HYDROLOGIC EFFECTS OF FORESTRY PRACTICES IN MISSISSIPPI

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INTRODUCTION

Of the many environmental concerns related to forestry, a prime consideration is how forests and forestry practices affect the disposition of precipitation and the quality of streamflow. This report discusses the hydrology of undisturbed forests and changes related to reforestation, species change, and harvesting.

HYDROLOGY OF UNDISTURBED FORESTS

Stormflows

Well-stocked stands of loblolly pine (*Pinus taeda* L.)–the main commercial species–utilize about two-thirds of the annual rainfall through evapotranspirational processes. Interception alone, adjusted for stemflow, accounts for about 15 percent (Helvey, 1971). In addition, the forest floor intercepts 4 to 6 percent, so about one-fifth of annual rainfall never reaches the soil. In north Mississippi, 35 inches of the average annual rainfall of 53 inches is evaporated and transpired. About 10 inches is lost to interception, and 25 inches is transpired by the forest and evaporated from the soil. Because pine can extract water from soil depths of 6 feet or more, the 35 inches of evapotranspiration is more or less constant, becoming significantly less only in years of severe summer drought. The residual, rainfall minus gross evapotranspiration, of about 18 inches is the water available for streamflow. How forestry practices change these proportions and how they affect the quality of water that leaves the forested landscape are major concerns.

Much of our information on water yields and distribution has been obtained from studies of small forested catchments. In hilly terrain, flow from small Mississippi catchments seldom includes a contribution from permanently saturated channel zones or from ground water, i.e., the channels do not incise the water table. Runoff from small catchments consists largely of ephemeral and intermittent stormflows that occur during and shortly after a rain event. Rainfall intensities seldom exceed infiltration rates, and contributions to stormflows largely follow subsurface flow paths. Overland flow rarely occurs.

Annual volumes of stormflow from small forested catchments can vary widely because of soil differences and erosion history. Five-year means of stormflows as a percentage of rainfall for eight small catchments of loblolly pine on the eroded hills of north Mississippi ranged from 0.1 to 16 percent. The mean annual values could be predicted reliably from annual rainfall and the portion of a catchment having restricted soil drainage (Ursic and Duffy, 1972). Small catchments with high, erosion-caused drainage densities also have high stormflow-precipitation ratios (Van Lear and Douglass, 1983).

Water Quality

Although flows from pine types in the hilly sections of the South carry less sediment than runoff from other forest types and from other land uses, sediment is the main pollutant of concern. Based on information collected in north Mississippi, the average annual base rate, or natural background level, initially suggested for sediment concentrations from undisturbed pine types was 0.007 ton per acre-inch of stormflow (ton/AI) or about 60 ppm (Ursic and Duffy, 1972). Subsequent catchment studies in the hilly sections of the Coastal Plain and Piedmont have substantiated this base rate for undisturbed pine cover types. Average annual concentrations for 14 data sets from 12 studies ranged from 0.002 to 0.012 ton/AI and averaged 0.006 ton/AI. The studies included 37 catchments in 8 Southern States and represented 189 years of record (Ursic, 1986). Concentrations for large, individual stormflows from small catchments may exceed the annual base rate by a factor of 10 or more due to the occasional flushing of the sediment accumulated in channels. Such natural variation should be considered in any monitoring effort.

As forested catchments increase in size, average annual concentrations also increase as a result of channel contributions. However, to provide a further perspective, forests occupying about one-third of large Mississippi watersheds contribute less that 1 percent of total sediment yields due to much larger contributions from gullies, channels, and other land uses (Dendy et al., 1979).

Dissolved concentrations of nitrogen (N) and phosphorus (P) in stormflows from undisturbed pine catchments in north Mississippi may equal the concentrations of these elements in rainfall. However, because stormflow is only a small part of rainfall, losses in stormflow are much less than the atmospheric inputs of these elements. Sediment from small undisturbed pine catchments transports about twice the P and nearly as much N as the losses in solution. Thus, forestry practices that increase sediment yields can have a relatively large impact on the nutrient quality of streamflow (Duffy, 1985).

EFFECTS OF FORESTRY PRACTICES

Changes in hydrologic performance are best determined by long-term studies of paired, calibrated catchments using regression and covariance analyses. For the studies described here, calibrations were developed for individual stormflow volumes. Changes in sediment characteristics were generally clearcut, and before-and-after comparisons sufficed.

