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Erosion on Very Stony Forest Soil During Phenomenal Rain in Webster County, West Virginia

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Abstract

On July 15 and 16, 1979, at least 6 inches of rain fell in central West Virginia during 3 hours, a storm of return period longer than 1,000 years. More than 6 miles of logging roads were examined for evidences of soil erosion and sediment delivery to streams. Erosion was negligible on very stony soils where (a) logging roads were litter covered, (b) road grades were less than 15 percent, and (c) volumes of overland flow on logging roads had been small. Severest erosion ranged from 0.6 to 0.8 ton of soil and rock per foot of logging road. Average rate of erosion (from logging roads only) was about 5 tons per acre of loggedover land; higher rates seem possible only after greater soil exposure or in the unlikely event of harder rain. About two-thirds of the detritus from the most severely eroded road was believed to reach a nearby river and contribute to its sediment load, but only about one-third of the detritus reached the river where roads eroded less severely. Formation of an erosion pavement on most of the roads prevented greater soil loss, and it will minimize future erosion. The evidence suggests that more attention to the proper location and management of logging roads could have held erosion on very stony soils to little in excess of geologic rates.

Introduction

Foresters point with pride to forest streams as sources of the cleanest (i.e., highest quality) surface water available. Their cleanness maximizes the usefulness of forest streams, prized water fit to meet most human needs. But all streams, even those originating on pristine forests, carry a little sediment between storms that lessens their cleanness. Streams can become turbid with larger amounts during storms, and heavily laden with sediment during infrequent large storms. Human activities in forests sometimes accentuate this problem, especially where logging roads are involved (Packer 1967). The problem of stream sedimentation is widely perceived as a major environmental issue of our time.

The complexity of stream sedimentation is seldom recognized. Sediment is an input of geologic erosion, the continual but gradual wearing down of the land surface that—even under eons of forest cover—has shaped the existing landscape. Wood products harvest and associated activities often accelerate soil erosion on forest land, adding sediment to streams at rates in excess of geologic erosion. Carelessly managed logging roads can become sites of rapidly accelerated erosion, adding sediment at rates far exceeding those of geologic erosion.

Additives to water perceived as detrimental to human uses, or as harmful to natural systems, are regarded as pollutants. Sediment is generally accepted as the major pollutant of forest streams (EPA 1975). It is the combined product of geologic and man-caused or accelerated erosion. Sediment sources and pathways to forest streams are shown in Figure 1.

