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EROSION RATES FROM FORESTS AND RANGELANDS FOLLOWING FUEL MANAGEMENT

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Abstract. In both forest and rangelands, fuel reduction operations are now common practices. Mechanical thinning followed by prescribed fire is common in forests, while fire is frequently applied to rangelands. Studies at different scales (50 sq m to 389 ha) measure the erosion from fuel management. This presentation compares runoff and erosion from these studies. Plot size has the greatest influence on runoff, with larger watersheds generating more runoff. Runoff ranged from zero on a number of 4-ha forested watersheds to 376 mm on a 386 ha forested watershed. Erosion rates were most influenced by surface cover. Observed erosion rates on rangelands were about 0.04 Mg ha^{-1} on undisturbed plots and 0.06 Mg ha^{-1} on burned plots. On forests, measured erosion rates were zero to 0.03 Mg ha^{-1} y^{-1}, increased up to 0.1 Mg ha^{-1} y^{-1} for prescribed fire, and up to 6.7 Mg ha^{-1} y^{-1} following wildfire.

Keywords Runoff; Erosion; Thinning; Prescribed Fire; Wildfire.

INTRODUCTION

One of the ecosystem services provided by our nation's forests and rangelands is quality surface runoff. The quality and quantity of that runoff are of critical interest to growing urban centers in all parts of the US, particularly in the West (Dissmeyer, 2000). Water quality and quantity are also important to support hydroelectric generation and industry, provide recreation, and maintain aquatic ecosystem health.

Managers have been increasingly active in reducing excessive fuel loads on wildland watersheds. Their main tools are thinning in forests, and prescribed fire in both forests and rangelands. In the absence of such management, wildfires will occur, with the severity of the fire often linked to the availability of fuel. Managers are attempting to reduce wildfire severity and/or frequency by reducing wildland fuel loads. It is generally recognized that runoff and erosion from wildland watersheds will increase following human and natural disturbances. Managers need to have some knowledge of the magnitude of runoff and erosion associated with such disturbances to support their planning activities. Model developers also require observed runoff and erosion data to assist in model validation. There are, however, limited data available to quantify such increases. The objective of this paper is to present research data collected in forest and rangeland plots and watersheds in the Northern Rocky Mountains, to aid resource managers and model developers.

RESEARCH SITES

Information on the watershed impact of fuel management has been collected at several research sites in the northern Rocky Mountains (Table 1). Figure 1 shows the location of those research sites. The rangeland sites were 50 sq m plots with tipping buckets measuring the runoff (Figure 2). The runoff and erosion values are averages from 3 years for the prescribed fire plots, and two years for the control plots. Two sites have sets of ten small watersheds located in forests (Figure 3). There are three years of runoff data for Priest River, ID, and two for Boise Basin, ID. At Priest River, the main watershed containing the ten small watersheds has over 60 years of runoff data. The average annual runoff for the period between 1938 and 1955 is shown in Table 1 (Stage, 1957). The small forested watersheds had not been disturbed in at least ten to more than 100 years at Priest River, and almost fifty years in Boise Basin. Another forested site near Moscow, ID had a set of nested watersheds, with the smaller 106 ha watershed contained within a larger 177 ha watershed (Zhang et al., 2006). These watersheds had one to three years of runoff and sediment data. The results from three sites had been harvested and then treated with a prescribed fire are described in more detail in Covert (2003), Covert et al. (2005) and Dun et al. (2006). These sites had three to five years of monitoring data. Two sites had two watersheds that had experienced a wildfire. One wildfire watershed on each site was treated with contour-felled logs to reduce runoff and erosion, and the other left untreated. The wildfire erosion rates that are presented are for the first year following the fire. Four of the plots had been burned, and three were not treated. The forested watersheds ranged from 2 to 13 ha, and measured runoff with either H-flumes (Figure 3) for forest and prescribed fire, or V-notch weirs for wildfire (Figure 4). All plots had sediment basins or collectors to retain eroded sediments.

