# Logging and Prescribed Burning Effects on the Hydrologic and Soil Stability Behavior of Larch/Douglas-Fir Forests in the Northern Rocky Mountains

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## INTRODUCTION

UNDER natural conditions, nearly all major forest types of the Northern Rocky Mountain region are dependent on fire for their existence. Ponderosa pine, white pine, lodgepole pine, larch, and Douglas-fir are all seral types, largely perpetuated by wildfire. The role played by fire in regeneration of these forests is principally that of opening up the forest and creating a mineral soil seedbed. Where these forests are protected from wildfire, but are opened up by timber harvesting, controlled fire is a convenient way of obtaining a mineral soil seedbed. Another reason for controlled burning is to reduce the wildfire hazard created by logging residue.

One of the most efficient methods for harvesting mature or over-

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mature seral timber stands is clearcutting, followed by burning of slash and, in some cases, by planting. Larch forests, particularly older stands, do not respond well to partial cutting; residual trees tend to deteriorate rapidly. In the commercial larch—Douglas-fir forests in western Montana and northern Idaho, it appears that much of the timber to be harvested will be removed by clearcutting. Where clearcuts are created, natural reproduction from surrounding trees usually will be adequate on areas that are no more than about 200 to 300 feet from the edge of the surrounding uncut forest.

Where these forests are clearcut and the logging residue is burned, soil properties and vegetative characteristics that influence the hydrologic stability of the forest floor can be altered drastically. Immediate effects of such treatment include bearing of the soil surface, thereby making it vulnerable to the impacts of overland flow and raindrop splash from summer storm. Such treatment also means that the interception and shading effects of the forest cover will be negligible for a period of perhaps 10 to 20 years following timber harvest. Research in white pine forests in this same region (Packer, 1962) reveals that the soil mantle and substratum in clearcut areas may have to handle in excess of 4 inches more water from snow alone than is necessary where a full forest canopy exists. These additional amounts of water, together with sharp reduction in transpirational draft caused by removal of timber, means that more water is available for streamflow. Added to a soil mantle already overtaxed during spring periods of rapid snowmelt, often accompanied by rain, this additional water may create overland flow and rapid subsurface seepage flow, thus heightening runoff peaks and soil erosion leading to sediment production.

Although the hydrologic consequences of fire have received research attention in many parts of the country, virtually no information has been developed in the Rocky Mountain region about the quantitative effects of fire upon soil properties, vegetal characteristics, hydrologic and soil stability behaviors of forest land, and the length of time over which these effects prevail. This paper reports the immediate and 7-year effects of jammer logging and prescribed burning in western Montana on forest watersheds having stable soils.

## THE STUDY AREA AND THE STUDY METHODS

In the spring of 1967, the merchantable timber on sixty, 10-acre forest units in Miller Creek on the Flathead National Forest in western Montana was clearcut. Remaining unmerchantable timber was felled and slashed on a schedule that permitted the slash to dry for 2 to 3 months prior to burning. Mean annual precipitation on these forest units is 25 inches, two-thirds of which is winter snow. Slopes range to 20 percent on ridges and to 35 percent on hillsides. Soils are mainly silty loams derived from metamorphosed marine sediments of the Belt series and have been glaciated. Before harvesting; the tree cover consisted of about equal portions of western larch, Douglas-fir, and Engelmann spruce. The timber volumes in these forest stands averaged about 24,000 bd. ft. per acre, and, when logged, they left an average of 115 tons per acre of logging residue. Understory vegetation was predominantly myrtle boxleaf (*Pachystima*) and beargrass (*Xerophyllum*) together with various forb and grass species.

Fifteen of the 10-acre units that were logged and burned face each of the cardinal aspects. Surface runoff and soil erosion plots, each 0.02 acre in size, were installed in two of these 10-acre units on each cardinal aspect. Similar plots were also installed in unlogged and unburned forest areas on each of the cardinal aspects.

