Postwildfire Debris Flow Hazard Assessment for the Area Burned by the 2011 Track Fire in Northeastern New Mexico and Southeastern Colorado

By Anne C. Tillery, Michael J. Darr, Susan H. Cannon, and John A. Michael

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Frontispiece: Aerial view of Track fire burn area, looking southwest across Lake Maloya. Photograph provided courtesy of the City of Raton. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Contents

Plates

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)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Flow rate	
millimeter per hour (mm/hr)	0.03937	inch per hour (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).

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Abstract

In June 2011, the Track Fire burned 113 square kilometers (km^2) in Colfax County, northeastern New Mexico, and Las Animas County, southeastern Colorado, including the upper watersheds of Chicorica and Raton Creeks. The burned landscape is now at risk of damage from postwildfire erosion, such as that caused by debris flows and flash floods. This report presents a preliminary hazard assessment of the debris-flow potential from basins burned by the Track Fire. A pair of empirical hazard-assessment models developed using data from recently burned basins throughout the intermountain western United States was used to estimate the probability of debris-flow occurrence and volume of debris flows at the outlets of selected drainage basins within the burned area. The models incorporate measures of burn severity, topography, soils, and storm rainfall to estimate the probability and volume of postwildfire debris flows following the fire.

In response to a design storm of 38 mm of rain in 30 minutes (10-year recurrence-interval), the probability of debris flow estimated for basins burned by the Track fire ranged between 2 and 97 percent, with probabilities greater than 80 percent identified for the majority of the tributary basins to Raton Creek in Railroad Canyon; six basins that flow into Lake Maloya, including the Segerstrom Creek and Swachheim Creek basins; two tributary basins to Sugarite Canyon, and an unnamed basin on the eastern flank of the burned area. Estimated debris-flow volumes ranged from 30 cubic meters (m^3) to greater than 100,000 m^3. The largest volumes (greater than 100,000 m^3) were estimated for Segerstrom Creek and Swachheim Creek basins, which drain into Lake Maloya. The Combined Relative Debris-Flow Hazard Ranking identifies the Segerstrom Creek and Swachheim Creek basins as having the highest probability of producing the largest debris flows. This finding indicates the greatest postwildfire debris-flow impacts may be expected to Lake Maloya. In addition, Interstate Highway 25, Raton Creek and the rail line in Railroad Canyon, County road A-27, and State Highway 526 in Sugarite Canyon may also be affected where they cross drainages downstream from recently burned basins. Although this assessment indicates that a rather large debris flow (approximately 42,000 m^3) may be generated from the basin above the City of Raton (basin 9) in response to the design storm, the probability of such an event is relatively low (approximately 10 percent). Additional assessment is necessary to determine if the estimated volume of material is sufficient to travel into the City of Raton. In addition, even small debris flows may affect structures at or downstream from basin outlets and increase the threat of flooding downstream by damaging or blocking flood mitigation structures. The maps presented here may be used to prioritize areas

where erosion mitigation or other protective measures may be necessary within a 2- to 3-year window of vulnerability following the Track Fire.

Introduction

Debris flows have been documented after many fires in the western United States (Cannon and others, 2007; Cannon and others, 2009; DeGraff and others, 2011). The net result of rainfall on burned areas is often the transport and deposition of large volumes of sediment, both within and down-channel from burned areas. The rapid transport of large amounts of material makes debris flows particularly dangerous. Following a wildfire, debris flows can occur in places where flooding or sedimentation has not been observed in the past, and can be generated in response to low-magnitude rainfall.

