U.S. Soil Erosion Rates: Myth and Reality

Stanley W. Trimble; Pierre Crosson

Science, New Series, Vol. 289, No. 5477. (Jul. 14, 2000), pp. 248-250.

Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2820000714%293%3A289%3A5477%3C248%3AUSERMA%3E2.0.CO%3B2-M

Science is currently published by American Association for the Advancement of Science.

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/about/terms.html. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at http://www.jstor.org/journals/aaas.html.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is an independent not-for-profit organization dedicated to and preserving a digital archive of scholarly journals. For more information regarding JSTOR, please contact support@jstor.org.

http://www.jstor.org
Wed May 9 18:31:37 2007

POLICY FORUM: LAND USE

U.S. Soil Erosion Rates—Myth and Reality

Stanley W. Trimble and Pierre Crosson

Soil erosion in the United States has been a matter of public concern since the 1930s. Conditions were improved by the 1960s, although no one knew just how much (*1*). Starting in the 1970s, however, several studies concluded that erosion was high. Although a few studies have been skeptical of these high rates (*2*, *3*), most have suggested that soil erosion is an extremely serious environmental problem, if not a crisis (*4*–*7*). Quantification of the problem has been elusive, and average annual U.S. cropland soil erosion losses have been given as 2 billion (*8*), 4.0 billion (*9*, *10*), 4.5 billion (*5*), 4.8 billion (*11*), 5 billion (*6*), or 6.8 billion tons (*12*). The U.S. Department of Agriculture (USDA) National Resource Inventory (NRI), based on models, gave high values in the 1970s and 1980s (*13*) but has shown decreases in the past decade. Some sources have suggested that recent erosion is as great as or greater than that of the 1930s, when the soil conservation effort was begun (*10*, *11*, *14*). Increases in spending for soil conservation have been many billion dollars (*15*).

Studies of the on-farm productivity effects based on 1982 NRI cropland erosion rates indicated that if those rates continue for 100 years, crop yields (output per hectare) would be reduced only 2 to 4% (*16*). These results indicate that the productivity effects of soil erosion are not significant enough to justify increased federal outlays to reduce the erosion, but not all agree (*7*).

The remarkable feature of all this discussion and attempted rectification is that it was based mostly on models. Little physical, field-based evidence (other than anecdotal statements) has been offered to verify the high estimates. It is questionable whether there has ever been another perceived public problem for which so much time, effort, and money were spent in light of so little scientific evidence. Here, we assess the techniques now used to estimate erosion and the resulting off-farm movement of sediment and suggest new directions for research that may provide more policy-relevant information.

Fig. 1. Areas of cropland erosion. Areas of the United States having cropland erosion rates of >25 tons ha^{-1} $year^{-1}$ as predicted by the U.S. Department of Agriculture in 1982 [modified from (*13*)]. "Driftless Area" is approximately coincidental with Major Land Resource Area 105, Northern Mississippi Valley Loess Hills.

The Models

Two models have been used to estimate soil erosion (*17*). The first, the universal soil loss equation [USLE (*18*)], attempts to predict sheet and rill erosion by water. Although the USLE has been criticized, it is an excellent planning tool for estimating the relative values of varying land uses and conservation measures. However, it only presumes to predict the amount of soil moved on a field, not necessarily the amount of soil moved from a field (*17*). The latter is estimated by a sediment delivery ratio [SDR (*19*)], a simple empirical model that shows a highly generalized decrease of sediment with increasing area. Implicit in this model is that only a small proportion of eroded soil leaves a field or stream basin. Some sediment is presumed to be deposited by wind on the field, or downslope of the field along fencerows or in woods, or along streams as alluvium. In reality, not nearly enough is known about this sediment delivery process, and using it for analysis is a continuing problem in fluvial geomorphology (*20*). However, many investigators have termed the output of the USLE as "removed from the land" (*7*). Another problem is that the potential variance of SDR has not been appreciated. In Coon Creek, WI, for example, sediment delivered to streams from about a 3-km^2 drainage area in the 1970s was only about 8% of the amount estimated by the USLE; the difference was presumably sediment stored as colluvium. In the 1930s, however, when gullying downslope from agricultural fields was common, the sediment delivered was 123% of upland soil erosion as estimated by the USLE (*21*).