To our knowledge, these surface runoff and soil erosion plots are a type that has not been used before. Essentially, each plot consists of a steel collector trough positioned lengthwise on a contour and installed in concrete with the lip of the trough flush with the ground surface. Water and solid material collected in this trough were conveyed through a large diameter pipe to a holding tank located downslope. The top edge or boundary of the plot can be defined naturally by a ridge or watershed line or artificially by an inverted V-shaped wooden plot boundary. The purpose of this wooden boundary at the top of the plot is to divert overland flow and eroded material away from the plot, thus defining the effective plot length. To permit more natural overland flow and movement of soil downslope over the plot surface without the undesirable effects of disturbance caused by installing conventional lateral plot boundaries, such boundaries have been eliminated. Each plot was microtopographically surveyed and mapped to determine the effective area draining into the runoff collection system.

Soil bulk density and total pore space measurements were obtained from soil cores replicated in quadruplicate at prerandomized locations within each plot. Soil organic matter content, particle-size distribution, and water-stable aggregation were measured from composited bulk soil samples taken at four prerandomized locations within each plot. Except for a one-time measurement of soil particle-size distribution, all soil properties and vegetal characteristics were measured on the unlogged-unburned plots once each year. They were also measured on the logged-burned plots prior to burning, immediately after burning, and once each year thereafter. Measurements of live plant cover and litter were obtained with a point analyzer on 200 points established on transects within each plot. Late fall; winter, and early spring precipitation, mostly snow, was accumulated and measured in a Colorado snow storage gage. Summer storm rainfall was measured in a weighing intensity rain gage. Total overland flow and eroded material were measured each year following spring snowmelt runoff; after each major high-intensity summer rainstorm; and in the fall, prior to the onslaught of winter.

## LOGGING AND BURNING TREATMENT EFFECTS

Both the logging and prescribed burning treatments significantly influenced soil and vegetative characteristics and altered runoff and soil erosion behavior.

### Effects on Soil Properties

**Bulk Density.**—Bulk density of the surface 1-inch of soil increased progressively with a shift of aspect from north to east to west to south (Fig. 1). Inasmuch as these differences in bulk density associated with aspect occurred on both unlogged-unburned plots and logged-burned ones, they apparently were not caused by either logging or fire.

Bulk densities decreased significantly on all aspects following logging. These changes are believed to have resulted from incorporation of fine logging residue into the surface layers of soil during logging operations.

Burning of logged units had the opposite effect from logging, resulting in significant increases in soil-bulk densities on all aspects. These increases are interpreted as resulting from partial destruction by fire of fine organic material previously incorporated in the surface layers of the soil mantle by logging disturbances. During the 4-year period following logging and burning, or through 1971, soil-bulk densities on all aspects increased still further. This trend then reversed, decreasing toward the bulk-density values that occurred on the logged, but unburned, plots in 1967. In other words, there has been a general decrease, and hence improvement of bulk densities on all aspects, from the bulk-density values that existed on these plots

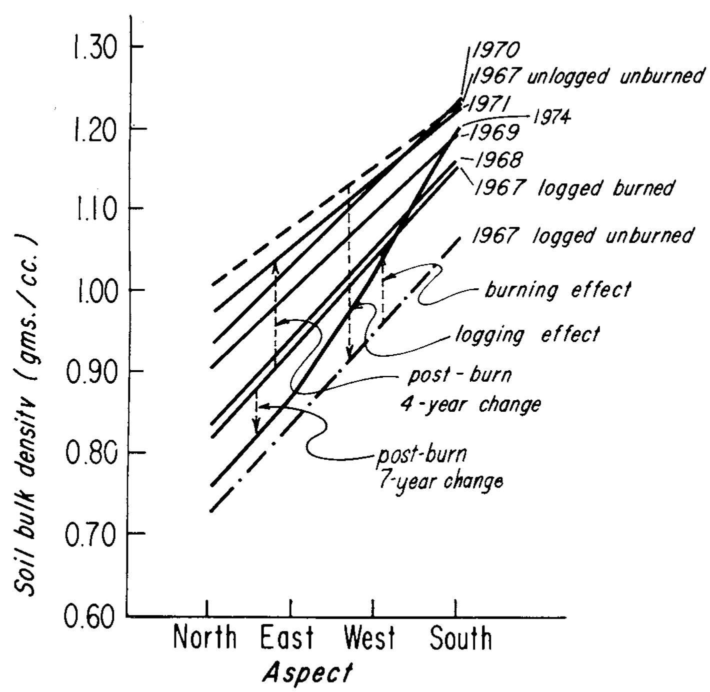


Fig. 1. Effects of logging and prescribed burning on bulk density of surface 1-inch of soil.

