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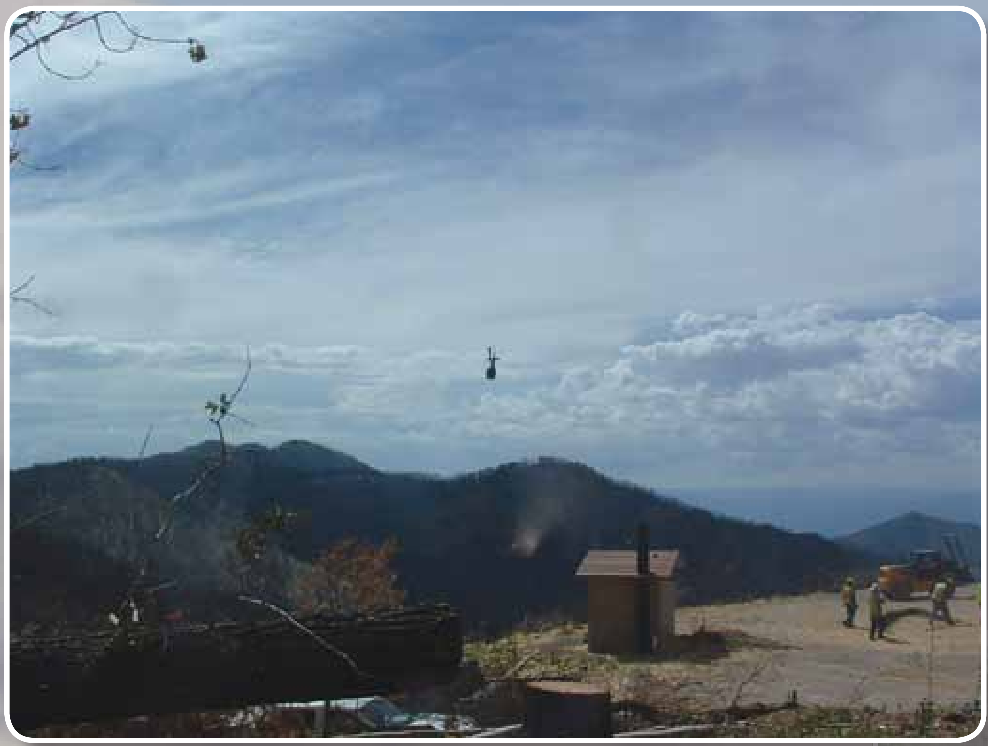
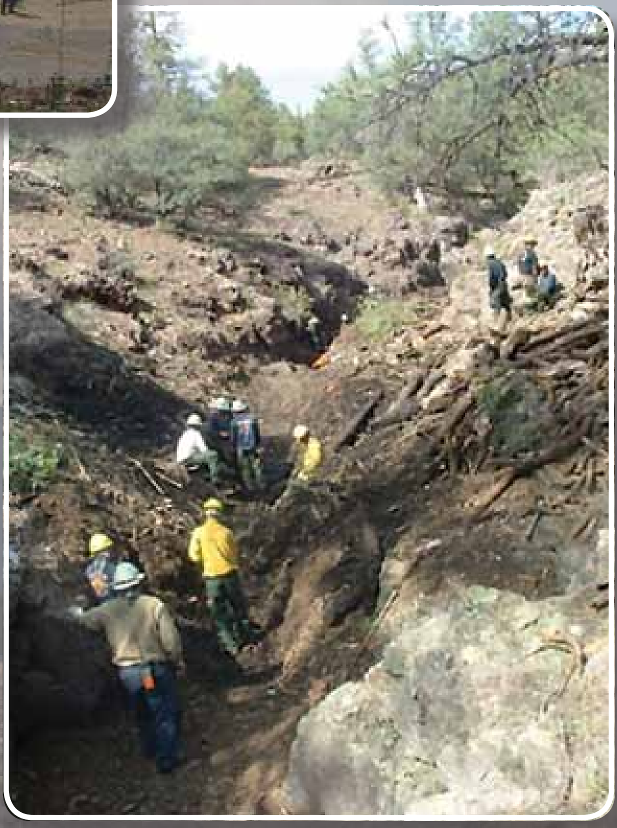
Estimated Probability of Postwildfire Debris Flows in the 2012 Whitewater–Baldy Fire Burn Area, Southwestern New Mexico





Open-File Report 2012–1188

U.S. Department of the Interior
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Cover:

Left, The Sandy Point staging area for aerial mulching, Gila National Forest, N. Mex. (photograph by U.S. Forest Service).

Right, Crews clearing log jam in Copper Creek, Gila National Forest, N. Mex. (photograph by U.S. Forest Service).

Background, View of the Whitewater–Baldy Complex oriented east from U.S. Route 180, May 23, 2012, Gila National Forest, N. Mex. (photograph by U.S. Forest Service).

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U.S. Department of the Interior
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Suggested citation:
Tillery, A.C., Matherne, A.M., and Verdin K.L., 2012, Estimated probability of postwildfire debris flows in the 2012 Whitewater–Baldy Fire burn area, southwestern New Mexico: U.S. Geological Survey Open-File Report 2012–1188, 11 p., 3 pls.

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Plates

(Available online at http://pubs.usgs.gov/of/2012/1188/.)

Conversion Factors and Datums

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 kilometer (km^2)	0.3861	square mile (mi^2)
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
millimeter per hour (mm/h)	0.03937	inch per hour (in/h)

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 May and June 2012, the Whitewater–Baldy Fire burned approximately 1,200 square kilometers (300,000 acres) of the Gila National Forest, in southwestern New Mexico. 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 128 basins burned by the Whitewater–Baldy Fire. A pair of empirical hazard-assessment models developed by 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 along the burned area drainage network and for selected drainage basins within the burned area. The models incorporate measures of areal burned extent and severity, topography, soils, and storm rainfall intensity to estimate the probability and volume of debris flows following the fire.

