SEDIMENT YIELD AS A FUNCTION OF LAND USE IN CENTRAL APPALACHIAN FORESTS[1/]

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Abstract.--Total sediment yield was measured for up to 6 years from 3 forested watersheds with different land use histories. Average annual sediment yield was 31 lb/acre from a 96-acre watershed that had not been logged for 80 years; 166 lb/acre from a 94.4-acre watershed that was partially logged in 1977; and 253 lb/acre from a 28.6-acre watershed that was farmed for many years and then allowed to revegetate naturally during the past 50 years. Sediment deposits in a 2.6-acre reservoir at the mouth of an intensively managed 1,600 acre forested drainage averaged 463 lb/acre/yr over an 18-year period. A comparison of suspended sediment (mg/l) and turbidity in nephelometric turbidity units (NTU) based on more than 500 samples from each of 2 watersheds showed excellent correlation.

Keywords: sediment yield, forested watersheds, land use, erosion, turbidity, Appalachian Mountains

INTRODUCTION

The 1972 Federal Water Pollution Control Act Amendments (P.L. 92-500) emphasized the importance of nonpoint sources of pollution that enter streams. Sediment generally is recognized as the most serious stream pollutant that is caused by forest practices. Activities that remove protective soil cover and expose bare soil can cause substantial increases in sediment export if recommended practices are not followed. For example, improper road location and indiscriminate logging in the riparian zone of a Piedmont watershed increased total sediment export by 80% (Hewlett 1979). But when roads are located properly and care is used in harvesting, there is little increase in sediment export (Kochenderfer et al. 1980; Patric 1980).

In carefully managed and undisturbed watersheds, most sediment results from erosion of stream channels. Overland flow, which is necessary for erosion on slopes, is extremely rare in the undisturbed forest. The stability of stream channels and banks varies widely even among undisturbed watersheds because of differences in channel steepness, rock abundance, and stream sinuosity. Sediment contributions from forestry activities must be evaluated apart from these highly variable and unpredictable channel contributions (Ursic et al. 1978). To evaluate sediment levels associated with different forestry practices in the central Appalachians, more information is needed on baseline levels of sediment production from forested watersheds.

The objectives of this research were to (1) quantify sediment production from 3 forested watersheds in the central Appalachians which have not been recently disturbed, and (2) compare these results with estimated sediment export from a 1,600-acre municipal watershed that is under intensive multiple use management.

STUDY AREA AND METHODS

The watersheds are located within a 10 mile radius of Parsons, West Virginia, in the unglaciated Allegheny Plateau region of north-central

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West Virginia, a section of the Allegheny mountains with steep slopes and narrow valleys. Annual precipitation is similar on all the watersheds and is about evenly distributed between dormant and growing seasons, averaging 57 inches during the study period. Annual runoff from the Fernow Watershed during the study period ranged from 25 to 34 inches, averaging 30 inches, 10 inches during the growing season and 20 inches during the dormant season. Some pertinent watershed characteristics are listed in table 1.

Table 1. Some characteristics of the study watersheds.

Watershed name	Total area	Channel area	Road area	Source area[1/]	Stream gradient
	acres (percent)				
Fernow	96.0	0.41(0.4)	0.75(0.8)	1.16(1.2)	(9.0)
Clover	28.6	0.06(0.2)	0.00	0.06(0.2)	(10.0)
Haddix	94.4	0.81(0.9)	2.55(2.7)	3.36(3.6)	(10.0)
Elk Lick	1600.0	7.17(0.4)	14.54(0.9)	21.71(1.4)	(9.0)

[1/] Defined as channel area + road area.

The Fernow watershed has not been disturbed since the original timber was removed between 1905 and 1910, except for a road constructed adjacent to its upper boundary in the 1930's. Common tree species are yellow-poplar (Liriodendron tulipifera L.), sugar maple (Acer saccharum Marsh.), and northern red oak (Quercus rubra L.). The predominant soil (Losche et al. 1967) is Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) underlain with fractured sandstone and shale of the Hampshire formation. The stream channel is well armored with sandstone rock and stream banks are protected with vegetation.

The Clover watershed was part of a mountain farm for many years before 1930 (Lima et al. 1978). After farming ended, natural revegetation on the watershed by poor-quality hardwoods proceeded without further disturbance. The species mix includes red maple (Acer rubrum L.) and sassafras (Sassafras albidum (Nutt.) Nees), and various species of oak (Quercus spp.) and hickory (Carya spp.). The predominant soil is Calvin channery silt loam. Evidence of past land erosion is visible in the silted stream channel which appears to be unstable due to a noticeable lack of rock and the stream is eroding the banks in several places.

