Sediment Production in Forests of the Coastal Plain, Piedmont, and Interior Highlands

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Introduction

A primary environmental concern related to forestry in the South is the effects of forests and forestry practices on sediment production. Sediment is the most significant pollutant of southern waters. A liability in itself, sediment also accounts for most nutrients removed by water. This paper discusses sediment production from small catchments of undisturbed forests in the Coastal Plain, Piedmont, and Interior Highlands and presents findings on the magnitude and duration of changes associated with silvicultural practices. The information represents sediment production from forested slopes and ephemeral or intermittent channels. Most cited studies do not include sediment from forest roads. In the past, small catchments (0.5 to 5.0 ha) were used to minimize the confounding effects of channel erosion; however, even on undisturbed small catchments, much of the sediment may be contributed by channels. This paper concludes by identifying several research needs that must be addressed to better understand sediment production in southern forests.

Forests of the Coastal Plain, Piedmont, and Interior Highlands

The region considered in this paper encompasses the Coastal Plain and the Piedmont south of the Potomac River and the Interior Highlands physiographic provinces. The Coastal Plain consists of sedimentary formations that vary in age from Cretaceous to Quaternary. Overall, relief is low (less than 90 m), but extensive areas of rolling hills exist with moderately steep slopes. Soils developed from these formations and landforms are highly erodible, and indurated bedrock exposures are rare. The Piedmont has highly erodible soils and relief comparable to the Coastal Plain but is also underlain by older Precambrian and Paleozoic metamorphic and sedimentary rocks. The Ozark Plateau and Ouachita Mountains combine to form the Interior Highlands province. In contrast to the Coastal Plain and the Piedmont, the Interior Highlands have extensive outcrops of indurated sedimentary bedrock, relatively moderate to high relief, and soils that are thinner, much rockier, and less erosive.

The region's climate is humid subtropical. Annual precipitation ranges from 1,200 to 2,000 mm and occurs mostly as intense rainstorms that are evenly distributed throughout the year. Temperatures commonly range between 0 to 15°C in winter and 20 to 35°C in summer. Natural vegetation was once extensive stands of oak, oak-hickory, mixed pine-hardwood, and predominantly pine vegetation types. Vegetation composition has been greatly changed by human activities over the past 200 years.

The 12 southern States now produce almost half the Nation's wood fiber, and demand is projected to increase substantially during the next several decades (U.S. Dep. Agric. Forest Serv. 1982). Pine species predominate on 26 of the 76 million hectares of southern commercial forestland and comprise up to 50 percent of the stocking on some 14.6 million additional hectares (Murphy and Knight, 1974). To meet anticipated demand, most of the low quality hardwoods occupying some 28 million acres unsuited for hardwood production need to be replaced with southern pine (S. Forest Resour. Anal. Comm. 1969).

The three forest management activities most likely to increase sediment production are logging, site preparation, and road construction. Harvesting and regeneration activities are important because the area under even-aged management is extensive; rotation periods are short (17 to 35 years) and heavy equipment is often used to prepare sites. Soil and water hazards related to these activities vary among physiographic provinces but are most severe on the hilly topography of the Piedmont and the Coastal Plain. After forest clearing and decades of abusive row-crop agriculture, millions of hectares were abandoned, while remaining forestlands were subjected to exploitative harvesting, frequent burning, and overgrazing. Of the Coastal Plain's 49 million hectares of forestland, nine million hectares have been subjected to accelerated erosion (McClurkin, 1967). Excessive runoff and sediment from eroding lands contributed to downstream damage, covered minor flood plains, and created sand-filled channels that are important sediment sources today.

Base Rates of Sediment Concentrations

Sediment is supplied to southern forest streams primarily through surface and channel erosion. Overland flow or sheetwash is rarely observed in well-stocked forest stands that have not been recently disturbed. Overland flow does occur, however, where soils are compacted or directly exposed to precipitation. Where surface runoff occurs, it quickly becomes channelized in this region's erosive soils, which leads to expanded rill and gully development and rapid sediment delivery to existing stream channels. In contrast to surface erosion, mass erosion processes occur infrequently and probably account for only a small portion of total sediment production.

To measure sediment production, the authors use a data set compiled by Ursic (1986) that contains results from research throughout the Coastal Plain, Piedmont, and Interior Highlands (Table 1). Although sediment is sometimes expressed as yields, which can be important for assessing reservoir sedimentation rates, the authors use discharge-weighted annual or average annual sediment concentrations to evaluate forestry practices and compare sediment production rates for undisturbed southern pine forests. By analyzing many data sets, Ursic (1986) found that sediment concentrations were independent of individual or annual stormflow volumes; therefore, annual sediment yields were largely a linear function of flow volume.

