Probability and Volume of Potential Postwildfire Debris Flows in the 2011 Wallow Burn Area, Eastern Arizona

By Barbara C. Ruddy

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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)”

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Abstract

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned in 2011 by the Wallow wildfire in eastern Arizona. 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 debris-flow volumes 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) 10-year-recurrence, 1-hour-duration rainfall and (2) 25-year-recurrence, 1-hour-duration rainfall.

Estimated debris-flow probabilities in the drainage basins of interest ranged from less than 1 percent in response to both the 10-year-recurrence, 1-hour-duration rainfall and the 25-year-recurrence, 1-hour-duration rainfall to a high of 41 percent in response to the 25-year-recurrence, 1-hour-duration rainfall. The low probabilities in all modeled drainage basins are likely due to extensive low-gradient hillslopes, burned at low severities, and large drainage-basin areas (greater than 25 square kilometers). Estimated debris-flow volumes ranged from a low of 24 cubic meters to a high of greater than 100,000 cubic meters, indicating a considerable hazard should debris flows occur.

Introduction

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 rainstorms after a fire can increase overland runoff that erodes soil, rock, ash, and vegetative debris from hillslopes (Cannon and others, 2008). This increased runoff concentrates in drainage networks and entrains additional sediment that may 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 not been documented from the area burned by Wallow fire in the past, yet potential debris flows in such a large burned area remain a concern for emergency managers.

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned in 2011 by the Wallow wildfire in eastern Arizona (figs. 1, 2, 3, and 4, table 1). This assessment was done by the U. S. Geological Survey (USGS) 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 debris-flow occurrence and volume of debris that could flow from 42 drainage-basin outlets in response to two design storms: (1) 10-year-recurrence, 1-hour-duration rainfall of 39–49 millimeters (mm) (a 10 percent chance of occurrence in any given year) and (2) 25-year-recurrence, 1-hour-duration rainfall 47–58 mm (a 4 percent chance of occurrence in any given year). The methods used for this assessment are based on the work by Cannon and others (2007; 2010) and Ruddy and others (2010).

