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Probability and Volume of Potential Postwildfire Debris Flows in the 2011 Monument Burn Area, Southeastern Arizona

By Barbara C. Ruddy and Kristine L. Verdin

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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 2011 Monument Burn Area, Southeastern Arizona

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Abstract

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned by the Monument wildfire in southeastern Arizona, in 2011. Empirical models derived from statistical evaluation of data collected from recently burned drainage 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. Input for the models include measures of burn severity, topographic characteristics, soil properties, and rainfall total and intensity for a (1) 2-year-recurrence, 30-minute-duration rainfall, (2) 5-year-recurrence, 30-minute-duration rainfall, and (3) 10-year-recurrence, 30-minute-duration rainfall.

Estimated debris-flow probabilities in the drainage basins of interest ranged from a low of 26 percent in response to the 2-year-recurrence, 30-minute-duration rainfall to 100 percent in response to the 10-year-recurrence, 30-minute-duration rainfall. The high probabilities in all modeled drainage basins are likely due to the abundance of steep hillslopes and the extensive areas burned at moderately to high severities. The estimated volumes ranged from a low of about 2,000 cubic meters to a high of greater than 200,000 cubic meters.

Introduction

The objective of this report is to present a preliminary emergency assessment of the debris-flow hazards from drainage basins burned by the Monument wildfire in southeastern Arizona, in 2011 (figs. 1, 2, and 3, table 1). Debris flows, fast-moving slurries of sediment and water, have been documented after many wildfires 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 can 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 additional 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).

Debris flows have been documented in parts of the burned area where wildfires have occurred in the past (1977 in the Miller Creek drainage and 1988 in Ash Canyon) (Wohl and Pearthree, 1991). In addition, on July 10, 2011, a postwildfire debris flow occurred in the Miller Creek drainage (Ann Youberg, Arizona Geological Survey, written commun., 2011).

