Summary of Sediment Yield Data From Forested Land in the United States

James H. Patric, James O. Evans, and J. David Helvey

ABSTRACT—Statistical analyses were made on 812 forest soil erosion measurements and estimates of sediment yield in forest streams. More than 100 of those reports showed that streams draining forested land along the Pacific Coast yield far more sediment per unit area of watershed than do streams of forested regions elsewhere in the nation. In the other 700 reports, no significant differences (P = 0.05) were found among sediment yields in streams draining predominantly forested land of the eastern United States and of western regions other than the Pacific Coast. About one-third of these eastern and western observations denoted sediment yields not exceeding 0.02 ton per acre per year, and three-fourths of the total did not exceed 0.25 ton. About one-fourth fell between 0.25 and 1.00 ton, and a few exceeded 1.00 ton per acre annually. Nonforest land use within some of the larger watersheds may account for many of the higher sediment yields. These nationwide results are consistent with regional compilations. A long-term average of not more than 0.25 ton per acre per year in streams of the eastern and western United States (but not of the Pacific Coast) can provide a first approximation of sediment yield from predominantly forested land. Amounts derived by prediction equations should be questioned if they greatly exceed 0.25 ton per acre per year.

The Federal Water Pollution Control Act of 1972 stimulated many attempts to quantify stream sediment resulting from all uses of the land, including forestry. Subsequent planning acts for the USDA Forest Service and Soil Conservation Service require plans to deal with sediment yield in streams draining forested land. Sediment is the major pollutant of streams draining forested land, and much effort is expended to quantify it in compliance with the planning acts. In this context, forested land is defined as land managed primarily to grow trees, and erosion as the detachment and displacement of organic and mineral soil particles by flowing water. Sediment is a product of erosion, and consists of displaced particles suspended in or deposited by streams. Sediment yield is the mass of displaced particles moving past or deposited at some given point on a stream.

Only a few plot data record direct measurements of forest soil erosion; these data are scarce because such observations are intricate and time-consuming, hence costly. During recent years, an expanding network of stream-gaging stations, sites for routine and frequent sampling of suspended sediment, has provided increasingly more observations of sediment yield. For our purposes, an observation is defined as soil loss or sediment production for one year; average annual values were used for those few locations where data for two or more years were available. In this article, we have assembled many of the pertinent data and examined them for regional (climatic and physiographic) similarities and differences. To ensure that no reputable source of historic or current data was overlooked, we contacted most people now or recently active in relevant research.

In all, erosion and sediment data from 812 forested plots and watersheds were analyzed. Many of the data are not completely compatible with each other; i.e., some sediment estimates include both bedload and suspended load, some are for suspended load only, still others quantify deposits. Stormflow periods were sampled more intensively in some studies than others. In spite of these limitations in compatibility, we believe that a hard look at existing data can provide useful approximations of sediment yield from forested areas. Also, the generalized values can be used to check the reasonableness of estimates derived from erosion models.

Data and Analysis

Colman (1953) reviewed most of the earliest studies on forest soil erosion. Reports by Anderson (1974, 1981) and Dodge (1948) provided many of the sediment yield data from California. A catalog of erosion and sedimentation (Larson and Sidle 1981) assembled data from the Pacific Northwest. Detailed information was available for the Potomac River Basin (Wark and Keller 1963), South Dakota (Black Hills Conservancy Subdistrict 1973), Wisconsin (Hindall and Flint 1969), and Minnesota (Otterby and Onstad 1981). Accounts of reservoir sedimentation (Dendy and Champion 1978) were used when the contributing watersheds were known to be heavily forested. The richest data source was the U.S. Geological Survey's Water Supply Papers, mostly those published since 1960; papers reporting only one to a few observations are not cited in this article.

Extensive compilations of unpublished sediment yields were furnished by Peter Bengefield (Idaho Panhandle National Forests) and David Rosgen (Arapaho and Roosevelt national forests). Finally, several of our colleagues generously shared information on erosion and sediment yield from studies in progress.