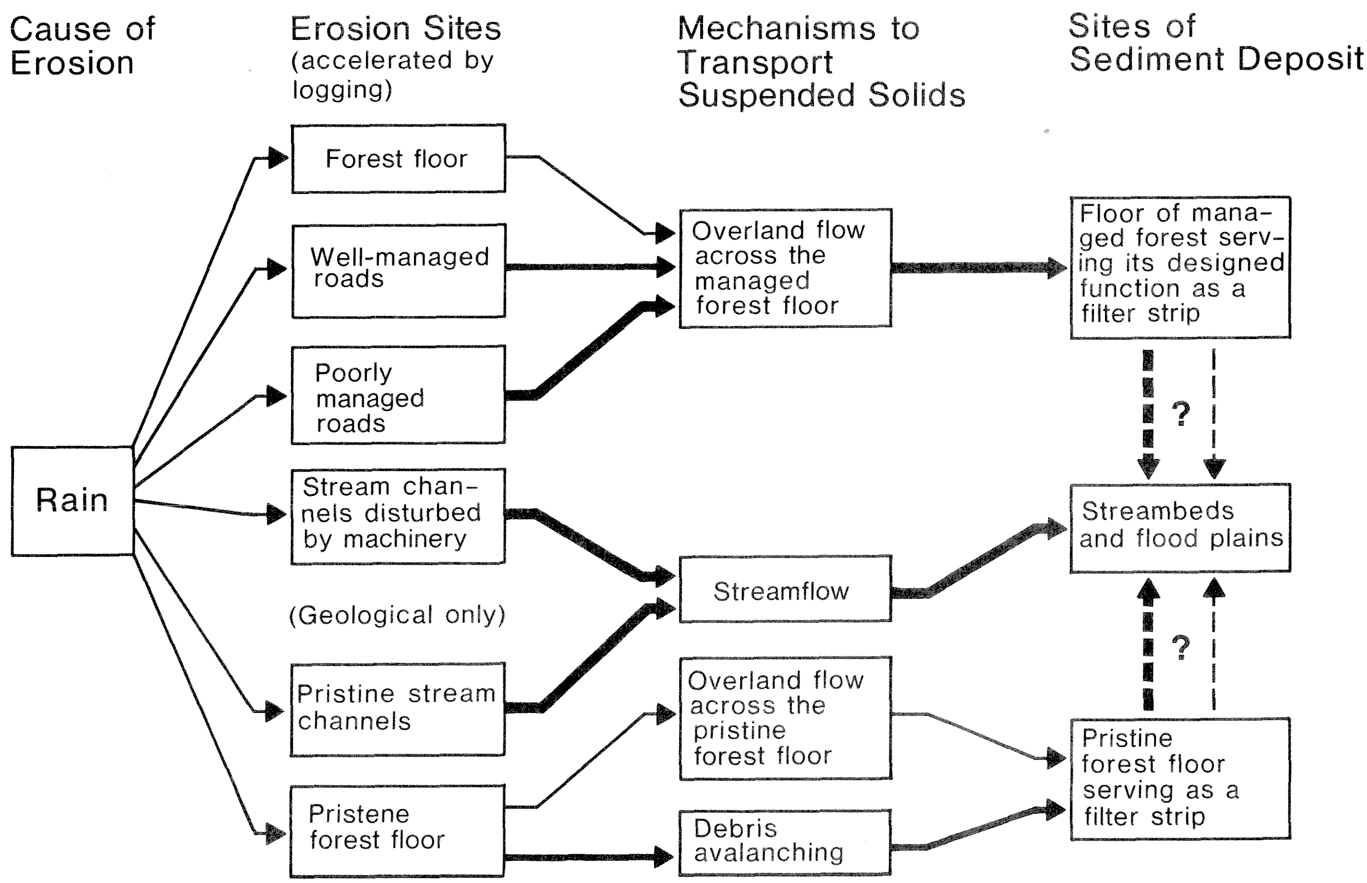

Figure 1.—A model of soil erosion and stream sedimentation for the eastern forest. Arrow widths imply relative importance, broken arrows, the possibility of variable efficiency.

The process of soil erosion differs from, though is related to, sediment deposition. Soils erode when particles are detached and removed from their place of origin by flowing water. Sediment deposition occurs when eroded soil particles fall out of flowing water at other than their original place—elsewhere on the forest floor, on stream banks, or in stream channels. From as little as 5 percent to nearly 100 percent of the eroded soil may be delivered to a downstream point (Gottschalk 1964); the amount deposited is determined largely by the efficiency of the forest floor as a filter strip. But during rare phenomenal storms, huge amounts of sediment can be swept into streams, even from heavily forested land (Williams and Guy 1973).

Some mechanism, often overland flow, is a prerequisite to erosion of the forest floor and to sedimentation of forest streams from that source. Indeed, it is the virtual absence of overland flow across the undisturbed forest floor (Hewlett and Hibbert 1967) that holds geologic erosion near characteristically low levels in the eastern forest. Nevertheless, overland flow across the forest floor does occur, especially during exceptionally heavy rains (Woodruff 1971). It is generally accepted that soil erosion at minimal rates holds sediment content lower than 0.1 ton per acre per year in streams draining the relatively undisturbed eastern forest (Patric 1976).

Erosion can become frequent and voluminous when rain of even ordinary intensity falls on soil bared by logging roads, defined by Packer (1967) as the major source of sediment in forest streams. Tree cutting (NEFES 1975) and logging by recommended methods (Hewlett 1978; Kochenderfer and Wendel 1980; Patric 1980) increases sediment production only negligibly. It is erosion on carelessly built logging roads, when wood products are harvested without regard to effects on soil and water, that most often increases sediment to troublesome levels in streams draining forested land.

There are no published accounts of soil erosion on logging roads during exceptionally severe storms or of the sediment loading caused by them. So great are the amounts of eroded soil that measurement systems are overwhelmed.

The objective of our study was to describe what happened to forest soil and water after exceptionally severe rain fell on typical forest land in central West Virginia.

The Study Site

Webster County is near the center of West Virginia; it is a mountainous, densely wooded area with a sparse population heavily dependent on the harvest of wood products for income. Most of the soils, derived from horizontally bedded sandstones and shales, tend to be shallow, coarse textured, and very stony, and thus relatively resistant to erosion. Colluvial soils are common on hillside benches and at the bases of slopes. Rainfall averages about 50 inches annually, with little seasonal variation. Winter rains tend to be gentle and prolonged, but summer rains, often convectional thunderstorms, tend to be brief and violent. The 3-hour, 100-year rainfall for West Virginia is 3.5 to 4.0 inches (Hershfield 1961).

A severe flash flood occurred in northern Webster County during the night of July 15 and 16, 1979. On the evening of July 15, a line of thunderstorms along the central Appalachians extended from Wheeling, West Virginia, to Roanoke, Virginia. Around midnight, a number of cells within this line produced heavy rain which extended into the morning of July 16 (personal communication, National Oceanic and Atmospheric Administration (NOAA), Elkins, West Virginia). The NOAA maintains a standard rain gauge near the post office at Hacker Valley, in Webster County. Its 24-hour (8 a.m. 7/15 to 8 a.m. 7/16) catch was 5.68 inches. The postmistress believed that most of the rain fell between midnight and 4 a.m.

The NOAA gauge is located near the northern edge of flash flooding, where rainfall presumably was less heavy than at the storm center. About 2 miles south of the post office, a farmer noted a 15-inch bucket more than half full (presumably 8 or more inches) after the storm. He recalled that the rain was heaviest from midnight to 3 a.m. Flash flooding was severe in this vicinity. About 4 miles south of the severely flooded area, a catch of 4.19 inches was reported in a plastic wedge gage. A storekeeper at Diana did not know how much rain fell but recalled that the heaviest rain fell between 11 p.m. and 2 a.m. We assume that 6 or more inches of rain fell within 3 hours on the most severely impacted area, a storm of return period greater than 1,000 years (Bernard 1932).

Forested land subject to this phenomenal storm was examined during several subsequent weeks. The examining group always included a woodland conservationist (USDA Soil Conservation Service), a forester (Extension Service, West Virginia University), and a forest hydrologist (USDA Forest Service). Logging roads were mapped by use of aerial photographs and a plane table. Slopes were measured with an abney level, distances by pacing. Estimates of soil loss were based on cross sections at 50- to 150-foot intervals along eroded logging roads. Longitudinal concavities on the logging roads were interpreted as evidence of soil erosion, even though some surely resulted from machinery displacement and log skidding. Erosion was deemed insignificant where (1) machinery tracks were visible on recently used logging roads, and (2) unused roads were covered with litter after the storm.

