# Emergency Assessments of Postfire Debris-Flow Hazards for the 2009 La Brea, Jesusita, Guiberson, Morris, Sheep, Oak Glen, Pendleton, and Cottonwood Fires in Southern California

By Susan H. Cannon, Joseph E. Gartner, Michael G. Rupert, and John A. Michael

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Cover photograph: Flames from the 2009 Jesusita fire.

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# Emergency Assessments of Postfire Debris-Flow Hazards for the 2009 La Brea, Jesusita, Guiberson, Morris, Sheep, Oak Glen, Pendleton, and Cottonwood Fires in Southern California

By Susan H. Cannon, Joseph E. Gartner, Michael G. Rupert, John A. Michael, and Dennis M. Staley

## Abstract

This report presents an emergency assessment of potential debris-flow hazards from basins burned by the 2009 La Brea and Jesusita fires in Santa Barbara County, the Guiberson fire in Ventura County, the Morris fire in Los Angeles County, the Sheep, Oak Glen and Pendleton fires in San Bernardino County, and the Cottonwood fire in Riverside County, southern California. Statistical-empirical models developed to analyze postfire debris flows are used to estimate the probability and volume of debris-flows produced from drainage basins within each of the burned areas. Debris-flow probabilities and volumes are estimated as functions of different measures of basin burned extent, gradient, and material properties in response to both a 3-hour-duration, 2-year-recurrence thunderstorm and to a widespread, 12-hour-duration, 2-year-recurrence winter storm. This assessment provides critical information for issuing warnings, locating and designing mitigation measures, and planning evacuation timing and routes within the first two winters following the fire.

## Introduction

Debris flows can pose substantial hazards to life and property. Fast-moving debris flows generated from recently burned areas are particularly dangerous because they can occur in places where flooding or debris flows have not been observed in the past and can be generated in response to very little rainfall (Cannon and others, 2008, 2010). In recently burned areas, rainfall that is normally captured and stored by vegetation can run off almost instantly, causing creeks and drainage areas to flood much sooner during a storm and with more water than is expected under unburned conditions. Soils in a burned area can be highly erodible, and so runoff will contain large amounts of ash, mud, boulders, and vegetation. Within the burned area and downstream, the powerful force of rushing water, soil, and rock can destroy buildings, roadways, culverts, and bridges and can cause injury or death. In addition, sediment transported by debris flows can degrade water quality and reduce the storage capacities of reservoirs.

The association between debris flows, floods, and wildfires is well established in the steeplands of southern California. When the fires that consume the vegetation from the extremely steep, rugged canyons are followed by the high-intensity rainstorms that characterize the area, destructive floods and debris flows are a common result (for example, Eaton, 1936; Krammes and Rice, 1963; Scott and Williams, 1978; Wells, 1987; McPhee, 1989; Spittler, 1995; Cannon, 2001).

In response to the potential for damaging debris flows from basins burned by the La Brea, Jesusita, Guiberson, Morris, Sheep, Oak Glen, Pendleton, and Cottonwood fires of 2009 in southern California, we provide here an emergency assessment of debris-flow hazards for the each of the fires (fig. 1). This assessment uses a pair of predictive models developed specifically for postfire debris-flow processes that address two fundamental questions in debris-flow hazard evaluations: What is the likelihood that a given basin will produce debris flows, and how big will the debris flows be? This information is critical for issuing warnings for specific areas, locating and designing mitigation measures, and planning for evacuation timing and routes. See Cannon and others (2009) for a similar assessment for the Station fire that burned in the San Gabriel Mountains in 2009.

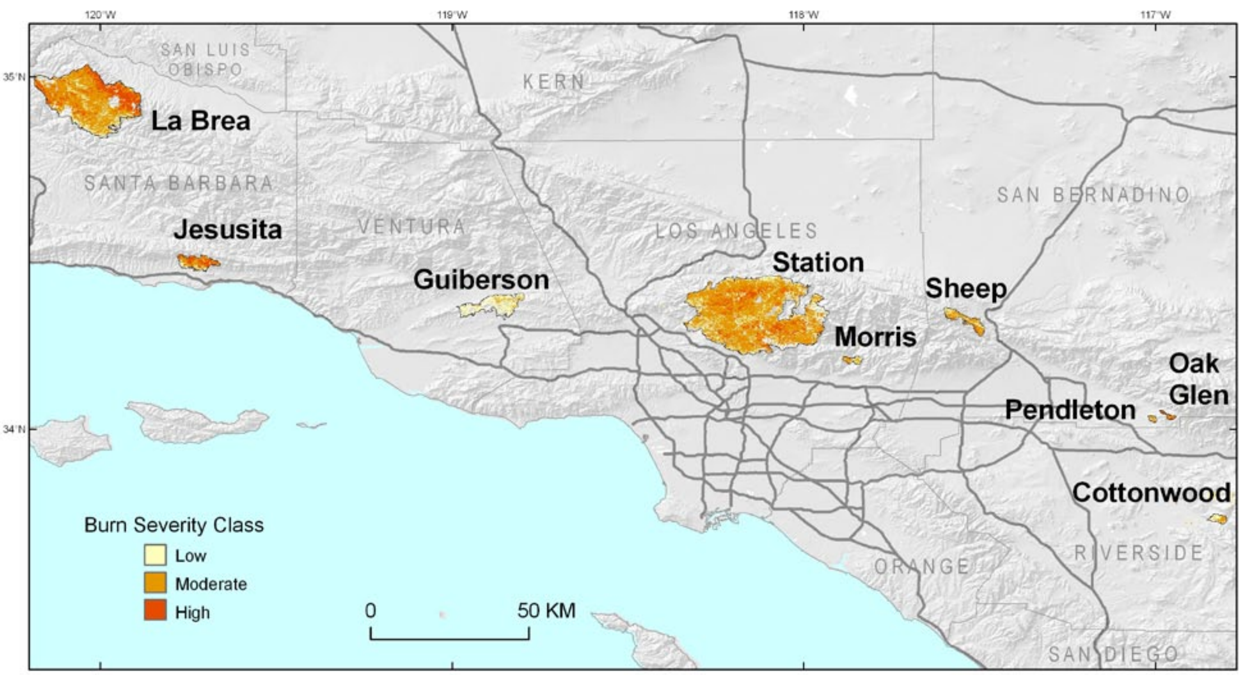



**Figure 1.** Burn severity and areas burned by the 2009 La Brea, Jesusita, Guiberson, Station, Morris, Sheep, Oak Glen, Pendleton, and Cottonwood fires in southern California. For assessment of debris-flow hazards for the Station fire, see Cannon and others (2009).

## Methods and Approach

In studies of postfire debris-flow processes throughout the western United States, Cannon and Gartner (2005) demonstrated that the great majority of fire-related debris flows initiate through a process of progressive bulking of storm runoff with sediment eroded both from hillslopes and from channels. Any infiltration-triggered landsliding that may occur in burned basins generally contributes little to the total volume of material transported from the basin (Cannon and others, 2001). These findings point to a striking postfire shift from an infiltration-dominated system to one dominated by runoff processes and indicate that methods traditionally used to assess landslide hazards are not appropriate in a postfire environment. Accordingly, it is necessary to use methods that are specifically for postfire processes.

For this effort, a pair of statistical-empirical models was used to estimate the probability of a debris flow and the volume of a debris-flow from individual drainage basins in response to given storm events in southern California. The probability model was developed using logistic multiple regression analyses of data from 517 basins in 21 fires that burned between 2003 and 2008 in southern California (S.H. Cannon, unpub. data, 2009). Conditions in each basin were quantified using several measures of areal burned extent, basin gradient, soils, and storm rainfall. Statistical analyses were used to identify the variables that most strongly influenced debris-flow occurrence and to build the predictive model (table 1).

**Table 1.** Variables in the debris-flow probability and volume models.

| | Probability model | Volume model |
|---|---|---|
| Burned Extent | Percentage of basin burned at high and moderate severity | Total area burned |
| Soil Properties | Percent clay<br>K-factor (erodibility) | None |
| Basin Characteristics | Length of the longest flow path<br>Elevation change<br>Percentage of burned basin with slopes greater than or equal to 30 percent | Length of the longest flow path<br>Elevation change |
| Storm Rainfall | Average storm intensity<br>Storm duration | Total storm rainfall |

A different statistical model was used to estimate the volume of material that could issue from a basin mouth in response to a given storm. This model was developed using multiple linear regression analyses of data compiled from 40 debris-flow-producing basins burned by nine fires in southern California where the measured debris-flow volume could be attributed to a single storm (J.E. Gartner, unpub. data, 2009). Volume measurements were based on sediment-retention basin cleanout records and field measurements. As with the probability model, statistical analyses were used to identify the variables that most strongly influenced debris-flow volume and to build the predictive model (table 1).

## Model Implementation

The two models were implemented for each of the fires by first delineating the basins to be evaluated within the burned perimeter by using topographic information derived from 10-meter (m) digital elevation models (DEMs) and geographic information system (GIS) hydrological tools. Basin outlets were positioned at breaks in slope along mountain fronts, along drainages, and at the burned perimeter. Basin areas ranged between 0.01 square kilometers ($km^2$) and 30 $km^2$, comparable to the basin sizes used in the development of the regression models. Basins larger than 30 $km^2$ were subdivided into tributaries to the main channel. Measures of the physical properties of soils within each basin were obtained from the STATSGO soils database (Schwartz and Alexander, 1995). Soil burn severity maps were used to identify the areas burned at high, moderate, and low severity within each basin. Soil burn severity maps of the La Brea and Jesusita fires were provided by the U.S. Department of Agriculture (USDA) Forest Service Burned Area Emergency Response (BAER) Team. The U.S. Geological Survey Earth Observation and Science Center (EROS) BAER Image Support Team provided the burn severity mapping of the Guiberson fire, and USDA Forest Service Remote Sensing Applications Center (RSAC) BAER Image Support Team (http://activefiremaps.fs.fed.us/baer/download.php) provided the maps of the remaining fires.

### Storm Rainfall

Postfire debris flows in southern California can be triggered in response to short-duration, high-intensity thunderstorms, as well as during longer duration, lower intensity storms, both of which are short-recurrence-interval storms (Cannon and others, 2008, 2010). To identify the potential effects of both types of storms, we estimated the probability that a given basin will produce debris flows and a possible debris-flow volume at the basin outlet in response to both a 3-hour-duration, 2-year-recurence thunderstorm and to a widespread, 12-hour-duration, 2-year-recurrence storm (table 2). Any storm with a 2-year-recurrence interval is considered to have a 50 percent chance of occurring in any given year.

Table 2. Storm rainfall used in hazard assessments for each fire evaluated in this report.
[in., inches; hr, hours; mm, millimeters]

| Fire | 3-hour-duration, 2-year-recurrence storm | | 12-hour-duration, 2-year-recurrence storm | | Source |
|---|---|---|---|---|---|
| | Total rainfall, in mm (in) | Average rainfall intensity, in mm/hr (in/hr) | Total rainfall, in mm (in) | Average rainfall intensity, in mm/hr (in/hr) | |
| La Brea | 19.1 (0.75) | 6.37 (0.25) | 63.5 (2.50) | 5.3 (0.28) | Hershfield, 1961 |
| Jesusita | 38.1 (1.5) | 12.7 (0.50) | 76.2 (3.00) | 6.3 (0.30) | Hershfield, 1961 |
| Guiberson | 29.2 (1.15) | 9.7 (0.38) | 58.4 (2.30) | 4.9 (0.19) | Hershfield, 1961 |
| Morris | 44.5 (1.75) | 14.8 (0.58) | 108.0 (4.25) | 9.0 (0.25) | Bonnin and others, 2006 |
| Sheep | 39.6 (1.56) | 13.2 (0.52) | 87.6 (3.45) | 7.3 (0.19) | Bonnin and others, 2006 |
| Oak Glen | 25.4 (1.00) | 8.5 (0.33) | 50.8 (2.00) | 4.2 (0.17) | Hershfield, 1961 |
| Pendleton | 25.4(1.00) | 8.5 (0.33) | 50.8 (2.00) | 4.2 (0.17) | Hershfield, 1961 |
| Cottonwood | 22.9 (0.9) | 7.6 (0.30) | 43.7 (1.72) | 3.6 (0.14) | Bonnin and others, 2006 |

### Identification of Potential Debris-Flow Hazards

Maps of each of the burned areas viewed at approximately 1:6,000 scale on the Geospatial Multi-Agency Coordination (GeoMAC) web site (*http://www.geomac.gov/*) and Google Earth were used to identify potential rivers, canyons, roads, and neighborhoods that could be damaged by debris flows.

## Debris-Flow Probability and Volume Estimates

In the follow section, we present estimates of postfire debris-flow probabilities and volumes and potential debris-flow impacts in response to the 3-hour-duration, 2-year-recurrence and 12-hour-duration, 2-year-recurrence storms for each of the burned areas. These results are presented starting with the northernmost fire (the La Brea) and proceeding toward the south to the southernmost (the Cottonwood fire).

