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Storm Flow and Sediment Losses From Site-Prepared Forestland in East Texas

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Nine small (2.57 to 2.79 ha) forested watersheds in East Texas were instrumented in December 1979 to determine the effect of harvesting and site preparation on storm flow and sediment loss. Three replications of three treatments were used: (1) clearcutting, followed by shearing, windrowing, and burning, (2) clearcutting, followed by roller chopping and burning, and (3) undisturbed control. Prior to treatment, mineral soil was exposed on 3% of the watersheds. Following treatment in June 1981, 57% of the mineral soil was exposed on the sheared and windrowed watersheds compared to 16% on the chopped watersheds. At the end of the second, third, and fourth years' growing season, mineral soil was exposed on 20, 9, and 10% of the sheared and 4, 4, and 3% of the chopped watersheds, respectively. The first year following treatment, mean storm flow was greater from the sheared watersheds (14.6 cm) than from the chopped (8.3 cm) watersheds, with the storm flow from the latter greater than from the undisturbed (2.6 cm) watersheds. Mean storm flow was less from all watersheds the second year after treatment; however, storm flow from the sheared watersheds (5.0 cm) was similar to that from the chopped (3.6 cm) watersheds, and both were greater than that from the undisturbed (1.2 cm) watersheds. During the third posttreatment year there was no significant difference in mean storm flow from the sheared and chopped watersheds or from chopped and undisturbed watersheds. Storm flow during the fourth posttreatment year was greater from the sheared watersheds (6.1 cm) than from the chopped (3.5 cm) watersheds, which had greater stormflow than the undisturbed (1.4 cm) watersheds. First-year sediment losses were greater from the sheared (2937 kg/ha) than from the chopped (25 kg/ha) or undisturbed (33 kg/ha) watersheds. Although second-year sediment losses were greatly reduced from the sheared watersheds (79.9 kg/ha), they remained greater than losses from chopped (5.5 kg/ha) or undisturbed (5.1 kg/ha) watersheds. Sediment losses from the sheared watersheds (34.6 kg/ha) decreased during the third posttreatment year and were similar to losses from the chopped (5.4 kg/ha) watersheds. During the fourth posttreatment year, sediment loss was greater from the sheared watersheds (165 kg/ha) than from the chopped (16 kg/ha) or the undisturbed (29 kg/ha) watersheds. Although sediment losses were significantly different between treatment, they were small and below Soil Conservation Service tolerable levels. Mean sediment concentrations and losses from the chopped and undisturbed watersheds were similar during the four posttreatment years. Sediment concentrations from the sheared watersheds were greater than from chopped or undisturbed watersheds during the four posttreatment years; however, concentrations the first year after treatment (2119 mg/L) were greatly reduced the second (167 mg/L), third (54 mg/L), and fourth year (331 mg/L).

INTRODUCTION

Site preparation plays a vital role in the intensive management of even-aged stands of southern pine. Forest managers rely on site preparation to accomplish several important objectives: to (1) prepare a proper seedbed, (2) facilitate planting, and (3) control competition. Selection of the proper site preparation technique to meet management goals for a given location is critical.

The Clean Water Act of 1977 (P.L. 95-217) emphasized the importance of nonpoint source pollution from silvicultural practices. As a result, several states have developed and implemented plans which prescribe best management practices to control nonpoint sources of pollution. Increases in sediment concentrations and soil losses following site preparation can be important both to water quality and site productivity. Maintaining optimum site productivity by minimizing sediment export is of concern to private and public forestland managers.

The natural sediment loss from undisturbed forest varies with location, soils, geology, vegetation, watershed size, and season. Research in the southeast has demonstrated that natural erosion rates are very low from undisturbed forestland [*Schrieber et al.*, 1980; *Beasley*, 1982]. Sediment loss from undisturbed forests in the south ranges from a trace to 717 kg/ha/yr [*Yoho*, 1980].

Ursic [1979] has suggested 61 mg/L as the average annual sediment concentration in stormflows from small, undisturbed southern pine watersheds. He found, however, that owing to natural variation, concentrations for individual events may be greater by a factor of 10 or more. Periodic flushing of sediments collected in the stream channel accounted for most of these occasionally higher values. *Beasley* [1982] reported annual sediment concentrations between 17 and 194 mg/L from undisturbed forested watersheds in southeastern Arkansas.

