WRC Report No.204

Economic Differences Between Cumulative and Episodic Reduction of Sediment from Cropland

by

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Project Report No. S-099-ILL

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September 1986

ABSTRACT

This study compares measures for reducing cumulative sediment loads from cropland with measures for reducing sediment loads from extreme storms. The issue is whether the optimal means of controlling cumulative loads are very different from the optimal controls for storm event loads. Differences are described in terms of costs and management practices.

The analysis entailed developing a storm-event simulation model analogous to the SEDEC sedimentation economics model. The analogue model was used to identify the respective optimal cropland management strategies for various extreme storm conditions. These strategies were then analyzed using the annual average SEDEC, and the optimal strategies from SEDEC were analyzed for their storm-event properties. The comparisons permit conclusions concerning the relative effectiveness of management strategies for achieving cumulative sediment goals versus storm-event load goals. Data for a 223 study site in the Highland-Silver Lake Watershed in Southwestern Illinois were analyzed using this approach.

The study produced four main conclusions. First, control costs for episodic sediment loads were consistently higher than the costs for proportionate reductions in annual average loads. Furthermore, strategies for reducing cumulative loads generally achieve less than proportionate reductions in cumulative loads. Second, the highest control costs were generally for the most extreme storms. Third, contour cultivation is a key element of efficient management strategies for row crops. Finally, where a permanent grass crop is grown adjacent to the stream, there is generally little more to be gained by changing upslope management practices. This suggests that grass strips along streams would greatly reduce the need to modify farming practices elsewhere in order to limit sedimentation.

Keywords: agriculture, pollution, sediment, optimization

ACKNOWLEDGEMENTS

This report is taken from the master's thesis by Pei-Ing Wu submitted to the Department of Agricultural Economics, University of Illinois. Professors Braden and Johnson jointly supervised the thesis, and contributed significantly to this report.

The research reflected here was made possible in large measure by a grant from the State of Illinois through the Illinois Water Resources Center between 1983 and 1985. Other aspects of the Water Resource Center Project will be reflected in a separate, subsequent report. Additional support was provided through project no. 330 of the Illinois Agricultural Experiment Station, College of Agriculture, University of Illinois, and by the Illinois Department of Energy and Natural Resources, through project no. WR7. While we are grateful for the support of these agencies, they are in no way responsible for the contents of this report.

Following is a list of individuals who have aided this study by providing data, conceptual guidance, and technical support: Glenn Stout, of the Illinois Water Resources Center; John Vogel, Michelle Pumphry, and Ming Lee, Illinois State Water Survey; Robert Dickerson and Wayne Kinney, U.S. Soil Conservation Service; Wesley Seitz, James Taylor, and David White, Department of Agricultural Economics; Michael Hirschi and Kent Mitchell, Department of Agricultural Engineering; David Miltz, Jeong Lim, and Changwoo Pyo, Institute for Environmental Studies. Their help is appreciated, but they are not accountable for this report.

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CHAPTER I

INTRODUCTION

1.1 General Background

Although sedimentation is a natural process, the rates can be accelerated and decelerated by man's activities on land and in water. Agricultural activity has been considered one of the leading contributors to the nation's water quality problems. Sediment is the major source of pollution from agriculture (Miller and Everett, 1975). With sediment comes various agricultural chemicals. A study by Duda and Johnson (1985) revealed nutrient levels up to 100 times greater in agricultural watersheds than in forested watersheds.

As site-specific sources of pollution have been reduced by municipalities and industries, nonpoint sources have accounted for an increasing share of remaining water pollution. The problems created by sediment include increases in the turbidity level of waterways and reservoirs, reductions of channel flow and water storage capacities, and restriction of drainage systems (Seitz et al., 1975). A recent estimate places U.S. economic losses due to sediment and associated contaminants at between $3.2 billion and $13 billion, with the "best guess" estimate being $6.1 billion per year (Clark et al., 1985).

Approximately one-third of the total sediment and a comparable share of the nutrients delivered to lakes and streams in the U.S. is from cropland (Clark et al., 1985). Cropland erosion is concentrated geographically. On a per acre basis, the erosion is especially serious in the Southern Plains, Mountain States, Corn Belt, and Appalachia. Soil erosions in these regions are 13.1, 8.8, 8.4, and 8.0 tons per acre, respectively (Crosson, 1986). Wind erosion accounts for 10.6 of the 13.1 tons per acre soil lost on average per year in the Southern Plains, and 6.7 of the 8.8 tons per acre soil lost on average each year in the Mountain States. However, rainfall accounts for most soil erosion in the Corn Belt (Crosson, 1986). In Illinois, "excessive" soil erosion occurs on 40 percent or 9.6 million acres, of cropland. Erosion is termed excessive when it more than offsets soil formation processes. Overall, 112.3 million tons/year of soil are eroded from Illinois cropland, which is equivalent to an average of 11.7 tons per acre (Walker and Peterson, 1982).

The losses of soil, nutrients, and chemicals removed by runoff represent a loss of resources, the costs of which are borne by individual farmers. Maintenance of the soil resource at a high level of productivity for this and future generations, and minimization of off-site damage from soil, fertilizers, and pesticides lost from fields, are the two economic problems related to agricultural erosion and runoff (Moldenhauer and Onstad, 1975). Diminished productivity is called an on-site effect of soil erosion. McConnell (1983) and Ervin and Mill (1985) believe that on-site impacts affect land prices to some extent and are internalized by the farm firm. On the other hand, farmers do not bear most costs due to off-site impacts of soil and other materials entering water courses from cropland. The fact that these impacts are external to the firm's own interests creates a clear justification for public policy concerning agricultural pollution.

Of all sources of nonpoint pollution, sediment comprises the greatest volume in terms of weight of materials transported. Other pollutants can be transported in association with sediment (adsorbed pollutants) or in solution (soluble pollutants) (Chesters and Schierow, 1985). Methods contributing to a reduction in sediment pollution may also reduce nutrients and other nonpoint pollution parameters. Schuman and associates (1973) measured four agricultural watersheds near Treynor, Iowa and found that 92 percent of the total nitrogen (N), potassium (K) and phosphorus (P) lost in the runoff from contour-planted corn watershed was associated with sediment. Alberts et al. (1978) also found that most of the nitrogen loss was associated with soil loss which indicated that conservation practices for controlling erosion were also effective in reducing nutrient losses.

1.2 Statement of Problem

A key concern of this thesis is the relationship between cumulative sediment loads and episodic loads from agriculture. Cumulative loads are related to annual average erosion rates, a common measure of sediment discharges. They affect stream flow characteristics and reservoir capacity. Episodic loads are storm-related, and may create ambient conditions that are limiting for the aquatic ecosystem. This thesis provides insight into the following question: Can programs for managing one aspect of the sediment problem be effective and efficient in managing the other?

It is generally argued that annual mass export (loading) is largely determined by a few major runoff events (Lake and Morrison, 1977). These major events result in sudden bursts of high turbidity levels in streams. The timing of these events will determine whether they will have adverse effects on fish populations and aquatic ecosystems. Annual erosion losses from a field may be greatly influenced by whether most of the severe rains occur during the period when cover is established or whether they occur during the seeding or winter period (Wischmeier and Smith, 1978).

In the western Corn Belt, severe thunderstorms are likely in the spring and early summer when there is little or no surface cover (Alberts et al., 1978). In much of the Corn Belt, more than one-third of the year's erosive rain usually occurs during the first two months after seedbed preparation for corn and soybeans (Wischmeier 1962). So, conservation systems which provide the greatest possible protection from erosive rainfall during the seedbed period are very important in this area. In Illinois, it is predictable that the highest turbidity levels occur during May and June, usually the season of greatest rainfall (Stall, 1972).

The generation of agricultural pollutants is intermittent, occurring largely during storm events which occur less frequently and over shorter periods of time than point discharges (Chesters and Schierow, 1985). The amount of sediment reaching a water body and streamflow conditions together determine ambient water quality conditions. During periods of high sediment loading and low streamflow, a high concentration of sediment (the quantity of sediment contained in a certain volume of water) might lead one to expect poor water quality (O'Connor, 1967). This effect cannot be examined using information about cumulative sediment loads (the total amount of sediment produced from a certain area of land during a fixed period of time).

In the past, soil conservation programs have been focused on the effects of soil erosion on productivity. And it has been assumed that controls sufficient to maintain the soil's productivity would control soil movement enough to hold off-site impacts in right direction. Therefore, examining the economic impacts of alternative policies for erosion control has been the focus of much research. In part because of a lack of direct attention to water quality problems, agricultural nonpoint source pollution control programs have been marked by inefficiency (U.S. General Accounting Office, 1983). In order to redress this institutional weakness, procedures are needed to identify the measures that can control agricultural sediment pollution in an efficient manner. The relative efficiency and attractiveness of each regulatory policy depends upon the objective being addressed. From society's viewpoint, one of the objectives is minimizing the costs of achieving a given level of overall damages reduction (Griffin and Bromley, 1982).

Although the estimation of erosion and sediment models and economic examination of erosion and sediment controls are by no means new, this study differs from previous research by comparing efficient controls for total sediment loading to controls for episodic sediment concentrations. In doing so, the control costs for achieving the above objectives need to be generated. SEDEC, the SEDiment EConomics simulation model, designed to identify economically efficient cropland management strategies for reducing sediment deposition in streams (Braden et al., 1985), is used in this study. The model can be used to identify minimum payments needed to make a landowner indifferent between unconstrained farming and land management practices that attain a specified reduction in sediment loads. When applied to a watershed, a least-cost set of practices for limiting sediment deposition from all farm units can be delineated.

SEDEC is composed of the SOILEC model, a Sediment Delivery Model, and an optimizing procedure. SOILEC, the SOIL conservation EConomics model, addresses the economic impacts of long-term losses in productivity for the farm where the erosion takes place due to sheet and rill erosion (Dumsday and Seitz, 1982; Eleveld et al.; 1983, and Johnson, 1985). The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) serves as the basic erosion model in SOILEC. The sediment delivery model, using data from SOILEC outputs, computes total sediment deposition and net sediment loads in a watershed subdivision. The optimizing procedures select cropland management practices and an associated spatial allocation of transfer payments to meet a specified rate of sediment deposition at least cost (Braden et al., 1985).

1.3 Objectives of Study

An efficient sediment control management strategy must be based on an understanding of the role of physical phenomena in watersheds. Usually, a sediment control management strategy is deemed to be economically efficient based on annual average erosion levels. Are management practices that control annual average sediment loads efficiently also effective for controlling limiting ambient conditions? And, how is the efficient set of management practices affected by different criteria for the ambient standard? The broad objective of this study is to answer these questions. This is done by addressing two specific objectives:

1. To compare the management systems that achieve annual average pollutant load goals at least cost to those that achieve comparable storm event at least cost;

2. To analyze the effects on the efficient episodic sediment control strategy of different definitions of an episodic standard; specifically, the definition of the frequency with which a given storm intensity can be expected.

1.4 Methods and Procedures

The basic procedural requirement of the analysis involves developing a storm event model analogous to SEDEC. Then, the annual average and storm event models are applied in a case study of a 223.4 acre site in the Highland Silver Lake Watershed in Madison County, Illinois. The storm event model is accomplished by disaggregating the management (C) and rainfall (R) factors in the USLE for particular phases of the crop-growth cycle (Phase I "PI": April-June, Phase II "PII": July-September, Phase III "PIII": October-November, and Phase IV "PIV": December-March). The maximum rainfall erosivity factor (R) associated with each phase and a specific frequency of occurrence (return period) are used in a modified USLE to represent a "worst case" pollution episode. By taking the highest product of a phase C factor and the maximum R factor, the phase in which most of the extreme erosion event occurs is identified and it is possible to determine how much sediment is created by the worst episode. Annual average loads for the same management practices (C factor) can be determined using the annual average version of SEDEC.

The assumption of a fifty-year planning horizon is used to capture the effects of soil erosion on productivity. Net returns associated with each maximum episodic event and annual average case for each possible set of management practices are based on this assumption.

The comparative methodology involves setting the same percentage sediment reduction for the annual average loads and storm event loads and applying the optimal management practices from one model in the other model to see its effects. The comparison indicates the inefficiency arising from using an annual average standard to address episodic water quality problems and vice-versa.

The results are subject to sensitivity analysis on the level of sediment reduction in the annual average model and storm event model. In addition, several maximum storm frequencies are analyzed.

1.5 Outline of Thesis

Chapter 2 contains the theoretical framework of this study and a literature review. Along with a brief description of the study area, Chapter 3 describes the SEDEC model and the development of a companion storm event model. Various data required in the annual average SOILEC and SEDEC models and data collected for the storm event model are discussed in Chapter 4. In the fifth Chapter, the results from the annual average and storm event models are summarized and analyzed and a discussion of policy implications is presented. The final Chapter draws conclusions.

CHAPTER II

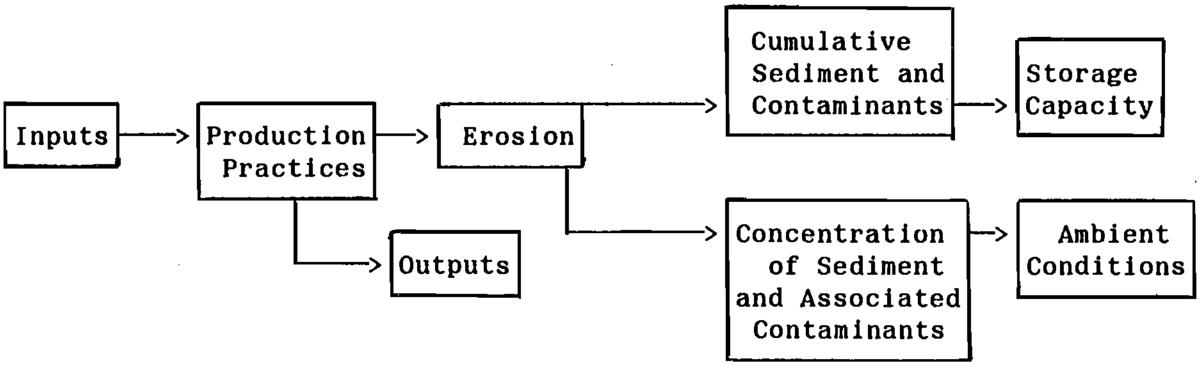
THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Choosing the Target

Choosing the target is described by Nichols (1984, p. xvi) as "selecting the specific point(s) - stage(s) at which an instrument will be imposed." In economic analyses of environmental externalities, researchers tend to stress efficiency on the cost side, and pay less attention to the importance of defining the target. However in the real world, "most environmental externalities are the products of complex, multistage processes that offer many potential points of intervention" (Nichols, 1984, p. 69).

In the case of soil erosion, Figure 2.1 represents the pollution process as a sequence of stages from the inputs used in the production practices, through various stages, to the final effects. The diagram begins with the inputs -- labor, machinery, fertilizer, seed, chemical, and so on -- used in field production practices. The impacts from chemical or biological interactions are more difficult to observe than are sediment impacts.

Figure 2.1 Multiple Stages Provide Multiple Targets for Intervention



The second stage is the production practices. Cultivation or intensive grazing makes soil more vulnerable to dislocation by rain or wind, and chemical inputs introduce additional pollution hazards. The ways in which land is cultivated and chemicals are used can reduce soil and chemical migration. "Best management practices" are techniques that are considered to be the most reasonable and effective for controlling agricultural pollution and that are suitable to local conditions. The techniques include more diverse crop rotation, less intensive cropping system, conservation tillage, and structural controls, such as terracing.

The third stage is the split between outputs and soil erosion. The former are the goods produced, whereas the latter is the amount of soil leaving the field during the production practices. Due to the depletion of nutrients and reduction of soil's ability to supply moisture, erosion of topsoil often poses a threat to the long term productivity of farmland. Productivity is generally defined as the natural capacity of the soil to produce agricultural crops, and is usually expressed in terms of crop yield. Wischmeier and Smith (1978, p. 2) have defined a "tolerance level" of erosion as "the maximum level of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely." The so called T-value varies according to soil type. It usually ranges from 1 to 5 tons of soil loss per acre per year in Illinois (Walker and Peterson, 1983). The reduction of soil productivity due to soil loss could be offset by substituting other inputs, such as fertilizers (Burt, 1981). If so, farmers have less incentive to reduce erosion in order to maintain yields. For a proper social benefit-cost comparison, the on-site damages due to soil loss need to be added to off-site damages (McConnell, 1983; Ervin and Mill, 1985).

The fourth stage, the focus of this study, represents the off-site effects of eroded soils and chemical contaminants. The discussion here focuses on the effects of eroded soils. These effects can be separated into cumulative effects and concentration effects. The main cumulative effects are reducing reservoir capacity and clogging stream channels. These impacts are stressed in most literature on agricultural nonpoint source pollution problems. Concentration effects refer to impacts on the in-stream ambient conditions which create stress for the aquatic ecosystem. For example, turbidity may interfere with fish feeding and spawning, or biochemical oxygen demand due to organic fractions of soil may impair dissolved oxygen in the water column. These impacts, however, have received little attention in the economic literature.

Public policies concerned with sediment from agriculture are primarily oriented toward on-site impacts. Some states encourage or require compliance with T-values. Illinois, for instance, has developed a step-by-step plan to achieve the standards that erosion cannot exceed the T-value on all Illinois farmland by January 1 of the year 2,000 (Walker and Peterson, 1983). Others encourage the use of best management practices (BMPs), which are frequently developed as efficient measures for achieving tolerance rates of soil loss. Both approaches are oriented toward annual average erosion rates -- an indicator of accumulation -- and do not address the timing of pollution events, which is a key determinant of concentration impacts. They both submerge off-site impacts, and the critical issue of location -- that is, the fact that small portions of most watersheds are responsible for the bulk of off-site impacts. Thus, efficiency can be enhanced and disruption can be minimized by selectively choosing the land areas on which to control agricultural nonpoint source pollution.

2.2 Review of Literature

Under the directives of Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972 (U.S. Congress, 1972), state environmental quality agencies are directed to investigate and control sources of water quality degradation. Until then, most efforts on water pollution had been directed toward "point sources." Point source pollutants enter the pollution transport routes at discrete, identifiable locations and usually can be measured directly or quantified, and their impacts can be evaluated directly (Novotny and Chesters, 1981). Major point sources include industrial and sewage treatment plants.

The strong linkage between the agricultural production sector and the quality of the environment has turned the attentions of policy makers toward nonpoint source pollution (Wade and Heady, 1978). Section 208 of the Act created a planning process that put a focus, for the first time, on nonpoint sources pollution -- pollutants entering the environment from diffuse sources, such as general runoff water. Sediment, the result of soil erosion, was declared a major source of water pollution. The physical and biological processes that connect land activities to water quality are complex and poorly understood. Soil loss has been a major proxy indicator for nonpoint pollution problems.

In general, previous economic studies of agricultural nonpoint source pollution controls may be classified into two categories: 1) those using soil loss as a indicator for off-site impacts, 2) those that attempt to use some indicator of sediment delivery for a measure of off-site impact.

Most economic studies mainly address costs and benefits of agricultural nonpoint source pollution control by using erosion rates and/or other sediment contaminants. The use of tolerance limits for erosion are helpful when one is analyzing policies aimed at maintaining long-term soil productivity. However, they are not related directly to water quality which is degraded by sediment resulting from soil erosion. Examples of using soil loss as indicator of off-site impacts are studies by Kasal (1976), Heady and Meister (1977), Taylor and Frohberg (1977), Osteen and Seitz (1978), Taylor et al. (1978), Foster and Becker (1979), Seitz et al. (1979), Boggess et al. (1980), and Kramer et al. (1984). Studies reviewed in next section have made explicit attempts to link erosion to sedimentation.

2.2.1 Sediment Delivery

The study by Onishi et al. (1974) assessed the impact of improvements in certain water quality characteristics on economically optimal crop systems (see also Onishi, 1973; Narayanan, 1972). They analyzed the effects of crop practices on water quality by assuming that farmers would alter their cropping practices in the most economical way in order to conform to various water quality constraints. One of the constraints applied to sediment entering the reservoir, and another applied to nitrates. The USLE was the basic erosion equation used in this study to calculate the soil erosion level. Sediment delivery ratios were calculated for four elevation classes of land in the study area. The sedimentation rate was the gross erosion values from the USLE multiplied by the sediment delivery ratio for the elevation division in which the particular area is located. Because knowledge about the nitrate migration from the site of crop production to the reservoir was inadequate, the nitrate constraint was applied to the leachate leaving the root zone. In contrast, the sediment constraint applied to deposition in the reservoir. By varying the constraints dealing with water quality parameters, the researchers obtained a set of optimal solutions. Results indicated that requiring successively lower amounts of sediment to enter the reservoir and lowering the nitrate limit on the leachate caused farm income to decrease at an increasing rate.

Alternative policies for reducing the level of erosion and sedimentation at both the watershed and farm levels were evaluated with a linear programming analysis of farms in the Big Blue Watershed in Pike County, Illinois (Seitz et al., 1975). The impacts of conservation practices on crop production, costs, and yields were considered as were the impacts on the off-site drainage system and reservoir.

Gross soil loss coefficients were estimated with the USLE. The individual farm delivery ratios were estimated from published sources which were based on the delivery ratio and drainage size relationships. These individual farm delivery ratios indicate the proportion of eroded soil that can be expected to leave the farm. The proportion of sediment leaving a farm and delivered to the reservoir were expected to vary inversely with the distance between the farm and the reservoir. Hence, distance adjusted farm sediment delivery ratios were used to convert the gross soil losses estimated by the USLE to the sediment load ultimately delivered to the reservoir from a particular farm.

The analysis of Seitz et al. indicated that the off-site damages were major factors in determining the optimal set of cropping and conservation practices in the watershed, if net crop returns minus off-site damages were considered. It was found to be optimal to reduce the level of soil losses from approximately 20 tons per acre per year to approximate 6 tons per acre per year. If the Soil Conservation Service tolerance limits were adopted by farmers, the off-site damages would be reduced to or below optimal levels. If off-site damages resulting from sedimentation were used to constrain soil losses in the watershed, the erosion rate would exceed soil conservation standards.

Miller and Gill (1976) used a linear programming model: 1) to compare the relative economic impacts on large and small farms of applying a statewide soil loss standard to achieve specified levels of pollution controls as measured in tons of soil loss per acre per year; 2) to compare the relative impact between two different topographic areas in Indiana with respect to the statewide standard; 3) to compare the relative economic impact between large and small farms and between different topographic areas resulting from application of taxes or subsidies on soil loss. The objective function was to maximize net revenue to the farm firm under constraints on total acres of soil groups and soil losses permitted for each farm size. Soil erosion was likewise derived from the USLE. A fixed percentage of all eroded soil was assumed to be deposited in streams or reservoirs. The results showed that the imposition of standard state soil loss rules has an unequal impact on the income of different sized farm located in different topographic regions. Furthermore, tax and subsidy programs were revealed to achieve reductions in soil losses with a more equal loss in net revenue among different farm sizes and topographic areas than would occur under the application of a statewide standard for soil loss.

Wade and Heady (1978) developed a national agricultural model to evaluate hypothetical policies of sediment control viewing the problem as primarily a national problem of agricultural land use. Some components of the model represent elements of the National Water Assessment (NWA) model. They used an interacting three-tiered set of producing, marketing, and river region to provide a foundation for production, consumption, and environmental activities of the model. The regions are approximate subbasins of the 18 major river basins of the continental United States. The production areas (PA's) are the county aggregations of river sub-basins. Cropland in active use, cropland not used in crop production, all noncropland were three types of erosion sources included in the model. The soil loss for each cropping activity was also computed by using the USLE. Sediment delivery from the land to the stream was assumed to be a fixed proportion of the total gross soil loss from all sources within each PA's. The sediment delivered from each PA joined the sediment delivered from other PA's in a flow path that simulated the river systems of the United States.

Linear programming was used in their model to consider five sediment control alternatives: unrestricted (serving as a base case, no restraints placed on sediment loads in the stream system), minimum sediment (minimizing the total national sediment loads), T limit (soil loss from each cropping activity in each PA to the limiting level for each soil), PA limit (restricting cropland sediment loads to 20% less than in the base case for each PA), and river basin limit (restrict river basin sediment to 20% less than in the base case). The conclusions of the study showed that the minimum sediment alternative increased annual costs for agricultural production and transporting commodities by $ 13.4 billion or 42.2% while it decreased the total sediment by 23.2%. The costs greatly exceeded expected benefits if compared with the $1 billion estimated annual damages from sediment. However, the river basin limit alternative policy increased total costs by $26 million or 0.1% and decreased the total sediment load by 5.1%. Potential gains appeared to outweigh total costs for that policy.

Walker and Timmons (1980) evaluated twelve policy options for reducing soil erosion and sediment discharge from agricultural land in terms of the effects on net farm income, cropping patterns, average annual per acre soil losses, agricultural contribution to stream sediment loads, choices of technology, and land uses. The twelve policies can be grouped into regulatory policies; economic incentives and disincentives -- taxes and subsidies; and policy combinations. Among the combination policies, for instance, were a contour plowing subsidy combined with a ban on fall plowing, a subsidy for minimum tillage combined with a ban on fall plowing, and a soil loss tax with a ban on fall plowing.

The amount of soil loss was again estimated from the USLE. Three sediment delivery ratio values, 0.20, 0.25, and 0.30, were used for sensitivity analysis. Their results indicated that some erosion control policies appeared to be effective in reducing soil loss by 50 percent -- to an average of about 10 tons per acre compared to the base run with 20.3 tons per acre per year. Other control policies appeared to be effective in reducing soil loss to 90 percent, an average of about 2 tons per acre. Overall, the most cost-effective policy that succeeded in cutting average soil loss by 90 percent was the dual ban on fall plowing and straight-row cultivation on slopes. They concluded that the policies that would cut average soil losses by 90 percent were of interest because those policies approximate the degree of erosion control specified by the Soil Conservation Service, 5 tons per acre or less.

2.2.2 Physical and Economic Linkages for a Storm Event Model

From the literature reviewed in last section, it is apparent that past efforts by economists to analyze agricultural nonpoint source pollution problems focus either on erosion rates or using simple fixed delivery ratios. The erosion rates are usually estimated from the USLE. Delivery ratios may be simple constants or based on length, elevation, or other invariant attributes of watersheds. In reality, erosion and sedimentation vary across time and space and are not linked in simple ways. If land use practices are to be targeted so as to control water quality impacts in an efficient manner, the hydrologic relationships must be represented in greater detail. Furthermore, the annual average USLE is not appropriate to estimate soil losses for specific storm events or time periods. Many modifications that are consistent with the basic erosion principles of the USLE have been developed to estimate soil losses or sediment yields for individual storms. Examples can be found in the studies by Williams (1972), David and Beer (1975), Onstad and Foster (1975), and Foster, Meyer, and Onstad (1977). Only a few of these have been linked to economic considerations. The major efforts to connect economic considerations to the hydrologic relations involved in nonpoint pollution are associated with three models: ANSWERS, WATERS, and CREAMS.

