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Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Piru, Simi, and Verdale Fires of 2003, Southern California

Susan H. Cannon, Joseph E. Gartner, Michael G. Rupert, John A. Michael
U.S. Geological Survey, Box 25046, DFC, MS 966, Denver CO 80225, (303) 273-8604, cannon@usgs.gov

ABSTRACT

These maps present preliminary assessments of the probability of debris-flow activity and estimates of peak discharges that can potentially be generated by debris flows issuing from basins burned by the Piru, Simi and Verdale Fires of October 2003 in southern California in response to the 25-year, 10-year, and 2-year 1-hour rain storms. The probability maps are based on the application of a logistic multiple regression model that describes the percent chance of debris-flow production from an individual basin as a function of burned extent, soil properties, basin gradients and storm rainfall. The peak discharge maps are based on application of a multiple-regression model that can be used to estimate debris-flow peak discharge at a basin outlet as a function of basin gradient, burn extent, and storm rainfall. Probabilities of debris-flow occurrence for the Piru Fire range between 2 and 94% and estimates of debris flow peak discharges range between 1,200 and 6,640 ft^3/s (34 to 188 m^3/s). Basins burned by the Simi Fire show probabilities for debris-flow occurrence between 1 and 98%, and peak discharge estimates between 1,130 and 6,180 ft^3/s (32 and 175 m^3/s). The probabilities for debris-flow activity calculated for the Verdale Fire range from negligible values to 13%. Peak discharges were not estimated for this fire because of these low probabilities. These maps are intended to identify those basins that are most prone to the largest debris-flow events and provide critical information for the preliminary design of mitigation measures and for the planning of evacuation timing and routes.

INTRODUCTION

The objective of this paper is to present a preliminary emergency assessment of the potential for debris-flow generation from basins burned by the Piru, Simi, and Verdale Fires in southern California for given rainfall events (Fig. 1). The assessments are intended to identify those basins most likely to produce debris flows, and to estimate the magnitude, in terms of peak discharge, of the possible debris-flow response at the outlets of the basins. Identification of potential debris-flow hazards from burned drainage basins is necessary to make effective and appropriate mitigation decisions, and can aid in decisions about evacuation timing and routes.

Fire-Related Debris-Flow Hazards

Wildfire can have profound effects on a watershed. Consumption of the rainfall-intercepting canopy and of the soil-mantling litter and duff, intensive drying of the soil, combustion of soil-binding organic matter, and the enhancement or formation of water-repellent soils can result in decreased rainfall infiltration into the soil and subsequent significantly increased overland flow and runoff in channels. Removal of obstructions to flow (e.g. live and downed timber, plant stems, etc.) by wildfire can enhance the erosive power of overland flow, resulting in accelerated stripping of material from hillslopes. Increased runoff can also erode significant volumes of material from channels. The net result of rainfall on burned basins is often the transport and deposition of large volumes of sediment, both within and down-channel from the burned area.

Debris flows are among the most hazardous consequences of rainfall on burned hillslopes. Debris flows pose a hazard distinct from other sediment-laden flows because of their unique destructive power. They can occur with little warning, can exert great impulsive loads on objects in their paths, and even small debris flows can strip vegetation, block drainage ways, damage structures, and endanger human life. For example, record-breaking winter storms in 1969 triggered debris flows from steep basins burned the previous summer above the city of Glendora, California (Scott, 1971). More than one million cubic meters of rock, mud, and debris came racing downhill, and at least 175 homes were either completely destroyed or damaged by these events. Damage from debris flows and associated flooding totaled $2,500,000 in the Glendora area in 1969.

In studies of debris-flow processes throughout the western U.S. and in southern California, Cannon (2000, 2001) demonstrated that the great majority of fire-related debris flows initiate through a process of progressive bulking of storm runoff with sediment eroded from both hillslopes and channels. Although some infiltration-triggered landsliding can occasionally occur in burned basins, and generally in response to prolonged rainfall events, these failures generally contribute a small proportion to the total volume of material transported from the basin (Cannon et al., 2001; Scott, 1971). This finding points to the relative importance of runoff-dominated, rather than infiltration-dominated, processes of debris-flow initiation in recently burned basins, and indicates that methodologies developed to map landslide potential for unburned basins are generally not appropriate for recently burned areas. As an alternative, this finding suggests that the relations traditionally defined between peak discharges of floods and basin characteristics may be useful in predicting the magnitude of potential debris-flow response from burned basins.

