STORMFLOW CHANGES AFTER PRESCRIBED BURNING AND CLEARCUTTING PINE STANDS IN THE SOUTH CAROLINA PIEDMONT

James E. Douglass, David H. Van Lear, and Carmen Valverde

Abstract.—Four small pine-covered watersheds in the South Carolina Piedmont were prescribe-burned in September 1979 and clearcut 3 months later. During the next 20 months, highly significant increases in peak discharge and stormflow volume occurred on three of the watersheds. Relative increases as determined by the paired watershed approach were greater than those reported for larger watersheds. The changes were smaller than those to be expected from mechanical site preparation after clearcutting, however. Time to peaking and duration of stormflow were not significantly affected by burning and clearcutting.

INTRODUCTION

Heavy equipment is often used to prepare harvested sites for regeneration of pine in the South. Such treatment often compacts soil and greatly increases soil erosion (Douglass and Goodwin 1980, Ursic and Douglass 1978). Prescribed burning to prepare seedbeds for natural seeding is an alternative that may be less damaging than mechanical methods. In 1976, a study was begun in the South Carolina Piedmont to evaluate the silvicultural potential and hydrological impacts of low-intensity prescribed burning followed by natural regeneration of loblolly pine (Pinus taeda L.) as an alternative to mechanical site preparation and artificial regeneration. Neither runoff, sediment concentration, nor sediment export was significantly affected by the first two prescribed burns (Douglass and Van Lear In Press). After the third burn, the stand was regenerated by clearcutting with seed in place. Van Lear et al. (this conference) have discussed the silvicultural effects of these treatments. In this paper, we review the stormflow effect of the third prescribed burn followed closely by clearcutting.

METHODS AND SITE DESCRIPTION

Control and treatment watersheds were replicated at four locations on the Clemson Forest in a randomized complete block design. This arrangement also allows responses at each location to be examined by the paired watershed approach.

The watersheds are on uplands and range from 1 to about 5.3 acres in size (Table 1). All were in row crops prior to establishment of loblolly pine plantations nearly 40 years ago. Soils are Typic Hapludults. They are well drained and highly weathered soils derived from granite and gneiss. Much of the original surface layer was washed away during decades of row cropping. Typically, the surface soil of upper slopes is a sandy loam plow layer of variable depth overlaying a slowly permeable, clay B horizon. Because of differences in the conservation practices applied and erosion during the agricultural period, the physical conditions of the watersheds are quite variable. Some still have recognizable terraces with little visible sign of erosion and short channels. Others have extensive ephemeral channel systems formed by inactive gullies remaining after farming. Upper slopes showed least signs of past erosion, whereas middle and lower slopes were more severely eroded.

Air temperature of the sites ranges from a mean of 36° F in January to 80° F in July. Annual rainfall in the Clemson area averages 51 inches and is well distributed throughout the year. Thirty percent of the rainfall occurs in winter, and runoff is normally greatest in that
Table 1.—Characteristics of study watersheds

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Size</th>
<th>Slope</th>
<th>Length of uninterrupted channel above flume</th>
<th>Soil series</th>
<th>Basal area of loblolly pine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ac</td>
<td>%</td>
<td>Ft</td>
<td></td>
<td>ft²/ac</td>
</tr>
<tr>
<td>61-Treated</td>
<td>1.6</td>
<td>13</td>
<td>75</td>
<td>Cecil, Madison</td>
<td>143</td>
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<tr>
<td>62-Control</td>
<td>3.8</td>
<td>19</td>
<td>39</td>
<td>Pacolet, Madison</td>
<td>191</td>
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<tr>
<td>63-Control</td>
<td>5.4</td>
<td>13</td>
<td>46</td>
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<td>65</td>
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<tr>
<td>64-Treated</td>
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<td>16</td>
<td>16</td>
<td>Pacolet</td>
<td>97</td>
</tr>
<tr>
<td>65-Control</td>
<td>1.0</td>
<td>10</td>
<td>324</td>
<td>Pacolet</td>
<td>82</td>
</tr>
<tr>
<td>66-Treated</td>
<td>3.1</td>
<td>11</td>
<td>676</td>
<td>Pacolet</td>
<td>78</td>
</tr>
<tr>
<td>67-Control</td>
<td>1.2</td>
<td>12</td>
<td>384</td>
<td>Cecil, Madison</td>
<td>104</td>
</tr>
<tr>
<td>68-Treated</td>
<td>1.5</td>
<td>12</td>
<td>571</td>
<td>Madison</td>
<td>100</td>
</tr>
</tbody>
</table>

1/ All plantations were 36 years old at the beginning of the study except Watershed 61 and 62 which were 37 years old. Watersheds 63 and 68 had previously been thinned one or more times.

season. Because the study watersheds are small upland drainages, all flow occurs only during and for a short time after substantial rain storms.

