Effectiveness of Road Ripping in Restoring Infiltration Capacity of Forest Roads[1]

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Abstract: Many forest roads are being closed as a step in watershed restoration. Ripping roads with subsoilers or rock rippers is a common practice to increase the infiltration capacity of roads prior to closure. When considering the effectiveness of ripping for reducing runoff and erosion and the potential reduction in slope stability by saturating road fills, it is important to know how ripping changes the infiltration capacity of forest roads. Hydrographs from simulated rainfall on 1-m x 1-m plots were analyzed to find the saturated hydraulic conductivity, an indicator of infiltration capacity. I examined saturated hydraulic conductivity for three treatments on two different soils. One road was built in a soil derived from the metamorphic belt series geology of northern Idaho, a soil noted for its high rock fragment content. The second road was built in a sandy soil derived from decomposed granitics of the Idaho batholith. On each soil, five plots were installed on a road prior to ripping, and nine plots were installed on the same road segment following ripping, four covered with a heavy straw mulch and five without. Three half-hour rainfall events with intensities near 90 mm/hr were simulated on each plot. Results show that ripping increases hydraulic conductivities enough to reduce risk of runoff but does not restore the natural hydraulic conductivity of a forested slope. The unripped road surfaces had hydraulic conductivities in the range of 0-4 mm/hr, whereas ripped roads were in the range of 20-40 mm/hr after the second event. Surface sealing and tilled soil subsidence processes are important in reducing the hydraulic conductivity of the soils with repeated wetting. Subsidence appears to be important on the granitic soil, whereas surface sealing was more important on the belt series soil.

Key Words: road closure, infiltration, runoff

Introduction

Natural surface runoff in most forests is restricted to channels and nearby areas. Construction of forest roads substantially alters the hillslope hydrology by causing surface flow in areas far from established channels. Overland flow from forest roads can carry sediment eroded from the road surface, extend channel systems (Montgomery, 1994, Wemple, 1994), and increase the probability of landslides (Sidle et al., 1985). Watersheds with dense road networks commonly experience increased sedimentation and peak flows.

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To reduce watershed degradation by roads that are no longer needed, many roads are being closed and obliterated. Methods to carry this out vary from simple closure with an earth berm at the road entrance to complete recontouring of the surface. One of the more popular methods is ripping, where a bulldozer drags rock rippers or subsoilers through the road to break up the compacted layers forming the road. This method produces a result similar in appearance to plowing and is meant to enhance infiltration to reduce runoff and flow concentration. The loosened surface deters further vehicle access, and the improved seedbed enhances revegetation. Vegetation, in turn, maintains infiltration capacity, stabilizes the road prism, and protects against erosion.

Several researchers have examined the problem of surface soil compaction in reclaiming roads, mined lands, and degraded rangeland. Some of the early research on roads examined plant densities following various treatments. Kidd and Haupt (1968) examined effectiveness of scarification to a 12-inch depth and other factors on growth of grass species on recently closed logging roads. Scarification followed by seeding increased the number of surviving plants per unit area but did not change the percentage ground cover relative to no scarification.

Ripping and related activities are an important part of reclaiming mined lands, and there is substantial literature on the effectiveness of various treatments for mine reclamation. Most studies have examined the effectiveness of soil amendments and plant selection in achieving appropriate plant cover (see for example Farmer et al., 1974). Ripping is considered so fundamental that few studies have addressed it directly. Verma and Thames (1978) point out that deep chiseling (a specific tillage technique similar to ripping but shallower) is effective in preventing runoff and erosion on relatively flat slopes. They also point out that the effect is temporary, usually less than one year, and that chiseling must be used in conjunction with other treatments.

Gifford (1975) reviewed a few studies on the effectiveness of ripping in decompacting rangeland soils. The articles reviewed there showed that deep ripping could greatly decrease runoff from natural events, while shallow ripping with little surface disturbance had little effect. The papers reviewed also suggested that effectiveness of ripping treatments on rangelands decreases over time.