ANSWERS (Beasley et al., 1980) is a distributed parameter, storm-event oriented deterministic model called Areal Nonpoint Source Watershed

Environment Response Simulation. This model simulates runoff, erosion, and sediment transport using several routing components to describe the movement of water in overland, subsurface and channel flow phases for a particular storm. The hydrologic components describe surface runoff, subsurface flow, and channel flow in a 1 to 4 ha units within a watershed. The infiltration element of the model is a slightly modified form of the relationship described by Holtan (1961) and Overton (1964). The erosion component of ANSWERS is the continuity equation as proposed by Foster and Meyer (1972). Soil detachment by raindrop and overland flow is based on the work of Meyer and Wischmeier (1969). Sediment transport of both overland and channel flow is based on transport capacity of water moving across the soil surface.

ANSWERS has been used to evaluate four voluntary subsidy programs in terms of sediment delivery and project costs (Lee and Lovejoy, 1984; Lovejoy et al., 1985). The model was utilized to predict reductions in sediment yields for various levels of participation based on the percentage of total land area in alternative policy programs. However, ANSWERS requires very extensive data, including topographic details, climatic details, soil characteristics, field boundaries and so on. It requires a rather large computer in order to simulate a large watershed.

The Watershed Evaluation and Research System (WATERS) is similar in many ways to ANSWERS (Carvey and Croley, 1984). It also requires detailed spatial and climatic data and simulates environmental processes on a storm-event basis. Using pre-specified land management alternatives, WATERS applies multiple objective programming techniques to assess competing economic and hydrologic objectives. To date, WATERS has been applied only to single storm events.

A field scale model entitled Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) was developed by the U.S. Department of Agriculture, Science and Education Administration (Knisel and Foster, 1981). The components of CREAMS simulate erosion and sediment yield, hydrology, and movement of nutrients and pesticides. The simulation of pesticide, nitrogen, and phosphorus is lacking in the ANSWERS and WATERS models. Depending upon the availability of rainfall data, the hydrologic component can estimate storm runoff when only daily rainfall are available, and estimate storm runoff by an infiltration-based method when hourly or "breakpoint" rainfall data are available. Total amounts and average concentrations of chemicals adsorbed to sediment and those suspended or dissolved in the runoff and percolate fractions are estimated.

The study by Crowder et al. (1984) was the first application of CREAMS for analyzing environmental protection policies and determining optimal strategies for the farm operator to meet constraints on agricultural pollution for the representative Pennsylvania dairy farm. The CREAMS model was used to provide technical coefficients for a linear programming model.

The existing hydrologically-oriented models have not been integrated with economic models. Their use in economic analysis is rather arbitrary. For example, WATERS was designed to search among a few, pre-specified spatial distributions of land management practices for the one that optimized a linear objective function containing net returns for farmers and water quality. Similarly, CREAMS and ANSWERS were applied to estimate erosion, sedimentation, or other discharges for a limited set of land use alternatives that were selected without explicit economic consideration. These arbitrary alternatives were then subjected to economic optimization after the physical simulation had been completed. In all cases, the choice of which farming scenarios to analyze was not guided explicitly by economics.

SEDEC, the SEDiment EConomics model, is the first model to integrate economic and physical concerns for controlling agricultural nonpoint pollution (Braden et al., 1985). This model allows economics to guide the identification of land management practices, at the field-level, that will achieve sedimentation goals at least cost. Choices on one field are tied to actions on other fields through the effects of crop rotations and tillage practices on runoff rates.

SEDEC has been used in connection with cumulative erosion and sedimentation rates for various farm practices. However, cumulation is but one of several water quality problems associated with sediment. Other problems include chemical loads, BOD, turbidity, etc., which have not previously been incorporated in the SEDEC model and which relate more to episodic runoff events than to annual averages. One of the goals of this thesis is to construct a method for dealing with episodic impacts of sediment in a SEDEC-type model.

2.3 Annual Average and Episode Sediment Controls

This section contains a simple theoretical model of sediment control that distinguishes between annual average sedimentation rates and episodic sediment loads. Assume that soil erosion from land unit i $(i=1,2,...,n)$, which we denote by g_i, depends on the management practices m_{ij} $(j=1,2,...,J)$ applied to the land unit i. Let the soil type and slope conditions be represented by variable k_i. Finally, define the energy intensity of rainfall (EI) as a random variable with probability density function $P(x,y)$. $P(x,y)$ is a continuous function of x, the storm type defined over space R, and y, the time within a year defined over space T. That is:

$$\int_x \int_y P\ (x,y)\ dx\ dy = 1.$$

Extreme storm events are often described in terms of their frequency of occurrence. For example, a "five-year storm" is one that can be expected, an average, to occur once every five years. Thus, the probability that it will occur in any one year is 0.20. In the context of the probability density function introduced above, a 5-year storm (x_5) and a 100-year storm (x_{100}) are described as follows:

$$\int_y P\ (x_5,\ y)\ dy = 0.20 \qquad \int_y P\ (x_{100},\ y)\ dy = 0.01.$$

Formally, the erosion function for a particular storm under management practice j on land unit i can be written:

$g_i(\ ) = g[x;\ y;\ m_{ij};\ k_i].$

Assume that the objective of nonpoint pollution control policy is to achieve a prescribed water quality standard, z^*, at least cost. Also assume that the water quality standard of concern involves total sediment loads delivered to the water body. The pollution management agency must induce changes in land use to achieve z^*.

Let $\underline{m}_i$ denote a vector of management practices (m_{ij}'s) applied to land unit i. $\underline{M}$ denotes the vector of all practices on all land units. That is:

$$\underline{m}_i = \left| \begin{matrix} m_{i1} \\ \cdot \\ \cdot \\ \cdot \\ m_{iJ} \end{matrix} \right| \qquad \text{vector of all practices on i}$$

$$\underline{M} = \left| \begin{matrix} \underline{m}_1 \\ \cdot \\ \cdot \\ \cdot \\ \underline{m}_n \end{matrix} \right| \qquad \text{vector of all practices on all LMU's}$$

$\underline{M} \in$ M, where M is set of all feasible $\underline{M}$'s.

K_i is a vector of topographic features of land unit i.

Let

$$f(\ ) = f\{g[x;\ y;\ \underline{m}_1,\ K_1],\ \ldots,\ g[x;\ y;\ \underline{m}_n,\ K_n];\ \underline{m}_1,\ldots\underline{m}_n;\ K_1,\ \ldots,\ K_n\}$$

be the transport function, translating spatially distributed erosion rates into cumulative sediment loads from a specific storm (x,y). The transport function also captures topographic features and spatial relationships between land units. Owing to variation in the timing, intensity, and amounts of rainfall, the mean of annual erosion (E) from land unit i and sediment loads (A) from all land units are shown as follows:

$$E_i = \int_{x \varepsilon R} \int_{y \varepsilon T} g_i(\cdot) \cdot P(x,y)\ dx\ dy \qquad A = \int_{x \varepsilon R} \int_{y \varepsilon T} f(\cdot) \cdot P(x,y) dx\ dy.$$

Let $\underline{m}_i^*$ be the vector of land management practices that maximizes profits in the absence of pollution control, and $(\underline{m}_i,\ K_i,\ E_i)$ be a profit function for land unit i.

With the foregoing definitions and assumptions, a pollution control policy oriented toward limiting cumulative loads of sediment while protecting profits insofar as possible might be expressed as follows:

$$\min_{\underline{M}\varepsilon M} \quad TC\ (\underline{M}) = \sum_{i=1}^{n} \pi\ [(\underline{m}^*{}_i,\ K_i,\ E_i) - \pi\ (\underline{m}_i,\ K_i,\ E_i)]$$

$$\text{s.t.:} \int_{x\varepsilon R} \int_{y\varepsilon T} f(\cdot)\cdot\ P(x,y)dx\ dy \leq Z^*. \qquad (2.1)$$

Constraint (2.1) shows that the average annual sediment loads from all land units can not exceed the amount Z^*.

A second environmental objective is to maintain specific ambient conditions relating to the concentration of sediment in the water column. With respect to this objective, a severe storm that occurs when fields are highly susceptible to erosion and streamflows are low will test the concentration limit. Assume that a severe storm x^* occurs at time y and the background streamflow is s. The delivered sediment is:

$$f^* = f(g[x^*;\ y;\ \underline{m}_1,K_1],\ldots,g[x^*;\ y;\ \underline{m}_n,K_n];\ \underline{m}_1,\ldots\underline{m}_n;K_1,\ldots,K_n).$$

The associated sediment concentration , a function of sediment and streamflow, can be expressed as $h[f^*,\ s]$. Due to random variations of individual storms and streamflow rates, the concentration of sediment is stochastic. In other words, a pollution control standard for sediment concentration can realistically be formulated only in probabilistic terms. Such a constraint, following the form proposed by Beavis and Walker (1983), is:

$$\Pr\{\ h[f^*,\ s] \geq Q\ \} \leq \alpha \qquad (2.2)$$

where Q and $\tilde{a}$ are specified parameters. (Typically $\tilde{a}$ will be small.) That is, a concentration standard Q must be expressed in terms of an acceptable frequency of violation, $\tilde{a}$.

For river water quality management, standards are usually based on the so-called critical dry-weather period (Novotny and Chesters, 1981). This is an extreme condition "with a defined duration and with a probability of occurrence once in x number of years. A typical example of such a critical period is the 7 days duration-10 years expectancy low flow characteristic" (Novotny and Chesters, 1981, p. 496). However, a concentration standard for agricultural nonpoint source pollution must recognize that emissions are stochastic in addition to background conditions. A nonpoint source standard must be based on the joint probabilities of low stream flow conditions and extreme storm events. The worst water quality conditions are generally observed when surface runoff from a large storm enters the receiving water body after a prolonged period of low flow. No ambient standards have been defined for the impact of nonpoint pollution under these circumstances.

This study does not intend to generate a water quality standard for sediment pollution. Rather, the intent is to determine whether optimal responses to cumulative sediment constraints are similar to, or different from, optimal responses to constraints on episodic impacts of agricultural pollution. Arbitrary prescribed sediment constraints are therefore set for severe storms associated with particular probabilities of occurrence. Aside from a general determination of the most critical season for water quality, stream flow conditions are not addressed.

In the real world, pollution control policy could combine targets, rather than aiming at the long-term effects of cumulative sedimentation to the exclusion of short-term effects of pollution episodes or vice-versa. If satisfying both goals at least cost is the objective of nonpoint pollution control policy, the pollution control problem would combine expression (2.2) with problem (2.1).

Current nonpoint pollution control policy has focused mainly on the long-term effects of cumulative sediment. That is, only constraint (2.1) has received much attention in policy considerations. From the fundamental theory of mathematical programming, we know that adding effective constraints will probably cause the optimal solution to deteriorate, and the optimal set of management choices to change. In subsequent chapters, we asses the degree to which a solution that satisfies constraint (2.1) alone diverges from solutions to constraints on episodic loads, such as (2.2), and vice-versa.

The empirical work of this study involves developing a storm event model for simulating erosion and sediment of specified return period maximum storms. We then search for the crop-growth phase within a year when the joint probability of high erosion loads and low background streamflow is highest. This crop-growth phase is assumed to present the limiting ambient water quality conditions when confronted with an extreme storm event. According to the distribution of maximum storms, episodic events with various frequencies of occurrence are arbitrarily selected. The simulation model is then run for each episode. The storm event oriented simulation model is used to show: 1) how an annual average sedimentation model can be adapted to deal with impacts that are more closely tied to weather episodes, and 2) the differences of land uses and costs between policies directed to sediment accumulation versus those aimed at controlling episodic sediment loads. These issues have not been investigated in previous studies. Description of the SEDEC model and detailed discussion of the methodology for developing a storm event model are presented in the next chapter.

CHAPTER III

METHODOLOGY

3.1 General Outline of Sediment Economics Simulation Model (SEDEC)

SEDEC, the SEDiment EConomics model, simulates the delivery of sediment from cropland to water bodies and optimizes cropland management practices (Braden, et al., 1985). The optimal management practices are those which maximize profits in the watershed while achieving specified constraints on sediment loads. The model requires information on farm profit functions, the erosion function, and the spatial sediment movement function. Such functions have been joined in SEDEC, as indicated in Table 3.1. The financial and erosion relationships are simulated with the SOILEC model. A relationship proposed by C. D. Clarke (1983) of the U.S. Soil Conservation Service is used to simulate the sediment delivery process.

The SEDEC model portrays only the portion of sediment yields due to sheet and rill erosion. Only management practices on cropland are analyzed. Sediment loads from gully erosion, streambank erosion, noncropland erosion, and wind erosion are not considered, nor is in-stream sediment transport addressed. A management practice is defined as a system characterized by a crop rotation, tillage method, and mechanical control practices. For this study, a portion of the Highland Silver Lake Watershed in Madison County, Illinois containing 223.4 contiguous acres was selected for analysis. The study area contains significant topographic and soil type variability. The study area is located in sections 26 and 27 of township 5 north and range 5 west of the Grantfork quadrangle map. Figures 3.1 and 3.2 show the

Table 3.1 General outlines of SEDEC

SOILEC Model

Data:	Soil types and depths, crop budgets and yields, crop prices, discount rates, rates of crop residue production, C, L, S, P, R, and K factors for field or LMU in watershed; baseline management practices
Compute:	Erosion rates and long-term net returns for each management system.
Output:	select nondominated management practices for each land management unit or field.

⇓

Sediment Delivery Model

Data:	Number of transects, total number of LMUs in each transect, number of acres in each LMU, number of nondominated management practices on each LMU, slope of each LMU, and C and P factors, erosion rates and net revenue change relative to the baseline system for each nondominated practice on each LMU.
Compute:	Total sediment from each transect for each possible combination of management systems to be used on LMUs within that transect and associated costs relative to the baseline.
Output:	Lists of possible combinations of management practices (option lists) for each transect together with total sediment and total cost for each option list.

⇓

Binary Integer Optimizer

Data:	Sediment Delivery Model output and sediment delivery constraint (% of Base Case)
Compute:	Total cost for entire area (watershed or subwatershed) under certain level of sediment constraint.
Output:	Set of management practices on each transect that minimize total cost for entire area without violating sediment constraint.

Source: Braden, Johnson, and Martin, (1985).

Figure 3.1 Location of the Highland Silver Lake Watershed (Madison County, Illinois)

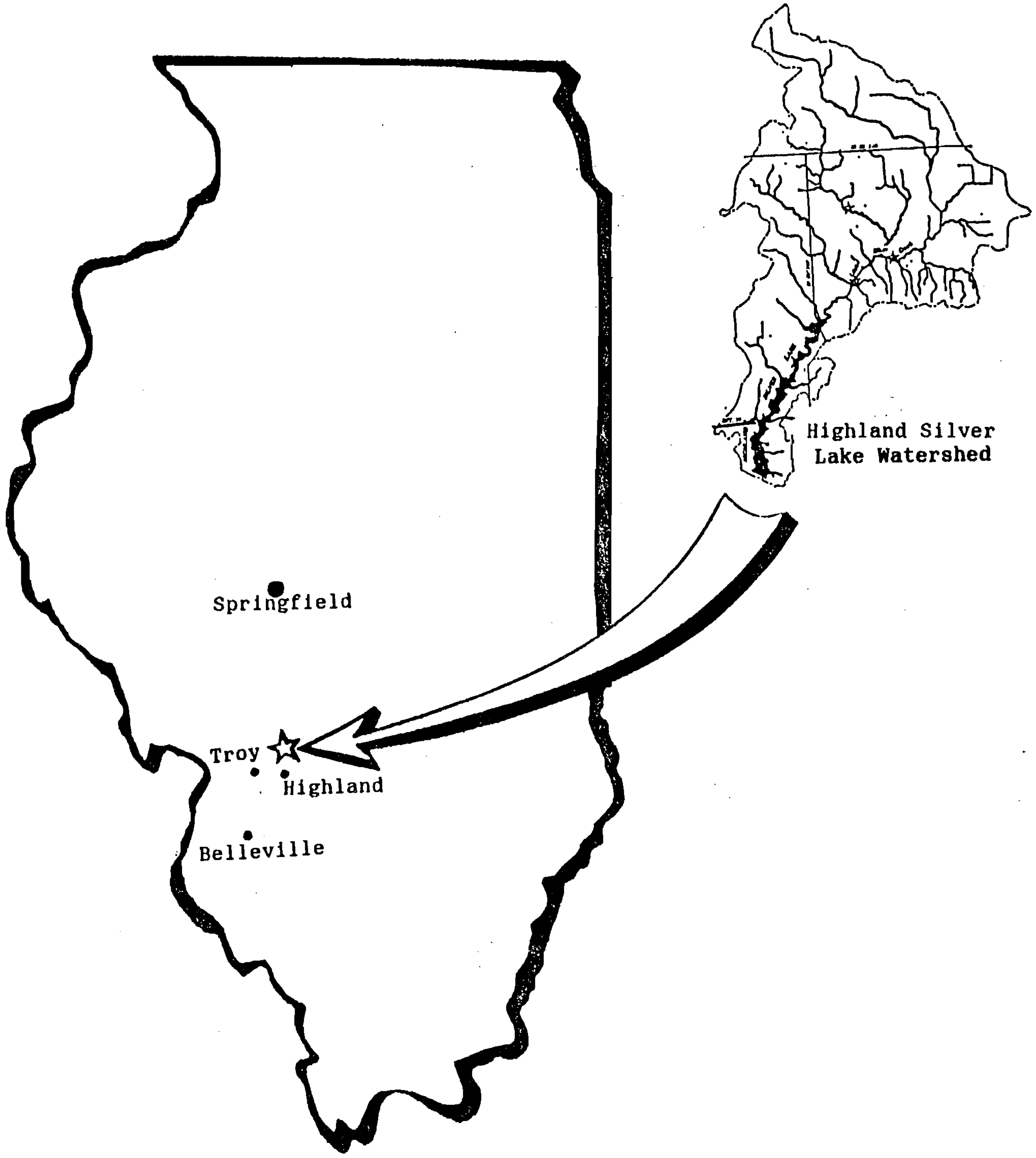
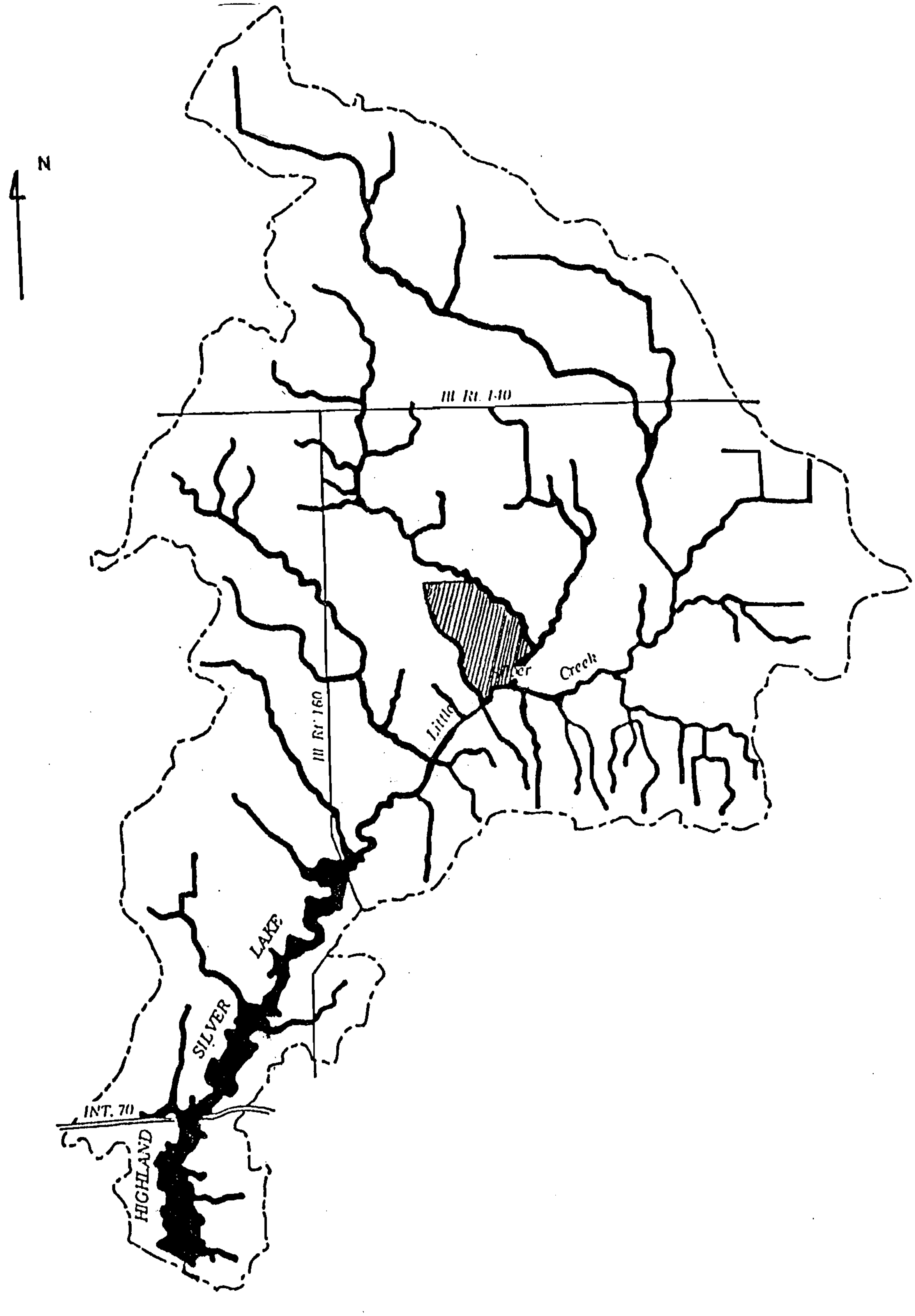


Figure 3.2 The Highland Silver Lake Watershed With the Study Area Outlined



approximate location of the site. The Highland Silver Lake (HSL) Watershed encompasses approximately 36,000 acres in Northeast Madison County, Illinois (Davenport, 1984). Highland Silver Lake was constructed in 1962 by the city of Highland as a public water supply reservoir, but it also helps to control downstream flooding and is used for noncontact recreation (Davenport, 1984). Through Silver Creek and its numerous tributaries, the watershed drains into Silver Lake.

Agriculture is the predominant land use in HSL Watershed. Table 3.2 lists land uses in the Watershed. The production of row crops (utilizing 82 percent of the land) and livestock are the major agricultural enterprises. The predominant crop is soybeans (utilizing 48 percent of the cropland acreage). Corn, wheat and forage crops are also important (Davenport, 1984).

Agricultural nonpoint sources release sediment, nutrients, and pesticides into Highland Silver Lake. The primary pollutant of concern within the watershed is sediment. Owing to the presence of high sodium levels in the fine-textured soils and extensive cultivation, rates of soil detachment are high (Davenport, 1984). Figures 3.1 and 3.2 outline the Highland Silver Lake Watershed and the study area.

In order to apply SEDEC to a watershed, we have to divide the land area into units that are significant hydrologically and meaningful for management purposes. Each "land management unit" (LMU) must have relatively uniform topographic characteristics and a single cropping system. LMU boundaries are set at 1) field boundaries -- here the crop and/or management practices may change, and 2) points within a field where the slope changes significantly. Thus, an LMU is a land area of relatively uniform steepness and uniform management. LMUs must also relate to natural hydrologic subdivisions with

Table 3.2 Land Use/Cover in the Highland Silver Lake Watershed, 1981, by Acres and Percent.

Land Use/Cover	#of Acres	% of Total Land
Cropland	25,205	82.3
Pasture/Hayland	1,662	5.4
Woodland	1,250	4.1
Urban	210	0.7
Feedlots	116	0.3
Interstate Highway	49	0.2
Wildlife	327	1.1
Farmsteads	619	2.0
Residential	356	1.2
Gravel Pits	15	0.0
Water	830	2.7
Total	30,639	100.0

Source: Davenport (1984)

respect to surface drainage. An area on one side of a stream channel that drains into a stream segment (a "catchment") is represented by a single drainage path, or "transect". Each LMU must lie in only one catchment, and can be crossed by no more than one transect. A transect line is drawn perpendicular to contour lines on a topographic map, beginning at streambed (or another base point) and extending to the "top" (outer limit) of the watershed. A transect must never cross the same contour line twice.

3.2 Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is the most widely used model of erosion. It serves as the basic erosion model in SOILEC. Before introducing SOILEC, this section briefly reviews the development of the USLE and elements in the equation.

The USLE is a methodical procedure developed from statistical analysis of more than 10,000 plot-years of data from 47 research stations located in 24 states lying east of Rocky Mountain (Wischmeier and Smith, 1978). It is designed to predict long-term average soil losses generated by sheet and rill erosion, which is usually the major portion of a watershed's gross erosion. The soil losses are estimated for field-size areas as a function of the particular combination of rainfall and soil characteristics, topographic features, crop cover, and management practices at each site (Wischmeier, 1984). Soil losses computed by the equation are recognized as the best available estimates rather than as absolute data (Wischmeier, 1976). The equation takes the following form:

$$A = R\ K\ L\ S\ C\ P$$

where:

A is the computed soil loss per year per unit area of land. It is usually computed as tons per acre.

R is the rainfall and runoff factor, and equals the average annual rainfall erosion index units, or plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K is the soil erodibility factor. It is a measure of the rate per erosion index for a specified soil as measured on a unit plot for a uniform 9 percent slope 72.6 feet long under continuously clean-tilled fallow.

L is the slope-length factor. It is the ratio of soil loss from a pecified slope length to that from a slope length of 72.6 feet long, which is the slope length for the K value in the equation.

S is the slope gradient factor. It is the ratio of soil loss from a specific slope gradient to that from a gradient of 9 percent, which is the slope gradient specified for the K value in the soil loss equation. L and S are usually in combination.

C is the cropping management factor. It is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from an identical land in clean-tilled continuous fallow.

P is the conservation support practice factor. It is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing, to that from up-and down hill tillage operations.

The reason for a reference base plot 72.6 feet long with a 9 percent slope gradient is because most of the 10,000 plot-years of soil loss data were obtained for plots of about this description. Using them as bases for estimating L, S, and K minimized potential errors in adjusting the data to a common base. Choosing continuous fallow with shallow tillage as a reference base essentially eliminates the effects of crop residuals, crop management, and vegetative cover. Rows and tillage parallel to the land slope were used as a reference base because nearly all of the existing plot data had been obtained in this manner and contouring effect cannot be measured on narrow plots (Wischmeier, 1984).

