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Water Quality Benefits from Control
of Soil Erosion

by

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Abstract

Nonpoint source agricultural pollution is a significant water quality problem. An understanding of the linkages between erosion and offsite damages is needed to effectively evaluate the benefits from erosion reduction. The linkages were modeled for several impact categories, and the offsite benefits from the 1983 soil conservation programs were estimated.

WATER QUALITY BENEFITS FROM CONTROL OF SOIL EROSION

Nonpoint source pollution resulting from agricultural production is a significant water quality problem throughout the United States. As point source discharges from municipalities and industrial plants come under greater control, the magnitude of nonpoint source contributions is being illustrated. Clark, et. al. estimate that sediment and the chemicals attached to it cause \$6.8 billion in offsite damages every year, of which \$2.2 billion can be attributed to cropland erosion. The implication of this is that the potential offsite benefits from reducing soil erosion are significant. Programs aimed at conservation, such as the Agricultural Conservation Program (ACP), Conservation Technical Assistance Program (CTA), and the Great Plains Conservation Program (GPCP) probably have a sizable offsite benefit component. In addition, agricultural programs which influence land use or cropping patterns will alter the amount of soil reaching waterways, and generate offsite impacts. The conservation components of the 1985 Farm Bill, including the conservation reserve, sodbuster, swampbuster, and conservation compliance, may have tremendous impacts on water quality. Offsite impacts need to be considered in evaluating the relative merits of the programs.

In this paper, the linkage between soil erosion and offsite damages are first presented. These linkages must be fully understood before the offsite benefits from erosion reductions can be assessed. Next, the results of an empirical evaluation of the offsite benefits from the major USDA soil conservation programs, and implications are presented.

Conceptual Framework

The relationship between soil erosion and offsite damages is a complex one, involving physical, biological, and economic linkages (Figure 1). An understanding of these linkages is required in order to evaluate the offsite impacts of soil conservation measures. An understanding of these linkages can also illuminate areas where additional research is needed.

The first stage of the erosion process is the dislocation of soil at a site and its transport to the edge of the field. Soil loss is generally considered to be a function of rainfall erosivity, soil erodibility, slope length, slope, crop, management, and conservation practice. Soil is not the only item carried off the field by runoff. Nutrients and pesticides are also transported. These chemicals can either be adsorbed to soil particles, or be dissolved in the runoff. The Universal Soil Loss Equation describes the loss of sediment, and is the standard soil loss prediction tool (Wischmeier and Smith). Field scale models such as CREAMS (Knisel) have been developed which can trace the movement of nutrients to the edge of the field.

The second link consists of the movement of soil and agrichemicals from the edge of the field to a natural or manmade waterway. The amounts of sediment and chemicals which reach a waterway depend on factors such as distance, slope, and the amount of vegetation. Several watershed scale models have been developed which predict sediment and chemical discharges into waterways, including LANDRUN (Novotny and Chin), ARM (Donigian and Crawford), and ANSWERS (Lake). Resources for the Future has developed a national scale inventory of long run sediment and chemical delivery to waterways (Gianessi, Peskin, and Puffer). While not technically a model, this inventory can be used to predict changes in the delivery of pollutants to waterways given changes in erosion.

The third link is the impact that the agricultural pollutants which are discharged into waterways have on physical and biological measures of water quality. Physical measures of water include dissolved oxygen, temperature, turbidity, pH, odor, nutrient concentrations, and the concentrations of other chemicals. Biological measures of water quality include fish populations, algae levels, and zooplankton and bacteria concentrations. This link has not been modeled to a great degree. Resources for the Future has come closest to developing a national discharge to which links pollutants discharge to physical water quality parameters (Gianessi, Peskin, and Young). Impacts of pollutants on biological water quality parameters have been studied in the laboratory, but generally have not been modeled in a natural setting.

