Soil Erosion and Soil Conservation Policy in the United States

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SOIL EROSION AND SOIL CONSERVATION

POLICY IN THE UNITED STATES

A report prepared by An

American Agricultural Economics

Association Task Force*

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*Task Force members were: Pierre Crosson, Resources for the Future, Chairman; Klaus Alt, Economic Research Service, U.S. Department of Agriculture; Oscar Burt, Montana State University; Edwin H. Clark, II, The Conservation Foundation; William E. Larson, University of Minnesota; Lawrence Libby, Michigan State University; Don McCormack, Soil Conservation Service, U.S. Department of Agriculture; Earl Swanson, University of Illinois; David Walker, University of Idaho.

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Preface

The American Agricultural Economics Association Task Force on Soil Conservation Policy was appointed by Association President Leo Polopolus on January 28, 1983. The Task Force, one of three authorized by the AAEA Executive Board at its November, 1981 meeting in St. Louis, was charged by President Polopolus to prepare a "think piece" that would discuss key issues of soil conservation policy and identify the research needed to strengthen the policy process.

The report deals exclusively with problems and policies associated with soil erosion. Land degradation resulting from soil compaction and salination in irrigated areas may also raise policy issues. We believe, however, that in a national perspective, these issues are probably substantially less important than soil erosion, and we do not address them.

This discussion deals primarily with sheet and rill erosion. Data on wind erosion are presented, but the processes and consequences of wind erosion are less well understood than those of sheet and rill erosion. For the nation, sheet and rill erosion moves about twice as much soil as wind erosion, and wind erosion presents much the same sorts of policy issues as sheet and rill erosion. While for these reasons we believe our neglect of wind erosion is not a major weakness, we also maintain that more research is needed to better understand wind erosion.

Gully erosion may reduce the productivity of the soil and contribute significantly to downstream sedimentation in some areas. However, little reliable information is available about gully erosion, and we do not discuss it.

This report represents a joint effort. Not all Task Force members are completely comfortable with all parts of it, one or two believing that the main thrust may give less weight to the erosion problem than it deserves. The members are unanimous in their belief, however, that the problem is significant and deserving of increased analytical efforts to understand it better, and that vigorous policy action is required to bring it within socially acceptable limits.

The Task Force received excellent support and encouragement from past AAEA Presidents G. Edward Schuh, Leo Polopolus, and Neil E. Harl and from current President Chester Baker. We appreciate their help.

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Chapter 1

WHY IS SOIL EROSION A POLICY ISSUE?

Introduction

Since the early 1970s, soil erosion has attracted more attention from conservationists, agricultural economists, and the general public than at any time since the Dustbowl years of the 1930s. The main reason for this was a perception that erosion increased sharply in the 1970s, and an expectation that additional increases were likely. Evidence supported the perception, and the expectation was not unreasonable. After several decades of decline, harvested cropland increased about 60 million acres from 1972 to 1981 as farmers responded to the pressure of rising export demand and relatively slow growth of crop yields.

A survey by the Soil Conservation Service (SCS) in 1975 showed that erosion on the additional land was typically much higher than on land already in production. And the National Resources Inventory (NRI) of 1977 indicated that on 23 percent of the nation's cropland sheet and rill (water) erosion exceeded 5 tons per acre per year, the amount believed by many conservationists to be the maximum consistent with indefinite maintenance of the productivity of the soil. (On thin soils with unfavorable sub-soils the maximum is less than 5 tons.) Taking wind erosion into account, soil loss exceeded 5 tons per acre per year on about one-third of the cropland base.

A number of projections of crop demand and of technology suggested that some tens of millions of additional acres of land would be brought under crop over the next several decades and that this would induce a substantial increase in erosion over the perceived high levels of the 1970s.[1] Taken together, the experience of the 1970s and the expectations for the future were seen by many as grounds for serious concern that erosion threatened the nation's capacity to meet rising domestic and foreign demand for food and fiber at reasonable cost.

Kinds of Erosion Damage

Erosion poses the threat of two kinds of damage: (1) on-farm losses of soil productivity and (2) off-farm pollution of air and water and accelerated sedimentation of lakes, reservoirs, and harbors. The principal rationale for erosion control policies has always been prevention of productivity loss.[2] Reduction of off-farm damages has been regarded as much less important, almost an afterthought. However, the intellectual case for policies to control off-farm damages is much stronger than the case for preventing productivity loss. Off-farm damages are clearly external costs of farm operations, imposed under technical and institutional conditions which make unfeasible the kind of private bargaining envisioned by Coase (1960) that would lead to internalization of the costs, hence to a socially satisfactory outcome. Off-farm damages, therefore, invite public intervention under market failure criteria accepted not only by economists but by the general public as well. In the absence of intervention, the farmer has no more incentive to reduce off-site damages by controlling erosion than the power plant operator has to reduce sulphur dioxide emissions by installing scrubbers. We have not hesitated to make the latter a necessary requirement , but the farmer has been virtually exempt.[3]

By contrast, the costs imposed by productivity loss are internal to the farm. The farmer bears them and has the incentive to hold them in check whenever they threaten to exceed the cost of erosion control. What are the arguments for believing that the social interest requires policies to achieve a measure of control beyond what the farmer will undertake on his own initiative? There are two such arguments. One is based on traditional market failure criteria and the other on the ethical precept of intergenerational equity.

Rationale for Policies to Protect Soil Productivity

Market failure. The market failure argument rests on the key assumption of welfare economics that in the absence of failure the amount of investment in soil conservation (and everything else) will be both socially optimal and optimal for each individual farmer. Failure results in divergence between the social interest and the private interest in conservation.

There are two reasons why failure might occur: (1) the market may not signal to farmers that they should invest more to protect the productivity of the land; (2) while the market signals may be appropriate, the farmers' responses could be inhibited by institutional constraints.

The market sends many signals to farmers. The one that counts in this context is the market determined present value of agricultural land in agricultural production, and the issue is the sensitivity of present value to effects of past erosion on the productivity of the soil. Suppose x is a continuous variable, such as depth of topsoil, which has been substantially affected by erosion rates in the past. Define the function f(x) as present value of the stream of rents earned by an acre of land when the <u>initial level</u> of the variable is x units and an optimal soil conservation policy is followed over an infinite planning horizon. The critical question is whether the market correctly reflects the slope of f(x) because the slope is marginal value of the variable x, that is, the increment in present value per acre associated with an increment in depth of topsoil. Thus, the level of the market value for land is unimportant; only its sensitivity to changes in state variables which describe future productivity of the soil is of consequence in the efficiency of the land market. To argue that the market does not signal farmers to invest enough in erosion control, therefore, is to argue that it underestimates the slope of a present value function such as f(x), as in figure 1-1.[4]

The literature gives a number of reasons why land markets might fail in this respect. (1) Sheet and rill erosion is an insidious process, not readily detectable on a yearly basis. Farmers may be unaware of it, therefore, leading them to systematically underestimate the long-term impact of erosion on productivity, thus overestimating the future supply of land. (2) The market may underestimate future demands for food and fiber, and so underestimate future commodity prices. (3) The market may overestimate the long-term interest rate appropriate for discounting returns to the land. (4) The market may overestimate the rate of development of new land-substituting technologies.[5]

The only honest response to the assertion that current markets may misvalue agricultural land for one or more of these reasons is "of course!" But is this sufficient to justify public intervention to achieve more erosion control than farmers would undertake on their own? Each of the various sorts of "market failure" reflects ignorance among farmers about future events affecting the supply of, and demand for, agricultural land for agricultural production. To use this as an argument for intervention, it is necessary to assume that those who would intervene are less ignorant about these events than farmers are.

The assumption may be legitimate, but it is not obviously so. Conservationists sometimes assert that farmers must be ignorant of the productivity effects of erosion, since so many of them regularly accept rates of erosion higher than the Soil Conservation Service believes are consistent with maintenance of long-term productivity. But, aside from questions about the scientific validity of the SCS standard (more on that later), the fact that a given rate of erosion will eventually reduce productivity does not mean that the time to control it is "now." The issue of intergenerational equity aside, the proper time, both for society and the farmer, is when the present value of marginal control costs falls below the present value of the marginal productivity loss. Farmers know this even if they do not engage in the details of present value calculations.

Further, farmers have a powerful incentive to learn about the effects of erosion on the productivity of their

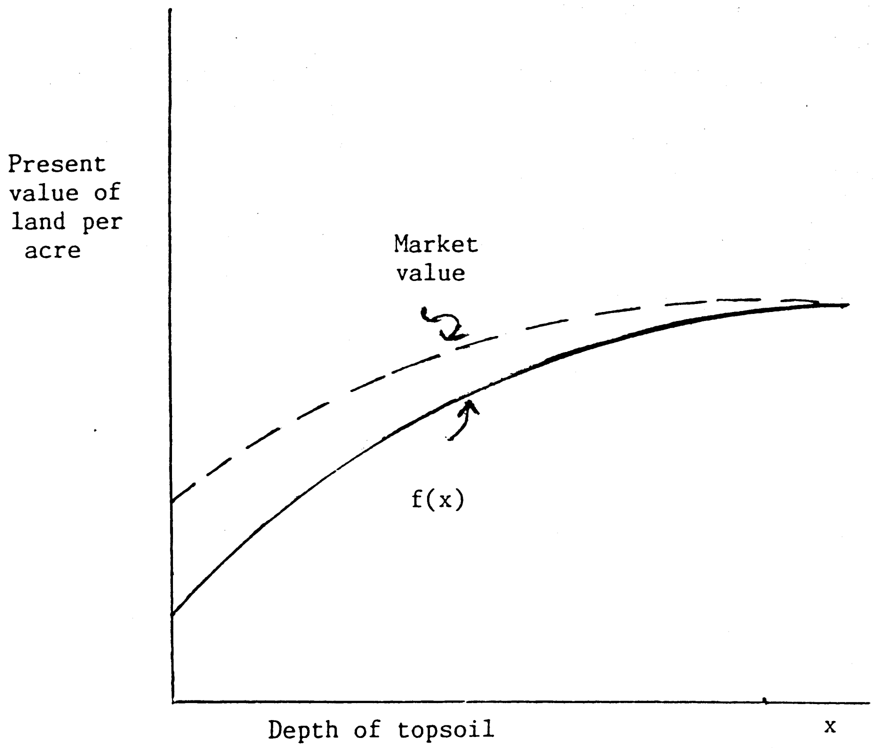

Figure 1-1.

IIllustrative Relationship Between
Soil Depth and Crop Yield

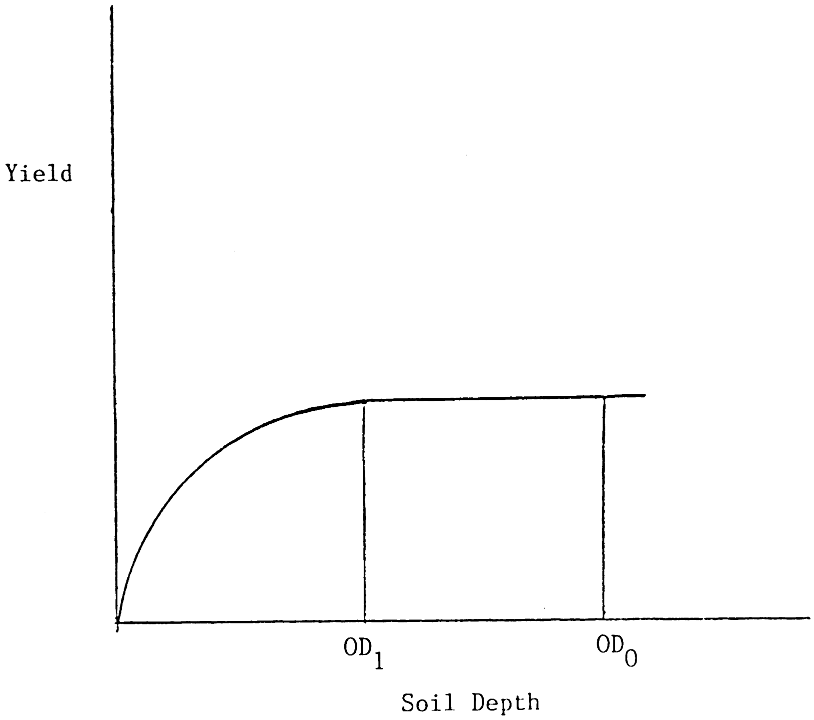

Figure 1-2.

land. For most of them, the land is by far their most important single asset. If it is threatened by erosion, it is very much in their interest to find out about it. No one has a greater incentive to get that information.

All this is not to argue that farmers are as well informed about the productivity effects of erosion as they could be, or in the social interest should be. Farmers are not soil scientists. What they know about erosion-productivity relationships is based primarily on their own experience with their own land. There is some scientific evidence, discussed in chapter 3, that on some soils (e.g., in western Iowa) even high rates of erosion have little effect on productivity over long periods, but that as soil depth diminishes the effect rather abruptly becomes increasingly severe. Figure 1-2 illustrates this relationship. A farmer who began with a soil depth of OD_0 inches and now has OD_1 inches could reasonably assume from his experience that continued erosion at the rate which brought him from OD_0 to OD_1 would pose little threat to the productivity of his land. He would be badly mistaken, however, and if he knew the shape of the erosion-productivity curve he would begin to think seriously about controlling erosion when he arrived at OD_1.

Clearly, farmers do not necessarily know enough about erosion-productivity relationships to assure a socially optimal level of investment in erosion control. It does not follow, however, that under present circumstances anyone else is sufficiently better informed about these relationships to override the farmers' decisions.

If farmers were wholly ignorant of the productivity effects of erosion, we would expect to find no difference between the prices of badly eroded and uneroded cropland. Though we have found no studies focused specifically on the relationship between land prices and degree of erosion, an analysis of the relationship between prices and indexes of crop yield of land in western Illinois found the relationship to be strongly positive (Reiss and Kensil, 1979). Although the study did not identify the sources of yield differences, it suggests that farmland prices do in fact reflect some if not all of the productivity effects of erosion insofar as these can be anticipated. Farmers may anticipate them poorly, particularly if the situation is as depicted in figure 1-2. But is anyone else likely to do better?

The same point can be made with respect to the other sources of possible market failure. Is there reason to believe that those who would override the market can do better than the market in predicting future prices of food and fiber, interest rates, and the rate of emergence of economical land-saving technologies?[6] The answer is not obviously yes, to say the least. These are matters about which everyone is ignorant, and it is by no means clear that those who make the market for agricultural land are more ignorant of them than those who would alter the market outcome.

We do not mean to imply that soil conservation efforts could not be strengthened by publicly supported research to improve our ability to forecast the future demand for, and supply of, agricultural land. In particular, study of the long-term effects of erosion on the productivity of different types of soils could help farmers to make better informed decisions about how much and when to invest in soil conservation. Our point here is that in our present state of knowledge it is questionable whether farmers are less well informed about the need for more soil conservation than anyone else.

The other line of argument for market failure focuses on institutional constraints which inhibit farmers from undertaking the socially optimal amount of soil conservation. Tenants are alleged to have weaker incentives to control erosion than owner-operators. The main reason is that because leases are typically short-term with no firm assurance of renewal, tenants cannot expect to reap the benefits of long-term investments in erosion control, such as terracing. The argument is also sometimes made that farmers underinvest in erosion control because their own resources are too limited and credit is rationed or in terms not sufficiently favorable. Once implication of this is that smaller farmers are more likely to underinvest than larger farmers.

Lee (1983), using data from the 1977 NRI and a 1978 survey of land ownership done by the U.S. Department of Agriculture (USDA), found that erosion on small farms was higher than on larger farms. This was not because smaller farmers had more erodible land, since the percentage distribution of erosion-prone land did not vary among size classes. Nor was the difference attributable to tenure differences across size classes. Lee found that relatively fewer smaller farmers used minimum tillage, and she cites other studies showing that smaller farmers are less likely to invest in terraces and other erosion control practices than larger farmers. She speculates that lower profit margins among smaller farmers may explain the latter and that larger farmers are more likely to adopt minimum tillage because its labor saving characteristics are more valuable to them.

Using the 1977 NRI data and 1978 land ownership data Lee (1980) also studied the relationship between tenancy and erosion. Though she found no statistically significant relationship in this study, she did not take into account differences in soil erodibility, and this may have affected her results.

Ervin (1982) studied 121 randomly selected farms in a county in northern Missouri. He found that erosion per acre was higher on rented land than on owner-operated land, although there was some doubt whether the difference was statistically significant. He also found, however, that <u>potential</u> erosion on owner-operated land was significantly higher, suggesting that the lower actual erosion on that land reflected greater erosion control efforts by owners than by renters.[7] In fact owner-operators had more of their land under some kind of erosion control than renters.

Dillman and Carlson (1982) reported the results of a study of the relationship between tenure and attitudes toward erosion control among farmers in the Palouse region of the Pacific Northwest. They addressed the hypothesis that absentee-owner attitudes discourage the adoption of soil conservation practices by renter-operators, a twist on the usually accepted theory which sees the latter as the principal obstacle. The results gave little support to the hypothesis, however, and Dillman and Carlson concluded that

> ...landlords have not abdicated their stewardship responsibility by establishing lease arrangements that encourage exploitation by farm operators. Crop-share arrangements, low-turnover rates, long-term leases and significant kinship relationships suggest an enduring, trusting relationship between most landlords and their farm operators. (p. 41)

Dillman and Carlson do not generalize their results to other regions, nor does Ervin.

If there have been any careful studies on the impact of credit market constraints on erosion control incentives, we have not found them. It is easy to believe that in times of tight credit, as in 1981-82, some farmers would find difficulty in getting all the credit they would be willing to pay for. And it is not hard to believe that smaller farmers are more likely to be found in this position than larger farmers. But the issue is the importance of this constraint over the longterm in deterring erosion control investments that farmers would otherwise like to make. To the best of our knowledge, this issue has not been investigated.

On balance, the market failure rationale for inducing farmers to invest more in erosion control than they would on their own initiative is not compelling. The argument that the capitalized value of the returns to land in agricultural production systematically understates the social value of the land in that use, leading to underinvestment in soil conservation, requires the assumption that those making the argument are better able than farmers to foresee the

Soil erosion

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SOIL CONSERVATION

long-term effects of supply and demand conditions on the value of agricultural land. We see little reason to make that assumption. This, however, does not rule out the the need for publicly-funded research to improve information available to farmers about long-term productivity effects of erosion and about other factors bearing on the future value of agricultural land.

Credit rationing as a constraint on soil conservation investments also appears not to have been adequately investigated, and the analysis of tenure effects is limited and gives somewhat conflicting results. Even if it were conclusively shown that on land of equal erosivity investment in soil conservation was systematically less on tenant-operated land than on owner-operated land, the inference of market failure would not necessarily follow. Assuming that the productivity effects of erosion were the same on both kinds of land, why would absentee landlords be less protective of the value of their land than owner-operators? An image is sometimes conveyed of widows or retired owners of midwestern farmland now living in Florida or California, ignorant of what is happening to their land and not interested enough to find out. This image evidently does not square with the actuality of the landlord's role in the Palouse region, as reported by Dillman and Carlson (1982). And we submit that this image does not correctly fit absentee owners of American farmland. For these people too land is a valuable asset, as it is for owner-operators. There is nothing about absenteeism per se that would make absentee owners less interested in maintaining the value of the land than owner-operators. This is not to say that absentee owners necessarily are as well informed as owner-operators about the productivity effects of erosion. The latter have day-to-day "hands on" contact with the land. But if absentee owners are less well informed, the extra cost of acquiring the information is a more likely explanation than lack of interest in the value of the land. Information costs are like any other costs of farming. Their existence is not evidence per se of market failure. The issue is whether the social value of the additional information is worth the costs of acquiring it.

Lee's study of the relationship of farm size to erosion demonstrates persuasively that smaller farms have more erosion than larger farms. If credit rationing to small farmers were the cause of this, the inference of market failure would have weight. No showing of credit rationing has been made, however. Lee speculates that smaller farmers have lower profit margins, and this inhibits them from investing as much in erosion control as they otherwise would. This suggests a kind of disequilibrium in farming, a tilt toward larger farms. For reasons of social policy, we may wish to resist this tendency toward increasing farm size, although we should recognize that, judging from Lee's data, higher erosion would probably be one of the costs of such a policy. But the rationale of the policy would be the preservation of social values associated with small farm size, not market failure resulting in higher erosion. On the contrary, Lee's data suggest that the market induced trend toward larger farms would reduce erosion.

<u>Intergenerational equity</u>. The ethical precept that each generation's management of resources should not disadvantage subsequent generations has always been at the core of the conservation movement. In the case of soil conservation, the precept has been stated as an obligation to so manage the soil as to maintain its productivity from one generation to the next.

Two questions arise. Is there an intergenerational obligation in the management of resources? Does acceptance of an obligation imply a role for soil conservation policy?

We do not here attempt to make an independent case for an answer to the first question. To do so would require a discussion of the philosophy of ethics, a field in which none of us has expertise. Instead, we make two points. One is that in our judgment the notion of an intergenerational obligation in resource management is widely accepted among the American people. The enduring strength of the environmental movement is partial evidence of this, although the movement is not concerned just with intergenerational equity. Further evidence is the appropriation and expenditure of tens of billions of public dollars (expressed in 1980 prices) for soil conservation over the last 50 years. As noted above, the principal rationale for these outlays was maintenance of the long-term productivity of the soil.

The second point is that there is a substantial body of literature in economics which explicitly accepts the notion of an intergenerational ethic. This is true of much of the literature on discounting, beginning with Ramsey's famous 1928 article in which he criticized discounting as "ethically indefensible" because it gives more weight to the interests of the present generation than to those of future generations. More recently, other economists (e.g., Solow, 1974 and Page, 1977), building on the work of the philosopher John Rawls (1971), have developed arguments for an intergenerational obligation in resource management and have considered the conditions necessary for meeting the obligation.

We thus duck the question of whether there is, in some objectively verifiable sense, an intergenerational ethical imperative to which each generation must conform in the management of the resources available to it. For our purposes, it is sufficient that the American people evidently accept such an imperative (however imperfectly they may abide by it) and that it finds a place in the intellectual tradition of economics.

The second question posed above was whether acceptance of an intergenerational obligation in soil management implies a role for soil conservation policy. One school of thought says no, unless it can be shown that the land market fails to properly reflect the effects of erosion on the future productivity of the land. The basis of the argument is that since the value of the land in agriculture is the present value of future returns to the land, a properly functioning land market will make socially adequate provisions for meeting future demands on the land. If the market indicates that demand will rise, or supply diminish, the present value of the land in agriculture will increase and farmers will be induced to protect it better against erosion. The future is adequately accommodated and there is no basis for public intervention to secure more erosion control than farmers voluntarily provide. With this argument, acceptance of the notion of intergenerational equity in land management does not per se make a case for intervention. For this it is necessary to show failure in the land market.

For reasons given above, we think the market failure case for intervention to protect soil productivity is weak. However, the argument for intervention based on intergenerational equity is not a market failure argument. Intergenerational equity concerns the distribution of income between the present and the future generations. Market failure concerns departures from social optima in resource allocation <u>within a given distribution of income</u>. It provides no criteria for judging better or worse among alternative distributions. Welfare economics, which provides the intellectual rationale for market failure analysis, regards income distribution as an ethical issue and therefore outside its purview. We think it significant in this connection that in a probing discussion of market failure issues, Randall (1983) had nothing to say about intergenerational equity, nor did he address any other aspects of income distribution as instances of market failure.[8]

Acceptance of the imperative of intergenerational equity thus makes a case in principle for policies to protect the productivity of the soil even if land and all other markets are working perfectly. No showing of market failure is necessary to justify intervention. Making the case for particular policies specifying where, when, how and how much, or even whether to intervene at all, is quite another matter, and we discuss it in detail in chapter 5.

Before these issues can be usefully addressed, however, it is necessary to have some understanding of the quantitative dimensions of the erosion problem in both its on-farm (productivity) and off-farm aspects. These matters are discussed in the next three chapters. Chapter 2 deals with what we now know about the amount of erosion from U.S. cropland, forest land, range and pasture. Chapter 3 discusses the effects of this on the productivity of cropland and on crop production costs, and chapter 4 assesses the magnitude of off-farm damages. Chapter 5 draws on chapters 2-4 to address the principal issues for soil conservation policy.

