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# An economic analysis of alternative government policies for controlling soil erosion

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# CHAPTER I. INTRODUCTION

The purpose of this chapter is to explain the agricultural water pollution problem, its sources and effects, and to investigate means of control. The factors influencing soil erosion are examined with regard to natural components and man-made ones. Finally, the economic rationalization for the reduction of the externality is examined and the effect of abatement tools upon the level of pollution are analyzed.

Water pollution from nonpoint sources (NPS) is a serious problem in the United States, affecting eighty-seven percent of all river basins (U.S.E.P.A. (39)). The U.S. Environmental Protection Agency, through its congressional mandate from the Federal Water Pollution Control Act Amendments of 1972, has declared a 1983 goal of "fishable and swimmable" waters throughout the country. Because of the magnitude of NPS water pollution, the nation most probably will not meet this goal (Portney (29)).

The sources of NPS water pollution are varied, and include urban runoff, construction site erosion, mining activity, forest area runoff and agricultural runoff. The major source of NPS water pollution is agricultural activity, affecting sixty-two percent of all river basins (U.S.E.P.A. (40)).

For Iowa's rivers, particularly the Iowa and Cedar rivers basins, the major problems resulting from NPS water pollution are bacteria growth, the presence of excess nutrients, dissolved solids and pesticides. There are agricultural sources of all these residuals

(U.S.E.P.A. (39)). The problem of bacteria growth, and to some extent excess nutrients, is due mainly to feedlot operations (Wilson (43)). The remaining problems of dissolved solids and pesticides, as well as a large portion of the nutrient problem, are attributable to crop production practices.

The pesticide and fertilizer residuals result from the same chemicals the farmer uses to produce his crops. These ingredients are washed from the soil in rain water or are transported into the stream with the sediment. The pesticides, particularly the oil-based ones, adhere to the soil particles and enter the stream with the water. Other chemicals, such as nitrogen, assimilate with the soil and enter the stream with the sediment (Wilson (43)).

The effects of pesticides on man and aquatic life are not well known. Man normally ingests small amounts of pesticides over a long period, storing the substances in his fatty tissue. The levels build up over time, increasing the risk to the carrier. This risk includes possible genetic problems and increased risk of cancer (Miranowski (26)). The pesticide issue will not be examined in this paper.

The effects of the nutrients, while thought to be pervasive, are also not well-documented. The interaction of nitrogen and water will often result in nitrite formation; nitrites interfere with the movement of oxygen by hemoglobin in the blood of mammals. Phosphorous and the resulting phosphates act as a nutrient for plant algae. When phosphates are present in concentrated forms, their presence causes the algae to grow rapidly or bloom. This is part of the eutrophication process, a natural process which normally takes thousands of years, turning lakes into marshes. However, when the bloom occurs, the algae die from lack of carbon dioxide and then decay. This decaying process upsets the ecological balance of the water body as it absorbs the available oxygen, depriving aquatic life of its needed oxygen. This furthers the eutrophication process, prematurely "killing" the body of water. Nitrites also contribute to the eutrophication process (Wilson (43); U.S.E.P.A. (40)).

The sediment from agricultural land, beyond serving as a delivery mechanism for the chemicals, is a direct problem. The sediment increases the turbidity of the water it enters, generally reducing the water's aesthetic value (Freeman (14)). The sediment also reduces the life of reservoir projects. When a river carrying sediment is impounded, that sediment will be dropped at the dam site, decreasing the reservoir's storage capacity. Also, to the extent that erosion is not planned for in the project, dam life will decrease.

This paper proposes several ways to abate this sediment pollution. All strategies involve government intervention, justified on economic grounds because of the externalities produced by the pollution. The policy methods for dealing with the problem are compared based on costs, production levels, farmer incomes and pollution abatement.

## Organization

This paper is organized into four sections. The first is a general introductory chapter, detailing the water pollution problem and possible remedies. This chapter includes a brief rationale for economic involvement in the pollution problem. The second chapter presents the linear programming model used for analysis as well as some of its limitations. The third chapter discusses the data needs, how they are met, and the necessary assumptions. Finally, the results of the model and policy alternatives are detailed in the final chapter.

## Factors Influencing Soil Erosion

The amount of soil loss in any time period is a function of many variables. There are both natural factors, inherent in the soil, and management factors, controllable by man's choices. Soil type, determined by the soil's parent material, greatly influences erosion levels. That quality of the soil which influences erosion is called erodibility, or the resistance of the soil to both transport and detachment. This erodibility is determined in part by the soil texture, the organic content, the stability of the soil, its shear strength, and its infiltration capacity (Morgan (27)).

Another key factor is the slope of the plot. Holding other factors constant, an area which has a steeper slope than another can be expected to yield more soil. First, long steep slopes are generally characterized by less top soil and so are less permeable, resulting in more runoff. Second, the greater the slope the more energy the water collects. The water runs off the slope with a greater velocity, thereby increasing the water's capacity to carry a load.

These factors are natural. Other factors influence erosion which are management controlled. These factors include the choice of crop and tillage method. Crop cover is an important factor in soil erosion. When rain drops fall they bombard the soil particles, forcing the particles loose. The crop cover or canopy shields the soil particles from the full erosive force of the rain. Leafy plants allow the rain to collect and drop slowly onto the soil, decreasing the rain's erosivity (Morgan (27); Wischmeier and Smith (44)).

Tillage practices affect erosion by both changing the soil's canopy and the soil's physical properties. Depending on the type of tillage an operator uses, the timing of the tillage operation, and the direction of tillage, the soil erosion from a given plot can be expected to differ. For instance, the use of a moldboard plow reduces the amount of residue from the crop, instead incorporating the residue into the soil. This allows the rain to impact the soil with greater force. This residue incorporation does, however, increase the organic content of the soil, at least partially offsetting the increased erodibility.

The timing of the primary tillage operation is also important as it determines how long the soil will be exposed to the natural forces. Soil which is tilled in the fall will be exposed to erosion forces longer than soil tilled in the spring and still longer than soil which is not tilled but is simply planted. By choosing the direction of planting, the operator can influence the soil erosion level. Tillage up and down the slope of the land will result in more erosion than contour tillage which follows the contours of the land. This is due to the velocity of the water. Up-and-down tillage, especially with a row crop such as corn, leaves little to impede the running water; in fact the valley between the planting ridges serves as a channel, increasing the velocity and therefore the load carrying capacity of the water.

Contour tillage serves to decrease the water's velocity, forcing the water to drop its load. As the water slows, more can infiltrate the top soil.

A derivation of contour tillage, referred to as terracing, serves much the same purpose as contouring. Contour tillage is practicable only on soils of sufficient slope length; plots with slope lengths less than the minimum will result in destroyed contours. Terracing changes the slope length by physically changing the length of the plot. Embankments are placed so that contouring is possible. While this has all the benefits associated with contouring, it also has the added detriment of decreasing the land available for tillage and complicating the tillage process.

## Externalities and Economics

One basic goal of economics is to provide an efficient allocation of resources. For a system to meet this goal, certain conditions must be met. Furthermore, through the economist's definition of efficiency, for any allocation to be Pareto-efficient, specific conditions must be met. For a market economy, these specific conditions include price competition in all markets, all goods produced with constant or increasing costs, perfect knowledge, perfect mobility of resources, and no public goods. In general, a Pareto-efficient outcome is where the marginal rate of substitution for any pair of goods is equal to the marginal rate of transformation (Baumol (4)). In a private market economy, an efficient outcome is where the price of any good or service is equal to its marginal rate of transformation which is in turn equal to its marginal private cost. Since no public goods exist, price will then equal marginal social cost (MSC), seen as society's valuation for the production of a marginal unit.

If we assume a social welfare function exists, we can find a Pareto-efficient resource allocation. This social welfare function must accurately relate the utility levels of all members of society; such a function is maximized where MSC equal marginal social benefits equal marginal private costs or price. If these conditions are not met, a Pareto-efficient allocation is not possible and resource misallocation will result.

The source of this misallocation is usually referred to as an externality. If for whatever reason price does not equal MSC, i.e., price does not reflect the true marginal cost to society, then an externality exists which results in a misallocation of resources. However, the presence of an externality does not preclude Pareto-optimality; ceteris paribus, if the externality's price does not equal its MSC, a misallocation will occur (Baumol and Oates (5)). If the externality's price does equal the MSC of the externality, the resulting allocation will be Pareto optimal although the externality may still exist.

The conditions for a particular Pareto optimum, assuming the first-order and second-order conditions for Pareto optimality are met, can be determined with regard to a given market by maximizing producer and consumer surpluses. Assume some externality, created by the production of output Q, yields a social damage function whose principal is the level of output, Q. Further, assume that this social damage function is Pareto-efficiently priced. Then the value of producer and consumer surpluses is given by

$$(1.1) \quad \int_0^Q P(\theta)\, d\theta - [C(Q) + D(Q)]$$

where $P(\theta)$ can be seen as the demand function for the output Q, C(Q) as the total private cost, and D(Q) is the damage function relating society's valuation of the externality, Pareto-efficiently priced.

Pareto optimality is attained where this expression is maximized, or where

$$(1.2) \quad \frac{\partial \int_0^Q P(\theta) d\theta}{\partial Q} - \left[\frac{\partial C(Q)}{\partial Q} + \frac{\partial D(Q)}{\partial Q}\right] = 0$$

or:

$$(1.3) \quad \frac{\partial \int_0^Q P(\theta) d\theta}{\partial Q} = \frac{\partial C(Q)}{\partial Q} + \frac{\partial D(Q)}{\partial Q}$$

with the appropriate second-order conditions of increasing costs or a downward sloping demand curve being satisfied.

The left-hand side can be interpreted as price, the right-hand side as marginal social cost. If the damage done by the production of Q is not priced, then the economy will not achieve Pareto optimality. Price will not equal MSC but rather marginal private cost, $\frac{\partial C(Q)}{\partial Q}$ .

When this condition of price equaling MSC is not met, society is not operating along its production possibilities frontier. The production mix is suboptimal by the Kaldor criteria and some change is possible which will benefit at least one person without making others worse off.