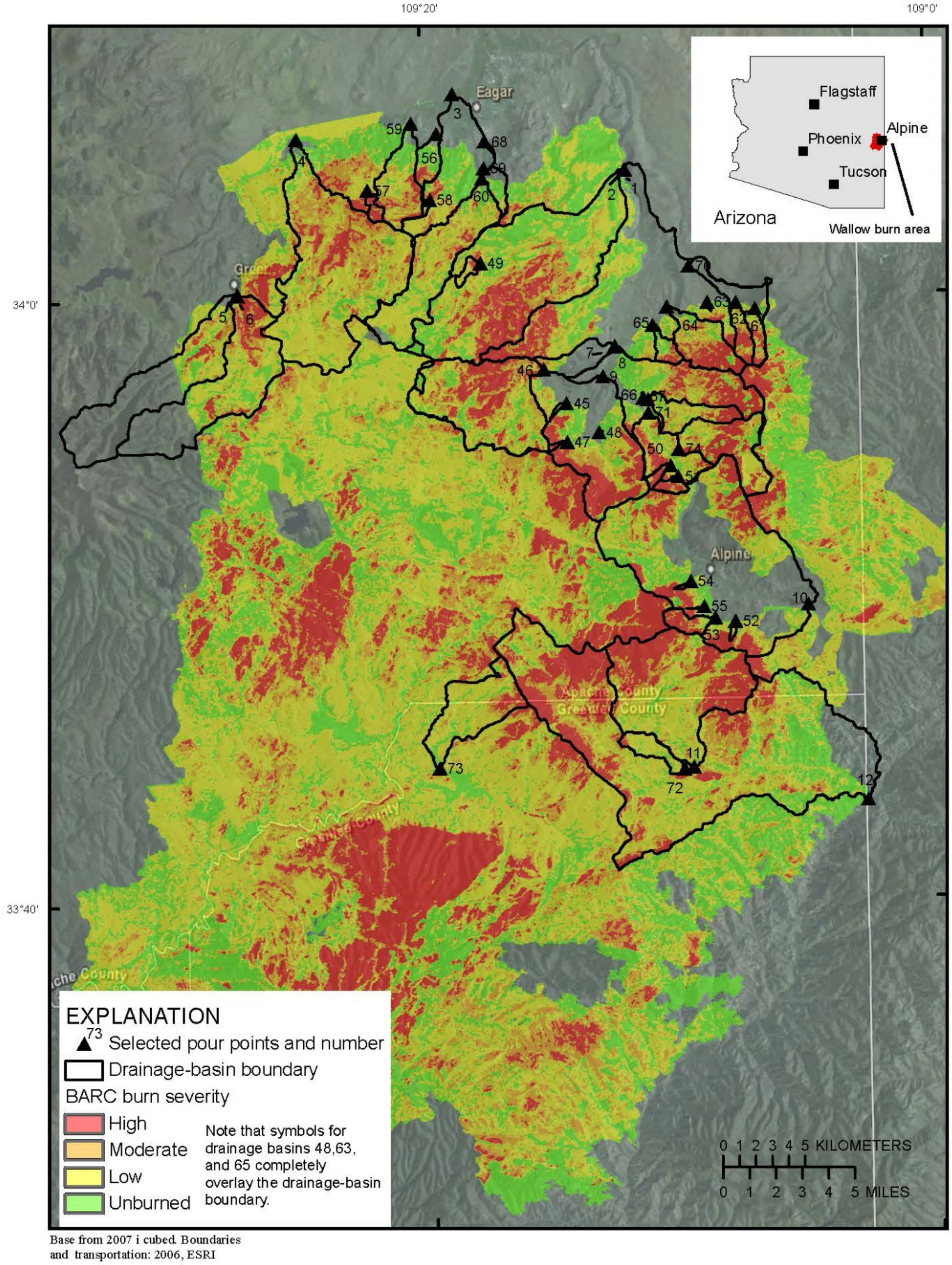

Figure 1. Location of drainage basins of interest and BARC burn severity map of the 2011 Wallow burn area, eastern Arizona (BARC, Burned Area Reflectance Classification).