## La Brea Fire, Santa Barbara County

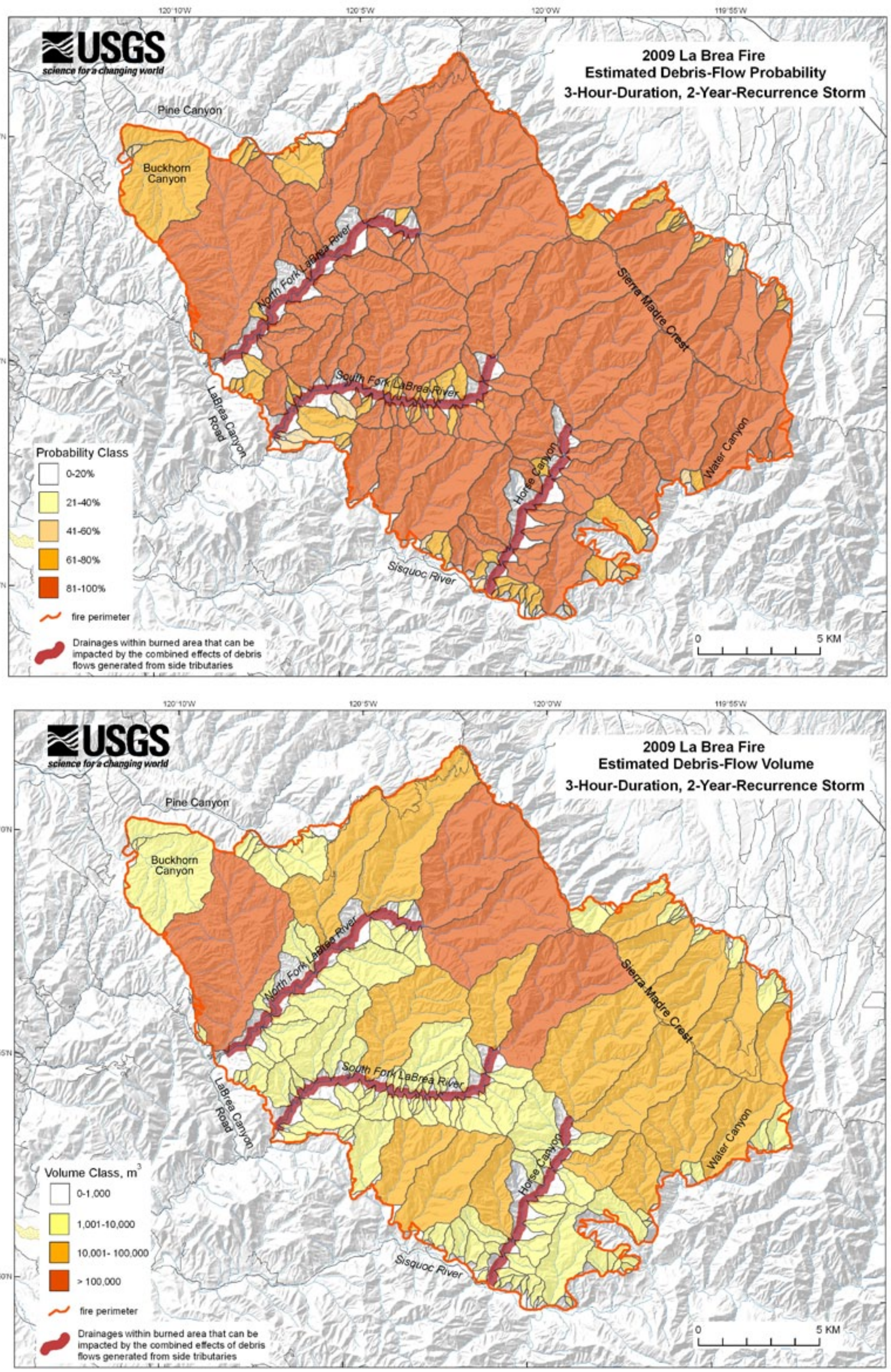
### 3-Hour-Duration, 2-Year-Recurrence Storm

In response to the 3-hour-duration storm, probabilities of debris-flow occurrence greater than 80 percent were estimated for 71 of the 152 basins evaluated in the La Brea fire, probabilities between 61 and 80 percent were calculated for 59 basins, between 41 and 60 percent for 17 basins, and 40 percent or less for 5 basins (fig. 2*A*). Those basins having probabilities greater than 80 percent drain both sides of the Sierra Madre Crest and contribute to the North and South Forks of the La Brea River, Horse Canyon, and the Sisquoc River. Compared with the number of high-probability basins in past hazard assessments of recently burned areas, this is a large number of basins with high probabilities and reflects the combined effects of extensive areas burned at high and moderate severity, steep slopes, and low clay content of soils in the area.

Also in response to the 3-hour-duration storm, debris-flow volumes greater than 100,000 $m^3$ were estimated for three of the tributary basins to the North Fork of the La Brea River and one basin that drains into the South Fork of the La Brea River (fig. 2*B*). Debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for 18 additional tributaries to the North and South Forks of the La Brea River, Horse Canyon, the Sisquoc River (including Water Canyon), and on the east side of the Sierra Madre Crest, and volumes of 10,000 $m^3$ or less were calculated for the remaining basins.

The high probabilities of debris flow and large debris-flow volumes identified in response to the 3-hour-duration, 2-year-recurrence storm indicate a substantial debris-flow hazard to the North and South Forks of the La Brea River. This assessment also indicates high probabilities that large debris flows will travel into the Sisquoc River, Horse and Water Canyons, and the basins on the east side of the Sierra Madre Crest. These debris flows could damage any neighborhoods, buildings, roads, bridges, culverts, and reservoirs located within and downstream of the burned area.

Stream reaches of the North and South Forks of the La Brea River and Horse Canyon within the burn perimeter that could be impacted by debris flows contributed from side tributaries are indicated in figure 2*A*, *B*. Additional assessment is necessary to identify how far these flows could extend beyond the burn perimeter and to characterize how debris flows from Water and Horse Canyons might affect the Sisquoc River.




(A)

(B)

**Figure 2.** La Brea fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the La Brea fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

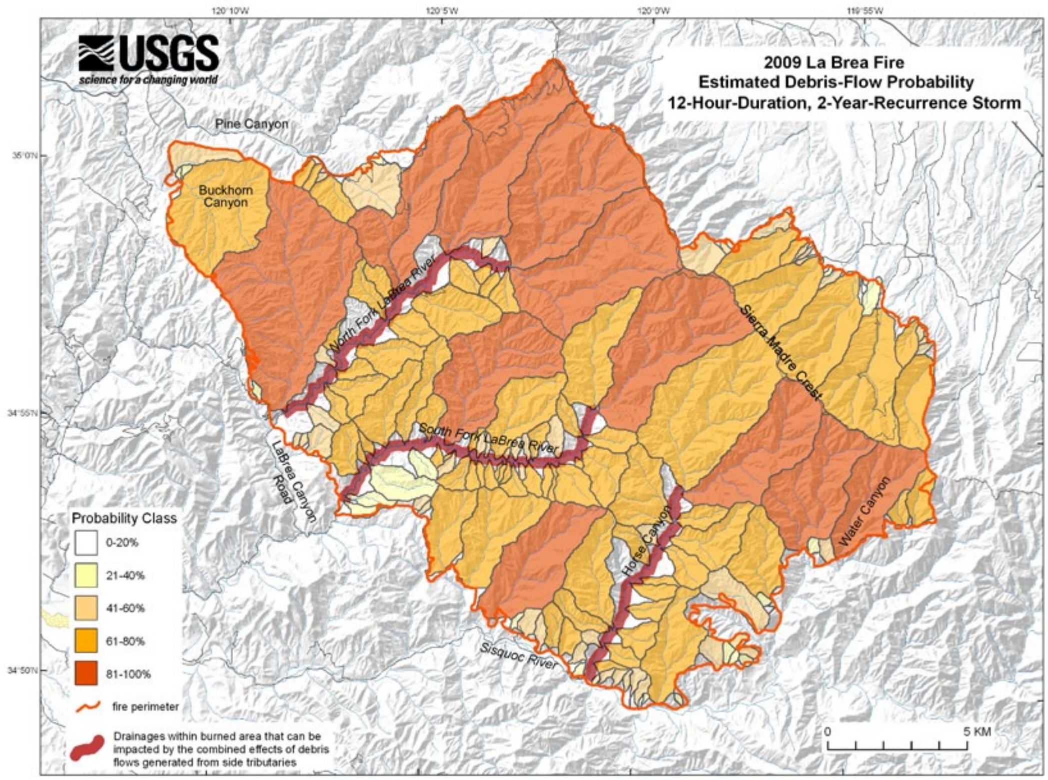
### 12-Hour-Duration, 2-Year-Recurrence Storm

In response to the 12-hour-duration storm, probabilities of debris-flow occurrence greater than 80 percent were estimated for 11 of the 152 basins evaluated in the La Brea fire (fig. 3*A*). Debris-flow probabilities between 61 and 80 percent were estimated for 74 basins, between 41 and 60 percent for 43 basins, between 21 and 40 percent for 21 basins, and of 20 percent or less for three basins. Those basins with probabilities greater than 80 percent contribute to the North and South Forks of the La Brea River, Horse Canyon, and the Sisquoc River.

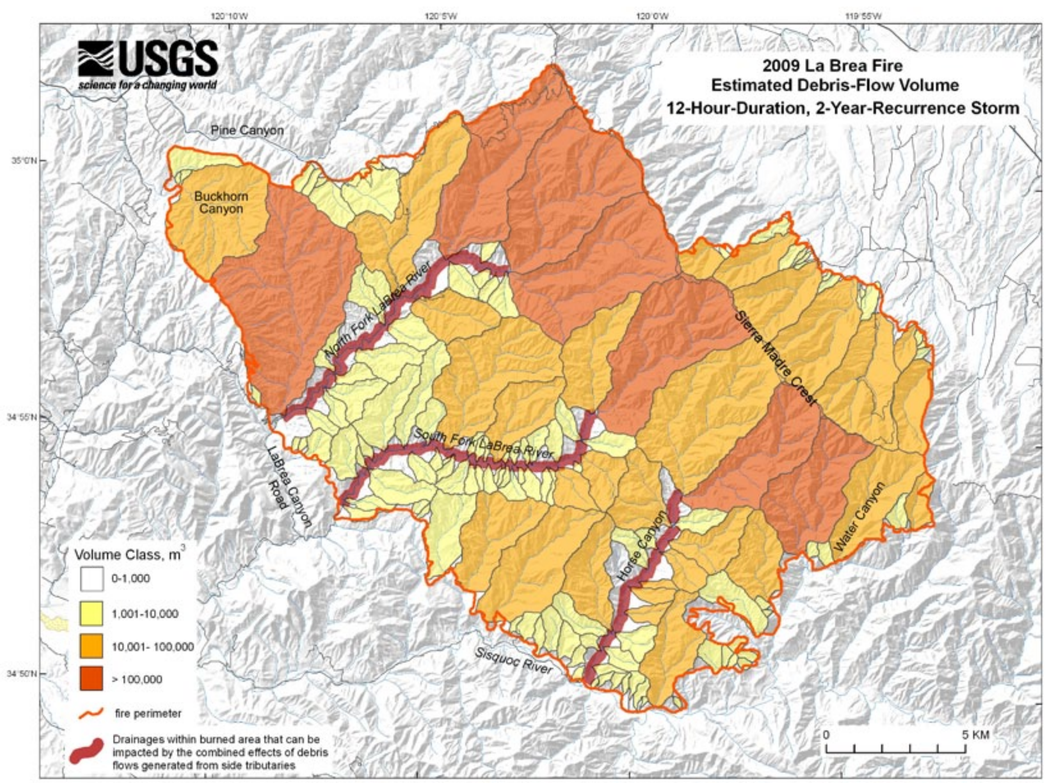
Also in response to the 12-hour-duration storm, debris-flow volumes greater than 100,000 $m^3$ were estimated for four of the tributary basins to the North Fork of the La Brea River, and one basin each that drain into the South Fork of the La Brea River, Horse Canyon and the Sisquoc River (fig. 3*B)*. Debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for 29 tributaries to the North and South Forks of the La Brea River, Horse Canyon, the Sisquoc River (including Water Canyon), and on the east side of the Sierra Madre Crest. Debris-flow volumes between 1,001 and 10,000 $m^3$ were estimated for the remainder of the basins.

The high probabilities of debris flow and large debris-flow volumes identified in response to the 12-hour-duration, 2-year-recurrence storm for basins burned by the La Brea fire indicate considerable debris-flow hazards for tributaries to the North and South Forks of the La Brea River, Horse Canyon and the Sisquoc River. There is also a high probability of debris flows with volumes between 10,001and 100,000 $m^3$ being produced from additional tributaries to these rivers, as well as from Water Canyon and the basins on the east side of the Sierra Madre Crest. This assessment indicates the potential for destructive debris-flow to damage buildings, roads, bridges, culverts, and reservoirs located within and downstream of the burned area.

Stream reaches of the North and South Forks of the La Brea River and Horse Canyon within the burn perimeter that could be impacted by debris flows contributed from side tributaries are indicated in figure 3*A*,*B*. Additional assessment is necessary to identify how far these effects could extend beyond the burn perimeter and to characterize the impacts of debris flows from Water and Horse Canyons on the Sisquoc River.




(A)




(B)

**Figure 3.** La Brea fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the La Brea fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