The externality problem has long been recognized by economists and many classification systems have been developed to aid in rectifying the problem. By one set of terminology, the pollution resulting from soil erosion is a technological externality. Such an externality exists when the assumption of independent utility or production functions is violated.

Associated with the concept of a technological externality is a classification system distinguishing between unpaid factors of production and the creation of an atmosphere effect. This unpaid factor of production classification is very similar to a common property resource problem, with Meade's example of apple nectar and bees being the often-cited case (Meade (25)).

Bator extended theoretically the previous system to include three types of technological externalities: ownership, technical, and public good (Bator (2)). An ownership externality is basically Meade's unpaid factor of production and results from a divorce of effective resource ownership from the user. Utilizing Bator's terminology, a technical externality is an example of a natural monopoly, or the case of increasing returns to scale. A public good externality closely follows the definition of a public good: when one person's consumption of the externality does not reduce the level available for others and no price exists for the product, i.e., the externality.

Water pollution resulting from soil erosion, and most other pollution problems, are examples of Bator's public good externality. With the soil erosion problem, the system fails for lack of existence. A priori, no market for large numbers of participants exists which will accurately price the soil erosion by incorporating the costs such erosion forces on others downstream. It is the divergence between the farmer's private costs and the total cost to society which causes the externality and the resulting misallocation.

## Control Mechanisms

Economists have suggested various policy options for controlling externalities, all of which are relevant for soil erosion. These options include taxation, subsidization, auction rights for polluting, direct regulation and other means incorporating certain aspects of these primary options.

The economic goal of these methods is to reduce the pollution to the socially optimal level. To meet this goal, a tax may be levied on the pollutant or some directly related agent. The rationale for the tax is straightforward: the marginal private costs are less than the marginal social costs. A properly designed tax will increase marginal private costs to the level of MSC. This is a Pigouvian tax in the tradition of the literature, where the tax on the externality producing activity is equal to the difference between marginal social and marginal private costs (Baumol (4); Baumol and Oates (5)).

The subsidy tool is very similar to the tax in its effect on the resulting level of pollutant, but different in its approach. The method is to subsidize the reduction in pollutant emission, with the subsidy payment being directly related to the level of reduced externality, on a per-unit basis. Frequently, the units are such that the subsidy may take on the character of a lump sum subsidy. Also, the nature of the subsidy may be either general or specific. The general form is directed solely at abatement. The specific form subsidizes one or a set of specific practices which may or may not be the least cost means of abatement. In either case, the subsidy is on the pollution creating activity.

The question of symmetrical effects between Pigouvian taxes and subsidies has generated a great deal of discussion in the literature; does a per-unit subsidy for pollution abatement yield the same outcome as a per-unit tax on pollutant emission, if both account for the marginal damage of the pollution? There seems to be general agreement that in a static equilibrium with all firms sharing the same technology, plant and equipment, properly designed taxes or subsidies are equivalent in their effects (Kamien, et al. (19); Bramhall and Mills (8)). However, as these conditions are relaxed this symmetry breaks down.

In a dynamic context, bribes and charges may not be symmetrical, especially if production functions are not known to the bribe/charge setting authority. Assume the maximum bribe the authority sets is a static value and for whatever reason the discharging firm's marginal revenue function increases. If the marginal revenue function increases sufficiently, the profit maximizing firm will ignore the bribe and produce as before the authority intervened. If the authority increases the maximum bribe for every change in the demand function, then the result will be symmetrical with the tax result, assuming the information needed to adjust the bribe is costless. If this information is not costless, then the subsidy will be inferior to the tax with respect to controlling pollutant emissions (Kamien, et al. (19), (20); Tullock (36)).

Now assume all firms do not share the same capital stock nor the same technology. Then, within an industry at any time some firms are barely staying in operation, some have marginally failed and left the industry, and some may be enjoying profits. If a subsidy is introduced, ignoring the aforementioned problems, then each firm will reduce its emissions to the level where the marginal cost of emission reduction is equal to the subsidy. However, if the subsidy is not firm-specific but is based on industry-wide emissions, it is possible that some firms may make a profit on the subsidy. It is also possible that this profit will result in increased output industry-wide through an increase in the number of firms in the industry. There now is profit to be made if the appropriate pollution minimizing production function is used (Baumol and Oates (5)).

The asymmetry which develops between these two control options when these conditions are relaxed implies a tradeoff in efficiency exists.

The tool of pollution rights auction involves setting up a pseudo-market for pollution. In general, a relevant externality exists because a market does not exist which accurately prices this externality, a result of the lack of property rights of the polluted medium or perhaps the high transactions costs associated with a solution. To remedy this situation, a market may be established where polluters bid for the right to pollute. If the number of participants is sufficiently large and the necessary information is known, then this market will approach a competitive situation. The polluters involved will increase their bids to approach their maximum willingness to pay. In this way, firms which value their pollution rights more heavily can still produce and at the same time society has controlled the amount of pollution.

In an imperfect world where information is not costless, the auction method may be desirable. Both the Pigouvian tax and subsidy methods require knowledge of pollution's marginal damage function. The auction rights method also requires this knowledge to a degree. The difference is that a tax and subsidy program must be administered on a continuing basis in a changing economy; the auction method need not.

The remaining tool, that of direct regulation of the polluter, is perhaps the least "economic" of all means. The method involves the use of raw government power and is basically an extension of the "taking" power of government. Under this policy, a maximum amount of pollutant is allowed, with the level being chosen with regard to human health and safety. Under the static situation described above with respect to the symmetry argument, the direct regulation tool is inferior. Assume that within an industry each firm has a different production function and a different marginal cost relationship. Then an across-the-board limitation, which limits each firm's emission to the same level, will not be the least cost means of attaining the desired abatement level.

For the soil erosion case, such a restriction may be a physical limit equal to the tolerance (t) value on soil loss per acre. Such a t value is selected toward the goal of maintaining long term soil productivity (Logan (23)).

# CHAPTER II. MODEL

To examine the effects of different policies on soil erosion in the Four Mile Creek watershed, a linear programming model was developed. The unit of analysis is a set of aggregate farms, each of which is representative of a subset of farms in the watershed. These aggregate farms reflect the physical factors associated with a particular subset of farms, such as soil type and field slope. This representation of physical factors is important for soil erosion considerations. Each of these aggregate farms is made up of several soil types which represent the proportion of soils in the individual aggregate.

These aggregate farms are made up of a number of smaller farms. Per farm or average estimates of net income and soil loss by both farm type and for the basin can be obtained.

I assume the objective function of the farmers is to maximize net farm income. The aggregate farm units are made up of several individual farms; assuming no scale economies or diseconomies are associated with the aggregate unit, then both the individual farms and the aggregate farms share the same objective function.

I further assume each of the aggregates act independently of all other aggregates. Therefore, the goal of maximizing net income for each of the aggregates is the same as a goal of maximizing net income for the entire basin. Also, in this manner policy options which serve to restrict soil losses can yield information about how income changes between aggregates, even if total basin-wide income remains constant.

Similarly, a policy which seeks to optimally allocate these restrictions on a watershed basis would consider these five aggregates simultaneously.

For our purposes, net income is taken to be total revenue from cropping activities, minus all costs except returns to land, risk and management. All other labor is assumed to be hired by the operator.

A "baseline" solution is first obtained, reflecting current patterns of cropping practices. This baseline solution necessarily assumes optimality. That is, the solution assumes that with given prices and technology, the farms are operating at their optimal levels of inputs and outputs. Although this may or may not be true, to analyze policy effects this assumption is needed.

Before explaining the model's objective function and constraints, it should be noted that the solution is not the long run solution. Only if the current mix of inputs and outputs is the same as the optimal long run mix, including the farm size variable, will the baseline solution be the long run preintervention solution.

The model assumes a given technology. When looking at long term effects, this technology must be allowed to change. Ruttan and others have stated that scarcity of agricultural production factors induces technological change. Specifically, the presence of scarcity tends to induce technological change in the direction of augmenting the scarce factor's productivity. But as this model seeks to describe a given situation and account for the somewhat shorter term effects of policy actions, the model is not capable of incorporating this change.

While this analysis is assumed to occur in a partial equilibrium setting, this may not be representative. If any or all of these programs were to be adopted nationwide, general equilibrium adjustments could be expected. Prices for farm products would adjust; for a program which forced the dramatic reduction in the acres planted in row crops, one could expect a shift to hay and so a decrease in the price of hay. Also, since the distribution of soil erosion is not homogenous throughout the country, these programs could result in some redistribution of income between farms and regions.

Many assumptions are implicit in the use of a linear programming model. The first of these is the linearity or proportionality assumption. This assumption, put simply, means that outputs are linearly or proportionally related to the input level. This is not a restrictive assumption given the model's linear objective function. However, this implies no scale effects exist for the farmer. If historical patterns reveal anything, larger farms become more prevalent over time. This implies scale effects do exist. Considering the huge investment in machinery needed to farm, it seems reasonable that economies in farm size are present for certain ranges of acreage. It is also possible that new technologies may have the opposite impact on farm size; this is an empirical question the model does not address.

The second assumption is divisibility. The use of the model implies all the inputs are perfectly divisible and continuous. This means that if the results involve one half an acre, the optimum is one half an acre, not necessarily a whole acre. However, the results will be reported to the next smallest integer.

The third assumption needed is additivity. This assumption requires the sum of inputs used in each cropping mix must equal the total amount of these inputs used by each cropping mix for all the inputs. This assumption must be met for each input and collectively for all inputs.

The fourth assumption is that the model must be constrained or finite. There must be restrictions on the amounts of inputs and outputs that can be used or withdrawn from the system. This requirement is met by having a finite number of possible activities and constraints. In addition, we must assume all variables are nonnegative (Randolph, and Meeks (30)).

The model simulates the effects of different control policies on the level of erosion; the effects of these policies are then analyzed with regard to the baseline solution. Aggregate soil erosion levels and net farm income levels are compared. Finally, administrative costs and the cost effectiveness of each program in controlling soil erosion are compared.

