



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



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Cover photograph: Ash cloud from Station fire above the San Gabriel Mountains, September 2009. Los Angeles Times photograph

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

By Susan H. Cannon, Joseph E. Gartner, Michael G. Rupert, John A. Michael, Dennis R. 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 along the San Gabriel mountain front 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 12-hour-duration, 2-year recurrence storm. Debris-flow inundation areas are mapped for scenarios where all sediment-retention basins are empty and where the basins are all completely full. 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 m³, 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 downstream from the burned area. These areas will require appropriate debris-flow mitigation and warning efforts.

Probabilities of debris-flow occurrence greater than 80 percent, debris-flow volumes between 10,000 and 100,000 m³, and high Combined Relative Debris-Flow Hazard Rankings were estimated in response to both short recurrence-interval (1- and 2-year) storms for all but the smallest basins along the San Gabriel mountain front between Big Tujunga Canyon and Arroyo Seco. The combination of high probabilities and large magnitudes determined for these basins indicates significant debris-flow hazards for neighborhoods along the mountain front. When the capacity of sediment-retention basins is exceeded, debris flows may be deposited in neighborhoods and streets and impact infrastructure between the mountain front and Foothill Boulevard. In addition, debris flows may be deposited in neighborhoods immediately below unprotected basins. Hazards to neighborhoods and structures at risk from these events will require appropriate debris-flow mitigation and warning efforts.

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, 1934, along the mountain front between La Cañada and Sunland. Rain started falling on December 12, 1934, and on December 31, 1934, short periods of intense rain triggered debris flows that caused 30 deaths and completely swept away or destroyed 483 homes (Eaton, 1936). 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 m³ (535,000 yd³) of debris-flow deposits from private property and streets and 95,000 m³ (124,000 yd³) in the existing sediment-retention basins, giving a total volume of 504,000 m³ (659,000 yd³) of material deposited beyond the mountain front from this single event.

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, resulted in the deaths of 16 people (U.S. Army Corps of Engineers, unpub. data, 2005) (fig. 2B).

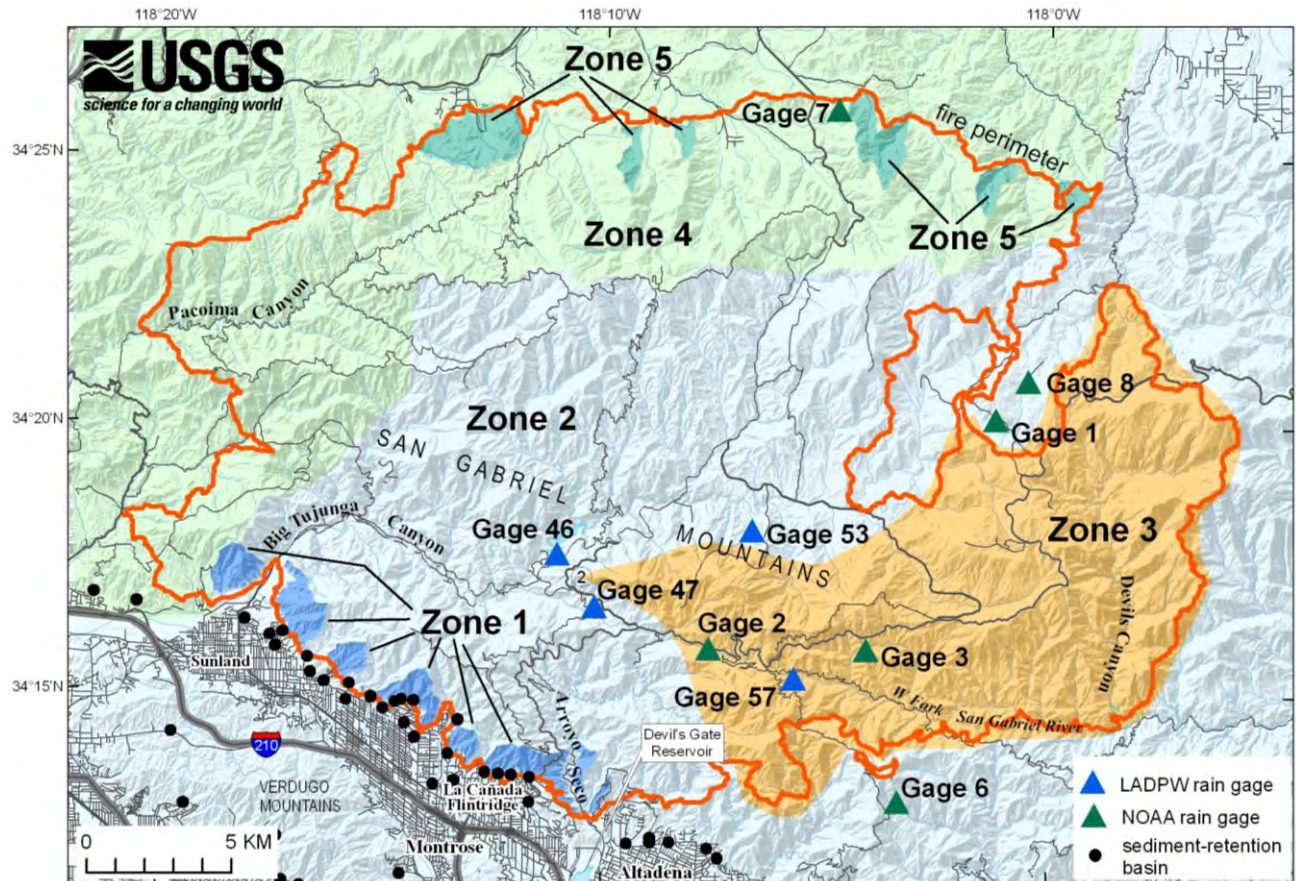


Figure 1. Perimeter of Station fire in the San Gabriel Mountains, locations of rain gages and precipitation zones defined for hazard assessment, and locations of sediment-retention basins in the vicinity of the burned area. LADPW, Los Angeles Department of Public Works. NOAA, National Oceanic and Atmospheric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



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 December 2003 storm (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-dominated 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 were 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	None
Basin gradients:	K-factor (erodibility)	
	Length of the longest flow path	Length of the longest flow path
	Elevation change	Elevation change
	Percentage of burned basin with slopes greater than or equal to 30 percent	
Storm rainfall:	Average storm intensity	Total storm rainfall
	Storm duration	

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 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 be represented by a combination of both probability of occurrence and volume (Cannon and others, in press). 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 and that will produce the smallest events (Cannon and others, in press).

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 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 (B.B. Worstell, U.S. Geological Survey, unpub. data, 2009). We then developed 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). A 10-m digital elevation model (DEM) of the area is used to simulate inundation by determining the cross-sectional area of a 10-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 10-m cell by 10-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 channels on relatively low gradient surfaces, such as the setting along the front of the San Gabriel Mountains between Arroyo Seco and Big Tujunga Canyon (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 within a 10-m DEM, channel and depositional features smaller than 10 meters are not represented. Uncertainties associated with the method are indicated by simulating the inundation area of ranges of potential volumes within an order of magnitude for each basin.

Several sediment-retention basins that could potentially decrease the volume of material available for downstream inundation are located along the front of the San Gabriel Mountains (fig. 1). In this assessment, we first evaluate the situation where there has been time to empty all of the basins before the onset of winter rains (the best-case scenario) by subtracting the sediment-retention basin capacity from the predicted debris-flow volumes before running the inundation simulation. We also run the inundation simulation using the total predicted debris-flow volume to evaluate the case where previous storms have filled the retention basins with sediment and there has not been sufficient time to empty the basins before the next storm arrives (a worst-case scenario).

