HYDROLOGIC IMPACTS OF MECHANIZED SITE PREPARATION IN THE CENTRAL APPALACHIANS[1]

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Abstract.--The effects of mechanized site preparation on sediment yield, streamflow chemistry, water temperature, and water yield were evaluated for a 4-year period on a 28.6 acre watershed. Annual sediment yields were slightly higher after site preparation, but not enough to be statistically significant (0.05 level). Growing season streamflow increased by 3.9, 2.8, and 1.5 inches during the first, second, and third growing seasons after the treatments, respectively. Nitrate concentrations of streamflow increased slightly, but stream temperature did not change.

INTRODUCTION

While mechanical site preparation is common in the South prior to planting pine species, similar methods are relatively new in the central Appalachians. Foresters are concerned that this method will increase erosion and cause other environmental problems on the steep slopes of the central Appalachians, where annual precipitation averages 50 to 60 inches. During mechanical site preparation, the surface litter layer is commonly removed or displaced and surface soil may be pushed into windrows. Douglass and Goodwin (1980) believed it is one of the most severe practices applied to forest land. Mechanical site preparation commonly exposes soil on 50 percent or more of treated areas. Thus, disturbance is much greater than the 10 percent required for roads and landings where wheeled skidders are used for timber harvests in the central Appalachians (Kochenderfer 1977). The large percentage of soil exposure associated with mechanical site preparation, when combined with soil compaction, can lead to sediment-producing overland flows and large increases in stormflow volumes (Ursic and Douglass 1978).

The objective of this study was to evaluate the hydrologic responses of mechanical site preparation on an Appalachian watershed.

THE STUDY AREA

Two watersheds were used for the study, both in the unglaciated Allegheny Plateau region of north-central West Virginia, within a 10-mile radius of Parsons. One of the watersheds was treated (Clover) and the other retained as a control (Fernow). Precipitation is distributed evenly between dormant and growing seasons on both watersheds; the annual average is 58 inches at Fernow, 61 inches at Clover. Annual runoff from the Fernow watershed for the same period of record averaged 28 inches, 8 inches during the growing season and 20 inches during the dormant season.

The Clover watershed (28.6 acres) has a southern aspect and an average slope of 25 percent. The predominant soil is Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrept) underlain with fractured sandstone and shale of the Hampshire formation (Losche and Beverage 1967). It is rated as having a moderate erosion hazard (Losche and Beverage 1967). The Clover watershed was farmed for many years before 1930 (Lima and Patric 1978). After farming ended, natural revegetation by poor-quality hardwoods proceeded until this study began in 1983. Past erosion is visible on the upper slopes. Colluvial soil deposits along the stream apparently were eroded from upper slopes during the many years of cultivation. Even before site preparation, the silted stream channel was unstable, with a noticeable lack of rock. Stream banks were raw and eroding in several places.

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The Fernow watershed (96 acres) which faces southeast has not been disturbed since the original timber was removed between 1905 and 1910, except for a road constructed along its upper boundary in the 1930's. Common tree species are yellow-poplar (Liriodendron tulipifera L.), sugar maple (Acer saccharum Marsh.), and northern red oak (Quercus rubra L.). The predominant soil also is Calvin channery silt loam. The stream channel is well armored with sandstone rock and stream banks are protected with vegetation.

METHODS

Streamflow and Sediment Loss

Streamflow was measured with 120° V-notch weirs. Each weir was equipped with an FW-1 water-level recorder and a Coshocton wheel sediment sampler which diverted 0.5 percent of the total flow into a 600-gallon storage tank. Two samples from each tank were taken weekly during base flow and before the tanks overflowed during storms. Tank contents were agitated vigorously while two 800-ml samples were collected from a spigot on the bottom of the storage tanks. These samples were vacuum-filtered in the laboratory to determine sediment concentrations (mg/l).

Yield of suspended sediment was computed as measured streamflow for the sampling period multiplied by average sediment concentration of the two tank samples. Annual suspended sediment yield is the sum of these computed periodic yields.