Agricultural operations and the reactions of soil to tillage have been under scrutiny for centuries. Two processes examined by contemporary researchers, soil crusting (also called surface sealing) by rainfall and tilled soil subsidence, are important to freshly tilled mineral road soils. Among authors who have measured the development of crusts on soils during rainfall are Mohammed and Kohl (1987), Loch and Foley (1994), Sharma et al. (1981), Jennings et al. (1987), and Bosch and Onstad (1988). High-energy raindrop impact drives the process by breaking apart aggregates on the surface and redistributing the fine particles to fill pores, thereby reducing the saturated hydraulic conductivity of the surface layer. This process seems most important in soils with enough clay content to form aggregates that are otherwise water stable. To study the effects of soil settlement on four freshly tilled soils, Onstad et al. (1984) examined bulk density, saturated hydraulic conductivity, and random roughness height while applying 15.2 cm of water with no raindrop impact energy (using furnace filters). They found that dry bulk density rose quickly, and saturated hydraulic conductivity dropped quickly, as water was added. Soil settlement is a well-known problem in regions of silty and sandy soils because of their low cohesion under saturated conditions.

Tilled agricultural soils typically have saturated hydraulic conductivities in the range of 2-30 mm/hr, whereas mildly disturbed forest soils (bare mineral soil, no compaction) have conductivities in the range of 60-80 mm/hr (Luce, 1995). These figures suggest that ripping may not entirely restore the hillslope hydrology. Roads generally have saturated hydraulic conductivities less than 4 mm/hr, so a tilled soil still represents an improvement.

Given these insights, one must seriously question the degree of hydrologic recovery provided by ripping. If the purpose of the ripping is, in part, to prevent surface runoff, it must increase the infiltration capacity of the soil. Infiltration capacity at a particular time is a function of soil properties and the soil moisture content at that time. Saturated hydraulic conductivity is a reasonable standard for comparing infiltration capacity among soils or treatments, as it is independent of soil moisture and represents the infiltration capacity of a soil near saturation. This study examined the response of saturated hydraulic conductivities of roads to ripping.

Methods

Saturated hydraulic conductivities were measured on an unripped road, a ripped road, and a ripped road with a heavy straw mulch application, on two soils during three sequential simulated rainfall events. The three sequential simulated rainfall events were used to determine hydraulic conductivity changes with added water and rainsplash. The first soil was derived from metasedimentary belt series parent materials. Belt series soils have high rock fragment content and high fine content (Figure 1). Plasticity indexes for road soils in the belt series soils range from 5-10%, and clay content ranges from 18-25% of the fraction finer than 4 mm (unpublished data, Idaho Panhandle National Forests). The second soil was derived from Idaho batholith granitics. Most of the road material came from alluvial deposits of the South Fork of the Salmon River. These materials were sandy with some rock fragments and low fines (Figure 1). Plasticity indexes for road soils on the South Fork Salmon River road range from 0-10% (unpublished data, Payette National Forest). The mulch was added to reduce the raindrop kinetic energy impact important to the surface sealing processes and to determine the result of wetting only on soil consolidation. This provided a control to see whether surface sealing contributed to a decline in saturated hydraulic conductivity following ripping.

Ripping on the belt series road was accomplished using a Caterpillar D-9 bulldozer with three 4-foot ripping teeth spaced 2.5 feet apart. Small, 8-inch “wings” were welded to the