Runoff from each watershed was measured with a 1-foot H-flume attached to a plywood cut-off wall embedded in the gully channel. Flow was recorded by an analog-to-digital punch tape recorder. Flow volumes in cubic feet/second/square mile (csm) were calculated by the procedures described by Hibbert and Cunningham (1967).

Watershed calibration began in June 1976. The first prescribed burn was on March 11, 1977, 3 days after a cold front delivered about 0.8 inch of rain. Air temperature was about 50°F, relative humidity varied from 35 to 50 percent, and windspeed ranged from 5 to 10 miles per hour. The burning technique was to backfire along the upper ridge and then ignite strip headfires at about 30-foot intervals. Burning intensity varied considerably among watersheds, but each watershed was burned entirely. Flame heights averaged about 1 foot on Watershed 68 and about 3 feet on Watersheds 64 and 65, the last two burned. The second burn was on September 20, 1978, about 2 weeks after a rain. The same burning technique was used but fires were less intense because less fuel was available. Air temperature ranged from 78°F to 90°F, relative humidity varied from 38 to 50 percent, and windspeed was about 10 miles per hour. The third burn was on September 12, 1979, to prepare a seedbed prior to harvest of timber. Relative humidity ranged between 55 and 60 percent, temperature was in the 80's, and a 10 mile per hour breeze fanned flames to an average height of 1 foot. Overall, it was the coolest of the three burns.

Prior to burning, litter weight on the watersheds was about 11 tons per acre. The first burn consumed the most litter and the third burn the least. After the third burn, 12 tons per acre of protective litter remained.

Timber harvest began in December 1979 and ended in mid-January 1980. During logging, care was exercised to prevent unnecessary damage to the soil and litter. Logs were skidded uphill to a landing and loaded on trucks. Logging slash was left in place on Watersheds 61, 66, and 68. On Watershed 64, slash was bladed off the watershed with a bulldozer to simulate whole-tree harvesting. This treatment approximately doubled the exposure of mineral soil on the watershed.

Previous analyses indicated no significant effect of the first two prescribed burns on water yield or stormflow (Douglass and Van Lear In Press). Therefore, flow data for the calibration period and the first three burns (June 1976 until December 1979) were combined for Watershed pairs 61-62, 63-64, and 65-66. However, Watershed 68 experienced an outbreak of the southern pine beetle (Dendroctonus frontalis Zimm.) after the first burn and by October 1978, 20 percent of the pine basal area was dead. Most of the mortality occurred along the ephemeral channel in the lower portion of the
watershed. The calibration period for this watershed pair was from June 1976 until October 1978. The treatment period was the 21 months from February 1980 through October 1981.

The earlier analysis revealed large differences in runoff volumes between locations. Because the paired watershed method provides greater precision in comparing treatment effects, it was used to determine effects of treatment (Hewlett et al. 1969). Treatment is defined as the combined effect of the third burn and clearcutting. With the paired watershed method, the characteristic of interest for the calibration period on the watershed to be treated is regressed against the same characteristic on the control watershed. After calibration, the difference between the observed value and the value predicted for the treatment watershed using the calibration regression is taken as the treatment effect.

The technique of Hibbert and Cunningham (1967) was used to divide the storm hydrograph into parameters for testing (Figure 1). Total runoff is separated into several hydrograph parameters and total flow is divided into baseflow and stormflow volume. The flow parameters examined in this study were:

- **Qp**: peak rate of runoff
- **qi**: flow rate of the beginning of the runoff event
- **v1**: volume of storm runoff before the peak
- **v2**: volume of storm runoff after the peak
- **v1 + v2**: total volume of storm runoff
- **Tp**: time to peak, the time in hours from the beginning of storm runoff to peak runoff
- **R**: recession time, the time in hours from the peak runoff rate to the intersection of the separation line and the hydrograph recession line
- **D**: time in hours from the beginning of runoff until the time of intersection of the recession hydrograph and the separation line.

Storm events were selected for analysis if both watersheds had minimum flows of 10 csm and single peak hydrographs.

