

Prepared in cooperation with the U.S. Department of Agriculture Forest Service Arapaho  
and Roosevelt National Forests and Boulder County

# Probability and Volume of Potential Postwildfire Debris Flows in the 2010 Fourmile Burn Area, Boulder County, Colorado

Open-File Report 2010–1244

Cover Photograph: Older debris flow sediment deposits in Emerson Gulch. View is upstream. Photo by John G. Elliott, USGS, September 23, 2010.



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U.S. Department of the Interior  
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## Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
square meter ( $m^2$ )	10.76	square foot ( $ft^2$ )
square kilometer ( $km^2$ )	0.3861	square mile ( $mi^2$ )
Volume		
cubic meter ( $m^3$ )	35.31	cubic foot ( $ft^3$ )
cubic meter ( $m^3$ )	1.308	cubic yard ( $yd^3$ )
cubic meter ( $m^3$ )	0.0008107	acre-foot (acre-ft)
Flow rate		
millimeter per year (mm/hr)	0.03937	inch per year (in/hr)

Vertical coordinate information is referenced to the "North American Vertical Datum of 1988 (NAVD 88)"

Horizontal coordinate information is referenced to the "North American Datum of 1983 (NAD 83)"

# **Probability and Volume of Potential Postwildfire Debris Flows in the 2010 Fourmile Burn Area, Boulder County, Colorado**

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## **Abstract**

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned by the Fourmile Creek fire in Boulder County, Colorado, in 2010. Empirical models derived from statistical evaluation of data collected from recently burned basins throughout the intermountain western United States were used to estimate the probability of debris-flow occurrence and volumes of debris flows for selected drainage basins. Data for the models include burn severity, rainfall total and intensity for a 25-year-recurrence, 1-hour-duration rainstorm, and topographic and soil property characteristics.

Several of the selected drainage basins in Fourmile Creek and Gold Run were identified as having probabilities of debris-flow occurrence greater than 60 percent and many more had probabilities greater than 45 percent, in response to the 25-year-recurrence, 1-hour-duration rainfall. None of the Fourmile Canyon Creek drainage basins selected had probabilities greater than 45 percent. Throughout the Gold Run area and the Fourmile Creek area upstream from Gold Run, the higher probabilities tend to be in the basins with southerly aspects (southeast, south, and southwest slopes). Many basins along the perimeter of the fire area were identified as having low probability of occurrence of debris flow. Volume of debris flows predicted from drainage basins with probabilities of occurrence greater than 60 percent ranged from 1,200 to 9,400 m<sup>3</sup>. The predicted moderately high probabilities and some of the larger volumes responses predicted for the modeled storm indicate a potential for substantial debris-flow effects to buildings, roads, bridges, culverts, and reservoirs located both within these drainages and immediately downstream from the burned area. However, even small debris flows that affect structures at the basin outlets could cause considerable damage.

## **Introduction**

The objective of this report is to present a preliminary emergency assessment of the debris-flow hazards from basins burned by the Fourmile Creek fire in Boulder County, Colorado, in 2010 (plates 1 and 2). Debris flows have been documented after many fires in the western United States (Cannon and others, 2010) and can threaten lives, property, infrastructure, aquatic habitats, and water supplies.

Wildfires can denude hillslopes of vegetation and change soil properties that affect watershed hydrology and sediment-transport processes. Even small postwildfire rainstorms can increase overland runoff that erodes soil, rock, ash, and vegetative debris from hillslopes (Cannon and others, 2008). This increased runoff concentrates in stream channels and entrains the sediment that can lead to the generation of destructive debris flows. Debris flow hazards are most significant 1 to 3 years following wildfires (Susan Cannon, U.S. Geological Survey, written commun., 2010). This emergency debris-flow hazards

assessment, done in cooperation with the U.S. Department of Agriculture Forest Service (USDA) Arapaho and Roosevelt National Forests and Boulder County, is presented as an estimate of the predicted probability of occurrence and volume of debris that can flow from basin outlets in response to 0.90 inches (23 millimeters) of rainfall in a 1-hour period. Such a storm affects the area burned by the Fourmile Canyon fire approximately every 25 years (a 4 percent chance in any given year) (Miller and others, 1973).

A set of empirical equations (models) documented in Cannon and others (2010) and derived from statistical evaluation of data collected from recently burned basins throughout the intermountain western United States were used to estimate the probability of debris-flow occurrence and volumes of debris flows for selected drainage basins. The regression equation (eq. 1) of debris-flow probability is based on empirical data described by Cannon and others (2010, model A). The equation is as follows:

$$P = e^x / (1 + e^x), \quad (1)$$

where  $P$  is the probability of debris-flow occurrence in fractional form; and

$$x = -0.7 + 0.03(\%SG30) - 1.6(R) + 0.06(\%AB) + 0.07(I) + 0.2(\%C) - 0.4(LL),$$

where,  $\%SG30$  is the percentage of the drainage basin area with slope equal to or greater than 30 percent;  $R$  is drainage basin ruggedness, the change in drainage basin elevation (meters) divided by the square root of the drainage basin area (square meters) (Melton, 1965);  $\%AB$  is the percentage of drainage basin area burned at moderate to high severity (data for this investigation from Eric Schroder, U.S. Department of Agriculture Forest Service, written commun., 2010);  $I$  is average storm intensity (calculated by dividing total storm rainfall [Miller and others, 1973] by the storm duration, in millimeters per hour);  $\%C$  is clay content of the soil (in percent), and  $LL$  is the liquid limit of the soil (percentage of soil moisture by weight) (U.S. Department of Agriculture, National Resources Conservation Service, National Soil Survey Center, 1991).

