# Emergency Assessment of Postfire Debris-Flow Hazards for the 2009 Station Fire, San Gabriel Mountains, Southern California

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Cover photograph: Debris-flow deposits in tributary to Big Tujunga Canyon following storm on February 6, 2010

# Contents



# Figures



# Tables

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

## Abstract

This report presents an emergency assessment of potential debris-flow hazards from basins burned by the 2009 Station fire in Los Angeles County, southern California. Statistical-empirical models developed for postfire debris flows are used to estimate the probability and volume of debris-flow production from 678 drainage basins within the burned area and to generate maps of areas that may be inundated by the estimated volume of material. Debris-flow probabilities and volumes are estimated as combined functions of different measures of basin burned extent, gradient, and material properties in response to both a 3-hour-duration, 1-year-recurrence thunderstorm and to a widespread 12-hour-duration, 2-year-recurrence storm. Debris-flow inundation areas along the northern margin of the fire are mapped using the volumes of material estimated for both storms. Inundation areas along the San Gabriel mountain front are also mapped using the volumes estimated for both storms, and consider situations when the total capacity of each sediment-retention basin is available for storage, and when basins experience drain, spillway, or outflow channel blockages or failures. 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.

Tributary basins that drain into Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon were identified as having probabilities of debris-flow occurrence greater than 80 percent, the potential to produce debris flows with volumes greater than 100,000 cubic meters, and the highest Combined Relative Debris-Flow Hazard Ranking in response to both storms. The predicted high probability and large magnitude of the response to such short-recurrence storms indicates the potential for significant debris-flow impacts to any buildings, roads, bridges, culverts, and reservoirs located both within these drainages and immediately downstream from the burned area.

Conditions in all but the smallest basins along the San Gabriel mountain front between Big Tujunga Canyon and Arroyo Seco resulted in probabilities of debris-flow occurrence greater than 80 percent, debris-flow volumes between 10,000 and 100,000 cubic meters, and high Combined Relative Debris-Flow Hazard Rankings in response to both storms. The combination of high probabilities and large magnitudes determined for these basins indicates a significant potential for debris-flow impacts to neighborhoods and infrastructure along the San Gabriel mountain front.

Debris-flow inundation simulations along the San Gabriel mountain front when the storage capacity of all of the sediment-retention basins is available indicate that debris-flow material may be deposited in neighborhoods immediately below unprotected drainages and along the Angeles Crest Highway. When sediment-retention basins are overtopped, or experience drain, spillway, or outflow

channel blockages or failures, debris flows may be deposited in neighborhoods and streets, and impact infrastructure, between the mountain front and beyond Foothill Boulevard.

High debris-flow probabilities and large volumes estimated for the largest basins on the north edge of the burned area in response to both storms also indicate the potential for debris-flow impacts to infrastructure on this side of the fire. Simulations of potential debris-flow inundation areas indicate that in response to the 3-hour-duration, 1-year-recurrence storm, debris flows may travel between 2.0 and 3.0 km from the mouths of some canyons, while in response to the 12-hour-duration, 2-year-recurrence storm, debris flows may travel up to 5 km from canyon mouths.

## Introduction

Debris flows can pose significant 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). 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, so runoff will contain significant 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 affect water quality and the storage capacities of reservoirs.

The association between debris-flow occurrence and wildfire was first described in the San Gabriel Mountains (fig. 1) in the 1930s when Eaton (1936) pointed out that the area is frequently subject to brief torrential storms that result in floods of exceptionally high intensity, and when fires denude the vegetation from steep mountain canyons, the same storms result in flooding and debris flows of even greater magnitudes. Eaton (1936) documented the debris-flow response and triggering storm rainfall from several recently burned basins in the San Gabriel Mountains between 1914 and 1935, and of particular relevance to our evaluation of the Station fire is the La Crescenta–Montrose debris flow of January 1, 1934. Seventeen contiguous watersheds were burned by a wildfire from November 21 to 24, 1933 along the mountain front between La Cañada and Sunland. Rain started falling on December 12, 1933, and on December 31, 1933 up to 14 inches of rain in approximately 24 hours triggered debris flows that caused at least 30 deaths and completely swept away or destroyed 483 homes (Chawner, 1934; Eaton, 1936). The recurrence interval of approximately 50 years for this storm (Hershfeld, 1961) indicates a 2 percent chance of this rainfall occurring in any given year. Boulders weighing up to 10 tons were transported within the canyons, and one 59.5-ton boulder rolled out of Dunsmore Canyon and onto a paved street (Eaton, 1936). Material was deposited throughout neighborhoods and businesses between the San Gabriel mountain front and the Verdugo Mountains (Eaton, 1936). Eaton measured 409,000 $m^3$ (535,000 $yd^3$) of debris-flow deposits from private property and streets and 95,000 $m^3$ (124,000 $yd^3$) in the existing sediment-retention basins, giving a total volume of 504,000 $m^3$ (659,000 $yd^3$) of material deposited beyond the mountain front from this single event. In contrast, Chawner (1934) estimated 535,000 $m^3$ (700,000 $yds^3$) of material having been produced from Hall Beckley and Pickens Canyons alone. We are not able to reconcile the difference between the two measurements at this time.

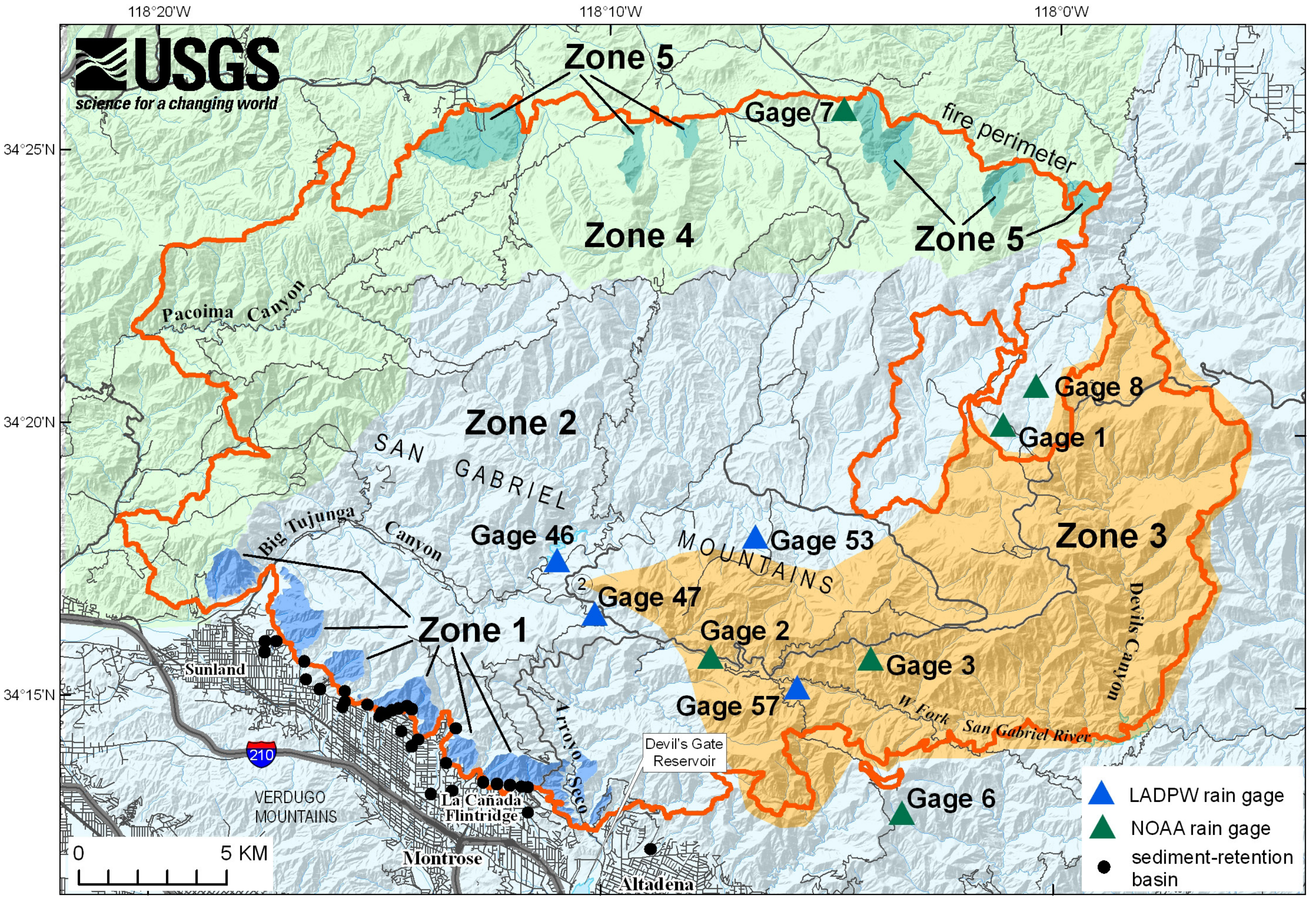


**Figure 1.** Perimeter of Station fire in the San Gabriel Mountains, locations of rain gages and precipitation zones defined for hazard assessment, and locations of sediment-retention basins in the vicinity of the burned area. (LADPW, Los Angeles Department of Public Works; NOAA, National Oceanic and Atmospheric Administration).

On January 22, 1969 debris flows generated from basins burned the previous summer along the San Gabriel mountain front east of the La Crescenta–Montrose event enveloped buildings, poured through doors and windows, and surrounded the automobiles of the residents attempting to flee the disaster (Scott, 1971) (fig. 2A). Debris flows following wildfires also have occurred more recently farther east along the San Gabriel mountain front and in the San Bernardino Mountains. Debris flows and floods generated from nearly every basin burned by the 2003 Old and Grand Prix fires in response to a 2-year-recurrence-interval storm on December 25, 2003, killed 16 people (U.S. Army Corps of Engineers, unpub. data, 2005) (fig. 2B).


(A)

(B)

**Figure 2.** Debris-flow damage to homes in (A) Glencoe Heights along the San Gabriel mountain front in response to January 1969 storm (LADPW photograph), and (B) Devore along the San Bernardino mountain front following storm on December 25, 2003(U.S. Geological Survey photograph).

In response to the potential for damaging debris flows from basins burned by the Station fire of August and September of 2009 in the San Gabriel Mountains of southern California, here we provide an emergency assessment of debris-flow hazards for the area (fig. 1). This assessment uses a set of predictive models developed specifically for postfire debris-flow processes that address three fundamental questions in debris-flow hazard evaluations: What is the likelihood of a given basin to produce debris flows, how big will the debris flows be, and where will they go? This information is critical for issuing spatially specific warnings, locating and designing mitigation measures, and planning for evacuation timing and routes for the first two winters following the fire.