Footnotes

[1]See, for example, Crosson and Brubaker (1982) and National Agricultural Land Study, Final Report (1981).

[2]In the 1930s and 1940s, and even later, federal government payments to farmers for adoption of soil conservation practices also were seen by both the Congress and the executive branch as helping to maintain farm income. Indeed, that purpose probably was as important as soil conservation in the early years. Nevertheless, the stated rationale for such payments always has been erosion control to reduce productivity losses.

[3]Under section 208 of the Clean Water Act of 1972 (PL 92-500), the U.S. Environmental Protection Agency (EPA) evidently has authority akin to that it uses against air polluters to require farmers to control erosion where it threatens water quality objectives. The EPA, however, has elected not to use this authority, in effect delegating responsibility in this to the states. Each of the states has devised a so-called 208 plan for control of non-point pollution, but to our knowledge none of these contains strong provisions for dealing with off-farm erosion damages.

[4]An empirical estimate of the slope of f(x) for the Palouse region of the Northwest is given in Burt (1981), where x is defined as the percent organic matter in the top six inches of soil.

[5]It often is argued also that farmers underinvest in erosion control because their time horizon in considering the productivity of the land is short compared to society's. This argument is specious. The present value of the land in agricultural production reflects the market's assessment of net returns to it discounted into perpetuity. If the land market is working properly and erosion threatens the future productivity of the land, its present value will decline and the farmer suffers an immediate capital loss. Regardless of his time horizon, therefore, he has incentive to control erosion so long as the present value of the marginal cost of control is less than the marginal capital loss. Differences between social and private time horizons are not a source of market failure. The real issue is whether erosion-induced productivity losses are reflected in the price of the land.

[6]The role of the interest rate as a device for dealing with intergenerational equity is discussed in chapter 5. The issue here is whether those who think the market rate of interest at which farmers currently discount conservation investments is too high are more able to predict long-term movements in this rate than farmers are.

[7]Potential erosion was measured by the product of the RKLS factors (rainfall, soil erodibility, slope length, and steepness) in the Universal Soil Loss Equation (USLE). The USLE is discussed below.

[8]Rausser (1980) treats intergenerational equity as an issue in the analysis of market failure, but he interprets failure broadly to encompass "conventional exchange markets, contract markets and political markets" (pp. 1091). In this discussion we prefer to stay with the narrower, more conventional, definition of market failure.

References

Castle, E. N. and I. Hoch. 1982. "Farm Real Estate Price Components, 1920-1978." American Journal of Agricultural Economics, vol. 64, no. 1, pp. 8-18 (Feb.).

Coase, R. H. 1960. "The Problem of Social Costs," Journal of Law and Economics, no. 3, pp. 1-44.

Crosson, P. and S. Brubaker. 1982. Resource and Environmental Effects of U.S. Agriculture. Resources for the Future, Washington, D.C.

Dillman, D. A. and V. E. Carlson. 1982. "Influence of Absentee Landlords on Soil Erosion Control Practices," Journal of Soil and Water Conservation, vol. 37, no. 1, pp. 37-41.

Ervin, D. 1982. "Soil Erosion Control on Owner-Operated and Rented Cropland," Journal of Soil and Water Conservation, vol. 37, no. 5, pp. 285-288.

Lee, L. 1980. "The Impact of Land Ownership Factors on Soil Conservation," American Journal of Agricultural Economics, vol. 62, no. 5, pp. 1070-1076.

______. 1983. Adoption of Soil Conservation: Implications for Soil Conservation Policy. Statement before the Joint Economic Committee, U.S. Congress (June 22).

Page, T. 1977. Conservation and Economic Efficiency, Johns Hopkins Press for Resources for the Future, Baltimore.

Ramsey, F. P. 1928. "A Mathematical Theory of Saving," Economic Journal, vol. 38, pp. 543-559.

Randall, Alan. 1983. "The Problem of Market Failure," Natural Resources Journal, vol. 23, pp. 131-148 (Jan.).

Rausser, G. C. 1980. "Economics of Soil Conservation from the Farmer's Perspective: Discussion," American Journal of Agricultural Economics, vol. 62, no. 5, pp. 1093-04 (Dec.).

Rawls, J. 1971. A Theory of Justice (Cambridge, Mass., Harvard University Press).

Reiss, F. J. and D. R. Kensil. 1979. The Farmland Market in Ten Counties of Western Illinois: A Cross-Sectional Analysis of Prices Paid. Research Report no. 162 (Urbana, University of Illinois Agricultural Experiment Station).

Solow, R. M. 1974. "Intergenerational Equity and Exhaustible Resources," Review of Economic Studies, Symposium on the Economics of Exhaustible Resources, pp. 29-45.

U.S. Department of Agriculture and Council on Environmental Quality. 1981. National Agricultural Lands Study, Final Report. Washington, D.C.

Chapter 2

AMOUNTS OF EROSION

What the Data Show

Despite decades of concern about erosion and the expenditure of billions of dollars of public funds to control it, reliable estimates of the amount of erosion on a national scale were first collected in the National Resources Inventory of 1977. Table 2-1 shows these estimates for cropland and table 2-2 for land in pasture, range, and forest. Total erosion on the four categories of land was 5.3 billion tons, 3.8 billion tons of it being sheet and rill erosion and 1.5 billion tons erosion by wind.[1]

The table indicates that erosion was geographically concentrated. Texas, with only 7.4 percent of the nation's cropland, accounted for almost 20 percent of sheet, rill, and wind erosion from cropland. Considering only sheet and rill erosion from cropland, Iowa, with 6.4 percent of the cropland, had almost 14 percent of the erosion.

Sheet and rill erosion in excess of USDA specified "tolerance" levels (T values), which vary from 2 to 5 tons per acre per year, was even more concentrated, occurring on only 110 million acres of cropland (27 percent of the total). Most of the sheet and rill erosion in excess of T was in 4 of the 10 USDA producing regions: Corn Belt, Appalachia, Southeast, and Mississippi Delta. Among the four regions the ex-

Table 2-1. Erosion from Cropland in the United States, 1977

Region	Wind		Sheet and rill		Total		Percentage of total	
	Million tons	Tons per acre	Million tons	Tons per acre	Million tons	Tons per acre	Erosion	Cropland
Nation	891.0	2.1	1,908.0	4.7	2,799.0	6.8	100.0	100.0
Northeast	n.e.		82.9	5.0	82.9	5.0	3.0	4.0
Lake States	n.e.		117.5	2.7	117.5	2.7	4.2	10.7
Corn Belt	n.e.		688.3	7.7	688.3	7.7	24.6	21.8
Iowa	n.e.		261.3	9.9	261.3	9.9	9.3	6.4
Northern Plains	212.3	2.2	322.4	3.4	534.7	5.6	19.1	22.9
Nebraska	25.9	1.3	117.8	5.7	143.7	7.0	5.1	5.0
Appalachia	n.e.		186.3	9.0	186.3	9.0	6.7	5.0
Tennessee	n.e.		69.5	14.1	69.5	14.1	2.5	1.2
Southeast	n.e.		111.0	6.3	111.0	6.3	4.0	4.2
Georgia	n.e.		42.7	6.6	42.7	6.6	1.5	1.6
Delta	n.e.		154.9	7.3	154.9	7.3	5.5	5.1
Arkansas	n.e.		46.7	5.9	46.7	5.9	1.7	1.9
Southern Plains	488.8	11.6	141.4	3.4	630.2	15.0	22.5	10.2
Texas	453.5	14.9	99.5	3.3	553.0	18.2	19.6	7.4
Mountain	190.3	4.5	70.8	1.7	261.1	6.2	9.3	10.2
Pacific	n.e.		31.9	1.4	31.9	1.3	1.1	5.6
California	n.e.		8.6	0.9	8.6	0.9	0.3	2.4

Notes: n.e. = not estimated. Erosion data are for the 48 contiguous states only.

Source: USDA. 1980. Basic Statistics, 1977 National Resources Inventory (Washington, D.C., Soil Conservation Service); and 1981a. Soil, Water and Related Resources in the United States: Status, Conditions and Trends: 1980 RCA Appraisal, Part 1 (Washington, D.C., Government Printing Office).

Erosion data are for the 48 contiguous states only.

Table 2-2

Erosion from Pasture, Range and Forestland in the United States, 1977

Region	Pasture		Range		Forest			
					Grazed		Not grazed	
	Million tons	Tons/ acre	Million tons	Tons/ acre	Million tons	Tons/ acre	Million tons	Tons/ acre
Sheet and Rill								
Nation	346	2.6	1154	2.8	239	3.9	196	0.6
Northeast	10	1.7	--	--	4	2.8	28	0.5
Lake States	8	1.2	*	0.3	17	5.4	6	0.2
Corn Belt	96	3.8	*	0.4	55	8.7	23	1.2
Northern Plains	16	1.7	134	1.9	4	4.0	1	0.8
Appalachia	89	4.8	--	--	32	5.6	69	1.2
Southeast	8	0.6	1	0.3	4	0.9	21	0.4
Mississippi Delta	39	3.1	2	3.8	39	4.9	19	0.6
Southern Plains	35	1.3	391	3.6	9	1.0	2	0.4
Mountain	10	1.4	458	2.4	42	3.2	5	0.6
Pacific	2	0.5	164	4.9	31	3.6	13	0.6
Wind								
10 Plains states	5	0.2	559	2.0	4	*		

*Less than .5

Source: USDA. 1981b. RCA Final Program Report and Environmental Impact Statement, Washington, D.C.

cess was greatest in the Corn Belt. Among all the states, however, Tennessee (part of Appalachia) at 14.1 tons had by far the highest per acre rate of sheet and rill erosion.

In the NRI, wind erosion was assumed to be a significant problem only for the ten Great Plains states.[2] More than half the wind erosion was in Texas, and Texas had 40 percent of the 39 million acres of cropland in the Plains states on which wind erosion exceeded 5 tons per acre. The 39 million acres were 23 percent of total cropland in those states.

Taking them together, sheet, rill, and wind erosion exceeded 5 tons per acre on about 36 percent of the nation's cropland in 1977.

Sheet and rill erosion on pasture, range, and forestland in total was about the same as on cropland (1,935 million tons and 1,908 million tons, respectively). As on cropland, sheet and rill erosion on pasture, range, and forestland was geographically concentrated.

On a per acre basis, sheet and rill erosion on pasture, range, and forestland was substantially less than on cropland, and among regions, it exceeded 5 tons only on rangeland in the Pacific region. (This was in California where sheet and rill erosion from rangeland was 8.1 tons per acre. In Oregon and Washington, the other two states in the region, it was less than 2 tons). Considering individual states, sheet and rill erosion exceeded 5 tons per acre on pastureland in only three (Illinois, Kentucky, and West Virginia); on rangeland in four (Arkansas, California, Colorado, and Mississippi); and on forestland in one (Colorado).

On land in pasture, range, and forest in the 10 Great Plains states, wind erosion was negligible except on rangeland, where it amounted to 559 million tons. On a per acre basis, however, wind erosion from rangeland was only 2 tons. In none of the 10 states did it exceed 5 tons.

The estimates of erosion in tables 2-1 and 2-2 are the basis for all assessments of erosion in the United States and its consequences from national and regional perspectives. Some discussion of the derivation and limitations of the estimates, therefore, is necessary. We focus primarily on sheet and rill erosion, for two reasons: (1) there was more than two and a half times as much of it as of wind erosion; (2) all the studies of regional and national level effects of erosion on soil productivity deal exclusively with sheet and rill erosion.[3]

<u>Estimates of Sheet and Rill Erosion</u>

The NRI estimates are based on a 0.7 percent sample of all nonfederal rural land in the country. The main objective of the survey was to collect data on patterns of land use and their erosion consequences. Accordingly, sampling universes were defined in each state according to land use characteristics that would affect sampling reliability. For example, irrigated areas in the Southwest were treated as separate sampling universes from neighboring unirrigated areas because the patterns of land use were quite different. In most cases, the sampling universes were taken from the Conservation Needs Inventory of 1958.

Within each sampling universe, blocks of land called Primary Sampling Units (PSUs) were randomly selected, the number in each universe rising with the diversity in land use patterns. Most PSUs were 160 acres, but a few were as small as 40 acres and some as large as 640 acres. Three sampling points were selected in each PSU, except in those of 40 acres where only two points were identified. Only nonfederal was sampled. SCS personnel visited and collected data from about 200,000 sampling points. The data from each point were multiplied by the number of acres per point in the sampling universe and summed to give the totals for the universe. Where there was more than one universe in a state, the universe totals were summed to give the state totals.

<u>The Universal Soil Loss Equation (USLE)</u>. Data was collected from each point showing the use of the land in

1977 as well as land management practices in 1974-77 to identify crop rotations, soil characteristics affecting erodibility, slope length and steepness, and whether the land was terraced or otherwise protected by soil conservation practices. These data, combined with information about the seasonal amount and intensity of rainfall in the sampled area, were fed into the USLE to calculate the amount of sheet and rill erosion on each sampling point. The USLE is written:

A = RKLSCP, where
A = sheet and rill erosion, usually in tons per acre per year, but other units may be used
R = a measure of rainfall amount and intensity
K = a measure of soil erodibility
L = a measure of the effect of length of slope on erosion
S = a measure of the effect of steepness of slope on erosion
C = a measure of the effect on erosion of kind of land use, including crop rotations and tillage practices
P = a measure of the effect of conservation practices, such as contour plowing or terracing

R is expressed as an index which captures the combined energy of raindrops striking the soil and of water moving across the soil as runoff. K is expressed as the soil loss per unit of R from a plot 72.6 feet long of uniform 9 percent slope in continuous clean tilled fallow.[4] L is the ratio of soil loss from the sampled land to the loss from a 72.6 foot plot under otherwise identical conditions; S is the ratio of soil loss from the sampled land to the loss from a 9 percent slope under otherwise identical conditions; C is the ratio of soil loss from the sampled land, given its use, rotation, and other management factors, to the loss from the same land if it were in continuous clean tilled fallow; and P is the ratio of soil loss from the sampled land, given the conservation practice on it, such as contouring, to the loss from the same land farmed in straight rows up and down the slope.[5]

Defined in this way, erosion is calculated with the USLE as a multiplicative function of the six factors in the equation. On a 72.6 foot plot of uniform 9 percent slope in continuous clean tilled fallow, L, S, C, and P all equal 1 and A, the amount of soil loss, equals R times K. A slope length of 72.6 feet and slope steepness of 9 percent are used as standards because much of the experimental work from which the USLE was developed was done on plots of that length and that average slope (Wischmeier and Smith, 1978, p. 8). The equation is designed to predict average erosion over a period of years, not the amount from a single rainfall event.

Parameters for the factors in the USLE are based on data representing thousands of experimental plot years, and vary widely around the country, some of them even on a single farm. The R (rainfall) factor varies generally between 150 and 250 in the Corn Belt, between 250 and 400 in the Southeast and Mississippi Delta, between 50 and 200 in the Northern Plains, and between 50 and 300 in the Southern Plains. Judging from Wischmeier and Smith (p. 9), the K (soil erodibility) factor for most soils in the country falls between 0.2 and 0.5. The erosion effects of slope length and steepness interact in the way described mathematically by Wischmeier and Smith (p. 12). Except on gently sloping land (less than 2 percent), the erosion effect of increasing slope steepness is proportionally greater than the effect of increasing slope length. For example, increasing L from 100 feet to 400 feet on a 2 percent slope increases LS from 0.201 to 0.305 (52 percent). But a comparable increase in S from 2 percent to 8 percent on a 100 foot slope increases LS from 0.201 to 0.992 (394 percent).[6]

The C (management) factor is easily the most complex element in the USLE. C is designed to capture all the things the farmer might do (with two exceptions, noted below) to reduce the energy with which raindrops strike the soil or the energy in runoff water. Consequently, the proportion of the field covered by the crop canopy and the distance of the canopy from the soil are of crucial importance. So is the nature of the cover (for example, grass reduces runoff far more than corn) and whether the land is rough or smooth tilled (rough tillage reduces runoff). The rotation is also important because experimental work shows that erosion from land continuously in a row crop, such as corn, is greater than if the same crop were rotated with grass or hay. Finally the tillage system has a major impact, C values for no-tillage systems being orders of magnitude less than values for conventional systems using the moldboard plow and removing all crop residue after harvest.

Because of the importance of canopy, the C factor will vary over the growing season, being highest before planting and lowest at harvest. Because the importance of canopy varies with the amount and intensity of rainfall (no rain, no canopy effect no matter how much canopy), the canopy component of the C factor, for a given amount of canopy, will vary with the seasonality of rainfall.

The P factor also measures the effects on erosion of steps taken by the farmer, and in this sense it too is a management factor. Three practices are included in the P factor: contour tillage, strip cropping on the contour, and terracing. Both the range and number of P values for the three practices are far smaller than the range and number of C values (Wischmeier and Smith, 1978, pp. 34-39).

The K (soil erodibility) factor is generally not regarded as subject to change by management decisions. In fact, however, the percentage of organic matter in the soil is of major importance in determining the K factor, and, within limits, farmers can affect the amount of soil organic matter. Erosion selectively removes organic matter, and plowing under crop residues tends to increase it. The effect on erosion of altering soil organic matter can be significant. Arithmetical experiments based on numbers and relationships given by Wischmeier and Smith (pp. 10-11) indicate that reducing soil organic matter from 3 percent to 1 percent (other characteristics determining K remaining the same) can increase the K factor by 25 to 50 percent. With the other factors in the USLE constant, this means a proportionate increase in predicted erosion. Alternatively, of course, increasing soil organic matter would reduce predicted erosion.

<u>Evaluation of the estimates</u>. The USLE is fundamental to the NRI estimates of sheet and rill erosion. There are two questions to ask about the USLE. One concerns its reliability as a predictor of erosion when the values of the several factors in the equation are clearly established under experimental conditions. The other concerns its reliability when the values for some of the key factors are collected by many different people under field conditions, as in the NRI.

As indicated above, representative values of the factors in the USLE were calculated on the basis of data collected over thousands of experimental years. Wischmeier and Smith (1978, p. 47) report that the accuracy of these values was tested by using them to predict long-term average erosion from various experimental plots and comparing the predicted amounts with those actually reported. On the basis of these tests, Wischmeier and Smith concluded that the USLE predicts best when it is used for land with medium textured (loamy) soils, slope lengths less than 400 feet, slope gradients between 3 and 18 percent, and with cropping and management systems well represented in te experimental plot studies. It is also more accurate where erosion results from rainfall and subsequent runoff rather than irrigation water or snowmelt. For the latter reason, the USLE is a less reliable predictor in the arid and semiarid West than in the Midwest, where most of the experimental work developing it was done.

Legitimate questions may be raised about the accuracy of the USLE wherever soil and climatic conditions are markedly different from those of the Midwest. This is not as significant as it may first appear, however, because production of the two most erosive crops, corn and soybeans, is strongly concentrated in the Midwest. Thus, considerable confidence can be placed in USLE erosion estimates for that major region and, to a lesser extent, for the country as a whole, even though the estimates may be subject to large errors for some regions, such as the Palouse.

All this concerns the accuracy of the USLE's estimates of sheet and rill erosion when the values of the factors in the equation are accurately specified, as they can be under experimental conditions. But accurate specification may be more difficult with a large-scale field survey conducted by many people over an area of hundreds of millions of acres. When SCS personnel went into the field to collect data from each NRI sample point they carried with them instructions which specified the data needed for the USLE for the R, K, and C factors, and a table for P values. Slope length (L) was defined in the instructions as the distance from the point of origin of overland flow of water to the point where deposition begins or where the runoff enters a well-defined channel. No instructions were given on how to measure slope percentage except that measurement should be in the same direction as used in measuring slope length.

The knowledge and judgment of the SCS field personnel was particularly important in calculating degree of slope and slope length, and in assigning C values. Deficiencies in knowledge and judgment would contribute to two sorts of errors: (1) data for individual sample points might be incorrect; (2) the errors might be systematic, producing either an upward or downward bias in the estimates of erosion. The first kind of error would be important for the design of erosion control practices for a particular farm, but for state or national level estimates of erosion the second kind of error is the one that matters.

Recognizing the possibility of error in the collection of the data, the SCs did a quality check on the NRI (Goebel and Schmude, 1981). In the summer of 1978 almost 2,000 PSUs (4,000 to 6,000 sampling points) were revisited by agronomists who had not been involved in the original survey. National level acreage and erosion estimates derived from the quality check survey were compared with those from the original. No significant differences were found. As Goebel and Schmude put it "...the original estimates and the quality check seemed to be estimating the same quantity." (p. 11).

Summary of the evaluation. The tests of the USLE reported by Wischmeier and Smith indicate that the equation gives reasonably reliable predictions of erosion under experimental conditions, with its best performance in the Midwest and less success where snowmelt and irrigation are the main causes of erosion, or where soils are markedly different from those of the Midwest, on which USLE estimates are based. The reliability of the equation under field conditions depends importantly on the knowledge and judgment of field personnel, especially in measuring slope length and slope percent and in assigning C factors. The NRI quality check indicates consistency (although not necessarily accuracy) among field personnel in performing these operations.

Estimates of Wind Erosion

Discussions of erosion's effects on productivity typically focus on the effect of sheet and rill erosion--the predominant way topsoil is lost in the United States. But wind erosion can be a serious factor, too, although the literature contains little analysis of the effects of wind erosion on productivity. The principle reason for this may well lie with the difficulty of isolating wind erosion effects from other productivity factors and the difficulty of predicting wind erosion accurately.

The 1977 NRI estimates of wind erosion in the 10 Great Plains states are listed in tables 2-1 and 2-2. Of the 168 million acres of cropland in those states, 39 million acres, or 23 percent, had wind erosion in excess of 5 tons per acre per year. Colorado, New Mexico, and Texas had 40, 53 and 51 percent, respectively, of this cropland with wind erosion over this rate. Texas alone had 454 million tons of cropland soil eroded by wind in 1977--half of all cropland wind erosion in the Great Plains. Overall, the average rate of cropland wind erosion in the Great Plains was 5.3 tons per acre in 1977.

It is not certain how many more acres of cropland experiencing wind erosion would have exceeded 5 tons per acre per year if sheet and rill erosion had been included. It would certainly be higher. Nonetheless, nearly one quarter of the cropland in the Great Plains experiences wind erosion in excess of 5 tons per acre per year. No doubt some unknown portion of cropland outside the Great Plains also experiences high rates of wind erosion, but data for these lands were not collected in the 1977 NRI.

The estimates of wind erosion were made by use of the Wind Erosion Equation (WEQ). The WEQ was born out of extensive research by W. S. Chepil, N. P. Woodruff, F. H. Siddoway, and others at the Kansas State University Wind Erosion Laboratory (Craig and Turell, 1964). The model these researchers developed can be written in the form:

E = f (I K C V L), where:

E - potential annual soil loss.

I - soil erodibility value, expressed as the average annual soil loss per acre that would occur from an isolated, level, smooth, unsheltered, wide, and bare field with a noncrusted surface in Garden City, Kansas

K - soil ridge roughness factor, a field being smooth, semi-ridged, or ridged.

C - climatic value, based on the average wind velocity and on a precipitation evaporation index

V - vegetative cover value, expressed as a residue equivalent to flat, small grain residue.

L - value for the unsheltered distance across a field along the prevailing wind direction. (A field is sheltered within a distance perpendicular to the wind which is less than 10 times the height of a wind barrier).

(USDA, 1980)

For a detailed discussion of the soil and water residue factors, see Woodruff and Siddoway (1965). For a full discussion of the wind factors, see Skidmore and Woodruff (1968).

The soil erodibility value (I) decreases with an increase in the percentage of dry soil particles or aggregates with a diameter greater than 0.84 millimeters as determined with a standard sieve. For sandy soil with only 10 percent of its aggregates larger than this threshold, the value for I is 134 tons per acre per year, while it is only 38 tons per acre per year for silty soils having 50 percent of the soil aggregates larger than 0.84 millimeters (Skidmore and Woodruff, 1968). Crusting reduces the I value by as much as one-sixth on some soils. Thus, dry, sandy textured soils which are not crusted over should have the highest inherent ability to erode.