Sediment yields are highly variable, depending on the land use history and the amount and characteristics of rainfall during that particular year. Annual precipitation over much of the South averages about 1,300 mm but can vary from less than 1,000 to over 2,000 mm. This variation greatly affects water and sediment yields. Even in replicated studies, both water and sediment yields vary widely among similarly treated catchments, while sediment concentrations are more uniform. In one study, expressing soil loss as concentrations reduced the coefficients of variation from approximately 100 to 50 percent (Douglass and Goodwin, 1980). Because sediment concentrations vary less than sediment yields, thereby facilitating comparisons among and within studies, the authors use concentrations for this study.

Based on previous work, the average annual concentration of 6.2 kg/ha-cm was suggested as the natural background level or base rate for pine types in the Coastal Plain. Later catchment studies in the hilly Coastal Plain and Piedmont appear to substantiate this base rate for undisturbed pine cover types. Annual concentrations for 14 data sets from 12 studies ranged from 1.8 to 10.6 kg/ha-cm and, either weighted by study years or unweighted, averaged 5.3 kg/ha-cm (Ursic, 1986). The studies included 37 catchments and represent 189 years of record (Fig. 1). This mean excludes a 35.6 ha catchment in Tennessee that had an average annual concentration of 77.7 kg/ha-cm as a result of channel erosion.

Most of the sediment from small pine catchments comes not from forested slopes, but from erosion of minor channels developed during former land uses. Compared to poor quality hardwoods, the lower sediment concentrations from pine catchments probably result from more litter in the channel network. Pine litter forms a loose, interwoven cover that reduces flow velocities and is not as easily dislodged by flowing water as hardwood litter. Storm-to-storm variation in sediment concentration may be strongly controlled by the periodic flushing and reformation of litter accumulations within these minor channels. Thus, sediment concentrations for large stormflow events sometimes exceed the suggested base rate by a fac-

Table 1.—Geographic location and vegetation cover type for research sites used to evaluate sediment production from small forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions.[1]

LOCATION	COVER TYPE	FIGURE CODE[2]	REFERENCE[3]	DRAINAGE AREA (ha)
Coastal Plain Uplands (CPU)				
East Texas	Loblolly-shortleaf	CPU_1	1	2.4
	Loblolly-shortleaf	CPU_2	26	2.4
Southeast Arkansas	Flatwoods	CPU_3	2	2.4–41.
	Loblolly-shortleaf	CPU_4	2	2.4–4.1
	Pine-hardwoods	CPU_5	3	2.0–4.5
Southwest Arkansas	Athens Plateau	CPU_6	3	2.0–4.5
	Loblolly-shortleaf	CPU_7	3	2.8
North Mississippi	5 to 15-yr loblolly	CPU_8	4	1.0
	10 to 15-yr loblolly	CPU_9	4	0.8
	39-yr loblolly	CPU_10	5	1.6–2.8
	Pine-hardwood	CPU_11	25	0.8
	Pine-hardwood	CPU_12	25	0.8
	Pine-hardwood	CPU_13	25	0.8
	Mature shortleaf	CPU_14	6	1.3–1.9
	Depleted hardwoods	CPU_15	7	1.1
	Depleted hardwoods	CPU_16	8	0.8–1.1
	Abandoned fields	CPU_17	9	1.1
	Abandoned fields	CPU_18	10	1.0
Tennessee	Loblolly pine	CPU_19	11	35.6
	29-, 37-yr loblolly	CPU_20	12	0.2–0.6
Piedmont (PD)				
North Carolina	Unknown	PD_1	13	0.2–0.6
	Unknown	PD_2	13	0.4–0.8
	Unknown	PD_3	13	0.4–0.8
South Carolina	40-yr loblolly	PD_4	14, 24	0.6–1.3
Virginia	Virginia pine	PD_5	15	1.6
Georgia	Loblolly pine	PD_6	16	42.5
Coastal Plain Lowlands (CPL)				
South Carolina	Hardwoods	CPL_1	17	—
	15-yr loblolly	CPL_2	17	—
	Carolina Bay	CPL_3	17	2,266.0
Florida	40-yr slash pine	CPL_4	18	57.0
	40-yr slash pine	CPL_5	18	49.0
	40-yr slash pine	CPL_6	18	140.0
Interior Highlands (IH)				
Arkansas Ozark Plateau	Hardwoods	IH_1	19	1.6–2.4
Ouachita Mountains	Shortleaf pine	IH_2	20	0.5–0.7
	Shortleaf pine	IH_3	20, 23	0.5
	Shortleaf pine	IH_4	20, 23	0.5
	Grass cover	IH_7	23	0.6
Oklahoma Ouachita Mountains	Shortleaf pine	IH_5	21	1.6–4.0
Oklahoma/Arkansas Ouachita Mountains	Shortleaf pine	IH_6	22	4.0–6.1

[1] These data were first compiled and presented in Ursic (1986). The entries listed in the first and second columns also serve as a cross-reference to entries in Tables 1 to 3 in Ursic (1986).