## 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. The infiltration-triggered landsliding that does occur in burned basins generally contributes little to the total volume of material transported from the basin. These findings point to the striking postfire shift from an infiltration-driven system to one dominated by runoff processes and indicates that methods traditionally used to assess landslide hazards are not appropriate in a postfire environment. Accordingly, it is necessary to use methods that are specific to postfire processes.

A suite of three statistical-empirical models was used to estimate the probability and volume of debris-flow production from individual drainage basins in response to given storm events and to generate maps of areas that may be inundated by the estimated volume of material. The probability model was developed using logistic multiple regression analyses of data from 517 basins in 21 different fires that burned between 2003 and 2008 in southern California (S.H. Cannon, U.S. Geological Survey, unpub. data, 2009). Conditions in each basin were quantified using several different 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 properties:** | 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 may issue from a basin mouth in response to a given storm. This statistical 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, U.S. Geological Survey, unpub. data, 2009). Volume measurements were from 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).

Debris-flow hazards from a given basin can also be represented by a combination of both probability of occurrence and volume (Cannon and others, 2010). For example, for a given setting, the most hazardous basins will show both the highest probabilities of occurrence and the largest estimated volume of material. Slightly less hazardous would be basins that show a combination of either relatively low probabilities and larger volume estimates or high probabilities and smaller volume estimates. The lowest relative hazard would be for basins that show both the lowest probabilities and the smallest volumes. For this assessment, the estimated values of debris-flow probability and volume are categorized into relatively ranked classes, and these classes are combined to calculate a "Combined Relative Debris-Flow Hazard Ranking." This ranking identifies a possible range of responses from basins that are most prone to producing debris flows with the largest volumes, to basins with the lowest probabilities that will produce the smallest events (Cannon and others, 2010).

To estimate the area that may be inundated by the volumes of material estimated for each basin, we used an approach modified from that developed by Iverson and others (1998) to map inundation areas of lahars (debris flows generated from volcanoes). We first used a terrain analysis to identify the position within drainage networks where the onset of continuous deposition is likely to occur as a function of channel gradient and degree of confinement. The onset of deposition may be located either within a basin itself if the channel is wide with a gentle gradient, at the mountain front, or downstream from the mountain front if the channel is incised into the mountain-front alluvial fan. For those basins where the onset of deposition was mapped within the channel itself, we used the range of volumes estimated for the entire basin (and not those that would have been estimated just to the onset of deposition) for the inundation simulations. Similarly, for those basins with the onset of deposition mapped beyond the basin outlet, we used the range of volumes estimated for the entire basin, but started the simulation downstream from the basin outlet. Next, a set of regression equations that relate debris-flow volume to cross-sectional and planimetric inundation areas from field measurements of 22 postfire debris-flow deposits in southern California (Bernard, 2007) were used to map potential inundation areas using a preliminary 3-m digital elevation model (DEM) of the area made available through a partnership between U.S. Geological Survey and Los Angeles County. The inundation was estimated by determining the cross-sectional area of a 3-m-long channel reach (including the area adjacent to the channel, if necessary) that will fill with the volume of material estimated by the relation between volume and channel cross-sectional area. The simulation moves downstream 3-m cell by 3-m cell, filling the channel and decreasing the available volume until no material remains and the planimetric area estimated for the initial available volume is inundated.

The described method identifies the area that will be covered or filled with debris-flow deposits and is appropriate for single debris flows that travel from steep, tightly confined drainage basins into wide channels on relatively low gradient surfaces, such as the settings along the front of the San Gabriel Mountains between Arroyo Seco and Big Tujunga Canyon and along the northern margin of the fire (fig. 1). The method does not identify channel reaches that are eroded by debris flows or those that experience both erosion and deposition. Because this approach is implemented using a 3-m DEM, channel and depositional features smaller than 3 meters are not represented. Uncertainties associated with the method are accounted for by simulating the inundation area for potential volumes that range over an order of magnitude for each basin.

Thirty sediment-retention basins (also known as debris basins) are located along the front of the San Gabriel Mountains affected by the Station fire (fig. 1). In general, the basins are designed to trap and hold larger sediment and vegetation, while water and finer sediments drain off, either through an internal drainage structure, over a spillway, or both (Los Angeles County Department of Public Works, 2006). Most spillways empty into an engineered, concrete-lined outflow channel, but not all, and some outflow channels transition to underground tunnels a short distance from the debris basin. Material that accumulates in the basins is periodically removed to maintain capacity. When sediment-retention basins are near or at capacity, or the internal drain in a debris basin is damaged or blocked during a storm, the contribution of additional debris-flow material may result in overtopping of the basins. Should this occur, debris flows may travel directly into those neighborhoods below debris basins without engineered spillways and outflow channels. Neighborhoods below debris basins with spillways and channels may also be impacted by debris flows should the spillways or channels become blocked by debris-flow material or vegetation.

In this assessment, we evaluate the situation where the entire capacity of the sediment-retention basins is available for storage (the best-case scenario) by subtracting the basin capacity from the predicted debris-flow volumes before running the inundation simulation. We also evaluate a worst-case scenario where previous storms have left the basins filled with sediment and there has not been sufficient time to empty the basins before the next storm arrives. In this case, we run the inundation simulation using the total predicted debris-flow volume. These assessments characterize the potential debris-flow impacts when sediment-retention basins are overtopped, or basin drains, spillways, or outflow channels fail or are blocked during a storm. Although it is unlikely that every sediment-retention basin will experience such a failure during a single storm, this assessment provides information that can be used for preparing for such an occurrence downstream from each of the basins within the flood-control system.

## Model Implementation

The three models were implemented for the Station fire by first delineating the basins to be evaluated within the burned perimeter by using topographic information derived from a 3-meter DEM and Geographic Information System (GIS) hydrological tools. Basin outlets were positioned at breaks in slope along the front of the San Gabriel Mountains and within the primary drainages. Basin areas ranged between 0.01 $km^2$ 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. A total of 678 basins were defined and evaluated. Measures of the physical properties of soils within each basin were obtained from the STATSGO soils database (Schwartz and Alexander, 1995). The soil burn severity map of the Station fire provided by the USDA Forest Service Burned Area Emergency Response (BAER) Team on September 16, 2009, was used to identify the areas burned at high, moderate, and low severity within each basin.

## Storm Rainfall

We have found that postfire debris flows in southern California can be triggered by localized, short-duration, high-intensity thunderstorms as well as in response to widespread, longer duration, lower intensity storms (Cannon and others, 2008). 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 thunderstorm and a widespread 12-hour-duration storm. We have also found that debris flows can be triggered by frequently occurring or short recurrence-interval storms (Cannon and others, 2008). For this reason, we chose to evaluate the debris-flow response to the 3-hour-duration storm with a 1-year-recurrence interval, and to the 12-hour-duration storm with a 2-year recurrence interval. A 1-year-recurrence interval storm has a 100 percent chance of occurring each year, while a 2-year-recurrence storm has a 50 percent chance.

Because the precipitation totals for these two storms vary considerably across the burned area, we divided the area into five precipitation zones (fig. 1) using visual and quantitative comparisons of rainfall-frequency data and rain-gage records from Los Angeles County Department of Public Works (LADPW) (LADPW unpub. data, 2009) and NOAA (Bonnin and others, 2006), the pattern of precipitation isohyets for the 24-hour-duration, 50-year-recurrence storm used by LAPDW in the design of debris-flow control facilities (LADPW written commun., 2009), and the pattern and values of precipitation isohyets for the 3-hour-duration, 1-year-recurrence and 12-hour-duration, 2-year-recurrence storms in Hershfield (1961). Separate storm rainfall accumulations appropriate to each zone were identified from available data (table 2). Each basin in the burned area was linked with rainfall accumulations depending on the zone in which it lies. A spatially weighted average rainfall was estimated for those basins located in two precipitation zones.

It would be unlikely that the 3-hour-duration, 1-hour-recurrence thunderstorm would affect the entire burned area. However, without information on typical or expected spatial extent of such storms, or the tracks they might take, it is necessary to consider the entire burned area in our assessment.

**Table 2.** Storm rainfall in precipitation zones defined for hazard assessment.
[mm, millimeters; in, inches; hr, hours]

| Zone | 3-hour-duration, 1-year-recurrence storm | | 12-hour-duration, 2-year-recurrence storm | | |
|---|---|---|---|---|---|
| | 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) | Source |
| 1 | 30.1 (1.2) | 10.0 (0.40) | 85.2 (3.4) | 7.1 (0.28) | LADPW design storm; Hershfield, 1961 |
| 2 | 33.0 (1.3) | 11.0 (0.43) | 91.4 (3.6) | 7.6 (0.30) | LADPW Gages 46, 47 and 53; LADPW design storm; Hershfield, 1961 |
| 3 | 34.9 (1.4) | 11.6 (0.47) | 106.0 (4.2) | 8.8 (0.35) | NOAA Gages 1, 2, 3 and 6; LADPW Gage 57; LADPW design storm; Hershfield, 1961 |
| 4 | 26.7 (1.1) | 8.9 (0.37) | 74.9 (3.0) | 6.2 (0.25) | LADPW design storm; Hershfield, 1961 |
| 5 | 20.3 (0.8) | 6.8 (0.27) | 58.4 (2.3) | 4.9 (0.19) | NOAA Gage 7; Hershfield, 1961 |

# Results

## Debris-Flow Probability

In response to the 3-hour-duration, 1-year-recurrence thunderstorm, probabilities of debris-flow occurrence greater than 80 percent were estimated for all of the drainage basins along the San Gabriel mountain front between Big Tujunga Canyon and Arroyo Seco (fig. 3A). In addition, conditions in every basin that contributes to Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, the West Fork of the San Gabriel River, and Devils Canyon resulted in estimated debris-flow probabilities greater than 80 percent, as did those in the largest basins along the northern margin of the burned area. These high probabilities, in combination with the estimated 100-percent chance that the 3-hour-duration, 1-year-recurrence storm will occur somewhere within the area during any given year, indicates a significant possibility for debris-flow impacts to neighborhoods, buildings, roads, culverts, bridges, and any reservoirs located within these drainages as well as immediately downstream from the burned area.