Stormflows

Reforestation and Harvesting

Planting loblolly pine on abandoned-field catchments in north Mississippi reduced annual stormflow volumes about 50 percent in less than 10 years (Table 1). The change for a silt-loam catchment having fragipan soils was best expressed as a decrease of 0.14 area-inch per stormflow event. For a sandy- loam catchment, flow volumes were significantly less than expected for all events predicted to yield 0.25 area-inch or more, with the reductions trending directly with stormflow size (Figure 1). Increased interception of rainfall by the developing pine plantations accounted for essentially all of the decreases of individual stormflow volumes for both silt-loam and sandy-loam catchments.

Table 1.
Changes in stormflow volumes during postplanting and postharvesting periods for abandoned-field catchments.[1]

Period Soils	Total changes from predicted volumes		Mean annual changes
	Percent	Area-inches	Area-inches
Postplanting–pine ages 9-15.5			
Silt loams	-42	-20.2[2]	-2.7
Sandy loams	-55	-7.0	-0.9
Two-year postharvest			
Silt loams	23	4.1	2.1
Sandy loams[3]	8	0.4	0.2

1 Comparisons with pretreatment calibrations.
2 Postplanting equation change in level. Change best expressed as a decrease of 0.14 area-inch per stormflow event.
3 Postharvest equation did not differ from calibration equation.

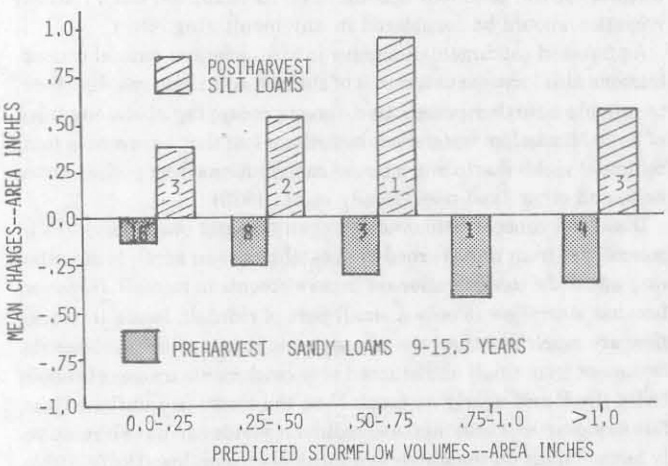

Figure 1. –Significant changes of stormflow volumes by size-class before and after harvest for the abandoned-field catchments. Numerals on histograms indicate number of events.

The plantations were clearcut during the 16th growing season. In the 2- year postharvest period, stormflow behavior of the sandy-loam catchment reverted to that of the original old-field condition, i.e., stormflow reductions were largely nullified. Stormflow volumes for the silt-loam catchment, when compared to the original old-field performance, increased (Table 1). Events that increased significantly (figure 1) exceeded decreases of interception, indicating an additional effect of harvesting disturbance. Clearly, this worst-case example of severely eroded, silt-loam soils with restricted soil drainage emphasizes that such sites are not candidates for early clearfelling where stormflow reductions are important.

Replacing Depleted Hardwoods with Pine

Poor-quality upland hardwoods should be replaced with pine in large areas of Mississippi to restore productivity of these lands and to furnish anticipated wood demands. In a companion study to determine the hydrologic effects of the practice, two catchments were planted with loblolly pine and the hardwood overstory chemically deadened (Ursic, 1985).

Stormflows gradually declined as the pine developed and decreased an average of over 80 percent from predicted volumes after pine ages 12 or 13 years (Table 2). Stormflow volumes were significantly less than expected for all events predicted to yield 0.25 area-inch or more. The mean decreases varied directly and positively with stormflow size (Figure 2). Individual decreases ranged up to 1.7 area-inches for the silt-loam catchment and 1.0 area-inch for the sandy-loam catchment.

Table 2.
Changes in stormflow volumes during postplanting and postharvesting periods for depleted-hardwood catchments.[1]

Period Soils	Total changes from predicted volumes		Mean annual changes
	Percent	Area-inches	Area-inches
Postplanting–Pine ages 13-15.5			
Silt loams	-79	-20.4	-5.8
Sandy loams[2]	-87	-14.0	-3.1
Two-year postharvest			
Silt loams	-41	-4.8	-2.9
Sandy loams[3]	-58	-3.9	-2.3

