FIRE EFFECTS ON SEDIMENT AND RUNOFF IN STEEP RANGELAND WATERSHEDS

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INTRODUCTION

Fire is a natural component of the Intermountain sagebrush-steppe ecosystem (Wright and Bailey 1982) with a return period of 25 to 100 years, depending on community type and natural fuel load and distribution. However, fuel and land management activities in the past century have placed wildland values such as soil and water quality at greater risk from wildfire. Increased soil erosion over natural levels following wildfire can lead to loss of soil productivity. Additionally, higher runoff rates from severely burned landscapes can lead to flooding, sedimentation, and increased risk to human life and property. This increased risk of runoff and erosion following wildfire continues to generate concern at the expanding urban-wildland interface throughout the western United States.

While the hydrological consequences of fire have been widely examined in forest ecosystems, few studies have examined wildfire impact on rangeland hydrology and erosion. Most of these studies have shown an increase in runoff and erosion rates the first year following fire, with recovery to pre-fire rates generally within five years (Wright and Bailey 1982). Timing and extent of recovery is highly dependent on slope and vegetation type (Branson et al. 1981, Knight et al. 1983, Wright et al. 1982, Wilcox et al. 1988). Many rangeland plant communities have naturally occurring hydrophobicity (DeBano and Rice 1973), but litter and vegetative cover protect the soil and enhance infiltration. Fire removes this protective covering, exposing the soil to erosion by raindrop impact and overland flow. Fire can also vaporize some of the organic compounds on the soil surface and distill the rest downwards, creating concentrated hydrophobic layers within the upper soil. Degree and longevity of hydrophobicity is dependent on compounds present and intensity and duration of fire (Wright and Bailey 1982). Fire can also reduce the organic matter content in the upper layers, thus reducing infiltration.

Major unknowns associated with rangeland wildfire are effects on vegetation and soil conditions affecting hydrologic processes, including infiltration, surface runoff, erosion, sediment production and transport, flooding, and the effectiveness of mitigation practices. The USDA-ARS Northwest Watershed Research Center (NWRC) has been investigating the impact of fire on rangeland hydrology and erosion in the mountains above Boise, Idaho (Boise Front) and in the Pine Forest Range near Denio, Nevada. The objective of the NWRC investigations are to quantify fire impacts on infiltration capacity, runoff, and erosion following fire, gain insight into the processes involved and determine how long the fire effects persist.

STUDY AREA AND METHODS

The Idaho study site is located on the Boise Front immediately above the city of Boise, Idaho (Eighth Street Fire) and the Nevada study site is located approximately 50 km south of the town of Denio, Nevada (Denio Fire). Both sites have vegetation consisting of bitterbrush (*Purshia tridentata*) /big sagebrush (*Artemisia tridentata* spp. *Wyomingensis*) /bluebunch wheatgrass (*Pseudoroegneria spicata*) - Thurber' s needlegrass (*Stipa thuberiana*) communities on south aspects, and big sagebrush/Idaho fescue (*Festuca idahoensis*) communities on north slopes (Interagency Fire Rehabilitation Team 1996). Some areas are characterized by an increase in three-awn (*Aristida spp*), Sandberg' s bluegrass (*Poa sandbergii*), and rabbitbrush (*Chrysothamnus* spp). Soils on both sites were derived from granite and consisted of fine gravelly coarse sandy loams, shallow (south slopes) to very deep (north slopes), well drained, on slopes of 35 to 60%.

Treatments on the Boise Front included combinations of slope aspect (north and south) and fire intensity (moderate, high). Treatments in Denio consisted only of intensely burned, north facing aspects. In both studies, burned sites were compared to unburned sites with the same soil type and vegetation as that found before fire. Sampling on both burned and unburned sites was stratified based on coppice areas (areas strongly influenced by the existence of a shrub) and interspace areas (areas between shrubs primarily dominated by grasses and forbs) (Pierson et al. 1994).