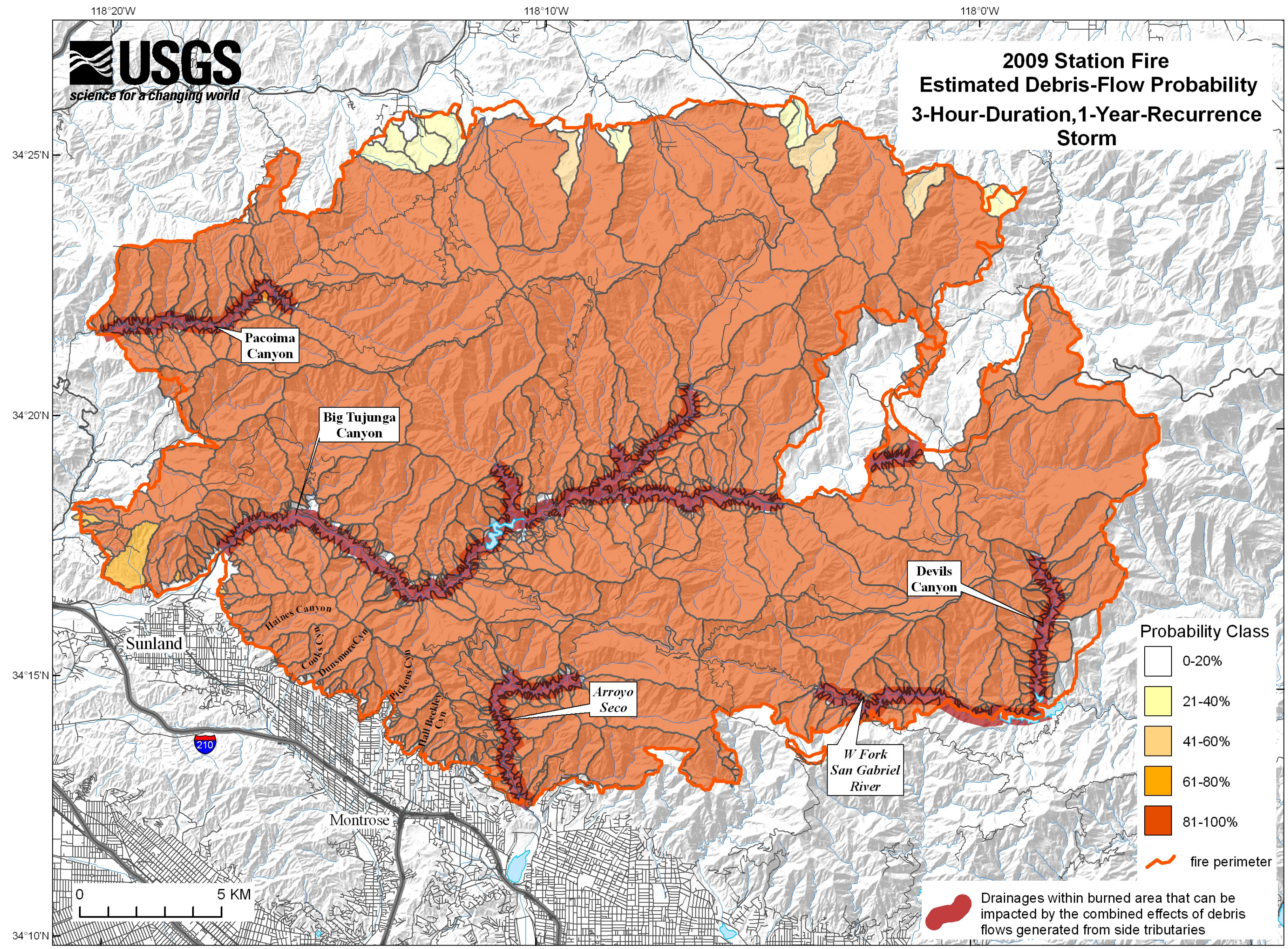


**Figure 3A.** Probability of debris flow estimated for basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

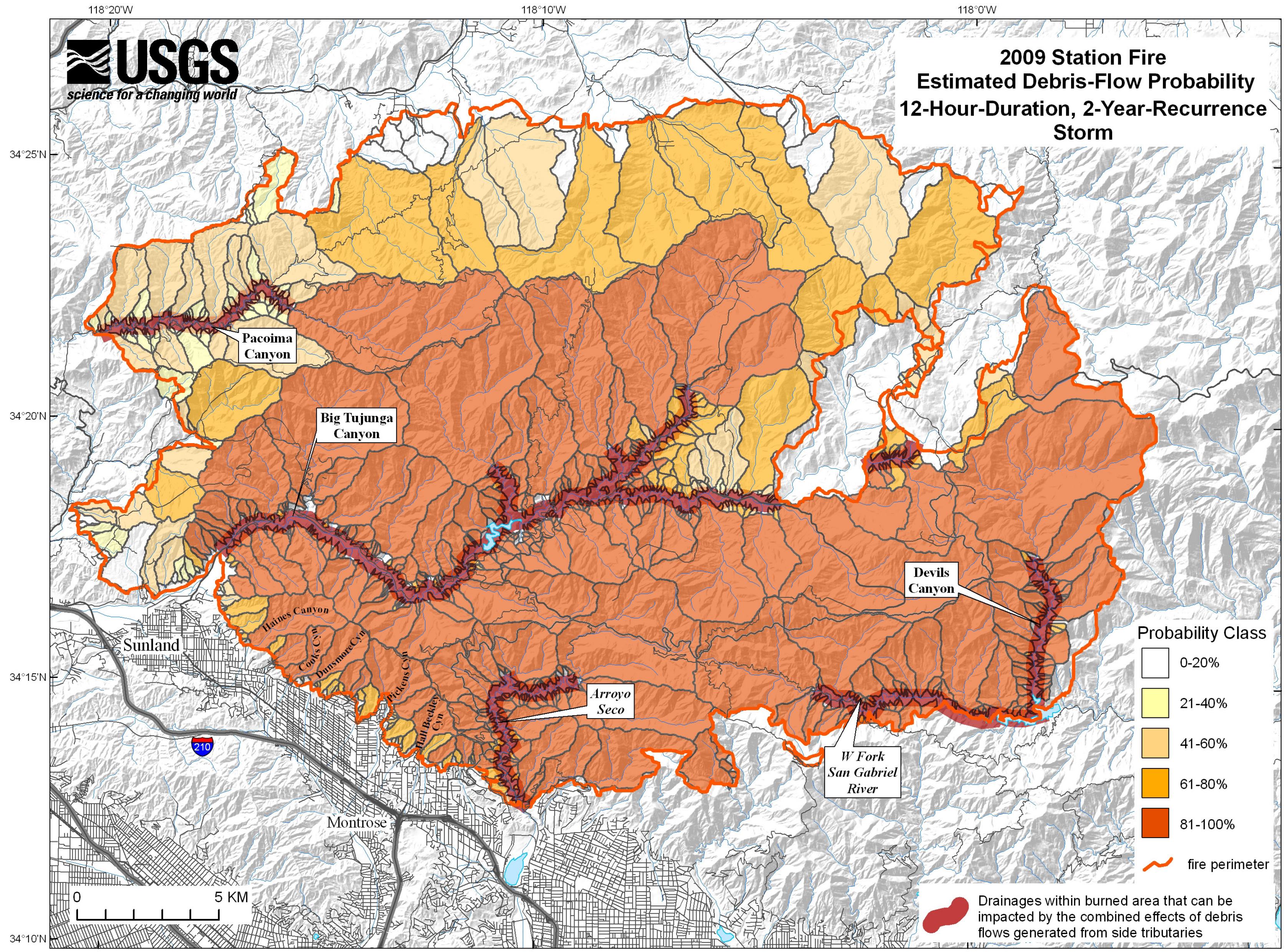


**Figure 3B.** Probability of debris flow estimated for basins burned by the Station fire in response to a widespread, 12-hour-duration, 2-year-recurrence storm.

In response to a widespread, 12-hour-duration, 2-year-recurrence storm, debris-flow probabilities greater than 80 percent were estimated for nearly all basins along the San Gabriel mountain front with areas greater than approximately 0.5 $km^2$ (0.2 $mi^2$) (fig. 3B). These high probabilities, in combination with the estimated 50 percent chance that the 12-hour-duration, 2-year-recurrence storm will occur somewhere within the area within a year, indicate a significant potential for debris flows to impact neighborhoods along the mountain front.

Also in response to a widespread 12-hour-duration, 2-year-recurrence storm, debris-flow probabilities of greater than 80 percent were estimated for one of the largest tributary basins that drains into Pacoima Canyon, and for nearly every basin that feeds into Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon (fig. 3B). These high probabilities indicate a significant potential for debris-flow impacts to any buildings, roads, culverts, bridges, and reservoirs located within these drainages, as well as immediately downstream from the burned area.

Debris-flow probabilities between 61 and 80 percent were calculated for seven of the largest basins on the northern margin of the burned area in response to the 12-hour-duration, 2-year-recurrence storm, with the remaining basins showing probabilities of less than 60 percent (fig 3B). These probabilities indicate a moderate possibility for debris-flow impacts to any buildings, roads, culverts, bridges, and reservoirs located within these drainages, as well as immediately downstream from the burned area.

The fact that the shorter duration (but higher intensity) 1-year-recurrence thunderstorm resulted in more basins with higher probabilities than did the longer duration (but lower intensity) 2-year recurrence storm (table 2) reflects the strong effect of rainfall intensity on postfire debris-flow occurrence.

When compared with similar evaluations for past fires (for example, Cannon and others, 2007), these are the most basins with such high probabilities in response to such short (1- to 2-year) recurrence-interval storms. These probabilities are also higher than those estimated for basins burned by the 2003 Old and Grand Prix fire in the San Bernardino Mountains using rainfall data from the December 25, 2003, storm that triggered debris flows from nearly every burned basin. The high probabilities of debris-flow occurrence from basins burned by the Station fire reflects the combined effects of the steep slopes throughout the area and extensive areas burned at high and moderate severities.

## Debris-Flow Volume

In response to the 3-hour-duration, 1-year-recurrence thunderstorm, debris-flow volumes greater than 100,000 $m^3$ were estimated for one of the tributary basins to Pacoima Canyon, five of the tributary basins to Big Tujunga Canyon, one of the tributary basins to Arroyo Seco and to Devils Canyon, and two of the basins on the northern margin of the burned area (fig. 4A). Debris-flow volumes between 10,000 and 100,000 $m^3$ were estimated for three of the basins that contribute to Pacoima Canyon, several of the basins that contribute to Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon, and seven of the basins on the northern edge of the burned area. These large volumes of material moving into primary drainages indicate the potential for significant debris-flow impacts to buildings, roads, bridges, and reservoirs both within these drainages and immediately downstream from the burned area. The reaches of Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon within the burn perimeter that may be affected by debris flows contributed from tributary basins are indicated in fig. 4A.

