AN ECONOMIC ASSESSMENT OF THE DISTRIBUTION OF BENEFITS ARISING FROM ADOPTION OF CONSERVATION TILLAGE PRACTICES IN CROP PRODUCTION I N SOUTHWESTERN ONTARIO*

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Executive Summary

The purpose of this study is to compare the on-farm and off-farm costs of soil erosion and assess the distribution of benefits arising from adoption of conservation tillage practices in selected watersheds in southwestern Ontario. The three watersheds studied are the Big Creek watershed in Essex County, the Newbiggen Creek watershed in Middlesex County, and the Stratford/Avon watershed in Perth County. The conventional tillage practice in all three watersheds is fall moldboard ploughing.

Simulation models are used to estimate changes in gross erosion, sediment delivery to streams, and farm net returns that accompany adoption of conservation tillage systems. A budgeting approach is used to estimate the off-farm costs of sedimentation from cropland and the off-farm benefits of adoption conservation tillage practices. These benefits range from $9.93 to $71.70 per hectare and outweigh the on-farm cost of adoption in most cases.

In the past, the principal rationale for soil conservation policy in Ontario has been to preserve soil productivity. Recent emphasis on both soil and water quality with respect to soil erosion indicates that policy makers have begun to realize the magnitude of the off-farm impacts. The results of this study imply that this shift in emphasis should continue.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Concern for the adverse effects of soil erosion, and particularly for the lost productive capacity of eroded farmland has a long history in Canadian agriculture (McConkey, 1952, Fairbairn, 1984, Sparrow, 1984). The popular view is that the cost of soil erosion to the farmer is quite high and unless something is done to reduce the rate of soil depletion the future of agricultural production is in jeopardy. Estimates of the on-farm costs of soil erosion to Canadian farmers have indicated that annual losses are substantial. However the usefulness of these cost calculations has been questioned (Van Kooten and Furtan, 1987) due to the controversial methods that have been utilized. For the economist, the magnitude of these estimates creates a paradox. As erosion reduces the productivity of the land, the self-seeking behaviour of farmers gives an incentive to apply a suitable amount of erosion control (Schultz, 1982). If the on-farm costs are indeed high, why have farmers not acted to slow the erosion process?

Measurement of the off-farm costs of soil erosion has only recently been added to the agenda of applied researchers in this field of study. The off-farm costs occur as sediment and other erosion-related contaminants entering streams and lakes. This disrupts fish reproduction and feeding, reduces the value of water recreation activities, reduce the capacity of water-storage facilities and navigation channels, affects preservation values of concerned individuals, increases the frequency and volume of floods, increase water-treatment costs, augments maintenance costs of water-using machinery and appliances, and clog water-conveyance systems, such as drainage ditches and irrigation canals. Recent research (Crosson, 1984, Clark et al.,1985, DCH/LRRI, 1985) has indicated that the off-farm costs of soil erosion are substantial and may in fact be larger than the on-farm costs. This result implies that society, rather than farmers, may be the major beneficiary of efforts to reduce the rate of soil erosion and sediment delivery from cropland. This would have important implications on the objectives of programs and policies intended to reduce soil loss and on the nature of cost recovery efforts.

1.2 The Problem

An economic problem exists if soils are not being depleted in a socially optimal manner. Complete elimination of soil erosion is not possible, since some erosion will occur regardless of the amount of control, nor is it economically feasible, since at some point the cost of erosion control will outweigh the benefits arising on and off the farm. In determining the optimal rate of erosion control the farmer will consider the on-farm costs and benefits of reducing erosion rates. Excessive depletion could occur if erosion generates off-farm costs which are not considered by the farmer. The existence of production and production/consumption externalities, such as, sediment increasing the cost of water-treatment for public use and sediment decreasing the recreational value of streams and lakes, suggests that gains in social welfare would result from internalizing the externalities.

1.3 Purpose

The purpose of this study is to compare the on-farm and off-farm costs of soil erosion and assess the distribution of benefits arising from the adoption of conservation tillage practices in selected water-sheds in southwestern Ontario. If conservation tillage practices reduce soil erosion and sediment delivery to streams and lakes, what are the costs and benefits accruing to farmers after switching to conservation tillage practices and what benefits accrue to society as sediment delivery is reduced? This study will address the notion that the off-farm damages of sedimentation suggest that excess rates of soil depletion are occurring on cropland. The estimates of the distribution of costs between on-farm and off-farm damages and the resulting benefits arising from conservation tillage adoption will also be discussed in relation to current efforts to control soil erosion in southwestern Ontario.

1.4 Definition of the Types of Tillage Practices

Conservation tillage is defined by the Soil Conservation Society of America (1982) as "any tillage system that reduces loss of soil or water relative to conventional tillage; often a form of noninversion tillage that retains protective amounts of residue mulch on the surface." Conventional tillage is defined as "the combined primary and secondary tillage operations performed in preparing a seedbed for a given crop grown in a given geographical area.

Within the guidelines of the Ontario Land Stewardship Program, the Ontario Ministry of Agriculture and Food (1987c) defines conservation tillage as any rotation-tillage combination which leaves at least 20 percent of crop residue on the soil surface after planting. Conservation tillage reduces the loss of soil and water by increasing the amount of crop residue left on the soil surface and/or leaving the soil surface rough or ridged. Increasing crop residue and surface roughness reduces the soil and water runoff velocity and sediment transport.

Four different forms of row crop tillage analyzed in this study are fall moldboard ploughing, fall chisel ploughing, ridge planting and no-tillage. Fall moldboard ploughing is the conventional tillage system used on cropland in southwestern Ontario. Approximately 10 to 15 centimeters of the topsoil depth is inverted with the moldboard plough leaving very little residue on the soil surface. This operation exhibits excellent weed control due to the burial of surface vegetation.

Fall chisel ploughing, along with field cultivators, is a conservation tillage system that leaves crop residue on the soil surface at all times. The chisel plough uses large spikes, approximately 30 centimeters apart, that dig roughly 15 to 20 centimeters into the soil. A fall chisel ploughing operation destroys weeds by disturbing the soil and weed roots, however the need for chemical weed control is greater than with moldboard ploughing.

Ridge planting is a form of row crop tillage in which crops are planted on ridges. To prepare the seedbed, the surface of the ridges are scalped while crop residue is left on the soil surface between crop rows. No-tillage or zero tillage is a technique that involves opening a narrow path in the soil into which seed is planted, while the remaining soil surface is undisturbed. Chemical weed control substitutes for cultivation when utilizing till-plant or no-tillage operations (Mannering and Fenster, 1983).

1.5 Location and Description of Selected Watersheds

This study focuses on the Thames River Basin as shown in Figures 1 and 2. The lightly shaded area in Figure 1 shows the location of the Thames River Basin within southern Ontario. Figure 2 shows the location within the Thames River Basin of the three watersheds used in this study.

1.5.1 The Big Creek Watershed

This watershed lies on the eastern end of Essex County and is approximately 18 kilometers from the mouth of the Thames River at Lake St. Clair. The area of this watershed is 3300 hectares and the cropland is very flat, consisting primarily of clay and silty clay soils. The conventional rotation-tillage system in this area is a corn-soybean rotation (one year each) with fall moldboard ploughing.

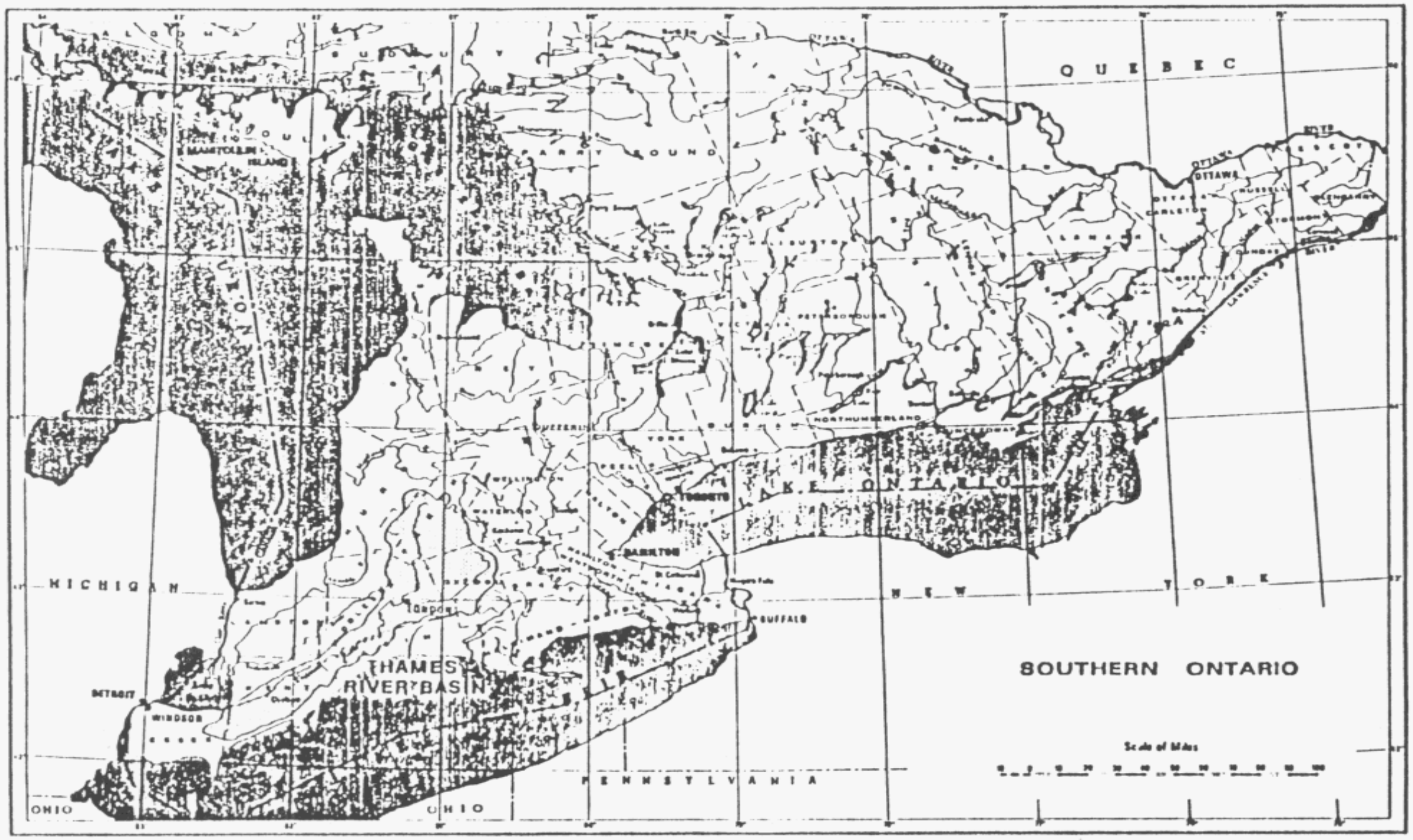
1.5.2 The Newbiggen Creek Watershed

This watershed lies in southwestern Middlesex County, immediately east of the town of Glencoe, and approximately at the midway point of the Thames River Basin. The area of this watershed is 2647 hectares and the cropland is fairly flat, with slopes averaging 0.4 percent, and consisting primarily of silt loam and silty clay loam soils. The conventional rotation-tillage system in this area is continuous corn with fall mold-board ploughing.