A portable oscillating-arm rainfall simulator with specifications as described by Meyer and Harmon (1979) was used to achieve intermittent rainfall similar to naturally occurring rainfall. Simulations were run on undisturbed plots, 0.5 m^2 in size, without pre-wetting. Soil moisture for all plots was extremely low (generally <10%). Rainfall was applied at a rate 67 mm hr^{-1} on the Boise Front and 85 mm hr^{-1} on the Denio sites. Runoff samples were collected at two-minute intervals throughout the 60-minute simulation and analyzed for runoff volume and sediment concentration. Infiltration capacity for each two-minute interval was calculated as the difference between applied rainfall and measured runoff. Suspended sediment samples were weighed, dried at 105°, and re-weighed to determine soil loss. Plot vegetative cover for each plant functional group was ocularly estimated, and vegetation within plots was harvested, dried and weighed following each simulator run to determine vegetation biomass by functional group for each plot. Microtopography was estimated using a point-frame to measure average deviation of the soil surface compared to a flat surface.

RESULTS AND DISCUSSION

Boise Front, Idaho: Fire had little effect on the initiation of overland flow. Runoff on all plots began within 4 minutes after start of rainfall (67 mm hr^{-1}, 5 mm cumulative rainfall) for both burned and unburned sites on north and south facing slopes (Figure 1). All sites also reached their peak runoff rates from 8 to 12 minutes following the start of rainfall (Figure 1). Very dry soils, waxy substances on the soil surface, or fire can create a temporary hydrophobic soil condition (Robichaud 2000, De Bano et al. 1967), such that during the first minutes (or longer) of rainfall, water beads on the soil surface and quickly runs off the plot. The water repellency can deteriorate as simulated rainfall continues, resulting in a gradual infiltration rate recovery over the duration of the run. This phenomenon was observed for the unburned plots on both the north and south slopes, and on the moderate and high intensity burns for the north slope, but disappeared within 30 minutes after start of simulated rainfall (Figure 1). For the remainder of the rainfall simulation, there was no difference in infiltration rates demonstrated between unburned sites and north-facing slopes with either moderate or high intensity fires.

Fire intensity had the greatest impact on runoff on the south slopes (Figure 1). Intensively burned south-facing slopes had the lowest cumulative infiltration (34.2 mm) followed by the moderately burned south slopes (46.2 mm), compared to the unburned south slopes (58.0 mm). This represents nearly a two-fold increase in runoff produced by the fire. Fire intensity also produced significantly greater erosion from south aspects as well (Figure 2). Cumulative erosion was up to 34 times higher on intensively burned south slopes compared to unburned conditions or even burned north aspects. This was due to the devastating removal of nearly all the vegetative ground cover that protects the soil and much of the soil organic matter that helps to bind soil particles together.

Closer examination of the spatial variability of infiltration and erosion processes following fire was accomplished by studying the differing effects of fire on coppices (areas directly under shrubs) and interspace areas (areas between shrubs). While both the coppice and interspace sites on south slopes were affected by fire, the fire had the greatest impact on infiltration of coppice areas where terminal infiltration rates were reduced 62 % compared to the unburned treatment. Infiltration on north slopes was little affected by burning and thus, no significant differences were found between coppice and interspace areas. The greatest difference in sediment yield came from intensely burned south-facing interspace sites, where severely burned interspace sediment yield increased immensely over that of even the moderate burn. Aspect differences in fire impacts on erosion have also been noted on forests, where south-facing slopes yielded six times the sediment as north-facing slopes (Marques and Mora 1992). This difference was attributed to the denser vegetative cover and more developed soils found on north-facing slopes. These findings are also consistent with observations made following an intense thunderstorm that occurred over the study area where the south-facing slopes had the highest concentration of rills and suffered significant soil losses.