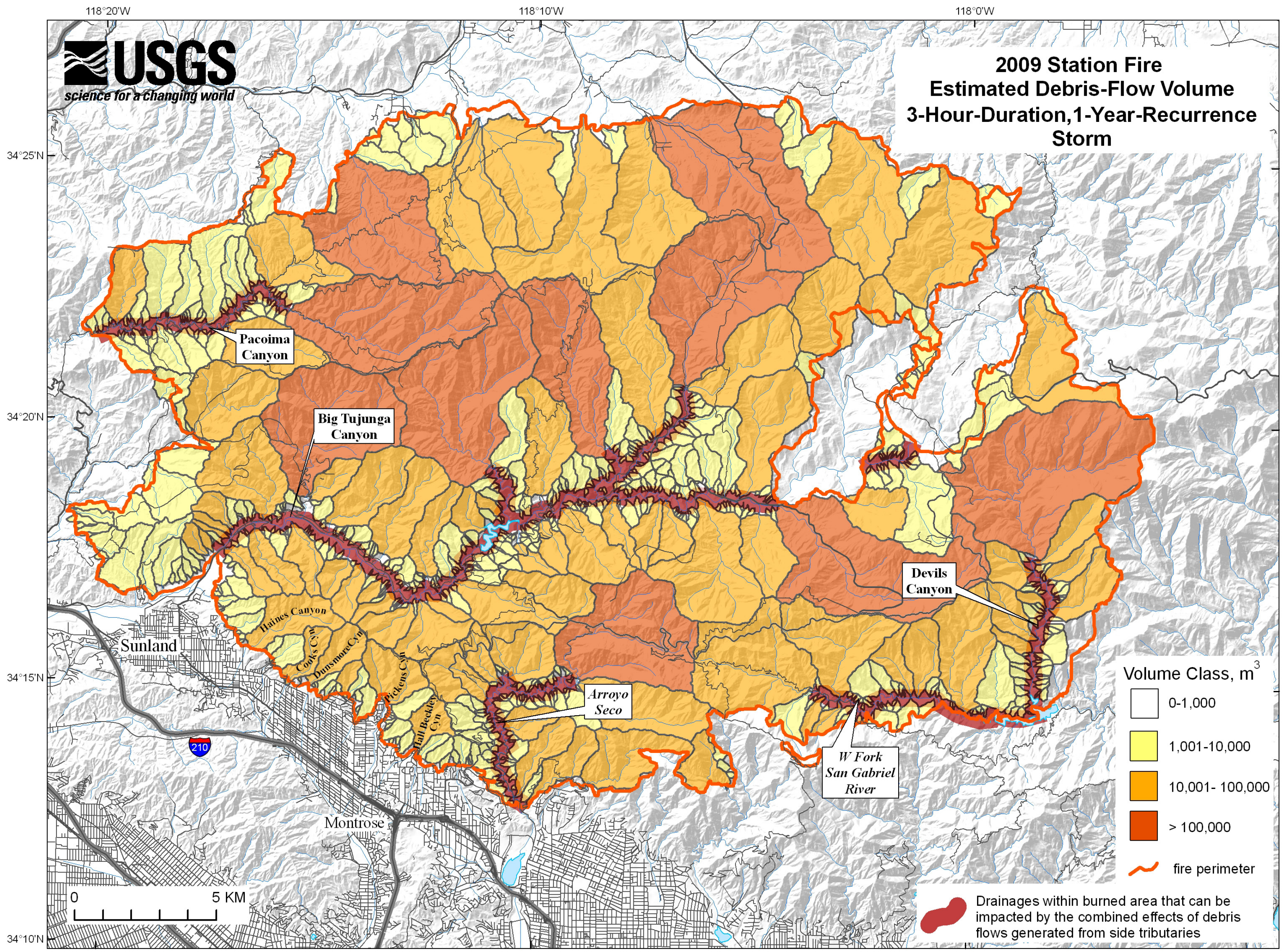


**Figure 4A.** Volume of debris flows estimated at the outlets of basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that a thunderstorm of this magnitude would impact the entire burned area, not every basin shown would produce debris flows in response to the same storm.

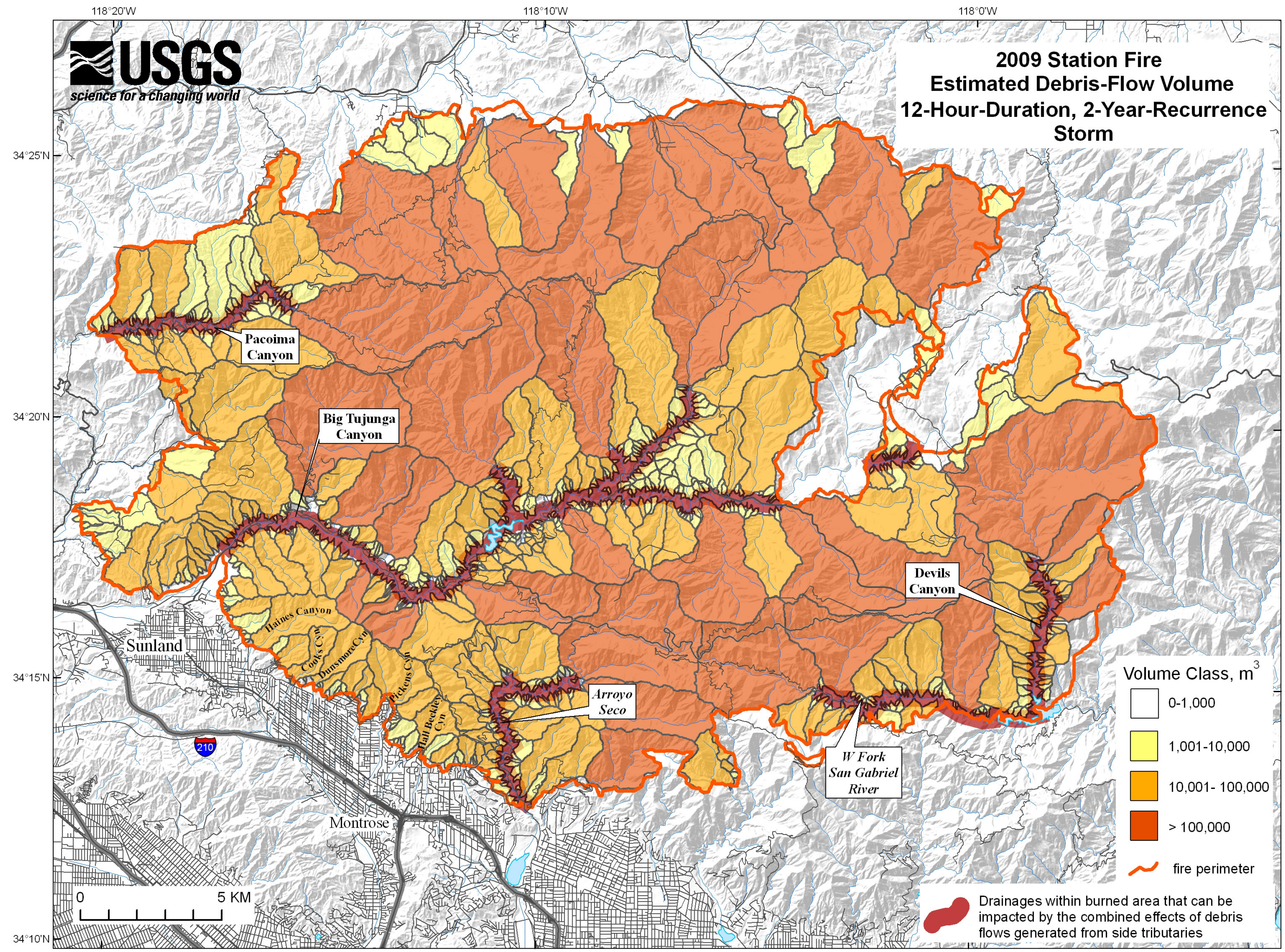


**Figure 4B.** Volume of debris flows estimated at the outlets of basins burned by the Station fire in response to a widespread, 12-hour-duration, 2-year-recurrence storm.

Debris-flow volumes between 10,000 and 100,000 $m^3$ were estimated in response to the 3-hour-duration, 1-year-recurrence thunderstorm for basins along the San Gabriel mountain front, including Haines, Cooks, Dunsmore, Shields (the unlabeled canyon between Dunsmore and Pickens), Pickens and Hall Beckley Canyons, and the three basins east of Arroyo Seco (fig. 4A). Debris flows of these magnitudes may pose significant hazards to life and property within and immediately downstream from these canyons and basins.

In response to the widespread, 12-hour-duration, 2-year-recurrence storm, debris-flow volumes greater than 100,000 $m^3$ were estimated for one of the tributary basins to Pacoima Canyon, several of the tributary basins to Big Tujunga Canyon, two of the tributary basins to Arroyo Seco, three of the tributary basins to both the West Fork of the San Gabriel River and Devils Canyon, and several of the basins on the northern edge of the burned area (fig. 4B). Debris-flow volumes between 10,000 and 100,000 $m^3$ were estimated for several of the basins that contribute to Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon. The effects of these large volumes of material moving into primary drainages indicate the potential for significant debris-flow impacts to buildings, roads, bridges, and reservoirs both within these drainages and immediately downstream from the burned area. The reaches within the burned area of Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon that have the potential to be affected by debris flows contributed from tributary basins are indicated in fig. 4B.

Debris-flow volumes between 10,000 and 100,000 $m^3$ were estimated in response to the 12-hour-duration, 2-year-recurrence storm for basins along the San Gabriel mountain front, including Haines Canyon and three unlabeled basins to the west, Cooks Canyon and the unlabeled canyon to the west, Dunsmore Canyon and four unlabeled basins to the east, Pickens Canyon and the unlabeled canyon to the east, Hall Beckley Canyon and three unlabeled canyons to the east, and three basins east of Arroyo Seco (fig. 4B). Debris flows of these magnitudes may pose significant hazards to life and property in neighborhoods within and immediately downstream from these canyons and basins.

The fact that the longer duration (but lower intensity) storm resulted in more basins with larger volumes than did the shorter duration (but higher intensity) thunderstorm (table 2) reflects the effect of storm rainfall totals on postfire debris-flow magnitude.

## Combined Relative Debris-Flow Hazard Ranking

When debris-flow hazards were considered as a combination of both probability and volume, we found that in response to the 3-hour-duration, 1-year-recurrence storm, one basin that drains into Pacoima Canyon, several basins that drain into Big Tajunga Canyon, one basin that drains into Arroyo Seco, one basin that drains into Devils Canyon, and two of the basins on the northern edge of the burned area showed the highest possible Combined Relative Debris-Flow Hazard Ranking (fig. 5A). The second highest Combined Relative Debris-Flow Hazard Ranking was estimated for all of the basins along the San Gabriel mountain front, as well as for additional basins throughout the burned area in response to the 3-hour-duration thunderstorm. These rankings reflect hazardous conditions within and immediately downstream from these basins.