The data were tabulated by region of origin and watershed size. The regions were defined as (1) east of the 100th meridian, (2) Pacific Coast of California and Oregon, and (3) the remaining area west of the 100th meridian. Watershed sizes were categorized as <0.15, 0.15 to 2, 2 to 10, 10 to 100, 100 to 1,000, and >1,000 square miles.

Our first step in the analysis was to compare measured erosion rates from plots with estimates of sediment yield. Then the mean, range, standard deviation, and coefficient of variation were computed for each region. Finally, a chi-square and a 2-way analysis of variance were computed to test for significant difference (P = 0.05) in average sediment yield between regions and among watersheds of various sizes, within and among regions.

Erosion measurements from 54 plot studies were combined with estimates of sediment yield from smallest (<0.15

square mile) watersheds because there was no significant difference between those values. Measured erosion rates from plots ranged between 0.003 and 0.32 ton per acre per year (tn/a/yr). Chi-square analysis and analysis of variance provided identical results.

Stream Sediment

The summarized statistics for the three regions are presented in *table 1*. The minimum estimates of sediment yield were 0.01 tn/a/yr in the eastern and western regions and 0.02 tn/a/yr along the Pacific Coast. Average values from the eastern and western regions did not differ significantly, but average sediment yield in the Pacific Coast region was about 25 times greater than in other regions.

Sediment yield among the six size categories of watersheds did not differ significantly. However, when the data were grouped into watersheds of < 2 and >2 square miles, yield from the larger drainages was greater than from the smaller drainages. This relationship is illustrated by *table 2*, where sampling points on drainage systems are below increasingly larger drainage areas. The smallest drainage is a first-order stream in West Virginia; the largest is the entire Mississippi River Basin.

The tendency for greater sediment yield from watershed areas exceeding 2 square miles *(table 3)* probably is related to land use. Many of the Category A drainages are research plots and small watersheds under rigorous observation and control of land use. Mixed land use was unavoidable on most of the larger (Category B) watersheds, especially those having broad valleys; there soils exposed to erosion by nonforest uses almost surely yielded most of the sediment. Sampling was less rigorously scheduled on the larger watersheds, occurring sometimes at daily, weekly, or even monthly intervals. Category B watersheds include all of those containing reservoirs; there, sediment deposits often exceeded the observed loading of streams draining into them, probably because sampling did not adequately account for heavy deposits during storms. Unaccounted bank erosion also contributed to sediment deposits in reservoirs (Porterfield and Dunnan 1964).

Table 1. Sediment yield from forested regions of the United States.

Region	Observations	Range	Mean	Standard deviation	Coefficient of variation
	Number	*Tn/a/yr*			*Percent*
Eastern	291	0.01–1.97	0.139	0.198	14.2
Western	392	.01–5.97	.165	.331	20.1
Pacific Coast	129	.02–49.9	3.983	5.687	14.3

Table 2. Sediment loading in connected streams of the Mississippi River Basin.

Tributary name and location	Watershed area	Sediment yield	Sources
	Sq mi	*Tn/a/yr*	
Forested headwater in WV	0.13	0.04	Patric 1981
Shaver's Fork, WV	151	.20	U.S. Geological Survey 1979
Monongahela River at Braddock, PA	7,337	.26	U.S. Geological Survey 1979
Ohio River at Cincinnati, OH	76,580	.31	Holeman 1968
Mississippi River at Baton Rouge, LA	344,000	.43	Holeman 1968

Table 3. Sediment yield on completely forested small watersheds (Category A)[1] and on larger watersheds of mixed land use (Category B)[2].

