A SYSTEMS APPROACH TO EVALUATE WATER QUALITY ORIENTED LAND MANAGEMENT PLANS

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(ABSTRACT)

A systems approach, utilizing a deterministic hydrologic simulation model and an optimization model, was developed to evaluate and optimize cropland Best Management Practices (BMPs). The approach consisted of using the Finite Element Storm Hydrograph Model (FESHM) to simulate runoff and sediment yield from a series of design storms with known return periods. The design storm simulations were the basis for sediment distributions representing unique cropland areas and management practices. The distributions were evaluated to obtain average annual sediment yields which were used as activity coefficients in a linear programming (LP) optimization model. The LP model selected the set of cropland management practices that minimized total sediment yield while meeting economic and agricultural production constraints.

A postoptimality analysis was performed on the optimal solution to examine the effects of variations in: (1) income levels representing subsidy, and (2) sediment coeffi-

cients. The optimal solution was found to be insensitive to reductions in income levels (representing subsidy) and extremely sensitve to changes in the sediment coefficients.

Limitations of the systems procedure models were discussed along with suggestions for improving the sediment coefficients and their practical usage.

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INTRODUCTION

1.1 JUSTIFICATION FOR SEDIMENT CONTROL

With the advent of Public Law 92-500, managing our nation's water resources has become an expensive and time consuming problem. This law exemplifies the growing concern for the degradation of stream quality. The law emphasizes a land management approach to protecting water quality and desired stream uses. A main concern is limiting runoff and soil erosion. Limiting erosion is important since sediment is considered to be the biggest polluter by volume (Wade and Heady, 1976). Although sediment is a less dramatic pollutant than the toxics, its damages exceed billions of dollars per year (Wade and Heady, 1978a). Sediment is harmful in itself as a pollutant, carrying productive top soil from land and depositing it elsewhere, and filling up streams and reservoirs. The soil erosion process carries not only soil particles but also pathogens, sediment, adsorbed chemicals and dissolved chemicals (i.e., nutrients and pesticides, heavy metals and easily oxidized organics) (Bailey and Waddell, 1979). When water runs off the land carrying sediment and chemicals, it may reach waterways, percolate into ground water and interflow regions, and could be discharged into subsurface flow. The object of minimizing runoff, therefore, is to manage the runoff at its origin, namely on the land.

1.2 CONTROLLING SEDIMENT

Because sediment comes from nonpoint sources, its exact origin is difficult to identify and even more difficult to control. In rural river basins runoff from agricultural cropland is a major source of sediment water quality pollution. Therefore, to minimize this dispersed source of pollutant in rural river basins, we must rely on crop production and land management systems. The management systems designed to improve water quality are called Best Management Practices (BMP). They were set up in response to Section 208 of PL 92-500. Typical crop BMP systems involve the following:

1. using crop rotations,
2. implementing improved tillage practices,
3. matching crops to soil erosivity, and
4. incorporating grass waterways and filter strips.

Ideally, in determining the Best Management Practice(s) for an agricultural watershed, all alternatives must be evaluated. This evaluation involves the monitoring of the water quality effects of the practices and a determination of their economic feasibility.

Physical monitoring of all of the land management practices would be expensive, and very difficult to accomplish with current technology. Therefore, a procedure is needed to simulate and examine the effects of changing land management practices in a specific watershed. The objective of such a procedure would be to evaluate and select land management practices for minimizing nonpoint pollution that would not impose economic hardship on the watershed operator.

1.2.1 Study Objective

The overall objective of this study was to develop a procedure to aid in the land use planning of an agricultural watershed where nonpoint pollution is a problem. The procedure involved a systems approach consisting of two models: (1) a hydrologic simulation model, and (2) an optimization model. The hydrologic model was used to predict the effects that different land management alternatives had on sediment yield. The sediment yield was then used as input to the optimization model. The optimization model was designed to select the best set of agricultural practices to minimize sediment yield while maintaining the farm income level derived from the original agricultural prcatices.

Chapter II

MODELING NONPOINT SOURCE POLLUTION - A LITERATURE REVIEW

2.1 GENERAL

This chapter reviews current models concerned with nonpoint pollution. These models either simulate an agricultural watershed's hydrologic response, evaluate management policies, or do both.

There are two objectives involved in modeling nonpoint source pollution: (1) the estimation of losses (i.e., water, sediment or nutrient) and (2) the evaluation of management policies. Many modeling studies concern themselves with the first objective. Other studies involve the analysis of both objectives, which often is referred to as a systems approach. In the system analysis the first objective is achieved with a hydrologic simulation model, and the second objective is accomplished with an optimization model. Because the pollution from agricultural watersheds usually has no specific point source, the estimation and minimization of soil loss and nutrients is difficult. Pollution monitoring studies of agricultural watersheds are expensive and plagued with technical difficulties. Therefore, a means of predicting or simulating pollution from an agricultural watershed is appropriate. Since trial and error is an inefficient means of predicting watershed response, simulation models were developed for nonpoint source management. These hydrologic models, though imperfect, allow the forecasting of the impacts of alternate watershed management policies before their implementation. From the subsequent analysis of the physical impact of control measures came the need to consider the economic and managerial constraints of altering a watershed's land use. The economic analysis of the land use alternatives is most commonly achieved through optimization models. This review will cover the application of simulation models, optimization models, and models utilizing the systems approach to rural watershed management.

2.2 SIMULATION MODELS

In general, nonpoint source simulation models are abstractions of a watershed's response to the hydrologic cycle. The simulation model is a detailed mass balance procedure where within each computational time step, water balance and soil loss estimates are completed. With computers at the forefront of our society, digital simulation models have become invaluable research tools.

Generally the models use computational devices to simulate a watershed's response during the conversion of precipitation to streamflow (England, 1973). These models incorporate information on soils, topography, land use and channel characteristics into the simulation. The models then predict the flux of water and often water quality components across the watershed.

The hydrologic simulation models are classified generally as either lumped or distributed parameter models. Lumped parameter models treat the watershed as a single unit. The input parameters, i.e. soil and land use information, are averaged and the resulting runoff and water quality responses are given for the watershed outlet. Distributed parameter models consider the watershed to consist of many sections of unique hydrologic response units. The runoff and water quality responses are given over each of the hydrologic units and are then routed to the watershed outlet. Both distributed and lumped parameter models have been reviewed extensively (Woolhiser, 1973). A few simulation models will be mentioned here.

Perhaps the best known lumped parameter simulation model is the Standford watershed model (Crawford and Linsley, 1966). To this model, others have added pollutant transport components (Huff, 1968; Crawford and Donigian, 1973). When evaluating land management alternatives, though, the lumped parameter models may be inappropriate because they lack the spatial differentiation found in distributed parameter models.

Models like USDAHL-74 (Holtan et al., 1974), ANSWERS (Beasley et al., 1977) and FESHM (Ross et al., 1982) are distributed parameter models which have been designed to reflect the hydrologic changes resulting from altering land use patterns. The USDAHL model discretizes the watershed into land classification zones. There is a possibility of one to four zones distinct in elevation. The ANSWERS discretization utilizes a uniform grid method where the input parameters are averaged for each grid element. FESHM utilizes a free style of discretization that allows the watershed to be divided into any number or shape of 'elements'. Of these three distributed parameter models mentioned above, the USDAHL model possess the least descriptive level of differentiation.

2.3 OPTIMIZATION MODELS

In implementing any pollution control program, the ultimate determining factors are the evaluations of the benefits and costs associated with the nonpoint source management alternatives. The vast majority of the economic studies associated with agricultural production planning have utilized mathematical programming. Of these, the majority have been linear programming models. Classically, linear programming (LP) allows the modeler to minimize cost or maximize the benefits associated with the production activities for a planning area subject to allowable limits of pollutant losses. The flexibility of LP allows for a variety of constraints: nutrient limits for livestock, machinery and labor availability, etc. Conversely,the LP model can be formulated to minimize sediment from production areas subject to costs and other constraints. With the appropriate coefficients as input, the results of the LP model give the optimum land use plan or production scheme considering economic and managerial factors if the problem is mathematically solvable.

The key to the LP optimization model is the adequate estimation of the input coefficients. In particular, the estimation of the pollutant loss coefficients is crucial for nonpoint source analysis.

2.3.1 Estimation of Pollutant Losses

The most common means of deriving pollutant loss coefficients for the LP models are from the following:

1. literature (Miller and Byers, 1973), and
2. relatively simple equations including the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965).

Almost exclusively, optimization studies have included soil loss estimates obtained from using the USLE or modified forms of the USLE (Coote, 1973; Onishi and Swanson, 1974; Wade and Heady, 1978b; White and Partenheimer, 1980). Coote (1973) developed an interesting optimization model which utilized coefficients derived from a modified USLE analysis. His objective was to maximize farm revenue while maintaining mass balances on nutrients for animal feeding and plant growth. His loss estimates were derived from the soil loss equation and the Soil Conservation Service (SCS) runoff model (Mockus, 1971), and simple seasonal mass balances.

Most modelers using the USLE chose to: 1) minimize the cost of the erosion control practices or 2) maximize profit at various set soil loss tolerances (Heady and Vocke, 1978b; Miller and Gill, 1976; Narayanan and Swanson, 1972; White and Partenheimer, 1980).

Heady and Vocke (1978b) utilized a multiple objective LP model that minimized cost at several soil loss tolerances. The model analyzed the soil loss by USLE for 13 crops and 5 conservation practices.

Miller and Gill's LP model (1976) analyzed the economic impact of meeting soil loss standards on large and small farms. Narayanan and Swanson (1972) were concerned with maximizing profits while meeting SCS soil loss tolerances with various cropping activities. White and Partenheimer (1980) were concerned with maximizing income while meeting soil loss standards.

One model worthy of more consideration is the national sediment model derived by Wade and Heady (1978b). This national model was formulated mainly to minimize the cost of agricultural production subject to soil loss limits. The authors have also formulated the LP to minimize sediment. In all formulations the sediment coefficients were derived from the USLE, and simplified sediment transport and delivery equations to obtain the sediment from various crop rotations and tillage practices.

2.4 SIMULATION VS. OPTIMIZATION

In addressing nonpoint source evaluation, simulation models are invaluable in that

1. they can incorporate details in describing complex natural systems, and
2. they are capable of simulating changes in water quality due to climatic conditions and land modification.

The drawback of simulation models is their complexity. This complexity makes the evaluation of large numbers of management alternatives inefficient. Optimization models, though, are not as detailed and can determine efficiently the optimum management alternatives given specific requirements. It is obvious that both models are invaluable to nonpoint source management. The models represent two levels of analysis. The simulation or "fact finding" analysis provides the detailed evaluation of the watershed. The optimization or "decision making" analysis evaluates the large number of alternatives simultaneously. One model analysis is not complete without the other. The optimization model relies on estimates of pollutant losses. These estimates can come from literature, simple equations, or from simulation models. It is the purpose of the simulation model to support the optimization model; together they form the systems approach.

2.5 COMBINED USE OF OPTIMIZATION AND SIMULATION

For the most part, agricultural simulation and optimization models have been developed separately. Studies on the development of optimization models generally reflect the application of simulation models and possible linkages, and vice versa.

The combined use of optimization and simulation models have utilized two approaches. The first approach uses the optimization model to screen out the most feasible set of alternatives to be evaluated by the simulation model. The second approach uses the output from the simulation model as input to the optimization model.

2.5.1 Screening Approach

The first approach uses the optimization model as a screening device to find the better management alternatives from all potentials. The criteria for the screening is the maximization of profit, constrained to gross estimates of water quality, livestock feed and other production management variables. The better sets of alternatives are then evaluated in detail by the simulation model. Using the optimization model to screen out undesirable alternatives saves computer time and money by reducing the number of management systems to be evaluated.

Several systems approaches have utilized screening models in large river basin resource planning models (Viessman et al., 1975; Jacoby and Loucks, 1972). More detailed models for agriculture watershed planning have been developed by Huber et al. (1976) and Tseng (1978).

Huber et al. (1976) developed a LP model designed to apportion land among different uses and soil types. The land was apportioned on the basis of demand, cost and runoff factors. The runoff constraint was developed from data provided by the SCS. The better land use plans for the watershed were then evaluated with the HLAND simulation model. The HLAND model generated daily runoff, from which the yearly totals were obtained. These yearly totals were then used as indices for evaluating environmental standards and flood control measures.

Tseng's screening model (1978) evaluated land use plans on the basis of the land practice combinations suggested by the SCS for the areas in question. Also included in the LP was cost minimization, and land and livestock feed constraints. Tseng then evaluated the better alternatives using the USDAHL-74 model. The simulation model outputted nutrient loadings and sediment totals which were subsequently used to evaluate the impact of the land use alternatives. An important aspect to note in Tseng's systems approach was the application of his model. With the use of the screening approach Tseng could evaluate existing and improved cropping strategies. The improved cropping plan was also evaluated by the simulation model for critical climatic conditions.

2.5.2 Linked Approach

The second or linked approach utilizes the water quality results from the simulation of the management alternatives as input parameters to the optimization model. This approach, although requiring more computer simulation time, attempts to quantify clearly the water quality parameters.

Models using the second approach analyze the land management alternatives via the simulation model (Carvey and Robb, 1980; Sharp and Berkowitz, 1979; and Williams and Hann, 1978). Carvey and Robb's systems model (1980) interfaced the simulation and optimization models. Sharp and Berkowitz (1979), and Williams and Hann (1978) treated the simulation and optimization as separate model runs.

Carvey and Robb's simulation and optimization models (1980) interacted together. The simulation model was a distributed parameter model capable of reflecting the hydrologic response of the cropping activities, and the tillage and conservation practices. A budget generator then estimated the economic return for the managememnt activities currently being addressed in the resource base. The output of the hydrologic model (sediment and runoff) and the budget generator were inputted into the optimization model from the selected management options. The optimization model maximized the economic returns while minimizing the flooding and soil loss according to predetermined objectives.

Sharp and Berkowitz's systems approach (1979) used the simulation model LANDRUN to evaluate the sediment loads for different management and land practices. The sediment loads for all management practices were estimated by simulations over the growing season and used as inputs into the optimization model. The optimization model then maximized profit subject to the Soil Conservation Service (SCS) soil loss limits of 2, 3, and 5 tons per acre.

Williams and Haan's systems model (1978) was unique in its derivation of the sediment coefficients for use in the optimization model. Sediment frequency distributions were derived for each land class and cropping activity utilizing the results from the simulation of design storm in the HYMO-SPNM model. The optimization model contained a multiattribute objective function reflecting income, production cost, dependability, and disease, insect and weed control. This objective function was resolved using LP to determine the most acceptable set of cropping strategies constrained to water quality limits.

