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Protection from Erosion Following Wildfire

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Abstract. Erosion in the first year after a wildfire can be up to three orders of magnitude greater than the erosion from undisturbed forests. To mitigate potential postfire erosion, various erosion control treatments are applied on highly erodible areas with downstream resources in need of protection. Because postfire erosion rates generally decline by an order of magnitude for each year of recovery, effective erosion mitigation treatments are most needed during the first year or two after a fire. Postfire treatments include broadcast seeding, scarification and trenching, physical erosion barriers such as contour-felled logs and straw wattles, and mulching with wheat straw, wood straw, and hydromulch. This paper summarizes data from more than seven years of studies to evaluate the effectiveness of postfire erosion mitigation treatments at the hillslope and small watershed-scale in the western U.S. Results suggest that some mitigation treatments may help reduce erosion for some, but not all, rainfall events. Generally, mulching is more effective than seeding, scarifying, or erosion barriers. For small rainfall events, reduction in first year erosion rates have been measured for engineered wood straw and straw mulch (60 to 80%), contour-felled log erosion barriers (50 to 70%), and hydromulch (19%). Grass seeding treatments have little effect on first year erosion reduction. For intense rain events (I_{10} greater than 40 mm h^{-1}) there was little difference between treated and non-treated areas.

Keywords. erosion mitigation, sediment yield, forest fire

Introduction

In the past decade, due to the number, size, and severity of wildfires in the western USA, land management agencies have spent tens of millions of dollars on postfire emergency watershed stabilization measures. These postfire efforts were intended to minimize flood runoff, peakflows, onsite erosion, offsite sedimentation, mud and debris flows, and other hydrologic damage to natural habitats as well as roads, bridges, reservoirs, and irrigation systems (General Accounting Office 2003). The growing costs and the public demand for emergency postfire rehabilitation have prompted economic and scientific studies to determine the most cost-effective approaches to mitigate the effects of fire on human lives and property, water supplies, water quality, soil productivity, and endangered species and habitat (Robichaud 2005).

Hillslope postfire rehabilitation treatments, intended to reduce surface runoff and keep soil on the hillslope, can generally be categorized into three groups: 1) seeding for vegetative regrowth and invasive weed control; 2) ground covers or mulches; and 3) barriers and trenches that physically hold runoff and sediment.

Seeding—Historically, broadcast seeding of grasses, usually from aircraft, has been the most common postfire rehabilitation treatment. Robichaud et al. (2000) examined nine seeding studies in conifer forests that provided quantitative ground cover data. In the first growing season after the fire, only 22% of the sites reported at least 60% ground cover, the minimum needed for erosion reduction (Pannkuk and Robichaud 2003). Robichaud *et al.* (in press) reported no significant differences in erosion rates from seeded and/or fertilized hillslope plots on steep, severely burned hillslopes in north-central Washington. In the first year, the seeded winter wheat provided about a fourth of the total canopy cover (17%) on the seeded plots; however, the total canopy cover on the seeded plots did not differ from the unseeded plots. Beyers (2004) found postfire seeding treatment reduced sediment movement in less than half of the studies reviewed, and that when postfire seeded grasses do provide the ground cover needed to affect erosion, they appear to displace native or naturalized species, including shrub and tree seedlings.

Mulching—Mulch (with or without grass seed mixed in) is material spread over the soil surface to protect it from rain impact and reduce overland flow. Many materials, including paper, wood chips, wheat and rice straw, jute, and natural and synthetic fabrics, have been used as mulch. Straw mulch has been shown to reduce erosion rates after wildfires by 50 to 94% (Bautista *et al.* 1996). Hydromulch, a relatively new postfire rehabilitation treatment, is available in numerous combinations of tackifier, polymers, bonded fiber, seeds, etc. that, when mixed with water and applied to the soil surface, form a matrix that may reduce erosion and foster plant growth.

In some burned areas, natural mulch may provide adequate ground cover making the 'no treatment' option a practical choice for those areas. In conifer forests, low and moderate severity burned sites often have trees that are lightly charred and partially consumed by fire, leaving dead needles in the canopy. These needles fall to the ground and provide a natural mulch ground cover. Pannkuk and Robichaud (2003) found a 60 to 80% reduction in interrill erosion and a 20 to 40% reduction in rill erosion due to a 50% ground cover of dead needles.

Erosion barriers—Straw wattles, straw bales, contour-felled log erosion barriers (LEBs), contour trenching and scarification, and other natural and engineered structures have been used to provide a mechanical barriers to slow overland flow, promote infiltration, trap sediment, and thereby reduce sediment movement on burned hillsides.

Methods

Postfire runoff and erosion are often estimated from related data, because direct measurement is often expensive, complex, and labor-intensive (Robichaud 2000). However, recent scientific efforts have focused on developing and implementing methods that directly measure hillslope erosion to assess the effectiveness and the limitations of various postfire rehabilitation treatments.