3.3 Soil Conservation Economics Simulation Model (SOILEC)

SOILEC, the SOIL conservation Economics model, is a direct outgrowth and extension of research concerning the economics of soil erosion developed by Dumsday and Seitz. SOILEC addresses the economic value of long-term losses in cropland productivity due to sheet and rill erosion (Eleveld et al., 1983; Johnson, 1985). For a given soil type, the SOILEC model quantifies the onsite physical and financial consequences of soil erosion for alternative cropland management systems.

Four basic relationships underlie the SOILEC model (Johnson, 1985).

1. The Universal Soil Loss Equation (USLE):

$A = R \quad LS \quad K \quad C \quad P$

2. Discounted net returns: This is the basic economic relationship in SOILEC. Each management system is characterized by a set of operating costs and revenues. (Revenues are based on average yield and price assumptions.) The sum of discounted annual net returns gives the present value of net returns ($PVNR_ts$) over a planning horizon for a given management system.

An example for the two-crop case is:

$$PVNR_ts = \frac{P_1 Y_{t1} + P_2 Y_{t1} - C_{t1} - C_{t1}}{(1 + r)^t}$$

where:

$PVNR_ts$ = the discounted net returns in year t for a management system

P_i = the price for the crop i (i=1,2)

Y_{ti} = the yield for crop i in year t for the management system Y_{ti}

C_{ti} = the cost for the crop i in year t for the management system

r = the real rate of interest

t = number of years in the planning horizon

3. The relationship between crop yields and soil loss from erosion: Sustained soil erosion, d_t, is assumed to reduce long-term productivity, Y_t, of any particular soil type.

$$Y_T = f\left(D_0 - \sum_{t=1}^{T-1} d_t\right)$$

Y_T = yield for a crop in time T

D_0 = initial soil depth

d_t = annual soil loss

4. The relationship between costs and soil loss: It is assumed that the farmer tries to maintain yields in the face of lost native productivity, due to soil erosion, by increasing the use of inputs such as fertilizer. Thus:

$$C_T = g\left(D_0 - \sum_{t=1}^{T-1} d_t\right)$$

where:

C_T = the cost in year t for a given crop and management system

d_t = depth of top soil lost as defined in relationship 3.

The SOILEC model can be used to simulate soil losses and economic outcomes of each management system for the short run (one year planning horizon) or long run (two to fifty years planning horizon). The simulation model calculates annual average net returns on a per acre basis for each management systems. These annual net returns are discounted and summed to their present values at the beginning of the planning horizon. An estimate is made of the remaining or salvage value of land, which is also discounted to the present and included in the present value sum for each management system (Johnson, 1985). All factors in the SOILEC model are assumed to be constant over a long run planning horizon.

Most farms and fields contain more than one type of soil. SOILEC allows for multiple soils in a field-level analysis by weighing the financial and erosion values for each soil type by its proportionate presence in the field.

Another feature of SOILEC, frontier analysis, applies an economic dominance criterion to distinguish the management systems that are potential optima. A management system is dominated when the same or lower annual soil loss can be obtained with the same or greater annual net returns. The nondominated options lie on the profit-erosion "frontier." The remaining points are inferior in that they are not profit-maximizing for particular rates of erosion. Therefore, they may be excluded without affecting optimization. The determination of dominance is done by a cutting plane algorithm within SOILEC (Johnson, 1985). This algorithm includes a distance function that makes it possible to specify a "thick" frontier so that "small" differences in profits or erosion rates do not result in excluding some points from further consideration.

3.4 Sediment Delivery Relationship

Of the soil that erodes, only a fraction reaches a receiving water body. Factors such as the distance of the source from the receiving water body, vegetative buffers, slope and roughness characteristics of the land, and ponding and presence of depositional areas during overland flow can affect delivery of soil from a source to the receiving water body (Novotny and Chesters, 1981). The process of sediment migration is complex and difficult to simulate in a general way. This has resulted in the use of erosion restrictions rather than sediment controls in some states (Davenport, 1984). Efficient control of sediment demands reliable tools for the prediction of sediment yields and migration.

One of the methods used to estimate the sediment yield from a watershed is the sediment delivery ratio method:

$$\text{Sediment Delivery Ratio} = \frac{\text{sediment yields}}{\text{gross erosion amount}}$$

The sediment delivery ratio method requires a factor expressing the percentage relationship between sediment yield from a watershed and gross erosion in the watershed in the same time period (Glymph, 1975). It depends on land management practices indirectly, as they affect measured sediment yields and predicted erosion rates over an entire watershed area. An alternative method proposed by Clarke (1983) computes sediment delivery for individual land parcels within a watershed as functions of topographic and management features along overland flow profiles selected to be representative of the watershed. Clarke's method is predictive. By contrast to the sediment delivery ratio method, the sediment delivery ratios in Clarke's procedure can depend directly on specific land management practices. Clarke's procedure has been shown to be a promising technique for estimating sediment yields (Davenport, 1984). Clarke's procedure for approximating overland soil migration within a watershed is the basic sediment delivery relationship in the SEDEC model.

The purpose of Clarke's procedure is to rank slope zones within watersheds according to relative contributions to sediment yield (Clarke, 1983). The overland transport and deposition of sediment is highly dependent on watershed characteristics. Assuming that the depth of flow along a given flow path is unchanging, slope and roughness, reflected by the C and P factors in the USLE, influence the velocity of flow. The concept in this procedure is that a downslope reduction in slope (the S factor) or the C or P values is accompanied by a proportionate reduction in transport capacity and that deposition is inversely proportional to the reduction in transport capacity (Clarke, 1983). Eroded soil that is deposited on land due to a reduction in sediment transport capacity is not carried all the way to the stream channel. Sediment delivered to live water is the difference between the tonnage of eroded soils and the tonnage of soil deposited on land.

The Clarke procedure recognizes that wherever slope declines or crops or support practices change, deposition may occur. Because slope or management changes define boundaries between land management units (sec. 3.1), each such boundary must be characterized by its effect on sediment transport capacity:

$$D_{ij-1}\ (u,S) = \frac{P^*_{ij-1}}{P^*_{ij}} * \frac{C^*_{ij-1}}{C^*_{ij}} * \frac{S^*_{ij-1}}{S^*_{ij}} \qquad (3.1)$$

where:

$j = 1,2,3,\ldots Ji$

C_{ij}, P_{ij}, S_{ij} = respective coefficients of the USLE associated with crop management, support practices, and slope of the jth LMU in transect i.

Expression (3.1) gives the proportionate relationship between the sediment "transport capacity" of land unit j-1 and the adjacent uphill unit j. It is subject to the following conditions which indicate that the sediment delivered (transport capacity) through boundary j cannot exceed the erosion originating above that point.

$$\frac{P^*_{ij-1}}{P^*_{ij}} = \begin{cases} \dfrac{P_{ij-1}}{P_{ij}} & \text{if ratio} < 1 \\ 1 & \text{if ratio} \geqslant 1 \end{cases}$$

$$\frac{C^*_{ij-1}}{C^*_{ij}} = \begin{cases} \dfrac{C_{ij-1}}{C_{ij}} & \text{if ratio} < 1 \\ 1 & \text{if ratio} \geq 1 \end{cases}$$

$$\frac{S^*_{ij-1}}{S^*_{ij}} = \begin{cases} \dfrac{S_{ij-1}}{S_{ij}} & \text{if ratio} < 1 \\ 1 & \text{if ratio} \geq 1 \end{cases}$$

It is also assumed that all sediment that reaches the streambank enters the stream:

$D_{i0} = 1.$

Based on Clarke's procedure, the erosion relationships are embedded in a spatial model in SEDEC (Braden and Johnson, 1985). The proportion of erosion that reaches the stream from an LMU in a transect, Z_{ij}, is computed as a product of the intervening sediment transport capacity ratios:

$$Z_{ij} = a_{ij} \cdot E_{ij} \cdot D_{ij-1} \cdot \ldots \cdot D_{i0}$$

$$= a_{ij} \cdot E_{ij} \cdot \overset{j-1}{\underset{m=0}{\pi}} D_{im}$$

where:

a_{ij} = acres of jth LMU of transect i

E_{ij} = soil erosion per acre on jth LMU of transect i

Total sediment delivery to the stream from all LMUs in a transect is computed recursively as follows:

$$TZ_i^1 = a_{ij} \quad D_i0 \quad E_i1$$

$$TZ_{i2} = TZ_{i1} + a_{i2} \cdot D_{i0} \cdot D_{i1} \cdot E_{i2}$$

$$TZ_{i3} = TZ_{i2} + a_{i3} \cdot D_{i0} \cdot D_{i1} \cdot D_{i2} \cdot E_{i3}$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$TZ_i = \sum_{m=1}^{Ji} \pi_{j=0}^{m-1} a_{im} \cdot D_{ij} \cdot E_{im} \qquad (3.2)$$

where:

TZ_i: is the total sediment loss from the transect i

The symbol   in (3.2) is the product operator.

3.5 SEDEC Model

Efficient sediment control requires minimizing the cost of meeting any particular level of deposition (Sharp and Bromley, 1979). The optimization portion of SEDEC is designed to minimize sediment control costs under a maximum amount of sediment to be allowed in a stream segment. Much of the model description in this section is taken from Braden, Johnson, and Martin (1985). The optimization problem is formulated as follows:

$$\underset{u \in U}{\text{Min}} : \quad TC = \sum_{i=1}^{I} \sum_{j=1}^{Ji} r_{ij}(u) \cdot a_{ij} \qquad (3.3)$$

$$\text{s.t.:} \quad \sum_{i=1}^{I} TZ_i(u) \leq D \qquad (3.4)$$

where:

u = a vector of discrete cropland management elements that constitutes a management "system"

U = the set of feasible combinations of management elements

i = 1,2,...I represent transects (hydrologic subdivisions) of a watershed

j = 1,2,...Ji "Land Management Units" within transect i

r_{ij} = the change in net returns per acre between a base management system and an alternative management system (u) in the area under consideration, assuming land management practices in the base case with the absence of pollution control policies; that is, $r_{ij}(u) = w_{ij}(u_{base}) - w_{ij}(u)$, where $w_{ij}(u)$ is net returns per acre under alternative management practices in LMU j of transect i. This reflects the cost needed for moving from base management system to any alternative practices under some level of pollution control. $w_{ij}(u_{base})$ = net returns per acre for base management practices in LMU j of transect i.

a_{ij} = acres for LMU j of transect i

D = the maximum amount of sediment to be allowed in the stream segment

$TZ_i(u)$ = a sediment delivery function for hydrologic subdivision i

TC = total costs of moving from u_{base} to u under the assumption that net returns are proportional to acres for a specific soil and slope class.

For computational considerations, an analogue to the frontier analysis used to identify nondominated erosion management practices at the LMU level is applied to sediment delivery at the transect level. Only those transect management combinations that cannot be improved upon through higher profits or lower sediment loads within each transect need to be considered. The nondominated transect management options are those which lie on the profit-sediment "frontier." The remaining management combinations are inferior because they are not profit-maximizing for particular rates of sediment. The determination of dominance involves a cutting plane algorithm within SEDEC at the transect level. Then, a branch-and-bound integer programming algorithm is used to find the most profitable combination of nondominated transect management options that meets the sediment load constraint. The optimal management combinations are determined when other set of management combinations can attain higher profit and also satisfy the sediment constraint.

3.6 Cover and Management (C) Factors for Crop-growth Phases

The value of the annual average cover and management (C) factor of the USLE on a particular soil type is determined by many variables, including crop canopy, residue mulch, incorporated residues, tillage, and their interactions. Each of these variables can be treated as a subfactor whose numerical value is the ratio of soil loss with the effect to corresponding loss without it. C is the product of these subfactors (Wischmeier and Smith, 1978). The soil loss ratios and erosion rainfall (EI) through the twelve months are used to evaluate C in terms of the interactions of the crop system with management and a rainstorm distribution (Wischmeier, 1976). Deriving the appropriate C values for a given location requires knowledge of the distribution of erosive rainfall through the twelve months of the year in that location, and knowledge of how much erosion control protection the growing plants, crop residues, and selected management practices will provide at the time when erosive rains are most likely to occur (Wischmeier and Smith, 1978).

To compute the C value for a particular crop and management system on a given soil type, we need to define dates for seeding and harvest, rates of canopy cover development and final canopy cover, and the crop and residue management practices. The annual average C factor can be disaggregated by crop development stage. The crop-stages are defined as follows (Wischmeier and Smith, 1978):

Crop-stage F (rough fallow)-- inversion plowing to secondary tillage.

Crop-stage SB (seedbed)-- secondary tillage for seed preparation until the crop has developed 10 percent canopy cover.

Crop-stage 1 (establishment)-- end of SB until crop develops a 50 percent canopy cover.

Crop-stage 2 (development)-- end of crop-stage 1 until canopy cover reaches 75 percent.

Crop-stage 3 (maturing crop)-- end of crop-stage 2 until crop harvest.

Crop-stage 4 (residue or stubble)-- harvest to plow or new seeding.

To calculate C for a crop rotation, we need to list chronologically all the land-cover changes and the date for each event and to find the corresponding crop-stage for each event. Summation of the products of erosive rainfall percentage and the soil loss ratios for each crop-stage yields the crop year C value. The same procedure is used for the second crop in the rotation, and so forth. Summing all crop year C values and dividing them by the number of crop years for the rotation produces the annual average C value for the rotation.

Agriculture Handbook No. 537, prepared by Wischmeier and Smith (1978), provides a primary table for choosing the ratio of soil loss from cropland to the loss from continuous fallow and some supplemental tables for conditions not listed in the primary table. However, not all situations that we want to evaluate can be determined from the primary and supplementary tables. For crop sequences and managements options not in the tables, soil loss ratios can be chosen from those having similar cover and growth characteristics.

Experiences from agronomists and natural resource specialists can help to evaluate and make judgments for any soil loss ratio chosen in calculating the C values. In order to choose the proper soil loss ratios for each crop stages of various management systems, Prof. Robert Walker (1986), of the Illinois Cooperative Extension Service, and Mr. Richard Dickerson (1986), of the Illinois State Office of the U.S. Soil Conservation Service, were consulted.

Typical dates for planting, development of canopy cover, and harvest dates for corn, soybean, wheat, and double crop soybeans in the Highland Silver Lake area are shown in Table 3.3 (Walker, 1986).

Table 3.3 Typical Dates of Crop Growth Stages for Various Crops in the Highland Silver Lake Area

Event	Dates			
	Corn	Soybean	Wheat	DCsoybean
Plow/Chisel	Oct. 15	Nov. 15	-----	-----
Disk	May 1	May 1	-----	-----
Planting*	May 10	May 21	Oct. 10	July 1
10% Canopy	June 1	June 15	Nov. 1	July 21
50% Canopy	June 20	June 30	Dec. 1	Aug. 5
75% Canopy	July 5	July 10	Apr. 15	Aug. 15
Harvest	Oct. 25	Oct. 5	June 30	Oct. 15

*: no-till plant for corn and soybean, planting wheat and double crop soybeans start from this stage.

According to the procedures described above, annual average C values for 15 rotation and tillage combinations are presented in Table 3.4. Based on the crop yield ranges varying by the soil types in the study area, five residue levels, 0-2000, 2000-3000, 3000-4000, 4000-5000, and above 5000 (lbs/acre), are specified to reflect residue amounts in selecting the C factors used in the SOILEC model.

Table 3.4 Annual Average C Values for Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	0.369	0.369	0.369	0.369	0.369
CSWDCSB	FP	0.270	0.267	0.261	0.261	0.261
CSWK	FP	0.173	0.170	0.165	0.164	0.164
CCSWMMMM	FP	0.155	0.152	0.149	0.148	0.148
AAAAA	FP	0.020	0.020	0.020	0.020	0.020
CS	FCH	0.338	0.298	0.257	0.236	0.235
CSWDCSB	FCH	0.254	0.225	0.187	0.172	0.168
CSWK	FCH	0.153	0.130	0.083	0.067	0.063
CCSWMMMM	FCH	0.137	0.105	0.067	0.053	0.048
AAAAA	FCH	0.020	0.020	0.020	0.020	0.020
CS	NT	0.164	0.138	0.109	0.103	0.100
CSWDCSB	NT	0.138	0.117	0.092	0.085	0.084
CSWK	NT	0.100	0.083	0.062	0.055	0.052
CCSWMMMM	NT	0.075	0.054	0.036	0.029	0.027
AAAAA	NT	0.020	0.020	0.020	0.020	0.020

CS: corn-soybeans, CSWDCSB: corn-soybean-wheat-double crop soybeans, CSWK: corn-soybean-wheat-clover, CCSWMMMM: corn-corn-soybean-wheat-meadow-meadow-meadow-meadow, AAAAA: permanent alfalfa rotation.
FP: fall plow, FCH: fall chisel, NT: No-till.

Instead of using the annual average C values, a storm event model requires the rotation average C value for each crop-growth phase. The rotation average C value is computed by summing the same crop-growth phase's C values for a rotation and dividing by the number of years in the rotation. Based on the growth stages identified in Table 3.3 above, it is reasonable to divide a calendar year into four crop-growth phases. Within each phase, crop cover and management effects may be considered relatively uniform. The periods are:

Phase I-- April 1 to June 30: About 1-1.5 months before planting corn and soybeans, to late June when corn and soybean reach 50 percent canopy cover. This is a phase of high erosion susceptibility.

Phase II-- July 1 to September 30: From 50 percent canopy cover for corn and soybeans, to 1-3 three weeks before harvesting soybeans and corn. Erosion susceptibility is relatively low.

Phase III-- October 1 to November 30: About 1-4 weeks before harvest soybeans and corn, to post-harvest tillage for the following season's crops, especially for corn and soybeans. If no-till is used, then residue will be left on the field through the winter. Erosion susceptibility depends on residue management.

Phase IV-- December 1 to March 31: Winter period for corn and soybeans. Erosion susceptibility depends on residue coverage.

Table 3.5 to Table 3.8 are the listings of crop-growth phase rotation average C values under various residue levels. All rotations are as defined in Table 3.4.

Table 3.5 C Values of Phase I for Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	0.157	0.157	0.157	0.157	0.157
CSWDCSB	FP	0.115	0.114	0.111	0.111	0.111
CSWK	FP	0.065	0.064	0.062	0.062	0.062
CCSWMMMM	FP	0.060	0.059	0.058	0.058	0.058
AAAAA	FP	0.020	0.020	0.020	0.020	0.020
CS	FCH	0.124	0.106	0.091	0.084	0.083
CSWDCSB	FCH	0.094	0.081	0.067	0.063	0.059
CSWK	FCH	0.047	0.039	0.024	0.019	0.017
CCSWMMMM	FCH	0.051	0.036	0.022	0.016	0.014
AAAAA	FCH	0.020	0.020	0.020	0.020	0.020
CS	NT	0.063	0.061	0.048	0.046	0.045
CSWDCSB	NT	0.057	0.048	0.038	0.036	0.036
CSWK	NT	0.033	0.027	0.018	0.016	0.015
CCSWMMMM	NT	0.028	0.019	0.011	0.009	0.008
AAAAA	NT	0.020	0.020	0.020	0.020	0.020

Table 3.6 C Values of Phase II for Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	0.104	0.104	0.104	0.104	0.104
CSWDCSB	FP	0.073	0.073	0.073	0.073	0.073
CSWK	FP	0.048	0.048	0.048	0.048	0.048
CCSWMMMM	FP	0.038	0.038	0.038	0.038	0.038
AAAAA	FP	0.020	0.020	0.020	0.020	0.020
CS	FCH	0.113	0.103	0.087	0.077	0.077
CSWDCSB	FCH	0.078	0.072	0.061	0.055	0.055
CSWK	FCH	0.052	0.047	0.029	0.022	0.021
CCSWMMMM	FCH	0.039	0.034	0.021	0.016	0.015
AAAAA	FCH	0.020	0.020	0.020	0.020	0.020
CS	NT	0.069	0.057	0.045	0.041	0.039
CSWDCSB	NT	0.050	0.042	0.034	0.031	0.030
CSWK	NT	0.032	0.025	0.018	0.015	0.014
CCSWMMMM	NT	0.024	0.017	0.011	0.008	0.007
AAAAA	NT	0.020	0.020	0.020	0.020	0.020

Table 3.7 C Values of Phase III for Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	0.043	0.043	0.043	0.043	0.043
CSWDCSB	FP	0.029	0.029	0.029	0.029	0.029
CSWK	FP	0.027	0.026	0.024	0.024	0.024
CCSWMMMM	FP	0.027	0.026	0.025	0.024	0.024
AAAAA	FP	0.020	0.020	0.020	0.020	0.020
CS	FCH	0.041	0.038	0.036	0.035	0.035
CSWDCSB	FCH	0.032	0.030	0.025	0.023	0.023
CSWK	FCH	0.027	0.023	0.016	0.014	0.014
CCSWMMMM	FCH	0.022	0.018	0.012	0.011	0.010
AAAAA	FCH	0.020	0.020	0.020	0.020	0.020
CS	NT	0.018	0.012	0.010	0.010	0.010
CSWDCSB	NT	0.018	0.015	0.011	0.010	0.010
CSWK	NT	0.018	0.016	0.013	0.012	0.011
CCSWMMMM	NT	0.013	0.009	0.007	0.006	0.006
AAAAA	NT	0.020	0.020	0.020	0.020	0.020

Table 3.8 C Values of Phase IV for Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	0.065	0.065	0.065	0.065	0.065
CSWDCSB	FP	0.053	0.051	0.048	0.048	0.048
CSWK	FP	0.033	0.032	0.031	0.030	0.030
CCSWMMMM	FP	0.030	0.029	0.028	0.028	0.028
AAAAA	FP	0.020	0.020	0.020	0.020	0.020
CS	FCH	0.060	0.051	0.043	0.040	0.040
CSWDCSB	FCH	0.050	0.042	0.034	0.031	0.031
CSWK	FCH	0.027	0.021	0.014	0.012	0.011
CCSWMMMM	FCH	0.025	0.017	0.012	0.010	0.009
AAAAA	FCH	0.020	0.020	0.020	0.020	0.020
CS	NT	0.014	0.008	0.006	0.006	0.006
CSWDCSB	NT	0.013	0.012	0.009	0.008	0.008
CSWK	NT	0.017	0.015	0.013	0.012	0.012
CCSWMMMM	NT	0.010	0.009	0.007	0.006	0.006
AAAAA	NT	0.020	0.020	0.020	0.020	0.020

3.7 Rainfall Erosivity Indices (R) for Crop-growth Phases

Soil erosion is a mechanical process that requires energy, generally from wind or falling raindrops. The rainfall erosion index (R) in the USLE captures the power of a rainstorm or rainfall pattern to erode soil from an unprotected field. The capacity of a single storm to erode soil depends on all the rainfall intensities involved in the storm and on the cumulative amount of rain (Wischmeier and Smith, 1958). To compute the overall energy of a rainstorm, a recording raingage chart listing the amount of rain falling at each intensity increment is needed. This is referred to as breakpoint data. The corresponding intensity value multiplied by the inches of rain falling at this rate determines the energy value of that increment of the storm. The regression equation from which the kinetic energy of rainfall was derived is:

$$Y = 916 + 333 \log_{10} I$$

where:

Y: kinetic energy in foot tons per acre inch

I: rainfall intensity in inches per hour

The total energy value for the storm is the sum of the Y's over the pertinent values of I (Wischmeier and Smith, 1958).

The rainfall erosivity data were assembled at Purdue University (from more than a quarter of a million individual-storm runoff and soil loss measurements from small field plots) to test and explain why two rainstorms of equal total amount falling on the same field and on comparable surface conditions often produce widely different soil losses. The first objective was to obtain the highest possible multiple correlation coefficient with individual-storm soil loss as the dependent variable. Nineteen variables were chosen simultaneously for multiple regression equations of soil loss. In addition to those 19 variables, special emphasis was placed on the interaction effects of the variables. The best variable found for prediction of soil loss from cultivated fallow soil was the product of the total rainfall energy of a storm and its maximum 30-minute intensity. It is referred to as the EI variable (Wischmeier and Smith, 1958). For 37 states of east Rocky Mountain, the EI values for storms are the values R used in USLE[1]. From the above definition, values of EI are computed directly from long-term "breakpoint" data. These are rainfall records measured at short time intervals during which the intensity is essentially constant. Owing to the scarcity of breakpoint rainfall data for most of the western United States, Istok and McCool (1985) proposed a method for estimating energy intensities from hourly

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[1] However, in the Pacific Northwest and in some Central Western States, the early spring erosion due to runoff from snowmelt, thaw, or light rain on frozen soil usually exceeds the average annual location's erosion index EI. So, the overall R factor is the sum of the snowmelt and thaw R's and the location's erosion index EI (Wischmeier and Smith, 1978).

rainfall data, which are widely available. Their method involves a regression equation which estimates 15-minute rainfall energy intensities as a function of 60-minute data. Based on results from three sites in western Oregon, they concluded that hourly rainfall data can be used to estimate EI for use in USLE.

Since no rainfall gauges are set within the Highland Silver Lake watershed, hourly precipitation data were obtained from the nearest weather station at Belleville, Illinois, 25 miles to the southeast. These data were used in the Istok-McCool procedure to estimate the rainfall erosivity (EI) for each and every storm. The Belleville hourly rainfall records are complete from 1949 to 1983. Because this study focuses on episodic impacts that create limiting ambient conditions for an aquatic ecosystem, only the most severe storms are analyzed here. The extreme storms evident in the Belleville data are summarized in Table 3.9. Based on these 35-year rainfall data, frequency distributions of maximum storm EI values for the four crop-growth phases, and various recurrence intervals, can be estimated.

