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RUNOFF AND SOIL LOSS FOLLOWING THE 1988 YELLOWSTONE FIRES

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Abstract. Fires burned 570,000 hectares (1.41 million acres) in the Greater Yellowstone Area during 1988 with accelerated runoff and soil loss as an expected result. A rainfall simulator was used in the summer of 1989 to measure runoff and soil loss on plots representing a range in geologic substrate, logging history, fire intensity, and geomorphic-pedologic conditions. Water repellent soils were common, producing high rates of runoff and soil loss for the experimental rainfall event. Rates of soil loss were highest on sites where litter cover was minimal, percent silt content in soils was high, and logging had occurred. Rates of runoff and soil loss did not exhibit statistically significant differences between glacial till and volcanic terrain, but the logging-fire history was associated with statistically significant differences in soil loss. Soil loss was highest on sites which had been logged before the 1988 fires and then burned, and this was attributed to the higher fuel load on the forest floor.

INTRODUCTION

Fires originating from both lightning and from human-caused ignition burned 570,000 hectares (1.41 million acres) in the Greater Yellowstone Area (GYA) during 1988 (Fig. 1). Based on data from fire scars, these fires were judged to be the most extensive since the early 1700's (Romme and Despain, 1989). The purpose of the present study was to describe, explain and predict changes in runoff and soil loss from rainsplash and erosion due to the 1988 fires.

Runoff and soil loss usually increase after fires because of vegetation removal and soil water repellency (Bethalmy, 1974; DeBano, 1981; Morris, 1986; Morris and Moses, 1987). With vegetation in-place, trees, ground cover and litter protect the soil from the direct impact of raindrops. Litter also absorbs runoff and traps sediment (Taylor, 1974; Hart et al., 1981). The roots of trees and grass bind the soil. Vegetation also decreases the water available to the soil surface for erosion by extracting soil water which is then lost through transpiration and by evaporating water which had been intercepted. Revegetation of burned areas in the GYA began immediately after the 1988 fires from the roots of grasses and forbs which were unaffected by all but the most intense fires (Greater Yellowstone Postfire Ecological Assessment Committee, 1989). Typically within one year after a fire, up to 20 percent of the pre-fire species may be found and within 25 years a maximum of species diversity may be expected (Taylor, 1974).