For wind erosion, the wind erosion equation [WEE (*22*)] has been used, for which results are uncertain but often exaggerated (*23*). Like the USLE, there is a mass continuity problem—even though soil may be eroded in one area, most of the particles are simply moved to other fields. During the 1930s when wind erosion was really a crisis, huge dust clouds from the Dust Bowl darkened the skies of the eastern United States and moved out over the Atlantic Ocean in the upper westerly winds. However, much wind erosion of the past few decades appears to be mainly local redistribution—some areas lose, others gain. But as is the case with water erosion, there has been little scientific evidence.

Sediment Budgets

Whatever the limitations of each equation for predicting soil detachment, the observation that much of the soil remains close by, and thus is not lost, is a concept clearly not taken into account (*17*). Although large areas of the United States were proclaimed to have erosion rates >25 tons ha^{-1} (*13*), sediment yields (efflux) were usually on the order of 0.5 to 2.0 tons ha^{-1}, and these yields were usually augmented by significant stream channel and bank erosion (*24*). Expressed another way, total sediment delivered to streams has been given as 2.7 to 4.0 billion tons (*6*, *16*, *25*), but the total sediment yield is estimated to be only about 0.5 billion tons (*26*). This huge disparity between presumed erosion and measured downstream sediment yield means that large volumes of sediment would have been stored in the watershed.

To investigate the set of processes linking erosion in upland areas with sediment delivery downstream requires construction of a sediment budget. For example, consider an agricultural watershed of 100 km^2

S. W. Trimble is in the Department of Geography and Institute of Environment, University of California at Los Angeles, Los Angeles, CA 90095–1524, USA. E-mail: trimble@geog.ucla.edu P. Crosson is with Resources for the Future, Washington, DC, 20036. E-mail: crosson@rff.org

(10,000 ha) where 90 km^2 is cropped upland eroding at a rate of 20 tons ha^{-1} $year^{-1}$. The remaining 10 km^2 is stream and flood plain subject to sediment deposition. Of the eroded material, assume that 60% is conveyed to streams. Further assume a high sediment yield (efflux) from the basin of 200 tons km^{-2} $year^{-1}$ (2 tons ha^{-1} $year^{-1}$). This would leave 8.8×10^5 tons of sediment to be deposited on the 1000 ha of flood plain. At a typical bulk density of 1.3 tons m^{-3}, this would cover the flood plain to an average depth of about 6.9 cm in only a decade. Such accretion is easily measurable, and even observable, since the root crowns of small trees would in places be buried. A specific example comes from the upper Mississippi River Loess Hills region (Driftless Area), which was designated a soil erosion problem region in the 1980s, when it ostensibly had cropland losses greater than 25 tons ha^{-1} (*13*) (Fig. 1). However, a long-term sediment budget for one stream in the region, Coon Creek, WI, showed that, of all upland erosion (including nonagricultural), only about 2 tons ha^{-1} $year^{-1}$ reached the streams and much of that was deposited (*27*).

Indeed, measures of alluvial sediment flux are usually better measures of basin processes than are estimates of upland erosion or measurements of sediment yield (*28*, *29*). During recent decades, when soil erosion rates were ostensibly so high, rates of alluviation declined in various regions (*21*, *27*, *30*). Studies of wind erosion mass budgets have been few, but these too show declining airborne dust (*31*). Thus, although mass budget studies of sediment and dust have been limited, much of the available field evidence suggests declines of soil erosion, some very precipitous, during the past six decades.

