

Impacts of Fire on Hydrology and Erosion in Steep Mountain Big Sagebrush Communities

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Abstract

Wildfire is an important ecological process and management issue on western rangelands. Major unknowns associated with wildfire are its affects on vegetation and soil conditions that influence hydrologic processes including infiltration, surface runoff, erosion, sediment transport, and flooding. Post wildfire hydrologic response was studied in big sagebrush plant communities on steep slopes with coarse-textured soils. Significant rill erosion was observed following both thunderstorm and rapid snowmelt events. Rainfall simulation and controlled overland flow techniques were used to study post-fire effects on infiltration, and interrill and rill erosion processes on burned and adjacent unburned areas. Results indicate that burn severity and the development of water repellent soil conditions play significant roles in determining infiltration and interrill erosion rates, particularly on shrub coppice dunes characterized by high surface litter accumulations. The most dramatic and long-lasting affect of fire was on rill erosion processes by reducing ground cover needed to slow and spread water as it moves across the soil surface. Ongoing research efforts are aimed at characterizing the hydrologic impacts of prescribed fire used as a tool to manage vegetation and mitigate the impacts of catastrophic wildfire events.

Keywords: rangeland, fire, hydrology, erosion, infiltration, water repellent soils.

Introduction

Fire is a natural component of the Intermountain sagebrush-steppe ecosystem (Wright and Bailey 1982) with return periods of 25 to 100 years, depending on community type and natural fuel load and distribution. Fuel and land management activities in the past century have disturbed fire frequencies putting wildland values such as soil and water quality at greater risk from devastating wildfires. Higher runoff rates from severely burned landscapes can lead to flooding and increased risk to human life and property. Increased soil erosion over natural levels following wildfire can lead to loss of soil productivity and a decline in rangeland health.

Hydrologic consequences of fire have been closely examined in forested ecosystems, but few studies have examined impacts of wildfire on rangeland hydrology. Many 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 precipitation, slope and vegetation type (Branson et al. 1981, Knight et al. 1983, Wright et al. 1982, Wilcox et al. 1988).

The USDA-ARS Northwest Watershed Research Center (NWRC) has been investigating the interaction of wildfire and rangeland hydrologic processes on steep, coarse textured, sagebrush dominated landscapes in Idaho and Nevada. Research objectives are aimed at quantifying impacts of wildfire on infiltration capacity, runoff, and erosion, gaining insight into the processes

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involved and determining how long fire effects persist. The NWRC is also implementing a prescribed fire research program on Reynolds Creek Experimental Watershed (RCEW) to examine the hydrologic impacts of using prescribed fire as a vegetation and fuels management tool.

Study Areas

Study areas are located on the Boise Front immediately above the city of Boise, Idaho (Eighth Street Fire), and in the Pine Forest Range, 50 km south of Denio, Nevada (Denio Fire). Both sites have vegetation consisting of big sagebrush (*Artemisia tridentata*)/ Idaho fescue (*Festuca idahoensis*) communities. Some areas are characterized by increases in three-awn (*Aristida* spp), Sandberg's bluegrass (*Poa sandbergii*), and rabbitbrush (*Chrysothamnus* spp). Soils on both sites were derived from granite and consist of well drained, fine gravelly coarse sandy loams, on slopes of 35 to 45%. Both sites were severely burned by wildfire. More complete descriptions of study sites are presented by Pierson et al. (2001, 2002).

Methods

At both locations burned sites were compared to unburned sites with the same soil type, slope and vegetation as that found before the fire. Sampling on both burned and unburned sites was stratified based on coppice (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 natural plots, 0.5 m² in size, without pre-wetting. Sampling was conducted in late summer when soil moisture for all plots was extremely low (<10% generally). The Boise Front sites were sampled one year following the fire and the Denio sites were sampled immediately following the fire. 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 one- or two-minute time intervals throughout the 60-minute simulation and analyzed for runoff volume and sediment concentration. Infiltration capacity for each time interval was calculated as the difference between measured rainfall and measured runoff.