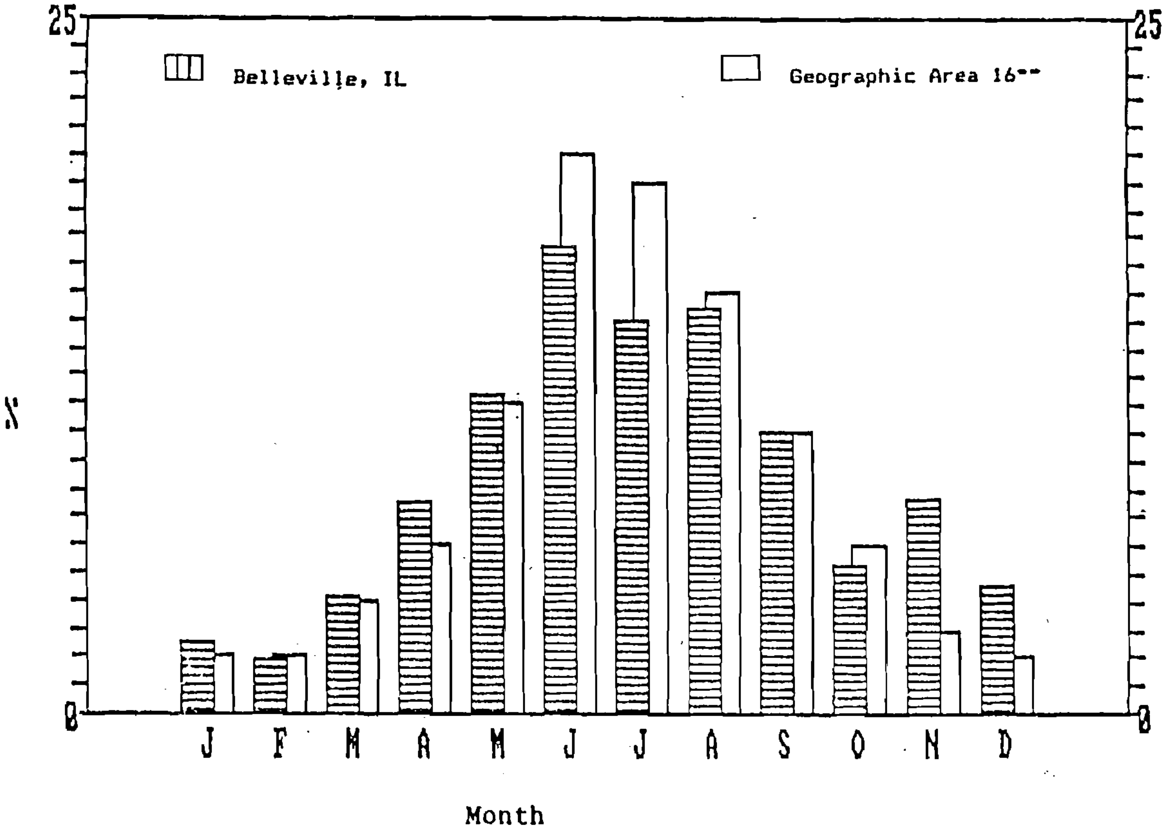
The Belleville data indicate that 35.5 percent of the annual total rainfall occurs in April to June, 38.4 percent in July to September, 13 percent in October to November, and 13.1 percent occur in December to March (see Figure 3.3). The percentage of annual maximum storm events happening in each phase is highest in July to September when 47.6 percent of the extreme events occur according to the Belleville rainfall records. Nearly 26 percent, 14.2 percent, and 11.4 percent occur in phase II, phase III, and phase IV, respectively.

The reason for not dividing the year into smaller intervals -- months -- is the independence and homogeneity of rainfall erosion data.

Table 3.9 Phase Maximum, Annual Maximum and Annual Total Rainfall Erosivity Index EI (R) for Belleville, Illinois from 1949 to 1983.

	Maximum					Annual
Year	Phase I	Phase II	Phase III	Phase IV	Annual	Total
1949	2.80	2.09	37.23	9.87	37.23	96.49
1950	7.16	15.97	15.42	5.83	15.97	107.81
1951	2.82	8.00	6.75	2.62	8.00	52.29
1952	15.58	9.71	5.88	5.26	15.58	61.58
1953	10.61	3.77	1.97	3.22	10.61	57.79
1954	15.83	38.03	15.55	3.10	38.03	152.43
1955	6.63	13.43	34.27	1.33	34.27	113.94
1956	72.99	30.97	11.63	19.09	72.99	325.38
1957	345.51	16.13	3.47	4.50	345.51	532.30
1958	21.72	50.84	57.66	8.70	57.66	286.19
1959	15.81	37.03	8.18	3.23	37.03	148.06
1960	23.97	3.60	5.53	11.10	23.97	100.12
1961	111.52	97.65	1.36	4.20	111.52	318.12
1962	0.57	68.22	1.01	3.15	68.22	90.63
1963	15.78	14.97	9.94	4.10	15.78	81.42
1964	5.70	16.21	3.00	1.49	16.21	72.14
1965	14.51	73.17	2.19	19.13	73.17	217.23
1966	4.39	21.06	6.81	3.92	21.06	90.62
1967	8.90	10.64	3.29	22.92	22.92	120.77
1968	24.35	82.09	9.55	19.11	82.09	225.34
1969	34.86	60.94	20.10	1.28	60.94	287.48
1970	20.10	18.98	3.76	3.38	20.10	144.37
1971	5.56	4.25	1.35	22.84	22.84	77.94
1972	2.94	15.18	179.66	5.17	179.66	254.94
1973	50.19	43.02	1.76	5.20	50.19	228.16
1974	9.93	92.96	4.81	31.46	92.96	209.99
1975	7.51	24.27	1.00	2.17	31.46	128.69
1976	6.36	21.52	6.78	26.07	21.52	85.73
1977	18.30	29.12	12.09	5.26	29.12	174.37
1978	1.46	26.59	6.10	9.06	26.59	110.38
1979	24.04	81.71	3.11	8.75	81.71	248.04
1980	58.45	15.31	3.81	1.81	15.31	143.90
1981	30.88	31.95	5.08	4.69	31.95	204.60
1982	27.99	15.79	3.29	46.06	46.06	220.47
1983	15.99	26.00	27.90	3.51	27.90	157.80

Figure 3.3 % of Monthly to Annual Total Rainfall Erosion Index (EI)*



*: Percentages for each data set sum to 100.
**: Thirty-seven states in the east of Rocky Mountain were divided into 33 geographic areas based on the isoerodent map (Wischmeier and Smith, 1978). Geographic Area 16 includes most of Ohio and Indiana, central Illinois, and northern Missouri. Data for Geographic Area 16 are from Agriculture Handbook No. 537 (Wischmeier and Smith, 1978).

That is, a hydrologic event does not enter the data more than once and all of the data are from the same population (Haan, 1977). For hydrologic data, the time interval for an extreme value series is usually taken as one water year and the series so selected is the annual series. When the time interval decreases, the dependence between observations and the number of selected values increases (Chow, 1964). However, homogeneity of the data may be maintained at least for practical purposes if the data are selected only from a particular season within a year (Rangarajan, 1960). These arguments support dividing a year into four phases, as shown in section 3.6.

3.7.1 Statistical Tests of Distributions

A U.S. government task force has determined that the log-normal, log-pearson type III, and extreme value type I frequency distributions are about equally good in representing flood frequencies for a sample of U.S. streams (Haan, 1977). Frequency distributions of the annual rainfall erosion index computed from rainfall records at 181 stations east of the Rocky Mountains tend to follow the log-normal distributions. Seasonal, monthly index values and annual maximum-storm values also follow the log-normal distribution (Wischmeier, 1959). When two or more distributions appear to describe a given set of data equally well, the distribution that has been traditionally used should be selected (Haan, 1977). So, the statistical tests of distributions of phase maximum-storm EI values, of annual maximum-storm EI values, and of annual total rainfall erosion indices are based on null hypotheses of log-normal distributions.

In frequency analysis, there are two ways of judging whether or not a particular distribution adequately describes a set of observations. One method is to compare the observed relative frequency curve with the theoretical relative frequency curve. The second method involves arranging the data in order of magnitude to form a frequency array, plotting the data on appropriate probability paper, and judging whether or not the resulting plot is a straight line (Haan, 1977). Both methods require a visual judgment of goodness of fit.

A common statistical test corresponding to these visual tests for goodness of fit of empirical data to specified theoretical frequency distributions is the Chi-square test. This test makes a comparison between the actual number of observations and the expected number of observations (expected according to the distribution under test) that fall in a class interval (Haan, 1977). The test statistic is calculated from the relationship

$$\chi_c^2 = \sum_{i=1}^{k} (Oi - Ei)^2 / Ei$$

where k is the number of class intervals, and Oi is the observed and Ei the expected (according to the distribution being tested) number of observations in the ith class interval. The distribution of χ_c^2 is a Chi-square distribution with k-p-1 degrees of freedom where p is the number of parameters estimated from the data. The hypothesis that the data are from the specified distribution is rejected if

$$\chi_c^2 > \chi^2_{1-\alpha,\ k-p-1}.$$

In the case at hand, considering the number of class intervals and the degrees of freedom with 35 observations, the Chi-square test may not be adequate to test the normality of data. Therefore, it was decided to use the method proposed by David et al. (1954) to test the distribution of each rainfall data set.

We assume as our null hypothesis that phase maximum-storm EI values, annual maximum-storm EI values, and annual total rainfall erosion indices all follow log-normal distributions. That is, the log arithmetic values of each storm are normally distributed. With null hypotheses of normal distributions, David et al. (1954) suggested that the ratio of the range to the standard deviation (R/S.D.) is useful in detecting heterogeneity of the data or departure from normality. This ratio is defined as R/S.D.= (Xmax-Xmin)/S.D., where Xmax is the largest value of X and Xmin is the smallest,and S.D. is the standard deviation, $S.D. = \sum_{i} (X_i-\bar{X})^2/n-1$. They derived the exact distribution of this statistic through the following relation:

$$U^2(\alpha, n) = 2(n-1)t^2 (\alpha', v)/\{v+t^2(\alpha',v)\},$$

where U=R/S.D. is the ratio of the range to the standard deviation, ā is the critical significance level, n is the number of observations, $\alpha' = \alpha/n(n+1)$, $v=n-2$ is the degrees of freedom, and t is the Student's t-statistic. The authors constructed a table of percentage points of the distribution of the ratio of the range to the standard deviation under the assumption of normality.

Fama and Roll (1971), using Monte-Carlo techniques, found that R/S.D. is a more powerful tool for distinguishing the normal distribution than other members of the stable class. The authors suggested this ratio as a goodness of fit test for a normal null hypothesis against non-normal alternatives at all sample sizes. In Table 3.10, the R/S.D. ratios are shown for each data set. Using these results, at significance level $\alpha = 0.05$, normal distributions of annual maximum-storms and maximum-storms for four crop-growth phases, and a normal distribution of annual total rainfall, cannot be rejected. This indicates that assuming log-normal distributions

Table 3.10 Ratios of Ranges to the Standard Deviations for Crop-growth Phase and Annual Maximum and Annual Total Rainfall Erosivity Index EI (R)

	Maximum					Annual
	Phase I	Phase II	Phase III	Phase IV	Annual	Total
Number of Observations	34[a]	35	35	35	34[b]	35
Range (R)	2.291	1.670	2.254	1.556	1.351	1.008
Standard Deviation (S.D.)	0.488	0.419	0.511	0.411	0.311	0.243
Sample Mean	1.083	1.339	0.809	0.708	1.533	2.162
R/S.D.	4.695	3.986	4.411	3.786	4.344	4.148

a,b: Initial analysis by using Weibull plotting position formula on probability paper for each data set, one observation in each data set appeared to be an "outlier". Though the treatments of "outliers" is an unresolved and controversial question (Haan, 1977), it was decided to eliminate these observations for this study.

for crop-growth phase and annual maximum and annual total rainfall erosivity indices is acceptable.

3.7.2 Recurrence Intervals (Return Periods) for Rainfall Erosivity Indices

The primary object of the frequency analysis of hydrologic data is to determine the recurrence interval of a hydrologic event of a given magnitude, say y. A recurrence interval, denoted by T in years, is defined as "the average interval of time within which the magnitude of the event y will be equaled or exceeded once on the average" (Chow, 1953, p. 15). That is, if an event equal to or greater than y occurs once in T years, the chance of occurrence in anyone year or the probability, P, is equal to 1 in T cases, or P = 1/T.

Based on the log-normal distributions being tested for phase and annual rainfall event maxima and total annual rainfall, we calculated maximum energy intensities for 2-year, 5-year, 20-year, 50-year, and 100-year return periods for each data set. The resulting energy intensities will be used to analyze the effects on the efficient sediment control strategy selections under different magnitudes of maximum storms.

In order to understand the reliability of using hourly precipitation data instead of breakpoint data in estimating EI values for use in the USLE, we compared the magnitudes of annual maximum-storm and annual total erosion index values calculated according to procedures described above to those in the Agriculture Handbook No. 537 (Wischmeier and Smith, 1978) for the nearest weather station reporting breakpoint data - Springfield, Illinois, about 73 miles north of the Highland Silver Lake Watershed. Table 3.11 presents the magnitudes of single-storm values for phase and annual maximum and annual total under various return periods.

Table 3.11 Expected Magnitudes of Erosion Index Values for Phase, Annual Maximum and Annual Total for Belleville and Springfield, Illinois*

	Erosion Index Values Normally Exceeded Once in				
	2-Year	5-Year	20-Year	50-Year	100-Year
Phase I	12.11	31.18	76.87	121.72	165.42
Phase II	21.82	49.18	106.72	158.35	206.07
Phase III	6.44	17.35	44.63	72.21	99.56
Phase IV	5.11	11.33	24.22	35.66	46.17
Annual Maximum	35.12 (52)	62.35 (75)	110.81 (117)	148.52	180.59
Annual Total	145.21 (154)	232.60 (210)	364.53 (283)	458.27	533.90

*Expected magnitudes of erosion index for Springfield from Agriculture Handbook No. 537 (Wischmeier and Smith, 1978) are in parentheses.

2-year and 5-year expected magnitudes of annual maximum and annual total erosion indices for Springfield and Belleville are very close. Given their proximity, this is expected, and it tells us that using hourly precipitation data to calculate a rainfall erosion factor for use in the USLE is acceptable. The difference becomes wider for a 20-year return period. (Fifty-year and 100-year expected magnitudes of erosion indices are not available for Springfield.) However, the reliability of frequency analysis decreases in a fixed sample as the length of the recurrence interval is increased, so this too is expected.

3.8 The Worst Erosion Crop-growth Phase in Terms of In-Stream Water Quality

From Table 3.5 to Table 3.8, it is apparent that C values for most of the rotation tillage practices and residue levels are greater in Phase I than those in Phases II-IV. But, it is evident in Table 3.10 that the maximum single storm energy intensities all are higher in Phase II than in Phases I, II, and IV for all return periods. C values and maximum erosion indices with various return periods are relatively low in Phase III and Phase IV.

To determine the worst erosion phase in terms of the highest products of C and R in the USLE, Tables 3.12 to 3.21 list the products of the C and R factors for maximum storm events at various return intervals for Phases I and II. For a 2-year return period, the products for all the rotation tillage practices and residue levels are highest in Phase II. Except for CCSWMMMM with fall plow under the 2,000 lbs/acre residue level, the products are still higher in Phase II with a 5-year return period storm. With a 20-year return period, products for all the residue levels for CS with FP, CSWDCSB with FP and CCSWMMMM with FP are higher in Phase I, but

Table 3.12 Products of C and 2-year Return Period R for Phase I under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	1.901	1.901	1.901	1.901	1.901
CSWDCSB	FP	1.393	1.381	1.344	1.344	1.344
CSWK	FP	0.787	0.775	0.751	0.751	0.751
CCSWMMMM	FP	0.727	0.714	0.702	0.702	0.702
AAAAA	FP	0.242	0.242	0.242	0.242	0.242
CS	FCH	1.502	1.284	1.102	1.017	1.005
CSWDCSB	FCH	1.138	0.981	0.811	0.763	0.714
CSWK	FCH	0.569	0.472	0.291	0.230	0.206
CCSWMMMM	FCH	0.618	0.436	0.266	0.194	0.170
AAAAA	FCH	0.242	0.242	0.242	0.242	0.242
CS	NT	0.763	0.739	0.581	0.557	0.545
CSWDCSB	NT	0.690	0.581	0.460	0.436	0.436
CSWK	NT	0.400	0.327	0.218	0.194	0.182
CCSWMMMM	NT	0.339	0.230	0.133	0.109	0.097
AAAAA	NT	0.242	0.242	0.242	0.242	0.242

Table 3.13 Products of C and 2-year Return Period R for Phase II under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	2.269	2.269	2.269	2.269	2.269
CSWDCSB	FP	1.593	1.593	1.593	1.593	1.593
CSWK	FP	1.047	1.047	1.047	1.047	1.047
CCSWMMMM	FP	0.829	0.829	0.829	0.829	0.829
AAAAA	FP	0.436	0.436	0.436	0.436	0.436
CS	FCH	2.466	2.247	1.898	1.680	1.680
CSWDCSB	FCH	1.702	1.571	1.331	1.200	1.200
CSWK	FCH	1.135	1.026	0.633	0.480	0.458
CCSWMMMM	FCH	0.851	0.782	0.458	0.349	0.327
AAAAA	FCH	0.436	0.436	0.436	0.436	0.436
CS	NT	1.506	1.244	0.982	0.895	0.851
CSWDCSB	NT	1.091	0.916	0.742	0.676	0.655
CSWK	NT	0.698	0.546	0.393	0.327	0.305
CCSWMMMM	NT	0.524	0.371	0.240	0.175	0.153
AAAAA	NT	0.436	0.436	0.436	0.436	0.436

Table 3.14 Products of C and 5-year Return Period R for Phase I under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	4.895	4.895	4.895	4.895	4.895
CSWDCSB	FP	3.586	3.555	3.461	3.461	3.461
CSWK	FP	2.027	1.996	1.933	1.933	1.933
CCSWMMMM	FP	1.871	1.840	1.808	1.808	1.808
AAAAA	FP	0.624	0.624	0.624	0.624	0.624
CS	FCH	3.866	3.305	2.837	2.619	2.588
CSWDCSB	FCH	2.931	2.526	2.089	1.964	1.840
CSWK	FCH	1.465	1.216	0.748	0.592	0.530
CCSWMMMM	FCH	1.590	1.122	0.686	0.499	0.437
AAAAA	FCH	0.624	0.624	0.624	0.624	0.624
CS	NT	1.964	1.902	1.497	1.434	1.403
CSWDCSB	NT	1.777	1.497	1.185	1.122	1.122
CSWK	NT	1.029	0.842	0.561	0.499	0.468
CCSWMMMM	NT	0.873	0.592	0.343	0.281	0.249
AAAAA	NT	0.624	0.624	0.624	0.624	0.624

Table 3.15 Products of C and 5-year Return Period R for Phase II under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	5.115	5.115	5.115	5.115	5.115
CSWDCSB	FP	3.590	3.590	3.590	3.590	3.590
CSWK	FP	2.361	2.361	2.361	2.361	2.361
CCSWMMMM	FP	1.869	1.869	1.869	1.869	1.869
AAAAA	FP	0.984	0.984	0.984	0.984	0.984
CS	FCH	5.557	5.066	4.279	3.787	3.787
CSWDCSB	FCH	3.836	3.541	3.000	2.705	2.705
CSWK	FCH	2.557	2.311	1.426	1.082	1.033
CCSWMMMM	FCH	1.918	1.672	1.033	0.787	0.738
AAAAA	FCH	0.984	0.984	0.984	0.984	0.984
CS	NT	3.393	2.803	2.213	2.016	1.918
CSWDCSB	NT	2.459	2.066	1.672	1.525	1.475
CSWK	NT	1.574	1.230	0.885	0.738	0.689
CCSWMMMM	NT	1.180	0.836	0.541	0.393	0.344
AAAAA	NT	0.984	0.984	0.984	0.984	0.984

Table 3.16 Products of C and 20-year Return Period R for Phase I under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	12.069	12.069	12.069	12.069	12.069
CSWDCSB	FP	8.840	8.763	8.533	8.533	8.533
CSWK	FP	4.997	4.920	4.766	4.766	4.766
CCSWMMMM	FP	4.612	4.535	4.458	4.458	4.458
AAAAA	FP	1.537	1.537	1.537	1.537	1.537
CS	FCH	9.532	8.148	6.995	6.457	6.380
CSWDCSB	FCH	7.226	6.226	5.150	4.843	4.535
CSWK	FCH	3.613	2.998	1.845	1.461	1.307
CCSWMMMM	FCH	3.920	2.767	1.691	1.230	1.076
AAAAA	FCH	1.537	1.537	1.537	1.537	1.537
CS	NT	4.843	4.689	3.690	3.536	3.459
CSWDCSB	NT	4.382	3.690	2.921	2.767	2.767
CSWK	NT	2.537	2.075	1.383	1.230	1.153
CCSWMMMM	NT	2.152	1.461	0.846	0.692	0.615
AAAAA	NT	1.537	1.537	1.537	1.537	1.537

Table 3.17 Products of C and 20-year Return Period R for Phase II under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	11.099	11.099	11.099	11.099	11.099
CSWDCSB	FP	7.791	7.791	7.791	7.791	7.791
CSWK	FP	5.123	5.123	5.123	5.123	5.123
CCSWMMMM	FP	4.055	4.055	4.055	4.055	4.055
AAAAA	FP	2.134	2.134	2.134	2.134	2.134
CS	FCH	12.059	10.992	9.285	8.217	8.217
CSWDCSB	FCH	8.324	7.684	6.510	5.870	5.870
CSWK	FCH	5.549	5.016	3.095	2.348	2.241
CCSWMMMM	FCH	4.162	3.628	2.241	1.708	1.601
AAAAA	FCH	2.134	2.134	2.134	2.134	2.134
CS	NT	7.364	6.083	4.802	4.376	4.162
CSWDCSB	NT	5.336	4.482	3.628	3.308	3.202
CSWK	NT	3.415	2.668	1.921	1.601	1.494
CCSWMMMM	NT	2.561	1.814	1.174	0.854	0.747
AAAAA	NT	2.134	2.134	2.134	2.134	2.134

Table 3.18 Products of C and 50-year Return Period R for Phase I under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	19.110	19.110	19.110	19.110	19.110
CSWDCSB	FP	13.998	13.876	13.511	13.511	13.511
CSWK	FP	7.912	7.790	7.547	7.547	7.547
CCSWMMMM	FP	7.303	7.181	7.060	7.060	7.060
AAAAA	FP	2.434	2.434	2.434	2.434	2.434
CS	FCH	15.093	12.902	11.077	10.224	10.103
CSWDCSB	FCH	11.442	9.859	8.155	7.668	7.181
CSWK	FCH	5.721	4.747	2.921	2.313	2.069
CCSWMMMM	FCH	6.208	4.382	2.678	1.948	1.704
AAAAA	FCH	2.434	2.434	2.434	2.434	2.434
CS	NT	7.669	7.425	5.843	5.599	5.477
CSWDCSB	NT	6.938	5.843	4.625	4.382	4.382
CSWK	NT	4.017	3.286	2.191	1.948	1.826
CCSWMMMM	NT	3.408	2.313	1.339	1.095	0.974
AAAAA	NT	2.434	2.434	2.434	2.434	2.434

Table 3.19 Products of C and 50-year Return Period R for Phase II under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	16.468	16.468	16.468	16.468	16.468
CSWDCSB	FP	11.560	11.560	11.560	11.560	11.560
CSWK	FP	7.601	7.601	7.601	7.601	7.601
CCSWMMMM	FP	6.017	6.017	6.017	6.017	6.017
AAAAA	FP	3.167	3.167	3.167	3.167	3.167
CS	FCH	17.894	16.310	13.776	12.193	12.193
CSWDCSB	FCH	12.351	11.401	9.659	8.709	8.709
CSWK	FCH	8.234	7.442	4.592	3.484	3.325
CCSWMMMM	FCH	6.176	5.384	3.325	2.534	2.375
AAAAA	FCH	3.167	3.167	3.167	3.167	3.167
CS	NT	10.926	9.026	7.126	6.492	6.176
CSWDCSB	NT	7.918	6.651	5.384	4.909	4.751
CSWK	NT	5.067	3.959	2.850	2.375	2.217
CCSWMMMM	NT	3.800	2.692	1.742	1.267	1.108
AAAAA	NT	3.167	3.167	3.167	3.167	3.167

Table 3.20 Products of C and 100-year Return Period R for Phase I under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	25.971	25.971	25.971	25.971	25.971
CSWDCSB	FP	19.023	18.858	18.362	18.362	18.362
CSWK	FP	10.752	10.587	10.256	10.256	10.256
CCSWMMMM	FP	9.925	9.760	9.594	9.594	9.594
AAAAA	FP	3.308	3.308	3.308	3.308	3.308
CS	FCH	20.512	17.535	15.053	13.895	13.730
CSWDCSB	FCH	15.549	13.399	11.083	10.421	9.760
CSWK	FCH	7.775	6.451	3.970	3.143	2.812
CCSWMMMM	FCH	8.436	5.955	3.639	2.647	2.316
AAAAA	FCH	3.308	3.308	3.308	3.308	3.308
CS	NT	10.421	10.091	7.940	7.609	7.444
CSWDCSB	NT	9.429	7.940	6.286	5.955	5.955
CSWK	NT	5.459	4.466	2.978	2.647	2.481
CCSWMMMM	NT	4.632	3.143	1.820	1.489	1.323
AAAAA	NT	3.308	3.308	3.308	3.308	3.308

Table 3.21 Products of C and 100-year Return Period R for Phase II under Various Residue Levels

		2000	3000	4000	5000	>5000
CS	FP	21.431	21.431	21.431	21.431	21.431
CSWDCSB	FP	15.043	15.043	15.043	15.043	15.043
CSWK	FP	9.891	9.891	9.891	9.891	9.891
CCSWMMMM	FP	7.831	7.831	7.831	7.831	7.831
AAAAA	FP	4.121	4.121	4.121	4.121	4.121
CS	FCH	23.286	21.225	17.928	15.867	15.867
CSWDCSB	FCH	16.073	14.837	12.570	11.334	11.334
CSWK	FCH	10.716	9.685	5.976	4.534	4.327
CCSWMMMM	FCH	8.037	7.006	4.327	3.297	3.091
AAAAA	FCH	4.121	4.121	4.121	4.121	4.121
CS	NT	14.219	11.746	9.273	8.449	8.037
CSWDCSB	NT	10.304	8.655	7.006	6.388	6.182
CSWK	NT	6.594	5.152	3.709	3.091	2.885
CCSWMMMM	NT	4.946	3.503	2.267	1.649	1.442
AAAAA	NT	4.121	4.121	4.121	4.121	4.121

the others are higher in Phase II. Products for two other rotation-tillage practices, CSWK with FP and CCSWMMMM with FCH, are higher in Phase I with 50 and 100-year return periods. With these exceptions, the C*R products are higher in crop-growth Phase II.

The damages done by sediment in terms of in-stream water quality depend not only on the amount of sediment but also on the timing of the sediment reaching the water body. For a given amount of sediment, the damages will vary inversely with the background streamflow. The ratio of sediment to streamflow will be a better indicator of sediment concentrations that affect in-stream water quality than are gross sediment loads. A higher ratio of sediment to streamflow suggests poorer water quality.

Average streamflow during each crop growth phase for Silver Creek near Troy, Illinois, about 10 miles east of the Highland Silver Lake Watershed, for water years from 1967 to 1984, is presented in Table 3.22. (A water year is defined from October through September of the following year.) The average streamflow is highest in the spring (Phase IV and I). Low flows are during summer and early fall (Phase II and Phase III). Average streamflow obviously is much lower in Phase II than in Phase I.

The growth phase C*R products point generally, but not universally, to Phase II as the most serious erosion phase. The streamflow data substantially reenforce Phase II as the time when most serious stress on in-stream water quality is likely to be exerted by eroded soil. Hence, all subsequent storm event analyses are focused on Phase II.