2.6 RESEARCH NEEDS

In general, the modeling systems proposed in the literature attempt to minimize the cost (maximize profit) associated with implementing land management practices that improve water quality. The approaches used to estimate the water quality parameters range from literature studies to sophisticated simulations. These models, though, have constrained the water quality parameters to fixed limits or tolerance levels. The water quality tolerance levels, specifically the soil loss levels, have been subject to much criticism. Therfore, an approach is needed that will evaluate the impacts of alternate land management plans without using these water quality tolerance levels. A systems approach should be formulated so that the minimization of sediment and/or other water quality parameters is the chief objective while the associated costs are held at predetermined levels. This approach would allow for a land management mix with the minimum level of soil loss (or other water quality parameters) regardless of any predetermined tolerance levels.

Chapter III

DEVELOPMENT OF THE SYSTEMS MODEL

3.1 OUTLINE OF THE SYSTEMS PROCEDURE

The systems approach in this study attempts to evaluate the effects that land management practices have on sediment pollution in an agricultural watershed. The systems approach involves the use of two models: (1) a hydrologic simulation model, and (2) an optimization model. The simulation model, provides a detailed evaluation of the sediment yield associated with each cropland area under various cropping activities. The second model, a linear programming model, selects the optimum land use plan for the cropping areas. The optimization objective is to minimize the sediment from the cropland subject to specific agricultural production activities.

Since the systems approach involves two distinct models, the procedure for the simulation of land management alternatives will be presented first with the derivation of the sediment yield data. Then the formulation of the optimization model and use of the sediment data as input to the optimization model will be presented.

3.1.1 Other Considerations

In using the systems modeling procedure, two general areas must be considered. The first is the systems model's planning time and the second is the data sources used. The customary planning time for systems models is one year. Economic and agricultural production data are available on an annual basis, as are the pollution data from simple models. Simulation models, though, generally operate with shorter time steps. The approach for determining annual sediment values from a simulation model will be addressed later. Ultimately, an annual or yearly analysis is most important in decision making (Kearl, 1968).

A study of a rural watershed was undertaken as a demonstration of this systems procedure. A 116 hectare agricultural watershed, located in the Prince Edward County, Virginia, was chosen for the systems modeling study. The Cunningham Creek Watershed was used because hydrologic, land use, cropping and economic data were available. It is important to note that the systems approach developed in this study is not specific to the Cunningham Creek Watershed. The modeling principles derived in this study are meant for general applications. The Cunningham Creek Watershed is used only as an example.

3.2 THE SIMULATION MODEL

The purpose of the simulation model is to provide the sediment values from all the land management alternatives so the optimization model can evaluate the alternatives further. Critical to the systems procedure is the selction and use of the simulation model. The simulation model must be able to incorporate the watershed's physical characteristics (i.e., soils, topography, etc.) so that the outcome from changes in the land use patterns will be reflected in the sediment yield.

3.2.1 Model Choice

The Finite Element Storm Hydrograph Model (FESHM) (Ross et al., 1982) was selected to simulate an agricultural watershed's response to alternate land management strategies. The FESHM is particularly well suited for this task since it integrates the spatial variability of soils, land use, topography, and rainfall in predicting the runoff and sediment yield from storm events. The 1982 version of the FESHM incorporates sediment algorithms similar to those in ANSWERS (Beasley, et al., 1977) and based in part on the USLE parameters which are attainable from literature (SCS publications and soil surveys). The decision for selecting the FESHM for this particular systems model was based on the following points:

1. The FESHM is strictly deterministic. It is not dependent on the availability of runoff records or calibration.
2. The input parameters are based on definable watershed and climatic properties.
3. The FESHM model is particularly suited for agricultural watersheds and has been used extensively in this context.
4. The author has experience with the model and has worked with the model's authors.

Finally, due to the nature of the FESHM's discretization scheme, it is possible to obtain the load of sediment recieved at the stream channel from spatially unique combinations of crops and management practices. These sediment yields are, as stated earlier, the purpose of the simulation study and the input to the optimization model.

3.2.2 Discretization Using FESHM

3.2.2.1 General Theory

The theory behind the finite element procedure suggests a method to subdivide a complex system into numerous, less complicated units or elements. The FESHM achieves this subdivision or discretization in two stages. The first stage involves a procedure outlined by Li et al. (1977). This procedure discretizes the watershed into units of a single soil type and land use combination. The units are called hydrologic response units (HRUs).

The second stage of discretization, independent of the first, involves the following steps:

1. the separation of the watershed into subsheds,
2. the separation of subsheds into unit source drainage areas or flowstrips, and
3. the separation of the flowstrips into one or more sequential elements.

The division of the flowstrips into elements also provides additional flexibility for incorporating spatial variations.

The two stages of discretization are linked in the FESHM submodels for determining rainfall excess and the routing of this excess to the stream channel. First the rainfall excess is found for each HRU. Then the HRU and element discretization are overlayed to estimate the fractional area of HRUs within elements. From the rainfall excess calculated for each HRU, the rainfall excess for each element is estimated by using the HRU fractional areas as weighting functions. The excess rainfall is routed accross the overland flow plane and through the stream channel. Detailed documentation of the FESHM can be found in the literature (Ross, 1978; Ross et al., 1982).

3.2.2.2 Discretization for Modeling BMPs

In using the FESHM for simulating the hydrologic response of an agricultural watershed for BMP evaluations, it becomes necessary to represent the watershed by a discretization scheme that separates cropland from forest and pasture areas. The separation isolates the flows from the crop elements so they may be analyzed independent from those areas not considered in the management study, specifically the forest and pasture areas. With this separation, only the effects of changing crops and management practices are evaluated. Figure 1 shows the results of discretizing the Cunningham Creek Watershed under the existing land use pattern.

3.2.3 Estimation of Average Annual Model Parameters

Since the FESHM is designed for use on ungaged watersheds, calibration of the model parameters should not be a requirement. A comparison of the simulated and observed hydrographs from the limited Cunningham Creek data base suggested that there was a miss match of runoff volume in some seasons. To improve the agreement between the FESHM hydrographs and those from the data base, the seasonal infiltration index, GI in the Holtan Equation, was adjusted. This GI factor is an index reflecting the seasonal changes in the crop cover. The Holtan Equation, as adapted for the FESHM, is as follows:

$$f = GI*a*S^{c} + f_{c} \tag{1}$$

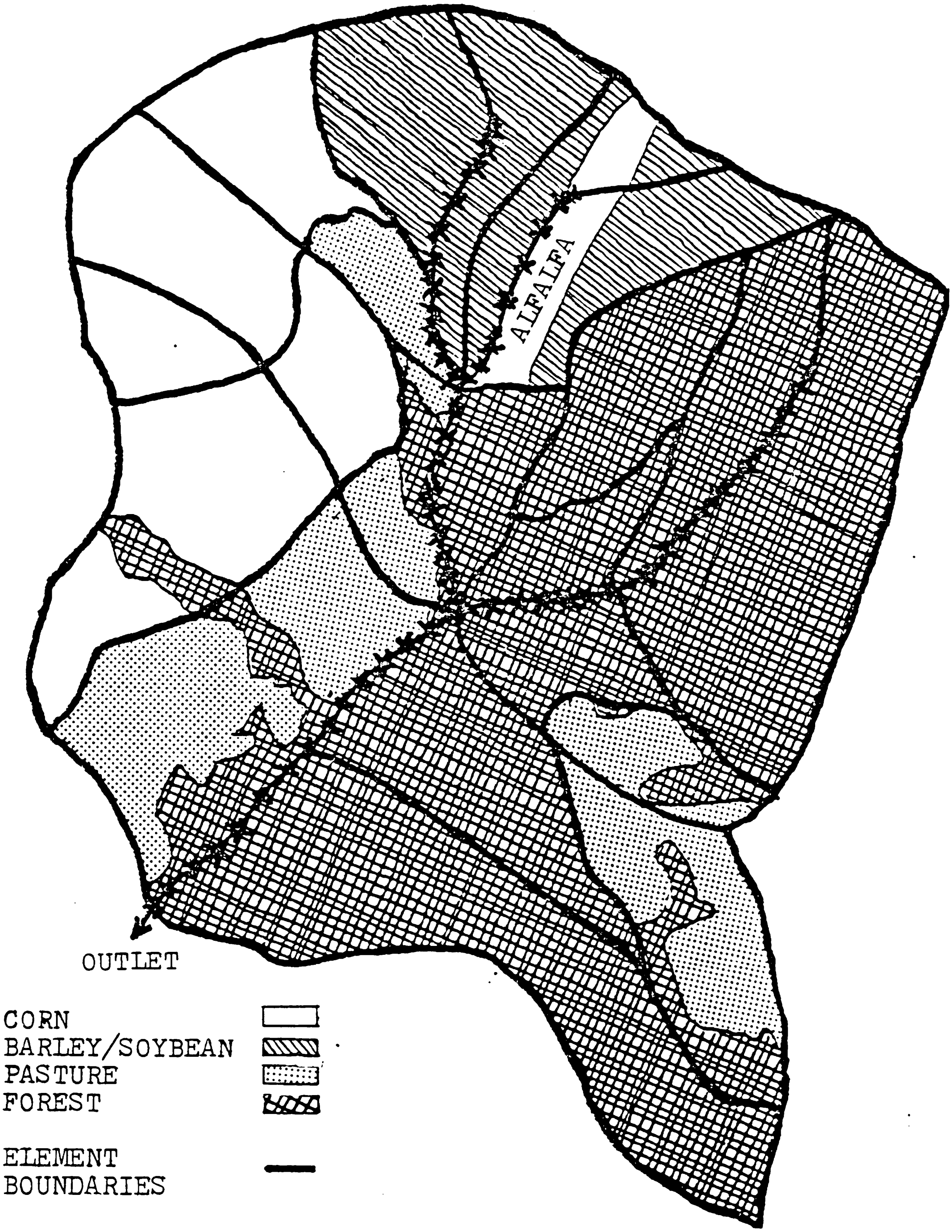


Figure 1. Discretization of the Existing Land Use Practices in Cunningham Creek Watershed. Total Area: 116 hectares.

where:

f = infitration rate in inches per hour;

GI = seasonal factor to index the effect of seasonal changes in cover on infitration;

a = coefficient for indexing the effect of cover conditions;

S = unfilled storage space to a restrictive layer, in inches, with the maximum value usually assumed to be the depth of the soil's A horizon;

f = constant infiltration rate after prolonged wetting in inches per hour; and

c = coefficient that is assumed to be a function of the soil hydraulic characteristics and is defined as the ratio of potential gravitational water to the potential plant available water in the soil profile (Ross et al., 1982).

Figure 2 shows an example of one of the discharge hydrographs before and after the adjustment of the GI factor. After the GI factors were modified, the monthly indices were averaged to obtain a yearly GI factor estimate. The monthly GI factors, before and after calibration, are given in Table 1. The other average annual model parameters needed for the FESHM were the cropping and management factors (C factors from the USLE). The average annual C factors for the study area were obtained from the literature (USDA-SCS, 1973).

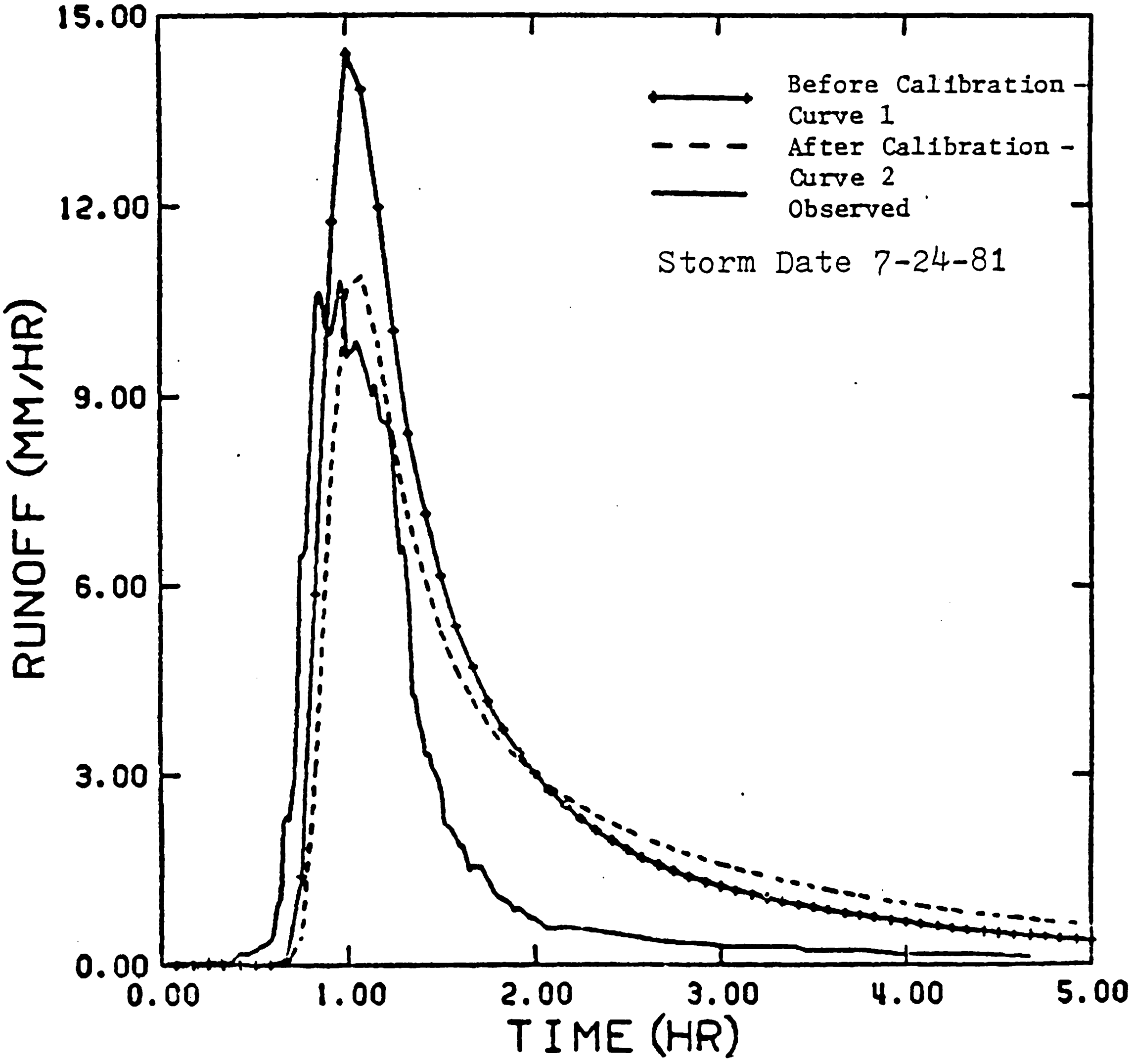


Figure 2: Comparison of the Discharge Hydrographs

Table 1. GI Factors.

