Effects of a Polyacrylamide (PAM) on Post-fire Runoff and Erosion from a Small Plot, Bobcat Fire, Colorado

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Introduction

High-severity wildfires have been shown to greatly increase runoff and erosion in forests and brushlands in sites ranging from the western United States to Australia and South Africa. After most large fires the responsible land management agencies embark on a series of treatments to try and minimize these increases in runoff and erosion, but there is little documentation of the effectiveness of the various techniques (Robichaud et al., 2000). Part of the difficulty in determining the effectiveness of these techniques is the lack of detailed study on the underlying processes. Many studies have suggested that intense fires cause a hydrophobic layer to form at or near the soil surface, and this non-wettable layer causes a change in runoff processes from slow, subsurface stormflow to infiltration-excess or saturation overland flow (Scott and Van Wyk, 1990; Scott, 1993; Prosser and Williams, 1998). Severe fires can also cause a loss of the protective litter layer and consume much of the soil organic matter (Robichaud and Waldrup, 1994; DeBano et al., 1996). These changes can then lead to soil sealing, breakdown of soil aggregates, and a loss of macropores, all of which can act to further decrease infiltration rates (Dyrness and Youngberg, 1954; Packer and Williams, 1973; Campbell at al., 1977; DeBano, 1981; Prosser and Williams, 1998). Similarly, erosion rates can be greatly increased as a result of the reduction in soil cohesion and the increase in both rainsplash and overland flow. Order of magnitude increases in runoff and erosion have been observed in Colorado following the 1996 Buffalo Creek fire and the June 2000 Bobcat fire.

The most common post-fire treatments include aerial seeding of grasses, mulching areas close to roads, and contour felling of burned trees (Robichaud et al., 2000). We are currently testing the effectiveness of these treatments on the Bobcat fire, but there also is considerable interest in techniques that could directly reduce the effect of the hydrophobic layer and help stabilize the soil surface. Polyacrylamides (PAM) are a class of chemicals that have been tested in agricultural areas and found to reduce erosion (e.g., Lentz and Sojka, 1994). Hence it has been suggested that these chemicals could be used in burned areas to minimize the observed increases in runoff and erosion.

Following the June 2000 Bobcat fire we initiated a series of experiments to evaluate the changes in runoff and erosion from small plots. These experiments used a rainfall simulator to apply approximately 80 mm of water to a 1 m^2 plot in one hour. Runoff rates were measured every minute and a water sample was taken every two minutes. These water samples were then dried to determine the amount of sediment and organic matter. Multiplying the runoff volumes by the sediment concentrations provides a total sediment yield from each plot. To date we have conducted 16 such experiments on the Bobcat fire and 10 experiments on other burned or unburned sites of varying ages and fire severity. At each site we have also measured important controlling variables such as percent cover, fire severity, percent moisture, and soil hydrophobicity.

This report summarizes the runoff and erosion observed from a rainfall simulation conducted on a site where a PAM was applied in order to test its effectiveness for reducing runoff and erosion. The results of this experiment are compared to our other plots in order to provide a relative indication of the effectiveness of this treatment. Since the experiment using PAM was not replicated, the results must be regarded as a case study rather than a rigorous scientific test. Nevertheless, the data suggest that the application of polyacrylamides are worthy of further study as a post-fire treatment that could reduce runoff and erosion.

Methods

The experiment using PAM was conducted on 16 September 2000. The plot was located in an area of ponderosa pine forest that had burned in late June. The site was characterized as having burned at high severity, and it was within 100 m of four earlier rainfall simulations on comparable sites. Rainfall was applied at a rate of 87 mm/hr using a single oscillating nozzle (Purdue-type). The nozzle was at a height of 3.0 m in order to mimic the amount of rainfall energy that would be expected from a similar storm intensity. The rainfall rate is roughly equal to the 1-hour, 100-yr storm, and this storm intensity was selected because this storm represents the type of event that is of greatest concern to resource managers.

The metal frame for the plot was inserted to a depth of approximately 5 cm, and a metal collection trench was used to collect the runoff at the same intervals as our other experiments. Prior to the experiment percent cover was determined within the plot by a point count on a 10 x 10 cm grid. Surface and shallow subsurface soil hydrophobicity was measured next to the plot using the water drop penetration test. Percent slope was measured with a clinometer. Antecedent soil moisture conditions were relatively dry.

In a typical post-fire application, the PAM would be applied under dry conditions before any rainfall. Most high-intensity convective storms begin with a slower rainfall rate before rapidly building to peak intensity. In order to mimic this situation and provide an opportunity for the PAM to react with the soil, we rained on the plot for one minute, waited one minute, rained for one minute, applied the PAM, waited another minute, and then applied rainfall for another 58 minutes so that the total rainfall was comparable to our other experiments.