The Haddix watershed is underlain with interbedded shale, siltstone, and sandstone of the Chemung geologic formation. The predominant soil is Berk's channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) and the stream channel is covered with sandstone rock and gravel. Channel stability appears to be intermediate between the Clover and Fernow Watersheds. Twenty-five acres on the upper slopes of the Haddix watershed were logged selectively using recommended practices in September and October 1977. Measured sediment discharge during the first 2 years after logging did not exceed 200 lb/acre/yr (Kochenderfer et al. 1980). The dominant tree species include various species of oak, hickory, sourwood (Oxydendrum arboreum (L.) DC.) and red maple.

The Elk Lick Reservoir, constructed in 1934, furnishes water for Parsons. It has a surface area of 2.66 acres and a storage capacity of 29.5 acre-feet. The 8 miles of graveled roads in the 1,600-acre drainage are open continuously. They are used extensively for timber removal and hunter access, and also provide access to a nearby wilderness area. About half of these roads are located within 50 feet of streams. Some portion of this watershed has been logged almost every year since the early 1950's. In addition to the graveled roads, a dense network of skidroads are used periodically.

Additional soil types are represented on the Elk Lick watershed. Calvin channery silt loam is the dominant type, but substantial acreages of Belmont silt loam (fine-loamy, mixed, mesic Typic Hapludalfs) of the Greenbrier limestone formation and DeKalb channery loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) of the Pocono geologic formation are present. The vegetation is similar to that described for the Fernow watershed.

The erosion hazard is moderate for each of the soil types on the watersheds used in this study (Losche et al. 1967).

Precipitation on each watershed was measured by a network of recording gauges and standard 8-inch rain gauges. Streamflow was measured with 120° V-notch weirs on the Fernow and Clover watersheds and with a 3-foot H-type flume on the Haddix watershed. Each gauging site was equipped with an FW-1 water-level recorder and a Coshocton wheel sediment sampler (fig. 1), which diverts 0.5% of the total flow into a 600-gallon storage tank. A sample of the tank contents was typically taken weekly, but more often during high flows. Tank contents were agitated vigorously while two 800-ml samples for sediment analysis were collected from a spigot on the bottom of the storage tanks. Turbidity was measured for each sample in Nephelometric Turbidity Units (NTU) and then filtered to determine parts per million (ppm) of suspended sediment by a standard method (AAPSE 1972). Proportions of organic matter by weight were determined by igniting randomly selected

sediment samples in a muffle furnace at 550°C for 1 hr. Total yield of suspended sediment leaving the watershed between tank emptyings was computed as total measured streamflow for the period times average concentration of sediment in the tank samples. Annual suspended sediment yield is the sum of these computed periodic yields.

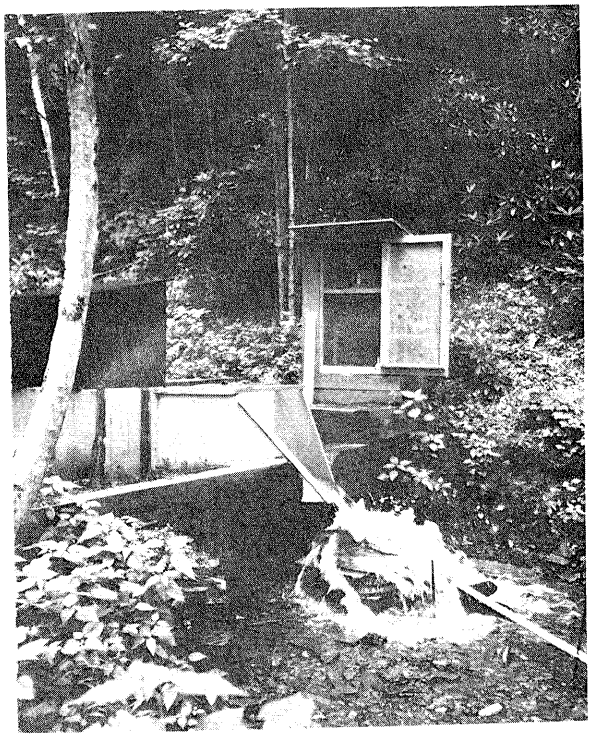

Figure 1.--The 3-foot H-type flume and 3-foot Coshocton wheel at the Haddix gauging station.