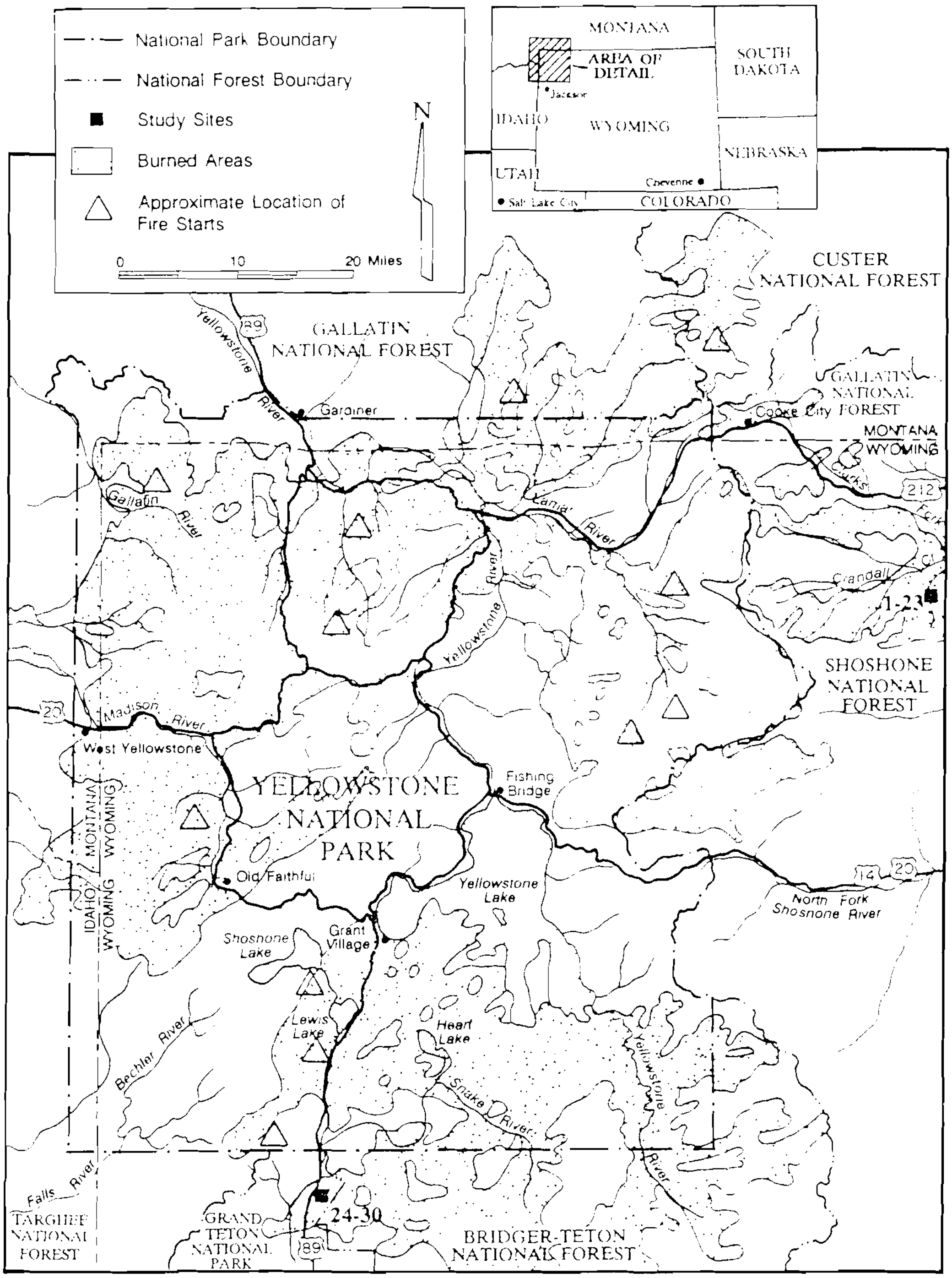

FIGURE 1. Study sites used in the present study relative to the extent of 1988 fires and surface drainages in the Greater Yellowstone Area. After Shovic (1988) and Greater Yellowstone Coordinating Committee (1989).

Soil water repellency (hydrophobic soils) occurs in burned and unburned forest soils, but is commonly induced by fire (DeBano and Rice, 1973; DeBano, 1981). This feature occurs when organic compounds in the soil are vaporized by intense heating. The vapors condense on mineral soil particles forming a coat that inhibits percolation of water. The combined effect of vegetation removal and water repellent soils is to cause snowmelt to begin earlier, especially on south and west slope aspects; increase peak flows, an effect which decays with distance downstream; and decrease the resistance of soils to erosion, with increased sediment supplied to streams. Increased runoff and soil loss lead to subsequent impacts on the integrity of riparian and aquatic ecosystems, a concern which has been expressed by resource management agencies charged with protecting these ecosystems in the GYA (Greater Yellowstone Postfire Ecological Assessment Committee, 1989).

METHODS

Runoff and soil loss were measured through a series of rainfall simulation experiments on 23 sites in the Crandall Creek drainage of Shoshone National Forest and 7 sites in the John D. Rockefeller Memorial Parkway (Fig. 1). These sites were selected to represent the ranges in burn intensities, history of logging before and after the fires, and dominant geologic substrates. Great variability was found in site conditions within short distances so that sites could be clustered in the two areas shown in Figure 1 while still maintaining a statistically valid sample. Replicate plots were established at each of the 30 sites for a total of 60 experiments (Table 1). The following characteristics were measured on the plots which had dimensions of 0.61 meters (2 feet) on a side:

Table 1. PLOT DISTRIBUTION FOR RAINFALL SIMULATION EXPERIMENTS

	Number of Plots	
History of Logging and Fires	Glacial Till	Volcanic
Logged before 1988 fires & burned	8	12
Unlogged before 1988 fires & burned	20	12
Burned and logged after 1988 fires	0	4
Unlogged and unburned by 1988 fires	4	0

1) slope aspect: measured with a hand-held compass to the nearest degree;
2) slope gradient: measured with a slope pantometer designed by Pitty (1968) to the nearest degree;

3) percent ground cover: visual estimate with field charts found in Gardiner and Dackombe (1983);
4) percent litter cover: visual estimate with field charts found in Gardiner and Dackombe (1983);
5) depth of wetting front: measured after completion of each experiment, record maximum and minimum depths along mid-plot transect to the nearest millimeter;
6) depth of soil charring: measured to the nearest millimeter at the surface and at depths of 1, 2, 5, and 10 centimeters;
7) water repellency: use a "drop test" designed by DeByle (1973) and described by DeBano (1981).

The runoff and soil loss experiments were conducted with a modified "Tahoe Basin" rainfall simulator. This particular instrument had proven useful in previous research conducted by Marston and Dolan (1988) who described the details of its operation. This model of rainfall simulator is portable (lightweight but durable, easy to operate), requires little water, and can be used on slope gradients up to 30 degrees. The kinetic energy of drops can be adjusted to match that of natural storm events. In the present study, the simulator was calibrated to deliver a storm intensity of 76 millimeters (3 inches) over a one-hour period. The diameter of drops was 3.2 millimeters (0.13 inches), fixed by drop-forming tubes which have an inside diameter of 0.58 millimeters (0.023 inches) and drain water from a plexiglass chamber. By having the drops fall from a height of 2.3 meters (7.5 feet), a storm was simulated with kinetic energy equivalent to the 100-year/1-hour event for the study area. This storm event was choosen to simulate the intense thunderstorms experienced in this area which were responsible for the majority of erosion in the first year following the fire. Runoff and sediment were collected in sample bottles at the downslope end of the plot. Soil samples were acquired from the top 20 centimeters (8 inches) adjacent to the plots for analyses of texture and organic matter content in the Soils Laboratory in the Department of Geography at the University of Wyoming.

RESULTS

The data in Table 2 indicate relative fire intensity between treatments, although much variance within treatments was recorded. Soils in the volcanic terrain were dominantly clay loams; soils in glacial till showed greater variability in texture, but overall tended to be slightly more coarse. The depth of wetting and litter cover data point to sites which were logged before the 1988 fires as having received the more intense burns. The depth of char and percent organic matter data indicate that sites which were burned then logged after the fires were more intense than elsewhere, but the small sample size for this treatment renders these differences as statistically insignificant (Kruskal-Wallis test). Statistically significant differences were noted between sites which were logged and then burned versus sites which were unlogged before the fires and then burned. The former received more intense burns according to depth of char and percent litter.

Table 2. INDICATORS OF FIRE INTENSITY BETWEEN TREATMENTS

History of Logging and Fires	Min. Depth of Wetting (mm)	Depth of Char (mm)	Percent Litter	Percent Organic
Logged before 1988 fires & burned	4.9	42.8	10.0	6.9
Unlogged before 1988 fires & burned	5.0	36.6	17.1	5.3
Burned and logged after 1988 fires	7.8	50.3	28.8	4.5
Unlogged and unburned by 1988 fires	3.8	0	72.5	14.8