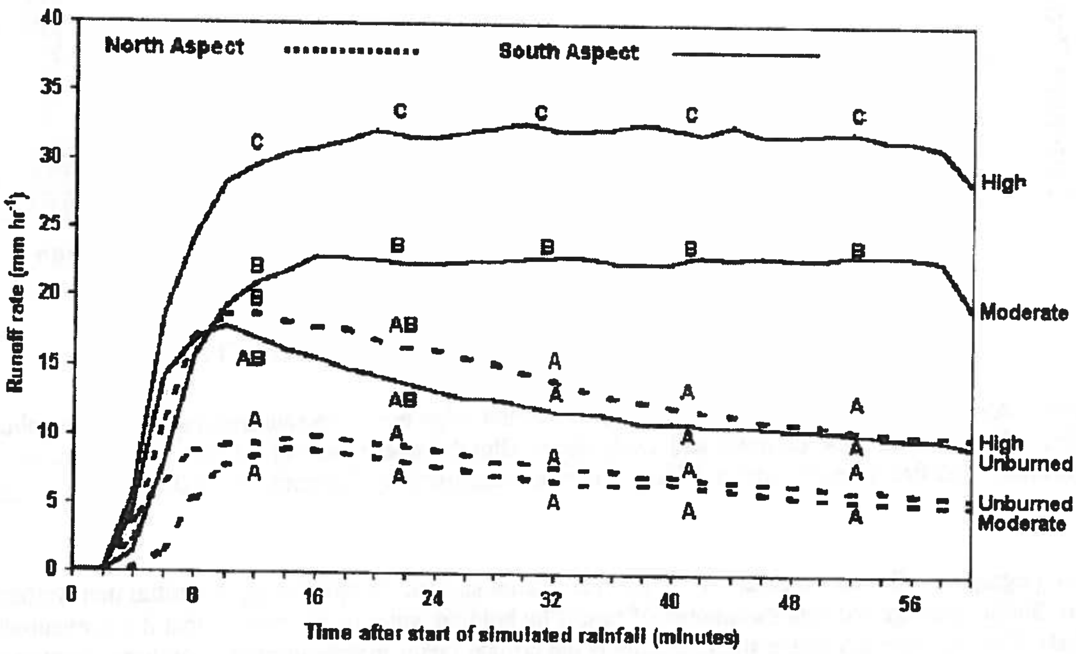


Figure 1. Runoff rate over time for burned (high and moderate fire intensity) and unburned, north and south slopes, Eighth Street Fire, Boise Front, Idaho. Means for each time period with a different letter are significantly different ($P \leq 0.05$).

Microtopography (R=0.51), clay content (R= -0.41), litter biomass (R=0.38), shrub canopy cover (R=0.35), and litter basal cover (R=0.35) were the variables most correlated with infiltration rate over the entire data set. On north slopes, microtopography tended to be greater on interspace (20.1 mm) vs. coppice (18.1 mm) sites and was unaffected by fire. Greater interspace microtopographic relief was probably associated with the dominance of perennial grasses (bunchgrasses). On south slopes, microtopography was reduced by fire, with the greatest reduction on the high intensity interspace site (9.8 mm) where essentially all vegetation and litter was removed. Ground cover (primarily litter) on unburned north slopes approached 100% for both coppice and interspace, but litter biomass was 4 times greater on coppice as compared to interspace sites. South slope unburned coppices had greater basal cover and litter biomass than the interspace sites. Basal cover was much reduced on all burned slopes (1.8 to 5.0 %), as was litter biomass. Virtually none of the litter remained after the fire, and litter biomass had not significantly increased one year after burning.