Bedload was trapped at the Haddix and Clover watersheds with 16 x 5 x 3-foot and 8 x 4 x 2-foot boxes, respectively. The Fernow watershed has a concrete block sediment box measuring 10.5 x 10.5 x 6 feet that traps larger size bedload material. The material in each box was measured periodically to determine its cubic-foot volume and subsamples were collected and ovendried to determine bulk density. Sediment volume times average bulk density gave sediment weight in each box. This value was added to the suspended sediment yield to provide total oven-dry weight of sediment exported from each watershed.

When the Elk Lick Reservoir was drained for cleaning (fig. 2), transects were established across the reservoir to calculate sediment accumulation. Depths were measured at 25-foot intervals along the transects, and then samples were collected and dried to determine sediment bulk density. Sediment volume multiplied by its average bulk density gave the total oven-dry weight of accumulated sediment. This value was divided by the number of years (18) since the previous cleaning to give average annual sediment accumulation. Trap efficiency of the reservoir was estimated at 50% using the capacity inflow (C/I) ratio as defined by Brune (1953). Therefore, measured sediment accumulation was doubled to obtain an estimate of total sediment yield exported from the 1,600-acre watershed.

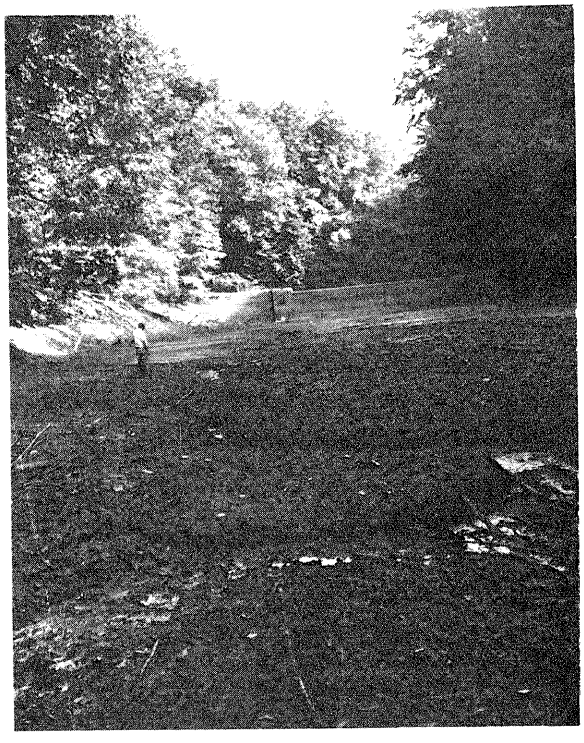

Figure 2.--The Elk Lick Reservoir after it was drained for cleaning.

RESULTS AND DISCUSSION

Sediment production from the 4 watersheds is summarized in Table 2. As expected, most of the sediment was produced during storm periods. For example, during the 6 years of record on the Fernow, 87% of the sediment was exported during the 6% of the time when flows exceeded 0.6 ft^3/s. On Haddix, 96% of the sediment was exported in only 14% of the time when flow exceeded 0.6 ft^3/s. Th Fernow has consistently yielded the least sedimen of the 3 small watersheds. The lower streamflow response to rainfall in Fernow, minimal disturbance for about 80 years, and the inherent stabil ity of the stream channel probably account for th lower sediment losses on this drainage. Clover, the abandoned farm, has historically yielded more

sediment than the other small watersheds. We are concerned that this is a lingering effect of the agricultural use that resulted in the silted stream channels visible on the watershed today.

Table 2. Annual sediment yield from the study watersheds.

Watershed	1979	1980	1981	1982	1983	1984	Mean
	----------pounds per acre----------						
Fernow	33	28	36	34	30	24	31
Clover	---	235	234	291	---	---	253
Haddix	193	139	124	349	74	117	166
Elk Lick	---	---	---	---	---	---	463

Annual variability of sediment yield was greatest on the Haddix watershed, where bedload accounted for a greater fraction of total export than from the other watersheds. The large increase in sediment export during the fourth year can be attributed to a 4-inch September convective storm during which 65% of the annual sediment yield was transported from that watershed. This storm did not occur on the other watersheds. During the last 2 years of record, streamflow on the Haddix watershed did not exceed 0.6 ft^3/s, an unusually low flow rate compared to previous records. Sediment yields were correspondingly low during that last 2 years of record.

Sediment yields from the Elk Lick municipal watershed are considerably larger than those from the smaller watersheds. The accuracy of the methods used to estimate sediment export from this large watershed are uncertain because reservoir trap efficiency was not known. However, a relatively high sediment yield was expected because the heavily used road system is located close to the stream.