Results

In general, erosion was negligible on unroaded parts of the litter-covered forest floor, as observed after flash flooding in other sections of West Virginia (Patric 1981). Evidences of overland flow were apparent on 10 to 50 percent of the forest floor and most extensive on shallowest soil. Overland flow removed or rearranged the litter but it never cut through the fibrous H and F layers beneath the litter to expose the underlying mineral soil. Deeply rutted, insloped, or entrenched logging roads often intercepted the overland flow, conducting it downslope to reaches of road which, if excessively long or steep, became the sites of severest erosion.

At least a dozen small debris avalanches were found on the fraction of the flash-flooded area examined. All were on slopes steeper than 50 percent, originating as oval-shaped slip-outs about 2 feet deep and perhaps 20 to 30 feet across. Two were in pasture, one in a white pine plantation, and the balance in hardwood forest. Debris slid as a block from most of the slip-outs, moving downslope from a few to many feet (Fig. 2). Debris from others must have moved downslope as a viscous mass to the nearest waterway, leaving little evidence of passage over the forest floor except a coating of mud and a speckling of small, flat stones. The debris avalanches are regarded as a form of geologic erosion because their occurrence seemed unrelated to tree cutting, logging roads, or other human activity.

Logging Roads on the Cecil Cogar Property

The Cecil Cogar property, near Hacker Valley, had been logged to a 12-inch diameter limit in 1966. Logging and road layout were supervised by foresters with the West Virginia Department of Natural Resources. Crawler tractors had yarded logs to contour roads, then skidded along them to the main

Figure 2.—This small debris avalanche originated where the man is standing, then came to rest as a block about 150 feet downslope.

haulroad, and down it to the landing near Replete Road (Fig. 3). The Holly River flows immediately east of Replete Road. There had been no attempt to control postlogging erosion on the less steep spur (contour) roads. On the steep and heavily used main haulroad, soil erosion before the storm of July 15 and 16 had been controlled by a series of log water bars installed soon after logging was finished.

Soils are of the Dekalb series; they are well drained, coarse textured, very stony, steep (30 to 70 percent), and shallow (30 inches) to bedrock. Most of the main haulroad paralleled an ephemeral stream on imperfectly drained and very stony colluvium—Ernest soil where a fragipan is present, Buchanan where it is absent. The hardwood forest is 2-storied, with a nearly complete canopy of 8- to 24-inch oak and maple overtopping a dense understory dating from the 1966 logging. Small, flat plates of sandstone are abundant on the forest floor and the litter is from 1/2 to 2 inches deep.

Only 114 acres of this property were logged; the remaining 18 acres were in fields. There were 19,345 feet (3.68 miles) of bulldozed logging roads, with each mile of road serving 31 acres of loggedover land. The road density was comparable to that for logging reported elsewhere in West Virginia (Kochenderfer 1977). The main haulroad (Fig. 3) was 2,840 feet (0.54 mile) long. Over 80 percent (16,155 feet or 3.06 miles) of the road network was fully covered with litter and revegetating to trees. Grades of all logging roads on this property were classified as:

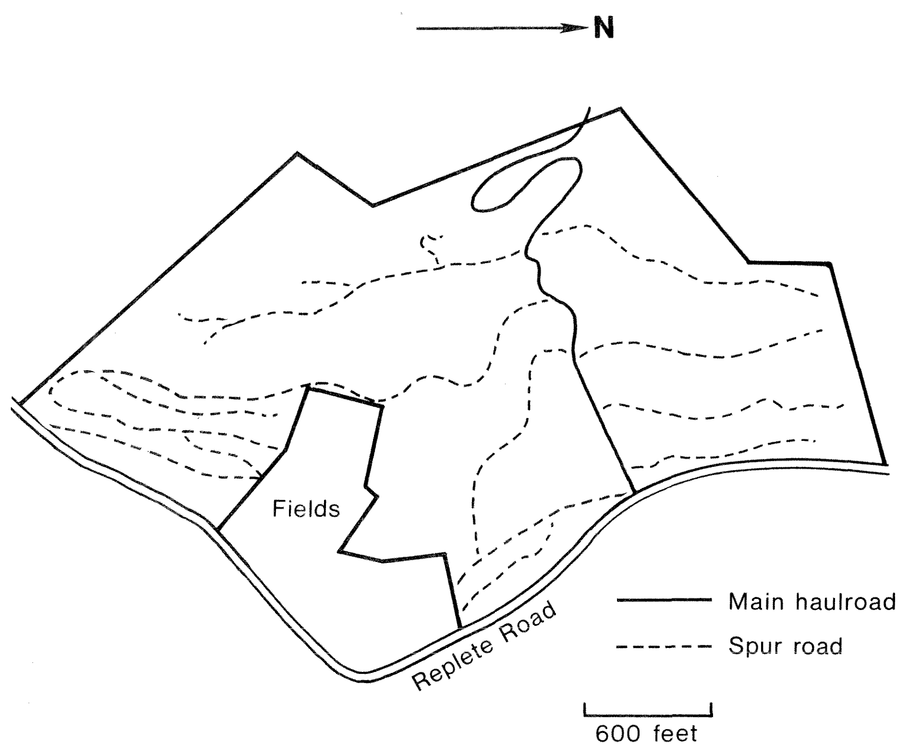

Figure 3.—Logging roads on the Cogar property.

