VARIATION BETWEEN DIFFERENT SURFACE CONDITIONS IN TIMBER HARVEST SITES IN THE SOUTHERN APPALACHIANS

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ABSTRACT

Information about differences in surface conditions on timber harvest hillslopes is important for hydrologic modeling. We measured and compared saturated hydraulic conductivity and interrill erodibility values for different conditions found on timber harvest sites. Plots with different surface conditions were subjected to three simulated rainfall events. Conditions sampled included bladed skid roads with and without treatments, many pass skid trails, few pass skid trails, low burn severity harvest sites, high burn severity harvest sites, and undisturbed forest. Results suggest these conditions can be divided into two or three groups for modeling purposes.

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INTRODUCTION

Timber harvest practices and site preparation techniques cause a wide range of disturbances on harvest units. Post-harvest slash burning, for example, is the most common site preparation treatment used nationwide, singly and in combination with other treatments. This treatment reduces wildfire danger, eases planting, suppresses plant competition, and prepares sites for both natural and artificial regeneration. This site preparation treatment may effect an entire harvest unit or just portions of it. The areal extent of these various surface conditions must be known to be able to predict runoff and sediment production from timber harvest units.

Previous studies by Robichaud and Waldrop (1992) and Robichaud and Shahlaee (1991) indicate large variation in runoff and sediment production from timber harvest units. This variation is attributed to differences in surface conditions throughout the timber harvest unit due to natural variation and management activities.

The objective of this study was to identify the different surface conditions normally found on clearcut harvest units in the Southern Appalachians and compare the saturated hydraulic conductivity and interrill erodibility values among these surface conditions to determine if they are significantly different.

METHODS AND SITE DESCRIPTION

Two sites were used for this study: Lower Buck in the Nantahala National Forest and Log Hollow in the Pisgah National Forest in North Carolina during the summer of 1992. The regions are transitional between the central deciduous forest and the prevailing pine forest of the Southeast. Soils at the Lower Buck site were coarse-loamy, micaceous, mesic Umbric Dystrochrepts and at the Log Hollow site were fine-loamy, mesic Typic Hapludults (Figure 1). The 12 ha Lower Buck site was clearcut and tractor logged in the summer of 1991. Logging activities created a network of skidder trails throughout the entire harvest unit. In late spring of 1992, a burn was conducted at this site as part of the prescription burn program of the District. To monitor the burn, a systematic method of measuring the fuel loading, fuel consumption and forest floor consumption was completed by the techniques of Brown (1974) and Robichaud and Waldrop (1992). After the burn, the entire harvest unit was mapped to delineate the surface conditions. Nine different conditions were identified at Lower Buck and two plots were randomly located within each condition except where three plots were located (Table 1).

Conditions included high fuel loading burn areas (H), low fuel loading areas (L), rootmat removed treatments (RR) where residual forest floor was carefully removed with minimal disturbance to the underlying mineral soil, an undisturbed natural vegetation area (NA), and several common skid trail/road treatments. These include a bladed skid road, in which the skidder plowed into the soil B or C horizon to make a temporary road to access timber and remove logs. Another condition was a newly constructed skid road (BN), before any compaction by skidder traffic (a piece of sheet metal was dragged across the fresh surface to smooth it out, this produced a very loose surface condition). After harvesting activities were complete, these bladed skid roads are often ripped to 4-6" and planted with grass seed (BPF-planted in the fall of 1991, BPS-planted in the spring of 1992). Additional skid road treatments found at Log Hollow, compared placing debris on the skid road (BD-bladed skid road covered with logging debris) to an untreated skid road (BU). Other skidder induced conditions include areas where skidders did not use their blade and used the skid trail no more than four passes (TF-skid trail few passes); and skid trails were the skidders did not use the blade and used the skid trail more than five times (TM-skid trail many passes).

Simulated rainfall events were applied to these 1 m^2 plots with a U.S. Department of Agriculture, Forest Service oscillating nozzle rainfall simulator. These plots were isolated by 15-cm sheet metal placed vertically 5-cm into the ground. The simulator produced an average rainfall intensity of 100 mm/hr, which represents a 10-yr event for a 30-min rainfall event (Purvis et al. 1988). Seven rain gauges were located around each plot to verify the rainfall amount. Each plot received three 30-min rainfall events (runs). Run 1 was conducted under existing soil moisture condition. Afterwards, the plots were covered with plastic tarps and Run 2 was conducted the following day. Run 3 was conducted about 30 minutes after Run 2. A covered trough at the lower end of each plot conducted runoff (water and sediment) through an outlet tube for timed volume samples, collected manually in 1000 ml bottles. At the end of each run, any sediment in the trough was washed into bottles. All runoff samples were weighed and oven-dried to develop hydrographs, sedigraphs, total runoff volumes and sediment yields.

