EFFECTS OF TRAFFIC AND DITCH MAINTENANCE ON FOREST ROAD SEDIMENT PRODUCTION

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Abstract: Observations of sediment yield from road segments in the Oregon Coast Range show that either heavy traffic during rainfall or blading the road ditch will increase erosion from forest roads. For the fine soils and high quality aggregate surfacing on the study plots, ditch blading increased sediment yield more than traffic equivalent to 12 log trucks per day. The combination of ditch blading and heavy traffic did not produce significantly more sediment than simply blading the ditch, a finding with important implications for sediment modeling and erosion control design. Increases in sediment production caused by traffic persisted after traffic ceased.

INTRODUCTION

Road maintenance and traffic are two of the primary activities affecting sediment production from forest roads. Given the large base of existing roads in forestlands, it is important that we understand how these activities affect sediment yield from road systems. While it is generally agreed that either traffic or ditch maintenance increase sediment production, observations showing the combined effects relative to individual effects are lacking.

Maintenance keeps roads in a condition suitable for travel and prevents severe erosion from failure of the drainage system. Unfortunately, road grading can break up armor layers on the road surface or the ditch and temporarily increase road surface erosion (Burroughs and King, 1989; Black and Luce, 1999; Luce and Black, 1999). Burroughs and King (1989) noted increased erodibility of the traveledway following road grading operations. However, Luce and Black (1999) noted that blading of only the traveledway on an aggregate surfaced road with well vegetated ditches yielded no increase in sediment production from a complete road segment, while blading of the ditch, cutslope, and traveledway substantially increased sediment yield from road segments. The recovery from ditch blading occurs rapidly during the first three years (Luce and Black, 2001) in an exponential pattern similar to that found by Megahan (1974) for new roads. Observations of vegetation and ditch particle size suggest that much of the reduction over time is due to armoring rather than revegetation (Black and Luce, 1999).

The role of traffic in increasing road sediment production is likewise well recognized and has had attention from several researchers (Reid and Dunne, 1984; Swift, 1984; Bilby et al., 1989; Burroughs and King, 1989; Coker et al., 1993; Foltz, 1999; Ziegler et al., 2001), who report a range from doubled sediment production to 30 times as much. Results are commonly reported as ratios between yields from roads with and without traffic, conceptually normalizing for precipitation and allowing generalization of the results beyond the particular events studied. Many of the studies are from rainfall simulation; some experiments were on the entire road prism, and some isolated sediment from the traveledway. Those studies where concentration samples were taken show a relatively brief effect from traffic passing during a storm, with significant recovery occurring on a time scale of tens of minutes. The postulated processes for

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the increase in sediment yield are through an increased availability of fines caused by crushing the road surfacing and by pressing larger particles down through a matrix of finer sediment.

An important question left unanswered by these studies is the combined effect of ditch maintenance and traffic. One hypothesis is that the effects are cumulative. Some models use the ratios from the studies to estimate the effect, one factor is applied for the time since construction or disturbance of the ditch and another is applied for the traffic level (e.g. Cline et al., 1984; and Washington Forest Practices Board, 1995). Another way to model the effect is through addition, where the traveledway and ditch contributions are calculated separately based on their individual treatments and then added. A third alternative would suggest that there might be tradeoffs, that the total effect may be less than the sum of the parts. Increasing the availability of sediment in the ditch and on the traveledway may be somewhat redundant. If the sediment transport capacity of the ditch is fully sated by material easily detached in the ditch, the additional available fine material on the traveledway may have little effect on the segment sediment yield.

Consideration of the flowpath is important in estimating the effects of treatments to roads. Burroughs and King (1989) showed an effect on traveledway sediment yield from blading, but Luce and Black (1999) found nearly no effect on sediment yield from an entire road segment given the same treatment. One explanation may be that sediment from the road surface was trapped in the well vegetated ditch, implying that grading the ditch would not only allow ditch erosion, but also allow passage of the traveledway sediment. This logic would support the idea that there is a positive non-linear interaction (e.g. multiplicative) between road surface treatments and ditch treatments on sediment yield. Alternatively, Burroughs and King (1989) noted that substantial reductions in traveledway sediment production by placing rock aggregate (~80%) did not reduce total plot sediment production as much (~30%) because of increased sediment detachment in the unprotected ditch. This observation suggests that high sediment yields can come from either unprotected ditches or unprotected (or heavily traveled) traveledways, supporting the tradeoff hypothesis. Another observation is that traffic forms ruts, causing sediment produced on the road surface to travel on the road surface independently of ditch sediments, supporting a simple additive model. Some would be quick to point out, however, that this also robs the ditch of much of its water as well, and if the road surface is constructed with material that is less erodible than the ditch, traffic could conceivably reduce sediment yields on roads with freshly cleaned ditches.