Bedload was trapped at each watershed with a box where stream velocity decreased prior to spilling onto the Coshocton wheel. The bedload trapped by each box was measured periodically to determine its cubic-foot volume. Subsamples were collected and ovendried to determine average bulk density. Sediment volume times average dry bulk density gave sediment weight in each box. Suspended sediment plus bedload provided annual sediment export from each watershed.

STREAMFLOW CHEMISTRY

Streamflow from both watersheds was grab-sampled at weekly or biweekly intervals starting in 1980. These samples were analyzed for pH, specific conductance, and concentrations of NO_3-N, SO_4, Ca, Mg, K, Na, and NH_4-N. Tests for site-preparation effects on streamflow chemistry were made in two ways. First, a plotting of annual average concentration for each chemical constituent indicated whether major changes were associated with site preparation. Second, streamflow losses of selected ions (NO_3-N, NH_4-N, SO_4, and Ca) were calculated by multiplying average weighted quarterly concentration of each ion by the measured quarterly streamflow. Although this is not the most rigorous method for computing losses, Dann et al. (1986) concluded that it provides reasonable results. Simple linear regressions of quarterly losses from the control (independent variable) and treated watershed (dependent variable) were tested for common slopes and intercepts for before-treatment and after-treatment periods.

STREAM TEMPERATURE

A maximum and minimum thermometer was placed just above the weir in each stream. Weekly maximum and minimum temperatures were recorded for both watersheds during several years prior to site preparation. Records for the first 2 years after site preparation were tested by regression analyses to determine whether weekly stream maximum temperature during the growing season (May-Oct) and minimum temperature during the dormant season (Nov-Apr) changed after site preparation.

WATER YIELD

The paired watershed technique was used to determine site preparation effects on growing- and dormant-season water yield. This procedure has been described many times in the literature. A unique feature of this study is the distance (about 12 miles) between the control and treated watersheds. Storms, especially during summer months, do not always occur equally on both watersheds. To compensate for differences in rainfall amounts between the two areas, a precipitation difference term is included in the following equations for predicting growing- and dormant-season streamflow:

Growing Season: (1)

$$Q_9 = 1.50 + 0.98\ Q_4 + 0.67\ (P_9 - P_4)$$

$$R^2 = 0.975$$

Dormant Season: (2)

$$Q_9 = 4.48 + 0.90\ Q_4 + 0.12\ (P_9 - P_4)$$

$$R^2 = 0.87$$

In these equations, Q_9 is predicted streamflow (inches) from the Clover watershed; Q_4 is measured streamflow (inches) from the Fernow Watershed; and P_9 and P_4 is average seasonal precipitation (inches) on the Clover and Fernow watersheds, respectively.

Vegetation Survey (pretreatment)

The overstory on the Clover watershed was tallied on 41 systematically located 0.01 acre plots in October 1983. All trees larger than 1 inch d.b.h. were included. Basal area was 56.5 ft^2/acre and volume was 807 ft^3/acre. Average diameter of measured stems was 4.7 inches.

Pretreatment ground cover was estimated on 41 milacre plots taken at the same points. About

39 percent of the pretreatment surface area was classed as "open"--not shaded by other vegetation (Table 1). Approximately 3 acres were still in old fields covered with a variety of grasses, e.g., Panicum spp. L. and tall redtop (Triodia flora L.); widely-scattered mountain laurel (Kalmia latifolia L.); clumps of blueberries (Vaccinium spp. L.); and small hardwoods. The remaining acreage was forested, common species being red maple (Acer rubrum L.), sassafras (Sassafras albidum (Nutt.) Nees), flowering dogwood (Cornus florida L.), blackgum (Nyssa sylvatica Marsh.), sourwood (Oxydendron arboreum (L.) DC), and hickory (Carya spp. Nutt.).

Table 1. Ground cover and soil disturbance on the Clover watershed.