[2] These codes are used in Figures 1–4.

[3] References: 1. DeHaven et al. 1984; 2. Beasley and Granillo, 1985a; 3. Beasley and Granillo, 1985b; 4. Ursic, 1985; 5. Schreiber and Duffy, 1982; 6. Ursic, 1977; 7. Ursic, 1982; 8. Ursic, 1970; 9. Ursic, unpubl.; 10. Ursic, 1969; 11. Ursic, 1975; 12. McClurkin et al. 1985; 13. Douglass and Goodwin, 1980; 14. Van Lear et al. 1985; 15. Fox et al. 1983; 16. Hewlett, 1979; 17. Askew and Williams, 1984; 18. Riekerk, 1985; 19. Rogerson, 1976; 20. Rogerson, 1985; 21. Miller, 1984; 22. Miller et al. 1985; 23. Lawson, 1985; 24. Douglass and Van Lear, 1983; 25. Beasley, 1979; 26. Blackburn et al. 1985.

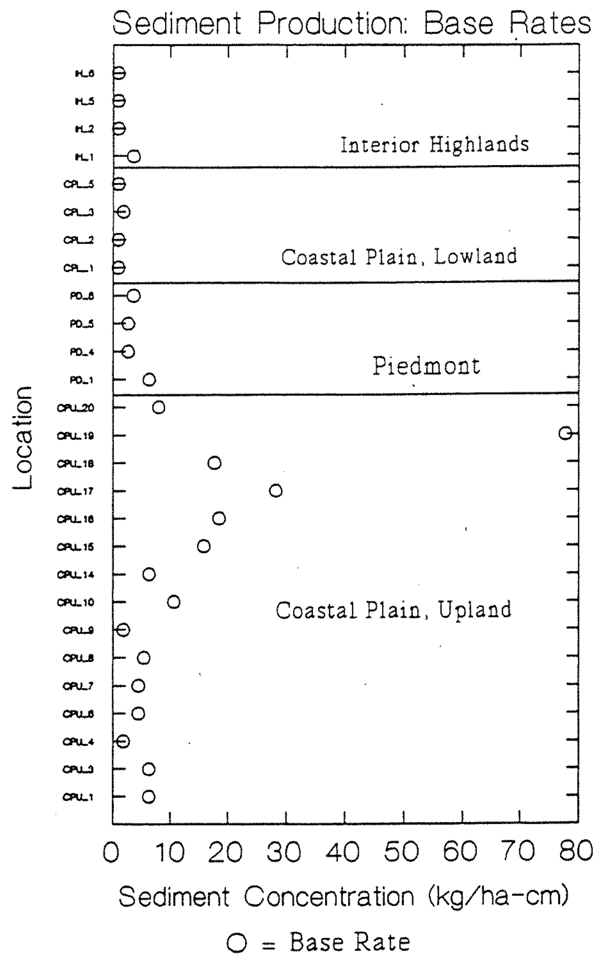

Figure 1.—Mean annual sediment concentrations from small, not recently disturbed forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions of the South. These values represent base rates (i.e., background levels) of sediment production.

tor of 10 or more. Such natural variation helps explain the poor correlation of sediment concentrations with stormflow volumes and should be considered in any monitoring effort.

Sediment concentrations from pine catchments are lower in channels that are more resistant to erosion. Measured over three to nine years, annual sediment concentrations for nine small (less than 6.1 ha) catchments in the Ouachita Mountains of eastern Oklahoma and western Arkansas averaged 0.9 kg/ha-cm (Miller, 1984; Miller et al. 1985; Rogerson, 1985; see Fig. 1).

Sediment production is typically greater from hardwood catchments. For example, sediment concentrations during nine years for three 1.6- to 2.4-ha catchments of hardwoods in the Ozark Plateau in Arkansas also averaged four times greater than pine types: 3.5 versus 0.9 kg/ha-cm (Fig. 1). Low stream gradients lessen the sediment concentrations for forests in the lower Coastal Plain wetlands; here the range is from 0.9 to 1.8 kg/ha-cm (Fig. 1).

Effects of Forestry Practices

Sediment yields can be increased by larger flow volumes, higher concentrations, or both. Forest practices that have been evaluated on small catchments in the South include

- prescribed burning;
- burning with chemical deadening;
- planting pine on abandoned fields;
- replacing low quality hardwoods with pine;
- mechanical site preparation (including shearing and piling, chopping, bedding, and tree crushing);
- strip-cutting with natural regeneration; and
- clear-cutting using skidders or Clearwater cable yarder.