Because the earlier studies on the individual effects of traffic and maintenance are used as the basis of sediment yield models, forest practice regulations, and best management practice design, it is important that some of the uncertainty associated with the question of combined effects be reduced. Unfortunately, the question cannot be answered with physically based models, because any of the three hypotheses can be generated using different choices of parameter values and flowpath. Observations showing the individual and combined effects of traffic and maintenance are needed to understand the interaction.

METHODS

The effects of traffic and ditch maintenance were examined on twelve road segments in the Oregon Coast range about 20 km northwest of Eugene, Oregon. The twelve plots were broken into four categories, those with no traffic and no ditch grading (NTNG), those with traffic and no ditch grading (TNG), those with no traffic but with a graded ditch (NTG) and those with both traffic and a graded ditch (TG). Traffic was applied to one contiguous set of six road segments for practical reasons, and the grading treatment was assigned randomly.

The road segments all had similar characteristics otherwise. All had lengths of 80 m and were isolated by ditch dams and rubber-flap/wood-box water bars and runoff was diverted into sediment traps. Road gradient was between 9 and 10 percent, and cutslope heights were approximately 2 m on all road segments. The roads were constructed on a silty clay loam soil over weathered sandstone. The roads were surfaced with high quality basalt aggregate and had inboard ditches. The traveledway was freshly bladed on all plots. All ditches and cutslopes were seeded with grass during the previous spring, and the ditches were bladed on October 14, 1999 for the segments with that treatment. The reader is referred to Luce and Black (1999) for more details on plot construction and soil attributes.

Traffic was provided by a short log truck and, later, a dump truck. Both vehicles had similar wheel arrangements, with two axles in the rear with dual tires and a front steering axle. The rear sets of duals carried 15,840 kg (33,850 lbs.) and the front axle carried 5,610 kg (12,340 lbs.). These weights are similar to those on full sized log trucks. The trucks made 10 round trips per weekday over the 6 traffic plots during the period November 15 to December 14. During this period traffic occurred on both rainy and dry days and on saturated and dry road surfaces. The traffic was roughly equivalent to 12 loaded full-length log trucks per day. On each day of traffic, 5 round trips (10 passes) were made over a 1 hr period with a 30-minute break followed by another 5 round trips.

Sediment was collected from the tanks on January 11th and again on June 13th. Tanks with the greatest amounts of sediment were weighed with sediment and water, emptied and weighed again filled only with water to obtain the submerged weight of sediment (see Luce and Black, 1999 for details). For tanks with little sediment, we decanted the clean water off of the tanks using a siphon (avoiding disturbance of the sediment). The sediment was transferred to small steel buckets for weighing on a more precise scale, allowing a more precise determination for the small sediment amounts. Precipitation between Nov 15 and Dec 14 was 351 mm. 151 mm fell between Dec 14 and Jan 11. 589 mm fell between Jan 11 and Jun 13. Average precipitation depths for these periods in Eugene, Oregon are 218, 170, and 551 mm respectively.

During one day of traffic, water samples were collected from the wheel ruts immediately following a vehicle pass to capture the peak sediment concentration. An additional sample was taken 20 minutes into the break between sets of passes, and three samples were taken at 20 minute intervals following cessation of traffic to see how concentration in the wheel rut at the base of the plot changed with time. In addition, concentration samples were taken from the plot outflow (ditch plus tread) at the same time.

We used t-tests on the log transformed sediment yields to test the statistical significance of specific contrasts. The transformation was used because earlier research has suggested that erosion is log-normally distributed (Megahan et al., 2001).