prior to logging in 1967. The smallest decrease, and hence the poorest recovery, has occurred on south aspects.

**Total Soil Porosity.**—Soil porosity decreased significantly as the aspect shifted from north to south (Fig. 2). Logging increased soil porosities, no doubt for the same reason that it decreased bulk densities. On the other hand, burning reduced soil porosities. By 1971, the fourth year after burning, soil porosities had further decreased toward prelogging and burning values. Subsequently, however, this trend reversed and total soil porosities have increased, and so improved, from prelogging values on all but the south aspects. There,

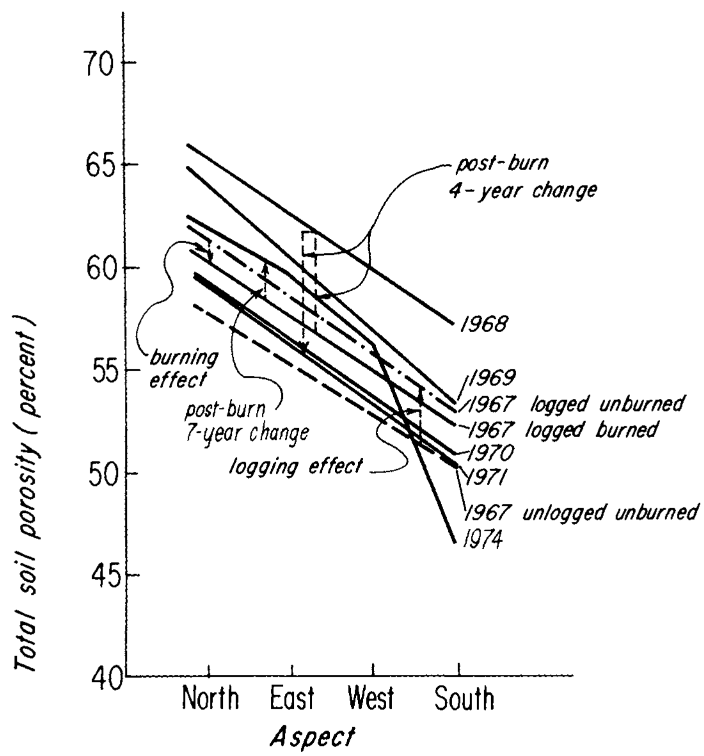


Fig. 2. Effects of logging and prescribed burning on total porosity of surface 1-inch of soil.

soil porosity values are the lowest, hence, the poorest, having decreased continuously since 1968.

**Soil Organic Matter.**—Organic matter content in the surface 1 inch of soil decreased as the aspect shifted from north to south (Fig. 3). Regardless of differences in organic matter content between aspects, logging significantly increased organic matter in the surface 1 inch of soil. Conversely, burning decreased the organic matter content of surface soil. During the next 2 years, organic matter continued to decrease, possibly by being blown or washed away, but primarily by decomposition of residual organic matter during the denuded period following fire when annual increments of organic debris were negligible. While there has been some fluctuation of organic matter