Cannon and others (2010) also developed an empirical model that can be used to estimate the volume of debris flow that would likely be produced from recently burned drainage basins:

$$\ln V = 7.2 + 0.6(\ln SG30) + 0.7(AB)^{0.5} + 0.2(T)^{0.5} + 0.3, \quad (2)$$

where  $V$  is the debris-flow volume, including water, sediment, and debris (cubic meters);  $SG30$  is the area of drainage basin with slopes equal to or greater than 30 percent (square kilometers);  $AB$  is the drainage basin area burned at moderate to high severity (square kilometers);  $T$  is the total storm rainfall (millimeters); and 0.3 is a bias correction factor that changes the predicted estimate from a median to a mean value (Helsel and Hirsch, 2002).

Each basin to be evaluated was identified by a single outlet (pour point) located at the basin mouth. Conditions within the basin area upstream from that pour point were used to estimate debris-flow probability and volume (Cannon and others, 2010). Locations of basin pour points were identified by the Burned Area Emergency Rehabilitation (BAER) team for the Fourmile fire (indicated by colored circles in plates 1 and 2). Additional basin pour points were identified by the U.S. Geological Survey (USGS) for evaluation (color-shaded basins in plates 1 and 2). When the BAER and USGS basin pour points were the same, no USGS basin number was assigned (BAER number is shown both for the circle symbol and within the shaded basin).

For selection of USGS basins, a preliminary map was created using a continuous parameterization technique. With this technique estimates of debris-flow probability and volume (Cannon and others, 2010) were obtained along the drainage network (or flow-direction matrix) (Verdin and Greenlee, 2003; Verdin and Worstell, 2008). This technique was developed as an alternative to traditional basin characterization approaches, which requires “*a priori*” definition of outlets (pour points) and their corresponding basins. This parameterization technique allows the quick identification of smaller, high-probability basins within a larger basin and a more detailed basin delineation plan could then be chosen. The continuous parameterization technique, based on a digital elevation model-derived flow-direction matrix, allows for faster parameter characterization and the ability for characterization above any location, not just predefined basin outlets. Additionally, this technique allows for a synoptic view of the entire study area, which aids in sampling design and monitoring-site selection.

Using the 1/3-arc-second National Elevation Dataset (Gesch and others, 2002) (10-meter nominal resolution) for the study area and the flow structure inherent in the digital elevation model (DEM), the independent variables driving the probability and volume equations were evaluated for every grid cell within the extent of the DEM. Rainfall total and rainfall intensity, calculated from Miller and others (1973), were assumed to be uniform over the entire burn area because spatial differences were not sensitive in the relatively small area of the burn. Values for all of the other independent variables driving the predictive equations were obtained using the continuous parameterization approach, although “ruggedness” required a separate ArcGIS program (ESRI, 2009) to evaluate this variable for each grid cell in the study area. Once the surfaces of the independent variables were developed, the probability and volume equations were solved by using map algebra for each grid cell and the 25-year-recurrence, 1-hour-duration rainfall of 23 mm. Identification of the probability or volume of a debris flow at any location within the study area is possible by querying the derived surfaces. For this assessment, a raster sampling technique was used to identify the values of debris-flow probability and volume at selected locations along the drainage network derived from a digital elevation model.

## Probability and Volume of Potential Debris Flows

In response to the 25-year-recurrence, 1-hour-duration rainfall, only 2 tributary basins to Gold Run, basins 7 and 167 (plate 1), were identified as having probabilities of debris-flow occurrence greater than 60 percent, and 7 basins (113, 154, 156, 162, 163, 168, and 170) had probabilities between 46 and 60 percent. The volume of the debris flow (plate 2) predicted for basins 7 and 167 were 9,400 and 1,100 m<sup>3</sup>, respectively. Among tributary basins to Fourmile Creek upstream from Gold Run (Plate 1), 4 basins (11, 12, 16, and 141) were identified as having probabilities of debris-flow occurrence greater than 60 percent, and only 4 basins (18, 134, 137, and 144) had probabilities between 46 and 60 percent. The volume of the debris flow (plate 2) predicted for these basins with greater than 60 percent probability ranged from 2,100 (basin 141) to 4,700 m<sup>3</sup> (basin 11). Among tributary basins to Fourmile Creek downstream from Gold Run (plate 1), 1 basin (106) was identified as having a probability of debris-flow occurrence greater than 60 percent, and only 1 basin (107) had a probability between 46 and 60 percent. The volume of the debris flow (plate 2) predicted for the basin with greater than 60 percent probability was 1,200 m<sup>3</sup>. Among tributary basins to Fourmile Canyon Creek (Plate 1), no basins were identified as having a probability of debris-flow occurrence greater than 45 percent. Throughout the Gold Run area and the Fourmile Creek area upstream from Gold Run, the higher probabilities tend to be in the basins with southerly aspects (southeast, south, and southwest slopes). Many basins along the perimeter of the fire area were identified as having low probability of occurrence of debris flow. Large basins such as the entire Gold Run basin (5), Fourmile Creek upstream from Gold Run (4), and the