In response to the 2-year-recurrence, 30-minute-duration rainfall, modeling indicated that four basins have high probabilities of debris-flow occurrence (greater than or equal to 80 percent). For the 10-year-recurrence, 30-minute-duration rainfall, an additional 14 basins are included, and for the 25-year-recurrence, 30-minute-duration rainfall, an additional eight basins, 20 percent of the total, have high probabilities of debris-flow occurrence. In addition, probability analysis along the stream segments can identify specific reaches of greatest concern for debris flows within a basin. Basins with a high probability of debris-flow occurrence were concentrated in the west and central parts of the burned area, including tributaries to Whitewater Creek, Mineral Creek, and Willow Creek. Estimated debris-flow volumes ranged from about 3,000–4,000 cubic meters (m^3) to greater than 500,000 m^3 for all design storms modeled. Drainage basins with estimated volumes greater than 500,000 m^3 included tributaries to Whitewater Creek, Willow Creek, Iron Creek, and West Fork Mogollon Creek. Drainage basins with estimated debris-flow volumes greater than 100,000 m^3 for the 25-year-recurrence event, 24 percent of the basins modeled, also include tributaries to Deep Creek, Mineral Creek, Gilita Creek, West Fork Gila River, Mogollon Creek, and Turkey Creek, among others. Basins with the highest combined probability and volume relative hazard rankings for the 25-year-recurrence rainfall include tributaries to Whitewater Creek, Mineral Creek, Willow Creek, West Fork Gila River, West Fork Mogollon Creek, and Turkey Creek. Debris flows from Whitewater, Mineral, and Willow Creeks could affect the southwestern New Mexico communities of Glenwood, Alma, and Willow Creek.

The maps presented herein may be used to prioritize areas where emergency erosion mitigation or other protective measures may be necessary within a 2- to 3-year period of vulnerability following the Whitewater–Baldy Fire. This work is preliminary and is subject to revision. It is being provided because of the need for timely "best science" information. The assessment herein is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

Introduction

Debris flows have been documented after many fires in the Western United States (Cannon and others, 2007, 2010; DeGraff and others, 2011). Rainfall on burned areas can result in 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. In addition, debris flows following a wildfire 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 (Cannon and others, 2007, 2010; DeGraff and others, 2011).

Under unburned conditions, the vegetation canopy, soil-mantling litter and duff, and soil serve to 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, 2001b; Meyer, 2002; Cannon and Gartner, 2005). Water-repellent qualities in some soils can be enhanced or induced 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, 2001b). The presence of fine ash, which may expand when wetted, can block soil pore spaces and further reduce infiltration of water (Romkens and others, 1990; Woods and others, 2006). After a wildfire, the watershed response to rainfall events shifts, in general terms, from an infiltration-dominated to a runoff-dominated response (Cannon and others, 2010). Because of reduced soil 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, rainfall can generate runoff that is rich in ash, soil, boulders, and dislodged vegetation. As additional sediment is entrained, sediment-laden flow in channels can progressively transition into debris flows that can affect lives, property, infrastructure, aquatic habitats, and water supplies (Cannon and Gartner, 2005). Debris flows are most frequent within 2–3 years after wildfires, when vegetative cover is absent or reduced and abundant materials are available for erosion and transport (Cannon and Gartner, 2005; Cannon and others, 2010).

In May and June 2012, the Whitewater–Baldy Fire burned approximately 1,200 square kilometers (km^2) (300,000 acres) of the Gila National Forest, including the Gila Wilderness, in southwestern New Mexico (plate 1) (Inciweb, Incident Information System, 2012). The fire started as two separate lightning-strike fires—one near Mogollon Baldy Peak and one in the headwaters of Whitewater Creek in the Gila Wilderness east of Glenwood, N. Mex. (U.S. Department of Agriculture Forest Service, 2012). The two fires joined to form the Whitewater–Baldy Complex. The fire severely burned a tract of land across the Gila National Forest, including the headwaters of Whitewater Creek, Mineral Creek, and Willow Creek. These three creeks drain into the southwestern New Mexico communities of Glenwood, Alma, and Willow Creek, respectively. (Willow Creek is unincorporated private land within the national forest.) The Gila National Forest directly or indirectly contributes to the economy of the surrounding area, primarily through wildlife and recreation visits and ranching (University of New Mexico Bureau of Business and Economic Research, 2007). The Gila National Forest contains hundreds of miles of recreational trails including the Catwalk National Recreation Trail, a popular tourist destination that follows the narrow gorge of Whitewater Creek.

The Gila National Forest is mountainous, with steep, narrow canyons and elevations as high as 3,321 meters (m) (10,895 feet [ft]). The Whitewater–Baldy Fire perimeter was complex and irregular in outline, with inclusion of unburned areas extending into and within the burned area (plate 1, inset). About 26 percent of the burned area was moderately to severely burned (U.S. Department of Agriculture Forest Service, 2012). The geology of the area is primarily an assemblage of Tertiary volcanic rocks, composed of welded and ash-flow tuffs, volcaniclastic deposits, and layered andesite, rhyolite, and basalt (Ratté and Gaskill, 1975; Ratté, 2008; Mack and others, 2008). Soils vary in clay content from about 16 to 40 percent (Schwartz and Alexander, 1995).

The area burned by the Whitewater–Baldy Fire is now at risk of substantial 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 2012 Whitewater–Baldy 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 debris flows along the drainage network and for selected drainage basins in response to a given storm event in the Gila National Forest. The model for predicting debris-flow probability was developed by Cannon and others (2010) by 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 by using readily obtained measures of areal burned extent and severity, 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, 2010):

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

where

- P is the probability of debris-flow occurrence in fractional form; and
- e^{x} is the exponential function where e represents the mathematical constant 2.718.

