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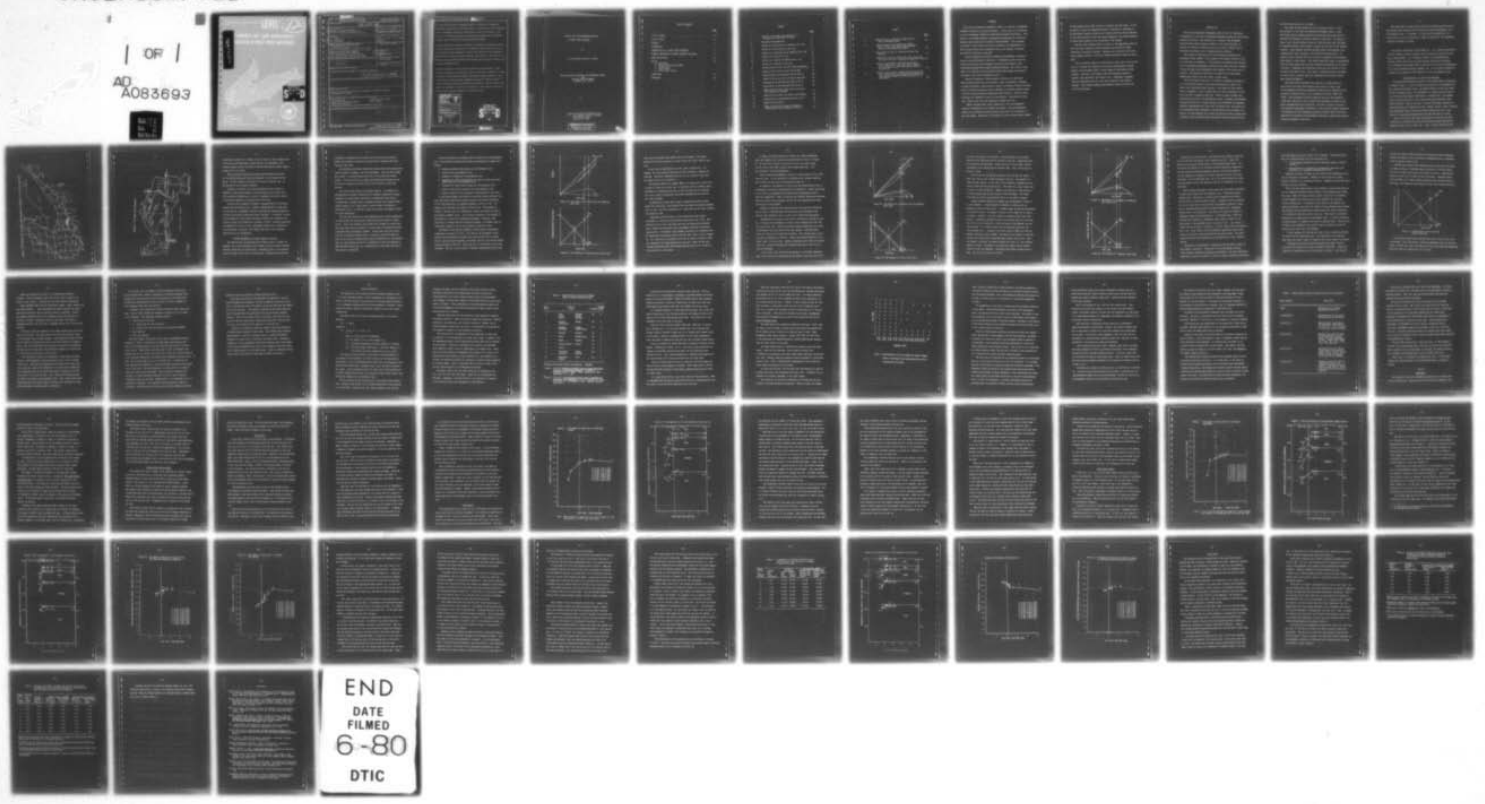
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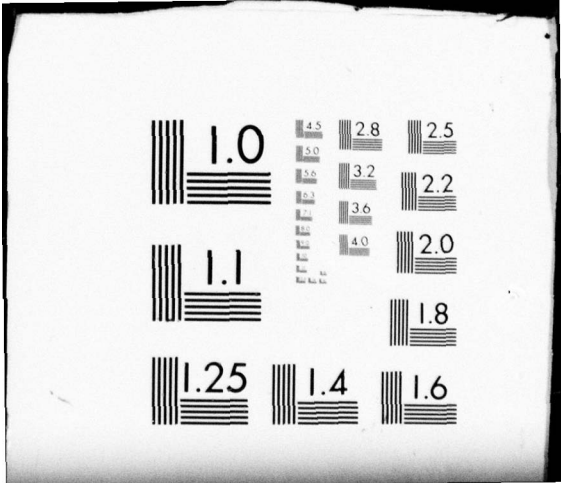
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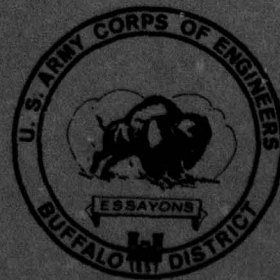
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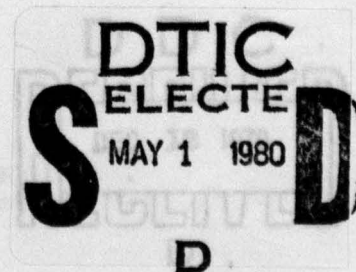
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The Lake Erie Wastewater Management Study is to develop a recommended management program for the Lake Erie Basin. A major part of this program is to be a management program for agricultural sources of pollution. This report is an economic analysis of alternative strategies for controlling nonpoint source pollution in the Honey Creek Watershed.

Earlier studies have pointed to sediment and phosphorus loadings as being critical pollutants in Lake Erie. In addition, previous work has inventoried existing farm management practices and alternative farm management practices which reduce pollutant loadings. The intent of this study is to identify the relationship between farm income and the major pollutants, soil loss and phosphorus loss.

Several strategies to reduce nonpoint pollution are identified. These include restrictions on pollutants, taxes on pollutants, subsidies to reduce pollutants, restrictions on inputs or processes causing pollutants, taxes on pollutant producing inputs, subsidies on pollutant abating inputs, or direct bargaining between perpetrators and sufferers. Three of these strategies are examined in detail in the analysis: restrictions on soil loss, taxes on soil loss and subsidies to reduce soil loss.

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ECONOMIC AND LAND MANAGEMENT ANALYSIS  
IN HONEY CREEK WATERSHED

by

D. Lynn Forster and Gary S. Becker

Ohio Agricultural Research and Development Center  
and  
The Ohio State University  
Columbus, Ohio 43210

1977

Lake Erie Wastewater Management Study  
U. S. Army Engineer District, Buffalo  
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## ABSTRACT

The Lake Erie Wastewater Management Study is to develop a recommended management program for the Lake Erie Basin. A major part of this program is to be a management program for agricultural sources of pollution. This report is an economic analysis of alternative strategies for controlling nonpoint source pollution in the Honey Creek Watershed. This watershed is located in north central Ohio and is thought to be representative of much of north central and northwestern Ohio, major sources of nonpoint agricultural pollution in Lake Erie.

Earlier studies have pointed to sediment and phosphorus loadings as being critical pollutants in Lake Erie. In addition, previous work has inventoried existing farm management practices and alternative farm management practices which reduce pollutant loadings. The intent of this study is to identify the relationship between farm income and the major pollutants, soil loss and phosphorus loss. <

Several strategies to reduce nonpoint pollution are identified. These include restrictions on pollutants, taxes on pollutants, subsidies to reduce pollutants, restrictions on inputs or processes causing pollutants, taxes on pollutant producing inputs, subsidies on pollutant abating inputs, or direct bargaining between perpetrators and sufferers. Three of these strategies are examined in detail in the analysis: restrictions on soil loss, taxes on soil loss and subsidies to reduce soil loss.

Results indicate that initial reductions in soil and phosphorus losses are inexpensive to the farmer and society. Soil and phosphorus losses can be reduced by nearly one-half with little or no reduction in net farm income. Reductions in pollutants are due to shifts toward reduced

tillage systems which either maintain or enhance net farm income. If the assumption is made that adequate drainage is available or installed in the watershed, minimum tillage and no tillage rotations could be employed on over three-fourths of the crop acreage compared to the current practice of using these systems on only 10 percent of the acreage.

The soil loss tolerance factor, T-value, is the approximate level of soil loss where substantial costs increases are incurred for added reductions in pollutant loadings. Reducing soil loss below the T-value forces dramatic shifts in crop and livestock production within the watershed.

The net economic impacts of restrictions on soil loss, a tax on soil loss, or a subsidy for reducing soil loss are approximately the same. However, the strategies differ in their impact on the farmer and the taxpayer. Generally, the farmers' order of preference would be a subsidy, then regulation, and finally a tax. Conversely, taxpayers' order of preference would be a tax, then regulation, and finally a subsidy. This ordering assumes administrative costs are similar for the three strategies.

## INTRODUCTION

The Lake Erie Wastewater Management Study of the U.S. Army Corps of Engineers is to develop a recommended management program for agricultural sources of pollution. The procedure is to identify land management practices which reduce pollutant loadings in the Lake Erie Basin, to quantify the effects of these practices on pollutant loadings, and to determine the economic cost of implementing the practices.

This study was completed by the Ohio Agricultural Research and Development Center (OARDC) at the request of the Buffalo District of the U.S. Army Corps of Engineers. It concentrates on estimating the economic cost of implementing management practices which reduce pollutant loadings. It uses the Honey Creek Watershed of North Central, Ohio as the unit of analysis. The purpose of the study is to identify the relationship between water quality and farm income in Honey Creek.

While the broader objective is to develop a management program for all of the Lake Erie Basin, this study concentrates on a small (189 square mile) watershed within the basin. The reason for this limited scope is threefold. First, northern Ohio is a major contributor to non-point pollution loadings in Lake Erie. There is strong evidence that agricultural activity is the predominant source of sediment and phosphate loadings from the area. Second, the Honey Creek Watershed is considered generally representative of rural land in Northern Ohio, and analysis of this watershed allows inferences to be made about much of Northern Ohio. Finally, limited resources and a close time horizon dictate a study which attempts to draw inferences about agricultural nonpoint pollution from a

relatively small portion of the Basin.

This study has been preceded by two significant efforts. First, during Phase I of the Lake Erie Wastewater Management Study, a large scale water quality sampling program was instituted across Lake Erie to determine the sources of pollutant loadings in Lake Erie. The result of Phase I was a strong indication that soil loss from crop land, delivered as suspended solids to water bodies, accounts for the bulk of the sediment loadings. These sediment loadings adversely affect fish spawning, lake transportation, water treatment, and recreational opportunities. In addition, plant nutrients which are carried by suspended solids stimulate plant growth in water bodies. This excess growth may create an unacceptable level of oxygen demand and eventually overwhelm the capacity of the lake's food chain. Phosphorus was identified as being the key nutrient in this process for the Basin (LJC). Thus, Phase I research pointed to the need for this study to consider explicitly phosphorus loss and soil loss as water quality parameters.

The second effort preceding this study was an identification of agricultural activities which improve water quality in Honey Creek. It was completed by Resource Managements Associates with assistance from Cooperative Extension Service, Soil Conservation Service, OARDC, and others. Farm management practices producing less soil and phosphorus losses were identified, and the current farm management practices in the Honey Creek Watershed were inventoried. This work, as part of the Lake Erie Wastewater Management Study Phase II, has provided valuable assistance in determining the farm management practices currently used in the watershed and the alternative farm management practices to improve water quality (Resource Management Associates).

This study adds to these previous efforts by quantifying the relationship between farm income and the two major water quality parameters, soil and phosphorus loss. It compares (a) water quality measures and (b) income accruing to the watershed as a result of alternative farm management practices available to farmers.

The specific objectives of this study are: (1) to identify alternative economic schemes to control nonpoint source agricultural pollution in the Honey Creek Watershed, (2) to develop a model of the watershed which includes current as well as soil loss reducing agricultural practices, (3) to determine the economic cost of reducing a unit of soil and phosphorus loss, under alternative economic schemes, and (4) to evaluate alternative economic policy schemes for the reduction of soil and phosphorus loss.

#### CHARACTERISTICS OF HONEY CREEK WATERSHED

The Honey Creek Watershed location in north central Ohio is identified in Figures 1 and 2. It is a 187 square mile portion of the Sandusky River basin located in Crawford, Huron, and Seneca counties, as well as a small portion of Wyandot county. The watershed is of moderate size and may be one of the most heterogeneous watersheds in northern Ohio. For example, alluvial and terrace soils in this region developed from western Ohio glacial material. Most of the soils of Seneca and Wyandot counties are comprised largely of limestone and clay. However, those of Huron, Crawford, and southeastern Seneca counties are medium textured and have a high content of extractable aluminum which increases the need for liming.

Most of the land of this area (approximately 87 percent) has been categorized by The Ohio Soil and Water Conservation Needs Committee as Capability Class I and II lands (18). Soils in these classes have few

Figure 1. The Location of the Honey Creek Watershed in Perspective to the Lake Erie Basin