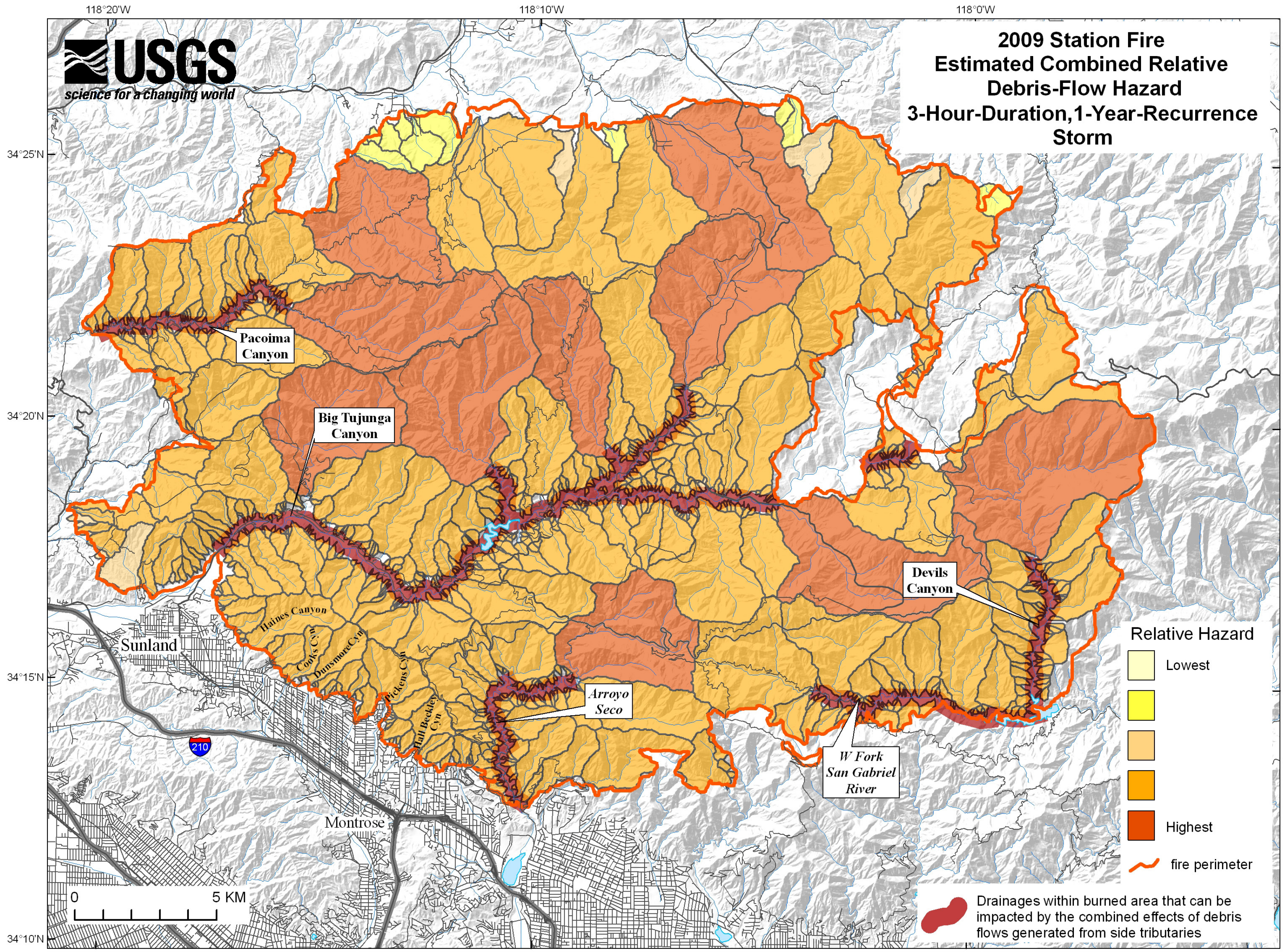


**Figure 5A.** Combined Relative Debris-Flow Hazard Ranking for basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

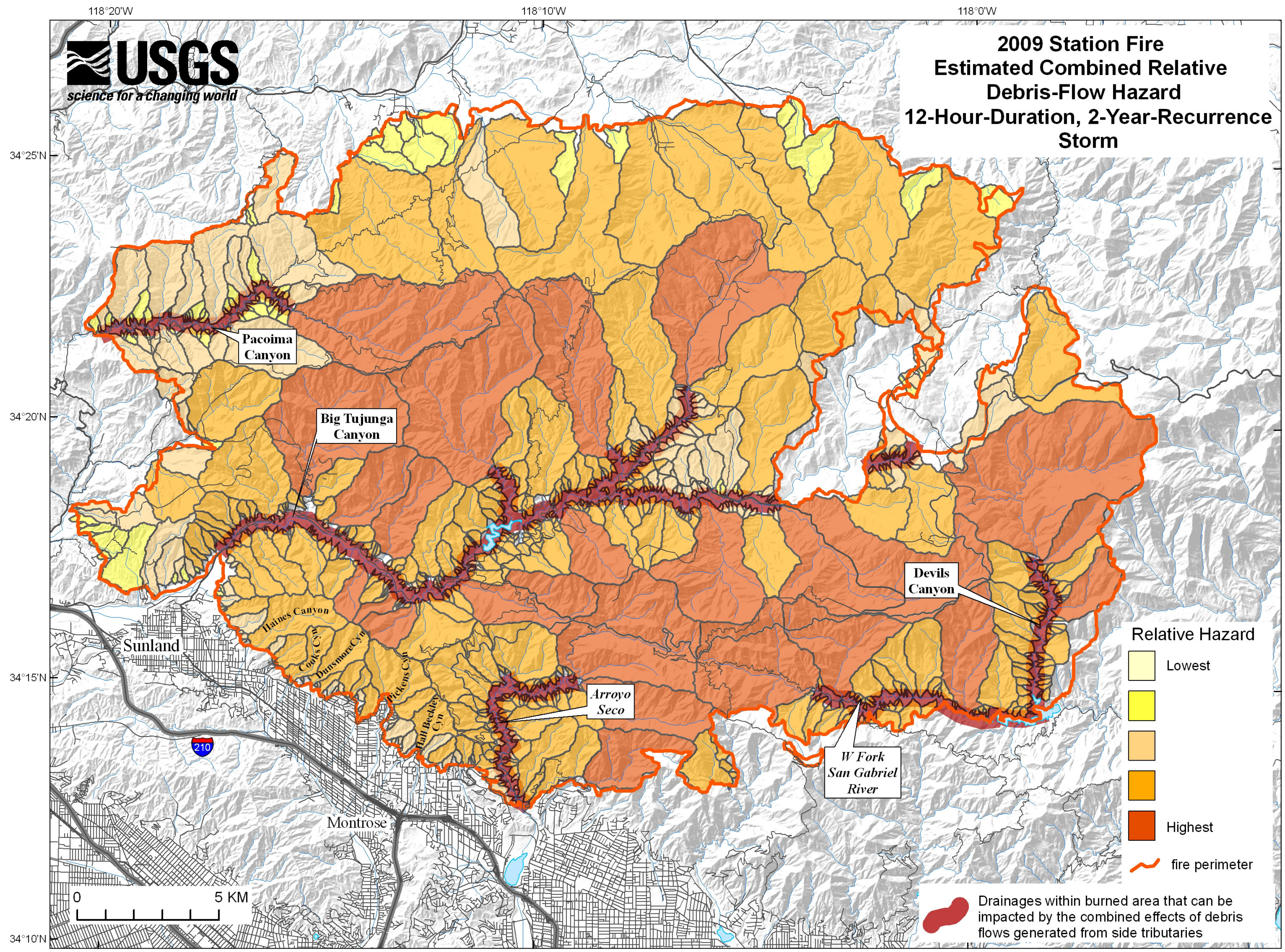


**Figure 5B.** Combined Relative Debris-Flow Hazard Ranking for basins burned by the Station fire in response to a widespread, 12-hour-duration, 2-year-recurrence storm.

In response to the 12-hour-duration, 2-year-recurrence storm, basins that drain into Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River and Devils Canyon showed the highest possible Combined Relative Debris-Flow Hazard Ranking (fig. 5B), while basins along the northern edge of the burned area showed the second highest Combined Relative Debris-Flow Hazard Ranking, as did additional basins throughout the burned area. The presence of basins with these high rankings indicates the potential for significant debris-flow impact both in these drainages and immediately downstream.

## Debris-Flow Inundation

The areas along the San Gabriel mountain front between Arroyo Seco and Big Tujunga Canyon that may potentially be inundated by debris flows in response to the 3-hour-duration and the 12-hour-duration storms when the full capacity of all sediment-retention basins is available are shown in figures 6A and B, respectively. If the capacity of any given sediment-retention basin is greater than the estimated volume of material generated for a given basin in response to either of the storms, no inundation area is shown. In addition, the areas that may potentially be inundated by debris flows in response to the 3-hour-duration and 12-hour-duration storms when the sediment-retention basins are completely full are shown in figures 7A and B, respectively. This assessment characterizes the potential debris-flow impacts if the drains or spillways of each basin fail or become blocked with debris-flow material or vegetation during a storm. Although it is unlikely that every sediment-retention basin will fail during a single storm, this assessment provides information that can be used for preparing for such an occurrence downstream from each basin within the flood-control system. We did not map debris-flow inundation for the two burned basins east of Arroyo Seco because they drain into the large-capacity Devil's Gate Reservoir (fig. 1). And lastly, the areas along the northern flank of the San Gabriel Mountains between Arrastre and Bare Mountain Canyons that may potentially be inundated by debris flows in response to the 3-hour-duration and the 12-hour-duration storms are shown in figures 8A and B, respectively.

The debris-flow inundation simulations use the maximum and minimum volumes associated with each volume class estimated for each basin in response to both storms (Figs. 4A and B). Note that the onset of deposition (the start of the inundation simulation) was located within Haines, Dunsmore, Goss, Snover, and Hay Canyons, as well as in most of the canyons on the northern side of the fire because the channel reaches near the mountain front are wide with gentle gradients. The inundation simulation started downstream from the mountain front for Zachau, Rowley, Blue Gum, Blanchard, Cooks, Pickens, and Hall Beckley Canyons because the channels are incised into the mountain-front alluvial fans.

The inundation simulations using the range of volumes of material estimated in response to the 3-hour-duration thunderstorm when the full capacity of all sediment-retention basins is available indicate that neighborhoods immediately below any of the small drainages that are unprotected by sediment-retention basins may be impacted by debris flows for a distance up to approximately 0.25 km (0.15 mi) from the mountain front (fig. 6A). These include streets and neighborhoods below the three basins immediately west of Haines Canyon, the basin east of Cooks Canyon, the three basins immediately east of Dunsmore Canyon, the two basins immediately west of Goss Canyon, the four basins between Mullally and Snover Canyons, the two canyons east of Snover Canyon, Weber Canyon, the basin east of Hay Canyon, and the three basins east of Gould Canyon.