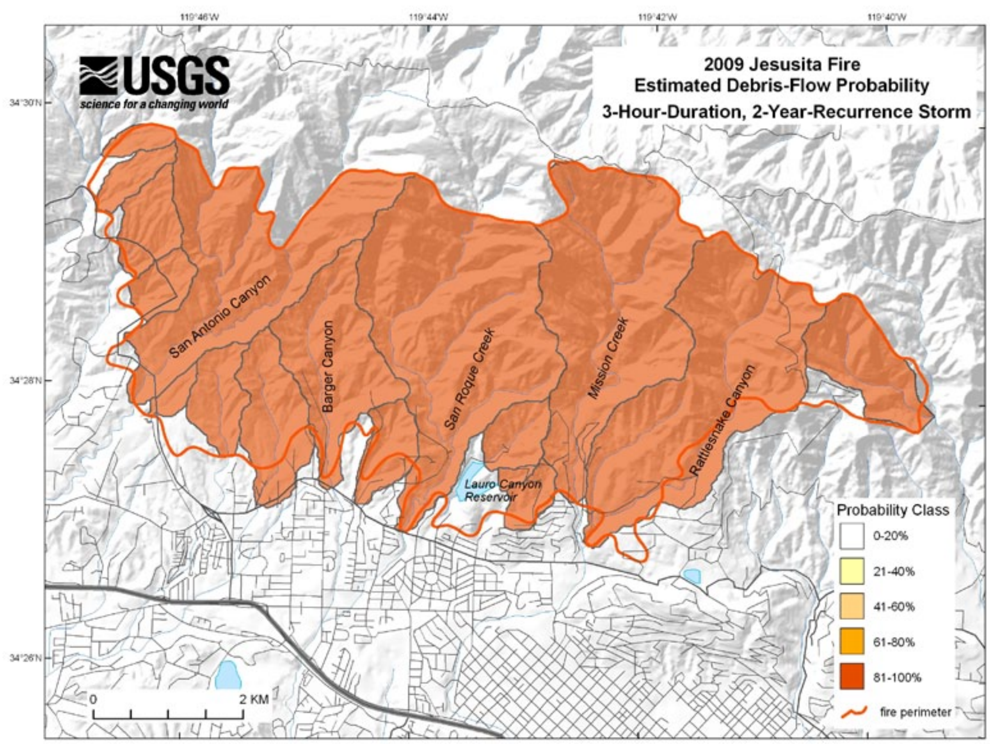
## Jesusita Fire, Santa Barbara County

### 3-Hour-Duration, 2-Year-Recurrence Storm

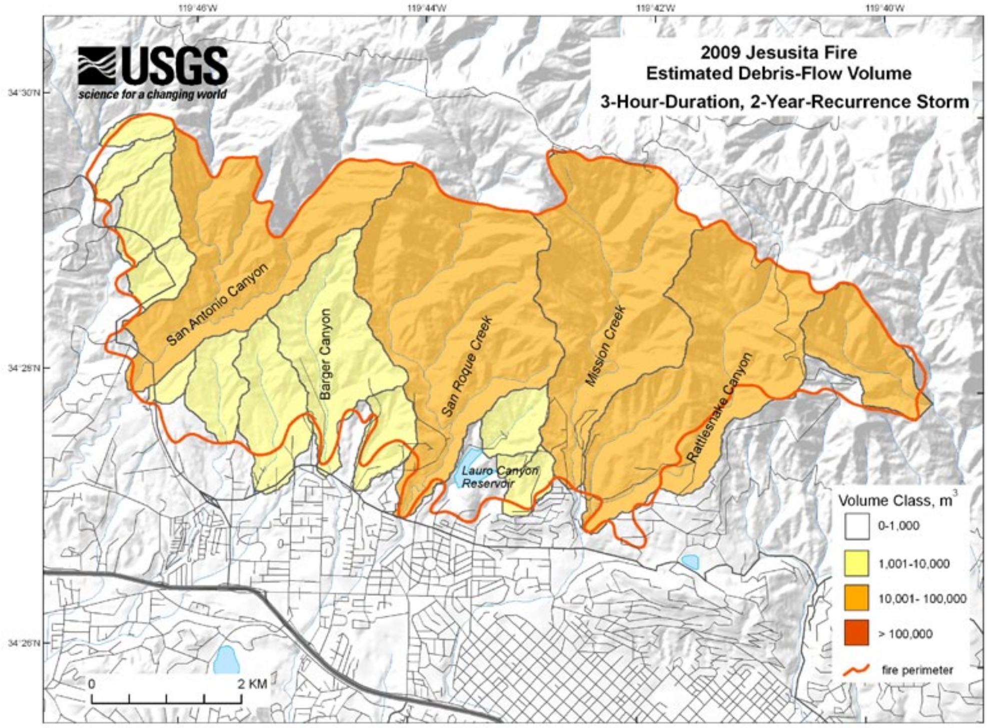
Conditions within all 16 basins evaluated for the Jesusita fire resulted in estimates of the probability of debris-flow occurrence greater than 80 percent in response to the 3-hour-duration storm (fig. 4*A)*. Compared with past hazard assessments of recently burned areas, these are very high probabilities that reflect the combined effects of extensive areas burned at high and moderate severity, steep slopes, and low clay content of soils in the area.

No debris-flow volumes greater than 100,000 $m^3$ were estimated for any of the basins in response to the 3-hour-duration storm. However, debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for San Antonio Canyon, San Roque Creek, Mission Creek, Rattlesnake Canyon, and the unnamed canyon on the easternmost edge of the burned area (fig. 4*B)*. Volumes between 1,001 and 10,000 $m^3$ were estimated for the remaining basins.

The high probabilities of debris flow and large debris-flow volumes identified in response to the 3-hour-duration, 2-year-recurrence storm for San Antonio Canyon, San Roque Creek, Mission Creek, Rattlesnake Canyon, and the unnamed canyon on the easternmost edge of the burned area indicate that postfire debris flows could pose considerable hazards to life and property within and downstream from these basins. Debris-flow probabilities greater than 80 percent and debris-flow volumes between 1,001 and 10,000 $m^3$ estimated for the remaining basins indicate a high probability for moderately sized debris flows to deposit sediment in Lauro Canyon Reservoir as well as damage neighborhoods, buildings, roads, bridges, and culverts located within and downstream of the burned area.



(A)



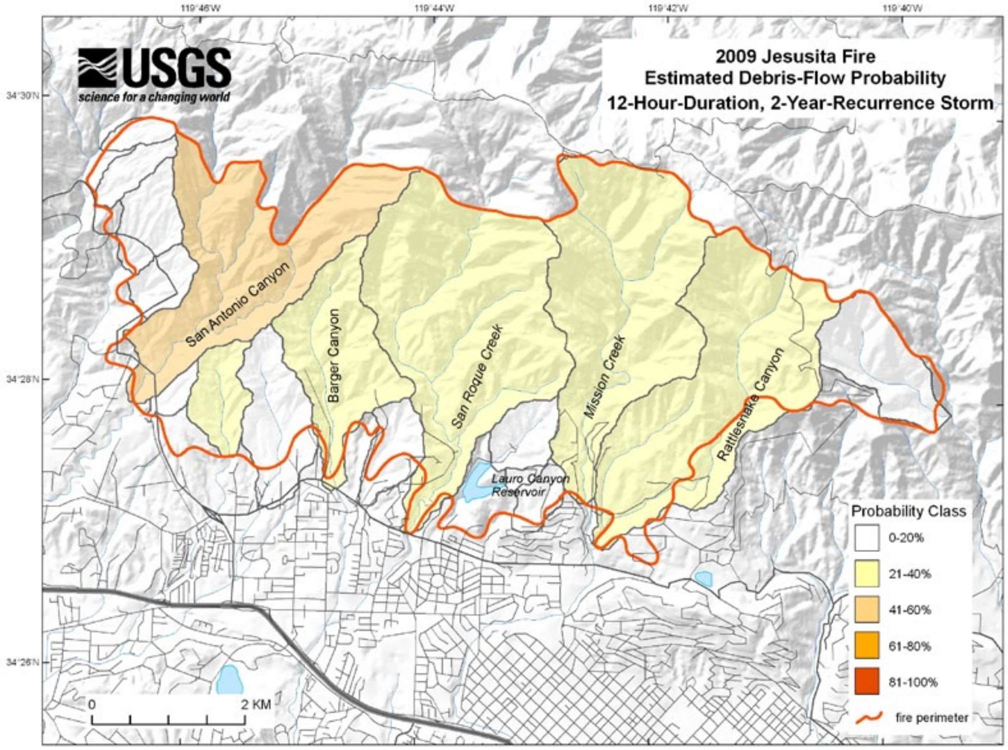
(B)

**Figure 4.** Jesusita fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Jesusita fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

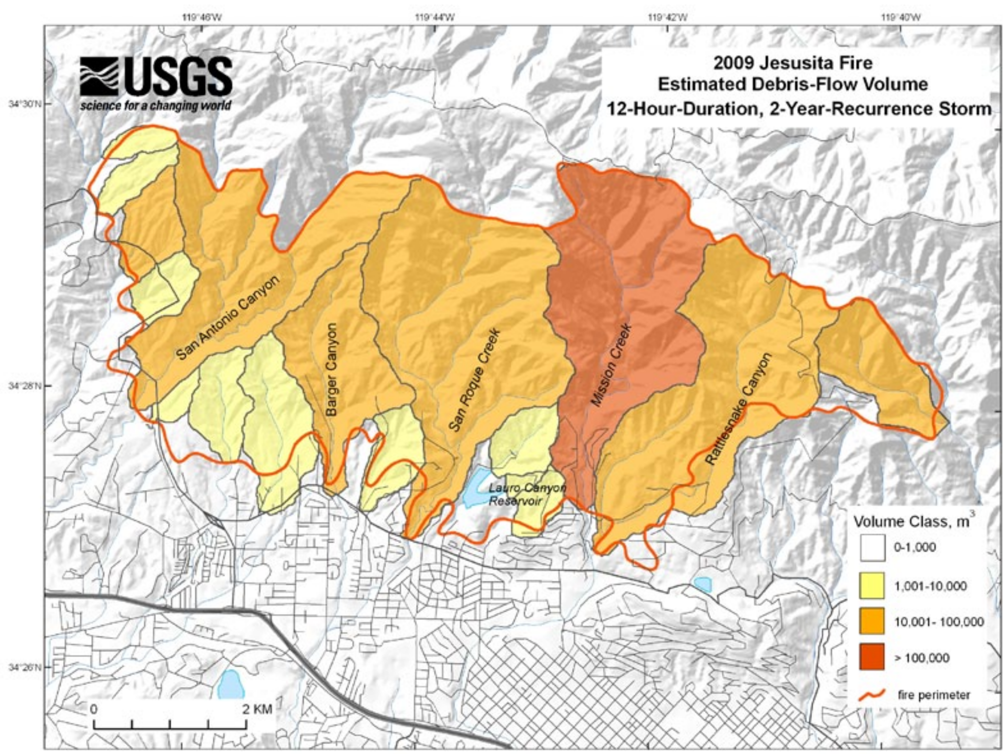
## 12-Hour-Duration, 2-Year-Recurrence Storm

A debris-flow probability between 41 and 60 percent was obtained for San Antonio Canyon in response to the 12-hour-duration storm (fig. 5*A)*. Debris-flow probabilities between 21 and 40 percent were estimated for Rattlesnake Canyon, Mission Creek, San Roque Creek, Barger Canyon, and an unnamed canyon west of Barger Canyon. For the remaining basins we estimated probabilities of 20 percent or less. A debris-flow volume greater than 100,000 $m^3$ was estimated for Mission Creek, whereas those for an unnamed basin west of San Antonio Canyon, San Antonio Canyon itself, Barger Canyon, San Roque Creek, Rattlesnake Canyon, and the unnamed canyon on the easternmost edge of the fire were estimated at between 10,001 and 100,000 $m^3$ (fig. 5*B)*. For the remainder of the basins, volume estimates were between 1,001 and 10,000 $m^3$.

This assessment indicates that although the probability of debris-flow occurrence is relatively low in response to the 12-hour-duration, 2-year-recurrence storm, should debris flows be produced from the unnamed basin west of San Antonio Canyon, San Antonio Canyon itself, Barger Canyon, San Roque Creek, Mission Creek, Rattlesnake Canyon, and the unnamed canyon on the easternmost edge of the fire, they could be of large and potentially destructive sizes. Such debris flows could pose considerable hazards to life and property within and downstream from these basins. There is a low probability that debris flows could contribute between 1,001 and 10,000 $m^3$ of sediment to Lauro Canyon Reservoir and to neighborhoods immediately adjacent to the burned area.




(A)




(B)

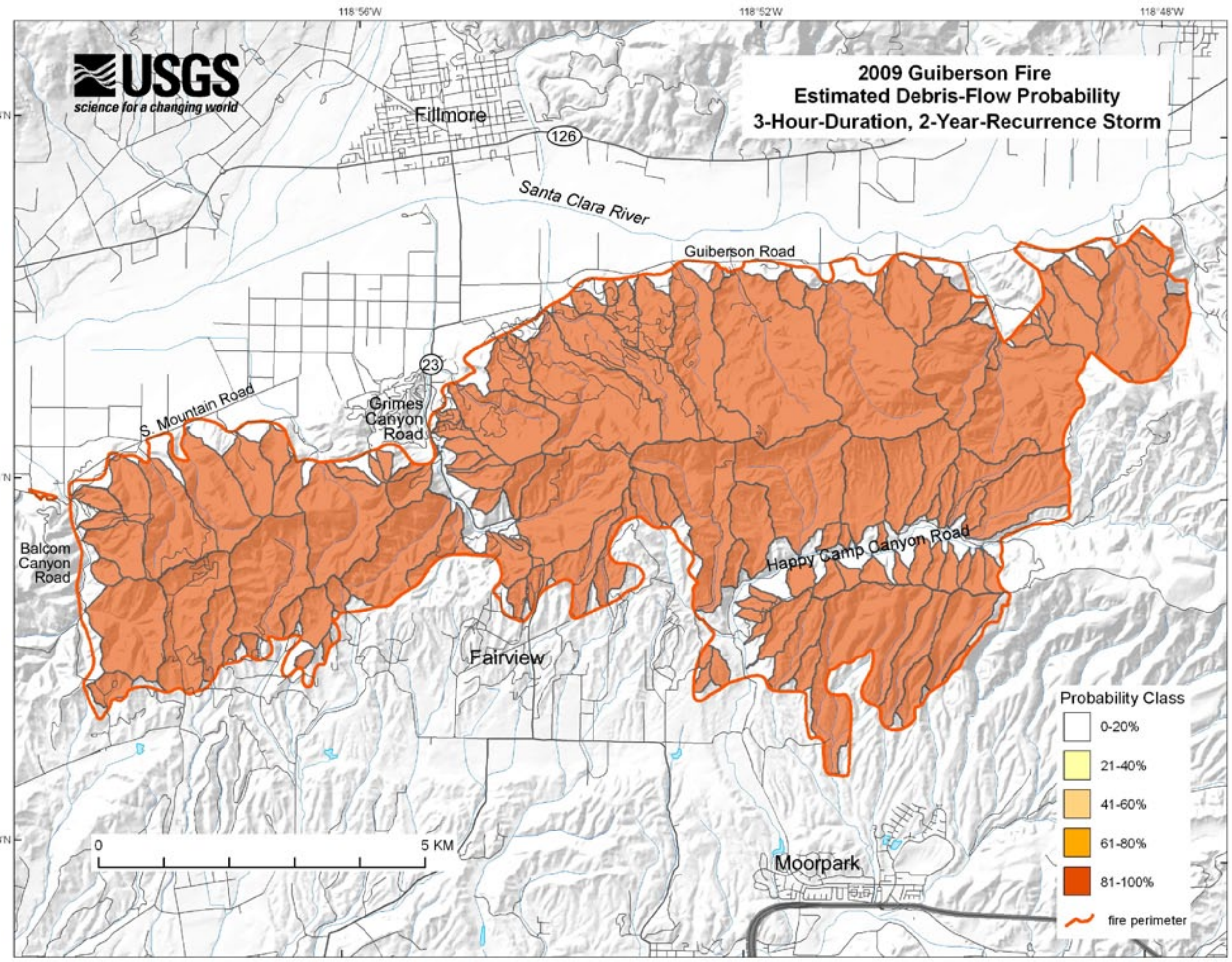
**Figure 5.** Jesusita fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Jesusita fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