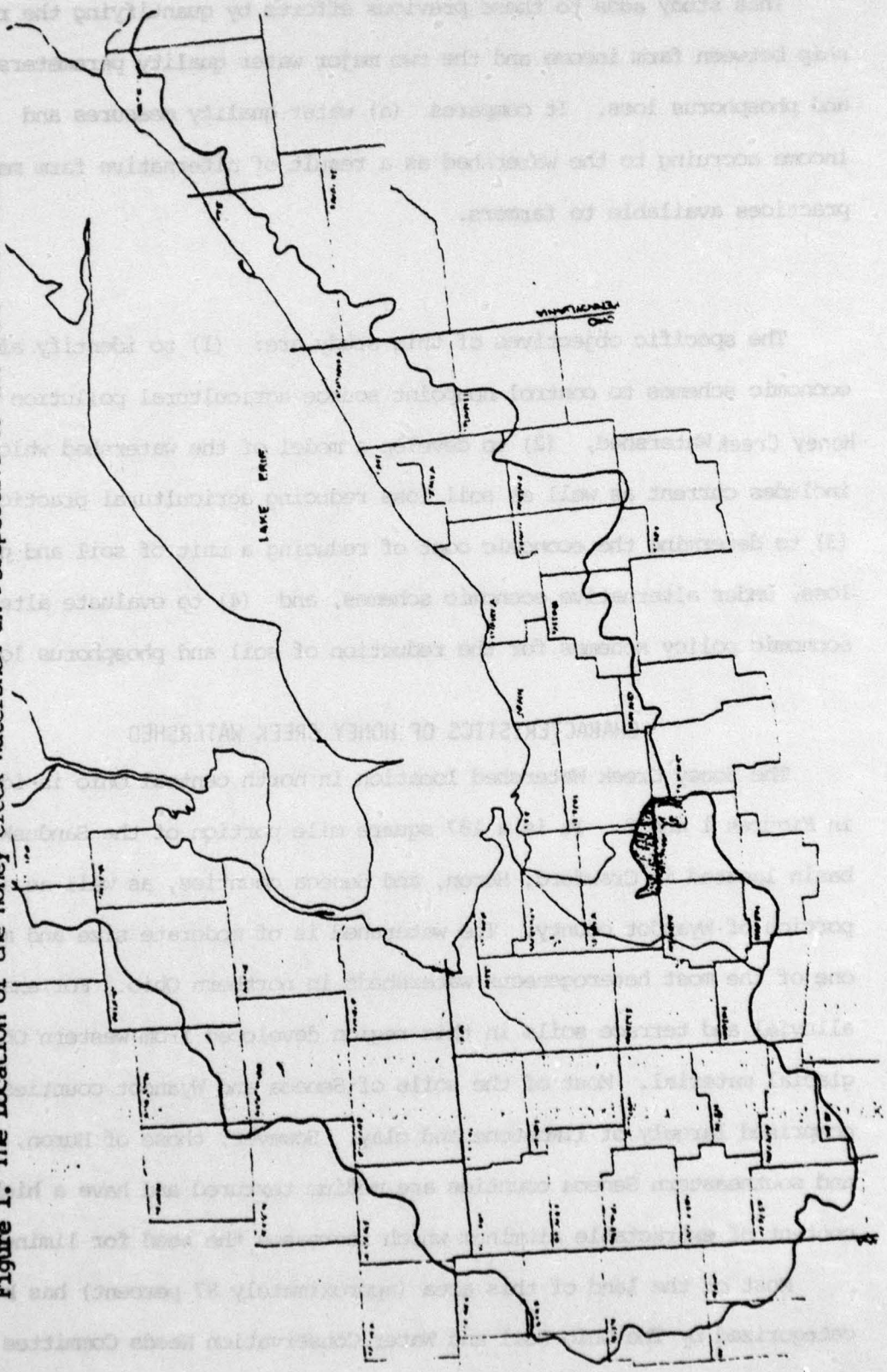
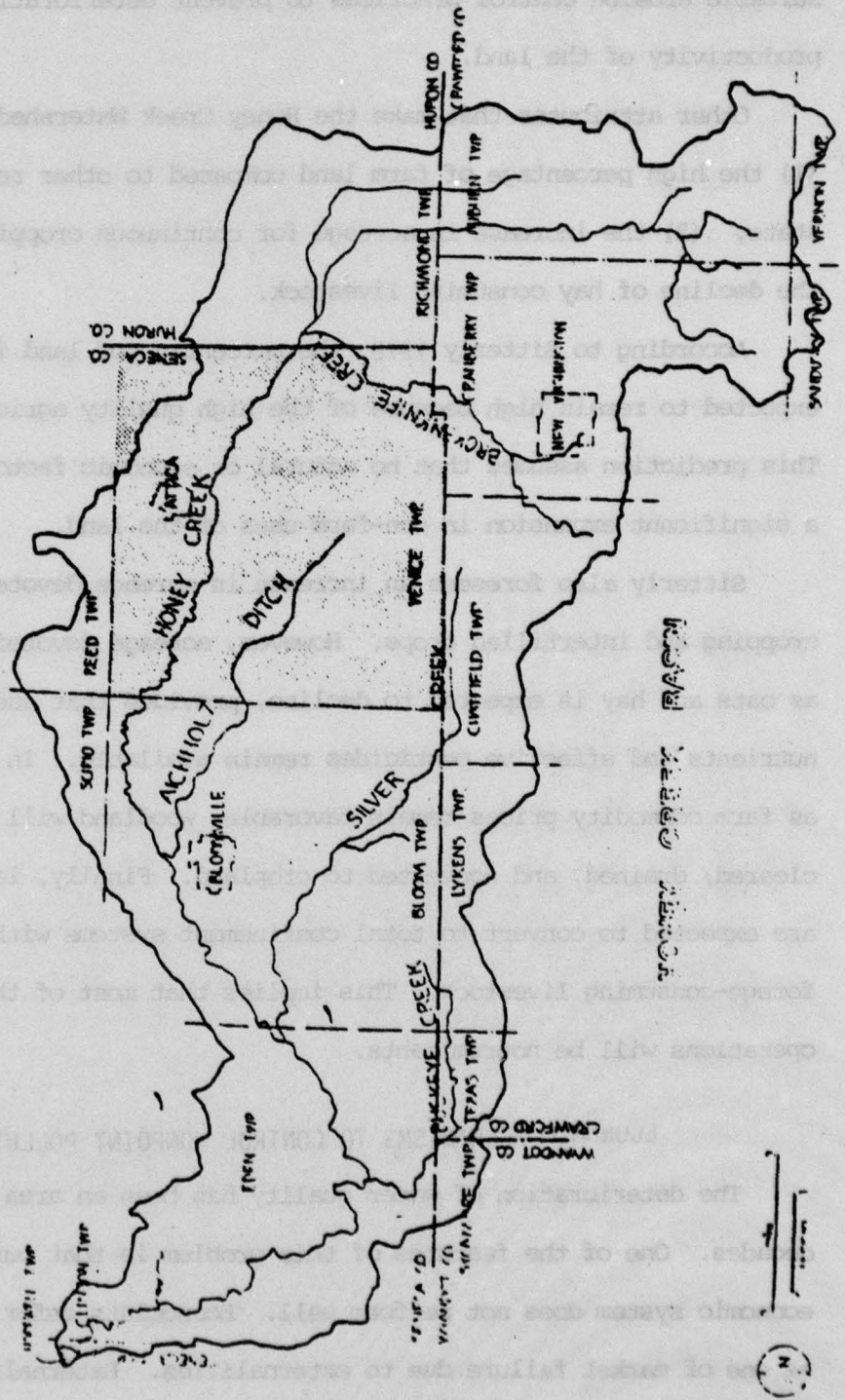


Figure 2. The Honey Creek Watershed





limitations on their use. However, soils of Class II, which comprise most of the Honey Creek Watershed, require careful soil management, with suitable erosion control practices to prevent deterioration and/or improve productivity of the land.

Other attributes that make the Honey Creek Watershed unique are:

(1) the high percentage of farm land compared to other regions of the state, (2) the increase in acreage for continuous cropping, and (3) the decline of hay consuming livestock.

According to Sitterly 1976, the percentage of land in farms is expected to remain high because of the high quality agricultural land. This prediction assumes that no natural or economic factors will lead to a significant expansion in non-farm uses of the land.

Sitterly also foresees an increase in acreage devoted to continuous cropping and intertilled crops. However, acreage devoted to crops such as oats and hay is expected to decline, provided that adequate amounts of nutrients and effective pesticides remain available. In addition, as long as farm commodity prices remain favorable, woodland will continue to be cleared, drained, and converted to cropland. Finally, livestock operations are expected to convert to total confinement systems with a reduction in forage-consuming livestock. This implies that most of the livestock operations will be nonruminants.

#### ECONOMIC MECHANISMS TO CONTROL NONPOINT POLLUTION

The deterioration of water quality has been an area of concern for decades. One of the features of this problem is that our market oriented economic system does not perform well. Economists refer to this problem as one of market failure due to externalities. Externalities exist when

a producer or consumer does not account for all costs of an activity. Rather, the incidence of some of the costs shift to someone other than those who cause them.

The efficient agricultural production machine faces such externalities. Farmers produce an abundant, low cost food supply. But also they produce soil erosion (or nonpoint source pollution if one prefers the latest jargon). Like the no-lead gas buyer, many farmers would rather not pay the price of lessening pollution since it's not always in their best interest.

Soil erosion has obvious environmental impacts. It produces soil sedimentation and higher concentration of chemicals (especially nitrogen, phosphorus, and pesticides) which lead to "downstream" costs such as increased water treatment costs, increased drainage ditch clearing costs, reduced reservoir life, algae growth in water bodies, and damage of recreational sites. In addition, severe soil erosion can damage the land for future generations.

Some say that the costs to those downstream and to future generations are high enough that agricultural producers should be forced to reduce erosion. While few producers would dispute the incidence of these costs, many would argue that the benefits of an efficient food production system overshadow these environmental impacts. Others argue that soil erosion needs to be reduced but charge that it is wrong to force the farmer to bear all the costs of reduced erosion when he receives few of the benefits. Thus, the issue centers around (a) a comparison of costs and benefits of improved water quality and (b) a determination of who bears the cost if water quality is improved.

A host of alternative strategies exist to restrict soil and phosphorus loss. The principle strategies which might be implemented in Honey Creek include:

1. emission standards restricting soil and phosphorus loss.
2. taxes on soil and phosphorus loss.
3. subsidy for reduced soil and phosphorus loss.
4. regulation of production processes or inputs to allow only those which reduce soil and phosphorus loss.
5. subsidies for inputs which reduce soil and phosphorus loss.
6. taxes on inputs which encourage soil and phosphorus loss.
7. market solutions to force producer internalization of all costs.

In the current debate over control of non point source pollution, the first and fourth alternatives usually surface as the control mechanism. In the first alternative, an emission standard is set on a firm. For example, soil loss shall not exceed 4 tons per acre. The producer is allowed to use his choice of technologies, inputs, and output as long as the emission standard is met. In the fourth alternative, the producer is restricted to a given set of production processes. Generally, less flexibility is allowed than with emission standards. An example might be restricting tillage to only no till systems on particular soils.

The impact of the emission standard on farm income is represented graphically in Figure 3a and 3b. Soil loss can be considered a joint product from the production process, thus total revenue (TR) is linear. That is, the more output produced, the greater the soil loss and the greater revenue received by the firm. Total cost (TC) is curvilinear as soil loss increases. That is, as more output is produced, diminishing returns cause

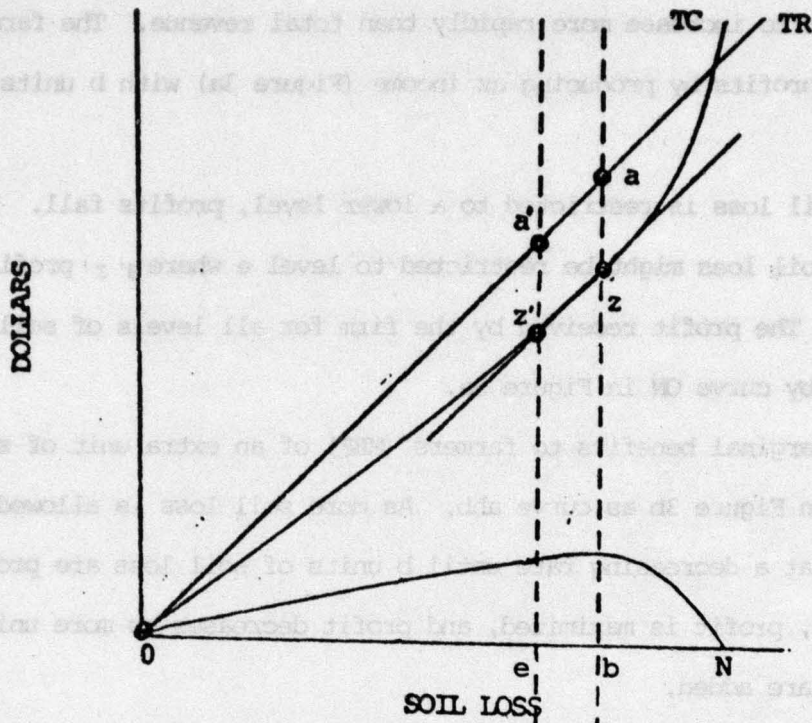


Figure 3a. The Effects of a Restriction for Reducing Soil Loss

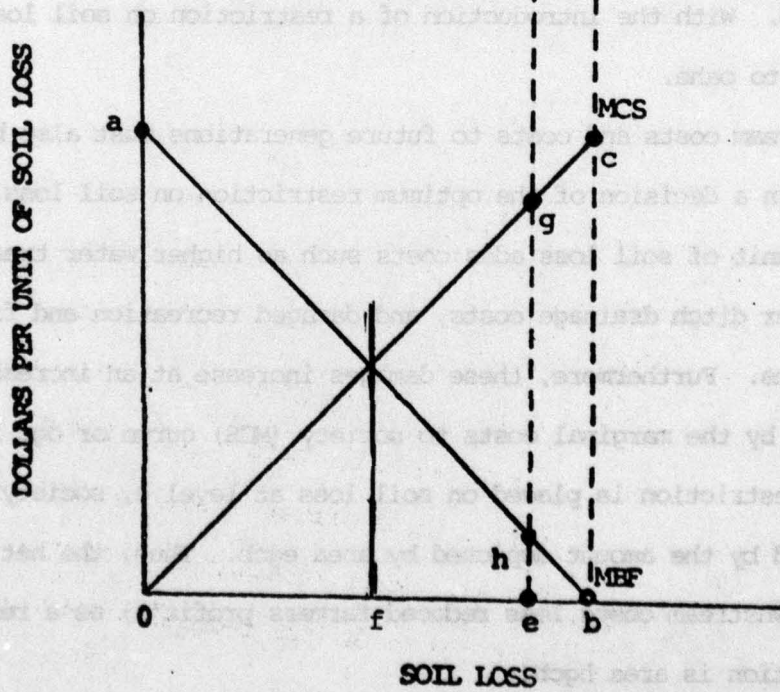


Figure 3b. The Effects of a Restriction on Soil Loss

total costs to increase more rapidly than total revenue. The farmer maximizes profits by producing  $az$  income (Figure 3a) with  $b$  units of soil loss.

As soil loss is restricted to a lower level, profits fall. For example, soil loss might be restricted to level  $e$  where  $a'z'$  profits are received. The profit received by the firm for all levels of soil loss are shown by curve  $ON$  in Figure 3a.

The marginal benefits to farmers (MBF) of an extra unit of soil loss is shown in Figure 3b as curve  $ahb$ . As more soil loss is allowed, profit increases at a decreasing rate until  $b$  units of soil loss are produced. At  $b$  units, profit is maximized, and profit decreases as more units of soil loss are added.

A restriction on soil loss to level  $e$  reduces farm income by  $ehb$ . Before the restriction, farm income is the area under the marginal benefits curve or  $oab$ . With the introduction of a restriction on soil loss, profits are reduced to  $oahe$ .

Downstream costs and costs to future generations must also be considered in a decision of the optimum restriction on soil loss. Each additional unit of soil loss adds costs such as higher water treatment costs, higher ditch drainage costs, and damaged recreation and fishing opportunities. Furthermore, these damages increase at an increasing rate as depicted by the marginal costs to society (MCS) curve or  $ogc$  in Figure 3b. As a restriction is placed on soil loss at level  $e$ , society's costs are lessened by the amount depicted by area  $egcb$ . Thus, the net gain (reduced downstream costs less reduced farmers profit's) as a result of the restriction is area  $hgcb$ .

In order to maximize benefits to society as a whole (downstream users and farmers), soil loss would be restricted to level  $f$  in Figure 3b. At that point, further restrictions on soil loss would reduce farmers profits more than it would reduce downstream costs. Soil loss less than  $f$  would be inefficient.

From an efficiency standpoint, society is clearly better off to allow some soil loss. If the interest is in maximizing net societal benefits, up to  $f$  units of soil loss are permitted in Figure 3b.

An important cost omitted in Figure 3b is the administrative cost of establishing, monitoring, and enforcing the restriction. Recent experiences at all levels of government would indicate that these administrative costs are substantial. They are borne by the taxpayer supporting government agencies as well as the consumer who pays for more administrative costs on the part of the producer.

Methods of reducing these administrative costs might be through the use of taxes or subsidies where the monitoring and enforcement costs would be less (Methods 2 and 3 on the list of alternative strategies).

Implementation of a tax on soil loss is illustrated in Figure 4a and 4b. In Figure 4a the producer is facing a total revenue curve (TR) and total cost curve (TC). When the vertical distance between the two curves is subtracted, the total profit curve (ON) emerges. Maximum profits occur at  $b$  units of soil loss with  $az$  profit. This initial level of soil loss also is depicted in Figure 4b. Again, the marginal benefits to the farmer (MBF) is the area  $oab$ . However, downstream water users are bearing costs  $ocb$ . Society's benefits are maximized when only  $f$  units of soil loss are produced.