Equation 2 is used to calculate x:

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

where

- $\%SG30$ is the percent of the drainage basin area with slopes 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 severities;
I	is average storm intensity (the total storm rainfall divided by the storm duration, in millimeters per hour);
%C	is the percent clay content of the soil; and
LL	is the liquid limit of the soil (the percent 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 the basin mouth of a recently burned drainage basin in response to a given magnitude storm. This model was developed by using multiple linear-regression analyses of data compiled from 56 debris-flow-producing basins burned by eight fires (Cannon and others, 2010). 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 basin. Statistical analyses were used to identify the variables that most strongly influenced debris-flow volume. The model provides estimates of the volume of material that may pass through a drainage-basin outlet in response to a single rainstorm event. The model has the following form:

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

where

Ln	is the natural log function;
V	is the debris-flow volume (in cubic meters);
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 severities (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 (Helsel and Hirsch, 2002; Cannon and others, 2010).

Values for both probability and volume were obtained along drainage networks by using the continuous parameterization technique (Verdin and Greenlee, 2003; Verdin and Worstell, 2008). With this technique, estimates of debris-flow probability and volume (Cannon and others, 2010) were obtained for every 10-m pixel along the drainage network (plates 1 and 2) as a function of conditions in the drainage basin upstream from each pixel. This technique was developed as an alternative to basin-characterization approaches used in the past (for example, Cannon and others, 2010), which require definition of outlets (pour points) and their corresponding basins at the beginning of the analysis. The technique used here allows for a synoptic view of conditions throughout the study area, which can be used to identify specific 10-m pixels or stream reaches that might pose a higher risk of debris flows; the technique also aids in sampling design and monitoring-site selection.

The base layer upon which the continuous-parameterization layers are built is the 1/3-arc-second National Elevation Dataset (Gesch and others, 2002). This digital elevation model (DEM) was transformed into a projection system appropriate to western New Mexico (Universal Transverse Mercator, Zone 12) and processed by using standard DEM-conditioning tools in ArcGIS (Environmental Systems Research Institute, Inc., 2009) and RiverTools (Rivix, LLC, 2012). Once the overland flow structure was derived (in the form of a flow-direction matrix) by using the DEM, the independent variables driving the probability and volume equations were evaluated for every grid cell within the extent of the DEM. Because of orographic effects of the mountainous terrain and the size of the burned area, input rainfall totals and rainfall intensities will vary over the extent of the burned area. For this study, however, the maximum rainfall amounts for each storm were assumed to be uniform over the entire burned area, providing the most conservative estimate of the probability and volumes of potential debris flows. Values for all of the other independent variables driving the debris-flow probability and volume equations were obtained by using the continuous-parameterization approach. The independent-variable values can be represented as forming continuous surfaces over the burned 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 along the drainage network, thus deriving the probability and volume surfaces. Identification of the probability or volume of a debris flow at locations within the study area can be obtained by querying the derived surfaces.

Debris-flow hazards from a given basin can also be represented by a combined relative debris-flow hazard ranking that is based on a combination of both probability of occurrence and volume (Cannon and others, 2010). For example, the most hazardous basins will have 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 low probabilities and larger volume estimates or high probabilities and smaller volume estimates.

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 probability and volume relative hazard ranking (plate 3). This combined ranking identifies a possible range of responses from basins with the highest probabilities of producing debris flows with the largest volumes to basins with the lowest probabilities of producing debris flows with the smallest volumes (Cannon and others, 2010).

Model Application

The two models were implemented for the Whitewater–Baldy Fire by first calculating the debris-flow probabilities and volumes along the drainage networks and then 128 basins within the burned perimeter were delineated for further evaluation. The basins were delineated by analyzing elevation data derived from 10-m DEMs (U.S. Geological Survey, 2011) with geographic information system (GIS) hydrological tools. Debris-flow probability and volume were estimated for every 10-m pixel along drainage networks of the burned area as a function of conditions in the drainage basin above each pixel (Verdin and Greenlee, 2003; Verdin and Worstell, 2008). Basins were delineated so that the area of the basin at the farthest downstream pixel modeled was within the size range for which the models were developed, 0.01–103 km² for the probability model and 0.01–27.9 km² for the volume model (Cannon and others, 2010). Drainage basins with a total area exceeding the range of the volume model, such as Mogollon Creek, were subdivided into side tributaries. Stream reaches draining the large basins are highlighted on plates 1 through 3 as "drainages within burned areas that can be affected by the combined effects of debris flows generated from side tributaries." These large basins fall within the size range of the probability model, and probability estimates are indicated along the streamline by segment, but no basin number is assigned for the combined basin, and no relative hazard ranking is calculated. Areas for basins analyzed for volume and relative hazard ranking averaged 7.7 km² and ranged from 1.3 km² to 33.4 km².

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 Whitewater–Baldy Fire, clay content of soil ranged from about 16 to 40 percent, and liquid limit of soils ranged from about 25 to 45 percent.

The Burned Area Emergency Response (BAER) Image Support Team of the U.S. Geological Survey Earth Observation and Science Center (EROS) and the U.S. Department of Agriculture Forest Service Remote Sensing Applications Center 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. Department of Agriculture Forest Service, written commun., 2012). The BARC map for the Whitewater–Baldy fire indicates that the moderate and high burn-severity areas totaled about 316 km² (78,000 acres), which is 26 percent of the total burned area of about 1,200 km² (300,000 acres). The basins selected for modeling included the moderate and high burn-severity areas where slope, watershed configuration, and topographic setting indicated susceptibility to debris-flow processes or where proximity to development indicated a vulnerability to hazards presented by debris flows.