1.5.3 The Stratford/Avon Watershed

This watershed lies in southeastern Perth County, approximately 13 kilometers east of the City of Stratford, and is located in the upper area of the Thames River Basin.

Figure 1. Location and Extent of the Thames River Basin



Source: Ontario Ministry of the Environment, 1975.

The area of this watershed is 537 hectares. The cropland is rolling, with slopes ranging from 0.1 to 10.8 percent, and consists primarily of silt loam and clay loam soils. The conventional rotation-tillage system in this area is a corn-alfalfa rotation (two years each) with fall moldboard ploughing.

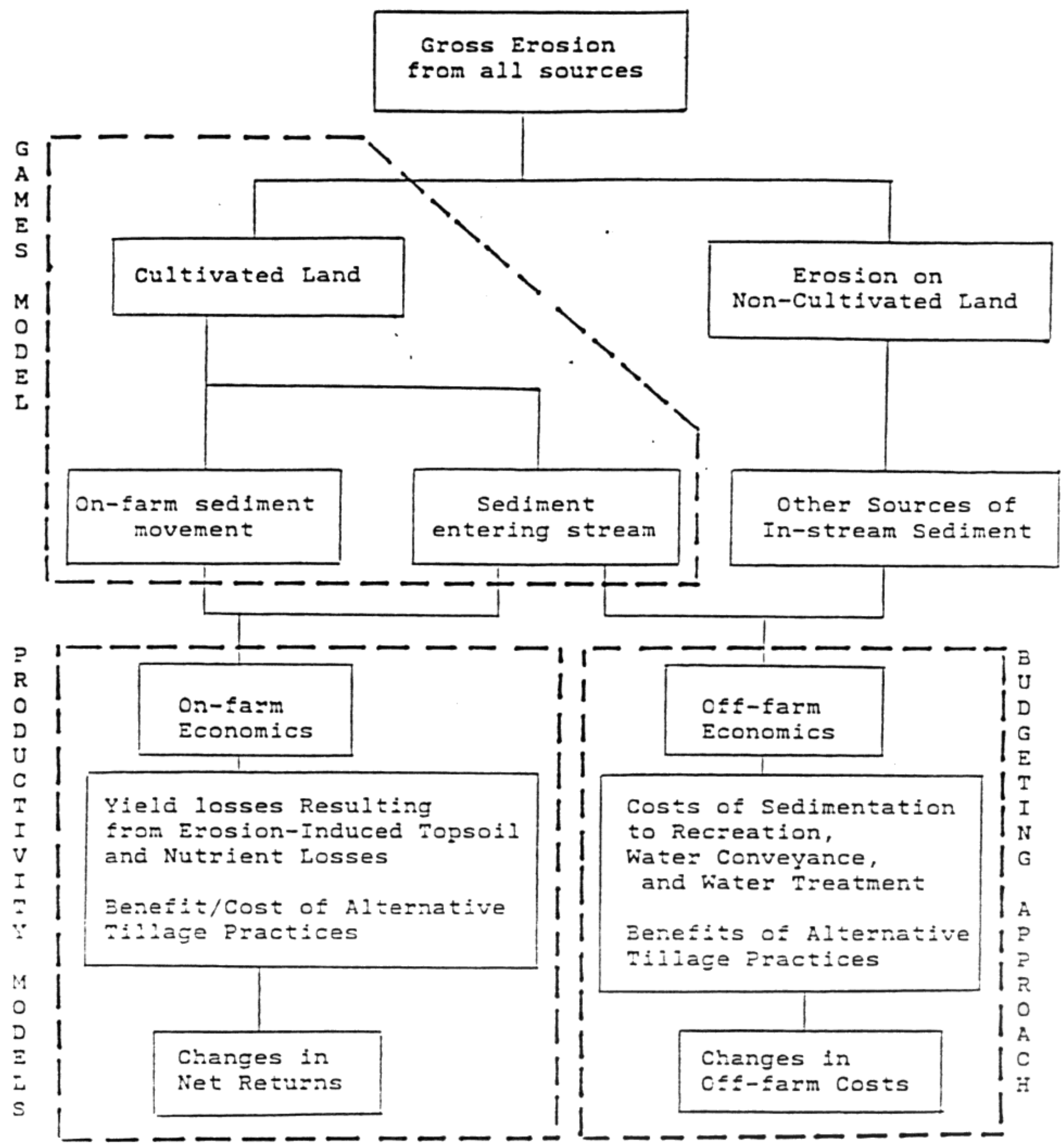
1.6 Overview of the Analytical Framework

Figure 3 provides an overview of the analytical framework utilized to estimate the distribution of benefits arising from the adoption of conservation tillage practices. Gross erosion is that which occurs on all types of land. Cultivated land is responsible for the majority of sediment delivered to streams and lakes within the study area.

Much of what is considered erosion on cultivated land is simply the movement of soil and nutrients on the soil surface. Only a portion of this transported soil will make its way to streams and lakes. The Guelph model for evaluating the effects of Agricultural Management systems on Erosion and Sedimentation (GAMES) developed in the School of Engineering at the University of Guelph (Cook et al.,1985) was used to estimate the rate at which sediment was transported into waterways in each of the three watersheds. The GAMES model uses the Universal Soil Loss Equation (see Appendix 1) to estimate on-farm sediment movement and an expression developed by Clark (1981) to determine the proportion of transported sediment that is delivered to the stream.

In order to analyse the on-farm impact of soil erosion and conservation tillage practices it was necessary to find a model which would allow the combination of GAMES model data and selected economic data. Based on a comprehensive assessment of available procedures (see Dickson and Fox, 1987), the Soil Conservation Economics

Figure 3. An overview of the Analytical Framework Utilized to Estiamte the Distribution of Benefits Arising from Adoption of Conservation Tillage Practices



(SOILEC) model developed at the U. of Illinois (Eleveld et al., 1983a) was chosen for use in the present study. The SOILEC model also utilizes the Universal Soil Loss Equation to estimate erosion. Thus the GAMES model data, which was previously collected for the Big Creek, Newbiggen Creek, and Stratford/Avon watersheds, fit well with SOILEC's physical data requirements.

The SOILEC model utilizes a topsoil depth - yield relationship to simulate erosion-induced changes in soil productivity. This relationship will generally represent how changes in available rooting depth alter the productive capacity of different soils. The effects of other yield affecting factors, such as erosion-induced nutrient depletion, can be incorporated into this relationship by simply increasing the magnitude of yield alterations. The model also utilizes a topsoil depth - cost relationship to simulate changes in the variable costs of production, such as increases in fertilizer costs, which may increase as erosion occurs. The model calculates the present value of net returns over the short (1 year) and long-run (50 years) assuming that current rates of erosion continue and also calculates changes in net returns resulting from the adoption of selected conservation tillage practices.

A substantial part of this research is concerned with estimating the off-farm costs of soil erosion. As mentioned above, the GAMES model calculates the proportion of eroded sediment that is discharged to the stream. The proportion of in-stream sediment from other sources, such as ditch banks, forests, and construction areas, was also estimated for each area where total sediment delivery incurred significant damage to water users.

A number of off-farm costs in the study area were estimated using a budgeting approach. Costs of sedimentation to recreational fishing, water treatment, and water conveyance were estimated for the Thames River Basin. The budgeting approach included the relationships between the off-farm costs and the volume of sediment discharged from the three watersheds. The GAMES model estimated changes in sediment delivery resulting from the adoption of alternative tillage practices. The sediment - water use relationships enabled estimation of the off-farm benefits (reduced off-farm costs) arising from the adoption of conservation tillage practices on cropland in southwestern Ontario.

CHAPTER 2

2.0 A REVIEW OF PROCEDURES DEVELOPED TO ESTIMATE ON-FARM AND OFF-FARM COSTS OF EROSION

2.1 The Nature of the On-Farm Impacts

Soil erosion imposes costs on farm operations by the reduction in the productivity of land and/or by the added costs of yield sustaining purchased inputs required as soil quality deteriorates. Time is an important dimension in the analysis of these costs. The relationship between soil erosion and reductions in crop yields is often only observed when extended time periods are considered. A simple economic model[1] is useful in illustrating the interaction of these various factors. The on-farm costs of soil erosion for the individual farmer can be represented as changes in the present value of the future stream of net returns. The present value of this stream of net returns for an acre of cropland can be illustrated as:

$$\sum_{t=1}^{\infty} \left[\frac{1}{1+r}\right]^{t} \left[P_t\ Q_t - w_t\ Z_t - C_t\right] \tag{1}$$

where r is the real discount rate, P_t the price of the product in year t, Q_t is output in year t, Z_t is a vector of non-land inputs, such as fertilizer, w_t represents the corresponding prices of the non-land inputs and C_t is the cost of soil conservation activities.