A tax on soil loss could move the producer in the proper direction. When a soil loss tax is levied against the farmer, a new cost curve (TC')

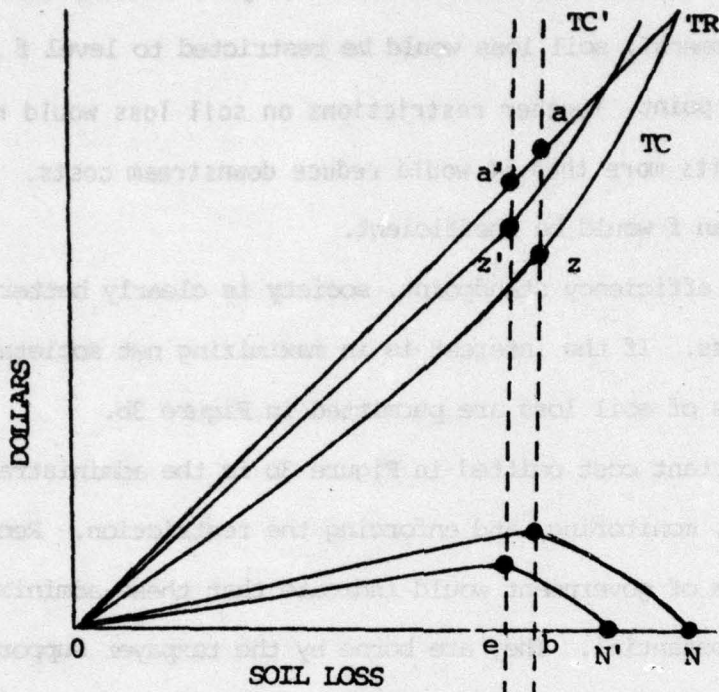


Figure 4a. The Effects of a Pollution Tax for Reducing Soil Loss

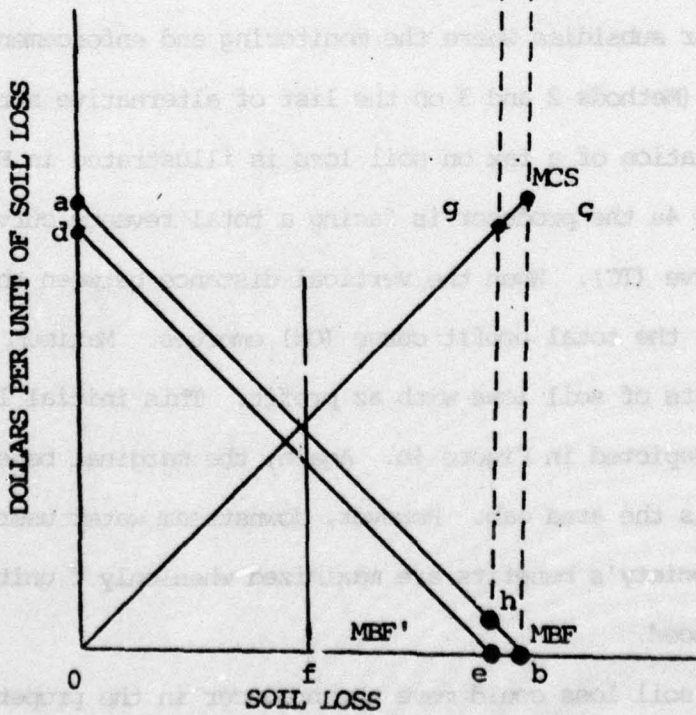


Figure 4b. The Effects of a Tax on Soil Loss

and profit curve ( $ON'$ ) are created. Marginal benefits to the farmer decline to  $de$ , and the profit of the farm is area  $ode$ . Downstream costs are reduced by the area  $egcb$ . Farmers realize a loss of  $dabe$ , and the governmental body levying the tax receives  $dahe$ . Thus, the net gain to society is  $hgcb$ .

Notice that the tax and the regulation have the same net effect. In each case, the net gain is  $hgcb$  (Figures 3b and 4b). The question is, "whose ox gets gored?" In the case of the regulation, taxpayers pay the costs of administering the regulation. The farmer has a only slight loss in profits of  $ehb$  (Figure 3b). However, with the tax a redistribution of income occurs away from the farmer to the tax coffer. The farmer loses  $dabe$  in profits of which  $dahe$  ends up in the public treasury.

Another economic mechanism to reduce soil and phosphorus losses is to use subsidies. A subsidy might be awarded for reducing soil or phosphorus loss below some limit. A subsidy scheme is depicted graphically in Figures 5a and 5b. No subsidy is given if soil losses are at level  $b$  or greater. However, a per unit subsidy is awarded if soil loss falls below  $b$ . Originally, the farmer faces total revenue ( $TR$ ) of  $oa$  and total cost ( $TC$ ) of  $oxz$  in Figure 5a. With the advent of the subsidy, the cost curve changes. If  $e$  units of soil loss are produced, the total cost curve becomes  $oxz'z$ . Initially, the profit curve is  $ORPN$ , but with the subsidy the profit curve is  $ORQPN$ . In Figure 5b, the farmer is originally enjoying  $oab$  profits while downstream users suffer costs of  $ocb$ . When the subsidy is enacted, the farmer reduces soil loss to  $e$ , and increases profits to  $oahfb$ . The amount of the subsidy is  $ehfb$ , and the farmers receive it from the taxpayers. Downstream users enjoy reduced costs of  $egcb$ . The net gain to society is  $hgcb$ .



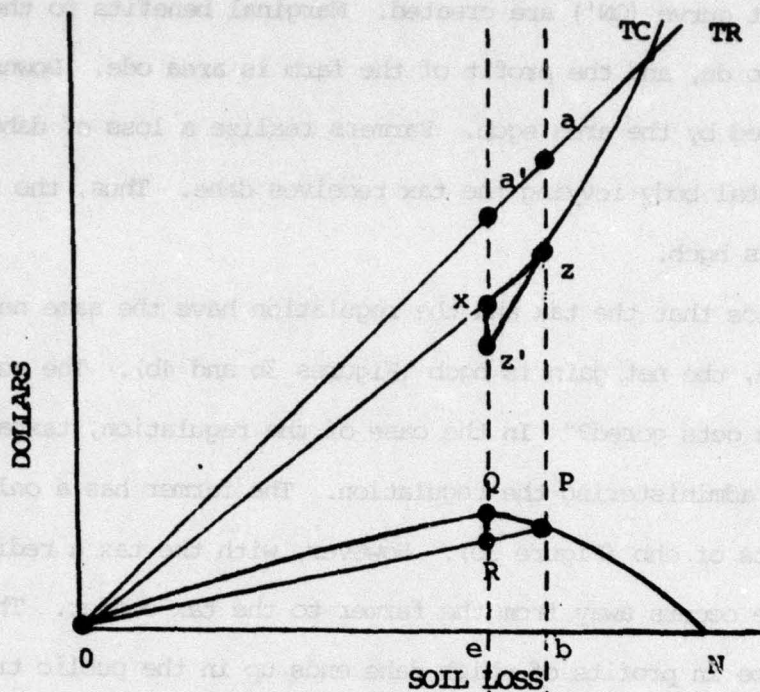


Figure 5a The Effects of a Subsidy for Reducing Soil Loss (1,34)

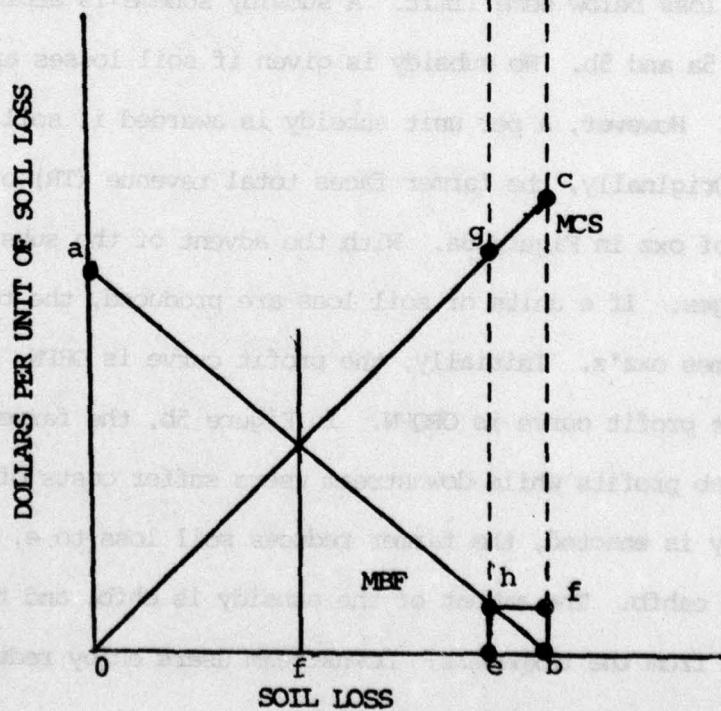


Figure 5b. The Effects of a Subsidy on Soil Loss

Notice the net gain of hgcb is the same with the subsidy (Figure 5b) as it is with the regulation or tax (Figures 3b and 4b). Again, the question of who gains and who loses is the differentiating factor. For the farmer the subsidy is the preferred economic mechanism, regulation is the next preferred economic mechanism, and tax is the least preferred. For the taxpayer the subsidy is the least preferred and tax is the most preferred. For the downstream user, any of the three methods can produce the same amount of soil loss reduction, and he is indifferent as to the mechanism.

Other economic mechanisms include regulation of production processes or inputs which reduce soil and phosphorus loss. Preliminary studies indicate that a restriction on inputs such as phosphorus would have a limited effect on improving water quality. Phosphorus loss is primarily due to soil loss and not the quantities of phosphorus applied to crops. Even if phosphorus applications are reduced dramatically, phosphorus remains tied to soil particles. Only when soil losses are reduced do phosphorus losses change dramatically. A watershed study in New York indicates that reduction in phosphorus usage causes a decline in row crops grown in the watershed (Casler and Jacobs 1975). Corn acreage is reduced and hay acreage is increased. A similar impact could be expected in Honey Creek. Thus, sharply limiting phosphorus application would cause land to be shifted to less profitable hay and small grains. The result would be less soil and phosphorus loss and dramatically lower incomes to farmers.

Regulation of technologies is consistent with the explicit goals of past federal legislation. Terms such as "best management practice", "best available technology economically achievable", and "best practicable technology currently available" are found in federal legislation concerning

point and nonpoint pollution control (U.S. Congress). The questions that need to be answered before using this mechanism are:

1. Is the mandated technology the most efficient method to achieve control?
2. Can regulations of technology be established, monitored, and enforced at a "reasonable" administrative cost?

Subsidies and taxes on inputs are the fifth and six mechanisms on the list of alternative strategies. Methods of taxing inputs are rather obvious, and there is no discussion of these. Subsidies can take many forms of which a few are discussed.

One of the more common forms is the allowance of accelerated depreciation to farmers who purchase certain types of farm implements that reduce soil loss. Under this type of policy, farmers using soil loss reducing tillage equipment can qualify much of their equipment for pollution control consideration. A variation of this theme is the proposal that farmers be granted a tax credit for reduced tillage equipment they purchase. This differs from the depreciation scheme because the credit constitutes a flat deduction from the emitter's tax bill. Other forms of government subsidies or tax exemptions are less commonly used. In some jurisdictions, tillage equipment is exempted from excise or property taxes. This practice is based on the assumption that certain forms of pollution can best be handled at the local level of government.

A final approach for reducing soil loss is direct bargaining between the farmer and the downstream users. This approach is only practical when there are a small number of sufferers and a small number of polluters.

Conceptually the direct bargaining approach has appeal since it alleviates the necessity for direct government regulation. Assume the farmers are overproducing soil loss as shown in Figure 6. Soil loss is

occurring at level b where the farmers own profits are being maximized. However, the farmer is not accounting for downstream costs. Downstream users are bearing costs of ocb.

Consider the incentive that downstream users could offer the farmer to reduce pollution. Downstream users would have to offer the farmer only ehb to "bribe" him to limit soil losses to level e. Both parties would be as well off or better off after the bribe. Downstream users would be better off by hgcb (reduced pollution costs less the amount of the bribe), and farmers would be equally as well off as before the bribe.

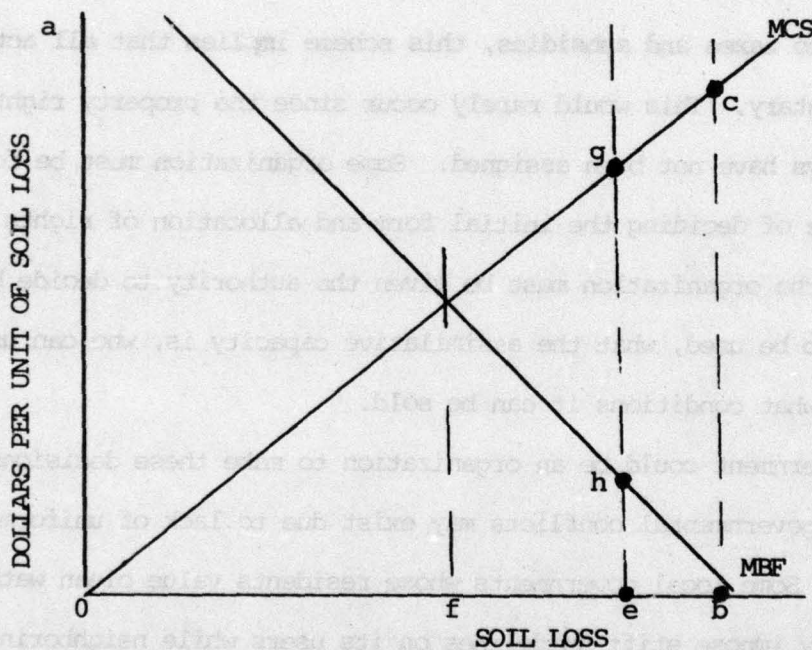


Figure 6. Optimum Level of Soil Loss With Direct Bargaining

This bribing process would continue until only f units of soil loss are produced. Until this point it would pay downstream users to bribe the farmer to reduce soil loss. But less than f soil loss would cost downstream users more than the reduced soil loss is worth.

Notice the resulting soil loss,  $f$ , is optimum from society's viewpoint. Here the marginal social cost of soil loss is equal to its marginal social benefit. Reducing soil loss more would be inefficient.

Three problems exist with this theoretical scheme. First, there is the free-rider problem. Some individuals may receive benefits for which they did not pay their share of the total costs of abatement. Second, the damages suffered by each of the downstream users are difficult to calculate. Finally, transaction costs are very high. This type of inducement would be very difficult to implement and be fair to all parties involved.

Contrary to taxes and subsidies, this scheme implies that all actions taken are voluntary. This would rarely occur since the property rights to the waterways have not been assigned. Some organization must be formed for the purpose of deciding the initial form and allocation of rights to users. Also, the organization must be given the authority to decide how the water is to be used, what the assimilative capacity is, who can use it, and under what conditions it can be sold.

Local government could be an organization to make these decisions. However, intergovernmental conflicts may exist due to lack of uniform restrictions. Some local governments whose residents value clean water very highly may impose stiff guidelines on its users while neighboring local governments who do not value clean water as highly will not bear their share of the clean-up costs. Also, farmers and downstream users are often in different local government units. This either forces those governments who value water highly to readjust their standards or cause local governments to mitigate their differences.

On the other hand, the federal or state government could be the decision making body. However, guidelines are imposed uniformly; those taxpayers who have relatively clean water might pay a relatively high and therefore disproportionate share of clean up costs as compared to those taxpayers whose water is polluted.

In summary, seven alternative economic strategies might reduce soil loss. Three of these schemes are examined in detail by use of a model of the watershed. The strategies examined include:

1. restriction on soil loss
  - a. restriction on a per acre basis.
  - b. a total soil loss restriction for the entire watershed
2. soil loss tax
3. soil loss subsidy

The first scheme, restriction on soil loss, is approached from two directions. First, a restriction is tested which would require each acre to meet some multiple of its soil loss tolerance factor or T-value (Bone, et al). These factors vary from soil to soil and represent the maximum rate of soil erosion that will allow a high rate of crop production to be sustained economically and indefinitely (Wischmeier and Smith 1965). In Ohio, the T-value ranges from 1 to 5 tons per acre. A restriction of this type has been suggested in recent discussions concerning state regulation of soil loss. The second approach to a restriction is to restrict total soil loss from the watershed. This restriction represents the outcome of a direct bargaining approach if no free rider problems or transaction costs are involved. Theoretically, it is appealing, but it is difficult to implement. This approach allows flexibility within the watershed. Some unproductive soils may be restricted substantially while

productive soils are allowed to produce heavy soil loss.

Soil loss taxes and soil loss subsidies are applied on a per ton basis throughout the watershed. The tax is applied to each ton of soil, thus a 4 ton per acre soil loss taxed at \$3 per ton would cost the farmer \$12 per acre annually. The subsidy is received by the farmer when soil loss is reduced below that produced by the most profitable cropping practice. Thus, if the farmer raises a low profit crop with 2 ton per acre soil loss but could raise a high profit crop with 5 tons per acre soil loss, the subsidy would be applied to 3 tons per acre.

