Winter Logging and Erosion in a Ponderosa Pine Forest in Northeastern Oregon

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ABSTRACT. *Trees are often harvested in small woodlots for the dual purpose of generating revenue and expanding or enhancing woodland pasture for livestock and wildlife. Following such an effort, in a two-part study we compared the runoff and erosion potential in harvested and nonharvested sites. The tree harvest was conducted on snow and frozen soil and used prescribed skid trails.In the first part of the study, runoff plots were installed and monitored for 2 winters and 1 summer to determine if runoff and erosion resulting from natural precipitation events occurred from either of two treatments; a harvested site or a comparable nonharvested site. In the second part of the study, simulated rainfall was applied to a separate set of runoff plots to determine endpoint infiltration capacity and to make projections of infiltration and erosion response to anticipated livestock grazing. Rainfall was applied to each plot at three subsequent levels of ground cover manipulation: undisturbed vegetation, clipped vegetation, and vegetation and organic soil horizon removed.No runoff or sediment production was recorded between September 1986 and December 1987 in either harvested or nonharvested treatments in the plots monitoring response to natural rainfall. In addition, runoff and sediment production did not occur as a result of simulated rainfall in either site regardless of the ground cover treatment. The same result was obtained when rainfall was applied for an extended period and at an increased rate of application.The lack of runoff can be attributed to site conditions, especially the well-developed biomass in the upper soil horizons, and the method and season of logging. If the tree harvest procedures are repeated in similar sites, similar results may be expected. West. J. Appl. For. 8(1): 19–23.*

The effects of logging on the hydrology and soil stability of a forested watershed can be numerous. Road building, tree falling and removal, and slash burning compact the soil, remove protective cover, and can lead to accelerated erosion (Dyrness 1965). Surface flow and erosion on skid trails often result from removal of ground cover by logging on the deep permeable soils of northeastern Oregon (Helvey and Fowler 1979). The soil loss from runoff on skid trails can be great; Heede (1960) reported 6.36 m^3 of soil washed from a 277 m long skid trail in the year following harvest. Revegetation alone may not be enough to prevent this problem (Helvey and Fowler 1979).

There have been few small plot studies of runoff and erosion resulting from natural precipitation events in ponderosa pine forests. The only similar research was conducted by Heede (1984, 1987) in Colorado and Arizona. Similar research has not been reported in the literature for ponderosa pine forests of the northwestern United States.

Simulated rainfall studies have been conducted on many rangelands of the western United States (Thurow 1991). However, few such studies have been conducted in the ponderosa pine forests of the Northwest. Buckhouse and Gaither (1982) and Gaither and Buckhouse (1983) tested potential sediment production and infiltration rates in a ponderosa pine forest in northeastern Oregon. However, their research did not examine hydrologic response to purposeful manipulation of these systems, e.g., the disturbance of litter and understory growth.

The method and season of harvest and the resulting disturbance are crucial considerations for soil and water conservation. Logging on snow and frozen soil is one possible method of reducing the impact of the harvest. The objective of this study was to determine whether runoff and sediment production from natural rainfall events or simulated rainfall differed between harvested (on snow-covered frozen soil) and nonharvested sites.

NOTE: Submitted as Technical Paper No. 9691, Oregon Agricultural Experiment Station, Corvallis. The authors gratefully acknowledge support and funding from the Eastern Oregon Agricultural Research Center, Burns and Union, Oregon. John D. Williams is currently Graduate Research Assistant, Department of Range Science, Utah State University, Logan, Utah 84322-5230.

Reprinted from the *Western Journal of Applied Forestry*, Vol. 8, No. 1, January 1993.

Methods

Description of Study Site

The study was conducted on the Hall Ranch, a part of the Eastern Oregon Agricultural Research Center (EOARC) at Union, Oregon in the southwestern foothills of the Wallowa Mountains (43°12'N, 117°53'W). The elevation at the site is 1060 m.

The climate is a dry midlatitude semi-arid climate group controlled by tropical masses producing westerly winds with polar air masses creating occasional polar winds. Based on monthly maximum and minimum records from 1963 to 1987, the average annual air temperature at the research site was 7.7°C; for 3 months of the year the mean temperature is below freezing and only July is typically frost-free. Annual potential evaporation ranges from 650 mm to 700 mm (Strahler and Strahler 1983). Storms may be either convectional or frontal. The average annual precipitation from 1963 to 1987 was 600 mm. Snow depth averages 230 mm from October through March. A weather station was located within 50 m of the research site and consisted of recording and standard rain gauges and maximum/minimum thermometers. The recording gauge measured 6-hr intensities. In addition, standard rain gauges were placed at each plot.

