Rill and Gully Formation Following the 2010 Schultz Fire

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Abstract: The Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks across moderate to very steep ponderosa pine and mixed conifer watersheds. There was widespread occurrence of high severity fire, with several watersheds classified as over 50% high severity. This resulted in moderate to severe water repellency in most soils, especially those on steep slopes. Prior to the fire there were no rills or gullies as the soil was protected by a thick O horizon. This protective organic layer was consumed leaving the soil exposed to raindrop impact and erosion. A series of flood events beginning in mid-July 2010 initiated erosion from the upper slopes of the watersheds. Substantial amounts of soil was eroded from hillslopes via a newly formed rill and gully system, removing the A horizon and much of the B horizon. The development of an extensive rill and gully network fundamentally changed the hydrologic response of the upper portions of every catchment. The intense, short duration rainfall of the 2010 monsoon interacted with slope, water repellency and extensive areas of bare soil to produce flood flows an order of magnitude in excess of flows produced by similar pre-fire rainfall events. Rill networks now cover much of the upper slopes and gullies are cutting to bedrock. Sediment delivery to the channel systems is likely to continue unabated for many years and hydrologic response will continue to be flashy.

INTRODUCTION

The Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks, a dormant Middle Pliocene to Holocene aged stratovolcano in northern Arizona (Figure 1). The fire burned in the Coconino National Forest between June 20th and 30th, 2010, across moderate to very steep ponderosa pine and mixed conifer watersheds (Neary et al. 2011, Youberg et al. 2011). About 40% of the fire area was classified as high-severity, mostly on mountain slopes greater than 30% and in places exceeding 100%. The upper slopes rise to over 3,300 m and are the source for high energy water, coarse sediments, and woody material. A steep gradient of nearly 1,000 m exists from the upper slopes to the base of the lower fans. Summer thunderstorms tend to develop over the mountain due to orographic lifting. Over the course of an active 2010 Monsoon, ranking the fourth highest in rainfall on record, the burned area received numerous precipitation events. The largest event occurred on July 20th, 2010, and was characterized by a peak rainfall (Peak I_{10}) of 24 mm in ten minutes, with a normalized Peak I_{10} of 144 mm hr^{-1}. This rainfall resulted in numerous debris flows, historic floods and substantial hillslope erosion. Flood flows were one to two orders of magnitude larger than those produced by similar pre-fire rainfall events. Another precipitation event on August 16th re-initiated debris flows from the July 20th storm. The Peak I_{10} was less at 15 mm. and the normalized Peak I_{10} was 90 mm hr^{-1}.

Figure 1. Schultz Fire burned area on the east flank of the San Francisco Peaks, July 2010.

OBJECTIVES

The upper slopes of the San Francisco Peak have gradients range from 60 to >100%. These areas developed unprecedented erosion after the intense July 20th storm. The objective of this study was to evaluate the extent and degree of new rill and gully formation, reactivation of old gullies, and how this network contributes to the substantially altered hydrologic response of the upper mountain slopes.

METHODOLOGY

New rill and gully formation were assessed along the Waterline Road using visual and photographic surveys. Long-term measurements are being done by on-the-ground measurements, terrestrial LIDAR, and repeat aerial photography. The first set of photos was taken on October, 27, 2010, at a scale of 1:12,000 by Kenney Aerial Mapping, Phoenix, Arizona. Repeat photography will be done in late September of each year to follow.

RESULTS

Substantial amounts of soil were eroded out of a newly developed rill and gully system, removing the A horizon and much of the B horizon. Prior to the fire there was a minimal presence of rills or gullies as the soil was protected by a thick O horizon. This protective organic layer burned off during the fire leaving the soil exposed to raindrop impact and erosion. There was widespread occurrence of high severity fire, with some watersheds classified as 70% high severity wildfire. This left most of the soils with moderate to severe water repellency, so surface runoff was extensive. Peakflows from the July 20th storm contained high concentrations of ash and topsoil material. Mineral soil loss is estimated to be >10 cm on 2,000 ha of the upper watersheds.

The development of an extensive rill and gully network fundamentally changed the hydrologic response of the upper portions of every catchment (Figure 2). Rills are self-organizing erosion systems characterized by numerous and randomly occurring small channels of only several centimeters in depth and centimeters to tens of meters long. Sediment yields increase with increasing slope, rill spacing decreases as slope angle increases, rill patterns show an increased

Figure 2. Large rill systems developing on a steep slope (right) and small gully development beginning (left). Schultz Fire, 2010, above the Waterline Road, Coconino National Forest, USA.

elongation and parallelism on steeper slopes, and hillslope rills tend to be evenly spaced on bare, straight slopes (Favis-Mortlock et al. 2000). Rills on the upper slopes of the San Francisco Peaks within the Schultz Fire perimeter are now 10-20 cm deep into the B and C horizons running the entire length of slopes. Parallel rills in the right photo of Figure 2 demonstrate the transition from sheet erosion to rill erosion. The rills are 30 to 40 cm apart crossing entire slopes. They are up to 5 cm deep and beginning to coalesce. The rills shown on the left are transitioning to small gullies 20 to 30 cm deep. They are cutting below the ponderosa pine surface root systems and into fragmented and weathered C horizon andesite and dacite.