Hydrographs were analyzed using the method of Luce and Cundy (in review) to obtain infiltration parameter values for Philip's (1969) equation. The analysis uses the Shuffled Complex Evolution method (Duan et al. 1992) to fit a model of infiltration and overland flow developed by Luce and Cundy (1992) to the field measured hydrographs. The slopes varied from 4 to 27 degrees, and infiltration parameter values were adjusted for slope using Philip (1990). The hydrographs from the natural plot (NA) could not be represented using this model because the process of unsaturated flow through the organic forest floor is not represented, so they were not used to obtain infiltration parameter values.

We compared saturated hydraulic conductivity values fitted for Philip's equation among the treatments and sites using Scheffé pairwise comparisons between the individual treatments and contrast testing between individual treatments and groups of treatments. Because the three events are essentially repeated measures, we used only the saturated hydraulic conductivity fitted from the very wet event, which is the most reliable of the three estimates.

Interrill erosion was observed and measured in the timed volume samples collected during each run. Interrill erodibilities were back calculated from Laflen's et al. (1991) delivery of sediment equation. The delivery of sediment is estimated by the expression:

$$K_i \, G_e = D_i \,/\, I^2 \, C_e \, S_f$$

where K_i is interrill erodibility (kg-s/m^4), G_e is ground cover adjustment factor, D_i is the delivery of sediment from interrill area (kg/m^2-s), I is effective rainfall intensity (m/s), C_e is canopy cover adjustment factor, and S_f is slope adjustment factor calculated by:

$$S_f = 1.05 - 0.85 \, e^{-4(\sin a)}$$

where a is slope.

Management conditions common to these timber harvest units affect both the percent ground cover and the physical disturbance of the soils. Because of this, we kept K_i and G_e

combined for this analysis. Since their is no canopy cover, C_e was set to one. Comparisons were made by Scheffé pairwise comparison test between individual treatments with repeated measures (rainfall events).

RESULTS AND DISCUSSION

A summary of site and plot conditions are presented in Table 2. Total runoff and total sediment were higher for the bladed skid road conditions than the harvest treatment conditions regardless of soil type. The soils from the two sites were slightly different in texture due to differences in the coarse fragments (Figure 1).

Representative fitted and measured hydrographs are shown for a bladed skid road and high severity burn harvest area treatments (Figure 2). These show an excellent fit to the measured hydrograph by Luce and Cundy's method. The means of saturated hydraulic conductivity are presented in Table 2, and were compared in a one-way analysis of variance. The main effect, condition, was significant, with a p-value of 1.7×10^{-5}. We did further contrast tests to determine where the differences were.

We systematically tested comparisons between bladed skid roads using five contrast tests. Table 3 presents the contrast tests performed and their p-values. There is no significant difference between hydraulic conductivities for the two roads at Log Hollow with test 1. Test 2 indicated that there was no significant difference between the hydraulic conductivity of the new skid road and the two ripped and planted skid roads at Lower Buck. This result was unexpected, and may be due to the small sample size. Table 3 suggested that the fall planted trail may have been different than the new trail and the spring planted trail, but test 3 was not significant. A contrast test between the two Log Hollow skid roads and the three Lower Buck skid roads (test 4) was significant. Based on this, we did not compare other treatments at Lower Buck to the bladed skid road treatments at Log Hollow.

A one-way ANOVA of only the Lower Buck sites showed that there were significant differences among the treatments with a p-value of 0.0003. A Scheffé pairwise comparison of variables is presented in Table 4. The Scheffé test is very low power, so is considered conservative in that only the most significant differences show up as significant. The most noticeable pattern is that the bladed skid roads are consistently different from the other conditions. The differences are not significant between many-pass skid trails and bladed skid roads, but they are greater than the differences between many-pass skid trails and other conditions. Contrast test 5 (Table 3) is a contrast between bladed skid trails and the other conditions as a group, and is highly significant. A notable difference that was expected but not detected is the difference between high and low severity burns. Robichaud and Waldrop (1992) suggest that runoff from high severity burns is greater than from low severity burns, but a more detailed field study is needed to discern the difference, if it exists.

Total sediment from the three rainfall events combined for each treatment are presented in Table 2. The new bladed skid trail condition (BN-bladed skid road-new) yielded the most sediment. The soil was loose, had not been compacted by skidder traffic, and was therefore easily detached and/or transported from the plots.

