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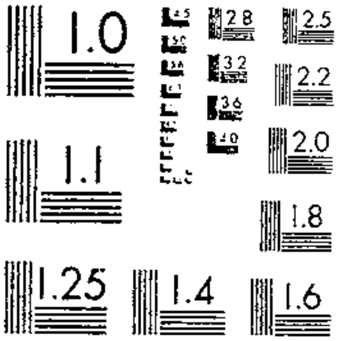

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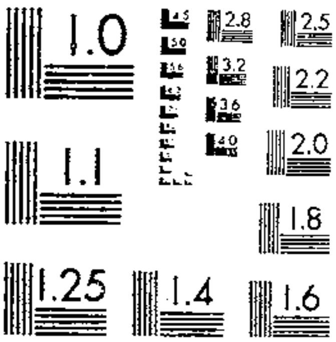

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Trade-offs Between Farm Income and Selected Environmental Indicators: A Case Study of Soil Loss, Fertilizer, and Land Use Constraints

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TRADE-OFFS BETWEEN FARM INCOME AND SELECTED ENVIRONMENTAL INDICATORS: A Case Study of Soil Loss, Fertilizer, and Land Use Constraints. James Kasal. Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin No. 1550.

ABSTRACT

Changes in farm income associated with alternative restrictions on soil loss, fertilizer use, and the land use mix are analyzed. A linear programming model is used to estimate the effects of the restrictions, which were developed as indicators of environmental quality. Effects of a partial flood control program on farm income and the environmental quality indicators are also examined.

Under conditions assumed in this analysis, restrictions on fertilizer use reduce net farm income more than constraints on either soil loss or the land use mix. Soil loss constraints reduce net revenue and fertilizer use while increasing the diversity of land use. Constraints on the land use mix reduce net revenue, soil loss, and fertilizer use. All of the constraints, either singly or in combination, decrease net revenue and fertilizer use. Flood retarding structures mitigate revenue losses only slightly and do not significantly change effects produced by environmental constraints.

Public policies requiring lower erosion rates, reduced fertilizer use, or increased diversity of land use could affect rural resources and food and fiber production. Achieving any of those environmental changes has accompanying trade-offs in farm income.

Keywords: Trade-offs, Economic impact, Environmental quality, Small watersheds, Soil loss, Fertilizer use, Spatial heterogeneity, Land use mix, Linear programming, Evaluation, Environmental constraints.

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CONTENTS

HIGHLIGHTS

What are the impacts on farm income of selected constraints that improve the environment? The constraints studied were efforts to reduce soil loss, to reduce fertilizer use, and to increase spatial heterogeneity (diversity of land use). Ten linear program solutions, based on these three constraints and their combinations plus a flood protection factor, were developed to depict varying levels of environmental enhancement.

If public policy mandates such changes, large incentives or severe penalties may be necessary to offset consequences of reduced farm income.

An unconstrained solution was developed to identify the profit maximizing potential of a case study river basin. Net farm income changes resulting from environmental constraints were computed and compared with this unconstrained solution. Although soil loss control is treated in this study as a factor constraining farm income, it is clear that unchecked soil loss would also lower farm income over time. Therefore, the cost of environmental constraints tends to be overestimated.

The unconstrained solution produced a total net revenue of $24.37 million or an average of $59.17 per productive acre. The land use mix resulting from the unconstrained solution yielded a spatial heterogeneity index (SHI) of .84235 compared to a possible maximum value of 2.19823. SHI is a measure of the diversity of the agricultural landscape and reaches a maximum value when the proportion of all land uses are equal.

Soil loss restrictions had the least negative impact on revenue of the three types of constraints applied. Restricting soil loss to less than 10 tons per acre reduced total basin revenue to $22.2 million, a decline of about 9 percent. But, 61 percent of the unconstrained soil loss from contributing acreage (26.2 tons per acre) was eliminated. The revenue cost of the 10-ton constraint was approximately 33 cents per ton for the reduced soil loss.

A 5-ton-per-acre soil loss constraint reduced soil loss by 80 percent and revenue declined by 16 percent to $20.4 million. This was equivalent to a decline in revenue of approximately 45 cents per ton of reduced soil loss per acre.

Fertilizer restrictions reduced net revenue more than did constraints on soil loss or land use. Restricting fertilizer use to about current average levels reduced fertilizer use by about 60 percent below the income-maximizing level. Such a restriction reduced total net revenue by 20 percent to $19.5 million. Each 1-pound reduction in fertilizer use results in a 9-cent-per-acre decrease in revenue. Reducing fertilizer use increases soil loss by 27 percent to 33.16 tons per acre per year.

Restricting fertilizer to a low level of use had an even greater negative effect on revenue. Total revenue in this case amounted to $17.5 million, or 28 percent below the unconstrained case. Each 1-pound reduction in fertilizer resulted in a 10.7-cent-per-acre decrease in revenue. Soil loss was increased to 34.18 tons per acre per year.

Constraints on the land use were designed to maximize the SHI. As in the other cases, when a constraint was imposed on the system, net revenue suffered. Total basin revenue fell by 17 percent to $20.1 million. Soil loss was also reduced by 19 percent and fertilizer use decreased 33 percent. The SHI rose to 2.00158.

Applying constraints in combination imposes a more restrictive set of conditions. Simultaneous restrictions on both fertilizer use and soil loss reduced revenue substantially more than when either variable was constrained individually. However, the reduction in revenue from a simultaneous combination of constraints was less than the sum of revenue reductions resulting from separate constraints.

A combination of a fertilizer constraint with a restriction on the land use mix also reduced net revenue while soil losses remained high. This combination of constraints tended to equalize land use and the SHI increased to 2.05448. This indicated that reduced fertilizer use was complementary with a restriction on land use in changing the cropping pattern. The SHI for this solution was higher than when the land use mix was constrained by itself because reduced fertilizer usage forced a more equal distribution of acres among corn, sorghum, and soybeans.

The combination of a low fertilizer constraint with a 5-ton-per-acre soil loss constraint was the most restrictive case studied. Total revenue for the basin amounted to only $13.36 million. This was a decrease of over 45 percent from the revenue obtained under unconstrained conditions. Average revenue per acre was $37.65. The SHI was 1.89314, relatively high when compared to other solutions.

The last case studied added a partial flood protection program, that is, floodwater-retarding structures, to the low fertilizer and 5-ton-per-acre soil loss solution. The addition of a partial flood protection program to the tight environmental constraints mitigated revenue losses slightly. Total revenue amounted to $13.43 million or an average of $37.98 per acre. Fertilizer use and soil losses remained almost identical to those obtained without the flood control program. Even though the SHI of 1.89856 showed marginal improvement, the addition of the structures produced no real discernible change in land use. In general, tight environmental constraints had rather large negative consequences, but the addition of flood protection did not provide any significant change in the effects of these constraints.

More alternatives need to be explored to fully assess the various interdependencies that take place between different environmental objectives. In sum, this analysis provides some evidence that achievement of lower erosion rates, reduced fertilizer use, and/or increased diversity of land use would involve significant reductions in net farm income.

TRADE-OFFS BETWEEN FARM INCOME AND SELECTED ENVIRONMENTAL INDICATORS

A Case Study of Soil Loss, Fertilizer, and Land Use Constraints

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INTRODUCTION

Water and related land resource development projects such as flood control, irrigation, or drainage works have usually been justified on the basis of economic efficiency. More recently, the American public has been pressing development program agencies for a broadened consideration of the beneficial and adverse effects of resource development.

In responding to these pressures, the Water Resources Council, composed of Federal agencies with responsibilities in developing natural resources, has specified a multi-objective approach to evaluation of development of projects.[1] This multi-objective approach gives equal weight to national economic development and environmental quality as objectives in planning water and related land resources. Public involvement in water resource development projects has also increased the importance of environmental quality as a planning objective.

Pressures to preserve or enhance environmental values in resource planning will probably intensify. Therefore, it is necessary to develop information not only on society's environmental goals but also on the opportunity costs (the types and amounts of economic goods that must be foregone) in achieving these goals. Such information should contribute to the information base on which government decisions regarding the use, management, and development of natural resources can be made.

This research does not endorse any specific evaluation technique nor does it present a better method for planning and evaluation. *The principal objective of this study is to formulate a methodology for identifying and analyzing some of the trade-offs between farm income and various environmental quality indicators.*

This study was aimed toward investigating ways in which government policies and controls can be directed or formulated to achieve desired social objectives of environmental improvement through the use and management of natural resources. Because local and national concerns about environmental quality have resulted in the establishment of new public programs and reorientation of existing ones, more information is needed in order to better understand the possible economic impact of these changes.

This study was limited to agricultural activities even though environmental degradation in rural areas is not caused by agriculture alone. This research sheds some light on the problem of preventing further environmental degradation and how actions aimed at ameliorating this problem interact with other USDA responsibilities of maintaining rural income and employment along with assuring an adequate food, feed, and fiber supply.

[1] Water Resources Council, "Water and Related Land Resources: Establishment of Principles and Standards for Planning," Federal Register, Vol. 38, No. 174, Part III, Monday, Sept. 10, 1973, Washington, D.C., pp. 24781-24783.

THE MODEL[2]

A trade-off is the exchange of estimated benefits and costs resulting from alternative plans of action. Alternative plans of action considered in this study were designed to have varying degrees of increased farm income and environmental quality as their objective. Environmental quality benefits were not handled explicitly in the model; they were assumed to be equal to the changes in farm income resulting from imposition of environmental constraints. Only income trade-offs were considered. The distribution of these trade-offs among farmers and various income groups is also important but was not considered in the model.

A linear programming model was developed as the most feasible method for evaluating the various alternatives. With linear programming analysis, economic alternatives can be evaluated as various traditional and environmental outputs are provided. Also, the linear programming system can be constructed to take into account quality as well as quantity considerations.

Economic efficiency was retained as the major objective of society, profit maximization was used as its measure. The selected environmental constraints produced changes in the revenue generated.

The environmental linear programming model used here incorporates some features of the Generalized Agricultural Production Analytical System (GAPAS) and the Forest Range Environmental Production Analytical System (FREPAS), both developed in previous USDA studies.[3] Briefly, the model is a matrix of land use, input-output coefficients, and demand equations. The system uses linear programming mathematics to maximize profits by combining soils and crop possibilities in the most efficient manner. In practice, constraints, watershed subdivision, soil resource groups, conservation practices, fertilizer rows, soil loss rows, and land use rows complicate the system.

While the model uses linear programming as a tool in performing analysis and evaluation, the model is better understood if it is described as a computerized resource inventory with controls to limit the choices of crops to levels within reasonable physical, cultural, and social limits. Its use is to simulate and measure the *change* in resource use and output that results from changing assumptions, technical coefficients, demands, and other parameters. This model is poorly suited to reproduce reality by reflecting each and every variable affecting current land use. The system can best be described as a set of relationships which show direction and magnitude of relative reactions to alternative assumptions. The system is well suited to analyze changes in land resource use and the resulting production effects on agriculture.

[2]For a more detailed explanation of the model, see the appendix.

[3]See, respectively, McDonnell Automation Co., *Generalized Agricultural Production Analytical System* for the U.S. Dept. Agr., May 1968, revised Dec. 1969, and Kenneth DeBower, Ronald Lockard et al, *Forest Range Environmental Production System: A Computer System Developed for Forest Range Task Force*, Forest Service, U.S. Dept. Agr., Lincoln, Neb., June 1971.

ENVIRONMENTAL CONSTRAINTS

A case study approach was used to test our generalized conceptual framework. A small river basin subdivided into seven watersheds was selected to provide the needed basic data for this test.[4] Three environmental constraints were selected: soil loss, fertilizer use, and spatial heterogeneity of land use mix.

SOIL LOSS

Sediment—eroded material deposited in water bodies and carried by water—may be the most extensive water pollutant known. Water quality is impaired by sediment because it provides the biological and physical mechanism through which a variety of pollution processes take place. It is also a transportation system for other pollutants. Control of erosion or soil loss, therefore, was selected as an indicator of environmental improvement.

Constraining soil loss for environmental reasons is not a new idea. Environmental arguments have been used in the justification of Federal programs for many years. However, in recent years, because of the greater awareness of environmental problems, a new emphasis is being placed on the reduction of soil loss. There are proposals calling for a sediment control act which would install controls over nonagricultural, land-disturbing activities.[5] Soil conservation districts are being forced to fill the need for some form of regulatory authority in controlling agricultural sediment. Laws have been enacted to

[4]The river basin is unnamed to avoid improper comparisons between actual conditions and programmed optima. The seven subwatersheds are hydrologic units hereafter referred to simply as watersheds.

[5]Council on Environmental Quality, *The President's Environmental Program*, pp. 15-38, and the President's Message on the Environment, Feb. 8, 1972.

strengthen State erosion control programs. Conservation districts are required to establish soil loss limits and provide for their implementation. Landowners would be required to employ erosion control practices provided cost-sharing funds are available equal to 75 percent of the cost.[6]

FERTILIZER USE

Fertilizer use was also selected as an indicator of environmental quality. Many contend that high levels of fertilizer use by agriculture make a major contribution to the pollution and eutrophication of water bodies. Phosphorus is usually considered the significant element in the process of lake eutrophication. Because of the pollution potential of phosphates, several States have enacted legislation to curb or ban the use of phosphates in detergents, an action primarily aimed at its urban use. Although no action has been taken to restrict agricultural use of phosphorus, such restrictions could be imposed.