entire Fourmile Creek basin (24) have substantially larger estimated volumes because of their large drainage basin areas.

The predicted moderately high probabilities and some of the larger volumes responses predicted for the modeled storm indicate a potential for substantial debris-flow effects to buildings, roads, bridges, culverts, and reservoirs located both within these drainages and immediately downstream from the burned area. However, even small debris flows that affect structures at the basin outlets could cause considerable damage.

## Use and Limitations of the Map

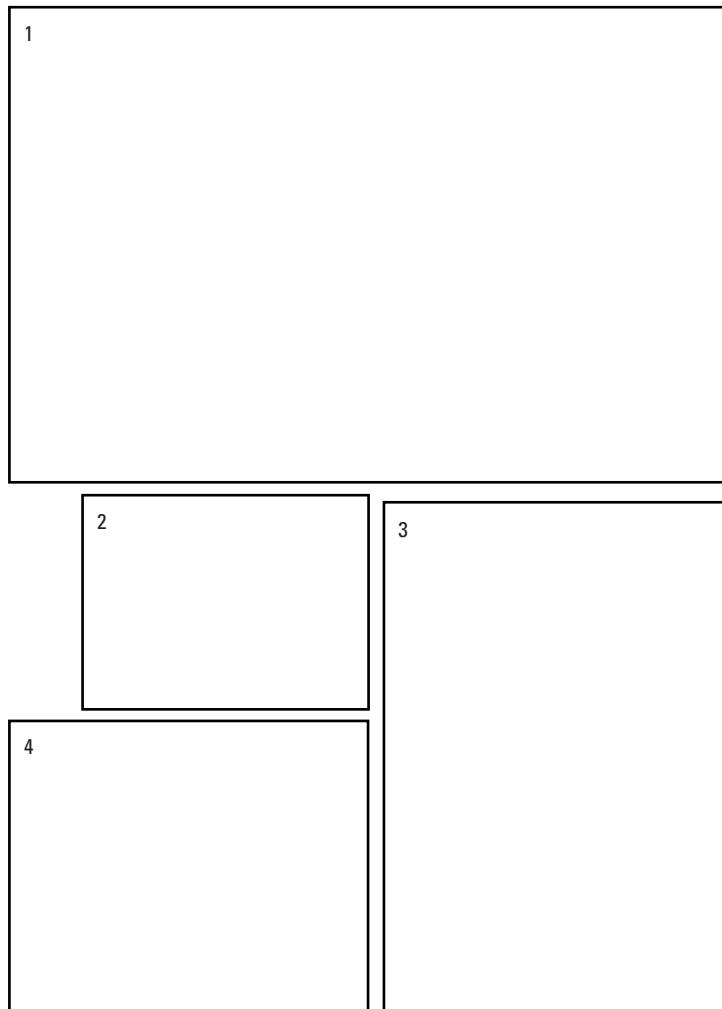
This assessment indicates estimates of debris-flow probability and volume for the area burned by the Fourmile Fire in response to a 25-year-recurrence, 1-hour-duration rainfall (a 4 percent chance in any given year). Larger, less frequent storms are more likely to produce much larger debris flows. Some areas within the selected basins may have higher debris-flow probabilities than those shown on plate 1, and debris flows may not be produced from all basins during a 25-year rainfall. The estimates are meant to be valid for 3 years after the fire (Susan Cannon, U.S. Geological Survey, written commun., 2010). The maps may be used to prioritize areas where emergency flood warnings or erosion mitigation may be needed prior to rainstorms within these basins, their outlets, or areas downstream from these basins. This assessment evaluates only postwildfire debris flows (Cannon and others, 2007). Substantial hazards from flash floods without debris flow may remain for many years after a fire.

This work is preliminary and is subject to revision. It is being provided owing 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.

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Cover Photographs:

- 1 View to the south in upper Emerson Gulch. Photo by John G. Elliott, USGS, September 23, 2010.
- 2 Close up of low burned soils. Photo by Barbara C. Ruddy, USGS, September 23, 2010.
- 3 Older debris-flow sediment stratigraphy in Ingram Gulch. Flow direction from left to right. Photo by John G. Elliott, USGS, September 23, 2010.
- 4 Dust devil in upper Emerson Gulch. Photo by Barbara C. Ruddy, USGS, September 23, 2010.