A flow regulator was used to apply rill flow rates of 7, 12 and 15 l/min to six randomly selected points at each site to simulate the rill development process. Flow samples were collected 4-m down slope of the release point. Suspended sediment samples for both rainfall and rill procedures were weighed, dried at 105°C then re-weighed to determine runoff rate and soil loss. Flow velocity in each rill was measured by releasing a concentrated salt solution into the rill and using electrical conductivity probes to estimate the mean travel time of the salt over a known rill length. Rill erosion sampling was done in early spring while soils were still moist. Vegetative cover and ground cover were also estimated for each rainfall simulation plot and rill using a combination of pin-point and ocular estimation procedures. Further description of the methodology can be found in Pierson et al. (2001, 2002).

Results and Discussion

Both the Boise Front and Denio study areas were severely burned with virtually all vegetation and litter being consumed during the fire. Bare ground for all burned sites was greater than 95% resulting in increased soil exposure to the erosive forces of raindrop impact and overland flow. Loss of surface litter, vegetative basal cover and associated microtopographic relief also reduced surface storage of water crucial for reducing runoff and increasing infiltration. Past studies have shown that fire can vaporize organic compounds on the soil surface and distill them downwards, creating concentrated water repellent layers within the upper the soil (De Bano 1981, Wright and Bailey 1982). Such water repellent soil conditions are generally temporary (Robichaud 2000b, De Bano et al. 1967), so that during the first minutes (or longer) of rainfall, water beads on or near the soil surface and quickly runs off the plot. Water repellency then deteriorates as rainfall continues, resulting in a gradual recovery in the infiltration capacity of the soil. The following results demonstrate the effects of these fire impacts on critical hydrologic and erosion processes.

Infiltration

The reduction in infiltration capacity due to the fire was concentrated on the coppice microsites for both study sites. Infiltration rates for coppices were reduced by over 30% in the initial stages of runoff (Figures 1 and 2). After one hour of rainfall, the initial fire-induced reductions in infiltration rates had

recovered to a point where no significant differences in final infiltration rates could be detected (Table 1). Coppice microsites are generally dominated by heavy litter accumulations providing ample organic material for the creation of hydrophobic compounds that in turn create water repellent soils. Pierson et al. (2001) defined a soil water repellency index (WRI) to quantify the percent reduction in infiltration capacity during the initial stages of the infiltration process. Burned coppices exhibited an average of 16 and 32% reduction in infiltration due to water repellency on the Boise Front and in Denio, respectively (Table 1).

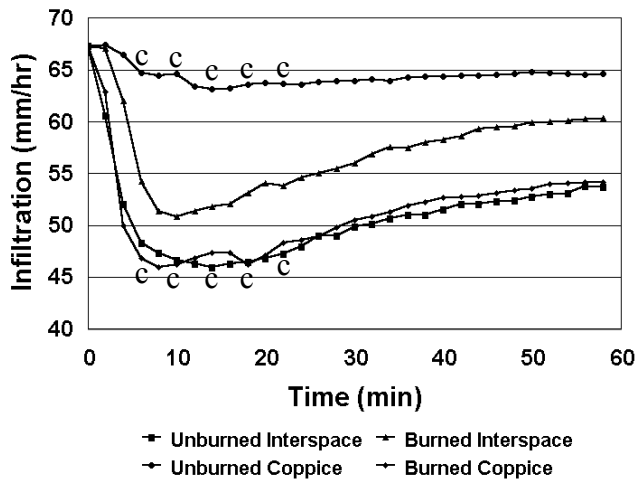


Figure 1. Infiltration rate for burned and unburned microsites, Boise Front, Idaho. Coppice rates within a level of time labeled with the same letter (C) are significantly different (P[0.05).

Under very dry conditions, unburned soils with sufficient waxy substances on the soil surface can also create water repellent soil conditions (DeBano et al. 1967, DeBano and Rice 1973). This phenomenon was observed for unburned interspace microsites at both locations. Unburned interspaces had soil water repellency values of 17% on the Boise Front and 9% in Denio (Table 1). Final infiltration rates for unburned interspaces were lower than all other burned or unburned microsites (Table 1).