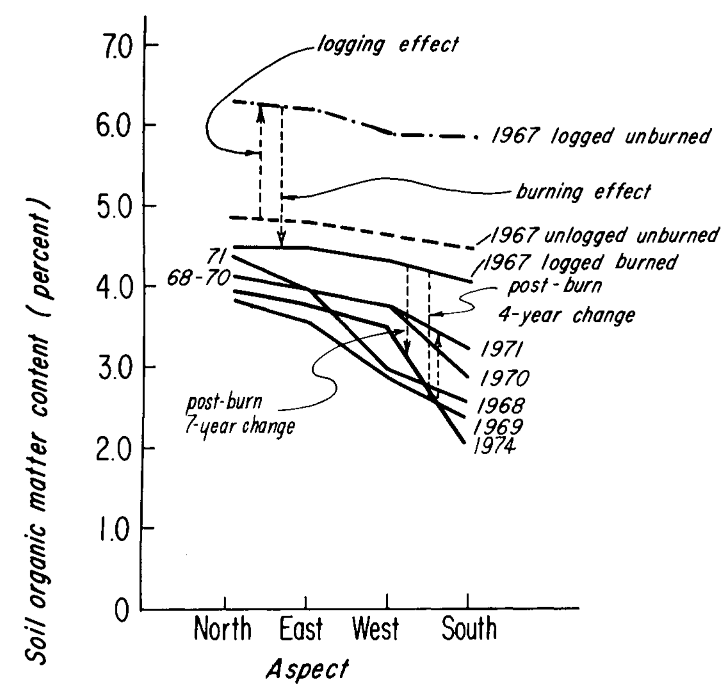


Fig. 3. Effects of logging and prescribed burning on organic matter in surface 1-inch of soil.

content on all aspects since 1971, the lowest content, and hence the poorest, organic matter in the soil had occurred on south aspects at the end of 7 years.

These then, are the significant influences that logging and burning exerted on the bulk density, porosity, and organic matter. These soil properties were not affected significantly at soil depths below the 1-inch level. The reductions in bulk density and the increases in porosity and organic matter content that attended logging indicate that jammer logging disturbance quite probably exerts a beneficial influence on soil infiltration and stability behavior. On the other hand, the opposite effects on these soil properties resulting from burning suggest that burning is probably detrimental to good soil infiltration and stability. The tendency for soil-bulk density and porosity properties to improve on north, east, and west aspects during the 7 years after burning indicates that the adverse changes in these properties observed on these aspects, though significant for a few years, are probably of only transitory importance. On the other hand, continued deterioration or failure of these soil properties to improve on south aspects during the same 7 years indicates that effects of logging and burning may exert adverse hydrological influences that are more long-lasting there than on other aspects. Though somewhat variable, the organic matter content of the soil has continued to decrease throughout the 7 years following burning. Decreases have been greatest on south aspects. This decline is believed to reflect reduced increments of organic debris to the soil surface resulting from removal of both the duff layer and the vegetative cover by burning. It suggests that the processes involved in rebuilding the organic matter content of the surface soil are slow.

### Effects on Vegetative Characteristics

**Total Cover Density.**—In 1967 prior to logging, the total vegetative cover at the ground surface (including plants, litter, and logging residue) was nearly complete, averaging 98 percent for all of the units. Logging contributed an average of 115 tons of residue per acre. Because the vegetative cover of the logged units was already nearly complete, even this large addition of residue had little effect on total groundcover density measurements, increasing them, on the average, to 99 percent (Fig. 4).