Under unburned conditions, the vegetation canopy, soil-mantling litter and duff, and soil capture and store rainfall, which results in relatively little, or no, runoff. Postwildfire hydrologic response is affected by a decrease in vegetation cover and altered soil properties. Wildfires can consume rainfall-intercepting canopy, litter, and duff (Moody and Martin, 2001a, b; Meyer, 2002; Cannon and Gartner, 2005). Water-repellent qualities in some soils can be enhanced or introduced by the intense heat of a wildfire (DeBano, 1981; Doerr and others, 2000; Letey, 2001; Woods and others, 2006) and increased overland flow and erosion can occur (Wells, 1987; Moody and Martin, 2001a, b). The presence of fine ash, which may expand when wetted, can block soil pore spaces and further reduce infiltration of water (Romkins and others, 1990; Woods and others, 2006). After a wildfire, the watershed response to rainfall events can be considered to shift, in general terms, from an infiltration-dominated to a runoff-dominated response (Cannon and others, 2009). Because of reduced infiltration, rainfall on wildfire burn scars can run off almost immediately as overland flow. This runoff in low-order channels can erode surficial materials, and with flow through the drainage network, runoff that is rich in ash, soil, boulders, and dislodged vegetation can be generated. As additional sediment is entrained, sediment-laden flow in channels can progressively transition into debris flows that can threaten lives, property, infrastructure, aquatic habitats, and water supplies (Cannon and Gartner, 2005). Debris flows are most frequent within 2 to 3 years after wildfires, when vegetative cover is absent or reduced and abundant materials are available for erosion and transport (Cannon and others, 2009).

In June 2011, the Track Fire burned 27,800 acres or 113 square kilometers (km^2) in Colfax County, northeastern New Mexico, and Las Animas County, southeastern Colorado (plate 1). The fire burned portions of Sugarite and Railroad Canyons, including the upper watershed of Chicorica Creek, which contains Lake Maloya, the municipal water source for the City of Raton and a popular tourist destination. Raton Creek, Interstate Highway 25, and a regional rail line run through Railroad Canyon, and the City of Raton lies immediately southeast of Railroad Canyon along Raton Creek. The burned area includes several large mesas (Bartlett, Horse, Barela, and Raton Mesas) that are capped by resistant basaltic lava flows and underlain by gently sloping shales, muds, very fine sands, and coal beds of the Paleocene-Cretaceous upper Raton Formation (McLemore, 1990).

The area burned by the Track Fire is now at risk of impact from postwildfire erosion, such as that caused by debris flows and flash floods. The purpose of this report is to present a preliminary hazard assessment of the debris-flow potential for basins burned by the 2011 Track Fire.

Methods Used to Estimate Debris Flow Hazards

For this preliminary hazard assessment, a pair of empirical models was used to estimate the probability, volume, and combined relative hazard ranking of a debris flow from individual drainage basins in response to a given storm event in northern New Mexico. The model for predicting debris-flow probability was developed by Cannon and others (2009) using logistic multiple regression analyses of data from 388 basins in 15 burned areas in the intermountain western United States. Conditions in each basin were quantified using several readily obtained measures of areal burned extent, basin gradient, soil properties, and storm rainfall. Statistical analyses were used to identify the variables that most strongly influenced debris-flow occurrence and to build the predictive model. Equation 1 is used to calculate debris-flow probability (Cannon and others, 2009):

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

where

P is the probability of debris-flow occurrence in fractional form; and e^{x} is the exponential function. Equation 2 is used to calculate the exponential function;

$$x = -0.7 + 0.03(\%SG30) - 1.6(R) + 0.06(\%AB) + 0.07(I) + 0.2(\%C) - 0.4(LL), \quad (2)$$

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 (in meters) divided by the square root of the drainage basin area (in square meters) (Melton, 1965);

%AB is the percentage of drainage basin area burned at moderate and high severity;

I is average storm intensity (the total storm rainfall divided by the storm duration, in millimeters per hour);

%*C* is clay content of the soil (expressed as percentage); and

LL is the liquid limit of the soil (the percentage of soil moisture by weight at which soil begins to behave as a liquid).

