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EVALUATION OF AGRICULTURAL POLICY ALTERNATIVES TO CONTROL SEDIMENTATION

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ABSTRACT

EVALUATION OF AGRICULTURAL POLICY ALTERNATIVES TO CONTROL SEDIMENTATION

Alternative policies for reducing the level of erosion and sedimentation are evaluated with a linear programming analysis of farms in a selected watershed. Three conservation practices and three tillage practices are considered in combination with six crop rotations on approximations of nine actual farms located in representative sections of the watershed. The impact of these practices on crop production costs and yields is considered, as is the impact on the off-site damages to the drainage system and the reservoir. Policies considered included subsidization of the cost of adopting conservation practices and subsidies to induce removing land from production, several forms of regulations and an effluent tax. Where appropriate the policies were analyzed assuming implementation at both the watershed and the farm level.

This analysis indicates that soil conservation practices should be increased substantially in order to reduce the gross soil loss in the watershed from over 20 to approximately 6 tons per acre per year. This reduction is most efficiently accomplished by modifying conservation practices, tillage practices, and crop rotations. An important finding is the indication that several alternative policies can be applied at either the watershed or the farm level and without regard to the farms' proximity to the reservoir, with very little difference in results.

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INTRODUCTION

Soil erosion, accelerated by man's activities, continues to be a primary factor adversely affecting productivity of agricultural land. It has been estimated that of approximately 414 million acres of arable cropland in the 48 states:

> 50 million acres are ruined by soil erosion insofar as crop production is concerned;
>
> 50 million acres have been severely damaged;
>
> 100 million acres have lost more than one-half of original topsoil; and another
>
> 100 million acres have lost more than a quarter of the topsoil.[1]

Another study indicates that 272 million acres of cropland in the 48 contiguous states is in need of some type of conservation treatment, with erosion control being a primary problem on 200 million acres.[2] Thus, nearly 75 percent of the arable land in the U.S. has been damaged by erosion and may warrant additional conservation treatment in the public interest. On nearly 60 percent of the area needing further treatment, erosion is the dominant problem.

It has been estimated that by the year 2000, world food output must triple that of 1965 to avoid widespread starvation and must increase considerably more than threefold to provide an adequate diet.[3] Increasing demand for nonagricultural uses of land along with increasing demand for food and feed grains will likely result in an expansion and intensification of crop production on erodible cropland soils. Thus, soil erosion is a continuing problem that may worsen as crop production activities are intensified in response to increased demand. It is imperative that further declines in soil productivity stemming from soil erosion must be prevented if demands for increased food production and nonagricultural uses of land are to be met.

Approximately 4 billion tons of soil are lost from agricultural lands annually.[4] This is equivalent to an 8 acre column of soil nearly 60 miles high. Alternatively, such a loss on an annual basis over a 10 year period is equivalent to removing 12 inches of soil from the 24 million acres of cropland in Illinois.

In addition to the adverse impacts of erosion on the producer, sedimentation imposes off-site costs on downstream users of the water resource. Erosion also is an environmental problem; its magnitude is suggested by the fact that suspended solid loads delivered to streams and lakes as sediment from surface runoff is 700 times greater than the load from sewage by weight.[5] Sediment generates four types of adverse physical effects leading to economic costs.[6] First, sedimentation of streams and reservoirs reduces channel flow and water storage capacity. This leads to a greater probability of flooding and greater flood damages when flooding does occur. In addition, sedimentation may preclude use of the waterway for shipping, or necessitate periodic dredging to maintain use value and/or avoid increased flood damages.

A second off-site effect of sediment is an increase in the turbidity level of waterways and reservoirs. Several different costs may result depending upon the uses made of the waterway. Additional treatment is necessary to remove the excess sediment from industrial or municipal water supplies. Turbidity may also impair or eliminate the recreational activities or the commercial fishing value of a waterway.

A third physical effect is the accelerated loss of reservoir capacity. The type of damage or cost depends upon the purpose of the reservoir and its uses. For example, some reservoirs were built exclusively for flood control while others provide recreation or are a source of industrial and municipal water supply.

A fourth physical effect of sediment is the restriction of drainage systems. Sediment deposition in grassed waterways, culverts, ditches, and other constructed drainage facilities may greatly reduce crop production and contribute to greater flood damages. In addition, flood-borne sediment may damage growing crops and when deposited on fertile soils, may reduce their productivity.

In order to clarify the range in economic effect of sedimentation, damages might be regrouped by type of damage, in terms of economic cost, rather than physical effect. The off-site costs of sedimentation would include: (1) dredging of rivers and reservoirs to maintain their use value, (2) greater flood damage, (3) increased water treatment costs, (4) reduced recreation benefits, (5) loss of commercial fishing value, (6) need to develop alternative sources of water supply, (7) increased maintenance cost of drainage systems, and (8) reduction in aesthetic values.

There are two demands for environmental services related to land use in addition to those expressed in the market or as economic costs: (1) a rising demand on the part of producers for environmental assimilation of residuals and by-product pollutants associated with higher levels of production,[7] and (2) a rapid growth in consumer demand for environmental amenities, arising from a rapid growth in per capita income and a relatively higher elasticity of demand for such environmental conditions as freedom from pollution.[8] The rising level of competition between demands on resources to produce food, and the related use of the environment's assimilative capacity as a receptacle for by-products of production activities and amenity demands is increasing the value of common property resources, such as air and water.[9]

Given the impacts of soil erosion on the farmer, along with the physical and economic consequences of sedimentation, there is little doubt that erosion damages are substantial. The cost of erosion and resulting sedimentation, in the state of Illinois alone, is estimated at over $296 million annually.[10]

The Soil Erosion Problem Within the Study Watershed[11]

The magnitude of soil erosion hazard in Pike County, Illinois, gives an indication of the problem within Big Blue Watershed. The SCS estimates average annual soil erosion losses in Pike County to be 1,275,000 tons from cropland, 353,000 tons from pastureland, 183,000 tons from woodland, and 167,000 tons from other rural land, or a total of 1,978,000 tons from agricultural land. The annual damage resulting from soil erosion and sedimentation was estimated at $5,520,000 and the cost of land treatment needs to cope with this erosion-sedimentation problem amounted to approximately $19,400,000.[12] With respect to cropland only, conservation treatment needs of the 295,500 acres in Pike County were estimated to be: 27 percent adequately treated, 15 percent needs additional crop residue and annual cover treatment, 5 percent needs sod crops in the crop rotation, 8 percent needs contouring, 26 percent needs a combination treatment consisting of strip cropping, terraces, and diversions, 5 percent needs improved permanent cover, and 13 percent needs additional drainage treatment measures.[13] In addition, of the 99,810 acres of pasture land in Pike County, 80 percent is in need of conservation treatment, of which

60 percent requires protection from overgrazing and fertilizer and weed control to improve stands, and 39 percent needs reestablishment of desirable vegetative cover.[14] Of the 85,800 acres of woodland in Pike County, only 37 percent is adequately treated with major needs being timber stand improvement and grazing control.[15]

Employment of conservation practices in Pike County is not extensive: (a) Contouring, in 1969, was used in grain or row-crop production on only 15.4 percent of the farms and 4.6 percent of the cropland; (b) Strip cropping systems to control erosion were reported on only 1 percent of the farms and .14 percent of the cropland; and (c) Terraced crop or pasture land was reported on 9.4 percent of the farms and 2.5 percent of the acreage.[16]

When the present multi-purpose reservoir in the Big Blue Watershed was in the planning stages, proposed land treatment measures were considered as essential to its successful functioning. Numerous measures intended to be effective in reducing floodwater, sediment, and erosion damage were proposed in the watershed work plan. Such treatment measures range from improved crop rotations, contouring, and terracing to tree planting, pasture renovation, and woodland protection from overgrazing and over-cutting. SCS personnel working with farmers in the watershed estimate that approximately half of the proposed land treatment measures have been installed. However, they also indicated that soil erosion and sediment continue to be a major problem and that without additional preventive measures the useful life of the reservoir may be substantially shortened, thus reducing the flow of benefits derived from the multi-purpose reservoir.

Research Objective

Recent public interest in environmental quality has generated an increased awareness of the sedimentation problem and its relation to agriculture. Past national agricultural policies have focused primarily on efforts to affect supplies of agricultural commodities and stabilize or increase farm income levels via land retirement, direct payments, and price supports. In addition, these policies have frequently contained provisions relating to soil conservation improvements. However, while past policies may have had a beneficial impact upon soil conservation efforts, they have not been particularly consistent.

The emerging public interest in sediment emanating from agricultural cropland has resulted in efforts by various state legislatures, most notably Iowa, to enact policies reducing soil losses from agricultural land. Public awareness of the sediment problem and an evident willingness to utilize policy channels to develop solutions indicates a need to examine the impact of agricultural price-income-production policies on soil erosion. Results of such analyses could be useful in the policy-making process by delineating selected alternative policy approaches to the sediment control problem and evaluating their expected impacts on both the environmental problem of sedimentation and the economic problems of producers.

More specifically, the objective is to evaluate several alternative public policies designed to control soil losses from agricultural cropland. Impacts of selected policies will be analyzed in terms of expected effects upon: (a) net return above land costs for crop production, (b) changes in cropping practices such as tillage methods, conservation practices, and crop rotations, and (c) off-site damages. The policies evaluated include conservation subsidies, diversion payments, effluent charges and several regulatory schemes.

Analytical Procedure

The unit of analysis is a set of nine hypothetical farms approximating farms in the Big Blue Watershed in Pike County, Illinois. The nine farms were delineated in general conformity with actual farm boundaries and are representative of the watershed in terms of soil types, slopes, and geographical distribution.

A linear programming model of the nine farms was constructed with activities defined according to farm, soil type, erosion class, and various combinations of conservation practices, tillage practices, and crop rotations. Net returns and soil loss coefficients were computed for each activity. A basic solution was generated with net returns above land costs maximized subject only to: (a) the acreage constraints on each soil type, slope, erosion class, and (b) a restriction of the historical crop distribution using conventional tillage practices. This solution reflects the present conditions within the watershed in terms of farm and watershed values for: (a) net returns above land costs, (b) soil losses, (c) acreages under each type of conservation practice, (d) acreages under each type of tillage practice, (e) acreages of each type of crop, and (f) off-site impacts of soil losses.

The same analyses are performed on four types of public policies: (a) acreage diversion, similar to past national agricultural production control-income support policies; (b) payments to adopt conservation practices and reduce soil erosion; (c) soil loss standards; and (d) effluent charges. In each case the linear programming model was modified or constrained to reflect the imposition of the policy under analysis.

The Evolving Policy Background

During World War I, expanding exports led to an increase in demand and relatively high prices for agricultural products. These higher prices prompted a substantial increase in output. With the end of the war and the role of the U.S. as a debtor trading partner, export demand declined and farm prices fell. The sharp decline in prices and resulting lower incomes brought pressure from farm groups for corrective legislation. Many of the proposals and programs adopted during the 1920's were attempts to increase the efficiency of the marketing system and thereby hopefully increasing the derived demand for agricultural products. Such attempts were regulatory in nature, while others took the form of trying to strengthen farmer cooperatives. No programs were estalished to support farm prices or income directly.

The first public price-income policy, the Agricultural Marketing Act of 1929, was enacted on the theory that cooperative marketing organizations aided by the federal government could provide a solution to the problem of low farm prices and incomes holding purchased farm goods temporarily off the market. By 1932, as the depression deepened, it was apparent that the efforts of the Federal Farm Board to stem the sharp decline in farm prices had failed. In their final report, the board recommended legislation which would provide an effective system for regulating acreage or quantities sold, or both.[17] This recommendation on acreage or marketing controls was a step toward the development of a production control program.

The Agricultural Adjustment Act of 1933 marked the initial governmental effort to influence the acreage of cropland devoted to the production of basic crops through voluntary agreements with producers and use of direct payments to encourage participation. However, it was not until passage of the Soil Conservation and Domestic Allotment Act of 1936 that an attempt was made to influence what was grown on acreage withheld from production. Farmers were paid for voluntarily shifting acreage from soil-depleting surplus crops to soil-conserving legumes and grasses. In addition, farmers were offered payments for seeding soil building crops on cropland and for carrying out approved soil building practices on cropland or pasture.

Beginning with the AAA of 1933 and the Soil Conservation and Domestic Allotment Act of 1936 the government programs exerted an element of control over both the level of crop production and the type of production occurring on withdrawn acreage. Continuing through the AAA of 1938, the Soil Bank Act of 1956, under which crop acreage could be diverted on a longer term basis, the Emergency Feed Grain Act of 1961, Food and Agricultural Act of 1965, the set-aside programs of the 1970 Agricultural Act and the Agricultural and Consumer Protection Act of 1973, there has been a sustained effort to control the quantity of land devoted to crop production and at the same time to protect retired acreage from soil erosion.

Generally, the major intent of these policies has been to stimulate agricultural prices and incomes by effecting a degree of production control and improving demand. The erosion control features of these policies were added to require participating farmers to do something in return for a government payment which embraced the public's interest in resource conservation.

There were also specific policies directed at the problem of preservation of farm land. While the primary policy approach to soil conservation problems has been through the technical programs administered by the Soil Conservation Service, both the production and erosion control provisions of the production-price-income policies have likely had several environmental effects.[18] Generally, overall crop production would have been greater and total sedimentation levels and resulting damages would therefore have been higher in the absence of these policies. However, production control policies may have intensified production in some areas, particularly those with a comparative advantage in certain crops, and decreased production of those crops in marginal areas. To the extent that diverted acreage is generally less productive and more erosion prone, the result is an increase in sediment production in intense cropping areas and a decrease in marginal areas that are most erosion prone. While this type of shift is generally desirable, present policies have not exerted a strong influence in this direction, since the policies are designed to have roughly equal impact across producing areas.

Generally, in the last decade, government policies have been voluntary in nature. As a result, producer participation has depended upon expected gains outweighing expected losses and on personal values. As rational economic decision makers, farm operators estimate the impacts of the program, including conservation practices, on the profitability of their farming operations over their planning horizon. Little or no economic incentive exists for the producer to consider the impact of soil erosion and sediment damage to streams, reservoirs, and other common property resources beyond his property lines.

ECONOMICS OF CONSERVATION POLICY

The theoretical aspects of the erosion-sedimentation problem are now explored from the perspective of the individual farm operator, from a societal perspective, and through a theoretical evaluation of the alternative of public policy responses to the problem.

Farm level

The erosion of farm land has two adverse impacts at the individual farm level, the physical loss of soil and the loss of plant nutrients and organic matter. Thus, declining yields will necessitate increasing other inputs. In the short run, one year, the farm operator will implement soil conservation practices only if there is a positive impact on his net returns in the year the practices are instituted. Since implementation of most practices involves some initial capital investment, either installation of facilites or purchase of equipment, soil conservation practices are not often implemented on the basis of this type of analysis. The economically rational farm operator will, however, invest in, or adopt, a conservation practice if the discounted expected net returns are higher with than without the practice. The important variables in this decision are the expected impact on costs and returns, the discount rate used and the length of the planning period. Thus, the decision process is a standard micro-economic theory investment problem.

Watershed level

As noted above, under the current institutional framework the impact of the eroded sediment on the watershed does not enter the calculations of the farm operator. The increase in the rate of sedimentation over the natural rate is an illustration of a technological external diseconomy or a spillover effect. The spillover effect of the agricultural production process, sediment, generally results in a deterioration of environmental quality or a direct economic loss to third parties.

The nature of this problem and the optimum theoretical solution is indicated in Figure 1. The demand for crops is symbolized by curve D. MPC is the marginal private cost of producing crops, ignoring off-site damages. MSC is the marginal social costs (private plus additional societal costs borne with no conservation practices) of production under the same conditions. Without policy restrictions, production will occur at 0 and MSC will be at Point A. The price of the product will be P. Under the assumption of an implementation of soil conservation practices the MPC curve has increased to MPC' and MSC is reduced to MSC'.* There are 0' units of crops being produced at a price of P'. Thus, output is reduced and price is increased, in achieving the reduction in social costs to the level desired by society thourgh a conservation program. However, the impacts on price and quantity are less if the soil conservation practices were not implemented and the level of soil erosion were reduced entirely through reductions in output, point B.

Alternative Sediment Control Policies

The social costs of sedimentation can be addressed in several ways, but each involves the implementation of public policies. Four general types of policies can be implemented. They are: a) regulations, b) subsidies, c) taxes, and d) educational programs. This analysis compares the first three in an evaluation of alternative policies for sedimentation control.

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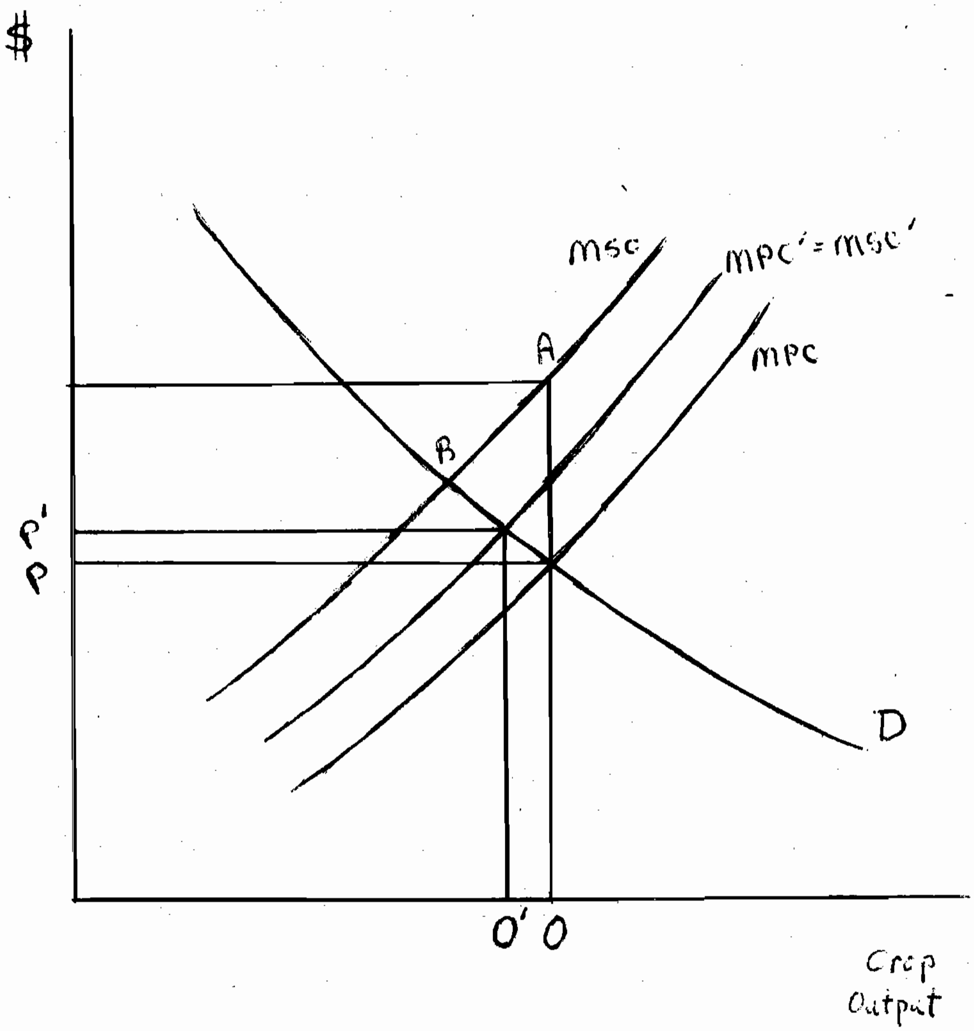
*MPC' and MSC' are not necessarily identical throughout.

Figure 1. Marginal Private and Social Costs of Crop Production With and Without Soil Conservation Activities



Regulations

A number of alternative regulations are considered in this study. The most efficient regulatory policy would be to establish soil loss limits on a watershed basis. This allows crop rotations and conservation and tillage practices to be optimally allocated within the watershed without regard to the impact on individual farm operations. Some farm operators would be forced to incur substantial reductions in income while others might have increases in order to reduce the total soil loss to the specified level. Thus, it would be quite difficult to achieve farmer acceptance for this policy and it would be very difficult to implement.

It is also possible to establish limits at the farmer level. Conceptually, this is a simple case of establishing the limits and allowing the operator to determine how it will be met, whether by reducing output, implementing conservation practices, changing tillage practices, altering crop rotations, or some combination thereof. Compared to the watershed limit, some farms would be forced to reduce erosion losses more than necessary for conservation objectives only for that farm in order to achieve watershed goals, resulting in an inefficient solution. Also, the non-point nature of the problem makes this regulation somewhat difficult to implement. Since the quantity of sediment leaving the farm cannot be measured, it must be estimated based on the nature of the farm operation. The regulating agency could either prescribe a set of practices or it could evaluate the set of practices selected by the farmer to determine whether it conformed.

Another alternative is to establish regulations on the quantity of acres allowed in row crop production per farm. This technique would be very inefficient since it would not take account of varying resource productivities among farms or take advantage of the value of soil conservation practices. It would be equivalent to operating at point B in Figure 1. If implemented rationally, it would effect relative crop prices. Another possibility is that farm operators could be required to install or implement soil conservation measures. This would also be inefficient in that some farms do not need such facilities or they can substitute modifications of tillage practices or crop rotations. Also, in both cases, the freedom of the farm operator to make such decisions is reduced.

Subsidies

A number of subsidy systems can also be devised. The classical system is to offer a payment to the producer if he will reduce the quantity of residuals discharged. The producer will consider the payment a source of income and adjust his operations to maximize total income. Thus, he will implement conservation practices or modify the crops produced if the payment for doing so is larger than the income foregone. In this case society pays for the increased environmental quality through general revenue sources rather than forcing the consumers of the polluting industry to bear the costs. This approach would be difficult to implement and monitor due to the non-point nature of the problem. Further, as in any subsidy program, the possibility that operators could exaggerate their requests for payments exists.

As in the case of regulations, a number of other subsidization schemes can be devised. Subsidies to farm operators to reduce the acres of row crops were used in the past to control production but could be used for this purpose. Such a subsidy would, however, be inefficient if the only policy objective is reducing sedimentation. Another alternative, which has been implemented in varying degrees in the past is the subsidization of the construction of soil conservation facilities. This has taken the form of federal cost sharing and it resulted in considerable improvement. It is more workable than the previously mentioned regulatory and subsidization schemes since these are investment type activities rather than recurring expenses and thus the monitoring difficulties are significantly reduced. It has the disadvantage of not taking advantage of the possible impacts of the other possible modifications such as crop rotations and tillage practices, and is an expense to the federal treasury rather than being passed to the consumer of the products produced.

