UNIVERSITY OF NEVADA-RENO

Nevada Bureau of Mines and Geology
University of Nevada-Reno
Reno, Nevada 89557-0088
(702) 784-6691

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FLOOD AND RELATED DEBRIS-FLOW HAZARDS ALONG PRINCIPAL DRAINAGES, CARSON CITY QUADRANGLE, NEVADA

Terry Katzer and C. V. Schroer
U.S. Geological Survey

In memory of C. V. Schroer,
an outstanding hydrologist
and good friend.

Prepared cooperatively by the
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This report has been edited, reviewed,
and approved by the U.S. Geological
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ABSTRACT

Estimates of 100-year frequency floods were made and flood-prone areas are delineated for the principal drainages in the Carson City quadrangle which lies on the western edge of the Great Basin. In addition, the probable limits of the area of maximum inundation resulting from a catastrophic flood are shown. Flood-debris hazard zones were assigned to the flood plains of the drainages based on estimated floodflows and potential debris movement.

The estimated 100-year floodflows range from 30 cubic feet per second (0.8 cubic meters per second) for an unnamed tributary to Eagle Valley to 790 cubic feet per second (22.4 cubic meters per second) on Ash Canyon Creek, a tributary to the Carson River. The most noticeable urban development has been on the flood plains of Kings Canyon and Ash Canyon Creeks west of Carson City, and on the flood plains of ephemeral streams draining the south flank of the Virginia Range north of Carson City. Urban flood-plain development in Washoe Valley is minor. As the population continues to increase, the demand for developable land also increases with a corresponding encroachment on the flood plains.

INTRODUCTION

Flood and debris flows of past years met only nature's obstacles on the flood plains; however, today's flows will encounter man's urbanization. As the population of the area depicted by the Carson City quadrangle continues to increase, most notably in the Carson City area, the demand for developable land increases, and much of the demand is for land on flood plains. If the potential for damage from floods and debris flows is recognized and the character of the floods better understood, man can hopefully modify his use of the land to live in harmony with nature.

To understand flood and debris flows requires a knowledge of the processes involved. Generally the upper reach of a typical stream channel occupies the floor of a steep canyon. A well-developed alluvial fan, which is built primarily of water-transported sediment from the mountain block, and extends to the valley floor, is located at the mouth of the canyon. As streamflow carrying sediment reaches the flatter slopes of the alluvial fan, the water velocity decreases and the sediment particles are deposited on the fan. The stream channels on the fans are poorly entrenched, and during floods, the water may spread to a relatively shallow depth over much of the fan. The fans are constantly being modified by shifting, braiding, and channel clogging which is inherent in their construction process. The direction of flow on the fans, therefore, is often indeterminate and becomes more complex where obstructed by manmade structures.

The flood hazard increases as urban development proceeds from the valley floor to the alluvial fan. The steeper slopes of the alluvial fan, located closer to the mountain front, are the most hazardous, for here the water velocities and sediment loads are the greatest.

Purpose and Scope

This study was done in cooperation with the Nevada Bureau of Mines and Geology to estimate the 100-year flood peak and outline flood and debris hazard areas along principal drainages on the Carson City quadrangle. Study results can be used by (1) planners to improve land-use zoning decisions, (2) prospective land developers to incorporate flood planning in their development, and (3) the general public to assist in their understanding of hydrologic hazards.

Because of a lack of long-term streamflow records, reconnaissance techniques were used to estimate the 100-year floodflow and to outline the corresponding flood plain; thus, study results should not be considered definitive, but should be used as a guide to problem areas.

Previous Work

Eagle Valley and the Carson City urban area have been the subject of several flood studies. Different methods of estimating the 100-year flood-frequency values and different degrees of accuracy in defining the respective flood plains were used in the studies, and they are as follows: 1. The flood plains of Kings Canyon and Ash Canyon Creeks were first delineated for the 100-year frequency flood as part of a Carson City watershed study prepared by the U.S. Soil Conservation Service (1972). 2. A storm drainage study was made by SEA Engineers (1974) at the request of the county commissioners. 3. In accordance with the "National Program for Managing Flood Losses, House Document 465," a flood-prone area map for the Carson City 7 1/2-minute quadrangle was prepared by the U.S. Geological Survey (1974). The flood-prone map was prepared by utilizing the existing Soil Conservation Service delineation for Kings Canyon and Ash Canyon Creeks, and by evaluating the 100-year flood hazard on the remaining principal streams and alluvial fans within the quadrangle.