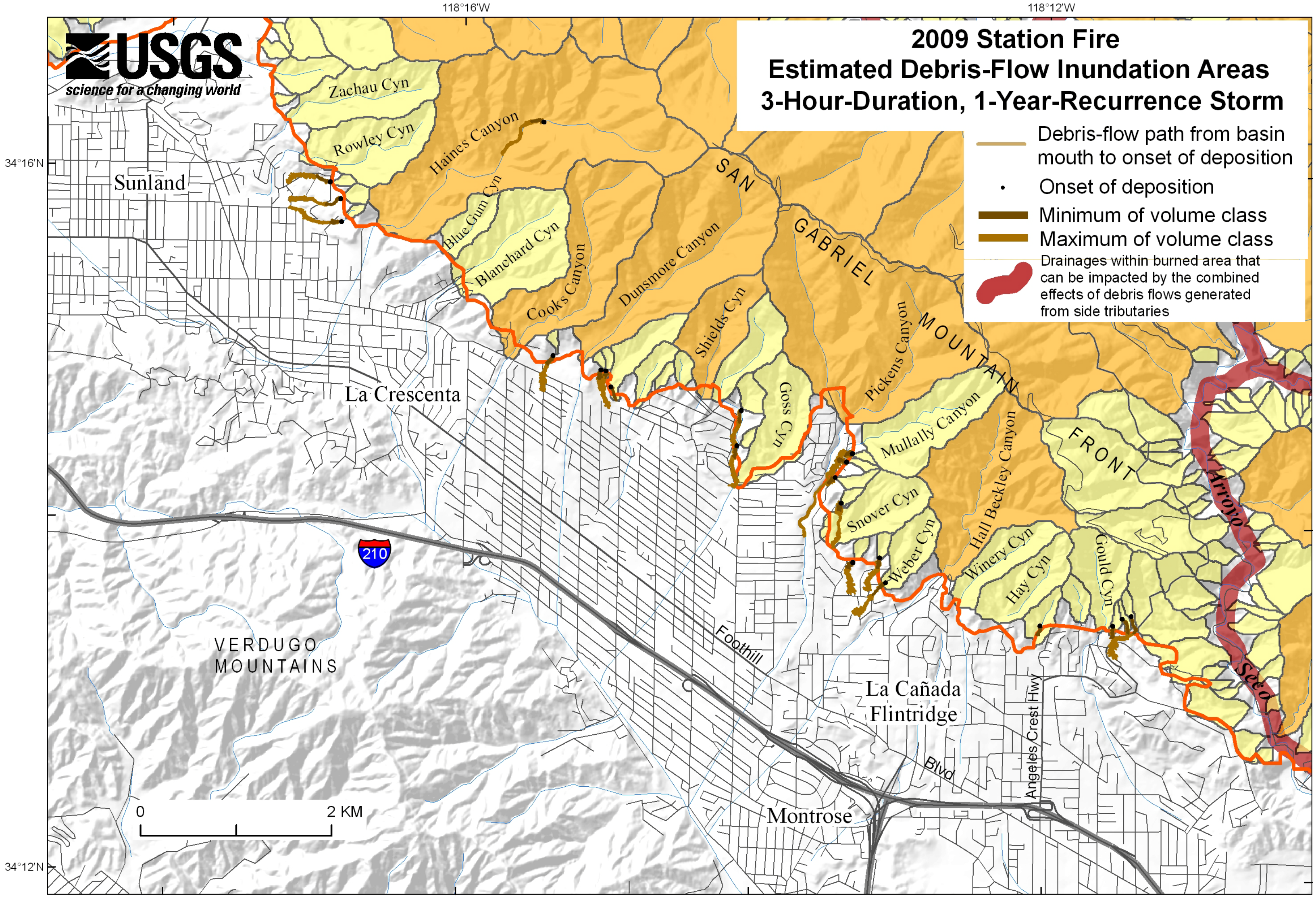


**Figure 6A.** The area that may be inundated by debris-flow deposits with the estimated volume class range for basins along the San Gabriel mountain front in response to the 3-hour-duration, 1-year-recurrence thunderstorm when all sediment-retention basins are empty. See figure 4A for volume classes. If the capacity of the sediment-retention basin is greater than the estimated volume of material, debris-flow inundation is not mapped. Because it is unlikely that any given thunderstorm would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

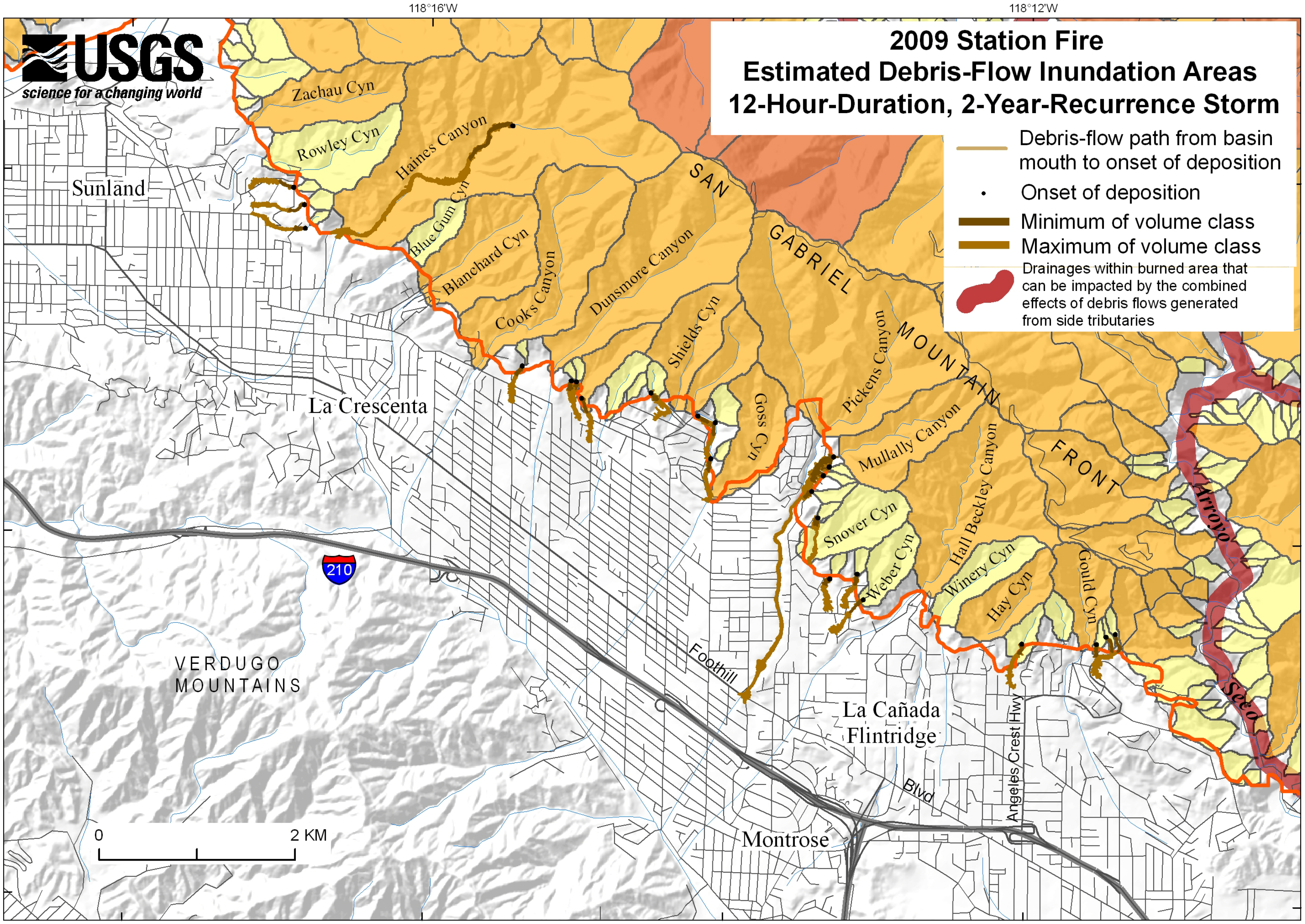


**Figure 6B.** The area that may be inundated by debris-flow deposits with the estimated volume class range for basins along the San Gabriel mountain front in response to a widespread 12-hour-duration, 2-year-recurrence storm when all sediment-retention basins are empty. See figure 4B for volume classes. If the capacity of the sediment-retention basin is greater than the estimated volume of material, debris-flow inundation is not mapped.