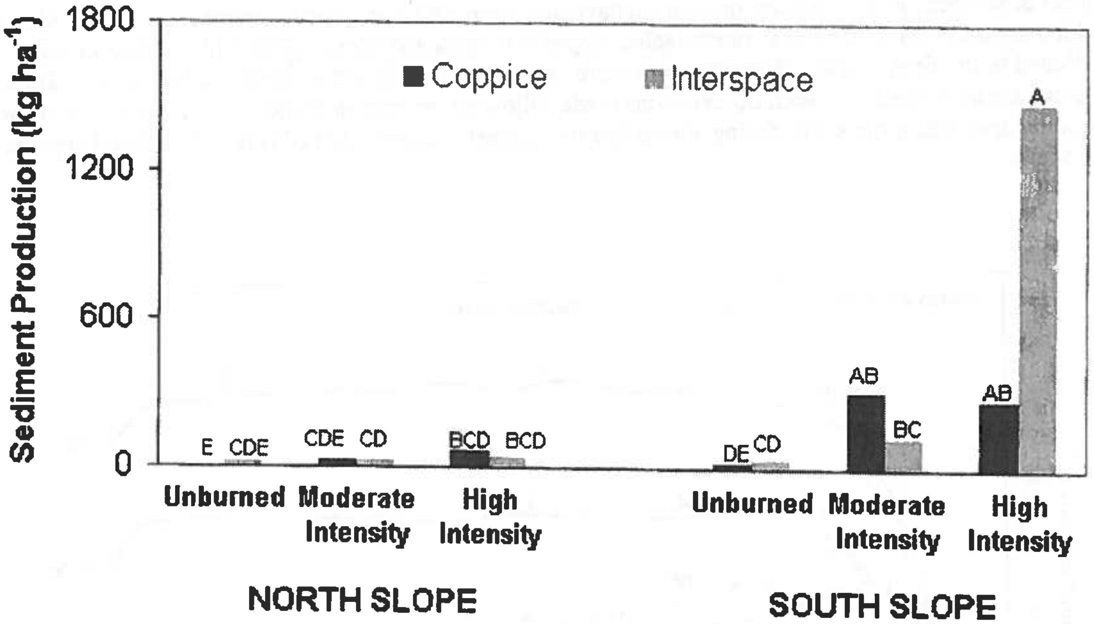


Figure 2. Average total sediment yield (kg ha^{-1}) for burned (high and moderate fire intensity) and unburned coppice and interspace areas on north and south slopes, Eighth Street Fire, Boise Front, Idaho. Means across aspect and fire intensity with a different letter are significantly different ($P < 0.05$).

Microtopographic relief and vegetation can provide crucial surface storage during the initial non-wettable period. Surface storage reduces the amount of runoff by holding water on the plot so that it can eventually infiltrate. Rainfall intensity rather than duration is the critical factor in determining hydrologic response on steeper slopes where initial storage capacity is limited. The study showed that north slopes experienced less runoff even on high intensity burn areas because the microtopography was not significantly reduced despite reduction in litter and cover. This was likely due to the predominance of robust perennial bunchgrasses on the site. The south slopes, however, lacked the microtopographic relief to provide initial storage, so most of the precipitation quickly ran off.

Denio, Nevada: All results presented for this study are preliminary and do not represent rigorous statistical analysis of the data. The study has not yet concluded and final conclusions are not possible.

All burned and unburned sites showed a rapid runoff response with overland flow beginning within 0-4 minutes after initiation of rainfall (85 mm hr^{-1}) (Figure 3). This result is consistent with the rapid hydrologic response measured on the Boise Front. Runoff from all unburned sites showed greater initial runoff from interspace areas compared to coppices, consistent with findings from other studies of the effects of coppice areas on infiltration processes (Pierson et al. 1994). In contrast, runoff from burned sites all had greater initial runoff from coppices that gradually decreased throughout the rainfall period

(Figure 3). In addition, fire had the greatest impact on erosion from burned coppices as well (Figure 4). However, the fire impacts on infiltration and erosion were relatively small, but do indicate that fire can produce a hydrophobic condition on the densely vegetated coppices whereby infiltration is decreased and soil erodibility is increased.