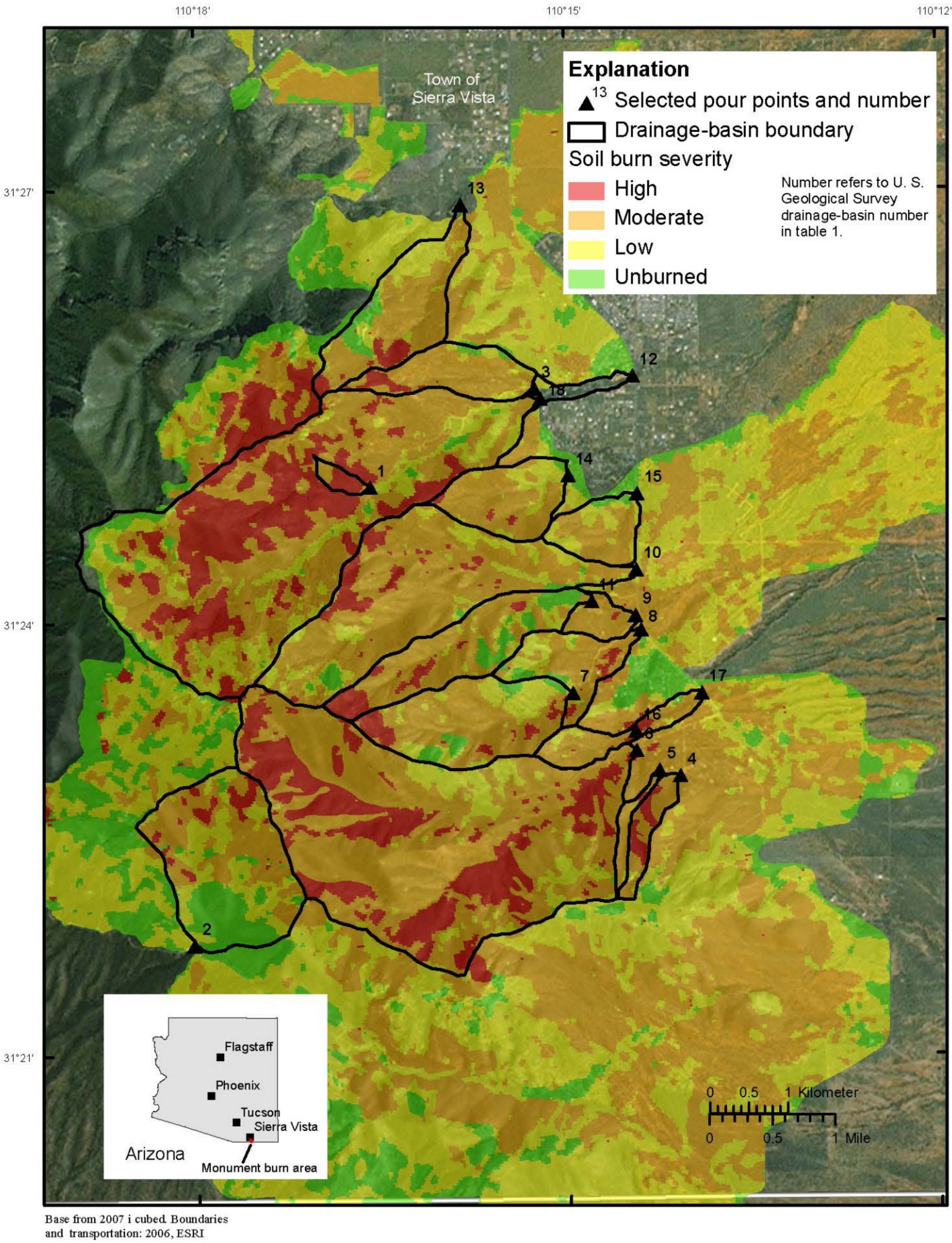

Figure 1. Location of drainage basins of interest and soil burn severity map of the 2011 Monument burn area, southeastern Arizona.