Using herbicides to deaden the forest without removal increases the water available for streamflow and deep recharge but seldom affects sediment concentrations from forested slopes. Increases in sediment concentrations probably result from channel erosion, because overland flow seldom occurs without soil disturbance and rainfall energy is dissipated by the forest floor.

Pine cover types are often purposely burned to reduce competition from hardwoods and prepare the site for natural or artificial regeneration. Prescribed burns of 40-year-old pine plantations in the Piedmont did not significantly change sediment concentrations (Fig. 2). Concentrations after one and two burns averaged 3.5 and 1.8 kg/ha-cm, respectively (Douglass and Van Lear, 1983).

Intense, pre-planting burns of grass-herbaceous covers did not increase sediment concentrations in the Interior Highlands, but concen- trations in the Coastal Plain were significantly increased by reactivation of gullies and channels (Fig. 2). Burning poor quality hardwood catchments and deadening hardwoods also significantly increased sediment concentrations in the Coastal Plain; however, neither of these increases lasted for more than two years.

Harvesting, including clear-cutting, did not significantly increase sediment concentrations in the Interior Highlands (Fig. 3). Excluding roads, harvesting in the Piedmont and Coastal Plain caused small or insignificant increases in sediment concentrations of short duration. Annual concentrations ranged from 2.6 to 36.2 kg/ha-cm the first year. They were highest for eroded catchments, but all returned to the base level within three years.

Timber harvesting followed by mechanical site preparation methods can result in sediment concentrations that remain very high even after several years (Fig. 4). First-year concentrations in the Piedmont and Coastal Plain Uplands ranged from 2.6 kg/ha-cm in eastern Texas to as much as 285.9 kg/ha-cm for catchments with steep slopes (25 to 40 percent) or with histories of severe erosion. Although concentrations declined substantially after the first year, they remain well above base rates even after two or more years. This was particularly true for those practices that cause the largest initial increases. Increases in sediment concentrations were lowest in the Interior Highlands and Coastal Plain Lowlands where they did not exceed 12.4 kg/ha-cm during the first year after treatment.