RESULTS AND DISCUSSION

Mean sediment yield during the first sample period, Nov. 15 to Jan. 11, was least for the plots with no traffic and no ditch grading, followed by the plots with traffic but no grading, and the plots with grading but no traffic, and the mean sediment yield was the greatest for segments with both traffic and a graded ditch (Figure 1). All contrasts were statistically significant except for the difference between the traffic and no traffic plots given a graded ditch (Table 1). These results suggest that blading the ditch has a greater effect than traffic on the sediment yield. This particular result may differ given a different soil texture in the ditch or poorer aggregate quality. More significant is the result that the traffic effect depends on whether the ditch is graded. Given that the statistical tests were for log transformed data and the low power inherent in a design with three samples per treatment, we can reject the multiplicative cumulative effect hypothesis, but we cannot statistically discern between the simple additive cumulative effect and the tradeoff hypothesis. Looking at the pattern of the scatter from the No-Traffic-Graded (NTG) plots, we can see that the mean and scatter are strongly influenced by one plot with low sediment yield (Figure 1). The other two NTG plots actually produced more sediment than any of the plots with both traffic and grading. It is worth noting that the sediment production of the one plot is uncharacteristically low for a graded plot given earlier observations (Black and Luce, 1999; Luce and Black, 1999, 2001) and concurrent observations from similarly treated plots. For example three shorter plots (42 m, 42 m, and 60 m) with slightly steeper, 10%, slopes, graded ditches, and no traffic measured during the same period produced 2467, 4533, and 2970 kg/km respectively. Armed with this additional information, removing some weight from the low observation, there is greater support for the tradeoff hypothesis than for the simple additive effect hypothesis.

These results underscore the importance of collecting observations of sediment yield from the entire portion of road prism that is contributing water and sediment when evaluating the effects of treatments, an idea also suggested by Burroughs and King (1989). Observations of individual

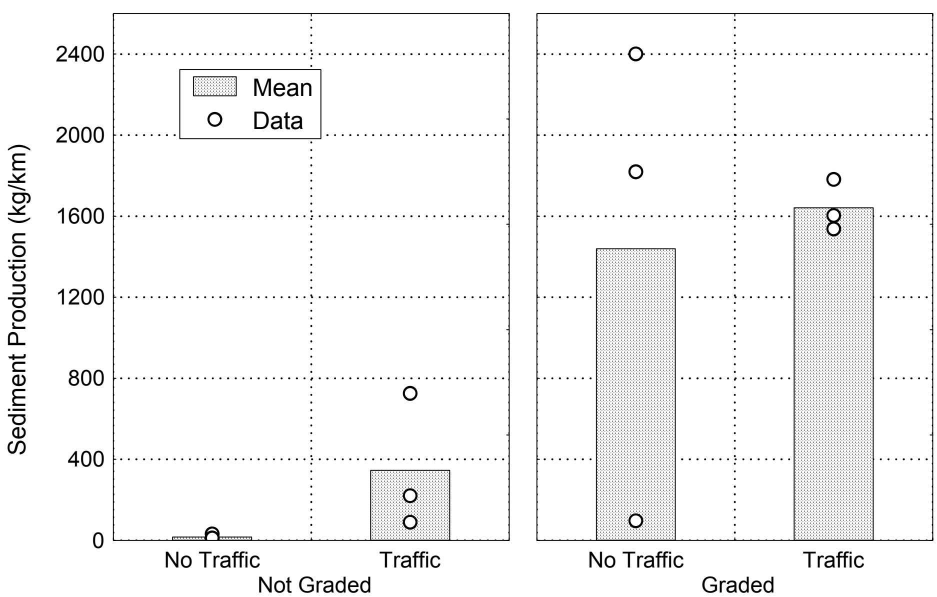

Figure 1: Sediment yield from road segments during the traffic period, November 15, 1999 to January 11, 2000. Bar graphs show mean and data points show specific observations.

Table 1: Statistical Significance of specific contrasts.

Effect of	Given	p value Nov--Dec	Jan-Jun
Grading	No Traffic	0.02	0.02
Grading	Traffic	0.03	0.02
Traffic	No Grading	0.02	0.04
Traffic	Grading	0.49	0.53

parts of the road prism can be misleading if there is potential for interaction of water and sediment from different parts of the road prism. It is also important to recognize the condition of the ditch and the cutslope/ditch contribution to the road segment sediment yield when interpreting results from studies. For example, it is useful to know that the results of Reid and Dunne (1984) showing substantial effect from traffic had little contribution from ditch and cutslope erosion.

Implications for modeling are fairly clear; independent factors applied for ditch maintenance and traffic are not appropriate. Nor would it appear that separate calculation of traveledway and ditch/cutslope contributions is the best option. The stronger support for the tradeoff hypothesis implies that sediment yield increases modeled to result from traffic must consider the condition of the ditch.