Associated Resources

Some assessments of U.S. erosion have warned that increasingly eroded soil profiles will allow less rainfall to be infiltrated and stored (*7*). This process would logically result in increased overland flow, erosion, and flooding, processes that might be occurring if the soils were eroding rapidly. However, detailed hydrologic studies in two large regions, the Southern Piedmont and the Driftless Area, indicate that just the opposite is occurring: Runoff is decreasing, flood peaks are smaller, and in some places, the base flow is greater. These field studies show that more water is infiltrating into the soil and, in some cases, that significantly more water is being transpired by plants. Investigators attribute these changes to improved land use (*32*).

Such hydrologic improvements, in turn, improve other resources. For example, the stability of tributary channels in the Driftless Area has been enhanced greatly over the past half century (Fig. 2), and channels have become smaller, reflecting the improved hydrologic regimes (*33*). Perhaps the most dramatic and convincing change there has been that of fish habitat. At the time of European settlement, streams were notable for large numbers of brook trout, *Salvelinus fontinalis*, which require high-quality water (*21*). Degradation of habitat was evident in the late 1800s, so that by the 1930s, only exotic brown trout, *Salmo trutta*, which had to be stocked, could survive the flooding, high sediment concentrations, warmer water temperatures, and stream channel instability of that period. Indeed, floods were so frequent and violent that improvement of fish habitat was not practicable [(*34*, *35*) and Fig. 2, top]. With the improved land use and soil conservation measures starting in the late

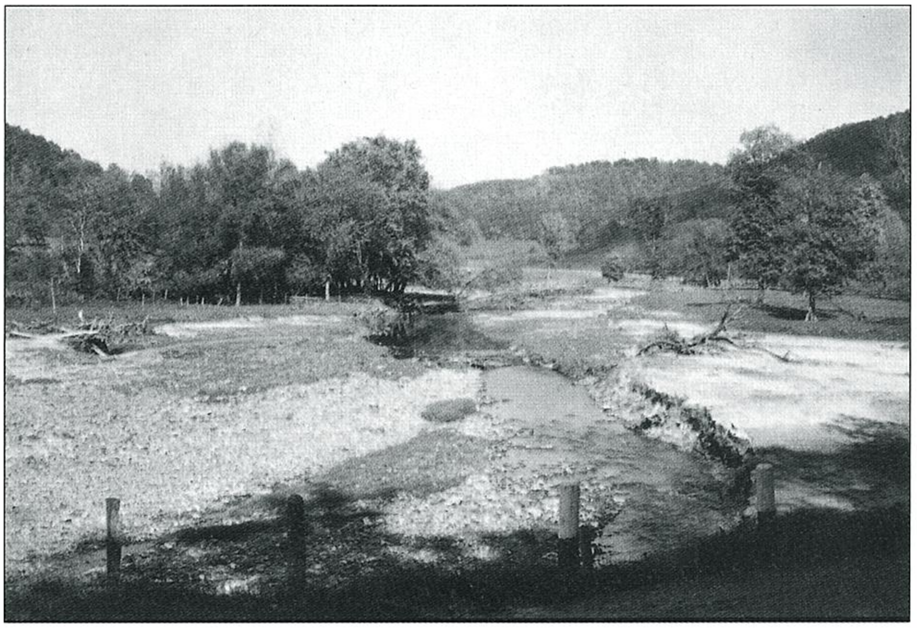

Fig. 2. Improvement of tributary stream channel conditions in the Driftless Area, 1940 to recent times. Photo set from Bohemian Creek, La Crosse County, WI. **(Top)** Photo made by S. C. Happ in 1940 to depict a "typical" tributary of the period. Note the eroded, shallow channel composed of gravel and cobbles, with coarse sediment deposited by overflows on the floodplain. Such tributaries were described as resembling "gravel roads." **(Bottom)** Remake of photo by S. Trimble in 1974. The stream channel is narrower, smaller, and more stable. The coarse sediment has been covered with fine material, and the floodplain is vegetated to the edge of the stream. This condition has continued and improved over the past 25 years.