Estimates from the Literature (Smolen and Younos, 1980)

Months

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0.30	0.30	0.30	0.35	0.35	0.60	0.65	0.75	0.80	0.80	0.30	0.30

Average = 0.44

Modified Values after Calibration

Months

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0.30	0.30	0.30	.45	0.60	0.80	1.00	1.00	0.75	0.30	0.30	0.30

Average = 0.53

3.2.4 Design Storm Derivation and Distribution Formulation

3.2.4.1 General

The event based FESHM was then used in an annual storm analysis to obtain average sediment yields. The analysis consisted of using design storms from depth-duration-frequency (DDF) analyses. These design storms were used in the event based FESHM in order to obtain a sediment frequency distribution.

The sediment yield was obtained from a series of known probability storms. From the simulations with the design storms, an approximate probability distribution of sediment for each flowstrip and crop management practice was obtained. From this distribution the expected value of the annual sediment yield was derived.

3.2.4.2 Remarks on the Use of Design Storms

Even though design storms follow a known probability distribution, the resulting sediment yields may not. No evidence was found in the literature to suggest that the probability distribution for simulated sediment yields follows the same distribution as the design storms used in the analysis. Still, for lack of a better method, modelers have chosen to use design storms to obtain the distribution and expected value of the annual sediment yield (Williams and Hann, 1978; Simons et al., 1977)

3.2.4.3 Derivation of Design Storms

First, design storms were derived from rainfall depth-duration-frequency distributions developed from data collected at a nearby continuous recording rainfall station in Virginia (Shanholtz and Lillard, 1974). Three-hour design storms were derived using the DDF method described in Barfield et al.(1981). An intermediate storm pattern with peak intensity at the midpoint was assumed. For input into the event-based FESHM, the design storm month of occurrence possessed the average GI factor and was at a moisture level of 50% of field capacity. The design storms derived for the simulation had return periods of 2,5,10, 15,20,25,50 and 100 years. As an example, Figure 3 shows the storm pattern for the 50 year return period storm.

3.2.4.4 Formation of Distributions

The simulation of the design storms resulted in sediments yields that were assembled as probability distributions. The inverse of the return periods of the design storms represented the probability of those particular storm events occurring one or more times in a year (Barfield et al., 1981). The sediment totals resulting from these design storm events were then associated with the storms' particular probabilities. This formed the basis for representing

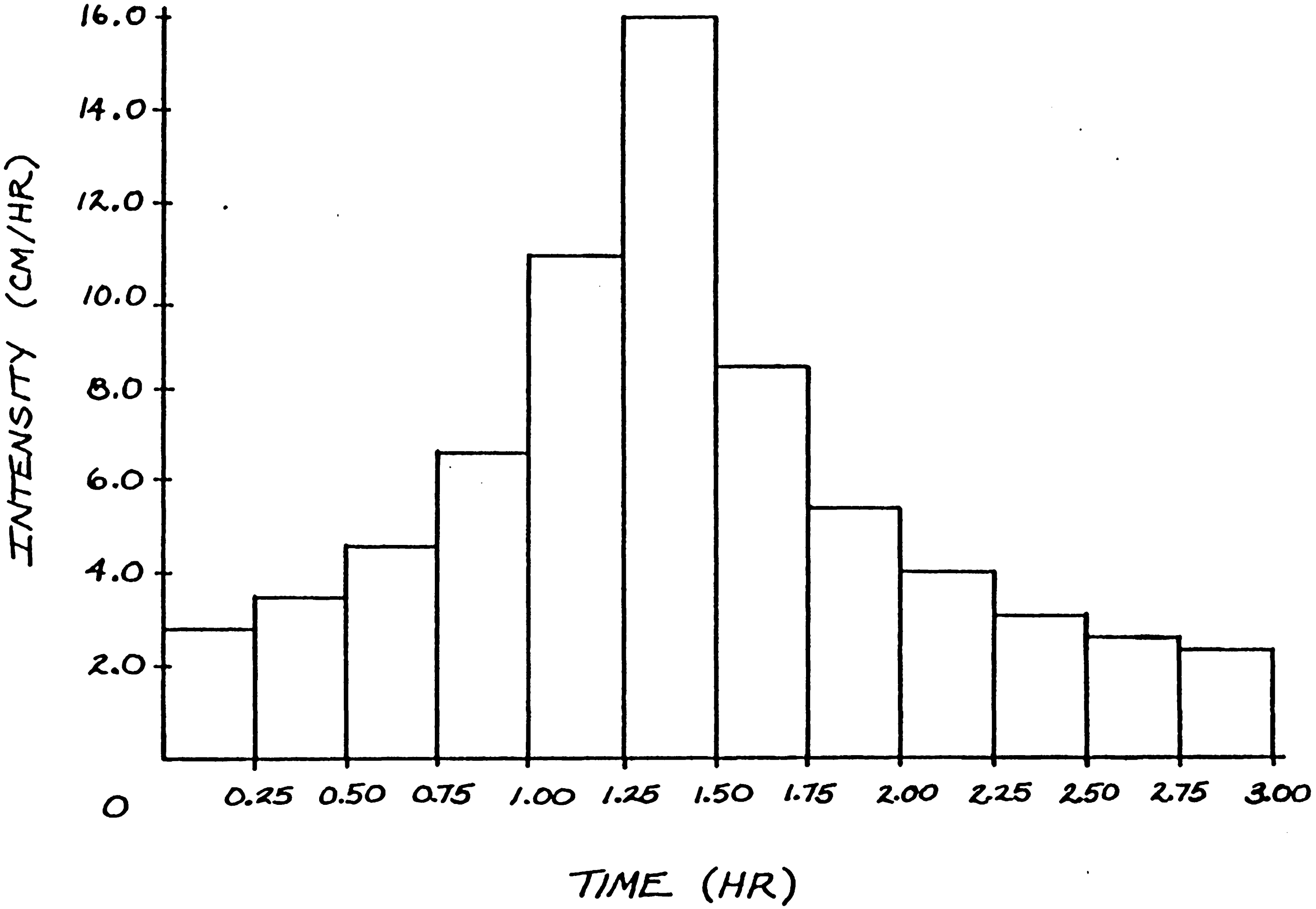


Figure 3. Three-Hour, 50-Year Storm Pattern by the DDF Method.

the sediment yields from various flowstrip and cropland management combinations as probability distributions.

3.2.5 Cropping Strategies

The possible combinations of crop and crop management practices, or cropland strategies, considered in the design storm analysis were as follows:

1. conventional corn (C)
2. alfalfa or hay (H)
3. no-till corn (NT)

Also, because the model representation of the watershed contained flowstrips that had more than one element of cropland, (eg., element 6 a,b,c and element 7 a,b,c in Figure 4) variations in the location of crops and practices along the flow path could be simulated. These variations are listed as follows:

1. corn above alfalfa (CH)
2. alfalfa above corn (HC)
3. no-till corn above alfalfa (NTH)
4. alfalfa above no-till corn (HNT)

Once the cropland strategies were chosen, the crop parameters were obtained from the literature, and reconaissance surveys of the actual crops in the study area. The cropping and management factors (C factors from the USLE),

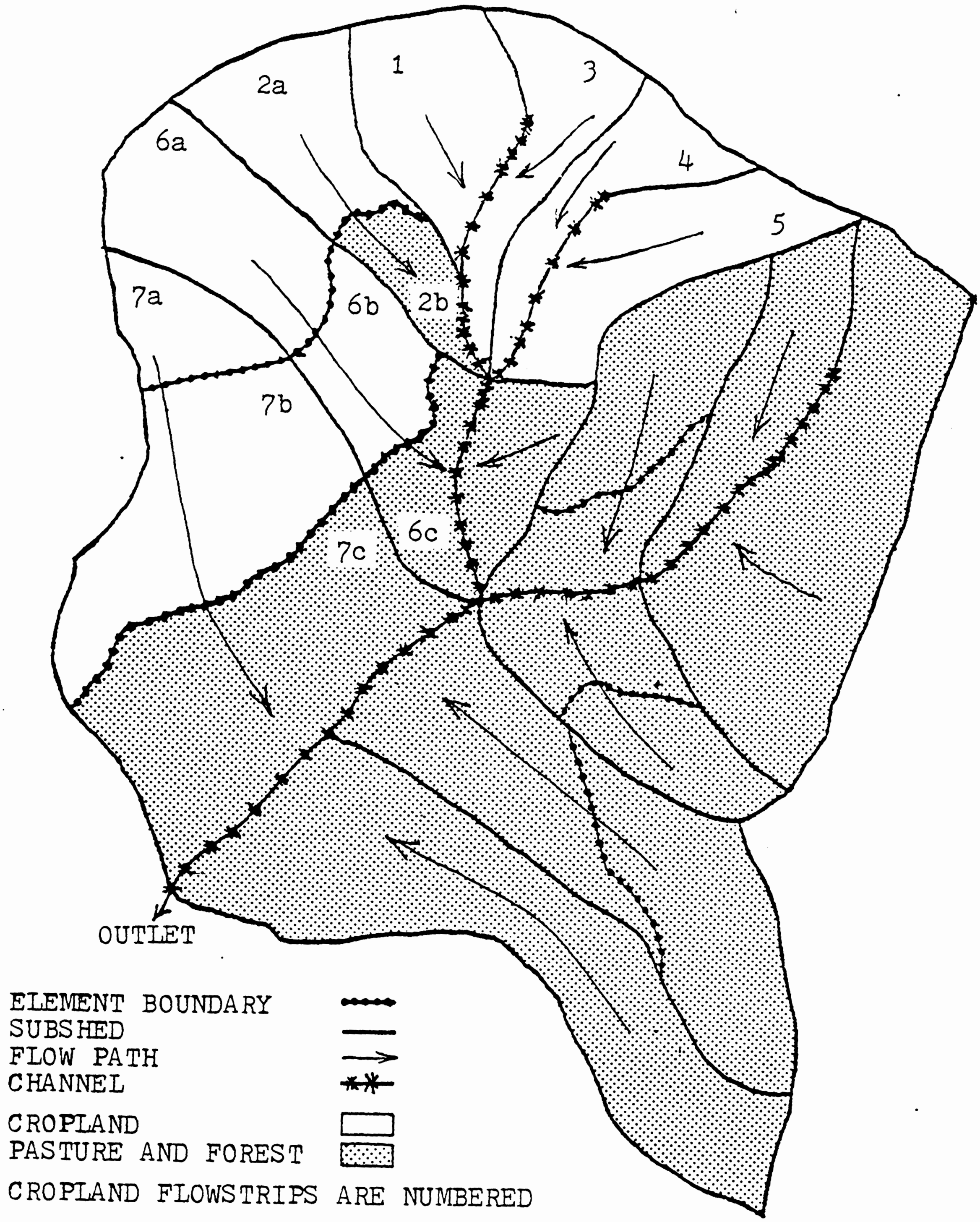


Figure 4. Discretization of the Cropland Area for the Systems Procedure.

which are used in the FESHM sediment algorithm, were taken from the USDA-SCS guide for Virginia (1973). The cropping and management factor estimates for the forests were obtained from the work of Dissmeyer and Foster (1981). The crop cover factors (a factors from Holtan's Equation) were obtained from the literature also (Ross, 1978; Ross et al., 1982). The C and a factors for the FESHM design storm analysis are given in Appendix A.

Once the strategies were assembled, they were used with the design storms in subsequent model simulations. Each cropping strategy was assigned to the cropland elements of the watershed and the set of design storms 2,5,10,15, etc. to 100 year) were used as the precipitation input. Sediment totals and runoff from each flowstrip were obtained from the FESHM simulation results. The sediment and runoff values from the flowstrips were the amount of sediment and runoff delivered from each strip into the corresponding stream channel. Since the FESHM does not simulate channel deposition (Ross, et al., 1982), all sediment transported to the channel from the overland flow plane is routed to the watershed outlet. Therefore, by varying the cropping strategies in a flow strip, the amount of sediment each area contributes to the overall watershed is obtained.

3.2.6 Simulation With Design Storms

Each flowstrip and cropping strategy combination was simulated with the set of design storms. The resulting sediment yields were assembled by flowstrip and cropping strategy. The set of design storm sediment yields obtained from each flowstrip and cropping strategy combination formed a unique distribution. This distribution represented the probability of occurrence of the resulting storm sediment yield for a particular crop and element. From these distributions, the average annual sediment yields from flowstrip and cropping strategy combinations were obtained.

3.2.7 Analysis of Distributions

The sediment loads obtained from simulated design storms have been analyzed by Simons et al. (1977) and Williams and Hann (1978) using exponential distributions; however, another distribution in the exponential family was considered in this study. Both exponential and Weibull distributions were tested against the Cunningham Creek results. A logarithmic transformation, as described by Simons et al. (1977), and a Weibull transformation, as described in Hahn and Shapiro (1967), were performed. The two transformation methods were performed to determine which distribution "best fit" the data. The data were transformed so that they would plot as a straight line. The method possessing the highest correlation coefficient was then chosen. The linear regression parameters (slope and intercept) were used to obtain the expected value of each distribution. The transformation methods and the equations for the determination of the expectation for each relationship are outlined below.

3.2.7.1 The Exponential Distribution

First, a logarithmic transformation was performed on the sediment values from the set of design storm simulation from a flowstrip and a single cropping strategy. The transformation was performed by taking the natural logarithm of the design storm return period. After the return period (Tr) was transformed, the corresponding sediment values (Qs) were plotted. From the resulting linear equation

$$Qs = m \log(Tr) + b \qquad (2)$$

the intercept (b) and slope (m) were obtained. The density function for the transformed data was formulated as

$$f_{Qs}(x) = \frac{1}{m} x \, e^{\left(\frac{b-x}{m}\right)} \qquad (3).$$

From this the expected value of Qs,

$$E[Qs] = \int_{b}^{\infty} \frac{1}{m} x \, e^{\left(\frac{b-x}{m}\right)} dx - m + b \qquad (4)$$

was derived (Simons et al., 1977). This equation yields the mean annual extreme sediment yield for a set of design storms.

3.2.7.2 The Weibull Distribution

In formulating the Weibull transform for the regression analysis, the return period and sediment yield were expressed in the Weibull cumulative distribution function

$$F(x) = 1 - \left[\exp - \left(\frac{x}{\sigma}\right)^{\eta}\right] \qquad (5)$$

where η and σ are shape and scale parameters respectively. Rearranging equation (5) and taking the natural logarithm of the left side twice and the natural logarithm of the right side once yields the Weibull equation necessary for the regression analysis and solution of the parameters. The transformed equation is as follows:

$$\log \log\left[\frac{1}{1 - F(x)}\right] = \eta \log x - \eta \log \sigma \qquad (6)$$

(Hahn and Shapiro, 1967).