There have been no flood studies published on that part of Washoe Valley on the Carson City quadrangle.

FLOODING AND DEBRIS FLOWS

Floods and associated debris flows probably constitute one of the more common natural threats to life and property within the area of the Carson City quadrangle. Water velocities are commonly many feet per second, and water in main channels can be several feet deep. Concentrated runoff from high-intensity precipitation, generally from summer thunderstorms, commonly mobilizes large quantities of sediment and initiates debris flows having great destructive potential. Debris quantities are often measured in thousands of cubic feet, sediment character varies from clay-size particles to boulders several feet in diameter, sediment yields per unit area are great and very difficult to quantify, transport time is generally less than an hour, and resulting landscape changes are striking.

The debris generally causes damage through impact during transit, by abrasion of fragile objects during transport, by burying objects and areas where debris comes to rest, and by erosion along the flow-path. The degree of hazard posed by moving debris depends on several factors, including quantity of debris, particle-size range, water-sediment velocity, specific land use in the flow path, and effectiveness of a flood-warning system.

In addition to the summer storms, widespread shallow flooding within the quadrangle has been caused by intense winter rain falling on previously wetted soil (see Historic Floods Section). Flood waters have caused damage to streets, storm drains, basements, and the ground floors of some buildings. The debris that has reached the valley floor is generally fine grained. The coarser material, including some boulders, is deposited on the upper parts of the alluvial fans and is evidence of the potential destructive force of these floods.

Damage from winter storms has been greater than damage from summer storms; however, increasing development on the alluvial fans will result in more damage and possible loss of life from summer thunderstorms.

Characteristics of the two storm types are given in table 1.

The flood and debris hazard map shows five different zones representing varying degrees of hazard based on a combination of floodflow and potential debris movement. The map shows the hazardous areas associated with principal drainage channels, but additional areas not investigated undoubtedly are subject to potential flood and debris hazards. The additional areas, including those associated with smaller drainages, also could be subject to considerable movement and deposition of debris.

Flood Frequency

Statistical analysis is a useful tool for characterizing floodflows. Flood-frequency curves relate peak discharge to recurrence interval. These curves are based on streamflow records; and generally the longer the period of record, the more reliable the relation. However, no estimate is made for regularity of recurrence. The 100-year flood is the discharge at 100-year recurrence interval. Statistically, a 100-year flood has a one percent chance of being exceeded in any one year; or the 100-year flood will be exceeded at intervals averaging 100 years in length. Floods with magnitudes greater or less than the 100-year floodflow, however, may occur in any area at any time.

The 100-year floodflows for principal streams in this study were determined by applying and evaluating several independent methods. The methods included the following: (1) A regional frequency curve developed from a relation between the rates of discharges at various recurrence intervals to the mean annual flood and related drainage area

TABLE 1. Storm- type characterization

Storm type	Areal extent	Antecedent conditions	Precipitation Character			Runoff characteristics			Source of Fluvial Sediment	Debris Hazard
			Intensity	Duration	Volume	Peak flow	Duration	Flow viscosity		
Winter rain	Large, many square miles	Generally snow cover, ground may be frozen, saturated, or dry. Highest risk from fresh saturated snow	Maybe a few inches per hour	Usually several days	Very large	Low	Hours	Low, largely a water-dominated mixture	Overland runoff generally dominant, channel erosion can be significant	Generally low, but can be high in and near main channels
Thunder-storm	Usually only a few square miles or less, occasionally, larger areas	Generally dry, has occurred on snow cover and saturated ground	Often several inches per hour	Several hours or less	Low	Generally high	Generally minutes occasionally hours	Low or high; often a debris-dominated mixture	Often channel and existing flood plains are dominant; occasionally substantial overland rill erosion occurs	Often high