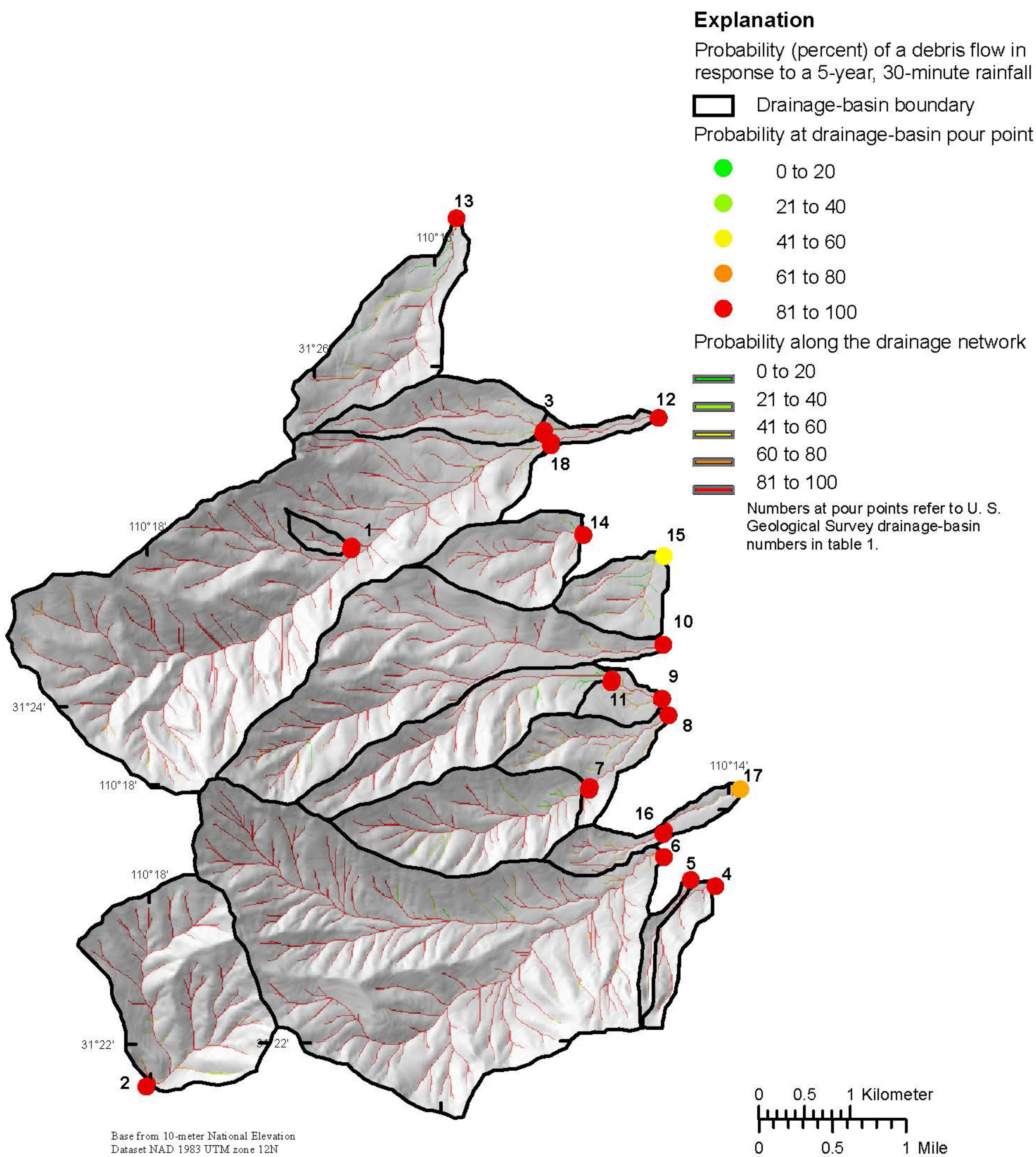

Figure 2. Estimated probability of potential postwildfire debris flows in the 2011 Monument burn area, southeastern Arizona, in response to a 5-year-recurrence, 30-minute-duration rainfall.