The objective function of the linear programming model is to maximize net revenue or income for each of the five aggregate farms, given as:

$$(2.1) \quad Z = (\max) \sum_{i=1}^{5} R_i$$

subject to the aggregate resource constraints and policy directives. The $R_i$ is the total net farm income for aggregate i, as defined earlier. These net income estimates are for an average or expected crop year and for a price vector which is assumed plausible. Crop yields were estimated on the basis of an average year, as were fertilizer and pesticide inputs.

The net income of the ith aggregate is given by:

$$(2.2)\quad R_i = P_C \cdot C_{irjt} + P_S \cdot S_{irjt} + P_H \cdot H_{irjt} + P_0 \cdot 0_{irjt}$$
$$- \sum^{335}_{rjt}\sum\sum A_{irjt}(P_L \cdot L_{irjt} + P_N \cdot N_{irjt} + P_P \cdot P_{irjt} + P_K \cdot K_{irjt}$$
$$+ P_{HB} \cdot HB_{irjt} + P_I \cdot I_{irjt} + P_M \cdot M_{irjt})$$

| | |
|---|---|
| $i = 1, 2, 3, 4, 5$ | referring to the watershed aggregate |
| $r = 1, 2, 3$ | referring to the rotation used |
| $j = 1, 2, 3$ | referring to the conservation practice used |
| $t = 1, 2, 3, 4, 5$ | referring to the tillage practice used |

where:

$P_C$ : price of corn

$C_{ijrt}$ : bushels of corn sold in the ith study aggregate using the rth rotation, the tth tillage practice, and the jth conservation practice.

$P_S$ : price of soybeans

$S_{irjt}$ : bushels of soybeans sold in the ith study aggregate using the rth rotation, the jth conservation practice, and the tth tillage practice

$P_H$ : price of hay

$H_{irjt}$ : tons of hay sold in the ith aggregate using the rth rotation, the jth conservation practice, and the tth tillage practice

$P_O$ : price of oats

$O_{irjt}$ : bushels of oats sold in the ith study aggregate using the rth rotation, the jth conservation practice, and the tth tillage practice

$A_{irjt}$ : acres in cultivation in the ith study aggregate, using the rth rotation, the jth conservation practice, and the tth tillage practice

$P_L$ : price of labor or wage rate

$L_{irjt}$ : hours of labor used in the ith study aggregate for the rth rotation, the ith conservation practice, and the tth tillage practice

$P_N$ : price of nitrogen

$N_{irjt}$ : pounds of nitrogen used in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice

$P_P$ : price of phosphorous

$P_{irjt}$ : pounds of phosphorous used in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice

$P_K$ : price of potassium

$K_{irjt}$ : pounds of potassium used in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice

$P_{HB}$ : price vector of herbicides

$HB_{irjt}$ : units of corresponding herbicide applied in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice

$P_I$ : price vector of insecticides

$I_{irjt}$ : units of corresponding insecticide applied in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice

$P_M$ : price vector of machinery services

$M_{irjt}$ : units of corresponding machinery service used in the ith study aggregate for the rth rotation, the jth conservation practice, and the tth tillage practice.

Given this formulation of the objective function, the only physical constraint in the model is that acreages in a given aggregate must not exceed the total acreage available:

$$(2.3) \quad \sum_{r}\sum_{j}\sum_{t} A_{irjt} \leq A_i$$

The effects of government policies are incorporated into the model by imposing new constraints and changing the parameter estimates in the model. The purpose of these changes is to reflect changes in the farmer's decision variables and to simulate the effect of direct regulation of soil loss in the study area. The policies are:

1. Government limitation on per acre soil loss. Soil loss comes about as a result of the farmer's choice of crop rotation, tillage practice, and conservation practice, and the given soil types of the

land. Due to its causes, soil loss can be regulated by either restricting the possible choices of practices or by restricting average soil loss per acre, as determined by the Universal Soil Loss Equation (Wischmeier and Smith (44)). These restrictions on practices are seen as eliminating certain practices by government edict, thereby reducing the farmer's choices. The per-acre soil loss restriction can be seen as limiting erosion to an average of three, five, or ten tons of soil loss per acre. All three levels are examined.

These levels are selected to be representative t values, mentioned earlier. A brief discussion of the t values is needed at this point. Tolerance values vary between one and five tons of soil loss per acre per year. They were originally formulated for benchmark soils in 1962, and were based on three criteria (Smith and Stamey (35); Logan (23)). A rate was needed that would reduce soil loss to a level which would maintain soil productivity over the long term. Also, a rate was needed which would retard severe gullying and at the same time be consistent with maintaining plant nutrient levels. These criteria are based on the recognition that soil is a renewable resource, albeit one with a long gestation period.

While the t values were selected with regard to topsoil thickness, their use should be prudent. Although this thickness in part determines the particular value, little regard was paid to the ability of the subsoil to grow crops in the event of total topsoil loss. Many of these subsoils could function well as top soil, especially once the organic content is increased. Thus, these t values may in fact hold little relevance for the true acceptable rate of soil loss, as defined by the three criteria (Logan (23)).

2. User charges or taxes. Under this policy, soil loss is taxed on a per-ton basis. The tax rate is determined by the change in the erosion level. Different tax levels are entered into the model to determine a relationship between soil erosion and tax levels. The soil erosion resulting from each tillage practice, rotation selection, and conservation practice mix is taxed at $1, $5, $10 per ton.

3. Subsidies. These subsidies can take two forms: a general per ton subsidy based on soil erosion abatement or a specific subsidy. The per ton subsidy is paid directly to farmers and is based on the decrease in soil erosion from a base level. This base level is the erosion level obtained in the baseline solution. For every ton of soil the operator saves above the base level, using the least cost means, the operator will receive $S, some subsidy level. This subsidy level varies between the same levels as the tax solution.

The practice-specific subsidy supports the use of certain practices, the decision having been made before hand that these practices were the most desirable for erosion abatement. The subsidy serves to decrease the costs associated with using these practices, thereby increasing the net income derived from acreages where these practices are relevant. These practices include terracing, contouring, and zero-till planting.

The tax or charge and the general subsidy are expected to be equivalent in their effect on the pollution level. A tax on the discharge will result in the profit maximizing operator discharging effluent or allowing soil erosion up to the level where marginal abatement costs just equal the tax. A general subsidy will result in the profit maximizer adopting soil conservation measures to the point where marginal abatement costs equal the subsidy. The tax program and the subsidy program are expected to result in the same level of abatement. However, income levels will be different. Also, a problem exists since the subsidy level is determined by abatement, figured from some level. The tax solution is based solely on erosion abatement, regardless of the base level.

Different subsidy levels are encountered in the model with respect to the practice specific subsidies. The costs of terracing and zero-till planting are hypothesized to be shared by some government agency, at varying rates. Levels of 50 percent, 75 percent, and 90 percent subsidization are examined for their effects. The selection of these levels to test was largely arbitrary and intended to be expository of the nature of farmers reactions to conservation practices.

# CHAPTER III. STUDY AREA DATA

## The Study Area

The study area under analysis is the Four Mile Creek watershed, a drainage basin for a tributary of Wolf Creek. The basin is wholly contained within Tama County, Iowa, and is principally located in Lincoln and Grant townships; a small portion of the basin is in Crystal township. The watershed is comprised of some eight thousand acres, nearly all of which are in agricultural use.

The predominant soil of the basin is Tama Silt Loam, although Downs Silt Loam and soils of the Wabash-Judson complex are present in considerable amounts. The basin is made up to a large extent by undulating to level, dark-colored, well-drained soils, i.e., soils having slopes of less than eight percent.

The more moderate colored soils, such as the Downs Silt Loams, are generally characterized by steeper slopes. Gradients of twelve to sixteen percent are not uncommon, although such soils do not make up a large portion of the basin (see Table 3.1).

All of these soils except the Wabash series are derived from loess, a finely textured silty deposit usually laid down by wind (Batten and Gibson, (3)). The thickness of this loess varies, but generally is about ten feet thick in the watershed (Aandahl and Simonson (1)). On the more hilly sections the loess is much less thick. The Wabash soils are flood plain deposits, usually gently sloping (gradients of two to five percent). These Wabash soils, due to their flood plain location, are

Table 3.1. Soil type acreages of Four-Mile Creek Watershed[a]

| Soil type | Slope classification[b] | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| Downs silt loam | 500 | | | | |
| Tama silt loam | 2100 | 2200 | 600 | | |
| Wabash-Judson | 2000 | | | | |
| Muscatine silt loam | 400 | | | | |

[a]Source: Aandahl and Simonson (1).

[b]Slope classifications: A = 0-2%; B = 2-5%; C = 5-9%; D = 9-14%.

Table 3.2. Corn suitability ratings for major soil types and slope phases in Four-Mile Creek Watershed[a]

| Soil type | Slope phase | Corn suitability rating |
|---|---|---|
| Downs silt loam | A | 90 |
| Tama silt loam | A | 100 |
| | B | 95 |
| | C | 78 |
| | D | 68 |
| Wabash-Judson | A | 60 |
| Muscatine silt loam | A | 100 |

[a]Fenton, et al. (12).

[b]Slope classifications: A = 0-2%; B = 2.5%; C = 5-9%; D = 9-14%.

usually fingerlike extensions which follow the streambed.

The basin is made up of soils ideally suited for row crops, particularly corn. A Corn Suitability Rating (CSR) is an index of a soil's ability to foster corn growth; the CSR's for the most prevalent soils in the Four Mile Creek watershed are very high and are given in Table 3.2. These soils are among the best in the world for growing corn and soybeans (Batten and Gibson (3)).

## Model Data Requirements

The formulation of the model required various types of data derived from very different sources. Principally, yield data for crop rotations, various input requirements, and soil erosion levels corresponding with different mixes of crop rotation, conservation practice, and tillage practice were needed. The first two sets were needed to obtain the net revenue figures the model seeks to maximize. Soil erosion levels were needed to simulate the effects of government action and to indicate the extent of the externality associated with different cropping practices.