Regulation of production practices, taxes on inputs and subsidies on inputs are not analyzed in this study. With farmers being scattered geographically, it would be extremely costly to monitor and enforce regulation of inputs used or production technology used. Preliminary analysis of a tax on phosphorus fertilizers indicates that little impact on soil loss or phosphorus loss occurs with phosphorus fertilizer taxes. Only a redistribution of farm income occurs. Taxes or subsidies on other inputs likely would cause the same limited impact on pollution.

### MODEL DESCRIPTION

The objectives of this study can best be achieved through the use of a linear programming model. Linear programming is a mathematical tool used to identify courses of action which will optimize some stated goal. It is a systematic method which will either maximize or minimize a linear objective function subject to restraints imposed by one or more linear inequalities.

The general form of the linear programming model is as follows:

Maximize

$$(1) \quad f = \sum_j C_j X_j$$

subject to

$$(2) \quad \sum_j a_{ij} X_j \leq b_i \quad i = 1, 2, 3, \dots, m.$$

where  $f$  is the value to be maximized.

$C_j$  = the effect on  $f$  of a unit change in  $X_j$

$b_i$  = a constant representing available supply of a resource

$a_{ij}$  = the input-output coefficient. A one unit change in  $X_j$  will affect the entity measured by  $b_i$  by  $a_{ij}$  units.

The objective function used in this model is the maximization of net revenue in the watershed. The activities ( $X_j$ 's) are agricultural enterprises found in the watershed which affect soil and phosphorous loss. These include growing corn, soybeans, wheat, oats, and hay on different soil types; using alternative levels of inputs and tillage practices on different sloping soils as well as raising dairy cows, feeder steers, beef cow-calves, feeder pigs, and finishing hogs.

The net revenue of each activity ( $C_j$ ) is the return above relevant cost. Resource restrictions ( $b_i$ 's) include constraints on total acreage in the watershed, limitations on corn, wheat, soybeans, oats, and hay



acreages, and upper and lower bounds on beef, swine and dairy raised.

Additional restrictions are imposed which force the various land characteristics to be equal to those actually found in the watershed.

Each category is unique with respect to such characteristics as soil type, slope, and length. Other restrictions in the model place an upper limit on soil and phosphorous loss from the watershed and upper limits on soil loss from each soil category.

There are four major sets of activities, each comprised of numerous individual activities. These activities include crop production, livestock production, crop marketing, and livestock marketing. However, due to limited computer storage space and costs, it was decided to focus most of the computer's resources on crop producing activities.

Each crop activity is comprised of five components-- S, soil type; R, rotation; T, tillage practice; Y, yield; and L, slope. S refers to the ten homogeneous groups of soils identified by series which will be denoted as "soil group." There are 44 different soil series in the watershed which comprise 114,506.4 acres or approximately 178 square miles. Since many of the soil series are homogeneous with respect to "K" value in the Universal Soil Loss equation, natural productivity, and response to no-tillage, for modelling purposes the watershed is viewed as being comprised of ten soil groups. Table 1 identifies the soil series in each of the ten soil groups as well as its homogeneous attributes.

Obviously, some of the soil series would not be homogeneous with any of the ten soil types identified. These are not incorporated into the model. Therefore,  $(107,921/114,506.4 = 94.2 \text{ percent})$  94.2 percent of all available land in the watershed is being modelled.

Table 1. Characteristics of Ten Soil Groups  
Used in Linear Programming Model

Soil Group	Soils in Group		K value <sup>a</sup>	Tillage Group <sup>b</sup>
1	Bono Lorain Luray	Marengo Toledo Walkill	.24	4
2	Chagrin Papakating	Shoals	.28	5
3	Lenawee Millsdale	Pewamo Pewamo-Urban	.28	4
4	Belmore	Gallman	.32	1
5	Haney	Hennepin-Ale.	.32	1
6	Digby	Haskins	.32	2
7	Belmore-Morley	Milton	.37	1
8	Condit		.37	3
9	Cardington Glynwood	Morley Ritchey	.43	1
10	Bennington Blount	Tiro	.43	2

<sup>a</sup>K value to be used in soil loss equation  $A=RKLSCP$

Source: U.S.D.A. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, by Walter H. Wischmeir and D.D. Smith. Agric. Handbook No. 282. Washington, D.C., 1965.

<sup>b</sup>Source: O.A.R.D.C. An Evaluation of Ohio Soils in Relation to No-Tillage Corn Production, by G.B. Triplett, Jr., D.M. Van Doren, Jr., and Samuel W. Bone. Research Bulletin 1068, 1973.

R identifies the alternative rotations being modelled. They are continuous corn, corn/soybeans, corn/wheat, corn/wheat/meadow, corn/oats/meadow, and continuous meadow. These were chosen because they represent rotations currently in practice, those proven to reduce soil loss, and crops grown in the region aside from corn (Becker and Forster 1976).

If a rotation consists of three crops while another, one or two, the yield of each crop in the rotation divided by the number of crops in the rotation is the yield represented in the model. This allows us to view the model in the time frame of one year.

There are four T tillage systems identified. They are (1) spring plow, residue left, (2) fall plow, residue left, (3) 33 percent soil surface tilled or minimum tillage, and (4) 10 percent soil surface tilled or no-tillage. Each has a different effect on soil loss, phosphorous loss, and yield in combination with the soil type and slope length factor.

Soils of tillage group three (See Table 1) may only be spring or fall plowed. According to Triplett, et al., the soils of this group will not respond to subsurface drainage since water can not effectively move through the soil. Thus, current technology in drainage improvements will not allow minimum or no-tillage activities for soil type eight.

Soils of tillage group five play an important role since these are mostly alluvial soils adjacent to streams. Even though there is little satisfactory data on soils of this group, reduced tillage does not seem to affect yield.

Y or yield level refers to the three levels of crop production. This is dependent upon the natural fertility of the soil, tillage practice, and the level of crop nutrients added during the crop year.

There are three base yield goals for each of the crops in the models. Yield goals for corn are 80, 120, and 160 bushels per acre, and yield goals for soybeans are 35, 50, and 65 bushels per acre. For wheat production, yield goals are 30, 50, and 70 bushels per acre and oat production, 50, 75, and 100 bushels per acre. Finally, if hay is grown on soil for less than two years, a yield goal of two tons per acre is expected, and if hay is in a rotation for two years or more, a yield goal of 3.5 tons per acre is expected. These goals are derived from nitrogen, phosphorous, and potassium recommendations for each of the identified crops in the 1976-77 Agronomy Guide.

The model implies two assumptions regarding crop yield. First, that the inputs into the system (tillage practice and fertilizer application) do not change during a rotation on a specific acre of land. Thus, management levels remain constant. Second, when there are two levels of hay production (as mentioned earlier) and the stand has not matured, then the lower yield is to be used.

The slope length factor  $L$  identifies the percent slope and slope length. There are ten different slope categories ranging from 0-2 percent to 18+ percent, each with a mean slope length for calculating soil loss. However, some soil groups are void of acreage of a particular percent slope. Table 2 identifies the combinations of soil group and slope length incorporated into the model.

For each crop activity, the Universal Soil Loss Equation is used to estimate gross soil loss (Wischmeier and Smith 1965). Phosphorus loss is assumed to be linearly dependent on soil loss (Logan).

The second set of activities considered in the model are the five different livestock producing enterprises. These are dairy cow, feeder

SOIL GROUP	PERCENT SLOPE										
	0.0-1.99	2.0-3.99	4.0-5.99	6.0-7.99	8.0-9.99	10.0-11.99	12.0-13.99	14.0-15.99	16.0-17.99	18+	
1	X	X	X	X	X						
2	X	X	X		X		X		X	X	
3	X	X	X	X	X						
4	X	X	X	X	X	X		X		X	
5	X	X	X	X							
6	X	X	X	X	X	X					
7	X	X	X	X						X	
8	X	X	X	X							
9	X	X	X	X	X	X	X	X	X	X	
10	X	X	X	X	X	X	X	X	X	X	

Table 2. Identification of Soil Groups and Percent Slopes Found in the Honey Creek Watershed Which are Incorporated into Model.

steer, cow-calf, feeder pig or swine breeding, and fed hog production. Inclusion of these activities provides us an alternative means to market the grain being produced. Also, the phosphorous obtained from manure can be used in raising crops as an alternative to purchasing phosphorous outright.

No phosphorous or soil loss is associated with livestock production in this model. Unlike large feedlots found west of the Mississippi River, the operations here are small and diversified. The amount of soil and phosphorous loss is negligible except in cases where the livestock are not fenced from streams or drainage ditches. According to the results of the Venice township survey prepared by Becker and Forster (1976), this is not a major problem in the area.

There are subdivisions within the activities of dairy cow, feeder steer, feeder pig or swine breeding, and fed hog production, according to whether the animals are fed on corn purchased inside or outside of the watershed. Corn purchased outside the watershed is 21 cents per bushel higher than that purchased inside. This is due to (1) a nine cent per bushel shipping charge from the port of Toledo to the watershed and (2) a twelve cent per bushel elevator operating margin.

The activities of livestock and crop marketing remain to be discussed. There is no hay selling activity per se in the watershed. It is assumed that hay is only sold to livestock enterprises inside the watershed. This assumption limits the amount of hay acreage receiving positive gross returns by the amount of bovine production. Such limitations have important implications for the model since hay is a low soil loss producing crop. To test this assumption, a multiple regression analysis was performed where the dependent variable was hay acreage harvested per

county divided by county size and the independent variables were all cattle and calves per county divided by county size, and milk cows and heifers per county divided by county size. Observations were obtained from 85 Ohio counties.

The  $r^2$  and adjusted  $r^2$  are .5574 and .5460 respectively. The  $t$  values for all cattle and calves is 3.007 and milk cows and heifers, 5.2009. With these results, we reject the null hypothesis  $H_0$ , that there is no relationship between the independent and dependent variables at the one percent level of significance.

One thing that a regression analysis cannot do is determine a causation-correlation relationship. However, the results indicate that hay is grown where ruminants are raised and ruminants are raised where hay is grown. It would be a safe assumption, given the fact that hay production is a less profitable enterprise than corn, soybeans, or wheat production, to sell hay only inside the watershed.

Price projections for corn, wheat, soybeans, beef, dairy, and hogs, have been prepared for 1977-81 by Davison and Ericksen of the Commodity Economics Division, Economic Research Service. Prices for output from the watershed are based on these projections. Costs are based on the Ohio Crop and Livestock Budgets developed by the Cooperative Extension Service (Lines, et al).

The model has a number of restrictions or  $b_i$  coefficients in equation (2). One set of these restrictions force the model to restrict the soil and phosphorous losses for the entire watershed. Another set forces soil and phosphorus losses to be restricted for each acre of soil.

Crop acreage restrictions for corn, wheat, soybeans, and oats limit the amount of land devoted to each enterprise in the watershed. These restrictions are an artificial means of limiting the amount of grain produced so that the results (1) represent the enterprises currently in the watershed as realistically as possible, and (2) represent maximum and minimum acreage devoted to crops based on historical data.

The amount of hay produced is dependent upon the demand for hay by livestock. The model is formulated such that more hay can be produced than sold. However, if all the hay is not consumed, it cannot be marketed.

Restrictions are also established for the production of beef, dairy, and hogs. The same logic used for the crop producing enterprises is used here to limit the numbers which may be produced.

Results of the model are obtained under six alternative scenarios as shown in Table 3. The first scenario, "base", represents current agricultural practices in the watershed. It requires that 90 percent of all tillage be done by conventional tillage methods. The results from this scenario provide estimates of net farm income, soil loss, and phosphorus loss under current practices.

The "unrestricted" scenario represents the watershed under the most profitable agricultural practices. It is known that, in the long run, minimum and no tillage practices are more profitable than conventional tillage on many soils. The unrestricted scenario removes the base model's restriction on conventional tillage and allows the most profitable tillage system to be used. If farmers tend to behave as profit maximizers, the results of this scenario estimate farmers long run behavior.



Table 3. Model Scenarios used in Long Run and Short Run Analyses

Model Scenario	Description
"Base"	Representation of current agricultural practices.
"Unrestricted"	Representation of most profitable agricultural practices.
Policy Set A	Restricts total soil loss in the watershed. Restrictions of 3.00, 2.57, 2.14, 1.29, and 1.13 tons per acre are tested.
Policy Set B	Restricts per acre soil loss by some proportion of the T value (Soil loss tolerance factor). Restrictions tested are 2.0T, 1.75T, 1.5T, 1.25T, 1.0T, .75T, and .50T.
Policy Set C	Restricts total soil loss by instituting a soil loss tax. Taxes of \$6.00, \$9.00, \$12.00, \$15.00, \$18.00, \$21.00 and \$24.00 per ton are modelled.
Policy Set D	Restricts total soil loss by instituting a soil loss subsidy. Subsidies of \$6.00, \$9.00, \$12.00, \$15.00, \$18.00, \$21.00 and \$24.00 per ton are modelled.

Policy set A restricts total soil loss in the watershed. It allows the model to allocate soil loss among soils in the watershed in order to maximize profits. Thus, soil loss may be quite heavy from some very productive soils and light from others.

Policy set B restricts soil loss on each acre of soil by some multiple of the T value. The T value, also called the soil tolerance factor, is the maximum rate of soil erosion that will allow a high level of crop production to be sustained economically and indefinitely. According to Wischmeier and Smith(1965) these factors are expressed in terms of average soil loss per acre per year. Using research data, experience, and knowledge of the soil series, alternative sets of practices or management plans can be selected to meet the T value for that soil. Using the unrestricted model and lowering each soils output of soil loss by increments of the T value, the model seeks those activities which maximize net revenue.

The next model, policy set C, taxes soil loss. In the objective function of the unrestricted model, the cost of a ton of soil is \$0.00. When a negative value is substituted in its place, the optimal solution will represent the watershed when a tax is levied on soil loss.

Policy set D is a subsidy for reducing soil loss. If the farmer reduces soil loss below that of the unrestricted model, a subsidy is awarded.

## RESULTS

### Base Model

The results of the policy schemes presented here are neither forecasts or predictions. They provide us with a means for estimating the

relative impacts of variations in policy. The first of policy scheme analyzed is that of the base model.

During 1976 in Seneca County, where the majority of the watershed lies, approximately 31 percent of the land was planted in corn, 35 percent in soybeans, 21 percent in wheat, 6.4 percent in oats and 6.3 percent in hay. The base model for the watershed allocates 46 percent of the land to corn, 28 percent to soybeans, 12 percent to wheat, 5.1 percent to oats and 8.7 percent to hay. Even though a model cannot duplicate reality perfectly, the values obtained are considered reasonable.

In recent years, corn and soybeans have alternated as the number one crop. Since their crop acreage totals 65 to 70 percent of total crop acreage, one would expect both crops to maintain their primary importance. The base model accurately reflects this importance.

The number of livestock represented in the base model closely represents that which actually exists. According to Ohio Agricultural Statistics 1976, 35.3 percent of all the animals produced are "all cattle and calves," 7.86 percent are "milk cows and heifers that have calved," and 56.86 percent are "hogs and pigs." The model devotes 36.39 percent of all livestock to "beef cows and calves" and "fed beef," 6.19 percent to "dairy," and 57.42 percent to "fed swine" and "breeding swine." In each case there is less than a two percent difference between the figures.

According to the Honey Creek base model, bushels of corn sold account for 68.5 percent of all grain sold, 18.6 percent for soybeans, 8.3 percent for wheat, and 4.5 percent for oats. In Seneca County during 1976, 57.49 percent of all grain produced and sold was corn, 20.59 percent soybeans, 14.93 percent wheat, and 6.97 percent oats. Considering

all aspects of production, the base model performs a satisfactory job of modeling current activities.

Base model results indicate that net returns to farmers in the watershed are \$16,168,743.93 or approximately \$149.82 per acre per year. Net returns are defined as returns above all costs except land costs. Land costs are excluded because each acre of land has the same opportunity cost regardless of usage. Soil loss is occurring at an average rate of 6.194 tons per acre per year, ranging from approximately 1.345 tons per acre to 8.316 tons per acre depending upon the soil type. Phosphorous loss is occurring at an average rate of 13 pounds per acre per year. The rotations most frequently seen in this model are fall plow corn/soybeans, fall plow corn/oats/meadow, and some fall plow corn/wheat.