Harvesting and site preparation increase the potential for sediment production by disturbing the soil and the protective forest floor. Compaction and destruction of surface soil structure and macropore space may cause an increase in surface runoff, thus increasing the sediment loss potential [*Dixon*, 1975; *Lull*, 1959; *Moehring and Rawls*, 1970]. Disturbing the protective vegetation and litter exposes the soil to raindrop impact, breaking soil aggregates into individual particles. These smaller particles are easily detached and may either leave the site in runoff water or clog soil pores. Thus infiltration is reduced and the possibility of surface runoff further increased [*Edwards and Larson*, 1969]. Removal of vegetation

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TABLE 1. Pretreatment and Posttreatment Watershed Ground Cover (percent) and Erosion (percent), Alto, Texas

	Pretreatment June 1980			Posttreatment							
				June 1981		October 1982		October 1983		October 1984	
	Undisturbed	Presheared	Prechopped	Sheared	Chopped	Sheared	Chopped	Sheared	Chopped	Sheared	Chopped
Litter	90	89	87	26	57	57	65	72	69	68	64
Slash	5	6	7	9	22	5	18	4	12	4	12
Grass	1	1	1	4	2	13	9	10	13	14	16
Forb	0	0	0	2	1	4	3	4	2	2	1
Rock	0	0	1	2	2	1	1	1	1	0	1
Mineral Soil	3	3	3	57	16	20	4	9	4	10	3
No erosion	3	3	3	10	11	17	4	9	4	5	2
Rill	0	0	0	1	0	1	0	0	0	0	0
Sheet	0	0	0	20	1	1	0	0	0	4	1
Deposition	0	0	0	26	4	1	0	0	0	1	0

splitter was used to collect a 0.05% per storm composite water sample. One block of watersheds (WS 2, shear; WS 9, chop; and WS 6, control) were equipped with automatic water pump samplers. Samples were drawn at 20-minute intervals by a floating intake nozzle in the approach section of the flume. The intake was located on a hinged arm which collects samples from the lower one third of storm flow. The day following each runoff event a subsample was taken from the composite sample and each of the pump sample bottles. Suspended sediment was determined by vacuum filtering 250 ml through 0.45-micron filters, over-drying at 105°C, and weighing. The volume of sediments deposited in a 1.7 m × 0.9 m × 0.2 m concrete drop box located at the front of the flume approach section was determined after each storm. A 500 mL subsample was collected, oven-dried at 105°C, weighed, and multiplied by the volume of sediments deposited. Total sediment concentration was the product of the concentration of the Coshocton wheel composite sample and the concentration of sediments deposited in the drop box. The sediment deposited by each storm was divided by watershed area and the volume of storm flow to determine the concentration. Annual discharge-weighted sediment concentration was determined by weighting the sediment concentration of each event by a ratio of the volume of each storm flow to the total annual storm flow. Total sediment loss from each event was calculated by multiplying sediment concentration by the volume of storm flow and dividing by the watershed area to convert to losses per hectare. To examine sediment concentrations during the storm flow, pump samples were separated according to hydrograph stage, rising limb, crest, or recession limb.

TABLE 2. Pretreatment (1980) Precipitation, Storm Flow, Peak Discharge Rate, and Sediment Concentration and Loss by Watershed, Alto, Texas

Watershed	Precipitation, cm	Storm Flow, cm	Peak Discharge Rate, m^3/s	Sediment Concentration, mg/L*	Sediment Loss, kg/ha
Presheared					
1	78.87	2.57	0.035	751	174.4
2	79.32	5.27	0.037	1019	529.7
3	79.05	2.24	0.025	1598	315.9
Mean	79.08	3.44*b*†	0.032*a*	1123*a*	340.0*a*
Prechopped					
5	79.92	3.74	0.050	157	55.5
7	78.16	3.65	0.050	208	64.9
9	78.28	6.08	0.052	225	135.3
Mean	79.04	4.49*a*	0.051*a*	197*b*	85.2*b*
Undisturbed					
4	79.38	2.59	0.030	928	221.1
6	79.55	5.46	0.043	507	263.0
8	79.44	2.60	0.065	265	67.9
Mean	79.46	3.55*b*	0.046*a*	567*b*	184.0*ab*

*Annual sediment concentrations are discharge weighted by storm flow.

†Treatment means for each parameter followed by the same letter are not significantly different ($P \leq 0.05$).

Ground cover was measured by point sampling [*Levy and Madden*, 1933] at 20-cm intervals in a systematic pattern of 15 to 18 10-m transects. Surface cover was classified as litter, slash, vegetation, rock, or mineral soil. If mineral soil was exposed, it was recorded as no erosion, sheet or rill erosion, or deposition.

