A New Technique for Implementing USGS Models for Assessing Postwildfire Debris Flows

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A debris flow can be one of the most devastating postwildfire hazards. Debris flows are fast-moving, high-density slurries of water, sediment, and debris that can be enormously destructive. Debris flows are frequently triggered by intense rainfall or rapid snowmelt on steep hillsides covered with erodible material. Although debris flows are a common geomorphic process in some unburned areas, a wildfire can transform conditions in a basin with no recent history of debris flows into conditions that pose a substantial hazard to residents, communities, infrastructure, aquatic habitats, and water-supply systems.

A new technique was used to estimate the probability and volumes of debris flows (using models developed by Cannon and others, 2010) for three wildfires in Arizona in 2011 and for two wildfires in Colorado in 2010 and 2011. Model inputs include rainfall intensity and basin characteristics of slope, percent of basin burned, and soils. While the old technique uses a conventional basin-characterization method at pre-selected points, this new technique uses continuous-parameterization, using the 1/3-arc-second National Elevation Dataset (10-meter nominal resolution) and its derived flow-direction grid as a base, to compute the debris-flow model predictions for every flow-direction pixel within the 10-meter digital-elevation basins.

One of the main advantages of the continuous-parameterization technique is that it provides a synoptic view of the entire study area. While the conventional basin characterization technique requires an analyst to select basins for equation evaluation, delineate the basin and perform multiple overlay analyses before predicting the debris flow volume and probability at the outlet, the continuous-parameterization technique predicts the probabilities and volumes at EVERY flow-direction location within the basin. This information is then readily available to the analyst. Basins with high probability and volume estimates, which may have not been modeled using the conventional technique, are readily identified. This technique can be implemented in a quicker fashion and provides more information than conventional approaches.

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:

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

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;

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

%C is clay content of the soil (in percent); and

LL is the liquid limit of the soil at which the soil changes from plastic to liquid behavior (percentage of soil moisture by weight).

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,

ln is the natural logarithm;

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);

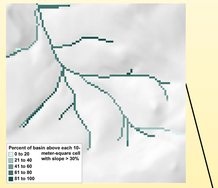
T is the total storm rainfall depth (millimeters); and

0.3 is a bias-correction factor that changes the predicted estimate from a median to a mean value (Helsel and Hirsch, 2002).

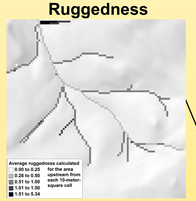
For the purpose of explaining the continuous-parameterization technique in this poster, only the probability equation is presented.

Probability Model Input

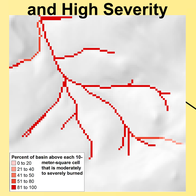
% Basin with Slopes > 30 %



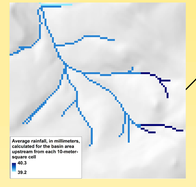
Ruggedness



% Burned at Moderate and High Severity



Rainfall Intensity



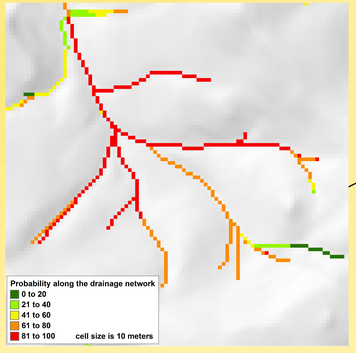
% Clay

Liquid Limit

Older debris-flow sediment stratigraphy in the Fourmile burn area, Boulder County, Colorado, September 2010. Flow direction from left to right.

Model Output

Probability of Debris Flow



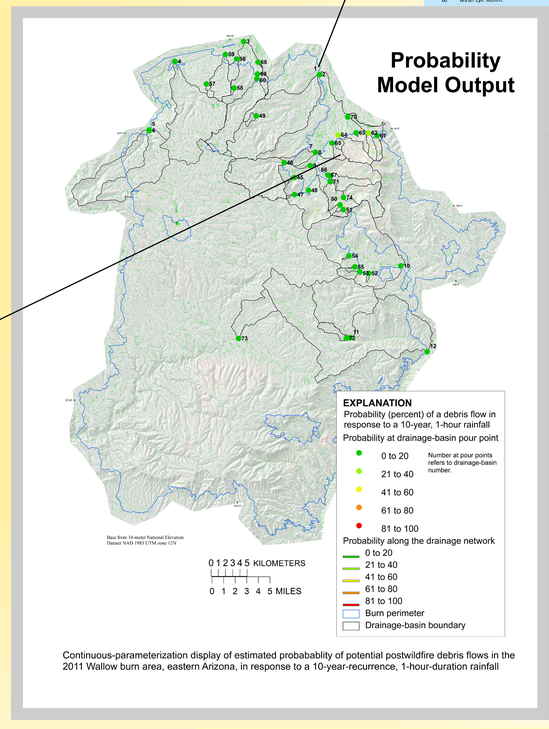
Fourmile Burn Area, Boulder County, Colorado, September 2010