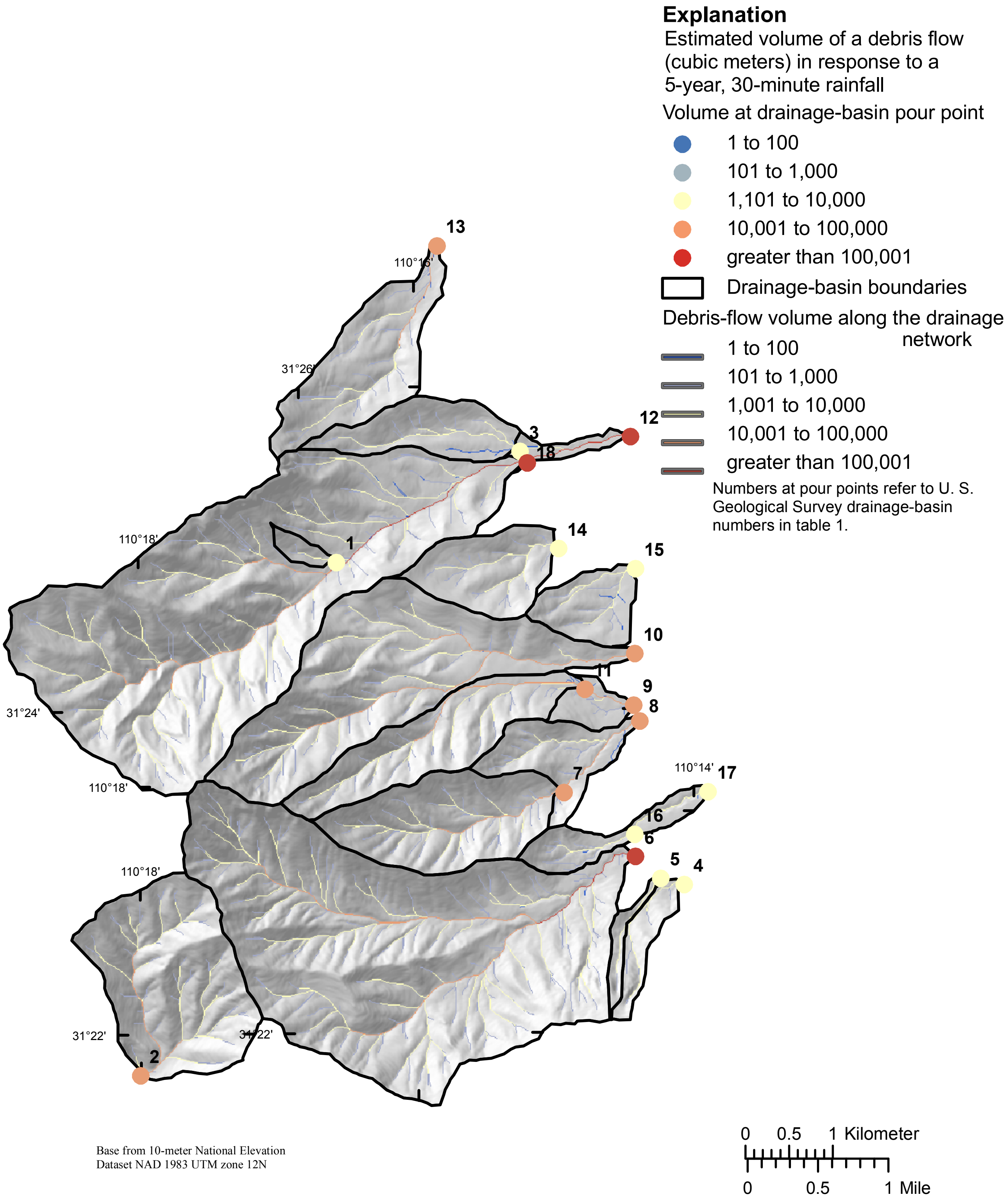

Figure 3. Estimated volumes of potential postwildfire debris flow in the 2011 Monument burn area, southeastern Arizona, in response to a 5-year-recurrence, 30-minute-duration rainfall.

Table 1. Estimated probabilities and debris flow volumes for the Monument burn area, southeastern Arizona.

[BAER, burned area emergency response; USGS, United States Geological Survey; na, not assigned]

BAER drainage-basin number for pour point	USGS drainage-basin number for pour point (fig.1–3)	BAER Description	Area	Latitude	Longitude	Debris flow in response to a 2-year, 30-minute rainfall		Debris flow in response to a 5-year, 30-minute rainfall		Debris flow in response to a 10-year, 30-minute rainfall	
			square kilometers	degrees, minutes, seconds	degrees, minutes, seconds	Probability (percent)	Volume (cubic meters)	Probability (percent)	Volume (cubic meters)	Probability (percent)	Volume (cubic meters)
1	1	Pond on private land	0.16	31°24'57"	110°16'36"	98	2,080	99	2,430	100	2,680
4	2	Large Wash with Steel Retainer Wall holding the road in place	3.28	31°21'45"	110°18'01"	95	28,000	99	32,900	100	36,500
8	3	First culvert on this road which has major drainage potential	1.14	31°25'38"	110°15'12"	81	7,280	93	8,400	97	9,240
20	4	Ash Canyon Creek tributary	0.46	31°22'55"	110°14'07"	96	4,480	99	5,180	99	5,690
21	5	Ash Canyon Creek tributary crossing Prince Placer Road	0.22	31°22'58"	110°14'15"	93	2,370	98	2,750	99	3,020
22	6	Ash Canyon Creek 2	1.07	31°23'06"	110°14'27"	98	170,000	99	196,000	100	216,000
25	7	Stump Canyon Creek	2.28	31°23'29"	110°14'57"	95	19,800	98	22,900	99	25,200
26	8[a]	Stump Canyon Dreek crossing Highway 92	3.33	31°23'56"	110°14'24"	87	26,800	95	30,900	98	33,900
27	9[b]	Stream crossing Highway 92	2.40	31°24'02"	110°14'27"	76	18,000	91	20,700	95	22,700
28	10	Hunter Canyon Creek crossing Highway 92	4.77	31°24'21"	110°14'26"	89	42,600	96	49,100	98	53,900
29	11	Stream Crossing Baumkirchner Road	2.03	31°24'08"	110°14'48"	84	16,100	94	18,600	97	20,500
33	12[c]	Miller Canyon Creek crossing Highway	12.17	31°25'42"	110°14'28"	92	161,000	97	185,000	99	203,000
na	13	na	1.95	31°26'51"	110°15'46"	71	12,000	88	13,900	94	15,200
na	14	na	1.27	31°25'03"	110°15'01"	91	8,380	97	9,660	99	10,600
na	15	na	0.80	31°24'51"	110°14'25"	26	3,780	50	4,350	69	4,770
na	16	na	0.43	31°23'14"	110°14'27"	66	3,140	86	3,630	93	3,990
na	17[d]	na	0.66	31°23'31"	110°13'55"	46	3,440	71	3,970	84	4,360
na	18[e]	na	10.80	31°25'33"	110°15'12"	96	144,000	99	167,000	99	183,000