Postwildfire debris flows in the intermountain Western United States often occur in response to short-duration, high-intensity rainfall events. Cannon and others (2008) found that most debris flows occur in response to storms with short recurrence intervals (from 2 to 10 years), and Kean and others (2011) demonstrated that intense rain in periods of less than 30 minutes generated postwildfire debris flows. To characterize the effects of these rainfall conditions, the probability that a given basin could produce debris flows and the volume of a possible debris flow at the basin outlet were estimated for three design storms: (1) a 2-year-recurrence, 30-minute-duration rainfall of 22 millimeters (mm) (a 50 percent chance of occurrence in any given year); (2) a 10-year-recurrence, 30-minute-duration rainfall of 33 mm (a 10 percent chance of occurrence in any given year); and (3) a 25-year-recurrence, 30-minute-duration rainfall of 39 mm (a 4 percent chance of occurrence in any given year). Precipitation data used were from Bonnin and others (2006) for a weather station at Glenwood. Results for the 25-year-recurrence rainfall are presented in plates 1 through 3. While the point precipitation data used to establish the 25-year rainfall event may indicate that the chance of occurrence at a given point is uncommon, because of the large area encompassed by the fire, the chance that a storm of this magnitude will occur somewhere in the burn area in the next several years is increased (Kerry Jones, National Weather Service, oral commun., 2011).

Debris-Flow Hazard Assessment

The hazards of debris flows from basins burned by the Whitewater–Baldy Fire were assessed by estimating the probability of occurrence, by estimating the volume of potential debris flows, and by combining the probability and volume into a relative hazard ranking.

Debris-Flow Probability Estimates

In response to the 2-year-recurrence, 30-minute-duration rainfall, modeling indicated that four basins (40, 90, 92, and 93) have high probabilities of debris-flow occurrence (greater than or equal to 80 percent) (table 1). For the 10-year-recurrence rainfall, an additional 14 basins (12, 41, 74, 91, 95, 96, 98, 99, 100, 105, 106, 107, 108, and 110) have high probabilities of debris-flow occurrence, and for the 25-year-recurrence rainfall, and an additional 8 basins (49, 57, 58, 86, 87, 88, 89, and 109), representing together 20 percent of the total, have high probabilities of debris-flow occurrence (plate 1; table 1). In addition, probability analysis along the stream segments can identify specific reaches of greatest concern for debris flows within a basin. For example, in basin 17 (plate 1), probability analysis by stream segment indicates that debris-flow probability increases from the headwaters (20–39 percent) to the midbasin (80–99 percent) and then decreases towards the basin outlet (40–59 percent). The overall basin color (plate 1) represents the debris-flow probability of 40–59 percent at the outlet, or pour point, of the basin.

Table 1. Estimated debris-flow probabilities and volumes for the 2012 Whitewater–Baldy Fire, Gila National Forest, New Mexico.

[mm, millimeters; km², square kilometers; %, percent; m³, cubic meters; <, less than; >, greater than]

Selected basin	Description	Drainage area (km²)	2-year, 30-minute rainfall 22 mm			10-year, 30-minute rainfall 33 mm			25-year, 30-minute rainfall 39 mm		
			Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking
1	Tributary to Negrito Creek	18.60	<1	20,000	1	<1	27,000	1	<1	31,000	1
2	Tributary to Negrito Creek	2.51	<1	6,300	1	<1	8,500	1	2	9,800	1
3	Tributary to Negrito Creek	4.63	<1	16,000	1	4	22,000	1	9	25,000	1
4	Tributary to Negrito Creek	4.38	<1	15,000	1	2	20,000	1	5	23,000	1
5	Tributary to Negrito Creek	3.56	1	14,000	1	5	19,000	1	11	22,000	1
6	Tributary to Negrito Creek	1.87	9	14,000	1	32	18,000	2	53	21,000	2
7	Tributary to Negrito Creek	8.72	1	40,000	1	5	54,000	1	11	62,000	1
8	Tributary to Negrito Creek	3.14	1	17,000	1	7	23,000	1	14	26,000	1
9	Tributary to Negrito Creek	9.57	2	64,000	1	10	86,000	1	20	99,000	1
10	Tributary to Negrito Creek	33.44	<1	63,000	1	<1	84,000	1	2	97,000	1
11	Quaking Aspen Creek	5.07	2	16,000	1	7	22,000	1	14	25,000	1
12	Willow Creek	20.23	66	>500,000	3	90	>500,000	4	96	>500,000	4
13	Little Turkey Creek	14.09	6	120,000	2	23	160,000	2	41	180,000	3
14	Tributary to Gilita Creek	2.76	<1	3,900	1	<1	5,300	1	<1	6,100	1
15	Tributary to Gilita Creek	2.43	<1	3,400	1	<1	4,600	1	<1	5,400	1
16	Tributary to Gilita Creek	4.04	<1	2,800	1	<1	3,800	1	<1	4,400	1
17	Tributary to Iron Creek	26.11	10	380,000	2	34	>500,000	2	55	>500,000	3
18	Tributary to Iron Creek	11.25	4	90,000	1	18	120,000	2	34	140,000	2
19	Tributary to Middle Fork Gila River	10.29	<1	12,000	1	2	15,000	1	4	18,000	1
20	Tributary to Middle Fork Gila River	1.28	<1	4,300	1	4	5,800	1	8	6,600	1
21	Tributary to Canyon Creek	8.76	<1	3,000	1	<1	4,000	1	<1	4,600	1
22	Tributary to Canyon Creek	8.45	<1	7,200	1	4	9,700	1	10	11,000	1
23	Tributary to Indian Creek	5.67	<1	6,900	1	3	9,300	1	6	11,000	1
24	Tributary to Middle Fork Gila River	11.95	3	43,000	1	11	58,000	1	23	67,000	2
25	Tributary to Middle Fork Gila River	4.87	9	17,000	1	33	24,000	2	53	27,000	2
26	Tributary to Middle Fork Gila River	4.09	3	15,000	1	13	20,000	1	26	23,000	2
27	Tributary to Middle Fork Gila River	4.74	<1	8,600	1	<1	12,000	1	<1	13,000	1
28	Tributary to Middle Fork Gila River	7.08	2	18,000	1	10	24,000	1	20	27,000	2
29	Tributary to Middle Fork Gila River	18.03	<1	13,000	1	<1	17,000	1	1	20,000	1
30	Tributary to Middle Fork Gila River	2.74	1	8,500	1	5	11,000	1	12	13,000	1
31	Tributary to Middle Fork Gila River	4.64	<1	9,000	1	<1	12,000	1	<1	14,000	1
32	Tributary to Middle Fork Gila River	2.25	1	8,600	1	5	12,000	1	12	13,000	1
33	Tributary to Middle Fork Gila River	15.40	5	34,000	1	18	46,000	1	34	53,000	2
34	Tributary to Middle Fork Gila River	7.89	<1	11,000	1	4	15,000	1	8	17,000	1
35	Tributary to Middle Fork Gila River	18.68	2	36,000	1	8	48,000	1	18	56,000	1
36	Tributary to Middle Fork Gila River	8.28	1	17,000	1	6	23,000	1	13	26,000	1
37	Tributary to Middle Fork Gila River	10.45	<1	11,000	1	<1	15,000	1	<1	17,000	1
38	Tributary to Middle Fork Gila River	5.85	<1	8,200	1	4	11,000	1	8	13,000	1
39	Tributary to Middle Fork Gila River	3.15	<1	6,200	1	3	8,400	1	6	9,700	1
40	Tributary to West Fork Gila River	8.10	81	120,000	4	95	160,000	4	98	190,000	4
41	Tributary to West Fork Gila River	11.92	77	210,000	3	94	280,000	4	97	320,000	4
42	Tributary to West Fork Gila River	3.52	11	23,000	1	36	31,000	2	57	36,000	2
43	Tributary to West Fork Gila River	5.86	2	22,000	1	10	29,000	1	20	34,000	2