(Dalrymple, 1960); (2) relationship between mean annual flow estimated by channel geometry measurements (Moore, 1968) and the 10-year flood from a log-Pearson Type III distribution of annual peak flow data for sites in the region; (3) relationship of 10-year unit-flood discharge to elevation zones (Moore, 1976); (4) relationship of 10-year to 100-year flood event from a log-Pearson Type III distribution of annual peak flow data for about 15 sites along the Sierra front; (5) application of regional relationships as developed by Butler and others (1966), and Hardison (1973); and (6) analysis of past storm events utilizing the relationship of runoff per square mile and log-Pearson Type III determination of the 100-year flood for nearby streams having similar hydrologic characteristics and drainage areas. The last above described method (No. 6) was used for this study, because it gave the most consistent values throughout the gaging station network used in the analysis and resulted in estimated runoff yield of 150 $(ft^3/s)/mi^2$ $[1.6(m^3/s)km^2]$ for the drainage areas in the study area. This yield when multiplied by the contributing drainage area above the mountain front gives the estimated 100-year floodflow in cubic feet per second.

Stream-channel cross sections were surveyed, Manning's roughness coefficients were estimated, and channel slopes were determined so that the Manning flow equation (Chow, 1964, p. 1532) could be solved in terms of discharge to develop depth-discharge relations. Depths of 100-year floods were determined from these relations; then inundated areas of the flood plains were defined on the basis of the 100 year flood depths.

In addition to the 100-year flood plain, the flood- and debris-hazard map shows the probable limits of the area of maximum inundation resulting from a catastrophic flood-debris event. The area of maximum inundation was defined by evaluating slope, channel capacity and roughness, land use, vegetation, and sediment particle-size distribution in the flood plain.

The potential exists for much greater floods than the 100-year floodflows in the region. Investigations by the U.S. Geological Survey in many western States have shown maximum peak runoff from extreme floods to range from about 3,000 to 7,000 $(ft^3/s)/mi^2$ [33 to 77 $(m^3/s)/km^2$] of contributing drainage area for drainage areas less than about 23 mi^2. These yields are much greater than the yields of the 100-year flood presented above.

Medium to high flows can change the course of a stream across its flood plain, or debris transported by the flow may block shallow channels at unpredictable places and times and cause the flow to be diverted. Therefore, areas that appear safe from inundation under existing conditions could be subjected to serious flooding and damage from debris during a flood in the future. The mapped area of maximum inundation includes the areas susceptible to channel changes.

The boundaries between the various flood-debris hazard zones are controlled by the relationship between water depth, velocity, and character of the debris. All hazard zones are probably present to some degree in any given flood; however, it is impractical to show them. The

change from one hazard zone to another is not at a stable, definitive boundary and should be considered as occurring over a gradational zone which can fluctuate under different types of flow conditions. Thus, detailed on-site mapping is required with great attention to the combined effects of the floodflows and their accompanying debris loads. Water depths and damage will generally increase from the 10-year to the 100-year flood in the canyons. However, this is not necessarily true for the valley margins and floor, where water may leave the channel and spread out to a shallow depth over a large area.

Flood Routing

In routing the 100-year floodflow downstream, no attempt was made to attenuate the flow on the alluvial fan or through the Carson City urban area. Although studies in other areas of the Great Basin have generally indicated severe floodflow losses on the lower fan and valley floor areas, past storm events in Eagle Valley have demonstrated that substantial flow accretion can occur when heavy snow or frozen ground exists on the alluvial fan and valley floor at the time of winter rainstorms that are accompanied by warm temperatures. Since antecedent conditions and the type of storm event cannot be predicted, meaningful changes in flow rates could not be made.

There are other considerations in alluvial-fan flow which tend to mitigate the importance of peak discharge in dictating flooding conditions. The nature of alluvial fans, with poorly entrenched and generally insignificant channels, often perched on a crown, produce widespread sheet flow and shallow flooding. Thus, relatively minor changes in depth or area of possible inundation will occur through a significant range in peak flow. In addition, the direction the flow will seek depending upon obstructions, both natural and manmade, is quite variable.