A randomized complete block analysis of variance was used to determine treatment differences ($P \leq 0.05$) in storm flow and in sediment concentrations or losses. Duncan's New Multiple Range Test was used to separate individual storm events or annual treatment means [*Steele and Torrie*, 1980]. Owing to the skewed distributions, sediment concentrations from pump samples were transformed using $\log_{10}$ before performing analysis of variance.

RESULTS

Ground Cover

Pretreatment. Prior to treatment, average ground cover on the watersheds was 89% litter, 6% slash, and 2% grasses (Table 1). Mineral was exposed on 3% of the watersheds with little evidence of erosion. Presheared, prechopped, and undisturbed watersheds were similar in all categories.

Posttreatment. After site preparation in June 1981, mineral soil was exposed on 57% of the sheared and 16% of the chopped watersheds. Litter and slash covered 79% of the chopped watersheds and 35% of the sheared watersheds. Eighty-three percent of the mineral soil exposed on the sheared watersheds (47% of the watersheds) displayed some form of erosion or soil deposition. In comparison, roller chopping exposed 16% of the mineral soil, but only 5% of the watersheds area showed signs of active erosion or soil deposition.

Herbaceous vegetation, slash, and litter covered most of the watersheds by the end of the second year's growing season (Table 1). Mineral soil was exposed on 20% of the sheared watersheds and 4% of the chopped watersheds. Active erosion

TABLE 5. Posttreatment (1981–1984) Storm Flow, Peak Discharge Rate, and Sediment Concentration and Loss by Treatment for the Largest* Storm Event, Alto, Texas

Treatment	Storm Flow, cm	% of Annual Storm Flow	Peak Discharge Rate, m^3/s	Sediment Concentration, mg/L	Sediment Loss, kg/ha	% of Annual Sediment Loss
First Year Posttreatment 1981; October 14, 1981, Precipitation 12.1 cm						
Shear	5.43*a*†	37	0.426*a*	1158*a*	607.5*a*	21
Chop	3.52*ab*	43	0.140*b*	30*b*	10.3*b*	41
Undisturbed	1.76*b*	67	0.090*b*	112*b*	29.7*b*	91
Second Year Posttreatment 1982; April 19, 1982, Precipitation 4.5 cm						
Shear	1.41*a*	28	0.954*a*	256*a*	35.7*a*	47
Chop	0.62*a*	17	0.024*b*	36*c*	2.5*b*	45
Undisturbed	0.35*a*	30	0.011*b*	79*b*	4.6*b*	90
Third Year Posttreatment 1983; May 21, 1983, Precipitation 3.9 cm						
Shear	1.18*a*	19	0.055*a*	113*a*	15.1*a*	44
Chop	1.09*a*	24	0.021*ab*	12*b*	1.2*a*	22
Undisturbed	0.60*a*	28	0.013*b*	31*ab*	1.9*a*	40
Fourth Year Posttreatment 1984; March 4, 1984, Precipitation 7.9 cm						
Shear	2.39*a*	39	0.099*a*	489*a*	112.4*a*	68
Chop	1.42*b*	41	0.050*b*	28*a*	4.6*a*	28
Undisturbed	0.67*c*	48	0.031*b*	213*a*	23.4*a*	82

*Storm event producing the greatest volume of stormflow for the year.

†Treatment means for each parameter followed by the same letter are not significantly different ($P \leq 0.05$).

(Table 5). This was significantly greater than the mean peak discharge rate recorded for chopped watersheds (0.14 m^3/s) or undisturbed watersheds (0.09 m^3/s). Mean storm flow from the sheared watersheds (5.43 cm) for this event was similar to that from the chopped watersheds (3.52 cm) but was significantly greater than that from the undisturbed watersheds (1.76 cm). Storm flow from the chopped and undisturbed watersheds was similar. This single event's storm flow represented an average of 37, 43, and 67% of the 1981 total storm flow from the sheared, chopped, and undisturbed watersheds, respectively.

1982 Storm flow volumes were substantially less during 1982 for all treatments (Table 4). Of the 73 rainfall events during 1982, 22 resulted in stormflow. Annual storm flows were 5.0, 3.6, and 1.2 cm for the sheared, chopped, and undisturbed watersheds, respectively. Annual storm flow volumes from the sheared and chopped watersheds were similar, although both were significantly greater than the undisturbed watersheds. Storm flow as a percent of annual precipitation averaged 4, 3, and 1% for the sheared, chopped, and undisturbed watersheds, respectively. The largest rainfall event (4.5 cm) of the year occurred on April 19 (Table 5). Mean storm flow from this event was 1.41 cm from the sheared, 0.62 cm from the chopped, and 0.35 from the undisturbed watersheds. Storm flows were similar from all three treatments. Peak discharge rates during this storm were significantly greater from the sheared watersheds (0.10 m^3/s) than rates recorded from chopped (0.02 m^3/s) or undisturbed watersheds (0.01 m^3/s).

