# Probability and Volume of Potential Postwildfire Debris Flows in the 2011 Horseshoe II Burn Area, Southeastern 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)”

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

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## Abstract

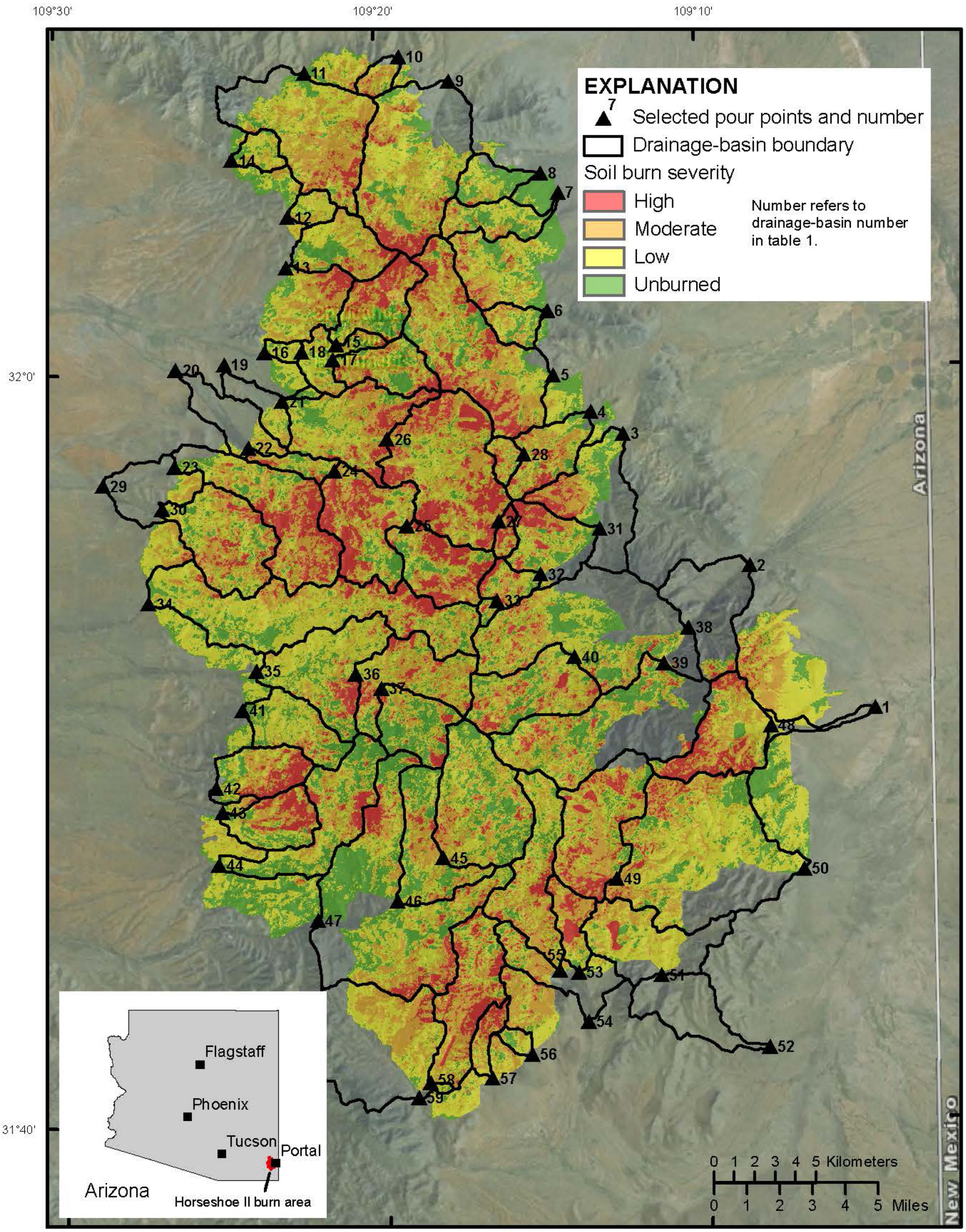
This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned in 2011 by the Horseshoe II wildfire in southeastern Arizona. Empirical models derived from statistical evaluation of data collected from recently burned drainage basins throughout the intermountain western United States were used to estimate the probability of debris-flow occurrence and debris-flows 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) 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 less than 1 percent in response to the 2-year-recurrence, 30-minute-duration rainfall to a high of 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 moderate to high severities. The estimated debris-flow volumes ranged from a low of 20 cubic meters to a high of greater than 100,000 cubic meters.