Effluent Charges

Another means of approaching the problem, at least conceptually, is through the imposition of effluent charges. In this case the farmer is charged a fee per ton of sediment erroded from his farm. The fee becomes an incentive to him to reduce erosion to acceptable levels through the use of the full range of possible modifications. It is, theoretically, an economically efficient procedure, but it is impossible to implement due to the inability to measure sediment losses.

Farmers are generally concerned only with the soil erosion aspect of this problem as it relates to reduction in productivity of their soil resources. Farmers adopt improved conservation measures in the expectation that net returns will be increased. The sedimentation damage aspect of the problem generally does not concern the individual producer. This is an external cost of crop production imposed upon society. Therefore, due to the divergence between private and social costs, perfect competition does not result in maximum social welfare.

Regulations, subsidies, and effluent charges have been suggested as a means of controlling externality problems. These incentive schemes are more easily applied to point sources of pollution, but subject to some limitations, may also be useful in dealing with non-point sources such as sediment. Several alternative programs, incorporating all three incentive schemes, are analyzed in this study with respect to their effect at the farm and on the societal level.

METHOD OF ANALYSIS

Kneese indicates that pollution problems generally occur within areas, such as a watershed or some other problemshed, not directly coinciding with existing government jurisdictional units.[19] It is within such problemsheds that spillover effects and the opportunities for their reduction are most likely to occur. Essentially, a watershed is a self-contained unit, a system of quasi-equilibrium storage which is defined by the interaction of all watershed practices, processes, and properties.[20] More than half of the flood damage and most of the drainage needs in the U.S. occur in small watersheds.[21] A watershed is an appropriate macro-unit since it allows for an accounting of soil losses, resulting damages, and an aggregation of physical and pecuniary impacts of proposed public policies. Thus, the problem of soil erosion and associated effects can best be approached at the watershed level.

However, soil erosion occurring on agricultural cropland and resultant sediment damages are generated at the farm level. Thus, policy actions intended to reduce erosion and sedimentation must influence the independently determined land use and crop production decisions made on the individual farms.

For this study a watershed was selected as representative of the Corn-Soy Belt. It is impossible to select a geographical area representative of the entire U.S., given its wide variation in climate, topography, and soils characteristics. The Corn-Soy Belt was selected because of its general physical uniformity, the importance of the crops produced, and the erosion problem associated with a commercial crops economy. The following criteria, in conjunction with advice and consultation of soil specialists, were used in selecting the specific watershed: (a) soil types that reflect the soil associations common throughout much of the Corn-Soy Belt; (b) predominant soil slopes ranging from zero to seven percent; (c) watershed size between 5,000 and 25,000 acres or containing natural subdivisions of this size; (d) a wide variety of sediment damages, both on-site and off-site; (e) a reservoir; (f) availability of detailed soils data, structure costs, and damage estimates for the watershed area; (g) primarily agriculturally oriented; and (h) located in Illinois. Based upon a combination of these criteria, the Big Blue Watershed located in northeastern Pike County, Illinois, was selected.

This watershed is naturally divided into three drainage sections: (a) an area associated with a relatively large multi-purpose reservoir; (b) an area associated with a smaller reservoir intended only for flood control; and (c) an area located below the two structures. To facilitate analysis and construction of the linear programming model, only part (a) of the watershed was selected for this study. Unless specifically indicated otherwise, subsequent references pertain only to this part of the watershed.

Hypothetical farm units approximating the size and location of actual major farm units were developed to incorporate the entire watershed using the 1972 plat map of Pike County. Relatively small land holdings, such as rural residences, were generally omitted from the hypothetical farm structure by combining them with larger farm units. Actual farm boundaries were generally modified to conform to existing soil type, slope, erosion class boundaries. This adjustment resulted in somewhat irregularly shaped farms and offers the advantage of reducing the number of divisions of small soil class acreages between adjacent farms. The procedure also reduced the number of activities and hence the size of the linear programming model, but is not expected to alter the results of the analysis. The hypothetical farm structure was transferred to the watershed map in order to identify soils data (type, slope, erosion class) for each farm.

Due to the limited time and resources available, it was necessary to select a sample of farms for the detailed analysis reported herein. Nine farms were selected to represent the physical and topographical characteristics of the watershed. This sample is well-distributed geographically and is representative of the watershed in terms of soil types and slope gradients as indicated by Tables 1 and 2. The acreage of the hypothetical farms is given in Table 3. Data concerning average farm size within the watershed was not avilable; however, average size of Pike County farms is 278.4 acres, which is only slightly larger than the average of the hypothetical farms.

Description of the Watershed[22]

The Big Blue Watershed is located in northeastern Pike County and covers 26,690 acres. It is approximately 13 miles long and 4½ miles wide, with Big Blue Creek flowing southeasterly through the length of the watershed.

Table 1: COMPARISON OF SOIL TYPE ACREAGES BETWEEN TOTAL WATERSHED AND NINE-FARM SAMPLE

Soil Type by Number	Acreage in Watershed	Acreage in Nine-Farm Sample	% of Watershed Acreage[a]	% of Nine-Farm Acreage[a]
8	268.7	158.8	3.7	7.4
17	221.9	25.0	3.0	1.2
18	3463.0	1032.7	47.6	48.4
19	28.6	0.0	0.4	0.0
35	10.0	0.0	0.1	0.0
36	147.6	90.7	2.0	4.2
41	307.7	84.4	4.2	4.0
43	6.3	0.0	0.1	0.0
61	180.7	6.9	2.5	0.3
68	37.0	23.8	0.5	1.1
75	228.1	44.4	3.1	2.1
257	66.3	0.0	0.9	0.0
258	228.0	46.8	3.1	2.2
278	45.5	9.3	0.6	0.4
279	613.7	198.2	8.4	9.3
280	889.9	271.2	12.2	12.7
331	17.5	0.0	0.2	0.0
333	76.3	39.3	1.0	1.8
386	253.6	33.8	3.5	1.6
415	192.0	70.1	2.6	3.3
TOTAL	7282.5	2135.5	100.0	100.0

[a] May not sum to 100.0 due to rounding.

Table 2: Comparison of Soil Slope Gradients Between Total Watershed and Nine-Farm Sample

Soil Slope Gradient Class	%	Acreage in Watershed	Acreage in Nine-Farm Sample	% of Watershed Acreage[a]	% of Nine-Farm Acreage[a]
A	0-2	369.9	270.1	11.9	12.6
B	2-4	2062.8	596.3	28.3	27.9
C	4-7	1501.6	436.2	20.6	20.4
D	7-12	1083.7	312.3	14.9	14.6
E	12-18	857.3	166.3	11.8	7.9
F	18-30	852.8	326.2	11.7	15.2
G	30+	54.4	28.1	0.7	1.3
Total		7282.5	2135.5	100.0	100.3

[a] May not sum to 100.0 due to rounding.

Table 3: Acreage of Hypothetical Farms

Farm Number	Acreage	Farm Number	Acreage
1*	187.5	17	122.4
2	572.4	18*	286.9
3	304.4	19*	116.8
4*	185.9	20	151.2
5	366.3	21	153.2
6	668.1	22*	432.2
7*	156.2	23	166.6
8	182.6	24	194.4
9	134.3	25	79.4
10*	296.2	26	185.7
11	329.1	27	248.0
12	124.4	28	130.6
13*	206.3	29*	267.5
14	166.3	30	237.1
15	96.1	31	204.3
16	148.2	32	181.9

Average Size of All Hypothetical Farm Units	227.6
Average Size of Sample Farms	237.3
Average Size of Actual Farms in Pike County	278.4

*Sample Farms

The area of primary concern here is located in the western one-third of the watershed and contains the headwater area of Big Blue Creek. It is characterized by gently rolling hills interspersed with a few level ridgetops and a broad and flat valley with gently sloping valley walls. The gradients of the main stream and its tributaries are moderate.

A major portion of the watershed soils are moderately thick loess. Except for an area of prairie soils in the northern part of the drainage area, a majority of the soils have developed under timber vegetation. Bottomland soils are generally cumulative types developed chiefly from silty deposits resulting from erosion of the upland areas. Watershed soils may be grouped into four general classes:

a. Upland Timber Soils: Light colored, silt loam soils with moderately slow permeability occurring on slopes ranging from one to fifteen percent. Typical Illinois soil types within the group are Bogota, Clary, and Fayette.

b. Upland Prairie Soils: Dark colored, silt loam soils with moderate permeability, occurring on nearly level to gently sloping land. These soils were developed under prairie vegetation in eight feet or more of loess. Typical Illinois soil types within the group are Muscatine and Tama.

c. Steeply Sloping Timber Soils: A heterogeneous group of soils developed on exposures of weathered glacial till, limestone outcrops, or thin loess. They generally occur on slopes exceeding fifteen percent and are not cultivated. They are utilized as pasture or woodland. Typical soil types are Hickory and Elco.

d. Bottomland Soils: Dark to moderately dark colored silt loam soils with moderate permeability occurring on nearly level valley floors adjacent to Big Blue Creek. These soils are moderate to highly productive if adequately protected from overflow. Typical soil types within this group are Arenzville and Radford.

Soil conservation district aerial photos were used to identify all land within the watershed according to soil type, slope, and erosion class. The hypothetical farm structure was then superimposed upon this soil mapping, thereby facilitating identification of all land types within each farm. A dot template was used to measure the acreage of each land type within each farm.

The watershed is located in the predominantly general farming area of West Central Illinois. Principal crops are corn, soybeans, wheat, and hay. The corn and hay are generally fed on the farm while wheat and soybeans are the primary cash crops. Of the farms located within the watershed, 46 percent derive their primary income from livestock, 33 percent from grain, 15 percent from general and 6 percent from dairy farming.

In total, Big Blue Watershed contains 15,624 acres of cropland, 4,117 acres of cropland pasture, and 5,380 acres of woodland and permanent pasture, with the remainder in roads, homesteads, idle and wildlife areas. Distribution of cropland is 50 percent row crops, 20 percent small grain, and 30 percent hayland.

District SCS personnel concluded that there was no substantial difference in farming practices between the three watershed divisions or between the watershed and the rest of Pike County. As a result, farming patterns both within the entire watershed and the remainder of Pike County were assumed to be indicative of practices prevailing in the drainage area of the multi-purpose reservoir. Therefore, 1969 Census of Agriculture data on Pike County was utilized to determine the approximate distribution of major specific crops for the nine farm group of sample farms.

Cropland and cropland pasture account for 19,741 acres or 74 percent of total watershed acreage. Assuming similar proportions, there are 1,580 acres of cropland and cropland pasture in the nine farm sample. Fifty percent or 790 acres of this land was programmed to produce row crops, 30 percent or 474 acres to produce hay, and 20 percent or 316 acres to produce small grain, with the 556 acres remaining being devoted to woodland, permanent pasture, and other non-cropland uses. Based on the 1969 Census, the following approximate crop distribution was determined for the sample of farms: 527 acres of corn, 263 acres of soybeans, 316 acres of wheat, 474 acres of hay, 278 acres of woodland, and 278 acres of permanent pasture.

METHODS OF CALCULATING LINEAR PROGRAMMING MODEL COEFFICIENTS

The presentation of coefficients necessary for model formulation and operation is organized as follows: (a) defintion of alternative activities within the model; (b) methods of calculating coefficients contained in the model matrix; and (c) determination of righthand side (RHS) constraints.

The activities included in the linear porgramming model are restricted to crop production. The omission of livestock or other productive enterprises from the model reflects the concern with soil erosion and sedimentation on agricultural cropland as the primary focus of this study. Crop production activities included in the linear programming model are framed in terms of crop rotations. These crop rotations include the major crops in the area and are assumed to be produced under a high level of management which is based on high input levels thought to be near those required for maximum profit.[23]

A set of crop rotations including common rotations and a range of intensity of land use was developed in order to reflect the differing capabilities of land types to support crop production activities with varying levels of soil losses.

The crop rotations included are:

1. C,
2. C - Sb,
3. C - C - Sb - Ox,
4. C - C - Sb - W - M,
5. W - Sb (double crop),
6. C - W - M - M,
7. Pasture, and
8. Woodland.

Where, C = Corn,
Sb = Soybeans,
Ox = Oats with an alfalfa catch crop,
W = Wheat,
M = Meadow or alfalfa.

These rotations may be produced on all land types with two exceptions. (a) Permanent pasture and woodland activities are not alternatives on land with slopes less than 4 percent (class) C. (b) Permanent pasture and woodland activities are the only alternatives offered on land types with slope gradients exceeding 18 percent (slope group E). The reasons for these modifications are that slope group E would not generally be used for continuous cropping activities and while C and D slopes might generally be cropped, pasture and woodland use permits additional flexibility in response to various public policy alternatives. Land with slope gradients A and B are generally most suitable for crop production and were, therefore, limited to the six regular cropping rotations. These model adjustments reduce the overall size of the matrix which facilitated model construction and reduced the costs of generating solutions.

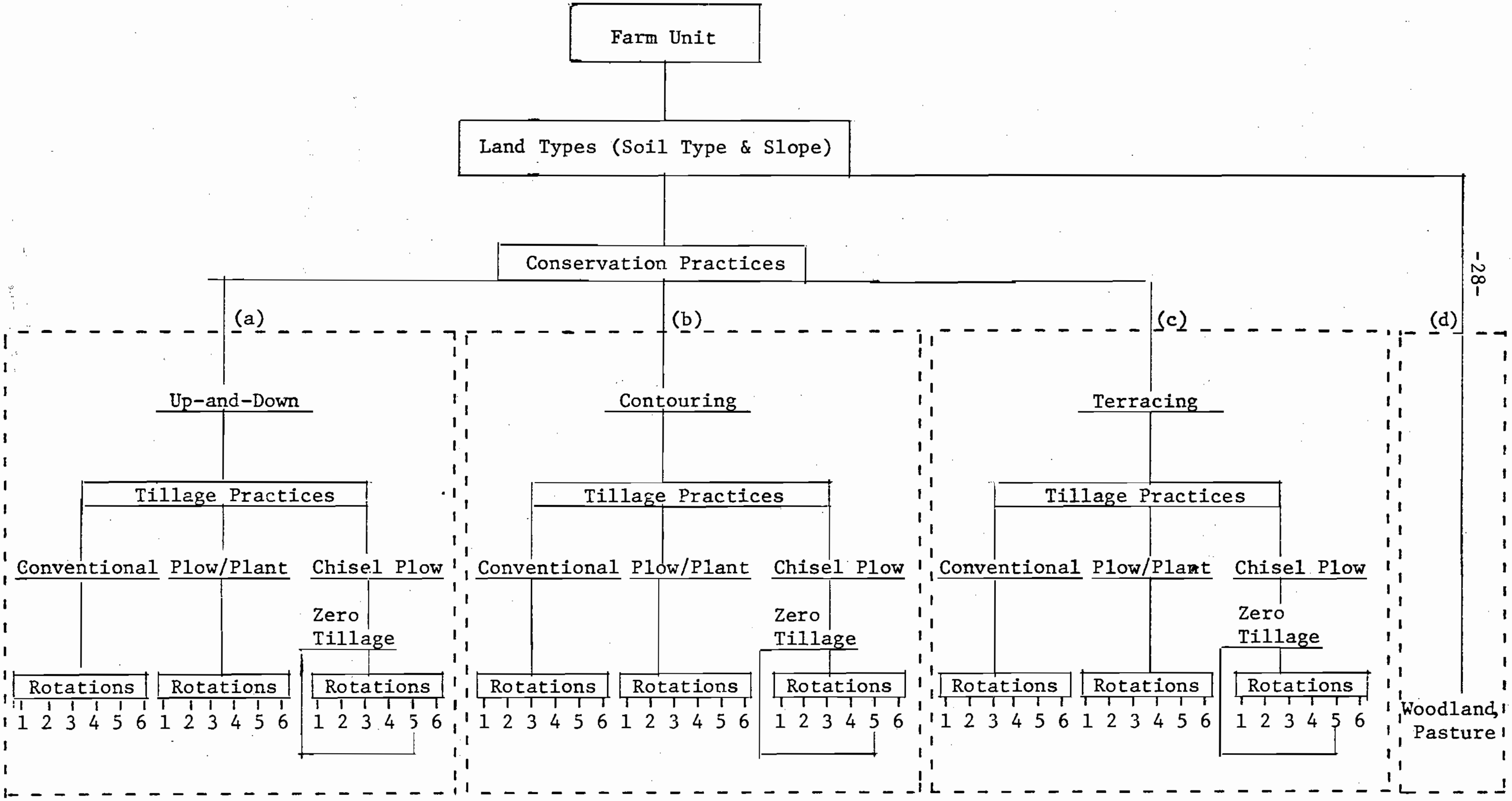
Three tillage practices are considered: conventional, plow plant, and chisel plowing. These tillage practices may be used for the six crop rotations specified above, with the exception that zero tillage replaces the chisel plowing alternative under the soybean-wheat double crop rotation. This adjustment reflects the moisture problem in soybean establishment and yields in this double-cropping rotation.[24] Zero tillage generally conserves more of the available moisture than traditional tillage methods.[25] Also, the permanent pasture or renovation of an existing stand is assumed to utilize only conventional tillage practices. The woodland alternative does not utilize any of the various tillage practices.

Three conservation practices are included: up-and-down, contouring, and terracing, but not all of them are available on each land type. The choice of conservation practices was based upon SCS recommendations concerning slope gradients. The alternative to up-and-down for A and B slopes is contouring, while for slopes of C and higher, the alternative is terracing.

The alternative crop production activities included in the linear programming model are depicted diagramatically in Figure 2. Each farm unit contains several land types. Under each land type, three conservation practices are possible: up-and-down, contouring, and terracing. Under each conservation practice, three tillage methods are possible: conventional, plow plant, chisel plow, and in the case of rotation 5, zero tillage. Under each tillage method, six crop rotations are possible, except chisel plow, which has five rotation alternatives. This generated many land type and slope gradient combinations. There are 36 alternative crop production activities with a slope of less than 4 percent, as shown in boxes a and b.

Figure 2

Diagrammatic Illustration of Crop Production Activities Included in the Linear Programming Model



With a greater than 4 percent but less than or equal to 18 percent slope, there are 38 alternative crop production activities, boxes a, c, and d. There are 2 alternative crop production activities where slopes are greater than 18 percent, box d.

The net returns above land costs for each crop production activity comprise the objective function of the linear programming model. A computerized system has been developed to calculate these net returns coefficients under various physical, economic, and cropping conditions.[26] These information inputs and general computation procedures are presented below.

Estimation of Net Returns Coefficients

Yield estimates of crops produced on differing soil conditions were obtained from published research results.[27] Yield estimates are presented by soil type under two levels of management for corn, soybeans, wheat, oats, alfalfa, pasture, and woodland. These yield estimates are generally based on the condition of A slope class, 0-1 erosion class, and a subsoil favorable to crop production. A separate table of yield adjustment coefficients was used to determine yields under other conditions.

The resulting yield estimates are based on levels published for 1968 under a conventional system of tillage and normal weather conditions. More detailed discussions of adjustments in yields and costs by tillage and cropping systems are contained in a later section dealing with crop and tillage systems.

Gross crop returns were estimated by multiplying yields times prices. The prices utilized are the averages for the five year period 1968 to 1972.[28] The average prices used are: corn, $1.18 per bushel; soybeans, $2.65 per bushel; wheat, $1.34 per bushel; oats, $.63 per bushel; alfalfa,

\$24.35 per ton; pasture, \$16.31 per ton;[29] and woodland, \$25.00 per 1,000 board feet.[30]

In estimating gross returns from the soybean-wheat double crop, it was necessary to make yield adjustments similar to those under the pasture alternative (footnote 29). Soybean yields are critically affected by the availability of moisture, especially at seeding time and during the early growth period--more so than under the traditional single crop system. Estimates by crops specialists of the yield reduction relative to standard crop soybean production with normal planting times is: (a) a 40 percent decrease with conventional tillage; (b) a 35 percent reduction with plow plant tillage; and (c) a 30 percent decrease with zero tillage.

Production cost data for the regular crop rotation components were developed from the Illinois Farm Management Manual.[31] Costs are divided into direct costs, labor costs, and fertilizer costs.

Direct costs include preharvest soil preparation, seeding, harvest, and conditioning power and machinery depreciation, repair, and fuel, custom machine hire, seed, spray, seasonal hired labor, and other materials. Labor is valued at two dollars per hour. Fertilizer cost is based on the estimated cost of nutrient removal per unit of yield. Total cost of crop production is a summation of all these components. A general total cost calculation of the following type was estimated for corn, soybeans, wheat, oats, and meadow:

1. $TC = D + F + L$

where, TC = Total Cost,

D = Direct Cost,

F = Fertilizer Cost,

L = Labor Cost.

The individual cost components included in estimating production costs for different crops are not fixed, but rather are related to yield levels. The cost function for corn (1972 costs) is developed as follows:

D_c = \$31.00 for yield, $Y_c \leq 80$ bu. per acre,

= \$31.00 + \$9.20/40 $(y_c - 80)$ for $80 < y_c < 120$ bu. per acre,

= \$40.20 for $y_c \geq 120$ bu. per acre;

F_c = \$0.14 X y_c;

L_c = \$8.80 for $y_c \leq 80$ bu. per acre,

= \$9.00 for $80 < y_c < 100$ bu. per acre,

= \$9.20 for $y_c \geq 100$ bu. per acre.

A similar discontinuous functional relationship also exists for soybeans:

D_{sb} = \$22.00 for yield, $y_{sb} \leq 33$ bu. per acre,

= \$22.00 + \$7.00/17 $(y_{sb} - 33)$ for $30 < y_{sb} < 50$ bu. per acre,

= \$29.00 for $y_{sb} \geq 50$ bu. per acre;

F_{sb} = \$0.18 X y_{sb};

L_{sb} = \$9.00 for $y_{sb} \leq 33$ bu. per acre,

= \$9.20 for $y_{sb} > 33$ bu. per acre.

and for wheat:

D_w = \$14.00 for yield, $y_w \leq 40$ bu. per acre,

= \$14.00 + \$1.30/15 $(y_w - 40)$ for $40 < y_w < 55$ bu. per acre,

= \$15.30 for $y_w \geq 55$ bu. per acre;

F_w = \$0.21 X y_w;

$$L_w = \$4.00 \text{ for } y_w \leq 40 \text{ bu. per acre,}$$
$$= \$4.20 \text{ for } y_w > 40 \text{ bu. per acre.}$$

The cost function for oats is fixed with respect to direct and labor costs, while fertilizer cost varies directly with yield:

$$D_o = \$12.20 \text{ at all levels of yield, } y_o;$$
$$F_o = \$\ 0.11 \text{ X } y_o;$$
$$L_o = \$\ 4.00 \text{ at all levels of } y_o.$$

For meadow crops the cost and yield values for alfalfa are assumed. The cost function for alfalfa is continuous, varying directly with yield at all levels:

$$D_m = \$9.95 \text{ X yield level, } y_m\text{, in tons per acre;}$$
$$F_m = \$3.30 \text{ X } y_m;$$
$$L_m = \$5.60 \text{ X } y_m.$$

In certain instances, oats and wheat are used as a nurse crop for meadow (alfalfa). In these cases, a direct cost, for seed, of \$5.60 is added to the cost function for oats and \$7.90 to the wheat function. The resulting yield of the combination crop, oats plus alfalfa or wheat plus alfalfa, is valued in terms of the main product, oats or wheat, disregarding the value of the catch crop.