Region	Watersheds	Sediment yield: Mean	Sediment yield: Range
	Number	*Tn/a/yr*	
East			
A	65	0.074	0.01–1.09
B	226	.158	.01–1.97
West			
A	80	.071	.01–0.52
B	312	.189	.01–5.97
Pacific Coast			
A	26	1.752	.02–19.43
B	103	4.626	.06–49.90

[1]*Category A includes all soil erosion plots and all completely forested watersheds less than 2 square miles in extent.*
[2]*Category B includes all reservoirs and the balance of watersheds not in Category A.*

Land use appears to have more influence on average sediment concentration than does any other single factor *(table 4)*. Even with a wide diversity of forest types, geology, climate, and physiography, watersheds which are predominantly forested yield far less sediment than areas where nonforest land uses occur.

Reliability and Use of the Average Value

We should make clear that data used in these analyses are from watersheds which are predominantly (>75 percent) forested, but we do not mean to imply that all of them are undisturbed. While some are undisturbed, most are under forest management of one kind or another. This means that some have an extensive logging road network, and many, especially in the East, have been logged more than once. It would be desirable to classify each watershed

Table 4. Suspended sediment in rivers of contrasting land use.[1]

River and state	Sediment concentration[2]: Mean	Standard deviation	Range
	Ppm		
Draining predominantly forested land:			
Penobscot, ME	5.0	2.3	1–9
Blackwater, VA	10.1	6.7	2–24
St. Mary's, FL	4.7	3.4	1–15
Ford, MI	5.3	6.1	0–20
St. Croix, WI	9.1	9.8	2–35
Mokelumne, CA	8.4	8.6	3–26
Elwha, WA	6.4	7.0	1–27
Pend Oreille, ID	5.3	4.2	2–16
Umpqua, OR	11.5	8.3	2–27
Heavily influenced by nonforest land uses:			
Susquehanna, PA	120.5	166.2	2–500
Pee Dee, SC	39.8	19.9	10–76
Alabama, AL	74.8	72.5	17–230
Ohio, IL	77.5	44.1	26–147
Platte, NE	723.0	883.3	222–3,270
Brazos, TX	773.5	676.6	157–2,300
Colorado, UT	1,298.1	1,673.0	138–5,230
Salinas, CA	1,089.2	1,055.5	107–3,520
Yakima, WA	88.8	131.9	7–490

[1]*Briggs and Ficke 1977.*
[2]*Sampled at least once per month.*

as to degree of disturbance, but these data were not available for our analysis.

We stress that our data encompass the gamut of vegetation, land use, topography, and weather likely to be encountered on any predominantly forested land in the contiguous United States. Averages, of course, mask large differences in sediment yield from that land. However, even the very largest annual yields from eastern and western regions seem modest in light of the 2 to 5 tn/a/yr amount accepted as tolerable from agricultural land (Wischmeier and Smith 1978). Considering that the data were collected by many people with a variety of methods and objectives, the results within the eastern and western regions are surprisingly uniform. The higher maximum values in the western region *(table 1)* may reflect the more rugged terrain, the more erosive soils in areas such as the Idaho Batholith, and soils derived from volcanic ejecta.

Sediment yield was significantly higher from the Pacific Coast region (a strip of land, seldom greater than 50 miles wide, extending from southwestern Oregon to Mexico and from the Pacific Ocean to the crest of the Coastal Range). Henry W. Anderson, a retired Forest Service scientist who spent many years studying soil erosion, attributes high sediment yield from Pacific Coast watersheds to the extensive steepening, faulting, and fracturing of bedrock caused by active overthrusts of tectonic plates in that region (personal communication, 1982). These processes cause rapid downcutting of stream channels and mass movement on upper slopes.