## 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 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 already been documented from the Horseshoe II fire, debris flows occurred in July 2011 along the 42 Road on the west side of Onion Saddle in response to a monsoonal thunderstorm (Ann Youberg, Arizona Geological Survey, written commun., 2011).

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned in 2011 by the Horseshoe II wildfire in southeastern Arizona (figs. 1, 2, and 3, 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 59 drainage-basin outlets in response to three design storms: (1) 2-year-recurrence, 30-minute-duration rainfall (24–31 millimeters (mm), a 50 percent chance of occurrence in any given year), (2) 5-year-recurrence, 30-minute-duration rainfall (33–40 mm, a 20 percent chance of occurrence in any given year), and (3) 10-year-recurrence, 30-minute-duration rainfall (37–46 mm, a 10 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; figs. 1, 2, and 3, table 1).




Base from 2007 i cubed. Boundaries and transportation: 2006, ESRI

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

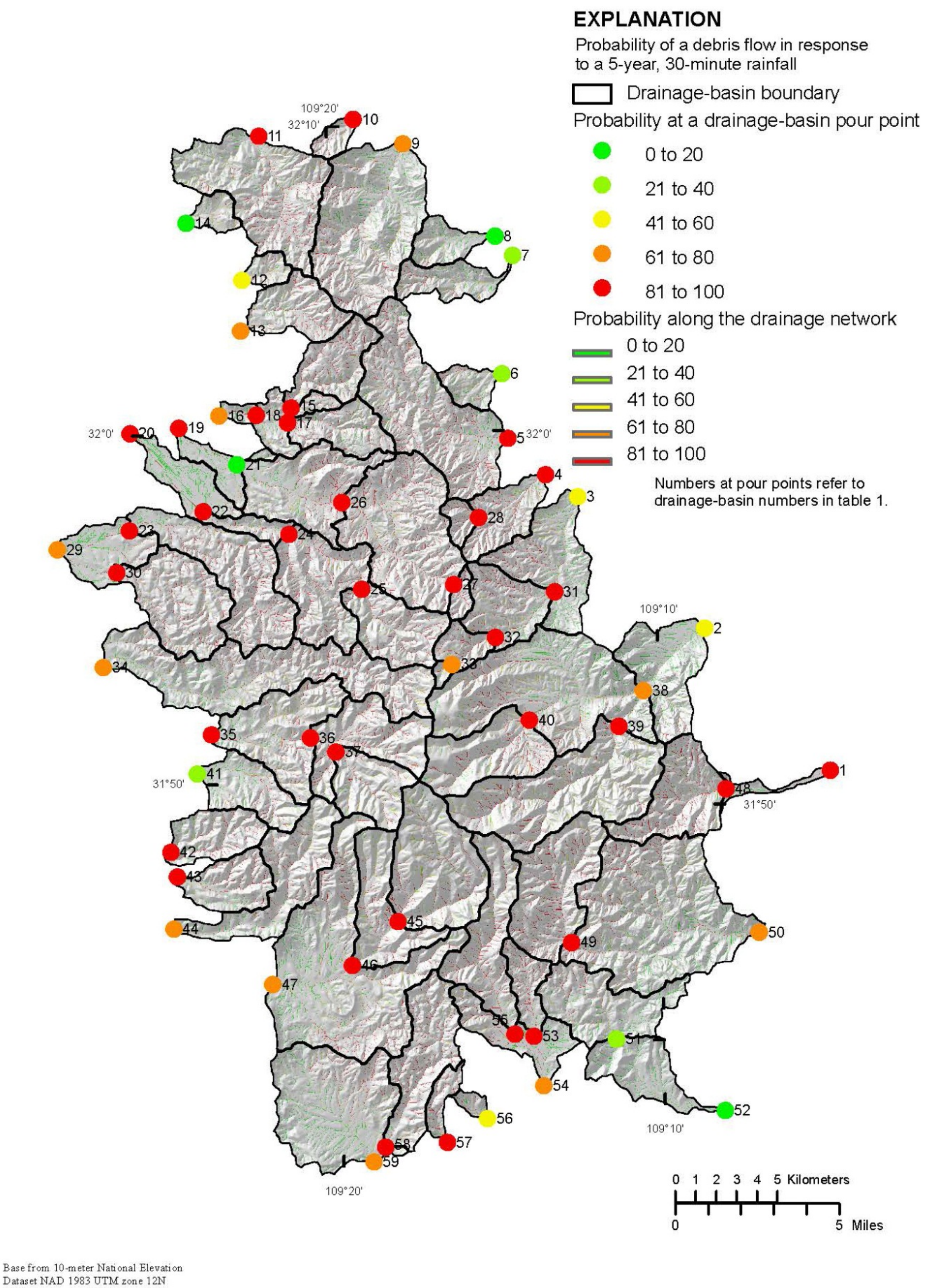



**Figure 2.** Estimated probability of potential postwildfire debris flows in the 2011 Horseshoe II burn area, southeastern Arizona in response to a 5-year-recurrence, 30-minute-duration rainfall.