Statistical significance was determined by the procedure described by Gharati (1970) and Swindel (1970) of testing the equality of sets of linear regression coefficients. The treatment period is handled as a dummy variable, and the differences between pretreatment and post-treatment slopes and intercepts are tested using the F statistic.

RESULTS AND DISCUSSION

Earlier findings on these watersheds indicated that, although the first two prescribed burns did not significantly affect storm runoff, large variation in runoff did occur between some watershed pairs and between some locations (Douglass and Van Lear In Press). Greatest variation was between the Watersheds 61-62 pair. Treated Watershed 61 had a large stone terrace or check dam about 75 feet upstream from the flume. Several cubic yards of sandy loam colluvial material were deposited behind this erosion control structure and provided appreciably more storage than was available on Watershed 62. Frequently, small storms would produce runoff from Watershed 62 but none from Watershed 61. During large storms flow from Watershed 61, because of the enlarged storage capacity, would continue for a longer period than would flow from Watershed 62. These factors caused poor correlation between storm hydrograph parameters for Watersheds 61 and 62, and only four events were available for inclusion in the treatment period (Figure 2). Therefore, this watershed pair was excluded from the complete analysis.

Length of the ephemeral channel network also differed within watershed pairs and between locations. The average fraction of rainfall that became streamflow increased with length of uninterrupted channel on the eight watersheds during the calibration period and varied from about 5 to 17 percent. A regression of the fraction of rain that became streamflow against the length of uninterrupted channel had an r of 0.80.
Figure 2.—Peak discharge in csm during the calibration (.) and treatment (x) periods for the four pairs of watersheds.

Results from the stormflow analysis for treated Watersheds 64, 66, and 68 were consistent except for the initial flow rate, which is the flow at the beginning of the storm. This parameter has little meaning for watersheds of this size because there is no flow at the beginning of most storms. There was no increase in initial flow rate due to treatment on Watersheds 64 and 66 and the increase on Watershed 68 was barely significant at the 0.05 level.
Time to peak and flow duration were unaffected by treatment. Burning and clearcutting significantly increased peak flow, stormflow volume before the peak, stormflow volume after the peak, and total stormflow volume at the 0.01 level (Table 2).

Table 2.—Effects of prescribed burning followed by harvesting timber by clearcutting on increasing stormflow

<table>
<thead>
<tr>
<th>Stormflow parameter</th>
<th>Watershed number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>64</td>
</tr>
<tr>
<td>Initial flow rate</td>
<td>NS</td>
</tr>
<tr>
<td>Peak flow rate</td>
<td>**</td>
</tr>
<tr>
<td>Time to peak</td>
<td>NS</td>
</tr>
<tr>
<td>Storm duration</td>
<td>NS</td>
</tr>
<tr>
<td>Stormflow volume before peak</td>
<td>**</td>
</tr>
<tr>
<td>Stormflow volume after peak</td>
<td>**</td>
</tr>
<tr>
<td>Total stormflow volume</td>
<td>**</td>
</tr>
</tbody>
</table>

1/ NS = nonsignificant; ** = is a significant increase at the 0.05 level; and ** = is a significant increase at the 0.01 level.

The calibration and treatment regression lines for peak flow for the four pairs of watersheds are shown in Figure 2. As previously noted, only four observations were available for Watersheds 61 and 62 during the treatment period and these were judged insufficient for valid statistical tests on this watershed pair. The increase in peak flow due to treatment as a percentage of pretreatment peaks was greatest on Watershed 64. Note, however, that absolute discharges were greater before and after treatment on Watersheds 66 and 68.

The effects of the third prescribed burn and clearcutting on the mean storm hydrograph are illustrated for the three watersheds in Figure 3. Because the scale is the same, relative differences in storm hydrographs between the pairs of watersheds can be judged visually. Watershed 64 obviously responds to precipitation differently from Watersheds 66 and 68, both before and after treatment. Peaks are smaller, time to peak is greater, and the duration of stormflow is 75 percent longer than on Watersheds 66 and 68. The average storm hydrograph for Watershed 64 (Figure 3a) is indicative of a stable watershed where most precipitation infiltrates and slowly drains from the watershed. Surface soil of Watershed 64 is deeper and more porous than that of Watersheds 66 and 68. Therefore moisture storage is greater, leading to smaller peaks and more prolonged flow. Treatment increased the average peak discharge over 150 percent and approximately doubled stormflow volumes on Watershed 64, about three times the percentage increase on Watersheds 66 and 68. This large increase may have been caused by the greater site disturbance when the logging slash was bulldozed off this watershed to simulate whole-tree harvesting. Mineral soil was exposed on about 50 percent of Watershed 64 compared to only 20 to 25 percent on Watersheds 66 and 68. Exposing mineral soil on 50 percent of the area during mechanical site preparation has been shown to greatly increase storm runoff in the Piedmont (Douglass and Goodwin 1980) and Coastal Plain (Beasley 1979).

