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FLOOD AND RELATED DEBRIS HAZARDS IN THE GENOA QUADRANGLE, WEST-CENTRAL NEVADA

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CONVERSION FACTORS AND ABBREVIATIONS

"Inch-pound" units of measure used in this report may be converted to metric (International System) units by using the following factors:

Multiply	By	To obtain
Cubic foot per second (ft^3/s)	28.32	Liter per second
Cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	Cubic meter per second per square kilometer
Feet (ft)	0.3048	Meter
Feet per foot (ft/ft)	1.000	Meters per meter
Inch (in.)	25.40	Millimeter
Mile (mi)	1.609	Kilometer
Square mile (mi^2)	2.590	Square kilometer

FLOOD AND RELATED DEBRIS HAZARDS IN THE GENOA QUADRANGLE, WEST-CENTRAL NEVADA

By David F. Meyer and David L. Berger

ABSTRACT

Flood and debris hazards in the area shown on the Genoa 7-1/2-minute quadrangle, Nevada, result mainly from the potential for debris flows and sediment-laden water floods on alluvial fans along the eastern front of the Carson Range. Alluvial fans at the mouths of canyons draining terrain composed of metavolcanic rocks, in the southern part of the study area, have received coarse-grained debris as a result of these fluid flow processes during the historic past, and can be expected to receive similar flows in the future. These flows present a significant hazard to people and structures. In general, the recurrence probabilities of such flows are greatest at the apexes of fans and near active stream channels. Alluvial fans at the mouths of canyons draining terrain composed of granitic rocks, in the northern part of the study area, generally receive relatively fine-grained debris. Shifting channels, erosion, and deposition pose hazards to structures and roadways on these fans, but pose minimal threat to personal safety. Similar hazards exist at the distal margins of the coarse-debris alluvial fans in the southern part of the study area. Precise probabilities cannot be assigned to the likelihood of occurrence of such flows in the study area because of an inadequate data base for flooding along small, steep mountain drainages and because of the difficulties of predicting sediment movement.

Alluvial-fan morphology (shape, size, gradient, grain-size characteristics, and sedimentary structures) is related to debris-transport processes, and thus to source terrain. The morphology of alluvial fan apexes was used to date large flows relative to the most recent movement along the Genoa fault. Flows also were dated by estimating relative times when lichens and trees were established on fan surfaces.

This report supplements earlier, standard flood-hazard studies that were made by the Federal Emergency Management Agency and deal with flooding along the Carson River and its tributaries.

INTRODUCTION

Flooding and the movement and deposition of fluvial-debris pose ever-present hazards to human activities in areas adjacent to streams. In the Genoa quadrangle, major flood and debris hazards are associated with alluvial fans. Alluvial fans are products of flood deposition; thus, any part of the fan is subject to some degree of flooding. However, many alluvial fans in the Great Basin were formed during periods having climatic conditions different from those of today; as a result, determination of the frequency and extent of fan flooding under current climatic conditions is speculative and uncertain.

Hazards normally associated with flooding include inundation by flood waters, destruction of crops, and erosion of transportation networks. Along large streams of relatively gentle slope, most sediment moved by such floods is generally fine-grained (sand-, silt-, and clay-size), and produces more of a nuisance than a hazard. In contrast, small, steep streams, such as those draining the Carson Range between Genoa and Carson City, Nev., are capable of transporting coarse-grained debris at high velocities and in high concentrations. In such drainages, the velocity and inertia of both streamflow and debris are more of a hazard than water inundation. Unfortunately, flood- and debris-generation processes and magnitudes of flooding from small, steep drainage basins are poorly documented relative to larger streams of much flatter gradient.

Purpose and Scope

This report and the related map (Meyer and Berger, in press) describe and delineate approximate zones of potential flooding and debris hazards for the area shown on the Genoa 7-1/2-minute quadrangle (fig. 1). Previous maps and related reports in this series have documented flood and related debris-flow hazards for the Washoe City, Carson City, Las Vegas SW, Las Vegas SE, and South Lake Tahoe 7-1/2-minute quadrangles (Glancy and Katzer, 1977; Katzer, 1981; 1986; Katzer and Schroer, 1981; Katzer and Squires, 1984; Katzer and Glancy, 1978; 1986). In addition to delineating areas of potential debris-movement hazard, those reports list estimated magnitudes of floods having 10-, 25-, 50-, or 100-year recurrence intervals for principal streams within the 10 quadrangles. As discussed later, in small, steep drainage basins, such as those along the east front of the Carson Range in the Genoa quadrangle, methods for determining the magnitude of flow for an event with a given recurrence interval may not be accurate, and flood-related hazards commonly are only loosely related to discharge magnitude. For these reasons, flow magnitudes associated with various recurrence intervals for given drainage basins are presented in this report, but were not delineated on the companion map (Meyer and Berger, in press). Other methods used to identify and delineate flood and debris hazards included aerial photographic mapping of alluvial fans, characterization of debris particle sizes, field mapping and interpretation of debris deposits, and approximate dating of debris on the basis of tree and lichen growth. Field mapping was done between August and October 1988.

The emphasis of this report is on streams that are small (drainage area less than 4 mi^2) and steep (gradient greater than 0.05 ft/ft). Larger streams within the study area have been studied under the authority of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 (Federal Emergency Management Agency, 1986a; 1986b). Those studies delineated the 100- and 500-year flood boundaries for the Carson River and selected low-gradient reaches of tributaries to the Carson River and to Clear Creek. (A 100-year flood is a flood with a probability of occurrence of 0.01 in any given year.) Larger streams pose hazards of inundation, minor deposition of fine-grained sediment, and erosion of roadways. Areas of potential flooding along these streams, as shown on the FEMA (Federal Emergency Management Agency) maps, are represented on the companion map report for this study. Areas of inundation by a 500-year flood are also presented on the companion map along the alluvial fans of Genoa, Schoolhouse, and Sierra Canyons (Federal Emergency Management Agency, 1986b).