Small lateral gullies that are 50 to 100 cm deep (Figure 3) merge into now deeply incised main drainage gullies (3 to 5 m deep) that occupy previous swales in the upper mountain slopes (Figure 4). Despite the elevation and precipitation regime there are no perennial stream channels. Flood flows in July and August of 2010 incised deeply into the slopes consisting of volcanic colluvial material and ash and tephra deposits. In many places the gullies have cut down to bedrock, thus

Figure 3. Rapidly deepening gullies on the upper mountain slopes of the San Francisco Peaks within the high-severity portion of the Schultz Fire of 2010.

allowing subsequent flood flows to scour out fresh, un-weathered material. The pre-fire slope surface was about 1 m above the individual on the left in Figure 4. The deep incisions of these main drainage gullies has lowered the base level of the smaller lateral gullies, leading to additional headward cutting of the gully system.

Wildfires often produce severe watershed impacts, especially in steep terrain (DeBano et al. 1998, Neary et al. 2008). Interruption of watershed processes results in significantly increased runoff (Ice et al. 2004). The intense, short duration rainfall of the 2010 Monsoon in northern Arizona interacted with slope, water repellency and extensive areas of bare soil to produce flood flows orders of magnitude in excess of flows produced by similar pre-fire rainfall events. These events eroded significant amounts of soil and led to the development of large rill and gully networks. The networks now cover much of the upper mountain. Sediment delivery to the channels is likely to taper off after 3 -5 years, but could increase due and future slope failures.
Crown-replacing wildfires like the Schultz Fire of 2010 have major impacts on the forest ecosystem and hydrology of the Mogollon Rim and the people that inhabit the region. Research will continue on the Schultz Fire for many years to document changes in the landscape and post-fire ecosystem recovery.

Figure 4. Deeply incised (3 m) main drainage gully within the Schultz Fire along the Waterline Road, Coconino National Forest, Arizona.

Over the 2010-2011winter, many of the distinct rills were muted by snowfall and freeze-thaw conditions. However they have been re-established by 2011 Monsoon rains. Gullys continued to down-cut and new ones have been emerging. A study by Carroll (2011) indicated that large amounts of sediment eroded from the upper watersheds in the Schultz Fire remain in the channel systems. Carroll (2011) estimated that in the Rope-Arabian-Campbell drainage alone over 15,500 m^3 of sediment were deposited in 2010. Several other channel systems have been identified for evaluation in 2011 to extend the database on sediment.

SUMMARY AND CONCLUSIONS

The Schultz Fire of 2010 burned over 6,100 ha on the east flank of the San Francisco Peaks. High severity fire in the upper portions of watersheds within the fire perimeter produced conditions which led to extensive rill and gully erosion during the 2010 Monsoon. Extensive rill systems now occupy steep slopes previously covered with a deep litter horizon. The rill and gully system has fundamentally altered the hydrology of the upper watersheds, greatly decreasing time to peak runoff and significantly increasing stormflow. Drainages and gullys have down-cut 3 to 5 m in some locations. Although sediment delivery to the channels is likely to taper off after 3 -5 years, it could increase due to subsequent storm events and future slope failures. Future Monsoon conditions and rainfall intensities in the upper watersheds will dictate the magnitude of future erosion and flood-producing runoff.

REFERENCES

Carroll, M.D. 2011. *Movement of channel borne sediments in the 2010 Schultz Fire burn area*. M.S. Thesis, College of Engineering, Forestry, and Natural Sciences, Northern Arizona University, Flagstaff, Arizona, 53 p.

DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. *Fire's effects on ecosystems.* John Wiley & Sons, New York. 333 p.

Favis-Mortlock, D.T.; Boardman, J.; Parsons, A.J.; Lascelles, B. 2000. *Emergence and erosion: a model for rill initiation and development*. Hydrological Processes 14**:** 2173–2205.

Ice, G.G.; Neary, D.G.; Adams, P.W. 2004. *Effects of wildfire on soils and watershed processes.* Journal of Forestry 102:16-20.

Neary, D.G.; Ryan, K.C.; DeBano, L.F. (Editors) 2005 (Revised 2008). *Fire effects on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO. 250 p.

Neary, D.G.; Koestner, K.A.; Youberg, A.; Koestner, P.E. 2011. Post-fire rill and gully formation, Schultz Fire 2010, Arizona, USA. Proceedings of FESP III International Meeting on Fire Effects on Soil Properties, March 15-19, 2011, NIGP – University of Minho, Guimarães, Portugal. Pp. 60-63.

Youberg, A.; Koestner, K.A.; Neary, D.G.; Koestner, P.E. 2011. Geomorphic aspects of post-fire soil erosion, Schultz Fire 2010. Proceedings of FESP III International Meeting on Fire Effects on Soil Properties, March 15-19, 2011, NIGP – University of Minho, Guimarães, Portugal. Pp. 140-143.