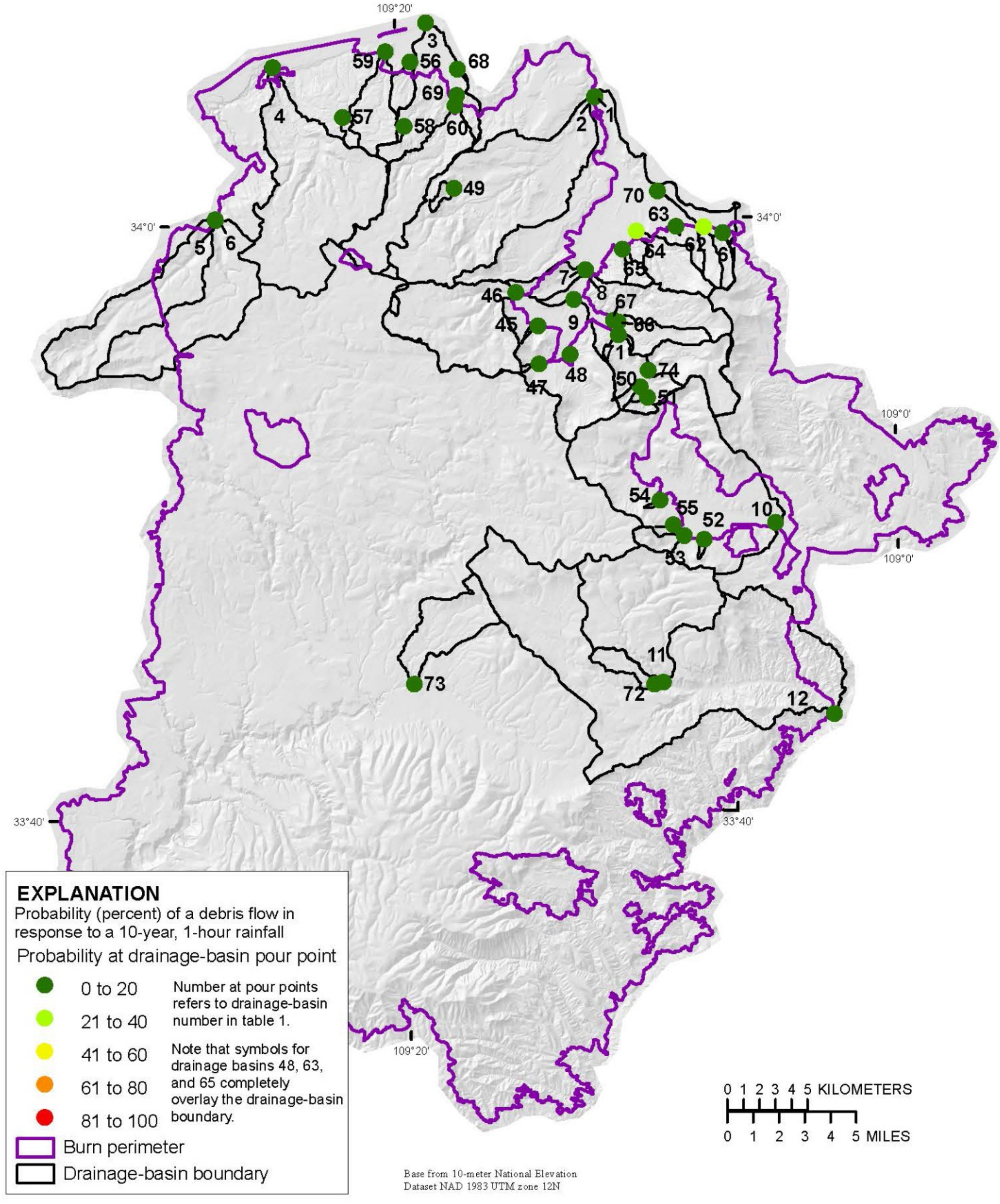

Figure 2. Estimated probability of potential postwildfire debris flows in the 2011 Wallow burn area, eastern Arizona, in response to a 10-year-recurrence, 1-hour-duration rainfall.