CREDIT: (TOP) STAFFORD C. HAPP; (BOTTOM) STANLEY W. TRIMBLE

1930s, stream conditions had improved enough by the 1960s so that brook trout could be stocked. By the 1980s, stream conditions were suitable for natural reproduction in some areas, a condition now widespread in this agricultural region.

Monitoring Soil Erosion and Associated Resources

The foregoing discussion suggests that the general impression of severe soil erosion with deteriorating associated resources is not correct in some regions and, by implication, is open to question in all others. What is required now is the initiation of continuing field studies and monitoring based on mass budgets. In humid areas of water erosion, baseline data should be collected from small sample stream basins so that changes of colluvium and alluvium can be monitored. Initially, this should be by ground surveys, which are quick, cheap, and precise, but this might eventually be augmented with cosmogenic isotopic dating and high-precision remote sensing techniques. Water quality, especially sediment concentrations, should be monitored. To more effectively measure annual sediment yield (including bedload), sample basins should ideally terminate in a reservoir to trap sediment, including bedload. In some cases, existing dams could be used. Basins with existing baseline data; e.g., those in the Vigil Network, would be especially valuable and are available for some regions (*36*). Ideally, biological and chemical indicators should also be monitored. Erosion and sediment fluxes should be studied annually in light of the land use and climatic conditions of that year.

Regions of wind erosion are more problematic, because efflux can go in any direction. Although some observations of dust are being made (*37*), it is important to have a better grasp of the size, concentration, and movement of dust clouds. Perhaps just as important are more measurements of dust deposition.

Conclusions

No problem of resource or environmental management can be rationally addressed until its true space and time dimensions are known. The limitations of the USLE and the WEE are such that we do not seem to have a truly informed idea of how much soil erosion is occurring in this country, let alone of the processes of sediment movement and deposition. The uncritical use of models is unacceptable as science and unacceptable as a basis for national policy. A comprehensive national system of monitoring soil erosion and consequent downstream sediment movement and/or blowing dust is critical. The costs would be significant; nevertheless, they would reflect efforts better focused on achieving better management of the country's land and water resources.