APPROACH AND METHODS

In a study of the erosional response of recently burned basins throughout the western U.S, including southern California, Cannon (2000, 2001) found that not all basins produce debris flows; most burned watersheds respond to even heavy rainfall events by sediment-laden flooding. However, debris flows are potentially the most destructive end of the potential response spectrum. Analysis of data collected from 398 burned basins from 15 fires throughout the inter-mountain west revealed that the probability of a given basin to produce debris flows can be readily identified by a combination of geologic, soil, basin morphology, burn severity, and rainfall conditions. Furthermore, because debris-flow kinematics are significantly distinct from those of streamflow (Iverson, 1997), we have taken the approach of developing predictive relations that are specific to debris flow, but based on common hydrologic analyses. Using data collected from debris-flow producing basins throughout the western U.S., including southern California (Bigio and Cannon, 2001), we developed an empirical relation that can be used to obtain estimates of debris-flow peak magnitudes as a function of the area of the basin burned, storm rainfall conditions, and basin gradients.

In this assessment, we use these recently developed models to predict which basins might produce fire-related debris flows, and how big these events might be. The results obtained in this assessment can be used to identify those watersheds that are most prone to the largest debris-flow events. Note that the models used for the generation of these maps are new and have not been thoroughly tested and reviewed. However, in light of the large extent of the Piru, Simi, and Verdale Fires and of the current emergency situation, this method presents a reasonable preliminary approach to evaluate hazards across a large geographic area.

Debris-flow probability model

A logistic multivariate statistical model developed using data measured from post-wildfire debris flows is used to define the probability of debris-flow occurrence from basins burned by the Piru, Simi and Verdale Fires. The database used in the development of the model consists of a number of variables that describe basin gradient, burn severity, geologic materials, soil properties, and storm rainfall conditions from 398 basins located in 15 recent fires throughout the western U.S. that were characterized either as having produced debris flows, or not. Because the dependent variable, debris-flow occurrence, is binomial (i.e. debris flows were produced, or not), we used a logistic regression approach for analysis. Where linear regression returns a continuous value for the dependent variable, logistic regression returns the probability of a positive binomial outcome (in this case, debris-flow occurrence) (Hosmer and Lemeshow, 2000; Griffiths et al., 1996).

Field observations of deposits made within 1 week of a runoff response were used to determine if a basin produced debris flows or not. Debris-flow deposits were identified as those consisting of poorly-sorted, unstratified materials showing either matrix support of the larger clasts, or a prevalent muddy coating on large materials (Cannon, 2001; Meyer and Wells, 1997).

Because we did not know which measures would best determine debris-flow probability, we evaluated a number of different measures for each of the independent variables to be used in the logistic regression. Six possible measures of basin gradient were compiled using either 30-m or 10-m DEMs, depending on availability. These include:

- the average gradient,
- average gradient multiplied by basin area,
- average gradient divided by basin area,
- percent of basin area with slopes greater than or equal to 30 percent,
- percent of basin area with slopes greater than or equal to 50 percent, and
- basin ruggedness (the change in basin elevation divided by the square root of the basin area (Melton, 1965).

Basin aspect was quantified from either 10- or 30-meter DEMs as degrees from north. Burn severity for each basin was characterized using maps of burn severity generated by either the Burned Area Emergency Rehabilitation (BAER) Team using a number of different techniques, or from the Normalized Burn Ratio (NBR), as determined from Landsat Thematic Mapper data (Key and Benson, 2000). The maps of burn severity are considered to reflect the effects of the fire on soil conditions and the potential hydrologic response, and are a representation of a combination of the condition of the residual ground cover, soil erodibility, and degree of fire-induced water repellency. We evaluated the effects of nine measures of burn severity, including:

- percent of the basin area burned at low severity,
- percent of the basin area burned at moderate severity,
- percent of the basin area burned at high severity,
- percent of the basin area burned at high and moderate severities,
- percent of the burned area of each basin burned at low severity,
- percent of the burned area of each basin burned at moderate severity,
- percent of the burned area of each basin burned at high severity,
- percent of the burned area of each basin burned at high and moderate severities,
- percent of basin area burned at high, moderate, and low severities.