Nitrogen, the principal agricultural nutrient, is also a potential polluter of surface water and groundwater. With the continued and rapidly increasing use of all plant nutrients, especially nitrogen, fertilizer will likely become a greater water pollution factor.

Because of the biological changes and loss of esthetic values associated with eutrophication brought about by improper or overuse of fertilizer, more restrictive limits may be imposed on fertilizer use in agriculture. The current shortage of natural gas has also created concern about the availability of nitrogen fertilizer, and could lead to restricted fertilizer use.[7]

LAND USE MIX

The third environmental constraint utilized in this study attempts to equalize land use. The results of this constraint are measured by means of a spatial heterogeneity index (SHI), a measure of the evenness of acreage distribution among selected land uses. This type of constraint is based on the idea that diverse crop patterns are more esthetically pleasing and less ecologically hazardous than are single use production patterns.

Because of the subjective nature of esthetic pleasure and visual beauty, the measurement of quality differences presents major difficulties.[8] It has been argued that landscape diversity, containing different primary uses, provides not only situations of interest and pleasure but in fact is important to human well-being.[9]

Despite theoretical and practical problems associated with quantifying esthetic values, the Water Resources Council, in their "Principles and Standards", recommends "protection, enhancement or creation of aesthetic areas" as one of four general classifications to be used in understanding and interpreting environmental effects.[10] It is also recommended that the measurement of esthetic areas be made not only with respect to size, but also with respect to its distribution and location. Therefore, for the purposes of this study, we will accept that diverse crop patterns are more esthetically pleasing than monoculture would be. The SHI developed serves as a measure of the proportional mix of land use.

Development of the land use constraint is also based on the ecological hazard of monoculture. Some ecologists and conservationists maintain that monoculture is like a time bomb--although it is used to make a profit, it carries within it the ingredients for disasters.[11] The rationale is that cultivated plants are biological weaklings and that monoculture exposes these plants to concentrated attacks by insects and disease organisms. Such attacks are countered by massive use of insecticides, and so on, which further aggravates the problem by eliminating the natural predatory insects, birds, and other species necessary or beneficial to crop production.

Other factors associated with monoculture include (1) increased agricultural pollution from pesticides, fertilizer, soil erosion, and animal wastes; (2) high energy consumption; (3) increased farm mechanization; (4) reduction in wildlife and plant species diversity; (5) increased dependency of farmers on a few commodities; (6) greater physical separation of production and consumption; and (7) reduced flexibility of farm operators to shift production between commodities in response to changing market demands.[12]

Imposition of a land mix constraint, then, does have economic implications for agriculture. The imposition of soil and fertilizer constraints also has the effect of changing the mix of land use by restricting cropping

[6] Chap. 22? (1971), Acts of the 64th General Assembly of Iowa, 1st Session.

[7] For further discussion of impaired water quality by fertilizer, see *Agricultural Practices and Water Quality*, ed. by Ted L. Willrich and George E. Smith, Iowa State Univ. Press, Ames, 1970.

[8] One person's esthetic enjoyment of an area may be and often is very different from the next individual's. This is one of the major sources of environmental quality controversy.

[9] See Charles C. Johnson, "Environment: The Health Perspective," talk at the 1970 National Agricultural Outlook Conference, U.S. Dept. Agr., Econ. Res. Serv., Feb. 17, 1970, Washington, D.C.; and Sigurd F. Olson, "Our Need of Breathing Space," *Perspectives on Conservation*, ed. by Henry Jarrett, published for Resources for the Future, Inc. by the Johns Hopkins Press, Baltimore, 1969.

[10] Water Resources Council, pp. 24809-24816 (see footnote 1).

[11] For instance, see Frank Graham, Jr., *Since Silent Spring*, Fawcett Publications, Inc., Greenwich, Conn., 1970, Chap. 19.

[12] For a more detailed examination of the problems associated with monoculture see U.S. Department of Agriculture, *Monoculture in Agriculture: Extent, Causes, and Problems - Report of the Task Force on Spatial Heterogeneity in Agricultural Landscapes and Enterprises*, Oct. 1973.

patterns. The SHI measures the extent of these changes.

Several other types of constraints dealing with recreation, employment, fish, wildlife, sediment yield, storm runoff, and pesticides were considered for inclusion in this study but were rejected because of a lack of data or other difficulties. Though this study analyzes the environmental constraints separately and in combinations, there are close interrelationships among the constraints. Significance of these interrelationships and how they affect the analysis will be pointed out where possible.

ASSUMPTIONS AND DATA REQUIREMENTS

BUDGETS

Crop budgets were used to provide revenue data required by the model. The budgets include only variable costs. No overhead and fixed costs are included. Budget computation was performed using several secondary data sources.[13] A separate budget was computed for each of nine basic crops—corn, sorghum, soybeans, continuous winter wheat, winter wheat on fallow, corn silage, oats, alfalfa, and tame hay. Rotation budgets were computed by combining the basic crop budgets in the proper proportion. Use of four fertilizer levels also required a separate budget for each fertilizer level of each crop.

The main budget was subdivided into two major categories—preharvest and harvest costs. These two costs were further broken down into major component costs. Not all costs were changed in the preharvest group when the fertilizer level was varied. This assumption lacks realism, but certain amounts of realism had to be sacrificed due to time restrictions and lack of data. Preharvest costs were based on typical average cost and yield situations for the general area of study. Harvest costs were based on a fixed yield level.

Two additional costs were computed to add flexibility and realism to the basic budgets. One of these was called variable harvest costs. These are not variable harvest costs in a strict economic sense but harvest costs that vary because of yield differences. These costs were positive or negative depending upon yields above or below a fixed base.

The second additional cost added to each basic production budget was titled soil resource group (SRG)[14] differential costs. SRG differential costs reflect those costs due to the increased power and labor requirements incurred in cultivating land with heavy soils or steep slopes. In addition to costs associated with soil texture and slope, there are costs of maintaining soil conserving mechanical practices, drainage systems, and other special requirements on steeper slopes. The SRGs were grouped into five categories for the computation of these differential production costs. The criteria used in placing an SRG within a particular category were soil texture, degree of slope, and the use of conservation or non-conservation practices. A constant cost-increasing factor was associated with each category which was applied to the labor and non-labor components of the operational segments of the basic production costs. In addition, a flat charge was added to cover maintenance costs of mechanical practices required to conserve or drain land in a manner which maintains the quality of the resource.

In addition to the basic budget material calculated for each crop and rotation described above, variable yields, and harvest and drying costs were calculated for each crop and rotation for each SRG.

ROTATION

While 17 cropping enterprises were incorporated in the linear programming procedure, only 14 can be considered basic to the system. The three additional land

[13] Prime sources of information include: 1) Thomas A. Miller, *Selected U.S. Crop Budgets—Yields, Inputs, and Variable Costs*, Vol. III, Great Plains Region, U.S. Dept. Agr., Econ. Res. Serv., ERS-459, Washington, D.C., Apr. 1971; 2) D. B. Ibach and J. R. Adams, *Crop Yield Responses to Fertilizer in the United States*, U.S. Dept. Agr., Econ. Res. Serv. and Stat. Rptg. Serv., Stat. Bull. 431, Washington, D.C., Aug. 1968; 3) ERS Staff Working Papers, Budgets for Comprehensive Missouri River Basin Study, Mimeo, U.S. Dept. Agr., Econ. Res. Serv. files, Lincoln, Neb.; 4) Glenn A. Helmers, Glenn J. Vollmar, and Melvin D. From, *Wheat Production Costs for Southwestern, South Central and Eastern Nebraska and Related Implications for Southeastern Nebraska*, Univ. of Neb., College of Agr., Agr. Exp. Sta., Stat. Bull. 514, Jan. 1971; 5) Gary Johnston and A. W. Epp, *Costs and Returns for Soybeans, Corn, Grain Sorghum and Wheat in Eastern and Central Nebraska, A Preliminary Report*, Mimeo, Dept. of Agr. Econ., Univ. of Neb.; 6) Rodney L. Walker and Darrel D. Kletke, *The Application and Use of the Oklahoma State University Crop and Livestock Budget Generator*, Okla. State Univ., Agr. Exp. Sta., Res. Rpt. P-663, July 1972.

[14] Soil resource groups (SRG) are defined as "a grouping of land capability units, or soils, that have similar cropping patterns, yield characteristics, response to fertilizer, management, and treatment measures." (Missouri Basin Inter-Agency Committee, *The Missouri River Basin Comprehensive Framework Study*, appendix: Land Resource Availability, Vol. 6, Washington, D.C., Dec. 1971, p. 29.) This classification transcends land resource regions, land resource areas, and political jurisdictions since SRG's were designed to adapt soil inventory data to river basin boundaries. For a description of SRGs used in this study, see appendix table 2.

uses were pasture and range, forest, and "other" land.[15] These land uses do not have any specific budgets associated with them because of inadequate data. Therefore, these land uses are not permitted to fluctuate freely within the system. A minimum acreage based upon current usage was assigned to each of these three land uses. When constraints are placed upon the system, acreage is allowed to shift into these land categories with a zero net return. As a result, the minimum acreage in each usage is maintained unless other crop enterprise systems show a negative net return or other constraints force land into these uses. The three nonbudgeted uses do have soil losses associated with them, however. Therefore, some costs are associated with the entrance of these land uses into the system.

Omission of budgets and the requirement of a minimum acreage for the three nonbudgeted land uses distort the solutions somewhat since the costs, in terms of soil loss, are entered into the evaluation while returns are omitted. It is believed, however, that this omission introduces a reasonable degree of realism into the resulting solutions without appreciably distorting the results. All three of these land uses usually produce minimum amounts of soil loss; therefore, the costs associated with these uses are negligible. The usual reasons why land is devoted to these uses are either because of the physical limitations of the associated soils—steep slopes, rocks, and swamps—or because alternative uses are not feasible—roads, ditches, and farm building sites. Allowing these land uses to be devoted to crop production, especially under the unconstrained solution, would also tend to introduce unrealistic distortions into our evaluation. Therefore, it was decided that imposing the requirements of a minimum acreage based upon current usage was the most realistic assumption to make.

The 14 basic cropping enterprises are rotation systems which are comprised of nine individual crops. Rotations were used to provide a more realistic description of the farming enterprise system. The limitation of the system to a consideration of only 14 rotations and nine basic crops was made to simplify the analysis. Other crops are grown in the area, but they are of minor importance. Rotations selected are believed to be those most commonly used within the region. The 14 rotations plus the three nonbudgeted uses (15, 16, and 17) included in this analysis were:

1 Continuous corn
2 Continuous milo
3 CMCM
4 CMCB
5 CBCB
6 MBMB
7 WBCCs
8 WCCF
9 WMMF
10 COAAA
11 MOAAA
12 MOHHH
13 Continuous alfalfa
14 Tame hay
15 Pasture and Range
16 Forest
17 "Other"

where:
C = corn
M = milo
B = soybeans
W = wheat
Cs = corn silage
F = fallow
O = oats
A = alfalfa
H = tame hay

One unrealistic aspect of the enterprise systems used in this study is the lack of livestock budgets. Although livestock is important in the general farming area analyzed, our primary interest was with land use. Exclusion of livestock from the analysis did not significantly affect this consideration. However, livestock enterprises could directly affect the environmental parameters by means of runoff from field-applied manure and could indirectly affect environmental parameters through crop enterprises. Leaving livestock activities out of the model was also a necessary simplifying assumption to enable clearer insights into the trade-off mechanism. Two other basic reasons for the non-inclusion of these enterprises were lack of data and lack of financial and manpower resources.

FERTILIZER USE AND RESPONSE

Fertilizer use directly affects crop yields and net returns. Because of this relationship, a measurable trade-off was available. Nitrogen was considered the principal nutrient in determining the yield response to the various levels of fertilizer. Other nutrients were given secondary consideration except that their rate of application was increased to be in balance with each increase in nitrogen. An exception to this was made in the yield response for alfalfa where phosphorus was considered the prime nutrient in yield response.

Four fertilizer levels were considered sufficient to reasonably determine the trade-offs involved. These levels—zero, low, average, and high—were set somewhat arbitrarily because of the differences in yield response by different crops.

The zero level obviously corresponds to no commercial fertilizer use. The low level corresponds to a level of use about one-half to two-thirds the current average. The average level corresponds to the current average usage in the study area. The high level corresponds to the approximate top of the production response curve for each crop in the general study area (table 1).

From the nine basic fertilizer application rates, average annual rotation fertilizer rates were calculated. The rotation application rates depend on the crop composition of each rotation (table 2).

[15] "Other" land refers to acreage of non-Federal rural lands which are not classified cropland, pasture, range, or forest land. It includes farmsteads, farm roads, fences, windbreaks, rural nonfarm residences, investment tracts, and similar uses.

Table 1 Average annual basic crop fertilizer application rates

Crop	Zero N-P-K[1]	Low N-P-K	Average N-P-K	High N-P-K
	Pounds per acre			
Continuous winter wheat	0	20-5-2	34-7-2	60-15-4
Winter wheat on fallow	0	15-5-2	19-7-2	60-15-4
Corn	0	40-10-2	88-15-3	180-30-6
Sorghum	0	40-8-2	74-10-2	180-30-5
Soybeans	0	5-3-3	10-5-5	40-20-10
Oats	0	20-5-1	60-14-10	80-20-10
Alfalfa	0	0-5-0	0-20-0	0-60-0
Corn silage	0	40-10-2	88-15-3	180-30-6
Tame hay	0	20-0-0	40-0-0	80-0-0

[1] N, nitrogen; P, phosphorus; and K, potassium.