1 Comparisons with pretreatment calibrations.
2 12-15.5 years.
3 20 months.

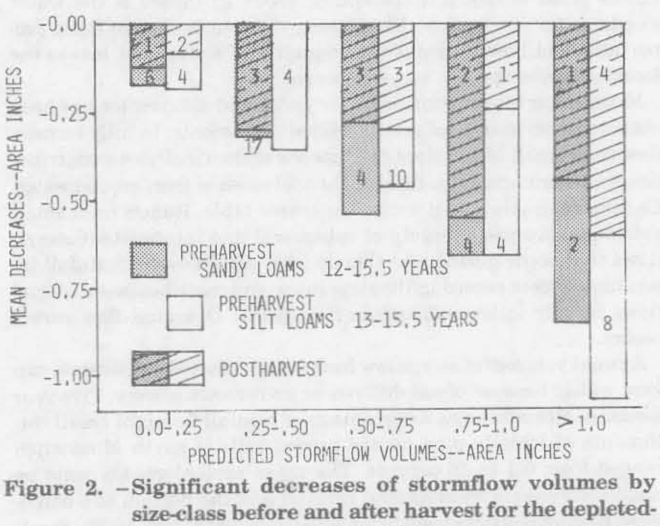

Figure 2. –Significant decreases of stormflow volumes by size-class before and after harvest for the depleted-hardwood catchments. Numerals on histograms indicate number of events.

The planted pine in this study were also clearcut during the 16th growing season. Compared to the original hardwood cover, stormflow decreases continued during the 2-year postharvest period and averaged about 50 percent (Table 2). All flows predicted to yield 0.25 area-inch or more from the sandy-loam catchment and more than 0.5 area-inch from the silt-loam catchment were significantly less in volume. Mean decreases continued to vary directly with stormflow size (Figure 2). Individual decreases ranged up to 1.1 area- inches for the silt-loam catchment and 0.8 area-inch for the sandy-loam catchment.

Stormflow behavior of the depleted-hardwood catchments during the 2 years after clearcut harvest was comparable to that at pine ages 9 to 12, during which total stormflow volumes decreased about 60 percent. In contrast, stormflow behavior on the catchments with the abandoned-field history reverted to the behavior they had before they were planted to pine; i. e., all benefits were lost.

All significant decreases in stormflow volumes after plantation age 9 for the sandy-loam catchment and age 12 for the silt-loam catchment were larger than the estimated increases in interception. During pine ages 12-15.5 for the sandy-loam catchment and 13-15.5 for the silt-loam catchment, decreases of stormflow volumes not attributable to interception accounted for 29 and 51 percent of the respective significant decreases of 13 and 18 area-inches. The latter figures represent 93 and 88 percent of the total stormflow changes during these intervals.

During the postharvest period, significant increases of stormflow volumes for the sandy-loam catchment were all less than decreases of interception. For the silt-loam catchment, three stormflow events in the first few months after harvest had increases in excess of interception decreases. However, for eight events having significant increases totaling 3.5 area inches during the postharvest period, the decrease in interception accounted for 3.3 area- inches. Thus, stormflow reductions not attributable to interception changes in the preharvest period were largely retained for both catchments during the postharvest period.

Overall, the erosion history of the catchments in these harvesting studies was important. The maximum absolute reductions in annual and individual stormflow volumes were obtained by replacing hardwoods with pine on moderately eroded, silt-loam soils. Of importance to management for the prevention of floods is the fact that maximum reductions of individual flows for catchments with moderately eroded soils were twice as great as for catchments with similar but more severely eroded soils.

Sediment

Protecting water quality depends largely on minimizing conditions that increase overland flow. The key is to minimize soil exposure and compaction. When forestry practices expose a large portion of the soils on a catchment, rainfall impacting on the bare soils causes overland flow that detaches, entrains, and delivers soil to channels. Douglass and Goodwin (1980) concluded that percentage of ground cover was the single most important factor affecting annual sediment concentrations, which increased rapidly as ground cover dropped below 40 percent.

In the two Mississippi harvesting studies, sediment concentrations for the depleted-hardwood control catchment during the entire course of the study averaged 0.018 ton/AI, and those for the abandoned-field control catchment averaged 0.032 ton/AI.

Concentrations for the two catchments with the hardwood history averaged 0.006 and 0.007 ton/AI during pine ages 5-15 and, after harvest, increased slightly on the silt-loam catchment but not on the sandy-loam catchment.

Concentrations for the two catchments with the abandoned-field history averaged 0.001 and 0.002 ton/AI during pine ages 10-15, these very low rates being fostered by the healing of channels and dense growth of honeysuckle in sections of the channels. Sediment concentrations increased to levels measured before pine establishment during the 2-year postharvest period, with most of the increases due to higher concentrations during the first 4 months after cutting. Concentrations beginning 4 months after harvesting fell to below 0.007 ton/AI. However, with rates and volumes of flow reverting to preplanting levels, any decreases in sediment concentrations achieved by the pine in sand channels downstream from the catchments were probably nullified.