Table 1. Summary of research sites where fuel management and wildfire data have been collected in the Northern Rocky Mountains

Vegetation	Location	Soil Texture	Average Slope (%)	Annual Precip (mm)	Plot Number and Size	Probability of runoff	Avg Annual Runoff (mm)	Erosion Rate (Mg ha^{-1} y^{-1})
Rangeland (Burned & Control)	Caribou-Targee NF, Montpelier, ID	Sandy loam	Cont: 30 Burn: 25	520	4 Burned, 3 Control 50 sq m	1.0	Control 5.0 Burned: 5.2	0.042 0.060
Forest	Boise Basin Exp Forest, Idaho City, ID	Sandy loam	33	825	10 watersheds Avg area 3.8 ha	0.3	-	-
Forest	Priest River Exp. Forest, Priest River, ID	Silt loam	29	918	10 watersheds, Avg area 4.6 ha 386 ha	0.23 1.0	- 376	- -
Forest	Moscow, ID	Silt Loam	37 30	620	106 ha 177 ha	1.0	130 230	0.01 0.03
Prescribed Fire	Payette NF, McCall, ID	Silt loam	50	600	2 ha	1.0	32	0.1
Prescribed Fire	Boise NF, Idaho City, ID	Sandy loam	40-60	748	9 ha	1.0	161	0.0
Prescribed Fire	Bitterroot NF, West Fork, MT	Silt loam	40-63	418	7 ha	1.0	57	0.0
Wildfire (Treated & Control)	Bitterroot NF, Sula, MT	Silt loam	39	934	2.8 & 3.6 ha	1.0	-	Control: 0.78 Treated: 0.31
Wildfire (Treated & Control)	Gallatin NF, Livingston, MT	Silt loam	37	750	11.8 & 13.3 ha	1.0	-	Control: 6.70 Treated: 6.11

Figure 1. Location of research sites

RESULTS AND DISCUSSION

The observed average annual precipitation, runoff and erosion rates are presented in Table 1.

Precipitation

Average annual precipitation ranged from 418 mm on the prescribed fire site in Montana to 918 mm on the forested site in Priest River, ID. The precipitation is dominated by winter snow, spring snowmelt, and rain-on-snow runoff events. The Gallatin site also had high intensity summer storms.

The precipitation on the prescribed burn site in Montana was lower than the rangeland site some 200 km further south (Figure 1) The winter precipitation at Priest River is more likely to be rain than it is at Boise Basin, so the snow accumulations are generally greater at the Boise Basin site.

Runoff

Table 1 shows that runoff is more influenced by watershed area than it is by precipitation amount. The runoff from the large forested Moscow and Priest River watersheds are much greater than the other smaller forested plots at Priest River or Boise Basin, where there was no measurable runoff from many of the plots. This is likely due to the fact that the dominant runoff process from forested watersheds is lateral flow rather

Table 2. Range of cover values for treatments.

Vegetation	Range of Cover (%)	Range of Erosion Rates (Mg ha^{-1} y^{-1})
Forest	98 – 100	0.01 – 0.03
Prescribed Fire	58 – 100	0.00 – 0.10
Rangeland	Control: 92 – 95 Burned: 48 – 76	0.05 - 0.07 0.02 – 0.10
Wildfire	8 – 10	0.31 – 6.70

than surface runoff. The larger the area, the more likely it is that subsurface lateral flow will become measurable in surface runoff.

Another influence on runoff is vegetation. The greatest runoff amounts from the small watersheds were from the prescribed fire site in the Boise NF. It is not clear from the data whether the large difference in runoff between the prescribed fire sites is due to size of watershed or some other attribute.

The observed runoff values from the wildfire plots are not included in Table 1 because they were only recorded during large erosion events. The low runoff rates from spring snowmelt did not fill the sediment basins, but rather infiltrated into the bottom of the large sediment basin required for the wildfire sites (Figure 4).

The paired rangeland sites had similar runoff values whether treated or not.

Erosion

Table 1 shows that erosion on the forested plots was the lowest, and ranged from 0.0 to 0.03 Mg ha^{-1} y^{-1}. The sediment delivered from the Moscow Mountain watersheds likely came from both hillslope and channel sources (Zhang et al., 2006). The prescribed fire forested sites also had very low erosion rates, ranging from immeasurable to 0.1 Mg ha^{-1} y^{-1}. The erosion on the rangeland sites averaged between 0.04 and 0.06 Mg ha^{-1} y^{-1}. The rangeland plots were the smallest in the study, and so they did not have the channel processes that were likely present on the other watersheds, and hence lacked any channel deposition of detached sediments, which may have occurred on the larger plots. The highest erosion rates were on the wildfire sites with erosion ranging from 0.31 to 6.07 Mg ha^{-1} y^{-1} the year following the fire. The erosion rates are directly linked to the observed ground cover for each of the treatments (Table 2).

