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ECONOMIC EVALUATION

OF THE

EFFECT OF SELECTED CROP PRACTICES

ON

NONAGRICULTURAL USES OF WATER

H. Onishi, A.S. Narayanan, T. Takayama, and E.R. Swanson

F I N A L R E P O R T

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ABSTRACT

ECONOMIC EVALUATION OF THE EFFECT OF SELECTED CROP PRACTICES ON NONAGRICULTURAL USES OF WATER

Cropping systems may have an unfavorable influence on the quality of nearby surface water. In this study, linear programming methods were used to assess the impact of improvements in certain water quality characteristics on economically optimal crop systems. Thus, the effect of crop practices on water quality is analyzed indirectly by assuming that farmers would alter their cropping practices in the most economical way in order to conform to various water-quality constraints. A 1,200-acre watershed was used to illustrate the procedure. Sediment entering the reservoir was treated as a variable constraint on maximization of farm income. Requiring successively lower amounts of sediment to enter the reservoir caused farm income to decrease at an increasing rate. The analysis was enlarged to include a constraint on nitrate in the leachate below the root zone. This phase of the analysis also included a charge for removing at least some of the sediment entering the reservoir. As the nitrate limit on the leachate was lowered, farm income decreased at an increasing rate. The requirement of removal of the sediment by itself had little or no effect on the nitrate concentration in the leachate. Extensions of the procedure for use in other situations are suggested.

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PREFACE

This research project was initiated on September 1, 1970, and terminated on December 31, 1973. The research was conducted in two phases, both of which centered on the analysis of a 1,200-acre watershed. The detailed description of the procedures and results of Phase One may be found in Dr. A. S. Narayanan's thesis [1]. Dr. H. Onishi's thesis [3] reports in similar detail on Phase Two. The principal findings of Phase One have been reported in the *Journal of Soil and Water Conservation* [2] and also in a book of readings on economic planning [4]. A summary of the approach to and results of Phase Two will appear in a forthcoming issue of the *Journal of Environmental Quality* [6]. In addition, the results of Phase Two were presented at a recent symposium [5]. Because the results of the research appear in the professional literature, this terminal report will sketch only the highlights of the findings and conclusions.

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I. INTRODUCTION AND PROJECT OBJECTIVE

The project proposal stated the objective of the project as follows:

> To develop and test a procedure for determination of the effect of altering quality standards in surface water on economically optimal crop production in a watershed.

Linear programming was the basic procedure employed in the study. This is a mathematical method by which a linear function called the objective function is maximized or minimized subject to constraints. The constraints may take the form of linear equalities or inequalities. Although the term "linear" may imply that, for example, crop yield response functions must be linear, such is not the case. Curvilinear relationships can be introduced into a linear programming model by using several linear segments to approximate a curvilinear relationship.

In the specific applications of linear programming in this study, the objective function was defined as the net farm income in the watershed. The constraints on maximizing net farm income were (1) areas of land of various types and (2) the levels of certain water quality parameters.

By varying the constraints dealing with water quality parameters, we obtained a set of optimal solutions. The solution for each set of water quality standards answers the question, "What is the highest-return combination of crops and management practices which will still make it possible to meet the water quality standards?" Since water quality standards may vary with the intended use of the water and since they also may be subject to change, it is of interest to know the impact on farm income of varying these standards. In a sense, the "cost" of achieving a given level of water quality is the income sacrificed to achieve an increase in the standard.

A brief description of the selected watershed is followed by the principal results of Phase One and Phase Two of the project. The conclusions include a discussion of the possible extensions of the analysis and the degree to which the project objective was accomplished. The appendices contain information on the procedures used to estimate the various coefficients required by the linear programming models.

II. FOREST GLEN WATERSHED

A 1,200-acre watershed, Forest Glen, in Vermilion county in eastern Illinois was selected as the site for our study. A watershed has a distinct advantage over a political unit for water quality analysis. The source of waterborne sediment and plant nutrients entering the reservoir or lake must come primarily from land in the watershed. Consequently, a more complete accounting can be made of the sources of sediment and plant nutrients than would be the case if the unit of analysis contained parts of several watersheds. However, this advantage is often offset by the need for an additional governmental administrative unit, organized to deal with problems on a watershed basis, if policies suggested by the analysis are to be implemented.

The planned reservoir of approximately 55 acres will be used primarily for recreation. Fishing, boating, and various water sports are planned for the reservoir. It is also possible that, at some time in the future, the need for such other uses as water for human consumption or irrigation may emerge. However, the immediate purpose is recreational.

The Forest Glen watershed is approximately two miles long and averages about one mile in width; it encompasses a drainage area of 1.8 square miles or about 1,200 acres (see figs. 1 and 2). This watershed lies between 620 and 680 feet elevation above the mean sea level and slopes generally from south to north. The proposed dam will be constructed at the northern tip of the watershed.