The cost functions associated with pasture and woodland activities differ somewhat from the other cropping activities in that they are a long term investment rather than annual cost. These costs were annualized in order to make them compatible.

Generally, the costs associated with establishing permanent pasture or improving already existing pasture land are approximately the same. Therefore, the pasture activity can be viewed as either new planting or renovation. The costs of the pasture activity can be expected to vary with the initial physical condition of the area to be planted or reseeded. The cost function developed for this activity is based on average estimates. Actual costs depend on the amount of brush or tree removal, gully repair, or fertilization required.

The costs of pasture establishment are separated into two types: (1) Those related to initial establishment, such as seedbed preparation, seeding, seed costs, and herbicides, which are treated as an investment; and (2) Fertilizer and management costs of a recurring nature. Investment costs, based on crops specialists' estimates are \$42.20 per acre, or \$3.68 annually over a 20 year period at 6 percent interest. Recurring annual costs were estimated at \$16 per acre.

These costs are based upon an assumed input level sufficient to produce a four-ton per acre yield. Therefore, the estimated annual cost of \$19.68 per year is equivalent to \$4.92 per ton and the cost function for pasture is:

$$TC = \$4.92 \text{ X estimated yield level.}$$

The woodland activity may also be viewed as a composite of two activities, tree planting and timber stand improvement. The coefficients are framed in terms of timber stand improvement, but the model also allocated existing timber stands within the watershed. This procedure permits the impact of improved timber management to be reflected on farm income and soil loss levels, and also indicates the land types that should optimally be devoted to woodland. The cost estimates related to the woodland activity are applicable to an average situation based upon published data combined with opinions of forestry specialists.[32] The woodland activity costs include fire control, livestock grazing control, improved forestry and sustained yield practices, and replacement planting. The initial investment costs, annualized over a 60-year period, plus the annual maintenance costs are estimated at $3.73 per acre per year.[33] Land conversion costs, such as clearing an existing woodlot for pasture or crop production, are not included.

All of these cost functions generally reflect 1972 costs with average or better managerial ability using a conventional tillage system.[34] Modifications of specified cost functions for alternative tillage systems and conservation practices are considered in a later section.

It may be noted that the prices and costs used in this study are substantially below present levels. However, it is believed those cost-price relationships used are similar to the 1968-1972 period.

Net returns per acre for individual crops are obtained by subtracting the appropriate estimated cost value from the estimated gross crop return. Net returns per acre for crop rotations included in the model are based on individual crop net returns weighted by the number of years a crop is in the rotation.

Alternative tillage systems and conservation practices influence production costs, and in some cases, yields, and thereby affect net crop returns. The tillage systems considered are plow plant, chisel plow, and, in the double crop rotation, zero tillage. The schedule of cost and yield changes is given in Table 4. Generally, the cost adjustments occur in the direct costs for row and grain crops. Yield values also change on certain soil types, depending on soil drainage characteristics, in response to alternative tillage systems.[35] As stated earlier, the affect of yield adjustments on net returns are most conveniently handled in the computation process by changing crop prices without altering the basic crop yield table contained in Circular 1016.

Table 4: Row and Grain Crop Cost and Yield Adjustments, Relative to a System of Up and Down Cultivation and Conventional Tillage, Under Specified Alternative Conservation and Tillage Practices[a]

Tillage and Conservation Practices	Crops Produced in Traditional Rotations		Soybeans in Double-Crop Rotation	
	Cost Change $	Yield Change %	Cost Change $	Yield Change %
Conventional Tillage	b	b	b	-40
Plow Plant Tillage	+1.05	None	+1.05	-35
Chisel Plow Tillage	-1.00	c, d	b	b
Zero Tillage	b	b	-1.50	-30
Contouring	+0.75	None	+0.75	None
Terracing	+4.50	None	+4.50	None
Conventional and:				
Contouring	+0.75	None	+0.75	-40
Terracing	+4.50	None	+4.50	-40
Plow Plant and:				
Contouring	+1.80	None	+1.80	-35
Terracing	+5.55	None	+5.55	-35
Chisel Plow and:				
Contouring	-.025	c, d	b	b
Terracing	+3.50	c, d	b	b
Zero Tillage and:				
Contouring	b	b	-0.75	-30
Terracing	b	b	+3.00	-30

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[a] These cost and yield adjustments were made in consultation with W. R. Oschwald, Extension Agronomist, University of Illinois.

[b] Not applicable.

[c] Yield on well drained soils reduced 5 percent.

[d] Yield on poorly drained soils reduced 15 percent.

A shift to conservation practices such as contouring or terracing involves additional costs in the form of increased investment for land modifications, equipment changes, or more time required to accomplish planting and harvesting operations. These investment costs are converted to an annual basis and combined with estimated yearly maintenance and timeliness charges. These cost adjustments are then accommodated through the total cost functions presented earlier.

In summary, given these series of data inputs, soil type, slope, erosion class, basic yields, prices, costs, etc., net return coefficients are generated for various combinations of crop rotations, conservation and tillage practices. Based on relevant crop prices, gross crop returns are calculated. The cost functions are used to determine total costs and net returns are computed by subtracting total costs from gross returns. Using weights based on the number of years a crop appears in a rotation, the weighted average net return for a given rotation produced on a particular land type is computed. These net return coefficients comprise the objective function row of the linear programming model.

Estimation of Gross Soil Loss Coefficients

Rainfall induced soil erosion is a function of: (a) rainfall characteristics such as storm length and intensity, (b) soil characteristics, such as permeability and resistance to the dispersion, splashing, abrasion, and transport forces of the rainfall and runoff, and (c) the treatment or management of the soil. These three factors have been expressed quantitatively and incorporated into the Universal Soil Loss Equation as a means of predicting gross soil erosion on an average annual basis.[36] This equation is:

A = RKLSCP

where,

A = average annual soil loss in tons per acre,
R = a rainfall factor,
K = a soil erodibility factor,
LS = the slope gradient and slope length factor,
C = the crop management factor, and
P = the erosion control practice factor.

The essence of the soil loss equation is to isolate several variables affecting soil erosion and reduce the effect of each to a quantitative value, the product of which is an estimate of soil loss in tons per acre per year.

R = Rainfall Factor. The soil losses from cultivated fields are directly proportional to the product of total kinetic storm energy and its maximum average 30-minute intensity.[37] The rainfall erosion index computed for a particular location is the long-time average yearly total of the storm erosion index values. Iso-erodent maps, indicating equally erosive average annual rainfall, are available for the area east of the Rocky Mountains.[38] The R value for Pike County, 180, along with the values for all Illinois counties have been published by the State SCS Office.[39]

K = Soil Erodibility Factor. K values reflect the fact that some soils erode more readily than others even though rainfall, slope, vegetative cover, and management practices are the same. The K factor includes the combined effects of the soil's water intake ability and its ability to resist erosion inducing forces. K factors for Illinois soil types have been published by the State SCS Office.[40]

LS = Slope Gradient and Length of Slope Factor. Slope gradient and slope length are actually separate variables, so numerical values for each can be developed. However, when land is modified by mechanical soil protection measures, such as terraces, the effective length of slope is the distance between the terraces and this distance is a function of slope. Therefore, these two factors are interrelated and can be conveniently treated as a single factor in the equation.

Generally, the steeper the slope, the greater the erosion due to increased downhill splash, run-off, and rate of run-off flow. The increase in erosion per unit area is more than proportional to the increase in slope, rising relatively more rapidly as slope increases. Length of slope has a similar effect on soil loss. The soil loss per unit area increases, but less than proportionally, as slope length increases, due to increased amount of surface run-off, velocity, and depth.

An exact representation of slope gradient and length would require field measurements. However, values for these variables may be approximated from published data. Land types within the watershed are identified according to soil type, slope, and erosion class. Thus, a specific slope gradient for each land type may be estimated for each land type by using the midpoint of each slope group. Slope length for particular land types was assigned by using the slope length limits for contouring. This corresponds with the view that length of slope generally varies inversely with slope gradient and slope length limits for contouring is a method of approximating this relationship.[41] The resulting slope gradient and slope lengths utilized are presented in Table 5. Given these values, LS factors for any land type were determined from published tables.[42]

C = Crop Management Factor. The C factor in the equation is the ratio of soil loss from land cropped under specified conditions to the corresponding losses under the standard condition of bare cultivated fallow.

Table 5: Determination of Specific Slope Gradient and Slope Length Values for Land Types in Various Slope Groups

Slope Group	Slope Range (%)	Slope Value (%)	Slope Length Limits for Contouring (ft.)
A	0-2	1.0	400
B	2-4	3.0	400
C	4-7	5.5	300
D	7-12	9.5	150
E	12-18	15.0	70
F	18-30	24.0	60
G	30+	30.0	50

With respect to crop management, the bare fallow condition will result in much higher levels of soil loss than under actual cropping conditions, other factors assumed equal.

The crop management factor is one of the most complex components of the soil loss equation, due primarily to the almost infinite number of different ways to manage crop growth. Generally, however, values for the crop management factor depend upon four major groups of variables: (1) crop rotation, (2) crop residue and its treatment, (3) climate, and (4) tillage system. The C values for any particular cropping system in a given location can be calculated from published data.[43] The C values used in this study are presented in Table 6.

P = Erosion Control Practice Factor. This is the ratio of soil loss with the supporting practice to the soil loss when cultivated up and down the slope. Values for the P factor depend upon the conservation practice used and on the soil slope group. The P values used in evaluating both contouring and terracing are also limited by slope length. The P factor values in Table 7 are considered accurate approximations for Illinois conditions.[44]

Given the values for the various components of the Universal Soil Loss Equation, average annual soil losses in tons per acre can be computed for any land type identified by soil type, slope, and erosion class. A computer software system has been developed to calculate these gross soil loss coefficients (see footnote 26). The calculated soil loss coefficients for each crop production activity contained in the linear programming model comprise the soil loss row of the model.

Table 6: Values for the Crop Management Factor Under the Cropping Systems Used in this Study

Crop Rotations	Tillage Systems			
	Conventional	Plow Plant	Chisel Plow	Zero Tillage[a]
Continuous Corn	.460	.240	.070	----
C - Sb	.540	.290	.084	----
C - C - Sb - Ox	.385	.210	.060	----
C - C - Sb - W - M	.220	.120	.006	----
C - Sb (double-crop)	.360	.336	----	.162
C - W - M - M	.052	.024	.020	----
Pasture[b]	.014	----	----	----
Woodland[c]	.014	----	----	----

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[a] Applicable only to the double crop rotation.

[b] Only conventional tillage is considered.

[c] The C value for woodland is not affected by tillage methods, but is listed here under conventional tillage for convenience.

Table 7: Values of the Erosion Control Practice Factor, P, Under Various Conservation Practices

Soil Slope Group	Slope Range %	P Values			Slope Length Limits for Contouring (ft.)
		Up and Down	Contouring	Terracing	
A	0-2	1.0	0.6	0.12	400
B	2-4	1.0	0.5	0.10	400
C	4-7	1.0	0.5	0.10	300
D	7-12	1.0	0.6	0.12	150
E	12-18	1.0	0.8	0.16	70
F	18-30	1.0	0.9	0.18	60
G	30+	1.0	1.0	0.20	50

Estimation of Sediment Delivered

Regulatory policies to restrict soil losses, analyzed in a following section, are generally framed in terms of constraining gross soil erosion. However, one of the soil loss regulations incorporates a constraint on quantities of sediment delivered to the reservoir which requires a farm level delivery ratio.

Delivery ratios have generally been formulated on a watershed basis and include as a primary variable the drainage area of the watershed. Watershed delivery ratios vary inversely with drainage area size, reflecting the fact that as drainage area increases, more of the eroded soil will be re-deposited on the suface of the watershed.[45]

Individual farm delivery ratios, (D_f, where f = 1...9), were estimated from published graphs expressing the delivery ratio-drainage size relationship.[46] These individual farm delivery ratios indicate the proportion of eroded sediment that can be expected to leave the farm. The proportion of sediment leaving a farm and delivered to the reservoir will vary inversely with the distance between the farm and the reservoir. This adjusted farm delivery ratio is an approximation of the proportion of gross erosion on a particular farm that is ultimately delivered to the reservoir. Techniques for estimating the actual delivery ratios do not exist.

The gross soil loss for each farm G_f was estimated under the base conditions of net return maximization using a system of conventional tillage and up-and-down cultivation (column 2, Table 8). The individual farm delivery ratios D_f were estimated from published sources (column 3). Their product is an estimate of the tons of sediment leaving each farm S_f (column 3). Assuming the nine farm sample is representative

Table 8

Distance Adjustment Factors and Individual Farm Adjusted Sediment Delivery Ratios

Farm Number	Gross Soil Loss (G_f) (tons)	Individual Farm Delivery Ratio (D_f)	Sediment Moved Off Farm (S_f) (tons)	Distance from Farm to Reservoir (l_f) (miles)	Individual Farm Distance Adjustment Factors (b_f)	Distance Adjusted Sediment Delivery Ratios
1	4719	.371	1751	5.4375	.154	.057
2	2787	.373	1040	4.1250	.308	.115
3	4935	.385	1900	2.3750	.575	.221
4	4102	.340	1395	3.7500	.353	.120
5	5771	.365	2106	3.2500	.419	.153
6	14198	.317	4501	2.3125	.587	.186
7	7223	.348	2514	1.2500	.776	.270
8	5765	.342	1972	2.8125	.497	.170
9	2838	.410	1164	2.4375	.564	.231
Nine Farm Total	52336		18343			
Watershed Total	178472	.175	31233			

of the watershed, a watershed gross soil loss estimate can be determined by expanding the data for the sample farms by an appropriate expansion factor, a = 3.4102.

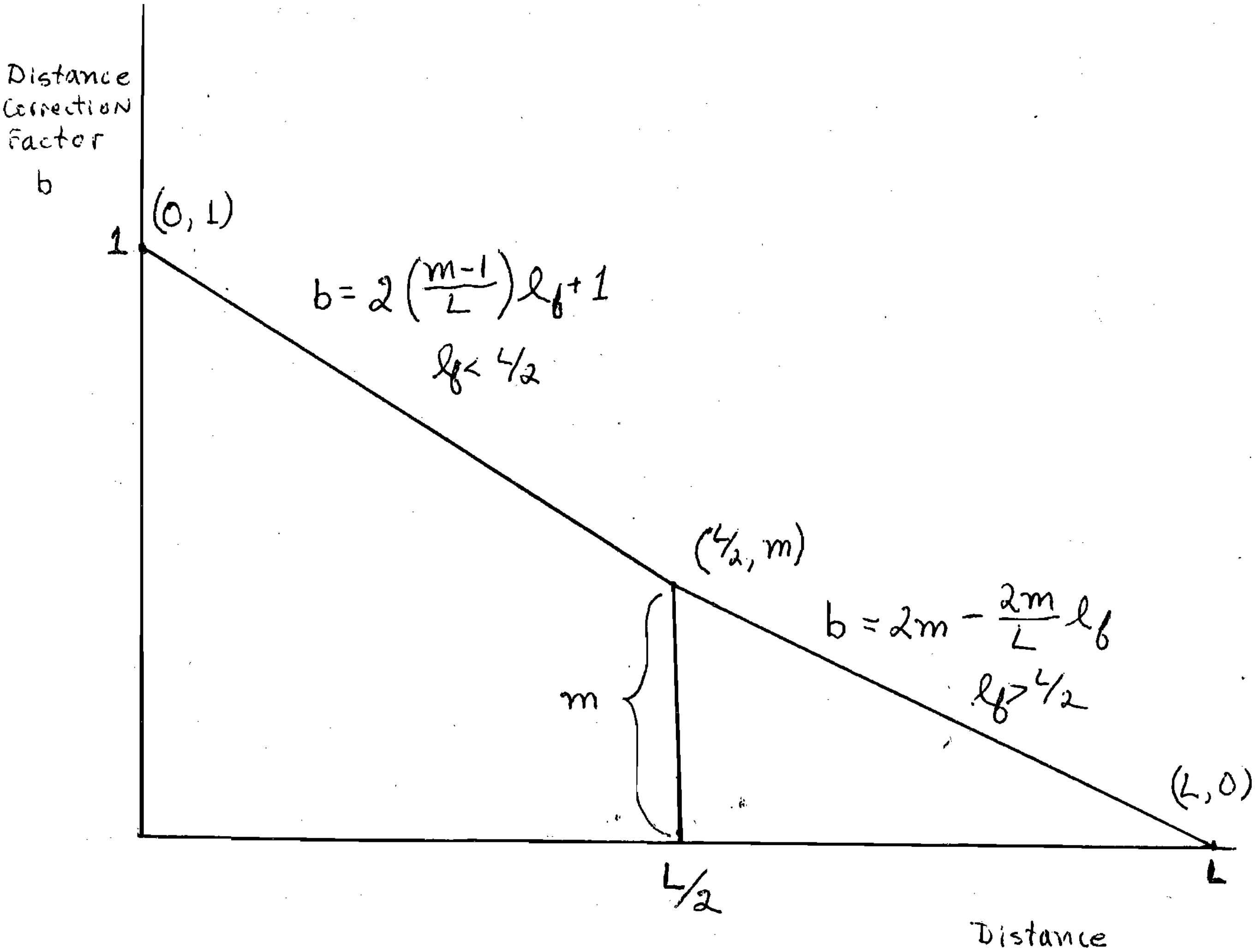
The distance correction factor for individual farm delivery ratios are based upon the model shown graphically in Figure 3. Linear line segments are used to approximate the expected curvilinear relationship between the sediment delivery ratio and distance to the reservoir. The endpoint values are based upon the following assumptions: (a) for farms located immediately adjacent to the reservoir, all sediment moved off the farm is delivered to the reservoir, (b) for farms located beyond the watershed boundary, the quantity of sediment will be equal to zero. This distance from the reservoir to the watershed boundary, L, is approximated by the maximum stream length of Big Blue Creek, 6.75 miles. The common endpoint of the two linear line segments, occurring at L/2 for convenience, is located at the point (L/2, m).

The value for m is determined by solving each line segment equation for b in terms of m by substituting values l_f into the appropriate equation (see Figure 3) depending upon the distance from the farm to the reservoir. This results in a $\hat{b}_f$ value containing an m term for each farm. The following equation which requires that the total quantity of sediment delivered from the nine farm sample multiplied by the expansion factor be equal to the quantity of sediment delivered to the reservoir, is then used to solve for the value of m:

$$a \left[\sum_{f=1}^{9} \hat{b}_f (G_f \cdot D_f) \right] = G \cdot D$$

Where G and D are watershed gross soil loss and delivery ratio estimates.

Figure 3. Individual Farm Distance Correction Factor



The value determined for m is then substituted back into the line segment equations to solve for b_f, resulting in a distance correction factor for each individual farm delivery ratio. (The value determined for m is .3967 and the estimated values for b_f are presented in Table 8, column 5.) The distance adjustment factors are then multiplied by the individual farm delivery ratios to determine the distance corrected sediment delivery ratio for each farm (Table 8, column 6). The relationships between (a) the unadjusted farm delivery ratios, (b) the distance adjustment factors, and (c) the adjusted farm delivery ratios are illustrated in Figure 4.

These distance adjusted farm level sediment delivery ratios are used to convert the gross soil loss coefficients, determined in the previous section using the Universal Soil Loss Equation, to a delivered sediment basis for each activity in the model. Under a regulatory policy designed to control sediment delivered to the reservoir, these delivered sediment coefficients replace the gross soil loss coefficients in the soil loss row of the linear programming model.

The Linear Programming Model

The basic linear programming model is formulated as follows:

maximize:

$$(1) \quad z = \sum_{f=1}^{F} \sum_{l=1}^{L} C_{flr} X_{flr}$$

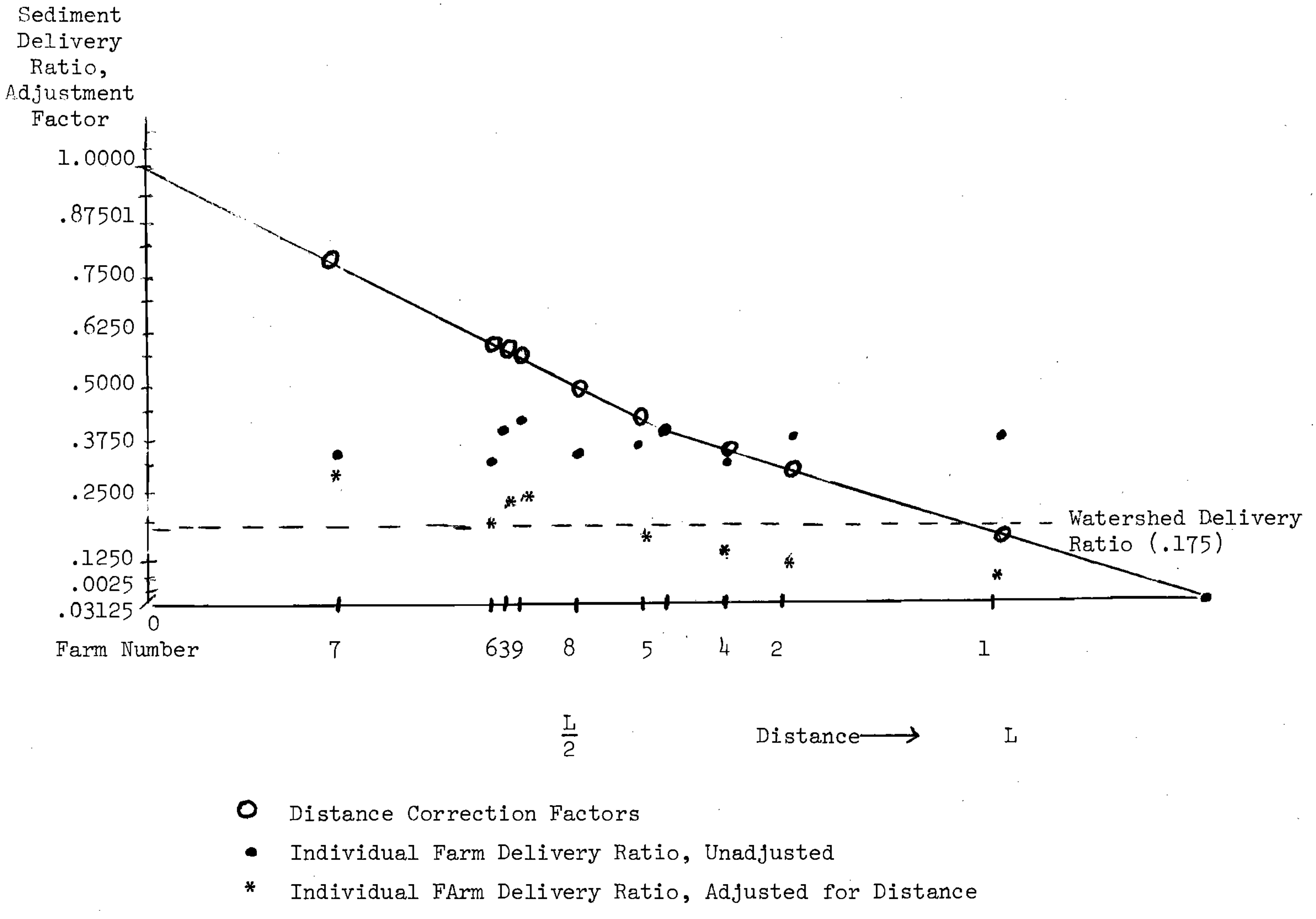
f = farm
l = land segment
r = crop production process - includes crop rotation
tillage practice ; conservation practice r = 1,...,R_1

subject to the following constraints:

$$(2) \quad \sum_{f=1}^{F} \sum_{l=1}^{L} \sum_{r=1}^{R_1} A_{flr} X_{flr} \leq B$$

$$(3) \quad \sum_{l=1}^{L} \sum_{r=1}^{R_1} X_{flr} = d_{fl} \text{ (for all F)}$$

Figure 4. Relationship Between Adjusted and Unadjusted Sediment Delivery Ratios and the Distance Adjustment Factor for Nine Individual Farms



(4) $X_{flr} \geq 0$ (f = 1...F, l = 1...L, and r = $1...R_1$)

where:

f identifies a farm, f = 1...F, farms in the watershed;

l denotes land segments within farms, l = 1...L; and

r identifies the crop production process, including the crop rotations, tillage practice, and conservation practice, r = $1...R_1$.