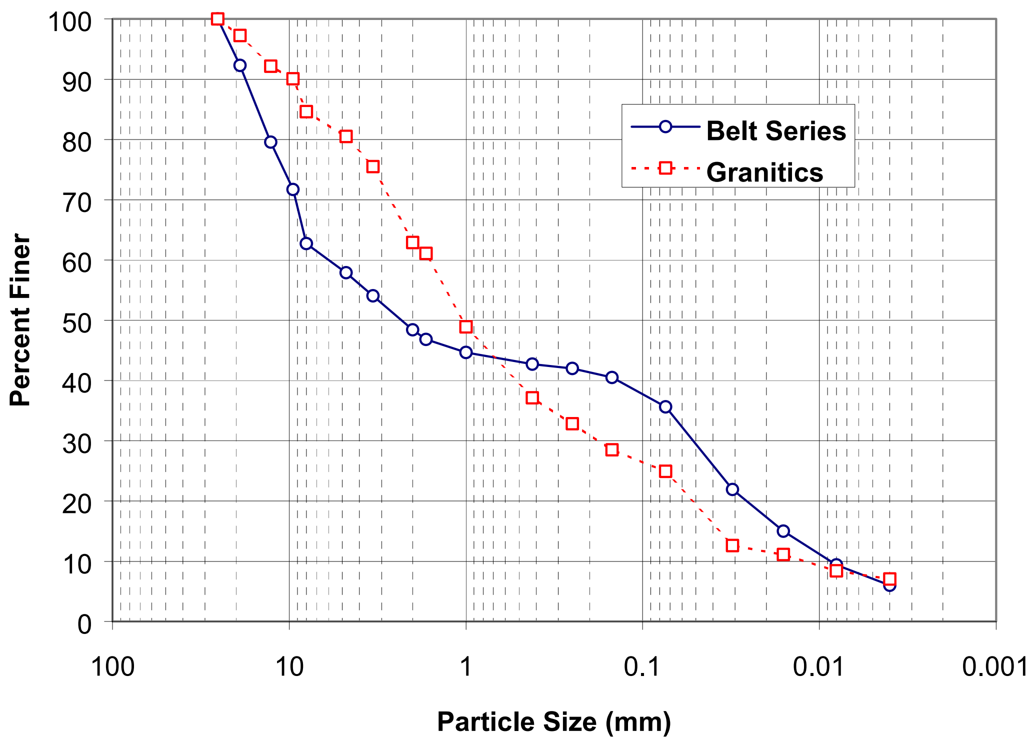

Figure 1: Particle size distribution for the two soils for all particles smaller than 20 mm. Steeper parts of the graph indicated areas of high relative frequency. The belt series soil shows a bimodal distribution, peaking in gravels (> 2 mm) and silts (< 0.05 mm). The granitics are sandier, peaking in the coarse sand to fine gravel region (< 3 mm and > 0.5 mm).

bars about 1 foot from the tip to promote fracture in the soil. The resulting ripped soil was well fractured and turned over to a depth of roughly three feet. On the granitics, a large Gallion road construction grader with two-foot ripping teeth with two foot spacing was used. The resulting ripped soil had large, flat clods, between 3 and 4 inches thick and 8-14 inches wide jumbled in a well tilled sand. The clods were formed from the original road surface, and the material underneath fractured more completely. The depth of tilled material was between 2 and 2.5 feet. Saturation overland flow was not observed from the rainfall simulations used here, so the lack of depth did not affect the results printed here. Mulch was added such that the soil underneath was not visible, a loading much greater than typically applied for erosion control.

The hypothesis was that the belt series soil would exhibit a modest increase in hydraulic conductivity with ripping; that the protection of the rock fragments would yield only a minor decrease over the course of the rainfall due to surface sealing; and that the matrix of cohesive fines would prevent tilled soil settling. It was further expected that the granitic soil would increase modestly in hydraulic conductivity with initial ripping; decrease slightly with increased rainfall due to settling, and show no difference in decrease when mulch was added.

For each treatment, 1-m by 1-m plots were constructed with sheet metal boundaries and a trough at the downslope end to collect runoff. On each soil, five plots were installed on a road prior to ripping, and nine plots were installed on the same road segment following ripping, four covered with a heavy straw mulch and five without.

A modified Purdue rainfall simulator provided rainfall for the sprinkling infiltrometer plots. The rainfall simulator oscillates a downward-pointed irrigation sprinkler nozzle through a small arc to cover the plot and immediately surrounding area with spatially uniform rainfall. Measurements of rainfall energy under a similar simulator (Foltz et al., 1995) suggest that the rainfall kinetic energy was about half that of natural rainfall. However, Mohammed and Kohl (1987) successfully used a similar design and nozzle to observe surface sealing on agricultural soils. Rainfall was applied at approximately 90 mm/hr to each plot during three 30-minute rainfall events. The first event was conducted under existing soil moisture conditions, the second event was carried out roughly 20 hours later, and the third event was typically started within 45 minutes of completing the second event. The high rainfall intensity and short interval between storms are not meant to simulate potential storm occurrences but are used to find the average saturated hydraulic conductivity of the plot. Sprinkling infiltrometers require that the precipitation intensity exceed the highest saturated hydraulic conductivity on the plot. Past experiences with forest soils and the potential of a ripped road to meet these hydraulic conductivities suggested that 90 mm/hr would be appropriate. Actual rainfall intensity for each event was measured at the beginning and end of each event using a sheet metal plot cover. Timed runoff samples were collected in 1,000-ml bottles.