Soil properties for each basin were characterized using measures of the grain-size distributions of samples of burned surficial soils collected within the basins (Inman, 1952), and the parameters for unburned soils included in the STATSGO soils database (Schwatrz and Alexander, 1995). The 1:250,000-scale STATSGO compilation was used to insure that similar measures of all parameters were available for each fire in the database. The soil properties evaluated include:

- mean particle size,
- median particle size,
- sorting of the grain-size distribution, and
- skewness of grain-size distribution,
- percent clay content,
- available water capacity,
- permeability,
- erodibility,
- percent organic matter,
- soil thickness,
- infiltration capacity,
- drainage,
- liquid limit, and
- hydric capacity.

The most extensive rock type underlying each basin was classified as sedimentary, plutonic, metamorphic, or volcanic. The characteristics of storms that affected the monitored basins were determined from tipping bucket rain gages located within 2 kilometers of each basin. For each storm to impact a monitored basin, we compiled the

- total storm rainfall,
- storm duration,
- average storm rainfall intensity,
- peak 10-minute rainfall,
- peak 15- minute rainfall,
- peak 30-minute rainfall, and
- peak 60-minute rainfall.

A series of univariate and multiple logistic regression analyses were used to identify those parameters which best determine debris-flow probability, and to build a robust statistical model (Hosmer and Lemeshow, 1989). All possible groupings of independent variables were evaluated to determine which combination produced the most effective model. The models were built by sequentially adding variables to the analysis and evaluating the resulting test statistics by comparing partial-likelihood ratios calculated before and after addition of that variable (Helsel and Hirsch, 2002). Overall model validity and accuracy was determined by evaluating the log-likelihood ratio, McFadden's rho-squared, p-values calculated for each independent variable, and the percent correct responses (M. Rupert, written communication, 2003).

The statistical analyses found that the probability of debris-flow occurrence (P) from an individual basin can best be best estimated as a function of:

- percent of the burned area in each basin burned at high and moderate severities (%Burn),
- sorting of the grain-size distribution of the burned soil (Sorting),
- percent of soil organic matter (%Organics)
- soil permeability (Permeability)
- soil drainage (Drainage), and
- percent of the basin with slopes greater than or equal to 30% (%GE30%)
- average storm rainfall intensity (I, in mm/hr)

These variables were used to develop a logistic multivariate statistical model of the form

$$P = e^x / 1 + e^x,$$

Where

$$x = -29.693 + 10.697(\%Burn) - 9.875(Sorting) + 0.208(I) + 5.729(\%Organics) - 0.957(Permeability) + 9.351(Drainage) + 2.864(\%GE30\%) - 8.335(\%Burn{*}\%Organics) + 4.669(Sorting{*}Drainage) - 0.174(\%GE30\%{*}I).$$

The McFadden's rho of 0.397 for this model, coupled with the additional tests of model quality, indicates that this is a robust model. Values of McFadden's rho between 0.20 and 0.40 are considered to indicate good results (Hosmer and Lemeshow, 2000). Graphical analyses indicated no apparent correlations between the soils properties included in the model. The additional measures of gradient, aspect, burned extent, soils properties and geologic materials produced significantly less satisfactory models. This model, when incorporated into a geographical Information System (GIS), can be used to estimate the probability of post-fire debris flow activity from individual drainage basins.

Debris-flow peak discharge model

A multiple-regression model developed using data measured from post-wildfire debris flows is used to define the range of peak discharges that can potentially be generated from the basins burned by the Piru, Simi, and Verdale Fires. The data used in the development of the model consists of measurements from 62 recently burned, and debris-flow producing, basins located throughout the western U.S. for which estimates of debris-flow peak discharge had been obtained (Bigio and Cannon, 2001). The database is a compilation of information both from the published literature and our own monitoring efforts. Peak discharge estimates used in the analysis were calculated based on either the assumption of critical flow (O'Connor et al., 2001), or from estimates of velocity obtained from measurements of banking flow around curves (Johnson and Rodine, 1984) coupled with measures of the cross-sectional area of conveyance reaches of channels.

The regression model consists of a physical representation of peak discharge at the basin outlet (Qp) as a function of basin gradient, burned extent, and storm rainfall. We considered the effects on Qp of three possible measures of gradient—the average basin gradient (in percent), and the percent of slopes within a basin greater than or equal to 30%, and the percent of slopes within a basin greater than or equal to 50% (determined from either 10- or 30-m DEMs). We also evaluated the effects of two measures of burned extent—the total area burned (in m^2), and the area burned at high severity (in m^2). Burn severity for each basin included in the database was characterized using information reported in the literature, or maps of burn severity generated by either the Burned Area Emergency Rehabilitation (BAER) Team, or the Normalized Burn Ratio (NBR), as described above.

