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Sediment Production from Forest Roads with Wheel Ruts

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Abstract

Artificial rainfall was applied to two sets of paired plots 30.5 m long by 1.52 m wide, each set on a different soil type. One plot in each set contained a wheel rut while the other did not. Measurements of water and sediment yield on rutted plots showed sediment production declined with cumulative runoff while unrutted plots did not show a significant sediment depletion. This difference was a result of concentrated flow versus sheet flow.

Introduction

Forest Service hydrologists, soil scientists, foresters, and engineers face the problem of estimating onsite sediment yield from surface erosion of forest roads. These estimates are used to gauge the impact of land management activities and to determine the most cost effective erosion control techniques for sites with specific climatic, topographic, and soil characteristics.

National Forest soil scientists identified soil/geologic parent materials with the highest priority for information on sediment production from road construction, timber harvest, grazing, mining, and other resource management activities. During the 1989 summer field season, studies were performed on the Caribou National Forest east of Idaho Falls, Idaho, and on the Routt National Forest north of Steamboat Springs, Colorado (Figure 1). The soil on the Caribou N.F. was derived from a highly weathered shale of the Wayan Formation. The soil on the Routt N.F. was a fine sandy loam of the Brown's Park Formation.

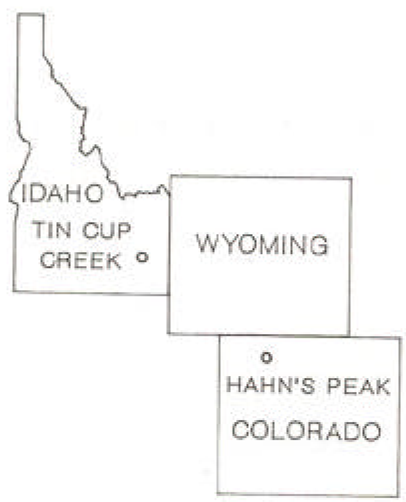

FIG. 1.—Location Map of Tin Cup Creek and Hahn's Peak Sites

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Two 1.52 m by 30.5 m plots were constructed on a freshly graded road at each of the two sites. The 1.52 m width corresponds to a typical wheel-to-wheel distance for pickup-sized vehicles. The 30.5 m length was near the maximum considering equipment, slope, soil uniformity, and water supply.

Either a sheet metal gutter or a wheel rut was installed aligned with the long dimension of each plot (Figure 2). Overland flow entered the gutter and the rut (uniform lateral inflow) and flowed parallel to the contributing area before measurement and sampling at the bottom of the plot. The wheel rut was made by digging a shallow (8 to 10 cm deep by 20 cm wide) trench, soaking the trench with water, then driving a pickup with a front and back tire in the trench. This shaped the rut and compacted the rut bottom. Overland flow paths were about 2.2 in long. Flow paths in the ruts were the full 30.5 m length of the plot.

A modified Colorado State University-type simulator with sixteen Rainjet 78 C sprinklers provided simulated rainfall at about 40% of the kinetic energy of a natural rainfall of the same intensity (Ward, 1986).

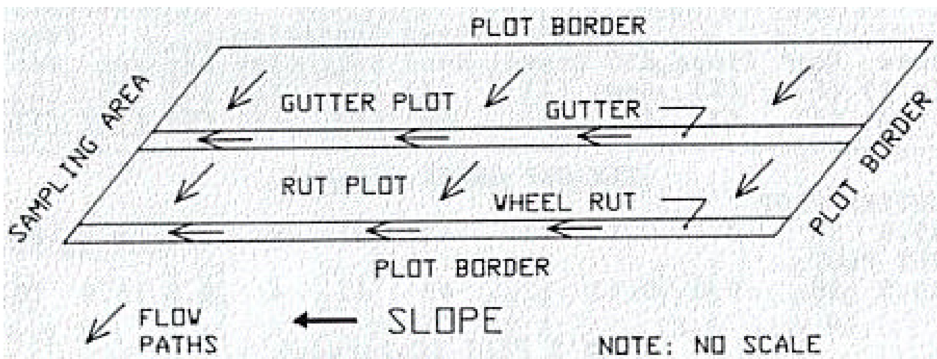

FIG. 2.—Schematic Layout of Gutter and Rut Plots

Three 30-minute applications of a 50 mm per hour intensity were applied to the paired plots. A dry run was made with the existing antecedent soil moisture. The plots were covered to reduce evaporation, left idle for 24 hours, then a wet run was performed. As soon as possible, a very wet run was made following the wet run.