Table 2 Average annual rotation fertilizer application rates

Rotation	Low N-P-K[1]	Average N-P-K	High N-P-K
	Pounds per acre		
C,B,C,B[2]	23-7-3	49-10-4	110-25-8
C,M,C,M.	40-9-2	81-13-3	180-30-6
M,B,M,B.	23-6-3	42-8-4	110-25-8
C,M,C,B	31-8-2	65-11-3	145-28-7
W,C,C,T	24-6-2	49-9-2	105-19-4
W,M,M,T	24-5-2	42-7-2	105-19-4
W,B,C,S,S	26-7-2	55-11-3	115-24-7
C,O,A,A,A	12-6-1	30-18-3	52-46-3
M,O,A,A,A	12-6-1	27-17-2	52-46-3
M,O,H,H,H	24-3-1	51-5-2	100-10-3

[1] N, nitrogen, P, phosphorus and K, potassium. [2] See code explanation p. 5.

YIELD ESTIMATION

Yield estimates were made for each of the nine basic crops from a variety of sources. Current average yields presented little problem. However, yield responses to fertilizer were somewhat more difficult. *Crop Yield Response to Fertilizer in the United States* (U.S. Dept. Agr. Stat. Bull. 431)was the principal source for making these estimates. A complete or continuous yield response curve for each crop was not computed. The procedure was confined to estimating four points on a curve corresponding to the four levels of fertilizer selected. These correspond to the zero, low, average, and high fertilizer application rates (table 3).

The base yields for each crop at the four fertilizer levels were then expanded to provide the yield response of each crop and fertilizer level for the 18 selected SRGs (app. table 2). Thus, instead of a single yield response curve to fertilizer for each crop, an array of yield responses depending upon the SRG involved was estimated. This technique considers natural fertility of the various soils as well as the variance in yield response to additional fertilizer on each soil. (For an example of yield responses by SRG, see app. table 3.)

Table 3 –Base yields for selected crops and fertilizer use[1]

Crop	Fertilizer level			
	Zero	Low	Average	High
	Bushels			
Continuous winter wheat	20.0	25.0	30.0	35.0
Winter wheat on fallow	23.0	29.0	35.0	40.0
Corn	36.0	50.0	64.5	100.0
Sorghum	40.0	50.0	64.9	100.0
Soybeans	23.0	27.3	29.0	32.4
Oats	28.0	40.0	51.9	64.1
	Tons			
Alfalfa	1.5	1.8	2.9	4.2
Corn silage	4.0	7.0	11.0	16.5
Tame hay	.7	1.0	1.6	2.4

[1] The base yield for each crop and fertilizer level was set equivalent to the estimated yields on SRG 730 (see app. tables 2 and 3).

In order to estimate yields for the various rotation systems, yields for each basic crop fertilizer level and SRG were combined in the needed proportion. A rotation of corn, soybeans, corn, soybeans (CBCB) would produce one-half of the corn yield estimate and one-half of the soybean estimate for each year of the 4-year rotation.

A basic budget was developed for each crop. These basic crop budgets were designed to reflect yields shown in table 3 at the zero fertilizer level. The yield estimates by crop, fertilizer level, and SRG were then used to calculate the variable harvest costs appropriate for each SRG budget.[16] All SRG yields above the base yields for the zero fertilizer level shown in table 3 were assumed to have harvesting costs higher than the basic budget. Those SRG s with yields below the base yields for the zero fertilizer level were assumed to have lower harvesting costs than estimated for the basic budgets. Yield estimates were also used in computing drying costs for corn and sorghum. It was assumed in making the drying cost estimates that one-half of corn for grain was dried while one-third of the sorghum was dried. The base drying cost was estimated at 7 cents per bushel for both corn and sorghum.

[16] The simplifying assumption made here is that crop rotations have no beneficial effect on yields over continuous cropping.

NET REVENUE COMPUTATION

Net revenue computations were made for each SRG, crop, fertilizer level, and conservation practice. Revenue figures were not computed for pasture and range, forest, and "other" cropland uses. No cost data were available to work up budgets for these land uses. Net revenue was a calculation of price times yield minus variable costs.

Prices were determined by taking a 5-year average (1966-70)[17] of prices received by farmers as reported in Nebraska Agricultural Statistics for the southeastern section of the State:

Crop	*5-year average price*
Corn (bu.)	$ 1.134
Wheat (bu.)	1.98
Oats (bu.)	.716
Sorghum (bu.)	.958
Soybeans (bu.)	2.482
Corn silage (ton)	7.23
Alfalfa (ton)	21.20
Other hay (ton)	23.20

The wheat price includes the 5-year average of the wheat certificate payments (average wheat price of $1.376 plus average certificate amount of $0.604).

SOIL LOSS CALCULATION

Soil loss calculations were made through the use of the universal soil-loss equation.[18] This equation provides a procedure for computing the expected average annual soil loss from alternative land practices on a particular land area. The universal soil-loss equation is A=RKLSCP, where A is the predicted soil loss in tons per acre per year, R the average annual rainfall erosion index, K the soil erodibility factor, L the length of slope in feet, S the slope gradient factor, C the cropping management factor, and P the erosion control practice factor. By placing appropriate values on these factors, the soil-loss equation can be used to predict soil losses under alternative production techniques on various types of soils.

The magnitude of the several variables needed in the computation of the soil losses were available from Soil Conservation Service (SCS) sources. Some interpretations and assumptions were necessary to completely fill in the soil loss estimates made for each of the 17 rotations used in this study. A separate soil loss was computed for each SRG by crop, by fertilizer level, and by conservation practice. This amounted to 136 different soil loss estimates for each of the 700 series SRGs (uplands). No soil losses were assumed to occur on 500 series SRGs (bottomlands). Bottomlands were assumed to have little if any water erosion problems and therefore to have no soil loss associated with them. (See explanation of SRG classification system in footnote 14 and app. table 2.)

Calculations for the R, K, L, and S variables in the soil loss equation were obtained from SCS and presented little difficulty. Some problems were encountered in determining the proper C and P values for some land uses. These problems were associated with the aggregation needed in order to make the detailed data usable for our purposes.

A value of 1.0 for P was used for all crops grown under nonerosion control conditions, i.e., up- and downhill tillage. P values of .5 to 1.0 were used for crops grown under the erosion control practice of contouring. Contour farming is the only conservation practice recognized in this formula. The P value varies, depending upon the percentage of land slope and the use of contour farming. This provided two P factor values for each fertilizer level of each crop rotation of each SRG.

The C value (crop management factor) was calculated to correspond to each P value. Since the C factor is influenced by the rotation and yields of various crops as well as the tillage practices followed, there is considerable variation in its value. For each P value representing erosion control (contouring), a C value representing conservation tillage was computed.[19] Another C value was also computed for each P value representing nonerosion control.[20]

One difficulty in determining applicable C values for pasture, forest, "other," fallow, and conservation use land was to ascertain the amount and kind of canopy normally associated with these land uses in the study area. Having determined the appropriate P values, these were used as an indicator for selecting reasonable C values for the problem land uses. If the land were farmed in an up- and down-hill manner, the canopy associated with these uses was assumed to be 20 percent weeds on summer fallow and conservation use lands, 60 percent grass on pasture land, and 60 percent weeds on "other" land. Forest land was considered to be unmanaged and to have a poor stand. If the land were operated in a con-

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[17] More recent price data would affect the level of net revenue but it is felt that this would not substantially change the results of this study since the same prices were used in each solution. Of major importance is the relative difference between solutions.

[18] Walter H. Wischmeier and Dwight D. Smith, *Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains*, U.S. Dept. Agr., Agr. Res. Serv. in cooperation with Purdue Agr. Exp. Sta., AH-282, Washington, D.C., May 1965.

[19] Conservation tillage includes such things as listing on the contour, till planting, strip tilling, the amount of residue left or removed, as well as the amount and kind of canopy associated with the crop management.

[20] Nonconservation tillage takes into account the amount of residue left or removed as well as the conventional tillage practices such as surface planting.

serving way, summer fallow and conservation use were assumed to have a soil loss equivalent to a 60-percent grass canopy, pasture a 95- to 100-percent grass canopy with "other" land a 95- to 100-percent weed canopy. Forest land was considered to be unmanaged but to have a good stand of trees.

The variation of soil loss on the different SRGs and crop rotations is tremendous. Soil loss per acre per year is as low as .04 tons and as high as 400 tons. The 400-ton figure is somewhat unrealistic in the sense that these steep-sloped lands are almost impossible to till in an up- and down-hill manner with continuous row crops.

SPATIAL HETEROGENEITY INDEX (SHI)

In attempts to measure diversity of the agricultural landscape, one faces the fact that no ready measure is available. Some techniques which attempt to quantify diversity are found in information theory.[21] The problem is that all known systems designed to measure diversity are one-dimensional: that is, only the portions of each use of the total area are considered. Available indices tell us little, if anything, about the intermix of the various land uses. Also, the proximity relations of the different uses are not quantifiable. That is, no distinction or information is available to determine which land uses are in proximity to each other. There is also the further problem of time. How are rotation practices incorporated into the diversity of use?[22] There is no known index system that incorporates all of the dimensions of diversity.

The system adapted and described below for comparing the degree or amount of diversity is an index system that is sensitive to the number of land use categories and the evenness of acreage distribution among these categories. The SHI is computed by multiplying the proportions of land in each use by the natural log of the proportion and then summing the quantities. $SHI = -\sum_{i=1}^{n} p_i(\ln p_i)$ where SHI is the spatial heterogeneity index, p_i is the proportion (percent) of land in the ith category, and land use categories range from 1 to n. The range of this index is dependent on the number of land use categories involved. If an area is devoted to only one land use, the index value would be zero (because the natural log of 1 is 0). An area with 50 land use categories, each comprising 2 percent of the land area, would yield an index of 3.91202. Ten uses evenly distributed would provide an index of 2.30259.[23] The value of the index rises at a decreasing rate as equality among categories increases.

In this study, nine land use categories were considered. An even distribution of acreage among the nine categories produces a maximum SHI of 2.19823.

The linear programming model used in this study was not designed to compute the SHI for the various watersheds or the total area. The program did summarize the acreage in each of the selected land uses. The actual computation of the index was done by hand outside of the programming problem.

The nine land use categories selected for use in the SHI computation were: 1) corn, 2) sorghum, 3) soybeans, 4) small grain, 5) forest and orchard, 6) "other" land, 7) hay, 8) pasture and range, and 9) summer fallow, conservation use, and idle. These land uses were consolidated from the 17 crop rotations.

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[21] H. Theil, *Economics and Information Theory*, North Holland Publishing Co., Amsterdam, 1967.

[22] U.S. Dept. of Agriculture, *Monoculture in Agriculture . . .*, chap. 2 (see footnote 12).

[23] U.S. Dept. of Agriculture. *Monoculture in Agriculture . . .*, Oct. 1973. (Another example of the use of this index system is used in chap. 2, pp. 6-17).

PROGRAMMING SOLUTIONS AND RESULTS

Ten linear program solutions are discussed in this analysis with each solution based upon a different set or level of constraints (table 4). The number of solutions is minimal for an analysis of this type, but it is believed that these solutions give some insight into the impacts and trade-offs resulting from the constraints used. Many more solutions would be needed to determine and present a complete marginal trade-off analysis between the various constraints.

Originally, plans called for at least one alternate to be constrained at a low level of fertilizer use along with a 5-ton, soil loss restriction plus a restriction on the land use mix. As it turned out, the simultaneous imposition of all three constraints at the prescribed levels proved to be unsolvable. Therefore, the land use constraint was modified by increments until a feasible solution was obtained. This occurred only when the land use constraint was completely removed. As a result, none of the 10 alternate solutions presented here uses all three of the constraints simultaneously. Table 17 presents a summary of results for the 10 solutions.

UNCONSTRAINED SOLUTION (NO. 1)

The unconstrained solution gives us a view of the profit maximizing potential of the basin as well as its component watersheds. This solution was not con-

Table 4 - Ten linear program solutions and constraints for each

Solution No.	Description of constraint
1	Unconstrained.
2	Soil loss constrained for each SRG[1] to less than 10 tons per acre per year.
3	Soil loss constrained for each SRG to less than 5 tons per acre per year.
4	Fertilizer use constrained for each watershed to an average level of use.
5	Fertilizer use constrained for each watershed to a low level of use.
6	Land use mix constrained on the basin to provide a high SHI.
7	Soil loss constrained for each SRG to less than 5 tons per acre per year and fertilizer use constrained for each watershed to an average level of use.
8	Fertilizer use constrained for each watershed to a low level of use and the land use mix constrained to provide a high SHI.
9	Soil loss constrained for each SRG to less than 5 tons per acre per year and fertilizer use constrained for each watershed to a low level of use.
10	Soil loss constrained for each SRG to less than 5 tons per acre per year and fertilizer use constrained for each watershed to a low level of use plus partial flood protection through elements of a P.L. 566 watershed program.[2]

[1] For a description of SRGs, see text footnote 14 and appendix table 2.