To ensure that measurements are made during the first postfire year when runoff and erosion are likely to be greatest, Robichaud and Brown (2002, 2003) developed and implemented ‘rapid response’ approaches to establish and maintain study sites. Catchment impoundments and/or sediment fence sites are located and constructed within weeks following a forest fire to monitor sediment yield and, with catchment impoundments, runoff response. Sites are monitored for three to five years to verify the initial recovery process. Site characteristics, including soil physical properties, water repellency characteristics, and ground cover measurements are used to validate similarity of compared sites and to correlate site characteristics with erosion and recovery rates. Rainfall and erosion data, along with site characteristics are used to compare the erosion rate and recovery processes between treated and untreated sites.

Paired catchments—A paired catchment experiment measures runoff and sediment yield from natural rainfall in two adjacent catchments (2 to 10 ha with natural drainage to a single exit point) that are closely matched for size, slope, aspect, elevation, soil characteristics, and burn severity. One catchment has a postfire rehabilitation treatment applied and one is left untreated as a control. Runoff is measured using a 90 degree V-notch weir and sediment, which is collected in the impoundment basin, is removed, weighed, and sampled manually after each rain event. Rainfall intensity, amount, and duration are related to the measured runoff and sediment yield (fig. 1).

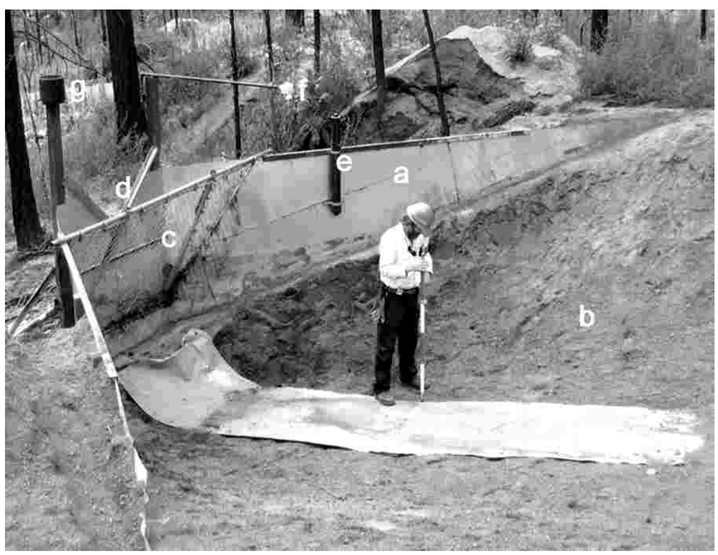

Figure 1. Typical paired catchment sediment basin after removal of sediment. a) sheet metal barrier wall; b) sediment basin area; c) debris collection rack; d) V-notch weir; e) magnetic/electronic stage sensor; f) ultrasonic depth sensor; g) tipping bucket rain gauge (Robichaud 2005).

Sediment fences—Sediment fences, constructed of silt fence fabric, provide a less expensive method to directly measure hillslope erosion (Robichaud and Brown 2002). Although runoff cannot be assessed, multiple fences allow for several replicates of each treatment. Sediment fences are best located on uniform slopes with minimal obstructions or in small swales (less than 0.5 ha in size). As with paired catchments, collected sediment is removed, weighed, and sampled manually after each storm event, and data from continuous-recording tipping-bucket rain gauges allow rainfall intensity, amount, and duration to be related to sediment yields (fig. 2).

Figure 2. Typical sediment fence where accumulated sediment is being removed (Robichaud 2005).

Preliminary Data and Discussion

Studies to date show that the effectiveness of any hillslope rehabilitation treatment depends on the actual rainfall amounts and intensities—especially in the first one to three years after the fire. For example, in the first postfire year on the Fridley fire, three rainfall events occurred in 7 days, which resulted in 49.7 mm of rainfall and an average maximum 10-min rainfall intensity (I_{10}) of 48.9 mm h^{-1}. The contour-felled log treated watershed had similar erosion (5.8 Mg ha^{-1}) to the control watershed (6.7 Mg ha^{-1}). However, in the first postfire year of the Valley Complex fire, two rain events occurred in two days, resulting in 19.0 mm of rain with an average maximum I_{10} of 37.2 mm h^{-1}. In this site, not only was there much less erosion than in Fridley, but the 0.56 Mg ha^{-1} from the control watershed was significantly more than the 0.15 Mg ha^{-1} from the contour-felled log treated watershed. Similar results were reported by Wagenbrenner *et al.* (in press) from a study on the 2000 Bobcat Fire in Colorado, where dry straw mulch, seeding, and contour-felled log erosion barriers did not significantly reduce sediment yields during the first postfire summer when an intense rain event (I_{30}=48 mm h^{-1}) overwhelmed all the applied treatments.

Preliminary data from the first and second postfire years are available from six paired catchment sites where contour-felled log erosion barriers (LEBs) are being studied. These preliminary results generally show the greatest erosion during the first year following a fire (Table 1). At the

Table 1. Preliminary results from paired catchment studies of contour-felled log erosion barrier (LEB) treatment effectiveness.