#### Unrestricted Long Run Model

The unrestricted long run model, which maximizes net revenue, absent of any soil loss restriction, yields some very surprising results. Acreages devoted to each crop are the same as the long run base model, however, total bushels of corn increase while others decline. Also, there is a slight decrease in the number of dairy livestock produced. Net revenue in the watershed is almost one million dollars greater in the unrestricted model than in the base model ( $\$17,154,062.99 - \$16,168,743.93 = \$985,319.06$ ) and yearly soil loss is reduced by more than three tons per acre to 3.191 tons per acre. Phosphorus loss is reduced to 6.98 pounds per acre.

The results indicate that an incentive to reduce soil loss is present and total net revenue can easily rise if soil loss reducing technology is adopted. Apparently, short run transition costs including yield risk and uncertainty are much greater than the increased returns due to higher

yields and reduced soil loss. In the unrestricted model, the predominant rotations are reduced tillage corn/soybeans and no-tillage corn/oats/meadow. Some no-tillage corn/wheat is also grown.

#### Policy Set A

Policy set A restricts total soil loss in the watershed. The maximum soil loss allowable in the watershed summed over all soil types for the first run of this set is 3.00 tons per acre per year. Soil losses range from 1.264 tons per acre to 4.446 tons per acre depending on soil type. Phosphorus losses total 6.3 pounds per acre. Compared to the unrestricted model, net revenue declined by \$1,214.37 in the watershed due to the added restriction. Again, as in the unrestricted model, acreages devoted to each crop does not change; however, the marketed number of bushels of corn decreases. This is due to shifts in production from the more productive soils to the less productive ones. Also, there are additional bushels of soybeans, wheat, and oats sold. The new rotations which include these crops probably account for the reduced soil loss even though soybeans are just as erosive as corn.

The predominant rotations seen in this run are reduced tillage corn/soybeans and reduced tillage corn/wheat. Some reduced tillage corn/wheat/meadow is also grown except on soil type eight where fall plowed corn/wheat/meadow is the only activity engaged in. As discussed in the previous chapter, this is due to the inherent drainage problems of the soil.

When the soil loss restriction is 2.572 tons per acre per year the new objective function is \$16,968,857.66. The decrease in net revenue is \$183,990.96. Therefore, if soil loss is reduced from an average of 3.00

tons per acre to an average of 2.572 tons per acre in the entire watershed, the marginal cost of reducing soil loss is \$3.98 per ton per year. Phosphorus loss is reduced to 5.42 tons per acre.

Other differences between the 3 ton per acre average restriction and the 2.572 ton per acre average restriction are the number of bushels sold in the watershed and the number of dairy cows produced. Apparently, a smaller number of bushels of corn and wheat are sold and a larger number of bushels of soybeans and oats are marketed. Dairy cow production also declines slightly.

Next, soil loss is restricted to averages of 2.14, 1.72 and 1.29 tons per acre. When soil loss is reduced to these levels, the income in the watershed and crop rotations are similar to previous restrictions. The only exception is that acreage devoted to corn and soybeans is drastically reduced and consequently hay acreage increases. Obviously, if the hay cannot be marketed outside the watershed, the number of livestock must increase to equate the excess supply with demand. Otherwise the hay will remain unconsumed.

When soil loss is restricted to 1.129 tons per acre and phosphorus to 2.38 pounds per acre, many changes take place in the watershed. First, corn and soybean acreage decreases to 76.6 percent and 62.1 percent of their unrestricted run levels. Second, hay acreage increases more than three-fold to 23,226.94 acres or 21.6 percent of the total acreage in the watershed. The only way the additional hay can be consumed at this time is to produce other livestock, even if it is unprofitable. It appears that introducing the beef cow-calf activity and selling calves at 210 days of age is less a losing proposition than leaving hay unconsumed.

As a result of this policy restricting soil loss to 1.129 tons per acre, farmers use new soil conserving rotations to maximize net revenue. Although reduced tillage corn/soybeans, and reduced tillage corn/oats/meadow are still being used, farmers are now using reduced tillage corn/wheat/meadow and continuous meadow. These rotations are seen on the more steeply sloping soils, while the more profitable soil eroding rotations are used on the less steeply sloping soils.

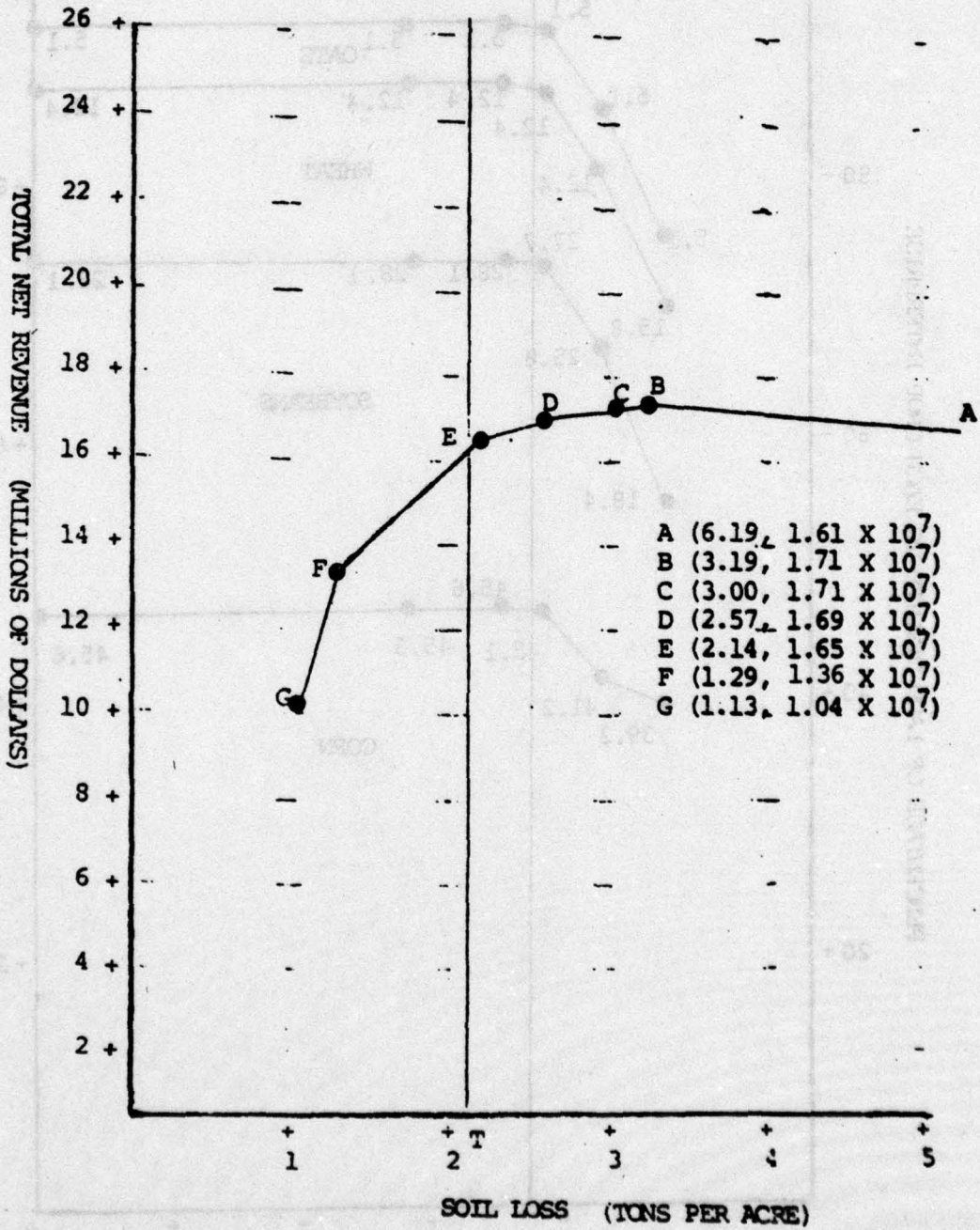
Figure 7 summarizes the results of this policy. As the constraint becomes more restrictive, net revenue in the watershed decreases rapidly. As soil loss approaches one ton per acre in the entire watershed, the marginal cost of reducing soil loss between 1.289 and 1.129 tons per acre is \$182.64 per ton.

When a substantial reduction in soil loss occurs, the number of acres devoted to each crop each year changes drastically (see Figure 8). Originally 45.6 percent and 28.2 percent of the land was in corn and soybeans respectively. After soil loss is reduced to 1.129 tons per acre on the average in the watershed, only 39.2 percent and 18.4 percent of the land is devoted to corn and soybeans. Total land acreage of these two crops declined 22 percent. However, hay acreage increased from 8.7 percent to 21.6 percent of the total land area. Given the present crop enterprises seen in the watershed, this is the lowest attainable soil loss.

#### Policy Set B

The second policy plan, policy set B, is the scheme for reducing soil loss by soil type in the entire watershed. Soil losses are reduced by an increment of the T value for each acre in the watershed. Again, the T value is the maximum rate of soil erosion that will allow a high level of crop production to be sustained economically and indefinitely. The first

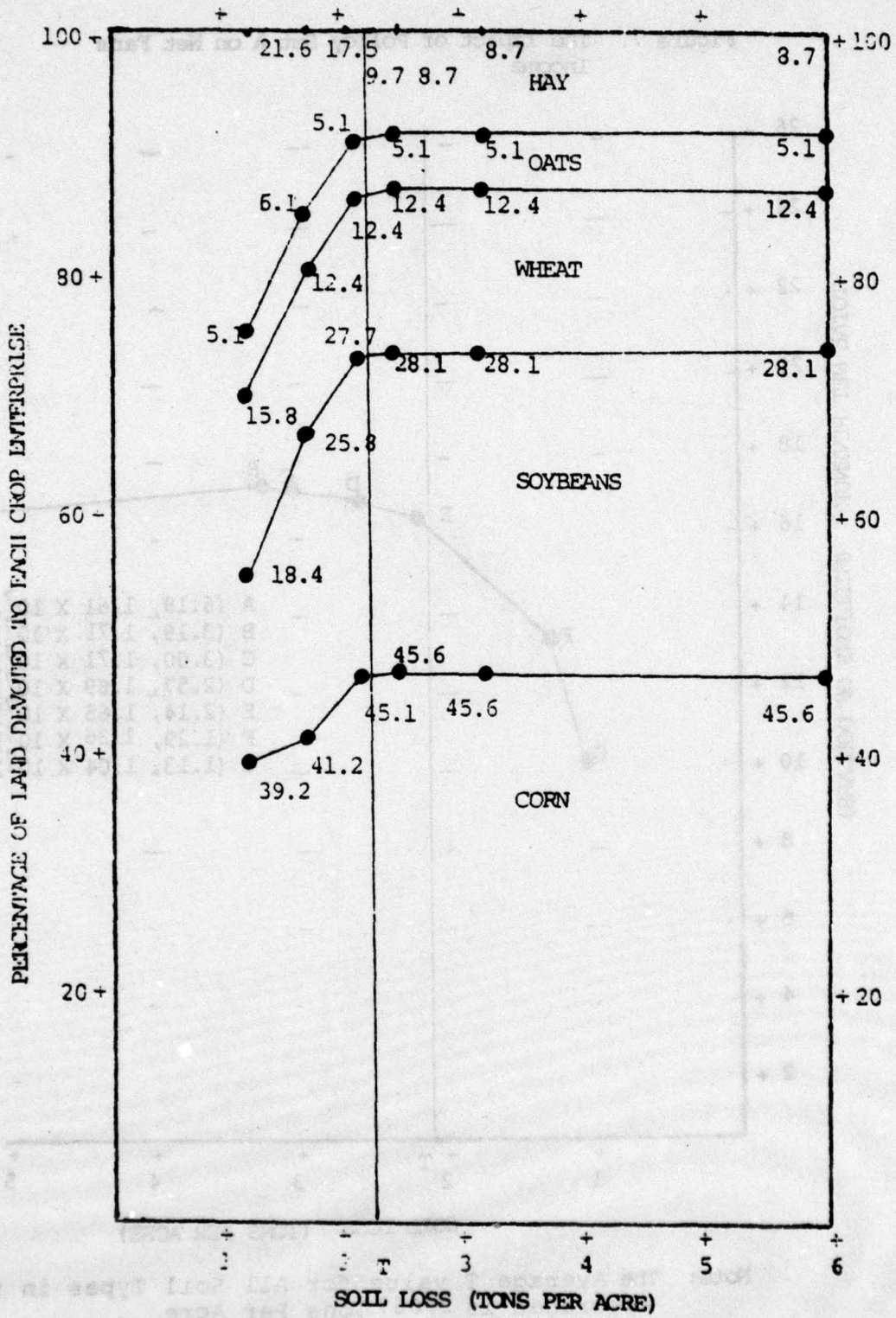
Figure 7. The Impact of Policy Set A on Net Farm Income



Note: The Average T value for All Soil Types in the Watershed is 2.067 Tons Per Acre



Figure 8. The Organization of the Watershed (Policy Set A)



run restricts all soil losses to 2 times the T value. Then parametric programming is performed on every soil type and slope-length factor to reduce soil loss to 1.75, 1.50, 1.25, 1.00, .75, and .50 of the T value.

When soil loss on all soil types is reduced to 2T, the average soil loss for soils in the watershed is 3.00 tons per acre, and phosphorus losses average 6.3 pounds per acre. At this level some soil loss is reduced where it had been extremely high, however, most soil loss was less than 2T. Soil losses range from 1.292 tons per acre to 3.448 tons per acre. The variation in soil losses over all soil types is significantly less than the least restrictive run of policy set A. Because of the added restriction, the net revenue in the watershed is \$6,987,54 less than the net revenue figure arrived at in the unrestricted model. Again, as in the unrestricted model, acreages devoted to each crop remains unchanged, however the number of bushels of corn sold decreases. Also, the model is selling additional bushels of soybeans and oats. The added rotations which include these crops probably accounts for this increase in production even though soybeans are just as erosive as corn.

The predominant rotations found in this run are reduced tillage corn/soybeans, reduced tillage corn/wheat, and reduced corn/oats/meadow. This is slightly different from the results of the unrestricted model where no tillage corn/oats/meadow was seen less frequently on steeply sloping soils.

The second run for this policy set restricts soil loss 1.75T per acre, and net revenue is now \$17,129,685.01. Compared to the 2T restriction, profits decline only \$17,390.44, and soil loss is reduced to 2.938 tons per acre on the average. Again, phosphorous loss declines directly with soil loss and averages 6.18 pounds per acre. At this rate,

soil loss is reduced from 3.00 to 2.938 in the entire watershed, and the reduction in net revenue averages \$2.60 per ton.

Other differences between the 2T per acre restriction and the 1.75T per acre restriction are the number of bushels sold in the watershed and the number of dairy cows produced and sold. Apparently, a reduction in the number of dairy cows is taking place, due to a shift in hay production from more productive soil to less productive soil (31,092.13 tons of hay for 2T restriction versus 30,186.33 tons of hay for 1.75T restriction). Bushels of corn sold increases slightly, but there is a reduction in the number of soybeans, oats, and wheat sold.

The predominant rotations found in this run are similar to those rotations where the restriction is only 2T. There is no increase in the amount of hay produced.

When a soil loss restriction of T is imposed on those farms in the watershed, moderate changes take place. Corn and soybean acreage decreases to 93.3 percent and 86.3 percent of their initial level. Second, hay acreage increases almost two-fold to 16,968.93 acres. By producing more livestock, namely dairy cows, the additional hay is consumed. When soil loss is reduced to T, the maximum number of dairy cows produced is raised.

As a result of imposing this policy, new soil conserving rotations other than those previously identified are being used. These are no-tillage corn/wheat and no-tillage corn/wheat/meadow. These rotations are seen more frequently on the less steeply sloping soils and additional continuous meadow is being raised on the more steeply sloping soils. If soil loss on all soil types were reduced to a level of T, the marginal cost of reducing soil loss is \$19.32 per ton.

If policy set B is imposed at T level, the marginal cost of a ton of soil averages \$9.78 more than the marginal cost of a ton of soil under the policy set A at the same level of reduction. Results of this magnitude would be expected. Soil loss would be reduced on all soil types regardless of slope, natural productivity or profitability, even though soil loss on some soil types may already be acceptable.