Yield data were required to find gross revenue or income figures from cropping activities for each of the five study aggregates. These data came from two sources: a survey of farmers in the watershed and publications of the Iowa State University Agronomy Extension office.

The farmer survey was conducted by Dr. John Miranowski during the months of March and April, 1980. This survey provided data for different crop rotation and tillage practice mixes and was useful in determining the timing of tillage operations. The Extension Office publications provided yield data for specific crops.

Input data were required so that net revenue figures could be determined. These estimates came from a variety of sources, including both the survey and Extension publications mentioned above. Fertilizer requirements were derived from Extension publications. Suggested fertilizer levels were available for different management levels and subsoil moisture levels (Voss (41)). The higher levels were chosen because generally the farms in the watershed are intensely managed, based upon a survey of local producers.

These fertilizer requirements were given for basic soil types; in calculating fertilizer requirements for different slope phases of the same soil type, a proportionate measure was used. That is, a proportion of the fertilizer requirements similar to the proportionate yield of the soils was used. A soil whose yield was ninety percent of the best soil within that classification was assumed to require ninety percent of that best soil's fertilizer requirements. This interpolation method is consistent with the method used by the Extension Service for the general fertilizer recommendations (Voss (41)). These fertilizer requirements are given in Tables A.1 and A.2.

Pesticide requirements were determined in a three stage process. First, the percent of organic matter in the soils was determined. This percent divided the soils into three classifications: heavy, medium and light. Next, the survey data were examined to determine the type of pesticide used. Finally, a pesticide guide was consulted to determine the correct level of application for both herbicides and insecticides. These values were selected for specific crop rotations and tillage practices, the respective herbicide values are given in Tables A.3a to A.3e. The insecticide requirements are the same for all soil types and are relevant only for corn; the insecticide Counter 15G is applied at a rate of six and one-half (6.5) pounds per acre (1978 Chemical Crop Protection Guide (28)).

Net revenue figures were derived for each crop rotation, tillage practice, and conservation mix for each study aggregate. These net revenue figures were obtained using the farm budget generator. This generator takes described input and output levels and, using given prices, yields a set of data from which net revenue as defined for the model can be derived. These prices are given in Table A.4.

The soil composition of the study aggregates was determined on an ad hoc basis. A map of farm ownership boundaries was superimposed on a map of soil types in the basin. Visual inspection led to the conclusion that there were five types of farms, or five sets of farms which generally shared the same soil makeup. The description of each study aggregate is given in Table 3.3.

## Measurement of Soil Erosion

The study area contains six prevalent soil types and slope phases of those types; in addition, approximately nine soil types are present in insignificant amounts. The measure of soil erosion from these soils is given by the Universal Soil Loss Equation (USLE). The USLE was

Table 3.3. Aggregate farm soil types and corresponding proportion and acreage

| Farm | Soil type[a] | Proportion | Acreage |
|---|---|---|---|
| 1 | WM | .5 | 15% |
| | DSL | .5 | |
| 2 | TSL | .5 | 35% |
| | TSR | .25 | |
| | TSE | .25 | |
| 3 | TSE | .50 | 20% |
| | WM | .33 | |
| | TSR | .17 | 15% |
| 4 | TSL | .5 | |
| | TSR | .33 | |
| | WM | .17 | |
| 5 | TSL | .5 | 15% |
| | TSR | .25 | |
| | MS | .25 | |

[a] WM: Wabash silt loam - 0-2%
DSL: Downs silt loam - 2-5%
TSL: Tama silt loam - 2-5%
TSR: Tama silt loam - 5-9%
TSE: Tama silt loam - 9-14%
MS: Muscatine silt loam - 0-2%.

developed by a branch of the U. S. Department of Agriculture as an attempt to reduce the gross soil loss in tons per unit area to all major factors influencing sheet and soil erosion (Wischmeier and Smith (44)). Its use is most valid east of the Mississippi river and in Iowa and Missouri. The USLE has the form:

(3.1) $A = R \cdot K \cdot L \cdot S \cdot C \cdot P$

where: A = computed soil loss in tons per acre for a given period.

R = the rainfall erosivity index for the given period in feet ton units. This represents the effect of a raindrop's impact and the intensity of the rainfall.

K = the soil erodibility factor. K reflects the inherent erosion characteristics of the soil. The factor is determined empirically and is the ratio of erosion per unit of R from a unit plot of each soil type. This unit plot was chosen to be one acre of land in continuous fallow condition, tilled for a period of at least two years, having a slope of nine percent and a slope length of seventy-two and six-tenths (72.6) feet. On the unit plot, L, S, C, and P equal unity and K then becomes A divided by R (Morgan (27)).

$L \cdot S$ = the slope length and steepness factors. The slope length factor, L, and the slope steepness factor, S, are usually combined into a single factor, LS. LS is the ratio of soil loss per unit area from a particular field to that of the unit plot. This factor is computed with a formula estimated by Wischmeier and Smith (44).

$$(3.2)\ LS = L^{1/2}(.0076 + .0535 \cdot S + .00076 \cdot S^2).$$

C = the crop factor. It is the ratio of soil loss for a given rotation to that from bare soil.

P = the conservation practice or support practice factor. It is the ratio of soil loss under a given practice on a particular soil to the soil loss resulting from straight row tillage.

The R value for the study area was supplied by the U.S.D.A. and was found to be 175. The K values for each of the major soil types and associated slopes are given in Table 3.4.

The C values, relating crop and management effects on erosion, were determined by the use of a U.S.D.A. technical publication (U.S.D.A. (37)). These values are given for each rotation, tillage method, and conservation practice. These rotations include continuous corn (C-C), corn followed by soybeans (C-B), and corn followed by corn followed by oats followed by two years of meadow (C-C-O-M-M). The tillage methods considered are fall moldboard plowing (FM), fall chisel plowing (FC), spring moldboard plowing (SM), spring chisel plowing (SC), and a zero tillage method (NT). The conservation practices considered are straight row or up-and-down plowing, contour plowing, and terraced fields. The C factors for crop rotations and tillage practices are contained in Table 3.5.

Table 3.4. K values for major soil types[a]

| Soil type | K |
|---|---|
| Downs silt loam | .32 |
| Tama silt loam | .32 |
| Wabash-Judson | .10 |
| Muscatine silt loam | .28 |

[a]Paul Rosenberry, Economics and Statistics Service, U.S.D.A., Iowa State University. Private communication, June 15, 1980.

Table 3.5. USLE C factors for crop rotations and tillage practice[a]

| | Crop rotation | | |
|---|---|---|---|
| Tillage practice | C-C | C-B | C-C-O-M-M |
| Fall moldboard plow | .48 | .56 | .17 |
| Fall chisel plow | .25 | .32 | --[b] |
| Spring moldboard plow | .36 | .46 | .10 |
| Spring chisel plow | .22 | .28 | .09 |
| Zero tillage | .07 | .09 | .04 |

[a]Source: U.S.D.A. (37).

[b]C-C-O-M-M rotation is not associated with the fall chisel plow tillage practice.

The P values, the support practice factors, were derived from the Wischmeier and Smith publication (44). These values are given for contour tillage and contour tillage on terraced fields. Contour tillage is effective only on fields of sufficient slope length. If a field's slope is sufficiently steep and its length short enough, then the ridges formed by contour plowing will be destroyed more frequently as storms increase in intensity. Maximum slope lengths for contouring without terracing are given below. I assume no contour plowing can occur on fields which exceed these values. Rather, for the operator to contour plow these steep slopes, he must first terrace (Wischmeier, and Smith (44)).

| Slope phase | Maximum length (feet) |
|---|---|
| A | 400 |
| B | 300 |
| C | 200 |
| D | 120 |
| E | 80 |

Terracing serves to decrease the field's slope length, reducing the speed of the runoff. Because of this, terracing affects the USLE not only through the P or support practice factor but also through LS, the slope length factor (Wischmeier and Smith (44)). The new maximum slope lengths are given below:

| Slope phase | Maximum length (feet) |
|---|---|
| A | 175 |
| B | 130 |
| C | 120 |
| D | 120 |
| E | 110 |

The P values for contour plowing, including the use of terraces, are given in Table 3.6. Terracing costs are assumed to be only construction costs and increased fuel usage. The increased fuel usage is the same as the increase for contouring. The terraces considered are backslope terraces where the backslope of the terrace is grass covered. The construction costs of these terraces are based on a price per linear foot; the amount of linear feet needed varies according to the terrace spacing requirement. For a given area, this spacing requirement is determined by the slope of the land (James (17)). Terrace spacing requirements for different slopes are given in Table 3.7. The amount of linear feet of terracing that each slope classification requires can be estimated by the ratio of the number of square feet in an acre to the required spacing, yielding the second column of Table 3.7. Terracing costs were then estimated to be the number of linear feet of terracing needed times a fixed rate per linear foot of $1.11 (James (17)).

The cost of contour plowing is assumed to be entirely increased fuel usage. The percentage increase in fuel use by slope classification is: A-5%, B-5%, C-5%, D-7%, E-7% (Walker (42)).

A note of caution in the use of the USLE is needed. The USLE was designed to predict the long term average soil losses in runoff for specific cropping and management practices. It is an average measure of gross soil loss through runoff and as an average measure has some variability. The parameter values can be expected to vary greatly from storm to storm but it is thought these variations tend to offset

Table 3.6. USLE P factor for slope classification

| Slope phase | Contour tillage P value |
|---|---|
| A | .60 |
| B | .50 |
| C | .50 |
| D | .60 |
| E | .70 |

Table 3.7. Terrace spacing requirement[a]

| Slope phase | Horizontal spacing (feet) | Linear feet requirement |
|---|---|---|
| A | 220 | 198 |
| B | 110 | 396 |
| C | 100 | 435 |
| D | 82 | 530 |
| E | 75 | 580 |

[a]Source: James (17).

one another in the long term.

Also, the USLE was originally presented as a model explaining soil loss east of the Rocky Mountains. Experience has shown it to be most reliable in the humid areas where rainfall is more frequent and soils have better infra-structures (Morgan (27)).