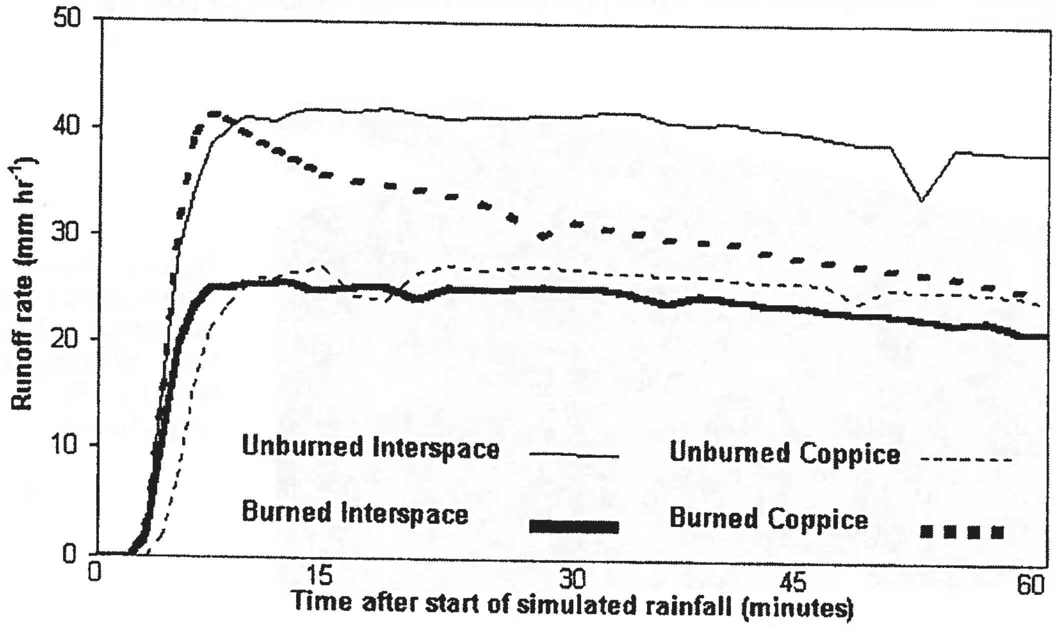
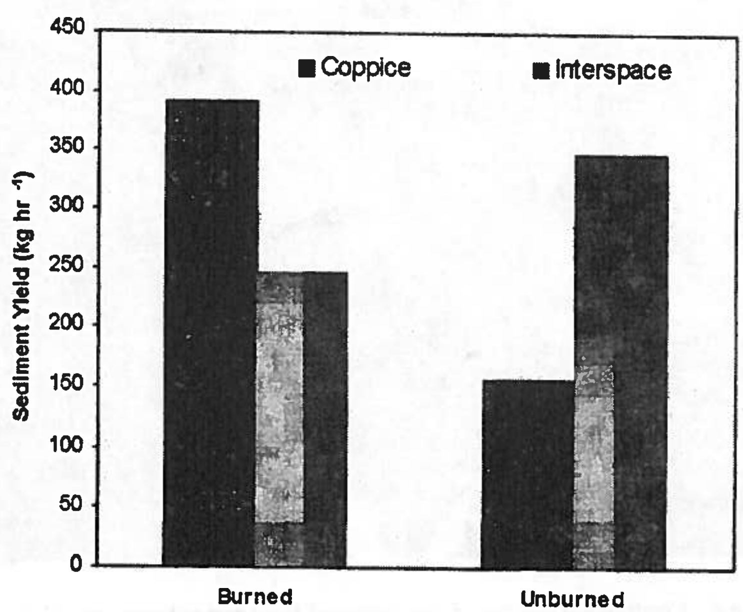


Figure 3. Runoff rate over time for burned and unburned coppice and interspace areas, Denio Fire, Pine Forest Range, Nevada.

Figure 4. Average sediment yield for burned and unburned coppice and interspace areas, Denio Fire, Pine Forest Range, Nevada.



Significant rilling was observed on the burned Denio study sites following periods of rapid snowmelt during the first winter following fire (Figure 5). No rills were observed on the unburned sites. Measurements of rill erosion were then initiated, but results have not yet been summarized. However, very strong differences were observed in overland flow characteristics and rill formation between burned and unburned areas (Figure 6). While fire may not significantly affect infiltration and interrill erosion in these sagebrush/grass ecosystems, it may have a profound effect on concentrated flow paths and rill erosion processes.

Figure 5. Photo of rill erosion during period of rapid snowmelt in late March following the Denio Fire, Pine Forest Range, Nevada.