Peaks for the mean storm on Watersheds 66 and 68 were increased by 55 to 60 percent (Figure 3b and c). The percentage increase in peaks after treatment was less for these watersheds than for Watershed 64, but the pretreatment peaks were about 7 times greater; thus, initially they were much more responsive to rainfall. The greater responsiveness is attributed to the general hydrologic characteristics of eroded Piedmont soils and the greater dissection of Watersheds 66 and 68. Typically, former agricultural soils have a permeable sandy loam to loam residual plow layer that is limited in moisture storage capacity. A dense, slowly permeable B horizon lies beneath the plow layer and severely restricts vertical drainage (Hoover 1950). Because rates of rainfall often exceed the percolation rate of the B horizon, the plow layer becomes partly or completely saturated. On sloping land, the predominate flow path of water is downslope at the top of the B horizon. Where past erosion has exposed the B horizon and interrupts subsurface flow, free water enters the ephemeral drainage. The denser the channel or gully network, the shorter the subsurface flow path and the more rapid the storm runoff.

Because earlier analyses indicated no significant direct effect of prescribed burning on water yield, we suggest that it is unlikely that the third burning significantly affected stormflow characteristics. More likely, treatment effects resulted from the harvest and removal of timber from the site. A modest increase in both peak flow rates and volumes of stormflow is normal in the Appalachians when the forest is clearcut and felled trees are left in place (Hewlett and Melvey 1970). When felled trees are skidded, the increases are usually larger (Douglass and Swank 1976, Swank et al. In Press, Lynch 1969, Reinhart et al. 1963). The size of the effect depends on the care exercised during road construction and skidding operations.
Figure 3.—Graphic representation of the average storm hydrographs for the calibration and treatment periods for Watersheds 64, 66, and 68. The shaded area indicates the change associated with the prescribed burn-clearcut treatment.

In general responses to the burning and clearcutting treatment are much less than responses to mechanical site preparation practices in the Piedmont (Douglass and Goodwin 1980) and steep Coastal Plain watersheds (Beasal 1979). Mechanical treatments have increased stormflow volumes 3- to 18-fold, depending on the particular practice involved.

Interpretation of our data in relation to the larger bulk of the literature on timber harvest is difficult because of the uncertainties associated with watershed size. Magnitude of increases in both peak rates and stormflow volumes on our small Piedmont watersheds exceeded by a factor of 2 or more the responses observed on larger Appalachian watersheds and on a larger Piedmont watershed which was roaded, clearcut, roller chopped, and planted (Hewlett 1979). Our watersheds are 1 to 5 acres in size, as are most watersheds on which site preparation responses have been measured. Most past studies of harvesting effects, however, have been on watersheds covering from 30 to over 300 acres. Differences in basin hydrology and possibly watershed size influence the response. Most studies on larger watersheds measure, or are assumed to measure, total flow, whereas only quick return subsurface and overland flow were measured in our study. The greater storage potential of large watersheds may explain, at least in part, the difference in hydrology of small versus large basins.

Although there may be uncertainties as to whether results from very small and larger watersheds are directly comparable, clearly stormflow was significantly increased by the treatment applied. From past experience, we would expect higher peaks and greater stormflow volumes from clearcutting the watershed, and we would expect the magnitude of the response to be proportional to the degree of site disturbance. Thus, findings from our watersheds are consistent with findings from other cutting experiments.
We conclude that the effects on peak flow and stormflow volume of prescribed burning for seedbed preparation followed by clearcutting with seed in place were much less severe than effects reported for mechanical methods of site preparation. A review of agricultural history of the Piedmont clearly indicates the sensitivity of these soils. It appears only prudent to recognize this sensitivity and to carefully weigh the impact of operations on the hydrologic functioning of these lands. Hydrologically, silviculturally, and economically, the method proved to be a viable and desirable regeneration technique in this study.

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