For the design storm analysis, the probability (P_{Tr}) that a design storm (Tr) will be equaled or exceeded at least once in an n-year period is:

$$f(P_{Tr},n) = 1 - \left(1 - \frac{1}{Tr}\right)^{n} \qquad (7).$$

Since the storm analysis is concerned with a yearly or annual basis, n=1 and

$$f(P_{Tr},1) = \frac{1}{Tr} \qquad (8).$$

Therefore the cumulative probability function is

$$F(P_{Tr},1) = 1 - \frac{1}{Tr} \qquad (9)$$

(Barfield, Warner and Haan, 1981).

Substituting the left-hand-side of this equation into equation (5), and substituting Qs for X gives the Wiebull transformation for the study data:

$$\log[\log(Tr)] = \eta \log Qs - \eta \log \sigma \qquad (10).$$

Equation (10) can also be written as

$$W = mz + b \qquad (11)$$

where:

$$W = \log\left[\log\left(\frac{1}{1 - F(x)}\right)\right] \qquad (12),$$

$$z = \log x \qquad (13),$$

$$b = \eta \qquad (14),$$

and

$$a = - \eta \log \sigma \qquad (15).$$

(Hahn and Shapiro, 1967).

Plotting equation (12) as the ordinate and equation (13) as the abscissa will yield a straight line if the Weibull analysis is valid. The regression analysis of the transformed data was then used to obtain the Weibull parameters necessary to the solution of the expected or average value of each flowstrip and cropping strategy combination. The Weibull parameters could then be estimated from the regression analysis since

$$\hat{\eta} = b \quad (16)$$

and

$$\hat{\sigma} = e^{-a/b} \quad (17).$$

Once the distribution parameters were found, the expected value of Qs was obtained by

$$E[Qs] = \sigma\Gamma\left(1 + \frac{1}{\eta}\right) \quad (18),$$

where:

$$\eta = \hat{\eta}$$

$$\sigma = \hat{\sigma}$$

and

$$\Gamma = \text{gamma function.}$$

Values of the gamma function can be found in standard mathematics tables.

3.2.8 <u>The Correlation Coefficients</u>

From the regression analyses of both the exponential and Weibull transformations, the associated correlation coefficients were determined. The correlation coefficients were the basis for selecting the best distribution to represent the Cunningham Creek sediment data. The distribution, Weibull or exponential, which exhibited the highest correlation coefficients for the most data sets was used to obtain the average annual sediment yields.

3.2.9 The Averages

Once each storm data set representing the sediment distribution of a particular cropping strategy and flow strip was transformed by each method (Weibull and exponential). The distribution possessing the highest correlation coefficient for the most cropping strategy-flowstrip combinations was chosen. Once the single distribution reflecting the most data sets was obtained, the expected value for each flowstrip and cropping strategy combination was determined. The average annual sediment values for each cropping strategy and flowstrip combination were then used in the formulation of a linear programming model designed to minimize sediment.

3.3 OPTIMIZATION MODEL

3.3.1 General

The optimum selection of land use plans can be determined by using a linear programming (LP) optimization model. The LP procedure is designed to make decisions that involve many alternatives and, thereby, can determine the optimal set of cropping practices for a watershed. The LP model simultaneously selects the optimum set of strategies to minimize sediment while meeting predetermined agricultural production constraints. These constraints may be formulated to maintain economic acceptability and land use restrictions.

3.3.2 The Objective

The objective of the LP model is to select the optimum land use strategy that will minimize the total cropland sediment yield while maintaining profit levels and land use allocations that are acceptable to the watershed operator. The objective function links the simulation model to the optimization model by using the sediment activity coefficients derived in the simulation model. The LP objective is formulated to:

$$\text{Minimize: } Z = \sum_{i=1}^{n} a_i \, x_i \qquad (19)$$

where:

Z = sum of the sediment yields for all the cropping strategy-flowstrip combinations selected;

n = total number of possible cropping strategy combinations;

a_i = annual sediment yield from a particular cropping strategy-flowstrip combination; and

x_i = a particular cropping strategy-flowstrip combination.

3.3.3 Zero-One Formulation

A zero-one LP constraint requires that the variable(s) be constrained to take on the value of zero or one. The constraint is a practical option when dealing with a physical list of alternatives. In this model the cropping strategy-flowstrip combinations are constrained to zero-one variables.

Each cropping strategy-flowstrip combination possesses a sediment value totally unique to the physical make-up of the flowstrip. Therefore, the zero-one constraint on activities (the set of cropping strategy-flowstrip combinations) is a rigorous requirement because only one strategy can be selected per flowstrip, and any mixing of strategies in a flowstrip violates the specificity of the sediment coefficients. The zero-one constraint is formulated as:

$$\sum_i \sum_j x_{ij} = 1 \qquad (20)$$

where x_{ij} is the binary integer variable, or

$$x_{ij} = \begin{cases} 1 & \text{if site i - strategy j is selected} \\ 0 & \text{if otherwise} \end{cases}$$

and

i = index for the number of flowstrips, and

j = index of cropping strategies

3.3.4 Land Constraint

The optimization model was formualted to restrict total freedom in altering the land use pattern of the farm watershed. The model is constrained to (1) only modify cropland, and (2) maintain the amount of cropland devoted to livestock feed.

Only land areas designated as cropland in the land use survey were considered by the LP model. The forested, residential, and pasture areas were considered, for all practical purposes, to be permanent. The amount of pasture land was fixed at the existing level to maintain the grazing needs of the farm livestock. The amount of cropland and type of crop specific to the livestock feed requirements were constrained also. The constraining of the amount of pasture land, alfalfa and corn silage was considered to be a practical requirement.

If the farmer's present production scheme or land allocation is optimal from a profit standpoint, a reallocation of land would have a negative effect on the profit. A decrease in corn silage on a dairy farm would require increased expenditures for high energy concentrates. A reduction in alfalfa would require greater expenditure in protein supplements. Both expenditures would be above and beyond any savings over the original plan (White and Partenheimer, 1980). Since the farmers' allocations of land may be imperfect, the amounts of land in corn silage and alfalfa can be loosely constrained.

The object of the land management study was not to change the existing crops but to test the crop management practices and field locations. Therefore the amount of land allocated to alfalfa and corn silage was not allowed to be lower than the existing amounts. An upper level constraint, though, was placed on the alfalfa. This constraint was invoked to reduce the possibility that all the available land would be forced to be cropped in alfalfa.

White and Partenheimer's (1980) analysis of farms supporting dairy activities revealed that changing the amount of areas devoted to corn to less erosive crops (i.e., alfalfa) caused severe reduction in farm income. Therefore watershed planners could keep the corn area at existing or greater than existing amounts if maintenance of current income is desired (White and Partenheimer, 1980).

The land allocation constraints are formulated as follows:

Corn Constraint

$$\sum CS_k x_k \geq ECS \qquad (21)$$

where

x_k = 0 or 1 from the zero-one constraint;

k = set of flowstrips with corn in the strategies (C,NT,CH,HC,NTH, HNT);

CS_k = area each flowstrip devotes to corn; and

ECS = existing amount of area in corn silage.

Alfalfa Constraint

$$TVAH > \sum AH_l x_l > EAH \qquad (22)$$

where:

x_l = 0 or 1;

l = set of flowstrips with the hay in the strategies (H,CH,HC,WTH, HNT);

AH_l = area each flowstrip devotes to hay;

TVAH = target value on the upper limit of area in alfalfa allowed; and

EAH = existing amount of area in alfalfa.

3.3.5 Economic Constraint

An economic constraint was added to the LP model so that the farmer's level of income would not be sacrificed to achieve reductions in sediment yield. This constraint insured that the net returns the farmer realized from the optimum cropland use plan would not be less than the revenue realized from the existing cropland.

The constraint formulation is

$$\sum CB_m x_m > REC \tag{23}$$

where:

$x_m = 0$ or 1;

m = index of the possible combinations of flowstrips and cropping strategies;

CB_m = crop budget for each cropping strategy-flowstrip combination; and

REC = revenue from existing cropland.

The information for the Prince Edward County crop budgets were supplied by the district extension office (Waddell, 1982; Brant and Moore, 1981). The target value or revenue from existing cropland was determined from the crop budget information and the surveyed cropland area in the Cunningham Creek Watershed.

3.3.6 Computer Solution

Computer alogrithms and software packages have been developed to handle large and complex linear programming models and their associated data bases. The general programming package chosen for the optimization of the study area data was the Mathematical Programming System (MPSIII) (Management Science System Division, 1977). MPSIII is a well documented and tested programming system that offers many options in formulating and solving linear programming problems. The MPSIII package was chosen for its compatibility with the IBM 360/370 computer system and the availability of a procedure that could solve a zero-one linear program.

The MPSIII procedure dedicated to solving zero-one problems is called MISTIC (Management Science System Division, 1977). MISTIC uses a branch and bound procedure which attempts to find the optimal solution to LP problems. The variables in the LP optimization formulation can be continuous or integer. The integer variables, though, are restricted to values of zero and one. Detailed documentation of MPSIII and MISTIC can be found in the Management Science System Division's user manual.

Additional reasons for using computer packages for solving linear programming models are as follows:

1. The computer procedures are generally cost efficient.
2. Subsequent analyses are easily accomplished once the initial problem is formulated.
3. Procedures for performing postoptimality or sensitivity analysis are readily available.

3.3.6.1 Postoptimality Analysis

Since most optimization models for nonpoint source are linear programming models, they are ideally suited for postoptimality or sensitivity analysis. Sensitivity analysis can be used to provide additional insight on the adequacy of the input parameters. The outcome of the optimization is based on these input coefficients. In practice, the values of the coefficients are seldom known with absolute certainty (Phillips et al., 1976). If those parameters that affect the objective value most can be identified, then emphasis can be placed on estimating these parameters to increase the reliability of the solution.

In systems modeling sensitivity analysis can be useful in performing tests on the following:

1. the general stability of the solution in the presence of small data errors,
2. alternate cropping configurations which may produce similar solutions,
3. the addition of new crop production requirements, and
4. the effect government or other planning influences have on the management mix.

The specific postoptimality changes made on the study LP model will be discussed in the next chapter following the presentation of the optimal solution.

Chapter IV

RESULTS

4.1 DISCRETIZATION OF SIMULATION MODEL

Simulating the hydrologic response of BMPs involves discretizing the study area into elements that best reflect changes in the cropping patterns or strategies. Figure 1 shows the flowstrip and element discretization of the Prince Edward County Watershed under the existing land practices. The flowstrips were discretized into elements to follow the existing field boundaries and to achieve separation from the non-cropland areas. Figure 4 shows the flowstrip numbering of the cropland areas evaluated in the systems approach. Also indicated are the two flowstrips (6 abc and 7 abc) which contain two cropland elements each (a and b). The physical makeup of these flowstrips allowed for the analysis of filter strips by placing a hay crop (alfalfa) between the corn field (the top element) and the channel.

4.2 DESIGN STORM SIMULATIONS

After the discretization, each flowstrip and cropping strategy combination (there were 29 possible combinations) was used in the FESHM model for simulation with the set of design storms. The results of the simulation of the set of design storms with one cropping strategy (no-till corn) and all the flowstrips is given in Table 2. Similarly, the other flowstrip-cropping strategies were simulated with the design storm sets. The results from Table 2 were selected as an example.

The design storm simulation of each flowstrip and cropping strategy combination is a sediment distribution representing the annual probability of occurrence of the resulting design storm sediment yield. Figure 5 is an example of one such distribution. The abscissa or probability of occurrence is simply the inverse of the design storm return period. The ordinate is the sediment yields corresponding to the probability of the storm's occurrence in a year's time.

The design storm simulations of the flowstrip and cropping strategy combinations were then transformed to determine which distribution, exponential or Weibull, best fit the data. The criteria for determining the best distribution for all the combinations was achieved through examining

Table 2. The FESHM Simulated Sediment Yields in Metric Tons for Each Flowstrip Under No-Till Corn.

Design Storm Return Periods	Flow Strip Numbers 1	2ab	3	4	5	6abc	7abc
2	2.8	1.8	1.8	1.4	2.5	6.8	10.6
5	5.9	3.4	3.6	2.8	4.2	13.7	20.5
10	8.0	5.2	5.1	4.3	6.2	18.8	29.1
15	9.4	6.4	6.5	5.1	6.2	22.2	35.8
20	10.4	6.6	7.2	5.7	7.2	25.8	38.6
25	11.2	7.5	7.8	6.2	8.0	27.3	42.2
50	15.5	10.3	9.6	7.5	11.1	35.2	52.7
100	21.2	14.0	11.5	9.0	15.9	43.3	64.7

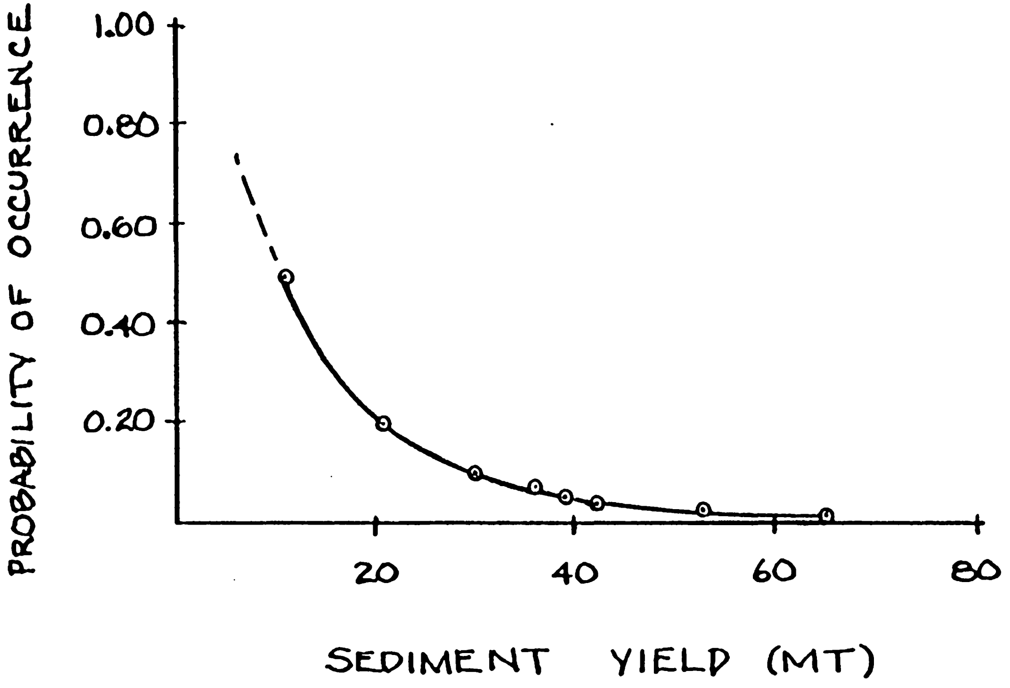


Figure 5. The Sediment Probability Distribution of Flowstrip 7ab in No-Till Corn.

the transformation correlation coefficients. It was found that the Weibull distribution represented 76% of the data sets better than the exponential. The range of the Weibull data sets correlation coefficients (0.97 to 1.00) was also higher than the range of correlation coefficients from the exponential distribution (0.93 to 0.99). Thus, the Weibull distribution was chosen for the analysis of the expectation of each probability distribution. A plot of the transformed data for flowstrip 7abc cropped in no-till corn is shown in Figure 6. Also indicated in the figure are the Weibull parameters determined from the regression analysis. These parameters were then used to obtain the expected value or the average annual sediment yield from flowstrip 7abc planted in no-till corn.