1983 Precipitation of 118.1 cm during the third year (1983) following treatment generated storm flow from 22 of the 64 rainfall events. Mean annual storm flow was similar from the sheared and chopped watersheds and from the chopped and undisturbed watersheds (Table 4). Annual storm flow from the sheared watersheds remained significantly greater than from the undisturbed watersheds. The greatest storm flow producing event in 1983 occurred on May 21 with no significant differences between treatments (Table 5). This event generated 19% of the mean annual storm flow for the sheared, 24% for the chopped, and 28% for the undisturbed watersheds. Peak discharge rates continued to decline during 1983 with no difference between sheared and chopped or chopped and undisturbed watersheds for the May 21 event.

1984 The fourth year following treatment (1984), 56 rainfall events occurred with only 16 resulting in storm flow. Mean annual storm flow of 6.1, 3.5, and 1.4 cm from sheared, chopped, and undisturbed watersheds, respectively, was significantly different between all treatments (Table 4). A rainfall event of 7.9 cm on March 4 produced the greatest storm flow of the year. Storm flow was significantly different between all treatments (Table 5). This event resulted in 39% of the mean annual storm flow for the sheared, 41% for the chopped, and 48% for the undisturbed watersheds. Annual and largest event peak discharge rates were significantly greater from the sheared watersheds than from the chopped or undisturbed watersheds. Cumulated storm flow for the pretreatment year and posttreatment years was greater from the sheared and chopped than from the undisturbed watersheds (Figure 1).

Sediment

1980 *Pretreatment.* Only six storm flow events during 1980 were of sufficient size to collect water samples, with just two of these events generating runoff from all nine watersheds. The mean annual discharge-weighted sediment concentration for the watersheds was 629 mg/L (Table 2). Mean annual discharge-weighted sediment concentrations were significantly greater from presheared watersheds (1123 mg/L) than from prechopped (197 mg/L) or undisturbed (567 mg/L) watersheds. The greatest sediment concentration occurred during a single storm event on May 15. Sediment concentrations for this event varied from 172 to 1882 mg/L with a mean of 812 mg/L (Table 3).

Sediment loss during 1980 averaged 203 kg/ha (Table 2). Watershed 5 recorded the minimum (56 kg/ha) and WS 2 the maximum (530 kg/ha) annual sediment loss. Mean annual sediment loss was significantly greater from presheared water-

