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Postfire Rehabilitation Treatments: Are We Learning What Works?

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Abstract

Major concerns after wildfires are the increased erosion and flooding potential due to loss of the protective forest floor layer, loss of water storage, and the creation of water repellent soil conditions. Treatments to mitigate postfire erosion and runoff are commonly applied on highly erodible areas; however the effectiveness of these treatments has had limited scientific evaluation. In recent years postfire hillslope treatment effectiveness has been evaluated by using sediment fences and small catchments to directly measure sediment yields from burned hillslopes and relate those results to the specific rain events that caused them. In addition, the erosion from areas treated with various rehabilitation treatments (seeding, mulching, erosion barriers, etc.) is compared to non-treated areas. Although many of these studies are still in progress, preliminary results suggest that some mitigation treatments may help reduce erosion for some, but not all, rain events. Immediately after installation, contour-felled log erosion barriers can reduce erosion up to 70% for small rain events. For high intensity rain events (10-min max intensity of 40 mm hr^{-1} or greater) there little difference in erosion reduction between treated and non-treated areas. Other studies suggest that the natural mulch provided by dead conifer needles in areas of low and moderate burn severity can reduce rill erosion by 30 to 40% and interrill erosion by 50 to 70%.

Introduction

Fire is a natural and important disturbance mechanism in many ecosystems. However, fire suppression in the western United States, beginning in the early 1900's, has altered natural fire regimes in many areas (Agee 1993) resulting in a significant increase in the number, size, and severity of wildfires (Joint Fire Science Program 2004). In recent years, more than 2 million hectares of forest and grasslands have burned annually. High severity fires are of particular concern because they not only consume or deeply char all the vegetation, but also affect the physical properties of soil (DeBano *et al.* 1998). Altered watershed response to rainfall can cause increased runoff, erosion, downstream sedimentation, which can threaten human life and damage property (Robichaud *et al.* 2000).

The USDA Forest Service and other land management agencies have spent tens of millions of dollars on postfire emergency watershed stabilization measures 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).

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In the mid 1990's, as rehabilitation expenditures continued to escalate, a revision of the federal funding process was implemented that now requires verification that treatments being implemented are minimal, necessary, reasonable, practicable, cost-effective, and will provide significant improvement over natural recovery. However, there were few data that could be used to verify that treatments were worth the cost and would, indeed, provide significant improvement over natural recovery. Measuring erosion and runoff is expensive, complex, and labor-intensive, and few researchers have done it. In the late 1990's the postfire rehabilitation policies were integrated across several different federal land management agencies and, at the same time, the scope and application of postfire analysis and treatment was broadened to include monitoring to determine if additional treatment is needed and evaluating to improve treatment effectiveness.

Despite expanded land management agencies responsibilities to verify treatment necessity and monitor treatment effectiveness, the U.S. General Accounting Office (2003) recently reported that postfire mitigation treatments used to reduce runoff and erosion have not been rigorously evaluated to determine if they are meeting treatment objectives. Most emergency postfire rehabilitation efforts have been evaluated qualitatively in written reports with some photographic support, but few quantitative data have been collected (Robichaud *et al*. 2000). However, recent scientific efforts have focused on developing and implementing methods that assess the effectiveness and the limitations of specific postfire rehabilitation treatments through direct measurement of watershed processes, such as erosion, runoff, peakflows, sedimentation, etc.

Fire-induced watershed effects that impact erosion rates

Watersheds with good hydrologic conditions (greater than 75% of the ground covered with vegetation and litter), and adequate rainfall, sustain stream baseflow conditions for much or all of the year and produce little sediment. Under these conditions, two percent or less of the rainfall becomes surface runoff, and erosion is low. Fire can destroy accumulated forest floor material and vegetation, altering infiltration by exposing soils to raindrop impact or creating water repellent soil conditions. When severe fire produces hydrologic conditions that are poor (less than 10% of the ground surface covered with plants and litter), surface runoff can increase more than 70% and erosion can increase by three orders of magnitude (DeBano *et al.* 1998).