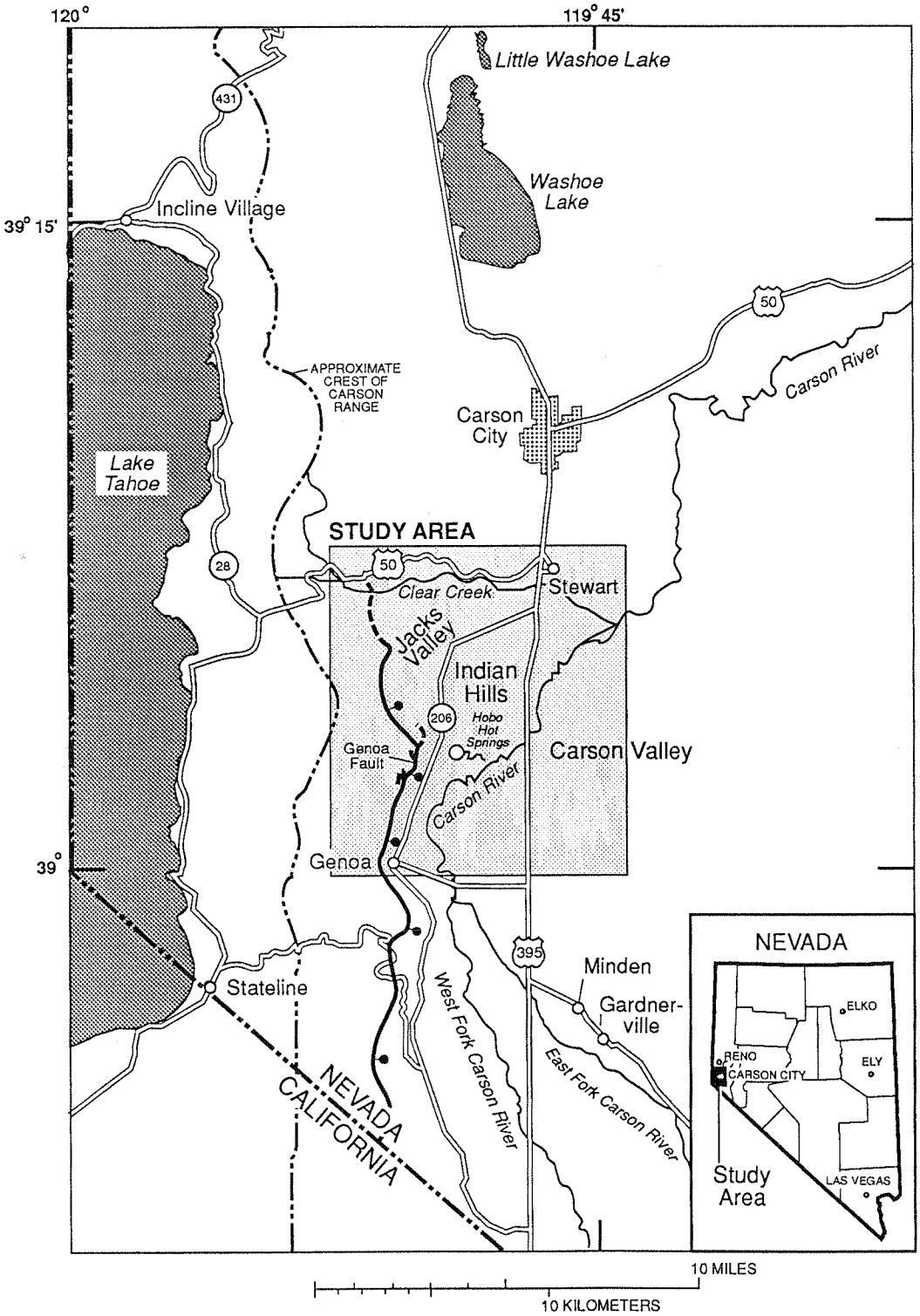

FIGURE 1.--Location of the study area.

Types of Flooding, Debris Movement, and Associated Hazards in the Study Area

Floods in the Great Basin in general, and the Carson Range in particular, are caused by: (1) snowmelt, (2) frontal-storm rainfall, (3) frontal-storm rainfall on snow, and (4) convective-storm rainfall during localized thunderstorms (Burkham, 1988, p. 5). Most flooding along major streams results from causes (1) and (3), whereas flooding along smaller streams results primarily from causes (3) and (4) (U.S. Department of Agriculture, 1973; Goodwin, 1977; Federal Emergency Management Agency, 1986a; 1986b).

Flooding along the Carson Range front presents three types of hazards: coarse-grained debris hazards, fine-grained debris hazards, and floodwater inundation. Coarse-grained debris hazards include those resulting from both debris flows and debris-laden streamflows. Debris commonly includes cobbles and boulders (grain diameter greater than 2.5 in.). These flows are capable of causing extensive damage to structures, including houses, and can fatally injure anyone caught in a flow. Debris flows, in particular, can destroy buildings in their paths. Extremely rapid velocities that commonly characterize these flows make them difficult to escape.

Fine-grained debris hazards and flood-water inundation present more of a nuisance than a threat to personal safety. Clear Creek and smaller basins along the northern part of the study area drain granitic rock terrain, and would transport mainly abundant fine-grained sediment (sand and pebble gravel) not large enough to present an impact threat to structures. Deposition of this material can destroy range and cropland and commonly covers roads to depths of a few feet. The primary threat to structures from these flows results from erosion or partial burial. Alluvial fans dominated by sand and pebble gravel erode rapidly, and flood-charged channels can shift laterally on the fan surface in a period of minutes. Although debris flows are infrequent at most sites, they present significant hazards. Several debris flows have occurred in first-order tributaries to trunk canyons in the study area during the last 100 years. Debris-flow deposits are present on most of the alluvial fans at the mouths of canyons draining metavolcanic terrain, and at least one of these deposits is probably less than 100 years old.

Debris flows are intermediate in composition between water flows and landslides and possess physical properties that differ from either of the two "end members." Most significant among the properties of debris flows are shear strength and high sediment concentration (Johnson, 1970; Pierson and Costa, 1987). In water flows, sediment concentrations can be as great as 40 percent, by weight, and sediment is transported by a combination of turbulence, shear, lift, drag, and electrostatic force. Solid particles and water move as two distinct phases. Hyperconcentrated flows are intermediate between water flows and debris flows, and their sediment concentration ranges from 40 to 70 percent, by weight. Deposits from hyperconcentrated flows were not observed during mapping in the Genoa quadrangle. Debris flows have sediment concentrations between 70 and 90 percent, by weight, and sediment is transported by a combination of cohesion, buoyancy, dispersive stress, and structural support. Solid particles and water move together as a single body (Costa, 1988). In other words, debris flows can support, and thus transport, large boulders and other debris within or on top of the flow, in a manner similar to gravel being supported in wet concrete.

Because of high velocities and high sediment concentrations, debris flows attain considerable inertia, capable of destroying structures and vegetation along their paths. The ranges of attainable velocity and volume of sediment transported by water floods and debris flows are generally similar; however, maximum velocities of water floods in the streams in the Genoa quadrangle are probably less than those of debris flows.

