



## Rill erosion rates in burned forests

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### Introduction

Wildfires often produce large increases in runoff and erosion rates (e.g., Moody and Martin, 2009), and land managers need to predict the frequency and magnitude of post-fire erosion to determine the needs for hazard response and possible erosion mitigation to reduce the impacts of increased erosion on public safety and valued resources. The Water Erosion Prediction Project (WEPP) hillslope erosion model uses parameters based on field measurements to calculate the interrill and rill components of erosion (Nearing et al., 1989). Since rill erosion is the dominant hillslope erosion process in burned forests (Pietraszek, 2006), Robichaud et al. (2010) used simulated runoff experiments to compare rill erosion rates among unburned and burned forest plots in the western U.S. These experiments provided measurements of the magnitude of rill erosion in burned areas as compared to rates in unburned areas and also were used to calculate the rill erosion parameters needed for accurate prediction of post-fire erosion rates.

Rill flow, which occurs when sheet or interrill flow becomes concentrated, has more energy available for soil detachment than sheet wash because of the higher shear stresses resulting from the greater flow depths. Rill erosion can occur via several mechanisms, all analogous to stream channel erosion, including bed erosion, bank erosion, headcut formation, and sloughing. The rill erodibility parameter used in the WEPP model relates the sediment load of the flow to the hydraulic shear stress acting on the soil and, along with the hydraulic properties computed from the hydrologic model, is used to predict the rill erosion rates (Foster et al., 1995).

We recently reported some rill erodibility parameters for unburned and burned forests (Wagenbrenner et al., 2010), but it is unclear how much the parameter varies by location (e.g., climate, soil type, vegetation, etc.). Also, we do not know how quickly the rill erodibility parameter changes over time as the burned site recovers to its pre-burned hydrologic condition. Accurate predictions of post-fire erosion rates require that we address these questions.

### Objectives

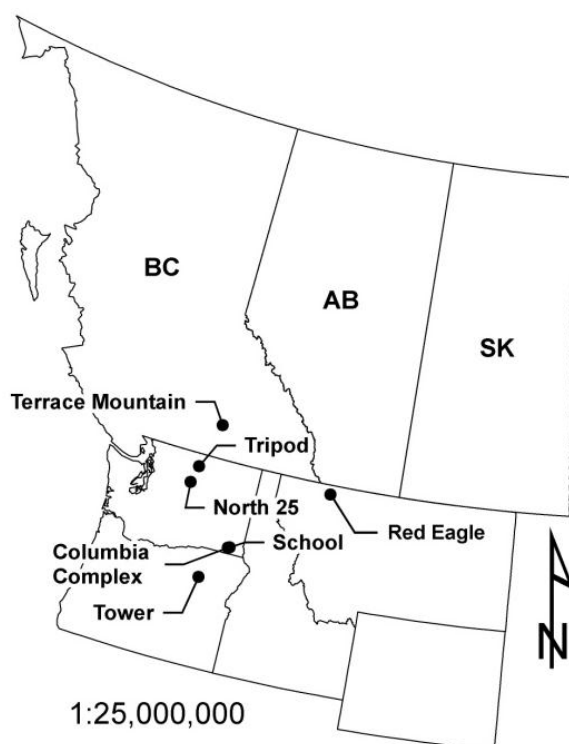
The goal of this study was to compare runoff rates, sediment flux rates, and rill erodibility parameters from simulated rill experiments among burned hillslopes in the western U.S. and Canada. The objectives were to: 1) Determine if the runoff rates or sediment flux rates varied by location or within 3 years of burning; 2) Determine if there are differences among rill erodibility parameters for burned areas based on location; and 3) Determine if the rill erodibility parameters for burned areas change within 3 years of burning.

### Methodology

The seven study sites (North 25, Columbia Complex, Tripod, Terrace Mountain, Tower, School, and Red Eagle) (Figure 1) were in coniferous forests burned at high soil burn

severity and ranged in elevation from 1000 m to 1800 m. Soils and parent materials varied among the sites although the soil textures were all silt loams or sandy loams. Mean annual precipitation at the sites was between 600 and 1400 mm. Slopes ranged from 36 to 51%.

Hillslope plots, 9 m (4 m at the North 25 site) in the direction of the slope gradient, were established within either a few weeks (North 25, Columbia Complex, Tripod, and Terrace Mountain sites) or one year (Tower, School, and Red Eagle sites) of burning (Figure 1). The experiments consisted of controlled releases of water at 5 flow rates (nominally 7, 22, 30, 15, and 48 L min<sup>-1</sup>) each for 12 min in succession. Runoff samples were collected approximately every 2 min during the 60 min experiments to calculate runoff and sediment flux rates (Robichaud et al., 2010). Runoff velocities and flow depths and widths were measured at each flow rate to calculate the rill erodibility parameters (Wagenbrenner et al., 2010). The experiments were repeated one year later at all sites except Tower and North 25, and two years later at all sites except Tower, North 25, and Terrace Mountain.



**Figure 1.** Locations of the seven sites in western North America

### Results and conclusions

Runoff rates were highest in the year of the fire and averaged 17 L min<sup>-1</sup> (n = 4) with values ranging from 12 to 20 L min<sup>-1</sup> (Table 1). The runoff rates were lower in the first post-fire year (n = 6), when the mean value was 12 L min<sup>-1</sup>, but ranged from 4 to 18 L min<sup>-1</sup>. The means continued to decrease in the second and third post-fire years to 8 and 5.6 L min<sup>-1</sup>, but the ranges were also relatively large (3 to 15 L min<sup>-1</sup> [n = 4] and 1 to 10 L min<sup>-1</sup> [n = 2], respectively) (Table 1). The mean runoff rates in the burned areas initially were 6 times greater than rate measured in unburned plots in the North 25 and Tower sites (2.7 L min<sup>-1</sup>) (Robichaud et al., 2010) and by the third post-fire year the

burned runoff rates were still 2 times greater than the previously reported unburned rates (Table 1).