Yield per acre of a representative crop can be represented as:

$$Q_t = f(S_t, Z_t) \tag{2}$$

where S_t is a vector of soil characteristics in crop year t. Over time, each element of the vector of soil characteristics evolves according to the intensity of cropping activity (measured as crop yield) in the previous year, Q_{t-1}, as well as through the effects of natural soil generation processes, K_t, and in response to efforts on the part of the farmer to conserve soil structure, C_t. The interaction of these effects can be expressed as:

$$\overset{i}{S}_t = g(Q_{t-1})\ \overset{i}{S}_{t-1} + \overset{i}{h}\ (C_t) + \overset{i}{K}_t \qquad (3)$$

where the superscript identifies a particular element in the vector of physical soil characteristics. In general, the following conditions would be expected to characterize the component functions of this equation of motion;

$h'>0, \quad h''<0$

$g(0) = 1.0, \quad g'<0, \quad g''<0$

A farm operator attempting to maximize the net present value equation (1) would select a soil management strategy that would depend on the expected time path of commodity prices, the discount rate. the extent to which purchased inputs can be substituted for elements in the vector of soil characteristics, the expected prices of those purchased inputs, and the particular characteristics of g(●) and h(●). Interrelationships among these factors are potentially complex, compounding the problems of measuring the economic costs of soil degradation.

2.1.1 Research in Ontario

The impact of erosion on yields in Ontario has been well documented. Ketcheson and Webber (1978) studied yield and erosion data collected for alternative management practices on Guelph loam soil in Ontario from 1953-1962 and from 1971-1976. They concluded that reducing soil erosion may not increase crop yields where other good soil management practices are used. Van Vuuren (1978) discussed the increasing area in Ontario devoted to erosion-inducing row crop production and also economic factors such as high land values, which make it economically impossible to grow low value, less erosive crops. Baffoe (1982) found that continuous corn production in Ontario led to the highest rate of erosion. However, the economically rational farmer would opt for this system since it provided the highest net returns in both the short and the long-run.

Wall and Driver (1982) estimated annual on-farm soil erosion costs in Ontario to be $68 million, with $57 million of this total occurring in southwestern Ontario. They assumed an annual erosion-induced yield reduction of 25% for continuous corn and bean crops and 15% for remaining corn crops.[2] Nutrient and pesticide losses were also included in the cost calculation.

The Land Evaluation Project (Bond et al.,1983) measured the long-run on-farm effects of soil erosion in Huron County. It was estimated that erosion on land in continuous corn would cause yields, in 25 years, to be approximately 5 percent lower than they were initially.

Battison and Miller (1984) studied crop growth and soil data on 14 plots in Waterloo and Wellington counties in Ontario in 1982 and 1983. Eighteen percent of the cropland was noted as moderately to severely eroded. In 1982, yields of corn on severely-eroded soil averaged 34% less than those reported on non-eroded soil and in 1983 yields of corn on severely-eroded soil averaged 43% less than those on non-eroded soil.

Van Vuuren (1986) discussed the possible consequences of soil erosion in southwestern Ontario and mentions that forces exerting their influence in the market, such as the demand for agricultural products and output increasing technologies, may exert a negative influence on soil conservation efforts and that the market is often unable to counterbalance these effects. More recently, research has been conducted at the University of Guelph on the profitability of conventional versus alternative cropping and tillage systems (Zantinge et al.,1986, Baffoe et al.,1987, Bohl, 1987, Stonehouse and Henderson, 1987, Stonehouse et al., 1987a and 1987b). It was found for both short and long-run planning periods that the most profitable production system is the conventional system which also produces the highest rate of soil erosion. That is. conservation tillage systems will lead to a reduction in the rate of soil erosion but also a loss of income due to associated yield reductions. Bohl (1987) also estimated the on-farm impacts of different soil conservation policy strategies, concluding that conventional practices were the most erosive and economically viable, and that political action to reduce erosion would be costly.

2.1.2 Simulation Models

There are a number of reports available that provide a review of research on the on-farm effects of erosion (see Crosson and Stout, 1983, Dumanski et al.,1986, Dickinson et al.,1987, Dickson and Fox, 1987). A complete review of the vast research on the effects of soil erosion would be very lengthy. A survey of some of the recently developed procedures to measure the effect of soil erosion on the productivity of cropland is given below.

As a result of increasing demand in the U.S. for models to estimate the effects of soil erosion on cropland productivity a number of model-ling procedures have emerged. The Erosion-Productivity Impact Calculator (EPIC) was developed by Williams et al.(1983) at the U.S. Department of Agriculture's research station at Temple, Texas. This model simulates the growth of crops and their yields as a function of weather, hydrology. soil chemical, management and erosion factors. Since erosion is a lengthy process, EPIC is able to simulate hundreds of years of effects. The economic component of the model translates the effects of many years of erosion in changes in yields and net profits. The EPIC model has been tested at over 160 locations in the United States covering approximately 52 percent of U.S. cropland in 48 states. The results revealed that after 100 years of erosion, assuming management, cropping patterns and the level of technology remain constant, average yields will be 3 percent less in 2082 than they were in 1982.

The Productivity Index model (Pierce et al.,1983), developed at the University of Minnesota, calculates a numerical index of the productive potential of soil. This method rests on the assumption that soil is a major determinant of crop yield due to the environment it provides for root growth. The productivity index is a function of the soil's sufficiency of available water capacity[3], bulk density[4], pH[5]. and the topsoil depth. The Productivity Index model was tested for a number of crops on 98 million acres of cropland in the Cornbelt region of the U.S. and results revealed that the total decline in, productivity due to erosion would be 2 percent after 50 years and 4 percent after 100 years.

The Soil Conservation Economics (SOILEC) model (Eleveld et al.,1983a), developed at the University of Illinois, calculates the physical and economic effects of erosion. This model (described in detail in section 3.1) uses a soil depth - yield relationship and a soil depth-cost relationship to simulate the effects of erosion on yields and costs of production for up to 50 years. An application of the SOILEC model in the black soil zone of Alberta was reported by Narayanan (1986). The results of Narayanan's simulation revealed that after 50 years of currenterosion rates the annual net returns on cropland in that area would be 1 percent lower than current annual net returns. Narayanan could find no financial incentive for the adoption of conservation tillage practices.

The Resources for the Future (RFF) modelling procedure (Crosson, 1986, pp. 6-12) uses regression analysis to estimate the relationship between the yields of corn, soybeans and wheat, and physical soil loss. soil characteristics affected by erosion and other variables. The regression showed that topsoil depth was the most significant variable explaining the effect of erosion on productivity. Application of the RFF modelling procedure in the Cornbelt region of the U.S. showed that after 50 years of erosion at current rates yields would be 5 percent lower for corn and 3 percent lower for soybeans.

The models, discussed above, that predict long-term changes in productivity resulting from soil erosion show surprisingly similar results despite the different methods of estimation used in each case.

2.2 The Nature of the Off-Farm Impacts

Most research on the impact of soil erosion in Ontario has focused oncropland productivity losses. In the U.S., increased attention has been given to the damages caused by sediment and other erosion-related contaminants in streams and lakes. Clark et al.(1985) identified a number of the off-farm impacts of soil erosion and classified them as in-stream and off-stream damages. In-stream damages are those that occur in streams and lakes. Off-stream damages occur during floods, as sediment settles in water-conveyance systems, or after water is taken from the waterway for public, farm, or industrial use.

In-stream Damages

Sediment and other erosion-related contaminants have adverse effects on the quality of recreation activities, such as fishing, boating, and swimming. In addition, eroded sediment clogs water-storage facilities that supply water to farms, towns. and industries. These facilities often require dredging or new reservoir construction at a significant cost. Sedimentation causes navigation channels to become narrower and shallower leading to increases in the number of shipping accidents and in severe cases channel dredging is required. As excess sediment impairs biological systems and aquatic life, commercial fisheries suffer from reductions in the supply and quality of fish available. Preservation values, the values that concerned individuals or groups place on clean water even though they may never make direct use of the water body, will be adversely affected as sediment and other erosion-related contaminants pollute streams and lakes.

Off-stream Damages

Due to the variability of weather, flooding would occur in many areas regardless of erosion. However, sediment accumulation can cause flooding to be more severe. Water-conveyance systems, such as drainage ditches and irrigation canals, often become obstructed with sediment and must be dredged. Water-treatment facilities, that supply public drinking water, incur increased costs to remove sediment and other contaminants.

Municipal and industrial water users incur increases in maintenance costs as poor water quality damages water-using equipment. Water from lakes and streams is used by many power plants in cooling systems for engines and turbines. Sediment and other contaminants, which increase the growth of algae in water, clog the water lines and filters of these cooling systems. This may lead to machinery breakdowns and plant shutdowns.

2.2.1 Research in Ontario

On April 15, 1972, the Governments of Canada and the United States signed the Great Lakes Water Quality Agreement. Subsequent to this agreement the Pollution from Land Use Activities Reference Group (PLUARG) was established to assess the extent and causes of pollution in the Great Lakes. Research on Canadian agricultural watersheds carried out as part of this agreement studied total phosphorus and sediment delivery to streams and the potential effects of remedial measures (Agriculture Canada, 1978). Coote (1980) reviewed the findings of PLUARG research. No attempt was made, however, to quantify the monetary value of the off-farm impacts.

Wall and Dickinson (1978), first mentioned the monetary value of one of the off-farm impacts by reporting that approximately $6 million (in 1978 dollars)[6] is spent annually on dredging municipal drains in Ontario. The Erosion and Sedimentation Control Committee (1983) reported $112.9 million (in 1983 dollars) as the annual off-farm costs of soil erosion in Ontario. The Committee also estimated annual benefits of approximately $32.5 million (in 1983 dollars) to fishing in Ontario would be brought about by a 10 year active program to control erosion and sedimentation and that such a program would reduce annual phosphorus inputs to Lake Erie by 106 tonnes.

2.2.2 Other Research

Calculation of the downstream benefits of soil erosion control in the U.S. has received much attention and effort. Clawson and Knetsch (1966) developed a travel cost method to estimate a demand function for a particular form of recreation in a particular area. The area beneath the demand function, consumer surplus, would represent the total value (per time period) of that form of recreation to participants. An approach to estimating changes in participation brought about by changes in water quality was developed by Davidson et al.(1966) and applied in the Delaware Estuary. Since 1966 a number of studies have emerged in the U.S. which have attempted to estimate a number of benefits resulting from water quality improvement. The majority of these studies are summarized by Freeman (1982). For example, using the travel cost and participation methods Vaughan and Russell {1982) reported annual water pollution control benefits to recreational fishing in the U.S. to be approximately $2 billion (in 1978 U.S. dollars).