Debris flows can stop abruptly when channel slope decreases or confining-channel banks change to broad valley floors or alluvial fans, leaving lobate deposits, or they can become diluted as sediment is deposited along the channel, and continue downstream as water flows. Debris flows can deposit many acre-feet of sediment within a period of a few minutes, whereas water flows from comparable storms may take several days to deposit the same amount of sediment. Along mountain fronts, debris flows are commonly the primary depositional process building alluvial fans (Beaty, 1974).

A debris flow generated by a thunderstorm in the Lake Tahoe drainage, northwest of the Genoa quadrangle, was documented by Glancy (1969). Similar flows occur sporadically throughout Carson Valley and adjacent areas (U.S. Department of Agriculture, 1973; Goodwin, 1977), but no comprehensive review or documentation exists.

DESCRIPTION OF THE STUDY AREA

This study examines the area included in the Genoa, Nev., 7-1/2-minute quadrangle produced by the U.S. Geological Survey (fig. 1). The study area contains four types of terrain: (1) steep mountain-range front, (2) dissected pediment hills, (3) river flood plain, and (4) alluvial fans.

Geology

The Carson Range, a fault-block chain of the Sierra Nevada, is composed of Triassic metavolcanic and Cretaceous granodioritic rocks, with minor exposures of Triassic schist and Jurassic diorite (Pease, 1980). These lithological distinctions are important in determining flood and debris hazards. Granitic rocks (granodiorite and diorite) weather to sand- and gravel-size material that is readily transported by fairly minor flows and has rapid infiltration rates. Metamorphic rocks (metavolcanic rocks and schist) weather to form sediments that range from large boulders (1 foot or more in diameter) to silt- and clay-size material, but with relatively little sand- to cobble-size material; water infiltrates into this material slowly. The boulders are moved only by infrequent high flows.

The Genoa fault bounds the Carson Range from the vicinity of Clear Creek, in the northwest part of the study area, southward to, and beyond, the town of Genoa (Pease, 1979). Pease estimated the age of the fault scarp at 200 to 1,000 years. Eastward from the fault to the Carson River flood plain, the area consists almost entirely of coalescing alluvial-fan deposits of Holocene age. Soils formed on the surface of the distal parts of the fans are about 5,000 years old (Pease, 1980). Most of the alluvial fans near the mouths of basins greater than 0.2 mi^2 in the area are mantled by historical deposits (less than about 100 years old) at their apexes.

Jacks Valley is a small graben, bounded on the west by the Genoa fault and the Carson Range, and on the east by several normal faults and the Indian Hills (sec. 14 and adjacent parts of sec. 13, 23, and 24, T. 14 N., R. 19 E.; Pease, 1979). The Indian Hills area is underlain by pediment deposits of sand and gravel of late Tertiary to early Pleistocene age and minor exposures of Tertiary metavolcanic rocks and Tertiary and Quaternary alluvium (Pease, 1980). Soils are well developed on the Indian Hills, and the basins draining the hills are gently sloping.

The Carson River flood plain is underlain entirely by Holocene-age sand and silt alluvium (Pease, 1980). Deposits in the area southeast of the river are older and at higher elevations than the flood-plain alluvium.

Few geologic tools exist for establishing precise ages of historic deposits on alluvial fans in the Genoa quadrangle. Trees, often used for dating recent alluvial landforms (Hupp, 1984), are generally sparse or absent from the alluvial fans. Where trees are present, none presumably are older than about 100 years, because nearly all trees in the region were cut during the late 1800's. In canyons upstream from the Genoa fault, young trees (younger than about 50 years) can be used for dating some small debris-flow deposits. However, none of these small deposits relate directly to deposits on alluvial fans downstream from the fault. Lichens have become established on 100-year-old gravestones in the Genoa and Jacks Valley Cemeteries, but not on younger gravestones. Therefore, as an approximate indication of age, we assume that alluvial fan deposits containing stones with well established lichen growth are at least 100 years old, and deposits without lichens are less than 100 years old.

Sizes and Slopes of Drainage Basins

Drainage basins along the Carson Range front in the Genoa quadrangle are generally small and steep (table 1). Drainage basins exclusively in granitic-rock terrain are not as steep as those that contain exposures of metavolcanic rocks. Valley sideslopes in metavolcanic terrain are commonly very steep, and small debris flows sometimes occur in swales and first-order tributaries. The Carson River and Clear Creek drainage basins are steep for their size, but not as steep as most of the smaller basins in the study area. The Carson River flood plain is nearly flat. Indian Hills drainage basins are small but relatively gently sloping.

CHARACTERISTICS OF SPECIFIC FLOOD-PRONE TERRAINS

Flood-related hazards vary as a result of the magnitude of flow expected, the timing and energy of the flow, and the size and amount of transported debris. These factors can be generalized for individual types of terrain such as alluvial fans, mountain stream channels, hills, and flood plains of large rivers.

Alluvial Fans

Alluvial fans are fan-shaped deposits that form where sediment-laden, steep, mountain streams emerge at canyon mouths onto adjacent valley floors. Individual fans generally are cone-shaped, but adjacent fans along mountain fronts, such as that of the Carson Range, may coalesce to form a bajada. A fan apex is the upstream part of an alluvial fan, where a canyon mouth begins to widen abruptly and the stream gradient begins to decrease.

Geologic Controls

The northern end of Jacks Valley drains granitic-rock terrain exclusively. Near the mountain front, sand and gravel fans coalesce to form a bajada 1,000 to 1,500 ft wide that is susceptible to fine-grained debris movement, sheet flooding, and erosion and deposition. One well-defined fan, at the mouth of Water Canyon, is mostly inactive. Downstream from the bajada, channel slopes are too gentle and flow is too poorly channelized to allow significant sedimentation. Shifting channels on the bajada may cause flood-prone areas (delineated on the Federal Emergency Management Agency maps) to migrate.

TABLE 1.--Geologic and physiographic characteristics of selected drainage basins

Basin name.--Location of unnumbered basins is indicated in table 2 (referenced to map number). Basins are listed and numbered in north-to-south sequence.
Map number.--See Meyer and Berger (in press).
Rock type.--Abbreviations: G, granitic rocks (Cretaceous granodiorite, Jurassic diorite); M, metamorphic rocks (Triassic metavolcanic rocks and schist).
Drainage-basin area.--Tributary area upstream from range-front canyon mouth.
Drainage-basin relief ratio.--Equals maximum relief in basin, divided by drainage-basin length.
Alluvial-fan area.--Listed for fans having identifiable boundaries on aerial photographs.
Alluvial-fan slope.--Measured from apex to toe of fan; where fans were not apparent on aerial photographs, distance of slope measurement below canyon mouth is determined from ratio between drainage area and apex-to-toe distance for basins having alluvial fans.