Results and Analysis

Data from the Idaho and Colorado sites were analyzed and summarized. Results are presented in this section as a comparison of the two plots at each location, and a comparison between the two locations.

Site Characteristics

Table 1 lists the site characteristics for each plot at each location. Gradation was determined by wet sieving the bulk soil samples with pipet analysis to determine the silt and clay content. Gravel content was the weight percentage of particles larger than 4.75 mm, sand from 4.75 mm to 0.075 mm, silt from 0.075 to 0.002 mm, and clay less than 0.002 mm.

Soil moisture was sampled gravimetrically before and after each rainfall application. Ten soil moisture locations were used on each plot.

TABLE 1. – Plot Characteristics for each site

Area (m^2) (1)	Por[1] (%) (2)	Slope (%) (3)	d50 (mm) (4)	Wet Sieved Gradation: Gravel (%) (5)	Sand (%) (6)	Silt (%) (7)	Clay (%) (8)	Soil Moisture (Weight): Dry (%) (9)	Wet (%) (10)	Very Wet (%) (11)
TIN CUP CREEK (Idaho)										
GUTTER PLOT										
45.8	38	8.4	0.13	12	43	41	4	5.3	18.1	21.0
RUT PLOT										
53.5	38	9.0	0.13	12	43	41	4	9.8	15.9	18.7
HAHN'S PEAK (Colorado)										
GUTTER PLOT										
58.6	33	6.8	0.27	1	84	14	1	10.3	12.6	14.4
RUT PLOT										
56.6	35	6.8	0.27	1	84	14	1	9.5	11.1	11.8

[1]Porosity

Water Yields

Table 2 summarizes water yield for each plot. Water volumes are adjusted for the volume of sediment. This correction reduces the apparent flow rates by up to 5%.

There are notable differences between the Tin Cup and Hahn's Peak sites for time to runoff and the runoff/rainfall ratio. Of greater significance was the difference in the runoff/rainfall ratios between the gutter plots and rut plots. Rut plots produced greater runoff than gutter plots for both sites.

The runoff/rainfall ratio for these two locations was nearly 1.00. This made accurate measurement of runoff volume critical and derivation of infiltration parameters difficult. For example, a 2% error in runoff measurement on agricultural lands, where 40% runoff is expected is not as critical as a 2% error on road surfaces where 97 to 99% runoff is expected.

TABLE 2.—Water Yields for each Site

AMC[1] (1)	Time to Runoff (min) (2)	Rainfall Depth (mm) (3)	Rainfall Intensity (mm/hr) (4)	Runoff Depth (mm) (5)	Runoff/ Rainfall Ratio (6)
TIN CUP CREEK (Idaho)					
GUTTERPLOT					
Dry	0.41	21.3	47.7	11.7	0.55
Wet	0.48	22.1	46.9	17.2	0.78
Very wet	0.35	26.2	52.2	23.6	0.90
RUT PLOT					
Dry	0.65	21.3	47.8	20.1	0.94
Wet	0.79	22.1	48.7	22.0	0.96
Very Wet	0.67	26.4	53.0	26.4	0.99
HAHN'S PEAK (Colorado)					
GUTTERPLOT					
Dry	1.03	23.7	47.4	18.9	0.80
Wet	1.06	19.2	38.3	16.5	0.86
Very Wet	1.10	20.3	41.9	18.2	0.87
RUT PLOT					
Dry	1.10	24.4	48.8	21.3	0.87
Wet	1.04	22.7	45.5	20.4	0.90
Very Wet	0.97	22.5	45.1	20.4	0.91

[1]Antecedent Soil Moisture Condition.

Sediment Yields

Sediment yields calculated for each plot and run are summarized in Table 3. The mass of sediment included both bed load and suspended load. Yields were calculated in mass per area (kg/ha) and mass per area per depth of runoff (kg/ha-mm). The latter values are equivalent to concentrations in milligrams per liter divided by 100 and are normalized to remove the effects of different runoff volumes. Both sites had different slope gradients, which affect sediment production, but no correction for slope was made.