[2] The Watershed Protection and Flood Protection Prevention Act of 1954, P.L. 83-566, 83rd U.S. Congress. Act is administered by the Soil Conservation Service, U.S. Dept. Agr.

strained in any way except for restrictions on cropland acres by SRG and the acreage restriction on forest land, pasture and rangeland, and "other" land which were built into the model. The acreages of forest, "other," and pasture and rangeland were fixed at current levels of use by means of a lower limit. Because no budgets were included in the program for these fixed land uses, no revenues are generated or associated with these acreages; however, soil loss is associated with each land use. In effect, the lower limit acreage on the three restricted land categories brings them into the program at a zero profit level. The only time that these activities compete for acres is when net returns to alternative activities are zero or negative or soil loss constraints prohibit other usage.

Revenue Effects

Solution No. 1 shows a total net revenue for the basin of approximately $24.37 million. This revenue is generated from 411,894 acres of the 568,500 acres in the basin. The remaining 156,606 acres are in the nonrevenue generating uses (forest, pasture and range, and "other"). This is equivalent to an average revenue per productive acre[24] of $59.17 for the basin. The average revenue per acre varies by watershed from $52.27 to $62.10. This variation in average revenue per acre among watersheds can be attributed to the distribution and amount of SRG acreage within the various watersheds. Since each SRG has a different productive capability, the average revenue per acre by watershed is significantly affected.

Soil Loss Effects

Soil loss associated with solution No. 1 amounted to over 12.8 million tons. This is equivalent to an average soil loss rate of 22.6 tons per acre per year for the entire basin acreage. However, since only 490,997 acres of the basin acreage contribute to the soil loss,[25] the average soil loss from contributing acreage is about 26.2 tons per acre.

Average soil loss for the individual watersheds on upland areas (700 series SRGs) ranges from 20.41 to 28.54 tons per acre per year. The difference in average soil loss among watersheds can be accounted for by differences in the mix of 700 series soils.

The high average soil loss does not give a very true picture of the actual soil loss associated with each SRG. Soil losses by SRG vary from less than 0.4 ton per acre per year to over 64 tons per acre per year. Of the 13 SRGs in the 700 series found in the basin, only four have an average loss greater than 15 tons per acre per year. But two of these SRGs produce over three-fourths of the 12 million plus tons of soil loss (table 5).

Fertilizer Use

Crop production under the unconstrained solution (No. 1) is devoted almost exclusively to continuous corn. Of the productive acres, 408,507 acres are corn with the remaining acreage divided equally between soybeans and sorghum. All of the corn is produced with high fertilization levels. This results in over 41 million bushels of grain, or an average yield of about 101 bushels per acre. A total for the year of about 73.6, 12.3, and 2.5 million pounds of nitrogen, phosphorus and potash, respectively, were used in the production of crops

[24] Productive acres refer to those acres which enter the solution as a budgeted rotation. The fixed acres of forest, pasture and rangeland, and "other" land are not included as productive acres in the sense used here even though most are productive in an agricultural sense. Average revenue data presented throughout this study are calculated on a productive acre base.

[25] It was assumed that the 77,503 acres of bottomlands (500 series SRGs) do not have significant soil loss. It is recognized that 500 series SRGs are somewhat subject to flood hazards. A potential for flood plain scour and/or sediment deposition therefore exists. In our analysis, these are considered to be of minimal significance as a contributing factor to soil loss.

Table 5 – Annual soil losses for each SRG for the unconstrained solution (No. 1)

SRG[1]	Area	Soil loss	Soil loss per acre
	Acres	*Tons*	*Tons*
710	3,041	16,847	5.54
720	124,582	1,161,323	9.32
722	89	545	6.12
723	2,571	10,622	4.13
730	189,568	6,571,249	34.66
731	100,187	1,228,431	12.26
732	177	61	.35
740	59,295	3,251,861	54.84
741	709	1,473	2.08
760	8,968	575,632	64.19
761	177	522	2.95
764	709	935	1.32
770	924	29,891	32.35
Total	490,997	12,849,392	26.17

[1] See explanation of SRG classification system in footnote 14 and appendix table 2.

throughout the basin. This is equivalent to about a 179-30-6 annual application rate per productive acre.

Average fertilizer use shows only minor variation by watershed. Total nutrients applied to productive acres range from 216.00 to 210.27 pounds per acre per year.[26] The range of fertilizer use is narrow because almost all of the basin acreage is devoted to corn production with high fertilization rates. A greater variety of crops within the basin would tend to increase the differences in fertilizer use between watersheds.

[26] Productive basin acreage is used to compute average fertilizer use. The productive acre base is used because these acres are the only ones which are allocated fertilizer within the problem.

Land Use

The SHI is low for solution No. 1. This is not unexpected since all of the productive acres are devoted to corn while most of the nonproductive acres are in pasture and range. These two land uses comprise over 91 percent of total land in the basin. The index for the basin given unconstrained conditions is .84235.[27] This compares to a probable maximum index of 2.19823.

The SHI for the individual watersheds ranges from .70970 to 1.07028. Table 6 demonstrates the dominance of corn production along with the variability of the SHI between watersheds.

SOIL LOSS CONSTRAINED SOLUTIONS (NOS. 2 AND 3)

Two linear programming solutions constrained only soil loss (Nos. 2 and 3 in table 4). Alternate solution No. 2 constrains soil loss to less than 10 tons per acre by SRG. Alternate solution No. 3 constrains soil loss to less than 5 tons per acre per year by SRG.

Revenue and Soil Loss Effects

Solution No. 2 reduces soil loss to 4.97 million tons and net revenue to $22.20 million for the basin. The average revenue per productive acre under the 10-ton soil loss constraint (No. 2) amounts to $53.89, while the

[27] Five decimal places are reported because of the narrow range of the index and the slope of the function at higher levels of the index. No empirical tests have been conducted to determine at what level differences can be detected visually.

Table 6—Land use distribution and SHI for the unconstrained solution (No. 1)

Land use	Watershed							Basin
	1	2	3	4	5	6	7	
	Percentage of land use							
Corn	73.5	74.6	76.1	70.5	70.6	61.5	72.0	71.8
Sorghum	.2	--	--	.5	.3	1.0	.4	.3
Soybeans	.2	--	--	.5	.3	1.0	.4	.3
Small grain	--	--	--	--	--	--	--	--
Forest and orchard ...	2.7	2.6	1.3	3.4	3.3	7.9	3.5	3.4
"Other"	4.6	4.4	4.3	4.1	3.9	4.4	4.4	4.3
Hay	--	--	--	--	--	--	--	--
Pasture and range	18.8	18.4	18.3	21.0	21.6	24.2	19.4	19.9
Summer fallow, conservation use, and idle	--	--	--	--	--	--	--	--
	Index							
SHI	.80323	.76908	.70970	.87579	.84889	1.07028	.84981	.84235

average soil loss on 700 series SRG acres is 10.12 tons per acre per year.[28] The reduction of slightly over 61 percent of the soil loss is accompanied by about a 9-percent reduction in total revenue. The average costs of reducing soil loss on 700 series SRG acres from 26.17 tons to 10.12 tons per acre is about 33 cents per ton. This cost per ton of soil loss has a wide variation among watersheds ranging from 10 to 57 cents.

The No. 2 solution has a varying effect among the various watersheds. The basinwide revenue change induced by the 10-ton constraint is $5.28 per acre per year, yet only one of the seven watersheds has an average revenue change larger than this (see table 7). Revenue changes among watersheds range from $1.42 to $13.59 per productive acre, soil loss by watershed ranges from 4.81 to 14.11 tons per acre. The relative average revenue position of the watersheds is also changed by the imposition of the soil loss constraint.

Reducing soil loss to less than 5 tons per acre lowers total basin revenue to $20.41 million and soil loss to 2.57 million tons. Under this No. 3 solution, average revenue per productive acre is $49.06. The maximum difference in average revenue among watersheds is $16.88. The variation among watersheds can be attributed to changes in productive acres and the proportion of the various SRGs within each watershed. The soil loss averages 5.25 tons per acre per year on 700 series SRG acres.[29] However, soil loss for individual watersheds ranges from a high of 10.11 tons per acre to a low of 3.28 tons per acre. These differences can once again be attributed to the SRG mix in the watersheds. The unrealistic high soil loss of over 10 tons per acre with a 5-ton soil loss constraint can be attributed to the modifications made to prevent an infeasible solution (see footnote 28). There is a general tendency for watersheds with higher remaining average soil losses to have higher average revenue, but the relationship is not perfectly correlated. From this, it can be concluded that even though a reduction in soil loss is accompanied by a loss in revenue, other influences are present to accentuate or modify these changes. The amount of soil loss that needs to be controlled varies by watershed, depending upon the erosion susceptibility of each watershed.

Differences in average soil loss between the 10-ton and 5-ton solutions amount to 4.87 tons per acre in the 700 series acres. The additional reduction in soil loss costs an average of $4.23 per acre or about 87 cents per ton per acre. This cost varies at the watershed level from about 2 cents to $1.62. On a percentage basis, soil loss is reduced about 48 percent, while revenues decline about 8 percent between the 10- and 5-ton constraint alternatives.

A comparison between the unconstrained and 5-ton alternative shows that soil loss is reduced about 80 percent, while revenue declines about 16 percent. The

[28] Even though the constraint calls for soil loss of less than 10 tons per acre, the average soil loss over the 700 series SRG acres is slightly above that. This anomaly results because three SRGs (740, 760, 770) with high soil loss problems are unable to meet the 10-ton constraint. Therefore, special adjustments in the constraint on these SRGs were required in order to avoid an infeasible solution. This problem was caused by the minimum level of acreage required in pasture and rangeland. The Conservation Needs Inventory (Nebraska Conservation Needs Committee, *Nebraska Conservation Needs, 1969*, U.S. Dept. Agr., Soil Conserv. Serv.) was used to determine what proportion of this land use was adequately treated and what proportion needed treatment. It was found that a significant proportion of pasture and range was in need of adequate treatment. The portion of pasture and rangeland that was in need of treatment had associated with it higher levels of soil loss than found in our soil loss constraints. Therefore, the average soil loss over all 700 series SRG acres is slightly above 10 tons per acre.

[29] The average soil loss for the basin is again above the set constraint. The explanation given in footnote 28 applies.

Table 7 – Revenue loss associated with each ton of soil loss, by various soil loss constraint ranges

Watershed	Unconstrained to 10 tons			Unconstrained to 5 tons			10 tons to 5 tons		
	Average revenue change[1]	Average soil loss change[2]	Revenue lost per ton	Average revenue change[1]	Average soil loss change[2]	Revenue lost per ton	Average revenue change[1]	Average soil loss change[2]	Revenue lost per ton
	Dollars	*Tons*	*Dollars*	*Dollars*	*Tons*	*Dollars*	*Dollars*	*Tons*	*Dollars*
1	13.59	23.73	0.57	13.62	25.26	0.54	0.03	1.53	0.02
2	1.72	14.63	0.12	3.67	17.25	0.21	1.95	2.62	0.74
3	2.04	15.80	0.13	17.14	25.13	0.68	15.10	9.33	1.62
4	1.66	13.44	0.12	10.59	19.13	0.55	8.93	5.69	1.57
5	1.42	13.85	0.10	6.98	21.34	0.33	5.56	7.49	0.74
6	1.63	9.28	0.18	2.27	14.74	0.15	0.64	5.46	0.12
7	4.96	14.28	0.35	11.35	20.13	0.56	6.39	5.85	1.09
Basin ...	5.28	16.05	0.33	9.51	20.92	0.45	4.23	4.87	0.87

[1] Average revenue computed with productive acre base. [2] Average soil loss computed with 700 series SRG acres.

overall cost per ton per acre amounts to about 45 cents. The range among watersheds is from 15 cents to 68 cents per ton per acre.

A prime consideration in determining effects of soil loss constraints on the average revenue generating capabilities of a basin or individual watershed should be the SRG composition of the area. Even when the composition of soils among watersheds appears to be rather homogeneous, major changes in average revenue production can take place. Soil loss constraints have a large differential effect on SRGs. The erosion potential of soils needs to be carefully examined in order to predict the magnitude of revenue changes that will occur when a soil loss constraint is applied.

Fertilizer Use Effects

Soil loss constraints also reduce fertilizer usage because erosion control procedures require different cropping patterns. Corn production on highly erosive land is switched to alfalfa production. Since alfalfa production has a lower fertilizer requirement, overall fertilizer use declines. The 214.51 pounds of total nutrients used per acre in the No. 1 solution falls to 179.74 pounds per acre in the No. 2 solution and 152.02 pounds per acre in the No. 3 solution. This is a reduction in total fertilizer use of about 29 percent between the unconstrained and 5-ton soil loss solutions. Changes in individual nutrient use vary. Nitrogen and potassium use declines 22 percent, while phosphorus use increases 23 percent among the unconstrained and 10-ton soil loss solutions. The changes in individual nutrient use between the 10-ton and 5-ton solutions amount to a decline of 23 percent for nitrogen and potassium and an increase of 14 percent for phosphorus. Nitrogen and potassium use declines 41 percent, while phosphorus use increases 41 percent between the unconstrained and 5-ton soil loss solution. These changes are due to shifts in the acreages and kinds of crops grown. Corn and sorghum, higher users of nitrogen, are replaced by alfalfa, a heavy user of phosphorus.