A series of statistical analyses were used to determine those factors that most strongly affect debris-flow peak discharges, and to build the most robust regression model possible. All possible combinations of independent variables were evaluated to determine which combination produced the most effective model. We used a combination of statistical measures including Mallow's Cp, adjusted R^2, the variance inflation factor, and the prediction error of the sum of squares to assess the quality of each model (Helsel and Hirsch, 2002). For a model to be accepted, we also tested for adherence to the assumptions of linearity, constant variance, and normally distributed residuals (Helsel and Hirsch, 2002).

We found that the peak discharge of debris flows (Qp, in m^3/s) issuing from the outlet of recently-burned basins could be estimated as a function of:

- average basin gradient (AvgSlope, in percent),
- the area of the basin burned at all severities (Ab, in m^2), and
- the average storm rainfall intensity (I, in mm/hr).

These variables form the basis of a multi-variate statistical model of the form

$$Qp = 171 + 0.552(AvgSlope) + 2.84(\log Ab) + 3.6 \times 10^6(I).$$

The adjusted R^2 of this model of 0.67, coupled with additional tests of model quality, indicates that this result is the best possible model, given the available data. Graphical analyses indicated no apparent correlation between average basin gradient and burned area. The additional measures of gradient and burned extent considered here produced less satisfactory models. This model, when incorporated into a Geographical Information System (GIS), can be used to estimate the peak discharge of post-fire debris flow at the outlets of individual drainage basins.

Mapping debris-flow probability and peak discharge

As the first step in this assessment, the perimeters of 121 basins burned by the Piru Fire, 169 basins burned by the Simi Fire, and 14 basins burned by the Verdale Fire were delineated. Basin outlets were located using a shaded relief image from a 30-m DEM overlain by a detailed stream network generated using Arc Hydro©. Basin outlets were positioned at breaks in slope between mountain fronts and valleys, or if present, at road crossings or above development. Using the ranges of data in the database that were used to derive the statistical models, we focused on basins between 0.04 mi^2 (0.1 km^2) and 10 mi^2 (25 km^2) in area. Basins larger than 10 mi^2 (25 km^2) were sub-divided into tributaries to the main channel. Although debris flows may be generated in the lower order drainages of such basins, they are generally not of sufficient size or energy to travel the entire length of the basin. Basins larger than 10 mi^2 (25 km^2) with negligible potential impact to facilities and structures were not included.

For each basin, we then compiled values for each of the input variables for the two models. Basin area and measures of gradients were obtained from 30-m DEMs, the basin areas burned at different severities were characterized from the burn severity map developed by the BAER Team, and soil organic matter, permeability and drainage were obtained from the STATSGO database (Schwartz and Alexander, 1995). If more than one value for any one parameter is present in a basin, we calculated a single spatially-weighted value for that parameter. The time available to conduct this emergency assessment did not allow for the collection and analysis of samples of burned surficial soils. As an alternative, we used 1:250,000-scale geologic mapping of the area (State of California, 1969) as a surrogate for soils, and substituted median values of known measures of sorting of the grain-size distribution of burned soils for each primary rock type present in each basin.

The probability of debris flow and estimates of debris-flow peak discharge for the 25-year, 10-year and 2-year recurrence, 1-hour duration storms are calculated using the logistic multivariate regression model for debris-flow probability and the multivariate statistical model for debris-flow peak discharge described above. Storm rainfall values used in the models for each of the fires are shown in Table 1, and the locations of the gages that provide the information are shown on the accompanying maps. Although there is some variability in storm-rainfall characteristics across the burned areas, the present versions of the models allow for only single storm input. We thus selected gages located as close as possible to the center of the fires as representative. The calculated values of debris-flow probability and peak discharge were then proportioned into classes, and the class value for both probability and discharge were attributed to each basin. The basin class values are presented for each basin in map form as Map 1A and B, Map 2A and B, and Map 3A and B.

Table 1. Storm rainfall values used in assessment. Rainfall information provided by Ventura County.