## Guiberson Fire, Ventura County

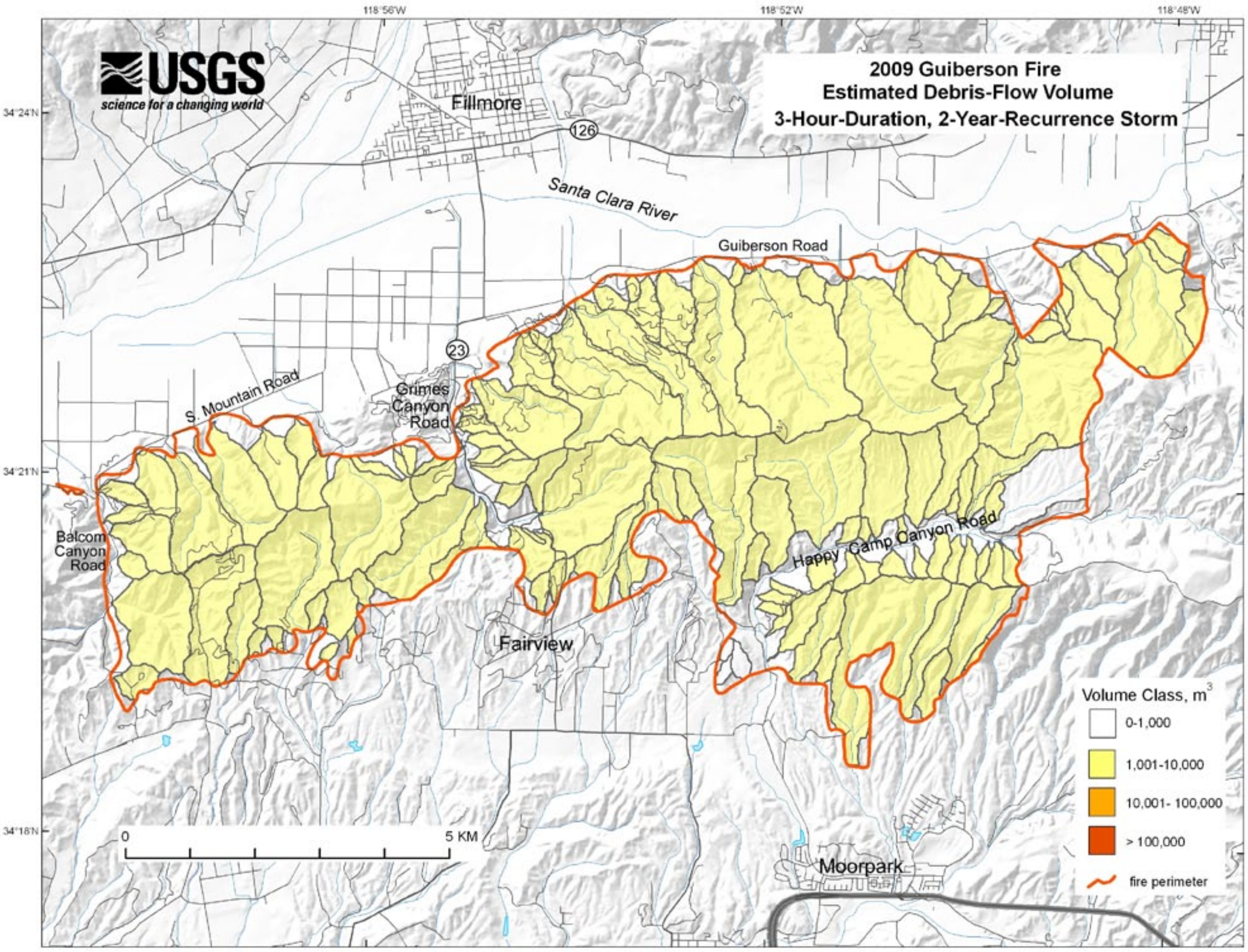
### 3-Hour-Duration, 2-Year-Recurrence Storm

Conditions within all 121 basins evaluated for the Guiberson fire resulted in estimates of the probability of debris-flow occurrence greater than 80 percent in response to the 3-hour-duration storm (fig. 6*A*). Debris-flow volumes between 1,001 and 10,000 $m^3$ were estimated for 117 of the burned basins (fig. 6*B*). Debris-flow volumes of 1,000 $m^3$ or less were estimated for the remaining basins.

This evaluation indicates that in the event of a 3-hour-duration, 2-year-recurrence storm, there is a high probability that debris flows could produce as much as 10,000 $m^3$ of material from some of the basins burned by the Guiberson fire, particularly where Happy Camp Canyon Road, Guiberson Road, Grimes Canyon Road, South Mountain Road, and Balcom Canyon Road cross, or are intersected by, burned drainages.



(A)



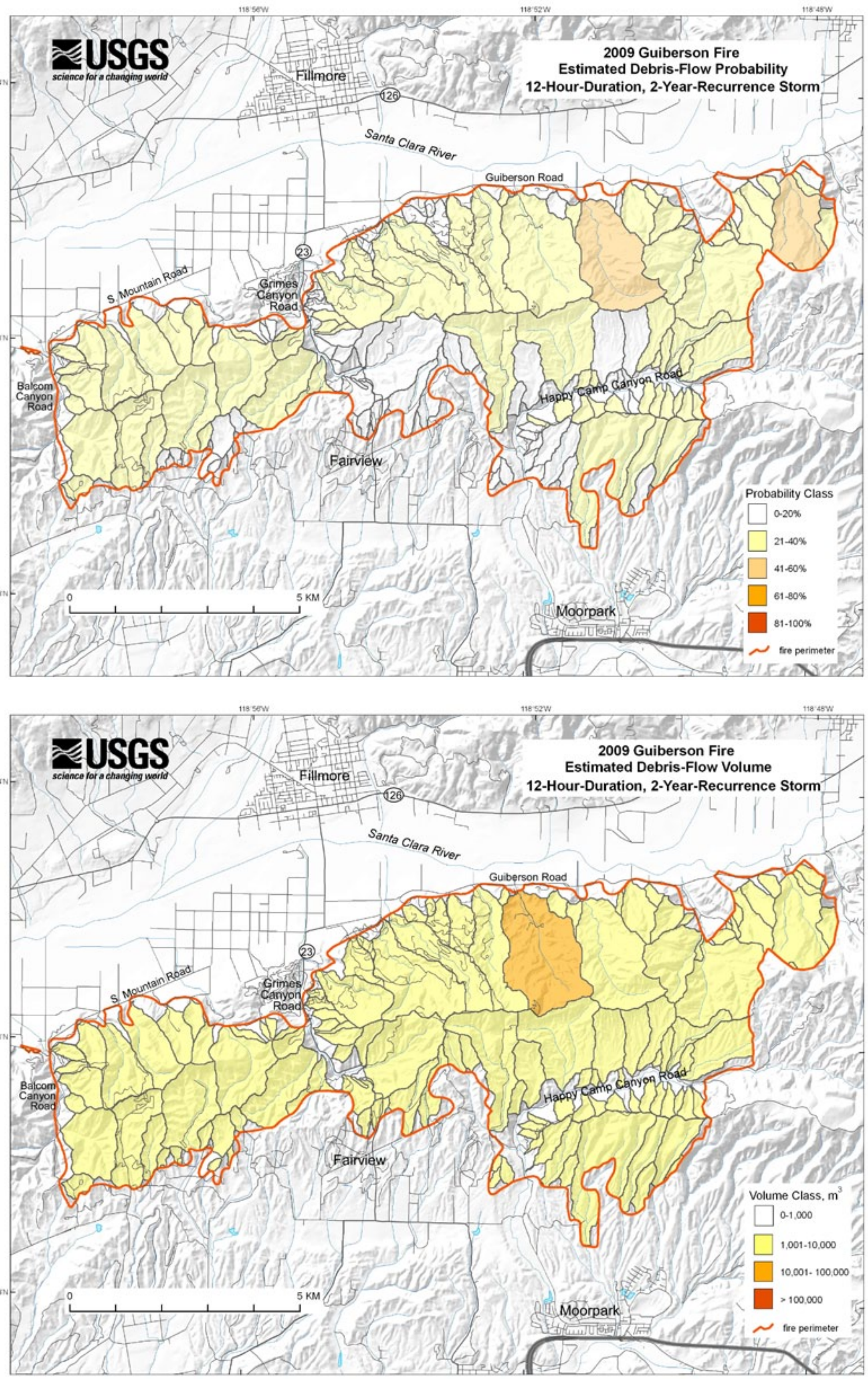
(B)

**Figure 6.** Guiberson fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Guiberson fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

## 12-Hour-Duration, 2-Year-Recurrence Storm

Debris-flow probabilities between 41 and 60 percent were obtained for two of the basins on the northeastern edge of the area burned by the Guiberson fire response to the 12-hour-duration storm (fig. 7*A)*. Debris-flow probabilities between 21 and 40 percent were determined for 74 basins, and 20 percent or less for the remaining basins. A debris-flow volume between 10,001 and 100,000 $m^3$ was estimated for one burned basin adjacent to Guiberson Road, and volumes less than 10,000 $m^3$ were determined for the remaining basins (fig. 7*B)*.

This evaluation indicates that in the event of a 12-hour-duration, 2-year-recurrence storm, the highest potential for debris-flow damage is along Guiberson Road at the outlets of the three basins that show either the highest probability or the largest volume estimates. The relatively low probabilities of debris flow and small debris-flow volumes identified for the remaining basins indicate a negligible postfire debris-flow hazard elsewhere in the burned area.




(A)

(B)

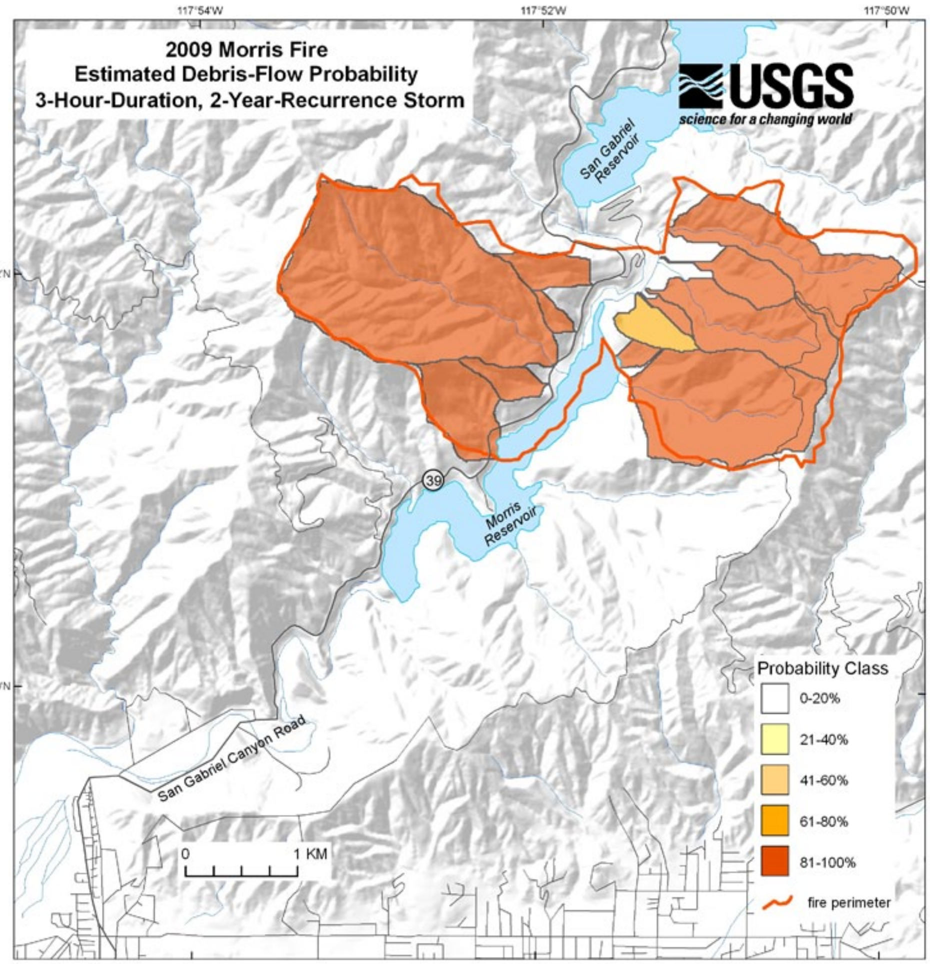
**Figure 7.** Guiberson fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Guiberson fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

## Morris Fire, Los Angeles County

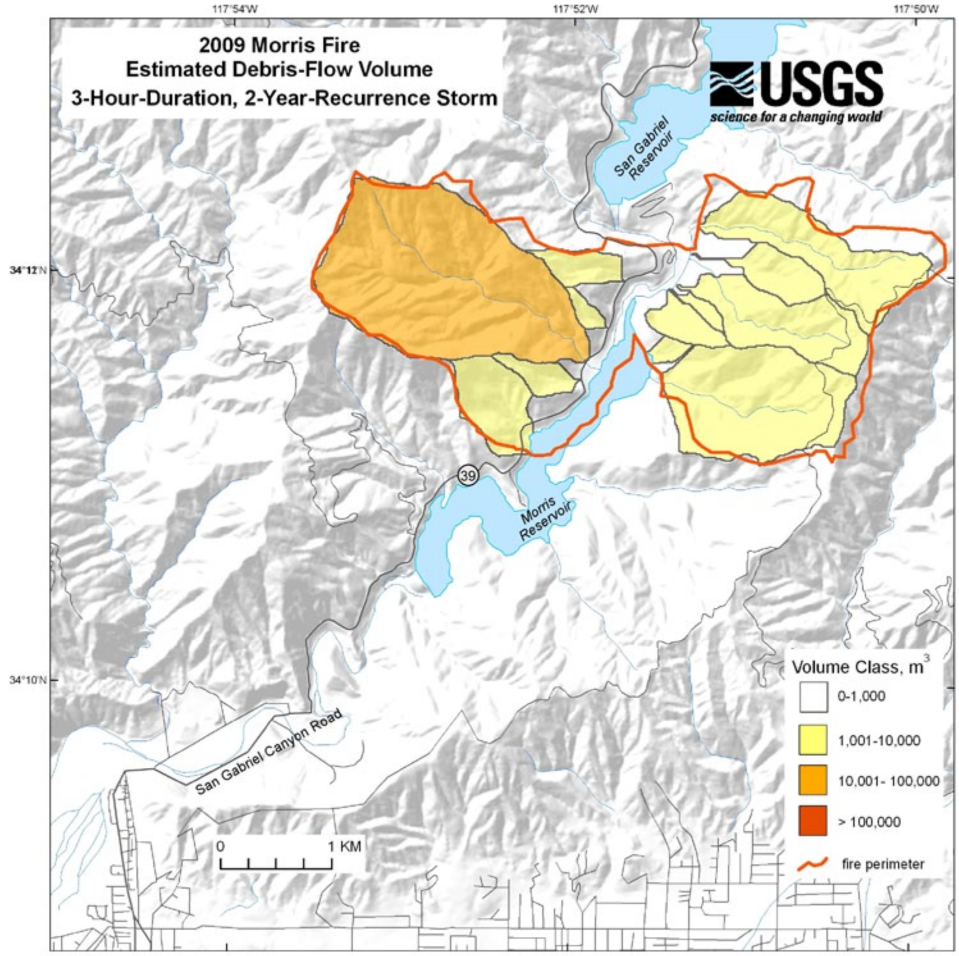
### 3-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence greater than 80 percent were estimated for all but one of 12 basins evaluated for the Morris fire in response to the 3-hour-duration storm (fig. 8*A*). A debris-flow volume between 10,001 $m^3$ and 100,000 $m^3$ was estimated for the largest basin on the northwest edge of the area burned by the Morris fire, whereas volumes between 1,001 $m^3$ and 10,000 $m^3$ were estimated for the remaining basins (fig. 8*B*).