0-9 percent	*10-19 percent*	*20-29 percent*	*30 percent or more*
13,180 feet or 68 percent	1,700 feet or 9 percent	2,510 feet or 13 percent	2,045 feet or 10 percent

Figure 4.—This logging road, on an 8 percent grade, showed no sign of erosion after the storm of July 15 and 16.

There was no evidence of accelerated soil erosion except on the tread (traveled) portion of the steepest logging roads. Tread width seldom exceeded 8 feet. Assuming that all longitudinal depressions in the road tread resulted from erosion, roads sloping 10 to 29 percent eroded up to 6 inches, and roads sloping over 30 percent usually eroded deeper than 6 inches. Gently sloping (0 to 9 percent) roads always were covered completely with litter (Fig. 4); steeply sloping (>30 percent) roads had little or no litter cover. The cover ranged from complete to absent between these extremes of slope.

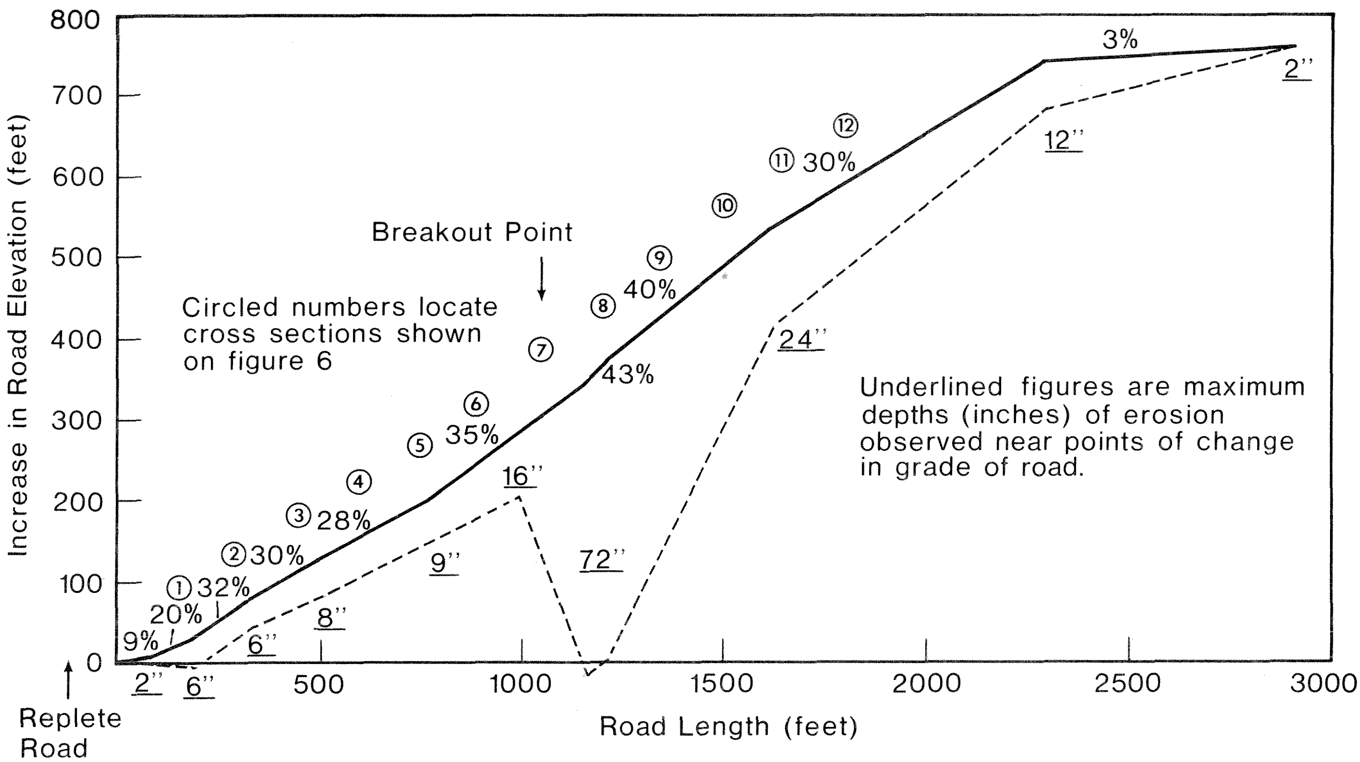

Figure 5.—A profile of the main haulroad on the Cogar property.

The steepest reach of the main haulroad was the only site of severely accelerated soil erosion. A profile (Fig. 5) and 12 cross sections along its worst eroded reach (Fig. 6) provided an estimate of soil loss. Data from these figures overestimated erosion, presuming that all soil loss occurred during the storm of July 15; some soil, of course, had been lost since 1966.

1. Approximately 11,000 cubic feet (407 cubic yards) of soil and rock eroded from the main haulroad.

2. At 2,800 pounds per cubic yard of very stony soil (personal communication, Fairfax Sand and Crushed Stone Company), the loss was 570 tons.

3. Average erosion loss per foot of main haulroad was 0.2 ton of soil and rock.

4. The maximum loss was 0.6 cubic yard (0.8 ton) per haulroad.

5. Average erosion rate was 5.0 tons per acre when soil loss from the main haulroad was distributed across all of the loggedover land.

On-site observation established some reasons for erosion of this severity:

- The main haulroad included a segment more than 1/2 mile long, ranging in grade from 28 to 43 percent.
- Most of the main haulroad was entrenched before the storm; hence, overland as well as subsurface flows were intercepted by the road, contained within it, and unable to escape from it.
- Relatively deep colluvium underlying the main haulroad probably eroded more easily than the Dekalb soil underlying most of the spur roads.
- The wooden water bars, adequate to divert overland flow from the main haulroad during rains of commonly experienced intensity, were overtopped and swept away by the far greater and swifter flows resulting from the storm of July 15 and 16.