Fire and Gage Name	25-year, 1-hour storm (inches)	10-year, 1-hour storm (inches)	2-year, 1-hour storm (inches)
Piru: Sespe-Oil Field-Westes	1.48	1.21	0.67
Simi: Tripas Canyon	1.40	1.15	0.64
Verdale: Piru-Cumulos Ranch	1.12	0.92	0.51

Use and Limitations of the Maps

These maps provide estimates of the probability of debris-flow occurrence and the ranges of debris-flow peak discharges that can potentially issue from the outlets of basins burned by the Piru, Simi and Verdale Fires in response to the 2-year, 10-year, and 25-year 1-hour storms. The maps are intended to identify those basins most likely to produce debris flows, and to provide estimates of the possible magnitude, in terms of peak discharge, of the debris-flow response at the outlets of basins. This information can be used to prioritize mitigation efforts, to aid in the design of mitigation structures, and to guide decisions for evacuation, shelter, and escape routes in the event that storms of similar magnitude to those evaluated here are forecast for the area.

The potential for debris-flow activity decreases with time and the concurrent revegetation and stabilization of hillslopes. A compilation of information on post-fire runoff events reported in the literature from throughout the western U.S. indicates that most debris-flow activity occurs within about 2 years following a fire (Bigio and Cannon, 2001). We thus conservatively expect that the maps presented here may be applicable for approximately 3 years after the fires for the storm conditions considered here. Further, the assessments presented here are specific to post-fire debris flows; significant hazards from flash flooding can remain for many years after a fire.

The methods used to derive the probability and peak discharge estimates are new and have not been thoroughly tested and reviewed. However, in light of the large extent of the Piru, Simi, and Verdale Fires and of the current emergency situation, this method presents a reasonable approach to preliminarily evaluate debris-flow hazards across a large geographic area. A significant advantage to this approach is that it is based on analysis of data specifically from post wildfire debris-flow events, rather than on estimates of flood runoff with assumed sediment-bulking factors.

In this approach, we considered peak discharge as the measure of the magnitude of the potential debris-flow hazards; debris-flow hazards can also be characterized by measures of potential volumes emanating from basin outlets. Measures of volume are of particular use in evaluating the effectiveness of debris basins. We conducted analyses similar to those described above using measures of debris flow volume as the dependent variable. However, it was not possible to develop a robust, statistically significant model with the available data set. Hopefully, data collected in the following winters will allow for the definition of such a relationship.

And last, the parameters included in the models are considered to be possible first-order effects that can be rapidly evaluated immediately after a fire. Other conditions than those used in the model may certainly affect debris-flow occurrence and peak discharge from recently burned basins in southern California. For example, an abundance of dry-ravel material in a specific channel may certainly affect peak discharges, and the frequently occurring fire–flood sequence that characterizes southern California basins may similarly limit material availability (e.g. Spittler, 1995). Data necessary to evaluate these effects is not currently available to account for their effects in this approach.

RESULTS

Piru Fire—25-year, 1-hour storm of 1.48 inches (37.6 mm)

Of the 121 basins evaluated in this assessment, 31 were identified as having probabilities greater than 67% that debris flows will occur in response to the 25-year, 1-hour rainstorm (Map 1A). From east to west, these include Dominquez Canyon, Lime Canyon, and three unnamed basins; many of the tributaries to Hopper Canyon; three of the tributaries to Pole Creek; and nine of the tributaries to Sespe Creek. Dominguez Canyon, Lime Canyon and the small unnamed canyon at the south end of the valley produced debris flows after the 1997 Hopper Fire during the winter of 1997-98 (Cannon, 2001). In response to a 25-year, 1-hour storm, debris-flow peak discharges between 4,501 and 6,640 ft^3/s (127 and 188 m^3/s) are estimated for these basins (Map 1B).

Fifty-eight additional basins show probabilities of debris-flow occurrence greater than 33%, still an appreciable hazard (Map 1A). These include Reasoner, Blanchard, and Modelo Canyons, and three unnamed basins on the east side for the fire; 14 of the tributaries to Hopper Canyon; three basins along the mountain front between Hopper Canyon and Pole Creek; six tributaries to Pole Creek; and numerous tributaries to Sespe Creek, including Little Sespe Creek, Maple Creek, and Tar Creek. Debris-flow peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are also estimated for these basins (Map 1B).

Piru Fire—10-year, 1-hour storm of 1.21 inches (30.7 mm)

In response to a 10-year, 1-hour storm, a probability of debris-flow occurrence greater than 67% is identified for seven basins within the Piru Fire (Map 2A). These include Dominguez and Lime Canyons; nine tributaries to Hopper Canyon; two small basins within Pole Creek; and one small tributary to Sespe Creek. Debris flows with peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are estimated for these basins (Map 2B).