References and Notes

1. R. Held and M. Clawson, *Soil Conservation in Perspective* (John Hopkins Univ. Press, Baltimore, 1965).
2. S. Trimble and S. Lund, *J. Soil Water Conserv.* **37**, 355 (1982); S. Batie, *Soil Erosion: Crisis in America's Croplands* (The Conservation Foundation, Washington, DC, 1983); S. Trimble, *Agric. Hist.* **59**, 162 (1985).
3. P. Crosson [letter], *Science* **269**, 461 (1995); "Soil erosion and its on-farm productivity consequences: What do we know?" (Discussion Paper 95-29, Resources for the Future, Washington, DC, 1995); *Environment* **39**, 4 (1997).
4. F. Steiner, *Soil Conservation in the United States: Policy and Planning* (Johns Hopkins Univ. Press, Baltimore, 1990)
5. D. Pimentel *et al.* [response, see (*3*)], *Science* **269**, 461 (1995).
6. D. Pimentel *et al.*, *Science* **194**, 149 (1976).
7. D. Pimentel *et al.*, *Science* **267**, 1117 (1995).
8. USDA, Soil and Water Resources Conservation Act, 1980 Appraisal, Part I: Soil, Water, and Related Resources in the United States: Status, Conditions and Trends, and Appraisal; Part II: Soil, Water, and Related Resources in the United States, Analysis of Resources Trends (USDA, Washington, DC, 1981).
9. R. Beasley, *Erosion and Sediment Control* (Iowa State Univ. Press, Ames, 1972); P. Raven, L. Berg, G. Johnson, *Environment* (Saunders, Philadelphia, 1995).
10. General Accounting Office (GAO), "To protect tomorrow's food supply, soil conservation needs priority attention" (CED 77-30, GAO, Washington, DC, 1977).
11. T. Barlowe, in *Soil Conservation Policies: An Assessment* (Soil Conservation Society of America, Ankeny, IA, 1979).
12. J. Harlin and G. Barardi, *Agricultural Soil Loss* (Westview, Boulder, CO, 1987).
13. L. Lee, *J. Soil Water Conserv.* **39**, 226 (1984).
14. D. Popper and F. Popper, *Planning* **53**, 12 (1987); O. Owen, D. Chrias, J. Reganold, *Natural Resource Conservation* (Prentice-Hall, Upper Saddle River, NJ, 1998).
15. Although instituted only partially for soil conservation, the Conservation Reserve Program cost $22 billion from 1985 to 1999, and other federal conservation costs, much for soil conservation, were $17 billion for the same period (written communication, Natural Resources Conservation Service, Resource Economics and Social Science Division, 18 November 1999. All figures are in constant 1999 dollars). None of this includes state and private expenditures, much of which were spent in conjunction with federal expenditures.
16. F. Pierce *et al.*, *J. Soil Water Conserv.* **39**, 131 (1984), *The Second RCA Appraisal: Soil, Water, and Related Resources on Nonfederal Land in the United States* (USDA, Washington, DC, 1989).
17. National Research Council, *Soil Conservation; Assessing the National Resources Inventory* (National Academy Press, Washington, DC, 1986).
18. W. Wischmeier and D. Smith, *U.S. Dep. Agric. Agric. Handb.* **537** (1978).
19. Natural Resources Conservation Service, *National Engineering Handbook*, Section 3, Sedimentation (USDA, Washington, DC, 1983).
20. M. Wolman, *Water Resour. Res.* **13**, 50 (1977); D. Walling, *J. Hydrol.* **65**, 209 (1983).
21. S. Trimble and S. Lund, *U.S. Geol. Surv. Prof. Pap. 1234* (1982).
22. E. Skidmore and N. Woodruff, *U.S. Dep. Agric. Agric. Handb.* **346** (1968).
23. D. Gillette, in (*17*), vol. 2, 129.
24. J. Milliman and R. Meade, *J. Geol.* **91**, 1 (1983); R. Meade and R. Parker, *U.S. Geol. Surv. Water Supply Pap. 225* (1985); R. Meade, T. Yuzyk, T. Day, in *Surface Water Hydrology*, M. Wolman and H. Riggs, Eds. (Geological Society of America, Boulder, CO, 1989), pp. 255–280.
25. D. Pimentel and E. Skidmore [letter], *Science* **286**, 1477 (1999).
26. W. Curtis, W. Culbertson, E. Chase, *U.S. Geol. Surv. Circ. 670* (1973).
27. S. Trimble, *Science* **285**, 1244 (1999); [response, see (*25*)], *Science* **286**, 1477 (1999).