The fourth link in the process is how changes in water quality parameters affect the use of water resources, both instream and offstream. The recreation potential for a site can be affected by changes in the biological characteristics of the waterbody, and its physical appearance. Reductions in fish populations, algae blooms, turbidity, and foul odors can all reduce the attractiveness of a recreation site. Suspended sediment, algae, and dissolved chemicals can increase the amount of filtering and other treatment required by withdrawal users of water. Eroded soil can clog navigation channels and water conveyance systems, such as roadside ditches. Sediment can fill valuable reservoir capacity. Sedimentation of stream beds can also lead to an increase in the frequency and severity of flooding. This link has been modeled for several localized problem areas, including the sedimentation of reservoirs

(Lee and Guntermann) and ditches (Ibrahim and Forster), and increased treatment needs for drinking supplies (Moore and McCarl). Impacts on other activities such as recreation and commercial fishing have not been modeled because the relationships between pollutants and biological parameters (third link), and between water quality and recreation behavior are not clearly understood.

The fifth and final linkage is the economic value of the erosion-induced impacts on human activity. These are measured by changes in treatment and dredging costs, changes in damages due to agricultural pollutants, and changes in the willingness to pay for recreation at a site. Damage functions which link erosion to economic values have been developed for ditch and reservoir siltation (Lee and Guntermann), and for drinking water treatment (Birch, Sandretto, and Libby; SIMPAC). Economists have at their disposal methods for valuing changes in activities such as recreation and commercial fishing, but the third and fourth linkages need to be better developed before such tools can be effectively applied.

The above discussion indicates areas of research which could provide major contributions to the analysis of how erosion affects water users. The major gaps in understanding the relationship between erosion and offsite damages is being able to model how marginal changes in discharged pollutants affect the physical and biological measures of water quality, and how these changes affect technology and human behavior. Given the growing interest in the relationship between agriculture and the offsite impacts of soil erosion, the development of a model which links behavior to erosion would be of prime importance.

Conservation Program Evaluation

We undertook a study to determine the magnitude of the offsite benefits attributable to USDA's soil conservation programs for fiscal year 1983 as part of a larger Economic Research Service study of the cost and benefits of the programs. The programs evaluated were ACP, CTA, and GPCP. The procedures developed for estimating offsite benefits were based on the linkages outlined above. However, a lack of data at times necessitated making assumptions about certain linkages, rather than explicitly modeling them.

Procedures

Before the procedures could be developed, the extent of the offsite damages from soil erosion had to be determined at the regional level (Farm Production Regions). Ten major categories of offsite damages were addressed: recreation, water storages, navigation, commercial fishing, flooding, water conveyance, water treatment, municipal and industrial use, stream electric cooling, and irrigated agriculture. Regional damages for each of the categories were based on the national estimates developed by Clark, et al. These damages served as the baseline for determining benefits. (For a discussion of how the regional damage estimates were derived, see Ribaudo (1986b)).

The offsite economic benefits from a reduction in soil erosion is equal to the reduction in offsite damages caused by soil erosion. Damage reductions take the form of reduced dredging costs, reductions in the operating costs to industry and other offstream water users, reduced flooding damages, and increase consumer surplus to recreationists. Reductions in damages can only be determined by accounting for all the links between onsite erosion and the actual measurement of damages.

Reductions in sheet and rill, gully, and streambank erosion generated by soil conservation practices installed in 1983 under ACP, CTA, and GPCP were estimated using data from the Conservation Reporting and Evaluation System (CRES). This data represents the first linkage. The CRES data set consisted of 32,000 observations in 227 sample counties, and represented 35 million acres of land treated for water induced soil erosion in 1983.

In order to simplify the analysis, the ten damage categories were lumped into three groups. It was assumed that benefits accruing to each category in a particular group could be estimated using the same procedure, or the same assumptions about the characteristics of the linkages between erosion and damages. The three groups are recreation and commercial fishing; drainage and irrigation ditches; and water storage, flooding, navigation, and municipal and industrial withdrawal.