Table 1. Estimated debris-flow probabilities and volumes for the 2012 Whitewater–Baldy Fire, Gila National Forest, New Mexico.—Continued

[mm, millimeters; km², square kilometers; %, percent; m³, cubic meters; <, less than; >, greater than]

Selected basin	Description	Drainage area (km²)	2-year, 30-minute rainfall 22 mm			10-year, 30-minute rainfall 33 mm			25-year, 30-minute rainfall 39 mm		
			Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking
44	Tributary to West Fork Gila River	4.86	9	20,000	1	32	28,000	2	53	32,000	2
45	Tributary to West Fork Gila River	2.11	<1	5,200	1	1	7,000	1	3	8,100	1
46	Tributary to West Fork Gila River	16.41	15	180,000	2	45	240,000	3	65	270,000	3
47	Tributary to West Fork Gila River	9.09	1	33,000	1	5	45,000	1	10	52,000	1
48	Tributary to West Fork Gila River	17.24	5	140,000	2	18	180,000	2	34	210,000	2
49	Tributary to West Fork Gila River	13.71	33	150,000	2	69	200,000	3	84	230,000	4
50	Tributary to West Fork Gila River	23.41	<1	58,000	1	2	79,000	1	5	91,000	1
51	Tributary to West Fork Gila River	9.29	<1	10,000	1	<1	14,000	1	2	16,000	1
52	Tributary to West Fork Gila River	6.49	4	15,000	1	17	20,000	1	33	23,000	2
53	Tributary to West Fork Gila River	7.58	3	17,000	1	13	23,000	1	26	27,000	2
54	Tributary to West Fork Gila River	5.80	2	14,000	1	7	19,000	1	15	22,000	1
55	Tributary to Turkey Creek	1.96	10	10,000	1	35	14,000	2	56	16,000	2
56	Tributary to Turkey Creek	18.88	22	76,000	2	57	100,000	3	76	120,000	3
57	Tributary to Turkey Creek	7.62	27	51,000	2	63	69,000	3	80	79,000	3
58	Tributary to Turkey Creek	13.10	45	120,000	3	79	160,000	3	90	180,000	4
59	Tributary to Turkey Creek	2.84	13	12,000	1	40	16,000	2	61	19,000	3
60	Tributary to Turkey Creek	4.22	16	15,000	1	47	20,000	2	67	24,000	3
61	Tributary to Mogollon Creek	2.39	12	12,000	1	38	17,000	2	59	19,000	2
62	Tributary to Mogollon Creek	1.80	<1	12,000	1	2	17,000	1	6	19,000	1
63	Tributary to Mogollon Creek	3.48	2	27,000	1	8	36,000	1	17	42,000	1
64	Tributary to Mogollon Creek	4.31	<1	22,000	1	2	30,000	1	5	34,000	1
65	Tributary to Mogollon Creek	7.80	16	25,000	1	47	33,000	2	68	39,000	3
66	Tributary to Mogollon Creek	4.13	16	17,000	1	47	22,000	2	68	26,000	3
67	Tributary to Mogollon Creek	4.80	4	21,000	1	16	28,000	1	31	32,000	2
68	Tributary to Mogollon Creek	3.63	2	17,000	1	7	24,000	1	15	27,000	1
69	Tributary to Mogollon Creek	7.82	6	77,000	1	23	100,000	2	42	120,000	3
70	Tributary to Mogollon Creek	13.45	<1	73,000	1	4	98,000	1	10	110,000	2
71	Tributary to Mogollon Creek	9.67	8	110,000	2	28	150,000	2	48	170,000	3
72	Tributary to Mogollon Creek	3.87	6	37,000	1	23	50,000	2	42	58,000	2
73	Tributary to Mogollon Creek	19.95	5	290,000	2	21	390,000	2	39	450,000	2
74	Tributary to West Fork Mogollon Creek	14.92	67	370,000	3	90	500,000	4	96	>500,000	4
75	Tributary to West Fork Mogollon Creek	5.06	18	63,000	1	51	85,000	2	71	98,000	3
76	Tributary to Rain Creek	4.96	2	41,000	1	11	55,000	1	22	64,000	2
77	Tributary to Rain Creek	4.91	13	52,000	1	40	70,000	2	61	81,000	3
78	Tributary to Rain Creek	4.39	26	58,000	2	62	78,000	3	79	90,000	3
79	Tributary to Rain Creek	5.06	14	62,000	1	44	84,000	2	65	97,000	3
80	Tributary to Sacaton Creek	8.12	1	46,000	1	5	62,000	1	10	72,000	1
81	Tributary to Sacaton Creek	12.69	2	84,000	1	8	110,000	2	18	130,000	2
82	Duck Creek	9.13	<1	16,000	1	3	21,000	1	7	24,000	1
83	Tributary to Little Dry Creek	10.51	3	91,000	1	13	120,000	2	26	140,000	2
84	Tributary to Big Dry Creek	10.51	6	100,000	2	23	140,000	2	42	160,000	3
85	Tributary to Big Dry Creek	9.21	18	68,000	1	50	92,000	2	70	110,000	3
86	Tributary to Big Dry Creek	9.17	27	67,000	2	63	91,000	3	80	100,000	3