Clark et al.(1985) utilized a budgeting approach to provide a comprehensive set of estimates for the annual off-farm costs of soil erosion in the U.S. They estimated the total annual off-farm costs cf erosion at approximately $6.1 billion (in 1985 U.S. dollars), with cropland's share at $2.2 billion. Only a percentage of the total damages will be attributable to cropland erosion since cropland supplies only a portion of total sediment and other contaminants in streams and lakes.

Econometric cost function models are being used to estimate costs for certain activities, such as water treatment, as a function of relevant variables. These cost functions allow changes in specific variables, such as erosion and sediment delivery rates, to explain changes in costs. Bardos et al. (1987)estimated changes in water-treatment costs that would result from altering soil erosion rates. Data was collected from 12 communities and upland watersheds in western Ohio. They found that water-treatment costs would change by .4 percent for every 1.0 percent change in cropland soil erosion rates. Ribaudo (1987) used the a cost function to estimate the percentage change in the cost ofsediment removal from roadside ditches in the U.S. that may result from reductions in soil erosion rates. Ribaudo found that every 1000 ton reduction in gross erosion would lead to a $72 reduction in sediment removal costs.

2.3 The Current Consensus

Much of the research prior to 1982 on soil erosion in the U.S. and Canada simply documented sporadic cases where erosion was threatening the productivity of cropland. Recent research in the U.S., as discussed in the previous section, suggests that the principal problem of soil erosion is not deterioration of the long-term productivity cf cropland. The more immediate problem is the off-farm costs of erosion. Crosson (1984reported that several studies have emerged indicating that the off-farm costs of erosion in the U.S. are several times higher than on-farm costs. This new perspective has sparked much interest in the study of off-farm benefits of erosion control.

Wall and Driver (1982) estimated that the annual on-farm cost of soil erosion in Ontario is $68 million (in 1982 dollars). Damage of this magnitude implies that the on-farm benefits of erosion control would be substantial. However, Wall and Driver include the on-farm costs resulting from many previous years of erosion and give no estimate of what proportion of the costs, if any, would be recoverable through altering management practices. In Ontario, researchers have often mentioned off-farm damages, but very little work has been done to quantify the off-farm costs of soil erosion and the benefits arising from erosion control on cropland.

CHAPTER 3

3.0 DESCRIPTION OF SIMULATION MODELS

This chapter provides a description to two computer models which aid in the estimation of costs and benefits associated with adoption of conservation tillage practices. Within the analytical framework (de-scribed in section 1.6), the Soil Conservation Economics (SOILEC) model assists in the estimation of the on-farm impacts of alternative management practices and the Guelph model for evaluating the effects of Agricultural Management systems on Erosion and Sedimentation (GAMES) assists in estimating changes in sediment delivery to streams and lakes resulting from changes in cropland management practices.

3.1 The Soil Conservation Economics (SOILEC) Model

The SOILEC model, developed at the University of Illinois (Eleveld et al., 1983a) was chosen to estimate the economic effects of soil erosion on the farm. Erosion rates given by the Universal Soil Loss Equation are translated into reductions in soil productivity by estimating changes in the depth of soil horizons and changes in bulk density[4](see also Narayanan, 1986). Topsoil depth is separated into two horizons. Horizon A is the surface layer of the soil which is rich in organic matter. Horizon B, rich in minerals, lies beneath A and extends to the depth specified by the user.

Based on the assumption that soil erosion results in declining long-term productivity, SOILEC relates crop yields to soil loss from erosion. The soil depth - yield relationship is represented as:

$$Q_T = f[\sum_{t=0}^{T-1} d_t] \qquad (1)$$

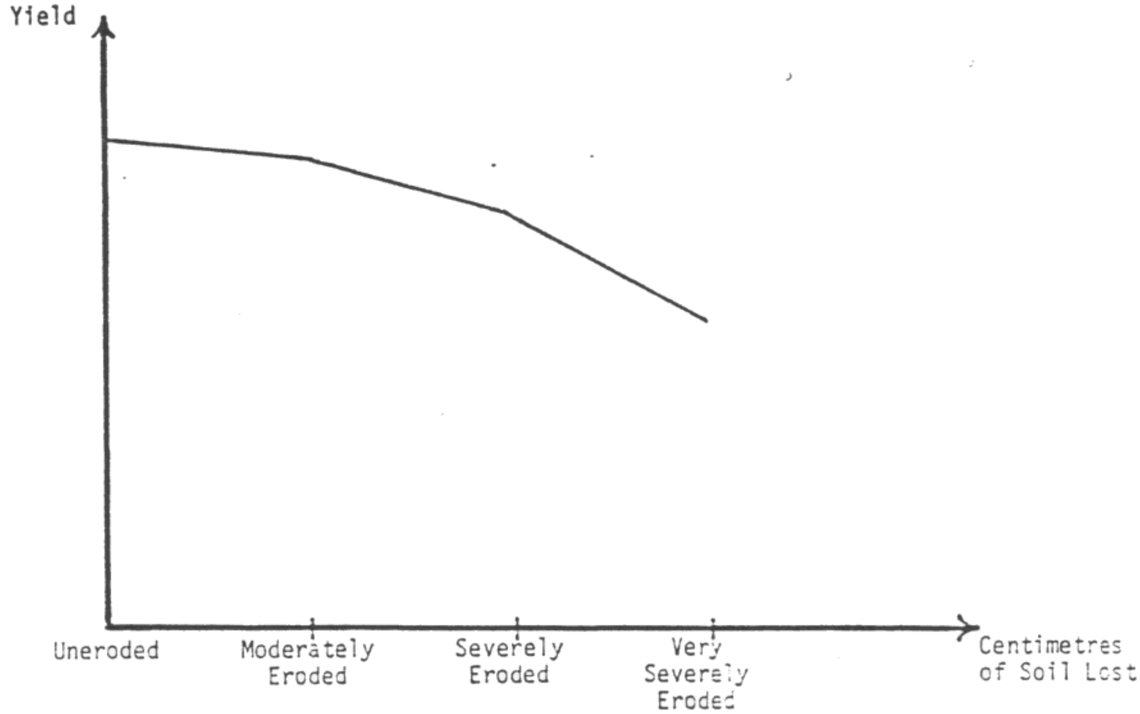
where, Q_T is yield in year T, and d_t is the depth of surface topsoil lost due to erosion in year t (Setia, 1987). The first derivative of the function, f', will be less than zero, that is, yields will decline as total topsoil loss accumulates over time. SOILEC uses linear interpolation to calculate the relationship between topsoil depth and crop yield rates as soil proceeds through four erosion phases (Figure 4). The four phases are: uneroded, where horizons A and B are unchanged; moderately eroded, where 10 centimeters of horizon A remains; severely eroded, where nothing of horizon A remains; and very severely eroded, where neither A nor B remains.

The soil depth-yield relationship can capture many erosion-related effects besides simple topsoil loss. For example, a change in topsoil depth from 10 to 5 centimetres may cause crop yields to fall by 15 percent, all other things remaining constant, while the erosion-induced loss in nutrients occuring at the same time may cause an additional 15 percent reduction in crop yields. To account for both of these effects the reduction in yield recorded for a change in topsoil depth from 10 to 5 centimetres can be specified as 27.75 percent (ie. 15 + 0.15 x 85).

To reflect efforts by farmers to maintain soil productivity by increasing non-land inputs such as fertilizer, a soil depth - cost relationship is presented as:

$$C_T = g[\sum_{t=0}^{T-1} d_t] \qquad (2)$$

Figure 4. The SOILEC Model's Yield - Soil Depth Relationship



Source: Setia, 1987.

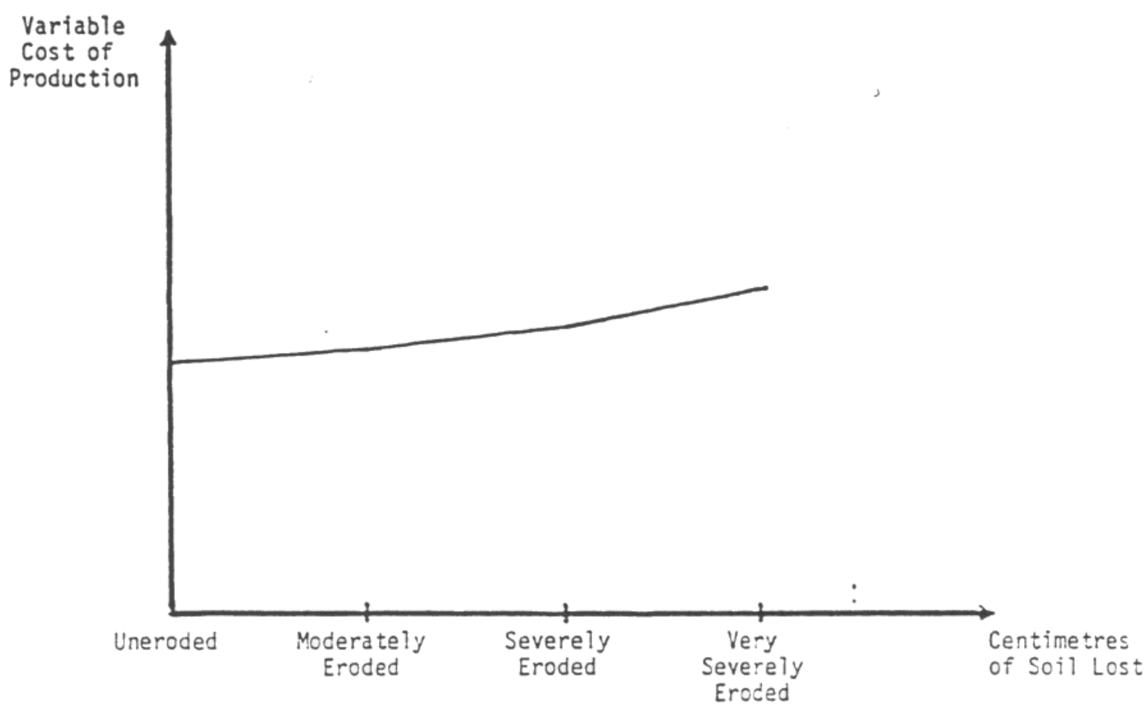
where, C_T is the variable cost of production in year T for a given crop and management practice, and $d_t$is the depth of surface topsoil lost dueto erosion in year t (Setia, 1987). The first derivative of this function, g', will be greater than zero, that is, costs will increase astotal topsoil loss accumulates over time. SOILEC uses linear interpolation to calculate the relationship between topsoil depth and variablecost of production as soil proceeds through four erosion phases (Figure 5).