C_{flr} = the net return above land costs for crop process r produced on land segment (defined by soil type, slope, erosion class) l on farm f;

X_{flr} = the solution variable to be determined; the acreage of crop process r produced on land segment l of farm f;

A_{flr} = the gross soil loss or sediment yield per acre occurring under process r produced on land segment l of farm f;

d_{flr} = the acreage of land segment l available for production activity in farm f;

B = the allowable gross soil loss or sediment yield for the watershed.

The basic model formulation is presented in tableau form in Table 9. This is the general model form incorporating only the basic restrictions. Analysis of additional policy approaches are performed by incorporating them into the basic model format of Table 9 via adjustments in such model components as the constraint sets, alternative production activities, and the objective function coefficients.

SOIL LOSSES AND SEDIMENT DAMAGES

The soil loss tolerances set by the Soil Conservation Service is an attempt to reflect the level of soil loss that various soils may experience on an annual basis and still maintain their long run productive potential. However, these tolerances do not take into account the off-site damages imposed by soil losses. It is possible that soil loss levels falling within

Table 9

Basic Linear Programming Model in Tableau Format

FARM UNIT	1										...	F							RHS
Land Segment	1	1	... 1	2	2	... 2	...	L	L	... L	...	1	1	... 1	...	L	L	... L	
Production Process	1	2	... R_1	1	2	... R_2	...	1	2	... R_L	...	1	2	... R_1	...	1	2	... R_L	
Objective Function	C_{111}	C_{112}	... C_{11R}	C_{121}	C_{122}	... C_{12R}	...	C_{1L1}	C_{1L2}	... C_{1LR}	...	C_{F11}	C_{F12}	... C_{F1R}	...	C_{FL1}	C_{FL2}	... C_{FLR}	
Soil Loss or Sed. Yield	A_{111}	A_{112}	... A_{11R}	A_{121}	A_{122}	... A_{12R}	...	A_{1L1}	A_{1L2}	... A_{1LR}	...	A_{F11}	A_{F12}	... A_{F1R}	...	A_{FL1}	A_{FL2}	... A_{FLR}	B
Land Segment Constraints	1	1	... 1																d_{11}
				1	1	... 1	...												d_{12}
							...	1	1	... 1	...								d_{1L}
											...								
											...								
											...	1	1	... 1	...				d_{FL}
															...	1	1	... 1	d_{FL}
Variables	X_{111}	X_{112}	... X_{11R}	X_{121}	X_{122}	... X_{12R}	...	X_{1L1}	X_{1L2}	... X_{1LR}	...	X_{F11}	X_{F12}	... X_{F1R}	...	X_{FL1}	X_{FL2}	... X_{FLR}	

the tolerance limits may be judged excessive if they contribute to substantial off-site damages. The relationship between average soil loss per acre, net crop income, and off-site sediment damage is determined by estimated "net social income" resulting from crop production. Net social income is defined as net crop return per acre (above land costs) minus sediment damage per acre.

The sediment damages considered here relate only to those resulting from crop production activities while it is recognized that other activities within the watershed may contribute to the overall level of sediment damages. The sediment resulting from crop activities impacts upon the function operation of the reservoir. To evaluate these impacts, the following definition of sediment damage is employed. Both on-site and off-site damages refer to the reduction of benefits or increase in costs of other activities inside or outside the watershed, with off-site damages excluding the on-site effects such as damage to crop production and increases in the cost of tillage and conservation practices.[47]

The estimate of off-site sediment damages includes several types of damage:

(1) Increase in annual reservoir cost, $(D_s)_1$. Theoretically, in the absence of sediment deposition, the reservoir would continue to perform its intended function indefinitely and its cost could be amortized in perpetuity. Sediment deposition reduces the useful life of the reservoir and hence, increases its annual cost. Capacity of the reservoir within Big Blue Creek Watershed may be divided into the sediment pool, municipal and industrial water supply pool, and the flood water detention pool, both of which are located on top of the sediment pool. When the sediment pool is filled with silt, further siltation of the reservoir interferes with intended reservoir functions. The increase in annual cost as a result of sediment deposition in the reservoir can be expressed as the difference between (a) the annuity corresponding to total cost for the

estimated economic life of the reservoir taking sedimentation into account and (b) the annuity corresponding to an infinite life in the absence of sediment.[48, 49]

(2) Increase in flood damage following the useful life of the reservoir $(D_s)_2$. The flood prevention benefit of the reservoir is eliminated following the end of the reservoir's useful economic life. It is assumed that flood damage in the watershed returns to its level prior to the construction of the reservoir. Thus, this damage estimate includes (a) the annual flood damage that occurs prior to the end of the sediment pool capacity; (b) the increase in flood damage following the end of the estimated life of the reservoir capacity; and (c) the increasing level of flood damage occurring between (a) and (b).[50]

(3) Increase in upstream drainage maintenance cost, $(D_s)_3$. This part of the total off-site damage estimate reflects the fact that a portion of gross erosion does not reach the reservoir, but is trapped over the surface of the drainage network of the watershed. Sedimentation of the drainage system imposes a damage in the form of a cleaning or dredging cost to maintain its viability.

(4) Sediment damage as a part of downstream flood damage, $(D_s)_4$. Whatever the magnitude of downstream flood damage, sediment damage is a part of the total flood damage. This part of the total sediment damage function reflects that fraction of total flood damage imparted by sediment deposition over flooded areas.

(5) Increase in water supply costs after the end of the reservoir's economic life $(D_s)_5$. The municipal and industrial water supply benefit of the reservoir ceases at the end of the economic life of the reservoir. The reduction in water supply benefit due to sedimentation of the reservoir constitutes a part of total sediment damage and, similar to 2 above, includes

(a) the increase in water supply costs following the end of the estimated life of the water supply pool capacity, and (b) the increasing level of damage to the water supply following the end of the sediment pool capacity, but prior to the end of water supply pool capacity.

(6) Increase in water treatment cost due to sedimentation of the reservoir, $(D_s)_6$. This aspect of the sediment damage problem relates to the treatment cost necessary to remove suspended sediment from the municipal and industrial water supply. Data from which this damage might be estimated for Big Blue Watershed was not available. Therefore, estimates are based on data from published sources.[51]

The total annual off-site sediment damage function is expressed as follows:[52]

$$D_s = \sum_{i=1}^{6} (D_s)_i$$

where:

$$(D_s)_1 = C_p \, [(A/P,\ i,\ \bar{N}) - (A/P,\ i,\ \infty)] +$$

$$(D_s)_2 = (D_{af} - D_{ar}) \, (P/A,\ i,\ \infty) \, (P/F,\ i,\ N_2) \, (A/P,\ i,\ \bar{N}) +$$

$$(D_{af} - D_{ar}) \, / \, (N_2 - N_1) \, [P/G,\ i,\ N_2 - N_1] \, [P/F,\ i,\ N_1]$$

$$[A/P,\ i,\ \bar{N}] +$$

$$(D_s)_3 = G_e \, (1 - D_r) \, \alpha_1 \, P_r +$$

$$(D_s)_4 = D_{ar} \, \alpha_2 +$$

$$(D_s)_5 = D_{ws} \, (P/A,\ i,\ \infty) \, (P/F,\ i,\ N_3) \, (A/P,\ i,\ \bar{\bar{N}}) +$$

$$D_{ws}/N_3 - N_1 \, (P/G,\ i,\ N_3 - N_1) \, (P/F,\ i,\ N_1) \, (A/P,\ i,\ \bar{\bar{N}}) +$$

$$(D_s)_6 = (\alpha_3 T) \, C_{ws}.$$

These variables are defined as follows:

The life of the sediment pool, total reservoir capacity, and the water supply pool are expressed as:

$$N_1 = \frac{K_1 C_{rs}}{G_e D_r T_e}, \quad N_2 = \frac{K_1 C_{rt}}{G_e D_r T_e}, \quad \text{and } N_3 = \frac{K_1 C_{ws}}{G_e D_r T_e}$$

where C_{rs} is the capacity of the sediment pool in acre feet,

C_{rt} is total reservoir capacity in acre feet,

C_{ws} is the capacity of the water supply pool in acre feet,

G_e is gross soil erosion for the watershed, which is equal to nine farm total soil loss times the expansion factor of 3.4102,

D_r is the watershed delivery ratio,

T_e is trap efficiency of the reservoir in percent,

K_1 is the conversion constant from acre feet to tons,

N_1 is the life of the sediment pool in years,

N_2 is the life of the total reservoir capacity in years,

N_3 is the life of the water supply pool in years.

To simplify, the useful life, $\bar{N}$, of the reservoir is assumed to be the average of the lives of the sediment pool and the total capacity, and the useful life, $\bar{\bar{N}}$, of the water supply pool is assumed to be the average of the lives of the sediment pool and the water supply pool. Therefore,

$$\bar{N} = (N_1 + N_2)/2 \text{ and } \bar{\bar{N}} = (N_1 + N_3)/2.$$

C_p = total installation cost of the reservoir,

i = interest rate

$(A/P, i, N)$ = annuity with present value of 1, based on interest rate i, and N years,

$$= \frac{i(1 - i)^N}{(1 - i)^N - 1},$$

D_{af} = annual damage level after year N_2,

D_{ar} = annual damage level before year N_1,

(P/A, i, N) = present value of annuity 1 based on interest i and N years,

$$= \frac{(1 - i)^N - 1}{i(1 - i)^N} ,$$

(P/F, i, N_2) = present value of 1, based on interest i and N_2 years,

$$= \frac{1}{(1 + i)^N} ,$$

(A/P, i, $\bar{N}$) = the annuity of the future value of 1 based on interest i and $\bar{N}$ years,

$$= \frac{i}{(1 + i)^N - 1} ,$$

(P/G, i, N) = the uniform-gradient-series present worth factor based on interest i and N years,

$$= \frac{(1 - i)^{N+1} - (1 + N_i + i)}{i^2 - (1 + i)^N} ,$$

α_1 = fraction of sediment causing damage to drainage system,

P_r = dredging cost,

α_2 = fraction of total flood damage caused by sediment,

D_{ws} = water supply benefit,

α_3 = the proportional reduction in suspended sediment as G_e is reduced,

T = tons of suspended sediment per acre foot of water supply.

The data used to estimate the offsite damage function is listed in Table 10.

Table 10

Input Data for Estimating Offsite Damage Function for Big Blue Watershed

	Item	Quantity	Remarks and Sources
1.	Drainage Area	7282.5 acres	Watershed soils map
2.	Installation Cost	$1,039,815	Values for Items 2-5 were obtained from the watershed workplan which pertained to a 1958 basis. Values were converted to a 1972 basis using the Handy-Whitman Index[a]
3.	Damage cost with reservoir	$7,992	
4.	Damage cost without reservoir	$21,775	
5.	Water supply benefit	$30,953	
6.	α_1 (fraction of sediment causing damage in drainage area)	0.5	Hambaugh-Martin study[b]
7.	α_2 (sediment damage as a fraction of flood damage)	0.1	Mendota study[c]
8.	Delivery ratio	0.175	Nelson[d]
9.	Sediment pool capacity	418 acre feet	Watershed work plan[e]
10.	Water supply pool capacity	4391 acre feet	Watershed work plan[e]
11.	Total reservoir capacity	6959 acre feet	Watershed work plan[e]
12.	Trap efficiency	0.95	Hambaugh-Martin study[b]
13.	Conversion factor from acre feet to tons	1 acre foot = 1300 tons	Mendota study[c]
14.	Interest rate	0.075	
15.	Drainage ditch maintenance and dredging	$0.50	Mendota study[c]

[a] Whitman, Requardt, and Associates, "The Handy-Whitman Index of Water Utility Construction Costs", Baltimore, Maryland, 1972.

[b] Lee, M. T., et al., "Economic Analysis of Erosion and Sedimentation, Hambaugh-Martin Watershed," University of Illinois, Department of Agricultural Economics, Urbana, Illinois, and Illinois Institute for Environmental Quality, Chicago, Illinois, Ag. Econ. Publication No. AERR 127, 1974.

[c] Narayanan, A. S., et al., "Economic Analysis of Erosion and Sedimentation, Mendota West Fork Watershed," University of Illinois, Department of Agricultural Economics, Urbana, Illinois, and Illinois Institute for Environmental Quality, Chicago, Illinois, Ag. Econ. Publication No. AERR 126, 1974.

[d] Nelson, T. F., "A Method of Determining the Reduction in Sediment at the Mouth of PL-566 Watersheds," U.S. Department of Agriculture, Soil Conservation Service, 1972, mimeographed.

[e] U.S. Department of Agriculture, Soil Conservation Service, Work Plan, Big Blue Watershed, Pike County, Illinois, January, 1959.

RESULTS OF SOIL LOSS CONTROL POLICY ANALYSIS

Basic Model Solutions

Solutions to the linear programming model were generated to compare alternative sediment control policies. These solutions were generated under the assumption that net crop returns are maximized: (a) without crop, soil loss, or conservation and tillage practice constraints; (b) subject to constraints on the conservation and tillage practices used; and (c) subject to constraints specifying amounts of crops produced.

Base Solution #1, BS1. This initial model solution, constrained only by the individual land type restrictions, is presented in Table 11. Crops produced are: corn, 1,322.4 acres; soybeans-wheat (double crop), 460.6 acres; and pasture, 354.3 acres. Conventional tillage and chisel plowing are the only tillage practices and up-and-down cultivation is the only conservation practice employed. Net returns of $121,519 are generated on the nine farms with a total soil loss of 46,946 tons or an average of 22 tons per acre per year.

Base Solution #2, BS2. The general cropping practices in Big Blue Watershed are primarily conventional tillage and up-and-down cultivation and do not include minimum tillage methods or conservation practices. To reflect this situation, the basic model is constrained to permit production activities using only these conservation and tillage methods and the results are presented in Table 12. The primary effect is to eliminate the soybean-wheat double crop from the optimal solution. The effect of removing the zero tillage version of this activity from the model is to increase soil losses 11 percent and reduce net returns .3 percent relative to BS1. Corn and pasture enter the solution and the average soil loss increases from 22 to 24.5 tons per acre. Thus, to the extent that BS2 represents cropping practices in the watershed, soil losses

Table 11

Base Solution #1, Optimal Results by Individual Farm and Nine Farm Total with Soil Losses Non-Constrained

	Crop Activities			Tillage Practices		Conservation Practices			
Farm Number	Row Crops (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Zero Tillage (acres)	Up and Down (acres)	Net Return (dollars)	Total Soil Loss (tons)	Soil Loss Per Acre (tons)
1	187.5	16.9		170.6	16.9	187.5	12821	4514	24.1
2	185.9			185.9		185.9	16325	2787	15.0
3	156.2	41.2		115.0	41.2	156.2	9544	4356	27.9
4	161.8	125.6	134.4	36.2	125.6	161.8	12415	2600	8.8
5	191.9	33.8	14.4	158.1	33.8	191.9	12330	5378	26.1
6	401.6	38.1	30.6	363.5	38.1	401.6	23911	13744	31.8
7	193.2	63.1	74.3	130.1	63.1	193.2	12982	6459	24.1
8	219.4	100.0	67.5	119.4	100.0	219.4	15405	4778	16.7
9	83.7	41.9	33.1	41.8	41.9	83.7	5727	2331	20.0
Total[a]	1781.2[b]	460.6[c]	354.3	1321.4	460.6	1781.2	121514	46946	22.0

[a] Columns may not sum to total due to rounding error.

[b] Includes corn, 1321.4 acres, and soybeans, 460.6 acres.

[c] Wheat-soybeans, 460.6 acres.

Table 12

Base Solution #2, Optimal Results by Individual Farm, with Land Type, Tillage, Conservation Practice Constraints

Farm Number	Crop Activities		Tillage Practices	Conservation Practices	Net Return (dollars)	Total Soil Loss (tons)	Soil Loss Per Acre (tons)
	Row Crops (acres)	Pasture (acres)	Conventional (acres)	Up and Down (acres)			
1	187.5		187.5	187.5	12817	4719	25.2
2	185.9		185.9	185.9	16325	2787	15.0
3	156.2		156.2	156.2	9462	4935	32.0
4	161.8	134.4	161.8	161.8	12339	4102	13.8
5	191.9	14.4	191.9	191.9	12233	5771	28.0
6	401.6	30.6	401.6	401.6	23873	14198	32.8
7	193.2	74.3	193.2	193.2	12959	7223	27.0
8	219.4	67.5	219.4	219.4	15371	5765	20.1
9	83.7	33.1	83.7	83.7	5710	2838	24.3
Nine Farm Total[a]	1781.2[b]	354.3[c]	1781.2	1781.2	121089	52336	24.5

[a] Columns may not sum to total due to rounding error.

[b] Corn

[c] Pasture

exceed and net returns are below what could be generated with additional economically justifiable conservation practices.

Base Solution #3, BS3. This historical crop distribution for major crops in Big Blue Watershed[53] was added to BS2. The maximum net returns, producing the specified crop distribution under conventional tillage and up-and-down cultivation, are presented in Table 13.

Soil losses and net returns are substantially reduced below BS1 and BS2. Both of these changes are due primarily to the large shift from corn and soybean to hay and woodland production.

Soil Loss Regulations

Three types of regulations are evaluated: (a) limits on soil losses at the watershed level; (b) regulations on soil losses, at both the watershed and the individual farm level, based upon Soil Conservation Service soil loss tolerances; and (c) a regulation on sediment delivered to the reservoir, established at the watershed and individual farm level, based upon the design life of the reservoir.

Watershed Soil Loss Regulations. Watershed level soil loss constraints were parameterized downward at 15 percent increments from BS2. Thus solutions were obtained at 7,850 ton increments from the initial soil loss level of 52,336 tons. The watershed level results of these solutions are presented in Table 14, along with those from BS1 and BS2. Continuous corn, soybean-wheat double crop, and pasture, are the only crop activities included. As the allowable level of soil loss is reduced, crop activities shift from continuous corn to the soybean-wheat double crop. Pasture acreage remains constant. Tillage practices shift from conventional to plow plant and chisel plow.

There are shifts in cropping activities, tillage, and conservation practices when soil loss limits are reduced. Generally, continuous corn under

Table 13

Base Solution #3, Optimal Results, by Individual Farm, with Land Type, Tillage Conservation Practices, and Crop Production Constraints

	Crop Activities			Tillage Practices	Conservation Practices			
Farm Number	Row Crops (acres)	Small Grain (acres)	Pasture and Woodland (acres)	Conventional (acres)	Up and Down (acres)	Net Returns (dollars)	Total Soil Loss (tons)	Average Soil Loss Per Acre (tons)
1	88.1	99.4		187.5	187.5	10171	1363	7.3
2	163.0	22.9		185.9	185.9	14397	2265	12.2
3	78.5	83.7	7.1	149.1	149.1	7373	1144	7.3
4	86.9	78.0	142.5	153.7	153.7	8539	1797	6.1
5	68.7	103.8	33.8	172.5	172.5	8619	1027	5.0
6	143.8	185.7	104.4	327.8	327.8	16034	2129	4.9
7	44.4	75.0	148.1	119.4	119.4	9430	1048	3.9
8	89.9	120.1	76.9	210.0	210.0	12202	1450	5.1
9	26.7	21.4	68.7	48.1	48.1	3941	588	5.0
Nine Farm Total[a]	790.0[b]	790.0[c]	581.5[d]	1554.0	1554.0	90706	12812	6.0

[a] Columns may not sum to total due to rounding errors.

[b] Includes 527 acres of corn and 263 acres of soybeans.

[c] Includes 316 acres of wheat and 474 acres of meadow.

[d] Includes 278 acres of pasture and 303.5 acres of woodland.

Table 14

Watershed Level Results as Allowable Soil Loss is Incrementally Reduced From the Maximum Net Return Level of BS2

	Crop Activities			Tillage Practices			Conservation Practices					Average
Soil Loss (tons)	Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	Net Returns (dollars)	Shadow Prices (dollars)	Soil Loss Per Acre (tons)
52336 (BS2)	1781.2		354.3	1781.2			1781.2			121089	0.00	24.5
46946 (BS1)	1321.4	460.6	354.3	1321.4		460.6	1781.2			121519	0.00	22.0
44486	1189.0	592.2	354.3	1189.0		592.2	1781.2			120712	0.01	20.8
36636	1177.6	603.6	354.3	890.5	287.0	603.6	1781.2			120461	0.05	17.2
28786	1177.6	603.6	354.3	438.6	739.0	603.6	1781.2			119895	0.09	13.5
20936	1044.4	736.8	354.3	397.1	422.8	961.3	1615.4	165.8		119112	0.18	9.8
13086	1028.3	752.9	354.3	550.0	352.1	879.2	595.0	827.6	358.6	118019	0.32	6.1
5236	835.2	946.0	354.3		497.1	1284.1		866.4	914.8	113862	1.57	2.5

[a] Includes both chisel plow and zero tillage methods.

conventional tillage and up-and-down cultivation provides the greatest net return per acre, although it is exceeded on certain soil types by the double crop rotation under zero tillage. Also, relative to other crop activities, this system of corn production generally results in the highest rate of soil loss per acre. Thus, as soil loss limits are reduced, the initial shift occurs in the crops produced and the tillage practices used. Additional reduction in soil loss limits result in first, additional shifts toward conservation tillage methods, second, in conservation practices, and last, substantial shifts in crop activities.