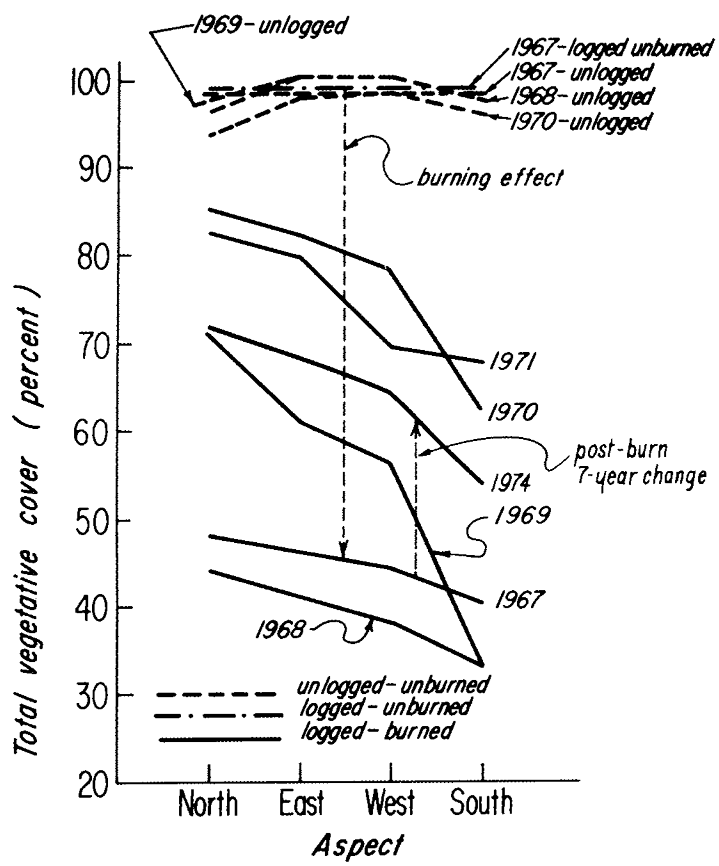


Fig. 4. Effects of logging and prescribed burning on total vegetative cover.

Burning drastically reduced the proportion of the ground surface protected by plants, litter, and logging residue to less than 50 percent on all units. These reductions were greatest on south aspects. As the driest, the south aspects should support the most effective fire. Data from water can analogs on the plots during burning confirmed that fire intensities were in fact highest on south-facing units.

During the first year after burning, the total vegetative cover on the burned units continued to decline, leaving from 56 percent to 67 percent of the soil surface exposed. Over the next 3 years, or through 1970, as herbaceous ground vegetation developed, the density of total cover protecting the soil surface approximately doubled. Recovery was slowest on south-facing units. A reverse trend began in 1971, and the density of total cover has declined through the 1974 growing season.

Thus, the prescribed burns to which the logged units were subjected were effective in removing from one-half to two-thirds of the vegetative cover that protects the watershed. This condition is only temporary, protective plant cover reappears within about 2 years. The flush of herbaceous ground vegetation between 1968 and 1970 can probably be attributed to increased availability of mineral nutrients after burning. The decline in density of total cover since 1970 is believed to reflect a reduction in the supply or availability of these nutrients.

### Effects on Overland Flow and Soil Erosion

**From Snowmelt.**—In the winter of 1967-68, the first winter after burning, precipitation totaled 12 inches (Fig. 5). Total precipitation was 18 inches during the second winter after burning and 17 inches during the third winter. Thereafter, beginning in the winter of 1970-71, total winter precipitation exceeded 30 inches each year. Most of this precipitation reached the soil surface the following spring either as snowmelt water or as rain percolating through the snowpack. Both the logged-burned and unlogged-unburned plots produced overland flow from spring snowmelt each year. In all cases, however, overland flow from the logged-burned plots was from two to several times greater than that from the unlogged-unburned ones. The quantities of overland flow during the first 3 years after burning were directly correlated with the amounts of precipitation during the previous winter. Thereafter, even with increasing amounts of winter precipitation, overland flow on both logged-burned and unlogged-unburned plots tended to decrease.

None of the unlogged-unburned plots produced any soil erosion due to overland flow from snowmelt during the 7 years following burning (Fig. 6). This lack of soil erosion even though overland flow occurred attests to the protective influence of vegetative cover on