Item	Measurement date				
	9/83[a]	5/84	9/84	9/85	10/86
	Percent				
Woody	22	2	28	30	22
Semi-woody	15	-	20	24	26
Grasses	13	8	17	30	42
Herbaceous	11	4	6	8	4
Open	39	82	27	7	5
Debris	-	4	2	1	1
Total	100	100	100	100	100
Bare soil	-	45	15	7	5
Mixed litter and soil	-	38	-	-	-
Undisturbed litter	-	17	-	-	-

[a]Pretreatment year.

Treatments

A "minimum-standard" access road as described by Kochenderfer et al. (1984) was constructed into the Clover watershed in June 1983. About 30 Mbf of widely scattered sawtimber trees were removed in August. The area was opened to the public for free firewood in September. Additional skidroads, suitable for dry weather use by pick-up trucks, were constructed in October. Most trees larger than 6 inches d.b.h. were removed.

Site Preparation

We attempted to use the same site-preparation procedures observed on private land. It was done by the same contractor who does much of the work on private lands in this area. The D7F tractor was equipped with a root rake (Fig. 1). The brush was windrowed, mostly along the contour and around the perimeter of the treated area (Fig. 2). Root raking was done carefully to minimize soil disturbance and windrows were not burned. Stumps were cut low so they could be left intact, even when it meant leaving scattered pieces of slash around them. Roads were used for windrow locations when possible. The site treatment was completed in three days--November 30-December 2, 1983.

Figure 1.--Root raking on Clover watershed November 1983.

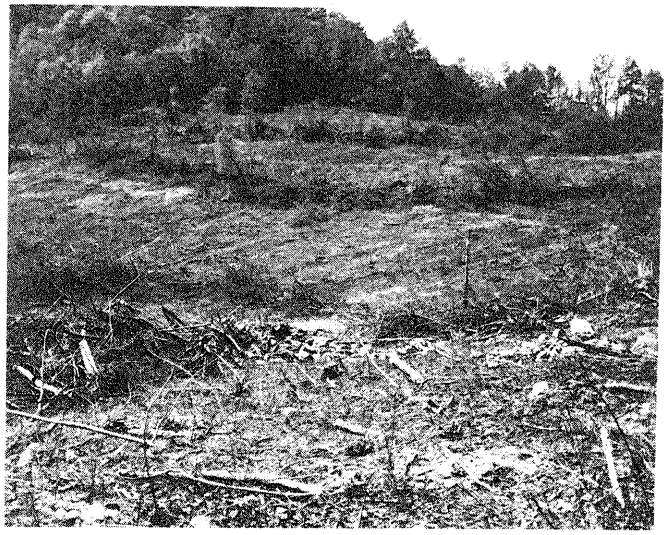

Figure 2.--Freshly root-raked watershed showing brush windrowed along contour.

An aerial view of the Clover watershed is shown in Figure 3. An undisturbed 3.5-acre buffer zone was left untreated along the stream. A steep (30+ percent) 3-acre area in the northwest corner of the watershed was not site prepared. Instead, trees on this area that were larger than 1 inch in diameter were injected with an herbicide during the summer of 1984. Except for the untreated

3.5-acre buffer strip, the watershed (25.1 acres) was planted with Japanese larch (Larix leptolepis Sieb. and Zucc.) in the spring of 1984.

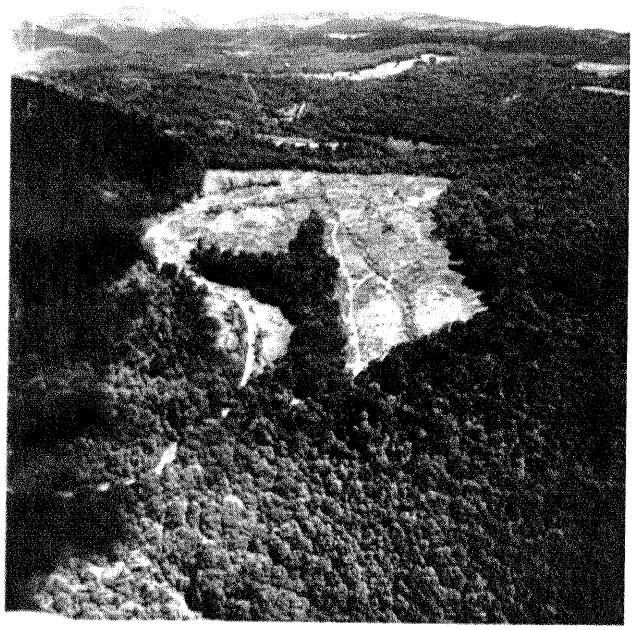

Figure 3.--Aerial view of Clover watershed in 1984 shows 3.5-acre buffer zone. The 3-acre area not site prepared is in upper left corner.