Table 3 gives the expected value of the Weibull distribution representing each flowstrip and cropping strategy combination be studied in the systems model. The sediment averages derived from the FESHM for the corn-hay combination strips (strips 6abc and 7abc) contradicted the expected response of the filter strips. The FESHM simulation results and subsequent average sediment yield for the corn field above the hay were higher than the hay above the corn. The FESHM simulation with design storms seemed to be inadequate in modeling the response of the filter strip (corn above

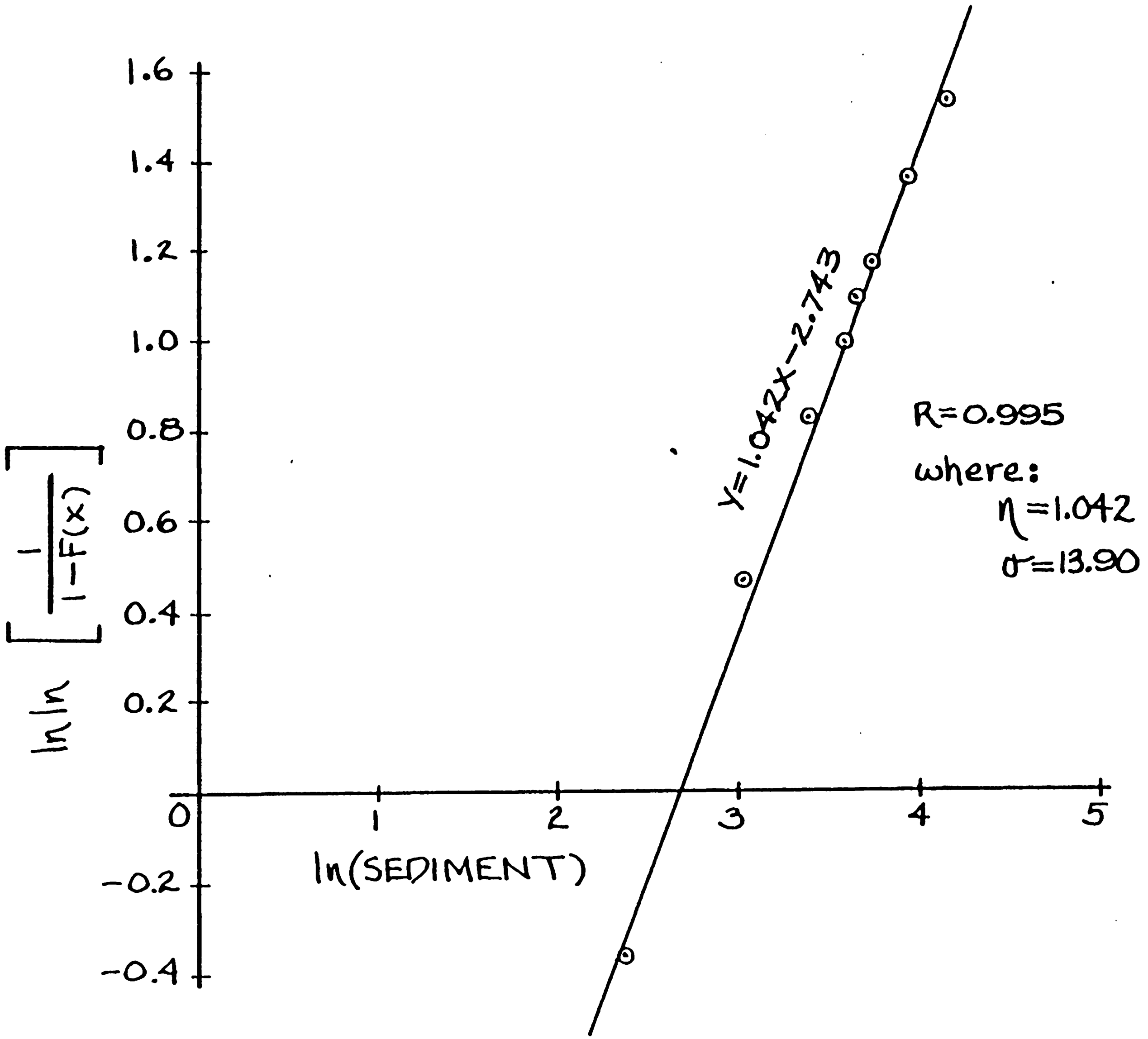


Figure 6. Weibull Transform of Flowstrip 7ab in No-Till Corn.

Table 3. Annual Sediment Yields for Flowstrips in Cunningham Creek Watershed. Strips are shown in Figure 2.

Flow Strip Number	Crop	Metric Tons
1	Corn	24.26
	Hay	7.06
	No-Till Corn	3.66
2a, b	Corn	13.50
	Hay	4.35
	No-Till Corn	2.41
3	Corn	15.50
	Hay	4.87
	No-Till Corn	2.74
4	Corn	12.54
	Hay	3.91
	No-Till Corn	2.41
5	Corn	18.09
	Hay	5.47
	No-Till Corn	2.82
6a, b, c	Corn	41.92
	Hay	17.57
	No-Till	8.74
	Corn into Hay	43.99
	Hay into Corn	25.30
	No-Till into Hay	14.98
	Hay into No-Till	11.40
7a, b, c	Corn	70.14
	Hay	23.54
	No-Till Corn	13.67
	Corn into Hay	50.38
	Hay into Corn	43.81
	No-Till into Hay	19.26
	Hay into No-Till	17.71

hay). There was not a logical explanation of why the FESHM did not respond as expected to this flowstrip-cropping strategy condition. The model values for the corn above hay and the hay above corn were switched so that they would reflect the logical response of these cropping patterns. This was done so the input data to the optimization would be more acceptable. Further study of the FESHM's response to design storms and extreme cropping sequences should be analyzed. This study, though, will not address this issue.

For comparison, the existing cropping pattern of the Cunningham Creek Watershed was simulated with the design storms and the averages obtained from the distributions. These averages were then compared to those obtained from: (1) the USLE as adapted for the Piedmont region of Virginia (USDA-SCS, 1973), and (2) the year of monitoring study data. These comparisons are shown in Figure 7. The average sediment yields for the existing cropping pattern predicted from the FESHM results were much lower than the USLE estimates. The average annual sediment yield for the watershed outlet was reasonably close to the value estimated from the study area data, but both values were significantly lower than the USLE estimate. Without more sediment data from monitoring the study area, conclusions about the adequacy of the sediment averages derived from the design storms can not be evaluated.

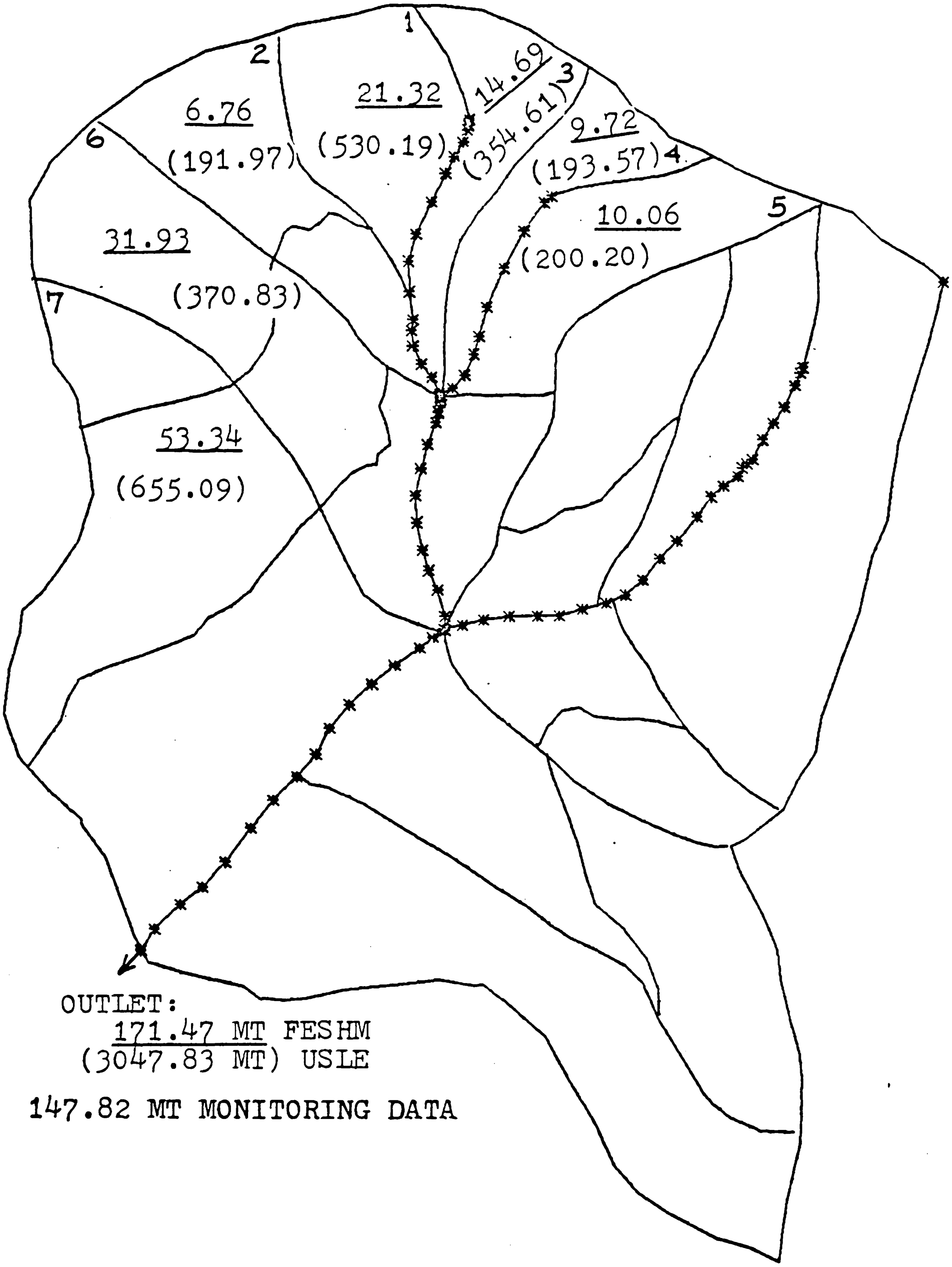


Figure 7. Comparison of the FESHM and the USLE Soil Loss Estimates for the Cropland Flowstrips.

4.3 OPTIMIZATION MODEL

The average annual sediment values were then formulated as the activity coefficients in the objective function, and constraints were formulated from information provided by district extension agents and field surveys. The land constraints set minimum and maximum levels on the amount of area in hay allowed in the watershed. The land constraints insured that the amount of area in corn silage would not be less than the existing land use mix.

The cost constraint was formulated from interviews with the district extension agent (Waddell, 1982) and also the Agricultutal Economics Department at Virginia Polytechnic Institute and State University (Brant and Moore, 1981). Waddell (1982) provided the data necessary to determine the costs per hectare for the crops in the study area while Brant and Moore (1981) furnished the crop revenue levels. From this information, crop budgets for the study area were obtained. Crop budgets for the existing crops and those to be analyzed in the optimization model are given in Appendix B. The overall crop budget for the existing farm land was used to formulate the target value or profit level for the constraint. The preset profit level was considered to be the minimum allowable revenue acceptable to the farmer. The practices selected were constrained to meet or exceed this profit level.

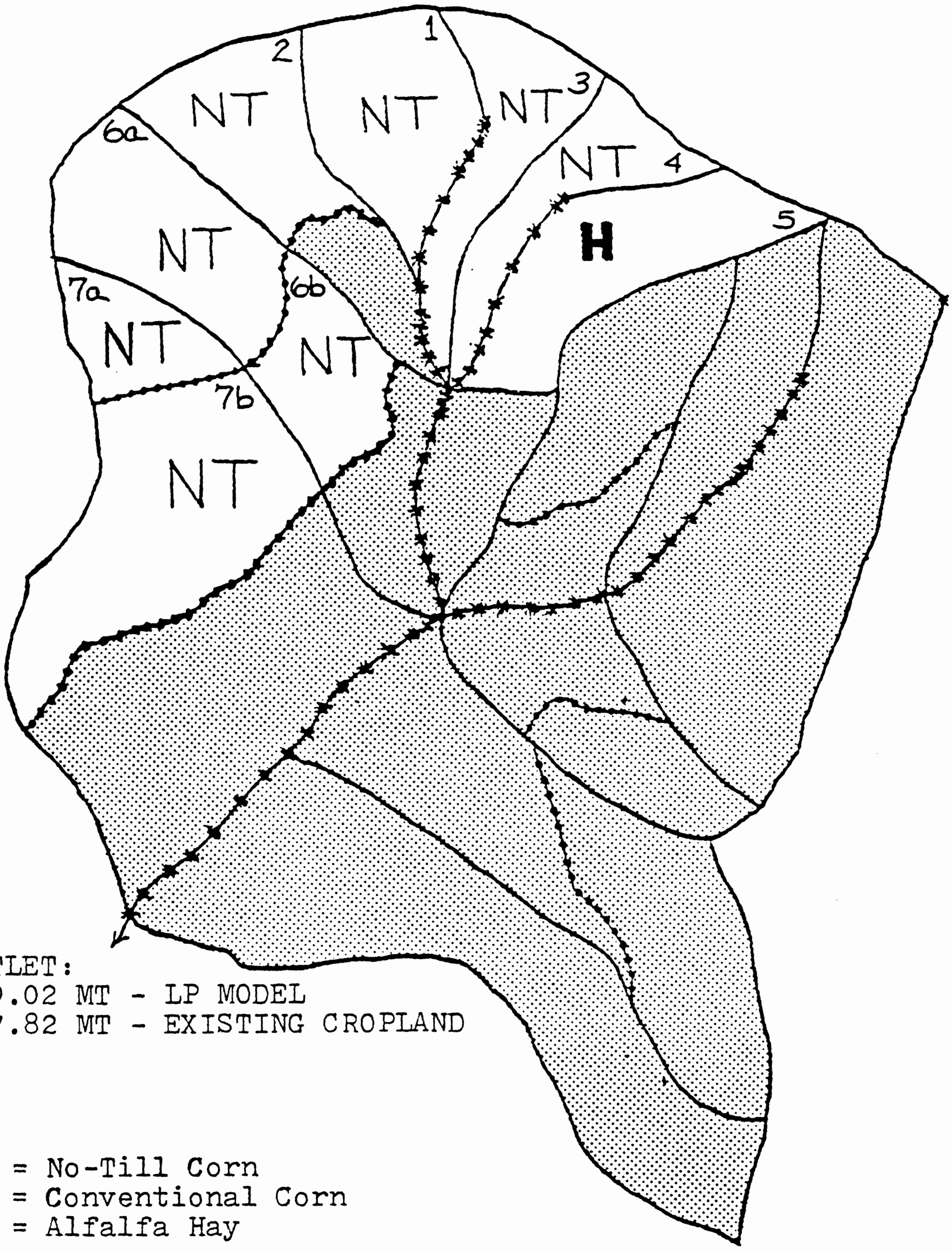
The LP model's selection of the optimal cropping strategies for the flowstrips is shown in Figure 8 with the associated cropland sediment value. As is evident from Figure 8, no-till corn was selected almost exclusively because the revenue from no-till corn for silage was higher than that of the conventional corn for silage (see the crop budgets in Appendix B). Other feasible solutions (but not optimum) that offered alternate spatial arrangements of the cropping strategies are listed in Table 4 along with their associated sediment levels. Most of these feasible solutions lie within five percent of the optimal value of 39.02 metric tons of sediment per year.