Runoff

Fire had a significant, but small affect on the initiation of overland flow on all burned sites. Both sites showed a consistent and rapid runoff response to intense rainfall for all burned and unburned microsites. Runoff on burned coppices consistently began approximately 2 min after the start of rainfall.

Runoff began within 5 min for all burned and unburned microsites (Table 1). Also, all microsites reached their peak runoff rates from 5 to 14 min following the start of rainfall (Table 1).

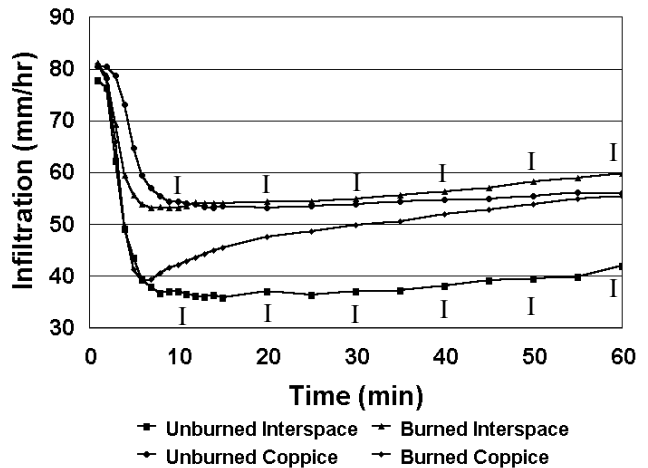


Figure 2. Infiltration rate for burned and unburned microsites, Denio Fire, Nevada. Coppice rates within a level of time labeled with the same letter (I) are significantly different (P[0.05).

The greatest impact of fire in these steep coarse-textured sagebrush systems is not on generating runoff, but its effect on the dynamics of runoff as it begins to move down slope over the soil surface. A year after the fire on the Boise Front, significant rilling was observed following a short intense thunderstorm that flooded the town of Boise, Idaho. In Denio, significant rilling was observed on the burn following numerous rapid snow melt events during the winter following the fire. As a relative measure of how a burned hillslope responds to concentrated overland flow, varying rates of water were released at points on the landscape and the rate of discharge (l/min) was measured at 4 m down slope (Figure 3). At a release rate of 7 l/min, no water reached 4 m on the unburned sites. An average of 2 l/min reached 4 m on the burned sites after the fire and was nearly zero after one growing season. At a flow rate of 12 l/min, water was just beginning to reach 4 m on the unburned sites, while the burned sites flowed at over 4.5 l/min after the fire. Flow declined to less than 1 l/min on the burn after two growing seasons. At a release rate of 15 l/min, the unburned sites flowed at less than 0.3 l/min on the unburned sites. Flow on the burned sites dramatically increased to over 8 l/min after the burn and still flowed at 2 l/min after two growing seasons of vegetation recovery.

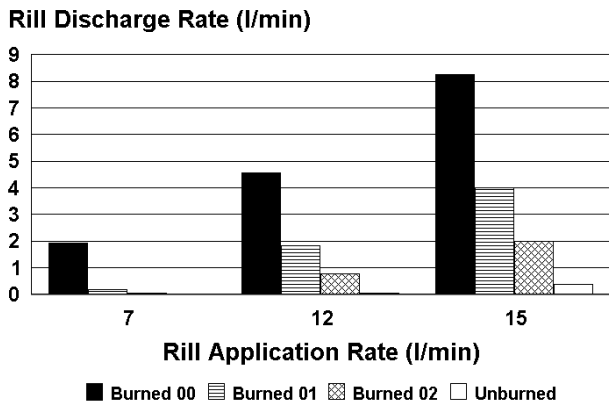


Figure 3. Rill discharge rate for burned and unburned sites on the Denio Fire, Nevada.

Vegetation, litter, rocks and other forms of ground cover create barriers that slow and spread water movement across the soil surface allowing more time for water to infiltrate over a larger surface area. Fire removes most of these barriers and allows the water to concentrate into rills where flow depth and velocity increase. This significantly decreases runoff response time and increases the runoff volume delivered to the bottom of a hillslope and into a stream channel. After the Denio fire, nearly all the soil ground cover was removed exposing over 95% bare ground compared to less than 5% bare ground on the unburned sites (Figure 4). It took two growing seasons and three winters for litter accumulation to reduce the amount of bare ground on the burned sites to near 50% (Figure 4). A ground cover of 60% is often used to gauge adequate hydrologic protection of a site (Gifford 1985, Robichaud 2000a). These results indicate that while 50% vegetation and litter cover does induce a significant reduction in overland flow, the site is not yet fully protected compared to unburned conditions.