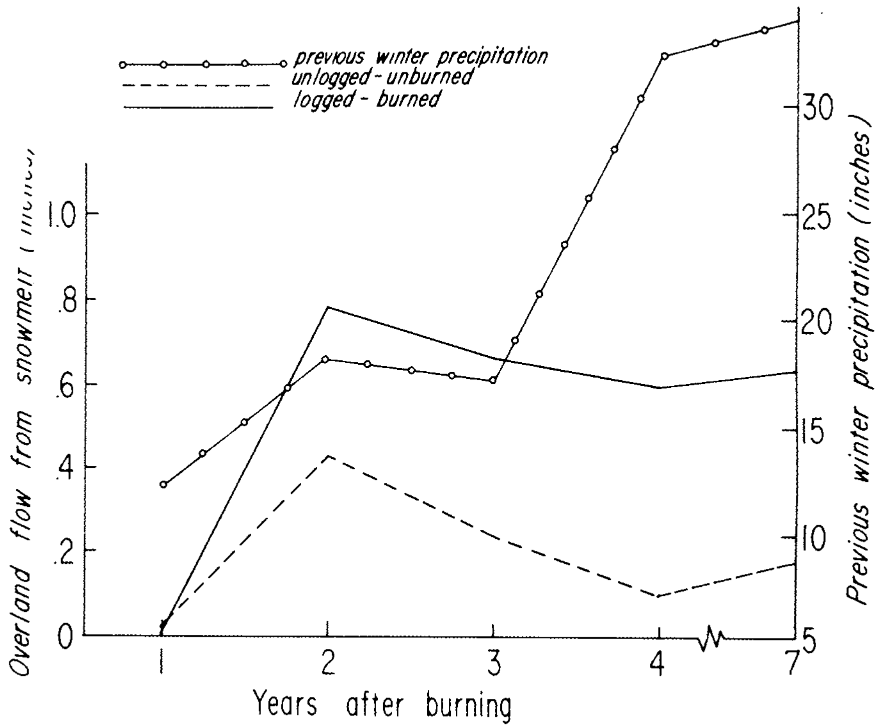


Fig. 5. Relation of overland flow from snowmelt to previous winter precipitation during a 7-year period following logging and burning.

the unburned plots. Soil erosion from the logged-burned plots averaged 56 lb per acre the first year after burning, but then increased to 168 lb per acre the second year. This increase is directly correlated with the increase in winter precipitation the second year. By the third year, soil erosion due to overland flow from snowmelt on the logged-burned plots had decreased to 15 lb per acre, despite the fact that overland flow from these plots was almost as great as it had been the previous year when 168 lb per acre of soil were eroded. The fourth year after burning, although precipitation during the previous winter was much greater than any time before, exceeding 30 inches, soil erosion from the logged-burned plots showed little change, remaining at

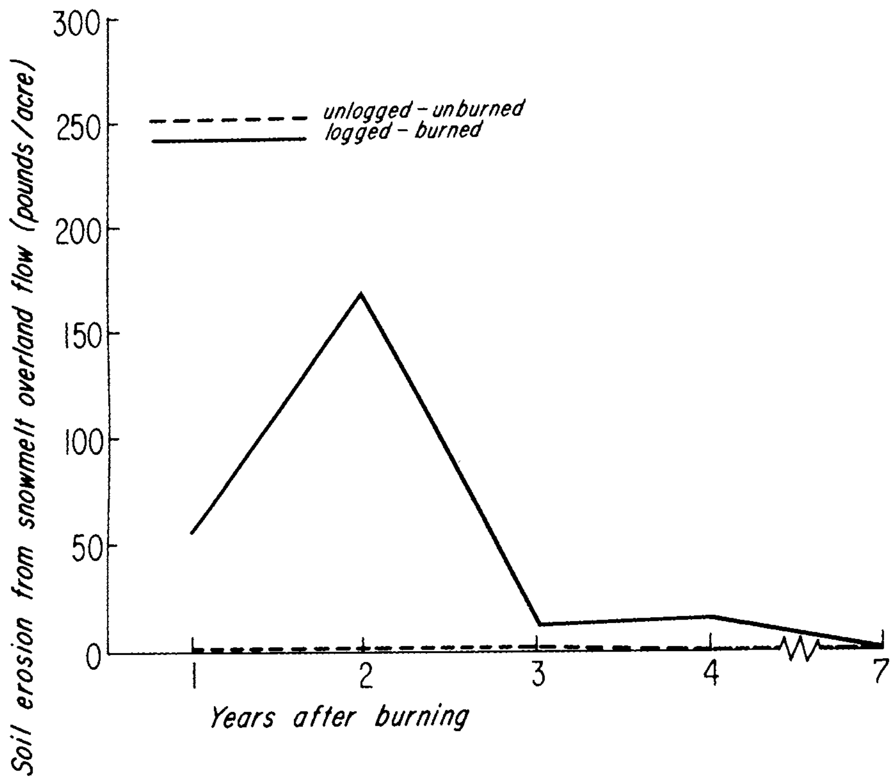


Fig. 6. Soil erosion from snowmelt overland flow on burned and unburned blocks during a 7-year period following logging and burning.