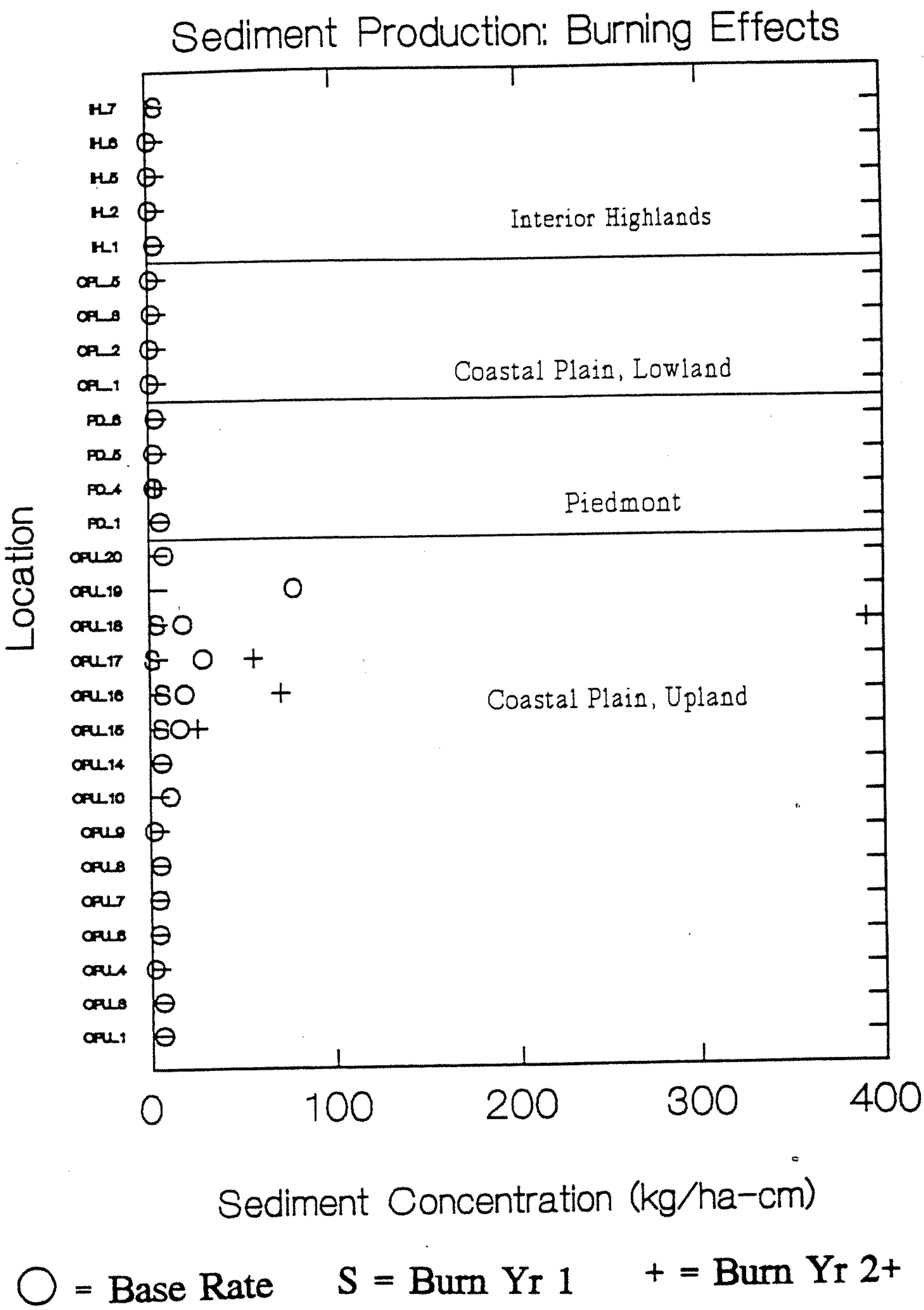

Figure 2.—Mean annual sediment concentrations from small forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions following prescribed burning. Values are given for the first year and the second or later year after burning. Base rates from the same or similar catchments are shown for comparison.

Sediment concentrations increase when forestry practices expose large portions of the soil. Rainfall energy impacting on bare soils causes overland flow that detaches, entrains, and delivers sediment to channels. Douglass and Goodwin (1980) concluded that the percent of ground cover was the most important factor affecting annual sediment concentrations. They found that sediment concentrations increase rapidly as cover drops below 40 percent.

Practices that greatly disturb soils are not suitable for Piedmont and Coastal Plain sites where slopes exceed 20 percent or for sites that have been severely eroded in the past. Cover crops can ameliorate the consequences of such treatments. Techniques that create detention-retention storage (such as roller-chopping) are desirable but may pose a substantial risk on steep slopes. Tree crushing left contour-oriented soil depressions of sufficient volume to store 1.91 cm of water and sediment in one north Mississippi plot study. The storage opportunity for some 36.7 tonnes/ha of sediment was almost fully used within two years and, although stormflow volumes increased, sediment concentrations were not greatly affected (Ursic, unpubl.). In