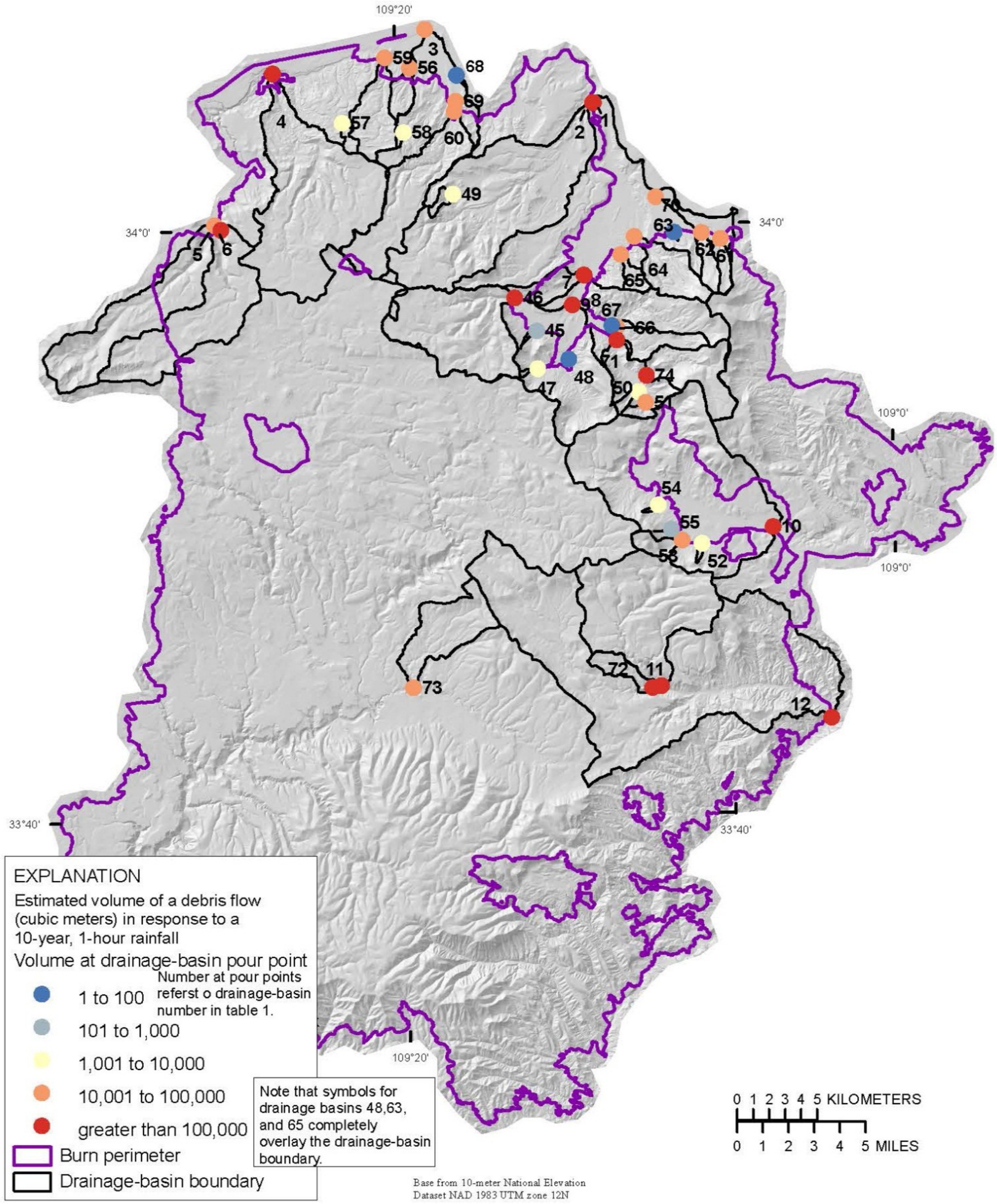

Figure 3. Estimated volumes of potential postwildfire debris flows in the 2011 Wallow burn area, easternArizona, in response to a 10-year-recurrence, 1-hour-duration rainfall.