Burn severity is a qualitative measure of the effects of fire on various environmental factors and, although some aspects can be quantified, burn severity cannot be expressed as a single quantitative measure that relates to resource impact (Jain 2004, Ryan and Noste 1983). In terms of postfire erosion and runoff rates, burn severity is most closely tied to postfire soil characteristics and protection, i.e., the temperature and duration of the soil heating during the fire and the amount of forest floor material remaining after the fire (Ryan and Noste 1983). Postfire field evaluation of burn severity is based on the color of the mineral soil and the amount of litter, or forest floor material, remaining. Recent advances in remote sensing have made it possible to map postfire burn severity using satellite data with some field validation.

Within a watershed, sediment and runoff responses to wildfire are often a function of burn severity and the occurrence of hydrologic events. Even severely burned areas will have minimal soil loss in the absence of rainfall. However, when a major rainfall event follows a large, high burn severity fire, large-scale hydrological responses and erosion are likely. In particular, high-intensity, short-duration rainfall has been associated with high stream peakflows and significant erosion events after fires (DeBano *et al.* 1998; Neary *et al.* 1999). After the Buffalo Creek Fire in the Colorado Front Range, Moody and Martin (2001) measured 30-minute maximum rainfall intensities (I_{30}) that were greater than 60 mm hr^{-1}. Short duration rainfall events of such intensity tend to exceed the average infiltration rates of many soils. Recent data from the 2000 Bitterroot Complex Fires indicate the rainfall intensity may be more significant than rainfall amount or duration (Fig. 1), with significantly greater erosion occurring when 10-minute maximum rainfall intensity (I_{10}) exceeds 50 mm hr^{-1} (Spigel 2002).

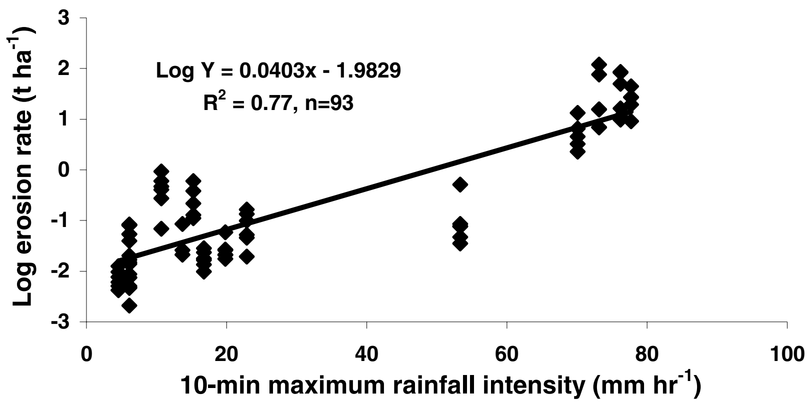


Figure. 1. Ten-minute maximum rainfall intensity vs the log of the erosion rate as measured with sediment fence plots after the 2000 Bitterroot Complex Fire.

Postfire soil erosion amounts vary with rainfall, burn severity, topography, soil characteristics, and amount of vegetative recovery. Published sediment yields after wildfires vary from 0.01 to over 110 Mg ha^{-1} yr^{-1} in the first postfire year (Robichaud *et al*. 2000), which decreases by an order of magnitude the following year, and recovers with no measurable erosion by the fourth year (Robichaud and Brown 2000). For example, after an eastern Oregon wildfire, the mean first year erosion rate was 1.9 Mg ha^{-1}, decreasing to 0.1 Mg ha^{-1} the second year, then to 0.03 Mg ha^{-1} the third year. Consequently, if erosion mitigation is required, treatments need to be applied immediately after fire suppression, and effectiveness monitoring needs to begin at the same time.

