. Unless otherwise noted in the description, the photographs were taken January 9-11, 1978.

PICTURE 1.--Furnace Creek Wash at Zabriskie Point: View from left bank across notch, Furnace Creek wash, and Route 190. Headwall just left of center; flow in wash is from right to left.

PICTURE 2.--Furnace Creek Wash at Zabriskie Point: View across wash from left bank. Diversion to Gower Gulch is notch in foreground.

PICTURE 3.--Furnace Creek Wash at Zabriskie Point (March 1977): View across wash from right bank to notch. Trailer at right is just downstream from headwall.

PICTURE 4.--Furnace Creek Wash at Zabriskie Point: Looking downstream to headwall. Car is parked downstream from headwall.

PICTURE 5.--Furnace Creek Wash at Zabriskie Point: Looking across Wash from near head of diversion notch. Flow comes down Wash from right.

PICTURE 6.--Furnace Creek Wash at Zabriskie Point: Looking downstream (southwest)into diversion notch from Wash.

PICTURE 7.--Furnace Creek Wash at Zabriskie Point: Looking upstream in diversion notch.

PICTURE 8.--Furnace Creek Wash at Zabriskie Point: View from Wash, just upstream from headwall, looking toward notch.

PICTURE 9.--Furnace Creek Wash at Zabriskie Point: Looking upstream in Wash, from headwall.

PICTURE 10.--Furnace Creek Wash at Furnace Creek Inn (March 1977): View upstream along wash from Inn driveway.

PICTURE 11.--Furnace Creek Wash at Furnace Creek Inn: View upstream along right bank from cross section.

PICTURE 12.--Furnace Creek Wash at Furnace Creek Inn: Looking downstream from cross-section. High flows may be split into right and left directions by rise on curve near sign at right.

PICTURE 13.--Furnace Creek Wash at Furnace Creek Inn (March 1977): Looking northeast across right side of Wash from Route 190, just west (downstream) from junction with Badwater road.

PICTURE 14.--Furnace Creek Wash at Furnace Creek Inn: Looking upstream across paved overflow apron on Badwater road.

PICTURE 15.--Furnace Creek Fan (March 1977): Aerial view of apex of fan. Furnace Creek Inn at center, Badwater road leads to upper right.

PICTURE 16.--Furnace Creek Fan: View upstream (east) showing traces of overflow of Route 190 near north side of fan, 3300 feet north of main entrance to Ranch.

PICTURE 17.--Nevares Creek (March 1977): View upstream near cross section. Vertical banks are typical of the cuts by recent moderately high flows.