[Symbol: --, information not available]

			Drainage basin		Alluvial fan	
Basin number	Map number	Rock type	Area (square miles)	Relief ratio (feet per foot)	Area square miles	Slope (feet per foot)
Carson River	1	G,M	[a]876.	--	--	--
Clear Creek	2	G	[b]15.5	0.15	--	--
Unnamed	3	G,M	1.96	.13	--	0.04
Unnamed	4	G	.292	.20	--	.04
Unnamed	5	G	.308	.11	0.033	.06
Bennett Canyon	6	G	.781	.38	--	.05
Chedic Canyon	7	G	.810	.37	--	.03
Unnamed	8	G	.177	.36	--	.06
Unnamed	9	G	.307	.42	--	.07
Water Canyon	10	G,M	2.67	.30	.14	.10
Unnamed	11	G	.267	.47	.071	.11
Unnamed	12	G,M	.239	.49	.051	.13
Unnamed	13	M	.177	.51	.22	.14
James Canyon	14	M	2.08	.23	1.02	.12
Unnamed	15	M	.056	.60	.070	.14
Unnamed	16	M	.068	.59	.022	.21
Unnamed	17	M	.108	.58	--	.32
Childs Canyon	18	M	.444	.49	.011	.16
Adams Canyon	19	M	.440	.48	.20	.17
Unnamed	20	M	.279	.47	--	.13
Sierra Canyon	21	G,M	3.17	.30	.17	.08
Schoolhouse Canyon	22	G,M	.442	.40	--	.14
Genoa Canyon	23	G,M	2.20	.36	--	.10

[a]Measured at gage near Carson City.
[b]Measured at former gage 3 miles upstream from mouth.

The area from Water Canyon south to, and including, the town of Genoa is characterized by alluvial fans downstream from metavolcanic and other rocks. The hazard from coarse-grained-debris movement at the apexes of these fans is great. Some of the channels are recently incised across the Genoa fault and show evidence of recent, coarse-debris-laden flows (Sierra and Schoolhouse Canyons, and unnamed basins 11, 12, and 16; table 2 lists the location of unnamed basins). However, channel filling or bank erosion could cause debris movement anywhere on the apexes of these fans. On other fans, channels are too deeply incised into the fan deposits for normal erosion and deposition to cause channel relocation (Childs Canyon and unnamed basins 13 and 15). Several channels are not incised at the apexes of their fans (Genoa, Adams, and James Canyons). These have a higher probability of channel relocation. James Canyon has an alluvial fan that is large in proportion to its drainage area and that may be inherited from different climatic or geologic conditions in the past. Nonetheless, recent sediment movement has occurred over much of the fan, probably as a result of local erosion and deposition of surficial material.

TABLE 2.--Location of range-front canyon mouths for selected unnamed drainage basins

Map number (table 1)	Canyon mouth
3	NW1/4 SW1/4 sec. 7, T. 14 N., R. 20 E.
4	SE1/4 NW1/4 sec.12, T. 14 N., R. 19 E.
5	center, sec.10, T. 14 N., R. 19 E.
8	SE1/4 NE1/4 sec.16, T. 14 N., R. 19 E.
9	NE1/4 SE1/4 sec.16, T. 14 N., R. 19 E.
11	NE1/4 NE1/4 sec.21, T. 14 N., R. 19 E.
12	SE1/4 NE1/4 sec.21, T. 14 N., R. 19 E.
13	NE1/4 SE1/4 sec.21, T. 14 N., R. 19 E.
15	NW1/4 SE1/4 sec.27, T. 14 N., R. 19 E.
16	SW1/4 SE1/4 sec.27, T. 14 N., R. 19 E.
17	NE1/4 NW1/4 sec.34, T. 14 N., R. 19 E.
20	SE1/4 NE1/4 sec. 4, T. 13 N., R. 19 E.

Fan Size and Slope

Individual alluvial fans in the Genoa quadrangle are small due to the relatively small size of the associated drainage basins. Thus, the bajada along the Carson Range front is narrow (1,000 to 7,000 ft wide), but extends from the north end of Jacks Valley to beyond the southern end of the study area (Meyer and Berger, in press).

Fans at the mouths of canyons draining granitic-rock terrain tend to have relatively gentle slopes (table 1) and, in Jacks Valley, commonly support stands of large pine trees. Thus, they are difficult to recognize on vertical aerial photographs or topographic maps. Because of the semi-circular shape of the north end of Jacks Valley, where these canyons terminate, the alluvial fans tend to coalesce, forming a broad sandy flat on which deposits from one canyon are indistinguishable from those of adjacent canyons only a few hundred feet downgradient from the fan apexes.

Alluvial fans at the mouths of canyons draining metavolcanic-rock terrain are significantly steeper and more conical than those draining granitic terrain. These deposits extend 500 to 7,000 ft from the mouths of canyons. They are visually obvious features on aerial photographs and topographic maps.

Grain-Size Characteristics

The grain size of sediments on alluvial-fan surfaces in the Genoa quadrangle area is mainly a function of the lithology of the source rock, because all of the drainage basins are too small to allow for any appreciable sorting during transport.

The grain-size distributions of alluvial-fan deposits at mouths of basins draining granitic-rock terrain are bimodal; that is, coarse grains and fine grains are abundant but grains of intermediate size are not. Large, rounded granitic boulders are scattered over the surface of most of the fans in northern Jacks Valley. These large boulders (diameter up to 5 ft) are subrounded to rounded and support abundant lichen growth on their surfaces. Some of the large boulders, on the inactive fans, clearly were deposited at least several hundred years ago, perhaps as long ago as the Pleistocene Epoch.

Streambeds on fans at the mouths of canyons draining granitic terrain consist almost exclusively of sand and gravel (grain diameter less than 2.5 in.). Where recent stream incision exposes vertical sequences of stream deposits, bedding is commonly planar and has lenses of gravel. Rare large boulders in modern stream beds otherwise composed of sand and gravel probably result from mass wasting of terraces and hillslopes. Alluvium of recent age includes large boulders only along steeper stream reaches, upstream from canyon mouths.

Fans at the mouths of basins draining metavolcanic and mixed metavolcanic and granitic terrain consist of sediments that are poorly sorted, and the grain size of the deposits ranges from silt to large boulders. Where exposed in vertical cuts, deposits from individual flow events commonly are massive and poorly sorted, which is typical for debris-flow deposits. Interspersed between these massive deposits are lenses of better sorted cobbles and boulders, typical of streamflow deposits. Boulders and cobbles are mainly angular to sub-angular, indicating limited transport within stream channels.