The interrill erodibility terms K_i combined with ground cover term G_e calculated for each condition are presented in Table 2. Since different erodibility values were expected from different soil types, K_i G_e between Log Hollow and Lower Buck were not compared, but sites were analyzed independently for significant differences between conditions within the same site. A one-way ANOVA of the Lower Buck sites showed that there were significant differences among the treatments with a p-value of 0.0002. The Scheffé pairwise comparison test was then used to compare treatments at the Lower Buck site (Table 5). The K_i G_e term from the bladed skid road-new conditions was significantly different than the all other conditions by this comparison. Next we removed the BN condition and compared the BPS and BPF conditions to the other harvest area condition. These were significantly different (P-value of 0.0076). Thus the combination of less ground cover and more soil disturbance by the bladed conditions are more erodible.

Next we compared the bladed skid road treatments at Log Hollow. The debris covered skid road was significantly less erodible than the untreated skid road (P-value of 0.0014).

CONCLUSIONS

Timber harvest units can be separated into different surface conditions to analyze differences in infiltration and erodibility. Twelve conditions were identified from two locations that are typical for forest management in the southern Appalachians.

Data show that bladed skid roads treatments produce more runoff and sediment than harvest areas. This increase may be due to changes in ground cover conditions and soil disturbance associated with skid trail practices.

The number of conditions present on timber harvest units can be reduced from the twelve conditions observed. These conditions can be lumped to two or three categories (treated bladed skid road, untreated bladed skid road-new, and harvest area treatments). The exact number of conditions that it can be reduced to must be evaluated with an experiment with a larger sample size.

Our results suggest debris placed on skid roads after harvest operations may reduce sedimentation significantly until revegetation occurs. This may be an simple and inexpensive method to reduce sediment from leaving the site.

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TABLE 1. Summary of conditions for rainfall simulator plots.

Site	Condition Code	Condition	Number of Plots	Average Ground Cover (%)	Average Slope (%)
Log Hollow	BD	Bladed Skid Road-Covered With Logging Debris	3	94.3	29.6
Log Hollow	BU	Bladed Skid Road-Untreated	3	49.9	34.3
Lower Buck	BPF	Bladed Skid Road-Planted Fall 1991	2	62.3	7.0
Lower Buck	BPS	Bladed Skid Road-Planted Spring 1992	2	65.5	9.0
Lower Buck	BN	Bladed Skid Road-New	2	22.2	10.7
Lower Buck	STF	Skid Trail-Few Passes	2	99.5	30.5
Lower Buck	STM	Skid Trail-Many Passes	2	98.0	30.5
Lower Buck	RR	Root Mat Manually Removed	2	43.0	39.7
Lower Buck	H	High Severity Burn	2	65.3	44.5
Lower Buck	L	Low Severity Burn	2	71.0	41.5
Lower Buck	NA	Natural Plot; Undisturbed	2	99.8	37.0

TABLE 2. Summary of total runoff, total sediment, hydraulic conductivity values, and interrill erodibility times ground cover factor for each condition.

Condition Code	Total[1] Runoff (mm)	Total[1] Sediment (g)	Hydraulic Conductivity (mm/hr)	Interrill Erodibility × Cover Factor ($K_i\ G_e$)
BD	72.6	20.2	33.3	6,500
BU	101.2	1796.1	19.3	553,900
BPF	127.2	1179.9	14.3	635,200
BPS	120.9	2543.0	7.9	1,335,700
BN	142.9	8736.8	5.9	4,053,900
STF	27.2	9.4	81.8	2,900
STM	47.8	56.3	60.4	18,400
RR	31.2	290.2	80.9	80,500
H	36.2	263.9	83.7	72,100
L	29.2	114.5	90.7	31,100
NA	7.2	2.5		700

[1]The summation of the three rainfall events averaged over the number of plots.

TABLE 3. Results of contrast tests for hydraulic conductivity. Groups marked with "×" compared to groups marked with "○".

Site	Condition Code	Test # 1	2	3	4	5
LH	BD	×			×	
LH	BU	○			×	
LB	BPF		×	×	○	×
LB	BPS		×	○	○	×
LB	BN		○	○	○	×
LB	STF					○
LB	STM					○
LB	RR					○
LB	H					○
LB	L					○
P-Value[1]		0.22	0.66	0.53	0.046	<0.001

[1]P-Values are probabilities that the two groups have the same mean.

TABLE 4. Results of Scheffé pairwise comparisons for hydraulic conductivity at the Lower Buck site only. P-Values are probabilities that two means can be considered equal. Significant values are underlined.

Condition Code	BPF	BPS	BN	STF	STM	RR	H	L
BPF								
BPS	1.000							
BN	0.999	1.000						
STF	<u>0.032</u>	<u>0.019</u>	<u>0.016</u>					
STM	0.188	0.110	0.094	0.865				
RR	<u>0.034</u>	<u>0.026</u>	<u>0.018</u>	1.000	0.888			
H	<u>0.027</u>	<u>0.016</u>	<u>0.014</u>	1.000	0.815	1.000		
L	<u>0.016</u>	<u>0.010</u>	<u>0.008</u>	0.999	0.588	0.998	1.000	

TABLE 5. Results of Scheffé pairwise comparisons for K_i G_e at the Lower Buck site only.