A second statistical model was used to estimate the volume of material that could issue from a basin mouth in response to a given storm. This model was developed using multiple linear regression analyses of data compiled from 56 debris-flow producing basins burned by eight fires (Cannon and others, 2009). Debris-flow volume measurements were derived from records of the amount of material removed from sediment-retention basins and from field measurements of the amount of material eroded from the main channels within a burned drainage. Statistical analyses were used to identify the variables that most strongly influenced debris-flow volume. The model predicts the volume of material that may pass through a drainage basin outlet in response to a single rainstorm event. The model has the form:

$$\text{Ln } V = 7.2 + 0.6(\text{Ln } SG30) + 0.7(AB)^{0.5} + 0.2(T)^{0.5} + 0.3, \quad (3)$$

where

V is the debris-flow volume (in cubic meters);

Ln is the natural log function;

SG30 is the area of drainage basin with slopes equal to or greater than 30 percent (in square kilometers);

AB is the drainage basin area burned at moderate and high severity (in square kilometers);
T is the total storm rainfall (in millimeters); and
0.3 is a bias correction factor that changes the predicted estimate from a median to a mean value (Cannon and others, 2009; Helsel and Hirsch, 2002).

Debris-flow hazards from a given basin can also be represented by a combination of both probability of occurrence and volume of material passing through the basin outlet (Cannon and others, 2009). For example, the most hazardous basins will show both the highest probabilities of occurrence and the largest estimated volumes 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 where both the lowest probabilities and the smallest volumes are identified. For this assessment, the estimated values of debris-flow probability and volume are categorized into relatively ranked classes, and these classes are added together 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, 2009).

Model Implementation

The two models were implemented for the Track Fire by first delineating 53 basins to be evaluated within the burned perimeter. The basins were delineated by analyzing topographic information derived from 10-meter (m) digital elevation models (DEMs) with geographic information system (GIS) hydrological tools. Basin outlets (pour points) were positioned at breaks in slope along mountain fronts, along drainages, and at the burned perimeter. Each basin to be evaluated was identified by a single outlet (pour point) located at the basin mouth, and conditions within the basin area upstream from that pour point were used to estimate debris-flow probability and volume (Cannon and others, 2009). Measured basin areas averaged 1.8 km^2 and ranged between 0.01 km^2 and 13 km^2, comparable to the basin sizes used in the development of the predictive models.

Measures of the physical properties of soils within each basin were obtained from the State Soil Geographic (STATSGO) database (Schwartz and Alexander, 1995). If more than one soil unit occurred within a given basin, a spatially weighted average of the soil variable values was calculated. In basins burned by the Track fire, the clay content ranged from 25.7 percent to 37.7 percent, and liquid limit ranged from 32 percent to 42.4 percent.

The Burned Area Emergency Response (BAER) Image Support Team of the U.S. Geological Survey Earth Observation and Science Center (EROS) and U.S. Forest Service (USFS) Remote Sensing Applications Center (RSAC) provided a map of Burned Area Reflectance Classification (BARC), which was used as an indicator of the distribution of burn severity within the fire perimeter (U. S. Forest Service, 2011). The total area encompassed by the fire perimeter was 113 km^2 (about 28,000 acres), of which 24 percent was classified as high burn severity and 37 percent as moderate burn severity.

Postwildfire debris flows in the intermountain western United States are often triggered in response to short-duration, high-intensity thunderstorms. Cannon and others (2008) found that most debris flows are triggered in response to storms with short recurrence intervals, and Kean and others (2011) demonstrated that periods of intense rain in less than 30 minutes were most likely to generate postwildfire debris flows. To characterize the effects of these rainfall conditions, the probability that a given basin will produce debris flows and a possible debris-flow volume at the basin outlet in response to a 30-minute-duration, 10-year recurrence rainstorm of 38.0 mm were estimated (Bonnin and others, 2006). Any storm with a 10-year recurrence interval is considered to have a 10 percent chance of occurring in any given year. This design storm was selected to represent a storm event that is likely to produce debris flows.