Table 3.22 Crop-growth Phase Stream Flow for Silver Creek near Troy, Illinois for Water Year from 1967 to 1984

	Discharge (cubic feet per second)			
Year	Phase I	Phase II	Phase III	Phase IV
1967	49.87	21.32	30.17	207.75
1968	118.47	11.58	3.65	262.08
1969	123.63	202.13	16.69	224.55
1970	290.67	6.44	65.75	51.23
1971	82.10	16.28	1.47	72.25
1972	161.23	10.86	0.29	97.18
1973	215.33	20.03	66.56	281.63
1974	188.77	24.88	35.06	349.50
1975	247.33	39.70	27.60	303.63
1976	14.27	8.79	5.19	66.00
1977	12.99	40.59	7.86	108.26
1978	156.67	6.24	97.95	328.27
1979	257.03	27.53	10.35	241.33
1980	50.43	13.45	1.03	21.27
1981	44.67	89.01	0.91	11.31
1982	115.50	98.84	11.28	239.80
1983	483.67	10.53	87.10	322.00
1984	210.17	26.01	199.70	402.90
Mean	156.82	37.46	37.15	199.52

Source: U.S. Geological Survey, Water Resource Data for Illinois from water year 1967 to 1984.

CHAPTER IV

DATA REQUIREMENTS

4.1 Characterization of the Study Area

A watershed is defined here as the land area for which a specific stream segment captures all surface drainage. By this definition, a watershed may include several subdivisions (catchments) which are independent in their surface runoff hydrologies outside the stream channel. Each subdivision is characterized by a typical path for surface drainage, or transect, along which all sediment is assumed to flow. Every land management unit in a watershed must be crossed by only one transect.

4.1.1 Data Sources and Procedures for Identifying Transects and LMU's

Most of the information necessary for characterizing the surface hydrology in the Highland Silver Lake Watershed was extracted from an Illinois State Water Survey data base which includes a mapping capability. The components of the data base of immediate relevance include data on soils and land uses. The sources used in compiling these components were, respectively, the Madison County Soil Survey produced by the SCS, and aerial photographs. Two maps were extracted from the data base, the first reflecting soils data and representative slopes, and the second showing land usages.

The soil map was simplified by removing boundaries between soil types that did not reflect changes in slope. Each of the polygons remaining could contain multiple soil series[1], but all series within a polygon were in the same representative slope class[2]. The acreage of each soil series within the polygon was maintained.

The next step involved super-imposing the land use map on the simplified soils map. Polygons representing small areas (that were artifacts of the process of overlapping the computer maps) were eliminated by allocating their areas to adjacent polygons. The remaining polygons then represented LMUs, i.e. areas within a field and with a uniform slope.

The drainage pathways needed to define transects were obtained by looking at the topography of the area as reflected in the U.S. Geological Survey 7.5 minute quadrangle map (Grantfork, Illinois). In order that the number of transects would not become too great, the boundaries separating the drainage pathways were assumed to coincide with LMU boundaries wherever possible.

Using estimated watershed-average values of USLE factors S, K, C, and P with average slope length and average slope fails to reflect how the factors levels are combined in each significant subarea. For computational purposes, the division of a large area into LMUs can provide a more accurate simulation of soil losses and sediment delivery rates.

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[1] In the classification system used here, a soil series is broken down by slope class and erosion phase. An example for defining a phase within soil series 517 follows:

517 A 1

517: soil series
A: slope class
1: erosion state

[2] Representative slope classes were obtained from SCS officers by assigning typical slopes identified in field investigations to individual soil series.

4.1.2 Summary Information for each LMU

Given the definition of LMU's as described in section 3.1, data were prepared for running SOILEC as summarized in Table 4.1. Figure 4.1 shows the transect lines and associated LMUs and field boundaries. In reality, the runoff drainages are curvilinear. So, the transect lines need not be straight, as they are shown in the figure. (Also note that the order of LMU numbers in the SEDEC model is actually opposite to the order shown in this section.)

Table 4.1 Summary Information for Each LMU

TRANSECT No.	LMU No.	SOIL-SERIES^a	%LMU	ACRES	SLOPE (%)	SLOPE-LENGTH (ft)	FIELD^b No.	FARM^c No.
A	1	581B2	23	20.90	3.28	1416	1	1
		620B2	29					
		916B1	48					
	2	995A1	100	6.30	1.00	790	1	1
B	1	916B1	100	5.20	2.50	362	2	2
	2	68A1	81	21.50	1.00	889	2	2
		995A1	19					
C	1	620B2	26	16.80	2.89	1448.7	3	3
		916B1	74					
	2	620B2	40	21.70	3.10	1185	4	4
		916B1	60					
	3	68A1	100	3.40	1.00	625.6	5	4
D	1	120A1	100	5.00	1.00	856	6	4
	2	914D3	100	2.30	13.00	263.4	7	4
E	1	620C3	62	6.70	6.76	790	5	4
		914C3	38					
	2	914C3	100	1.50	8.00	263.4	6	4
F	1	995A1	100	3.30	1.00	263.4	4	4
	2	620C3	62	9.60	6.76	1185	5	4
		914C3	38					
G	1	68A1	16	2.90	1.00	296	8	3
		995A1	84					
	2	620C3	100	4.70	6.00	592.7	8	3
H	1	68A1	16	6.90	1.00	461	8	3
		995A1	84					
	2	517B1	24	8.00	2.86	526.8	8	3
		916B1	76					
I	1	581B2	23	6.30	3.28	856.1	9	1
		620B2	29					
		916B1	48					

Table 4.1 (continued)

J	1	620C3	100	5.80	6.00	526.8	9	1
K	1	120A1	100	5.00	1.00	790	6	4
	2	620C3	39	14.20	7.22	1152.4	7	4
		914C3	61					
	3	415A1	65	2.00	1.35	197.6	*	*
		451A1	35					
L	1	120A1	100	10.00	1.00	757.3	6	4
	2	914D3	100	5.00	13.00	461	7	4
	3	415A1	100	2.40	1.00	263	7	4
	4	415A1	65	3.00	1.35	131.7	*	*
		451A1	35					
M	1	914D3	100	3.20	13.00	526.8	10	4
	2	415A1	100	7.70	1.00	461	10	4
N	1	517B1	100	2.70	4.00	592.7	11	4
	2	914D3	100	3.80	13.00	526.8	*	*
O	1	914D3	100	2.60	13.00	395.1	12	5
	2	415A1	65	3.00	1.35	131.7	*	*
		451A1	35					

a: Soil series:
68A1 - SABLE
120A1 - HUEY
415A1 - ORION
451A1 - LAWSON
517B1 - MARINE
581B2 - TAMALCO
620B2 - DARMSTADT
620C3 - DARMSTADT
914C3 - ATLAS-GRANTFORK
914D3 - ATLAS-GRANTFORK
916B1 - DARMSTADT-OCONEE
995A1 - HERRICK-PIASA

b: A field is defined as an area with a single management practice. A field number from 1 through 12 is assigned to each field in the study area to allow imposition of intra-field constraints on management practices.

c: Each of the five farmers operating in the study area was assigned a number from 1 through 5. This allows imposition of intra-farm constraints.

*: Woodland (noncrop land) was assigned 99 for a field number and 99 for a farm number.

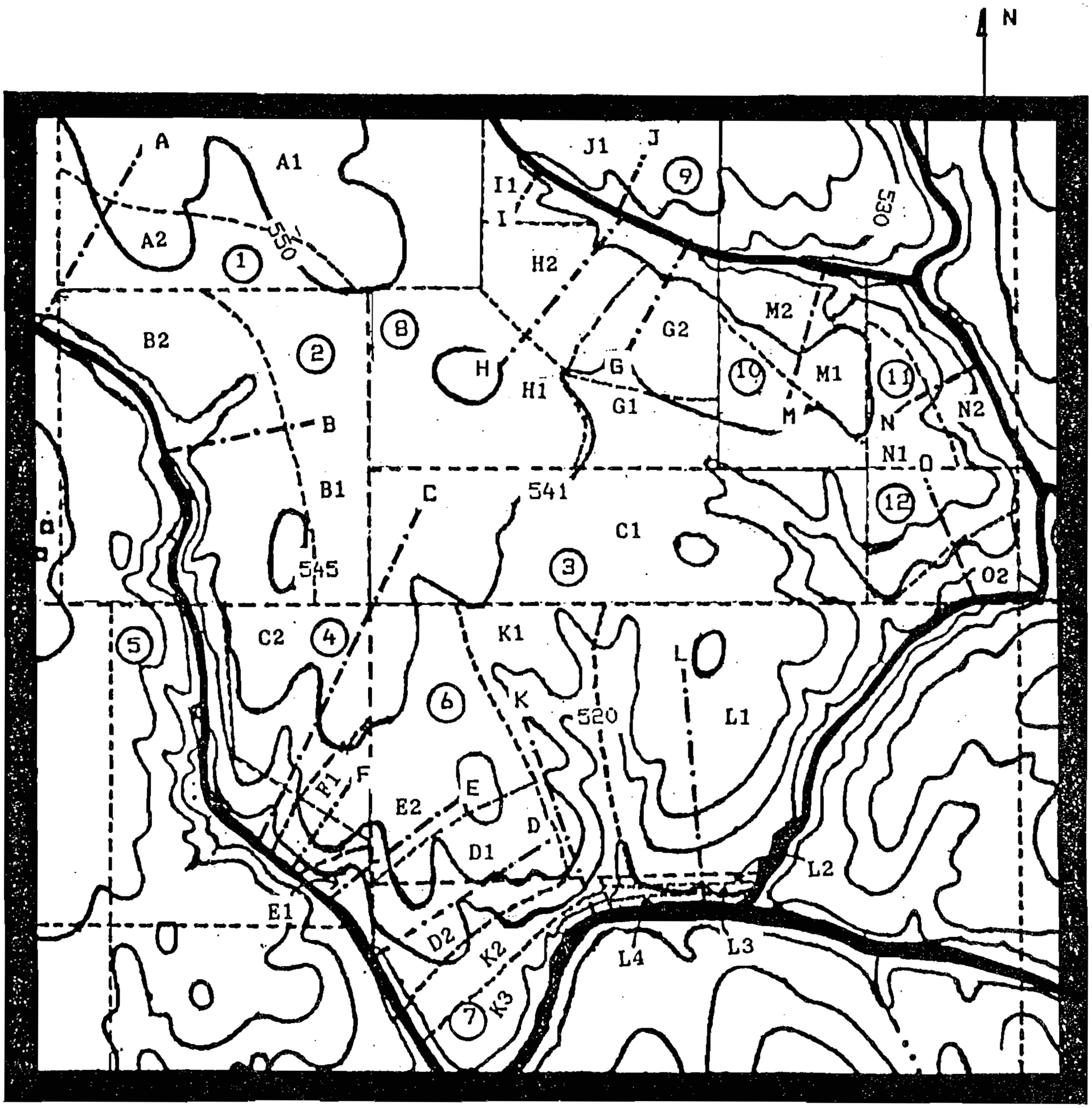
4.2 Soil Types and Associated Crop Yields

SOILEC requires crop yield data at four stages of erosion for each soil type: no-erosion (no A horizon eroded away); moderate erosion (four inches of A horizon remaining); severe erosion (no A horizon remaining); and very severe erosion (no A or B horizon remaining). Crop yields on uneroded soils were taken from University of Illinois Cooperative Extension Service, Circular No. 1156 (1978), Soil Productivity in Illinois. Adjustments were made based on reactions from farmers in the HSL area to get close to the real situation (Starr, 1983). Crop yields for the other three erosion stages were estimated based on relative productivity indices listed in Soil Productivity in Illinois under the assumption of high level management. Table 4.2 contains a list of crop yields for each soil type and erosion stage found in the study area.

Table 4.2 Crop Yields at Various Erosion Levels for Each Soil Type in Study Area

Soil Types	Depth[a] (inch)	Corn (bu/ac)	Soybean (bu/ac)	Wheat (bu/ac)	DCSoybean (bu/ac)	Alfalfa (ton/ac)	Clover (ton/ac)
Sable	0	167.0	60.0	77.0	36.0	5.6	4.5
(68A1)	12	162.0	58.2	74.7	34.9	5.4	4.3
	16	150.3	54.0	69.3	32.0	5.0	4.0
	47	58.0	17.0	18.0	10.2	2.0	1.8
Elco	0	80.0	29.0	46.0	17.4	3.8	3.2
(119C3)	2	76.0	27.6	43.7	16.5	3.6	3.0
	6	72.0	26.1	41.4	15.7	3.4	2.9
	62	48.0	14.0	17.0	8.4	1.8	1.5
Elco	0	83.0	30.0	47.0	18.0	4.0	3.1
(119D2)	2	74.7	27.0	42.3	16.2	3.6	2.8
	6	70.6	25.5	40.0	15.3	3.4	2.6
	62	48.0	14.0	17.0	8.4	1.8	1.5
Huey	0	52.0	21.0	37.0	12.6	2.6	2.3
(120A1)	5	50.4	20.4	35.9	12.2	2.5	2.2
	9	46.8	18.9	33.3	11.3	2.3	2.0
	37	38.0	17.0	18.0	10.2	2.0	1.8
Rozetta	0	99.9	34.6	57.4	20.8	4.8	3.9
(279C2)	2	94.9	32.9	54.5	19.8	4.6	3.7
	6	84.0	32.0	49.0	19.2	3.8	3.1
	49	58.0	17.0	18.0	10.2	2.0	1.8
Orion	0	111.0	40.0	59.0	24.0	4.7	3.4
(415A1)	3	107.7	38.8	57.2	23.3	4.6	3.3
	7	99.0	36.0	53.1	21.6	4.2	3.0
	60	58.0	17.0	18.0	10.2	2.0	1.8
Lawson	0	161.0	48.0	62.0	28.8	5.7	4.4
(451A1)	5	156.2	46.6	60.1	28.0	5.5	4.2
	9	144.9	43.2	55.8	25.9	5.1	3.9
	60	58.0	18.0	17.0	10.2	2.0	1.8
Marine	0	97.0	34.0	57.0	21.0	4.8	3.5

Figure 4.1 Location of Transects and LMUs Boundaries in the Study Area



Legend

------ = Approximate LMU Boundaries
-.-.- = Approximate Location of Transects
——— = Waterway
A = Transect number
A1 = LMU number (see Table 4.1 for location of LMU's by Transect number)
① = Field number
520 = Elevation (ft)

Table 4.2 (continued)

(517B1)	8	94.1	33.0	55.3	19.8	4.7	3.4
	14	87.2	30.6	51.2	18.8	4.3	3.1
	57	58.0	17.0	18.0	10.2	2.0	1.8
Tamalco	0	54.0	21.0	36.0	12.6	2.7	1.4
(581B2)	2	52.9	20.6	35.3	12.4	2.6	1.3
	6	51.3	19.9	34.2	11.9	2.5	1.2
	39	40.0	14.2	15.0	8.5	1.7	1.1
Darmstadt	0	51.2	21.3	36.7	12.8	2.7	2.0
(620B2)	2	50.2	20.9	36.0	12.5	2.6	1.9
	6	43.0	17.9	30.9	10.7	2.3	1.7
	49	40.0	14.2	15.0	8.5	1.7	1.5
Darmstadt	0	41.4	17.2	28.8	10.3	2.2	1.6
(620C3)	2	39.3	16.3	27.4	9.8	2.1	1.5
	6	37.3	15.5	25.9	9.3	1.9	1.4
	46	33.1	13.8	23.0	8.2	1.8	1.3
Atlas-	0	50.0	12.7	18.6	7.6	2.1	1.2
Grantfork	2	46.0	11.7	17.1	7.0	1.9	1.1
(914C2)	6	34.3	8.7	12.8	5.2	1.7	0.8
	61	20.0	5.0	10.0	3.0	1.0	0.7
Atlas-	0	32.3	11.8	16.7	7.1	1.6	1.2
Grantfork	2	29.1	10.6	15.0	6.4	1.4	1.1
(914D3)	6	27.5	10.0	14.2	6.0	1.3	1.0
	61	20.0	5.0	10.0	3.0	1.0	0.7
Darmstadt-	0	77.0	28.0	48.0	16.8	3.8	2.6
Oconee	5	73.1	26.6	45.6	16.0	3.6	2.5
(916)	9	61.4	22.3	38.3	13.4	3.0	2.1
	60	58.0	17.0	18.0	10.2	2.0	1.8
Herrick-	0	125.0	44.0	64.0	26.4	4.5	3.0
Piasa	13	121.3	42.7	62.1	25.6	4.4	2.9
(995A1)	17	112.5	39.6	57.6	23.8	4.1	2.7
	60	58.0	17.0	18.0	10.2	2.0	1.8

a: First level is no soil erosion. Second level is 4 inches of A horizon remaining. Third level is no A horizon remaining. Fourth level is the sum of A and B horizons.

4.3 Crop Prices

The other basic variables in determining total revenues for each management system are crop prices. The crop prices used here, with the exception of clover hay, are based on 1980-1983 monthly average nominal prices reported in Illinois Agricultural Statistics-Annual Summary (Illinois Cooperative Crop Reporting Service, 1984). For each year, the high and low monthly average prices were identified for each crop. These highs and lows were averaged over the four year sample. Because clover hay prices are not available in these data, "other hay" is substituted. The prices for corn, soybeans, wheat, double crop soybeans, alfalfa, and clover are 2.75 ($/bu), 6.73 ($/bu), 3.66 ($/bu), 6.73 ($/bu), 61.69 ($/ton), and 43.67 ($/ton) respectively. The relative rankings of management systems analyzed in the study will not be changed due to the inflation, if inflation has the same effects on these crops. Therefore no inflation adjustments were made for these prices.

4.4 Production Variable Costs - MBMS Budget Generator

The Microcomputer Budget Management System (MBMS) computer software package (Olson et al., 1985) was used to generate budgets for different combinations of crop rotations and tillage practices. MBMS provides systematic information storage for crop and livestock enterprise budgets. The data requirements for MBMS are divided into three general categories. The first is concerned with production. The yields and price per unit are needed for each crop. The second section requires information concerning all operating inputs, including fertilizer, seed, chemical, and lime application rates, costs per acre of any custom work such as spraying or fertilizing, rental costs for machinery including a fertilizer spreader or anhydrous knife, and any other items used in the production and harvest of a given crop. The final category deals with machinery information. It is necessary to specify the machine or implement used, the power unit (i.e. tractor or pickup truck used to pull the implement, implement size, month(s) of use, and number of times used per acre in any given month.

Data on input use and cost were obtained from the U.S. Soil Conservation Service. The base budgeting year for costs was 1982. Total variable costs per acre for a rotation were computed by adding the variable costs for the proper crops and tillage together and dividing by the number of years the rotation encompassed. For example, for a corn-soybean rotation with fall plow tillage, the variable costs for fall plow corn following soybeans were added to the variable costs for fall plow soybeans following corn, and divided by 2.

4.5 Rotation Tillage Systems and Mechanical Control Practices

In general, tillage systems are classified as conventional, reduced, or no tillage. Traditionally, eastern Corn Belt farmers have prepared the soil for planting corn or soybean by moldboard plowing and working the seedbed with several secondary tillage operations. By the mid-1960s, farm innovators and some researchers reported success with various tillage techniques that did not include the moldboard plow. Chiseling, for example, which had been practiced by a few conservation-minded farmers for years, become more popular (Griffith et al., 1977).

In the moldboard plow system, more passes over the field are required relative to the other systems. The result is higher labor, fuel, and power unit expenses. Yields with the moldboard plow are as high or higher than with alternative tillage systems over a wide range of soil and weather conditions. But, the great disadvantage of moldboard plowing is that bare soil is very susceptible to wind and water erosion (University of Illinois, Cooperative Extension Service, 1982).

In chisel plowing, one of the reduced tillage systems, primary tillage is done with a chisel plow, usually in the fall, followed by use of a disk or field cultivator in the spring. Under this system, the soil surface is rough and partially covered by crop residues. The residues and roughness reduce raindrop impacts and runoff, resulting in more water infiltration and less soil erosion. At the same time, soil roughness and crop residues protect the soil from wind erosion. However, crop residues on the soil surface may harbor insects and disease-causing organisms.

In no-tillage system (zero-tillage), seeds are planted in previously undisturbed soil by means of a special, heavy-duty planter equipped to plant through residue in firm soil. Soil erosion is greatly reduced compared to other systems, and plant residues on the soil surface reduce evaporation, conserving soil moisture for use by the crop. However, larger amounts of chemicals are usually applied to control weeds and pests since cultivation and plowing are eliminated. In addition, soil warming and drying in the spring may be retarded.

Proper use of crop residues is one of the most powerful tools available for controlling or reducing soil losses due to runoff. Reduced tillage and no-tillage have proven to be very effective in reducing runoff and soil losses. For most crops, the amount of residue produced is related to yields. Higher yields generally produce greater amounts of residue. Consequently, fertilization and good crop management that will produce adequate yields are important considerations in erosion control.

Estimates of residue per bushel of harvested yield are given in Table 4.3. Admittedly, exact amounts of residue will vary by species or varietal differences within a crop or due to weather conditions during the growing

Table 4.3 Approximate Residue Production by Various Crops

Corn and Sorghum	1bu. grain = 56 bu. residue
Wheat and Rye	1bu. grain = 100 bu. residue
Oats	1bu. grain = 50 bu. residue
Soybeans	1bu. grain = 80 bu. residue

Source, Walker (1981)

season. In addition, as shown in Table 4.4, the amount of residue remaining decreases after each tillage operation.

Table 4.4 Reduction of Surface Residue from Tillage Operations

Tillage Operation	Percent of Crop Residue Remaining After Tillage	Percent Reduction of Crop Residue
No-till planting	90-100	0-10
Chisel plow straight shanks	75-80	20-25
Chisel plow twisted shanks	40-50	50-60
Field cultivator (with sweeps)	75-80	20-25
Tandem disk after harvest before other tillage	85-90	10-15
Tandem disk after previous tillage	40-60	40-60
Offset disk (24 inch blades, 6" deep)	25-50	50-75
Moldboard plow	0-5	90-100
Overwinter decomposition	70-75	20-25

Source : Walker (1981)

Mechanical control practices change the flow pattern of runoff water. Examples are contour cultivation, contour strip cropping, and terracing. Contouring is a technique used to slow down the speed at which the rainfall runs down a slope by aligning furrows perpendicular to the slope rather than parallel to it. Strip cropping entails growing alternate swaths of crops in a field. Strip cropping is commonly performed with contouring to further reduce erosion. Terraces are embankments of soil constructed to shorten the length of slope in a field. Surface runoff water collects above a terrace and can be removed from the field by tile or grassed outlets, preventing additional damage further down the slope.

In this study, a management system consists of a particular crop rotation, a tillage system and a mechanical control practice. As indicated in Chapter III, five crop rotations (corn-soybean (CS), corn-soybean-wheat-double crop soybeans (CSWDCSB), corn-soybean-wheat-clover (CSWK), corn-corn-soybean-wheat-meadow-meadow-meadow-meadow (CCSWMMMM), and continuous alfalfa (AAAAA)) are considered here. These are the typical rotations used by farmers in the Highland Silver Lake Watershed (White et al., 1985). Three tillage systems are considered -- fall plow (FP), fall chisel (FCH), and no-till (NT) -- along with four mechanical control practices, -- up-and-down-slope (vertical) cultivation (VT), contour cultivation (CN), and contour strip cropping (ST), contour and terracing (CN&TR). Overall, 60 different management systems are analyzed for each farm field.

4.6 Rainfall Erosivity Factor (R)

A storm is defined by Wischmeier and Smith (1978) as a rain shower with at least 0.5 inches of rainfall and which is separated from other rain periods by more than 6 dry hours. An exception is that if 0.25 inches of rain fall in 15 minutes. Hourly precipitation data for 35 years were obtained from the Climate Information Unit of the Illinois State Water Survey for the Belleville, Illinois weather station. These were used to estimate storm event R factors according to the procedures outlined in section 3.7. The following formula was used to calculate the energy of every single storm and its maximum 30-minute intensity from breakpoint data (Wischmeier and Smith, 1978):

$$EI_{30} = \frac{1}{100} \left[\sum_{i=1}^{k} 916 + 331 \log_{10} (I_{60})_i \, I_i \right] \cdot \text{Max} \left[\sum_{i=q}^{m} I_i \right]_{60} \qquad (4.1)$$

$$q \geqslant 1, \quad m \leqslant k$$

where:

EI_{30}: storm energy based on maximum 30-minute intensity (foot-tons/acre-inch).

I_i: amount of rainfall in each interval, each interval usually shorter than one hour, (inches/interval),

$(I_{60})_i$: conversion of rainfall in inches per interval to inches per hour,

i: duration of each storm based on the constant intensity of each interval divided into k intervals, $i = 1, 2, \ldots, k$,

$\text{Max}\left[\sum_{i=q}^{m} I_i\right]_{60}$: the maximum amount of rain falling within 30 consecutive minutes converting to inches per hour.

Following an analogous procedure, a formula that calculates the energy of each storm and its maximum 30-minute intensity from hourly precipitation rainfall data is:

$$EI = \frac{1}{100} \left[\sum_{j=1}^{n} (916 + 331 \log_{10} P_j) \, P_j \right] \cdot 1.5 \, \text{Max} \, (P_j) \qquad (4.2)$$

where:

EI: storm energy calculated by converting from 60-minute measurement interval data to maximum 30-minute intensity (foot tons/acre-inch),

P_j: hourly intensity of rainfall in the jth increment of a storm

j: duration of each storm in hours, $j = 1,2,\ldots, n$.

Measurement of total energy for a rainfall is in foot-tons/acre. This is multiplied by a constant factor of 100 to be expressed in units used for EI values (Wischmeier and Smith, 1978).

Maximum 30-minute intensity was chosen from the highest hourly rainfall intensity of each storm multiplied by 1.5 for converting from 60-minute to 30-minute intervals. This is the approach recommended by Barfield et al. (1981) based on data for Lexington, Kentucky. The maximum intensities for 30-minute intervals were about 1.5 times the intensities for 60-minute intervals. We applied this relationship to each storm and adjusted the calculation of EI as close as possible to that from breakpoint data.

Two differences between the procedure used here and the one used by Wischmeier and Smith, based on breakpoint data, should be noted. First, $(I_{60})_i$ is converted from the amount of rainfall I_i in each breakpoint interval, whereas the amount of rainfall in expression (4.2), P_j, is taken directly from hourly rainfall amounts. The amount of rainfall (P_j) might occur in less than an hour. The second difference is the maximum 30-minute intensities. In expression (4.1), it is the maximum amount of rain falling within 30 consecutive minutes, which may be the sum of the rainfall intensity for several internals, $\sum_{i=q}^{m} I_i$, and is converted to the intensity for an hour. However, the only information in hourly precipitation rainfall data is the maximum intensity for an hour during the storm. Because of these two differences, underestimation of the EI values for each storm is expected. In order to offset the possible underestimation of EI value for each storm, a storm is defined in this procedure as a rainfall event separated from other rainfall periods by at least 6 hours. No minimum rainfall intensity was required. These decisions do not affect EI values for large storms, but may include some small rain showers that would not otherwise be included. The effect would be to increase slightly the annual total EI values.