The erosional influence of agriculture and other nonforest uses is clearly expressed by sediment yields in the upper Mississippi River Basin (Mack 1967). There, sediment yield of about 0.02 tn/a/yr in forested headwaters rose to more than 3.0 tn/a/yr at Cairo, Illinois, where the influence of other land uses, including agriculture, increased the yield 150-fold. Reasons for lower yields from forested land are obvious. The tree canopy and litter layer serve as energy dissipators to rain drops. Also, a continuous litter layer maintains a porous soil surface and high water infiltration rates; consequently, overland flow rarely occurs in the forest. When mineral soil is exposed by road building, however, or for nonforest land uses, falling rain can dislodge soil particles which may be carried by overland flow to the stream.

How consistent is a sediment yield up to 0.25 tn/a/yr with other computations of forest soil loss? It is close to regional denudation rates (0.20 to 0.31 tn/a/yr) reported for heavily forested regions of the United States (Judson and Ritter 1964). Sediment yields from the eastern forest were reported as 0.05 to 0.10 tn/a/yr (Patric 1976), and as 0.02 to 0.03 but rising temporarily to as much as 0.5 during disturbance by human activity (Lull and Reinhart 1972). As for western conditions, "Erosion is an undisturbed forest represents a minimum for the site, and most of man's activities will increase the erosion rate to some extent" (Rice et al. 1972). Given average annual streamflow ranging from 4 to 45 inches on western forestland (U.S. Senate 1960) and 0.007 ton of sediment per acre-inch of streamflow per year (Ursic and Douglass 1978), sediment yields might range from 0.03 to 0.32 tn/a/yr. Even though all of these are "ball-park" figures, derived for specific locations, they are surprisingly consistent.

This analysis of nationwide data provides averages and ranges of sediment yield from watersheds which are managed primarily for wood production. We believe these averages will answer many questions about regional sediment yields. When data are needed for a specific site, the best course is to set up a sampling station and quantify suspended sediment and bedload during base flow and storm periods. Since a sampling program is both expensive and time-consuming, sediment yield often is predicted with an erosion model.

When predictive methods are used, care must be taken to ascertain that conditions for the test site are within the range experienced during the model development. For example, the universal soil loss equation (USLE) was designed to predict long-term average annual erosion on agricultural land (Wischmeier and Smith 1978). The equation predicts rill and sheet erosion resulting from overland flow. Since overland flow rarely occurs in the undisturbed forest, the USLE has limited application under forested conditions (Wischmeier 1976). Although attempts have been made to modify it to accommodate forested conditions (Wischmeier 1975, 1976, Dissmeyer and Foster 1981, Burns and Hewlett 1983), questions remain about its general applicability (Patric 1982). When estimated erosion rates for forested watersheds greatly exceed the average values in *table 1*, the assumptions and coefficients of the prediction model should be carefully checked and perhaps at least a cursory sampling program initiated to verify the predicted values.

Conclusion

Sediment yields are low for most forested land and are routinely quantified by use of several carefully applied sampling methods. For eastern and western regions of the United States, we believe a sediment yield not greater than 0.25 ton per acre annually from minimally disturbed forested land provides a prediction suitable for many planning purposes. The universal soil loss equation and its modifications have not been extensively validated for predicting sediment yield from forested land and should be used with great caution for that purpose. No prediction method is yet applicable to forested land of the Pacific Coast or other regions where the forest floor is subject to severe mass wastage. Methods are needed to improve capabilities for predicting sediment yields from such lands. ■

Literature Cited

ANDERSON, H.W. 1974. Sediment deposition in reservoirs associated with rural roads, forest fires, and catchment attributes. P. 87–95 *in* Effects of Man on the Interface of the Hydrologic Cycle with the Physical Environment, proc. Paris Symp. Int. Assoc. Sci. Hydrol. Publ. 113.

ANDERSON, H.W. 1981. Sources of sediment-induced reductions in water quality appraised from catchment attributes and land use. J. Hydrol. 51:347–358.

BLACK HILLS CONSERVANCY SUBDISTRICT. 1973. Comprehensive Water Quality Management Plan for the Black Hills Region: Appendix A, Lake Management Data. 221 p. (typewritten). Rapid City, SD.