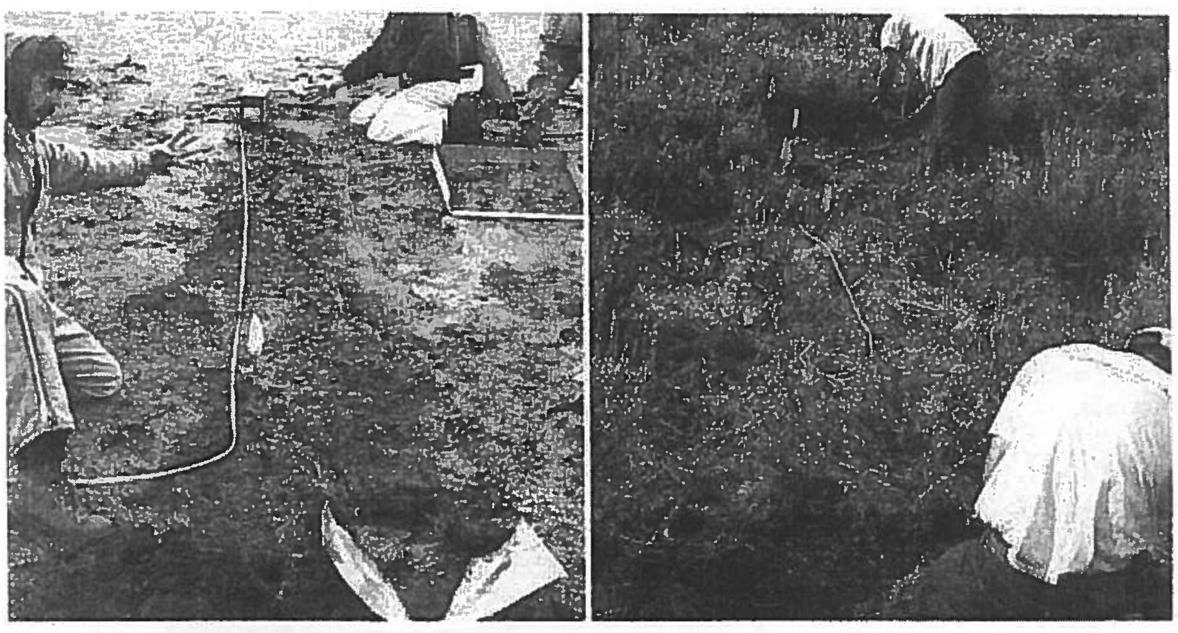


Figure 6. Contrasting photos of concentrated flow and subsequent rill formation between intensely burned areas on the Denio Fire and adjacent unburned areas, Pine Forest Range, Nevada.

IMPLICATIONS

The results of these studies provide a relative index of the increased risk of runoff and erosion following fire. The results imply that south-facing slopes are at greater risk for increased runoff and erosion, and this risk increases as the fire intensity increases. Increased risk comes primarily from the interspace areas that have become devoid of protective vegetative and basal cover. Follow-up treatments for rehabilitation may be most cost-effective when applied to these south-facing slopes. While initiation of runoff (0-4 minutes) was similar for all of these sites, the amount of runoff was primarily determined by both initial storage capacity (microtopography) and soil surface characteristics (soil properties and vegetation).

Burning of litter can create hydrophobic soil conditions in forest systems, and is common where fire burns vegetation with waxy coatings or secondary compounds, resulting in the wax reforming a coating on soil particles (DeBano 1981). This type of fire effect did not seem to dominate on sagebrush grassland. Natural hydrophobicity possibly due to soil surface dryness appeared to be a natural part of the system, at least during dry summer periods. Therefore, fire-induced soil hydrophobicity was not an apparent factor in increasing runoff and erosion from steep burned slopes in this study. Microtopographic relief following fire seemed to provide the best indicator of infiltration rate and sediment yield following fire on steep slopes.

Unanswered Questions: While the Boise Front and Denio studies provide insight into hydrologic processes on steep rangeland slopes and the impacts of wildfire, there are still many unanswered questions. Although hydrophobic soils seem to be a natural part of sagebrush plant communities in dry summer periods, how does the response differ with season of the year? Is this type of hydrophobicity consistent with similar plant communities on different soils? Does wildfire exacerbate or initiate hydrophobic soils on other rangeland communities? If so, what is the spatial and temporal distribution of hydrophobic soils? Is microtopography an important factor on all steep rangelands, or is the factor specific to certain plant community/soil associations? What is the immediate response of sagebrush communities to wildfire, and how does the response change over time? How does recovery differ between sagebrush communities? Are wildfire effects highly site specific, and how can we begin to provide predictive capabilities about the impact of wildfire?

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