Stormflow broke out from the main haulroad where its slope moderated from 43 to 35 percent (Fig. 5). The stormflow had slowed and deepened here, dropping its heavier debris. In effect, overland flow was dammed within the entrenched road, causing storm waters to break

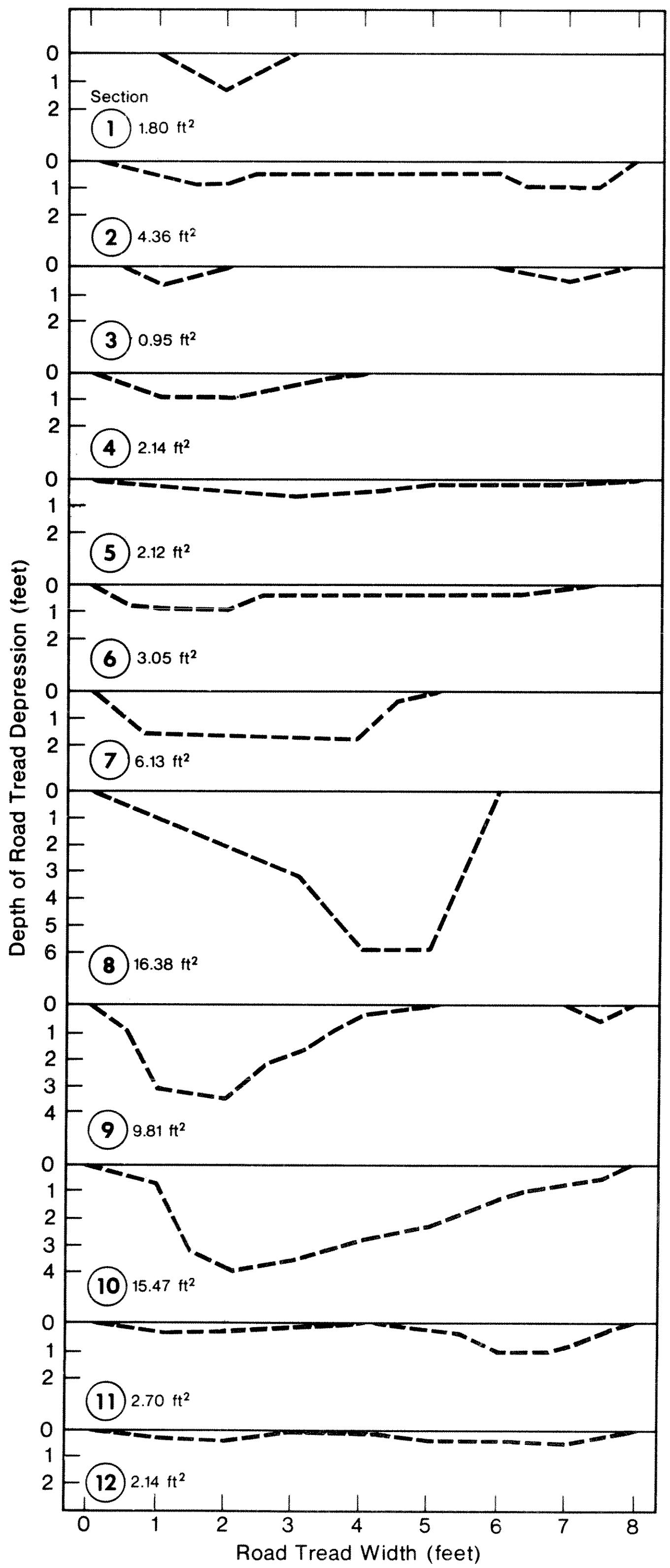

Figure 6.—Cross sections along severely eroded reaches of the main haulroad, Cogar property.

out at that point, about 1,200 feet upslope from Holly River. Tons of rock were dumped along the 60 percent slope immediately below the breakout point (Fig. 7) though the stormflow also swept away some litter, soil, and small stones from that slope. The net effect, in terms of eroded material actually reaching the Holly River, can only be guessed. But even on so steep a slope, a considerable volume of soil and rock was deposited before it reached the river. This is, of course, the function of a filter strip, but the volume of stormflow vastly exceeded any absorptive capacity of the forest floor, largely nullifying much of its filter-strip function. We estimate that about one-third of the eroded material was deposited between the breakout point and the stream, and that the remainder (380 tons) was swept into the Holly River.

Figure 7.—Tons of rock and soil were trapped below the breakout point. Overland flow also swept large amounts of litter and soil from inundated parts of this slope.

Logging Roads on the Marion Bruffy Property

Timber on this 60-acre property near Diana was marked for selection harvest by a forester with the West Virginia Department of Natural Resources and logged during the spring of 1979. The road system (Fig. 8) was designed for wheeled-skidder logging, though several "shortcuts" were installed as the logger felt the need for them. After harvest, a few water bars were installed to control soil erosion, mostly on the shortcuts. Many spur roads were left choked with logging debris, another effective measure to control erosion. At Mr. Bruffy's request, no erosion control was attempted on the main haulroad or on that spur road closest to Holly River; both were left unobstructed to facilitate the collection of firewood. The landing, within the high-water channel of Holly River, was unvegetated sand and rounded river rock.