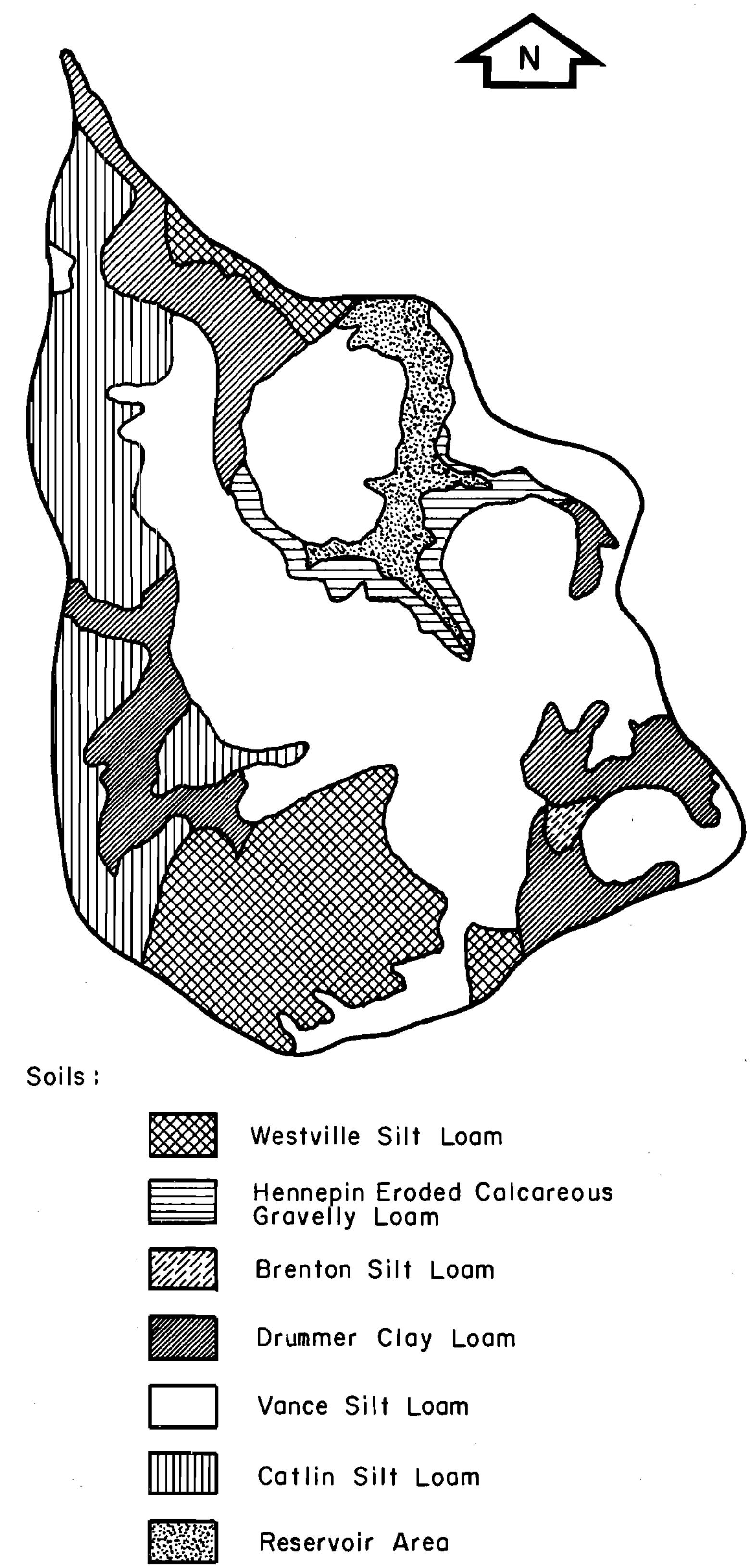


FIG. I FOREST GLEN WATERSHED – SOIL TYPES

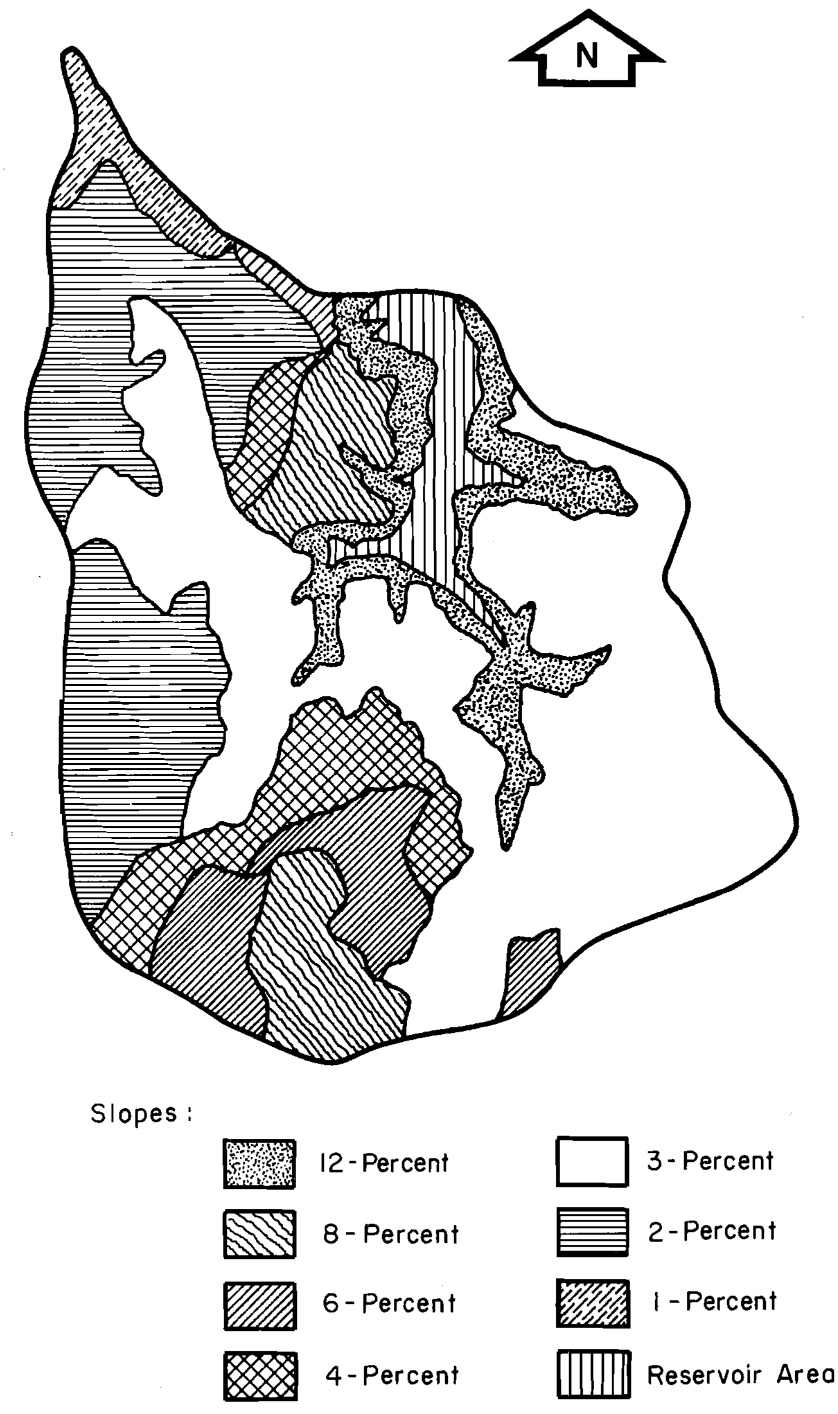


FIG. 2 FOREST GLEN WATERSHED—SLOPES

Vance and Catlin are the predominant soil types in the watershed and account for about 65 percent of all soils (fig. 1). Other soil types are Drummer, Brenton, Westville, and Hennepin. A brief description of the nature of these soils follows.

Westville silt loam is a light-colored soil developed on rolling topography under a deciduous forest vegetation. The surface horizon is yellowish gray silt loam about 5 to 7 inches thick. This soil occurs in varying slopes (6 to 12 percent). The loss of surface material by erosion is a serious problem. Consequently, any fields in which this soil occurs should be protected by a vegetative cover as much of the year as possible. This is a relatively infertile soil. The first step in any improvement program is the adoption of practices to retard soil erosion.

Hennepin eroded calcareous gravelly loam occurs in the watershed on the steep bluff land along the stream valleys. Destructive erosion has followed the removal of tree and brush vegetation from the steep slope occupied by this soil. In badly eroded areas, the calcareous pebbly till is often exposed. In virgin areas, it has a 3- to 5-inch yellowish gray surface which includes 1 to 2 inches of dark decaying leaf mold. Because this soil is heavily susceptible to and damaged by erosion, forest land or some protective vegetation is advised.

Brenton silt loam is a dark-colored silt loam developed under heavy prairie grass on undulating topography. Very little of this soil is found in the watershed. It is a very desirable, productive general farming soil, occurring on 1/2- to 3-percent slopes and does not seriously erode.

Drummer clay loam is a heavy, dark-colored soil that has developed under slough-grass vegetation, on near-level to depressional topography. This is a good corn soil. Surface drainage is slow or entirely absent. Like Brenton soil, Drummer does not easily erode.

Vance silt loam is a light-colored soil developed under a deciduous forest vegetation on undulatory to rolling topography. This soil occurs over a large area in the watershed. The surface horizon is 5 to 7 inches thick and yellowish gray. Even though the subsoil and underlying material are both moderately permeable, erosion is a problem on slopes greater than 3 to 4 percent that are under cultivation.

Catlin silt loam is the predominant soil group found in the watershed. It is a medium-dark soil developed on gently rolling to rolling topography under prairie vegetation. Catlin silt loam normally occurs with slopes of 2 to 4 percent. The subsoil and underlying material are permeable. Consequently, drainage is good. Although, in general, erosion is not particularly destructive, it often causes serious damage on the steeper slopes. This is a good alfalfa soil, although other crops can be raised on moderate slopes without serious loss. It is a fairly good general farming soil and responds to intelligent management. But deterioration is rapid under poor farming conditions.

Most areas in the watershed are moderately sloped (fig. 2). There are, however, some areas having over 6-percent slopes, and slopes up to 12 percent may be seen on the fringes of the reservoir area. Also, there are some isolated steep-slope areas (6 to 8 percent) in the body of the watershed. For the purpose of computing sediment yield and delivery rates, we made four broad divisions of the watershed area on the basis of elevation above sea level (see table 1 and Appendix A). The classification of land in the watershed on the basis of soil type, elevation, and slope resulted in 51 separate land areas for Phase One of the analysis (table 1).

Phase Two of the analysis considered each farm in the context of the total watershed model. There are presently 19 farms within the watershed boundary. Corn and soybeans are the main crops now grown on these farms. There are no large feedlots in the watershed. Therefore, the principal source of any nitrate in the leachate below the root zone is from crop production. Since the crops grown are cultivated row crops, the amount of soil erosion is higher than it would be if, for example, the watershed had more of the area in meadow.

Table 1. Land Area by Soil Type, Elevation, and Slope, Forest Glen Watershed

Soil Type, Elevation, & Slope[a]	Area (acres)	Soil Type, Elevation, & Slope	Area (acres)	Soil Type, Elevation, & Slope	Area (acres)
1 WAE	52.57	18 HDF	0.92	35 VAT	57.16
2 WAS	84.70	19 BCF	5.05	36 VBD	4.13
3 WAF	6.43	20 BDT	2.30	37 VBE	22.50
4 WAT	3.21	21 DAS	0.23	38 VBF	39.30
5 WBE	1.15	22 DAF	1.38	39 VBT	99.60
6 WBS	11.48	23 DAT	91.15	40 VCD	12.63
7 WBF	1.84	24 DBD	0.46	41 VCE	30.77
8 WBT	6.66	25 DBS	0.61	42 VCT	152.90
9 NCD	2.29	26 DBF	0.92	43 VDD	98.00
10 WCS	1.38	27 DBT	20.43	44 VDE	6.66
11 WCF	6.98	28 DCD	0.69	45 VDF	3.40
12 WDD	2.98	29 DCF	5.28	46 VDT	36.50
13 HCE	0.92	30 DCT	53.00	47 CAF	16.99
14 HCF	2.53	31 DDD	0.23	48 CAT	170.10
15 HCT	0.69	32 DDF	0.46	49 CBF	0.92
16 HDD	25.94	33 DDT	9.64	50 CBT	25.74
17 HDE	1.61	34 VAF	15.15	51 CCT	1.38

[a] The first letter gives the soil type, the next gives the contour divisions, and the last gives the slope. The key is as follows:

Soil type
W = Westville
H = Hennepin
B = Brenton
D = Drummer
V = Vance
C = Catlin

Elevation above reservoir
A = 50 feet or more
B = 40 to 50 feet
C = 30 to 40 feet
D = less than 30 feet

Slope
D = 12% and above
E = 8 to 12%
S = 6 to 8%
F = 4 to 6%
T = 3% and below

III. PHASE ONE

We constructed a linear programming model with the following components:

1. Constraints: The land areas in each of the soil type-elevation-slope classes in table 1 form a set of 51 constraints on maximization of farm income in the watershed. The final constraint is the permitted level of annual sedimentation in the reservoir. As shown later, this constraint is parameterized and the consequences on net farm income are estimated.

2. Activities: For each of the land areas, except the very unproductive Hennepin soil, nine crop sequences are considered as alternatives (table 2). These crop sequences span a wide range in farm income per acre. The crop sequences also vary greatly in their susceptibility to soil erosion and hence in the rate at which sediment enters the reservoir. The gross soil erosion for each activity was estimated by the Universal Soil Loss Equation. Estimates of sediment deposited in the reservoir were made for each activity by adjusting the gross erosion with a factor representing the delivery ratio (see Appendix A for procedure).

3. Objective function: Each crop sequence contributes an expected net income per acre to the objective function, which is total net income for the watershed (table 2). These incomes differ according to the soil type and slope. The procedure for estimating crop yields and net incomes is presented in Appendix B.