The procedure for estimating the benefits to drainage and irrigation ditches assumed a linear relationship between sheet and rill and gully erosion, and damages. It was assumed that streambank erosion has no impact on drainage ditches and irrigation canals. The procedure implies that the linkages between erosion and damages are very simple, and do not need to be explicitly modeled.

The procedure for estimating the benefits to water storage, navigation, water withdrawal, and from reduced flooding assumed a direct relationship between sediment discharged into waterways and damages. The second linkage, the movement of soil from the edge of the field to the waterway, was accounted for with the use of sediment delivery ratios developed by Resources for the Future (Gianessi, Peskin, and Poles). These ratios are defined as the portion of eroded sediment reaching a stream, rather than the usual definition of the portion of eroded sediment exiting a watershed. Streambank erosion was assumed to have a sediment delivery ratio of one. Sediment delivery ratios were otherwise between .3 and .5. To calculate benefits, the percent reduction in eroded material being discharged into waterways was applied to regional offsite damages.

Estimation of benefits for recreation and commercial fishing, both freshwater and marine, required a much different procedure. Damages to recreation and commercial fishing are largely dependent upon ambient concentration of pollutants. A direct relationship between eroded material reaching waterways and damages could not be assumed. Instead, the third and fourth linkages were explicitly modeled. Each Farm Production Region (FPR) was disaggregated into smaller watershed units called Aggregated Subareas (ASA). The concentrations of pollutants in each ASA were determined using 1982 and 1983 data from the National Stream Quality Monitoring Network (NASQUAN) maintained by the U.S. Geological Survey. These concentrations of pollutants were used in determining the degree to which activities in each FPR are affected by erosion related pollutants. If the level of suspended solids, total phosphorus, or total nitrogen in an ASA were greater than predetermined threshold levels, then water uses in that region were assumed to be adversely affected (fourth linkage). For each FPR, the total amount of soil saved was converted to pollutant loadings by using the sediment delivery ratios and attached pollutant coefficients calculated by RFF (second linkage). A linear relationship between ambient pollutant concentrations and pollutant loadings was assumed (third linkage). Percentage reductions in loadings were calculated at the FPR level, and applied to pollutant concentrations in the ASA's within the region. If ambient concentrations of all pollutants in an ASA dropped below the threshold level, then benefits could be calculated by determining the reduction in the amount of the activity being affected by poor water quality (fifth linkage).

The above procedure makes the assumption that benefits are generated only when the threshold levels are passed. When pollutant concentrations remain above the thresholds after erosion reductions (water quality remains poor), this assumption is probably a good one. However, there is evidence that benefits may result when improvements occur to water which was of already acceptable quality (concentrations are below the thresholds). This is likely to result in the generation of recreation benefits. Unfortunately, very little work has been done on linking recreation behavior or fishing success to small changes in water quality. It was therefore necessary to assume that benefits result only when predetermined threshold levels of pollutant concentrations are passed.

Results

The present value of offsite benefits from installation of practices and structures in 1983 to reduce sheet and rill, gully, and streambank erosion total $340 million over the lifespans of the practices installed, assuming a 4% discount rate. The 4% rate was selected as the approximate long term real rate of return on capital. Benefits were found to range between $201 and $507 million, based on the range of offsite damages presented by Clark. Our estimate of benefits is not directly comparable to Clark's estimate of damages, since he estimated annual damages while we estimate the present value of the streams of benefits generated over the service lives of the conservation practices installed.

For the three damage categories outlined above, the benefits from reduced damages to ditches and canals totalled $31 million, the benefits to water storage, flooding, navigation, and municipal and industrial withdrawal totalled $309 million, and the benefits to recreation and commercial fishing were zero (Table 1). The reason for this last, surprising, result is that the estimated reduction in soil erosion from the programs was so small that the estimated reductions in pollutant loadings were not sufficient in any of the polluted ASA's to lower the ambient concentrations of suspended solids, nitrogen or phosphorus below the threshold levels.