Runoff hydrographs were analyzed by the method of Luce and Cundy (1994) to find infiltration parameters for Philip's (1969) equation, including saturated hydraulic conductivity and sorptivity. The method is essentially a curve fitting procedure for a kinematic wave model of Hortonian overland flow (Cundy and Tento, 1986; Luce and Cundy, 1992). The curve fitting procedure uses a genetic algorithm, which robustly finds the optimum fit for three variables simultaneously and makes it possible to detect changes in saturated hydraulic conductivity independent of routing effects and changes in moisture content and depression storage that occur over time.

Bulk density and moisture content were measured with a calibrated nuclear densiometer. Between two and four measurements were taken on the surface within or adjacent to each plot before and after each rainfall event.

The treatments, plots, soils, and events constitute a full-factorial ANOVA design. There were three treatments, two soils, with three events as repeated measures and five replicates (plots) for each cell in the design. Analysis consisted primarily of planned comparisons within this ANOVA design.

Results and Discussion

Hydraulic conductivities for all soils, treatments, and events are summarized in Figure 2.

Figure 3 shows the variation within the treatment for each soil. Prior to ripping, the roads were nearly impervious. Saturated hydraulic conductivities for the roads fell in the range of 0-12 mm/hr (Figure 3). These values agree well with other observations (Reid, 1981; Luce and Cundy, 1994).

The saturated hydraulic conductivity of a ripped road following three rainfall events was significantly greater than that of the road surface prior to ripping ($p(K_p=K_{r3}) = 0.005$ for granitics, and $p(K_p=K_{r3}) < 10^{-6}$ for the belt series). Results varied greatly from plot to plot, but most saturated hydraulic conductivities after the third rainfall event on a ripped road were in the range of 22-35 mm/hr for the belt series and 7-25 mm/hr for the granitics. These conductivities are modest compared to the saturated hydraulic conductivity of a lightly disturbed forest soil of 60-80 mm/hr (Luce, 1995). The increase in conductivity probably represents significant gains in terms of reducing runoff, however. For example, snowmelt, which was observed ponding on the South Fork road prior to ripping, would most likely infiltrate with the road in a ripped condition because