Table 2. Net Returns for Various Crop Sequences on Different Soils and Slopes

Crop Sequence[b]	Westville soil		Hennepin soil[a]			Brenton soil	Drummer soil		Vance soil		Catlin soil
	0-4% slope	4-12% slope	0-4% slope	4-8% slope	8-12% slope	0-4% slope	0-4% slope	4-12% slope	0-4% slope	4-12% slope	0-4% slope
Continuous Corn	$32.70	$30.80				$68.85	$67.15	$56.50	$46.60	$36.69	$62.65
CSbCOx	25.20	21.23				51.39	50.98	46.00	33.81	26.43	46.95
CSbOx	23.00	18.69				46.38	46.41	38.80	29.76	23.32	41.86
COx	21.20	17.88				43.40	41.24	34.30	28.63	21.67	39.83
CSbCOM	28.60	23.27				49.88	49.01	43.90	34.47	26.82	45.93
CCOM	29.11	24.38				49.44	47.56	41.23	35.25	26.99	46.10
CSbWM	26.80	21.63				45.92	45.64	38.91	31.30	24.83	42.11
COMM	28.66	23.52				42.15	39.76	34.23	31.73	24.00	39.65
OMMM	27.42	22.34	$16.50	$18.31	$11.87	34.09	31.49	26.21	27.72	20.52	32.72

Note: Net returns are given in dollars per acre and refer to returns above direct costs, labor costs, and fertilizer costs.

[a] Under the Hennepin soil type only the OMMM sequence is considered in the model.

[b] The key to the letters is as follows:

C = corn
Sb = soybeans
O = oats
Ox = oats with legume catch crop
M = meadow

To summarize, we maximize

$$\sum_i \sum_j \sum_k \sum_s C_{ijks} X_{ijks}$$

subject to $\sum_s X_{ijks} \leq B_{ijk}$ for all i, j, k

and $\sum_i \sum_j \sum_k \sum_s Q_{ijks} X_{ijks} \leq Q$

where X_{ijks} is the acreage of the s^{th} crop sequence on the i^{th} soil type, j^{th} slope group, and k^{th} elevation class,

C_{ijks} is the net return above direct costs for the indicated crop sequence on the indicated area of land,

B_{ijk} is the area of land in the i^{th} soil type, j^{th} slope group, and k^{th} elevation class,

Q is the maximum annual quantity of sediment permitted to enter the reservoir, and

Q_{ijks} is the amount of sediment deposited from the indicated area of land and crop sequence.

The principal findings of Phase One resulted from maximizing the objective function subject to the land constraints but with the permitted quantity of sediment, Q considered to be a variable. Because there is no explicit, easily calculated market price for the sedimentation damage to the reservoir, the consequences of a range of values of Q were estimated (fig. 3). Given the present agricultural practices in the watershed, sedimentation is estimated to be approximately 3,400 tons per year. From the standpoint of capacity alone, this would mean a reservoir life of about 670 years. This estimate is based on generalized reservoir-sedimentation relationships for watersheds in Illinois.

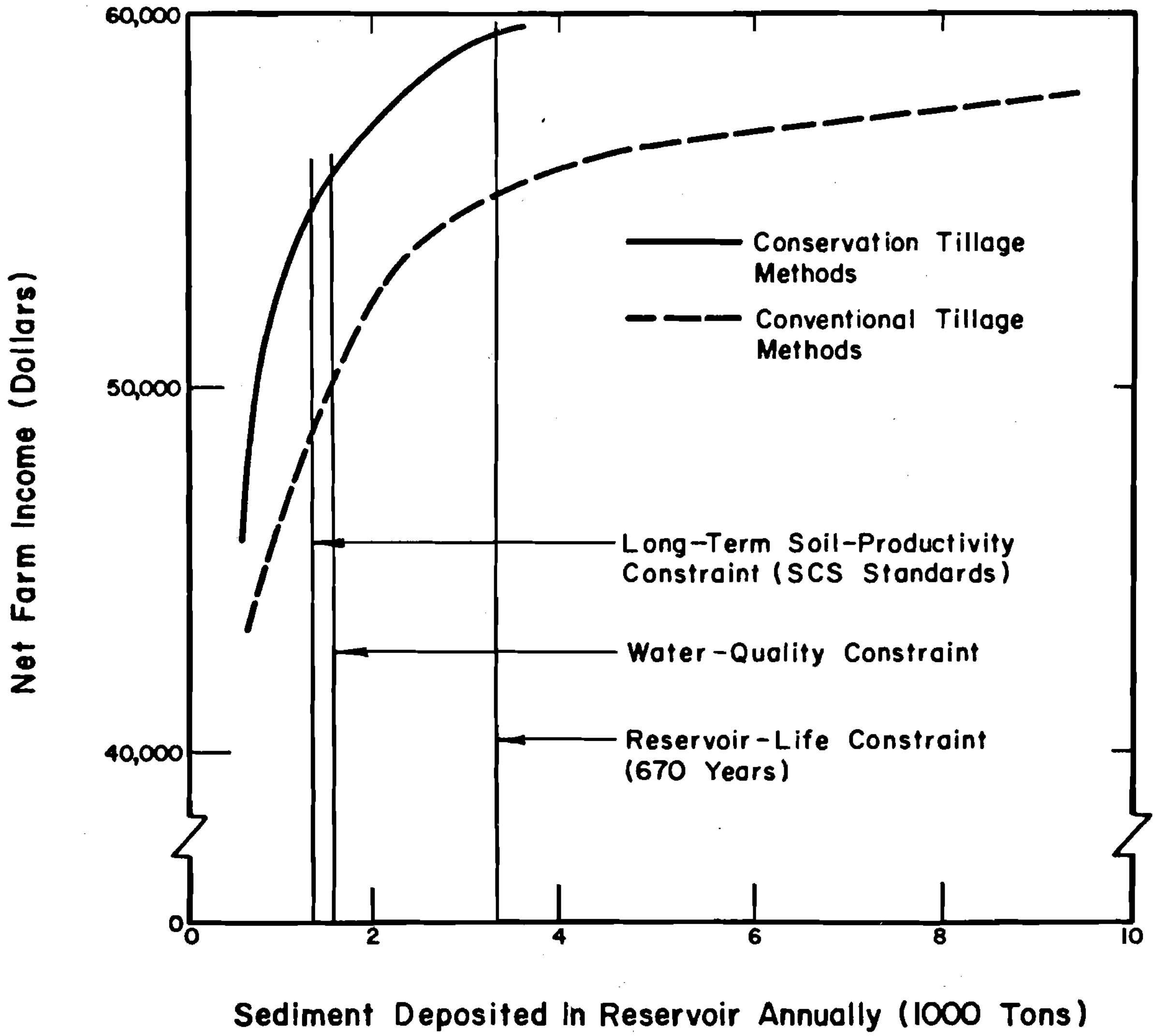


FIG. 3 EFFECT OF SEDIMENTATION LEVEL ON NET FARM INCOME. FOREST GLEN WATERSHED

However, the quality of the water in terms of turbidity and its suitability for recreation is estimated to be adequate at an annual sedimentation rate of 1,700 tons. It should be noted that achieving this level of sedimentation with conventional tillage methods reduces farm income from $55,000 to $50,570 (fig. 3).

There is also a productivity loss to the soil as a result of erosion. The Soil Conservation Service has made estimates of the loss that each soil could tolerate and still maintain its productivity at an adequate level. Although these tolerances are somewhat arbitrary, they do provide a set of guidelines. Using these soil loss tolerances as a standard would restrict the sediment to 1,500 tons per year, a more demanding restriction than that assumed necessary to meet water quality standards. The gains, in both income and reduction in sedimentation, from using conservation tillage can be estimated from figure 3. Note that, for a given level of sedimentation, income can be increased by adoption of conservation tillage. This increase occurs because a more intensive, higher-return cropping system can be adopted with conservation tillage than with conventional tillage, without an increase in erosion.

IV. PHASE TWO

Phase Two added several dimensions to the analysis of Phase One. A diagram of the Phase Two model is presented in figure 4. The following represent the principal modifications of the Phase One model.

First, optimal farm plans for each of the 19 individual farms in the watershed were developed in the context of the total watershed model. Such information would be important in the implementation of a watershed plan that meets water quality constraints. In order for a policy to become operational, it must eventually be translated into action at the level of the individual farm. The tracts within farms (fig. 4) represent combinations of soil type, slope, and location which required separate consideration in the analysis.

A second refinement in Phase Two dealt with the time period. Many physical processes involving the relationship of agricultural activity to water quality are cumulative. One example is the impact of erosion on sedimentation in a reservoir. Also, the planning horizon of both farmers and society usually extends beyond a single year. Accordingly, a five-year model was constructed to indicate the time path of various optimal cropping systems under constraints dealing with sedimentation in the reservoir and nitrate concentration in the leachate below the root zone.

The third major revision of the Phase One model is the inclusion of the impact on water quality of various levels of application of nitrogen fertilizer. Unfortunately, our knowledge of the process by