The soil ridge roughness factor (K) is highest for a flat and smooth field, but decreases quickly with roughness of the soil. However, the factor increases again on severely ridged soils, apparently the result of the ridge tops being exposed to the wind.

The climatic factor (C) appears to be the most difficult factor to estimate accurately, both because of variability in wind direction and velocity, and because of variability in any given soil's ability to retain precipitation and thus resist the wind's shearing action. Before their publication on wind erosion forces in 1968, Skidmore and Woodruff lamented the "meager" and geographically "limited" information on wind forces. They were forced to rely heavily on hourly observations by military and civilian agencies.

Generally, wind is not erosive until it exceeds 12 miles per hour (Skidmore and Woodruff, 1968), so only strong prevailing winds need be considered. Wind velocity appears highly variable geographically, and shows seasonal variation, being highest in the spring and lowest in the summer (Skidmore and Woodruff, 1968).

The value for vegetative cover (V) and its importance in reducing wind erosion increases with the amount of residue on the surface and increases again if the residue is still standing in the field. Furthermore, residue which is on smooth ground reduces erosion more than if it is concentrated in the furrows.

The unsheltered distance factor (L) contributes more to erosion as the height and number of shelters decreases, or as the effectiveness of shelters is reduced by the difficulties of identifying the prevailing wind direction.

In the 1977 NRI, data for the factors of the WEQ were collected at randomly selected sampling points in the 10 Great Plains states, as discussed above. Estimates of wind erosion in these states were thus obtained. The 1982 NRI will provide wind erosion estimates for other states as well. Preliminary data from the 1982 NRI indicate that about 75 percent of wind erosion from the nation's cropland is in the Plains states.

We are not able to evaluate the accuracy of the wind erosion estimates in the 1977 NRI. Little information as to the WEQ's reliability is available. Thoughout the soil conservation community, however, the 1977 wind erosion estimates are treated more cautiously than those for sheet and rill erosion.

Is Eroded Soil Lost?

Both the USLE and the wind erosion equation give estimates of the amount of soil moved by water or wind on an acre of land under certain conditions specified in the equations. For a sample point in the NRI, for example, the USLE tells us how much soil would be moved in an average year on an acre of land having the R, K, L, S, C, and P characteristics observed on the land at the sample point.

The soil moved by erosion is commonly referred to as "lost." The NRI results, for example, are frequently interpreted as showing that each year the nation "loses" 1.9 billion tons of topsoil from its cropland because of sheet and rill erosion.[7] But where does the "lost" soil go? A model developed at Resources for the Future by Henry Peskin and Leonard Gianessi shows that only about 40 percent of the 1.9 billion tons of sheet and rill eroded soil in 1977 ended up in the nation's waterways. (Work done at the SCS suggests that even this figure may be too high.) What happened to the other 60 percent? And what happened to the 1.5 billion tons of soil which the NRI tells us was eroded by wind in 1977 from land in crops, pasture, range, and forest?

Present information does not provide answers to these questions, although it seems clear that most of the eroded soil remains on the land. If this is so, in what sense is the soil "lost"? What most people seem to have in mind is that it is lost to agriculture, that it is no longer available to support agricultural production. But is this really the case? Even some of the soil entering streams will be deposited on flood plains as alluvium, or at the river mouth. And what of the soil which never reaches water? It settles out at the foot of slopes or in low-lying areas where runoff slows enough to permit deposition. Some of it will end up in gullies and other nonfarmable places, but some of it never leaves the farmer's field. The soil has simply been moved from a higher place on the farm to a lower place. Indeed, Larson et al. (1983) assert that in the central Corn Belt, much of the soil eroded from cropland slopes probably is deposited on other cultivated land.

Results of a study of erosion and deposition in a small watershed in western Iowa are consistent with this (Piest et al., 1977). The deep loess soils on hilly terrain in western Iowa are among the most erosive in the nation. In the

75 acre watershed studied, erosion over a five year period, measured by the USLE, averaged 34.6 tons per acre per year, well above the average for the region as a whole. A combination of low level aerial photography and ground instrumentation was used to calculate the amount of eroded soil that actually left the watershed over the five years (1969-1974). The calculations showed that of the cumulative five year total of 173 tons per acre of eroded soil, only 42 tons--24 percent-- actually left the watershed. The rest was simply moved from higher levels to lower levels in the watershed. Whether these results are representative of the long-term delivery of sediment from the watershed depends on how representative the weather was during the five year period, especially with respect to the occurrence of large storms. Since the probability of, for example, a 100 year storm in this period was only 5 percent, calculations over a longer period may have shown a sediment delivery ratio of more than 24 percent.

It is clear that some--no one knows how much--sheet and rill eroded soil is simply moved about on the farm and so is not lost to agriculture. This would seem to be even more true of soil eroded by wind. While the famous dust storm of 1935 carried soil over much of the eastern part of the country and deposited some of it in the Atlantic Ocean, wind-eroded soil usually moves much shorter distances (Lyles, 1977). Wind erosion is concentrated in the plains states where much the greater part of the land is in crops, pasture, and range. Most of the soil picked up by the wind in one place must come to rest on land in much the same actual or potential use somewhere else.

In this connection, Hall, Daniels, and Foss (1982) cite an early estimate (1911) by Free that airborne dust added at least 0.025 cm (1.5 tons per acre) per year to the area west of the Mississippi River. Another study showed that in southwestern Kansas, an annual average of at least 0.12 cm (7.2 tons per acre) of airborne soil was trapped by grass between 1946 and 1956. Yet another study of twelve sites from Kansas and Nebraska to Ohio showed depositions of airborne sand plus silt ranging from 0.4 tons per acre at North Platte to 0.09 tons per acre at Coshocton. Hall, Daniels, and Foss do not say so, but presumably these amounts would vary from year to year according to the amount of wind erosion.

It seems likely, therefore, that much, and in the case of wind erosion most, eroded soil is not lost to agriculture. This does not mean that the NRI estimates of sheet and rill erosion or of wind erosion are wrong. It does mean, however, that interpreting the estimates as measures of the amount of soil no longer available for agricultural production is misleading.

It is not enough, however, to show that most eroded soil is not lost. The key question is what effect it has on productivity in the places of deposition. The review of the literature undertaken for this report revealed little discussion of this question. Sampson (1981) states that if sand and coarse soil particles come to rest on fertile bottomland soils, the result may be lowered productivity. However, if fertile material is deposited on sand or gravel bars, productivity may increase. Sampson's "intuitive" estimate is that the net productivity effect of deposited soil is negative, but he notes that "...there is little data to support such a conclusion, let alone calculate its magnitude." (Sampson, 1981, p. 124)

The Committee on Soil as a Resource differs with Sampson about the net productivity effect. It asserts that "some sites are degraded by sedimentation because the sediment is inferior to the underlying soil. Considerably larger areas, however, are unaffected or are actually improved by sedimentation. The sediment is in many instances as fertile, or more fertile than the underlying soils." (1981, p.98)

The Task Committee (1969) also notes that sediment deposition may have bene ficial results:

> Some phases of the sedimentation problem are beneficial to man, and the fact that "good" can result from the movement of sediment should not be overlooked. The rich bottom lands that border rivers and oceans are the result of sediment deposition in earlier times, and to some extent sediment is being deposited at the present time. The deltas of streams may be growing and slowly increasing the amount of useful land. Sediment-bearing water that overflows streambanks deposits silt and humus, which improve the topsoil. Swamps, refractory clays, or saline soils may be buried by sediment, and the covered land is then available for agriculture. (p. 198)

In some landscapes, deposition of eroded soil tends to level the land. Paul Jacobson, a farmer in western Iowa with land similar to that studied by Piest et al., has devised a technique to exploit this characteristic of erosion to improve conditions for farming his land.[8] The farm, which Jacobson has worked since 1961, has deep loess soils on slopes varying from 2 to 20 percent. The essence of Jacobson's technique is to build parallel terraces and fills across waterways to slow runoff and permit deposition of soil eroded from higher elevations. Over time, this levels or "benches" the land above the terraces and fills. Excess water is removed by underground drainage pipes. Jacobson asserts that with his technique very little eroded soil leaves the farm. Moreover, the areas on his farm where deposition benched the land can be managed more efficiently than the same areas before benching. Jacobson also asserts that the increase in efficiency was enough to cover whatever productivity loss occurred on the eroded areas and to justify the investments in terraces, fills, and drainage needed to make the benching system work.

Jacobson's situation is unusual, although not unique. Addressing the general question of what happens to eroded soil, the Committee on Soil as a Resource states that ". . . some topographic improvement may result from sediment accumulating in low areas. Depressions that now collect water may be filled, or steepness of hill slopes might be reduced" (1981, p. 98).

The only other reference we found bearing on the effect of erosion in places of deposition was in an article by Cook (1982), in which he quotes from a draft SCS report on soil loss tolerance saying that "a bottomland farm in the nongrowing season may tolerate large amounts of sediment; in fact, the productivity of some areas is enhanced by annual sediment deposition." (p. 92)

The discussion has focused on the effects on the productivity of the soil in places of deposition. However, the effect on soil depth must also be taken into account. As will be noted in the next chapter, erosion ultimately limits soil productivity by restricting the crop rooting zone, the area in which crop roots can find the nutrients, water, and air needed for healthy plant growth. Rates of generation of new soil from underlying parent material are very slow. Consequently, continuation of 1977 rates of erosion would eventually restrict crop rooting zones if parent material were the only source of new soil. However, if most eroded soil is merely moved from a higher place to a lower place on the landscape, then average soil depth is not reduced nearly as much as the 1977 erosion data would suggest.

We find it astonishing that so little is known about the fate of eroded soil, given the importance of the issue for judging both the productivity and off-farm impacts of erosion. It seems clear, however, that most eroded soil is not permanently lost to agriculture. The soil not deposited in lakes, reservoirs, or the oceans is potentially available for agricultural production. The real issue is the economic cost of turning it to that use. No doubt the costs of farming soil in places of deposition is often higher than costs of farming it in places of origin. But as Jacobson's experience and other material reviewed here shows, the reverse may also be true. In any event, eroded soil which remains available for agricultural production, albeit at higher cost, clearly is not permanently lost. Interpreting the NRI erosion data in that way is incorrect.

In this section we have tried to correct a commonly held erroneous interpretation of soil erosion estimates. Nothing we have said implies that on a correct interpretation the productivity effects of erosion are unimportant, or less important than they are often perceived to be. Data on amounts of eroded soil say nothing about productivity effects. Measurement of these effects requires additional analysis, which is the subject of the next chapter.

Footnotes

[1]Sheet and rill erosion are caused by water. Sheet erosion removes layers of soil all across the field. If the water moves fast enough it tends to scour the land unevenly, cutting small channels in the surface. The soil moved in this way is rill erosion.

[2]Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Montana, Wyoming, Colorado, and New Mexico.

[3]The discussion deals with the data from the 1977 NRI. Data from the 1982 NRI arrived too late for consideration in this report. Preliminary 1982 results show no significant differences from 1977 sheet and rill erosion. However, wind erosion data were collected for all states in 1982, not just for the 10 Plains states. Wind erosion estimates therefore are higher for 1982.

[4]The slope percentage is found by dividing the vertical leg by the horizontal leg of the right triangle formed by the slope.

[5]The definitive statement and discussion of the USLE is in Wischmeier and Smith, 1978, p. 4. This description of the factors in the USLE is from that source.

[6]Calculated from numbers in Wischmeier and smith 91978, p. 12, table 3).

[7]Referring to erosion on all types of land, a report of the Conservation Foundation states that "nationally, over 6.4 billion tons of soil a year are lost in wind and water erosion." (Conservation Foundation, 1982, p. 234)

[8]For a description of the technique see Jacobson (1981).

References

Committee on Soil as a Resource in Relation to Surface Mining for Coal. 1981. Surface Mining: Soil, Coal and Society (Washington, D.C., National Academy of Sciences, National Resource Council, National Academy Press).

Conservation Foundation. 1982. State of the Environment 1982. (Washington, D.C., Conservation Foundation).

Cook, K. 1982. "Soil Loss: a Question of Values," Journal of Soil and Water Conservation vol. 37, no. 2, pp. 89-92.

Craig, D. G., and J. W. Turell. 1964. Guide for wind Erosion Control on Cropland in the Great Plains States (Washington, D.C., USDA, Soil Conservation Service).

Goebel, J. J., and K. O. Schmude. 1981. "Quality Control and Evaluation for the SCS National Resources Inventories." Paper presented at the In-Place Resource Inventories Workshop, University of Maine, Orono, August 9-14 (Orono, University of Maine).

Hall, G. F., R. B. Daniels, and J. E. Foss. 1982. "Rates of Soil Formation and Renewal in the U.S." in B. L. Schmidt, R. R. Allmaras, J. V. Mannering, and R. J. Papendick, eds., Determinants of Soil Loss Tolerance. ASA Special Publication no. 45 (Madison, Wisconsin, American Society of Agronomy and Soil Science Society of America).

Jacobson, P. 1981. "Terrace Planning Criteria for Runoff Control for Deep Loess Soil," Transactions of the American Society of Agricultural

Engineers vol. 24, no. 3, pp. 699-704.

Larson, W. E., F. J. Pierce, and R. H. Dowdy. 1983. "The Threat of Soil Erosion to Long-Term Crop Production," Science vol. 219, no. 4584, pp. 458-465.

Lyles, L. 1975. "Possible Effects of wind Erosion on Soil Productivity," Journal of Soil and Water Conservation, vol. 30, no. 6, pp. 279-283.

Piest, R. F., R. G. Spomer, and P. R. Muhs. 1977. "A Profile of Soil Movement on a Cornfield," in Soil Erosion: Prediction and Control. Proceedings of a National Conference on Soil Erosion, May 24-26, 1976, Soil Conservation Society of America (Ankeny, Iowa).

Sampson, R. N. 1981. Farmland or Wasteland (Emmaus, Pa., Rodale Press).

Skidmore, E. L. and N. P. Woodruff. 1968. Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss. Agricultural Handbook no. 346 (Washington, D.C., Government Printing Office).

Task Committee for Preparation of Manual on Sedimentation. 1969. "Sedimentation Engineering, Chapter VI: Economic Aspects of Sedimentation," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, vol. 95, no. HY1, pp. 191-207.

U.S. Department of Agriculture. 1980. Basic Statistics, 1977 National Resources Inventory (Washington, D.C., Soil Conservation Service).

_____. 1981. Soil, Water and Related Resources in the United States: Status, Condition, and Trends: 1980 RCA Appraisal, Part I (Washington, D.C., Government Printing Office).

Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses. USDA Agricultural Handbook no. 537 (Washington, D.C., Government Printing Office).

Woodruff, N. P., and F. H. Siddoway. 1965. "A Wind Erosion Equation," Proceedings of the Soil Science Society of America, vol. 29, no. 5, pp. 602-608.

Chapter 3

EFFECTS OF EROSION ON PRODUCTIVITY AND PRODUCTION COSTS

Introduction

The focus here is on cropland. As noted in the previous chapter, total sheet, rill, and wind erosion on pasture, range, and forestland is substantially less than on cropland. Moreover, erosion per acre is even higher on cropland relative to land in the other uses. Indeed, per acre erosion on land in these uses in 1977 exceeded the USDA's maximum 5-ton T value in only a few states. Moreover, the effect of erosion on the nation's capacity to meet future crop demand at reasonable cost is the main focus of public concern about erosion. Finally, virtually all studies of the effect of erosion on productivity have dealt with cropland.

Definitions

In general, productivity is defined as a ratio of output of product or services per unit of resources used per unit of time to produce the output. With this definition the productivity of cropland in the U.S. is usually measured in bushels per acre per year. This is the definition employed in all the studies reviewed in this chapter.

Bushels per acre is a partial measure of productivity because it leaves out the yield effects of management and technology. This is legitimate since the focus of the studies is on the effects of erosion on the productivity of the land. However, to attribute measured effects to erosion requires controlling somehow for the yields effects of changes in technology and management. As we shall see, this presents problems for some of the productivity studies reviewed here.

How Erosion Affects Productivity

Erosion reduces productivity primarily by carrying away soil nutrients, reducing available water holding capacity of the soil and, ultimately, by restricting the crop rooting zone. Soil nutrients can be replaced by adding fertilizer, and on many soils water infiltration and holding characteristics of the soil can often be improved by farm management practices which restore some of the soil organic matter lost to erosion. Rooting zone limits will eventually be encountered wherever erosion persistently exceeds the rate of soil accretion. Even these limits may be extended on some soils, e.g., adding irrigation may increase plant available water in an otherwise water-short rooting zone. And, as noted in the previous chapter, soil accretion depends upon deposition of soil eroded elsewhere as well as on the slow process of soil generation from underlying parent material.

All these ways of offsetting the yield effects of erosion cost something, except perhaps for the soil building aspects of soil deposition. Indeed, these costs, relative to the cost of the yield loss and of erosion control measures to avoid the loss, are central to the issue farmers and society face in deciding whether to accept the yield loss, offset it, or avoid it by reducing erosion. This issue is the main focus of chapter 5.

Studies of Productivity Effects[1]

The studies are of two sorts. One compares yields on land where some or all the topsoil has been stripped away with yields on undisturbed land of the same sort in the same area cultivated in the same way. Virtually all these studies have been on agricultural experiment station plots or on parts of farmers' fields under experimental conditions. We call these investigations microstudies because of their small scale and highly area-specific focus.

The other sort of study examines the productivity effects of erosion on cropland in major producing regions and for the nation as a whole. All these studies make use of erosion data from the 1977 NRI and were not possible until those data became available. Because of their broad geographical scope and simplifying assumptions about erosion-productivity relationships, we call these macrostudies.

The Microstudies

Many of these studies were conducted from the 1930s through the 1950s at agricultural experiment stations scattered around the country. There was great diversity in the soils studied, in climate (both among the study sites and over time) and in the technologies and management practices employed. Consequently, the research results do not support valid general statements about the quantitative effects of erosion on crop yields, even for the three decades in which so much of the research occurred. The relevance of the results to present conditions is even less clear.

A review by Langdale and Shrader (1982) provides a useful summary of microstudies undertaken in the 1960s and 1970s. A report relating corn yield to topsoil depth on a medium textured soil in southern Iowa showed that reducing depth from 22 inches to 12 inches had no effect on yield. With 10 inches of topsoil, however, corn yields were 6 percent less than with 12 inches (Webb and Beer, 1972, cited in Langdale and Shrader, 1982, table 1). On sandier soils in eastern North Carolina, the yield effect of topsoil reduction was more marked, a decline from 18 inches to 15 inches being associated with a yield decline of almost 20 percent, with an additional 20 percent decline when topsoil was reduced from 15 inches to 10 inches (Thomas and Cassel, 1979, cited in Langdale and Shrader, 1982, table 1).

Langdale and Shrader also review eight studies done between 1961 and 1977 on deep, medium textured soils showing the effects of total topsoil removal on yields of corn, soybeans, cotton, small grains, and forages.

For corn the yield reductions ranged from 8 to 30 percent, for soybeans from 20 to 40 percent, for cotton from 12 to 20 percent, for small grains from 11 to

24 percent, and for forages from 5 to 17 percent. Studies of the same crops on shallow medium-to-coarse textured (sandy) soils showed greater percentage declines in yield when all topsoil was removed.

Langdale and Shrader cite other studies in the southeast and midwest of erosion effects on yields of these same crops which show the same pattern of high variability according to crop, region, degree of erosion, and soil type. As in the other studies, these show that the percentage reduction in yield for a given amount of erosion was generally greater on coarse textured (sandy) soils than on medium textured (loamy) soils.

Yet other studies reviewed by Langdale and Shrader report results from Iowa, Montana, North Dakota, western Virginia, and the Atlantic coastal plains of North Carolina, showing that addition of nutrients, particularly nitrogen and phosphorus, restored yields on eroded soils to their previous levels.

Langdale and Shrader concluded from their survey that on deep, medium textured soils the yield loss to erosion can be restored by additional nitrogen and phosphorus, sometimes supplemented by micronutrients. With respect to more shallow soils with unfavorable subsoils, such as those in the Southeast, they state somewhat ambiguously that "...the crop, the soil, and the level of technology to be applied must be specified before an accurate appraisal of the effect of erosion on crop yield can be made." (p. 49) Elsewhere, however, Shrader (1980) distinguishes clearly between the kind of erosion damage for which additional fertilizer can compensate and the kind for which it cannot. On some deep, medium textured soils the principal damage is loss of nutrients, and these can be restored with more fertilizer. Where the damage takes the form of reduced tilth, water holding capacity, infiltration rate, or rooting depth, the yield loss persists even with additional fertilizer.

Young (1980) makes essentially this same distinction. As he puts it, technology, specifically chemical fertilizers, can restore nutrients carried away by erosion from the A horizon (topsoil), and tend to maintain yields. However, the technology has little effect on the processes by which new soil is formed at the base of the root zone. Consequently, where erosion narrows the root zone sufficiently to reduce water-holding capacity, addition of fertilizer cannot compensate for the adverse yield affect.

The microstudies provided much information useful to farmers and soil conservationists working with them in areas where soil and climatic conditions were similar to those reflected in the studies. However, the small-scale and highly site-specific nature of the studies make it difficult to interpret their significance for erosion as a national issue. For this, studies of erosion effects on productivity for major regions and the nation as a whole--macrostudies--are needed.

<u>The Macrostudies</u>

At this writing there are only three macrostudies that have produced estimates of long-term effects of erosion on soil productivity in major crop-producing regions or in the nation as a whole.[2] These are the Yield-Soil Loss Simulator prepared by USDA researchers as part of the 1980 Resource Conservation Assessment (RCA) process; a model developed by William Larson and associates at the University of Minnesota; and a regression model done at Resources for the Future.

<u>The Yield-Soil Loss Simulator</u>. When work began on the 1980 RCA, people in the Department of Agriculture recognized that the microstudies did not provide the kind of comprehensive information about erosion-productivity relationships required for RCA purposes. The Yield-Soil Loss Simulator (Y-SLS) was developed to fill this gap. Specifically, the model estimates the loss of national average yields of main crops that would occur over the long term because of erosion. In the RCA report (USDA, 1981), the resulting production loss was found to be 8 percent over the 50 years ending in 2030. That is, continuation of 1977

rates of cropland erosion would cause crop yields in 2030 to be 8 percent less than they otherwise would be. In the RCA report this was expressed as an equivalent loss of cropland.

A major reason for the difficulty in understanding the Y-SLS is that documentation for it was never published. The main source of information about the methodology and data sources employed in constructing the model is a lengthy memorandum prepared in the summer of 1980 by Charles Benbrook, an economist then with the Council on Environmental Quality and a member of the RCA Coordinating Committee. The discussion here is based on that memorandum.

The basic component of the Y-SLS was the yield-soil loss equation. The equation was calculated for each of 10 crops in each of 21 water resource regions (or subregions) into which the country was divided. There were, therefore, 210 yield-soil loss equations. In the equations crop yield was made a function of depth of topsoil and of two subsoil horizons; average slope of the land; land capability subclass;[3] soil texture; whether the land was irrigated or rainfed; and the producing area where the land was located within the water resource region. The coefficients for each of these variables were estimated by regression analysis.

The Y-SLS was derived from the basic yield-soil loss equations by multiplying the equation coefficients by the mean values of the independent variables for each crop in each region and summing the results. The sum is the Y-SLS base yield for each crop in each region.

As noted above, the Y-SLS was used to estimate the loss of yields over 50 years because of erosion. This is the use of principal interest here. The estimate of yield loss was made in four steps. First, annual erosion data in each region by land capability class were taken from the 1977 NRI, and the total soil loss over 50 years was calculated. Second, this was converted to inches of soil loss. Third, the mean topsoil depth in the yield-soil loss equation, taken from soil surveys for each region, was adjusted to reflect the soil loss, and fourth, the Y-SLS was run to estimate the revised (lower) yields for each crop in each region. The estimates abstract from changes in yields that would occur over the 50 years because of changes in technology and management.