This evaluation indicates that in the event of the 3-hour-duration, 2-year-recurrence storm, there is a high probability that postfire debris flows with volumes less than about 100,000 $m^3$ could cross Highway 39 (San Gabriel Canyon Road) and contribute sediment to Morris Reservoir.




(A)



(B)

**Figure 8.** Morris fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Morris fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

## 12-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence greater than 80 percent were estimated in response to the 12-hour-duration storm for all 12 basins evaluated for the Morris fire (fig. 9*A)*. Debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for 10 basins, whereas volumes between 1,001 and 10,000 $m^3$ were estimated for the remaining two basins (fig. 9*B)*.

This evaluation indicates that in the event of the occurrence of a 12-hour-duration, 2-year-recurrence storm, there is a high probability that debris flows with volumes between 1,001 and 10,000 $m^3$ could cross Highway 39 (San Gabriel Canyon Road) and contribute sediment to Morris Reservoir.

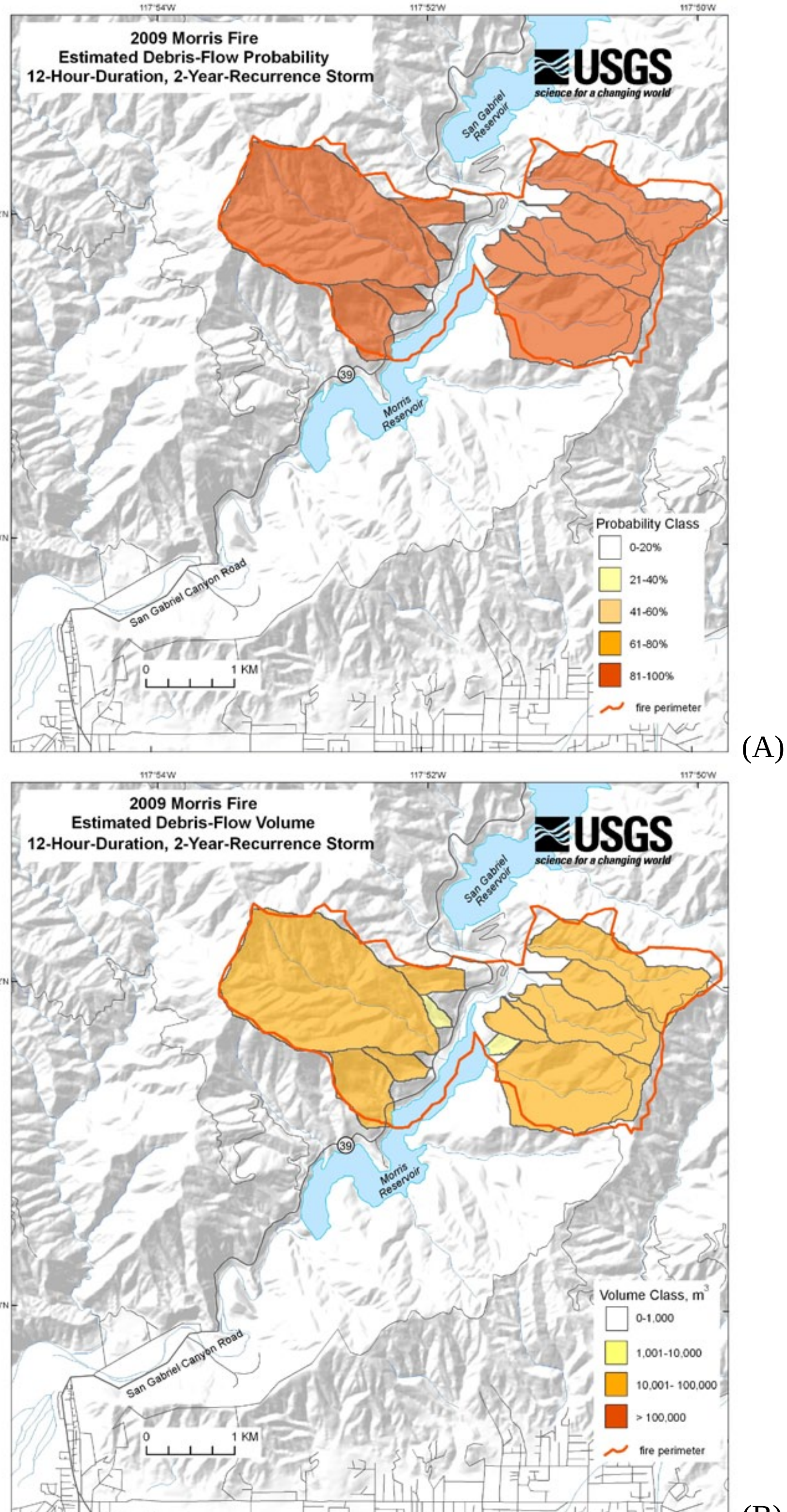


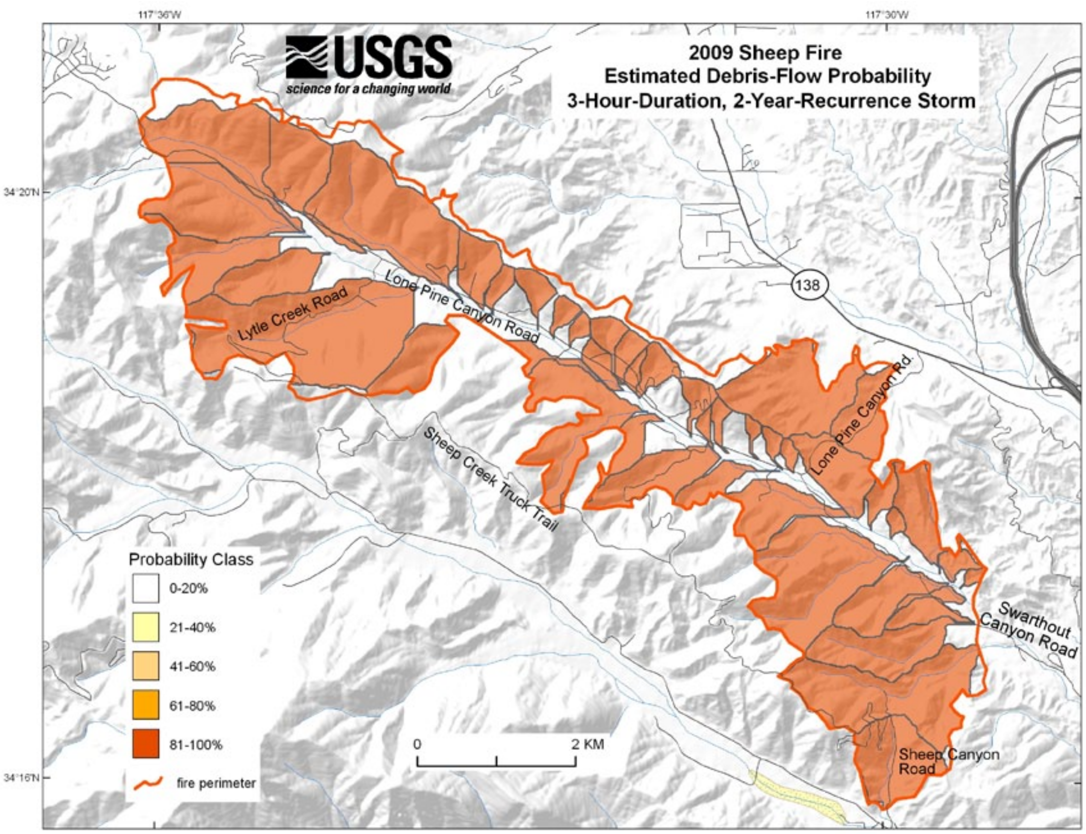

**Figure 9.** Morris fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Morris fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

## Sheep Fire, San Bernardino County

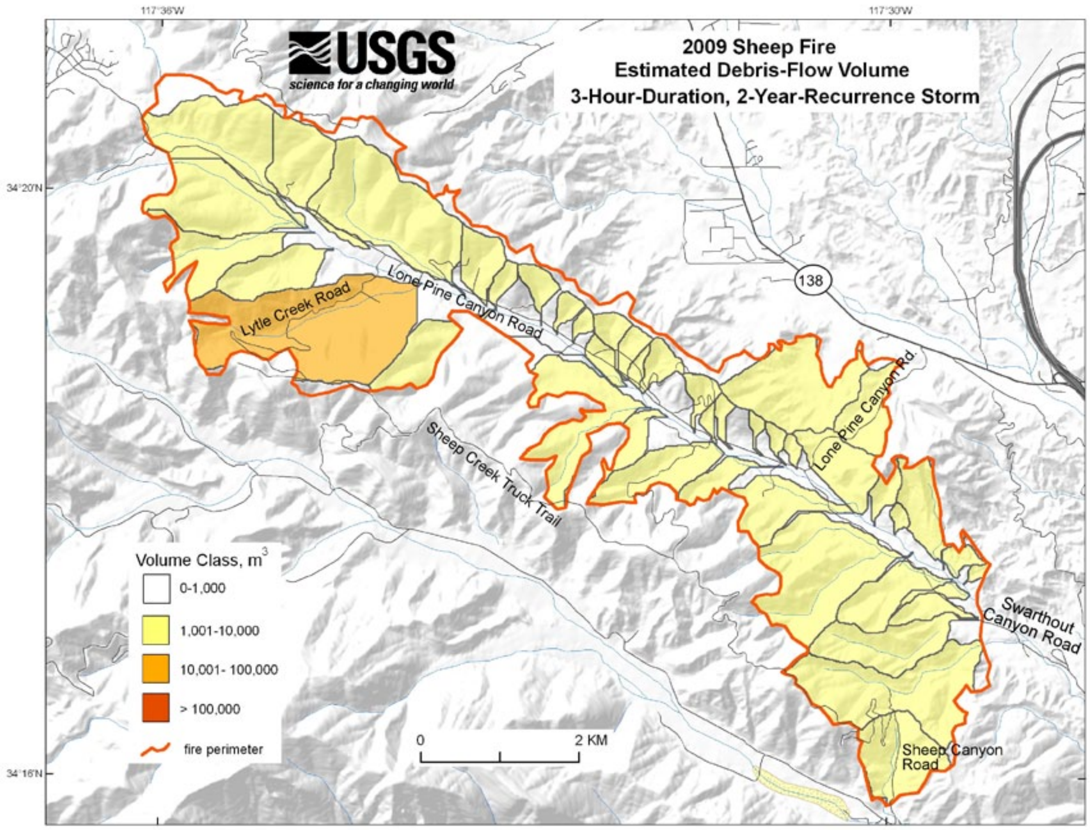
### 3-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence greater than 80 percent were estimated for all 45 basins evaluated within the area burned by the Sheep fire in response to the 3-hour-duration storm (fig. 10*A)*. A debris-flow volume between 10,001 $m^3$ and 100,000 $m^3$ was estimated for the basin crossed by Lytle Creek Road, between 1,001 and10, 000 $m^3$ for 43 other basins, and of 1,000 $m^3$ or less for one basin (fig. 10*B)*.

This evaluation indicates that in the event of the 3-hour-duration, 2-year-recurrence storm, there is a high probability that large (greater than 10,000 $m^3$) debris flows could damage Lytle Creek and Lone Pine Canyon Roads, and a high probability that moderately sized debris flows (less than 10,000 $m^3$) could damage Sheep Creek Truck Trail, Lone Pine Canyon Road, Sheep Canyon Road, and Swarthout Canyon Road where they cross burned drainages in, or downstream from, the burned area.