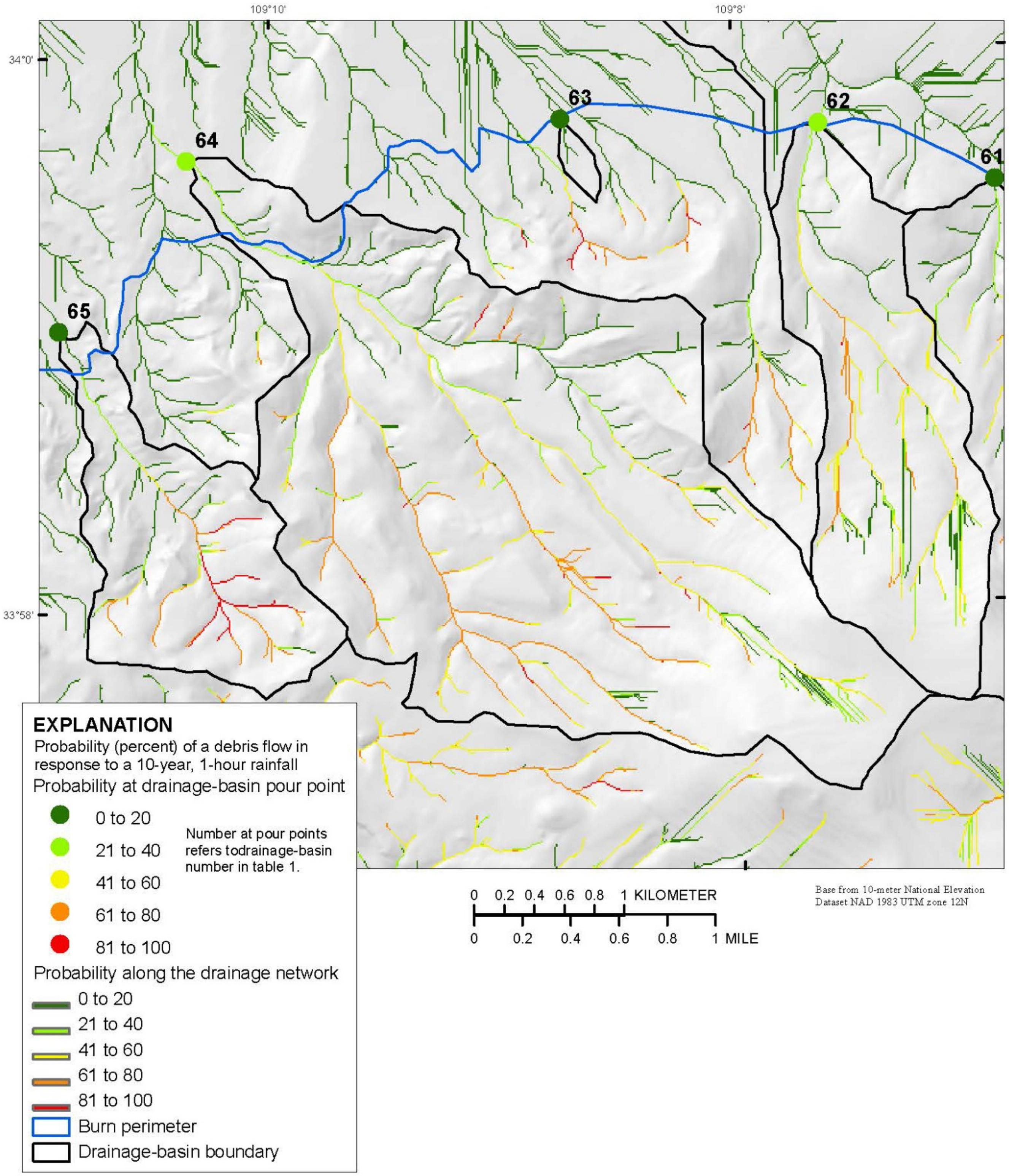

Figure 4. Estimated probability of potential postwildfire debris flows along the drainage network in drainage basins 62 through 65 in the 2011 Wallow burn area, eastern Arizona, in response to a 10-year-recurrence, 1-hour-duration rainfall.

Table 1. Estimated debris-flow probabilities and volumes for the Wallow burn area, eastern Arizona.

[BAER, burned area emergency response; HUC, U.S. Geological Survey hydrologic unit code;>, greater than; <, less than]

Drainage-basin number for pour point (fig.1–4)	BAER Description or HUC 12 number and name	Area	Latitude	Longitude	Debris flow in response to a 10-year, 1-hour rainfall		Debris flow in response to a 25-year, 1-hour rainfall	
		square kilometers	degrees, minutes, seconds	degrees, minutes, seconds	Probability (percent)	Volume (cubic meters)	Probability (percent)	Volume (cubic meters)
1[a]	150200010105 Riggs Creek-Nutrioso Creek	88.63	34°04'11"	109°11'56"	2	> 100,000	3	> 100,000
2[b]	150200010104 Rudd Creek	71.79	34°04'11"	109°11'56"	1	> 100,000	1	> 100,000
3[c]	150200010206 Water Canyon Creek	50.04	34°06'46"	109°18'47"	< 1	80,500	< 1	90,500
4	150200010204 South Fork Little Colorado River	65.61	34°05'20"	109°24'58"	< 1	> 100,000	1	> 100,000
5	150200010201 West Fork Little Colorado River	32.91	34°00'14"	109°27'25"	1	95,600	1	> 100,000
6	150200010202 East Fork Little Colorado River	36.28	34°00'12"	109°27'25"	1	> 100,000	1	> 100,000
7[d]	150200010102 Colter Creek	41.48	33°58'21"	109°12'25"	1	> 100,000	2	> 100,000
8[e]	150200010103 Paddy Creek-Nutrioso Creek	59.32	33°58'20"	109°12'25"	7	> 100,000	12	> 100,000
9[f]	150200010101 Auger Creek	38.09	33°57'21"	109°12'58"	4	> 100,000	6	> 100,000
10[g]	150400040301 San Fracisco River-Luna Lake	93.03	33°49'42"	109°04'55"	1	> 100,000	2	> 100,000
11	150400040501 Coleman Creek	47.99	33°44'23"	109°09'36"	2	> 100,000	3	> 100,000
12[h]	150400040503 Campbell Blue Creek	138.48	33°43'13"	109°02'42"	2	> 100,000	3	> 100,000
45	Gary Hart	0.20	33°56'29"	109°14'24"	< 1	781	< 1	878
46	Home by Colter Cr.	36.50	33°57'37"	109°15'18"	1	> 100,000	2	> 100,000
47	Home with Headcut	0.26	33°55'12"	109°14'24"	16	2,890	25	3,250
48	Lena Hamblin Home	0.01	33°55'30"	109°13'08"	1	96	1	107
49	Milligan B. Olsen Property	1.16	34°01'10"	109°17'42"	1	6,400	2	7,220
50	Sec. 21 Pourpt. (Mulching Anaysis)	0.93	33°54'22"	109°10'19"	9	6,890	14	7,740
51	Sec. 22 Pourpt. (Mulching Analysis)	1.46	33°54'00"	109°10'01"	14	10,300	21	11,600