28. L. Leopold, W. Emmett, R. Myrick, *U.S. Geol. Surv. Prof. Pap. 352-G*, 193 (1966); S. Trimble, *Science* **188**, 1207 (1975), [response], *Science* **191**, 871 (1976); S. Schumm [letter], *Science* **191**, 871 (1976); W. Dietrich and T. Dunne, *Z. Geomorphol. Suppl.* **29**, 191 (1978); H. Kelsey, *Geol. Soc. Am. Bull.* **91**, 190 (1980); F. Swanson, F. Janda, T. Dunne, D. Swanston, Eds., *Sediment Budgets and Routing in Forested Drainage Basins* (USDA, Forest Service General Tech. Rep. PNW 141, 1982); R. Meade, *J. Geol.* **90**, 235 (1982); P. Patton and P. Boison, *Geol. Soc. Am. Bull.* **97**, 369 (1986); J. Phillips, *Am. J. Sci.* **287**, 780 (1987); M. Church and O. Slaymaker, *Nature* **337**, 352 (1989); J. Phillips, *Geomorphology* **4**, 231 (1990); P. Ashmore, *Prog. Phys. Geogr.* **17**, 190 (1993); A. Schick and J. LeKach, *Prog. Phys. Geogr.* **17**, 225 (1993); O. Slaymaker, *Prog. Phys. Geogr.* **17**, 305 (1993); S Trimble, in *Changing River Channels*, A. Gurnell and G. Petts, Eds. (Wiley, Chichester, UK, 1995), pp. 201–215; L. Reid and T. Dunne, *Rapid Evaluation of Sediment Budgets* (Catena, Reiskirchen, 1997); S. Trimble, *Science* **278**, 1442 (1997).
29. M. Wolman in *Population and Land Use in Developing Countries*, C. Jolly and B. Torrey, Eds. (National Academy Press, Washington, DC, 1993).
30. R. Hadley, in *Effects of Man on the Interface of the Hydrological Cycle with the Physical Environment* (Pub. 113, International Association of Scientific Hydrology, 1974), pp. 96–98; R. Meade and S. Trimble, *Effects of Man on the Interface of the Hydrological Cycle with the Physical Environment* (Pub. 113, International Association of Scientific Hydrology, 1974), pp. 99–104; S. Trimble, *Man-Induced Soil Erosion on the Southern Piedmont, 1700–1970* (Soil Conservation Society of America, Ankeny, IA, 1974); R. Jacobson and C. Colman, *Am. J. Sci.* **286**, 617 (1986); J. Knox, *Ann. Assoc. Am. Geogr.* **77**, 224 (1987); S. Miller *et al.*, *Geomorphology* **6**, 309 (1993); W. Wolfe and T. Diehl, *U.S. Geol Surv. Water Resour. Inv. Rep. 92-4082* (1993); T. Beach, *Ann. Assoc. Am. Geogr.* **84**, 5 (1994); J. Oppenheim, thesis, Univ. of Georgia (1996); A. Gellis *et al.*, *U.S. Geol. Surv. Water-Resource Inv. Rep. 99-4010* (1999); C. Craft and W. Casey in *Proceedings of the 1999 Georgia Water Resources Conference*, K. Hatcher, Ed. (Inst. of Ecology, Univ. of Georgia, Athens, 1999), pp. 443–446.
31. R. Ervin and J. Lee, *J. Soil Water Conserv.* **49**, 430 (1994); N. Godon and P. Todhunter, *Atmos. Environ.* **32**, 1587 (1998); P. Todhunter and L. Cihacek, *J. Soil Water Conserv.* **54**, 543 (1999).
32. S. Trimble, F. Weirich, B. Hoag, *Water Resour. Res.* **23**, 425 (1987); K. Potter, *Water Resour. Res.* **27**, 845 (1991); W. Gebert and W. Krug, *Water Resour. Bull.* **32**, 733 (1996); W. Krug, *J. Am. Water Resour. Assoc.* **32**, 745 (1996); P. Price, thesis, Univ. of Calfornia, Los Angeles (1998); J. Knox, in *Fluvial Processes and Environmental Change*, A. Brown and T. Quine, Eds. (Wiley, Chichester, UK, 1999), pp. 255–282.
33. S. Trimble, in *Landscapes of Wisconsin*, B. Zakrzewska-Borowiecki, Ed. (Association of American Geographers, Washington, DC, 1975), pp. 24–29; S. Trimble, in *Proceedings of the Third Federal Interagency Sedimentation Conference* (Water Resources Council, Washington, DC, 1976), section 5, pp. 100–112. J. Knox, *Ann. Assoc. Am. Geogr.* **67**, 323 (1977); F. Magilligan, *Ann. Assoc. Am. Geogr.* **75**, 583 (1985).
34. W. Thorn *et al.*, *N. Am. J. Fish. Manag.* **17**, 860 (1997).
35. S. Trimble, *Phys. Geogr.* **14**, 285 (1993); S. Trimble, *Environ. Geol.* **32**, 230 (1997).
36. L. Leopold and W. Emmett, *Bull. Int. Assoc. Sci. Hydrol.* **10**, 12 (1965); W. Emmett and R. Hadley, *U.S. Geol. Surv. Circ. 460-C* (1968); W. Emmett, *Zeits. F. Geomorph. Suppl.* **21**, 52 (1974); W. Osterkamp, W. Emmett, L. Leopold, *Eos* **71**, 338 (1990); T. Orr and W. Osterkamp, *Eos* **80** (3 August 1999).
37. National Oceanic and Atmospheric Administration, Storm Data (National Climatic Data Center, Asheville, NC, published monthly).