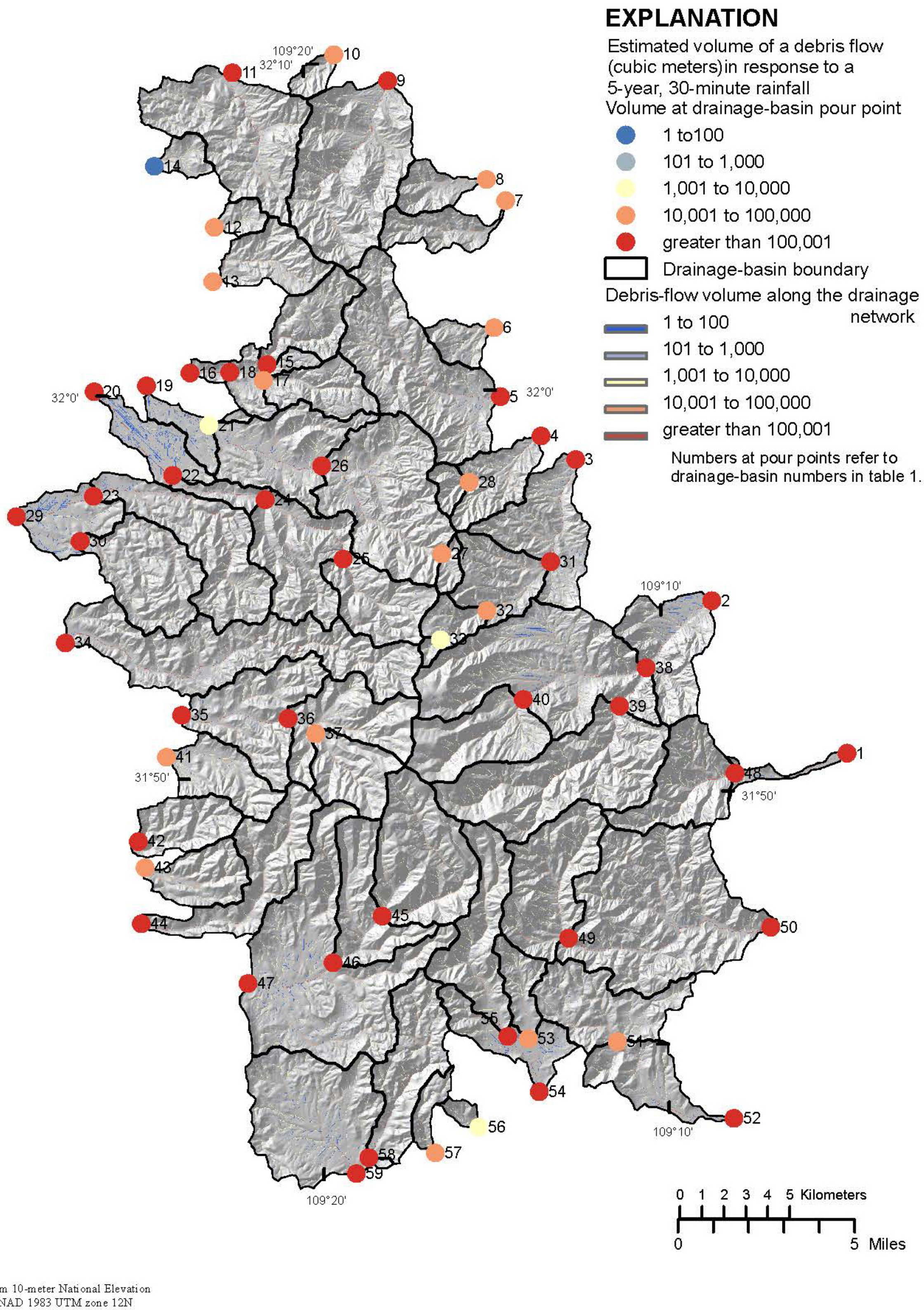



**Figure 3.** Estimated volumes of potential postwildfire debris flows in the 2011 Horseshoe II burn area, southeastern Arizona in response to a 5-year-recurrence, 30-minute-duration rainfall.

Table 1. Probabilities and estimated debris flow volumes for the 2011 Horseshoe II burn area, southeastern Arizona.

[BAER, burned area emergency response; >, greater than; <, less than]

