

Rainfall and Geomorphic Aspects of Post-Fire Soil Erosion – Schultz Fire 2010

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Introduction

The human-caused Schultz Fire near Flagstaff, Arizona burned 6,100 ha (15,075 acres) on the Coconino National Forest between June 20th and 30th, 2010. Ignited by an abandoned campfire, high winds drove the fire over approximately 60% of the total area burned during the first 12 hours (U.S. Forest Service, 2010). The majority of the area burned at moderate (27%) or high (40%) severity across slopes of 30% to over 100%, through forests of ponderosa pine and mixed conifer. Nine of eleven 6th code watersheds were almost completely burned, with areas of high burn severity covering more than 50% in three watersheds and more than 70% in two others. Subsequent rains from the 4th wettest monsoon on record produced numerous floods and debris flows across the burned area and caused extensive damage to downstream communities.

The San Francisco Peaks rise nearly 1,500 m above surrounding alluvial fans. Within the Schultz Fire burn area steep, east-facing mountain slopes are flanked by incised Pleistocene fans. East and downstream of the burn area are unincised, coalescing Holocene alluvial fans that have been heavily modified by residential developments. Prior to the fire, drainages in the burned area generally consisted of low swales located between thickly forested ridges or on broad Pleistocene fan heads. Few channels were well-defined. East of the fan heads, swales transitioned to channels confined several meters below the Pleistocene piedmont surface. Near the eastern forest boundary, flows from the channels emerge onto the unincised Holocene fans.

Rains from the 4th wettest monsoon on record in Flagstaff caused significant erosion across the burn area. The first rainfall occurred on July 16th and produced only flood flows. The second storm, on July 20th, produced debris flows in numerous small, steep sub-basins on the upper mountain slopes. Several more storms produced flood flows interspersed with a second debris-flow producing storm on August 16th. These floods and debris flows eroded former swales into channels up to 4 m deep, and formed rills and gullies on the hillslopes. Erosion from debris flows, floods, rills and gullies removed a substantial amount of soil from the burned area. While debris flows were confined to forest lands, multiple sediment and ash-laden floods caused extensive damage to residential homes, property and infrastructure up to 10 km from the burn, east of the forest boundary.

Objectives

Wildfires can dramatically change the hydrologic responses in burned watersheds, decreasing interception and infiltration, and considerably increasing runoff and erosion (DeBano et al. 1998, Neary et al. 2008). Post-fire sediment-laden flood flows occur more frequently than debris flows, but debris flows can be significantly more destructive than floods. Evaluating the potential for debris flows following a fire is an important aspect of post-fire hazard assessments. Factors affecting the occurrence of debris flows include burn severity, geology, catchment size and gradient, storm characteristics, especially short-duration, high-intensity precipitation, and storm movement through the basin (Cannon et al., 2004; Cannon et al., 2000; Wohl and Pearthree, 1991). The objective of this study is to document the characteristics of the debris-flow producing storms and to assess geomorphic factors that may influence the occurrence of post-fire debris flows in the small, steep upper basins of burned watersheds. The goal is to identify those factors more likely to influence debris-flow occurrence, thus providing better information for assessing post-fire geologic hazards in Arizona.

Methodology

Three ALERT rain gauges were installed in the burn area immediately following the fire. Due to time constraints and access, the gauges were installed along Forest Road 420 (Schultz Pass Road) which is located below the steep mountain slopes. To document the characteristics of debris-flow producing storms raw rainfall data (B. Iserman, written communication) was used to calculate storm total precipitation, duration and intensity, and actual and normalized peak 10-minute intensity. Because the gauges were low in the landscape, radar data capturing storm total estimates on 5-minute intervals were downloaded from the National Climate Data Center (<http://www.ncdc.noaa.gov/oa/ncdc.html>) and compared with the raw rainfall data.

Hydrologic responses of 30 small, steep upper sub-basins, located within five 6th code watersheds, were documented in the field based on deposit characteristics. The field work consisted of four north-south transects across the burned 6th code watersheds and west-east traverses in the main channels of three of those watersheds. Deposit characteristics were used to determine the occurrence of debris flows or flood flows, and to document the downstream extent of debris flows.