38. We thank the following for reviews of earlier versions of this paper: R. Brown, T. Diehl, T. Dunne, W. Emmett, D. Favis-Mortlock, J. Lee, R. Mattoni, A. Mendel, R. H. Meade, D. Richter, S. Schumm, L. Smith, P. Todhunter, R. Vance, and M. G. Wolman. We also thank three anonymous *Science* reviewers.

http://www.jstor.org

LINKED CITATIONS

You have printed the following article:

U.S. Soil Erosion Rates: Myth and Reality
Stanley W. Trimble; Pierre Crosson
Science, New Series, Vol. 289, No. 5477. (Jul. 14, 2000), pp. 248-250.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2820000714%293%3A289%3A5477%3C248%3AUSERMA%3E2.0.CO%3B2-M

This article references the following linked citations. If you are trying to access articles from an off-campus location, you may be required to first logon via your library web site to access JSTOR. Please visit your library's website or contact a librarian to learn about options for remote access to JSTOR.

References and Notes

[3] **Soil Erosion Estimates and Costs**
Pierre Crosson; David Pimentel; C. Harvey; P. Resosudarmo; K. Sinclair; D. Kurz; M. McNair; S. Crist; L. Shpritz; L. Fitton; R. Saffouri; R. Blair
Science, New Series, Vol. 269, No. 5223. (Jul. 28, 1995), pp. 461-465.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819950728%293%3A269%3A5223%3C461%3ASEEAC%3E2.0.CO%3B2-T

[5] **Environmental and Economic Costs of Soil Erosion and Conservation Benefits**
David Pimentel; C. Harvey; P. Resosudarmo; K. Sinclair; D. Kurz; M. McNair; S. Crist; L. Shpritz; L. Fitton; R. Saffouri; R. Blair
Science, New Series, Vol. 267, No. 5201. (Feb. 24, 1995), pp. 1117-1123.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819950224%293%3A267%3A5201%3C1117%3AEAECOS%3E2.0.CO%3B2-4

[6] **Land Degradation: Effects on Food and Energy Resources**
David Pimentel; Elinor C. Terhune; Rada Dyson-Hudson; Stephen Rochereau; Robert Samis; Eric A. Smith; Daniel Denman; David Reifschneider; Michael Shepard
Science, New Series, Vol. 194, No. 4261. (Oct. 8, 1976), pp. 149-155.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819761008%293%3A194%3A4261%3C149%3ALDEOFA%3E2.0.CO%3B2-7

NOTE: *The reference numbering from the original has been maintained in this citation list.*

http://www.jstor.org

LINKED CITATIONS

[7] **Environmental and Economic Costs of Soil Erosion and Conservation Benefits**
David Pimentel; C. Harvey; P. Resosudarmo; K. Sinclair; D. Kurz; M. McNair; S. Crist; L. Shpritz; L. Fitton; R. Saffouri; R. Blair
Science, New Series, Vol. 267, No. 5201. (Feb. 24, 1995), pp. 1117-1123.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819950224%293%3A267%3A5201%3C1117%3AEAECOS%3E2.0.CO%3B2-4

[25] **Rates of Soil Erosion**
David Pimentel; Edward L. Skidmore; Stanley W. Trimble
Science, New Series, Vol. 286, No. 5444. (Nov. 19, 1999), pp. 1477-1478.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819991119%293%3A286%3A5444%3C1477%3AROSE%3E2.0.CO%3B2-L