There are important implications for the design of BMPs or forest practice regulations. Ditch grading can increase sediment yields on a level comparable to or greater than wet weather hauling. Ditch grading is an important and necessary step in the maintenance of roads when significant sediment inputs (e.g. from a slump or upslope gully) block the ditch, however indiscriminate ditch grading to clean ditches may not be the best use of equipment time. The practice of placing rock in ditches and design criteria for ditch rocking were proposed by Burroughs and King (1989), and our results support their suggestion. The question of whether wet weather haul increases sediment yields on recently constructed or reconstructed roads is important for BMP design. Wet weather haul restrictions provide little and uncertain benefit on roads with recently bladed ditches. Sediment delivery control through crossdrain placement is probably the preferred design, but at locations where delivery is likely (e.g. stream crossings), thorough control of sediment would require protection of both the ditch and the traveledway. Note that the roads in this study were built well enough that the subgrade showed through the aggregate surfacing in only a few places, and the deepest ruts were about 90 mm. The results of this study do not apply to roads where the integrity of the surfacing may be severely damaged by traffic.

For the post traffic period, January 11 to June 13, rankings are similar to those seen in the traffic period, although there was less erosion (Figure 2). The reduced erosion is due in part to armoring during the previous months. The contrasts are similar in statistical significance (Table 1). The difference in graded versus ungraded plots is expected because we know that the effect of grading persists for more than one year in the increased availability from ditch grading (Luce and Black, 2001). The fact that the pattern of differences is maintained suggest that traffic effects may persist beyond the time scale of a few events. Reid and Dunne (1984) noted some persistence beyond the event time scale in their “temporary non-use” segments.

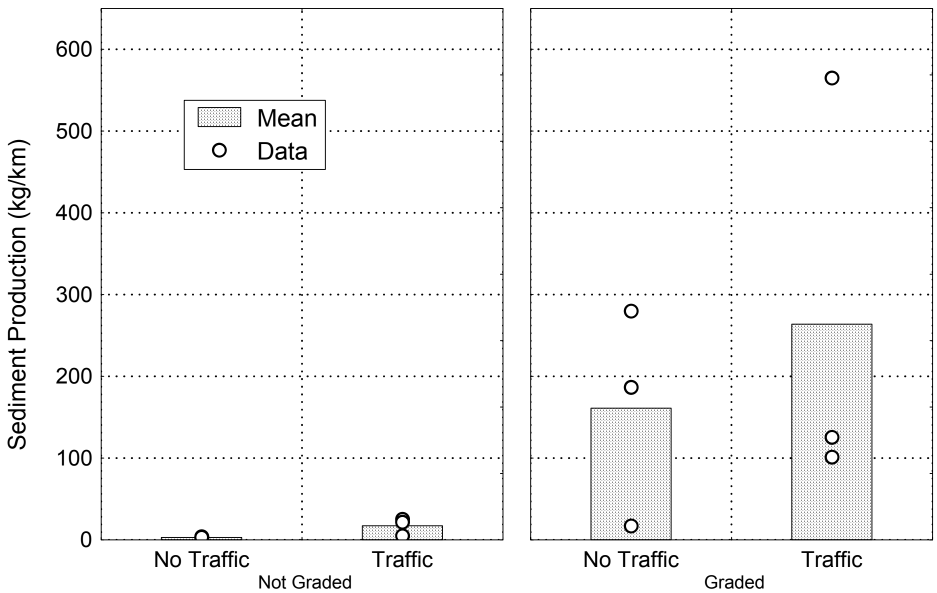

Figure 2: Sediment yield from road segments during the post-traffic period, January 11 to June 13, 2000. Bar graphs show mean and data points show individual observations.

Examination of sediment concentrations during an event showed a rise in concentration as several passes were made, and a rapid drop to lower concentrations after the traffic stopped (Figure 3). Plot runoff showed substantially lower concentrations than the peaks measured by the rut sampling because of dilution from cutslope runoff areas of the road surface where the truck had not recently passed. These patterns agree with other observations of event scale variations in sediment availability (e.g. Reid and Dunne, 1984; Ziegler et al., 2000, 2001). As the vehicle passed, fines were pressed into the tread of the tire while the lugs pressed larger pieces of gravel into the matrix of fines and gravel comprising the road bed. The treaded pattern of fine material was quickly dissipated by precipitation and flowing water. During the course of the traffic, wheel ruts developed varying in depth from 10 mm to 90 mm, and exposure of the subgrade through the aggregate was rare.