The results of a restriction to .75T are similar as when soil loss on all soil types is equal to T. However, if a restriction of .50T is imposed on farms in the watershed, major changes must take place to maintain current levels of production. When soil loss is reduced from T to .50T, net revenue is reduced \$5,924,510.57 or on the average of \$72.46 per acre.

When a soil loss restriction of .50T is imposed on all farmers in the watershed, farm output changes in different areas of the watershed. First, corn and soybean acreage decreases to 76.6 percent and 62.12 percent of their initial level. This response is the same when soil loss is restricted to 1.129 tons per acre under policy set A. If restrictions of this magnitude must be imposed, restricting soil loss by soil type and slope length reduces net revenue more than restricting soil loss under policy set A. Second, hay acreage increases more than three-fold to 32,404.7 acres, as in policy set A. The only way the additional hay can be consumed at this time is to produce other livestock, namely beef calves. Introducing the beef cow-calf activity and selling calves at 210 days of age is less of a losing proposition than leaving hay unconsumed.

When soil loss is restricted to .50T, those rotations which conserve the soil the most are used by farmers to maximize net revenue. Almost one-third of the soil type slope length combinations have continuous

meadow growing, and nearly one-fourth of all soil type, slope length combinations produce corn/wheat/meadow.

Figures 9 and 10 summarize the results of this policy. As the constraint becomes more restrictive (approaching one ton of soil loss per acre per year), net revenue in the watershed decreases rapidly. However, it seems that reducing soil loss to the soil tolerance factor (T) will allow a high level of crop production to be sustained economically and indefinitely as proposed by Wischmeier and Smith, (1965).

This being the case, policy set A appears less costly for the farmer. If soil loss is reduced from current levels to the average T value or 2.07 tons per acre for all soils in the watershed, there is an increase in net revenue of 45¢ per ton per acre. If soil loss is reduced from current levels to the T value for each acre the average cost is 76¢ per ton.

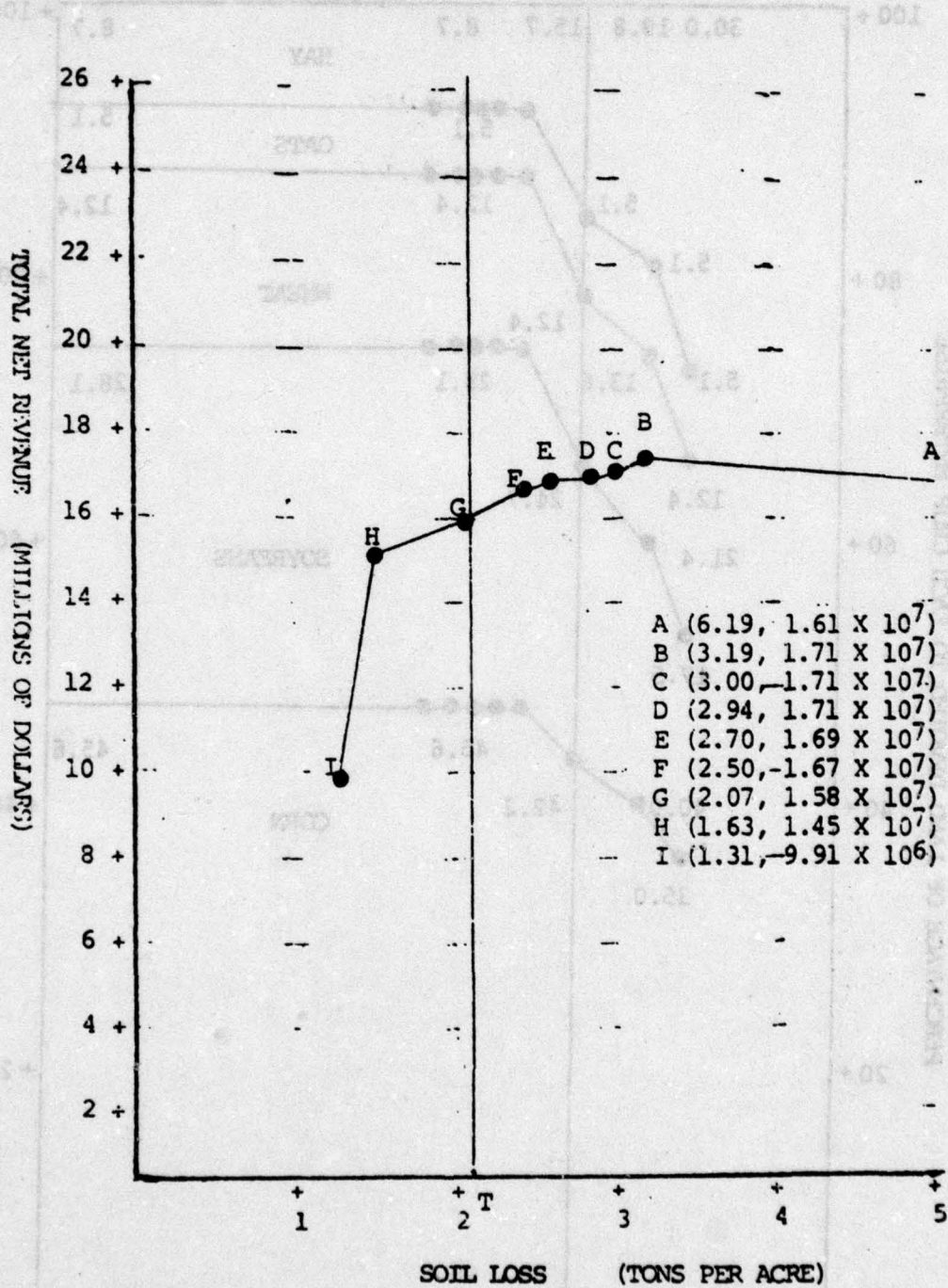
#### Policy Sets C and D

Policy set C is a soil loss tax which directly restricts total soil loss in the watershed. Levied on a per ton basis, the implicit assignment of property rights is to the downstream user. On the other hand, Policy set E is a soil loss subsidy. Total soil loss in the watershed is reduced by subsidizing the polluter to produce crops which minimize soil loss. Thus, the implicit assignment of property rights is to the polluter.

Taxes and subsidies ranging from six dollars to twenty-four dollars per ton are modelled. Then the associated soil loss and farm income in the watershed are compared.

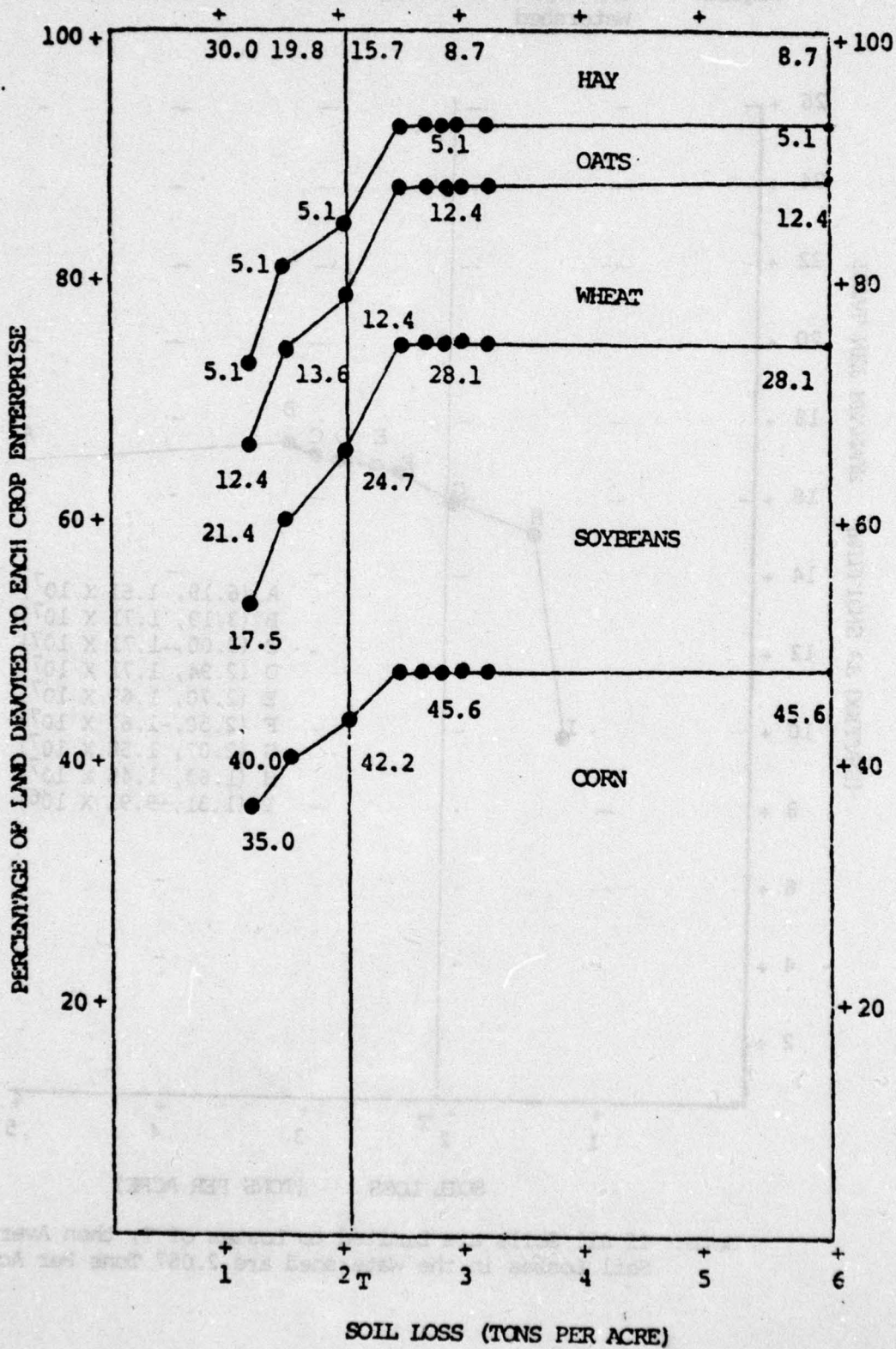
The first tax for six dollars reduces soil loss from 3.19 tons per acre in the unrestricted model to 2.72 tons per acre. Phosphorus loss is reduced from 6.98 to 5.71 pounds per acre. In this run, net revenue is reduced to \$15,308,907.42. When the receipts from the soil loss tax and

Figure 9 The Impact of Policy Set B on the Entire Watershed



Note: If all Soils are Limited to Losses of T, then Average Soil Losses in the Watershed are 2.067 Tons Per Acre

Figure 10. The Organization of the Watershed (Policy Set B)



total net revenue are combined, total watershed net revenue declines \$71,947.49 to \$17,082,115.49 from the unrestricted model.<sup>1/</sup> At this rate, if soil loss is reduced from 3.191 tons per acre to 2.723 tons per acre in the entire watershed, net revenue only declines \$1.42 per ton per year..

With the tax of \$6 per ton, soil losses range from 3.318 tons per acre to 1.588 tons per acre. Acreages devoted to each crop grown remain at approximately the same level (Figure 11). Hay and oat production are now occurring on the steeper slopes while corn and soybean production are occurring exclusively on the less steep slopes. These two effects (a slight change in grain production and change in production from one slope to another) account for the .5 percent reduction in net revenue and 15.3 percent reduction in soil loss (Figure 12).

A nine dollar tax reduces total soil in the watershed to 2.31 tons per acre and phosphorus losses to 4.85 pounds per acre. In this run, net revenue is reduced to \$14,545,030.85 (Figure 13). When tax receipts and total net revenue are combined, the new objective function is \$16,784,023.22 or \$370,039.77 less than total net revenue in the unrestricted model (Figure 12). At this rate, if soil loss is reduced from 3.191 tons per acre to 2.31 tons per acre in the entire watershed, net revenue only declines \$3.89 per ton per acre per year.

Soil losses range from 3.02 tons per acre on soil group seven to 1.28 tons per acre on soil group eight. As compared to the unrestricted model,

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<sup>1/</sup> In this case, net revenue is defined as the sum of the watershed's net revenue plus tax receipts.



Figure 11 The Organization of the Watershed (Policy Set C)

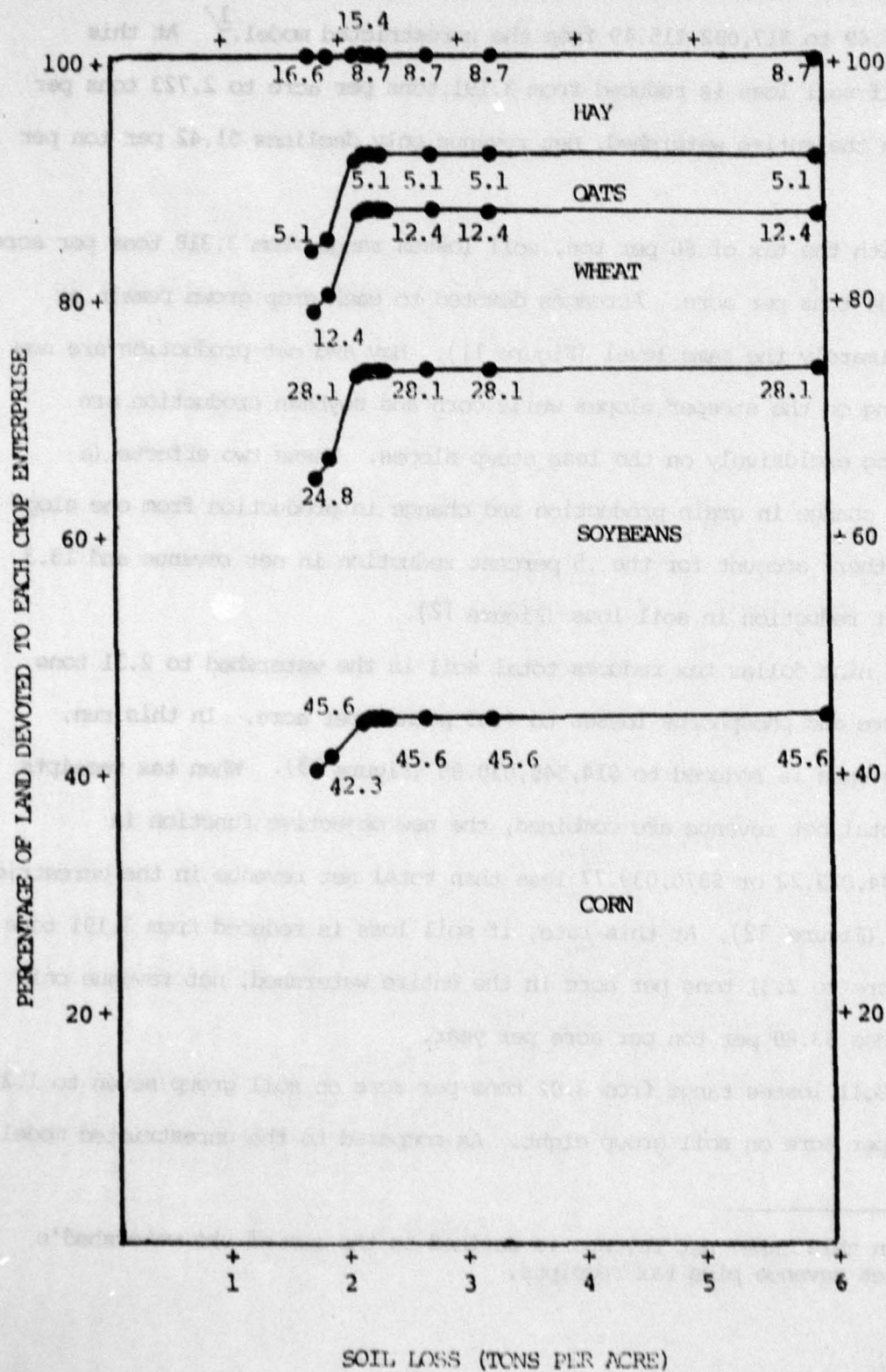


Figure 12. The Impact of Policy Set C when the Tax and Total Net Revenue are combined