The routing of estimated peak discharges below the confluence of two or more canyon drainages will have low reliability because of uncertainties in proportioning discharge where division of flow occurs on the alluvial fan and because timing of merging peaks cannot be predicted. It should be recognized that the probability of simultaneous peaks at the point of merger is low, however, those from winter rainstorms would have a higher probability of occurring simultaneously than would those from summer thunderstorms.

Flood boundaries for the 100-year discharge along all water courses evaluated were estimated on the basis of slope-conveyance estimates (Dalrymple and Benson, 1967), theoretical rating development at many culvert sites (Bodhaine, 1968), computation of flow over road or embankment (Hulsing, 1967), topographic maps, aerial photos, local accounts and observation of past floods, and detailed field inspections.

Flood and Debris Hazard Factors

The potential hazards from flooding and debris within any drainage area depend on the interrelations of several factors; the main factors are storm type (table 1), geology, land cover, and channel characteristics.

Geology

Runoff rates and the availability of sediment with potential to contribute to debris flows are dependent on the local geology and geomorphic characteristics of individual drainages. Drainage patterns and channel development may be strongly influenced by geologic structure. Faulting within the bedrock enlarges fracture systems and joint patterns which increases the erodibility of the rock. As the depth of the overburden on the mountain block increases, the amount of available sediment also increases, thus increasing the downstream hazard; however, as the depth of overburden increases so does the waterholding capacity which, potentially, can reduce the runoff.

The geology of the Carson City quadrangle has been mapped by Trexler (1977) and can be classified for this report according to the erodibility of the bedrock. The granitic terrain, which is the most abundant in the quadrangle, is also the most erodible and decomposes to form coarse to fine sand with few cobbles and boulders. This contrasts with the remainder of the mountain block which is composed of metavolcanics, volcanic flows, and metasediments. These rocks are characterized by being much harder, more fine grained, and slower to weather than granite. They are susceptible to extensive fracturing and weather to boulders and cobbles, thus, providing abundant material to be mobilized as debris flows.

Land Cover

Much of the Carson City quadrangle land surface is scantily covered by vegetation typical of arid and semiarid environments. This type of vegetation does little to retard or reduce erosion from intense storms. Part of the study area is covered by dense brush and heavily forested slopes characteristic of the Carson Range which tend to reduce flow velocities thus reducing erosion and promoting infiltration. This type of land cover greatly reduces downstream hazards from floods and debris flows. The perennial stream channels generally have a very thick vegetal growth covering not only their banks, but their drainage areas as well. The ephemeral channels have only scanty vegetal cover.

Channel Characteristics

Channel characteristics which control flooding and debris flows are slope, shape, roughness, capacity, and bed and bank material. While all of these are interrelated, slope has a dominating influence. The slope, not only of the channel, but also of the land surface in the basin

strongly controls the initial movement of the water and debris, and its continued motion and subsequent disposition.

LAND ALTERATION

The hazardous areas outlined on the flood and debris hazard map may either increase or decrease in size and degree of hazard in the future because of man's and nature's activities. For example, the field work for this study was done prior to the July 1976 fire in the Virginia Range. The degree of hazard from flood and debris after the fire may be higher than the values estimated prior to the removal of the vegetal cover.

Several years ago part of the lower Ash Canyon drainage and Taylor Spring area was burned by a forest fire, and contour trenches were subsequently built to reduce erosion. Contour trenches have also been constructed on some of the bare slopes of the upper Ash Canyon drainage. The trenches do have the effect of reducing runoff and erosion, however, there is always the danger of trenches breaching, and there is evidence of this in the upper Ash Canyon drainage. The consolidation of water in the trench and subsequent breach may actually increase local runoff and erosion.

Construction on flood plains may divert floodflows into areas that otherwise would be flood free. By increasing and maintaining channel capacities, hazards could be reduced. A flood-channel bypass system could be constructed to alleviate flooding. Thus, any modification of the present hydrologic system has many ramifications and should be made only after careful evaluation of the probable effects.