Table 1. Estimated debris-flow probabilities and volumes for the 2012 Whitewater–Baldy Fire, Gila National Forest, New Mexico.—Continued

[mm, millimeters; km², square kilometers; %, percent; m³, cubic meters; <, less than; >, greater than]

Selected basin	Description	Drainage area (km²)	2-year, 30-minute rainfall 22 mm			10-year, 30-minute rainfall 33 mm			25-year, 30-minute rainfall 39 mm		
			Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking	Probability (%)	Volume (m³)	Combined hazard ranking
87	Tributary to Big Dry Creek	7.39	31	56,000	2	68	75,000	3	83	87,000	3
88	Tributary to Big Dry Creek	6.95	34	46,000	2	71	62,000	3	85	72,000	3
89	Tributary to San Francisco River	3.91	41	29,000	2	76	39,000	3	88	45,000	3
90	Little Whitewater Creek	7.80	83	96,000	3	96	130,000	4	98	150,000	4
91	Tributary to Whitewater Creek	27.96	55	350,000	3	85	470,000	4	93	>500,000	4
92	Tributary to Whitewater Creek	4.72	85	67,000	3	96	90,000	3	98	100,000	4
93	Tributary to Whitewater Creek	17.95	88	>500,000	4	97	>500,000	4	99	>500,000	4
94	Tributary to Whitewater Creek	1.87	17	17,000	1	49	23,000	2	70	27,000	3
95	Tributary to Whitewater Creek	1.69	65	20,000	3	90	27,000	3	95	31,000	3
96	Tributary to Whitewater Creek	2.61	47	25,000	2	80	34,000	3	91	39,000	3
97	Tributary to Whitewater Creek	2.65	18	23,000	1	51	31,000	2	71	36,000	3
98	Tributary to Whitewater Creek	1.96	68	21,000	3	91	28,000	3	96	33,000	3
99	Tributary to Whitewater Creek	1.42	74	15,000	3	93	20,000	3	97	23,000	3
100	Tributary to Whitewater Creek	1.58	77	17,000	3	94	22,000	3	97	26,000	3
101	Tributary to Silver Creek	3.19	2	16,000	1	8	22,000	1	16	26,000	1
102	Tributary to Silver Creek	11.48	24	80,000	2	60	110,000	3	78	120,000	3
103	Tributary to Mineral Creek	5.14	23	47,000	2	58	64,000	2	76	74,000	3
104	Tributary to Mineral Creek	8.14	17	86,000	1	49	120,000	3	69	130,000	3
105	Tributary to Mineral Creek	2.81	48	29,000	2	81	40,000	3	91	46,000	3
106	Tributary to Mineral Creek	1.79	66	19,000	3	90	25,000	3	96	29,000	3
107	Tributary to Mineral Creek	5.17	74	65,000	3	93	87,000	3	97	100,000	4
108	Tributary to Mineral Creek	2.21	72	26,000	3	92	35,000	3	97	40,000	3
109	Tributary to Mineral Creek	6.02	32	71,000	2	69	95,000	3	84	110,000	4
110	Tributary to Mineral Creek	4.14	65	39,000	3	90	53,000	3	95	61,000	3
111	Tributary to Mineral Creek	7.93	7	52,000	1	26	70,000	2	45	81,000	2
112	Tributary to Mineral Creek	1.61	11	10,000	1	38	13,000	2	59	15,000	2
113	Tributary to Mineral Creek	4.10	<1	15,000	1	2	20,000	1	4	23,000	1
114	Copper Creek	20.11	8	110,000	2	28	140,000	2	47	170,000	3
115	Tributary to Deep Creek	4.63	8	27,000	1	30	36,000	2	50	42,000	2
116	Tributary to Deep Creek	2.08	9	14,000	1	31	19,000	2	51	22,000	2
117	Tributary to Deep Creek	3.75	9	26,000	1	32	35,000	2	53	40,000	2
118	Tributary to Deep Creek	1.74	4	9,000	1	16	13,000	1	31	15,000	2
119	Tributary to Deep Creek	9.22	3	55,000	1	12	74,000	1	25	85,000	2
120	Tributary to Deep Creek	10.65	<1	23,000	1	3	30,000	1	6	35,000	1
121	Tributary to Deep Creek	9.03	4	66,000	1	16	89,000	1	31	100,000	2
122	Tributary to Deep Creek	2.18	3	15,000	1	13	20,000	1	26	24,000	2
123	Tributary to Deep Creek	1.69	1	8,000	1	6	11,000	1	14	13,000	1
124	Tributary to Devils Creek	17.73	1	58,000	1	6	78,000	1	14	90,000	1
125	Tributary to North Fork Devils Creek	6.45	<1	11,000	1	<1	15,000	1	<1	17,000	1
126	Tributary to North Fork Devils Creek	3.19	<1	14,000	1	1	19,000	1	3	22,000	1
127	Tributary to North Fork Devils Creek	2.55	<1	9,500	1	<1	13,000	1	2	15,000	1
128	Tributary to North Fork Devils Creek	1.29	<1	5,300	1	<1	7,000	1	1	8,000	1