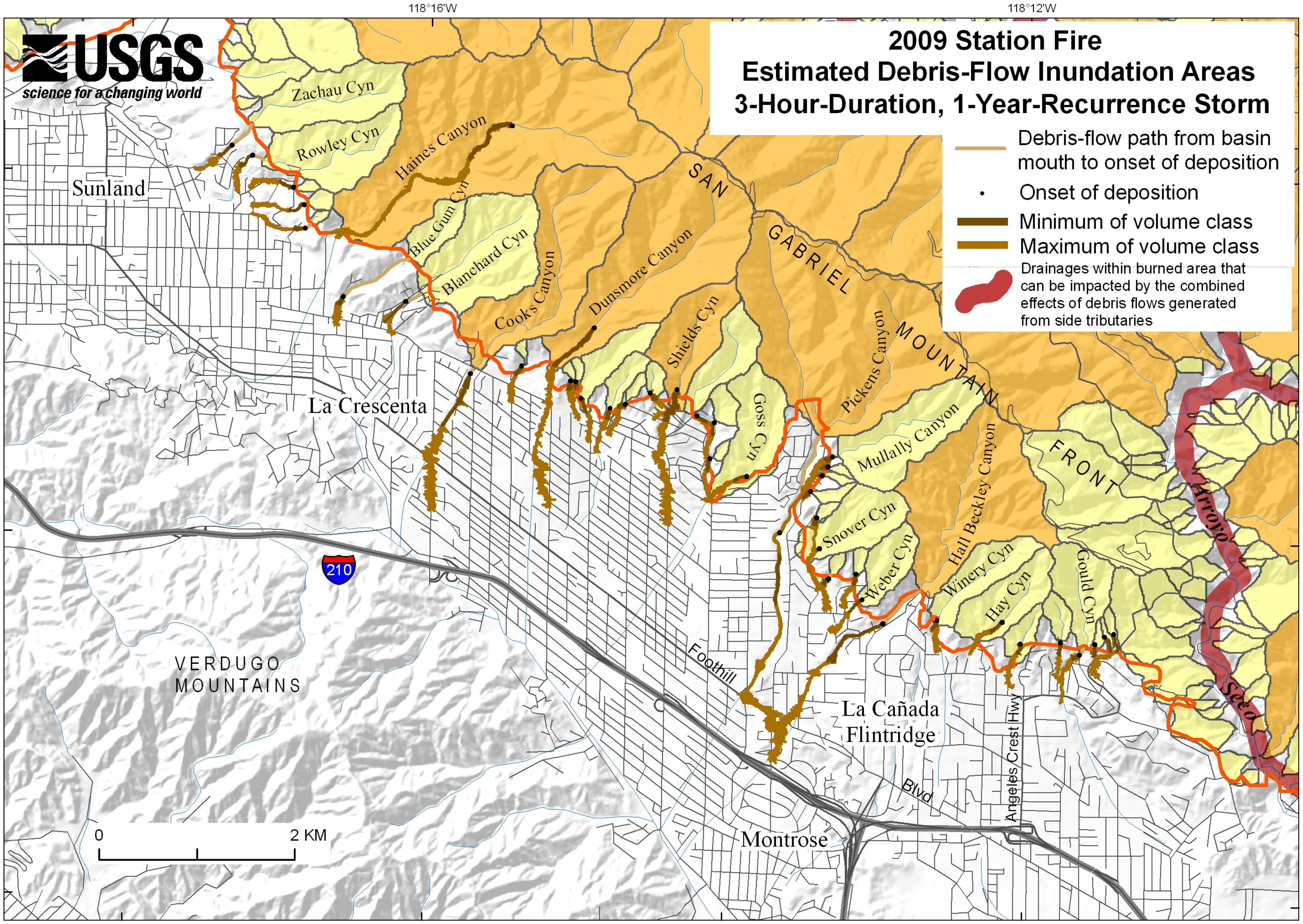


**Figure 7A.** The area that may be inundated by debris-flow deposits in response to the 3-hour-duration, 1-year-recurrence thunderstorm when sediment-retention basins overtop or basin drains, spillways, or outflow channels experience blockages or failures. Because it is unlikely that a thunderstorm of this magnitude would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm. In addition, it is unlikely that the every sediment-retention basin would fail during a single storm.

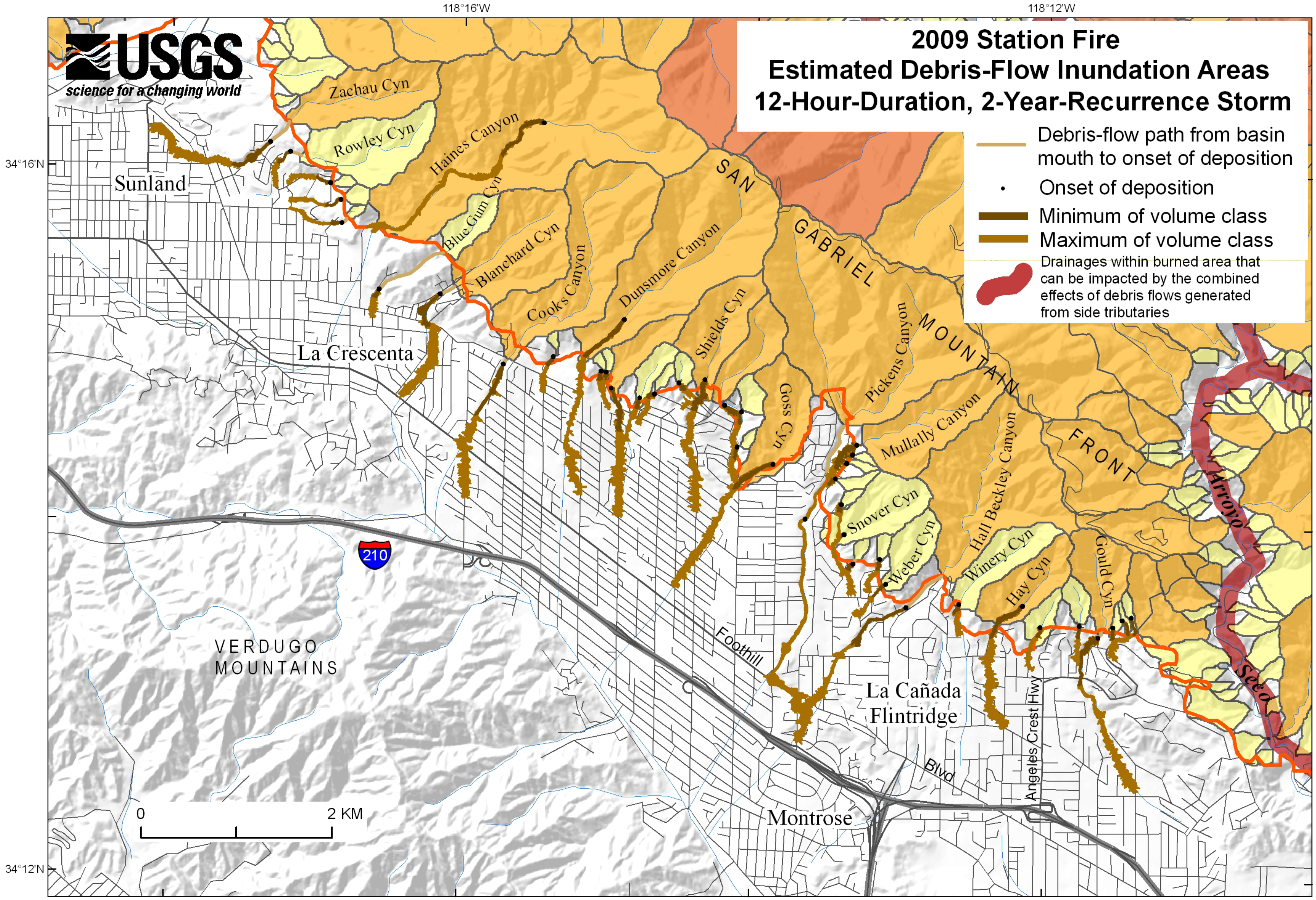


**Figure 7B.** The area that may be inundated by debris-flow deposits in response to a widespread, 12-hour-duration, 2-year-recurrence storm when sediment-retention basins overtop, or basin drains, spillways or outflow channels experience blockages or failures. It is unlikely that every sediment-retention basin would fail during a single storm.

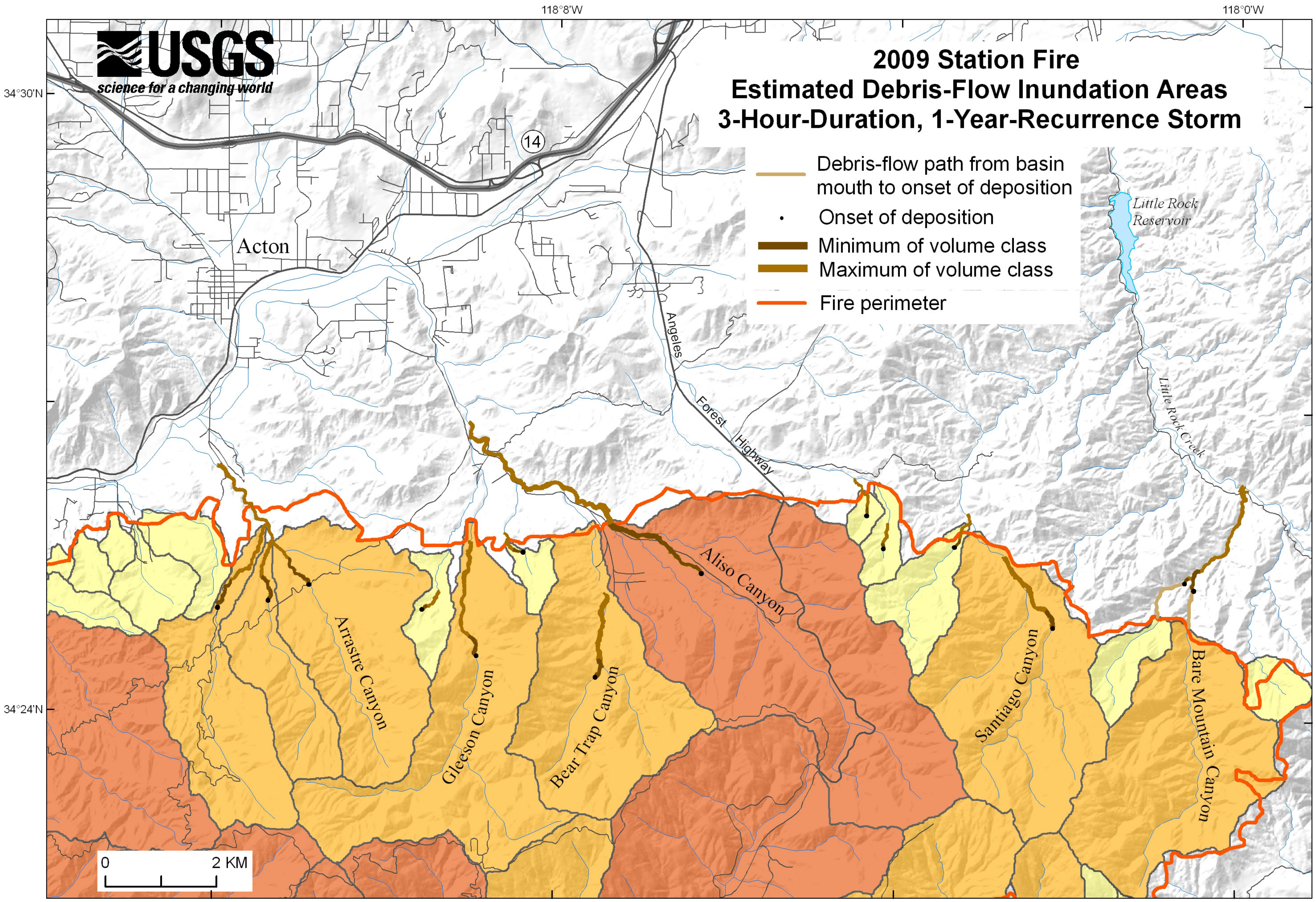


**Figure 8A.** The area that may be inundated by debris-flow deposits with the estimated volume class range for basins along the northern edge of the burned area in response to the 3-hour-duration, 1-year-recurrence storm. See figure 4A for volume class for each basin.