Channel profiles and basin morphology were derived for 30 small, steep upper sub-basins, where debris flows and floods were generated, using GIS software, tools and methods (Figure 1). Basin outlets were identified using channel profile gradient changes, field observations, location of deposits, and analysis of aerial photographs flown in October, 2010, at a scale of 1:12,000. Basins were classified based on evidence of the occurrence of debris flows or flood flows. All debris-flow basins (Figure 1, orange basins) also had flood flows, but basins classified as flood (Figure 1, blue basins) only experienced flood flows. Spatial analyses were conducted to determine proportional areas of burn severity in each basin.

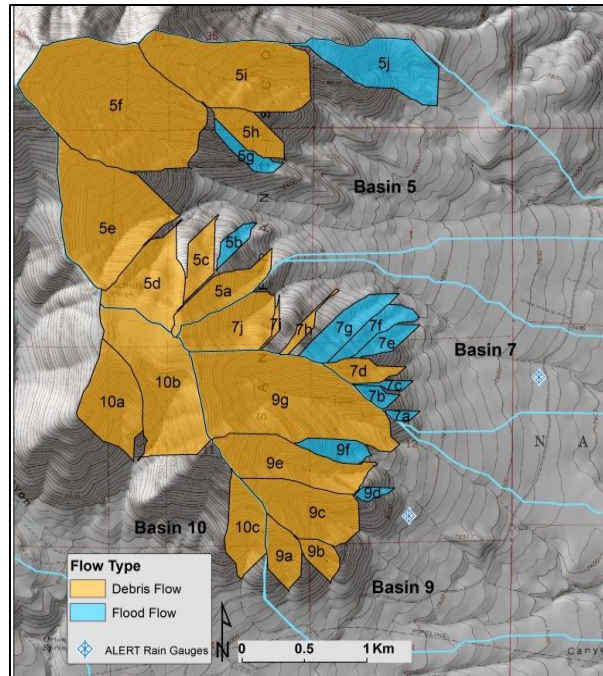


Figure 1. Small, steep basins mapped according to flow types. Basins with evidence of debris flows, along with floods, are in orange. Basins with evidence of only flood flows are in blue. Yellow dots represent locations of basin outlets.

Results and Conclusions

The Shultz Fire was followed by rains from the 4th wettest monsoon on record in Flagstaff. The largest storm occurred on 20 July and produced 45 mm of rain in 45 minutes, with a peak 10-minute intensity of 24 mm (Table 1). This short duration, high-intensity precipitation event produced debris flows from 19 small, steep sub-basins on the upper mountain slopes. Floods and debris flows eroded former swales into channels up to 4 m deep. Rills and gullies formed on the hillslopes. A second high-intensity storm on 16 August delivered 27 mm of rain in 46 minutes, with a peak 10-minute intensity of 15 mm, producing more debris flows in the same basins. Radar data was assessed and found to be close to precipitation totals based on the raw rainfall data, thus indicating that it is reasonable to use the gauge data for debris-flow initiation analyses.

Table 1. Rainfall, duration and intensity data for two debris-flow producing storms.

Date	Basin	Storm Duration	Storm Total (mm)	Return Interval (Range)	Normalized 10-min Peak Intensity (mm/hr)	Actual 10-min Peak Intensity (mm/10min)	Time into storm when peak occurred	Return Interval (Range)
7/20/2010	Basin 4	0:52:13	37	10 (5-25)	90	0.59	22:53	5 (2-5)
7/20/2010	Basin 7	0:45:36	45	25 (10-50)	132	0.87	11:08	25 (10-50)
7/20/2010	Basin 9	0:45:26	43	10 (10-50)	144	0.94	12:43	50 (25-100)
8/16/2010	Basin 4	0:35:23	9	<1	12	0.08	10:28	<1
8/16/2010	Basin 7	0:30:42	26	5 (5-10)	84	0.55	10:01	5 (2-10)
8/16/2010	Basin 9	0:46:41	27	5 (2-10)	90	0.59	16:38	5 (2-10)

Rainfall data from these storms were compared to published rainfall data that generated debris flows following two wildfires in southwestern Colorado, the Missionary Ridge and Coal Seam Fires (Cannon et al., 2008). Storm totals between the three fires were consistent, however storm intensity and normalized peak 10-minute intensity were higher from the Schultz Fire than from either the Missionary Ridge Fire or the Coal Seam Fire (Cannon and others, 2008). Data from the southwestern Colorado fires illustrate that post-fire debris flows can be produced from high-frequency, low-magnitude storms, thus it is not surprising that a less-frequent, higher magnitude storm with higher storm and peak intensities produced debris flows.