Based on the procedures described above, Table 4.5 and Table 4.6 present the estimated monthly total and monthly maximum rainfall erosivity indices (EI(R)) for Belleville, Illinois.

4.7 Crop and Management Factors C

In order to compute the annual average C values and rotation average C values for each crop-growth phase, we follow the procedures recommended by Wischmeier and Smith (1978). The needed information was obtained as follows (Column numbers are as they are shown in Appendix):

Column 1: list in chronological sequence all the land-cover changes that begin each new crop-stage

Column 2: list the date on which each crop-stage begins

Column 3: identify the crop-stages

Column 4: percentage of EI in each crop-stage by referring to Figure 3.3

Column 5: soil loss ratios for each crop-stage under different rotations and tillage practices. All information is obtained from Table 5 and supplement Tables 5-B, 5-C, and 5-D in Agriculture Handbook No. 537 (Wischmeier and Smith, 1978).

Column 6: the product of values in columns 4 and 5. The sum of these products is the C value for the entire rotation. Annual average C value is this sum divided by the number of years in the rotation.

Table 4.5 Monthly Total Rainfall Erosivity Index ((EI(R)) for Belleville, Illinois from 1949 to 1983.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1949	22.59	14.41	2.88	0.80	0.78	3.31	0.00	0.00	2.09	37.23	0.59	11.79
1950	5.38	9.46	4.93	11.05	10.26	8.71	2.48	23.13	8.41	0.00	22.94	1.05
1951	5.83	3.96	1.82	0.71	2.22	10.79	2.34	1.65	10.20	2.84	9.07	0.85
1952	0.64	1.03	2.89	6.67	1.50	15.66	14.06	5.83	4.97	0.11	7.10	1.12
1953	1.34	0.85	8.94	17.31	0.52	18.89	3.87	1.32	0.71	2.91	0.75	0.37
1954	3.74	1.38	1.99	39.13	6.31	6.69	5.33	23.59	38.04	21.48	0.93	3.82
1955	0.30	3.48	3.54	3.18	4.86	8.38	11.33	13.46	22.53	39.34	3.46	0.07
1956	0.00	1.34	0.23	0.07	84.63	67.56	56.72	45.74	34.61	1.43	13.69	19.37
1957	1.98	4.79	4.22	32.34	38.11	380.35	15.76	31.60	4.94	4.73	7.25	6.23
1958	1.04	0.32	2.77	5.26	9.35	26.08	84.32	67.50	4.51	19.13	65.71	0.20
1959	1.66	8.98	3.71	2.97	43.55	1.36	10.27	43.67	6.83	14.80	4.63	5.63
1960	3.63	1.23	1.66	8.03	15.45	44.34	3.03	4.70	0.76	3.81	8.06	5.42
1961	0.14	0.32	16.40	1.58	124.97	16.85	45.61	105.64	1.28	1.59	0.00	3.75
1962	4.63	6.82	0.01	1.31	0.03	0.00	0.00	69.19	8.61	0.00	0.01	0.01
1963	0.08	0.15	4.66	18.66	23.48	2.04	15.57	2.30	2.80	0.55	10.37	0.76
1964	0.37	3.12	7.20	13.76	3.83	3.96	16.93	14.06	3.24	0.29	3.75	1.65
1965	2.86	1.42	2.32	9.59	18.10	36.94	8.93	16.86	102.03	0.00	2.62	15.57
1966	0.88	1.03	19.57	13.78	3.52	2.29	0.00	2.88	23.17	6.61	11.35	5.53
1967	4.26	1.79	3.16	3.05	24.06	10.11	9.40	10.91	8.93	7.16	4.25	33.71
1968	2.44	2.47	2.71	4.29	49.75	0.00	108.50	10.74	10.46	0.44	24.24	9.31
1969	23.25	3.14	3.60	7.86	2.81	63.57	115.42	0.00	34.68	28.64	1.93	2.58
1970	0.09	1.20	3.57	32.29	8.97	43.34	1.35	16.11	31.43	5.84	0.18	0.00
1971	0.70	6.23	1.71	2.32	12.81	4.91	0.44	0.18	5.52	1.93	2.05	39.15
1972	2.06	0.09	7.12	9.12	1.73	2.09	0.00	0.00	23.01	6.04	188.31	15.38
1973	1.99	1.64	13.63	22.45	32.87	66.49	8.23	13.13	61.90	4.52	0.00	1.32
1974	4.48	6.61	9.37	7.80	28.04	12.06	0.85	125.39	7.63	5.07	2.69	0.00
1975	38.92	1.00	8.44	17.50	7.72	3.40	24.89	17.15	3.17	0.61	2.73	3.14
1976	0.70	0.61	8.00	2.35	11.69	6.49	23.57	11.68	8.03	11.82	0.18	0.61
1977	0.88	6.72	37.81	3.17	3.64	28.99	10.31	45.54	4.28	16.46	12.59	3.99
1978	0.72	0.72	9.51	3.32	3.78	2.55	45.95	5.76	28.12	6.72	0.00	3.28
1979	1.40	6.43	18.97	28.71	5.87	24.98	89.11	61.46	0.00	0.88	7.04	3.19
1980	0.76	1.73	12.03	64.91	6.28	5.02	9.59	8.69	26.91	6.40	0.88	0.70
1981	0.97	2.43	2.14	9.11	36.65	28.09	57.20	10.92	37.14	17.46	0.18	2.31
1982	8.17	1.37	4.42	30.01	26.86	14.52	26.04	16.60	16.91	7.63	3.28	64,65
1983	0.70	0.97	6.06	13.11	17.69	15.68	4.55	26.35	5.02	31.09	30.08	6.50

Table 4.6 Monthly Maximum Rainfall Erosivity Index (EI(R)) for Belleville, Illinois from 1949 to 1983.

Year	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1949	0.36	14.19	1.69	0.34	0.45	2.80	0.00	0.00	2.09	37.23	0.57	9.87
1950	5.19	5.08	1.95	7.16	5.77	6.92	1.68	15.97	3.63	0.00	15.42	0.94
1951	5.83	3.08	0.88	0.68	1.87	2.82	2.16	0.91	8.00	2.84	6.75	0.28
1952	0.33	0.63	2.62	3.28	1.10	15.58	9.71	5.27	3.72	0.08	5.88	0.57
1953	0.54	0.75	5.26	10.61	0.22	8.17	3.77	1.12	0.47	1.97	0.70	0.20
1954	3.22	0.93	0.82	15.83	3.10	5.98	3.94	15.62	38.03	15.55	0.43	1.93
1955	0.16	1.62	3.10	0.93	2.77	6.63	9.77	13.43	11.87	34.27	3.45	0.07
1956	0.00	1.33	0.22	0.06	72.99	51.81	25.46	28.62	30.97	1.42	11.63	19.09
1957	1.92	3.89	2.48	16.95	19.54	345.51	15.04	16.13	3.91	3.47	2.57	4.50
1958	0.65	0.32	1.63	3.36	5.07	21.72	39.70	50.84	1.91	11.86	57.66	0.19
1959	1.65	8.70	2.42	2.47	15.81	1.06	7.17	37.03	5.27	8.18	4.34	3.23
1960	2.47	0.70	1.34	3.12	5.34	23.97	1.84	3.60	0.76	2.63	5.53	5.02
1961	0.12	0.19	11.10	1.01	111.52	16.08	30.07	97.65	1.28	1.36	0.00	1.87
1962	4.20	2.90	0.01	0.57	0.03	0.00	0.00	68.22	4.29	0.00	0.01	0.01
1963	0.04	0.07	3.15	15.78	11.47	1.48	14.97	1.42	2.80	0.26	9.94	0.41
1964	0.11	1.62	4.10	5.70	2.95	1.91	16.21	11.27	1.11	0.29	3.00	1.31
1965	1.49	1.25	1.03	7.91	14.51	9.07	7.04	7.89	73.17	0.00	2.19	12.64
1966	0.44	0.76	19.13	4.39	1.88	1.62	0.00	1.62	21.06	5.26	6.81	3.92
1967	3.90	1.17	2.11	1.52	8.90	6.11	5.17	10.64	5.60	3.05	3.29	22.92
1968	1.00	1.88	1.27	2.67	24.35	0.00	82.09	4.09	9.34	0.26	9.55	4.43
1969	19.11	1.17	2.81	1.88	0.94	34.86	60.94	0.00	19.32	20.10	1.11	1.29
1970	0.09	0.59	1.00	13.00	6.35	20.10	1.00	5.80	18.98	3.76	0.09	0.00
1971	0.44	3.38	1.27	1.79	5.56	2.58	0.26	0.09	4.25	1.35	0.76	22.84
1972	1.88	0.09	4.74	2.94	0.76	1.00	0.00	0.00	15.18	4.25	179.66	5.17
1973	0.94	1.29	4.55	12.80	17.38	50.19	3.50	8.11	43.02	1.76	0.00	0.26
1974	2.81	5.20	4.55	2.40	9.83	9.93	0.59	92.96	4.46	4.81	1.11	0.00
1975	31.46	1.00	2.23	7.51	2.58	1.27	24.27	9.83	1.79	0.26	1.00	2.17
1976	0.44	0.26	2.24	1.17	6.36	3.41	21.52	7.59	6.36	6.78	0.18	0.53
1977	0.18	3.37	26.07	2.23	1.27	18.30	4.27	29.12	0.82	12.09	7.37	2.67
1978	0.35	0.61	5.26	1.11	1.46	1.00	22.46	3.06	26.59	6.10	0.00	1.87
1979	0.35	4.73	9.06	15.94	4.55	24.04	81.71	18.96	0.00	0.44	3.11	2.75
1980	0.41	1.11	8.75	58.45	3.38	3.53	6.74	5.78	15.31	3.81	0.35	0.35
1981	0.44	1.81	0.94	3.06	30.88	13.74	24.57	4.39	31.95	5.08	0.18	2.05
1982	4.69	0.41	1.29	27.99	12.79	6.36	15.79	6.97	13.33	3.29	1.11	46.06
1983	0.26	0.70	3.05	6.58	15.99	9.19	4.38	26.00	3.06	27.90	13.95	3.51

Regrouping the percentage of EI and soil loss ratios by the crop-growth phases defined in section 3.6 allows computation of the rotation average C values for each crop-growth phase. For each crop in a rotation, the product of the percentage of EI and soil loss ratio for a crop-growth phase is the phase C value for that crop. The rotation average C value for a crop growth phase is the average of the phase C values for all crops in the rotation. The results of these calculations are shown in Table 3.4 to Table 3.7. Detailed information for calculating annual average and rotation average C values for each crop-growth phase is shown in Appendix A.

4.8 Other Factors for Computation of Soil Erosion in USLE

K factors and bulk densities were needed for both the A and B horizons of each soil type, which were obtained from Madison County Soil Survey unpublished data. Also, it was necessary to define the depths of these two horizons. These values are summarized in Table 4.7 for each soil type.

Table 4.7 K Factor, Soil Bulk and Depths for A and B Horizon

Soil Type (inches)	K Factor		Soil Bulk (g/cm^3)		Soil Depth	
	A	B	A	B	A	B
Sable	0.28	0.28	1.30	1.40	16	31
Elco	0.37	0.37	1.40	1.50	6	56
Huey	0.43	0.43	1.40	1.50	9	28
Rozetta	0.37	0.37	1.30	1.40	6	43
Orion	0.37	0.37	1.25	1.33	7	53
Lawson	0.32	0.43	1.30	1.50	9	51
Marine	0.37	0.37	1.40	1.50	14	43
Tamalco	0.43	0.43	1.40	1.40	6	33
Darmstadt	0.43	0.43	1.40	1.50	6	43
Atlas-Grantfork	0.43	0.43	1.50	1.60	6	55
Darmstadt-Oconee	0.37	0.43	1.40	1.50	9	51
Herrick-Piasa	0.32	0.34	1.30	1.40	17	43

CHAPTER V

ANALYSIS AND RESULTS

The simulation and optimization results for the annual average and storm event sedimentation models are discussed in this chapter. Before we analyze the results, several important assumptions are presented at the outset of this chapter. In the remaining sections, we: 1) investigate control costs of cumulative sediment and control costs of sediment from episodic events, 2) analyze how the annual average sedimentation model can be adapted to deal with impacts of weather episodes and vice versa, and 3) discuss how the land uses change with policies directed to sediment accumulation versus those aimed at controlling episodic sediment loads.

5.1 Assumptions

Crop prices were assumed fixed in real terms over a 50-year planning horizon. An 8% real discount rate was used in this study to determine the present value of a 50-year income flow. A previous study by Harshbarger and Swanson (1964) showed that changing the discount rate from 5% to 20% affected the present values of various long-run farm plans but did not usually alter their relative rankings. A study by Johnson et al. (1984) also found that the percentage change in compensation required to achieve the T-value was relatively small with discount rate changing from 4% to 12%.

The SEDEC model requires that tillage be the same for all fields in each farm and that the same rotation be used on all LMU's in a field. These restrictions apply only within a transect, not across transects, due to computational demands that arise if cross-transect constraints are introduced.

Realism is sacrificed where a crop rotation is allowed to vary within a field that crosses catchment boundaries or where a farm with land in several catchments is depicted in the simulation results as using several tillage practices.

The budgets for some LMU's with steep slopes or low-productivity soils revealed that net returns would be negative for all management options. Such an area would not be farmed by a profit-oriented farmer, unless doing so somehow facilitated operations on surrounding fields. To deal with such areas for the purposes of this study, each unprofitable LMU was analyzed as part of the larger farm field in which it occurs. The field-level analysis revealed one field (number 7) (see Table 4.1 and Figure 4.1) in which all management options yielded negative net returns. As such, it was decided that this field should be left fallow, with a permanent alfalfa rotation assigned, to reflect the economic assumption that farmers would not operate this field without covering the variable costs.

Unprofitable LMUs that were part of fields for which positive profits could be realized overall were not restricted to permanent cover. Rather, the full range of rotations and tillage practices were permitted, with the choice of practices based on relative operating returns over the whole field, not just the unprofitable LMU. This approach is justified on the grounds that breaking fields down into smaller areas fails to capture economies due to uniform operation over a large area. Thus, to let a few areas of a field lie fallow because of an outcrop of poor soil would interfere with operations on the surrounding areas.

According to aerial photographs, four of the LMUs included in the area analyzed in this study are woodland. It was assumed that woodland could be reasonably approximated in terms of soil loss by a permanent cover of alfalfa. This was the only management option permitted for the wooded LMUs.

5.2 Sediment Control Costs

Two levels of sediment reduction were analyzed for this study: reductions of 25 and 50 percent below the sedimentation rate associated with the profit maximizing management practices (base case). Management practices were evaluated in terms of annual average net operating returns. It was assumed implicitly that the land management practices which maximize net operating returns would be used in the absence of sediment control restrictions. However, due to the restrictions on crops within a field, and tillage within a farm, some LMUs were required to be farmed using management practices that did not maximize net operating returns considered alone, but which did maximize net operating returns for the whole field or farm within the applicable constraints. This was the management constrained base case for the analyses of both cumulative sediment loads and episodic loads. Thus, the management-constrained base case that resulted in maximum profits was the same irrespective of the sedimentation measure used. Zero abatement costs were assumed to be associated with this base case.

Total sediment control costs for 25 and 50 percent reductions in annual average sediment loads and episodic sediment loads are summarized in Table 5.1. For 25 percent sediment reductions, sediment control costs for episodic events with 2, 5, 20, 50, 100 year return periods are 94, 109, 59, 118, and 118 percent higher than the costs of reducing annual average loads by the same fraction. At the 50 percent level, the control costs for episodic loads are 144, 189, 143, 183, and 184 percent higher than the

Table 5.1 Sediment Control Costs with Three Levels of Sedimentation for Annual Average and Various Episodic Events

		Cost ($)			Sediment (tons)	
		Sediment Reduction			Reduction of	
	Base case	25%	50%	Base Case	25%	50%
Annual Average	0	177.78	573.62	675.82	483.02	337.13
2-Year Return Episode	0	345.30	1402.18	36.94	27.40	18.35
5-Year Return Episode	0	372.41	1658.40	86.13	64.38	42.72
20-Year Return Episode	0	282.51	1391.90	187.02	140.19	93.08
50-Year Return Episode	0	387.49	1625.80	279.12	207.15	139.01
100-Year Return Episode	0	387.49	1628.85	362.53	269.12	180.41

costs of reducing annual average loads by half, for 2, 5, 20, 50, 100 year return period, respectively.

Total sediment control costs vary among different episodic events. The least sediment control costs occur in 20-year return episodic event at 25 and 50 percent sediment reductions. With some exceptions, sediment control costs generally seem to increase as the storm event return period (implicitly, the storm severity) increases. The reason for this inconsistency in control costs as return periods increase is the discrete choices of optimal management practice among different combinations of management practices for the same transect under various episodic events. The small study area providing less choices, especially, will make this inconsistency obvious.

As shown in Table 5.2, per acre control costs for a 25 percent reduction in annual average loads is $0.80. The comparable per acre costs for episodic events with 2, 5, 20, 50, 100 year return periods loads are $1.54, $1.67, $1.26, $1.73, and $1.73 per acre, respectively. With a 50 percent sediment reduction, the control cost is $2.57 per acre for the annual average sediment load. The comparable episodic sediment control costs are $6.27/acre, $7.42/acre, $6.23/acre, $7.27/acre, and $7.29/acre for 2, 5, 20, 50, 100 year return periods, respectively.

Table 5.2 Control Costs for Annual Average and Episodic Events with Various Return Periods ($/Acre)

	Sediment Reduced by	
	25%	50%
Annual Average	0.80	2.57
2-Year Return	1.54	6.27
5-Year Return	1.67	7.42
20-Year Return	1.26	6.23
50-Year Return	1.73	7.27
100-Year Return	1.73	7.29

The control costs with a 25 percent sediment reduction in annual average sediment loads is $0.92/ton/year. The costs per ton with a 25 percent sediment reduction for 2, 5, 20, 50, 100 year return period episodic events are $36.19, $17.12, $6.03, $5.38, and $4.15, respectively. Using linear interpolation to compute marginal control costs, which are the crude arc estimates of marginal costs, it is apparent that marginal costs decline as the critical storm frequency is decreased from that of a 2-year storm to a 100-year storm. It is evident in Table 5.3 that, if percentage of sediment reduction for annual total sediment load and every episodic sediment load is increased to 50 percent, the control costs are higher than those with 25

Table 5.3 Average and Marginal Control Costs for Annual Average and Episodic Events with Various Return Periods ($/Ton)

	Average Costs for Sediment Reduced by		Marginal Costs for Sediment Reduced by	
	25%	50%	25%	50%
Annual Average	0.92	1.69	____	____
2-Year Return	36.19	75.43		
5-Year Return	17.12	38.20	6.36	12.41
20-Year Return	6.03	14.82	0.74	1.50
50-Year Return	5.38	11.60	0.02	0.11
100-Year Return	4.15	8.94	0.02	0.05

percent sediment reduction.

As shown in Table 5.4, net returns per acre with no sediment constraint vary for each LMU from $-64.96 to $321.63. Zero net returns were assigned to the land units committed to permanent cover. LMUs with negative net returns occur in fields that have positive net returns overall -- see section 4.1.1 for summary information on each LMU. The higher net returns per acre occur consistently on the LMUs with predominantly high productivity soils. Most of these soils have yields higher than 97 bushels per acre in term of corn production. Soils with corn yields more than 97 bushels per acre are classified as "good" to "high" productivity soils (Wischmeier and Smith, 1978).

Under the assumption of a 50-year planning horizon, an 8% discount rate, and no sediment constraint, the present value of total net returns for the entire study area is $18,317.84. The total is broken down in Table 5.4. As shown in Table 5.5, control costs with 25 and 50 percent sediment reductions for annual total sediment load are only 0.97% and 3.1% of total net returns, respectively. Higher costs are required to reduce episodic loads by 25 and 50 percent: not more than about 2.0% reduction for the lesser constraint and up to about 9% for the more stringent constraint.

Table 5.4 Net Returns for Each LMU with No Sediment Constraint

Transect	LMU	Net Return[a] ($/Acre)	Total Net Returns ($)
A	1	49.74	1039.57
	2	208.20	1131.66
B	1	84.52	439.50
	2	300.05	6451.08
C	1	76.41	1283.69
	2	66.87	1451.08
	3	321.63	1093.54
D	1	24.72	123.60
	2	0.00	0.00
E	1	-15.73	-105.39
	2	-11.46	-17.19
F	1	208.25	687.23
	2	-23.63	-226.85
G	1	226.40	679.20
	2	-25.13	-118.11
H	1	226.38	1562.02
	2	96.16	769.28
I	1	58.02	365.53
J	1	-14.80	-85.84
K	1	24.73	123.65
	2	0.00	0.00
	3	0.00	0.00
L	1	24.73	247.30
	2	0.00	0.00
	3	0.00	0.00
	4	0.00	0.00
M	1	-64.96	-207.87
	2	173.65	1337.11
N	1	149.14	402.68
	2	0.00	0.00
O	1	-41.78	-108.63
	2	0.00	0.00
Total			18,317.84

[a] Net returns ($/Acre) are zero for woodland LMUs or fields as a whole with negative net returns.

Table 5.5 Sediment Control Costs as a Percentage of Total Net Returns for Annual Average and Various Episodic Loads

	Sediment Reduction by	
	25%	50%
Annual Average	0.97%	3.10%
2-Year Return Episode	1.89%	7.65%
5-Year Return Episode	2.03%	9.05%
20-Year Return Episode	1.54%	7.60%
50-Year Return Episode	2.12%	8.88%
100-Year Return Episode	2.12%	8.89%

5.3 Control Efficiency of Management Practices

Are the management practices that most efficiently control annual average sediment loads also most efficient for reducing extreme episodic sediment loads? Or, are the management practices aimed at protecting episodic events also effective in controlling cumulative sedimentation? To analyze these questions, we apply the optimal management practices from the annual average model in the storm event model, and vice versa.

Adopting the optimal set of management practices from the annual average model with a 25% annual total sediment reduction in every storm event model, the control costs do not change from the annual average model because the same net operating returns for each management system are used in the annual and storm event models. However, as shown in Table 5.6, the percentages of sediment reduction are always lower than the 25% sediment reduction in annual average model, and generally decrease as the return period increases. Similarly, as shown in Table 5.7, when the optimal management practices from the episodic model were analyzed for their annual average consequences, annual average sedimentation was reduced more than in proportion to the storm event reduction. However, there is no clear trend in the results from analyses of management practices that were optimal for different extreme storm return intervals.

Figures 5.1 and 5.2 summarize the preceding discussion. C1 is the total cost of achieving a 25 percent sediment reduction in annual average sedimentation. When the management practices which achieving a 25% reduction optimally in the annual average model are applied to an episodic case, only X_1^* ($X_1^* < 25\%$) in sediment reduction can be achieved. When sediment is reduced optimally by 50%, following the same procedures, management practices with C2 total costs only reduced sedimentation to X_2^* in a storm event models ($X_2^* < 50\%$). This implies that the management practices that achieving a particular proportionate sediment reduction in the annual average case will achieve a less than proportionate reduction in extreme episodic loads. On the other hand, management practices that reduce extreme episodic loads by a particular percentage produce greater than proportionate reductions of annual average loads.

5.4 Change of Management Practices

Optimal unconstrained management of the 223.4 acre study site includes 94 acres (42.1% of the total study area) with a corn-soybean-wheat-double crop soybeans rotation and fall chiseling up and down slopes, 28.4 acres (12.7%) with a corn-soybean-wheat-clover rotation and fall chiseling up and down slopes, and 65.3 acres (29.2%) with a permanent alfalfa rotation. No tillage is needed for a permanent alfalfa rotation. The only plausible mechanical practice for permanent alfalfa is terracing. The remaining 35.7 acres (16%) are either woodland or fields forced to have permanent alfalfa rotation due to negative net returns for all cropping options.

Generally speaking, as a sedimentation constraint is tightened, more

Table 5.6 Episodic Events Consequences of Management Programs that are Optimal for 25% and 50% Reductions in Annual Average Loads

		Annual Average Sediment (tons) Reduced by	
		25%	50%
cost $	2-Year Return Episode	177.78	573.62
	5-Year Return Episode	177.78	573.62
	20-Year Return Episode	177.78	573.62
	50-Year Return Episode	177.78	573.62
	100-Year Return Episode	177.78	573.62
sediment tons[a]	2-Year Return Episode	29.99 (18.91%)	25.45 (31.10%)
	5-Year Return Episode	70.82 (17.78%)	59.21 (31.26%)
	20-Year Return Episode	153.24 (18.06%)	129.70 (30.65%)
	50-Year Return Episode	229.75 (17.69%)	193.27 (30.76%)
	100-Year Return Episode	298.32 (17.71%)	251.23 (30.70%)

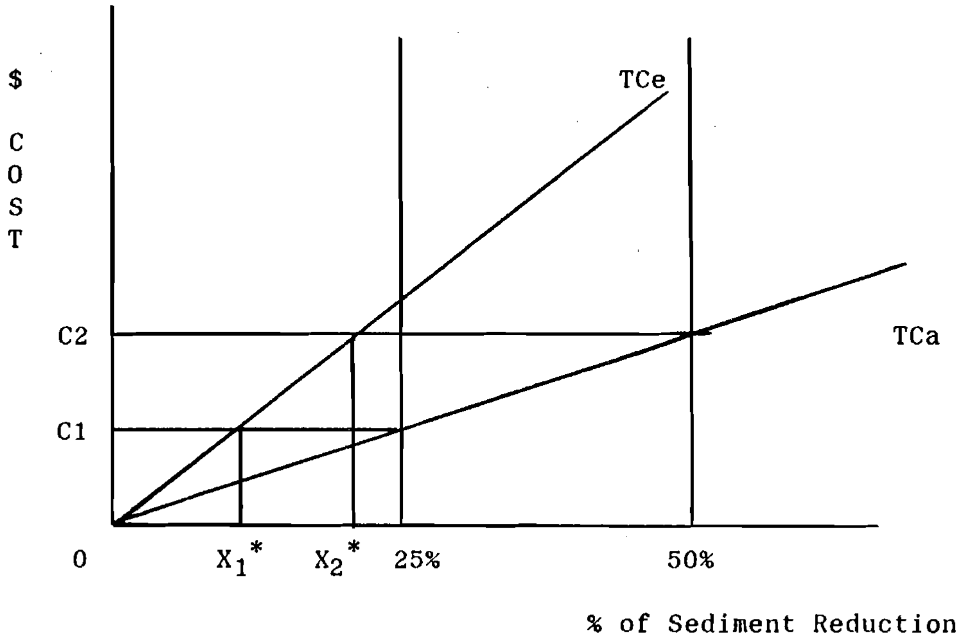
a: Values in parentheses are the percentages of sediment reduction from the base cases sediment loads for episodic events.