Land Use Effects

Soil loss constraints cause the SHI to rise from .84235 for the unconstrained solution to 1.21733 for the 10-ton soil loss solution to 1.30924 for the 5-ton soil loss solution. This change in SHI is brought about as shifts to more soil conserving crops occur (see table 8). As each tighter soil loss constraint is imposed, corn production decreases and hay (alfalfa) production increases. Forest land, "other" land, and pasture and rangeland acreages change very little. This is because these acres have a fixed minimum and have zero net returns associated with their use. It was also found that the range of the SHI values among watersheds decreases as the soil

Table 8—Land use acreage, unconstrained and soil loss constrained solutions

Land use	Solution number[1]		
	No. 1	No. 2	No. 3
	Acres		
Corn	408,507.0	316,289.6	242,870.8
Sorghum	1,693.5	969.2	596.5
Soybeans	1,693.5	596.5	596.5
Small grain	0	186.3	0
Forest and orchard	19,046.0	19,046.0	19,046.0
"Other" land	24,399.0	24,576.0	24,576.0
Hay	0	93,666.1	166,888.2
Pasture and range	113,161.0	112,984.0	113,926.0
Summer fallow, conservation use, and idle	0	186.3	0

[1] See table 4 for a description of solutions.

loss constraint becomes more restrictive. This indicates that soil loss constraints force the watersheds to become more homogeneous with respect to each other, while land use becomes more heterogeneous within each watershed.

FERTILIZER CONSTRAINED SOLUTIONS (NOS. 4 AND 5)

There are two program alternative solutions which show the direct effects of an average level of fertilizer constraints Nos. 4 and 5 (see table 4). An average level of fertilizer use (solution No. 4) is an approximation of current average use on nonirrigated cropland in southeastern Nebraska. A low level of fertilization (solution No. 5) is equivalent to about two-thirds the average level of usage. Both fertilizer constraints were imposed at the watershed level. The placing of the constraint at this level allowed for variation in usage between SRGs within watersheds but prevented usage from shifting among watersheds.

Revenue Effects

As fertilizer use is reduced from the levels utilized under unconstrained conditions to an average level, total nutrients are reduced from 88.36 million pounds to 35.80 million pounds, and revenue falls from $24.37 million to $19.45 million. This is equivalent to approximately a 60-percent reduction in total nutrients and a 20-percent drop in revenue. A productive acre base produces an average fertilizer use of 214.51 pounds per acre with no constraints but only 86.91 pounds of nutrients per acre with solution No. 4.

Individual nutrients show varying amounts of change. Nitrogen use declines by more than 61 percent, while phosphorus and potassium show decreases of about 54 and 30 percent, respectively. In general, a 1-pound reduction in nutrients is accompanied by a reduction of approximately 9 cents in net revenues per acre.

Solution No. 5 decreases total net revenues to $17.47 million. Average revenue per productive acre falls to $42.41 while the average fertilizer use per acre drops to 57.97 pounds. The additional 29-pound reduction in fertilizer use is accompanied by an additional $4.82 decline in per-acre revenue a drop of 16.66 cents in per-acre revenue per pound of fertilizer. The low level fertilizer solution reduces nutrient use about one-third, while net revenue falls about 10 percent compared with the average level fertilizer solution.

The total difference between the unconstrained and low level fertilizer alternatives on a productive acre basis is $16.76 in average revenue and 156.54 pounds in average nutrient use. The percentage declines are about 73 percent for fertilizer and 28 percent for revenue. The per-acre revenue impact of a low level fertilizer constraint is 10.7 cents per pound per acre. The individual nutrients show negative changes in use of 74 percent for nitrogen, 72 percent for phosphorus, and 54 percent for potassium.

Soil Loss Effects

Average soil loss per acre is also affected by fertilizer constraints. When soil loss constraints were imposed, fertilizer use declined. However, when fertilizer use is decreased through a fertilizer constraint, soil losses increase primarily because of the resulting cropping pattern change. As more soybeans are brought into the solution because of the fertilizer constraints, erodability increases as a result of the reduced residue and canopy cover. Average soil losses on SRG 700 series soils increase about 7 tons per acre from 26.17 tons per acre with the No. 1 solution to 33.16 tons per acre with the No. 4 solution.[15]

The No. 5 solution further increases basinwide average soil loss to 34.18 tons per acre. The variation in average soil loss among watersheds also increases. Those watersheds possessing the highest average soil losses show the largest soil loss increases. There is a difference of 13.51 tons in average soil loss among watersheds with soil losses ranging from 26.18 tons to 37.69 tons per acre.

An examination of the average soil loss by SRG gives an indication of the soil loss changes taking place (see table 9). Three SRGs account for the majority of the soil loss increase. These are SRG 730, 731, and 740. These three SRGs also make up a significant proportion of the total acres within the basin. SRG 730 shows a soil loss per acre of 34.66 tons with the unconstrained solution, 43.25 tons per acre in the average level fertilizer solution, and 45.63 tons per acre in the low level fertilizer solution. SRG 740 jumps from an average soil loss per acre of 54.84 tons to 76.58 tons in the average level fertilizer solution. But no additional change was indicated between the average and low level solutions. Several other SRGs also show soil loss increases of lesser magnitudes as fertilizer constraints are applied.

Table 9–Average soil loss on 700 series SRGs for unconstrained and fertilizer constrained solutions

SRG[1]	Solution number[2]		
	No. 1	No. 4	No. 5
	Tons per acre		
710	5.54	5.54	5.54
720	9.32	9.78	10.04
722	6.12	7.80	8.64
723	4.13	5.83	5.83
730	34.66	43.25	45.63
731	12.26	16.78	16.97
732	0.35	0.35	0.35
740	54.84	76.58	76.58
741	2.08	2.50	2.50
760	64.19	64.19	64.19
761	2.95	2.95	2.95
764	1.32	1.45	1.98
770	32.35	32.35	32.35
Total	26.17	33.16	34.18

[1] See explanation of SRG classification system in footnote 14 and appendix table 2. [2] See table 4 for a description of solutions.

Land Use Effects

The SHI is also affected by constraints on fertilizer use, as shifts in land use occur in reaction to added fertilizer constraints. The index for the unconstrained alternative of .84235 is almost doubled under the average fertilizer level alternative to 1.60886. However, as the fertilizer constraint is tightened to portray a low level of fertilizer use, the index falls to 1.53932. This seems to indicate that as one reduces fertilizer use, the objective of a more diverse land use pattern is facilitated, but to a point. At what level of fertilizer constraint the SHI would be the highest cannot be determined from the limited number of observations in this study. Table 10 presents the respective land use acreage for the solutions discussed here.

[15] Even though these average soil loss estimates seem high, they are typical of losses from soils in this region. See estimates by R. G. Spomer, K. E. Saxton, and H. G. Heinemann, "Water Yield and Erosion Response to Land Management," *J. Soil and Water Conserv.*, July-Aug. 1973, pp. 168-171.

Table 10—Land use acreage for unconstrained and fertilizer constrained solutions

Land use	Solution number[1]		
	No. 1	No. 4	No. 5
	Acres		
Corn	408,507	117,918	63,167
Sorghum	1,694	120,661	174,364
Soybeans	1,694	171,110	174,364
Small grain	0	0	0
Forest and orchard	19,046	19,046	19,046
Other land	24,399	24,576	24,399
Hay	0	2,204	0
Pasture and range	113,161	112,984	113,161
Summer fallow, conservation use, and idle	0	0	0

[1] See table 4 for a description of solutions.

Yield Effects

Reduction in fertilizer use is achieved by altering the cropping pattern throughout the basin. Cropping practices are changed little, if any, by fertilizer constraints. The negative effect on farm income is the expected result of a fertilizer limitation. In addition to the change in cropping pattern which brings about the production of lower revenue crops, lower yields are expected because of the fertilizer restriction. The positive relationship between yields and fertilizer application was built into the model. However, an examination of the solution results would appear to contradict this basic assumption. Table 11 shows the average yields for the three major crops for the alternatives under consideration, with seemingly surprising results.

Table 11—Average crop yields for unconstrained and fertilizer constrained solutions

Crop	Solution number[1]		
	No. 1	No. 4	No. 5
	Bushels per acre		
Corn	101.04	112.60	116.94
Sorghum	26.20	49.53	53.12
Soybeans . . .	12.29	27.55	25.87

[1] See table 4 for a description of solutions.

The apparent anomalies can be explained in the following way. As corn acreage decreases from over 408,000 acres to approximately 118,000, and then to about 63,000 acres (table 10), the average yield increases from 101 bushels per acre to almost 117 bushels per acre even though fertilizer usage has been severely restricted. What has happened is that the rate of fertilizer application on corn grown has not changed. Corn is still grown with a high rate of fertilization. But, as naturally less productive SRG acres are removed from corn production, the average yield of the remaining more productive corn acres rises.

An opposite line of reasoning explains the rising sorghum yields. Sorghum in the unconstrained solution is relegated to low-yielding SRGs. But, as more productive SRG acres are shifted from corn to sorghum production, the average yield for sorghum rises. Such a rise in yields can take place even though less fertilizer is used because an alternate sorghum-soybean rotation which has a built-in complementarity is introduced. The large difference between corn and sorghum yields (which normally tend to be similar) substantiates this reasoning.

When analyzing responses to fertilizer restrictions, it must be remembered that the rate of application is not the principal way in which fertilizer use is reduced. Change in the cropping rotation and pattern is the principal way fertilizer use is reduced, especially under the average level constraint.

The yield increase of soybeans is the result of a combination of effects. The average yield increases from about 12 bushels per acre under unconstrained conditions to over 27 bushels per acre under the No. 4 solution and then decreases slightly to about 26 bushels per acre under the No. 5 solution. The same reasoning that explains the yield changes for sorghum can be used to explain most of the changes in soybean yields. As corn acreage is decreased, more productive land is shifted to soybeans and the yield differential between SRGs brings about a higher average yield even though less total fertilizer is used. Actually, the shift from corn to soybean production accounts for most of the reduction in fertilizer use because soybeans have a much lower fertilizer requirement.

The decrease in average soybean yield between the No. 4 and No. 5 solutions can be accounted for by the fact that, under the average constraint, about 50,000 acres of soybeans are grown with a high fertilizer use corn-soybean rotation and this rotation is completely eliminated in the No. 5 solution. The No. 5 solution produces more acres of soybeans but they are grown in a sorghum-soybean rotation with average and zero levels of fertilizer use. As a consequence, the average soybean yield falls. The fertilizer-yield response effect is stronger under the No. 5 solution than under the No. 4 solution. The fertilizer-yield response of soybeans under the low use solution is also stronger than the SRG yield differential effect.

LAND USE CONSTRAINED SOLUTION (NO. 6)

The land use constraint was applied singly to only one alternative solution No. 6. Other constraints changed the land use mix and thereby the SHI, but the land use distribution was not pre-specified. The constraints placed on this solution called for lower and upper limits on the total basin acreage within each of nine land uses. The following upper and lower limits were imposed.

Land use	*Lower limit*	*Upper limit*
	Acres	
Corn	80,000	175,000
Sorghum	80,000	175,000
Soybeans	45,000	100,000
Small grain	45,000	100,000
Forest and orchard	19,000	44,000
Other land	24,000	54,000
Hay	45,000	100,000
Pasture and range	110,000	225,000
Summer fallow, conservation use, and idle	45,000	140,000

In most instances the lower limit was the constraining factor. This, of course, was expected since no other constraints were applied.

The highest or ideal SHI is obtained when the proportion of all land uses is equal. In setting up the land use constraint, it was recognized that attainment of the ideal was infeasible as well as unrealistic because three land uses—forest, "other," and pasture and rangeland—have a fixed minimum acreage under all conditons (see discussion on page 5). In the constrained solution, all of the land uses are at or near the lower limit except for corn which was the most profitable crop (table 12).

Table 12—Land use distribution, unconstrained land mix and constrained solution

Land use	Solution number[1] No. 1	Solution number[1] No. 6
	Acres	
Corn	408,507.0	152,130
Sorghum	1,693.5	80,000
Soybeans	1,693.5	45,000
Small grain	0	45,000
Forest and orchard	19,046.0	19,046
Other land	24,399.0	24,340
Hay	0	45,000
Pasture and range	113,161.0	112,984
Summer fallow, conservation use, and idle	0	45,000

[1] See table 4 for a description of solutions.

Revenue Effects

As in all cases when a constraint is imposed on the programming system, net revenue is reduced. In the SHI constrained solution, total basin revenue fell to $20.14 million or about 17 percent compared to the unconstrained solution. Average revenue per productive acre amounts to $48.86 compared to $59.17 per acre with no constraints.

Soil Loss Effects

Imposition of the land mix constraint reduces soil loss throughout the basin. Average soil loss with the constraint is 21.10 tons per acre per year over SRG 700 series acres, or 19 percent below the unconstrained solution. Reduction in soil loss due to the land use mix constraint results from more acres of less erosion-prone rotations entering the solution. The constraint does not require conservation measures to be used, but the crops produced are more protective of the land.

Fertilizer Use Effects

Solution No. 6 reduces fertilizer use throughout the basin. The constraint on land use reduces the acreage of corn and increases the acreage of soybeans, small grain, and hay. Since soybeans, small grain, and hay have much lower fertilizer requirements, total fertilizer use falls. Total average nutrients are 214.51 pounds per productive acre in the unconstrained solution and 144.22 pounds with the land use constraint, a decline of almost one-third. Individual nutrients show different amounts of decreased use. Overall basin nitrogen use falls by about 37 percent, but this decrease varies from about 30 to 52 percent, depending upon the watershed. Phosphorus use declines about 9 percent at the basin level but varies at the watershed level from an increase of 6 percent to a decrease of 28 percent. Potassium use falls by about 18 percent with a variation among watersheds from a 4-percent increase to a 37-percent decrease.