[a] includes USGS drainage-basin number 7

[b] includes USGS drainage-basin number 11

[c] includes USGS drainage-basin number 1, 3, 18

[d] includes USGS drainage-basin number 16

[e] includes USGS drainage-basin number 1

This report presents an emergency debris-flow hazards assessment, done by the U. S. Geological Survey in collaboration with the State of Arizona, U. S. Department of Agriculture Forest Service, and the Federal Emergency Management Agency Region IX. Estimates are provided of the predicted probability of occurrence and volume of debris that could flow from 18 drainage-basin outlets in response to three design (or reference) storms: (1) 2-year-recurrence, 30-minute-duration rainfall (25–35 mm, a 50 percent chance in any given year), (2) 5-year-recurrence, 30-minute-duration rainfall (33–45 mm, a 20 percent chance in any given year), and (3) 10-year-recurrence, 30-minute-duration rainfall (38–52 mm, a 10 percent chance in any given year). The procedures used for this report are based on the work by Cannon and others (2007; 2010) and Ruddy and others (2010).

A set of empirical equations (models) developed by Cannon and others (2010) and derived from statistical evaluation of data collected from recently burned drainage 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 model for debris-flow probability is as follows:

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

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 and high severity (data for this investigation from Dave Young, U.S. Department of Agriculture Forest Service, written commun., 2011);

I is average storm intensity (calculated by dividing total storm rainfall [Mike McLane, National Weather Service, written commun., 2011] by the storm duration, in millimeters per hour);

%*C* is clay content of the soil (in percent) (U.S. Department of Agriculture, National Resources Conservation Service, 1991, and Schwarz and Alexander, 1995), and

LL is the liquid limit of the soil (percentage of soil moisture by weight) (U.S. Department of Agriculture, National Resources Conservation Service, 1991, and Schwarz and Alexander, 1995).

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:

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

where,

V is the debris-flow volume, including water, sediment, and debris (cubic meters);

SG30 is the area of the 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 depth (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 of the 18 drainage basins to be evaluated was identified by a single outlet (pour point) located at the drainage-basin mouth, but some basins are included within larger basins (table 1). Conditions within the drainage-basin area upstream from that pour point were used to estimate debris-flow probability and volume for a specific design storm (Cannon and others, 2010). Locations drainage-basin pour points were identified by the Burned Area Emergency Response (BAER) team for the Monument fire (indicated by USGS drainage-basin numbers in figures 1, 2, and 3 and table 1).

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 continuously 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 drainage-basin outlets (pour points) and their corresponding basins.

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 10-meter grid cell within the extent of the DEM. Rainfall total and rainfall intensity were calculated from 800-meter precipitation grids provided by the National Weather Service (Mike McLane, National Weather Service, written commun., 2011). Values for all of the independent variables driving the predictive equations were obtained using the continuous parameterization approach in a geographic information system (GIS), 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 evaluated for every grid cell within the study area, the probability and volume equations were solved by using map algebra for each location. 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.

