Hazard Analysis of Post-Fire Debris-Flow Potential in Arizona

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ABSTRACT

Several large, devastating wildfires occurred in Arizona during the past 2 years, after a 4-year period without any large wildfires. In June, 2010, the human-caused Schultz Fire near Flagstaff burned 6,100 ha of mostly steep terrain. Subsequent rains from the 4th wettest monsoon on record produced numerous debris flows, significant erosion, and substantial flooding of the downslope residential areas. In May and June of 2011, 3 very large human-caused wildfires (Wallow, Horseshoe 2, and Monument Fires) burned over 320,000 ha, posing serious threats to communities below burned slopes. The USGS assisted the Burned Area Emergency Response (BAER) teams, tasked with rapid assessment of damages from wildfires, in predicting the probability of post-fire debris flows from burned basins using models developed for this purpose [Cannon and others, 2010, GSA Bull, 122(1-2), 127-144]. These models, while providing quick results, have not been evaluated for use in Arizona's varied physiographic provinces. Here we use data from the Schultz Fire to compare basin responses with the modeled probabilities from the 3 USGS post-fire debris-flow models (Models A, B and C). Data from the Schultz Fire includes detailed field documentation of debris-flow occurrence and runout distances, 1:12,000 stereo aerial photographs, photogrammetrically derived 1- and 3-m digital elevation models (DEMs), 10-m USGS DEMs and tipping-bucket rainfall data. Hydrologic responses from 48 nested basins burned by the Schultz Fire were assessed for debris or flood flow occurrences. Thirty-four basins produced debris flows during a July 20th storm that had a peak 10-minute intensity of 24 mm. A second storm on August 16th, with a peak 10-minute intensity of 15 mm, produced additional debris flows in 23 of the same basins. Morphometric, soils, and burn severity data from the 48 basins were entered into the 3 USGS models along with average rainfall intensity and storm totals from 5 storms, including the July 20th and August 16th storms. Models A and B predicted a high probability (≥60%) of debris flows in 33 and 53 basins, respectively, for the July 20th and August 16th storms. Data from the other 3 storms resulted in 0 basins from Model A and 4 basins from Model B with a predicted high probability of debris flows. Model C failed to predict debris flows under any of the study storm conditions. Detailed data and documented debris-flow occurrences from the 2010 Schultz Fire provides an opportunity to compare post-fire basin responses in Arizona with predicted responses from the USGS post-fire debris-flow models. This work is continuing with data from the 2011 Wallow, Horseshoe 2 and Monument Fires.

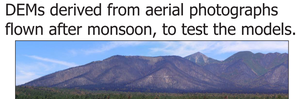
INTRODUCTION

Photos taken on June 20th, 2010, at the beginning of the Schultz Fire by M. Elson, District Ranger, Peaks District, Coconino National Forest.

Burned Area Emergency Response (BAER) teams assess damages to resources and potential hazards to values at risk after a wildfire, and make recommendations for emergency stabilization. Part of this work includes assessing the potential for post-fire debris flows. BAER team geologists on the 2010 Schultz Fire and the 2011 Monument and Horseshoe 2 Fires used evidence of past debris flows, burn severity and topographic information to assess the likelihood of post-fire debris-flows [Coconino National Forest, 2010] (Figure 1). The USGS also assessed areas burned by the 2011 Wallow, Horseshoe 2 and Monument Fires (Figure 1) using a model developed with data from the Intermountain West [Model A, Cannon and others, 2010] to identify burned basins with a high probability for post-fire debris-flows [Ruddy, 2011a, b, c]. Neither Model A, nor the other 2 Intermountain West USGS models (Models B and C), however, have been tested for the varied physiographic provinces of Arizona. To begin testing these 3 models, we used data collected from the 2010 Schultz Fire.

The Schultz Fire was a wind-driven fire burning nearly 60% of the entire burned area within the first 24 hours, mostly at high severity (Figure 2). We documented the occurrence of floods and debris flows from basins within the study area in response to different rainfall events during the 2010 monsoon. We used these data, in addition to detailed precipitation data and high-resolution DEMs derived from aerial photographs flown after monsoon, to test the models.

Figure 1. Location map of the 2010 Schultz Fire and the 2011 Wallow, Horseshoe 2 and Monument Fires.



Burned slopes of the study area. (D. Neary, RMRS)

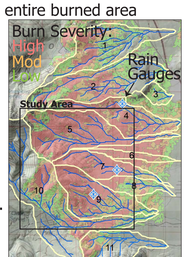


Figure 2. Burn severity map of the Schultz Fire.

POST-FIRE DEBRIS FLOW MODELS

Three post-fire debris-flow models developed by the USGS [Cannon and others, 2010] were tested using Schultz Fire data. The probability of debris-flow occurrence is calculated by: $P = e^x/(1+e^x)$. Three models calculate the variable 'x'.