The net crop returns for the watershed decline as soil loss limits are reduced due to the lower net returns associated with crop activities produced under improved soil conservation and tillage practices, and to changes in crops produced. However, at a soil loss of 2.5 tons per acre, soil losses are reduced by 89 percent from the level of BS1 or BS2 while net returns decline only 6 percent. Both reductions are due to the large shift in crop activity from continuous corn to double cropping, from conventional tillage to plow plant and chisel plow, and from up-and-down cultivation to contouring and terracing.

The effect of reducing allowable soil loss limits affects all farms in the same general manner; however, some differences are apparent. The distribution of land in each farm unit by slope group and the average productivity index of each farm is presented in Table 15. These data indicate that farm 2 is relatively flat and highly productive while farm 7 is hilly and not as productive. These two farms generally represent the extremes and will be used to point out the differential impacts of soil loss control policies on different types of farms.

Table 15

Productivity Index and Distribution of Land in Each Farm Unit by Slope Group

Farm		A	B	C	D	E	F	G	Total	Productivity Index
1	acres	10.6	95.7	49.4	31.8				187.5	125
	percent	(5.7)	(51.0)	(26.3)	(17.0)				(100.0)	
2	acres	77.0	69.4	30.7	8.8				185.9	150
	percent	(41.4)	(37.3)	(16.5)	(4.7)				(100.0)	
3	acres	28.8	29.3	40.6	36.9	20.6			156.2	120
	percent	(18.4)	(18.8)	(26.0)	(23.6)	(13.2)			(100.0)	
4	acres		125.6	28.1	5.6	2.5	134.4		296.2	110
	percent		(42.4)	(9.5)	(1.9)	(0.8)	(45.4)		(100.0)	
5	acres	20.6	57.0	64.3	30.6	19.4	14.4		206.3	120
	percent	(10.0)	(27.6)	(31.2)	(14.8)	(9.4)	(7.0)		(100.0)	
6	acres	92.4	48.1	84.3	84.9	91.9	10.6	20.0	432.2	105
	percent	(21.4)	(11.1)	(19.5)	(19.6)	(21.3)	(2.5)	(4.6)	(100.0)	
7	acres		63.1	56.3	41.9	31.9	66.2	8.1	267.5	100
	percent		(23.6)	(21.1)	(15.7)	(11.9)	(24.7)	(3.0)	(100.0)	
8	acres	40.7	66.2	82.5	30.0		67.5		286.9	105
	percent	(14.2)	(23.1)	(28.7)	(10.5)		(23.5)		(100.0)	
9	acres		41.9		41.8		33.1		116.8	100
	percent		(35.9)		(35.8)		(28.3)		(100.0)	

Results for farms 2 and 7, as allowable soil losses for the watershed are parameterized downward, are presented in Table 16. Initial decreases in watershed soil loss limits leave farm 2 unaffected while farm 7 experiences substantial shifts in crop activities and tillage practices. Generally, this is a result of the relatively higher initial soil loss levels on farms 7, which are related to soil slope characteristics. As soil loss limits are reduced further, farm 2 adjusts primarily by alternating tillage and conservation practices. Farm 7, however, undergoes a complete shift from conventional to chisel plow (zero tillage) and a relatively larger shift to terracing than does farm 2. In addition, crop production on farm 7 is altered substantially more than farm 2. The relatively greater slopes of farm 7 contribute to greater soil losses, while the lower productivity index implies that it is cheaper in terms of reduced net watershed returns to make the necessary adjustments to reduce soil losses on farm 7 than on farm 2.

Similarity Between Effluent Charges and Soil Loss Constraints. As indicated, solutions generated with constraints at the farm or watershed level are symmetrical to solutions generated with the shadow prices imposed as charges per ton of soil loss.[54] The shadow price related to a constraint indicates the change in the values of the objective function associated with a one unit change in the constraint. Imposition of these shadow prices as an effluent charge per ton of soil loss would result in the same model solution as the regulatory constraint that generated the price initially. Therefore, the tables indicating the results of soil loss regulations can also be interpreted in terms of the shadow prices associated with the relevant soil loss constraints.

Table 16

Impact on Two Selected Farms as Allowable Soil Loss for the Watershed is Incrementally Reduced from the Maximum Net Return Level of BS2

Watershed Total Soil Loss (tons)	Individual Farm Soil Loss (tons)	Average Soil Loss Per Acre (tons)	Crop Activities			Tillage Practices			Conservation Practices			Net Return (dollars)
			Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	
Farm 2:												
52336 (BS2)	2787	15.0	185.9			185.9			185.9			16325
44486	2787	15.0	185.9			185.9			185.9			16325
36636	2787	15.0	185.9			185.9			185.9			16325
28786	2621	14.1	185.9			177.1	8.8		185.9			16316
20936	1700	9.1	185.9			146.4	39.5		116.5	69.4		16236
13086	1037	5.6	177.1	8.8		85.8	91.3	8.8	30.7	146.4	8.8	16054
5236	497	2.7	158.3	27.6			158.3	27.6		146.4	39.5	15781
	(Percent Change as the Watershed Level Soil Constraint is Reduced from the Level of BS2)											
	-82	-82	-15			-100			-100			-3
Farm 7:												
52336 (BS2)	7223	27.0	193.2		74.3	193.2			193.2			12959
44486	5993	22.4	107.6	85.6	74.3	107.6		85.6	193.2			12881
36636	4662	17.4	107.6	85.6	74.3	58.7	48.9	85.6	193.2			12883
28786	3635	13.6	107.6	85.6	74.3		107.6	85.6	193.2			12773
20936	2647	9.9	73.8	119.4	74.3		41.9	151.3	193.2			12749
13086	1612	6.0	73.8	119.4	74.3	41.9	7.5	143.8	80.7	63.1	49.4	12544
5236	655	2.4	73.8	119.4	74.3			193.2		63.1	130.1	11986
	(Percent Change as the Watershed Levl Soil Loss Constraint is Reduced from the Level of BS2)											
	-91	-91	-61.8		0	-100			-100			-8

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[a] Includes zero tillage practice associated with double crop rotation.

In Table 14 for example, the watershed level results of incrementally reducing the allowable soil loss limit could also be achieved by implementing a charge equal to the shadow prices corresponding to each total soil loss level. The relationships between total net returns, shadow price, and soil loss limits of Table 14 are presented graphically in Figure 5. At the non-constrained maximum net return level, the shadow price is equal to zero. As the soil loss constraint is reduced, total net returns decline at an increasing rate while shadow prices increase at an increasing rate. Thus, it requires increasingly higher soil loss charges to achieve additional reductions in soil losses, which in turn, result in lower levels of total net return.

<u>Soil Loss Regulations Based on SCS Soil Tolerances</u>. The Soil Conservation Service has developed soil loss tolerances for various soils indicating the maximum soil loss in tons per acre per year that can be tolerated while maintaining sustained economic production in the foreseeable future with present technology.[55] These soil loss tolerances can be established as limits for the farm or the watershed.

<u>Watershed Level Soil Loss Constraint Based on SCS Tolerances</u>. SCS tolerances were aggregated to find a soil loss limit for the nine farms in the watershed and it was used as a constraint. Results are presented in Table 17. Compared to the maximum net returns solution, BS1, average soil loss decreases by 18 tons per acre, or 82 percent, and total net returns decrease $2.38 per acre or 4 percent. Thus, it costs producers an average of $2.38 per acre in foregone net income to reduce average soil loss 18 tons per acre or $.13 per ton.

Relative to simulated present conditions, BS3, the watershed level SCS tolerance constraint results in a 33 percent or 2 ton per acre decrease in

Figure 5. Relationship Between Soil Loss Constraints, Shadow Prices, and Total Net Farm Income as Soil Loss Restrictions are Reduced or Shadown Prices are Increased

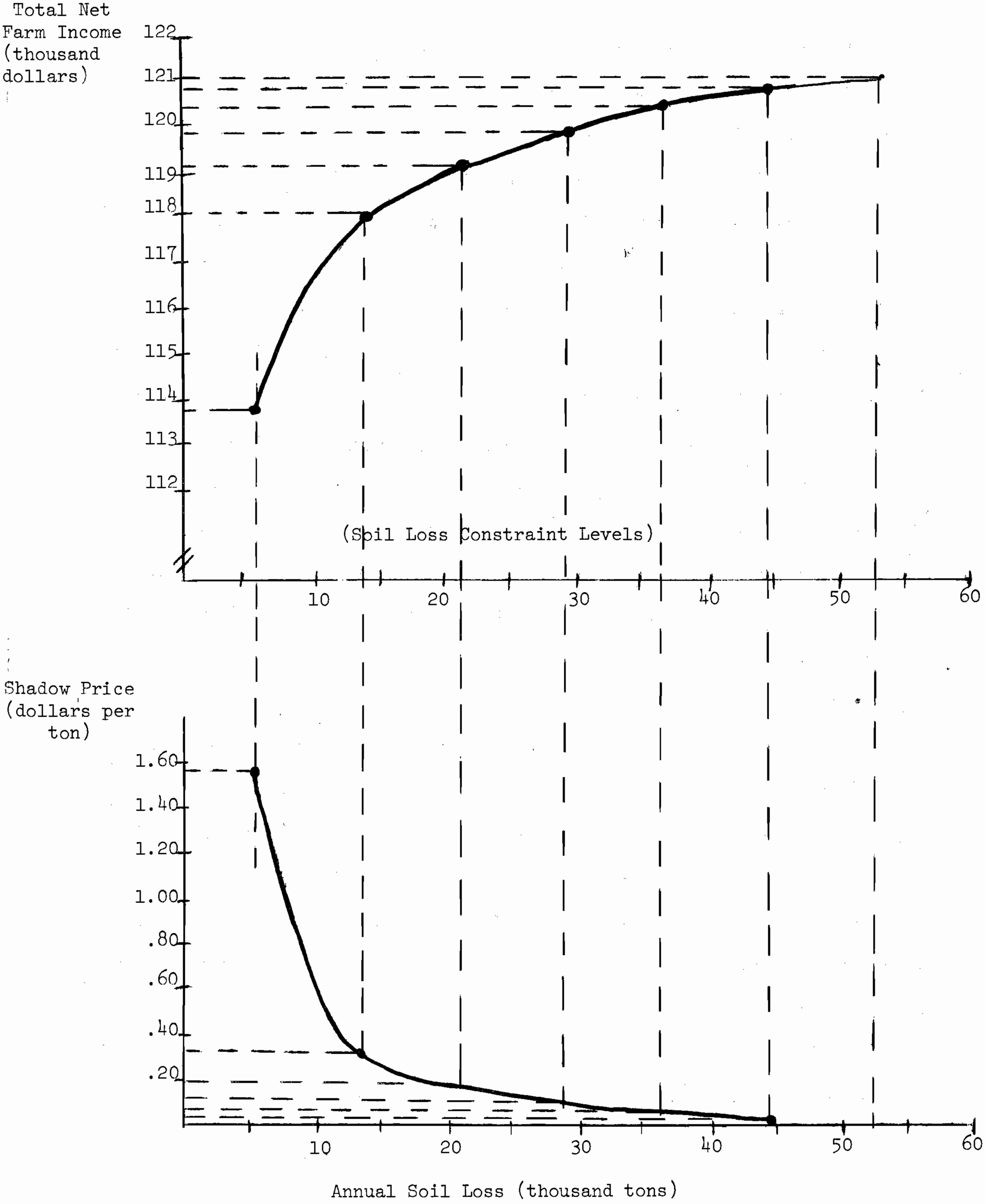


Table 17

Individual Farm and Watershed Results of Restricting Watershed Soil Losses to Soil Conservation Service Tolerances[a]

Farm Number	Crop Activities			Tillage Practices			Conservation Practices			Net Return (dollars)	Total Soil Loss (tons)	Average Soil Loss Per Acre (tons)
	Row Crop (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[b] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)			
1	187.5	52.5		55.6	79.4	52.5		106.3	81.2	12271	635	3.4
2	185.9	8.8		107.7	69.4	8.8	8.8	146.4	30.7	15956	783	4.2
3	156.2	41.2		51.9	63.1	41.2	17.5	58.1	80.6	9050	665	4.2
4	161.8	148.7	134.4	5.0	8.1	148.7	23.1	125.6	13.1	12254	1207	4.1
5	191.9	49.4	14.4	67.5	75.0	49.4	11.2	77.6	103.1	11642	785	3.8
6	401.6	44.3	30.6	145.5	211.8	44.3	10.0	135.5	256.1	22379	1730	4.0
7	193.2	85.6	74.3	33.8	73.8	85.6	18.2	63.1	111.9	12357	1108	4.1
8	219.4	155.6	67.5	26.9	36.9	155.6	89.4	73.1	56.9	15055	1331	4.6
9	83.7	41.9	33.1		41.8	41.9		41.9	41.8	5465	387	3.3
ine Farm Total[c]	1781.2[d]	628.0[e]	354.3	493.9	659.3	628.0	178.2	827.6	775.4	116427	8631	4.0

[a] Shadow price = $.48

[b] Includes zero tillage associated with the double crop rotation.

[c] Columns may not sum to total due to rounding error.

[d] Continuous corn, 1153.2 acres; Soybeans, 628 acres

[e] Wheat and Soybeans, 628 acres.

total soil loss. Total net returns were 28 percent or an average of over $12 per acre higher under the SCS tolerance constraint. These results suggest the row crop acreage and acreage of soil conserving practices are substantially higher under the SCS constraint, but the relatively low net return woodland and meadow crops do not appear.

Table 17 also indicates the differential impact of the SCS tolerance applied at the watershed level on individual farms. Relative to BS2, Table 12, farm 2 adjusts to the soil loss limit primarily by altering tillage and conservation practices with a minor change in crop activities. Farm 7, however, must make a much larger shift in conservation and tillage practices and crop activities.

Individual Farm Soil Loss Constraints Based on SCS Tolerances. The total soil loss level under this regulation is the same as above, except that the total soil loss constraint is applied directly to each farm. Therefore, each farm must adjust to its own soil loss constraint rather than allowing the model to make adjustments in response to a watershed level constraint. This is, of course, the most practical of the regulations discussed from an administrative standpoint.

The system of individual farm SCS constraints results in identical total soil losses, but a slightly lower level of total net returns, Table 18, than the watershed constraint. Generally, the higher constraints are on the more productive farms, lower constraints are on the less productive farms.

The individual farm SCS tolerances were parameterized over the 3-5 ton range generally set by SCS, in increments of 15 percent, to illustrate the effects of varying soil loss constraints. The results for the nine farms are presented in Table 19.

Table 18
Individual Farm and Watershed Results of Restricting Soil Loss to Soil Conservation Service Tolerances by Individual Farms

	Crop Activities			Tillage Practices			Conservation Practices			Net	Total	Average	Shadow
Farm Number	Row Crops (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	Return (dollars)	Soil Loss (tons)	Soil Loss Per Acre (tons)	Price
1	187.5	54.2		84.5	48.8	54.2	7.3	106.3	73.9	12334	792	4.2	.35
2	185.9	8.8		97.4	79.7	8.8	19.1	146.4	20.4	16002	902	4.8	.39
3	156.2	41.2		30.8	84.2	41.2	17.5	58.1	80.6	9028	625	4.0	.53
4	161.8	148.7	134.4	5.0	8.1	148.7	6.2	125.6	30.0	12177	1050	3.5	.48
5	191.9	54.4	14.4	79.4	58.1	54.4	16.2	77.6	98.1	11676	863	4.2	.42
6	401.6	44.3	30.6	137.0	220.3	44.3	10.0	135.5	256.1	22370	1714	4.0	.53
7	193.2	85.6	74.3	33.8	73.8	85.6	14.1	63.1	116.0	12339	1070	4.0	.48
8	219.4	155.6	67.5	26.9	36.9	155.6	69.8	73.1	76.5	14967	1148	4.0	.48
9	83.7	41.9	33.1	30.8	11.0	41.9	160.2	41.9	41.8	5496	467	4.0	.38
Total[b]	1781.2[c]	634.7[d]	354.3	525.6	620.9	634.7		827.6	793.4	116389	8631	4.0	

[a] Includes zero tillage associated with double crop rotation.

[b] Columns may not sum to total due to rounding error.

[c] Corn, 1146.5 acres and soybeans, 634.7 acres.

[d] Wheat and soybeans, 634.7 acres.

Table 19

Individual Farm and Total Nine Farm Results of Parameterizing Individual Farm SCS Soil Loss Tolerances

Nine Farm Total Soil Loss Level (tons)	Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	Total Net Return (dollars)	Average Soil Loss Per Acre (tons)
13811	977.4	803.8	354.3	548.2	218.3	1014.7	926.9	566.5	287.7	118161	6.5
12516	997.6	783.6	354.3	632.1	201.6	947.5	704.1	677.5	399.6	117787	5.9
11221	1078.5	702.7	354.3	672.1	261.2	847.6	507.6	760.5	513.1	117377	5.3
9926	1133.1	648.1	354.3	621.2	450.5	709.5	299.9	827.5	653.9	116932	4.6
7336	1183.4	597.8	354.3	361.9	757.5	661.8	77.7	827.6	875.9	115512	3.4
6041	1227.7[b]	542.1	354.3	189.1	754.0	838.1	25.1	841.3	914.8	113896	2.8
4766	1034.0	747.2[c]	354.3[d]		560.5	1220.7		866.4	914.8	108739	2.2

[a] Includes zero tillage.

[b] Includes 11.4 acres of soybeans

[c] Double crop, 625.9; wheat, 40.4; meadow, 80.9.

[d] Pasture, 219.9; woodland, 134.4.

As average soil losses per acre are reduced from 6.5 to 2.2 tons, a decrease of 66 percent, total net returns decrease 8 percent, or $4.40 per acre. However, reductions in soil losses result in increasingly larger declines in total net returns. For example, a reduction from 6.5 to 2.8 tons causes total net returns to fall by $4,265, but the additional reduction to a 2.2 ton average reduces total net returns another $5,158.

The changes in tillage and conservation practices as soil loss levels are reduced follow a pattern similar to that indicated in Table 14; with conventional tillage and up-and-down cultivation declining while plow plant, chisel plow (zero tillage), contouring and terracing increase. A dissimilar pattern of change in crop activities was generated. As watershed constraints are lowered, a gradual shift from continuous corn to the double crop rotation occurs. However, as individual farm constraints are reduced, Table 19, continuous corn production increases from 977.4 to 1,227.7 acres, double cropping decreases, and soil losses are reduced from an average of 6.5 to 2.8 tons per acre. Generally, continuous corn yields a higher net return than the double crop rotation under the same production conditions. Continuous corn using conventional tillage and up-and-down cultivation generally results in the highest net returns, followed closely by the double crop rotation using zero tillage and up-and-down cultivation. As soil loss constraints become more restrictive, some acreage moves out of the double crop (zero tillage, up-and-down) into the continuous corn rotation with improved conservation and tillage methods, at only a slight reduction in net returns. This type of shift continues until average soil losses are reduced to 2.8 tons per acre. Past that point, acreage is shifted to less intensive rotations containing wheat and meadow crops and increasing woodland acreage, which results in the larger drop in net returns.

These changes did not appear in the watershed parameterization for two possible reasons. First, the incremental reductions in the soil loss limits were much larger so that such shifts may have occurred between increments. A second possibility is that implementing soil loss constraints on a watershed is less restrictive.

Individual Farm Constraints Based on Farm Size as a Proportion of Watershed Area. The total soil loss level under this approach is identical to the previous cases but it is apportioned to indivudal farms on the basis of farm size, Table 20. Under this regulation all farms are faced with an identical average per acre soil loss limit of 4.0 tons.

Approximately the same crop rotation, tillage, and conservation impacts are achieved under this system as under other SCS based regulations but there are interesting income consequences, due to the way in which the possible soil losses are distributed, Table 21. The total watershed level constraint generates the highest net returns, as expected, due to the added flexibility. This is followed by the proportional and the farm level SCS constraint systems. The same results occur for farm 7, the relatively low productive, highly erodible farm. However, for farm 2, the farm level SCS constraint results in the highest net returns. This is due to the higher soil losses allowed on high quality (thick A horizon) soils which generate high net returns.

SEDIMENT DELIVERED BASED SOIL LOSS CONSTRAINTS

Results and discussion to this point have centered on the effects of constraints formulated on gross erosion rates at the farm or watershed level. The soil loss constraints discussed in this section are based upon quantities of sediment delivered to the reservoir.

Table 20

Individual Farm and Watershed Results of Farm Level Soil Loss Constraints Established in the Same Proportion of the SCS Watershed Tolerance as the Proportion Between Farm Size and Watershed Acreage

Farm Number	Crop Activities			Tillage Practices			Conservation Practices			Net Return (dollars)	Average Soil Loss Per Acre (tons)	Shadow Price
	Row Crops (acres)	Double Crop (acres)	Pasture (acres)	Conven- tional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Con- touring (acres)	Ter- racing (acres)			
1	187.5	52.5		86.2	48.8	52.5	3.8	106.3	77.4	12322	4.0	.38
2	185.9	7.0		100.7	78.2	7.0	7.0	146.4	32.5	15940	4.0	.52
3	156.2	41.2		34.0	81.0	41.2	17.5	58.1	80.6	9032	4.0	.53
4	161.8	148.7	134.4	5.0	8.1	148.7	22.0	125.6	14.2	12249	4.0	.48
5	191.9	54.4	14.4	68.2	69.3	54.4	16.2	77.6	98.1	11664	4.0	.43
6	401.6	44.3	30.6	152.8	204.5	44.3	10.0	135.5	256.1	22386	4.0	.43
7	193.2	85.6	74.3	33.8	73.8	85.6	15.3	63.1	114.8	12344	4.0	.48
8	219.4	155.6	67.5	26.9	36.9	155.6	71.1	73.1	75.2	14973	4.0	.48
9	83.7	41.9	33.1	32.8	9.0	41.9		41.9	41.8	5498	4.0	.38
Nine Farm Total[b]	1781.2[c]	631.2[d]	354.3	540.3	609.7	631.2	162.8	827.6	790.8	116405	4.0	

[a] Includes zero tillage associated with double crop rotation.