The largest storm recorded in the last 40 yr at the Union meteorological station was 26 mm h^{-1}. The estimated return period for the next largest storm, 19 mm h^{-1} is 13 to 20 yr. The maximum precipitation rate at the research site during the study period was 17 mm 6 h^{-1} from a total of 120 6-hr periods of precipitation. The largest 6-hr accumulation during the same period at EOARC was 9 mm.

The study was conducted in a ponderosa pine (*Pinus ponderosa*)/snowberry (*Symphoricarpos albus*) plant community type common in northeastern Oregon, eastern Washington, and adjacent portions of Idaho (Riegel 1992). Two sites were harvested after which tree density averaged 1 stem per 68 m^2 (Site 1) and one stem per 132 m^2 (Site 2). In both sites, trees were selectively removed by rubber tired skidders using predetermined skid trails during the winter of 1986 while snow covered the ground and soils were frozen. Before removal, the trees were limbed and cut to commercial saw-log length; all limbs were left on site and the tree tops were removed and piled outside of the treatment area. Smaller, excess trees were felled in July and August 1986 and left in place.

The following site characteristics were measured within each logging treatment; means for precipitation per sediment collection period, total accumulated precipitation, slope, aspect, ground cover (Daubenmire 1959), canopy cover (Jones and Campbell 1979), potential solar radiation (Chan et al. 1986), the depth of the organic soil horizon, bulk density (Blake and Hartge 1986), and penetrometer ratings (Davidson 1965). A one-way ANOVA was used to test for differences between sites for each of the above characteristics with the exception of cover class data which were tested using a Chi-squared statistic. Fisher's two-tail exact test was used to test cover class data where expected frequencies were not accepted for computed Chi-squared analysis (Steel and Torrie 1980).

The soil within the study site is a Tolo series (medial over loamy, mixed, frigid Typic Vitrandepts) and occurs on 2% to 35% slopes. It is a well-drained soil, and the average available water holding capacity is 320 mm (Dyksterhuis and High 1985).

Experimental Design

Bordered runoff plots (Williams and Buckhouse 1991) were installed in August 1986. At this time, no evidence of harvest (e.g., tracks, trails, or otherwise disturbed soil), remained from the previous winter's harvest activities. Plots were positioned to exclude slash piles, rock outcroppings, and trees. All plot construction traffic was outside of the plots. Plot border installation disturbance was limited to 10 mm within each plot due to border installation. The plots were 1 x 5 m, with a collection trough at the bottom which carried runoff into a collection bucket. Had runoff occurred, it would have been measured using a 1000 ml graduated cylinder and subsequently filtered to determine sediment production. Hypotheses were designed to test for differences in runoff and sediment production between harvested and nonharvested sites and different levels of understory disturbance (undisturbed, clipped, and organic soil horizon removed).

Hydrologic and erosion responses to natural precipitation were measured in 30 plots with similar slope (20 ± 3%) and aspect; half of which were located in Site 1 and adjacent nonharvested site, respectively. Collection buckets were examined for accumulated runoff monthly from September 1986 through May 1987, after every storm from June through September, and once again monthly through December 1987.

Simulated rainfall was applied to 12 plots with similar slope (30 ± 2%) and aspect; 6 each in Site 2 and adjacent nonharvested site, respectively. Three infiltrometer runs were made onto each plot in a sequence of ground cover disturbances: (1) undisturbed understory vegetation, (2) understory vegetation on all plots clipped to a 25 mm stubble height and the clippings removed, and (3) remaining vegetation and the organic horizon were removed by shovel and all loose biomass removed from the plots leaving bare mineral soil. Rainfall was simulated for 28 min. on each plot using an overhead sprinkler system consisting of three sprinkler heads distributing water in a rectangular pattern with an average delivery rate of 29 mm hr^{-1}. Rainfall intensity was measured by rain gauges at eight places within each plot. Ten days elapsed between each infiltrometer run to allow the soil profile to drain. The plots were covered with plastic for that period to prevent uncontrolled wetting and possible unrecorded surface flow and sediment production. Infiltration runs were initiated onto dry soil to duplicate conditions which occur with the first storm in fall following a summer dry period.

Results

Observations of 41 plots to measure runoff and erosion resulting from natural precipitation or simulated rainfall were recorded. No runoff or erosion were observed at any time

Table 1. Tests for difference between means of site characteristics in natural precipitation plots means.