The results of the rainfall simulation experiments on runoff and soil loss are summarized in Tables 3-4. The rates of runoff reached a maximum of 96 percent of the applied rainfall on a plot with water repellent soils and no litter. The rates of runoff were generally higher on volcanic (finer texture) soils than on glacial till (Table 3), but the differences were not statistically significant at $p < 0.001$ (Mann-Whitney test). The differences between plots with contrasting histories of logging and fires were also not statistically significant at $p < 0.001$ (Kruskal-Wallis test). The differences in runoff stratified by both geology and logging/fire history were not statistically significant at $p < 0.001$ (Kruskal-Wallis test). Water repellent soils were even found in unlogged and unburned sites, although the effect was not as deep as in the disturbed sites. This helps to explain the runoff observed in the undisturbed sites on glacial till; normally one does not expect runoff on undisturbed forest soils. The runoff data were also analyzed using stepwise multiple regression. The resulting equation, with independent variables listed in the order they entered the equation, was:

$$\text{Log } R = 2.11 - .042 (\text{Log } L) - .610 (\text{Log } S) - .063 (\text{Log } W) + .260 (\text{Log } H1) + .233 (\text{Log } H2) + .194 (\text{Log } H3) \quad (1)$$

where R = runoff for the 1-hour storm (liters)
L = litter cover (percent)
S = silt content of soil (percent)
W = minimum depth of wetting (millimeters)
H1 = dummy variable for logging/fire history (1 if unlogged; 0 if logged)
H2 = dummy variable for logging/fire history (1 if logged before 1988 fires; 0 if not logged before 1988 fires)
H3 = dummy variable for logging/fire history (1 if logged after 1988 fires; 0 if not logged after 1988 fires)

This regression was significant at the $p < 0.001$ level, with a cumulative r^2 of 0.38.

Table 3. RUNOFF FOR ONE-HOUR RAINFALL SIMULATION EXPERIMENTS

	Mean Runoff (liters)	
History of Logging and Fires	Glacial Till	Volcanic
Logged before 1988 fires & burned	16.2	21.1
Unlogged before 1988 fires & burned	18.7	22.1
Burned and logged after 1988 fires	----	19.7
Unlogged and unburned by 1988 fires	15.7	----

Table 4. SOIL LOSS FOR ONE-HOUR RAINFALL SIMULATION EXPERIMENTS

	Mean Soil Loss (grams)	
History of Logging and Fires	Glacial Till	Volcanic
Logged before 1988 fires & burned	562.2	511.8
Unlogged before 1988 fires & burned	300.4	422.3
Burned and logged after 1988 fires	----	393.1
Unlogged and unburned by 1988 fires	8.5	----

The rates of soil loss reached a maximum of 2.5 $kg/m^2/h$. The differences in rates of soil loss were not statistically significant between volcanic and glacial terrain at $p < 0.001$ (Mann-Whitney test). The differences between plots with contrasting histories of logging and fires (Table 4) were statistically significant at $p < 0.001$ (Kruskal-Wallis test). The rates of soil loss were highest at sites which had been logged and subsequently burned by the 1988 fires. This can be attributed to the higher fuel loads which would have existed on the forest floor, leading to more intense burns. The differences in soil loss stratified by both geology and logging/fire history were statistically significant at $p < 0.001$ (Kruskal-Wallis test). The data were also analyzed using stepwise multiple regression. The resulting equation, with independent variables listed in the order they entered the equation, was:

$$\text{Log } E = .129 - .162 (\text{Log } L) + 1.52 (\text{Log } H1) - 1.32 (\text{Log } H2) + 1.61 (\text{Log } H3) + .679 (\text{Log } S) \qquad (2)$$

where E = soil loss for the 1-hour storm (grams)
L, $H1$, $H2$, $H3$, S as above

This regression was significant at the $p < 0.001$ level, with a cumulative r^2 of 0.85. Litter density was the key variable controlling both runoff and soil loss. The timber harvest methods contribute to the degree to which litter will suppress soil loss after the fires. Lodgepole forests are typically clearcut which leaves no source of post-fire needlefall to replenish litter cover. Even in lodgepole forests which were not logged before the 1988 fires needles were easily burned. Douglas-fir forests which were selectively logged prior to the fires provided post-fire needlefall because the needles are more fire-resistant. In the Colorado Front Range, Morris and Moses (1987) also noted that the absence of a dense litter cover was the leading cause of accelerated soil loss in severely burned areas. Water repellency did not enter the regression equations, but only because of the high intercorrelation with depth of wetting.