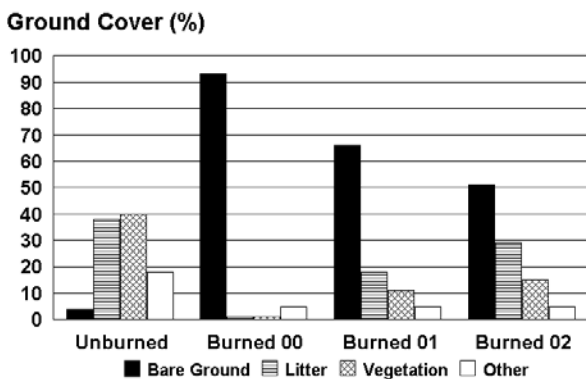


Figure 4. Ground cover for burned and unburned sites on the Denio Fire, Nevada.

Erosion

Fire had far greater impact on rill erosion compared to interrill erosion. Interrill erosion was relatively low for all burned and unburned microsities after both fires. The only significant fire effect observed was for burned coppice microsities on the Denio fire (Table 1). To examine the impact of the fire on rill erosion, the sediment concentration of the rill discharge collected 4 m down slope was used as a relative index to compare burned and unburned sites (Figure 5). No measurable sediment was collected on the unburned sites at any of the flow rates applied. At a flow rate of 7 l/min, over 175 g/l of sediment were measured after the Denio fire and dropped to zero after two vegetation growing seasons. At a flow rate of 12 l/min, over 110 g/l of sediment were measured for the burned sites after the fire and near 10 g/l of sediment were measured after two growing seasons. At a flow rate of 15 l/min, burned sites exhibited sediment concentrations of over 75 g/l after the burn and less than 10 g/l after two growing seasons. The observed decline in post-fire sediment concentrations as the rill flow rates increased was due to the rills becoming "armored". Rills became sediment limited as the detachable sediment was removed by lower flow rates.

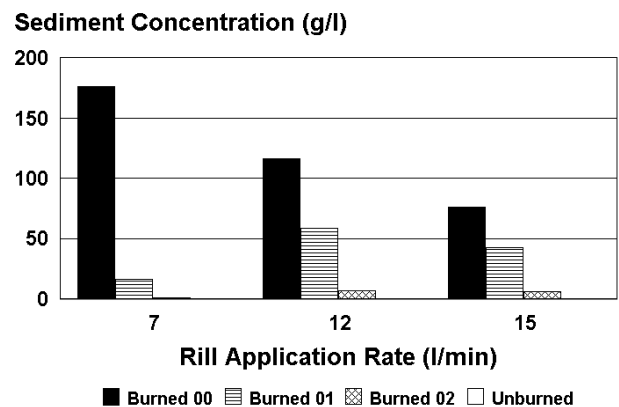


Figure 5. Rill sediment concentration for burned and unburned sites on the Denio Fire, Nevada.

The velocity of the water flowing in a rill is directly related to its ability to detach and carry sediment. As an example, the rill velocity at the 15 l/min release rate for the unburned sites was consistently under 0.05 m/s throughout the study (Figure 6). Such a velocity is apparently insufficient to detach and carry sediment down slope in a fully protected system with high ground cover of vegetation and

Table 1. Hydrologic and erosion variables for the Boise Front and Denio study sites. Values across a row followed by different letters are significantly different ($p < 0.05$).