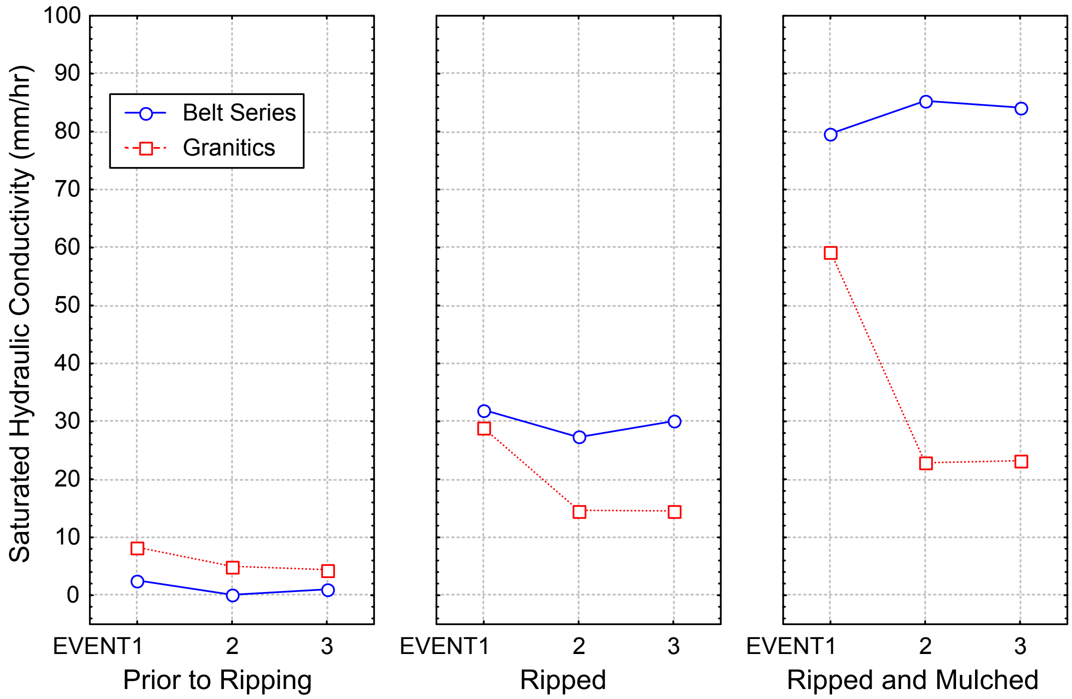

Figure 2: Average hydraulic conductivities by treatment and rainfall event. Prior to ripping there is no statistical difference between the granitics and belt series. The increase in hydraulic conductivity following ripping was statistically significant and significant relative to probable rainfall. Mulching following ripping protected the belt series soil from surface sealing, but did not prevent the collapse of the granitic soil. Following collapse, the differences between the ripped and ripped and mulched granitic soil are not statistically significant.

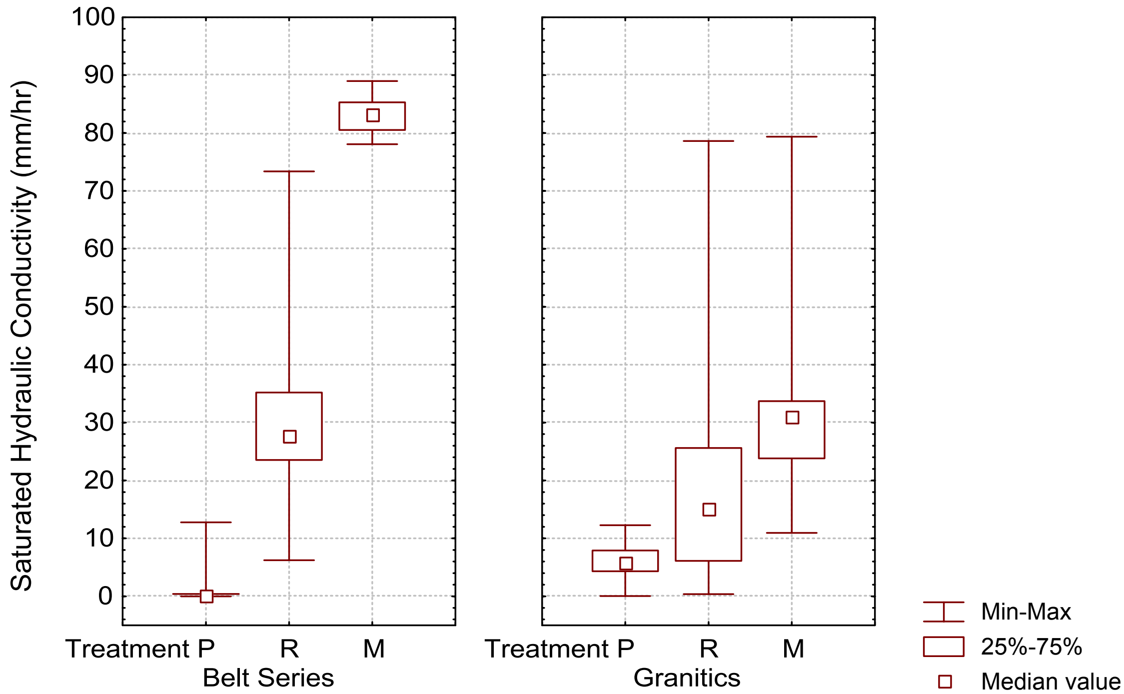

Figure 3: Distribution of saturated hydraulic conductivities by treatment across all events. P = prior to ripping, R = ripped, M = ripped and mulched.

snowmelt rates seldom exceed 15 mm/hr. Snowmelt rates measured during the peak snowmelt season of 1986 at the Central Sierra Snow Lab never exceeded 4 mm/hr (Tarboton et al., 1995). Precipitation-duration-frequency information for northern and central Idaho show that the 1-hr 100-yr event is between 25 and 33 mm/hr (Miller et al., 1973). This indicates that ripping provides some protection for rare events as well.

Hydraulic conductivity values for the ripped treatment on the granitic soil decreased about 50% with added rainfall ($p(K_1=K_2) = 0.00015$). This corresponded to field observations of soil settlement and large clods of soil created by the fracture of the road surface dissolving under the rainfall. Figure 4 shows bulk density responses to treatments and rainfall, including the large increase in bulk density with the first rainfall event on the granitics ($p(\rho_{rg0} = \rho_{rg45}) = 0.000094$). Both results compare well with those of Onstad et al. (1984).