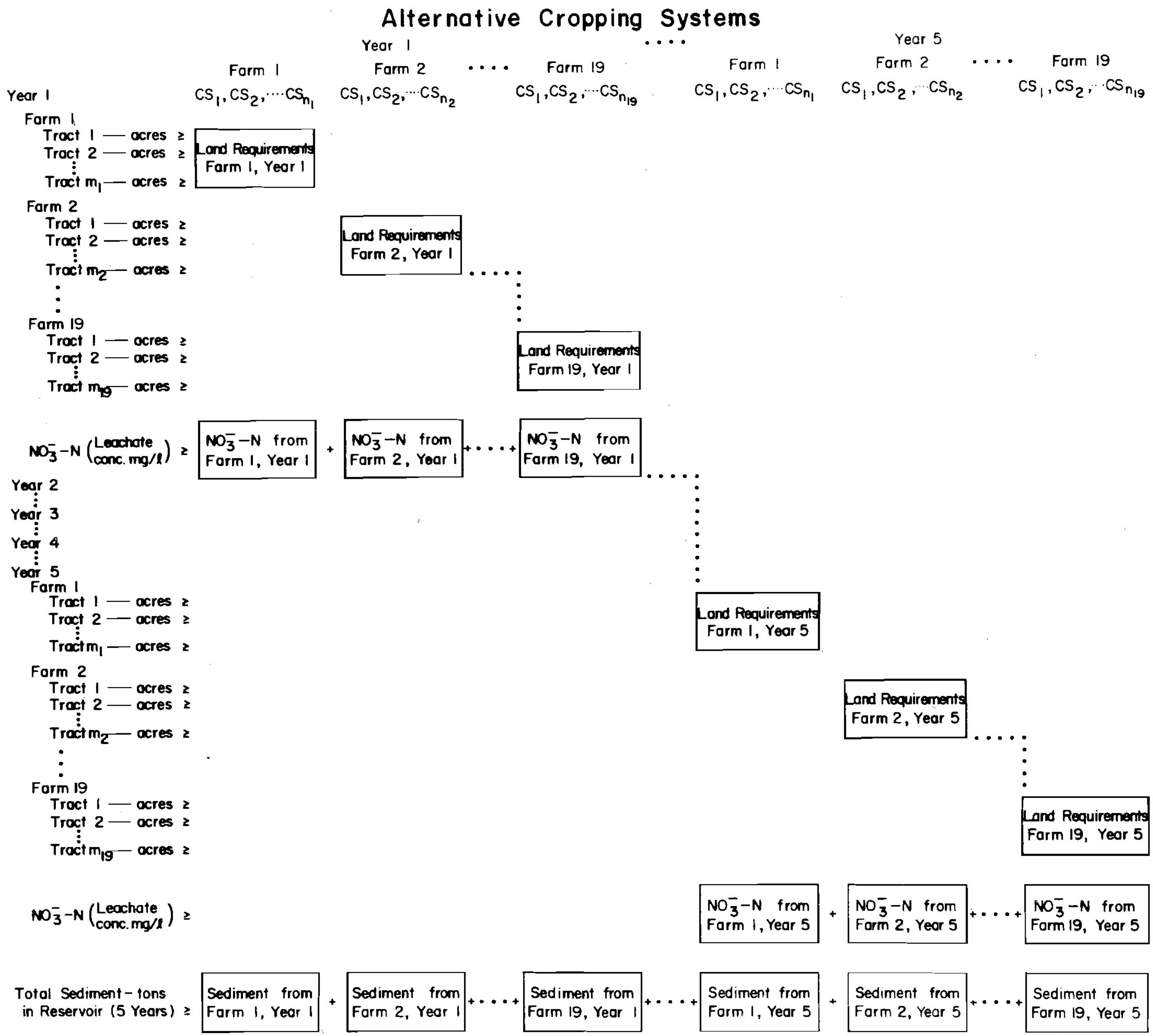
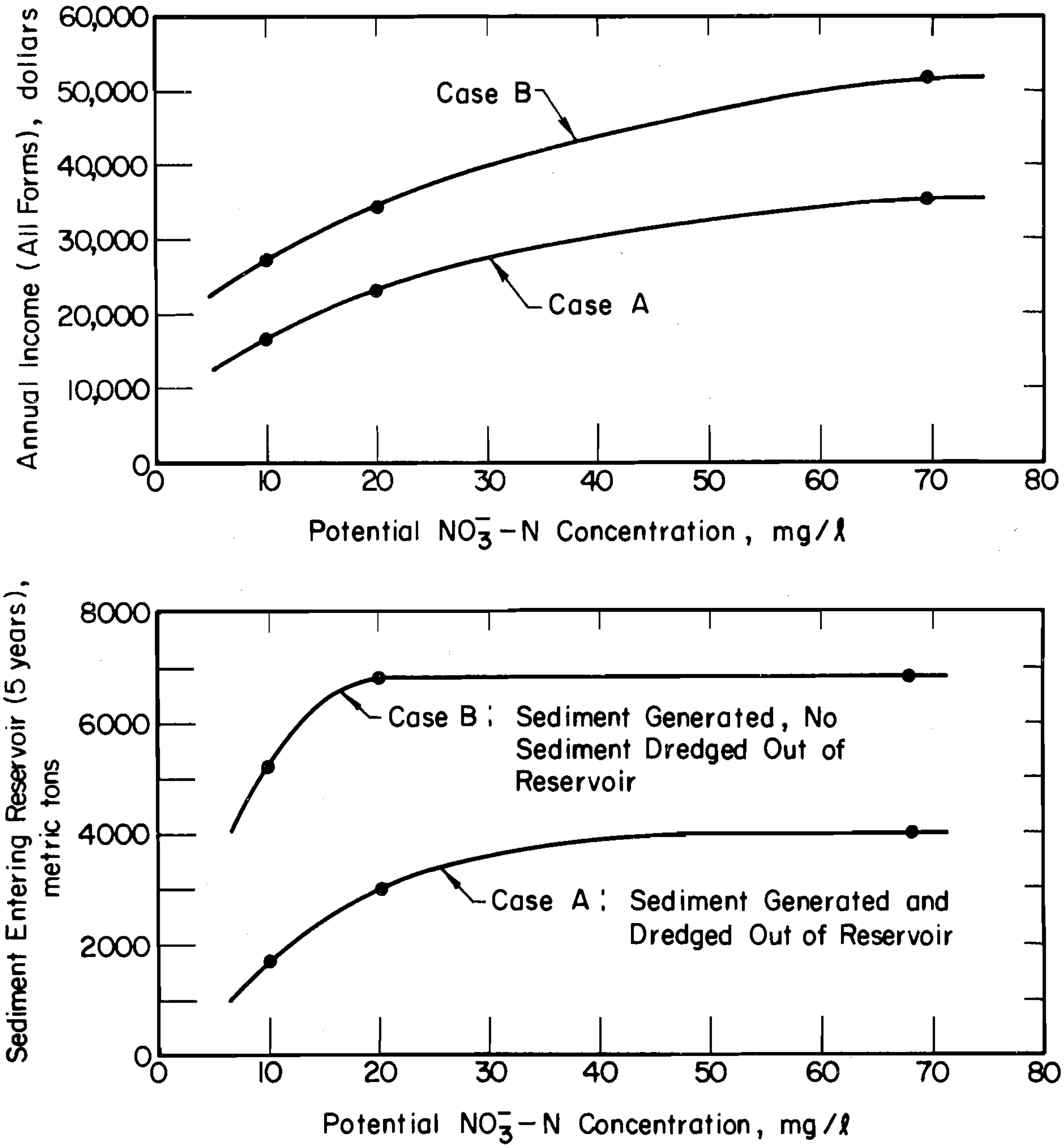


FIG. 4 DIAGRAM OF LINEAR PROGRAMMING MODEL-PHASE TWO

which nitrate travels from the site of crop production to the reservoir is inadequate. For this reason, the nitrate constraint was applied to the leachate leaving the root zone, in contrast to the sediment constraint, which was considered at the reservoir. The procedure for calculating nitrate concentration in leachate is set forth in Appendix C. Including the influence of the level of nitrogen fertilizer on leachate means that its influence on yield must be considered also. Corn yields in Phase Two, unlike those in Phase One, are variable, and costs are adjusted for yields (Appendix D). The procedure used in Phase Two for calculating sedimentation was essentially the same as that used for Phase One (Appendix A). However, the Phase Two model provided for the accumulation of sediment over the five-year planning period (see last row of fig. 4).

Finally, the range of conservation tillage practices considered in Phase Two was expanded to include the chisel-plow and plow-plant methods.

On the basis of the requirements for the control of sediment, two situations were analyzed. In the first situation, complete dredging of the reservoir is required, with the costs borne by the farmers. Thus, the allowable upper limit on sedimentation in the reservoir is zero. In the second situation, there is an upper limit of sediment for the five-year period (fig. 5). Dredging is required for all amounts in excess of this limit, with the costs borne by the farmers. This limit of sediment, it is estimated, would fill one-half of the proposed reservoir in about 300 years.



Case A: Charges Made for Dredging All Sediment from Reservoir

Case B: Charges Made for Dredging Sediment In Excess of 7711 metric tons (5 year period)

FIG. 5 EFFECT OF RESTRICTING POTENTIAL NO_3^--N IN LEACHATE BELOW ROOT ZONE ON INCOME ABOVE NON-LAND COSTS (UPPER PANEL) AND SEDIMENT ENTERING FOREST GLEN RESERVOIR (LOWER PANEL)

Three assumptions about NO_3^--N concentration in the leachate from the root zone are considered, in turn, with each sediment control situation. The three assumptions are (1) 10 mg/ℓ as the upper limit on potential NO_3^--N concentration, (2) 20 mg/ℓ as the upper limit, and (3) no upper limit at all.

For the Forest Glen watershed, the following general patterns emerge as crop production is constrained by charges on sediment released into the reservoir and limits on potential NO_3^--N in leachate below the root zone. Income above nonland costs increases rapidly as the potential NO_3^--N limit is relaxed (fig. 5, upper panel). Since any large-scale imposition of controls on sedimentation and NO_3^--N leachate would affect prices, the income data reported should be viewed as indexes of physical production. Requiring farmers to pay for dredging all of the sediment entering the reservoir (Case A) reduces income below the level which results from making a dredging charge only for the sedimentation above a fixed amount for the five-year period (Case B). Still, charging for the removal of all sediment reduces sedimentation markedly (fig. 5, lower panel).

Because sediment yield decreases or remains constant as corn yield increases with application of increasing amounts of N, the requirement that farmers dredge out all of their sediment (Case A) cannot, by itself, prevent nitrate pollution from occurring.

V. CONCLUSIONS

The analyses of the trade-offs between farm income and improving water quality in a 1,200-acre watershed represent only an illustration of the logic and method which are needed in a wide variety of environmental problem areas. Given the watershed as a unit of analysis, there are many straightforward extensions of the model which can, in principle, be easily made. For example, in addition to sediment and nitrate, agricultural activity generates other possible pollutants, such as plant nutrients other than nitrates, and pesticides. The levels of these pollutants in the waters of interest can be treated as additional constraints. This would permit a more comprehensive analysis of the implications of water quality improvement. However, although we can describe in detail the movement of sediment from various locations to the reservoir, we know very little about the dynamic changes in form and location of the other potential pollutants.