Flows in 30 sub-basins were classified as either producing post-fire debris flows, in addition to floods, or flood flows only. Nineteen of the 30 sub-basins were completely burned (100%), while total burned areas in the other 11 basins ranged from 88% to 99%. The percent of the basins burned at high severity ranged from 37-100%; three basins were completely burned at high severity. The basin with the lowest percent area burned (57%) produced debris flows while one basin that was completely burned (100%) produced only flood flows. Research indicates that the percent of a basin burned at moderate to high severity on slopes $\geq 30\%$ is a key factor for the generation of post-fire debris flows (Cannon and others, 2010). These data do not indicate a difference between flood-flow and debris-flow basins when considering percent slopes $\geq 30\%$ burned at moderate to high severity. There is a difference, however, between flood-flow and debris-flow producing basins when considering percent slopes $\geq 50\%$ burned at moderate to high severity.

Watershed area for flood-flow basins ranged from 0.02-0.34 km^2 with an average area of 0.08 km^2 (Figure 2). Debris-flow basin areas ranged from 0.01-1.11 km^2 with an average area of 0.34 km^2 (Figure 2). A student's t-test of the log of basin areas for debris flows and floods indicates the populations are statistically different. Mean basin slopes varied from 35-52% with an average of 45% for flood-flow basins, while debris-flow basins varied from 42-64% with an average of 57%. The average channel slope ranged from 25-44% with an average of 34% for flood-flow basins, and 26-48% with an average of 38% for debris-flow basins. Although there is substantial overlap in many of the morphologic characteristics of these basins, the debris-flow producing basins were generally larger and steeper than the flood-flow only basins.

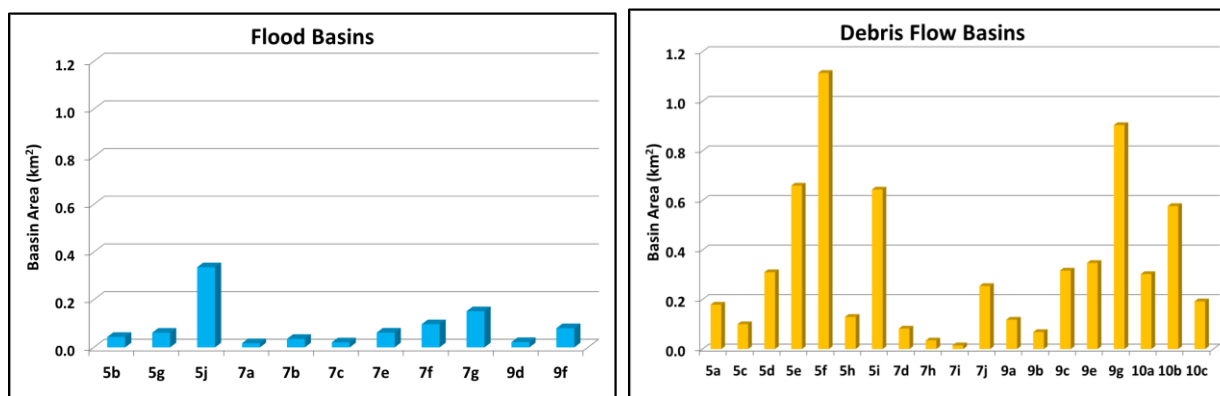


Figure 2. Plots of drainage area for sub-basins producing only flood flows (left, blue) and debris flows (right, orange).

Changes to watershed soils and hydrologic characteristics can be quite dramatic following a wildfire. The Schultz Fire was a high-impact fire dominated by moderate to high burn severity across steep, densely forested slopes that were completely, or nearly completely, burned. In Arizona, the wildfire season is immediately followed by monsoon precipitation. Short-duration, high-intensity rainfall on severely burned basins can result in a dramatic amount of geomorphic work and landscape changes in a short period of time. In the Schultz Fire burn area 19 of 30 sub-basins had post-fire debris flows following a low-frequency, short-duration, high-intensity rainfall. Several of these basins had additional debris flows following a second short-duration, high-intensity rainfall. Basin morphometric factors that may have influenced debris-flow generation within the Schultz Fire burn area include percent of slopes $\geq 50\%$ burned at moderate to high severity, basin area and gradient. Work continues to identify those factors more likely to influence debris-flow occurrence, thus providing better information for assessing post-fire geologic hazards in Arizona.

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