Post-Treatment Vegetation Measurements

To determine surface disturbance and ground cover, 93 permanent sampling points were systematically distributed on a 100 x 100-foot grid on the Clover watershed. The percentage of disturbance created by root raking and percent groundcover were subjective estimates made on circular milacre plots at each sampling point. Three classes were used to estimate surface disturbance when the first observations were made in May 1984: (1) undisturbed, litter intact, (2) mixture of litter and soil, (3) bare mineral soil exposed. Later it was not possible to distinguish the less disturbed classes so only bare soil was recorded. The percentage of ground cover also was estimated to the nearest 5 percent on the same milacre plots. Species that covered at least 5 percent of plot area were recorded. Ground cover was separated into four vegetation classes: (1) woody, (2) semi-woody (blackberry, greenbrier, grape), (3) grasses, and (4) herbaceous (herbs and ferns).

RESULTS AND DISCUSSION

Ground Cover

Except for some grasses (mostly Panicum spp. L. and redtop) and scattered patches of clubmoss (Lycopodium spp. L.), root raking removed a large proportion of vegetation from the area. Natural revegetation was rapid (Fig. 4). After root raking, the amount of ground cover classed as open (no live vegetative cover) increased by about 43 percent beyond pretreatment conditions (Table 1). Then the open class decreased by about 55 percent over the first growing season; by the end of the second growing season, the area classed as open had decreased to 7 percent, much less than was measured before treatment.

Figure 4.--View of Clover watershed in September 1985 shows dense ground cover developed in two growing seasons.

At the end of the 1986 growing season, grasses accounted for 42 percent of the ground cover. The next largest group of plants (semi-woody) was composed about equally of blackberry (Rubus spp. L.) and greenbrier (Smilax spp. L.). The most common woody species was Sassafras. The decrease of woody component in 1986 probably can be attributed to a herbicide applied to stump sprouts growing near larch trees during the summer of 1986.

Natural succession greatly reduced exposure of bare soil (Table 1). The longest lasting soil exposure was in parts of the road system not covered with windrows and in depressions left when occasional large stumps were pushed out.

SEDIMENT LOSSES

The Fernow watershed consistently yielded much less sediment (Table 2). The inherent stability of its stream channel and minimal disturbance for over 80 years probably account for consistently lower yields. The Clover watershed, its silted stream channel attributed to its past farming history, yielded more sediment throughout the measurement period.

Table 2. Annual sediment yield from the study watersheds.

Watershed	Pretreatment				Post-treatment				
	1980	1981	1982	1983	1984	1985	1986	1987	Mean
	lb/acre								
Clover	235	234	291	-	318	363	521	173	305
Fernow	28	36	34	30	24	35	193	23	50

Measured sediment losses from the Fernow watershed always was less than the 300 lb/acre/yr that Douglass (1975) considered as normal erosion from fully stocked forests. Source areas of eroded soil are primarily stream channels and banks. Sediment losses from the Clover watershed were an average of 6 times greater than losses from the Fernow watershed, averaging 305 lb/acre/yr over a 7-year period. Sediment yields from the Clover watershed are only slightly higher than those summarized by Patric et al. (1984) for undisturbed forest plots and small watersheds in the Eastern United States.

The average annual sediment concentration for the 7 years of record was only .0009 ton/acre-inch (8 ppm) for the Fernow watershed and .005 ton/acre-inch (40 ppm) on the Clover watershed. Both concentrations are lower than the representative base rate suggested for undisturbed forest in the Piedmont and Coastal Plain, but they are within the range for undisturbed forests in the Ozarks and Quachita Mountains (Ursic 1986).