Benbrook undertook a detailed evaluation of the YSL-S, examining the methodology and assumptions on which it was based and the availability of the data needed to implement the model. He also compared the YSL-S estimates of yield loss with those in the microstudies, finding that the latter were generally larger. Benbrook's review raises doubts about the accuracy of the Y-SLS results, doubts that were shared by many soil scientists and others associated with work on the 1980 RCA. Indeed, these doubts were a major reason for the decision to develop the EPIC model (see appendix A). Despite these reservations about the YSL-S, however, it is worth noting that its results are broadly consistent with those obtained from models developed at the University of Minnesota and at Resources for the Future.

<u>The University of Minnesota model</u>.

Pierce et al. (1983) modified a numerical index method developed by Neill (1979). Neill considered five soil parameters--available water capacity, bulk density, aeration, pH, and electrical conductivity--as those most influential to root growth. Each parameter was evaluated in terms of root response, and each soil layer was weighted according to an ideal rooting distribution. Response of each soil parameter was normalized to range from 0.0 to 1.0.

Pierce et al. modified Neill's model to include the following:

$$PI = (A_1 \times B_1 \times C_1 \times WF)$$

where A_1 is sufficiency of available water capacity, B_1 is sufficiency of bulk density (adjusted for permeability), C_1 is sufficiency of pH, WF is a weighting factor, and r is the number of horizons in the depth of rooting.

The model assumes that nutrients are not limiting to plant growth throughout the soil profile and that pH and bulk density are not limiting in the top 20 cm. A high level of management is assumed but not specified. Climate and plant differences are assumed to be constant. The model, as used, applies to deep rooted crops such as corn and soybeans in the Cornbelt.

A sufficiency curve was developed for A_1, B_1, and C_1, relating measured values to sufficiency coefficients that range from 0 to 1.0. These relationships were developed from the research literature. The WF for any soil horizon is the integral of the curve between the upper and lower boundary of the horizon. The total area under the curve was normalized to a value of 1.0; a rooting depth of 1 meter was assumed. Thus, the product of A_1, B_1, and C_1 and WF resulted in a PI range of 0 to 1.0 with 1.0 being the most productive soil.

The change in PI with simulated erosion reflects changes in soil attributes that cannot usually be replaced, i.e., water storage capacity. As noted, it is assumed that nutrient losses are replaceable and that through management, bulk density (B_1) and pH(C_1) can be optimized in the top 20 cm layer. The model does not estimate losses from gullying or from direct damages to a plant as from wind erosion or from sediment deposition.

The model was tested by regressing it with estimated corn yields as given in the SOILS-5 data file. The R^2 for different Major Land Resource Areas was usually about 0.7 (unpublished data). Imperfections in the model, the SOILS-5 data base, and the corn yield estimates probably combined to prevent a closer relationship.

Using data from the SOILS-5 file prepared by the SCS, PI was calculated for 15 Major Land Resource Areas (MLRAs) in the Cornbelt. To estimate changes in PI attributable to erosion, PI was calculated after removing successive 2 cm increments of soil from the surface and adding an equal depth to the base of the root zone. Obviously, if the soil material added to the base of the rooting zone was less desirable than that removed at the surface, PI would decrease. Likewise, if an undesirable layer moved closer to the surface, PI would decrease because WF decreases with depth.

The results of this exercise, on the assumption that 1977 rates of erosion in each MLRA would continue for 25, 50, and 100 years, are shown in table 3.1. The area covered is 98.3 million cropland acres in the Cornbelt (from Ohio west through Iowa and most of Missouri) plus parts of southern Minnesota, southwest Wisconsin, and eastern South Dakota, Nebraska and Kansas. Most of the cropland in this area is in corn and soybeans. In 1977, total land in these crops nationwide was about 150 million acres. Consequently, the data in table 3.1 apply to roughly two-thirds of all land in corn and soybeans in 1977.

The table shows that with continuation of 1977 erosion average yields on the 98.3 million acres would be 1 percent less after 25 years, 2 percent less after 50 years, and 4 percent less after 100 years, than they otherwise would be. Recall that the estimates assume that farmers adopt management practices which maintain soil nutrients, pH, and bulk density at optimum levels.

The table also shows, not surprisingly, that on more steeply sloped land erosion rates are higher and yields generally decline more over 100 years. The minimum yield loss over that period is 1 percent on 27 million acres of land (27 percent of the total) with slopes between 0 and 2 percent. (The zero loss on land with slopes between 20 and 45 percent is an anomaly on 2 thousand acres of land in an MLRA with 3.9 million acres in northeast Iowa and southeastern Minnesota). The table shows the maximum 100 year loss to be 100 percent, occurring on one thousand acres of land with slopes of 12 to 20 per unit. But that is unrealistic. Long before erosion reduced yields by 100 percent the land would be shifted into some lower

Table 3.1. Erosion and Its Productivity Effects in the Cornbelt

I. By Period

Years of Erosion	Percent decline in PI Average	Percent decline in PI Range	Cm soil removed Average	Cm soil removed Range
25	1	1-3	3.3	1.0-7.0
50	2	1-5	6.6	2.0-14.0
100	4	2-8	13.2	4.0-28.0

II. By Slope Percent

Slope percent	Erosion (tons/ac./yr) Average	Erosion (tons/ac./yr) Range	Percent decline in Pi after 100 years Average	Percent decline in Pi after 100 years Range	Percent total land
0-2	2	1-5	2	1-4	45.3
2-6	7	3-12	4	2-11	38.1
6-12	20	8-30	9	5-48	13.4
12-20	45	15-75	10	3-100	3.0
20-45	101	58-269	18	0-48	.2

Notes: 1977 rates of erosion in each of 15 Cornbelt MLRAs are assumed to continue for 25, 50, and 100 years.
total land = 98.3 million cropland acres.
average erosion = 7.8 tons per acre per year.
average number years to remove 2 cm soil = 19.6.
average initial PI = .83.

Source: Pierce et al. (1984).

Table 3.2. Prices Received and Paid by Farmers, 1950-54 and 1975-79

		Prices received ($/bu.)					
		Nominal		Real			
				Deflated by prices paid		Deflated by the CPI[b]	
Period	Index of real prices paid by farmers[a] (1967=100)	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans
1950/54	104	1.52	2.62	1.89	3.25	1.96	3.36
1975/79	114	2.27	6.09	1.10	2.94	1.24	3.31

Sources: USDA 1972 and 1980.

[a]Prices of inputs purchased for production plus wages, interest, taxes, and expenditures for family living, deflated by the CPI.

[b]Consumer Price Index, 1967=100.

valued, less erosive use, such as pasture or woodland, or simply abandoned.

In earlier work involving the Minnesota model, Larson et al. (1983) interpreted their results as suggesting that continuation of 1977 rates of erosion for 100 years would reduce national average crop yields by 5 to 10 percent from what they would otherwise be. The more recent and comprehensive work with the model summarized in table 3.1 suggests that this estimate may have been too high. The table shows the average 100 year decline to be 4 percent. Moreover, average erosion on all 415 million acres of the nation's cropland was 4.7 tons per acre in 1977 compared with 7.8 tons per acre on the 98 million acres reported in table 3.1. This implies that on cropland not included in the Minnesota analysis erosion in 1977 was less than 4 tons per acre. Why would the lower rate of erosion on this land reduce yields more rapidly than the substantially higher rate on the 98 million acres reported in table 3.1? The answer may be that the 98 million acres include some of the richest and deepest soils in the country, which can sustain more erosion with less loss. Clearly, this is an issue that needs further investigation before firm conclusions can be reached about the long-term effects of 1977 erosion rates on national average crop yields.

The estimates from the Minnesota model reported in table 3.1 indicate a smaller impact of 1977 erosion rates on crop yields than the Y-SLS estimates reported in the 1980 RCA (a 2 percent reduction compared with an 8 percent reduction in 50 years). The difference would be smaller if Larson et al. (1983) are right in asserting that the results for the areas they studied understate the national average yield decline. In any case, the similarity of the results from the Minnesota model and the YSL-S is more striking than the difference, given the quite different methodologies employed in the two approaches.

The RFF Regression Study. The Y-SLS and the model developed by Larson et al. were used to project erosion-induced declines in crop yields over the long-term future, assuming continuation of 1977 rates of erosion. The RFF regression work sought to isolate the effects of erosion on the past growth of crop yields. The approach taken was to regress trends in county yields of corn, soybeans, and wheat in 1950-1980 against erosion by county and certain other county variables (a dummy variable to capture the effect of irrigation on the trend growth of yields, and a couple of others). Erosion was measured by the USLE and taken from the 1977 NRI showing erosion by crop and by county. The counties were in the Corn Belt, Northern Plains, and the Palouse region of the Pacific Northwest. The trend growth of yields is in bushels per acre per year, and was found for each crop in each county by least squares analysis of annual yield data.

Details of the RFF model and its results are in Crosson and Stout (1983). The main findings were as follows:

1. Erosion had a negative but statistically insignificant effect on the growth of wheat yields in the selected counties between 1950 and 1980.

2. The effect on growth of corn and soybean yields was negative and statistically significant. For each crop annual yield growth was reduced about 4 percent because of erosion. In 1980, yields of each crop were 2-3 percent less than they would otherwise have been.

The RFF analysis left out most technological variables, and some of them, e.g., fertilizer, may be positively correlated with both erosion and the growth of crop yields. This would tend to bias downward the estimated regression coefficients for erosion. We noted above that on deep soils with favorable subsoils fertilizers can compensate for much if not all of the soil nutrients lost by erosion, and there is every reason to believe that some farmers apply additional fertilizer for this purpose. Some downward bias in the erosion regression coefficients, therefore, seems likely, but we are unable to judge its importance. We note, however, that the

RFF regression results--yields 2-3 percent less after 30 years--are "in the same ballpark" as those obtained with the Minnesota model--yields 4 percent less after 100 years.

The results from the Y-SLS, the Minnesota model, and the RFF model are interesting and in general agreement. They are inadequate, however, as guides to soil conservation policy because they lack an economic dimension. For policy the issue is not losses in terms of bushels per acre but the effect of the losses on costs of producing crops over the long term. We discuss this in the next section.

Effects on Production Costs

The productivity costs of erosion are of four sorts: (1) the value of the output lost because of the decline in soil productivity which occurs despite measures by farmers to reduce erosion (e.g., terracing) or to compensate for its effects (e.g., adding fertilizer). This is the cost of the loss measured by the three macro-models. (2) The costs of the things farmers do to offset the productivity loss, such as adding fertilizer to replace soil nutrients or liming to maintain soil pH. (3) The cost of erosion reduction measures to avoid losses, such as terracing. (4) The cost of damage to growing crops from soil deposition or the cutting action of wind-blown soil.

The first two kinds of cost are exclusively internal to the farm, and most of the third kind is.[4] Some costs of the fourth kind, so-called "ephemeral" costs because they do not have a cumulative effect on productivity, are internal to the farm, but many of them must be external. Wind-blown soil picked up in one set of fields may cut a wide swath through others belonging to several different owners. And soil carried by run-off must often be deposited, and do damage, on farms other than the one where it originated. That part of ephemeral costs which are "off-farm" are of the sort treated in the next chapter.

We know of no comprehensive data about the fourth kind of cost. Data about the other three kinds also are sparse, but enough are available to permit some interesting speculations. We first consider developments since World War II, then take a look at future costs.

Cost Experience Since World War II

The RFF regression results indicate that erosion effects on productivity must have tended to increase the cost of producing corn and soybeans in the post-World War II period. The slowing of yield growth would have tended to increase costs of the first kind, and erosion probably induced some farmers to adopt practices to offset yield losses (second kind of cost), or to avoid the losses in the first place by controlling erosion (third kind).

Whatever these cost increasing tendencies of erosion, they were overwhelmed by the cost decreasing tendency of advances in technology and management. This is indicated by the decline in real prices of corn and soybeans from the early 1950s to the late 1970s (see table 3.2).[5] Indeed, the productivity advances from new technology and managerial improvement not only offset the productivity effects of erosion, they also more than compensated for a 10 percent increase in real prices of farm inputs (table 3.2) and for a substantial increase in demand for corn and soybeans.[6]

Present and Future Costs.[7]

Costs of measured productivity loss. The Minnesota model is useful in estimating the first kind of cost of erosion-induced productivity loss: the cost of the loss which remains after allowing for whatever farmers do to prevent the loss by reducing erosion or otherwise offsetting its productivity effects. The model showed that continuation of 1977 rates of erosion for 100 years would reduce yields in the Cornbelt by an average of 4 percent from what they would otherwise be (table 3.1). Larson et al. (1983) assert that for the nation as a whole the loss would more likely be 5 to 10 percent, and we accept a 10 percent loss for purposes of this discussion. Because the RFF study showed no significant erosion-induced productivity loss on land in wheat, we deal here only with land in corn and soybeans.

We make the following assumptions:

1. The 10 percent decline in corn and soybean yields over 100 years occurs in equal annual increments (0.1 percent per year). The annual losses are cumulative, since they remain after whatever farmers do to prevent or offset losses.

2. The initial annual per acre yields of corn and soybeans are 110 bushels and 32 bushels respectively. The annual declines in yield thus are .11 bushels and .032 bushels respectively.

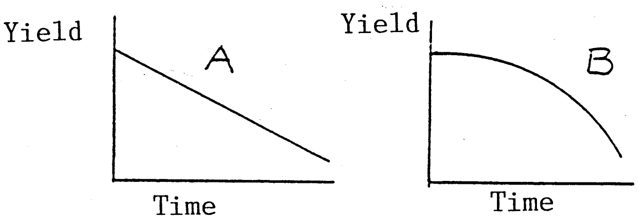
3. Corn is priced each year at $3 per bushel and soybeans at $7 per bushel.

4. Seventy-two million acres of land are in corn each year and 70 million are in soybeans.

5. Rates of discount or either 10 percent or 5 percent.

Under these assumptions, the value of the first year decline in corn yields is almost $24 million. (A decline in yield of .11 bushels times $3 per bushel times 72 million acres). For soybeans the annual decline is almost $16 million, so for the two crops combined the first year loss is about $40 million. Since the losses are cumulative, the second year loss is $80 million, and so on, reaching $4 billion in the 100th year. For the period as a whole, the present value of the loss is the sum of the discounted losses for each year. If the annual incremental loss is $40 million and the rate of discount is 10 percent, then the present value of the loss over 100 years would be about $4.3 billion.[8] At 5 percent it would be $17 billion.

Given the projected per acre productivity loss, the present value of the total loss is highly sensitive not only to the discount rate but also to the time pattern of the loss, crop prices, and the amounts of land in the two crops. With prices, the discount rate, and the amount of land given, the present value of the total loss will be less if the decline is not linear but more concentrated at the end of the period; that is, if the productivity decline is not like A but like B:



The reason, of course, is that losses more distant in time have a smaller present value. Given the amount and time pattern of decline and the discount rate, the present value of the total loss will vary directly with crop prices and the amount of land in the two crops, for obvious reasons.

The calculations assumed that yields change only in response to erosion and that the amount of land in corn and soybeans is constant over the 100 years. Changes in demand for the two crops and advances in technology and management for producing them were thus not taken into account. In fact, advances in technology and management are highly probable, as is growth of demand unless world economic growth is seriously retarded. If demand growth exceeds the growth of yields (the latter reflecting the negative effects of erosion and the positive effects of advances in technology and management), then, with prices constant, the present value of the erosion-induced loss in productivity would be higher than estimated, for several reasons.

In the first place, with a net increase in yields, a given percent decline because of erosion would increase the annual loss measured in bushels per acre. In the second place, the greater yield loss would be spread over more acres since the growth in demand is assumed to outpace the growth in yields. Finally, although this is more problematic, the erosion-induced decline in yield might be greater than the Minnesota model shows because the additional land in corn and soybeans would probably be more erosive and more likely to suffer erosion-induced productivity losses than land already in production.

If the pace of advance in technology and management is sufficient to increase yields more than demand growth, despite erosion effects on yields, then the amount of land in corn and soybeans would decline, and this would tend to reduce the present value of the erosion-induced productivity loss, prices assumed constant. However, because of higher yields, the per acre value of given percentage losses would be higher, tending to offset the effect of less land on the total value of the losses.

Introducing future demand changes and advances in technology and management clearly complicates the problem of estimating the future value of erosion-induced productivity losses, even when crop prices are assumed to remain constant. In fact, however, prices are likely to change in response to changes in demand and in supply side factors: technology and management, erosion-induced productivity loss, and input prices. The direction of the crop price changes will depend on the strength of demand growth relative to the combined strength of the supply side factors. Over the last 40 years the relative strengths were such that real corn and soybean prices fell, as noted above. What the future holds in this respect is highly uncertain. This has implications for policies to protect the productivity of the soil, and we discuss these in chapter 5.

Costs of offsetting measures. Where erosion threatens to reduce productivity it can be assumed that farmers will consider countering the threat by such measures as more fertilizer to replace lost nutrients, liming to maintain favorable pH, and tillage or other practices to maintain favorable bulk density. The Minnesota model assumes that over the next 100 years farmers will in fact incur the costs of these measures, whatever they may be.

The problem is that there are no reliable estimates of these costs reflecting even present conditions, let alone what they may be in the distant future. One approach used to estimate nutrient replacement costs is to multiply nutrient prices by estimates of the amount of nutrients carried away by erosion. Using this technique, Larson et al. (1983) estimated the nutrient cost of cropland erosion in 1977 at about $1 billion. The estimate assumes nitrogen, phosphorus and potassium prices per metric ton of $440, $500, and $300 respectively. Valued at prices of the early 1980s the estimated cost would be substantially less, perhaps not much more than $500 million. Clearly, judgments about future costs of nutrient losses will be powerfully affected by judgments of trends in fertilizer prices.

Apart from high uncertainty about these trends, the technique is questionable for estimating nutrient costs even when fertilizer prices are known. The difficulty is estimating the amount of nutrients actually lost. The following information is required: (1) the amount of each nutrient in the soil body; (2) the nutrient enrichment ratio (soil carried away is generally richer in nutrients than the entire soil body because nutrients tend to concentrate in the surface layer); (3) the percentage of the nutrient in the soil moved which is available to support plant growth; (4) the amount of nutrient replacement which occurs naturally as a result of biological and chemical processes in the soil; (5) the extent to which soil counted as eroded from one place on the landscape replaces soil counted as eroded from another place.

No completely reliable estimates are available for any of this information, but the last two are the most problematic. The concept of T values does not explicitly assume that natural soil processes will maintain nutrient supply and other productivity characteristics of the soil if erosion is less than T (5 tons per acre per year maximum on any soil, less on some soils). If this were assumed, one should calculate nutrient losses only in the amount of soil lost in excess of T. However, even among soil scientists there is much disagreement about what T is for different soils.

We noted in chapter 2 the deep mystery of what happens to soil counted as eroded and of what its productivity consequences are in the place where it comes to rest. The mystery greatly complicates the estimation of erosion-induced nutrient loss. For example, consider one of the Major Land Resource Areas (MLRAs) included in the study of erosion-induced productivity loss by the group at the University of Minnesota (Pierce et al., 1984). The MLRA 103, located in southern Minnesota and northern Iowa, contains 12.7 million acres of cropland which eroded at an average rate of 4.7 tons per acre in 1977. Almost half this land eroded at 5 tons per acre or more. The topography of MLRA 103 is common in areas of the north central region with glacial-derived soils (Larson et al., 1983). It is characterized by "small relief, no major surface outlet, and containment of run-off water and transported sediment in depressional areas... In this landscape very little or no sediment may leave the cultivated area" (Larson et al., 1983, p. 459). If all soil counted as eroded in such a landscape were deposited in places from which there were no erosion, and if the nutrient supply (and other soil productivity characteristics) in the places of deposition was already sufficient, then the nutrients lost from the eroded places would be a net loss from the entire region even though no soil actually left the region, (leaving aside the disputed issue of natural nutrient replenishment in the eroded places). However, this does not appear to be what happens in MLRA 103, or any of the other 14 MLRAs in the Cornbelt studied by Pierce et al. (1984). Sixteen percent of the eroded soil in MLRA 103 came off 0-2 percent slopes and 44 percent came off slopes of 2-6 percent. Since little soil leaves the MLRA, most of the soil counted as eroded on slopes of 6 percent or less must simply have been moved from the steeper to the less steep slopes. The remaining 40 percent of the soil counted as eroded came off slopes of 6 percent or more, and much of it must have been deposited on slopes of 6 percent or less. That is to say, much of the more gently sloping land must have been both sending and receiving soil, hence both sending and receiving nutrients. There may still have been a net loss of nutrients because some receiving sites were already nutrient rich, but the loss was surely less, probably substantially less, than if all sites in the MLRA had been either exclusively senders or exclusively receivers of eroded soil. Accordingly, estimates of the cost of nutrient loss which assume that all nutrients carried by eroded soil are lost would be overstated.

The costs of offsetting the effects of erosion on soil productivity are surely positive, and they may be important. Our lack of knowledge of them is a serious obstacle to an overall assessment of the costs of erosion and hence to our ability to formulate more effective soil conservation policies. Study of these off-setting costs would seem to present a challenging, high pay-off opportunity for inter-disciplinary research involving teams of soil scientists and agricultural economists. A soil model specifying the relation between erosion and varying amounts of nutrients, pH, bulk density and available water capacity, and how yields change with fluctuations in each of these characteristics, would provide information the economist could use in studying the choices the farmer faces. Each of the choices, including acceptance of the yield loss, carries a cost, the investigation of which would provide insights into how farmers are likely to respond under different conditions, and the costs of the responses.

Costs of control measures. The costs of terracing, strip cropping, contour farming, establishment and maintenance of grassed waterways and windbreaks, and of anything else farmers do to avoid erosion-induced losses of productivity must be included in the cost accounting of such losses. Thanks to the work of the USDA's George Pavelis, we have estimates of gross and net stocks of capital invested in erosion control works (Pavelis, 1983). The estimates are in both nominal prices and prices of 1977. Net stocks are depreciated gross stocks. Gross stocks are cumulated annual investments in the works, less retirements.

Between 1935 and 1980 about $39 billion was invested in on-farm conservation measures (in 1977 dollars). Gross stocks (in 1977 dollars) increased from 1940 to 1965, reaching a peak of $28 billion. They declined steadily after that, and in 1980 were $16 billion. Net stocks followed a similar course, but had peaked earlier, rising to $16 billion in 1955 and then declining to $10 billion in 1980. (Pavelis, 1983).

We believe that the way to estimate the annual cost of conservation investments is to take the annual return to the capital represented by gross stocks of such investments. Applied to the Pavelis data, the estimated annual cost in 1980 was $800 million if the rate of return was 5 percent and $1.6 billion if it was 10 percent.

These estimates are too high, however, probably substantially so. Although the investment studied by Pavelis was ostensibly for soil conservation, much of it in fact was not related to erosion control. The 1977 NRI showed that one-half of the nation's terraced cropland had slopes less than 3 percent and on two-thirds slopes were less than 4 percent (American Farmland Trust, 1984, p. 40). Seventy-five percent of the terraced land was in the Great Plains states. Of that, 35 percent was land in which bare fallow would erode at only 0-10 tons per acre per year, according to the RKLS factors in the Universal Soil Loss Equation. On another 33 percent of the terraced land in these states, the RKLS factors indicated erosion of 10-20 tons per acre per year. (AFT, 1984, p. 41). When cropped in continuous corn, soybeans or wheat, the crop cover provided would reduce erosion by 65 to 70 percent, compared to the bare fallow condition (i.e., the C factor in the USLE for these crops is .30 to .35). Consequently, on 35 percent of the terraced land in the Plains states erosion would be between 0 and 3.5 tons per acre per year, if the land were in one of the three crops mentioned, even in the absence of terraces or any other soil conservation practice. On another 33 percent of the terraced land, erosion would be 3.5 to 7.0 tons per acre per year, if in one of the three crops.

Why should such a preponderance of the nation's terraced land be on gently sloping, unerosive land? The reason, evidently, is that the terraces are intended not primarily for erosion control but for water conservation (AFT, 1984, p. 41). This is clearly consistent with the fact that three-quarters of the terraced land is in the semiarid Plains.