Total revenue for each year in the planning period (1-50 years) is calculated as the product of the yields generated and a constant market price. The annual per unit area variable costs of production are calculated using a crop budgeting system and the stream of net returns over 50 years is converted to a present value. The SOILEC model allows simulation under alternative management systems and the results of each simulation enable comparison of the financial attractiveness of various rotation-tillage systems.

3.2 The Guelph Model for Evaluating the Effects of Agricultural Management Systems on Erosion and Sedimentation (GAMES)

The GAMES model, developed at the University of Guelph (see Cook et al. 1985). uses an expression developed by Clark (1981) to calculate theproportion of eroded sediment in a watershed that is discharged to the stream. The modelling procedure involves the division of a watershed into field-sized, individual cells with homogeneous features, such as land use, slope and soil characteristics. Gross erosion from an individual cell is calculated by use of the Universal Soil Loss Equation (see Appendix). The sediment delivered to the stream is calculated as:

Figure 5. The SOILEC Model's Cost - Soil Depth Relationship



Source: Setia, 1987.

$$TSL = \sum_{i=1}^{N} E_i \; DR_i \tag{3}$$

where, TSL is total sediment loading, E_i is gross erosion from an individual cell and DR_i is the individual cell delivery ratio to the stream. This delivery ratio is described by Clark (1981) as:

$$DR_I = f(V_i / L_i) \tag{4}$$

where, V_i is the average velocity of overland flow between the initial point of erosion and the stream, and L_i is the distance from the initial point of erosion to the stream.

Equation 4 illustrates how the delivery ratio varies inversely with the travel time of overland flow from the individual cell to the stream. That is, as the distance from the cell to the stream (L_i) increases, the travel time of overland flow increases and the delivery ratio declines, and as the velocity of overland flow (V_i) increases, travel time de-creases and the delivery ratio increases.

A certain proportion of gross erosion (total sediment movement) willbe delivered to an adjacent downhill cell and some of this sediment will settle on that cell while the remaining proportion passes through the adjacent cell to the next cell and so on. This type of calculation is done for each cell in the watershed. Thus, the Universal Soil Loss Equation measures the total sediment movement within a watershed and the GAMES model calculates the proportion of the mobile sediment that enters the stream.

The model accommodates analysis under analytical and predictive modes. The analytical mode uses observed data under current conditions to calculate delivery ratio parameters. That is, since the delivery ratio varies inversely with the travel time of overland flow (equation 4) the delivery ratio assigned to each cell is calculated by the expression:

$$DR_{I} = A\ [TT_{i})^{B} \qquad (5)$$

where TT_i is the travel time of overland flow from the i^{th} cell to the stream and A and B are the delivery ratio parameters. Under the predictive mode the predetermined values of A and B are placed in the input set and the user may then alter any other variables, such as cropping practices, and observe resulting changes in sediment delivery.

The model can be run under seasonal or annual time periods and sincethe watershed is divided into field-sized cells it can also identify critical sediment source areas within the watershed. Input data for the GAMES model was previously collected for a number of watersheds in southwestern Ontario, including those utilized in this study.

CHAPTER 4

4.0 MODEL SIMULATIONS AND RESULTS

4.1 Data Requirements for SOILEC

The SOILEC model requires specification of physical and economic data. The required physical data includes topsoil depths by A and B horizons, variables of the Universal Soil Loss Equation, rates of crop residue production and soil bulk density. The economic data required includes commodity yields and costs of production under four erosion phases, commodity prices, the real discount rate, the rate of technological change, erosion-induced adjustments of yields and costs of production for alternative tillage systems.

4.1.1 Physical Data (see Tables 1 and 2)

Topsoil depths by A and B horizons and corresponding bulk densities for the Brookston soil series of the Big Creek Watershed are reported by Acton et al.(1979). Topsoil depths for the Brantford silt loam of the Newbiggen Creek watershed are reported by Bentley (1979). The remaining topsoil depths and bulk densities as illustrated in Table 1 were supplied by Wall (1987). Average length (L) and slope (S) values needed for use as Universal Soil Loss Equation factors were obtained from data previously collected for research by the School of Engineering, University of Guelph (see Dickinson and Pall. 1982). Due to variable topography and soil types, the Stratford/Avon watershed was divided into 5 sub-regions. Sub-regions 1,2, and 3 are areas of Harriston silt loam soils with average slopes ranging from 1.3 to 7.8 percent. Sub-regions 4 and 5 are areas of Huron clay loam soils with average

Table 1: Physical Data and Soil Characteristics for Selected Watersheds in Southwestern Ontario

Watershed	Sub-Region	'R' Factor	Top Soil Depth (cm)		Bulk Density (g/cc)		Slope (%)	Length (m)	'K' Factor
			"A"	"B"	"A"	"B"			
Big Creek	1	95.00	16.75	83.25	1.60	1.70	0.1	224.0	0.24
Newbiggen Creek	1	95.00	12.95	44.95	1.01	1.38	0.4	184.1	0.37
Stratford/Avon	1	95.00	11.90	38.10	1.30	1.40	1.3	98.1	0.37
Stratford/Avon	2	95.00	11.90	38.10	1.30	1.40	4.4	119.0	0.37
Stratford/Avon	3	95.00	11.90	38.10	1.30	1.40	7.8	100.8	0.37
Stratford/Avon	4	95.00	12.95	41.15	1.10	1.37	1.1	101.4	0.29
Stratford/Avon	5	95.00	12.95	41.15	l.10	1.37	4.5	132.3	0.29

Sources: Bentley, 1978,
School of Engineering, University of Guelph, Department of Soil Science, University of Guelph

Table 2: Cover and Management Factors (C)for Selected Watersheds in Southwestern Ontario

Watershed	Crop Rotation	Tillage	Residue accumulated (kg/ha) 0+	2240+	3360+	4480+	6720
Big Creek	CC	FPL	.440	.440	.440	.440	.440
	CC	FCH	.300	.200	.110	.060	.035
	CC	RIPL	.290	.160	.110	.060	.040
	CS	FPL	.500	.500	.500	.500	.500
	CS	FCH	.370	.250	.180	.140	.120
	CS	RIPL	.300	.170	.120	.070	.050
Newbiggen	CC	FPL	.440	.440	.440	.440	.440
Creek	CC	FCH	.300	.200	.110	.060	.035
	CC	RIPL	.290	.160	.110	.060	.040
Stratford/	2C2A	FPL	.130	.180	.180	.130	.130
Avon	2C2A	FCH	.120	.080	.060	.045	.040
	2C2A	NT	.080	.060	.045	.040	.030
	3C3A	FPL	.180	.180	.180	.180	.180
	3C3A	FCH	.120	.080	.060	.045	.040
	3C3A	NT	.080	.060	.045	.040	.030

CC = continuous corn
CS = alternating corn and soybeans (one year each)
2C2A = alternating 2 years corn and 2 years alfalfa
3C3A = alternating 3 years corn and 3 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Sources: Wischmeier and Smith, 1978.
Presant and Acton. 1934,
Eleveld et al., 1983

slopes of 1.1 and 4.5, respectively. The rainfall factor (R)for each watershed was assumed to be 95.0, the value for the nearest climatic station to the Big Creek watershed. The values for the Newbiggen Creek and Stratford/Avon watersheds are most likely to be similar (Cook et al.,1985, p.22). Soil erodibility factors (K) were based on information supplied by the Ontario Institute of Pedology (Cook et al.,1985, p. 28).

Initial estimates of the cover and management factors (C) were based on data collected by Presant and Acton (1984) and Wischmeier and Smith (1978). Initial estimates of the C factors were adjusted according to the amount of residue accumulating on the field surface based on data from Eleveld et al. (1983b). The C factors and their adjustments are illustrated in Table 2 for each tillage-rotation combination in each watershed. Table 3 illustrates the percentage residue left on the soil surface by each tillage system and the amount of residue production by each crop. Percentage residue left by fall moldboard ploughing, fall chisel ploughing and no-tillage systems were found in Vyn (1985). Percentage residue left by the ridge planting system was found in Vyn et al. (1986). Residue production by crop, measured in tonne per tonne of yield, was based on data in Eleveld et al. (1983b).

4.1.2 Economic Data

Commodity prices and yields for each watershed area, as shown in Table 4, were based on 5 year averages (1982-1988) as reported by the Ontario Ministry of Agriculture and Food (1987a). Initial estimates of per hectare variable costs of production for conventional tillage (fall moldboard ploughing) are as reported by the Ontario Ministry of Agriculture and Food (1987b).

Table 3: Crop Residue Production for Each Crop and Percentage Crop Residue Remaining for Each Tillage System

Crop	Residue Production (tonne per tonne yield)	Tillage System	Percent Residue Remaining After Planting
Corn	1.00	FPL	7.0
Soybeans	1.50	FCH	30.0
Alfalfa	1.00	RIPL	45.0
		NT	62.0

FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Sources: Vyn (1985)
Vyn et al. (1986)
Eleveld et al. (1983a)

Table 4: Commodity Prices and Yields in Selected Watersheds in Southwestern Ontario

Watershed	Commodity	Yield (5 year ave.) (tonne/ha)	Price (5 year ave.) (1986$/tonne)
Big Creek	Corn	6.65	$117.32
	Soybeans	2.42	$266.36
Newbiggen Creek	Corn	6.84	$120.47
Stratford/Avon	Corn	6.46	$120.87
	Alfalfa	6.95	$ 54.06

Source: Ontario Ministry of Agriculture and Food, 1987a.