(A)



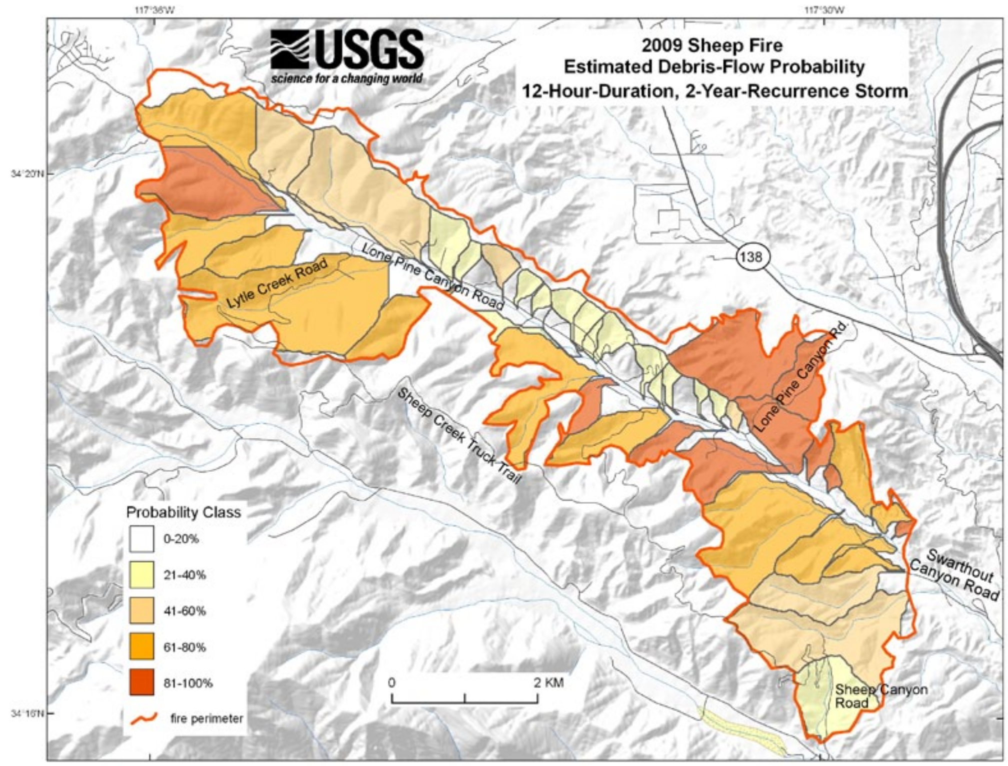
(B)

**Figure 10.** Sheep fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Sheep fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

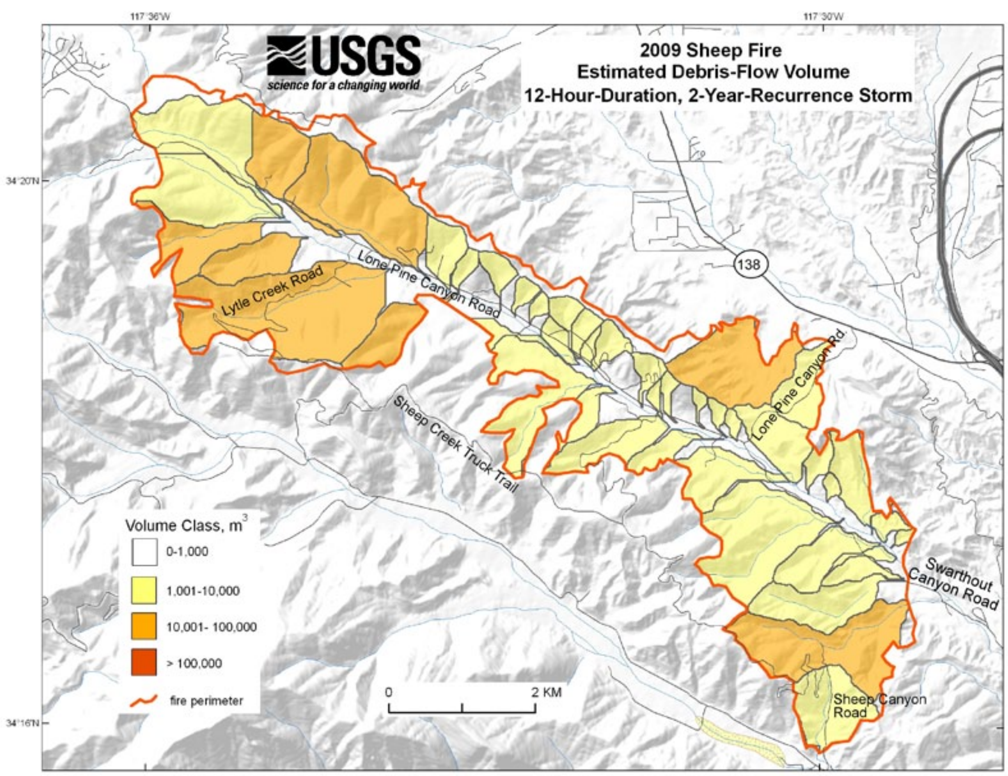
## 12-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence greater than 80 percent were estimated for 10 of the 45 basins evaluated within area burned by the Sheep fire in response to the 12-hour-duration storm (fig. 11*A)*. Probabilities between 61 and 80 percent were estimated for 13 basins, 41 and 60 percent for 6 basins, 21 and 40 percent for 15 basins, and of 20 percent or less for 1 basin. Debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for eight basins and between 1,001 and10,000 $m^3$ for all remaining basins(fig. 11*B)*.

This evaluation indicates that in the event of a 12-hour-duration, 2-year-recurrence storm, there is a high probability that large debris flows could endanger lives and property within and downstream from the basins burned by the Sheep fire, particularly where Lone Pine Canyon Road, Lytle Creek Road, Sheep Canyon Road, Sheep Creek Truck Trail, and Swarthout Canyon Road cross drainages in, or downstream from, the burned area.




(A)




(B)

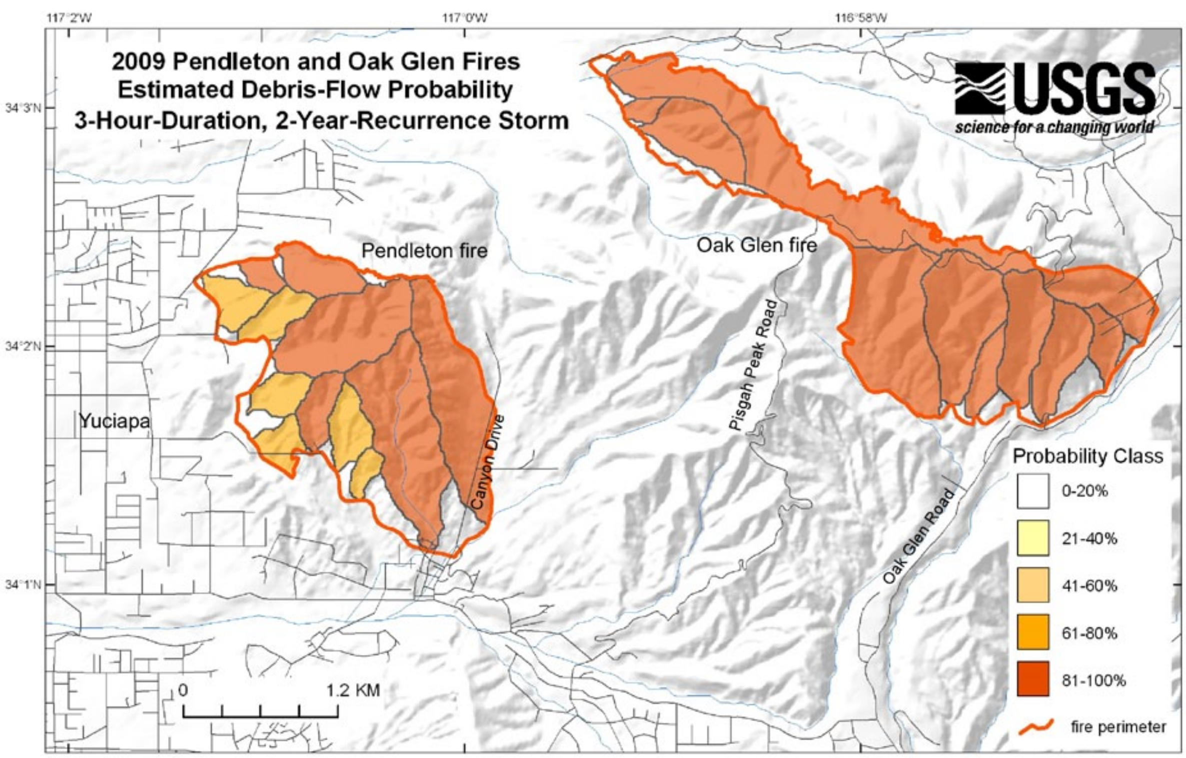
**Figure 11.** Sheep fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Sheep fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

## Oak Glen and Pendleton Fires, San Bernardino County

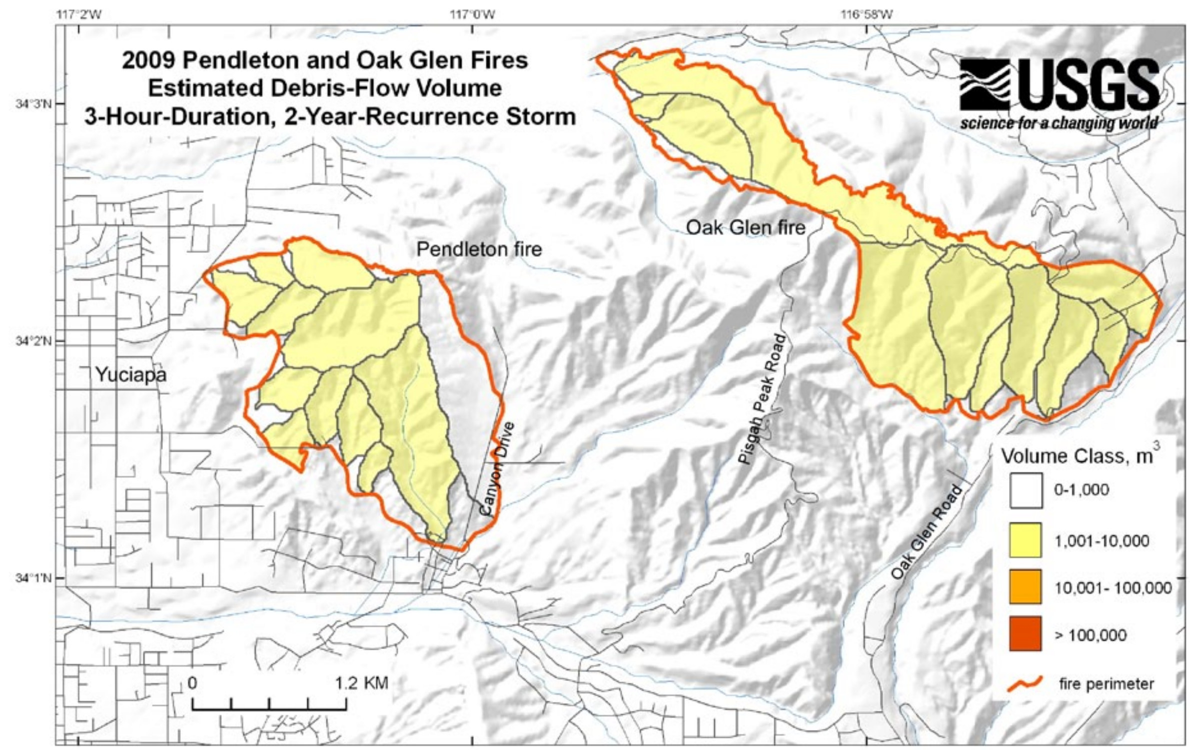
### 3-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence greater than 80 percent were estimated for all 10 of the basins burned by the Oak Glen fire and for 6 of the 12 basins burned by the Pendleton fire, in response to the 3-hour-duration storm (fig. 12*A)*. Probabilities between 61 and 80 percent were estimated for the remaining basins in the Pendleton fire. Debris-flow volumes between 1,001 and 10,000 $m^3$ were estimated for all of the basins evaluated in the Oak Glen fire, and for all but the basin crossed by Canyon Drive in the Pendleton fire (fig. 12*B)*; a volume of 1,000 $m^3$ or less was estimated for that basin.

This evaluation indicates that in the event of a 3-hour-duration, 2-year-recurrence storm, there is a high probability that debris flows with volumes between 1,001 and 10,000 $m^3$ could deposit material on Oak Glen and Pisgah Peak Roads where they cross drainages in, or downstream from, the burned area. Debris flows with volumes between 1,001 and 10,000 $m^3$ could also damage streets and neighborhoods adjacent to the area burned by the Pendleton fire, as well as the trail network within the burned area. Debris flows with volumes of 1,000 $m^3$ or less can be expected where Canyon Drive crosses the burned basin.




(A)



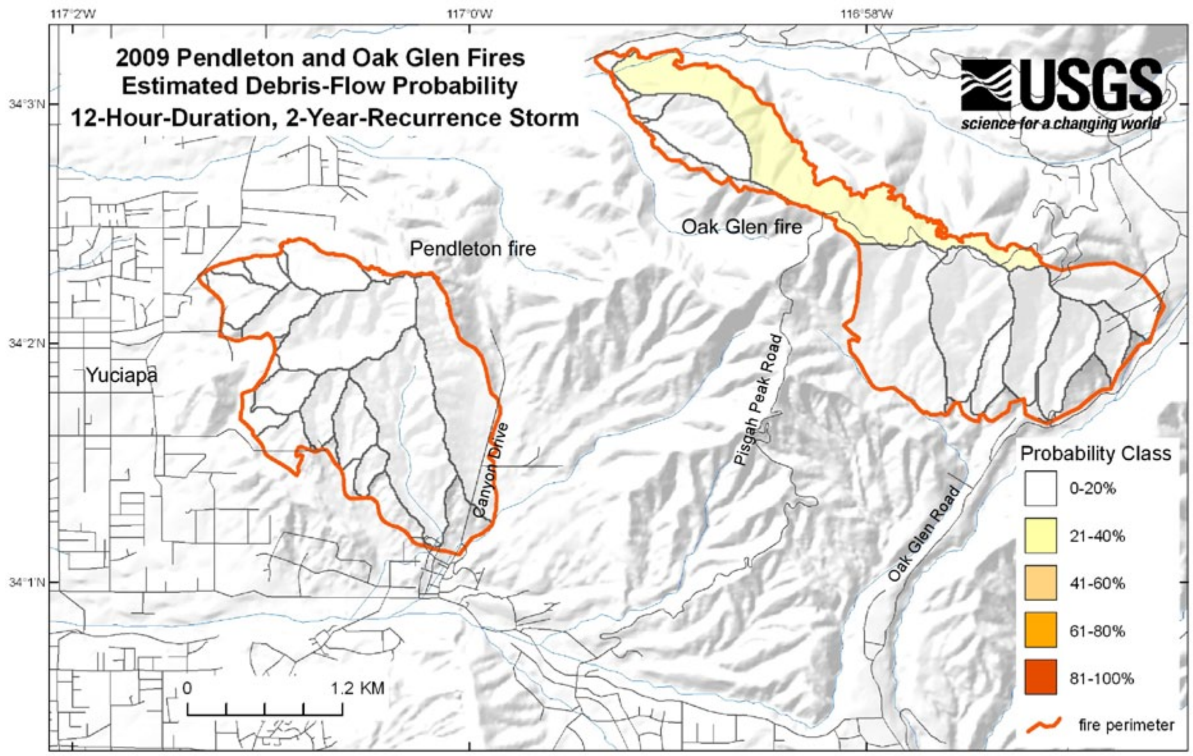

(B)