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 10-meter DEMs and Geographic Information System (GIS) hydrological tools. Basin outlets were positioned at breaks in slope along the front of the San Gabriel Mountains and the primary drainages and at the burned perimeter. Basin areas ranged between 0.01 km² and 30 km², comparable to the basin sizes used in the development of the regression models. Basins larger than 30 km² 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 short-duration, high-intensity thunderstorms as well as 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 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 LADPW 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 (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		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)	
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. 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 within a 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 downstream from the burned area. These areas will require appropriate debris-flow hazard mitigation and warning efforts.

In response to the 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 km² (0.2 mi²) (fig. 3B). These high probabilities indicate a significant potential for debris flows to impact neighborhoods along the mountain front. These areas will require appropriate hazard mitigation and warning efforts.

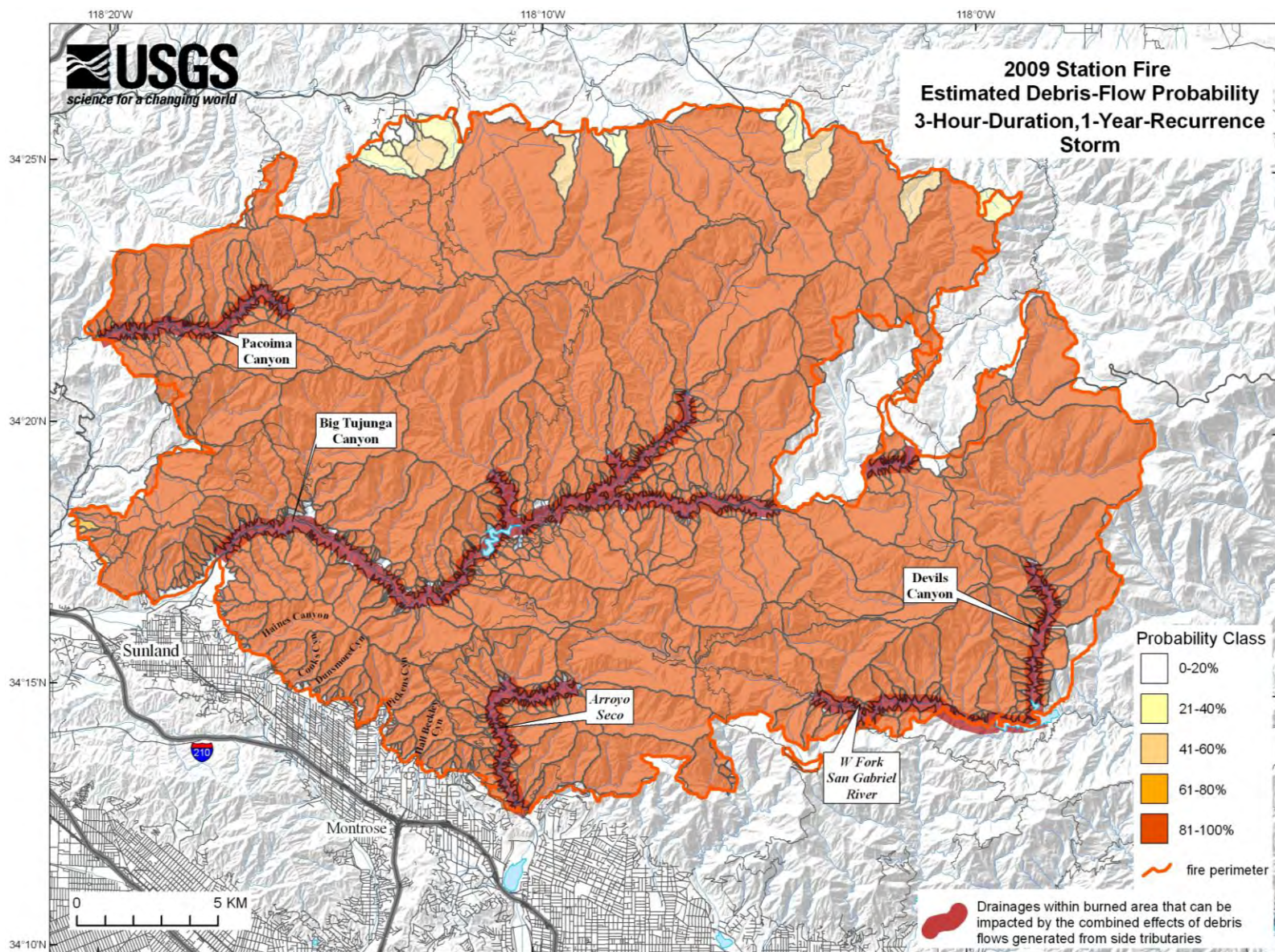


Figure 3A. Probability of debris flow estimated for basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that any given thunderstorm would affect the entire burned area, not every basin shown would produce debris flows in response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

