



Depositional characteristics of post-fire flooding following the Schultz Fire, San Francisco Peaks, Arizona

Karen A. Koestner^{a*}, Mike D. Carroll^b, Daniel G. Neary^a, Peter E. Koestner^c, Ann Youberg^d

^a USDA Forest Service, Rocky Mountain Research Station, 2500 Pine Knoll Drive, Flagstaff, AZ 86001(USA);

^b USDA Forest Service, Okanogan-Wenatchee National Forest, Naches Ranger District, 10237 Hwy 12, Naches, WA 98937 (USA);

^c USDA Forest Service, Rocky Mountain Research Station, Tonto National Forest, Phoenix, AZ 85006 (USA);

^d Arizona Geological Survey, 416 W Congress Street, Suite 100, Tucson, AZ 85701 (USA).
*kkoestner@fs.fed.us

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Introduction

During the summer of 2010 the northern Arizona mountain town of Flagstaff experienced three fires all blazing the same week in late-June, the height of the fire season for this region. By July 1st, all three were extinguished, but that was only the first phase of disturbance. The largest and most detrimental of these fires was the Schultz Fire. From June 20th to July 30th 2010, the Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks, a dormant Middle Pliocene to Holocene aged stratovolcano (Figure 1). This was a wind driven fire, consuming approximately 60% of the total burn area in the first day. Ponderosa pine and mixed conifer forest on steep to moderate slopes of the mountain front and upper piedmont zone of 11 watersheds were impacted.

The US Forest Service Remote Sensing Application Center (RSAC) estimated the burn severity of the Schultz Fire using Burned Area Reflectance Classification (BARC). The BARC process combines Normalized Burn Ratio (NBR) data derived from Landsat satellite imagery with National Land Cover Database vegetation layers to accurately estimate burn severity across different vegetation types within the burn (Hudak et al. 2004). 70% of the Schultz Fire was classified as high to moderate severity, while 25% was classified as low severity, and another 8% was unburned. The high severity burned areas are concentrated on the steep mountain face with slopes greater than 30% and in places exceeding 100% (USDA Forest Service 2010).

Prior to the fire and subsequent flooding, the upper mountain had few defined channels consisting largely of ridge-swale topography with thick mixed-conifer forest cover and a well-developed O horizon (10-30 cm). These swales become more defined channels in the ponderosa pine-dominated piedmont zone. Prior to the fire they rarely carried flows. The slope varies from 60 to >100% on the upper mountain face to 30 to 60% in the piedmont zone and to 5 to 7% at the head of the alluvial fans. Scattered housing developments, most of which are less than 40 years old, occupy the fans.

The onset of summer monsoon precipitation in mid-July 2010, the 4th wettest on record, resulted in debris deposition on the alluvial fan with a series of discrete flood events over the following 6-weeks of summer precipitation. Over 1000 residents in this area were evacuated from their homes during the fire itself and several hundred experienced damages to property due to repeated flooding.

Post-fire debris flows scoured the swales on the upper slopes of most watersheds 1-4 m to expose bedrock channels. Well-defined channels in the piedmont zone were

simultaneously filled with coarse material from debris flows and flood-flow bedloads in less confined reaches, and incised over a meter beneath the previous channel surface in confined reaches. The piedmont channels coalesce and diverge on an alluvial fan surface that was constantly being reworked by multiple flood events. As defined channels emerge onto fan heads, flood flows fan out into sheet flows across the alluvial fans, passing through Coconino National Forest lands and several residential developments.