**Figure 12.** Oak Glen and Pendleton fires burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Oak Glen and Pendleton fires if those areas were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

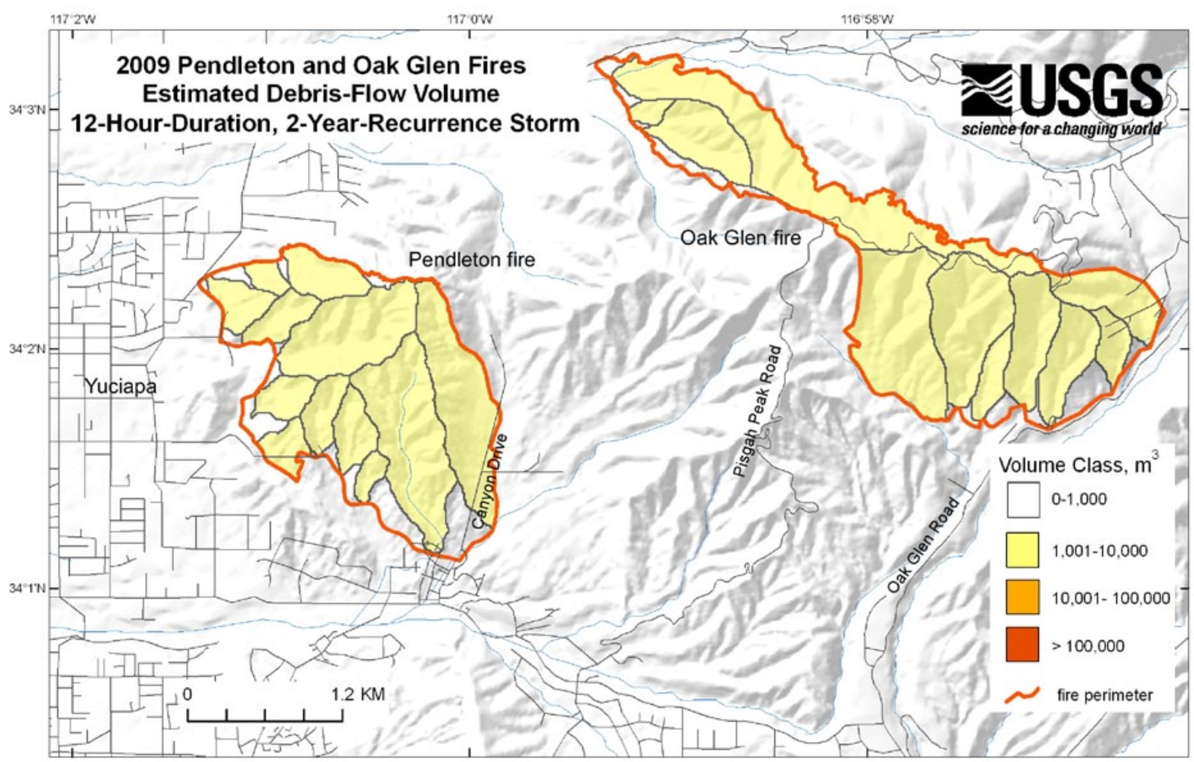
## 12-Hour-Duration, 2-Year-Recurrence Storm

A probability of debris-flow occurrence between 21 and 40 percent was estimated for one of the basins burned by the Oak Glen fire in response to the 12-hour-duration storm, whereas conditions in all remaining basins in both the Oak Glen and Pendleton fires resulted in probabilities of 20 percent or less (fig. 13*A)*. Estimated debris-flow volumes ranged between 1,001 and 10,000 $m^3$ (fig. 13*B)*.

The low debris-flow probabilities and small volume estimates identified in this evaluation indicate that in the event of a 12-hour-duration, 2-year-recurrence storm, any hazard posed by postfire debris flows within and downstream from the basins burned by the Oak Glen and Pendleton fires would be negligible.




(A)




(B)

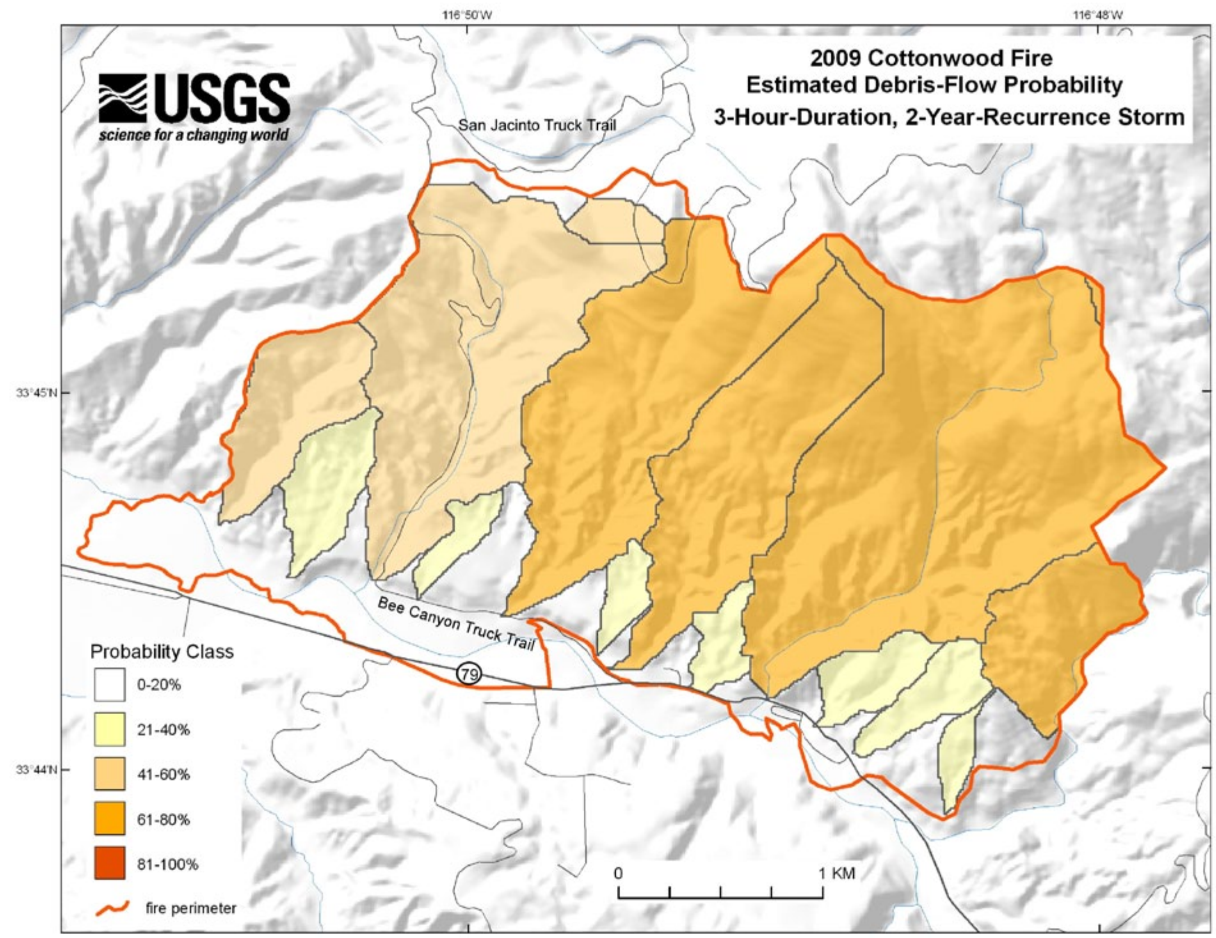
**Figure 13.** Oak Glen and Pendleton fires burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Oak Glen and Pendleton fires if those areas were affected by the 12-hour-duration, 2-year-recurrence storm.

## Cottonwood Fire, Riverside County

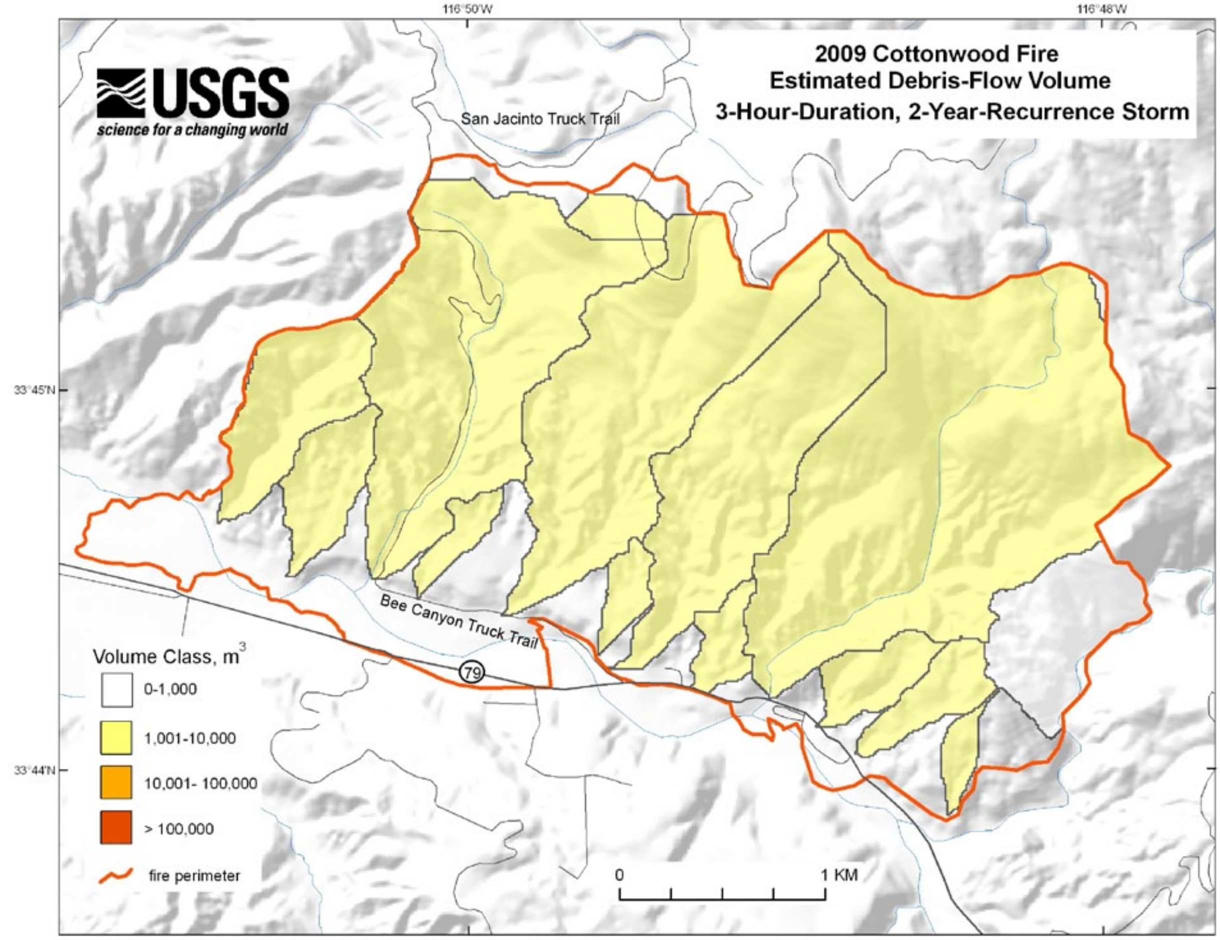
### 3-Hour-Duration, 2-Year-Recurrence Storm

Probabilities of debris-flow occurrence between 61 and 80 percent were estimated for 4 of the 13 basins evaluated in the area burned by the Cottonwood fire in response to the 3-hour-duration storm (fig. 14*A)*. Debris-flow probabilities between 41and 60 percent were estimated for two basins, and probabilities between 21 and 40 percent were estimated for the remaining basins. Debris-flow volumes between 1,001 and 10,000 $m^3$ were estimated for all but one of the burned basins, and a volume of 1,000 $m^3$ or less was estimated for that basin (fig. 14*B)*.

This evaluation indicates that in response to the 3-hour duration, 2-year-recurrence storm, a moderate potential exists for as much as 10,000 $m^3$ of debris-flow material to damage the Bee Canyon Truck Trail where it crosses burned drainages and State Highway 79 where it is closest to basin outlets.



(A)



(B)

**Figure 14.** Cottonwood fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Cottonwood fire if that area were affected by the 3-hour-duration, 2-year-recurrence storm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

## 12-Hour-Duration, 2-Year-Recurrence Storm

Conditions within all 13 of the basins evaluated for the Cottonwood fire resulted in estimates of the probability of debris-flow occurrence of less than 20 percent in response to the 12-hour-duration storm (fig. 15*A)*. Debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for 2 basins, between 1,001 and 10,000 $m^3$ for 10 basins, and of 1,000 $m^3$ or less for 1 basin (fig. 15*B)*.

This evaluation indicates that in the event of a 12-hour-duration, 2-year-recurrence storm, the highest potential for debris-flow damage in the burned area is where the Bee Canyon Truck Trail and Highway 79 cross burned drainages. The relatively low probabilities of debris flow and small debris-flow volumes identified for the remaining basins indicate a negligible postfire debris-flow hazard elsewhere in the burned area.