Operator labour and management, and machinery expenses were included in the variable costs of production, since these would vary between tillage systems. The net return is then a before tax return to land and buildings.

Adjustments to the variable costs of production for chisel ploughing, ridge planting and no-tillage systems[7] were taken from Siemens and 0schwald (1978) and Hinman et al. (1981). These adjustments were very similar to recent results in southwestern Ontario recorded for conservation tillage trial programs (see Aspinall et al..1987, and Ontario Ministry of Agriculture and Food. 1987d). Costs of production for the fall chisel ploughing system averaged 1.0 percent less than that for fall moldboard ploughing. Ridge planting and no-tillage operations were found to be approximately 2.5 percent less costly than fall moldboard ploughing. Cost of production for corn grown the year after alfalfa was calculated to be 9.0 percent lower than that for continuous corn based on the assumption that 70 percent of the nitrogen requirements for corn are supplied by the previous crop of alfalfa (Bolton et al.,1976). Estimated variable production costs for selected rotation-tillage combinations are shown in Table 5.

Yield adjustments for crop-tillage combinations in each watershed are shown in Table 6. Yield adjustments for the fall chisel ploughing and no-tillage systems were based on recent tillage trial results as reported by Aspinall et al. (1987).

Yield adjustments for the ridge planting system are average adjustments as reported in Vyn et al. (1986). The adjustments for corn after soybeans and corn after alfalfa are averages found in research by Vyn (1985 and 1986).

The relationship between topsoil loss and yield used on all watersheds in this

Table 5: Cost of Production Data for Rotation-Tillage Combinations in Selected Watersheds in Southwestern Ontario

Watershed	Rotation	Tillage	Variable Cost of Production (1986$/ha/yr)
Big Creek	CS	FPL	520.50
	CS	FCH	515.30
	CS	RIPL	507.49
	CC	FPL	628.00
	CC	FCH	621.72
	CC	RIPL	612.30
Newbiggen	CC	FPL	628.00
Creek	CC	FCH	621.72
	CC	RIPL	612.30
Stratford/Avon	2C2A	FPL	543.37
	2C2A	FCH	537.94
	202A	NT	529.79
	3C3A	FPL	548.08
	3C3A	FCH	542.60
	3C3A	NT	534.38

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
3C3A = alternating 3 years corn and 3 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Sources: Ontario Ministry of Agriculture and Food, 1987b and 1987d,
Aspinall et al..1987,
Siemens and Oschwald (1978)
Hinman et al. (1981;

Table 6: Yield Adjustments for Crops and Tillage Systems as Compared to Base Crop Yields in Selected Watersheds in Southwestern Ontario

Watershed	Crop	Tillage	Yield Adjustment (percentage change relative to base)
Big Creek	Continuous Corn	FPL	Base
	Corn after Soybeans	FPL	+8.0
	Soybeans	FPL	Base
	Continuous Corn	FCH	-3.0
	Corn after Soybeans	FCH	+5.0
	Soybeans	FCH	-3.0
	Continuous Corn	RIPL	-9.0
	Corn after Soybeans	RIPL	-1.0
	Soybeans	RIPL	-3.0
Newbiggen Creek	Continuous Corn	FPL	Base
	Continuous Corn	FCH	-3.0
	Continuous Corn	RIPL	-9.0
Stratford/Avon	Continuous Corn	FPL	Base
	Corn after Alfalfa	FPL	+9.0
	Alfalfa	FPL	Base
	Continuous Corn	FCH	-3.0
	Corn after Alfalfa	FCH	+6.0
	Alfalfa	FCH	0.0
	Continuous Corn	NT	-5.0
	Corn after Alfalfa	NT	+4.0
	Alfalfa	NT	-3.0

FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Sources: Aspinall et al.,1987,
Ontario Ministry of Agriculture and Food, 1987d,
Vyn et al.,1986,
Vyn, 1985. 1986.

study was reported by Battison and Miller (1984). Yields on moderately eroded soils, where 10 cm of the A horizon remains, were found to be 2.1 percent less than yields on non-eroded soils. Yields on severely eroded soils, where no A horizon remains, were found to be 8.6 percent less than yields on non-eroded soils. Yields on very severely eroded soils, where no B horizon remains, were found to be 38.5 percent less than yields on non-eroded soils. These yield reductions were utilized in this soil depth - yield relationship. The costs of production were held constant for all soil depth levels in the Battison and Miller study and for this reason were held constant in the soil depth-cost relationship. Battison and Miller noted that increasing fertility losses due to excess denitrification and leaching on eroded soils were partially responsible for the reduction in yields. Increasing the input levels on eroded soils would cause the recorded yield levels to increase substantially[8]. Thus the yield reductions assumed by this study may be considered as upper bounds.

The real discount rate used in this study is 5.0 percent based on Kula (1984). In the past few decades, while soil erosion has been occurring, advances in the level of technology have caused yields to increase and unit costs of production to decrease. This may also occur in the future. In order to estimate the costs of erosion to cropland productivity, this study will assume that the future rate of technological advancement is zero.

4.2 SOILEC Simulation and Results

Once all relevant information was collected and formed into master data files for each watershed. model simulations were executed. The SOILEC model was run for 50 years of erosion at current rates.

4.2.1 Average Annual Soil Erosion

Average annual soil erosion rates are shown in Table 7 for all watersheds and rotation-tillage combinations. These rates range from a high of 6.95 tonnes/ha to a low of 0.90 tonnes/ha. A fall chisel ploughing system reduced annual soil erosion, compared to conventional systems, by an average of 31 percent. The ridge planting system reduced average annual soil erosion by 65 and 63 percent in the Big Creek and Newbiggen Creek watersheds, respectively. The no-tillage system reduced average annual soil erosion by 75 percent in the Stratford/Avon watershed.

The Stratford/Avon watershed is an area of variable topography. When it is divided into sub-regions of different average slopes large differences in soil erosion rates are noticed, as illustrated in Table 8. In sub-region 3, which represents 7.0 percent of the watershed, the average annual soil erosion under conventional tillage was 24.67 tonnes/ha. Adopting a fall chisel ploughing system in this sub-region would reduce soil erosion by 33 percent and a no-tillage system would reduce soil erosion by 75 percent. On over half of the cropland in this watershed, namely sub-regions 1 and 4, soil erosion rates were comparable to the low erosion rates recorded on the Big Creek and Newbiggen Creek watersheds.

4.2.2 The Annual On-farm Cost of Soil Erosion

Several reference points have been used by researchers to measure the on-farm costs of soil erosion. Figure 6 illustrates the different cost measurements which result from the use of different points of reference. The line Z shows the time path of net returns per hectare if

Table 7: Annual Soil Erosion Rates for Selected Watersheds and Rotation-Tillage Combinations in Southwestern Ontario

Watershed	Rotation	Tillage	Annual Soil Erosion Rate (tonnes/ha)
Big Creek	CS	FPL	2.91
	CS	FCH	2.02
	CS	RIPL	1.79
	CC	FPL	2.46
	CC	FCH	1.79
	CC	RIPL	0.90
Newbiggen Creek	CC	FPL	4.48
	CC	FCH	3.14
	CC	RIPL	1.57
Stratford/Avon	2C2A	FPL	6.95
	2C2A	FCH	4.71
	3C3A	FPL	6.95
	3C3A	FCH	4.71
	2C2A	NT	2.24
	3C3A	NT	2.24

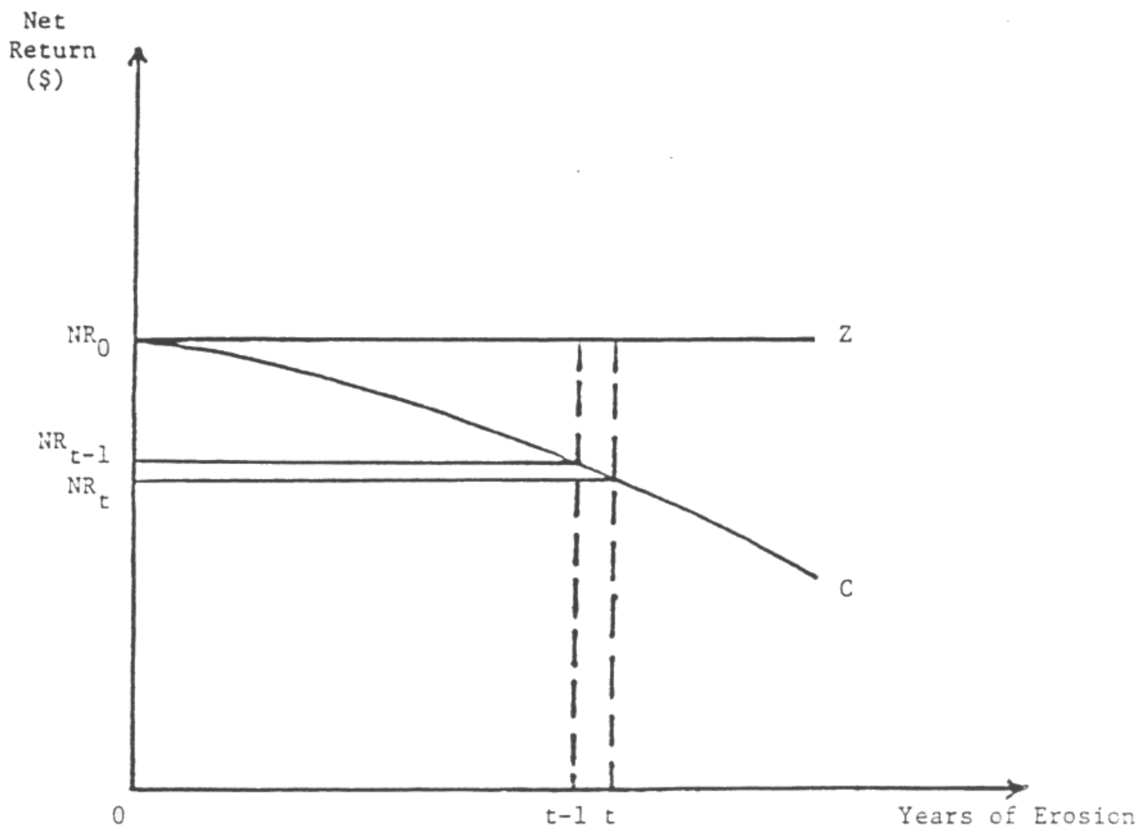
CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
3C3A = alternating 3 years corn and 3 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Table 8: Annual Soil Erosion Rates for Different Slopes and Rotation-Tillage Combinations in the Stratford/Avon Watershed