## Administrative Costs

Administrative costs for each policy program were determined on the basis of conversations with Ted Hall, Soil Conservation Service district agent for Tama County. I questioned Mr. Hall as to personnel needs for each program and anticipated legal costs. I felt the largest cost associated with each program would be in personnel and their time. Accordingly, the only costs included were those pertaining to personnel and their support. These personnel costs are broken down into four categories: farm-needs-analysis costs, monitoring costs, reporting costs, and fixed costs of needed personnel. This breakdown is not meant to totally account for all costs of each program; printing, transportation, laboratory testing and many other costs are sure to be incurred. However, I felt these were either insignificant or would be the same for all programs. Thus the costs given are meant to be expository of each program's total cost, not necessarily a true delineation.

The costs as presented can be seen as continuing costs and one-time or start-up costs. The farm needs analysis costs are best seen as one-time costs, since they do not recur over the life of a policy. The monitoring costs, reporting costs and fixed costs of personnel are continuing costs and so are given on an annual basis.

The costs of each program, in terms of time, are different although some factors are nearly the same. For instance, reporting costs do not vary greatly between programs. This is because I assumed writing and typing requirements were nearly the same for all programs, an assumption Mr. Hall agreed with.

Farm-needs-analysis costs are based on the number of trips a technician needs to make to the farm site. Each hour of the technician's time is assumed to cost \$7.00, based on an annual salary of approximately \$14,500. Each hour of a secretary's time costs \$4.50, based on an annual salary of approximately \$9,500. These needs-analysis-costs vary with the intensity of observation and the number of trips. The intensity of observation is reflected in the time spent per trip. Generally, a program which requires more time to analyze the problem will cost more than a simpler program. For instance, direct regulation of soil loss is very time consuming in the needs analysis stage whereas the direct regulation of specific practices is not. The former requires a knowledge of what is occurring whereas the latter is only concerned with what practices are used in the future. The needs analysis costs of the terracing program include fifty hours of planning and supervision of construction per farm.

Monitoring costs are determined in much the same way. These costs vary with the number of trips needed to each farm and with the amount of work to be done at each farm. The direct regulation of soil loss requires several visits per year with approximately one hour per visit to check the soil loss, whereas a program such as the direct regulation of specific practices requires very little monitoring time per visit. Both the tax solution and the general subsidy solution require large amounts of monitoring time to enable an accurate determination of the tax and subsidy levels. The specific subsidy program's costs do not vary much between each program. The terracing option requires much the same monitoring time as does the zero tillage subsidy.

Office maintenance costs include office space, at thirty-five square feet per person, and fixed labor costs of twenty percent of salary. The office space costs are not charged to any program, only set forward. The fixed labor costs are determined by the number of employees needed. These costs are given in Tables B.1 to B.5.

The presence of these administrative costs serves to increase the social cost of erosion abatement for each program. The administrative costs, as presented, are not intended to represent all of the administrative costs of a program. Information costs and enforcement costs would be incurred. It is plausible to assume that as abatement increases information costs would remain constant; the same assumption is not necessarily plausible for enforcement costs. As pollution decreases, the enforcement of further prescribed decreases could become more difficult. At these higher abatement levels more incentive exists to avoid the program.

It is in the area of enforcement costs that legal costs are most relevant. No figures for anticipated legal costs are given because none were available. However, Mr. Hall felt that generally any program which took a farmer's money would meet stiff legal resistance. Thus it was felt the subsidy and direct regulation policies would result in lower legal costs than the tax program. Also, the direct regulation, by both practice and soil loss, would result in higher legal costs than the subsidy approaches. Only the relative costs were discussed, as Mr. Hall was reluctant to place a monetary figure on any program's legal costs.

If the enforcement costs of these programs were known and accounted for, the optimal level of abatement would certainly be less. The results presented in the next chapter would change. The marginal costs of abatement would increase with the exact magnitude depending upon the enforcement cost function. The relative marginal social costs of each set of programs could be expected to change, implying a different optimal policy.

# CHAPTER IV. ANALYSIS OF POLICY OPTIONS FOR CONTROLLING SOIL EROSION

In order to compare the effects of different policies, the computer simulation was initially run with no policy constraints. This initial simulation will be referred to as the base line solution or the base run. The results of this and all other simulations are given in Appendix C.

## Base Line Solution

In the base line solution the model selected a continuous corn rotation on all soils except those of the Wabash series. The corn-soybeans rotation was selected for the Wabash soils. All farmland was tilled in a straight row fashion, with no contouring or terracing occurring. The optimum result involved all the continuous corn being tilled using a chisel plow in the fall. A chisel plow in the spring was the optimal tillage method for the corn-soybeans rotation, used on the Wabash soils.

This baseline solution resulted in a net income of $1,782,510 from cropping activities, or approximately $228.53 per acre in the basin. Since there are one hundred and four farms in the basin, this solution implies a net income of $17,139,75 per farm; this is an average figure based on an average of seventy-five acres per farm. Associated with this net income figure is a gross soil loss estimated to be approximately 73,815 tons within the entire watershed. This is an average soil loss per acre of 9.46 tons. The results of this baseline simulation are given in Table C.1.

## Tax on Soil Loss

The analysis of government intervention in the soil erosion problem first involved the use of a tax on soil erosion. This tax is on a per-ton basis and the same rate applies throughout the basin. Levels of \$1.00, \$2.00, \$5.00, and \$10.00 per ton were investigated for their effect on soil loss and net income from cropping activities. The results of these taxes are given in Table C.1.

A tax of \$1.00 per ton of soil loss dramatically decreased basin wide soil loss while barely decreasing basin net income. Under this policy, gross soil loss was estimated to be 39,062 tons or a decrease of 34,753 tons. Meanwhile, net income decreased from \$1,782,510 to \$1,741,720, a drop of \$40,790; this decrease in net income is very close to the amount of revenue the government is assumed to have collected.

The imposition of the \$1.00 per ton tax resulted in substitution between tillage practices and conservation practices, but no substitution between crop rotations. The Wabash soils still used the chisel plow in the spring for the corn-soybeans rotation, but they were the only soils unchanged. The use of a chisel plow in the fall became the prevalent tillage practice. Also, contour plowing became the most prevalent direction of plowing, occurring on 5,400 acres.

A tax of \$2.00 per ton did not result in as dramatic a change as the \$1.00 tax; under this program, erosion decreased to 37,723 tons, a decrease from the baseline erosion level of 36,092 tons. Basin wide net income decreased from the baseline level by \$79,850 to

$1,702,660. While this may be a significant effect, the difference in erosion abatement between tax levels of $1.00 and $2.00 per ton is 1,339 tons. Meanwhile, net income decreased from the $1.00 tax level result of $1,741,720 to the $2.00 tax level result of $1,702,660, a drop in net income of $39,060. At this tax level, there is no change in cropping practices or crop rotations from the $1.00 tax level.

The decrease in soil loss from the $1.00 tax level to the $2.00 tax level was entirely due to a change in tillage practice on the steeper slopes. Under the $1.00 tax, the D-slope classification land was farmed using a chisel plow in the fall in a contour direction for the continuous corn rotation. With the $2.00 tax per ton on soil erosion, these more steeply sloped soils are farmed using a chisel plow in the spring, still following the contour and using the continuous corn rotation.

The next run involved a tax of $5.00 per ton of soil erosion. With a tax levy of this rate, soil erosion decreased by 45,160 tons to 28,655 tons basin wide. Income also decreased to $1,607,310, a drop of $175,200. At this tax level, there is a large amount of substitution between tillage practices, although contour cropping and straight row cropping are the only conservation practices entering into the solution. The use of a chisel plow in the spring is now a common tillage practice and a zero tillage practice becomes profitable on the steeper slopes.

The final tax level examined is the $10.00 per ton rate. A tax at this level reduces net income for the basin to $1,516,690, a drop of

$256,820 from the baseline solution. Gross soil erosion is estimated to be 15,835 tons a decrease of 57,980 tons from the baseline solution. While contour plowing was still the most prevalent plowing direction, a large amount of land moved from using a chisel plow in the spring to using a zero tillage method of plowing and planting. There was also a large amount of substitution between crop rotations; whereas under the $5.00 tax program, 2,600 acres were planted in the corn-soybeans rotation, with the $10.00 tax, 4,700 acres used this rotation.

The tax policy incurs certain administrative costs and these administrative costs are the same regardless of the tax level. These costs were estimated to be approximately $17,260 (see Table B.1). As an attempt to present the administrative costs of each policy in a more integrated form, the per ton social costs of erosion abatement are presented in Tables 4.1 to 4.3. These are average social costs of abatement only to the extent that the administrative costs, as presented, are reflective of each program's social costs. Also included in the social cost is a measure of the dead weight loss of each program, seen as the difference between the change in income and the change in government revenues. No marginal social costs of abatement are given because the enforcement costs, which are functionally related to the abatement level, were not available.

## Subsidy for Soil Loss Abatement

Under this program, a subsidy of $1.00, $2.00, $5.00, and $10.00 per ton of soil erosion abatement is offered. The subsidy is figured from the baseline erosion. For every ton of soil loss decreased from

Table 4.1. Social cost of a one-year per ton tax program

| | Tax rate (per ton) | | | |
|---|---|---|---|---|
| | $1.00 | $2.00 | $5.00 | $10.00 |
| Decrease in basin income | $40,790 | $79,850 | $175,310 | $265,820 |
| Decrease in basin soil erosion (tons) | 34,755 | 36,102 | 45,155 | 57,980 |
| Net increase in government revenue[a] | +17,495 | +54,945 | +208,515 | +562,540 |
| Social cost of erosion abatement (per ton)[b] | .33 | .69 | .74 | 5.12 |

[a]Net increase in government revenue is defined to be the government tax revenue less administrative costs.

[b]Social cost of erosion abatement defined as the difference between the change in basin income and the net change in government revenue.