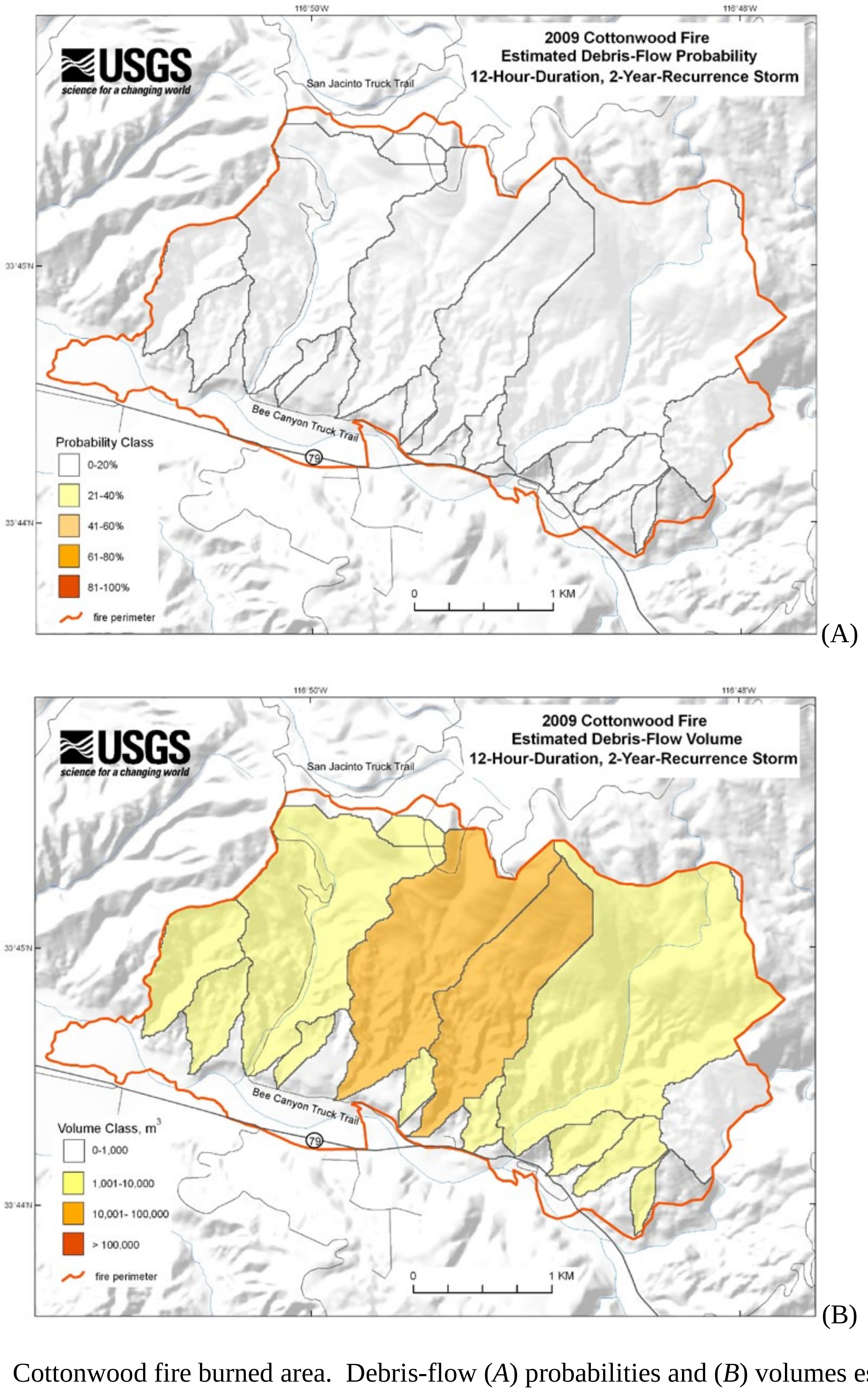



**Figure 15.** Cottonwood fire burned area. Debris-flow (*A*) probabilities and (*B*) volumes estimated for basins burned by the Cottonwood fire if that area were affected by the 12-hour-duration, 2-year-recurrence storm.

## Limitations of Assessments

Storms producing greater rainfall accumulations and intensities, or longer durations, than those evaluated in this assessment could present more severe hazards than those shown in figures 2–15. In addition, the assessments presented here refer only to postfire debris flows; the hazards from flash flooding will require a separate assessment. Site-specific evaluations are necessary to identify potential hazards for individual properties or structures.

The parameters included in the models used in this assessment are considered to be first-order effects on debris-flow generation that can be rapidly evaluated immediately after a fire in southern California. Conditions other than those used in the models—for example, the amount of sediment stored in a canyon—could also affect debris-flow production. Data necessary to evaluate such effects, however, are not currently available.

The potential for debris-flow activity decreases with time as revegetation stabilizes hillslopes and material is removed from canyons. Our experience in southern California burned areas and a compilation of information on postfire runoff events reported in the literature from throughout the western United States (Gartner and others, 2005) both indicate that, with normal rainfall conditions, most debris-flow activity occurs within about two years following a fire. If dry conditions prevent sufficient regrowth of vegetation, this recovery period will be longer. We conservatively estimate that the assessment presented here might be applicable for as much as two years after the fire. However, substantial hazards from flash flooding could remain for many years after a fire.

Finally, this work is preliminary and is subject to revision. It is being provided owing to the need for timely "best science" information. This assessment is provided on the condition that neither the U.S. Geological Survey nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

## Summary and Conclusions

For these assessments, we estimated the probability and volume of debris-flow production in response to a 3-hour-duration, 2-year-recurrence thunderstorm and a 12-hour-duration, 2-year-recurrence storm from drainage basins burned by the La Brea and Jesusita fires in Santa Barbara County, the Guiberson fire in Ventura County, the Morris fire in Los Angeles County, the Sheep, Oak Glen, and Pendleton fires in San Bernardino County, and the Cottonwood fire in Riverside County, southern California. For each drainage basin identified within the burned areas, we used a set of multivariate statistical models to estimate the probability of debris-flow occurrence and the volume of material expected at the basin mouth. Debris-flow probabilities and volumes are estimated as a combination of different measures of basin burned extent, gradient, and material properties. Rivers, canyons, roads, and neighborhoods that could be in the path of debris flows generated from the burned areas were identified from nominally 1:6,000-scale maps. This assessment provides critical information for postfire decision making within the first two winters following the fires including, but not restricted to, issuing warnings for specific areas, locating and designing mitigation measures, and planning evacuation timing and routes.

Storms producing greater rainfall accumulations and intensities, or longer durations, than those evaluated in this assessment could present more severe hazards than described here. In addition, these assessments refer only to postfire debris flows; substantial hazards from flash flooding will require a separate assessment. Site-specific evaluations are also necessary to identify potential hazards for individual properties or structures.

Within the area burned by the La Brea fire, and in response to the 3-hour-duration, 2-year-recurrence storm, conditions in tributaries to the North and South Forks of the La Brea River basins resulted in estimates of debris-flow probabilities greater than 80 percent and debris-flow volumes greater than 100,000 $m^3$. Debris-probabilities greater than 80 percent and debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for tributaries to the Sisquoc River, Horse and Water Canyons, and the basins on the east side of the Sierra Madre Crest. High probabilities of debris flow (greater than 80 percent) and very large debris-flow volumes (greater than 100,000 $m^3$) identified in response to the 12-hour-duration, 2-year-recurrence storm indicate significant debris-flow hazards for tributaries to the North and South Forks of the La Brea River, Horse Canyon, and the Sisquoc River. There is also a high probability of debris flows with volumes between 10,000 and 100,000 $m^3$ being produced from additional tributaries to these rivers, as well as from Water Canyon and the basins on the east side of the Sierra Madre Crest. This assessment indicates the potential for destructive debris-flows that may damage buildings, roads, bridges, culverts, and reservoirs within and downstream of the burned area during or after either the 3-hour-duration or 12-hour-duration storm.

Within the area burned by the Jesusita fire, and in response to the 3-hour-duration, 2-year-recurence storm, debris-flow probabilities greater than 80 percent and debris-flow volumes between 10,001 and 100,000 $m^3$ were estimated for San Antonio Canyon, San Roque Creek, Mission Creek, Rattlesnake Canyon, and an unnamed canyon on the easternmost edge of the fire, indicating a high probability of large debris flows endangering lives and property within and downstream from these basins. Debris-flow probabilities greater than 80 percent and debris-flow volumes between 1,001 and 10,000 $m^3$ estimated for the remaining basins indicate a high probability of moderately sized debris flows that could deposit material in Lauro Canyon Reservoir and damage neighborhoods, buildings, roads, bridges, and culverts located within and downstream of the burned area.

In response to the 12-hour-duration, 2-year-recurrence storm, conditions in basins burned by the Jesusita fire resulted in debris-flow probabilities less than 60 percent for San Antonio Canyon and probabilities less than 40 percent for all other basins. However, should debris flows be produced from the unnamed basin west of San Antonio Canyon, San Antonio Canyon itself, Barger Canyon, San Roque Creek, Mission Creek, Rattlesnake Canyon, and the unnamed canyon on the easternmost edge of the fire, they could be of potentially destructive volumes (greater than 100,000 $m^3$). Such debris flows could pose significant hazards to life and property within and downstream from these basins. This assessment also identified a low (less than 20 percent) probability that debris flows could contribute between 1,001 and 10,000 $m^3$ of sediment to Lauro Canyon Reservoir and damage neighborhoods immediately adjacent to the burned area.

Debris-flow probabilities greater than 80 percent and debris-flow volumes of 10,000 $m^3$ or less were estimated in response to the 3-hour-duration, 2-year-recurrence storm for all of the basins evaluated in the Guiberson fire, indicating a high probability that moderately sized debris flows could damage Happy Camp Canyon Road, Guiberson Road, Grimes Canyon Road, South Mountain Road, and Balcom Canyon Road where they cross burned drainages. In response to the 12-hour-duration, 2-year-recurrence storm, the highest potential for debris-flow damage is along Guiberson Road at the outlets of the two basins that have the highest probabilities (less than 60 percent) or the one basin with the largest volume estimate (10,001 to 100,000 $m^3$). The relatively low probabilities of debris flow and small debris-flow volumes identified for the remaining basins indicate a negligible postfire debris-flow hazard elsewhere in the burned area.

Within the area burned by the Morris fire, and in response to the 3-hour-duration, 2-year-recurrence storm, estimates of debris-flow probabilities greater than 80 percent and a debris-flow volume between 10,001 and 100,000 $m^3$ for the largest basin on the northwestern side of Morris

Reservoir indicate a high probability that large debris flows could damage Highway 39 (San Gabriel Canyon Road). Debris-flow probabilities greater than 80 percent and debris-flow volumes of 10,000 $m^3$ or less determined for the remainder of the basins indicate a high probability that moderately sized debris flows could also damage Highway 39 as well as contribute sediment to Morris Reservoir. In response to the 12-hour-duration, 2-year-recurrence storm, there is a high probability that debris flows with volumes between 10,001 and 100,000 $m^3$ could damage Highway 39 (San Gabriel Canyon Road) and contribute sediment to Morris Reservoir.

Debris-flow probabilities greater than 80 percent were estimated for all of the basins burned by the Sheep fire in response to the 3-hour-duration, 2-year-recurrence storm, and a volume between 10,001 and 100,000 $m^3$ was identified for the basin crossed by Lytle Creek Road. Debris-flow volumes of 10,000 $m^3$ or less were determined for the remainder of the basins. These values indicate a high probability that large (but less than 100,000 $m^3$) debris flows could damage Lytle Creek and Lone Pine Canyon Roads, and a high probability that moderately sized debris flows (10,000 $m^3$ or less) could damage Sheep Canyon Road, Sheep Creek Truck Trail, Lone Pine Canyon Road, and Swarthout Canyon Road where they cross burned drainages in, or downstream from, the burned area. In the event of a 12-hour-duration, 2-year-recurrence storm, there is a greater than 60 percent probability that debris flows with volumes up to 100,000 $m^3$ could damage Lone Pine Canyon Road, Lytle Creek Road, Sheep Canyon Road, Sheep Creek Truck Trail, Lone Pine Canyon Road, and Swarthout Canyon Road where they cross drainages in, or downstream from, the burned area.

Within the area burned by the Oak Glen fire, debris-flow probabilities greater than 80 percent and debris-flow volumes less than 10,000 $m^3$ estimated in response to the 3-hour-duration, 2-year-recurrence storm indicate a high probability that moderately sized postfire debris flows could damage Oak Glen and Pisgah Peak Roads where they cross burned drainages. The low (less than 40 percent) debris-flow probabilities and small volume estimates (less than 10,000 $m^3$) identified in response to the 12-hour-duration, 2-year-recurrence storm indicate that hazards posed by postfire debris flows within and downstream from the basins burned by the Oak Glen fires would be negligible.

Debris-flow probabilities less than 80 percent were estimated for six of the basins burned by the Pendleton fire and between 41 and 60 percent for the remaining basins. Estimates of debris-flow volumes were less that 10,000 $m^3$ for all of the basins, and a volume of less than 1,000 $m^3$ was estimated for the basin that is crossed by Canyon Drive. This evaluation indicates a high probability that debris flows with volumes up to 10,000 $m^3$ could damage the trail network within the burned area as well as streets and neighborhoods adjacent to the burned area. Debris flows with volumes less than 1,000 $m^3$ could be expected where Canyon Drive crosses the burned basin. The low debris-flow probabilities (less than 20 percent) and small volume estimates (less than 10,000 $m^3$) identified in this evaluation indicate that in the event of the 12-hour-duration, 2-year-recurrence storm, hazards posed by postfire debris flows within and downstream from the basins burned by the Pendleton fires would be negligible.

Within the area burned by the Cottonwood fire, debris-flow probabilities between 61 and 80 percent and debris-flow volumes between 1,001 and 10,000 $m^3$ were estimated for the four largest basins on the east side of the fire, whereas probabilities of less than 60 percent and volumes less than 10,000 $m^3$ were estimated for the remaining basins. This evaluation indicates moderate to low probabilities that debris flows with volumes as large as 10,000 $m^3$ could damage the Bee Canyon Truck Trail where it crosses burned drainages and State Highway 79 where it is closest to basin outlets. In response to the 12-hour-duration, 2-year-recurrence storm, the potential for debris-flow damage also is highest where the Bee Canyon Truck Trail and Highway 79 cross burned drainages. In this case, there are two basins with low estimates of debris-flow probability (less than 20 percent), but debris-flow volumes are estimated to be between 10,001 and 100,000 $m^3$. The low probabilities (less than 20 percent) of debris flow and small debris-flow volumes (10,000 $m^3$ or less) identified for the remaining basins indicate a negligible postfire debris-flow hazard elsewhere in the burned area.

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