We emphasize that planting, harvesting, and replanting pine in the studies cited were accomplished with minimum site disturbance. Establishing pine with intensive mechanical site preparation in north Mississippi resulted in 20 inches of annual stormflow and first-year sediment losses of 6 tons/acre (Beasley, 1979).

Nutrient Quality of Water

In the studies described, harvesting did not significantly change soil solution concentrations of total Kjeldahl nitrogen (TKN), total phosphorus (TP), or potassium (K). Average postharvest concentrations over all catchments were as follows:

Year	TKN	TP	K
	Lb/acre-inch		
First	0.11	0.01	0.44
Second	0.14	0.01	0.41

For Coastal Plain conditions, these concentrations represent the nutrient quality of seepage potentially available for ground water accretion.

Analyses of proportional-to-flow stormflow samples indicated no significant changes of solution concentrations of TKN or TP, or of organic matter when comparing the controls and harvested catchments either before or after harvesting.

Concentrations of K increased significantly in stormflows from two of the harvested catchments when compared with the controls. Preharvest comparisons showed no significant differences. The increase of solution K of about 0.22 lb/AI does not portend a loss of site productivity on the sites studied. Too, the annual input from atmospheric deposition exceeds the additional loss of K. Similar nutrient relationships were found in a study of eight similar clearcut catchments of 27- and 37- year-old loblolly pine in west Tennessee (McClurkin et al., 1985).

Far more important than stormflow and soil solution losses are the nutrient exports in the sediment phase. Averaging all catchments before and after treatment for the 4.5 years of sampling, about three-quarters of the TKN and TP losses in stormflows were via sediment. Mean sediment concentration of TKN was 1.23 percent by weight of sediment, and mean concentration of TP was 0.04 percent by weight. Thus, while a 4-inch increase in stormflow volumes would result in a loss of about 0.3 lb/acre of TKN in solution, the very low base-rate of sediment concentrations (0.007 ton ton/AI) would result in twice this loss. Similarly, a 4-inch increase in stormflow volumes would export about the same amount of TP in solution as would the base-rate of sediment concentrations. The loss of nutrients from the catchments in these studies was largely that in the biomass removed. Additional nutrient losses on similar sites would be almost wholly a function of sediment yields.

DOWNSTREAM IMPLICATIONS OF FORESTRY PRACTICES

Compared to the regulatory forest practice acts adopted by the westernmost states, the approach promulgated in the Southern States is that of voluntary Best Management Practices (BMP's). Evaluation of BMP's is based on the quality of water leaving a particular forest area that has been subjected to some disturbance. However, increases of stormflow volumes, not increases of sediment concentrations, may be the dominant factor affecting water quality downstream from the site disturbed. And forestry practices that remove a large part of the biomass cause increases in stormflow volumes that persist longer than corresponding increases in sediment concentrations.

The quality of water from forested lands in the Coastal Plain progressively degrades as it continues downstream. Water from small ephemeral channels flows to larger channels, which today are major sources of sediment because they are typically aggraded, sand-textured, and sensitive to the erosive power of flowing water. Many streams are reestablishing channel stability by removing large quantities of alluvium of anthropogenic origin. For example, the average annual sediment concentration from an 88-acre catchment of loblolly pine was 13 times higher than the base rate of 0.007 ton/AI for small headwater areas, primarily due to channel erosion (Ursic, 1975). Increases in stormflow volumes also affect reaches of larger, first- and second-order Mississippi streams where channels can erode at the rate of 1 ton per foot of channel annually, and 1 mile of channel can contribute sediment loads equivalent to 6 tons/acre/year from an entire watershed (Murphey and Grissinger, 1985). Large flow increases caused by severe forest land disturbances can only aggravate such effects.

WATER SUPPLIES

Mississippi has ample water, but localized shortages are increasing. In such areas the consumptive use of water by forests will be increasingly scrutinized. Replacing hardwoods with loblolly pine in the South Carolina Piedmont increased interception by about 4 inches or about 25 percent of average annual streamflow (Swank et al., 1972). In north Mississippi, replacing poor-quality hill hardwoods with loblolly pine increased interception losses an average of 6 inches during pine ages 5 through 15, and 8 inches during the 15th year when rainfall equalled the long-term mean and the number of rains was less than average. These increases were equivalent, respectively, to 30 and 40 percent of average annual streamflow. The additional water use by pine in these studies would have been greater if the higher rates of transpiration had been considered. Such information is important in areas where water use by pine forests may compete with increasing demands for water for industry, municipal use, and irrigation. This potential conflict may eventually require area planning involving choice of species, frequency of harvesting, and other activities.

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