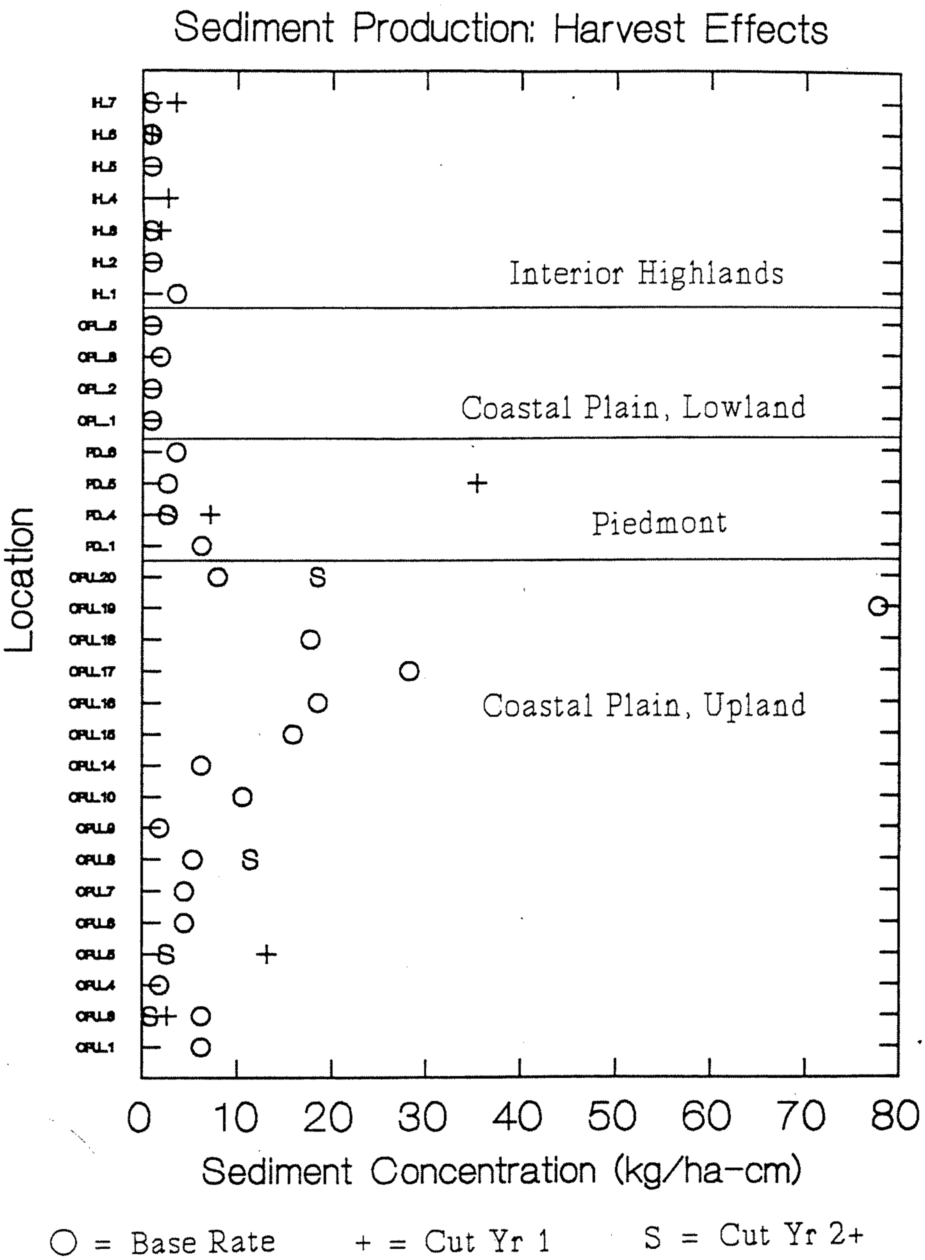

Figure 3.—Mean annual sediment concentrations from small forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions following timber harvesting. Values are given for the first year and the second or later year after harvesting. Base rates from the same or similar catchments are shown for comparison.

Oklahoma's Ouachita Mountains, tree crushing plus ripping soils on the contour increased water yields the second year but not the first, which reflects the initial storage opportunity (Miller, 1984).

Although effects of timber harvesting on sediment concentrations are often relatively minor, they can be greatly exacerbated by unusually high rainfall and flow volumes. Sediment concentrations during the first two years after harvesting mature shortleaf pine with the Clearwater yarder were respectively higher (64.1 and 162.9 kg/ha-cm) than those for the control (23.1 and 3.1 kg/ha-cm) and for a catchment logged with skidders (13.4 and 22.9 kg/ha-cm). Sediment yields were also highest (6,502 and 12,086 kg/ha) for the yarded catchment during the first two years. The higher values, especially for the yarded catchment, were primarily attributed to transport of sediment stored in the channel and erosion of subsurface flow paths. Because of 442 mm of rainfall the first month after harvest and 1,876 mm during the first year, these high values probably approximate maximum responses to clear-cut harvesting in the uplands of the southern Coastal Plain (Ursic, 1991).

Future Research Needs

The previously summarized research indicates that southern pine stands can be harvested and burned without substantial, long-term (great-er than three years) increases in sediment production (Fig. 5). In contrast, research also shows that persistent increases in sediment production can occur when intensive mechanical site preparation is employed. Current harvest practices that minimize ground disturbance and protect channel areas will probably not increase onsite sediment production. In fact, flow increases resulting from timber harvesting — not increases of sediment concentrations — may be more important in affecting downstream water quality.

Channels downstream of forested areas presently contain large in-channel sediment sources. These channels (typically aggraded, sand-bed channels that erode easily) are already moving large quantities of alluvium of anthropogenic origin. For example, the average annual sediment concentration from an 35.6-ha catchment of loblolly pine was 13 times higher than the 6.2 kg/ha-cm base rate for small headwater areas, primarily because of in-channel erosion (Ursic, 1975).

Increased stormflows from upstream harvested areas can aggravate erosion in first- and second-order streams where channels can erode at the rate of 3.0 ton/m of channel annually; 1.6 km of channel can contribute sediment loads equivalent to 13.4 ton/ha/yr (Murphey and Grissinger, 1985). In larger watersheds, channels increasingly become the main source of sediment. In a study of five mixed land use catchments that drain 457 to 9,227 ha, forests comprising 25 to 43 percent of the areas contributed less than 1 percent of the sediment. Gullies and channels that made up 2 percent of the catchments' area contributed over 50 percent of the sediment (Dendy et al. 1979).

Forestry practices that remove most of the biomass cause stormflow volume increases that can persist longer than the corresponding increases in sediment concentrations. Loblolly pine established on eroded, abandoned-field catchments in north Mississippi reduced annual stormflow volumes by about 50 percent after nine years; however, clear-cutting the pine at age 15 caused flow rates and volumes to revert to preplanting levels. Similarly, replacing depleted hardwoods with loblolly pine on less eroded catchments decreased annual stormflow volumes 83 percent after 12 to 13 years, but this reduction decreased to only 50 percent after clear-cutting at age 15 (Ursic, 1985).