While not evident in Figure 2 or the statistics, the saturated hydraulic conductivity of the ripped belt series soils also dropped from its initial value. Initially, and for much of the first event, the ripped plots on the belt series soil showed no runoff. During these periods, runoff from higher areas flowed to low areas and into macropores. On some plots, runoff from nearly the entire plot could be seen draining into a single macropore for short periods. The macropores were formed during the ripping by fracturing of large, weak, brittle boulders. Trenching revealed that the ripping process had changed the soil

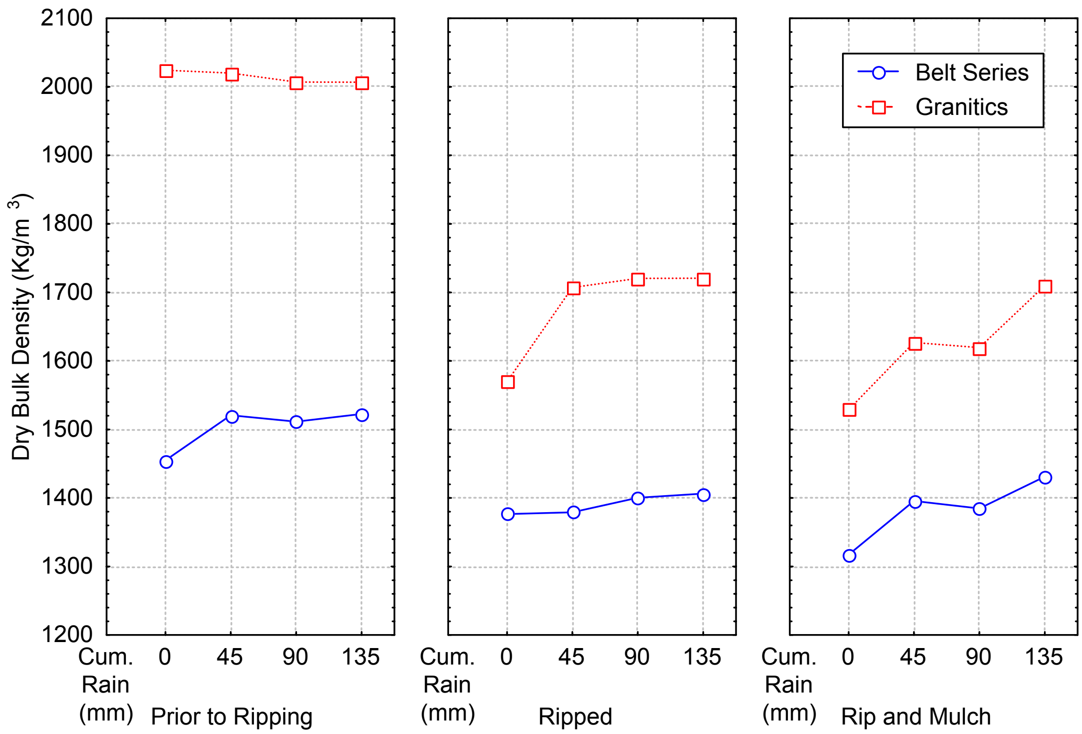

Figure 4: Dry bulk density of soil near the surface by treatment and cumulative rainfall applied to the plot. Density is statistically constant prior to ripping on both soils. Following ripping the belt series maintained a constant density, while the density of the granitics rose after the first event. After mulching the density increase of the granitics was again statistically significant, and the increase in density for the mulched belt series soils was only marginally significant.

from a matrix and clast-supported fabric to a partly open work fabric (Selby, 1993) leaving a few large voids. Erosion of fine sediment and small gravel eventually clogged these macropores. Most macropores clogged within the first 30-minute rainfall. This is one process described by Mohammed and Kohl (1987) as important in surface sealing. Because of the nearly binary response of the plot runoff to macropores at this scale, the fitting algorithm interpreted this process as a high depression storage and fit the hydraulic conductivity to the final 10-15 minutes of high flow on the hydrograph. The hydraulic conductivity during the last 10-15 minutes differed little from the hydraulic conductivity for the next rainfall event. Comparison of the amount of rainfall applied in 15 minutes, about 0.04 m to the porosity times the ripped depth, 0.40 m, suggests that saturation overland flow was not observed, and that the response was due to a change in the infiltrating surface. Saturation overland flow would yield runoff rates close to the rainfall rate; this situation was not recorded.