Investments in establishment and improvement of permanent vegetative cover are an important component of Pavelis' estimates of stocks of erosion control capital. In a review of the USDA's Agricultural Conservation Program (ACP), the Agricultural Stabilization and Conservation Service (ASCS), the agency responsible for funding the program, found that in over half the cases checked for use of vegetative cover, erosion was not a serious problem. In a separate study of the ACP, the General Accounting Office (GAO) came to the same conclusion (1983). The ASCS and GAO studies were of practices in which the costs were shared between the federal government and the farmer. Where farmers bear the full costs of the practices they may be more directly related to erosion control. However, Pavelis' data show that over time about one-half of the total investment in soil conservation practices has been under cost-share programs.

Summary on Costs

Erosion must have tended to increase costs of producing corn and soybeans since the end of World War II. However, technological advance was sufficient to more than offset this tendency, as well as the tendency of rising demand and input prices to increase costs.

The model developed by soil scientists at the University of Minnesota permit estimates of the current and present value of prospective costs of erosion-induced productivity losses, depending upon assumptions about the time distribution of losses, crop prices, the amount of land involved, and discount rates. Under the assumptions we made, these costs for land in corn and soybeans are currently about $40 million per year, with present values over 100 years of $4.3 billion to $17 billion, depending on whether the discount rate is 10 percent or 5 percent. The annual losses are cumulative.

Tentative though these estimates are, those for the other three kinds of productivity costs of erosion are even more subject to doubt. There are no comprehensive estimates of ephemeral costs (the fourth kind). Estimates of nutrient loss (a component of the second kind of costs) range from $1 billion annually (Larson et al., 1983) to roughly half as much, depending upon assumed fertilizer prices. But these estimates almost surely are too high, probably substantially so, because they assume that all nutrients carried by eroded soil are lost. In fact, it is likely that across the landscape, much of the soil is moved about in a musical chairs fashion. Many sites, therefore, both receive and send nutrients, so the net loss is less than the gross loss. More research is needed, combining the skills of both soil scientists and agricultural economists, to estimate the nutrient and other costs of the second kind.

Estimates do exist of the stock of capital invested in soil conservation practices, like terracing. From these, estimates can be derived of the third kind of costs, i.e., costs of things farmers do to avoid erosion-induced productivity losses. However, these cost estimates--$800 million per year to $1.6 billion per year, depending on the assumed rate of return to capital--may be substantially too high because some of the capital invested in soil conservation practices has little to do with erosion control. This is particularly true of terraces.

We are thus unable to provide acceptable estimates of the current or prospective productivity costs of erosion. It is reasonably clear, however, that the first kind of cost--value of lost productivity--is currently a relatively small component of total productivity costs. The difficulty of estimating total costs is a serious hindrance to formulation of soil conservation policies. We need these costs to judge how much should be spent to protect the soil against productivity loss. We need them also to judge how much we should spend for that purpose relative to how much we should spend to reduce off-farm costs of erosion. We consider these latter costs in the next chapter.

Footnotes

[1]All the studies reviewed here are of effects of sheet and rill erosion. We found no recent studies of the productivity effects of wind erosion.

[2]A fourth major study is underway at Temple, Texas under the direction of Jimmy Williams of the USDA's Agricultural Research Service. This study is developing a model called EPIC (Erosion Productivity Impact Calculator) as part of the USDA's work for the 1985 Resource Conservation Assessment (RCA). The model is promising, but it is still under development and estimates from it of national level effects of erosion on productivity are not available. A brief account of it is given in the appendix to this chapter.

[3]The USDA classifies land according to its capability for crop production. There are eight classes, ranging from land with no limitations to that which should not be in crop production. Each of the eight classes has four subclasses according to specific limitations. These limitations include (e) erosion,

(w) excess water, (s) soil limitations within the rooting zone, such as stoniness, and (c) climatic limitations.

[4]Some erosion control investments are made to protect groups of farms, but much the greater part is made by farmers (often with financial assistance from the federal government) to control erosion on their own farms. (Personal communication with George Pavelis, U.S. Department of Agriculture, Economic Research Service)

[5]Movements of real prices only approximate movements in costs because prices are also affected by transitory and non-cost factors. The decline in corn prices, for example, probably overstates the decline in costs of producing corn because price supports for corn in 1975-79 were weaker than in 1950-54.

[6]We have not attempted to measure the growth of demand for corn and soybeans, but that substantial growth occurred is suggested by the fact that corn production increased 139 percent from 1950/54 to 1975/79 and soybean production increased 486 percent.

[7]For lack of data this discussion excludes ephemeral costs--the fourth kind.

[8]

$$\text{Present value} = \frac{\$40 \text{ million}}{1.1} + \frac{\$80 \text{ million}}{(1.1)^2} + \ldots + \frac{\frac{\$4 \text{ billion}}{.1}}{(1.1)^{100}}$$

if the annual incremental loss over 100 years is $40 million and the rate of discount is 10 percent. The last term is the capitalized value of the last year's loss, expressed in present value terms.

REFERENCES

American Farmland Trust. 1984. Soil Conservation in America: What Do We Have to Lose? (Washington, D.C.).

Benbrook, C. 1980. "An Appraisal of the Yield-Soil Loss Simulator and Its Application in RCA." Paper presented to the RCA Coordinating Committee, U.S. Department of Agriculture.

Crosson, P. with A. T. Stout. 1983. Productivity Effects of Cropland Erosion in the United States, Resources for the Future (Washington, D.C.).

General Accounting Office. 1983. Agriculture's Soil Conservation Programs Miss Full Potential in the Fight Against Soil Erosion. (Comptroller General of the United States, Washington, D.C.).

Langdale, G. W., and W. D. Shrader. 1982. "Soil Erosion Effects on Soil Productivity of Cultivated Cropland." In B. L. Schmidt, R. R. Allmaras, J. V. Mannering, and R. J. Papendick, eds., Determinants of Soil Loss Tolerance. ASA Special Publication No. 45 (Madison, Wisconsin, American Society of Agronomy and Soil Science Society of America).

Larson, W. E., F. J. Pierce, and R. H. Dowdy. 1983. "The Threat of Soil Erosion to Long-Term Crop Production." Science, vol. 219, no. 4584, pp. 458-465.

Neill, L. L. 1979. An Evaluation of Soil Productivity Based on Root Growth and Water Depletion. M.S. Thesis, University of Missouri, Columbia.

Pavelis, G. 1983. Farm Conservation in the United States: Investment and Capital Values, 1935-80. NRE Staff Report, U.S. Dept. of Agriculture, ERS. Washington, D.C.

Pierce, F. J., W. E. Larson, R. H. Dowdy, and W. A. P. Graham. 1983. "Productivity of Soils: Assessing Long-Term Changes Due to Erosion," Journal of Soil and Water Conservation, vol. 38, no. 1, pp. 39-44.

Pierce, F. J., R. H. Dowdy, W. E. Larson, and W. A. P. Graham. 1984. "Productivity of Soils in the Corn Belt: An Assessment of the Long-term Impacts of Erosion." Jour. of Soil and Water Conservation, Vol. 39, No. 2 (March-April).

Shrader, W. D. No date, but probably 1980. "Effect of Erosion and Other Physical Processes on Productivity of U.S. Croplands and Rangelands." Paper prepared for the Office of Technology

Assessment (Washington, D.C., Congress of the United States).

Thomas, D. J. and D. K. Cassel. 1979. "Land Forming Atlantic Coastal Plain Soils: Crop Yield Relationships to Soil Physical and Chemical Properties," Journal of Soil and Water Conservation, vol. 34, no. 1, pp. 20-24.

USDA. 1981. Soil, Water and Related Resources in the United States: Analysis of Resource Trends. 1980 RCA Appraisal, Part II (Washington, D.C., Government Printing Office).

_____. 1981a. Soil, Water and Related Resources in the United States: Analysis of Resources Trends. 1980 RCA Appraisal, Part I (Washington, D.C., Government Printing Office).

Young, K. 1980. "The Impact of Erosion on the Productivity of Soils in the United States." In M. DeBoodt and D. Gabriels, eds., Assessment of Erosion (New York, John Wiley & Sons).

Appendix to Chapter 3[1]

The Erosion-Productivity Impact Calculator

The Erosion-Productivity Impact Calculator (EPIC) model simulates the interaction of the soil-climate-plant-management processes in agricultural production. EPIC is a very complete simulation of a physical crop production function which is specifically designed for use in estimating the relationship between soil erosion and soil productivity.

EPIC is composed of physically based components for simulating erosion, plant growth, and related processes and economic components for assessing the cost of erosion, and determining optimal management strategies. EPIC simulates the physical processes simultaneously involved and realistically using readily available inputs. Commonly used EPIC input data (weather, crop, tillage, and soil parameters) are available from a computer filing system assembled especially for applying EPIC throughout the U.S.

Since erosion can be a relatively slow process, EPIC is capable of simulating hundreds of years if necessary. Even though EPIC operates on a daily time step throughout such lengthy simulations, it is computationally efficient and capable of computing the effects of management changes on outputs.

The components of EPIC can be placed into eight major divisions for the purposes of discussion--hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, and economics. The hydrology model simulates surface runoff volume and peak discharge rate given daily rainfall amounts. Other hydrology components include evapotranspiration, percolation, lateral subsurface flow, drainage, irrigation, and snow melt. The weather component draws upon historical weather data to simulate a synthetic weather pattern that has the same monthly means, variances, skewness, and sequential correlation of weather variables as found in the historical series.

Wind erosion is predicted using a wind erosion model modified to operate with a daily time step. Water erosion is simulated with the Onstad and Foster modification to the Universal Soil Loss Equation. The two plant nutrients considered in EPIC are nitrogen and phosphorus. Nitrogen processes simulated include runoff of NO_3 organic N transport by sediment, leaching, upward NO_3 movement by soil evaporation, denitrification, immobilization, mineralization, crop uptake, rainfall contribution, fertilizer additions, and fixation. Phosphorus processes simulated include runoff of soluble P, sediment transport of mineral and organic P immobilization, mineralization, sorption-desorption, crop uptake, and fertilizer additions. A general plant growth model is used to simulate growth of above-ground biomass, grain or fiber, and roots for corn

[1]This appendix draws upon materials prepared by John Putman and Paul Dyke, both NRED/ERS/USDA.

grain, corn silage, corn sorghum, sorghum silage, spring and winter wheat, barley, oats, peanuts, sunflowers, soybeans, alfalfa, cotton, and grasses. The plant growth model simulates energy interception; energy conversion to roots, above-ground biomass, and grain and fiber production; and water and nutrient uptake. Plant growth is constrained by water, nutrient, and air temperature stresses. EPIC can be set to increase the rates of fertilizer applications to avoid plant nutrient stress as erosion strips away the most fertilizer-rich layers of the soil. Similarly, water stress can be avoided by allowing EPIC to increase irrigation water application rates or frequencies. Soil temperature is related to the nutrient cycling and root growth components of EPIC. Soil temperature is predicted throughout the rooting zone as a function of the previous day's soil temperature and the present day's air temperature and solar radiation. The EPIC tillage model simulates row height, surface roughness, and mixing of soil layers, nutrients, and plant residue for any tillage operation. The economics component of EPIC uses a crop budget to calculate crop production costs. Income is determined from simulated annual crop yields. Net profit (income minus cost) is subject to change as the soil erodes away.

The removal of topsoil, by erosion, impacts soil productivity by the loss of root zone and soil moisture holding capacity, the mixing of subsoil into the plow layer and the loss of nutrients in sediment and accelerated runoff. Such losses, even at high erosion rates, are so gradual and so dependent upon highly variable, individual storm events that they are essentially unmeasurable in a single year. Hence, EPIC usually simulates the sequential impact of these variables over many years (usually 100) to develop accurate estimates of average annual change over time. Because of this, EPIC is commonly thought of as a projection model. This perception is not exactly correct.

EPIC is clearly <u>static</u> with respect to management. A single, unique crop, plant variety rotation, tillage budget, crop calendar, conservation practice, level of inputs, other physical relationships, and set of prices must be specified prior to an EPIC simulation and cannot be varied during a simulation (except for erosion-induced changes in fertilizer or irrigation rates).

EPIC is clearly <u>dynamic</u> in the way daily time steps are sequentially linked to simulate the interactive plant growth processes. Tillage budgets and crop calendars specify the precise Julian day of seed bed preparation, planting (seeding), cultivating, fertilizing, harvesting and residue management functions associated with farm crops. A host of algebraic functions control the way these agronomic operations interact with the soil's physical and chemical environment, to modify that environment daily through a growing season, and sequentially from season to season.

The environmental portion of EPIC as reflected by the climatic generator is <u>conditionally predictive</u>. EPIC is driven by a synthetic pattern of daily weather events that initiate the chain reaction and day-by-day change in values of the many physical and chemical processes. However, this synthetic weather series has no relation to forecasting. It should more correctly be thought of as multiple samples drawn from a frequency distribution of weather day sequences that might occur next year.

EPIC is <u>predictive</u> in the sense that it simulates the sequential, daily physical processes through a series of synthetic weather occurrences under assumptions of constant management and technology. Thus, EPIC predicts the soil loss and change in inherent productivity which might result from a specified number of years under static management. These predictions will be used in the forthcoming analyses of the 1975 Resources Conservation Act Appraisal.

Chapter 4

OFF-FARM COSTS OF EROSION[1]

Kinds of Off-Farm Damage

Soil carried as suspended sediment increases the turbidity of water, which may damage fish and other forms of aquatic life and reduce the aesthetic value of the water for swimmers and boaters. Suspended sediment also imposes costs of clean-up before the water can be used for residential and some commercial and industrial uses. When the soil settles as sediment, it gradually reduces the useful life of lakes and reservoirs, raises shipping and navigation costs and, by reducing the depth of stream channels, may cause increased flooding costs. Soil particles often carry nutrients, particularly phosphorus, which stimulate algal growth in lakes and reservoirs, impeding boating, fishing and swimming. Recreational values are also diminished because the pollutants and resulting eutrophication gives the water an unpleasant appearance, and in extreme cases, a bad odor, while making conditions difficult for fish by reducing the water's supply of oxygen. Some pesticides also adhere to soil particles, and when released in the water may kill fish or otherwise damage aquatic ecological systems.

Costs and Sources

Effective policies to deal with off-farm damages of erosion require three kinds of information: (1) estimates of the dollar value of the various kinds of costs; (2) location of the specific water bodies where the damage is incurred; (3) location of the land supplying the damaging sediment. The second and third kinds of information are further needed for targeting damage control efforts.

In this chapter we deal primarily with the first kind of information. Some data are available on the locations of damaged water bodies, but pulling it together for a comprehensive assessment is beyond our reach. Information linking sediment damages with the location of sediment supply is scarcer still, indeed virtually non-existent.

Our estimates of economic damages are admittedly very crude, and our estimate of cropland's share of these costs even more so.[2] They provide, however, a basis for roughly judging the importance of cropland relative to other sources of off-farm erosion damage, information of some value to policy-makers. They further permit a comparison of the productivity costs of cropland erosion with off-farm costs, again a matter of policy interest. Table 4-1 showing the relative importance of various sources of erosion is relevant in this connection.

We cannot stress too emphatically that most of the cost estimates presented here are subject to wide margins of error. And for some potentially important kinds of damage, the available information is either so scarce or so unreliable that we made no estimates at all. Because of these omitted damages, we consider our estimate of total off-farm costs to be conservative.

It is also important to recognize that these estimates pertain to the damages caused by sediment and related contaminants, and are not estimates of the benefits that would result from sediment control. There are several reasons why the benefits would be expected to be lower than the costs given here. Most important among these is that reducing the amount of erosion on the land would not directly translate into reduced sediment loads in streams. If the sediment entering streams is reduced, the streambanks will tend to erode faster, partially compensating for this loss, and many of the sediment related damages will continue to occur. Eventually, the stream should return to equilibrium conditions with a lower sediment load, but achieving this new equilibrium may take many years.

Given the highly unsatisfactory information available, it can be argued that any attempt to make a comprehensive estimate of off-farm erosion costs is not worth the effort. We concluded, however, that all things considered we

Table 4.1. Erosion from Non-Federal Lands: 1977

	Water		Wind[a]		Total	
	Amount[b]	Percent	Amount[b]	Percent	Amount[b]	Percent
Cropland	1,926	38.8	892	61.1	2,818	43.9
Rangeland	1,155	23.3	559	38.3	1,714	26.7
Pastureland	346	7.0	5	.3	351	5.5
Forestland	435	8.8	4	.3	439	6.8
Gullies	298	6.0	-	-	298	4.6
Streambanks	553	11.1	-	-	553	8.6
Roads	169	3.4	-	-	169	2.6
Construction	80	1.6	-	-	80	1.2
Total	4,962	100.0	1,460	100.0	6.422	99.9

Sources: Cropland, rangeland, pasture land and forestland from RCA Final Program Report and EIS, p. 9; gullies, streambanks, roads, and construction from RCA Appraisal, Part I, p. 98.

[a]Includes only 10 Great Plains states.

[b]Amounts are in millions of tons per year.

Table 4.2. Summary of Costs of Off-Farm Erosion Damages (all estimates rounded)

Type of damage	Range of Estimates	Point Estimate	Cropland's Share
		(millions)	
Instream			
Biological impacts		no estimate	
Recreational	950-5,600	2,100	830
Water storage facilities	500-1,300	810	260
Navigation	420-800	560	180
Other instream uses	420-2,800	830	330
Total Instream (rounded)	(2,300-10,000)	(4,300)	(1,600)
Offstream			
Flood damages	490-1,400	770	250
Water conveyance facilities	140-300	200	100
Water treatment facilities	50-500	100	30
Other offsteam uses	(-)90-(-)370	(-)130	(-)40
Total Offstream (rounded)	(590-1,800)	(940)	(340)
TOTAL ALL EFFECTS (rounded)	2,900-12,000	5,200	1,900

should go ahead, despite the uncertainties of the results. The nation spends some hundreds of millions of dollars each year on soil conservation. We believe that the cost estimates presented here can contribute at least marginally to more effective use of those funds. And by putting forward some specific estimates of costs we may inspire others who disagree with us to develop a better set of estimates.

Recreation: Providing recreational services is now big business in the United States. Spending for these services increased from $58 billion in 1965 to $244 billion in 1981 (Recreation Assessment, 1983). In prices of 1980 the increase was 47 percent, almost 2.5 percent annually, and well in excess of the growth of population.

Assigning values to specific recreational activities is difficult, but some estimates of water based recreation are available. In Michigan alone over $157 million is spent annually on sport fishing in the Great Lakes. A more comprehensive assessment done at Resources for the Future (Vaughn and Russell, 1982) estimated that the total value of recreational freshwater fishing in the United States (apart from Great Lakes fishing) is $12 billion to $27 billion annually. The RFF study also estimated that, after pollution from "point sources" has been controlled, eliminating sediment from cropland would add another $22 million to $105 million per year worth of freshwater recreational fishing benefits (13 to 17 percent of the total). These estimates, however, ignore many kinds of erosion related damages as well as the benefits of reducing sediment from sources other than cropland.

Our estimates of recreational damages are derived from another RFF study assessing the recreational benefit associated with expected water quality improvements (Freeman, 1982). The estimates assume that cropland erosion is responsible for 13 to 17 percent of these benefits, and that total erosion related damages are equivalent to 250 percent of croplands share. Based on these assumptions, recreational damages associated with erosion total $950 to $5,300 million annually, 21 percent of which is for freshwater fishing, 21 percent for marine recreational fishing, 21 percent for swimming, 32 percent for boating, and 5 percent for wildfowl hunting. These numbers do not include losses from fatal or non-fatal accidents caused, in part, by erosion related problems.

Water storage facilities. The main cost of erosion to these facilities is the loss of storage capacity resulting from sedimentation. Lesser impacts are on the rate of evaporation and transpiration of the stored water. The sedimentation costs may appear as costs of increased sediment storage capacity built into newly constructed reservoirs, as costs of either dredging, or building new reservoir capacity to compensate for the loss. Estimates of these costs suggest that they are high. In areas experiencing high erosion rates the sediment storage pool of reservoirs constitutes 15-30 percent of reservoir capacity (Beasley, 1972; U.S. Army Corp of Engineers, 1981). Building sediment storage capacity increases costs because it requires dams to be higher and more land to be flooded. Construction cost data from the Department of Agriculture, the Bureau of Reclamation, and the Corps of Engineers indicate that a conservative estimate of current reservoir constructions costs is $300 to $500 per acre foot of capacity. The nation is currently building about 5 million acre feet of new reservoir capacity each year (Langbein, 1982). Assuming that 15 to 25 percent of this is needed for sediment storage and that the cost per acre foot of capacity is $300 to $500, the annual cost of constructing additional capacity for the purpose of storing sediment is $225 million to $625 million.

Excess sediment can be removed from reservoirs by dredging. A 1969 estimate by the Federal Water Pollution Control Administration indicated that (when adjusted to 1980 prices) these dredging costs were running at $200 million to

$250 million per year (Harris and Seitz, no date). Our review of material available since then gives no reason to believe that dredging costs have changed since the earlier estimate.

The third kind of cost of reservoir sedimentation is the loss of reservoir capacity. An estimated 1.4 to 1.5 million acre feet of capacity is being filled each year (Clark, Haverkamp, and Chapman, 1985). This capacity will have to be replaced in the future, and we estimate that the present value of these costs runs from $60 million to $450 million per year, depending on whether the discount rate is 5 to 10 percent and what period will elapse before the replacement capacity is built.

Curiously, turbidity may also have some benefits on reservoir capacity. Because turbidity decreases surface water temperature, (Schiebe, Ritchie and McHenry, 1975) it also reduces evaporation losses. The effect is small, but so large are evaporation losses (14 billion acre feet per year from U.S. reservoirs-USDA, 1981) that even a small reduction may be significant. Assuming the estimates of reservoir costs given above, we estimate the present annual benefits of turbidity reduced evaporation losses at $10 million to $200 million.

On the other hand, Maddock also reported that sedimentation can increase evaporation (Maddock, 1947). There is insufficient information to allow a nationwide estimate of these costs, but we believe that they are likely to be smaller in magnitude (we have assumed 50 percent less) than the cost savings associated with reduced evaporation.[3] Finally, evidence from the EPA, the North American Lake Management Association (Duda and Johnson, 1983) and other sources indicate that governments are spending substantial amounts--we estimate $17 to $85 million a year--to clean up lakes damaged by erosion associated pollutants.

Navigation. Sedimentation lessens the depth of channels and harbors, increasing the likelihood of shipping accidents, causing delays in movement, forcing the use of smaller, less economical ships, and running up costs of dredging. Data on navigation accidents collected by the Coast Guard indicates that these damages may amount to $20 to $100 million annually (U.S. Coast Guard, 1983). There is no information on the cost of delays or using smaller ships, but they may also be high. In the spring following the Mississippi River flood of 1974, siltation of the south pass of the river below New Orleans reduced foreign shipping into and out of that city by about $500 million (Corps of Engineers, 1974-75). This is not a measure of the cost of siltation since most of this trade was probably eventually diverted to other ports. Nonetheless, the cost of the associated delays, whatever the amount, may be attributed to siltation in the approaches to the port.

Estimates are available for the costs of dredging navigation channels and harbors. The Corps of engineers, which is responsible for only about half the dredging of these facilities, spent $305 million in 1980 on maintenance dredging.[4] Including non-federal expenditures, the total maintenance dredging costs, therefore, would be $400 to $700 million per year.

Miscellaneous in-stream damages. Sediment also damages commercial fisheries in inland waterways, decreases riparian property values, and reduces "preservation values," i.e., the value people place on preserving the amenities associated with clean water even though they may never directly use it. The knowledge that the amenities exist and may someday be experienced by them or others is itself of value.

In a manner similar to that adopted for estimating recreational damages, we have based our estimates of damages to commercial fishing on Freeman's (1982) assessment of the benefits ($0.4 billion to $1.2 billion in 1978 dollars) that would result from water quality improvement. We attribute $260 to $410 million to erosion.

A number of studies have shown that riparian property values can be adversely affected by poor water quality (National Commission on Water Quality, 1976; Freeman, 1982; Monteith et al. 1981). It is not possible, however, to determine the extent to which changes in property value reflect other types of damages which are already included. For this reason, we have not included them in our estimates.