Postwildfire basin conditions that contribute toward debris flows:

- Little vegetation or duff
- Steep hillslopes
- Hydrophobic soils
- Minimal water infiltration

Model Output

Probability Model Output



Continuous-parameterization display of estimated probabablity of potential postwildfire debris flows in the 2011 Wallow burn area, eastern Arizona, in response to a 10-year-recurrence, 1-hour-duration rainfall

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	BAER Description or HUC 12 name or end name [1]	Area	Latitude[2]	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[3]	150200010505 Riggs Creek-Nutrioso Creek	88.63	34°04'11"	109°11'56"	2	> 100,000	3	> 100,000
2[3]	150200010504 Rudd Creek	71.79	34°04'11"	109°11'56"	1	> 100,000	1	> 100,000
3[3]	150200010206 Water Canyon Creek	50.04	34°06'46"	109°18'43"	< 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	150200010203 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[3]	150200010102 Colter Creek	41.48	33°58'21"	109°12'25"	1	> 100,000	2	> 100,000
8[3]	150200010103 Paddy Creek-Nutrioso Creek	59.32	33°58'20"	109°12'25"	7	> 100,000	12	> 100,000
9[3]	150200010101 Auger Creek	38.09	33°57'21"	109°12'58"	4	> 100,000	6	> 100,000
10[3]	150400040501 San Francisco 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[3]	150400040503 Campbell Blue Creek	138.48	33°43'13"	109°02'42"	2	> 100,000	3	> 100,000
45	Gary Hunt	0.20	33°56'20"	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 Headout	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 Analysis)	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	Ruben ODell	3.01	33°45'18"	108°58'38"	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°13'20"	< 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 2610#2	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
		2.32	33°59'31"	109°04'54"	19	15,600	28	17,500
		3.29	33°59'43"	109°07'37"	26	23,000	37	25,900
		0.08	33°59'45"	109°08'46"	< 1	48	< 1	54
		10.31	33°59'37"	109°10'23"	29	100,000	41	> 100,000
		2.29	33°59'01"	109°10'55"	17	15,400	26	17,300
		6.85	33°56'34"	109°11'10"	7	31,500	11	35,400
		0.03	33°56'37"	109°11'20"	< 1	25	1	29
		0.06	34°05'11"	109°17'31"	< 1	24	< 1	26
		2.76	34°04'18"	109°17'35"	< 1	83,400	< 1	93,700
		4.38	34°00'58"	109°09'29"	1	47,000	2	52,800
		9.85	33°56'07"	109°11'10"	11	> 100,000	17	> 100,000
		4.19	33°44'19"	109°09'58"	2	> 100,000	4	> 100,000
		17.68	33°44'23"	109°10'37"	< 1	38,400	1	43,200
		13.96	33°54'55"	109°09'58"	15	> 100,000	23	> 100,000

[1] Includes drainage-basin numbers 65, and 70

[2] 69

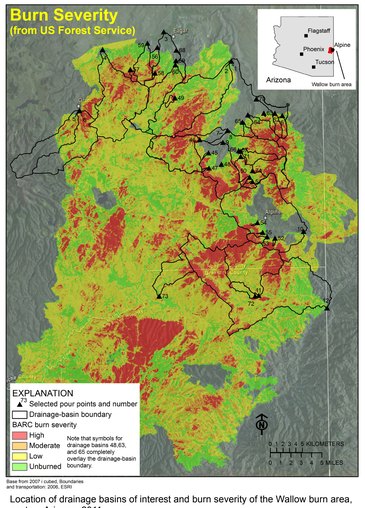
[3] Includes drainage-basin numbers 50, 51, 66, 67, 71, and 72

[4] Includes drainage-basin numbers 45, 47, and 48

[5] Includes drainage-basin numbers 52, 53, 54, and 55

[6] Includes drainage-basin number 72

Model does not estimate volume; 400,000



Location of drainage basins of interest and burn severity of the Wallow burn area, eastern Arizona, 2011

For the continuous-parameterization technique, each of the independent variables in the equations needs to be developed.

- The 1/3-arc-second National Elevation Dataset was used to create the flow-direction grid (which defines the basin boundaries and stream channels), the flow-accumulation grid (which provides the basin area), and slope grids.
- The rainfall intensity grid for a 10-year 1-hour storm was provided by the National Weather Service (Mike McLane, National Weather Service, written commun., 2011).
- The soils characteristics of percent clay and liquid limit were extracted from the STATSGO soils characteristics database (Schwarz and Alexander, 1995 and U.S. Department of Agriculture, 1991).
- The burn-severity data were provided by USFS BAER team.

Both the probability and volume equations were evaluated for every flow-direction pixel within the 10-meter digital-elevation basins using map algebra within the ARCGIS software. The predicted values of probability or volume at each pixel represent the probability or volume for the entire drainage basin upstream from that point.

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