Land Use Effects

As would be expected from constraining the land use mix, the SHI rises to 2.00158. This compares to an absolute maximum index of 2.19823 if the acreage distribution for all nine land use categories was identical. The No. 6 solution has a varying effect among watersheds because of the different amounts of land shifted to different uses within each one. This is reflected in the varying SHI—from 1.70377 to 2.02998 for the individual watersheds.

FERTILIZER AND SOIL LOSS COMBINATION CONSTRAINTS (NOS. 7 AND 9)

Two solutions combine constraints on fertilizer use and soil loss. Solution No. 7 constrains fertilizer use at an average level with soil loss held at less than 5 tons per acre. Solution No. 9 constrains fertilizer use at a low level with soil loss also held at less than 5 tons per acre.

Revenue Effects

Combining fertilizer and soil loss constraints has the expected result of reducing revenue substantially more than when either of the constraints is used individually. The No. 7 solution reduces the total basin revenue to $15.96 million, or 34.5 percent below the total revenue obtained under unconstrained conditions. The low level fertilizer and 5-ton soil loss constraints (No. 9) reduce total revenue to $13.36 million, or 45.2 percent below unconstrained conditions.

Revenue under the average level fertilizer and soil loss constraint is about 18 percent less than when only the average fertilizer constraint was used. Revenue from the combination low level fertilizer and soil loss solution is 23.5 percent less than the revenue when only the low level fertilizer solution was used. Average revenue per productive acre is $38.96 under the No. 7 solution and $37.65 under the No. 9 solution. These revenues are significantly less than the average revenues of the singly applied, 5-ton soil loss (No. 3) solution, the average fertilizer (No. 4) solution, and the low level fertilizer (No. 5) solution (see table 13).

Table 13 Average revenue, soil loss, fertilizer use, and SHI for selected solutions

Solution number[1]	Average revenue	Average soil loss	Average fertilizer use	SHI
	Dollars	*Tons*	*Pounds*	*Index*
No. 1	59.17	26.17	214.51	.84235
No. 3	49.66	5.25	152.02	1.30924
No. 4	47.23	33.16	86.90	1.60886
No. 5	42.41	34.18	57.97	1.53932
No. 7	38.96	5.25	86.72	1.71386
No. 9	37.65	5.25	68.50	1.89314

[1] See table 4 for a description of solutions.

Soil Loss Effects

Under both combination solutions, soil loss at the basin level is the same because of the identical soil loss constraint imposed. However, there are differences among watersheds in the amount of soil loss. This variability takes place since the soil loss constraint was applied at the SRG level and the combination of a low level fertilizer constraint with the soil loss constraint is much more restrictive than is the combination with an average level fertilizer constraint. The changes which take place in watershed soil losses are due to changing crop patterns and practices which are induced by the different fertilizer constraints.

The change in cropping patterns and practices between these two solutions helps one to understand the variation of average revenue as well as the changing relative position of each watershed. The soil loss in any given watershed is not determinable from the constraints themselves since the soil loss in a watershed changes under each combination of constraints in relationship to what cropping pattern is followed and what cropping practices are employed. When fertilizer use is constrained by itself, all of the watersheds have a higher soil loss under the lower fertilizer situation than they do under the average fertilizer use situation. But, when soil loss and fertilizer use are constrained in conjunction with one another, the effect of the constraints is not felt uniformly by the watersheds because of the different SRG composition of each watershed.

Fertilizer Use Effects

Fertilizer use also changes as a result of the various constraints. The average fertilizer use under unconstrained conditions was 214.51 pounds per productive acre. Average fertilizer use under the No. 7 solution was 86.72 pounds per productive acre while it was 68.5 pounds under the No. 9 solution. Since fertilizer use was constrained at the watershed level, there was not interwatershed shifting of fertilizer use. All watersheds use less total fertilizer under the more restrictive constraint.

Fertilizer use in these combination solutions is very similar to that which occurs when fertilizer is constrained by itself. There is only fractional difference in the average use of fertilizer between the two solutions which constrain fertilizer use at an average level. Fertilizer use in the No. 9 solution is higher than in the No. 5 solution which constrains only fertilizer usage at a low level (see table 13). An explanation of why this increase occurs can be traced to the cropping pattern differences existing between the two solutions.

Land Use Effects

Basin and watershed SHIs show the differential effects of the various constraints. The combination constrained solutions have higher SHIs than any of the solutions where soil loss or fertilizer are constrained individually (see table 13). This indicates that the combination of constraints forces more land into less productive uses and thereby increases the amount of land use diversity.

LOW FERTILIZER AND LAND USE CONSTRAINED SOLUTION (NO. 8)

The constraints of this solution (No. 8) are a combination of solution Nos. 5 and 6. Fertilizer use is constrained to a low level (No. 5) and the land use mix is constrained on the basin to provide a high SHI (No. 6).

Revenue Effects

Solution No. 8 causes total basin revenue to plummet to $14.91 million, or 38.8 percent below the total revenue obtained in the unconstrained solution. Average revenue is $36.18 per productive acre compared with an average revenue of $59.17 per acre unconstrained, $42.41 per acre in the No. 5 solution, and $48.86 per acre in No. 6 solution. Average revenue by watershed ranges from $31.19 to $40.17. The difference of $8.98 among watersheds in the combination No. 8 solution compares with a difference of $3.86 when the low fertilizer constraint is used alone and $15.22 when the land mix constraint is used alone.

Soil Loss Effects

Total soil losses are higher than those found under unconstrained conditions. Total soil loss for No. 8 solution lies approximately midway between that found when its two component constraints were applied individually. That is, soil loss is less in this solution than it was in the low fertilizer solution but higher than in the land mix solution. Average soil loss per 700 series acre is 27.82 tons with the No. 8 combination of constraints, 26.17 (No. 1), 34.18 (No. 5), and 21.10 (No. 6). The land mix constraint (No. 6) tends to lower the average soil loss while the fertilizer constraint (No. 5) tends to increase soil losses.

The No. 8 combination increases the variation of soil losses among watersheds compared to the unconstrained solution (No. 1) and individually applied solutions Nos. 5 and 6. The maximum average soil loss difference among watersheds is 16.66 tons for No. 8, 12.58 for No. 6, 11.51 for No. 5, and 8.13 for No. 1.

Fertilizer Use Effects

Since fertilizer use is restricted to a low level, the use of nutrients is predetermined even though total potassium use decreases slightly and nitrogen use increases slightly, compared with the usage in the low fertilizer constrained solution. Average total fertilizer use is 59.14 pounds per productive acre in this combination solution and 57.97 pounds in the low fertilizer solution. Average nitrogen use per productive acre under the combination constraint (No. 8) is 48.28 pounds, average phosphorus use is 8.27 pounds, and average potassium use is 2.59 pounds.

Land Use Effects

The SHI is higher (2.05633) under the No. 8 solution than it is (2.00158) under the land mix constraint. Combining the land mix and low fertilizer constraints has a differential effect on the watersheds because of the amounts of land shifted to different uses within the individual watersheds. This is reflected in the SHI which varies from 1.87239 to 2.06165 among watersheds.

Yield Effects

Average yields in the No. 8 solution generally tend to be lower than the average yields in the No. 6 or No. 5 solutions (table 14). This is attributed to the fertilizer restriction. However, other changes also take place to accentuate the effect of reduced fertilizer use. Alfalfa yields fall dramatically when compared with the average yields of the land mix constraint. Fertilizer application rates on the alfalfa are reduced and there is a shift in acreage to the production of tame hay because of the constraint on phosphorus use.

Table 14.--Average yields under three solutions

Crop	Solution number[1]		
	No. 6	No. 5	No. 8
Alfalfa (*T*)	3.59	--	1.30
Soybeans (*bu*) . .	34.14	25.87	28.82
Corn (*bu*)	111.26	116.94	91.42
Sorghum (*bu*) .	92.51	53.12	57.95
Tame hay (*T*) . .	([2])	--	2.21
Wheat (*bu*)	37.28	--	34.78

[1] See table 4 for a description of solutions. [2] The land use constraint related to all hay. Since alfalfa is more profitable, no tame hay came into the solution and thus there was no yield.

Sorghum and corn yields also show a large downward change in average yields under combination conditions compared with those in a land mix constraint solution. All of the sorghum in the combination solution is grown at a low rate of fertilizer application, whereas a high rate is used under the single constraint. Acreage shifts also take place. Sorghum acreage is held to a minimum in the combination solution. These kinds of acreage shifts change average yields because of the productivity differences in SRGs.

FLOOD PROTECTION CONSIDERATION (NO. 10)

Alternate solution No. 10 considered two aspects of P. L. 566 flood protection (see footnote to table 4) in addition to constraints on soil loss and fertilizer use (No. 9). The aspects of flood protection considered were the water impounded acreage of floodwater structural measures and the reduced average annual acres flooded. An explanation of how flood protection was included in the linear programming model follows.

Acreage removed from production through the construction of floodwater structures was determined from watershed work plans and SCS working data. Acreage removed from production by the flood pools was considered to be the surface acreage of the permanent pool plus 12.5 percent of the floodwater pool. Floodwater pools are temporarily flooded during and immediately after periods of high runoff. The inundated acreage was calculated for each watershed and was then allocated between bottomlands and uplands. Based on some already planned watersheds, permanent pool acres were considered to be distributed 50-50 between bottomlands and uplands. Floodwater pool acres lost to production were allocated on the basis of 25 percent bottomlands and 75 percent uplands. A further allocation was then made of bottomlands and uplands to SRG classifications. This was done in accordance with the current proportion of SRG acreage in the respective watersheds. For example, if 20 percent of the bottomland in a watershed was in SRG 510, then 20 percent of the inundated bottomland was assumed to be SRG 510 acres. The acres of each SRG that were devoted to fixed land uses were also determined. This was done by calculating the current proportion of these uses on each SRG and allocating the inundated acreage accordingly.

Enhancement benefits from flood protection were based on acreage protected by the projects. This acreage was computed in the following way. Printouts of the average annual acres flooded with the most likely project alternative and without project protection by watershed were obtained from SCS. The differences in flooded acreage between those with and without this protection were determined for each watershed by increment. The increments used were flooding depths of 0 to 1 foot, 1 to 3 feet, and 3 feet and over. It was assumed that flood protection of agricultural lands changes the productive capability of those lands. Therefore, in accordance with this assumption, it was decided that the acreage enhanced by flood protection underwent a change in SRG classification. The benefits to acres in the 0- to 1-foot increment were assumed to be equivalent to upgrading land from SRG 522 to SRG 510. Acres in the 1- to 3-feet increment were changed from SRG 535 to SRG 522 and acres in the 3-feet and over increment were shifted from SRG 562 to SRG 535. These four SRGs were used because of their susceptibility to flooding problems. In general, only bottomland acres were treated in this way because of their flood hazard potential, but additional adjustments were needed in some cases because of individual peculiarities of watersheds. Acreage was not shifted to or from an SRG that did not already exist in a watershed. This was done in order to avoid changing the entire makeup of the linear program coefficients.

It should be emphasized that the whole procedure used to analyze the changes brought about by flood protection aspects of P.L. 566 programs is not a complete assessment of P.L. 566 benefits. Table 15 shows the total acreage changes that were made by watershed in order to introduce the flood protection program.

Table 15 - Acres enhanced and removed through watershed program

Watershed number	Enhanced acres	Acres removed
1	4,193	1,294
2	[1] 2,716	808
3	0	0
4	426	72
5	1,658	600
6	1,683	264
7	2,570	678
Basin total	13,246	3,716

[1] Adjusted down from an original estimate of 3,454 because there are not enough soil acres in series 500 to accommodate so large a change.

The acreage enhanced and removed as shown in table 15 was included in the model by making various SRG acreage adjustments by watershed. These are shown in table 16.

The analysis used is partial since it covers only the production and enhancement benefits to cropland and the acreage removed from agricultural production by water retention. The cost side -inundated acres--is probably fairly accurate because data on this physical aspect are quite accurate. However, the benefit estimates are considerably more conservative because the estimation of acreage protected is less accurate than acres flooded, and whatever adjustments were needed because of data gaps were made on the conservative side. No consideration or account was taken of land treatment practices, grade stabilization structures, or downstream effects. Reasons for this lack of consideration included a lack of data and an inability to handle the necessary changes in the model. Therefore, changes which do appear in the following analysis are not only partial but are also conservative.

Revenue Effects

Since two of the constraints used in solution No. 10 were the same as in solution No. 9 (5-ton soil loss and low level fertilizer use), a comparison between Nos. 9 and 10 was made in order to assess the effects of flood

Table 16. Acreage adjustments by SRG and watershed for inclusion of watershed program[1]

SRG[2]	1	2	3	4	5	6	7	Total
	Acres							
510	+3,572	+2,218				+1,090	+342	+7,222
522	3,446	1,504			+815	570	+456	4,249
534	43				7			50
538					349		+180	169
562	648	1,068		457	714	635	1,270	4,792
710	6			+414	6		1	+401
720	214	133			86	14	92	539
722								0
723					3		4	7
730	390	232		15	67	3	159	866
731	27	39		9	84	106	103	368
732								0
740	79	48		3	90	18	15	253
741							2	2
750	9			2	6	8	10	35
762								0
764	4	2						6
770					3			3
Total	1,294	868		72	600	264	678	3,716

[1] All acreage changes in this table are negative values unless specified as positive. [2] See explanation of SRG classification in footnote 14 and appendix table 2.

protection. In the No. 9 solution, total basin revenue was $13.36 million. Average revenue per productive acre was $37.65. Addition of the partial flood protection program did little to change the restrictions imposed by the fertilizer and soil loss constraints. Total basin revenue increased slightly to $13.43 million. Average revenue per productive acre was $37.98. Revenue differences between the two solutions were marginal.