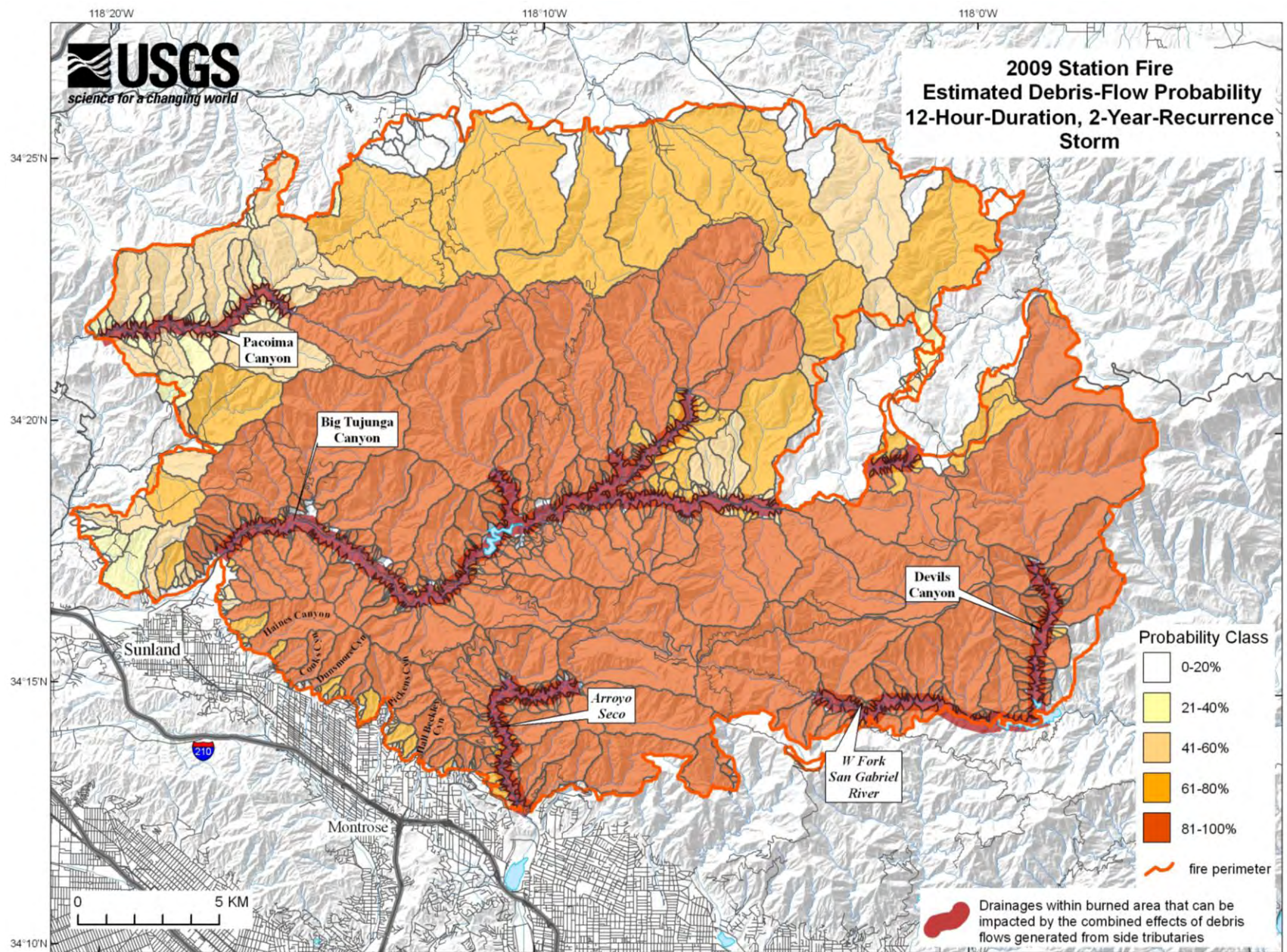


Figure 3B. Probability of debris flow estimated for basins burned by the Station fire in response to the 12-hour-duration, 2-year-recurrence storm.

Also in response to the 12-hour-duration, 2-year-recurrence storm, debris-flow probabilities of greater than 80 percent were estimated for one of the larger tributary basins to Pacoima Canyon, and 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, in combination with the 50 percent chance that the 12-hour-duration, 2-year-recurrence storm will occur in the area, indicates a significant possibility for debris-flow impacts to any buildings, roads, culverts, bridges, and reservoirs located within these drainages, as well as downstream from the burned area. These areas will require appropriate hazard mitigation and warning efforts.

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 influence of rainfall intensity on postfire debris-flow occurrence.

When compared with similar evaluations for past fires (e.g., Cannon and others, 2007), these are the most basins we have seen 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 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 m³ were estimated for one of the tributary basins to Pacoima Canyon, five of the tributary basins to Big Tujunga Canyon, and one of the tributary basins to both Arroyo Seco and Devils Canyon (fig. 4A). Debris-flow volumes between 10,000 and 100,000 m³ were estimated for three of the basins that contribute to Pacoima Canyon and several of the basins contributing to Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon. 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 downstream from the burned area. The reaches of these drainages within the burn perimeter that may be affected by debris flows contributed from tributary basins are indicated in fig. 4A. Additional assessment is necessary to identify the distance beyond the burn perimeter that these effects may extend.

Debris-flow volumes between 10,000 and 100,000 m³ 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 downstream from these canyons and basins and will require appropriate mitigation and warning efforts.

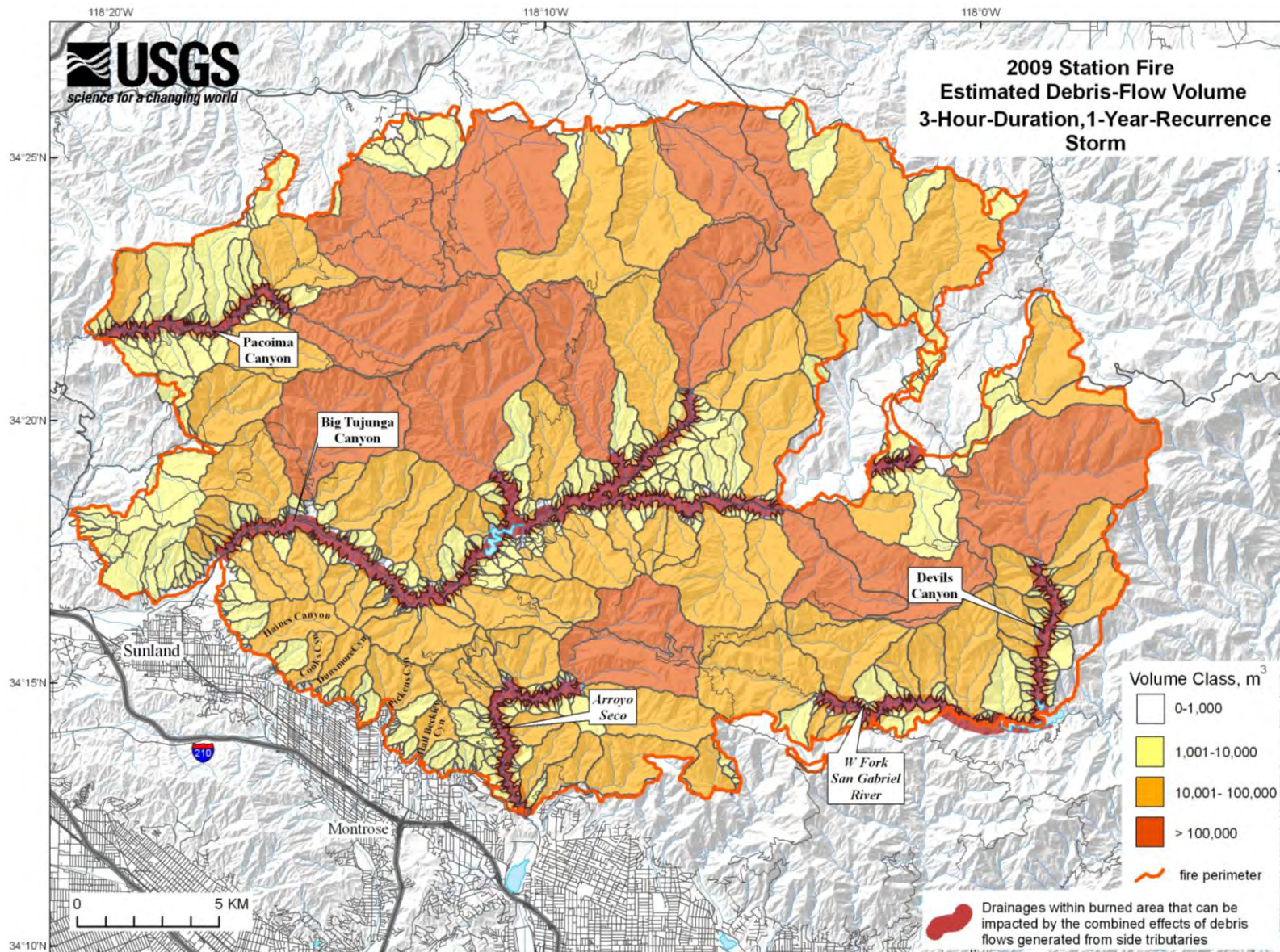


Figure 4A. Volume of debris flows estimated at the outlets of basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that any given thunderstorm would impact the entire burned area, not every basin shown would produce debris flows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