Model A: $x = -0.7 + 0.03(SG30) - 1.6(R) + 0.06(AB) + 0.02(C) - 0.4(LL) + 0.07(I)$

Model B: $x = -7.6 - 1.1(R) + 0.06(AB) + 0.09(C) - 1.4(OM) + 0.06(I)$

Model C: $x = 4.8 + 0.05(AB) + 0.2(C) - 0.4(LL) - 1.5(HG) + 0.07(I)$

Model Parameters

- SG = %basin area w/slopes ≥ 30%
- R = ruggedness (basin area$^{1/2}$/elev range)
- AB = %basin area burned at high and moderate severity
- C = %clay content
- LL = liquid limit
- OM = %organic matter
- HG = hydrologic group
- I = average storm intensity (mm/hr)

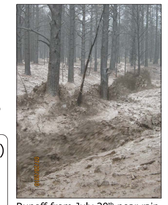
METHODS

Rainfall Data

Three tipping-bucket rain gauges were installed within the burned area (Figs 2, 4-6). Five storms with the shortest duration and highest intensity were selected for model testing (Figure 3, Table 1).

Table 1. Storm Data

Storm	I (mm/hr)	Total (mm)	Duration (hrs)
July 20th	58.0	44.0	0.75
July 22nd	24.2	19.0	0.8
July 27th	4.2	13.0	2.8
August 1st	5.0	20.0	3.3
August 16th	42.8	26.5	0.6



Runoff from July 20th near rain gauge B7 (Figure 4). Photo: A. Stevenson, CNF

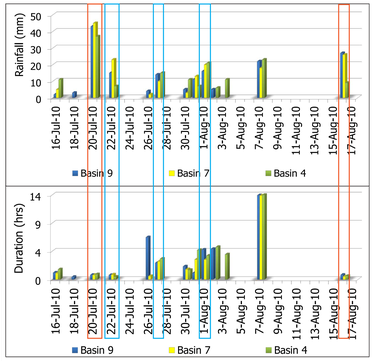


Figure 3. Rainfall storm totals by rain gauge (top) with corresponding storm duration (bottom). Study storms are highlighted; July 20th and August 16th produced debris flows (orange boxes), the July 22nd, July 27th and August 1st storms produced floods and sediment-ladens flows only (blue boxes).

Geomorphic Mapping

Basin responses to rainfall determined by:

- basin & channel conditions after significant storms,
- field-mapped flood & debris-flow deposits,
- photographs & reports from the BAER assessment & implementation teams.

A geomorphic map (Figure 4) based on:

- field data, mapping and ground photos,
- 1:12000 scale aerial photographs (10/2010),
- 1- and 3-m DEMs derived from the air photos (partial coverage of study area).

Basins classified, at outlet, as either:

- flood (blue) - no evidence of debris flows,
- debris (brown) - debris-flow deposits or evidence of a debris-flow transport zone.

Basin condition: post-fire, pre-storm (above), post-storms (below). (#s match trees between photos)

Arrow shows map location.

GIS Analysis

Three sets of nested basins, for a total of 48 basins, were derived based on deposit locations. Model morphometric data were extraced for each basin.

- Mid Basins, (Figure 4, n=9) outlets are located to create the largest hydrologically correct basins possible within the confines of the 10-m DEM, which was inconsistent with on-the-ground channels.
- Upper Basins (Figure 5, n=19) outlets are either at or just below the base of the steep, upper slopes.
- Inner Basins (Figure 6, n=20) outlets are within drainages on the steep, upper slopes.

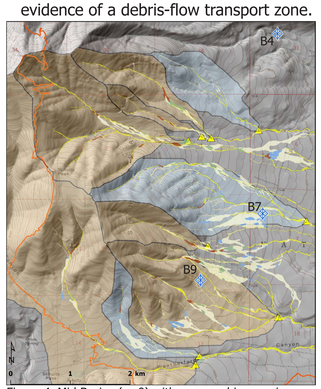


Figure 4. Mid Basins (n=9) with geomorphic mapping. Outlets located for largest hydrologically correct basins.

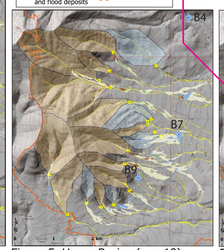


Figure 5. Upper Basins (n = 19) nested within Mid Basins. Outlets based on deposit locations.

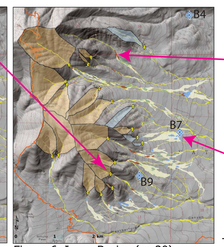


Figure 6. Inner Basins (n=20) nested within Upper Basins. Outlets based on deposit locations.

Top: debris-flow deposits (A. Stevenson, CNF). Bottom: flood deposits (A. Youberg, AZGS). Arrows show locations on map.