Although the above extensions would require no conceptual modification of the model, there are others, more difficult, which demand attention. Clearly, the problem of pricing the quality of the water is a critical one. The analysis presented above gives only the opportunity cost of achieving various levels of water quality, with respect to only two quality characteristics--sedimentation and nitrate concentration. Nothing is said about the gains from such quality improvement. Even if standards are established, pricing of the benefits is implicit. At the core of the valuation problem is the manner in which institutions provide for aggregation of individual preferences regarding environmental quality and the translation of such collective preferences into decisions. The operational value of the type of analysis presented above would be enhanced if these essentially political processes were more adequately recognized in the type of research conducted in this project.

Many of the extensions of the watershed model suggested above could also be made from a model covering a larger geographic area, such as a river basin. The larger model would be appropriate if, for example, substantial sedimentation or pollution damage occurred beyond the limits of the watershed.

Further, as we extend our analysis to a larger geographic area, the prices of products and costs of inputs can no longer be assumed to be independent of quantities sold or purchased, and some type of nonlinear programming may be employed. The close connection between the rates of use of the natural resources over periods of time and the environmental quality problem implies that an intertemporal extension going beyond the five-year model of Phase Two may be important in some applications. The spatial aspects of the watershed analysis presented above consisted primarily of the area-to-area flow of sediment within the four areas of the watershed. A larger river-basin model might consider separation of the basin into production and consumption regions, with provision for transport costs for interregional transfers of commodities.

For all of these modifications of the basic programming model we have precedents and experience. More difficult, and also more important for operational realism, are those modifications which incorporate the institutional alternatives for reflecting individual preferences in the management of the publicly held environmental resources. The payoffs to successful research in this area will be substantial.

In terms of the specific objective of this project--the development of a procedure for determining the effect of altering water quality standards on optimal crop production--we believe that we have succeeded in demonstrating the operational potential of the models used. As indicated above, some extensions will be relatively easy and others difficult. Nevertheless, it is our belief that both the logic and the potential empirical results of this type of systematic analysis should be an integral part of the public decision-making process regarding the interrelationships between agriculture and environmental quality.

VI. PUBLICATIONS RESULTING FROM PROJECT

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4. Swanson, Earl R., and A.S. Narayanan. "Evaluation of the effect of alternative agricultural systems on water quality: A linear programming approach." Chapter 33 in *Studies in economic planning over space and time,* edited by George G. Judge and Takashi Takayama. Contributions to economic analysis, vol. 82. Amsterdam: North-Holland Press, 1973.

5. Swanson, Earl R. "Two environmental analyses involving agriculture." In *Proceedings of computer science and statistics: Seventh annual symposium on the interface.* Ames: Iowa State University, 1973.

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APPENDIX A

PHASE ONE - PROCEDURE FOR ESTIMATING SEDIMENTATION

The first step is the calculation of the sheet erosion, based on the Universal Soil Loss Equation. Probable soil erosion losses caused by rainfall can be predicted rather accurately with this equation, which reflects the major factors known to influence soil erosion by rainfall. It is as follows: $A = RK\underline{LS}CP$

A is the average soil loss in tons per acre.

R is the rainfall erosion factor.

K is the soil erodibility factor. It reflects the fact that different types of soil erode at different rates when the other factors affecting erosion are held constant.

LS is the factor for length and steepness of slope. A 9-percent slope 73 feet in length has value of 1.0.

P is the erosion control practice factor. It is the rate of soil loss with a specified practice (terracing, strip cropping, or contouring) compared with up-and-down hill farming when other conditions are equal.

C is the cropping and management factor, which reflects the effects of the crop sequences.

Before we show the actual computational procedure, it is necessary to indicate the fixed values of the factors used in the soil loss equation. (1) An *R* value of 187 for the area under study is used.

(2) The K value for Westville, Hennepin, and Vance soils is 0.37 and for Drummer, Brenton, and Catlin soils is 0.32. (3) The average slope length of the different soils is as follows: Westville, 150 ft.; Hennepin, 100 ft.; Brenton, 90 ft.; Drummer, 150 ft.; Vance, 150 ft.; Catlin, 200 ft. Slopes for the various areas in the watershed are indicated in figure 2. The values of the equation which are subject to variation by the farm manager are P and C. The P value depends on the erosion control practices and the slope percentage. For this purpose the erosion control practice is assumed to lie halfway between up-and-down cultivation and contouring, in order to make it comparable to the actual field situation. The C factor is subject to variations due to cropping management systems and crop yield levels.

By using these values in the soil loss equation, we can compute in tons per acre the annual soil loss due to rainfall erosion for all the areas in the watershed falling under the known soil types and slopes and treated with the chosen crop sequences. Since we are primarily interested in gross erosion for the computation of sediment yields, the amount of sheet erosion per acre per year, so computed, is increased by 20 percent to allow for channel (gully) erosion. This adjusted figure gives the gross erosion rate for the areas in the chosen watershed. To illustrate this computation, let us take an area of Westville silt loam with a 6-percent slope and a slope length of 150 feet, on which may be grown two different sequences: (1) continuous corn and (2) oats followed by meadow (OMMM). The respective values are as follows:

	Continuous corn	OMMM
R	187	187
K	0.37	0.37
LS	0.80	0.80
P (average of 1.0 and 0.5)	0.75	0.75
C	0.50	0.016
Annual soil loss per acre	20.76 tons	0.66 tons
Additional 20% to include gully erosion	4.15 tons	0.13 tons
Gross erosion per acre per year	24.91 tons	0.79 tons

We said earlier that sediment is the product of erosion, and factors which influence erosion must necessarily influence sediment yields. Rates of on-site erosion and rates of sedimentation are not numerically equal. Part of the soil lost is trapped in various parts of the watershed, the amount depending upon the morphological character of the watershed. A sediment delivery ratio is the percentage relationship between the sediment yield at the specified measuring point in a watershed and the gross or total erosion in the watershed upstream from that point. If realistic estimates of both the erosion and the sediment delivery ratios can be made, sediment yield rates can be predicted with reasonable accuracy. Estimates of sediment yield rate per year are expressed in tons of sediment deposited in the reservoir from the different locations in the watershed; the locations are identified by slope and soil types. The following equation is used to calculate the sediment delivery ratio:

$$\text{Log } DRe = 1.91349 - 0.33852 \log 10w$$

where *DRe* is the sediment delivery ratio and *w* is the drainage area of the watershed in square miles.

The Forest Glen watershed drainage area lies at an elevation of 620 to 680 feet above sea level. Starting from the 650-foot countour, the drainage area is divided into four divisions: (*a*) the area above the 670-foot contour, (*b*) the area between the 660- and the 670-foot contours, (*c*) the area between the 650- and the 660-foot contours, and (*d*) the area below 650 feet and above the reservoir. A sediment delivery ratio was calculated for each of the divisions of the watershed in such a way that, on the basis of the gross erosion rate, the sediment yield can be computed. The following ratios were calculated (see table 1):

		sediment delivery ratio (percent)
A	670 feet and above	22.02
B	660 to 670 feet	25.90
C	650 to 660 feet	31.66
D	620 to 650 feet	56.83

These ratios are then used to calculate the sediment yields from the gross erosion values obtained for the various crop activities in each division of the watershed. For example, the gross erosion value of 24.91 tons per acre computed earlier for Westville silt loam is converted into sediment yield by multiplying by the appropriate sediment delivery ratio given above. The ratio to be used depends upon the contour division in which the particular soil type area is located. When land is left idle, the sediment yield values are taken as 70 percent of the values for the rotation of oats followed by three years of meadow.

APPENDIX B

PHASE ONE - PROCEDURE FOR ESTIMATING CROP YIELDS AND NET INCOMES

The following steps were taken in the computational procedure for the net income coefficients:

1. Estimated crop yields per acre were taken from a recent publication of the University of Illinois College of Agriculture,[1/] which reports estimated yields of grain, forage, and tree crops on various soil types found in the state of Illinois, for basic and high levels of management. We used an average of the two levels of management for this phase of the study. Yields were then adjusted for the extent of erosion on the various gradients found in the watershed drainage area. These adjustments made it possible to estimate yield per acre of the various crops under an average level of management and with average erosion.

The procedure may be illustrated as follows:
The reported yield of corn grown on Vance soil with a 0- to 4-percent slope, in the CSbOx rotation, is 64 bushels per acre with a basic management level and 106 bushels with a high management level. If we average these two yields, we get 85 bushels per acre under an "average" management level. This figure is then adjusted for erosion.[2/] For no erosion or very slight erosion, no adjustment is necessary. For moderate

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1/ *Productivity of Illinois Soils*, Circular 1016 (Urbana-Champaign: University of Illinois, College of Agriculture and Cooperative Extension Service, 1970) pp. 13-17.

2/ *Productivity of Illinois Soils*, p. 12.

to severe erosion, we take 86 percent of the 85-bushel yield, which is 73.1 bushels per acre. Finally, we average the two yields--85 bushels and 73.1 bushels--to obtain an estimated yield per acre of 79.2 bushels, the yield under average erosion conditions. When the slope is steeper; further adjustment is made. This procedure was used to estimate yields per acre for all the crops used in the crop sequences, namely, corn, soybeans, oats, wheat, and meadow (alfalfa).

2. The next step in the procedure is to adjust for relative effects of the cropping system on the estimated yields of crops chosen. This adjustment is made because individual crops may fare better when grown in rotation with other crops. For this purpose we used a table in Circular 1016 showing the relative effects of cropping systems on estimated corn yields. In contrast with our procedure in Phase Two of the study, we assumed a fixed rate of nitrogen fertilizer. The computational procedure may be illustrated as follows for Vance silt loam on 4-12% slope. For continuous corn the computed average corn yield of 68.3 bushels per acre is adjusted by multiplying by 0.95 to get 64.9 bushels (Table 3). For C-Sb-C-Ox the average yield of 68.3 bushels is adjusted by multiplying by 0.98 to get 66.9 bushels (Table 3). Table 3 gives the estimated crop yields under different soil types, slopes, and crop sequences, needed to calculate the net return coefficients.