The surfaces of fans at the mouths of canyons draining metavolcanic and mixed-lithology terrains are covered with scattered linear ridges that radiate from the fan apex and are composed of large boulders. Some of these surficial deposits are devoid of a fine-grained matrix, and some are similar, in the lack of size sorting, to the massive buried deposits exposed in vertical cuts. Most of the deposits devoid of a matrix have lichens growing on the surficial boulders. Some of the poorly sorted deposits have lichens, and others do not. The linear deposits are interpreted to be debris-flow levees because they are similar in plan form to modern debris-flow deposits. Fine-grained material apparently has been winnowed from the matrix-free deposits.

Relation of Fans to the Genoa Fault

The apexes of all of the recognized fans are at or near the Genoa fault (see Fig. 1 and Meyer and Berger, in press). Some of the apexes extend several hundred feet upstream from the fault. Four situations were observed: (1) Some small fans were cut by the fault and the channels, where present, are offset (for example, unnamed basin 17; table 2) (2) Some small and intermediate fans were cut by the fault, and single, well-defined channels have incised through the fault scarp during the last 100 years. Generally, the incised channels extend both downstream and upstream from the fault scarp. Upstream, the degree of incision of some channels is limited by bedrock outcrops. Downsteam, the incised channels grade onto the fan surface (for example, unnamed basin 13; table 2) (3) Some intermediate and large fans were cut by the fault, and single, well-defined channels were incised through the fault scarp more than 100 years ago (for example, Water Canyon). Generally,

well-defined flood plains are inset into the fans and extend both upstream and downstream from the scarp. The fans exist as terraces above the incised channels and their flood plains (4) Some fans of all sizes show no trace of the fault, and the channels show signs of recent debris movement (for example, James Canyon).

The four situations can be used to date fault movement relative to flood occurrence, but because of the lack of datable material and the probabilistic nature of flood frequency, no range of dates can be assigned to either the latest flow or the latest fault movement. Small basins in this climate infrequently generate streamflow capable of regrading a channel or fan offset by a fault. The offset fans that do not have channels incised through the fault scarp drain small basins. These basins probably have not generated flows capable of eroding a stream channel in response to the knickpoint formed by the fault scarp.

One fan (unnamed basin 13; table 2) illustrates how the channels may regrade across the fault scarp. The channel is incised to bedrock at the fault scarp, and is 10-15 ft below the alluvial-fan surface. On top of the north bank, on the alluvial-fan surface just downstream from (east of) the fault scarp, a recent splay deposit of boulders forms a small berm. The boulders have a maximum diameter of 3 ft, and a mean diameter of 1-8 in. The deposit is 3-4 ft deep, about 25 ft wide, and extends several hundred feet downstream from the fault scarp. The splay deposit is indistinguishable from bed material in the channel; both are moderately sorted, devoid of fine-grained sediment, have angular to sub-angular grains, and are completely unvegetated.

Prior to formation of the fault scarp, flow probably was unchannelized, and spread across the fan. Fans at the mouths of basins comparable in size to unnamed basin 13 generally do not have channels. Following formation of the fault scarp (dated as 200 to 1,000 years old by Pease [1979]), the next large flow immediately began to incise a channel at the knickpoint formed by the fault scarp. Sediment eroded upstream of the knickpoint spread out across the fan downstream from the knickpoint to form the deposit now occupying the top of the north bank. As incision progressed upstream, more of the flow that had previously spread across the fan was concentrated into the single, incised channel. With increased concentration of flow, the channel incised below the fault scarp. Incision of channels below the reaches where flow is concentrated is well documented (Cooke and Reeves, 1976).

The above scenario produces a channel that is deeply incised, both upstream and downstream from the fault scarp. Such a deeply incised channel can contain even the theoretical maximum discharge without overtopping its banks. Thus, although a fan may have received flow within the Holocene Epoch, current conditions will not allow flow from the main channel to reach the fan apex. However, large-scale channel aggradation is still conceivable, though unlikely. Therefore, debris hazards are defined on the basis of current conditions, and coarse-grained debris movement is not considered a hazard beyond active, deeply incised channels. The term "active alluvial fan" includes areas where debris movement may be considered likely or unlikely under current conditions, but where debris movement has occurred during the Holocene Epoch. The term "inactive alluvial fan" is reserved for fans that are presumed to have followed the scenario outlined above, but appear to have stable channels (that is, no signs of recent [Holocene-age], large changes in channel elevation).

Influence of Vegetation

Many of the larger, perennial streams, especially in the metavolcanic-rock terrain, have heavily vegetated channels and flood plains in the basins upstream from the alluvial fans. Elm and quaking aspen trees are most common, but willow, cottonwood, pine, and--in a few places--cedar are also present. In granitic-rock terrain, pine trees and sagebrush are common in flood plains, but they are not as

thick as deciduous trees in the metavolcanic terrain. The dense canyon-bottom vegetation retards movement of both streamflow-transported sediment and debris flows. In Schoolhouse Canyon, deposits of water-lain boulders from the flow of August 1971 (see following section) are as thick as 4 ft behind living elm trees. In canyons where debris flows extend into the channel, debris-flow material is deposited on and around canyon-bottom trees.

Canyon-bottom vegetation has the effect of storing sediment and reducing debris movement during most floods. However, during extreme floods that approach the maximum discharge (table 3), the stored sediment may pose a greater hazard than if the channels were barren. When enough material accumulates in canyons to increase the gradient, the sediments in the entire canyon bottom can be swept out during an extreme flood, in spite of the stabilizing effect of the vegetation.

TABLE 3.--Estimated discharge for various recurrence intervals and estimated maximum discharge for selected drainage basins

Basin name.--Location of unnamed basins is listed in table 2 (referenced to map number; Meyer and Berger, in press). Basins are listed in north-to-south sequence.
Drainage area.--Tributary area upstream from range-front canyon mouth.
Estimated discharge.--Q_{10}: discharge for flow with 10-year recurrence interval (probability of exceedance of 0.1 in any given year), from equations presented by Christensen and Spahr (1980). Q_{50}: 50-year recurrence interval. Q_{100}: 100-year recurrence interval. Maximum: interpolated from envelope curve of maximum measured discharges from rainfall runoff floods in conterminous United States (Costa, 1987, p. 317).