Debris –Flow Probability Estimates

In response to 38.0 mm of rain falling in a 30-minute period, probabilities of debris-flow occurrence greater than 80 percent were estimated for most of the tributary basins to Railroad Canyon; three of the basins (numbers 1, 2 and 4) that drain into Lake Maloya from the northwest, including Segerstrom and Swachheim Creeks; three basins (numbers 6, 7, and 8) that drain into Lake Maloya from the southeast; two tributary basins (numbers 17 and 28) to Sugarite Canyon; and an unnamed basin (number 24) on the east edge of the burned area (plate 1). These high probability values are partly due to the basins being nearly completely burned at high and moderate severities, and to the steep slopes within these basins. Debris flows generated from these basins may directly impact Interstate Highway 25, Raton Creek, and the rail line that travels through Railroad Canyon, Lake Maloya, State Highway 526, and County road A-27 (plate 1).

Debris –Flow Volume Estimates

The predicted volumes of the debris flows in this assessment are independent of the estimated probabilities. As a result, basins with even high predicted probabilities represent a range of threats downstream that depend upon the predicted volume of material mobilized by the debris flow. Conditions in both Segerstrom Creek (basin 1) and Swachheim Creek (basin 4) resulted in estimated debris-flow volumes in excess of 100,000 m^3, while volumes between 10,000 m^3 and 100,000 m^3 were estimated for two tributary basins (numbers 44 and 10) to Railroad Canyon, basin number 9 above the City of Raton, two tributary basins (numbers 14 and 15) to Sugarite Canyon, two basins (numbers 3 and 5) that empty into Lake Maloya, and basins 12 and 26 on the southeast side of the fire (plate 2).

Debris flows at, and downstream from basins in Railroad Canyon could potentially affect Interstate Highway 25, Raton Creek, and the rail line that travels through Railroad Canyon. It is not known if the estimated volumes of material are sufficient to dam Raton Creek, or to travel into the City of Raton. Similarly, it is not know if the approximately 42,000 m^3 of material estimated at the mouth of basin 9 will be sufficient to travel into the City of Raton. These potential hazards require further assessment. The large debris-flow volumes estimated for Segerstrom Creek (basin 1) and Swachheim Creek (basin 4) indicate the potential for significant sediment contributions to Lake Maloya, which may affect water quality. In addition, debris flows at or downstream from basins 14 and 15, and basins 12 and 26, may potentially affect New Mexico State Highway 526 in Sugarite Canyon, and County Road A-27 at locations where the roads cross drainages within or downstream of the burned area.

Combined Relative Debris-Flow-Hazard Rankings

Combined relative debris-flow hazard rankings for a 30-minute duration, 10-year recurrence storm indicated the highest postwildfire debris flow susceptibilities are associated with Segerstrom Creek (basin 1) and Swachheim Creek (basin 4) (plate 3). These rankings reflect extremely hazardous conditions within and immediately downstream from these basins, where debris flows may impact Lake Maloya and pose significant hazards to life and property. The second highest possible combined relative debris-flow hazard rankings were estimated for most of the tributary basins to Railroad Canyon; basin 2, which empties into the northwest shore of Lake Maloya; basins 5, 6, 7, and 8, which empty into the east shore of Lake Maloya; basins 17 and 28 in Sugarite Canyon; and basins 12 and 24 on the southeast edge of the fire. Debris flows at and downstream from these basins could affect Interstate Highway 25, Raton Creek, and the rail line that travels through Railroad Canyon; Lake Maloya; State Highway 526; and County road A-27.

Limitations of Assessments

This assessment estimates debris-flow probability and volume for the area burned by the Track Fire in response to a 10-year-recurrence, 30-minute-duration rain storm. Larger, less frequent storms (for example, a 25-year recurrence storm) are likely to produce larger debris flows, and smaller storms (for example, a 2-year recurrence storm) could also trigger debris flows. Higher probabilities of debris flow than those shown on plate 1 may exist within any of the basins. Because not all rainstorms will be large enough to affect the entire burned area, debris flows may not be produced from all basins during a given storm.