Forest soils are of the Gilpin series; well drained, very stony, and steep (30 to 70 percent) but finer textured, more friable, and deeper (more than 30 inches to bedrock) than Dekalb soils. A fine stand of hardwoods had covered the predominantly north-facing slopes, where litter was 1/2 to 2 inches deep. Timber cutting ranged from single-tree to large group selection, with harvest completed early in July 1979. After the storm of July 15 and 16, evidences of overland flow were observed on perhaps 10 percent of the forest floor. The ephemeral hillside channels had not scoured severely and only one debris avalanche was found on this property.

Total length of logging roads was 11,885 feet or 2.25 miles. Thus, 1 mile of road served 26.7 acres, a lesser density of wheeled-skidder roads than reported by Kochenderfer (1977) at other sites in West Virginia. The main haulroad was 4,475 feet (0.85 mile), the total length of spur roads was 7,140 feet (1.40 miles). Grades of the logging roads were classified as:

0-9 percent	*10-19 percent*	*20-29 percent*	*30 percent or more*
4,205 feet or 35 percent	3,070 feet or 26 percent	3,105 feet or 26 percent	1,505 feet or 13 percent

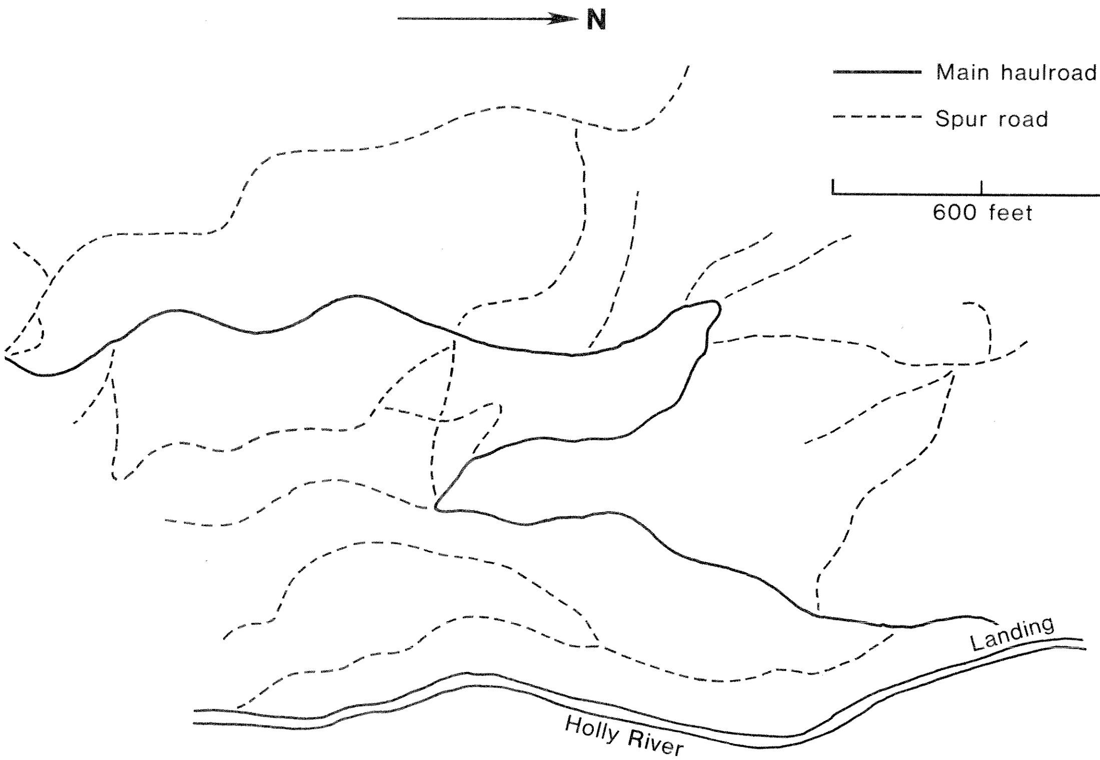

Figure 8.—Logging roads on the Bruffy property.

Figure 9.—This road suffered little or no erosion even though it was insloped and on a 15 percent grade.

There was neither living vegetation nor litter to protect these logging roads from erosion during the storm of July 15 and 16. Typically, the wheeled skidders had left most of the roads insloped (Fig. 9), providing much opportunity to channel overland flow along the unprotected road surfaces, and infrequent opportunities for water to spill over in small quantities to the litter-covered forest floor downslope from roads. None of these roads had been gullied deeply (Fig. 10) and most of them had well-defined erosion pavements. Part of this natural protection from erosion probably had developed during the persistent rain that fell throughout the logging period. Cross sections were made at 50 to 100-foot intervals along those roads (5,379 feet or 1.02 miles) where tracks of logging machinery had been obliterated by erosion. The following estimates too, probably inflate erosion so computed because some longitudinal depressions on road surfaces resulted from logging, not erosion.

1. About 8,240 cubic feet (305 cubic yards) of soil and small stones were lost from the cross-sectioned roads.

2. At 2,200 pounds per cubic yard of relatively stone-free soil (personal communication, Fairfax Sand and Crushed Stone Company), this loss totalled 336 tons.

3. Average soil loss was 0.1 ton per foot of eroded logging road.

4. The maximum loss was 0.5 cubic yard (0.6 ton) per foot of main haulroad.

5. Average erosion rate was 5.1 tons per acre when soil loss from the cross-sectioned roads was distributed across all of the loggedover land.

How much of this eroded soil actually reached the Holly River? Wherever overland flow had spilled across the shoulder of a logging road, we traced its course downslope, pacing to a point where sediment could not be discerned on the forest floor. Presumably, overland flow had infiltrated when it reached that point. By far the majority of sediment had been deposited within 200 feet of the logging road from which it originated (Fig. 11). The freshness of the evidence gave us considerable confidence in the validity of the following estimates:

Figure 10.—The most severely eroded segment of the main haulroad, Bruffy property.