52	Sec. 24 House	0.31	33°49'11"	109°07'52"	4	1,940	7	2,170
53	RobertODell	3.03	33°49'18"	109°08'38"	12	20,000	18	22,400
54	Aspen Lodge	0.20	33°50'31"	109°09'36"	11	1,390	18	1,560
55	S. Mountain Home #14	0.06	33°49'41"	109°09'04"	< 1	407	< 1	456
56	Eager Wash A Drainage	3.56	34°05'28"	109°19'26"	< 1	10,300	< 1	11,500
57	Coon Spr.	1.28	34°03'37"	109°22'12"	15	7,560	23	8,520
58	W. Fork Dry Rd 261H2	0.33	34°03'17"	109°19'41"	1	1,930	2	2,170
59	Grapevine Residence	11.31	34°05'49"	109°20'24"	< 1	39,800	< 1	44,800
60	Water Cyn. Admin.	26.36	34°03'58"	109°17'38"	< 1	73,000	< 1	82,100
61	E. Fork Davis Culvert	2.32	33°59'31"	109°06'54"	19	15,600	28	17,500
62	W. Fork Davis Culvert	3.29	33°59'43"	109°07'37"	26	23,000	37	25,900
63	Woods Cr. Culvert	0.08	33°59'45"	109°08'46"	< 1	48	< 1	54
64	Watts Cr.	10.31	33°59'37"	109°10'23"	29	100,000	41	> 100,000
65	Alpaca Residence	2.29	33°59'01"	109°10'55"	17	15,400	26	17,300
66	Hulsey Cr.	6.85	33°56'34"	109°11'10"	7	31,500	11	35,400
67	Milk Cr. Terry Ranch	0.03	33°56'37"	109°11'20"	< 1	25	1	29
68	Slade Res. 1320	0.06	34°05'11"	109°17'31"	< 1	24	< 1	26
69	Slade Res. 2	2.76	34°04'18"	109°17'35"	< 1	83,400	< 1	93,700
70	John May Res.	4.38	34°00'58"	109°09'29"	1	47,000	2	52,800
71	Casita Escondia	9.85	33°56'07"	109°11'10"	11	> 100,000	17	> 100,000
72	Luce Ranch	4.19	33°44'19"	109°09'58"	2	> 100,000	4	> 100,000
73	Sprucedale	17.68	33°44'27"	109°19'37"	< 1	38,400	1	43,200
74	Paddy Cr. Res.	13.96	33°54'55"	109°09'58"	15	> 100,000	23	> 100,000

[a] includes drainage-basin numbers 61, 62, 63, 64, 65, and 70
[b] includes drainage-basin number 49
[c] includes drainage-basin numbers 58, 60, 68, and 69
[d] includes drainage-basin number 46
[e] includes drainage-basin numbers 50, 51, 66, 67, 71, and 74
[f] includes drainage-basin numbers 45, 47, and 48
[g] includes drainage-basin numbers 52, 53, 54, and 55
[h] includes drainage-basin number 72

A set of empirical equations (models) was used to estimate the probability of debris-flow occurrence and volumes of debris flows for selected drainage basins. These models were developed by Cannon and others (2010) and were derived from statistical evaluation of data collected from recently burned drainage basins throughout the intermountain western United States. 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:

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

where P is the probability of debris-flow occurrence in fractional form and e is the mathematical constant (approximately 2.718…); 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 assessment provided by Nancy Loving, 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 at which the soil changes from plastic to liquid behavior (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:

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

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 42 evaluated drainage basins was identified by a single outlet (pour point) located at the drainage-basin mouth, however, some subbasins are included within larger basins (table 1 and figure 1). Conditions within the drainage-basin area upstream from the identified pour point were used to estimate debris-flow probability and volume for a specific design storm (Cannon and others, 2010).

Locations of drainage-basin pour points were identified by the Burned Area Emergency Response (BAER) team for the Wallow fire (indicated by drainage-basin numbers in figures 1, 2, and 3 and table 1).