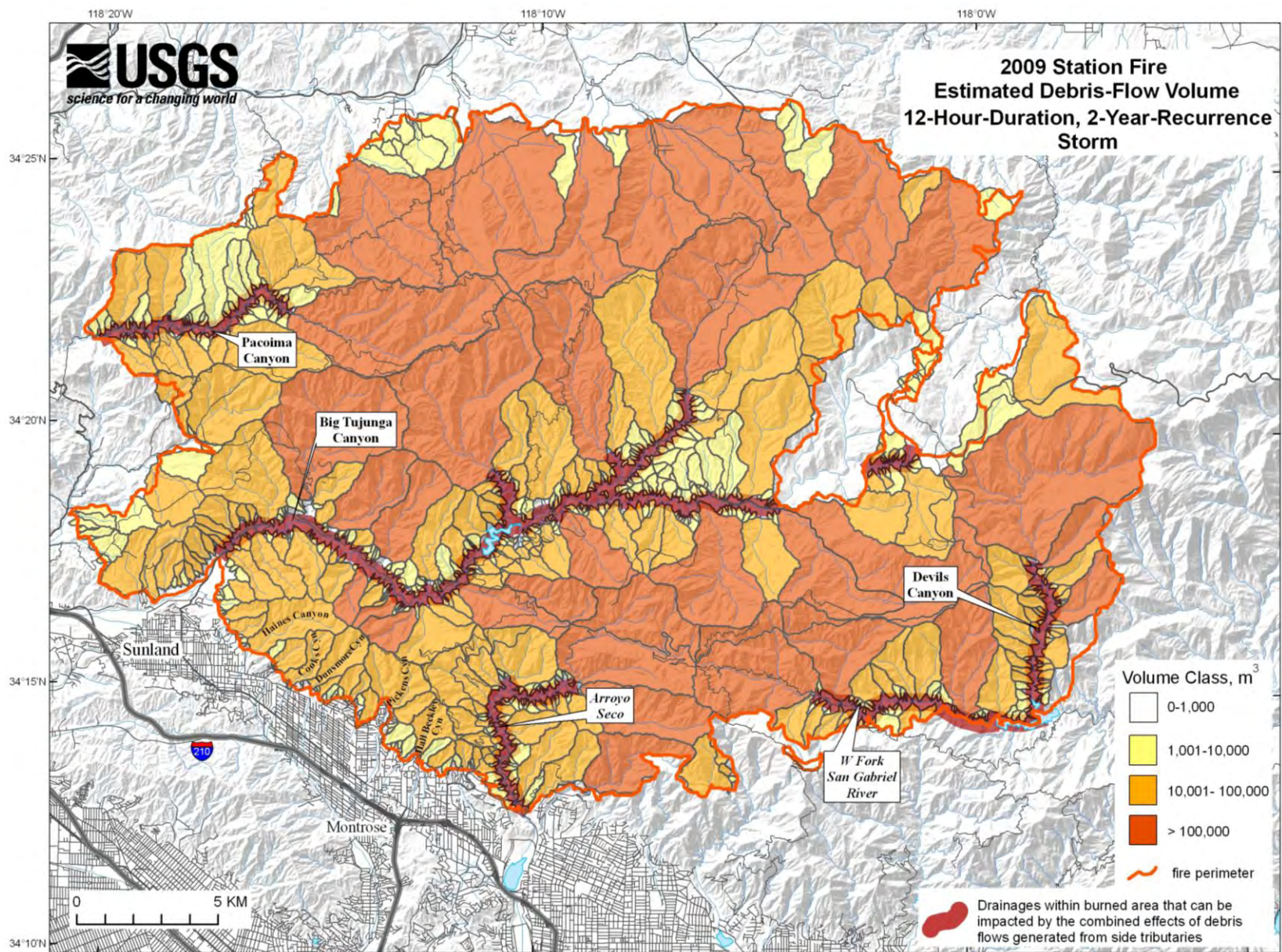


Figure 4B. Volume of debris flows estimated at the outlets of basins burned by the Station fire in response to the 12-hour-duration, 2-year-recurrence storm.

In response to the 12-hour-duration, 2-year-recurrence storm, debris-flow volumes greater than 100,000 m³ 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, and three of the tributary basins to both the West Fork of the San Gabriel River and Devils Canyon (fig. 4B). Debris-flow volumes between 10,000 and 100,000 m³ 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 downstream from the burned area. The reaches of these drainages within the burn perimeter that have the potential to be affected by debris flows contributed from tributary basins are indicated in fig. 4B. Additional assessment is necessary to identify the distance beyond the burn perimeter that these effects may extend.

Debris-flow volumes between 10,000 and 100,000 m³ were estimated in response to the 12-hour-duration, 2-year-recurrence storm for basins along the San Gabriel mountain front, including three unlabeled basins west of Haines Canyon, Haines Canyon itself, unlabeled canyon west of Cooks Canyon, Cooks Canyon itself, Dunsmore Canyon, four unlabeled basins east of Dunsmore Canyon, Pickens Canyon, the unlabeled canyon east of Pickens Canyon, Hall Beckley Canyon, three unlabeled canyons east of Hall Beckley Canyon, and three basins east of Arroyo Seco (fig. 4B). Debris flows of these magnitudes may pose significant hazards to life and property within and downstream from these canyons and basins and will require appropriate hazard mitigation and warning efforts.

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 influence 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 the same basins for which debris-flow volumes greater than 100,000 m³ were estimated in response to both storm scenarios (with the exception of the basins on the northern edge of the fire for the 12-hour-duration storm) also showed the highest possible Combined Relative Debris-Flow Hazard Ranking (figs. 4A and B, 5A and B). The presence of basins with these high rankings draining into Pacoima Canyon, Big Tujunga Canyon, Arroyo Seco, West Fork of the San Gabriel River, and Devils Canyon indicates the potential for significant debris-flow impact both in these drainages and downstream from the burned area. The reaches of these drainages within the burn perimeter that have the potential to be affected from debris flows contributed from side tributaries are indicated in figures 5A and B. Additional assessment is necessary to identify the distance beyond the burn perimeter that these effects may extend.

The second highest Combined Relative Debris-Flow Hazard Ranking was estimated for all of the basins along the San Gabriel mountain front in response to the 3-hour-duration thunderstorm, and for all but some of the basins with areas less than about 0.4 km² (0.15 mi²) in response to the 12-hour-duration storm. These rankings reflect hazardous conditions within these basins.