The large sediment losses from both watersheds in 1986 was caused by a 5-inch storm with an estimated recurrence interval of 100+ years. This single storm, which set flow records on all Fernow experimental watersheds, caused widespread flooding along local rivers and produced 77 percent and 69 percent of the annual sediment losses on the Fernow and Clover watersheds during 1986, respectively. The importance of occasional large storms in exporting sediment has been noted by other investigators. A single large storm accounted for 90 percent of annual sediment loss on a control watershed in northern Mississippi (Beasley 1979). Kochenderfer and Wendel (1980) found that 90 percent of the annual sediment loss from a 140-acre watershed in central West Virginia was exported in only 5 percent of the time.

Although average annual sediment yields from the treated watershed were greater after site preparation (Table 2) because of uneven storm distribution between the two watersheds, the increase was not significant at the 95-percent probability level. We believe that the following factors were responsible for preventing larger sediment losses. First, roads were built on the contour, then most of the slash was windrowed in them or on the contour. No sediment accumulations were observed behind the windrows but they probably kept water from building enough volume and velocity to cause erosion, especially during the first four critical months when ground cover was at a minimum. Root raking was done carefully to minimize soil disturbance and the windows were not burned. Second, regrowth of vegetation on the watershed was rapid. Douglass and Goodwin (1980) concluded that ground cover was the single most important variable that influenced soil losses after mechanical site preparation in the North Carolina Piedmont. Third, a buffer area was left around the live stream. This untreated area extended about 66 feet on each side of the live stream and encompassed the extensions of the live stream channels during normal storm events.

In general, sediment losses reported here are much less than those reported following mechanical site preparation on the more erodible soils in the South. Douglass and Goodwin (1980) reported that a shearing, windrowing, and burning treatment on four small watersheds in the Piedmont of North Carolina produced first-year average annual soil losses of 3,123 lb/acre. Average annual sediment losses on two watersheds subjected to a similar treatment in Arkansas were higher the second year (1,342 lb/acre) than the first year (714 lb/acre) because of four large storms that accounted for 88 percent of total sediment yield the second year (Beasley et al. 1986).

STREAMFLOW CHEMISTRY

Figure 5 indicates a 28-percent increase in average annual specific conductance after site preparation. Of the chemical constituents tested, only NO_3-N showed an increase in quarterly losses (Fig. 6). The difference between measured and computed losses was about 1.5 lb/acre/yr. These results generally agree with the minor changes in streamflow chemistry that occurred after a watershed was clearcut on the Fernow Experimental Forest (Patric 1980). Even those minor increases lasted only 3 years.

No major increase in nutrient losses was anticipated after the site-preparation treatment. The soils on this watershed are nutrient-poor after many years of farming. Soil base saturation averages only 5 percent and cation exchange capacity only 13 percent. The buffer strip around the stream provided an opportunity for nutrients leached from the treated area to be used by vegetation on the strip. Finally, as indicated by Table 1, native plants quickly reclaimed the site and prevented long-term nutrient leaching.

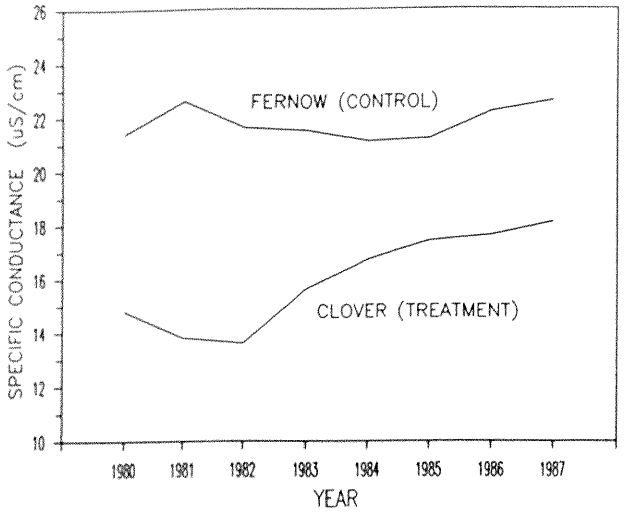

Figure 5.--Time trends of specific conductance in streamflow from control and treated watersheds.