about 17 lb per acre. Seven years after burning, and despite more winter precipitation than at any previous time of the study, no soil erosion occurred from any of the logged-burned plots as a result of snowmelt runoff. This is interpreted as reflecting the increased effectiveness of higher cover densities in protecting the soil surface against erosion from overland flow.

**From Summer Storms.**—The most rainfall from summer storms, some 12 inches, occurred the first year after burning (Fig. 7). Rainfall totaled 8½ inches the second summer, 3 inches the third summer, 6 inches the fourth summer, and only 2 inches the seventh sum-

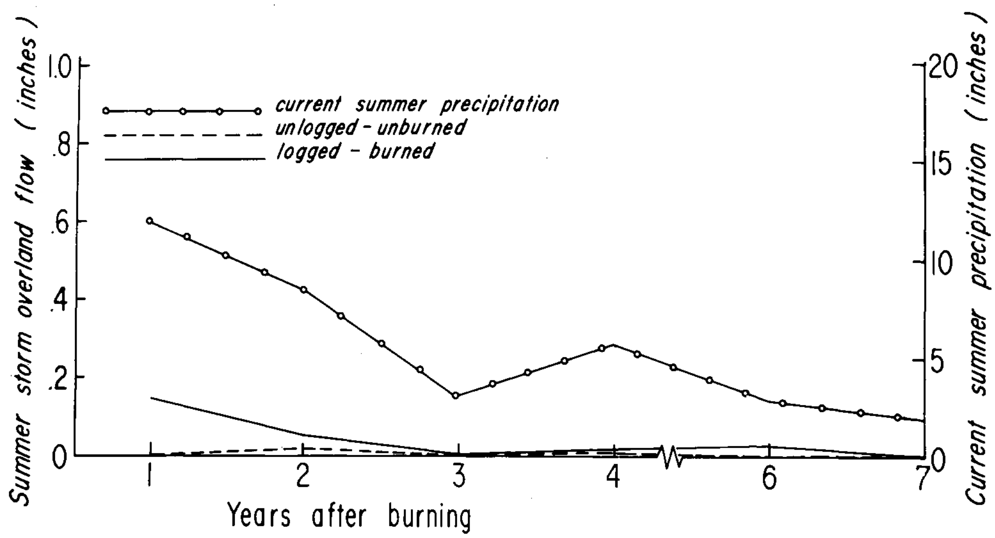


Fig. 7. Relation of overland flow from summer rainstorms to current summer precipitation during a 7-year period following logging and burning.

mer. The quantities of overland flow from both logged-burned and unlogged-unburned plots during summer storms were very much less than the amounts resulting from snowmelt. Except for a very small amount the second summer after burning, the unlogged-unburned plots produced no overland flow from summer storms. The amounts of overland flow from logged-burned plots were highly correlated with total summer precipitation. Largest amounts occurred the first year after burning and declined to zero thereafter, except for a small amount associated with a short burst of high-intensity rainfall during the sixth summer. This reduction in overland flow from summer storms is attributable to a combination of much less precipitation and a vastly improved protective cover that began the third year after burning.

None of the unlogged-unburned plots produced any summer storm soil erosion (Fig. 8). The largest amount of soil erosion from logged-burned plots, some 151 lb per acre, occurred the first year after burning when summer rainfall and overland flow were also greatest.