TABLE 3.—Sediment Yields

AMC[1]	Runoff Depth (mm)	Mass Sediment (kg)	Sediment Production (kg/ha)	(kg/mm)	(kg/ha-mm)
(1)	(2)	(3)	(4)	(5)	(6)
TIN CUP CREEK (Idaho)					
GUTTERPLOT					
Dry	11.7	38.0	8300	3.23	706
Wet	17.2	54.0	11800	3.14	686
Very Wet	23.6	50.5	11000	2.14	467
RUT PLOT					
Dry	20.1	105.0	19600	5.22	976
Wet	22.0	81.2	15200	3.69	690
Very Wet	26.4	59.7	11200	2.27	424
HAHN'S PEAK (Colorado)					
GUTTERPLOT					
Dry	18.9	22.6	3860	1.20	205
Wet	16.5	19.2	3270	1.17	199
Very wet	18.2	22.3	3800	1.22	209
RUT PLOT					
Dry	21.3	162.0	28700	7.61	1350
Wet	20.4	72.8	12870	3.57	630
Very Wet	20.4	49.2	8700	2.41	426

[1]Antecedent Soil Moisture Condition.

Sediment production was higher from the Tin Cup Creek gutter plot because of the higher silt content on that site. A "surface armoring" or supply-limited condition is shown on the Tin Cup site from the dry through the very wet run. This is not seen on the Hahn's Peak gutter plot, probably because the coarser material at Hahn's Peak causes a transport limited situation.

Sediment production from the Hahn's Peak rut plot was nearly 1.5 times that from the Tin Cup site on the dry run. For the wet and very wet runs, sediment production from the rut plots at the two locations were nearly identical. Note that sediment production from ruts includes sediment from overland flow areas tributary to the ruts (see Figure 2). A supply limited situation developed on both sites from the dry through the very wet rainfall application. This rapid reduction in sediment production with successive rainfall events, both natural (Megahan, 1974) and artificial (Burroughs and King, 1989), is quite common on forest road surfaces, cutslopes, fillslopes, and ditches.

Sediment Production Rate from Plots

Sediment production rates for the Tin Cup Creek plots are shown in Figure 3 and the Hahn's Peak plots In Figure 4. Note that the ordinate is in units of sediment flow rate, not sediment concentration. Sediment flow rate includes both suspended and bed load and was computed as the product of sediment concentration and water flow rate.

The Tin Cup Creek gutter plots reached a sediment flow rate of about 30 grams per second for the latter half of the dry run and the first half of the wet run, then fell to about 26 grams per second for the last half of the wet run and all of the very wet run (Figure 3). This indicates that a transport limited condition existed until about 20 minutes into the dry run and a supply limited condition thereafter.

The Hahn's Peak gutter plots show a different response (Figure 4). The dry and the very wet runs appear to have the same sediment rate of about 13 grams per second, while the wet run had a rate of 11 grams per second. The lower sediment rate on the wet run was the result of the 14% lower rainfall intensity. On this site, the loose material did not appear as a thin layer over a compacted, bladed road surface, as was seen at Tin Cup Creek. Rather, it was a continuous, relatively deep layer over the weathered bedrock causing a transport limited condition to exist for all the runs.

Sediment production rates from the rut plots at both locations showed a strong decrease in sediment rate with cumulated runoff. Sediment production on the Tin Cup Creek rut plot (Figure 3) consists of two parts: a rise in sediment rate at a decreasing rate to about 20 minutes, then a slowly decaying sediment production rate from the peak of 90 grams per second to the final rate of 32 grams per second. Probably the initial rise, to about 20 minutes, represents a transport limited condition where insufficient runoff was available to move the sediment. The declining portion is due to armoring of the road surface when the sediment rate had become supply limited during the dry run, well before the runoff rate had reached its maximum at the end of the very wet run. Similarly, a transport limited condition existed until about 25 minutes into the dry run at Hahn's Peak, and a sediment limited condition existed thereafter. Because of the apparently uniform size distribution of the soil at Hahn's Peak, it is questionable whether this decline represents true "armoring", but instead represents a decrease in supply (Figure 4).