It is important to note that the maps shown in plates 1, 2, and 3 do not identify those areas that can be affected by debris flows as the material moves downstream from the basin outlets (Cannon and others, 2009). Areas within the City of Raton are not directly downstream from basins with high predicted debris-flow probabilities or large volumes; however, it is necessary to emphasize that a debris flow in upper Raton Creek, or in basin 9 above the City of Raton, may also pose a hazard to the City of Raton if debris flows travel down the streambed through the center of the City. Additionally, flooding may be caused by the breaching of channels dammed by debris flow material and may impact locations downstream from the examined drainage basins. Similarly, if a large debris flow were to mobilize in upper Chicorica Creek, it would also have the potential to damage property and infrastructure in downstream sections of Sugarite Canyon.

Although landslides are common on the flanks of the mesas in the Track Fire area and in Sugarite Canyon (McLemore, 1990), stability of these pre-existing landslide deposits was not evaluated in this study. In general, infiltration-dominated landslide processes that may occur in burned basins are significantly less frequent than are runoff-triggered debris flows, and contribute little to the total volume of material transported from the basin (Cannon and others, 2009). In addition, flash flooding was not considered in this analysis, but remains a potential postwildfire hazard.

The variables included in the models and used in this assessment are considered to directly affect debris-flow generation in the intermountain western United States. Conditions other than those used in the models—for example, the amount of sediment stored in a canyon—could also affect debris-flow production. Data necessary to evaluate such effects, however, are not readily available.

The potential for debris-flow activity decreases with time as revegetation stabilizes hillslopes and material is removed from canyons by erosion. If dry conditions prevent sufficient regrowth of vegetation, this recovery period will be longer. Similarly, if rainfall events for the first year are mild, recovery and stabilization of soil with vegetation may occur rapidly and diminish debris-flow hazards the following year. The assessment given here is estimated to be applicable for up to 2 to 3 years after the fire depending on precipitation distribution (Cannon and others, 2009).

The maps may be used to prioritize areas where emergency erosion mitigation or other protective measures may be needed prior to rainstorms within these basins, their outlets, or areas downstream from these basins. This assessment evaluates only postwildfire debris flows, and does not consider hazards associated with flash floods, which 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.

Summary

In June 2011, the Track fire burned 113 km^2 (27,800 acres) in northeastern New Mexico and southeastern Colorado, including the upper watersheds of Chicorica and Raton Creeks. The majority of the watershed for Lake Maloya Reservoir, the municipal water source for the City of Raton, was also burned. Basins within the burned area are now at risk of damage from postwildfire erosion hazards such as those associated with debris flows and flash floods.

A pair of empirical models developed from data collected in recently burned basins throughout the intermountain western United States was used to estimate the probability of occurrence and volume of debris flows for selected drainage basins within the Track Fire burn area in response to a 10-year recurrence, 30-minute duration rainstorm of 38.0 millimeters.

Probabilities of debris flow greater than 80 percent and debris-flow volumes greater than 100,000 m^3 were identified for Segerstrom Creek (basin 1) and Swachheim Creek (basin 4), indicating the potential for a considerable impact to Lake Maloya and significant hazards to life and property within and downstream from these basins.

Debris-flow probabilities greater than 80 percent and debris-flow volumes between 10,000 and 100,000 m^3 estimated for the majority of the tributary basins to Raton Creek in Railroad Canyon indicate the potential to impact Interstate Highway 25, Raton Creek, and the rail line through Railroad Canyon. Additional evaluation is necessary to determine if debris flows produced from these basins could dam Raton Creek or travel into the City of Raton. Similar hazardous conditions are identified for basins that empty into Lake Maloya and tributary basins to Sugarite Canyon downstream from the lake.

Although in this report the infrastructure and areas have been identified for which the assessment indicated the largest risks, the debris-flow probabilities and volumes estimated in response to the design storm also indicate a potential for debris-flow impacts to buildings, roads, bridges, culverts, and reservoirs downstream from the burned area.

The maps presented here may be used to prioritize areas where emergency erosion mitigation or other protective measures may be needed prior to rainstorms within these basins, their outlets, or areas downstream from these basins within the 2 to 3-year window of vulnerability.

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