This last result is not likely to be accurate, and may indicate problems in the procedures used. One of the drawbacks of an aggregate analysis such as this is that local improvements in water quality within an FPR would be missed. If most of the erosion reduction in a region was concentrated in a few ASA's, instead of being evenly distributed across an FPR, as was implicitly assumed, then it is likely that there would be a significant improvement in water quality in these ASA's. Positive benefits would then be generated in FPR's containing those ASA's. For example, analysis of the experimental Rural Clean Water Program found positive offsite recreation benefits attributable the use of soil conservation practices (Young and Magleby). The concentration of practices in a project area was much greater for the Rural Clean Water Program than for the programs evaluated in this analysis, which increases the likelihood of threshold's being exceeded.

Another potential problem is the NASQUAN data set. There is some question as to whether the NASQUAN data adequately represents the average water quality of a region. However, the NASQUAN data were deemed the best available.

Benefits were probably also underestimated for the reasons outlined earlier; improvements in already acceptable water quality were assumed to generate no benefits. However, due to the small changes in water quality estimated for the programs, this downward bias in benefits is likely to be small. Further refinement of the benefit estimates is dependent on developing a better understanding of the relationships between marginal changes in water quality and marginal changes in offsite impacts, especially for changes in fish populations and recreational activities. For example, if the threshold assumption is relaxed the potential increase in recreation and commercial fishing benefits is significant. If we assume that recreation and commercial fishing damages are reduced proportionately to the reductions in pollutant loading, total offsite benefits increase by $231 million, a 68 percent increase.

Implications

From society's perspective the offsite benefits generated from control of soil erosion are significant. Data on magnitude of offsite benefits and damages can be useful in designing new programs or in altering existing ones in order to maximize net benefits. By targeting critical areas for erosion control offsite benefits can be increased significantly. We calculated that 61 percent of the offsite benefits were generated on land eroding at greater than two times the accepted soil loss tolerance level, which constituted only 30 percent of the acreage treated. In a recent article, Ribaudo (1986 a) demonstrated that physical measures of damages can be used to target erosion control programs. Estimates of the economic value of these damages enhances our ability to target.

From an offsite benefits perspective the origin of the eroded soil is generally unimportant, unless the characteristics of the soil are such that it is more damaging (eg, has more nutrients associated with it). Thus, benefits per ton of erosion reduction may depend more on the demand for water resources and water quality than on the magnitude of erosion. Targeting efforts can be further refined by focusing on offsite impacts that have high economic values. In discussing recreation benefits we illustrated potentially high benefits estimates that can be obtained if water quality improves sufficiently. If nonpoint source programs are focused in smaller areas, such as in the manner of the Rural Clean Water Program, targeting for improved recreational opportunities can result in significant offsite benefits.

This study is, to our knowledge, the first attempt to estimate the offsite benefits of specific reductions in erosion resulting from national soil conservation programs. Shortcomings in the data and in analytical techniques surfaced as a result of this analysis. However, the estimated offsite benefits are quite sizable, especially when the relatively small reductions in erosion are considered. These benefits need to be considered in conjunction with productivity and offsite wind erosion benefits when evaluating agricultural programs, especially soil conservation programs.