The sediment flux rates averaged  $2.4 \text{ g s}^{-1}$  and ranged from  $0.8$  to  $4.6 \text{ g s}^{-1}$  among the 4 sites in the year of the fire. In the first post-fire year, the mean sediment flux increased to  $3.8 \text{ g s}^{-1}$ , despite measured decreases in the 3 sites with data from the year of the fire and the first post-fire year (Table 1); the range also increased in the first post-fire year, and site values were between  $0.3$  and  $9.2 \text{ g s}^{-1}$ . The mean sediment flux decreased to  $1.6 \text{ g s}^{-1}$  in the second post-fire year, and the 4 site values were between  $0.2$  and  $6.6 \text{ g s}^{-1}$ . There was no change in sediment flux in the third post-fire year, when the mean for the 2 sites was  $1.7 \text{ g s}^{-1}$  (Table 1). As with the runoff rates, the sediment flux rates in the burned areas were initially 185 times greater than those reported in the unburned plots at the North 25 and Tower sites ( $0.013 \text{ g s}^{-1}$ ) (Robichaud et al., 2010). While this ratio decreased over time, the burned rates were still 130 times greater than the unburned plots in the third post-fire year.

**Table 1.** Mean runoff rates, sediment flux rates, and rill erodibility parameters by site and post-fire year. PFY refers to post-fire year; PFY 0 is the year of the fire.

| Site             | PFY | Runoff<br>( $\text{L min}^{-1}$ ) | Sed. flux<br>( $\text{g s}^{-1}$ ) | Erodibility<br>( $\text{s m}^{-1}$ ) |
|------------------|-----|-----------------------------------|------------------------------------|--------------------------------------|
| North 25         | 0   | 20                                | 1.7                                | ++                                   |
| Columbia Complex | 0   | 17                                | 4.6                                | $1.1 \times 10^{-5}$                 |
| Tripod           | 0   | 20                                | 2.7                                | $7.0 \times 10^{-6}$                 |
| Terrace Mountain | 0   | 12                                | 0.76                               | $8.8 \times 10^{-6}$                 |
| Columbia Complex | 1   | 9.5                               | 3.1                                | $1.0 \times 10^{-3}$                 |
| Tripod           | 1   | 17                                | 2.1                                | $6.3 \times 10^{-6}$                 |
| Terrace Mountain | 1   | 8.7                               | 0.29                               | $1.1 \times 10^{-5}$                 |
| Tower            | 1   | 18                                | 9.2                                | $5.7 \times 10^{-4}$                 |
| School           | 1   | 16                                | 7.2                                | $4.7 \times 10^{-5}$                 |
| Red Eagle        | 1   | 4.3                               | 0.54                               | $4.3 \times 10^{-5}$                 |
| Columbia Complex | 2   | 5.1                               | 0.20                               | $1.8 \times 10^{-6}$                 |
| Tripod           | 2   | 15                                | 1.6                                | $2.0 \times 10^{-4}$                 |
| School           | 2   | 9.1                               | 4.5                                | $1.0 \times 10^{-4}$                 |
| Red Eagle        | 2   | 2.8                               | 0.27                               | $1.4 \times 10^{-5}$                 |
| School           | 3   | 10                                | 3.2                                | $3.3 \times 10^{-5}$                 |
| Red Eagle        | 3   | 1.1                               | 0.21                               | ++                                   |

++ The erodibility was negative for this site/year combination.

The rill erodibility parameters averaged  $8.9 \times 10^{-6} \text{ s m}^{-1}$  for the 3 sites with available data in the year of the fire and there was surprisingly little variation among the sites, despite the wide range in the sediment flux rates (Table 1). The rill erodibility values increased substantially to  $2.0 \times 10^{-4} \text{ s m}^{-1}$  in the first post-fire year because of the very large value in the Columbia Complex site (Table 1). The mean rill erodibility decreased to  $7.9 \times 10^{-5} \text{ s m}^{-1}$  in the second post-fire year. Only one of the two rill erodibility values was physically realistic in the third post-fire year, and the value was  $3.3 \times 10^{-5} \text{ s m}^{-1}$ . As with the runoff and sediment flux data, the rill erodibility values from the burned sites were between 6 and 130 times greater than the  $1.5 \times 10^{-6} \text{ s m}^{-1}$  reported for the North 25 and Tower unburned sites (Wagenbrenner et al., 2010).

There were large variations in runoff rates, sediment fluxes, and rill erodibility parameters among the seven burned sites in this study. The post-fire runoff and sediment flux rates within sites decreased as time passed, but because of the averaging across sites, the means did not always decrease over time. There was much variability in the rill erodibility



values, and so there was no clear trend over time in these data. It appears that the differences in site characteristics cause enough of a difference in the data that different parameters may be needed to model rill erosion at different burned sites. It is not clear whether each site will need its own set of parameters, or if parameters can be grouped by some physical attribute such as soil texture or some fire-induced effect such as residual organic matter and still accurately represent the physical setting. The model(s) should also account for the rapid changes in the measured runoff and sediment flux rates in the first few years after burning. These results will help focus future analysis and research, and also allow land management agencies to better predict the effects of wildfire, especially with respect to hydrologic recovery.

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