[27] **Decreased Rates of Alluvial Sediment Storage in the Coon Creek Basin, Wisconsin, 1975-93**
Stanley W. Trimble
Science, New Series, Vol. 285, No. 5431. (Aug. 20, 1999), pp. 1244-1246.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819990820%293%3A285%3A5431%3C1244%3ADROASS%3E2.0.CO%3B2-V

[27] **Rates of Soil Erosion**
David Pimentel; Edward L. Skidmore; Stanley W. Trimble
Science, New Series, Vol. 286, No. 5444. (Nov. 19, 1999), pp. 1477-1478.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819991119%293%3A286%3A5444%3C1477%3AROSE%3E2.0.CO%3B2-L

[28] **Denudation Studies: Can We Assume Stream Steady State?**
Stanley W. Trimble
Science, New Series, Vol. 188, No. 4194. (Jun. 20, 1975), pp. 1207-1208.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819750620%293%3A188%3A4194%3C1207%3ADSCWAS%3E2.0.CO%3B2-6

[28] **Unsteady State Denudation**
S. A. Schumm; M. P. Mosley; G. L. Zimpfer; S. W. Trimble
Science, New Series, Vol. 191, No. 4229. (Feb. 27, 1976), p. 871.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819760227%293%3A191%3A4229%3C871%3AUSD%3E2.0.CO%3B2-2

NOTE: *The reference numbering from the original has been maintained in this citation list.*

LINKED CITATIONS

[28] **Unsteady State Denudation**
S. A. Schumm; M. P. Mosley; G. L. Zimpfer; S. W. Trimble
Science, New Series, Vol. 191, No. 4229. (Feb. 27, 1976), p. 871.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819760227%293%3A191%3A4229%3C871%3AUSD%3E2.0.CO%3B2-2

[28] **Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed**
Stanley W. Trimble
Science, New Series, Vol. 278, No. 5342. (Nov. 21, 1997), pp. 1442-1444.
Stable URL:
http://links.jstor.org/sici?sici=0036-8075%2819971121%293%3A278%3A5342%3C1442%3ACOSCET%3E2.0.CO%3B2-9

[30] **Historical Valley Floor Sedimentation in the Upper Mississippi Valley**
James C. Knox
Annals of the Association of American Geographers, Vol. 77, No. 2. (Jun., 1987), pp. 224-244.
Stable URL:
http://links.jstor.org/sici?sici=0004-5608%28198706%2977%3A2%3C224%3AHVFSIT%3E2.0.CO%3B2-1

[30] **The Fate of Eroded Soil: Sediment Sinks and Sediment Budgets of Agrarian Landscapes in Southern Minnesota, 1851-1988**
Timothy Beach
Annals of the Association of American Geographers, Vol. 84, No. 1. (Mar., 1994), pp. 5-28.
Stable URL:
http://links.jstor.org/sici?sici=0004-5608%28199403%2984%3A1%3C5%3ATFOESS%3E2.0.CO%3B2-E

[33] **Human Impacts on Wisconsin Stream Channels**
James C. Knox
Annals of the Association of American Geographers, Vol. 67, No. 3. (Sep., 1977), pp. 323-342.
Stable URL:
http://links.jstor.org/sici?sici=0004-5608%28197709%2967%3A3%3C323%3AHIOWSC%3E2.0.CO%3B2-H

[33] **Historical Floodplain Sedimentation in the Galena River Basin, Wisconsin and Illinois**
Francis J. Magilligan
Annals of the Association of American Geographers, Vol. 75, No. 4. (Dec., 1985), pp. 583-594.
Stable URL:
http://links.jstor.org/sici?sici=0004-5608%28198512%2975%3A4%3C583%3AHFSITG%3E2.0.CO%3B2-H

NOTE: *The reference numbering from the original has been maintained in this citation list.*