Table 4.2. Social cost of a one-year per ton subsidy program

| | Subsidy rate (per ton) | | | |
|---|---|---|---|---|
| | $1.00 | $2.00 | $5.00 | $10.00 |
| Increase in basin income | $50,790 | $79,850 | $175,210 | $265,820 |
| Decrease in basin soil erosion (tons) | 34,755 | 36,102 | 45,155 | 57,980 |
| Net decrease in government revenue[a] | 54,205 | 91,655 | 245,225 | 599,250 |
| Social cost of erosion abatement (per ton)[b] | .39 | .33 | 1.55 | 5.75 |

[a]Total decrease in government revenue is defined to be the sum of the government outlays for the subsidy program and the administrative costs.

[b]Social cost of erosion abatement is defined as the difference between the change in basin income and the total decrease in government revenue.

Table 4.3. Social cost of a one-year policy restricting per acre soil erosion

| | Limitation level (per acre) | | |
|---|---|---|---|
| | 10 tons | 5 tons | 3 tons |
| Decrease in basin income | $20,260 | $99,940 | $152,510 |
| Decrease in basin soil erosion (tons) | 37,760 | 51,995 | 57,460 |
| Social cost of erosion abatement (per ton)[a] | .97 | 2.24 | 2.94 |

[a]Social cost of erosion abatement is defined as the sum of the decrease in basin income and the administrative costs.

the baseline solution, the farmer receives the subsidy level. Just as with the tax solution, this soil loss level is assumed to be based on the USLE.

Assuming the farmer is a net revenue maximizer, a per-unit subsidy will reduce soil erosion by the same level as a per unit tax. The difference in the short run is that income will increase. The results of the per-unit subsidy analysis are given in Table C.2. This per-unit subsidy program's administrative costs and the per-ton social cost of erosion abatement are presented in Tables B.1 and 4.2, respectively.

## Direct Regulation of Practices

The policy option of direct regulation of certain practices involves eliminating these practices from the farmer's set of choices. The only practice that is considered is a ban on the use of a moldboard plow in the fall. This ban has no effect since the preintervention optimal solution does not involve the use of a moldboard plow at any time.

## Direct Regulation of Per Acre Soil Loss

This policy option limits soil erosion to certain levels per acre. This restriction can be seen in two ways: limiting average soil loss for the entire basin to certain levels and limiting soil loss on any acre to certain levels.

The first method allows a great amount of variation in the erosion from fields in the basin. Erosion may vary from none to essentially any level within the basin, so long as the average is less than the limit. This method may be valid if one is more concerned with sediment in the stream than actual soil loss. One may be more concerned about the soil actually leaving the basin; in that case, it may be of no concern how variable erosion is within the basin.

The second method allows less variation in soil loss than the average restriction. This method limits erosion on every acre within the basin to less than prescribed levels. The average restriction is examined first. The results of both the average and per acre restrictions are reported in Table C.3.

Initially an average soil loss restriction of ten tons per acre was imposed. This restriction, however, was not a binding restriction and resulted in the baseline solution being optimal. This was because the average loss under the baseline was less than the ten ton restriction imposed.

Next, an average soil loss restriction of five tons per acre was imposed. This became a binding restriction, decreasing basin-wide net revenue and basin wide soil erosion. Soil erosion for the basin was 39,000 tons, a decrease of 34,815 tons. Basin wide net revenue decreased by only $1,855 to $1,780,650. Almost the entire decrease in erosion is due to a shift in production to contouring from straight row operations. There was no change in crop rotations selected and a shift of twenty-five acres of the most steeply sloped soil from the use of a chisel plow in the fall to using a chisel plow in the spring.

The final average soil loss restriction was one of three tons per acre. Erosion was reduced to 23,400 tons for the entire basin, a drop of 50,415 tons. Basin wide income was $1,724,310, a drop of $58,200. The decreased erosion and revenue was due in part to changes in crop rotations, tillage practices and conservation practices. Six hundred acres changed from continuous corn rotation to a corn-soybeans rotation on the steeper sloped soils. Twenty-nine hundred acres changed tillage practices, compared to the baseline solution. Of these 2,900 acres, 2,300 acres changed to using a chisel plow in the spring while 600 acres changed to using a zero tillage method. All soils except those of slope class A adopted contour tillage under this restriction.

Under the more restrictive per acre limitation, a limit of ten tons per acre was first tried. This limitation served to reduce basin wide net revenue to $1,762,250, a decrease of $20,260 from the baseline solution. This same ten ton limitation resulted in a basin wide gross soil loss of 36,055 tons, a drop of 37,760 tons from the erosion resulting from the baseline solution. Most of this decrease in soil erosion came about because of a change in tillage direction away from straight, up and down tillage toward contouring. Twenty-eight hundred acres shifted from straight tillage to contour tillage. Some acreages were planted with new crop rotations; 600 acres which used the continuous corn rotation under the baseline solution had a corn-soybeans rotation under the ten ton per acre limitation. In addition, these same 600 acres were now tilled using a zero-tillage method instead of a chisel plow in the fall.

Next, a per-acre soil loss restriction of five tons was imposed. Under this restriction, soil loss on any acre in the basin was not allowed to exceed five tons. Basin wide net revenue decreased by $99,940 from the baseline solution to $1,687,570. Concurrently, soil erosion for the basin as a whole decreased to 21,820 tons, a drop of 51,995 tons from the baseline solution. This decrease in basin wide soil erosion was due primarily to a shift on 2,800 acres from using a chisel plow in the fall to using a zero-tillage method and a shift on those same 2,800 acres to using contour plowing. Under the baseline solution, all 2,800 acres had used straight row plowing.

The final per acre soil loss restriction used was a three tons per acre maximum loss. This is a very restrictive policy because the more steeply sloped soils usually lose more than three tons per acre under almost any combination of crop rotation, tillage practice and conservation practice. In light of the serious restriction this imposes, the resulting basin wide net revenue total of $1,630,000 is somewhat surprising. This represents a decrease of basin wide net revenue of $152,510 from the baseline solution. However, basin wide gross soil erosion decreased by 57,460 tons from the baseline solution level of 73,815 tons, to a level of 16,355 tons. The use of terraces on the most steeply sloped soils became optimal under this restriction. These steeply sloped soils also adopted the zero-tillage operation method instead of the previously used chisel plow in the fall. The zero-tillage method was used on 2,800 acres within the basin on the moderate to steeply sloped soils. The results of these restrictions are given in Table C.3.

No attempt was made to determine the administrative costs of the first form of restriction, the average restriction for the entire basin. It seems this form of restriction would have its best application at the farm level, restricting a farm's average soil loss to some level. However, administrative costs were estimated for the per acre restriction policy; these costs are assumed not to vary as the restriction level changes. These costs were estimated to be $159.25 per farm or a basin wide cost of $16,560. The per-ton social costs of erosion abatement for this policy are presented in Table 4.3.

erosion abatement of approximately 57,000 tons has an average social cost of approximately $2.94 per ton of abatement while a similar level of abatement under the tax and subsidy programs indicate an average social cost of $5.12 and $5.75 per ton, respectively. These figures imply the policy of restriction is the most efficient. This is not necessarily true.

Conversations with the Iowa Department of Environmental Quality and the Iowa Attorney General's office indicate that legal costs for the policy of restriction would be quite large. The general feeling was that in attorney's time alone, such a policy would easily require between fifty and one hundred hours of time per case. Using the estimate of the number of possible cases which Seitz developed, such a program would imply between two and eight cases for the watershed in the first year (Seitz (32)). Assuming a per-hour cost of fifty dollars for an attorney's time, this policy would result in added legal costs of $5,000 to $40,000 for the watershed.

If we make the assumption that the $5,000 figure applies to the five ton restriction and the $40,000 figure applies to the three ton restriction, then the social costs of this policy are considerably higher, especially at the larger abatement level. The per ton social costs of abatement, under the five ton per acre policy, increase from $2.24 to $2.37 per ton when these additional legal costs are included. Also, the costs of the three ton per acre policy increase, but more dramatically; previously these costs were $2.94 per ton of abatement but are now $3.64 per ton.

## Subsidization of Terracing Costs

Under this policy, the costs of constructing terraces is subsidized at levels of 50 percent, 75 percent and 90 percent. However, this subsidization does not affect the baseline solution; even at the 90 percent subsidy level, terracing does not become optimal. It is entirely possible that terracing would not become optimal at any level less than 110 percent. This is because the use of terraces also incurs a yield penalty by decreasing the land available for use. So even if construction costs are subsidized at a 100 percent level, terracing would still not become optimal without some restriction on soil loss.

In order to examine the effect of subsidizing terracing and at the same time restricting soil erosion, such a restriction was entered in the model. A subsidy of 50 percent of construction costs is considered in conjunction with a restriction on average soil loss of ten, five, and three tons per acre.

Initially a restriction of ten tons per acre was tried at the same time construction costs were subsidized at a 50 percent level. This subsidy had no effect on the results; that is, the basin wide net revenue and gross soil erosion were the same as under the ten ton per acre restriction without the subsidy.

Next, a restriction of five tons per acre was entered in the model with a 50 percent construction cost subsidy. This mix of construction cost subsidy and per acre restriction resulted in the same basin wide net revenue and gross soil loss as this per acre restriction did without the subsidy. This is because of the large number of choices available which result in soil erosion less than five tons per acre while yielding more net revenue than terraced operations.

Finally, a restriction of three tons per acre was considered in conjunction with a subsidy of 50 percent of construction costs. It was at this restriction level that terracing was chosen. However, terracing was selected only on the most steeply sloped soils, the same result that was obtained by considering only a per acre restriction of three tons and not considering a subsidy. Basin wide net revenue increased but only by the subsidy level for terracing. Gross soil erosion was the same as under the restriction policy alone. Net revenue was $1,656,000 and gross erosion was estimated to be 16,355 tons.

The policy of subsidizing terracing costs incurs administrative costs of approximately $91.40 per farm or $9,500 for the entire basin. However, such a program, when used in conjunction with a program of direct regulation of gross soil loss, will incur the administrative costs of the direct regulation program. These costs are estimated to be $159.25 per farm, or approximately $16,560 for the entire basin. If we assume no economies in administrative costs come about because of the concurrence of the programs, the total administrative costs for such a combination would be the sum of the individual costs, or $26,060 for the basin.