3. The next step is the computation of gross revenues and the cost of production. The estimates of costs and the needed adjustments were

Table 3. Crop Yield Estimates in Bushels for Grain Crops and in Tons for Meadow

Crop Rotation		Westville Soil		Hennepin[a/] Soil			Brenton Soil	Drummer Soil		Vance Soil		Catlin Soil
		0-4% Slope (1)	4-12% Slope (2)	0-4% Slope (3)	4-8% Slope (4)	8-12% Slope (5)	0-4% Slope (6)	0-4% Slope (7)	4-12% Slope (8)	0-4% Slope (9)	4-12% Slope (10)	0-4% Slope (11)
	Cont. Corn bu.	65.5	59.0				100.4	98.7	78.0	75.20	64.9	94.2
CSbCOx	Corn bu.	67.6	60.9				103.5	101.9	81.5	77.60	66.9	97.2
	Soy bu.	21.7	19.6				33.8	35.6	28.5	25.10	21.7	31.1
	Oats bu.	39.7	37.7				65.2	60.3	48.2	48.9	42.1	63.1
CSbOx	Corn bu.	68.9	62.1				105.7	103.9	82.5	79.2	68.3	99.2
	Soy bu.	22.2	20.0				34.5	36.4	28.9	25.6	22.1	31.7
	Oats bu.	40.5	38.5				66.6	61.5	49.2	49.9	43.0	64.3
COx	Corn bu.	68.9	62.1				105.7	103.9	82.5	79.2	68.3	99.2
	Oats bu.	40.5	38.5				66.6	61.5	49.2	49.9	43.0	64.3
CSbOM	Corn bu.	68.1	61.5				104.6	102.9	82.3	78.4	67.6	98.2
	Soy bu.	21.9	19.8				34.2	36.0	29.0	25.3	21.9	31.4
	Oats bu.	40.0	38.1				65.9	60.9	48.5	49.4	42.6	63.7
	Meadow ton	2.8	2.7				4.16	3.2	2.5	3.42	2.82	4.06
CCOM	Corn bu.	68.1	61.5				104.6	102.9	82.3	78.4	67.6	98.2
	Oats bu.	40.0	38.1				65.9	60.9	48.5	49.4	42.6	63.7
	Meadow ton	2.8	2.7				4.16	3.91	3.1	3.42	2.82	4.06
CSbWM	Corn bu.	68.9	62.1				105.7	103.9	82.5	79.2	68.3	99.2
	Soy bu.	22.2	20.0				34.5	36.4	28.9	25.6	22.1	31.7
	Wheat bu.	27.2	24.5				39.6	38.7	31.0	30.8	26.5	38.2
	Meadow ton	2.9	2.7				4.2	3.95	3.1	3.45	2.85	4.1
COMM	Corn bu.	68.9	62.1				105.7	103.9	82.5	79.2	68.3	99.2
	Oats bu.	40.5	38.5				66.6	61.5	49.2	49.9	43.0	64.3
	Meadow ton	2.9	2.7				4.2	3.95	3.1	3.45	2.85	4.1
OMMM	Oats bu.	40.5	38.5	35.0	34.0	28.2	66.6	61.5	49.2	49.9	43.0	64.3
	Meadow ton	2.9	2.7	2.3	2.0	1.85	4.2	3.95	3.1	3.45	2.85	4.1

[a/] Because of Hennepin soil's susceptibility to heavy erosion and its general unproductivity only the OMMM sequence is considered in the model.

obtained from the *Farm Management Manual*.[1/] The costs included are direct costs, fertilizer cost--varied relative to the amounts of fertilizer nutrients removed for the yields as given in the manual--and, the labor cost. The land rent is not included because land appears as a constraint in the model.

4. The next step is the evaluation of gross revenues. For this purpose we used the average price per bushel received by farmers at local markets.[2/] The procedure used to compute yield data has already been shown. The average prices per bushel are as follows: corn, $1.14; soybeans, $2.47; oats, $0.60; wheat, $1.21. The average price of alfalfa hay was $23.50 per ton. For example, the net return per acre for continuous corn on Westville silt loam is calculated as follows:

Corn yield		= 59.0 bushels per acre
Gross revenue from corn:	59 x $1.14	= $67.26 per acre
Cost of production		= $36.46 per acre
Net return		= $30.80 per acre

5. We have now reached the final step of computing net returns for the crop sequences. Let us, for example, take the sequence corn, soybeans, corn, oats with intercrop--a four-year rotation to be used on Westville soil with a 4- to 12-percent slope. The net returns, computed individually for these crops, are given below:

1/ AE 4200 (Urbana-Champaign: University of Illinois, College of Agriculture, Department of Agricultural Economics, and Cooperative Extension Service, 1969)

2/ *Illinois Agricultural Statistics, Annual Summary*, 1970 (Springfield, Ill., Illinois Cooperative Crop Reporting Service. 1971.

	Net Returns per acre	Weights	Weighted Sum
Corn	$32.70	2	$65.40
Soybeans	18.06	1	18.06
Oats with intercrop	1.47	1	1.47
Total		4	$84.93

Since corn appears twice in the sequence, it is given a weight of two and other crops are assigned weights of one. A weighted average is taken, that is, $84.93/4 = $21.23, the annual net return per acre. Similar computations were made for all crop sequences and for all soils and slopes in the watershed. The only exception made was in the case of Hennepin soils, on which, because of erosion danger and general unproductivity, only one crop sequence is used: oats followed by three years of meadow. The net return coefficients for the various crop sequences are given in table 2.

APPENDIX C

PHASE TWO - PROCEDURE FOR ESTIMATING NITRATE CONCENTRATION IN LEACHATE

In 1967, Stout and Burau developed an equation for the potential nitrate concentration in water leaching beyond the root zones, based on equilibrium conditions for nitrogen.[1/] The equation is a function of (1) the units of nitrogen fixed in pounds per year (N_f), (2) rainfall in inches (P_i), and (3) water leached beyond the root zones in percentage of rainfall (L_P). If C_N and C denote the potential nitrate concentration and the potential nitrate nitrogen concentration in the leaching water, respectively, the equations are expressed as follows:

$$C_N = (19.6)(N_f)/[(P_i)(L_P/100)]\ ppm \text{ of } NO_3^-, \text{ or}$$

$$C = (4.4244)(N_f)/[(P_i)(L_P/100)]\ mg/\ell \text{ of } NO_3^-\text{-N}.$$

Adriano, Pratt, and Bishop developed the equation for average NO_3^--N concentration in the water in the unsaturated zone.[2/] The equation is expressed in terms of (1) excess nitrogen in kg/ha per year (excess N) and (2) drainage volume expressed in surface *cm* (D) as follows:

$$NO_3^-\text{-N},\ ppm = (10 \text{ excess N})/D,$$

where the unit for the constant is $mg \cdot cm \cdot kg^{-1} \cdot liter^{-1}$.

1/ P.R. Stout and R.G. Burau, The extent and significance of fertilizer buildup in *Agriculture and the Quality of our Environment,* (Washington, D.C.: Am. Assn. Adv. Sci., 1967).

2/ D.C. Adriano, P.F. Pratt, and S.E. Bishop, Nitrate and salt in soils and ground water. *Soil Science Society of America* 35:759-762. 1971.

These equations are based on excess amounts of nitrogen and volume of water not evapotranspirated. The water leaching beyond the root zones is considered equivalent to the water drained by a tile or entering a well.

In our models we use the potential nitrate (or nitrate nitrogen after the conversion of nitrate to nitrate nitrogen) concentraion equation developed by Stout and Burau, who say specifically that the equation is applicable to the soils and climate found in our watershed. However, direct calculations of potential nitrate nitrogen by means of the equation showed that crops to which 100 pounds of nitrogen or less is applied per acre do not release any nitrogen into the groundwater because nitrogen uptake by the crops is more than the amounts of nitrogen supplied. This result arises from the fact that the equation is based on equilibrium conditions of nitrogen added to and taken up by plants. In reality, even if less than 100 pounds of nitrogen per acre is applied to a crop, say corn, some nitrogen is released into the leaching water. From discussions with Drs. L.F. Welch, A.A. Bomke, and W.R. Oschwald, we concluded that available amounts of nitrogen per acre for a crop to which X pounds of nitrogen per acre are applied will be the sum of X and the pounds of nitrogen taken up by the crop to which no nitrogen is applied (Y); and the units of nitrogen fixed in pounds per year, denoted by N_f in the equation, are treated as X plus Y minus the nitrogen amount actually taken up by the crop. The equation thus modified would be useful to indicate a kind of maximum possible or potential nitrate concentration. As an example, we may calculate the potential nitrate nitrogen concentration in the leaching water from a continuous corn crop tilled by conventional tillage methods. We assume Drummer silty clay loam with applications of 50 and 100 pounds of nitrogen per acre, either in fertilizer or from the preceding legume crop.

1. Continuous corn on Drummer soil tilled by conventional methods with no nitrogen applied yields 44 bushels per acre, so that the nitrogen uptake by the grain is 44 (bushels per acre) x 0.92 (pounds of nitrogen per bushel) = 40.48 pounds of nitrogen per acre.

2. The total available amounts of nitrogen per acre are, in the one case, 50 + 40.48 = 90.48 pounds per acre and, in the other, 100 + 40.48 = 140.48 pounds per acre.

3. The yield per acre with a 50-pound application of nitrogen is 86.72 and with a 100-pound application is 115.21 bushels per acre, and nitrogen uptakes are therefore 86.72 x 0.92 = 79.78 and 115.21 x 0.92 = 105.99 pounds per acre, respectively.