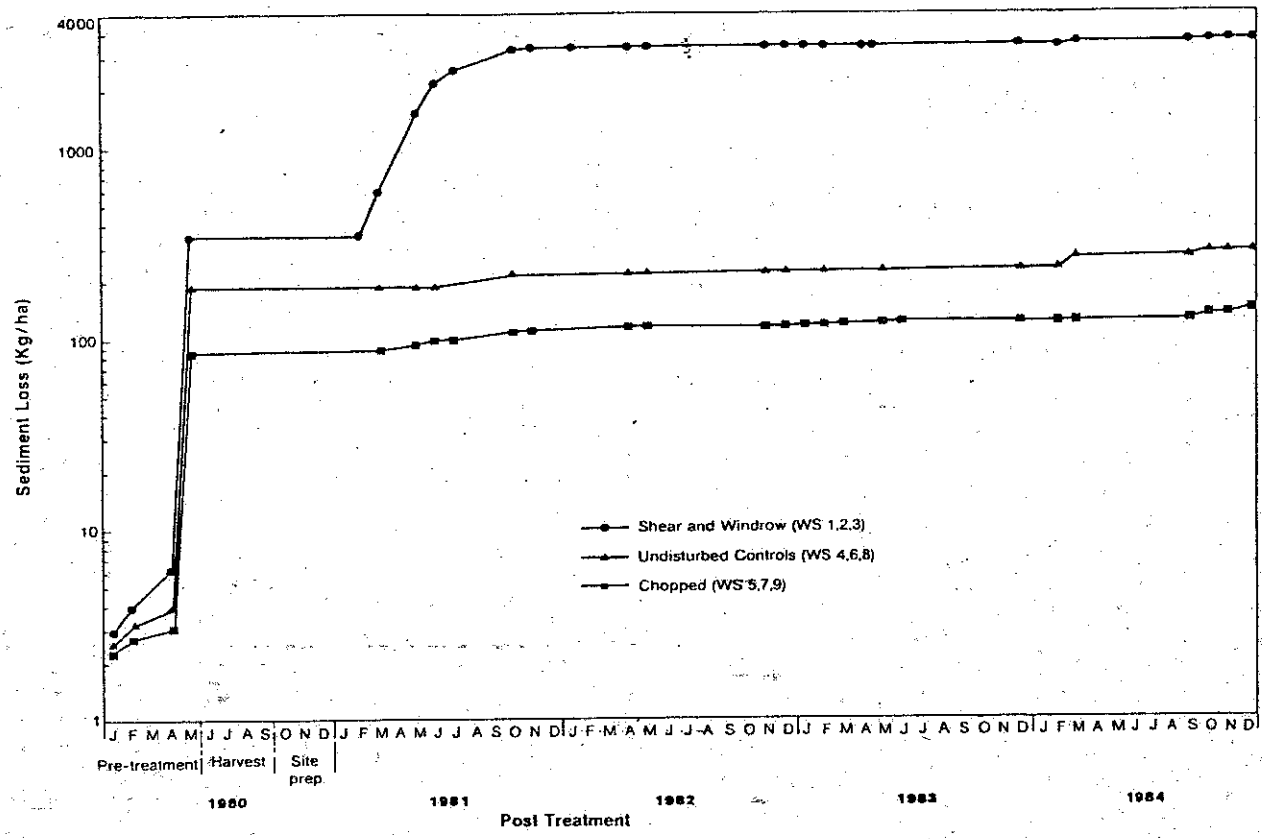

Fig. 2. Cumulated sediment loss by treatment for the pretreatment year and four posttreatment years, Alto, Texas.

and 100% of the first-year sediment loss from the sheared, chopped, and undisturbed watersheds, respectively. A single storm of 12.1 cm on October 14 produced 21% of the annual sediment loss from the sheared watersheds, 41% from the chopped, and 91% from the undisturbed watersheds (Table 5). Sediment loss for this storm was similar from the chopped and undisturbed watersheds but significantly less than from the sheared watersheds.

1982 Sediment concentrations the second year (1982) following treatment were consistently lower than during 1981. Sediment samples were collected from 14 storm flows occurring mostly during winter and spring. The mean annual discharge-weighted sediment concentration was 167, 24, and 58 mg/L from the sheared, chopped, and undisturbed watersheds, respectively (Table 4). Although sediment concentrations from the sheared watersheds were significantly greater than from the chopped or undisturbed watersheds, they were considerably lower than the 2119 mg/L recorded in 1981. Sediment concentrations from the undisturbed watersheds were significantly greater than from the chopped watersheds. Sediment concentrations from the largest storm event of April 19 displayed a similar trend, with sheared watersheds having a significantly greater concentration than undisturbed watersheds, which in turn had significantly greater concentration than chopped watersheds (Table 5).

Sediment concentrations measured from automated pump samples were much lower during the second posttreatment year. Sediment concentration from the sheared watershed was greater than from the undisturbed watershed for all hydrograph segments (Table 6). Concentrations from the chopped watershed during the recession were similar to those from the sheared watershed and greater than from the undisturbed watershed. Mean sediment concentrations from the sheared watershed for the hydrograph segments were significantly different from each other. The greater mean concentration from the sheared watershed was associated with the crest segment, and the lowest concentration, with the recession segment. Sediment concentrations from the chopped or undisturbed watersheds were similar regardless of hydrograph stage.

Sediment loss was significantly greater from sheared watersheds than from chopped or undisturbed watersheds (Table 4). The largest storm flow event of the year occurred on April 19 and produced 47, 45, and 90% of the annual sediment loss from the sheared, chopped, and undisturbed watersheds, respectively (Table 5). Similar sediment loss occurred from the chopped and undisturbed watersheds; however, significantly greater sediment was lost from the sheared watershed.

1983 During the third posttreatment year (1983), mean discharge-weighted sediment concentrations were 54, 12, and 24 mg/L for the sheared, chopped, and undisturbed watersheds, respectively (Table 4). The sediment concentration remained significantly greater from the sheared watersheds than from the chopped or undisturbed watersheds. The largest storm event on May 21 produced sediment concentrations similar to those of previous posttreatment years; however, differences were significant only between sheared and chopped watersheds.

Automatic pump sample sediment concentrations from sheared and chopped watersheds were similar among hydrograph segments (Table 6). Significantly greater concentrations occurred from the undisturbed watershed during the rising segment than during the crest or recession segments. Treatment difference diminished during the third year, with only the sheared watershed having a significantly greater sediment concentration than the chopped or undisturbed watershed during the recession segment.

Mean sediment loss in 1983 from sheared watersheds (35

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