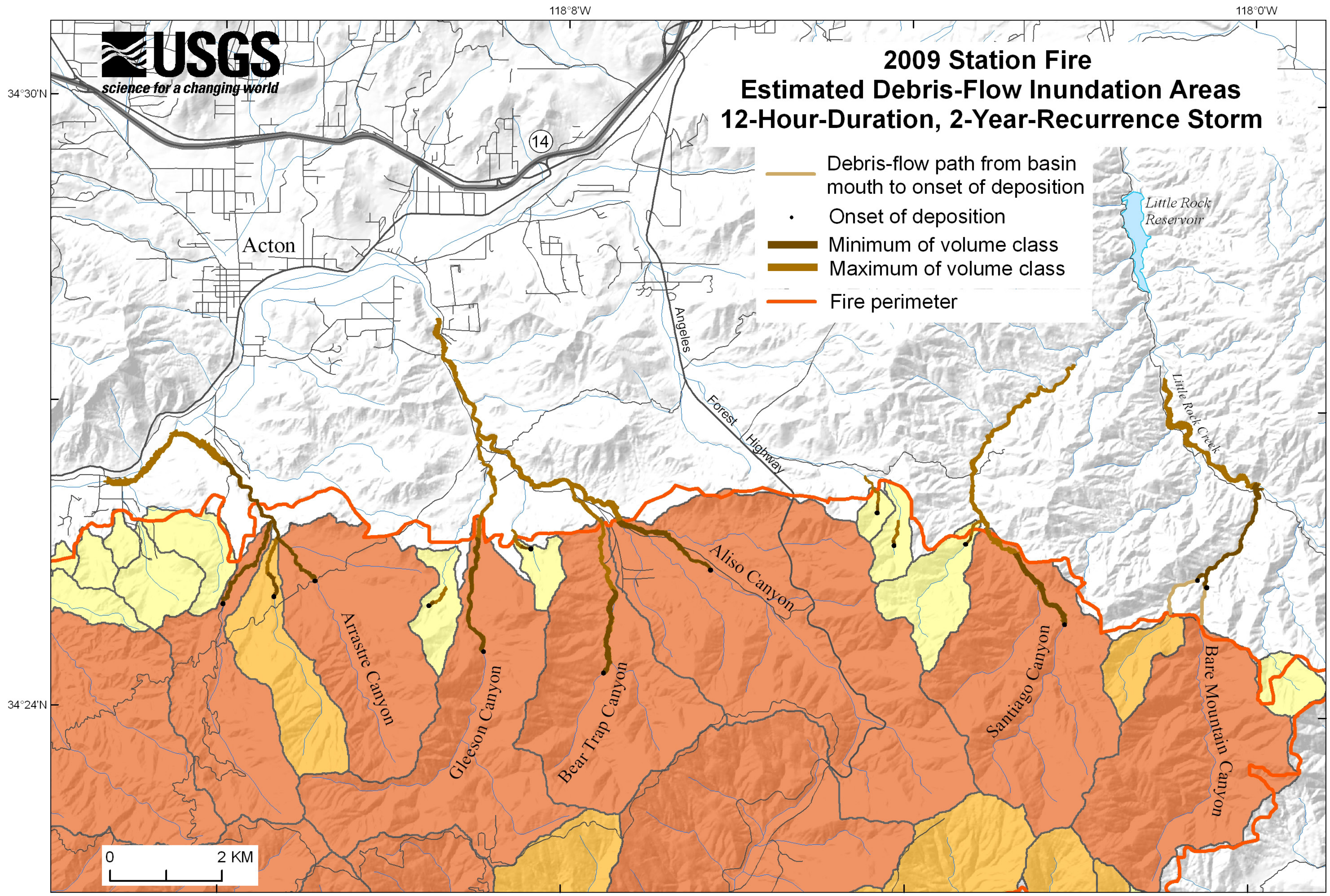


**Figure 8B.** The area that may be inundated by debris-flow deposits with the estimated volume class range for basins along the northern edge of the burned area in response to a widespread, 12-hour-duration, 2-year-recurrence storm. See figure 4A for volume class for each basin.

The inundation simulations using the somewhat larger range of volumes of material estimated in response to the 12-hour-duration storm when sediment-retention basins are empty also indicate that neighborhoods immediately below any unprotected drainages may be impacted by debris flows (fig. 6B). In this case, debris-flow material may be deposited over a distance of approximately 0.5 km (0.30 mi) from the mountain front and impact streets and neighborhoods below the three basins immediately west of Haines Canyon, the basin east of Cooks Canyon, the three basins immediately east of Dunsmore Canyon, Goss Canyon and the two basins immediately to the west the four basins between Mullally and Snover Canyons, the two canyons east of Snover Canyon, Weber Canyon, the basin east of Hay Canyon, and the three basins east of Gould Canyon. Material may also be deposited below Shields Canyon, may extend from the outlets of Pickens and Mullally Canyons to Foothill Boulevard, and below the unnamed canyon east of Hay Canyon.

In this assessment we considered the effects of three small basins along the San Gabriel mountain front that could impact the Angeles Crest Highway. In response to both storm scenarios, material crosses the highway and travels onto the gentle hillslopes below (figs. 6A, 6B, 7A, 7B). Although relatively small volumes of material are estimated, these events have the potential to damage the road and endanger vehicle traffic.

Should the sediment-retention basins overtop, or experience drain, spillway, or outflow channel blockages or failures during the 3-hour-duration thunderstorm, debris-flow material may be deposited within several neighborhoods up to 2.0 km (1.24 mi) from the San Gabriel mountain front (fig. 7A). In particular, debris-flow material generated from Cooks Canyon, Pickens and Mullally Canyons, and Hall Beckley Canyon may be deposited beyond Foothill Boulevard, while material from Dunsmore and Shields Canyons may travel well into neighborhoods along the mountain front.

Should the sediment-retention basins overtop, or experience drain, spillway, or outflow channel blockages or failures during the 12-hour-duration storm, debris-flow material may be also deposited in neighborhoods up to approximately 2.0 km (1.24 mi) from the San Gabriel mountain front (fig. 7B). In particular, debris-flow material generated from Zachau and Rowley Canyons may be deposited in parts of Sunland, and debris-flow material from Cooks Canyon, Pickens and Mullally Canyons, and Hall Beckley Canyon may be deposited beyond Foothill Boulevard. Debris flows from Blanchard, Dunsmore, Shields, Goss, Hay and Gould Canyons may also be deposited within a significant area of the neighborhoods between the mountain front and Foothill Boulevard.

The area that may be impacted along the San Gabriel mountain front by debris flows generated by the two storms used in this assessment is smaller than that mapped by Eaton (1936) following the 1933–34 events, most likely because we are considering the effects of significantly smaller storms. The 1933–34 storm had greater rainfall accumulations over significantly longer durations, and thus generated significantly larger debris flows than those estimated here.

The inundation simulations from basins along the northern flank of the San Gabriel Mountains using the range of volumes of material estimated in response to the 3-hour-duration thunderstorm indicate that material may travel approximately 2.0 km (1.2 mi) from the mouth of Arrastre Canyon, approximately 3.0 km (1.9 mi) from the mouth of Aliso Canyon, and into Little Rock Creek (figure 8A).

In response to the 12-hour-duration, 2-year-recurrence storm, the inundation simulations indicate the possibility that debris flows generated in Arrastre Canyon may travel into neighborhoods and streets within about 5.0 km (3.1 mi) from the canyon mouth, and debris flows from Gleeson, Bear Trap, and Alison Canyon may travel into the outskirts of the town of Acton (figure 8B). In addition, debris flows are shown to impact Santiago Canyon and Little Rock Creek.

## Limitations of Assessment

Storms with greater rainfall accumulations and intensities, or longer durations, than those evaluated in this assessment will present more severe hazards than those shown in figures 3 – 8. In addition, the assessments presented here are specific to postfire debris flows; significant hazards from flash flooding will require a separate assessment.

The parameters included in the models used in this assessment are considered to be first-order controls 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— may also affect debris-flow production. However, data necessary to evaluate such effects are not presently 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 2 years following a fire. If dry conditions prevent sufficient regrowth of vegetation, this recovery period will be longer. We suggest that the assessment presented here may be applicable for up to 2 years after the fire. However, significant hazards from flash flooding may remain for many years after a fire.

Finally, this work is preliminary and is subject to revision. It is being provided due to the need for timely "best science" information. The 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 this assessment, we estimated the probability and volume of debris-flow production from basins burned by the Station fire in response to a 3-hour-duration, 1-year-recurrence thunderstorm and a widespread, 12-hour-duration, 2-year recurrence storm, and we generated maps that show the areas along the San Gabriel mountain front and the northern edge of the burned area that may be inundated by the estimated volume of material. Multivariate statistical models that describe debris-flow probability and volume as a combination of different measures of basin burned extent, gradient, and material properties were used to estimate the probability of debris flow and the expected volume of material for each of the 678 basins within the burned area. Debris-flow depositional areas on the north edge of the burned area were mapped using the range of predicted volumes. Depositional areas were mapped along the San Gabriel mountain front for a best-case scenario when all available sediment-retention basin storage capacity is available, and a worst-case scenario when the basins are overtopped, or drains, spillways, or outflow channels become blocked during a storm. This assessment provides critical information for issuing spatially specific warnings, locating and designing mitigation measures, and planning evacuation timing and routes within the first two winters following the fires.

Basins that drain into Big Tujunga Canyon, Pacoima Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon were identified as having probabilities of debris-flow occurrence greater than 80 percent, the potential to produce debris flows with volumes greater than 100,000 $m^3$, and the highest Combined Relative Debris-Flow Hazard Ranking in response to both a 3-hour-duration, 1-hour recurrence thunderstorm and a 12-hour-duration, 2-year recurrence storm. The number of basins for which such a high potential hazard is identified in response to these short-recurrence-interval storms indicates the possibility for significant impacts by debris flows to homes, buildings, roads, bridges, culverts, and reservoirs located both within these drainages as well as immediately downstream from the burned area.

All but the basins with areas less than approximately 0.5 $km^2$ (0.2 $mi^2$) along the San Gabriel mountain front between Big Tujunga Canyon and Arroyo Seco showed estimated probabilities of debris-flow occurrence greater than 80 percent, volumes between 10,000 and 100,000 $m^3$, and high Combined Relative Debris-Flow Hazards Rankings in response to the two storms evaluated. The combination of high probabilities and large magnitudes determined for these basins indicate a significant potential for debris flows to affect neighborhoods along the mountain front.

Debris-flow inundation simulations along the San Gabriel mountain front for the situation when the storage capacity of all of the sediment-retention basins is available indicate that debris-flow material may be deposited in neighborhoods immediately below unprotected basins and along the Angeles Crest Highway. When sediment-retention basins overtop, or drains, spillways or outflow channels become blocked or fail, debris flows may be deposited in neighborhoods and streets and impact infrastructure between the mountain front and beyond Foothill Boulevard.

High debris-flow probabilities and large volumes estimated for the largest basins on the north edge of the burned area in response to both storms also indicate the potential for debris-flow impacts to infrastructure on this side of the fire. Simulations of potential debris-flow inundation areas along the northern extent of the fire indicate that in response to the 3-hour-duration, 1-year-recurrence storm, debris flows may travel between 2.0 and 3.0 km (1.2 and 1.9 mi) from the mouths of some canyons, while in response to the 12-hour-duration, 2-year-recurrence storm, debris flows may travel up to 5 km (3.1 mi) from the basin mouths.

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