•Thirty-nine tons of soil eroded from the most southerly segment (650 feet; grade: 9 to 20 percent) of the spur road parallel to Holly River. We believe that only sand-size and smaller particles (about two-thirds of the eroded soil volume or 26 tons) reached the river.

•One hundred sixteen tons of soil eroded from that portion of the main haulroad (650 feet; grade: 21 to 27 percent) extending upslope from the landing. Here, too, the evidence suggests that only sand-size or smaller particles (about two-thirds or 78 tons) contributed to sediment loading in Holly River.

•Far smaller proportions of eroded soil reached Holly River from other (not cross sectioned) segments of logging roads (Fig. 11). Most of these were distant enough from the river to allow effective functioning of the forest floor as a filter strip.

•The entire channel of Holly River, including the log landing, was covered by several feet of fast-moving flood water. The landing was obliterated by erosion and deposition. We believe that sediment loading contributed by the landing was little more or less than that along the entire channel of Holly River.

Discussion

Were the preceding observations typical of erosion on logged-over land elsewhere in the flash-flooded area? We believe they were. No vegetated or litter-covered road eroded perceptibly on other logged land. Erosion was negligible wherever postlogging measures had been applied to control it. For example, one recently used logging road extended several hundred feet straight up a 38 percent slope; four small water bars prevented severe erosion on the shorter road segments between them. A 52 percent skid trail, protected only by its short length (190 feet), had eroded only negligibly. On the other hand, most of the long, steep, and entrenched roads were deeply eroded, some of them to bedrock. Thus, more than bareness and steepness seem a prerequisite for severe erosion when logging roads are built on very stony soils; they must also extend for long distances up steep slopes with no breaks in grade. On the ba-

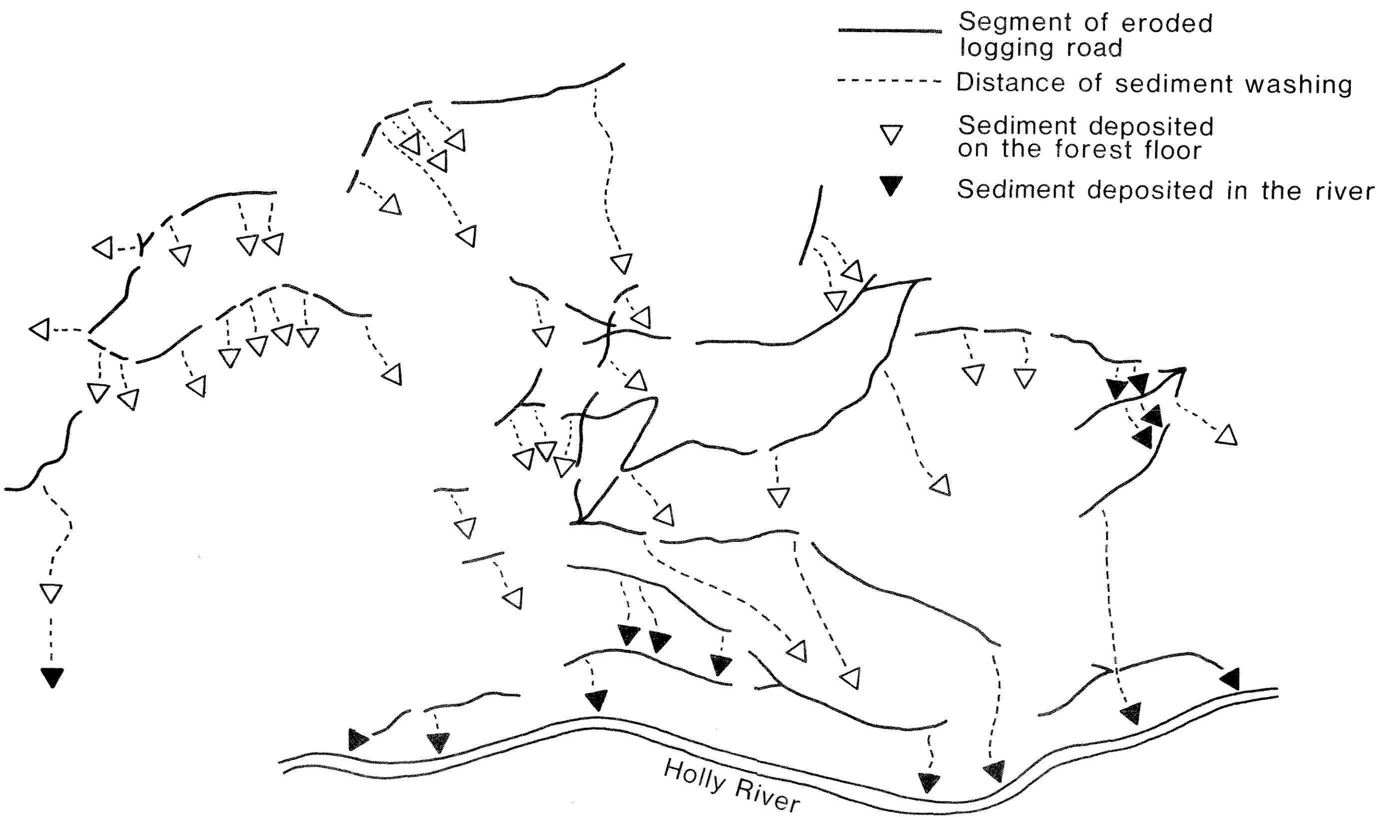

Figure 11.—Origin, movement, and deposition of sediment from logging roads on the Bruffy property.

sis of these and similar ancillary observations, our results do seem typical of loggedover land throughout the flash-flooded area.