[--, information not available]

Basin name	Map number (table 1)	Drainage area (square miles)	Estimated discharge (cubic feet per second)			
			Q_{10}	Q_{50}	Q_{100}	Maximum
Carson River[1]	1	876	1,000	2,300	30,000	--
Clear Creek[2]	2	15.5	9.8	33	260	63,000
Unnamed	3	1.96	67	240	380	17,000
Unnamed	4	.292	19	79	130	2,700
Unnamed	5	.308	20	84	140	2,900
Bennett Canyon	6	.781	30	120	180	8,100
Chedic Canyon	7	.810	30	110	180	8,500
Unnamed	8	.177	13	56	93	1,300
Unnamed	9	.307	16	67	110	2,900
Water Canyon	10	2.67	64	220	330	20,000
Unnamed	11	.267	14	59	96	2,400
Unnamed	12	.239	13	55	90	2,000
Unnamed	13	.177	11	49	81	1,300
James Canyon	14	2.08	54	190	290	17,000
Unnamed	15	.056	6.0	28	49	--
Unnamed	16	.068	--	--	--	--
Unnamed	17	.108	8.7	39	66	--
Childs Canyon	18	.444	20	79	130	4,600
Adams Canyon	19	.440	20	76	120	4,600
Unnamed	20	.279	16	65	110	2,500
Sierra Canyon	21	3.17	72	240	370	23,000
Schoolhouse Canyon	22	.442	21	84	140	4,600
Genoa Canyon	23	2.20	58	200	310	18,000

[1]Data are for gage near Carson City. Recurrence interval discharges are computed from published streamflow records.
[2]Data are for former gage site 3 mi upstream from mouth. Recurrence interval discharges are computed from published streamflow records

Mountain Stream Channels

Most of the stream channels in the Carson Range front, upstream from alluvial fan apexes, transport coarse-grained debris (diameter greater than 2.5 in.) along their beds during periods of high flow. Many of these streams are incised into alluvial valley fills, and are therefore prone to bank erosion. Except at culverts and old impoundments (circa late 1800's), overbank flow is rare. Most swales and first-order tributaries within the Carson Range are not delineated by blue drainage lines on topographic maps, yet they pose a hazard from hill-slope failures and debris flows that has not been quantified. In general, the hazard is greater in metavolcanic and mixed-lithology terrain than in granitic-rock terrain.

The mainstem of Clear Creek has a gentler slope and wider valley bottom than other mountain stream channels. Debris movement there is thus limited to sand and gravel.

The extent of the 100-year flood plain along Clear Creek was mapped earlier (Federal Emergency Management Agency, 1986a; 1986b); our investigation did not reevaluate the FEMA interpretations. However, the FEMA study did not assess debris hazards, and the area mapped as being within the 100-year flood plain is susceptible to dominantly fine-grained sediment movement. Debris movement along Clear Creek is mainly limited to sand and gravel. Recent highway improvements in the headwaters of Clear Creek have accelerated fine-grained sediment production, but recent movement of this sediment beyond the base of hillslopes is not evident.

Indian Hills

Stream channels on all flanks of Indian Hills have relatively gentle slopes and transport dominantly sand-sized debris. Many reaches of these channels are incised, channelized, or lined, and fine-grained debris movement is expected to be contained within stream channels. The headwater reach of the largest basin draining Indian Hills (unnamed basin 3; table 2) is deeply incised into partially indurated sands and gravels. Severe erosion, including channel widening and tributary headcutting, can be expected there during high flow.

Floor of Carson Valley

The flood plain of the Carson River throughout the Genoa quadrangle area is broad and flat. Local relief across the 3-mi-wide flood plain is less than 10 ft. Debris deposited by Carson River floodwater is mainly fine sand and silt.

FLOODING HISTORY

Carson River Flooding

The history of flooding on the Carson River is well documented from a social perspective by the U.S. Department of Agriculture (1973; see table 4). On the average, overbank flooding occurs about once every 5 years (Federal Emergency Management Agency, 1986b). Recorded discharges greater than 9,000 ft^3/s (recurrence interval of 10 or more years) consistently have caused flooding of a magnitude to hinder everyday life. No direct flood-caused deaths as yet have been reported, although traffic accidents at damaged roads and bridges are common during floods. Sufficient warning usually is available to permit evacuation of people and livestock from ranches on the flood plain. Until recently, memories of past floods deterred construction in this vulnerable area.

TABLE 4.--Date and magnitude of floods on the Carson River

Period of flooding.--From U.S. Department of Agriculture (1973) and Pupacko and others (1988).
Date of peak.--Where peaks occurred on different days at different stations, date of peak is given for Carson River near Carson City (station 10311000).
Peak discharge.--Gaging stations: 10309000, East Fork Carson River near Gardnerville, Nev.; 10310000, West Fork Carson River at Woodfords, Calif.; 10311000, Carson River near Carson City. Peak discharges from Butler and others (1966), U.S. Geological Survey (1941, p. 99), and Pupacko and others (1988).
Recurrence Interval.--Estimated for peak discharge at Carson City gage (Interagency Advisory Committee on Water Data, 1982).

[Symbol: --, information not available]

Period of flooding		Date of peak	Peak discharge at indicated gaging station (cubic feet per second)			Recurrence interval (years)
Year	Date		10309000	10310000	10311000	
1852	Dec. 24-30	--	--	--	--	--
1861-62	Dec. 20-Jan. 2	--	--	--	--	--
1867-68	Dec. 20-Jan. 2	--	--	--	--	--
1874	Dec. 20-29	--	--	--	--	--
1875	Jan. 16-21	--	--	--	--	--
1886	Jan. 20-26	--	--	--	--	--
1889	Jan. 15-Feb. 1	--	--	--	--	--
1889	Mar. 1-June 15	--	--	--	--	--
1907	Mar. 16-20	--	--	--	--	--
1909	Jan. 12-15	--	--	--	--	--
1928	Mar. 24-30	Mar. 26	2,570	--	--	--
1937	Dec. 9-13	Dec. 11	10,300	3,500	--	--
1938	Mar. 11-12	--	--	--	--	--
1943	Jan. 20-23	Jan. 22	5,420	--	8,500	9
1950	Jan. 13-21	--	--	--	--	--
1950	Nov. 10-20	Nov. 22	12,100	4,730	15,500	25
1950	Dec. 6-10	Dec. 4	6,320	3,400	11,300	14
1955	Dec. 18-23	Dec. 24	17,600	4,810	30,000	100
1963	Jan. 29-Feb. 2	Feb. 1	13,400	4,890	21,900	50
1986	Feb. 15-23	Feb. 18	7,380	551	13,200	18

Carson Range Flooding

Available historic and geologic evidence indicates that flood and debris hazards exist in Carson Range drainage basins under current climatic conditions. Historical evidence is biased toward the Carson River, but flooding and, especially, debris movement has been significant on alluvial fans at the mouths of small, steep drainage basins west of the river.