Table 5.7 Annual Average Consequences of Management Programs that are Optimal for 25% and 50% Reductions in Episodic Sediment Loads

		Annual Average Model	
		Cost ($)	Sediment^{a} (tons)
sediment 25% reduction	2-Year Return Episode	345.30	404.72 (41.11%)
	5-Year Return Episode	372.41	442.41 (34.54%)
	20-Year Return Episode	282.51	463.24 (31.46%)
	50-Year Return Episode	387.49	377.77 (44.10%)
	100-Year Return Episode	387.49	419.15 (37.98%)
sediment 50% reduction	2-Year Return Episode	1402.18	263.16 (61.06%)
	5-Year Return Episode	1658.40	244.73 (63.79%)
	20-Year Return Episode	1391.90	263.53 (61.01%)
	50-Year Return Episode	1625.80	279.93 (58.58%)
	100-Year Return Episode	1628.85	259.44 (61.61%)

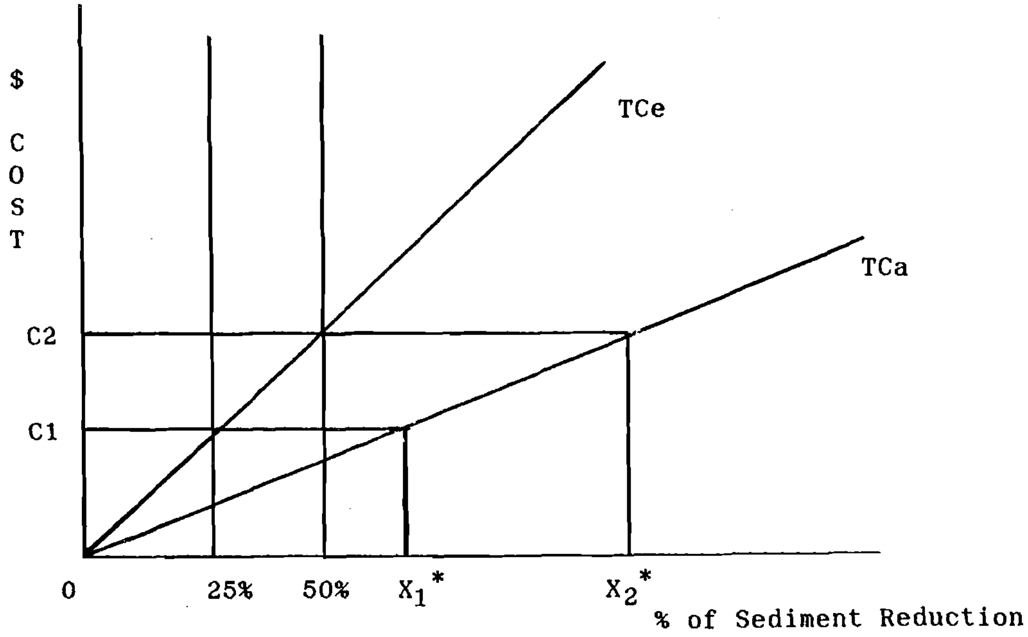
a: Values in parentheses are the percentages of sediment reduction from the base case for annual average sediment loads.

Figure 5.1 Adopting Efficient Management Practices of Annual Average Model in Storm Event Model



TCa: total cost of sediment control for annual average case
TCe: total cost of sediment control for storm event(s)

Figure 5.2 Adopting Efficient Management Practices of Storm Event Model in Annual Average Model



TCa: total cost of sediment control for annual average case
TCe: total cost of sediment control for storm event(s)

acres are shifted from a non-meadow rotation to rotations with meadow or even to permanent alfalfa. This is true for both the annual average and storm event models. But as is evident in Table 5.8, the changes to permanent alfalfa were less significant than the changes to a crop-meadow mixed rotation for both annual average and episodic sediment loads. Under a 25 percent sediment reduction constraint for the annual average model, only 13.4 acres, about 6% of the study area, had to be shifted to management practices that yielded less than maximum net returns. For the same percentage sediment reduction, 25.8 acres (12%), 34.8 acres (16%), 29.2 acres (13%), 53 acres (23.7%), and 57 acres (26%) were shifted to less profitable management options for the storm event model with 2-, 5-, 20-, 50-, 100-year return periods, respectively. Under a 50 percent sediment reduction, 23%, 32%, 36%, 35%, 28%, and 36% of the study area were shifted to less profitable management practices for the annual average model and 2-, 5-, 20-, 50-, 100-year return period episodic events, respectively.

The changes affect tillage practices (see Table 5.9), and mechanical controls (see Table 5.10) in addition to rotation. Changes to completely different management practices occurred on no more than 8.1 acres in any of the cases analyzed. Tillage practices under optimal unconstrained managements were either fall chisel or permanent alfalfa. With a 25 percent sediment reduction tillage practices were shifted from fall chisel to no-till practices or alfalfa in all cases. However, increasing sediment constraint to 50 percent reduction, only 5-, 50-, and 100-year episodic cases have more acres shifted to no-till practices and alfalfa.

With adherence to 25 percent sediment reduction, changes in mechanical control practices only occurred in the episodic cases. Conservation practices

Table 5.8 Change in Rotations[a] under Three Levels of Sediment for Annual Average and Storm Event Models

	Non-meadow Rotation[b]			Crop-Meadow Mixed Rotation[c]			Permanent Alfalfa		
	Base Case	Sediment Reduced		Base Case	Sediment Reduced		Base Case	Sediment Reduced	
		25%	50%		25%	50%		25%	50%
Annual Average	94 (42.1%)	86.4 (38.7%)	48.3 (21.6%)	28.4 (12.7%)	30.2 (13.5%)	60.7 (27.2%)	101 (45.2%)	106.8 (47.8%)	114.4 (51.2%)
2-Year Return Episode	94 (42.1%)	75.5 (33.8%)	48.3 (21.6%)	28.4 (12.7%)	22.6 (10.1%)	49.8 (22.3%)	101 (45.2%)	125.3 (56.1%)	125.3 (56.1%)
5-Year Return Episode	94 (42.1%)	75.5 (33.8%)	33.4 (15.0%)	28.4 (12.7%)	41.1 (18.4%)	72.3 (32.4%)	101 (45.2%)	106.8 (47.8%)	117.7 (52.7%)
20-Year Return Episode	94 (42.1%)	75.5 (33.8%)	48.3 (21.6%)	28.4 (12.7%)	30.2 (13.5%)	49.8 (22.3%)	101 (45.2%)	117.7 (52.7%)	125.3 (56.1%)
50-Year Return Episode	94 (42.1%)	48.3 (21.6%)	44.9 (20.1%)	28.4 (12.7%)	57.4 (25.7%)	60.8 (27.2%)	101 (45.2%)	117.7 (52.7%)	117.7 (57.7%)
100-Year Return Episode	94 (42.1%)	44.3 (19.8%)	33.4 (15.0%)	28.4 (12.7%)	72.3 (32.4%)	72.3 (32.4%)	101 (45.2%)	106.8 (47.8%)	117.7 (57.7%)

a: Values in parentheses are the percentages of acres for each category of the total acres in the study area.

b: Non-meadow rotations include corn-soybean and corn-soybean-wheat-double crop soybeans.

c: Crop-meadow mixed rotations include corn-soybean-wheat-clover and corn-corn-soybean-wheat-meadow-meadow-meadow-meadow.

Table 5.9 Change in Tillage Practices[a] under Three Levels of Sediment for Annual Average and Storm Event Models

	Fall Chisel			No-Till			Permanent Alfalfa[b]		
	Base Case	Sediment Reduced		Base Case	Sediment Reduced		Base Case	Sediment Reduced	
		25%	50%		25%	50%		25%	50%
Annual Average	122.4 (54.8%)	109.0 (48.8%)	109.0 (48.8%)	0.0 (0.0%)	7.6 (3.4%)	0.0 (0.0%)	101.0 (45.2%)	106.8 (47.8%)	114.4 (51.2%)
2-Year Return Episode	122.4 (54.8%)	98.1 (43.9%)	98.1 (43.9%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	101.0 (45.2%)	125.3 (56.1%)	125.3 (56.1%)
5-Year Return Episode	122.4 (54.8%)	109.0 (48.8%)	98.1 (43.9%)	0.0 (0.0%)	7.6 (3.4%)	7.6 (3.4%)	101.0 (45.2%)	106.8 (47.8%)	117.7 (52.7%)
20-Year Return Episode	122.4 (54.8%)	98.1 (43.9%)	98.1 (43.9%)	0.0 (0.0%)	7.6 (3.4%)	0.0 (0.0%)	101.0 (45.2%)	117.7 (52.7%)	125.3 (56.1%)
50-Year Return Episode	122.4 (54.8%)	98.1 (43.9%)	94.7 (42.4%)	0.0 (0.0%)	7.6 (3.4%)	11.0 (4.9%)	101.0 (45.2%)	117.7 (52.7%)	117.7 (52.7%)
100-Year Return Episode	122.4 (54.8%)	109.0 (48.8%)	98.1 (43.9%)	0.0 (0.0%)	7.6 (3.4%)	7.6 (3.4%)	101.0 (45.2%)	106.8 (47.8%)	117.7 (52.7%)

a: Values in parentheses are the percentages of acres for each category of the total acres in the study area.

b: No tillage practices is needed for permanent alfalfa. So, we set it as a separate group.

Table 5.10 Change in Mechanical Control Practices[a] under Three Levels of Sediment for Annual Average and Storm Event Models

	Vertical Up-and-down Practices			Conservation Practices[b]		
	Base	Sediment Reduced		Base	Sediment Reduced	
	Case	25%	50%	Case	25%	50%
Annual Average	187.7 (84.0%)	187.7 (84.0%)	181.4 (81.2%)	35.7 (16.0%)	35.7 (16.0%)	42.0 (18.8%)
2-Year Return Episode	187.7 (84.0%)	186.2 (83.3%)	162.3 (72.6%)	35.7 (16.0%)	37.2 (16.7%)	61.1 (27.4%)
5-Year Return Episode	187.7 (84.0%)	177.2 (79.3%)	159.6 (71.4%)	35.7 (16.0%)	46.2 (20.7%)	63.8 (28.6%)
20-Year Return Episode	187.7 (84.0%)	178.1 (79.7%)	158.9 (71.1%)	35.7 (16.0%)	45.3 (20.3%)	64.5 (28.9%)
50-Year Return Episode	187.7 (84.0%)	186.2 (83.3%)	162.2 (72.6%)	35.7 (16.0%)	37.2 (16.7%)	61.2 (27.4%)
100-Year Return Episode	187.7 (84.0%)	186.2 (83.3%)	162.2 (72.6%)	35.7 (16.0%)	37.2 (16.7%)	61.2 (27.4%)

a: Values in the parentheses are the percentages of acres for each category of the total acres in the study area.

b; Conservation practices include contour cultivation, contour strip cropping, and contour & terracing.

were employed on about 2% of the area for the 2-, 5- and 100-year return period episodic events, and 10.5% and 9.6% of the land was managed with conservation practices for 5-year and 20-year return period episodic events. When the percent of sediment reduction was increased to 50 percent, there was a large increase in the acreage shifted from plowing up-and-down slopes to conservation practices, especially for the episodic events. Generally, more than 25 percent of the study area were treated with conservation practices for all episodic events. Only 6.3% of the study area was shifted to conservation practices for reducing annual average loads by half.

5.5 Summary

The initial results show that the control costs for proportionate reductions in annual average sediment loads are lower than those for episodic sediment whatever sediment constraints are imposed. On a per acre annual basis, the control costs for annual average loads are less than $1 under a 25 percent sediment reduction. The control costs for 25% reduction in all the episodic cases are more than $1.50/acre/year. Doubling the control requirement increased compliance costs to more than $2.50 per acre for annual average sediment loads. Control costs for 50% reductions from very extreme episodic events exceeded $7 per acre.

If we adopt the optimal management practices from the annual average model under a prescribed sediment reduction, it does not achieve the same percentage of sediment reduction in the storm event model, and vice versa. This suggests that ineffectiveness arises from using one standard for annual average sediment loads to address the pollutant concentration-induced water quality problem associated with weather episodes.

Crop rotations in the study area change markedly in response to annual average or storm event sediment constraints, but changes in tillage and mechanical control practices are minor. This suggests that rotation changes are the cheapest ways to achieve the prescribed sediment standards.

The limitations and conclusions of this study are presented in the next chapter. Policy implications and possible research directions are also discussed.

CHAPTER VI

CONCLUSION, IMPLICATIONS, AND LIMITATIONS

This study is an initial effort to compare measures for reducing cumulative sediment loads from cropland with measures that could reduce loads from weather episodes. Long-term sediment accumulations which affect storage capacity are related to annual average erosion rates. Sedimentation which affects ambient water quality conditions is storm-related. The approach used in this study involved developing a storm event oriented simulation model analogous to the annual average version of the SEDEC sedimentation economics model. The annual average loads and storm event loads were compared by applying the optimal management practices from one model to the other model to test the relative effectiveness. The following conclusions pertain to this study's objectives and shed some light on agricultural nonpoint source control policies.

6.1 Conclusions and Implications

First of all, control costs for episodic sediment loads were consistently higher than the control costs for proportionate reductions in annual average sediment loads. The differences in control costs reflect the ineffectiveness with which management practices that optimally control annual average losses address episodic water quality problems, and vice-versa. The main thrust of agricultural nonpoint source pollution control policy has been on reducing cumulative erosion or sediment loads from farm fields. A shift of emphasis from reducing erosion and cumulative sediment loads to reducing sedimentation from weather episodes may require changes in soil conservation policy and its implementation. However, a good watershed planning should include modeling both annual average and episodic models so that controls can be designed with both types of impacts in mind.

Second, although total control costs did not change consistently among episodic events, the highest control costs were generally associated with the most severe storms (long return periods). However, it was less costly to reduce sedimentation from a 20-year return period episode than for 2-year and 5-year return period episodes. This implies that an ambient water quality standard for agricultural sediment based on a 20-year extreme episode under low-flow conditions might be less costly to farmers than a standard based on shorter or longer return period storms.

Third, without sediment constraints imposed, fall chiseling in all optimal management systems was more profitable than conventional tillage because of lower machinery costs and labor requirements (except those 29.2% of the study area with alfalfa rotation.) These results are consistent with the conclusions by Crowder et al. (1984). Furthermore, mechanical practices for the optimal unconstrained management systems were all up-and-down slope, except where alfalfa was grown continuously. When episodic sediment constraints were set at 25 percent reductions, contouring replaced most of the up-and-down slope cultivation. The effectiveness of contouring is no surprise; it is one of the most widely used conservation techniques in the U.S. As Clark et al. (1985) pointed out, some studies have estimated suspended sediment reductions due to contouring at between 20% and 75%, with an average falling in the range of 25% to 50%. When 50% sediment constraints were imposed, the mechanical practices for some LMUs were shifted to contour strip cropping, in both the annual average and storm event models. Only a few

LMUs were managed with contouring and terracing when sediment constraints were increased to the 50% level. Terracing involves high initial construction costs. Even though terracing is one of the most effective ways to reduce sediment, it is usually the last resort for reducing soil losses because of the expense and the significant associated changes in farm practices.

Finally, for most of the transects with alfalfa growing permanently adjacent to the stream channel, the management systems for the upslope LMUs were never changed, whatever the sediment constraints imposed. Those management systems for upslope LMUs were either a corn-soybean-wheat-double crop soybeans with fall chiseling up-and-down slope or a corn-soybean-wheat-clover with fall chiseling up-and-down slope. This implies that if permanent grass strips were placed along the streams, most of the eroded soil would be captured before it entered the water body.

6.2 Limitations and Suggestions for Future Work

Constructing a detailed hydrologic model to estimate the sediment delivery for a single storm was beyond the scope of this study. Developing a comprehensive hydrologic model would require additional knowledge of relevant physical processes and linkages. The impacts of sediment on the aquatic ecosystem would also need to be reflected.

In this study, we did not deal with the phenomena of erosive rainfall and streamflow conditions stochastically. The "worst episodic scenario" was selected by deterministically dividing a year into various crop-growth phases. The extreme episodic sediment loads were represented by the effects of extreme storms in the field crop-growth phase during which erosion susceptibility is highest.

The annual average and storm event models dealt only with sediment. Other agricultural pollutants like toxic pesticides can have significant effects on ambient water quality. To include them will require multiple transport relationships, which will greatly exacerbate computational demands in a SEDEC-type model, Moreover, because toxicity is often a function of the application date, stochastic aspects of weather influences would be even more critical.

The objective functions in both models considered only the costs of control. From society's viewpoint, the benefits of reducing sediment from weather episodes and sedimentation from cumulative erosion need to be considered in order to identify appropriate goals for pollution control.

Despite it limitations, this study is a basis upon which to build future efforts. An ambient water quality standard for pollution from nonpoint sources must be based on the joint probabilities of low stream flow conditions and extreme storm events. The methodology for comparing management systems that was developed here should be adaptable to an analysis that explicitly incorporates the stochastic aspects of pollution episodes.

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APPENDIX

DETAILED INFORMATION FOR COMPUTING ANNUAL AVERAGE AND CROP-GROWTH PHASE C VALUES IN USLE

Table A.1 Working Table of C Values for CS with FP

Event	Date	Crop-stage Period	EI% (1)	Soil Loss Ratios (2)	Crop-stage C Value (3)
Fall Plow	10/15	F	0.300	0.53[a]	0.159
Disk	5/1	SB	0.031	0.81	0.025
Plant Corn	5/10	--	0.082	----	-----
10% Canopy	6/1	1	0.126	0.65	0.082
50% Canopy	6/20	2	0.061	0.51	0.031
75% Canopy	7/5	3	0.413	0.30	0.124
Harvest Corn	10/25	4	0.057	0.04[b]	0.003
Fall Plow	11/15	F	0.230	0.52[c]	0.120
Disk	5/1	SB	0.060	0.73	0.044
Plant Soybean	5/21	--	0.127	----	-----
10% Canopy	6/15	1	0.093	0.61	0.057
50% Canopy	6/30	2	0.041	0.41	0.017
75% Canopy	7/10	3	0.360	0.21	0.076
Harvest SB	10/5	4	0.023	0.15[d]	0.004

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)

a: line 113 from Table 5 in Agriculture Handbook No.537.

b: by using 90 percent mulch cover right after harvest from Table 5-C in Agriculture Handbook No.537.

c: line 127 from Table 5 in Agriculture Handbook No.537.

d: by using 70 percent mulch cover right after harvest from Table 5-C in Agriculture Handbook No.537.

Table A.2 Working Table of C Values for CS with FCH

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Chisel	10/15	F	0.300	0.51[a]	0.51	0.51	0.51	0.51	0.153	0.153	0.153	0.153	0.153
Disk	5/1	SB	0.031	0.56	0.56	0.56	0.56	0.56	0.017	0.017	0.017	0.017	0.017
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	--- -
10% Canopy	6/1	1	0.126	0.48	0.48	0.48	0.48	0.48	0.061	0.061	0.061	0.061	0.061
50% Canopy	6/20	2	0.061	0.43	0.43	0.43	0.43	0.43	0.026	0.026	0.026	0.026	0.026
75% Canopy	7/5	3	0.413	0.30	0.30	0.30	0.30	0.03	0.123	0.123	0.123	0.123	0.123
Harvest Corn	10/25	4	0.057	0.04[b]	0.04	0.04	0.04	0.04	0.002	0.002	0.002	0.002	0.002
Fall Chisel	11/15	F	0.230	0.46[c]	0.32[f]	0.19[i]	0.14[l]	0.13[o]	0.106	0.074	0.044	0.032	0.030
Disk	5/1	SB	0.060	0.51[d]	0.35[g]	0.21[j]	0.15[m]	0.14[p]	0.031	0.021	0.013	0.009	0.008
Plant Soybean	5/21	--	0.127	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/15	1	0.093	0.46	0.32	0.19	0.14	0.12	0.043	0.030	0.018	0.013	0.011
50% Canopy	6/30	2	0.041	0.42	0.31	0.18	0.12	0.11	0.017	0.012	0.007	0.005	0.004
75% Canopy	7/10	3	0.360	0.26	0.22	0.14	0.09	0.09	0.094	0.079	0.050	0.032	0.032
Harvest SB	10/5	4	0.023	0.28[e]	0.15[h]	0.09[k]	0.09[n]	0.09[q]	0.006	0.004	0.002	0.002	0.002

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)

a: line 117 from Table 5, by using soil loss ratio for seed-bed period as the ratio for fallow period, same for the other residue levels. Ratios for seed-bed to crop-stage 3 are 1.1 multiplying the corresponding ratios in Table 5. Same procedures are for the other residue levels.

b: same as b in Table

c: using soil loss ratio for seed-bed period in line from Table 5

d: Soil loss ratios for seed-bed period to crop-stage 3 are line 59 multiplying line 61.

e: by using 50 percent mulch cover right after harvest for crop-stage 4

f,i,l,o: using soil loss ratios for seed-bed periods in line 54, 47, 41, 36, rspectively

g,j,m,p: same as d with line 54, 47, 41, 36 multiplying line 61.

h: with 70 percent mulch cover from Table 5-C.

k,n,q: with 80 percent mulch cover in Table 5-C.

Table A.3 Working Table of C Values for CS with NT

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Plant Corn	5/10	SB	0.082	0.33[a]	0.33	0.33	0.33	0.33	0.027	0.027	0.027	0.027	0.027
10% Canopy	6/1	1	0.126	0.29	0.29	0.29	0.29	0.29	0.037	0.037	0.037	0.037	0.037
50% Canopy	6/20	2	0.061	0.25	0.25	0.25	0.25	0.25	0.015	0.015	0.015	0.015	0.015
75% Canopy	7/5	3	0.413	0.18	0.18	0.18	0.18	0.18	0.074	0.074	0.074	0.074	0.074
Harvest Corn	10/25	4	0.349	0.03[b]	0.03	0.03	0.03	0.03	0.010	0.010	0.010	0.010	0.010
Plant Soybean	5/21	SB	0.127	0.26[c]	0.15[e]	0.05[g]	0.03[i]	0.02[k]	0.033	0.019	0.006	0.004	0.003
10% Canopy	6/15	1	0.093	0.24	0.15	0.05	0.03	0.02	0.023	0.014	0.005	0.003	0.002
50% Canopy	6/30	2	0.041	0.22	0.14	0.05	0.03	0.02	0.009	0.006	0.002	0.001	0.001
75% Canopy	7/10	3	0.360	0.17	0.11	0.05	0.03	0.02	0.060	0.040	0.018	0.011	0.007
Harvest SB	10/5	4	0.352	0.19[d]	0.10[f]	0.06[h]	0.06[j]	0.06[l]	0.067	0.035	0.021	0.021	0.021

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)
a: line 121 from Table 5, same ratios for the other residue levels.
b: with 90 percent mulch cover from Table 5-C.
c,e,g,i,k: line 32, 30, 27, 26, 25 from Table 5.
d: 50 percent mulch cover right after harvest from Table 5-C.
f: 70 percent mulch cover right after harvest from Table 5-C.
h,j,l: 80 percent mulch cover right after harvest from Table 5-C

Table A.4 Working Table of C Values for CSWDCSB with FP

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Plow	10/15	F	0.300	0.53[a]	0.53	0.53	0.53	0.53	0.159	0.159	0.159	0.159	0.159
Disk	5/1	SB	0.031	0.81	0.81	0.81	0.81	0.81	0.025	0.025	0.025	0.025	0.025
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	--- -
10% Canopy	6/1	1	0.126	0.65	0.65	0.65	0.65	0.65	0.082	0.082	0.082	0.082	0.082
50% Canopy	6/20	2	0.061	0.51	0.51	0.51	0.51	0.51	0.031	0.031	0.031	0.031	0.031
75% Canopy	7/5	3	0.413	0.30	0.30	0.30	0.30	0.03	0.124	0.124	0.124	0.124	0.124
Harvest Corn	10/25	4	0.057	0.04[b]	0.04	0.04	0.04	0.04	0.002	0.002	0.002	0.002	0.002
Fall Plow	11/15	F	0.230	0.52[c]	0.52	0.52	0.52	0.52	0.120	0.120	0.120	0.120	0.120
Disk	5/1	SB	0.060	0.73	0.73	0.73	0.73	0.73	0.044	0.044	0.044	0.044	0.044
Plant Soybean	5/21	--	0.127	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/15	1	0.093	0.61	0.61	0.61	0.61	0.61	0.057	0.057	0.057	0.057	0.057
50% Canopy	6/30	2	0.041	0.41	0.41	0.41	0.41	0.41	0.017	0.017	0.017	0.017	0.017
75% Canopy	7/10	3	0.360	0.21	0.21	0.21	0.21	0.21	0.076	0.076	0.076	0.076	0.076
Harvest SB	10/5	4	0.026	0.15[d]	0.15	0.15	0.15	0.15	0.004	0.004	0.004	0.004	0.004
Plant Wheat	10/10	SB	0.012	0.38[e]	0.29[g]	0.16[i]	0.12[k]	0.12[m]	0.005	0.003	0.002	0.001	0.001
10% Canopy	11/1	1	0.076	0.30	0.24	0.14	0.12	0.12	0.023	0.018	0.011	0.009	0.009
50% Canopy	12/1	2	0.163	0.23	0.19	0.12	0.11	0.11	0.037	0.031	0.020	0.018	0.018
75% Canopy	4/15	3	0.323	0.07	0.06	0.04	0.04	0.04	0.023	0.019	0.013	0.013	0.013
Harvest Wheat	6/30	4	0.000	0.04[f]	0.04[h]	0.04[j]	0.04[l]	0.04[n]	0.000	0.000	0.000	0.000	0.000
Plant DCSB	7/1	SB	0.085	0.03[o]	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
10% Canopy	7/21	1	0.091	0.03	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
50% Canopy	8/5	2	0.060	0.03	0.03	0.03	0.03	0.03	0.002	0.002	0.002	0.002	0.002
75% Canopy	8/15	3	0.187	0.03	0.03	0.03	0.03	0.03	0.006	0.006	0.006	0.006	0.006
Harvest DCSB	10/15	4	0.000	0.06[p]	0.06	0.06	0.06	0.06	0.000	0.000	0.000	0.000	0.000

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)
a,c: line 113 and 127 from Table 5. Same ratios for the other residue levels.
b: 90 percent mulch cover right after harvest from Table 5-C.
d: with 70 percent mulch cover from Table 5-C.
e,g,i,k,m: line 138,135,130,129,129 from Table 5.
f,h,j,l,n: 90 percent mulch cover from Table 5-C.
o: line 26 in Table 5. Same ratios are for the other residue levels.
p: 80 percent mulch cover from Table 5-C. Same ratios are for the other residue levels.