Even the estimated high sediment losses determined for the Elk Lick watershed are less than the 500 lb/acre/yr upper limit considered acceptable for eastern forested land by Patric et al. (1984). Average annual sediment yields from all 3 of the small watersheds are less than the 300 lb/acre/yr considered by Douglass (1975) as normal geologic erosion from fully stocked forests in the Southeast. Sediment losses on all the watersheds are far less than the 2 to 5 tons/acre/year considered tolerable from agriculture land by Wischmeier et al. (1978). Ursic (1986) recommends the use of sediment concentrations (tons/acre-inch) rather than sediment yields to establish base rates. The average annual sediment concentration for the 6 years of record on the Fernow watershed was only 0.0005 ton/AI (5 ppm). Sediment concentrations averaged .004 ton/AI (36 ppm) on both Haddix and Clover watersheds. These concentrations compare favorably with the representative base rates suggested for various cover types by Ursic (1986).

On average, suspended material accounted for 82% of the sediment leaving the small watersheds (Table 3). The higher percentage of material measured in the Haddix approach box can be explained by the more gravelly nature of the stream channel. The larger percentage of material trapped in the Fernow watershed square sediment box probably is a reflection of the greater trap efficiency of this box compared to the boxes on the Clover and Haddix watersheds.

Table 3. Percentage of sediment and organic matter measured in the approach boxes and tanks during the study.

Watershed	Measured Sediment		Organic Content	
	Boxes	Tanks	Boxes	Tanks
	----------percent----------			
Fernow	21	79	18	62
Clover	8	92	5	20
Haddix	24	76	3	32
Elk Lick[1/]	100	--	14	--

[1/] Material deposited behind a dam during an 18-year period.

Table 3 also shows the percentage of organic matter in the sediment exported from the watersheds. The percentage of organic matter was highest on the Fernow watershed, but the total export of organic matter was higher from the Clover and Haddix watersheds. The well armored Fernow watershed has very little soil exposed in the stream channel. There is much mineral soil exposed in the sediment deposits on the Clover watershed and along the streambanks on the Haddix watershed. Stormflow collected in the storage tank on the Fernow watershed normally had a black color. Stormflow was usually reddish like Calvin soil on the Clover watershed and yellowish like Berks soil on the Haddix watershed.

Figure 3 shows the relationship between sediment concentrations and turbidity for 2 of the small watersheds. Turbidities ranged up to 240 nephelometric turbidity units (NTU) on the Haddix watershed and up to 320 NTU on Clover. Some authorities believe that while turbidity relates to sediment concentrations, the relationship cannot be quantified because the amount of light scattered by a particle is affected by too many

variables. However, Costa (1977) found a good correlation between turbidity and sediment concentrations in the Maryland Piedmont. Kunkle et al. (1971) concluded that turbidity readings could be used to estimate sediment concentrations on the Sleepers River in northern Vermont. A good correlation between suspended solids and turbidity was found for 5 streams in central Pennsylvania. But a single relationship was not suitable for all streams, and slopes generally ranged from 1.0 to 3.5 mg/l of suspended solids per NTU (VanBlargan et al. 1985). The slopes for our relationships were 2.45 and 2.82. Although suspended sediment can be accurately predicted in the study area from turbidity measurements, these prediction equations must be verified before they are used at other locations.

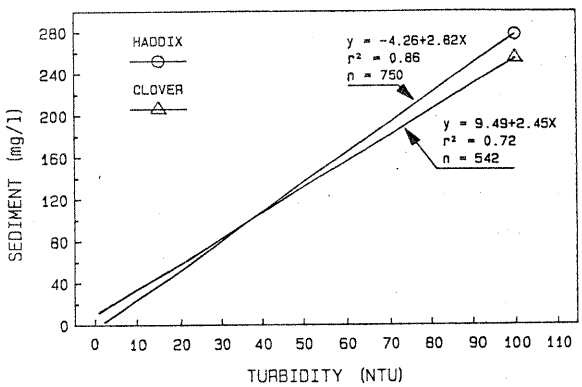

Figure 3.--Relationships between sediment concentrations and turbidity in streamflow from the Haddix and Clover watersheds.

CONCLUSIONS

Sediment yield was least (31 lb/acre/yr) from long undisturbed forested land. Higher sediment yields of 166 and 253 lb/acre/yr suggest lingering effects of logging and farming, respectively. The higher sediment yields measured on the Elk Lick watershed probably reflect the intensive, unregulated use of a poorly located road system. All of these sediment yields suggest erosion far below the 2 to 5 tons/acre/year generally accepted as tolerable from agriculture land. Total suspended sediment concentration was closely related to stream turbidity on the formerly farmed and logged watersheds.

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