In both cases, sediment concentrations decreased after planting pine, and these trends were interrupted only briefly by the second harvest. Therefore, even if sediment production is controlled during harvest and future onsite erosion reduced through pine planting, flow increases that result from timber harvest may still create higher sediment loads downstream. To assess downstream sediment risks, researchers need to better understand flow generation processes and how they are affected by forest management practices.

To better understand the effects of sediment production, researchers must also understand relationships between flow volume, sediment transport, and channel morphology. These relationships provide the key to how sediment production and transport affect downstream channel stability, aquatic habitat, and riparian resources.

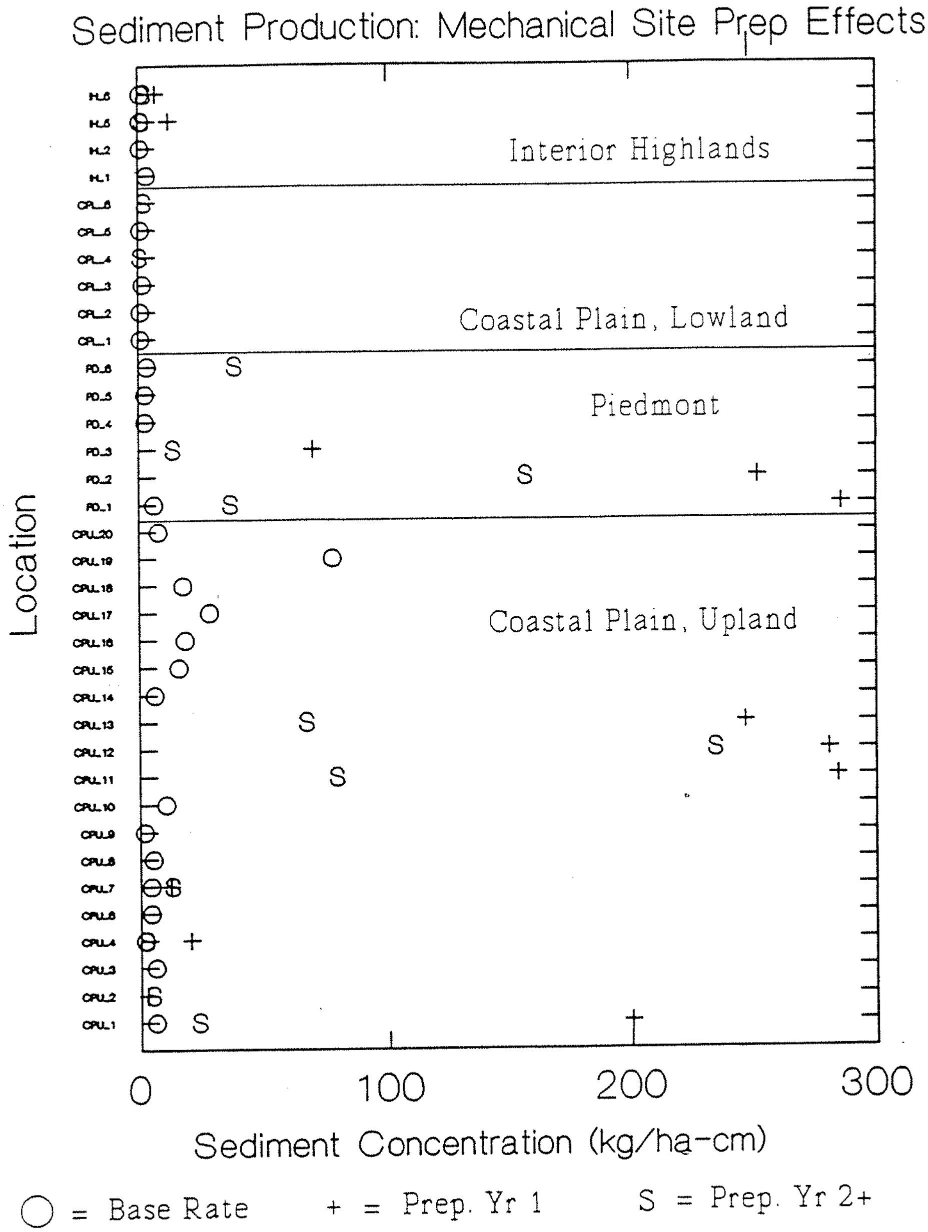

Figure 4.—Mean annual sediment concentrations from small forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions following mechanical site preparation. Values are given for the first year and second or later year after site preparation. Base rates from the same or similar catchments are shown for comparison.