Recovery rates vary by climate and geographic area as well as size and severity of the burn. DeBano *et al.* (1996) found that following a southwestern U.S. wildfire, sediment yields from a low severity fire recovered to normal levels after 3 years, but moderate and high severity burned watersheds required 7 and 14 years, respectively. Therefore, monitoring rehabilitation treatment effectiveness through the recovery process requires several years.

Treatments and known treatment effectiveness

BAER treatments are applied to burned hillslopes, channels, and roads (Robichaud *et al.* 2000). This paper focuses on hillslope treatments because these measures are regarded as a first line of defense against postfire erosion and unwanted sediment deposition, and more research has been done (Robichaud *et al.* 2000), and is being done, on the development and evaluation of hillslope treatments than on channel or road treatments.

Hillslope treatments

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. 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, on the 2000 Bobcat Fire in the northern Colorado Front Range, none of the three test treatments (seeding, dry straw mulch, and contour-felled log erosion barriers) significantly reduced sediment yields in the first year after the fire. During the first postfire summer, an intense rain event (I_{30}=48 mm hr^{-1}) overwhelmed all the applied treatments, resulting in the same or greater sediment yields on treated plots as compared to the untreated control plots. Some treatments did reduce sediment yields in the second year after burning, when rainfall occurred over several smaller events (Wagenbrenner 2003).

<u>Seeding</u>—Historically, broadcast seeding of grasses, usually from aircraft, has been the most common postfire rehabilitation treatment. Rapid vegetation establishment has been regarded as the most cost-effective method to promote water infiltration and reduce hillslope erosion. Despite persistent questions about the effectiveness of postfire grass seeding and its negative impacts on natural vegetative recovery, seeding remained a widely used rehabilitation treatment throughout the 1990's (Robichaud *et al*. 2000).

Because of the difficulty and expense involved in measuring hillslope erosion directly, most evaluations of seeding effectiveness have been reported in terms of ground cover or canopy cover produced, rather than any direct measurement of erosion reduction (Robichaud *et al.* 2000; Beyers 2004). The studies reviewed by Robichaud *et al.* (2000), suggest that seeding does not assure higher plant cover during the critical first year after burning. For example, 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, about half of the studies reported less than 30% ground cover and only 22% reported at least 60% ground cover. In other words, the 60 to 70% ground cover needed for erosion reduction (Robichaud *et al.* 2000; Pannkuk and Robichaud 2003), was attained in less than a fourth of the treated areas during the first growing season. Beyers (2004), in a recent review of postfire seeding effectiveness, reported that when postfire seed growth provides enough cover to substantially reduce erosion (60 to 70%), it generally suppresses revegation by naturally occurring species.

<u>Mulch</u>—Mulch is any organic material spread over the soil surface that increases the ground cover and reduces raindrop impact and overland flow. Both wet

mulch (hydromulch) and dry mulch (wheat straw, jute excelsior, rice straw, etc.) can be applied from the air or from the ground; however, mulches have only recently been used as a postfire rehabilitation treatment. Mulch mixed with grass seed is frequently applied to improve the germination of seeded grasses by increasing infiltration and enhancing soil moisture retention (Robichaud *et al.* 2000). In the past, seed germination from grain or straw mulch was regarded as a bonus as this increased the cover on a site; however, the introduction of noxious weeds and other non-native plants is now considered a drawback to the use of straw mulch, and certified 'weed-free' straw is usually require for postfire rehabilitation efforts. Due to the cost and logistics of mulching, it is typically used to protect high value resources, such as municipal water sources, water quality, habitat, roads, structures, and sensitive cultural sites, from upslope erosion. Both hydromulch and dry mulch were used to stabilize soils on the Cerro Grande Fire of 2000 and the Rodeo-Chediski and Hayman Fires of 2002. However, use of these treatments escalated the BAER treatment costs to \$10 to \$20 million per fire.