Basins with a high probability of debris-flow occurrence were primarily located in the west and central parts of the burned area, including tributaries to Whitewater Creek, Mineral Creek, and Willow Creek. Tributaries to the West Fork Gila River, Mogollon Creek, and Turkey Creek also included basins with high probabilities of debris-flow occurrence. These high probabilities reflect the combined effects of these basins being nearly completely burned at high and moderate severities and having steep slopes. Debris flows generated from these basins may directly affect the communities of Glenwood, Alma, and Willow Creek.

Debris-Flow Volume Estimates

The debris-flow volumes estimated in this assessment are independent of the estimated debris-flow probabilities. As a result, basins with high predicted debris-flow probabilities present a range of high to low threats to areas downstream, depending on the predicted volume of material mobilized in a debris flow. Estimated debris-flow volumes can vary by stream segment along a drainage network; basin color on plate 2 reflects the volume class at the basin outlet. Estimated debris-flow volumes ranged from about 3,000–4,000 cubic meters (m^3) to greater than 500,000 m^3 for all design storms modeled (table 1). Drainage basins with estimated debris-flow volumes greater than 500,000 m^3 included basins 12 and 93 for the 2-year-recurrence rainfall, an additional basin (17) for the 10-year-recurrence rainfall, and an additional two basins (74 and 91) for the 25-year-recurrence rainfall and include tributaries to Whitewater Creek, Willow Creek, Iron Creek, and West Fork Mogollon Creek (plate 2). Drainage basins with estimated debris-flow volumes greater than 100,000 m^3 for the 25-year-recurrence event, 24 percent of the basins modeled, also include tributaries to Deep Creek, Mineral Creek, Gilita Creek, West Fork Gila River, Mogollon Creek, and Turkey Creek, among others (plate 2). It is not known if the estimated volumes of material are sufficient to dam watercourses or cause flooding, which could affect resources in the valleys downstream from the basins evaluated.

Combined Relative Debris-Flow Hazard Rankings

Combined probability and volume relative hazard rankings of postwildfire debris flows are produced by summing the estimated probability and volume ranking to illustrate those areas with the highest potential occurrence of debris flows with the largest volumes. Rankings are shown for the 25-year-recurrence rainfall (plate 3). The highest combined hazard ranking is predicted for two basins, 40 and 93, for the 2-year-recurrence rainfall (table 1). For the 10-year-recurrence rainfall, an additional five basins (12, 41, 74, 90, and 91) were modeled with the highest combined hazard ranking, and for the 25-year-recurrence rainfall, an additional five basins (49, 58, 92, 107, and 109), representing together 9 percent of the total, were modeled with the highest combined hazard ranking (plate 3). Basins with the highest combined probability and volume relative hazard ranking for the 25-year-recurrence rainfall include tributaries to Whitewater Creek, Mineral Creek, Willow Creek, West Fork Gila River, West Fork Mogollon Creek, and Turkey Creek. Debris flows from Whitewater, Mineral, and Willow Creeks could affect the communities of Glenwood, Alma, and Willow Creek.

Limitations of Hazard Assessments

This assessment provides estimates of debris-flow probability, volume, and combined relative hazard ranking for drainage basins burned by the Whitewater–Baldy Fire in response to 30-minute-duration design storms with a 2-, 10-, and 25-year-recurrence probability. Larger, less frequent storms (for example, a 50-year-recurrence storm) are likely to produce larger debris flows, and smaller storms (for example, a 1-year-recurrence storm) could also trigger debris flows. Higher probabilities of debris flow than those shown on plate 1 may exist within any part 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, 2010). Additionally, further investigation is needed to assess the potential for debris flows to affect structures at or downstream from basin outlets and to increase the threat of flooding downstream by damaging or blocking bridges or flood-mitigation structures.

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 the supply of erodible material decreases in the canyons. If dry conditions prevent sufficient regrowth of vegetation, however, this recovery period will be longer. In contrast, 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 herein is estimated to be applicable for 2–3 years after the fire, depending on precipitation distribution (Cannon and others, 2010).

The maps in this report 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 period of vulnerability following the

Whitewater–Baldy Fire. This assessment evaluates only postwildfire debris flows and does not consider hazards associated with flash floods; such hazards may remain for many years after a fire.

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

Summary

In May and June 2012, the Whitewater–Baldy Fire burned approximately 1,200 square kilometers (300,000 acres) of the Gila National Forest, in southwestern New Mexico. About 26 percent of the burned area was moderately or severely burned. The fire severely burned a tract of land across the Gila National Forest and the Gila Wilderness, including the headwaters of Whitewater Creek, Mineral Creek, and Willow Creek, which drains into Gilita Creek. These three creeks drain into the southwestern New Mexico communities of Glenwood, Alma, and Willow Creek, respectively. These communities are now at risk of damage from postwildfire erosion hazards such as those associated with debris flows and flash floods. This report presents a preliminary hazard assessment of the debris-flow potential from 128 basins burned by the Whitewater–Baldy Fire.