[b] Columns may not sum to total due to rounding error.

[c] Corn, 1150 acres, and soybeans, 631.2 acres.

[d] Soybeans and wheat, 631.2 acres.

Table 21

Impact of Three Methods of Imposing SCS Soil Loss Tolerance Constraints on Two Selected Farms and Nine Farm Total

	Crop Activities			Tillage Practices			Conservation Practices			Net Return (dollars)	Total Soil Loss (tons)	Average Soil Loss Per Acre (tons)
	Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Zero Tillage (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)			
Farm 2:												
a) Watershed SCS Constraint	177.1	8.8		107.7	69.4	8.8	8.8	146.4	30.7	15956	783	4.2
b) Farm Level SCS Constraint	177.1	8.8		97.4	79.7	8.8	19.1	146.4	20.4	16002	902	4.8
c) Proportional SCS Constraint	178.9	7.0		100.7	78.2	7.0	7.0	146.4	32.5	15940	752	4.0
d) Non-Constrained Solution, BS1	185.9			185.9			185.9			16325	2787	15.0
Farm 7:												
a) Watershed SCS Constraint	107.6	85.6	74.3	33.8	73.8	85.6	18.2	63.1	111.9	12357	1108	4.1
b) Farm Level SCS Constraint	107.6	85.6	74.3	33.8	73.8	85.6	14.1	63.1	116.0	12339	1070	4.0
c) Proportional SCS Constraint	107.6	85.6	74.3	33.8	73.8	85.6	15.3	63.1	114.8	12344	1081	4.0
d) Non-Constrained Solution, BS1	130.1	63.1	74.3	130.1		63.1	193.2			12982	6459	24.1
Nine Farm Total:												
a) Watershed SCS Constraint	1153.2	628.0	354.3	493.9	659.3	628.0	178.2	827.6	775.4	116427	8631	4.0
b) Farm Level SCS Constraint	1146.5	634.7	354.3	525.6	620.9	634.7	160.2	827.6	793.4	116389	8631	4.0
c) Proportional SCS Constraint	1150.0	631.2	354.3	540.3	609.7	631.2	162.8	827.6	790.8	116405	8631	4.0
d) Non-Constrained Solution, BS1	1320.6	460.6	354.3	1321.4		460.6	1781.2			121519	46946	22.0

Analysis of this regulatory policy required converting the gross soil loss coefficients to quantities of sediment delivered to the reservoir. The gross soil loss coefficients for each activity were multiplied by the appropriate individual farm sediment delivery ratio adjusted for distance as noted above. The converted coefficients are approximations of the quantity of sediment delivered to the reservoir per acre.

Watershed Level Delivered Sediment Constraints. The multi-purpose reservoir in Big Blue Watershed was designed to accommodate .75 acre feet of sediment per square mile per year.[56] It is estimated that 1 acre foot of soil weighs approximately 1,300 tons.[57] Thus, the design life of the reservoir is based upon an average of 1.5 tons of sediment deslivered per acre per year, or 3,246 tons from the nine farm sample. Results of a model with this constraint level are presented in Table 22.

Generally, the effect of a regulation imposing soil loss constraints on a delivered basis confers a locational advantage on farms away from the reservoir. More distant farms may sustain a higher level of gross erosion and maintain a delivered sediment at the same level as closer farms. The higher level of gross soil loss generally implies a higher level of net farm returns. These patterns are generally evident from Table 22, and will be discussed further in a later comparison of individual farm results.

Comparison of the nine farm totals with BS1 indicates that delivered sediment constraints reduce gross soil loss by over 55 percent, but net returns decline less than 2 percent. Crop activities exhibit a shift from continuous corn to double cropping, with a 16 percent decrease in corn acreage and a 46 percent increase in double cropping. The large reduction in gross soil loss is primarily attributable to a 60 percent decline in conventional tillage and

Table 22

Individual Farm and Nine Farm Total Results of Restricting Delivered Sediment to a Watershed Average of 1.5 Tons Per Acre, or a Total of 3246 Tons[e]

Farm Number	Distance From Reservoir (miles)	Crop Activities: Row Crops (acres)	Crop Activities: Double Crops (acres)	Crop Activities: Pasture (acres)	Tillage Practices: Conven-tional (acres)	Tillage Practices: Plow Plant (acres)	Tillage Practices: Chisel Plow[a] (acres)	Conservation Practices: Up and Down (acres)	Conservation Practices: Contouring (acres)	Conservation Practices: Terracing (acres)
1	5.4	187.5	52.5		135.0		52.5	187.5		
2	4.1	185.9			146.4	39.5		116.5	69.4	
3	2.4	156.2	58.7		53.8	23.1	79.3	131.2	5.6	19.4
4	3.8	161.8	148.7	134.4		13.1	148.7	161.8		
5	3.3	191.9	33.8	14.4	48.8	89.9	53.2	163.7	28.2	
6	2.3	401.6	62.1	30.6	131.9	91.7	178.0	357.1	13.8	30.7
7	1.3	193.2	119.4	74.3			193.2	130.1	63.1	
8	2.8	219.4	155.6	67.5	6.9	56.9	155.6	219.4		
9	2.4	83.7	41.9	33.1	6.2		77.5	77.5		6.2
Nine Farm Total[b]		1781.2[c]	673.0[d]	354.3	529.0	314.2	938.0	1544.8	180.1	56.3

Farm Number	Net Return (dollars)	Soil Loss: Total (tons)	Soil Loss: Per Acre (tons)	Delivered Sediment (tons)	Average Delivered Sediment Per Acre (tons)
1	12818	4001	21.3	204	1.1
2	16236	1700	9.1	201	1.1
3	9309	1513	9.7	332	2.1
4	12402	1853	6.3	221	0.7
5	12134	2569	12.5	387	1.9
6	23157	4424	10.2	843	2.0
7	12571	1714	6.4	460	1.7
8	15346	2589	9.0	441	1.5
9	5553	682	5.8	157	1.3
Nine Farm Total[b]	119526	21045	9.9	3246	1.5

[a] Includes zero tillage associated with double crop rotation.
[b] Columns may not sum to total due to rounding error.
[c] Corn, 1108.2 acres and Soybeans, 673 acres.
[d] Soybeans and wheat, 673.0 acres.
[e] Shadow Price = $.96.

increase in plow plant and chisel plowing. Also contributing to a reduction in gross soil loss was the 13 percent fall in up-and-down cultivation in favor of contouring and terracing.

As shown in Table 17, the delivered sediment constraint is much less restrictive than the watershed level SCS tolerance constraint. It permits a 144 percent greater level of gross soil losses, and 2 percent greater total net returns. This constraint generates comparable acreages of crop activities, but much lower levels of erosion-retarding conservation and tillage practices.

In general, the watershed level constraint on sediment delivered to the reservoir results in lower gross soil losses than the non-regulated situation, but higher than those under the watershed level SCS tolerance constraint. Total net returns are affected in a similar, but less than proportional manner. At the individual farm level, delivered sediment constraints confer a locational advantage on farms relatively more distant from the reservoir.

Parameterization of the Watershed Level Delivered Sediment Constraint. To determine the effect of higher or lower regulations on quantities of delivered sediment, the constraint was parameterized at 1,000 ton increments from 746 to 5,746 tons. The results of this parameterization are summarized in Table 23. As with other types of regulations, the reduction in quantity of sediment delivered to the reservoir causes a change in crops produced and production practices used. There is a general change from continuous corn to double cropping and a complete shift away from conventional tillage and up-and-down cultivation.

As indicated in Table 23, an 87 percent reduction in total sediment delivered results in an 86 percent fall in total soil loss. The large reduction

Table 23

Total Nine Farm Results of Parameterizing the Delivered Sediment Constraint at 1000 Ton Increments Beginning 500 Tons Above and Below the Reservoir Design Constraint of 3246 Tons

Soil Loss		Sediment Delivered		Total Net Return (dollars)	Crop Activities			Tillage Practices			Conservation Practices			Shadow Price (dollars)
Total (tons)	Per Acre (tons)	Total (tons)	Per Acre (tons)		Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	
34148	16.0	5746	2.7	121023	1183.2	598.0	354.3	759.4	423.8	598.0	1781.2			-0.31
28680	13.4	4746	2.2	120611	1160.1	621.1	354.3	510.3	608.6	662.3	1761.8	19.4		-0.57
23595	11.0	3746	1.8	119962	1126.3	654.9	354.3	478.9	445.9	856.4	1662.4	112.6	6.2	-0.78
17949	8.4	2746	1.3	119000	1093.8	687.4	354.3	666.5	244.2	870.5	1267.3	272.0	241.9	-1.20
11891	5.6	1746	0.8	117362	1108.2	673.0	354.3	624.6	481.1	675.5	536.3	611.3	633.6	-2.20
4611	2.0	746	0.3	112163	1069.9	711.2	354.3		362.7	1418.5		866.4	914.8	-19.50
(Percent Change as Total Delivered Sediment is Reduced From 5746 to 746 Tons)														
-86	-86	-87	-87	-7	-10	+19	0	-100	-14	+137	-100			

in delivered sediment results in a relatively small decline in total net returns, and the largest change occurs with the last decrease in delivered sediment. The cost, in terms of reduced net return, of the 87 percent fall in delivered sediment, is $8,860 or $.56 per ton. The 86 percent reduction in total soil loss is achieved at a "cost" of $.30 per ton.

Individual Farm Level Delivered Sediment Constraint. The watershed level delivered sediment regulation of an average of 1.5 tons per acre over the entire watershed is more efficient than applying an equal restriction on all farms. The model restricts farms with low net returns per acre to less than a 1.5 ton average while farms with a higher net return per acre relative to delivered sediment exceed the average. This confers an advantage on the more productive farms with a lower erosion potential which are located relatively more distant from the reservoir.

In contrast to the watershed level delivered sediment regulation, a constraint was placed on each individual farm restricting delivered sediment to the 1.5 ton average. The results of this model solution are presented in Table 24. Maximizing watershed net crop returns under this system results in a higher total soil loss, but the same quality of sediment is delivered. Total soil losses are 3 percent or .3 tons per acre higher and net returns fall .2 percent or $.14 per acre, due primarily to relatively less continuous corn and more use of soil conserving tillage practices.

Generally, farms near the reservoir have higher, more distant farms lower, soil losses under the watershed level delivered sediment constraint than under the farm level constraints. Thus, the location advantage of relatively distant farms is greater under the individual farm constraint (two of the more distant farms, 1 and 4, are not affected by this watershed constraint in that the impact on total net income

Table 24

Individual Farm and Nine Farm Total Results of Restricting Delivered Sediment to a 1.5 Ton Average Per Acre on Each Farm

		CROP ACTIVITIES			TILLAGE PRACTICES			CONSERVATION PRACTICES				SOIL LOSS		
Farm Number	Distance From Reservoir	Row Crops (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	Net Return (dollars)	Total (tons)	Per Acre (tons)	Total Sediment Delivered
1	5.4	187.5	16.9		170.6		16.9	187.5			12821	4514	24.1	271
2	4.1	185.9			155.0	30.9		185.9			16294	2345	12.6	283
3	2.4	156.2	41.2		67.0	41.8	47.4	45.5	58.1	52.6	9230	1427	9.1	314
4	3.8	161.8	125.6	134.4	36.2		125.6	161.8			12415	2600	8.8	312
5	3.3	191.9	38.8	14.4	72.3	61.4	58.2	140.2	28.2	23.5	12048	2086	10.1	314
6	2.3	401.6	60.5	30.6	174.2	75.0	152.4	215.2	99.6	86.8	22993	3866	8.9	732
7	1.3	193.2	106.0	74.3	55.3	7.5	130.4	67.3	63.1	62.8	12511	1516	5.7	407
8	2.8	219.4	161.0	67.5	6.9	51.5	161.0	219.4			15341	2555	8.9	436
9	2.4	83.7	41.9	33.1	6.2	5.0	72.5	77.5		6.2	5568	770	6.6	177
Nine Farm Total[b]		1781.2[c]	591.9[d]	354.3	743.7	273.1	764.4	1300.2	249.0	231.0	119221	21679	10.1	3246

[a] Includes zero tillage associated with double crop rotation.

[b] Columns may not sum to total due to rounding error.

[c] Corn, 1189.3 acres; soybeans, 591.9 acres.

[d] Soybeans and wheat, 591.9 acres.

is minimized by allocating changes over all farms wherever they have the least impact on watershed net returns.

In summary, restricting delivered sediment to the engineering design capacity of the reservoir confers a locational advantage on relatively distant farms. This locational advantage is more evident under the individual farm than the watershed level delivered sediment restriction. The level of soil conserving practices, soil losses, and net crop returns are nearly the same under each type of sediment restriction. However, the watershed level constraint is slightly more efficient--total soil losses are slightly lower and total net returns are slightly higher.

SUBSIDY POLICIES TO CONTROL SOIL LOSSES

Two types of subsidy systems to control soil losses are evaluated: (a) a system of diversion payments designed to shift cropland from production into less intensive permanent cover crops such as pasture or meadow; and (b) a system of subsidies on improved conservation practices to encourage their adoption at the farm level.

Subsidy Payments for Cropland Diversion. Under this subsidy policy, cropland diversion on each farm is required to be between 20 and 50 percent of farm acreage. Payments for diversion begin at $20 per acre and are parameterized upward, in $10 increments, to $70 per acre and land is bid out of production when the payment exceeds the net return generated under the most profitable crop activity. This type of subisidy system is closely related to past production price-income policies which were directed to the problem of excess production. Since net returns tend to be higher on the more productive and relatively less eroded soils, the tendency is for less productive, more erosion prone land to be bid out of production under this subsidy system. As the diversion payment per acre is increased further all diverted acreage receives the higher payment level, not just the additional acreage diverted. Therefore, as the diversion payment rises, the total net return from crop production (total net return-total diversion payment) falls, but is more than offset by the rise in diversion payments.

The nine farm total results are summarized and compared with results under other soil loss control policies in Table 25. At a diversion payment of $20 per acre, slightly more than the 20 percent requirement is diverted with the majority of this acreage shifting from pasture. As the diversion payment is increased, additional diverted acreage is initially from the pasture activity, and then from the continuous corn activity followed by a slight shift from double crop production.

The increase in diversion payment per acre from $20 to $70 results in diversion of 47 percent of the most profitable crop production activity and a 51 percent decline in total soil loss. Over the same range, the total diversion payment, which may be viewed as the cost of reducing soil losses, increases 606 percent or approximately 12 percent for each 1 percent reduction in gross soil loss. In dollar terms, the 51 percent reduction in soil losses (19,104 tons) is achieved at a cost of $70,770 or $3.18 per ton.

Relative to the watershed level restrictions based upon SCS soil loss tolerances, the cropland diversion system, even at the $70 payment level, results in much higher levels of soil loss and significantly lower usage of improved conservation and tillage practices. Soil losses under the cropland diversion system remain at a higher level than under the watershed level delivered sediment restriction, until the diversion payment approaches $60 per acre.

Table 25

Total Nine Farm Results of Diversion Subsidies to Control Soil Losses, Ranging from $20 to $70 Per Acre, Compared to Results Under the Non-Constrained Solution, BS1, and Other Watershed Level Control Policies

	Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Diversion (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow (acres)	Up and Down (acres)	Contouring and Terracing (acres)	Total Net Return (dollars)	Diversion Payment (dollars)	Soil Loss Total (tons)	Soil Loss Per Acre (tons)
Non-Constrained Solution, BS1	1321.4	460.6	354.3		1321.4		460.6	1781.2		121519		46946	22.0
Watershed Restriction, SCS Tolerance	1153.2	628.0	354.3		493.9	659.3	628.0	178.2	1603.0[a]	116427		8631	4.0
Watershed Restriction Delivered Sediment	1108.2	673.0	354.3		529.0	314.2	938.0	1544.8	236.4[b]	119526		21045	9.9
Diversion Subsidies													
$20	1132.6	460.6	40.9	501.4	1132.6		460.6	1593.2		115157	10028	37515	17.6
$30	1132.6	460.6		542.3	1132.6		460.6	1593.2		120351	16269	37515	17.6
$40	1132.6	460.6		542.3	1132.6		460.6	1593.2		125774	21692	37515	17.6
$50	988.4	460.6		686.5	988.4		460.6	1449.0		131446	34325	30224	14.2
$60	718.3	455.6		961.6	718.3		455.6	1173.9		139415	57696	19514	9.1
$70	669.2	455.3		1011.0	669.2		455.3	1124.5		149444	70770	18411	8.6
(Percent Change as Diversion Subsidy is Increased from $20 to $70 Per Acre)													
	-41	-1		+102	-41		-1	-29			+30	-51	-51

[a] 827.6 contouring, 775.4 terracing.

[b] 180.1 contouring, 56.3 terracing.

In summary, the cropland diversion system is capable, at a relatively high cost, of reducing soil losses below the level attained under the non-constrained solution or the delivered sediment restriction. The $20 diversion subsidy results in a reduction in average soil loss per acre of 4.4 tons compared to the non-constrained solution, but the cost of this reduction is $10,028 in subsidies while the watershed SCS tolerance restriction achieves an 18 ton per acre reduction in soil loss at a cost of $5,092 in reduced total net returns. The cost of reducing soil losses increases proportionally more than the reduction in soil loss under either the regulatory or diversion policies, but the increase in cost is relatively greater under the cropland diversion system. The cropland diversion policy provides no incentive for farmers to adopt improved conservation or tillage practices. The individual farm impact of the diversion system generally favors the less productive more erosion prone farms in that the subsidy payment, event at relatively low per acre rates, offsets the decline in net crop returns, thereby actually increasing total net returns above the non-constrained maximum level. This implies that cropland diversion is a relatively costly and ineffective method of controlling soil losses. However, if production needs to be controlled for other reasons, the subsidy system will reduce soil losses.

Subsidy Payments on Improved Conservation and Tillage Practices. The subsidy payments are based upon the cost adjustment for improved soil conserving practices relative to the cost of the conventional tillage and up-and-down production. The effect of the subsidy is to increase the net return of all crop activities, by the amount of the subsidy, relative to the net return generated from crop activities produced with conventional tillage and up-and-down cultivation.

Model solutions were generated at five subsidy rates: 25, 50, 75, 100, and 102.5 percent of the additional cost of conservation and tillage practices. At the 102.5 percent rate, the cost differential between the base situation of conventional tillage and up-and-down cultivation and alternative conservation and tillage practice combinations is more than compensated. Therefore, at this subsidy rate, it costs the producer relatively less to adopt improved conservation and tillage practices than to use conventional tillage with up-and-down cultivation, although yield differences may still assure this production method's profitability on some soil types. It is conceivable, however, that at the 102.5 percent rate, producers would apply improved soil conserving practices not on the basis of need but rather as a potential source of increased net farm returns. This model formulation places a limit on this possibility. The choice of conservation and tillage practices offered as alternatives under each crop production activity were based upon SCS planning recommendations concerning slope gradients of the various land types.

Total nine farm results are summarized in Table 26, along with results from other model solutions, for comparative purposes. Subsidy rates below 75 percent have relatively little impact on either soil losses or net returns. The major reduction in soil losses does not occur until the subsidy rate is increased above the 100 percent level. As the rate of subsidy is increased from 25 to 102.5 percent, total soil loss decreases 73 percent while total net return increases .5 percent. Over this range, the total subsidy increases $5,289. The cost of achieving the 73 percent reduction in soil loss is $.16 per ton in subsidy payments. There is little impact upon the crops produced, but substantial shifts occur in tillage and conservation practices. There is a 74 percent decline in conventional tillage and a corresponding increase in

Table 26

Total Nine Farm Results of Subsidizing Conservation and Tillage Practices at Various Levels Compared to Results Under BS1 and Watershed Level SCS Tolerance and Delivered Sediment Constraint

	Crop Activities			Tillage Practices			Conservation Practices						
Control Policy	Continuous Corn (acres)	Double Crop (acres)	Pasture (acres)	Conventional (acres)	Plow Plant (acres)	Chisel Plow[a] (acres)	Up and Down (acres)	Contouring (acres)	Terracing (acres)	Subsidy (dollars)	Total Net Return (dollars)	Total Soil Loss (tons)	Average Soil Loss Per Acre (tons)
BS1	1321.4	460.6	354.3	1321.4		460.6	1781.2				121519	46946	22.0
BS3	527.0	26.5	278.0	1554.0			1554.0				90706	12812	6.0
SCS Tolerance	1153.2	628.9	354.3	493.9	659.3	628.0	178.2	827.6	775.4		116427	8631	4.0
Delivered Sed.	1108.2	673.0	354.3	529.0	314.2	938.0	1544.8	180.1	56.3		119526	21045	9.9
Subsidy Rates													
25%	1183.2	598.0	354.3	1183.2		598.0	1781.2			148	121608	44416	20.8
50%	1183.2	598.0	354.3	1183.2		598.0	1781.2			296	121756	44416	20.8
75%	1177.6	603.6	354.3	1177.6		603.6	1781.2			477	121907	44266	20.7
100%	1177.6	603.6	354.3	704.5	473.1	603.6	1618.0	163.2		1222	122182	34086	16.0
102.5%	1177.6	603.6	354.3	307.4	870.2	603.6	353.8	703.2	724.2	5437	122224	12009	5.6
(Percent Change as Subsidy Rates are Increased From 25 to 102.5 Percent)													
	-.5	+.9	0	-74		+.9	-80				+.5	-73	-73

[a] Includes zero tillage associated wtih double crop rotation.

plow plant. Up-and-down cultivation falls 80 percent while contouring and terracing are substantially increased.

Relative to BS1, non-constrained maximum, a 25 percent subsidy, reduces total soil loss 5 percent, due to a 10 percent reduction in corn production using conventional tillage and a 30 percent increase in double cropping with zero tillage. As subsidy rates are increased to 102.5 percent, soil losses are reduced 75 percent relative to BS1, while total net returns are increased due to the subsidy payment.

Compared to simulated present conditions, BS3, a 25 percent subsidization of conservation and tillage practices results in a much higher production of major crops. Also, the acreage of conventional tillage with up-and-down cultivation is relatively higher than under BS3, owing primarily to the higher level of crop production. As a result, the level of soil loss is 18 tons per acre higher and net crop returns are $14.40 per acre higher than under BS3. At a subsidy of 102.5 percent the acreage of soil conserving tillage and conservation practices is greater than under BS3 and average soil loss per acre is reduced .4 tons. However, net crop returns remain above the BS3 level by $12.21 per acre.