The use of helicopters to spread dry mulch is relatively new in postfire emergency rehabilitation. Straw bales suspended in cargo nets break apart as they fall and spread further upon impact, resulting in a fairly even distribution of straw mulch with approximately 70% ground cover when applied at a rate of 2.4 Mg ha^{-1} (Robichaud *et al*. 2003). Ground application of dry mulch is usually done by hand using ATVs to carry the straw from a staging area into the treatment area.

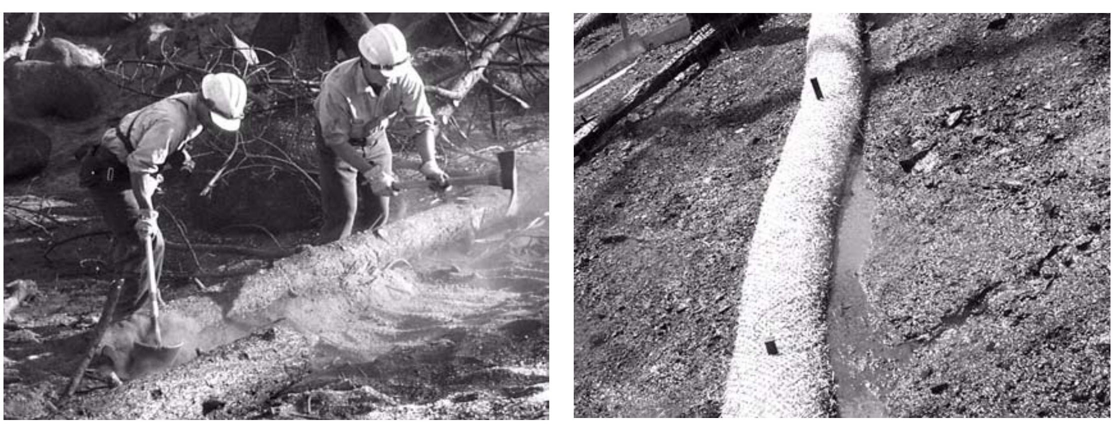
Straw mulch has been shown to reduce erosion rates after wildfires by 50 to 94% (Bautista *et al.* 1996). Straw mulch applied at a rate of 2 Mg ha^{-1} significantly reduced sediment yields on burned pine-shrub forest in Spain over an 18-month period with 46 rainfall events (Bautista *et al*. 1996). Sediment production was 0.18 to 2.9 Mg ha^{-1} on unmulched plots but only 0.09 to 0.18 Mg ha^{-1} on mulched plots. In a two year comparative study following the 2000 Cerro Grande Fire in New Mexico, plots treated with aerial seed and straw mulch yielded 70% less sediment than the control plots in the first year, and 95% less in the second year. Ground cover transects showed that aerial seeding without added straw mulch provided no increase in ground cover relative to untreated plots (Dean 2001). In the second year after the 2000 Bobcat Fire in Colorado, Wagenbrenner (2003) reported sediment yields from mulched hillslopes that were significantly less than those from both untreated and seeded-only slopes.

The use of hydromulch for postfire rehabilitation is a new effort to take advantage of the general success of hydromulch as an erosion mitigation treatment on road cut and fill slopes and in construction site rehabilitation. There are numerous combinations of tackifier, polymers, bonded fiber, seeds, etc. used in hydromulch that, when mixed with water and applied to the soil surface, form a matrix that can reduce erosion and foster plant growth. It has only been applied in a limited number of postfire situations. Ground application of hydromulch is done from spray trucks and is limited to an area 70 m on either side of a road. Large-scale application requires helicopters fitted with slurry tanks and access to a nearby staging area, making aerial application of hydromulch one of the most expensive hillslope treatments available. After the 2002 Hayman Fire in Colorado, 600 ha of aerial hydromulching was applied to steep, inaccessible areas that drain directly to the

South Platte River and the reservoir system that provides 90% of Denver's municipal drinking water (Robichaud *et al*. 2003).