It would seem that the active role of logging/fire history on soil loss must be reconciled with the more passive role of logging/fire history on runoff. The two results were not inconsistent, because the majority of soil was mobilized by rainsplash, not by runoff. This interpretation was further supported by the relative lack of soil loss in 1989 associated with snowmelt runoff, while soil loss from summer thunderstorms in that year was quite pronounced (Hydrology Assessment Team, 1989; Minshall et al., 1989). Regression analyses revealed that silty soils caused lower runoff but higher soil loss, further accounting for the poor correlation between runoff and soil loss. Slope gradient did not enter the regression equation for runoff or soil loss in the stepwise procedure. Although higher runoff and soil loss are normally expected as slope gradient increases, the effect of slope gradient on forest sites is overwelmed by the high microroughness of the soil surface contributed by litter, grass, and downed timber (Morris, 1986).

CONCLUSIONS

The 1988 fires in the Greater Yellowstone Area have increased sediment mobilization on hillslopes due to rainsplash and overland flow. Litter density was the key variable controlling both runoff and soil loss. The logging/fire history of sites exerted a stronger control on soil loss than on runoff. The greatest soil loss was from sites which had been logged prior to being burned. The reestablishment of ground cover and surface litter will suppress sediment movement by rainsplash and overland flow. Sediment stored behind fallen logs could be remobilized upon salvage logging. Ongoing research by the authors has begun to reveal that the sediment supplied to streams from rainsplash and overland flow will be too small to cause persistent changes in channel morphology, although some sediment storage can be expected in willow-covered floodplains.

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REFERENCES

Bethalmy, N. 1974. Water supply as affected by micro- and macro-watershed management decisions on forest lands. Northwest Science 48: 1-8.

DeBano, L. 1981. Water repellent soils: a state-of-the-art. General Technical Report PSW-46, U.S. Forest Service, 21 pp.

DeBano, L. and Rice, R. 1973. Water repellent soils: their implications in forestry. Journal of Forestry 71: 220-224.

DeByle, N. 1973. Broadcast burning of logging residues and the water repellancy of soils. Northwest Science 47: 77-87.

Gardiner, V. and Dackombe, R. 1983. Geomorphological field manual. London, England: Allen and Unwin, 254 pp.

Greater Yellowstone Postfire Ecological Assessment Committee. 1989. The Greater Yellowstone postfire assessment. Washington, D.C.: National Park Service and U.S. Forest Service, 58 pp.

Hart, G., DeByle, N. and Hennes, R. 1981. Slash treatment after clearcutting affects nutrients in soil water. Journal of Forestry 79: 446-450.

Hydrology Assessment Team. 1989. Water resource assessment. In Greater Yellowstone Postfire Resource Assessment and Recovery Program. Mammoth, Wyoming: National Park Service and U.S. Forest Service, 21 pp.

Marston, R.A. and Dolan, L.S. 1988. Estimates of upland erosion and runoff in an arid watershed in Wyoming. Report WWRC-88-06. Laramie, Wyoming: Wyoming Water Research Center, 106 pp.

Minshall, G.W., Brock, J.T. and Varley, J.D. 1989. Wildfires and Yellowstone's stream ecosystems. Bioscience 39: 707-715.

Morris, S.E. 1986. The significance of rainsplash in the surficial debris cascade of the Colorado Front Range Foothills. Earth Surface processes and Landforms 11:11-22.

Morris, S.E. and Moses, T.A. 1987. Forest fire and the natural soil erosion regime in the Colorado Front Range. Annals of the Association of American Geographers 77: 245-254.

Pitty, A.F. 1968. A simple device for the field measurement of hillslopes. Journal of Geology 76: 717-720.

Romme, W.H. and Despain, D.G. 1989. The Yellowstone fires. Scientific American 261: 36-47.

Shovic, H. 1988. Preliminary burned area survey of Yellowstone National Park and adjoining National Forests (map). Washington, D.C.: Greater Yellowstone Coordinating Committee.

Taylor, D. 1974. Forest fires in Yellowstone National Park. Journal of Forest History July: 68-77.