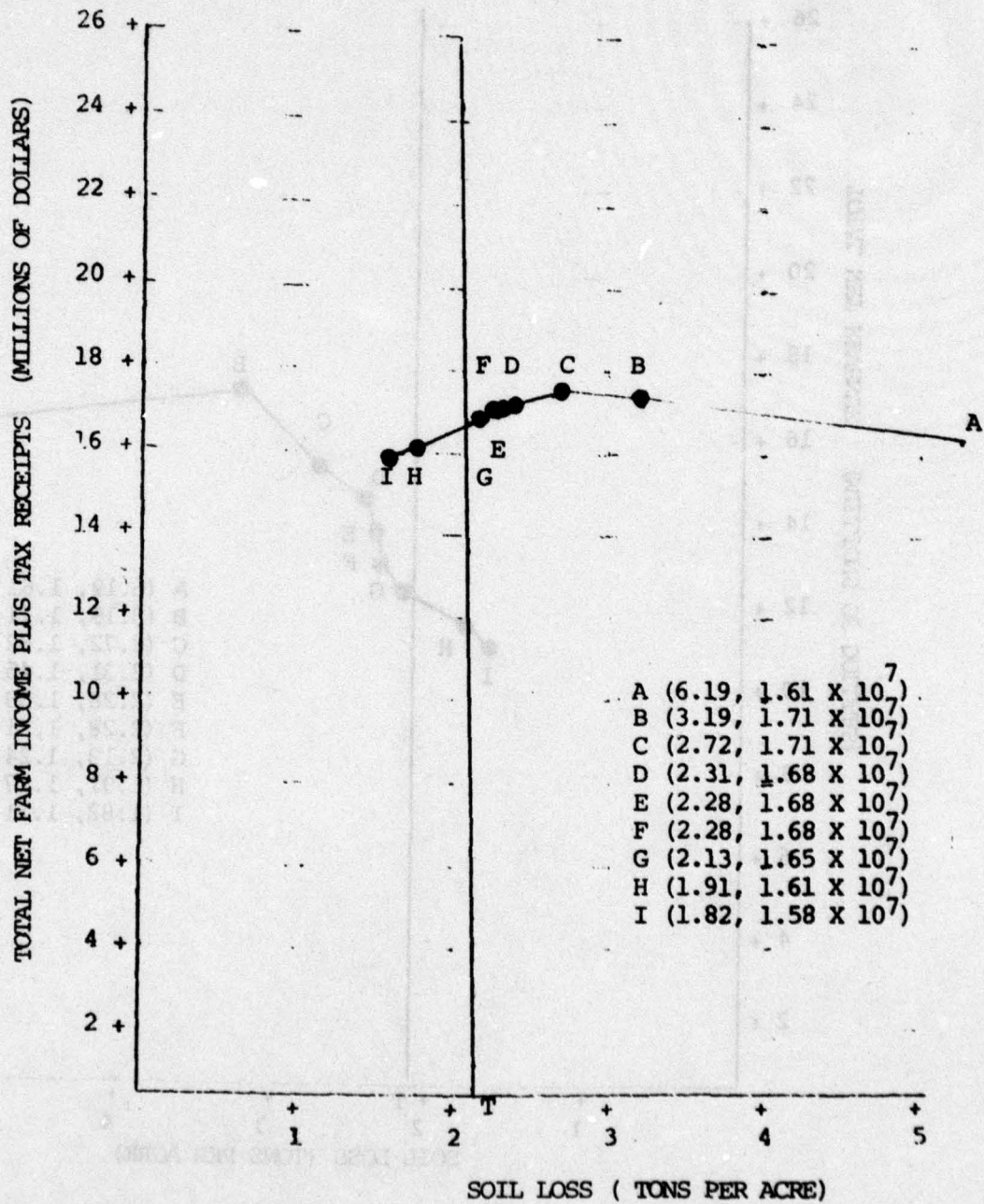
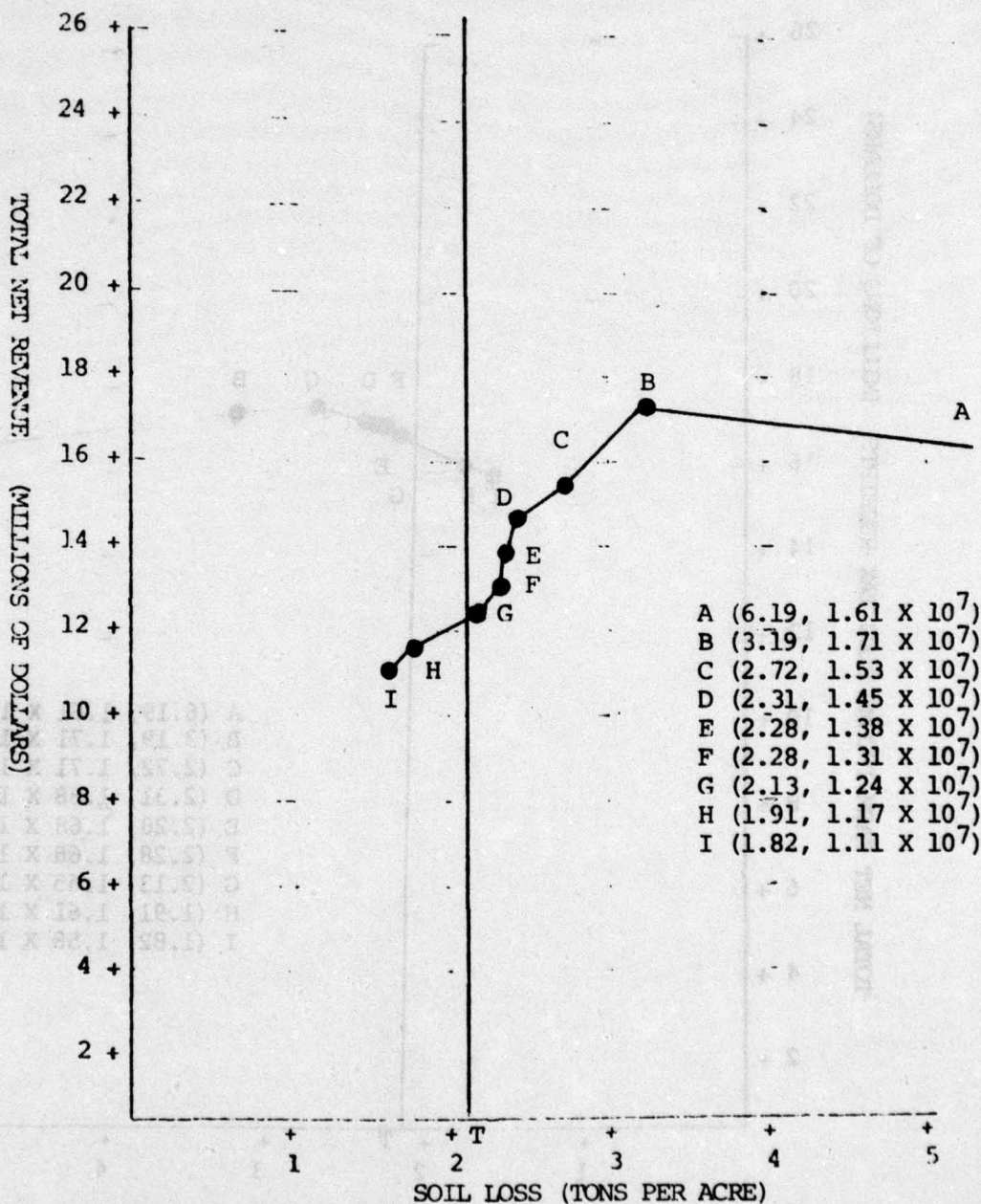


Figure 13. The Impact of Policy Set C on Farmers' Net Revenue



acres devoted to each crop remain unchanged; however, bushels of corn and wheat sold decline. On the other hand, bushels of soybeans and oats sold increase.

A twelve dollar tax causes a reduction in total soil loss to 2.28 tons per acre and phosphorus loss to 4.79 pounds per acre. In this run, total net revenue is reduced to \$13,804,630.10 (Figure 13). When the tax receipts from the soil loss tax and total net revenue are combined, the new objective function is \$16,762,818.25 or \$391,244.74 less than total net revenue in the unrestricted model (Figure 12). At this rate, if soil loss is reduced from 3.191 tons per acre to 2.28 tons per acre in the entire watershed, net revenue only declines \$3.98 per ton per acre per year.

Soil losses range from 2.91 tons per acre on soil group seven to 1.13 tons per acre on soil group eight. As compared to the unrestricted model, acres devoted to each crop grown do not decline (Figure 11); however there is a decline in bushels of corn and wheat sold. On the other hand, bushels of soybeans and oats sold increase.

A fifteen dollar tax causes an insignificant reduction in soil loss. It is still 2.28 tons per acre, the same as the twelve dollar tax. In this run, total net revenue is reduced to \$13,065,193.26. When the tax receipts from the soil loss tax and total net revenue are combined, the new objective function is \$16,761,314.49 or \$392,748.50 less than total net revenue in unrestricted model. At this rate, if soil loss is reduced from 3.191 tons per acre to 2.28 tons per acre in the entire watershed, net revenue declines \$3.99 per ton per acre per year.

With the \$15 per ton tax, soil losses range from 2.91 tons per acre on soil group seven to 1.15 tons per acre on soil group eight. These

results are nearly identical when compared to the twelve dollar tax. As compared to the unrestricted model, acreages devoted to each crop grown does not decline, however bushels of corn and wheat sold do decline. Compared to the twelve dollar tax all grain production has declined except for oats which has remained constant.

An eighteen dollar tax reduces total soil loss to 2.13 tons per acre and phosphorus loss to 4.47 pounds per acre. In this run, total net revenue is reduced to \$12,359,283.53 (Figure 13). When the tax receipts from the soil loss tax and total net revenue are combined, the new objective function is 16,502,278.07 or 651,784.92 less than total net revenue in the unrestricted model (Figure 12). At this rate, if soil loss is reduced from 3.191 tons per acre to 2.13 tons per acre in the entire watershed, net revenue only declines \$5.69 per ton per acre per year.

Soil losses range from 2.48 tons per acre on soil group seven to 1.63 tons per acre on soil group one. As compared to the previous runs, the variance in soil loss is much narrower. Acreages devoted to corn and soybeans decline and hay production acreage increases. This organizational change in the watershed is reflected in Figure 11. The impact of the tax on net revenue is shown in Figures 12 and 13. Net revenue in Figure 13 is simply net farm income, but net revenue in Figure 12 includes both net farm income and tax revenues.

Bushels of corn, soybeans and wheat sold show a significant decline while oat production increases compared to the unrestricted model. Also, the number of dairy cows produced has increased. In the unrestricted model 1,681 dairy cows are produced; there are now 2,113. The significant increase is due in large part to the increased hay production. Since additional hay is being raised to reduce soil loss, it is less costly to

feed it to livestock than to leave it in the field.

The results of a twenty one dollar tax are also depicted in Figures 12 and 13 as shown by point H. Soil loss is occurring at the rate of 1.91 tons per acre per year and phosphorus loss at 4.01 pounds per acre.

In this model run, total net revenue is \$11,721,565.75. When the tax receipts from the soil loss tax and total net revenue are combined, the new objective function is \$16,050,300.77 or \$1,103,762.22 less than total net revenue in the unrestricted model. At this rate, if soil loss is reduced from 3.191 tons per acre to 1.91 tons per acre in the entire watershed total net revenue declines \$7.98 per ton per acre per year.

Soil losses range from 2.66 tons per acre on soil group five to 1.28 tons per acre on soil group eight. Corn and soybean acreage decline, wheat and oat acreage remained constant, and hay acreage increased.

Also, bushels of corn and soybeans sold decline. However, oat production remains constant and wheat production slightly increase. Dairy cows increase while beef and swine production remain constant. Compared to the unrestricted model, the dairy increase is more than two-fold. Again, this significant change is due to the land devoted to hay. In this run, 16,641 acres or 15.4 percent of the land is in hay.

The last tax scheme modelled, a twenty four dollar tax reduces soil loss from 3.19 tons per acre in the unrestricted model to 1.82 tons per acre. In this run, farmers' net revenue is reduced to 11,118,482.69 (Figure 13). When the receipts from the soil loss tax and total net revenue are combined, total net revenue declines \$1,319,014.37 to 15,835,048.62 from the unrestricted model (Figure 12). At this rate if soil loss is reduced from 3.191 tons per acre to 1.82 tons per acre in the entire watershed, net revenue declines \$8.91 per ton per year.

Soil losses range from 2.50 tons per acre on soil group five to 1.58 tons per acre on soil group eight. Compared to the unrestricted model, acreages devoted to each crop change significantly (Figure 11). Corn and soybean acreage declines considerably, wheat and oat acreage remains constant, and hay acreage increases. Hay production increases but hay acreage shifts to less productive soils. The livestock activities are consuming all hay that is produced. If higher tax levels are modelled, it is hypothesized that some hay will be left unconsumed.

Results under Policy Set D, the subsidy for reducing soil loss, demonstrate the similarities between the effect of a tax and the effect of a subsidy. Notice in Table 4 that some of the impacts are identical under the tax or the subsidy. For example, a tax or subsidy of \$24 per ton reduces soil loss to an average of 1.82 tons per acre while reducing the net economic impact to \$15,835,000. The similarity between a tax and subsidy is illustrated in Figures 12 and 16. The difference is in who pays the price. As can be seen in columns 3 and 4 of Table 4, the farmer pays a much higher price with the tax than the subsidy. If one assigns soil loss rights to farmers and subsidizes income in order to reduce soil loss, farmers' income actually improves as soil loss is reduced. On the other hand, farmers' income drops drastically if clean water rights are assigned to downstream users and a tax is imposed. The differences in farmers' net revenues are illustrated by comparing Figures 13 and 15.

The similarities in farm organization are illustrated in Figures 11 and 14. For both the tax and the subsidy crop acreage remains relatively unaffected until a tax or subsidy of \$21 per ton.