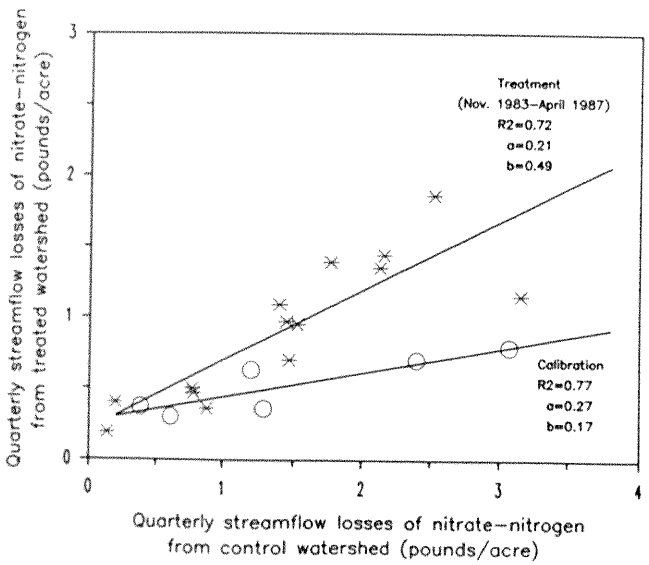

Figure 6.--Changes in NO_3-N following site preparation on Clover watershed.

STREAM TEMPERATURE

Of the 48 weekly growing-season observations after site preparation, 33 were greater than predicted by calibration data, 10 were less than predicted, and 5 were equal. The maximum positive deviation from the regression was 5°F and the maximum stream temperature measured during the calibration and treatment periods were 66°F and 69°F, respectively. Although the records indicate a slight increase in stream temperature after site preparation, the increases were not significant at the 95-percent confidence level. Swift and Messer (1971) evaluated changes in water temperature at the Coweeta Hydrologic Laboratory caused by forest removal in terms of requirements by brook trout. They stated that stream temperature should not exceed 68°F for optimum trout habitat. Although the stream in the treated watershed is too small to support a trout population, the maximum temperature (69°F) exceeded the optimum value for brook trout only twice.

Several investigators have reported that stream temperature was unaffected by forest harvest when streamside vegetation was left to shade the channel (Swift and Messer 1971; Levno and Rothacher 1967). Since a 66-foot-wide strip on each side of the stream channel was excluded from the site-preparation treatment, it is not surprising that increases in stream temperature in this study were not significant.

WATER YIELD

Water yield increased significantly (0.95 level) by 3.9, 2.8, and 1.5 inches during the first, second and third growing seasons after site preparation, respectively. No yield increases were detected during the dormant season.

The increases were slightly smaller than those reported for deforestation treatments on other Fernow Experimental watersheds (Kochenderfer and Aubertin 1975). Those authors reported a growing-season yield increase of about 4.5 inches during the first year after a commercial clearcut that removed 75 percent of the basal area and about 6.5 inches during the first year after all trees larger than 1 inch d.b.h. were harvested. Water yield returned to pretreatment levels within 5 years after the cuttings. Rapid revegetation was responsible for the short-term treatment effect on growing-season water yield.

CONCLUSIONS

A mechanical site-preparation treatment applied to a 28.6-acre watershed in the central Appalachians resulted in a slight increase in both water yield during the growing season and annual losses of NO_3-N. Sediment losses were slightly, but not significantly, greater after the site preparation compared to calibration values. Maximum and minimum weekly stream temperatures did not change significantly due to treatment. The relatively small effects of this treatment are attributed to (1) building roads on the contour well away from the stream, and windrowing the slash either in them or on the contour: (2) using care during root raking to minimize soil disturbance and not burning windrows: (3) rapid revegetation of the areas: and (4) the moderating effect of the 3.5-acre buffer area left around the stream.

We conclude that mechanical site preparation, as practiced in this study, is a hydrologically acceptable practice.

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