BRIGGS, J.C., and J.F. FICKE. 1977. Quality of rivers of the United States, 1975 water year—based on the national stream quality accounting network (NASQUAN). U.S. Geol. Surv. Open-File Rep. 78-200, 436 p. Reston, VA.

BURNS, R.G., and J.D. HEWLETT. 1983. A decision model to predict sediment delivery from forest practices. Water Resour. Bull. 19(1):9–14.

COLMAN, E.A. 1953. Vegetation and Watershed Management. 412 p. Ronald Press, New York, NY.

DENDY, F.E., and W.A. CHAMPION. 1978. Sediment deposition in U.S. reservoirs: summary of data reported through 1975. USDA Misc. Publ. 1,362, 84 p. Washington, DC.

DISSMEYER, G.E., and G. R. FOSTER. 1981. Estimating the cover-management factor (C) in the Universal Soil Loss Equation for forest conditions. J. Soil and Water Conserv. 36(4):235–240.

DODGE, B.H. 1948. Design and operation of debris basins. P. 274–284 *in* Proc. Federal Inter-agency Sedimentation Conf. USDI Bur. Reclamation, Denver, CO.

HINDALL, S.M., and R.F. FLINT. 1969. Sediment Yield of Wisconsin Streams. 16 p. (typewritten). U.S. Geol. Survey Library. Reston, VA.

HOLEMAN, J.N. 1968. The sediment yield of major rivers of the world. Water Resour. Res. (4):737–747.

JUDSON, S., and D.F. RITTER. 1964. Rates of regional denudation in the United States. J. Geophys. Res. 69(16):3395–3401.

LARSON, K.R., and R.C. SIDLE. 1981. Erosion and sedimentation catalog of the Pacific Northwest. USDA For. Serv. R6-WM-050-1981, 64 p. Pacific Northwest Region, Portland, OR.

LULL, H.W., and K.G. REINHART. 1972. Forests and floods in the eastern United States. USDA For. Serv. Res. Pap. NE-226, 94 p.

MACK, F. J. 1967. Sedimentation in the upper Mississippi Basin. P. 95–102 *in* Soil and America's Future, proc. 22nd annu. meet., Soil Conserv. Soc. Am. Des Moines, IA.

OTTERBY, M.A., and C.A. ONSTAD. 1981. Average annual sediment yields in Minnesota. USDA Agric. Res. Serv. ARR-NC-8, 9 p. Peoria, IL.

PATRIC, J.H. 1976. Soil erosion in the eastern forest. J. For. 74:671-677.

PATRIC, J.H. 1981. Soil-water relations of shallow forested soils during flash floods in West Virginia. USDA For. Serv. Res. Pap. NE-469, 20 p.

PATRIC, J.H. 1982. A Perspective on Soil Loss from Forested Land. USDA Soil Conserv. Serv. Nat'l. Bull. 190-2-18, 20 p. (typewritten). Washington, DC.

PORTERFIELD, G., and C.A. DUNNAN. 1964. Sedimentation of Lake Pillsbury, Lake County, California. U.S. Geol. Surv. Water-Supply Pap. 1619 EE, 46 p.

RICE, R.M., J.S. ROTHACHER, and W.F. MEGAHAN. 1972. Erosional consequences of timber harvesting: an appraisal. P. 321–329 *in* Watersheds in Transition, proc. symp. at Fort Collins, CO. Am. Water Resour. Assoc., Urbana, IL.

U.S. GEOLOGICAL SURVEY. 1979. Water Resources Data for West Virginia. Water Data Rep. WV-79-1, 417 p. Charleston, WV.

U.S. SENATE SELECT COMMITTEE ON NATIONAL WATER RESOURCES. 1960. Evapotranspiration reduction in water resource activities in the United States. Committee Print 21, 42 p. U.S. Gov. Print. Off. Washington, DC.