Modeling

Models were run for all 5 of the study storms. For each storm, each of the 48 basins were either classified as having a debris flow (1) or no debris flow (0). Thirty-four basins were classified as having debris flows during the July 20th storm; 23 of those basins also had debris flows during the August 16th storm.

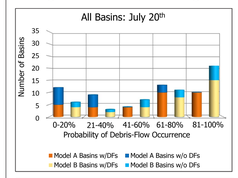
RESULTS

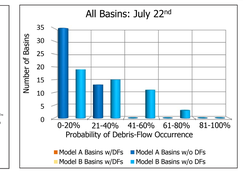
Models A and B predicted a high probability (≥60%) of debris flows under certain storm conditions. Model C did not predict debris flows under any storm conditions (Table 2).

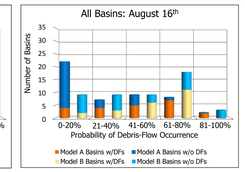
Histograpms plot results by probabilty and model. Top histograms plot all basins for 2 debris-flow storms and for the highest intensity, shortest duration flood storm. Left histograms plot by basin groups (Figs 4-6) for July 20th storm.

Table 2. Model Results

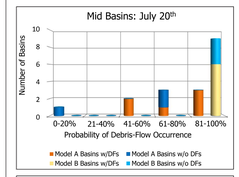
All 48 Basins	Max Predicted Probability of DFs (#basins ≥ 60% for DFs)		
	Model A	Model B	Model C
July 20th	93% (23)	98% (32)	7% (0)
July 22nd	54% (0)	84% (3)	<1% (0)
July 27th	22% (0)	61% (0)	<1% (0)
August 1st	23% (0)	62% (1)	<1% (0)
August 16th	81% (10)	94% (21)	2% (0)





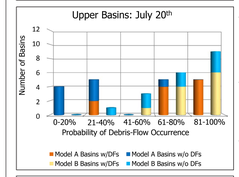


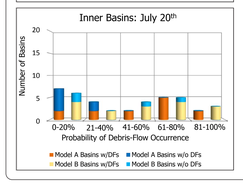
Top graphs from left to right show model results from Models A & B for all basins from 3 different storms (July 20, July 22, August 16). Left graphs from top to botton show model results for the July 20th storm by basin groupings (Figures 4-6.)



To understand the histograms, look at the upper left graph showing predicted results for all basins from the July 20th storm:

- bar height = #basins predicted by each model for a given probability class - For a 0-20% chance of debris flows Model A predicted 12 basins and Model B predicted 6 basins.
- bars are divided based on actual basin response - 5 basins under Model A and 4 basins under Model B actually had debris flows in this storm.





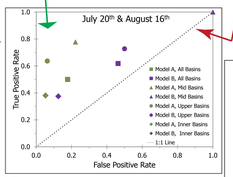
	debris flows	no debris flows
High Prob	True Pos = hi P w/DFs (TPsuccess)	False Pos = hi P w/o DFs (overpredict)
Low Prob	False Neg = lo P w/DFs (under-predict)	True Neg = lo P w/oDFs (TNsuccess)
	∑(#DFs)	∑(#no DFs)

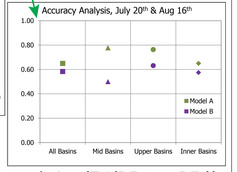
A 2x2 contingency table provides a means to compare successes (model predicts a high probability and debris flows occur) with overprediction (model predicts a high probability but no debris flows occur) [Godt and others, 2008].

Better performing models plot in this region.

Models with random results plot on the 1:1 line.

Perfectly accurate models plot at (0,1).





The True Positive Rate (#TPsuccess/#DFs) plotted against the False Positive Rate (#overprediction/#no DFs) indicates model performance.

Model accuracy = ∑#(TP+TN)successes/sample population (∑#(DFs+no DFs)).

CONCLUSIONS AND ONGOING WORK

Data from the 2010 Schultz Fire were used to begin assessing 3 post-fire debris-flow models for use in Arizona:

- Model A generally performed better than Model B in this environment.
- Model C failed to predict debris flows under any storm conditions.
- Results from both Model A and Model B plot above and to the left of the 1:1 line on the contingency table graph, with the exception of Model B Mid Basins, indicating that these models functioned in this study area.
- Results from basin groupings may indicate potential problems from the Mid and Inner Basin groups.
  - Mid Basins - potential problems may include the low population number (n=9) or issues with the 10-m DEM.
  - Inner Basins - results from Models A and B may indicate a lower basin-size limit for these models.

More work is necessary to determine which factors in the models are most important in Arizona.
Testing will continue with data collected from the 2011 Wallow, Horseshoe 2 and Monument Fires.

ACKNOWLEDGMENTS

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