In response to this storm, numerous basins show probabilities of debris-flow occurrence of greater than 33%, still an appreciable hazard (Map 2A). These include Reasoner and Blanchard Canyons and six unnamed basins on the east side of the fire; twelve of the tributaries to Hopper Canyon; six tributaries to Pole Creek; and most of the basins within the Sespe watershed. Debris-flow peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are estimated for these basins (Map 2B).

Piru Fire—2-year, 1-hour storm of 0.67 inches (17.0 mm)

Only three unnamed basins within Hopper Canyon, and one in Pole Creek, show a probability of debris-flow occurrence greater than 67% in response to the 2-year, 1-hour storm (Map 3A). Dominguez and Lime Canyons; five basins in Hopper Canyon; two basins in Pole Creek; and two within the Sespe watershed show probabilities of debris-flow occurrence greater than 33% (Map 3A). Debris-flow peak discharges between 1,501 and 4,500 ft^3/s (42 and 127 m^3/s) are estimated for these basins (Map 3B).

Simi Fire—25-year, 1-hour storm of 1.40 inches (35.6 mm)

Of the 169 basins evaluated in this assessment, 64 were identified as having probabilities greater than 67% that debris flows will occur in response to the 25-year, 1-hour rainstorm (Map 1A). From the northwest corner of the fire and proceeding east, these include two unnamed basins west of Loftus Canyon; Loftus Canyon; four unnamed basins immediately east of Shiells Canyon; two basins west of Smith Canyon; Potrero Canyon; Pico Canyon and the two adjacent unnamed basins; Towsley Canyon and the adjacent unnamed basin; and Rice Canyon. Proceeding to the west from the southeast corner of the fire, basins with probabilities greater than 67% include Devil and Blind Canyons; all of the tributaries to Llajas and Chivo Canyons; Gillbrand Canyon and four unnamed tributaries to Tripas Canyon; five basins along the Simi Valley mountain front, including Dry Canyon; three tributaries to Alamos Canyon and four unnamed basins to the west; and all of the tributaries to Happy Camp Canyon. In response to a 25-year, 1-hour storm, debris-flow peak discharges between 3,000 and 6,180 ft^3/s (85 and 175 m^3/s) are estimated for these basins (Map 1B).

Fifty-nine additional basins show probabilities of debris-flow occurrence greater than 33%, still an appreciable hazard (Map 1A). These include Richardson, Morgan and Willard Canyons, as well as two unnamed basins immediately to the west and one to the east; the basin immediately east of Loftus Canyon; Grimes Canyon and two unnamed basins to the west and two to the east; Sheills, Frey and Wiley Canyons; Eureka Canyon and four unnamed basins to the east; Tapo Canyon and the basin immediately to the west; and Salt and Lyon Canyons. Proceeding to the west from the southeast corner of the fire, basins with probabilities greater than 33% include an unnamed basin southeast of Llajas Canyon and two to the west; seven tributaries to Tripo Canyon; Brea Canyon; two tributaries to Alamos Canyon; three basins immediately south and east of Happy Camp Canyon and one tributary to Happy Camp Canyon; a small unnamed basin above Moor Park; an unnamed basin east of Long Canyon, Long Canyon, and three unnamed basins immediately to the west; Coyote Canyon; and ten basins west of Coyote Canyon. Debris-flow peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are also estimated for these basins (Map 1B).

Simi Fire—10-year, 1-hour storm of 1.15 inches (29.2 mm)

In response to a 10-year, 1-hour storm, a probability of debris-flow occurrence greater than 67% is identified for 48 basins within the Simi Fire (Map 2A). These include three small, unnamed basins along the south side of the Santa Clara River Valley; Potrero Canyon; Pico Canyon and two unnamed adjacent basins; Towsely Canyon and the adjacent unnamed basin; Rice, Devil, and Blind Canyons; all of the tributaries to Llajas and Chivo Canyons; Gillbrand Canyon; two tributaries to Tripas Canyon; Dry Canyon and two adjacent unnamed basins; a tributary to Alamos Canyon; and two unnamed basins west ot Alamos Canyon. Debris flows with peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are estimated for these basins (Map 2B).