URSIC, S.J., and J.E. DOUGLASS. 1978. The effects of forestry practices on water resources. P. 33–49 *in* Kelly Mosley Environmental Forum Proc. (Auburn University, May 1978). Auburn Univ. Press, Auburn, AL.

WARK, J.W., and F.J. KELLER. 1963. Preliminary study of sediment sources and transport in the Potomac River Basin. Interstate Commission on the Potomac River Basin, Tech. Bull. 1963-11, 28 p. Washington DC.

WISCHMEIER, W.H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. P. 118–124 *in* Sediment Yield Workshop. USDA ARS-S-40. Washington, DC.

WISCHMEIER, W.H. 1976. Use and misuse of the universal soil loss equation. J. Soil and Water Conserv. 31(1):5–9.

WISCHMEIER, W.H. and D.S. SMITH 1978. Predicting rainfall erosion losses—a guide to conservation planning. USDA Agric. Handb. 537, 58 p. Washington, DC.

THE AUTHORS — James H. Patric, Box 2154, Alexandria, VA 22301, recently retired from the USDA Forest Service. James O. Evans is staff research hydrologist with the Forest Service in Washington, DC. J. David Helvey is project leader, Forest Service, Northeastern Forest Experiment Station, Parsons, WV.

Larch—A Fast-Growing Fiber Source For the Lake States and Northeast

Dean W. Einspahr, Gary W. Wyckoff, and Marianne (Harder) Fiscus

ABSTRACT—Preliminary comparisons between Japanese (Larix leptolepis *Gord.) and European larch* (L. decidua *Mill.) plantings indicate that these species, together with their hybrids, will outgrow pine and spruce, particularly on the better Lake States forest soils. Larch has adequate genetic diversity and grows rapidly. It also hybridizes readily, has good wood quality, is resistant to scleroderris canker and spruce budworm, and is adapted to a variety of soils. Recently, the Institute of Paper Chemistry, at Appleton, Wisconsin, established a cooperative larch tree improvement program using a seed orchard approach. Pulping studies indicate that 18- to 23-year-old larch and larch hybrids (Larix × eurolepis* Henry) *can produce higher kraft yields than 50- to 60-year-old jack pine* (Pinus banksiana *Lamb.) and with pulp strength properties similar to those of jack pine.*

Forests of the Lake States contain enough hardwood to sustain a considerable increase in the cut of pulpwood. Expanded use, however, depends on having an adequate amount of conifers. Unless some of the long, strong fibers of conifers are mixed in, hardwood pulps are too weak to allow paper machines to operate at economic speeds. Thus increased supply of softwoods would allow increased use of northern hardwoods.

The matter is of some urgency. The nation's pulpwood requirements are expected to be 2.4 times greater by the year 2030 than they were in 1976, with conifer fiber predicted to be in short supply by 1990 (USDA Forest Service 1982, p. 60–61). Unless adequate measures are taken, wood shortages will restrict growth of the pulp and paper industry.

Red pine, spruce, and balsam fir have been the primary source of conifer fiber, but susceptibility of these species to insect and disease attack has prompted forest managers to look for alternate sources. Red pine, which is widely planted in Michigan, Wisconsin, Minnesota, and the Northeast, is genetically uniform. Recent outbreaks of the European strain of scleroderris canker in pole-size stands in New York State and southeastern Canada have demonstrated that red pine has little or no natural resistance to this disease. Mortality in affected stands is high, and spread of the disease to the Lake States would cause severe damage in areas planted principally with red pine (Nicholls 1979). Similarly, the spruce budworm, which has caused extensive mortality and growth loss to spruce and balsam fir in the Northeast, has already reached the Lake States and is spreading there. Alternative sources of conifer fiber are a high priority for these regions. This article presents the various growth and papermaking criteria that led the Institute of Paper Chemistry, Appleton, Wisconsin, to decide to pursue larch as an alternative conifer fiber source.