Results

The slope of the plot was 20%, and the site was a typical of a high severity fire in that bare soil occupied 50% of the plot, ash and burned litter represented another 49% of the plot, and just 1% of the surface was covered by rocks. Strong hydrophobicity was found below the ash-litter layer at a depth of approximately 0.5 cm into the mineral soil. Hydrophobicity was much less below a depth of 2-3 cm into the mineral soil. These observations are consistent with the other experiments in high severity sites.

The measured precipitation rate was approximately 75 mm/h. Runoff was first observed 195 seconds after the initiation of continuous rainfall. The runoff rapidly increased, and within three minutes after the initiation of rainfall reached an approximate steady-state rate of 0.9 liters/minute, or 54 mm/hr (Figure 1). This represents a steady-state runoff coefficient of approximately 72%. Runoff ceased 4.5 minutes after the rainfall simulator was stopped. The average runoff rate was 0.82 l/minute, or just under 50 mm/hr.

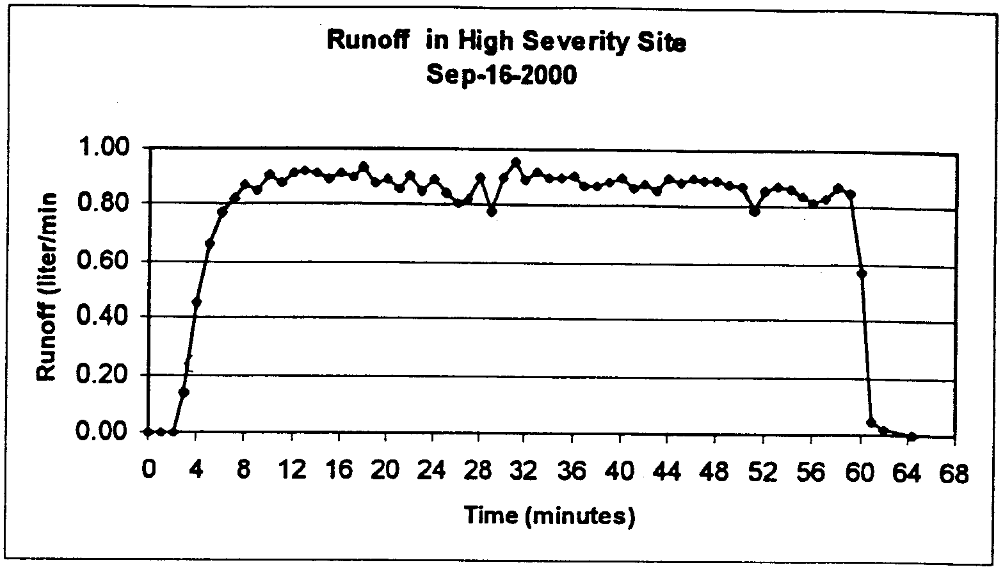

Figure 1. Observed runoff from the 1 m^2 plot after the application of a PAM on a high severity site in the Bobcat Fire.

The first 30 minutes or so of runoff was notable in that the water was quite viscous, and the amount of viscosity seemed to decline in the latter part of the experiment. This qualitative change seems to have had little effect on the volume of runoff. If anything, there is a very slight decline in runoff rates over time, and this can be attributed to the increase in infiltration as the hydrophobic layer wets up and thereby has less effect on infiltration rates (DeBano, 1981).

Figure 2 shows the sediment concentration over time in grams per liter of runoff and as sediment yield in grams per minute (i.e., concentration times runoff volumes). The overall pattern of the two graphs are very similar, as there was not a strong trend in runoff volumes over time (Figure 2). Both lines show a sharp increase in sediment production in the first minutes after runoff begins. This is followed by a gentle decline in sediment production from approximately minute 8 to minute 30. Measured sediment yields then nearly doubled to a maximum of 15 g/liter or 13 g/minute. Given the qualitatively observed change in viscosity, these data suggest that the PAM had a greater effect in the first half of the experiment, and became progressively less effective. This increase in sediment production is particularly striking given the small decline in runoff during the same period. The total sediment yield from this plot, including the material deposited in the runoff trench after runoff ceased, was 93 g. Since the plot was 1 m^2, this converts to 0.38 tons/acre (0.93 ton/ha).