4. The amounts of nitrogen left unused by the corn are 90.48 - 79.78 = 10.70 and 140.48 - 105.99 = 34.49 pounds per acre, respectively.

5. Denitrification expected to occur on Drummer soil is 25 percent of the remaining amount of nitrogen. So the nitrogen amounts which leach into the groundwater are 10.70 x 0.75 = 8.03 and 34.49 x 0.75 = 25.87 pounds per acre, respectively.

6. The rainfall leached beyond the root zones of corn on Drummer soil is 6 inches. In the equation, we can substitute 6 inches for $P_i L_P/100$ where P_i stands for rainfall in inches and L_P stands for water leached beyond the root zones in percentage of rainfall.

7. Utilizing the equation, we get

$$C = (4.4244)(N_f)/[(P_i)(L_P/100)],$$

$$C = (4.4244)(8.03)/6 = 5.92 \text{ NO}_3^-\text{-N } mg/\ell$$

and

$$C = (4.4244)(25.87)/6 = 19.08 \text{ NO}_3^-\text{-N } mg/\ell,$$

respectively.

8. The total amount of leachates under the whole cropland of the watershed is 2787.59 acres·inches. The nitrate nitrogen coefficients of the continuous corn on Drummer soil, treated with 50- and 100-pound applications of nitrogen per acre and tilled by conventional methods, are calculated as follows:

$$\frac{6(\text{inches}) \times 5.92 \ (\text{N-N } mg/\ell)}{2787.59 \ (\text{acres}\cdot\text{inches})} = 0.0127$$

and

$$\frac{6(\text{inches}) \times 19.08 \ (\text{N-N } mg/\ell)}{2787.59 \ (\text{acres}\cdot\text{inches})} = 0.0411,$$

respectively. The unit is N-N $mg/(\ell\cdot\text{acre})$.

To calculate the potential maximum nitrate nitrogen concentration of a cropping rotation, the potential maximum nitrate nitrogen concentrations of all the crops in the rotation are obtained; these are weighted with an equal percentage, say 25 percent for each crop of a four-year rotation; and the resultant figures are summed.

where Y stands for corn yield in bushels per acre and N is pounds of nitrogen applied per acre.

This response function is higher than one which would reflect farmers' management levels, because the data were obtained through experiments. The response function, therefore, was adjusted to approximate the management level of the farmers in the watershed. The intercept, 67.7, seems rather high, whereas the other coefficients, 0.9964 and 0.0028, seem reasonable. Accordingly, the adjustment involved only the substitution of 44.0 bushels for the 67.7 bushels in the above equation.

An average management level was assumed in the calculation of yields. Each yield was determined by finding the midpoint between high management and basic management.[1/] Thus, for example, the average corn yields on various soils, all with slopes of 4 percent or less and cultivated by conventional tillage, are as follows: on Brenton silt loam, 113.5 bushels per acre; on Catlin silt loam, 106.5 bushels; and on Drummer silty clay loam, 111.5 bushels.

When we substitute 113.5, 106.5, and 111.5 in the adjusted response equation, we obtain the amounts of nitrogen necessary to produce these yields of corn. Let N_B, N_C, and N_D be the nitrogen required on Brenton, Catlin, and Drummer soils, respectively: then $N_B = 95.47$, $N_C = 81.11$, and $N_D = 91.14$ pounds per acre.

1/ *Productivity of Illinois Soils*, Circular 1016 (Urbana-Champaign: University of Illinois, College of Agriculture and Cooperative Extension Service, 1970), p. 9 and pp. 13-17. Yields of other crops are also found in this publication pp. 13-17.

The technical optimum or maximum-yield nitrogen level resulting, denoted by N_T, is $N_T = 175.24$ pounds per acre, an application which produces 131.29 bushels per acre.

Additional yield adjustments were made to reflect the slope and degree of erosion according to the methods described in Circular 1016. Also, the effect of tillage methods on yields were estimated. The yields of corn cultivated by the plow-plant method are about the same as the yields of corn cultivated by conventional tillage. Since the corn yields with chisel-plow tillage are considerably affected by drainage properties of soil, it is necessary to adjust the corn yield functions when this method is used. A 10-percent yield reduction on well-drained soils and a 20-percent reduction on poorly drained soils was estimated to be the result of using the chisel-plow method rather than conventional tillage.

Soybean Yields

It is well known that soybeans do not usually respond to nitrogen fertilizer, although they respond well to P_2O_5 and K_2O. The soybean yields expected under average management on Brenton, Catlin, Drummer, Vance, and Westville soils are 37.00, 34.00, 39.00, 27.50, and 25.73 bushels per acre, respectively, if the slope is 4 percent or less.[1/] Adjustments were made for steeper slopes.

1/ *Productivity of Illinois Soils*, p. 12.

Wheat Yields

Although wheat yields may be increased by applying nitrogen, we did not consider this possibility because it would have increased the number of variables substantially. The average wheat yields under average management on Brenton, Catlin, Drummer, Vance, and Westville soils are 42.50, 41.00, 41.50, 33.00, and 31.58 bushels per acre, respectively, if the slope is 4 percent or less. Again, adjustments were made in yields for slopes of over 4 percent.

Alfalfa Yields

Alfalfa is used as the meadow crop in this study because it is popular in central Illinois, where it is possible to harvest four or five crops a year. Alfalfa is also used in the model as a catch crop. Alfalfa as a catch crop, or meadow, produces some nitrogen and organic matter, the amount depending on the yield per acre.

Alfalfa yields under average management, on Brenton, Catlin, Drummer, Vance, and Westville soils, are 4.45, 4.35, 4.20, 3.60, and 3.39 tons per acre, respectively, if the slope is 4 percent or less, with appropriate adjustments for steeper slopes.

In calculating fertilizer cost, it is important to take into consideration the effect of the nitrogen produced by alfalfa on the corn immediately to follow. Alfalfa was estimated to add to the soil approximately 85 pounds of nitrogen in the yield range of 2.5 to 4.0 tons per acre.

Net Revenues per Acre

Net revenue per acre of a crop is defined as the gross revenue minus the production cost. The following unit prices were used: corn, $1.16 per bushel; soybeans, $2.62 per bushel; wheat, $1.49 per bushel; and baled alfalfa, $23.22 per ton.

Production Costs per Acre

Corn production with conventional tillage without use of nitrogen produced by legume grasses. -- The production cost of corn consists of (1) depreciation of preharvest power and machinery, (2) repairs and fuel for preharvest power and machinery, (3) seed, (4) sprays and other materials used before harvest, (5) depreciation of harvesting and conditioning power and machinery, (6) repairs and fuel for harvesting and conditioning power and machinery, (7) custom machine hire at harvest, (8) other materials used at harvest, (9) fertilizer, and (10) labor. In this study, rent and taxes are not included because these costs are fixed and independent of the cropping system followed.

The depreciation cost of preharvest power and machinery is $6.00 per acre and of harvesting and conditioning power and machinery, $10.00 per acre, irrespective of corn yields. The cost of repairs and fuel for preharvest power and machinery is $3.50 per acre, irrespective of corn yields. Since the corn yield functions used are based on a plant population of 20,000 per acre, the seed cost is $6.00 per acre, irrespective of corn yields. The cost of sprays and other materials before harvest changes with corn yields. These costs are expressed in dollars per acre as follows:

$$C^C_{SO} = \$2.00, \text{ for } 20 \leqq Y \leqq 80, \text{ and}$$

$$C^C_{SO} = 3Y/40 - 4, \text{ for } Y > 80,$$

where C^C_{SO} denotes the cost per acre of sprays and other materials before harvest and Y denotes bushels of corn per acre.

The cost of repairs and fuel for the harvesting and conditioning power and machinery varies in this way:

$$C^C_{RFH} = Y/40 + 1.10, \text{ for } 20 \leqq Y,$$

where C^C_{RFH} denotes the cost per acre of repairs and fuel for harvesting and conditioning power and machinery.

Custom machine hire cost for harvesting and conditioning C^C_{CMH} is as follows:

$$C^C_{CMH} = Y/50, \text{ for } 20 \leqq Y.$$

The cost of other materials for harvesting and conditioning C^C_{OMH} is kinked as follows:

$$C^C_{OMH} = 0.80, \text{ for } 20 \leqq Y \leqq 80, \text{ and}$$

$$C^C_{OMH} = Y/100, \text{ for } 80 < Y.$$

To calculate the cost of fertilizer, we must add together the costs of nitrogen fertilizer, P_2O_5, K_2O, and limestone maintenance. The cost of nitrogen is 6.5 cents per pound, of P_2O_5, 9 cents, and of K_2O, 5 cents.

The cost of P_2O_5 per acre is estimated here by multiplying the P_2O_5 uptake per acre by 1.2, a procedure equivalent to adding 20 percent to allow for the amount of P_2O_5 which runs off into the reservoir, evaporates, and is absorbed by the soil. The P_2O_5 uptake by a bushel of corn is 0.37 pounds. With these figures then, we can estimate, for example, that the cost of the P_2O_5 required to produce 110.54 bushels of corn per acre on Drummer silty clay loam with a slope of 4 percent or less, under average management, cultivated by conventional tillage, would be 110.64 x 0.37 x 1.2 x \$0.09 = \$4.61 per acre. In mathematical form, the cost of P_2O_5 is

$$C_P^C = 0.03996Y, \text{ for } 0 \leqq Y,$$

where C_P^C denotes P_2O_5 cost in dollars per acre.

Similarly, the cost of K_2O is estimated by using the K_2O uptake of corn per acre multiplied by 1.2, 20 percent being added as in the case of P_2O_5. The K_2O uptake by a bushel of corn is assumed to be 0.24 pounds. In mathematical form the K_2O cost is expressed as

$$C_K^C = 0.0144Y, \text{ for } 0 \leqq Y,$$

where C_K^C denotes K_2O cost in dollars per acre.