P-Values are probabilities that two means can be considered equal. Significant values are underlined.

Condition Code	BPF	BPS	BN	STF	STM	RR	H	L
BPF								
BPS	.9106							
BN	<u>.0040</u>	<u>.0168</u>						
STF	.9441	.3779	<u>.0012</u>					
STM	.9503	.3897	<u>.0013</u>	1.0000				
RR	.9708	.4395	<u>.0014</u>	1.0000	1.0000			
H	.9685	.4325	<u>.0014</u>	1.0000	1.0000	1.0000		
L	.9551	.3996	<u>.0013</u>	1.0000	1.0000	1.0000	1.0000	

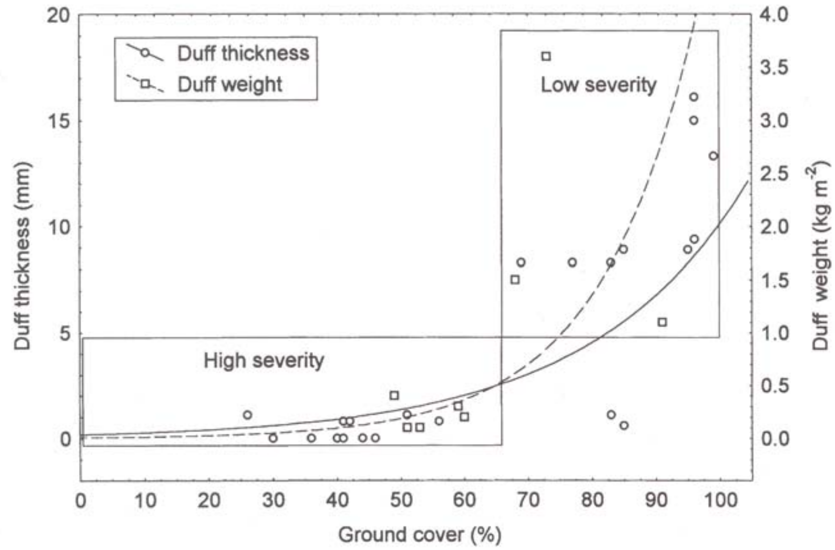

Figure 1: Particle size distributions for the bladed skid road condition at Log Hollow in the harvest area and bladed skid road conditions at Lower Buck.

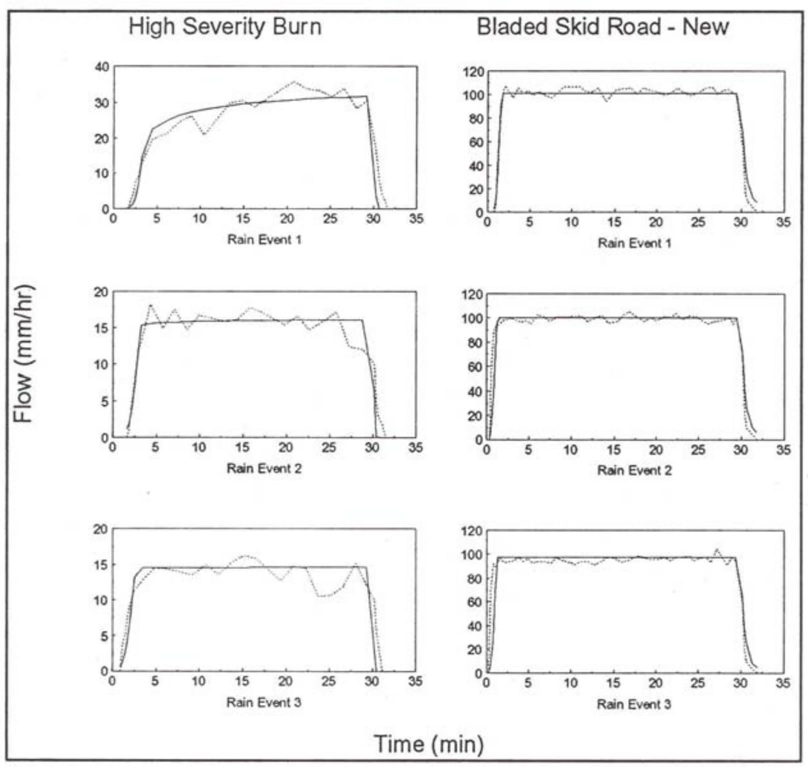

Figure 2: Measured and predicted hydrographs for a high severity burn plot and a newly bladed skid road plot. Solid lines are predicted and dots are measured.

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