Sub-Region	Percentage Area of Watershed	Average Slope	Rotation	Tillage	Annual Soil Erosion Rates (tonnes/ha)
1	42.0	1.2	2C2A	FPL	3.00
			2C2A	FCH	1.99
			2C2A	NT	0.74
			3C3A	FPL	3.00
			3C3A	FCH	1.99
			3C3A	NT	0.74
2	27.0	4.3	2C2A	FPL	10.89
			2C2A	FCH	7.26
			2C2A	NT	2.71
			3C3A	FPL	10.89
			3C3A	FCH	7.26
			3C3A	NT	2.71
3	7.0	7.8	2C2A	FPL	24.67
			2C2A	FCH	16.45
			2C2A	NT	6.16
			3C3A	FPL	24.67
			3C3A	FCH	16.45
			3C3A	NT	6.16
4	16.0	1.1	2C2A	FPL	2.15
			2C2A	FCH	1.43
			2C2A	NT	0.54
			3C3A	FPL	2.15
			3C3A	FCH	1.43
			3C3A	NT	0.54
5	8.0	4.5	2C2A	FPL	9.14
			2C2A	FCH	6.09
			2C2A	NT	2.28
			3C3A	FPL	9.14
			3C3A	FCH	6.09
			3C3A	NT	2.28

2C2A = alternating 2 years corn and 2 years alfalfa
3C3A = alternating 3 years corn and 3 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Figure 6. Different Cost Measurements Which Result from the Use of Different Points of Reference



current production practices were used but no erosion damage occurred. The line C shows the actual path of net returns under conventional rotation-tillage practices assuming crop yields, and thus net returns. decline as soil erosion occurs. Measure the annual cost of erosion in year t, using year 0 as the point of reference, the annual cost of erosion is $NR_0 - NR_t$. This is the method of calculation utilized by Wall and Driver (1982). It is not clear if any of the losses in net returns could be recaptured.

Calculation of the annual cost of erosion should use the previous year's level of net returns as a point of reference and thus derive the annual on-farm cost of erosion as $NR_{t-1} - NR_t$. The SOILEC model estimates the annual costs of erosion using the previous year's net returns as the point of reference for each of the 50 years of simulation for each rotation-tillage combination in each watershed. The annual costs are recorded in Table 9. Since it is uncertain if any of these costs are recoverable they simply show that the costs may be somewhat smaller in magnitude than previously thought.

4.2.3 Changes in Net Returns for Alternative Tillage Practices and the Cost of Erosion Control

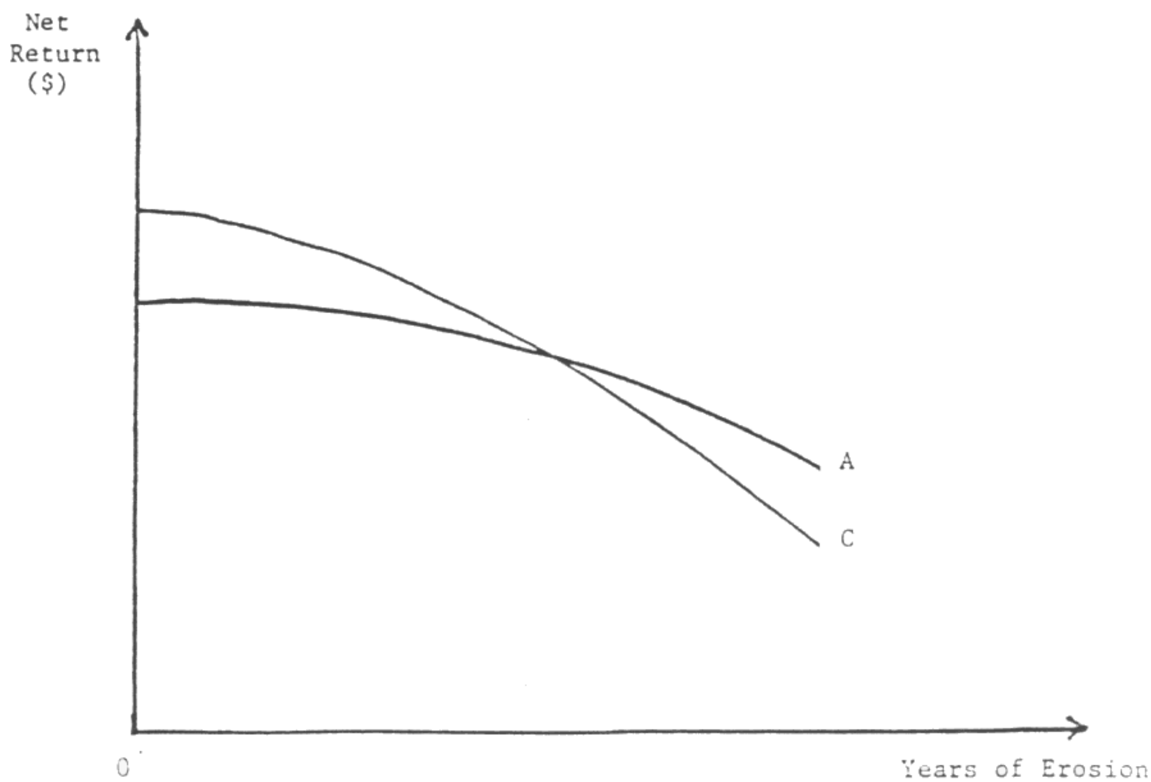
Figure 7 illustrates a hypothetical example of how the future stream of per hectare net returns may differ between alternative tillage practices. Line C shows the path of net returns for conventional rotation-tillage practices which exhibits a downward slope over time due to erosion-induced reductions in crop yields. Line "A" shows the path of net returns for alternative rotation-tillage practices which will reduce the rate of soil erosion. There will be an initial sacrifice in net returns with the alternative practice due to generally lower yields

Table 9: The Annual On-farm Cost of Erosion for Selected Rotation-Tillage Combinations and Watersheds in Southwestern Ontario

Watershed	Rotation	Tillage	Average Annual On-Farm Cost of Erosion ($/ha)
Big Creek	CS	FPL	0.04
	CS	FCH	0.03
	CS	RIPL	0.01
Newbiggen Creek	CC	FPL	0.07
	CC	FCH	0.05
	CC	RIPL	0.02
Stratford/Avon	2C2A	FPL	0.12
	2C2A	FCH	0.07
	2C2A	NT	0.04

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

Figure 7. Comparing the Future Stream of Net Returns for Conventional and Alternative Tillage Practices



associated with conservation tillage techniques, however this practice will become more attractive over time since the downward slope of this path of net returns will not be as steep as the slope of the path of net returns under conventional practices. These two lines will intersect at some point in the future.

Figures 1A to 7A in Appendix 2 illustrate the path of net returns for selected rotation-tillage practices in each of the three watersheds. Net returns in sub-region 3 of the Stratford/Avon watershed (Figure 5a), where erosion rates are 24.67 tonnes/ha, decline substantially under conventional rotation-tillage practices. After 30 years of erosion at current rates net returns for the conventional tillage practice fall below those recorded for both conservation tillage techniques. This sub-region, however. represents only 7 percent of cropland in the Stratford/Avon watershed. In all other sub-regions of each watershed conventional tillage practices exhibited the highest net returns throughout the 50 year analysis period.

The SOILEC model estimates the annual cost of switching to each alternative rotation-tillage technique by calculating the present value of each stream of net returns and transforming this present value to an annuity over 50 years. These annuity values are illustrated in Column (1) of Table 10 and are ranked from highest to lowest for each watershed. Column (2) shows the difference in annuity values for each rotation-tillage practice as compared to the conventional practices. Although erosion rates are reduced with conservation tillage practices, these systems all exhibit a cost to the farmer since initial reductions in yields associated with the alternative practices outweigh the savings in costs of production and the long-run benefits of protecting soil productivity.

Table 10: The Annual On-farm Costs of Adopting Alternative Management Practices in Selected Watersheds in Southwestern Ontario

Watershed	Rotation-Tillage	Present Value of Net Returns [1] ($/ha)	On-farm Costs of Adoption [2] ($/ha)
Big Creek	CS FPL	218.60	base
	CS FCH	201.83	16.77
	CS RIPL	184.91	33.69
	CC FPL	151.79	66.81
	CC FCH	134.89	83.71
	CC RIPL	97.72	120.88
Newbiggen Creek	CC FPL	182.21	base
	CC FCH	164.57	17.64
	CC RIPL	125.75	56.46
Stratford/ Avon	2C2A FPL	39.22	base
	2C2A FCH	33.42	5.80
	2C2A NT	28.77	10.45
	3C3A FPL	28.75	10.47
	3C3A FCH	23.14	16.08
	3C3A NT	18.72	20.50

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
3C3A = alternating 3 years corn and 3 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

[1] The present value of net returns is expressed as an annuity in order to find the annual costs of adoption of alternative management practices.

[2] These costs were found by comparing annuities in the previous column.

Thus, the values in Column (2) of Table 10 represent the annual per hectare cost of controlling erosion.

4.3 GAMES Model Simulation and Results

Previous research has revealed that the critical time for soil transport in Southern Ontario is the period from February to May (Dickinson and Pall, 1982). For this reason, the GAMES model was run under late winter and early spring conditions.