Limestone maintenance costs \$2.00 per acre, irrespective of corn yield.

Accordingly, total fertilizer cost, C_F^C, is

$$C_F^C = 0.03996\ Y(N) + 0.0144\ Y(N) + 0.065\ N + 2.00$$

$$= 0.05436\ Y(N) + 0.065\ N + 2.00,$$

where $Y(N)$ means the corn yield expected with the application of N pounds of nitrogen. Here we assume that the amounts of N, P_2O_5, and K_2O needed to produce a certain amount of corn on soils with slopes of 4 percent or less are the same as those required on soils with slopes of 4 to 12 percent, although corn yields on soils with the steeper slopes are lower than those where the slopes are less steep.

Farm labor cost, C_{FL}^{C}, can be obtained by the following formula:

$$C_{FL}^{C} = 2.00\ (Y/200 + 4.00),\ \text{for}\ 20 \leqq Y,$$

where labor cost per hour is assumed to be $2.00.

The above costs, which comprise the production cost of corn cultivated by conventional tillage, are applicable not only to continuous corn but also to the second year of corn in the rotation C-C-S-W_x when the tillage is conventional.

Corn production with conventional tillage using nitrogen produced by legumes. -- It is clear that the production cost of corn which is not supplied with nitrogen from a legume catch crop or meadow is a little higher than that of corn with nitrogen supplied by legumes.

For alfalfa yields exceeding 4 tons per acre, about 100 pounds of nitrogen per acre are produced, while for yields less than 4 but more than 2.5 tons per acre, 85 pounds of nitrogen per acre are produced. Alfalfa as a catch crop left unharvested and plowed under in spring produces almost the same amount of nitrogen as alfalfa left in meadow.

Corn production with plow-plant tillage. -- The production costs of continuous corn with plow-plant tillage differ from those of continuous corn with conventional tillage only in items 2, 4, and 10 of the list given on page 43. The other items of production cost are exactly the same for both kinds of tillage.

The cost of repairs and fuel for preharvest power and machinery (item 2) is \$2.90 per acre regardless of corn yields.

The cost of preharvest sprays and other material (item 4), denoted by C^P_{SO}, is expressed as follows:

$$C^P_{SO} = 2.50, \text{ for } 20 \leq Y \leq 80,$$

and

$$C^P_{SO} = 3Y/40 - 3.50, \text{ for } 80 < Y.$$

The farm labor cost (item 10), denoted by C^P_{FL}, is expressed as follows:

$$C^P_{FL} = 2.00\ (Y/200 + 3.40), \text{ for } 20 \leq Y.$$

All the other costs are the same as with conventional tillage.

Corn production with chisel plow tillage. -- The costs of corn production by chisel plow tillage differ from those of conventional and plow-plant tillage only in the same items--2, 4, and 10.

The cost of repairs and fuel for preharvest power and machinery is \$2.70 per acre, irrespective of corn yields.

The cost of preharvest sprays and other material, C^H_{SO}, is

$$C^H_{SO} = 2.50, \text{ for } 20 \leq Y \leq 80,$$

and

$$C^H_{SO} = 3Y/40 - 3.50, \text{ for } 80 < Y.$$

The farm labor cost of chisel-plow tillage, C^H_{FL}, is

$$C^H_{FL} = 2.00\ (Y/200 + 3.20), \text{ for } 20 \leq Y.$$

All the other costs are the same as those under both conventional and plow-plant tillage.

Soybean production

The cost items of soybean production in the watershed under study are (1) depreciation of preharvest power and machinery, (2) repairs and fuel for preharvest power and machinery, (3) seed, (4) sprays and other material used before harvest, (5) depreciation of harvesting power and machinery, (6) repairs and fuel for harvesting power and machinery, (7) custom machine hire at harvest, (8) fertilizer, and (9) labor. In contrast with corn production, nitrogen cost, seasonal hired labor cost before and at harvest, custom machine hire cost before harvest, and other material cost at harvest are not counted as cost items of soybean production.

The depreciation cost of preharvest power and machinery is \$6.00 per acre, independent of the level of soybean yields. The cost of repairs and fuel for preharvest power and machinery is constant at \$3.50 per acre. The depreciation cost of harvesting and conditioning power and machinery is constant at \$4.00 per acre.

The seed cost, $C^C_{S\cdot S}$, is a function of soybean yield:

$$C^C_{S\cdot S} = Y_S/17 + 1.06, \text{ for } 0 \leqq Y_S,$$

where Y_S denotes bushels of soybeans per acre.

The cost of preharvest sprays and other material, denoted by $C^C_{S\cdot SO}$, is

$$C^C_{S\cdot SO} = Y_S/34 + 2.53, \text{ for } 0 \leqq Y_S.$$

The cost of repairs and fuel for harvesting power and machinery is

$$C^C_{S \cdot RF} = Y_S/85 + 0.91, \text{ for } 0 \leqq Y_S.$$

The cost of custom machine hire for harvesting and conditioning, $C^C_{S \cdot CMH}$, is

$$C^C_{S \cdot CMH} = 0.3Y_S/17 + 0.12, \text{ for } 0 \leqq Y_S.$$

Farm labor cost, expressed by $C^C_{S \cdot FL}$, is

$$C^C_{S \cdot FL} = 2.00\ (Y_S/170 + 4.30), \text{ for } 0 \leqq Y_S.$$

The costs of P_2O_5 and K_2O, denoted by $C^C_{S \cdot P}$ and $C^C_{S \cdot K}$ respectively, are

$$P^C_{S \cdot P} = 0.095625\ Y_S, \text{ for } 0 \leqq Y_S,$$

and

$$P^C_{S \cdot K} = 0.06875\ Y_S, \text{ for } 0 \leqq Y_S,$$

respectively, where the P_2O_5 and K_2O uptakes by a bushel of soybeans are 0.85 and 1.10 pounds of P_2O_5 and K_2O, respectively. The P_2O_5 and K_2O costs for 39.00 bushels of soybeans (harvested yields on Drummer soils) are also assumed to be the costs for soybean production on other soils.

Wheat production

For wheat, the depreciation costs of preharvest and harvest power and machinery are \$3.00 and \$4.00 per acre, respectively, independent of wheat yields. The cost of repairs and fuel for preharvest power and machinery is also constant at \$1.40 per acre.

The seed cost, $C^C_{W\cdot S}$, is

$$C^C_{W\cdot S} = 7\ Y_W/150 + 0.93, \text{ for } 31.00 \leqq Y_W$$

where Y_W stands for bushels of wheat per acre.

The cost of preharvest sprays and other material, $C^C_{W\cdot SO}$, is

$$C^C_{W\cdot SO} = Y_W/150 + 0.43, \text{ for } 31.00 \leqq Y_W.$$

The cost of repairs and fuel cost for harvesting power and machinery, $C^C_{W\cdot RF}$, is

$$C^C_{W\cdot RF} = 2\ Y_W/150 + 0.77.$$

The cost of custom harvesting power machine hire, $C^C_{W\cdot CMH}$, is

$$C^C_{W\cdot CMH} \leqq Y_W/150$$

The farm labor cost, $C^C_{W\cdot FL}$, is

$$C^C_{W\cdot FL} = 2.00\ (Y_W/150 + 1.73).$$

In calculating fertilizer cost, we assume that straw is returned to the soil, and that only grain is harvested.

The nitrogen cost, $C^C_{W\cdot N}$, is

$$C^C_{W\cdot N} = 0.099125\ Y_W, \text{ for } 31.00 \leqq Y_W,$$

where nitrogen uptake by a bushel of wheat is 1.22 pounds, the unit price of nitrogen is 6.5 cents, and a 25-percent addition is made to account for losses of nitrogen.

The P_2O_5 cost, $C^C_{W \cdot P}$, is

$$C^C_{W \cdot P} = 0.059625\ Y_W, \text{ for } 31.00 \leqq Y_W,$$

where the P_2O_5 uptake by a bushel of wheat is 0.53 pounds.

The K_2O cost, $C^C_{W \cdot K}$, is

$$C^C_{W \cdot K} = 0.02\ Y_W, \text{ for } 31.00 \leqq Y_W,$$

where the K_2O uptake by a bushel of wheat is 0.32 pounds.

The cost of the amounts of N, P_2O_5, and K_2O required to produce 42.5 bushels of wheat per acre on Brenton soil with a slope of 4 percent or less also applies to the other soils and slopes.

Alfalfa production

The cost of herbicide material and its application and the cost of labor and machinery are $10.00 and $6.50 per acre, respectively.

The cost of seed and lime for a 3-year stand, $C^C_{A \cdot SL}$, is expressed as follows:

$$C^C_{A \cdot SL} = 2.50 + 0.50\ Y_A, \text{ for } 3.00 \leqq Y_A,$$

where Y_A denotes tons of alfalfa per acre.

Fertilizer cost (i.e., P_2O_5 and K_2O), $C^C_{A \cdot F}$ is

$$C^C_{A \cdot F} = 9.00 + Y_A, \text{ for } 3.00 \leqq Y_A \leqq 4.00,$$

and

$$C^C_{A \cdot F} = 5.00 + 2\ Y_A, \text{ for } 4.00 < Y_A,$$

respectively.

The cost of mowing, conditioning, baling, and handling, $C^C_{A \cdot M}$, is estimated for two yield ranges:

$$C^C_{A \cdot M} = 4.20 + 7.80\ Y_A, \text{ for } 3.00 \leq Y_A \leq 4.00,$$

$$C^C_{A \cdot M} = 5.00 + 7.60\ Y_A, \text{ for } 4.00 < Y_A \leq 5.00.$$

The estimated cost of mowing, conditioning, baling, and handling for yields greater than five tons per acre is not needed because this level is not achieved under average management on the soils in this watershed.