Characteristic	Means		Difference between means
	Harvested	Nonharvested	
Precipitation (mm)	370	305	Yes*
Canopy cover (%)	39	61	Yes*
Slope (%)	21	21	No*
Aspect (°)	101.7	99.3	No*
Ground cover (%)	99	99	No*
Organic horizon (mm)	36	71	Yes
Potential solar (x)	0.64	0.40	Yes
Bulk density ($g\ cm^{-3}$)			
100 mm depth	1.07	0.96	No*
450 mm depth	0.73	0.90	No*
Harvested 100 mm vs 450 mm			No*
Nonharvested 100 mm vs 450 mm			Yes
Penetrometer ($Kg\ cm^{-2}$)	0.11	0.06	Yes

* indicates significant difference between treatment variances, thus conclusion may not be valid $P < 0.05$.
Units: millimeters (mm), kilograms per hectare ($kg\ ha^{-1}$), percent (%), degree (°), probability of diffuse radiation (x), grams per cubic centimeter ($g\ cm^{-3}$), and kilograms per centimeter squared.

during the study in either harvest treatment (Site 1 or Site 2) or corresponding nonharvested plots. Because measurable runoff or sediment production was not recorded, statistical analysis was not required.

Precipitation (to reach the forest floor), canopy cover, depth of organic horizon, and potential diffuse solar radiation were significantly different between harvested and nonharvested sites containing the natural precipitation plots. Although there was not a significant difference in soil bulk density between sites, there was a significant difference between the upper and lower horizons within the nonharvested site (Table 1). Chi square analysis of vegetation data showed that current years forb and gramminoid growth and the forb component varied between the harvested site and the nonharvested site in which the natural precipitation plots were located. An examination of the original data (Williams 1988) indicate the growth and forb component were greater in the harvested site.

Table 2. Tests for difference between means of site characteristics in simulated rainfall plots.

Characteristic	Means		Difference between means
	Harvested	Nonharvested	
Slope (%)	30	30	No
Ground cover (%)	96	99	No*
Organic horizon (mm)	48	67	No*
Bulk density ($g\ cm^{-3}$)			
100 mm depth	0.95	0.89	No
450 mm depth	0.94	0.93	No*
Harvested 100 mm vs 450 mm			No*
Nonharvested 100 mm vs 450 mm			No
Penetrometer ($Kg\ cm^{-2}$)	0.26	0.27	No

* indicates significant difference between treatment variances, thus conclusion may not be valid $P < 0.05$.
Units: millimeters (mm), kilograms per hectare ($kg\ ha^{-1}$), percent (%), degree (°), grams per cubic centimeter ($g\ cm^{-3}$), and kilograms per centimeter squared.

There were no significant differences between the measured characteristics of the sites containing the simulated rainfall plots (Table 2).

Discussion

There was no runoff or sediment production on either harvested or nonharvested sites. Because this outcome is contrary to our expectations, we will now examine the site conditions and why they are conducive to high infiltration capacities across all sites.

Hortonian runoff will occur only when the rainfall rate exceeds the infiltration capacity of the soil. Gaither and Buckhouse (1983) reported a potential infiltration rate of 60 $mm\ hr^{-1}$ in a similar ponderosa pine forest in northeastern Oregon. The rate of natural precipitation at the research site during the study period did not reach the historical maximum rate recorded at the nearby Union meteorological station. Even if the rainfall intensity at the research site were twice that of the 40 yr maximum recorded at Union ($\approx 52\ mm\ h^{-1}$), it is doubtful that it would exceed the infiltration capacity at either of the harvested or nonharvested sites. In addition, the simulated rainfall in this research did not approach the potential infiltration capacity. It ranged from 20 to 47 $mm\ h^{-1}$ across the plots and averaged 29 $mm\ h^{-1}$, roughly 14 mm per 28 min. run. However, this was in excess of the 40-yr maximum storm intensities (26 mm h-1), which gives some indication what the response to a large natural event might have been.

Ground cover, live and dead biomass, and rocks that protect mineral soil from direct impact of raindrops has been cited in numerous studies as one of the most important factors controlling infiltration capacities and runoff (Thurow 1991). Ground cover in this study ranged from 77% to 100% with an average of 98%. At all sites bare ground was the result of rodent activity. If soil had been exposed by the harvest during the winter of 1985–86, it had overgrown by June 1986. Furthermore, understory vegetation on all sites was composed of greater than 50% gramminoid species resulting in a subsurface soil horizon with a well-developed fibrous root component in various degrees of decomposition. Many of the grasses and forbs found at the site are rhizomatous and contribute to infiltration and soil stabilization by reducing raindrop impact. Because of the near complete cover and intact belowground biomass, the surface was protected from raindrop impact, and the soil structure was retained thus maintaining conditions necessary for high infiltration rates.