HISTORIC FLOODS

There have been 17 winter floods between 1861 and 1963 documented in USDA reports (U.S. Dept. of Agriculture, 1973) and local newspaper accounts. Three summer floods resulting from July and August thunderstorms have also been reported during this period. In addition, a mudflow from a July 30, 1960, thunderstorm on the upper watershed of North Kings Canyon has been documented by the U.S. Geological Survey; peak discharge for this event was estimated at less than 150 ft^3/s (4.2 m^3/s).

Floods resulting from general winter storms producing rain on snow or frozen ground have historically been the most damaging. Significant flooding occurred in 1861, 1862, 1868, 1874, 1875, 1886, 1906, 1907, 1909, 1914, 1928, 1938, 1942, 1943, 1950, 1955, and 1963. Summer floods have been documented for 1875, 1913, and 1958.

Quantitative data are unavailable to categorize these events in terms of magnitude and probable frequency of recurrence.

PRINCIPAL DRAINAGES

Eagle Valley

Voltair Canyon

The estimated 100-year floodflow of 180 ft^3/s (5.1 m^3/s) from Voltair Canyon will be confined to the canyon floor until the flow reaches the mouth. Because of the steep slope, the canyon bottom will be an area of scour rather than deposition. A powerline and related automatic restarting equipment, which serves the Lake Tahoe area, is located in the canyon bottom and subject to flood-debris damage. Additionally, there are a few private residences built on the flood plain at the mouth of the canyon which are in a high-risk area if the flow is forced from the road (which acts as the channel) exiting from the canyon mouth, either by erosion or debris blockage. Debris from the primarily granitic terrain will consist mainly of fine- to coarse-grained sediment.

Kings Canyon

The combined estimated 100-year floodflow from North Kings and Kings Canyons below their confluence is 610 ft^3/s (17.3 m^3/s). The flow is divided nearly equally, but there is a much greater hazard on North Kings Canyon because of the availability of large boulders. The geology of Kings Canyon drainage is primarily granitic and North Kings Canyon is mostly metavolcanic. There are many homes built in high-risk areas on the 100-year flood plain. Additionally, the first drainage immediately to the north of North Kings Canyon, draining the Premier Mine area, has an estimated 100-year floodflow of 120 ft^3/s (3.4 m^3/s). This flow can go either south to Kings Canyon or north toward the Taylor Flat drainage and ultimately reach Kings Canyon. The channels indicate it has done both in the past.

The drainages between the Premier Mine drainage and Ash Canyon are tributary to the Kings-Ash Canyon flow. The estimated 100-year floodflows are low and would be unable to mobilize large amounts of debris, however, their flood plains are covered with large boulders indicating that past flooding has exceeded the estimated 100-year floodflow.

Ash Canyon

The incised channel of Ash Canyon will contain the estimated 790 ft^3/s (22.4 m^3/s) floodflow until reaching the mouth of the canyon. At this point the flow may take any one of several directions depending upon its debris load, which, with a granitic and metavolcanic source area, will include all size of debris up to and including large boulders and trees. Water-supply facilities at the mouth of the canyon could be destroyed by the flood and debris. All of the homes built at the mouth of the canyon and on the flood plain are in a high-hazard zone. There is evidence of landsliding in Ash Canyon (Trexler, 1977). Landslides can block

channels, and impound sufficient water to cause major flooding when the landslide material is breached. Scouring from floodflows has also been a problem in Ash Canyon. The winter flood of 1861-62 (Thompson and West, 1881, p. 539) reportedly scoured out the channel in the vicinity of a sawmill to a depth of about 14 ft (4 m), causing damage to some of the mill's facilities.

Vicee Canyon

The estimated 100-year floodflow of 240 ft^3/s (6.8 m^3/s) from Vicee Canyon will spread out to a fairly shallow depth in the wide canyon bottom as it emerges from the granitic mountain block. There are some large boulders in the canyon bottom, but these will probably not move very far during the 100-year flood. Once the flow crosses the abandoned Virginia and Truckee Railroad bed it can spread in several directions; one such direction is the sandpit just south of the junction between the stream and the railroad bed. It is possible that the peak flow may be diverted into the sandpit, thus reducing the overall hazard downstream.