Finally, researchers must improve their understanding of the cumulative effects of sediment production. It must be determined if and how knowledge gained from small catchment experiments can be applied to larger watersheds. The South's complex pattern of mixed land uses over small areas requires that many influences other than forestry be considered. Recent research indicates that small burrowing animals may have a strong affinity for pine forest types. The storage opportunity their burrows create increases with time and is believed to be an important factor in stormflow reductions (Ursic and Esher, 1988). Another area that requires more attention is the role road building and maintenance play in sediment production. Researchers currently possess great knowledge about the pieces, but they lack an effective understanding of the whole.

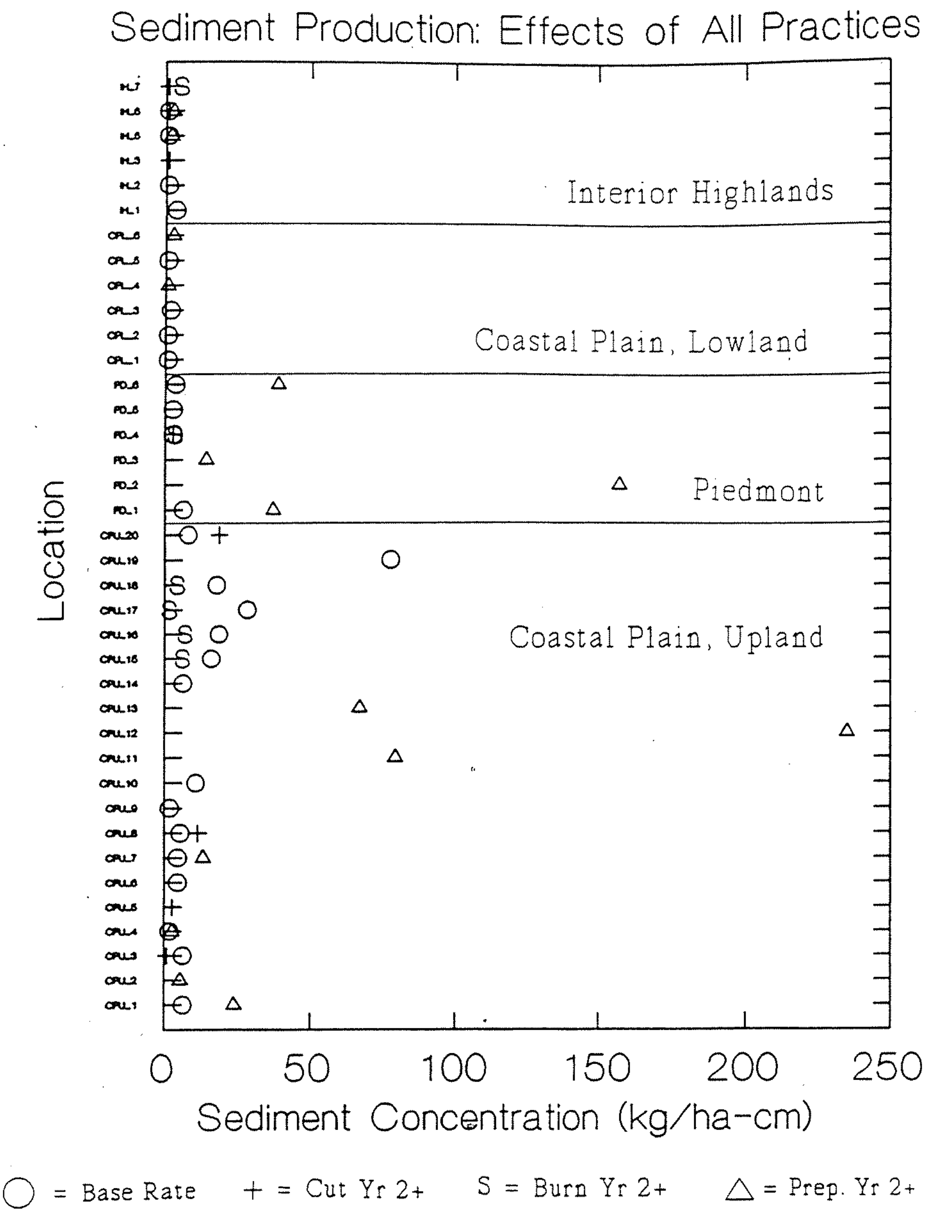

Figure 5.—Comparison of mean annual sediment concentrations resulting after two or more years from burning, timber harvesting, and mechanical site preparation to base rates from the same or similar catchments. Values were determined from small forest catchments in the Coastal Plain, Piedmont, and Interior Highlands physiographic regions.

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