



Geomorphic aspects of post-fire soil erosion – Schultz Fire 2010

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Introduction

The summer of 2010 brought wildfires and near record monsoon rains to northern Arizona, USA, which generated debris flows and floods that caused extensive damage. The human-caused Schultz Fire on the Coconino National Forest northeast of Flagstaff was the largest wildfire in Arizona during 2010, burning 6,100 ha between June 20th and 30th. 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 11 watersheds were almost completely burned, with areas of high burn severity covering more than 50% in 3 watersheds and more than 70% in 2 others.

The San Francisco Peaks are a remnant stratovolcano that rises nearly 1,500 m above the alluvial fans that surround it. Within the burned area, geomorphic zones include east-facing, steep, upper mountain slopes flanked by incised Pleistocene fan deposits of the upper piedmont. Immediately east of the burned area, unincised, coalescing Holocene alluvial fans have been heavily modified by residential developments. Prior to the fire, only a few well-defined channels existed on the steep mountain slopes and upper piedmont. Many drainages in these areas consisted of low swales located between thickly forested ridges or on broad Pleistocene fan heads. Gravel soils, derived from mixed igneous rocks and cinders, were quite permeable with high infiltration rates (51-152 mm hr⁻¹) under pre-fire conditions (U.S. Forest Service, 2010). 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 with residential developments. Upper mountain slopes are the source for high-energy water, coarse sediments, and woody material. Ephemeral swales and channels on the steep mountain basin have slopes that can exceed 30%, while well-defined ephemeral lower-piedmont channels slope up to 5-7%.

In this region, summer thunderstorms tend to develop preferentially over mountains due to orographic lifting. The Schultz 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. This short duration, high-intensity precipitation event produced debris flows from numerous small, steep 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 removing the O horizon (10-30 cm). 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. Numerous other storms from July through October produced sediment-laden flood flows. 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 infiltration and runoff responses in soils, especially on steep slopes (DeBano et al. 1998, Neary et al. 2008), significantly increasing runoff and erosion. 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 assess factors affecting the occurrence of post-fire debris flows in the small, steep upper basins of the burned watersheds in order to identify those factors more likely to influence debris-flow occurrence, thus providing better information for assessing post-fire geologic hazards in Arizona.

Methodology

There were two components to this work; a field study and a GIS analysis. The field study, focused on the southern half of the fire, consisted of four north-south transects across five burned 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 28 small, steep upper 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, and to assess the influence of the different soils in each basin. Soils data were extracted from the GIS-based Terrestrial Ecosystem Survey (TES; <http://alic.arid.arizona.edu/tes/units.asp>) mapped by the Coconino National Forest. TES map units are delineated based on soils, landscape position and vegetation.

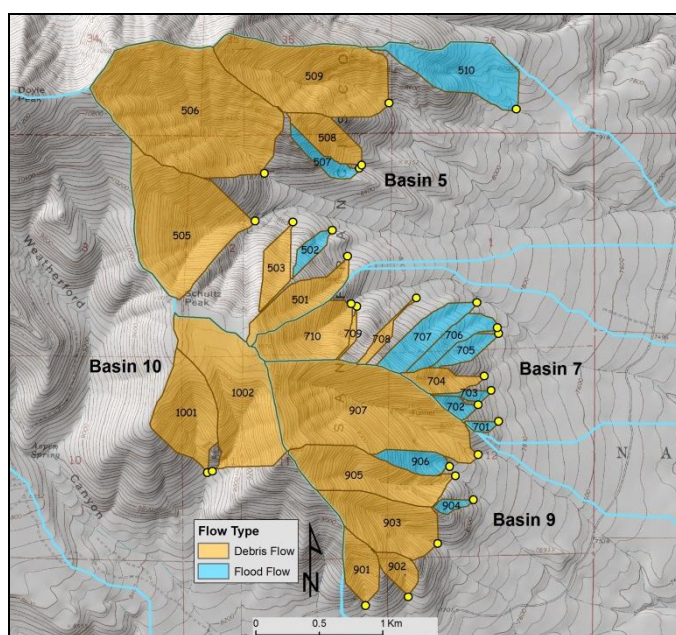


Figure 1. Small, steep basins mapped according to flow types. Basins with evidence of debris flows, along with floods, are in orange. Basins with evidence of only flood flows are in blue. Yellow dots represent locations of basin outlets.

Results and Conclusions

Flows in 28 basins were classified as producing post-fire debris flows, debris flows in addition to floods, or flood flows only. Seventeen of 28 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 produced debris flows while one basin that was completely burned (100%) produced only flood flows.

Watershed area for flood-flow basins ranged from 0.02-0.34 km² with an average area of 0.08 km². Debris-flow basin areas ranged from 0.01-1.11 km² with an average area of 0.34 km². 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.

Three TES map units (613, 785, and 790) composed the majority of the soils within the basins. The soils are well-graded gravels (GW) to silty, sandy gravels (GM) derived from mixed igneous rocks and cinders. These soils were quite permeable with high infiltration rates under pre-fire conditions. Erosion hazards for these three units are classified as severe. Mass wasting hazards are classified as moderate to severe. Soil losses due to sheet and rill erosion are estimated at 3 to 13 Mg ha⁻¹ yr⁻¹ under pre-fire conditions (<http://alic.arid.arizona.edu/tes/units.asp>). Under post-disturbance conditions these rates are expected to increase 8-19 times, with estimates ranging from 52 to 97 Mg ha⁻¹ yr⁻¹. TES unit 613 has the largest post-disturbance soil loss estimates of the 3 units. Soils from this unit covers the majority of mid to lower hillslopes for all basins, and entire hillslopes for 5 of 11 flood-flow basins and 3 of 17 debris-flow basins. TES units 785 and 790 are more limited in extent and compose soils in the headwaters and upper slopes of only a



few basins. Unit 785 is found in 3 flood-flow and 10 debris-flow basins, while unit 790 is found only in 3 debris-flow basins. Although the characteristics between these map units vary somewhat, and all are composed of highly erodible soils in a post-disturbance environment, post-fire debris flows tend to initiate high in channels and close to ridge tops. It is likely that TES units 785 and 790 played a larger role in debris-flow generation than TES unit 613, however additional analysis is required to understand this relationship. 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. A significant amount of soil was removed from the hillslopes and channels within the Schultz Fire burn area during the 2010 monsoon, and elevated sediment delivery and movement is likely to continue for several years. Research will continue on the Schulz Fire to document landscape changes and ecosystem recovery.

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