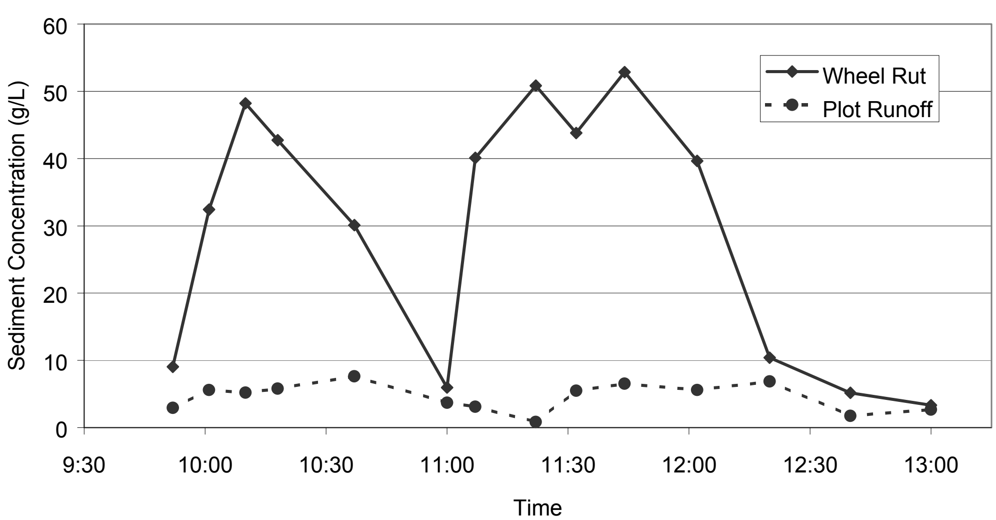

Figure 3: Concentration of sediment over time during one set of passes by a heavy vehicle.

Some persistence in availability of fines would be expected on traffic plots, as the supply of fines from the road over the traffic period would reduce the degree of armoring during that period, and the composition of the material in the ditch beds and wheel ruts should be finer at the end of the traffic period. It is not necessary that the increased availability of fine sediments persist into June for the observed differences in Figure 2. A brief period of increased erosion followed by a long period of essentially equivalent availability could account for the observations. A more likely scenario is an exponential decline in the availability of fine sediment as the finer sediments are selectively removed from the plot (e.g. Megahan, 1974).

CONCLUSIONS

Traffic and maintenance operations are activities normally experienced by forest roads at one time or another during their useful life. Both activities increase the susceptibility of a road to erosion. In order to better manage the spatial and temporal distribution of sediment inputs to streams, it is important to understand how maintenance and traffic affect sediment yield from forest roads.

Grading of the ditch increased sediment yields more than heavy traffic on a road built in a fine-grained parent material with high quality basalt aggregate. The combination of both traffic and ditch grading produced on average more sediment than either treatment alone, however the difference between grading-only and grading-with-traffic was not statistically significant with 3 samples in each treatment. A closer examination of the individual data points and results from similar plots in this year and earlier years provides support to the hypothesis that there is little difference in sediment yields between traffic and no-traffic plots given a graded ditch.

These results suggests that the multiplicative interaction model commonly used to estimate effects of multiple treatments on roads overestimates the effect of traffic on new roads or recently graded roads. A model of traffic effects that is conditional on ditch condition (e.g. time since construction or ditch grading) seems more appropriate. Although the ditch grading effect is much larger, its effect is seldom accounted for in road sediment yield modeling whereas traffic effects generally are, if only as a traffic regime. For roads with regularly scheduled maintenance, it may be desirable to model the effect of a maintenance regime.

Proscription of wet weather haul is an increasingly common best management practice that is effective in reducing sediment production from existing roads. Proscription of wet weather haul on roads with high quality aggregate and recently disturbed ditches may have little benefit. Reducing the amount of road with unnecessary ditch grading is unequivocally effective in reducing sediment production.

Observations in this study and in previous work show that sediment concentrations in runoff and, consequently, sediment yields varied on a time scale of 10s of minutes following traffic. Longer term observations in this study revealed that traffic effects may persist for longer periods, as armoring of the flow paths is prevented by the abundant fine sediment supply. This indicates that a traffic regime model may be appropriate as opposed to needing knowledge of each vehicle pass. It further indicates that any mitigations designed to trap traffic-enhanced sediment yields must be maintained after the traffic ends.

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