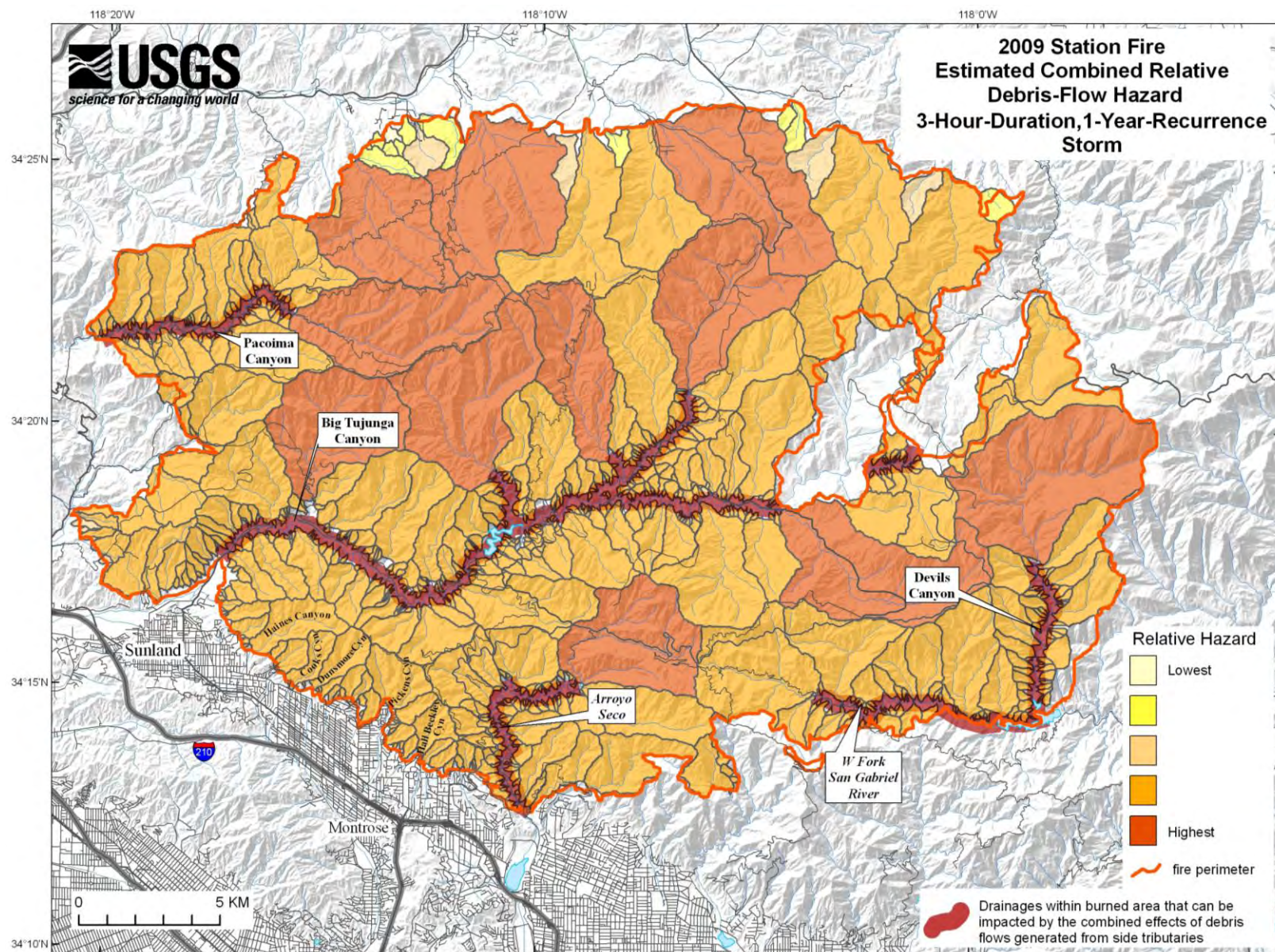


Figure 5A. Combined Relative Debris-Flow Hazard Ranking for basins burned by the Station fire if affected by the 3-hour-duration, 1-year-recurrence thunderstorm. Because it is unlikely that any given thunderstorm would affect the entire burned area, not every basin shown would produce debris flows in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

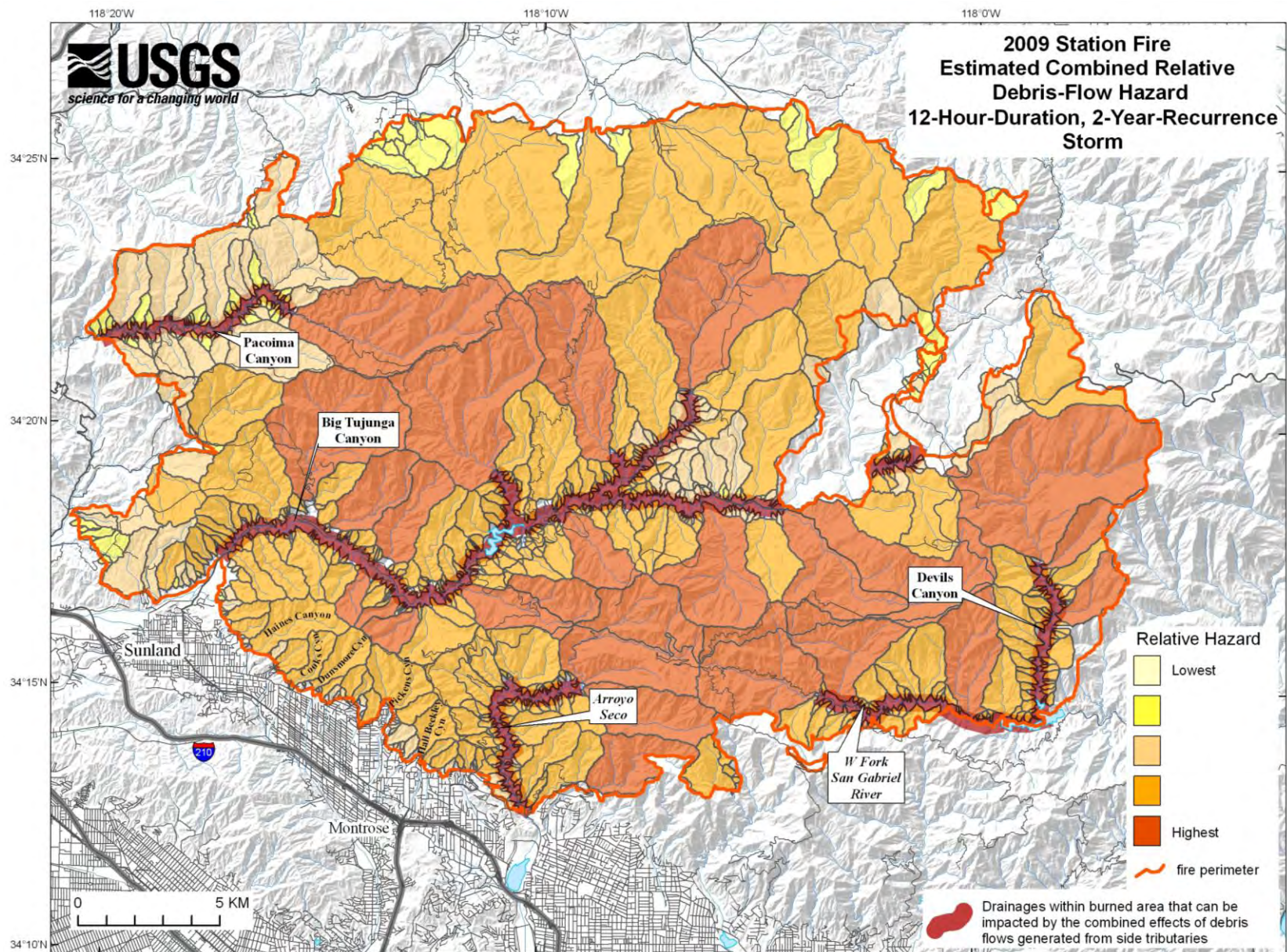


Figure 5B. Combined Relative Debris-Flow Hazard Ranking for basins burned by the Station fire in response to the 12-hour-duration, 2-year-recurrence storm.

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. We did not map debris-flow inundation for the two burned basins east of Arroyo Seco because they appear to drain into the large-capacity Devil's Gate Reservoir (fig. 1).

The debris-flow 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) may be located either within a basin itself if the channel is wide with a gentle gradient (as is the case for Haines, Dunsmore, Goss, Snover, and Hay Canyons), at the mountain front, or downstream from the mountain front if the channel is incised (as is the case for Zachau, Rowley, the small basin east of Rowley, Blue Gum, Blanchard, Cooks, Shields, Pickens, Mullally, Hall Beckley and Gould Canyons). For those basins with the onset of deposition mapped within the channel itself, for the inundation simulations 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). Similarly, for those basins with the onset of deposition mapped beyond the basin outlet, for the inundation simulations we used the range of volumes estimated for the entire basin, but started the simulation downstream from the basin outlet where deposition would start.

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 the unprotected small (less than approximately 0.05 km^2 [0.02 mi^2]) drainage 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.