Subsidy of Purchase of Zero-Till Planter

Under this policy, the purchase of a zero-till planter is subsidized at levels of 50 percent, 75 percent, and 90 percent. It is assumed the purchase price of a zero-till planter is \$5,310. However, the importance of the subsidy is how it affects the variable cost of using the zero-till planter. This effect is through two factors: the capital cost per acre of equipment investment, and the ownership costs of depreciation, taxes and insurance per acre for equipment.

A subsidy level of 50 percent results in a purchase price of \$2,655 and the farmers capital costs and ownership costs are figured on this price. The same is true for the other subsidy levels. Under the 50 percent subsidy program, costs per acre decrease by \$.74, assuming an interest rate of ten percent. With the 75 percent subsidy program, per acre costs decrease by \$1.11; the 90 percent subsidy program results in a per acre cost decrease of \$1.33. These decreases in cost are seen to increase net revenue per acre by the same amount.

Under each of the subsidy levels, the baseline solution did not change. All activities were the same and so basin wide net revenue remained unchanged as did total gross soil erosion.

# CHAPTER V. SUMMARY, CONCLUSIONS AND FURTHER RESEARCH NEEDS

The results of the analysis of Chapter IV indicate that several policies are equally effective in controlling soil erosion, but at different levels of administrative cost. The analysis also indicates that several policies are ineffectual in controlling soil erosion.

A \$1.00 per ton tax on gross soil loss resulted in an average soil loss per acre of 5.00 tons, as did the \$1.00 per ton subsidy. This level was the same as the basin average under the policy restricting average soil loss for the entire basin to less than five tons per acre. Basin wide net revenue was significantly different between the programs; the policy of restriction resulted in net revenue of \$1,780,650, while the tax policy resulted in a lower net revenue total of \$1,741,720, a decrease of \$38,930 or an average per farm decrease of approximately \$375. Policy cost comparisons of these two programs are not available.

The results of the \$2.00 tax and subsidy are very nearly equivalent to the ten ton per acre restriction policy, in terms of average gross soil loss. Under the \$2.00 tax program, average soil loss was estimated to be 4.84 tons per acre; under the ten ton per acre restriction, average soil loss was estimated to be 4.62 tons per acre, a difference in total tons for the basin of 1,668 tons. The analysis indicates a large difference, however, in basin net revenue. The \$2.00 per ton tax program resulted in net revenue of \$1,702,660, the \$2.00 per ton subsidy resulted in net revenue of \$1,854,695 and the ten ton per acre restriction resulted in net revenue of $1,762,250. Administrative costs also varied significantly between the programs, while these costs were the same for the per-ton tax and per-ton subsidy solutions, they were different for the per-acre restriction solution. The administrative costs for the tax solution were estimated to be $19,450, while the administrative costs for the per acre restriction policy were approximately $16,495.

This similarity between programs was present with the per-ton tax and subsidy policies of $10.00 per ton and the per-acre restriction of three tons per acre. The restriction policy resulted in an average gross soil loss for the basin of 2.10 tons per acre, compared with a loss of 2.03 tons per acre under the tax and subsidy solutions. However, total net revenue did differ significantly between programs. The $10.00 per ton tax program resulted in net revenue of $1,516,690, while the $10.00 per ton subsidy resulted in net revenue of $2,362,310. Under the three ton per acre restriction, net revenue was $1,630,000; these differences result in a range of income of $845,620, or approximately $8,130 per farm.

While several policies were effective in controlling soil erosion, others were not. The ineffectual policies include subsidies for terrace construction costs and subsidies for the purchase of a zero-till planter. A policy also not having any effect was the policy outlawing the use of a moldboard plow in the fall.

The reason for the ineffectiveness of the latter policy is more a function of the model and the assumptions made than anything else.

I assumed all tillage practices except the zero-till method yielded the same number of bushels, so that the most profitable tillage practice became the one with the least cost; in the base run, this was using a chisel plow in the fall.

The terrace subsidy program's lack of success is due to the costs of terraces, both construction costs and costs of lost land. This program only considered construction costs, but even if these costs are subsidized 100 percent, the farmer still suffers a revenue loss due to lost yield.

The program subsidizing the purchase of a zero-tillage planter failed because of the relative insignificance of the planter itself in the whole operation. The cost of the planter was relatively insignificant compared to the rest of the capital requirements and so effectively did not matter.

Further research needs to be done in a multiperiod framework, because the soil erosion problem is truly a dynamic one. The farmer is depleting his capital stock through soil erosion and may in fact not be acting rationally to maximize the net present value of his wealth. Also, the costs to society are a dynamic problem and are not best seen in a one period analysis.

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# APPENDIX A

Table A.1. Fertilizer applications for corn production[a]

| Soil type | Rotation | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|
| | | | (lbs. per acre) | |
| Downs silt loam | C-C | 200 | 18 | 50 |
| | C-B | 190 | 18 | 50 |
| | C-C-O-M-M | 100 | 18 | 50 |
| Tama silt loam | C-C | 200 | 18 | 33 |
| | C-B | 170 | 18 | 33 |
| | C-C-O-M-M | 100 | 18 | 33 |
| Wabash-Judson | C-C | 200 | 31 | 25 |
| | C-B | 190 | 31 | 25 |
| | C-C-O-M-M | 100 | 31 | 25 |
| Muscatine silt loam | C-C | 200 | 22 | 33 |
| | C-B | 190 | 22 | 33 |
| | C-C-O-M-M | 100 | 22 | 33 |

[a]Source: Voss (41).

Table A.2. Fertilizer applications for soybeans, oats, and hay production[a]

| Soil type | Crop | Rotation | Fertilizer Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|---|
| | | | | (lbs. per acre) | |
| Downs silt loam | Soybeans | C-B | -- | 9 | 17 |
| | Oats | C-C-O-M-M | 60 | 18 | 42 |
| | Hay | C-C-O-M-M | -- | 9 | 33 |
| Tama silt loam | Soybeans | C-B | -- | 13 | 8 |
| | Oats | C-C-O-M-M | 60 | 18 | 17 |
| | Hay | C-C-O-M-M | -- | 13 | 17 |
| Wabash-Judson | Soybeans | C-B | -- | 22 | -- |
| | Oats | C-C-O-M-M | 60 | 31 | 17 |
| | Hay | C-C-O-M-M | -- | -- | 17 |
| Muscatine silt loam | Soybeans | C-B | -- | 18 | 8 |
| | Oats | C-C-O-M-M | 60 | 22 | 17 |
| | Hay | C-C-O-M-M | -- | 13 | 17 |

[a]Source: Voss (41).

Table A.3a. Herbicide requirements for corn production, continuous corn, corn-soybeans, and corn-corn-oats-meadow-meadow rotations, on major soil types[a,b]

| Rotation | Soil type | Herbicide | Application (per acre) |
|---|---|---|---|
| C-C | Downs silt loam | Lasso | 2.0 quarts (qts.) |
| | | Atrazine | 1.2 qts. |
| | Tama silt loam | Lasso | 2.5 qts. |
| | | Atrazine | 1.6 qts. |
| | Wabash-Judson | Lasso | 2.0 qts. |
| | | Atrazine | 1.2 qts. |
| | Muscatine silt loam | Lasso | 2.5 qts. |
| | | Atrazine | 1.6 qts. |
| C-B or C-C-O-M-M | Downs silt loam | Bladex | 2.0 qts. |
| | | Atrazine | .8 qts. |
| | Tama silt loam | Bladex | 2.5 qts. |
| | | Atrazine | 1.3 qts. |
| | Wabash-Judson | Bladex | 1.2 qts. |
| | | Atrazine | .6 qts. |
| | Muscatine silt loam | Bladex | 2.5 qts. |
| | | Atrazine | 1.3 qts. |

[a]Source: 1978 Chemical Crop Protection Guide (28).

[b]These are the requirements for all tillage methods except zero-tillage. The requirements for this method are the same for all soil types and are: Lasso, 2.5 qts., Atrazine, 2.5 qts., Paraquat, 1.5 pints, and X-77 (tank mix), 8 ounces per 100 gallons of water, all per acre.

Table A.3b. Herbicide requirements for production of soybeans, corn-soybeans rotation, on major soil types[a,b]

| Soil type | Herbicide | Application (per acre) |
|---|---|---|
| Downs silt loam | Treflon | 1.5 pints (pts.) |
| | Sencor | .75 pts. |
| Tama silt loam | Treflon | 2.0 pts. |
| | Sencor | 1.0 pts. |
| Wabash-Judson | Treflon | 1.0 pts. |
| | Sencor | .5 pts. |
| Muscatine silt loam | Treflon | 2.0 pts. |
| | Sencor | 1.0 pts. |

[a]Source: 1978 Chemical Crop Protection Guide (28).

[b]These are the requirements for all tillage methods except zero-tillage. These requirements are given in Table 3.4c.

Table A.3c. Herbicide requirements for production of soybeans, corn-soybeans rotation, using the zero-tillage method of tillage, on major soil types[a]

| Soil type | Herbicide | Application (per acre) |
| --- | --- | --- |
| Downs silt loam | Lasso | 2.5 quarts (qts.) |
| | Lorox | 2.0 pounds (lbs.) |
| | Paraquat | 1.5 pints (pts.) |
| | X-77 (tank mix) | 8 ounces (oz.) per 100 gallons of water |
| Tama silt loam | Lasso | 3.0 qts. |
| | Lorox | 3.0 lbs. |
| | Paraquat | 1.5 pts. |
| | X-77 (tank mix) | 8 oz. per 100 gallons of water |
| Wabash-Judson | Lasso | 2.0 qts. |
| | Lorox | 1.5 lbs. |
| | Paraquat | 1.5 pts. |
| | X-77 (tank mix) | 8 oz. per 100 gallons of water |
| Muscatine silt loam | Lasso | 3.0 qts. |
| | Lorox | 3.0 lbs. |
| | Paraquat | 1.5 pts. |
| | X-77 (tank mix) | 8 oz. per 100 gallons of water |

[a]Source: 1978 Chemical Crop Protection Guide (28).