Documented Floods Prior to 1970

Flooding from streams in the Genoa quadrangle that drain the Carson Range is best documented for the town of Genoa (U.S. Department of Agriculture, 1973; Goodwin, 1977). Few floods have been recorded for the sparsely populated northern part of the area. On January 26, 1886, rain on snow produced flooding along most range-front streams from south of Genoa to Carson City. Many roads were washed out, and sand and gravel were deposited in buildings and over fields in Genoa. During the winter and spring of 1889, snowmelt from severe winter storms caused flooding along the East and West Forks and the mainstem of Carson River, and a dam break in Genoa Canyon caused flooding in Genoa. On July 24, 1891, a thunderstorm generated a debris-laden flow that destroyed some buildings and deposited sand, gravel, and boulders throughout Genoa (Genoa Weekly Courier, 1891, p. 1).

No flooding along streams draining the Carson Range after 1900 were documented by either Goodwin (1977) or the U.S. Department of Agriculture (1973). If flooding had occurred in the Genoa area during this seven-decade period, it probably would have been recorded; whereas, flooding along the northern part of the Carson Range in the study area might not have been recorded.

Flood of August 5, 1971

Two recent floods did not affect the town of Genoa to the reported extent of the 19th-century floods, but were studied in greater detail. On August 5, 1971, one of a series of thunderstorms throughout western Nevada was centered over Schoolhouse and Sierra Canyons. A resident of Genoa measured 3.5 in. of rainfall during a 58-minute period (P.A. Glancy, U.S. Geological Survey, written commun., 1988). A peak discharge of 340 ft^3/s from Sierra Canyon was measured by indirect methods (Moosburner, 1978, p. 77; drainage area 3.1 mi^2 where the measurement was made). This flow is equivalent to about 110 $(ft^3/s)/mi^2$, and has a probability of being equalled or exceeded of about 0.01 in any given year; that is, it represents a 100-year flood (Christensen and Spahr, 1980, p. 7). Two separate estimates of peak flow from Schoolhouse Canyon (drainage area 0.4 mi^2) were 500 to 1,000 ft^3/s, and 1,250 to 2,500 $(ft^3/s)/mi^2$. The peak discharge from Schoolhouse Canyon far exceeds the predicted 100-year flood for a drainage basin of this area and altitude in Nevada. Sediment as large as boulders was deposited on the alluvial fan along the stream channel of Schoolhouse Canyon. During the same storm, a debris flow was generated in a small, unnamed basin 0.7 mi south of Genoa; debris as deep as about 8 ft buried about 100 ft of State Highway 206 (P.A. Glancy, U.S. Geological Survey, written commun., 1988).

Flood of February 19, 1986

On February 19, 1986, widespread rainfall generated minor flooding throughout western Nevada. At an unnamed stream that crosses Highway 206, 1 mi north of Hobo Hot Springs (drainage area at least 5.5 mi^2), measured peak discharge was 300 ft^3/s, equivalent to a peak unit discharge of less than 55 $(ft^3/s)/mi^2$. This site is more than a mile from the mountain front, and peak discharge was probably attenuated as the flow crossed Jacks Valley. Peak unit discharges considerably greater than this were probably generated in many of the small, steep, range-front basins, but direct or indirect measurements of flow were made not in 1986.

Costa (1983) presents a method for estimating discharge from the size of sediment moved by a flow. This method is not calibrated for slopes greater than 0.10 ft/ft, whereas most of the channels draining the Carson Range have slopes exceeding 0.10 (channel slopes are locally much greater than the basin-wide relief ratio listed in table 1). Extrapolation of the method to a slope of 0.20 ft/ft, at an unnamed stream 0.6 mi south of Water Canyon (unnamed basin 12; table 2), draining an area of 0.24 mi^2, gives a discharge of 50 ft^3/s, or about 200 $(ft^3/s)/mi^2$. This value must be considered merely an estimate because of the uncertainty of several assumptions: (1) the largest boulders measured were loosely packed or deposited on top of other alluvium and were assumed, but not known, to have moved recently; larger boulders in the channel were tightly packed in alluvium and colluvium, and were assumed to have been derived from mass wasting of bank material or from previous flows; (2) the flow that moved the boulders was assumed to have occurred in February 1986, because this storm was the most recent to produce flows of appreciable magnitude in the area; and (3) the above-mentioned extrapolation is beyond the range of data used to develop Costa's method. These uncertainties would apply to most of the steep mountain-front basins studied, so similar analyses were not undertaken in other basins.

Several small (less than 0.1 mi^2) basins tributary to Sierra, Genoa, and James Canyons contain very recent debris-flow deposits. These flows are assumed to have resulted from the February 1986 storm. The flows commonly originated in shallow soil and colluvium in swales or small channels on steep canyon walls, and some of them originated below bedrock cliffs. These debris flows were not mobile enough to flow beyond the base of the mainstem-canyon walls. The deposits are lobate, massive, and poorly sorted sand and gravel, and they commonly fill one side of the canyon floor to which they are tributary. Where the deposits are found in pine forests, they are covered only with fresh layers of pine needles, whereas adjacent slopes are covered with decayed needles; the deposits, therefore, are probably less than 3 years old. Most of the debris flows halted before entering trunk streams. However, a debris flow tributary to James Canyon followed an old logging road parallel to the trunk stream, then entered the stream and traveled about 200 ft before becoming diluted by streamflow. This flow apparently did not remove any canyon-bottom vegetation.

At a Jacks Valley ranch, the stream draining a small (about 0.1 mi^2) unnamed canyon (N1/2, NW1/4, sec. 16, T. 14 N., R. 19 E.), 0.2 mi south of Chedic Canyon, incised 5 ft during the February 1986 storm. The water rapidly eroded sand and gravel from the interfan area and deposited it in a subjacent corral and across a gravel road. The road, which runs along the distal margin of alluvial fans from Bennett and Chedic Canyons, was buried by up to 2 ft of sand from these and other unnamed streams.

FLOOD- AND DEBRIS-HAZARD ZONES IN THE GENOA QUADRANGLE

Techniques Used to Delineate Hazard Zones

As a rough estimate of the magnitude of potential flooding, standard flood-hazard estimation techniques use peak-discharge data and easily obtainable drainage-basin characteristics to determine least-squares regression to estimate peak discharge of a given recurrence interval (Christensen and Spahr, 1980). The best characteristics generally are drainage area, latitude, and mean basin altitude. In Nevada, these estimates commonly have standard errors of 80 to 120 percent (Christensen and Spahr, 1980). Estimated 10-, 50-, and 100-year peak flows for basins in the study area are listed in Table 3. An estimate of the maximum discharge that can be expected from a drainage basin (table 3) was obtained from an envelope curve of the maximum measured discharge in the conterminous United States for drainage basins of a given size (Costa, 1987).