Figure 1 - Offsite Erosion Impact Linkages

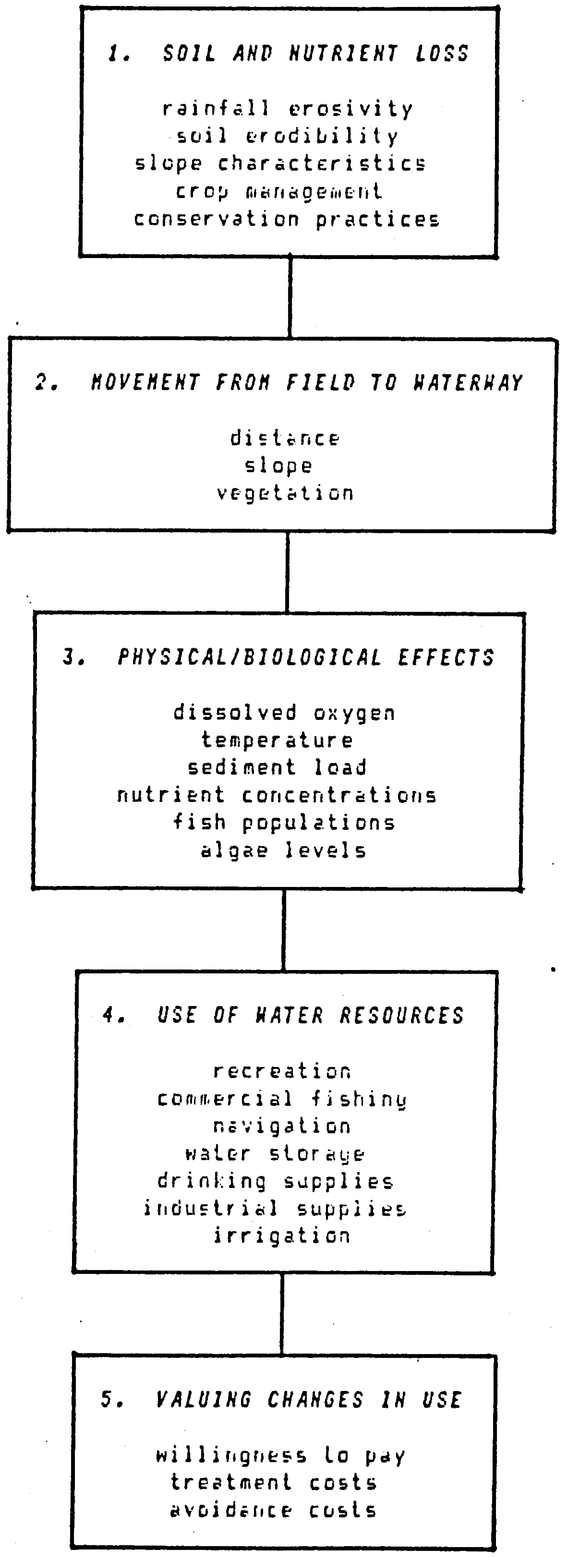

Table 1 -- Offsite Benefits from Erosion Reduction by Damage Category

Damage Category	Benefits "best"	range
	($million)	
Recreation	0	0
Water Storage	86	47-124
Navigation	54	38-67
Commercial Fishing	0	0
Flooding	70	46-111
Water Conveyance	31	16-36
Water Treatment	10	5-50
Municipal and Industrial	85	47-113
Stream-Electric Cooling	2	2-3
Irrigated Agriculture	2	0-3
TOTAL	340	201-507

Table 2 Acres Treated, Erosion Reduction, and Off-site Benefits from 1983 Soil Conservation Programs, by Region

Farm Production Region	Offsite Benefits	Erosion Reduction Over time 2/	Acres Treated 1/	Benefits Per ton Saved	Benefits Per Acre Treated
	($1000)	(1000 tons)	(1000 acres)	($)	($)
Appalachian	35,000	66,000	1,300	.53	126.90
Corn Belt	7,000	94,000	2,100	.29	12.80
Delta State	29,000	27,000	2,200	1.07	13.20
Lake State	15,000	11,000	1,000	1.36	15.00
Mountain States	33,000	72,000	6,900	.46	4.80
Northeast	12,000	8,000	500	1.50	24.00
Northern Plains	18,000	65,000	2,600	.28	6.90
Pacific	24,000	31,000	1,100	.77	21.80
Southeast	38,000	48,000	1,200	.79	31.70
Southern Plains	109,000	189,000	16,000	.59	6.80
Total	340,000	611,000	34,900	.56	9.70

1/ Includes acres treated for sheet and rill erosion only.
2/ Includes reductions in sheet and rill, gully, and streambank erosion.