| Drainage-basin number for pour point (figs. 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[a] | Sulphur HUC6 | 18.81 | 31°50'53" | 109°04'42" | 68 | > 100,000 | 84 | > 100,000 | 90 | > 100,000 |
| 2[b] | Cave Portal | 109.94 | 31°54'43" | 109°08'32" | 34 | > 100,000 | 58 | > 100,000 | 74 | > 100,000 |
| 3[c] | East Turkey Fireline | 35.93 | 31°58'15" | 109°12'24" | 35 | > 100,000 | 59 | > 100,000 | 75 | > 100,000 |
| 4[d] | East Whitetail Jhus Fireline | 12.78 | 31°58'51" | 109°13'24" | 76 | > 100,000 | 90 | > 100,000 | 95 | > 100,000 |
| 5 | East Whitetail at Fireline | 33.68 | 31°59'50" | 109°14'33" | 77 | > 100,000 | 91 | > 100,000 | 95 | > 100,000 |
| 6 | East Whitetail Oak Creek Fireline | 4.61 | 32°01'33" | 109°14'43" | 17 | 20,800 | 35 | 23,800 | 52 | 26,000 |
| 7 | Brushy at Fireline | 8.03 | 32°04'41" | 109°14'19" | 18 | 38,600 | 36 | 44,000 | 52 | 48,000 |
| 8 | Brushy Triangle Canyon | 5.90 | 32°05'12" | 109°14'51" | 7 | 18,800 | 16 | 21,500 | 28 | 23,400 |
| 9 | Wood HUC6 | 36.09 | 32°07'42" | 109°17"41" | 39 | > 100,000 | 62 | > 100,000 | 77 | > 100,000 |
| 10 | Littlewood at Fireline | 2.80 | 32°08'22" | 109°19'14" | 80 | 19,400 | 91 | 22,200 | 96 | 24,300 |
| 11 | Emigrant at Fireline | 30.09 | 32°07'57" | 109°22'11" | 65 | > 100,000 | 84 | > 100,000 | 92 | > 100,000 |
| 12 | Lower Pinery at Fireline | 3.00 | 32°04'08" | 109°22'46" | 30 | 12,600 | 57 | 14,500 | 74 | 15,900 |
| 13 | West Whitetail at Fireline | 11.13 | 32°02'47" | 109°22'50" | 56 | 79,500 | 79 | 91,600 | 89 | 100,000 |
| 14 | Anderson at Fireline | 3.64 | 32°05'40" | 109°24'29" | <1 | 20 | <1 | 23 | 1 | 25 |
| 15 | West Whitetail Bonita Canyon Camp | 11.00 | 32°00'44" | 109°21'18" | 85 | > 100,000 | 95 | > 100,000 | 98 | > 100,000 |
| 16[e] | West Whitetail Bonita Creek Fireline | 28.66 | 32°00'33" | 109°23'33" | 58 | > 100,000 | 80 | > 100,000 | 89 | > 100,000 |
| 17 | West Whitetail Visitor Center | 9.58 | 32°00'20" | 109°21'25" | 63 | 70,100 | 84 | 81,000 | 92 | 88,900 |
| 18[f] | West Whitetail Far Away Ranch | 27.11 | 32°00'33" | 109°22'23" | 67 | > 100,000 | 86 | > 100,000 | 93 | > 100,000 |
| 19[g] | Upper Pinery Hwy 181 | 59.75 | 32°00'14" | 109°24'48" | 74 | > 100,000 | 89 | > 100,000 | 94 | > 100,000 |
| 20[h] | Pine Hwy 181 | 45.14 | 32°00'07" | 109°26'20" | 61 | > 100,000 | 81 | > 100,000 | 90 | > 100,000 |
| 21[i] | Upper Pinery at Fireline | 54.25 | 31°59'15" | 109°23'01" | 4 | 965 | 11 | 1,110 | 20 | 1,220 |
| 22[j] | Pine at Fireline | 36.33 | 31°58'01" | 109°24'05" | 87 | > 100,000 | 95 | > 100,000 | 98 | > 100,000 |
| 23 | Five Mile Fife Canyon | 23.98 | 31°57'32" | 109°26'23" | 83 | > 100,000 | 93 | > 100,000 | 97 | > 100,000 |
| 24[k] | Pine at Green Canyon | 32.68 | 31°57'23" | 109°21'25" | 91 | > 100,000 | 97 | > 100,000 | 99 | > 100,000 |
| 25 | Pine at Methodist Camp | 13.50 | 31°55'53" | 109°19'11" | 94 | > 100,000 | 98 | > 100,000 | 99 | > 100,000 |
| 26[l] | Upper Pinery Grave Stone | 34.35 | 31°58'12" | 109°19'46" | 93 | > 100,000 | 97 | > 100,000 | 99 | > 100,000 |
| 27 | Upper Pinery Canyon Camp | 2.18 | 31°55'59" | 109°16'19" | 98 | 19,600 | 100 | 22,800 | 100 | 25,100 |
| 28 | East Whitetail Jhus Arch Site | 2.73 | 31°57'45" | 109°15'30" | 94 | 22,000 | 98 | 25,500 | 99 | 28,000 |
| 29[m] | Five Mile Hwy 181 | 53.50 | 31°57'04" | 109°28'38" | 52 | > 100,000 | 75 | > 100,000 | 86 | > 100,000 |