Soil Loss and Fertilizer Use Effects

Soil loss and fertilizer use, fixed at the same levels in solutions Nos. 9 and 10, show only minor differences between the two solutions. What differences did occur can be attributed principally to the way in which the constraints were applied and the changes in acreage needed to include the partial floodwater protection program. The average soil loss *for the basin* was 5.25 tons per acre in solution No. 9 and 5.27 tons per acre in No. 10. The average soil loss *by watershed* in No. 9 ranged from 3.83 tons per acre to 9.33 tons per acre—a difference of 5.50 tons. Average soil loss by watershed in No. 10 ranged from 3.66 tons per acre to 8.54 tons per acre—a difference of 4.88 tons.

Total fertilizer use for the basin in these two solutions is the same for both nitrogen and phosphorus. Total potassium use increases by a small amount when flood protection is added. As a result, average fertilizer usage per productive acre in solution No. 10 increases slightly. This is because fertilizer usage is constrained at the basin level and the flood protection solution has a smaller acreage base.

Land Use Effects

The addition of partial floodwater protection to the model produced some changes in the SHI. At the basin level, the index rises with the addition of floodwater protection to 1.89856 from 1.89314. However, at the watershed level, the index does not always react in the same way. In fact, only two of the seven watersheds show an increase in the SHI. The other five show a declining index. As in other measurements, differences between these two solutions (Nos. 9 and 10) are not great, but partial floodwater protection does produce minor changes in land use. The change in, or the magnitude of, the SHI at the watershed level does not necessarily indicate the change or magnitude of the index at the basin level. Therefore, even though five of the seven watersheds have a lower index, the basin index can still be larger.

OVERALL SUMMARY AND ANALYSIS

Throughout this study, the primary concern has been with the trade-offs that have resulted from the imposition of the various constraints either singly or in combination. Predicting the directional effects of any given constraint on the other variables is by no means as difficult as estimating the magnitude of the changes. However, when the constraints are used in combination, even predicting the directional effects is subject to error. The interaction between constraints is difficult to sort out even when one is aware an interaction is taking place. The interaction and relationship between the variables do not always work in the same direction or to the same degree when each constraint is applied individually or in combination. This disparity is typified by the fact that as soil loss is constrained, fertilizer use falls, but when fertilizer use is constrained soil loss increases.

Table 17 summarizes basin-level total and average revenue, soil loss, and fertilizer use for the ten alternate solutions analyzed in this study (see table 4). The SHI for each solution is also included. Table 17 is helpful in visualizing the magnitude of the different variables and how they change between solutions.

Table 18 is also a summary table which details average revenue and fertilizer use over productive acres, average soil loss per 700 series acres, and the SHI for each of the alternate solutions plus the differences between the unconstrained solution and each alternative. This table is helpful in determining the strength of the various constraints and the effect of the constraints on the four major variables.

SOIL LOSS CONSTRAINTS

Constraints used in this study vary in the degree to which they affect net revenue as well as every other environmental parameter. Soil loss restrictions are the least detrimental to revenue of the three types of constraints used. In general, constraining soil loss by SRG reduces revenue and fertilizer use and increases the SHI. Achieving various levels of erosion control has accompanying trade-offs in farm income, esthetic quality, and production input requirements. The 10-ton soil loss constraint reduces total revenue about 9 percent and fertilizer use about 16 percent, while 61 percent of the soil loss is eliminated. The revenue cost per ton of soil loss eliminated is 33 cents. The 5-ton soil loss constraint reduces soil loss by 80 percent with a 16-percent decrease in revenue and a 29-percent decrease in fertilizer use. Revenue cost per ton of soil loss eliminated is 45 cents.

Attention should be drawn to the fact that the reduction in soil loss is achieved by altering the cropping pattern and practices throughout the basin. The alteration of the cropping pattern means that lower net revenue crops are produced, while the alteration of the cropping practices means that production costs are increased. The erosion-reducing options built into the linear program model are lower net revenue producing because of the higher operating and maintenance costs associated with these erosion-reducing operations.

Soil loss constraints have a large differential effect at the watershed level. Average revenue for each watershed decreases but the relative revenue-producing capacity of the watersheds with respect to each other is changed. Soil loss constraints have a stronger revenue effect on some watersheds than others because of the different soil loss potentials of each SRG. Therefore, prime consideration in determining effects of soil loss constraints on net revenue is SRG composition. Even when the composition of soils among watersheds appears to be rather homogeneous, major changes in average revenue can take place. Therefore, the erosion potential of watershed soils needs to be carefully examined in order to anticipate the magnitude of change that can be brought about by a soil loss constraint.

FERTILIZER USE CONSTRAINTS

Fertilizer restrictions have a more negative effect on net revenue than do restrictions on either the land use mix or soil loss. The average level fertilizer constraint reduces total fertilizer use by 60 percent while revenue declines 20 percent and soil loss is increased 27 percent. The low level fertilizer constraint reduces total fertilizer use 73 percent and net revenue 28 percent, while soil loss increases by approximately 30 percent. In general, a 1-pound reduction in nutrients is accompanied by a reduction of approximately 9 cents in net revenue.

Even though all constraints used in this study decreased fertilizer usage, the most effective means of reducing this usage was through a direct constraint. The principal way in which the programming model achieves lower fertilizer use is by changing rotations rather than reducing fertilizer application rates on high fertilizer requirement crops. The highest possible fertilizer application rate is maintained wherever possible.

Since the fertilizer constraint was imposed at the watershed level, it was hypothesized that the effects of the constraint would be similar on all watersheds. This did not prove to be entirely true. In the solutions studied, it was found that the effect of a fertilizer constraint on individual watersheds is preconditioned by the proportion of productive acres within the various watersheds. The higher the proportion of productive acres in a watershed, the more restrictive is the fertilizer constraint. The variability in average revenue among watersheds was reduced by a fertilizer constraint. Changing the level at which a fertilizer constraint is applied or the rates of fertilizer application would probably have different results. However, given the

Table 17–Summary of results for the 10 solutions

Item	Solution number[1]									
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Total revenue (dollars)	24,372,675	22,195,560	20,410,820	19,453,247	17,466,222	20,136,256	15,963,726	14,912,019	13,358,327	13,430,320
Total soil loss (T)	12,849,392	4,967,978	2,573,282	16,281,425	16,782,839	10,359,289	2,575,816	13,513,803	2,577,083	2,576,950
Total fertilizer (pounds)	88,355,988	74,033,924	62,473,388	35,796,275	3,877,000	59,440,440	35,537,616	24,378,347	24,304,008	24,306,465
Total N (pounds)	73,623,408	57,010,391	43,716,749	28,425,000	19,329,000	46,283,400	28,425,000	19,897,500	19,897,500	19,897,500
Total P (pounds)	12,272,762	15,122,814	17,299,414	5,665,775	3,411,000	11,134,260	5,685,000	3,411,000	3,411,000	3,411,000
Total K (pounds)	2,459,818	1,900,719	1,457,225	1,705,500	1,137,000	2,022,780	1,427,616	1,069,847	995,508	997,965
Total productive acres[2]	411,894	411,894	410,952	411,894	411,894	412,130	409,760	412,130	354,787	353,620
Average revenue per productive acre (dollars)	59.17	53.89	49.66	47.23	42.41	48.86	38.96	36.18	37.65	37.98
Average soil loss per 700 series acres[3] (T)	26.17	10.12	5.25	33.16	34.18	21.10	5.25	27.52	5.25	5.27
Average total fertilizer per productve acre (pounds)	214.51	179.74	152.02	86.90	57.97	144.22	86.72	59.14	68.50	68.74
Average N per productive acre (pounds)	178.74	134.41	106.38	69.01	46.93	112.30	69.37	48.28	56.08	56.27
Average P per productive acre (pounds)	29.80	36.72	42.10	13.75	8.28	27.02	13.87	8.27	9.61	9.65
Average K per productive acre (pounds)	5.97	4.61	3.55	4.14	2.76	4.91	3.48	2.59	2.81	2.82
SHI	.84235	1.21733	1.30924	1.60886	1.53932	2.00158	1.71386	2.05448	1.89314	1.89856

[1] For a description of each solution, see table 4. [2] Total productive acres refers to those acres which enter the solutions as budgeted rotations. The acres of forest, pasture and rangeland, and "other" land are not included as productive acres in the sense used here even though most are productive in an agricultural sense. [3] 700 series acres are upland acres which have associated soil losses. 500 series acres are bottomland acres and did not have associated soil losses. 700 series acres are 490,997 for all solutions except number 10 where the 700 series acres are 489,319.

Table 18 – Average revenue, soil loss, fertilizer use, and SHI for the 10 solutions, plus change from the unconstrained solution (No. 1)

Solution[1]	Revenue		Soil loss		Fertilizer		SHI	
	Average[2]	Change	Average[3]	Change	Average[2]	Change	Index	Change
	Dollars	*Dollars*	*Tons*	*Tons*	*Pounds*	*Pounds*		
No. 1	59.17		26.17		214.51		.84235	
No. 2	53.89	5.28	10.12	16.05	179.74	34.77	1.21733	.37498
No. 3	49.66	9.51	5.25	20.92	152.02	62.49	1.30924	.46689
No. 4	47.23	11.94	33.16	+6.99	86.90	127.61	1.60886	.76651
No. 5	42.41	16.76	34.18	+8.01	57.97	156.54	1.53932	.69697
No. 6	48.86	10.31	21.10	5.07	144.22	70.29	2.00158	1.15923
No. 7	38.96	20.21	5.25	20.92	86.72	127.79	1.71386	.87151
No. 8	36.18	22.99	27.52	+1.35	59.14	153.37	2.05448	1.21213
No. 9	37.65	21.52	5.25	20.92	68.50	146.01	1.89314	1.05079
No. 10	37.98	21.19	5.27	20.90	68.74	145.77	1.89856	1.05621

[1] For a description of each solution, see table 4. [2] Average revenue and fertilizer use calculated on a productive acre base. [3] Average soil loss calculated on a 700 series acre base.

time and resource constraints of this study, these possibilities were not available for investigation. Considerations of these kinds are needed before many definitive conclusions can be drawn with regard to fertilizer restrictions.

Fertilizer constraints increase average soil losses as well as the variation in soil loss among watersheds. This indicates that to partially offset the negative revenue effects of reduced fertilizer use, higher soil loss cropping patterns were brought into the solution. This is a logical result when no discounting for possible future yield decreases is used. The greater part of the increased soil loss takes place on three SRGs, and because of the importance of these SRGs in the total makeup of the watersheds, all soil loss computations are affected.

The SHI is increased through fertilizer constraints, but individual watersheds are affected differently. The variation in watershed indices is reduced considerably by the fertilizer constraints. Under unconstrained conditions, the watershed with the highest average fertilizer use had the lowest level of spatial heterogeneity and the watershed with the lowest average fertilizer use had the highest. All other watersheds showed a corresponding inverse relationship. When fertilizer use is constrained, this inverse relationship is reversed. Fertilizer constraints are helpful in achieving a more diversified landscape but reach a point where this effect is nullified.

LAND USE CONSTRAINTS

It is recognized that the actual imposition of land use constraints to achieve greater spatial heterogeneity is rather impractical. But a numeric measure of the spatial heterogeneity associated with other program alternatives provides another way to appraise their value.

The relationship between spatial heterogeneity, fertilizer use, and soil loss tends to confirm the hypothesis of those who claim that monoculture aggravates agricultural pollution problems. A spatial heterogeneity constraint reduces revenue, soil loss, and total fertilizer use at the basin and watershed levels. However, the impact of this constraint has a differential effect on individual watersheds. Differences among watersheds in average revenue capabilities increase even though the level of average revenue decreases for all of the watersheds. Average soil loss differences among watersheds also increase under a land mix constraint, while the level of average soil loss decreases. A large reduction in fertilizer use occurs throughout the basin and the individual watersheds. Nitrogen use is the most severely curtailed, with lesser decreases taking place in the use of phosphorus and potassium. Individual watersheds also show large variations in the amount of nutrient use. The land use mix constraint increases the basin's SHI. But the variation of the index among watersheds is also increased, leading to a more diversified land use in addition to larger differences among watersheds. Watershed variations may result from constraining land use at the basin level rather than at the watershed level. However, this cannot be verified since none of the alternative solutions tested this possibility.

Since only one of the alternate solutions employed a land use mix constraint in combination with another constraint, it is hazardous to generalize what other combinations would do to the SHI. In the one alternative solution where a combination constraint of this type was employed, the index was higher than when the land mix constraint was used by itself. Combinations of soil loss and fertilizer use constraints also produce higher spatial heterogeneity than do single variable constraints. Table 19 displays the acreage in each land use for the 10 solutions discussed in this study.