The continuous parameterization technique allows for faster parameter characterization and the ability for characterization upstream from any location, not just predefined basin outlets. The continuous parameterization technique provides a synoptic view of the entire study area which aids in the identification of smaller, high-probability basins within a larger basin. This allows for rapid evaluation of potential "hot spots" within the burned area -- locations with potentially high probabilities of large debris flows.   Although modeled probabilities and volumes at the pour point of a predefined basin might be relatively low, locations within the drainage basin might have substantially higher debris flow potential. These can be easily identified with this technique.

Estimated Debris Flow Probabilities and Volumes

The estimated debris-flow probabilities and volumes in response to the different rainfall scenarios are presented in table 1. Estimated probabilities of debris flows were high for most basins. Conditions in 13 of the 18 basins resulted in debris-flow probabilities greater than 80 percent in response to the 2-year-recurrence, 30-minute-duration rainfall; 16 out of 18 basins in response to the 5-year-recurrence; 30-minute-duration rainfall; and 17 out of 18 in response to the 10-year-recurrence, 30-minute-duration rainfall. Drainage basin 15 showed the lowest probabilities, which ranged from 26 to 69 percent in response to the 2-year-recurrence, 30-minute-duration rainfall and the 10-year-recurrence, 30-

minute-duration rainfall, respectively. Debris-flow probabilities for USGS drainage basins 6, 12, and 18 ranged from 92 to 100 percent for 2-year-recurrence, 30-minute-duration rainfall and 10-year-recurrence, 30-minute-duration rainfall. These high probabilities are likely due to a combination of steep hillslopes burned at moderate and high burn severities, and indicate a potential for substantial debris-flow impacts to any 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.

Estimated debris-flow volumes ranged from 2,680 m3 for USGS drainage basin 1 to 216,000 m 3 for USGS drainage basin 6 for a 10-year-recurrence, 30-minute-duration rainfall. Estimated debris flow volumes for drainage basins 6, 12, and 18 were at least an order of magnitude greater than those estimated for the 15 other drainage basins. About 90 percent of USGS drainage basin 12 is composed of USGS drainage basin 18. Although larger rainstorms produced estimates of larger debris-flow volume, the increase in estimated volumes for most basins from a 2-year-recurrence, 30-minute-duration rainfall to a 10-year-recurrence, 30-minute-duration rainfall only increased by about 20 percent. A 2-year-recurrence, 30-minute-duration rainfall (a relatively “small” rainfall amount) is likely to produce a high probability of a debris flow.

An example of the additional detail provided by the continuous parameterization approach is shown in USGS drainage basin 15 on figure 2. While the probability of a debris flow occurring at the pour point of the drainage basin is 50 percent (table 1), the probabilities of a debris flow along the channels upstream from the pour point are much higher. The red channel reaches along the drainage network upstream from the pour point of basin 15 indicate higher debris flow probabilities at these locations with values as high as 81–100 percent.

Use and Limitations of the Assessment

This assessment presents estimates of debris-flow probability and volume for selected drainage basins in the area burned by the Monument wildfire. Estimates were made in response to three design [or reference] storms: (1) a 2-year-recurrence, 30-minute-duration rainfall (a 50 percent chance in any given year). (2) a 5-year-recurrence, 30-minute-duration rainfall (a 20 percent chance in any given year) and (3) a 10-year-recurrence, 30-minute-duration rainfall (a 10 percent chance in any given year). Larger, less frequent storms are more likely to produce larger debris flows; however, the analyses indicate that even relatively common rainfall events could result in substantial runoff and erosion producing debris flows. Some areas within the selected basins may have higher debris-flow probabilities than those shown at the drainage-basin outlet, or pour point, shown on figure 2, and debris flows may not be produced from all basins during a 2 or 5-year recurrence rainfall. The estimates are meant to be valid for up to 3 years after the wildfire (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, at their outlets, or in 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, but are beyond the scope of this analysis.

This analysis 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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