In response to this storm, numerous basins show probabilities of debris-flow occurrence of greater than 33%, still an appreciable hazard (Map 2A). These include many of the basins along the south side of the Santa Clara River Valley; Lyon Canyon; an unnamed basin southeast of Llajas Canyon; four of the tributaries to Tripas Canyon; and several of the basins along the mountain front behind Simi Valley. Debris-flow peak discharges between 3,001 and 6,000 ft^3/s (85 and 170 m^3/s) are estimated for these basins (Map 2B).

Simi Fire—2-year, 1-hour storm of 0.64 inches (16.3 mm)

Only 19 basins show a probability of debris-flow occurrence greater than 67% in response to the 2-year, 1-hour storm (Map 3A). These include Pico Canyon and the two adjacent unnamed basins; Towsley Canyon and the adjacent unnamed basin; Rice and Blind Canyons; all of the tributaries to Llajas Canyon; an unnamed basin west of Loftus Canyon; and one of the tributaries to Chivo Canyon. An unnamed basin between Wiley and Smith Canyons; Devil Canyon; a tributary to Chivo Canyon; Gillbrand Canyon; three unnamed basins behind Simi Valley; a tributary to Alamos Canyon; and all of the tributaries to Happy Camp Canyon show probabilities of debris-flow occurrence greater than 33% (Map 3A). Debris-flow peak discharges between 1,501 and 4,500 ft^3/s (42 and 127 m^3/s) are estimated for these basins (Map 3B).

Verdale Fire

The probabilities of debris-flow occurrence calculated for the Verdale fire in response to the 25-year, 10-year and 2-year recurrence, 1-hour duration storms are all less than 33% (Map 3A). Due to these low values, we did not calculate peak discharges for this fire.

CONCLUSIONS

The basins identified as having probabilities of debris-flow occurrence greater than about 33% and the highest peak discharges are extremely dangerous for anyone living, working, or recreating within or downstream from them during rainfall events similar to, or greater than, the storms used in this evaluation. Of the storms evaluated here, the hazard level is greatest for the 25-year storm, although the probability of this storm occurring is only about 4% in any given year. The probability of debris-flow occurrence is certainly lower for the 10- and 2-year storms; however, the estimated peak discharges of greater than 1,501 ft^3/s (42 m^3/s) associated with these storms can be quite destructive.

In addition to the potential dangers within these basins, areas downstream from the basin outlets are also at risk. In some of these areas homes were destroyed by the fire, and workers and residents may be busy cleaning and rebuilding sites. These people are at high risk for impact by debris flow during rainfall events such as those used in this assessment. In addition, in the event of the passage of a debris flow, there is a great possibility of culverts plugging or being overwhelmed, and of roads washing out. Such events can strand motorists for long periods of time. In some cases, drainages cross roads on blind curves where motorists could abruptly encounter debris-flow hazards on the road.

RECOMMENDATIONS

It is imperative to insure that people occupying businesses, homes, and recreational facilities downstream of the basins identified as the most hazardous are informed of the potential dangers from debris flows and flooding. Warning must be given even for those basins with mitigation structures at their mouths in the event that the structures are not adequate to contain potential debris-flow events. We further recommend site-specific debris-flow hazard assessments be performed above structures and facilities identified as being at risk and that could be impacted by flows from basins smaller than those evaluated here. In addition, this assessment is specific to post-fire debris-flow activity; further assessment of potential hazards posed by flash floods is necessary. And last, we highly recommend the establishment of an early-warning system for both flash floods and debris flows. Such a system should consist of an extensive reporting rain gage and stream-gage network coupled with National Weather Service weather forecasts. Any early-warning system should be coordinated with existing county and flood district facilities.

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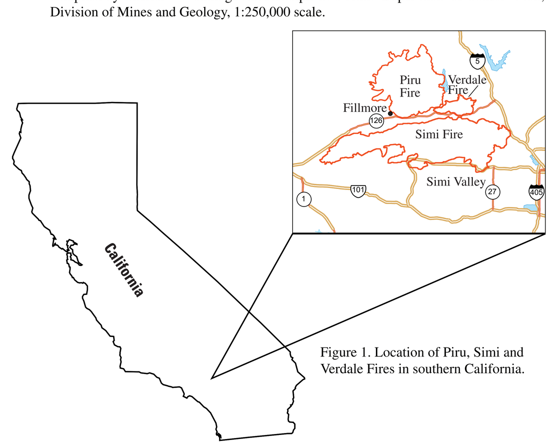

Figure 1. Location of Piru, Simi and Verdale Fires in southern California.

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