The 102.5 subsidy rate can be compared to several of the other alternatives:

a) it does not reduce soil losses to the level used in the watershed SCS soil loss tolerance regulation and therefore non-subsidy net returns are higher. Also, soil conservation practices are used to a lesser extent with the subsidy system (due to the yield changes);

b) it does reduce soil losses below the level observed under the delivered sediment restriction, through the increased use of soil conservation practices, and increases net returns;

c) it reduces soil losses 65 percent or 3 tons per acre below the level achieved with a $70 subsidy for acreage diversion. The cost of this subsidy system averages $2.55 per acre whereas the diversion payment system averages $13.14.

Estimating Net Social Income. The soil loss levels used as constraints in the parameterization procedures were expanded from the nine farm to the watershed level. The off-site damages associated with each of these soil loss levels were calculated for each category of damage. Sediment damages for the watershed were then estimated for each category of damage, Table 27. The damages estimated for $(D_s)_1$, $(D_s)_2$, and $(D_s)_5$ which relate to the life of the reservoir are all relatively small, especially at the low soil loss levels, because they occur at a relatively distant point in the future. The cost of drainage system maintenance, $(D_s)_3$, is the major damage item. Sediment damage as a part of downstream flood damage is also relatively small because of the high trap efficiency of the reservoir. The water treatment cost, $(D_s)_6$, is a major part of sediment damage, which as indicated in footnote 56, decreases in proportion to the reduction in gross soil loss. The relationship between gross soil loss and sediment damages is presented in part a of Figure 6.

The relationship between off-site sediment damage and average soil loss per acre for Big Blue Watershed is presented in section a of Figure 6. Off-site damage increases slightly more than proportionally as average soil loss per acre increases. The relationship between average net return and average soil loss per acre is presented in section b of Figure 6. As average soil loss increases, average net return per acre increases at a decreasing rate, reaching a maximum at the non-constrained optimum net return level, which

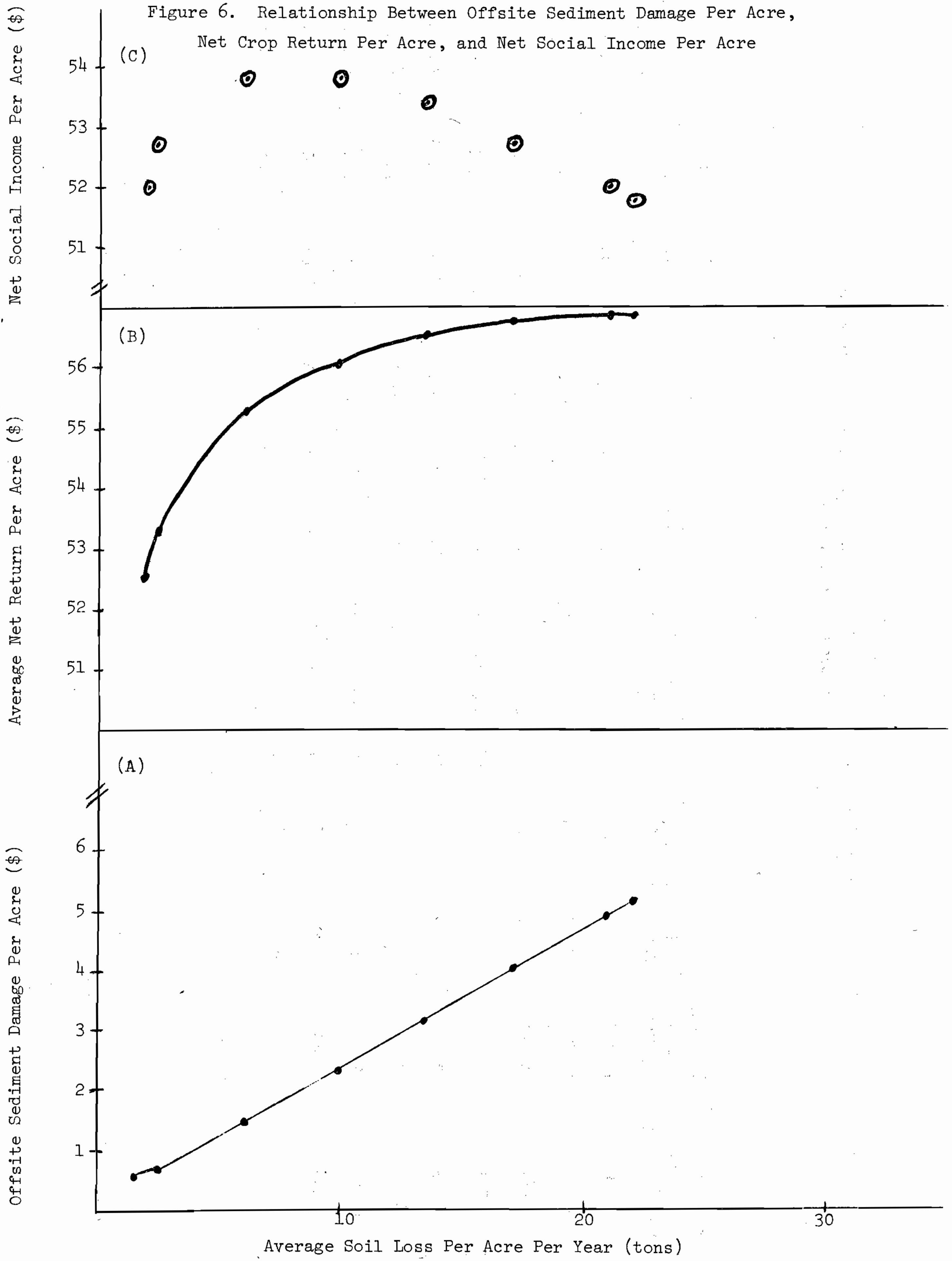
Table 27

Offsite Damages for Big Blue Watershed at Various Levels of Watershed Level Soil Loss Restrictions

Nine Farm Soil Loss Restrictions	Estimated Watershed Level Soil Losses	Average Soil Loss Per Acre	Damage Estimates by Category of Damage						Total Damages	Total Nine Farm Net Return	Average Sediment Damage Per Acre	Average Net Return Per Acre
			$(Ds)_1$	$(Ds)_2$	$(Ds)_3$	$(Ds)_4$	$(Ds)_5$	$(Ds)_6$				
52336	178478	24.5	240	333	36817	799	698	3261	42142	121089	5.79	56.70
46946	157367	22.0	199	301	32830	799	578	2802	37509	121519	5.18	56.90
44486	151706	20.8	163	120	31289	799	446	2772	35589	120712	4.89	56.88
36636	124936	17.2	77	84	25768	799	310	2284	29375	120461	4.03	56.74
28786	98166	13.5	8	40	20247	799	147	1795	23036	119895	3.16	56.53
20936	71395	9.8	1	13	14725	799	48	1307	16893	119112	2.32	56.07
13086	44455	6.1	[a]	2	9169	799	5	818	10793	118019	1.48	55.27
5236	17855	2.5	[a]	1	3683	799	3	329	4815	113862	.66	53.33
4451	15724	2.0	[a]	1	3130	799	2	299	4231	112205	.58	52.55

[a] Estimated damages were less than $1.

Figure 6. Relationship Between Offsite Sediment Damage Per Acre, Net Crop Return Per Acre, and Net Social Income Per Acre



corresponds to the highest average soil loss per acre.

The off-site sediment damages were subtracted from net crop returns per acre to generate the net social income estimates, which are plotted in section c of Figure 6. As average soil loss per acre increases, net social income first increases at a decreasing rate, reaching a maximum between six and ten tons per acre and then declines. Maximum net social income occurs at an average soil loss per acre of 6.1 tons, however, because of the relatively large increment between 6.1 and 9.8 tons per acre, the actual maximum may lie within this range. Thus, as average soil loss per acre increases, the rise in average net crop returns per acre is eventually offset by increases in off-site sediment damages causing net social income to decline. This implies that the optimum combination of net crop returns, conservation practices, and off-site damage occurs within the soil loss range between six and ten tons per acre per year.

Changes in Soil Conserving Practices with Reduced Soil Losses. The typical shifts in crop activities, conservation practices, and tillage practices that occur as soil losses are reduced from 22 to 2.5 are indicated in Figures 7 to 9. These curves were generated as the watershed soil loss constraint was parameterized downward from the non-constrained optimum net return level. These soil loss values were also used to estimate net social income. Results under solutions BS2 and BS3 are presented for comparative purposes.

Figure 7 indicates that continuous corn acreage declines and the double crop rotation increases while pasture acreage remains constant. Under BS2, soil losses average 24.5 tons per acre and only continuous corn and pasture are produced. BS3 includes more crops and soil losses are lower than under BS1 or BS2, but as indicated earlier, net crop returns are also

Figure 7. Changes in Crop Activity Levels as Soil Losses are Reduced

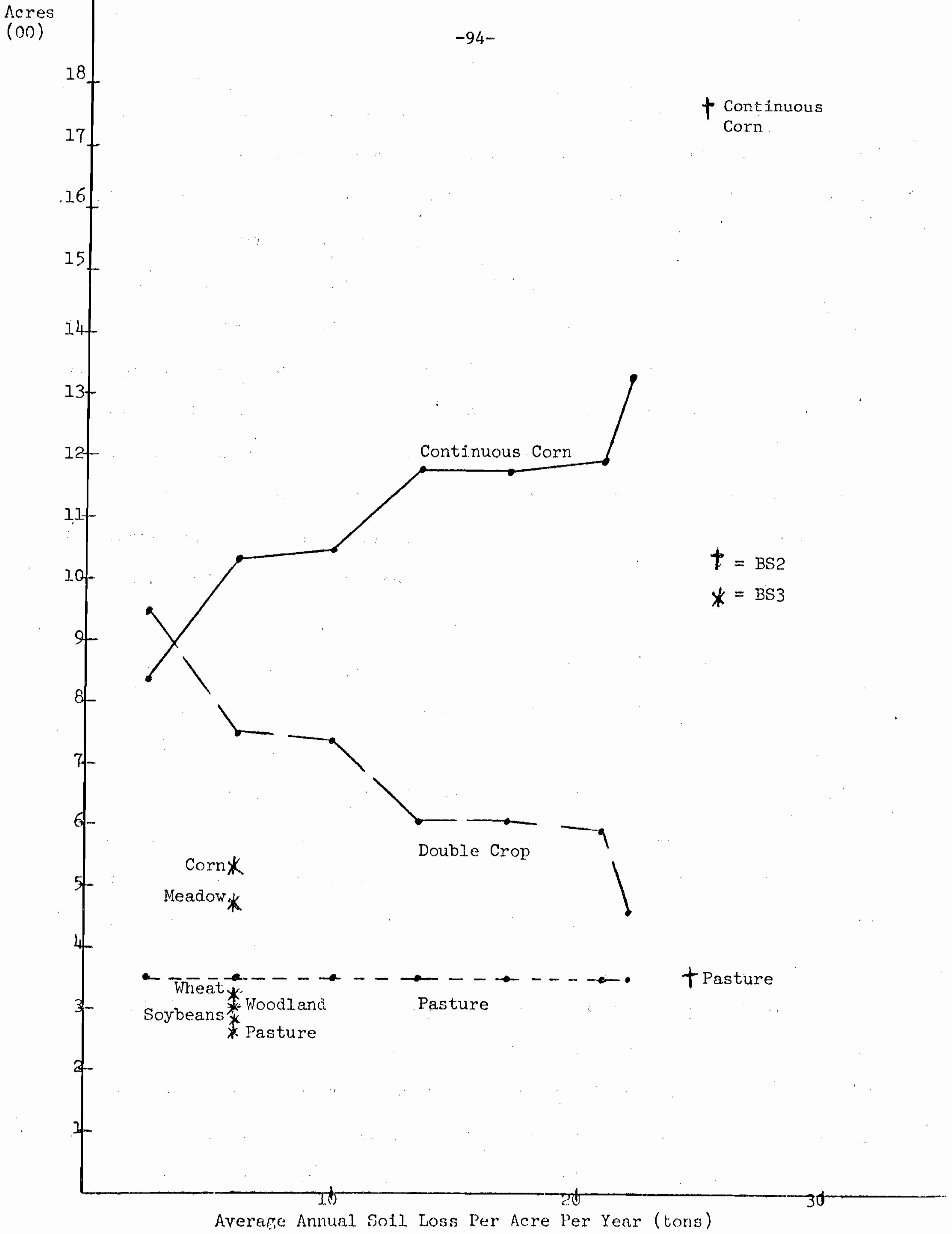


Figure 8. Changes in Tillage Practices as Soil Losses are Reduced

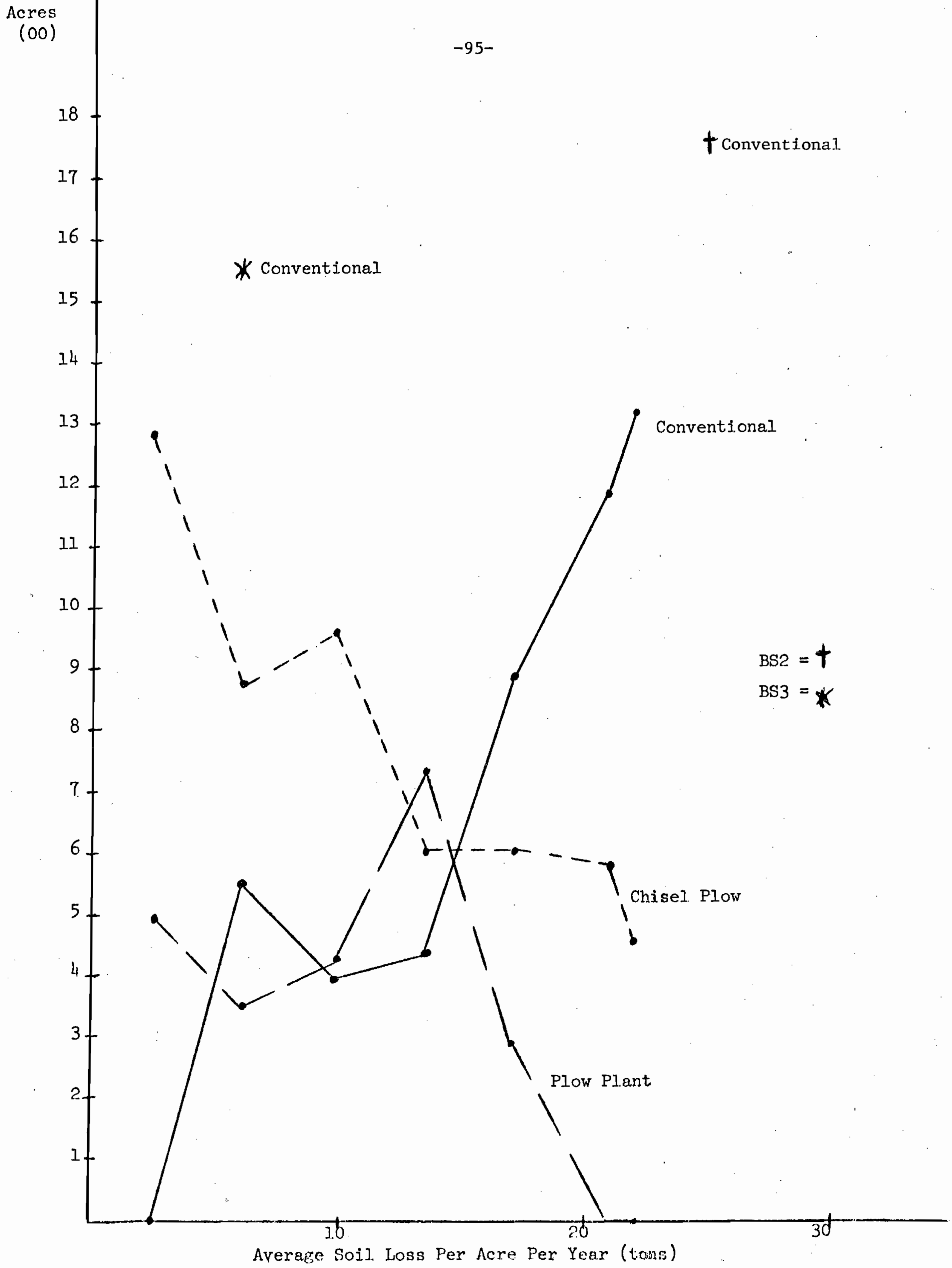
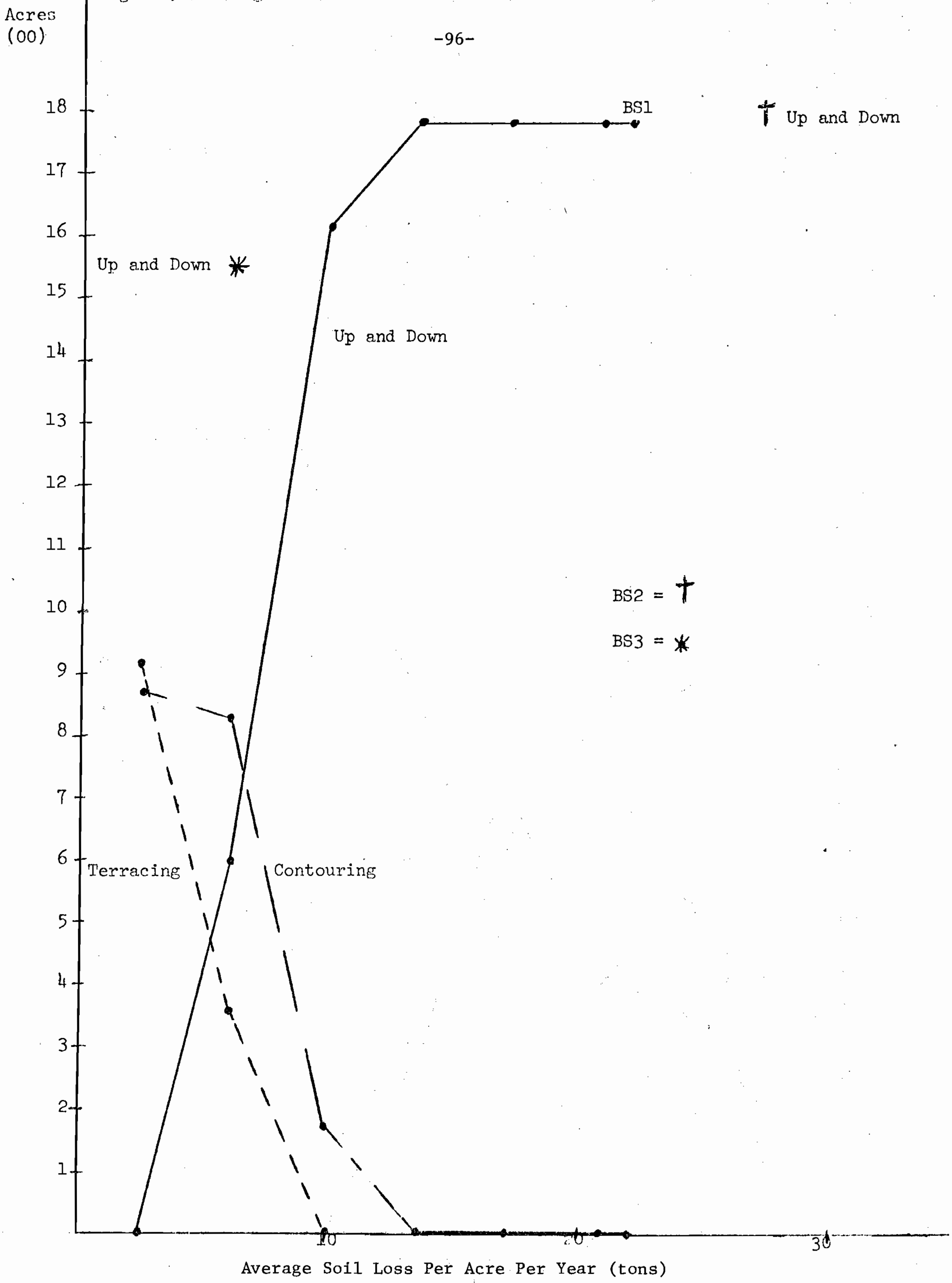


Figure 9. Changes in Conservation Practices as Soil Losses are Reduced



significantly lower. Changes in tillage practices are presented in Figure 8. Over the 22 to 13.5 tons per acre range production shifts from conventional to plow plant tillage. Further reduction in soil losses to 2.5 tons per acre increases chisel plow acreage significantly while conventional and plow plant tillage decline. Shifts among conservation practices as soil losses decline are indicated in Figure 9. Up-and-down cultivation is the primary conservation practice until soil losses are reduced to 13.5 tons per acre. Additional reduction of soil losses results in an increase in contouring followed by an increase in terracing as up-and-down cultivation declines to zero at the 2.5 ton per acre level.

The variation in these changes from a uniform trend is explained by the interaction with changes in crops grown and conservation practices. Thus, continuous corn may be produced under conventional up-and-down cultivation with high allowable levels of soil loss. As the soil losses are restricted parametrically, the following types of shifts might occur: (a) from corn to soybeans-wheat double crop with the first reduction, (b) from conventional to chisel plow, (c) from soybeans-wheat with chisel plow to continuous corn and plow plant tillage, (d) from plow plant on an up-and-down basis to conventional tillage on a contour or terrace system, and (e) with the final reduction in soil losses the land may revert to double crop with chisel plow or contour or terrace. Of course, not all of these changes occur on any one tract of land or at the same soil loss restraint.

Net Social Income of Alternating Soil Loss Control Policies. The off-site sediment damage function was used to estimate damages under each alternative soil loss control policy. The sediment damage, net crop return, and net social income for each policy alternative are given in Table 28.