The estimate of preservation values is also based on Freeman's work (Freeman, 1982). He concludes that water quality improvements would yield preservation benefits of $500 million to $4 billion per year in 1978 prices, with a best estimate of $1.2 billion (about $1.4 billion in 1980 prices). Using the same procedure as with recreational damages results in estimates of $160 million to $2.4 billion of damages caused by erosion related pollution.

Off-stream Costs

These include costs of flooding, damages to both water conveyance facilities and water treatment facilities, and costs imposed on steam electric power plants.

Costs of floods. Sediment and sedimentation increase flooding costs in three ways: (1) stream bed aggradation increases both the frequency of flooding and the depth of flooding associated with any particular volume of flood waters; (2) suspended sediment increases the volume of flood waters; and (3) sediment in the water causes much of the damage of flooding.

Despite many references to the flood damages attributable to sediment and sedimentation, we found only two studies containing estimates of damages for the country as a whole, one done in 1947 (Brown, 1947) and the second in 1964, which applied only to upstream reaches, in 1964 (Ford, 1964).

The Water Resources Council estimated total flood damages in the country to be about $5.3 billion in 1980 under normal conditions (U.S. Water Resources Council). Of the total, about $2.5 billion occurred in upstream reaches of watersheds. Estimating the contribution of erosion to these damages is very difficult. There is much evidence that streambed aggradation is occurring, but its effects on flooding are unknown. However, most of the aggradation would be expected to occur in upstream segments of basins, so we may assume arbitrarily that it could be responsible for up to 10 percent of the total upstream flood damages, or $250 million.

Analyzing sediment monitoring data collected by the U.S. Geological Survey (Briggs and Ficke, 1977) suggests that suspended sediment may have increased flood volumes by up to 4 percent in some basins. Assuming that the amount of flood damages are directly proportional to flood volume results in $10 to $50 million of flood damages annually which are attributable to the impact of suspended sediment on water volume.

The damages caused by sediment deposited by flood waters probably far exceed either of the two kinds of damage just discussed. Brown concluded from his examination of flood damage records that "a relatively high proportion of flood damages in urban areas are due to the cost of cleaning sediment from streets, houses, furniture, etc." (Brown, 1947) And Ford (1964) estimated that 8.6 percent of total upstream flood damages (primarily agricultural) were attributable to sediment deposition. Assuming that sediment deposition is responsible for 15 to 30 percent of urban flood damages and 5 to 10 percent of agricultural damages, sedimentation costs may be estimated at $445 million to $890 million per year.

These estimates of costs of flooding attributable to erosion do not take into account the value of human lives lost. Flooding caused an average of 176 deaths per year in the 1970s, varying from 74 in 1971 to 540 in 1972 (Conservation Foundation, 1982). In the 1960s and 1950s, annual flooding deaths averaged 72 and 79 respectively. If we assume that the typical number of annual flooding deaths is 100 and that sediment is responsible for the same proportion of deaths as for other flood damages, then 9 to 19 deaths per year would be attributable to sediment. However, we have made no estimates of the cost of these deaths.

In the last chapter we noted that in some cases sediment deposited from eroded land might lower agricultural productivity in the place of deposition, but in other cases might increase productivity. A study of the Piedmont area in North Carolina concluded that about 10 percent of the floodplain cropland was affected by sedimentation, and that half the affected area had suffered at least a 20 percent reduction in productivity (Yadkin, Pee-Dee River Basin Level B Recommended Plan, 1981). About 12 percent of the nation's cropland (16 percent of prime farmland) is in flood plains (USDA, 1981), and since much sediment deposition also occurs in upland areas, the total acreage of agricultural land "at risk" from deposition must be substantial. By inference, the question of the net productivity effect of sediment deposition is comparably important. If the Piedmont results were extrapolated to all cropland in floodplains, the costs would exceed $170 million per year. The true costs could be much lower--or much higher--than these. We assumed that because much riparian land is inherently very fertile, there are net costs of approximately $100 million a year attributable to sedimentation. Clearly, however, inclusion of the impacts of sedimentation on upland fields could change this estimate substantially.

Damages to water conveyance facilities. These damages impose three sorts of costs: (1) those associated with sedimentation of drainage ditches; (2) those resulting from sedimentation of irrigation canals and channels conveying water to points of off-stream use; and (3) the increased costs of pumping sediment laden waters. We estimated that sediment increases pumping costs less than $1 million annually, so we ignore these costs here.

Sediment deposited in drainage ditches causes damages from localized flooding (not included in flooding damages discussed above), and state and local highway departments spend a substantial part of their budgets to remove this sediment. The best estimate we have found of the cost of sediment removal is from a 1977 survey of state and county road maintenance departments in Illinois (Taylor, Kuder, Sefton, and Schaeffer, 1978). The survey found that 2.5 million cubic yards of sediment were removed annually from roadside ditches in the state at a cost of $6.3 million (about $8.1 million in 1980 prices). The 2.5 million cubic yards of sediment represents about 1.4 percent of total erosion in Illinois (Illinois Institute for Environmental Quality, 1978). If we assume from this figure that 0.75 to 1.5 percent of national gross erosion is deposited in drainage ditches and that the per cubic yard cost of removing it is the same as in Illinois, then the total cost of this operation nationwide would be $90 million to $185 million in 1980 prices.

The most recent estimate we found of costs of clearing sediment from irrigation canals was $34 million in 1966 (Robinson, 1971), about $80 million in prices of 1980. Based upon information provided by the Bureau of Reclamation[5] combined with data on canal maintenance costs collected in the 1978 agricultural Census (U.S. Bureau of the Census, 1982), we estimate that $30 million to $70 million may currently be spent for this purpose, and that another $15 million to $50 million is spent to control weed growth stimulated by nutirents in the water.

Damages to water treatment facilities. Sediment and its associated contaminants can increase the problems, and the costs, of providing safe drinking water and process water for off-stream users. For drinking water, the sediment has to be removed from the water either by filtration and/or sedimentation. Excess nitrogen has to be removed by a chemical process and pesticide contamination by an activated carbon filter. And even where these facilities have been installed (and they are still uncommon), health risks may continue to exist.

Very low levels of sediment can be removed in the same filtration process that is required to remove other suspended contaminants from the water, but the higher the sediment level, the larger the filter bed and more frequent the cleaning. As the turbidity increases, additional settling basins and other equipment need to be added.

Many industries also have to use process water which is at least as clean as that provided by municipal facilities. For instance, water used in textiles, paper making, food processing, and many other industrial activities has to be essentially free of turbidity and most other contaminants as well, requiring these industries to treat the water themselves if they do not use municipal supplies.

In 1980 municipal suppliers withdrew 22 billion gallons per day (bgd), and industries, except those of thermoelectric power, withdrew directly an average of 29 bgd of fresh water from surface water sources (Solley, Chase and Mann, 1983). Assuming that only 5 bgd of industrial withdrawals will be used as drinking water and treated adequately, the total requirement for public and industrial water treatment is 27 bgd.

A 1947 estimated placed the "cost of water purification as a result of excess turbidity" at $5 million annually (equivalent to $30 million dollars annually in 1980)(Brown, 1947). A 1966 estimate put the annual cost for "removing the excess turbidity from public water supplies" at $14 million (equivalent to $39 million in 1980), and "from miscellaneous sediment removal, cleaning and adding maintenance" at $31 million (equivalent to $87 million in 1980) (Robinson, 1971). Coagulants, disinfectants and filtration systems are major expenses in the operation of water treatment systems. The Senate Committee on Agriculture and Forestry (1976) reported that in 1974 $25 million (equivalent to $39 million in 1980) was spent on "added maintenance and turbidity removal by industry and cities."

The City of Baltimore estimates that it spends $200,000 to $250,000 to remove erosion related contaminants from one water supply (Stack and Gottfredson, 1981). Another recent study estimated that the cost savings associated with removing such pollutants from the water supplies for three communities in Michigan would not exceed $40,000 and could be much less (Birch, Sandretto, and Libby, 1983).

Other types of industrial costs have also been reported, but no national estimates have been made. Organic particles and suspended solids associated by phytoplankton growth can interfere with the ion exchange process of demineralization and so must be removed. Such treatment of boiler feed water costs between $2.14 and $3.13 per 1,000 gallons in 1974 (cited in Welch, 1978).

EPA cost data indicate that the cost of removing suspended sediment and associated contaminants can increase the cost of treating water by 15 to 35 percent (or more) for new facilities (EPA, 1979). For a new direct filtration plant these increases amount to $0.09 to $0.22 per 1,000 gallons in 1978 prices for a facility providing 1 million gallons per day (suitable for a population of 3,500 to 4,500) down to $0.018 to $0.043 per 1,000 gallons for one providing 100 mgd. For older plants, the additional costs would be lower because of lower construction costs. Assuming that treatment costs are increased an average of 0.5 to 5 cents per 1,000 gallons because of suspended sediments (and associated contaminants), we get an annual cost of $50 to $500 million dollars for increased water treatment expenditures.

<u>Damages to steam electric power plants</u>. Although steam electric power plants and other cooling water facilities do not require high quality water, sediment and algae can interfere with the efficient cooling process in these facilities. The plant may need to build a sedimentation basin to remove the sediment before the water is used for cooling, and may experience increased maintenance costs for removing deposits and dealing with increased wear on pumps and other hydraulic equipment.

As with drinking water systems, power plants are plagued by clogging and fouling of filters and heat exchangers.

Nuisance algae and weeds are primarily responsible, although fresh fish can also clog intakes. As eutrophication of the supply source progresses, routine maintenance and cleaning costs can be expected to increase correspondingly. In the town of Pickering on Lake Ontario, green algae persistently clogged water lines, occasionally to the point of forcing the plant to shut down, costing $40,000 each time in lost revenues (Welch, 1978). The utility was finally compelled to install heat exchangers at a cost of $2.7 million.

Research sponsored by the Electric Power Research Institute indicates that utilities have to spend $50 to $150 a year per installed megawatt to remove algae from condensers (Kasper, Chow, Graham, and Mussali, 1983). With 540,000 megawatts of installed capacity in 1981 (Loftness, 1984), the annual costs would total $27 million to $81 million. Because some nutrients come from point sources, we estimate that the costs related to erosion are in the range of $20 to $70 million a year.

We noted earlier that turbid ponds are cooler than clear ponds, indicating that the overall efficiency of steam electric power plants would be higher if they withdrew their cooling water from turbid water bodies. The average efficiency of steam electric power plants is currently about 33 percent. Using basic laws of thermodynamics, a two degree (centrigrade) reduction in the temperature of the cooling water could increase the efficiency by as much as 0.4 percent.

In 1980, a net total of 2×10^{12} kilowatt hours of electricity were generated by steam electric power plants (U.S. Department of Energy, 1983). Approximately 71 percent of the water withdrawn that year for cooling purposes by steam electric power plants came from fresh, surface water sources (Solley, Chase and Mann, 1983). The average production cost for electricity from each plant was 2.35 cents per kilowatt hour.[6] Assuming that the actual increase in efficiency could range from 0.1 percent to 0.4 percent gives a range of benefits of $100 million to $400 million per year, and we will assume a point estimate of $150 million.

Other off-stream impacts associated with erosion are caused primarily by other contaminants such as salt and nutrients, and not by the sediment itself. Salt carried off agricultural lands could be causing $500 million to $1,200 million in damages to industrial, commercial, and household equipment and appliances (Clark, Haverkamp and Chapman, 1985) particularly in the arid west. It could also be causing downstream irrigators $10 to $230 million in damages, but because these are not strictly related to erosion, we have not included them in our estimates.

Downstream irrigators do benefit from one aspect of cropland erosion, and that is the nutrients which are carried off with the sediment. Water quality monitoring by the U.S. geological Survey (Briggs and Ficke, 1977) indicates that the mean nutrient constant of surface water is 0.85 milligrams per lilter of nitrogen and 0.24 milligrams per liter (mg/l) of phosphorus. For both these nutrients, agricultural sources are estimated to account for 80 percent to 90 percent of total loadings (Clark, 1984). Assuming that agriculture supplies an average of 0.5 to 1.0 mg/l of nitrogen, and 0.1 to 0.3 mg/l of phosphorus, the total value of the nutrients contained in the 1 million acre feet of irrigation water consumed in the United States (Solley, Chase and Mann, 1983) would be $15 million to $37 million. This is substantially less than the $8 billion worth of nutrients that CAST estimates are washed off farmland in the erosion process (Council for Agricultural Science and Technology, 1982).

Summary and Conclusions

Table 4-2, summarizing all of the cost estimates made in this chapter, indicate that eroded soil and related pollutants created costs estimated in the range of $2.9 to $12 billion per year in 1980 (excluding the cost of salinity) with a point estimate of $5.2 billion per year. About one-third of these costs, $1.9 billion, can be attributed to erosion from cropland.

The estimates should only be considered as orders of magnitude, that is, the actual costs are more likely to be approximately the estimate provided than they are to be one-tenth as much or 10 times as much. However, as we noted at the outset, potentially significant costs have not been estimated at all. The costs of biological impacts and losses of human life are the most important of these. If these were included, our estimates of costs would probably be substantially higher than shown in table 4-2.

The costs indicated in the table also do not take into account the substantial amounts that are being spent to avoid off-farm damages of erosion. For flood control alone billions of dollars have been invested in constructing and maintaining dams, channelization projects, drainage projects, sediment traps, and other flood mitigation measures by the Corps of Engineers, the Soil Conservation Service, the Bureau of Reclamation, countless state and local governments, and miscellaneous private organizations (Johns, date not given). A part of these investments (as well as their operation and maintenance costs) were allocated to controlling sediment associated flood damages.

Thus, as estimates of the total cost of off-farm erosion damages, the figures in table 4-2 are probably significantly low. As estimates of the benefits of controlling erosion on the land, however, they may be high. There are four major reasons for this. The first is that in many cases, streams and rivers would react to the reduced sediment loads from cropland and other sources following the adoption of erosion controls by increasing the rate at which they erode their own channels and banks. Thus, the sediment load of the waterways would be reduced much less than the sediment yield from land erosion. The increased channel erosion would also pick up the many contaminants that are currently trapped in the bottom sediment. It would take many years for the nation's streams and rivers to return to an equilibrium which would result in erosion control benefits being realized to their fullest extent.

The second reason is that the accelerated channel and bank erosion caused by reduced sediment loads could create serious countervailing costs, undercutting bridges, pushing through protective levees and canal banks, and so forth. For instance, erosion in unlined canals has increased markedly when their water supply has been shifted from a naturally sediment-filled river to a reservoir which allows most of the sediment to settle out (Sabol, 1979).

The third reason is that erosion control measures cannot be 100 percent effective in reducing the amount of sediment and associated pollutants from entering the nation's waterways. Even with a fully operative erosion control program, many of these damages would continue to occur.

The fourth reason why the cost savings of erosion control would, at least initially, be less than the total costs imposed, involves the economics of dealing with sediment. In many cases, the investments required to deal with the sediment have already been made, and the costs of operating these investments would continue whether the sediment existed or not. For instance, most water treatment plants built in the past two decades have sedimentation basins. These would exist, and would probably continue to be used, regardless of the turbidity of the water supply (Birch, Sandretto and Libby, 1983). Eventually people's habits would adjust to the lower pollution loads and these costs would be reduced, but as with the geomorphological changes in the streams, this adjustment would take time.

In spite of all these caveats, it appears that soil erosion is imposing substantial off-farm costs on the nation at the present time. Since farmers have little or no incentive to control these costs, we can reasonably infer that there are potential net social benefits to be gained from implementing public policies to reduce the costs. In the next chapter we consider issues involved in developing and implementing such policies, as well as policies to reduce erosion-induced productivity losses.

Footnotes

[1]The estimates in this chapter are based primarily on work done by Clark, Haverkamp and Chapman (1985) and further information and discussion can be found in that source.

[2]We have generally assumed that cropland is responsible for approximately one-third of total damages. This is somewhat less than cropland's share of total erosion (see table 4-1), and approximately its share of nutrients such as phosphate and nitrogen, which also contribute to the damages.

[3]Personal communication to Edwin H. Clark, II from Frank Lapensee, U.S. Environmental Protection Agency.

[4]Personal communication to Edwin H. Clark, II from George Collins, U.S. Army Corps of Engineers.

[5]Personal communication to Edwin H. Clark, II from Jerome Schack, Bureau of Reclamation, August 1984.

[6]Personal communication to Edwin H. Clark, II from David Harwell, National Energy Information Administration.

References

Beasley, R. P. 1972. Erosion and Sediment Pollution Control, Iowa State University Press, Ames.

Birch, Alfred, Carmen Sandretto and Lawrence W. Libby, Toward Measurement of the Off-Site Benefits of Soil Conservation (E. Lansing: Dept. of Agricultural Economics, Michigan State University, May 1983).

Briggs, John C. and John F. Ficke, "Quality of Rivers of the United States, 1975 Water Year--Based on the National Stream Quality Accounting Network (NASQAN)," USGS Open File Report 78-200 (Reston, Va.: U.S. Geological Survey, May 1977).

Brown, Carl B. 1947. "Perspective on Sedimentation - Purpose of Conference," Proceedings of the First Federal Interagency Sedimentation Conference, May 6-8. Bureau of Reclamation Cost Index.

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

Corps of Engineers. 1981. Upper Little Arkansas River Watershed Survey Report and Environmental Impact Statement, Volume 1 of 2, October. Tulsa, OK.

Council for Agricultural Science and Technology, Soil Erosion: Its Agricultural, Environmental, and Socioeconomic Implications, Report no. 82 (Ames, Iowa: CAST, Jan. 1982).

Duda, Alfred M. and Robert J. Johnson, "1983 State Lake Survey," conducted by the North American Lake Management Society (unpublished).

WATER SPECTRUM, Vol. 6:4, Winter 1974-75.

Emerson, M. Jarvin, and Hossein Akhavipour. 1979. Benefit Assessment of Kansas Water Quality Management Plan, Kansas State University, Manhattan, Kansas.

Ford, E. C. 1964. "Upstream Flood Damage," in Journal of Soil and Water Conservation, Vol. 19(6), Nov.-Dec.

Freeman III, A. Myrick. 1982. Air and Water Pollution Control, A Benefit-Cost Assessment, John Wiley and Sons, New York, N.Y.

Harris, Kim S., and Wesley D. Seitz. (No date). Sediment Damages in Water, University of Illinois, Urbana.

Illinois Institute for Environmental Quality. 1978. "Task Force on Agriculture Nonpoint Sources of Pollution - Final Report," December.

Johns, E. "Sediment Problems in the Mohave Valley--A Case History," Proceedings of the 3rd Federal Interagency Sedimentation Conference.

Kasper, Joel, et al., "Use and Cost of Chlorination Systems," reprinted from Power Engineering, Oct. 1983, pp. 54-57 by Technical Publishing, 1983.

Langbein, Walter B., "Dams, Reservoirs and Withdrawals for Water Supply--

Historic Trends," USGS Open File Report 82-256 (Washington, D.C.: U.S. Department of the Interior, 1982).

Loftness, Robert L., Energy Handbook, 2nd Edition (New York: Van Nostrand Reinhold Co., 1984), table 4-7 "World Electric Power Capacity and Generation," p. 121.

Maddock, Thomas, Jr., "Reservoir Problems with Respect to Sedimentation," in Proceedings of First Interagency Sedimentation Conference, May 6-8, 1947, pp. 9-16.

Monteith, Timothy J., Melanie P. Boise, and Rose Ann C. Sullivan, 1981. Environmental and Economic Implications for Conservation Tillage Practices in the Great Lakes Basin, Great Lakes Environmental Planning Study, Contribution No. 20, January.

Outdoor Recreation for America, An Assessment Twenty Years After the Report of the Outdoor Recreation Resources Review Commission, 1983, pp. 15-16.

Robinson, A. R. 1971. "Sediment: Our Greatest Pollutant?" Agricultural Engineering, August.

Sabol, George V. 1979. "Desilted Irrigation Water: A Case Study," 1979 Irrigation and Drainage Division Specialty Conference, July 17-20, 1979, Albuquerque, N.M., American Society of Civil Engineers, New York, N.Y., p. 75.

Schiebe, Frank F., Jerry C. Ritchie and J. Roger McHenry, "Influence of Suspended Sediment on the Temperatures of Surface Waters of Reservoirs," in vol. 19 Proceedings of the International Association of Theoretical and Applied Limnology, Stuttgart, 1975.

Solley, Wayne, Edith Chase, and William Mann. 1983. "Estimated Use of Water in the U.S. in 1980," Geological Survey Circular 1001, pp. 22-23.

Stack, William P. and Jane C. Gottfredson. 1980. Data Evaluation for Determination of Eutrophication Control Criteria: Loch Raven Reservoir Project, Water Quality Management Office, Baltimore, December.

National Commission on Water Quality. 1976. Staff Report. Government Printing Office, Washington, D.C., April.

Taylor, A. G., H. Kuder, D. Sefton, and D. Schaeffer. 1978. "Costs of Sediment in Illinois Roadside Ditches and Rights of Way," Collection of reports on effects and costs of erosion in Illinois (Illinois EPA) October.

The Conservation Foundation, State of the Environment: 1982, The Conservation Foundation, Washington, D.C., p. 105.

U.S. Department of Agriculture. 1981. 1980 Appraisal Part I: Soil, Water, and Related Resources in the United States--Status, Conditions and Trends, U.S. Government Printing Office, Washington, D.C.

_____. 1981. 1980 Appraisal Part II: Soil Water, and Related Resources in the United States--Analysis of Resource Trends, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, Bureau of the Census, 1978 Census of Agriculture, vol. 4: Irrigation (Washington, D.C.: U.S. Government Printing Office, Feb. 1982).

U.S. Department of Energy. 1983. "Thermal Electric Plant Construction Costs and Annual Production Expenditures: 1980," Monthly Energy Review, June.

U.S. Environmental Protection Agency, "Estimating Water Treatment Costs," Municipal Environmental Research Laboratory, Cincinnati, Ohio; EPA 600/2-79-162, Vol. I, 1979; pp. 62-66. Using GNP deflator for state and local government purchase of goods and services.

U.S. Coast Guard, "Statistics of Casualties, Fiscal Year 1980," in Proceedings of the Marine Safety Council, Feb. 1983.

U.S. Senate Committee on Agriculture and Forestry, Conservation of the Land and the Use of Waste Materials for Man's Benefits, Committee print, 94th Congress, 1 session, March 25, 1975, U.S. Government Printing Office, Washington, D.C., 1976, p. 14.

U.S. Water Resources Council, The Nation's Water Resources 1975-2000, Volume 3: Analytical Data Summary, Second National Water Assessment (Washington, D.C.: U.S. Government Printing Office, Dec. 1978).

Vaughn, W. J. and C. Russell. 1982. Freshwater Recreational Fishing: The National Benefits of Water Pollution Control, Johns Hopkins University Press for Resources for the Future, Baltimore, Md..

Ward, Neville. 1983. "Rationale for Rest Reserves Around Lakes," in Lake Line, vol. 3, no. 2, June.

Welch, J. L., "The Impact of Inorganic Phosphates in the Environment," EPA-560/1-78-003, Office of Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C., pp. 48-49.

Yadkin-Pee Dee River Basin, Level B Comprehensive Water Resources Study: Recommended Plan, North Carolina-South Carolina, August 1981.

Chapter 5

POLICY ISSUES

Erosion raises policy issues when the costs it imposes exceed some socially acceptable amount. This poses two questions: (1) how do we determine when erosion costs are excessive, i.e., how much erosion is too much? (2) When the costs are excessive, what measures should we take to bring them within acceptable limits?[1] We have no precise answers to these questions. Discussing them, however, helps clarify the principal policy issues and available options.

HOW MUCH IS TOO MUCH?

T Values

Historically and at present, soil conservation policy as shaped by the U.S. Department of Agriculture (USDA) has relied on T values to identify places where erosion exceeds the socially acceptable amount. T values range from 2 tons per acre per year on shallow topsoils with unfavorable subsoils to 5 tons where topsoil is deep and subsoil favorable. ("Favorable" refers primarily to water holding capacity.) T values are defined as "the maximum rate of annual soil erosion that will permit a high level of crop productivity to be obtained economically and indefinitely." (McCormack, Young and Kimberlin, 1982, p. 99). The definition reflects the fact that the overriding concern of soil conservation policy is, and always has been, protection of the long-term productivity of the soil.