The storms and resulting flows on August 5, 1971, and February 19, 1986, illustrate some of the difficulties encountered in applying the results of standard flood-hazard techniques (table 3) to alluvial fans at the mouths of small, steep mountain streams. When floods are caused by localized, intense thunderstorms, such as the storm of August 5, 1971, the assumption that peak discharge of a given probability of occurrence is positively related to drainage-basin area, mean altitude, and latitude may not be valid. Attenuation of a flood peak downstream from a small storm cell causes the peak discharge and the peak unit discharge to decrease in a downstream direction. Because maximum intensities of rainfall during a storm of that type can be approximately equal for different altitudes and latitudes (Wolman and Gerson, 1978), relations between peak discharges of floods and altitude or latitude also are suspect.

In addition to the problem of determining a discharge with a given probability of occurrence, many debris hazards are independent of the magnitude of water discharge. For example, the debris flow south of Genoa on August 5, 1971, was probably produced by less water flow than was experienced at either Schoolhouse or Sierra Canyons, yet it presented a greater hazard.

For these reasons, a less quantitative, but hopefully more accurate approach was taken during this study. Alluvial fans and drainage basins were mapped to determine (1) the limits of modern debris movement (within the last 100 years; age estimates based on lichen establishment and tree growth); (2) the processes associated with debris movement, which are based on the particle size, sorting, and sedimentary structures of the deposits, both on alluvial fans and in the drainage basins upstream from alluvial fans, and the alluvial-fan gradient; (3) the amount and character of debris available in drainage basins feeding the alluvial fans, which is based on valley side-slope gradient, valley width, and the age and relative amount of valley fill; and (4) significant cultural and natural factors that might affect debris movement.

Classification of Hazard Zones

Flood and debris hazards are classified according to the following scheme, and hazard zones are delineated on the quadrangle map (Meyer and Berger, in press) by application of this classification:

Probable heavy debris movement.--Includes areas where (1) fast water velocities caused by steep (>0.19 ft/ft) channel slopes, (2) coarse-grained debris stored near the upstream channel, and (3) recent debris movement (within the last 50 to 100 years; grain diameter greater than 2.5 in.) indicate that a significant hazard of coarse-grained debris movement and impact exists during high flows. The debris movement includes sediment-laden streamflow and debris flow (slurries of sediment and water in which viscosity is not constant [non-Newtonian flow]). Assignment of a specific probability of occurrence to these flows is impossible because of an inadequate data base. These processes pose a significant risk to people, structures, roads, and agricultural fields.

Possible heavy debris movement.--Includes areas where location on alluvial fans indicates that, given a change in channel position, conditions listed above would apply. Sediment-laden streams frequently and rapidly shift their positions. This can be the result of rapid deposition that causes the channel to fill and spill over its banks, or of rapid erosion of the stream banks. In addition, some small alluvial fans in this classification show evidence of heavy debris movement that is probably more than 100 years old. These processes pose a significant risk to people, structures, roads, and agricultural fields.

Probable light debris movement.--Includes areas that are prone to sheet flooding and movement of fine-grained debris (grain diameter less than 2.5 in.). This classification includes three different types of areas: (1) Active alluvial fans that are composed of, and receive, debris dominated by sand and gravel; (2) the distal ends of coarse-grained alluvial fans, directly downstream from active channels, which can receive diluted runout that continues beyond the zone of heavy debris movement; and (3) the channel and flood plain of Clear Creek. Although flow velocities and debris-impact forces are not great, deposition of finer grained sediment and erosion of new channels can be rapid. These processes can damage or destroy agricultural fields, roads, and structures, but they pose minimal threat to life and limb.

Possible light debris movement.--Includes areas that are prone to sheet flooding and movement of fine-grained debris when the stream channels shift, as described in the possible heavy debris movement classification. These areas are at the distal margins of alluvial fans, but presently they are not directly downstream from active channels. These processes can damage or destroy agricultural fields, roads, and structures, but they pose minimal threat to life and limb.

Inter-fan areas.--The bajada along the eastern front of the Carson Range includes several areas where evidence of debris movement was not present, yet their location on the bajada downstream from steep drainage basins larger than about 0.1 mi^2 suggests a potential for flooding, landsliding, or debris movement. These zones were not specifically mapped. Large debris movements in these zones are possible, but unlikely.

Mountain stream channels.--Mountain stream channels are not specifically delineated on the companion flood and debris map by Meyer and Berger (in press), except on the topographic base map. Nonetheless, most of the stream channels along the Carson Range front, upstream from alluvial-fan apexes, transport coarse-grained debris (diameter greater than 2.5 in.) along their beds during periods of high flows. Many of these streams are incised into the alluvial valley fill, and are therefore prone to bank erosion. Except at culverts and old impoundments (circa late 1800's), overbank flow is rare. Most swales and first-order tributaries within the Carson Range are not delineated even on the topographic base map, yet a nonquantified hazard of hillslope failures and debris flows exists along these nonspecified channels. In general, the potential for hillslope failures and debris flows are higher in metavolcanic rock and mixed-lithology terrain than in granitic-rock terrain.

CONCLUSIONS

Debris movement on alluvial fans along the Carson Range front from south of the town of Genoa northward to Jacks Valley presents a significant hazard. On fans at the mouths of canyons draining granitic-rock terrain, at the north end of Jacks Valley, fine-grained debris presents minor hazards of personal injury, but potential rapid erosion, deposition, and channel relocation endangers structures, agriculture, and roads. Alluvial fans at the mouths of canyons draining metavolcanic-rock terrain are the sites of coarse-grained debris movement. Debris flows and debris-laden streamflows in these settings can be life threatening and present hazards to structures.

Any part of an active alluvial fan can be expected to experience flooding and erosion or deposition over periods of several centuries. During periods more commonly considered for planning purposes (100 years or less), probabilities of debris movement are highest near current stream channels. However, stream channels on alluvial fans can fill and shift rapidly and unpredictably. Thus, the possibility of flooding exists anywhere on most alluvial fans in the study area. The Carson River floods with greater regularity than any other stream in the study area (Federal Emergency Management Agency, 1986a; 1986b). Hazards on the Carson River flood plain are associated with erosion of roadways and inundation, and are not specifically addressed in this report.

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