Table 28

Offsite Sediment Damages, Net Crop Return, and Net Social Income Under Each Soil Loss Policy

	Total Soil Loss	Estimated Offsite Sediment Damages		Net Crop Return		Net Social Income Per Acre	Average Soil Loss Per Acre	Cost Reduction From Maximum Net Return Level		
		Total	Per Acre	Total	Per Acre			Total	Per Acre	Per Ton
					BASIC SOLUTIONS					
(BS1)	46946	37500	5.18	121519	56.90	51.72	22.0			
(BS2)	52336	42142	5.79	121089	56.70	50.91	24.5			
(BS3)	12812	10600	1.46	90706	42.88	41.02	6.0	30813	14.43	0.90
					WATERSHED SOIL LOSS CONSTRAINTS					
	44486	35589	4.89	120712	56.88	51.99	20.8	807	0.38	0.32
	36636	29375	4.03	120461	56.74	52.71	17.2	1058	0.50	0.10
	28786	23036	3.16	119895	56.53	53.37	13.5	1624	0.76	0.09
	20936	16893	2.32	119112	56.07	53.75	9.8	2407	1.13	0.09
	13086	10793	1.48	118019	55.27	53.79	6.1	3500	1.64	0.10
	5236	4815	.66	113862	53.33	52.67	2.5	7657	3.59	0.18
	4451	4231	.58	112205	52.55	51.97	2.0	9314	4.36	0.22
					WATERSHED SCS TOLERANCE					
	8631	7300	1.00	116427	54.52	53.52	4.0	5092	2.38	0.13
					EQUAL AVERAGE SCS TOLERANCE					
	8631	7300	1.00	116405	54.51	53.5	4.0	5114	2.39	0.13
					INDIVIDUAL FARM SCS TOLERANCE					
	13811	11450	1.57	118161	55.33	53.76	6.5	3358	1.57	0.10
	12516	10450	1.43	117787	55.16	53.72	5.9	3732	1.75	0.11
	11221	9450	1.30	117377	54.96	53.66	5.3	4142	1.94	0.12
	9926	8250	1.13	116932	54.75	53.60	4.6	4587	2.15	0.12
	8631	7300	1.00	116389	54.50	53.50	4.0	5130	2.40	0.13
	7336	6300	.86	115512	54.09	53.23	3.4	6007	2.81	0.15
	6041	5500	.76	113896	53.33	52.57	2.8	7623	3.57	0.20
	4766	4300	.59	108739	50.92	50.32	2.2	12780	5.98	0.30

Table 28 (continued)

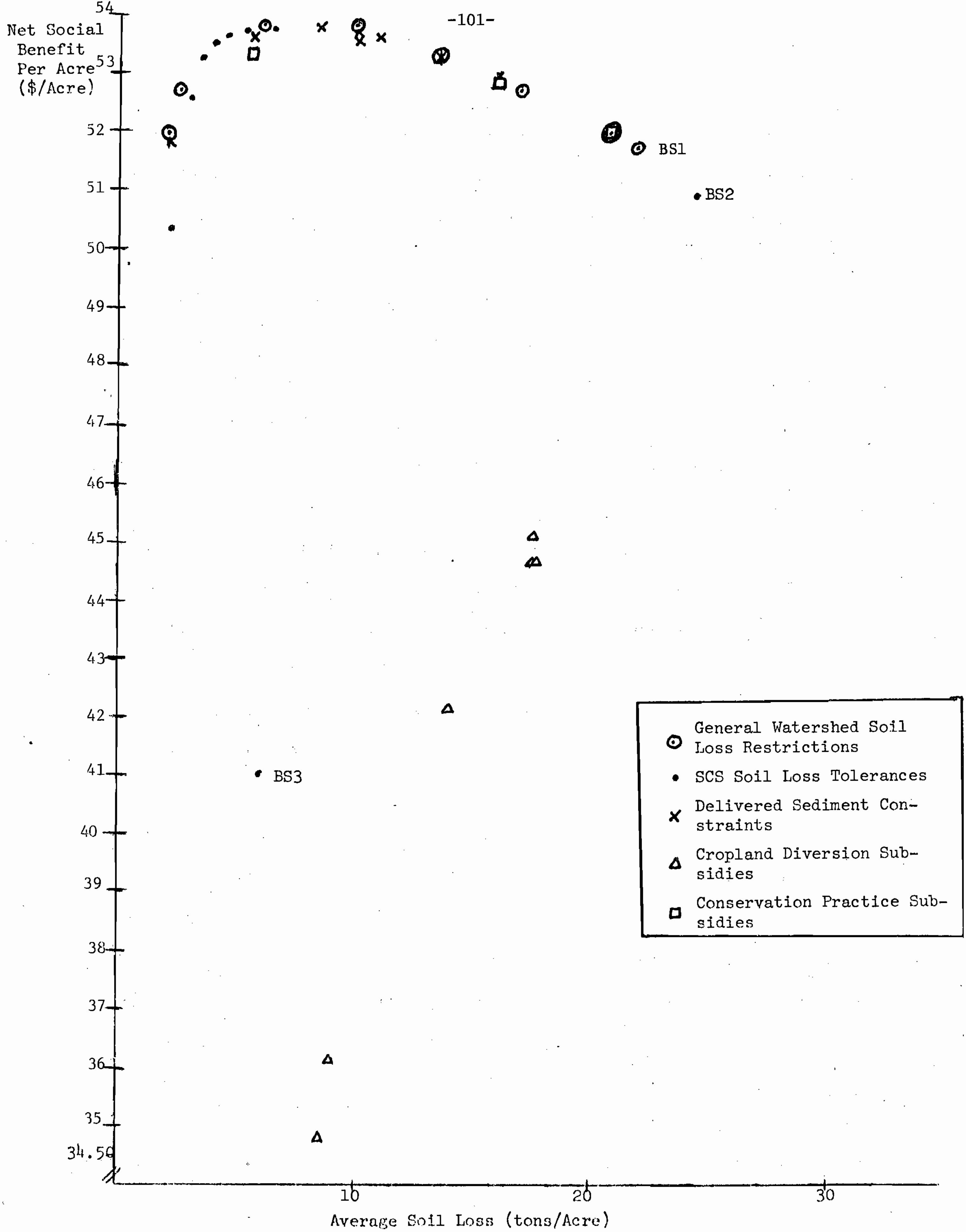
	Total Soil Loss	Estimated Offsite Sediment Damages Total	Estimated Offsite Sediment Damages Per Acre	Net Crop Return Total	Net Crop Return Per Acre	Net Social Income Per Acre	Average Soil Loss Per Acre	Cost Reduction From Maximum Net Return Level Total	Cost Reduction From Maximum Net Return Level Per Acre	Cost Reduction From Maximum Net Return Level Per Ton
WATERSHED DELIVERED SEDIMENT CONSTRAINT										
	34148	27400	3.76	121023	56.67	52.91	16.0	496	0.23	0.04
	28680	23000	3.16	120611	56.48	53.31	13.4	908	0.43	0.05
	23595	18750	2.57	119962	56.18	53.60	11.0	1557	0.73	0.07
	21045	16950	2.32	119526	55.97	53.65	9.9	1993	0.93	0.08
	17949	14600	2.00	119000	55.72	53.72	8.4	2519	1.18	0.09
	11891	9800	1.35	117362	54.96	53.60	5.6	4157	1.95	0.12
	4611	4230	.58	112163	52.52	51.94	2.0	9356	4.38	0.22
INDIVIDUAL FARM DELIVERED SEDIMENT CONSTRAINT										
	21679	16700	2.29	119221	55.82	53.53	10.1	2298	1.08	0.09
PER ACRE CROPLAND DIVERSION SUBSIDIES PAYMENTS										
$20	37515	29900	4.11	105129	49.23	45.12	17.6	16390	7.68	1.75
$30	37515	29900	4.11	104082	48.74	44.63	17.6	17437	8.17	1.86
$40	37515	29900	4.11	104082	48.74	44.63	17.6	17437	8.17	1.86
$50	30224	24100	3.31	97121	45.48	42.17	14.2	24398	11.42	1.46
$60	19514	15700	2.16	81719	38.27	36.11	9.1	39800	18.64	1.44
$70	18411	14750	2.03	78674	36.84	34.80	8.6	42845	20.06	1.49
CONSERVATION AND TILLAGE PRACTICE SUBSIDIES										
25%	44416	35589	4.89	121460	56.88	51.99	20.8	59	0.03	0.02
50%	44416	35589	4.89	121460	56.88	51.99	20.8	59	0.03	0.02
75%	44226	35500	4.87	121430	56.86	51.99	20.7	89	0.04	0.03
100%	34086	27400	3.76	120960	56.64	52.88	16.0	559	0.26	0.04
102.5%	12099	9800	1.35	116787	54.68	53.33	5.6	4732	2.22	0.14

Net social income values for each policy alternative are plotted in Figure 10. Generally, net social income increases as soil losses are reduced, via the various control policies, to the five to ten ton per acre range after which it declines rapidly as was shown in Figure 6. Therefore, policies falling within this range achieve the optimum combination of net crop return, conservation practices, and off-site sediment damage.

Relative to alternative methods, cropland diversion subsidies are an inefficient means of controlling soil losses. The cost of this policy at various subsidy rates exceeds the cost of alternative policies and achieves a smaller reduction of soil losses. The conservation practice subsidy was a less costly means of reducing soil losses. However, to reduce soil losses to the 5-10 ton per acre range required a subsidy of 102.5 percent of the cost difference between the conventional tillage with up-and-down production practice and more soil conserving alternatives. This high rate of subsidy may be unacceptable from a public policy standpoint, and is economically inefficient in that the net social income at this subsidy rate is slightly less than that achieved under alternative policies.

Net social income under simulated present conditions in Big Blue Watershed, BS3, is rather substantially less than under any of the soil loss control policies except the most restrictive crop diversion cases. Therefore, producers can attain a higher level of net crop income and reduce soil losses by producing relatively more continuous corn and wheat-soybeans double crop using improved soil conserving practices. However, livestock production was not included in this study and this may require production of forage crops and generate higher net farm and net social income per acre than present cropping practices indicate.

Figure 10. Net Social Income of Alternative Soil Loss Control Policies & Basic Solutions



Effluent charge policies may also be unacceptable from a public policy standpoint. While it is conceptually possible to establish a system of charges that achieve the desired level of soil loss, administrative complexities of levying and enforcing such charges on such a non-point pollution source make it unmanageable.

The policies providing the highest net social income per acre are those restricting soil losses. The maximum net social income, $53.76, occurs with an average soil loss of 6.1 tons per acre over the watershed. As indicated in Table 5.4, 1,028.3 acres of continuous corn, 752.9 acres of double crop, and 354.3 acres of pasture are produced. Under this policy, 550 acres would receive conventional, 352.1 acres plow plant, and 879.2 acres chisel plow or zero tillage. Finally, 595 acres would be cultivated up-and-down with 827.6 acres of contouring, and 358.6 acres of terracing. Net crop returns are $118,019 or $55.27 per acre. Other soil loss restriction policies with equivalent per acre average soil losses generate similar crop production, conservation, and tillage results. Also, when the restriction is applied on an individual farm basis nearly the same net social income results are produced.

Watershed or farm level soil loss restrictions have a greater impact on net returns and production practices on less productive, more erosion prone farms. However, the farm level restrictions generate a somewhat lower total net farm income due to the lack of flexibility in allocating crop and practices. Requiring all farms to restrict soil losses to an equal average level forces the more productive, less erosion prone farms to make greater adjustments and thereby reduce watershed net returns. When watershed level restrictions are based on sediment delivered, distant farms enjoy a locational advantage in that adjustments are made by farms close to the reservoir.

The cropland diversion subsidy policy reduces crop production and soil loss proportionally, and requires relatively large expenditures of funds. A major problem is that no incentive to adopt soil conserving conservation and tillage practices is provided.

The conservation and tillage practice subsidy provides an incentive to adopt improved soil conserving practices but is only effective reducing soil losses when subsidies reach 75 percent of the cost difference between conventional tillage and up-and-down cultivation practice and the more soil conserving practices. A substantial adoption rate occurred when the subsidy rate exceeded 100 percent. Even at this rate the subsidy payment is smaller and less soil loss occurs than with the crop diversion subsidy.

LIMITATIONS OF THE STUDY

Several limitations were, of course, imposed by the available time and resources. For example, the selection of a single watershed and the use of a sample of hypothetical farms reduces the number and diversity of observations. Not all of the possible crop rotations and conservation practices were considered and the number of production activities was also limited in that livestock operations were not included. All of these omissions limit the ability to generalize from the results of this study.

The assumed decision-making characteristics are a more important set of limitations: (a) not all of the long-run aspects of the problem are reflected; (b) all farmers are assumed to respond uniformly; and (c) not all of the policy alternatives were included. The fact that the long-run aspects of the problem are not adequately reflected is important given that the adoption of soil conservation practices is by definition a long-run concern.

A decline in productivity in some soils can be projected over a 20 to 50 year time horizon under conventional cropping practices. In many cases, this decline in productivity can be avoided by the use of soil conservation practices with conventional cropping practices. In other cases it is necessary and in many cases it is economically desirable to modify the crops produced. Thus, while in many cases we assume there is no difference in yield associated with the adoption of a conservation practice, this may not be true in the long run. The assumption of uniform responses was employed because the information available concerning the expected response of farm operators to a variety of soil conservation practices was not adequate to do otherwise. Thus, it was not possible to include a range of voluntary or educational policies which might achieve desirable results, at least in combination with other policy actions.

The use of a single set of costs and prices does have considerable impact on the specific outcome in terms of crop rotations specified. As a result, the model may not accurately reflect specific changes in crops produced. However, the utilization of the range of prices would not significantly affect the general nature of the results. Similarly, the hypothesized delivery ratio estimates utilized may have an impact on the specific estimates of the quantity of sediment delivered to the reservoir but the general nature of the results should not be affected. Better sediment delivery ratios are badly needed if research of this type is to be fine-tuned for use in policy implementation.

CONCLUSIONS

A basic conclusion of this study is that soil loss and income performance can be substantially improved by shifting from the present to a more intensive cropping pattern with substantially increased use of soil conservation practices. Of course, this implies a shift from the livestock-oriented economy to a cash crop operation. It is possible, however, to continue the same cropping operations and to improve the income and soil loss picture to a lesser degree by implementing soil conservation practices.

It is also clear that the off-site damages are a major factor in determining the optimal set of cropping and conservation practices in the watershed. If net crop returns minus off-site damages are considered, it is necessary to reduce the level of soil losses from approximately 20 tons per acre per year to approximately 6 tons per acre per year. If the net crop income is maximized and only income increasing soil conservation practices are adopted, the level of soil loss in the watershed will remain at the high level. The movement to the level of soil loss suggested by the Soil Conservation Service which is based upon the long productivity would, of course, suggest significant reductions in soil losses. This leads, then, to a consideration of the alternative policies for achieving substantial reductions in soil losses in order to maintain the productivity of the soil and protect the water resources.

The crop diversion policy, if required to produce an acceptable price-income-production performance level in the agricultural sector in total, will have a significant impact on the level of soil loss if the crops are efficiently allocated within the watershed. That is, if the more erosion prone land is removed from row crop production the quantity of soil loss will be reduced. This policy is not, however, an efficient means of achieving the single objective of a reduction in soil loss. If crop production does need to be reduced to achieve other objectives, it may be a viable policy alternative.

Given the soil conservation practice subsidy system assumed in this paper and the short-run aspects of the decision model, a very high subsidy rate is required to achieve a significant reduction in soil losses. If this program were combined with an effective educational program indicating the long-run impacts of excessive erosion or if it were an alternative to the imposition of mandatory soil loss restriction or specifications on crop rotations or conservation practices, the impact may be enhanced significantly. Even in the simple format considered in this analysis, the subsidy system would be desirable in that the "net social income" would increase.

There is very little difference in farm income, conservation practices, or crops produced, among the alternative policies of regulating the level of soil loss at the watershed or at the farm level. Each of these regulatory policies reduces the level of soil loss to the socially optimum rate of approximately 6 tons per acre per year at a cost of less than $2 per acre or approximately $.12 per ton of sediment in foregone income. The theoretically most efficient policy of imposing effluent charges achieves approximately the same level of performance but would be extremely difficult if not impossible to administer. It can therefore be dismissed without serious loss of economic performance.

If the Soil Conservation Service tolerance limits were adopted by farmers, the off-site damages would be reduced to or below acceptable levels. If, on the other hand, off-site damages resulting from delivered sediment is used to constrain soil losses in the watershed, the erosion rate will exceed soil conservation standards, especially on the farms at some distance from the reservoir. Thus, a location advantage is conferred on the more distant farms under this system. However, since the Soil Conservation Service limits are not met, the policy is not adequate to achieve both objectives. Since it is likely to be more difficult to develop acceptance for a policy which confers locational advantages (disadvantages) than for a policy of more equal impact, the Soil Conservation Service based option is desired.

It is important that there is very little difference between the farm and the watershed level regulatory policies. That is, while it is somewhat more economically efficient to apply the restrictions at the watershed level and allow crop rotations and conservation practices to be assigned in an optimal manner across soil types and farms, these advantages are not substantial. Further, it is the highly productive farms which tend to benefit from this allocation system. Thus, from a political standpoint, it would be easier to implement and gain acceptance for a policy designed at the farm level and, of course, such a policy would be much easier to implement from an administrative standpoint.

FOOTNOTES

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[4] Bennet, H. H., Elements of Soil Conservation, Prentice-Hall, Englewood Cliffs, New Jersey, 1955.

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[7] Kneese, A. V., R. U. Ayers, and R. C. D'Arge, Economics and the Environment: A Materials Balance Approach, The Johns Hopkins Press, Baltimore, Maryland, 1970.

[8] Ruttan, V. W., "Technology and the Environment," American Journal of Agricultural Economics, December, 1971.

[9] Kneese, et al., Op. Cit., 1970.

[10] U.S. Department of Agriculture, Soil Conservation Service, "Resource Conservation Planning Technical Note 3," U.S. Department of Agriculture, Soil Conservation Service, Champaign, Illinois, October, 1973.

[11] A description of Big Blue Watershed and reasons for its selection as the unit of analysis are presented in a section beginning on page 19.

[12] U.S. Department of Agriculture, Soil Conservation Service, Op. Cit., 1973.

[13] Cooperative Extension Service, College of Agriculture, University of Illinois, Illinois Soil and Water Conservation Needs Inventory, 1970.

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[21] Narayanan, A. V. S., "Economic Evaluation of the Impact of Selected Crop Practices on Water Quality and Productivity--An Application of Linear Programming," Unpublished Ph.D. Thesis, University of Illinois, January 1972.

[22] U.S. Department of Agriculture, Soil Conservation Service, Work Plan, Big Blue Watershed, Pike County, Illinois, January, 1959.

[23] Odell, R. T., and W. R. Oschwald, "Productivity of Illinois Soils," College of Agriculture, Cooperative Extension Service, University of Illinois, Circular 1016, May, 1968.

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[25] Ibid.

[26] The necessary software for computing both the net returns and soil loss coefficients contained in the matrix was developed by Drs. M. Lee and A. V. S. Narayanan in conjunction with computer science personnel. For additional information on the computation procedures, SEE Narayanan, A. V. S., "Crop Income Projections Under Selected Tillage/Conservation Systems for Illinois Counties," and Lee, M., "Methods of Calculating Gross Soil Erosion Based on CNI data for Each County in Illinois," both unpublished working papers, University of Illinois, 1973.

[27] Odell, R. T., and W. R. Oschwald, Op. Cit.

[28] See Illinois Cooperative Crop Reporting Service, "Illinois Agricultural Statistics, Annual Summary, 1972," Illinois Department of Agriculture, Springfield, Illinois, June, 1972.

[29] Pasture yields are estimated in terms of hay yield in Circular 1016, but this yield estimate must be adjusted for trampling losses. Hinton, in the Farm Management Manual, Department of Agricultural Economics, University of Illinois, January, 1973, indicates that hay yields should be reduced 33 percent to arrive at an estimate for pasture yield. In terms of computing gross returns from pasture (yield times price), this yield reduction is equivalent to an identical price reduction times the normal hay yield. This method of adjustment facilitates computations in the computerized system.

[30] Woodland is valued at stumpage price for upland woods, 1972 average.

[31] Hinton, R. A., Farm Management Manual, Cooperative Extension Service and the Department of Agricultural Economics, University of Illinois, Urbana, Illinois, January, 1972.

[32] U.S. Department of Agriculture, Soil Conservation Service, Work Plan, Big Blue Watershed, Pike County, Illinois, January, 1959.

[33] The 60 year annualization period was chosen because it approximates the time period necessary for replacement trees to reach harvest maturity and thus attain a complete woodlot turnover under a selective cutting system.

[34] Hinton, R. A., Op. Cit.

[35] University of Illinois, Agricultural Experiment Station, Cooperative Extension Service, and Soil Conservation Service, Drainage Guide for Illinois, Agricultural Engineering Bulletin 881, Urbana, Illinois.

[36] Wischmeier, W. H., and D. D. Smith, "Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains," Agricultural Handbook 282, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C., May, 1965.

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[39] U.S. Department of Agriculture, Soil Conservation Service, "Universal Soil Loss Equation," Agronomy Technical Note 1, Champaign, Illinois, 1970.

[40] Ibid.

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[42] U.S. Department of Agriculture, Soil Conservation Service, Op. Cit., 1970.

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[45] Roehl, J. W., "Sediment Source Areas, Delivery Ratios and Influencing Morphological Factors," International Association of Scientific Hydrology, Publication 59, Commission on Land Erosion, 1962.

[46] Ibid.

[47] Lacking specific data on Big Blue Watershed, this distribution is based on Census data for Pike County. The major crops in the watershed are corn, soybeans, wheat, and hay, along with pasture and woodland. The following approximate crop distribution was determined: corn, 527 acres; soybeans, 363 acres; wheat, 316 acres; hay, 474 acres; and 278 acres each of pasture and woodland.

[48] Narayanan, A. V. S., Op. Cit., 1972.

[49] U.S. Department of Agriculture, Soil Conservation Service, "Universal Soil Loss Equation," Agronomy Technical Note 1, Champaign, Illinois, April, 1970.

[50] U.S. Department of Agriculture, Soil Conservation Service, Work Plan, Big Blue Watershed, Pike County, Illinois, January, 1959.

[51] Narayanan, A. V. S., et al., Economic Analysis of Erosion and Sedimentation-Mendota West Fork Watershed, Department of Agricultural Economics, University of Illinois, and Illinois Institute for Environmental Quality, AERR-126, April, 1974.

[52] The discussion and procedure used to estimate sediment damages are based upon the detailed discussion in Lee, M. T., A. V. S. Narayanan, K. Guntermann, and E. R. Swanson, Economic Analysis of Erosion and Sedimentation, Hambaugh-Martin Watershed, Department of Agricultural Economics, University of Illinois, and Illinois Institute for Environmental Quality, AERR-127, July, 1974.

[53] Ibid.

[54] A graphical and mathematical explanation of this and other types of damage estimates is presented in the AERR cited in footnote 52.

[55] Lee, et al., Op. Cit.

[56] The suspended sediment load in Bay Creek near Pittsfield was estimated to average 50 mg/l, see Harmeson, R. H., and T. E. Larson, Quality of Surface Water in Illinois, 1956-1966, Illinois State Water Survey, Urbana, Bulletin 54, 1969. This estimated sediment load is equivalent to 2.396 tons of sediment per acre foot of water supply. It was assumed that the water supply capacity of the reservoir was utilized annually. Water treatment cost was estimated at $.31 per ton, see Brandt, G. H., et al., An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, The Dow Chemical Company, Midland, Michigan, 1972. Therefore, an estimate of water treatment cost is 2.396 · water supply capacity · $.31. In estimating the sediment damage function, the water treatment cost was reduced in direct proportion to the reduction in watershed level gross soil loss. Thanks is expressed to M. T. Lee for aiding in development of this estimate.

[57] Lee, et al., Op. Cit.