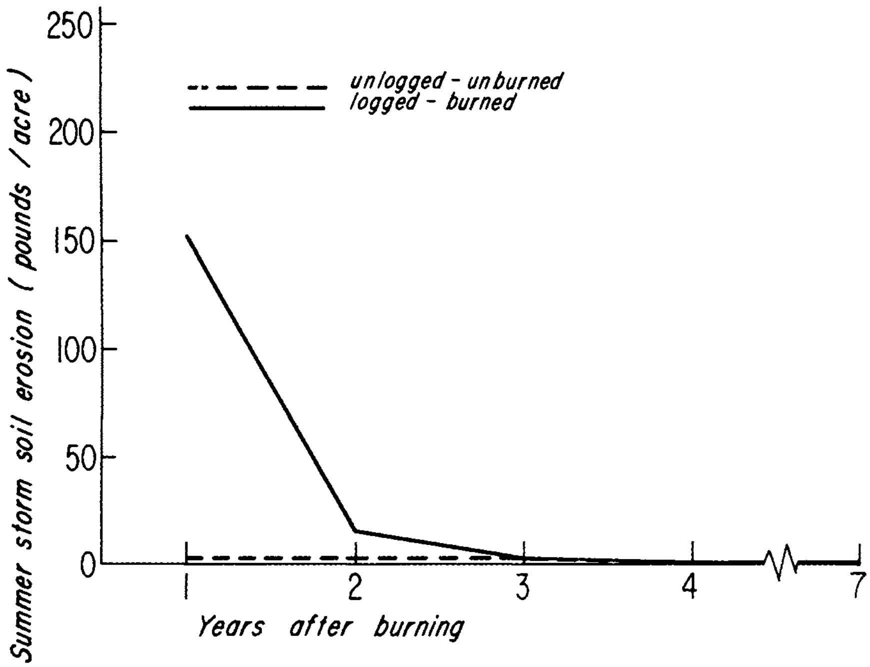


Fig. 8. Soil erosion from summer storm overland flow on burned and unburned blocks during a 7-year period following logging and burning.

From the third year after burning on, summer storms caused no soil erosion from the logged-burned plots. It is of interest to note that the largest amounts of soil erosion from summer storms and spring runoff are almost equal—151 and 168 lb per acre, respectively. Yet, the summer storm overland flow that produced this amount of erosion (0.15 inch) was only 27 percent of the overland flow from snowmelt (0.55 inch). It is apparent that summer storms provide a much more efficient eroding force than does snowmelt runoff. This, no doubt, is due to higher rates of overland flow and to splash erosion from raindrop impacts during these storms.

## CONCLUSIONS

Results of this study show that the jammer type logging employed on these timber harvest units produces changes in surface soil properties and vegetative characteristics that enhance the hydrologic and soil stability performance of larch—Douglas-fir watersheds on Belt series soils. They also show that prescribed burning exerts effects on these same soil properties and vegetative characteristics that are detrimental to watershed performance for runoff and soil erosion control. This impairment of watershed protection conditions and the attendant increases in runoff and erosion appear to be rather temporary, with recovery occurring within a few years. A possible exception of this conclusion may be the south-facing aspects. Being the driest, such aspects suffered the most intensive burns; exhibited the most adverse effects to soil and vegetative characteristics as a result of burning; and showed less improvement of these characteristics during the 7 years following burning. It is believed that the south aspects still remain in a more delicate runoff and erosional balance than other aspects.

Finally, the soil erosion behavior of the logged-burned units appears to be related more to the amount of total protective cover on the ground and to the magnitude of climatic events than to other measured site factors. The effects of logging and burning on protective cover conditions and on their subsequent change with time can be predicted. The magnitude and recurrence interval of climatic events capable of generating overland flow and soil erosion on logged and burned watersheds are not so readily predictable. There is no question but what logging and prescribed burning on gentle to moderately steep slopes of larch—Douglas-fir watersheds on Belt series soils create a runoff and soil erosion hazard. The moderate degree of this hazard and the relative rapidity with which it declines indicate that, with the possible exception of south-facing aspects, this type of treatment probably is not permanently damaging to the watershed protection characteristics of these forests. The extent to which this conclusion applies on steeply sloping watersheds is being investigated on Newman Ridge in the Lolo National Forest in western Montana.

## LITERATURE CITED

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