In some burned areas, natural mulch may provide adequate groundcover making the 'no treatment' option a practical choice for those areas. After a wildfire, there is a mosaic of low, moderate, and high burn severity conditions within the burned area (DeBano *et al.* 1998). Low and moderate burn severity areas produce less runoff and erosion than high severity burned areas (Benavides-Solorio and MacDonald 2001). 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. Thus, prudent use of postfire rehabilitation treatments would exclude areas where needles are present to provide sufficient ground cover.

Erosion Barriers—Straw wattles, contour-felled log erosion barriers, and other natural and engineered structures have been used to provide a mechanical barriers to overland flow, promote infiltration, trap sediment, and thereby reduce sediment movement on burned hillsides. Contour-felled log erosion barriers have been widely used in areas where fires leave dead trees that can be felled, placed along the contours of burned hillslopes, staked in place, and the gaps between the logs and soil surface filled with additional soil to prevent underflow (Fig. 2a) (Robichaud *et al*. 2000). Some recent installations have included the construction of soil berms at the end of the logs to increase their storage capacities. Straw wattles, 0.25 m diameter nylon mesh tubes filled with straw, are permeable barriers used to detain surface runoff long enough to reduce flow velocity and provide for sediment storage (Fig. 2b). Turning 0.6 m at each end of the wattle upslope can increase the sediment holding capacity. Straw wattles are a good alternative in burned areas where logs are absent, poorly shaped, or scarce.



(a) (b)

Figure 2. (a) Fire crews install a contour-felled log erosion barrier in a research catchment after the 1999 Mixing Fire (California, USA). (b) A straw wattle erosion barrier is tested during a rainfall simulation experiment following the 2000 Bitterroot Complex Fire (Montana, USA).

The potential volume of sediment stored on a hillslope treated with erosion barriers is highly dependent on slope, barrier diameter and length, construction of earth berms at the ends of the barriers, and ‘quality of installation’—i.e., the degree to which the barriers are adequately staked, aligned perpendicular to the flow path, and maintain ground contact throughout their length. The length of time the treatment remains functional depends on post-installation rainfall parameters (especially rainfall intensity), density of barrier installation (i.e., volume of sediment holding capacity per ha), soil erodibility, and topography. In some instances contour-felled log erosion barriers have filled with sediment following the first several storm events after installation, while others have taken 1 to 2 years to fill (Robichaud 2000).

Contour-felled log erosion barriers do provide immediate benefits after installation, in that they trap sediment during the first postfire year, which usually has the highest erosion rates (Robichaud and Brown 2000). Dean (2001) found that plots treated with both contour-felled log erosion barriers and straw mulch with seed yielded 77% less sediment in the first postfire year and 96% less in the second year; however, these results were not significantly different from the straw mulch with seed treatment alone. Preliminary data from on-going studies suggests that contour-felled log erosion barriers can be effective for low to moderate intensity rainfall events. However, during high-intensity rainfall events, their effectiveness is greatly reduced (Table 1). The effectiveness of contour-felled log erosion barriers also decreases over time as the sediment storage areas behind the logs become filled and the barrier can no longer trap mobilized sediment (Robichaud 2000; Wagenbrenner 2003).

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

		-----Annual sediment yield-----	
Fire name, Location	**Year**	**LEB treated ($Mg\ ha^{-1}$)**	**Untreated ($Mg\ ha^{-1}$)**
North 25,	1999	1.1	0.7
Washington	2000	0	0
Mixing,	2000	0.4	0.03
California	2001	0.09	1.8
Bitterroot Complex,	2001	0.15	0.48
Montana	2002	0.45	0.86
Fridley,	2002	10.4	10.2
Montana	2003	0.16	0.3
Cannon,	2002	0.11	0.2
California	2003	0	0
Hayman, Colorado	2003	12.5	23.4

Channel treatments

Channel treatments are implemented to modify sediment and water movement in ephemeral or small-order channels, to prevent or reduce sediment inputs into perennial streams during the first winter or rainy season following a wildfire and to prevent flooding and debris torrents that may affect downstream values at risk (Robichaud *et al*. 2000). Check dams and channel grade stabilizing structures are constructed of different materials (straw, wood, logs, and rocks) and anchored in channels to slow water flow, and thereby, reduce downcutting and allow sediment to settle out. Channel clearing is done to remove large objects that could become mobilized in a flood.