| 30 | Five Mile Witch Canyon | 19.23 | 31°56'26" | 109°26'48" | 85 | > 100,000 | 94 | > 100,000 | 97 | > 100,000 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 31[n] | East Turkey Paradise | 17.70 | 31°55'45" | 109°13'11" | 70 | > 100,000 | 88 | > 100,000 | 94 | > 100,000 |
| 32[o] | East Turkey Road 42 | 5.56 | 31°54'34" | 109°15'03" | 83 | 39,600 | 94 | 46,100 | 98 | 50,800 |
| 33 | East Turkey Rustler Station | 0.99 | 31°53'52" | 109°16'25" | 40 | 6,360 | 70 | 7,410 | 85 | 8,170 |
| 34 | Rock at Fireline | 38.58 | 31°53'55" | 109°27'16" | 45 | > 100,000 | 69 | > 100,000 | 82 | > 100,000 |
| 35[p] | Upper Turkey at Fireline | 47.01 | 31°52'05" | 109°23'56" | 62 | > 100,000 | 83 | > 100,000 | 91 | > 100,000 |
| 36[q] | Upper Turkey Creek GS | 27.07 | 31°51'58" | 109°20'51" | 79 | > 100,000 | 92 | > 100,000 | 96 | > 100,000 |
| 37 | Upper Turkey at Sycamore Camp | 11.17 | 31°51'35" | 109°20'04" | 64 | 68,300 | 85 | 79,000 | 93 | 86,700 |
| 38[r] | Cave Sunny Flat Camp | 93.29 | 31°53'05" | 109°10'28" | 53 | > 100,000 | 78 | > 100,000 | 89 | > 100,000 |
| 39[s] | Cave South Fork | 34.89 | 31°52'09" | 109°11'15" | 66 | > 100,000 | 86 | > 100,000 | 93 | > 100,000 |
| 40 | Cave Herb Martyr Camp | 17.02 | 31°52'21" | 109°14'02" | 75 | > 100,000 | 91 | > 100,000 | 96 | > 100,000 |
| 41 | Ash at Cottonwood | 11.32 | 31°51'03" | 109°24'23" | 14 | 44,200 | 32 | 50,800 | 50 | 55,600 |
| 42 | Ash at Standford | 10.27 | 31°48'59" | 109°25'14" | 78 | 96,000 | 91 | > 100,000 | 95 | > 100,000 |
| 43 | Pridham at Fireline | 10.11 | 31°48'20" | 109°25'03" | 72 | 84,900 | 88 | 97,600 | 94 | > 100,000 |
| 44 | John Long at Fireline | 19.40 | 31°46'57" | 109°25'11" | 50 | > 100,000 | 74 | > 100,000 | 86 | > 100,000 |
| 45 | Rucker Forest Camp | 25.50 | 31°47'03" | 109°18'13" | 70 | > 100,000 | 88 | > 100,000 | 94 | > 100,000 |
| 46[t] | Rucker at Fireline | 40.47 | 31°45'55" | 109°19'39" | 68 | > 100,000 | 86 | > 100,000 | 93 | > 100,000 |
| 47[u] | Rucker Camp Rucker | 90.36 | 31°45'27" | 109°22'08" | 43 | > 100,000 | 69 | > 100,000 | 82 | > 100,000 |
| 48 | Sulphur at Fireline | 16.31 | 31°50'27" | 109°07'57" | 92 | > 100,000 | 97 | > 100,000 | 98 | > 100,000 |
| 49 | Horseshoe Road | 21.91 | 31°46'26" | 109°12'50" | 92 | > 100,000 | 97 | > 100,000 | 99 | > 100,000 |
| 50[v] | Horseshoe at Fireline | 70.78 | 31°46'37" | 109°06'60" | 54 | > 100,000 | 75 | > 100,000 | 86 | > 100,000 |
| 51 | Jack Wood at Fireline | 17.63 | 31°43'51" | 109°11'29" | 19 | 80,000 | 39 | 92,000 | 58 | > 100,000 |
| 52[w] | Jack Wood HUC6 Adj | 29.69 | 31°41'55" | 109°08'09" | 4 | 97,300 | 10 | > 100,000 | 18 | > 100,000 |
| 53 | Price Brushy Canyon at Fireline | 6.06 | 31°43'58" | 109°14'03" | 77 | 47,300 | 90 | 54,300 | 95 | 59,500 |
| 54[x] | Price Brushy at Confluence | 34.26 | 31°42'39" | 109°13'46" | 51 | > 100,000 | 74 | > 100,000 | 85 | > 100,000 |
| 55 | Price Canyon at Fireline | 17.83 | 31°44'02" | 109°14'38" | 72 | > 100,000 | 88 | > 100,000 | 94 | > 100,000 |
| 56 | Blind at Fireline B | 1.61 | 31°41'48" | 109°15'32" | 22 | 7,900 | 44 | 9,080 | 62 | 9,930 |
| 57 | Blind at Fireline A | 3.57 | 31°41'11" | 109°16'47" | 93 | 25,800 | 97 | 29,700 | 99 | 32,400 |
| 58 | Tex Arch Site | 17.89 | 31°41'05" | 109°18'43" | 94 | > 100,000 | 98 | > 100,000 | 99 | > 100,000 |
| 59 | Tex at Fireline | 48.87 | 31°40'42" | 109°19'05" | 37 | > 100,000 | 63 | > 100,000 | 78 | > 100,000 |