The depth of the organic horizon plays an important role in infiltration capacity by maintaining a porous interface between the atmosphere and mineral soil. Between the natural precipitation plots, the organic horizon in the nonharvested site was significantly deeper than in the harvested site. However, this had no apparent effect on the infiltration capacity, because all precipitation not evaporated from plant and soil surfaces infiltrated into all sites. The organic horizon was well developed in both sites containing the simulated rainfall plots, averaging about 55 mm. This layer alone had the potential for absorbing 20 mm of rainfall (Clary and Ffolliott 1969).

There were no differences in bulk density between harvested or nonharvested sites for either set of plots. Increased bulk density results from activities that break down the soil structure, crushing pore space, which in turn can lead to decreased infiltration capacity. Bulk density typically increases with soil depth. This was the case in the nonharvested site in which the natural precipitation plots were located and in both sites of simulated rainfall plots. However, there was no difference between bulk density at the two depths in the harvested site in which the natural precipitation plots were located. This may indicate an increase in bulk density in the upper part of the profile, apparently the result of harvest activities. There was a large variation in the data from the harvested site which may be attributed to serendipitous location of a number of plots on skid trails or where trees fell. As noted previously, by the time positions for the plots were chosen, all signs of these activities, such as berms from soil displacement, were gone. But since there was no runoff in either set of plots, the degree to which bulk density may have been increased appears not to have been deleterious to infiltration capacities. This supports the contention of Snider and Miller (1985) that logging does not always severely alter a site. Generally, the soil had a low bulk density and was well drained, which is characteristic of the Tolo soil series.

The surprising outcome was that after all vegetation and loose organic material was removed and simulated rainfall applied to bare soil, no surface flow occurred. Rainfall striking a bare soil surface is generally acknowledged to dislodge soil particles, creating splash erosion which plugs the soil pores and eventually leads to surface flow. When not protected by a vegetative cover, the Tolo soil series is prone to rill and gully erosion (Dyksterhuis and High 1985).

The lack of runoff and erosion may be explained by the minimal disturbance to the soil structure. With only the vegetation and organic horizon removed, and assuming that the site originally had a potential infiltration capacity of 60 mm hr^{-1}, then the conditions of soil structure, texture and antecedent moisture may still have been adequate to maintain a higher rate of infiltration than the natural or applied rate of rainfall. A second explanation is that the size and velocity of the simulated raindrops were not great enough to have the kinetic energy required to dislodge soil particles. Thus infiltration would have continued to be controlled by soil structure and antecedent soil moisture. Finally, it is doubtful that the soil profile approached saturation in either natural or simulated parts of this study because the Tolo series is a well-drained soil, and the potential evapotranspiration of this area exceeds precipitation. In the natural precipitation plots, runoff might have occurred with a rain on snow and frozen soil event. This, however, did not occur during the period of study.

The likelihood that surface flow would have occurred if the rate of application had been greater was examined. We noted that the simulated rainfall was not evenly applied, and localized ponding and limited surface flow occurred in a small area (0.13 m^2) in the upper righthand corner of the plots. Therefore, an attempt was made to determine the final infiltration capacity of the site by increasing the rate of application across an entire plot. A single run was made that continued until the water supply was exhausted. A total of 84 mm of rainfall was applied at an average rate of 39 mm hr^{-1}. After 2 hr and 10 min., no surface flow was produced outside of the localized flow in the upper right hand corner of the plot. This lack of measured surface flow and sediment production attests to the residual soil structure and well-developed root mass in the soil profile.

Conclusion

No runoff or sediment production was observed under either harvested (on snow cover, frozen soils, and designated skid trails) or nonharvested conditions resulting from either natural precipitation or simulated rainfall. Furthermore, no runoff or sediment resulted from simulated rainfall from either harvested or nonharvested plots subjected to three different levels of ground cover disturbance the first year following harvest on this northeastern Oregon ponderosa pine site.

These results are similar to those of Hart (1984), where less than 1% of the simulated rainfall became runoff. We believe these results are due to the harvest method and the weather conditions during the study period.

This effort supports previous findings that runoff in undisturbed forested systems is rare and should not occur where logging systems create minimal on-site disturbance (Heede 1987). These findings show the importance of well-planned tree harvest to preserve belowground root structure and organic matter as well as soil structure in the initial year following harvest. If timber harvests in vegetation community types with similar site conditions are modeled after the logging practices (on snow cover, frozen soils, and prescribed skid trails) used in this study, the chances for runoff and soil erosion in the year following harvest will be diminished. Finally, the lack of runoff from the clipped plots suggests livestock grazing that does not significantly compact the soil or create extensive bare areas may be possible without severe erosion risk.

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