Table A.5 Working Table of Annual Average C Values for CSWDCSB with FCH

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Chisel	10/15	F	0.300	0.51[a]	0.51	0.51	0.51	0.51	0.153	0.153	0.153	0.153	0.153
Disk	5/1	SB	0.031	0.56	0.56	0.56	0.56	0.56	0.017	0.017	0.017	0.017	0.017
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	--- -
10% Canopy	6/1	1	0.126	0.48	0.48	0.48	0.48	0.48	0.061	0.061	0.061	0.061	0.061
50% Canopy	6/20	2	0.061	0.43	0.43	0.43	0.43	0.43	0.026	0.026	0.026	0.026	0.026
75% Canopy	7/5	3	0.413	0.30	0.30	0.30	0.30	0.03	0.123	0.123	0.123	0.123	0.123
Harvest Corn	10/25	4	0.057	0.04	0.04	0.04	0.04	0.04	0.002	0.002	0.002	0.002	0.002
Fall Chisel	11/15	F	0.230	0.46[b]	0.32	0.19	0.14	0.13	0.106	0.074	0.044	0.032	0.030
Disk	5/1	SB	0.060	0.51	0.35	0.21	0.15	0.14	0.031	0.021	0.013	0.009	0.008
Plant Soybean	5/21	--	0.127	----	----	----	----	----	----	----	----	----	-----
10% Canopy	6/15	1	0.093	0.46	0.32	0.19	0.14	0.12	0.043	0.030	0.018	0.013	0.011
50% Canopy	6/30	2	0.041	0.42	0.31	0.18	0.12	0.11	0.017	0.012	0.007	0.005	0.004
75% Canopy	7/10	3	0.360	0.26	0.22	0.14	0.09	0.09	0.094	0.079	0.005	0.032	0.032
Harvest SB	10/5	4	0.026	0.28	0.15	0.09	0.09	0.09	0.007	0.004	0.002	0.002	0.002
Plant Wheat	10/10	SB	0.012	0.38[c]	0.29	0.16	0.12	0.12	0.005	0.003	0.002	0.001	0.001
10% Canopy	11/1	1	0.076	0.30	0.24	0.14	0.12	0.12	0.023	0.018	0.011	0.009	0.009
50% Canopy	12/1	2	0.163	0.23	0.19	0.12	0.11	0.11	0.037	0.031	0.020	0.018	0.018
75% Canopy	4/15	3	0.323	0.07	0.06	0.04	0.04	0.04	0.023	0.019	0.013	0.013	0.013
Harvest Wheat	6/30	4	0.000	0.04	0.04	0.04	0.04	0.04	0.000	0.000	0.000	0.000	0.000
Plant DCSB	7/1	SB	0.085	0.03[d]	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
10% Canopy	7/21	1	0.091	0.03	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
50% Canopy	8/5	2	0.060	0.03	0.03	0.03	0.03	0.03	0.002	0.002	0.002	0.002	0.002
75% Canopy	8/15	3	0.187	0.03	0.03	0.03	0.03	0.03	0.006	0.006	0.006	0.006	0.006
Harvest DCSB	10/15	4	0.000	0.06	0.06	0.06	0.06	0.06	0.000	0.000	0.000	0.000	0.000

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)

a,b: all soil loss ratios for corn and soybean are the same as those for CS with FCH

c,d: all soil loss ratios for wheat and double crop soybean are the same as those for CSWDCSB with FP.

Table A.6 Working Table of C Values for CSWDCSB with NT

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Plant Corn	5/10	SB	0.082	0.33[a]	0.33	0.33	0.33	0.33	0.027	0.027	0.027	0.027	0.027
10% Canopy	6/1	1	0.126	0.29	0.29	0.29	0.29	0.29	0.037	0.037	0.037	0.037	0.037
50% Canopy	6/20	2	0.061	0.25	0.25	0.25	0.25	0.25	0.015	0.015	0.015	0.015	0.015
75% Canopy	7/5	3	0.413	0.18	0.18	0.18	0.18	0.18	0.074	0.074	0.074	0.074	0.074
Harvest Corn	10/25	4	0.349	0.03	0.03	0.03	0.03	0.03	0.010	0.010	0.010	0.010	0.010
Plant Soybean	5/21	SB	0.127	0.26[b]	0.15	0.05	0.03	0.02	0.033	0.019	0.006	0.004	0.003
10% Canopy	6/15	1	0.093	0.24	0.15	0.05	0.03	0.02	0.022	0.014	0.005	0.003	0.002
50% Canopy	6/30	2	0.041	0.22	0.14	0.05	0.03	0.02	0.009	0.006	0.002	0.001	0.001
75% Canopy	7/10	3	0.360	0.17	0.11	0.05	0.03	0.02	0.060	0.040	0.018	0.011	0.007
Harvest SB	10/5	4	0.026	0.19	0.10	0.06	0.06	0.06	0.067	0.035	0.021	0.021	0.021
Plant Wheat	10/10	SB	0.012	0.38[c]	0.29	0.16	0.12	0.12	0.005	0.003	0.002	0.001	0.001
10% Canopy	11/1	1	0.076	0.30	0.24	0.14	0.12	0.12	0.023	0.018	0.011	0.009	0.009
50% Canopy	12/1	2	0.163	0.23	0.19	0.12	0.11	0.11	0.037	0.031	0.020	0.018	0.018
75% Canopy	4/15	3	0.323	0.07	0.06	0.04	0.04	0.04	0.023	0.019	0.013	0.013	0.013
Harvest Wheat	6/30	4	0.000	0.04	0.04	0.04	0.04	0.04	0.000	0.000	0.000	0.000	0.000
Plant DCSB	7/1	SB	0.085	0.03[d]	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
10% Canopy	7/21	1	0.091	0.03	0.03	0.03	0.03	0.03	0.003	0.003	0.003	0.003	0.003
50% Canopy	8/5	2	0.060	0.03	0.03	0.03	0.03	0.03	0.002	0.002	0.002	0.002	0.002
75% Canopy	8/15	3	0.187	0.03	0.03	0.03	0.03	0.03	0.006	0.006	0.006	0.006	0.006
Harvest DCSB	10/15	4	0.329	0.06	0.06	0.06	0.06	0.06	0.020	0.020	0.020	0.020	0.020

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2).

a,b: all soil loss ratios for corn and soybean are the same as those for CS with NT

c,d: all soil loss ratios for wheat and double crop soybean are the same as those for CSWDCSB with FCH

Table A.7 Working Table of C Values for CSWK with FP

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Plow	10/15	F	0.300	0.33[a]	0.33	0.33	0.33	0.33	0.099	0.099	0.099	0.099	0.099
Disk	5/1	SB	0.031	0.48	0.48	0.48	0.48	0.48	0.015	0.015	0.015	0.015	0.015
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	--- -
10% Canopy	6/1	1	0.126	0.41	0.41	0.41	0.41	0.41	0.052	0.052	0.052	0.052	0.052
50% Canopy	6/20	2	0.061	0.32	0.32	0.32	0.32	0.32	0.019	0.019	0.019	0.019	0.019
75% Canopy	7/5	3	0.413	0.18	0.18	0.18	0.18	0.18	0.076	0.076	0.076	0.076	0.076
Harvest Corn	10/25	4	0.057	0.03[b]	0.03	0.03	0.03	0.03	0.002	0.002	0.002	0.002	0.002
Fall Plow	11/15	F	0.230	0.45[c]	0.45	0.45	0.45	0.45	0.103	0.103	0.103	0.103	0.103
Disk	5/1	SB	0.060	0.32	0.32	0.32	0.32	0.32	0.019	0.019	0.019	0.019	0.019
Plant Soybean	5/21	--	0.127	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/15	1	0.093	0.59	0.59	0.59	0.59	0.59	0.055	0.055	0.055	0.055	0.055
50% Canopy	6/30	2	0.041	0.41	0.41	0.41	0.41	0.41	0.016	0.016	0.016	0.016	0.016
75% Canopy	7/10	3	0.360	0.21	0.21	0.21	0.21	0.21	0.076	0.076	0.076	0.076	0.076
Harvest SB	10/5	4	0.026	0.15[d]	0.15	0.15	0.15	0.15	0.004	0.004	0.004	0.004	0.004
Plant Wheat	10/10	SB	0.012	0.25[e]	0.19[f]	0.10[g]	0.08[h]	0.08[i]	0.003	0.002	0.001	0.001	0.001
10% Canopy	11/1	1	0.076	0.20	0.16	0.09	0.08	0.08	0.015	0.012	0.007	0.006	0.006
50% Canopy	12/1	2	0.163	0.17	0.14	0.09	0.08	0.08	0.037	0.023	0.015	0.013	0.013
75% Canopy	4/15	3	0.323	0.16	0.05	0.04	0.04	0.04	0.028	0.017	0.012	0.012	0.012
Harvest Wheat	6/30	4	0.000	0.04[j]	0.04	0.04	0.04	0.04	0.000	0.000	0.000	0.000	0.000
Clover	4/15[k]	--	-----	0.015	----	----	----	----	-----	-----	-----	-----	----

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)

a: line 14 from Table 5 multiplies (6.5*0.02 + F), soil loss ratios increased by adding 0.02 for each additional month from October plow to May disking and added F as factors to credit residual effects to turned sod from Table 5-D by assuming 2-3 tons per acre hay yield for corn grown first year after meadow.
same ratios for the other residue levels.

b: with 90 percent mulch cover from Table 5-C multiplying (6.5*0.02 +0.65).

c: line 127 from Table 5 multiplies (5.5*0.02 +F1), same reasons as a by assuming 2-3 tons per acre hay yield for soybean grown second year after meadow in Table 5-D.

d: with 70 percent mulch cover from Table 5-C multiplying (5.5*0.02 + 1). The computed value is greater than 1, use as 1.
same ratios for the other residue levels.

e,f,g,h,i: line 138, 135, 130, 129,129 from Table 5 multiple the factors to credit residual effects of turned sod for winter grain in Table 5-D by assuming hay yield is 2-3 tons per acre.

j: with 90 percent mulch cover in Table 5-C.

k: planting clover before harvest wheat, by using established meadow with full-year percentages as soil loss ratios from Table 5-B in Agriculture Handbook No. 537.

Table A.8 Working Table of C Values for CSWK with FCH

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Chisel	10/15	F	0.300	0.20[a]	0.14[b]	0.08[c]	0.06[d]	0.06[e]	0.059	0.041	0.025	0.018	0.017
Disk	5/1	SB	0.031	0.30	0.20	0.12	0.09	0.08	0.011	0.006	0.004	0.003	0.003
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	----
10% Canopy	6/1	1	0.126	0.27	0.27	0.11	0.08	0.70	0.034	0.034	0.014	0.010	0.009
50% Canopy	6/20	2	0.061	0.26	0.26	0.11	0.08	0.01	0.016	0.016	0.007	0.005	0.001
75% Canopy	7/5	3	0.413	0.18	0.18	0.10	0.06	0.06	0.073	0.073	0.039	0.025	0.025
Harvest Corn	10/25	4	0.057	0.17[f]	0.09[g]	0.03[h]	0.03[i]	0.07[j]	0.010	0.005	0.002	0.002	0.002
Fall Chisel	11/15	F	0.230	0.40[k]	0.28[l]	0.16[m]	0.12[n]	0.11[o]	0.091	0.063	0.038	0.028	0.026
Disk	5/1	SB	0.060	0.49	0.34	0.20	0.14	0.13	0.029	0.020	0.012	0.009	0.008
Plant Soybean	5/21	--	0.127	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/15	1	0.093	0.44	0.31	0.18	0.13	0.12	0.041	0.029	0.017	0.013	0.011
50% Canopy	6/30	2	0.041	0.42	0.31	0.18	0.12	0.01	0.017	0.012	0.007	0.005	0.001
75% Canopy	7/10	3	0.360	0.26	0.22	0.14	0.09	0.09	0.094	0.079	0.050	0.032	0.032
Harvest SB	10/5	4	0.026	0.28[p]	0.15[q]	0.09[r]	0.09[s]	0.09[t]	0.007	0.004	0.002	0.002	0.002
Plant Wheat	10/10	SB	0.012	0.25[u]	0.19	0.10	0.08	0.08	0.003	0.002	0.001	0.001	0.001
10% Canopy	11/1	1	0.076	0.20	0.16	0.09	0.08	0.08	0.015	0.012	0.007	0.006	0.006
50% Canopy	12/1	2	0.163	0.17	0.14	0.09	0.08	0.08	0.028	0.023	0.015	0.013	0.013
75% Canopy	4/15	3	0.323	0.02	0.05	0.04	0.04	0.04	0.007	0.017	0.012	0.012	0.012
Harvest Wheat	6/30	4	0.000	0.04	0.04	0.04	0.04	0.04	0.000	0.000	0.000	0.000	0.000
Clover	4/15	--	-----	0.015[v]	----	----	----	----	-----	-----	-----	-----	----

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2)

a,b,c,d,e: line 59, 54, 47, 41, 36 in Table 5 multiply (5.5* 0.02 + F), same reasons as a in CSWK with FP.

f: soil loss ratio by using 50 percent mulch cover from Table 5-C multiplies (6.5* 0.02+0.65), 0.65 is the credit residual effects of turned soil from Table 5-D.

g: soil loss ratio by using 70 percent mulch cover multiplies (6.5*0.02 + 0.65), same reason as f.

h,i,j: soil loss ratios by using 90 percent mulch cover multiplies (6.5* 0.02 + 0.65), same reasons as f and g

k: soil loss ratio for seed-bed period in line 59 multiplies (5.5*0.02+F), F is by assuming 2-3 tons per acre hay yield for soybean grown second year after meadow in Table 5-D.

l,m,n,o: line 54, 47, 41, 36 multiply line 61 in Table 5 and multiply (5.5*0.02 +F) to get the credit residual effects of turned sod, same reasons as a and k.

p: with 50 percent mulch cover from Table 5-C.

q: 70 percent mulch cover from Table 5-C.

r,s,t: 90 percent mulch cover from Table 5-C.

u: same as wheat in CSWK with FP.

V: same as clover in CSWK with FP.

Table A.9 Working Table of C Values for CSWK with NT

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Plant Corn	5/10	SB	0.082	0.09^a	0.07^b	0.05^c	0.03^d	0.03^e	0.007	0.006	0.004	0.003	0.003
10% Canopy	6/1	1	0.126	0.09	0.07	0.05	0.03	0.03	0.011	0.009	0.006	0.004	0.004
50% Canopy	6/20	2	0.061	0.09	0.07	0.06	0.04	0.04	0.005	0.004	0.003	0.002	0.002
75% Canopy	7/5	3	0.413	0.08	0.06	0.05	0.04	0.04	0.032	0.025	0.020	0.016	0.016
Harvest Corn	10/25	4	0.349	0.14^f	0.08^g	0.05^h	0.03^i	0.03^j	0.050	0.027	0.016	0.009	0.009
Plant Soybean	5/21	SB	0.127	0.22^k	0.13^l	0.04^m	0.03^n	0.02^o	0.028	0.016	0.005	0.003	0.002
10% Canopy	6/15	1	0.093	0.20	0.13	0.04	0.03	0.02	0.018	0.012	0.004	0.002	0.002
50% Canopy	6/30	2	0.041	0.20	0.13	0.05	0.03	0.02	0.008	0.005	0.002	0.001	0.001
75% Canopy	7/10	3	0.360	0.16	0.10	0.05	0.03	0.02	0.058	0.038	0.017	0.010	0.007
Harvest SB	10/5	4	0.026	0.19^p	0.10^q	0.06^r	0.06^s	0.06^t	0.005	0.003	0.002	0.002	0.002
Plant Wheat	10/10	SB	0.012	0.25^u	0.19	0.10	0.08	0.08	0.003	0.002	0.001	0.001	0.001
10% Canopy	11/1	1	0.076	0.20	0.16	0.09	0.08	0.08	0.015	0.012	0.007	0.006	0.006
50% Canopy	12/1	2	0.163	0.17	0.14	0.09	0.08	0.08	0.028	0.023	0.015	0.013	0.013
75% Canopy	4/15	3	0.323	0.02	0.05	0.04	0.04	0.04	0.007	0.017	0.012	0.012	0.012
Harvest Wheat	6/30	4	0.000	0.04	0.04	0.04	0.04	0.04	0.000	0.000	0.000	0.000	0.000
Clover	4/15	--	------	0.015^v	----	----	----	----	-----	-----	-----	-----	---

(3) = (1) multiplies soil loss ratio with corresponding residue levels in (2).

a,b,c,d,e: line 82,81,80,79,77 multiply factors to credit residue effects of turned sod in Table 5-D by assuming 2-3 tons per acre hay yield.

f: soil loss ratio with 50 percent mulch cover right after harvest from Table 5-C multiplie 0.65 for credit residual from Table 5-D by assuming 2-3 tons per acre hay yield.

g: with 70 percent mulch cover multiplies 0.65 same reasons as f.

h: with 80 percent mulch cover multiplies 0.65 same reasons as f.

i,j: 90 percent mulch cover multiplies 0.65 same as f.

k,l,m,n,o: line 32,30,27,20,25 multiply credit residual effects of turned sod from Table 5-D by assuming 2-3 tons per acre hay yield for soybean grown second year after meadow.

p: 50 percent mulch cover from Table 5-C.

q: 70 percent mulch cover from Table 5-C.

r,s,t: 80 percent mulch cover from Table 5-C.

u: same as wheat for CSWK with FCH.

v: same as clover for CSWK with FCH.

Table A.10 Working Table of C Values for CCSWMMMM with FP

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Plow	10/15	F	0.300	0.33[a]	0.33	0.33	0.33	0.33	0.099	0.099	0.099	0.099	0.099
Disk	5/1	SB	0.031	0.48	0.48	0.48	0.48	0.48	0.015	0.015	0.015	0.015	0.015
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	--- -
10% Canopy	6/1	1	0.126	0.41	0.41	0.41	0.41	0.41	0.052	0.052	0.052	0.052	0.052
50% Canopy	6/20	2	0.061	0.32	0.32	0.32	0.32	0.32	0.019	0.019	0.019	0.019	0.019
75% Canopy	7/5	3	0.413	0.18	0.18	0.18	0.18	0.18	0.076	0.076	0.076	0.076	0.076
Harvest Corn	10/25	4	0.057	0.03	0.03	0.03	0.03	0.03	0.002	0.002	0.002	0.002	0.002
Fall Plow	11/15	F	0.230	0.66[b]	0.66	0.66	0.66	0.66	0.152	0.152	0.152	0.152	0.152
Disk	5/1	SB	0.031	0.71	0.71	0.71	0.71	0.71	0.022	0.022	0.022	0.022	0.022
Plant Corn	5/10	--	0.082	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/1	1	0.126	0.61	0.61	0.61	0.61	0.61	0.077	0.077	0.077	0.077	0.077
50% Canopy	6/20	2	0.061	0.50	0.50	0.50	0.50	0.50	0.031	0.031	0.031	0.031	0.031
75% Canopy	7/5	3	0.413	0.27	0.27	0.27	0.27	0.27	0.112	0.112	0.112	0.112	0.112
Harvest Corn	10/25	4	0.057	0.04[c]	0.04	0.04	0.04	0.04	0.002	0.002	0.002	0.002	0.002
Fall Plow	11/15	F	0.230	0.52[d]	0.52	0.52	0.52	0.52	0.120	0.120	0.120	0.120	0.120
Disk	5/1	SB	0.060	0.73	0.73	0.73	0.73	0.73	0.044	0.044	0.044	0.044	0.044
Plant Soybean	5/21	--	0.127	----	----	----	----	----	-----	-----	-----	-----	-----
10% Canopy	6/15	1	0.093	0.61	0.61	0.61	0.61	0.61	0.057	0.057	0.057	0.057	0.057
50% Canopy	6/30	2	0.040	0.41	0.41	0.41	0.41	0.41	0.016	0.016	0.016	0.016	0.016
75% Canopy	7/10	3	0.360	0.21	0.21	0.21	0.21	0.21	0.076	0.076	0.076	0.076	0.076
Harvest SB	10/5	4	0.026	0.15	0.15	0.15	0.15	0.15	0.004	0.004	0.004	0.004	0.004
Plant Wheat	10/10	SB	0.012	0.38[e]	0.29	0.16	0.12	0.12	0.005	0.003	0.002	0.001	0.001
10% Canopy	11/1	1	0.076	0.30	0.24	0.14	0.12	0.12	0.023	0.018	0.011	0.009	0.009
50% Canopy	12/1	2	0.163	0.23	0.19	0.12	0.11	0.11	0.037	0.031	0.020	0.018	0.018
75% Canopy	4/15	3	0.323	0.07	0.06	0.04	0.04	0.04	0.023	0.019	0.013	0.013	0.013
Harvest Wheat	6/30	4	0.000	0.22[f]	0.12[g]	0.07[h]	0.04[i]	0.03[j]	0.000	0.000	0.000	0.000	0.000
Meadow	4/15	--	-----	0.015[k]	----	----	----	----	-----	-----	-----	-----	---

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2).

a: soil loss ratios are same as corn for CSWK with FP.

b: line 14 from Table 5 multiplies (5.5*0.02+F). F is the factors to credit residual effects of turned sod from TAble 5-D by assuming 2-3 tons per acre hay yield for corn grown second year after meadow.

c: 90 percent mulch cover from Table 5-C.

d: same as soybean for CSWDCSB with FP.

e: same as wheat for CSWDCSB with FP.

f,g,h,i,j: with 50,70,80 90,95 percent mulch cover, respectively from Table 5-C, same other residual levels.

k: same as clover for CSWK with FP.

Table A.11 Working Table of C Values for CCSWMMMM with FCH

Event	Date	Crop Stage	EI% (1)	Soil Loss Ratios for Various Residue Levels (2)					Crop-stage C Values for Various Residue Levels (3)				
				2000	3000	4000	5000	>5000	2000	3000	4000	5000	>5000
Fall Chisel	10/15	F	0.300	0.20[a]	0.14	0.08	0.06	0.06	0.059	0.041	0.025	0.018	0.017
Disk	5/1	SB	0.031	0.30	0.20	0.12	0.09	0.08	0.011	0.006	0.004	0.003	0.003
Plant Corn	5/10	--	0.082	----	---	---	---	---	----	----	----	----	----
10% Canopy	6/1	1	0.128	0.27	0.27	0.11	0.08	0.70	0.034	0.034	0.014	0.010	0.009
50% Canopy	6/20	2	0.061	0.26	0.26	0.11	0.08	0.01	0.016	0.016	0.007	0.005	0.001
75% Canopy	7/5	3	0.413	0.18	0.18	0.10	0.06	0.06	0.073	0.073	0.039	0.025	0.025
Harvest Corn	10/25	4	0.057	0.17	0.09	0.03	0.03	0.03	0.010	0.005	0.002	0.002	0.002
Fall Chisel	11/15	F	0.230	0.55[b]	0.28[c]	0.16[d]	0.12[e]	0.11[f]	0.126	0.063	0.038	0.026	0.026
Disk	5/1	SB	0.031	0.49	0.34	0.20	0.14	0.13	0.015	0.010	0.006	0.004	0.004
Plant Corn	5/10	--	0.081	----	----	----	----	----	----	----	----	----	----
10% Canopy	6/1	1	0.128	0.44	0.31	0.18	0.13	0.12	0.056	0.039	0.023	0.017	0.015
50% Canopy	6/20	2	0.061	0.42	0.31	0.18	0.12	0.01	0.003	0.019	0.011	0.007	0.001
75% Canopy	7/5	3	0.413	0.26	0.22	0.14	0.09	0.09	0.107	0.091	0.058	0.037	0.037
Harvest Corn	10/25	4	0.057	0.22[g]	0.12[h]	0.07[i]	0.07[j]	0.07[k]	0.013	0.007	0.004	0.004	0.004
Fall Chisel	11/15	F	0.230	0.46[l]	0.32	0.19	0.14	0.13	0.106	0.074	0.044	0.032	0.030
Disk	5/1	SB	0.060	0.51	0.35	0.21	0.15	0.14	0.031	0.021	0.013	0.009	0.008
Plant Soybean	5/21	--	0.127	----	----	----	----	----	-----	-----	-----	-----	----
10% Canopy	6/15	1	0.093	0.46	0.32	0.19	0.14	0.12	0.043	0.030	0.018	0.013	0.011
50% Canopy	6/30	2	0.040	0.42	0.31	0.18	0.12	0.11	0.017	0.012	0.007	0.005	0.004
75% Canopy	7/10	3	0.360	0.26	0.22	0.14	0.09	0.09	0.094	0.079	0.050	0.032	0.032
Harvest SB	6/30	4	0.026	0.28	0.15	0.09	0.09	0.09	0.007	0.004	0.002	0.002	0.002
Plant Wheat	10/10	SB	0.012	0.38[m]	0.29	0.16	0.12	0.12	0.005	0.003	0.002	0.001	0.001
10% Canopy	11/1	1	0.076	0.30	0.24	0.14	0.12	0.12	0.023	0.018	0.011	0.009	0.009
50% Canopy	12/1	2	0.163	0.23	0.19	0.12	0.11	0.11	0.037	0.031	0.020	0.018	0.018
75% Canopy	4/15	3	0.323	0.07	0.06	0.04	0.04	0.04	0.023	0.019	0.013	0.013	0.013
Harvest Wheat	6/30	4	0.000	0.22	0.12	0.07	0.04	0.03	0.000	0.000	0.000	0.000	0.000
Meadow	4/15	--	-----	0.015[n]	----	----	----	----	-----	-----	-----	-----	---

(3) = (1) multiplies soil loss ratios with corresponding residue levels in (2).

a: soil loss ratios for first year corn are the same as those in CSWK with FCH.

b: soil loss ratio for seed-bed period of line 59 in Table 5 multiplies (5.5*0.02+0.75) as we did for b in CCSWMMMM with FP.

c,d,e,f: line 54,47,41,36 multiplied by line 61 in Table 5 and multiplied by (5.5*0.02+F). F is factors to credit residual effects of turned sod in Table 5-D by using 2-3 tons per acre hay yield for corn grown second year after meadow.

g,h,: 50 and 70 percent mulch cover from Table 5-C.

i,j,k: 90 percent mulch cover from Table 5-C.

l: soil loss ratios for soybean are same as those for CSWDCSB with FCH.

m: soil loss ratios for wheat are same as those for CCSWMMMM with FP.

n: meadow is grown before harvest wheat, soil loss ratio are same as that for CSWK with FP, continuing for four years.