The inundation simulations using the slightly 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 the unprotected small basins 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. In addition to the canyons and basins listed above, material may be deposited below Shields Canyon, well away from the outlets of Pickens and Mullally Canyons, and below the unnamed canyon east of Hay Canyon, and Gould Canyon.

When the sediment-retention basins are full prior to the 3-hour-duration thunderstorm (fig. 7A), debris-flow material may be deposited within several neighborhoods up to approximately 1.0 km (0.6 mi) from the San Gabriel mountain front. In particular, debris-flow material generated from Cooks Canyon may be deposited beyond Foothill Boulevard, while debris-flow material from Pickens, Mullally, and Hall Beckley Canyons may be deposited close to Foothill Boulevard.

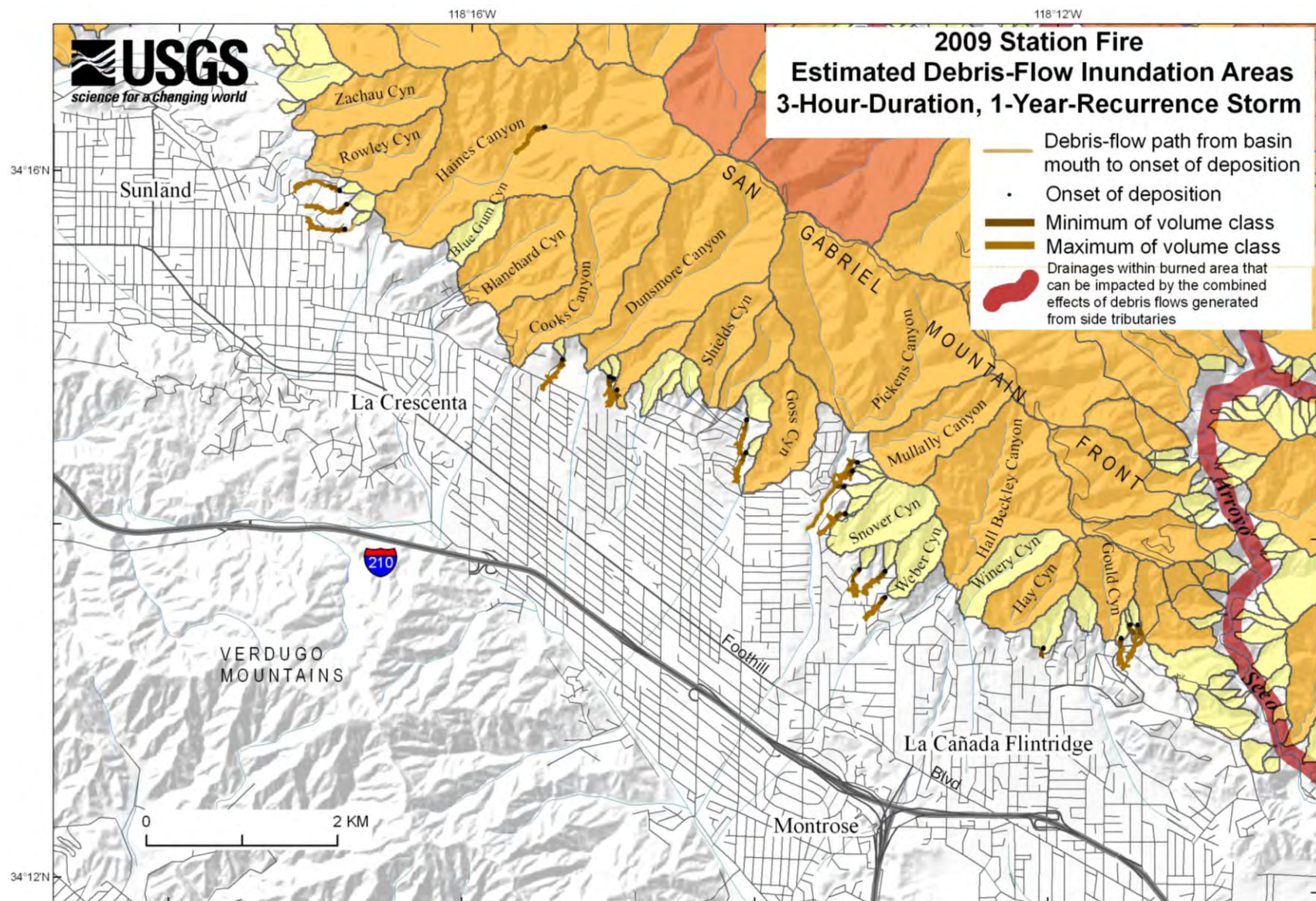


Figure 6A. The area that may be inundated by debris-flow deposits with the estimated volume class range for each basin when all sediment-retention basins are empty in response to the 3-hour-duration, 1-year-recurrence thunderstorm. See figure 4A for volume classes. If the capacity of the sediment-retention 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.