Straw bale check dams are inexpensive, easy to install, and effective at trapping sediment but eventually deteriorate due to climatic conditions, streamflows, or cattle and wildlife disturbance (Fig. 3). Straw bale check dams are often fill in the first few storms, so their effectiveness diminishes quickly and they tend to fail in large storms. Collins and Johnston (1995) evaluated the effectiveness of straw bales on sediment retention after the Oakland Hills fire. About 5000 bales were installed in 440 straw bale check dams and 100 hillslope barriers. Three months after installation, 43 to 46 percent of the check dams remained functional.

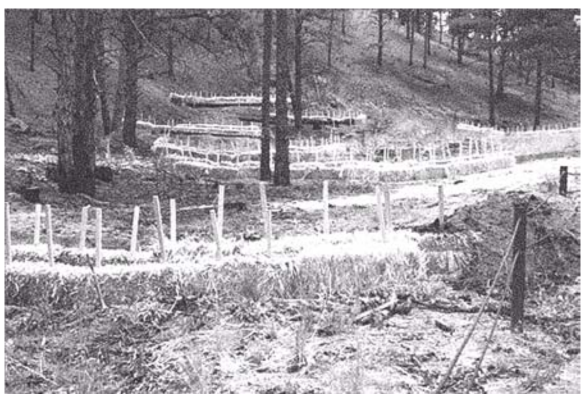


Figure 3. Straw bale check dams installed after the 2002 Hayman Fire in Colorado.

Log check dams are similar in function to straw bale check dams, but constructed of more durable material, usually small diameter fire-killed trees that are available nearby. Log check dams require more effort and skill to install, but will last longer than straw bale check dams. Properly designed and installed rock check dams (also called rock cage dams, gabions, or rock fence check dams) dams are semi-permanent structures capable of halting gully development and reducing sediment yields. The rock cage dams must be properly sited, keyed in, and anchored to stay in place during runoff events. Downslope energy dissipaters are recommended because they reduce the risk of the rock cage dams being undercut.

Other channel rehabilitation treatments, such as straw wattle dams, log and rock grade stabilizers, in channel debris basins, debris clearing, stream bank armoring have been used in rehabilitation efforts (Robichaud *et al*. 2000).

Road treatments

Postfire road treatments consist of a variety of practices aimed at increasing the water and sediment processing capabilities of roads and road structures, such as culverts and bridges, in order to prevent large cut-and-fill failures and the movement of sediment downstream. The functionality of the road drainage system is not affected by fire, but the burned-over watershed can affect the functionality of that system. Road treatments include outsloping, gravel on the running surface, ditch rocks, culvert removal, culvert upgrading, overflows, armored stream crossings, rolling dips, and water bars. The treatments are not meant to retain water and sediment, but rather to manage water's erosive force. Trash racks and storm patrols are aimed at preventing culvert blockages due to organic debris, which could result in road failure that would increase downstream flood or sediment damage. Trail rehabilitation treatments mimic road treatments but on a smaller scale. Trail treatment is labor intensive, as all the work must be done by hand with materials that can be carried or brought in on ATV's.

Comprehensive discussions of road-related treatments and their effectiveness can be found in Goldman *et al*. (1986), Burroughs and King (1989), and Copstead (1997). These references cover design standards, improvement techniques, and evaluation of some surface drainage treatments for reducing sedimentation.