Examination of what happens when the mulch is applied supports these observations. The straw mulch absorbs the kinetic energy of the raindrops and prevents splash erosion. Under the mulch one would expect little transport of sediment and little surface sealing, but soil settlement should be the same as under unprotected conditions. The effect on hydraulic conductivity is striking. The belt series soil responded by maintaining a high hydraulic conductivity through all three events ($p(K_1 = K_2 = K_3) = 0.51$). The hydraulic conductivities for the granitic soil dropped to values similar to those of the ripped condition without mulch for the second and third events ($p(K_{r(2,3)} = K_{m(2,3)}) = 0.203$). The bulk density of the granitics under a heavy mulch increased significantly ($p(\rho_{mg0} = \rho_{mg45}) = 0.03$), much as it did without the mulch. A less significant rise in bulk density also occurred in the belt series soil ($p(\rho_{mb0} = \rho_{mb45}) = 0.07$), but it is not clear why. Only minor settling was observed in the field.

Although it was not quantified, water flowing from the mulched plots was visibly cleaner than that flowing from the ripped plots. This observation fits with conclusions of many other studies (e.g., Burroughs and King, 1989) that reduction of the rainfall impact reduces erosion.

Little information exists on the durability of infiltration increases beyond these few initial rainstorms. Gifford (1975) reviewed several studies where the effect of ripping compacted rangelands decreased over a period of years, and similar behavior would be expected for roads. Anecdotal observations of roads ripped in earlier years revealed that after one winter, the surfaces were nearly as solid and dense as the original road surfaces. Near the South Fork Salmon River plots, dry bulk densities of a road ripped one year earlier were similar to the final (after third event) densities measured on the ripped and mulched plots. At this site, tree planters had difficulty inserting hoedads, normally an effective instrument, to dig small holes. Hand watering was necessary to keep the trees alive because of the low infiltration capacity and porosity.

Where a contractor had inadvertently incorporated some of the organic layer from the surrounding forest soil during the ripping operation, the ripped road retained its looseness. In mining and rangeland rehabilitation, endeavors similar to road rehabilitation, soil amendments are commonly used to increase soil organic content. Several studies (Skujins and Richardson, 1984; Hudson, 1994; Page-Dumroese et al., 1990; Sidle et al., 1993; Aguilar, 1992) highlight the importance of organic matter content for soil productivity, structure, and erosion protection. In those studies, organic matter was amended as topsoil, sludge, or surface mulch that later decomposed. Direct incorporation of composts may be necessary to prevent tilled soil settlement.

Conclusions and Recommendations

These results support the hypothesis that both soils increased in hydraulic conductivity immediately following ripping. I hypothesized that the belt series soil would retain most of this initial increase, whereas the granitic soil would lose hydraulic conductivity over time. However, the hypothesis that the rock fragments in the belt series soil would prevent surface sealing was not supported. Fines eroded from between fragments were sufficient to clog macropores. The combination of cohesive fines and large voids supported by fragmented clasts yielded little soil settlement. On the granitics, the hypothesized soil settling was observed under both mulched and unmulched conditions, which led to a decrease in hydraulic conductivity following the initial increase, as expected.

Ecological restoration of forest roads and watersheds requires improved vegetative cover and improved infiltration for forest road surfaces. These findings suggest that ripping can be a reasonably effective step in the restoration process. Even considering the effects of settling and surface sealing, ripping increases hydraulic conductivities modestly -- enough, perhaps, to prevent runoff and erosion from most rainfall and snowmelt events. These increases do not represent "hydrologic recovery" for the treated areas, however, and a risk of erosion and concentration of water into unstable areas still exists. These continuing risks must be considered in the design of the restoration project so that runoff does not drain to streams or unstable hillslopes. While the roughness of the seedbed is increased and traffic reduced, the increases in porosity are slight enough that only very hardy plants may initially take advantage of the improved surface.

The findings on soil settlement and surface sealing highlight the fact that freshly tilled road soils are sterile and poorly structured. Ripping and subsoiling alone provide only temporary and marginal improvements. Amended organic matter would likely enhance both the short-term effectiveness and durability of gains in porosity and infiltration capacity, greatly accelerating restoration of the road's hydrologic and ecological function.

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