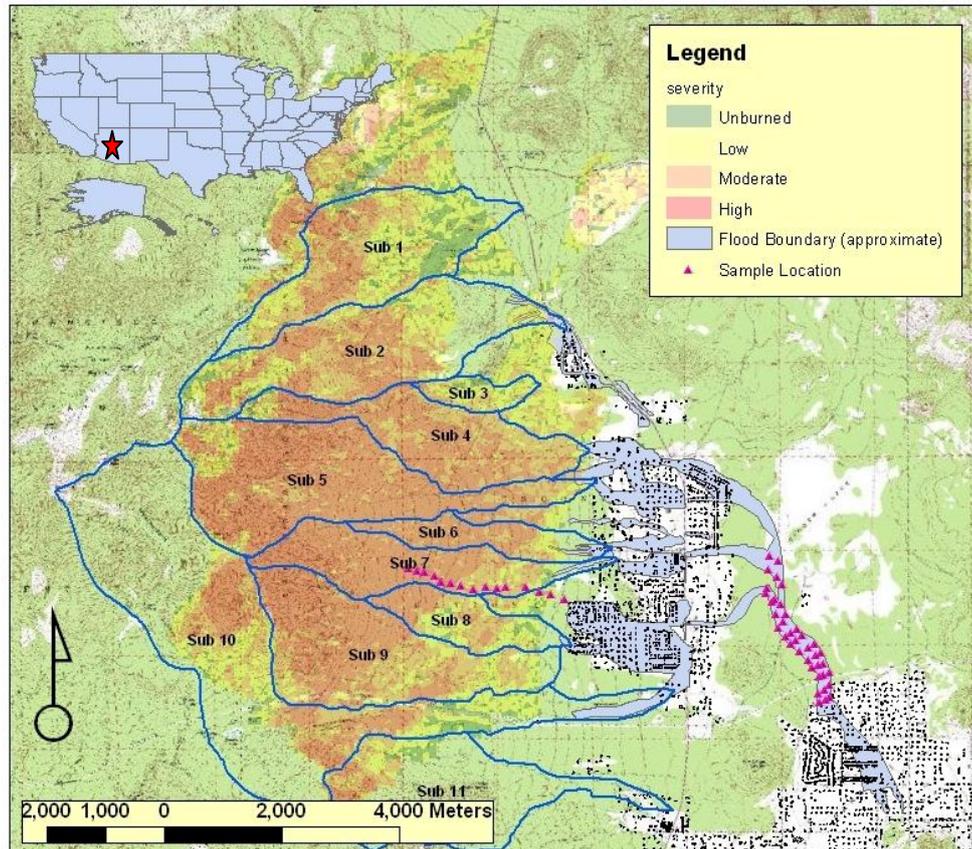


Figure 1. Schultz Fire boundaries with severity classification, watershed delineation, post-fire flood flow boundaries, and sediment sample locations.

Objectives

The intent of this study is to examine the hydrologic and depositional processes from the piedmont zone, across the alluvial fan, to the outwash plain by determining the variability in grain size. Data from the steep channels of the mountain front are excluded from this analysis because currently these steep channels are predominantly erosive supplying the material that is deposited below. The purpose of this research is to better inform land and civic managers of long-term impacts from post-fire sedimentation and depositional processes, and to assist efforts managing post-fire flows and recovery.

Methodology

The depositional characteristics of post-Schultz Fire flooding were evaluated by sampling sediments across landscape features to capture variability in grain size of material transported by the flows. Sampling techniques were based on landscape position within two primary zones: the confined channels of the piedmont zone, and the outwash plain of the depositional fan where flood-impacted developments are situated. Though there were widespread debris flows resulting from two high-intensity rainfall events on the 20th of



July and the 16th of August, the sampling of grain size described herein is of material that was transported by hyperconcentrated flood flows and fluvial processes (Pierson and Costa 1987).

Study Area Selection: Due to the extensive coverage of post-fire flooding from eleven watersheds across the eastern slopes of the San Francisco Peaks, one watershed was selected for initial study. Basin 7 (Figure 1), was sampled to determine sediment characteristics and availability for future transport in the piedmont zone. This watershed was chosen because it had direct impact on the developments downstream of the burn area. It is one of the smaller basins within the burn area (4th of 11), facilitating comprehensive sampling coverage in limited time. The entire basin was surveyed but the focus of this analysis is from the piedmont zone downstream. Basin 7 also ranks high (2nd of 11) in the percentage of high-severity burn, and has had debris flows in every tributary, providing ample sediment source for fluvial transport. Basin selection was also based on the availability of post-fire precipitation data due to the placement of two emergency rain gauges in the watershed.

The second landscape zone sampled was the depositional fan across the flood area between several developments that were inundated (Figure 1). Sampling was restricted to public lands to limit disturbance of flood deposits from human activities (e.g. the removal or reorganization of material), and the ability to determine what was indeed a recent flood deposit.

Sampling & Analytical Procedures: Sediment samples within the piedmont channel of Basin 7 were taken at randomly selected cross-section locations. The data from ten cross-section locations presented here (Figure 1) consist of samples collected downstream of the 2316.5 m (7600ft) topographic contour line. This contour was selected as the piedmont threshold because the slope becomes gradual, grading into the depositional fan. At each cross-section location the depth of the recently disturbed layer (flood deposited material) was determined at the channel thalweg and a sediment sample was taken. The depth of the flood deposit and the associated sediment sample were determined by excavating the channel bed until small intact tree roots (<1mm diameter) were present, indicating the boundary of the flood deposit and the preexisting material. At each cross-section location 1-2 sediment samples were taken.