The LP model's optimal selection of cropping practices and locations in the cropland area of the watershed reduced the cropland sediment yield by 73.60% without jepordizing income or radically changing the amount of area in corn and alfalfa.

4.4 POSTOPTIMALITY ANALYSIS

A postoptimality analysis was performed on the LP model to test the effects of certain changes. The following model changes were tested:

1. variations in the profit levels,
2. forcing of conventional tillage into the solution,



OUTLET:
39.02 MT - LP MODEL
147.82 MT - EXISTING CROPLAND

NT = No-Till Corn
C = Conventional Corn
H = Alfalfa Hay

Figure 8: Optimal Solution for the Cunningham Creek Watershed.

Table 4. Feasible Solutions to the Original LP Model.

Sediment Total (MT)	Flowstrip Number 1	2	3	4	5	6ab	7ab
39.02	NT	NT	NT	NT	H	NT-NT	NT-NT
39.03	NT	NT	NT	NT	NT	H-NT	NT-NT
39.77	H	NT	NT	NT	NT	NT-NT	NT-NT
39.89	NT	H	NT	H	NT	NT-NT	NT-NT
40.00	NT	NT	H	H	NT	NT-NT	NT-NT
40.41	NT	NT	NT	NT	NT	NT-NT	H-NT
40.52	NT	H	H	NT	NT	NT-NT	NT-NT
41.04	NT	H	NT	NT	H	NT-NT	NT-NT
41.15	NT	NT	H	NT	H	NT-NT	NT-NT
41.79	H	H	NT	NT	NT	NT-NT	NT-NT
41.90	H	NT	H	NT	NT	NT-NT	NT-NT

Possible Combinations of Cropping Practices:

NT = no-till corn
H = hay (alfalfa)
C = conventional corn

NT-NT = no-till in upper element a; and no-till in lower element b
H-NT = hay in element a; no-till in element b
NT-H = no-till in element a; hay in element b
H-H = hay in element a; hay in element b
C-H = conventional corn in element a; hay in element b
H-C = hay in element a; conventional corn in element b
C-C = conventional corn in element a; conventional corn in element b

3. increasing the no-till sediment coefficients, and
4. changing of the price of alfalfa hay.

First the original optimal solution was tested under a range of income levels. The income levels represented:

1. the revenue from the existing cropland (Figure 1),
2. 80 percent of the existing revenue, and
3. 50 percent of the existing revenue.

The 80 and 50 percent levels were chosen to represent the results of a 20 and 50 percent income subsidies by the government or other sources. The optimal solution was not changed by the profit level variation (same mix as Figure 8). This means that the optimal solution was insensitive to decreases in the acceptable profit level. The optimal set of practices provided the lowest sediment yield over a wide range of allowable income levels.

4.4.1 The Conventional Corn Constraint

The original LP formulation was altered by adding an additional constraint requiring at least one cropland element or field to contain corn under conventional tillage. Conventional corn was forced to enter the optimal solution mix for the following reasons:

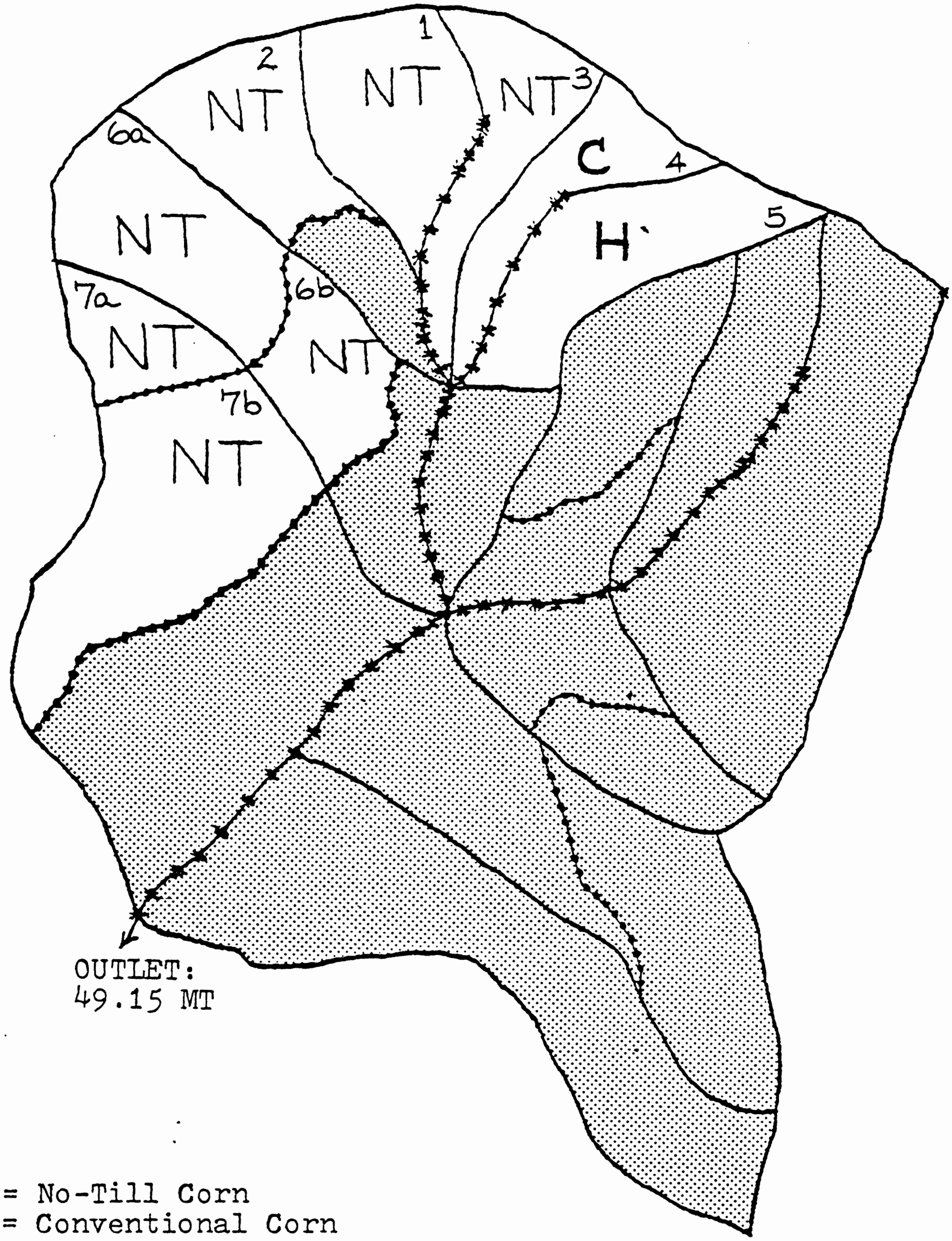
1. to test the outcome of the objective function (the sediment yield), and

2. to determine the best location for the most erosive cropping strategy.

Also, by forcing conventional corn into the solution, a practical consideration of farmer acceptability was addressed. A farmer would probably be reluctant to change his entire corn area from conventional to no-till corn, as the original LP solution suggests. This constraint requires that at least one cropland element be conventional corn.

Consequently the optimal sediment yield from the LP model with the conventional corn increased by 26 percent over the original LP formulation. The resulting optimal mix of land practices is given in Figure 9 along with the corresponding sediment yield. In this solution the conventional corn was placed in flowstrip 4. Flowstrip 4 was a logical choice since its associated sediment coefficient was the lowest of all the flowstrips under conventionally tilled corn. Table 5 gives all the feasible solutions to the LP model with the conventional corn constraint. Most of the feasible solutions were within 10 precent of the optimal (49.15 metric tons).

A test of the sensitvity of this optimal solution to profit levels was performed. Again the optimal solution remained unchanged for the acceptable profit levels of 50 and 80 precent of the existing cropland revenue. Since decreas-



NT = No-Till Corn
C = Conventional Corn
H = Alfalfa Hay

Figure 9: Optimal Solution to the LP Model With the Conventional Corn Constraint.

Table 5. Feasible Solutions to the LP Model With a Constraint of at Least One Area in Conventional Corn.

Sediment Total (MT)	Flowstrip Number 1	2	3	4	5	6ab	7ab
49.15	NT	NT	NT	C	H	NT-NT	NT-NT
49.16	NT	NT	NT	C	NT	H-NT	NT-NT
49.90	H	NT	NT	C	NT	NT-NT	NT-NT
50.20	NT	C	NT	NT	NT	H-NT	NT-NT
50.54	NT	NT	NT	C	NT	NT-NT	H-NT
50.65	NT	H	H	C	NT	NT-NT	NT-NT
51.28	NT	NT	H	C	H	NT-NT	NT-NT
51.79	NT	NT	C	NT	NT	H-NT	NT-NT
52.03	H	NT	H	C	NT	NT-NT	NT-NT
53.17	NT	NT	C	NT	NT	NT-NT	H-NT
54.30	NT	NT	NT	NT	C	H-NT	NT-NT

Possible Combinations of Cropping Practices:

NT = no-till corn
H = hay (alfalfa)
C = conventional corn

NT-NT = no-till in upper element a; and no-till in lower element b
H-NT = hay in element a; no-till in element b
NT-H = no-till in element a; hay in element b
H-H = hay in element a; hay in element b
C-H = conventional corn in element a; hay in element b
H-C = hay in element a; conventional corn in element b
C-C = conventional corn in element a; conventional corn in element b

ing the profit levels (offset by the subsidies) had no effect, the allowable profit level was increased to one cent higher than the revenue from the optimal crop mix ($16,179.11). This was accomplished in order to see how much profit could be gained at what level of sediment greater than the optimal. The new solution changed to 50.54 metric tons of sediment (the fifth solution in Table 5) and resulted in a final profit of $17,021.83 from the cropping mix. In other words, the farmer could increase his profit by 5.2 precent over the previous conventional corn optimum while allowing an increase in the total sediment yield by 2.8 precent.

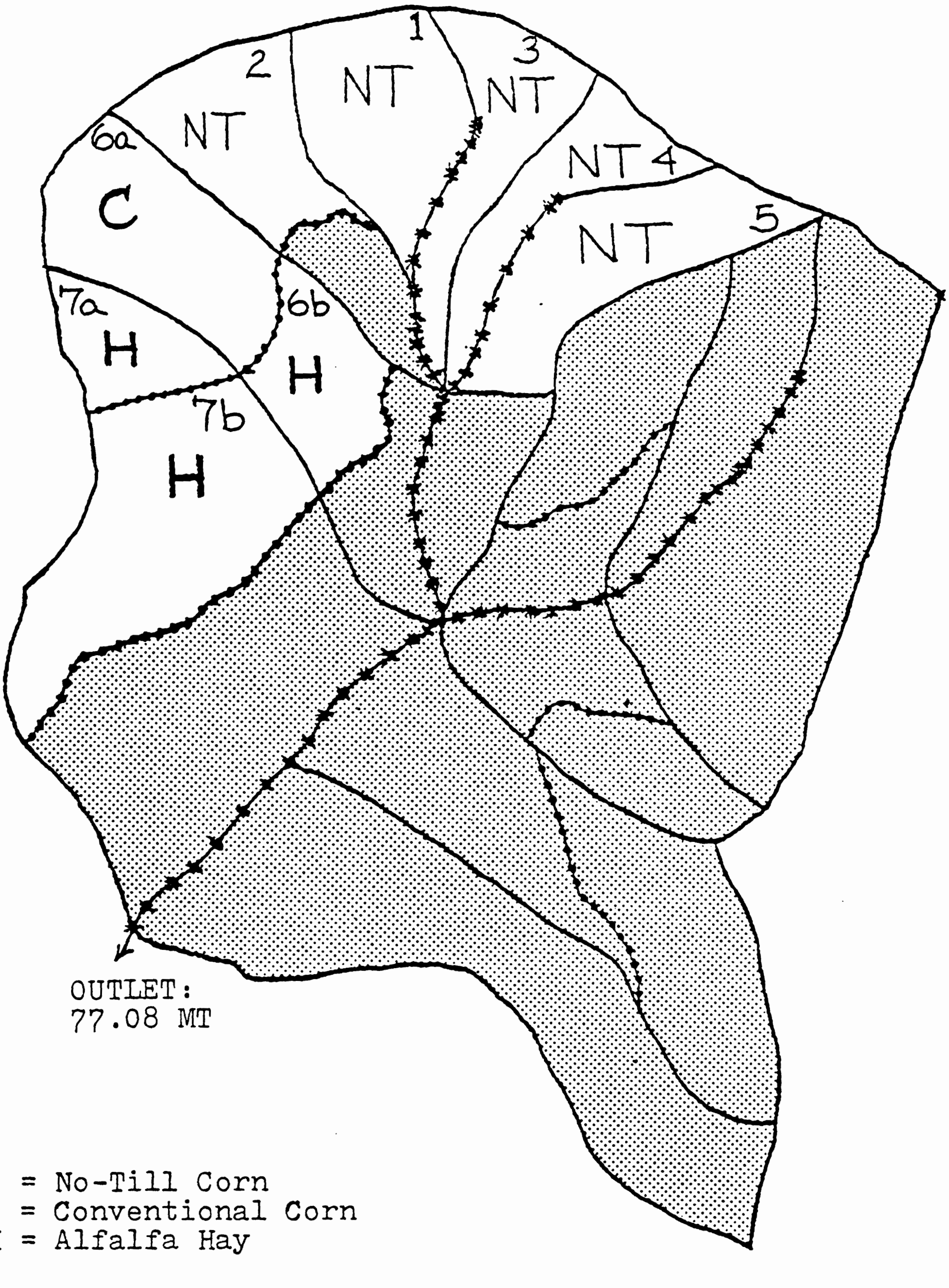
4.4.2 No-Till Sediment Coefficients

Even though literature (USDA-SCS, 1973) seems to indicate that no-till corn offers more cover protection than alfalfa hay, the author felt that the resulting no-till sediment coefficients were a bit optimistic. Consequently the LP model was modified by changing the no-till sediment coefficients to 110 percent of the corresponding alfalfa coefficients.