| | Burned Coppice | Burned Interspace | Unburned Coppice | Unburned Interspace |
|---|----------------|-------------------|------------------|---------------------|
| Final Infiltration Rate (mm hr^{-1}) | | | | |
| Boise Front, ID | 54.2a | 60.4a | 64.7a | 53.7a |
| Denio, NV | 55.5ab | 60.0a | 55.9ab | 40.4b |
| Water Repellency Index (%) | | | | |
| Boise Front, ID | 16.3a | 16.1a | 3.3b | 17.3a |
| Denio, NV | 32.2a | 11.6b | 5.3b | 9.4b |
| Time to Runoff (min) | | | | |
| Boise Front, ID | 2.5b | 4.3a | 5.4a | 2.1b |
| Denio, NV | 1.8b | 2.0ab | 3.0a | 2.0ab |
| Time to Peak Runoff (min) | | | | |
| Boise Front, ID | 12.4a | 12.8a | 14.0a | 13.6a |
| Denio, NV | 5.6a | 5.5a | 7.8a | 6.3a |
| Sediment/ Runoff Ratio ($\text{kg ha}^{-1} \text{mm}^{-1}$) | | | | |
| Boise Front, ID | 3.5a | 3.8a | 1.2a | 0.9a |
| Denio, NV | 13.6a | 8.7ab | 5.1b | 6.4b |

litter. The velocity for burned sites was near 0.21 m/s after the burn and declined to 0.075 m/s after two growing seasons. This indicates that a velocity of 0.075 m/s can still cause rill erosion in a system protected by only 50% ground cover.

Rill Flow Velocity (m/s)

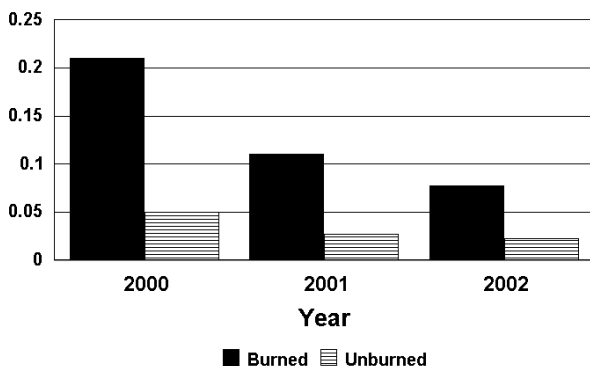


Figure 6. Rill flow velocity for a rill flow rate of 15 l/min for burned and unburned sites on the Denio Fire, Nevada.

Implications

The results of these studies provide a relative index of the increased risk of runoff and erosion and the rate of hydrologic recovery following fire in coarse-textured sagebrush dominated systems. Fire in these systems can induce significant water repellency, particularly in areas dominated by shrubs with large accumulations of litter to fuel the intensity of the fire and provide the hydrophobic substances necessary to create water repellent soils. However, it is important

to keep in mind that these systems have a certain degree of natural water repellency when they are extremely dry. This can confuse and confound the assessment of fire-induced water repellency often inventoried and used after wildfires to determine the need for post-fire mitigation. In general, the greatest impact of the fire is not on infiltration, but on overland flow dynamics and rill erosion. Whether burned or unburned, these types of sites are going to rapidly generate runoff under intense rainfall. The impact of the fire is that it leaves sites devoid of barriers to slow and store runoff once it begins to move. The water then concentrates and increases in velocity resulting in greater erosive energy. Water moves more rapidly down slope and ultimately into stream channels potentially causing downstream flood damage.

Future Research

The natural fire cycle of many rangeland ecosystems has been disrupted by past management and fire suppression activities. The result has been a dramatic increase in catastrophic wildfires across the western United States over the past decade. To reduce the threat of wildfire and return these ecosystems to a healthy state means to return them to a natural fire cycle. The NWRC in addition to the work on the hydrologic impacts of wildfire has established a long-term prescribed fire research program on RCEW in southwest Idaho. The goals of the research program are to: Determine the short- and long-term effects of prescribed fire on runoff, erosion, water quality and vegetation and forage in

rangeland ecosystems; develop pre-fire assessments for predicting post-fire soil, vegetation and hydrologic responses; and investigate interactions of prescribe fire and grazing for reducing the threat of wildfire. The NWRC intends to transfer research findings through decision support tools to help managers determine the risk of wildfire, to explore options for reducing such risk through the use of prescribed fire, and to predict post-fire impacts and optimize rehabilitation strategies.

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