T values are based on a particular formulation of the precept of intergenerational equity and on an assumption about the necessary condition for achieving it. The precept is that each generation should so manage the soil as to avoid imposing higher production costs on subsequent generations. The assumption is that any loss of soil productivity will violate this commitment.

It is fair to say that many soil conservationists, and most if not all agricultural economists concerned with conservation, are dissatisfied with the T value standard as presently formulated. Soil scientists point out that there is little scientific evidence indicating that the particular T values chosen are those consistent with maintenance of long-term soil productivity. Some argue that T values were set with reference to presumed rates of formation of topsoil even though it is the formation of new soil from parent material which in the long run determines how much soil will be available to support production. Finally, everyone recognizes that because T values are designed to protect soil productivity they do not necessarily identify places where erosion imposes socially unacceptable off-farm costs.[2]

Economists' have other reservations about the T value standard. Some do not accept the imperative of intergenerational equity, arguing that the land market will adequately reflect future demand and supply conditions for land. Among those who accept the imperative, there are many who are uncomfortable with the particular statement implicit in T values: avoid long-term increases in costs of producing food and fiber. They find this unacceptably restrictive. Solow's formulation--manage exhaustible resources so as to maintain real per capita consumption across generations--is more acceptable because it recognizes that the welfare of future generations will depend on the costs of all consumption goods and services, not just food and fiber.

Apart from the issue of intergenerational equity and how to define it, all agricultural economists fault the T value standard for its failure to incorporate economic criteria. Erosion may impose present and future costs, but so does erosion control. Rational decisions of where and when to control cannot be made without knowledge of all these costs, even if one accepts the T value concept of intergenerational equity. By the T value standard, however, costs are irrelevant. The place to control it is wherever erosion exceeds T, and the time is "now."

Clearly, the T value standard is an inadequate guide to soil conservation policy, and an alternative must be sought. Task force members had no problem accepting that any alternative should incorporate criteria of economic efficiency in soil management. Some of the economist members, however, had difficulty in dealing with equity as a policy criterion. All accepted that productivity consequences of soil management may raise issues of both intra- and intergenerational equity. But several pointed to the strong subjective content in the concept of equity and questioned whether generally acceptable definitions of it could be found. As one task force member noted succinctly, "My equity is your rip-off."

In the end, it was decided to avoid specific definitions of either intra- or intergenerational equity but to deal instead with conditions under which patterns of soil management and erosion might impose uncompensated costs across generations (on-farm damages) and among members of a generation (off-farm damages). Such conditions raise equity issues, but the criteria by which the issues are settled is a function of the political process.

On-Farm Damages

Efficiency. Erosion-induced losses of soil productivity violate efficiency criteria wherever they can be shown to result from market failure.[3] In the first chapter we reviewed the evidence on market failure and for the most part found it unconvincing or inconclusive. The exception was farmers' knowledge of the long-term effects of erosion on productivity. We referred to evidence that on many soils the effect is non-linear, so farmers' experiences with these soils are likely to be a poor guide to future effects.

Consider what the farmer needs to know about the erosion-productivity relationship if he is to devise an economically efficient response to erosion. To keep the discussion simple, suppose that one variable instead of a vector can describe the soil resource. Let u and x be soil losses (tons/acre) and the stock of soil (also tons/acre), respectively. The difference equation for stocks is

$$(1) \quad x_{t+1} = x_t - u_t + T$$

where T is the T-value representing natural formation of soil per year (assumed here to be independent of the level of stock x). Let the flow of net benefits annually be B(u,x), which is defined as the maximum possible with respect to farming practices under the condition that u tons of soil are eroded away. B(u,x) would be analogous to Heady's "trade-off frontier" in Figure 1, p. 258 in Halcrow, Heady and Cotner (1982), except that value of output as well as cost would be accounted for, and x is a second argument.

Under economic efficiency criteria the equilibrium state is given by the solution of the two equations

$$(2) \quad \partial B/\partial u = \frac{\partial B/\partial x}{r}$$

$$(3) \quad T - u = 0$$

in u and x. It is to be understood that each $\partial B/\partial u$ and $\partial B/\partial x$ are functions of u and x, and r is a discount rate. The criterion of optimality is maximum present value of net benefits over an infinite planning horizon subject to the constraint in (1) and some initial stock of soil, x_o. Cummings and Burt (1977) showed that (2) can be used as an approximately optimal decision rule by solving it in the variable u for any given stock level x. The intuitive economic interpretation of the rule is: let the rate of soil loss, u, increase until the annual net benefits associated with a further increment of soil loss this year is just matched by the present value of net benefits from an increment in the stock of soil, x, over an infinite planning horizon.

We do not pretend that farmers rigorously apply this rule in their calculations of what to do about erosion, but we argue that their thinking is in this mode, as it is with respect to other farm management decisions. Application of the rule requires information, and expectations, about future prices and interest rates, technology, and erosion-productivity relationships. Better information about all these variables would improve farmers' management decisions, hence bringing them closer to the efficiency frontier in soil management. Careful research could perhaps reduce some of the uncertainty about future trends in prices and technology, although whether farmers would take the results seriously in deciding about soil conservation investments is questionable. It seems likely, however, that they would welcome information about erosion productivity-relationships if they were satisfied that the information was relevant to their particular soils. Private investment in developing this kind of information is likely to fall well short of the socially optimal amount because establishing exclusive private property rights to the information would be difficult. Accordingly, there is a _prima facie_ case for public investment to develop this kind of information. Some guidelines for doing this are discussed in the section below on control measures.

Equity. The belief of the conservation community, expressed in the concept of T values, is that imposing higher costs on future generations is inequitable, and that any loss in soil productivity threatens to do this. As noted earlier, views of what constitutes intergenerational equity may differ widely, but few would dispute that production costs across genera-tions have something important to do with it. The flaw in the conserva-tionist argument, as represented by T values, is the presumption that _any_ loss in soil productivity threatens to increase future production costs. Since the soil is only one of the inputs in agricultural production, any particular intergenerational cost objective is consistent with some loss of soil productivity if it is compensated by increases in productivity of non-soil inputs.

The focus on costs as the key to thinking about intergenerational equity in soil management implies that soil conservation policies are a subset of a broader set of policies concerned with future production costs. Analysis of long-term trends in demand for food and fiber, in agricultural technology, and in productivity impacts of erosion would necessarily be an important part of the policy process. If it appears that the net outcome of this play of forces is an unacceptable increase in production costs, then a policy issue arises. Of course, all such forecasting exercises are subject to high uncertainty, with plausible scenarios ranging from decreasing costs to increasing costs. Even if the most probable outcome indicated acceptable future costs, prudence might induce policy makers to take a higher cost scenario as a guide, the costs of following it being viewed as an insurance premium against the risk of violating the commitment to intergenerational equity.

On principle, policies could aim at slowing the growth of demand, e.g., by imposing a tax on exports of grains and soybeans, or at accelerating land-saving technological advance by investing more in research and development, or at inducing farmers to invest more in erosion control to protect productivity, or more likely at some combination of these. As a practical matter, slowing the growth of demand is likely to be viewed as politically unpalatable--farm groups would vigorously oppose it--leaving policies to promote technology and more soil conservation as the principal components of the policy mix.

The policy problem is to find that combination of private and public investments in erosion control and new technology which satisfies the cost criterion at minimum cost. It can be argued that private investments in erosion control will be systematically underrepresented in the combination because farmers use the market rate of interest in evaluating them. The argument, which draws on a substantial and controversial body of literature, rests on the assumption that where intergenerational equity is the issue, the social rate of discount is less than the market rate. The implication of the argument is that investment in erosion control should receive more relative weight in the policy mix than the market rate will give it.

We find this argument unsatisfactory. As an indicator of the rate of return to capital, the market rate of interest measures the opportunity cost of investments in erosion control. Failure to charge this cost on these investments sacrifices income that could be earned elsewhere. It also distorts comparison of investments in erosion control with investments in new technology as parts of the policy mix.

Dasgupta (1982) argues that the way to handle intergenerational equity in management of exhaustible resources is not through manipulation of the interest rate but by specifying the equity objective in the social objective function. The market rate of interest is then used to obtain optimum resource use over time, subject to the constraint of intergenerational equity. Adapting this argument to soil conservation policy indicates that the market rate of interest would be used to discount investments in both erosion control and new technology. Accordingly, the fact that farmers discount the flow of net benefits of erosion control at the market rate of interest is not *prima facie* evidence that they are underinvesting in soil conservation.

At a more practical level of abstraction (compared to the elusive concept of a social objective function) intergenerational equity is essentially a trade-off between consumption and investment by the current generation, since society must save and thus forego consumption in order to invest (much like an individual). Under the assumption of diminishing marginal returns to investment at a moment in time (technology is fixed), the market interest rate can be forced downward by a government policy which penalizes consumption, and the lower interest rate encourages additional investment which is favorable to future generations because they receive a larger legacy of capital. Some of that capital is a natural resource component, and part of that component is the amount of the soil resource protected from loss by erosion. Therefore, provision for future generations is a policy of the broadest dimension in government, and singling out soil conservation policy by means of applying a reduced interest rate to the analysis is inconsistent with overall policy. Remember that the stock of human capital, and the knowledge embodied therein, is also part of the legacy of future generations, along with the more concrete forms of capital like soil resources.

The issue of the discount rate aside, implementation of the cost criterion requires information about costs and returns to investments in erosion control and new technology. Seeking this information and using it to develop the most cost-effective mix of investments should be an integral part of the policy process. We do not pursue this further. The point we wish to stress is that optimal erosion control policies to assure intergenerational equity cannot be determined without consideration of policies to develop new technology. As a guide to policy for dealing with on-farm erosion damage, the cost criterion allows no separation of the two.

Off-Farm Damages

Efficiency. It is easy to imagine situations in which off-farm erosion damages do not violate efficiency criteria. Where the damages are highly localized, e.g., sediment from farm A damages crops on neighboring farm B, and the law rules this a violation of farmer B's property rights, then, assuming transactions costs are less than the costs of damage, A and B should be able to reach an agreement whereby A either compensates B or takes measures to stop dumping on him. In either case, the costs of damage are internalized and efficiency criteria met.

But, as the discussion in chapter four made clear, much off-farm erosion damage is not localized and occurs under technical and institutional conditions which do not permit internalization of the costs. The sediment damaging a large reservoir, for example, typically originates on many farms scattered throughout the watershed, and technical difficulties of determining which farms contribute how much sediment prevents specification of individual responsibility for the damage. Overcoming these difficulties would require expensive research with no guarantee that the results would persuade upstream farmers of their responsibility or pass a legal test if it came to that. Consequently, even if property rights in the reservoir are clear and the damage substantial, high transaction costs inhibit an agreement between the reservoir owners and the offending farmers like that between farmers A and B.

Where the damage is to recreational values shared by numerous fishermen, boaters, swimmers, and picnickers scattered throughout an entire river basin, property rights in the values are ill-defined or non-existent, and even if they were clear the transactions costs of enforcing them would be exorbitantly high for any particular individual.

There is clearly a prima facie case that much, if not most, of the off-farm damage of erosion violates efficiency criteria, indicating a need for public policies to reduce the damage. The case is not as clearly made as may appear because the costs of policies to reduce damage (a form of transactions cost) may conceivably exceed the costs of damage. At a minimum, there is a case for publicly funded research to learn more about the costs of damage and of policies to reduce them. We are convinced, however, that even a rough cost-benefit analysis will justify damage reducing policies beyond those presently in place. This is discussed in the section on control measures.

Equity. Because off-farm erosion damages impose uncompensated costs, they clearly raise equity issues. It is not always clear, however, which way the issues tilt. Suppose that farmers in a watershed generate large quantities of eroded soil, much of which reaches the river, but that there are no users of the water in those reaches where the sediment load is heavy: there is no off-farm damage. Then suppose that a reservoir is subsequently built downstream, providing flood control, electric power and substantial recreational benefits, and that for whatever reason the reservoir is built with inadequate sediment storage capacity. Now the upstream erosion imposes uncompensated off-farm damage. Who is responsible for it: the farmers whose eroded soil is undeniably the damaging agent, or those who built and use the reservoir? It is not at all clear that equity places the burden of compensation on the farmers.

The fact that off-farm damages of erosion raise equity issues is sufficient to suggest a role for public policies to deal with the damages. At best it is a difficult role, as we discuss below, even where the responsibility for inequity is clear.

Summary

The case is strong that the present amount of erosion in the United States is "too much," indicating a role for public policies to do something about it. On-farm losses of productivity almost surely violate efficiency criteria because of underinvestment in research to provide farmers more information about long-term erosion-productivity relationships. Off-farm damages clearly raise equity issues and there is a strong prima facie case that they also are inefficient. It is not as clear, however, that present rates of erosion will force up future production costs, thus raising issues of intergenerational equity. Consequently, it is not clear that on this account policy should attempt to do any more than it does at present, either to reduce erosion or to stimulate more rapid advance in agricultural technology. It is worth noting in this connection that whatever the present threat to productivity, it should decline if research is undertaken to provide farmers more information about the threat. Moreover, measures to reduce off-farm damages are likely to increase the protection to on-farm productivity, even if the erosion which causes most off-farm damage is not necessarily that which most threatens productivity.

CONTROL MEASURES

Introduction

We take as given that some amount of public money--the present level is several hundred million dollars--will be spent each year on soil conservation. The question we now address is how those funds should be spent to achieve the maximum reduction in costs of erosion damage.

Note that the objective is reduction of costs of damage, not reduction of erosion per se. Soil conservationists generally have recognized that costs of damage are the real issue, and that the amount of erosion may be a poor indicator of the magnitude of costs. However, cost information was not available. Consequently, conservationists had no choice but to take the amount of erosion as a guide to policy, hoping for at least rough proportionality between this and costs.

Thanks to work reviewed in chapters 2-4 of this report cost information, albeit very rough and incomplete, is now becoming available for the first time. And there is reason to believe that this information can be improved and expanded, with consequent improvements in soil conservation policy.

The ensuing discussion is in two parts. One concerns the information needed for more effective targeting of efforts to reduce erosion costs. The other considers measures to achieve the cost reduction once the targets have been identified.

Information Needed for Targeting

There are two broad targeting issues about which better information is needed. One concerns the relative weights to give to on-farm and off-farm damages. The other is to identify and rank by cost of damage those places in the country where the two sorts of damage are occurring.

Relative importance of the two kinds of damage. To date, controlling costs of productivity loss has always received top priority in USDA policy statements, and the allocation of conservation funds over the years has been consistent with this. In 1940, the on-farm share of the gross stock of conservation capital was 100 percent. It subsequently declined to 95 percent in 1965 and to 79 percent in 1980 (Pavelis, 1983).

The cost data reviewed in chapters 3 and 4 raise a major question about the appropriateness of this allocation, at least in the present circumstances. If, as the Conservation Foundation study shows, off-farm damages are between $2 billion and $5 billion annually (not including some important kinds of damage) then these costs are probably greater than on-farm costs, perhaps very substantially so. This cannot be stated more firmly because of the lack of information about on-farm costs. Until more such information is available, the assignment of relative weights to the two sorts of damage must remain tentative. We are satisfied, however, that more complete information about on-farm costs will indicate that more weight should be given to off-farm costs than they have so far received.[4]

On-farm costs. More information is needed about on-farm damages apart from the issue of relative weights for the two kinds of cost. Farmers can make more efficient decisions about soil conservation if they have more information about long-term effects of erosion on soil productivity. The USDA, through the Agricultural Research Service (ARS), has supported research on erosion-productivity relationships for decades. Much of this research was highly site specific on small experimental plots, and the results were not readily translatable to the situations farmers face in their own fields. More recent work has greater promise in this respect. The crop rooting model developed by soil scientists at the University of Minnesota (see the discussion in chapter 3) is an important example of this, although the model needs additional work to incorporate the effects of erosion on soil nutrient supply, pH, and bulk density. Research under way at Iowa State University under the direction of R. Cruze has developed a model which improves on the Minnesota model in these respects. The USDA's EPIC model (see the appendix to chapter 3) also aims at providing more information about long-term erosion-productivity relationships for soils around the country.

The USDA has also established a new Soil-Crop Yield Data Base to assemble new crop yield data, along with data about soils, management, and weather at the point where the yield measurement is made (SCS, 1984). Emphasis is given to collection of yield data within farmers' fields on eroded and uneroded phases of the same soil series to determine erosion impacts. Further, impacts of tillage methods and other management practices on the yield of various soils within the field can be determined. This approach is known as sequential testing, and is being used in yield studies in Alabama, North Carolina, Indiana, and a number of other states, the selection of which resulted from discussions about the 1980 RCA reports.

We believe that research along these lines could significantly expand the supply of knowledge farmers need to more adequately reflect long-term erosion-productivity relationships in their erosion management decisions. At present the research is focused on the Cornbelt. We believe it should be expanded to cover other major crop producing areas of the country: the southeast, Mississippi delta, and Palouse region of the Pacific northwest. We suggest two criteria to guide the research: (1) within each region, a focus on soils where work already done suggests productivity is particularly vulnerable to erosion; (2) within this group of soils, a focus on those where previous research suggests the erosion-productivity relationships are non-linear, since it is on these soils that farmers are most likely to be confronted by unpleasant surprises.

The pay-off to the research of course depends upon the results being made available in a timely fashion to the farmers who most need it. It is important, therefore, that those doing the research work in coordination with SCS and extension specialists remain in regular contact with farmers about their erosion problems.

The information conveyed concerns long-term physical relationships between erosion and crop yields. To use the information most effectively farmers would have to combine it with information about future crop prices and interest rates, as well as about costs of alternative erosion control practices. There are models (e.g., SOILEC, developed by agricultural economists at the University of Illinois) which permit them to do this (Eleveld and Johnson, 1983). SOILEC is soil specific and incorporates long-term erosion effects on yield as well as costs of alternative erosion control practices. It was developed as a tool SCS technicians can use in working with farmers. Farmers using the model can make their own assumptions about future prices, interest rates and rates of erosion over periods of up to 50 years, and the model will indicate the most profitable combination of tillage systems and erosion control practices.

There is an obvious complementarity between physical models like EPIC, like those developed at the University of Minnesota and Iowa State University, and economic models like SOILEC. The USDA, through the SCS and Agricultural Research Service (ARS, which through its National Erosion Laboratory at Purdue University, and other facilities in other locations, does much research relevant to erosion-productivity relationships) could do much to promote this complementarity. It is likely that over time, the development of both sorts of models would increase the effectiveness of SCS technicians and extension agents in advising farmers about soil conservation. Unlike present T values, the results of the models would directly address the farmer's vital interest in profit and loss. He would surely be more inclined to listen than he is now.

The research described would target those places in the country, and those farmers, where the erosion threat to productivity is greatest. A second targeting issue concerns the allocation of resources between soil conservation and new technology to assure meeting the commitment to intergenerational equity in food and fiber production. A necessary condition for this is more information about productivity costs of erosion nationwide. We presently have no estimates of these costs, however crude. Information is needed particularly about costs of so-called ephemeral damages, and about those of things farmers do to offset productivity effects of erosion, such as putting on additional fertilizer. In thinking about how to allocate soil conservation funds, the USDA should give serious consideration to supporting research to develop these cost estimates. In the land grant universities there are soil scientists and agricultural economists both interested in and capable of doing the necessary research.

Off-farm costs. The targets for reducing these costs are those places where sediment imposes the kinds of damage discussed in chapter 4. Research is needed to identify these places. The targeting issue is complicated, however, by the difficulty of linking places suffering damage with the places supplying the damaging sediment. The movement of sediment through a watershed from places of origin to places where damage occurs is a halting, complex process. Given the initial erosion, the determinants of the rate and amount of soil moved are not well understood, but they include topography and drainage density of the watershed, kind of soil, patterns of land use, climate, and the volume and velocity of water available to transport sediment. If none of these conditions change, then after a number of years a kind of equilibrium will be established in which the amount of erosion upstream equals the amount of sediment delivered at the watershed outlet. But hydrologists and others who study these matters conclude that in the real world such equilibrium is seldom if ever found. The consequence in that for most watersheds the amount of sediment delivered each year at various points in the watershed may have left farmers' fields upstream many years ago and bear little relationship to current erosion on those fields. Controlling that erosion, therefore, would have little effect this year, and perhaps for many years, in reducing downstream sediment damage.

The matter is still more complicated by the fact that if erosion control reduces the amount of soil delivered to a stream below the stream's sediment carrying capacity, the water will probably scour more soil from the streambanks and bed, the amount depending on soil characteristics and the amount of unused carrying capacity. Where this occurs, reduction of erosion on the land may contribute little to reduction of downstream sediment damages.

These facts of life about movement of eroded soil have deep implications for targeting efforts to reduce off-farm damage. One is that more research is needed on sediment transport processes to improve our ability to link places where damage occurs with sources of the damaging sediment. Research on these processes is now under way at a number of USDA facilities around the country: the National Erosion Laboratory at Purdue University, the soil conservation experiment station at Morris, Minnesota, and the National Sedimentation Laboratory at Oxford, Mississippi. (Task Force members: are there other places that should be mentioned here?) USDA should consider increasing its support for this line of research in these institutions.

Another implication is that if the relationship between current erosion and current off-farm damage is so indirect and poorly understood, perhaps more effort should be concentrated on directly reducing the damage and less on controlling erosion. This would mean giving more attention to controlling sediment at the point of delivery to valuable bodies of water and reducing damaging deposition on valuable land. How best to do this gets into technical issues in the domain of the hydrologist and the engineer, and we do not pursue this further in this report. Whatever the technical alternatives, however, economists would play a role in examining their costs and benefits.

In urging consideration of this strategy we, of course, do not mean to say that all efforts to reduce off-farm damage by reducing erosion should be abandoned. But until knowledge of sediment transport processes improves, we may get more reduction in off-farm sediment damage per conservation dollar spent if we target relatively more effort on points receiving damaging amounts of sediment and relatively less on erosion sites.

Scale of the problem. If the information discussed were available, how much land would it indicate should be targeted? Since the information is still inadequate, no firm answer is possible. Moreover, stating the scale of the problem in amount of targeted land implies that the way to deal with the problem is to reduce erosion on the land. As just noted, this is not the only way to deal with off-farm costs, and in some situations may not be the most effective way.

Despite these limitations, we believe it useful to think in terms of the amount of targeted land. Issues of soil conservation policy cannot be fruitfully addressed without at least some rough idea of the scale of the problem. At present, the only measure of scale available is amounts of land suffering various amounts of erosion. Inadequate though it may be as an indicator of productivity loss, the measure is relevant as a rough guide to these losses. And even if more attention is given to reducing off-farm damages by targeting on the damaged sites, erosion control will continue to be important in dealing with these. In time, better information about the two kinds of cost will no doubt force a revision of our judgment here about the amount of targeted land. This is not sufficient reason, however, for avoiding the judgment if making it promotes the discussion of policy issues. We believe it does.

There is little doubt that the amount of land that ought to be targeted to protect productivity is a small percentage of the total amount of land in crops, pasture, range and forest. The information on erosion and its productivity effects in the Cornbelt, reviewed in chapter 3, showed that cropland erosion in the area averaged 7.8 tons per acre, well in excess of the maximum 5 ton per acre T value, but the prospective loss of productivity is small--4 percent on average over 100 years, 2 percent in 50 years. To be sure, we lack information on the other productivity costs of erosion in the area, and these may rise relative to the cost of the lost productivity. If this happens, however, it will probably be gradual, allowing time for corrective policy measures to be taken before drastic damage is done. Moreover, as noted earlier, if farmers are provided better information about erosion-productivity relationships, they are likely to voluntarily increase their erosion control efforts where the situation calls for it.