Table 19 – Land use acreage for the 10 solutions

Land use	Solution[1]									
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
	Acres									
Corn	408,507	316,290	242,871	117,918	63,167	152,130	76,196	80,000	33,085	32,948
Sorghum	1,693	969	596	120,661	174,364	80,000	41,309	106,670	94,788	94,709
Soybeans	1,694	597	597	171,110	174,364	45,000	108,361	90,460	90,638	89,806
Small grain	0	186	0	0	0	45,000	0	45,000	18,138	18.079
Forest and orchard	19,046	19,046	19,046	19,046	19,046	19,046	19,046	19,046	19,282	19,868
Other land	24,399	24,576	24,576	24,576	24,399	24,340	24,576	24,340	24,340	24,509
Hay	0	93,666	116,888	2,204	0	45,000	183,894	45,000	100,000	100,000
Pasturage and range	113,161	112,984	113,926	112,984	113,161	112,984	115,118	112,984	170,091	116,786
Summer fallow, conservation use, and idle	0	186	0	0	0	45,000	0	45,000	18,138	18.079
Total	568,500	568,500	568,500	568,500	568,500	568.500	568,500	568,500	568,500	564,784

[1] For a description of each solution, see table 4.

COMBINATION SOIL LOSS AND FERTILIZER USE CONSTRAINTS

When fertilizer and soil loss constraints are applied in combination, a more restrictive set of conditions is imposed on the system. As a result, the watersheds and basin show lower net returns. Lower net revenue is the principal trade-off resulting from the more restrictive conditions. In general, the SHI increases with each more restrictive solution, thereby partially offsetting some negative trade-offs.

Combination fertilizer and soil loss constraints, while reducing the level of the variables, do little if anything to interwatershed differences. In fact, this combination of constraints frequently increases differences among watersheds. The burden of meeting soil loss reduction in combination constraints was shifted among watersheds as fertilizer use was changed.

COMBINATION LAND AND FERTILIZER USE CONSTRAINTS

Combining a land mix constraint with a low fertilizer constraint brings about the expected large reduction in average revenue as well as in the amount of fertilizer used. Since the fertilizer constraint is applied at the watershed level, only a small variation in fertilizer use among watersheds is possible. Soil loss is lower under the land mix-fertilizer use constraint than in the unconstrained solution, but the variation among watersheds is increased. Since the land mix constraint tends to lower soil loss and fertilizer constraints tend to increase soil loss, the result of the combination is approximately midway between the effects of the two constraints applied individually. These two constraints do increase the SHI more than either constraint individually.

In general, the combination of low fertilizer and land mix constraints have a rather disastrous impact in terms of revenue upon the basin as well as the individual watersheds. Fertilizer use is held at a minimum while the SHI is near maximum. This type of constraint combination improves visual esthetics of the river basin and reduces potential water pollution from nutrient contamination. However, the major water pollutant – soil loss – continues unabated even though net farm income is severely impacted.

FLOOD PROTECTION CONSIDERATION

A partial flood protection program was considered in this study to determine the effect such a program would have on constraints used in this analysis. Although the inclusion of a flood protection program was only partial and rather conservative, it was discovered that the program did little to alleviate restrictions imposed by the constraints. Revenue, soil loss, fertilizer use, and land use were affected only marginally. Soil loss differences were more evident at the watershed level but what differences did occur can be attributed principally to the way the constraints were applied and the changes in acreage needed to include the floodwater program. In general, the consequences of tight environmental constraints are rather large, but adding a flood protection program to the problem did not provide any significant amelioration to the effects of the constraints. What minor evidence there is of program effects at the watershed level is more a consequence of the uneven application of floodwater structures among watersheds than the result of the program itself.

Table 20 – Average yields for the 10 solutions

Crop	Solution number[1]									
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Corn (bu.)	101.04	103.06	105.38	112.60	116.94	111.26	112.46	109.28	106.28	91.42
Sorghum (bu.) ...	26.20	28.33	14.80	49.53	53.12	92.51	60.11	66.55	66.71	57.95
Soybeans (bu.) ..	12.29	8.40	8.40	27.55	25.87	34.14	32.77	31.76	31.47	28.82
Wheat (bu.)	–	20.00	–	–	–	37.28	–	36.67	37.04	34.78
Alfalfa (T)	–	3.93	3.97	4.08	–	3.59	2.80	2.90	2.90	1.30
Tame hay (T)	–	–	–	–	–	–	2.23	2.40	2.40	2.21

[1] For a description of each solution, see table 4.

APPENDIX

PROGRAM

The linear program (L.P.) used was IBM's MPS/360.

Data on yields, fertilizer use, soil loss, and net revenue per acre were developed for all SRG s. The percentage of crops within each rotation for the spatial heterogeneity categories was also expanded to all watersheds and SRGs.

MATRIX GENERATOR

The various types of data must be in the proper format for input to the L.P. No calculations were required since all input data were previously put into the proper coefficient form. The following are types of input:

- Card A: Acres by Watershed, SRG these are the right-hand side (RHS) of the acre rows.
- Card B: Yields, Fertilizer Use, and Soil Loss by Watershed, SRG, and Crop -these are the cell values for the product rows.
- Card R: Net Revenue by Watershed, SRG, Crop these values are the coefficients of the objective function which are to be maximized.
- Card F: Production Goals products include crop production, fertilizer totals, and soil loss totals. These production goals are the RHS s of the product rows.
- Card M: Rotation Percents -for the calculation of the SHI, coefficients (percentages) are needed to allocate rotations to the nine land use categories.
- Card H2: Bounds on Crop Acreages absolute acre lower and upper bounds are specified on individual crops. The specification of an upper limit but a zero or blank lower limit results in a lower limit of zero acres. If the upper limit is left blank, the upper limit is infinity. A zero in the upper limit results in a zero acreage upper limit. If no bound or limit is desired, no card is needed.

DESCRIPTION OF MATRIX

A generalized scheme of the matrix is shown in appendix table 1. The rows and colums have the following interpretation:

Rows

Objective function - maximize revenue.

Land use - equality - total acres in a watershed, SRG.

Products - crop production - greater than or equality - rotations add various amounts to production of products.

Fertilizer use - greater than or less than - fertilizer for three nutrients will be accumulated for each watershed and the total basin. Initially, this is greater than zero RHS, but is later changed to a less than RHS.

Soil loss - same as fertilizer use plus an accumulation of tons lost by SRGs and by watersheds.

Spatial heterogeneity categories - greater than or equality - this is a summation section for later use in calculating the SHI outside of the program. This accumulation is made for the nine land use categories for each watershed and for the total basin.

Columns

There is only one type of column. Each column represents a watershed (W), SRG (S), crop (c) combination. The watershed-SRG possibilities (65) are derived from card A. The crop possibilities on these acres are derived from card B. There is no initial or current cropping pattern other than the constraints placed on specified crops through the H2 bounds cards.

Runs

In the initial run, all row types except the land use section were greater than or equal to zero. In subsequent runs, the row types were changed and RHS constraints were applied. Parametric ranging was also used on some of the RHSs. The activity coefficients were not changed. A revised procedure was used in making subsequent runs.

Appendix table 1—Environmental linear program model, abbreviated example

	$W_1S_1C_1$	$W_1S_1C_2$	$W_1S_1C_4$	$W_2S_1C_1$	$W_2S_1C_2$	$W_1S_2C_1$	$(W_1S_2C_4)$	Row type	RHS value
Max revenue	82.12	72.41	75.94	82.12	72.41	74.88	69.49	≥	0
Land use									
W_1,S	1	1	1			1	1	=	Ac.
W_2,S				1	1			=	Ac.
Products yields									
Corn	122		61	122		115	57	≥	Bu
Milo		122	30		122		29	≥	Bu
Beans			10				6	≥	Bu.
fertilizer									
W_1,N	180	180	145			180	145	≥	0 lbs.
W_1,P	30	30	28			30	28	≥	0 lbs.
W_1,K	6	6	7			6	7	≥	0 lbs.
W_2,N				180	180			≥	0 lbs.
W_2,P				30	30			≥	0 lbs.
W_2,K				6	6			≥	0 lbs.
Total, N	180	180	145	180	180	180	145	≥	0 lbs.
Total, P	30	30	28	30	30	30	28	≥	0 lbs.
Total, K	6	6	7	6	6	6	7	≥	0 lbs.
soil loss									
W_1	5.54	5.54	5.88			11.75	12.48	≥	0 Ton
W_2				5.54	5.54			≥	0 Ton
Total	5.54	5.54	5.88	5.54	5.54	11.75	12.48	≥	0 Ton
W_1S_1	5.54	5.54	5.88					≥	0 Ton
W_1S_2						11.75	12.48	≥	0 Ton
W_2S_1				5.54	5.54			≥	0 Ton
S_1	5.54	5.54	5.88	5.54	5.54			≥	0 Ton
S_2						11.75	12.48	≥	0 Ton
SHI									
W_1, LU_1	1	0	.50			1	.5	≥	0 Ac.
W_1, LU_2	0	1	.25			0	.25	≥	0 Ac.
W_1, LU_3	0	0	.25			0	.25	≥	0 Ac.
W_2, LU_1				1	0			≥	0 Ac.
W_2, LU_2				0	1			≥	0 Ac.
W_2, LU_3				0	0			≥	0 Ac.
Total, LU_1	1	0	.50	0	1	.5		≥	0 Ac.
Total, LU_2	0	1	.25	0	1	0	.25	≥	0 Ac.
Total, LU_3	0	0	.25	0	0	0	.25	≥	0 Ac.

Appendix table 2. Description of soil resource groups (SRGs)

SRG	Description	Major soils	Slope	Texture class	Problems
			Percent		
510	Deep, nearly level, well drained silty soils on bottomlands	Kennebec, Hobbs	1	Fine - silty	Slight, some areas subject to flooding
522	Deep, well drained to somewhat poorly drained, silty to loamy soils on bottomlands subject to flooding	Cole, Gibbon, Leshara, Wann, McCook	1	Fine - silty and coarse - loamy	Occasional flooding
534	Deep, nearly level clayey to loamy moderately saline or alkali soils on bottomlands	Saline or alkali phases of soils on bottomland	1	Coarse - loamy to fine	Saline and alkali
538	Deep, nearly level, somewhat poorly to very poorly drained, clayey or silty soils on bottomlands	Albaton, Luton, Wabash, Lawet drained	1	Fine	Wetness, subject to flooding
562	Deep to shallow nearly level to gently sloping, stratified sandy to clayey, frequently flooded soils on bottomlands	Alluvial land types	1	Sandy to clayey	Subject to flooding
710	Deep, nearly level, well drained to moderately well drained, silty soils on uplands	Hord, Hastings, Belfore, Holder, Hall	1	Fine - silty and fine	Slight
720	Deep, very gently sloping, well drained, silty soils on uplands	Moody, Hastings, Keith Holdrege, Holden	3	Fine - silty	Erosion
722	Deep, nearly level to gently sloping, loamy soils on uplands	Alice, Anselmo, Ortellie	3	Coarse - loamy	Erosion
723	Deep, nearly level, moderately well drained, silty soils with clayey subsoils on uplands	Crete, Wymore	1	Fine	Droughty, high clay content subsoils
730	Deep, very gently sloping to strongly sloping, deep and moderately deep, silty and loamy soils on uplands	Moody, Nora, Hastings, Keith, Holdredge, Alliance, Altvian	8	Fine - silty and fine	Erosion
731	Deep, moderately sloping, soils on uplands with silty, loamy surface layers and clayey subsoils	Pawnee, Wymore	2	Fine	Erosion, droughty, high clay content subsoil
732	Deep, very gently sloping or moderately sloping, well drained loamy soils on uplands	Bayard, Blendon, Chappell, Glenberg, Hersh, Keith, Mitchell, Moody Ortellie, Aselmo	3	Fine - silty to coarse - loamy	Erosion
740	Deep or moderately deep, moderately and strongly sloping, well drained silty soils on uplands	Coly, Uly, Colby	12	Fine - silty	Erosion
741	Deep, moderately sloping or strongly sloping excessively drained, sandy and loamy soils on uplands	Anselmo, Alice, Bayard Thurman, Valentine	6	Sandy and coarse - loamy	Erosion
760	Deep, strongly sloping to moderately steep, well drained, silty or loamy soils on uplands	Coly, Colby, Nora, Crofton	18	Fine - silty	Erosion
761	Deep, strongly sloping to moderately steep, well drained to excessively drained, sandy and loamy soils on uplands	Valentine, Thurman, Anselmo	10	Sandy	Erosion
764	Shallow, very gently sloping to moderately sloping loamy soils on uplands	Canlon, Canyon	8	Fine - loamy	Droughty, shallow
770	Deep or moderately deep, moderately steep or steep, silty or loamy, excessively drained soils on uplands	Coly, Colby	24	Fine - silty	Erosion

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Appendix table 3 -Corn yield response from fertilizer by SRG[1]

SRG	Fertilizer level			
	Zero	Low	Average	High
	Bushels per acre			
510	47.9	66.5	85.8	133.0
522	40.0	55.5	71.6	111.0
534	29.5	41.0	52.9	82.0
535	33.1	46.0	59.3	92.0
562	13.3	18.5	23.9	37.0
710	43.9	61.0	78.7	122.0
720	41.4	57.5	74.2	115.0
722	34.2	47.5	61.3	95.0
723	30.6	42.5	54.8	85.0
730[2]	36.0	50.0	64.5	100.0
731	32.4	45.0	58.1	90.0
732	33.1	46.0	59.3	92.0
740	28.8	40.0	51.6	80.0
741	25.2	35.0	45.2	70.0
760	18.0	25.0	32.3	50.0
761	16.2	22.5	29.0	45.0
764	7.2	10.0	12.9	20.0
770	12.6	17.5	22.6	35.0

[1] See explanation of SRGs in previous table. [2] The base yield for each crop and fertilizer level in this study was set equivalent to the estimated yields on SRG 730.

END