The resulting optimal cropping mix is shown in Figure 10. As a result of the new sediment coefficients, the total sediment yield increased to 57 percent more than the optimal

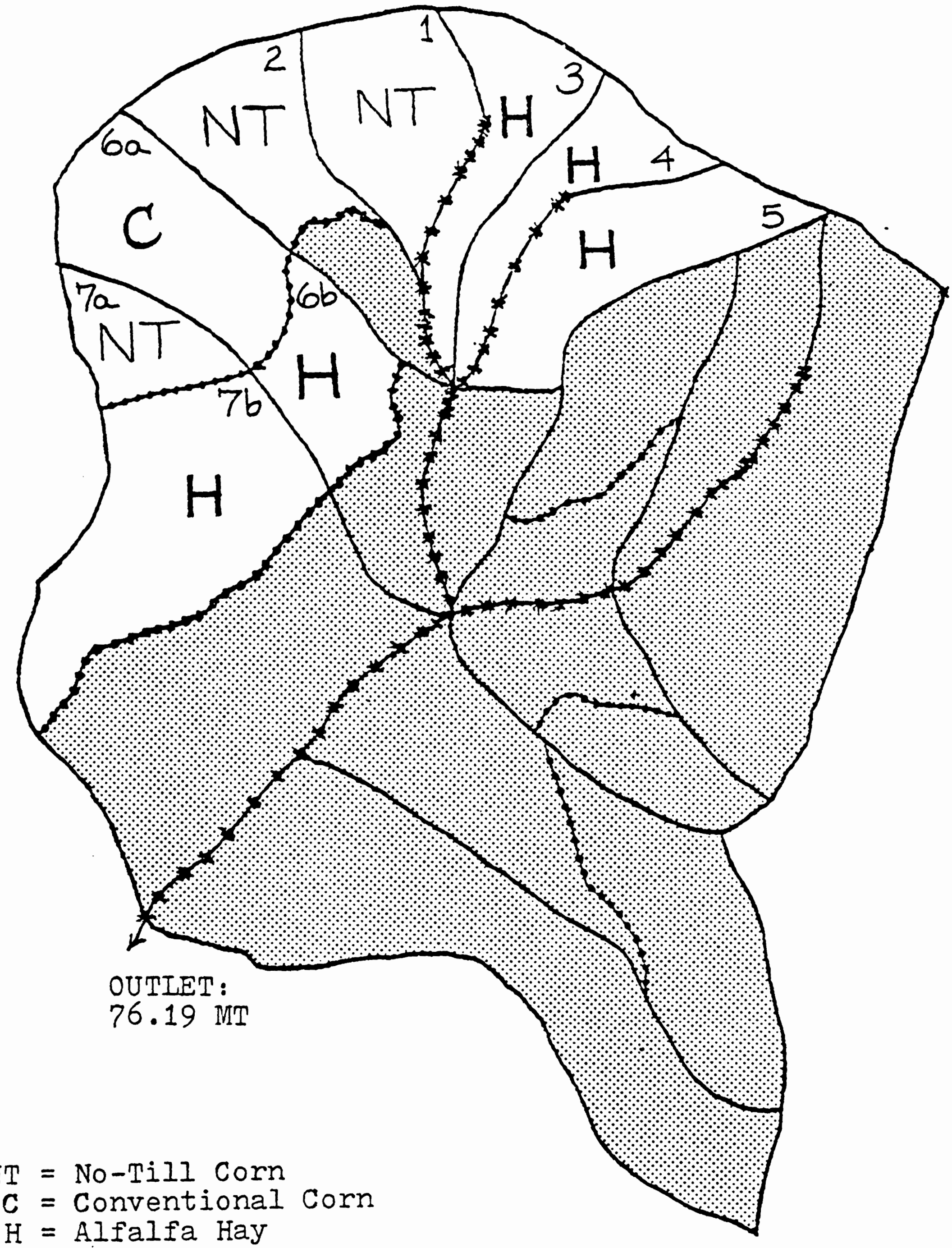
LP solution containing conventional corn. The revised cropping mix remained optimal for profit levels between 75 and 100 precent of the existing or target level profit. When the profit level was decreased by 33 precent, a cropping mix yielding only 1 precent less sediment became optimal.

The final postoptimality variation was performed on the revenue derived from the cropland under alfalfa hay. From interviews with extension agents, it became apparent that the crop prices vary greatly during a growing season. The most noteworthy of the price fluctuations was that of the alfalfa. The price of alfalfa hay was found to range from 70 to 130 dollars per ton. The low value was supplied by the universty agricultural economics department (Moore and Brant, 1981) and the high value by Samuel Waddell, the study area district extension agent (1982). The hay price was changed from the original $70 per ton to $100 per ton. The crop budget was revised, and the profit constraint and revenue level altered to meet this change. The optimal cropping mix resulting from the combination of (1) the altered hay prices, (2) increased no-till sediment levels, and (3) the conventional corn constraint is given in Figure 11. The optimum solution decreased the sediment yield from the revised no-till formulation by one percent and increased the income by 25 percent. If the price of hay is at an optimis-



NT = No-Till Corn
C = Conventional Corn
H = Alfalfa Hay

Figure 10: Optimal Solution to the LP Model With Revised No-Till Sediment Coefficients and the Conventional Corn Constraint.



NT = No-Till Corn
C = Conventional Corn
H = Alfalfa Hay

Figure 11: Optimal Solution to LP Model With Revised Hay Prices and No-Till Sediment Coefficients, and the Conv. Corn Constraint.

tic level, then a slight reduction can be achieved in the sediment level by allowing more hay to enter the solution mix.

Chapter V

DISCUSSION

5.1 SEDIMENT COEFFICIENTS

Table 6 shows the sediment averages used to formulate the LP model objective function. From these averages, several trends could be noticed. Because the objective of the LP model was sediment minimization, the model selected those flowstrip and cropping strategy combinations with the lowest sediment averages. Thus, the solution to the LP always contained as much no-till corn as the hay constraint would allow. Table 7 shows the ranking of the sediment averages from lowest to the highest for the no-till, hay, and corn strategies. The table indicates a trend in the flowstrip sequence (lowest to highest values): 4, 2, 3, 5, 1, 6, and 7. In order to minimize sediment, the LP model usually attempted to use the first flowstrips in the sequence to meet the constraints. Depending on the possible outcome of the sediment totals, though, the first couple of flowstrips (i.e. 4, 2, and 3) may have produced the overall minimum sediment when they were in no-till corn, and the higher ranked flowstrips were used to meet the hay constraint and the postoptimal conventional corn constraint. An additional reason for this pattern in the ranking of the flowstrip sed-

Table 6. Average Annual Sediment Yields for Flowstrips Under the Various Cropping Strategy Combinations

Cropping Strategies	Flowstrip Numbers 1	2	3	4	5	6	7
	metric tons						
Conventional corn	24.26	13.50	15.50	12.54	18.09	41.92	70.14
Hay	7.06	4.35	4.87	3.91	5.47	17.57	23.54
No-Till	3.66	2.91	2.74	2.41	2.82	8.74	13.67
Conv. Corn into Hay	-	-	-	-	-	25.30	43.81
Hay into Conv. Corn	-	-	-	-	-	43.99	50.38
No-Till into Hay	-	-	-	-	-	14.98	19.26
Hay into No-Till	-	-	-	-	-	11.40	17.71

Table 7. Ranking of Flowstrips by Sediment Yields from Lowest to Highest Values for No-Till Corn, Hay and Conventional Corn Strategies.

No-Till	Hay	Conventional Corn
4NT	4H	4C
2NT	2H	2C
3NT	3H	3C
5NT	5H	5C
1NT	1H	1C
6NT	6HNT	6CH
6HNT	6NTH	6C
7NT	6H	7CH
6NTH	7HNT	6HC
7HNT	7NTH	7HC
7NTH	7H	7C
	6CH	
	7CH	
	6HC	
	7HC	

H = hay
HNT = hay into no-till
NTH = no-till into hay
CH = corn into hay
HC = hay into corn
C = corn
NT = no-till

iment yields was the trend in the ranking of their areas. From lowest to highest in area, the flowstrips followed this order: 4, 3, 2, 5, 1, 6 and 7. Area had a significant role in the trend of the sediment values because the yield was in metric tons, not metric tons per hectare. Though not strictly so, for each cropping strategy, the flowstrips containing the most area had the greatest metric tons of sediment. A prioritizing of the sediment yield per area basis for flowstrip and cropping strategy combination will be discussed later along with its implications.

5.2 THE LP MODEL SOLUTIONS

A summary of the optimization results to the LP model and the postoptimality variations of the LP model are given in Table 8 along with data from the existing cropping practices. The sediment yield column indicates the expected results, namely, the existing practices exhibit the most sediment due to the high amount of acreage in conventional corn. The no-till corn model (Model 2) gave the lowest sediment value while the revised LP models (Models 3, 4, and 5) gave greater sediment yields. Model 3 gave more sediment than Model 2, the original LP, because conventional corn was forced to enter the solution. The sediment yield from Model 4 was greater than Model 3 because the no-till sediment

Table 8. The Existing Practices and the Optimum Solutions to the LP Model Formulations.

Model No.		Sediment (MT)	Profit	Ha in hay	Ha in conv. corn
1	Existing Practices	147.82	$ 9,926.31	2.23	21.83
2	Original LP Model	39.02	$16,374.96	4.16	0
3	LP Model revised with conventional corn constraint	49.15	$16,179.11	4.16	3.08
4	LP Model with revised no-till sediment coefficients and conventional corn constraint	77.08	$11,981.49	12.93	5.24
5	LP Model with revisions from 3 and 4 plus modified hay prices	76.19	$14,939.78	16.10	5.24

coefficients were increased. Model 5, though, gave a reduction in sediment over Model 4 by allowing more hay to enter the solution. Additional hay was not allowed into the solution of Model 4 because the profit level would have fallen below the allowable limits. Model 5 was able to add more hay and reduce sediment yield by increasing the amount of revenue derived from the hay crop.

Of significant importance were the fluctuations in revenue among five models in Table 8. The profit realized from the existing practices was much lower than those of the LP models (Models 2 through 5). The reason for the low estimate of profit for the existing cropland was due to the crop mix budgets. About 36 percent of the existing model's cropland was devoted to a barley/soybean double cropping practice. The crop budget (see Appendix B) or estimate of the net return for the barley/soybean was significantly lower than the corn crop budget revenues. Had the barley/soybean area been planted in conventional corn, the difference between the revenues would not have been so great.

The higher revenue from no-till corn production also affected the differences in profit between the models and the apparent sensitivity to any government subsidy. The revenue from no-till corn was reported to be about 25 dollars more than the conventional corn revenue. This had a small effect on the profit levels of the LP models as can be shown by the decrease in profit from Model 2 to Model 3 when conventional corn was allowed to enter the solution (Table 8). Model 4 exhibits an even lower profit since more of the less profitable crops, hay and conventionel corn, were allowed to enter the flowstrip solution matrix.

The most drastic effect the high no-till revenue had was on the results of the sensitivity test of the subsidy levels. The existing profit level was allowed to decrease between 20 and 50 percent to see if the sediment level could be lowered by relaxing the profit constraints. These decreases in profit levels are analagous to offering a 20 and 50 percent subsidy. The lowering of the profit levels generally had no effect on the outcome of optimal cropping mix from each LP model. This result was not unexpected because the previous LP models already met and exceeded the existing profit level. It would have been difficult for any LP model cropping mix to fall below the existing level of profit.

Therefore, allowing the profit level to decrease could not allow any less profitable but less erosive practice to enter the solution. The only LP solution that reduced profit and sediment simultaneously was one of the feasible solutions to Model 4. In this solution a reduction in profit of 33% allowed more of the less profitable hay to enter the solution matrix. Hay did not enter the other LP model solutions (Models 2 and 3) above its minimum level (10 acres) since its sediment level could not compete with the lower no-till sediment level. Model 5 indicated the results from raising the revenue of the hay to a more optimistic value. The increased hay revenue raised the income 25 percent above Model 4 and decreased sediment yield by one percent.

The only way that the effects of profit subsidy could be evaluated from an improved cropping selection point of view would be if the less erosive practices were less profitable. If no-till corn had been less profitable, relaxing the profit levels might have allowed significant reductions in the LP model sediment yield. Consequently, more flowstrips containing the less profitable no-till corn would have been allowed to enter the solution. But the no-till corn was the most profitable practice so no extensive analysis on profit levels and sediment reduction potentials could be performed.

5.3 IMPLICATIONS OF THE SEDIMENT COEFFICIENTS

The sediment coefficients derived from the FESHM design storm analysis can be useful to the watershed planners through the use of the optimization model or by themselves. The sediment coefficients were derived for each flowstrip and cropping strategy combination. The value of each coefficient is unique to its particular flowstrip. If these coefficients were standardized over the watershed, planners could use them for prioritizing fields for cultivation without having to solve the optimization model. The optimization model, however, is still an important tool for selecting the best practices, especially if cost constraints, subsidy levels, and other management decisions are to be considered simultaneously. The coefficients themselves can be invaluable in selecting the fields to put the most erosive crops.

Table 9 shows the sediment yield coefficients for each flowstrip on a unit area basis. The metric tons per hectare values make the comparison and prioritizing of the flowstrip-cropping strategies easier. The table shows that if a farmer wishes to plant conventional corn, flowstrip 2 should be his first choice for locating the practice. The table also indicates which flowstrips were the most erosive. Flowstrips 6ab and 7ab yield the most sediment for each of the cropping strategies; therefore, the farmer or watershed planner would restrict these flowstrips to the least erosive cropping strategies. Flowstrips 6 and 7 were probably most erosive due to their soil make-up and slope characteristics.