Coombs Canyon

An estimated 100-year floodflow value of 260 ft^3/s (7.4 m^3/s) from Coombs Canyon was determined at Foothill Road about 0.5 mi (0.8 km) downstream from the canyon mouth. About half of the floodflow comes from the drainage area above the canyon mouth and the other half comes from the remaining drainage area between the canyon mouth and Foothill Road. There are two roadfill dams at the canyon mouth; one is the abandoned Virginia and Truckee Railroad bed, the other provides access to a home on the north side of the drainage. Both roadfill dams have a large culvert at their base which, under highhead, will carry the floodflow. Both dams will impound several acre-feet of water which could effectively take the peak off of any large flow or could increase the downstream hazard by filling, overtopping, and failing. Homes in the upper reaches of the drainage that are built in the channel are in a high-hazard area. Debris will consist of mostly fine to coarse sand from the primarily granitic terrain.

Unnamed Tributary at the Eagle Valley Ranch Children's Foundation

A small reservoir [estimated capacity less than 5 acre-feet (6,200 m^3)] at the mouth of the canyon north of the Eagle Valley Ranch Children's Foundation would probably dampen out the estimated 100-year floodflow of 150 ft^3/s (4.2 m^3/s). All granite boulders and coarse-grained debris would drop out also. However, if the reservoir was at capacity during the flood the dam could overtop and fail. The resultant floodflow peak would depend on how the failure occurred. However, the areas of maximum inundation, as illustrated, allow for a flood peak of about 500 ft^3/s (14.2 m^3/s). Debris resulting from this type of failure would be mainly fine- to coarse-grained granitic sediment.

Virginia Range Tributaries

There are three main channels that drain the south slope of the Virginia Range in the study area. The first drainage terminates in a sandpit in the SW 1/4 of sec. 31,T16N,R20E. This drainage was not evaluated; however, the sandpit will probably impound most of the 100-year flood-debris flow. The second drainage enters the valley in the SE 1/4 of the same section. The estimated 100-year floodflow of 100 ft^3/s (2.8 m^3/s) is a hazard to the few homes built at the mouth of the canyon. There are a few boulders in the canyon that could be mobilized; however, most of the debris will be fine- to coarse-grained granitic sediment. The third drainage enters the valley in the south 1/2 sec. 32, T16N,R20E. The estimated 100-year floodflow of 30 ft^3/s (0.8 m^3/s) will carry a minor amount of sand and gravel from the metasedimentary terrain. There is one house that is flood prone because it is built directly across the channel.

Washoe Valley

There are several drainages tributary to Washoe Valley; however, only the largest, Big Canyon, was evaluated in any detail. The degree of hazard from the 100-year floodflow of the other drainages is low. The channels draining into the southeast corner of Washoe Lake had much of their cover burned off during the July 1976 range fire, and should be considered hazardous until normal growth is reestablished.

Big Canyon

The estimated 100-year floodflow of 350 ft^3/s (9.9 m^3/s) from Big Canyon will be confined to the channel until the flow reaches the Franktown Road. Probably the culvert will plug and the road will be overtopped. Most of the debris, which will consist of fine- to coarse-grained sediment from the predominately granitic terrain, will be deposited upstream from the road. The channel is not well incised downstream from the road and the floodflow will disperse.

Washoe Lake

If the total area tributary to Washoe Lake was subjected to a 100-year flood, the resultant runoff into the lake would raise the lake level about 4 ft (1.2 m) above the spillway (assuming very little outflow and that the lake was nearly full at the onset of flooding). Ponding west of the freeway (U.S. 395) will occur in some areas as a result of the high lake stage. The volume of inflow, about 24,000 acre-ft (29.6 km^3), was estimated by correlating the 100-year flood peak of nearby gaging stations with the resultant runoff. These data were then extrapolated to ungaged areas to obtain the total runoff.

CONCLUSIONS

The flood and debris hazard map shows that the most hazardous areas are on the upper alluvial slopes of the principal drainages. Winter rains on snow have historically, caused the most serious flooding, primarily in the downtown sections of Carson City. As urbanization increases with a corresponding encroachment on the alluvial fans, the damage potential also increases. Additionally, increased urbanization will mean increased runoff from flood events which will increase the flooding in Carson City.

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