Fire name, Location	Year	Mean annual sediment yield LEB treated (Mg ha^{-1})	Untreated (Mg ha^{-1})
North 25,	1999	1.2	0.64
Washington	2000	0	0
Mixing,	2000	0.44	0.02
California	2001	0.08	1.4
Valley Complex,	2001	0.15	0.64
Montana	2002	0.48	0.93
Fridley,	2002	6.1	6.7
Montana	2003	0.16	0.29
Cannon,	2002	0.12	0.13
California	2003	0	0.01
Hayman,	2003	11	24
Colorado	2004	1.4	7.1

North 25, Mixing, and Fridley sites, similar or greater erosion was measured from the catchments treated with contour-felled log erosion barriers than from untreated control catchments. In contrast, Bitterroot, Hayman, and Cannon sites show about a 50% reduction of erosion on the contour-felled log erosion barrier treated catchments as compared to the untreated catchments during the first year. Based on the current data, the expected first year erosion reduction from LEBs is about 20 to 50% in areas exposed to mid- to high-intensity rainfall events, and unlikely to be higher than 70% for any rainfall event. Once the LEBs are filled to capacity, any additional runoff causes sediment-laden water to flow around and over the logs.

After the 2002 Hayman Fire, a set of three adjacent catchments—one treated with wheat straw mulch, one treated with hydromulch, and the middle catchment left untreated as the control. In 2003, the untreated catchment produced 22.2 t ha^{-1}, while the wheat straw catchment produced only 8.9 t ha^{-1} (63% less than the control) and the hydromulch produced 18.2 t ha^{-1} (19% less than the control) (Table 2). Unlike most burned areas, there was an overall increase in sediment

Table 2. Preliminary results from a paired catchment study of wheat straw mulch and hydromulch treatment effectiveness after the 2002 Hayman Fire in Colorado.

Catchment treatments	2003 Sediment yield (t ha^{-1})	2004 Sediment yield (t ha^{-1})
Wheat straw	8.09	12.4
Untreated (control)	22.2	38.9
Hydromulch	18.2	28.3

yield during the second year (2004) since it received more rainfall and greater rainfall intensities than in 2003. Even with overall larger sediment yields, the wheat straw catchment produced 68% less sediment and the hydromulch catchment produced 27% less sediment than the control (Table 2).

Also within the 2002 Hayman Fire area, sediment fences on hillslope plots were used to evaluate the effectiveness of wheat straw and engineered wood straw. In 2003, the first postfire year, sediment yields from the untreated plots averaged 19.6 t ha^{-1} which decreased to 3.60 t ha^{-1} in 2004. Although all treated plots had lower average sediment yields as compared to the controls, only the wood straw had significantly lower sediment yields with 4.3 t ha^{-1} in 2003 and 0.67 t ha^{-1} in 2004.

Conclusions

Monitoring postfire rehabilitation treatment effectiveness is providing quantified data that can be used to determine the amount of postfire erosion reduction provided by the treatment, insight as to the limitations of specific treatment use, and the data needed to develop postfire erosion prediction models that include treatment effectiveness. Preliminary data suggests that treatment performance may be closely related to rainfall characteristics (intensity, amount, and duration) and length of time since the fire. In general, postfire rehabilitation treatments cannot prevent erosion, but they can reduce overland flow amounts, site soil loss, and sedimentation for some rainfall events. Paired catchment data suggests that wheat straw is an effective erosion mitigation treatment during the first two postfire years. Other dry mulches, such as wood straw and dead needles, also provide erosion control when ground cover is greater than 70%. Contour-felled log erosion barriers can slow runoff and trap some of the eroded sediment onsite during low-intensity rainfall events; however, these erosion barriers are not very effective during high-intensity rainfall events or after the sediment storage area behind the barrier has been filled. Balancing the increased risk of erosion, flooding, etc. against to the risk reduction expected from specific postfire erosion mitigation treatments requires quantified analysis of these treatments.

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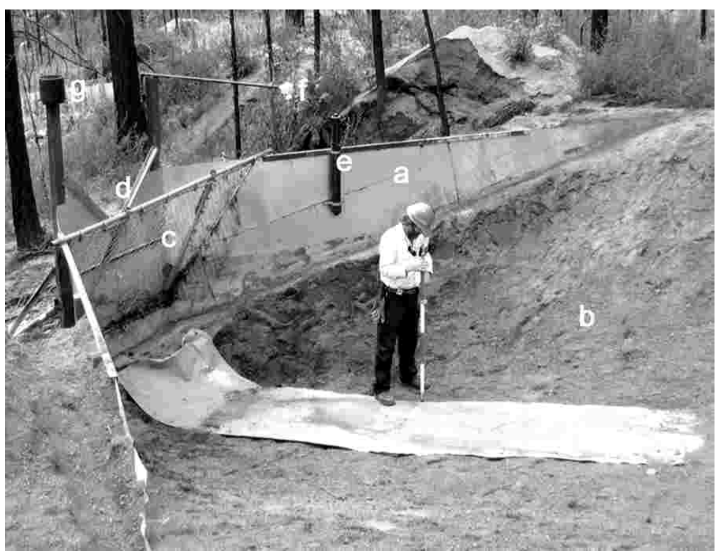

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