Table A.3d. Herbicide requirements for production of oats, corn-corn-oats-meadow-meadow rotation, on major soil types[a]

| Soil type | Herbicide | Application (per acre) |
|---|---|---|
| Downs silt loam | 2,4-D Amine | .75 pints |
| Tama silt loam | 2,4-D Amine | .75 pints |
| Wabash-Judson | 2,4-D Amine | .75 pints |
| Muscatine silt loam | 2,4-D Amine | .75 pints |

[a]Source: 1978 Chemical Crop Protection Guide (28).

Table A.3e. Herbicide requirement for production of hay, corn-corn-oats-meadow-meadow rotation, on major soil types[a]

| | | Application (per acre) | |
|---|---|---|---|
| Soil type | Herbicide | 1st year meadow | 2nd year meadow |
| Downs silt loam | Tolban | 1.0 pints | |
| | Princep | | 1.5 pounds |
| Tama silt loam | Tolban | 2.0 pints | |
| | Princep | | 1.5 pounds |
| Wabash-Judson | Tolban | 1.0 pints | |
| | Princep | | 1.5 pounds |
| Muscatine silt loam | Tolban | 2.0 pints | |
| | Princep | | 1.5 pounds |

[a]Source: 1978 Chemical Crop Protection Guide (28).

Table A.4. Price vector

| Item | Price | Unit |
| --- | --- | --- |
| Corn | $ 3.20 | Bushel |
| Soybeans | 6.50 | Bushel |
| Oats | 1.60 | Bushel |
| Oat silage | 18.00 | Ton |
| Hay | 35.00 | Ton |
| Seed corn | 55.00 | Bag |
| Soybean seed | 10.25 | Bag |
| Oat seed | 4.50 | Bag |
| Alfalfa seed | 1.20 | Pound |
| Nitrogen | .13 | Pound |
| Potassium | .09 | Pound |
| Phosphorus | .18 | Pound |
| Treflan | 3.25 | Quart |
| Sencor 50W | 6.95 | Quart |
| Bladex 80W | 2.28 | Quart |
| Atrazine 80W | 1.95 | Quart |
| Lasso 4E | 3.56 | Quart |
| Paraquat | 40.00 | Gallon |
| 2,4-D Amine | .98 | Quart |
| X-77 tank mix | 13.00 | Gallon |

# APPENDIX B

Table B.1. Administrative costs for tax and subsidy policies

| Type of costs | Explanation | Costs (per farm) |
|---|---|---|
| Farm needs analysis:[a] | | |
| Technician labor | Three hours per farm @ $7.00 per hour | $21.00 |
| Monitoring costs: | | |
| Technician labor | Two hours per farm per visit @ $7.00 per hour for three visits per year | $42.00 |
| Office labor | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Reporting costs: | | |
| Writing | Two hours per farm per year @ $7.00 per hour | $14.00 |
| Typing | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Office maintenance costs: | | |
| Personnel | Three technicians with fixed labor costs of 20% of their annual salary ($14,500) | $83.00 |
| | Two secretaries with fixed labor costs of 20% of their annual salary ($9.500) | $18.00 |
| Total | | $187.00 |

[a]The farm needs analysis costs are valid only for the subsidy policy; total cost for the tax policy is then $166.00 per farm.

Table B.2. Administrative costs for terracing costs subsidy

| Type of costs | Explanation | Costs (per farm) |
|---|---|---|
| Farm needs analysis: | | |
| Technician labor (to determine eligibility) | Fifty hours per farm @ $7.00 per hour | $350.00 |
| Monitoring costs: | | |
| Technician labor | Two hours per farm per year @ $7.00 per hour | $14.00 |
| Office labor | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Reporting costs: | | |
| Writing | One hour per farm per year @ $7.00 per hour | $ 7.00 |
| Typing | One half hour per farm per year @ $4.50 per hour | $ 2.25 |
| Office Maintenance costs: | | |
| Personnel | One technician, with fixed labor costs of 20% of their annual salary ($14,500) | $27.90 |
| | One secretary, with fixed labor costs of 20% of her annual salary ($9.500) | $18.25 |
| Total | | $423.90 |

Table B.3. Administrative costs for zero-till planter subsidy

| Type of costs | Explanation | Costs (per farm) |
|---|---|---|
| Farm needs analysis: | | |
| Technician labor | One hour per farm @ $7.00 per hour | $7.00 |
| Monitoring costs: | None | |
| Reporting costs: | | |
| Writing | One half hour per year @ $7.00 per hour | $3.50 |
| Typing | None | |
| Office maintenance costs: | | |
| Personnel | One technician, with fixed labor costs of 20% of his annual salary ($14,500) | $27.90 |
| | One secretary, with fixed labor costs of 20% of her annual salary ($9,500) | $18.25 |
| Total | | $56.65 |

Table B.4. Administrative costs for policy of direct regulation of specific practices

| Type of costs | Explanation | Costs (per farm) |
|---|---|---|
| Farm needs analysis: | None | |
| Monitoring costs: | | |
| Technician labor | One half hour per farm per visit, three visits per year @ $7.00 per hour | $10.50 |
| Office labor | Twenty minutes per farm per year @ $4.50 per hour | $ 1.50 |
| Reporting costs: | | |
| Writing | Two hours per farm per year @ $7.00 per hour | $14.00 |
| Typing | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Office maintenance: | | |
| Personnel | One technician, with fixed labor costs of 20% of annual salary ($14,500) | $27.90 |
| | One secretary, with fixed labor costs of 20% of her salary ($9,500) | $18.25 |
| Total | | $76.65 |

Table B.5. Administrative costs for policy regulating soil loss by limits

| Type of costs | Explanation | Costs (per farm) |
|---|---|---|
| Farm needs analysis: | | |
| Technician labor | Four hours per farm per visit @ $7.00 per hour, one analysis | $28.00 |
| Monitoring costs: | | |
| Technician labor | One square mile per day three times per year, in the spring, summer and fall. With 104 farms and approximately 8,000 acres, one technician can monitor 8.5 farms per day @ $56.00 per day | $ 6.60 |
| Office labor | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Reporting costs: | | |
| Writing | Two hours per farm per year @ $7.00 per hour | $14.00 |
| Typing | One hour per farm per year @ $4.50 per hour | $ 4.50 |
| Office Maintenance costs: | | |
| Personnel | Three technicians, with fixed labor costs of 20% of their annual salary ($14,500) | $83.00 |
| | Two secretaries, with fixed labor costs of 20% of their annual salary ($9,500) | $18.00 |
| Total | | $158.60 |

# APPENDIX C

Table C.1. Results of tax on soil loss

| Tax level per ton of soil loss per year | Choice of tillage practice (acres in each) FM[a] | FC | SM | SC | NT | Basin net revenue | Basin gross soil erosion (tons) | Ave. soil loss per acre (tons) |
|---|---|---|---|---|---|---|---|---|
| 1. Base run | | 5,900 | | 1,900 | | $1,782,510 | 73,815 | 9.46 |
| 2. $1.00 | | 5,800 | | 2,000 | | 1,741,720 | 39,060 | 5.00 |
| 3. $2.00 | | 5,260 | | 2,540 | | 1,702,660 | 37,723 | 4.84 |
| 4. $5.00 | | 3,000 | | 4,200 | 600 | 1,607,300 | 28,660 | 3.67 |
| 5.$10.00 | | 2,500 | | 2,500 | 2,800 | 1,516,690 | 15,835 | 2.03 |

[a]FM - fall moldboard plow
FC - fall chisel plow
SP - spring moldboard plow
SC - spring chisel plow
NT - zero tillage method.

Table C.2. Results of subsidizing soil loss abatement

| Subsidy level per ton of soil loss abated | Choice of tillage practice (acres in each) FM[a] | FC | SM | SC | NT | Basin net revenue | Basin gross soil erosion (tons) | Ave. soil loss per acre (tons) |
|---|---|---|---|---|---|---|---|---|
| 1. Base run | | 5,900 | | 1,900 | | $1,782,510 | 73,815 | 9.46 |
| 2. $1.00 | | 5,800 | | 2,000 | | 1,823,300 | 39,060 | 5.00 |
| 3. $2.00 | | 5,260 | | 2,540 | | 1,862,360 | 37,723 | 4.84 |
| 4. $5.00 | | 3,000 | | 4,200 | 600 | 1,957,720 | 28,660 | 3.67 |
| 5.$10.00 | | 2,500 | | 2,500 | 2,800 | 2,048,330 | 15,835 | 2.03 |

[a]FM - fall moldboard plow
FC - fall chisel plow
SP - spring moldboard plow
SC - spring chisel plow
NT - zero tillage method.

Table C.3. Results of policy directly controlling soil loss through limitations

| Limitation levels | Choice of tillage practice (acres in each) | | | | | Basin net revenue | Basin gross soil erosion (tons) | Ave. soil loss per acre (tons) |
|---|---|---|---|---|---|---|---|---|
| | FM[a] | FC | SM | SC | NT | | | |
| 1. Base run | | 5,900 | | 1,900 | | $1,782,510 | 73,815 | 9.46 |
| 2. 10 tons average | | 5,900 | | 1,900 | | 1,782,510 | 73,815 | 9.46 |
| 3. 5 tons average | | 5,775 | | 2,025 | | 1,780,650 | 39,000 | 5.00 |
| 4. 3 tons average | | 3,000 | | 4,200 | 600 | 1,724,310 | 23,400 | 3.00 |
| 5. 10 tons per acre | | 5,200 | | 2,000 | 600 | 1,762,250 | 36,055 | 4.62 |
| 6. 5 tons per acre | | 3,000 | | 2,000 | 2,800 | 1,682,570 | 21,820 | 2.80 |
| 7. 3 tons per acre | | 3,000 | | 2,000 | 2,800 | 1,630,000 | 16,355 | 2.10 |

[a]FM - fall moldboard plow
FC - fall chisel plow
SP - spring moldboard plow
SC - spring chisel plow
NT - zero tillage method.