Table 4. A Comparison of Results From Policy Set C (Soil Loss Tax) and Policy Set D (Subsidy to Reduce Soil Loss)

Amount of Tax or Subsidy (\$/ton)	Average Soil Loss (tons/acre)	Farmer's Net Revenue		Net Economic Impact	
		With Tax (\$000)	With Subsidy (\$000)	Farmer's Net Revenue Plus Tax Receipts (\$000)	Farmer's Net Revenue Minus Subsidy (\$000)
0	3.19	17,154	17,154	17,154	17,154
6	2.72	15,309	17,375	17,082	17,082
9	2.31	14,545	17,645	16,784	16,784
12	2.28	13,805	17,938	16,763	16,763
15	2.28	13,065	18,232	16,761	16,761
18	2.13	12,359	18,559	16,502	16,502
21	1.91	11,722	18,954	16,050	16,050
24	1.82	11,118	19,385	15,835	15,835



Figure 14 The Organization of the Watershed (Policy Set D)

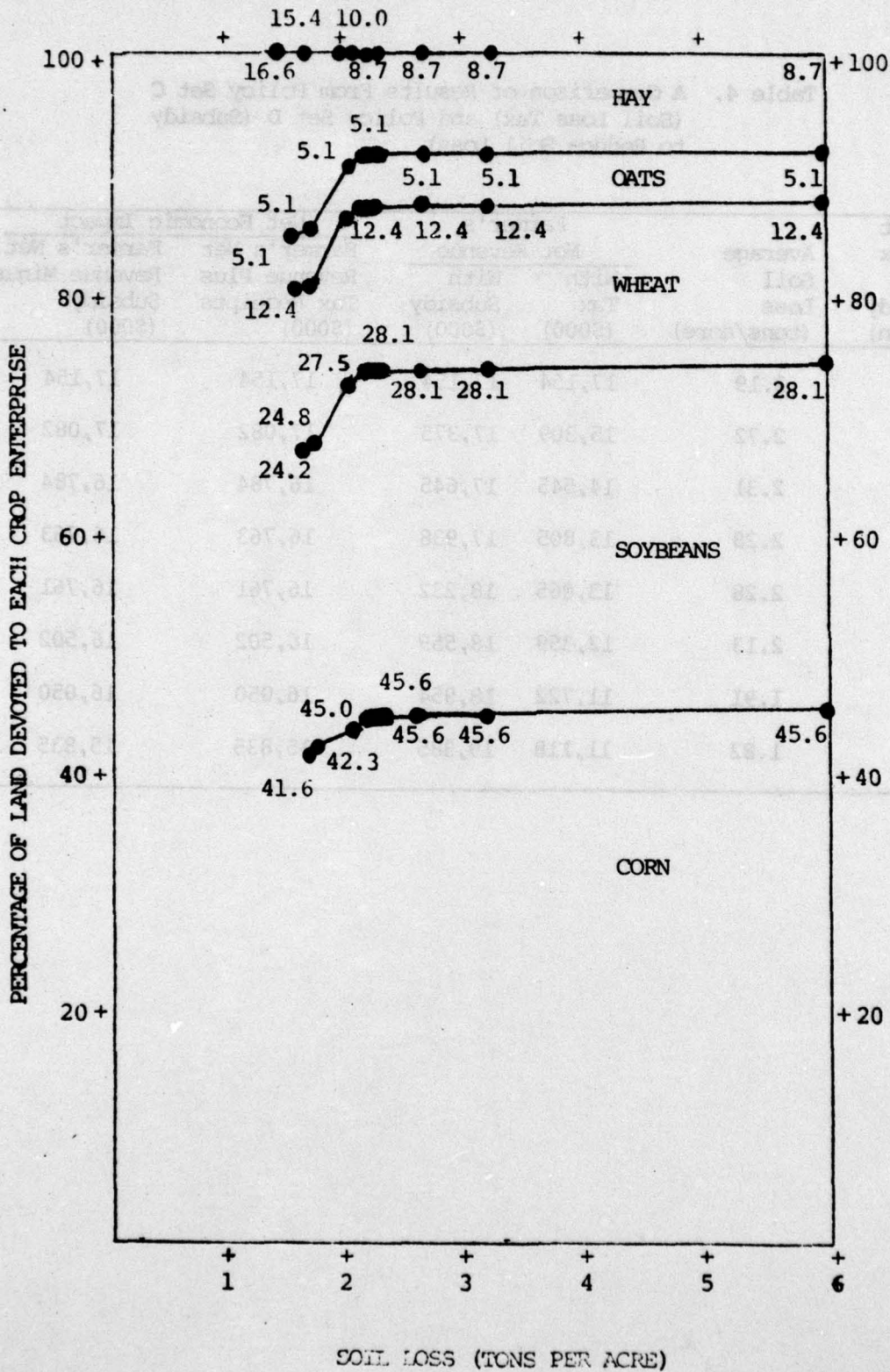


Figure 15 The Impact of Policy Set D

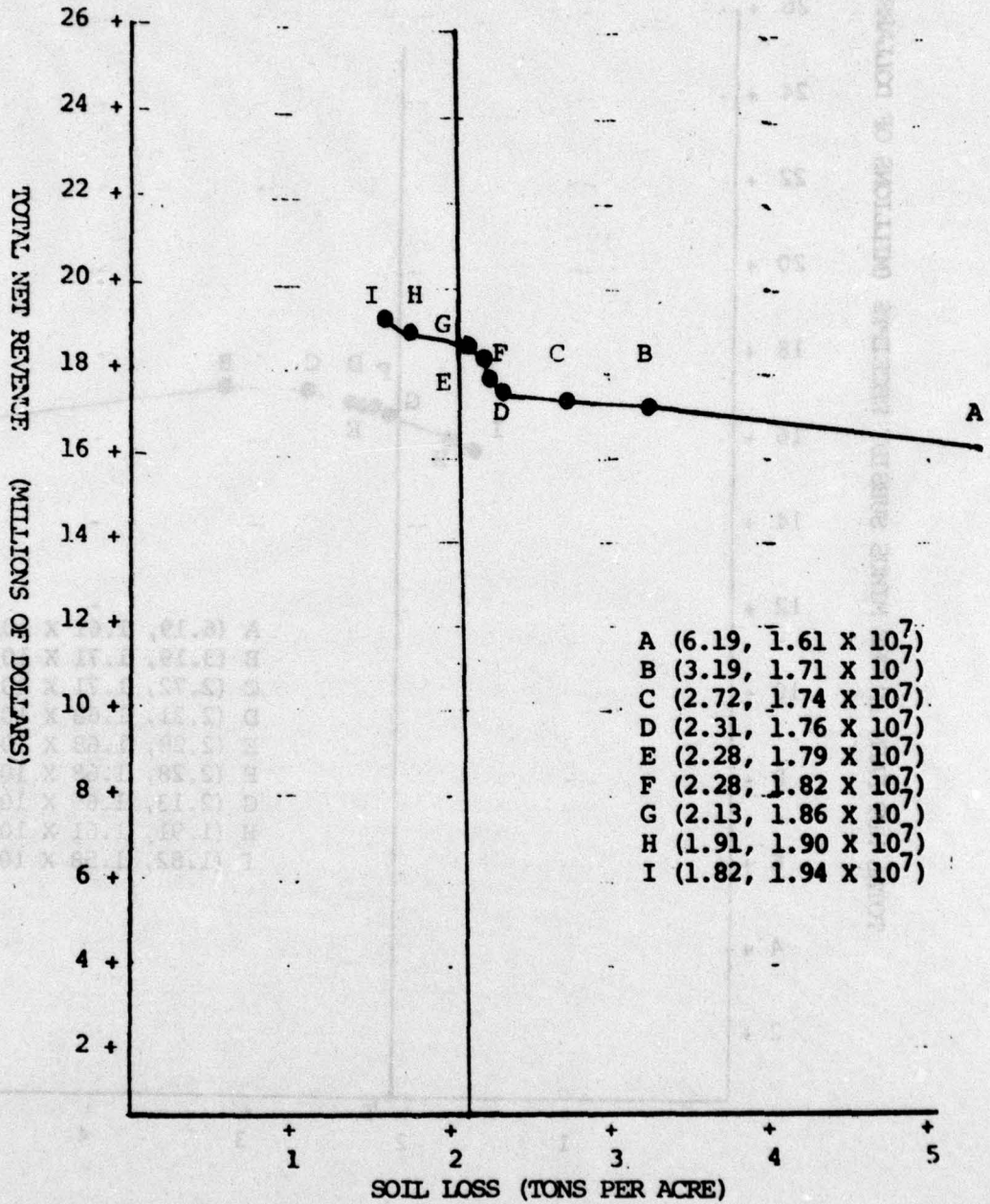
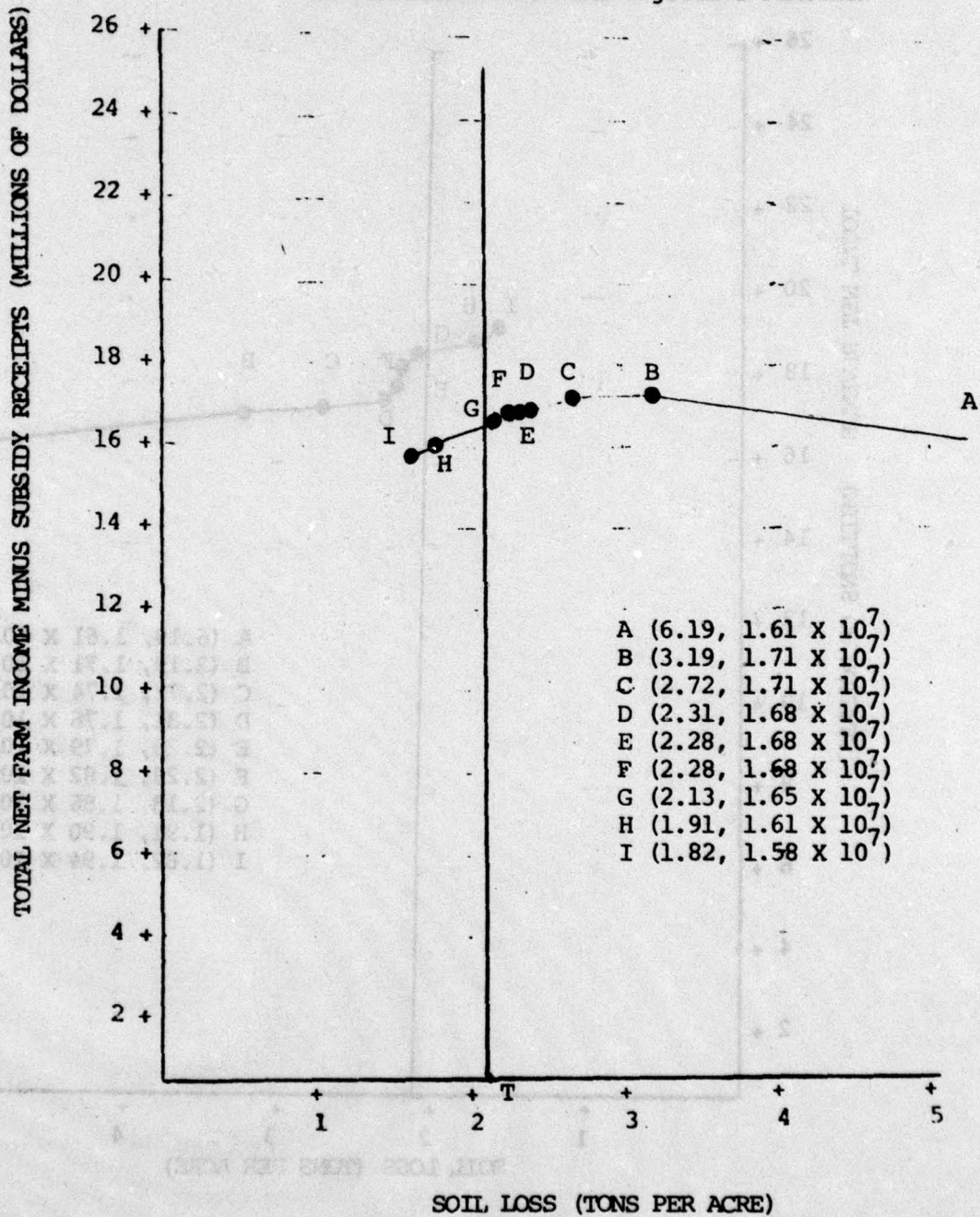


Figure 16. The Impact of Policy Set D When the Subsidy is Subtracted From the Objective Function



## CONCLUSIONS

The internalization of externalities in the agricultural sector depends upon many variables. These include the soils' response to minimum or no-tillage, the willingness of farmers to adopt soil loss reducing methods, the acceptance of moderate degrees of risk, the temporary loss of efficiency, and the feedback from those who bear the costs for which little or no benefits are derived.

In the Honey Creek Watershed, soil groups four, five, seven, nine, and ten respond to minimum or no-tillage more favorably than conventional tillage. This accounts for 78,575.9 acres or 72.8 percent of the land modelled. On soil group eight, conventional tillage is the only feasible tillage practice. Of the 107,921.2 acres modelled, 12.95 percent or 13,980.2 acres is of this group. Thus, 85.75 percent of the land strongly favors either conventional or reduced tillage.

Thus, as one moves from the "base" model to the unrestricted model, soil loss is reduced by one half with up to a five to ten percent increase in net revenue on those soil types responsive to minimum and no-tillage.

The models also show that of the factors man has control over, shifting to reduced tillage is the least expensive route to follow and spring plow conventional tillage is second most expensive. Finally, even though changing rotations decreases soil loss the most in many cases, it is the most expensive route.

The first policy set restricts soil loss in the entire watershed. If soil loss is reduced to 2.14 tons per acre, a value just larger than T (2.067), net revenue may increase as much as three percent over base model figures on those soils responsive to reduced tillage in the long

run. In this case, as in the other policy sets, average cost increases as the constraint becomes more restrictive (Table 5).

Policy set B restricts soil loss by fractional increments of T from 2.0T to .50T. If a soil loss restriction of T is applied to all soil types in the watershed, net revenue in the watershed would decrease slightly. However, compared to the more restrictive runs of policy set A, where production shifts to hay on the more steeply sloping land, crop rotations change to less erosive ones on all soil types and slopes (Table 5).

Policy set C is based on implementation of a tax on soil loss. As with the other policy sets, this model assumes that the farmer is completely rational and makes his decisions based upon perfect information. When a soil loss tax of six dollars per ton is levied against all farmers in the watershed, soil loss is only reduced to 2.72 tons per acre. Although the value is .656 tons greater than the T value, Narayanan, Lee, and Swanson feel that total damage sustained from a profitable crop rotation in a similar watershed is substantially less than this. Thus, it appears that levying a six dollar per ton tax would cover marginal social costs in the Honey Creek Watershed. This tax rate will decrease farmers' net revenue by approximately ten percent (Table 6).

If current policy recommendations require soil loss to be 2.067 tons per acre, an 18 dollar to 21 dollar tax must be levied to meet this requirement. This may not be justified since marginal costs may more than be covered. Strictly speaking, the additional revenue generated can be considered a sacrifice in efficiency and a redistribution of income from farmers to other taxpayers.

Table 5. Society's and Farmers' Costs Per Ton of Soil Loss to Reduce Soil Loss from Present Amounts to Those Occurring Under Alternative Levels of Restrictions

Average Soil Loss <sup>a</sup> (tons/acre)	Average Phosphorus Loss <sup>a</sup> (pounds/acre)	Average Cost to Society and Farmer <sup>b</sup>	
		Policy Set A <sup>c</sup> (\$/ton)	Policy Set B <sup>d</sup> (\$/ton)
3.19	6.98	-3.04 <sup>e</sup>	-3.04
3.00	6.30	-2.86	-2.84
2.50	5.25	-1.83	-1.40
2.07	4.35	-0.45	0.76
1.63	3.42	2.12	3.44
1.31	2.75	4.64	11.90

<sup>a</sup>Under current practices soil loss is estimated to average 6.19 tons per acre and phosphorus loss is estimated at 12.38 pounds per acre.

<sup>b</sup>Difference between net revenue under current practices and net revenue under restriction divided by reduction in soil loss.

<sup>c</sup>Policy Set A restricts average soil loss in the watershed.

<sup>d</sup>Policy Set B restricts soil loss on each acre in the watershed.

<sup>e</sup>-3.04 indicates that net revenues increase by \$3.04/ton if most profitable practices are adopted.

Table 6. Society's and Farmer's Average Cost Per Ton of Soil Loss to Reduce Soil Loss from Present Amounts to Those Occurring Under Alternative Levels of Tax and Subsidy

Amount of Tax or Subsidy (\$/ton)	Average Soil Loss <sup>a</sup> (tons/acre)	Average Phosphorus Loss <sup>a</sup> (lbs/acre)	Average Cost to Farmer <sup>b</sup>		Average Cost to Society <sup>c</sup>	
			With Tax (Policy Set C) (\$/ton)	With Subsidy (Policy Set D) (\$/ton)	With Tax (Policy Set C) (\$/ton)	With Subsidy (Policy Set D) (\$/ton)
0	3.19	6.98	-3.04 <sup>d</sup>	-3.04	-3.04	-3.04
6	2.72	5.71	2.30	-3.24	-2.44	-2.44
9	2.31	4.85	3.88	-3.52	-1.47	-1.47
12	2.28	4.79	5.69	-4.20	-1.41	-1.41
15	2.28	4.79	7.35	-4.89	-1.40	-1.40
18	2.13	4.47	8.69	-5.45	-0.76	-0.76
21	1.91	4.01	9.63	-6.03	0.26	0.26
24	1.82	3.82	10.71	-8.76	0.71	0.71

<sup>a</sup>Under current practices soil loss is estimated to average 6.19 tons per acre and phosphorus loss is estimated at 12.38 pounds per acre.

<sup>b</sup>Difference between farmer's net revenue under current practices and net revenue under tax or subsidy divided by reduction in soil loss.

<sup>c</sup>Difference between society's net revenue under current practices and net revenue under tax or subsidy divided by reduction in soil loss.

<sup>d</sup>-3.04 indicates that net revenues increase by \$3.04/ton if most profitable practices are adopted.

A subsidy results in the same net economic impact as a tax. The resulting distribution of income is the differentiating factor between the two. With the subsidy, farmers' net revenues actually increase while soil loss is reduced (Table 6).

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