A pair of empirical hazard-assessment 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 along the burned area drainage network and for selected drainage basins within the Whitewater–Baldy Fire burned area in response to 30-minute-duration design storms of 2-, 10-, and 25-year-recurrence intervals. The models incorporate measures of areal burned extent and severity, topography, soils, and storm rainfall intensity to estimate the probability and volume of debris flows following the fire.

Probabilities of debris flow greater than 80 percent were identified for 20 percent of the basins modeled for the 25-year-recurrence rainfall. In addition, probability analysis along the stream segments can identify specific reaches of greatest concern for debris flows within a basin. Basins with a high probability of debris-flow occurrence were concentrated in the west and central parts of the burned area, including tributaries to Whitewater Creek, Mineral Creek, and Willow Creek. Tributaries to the West Fork Gila River, Mogollon Creek and Turkey Creek also included basins with high probabilities of debris-flow occurrence. Estimated debris-flow volumes ranged from about 3,000–4,000 cubic meters (m^3) to greater than 500,000 m^3 for all design storms modeled. Drainage basins with estimated volumes greater than 500,000 m^3 included tributaries to Whitewater Creek, Willow Creek, Iron Creek, and West Fork Mogollon Creek. Drainage basins with estimated debris-flow volumes greater than 100,000 m^3 for the 25-year-recurrence event, 24 percent of the basins modeled, also include tributaries to Deep Creek, Mineral Creek, Gilita Creek, West Fork Gila River, Mogollon Creek, and Turkey Creek, among others. Basins with the highest combined probability and volume relative hazard rankings for the 25-year-recurrence rainfall include tributaries to Whitewater Creek, Mineral Creek, Willow Creek, West Fork Gila River, West Fork Mogollon Creek, and Turkey Creek. Debris flows from Whitewater, Mineral, and Willow Creeks could affect the communities of Glenwood, Alma, and Willow Creek.

The maps presented herein 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.

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

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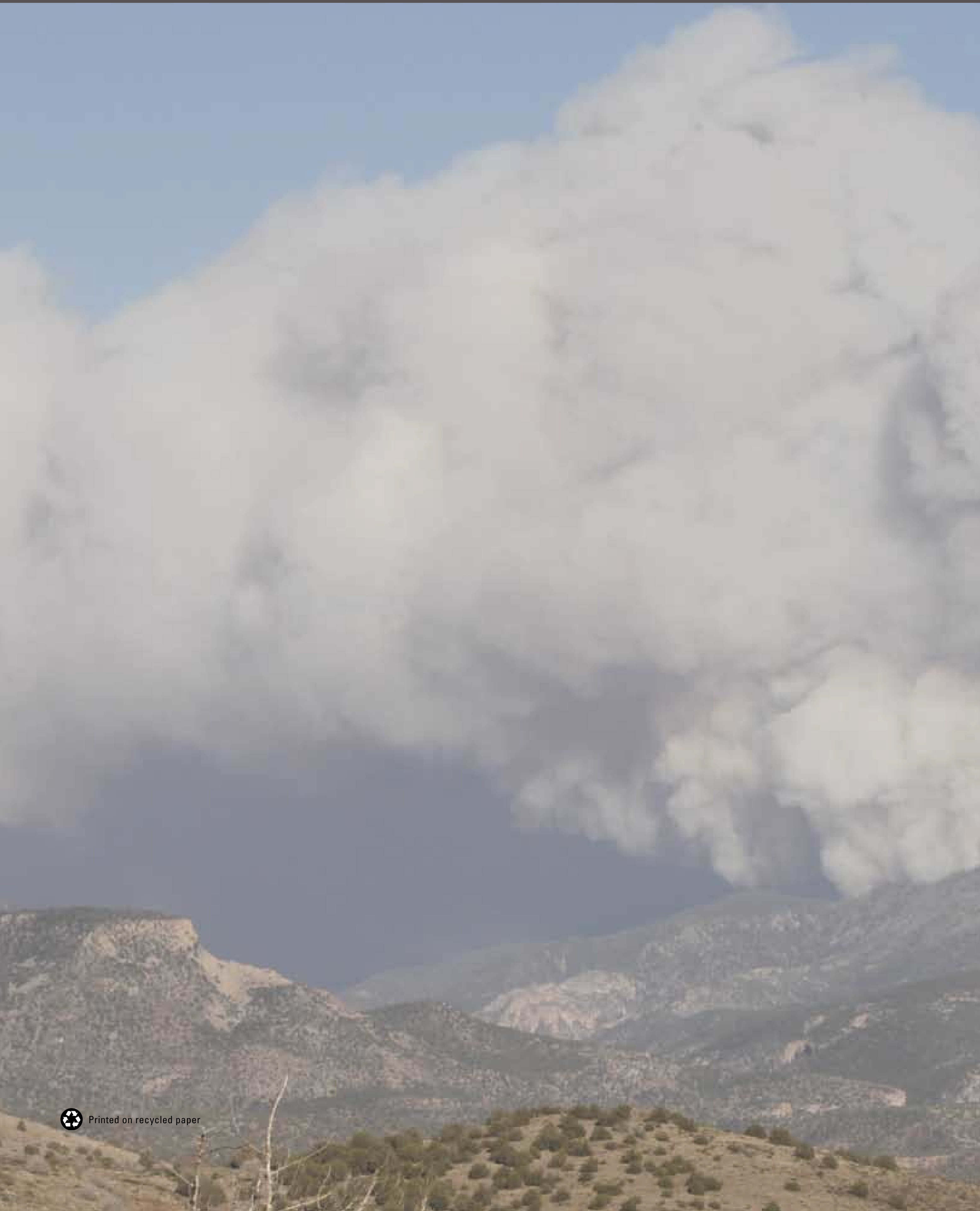
Publishing support provided by
Lafayette Publishing Service Center



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