Our results may not pertain to less stony soils. Erosion is a selective process, removing loose and finer textured materials first, leaving in place a residual surface of relatively immovable stones, gravel, and organic detritus. This is erosion pavement, a highly effective means of minimizing erosion on stony soils in agriculture (Grant and Struchtemeyer 1959; Epstein et al. 1966) as well as in forestry. Roads on finer textured, less stony soils contain less materials to form erosion pavement, so they erode more severely. Data on the more erosive soils are needed for a broader perspective on the sediment production from logging roads and on methods to prevent it.

Erosion pavements formed during rain of very high intensity will protect road surfaces from substantial soil loss during subsequent rains of lesser intensity. After the finer materials are removed, the remaining materials are too large to dislodge and move during ordinary rains. Thus, we foresee little or no further erosion on logging roads subject to the storm of July 15 and 16. The underlying soil particles are shielded beneath relatively immovable fragments of stone and organic detritus, so there will be little opportunity for detachment and transport. For this reason alone, excluding traffic is an important erosion control measure on unused logging roads. Just one trip by the spinning, churning wheels of a vehicle disrupts the erosion pavement and restarts the erosion process.

Our study and others show that simple and conventional practices provide adequate erosion control for most logging roads. Much erosion can be prevented merely by avoiding long, steep grades when building roads, and by installing a few water bars when closing them. Other recommended measures (e.g. gravel, ditching, culverts) are as pertinent to keeping logging roads passable in all weather as to controlling erosion on them, though this dual purpose takes nothing from their potential to reduce soil loss.

Well-designed filter strips can hold onslope much of the soil eroded from logging roads, and the strips need not be prohibitively wide. Figure 11 suggests that a 200-foot-wide strip—supplemented with judicious water barring—would have retained onslope nearly all soil eroded from logging roads during the storm of July 15 and 16. A strip about one-third as wide as judged adequate for less violent storms in the mountains of Europe (Kazankin 1976) and of Southeastern United States (Hewlett et al. 1979). Even the often cited formula by Trimble and Sartz (1957) seems unnecessarily complex for spacing water bars when mere prohibition of road building and use of logging machinery within 100 feet of a stream will keep most sediment out of streams during ordinary rains (Patric 1980). There are places, of course, where roads and logs must cross streams, but here, culverts and bridges are needed and another set of rules applies.

Perhaps no measure to decrease sediment has been more widely promulgated or more generally ignored than avoidance of stream channels during logging. The need to avoid them, clearly demonstrated by Reinhart et al. (1963), is still recommended (Lynch et al. 1979) and still ignored—with predictable consequences (Hewlett 1978). Despite widespread knowledge of the consequences, stream channels continue to tempt many forest users as the easiest and most direct access to forest land.

Soil loss from the forest floor is trivial during ordinary rain. But major soil loss by debris avalanching can become common, even on undisturbed forest land, when rain exceeds 5 inches per day (Eschner and Patric 1982). The erosional significance of debris avalanches was disregarded in this study but their presence was noted with interest as on-the-ground evidence of phenomenal rain at points distant from gages or other means to accurately quantify amounts of rainfall.

We submit that erosion on the order of 5 to 10 tons per acre from very stony forested land should be interpreted as a "ceiling," an upper limit of loss likely to be exceeded only during exceptional combinations of storm violence and soil exposure. Barring these or similar erosion-conducive conditions, some healthy skepticism seems warranted when proposed annual losses from stony forest soils substantially exceed 5 tons per acre. This "ceiling" presumes erosion on loggedover forest land to result from two indistinguishable sources: (a) some of geologic or natural origin, and (b) some of accelerated or man-caused origin. Because both forms of erosion occur concurrently, there is no way to distinguish sediment resulting from either form.

Conclusion

Soil erosion and stream sedimentation somewhat in excess of geologic rates can accompany the harvest of wood products on the very stony mountain soils of West Virginia—even during phenomenal storms—when temporary access routes are managed by these guidelines: (1) keep machinery out of stream channels, (2) avoid long, steep, unbroken grades on roads, (3) provide an adequate filter strip downslope from each road.

Acknowledgement

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- **Berea, Kentucky, in cooperation with Berea College.**
- **Burlington, Vermont, in cooperation with the University of Vermont.**
- **Delaware, Ohio.**
- **Durham, New Hampshire, in cooperation with the University of New Hampshire.**
- **Hamden, Connecticut, in cooperation with Yale University.**
- **Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.**
- **Orono, Maine, in cooperation with the University of Maine, Orono.**
- **Parsons, West Virginia.**
- **Princeton, West Virginia.**
- **Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.**
- **University Park, Pennsylvania, in cooperation with the Pennsylvania State University.**
- **Warren, Pennsylvania.**

Patric, J. H.; Kidd, Jr., W. E. Erosion on very stony forest soil during phenomenal rain in Webster County, West Virginia. Broomall, PA: Northeast. For. Exp. Stn.; 1982; USDA For. Serv. Res. Pap. NE-501. 13 p.

On July 15 and 16, 1979, at least 6 inches of rain fell in central West Virginia during 3 hours, a storm of return period longer than 1,000 years. More than 6 miles of logging roads were examined for evidence of soil erosion and sediment delivery to streams.

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