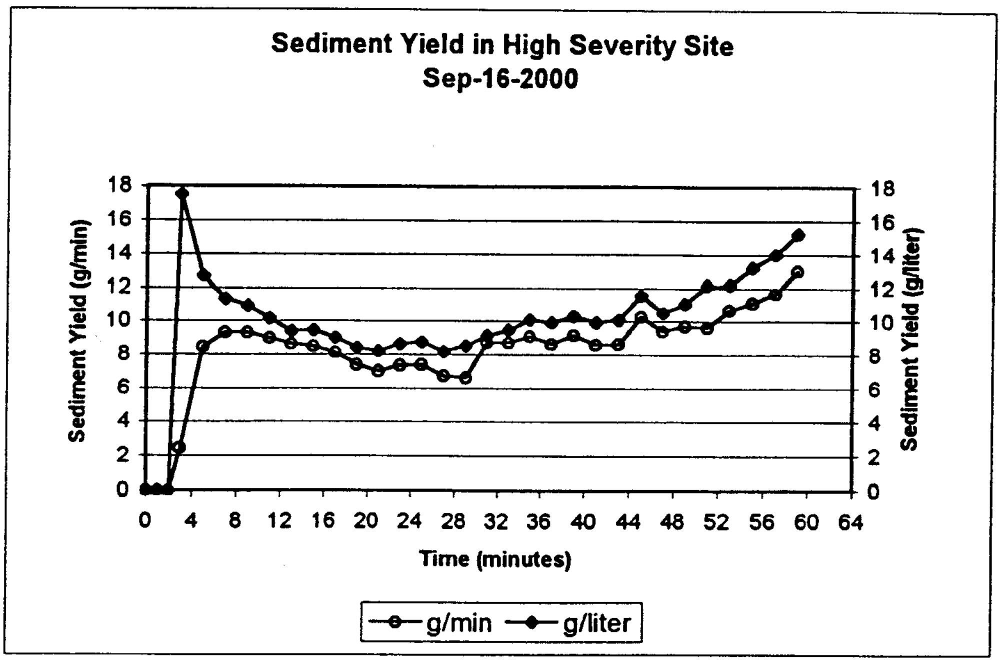

Figure 2. Observed sediment production in grams per liter of runoff and grams per minute from the 1 m^2 plot after the application of a PAM on a high severity site in the Bobcat Fire.

Discussion

The results of this experiment can be compared with our other rainfall simulations in the Bobcat fire. In high severity sites the average runoff rate was 0.95 liters/min, in moderate severity sites the average runoff rate 0.75 liters/min, and in low severity or no burn areas the average runoff rate was 0.71 liters/min. These data indicate that, at the relatively high rainfall rates applied with the rainfall simulator, the high severity sites produced only 34% more runoff. For comparison, the observed runoff rate from the plot treated with PAM treated plot was 0.82 liters/min, or 13% less that the average observed in other high severity plots.

With respect to sediment yields, our measured average values for total sediment yields are 428 g in plots burned at high severity, 89 g for plots burned at moderate severity, and 43 g for unburned plots or plots burned at low severity. In terms of sediment concentrations, the corresponding values are 23.5 grams/liter for high severity sites, 4.0 grams/liter for sites burned at moderate severity, and 1.9 grams/liter for unburned sites or sites burned at low severity. These data suggest that fire severity has a much greater effect on erosion than runoff, as total sediment yields and sediment concentrations in high severity sites are each about 10 times greater than the corresponding values in the unburned or moderate severity sites. In the case of the PAM-treated plot, the measured sediment yield of 93 g and average sediment concentration of 7.4 grams/liter is closer to the moderate severity sites. If we assume that the PAM treated plot is directly comparable to the plots burned at high severity, the treatment has reduced sediment yield by nearly 80% and sediment concentrations by 68%.

Excavation of the plot after the simulation showed that approximately 95% of area underneath the litter and ash was still dry. This suggests that the hydrophobicity in this plot was relatively consistent was not substantially affected by the application of the PAM. This observation is consistent with the relatively small reduction in runoff relative to other severely burned plots. The much larger reduction in sediment production from the PAM-treated plot implies that the PAM had a direct effect on the soil cohesion and hence the amount of rainsplash and sheetwash. Inferences about the effect of PAM on rill erosion are not possible because the size of the plot was too small to allow the development of rills (Ward, 1986; Stone and Paige, 1999).

Great care must be taken in the interpretation of these results, as the PAM treatment was only applied on site. The PAM treated plot was also conducted approximately one month after the other rainfall simulations in this area. During this time there had been one large storm event, and this may have already removed some of the easily erodible sediment from the plot surface. There may also have been a somewhat higher moisture content at the start of the experiment, and this would also contribute to a higher infiltration rate, as other work has shown a substantial reduction in soil hydrophobicity once soil moisture contents exceed 15-20% (Huffman and MacDonald, 2000).

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