APPLICATION TO TMDL ANALYSIS

The data presented in this paper are average annual values for all sites except wildfire, where they are the values the year following the fire. They are not Total Maximum Daily Loads (TMDLs). Elliot (2006 and 2007) and Elliot and Robichaud (2006) have suggested that for wildland watersheds, average annual values are likely better indicators for nonpoint sediment pollution than are TMDLs. If this is the case, then the methodology proposed by Elliot (2006 and 2007) and Elliot and Robichaud (2006) can be applied to these data. These papers propose that a "background" sediment value be estimated by adding the erosion from the wildfire divided by the fire return interval to the erosion from the undisturbed forest. The impact of the management practice can then be compared to this background value, and an appraisal made of the likely benefits of the management practice in reducing future wildfire frequency and/or severity. Table 3 expresses the data following this procedure, using average values for each condition from Table 1.

Table 3 shows that a "background" erosion rate calculated from the observed values is 0.11 Mg ha^{-1} y^{-1}. The observed values compare well with historical sediment yields from watersheds in this area. Megahan and Kidd (1972) estimated erosion rates from undisturbed forested watersheds to be about 0.09 Mg ha^{-1} y^{-1} but attributed this all to landslide activity. The average contribution of sediment from a prescribed burn is 0.0015 Mg ha^{-1} y^{-1}, or about 1.4 percent of the background value. It is generally believed that prescribed fire will reduce the severity or frequency of wildfire, and hence, any increase in sedimentation due to the prescribed fire will soon be offset by a decrease in erosion following wildfire.

Predictive Tools

An online prediction tool has been developed to aid in applying this average annual technology to forest hillslopes (Elliot and Robichaud, 2006). This tool, WEPP FuME, was run for a climate and topography similar to these sites. The output from WEPP FuME is for a hillslope, and is presented in Table 3. As the research sites were all watershed sites, a delivery ratio estimate is needed to compare the predicted values to the observed values. Delivery ratios from Elliot (2007) were used to make this adjustment, and are presented in Table 3. The stated accuracy of WEPP FuME is that the true erosion rate is likely within plus or minus 50 percent of the predicted value. From the data presented in this paper, it appears that in all cases, the observed values are within this predicted range after adjusting for sediment delivery. Variations in

Table 3. Application of observed erosion data to a watershed analysis.

Condition	Observed Annual Erosion Rate (Mg ha^{-1} y^{-1})	Frequency of Occurrence (y)	Average Annual Erosion Rate (Mg ha^{-1} y^{-1})	WEPP FuME Output (Mg ha^{-1} y^{-1})	Delivery Ratio	WEPP FuME Estimated Annual Erosion Rate (Mg ha^{-1} y^{-1})
Forest	0.02	1	0.02	0.067	0.55	0.04
WildFire	3.74	40	0.09	0.214	0.28	0.06
"Background"			0.11			0.10
Prescribed Fire	0.03	20	0.0015	0.080	0.41	0.03

climate and disturbance will lead to onsite erosion variations both above and below a predicted average value.

CONCLUSIONS

This paper presents erosion and runoff data from ten different studies varying in size and vegetation. From these watersheds, the runoff volumes are most closely related to the size of the watershed, with larger watersheds generating more runoff regardless of vegetation. Prescribed fire generates more runoff than undisturbed forest on watersheds of similar size. Watershed sediment delivery is dominated by ground cover, with the greatest sediment delivery from watersheds following wildfire, and the lowest values from undisturbed forests and watersheds that had been treated with prescribed fire. The observed erosion rates were within the stated range of the WEPP FuME predictions after adjusting for sediment delivery.

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Figure 2. Sediment basin and tipping bucket used on rangeland plots

Figure 3. Collector, sediment basin, and h-flume on forested watershed.

Figure 4. Large sediment basin and v-notch weir outlet