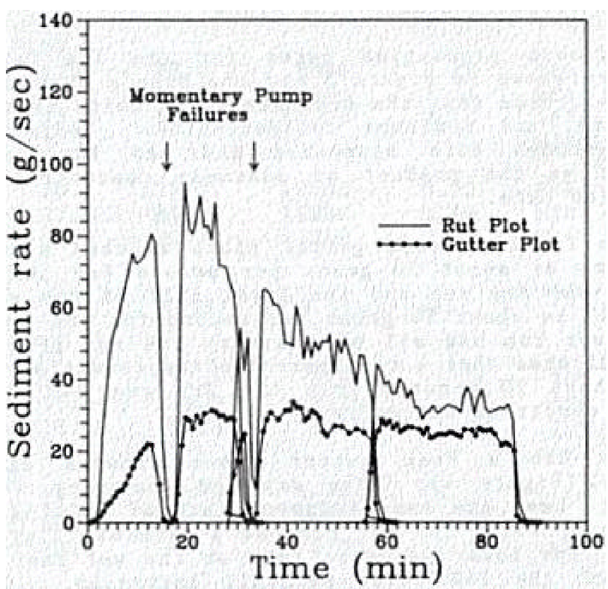

FIG. 3. - Total Sediment (Suspended and Bed load) Production Tin Cup Creek (Idaho)

Forest Road Management Implications

To apply these research results, sediment production from a hypothetical road section 30.5 m long by 4.52 m wide was calculated with and without two wheel ruts using a 30-minute 50 mm per hour rainfall. The no-rut condition consisted of three "gutter" plots while the rut condition consisted of two "rut" plots and one "gutter" plot. Table 4 gives the estimated sediment production.

Of greater Importance than the absolute values of the sediment production is the ratio of “with ruts” to “without ruts.” This ratio was over 2 for the Tin Cup site and nearly 5 for Hahn’s Peak. These values are consistent with other measurements of 2 times the yield from a surface rutted by a heavy truck compared to a smooth surface for a silt loam soil (Burroughs et al., 1984).

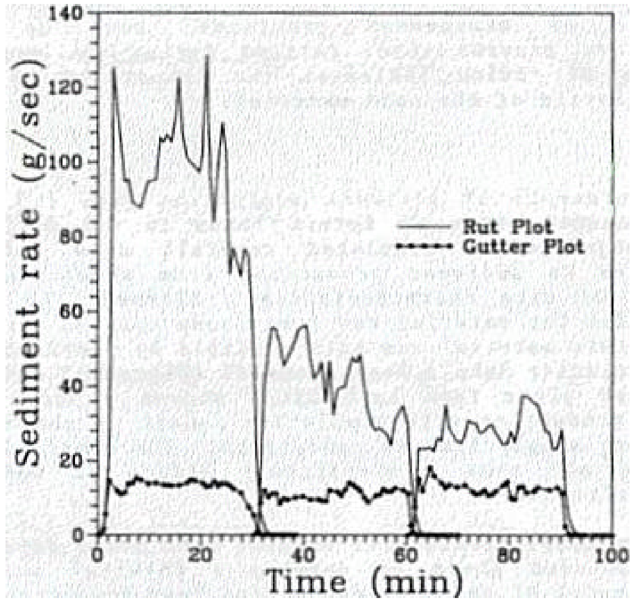

FIG. 4. – Total Sediment (Suspended and Bed load) Production Hahn’s Peak (Colorado)

TABLE 4. – Estimated Sediment Production from a Hypothetical 30.5 **m** Long by 4.52 m Wide Road Section

Location (1)	AMC[1] (2)	No Ruts (kg) (3)	Two Ruts (kg) (4)	No ruts/ Two ruts Ratio (5)
Tin Cup Creek	Dry	116	247	2.1
	Wet	164	196	1.2
	Very Wet	154	154	1.0
Hahn’s Peak	Dry	54	253	4.7
	Wet	46	134	2.9
	Very Wet	53	98	1.8

[1]Antecedent Soil Moisture Condition

The ratio of sediment production for roads with pickup-sized ruts to roads without ruts indicates the importance of management practices, such as road closures, to prevent wheel rutting during wet weather. The range of ratios indicates the importance of soil characteristics of the road material.

Summary

Measurements of sediment production from 1.5 m by 30.5 m bounded plots on forest roads in two different soils subjected to simulated rainfall show definite differences in sediment production from wheel ruts as functions of site characteristics. Although the finer textured Tin Cup material had less loose soil on the road surface, this material was more erodible by overland flow than the sandier Hahn’s Peak material (Figures 3 and 4).

Rutted plots from both sites showed a decline in sediment production with cumulative runoff as the result of sediment supply limited conditions. The overland flow plots did not show a significant effect of sediment supply depletion.

These measurements will be used with other data from smaller bounded plots to develop a physical process-oriented model of sediment production from forest roads.

Appendix 1.—References

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