In addition to the hazard assessments for the discrete drainage basins identified by pour points, a continuous parameterization technique was used to map potential debris-flow hazards along the drainage network of each basin. With this technique estimates of debris-flow probability and volume (Cannon and others, 2010) were obtained continuously along the drainage network (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 (m) 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-m grid cell within the extent of the DEM. Rainfall totals and rainfall intensities were calculated from 800-m 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). 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 (Verdin and Greenlee, 2003; Verdin and Worstell, 2008) was used to identify the values of debris-flow probability and volume at selected locations along the drainage network derived from a DEM.

The continuous parameterization technique allows for faster parameter characterization, and the ability to characterize debris-flow hazard upstream from any location, not just at predefined basin outlets. The continuous parameterization technique provides a synoptic view of the entire study area, which aids in the identification of smaller basins with high probabilities of debris flows 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 potential for debris flow. These can be easily identified with the continuous parameterization 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 generally were low. Conditions in all of the basins resulted in debris-flow probabilities less than 30 percent in response to the 10-year-recurrence, 1-hour-duration rainfall. Conditions in all of the basins except basin 64 (estimated probability was 41 percent) resulted in debris-flow probabilities less than 40 percent in response to the 25-year-recurrence, 1-hour-duration rainfall. These low probabilities are likely due to a combination of gentle gradient hillslopes and little drainage-basin area burned at moderate and high burn severities. The larger basins, especially those greater than 25 square kilometers (km^2), had the lowest estimated probabilities and the largest estimated volumes. It is possible for a larger drainage basin to have a low probability of a debris flow at the pour point and for debris flows to be produced from the subbasins within the larger drainage basin. Cannon and others (2010) found that debris flows were not observed at the outlets of drainage basins greater than about 30 km^2 (12 square miles) in area.

Although the estimated probabilities for the designated basins are mostly low, there still is the potential for debris-flow impacts to any buildings, roads, bridges, culverts, or reservoirs located both within these drainages and immediately downstream from the burned area. It is important to recognize that even small debris flows at the basin outlets could cause considerable damage to infrastructure.

Estimated debris-flow volumes ranged from 24 m^3 for drainage basin 68 in response to a 10-year, 1-hour rainfall to greater than 100,000 m^3 at several drainage basins in response to the two design rainfalls. The model predicts volumes greater than 100,000 m^3, however, there is high uncertainty at volumes greater than 100,000 m^3 (Susan Cannon, U.S. Geological Survey, written commun., 2011). Drainage basins with the largest areas had the largest estimated debris-flow volumes.

Although the estimated probabilities for the designated basins are low, the volume of debris flow that might be produced could be considerable for some drainage basins. Thus, one could expect debris-flow impacts to any buildings, roads, bridges, culverts or reservoirs located both within these drainages and immediately downstream from the burned area. Estimated debris-flow probabilities in the drainage basins of interest ranged from less than 1 percent in response to both the 10-year-recurrence, 1-hour-duration rainfall and the 25-year-recurrence, 1-hour-duration rainfall to a high of 41 percent in response to the 25-year-recurrence, 1-hour-duration rainfall.

Hazardous areas within drainage basins 62 through 65 are identified by the continuous parameterization approach and are shown on figure 4. The red channel reaches upstream from the pour point indicate debris flow probabilities as high as 81–100 percent. Although the probabilities of a debris flow occurring in response to the 10-year-recurrence, 1-hour duration rainfall at the pour points of these drainage basins are between 17 and 29 percent (table 1), the continuous parameterization techniques indicate locations along specific channel reaches where the probabilities are much higher.

Use and Limitations of the Assessment

This assessment presents estimates of debris-flow probability and volume for selected drainage basins and along their channels (or drainage networks) in the area burned by the 2011 Wallow wildfire. Estimates were made in response to two design storms: (1) a 10-year-recurrence, 1-hour-duration rainfall (a 10 percent chance of occurrence in any given year) and (2) a 25-year-recurrence, 1-hour-duration rainfall (a 4 percent chance of occurrence in any given year). Some areas within the selected drainage basins may have higher debris-flow probabilities than those shown at the drainage-basin outlet, or pour point, shown in figure 2, and debris flows may not be produced from all basins during a 10- or 25-year recurrence rainfall. The estimates are likely 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 wildfire, but are beyond the scope of this assessment.

This assessment is preliminary and is subject to revision. It is being provided due 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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