Table 9. Sediment Yield in MT/Ha for the Flowstrips and Cropping Strategy Combinations.

Cropping Strategy	Flowstrip Number 1	2	3	4	5	6ab	7ab
Conventional corn	5.10	3.69	4.32	4.08	4.35	5.12	7.03
Hay	1.48	1.19	1.36	1.27	1.32	2.15	2.36
No-Till Corn	0.77	0.66	0.76	0.78	0.68	1.07	1.37
Corn into hay	-	-	-	-	-	3.09	4.39
Hay into corn	-	-	-	-	-	5.37	5.05
No-Till into hay	-	-	-	-	-	1.83	1.93
Hay into No-Till	-	-	-	-	-	1.39	1.77
Area in hectares of flowstrip	4.75	3.66	3.58	3.08	4.16	8.19	9.98
Area of element a	-	-	-	-	-	a=5.24	a=2.33
Area of element b	-	-	-	-	-	b=2.95	b=7.65

With the information from Table 9, a watershed planner could select the best cropping strategy for each flowstrip and could determine, after the selection, the total sediment yield from the cropland. These modified flowstrip coefficients are expected to be an improvement over the USLE estimates since the coefficients were derived from a hydrologic model that considered the sediment transport process. The main advantage of using the coefficients derived from the simulation model is the specificity of these coefficients to the watershed area.

5.3.1 Additional Comments on the USLE

Table 10 shows the ranking of the flowstrips by sediment yield for the USLE and the FESHM. The trend in the flowstrip sediment values between the USLE and the FESHM seems close. The first four flowstrips in the USLE and the FESHM columns (Table 10) are the same numbers but are in a different order. The last three flowstrips are in the same sequence. In other words, the USLE and the FESHM rank the more erosive flowstrips alike. The FESHM flowstrip sediment values, however, are still about ten times less than the corresponding USLE estimates.

Table 10. Ranking of Flowstrips by Sediment Yield from Lowest to Highest Values for the USLE and the FESHM.

USLE	FESHM
7	2
6	5
5	7
2	6
4	4
3	3
1	1

Chapter VI

RECOMENDATIONS AND CONCLUSIONS

6.1 SUMMARY

This study presents a two stage systems procedure for selecting land management practices for improving water quality in agricultural watersheds. The first stage of the systems procedure involves the simulation of the hydrologic response of the watershed to various land use patterns. The output of the first stage is then used as input to the second stage, the optimization model. The optimization model selects the best land management activities and locations in the watershed.

In using the systems procedure, input data were collected from an agricultural watershed. The watershed was then represented in a discrete form consisting of HRUs. The simulated sediment yield from the various cropping strategies was then obtained from each flowstrip by running the hydrologic model. Various cropping strategies and flowstrip combinations were simulated with the event based FESHM using a series of design storms. The design storm simulation results represented a sediment probability distribution from which average annual values were obtained.

The averages were then used in the objective function of a LP optimization model. The LP was designed to select the best cropping strategy for each flowstrip in order to minimize the total sediment yield from the cropland.

6.2 RECOMENDATIONS

6.2.1 Simulation Model Limitations

The major question in the use of the simulation model is the accuracy of the design storm sediment yields. The FESHM did not respond as expected to the simulation of the flowstrips containing two elements of contrasting crop make-up under the 50 and 100 year return period storm events. The sediment yield for a flowstrip containing corn above hay was greater than the sediment yield for the same strip with hay above corn. When considering the effects of filter strips, the result seems contradictory. Without any further analysis it seems that the FESHM lost sensitivity to contrasting practices during the simulation of the extreme storm events (50 and 100 year return periods).

6.2.2 Optimization Model Limitations

Limitations in the optimization modeling procedure often arise from the following two conditions:

1. the subjective nature of the model input data, and

2. the assumption of linearity in the model relationships.

Of major concern to this study, though, is the acquisition of the sediment values or coefficients for the cropping strategy and flowstrip combinations. The development of the sediment coefficients from design storm simulations may be questionable because of the following:

1. the design storms used may not have the correct temporal distribution for the study area, and
2. the seasonal distribution of storms was not considered.

Therefore, using these design storms in a simulation model may not give the true annual sediment yield. The problem of seasonal variations could be approached, however, by using average seasonal values for all watershed parameters or by considering each season separately in a series of simulations. This level of complexity, however, would require considerably more data than were available.

Another limitation to using linear programming is the inherent assumption that the costs and revenues associated with each crop production activity are linear. This is not strictly true. Production costs and reveues tend to fluctuate during the yearly planning horizon. The crop budgets, therefore, are formulated from average production costs and revenues. These average production costs and revenues may be expected to vary greatly at any point in the planning time and from county to county.

The optimization model was also limited by the exclusion of the pasture land from the land management plan. The pasture land was excluded from the systems model because its quantity and location were considered to be permanent and acceptable to the farmer. This is probably not realistic since the farmer may rotate his pasture areas. The placement of the pasture land in the watershed, therefore, would have been a practical consideration. Keeping the amount of acreage devoted to pasture land constant could be considered valid since the farmer is probably meeting the current grazing needs of his livestock.

6.2.3 Practical Implications

This systems approach to modeling the selection of land management alternatives for improved water quality can be a valuable planning tool. The approach was unique in that a dynamic hydrologic simulation model was used to develop the soil loss coefficients, not simple equations. Also the optimiztaion model was concerned with minimizing sediment, not maximizing profit. The farm profit level was held at or above the existing profit while achieving the best mix of land practices to minimize sediment. Because the model minimizes sediment, there were no soil loss tolerance levels to meet. Soil loss tolerance levels are often used as minimum constraint values that the optimization model is forced to target on. Meeting such soil loss tolerance levels is often unrealistic and economically devastating (Hurt and Reinschmidt, 1979). By formulating the LP model to minimize sediment, no tolerance limits were needed. The resulting sediment value was the minimum amount achievable without imposing any additional economic hardship to the farmer.

Additionally, the development of the annual soil loss coefficients from the simulaton model might be transferable to other watersheds. Once refined the coefficients could be used to estimate roughly the soil loss potential for cropland areas in a watershed before an actual simulation or monitoring program is established. Caution, however, must be exercised in the use of the soil loss coefficients. At this point, there is some uncertainty in the accuracy of the sediment values and the method of their determination. Further testing of the FESHM and its response to extreme storm events is needed. Also, the question of the acceptability of using design storms in the probability analysis remains undetermined. The statistics behind the determintion of the average values from a known distribution is acceptable, but the derivation of the distribution from design storms, although documented, remains questionable.

Other methods could be used to develop the yearly soil loss values from the watershed. If several years of storm data were available from the study area, the analysis could involve seasonal variations of the watershed parameters and the development of a set of storms that would represent an average water year. This set of storms would be run in the simulation model using the watershed parameters that correspond to the most probable season of each storm's occurence. The simulated sediment yields for all the storms would be added to give the total sediment yield for the representative, average water year. This method, however, can not be used without many years of data and a lengthy analysis.

6.3 CONCLUSIONS

The systems procedure developed in the study is a planning model aimed at selecting the best cropland management practices for a watershed where little or no monitoring data are available. The procedure's strength lies in its use of a detailed, deterministic, distributed parameter model to simulate the hydrologic response of the study area. Most systems procedures use annual coefficients derived from the literature or delivery ratios and the USLE.

Questions remaining unanswered include the following:

1. How reliable are the existing hydrologic models for predicting changes in water quality due to changes in land use practices, climatic conditions, and other factors?
2. What is the best approach for evaluating the acceptability of the alternate land management practices?

Most investigators have only tested their models with a limited amount of data. The applications of these systems models has not been extensive. With the procurement of more extensive watershed monitoring data, the possibility of accurately evaluating land management alternatives before implementation may become a reality.

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Appendix A

Crop and Management Factor (C) and Cover Condition Factor (a) for Various Landuses

Landuse	$C^{(1)}$ (from USLE)	$a^{(2)}$ (Holtan's Equation)
Conventional corn	0.443	0.2
No-till corn	0.068	0.45
Alfalfa hay	0.136	0.5
Pasture	0.010	0.5
Forest	.005	0.9
Light forest	.03	0.8

(1) C factors from USDA-SCS (1973); except forests (Dissmeyer and Foster, 1981)

(2) a factors from Ross (1978) and Ross et al. (1982)

APPENDIX B

Crop Budgets

Alfalfa Hay

Item	Quantity	Cost Per Unit	Cost Per Acre
Gross Receipts from Production			
Alfalfa	4.5 tons	70.00	315.00
Total Cash Value			315.00
Cash Expenses			
Preharvest			
Prorated Establishment Cost (5 yrs)		-	50.77
Seed	-	-	-
Nitrogen	-	-	-
Phosphate	65 lbs.	0.33	21.45
Potash	160 lbs.	0.20	32.00
Custom Application	1 ac.	4.50	4.50
Herbicide	1 ac.	-	4.43
Insecticide	1 ac.	-	8.97
Custom Application	-	-	-
Lime	1/2 ton	18.50	9.25
Machinery			
Fuel	1 ac.	-	1.00
Repairs, oil, lube	1 ac.	-	2.00
Labor	.25 hrs.	4.00	1.00
Boron	3.0 lbs.	2.23	6.69
Interest on above	18% for 9 mos.		19.89
Preharvest Cash Expenses			161.95
Harvest Expenses			
Fuel	1 ac.	-	17.09
Repairs	1 ac.	-	14.90
Labor	10.5 hrs.	4.00	42.00
Hauling	-	-	-
*Storage	4.5 tons	-	-
Twine	180 bales	0.06	10.80
Harvest Cash Expenses			84.79
Total Cash Expenses			246.74
Ownership Expenses			
Machinery	1 ac.	-	57.54
Storage	-	-	-
Land	-	-	-
TOTAL OWNERSHIP EXPENSES			57.54
TOTAL EXPENSES			304.28
NET RETURNS			10.72

Corn-Silage Conventional Tillage

Item	Quantity	Cost Per Unit	Cost or Value per Acre
Gross Receipts from Production			
Corn Silage	15 tons	28.50	427.50
TOTAL CASH VALUE			427.50
Cash Expenses			
Preharvest			
Seed	0.30 units	67.00	20.10
Nitrogen	115 lbs.	0.30	34.50
Phosphate	60 lbs.	0.33	19.80
Potash	80 lbs.	0.20	16.00
Custom Application	1 ac.	4.50	4.50
Herbicide	1 ac.	-	16.00
Insecticide	1 ac.	-	9.00
Custom Application	1 ac.	4.50	4.50
Lime	1/2 ton	18.50	9.25
Machinery			
Fuel	1 ac.	-	8.13
Repairs, oil, lube	1 ac.	-	7.10
Labor	2 hrs.	4.00	8.00
Interest on above	18% - 9 mos.		21.96
	PREHARVEST CASH EXPENSES		178.84
Harvest Expenses			
Fuel	1 ac.	-	9.05
Repairs	1 ac.	-	9.18
Labor	2 hrs.	4.00	8.00
Hauling	-	-	-
Storage	15 tons	-	-
	HARVEST CASH EXPENSES		26.23
	TOTAL CASH EXPENSES		205.07
Ownership Expenses			
Machinery	1 ac.	-	50.21
Storage	15 tons	-	-
Land	1 ac.	-	-
TOTAL OWNERSHIP EXPENSES			50.21
TOTAL EXPENSES			255.28
NET RETURNS			172.22

Corn-Silage No-Till

Item	Quantity	Cost Per Unit	Cost Per Acre
Gross Recipts from Prod.			
Corn Silage	16.5 tons	28.50	470.25
Total Cash Value			470.25
Cash Expenses			
Preharvest			
Rye seed	1.5 bu.	7.50	11.25
Seed	0.30 units	67.00	20.10
Nitrogen	115 lbs.	0.30	34.50
Phosphate	60 lbs.	0.33	19.80
Potash	80 lbs.	0.20	16.00
Custom Application	1 ac.	4.50	4.50
Herbicide	1 ac.	-	28.66
Insecticide	1 ac.	-	9.00
Custom Application	1 ac.	4.50	4.50
Lime	1/2 ton	18.50	9.25
Machinery			
Fuel	1 ac.	-	4.80
Repairs, oil, lube	1 ac.	-	5.41
Labor	1 hr.	4.00	4.00
Interest on above	18% - 9 mos.		24.05
	Preharvest Cash Expenses		195.82
Harvest Expenses			
Fuel	1 ac.	-	9.05
Repairs	1 ac.	-	9.18
Labor	2 hrs.	4.00	8.00
Hauling	16.5 tons	-	-
Storage	16.5 tons	-	-
	Harvest Cash Expenses		26.23
	Total Cash Expenses		222.05
Ownership Expenses			
Machinery	1 ac.	-	50.21
Storage	15 tons	-	-
Land	1 ac.	-	-
TOTAL OWNERSHIP EXPENSES			50.21
TOTAL EXPENSES			272.26
NET RETURNS			197.99

Soybean/Barley Silage (Double Crop)

Item	Quantity	Cost Per Unit	Cost Per Acre
GROSS RECEIPTS FROM PRODUCTION			
Soybean	20 bu.	8.50	170.00
Barley Silage	6 tons	25.00	150.00
TOTAL CASH VALUE			320.00
Cash Expenses			
Preharvest			
Barley seed	2 bu.	5.60	11.20
Seed soybean	1 bu.	12.00	12.00
Nitrogen	70 lbs.	0.30	21.00
Phosphate	110 lbs.	0.33	36.30
Potash	110 lbs.	0.20	22.00
Custom Application	Split Nit. App.	4.50	9.00
Herbicide	1 ac.	4.50	15.00
Insecticide	-	-	-
Custom Application	1 ac.	4.50	4.50
Lime	1 ton	18.50	18.50
Machinery			
Fuel	1 ac.	-	5.52
Repairs,oil,lube	1 ac.	-	5.77
Labor	2 hrs.	4.00	8.00
Inoculant	1 ac.	-	.23
Interest on above	18% - 9 mos.	-	23.66
	PREHARVEST CASH EXPENSES		193.69
Harvest Expenses			
Fuel	1 ac.	-	10.40
Repairs	1 ac.	-	8.83
Labor	2.5 hrs.	4.00	10.00
Hauling	20 bu.	0.15	3.00
Storage	6 tons	-	3.00
Store beans	20 bu.	-	-
	HARVEST CASH EXPENSES		32.23
	TOTAL CASH EXPENSES		224.92
Ownership Expenses			
Machinery	1 ac.	-	77.56
Storage	ton 1 bu.	-	-
Land	1 ac.	-	-
TOTAL OWNERSHIP EXPENSES			77.56
TOTAL EXPENSES			302.48
NET RETURNS			17.52

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