On-going effectiveness monitoring

Recent findings show that postfire rehabilitation treatments are not as effective as many land managers believed. Robichaud *et al*. (2000) surveyed 98 postfire rehabilitation specialists from the western U.S. and found that their perceptions of treatment effectiveness were quite varied (Table 2). Because of the lack of quantitative data, postfire rehabilitation decisions have been, by necessity, largely based on experience, perceptions, and past practice.

Table 2. Postfire treatment effectiveness ratings from land managers who rated the effectiveness of the treatments, as installed, after a particular fire. Percentage of total responses are listed in each of the four classes (after Robichaud *et al*. 2000).

		-----------Rating categories---------			
Treatment	Responses (#)	Excellent (%)	Good (%)	Fair (%)	Poor (%)
Aerial seeding	83	24	28	28	20
Contour-felled log erosion barriers	35	29	37	14	20
Mulching	12	66	17	17	0
Ground Seeding	11	9	82	9	0

Determining treatment effectiveness and limitations is vital if cost-benefit analysis is used for making treatment decisions. Recent studies suggest that several factors, some of which have not always been considered, will influence the expected reduction in erosion risk from any given treatment. These include 1) where treatments are applied within a burned area (burn severity), 2) expected rainfall events (intensity, durations, and amounts), 3) topography, 4) soils, and 5) expected natural recovery rate.

Current research efforts are directed toward providing the quantitative data needed for risked-based decision. Since there is considerable published information on seeding effectiveness (Beyers 2004), we have focused our research efforts other treatments.

Some of the first and second postfire year data are available from six paired watershed sites where contour-felled log erosion barriers are being studied. These preliminary results generally show the greatest erosion occurring during the first year following the fire (Table 2). At the Twenty-Five Mile, Mixing, and Fridley sites, similar or greater erosion was measured from the catchments treated with contour-felled log erosion barriers than the untreated control catchments. A first year, high intensity rain event (I_{10} = 70 mm hr^{-1}) completely filled the Fridley catchment sediment traps and the data (overflow amounts were estimated) show that treatment had no effect on the average erosion rate for that year. In contrast, Bitterroot, Hayman and Cannon sites do show about a 50% reduction of erosion on the contour-felled log erosion barrier treated catchments during the first year. The expected first year erosion reduction from contoured-felled log erosion barriers is about 20 to 50% in areas exposed to high intensity rain events, and unlikely to be higher than 70% for any storm type. Once the contour-felled log erosion barriers are filled to capacity, any additional runoff causes sediment-laden water to flow around and over the top of the logs.

Conclusions

As wildfires continue to grow in number, size, and intensity, there has been concurrent growth in the treatment application and expense of postfire rehabilitation efforts. Postfire rehabilitation decisions must take into account the degree of protection warranted by the assets at risk, treatment costs, availability of treatment materials, short and long term effects of treatment applications, and the likelihood of treatment success in the area being considered. The choice to rely on natural recovery processes and not implement any rehabilitation treatments is often the preferable alternative.

Preliminary analysis of monitoring results suggests that treatment performance may be closely related to storm type and time since the fire. The greatest erosion is generally measured during the first postfire year, which often is an order of magnitude greater than the second postfire year. The contour-felled log erosion barriers trap runoff and sediment onsite, especially during the first series of storms. However, during intense rain events, many treatments, including the contour-felled log erosion barriers, have been overwhelmed.

Erosion after wildfire is a natural process. Postfire rehabilitation efforts will not stop erosion from occurring, but they may be able to reduce the amount of runoff and erosion for some, but not all, storm events. Current monitoring efforts are beginning to determine postfire erosion mitigation treatment effectiveness and delineate the fire effects, rainfall events, and environmental conditions that influence treatment effectiveness. Results from this research, combined with improved erosion prediction tools, will enable land mangers to make better risk-based postfire rehabilitation decisions.

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