[a] includes USGS drainage-basin number 48
[b] includes USGS drainage-basin numbers 38, 39, and 40
[c] includes USGS drainage-basin numbers 31, 32, and 33
[d] includes USGS drainage-basin number 28
[e] includes USGS drainage-basin numbers 15, 17, and 18
[f] includes USGS drainage-basin numbers 15 and 17
[g] includes USGS drainage-basin numbers 21, 26, and 27
[h] includes USGS drainage-basin numbers 22, 24, and 25
[i] includes USGS drainage-basin numbers 26 and 27
[j] includes USGS drainage-basin numbers 24 and 25
[k] includes USGS drainage-basin number 25
[l] includes USGS drainage-basin number 27
[m] includes USGS drainage-basin numbers 23 and 30
[n] includes USGS drainage-basin numbers 32 and 33
[o] includes USGS drainage-basin number 33
[p] includes USGS drainage-basin numbers 36 and 37
[q] includes USGS drainage-basin number 37
[r] includes USGS drainage-basin numbers 39 and 40
[s] includes USGS drainage-basin number 40
[t] includes USGS drainage-basin number 45
[u] includes USGS drainage-basin numbers 45 and 46
[v] includes USGS drainage-basin number 49
[w] includes USGS drainage-basin number 51
[x] includes USGS drainage-basin numbers 53 and 55