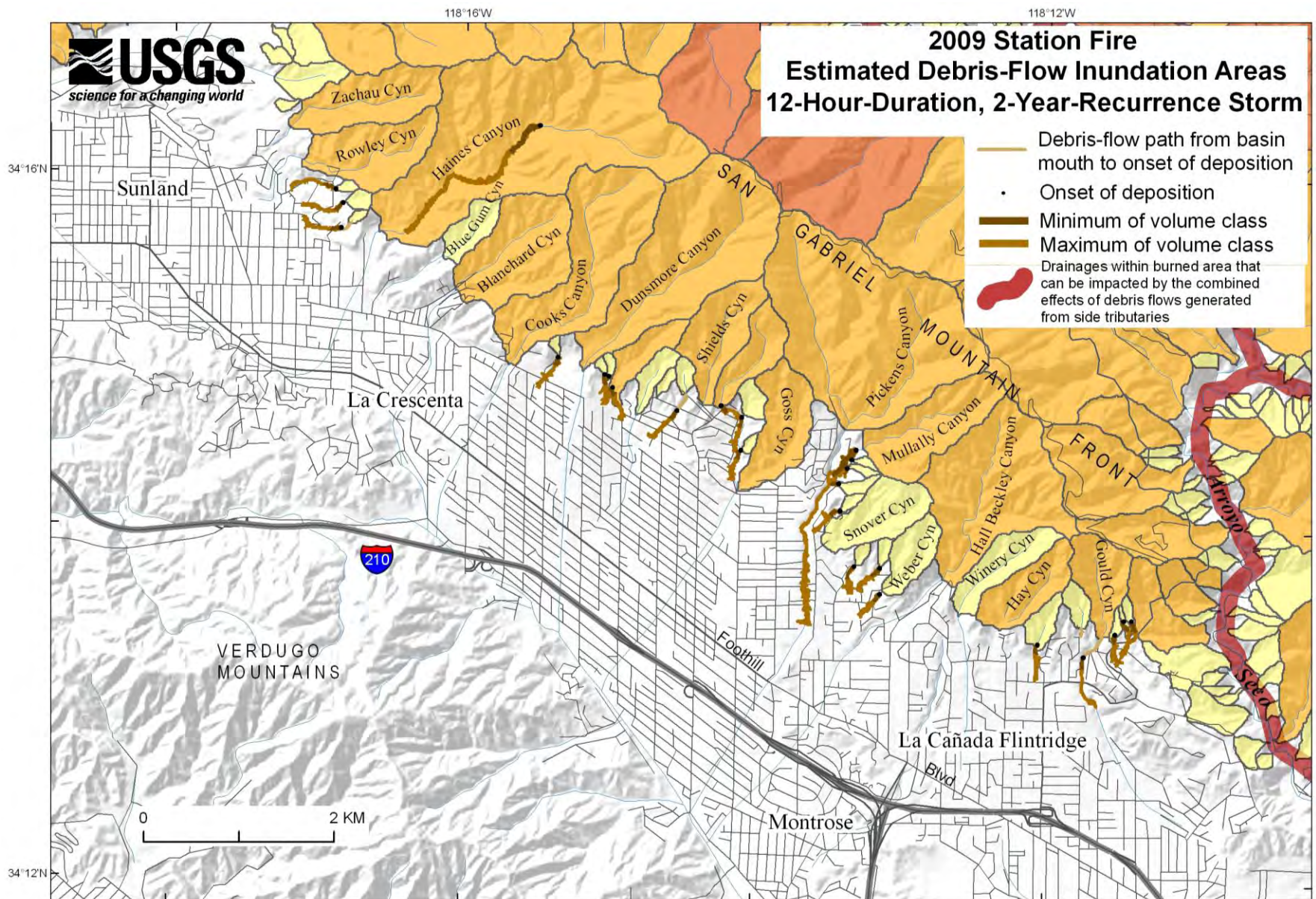


Figure 6B. The area that may be inundated by debris-flow deposits with the estimated volume class range for each basin when all sediment-retention basins are empty in response to the 12-hour-duration, 2-year-recurrence storm. See figure 4B for volume classes. If the capacity of the sediment-retention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

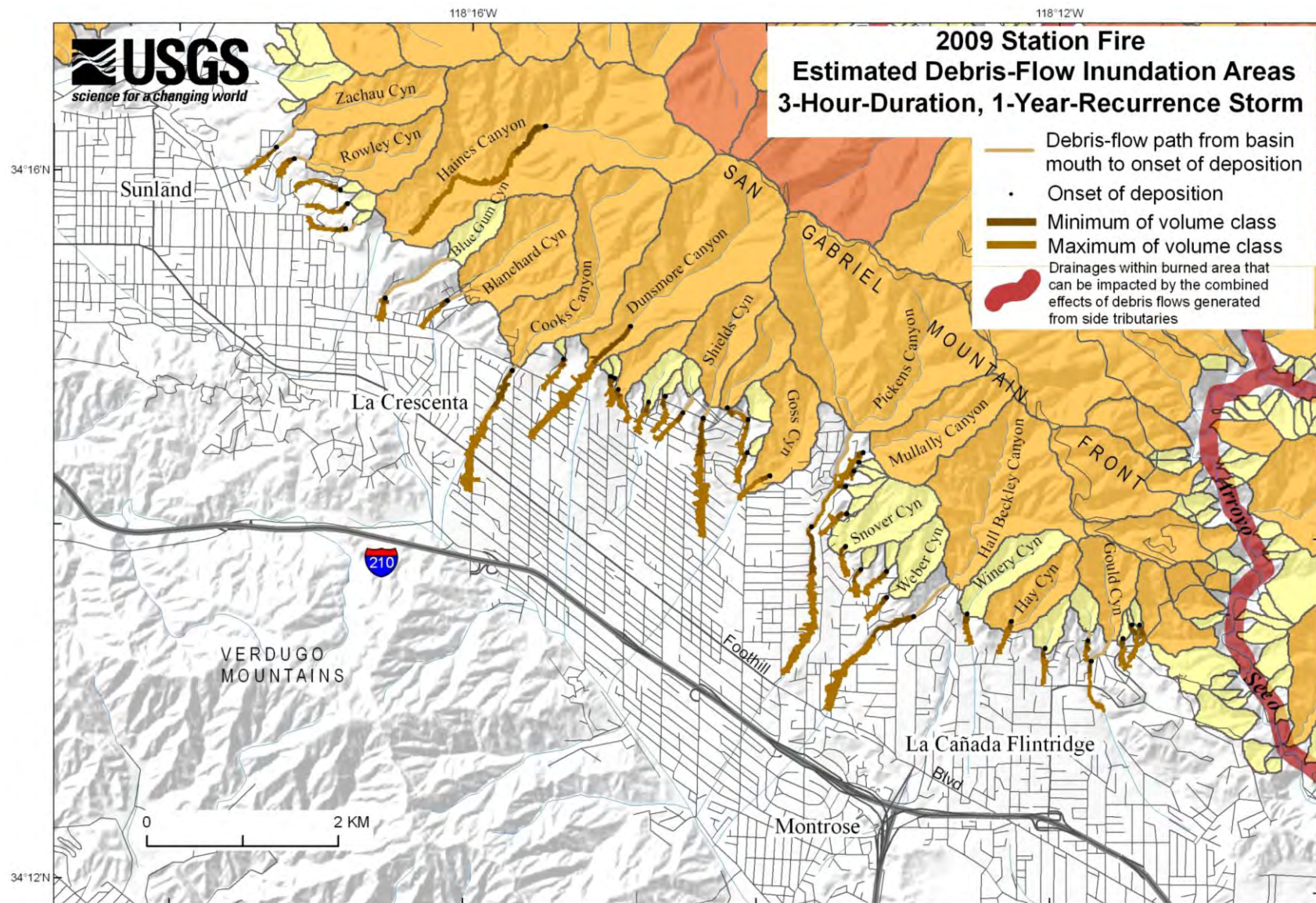


Figure 7A. The area that may be inundated by debris-flow deposits with the estimated volume class range for each basin when all sediment-retention basins are full in response to the 3-hour-duration, 1-year-recurrence thunderstorm. See figure 4A for volume classes. Because it is unlikely that any given thunderstorm would affect the entire burned area, not every basin shown would produce debris flows in response to the same storm.