Most Cornbelt soils are rich and deep, hence can sustain higher rates of erosion without serious productivity effect than other soils, e.g., those in the Southeast. However, production of corn and soybeans, the most erosive crops, is concentrated in the Cornbelt. If erosion is a serious threat to productivity on only a small percentage of land in that area, the percentage of land threatened in the country as a whole is also probably small. To be more specific, we hazard the judgment that most soils in corn and soybean production could sustain erosion of 10 tons per acre per year for many years without serious threat to productivity, realizing that as more information becomes available the judgment might have to be revised. By the 10 ton standard, however, sheet and rill erosion is a productivity problem on only 41 million acres of the nation's cropland (10 percent of total cropland). The acreages (and percentages) for nonfederal pasture, range, and forest land, respectively, are 7 million (5 percent), 19 million (5 percent) and 6 million (2 percent). Taking the nation's cropland, pasture, range and forest land together, sheet and rill erosion exceeded 10 tons per acre on 73 million acres, 6 percent of the total. Comparable data on wind erosion are not available, but they would raise these numbers somewhat. (All data from the 1977 National Resources Inventory.)

The amount of land that should be targeted to reduce off-farm damages is more difficult to estimate, but it may be more than that where the threat is productivity loss. Some land would no doubt be targeted for both purposes, although no one can now say how much. However, some, perhaps much, land now in pasture, range and forest should perhaps be targeted to reduce off-farm damages. Although per acre erosion on most of this land generally is no threat to productivity, the amount of such land is large, so its contribution to total erosion, and potential contribution to off-farm damage, is high.

This discussion indicates that at least so far as on-farm damage is concerned, the most serious erosion threat is concentrated on a relatively small number of acres. This was also the conclusion of the USDA in its early deliberations on targeting. These deliberations began only recently, and still only a small percentage of the agency's soil conservation resources are targeted on places where the perceived erosion threat is greatest. Instead, resources were, and largely still are, allocated so that all conservation districts (about 3,000 in all 50 states) received some. Within districts, resources were distributed in response to farmers' requests for assistance rather than according to SCS judgments of where the erosion problems were most severe. Since funds were often available for practices which had more to do with increasing production than reducing erosion, the farmers who sought assistance were not always those with the most serious erosion problems.

A GAO report (1977) first gave systematic attention to the USDA's procedures for allocating soil conservation funds and called for changes to target them more effectively. The USDA responded in two ways. One was to modify the formula for allocating funds for the SCS Conservation Operations Program (mostly technical assistance) among states to give greater weight to states where the perceived erosion threat is greatest. However, the change was minor--a planned reallocation of 450 SCS staff years over the 10 years 1983-1993--and in a careful review of this and other aspects of USDA soil conservation programs, the American Farmland Trust (AFT, 1984) concluded that the effect on erosion control would be inconsequential.

The other response was to commit a percentage of SCS and ASCS technical assistance and cost-share funds to targeted areas, beginning with 5 percent in 1983 and adding 5 percent each subsequent year to reach 25 percent in 1987. Severity of erosion is the principal targeting criterion, but water conservation, improved water quality, and other conservation objectives are also included.

In September 1982 the SCS set two criteria for erosion control targeting:

1. "Sensitive soils," i.e., those with T values less than 5 tons per acre, planted in row crops and eroding at 2T.

2. Less sensitive cropland soils eroding at more than 2.8T.

By the first criterion about 45 million acres of cropland were identified as targets, and by the second, 48 million acres were so identified (AFT, 1984).

In a subsequent revision of criteria, the SCS included land with high erosion and moderate productivity impact but with high off-farm damage. In addition, all land with T less than 5 tons which was eroding at more than T was included. No estimates of amounts of land covered by these criteria were given, but clearly it would be far more than the 93 million acres indicated by the initial criteria.

Funds available for soil conservation have declined over the last 5 to 10 years, and there is little present likelihood that they will increase. Consequently, any amount of targeting means that some conservation districts will get fewer funds than before. Moreover, targeting means that some SCS and ASCS personnel must be moved from places of lesser to places of greater need. For these reasons, targeting stirs both political and bureaucratic opposition. This is why it was so slow in coming and why the initial targeting criteria were subsequently broadened to incorporate substantially more land. Indeed, it is likely that knowledge of this opposition influenced the setting of the initial criteria. Allowing for this, and for the possible inclusion of wind eroded land among the 93 million acres identified by these criteria (the AFT discussion is not clear about the inclusion of wind eroded land), we conclude that our estimated target of 41 million sheet and rill eroded cropland acres is "in the same ball park" as the SCS estimate.

Reducing Erosion on Targeted Land

Traditional approaches. With the targets identified, the policy issue is to find and implement the measures which give the greatest reduction in erosion for the amount of conservation dollars available. The ASCS, in a report on its Agricultural Conservation program (ACP), provides useful information in this respect (Agricultural Stabilization and Conservation Service, 1981). The report reviewed 24,000 instances of use of nine erosion control practices in 171 sample counties in 1975-78. The practices included critical area treatment, water diversions, terraces, establishment of permanent vegetative cover, improvement of permanent vegetative cover, minimum tillage, interim cover, stripcropping and competitive shrub control. The practices were used on land which had average pre-practice sheet and rill erosion of 10.7 tons per acre, and they reduced erosion on average by 6.5 tons per acre. The average cost of the nine practices over the lifetime of each was $2.22 per ton of erosion reduction.[5] However, per ton costs declined sharply as pre-treatment erosion increased, e.g., on land where pre-treatment erosion was 1 to 2 tons per acre, a ton of soil saved $14.23. Where the pre-practice erosion rate was 10 to 11 tons, the per ton cost was $2.16. It ranged down from that to $0.21 per ton saved where pre-practice erosion was over 100 tons per acre (ASCS, 1981, p. 30).

Unpublished ASCS data, reviewed by the American Farmland Trust (AFT, 1984), shows that from 1975-78 to 1982 and 1983 the ASCS achieved a significant improvement in ACP performance, both in getting an increasing proportion of practices on more erosive land and reducing costs per ton of soil saved. The latter was particularly impressive in view of the general inflation between 1975-78 and 1982-83. In 1982, the nine practices were used on land with average pre-practice sheet and rill erosion of 13.8 tons and reduced erosion 9.9 tons. (In 1983 both figures were somewhat less, possibly because the PIK program that year induced farmers to take more erosive land out of production). Recall that the corresponding numbers for 1975-78 were 10.7 tons and 6.5 tons. In 1982 the average cost of the practices per ton of soil saved was $1.66 and in 1983 it was $1.50, compared to $2.22 in 1975-78 (AFT, 1984, pp. 66-67).

The improvements in ACP performance occurred because the ASCS made a determined effort to respond to the criticisms of the GAO (1977) and to the findings of its own review that many practices were being put on relatively unerosive land (ASCS, 1981).

However, unpublished ASCS data reviewed by the AFT indicate potential for substantial additional improvement. In 1983, only 46 percent of ACP practices were on land with pre-practice sheet and rill erosion of 10 tons per acre or more. For individual practices the percentages ranged from 64 percent for terraces to 23 percent for minimum tillage (AFT, 1984, pp. 130-131). A further effort to shift a greater proportion of practices onto land eroding in excess of 10 tons per acre would significantly reduce soil loss on land where the erosion threat is most serious, and also reduce costs per ton of soil saved. For example, the experience from 1975-78 to 1983 suggests that shifting practices to more erosive land could reasonably lower per ton costs to $1.00 in the near future. Assuming a 50-50 sharing of costs between farmers and the ASCS (roughly the proportions for the nine practices in 1975-78, ASCS, 1981, p. 58), then the current ACP spending level (about $190 million annually) would reduce erosion by 380 million tons if the entire amount were spent on erosion control. This is over 35 percent of total sheet and rill erosion on land eroding at 10 tons per acre or more in 1977. The ACP alone would thus make a major contribution to reducing "problem" erosion.

This calculation exaggerates what could be accomplished because only about two-thirds of ACP funding is available for erosion control, and some 5 percent of the total is allocated to the SCS for technical assistance (not included in the costs per ton of erosion reduction given above). Nonetheless, there seems little doubt that current levels of ACP funding would make a substantially greater contribution to controlling "problem" erosion if the practices were more concentrated on land eroding in excess of 10 tons per acre per year. The obstacle to this improved performance is neither lack of technical knowledge of what to do nor inadequate funding with which to do it.

The obstacles instead are two: (1) the political objections to more concentrated targeting, already mentioned; and (2) persuading farmers to accept the idea of shifting more practices to more highly eroding land. In the case of the ACP, the political constraints are fixed in an administrative rule that prevents any state's ACP allocation from being reduced by more than 1 percent annually (AFT, 1984, p. 68). Since erosion is highly concentrated in relatively few states in the Cornbelt, Plains, and Mississippi Delta, this rule seriously limits the ability of the ASCS to target more effectively. As noted above, SCS technical assistance programs are similarly limited.

The ACP and SCS technical assistance programs are based on securing farmers' voluntary acceptance of soil conservation practices. Farmers have been reluctant to accept the practices on more highly eroding land, even when they are cost-shared, and this has proved a major obstacle to more effective targeting. The ASCS report (1981, p. 20) considers a number of reasons for farmers' reluctance. One is that more affluent farmers are better able to meet the cost-share requirement, and more affluent farmers generally have less erosive land. Another possible reason is that most erosion control practices reduce run-off, hence increase water infiltration, and they do this more effectively on more gently sloping land. Thus, the water conserving characteristics of the practices give them a higher yield pay-off on this less erosive land. Yet a third possibility is that farmers regard their most erosive land as a high cost reserve to be brought into crop production only in years of relatively high prices. They might then be reluctant to make the investments in erosion control practices on this land that either would remove it from crop production for long periods (e.g., if it were put in permanent vegetative cover) or that would commit it to annual crop production (e.g., if it were terraced). A fourth reason, not discussed in the ASCS report but considered by the AFT, is that the trend toward larger farm machinery increases the economic value of maneuvering room in the fields, and a practice like terracing cuts into this more on steeper land than on more gently sloping land.

The success of the ASCS in improving the effectiveness of the ACP indicates that neither the political problem nor farmers' reluctance pose absolute barriers to improved targeting. And increased public awareness of the possibility of significantly improving performance of erosion control programs within current budget constraints should make it easier to penetrate the political barrier. As this occurs, it should be possible to offer more attractive cost-share terms to the relatively small number of farmers with "problem" erosion. In short, it appears that current soil conservation programs operating within current budgetary limits still have untapped potential for doing a better job of reducing erosion where it counts.

Nevertheless, alternative approaches should be considered, not as wholesale substitutes for the traditional ones but as supplements. We discuss a number of these, not in any great depth, but enough to show that they have a place on the soil conservation policy agenda.

Linkages to commodity programs. Increasing attention is being given by agricultural economists and members of the conservation community to ways of improving the performance of soil conservation programs by linking them to commodity price support programs. So-called "cross-compliance" is one such way. The argument is that farmers with "problem" erosion should be required to do something about it, perhaps under the ACP, as a condition for participating in commodity price support programs. The concept of cross-compliance met with stiff resistance in the Congress and among farmers when it was first introduced some years ago. Now the resistance appears to be softening. The problems with cross-compliance seem to be more in execution than in principle. There must be a commodity price support program the farmer can comply with, and there is none for soybeans, the nation's most erosive crop. To make cross-compliance an effective targeting tool--and it should aim to be--it would have to be highly discriminatory among farmers. If it is true, as the ASCS report (1981) suggests, that farmers with more erosive land are less affluent than other farmers, then the discriminatory feature of cross-compliance may raise serious equity and political issues. Despite these limitations, we believe cross compliance merits continued consideration as an instrument of soil conservation policy. At the very least, a minimum the USDA should be able to do a better job of linking conservation measures with land set-asides than it did in 1983 with the PIK program. Although land lying idle under the program was supposed to be put to use for conservation, reports indicate that much of it was not.

It is argued in the AFT report and elsewhere that commodity programs have encouraged farmers to keep erosive land in program supported crops instead of putting it in some conserving use. If this happens, and the evidence seems anecdotal--it is because farmers participate in the benefits of commodity programs in accordance with the amount of "base acreage" they have in the program crops. Hence the programs provide farmers incentive to maximize the proportion of their land in these crops, even though some of the land is highly erosive. The rather obvious solution, and it is being discussed in the conservation community, is to find a way to permit farmers to put their more erosive land in a conservation use without sacrificing commodity program benefits. It is difficult to see why this could not and should not be done.

It is also argued that the year-to-year manner in which commodity programs operate also discourages farmers from adopting conservation practices. If they are to serve a useful purpose, these practices require a commitment of at least several years, if not longer. Many farmers are reluctant to make this commitment, it is argued, because of uncertainty about the annual land use implications of commodity programs.

The evidence for this argument, like that for the previous one, seems to be anecdotal. In any event, it is difficult to see how this particular impact of commodity programs on conservation could be softened as long as the programs rely so heavily on land set-asides for supply management. The conditions which prompt the programs--weather both here and abroad, foreign political crises--are largely unpredictable from year to year. There are probably better responses to them than annual movements of land into and out of production, but that is the one which we have so far largely relied on. As long as this continues, the resulting conflict between conservation and commodity programs is not likely to be resolved.

A conservation reserve. There is little doubt that shifting relatively few highly erosive acres out of small grain and row crop production into hay, pasture or trees would make a major contribution to erosion reduction. The 1977 NRI shows that the 16.6 million cropland acres--4 percent of the total--eroding at 20 tons per acre more, or accounted for 697 million tons of sheet and rill erosion on cropland, 36 percent of the total. Unless demand for cropland increases, it seems probable that this highly erosive land could be permanently removed from crop production without a major impact on supplies, especially if retirement were spread over five to ten years. The question is how to do it. The AFT (1984) has suggested that the USDA offer owners of such land long-term contracts to retire the land, with compensation keyed to the farmer's estimated opportunity cost of retirement. The contracts could contain provisions for return of the land to production when market conditions portend sharply higher crop prices, although for land put into trees this provision would have little practical import.[6]

The AFT argues that a conservation reserve would contribute to price stabilization as well as to erosion reduction. However, as noted above, the retirement of these 15 to 17 million acres--about 7 percent of the total in row crops and small grains--would not have a major impact on production. The case for retiring this land rests primarily on the bene-fits of reduced erosion.

David Irvin has suggested as an alternative retirement mechanism that the USDA purchase permanent easements on the land. As under the AFT contracting proposal, provision would be made to permit the land back into crop production when market conditions indicate a sharp run-up in prices. Provision also would be made for the farmer to manage the land in some mutually agreed conserving use, and for him to keep the resulting income. The potential for this of course would condition the purchase price of the easement.

A conservation reserve scheme targeted on land eroding at 20 tons per acre or more would undoubtedly sharply reduce erosion. It would also probably require more spending on soil conservation. Suppose that the average price of such land is $1000 per acre and the real rate of return is 5 percent--$50 per acre. Suppose also that the land conserving use yields a net return of $20 per acre. The farmer's opportunity cost for signing a long-term contract is $30 per acre, which on, say, 15 million acres comes to $450 million per year. If these numbers are about right, then more conservation funding would be needed even if some considerable percentage of funds now spent on the ACP and SCS technical assistance were diverted to the conservation reserve scheme. Of course, such a scheme would be less expensive if it were targeted on fewer than the 15 to 17 million acres assumed in this illustration. And it could still yield substantial reduc-tions in erosion. Needless to say, any such scheme should be targeted on those highly erosive acres where research demonstrates that on-farm and off-farm erosion costs are highest.

Voluntarism vs. regulation. Inducing the voluntary cooperation of farmers always has been and still is the fundamental guiding principle of soil conservation policy. There are signs, however, that the principle is beginning to be questioned, at least so far as the most highly eroding land is concerned. For example, the AFT report (1984, p. 44) asserts that

> In our judgement, the new information demonstrating the concentration of erosion substantially undercuts both practical and political objections to manadatory policies that have been raised in the past. We believe that, in time, a consensus may form among agricultural and environmental policymakers, who will find the regulation of the small amount of highly erodible land an increasingly compelling proposition.

Quite apart from the practical and political objections, which clearly have not yet been undercut, we think it highly unlikely that a case can be made that productivity costs of erosion, even on the highly erosive land, are so high as to justify adoption of regulatory controls. Only a presently improbable combination of very high crop demand growth and very slow technological advance would change this.

A regulatory approach to reduce off-farm damages, however, is at least defensible in principle and may be worth considering in practice. The justification on principle is that off-farm erosion damages impose uncompensated costs on others. We use this effect to justify regulation of industrial and municipal pollutors; it is not obvious why on principle we should treat farmers any differently.

There are genuine practical objections to a regulatory approach, however. The political costs of adopting it would be high. It would be necessary to prove that off-farm erosion costs are even higher and that the voluntary approach would not bring them within socially acceptable limits. Even if the cost comparison makes a compelling case for regulation, the great difficulty of linking damaging sediment with erosion sites on the land would present a serious obstacle to a regulatory policy. If we cannot determine who is responsible for the damaging sediment, we do not know who to regulate. If a regulatory policy is to be justified, we must have much more information about the amounts and locations of off-farm erosion costs and about the linkages between damaged places and places where the damaging sediment originates.

CONCLUDING REMARKS

This is a time of ferment in soil conservation policy. The ferment began with concern about the consequences of increasing pressure on the land in the 1970s. It has been sustained by the emergence of data and analytical techniques which for the first time permit the measurement and location of erosion, its effects on productivity of the soil, and its off-farm costs. The new information promises to force some significant changes in perspective on soil conservation policy.

The possibility of estimating productivity costs of erosion is sure to cause a reassessment of T values as a guide to policy, both in Washington and on the farm. The focus on costs instead of tons of soil loss means that policymakers can evaluate costs of erosion in the context of all the factors affecting production costs, particularly the prospects for new technology. This implies no wavering in the commitment to intergenerational equity in soil resource management. It does imply making soil conservation policies to protect productivity a subset of policies aimed at avoiding unacceptably higher production costs in the future. At the farm level, SCS technicians and extension agents are likely to be talking to farmers more convincingly than they are now about the effects of erosion on profit and loss, and receiving a better hearing as a consequence.

The most fundamental change in perspective will come if additional research confirms the still incomplete evidence that off-farm costs are substantially higher than productivity costs. Making a reduction of off-farm costs the top policy priority would mark a revolution in thinking among conservationists. A shift to relatively greater emphasis on off-farm damages may imply less attention to control of erosion on the land and more to preventing sediment from entering places where it does damage, again a fundamental change in approach.

The evidence of the 1977 NRI, confirmed by that of 1982, that the most threatening erosion occurs on only a small percentage of the nation's cropland makes a compelling case that targeting is an idea whose time has come, another basic change in perspective. Political and bureaucratic resistance to targeting is strong, but in our judgment it must gradually give way in the face of the evidence.

The success of the ASCS in improving performance of the ACP indicates that targeting is consistent with good results from traditional cost-share programs within existing budgetary constraints. No change in perspective is implied. However, there is emerging interest in novel approaches involving closer linkages between soil conservation policies and commodity price support policies to increase the likelihood of hitting the targets. The idea of a conservation reserve targeted on the relatively few acres with very high erosion is also gaining currency, and is a direct result of evidence from the NRI showing the spatial concentration of erosion.

The evidence showing the importance of off-farm damage may cause a reevaluation of the voluntary and regulatory approaches to soil conservation policy, at least with respect to the most highly eroding land. If this occurs, it will mark a change in perspective as fundamental as any.

Finally, perspectives are likely to change on the amounts and kinds of needed conservation research. The realization that the primary policy objective is to reduce on-farm and off-farm costs should give impetus to research to provide better information about those costs. Work on models relating erosion to productivity loss in major producing areas is likely to continue and be supplemented by new research to get at the economic costs of the losses as well as of the things farmers do to avoid or offset losses. To improve estimates of off-farm costs and devise policies to reduce the costs, research is critically needed on both overland and instream sediment transport processes. Until we know much more about the fate of eroded soil through time and space, and about the responses of streambank and bed erosion to changes in erosion on the land, policies to deal with off-farm costs will be severely hampered.

We end on an encouraging note. The emerging changes in perspective strongly suggest that although soil erosion in the United States is socially excessive, it is not of crisis proportions. Moreover, there is every reason to believe that by targeting on the major problem areas we can achieve significant improvements within a decade, and with no major new commitment of public funds. The challenge is to squarely face the emerging perspectives on the nature and magnitude of the problem and to find the political will to re-shape policies accordingly. We hope our discussion of the issues will make that easier.

Footnotes

[1]A third question is how much should we spend on each of the control measures. The easy answer is those amounts which for each measure equate marginal costs and benefits. There is no evidence that this way of thinking has ever influenced either the funding authorized by Congress for soil conservation or the allocation of such funds by the USDA. We assume that some amount of money will be spent each year on soil conservation. Answers to the two questions posed in

the text would increase the conservation benefits per dollar spent.

[2]Reflecting this, a senior level committee was established in the SCS in 1983 to develop T values that will provide criteria for assessing both on-farm and off-farm damage. Discussion with committee members indicates that the criteria will continue to be stated as maximum acceptable rates of erosion in tons per acre per year.

[3]For the benefit of non-economist readers, erosion-induced losses of productivity are "efficient" (although not necessarily equitable) if the marginal value of the losses is just equal to the marginal cost of erosion control to reduce losses. If the markets affecting farmers' erosion control decision "fail," the equality will not be achieved and the amount of productivity loss will be inefficient.

[4]We have relied on the Conservation Foundation work because it provides a national perspective on off-farm damages. In a study of the Hambaugh Martin watershed in western Illinois, Lee et al. (1974) found that costs of off-farm damages were several multiples of costs of productivity loss.

[5]Costs are for installation of the practices, and include both the farmers' cost and those represented by the ASCS contribution under the ACP. Effects on farmers operating costs, if any, are not included, nor is the opportunity cost of practices which involve a shift of land to lower valued uses, e.g., a row crop to pasture or some other permanent vegetative cover.

[6]Paying farmers to retire their most erosive land from crop production may offend some in the conservation community because it seems to reward those who sin most against the conservation ethic and discriminate against those farmers who adopt conservation without public support. This objection to a conservation reserve could be met in part by requiring some kind of cross compliance by farmers participating in the reserve program.

References

Agricultural Stabilization and Conservation Service. 1981. National Summary Evaluation of the Agricultural Conservation Program, Phase I, U.S. Department of Agriculture.

American Farmland Trust. 1984. Soil Conservation in America: What Do We Have to Lose? Washington, D.C.

Burt, O. R. and R. G. Cummings. 1977. "Natural Resource Management, the Steady State and Approximately Optimal Decision Rules," Land Economics, Vol. 53, No. 1 (Feb.), pp. 1-22.

Dasgupta, P. 1982. "Resource Depletion, Research and Development, and the Social Rate of Discount," in R. C. Lind (ed.), Discounting for Time and Risk in Energy Policy. Resources for the Future. Washington, D.C.

Eleveld, B., G. Johnson, and R. Dumsday. 1983. "SOILEC: Simulating the Economics of Soil Conservation," Journal of Soil and Water Conservation, Vol. 38, No. 5, pp. 387-389 (Sept.-Oct.).

General Accounting Office. 1977. To Protect Tomorrow's Food Supply, Soil Conservation Needs Priority Attention. CED-77-30. (U.S. Congress).

Halcrow, H. G., E. O. Heady and M. L. Cotner. 1982. Soil Conservation Policies Institutions and Incentives. Soil Conservation Society of America, Ankeny, Iowa.

Lee, M. T., A. S. Narayanan, K. Guntermann, and E. R. Swanson. 1974. Economic Analysis of Erosion and Sedimentation: Hambaugh Martin Watershed, University of Illinois Agricultural Experiment Station in cooperation with the State of Illinois Institute for Environmental Quality, Urbana-Champaign.

McCormack, D. E., K. K. Young and L. W. Kimberlin. 1982. "Current Criteria for Determining Soil Loss Tolerance," in B. L. Schmidt, R. R. Allamaras, J. V. Mannering and R. J. Popendick, eds., Determinants of Soil Loss Tolerance, ASA Special Publication No. 45 (Madison, Wisconsin, American Society of Agronomy and Soil Science Society of America).

McCormack, D. E. and F. R. Morrmann. 1983. "Sequential Testing: Within Field Data Collection to Determine Erosion Impacts." Paper presented at the Malama Aina International Conference on Soil Erosion and Conservation, January 1983, Honolulu.

SCS. 1984. National Instruction No. 430-301 Re: Soils-USDA Soil-Crop Yield Data Base, June 14. Washington, D.C.