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:

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

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 from Jennifer Lecker, 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:

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

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 59 evaluated drainage basins was identified by a single outlet (pour point) located at the drainage-basin mouth; however, some basins 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 Horseshoe II 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), 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 (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 probability of debris flows within a larger basin. This allows for rapid evaluation of potential hot spots (locations with potentially high probabilities of large debris flows) within the burned area. 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 were highly variable. Conditions in 14 of the 59 basins resulted in debris-flow probabilities greater than 80 percent in response to the 2-year-recurrence, 30-minute-duration rainfall. Conditions in 35 of the 59 basins resulted in debris-flow probabilities greater than 80 percent in response to the 5-year-recurrence, 30-minute-duration rainfall. Conditions in 45 of the 59 basins resulted in debris-flow probabilities greater than 80 percent in response to the 10-year-recurrence, 30-minute-duration rainfall. Drainage basin 14 showed the lowest probabilities, which were never greater than 1 percent for all rainfall scenarios. Debris-flow probabilities for drainage basins 24–28, 48, 49, 57, and 58 ranged from 91 to 100 percent for the three design rainfalls. 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, 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 20 cubic meters ($m^3$) for drainage basin 14 in response to 2-year, 30-minute rainfall to greater than 100,000 $m^3$ at several drainage basins in response to all three 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.) Larger estimated debris- flow volumes usually were predicted for larger drainage basins except for drainage basin 19, which had the largest estimated volume and is the fifth largest basin (about 55 percent of the size of the largest basin). The upstream area of drainage basin 19 had a combination of steep hillslopes burned at moderate and high burn severities.

Hazardous areas with drainage-basin 7 identified by the continuous parameterization approach are shown on figure 2. The red channel reach that extends upstream from the pour point indicate debris flow probabilities as high as 81–100 percent. Although the probability of a debris flow resulting from the 5-year-recurrence, 30-minute duration rainfall occurring at the pour point of the drainage basin is 36 percent (table 1), the probabilities of a debris flow along this channel reach 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 Horseshoe II wildfire. Estimates were made in response to three design storms: (1) a 2-year-recurrence, 30-minute-duration rainfall (a 50 percent chance of occurrence in any given year), (2) a 5-year-recurrence, 30-minute-duration rainfall (a 20 percent chance of occurrence in any given year), and (3) a 10-year-recurrence, 30-minute-duration rainfall (a 10 percent chance of occurrence in any given year). Larger, less frequent storms than those considered in this study are more likely to produce even 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 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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