Table 3 -- Acres Treated, Erosion Reduction, and Offsite Benefits from 1983 Soil Conservation Program, by Erosion Rate.

Erosion Rate 1/	Acres Treated 3/	Erosion Reduction Over time	Offsite Benefits	Benefits per Acre Treated
	(1000 acres)	(1000 tons)	($1000)	($)
< T	15,800	66,000	35,000	2.20
T - 2T	8,500	117,000	69,000	8.10
2T - 4T	8,200	149,000	88,000	10.70
> 4T	2,400	221,000	115,000	47.90
Other 2/	-	58,000	33,000	-
Total	34,900	611,000	334,000	9.70

1/ Sheet and rill and wind erosion.
2/ Includes gully and streambank erosion.
3/ Sheet and rill erosion only.

References

Birch, A., C. Sandretto, and L.W. Libby. Toward Measurement of the Off-Site Benefits of Soil Conservation. Ag. Econ. Report No. 431, Michigan State University, East Lansing, MI (1983).

Clark, E.H., II, J.A. Haverkamp, and W.Chapman. Eroding Soils: The Off-Farm Impacts. The Conservation Foundation, Washington, D.C. (1985)

Donigian, A.S., Jr. and N.H. Crawford. Modeling Pesticides and Nutrients on Agricultural Lands. EPA-600/2-76-043, U.S. Environmental Protection Agency, Athens, GA (1976).

Gianessi, L.P., H.M. Peskin, and T.S. Poles. Cropland Soil Erosion and Sediment: Discharge to Waterways in the United States. Resources for the Future, Washington, D.C. (1980).

Gianessi, L.P., H.M. Peskin, and C. Puffer. A National Data Base of Nonurban Nonpoint Source Discharges and their Effect on the Nation's Water Quality. Resources for the Future, Washington, D.C. (1985)

Ibrahim, G., and D.L. Forster. "Sediment Deposits in Drainage Ditches: A Cropland Externality." paper presented at AAEA annual meeting, Urbana-Champaign. IL (1980).

Knisel, W.G., editor. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Dept. of Ag., ARS, Conservation Res. Rep. No. 26. (1980).

Lake, J. Environmental Impact of Land Use on Water Quality. EPA-905/9-77-007-B U.S. Environmental Protection Agency, Chicago, IL (1977).

Lee, M.T. and K.L. Guntermann. "A Procedure for Estimating Off-Site Sediment Damage Costs and an Empirical Test." Water Resources Bulletin, Vol. 12 No. 3, pp.561-575 (1976).

Moore, W.B. and B.A. McCarl. "Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley." Technical Paper No.___, Oregon State University Ag. Exp. Sta., Corvalis, OR (1985).

Novotny, V. and M.A. Chin. "Nonpoint Overland Pollution Transport Model." (In) LANDRUN Users Manual, Department of Engineering, Marquette University, Milwaukee, WI (1976).

Ribaudo, M.O. "Consideration of Offsite Impacts in Targeting Soil Conservation Programs. "Land Economics (forthcoming, 1986 a).

Ribaudo, M.O. "Regional Estimates of Damages from Soil Erosion." (In) Off-Site Costs of Soil Erosion. (E. Clark and T. Waddell, eds.), The Conservation Foundation, Washington, D.C. (forthcoming, 1986 b).

Southwestern Illinois Metropolitan and Regional Planning Commission (SIMPAC). Highland Silver Lake Comprehensive Monitoring and Evaluation Project: Assessment of Off-Site Socio-Economic Impacts. SIMPAC, Collinsville, Il (1983).

Wischmeier, W.H. and D.D. Smith. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountians. U.S. Dept. of Ag., ARS, Ag. Handbook No. 282, Washington, D.C. (1965).

Young, C.E. and R.S. Magleby. "Economic Benefits of Three Rural Clean Water Projects." (In) Off-site Costs of Soil Erosion, (E. Clark and T. Waddell, Eds.) The Conservation Foundation, Washington, D.C. (forthcoming 1986).