Sheet flow flood deposits on the fan were sampled along twelve randomly selected transects situated perpendicular to the direction of flow (Figure 1). On each transect 3-4 points across the flood deposit were sampled at undisturbed locations. The depth of the fresh deposit was measured down to the previous ground surface, as indicated by the presence of cinders and organic matter, and a sediment sample was taken.

Sediment samples from within the channel of the piedmont zone and from the sheet flow deposits on the fan were all analyzed for grain size using sieve analysis. Eleven sieves were used with screen sizes ranging from 50.8 to 0.074 mm. Samples were shaken for 15 min to sort grain sizes and the mass of residual sediment in each screen taken.

Results and conclusions

Grain size analysis of samples taken from post-fire flood deposits in the piedmont zone of Basin 7, and the alluvial surface and outwash plain between downstream housing developments indicate a reduction in particle diameter from coarse cobble and gravel to fine sands and clay. At the transition between the piedmont zone and the head of the alluvial fan the slope is 5 to 7%. On the alluvial fan the slope lessens to 2 to 4%, and



decreases further in the outwash plain to less than 2%. Channel confinement also decreases with slope. There are no channels extending from the alluvial fan to the outwash plain. The decrease in slope and lack of confinement caused flow velocity to drop off substantially driving differential deposition between landscape features. Extensive deposition of fine sediments on the toe of the fan and outwash plain created an impermeable layer on the alluvial surface easily observed before, during and after flood events. The scouring of channels on the mountain face and piedmont zone paired with fine grained deposition in the outwash plain has effectively reduced infiltration.

The burnt slopes of the San Francisco Peaks lost a substantial amount of material during the 2010 monsoon season following the Schultz Fire. Debris flows scoured material from the channel beds of several watersheds across the burn area supplying coarse sediments to the piedmont channels below. Hillslope erosion, facilitated by rill and gully formation across the landscape, supplied fine sediments and ash to form hyperconcentrated flows. Initial flood events of hyperconcentrated flow transported fine grained sediments and ash across the alluvial fan and outwash plain effectively sealing the previous surface of cinders. Surface flood deposits of fine sediments across the 750+ ha flood area of the alluvial fan and outwash plain, along with the scoured channels of the basins above caused secondary flood events to respond more quickly with increased sensitivity to precipitation.

The effects of fire on hydrologic response is well documented in DeBano et al. (1998) and Neary et al. (2008). The hydrologic impacts of the Schultz Fire will likely continue for several years, though it is unlikely flooding will be as extensive and detrimental as witnessed during the monsoon season of 2010. This is due to several actions taken by local land managers and civic planners to mitigate the effects of post-fire watershed response on the residents in the flood path. Continued research is needed to understand the efficacy of these mitigation efforts and the landscape changes during the post-fire recovery. Across the alluvial fan and outwash plain, research is needed on the depositional history of the basin by coring sample locations where surface properties have been described and dating samples when possible.

References

- DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. *Fire's effects on ecosystems*. New York, NY: John Wiley and Sons. 333 p.
- Hudak, A.T.; Robichaud, P.R.; Evans, J.B.; Clark, J.; Lannom, K.; Morgan, P.; Stone, C. 2004. *Field validation of Burned Area Reflectance Classification (BARC) products for post fire assessment*. In: Remote Sensing for Field Users, Proceedings of the Tenth Forest Service Remote Sensing Applications Conference, Salt Lake City, Utah, April 5-9, 2004. 13 p.
- Neary, D.G.; Ryan, K.C.; DeBano, L.F. 2005. (Revised 2008). *Wildland Fire in Ecosystems: Fire effects on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO.
- Pierson, T.C.; Costa, J.E. 1987. *A rheological classification of subaerial sediment-water flows*. In: J.E. Costa, J.E.; Wieczorek, G.F. Editors. Debris Flows/Avalanches: Process, Recognition, and Mitigation, Reviews in Engineering Geology **vol. VII**, Geological Society of America, Boulder, CO (1987), pp. 1–12.
- USDA Forest Service. 2010. *Burned Area Emergency Response Report, July 8, 2010*. Coconino National Forest, Flagstaff, Arizona. 167 p.