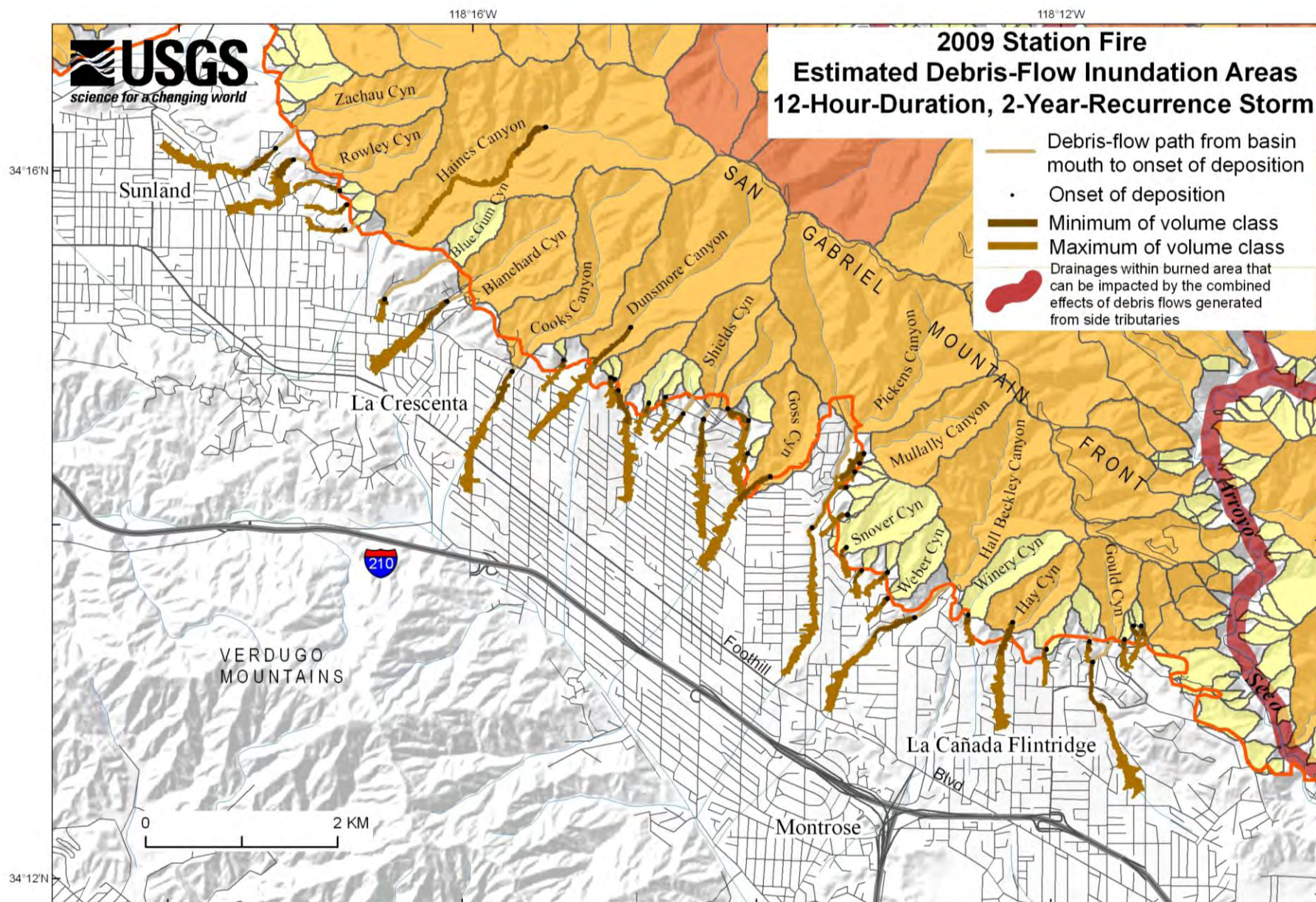


Figure 7B. The area that may be inundated by debris-flow deposits with the estimated volume class range for each basin when all sediment-retention basins are full in response to the 12-hour-duration, 2-year-recurrence storm. See figure 4B for volume class for each basin.

When the sediment-retention basins are full prior to the 12-hour-duration storm (fig. 7B), debris-flow material may be deposited in neighborhoods up to approximately 1.25 to 1.5 km (0.8 to 0.9 mi) from the San Gabriel mountain front. In particular, debris-flow material generated from Zachau and Rowley Canyons may be deposited in parts of Sunland, debris flows from Cooks Canyon may be deposited beyond Foothill Boulevard, while debris flows from Blanchard, Pickens, Mullally, and Hall Beckley Canyons may be deposited close to 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.

We are uncertain of the simulation results shown below Dunsmore Canyon in figures 7A and B. Although a flood-control channel (shown with a blue line in figs. 7A and B) is available to move material from the debris basin, the 10-m DEM topographic information indicates that flow will be primarily directed to the west into the neighborhood below the canyon. Because of this uncertainty, we recommend that the area between the mapped deposits and the flood-control channel be considered to be at risk for debris flows when the Dunsmore debris basin is nearing capacity.

The area that may be impacted 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 smaller storms.

Limitations of Assessment

Storms with greater rainfall accumulations and intensities, or longer durations, than those evaluated in this assessment may present more severe hazards than those shown in figures 3 – 7. 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 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—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 conservatively estimate that the assessment presented here may be applicable for as much as 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 urgent 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-hour-recurrence thunderstorm and a 12-hour-duration, 2-year recurrence storm, and we generated maps that show the areas along the San Gabriel mountain front 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 for the range of predicted volumes were mapped for situations when all available sediment-retention basins are empty and when the basins are all completely full. 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 m³, 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 downstream from the burned area.

All but the basins with areas less than approximately 0.5 km² (0.2 mi²) 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 m³, 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. These areas will require appropriate debris-flow hazard mitigation and warning efforts.

Although basins with areas less than approximately 0.05 km² (0.02 mi²) along the San Gabriel mountain front do not indicate the potential for generating debris flows with particularly large volumes, the inundation simulations indicate that debris-flow material may be deposited in neighborhoods and streets immediately below unprotected drainage basins. In addition, should the capacity of sediment-retention basins be exceeded, debris-flow material generated from all of the basins may be deposited in neighborhoods and on streets between the mountain front and Foothill Boulevard. Identified buildings and other structures at risk from these events will require appropriate debris-flow mitigation and warning efforts.

References Cited

- Bernard, David, 2007, Estimation of inundation areas of post-wildfire debris flows: Golden, Colorado School of Mines, unpublished Master's thesis, Department of Geology and Geological Engineering, 77 p.
- Bonnin, G.M., Martin, D., Lin, B., Parzybok, T., Yekta, M., and Riley, D., 2006, Precipitation-frequency atlas of the United States: NOAA Atlas 14, v. 1, version 4, NOAA, National Weather Service, Silver Spring, Md., http://hdsc.nws.noaa.gov/hdsc/pfds/sa/sca_pfds.html
- Cannon, S.H., and Gartner, J.E., 2005, Wildfire-related debris flow from a hazards perspective, chapter 15, in Hungr, O., and Jacob, M., eds., Debris-flow hazards and related phenomena: Springer-Praxis Books in Geophysical Sciences, p. 321–344
- Cannon, S.H., Gartner, J.E., Michael, J.A., Bauer, M.A., Stitt, S.C., Knifong, D.L., McNamara, B.J., and Roque, Y.M., 2007, Emergency assessment of debris-flow hazards from basins burned by the 2007 Poomacha Fire, San Diego County, southern California: U.S. Geological Survey Open-file Report OF2007-1411, <http://pubs.usgs.gov/of/2007/1411>.
- Cannon, S.H., Gartner, J.E., Rupert, M.G., Michael, J.A., Rea, A.H., Parrett, C., in press, Predicting the probability and volume of post-wildfire debris flows in the intermountain west, USA: Geological Society of America Bulletin.
- Cannon, S.H., Gartner, J.E., Wilson, R.C., Bowers, J.C., and Laber, J.L., 2008, Storm rainfall conditions for floods and debris flows for recently burned areas in southwestern Colorado and southern California: *Geomorphology*, v. 96, p. 250–269.
- Eaton, C.E., 1936, Flood and erosion control problems and their solution: *Proceedings of the American Society of Civil Engineers*, v. 62, no 8, p. 1302–362.
- Gartner, J.E., Cannon, S.H., Bigio, E.R., Davis, N.K., Parrett, C., Pierce, K.L., Rupert, M.G., Thurston, B.L., Trebish, M.J., Garcia, S.P., and Rea, A.H., 2005, Compilation of data relating to the erosive response of 606 recently burned basins in the Western U.S.: U.S. Geological Survey Open-File Report 2005–1218, <http://pubs.usgs.gov/of/2005/1218/>.
- Hershfield, D.M., 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Department of Commerce, Weather Bureau, Technical Paper no. 40, 61 p.
- Iverson, R.M., Schilling, S.P., and Vallance, J.W., 1998, Objective delineation of lahar-inundation hazard zones: *Geological Society of America Bulletin*, v. 110, p. 972–984.
- Schwartz, G.E., and Alexander, R.B., 1995, Soils data for the conterminous United States derived from the NRCS State Soil Geographic (STATSGO) data base: U.S. Geological Survey Open-File Report 95–449, <http://water.usgs.gov/lookup/getspatial?ussoils>.
- Scott, K.M., 1971, Origin and sedimentology of 1969 debris flows near Glendora, California: U.S. Geological Survey Professional Paper 750–C, p. C242–C247.