The model was run in three phases for each watershed. The first phase was the analytical mode run under conventional rotation-tillage practices. In this phase the GAMES model simulated current gross erosion and sediment delivery rates. The model was also run in two phases under the predictive mode. The first phase was to simulate gross erosion and sediment delivery when those areas currently being fall moldboards ploughed were switched to fall chisel ploughing. The second phase simulated gross erosion and sediment delivery when those areas currently being fall moldboard ploughed were switched to the ridge planting system in the Big Creek and Newbiggen Creek watersheds7 and to the no-tillage system in the Stratford/Avon watershed.

Based on a review of available data. it was assumed that the cropping factor ©) values (described in section 4.1.1) would be reduced by 1/3 and 2/3 for fall chisel ploughing and ridge planting respectively, and by 2/3 for the no-tillage system (Wischmeier and Smith, 1978, Presant and Acton, 1984, and Eleveld et al., 1983b). These reductions in C factor values are conservative since research in the U.S. has found that in most cases the reductions will be greater (see Wischmeier and Smith, 1978, p. 22-23).The results from the GAMES model simulation are shown in Table 11.The percentage reduction in gross erosion for each phase of the predictive mode were similar to the percentage changes in the C factor values as discussed above. The percentage reductions in sediment delivery were greater than the percentage changes in the C factor values. Using chisel ploughing in fall rather than fall moldboard ploughing reduced sediment delivery on average by 40.7 percent. Use of ridge-planting and no-tillage systems in these three watersheds reduced sediment delivery by 77.3 percent on average.

4.4 The Budgeting Approach

Methods developed to facilitate the estimation of different components of the off-farm costs were evaluated by Dickson and Fox (1937) and the budgeting approach was selected for use. Initially, this approach involves the collection of relevant research and records that pertain to the environmental impacts of erosion. The budgeting approach allows a researcher to estimate the total off-farm costs of erosion in a given area by utilizing data on the costs or magnitude of certain activities. For example. if magnitudes rather than costs are recorded, such as the amount of dredging in an area without actual dollars spent, then values can be assigned based on estimated per unit costs of the activity in question.

4.5 Estimates of the Off-farm Costs of Soil Erosion Under Alternative Tillage Practices

4.5.1 Recreational Fishing

Sediment harms fish in lakes and streams by damaging spawning and feeding areas and by reducing the respiratory efficiency of the fish.

Table 11: GAMES Model Results for Conventional and Conservation Tillage Systems in Selected Watersheds in Southwestern Ontario

Watershed (area in ha.)	Mode	Tillage System	Gross Erosion (tonnes/ha)	Percent[2] Reduction	Sediment Delivery (tonnes/ha)	Percent[2] Reduction
Big Creek	Analytical	FPL	2.54	base	0.65	base
(3300)	Predictive	FCH	1.69	33.5	0.38	41.5
	Predictive	RIPL	0.85	66.5	0.16	75.4
Newbiggen	Analytical	FPL	2.61	base	0.26	base
Creek	Predictive	FCH	1.75	33.0	0.14	46.2
(2647)	Predictive	RIPL	0.90	65.5	0.06	76.9
Stratford/	Analytical	FPL	6.15	base	0.64	base
Avon	Predictive	FCH	4.37	28.9	0.42	34.4
(537)	Predictive	NT	2.30	62.6	0.13	79.7

FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

1 These percentage reductions were calculated by comparing gross erosion rates of conservation tillage practices to gross erosion rates of conventional tillage practices.

2 These percentage reductions were calculated by comparing the amount of sediment delivery under conservation tillage practices to the amount of sediment delivery under conventional tillage practices.

The problem is not sedimentation itself but excess sedimentation, especially in the spring when spawning occurs. Fisheries officials generally agree that excess sedimentation exists in southwestern Ontario. In the Draft Chatham District Management Plan (Ontario Ministry of Natural Resources, 1987, p.5 and 9) which covers the area most affected by sedimentation from the Thames River Basin, it was stated:

> "Water quality and warm water fisheries habitat, especially for inland areas, have been severely altered by the presence of high suspended solid loads and turbidities. This situation has been caused by excessive erosion from the intensively farmed land and highly developed drainage schemes which have altered the natural habitat in most of the inland streams within the district...High intensity agricultural land use practices have severely degraded most inland fisheries habitat and water quality to a point where the cost of rehabilitation is potentially very high and involves application of soil conservation and review of drainage procedures across whole watersheds.

The Thames River is the principal spawning run for walleye from Lake St. Clair. Large numbers of walleye from lower Lake Huron and the St. Clair River also use the Thames River for spawning (Ontario Ministry of Natural Resources, 1987). Large numbers of bass, trout and northern pike, which are all adversely affected by excess sediment, are caught by fishermen in the southwestern region of Ontario (Ontario Ministry of Natural Resources, 1981). The fish that are most affected by excess sedimentation, are also the fish most preferred by resident sport fishermen in Ontario (Ontario Ministry of Natural Resources, 1981).

The Erosion and Sedimentation Control Committee (1983) reported the number of fish caught for sediment-sensitive species. The estimates of number of fish caught are conservative since they represent fish caught by resident sport fishermen only. For example, adding non-resident fishing may double the estimated number of walleye caught in this area (Ontario Ministry of Natural Resources, 1981). The number of fish caught for each listed species is shown in column (1) of Table 12.

The effect of excess sedimentation on fish population was estimated by the Erosion and Sedimentation Control Committee (1983) by the application of sediment factors to the affected species. For this analysis excess sediment is assumed to originate from cropland erosion. The sediment factor shows the potential percentage increase in fish populations that may result from elimination of excess sediment from waterways. For example, most trout species are given a sediment factor of 1.00 which suggests that elimination of excess sediment would result in a doubling of trout populations. Less sensitive species, such as largemouth bass, are given a sediment factor of 0.25 suggesting that their populations may increase by 25 percent. These sediment factors are conservative since some studies have suggested that trout populations, for example, could increase by 800 percent after a reduction in the level of sediment in sensitive areas (see Erosion and Sedimentation Control Committee, 1983). The sediment factors utilized along with the potential increase in the number of fish caught are shown in columns (2)and (3) of Table 12.

Calculating the number of angler days is important since most studies on the benefit of sport fishing report the value or willingness to pay for sport fishing on an angler day basis. with the average number of fish caught per day, as reported by the Erosion and Sedimentation Control Committee (1983), and shown in column (4) of Table 12, one can calculate current angler days as illustrated in column (5) of Table 12.

This study assumes that a 1.0 percent increase in the number of fish caught will lead to a 0.25 percent increase in the number of angler days. This is a conservative estimate since the Erosion and Sedimentation Control Committee assumed that a 1.0 percent

Table 12: Calculation of the Total Annual Cost of Cropland Sedimentation to Sport Fishing in Southern Ontario

Species	(1) No. of Fish Caught	(2) Sediment Factor	(3) [(1) x(2)] Potential Increase in No. of Fish Caught	(4) Average Catch Per Day	(5) [(1) - (4)] Current Angler Days	(6) [(5) x.25 (2)] Increase in Angler Days	(7) [(6) x (4)] No. of Fish Caught
Rainbow Trout	1,075,360	0.75	806,520	0.5	2,150,720	403,260	201,630
Brook Trout.	1,454,400	1.00	1,451,400	2	727,200	181,800	363,600
Brown Trout	180,000	1.00	180,000	1	180,000	45,000	45,000
Lake Trout	284,200	1.00	284,200	0.5	568,400	142,100	71,050
Walleye	5,412,000	0.5.	2,706,000	2	2,706,000	338,250	676,500
Whitefish	155,000	0.5.	77,500	1 . 0	155,000	19,375	19,375
Bass, largemouth	1,412,000	0.25	353,000	2857	494,200	30,888	88,247
Bass, smallmouth	2,549,000	0.75	1,911,750	2857	892,150	167,278	477,913
Maskinonge	108,000	0.25	27,000	0.5	216,000	13,500	6,750
Northern Pike	1,715,000	0.25	428,750	2	857,500	53,594	107,188

(Table 12 is continued on the next page)

Table 12 (continued)

Species	(8) Total Angler Days	(9) Remaining Increase in Fish Caught	(10) {(9) - [(1) + (7)]} Increase as Percent: of Current	(11) [(8) x $18] Fishing Dollar Value at Previous Catch Rates	(12) [(11) x (10) x.125] Increase in Value	(13) Total Increased Value
Rainbow trout	2,553,980	604,890	0.56	45,971,640	3,218,014	10,476,694
Brook trout:	909,000	1,090,800	0.60	16,362,000	1,227,150	4,499,550
Brown trout	225,000	135,000	0.60	4,050,000	303,750	1,113,750
Lake trout	710,500	213,150	0.60	12,789,000	959,175	3,516,975
Walleye	3,044,250	2,029,500	0.31	54,796,000	2,328,830	8,417,330
Whitefish	174,350	58,125	0.34	3,138,300	133,378	482,128
Bass, largemouth	525,088	264,753	0.18	9,451,584	212,661	768,645
Bass, smallmouth	1,059,428	1,433,837	0.47	19,069,704	1,120,345	4,131,349
Maskinonge	229,500	20,250	0.18	4,131,000	922,948	335,948
Northern Pike	911,094	321,562	0.18	16,399,692	368,993	1,333,685
						$35,076,054

increase in the number of fish caught would lead to an equal 1.0 percent increase in angler days, and another study by Russell and Vaughan (1982b) found that a 1.0 percent increase in the number of warm water game fish caught would lead to a 0.33 percent increase in the number of angler days. The potential increase in angler days is calculated in column (6)of Table 12. This increase in anglers will catch a proportion of the total increase in number of fish caught as shown in column (7) of Table 12. Total angler days, including the new increase, are shown in column (8). The remaining number of fish to be caught, column (9), will increase the catch per day for all fisherman (old and new) by the ratio of remaining number of fish to be caught to the current number of fish caught as shown in column (10). For example, the average catch of rainbow trout is 0.5 fish per day and the remaining number of fish to be caught will increase this figure by approximately 56 percent to 0.78 fish per day on average.

Vaughan and Russell (1982b) reported that every 1.0 percent increase in the catch per angler day of any type of fish would increase the value or willingness to pay for that angler day by approximately 0.125 percent. That is, it was found that fishermen were not extremely sensitive to the number of fish they catch on a trip. This study has utilized this calculation for valuing the increase in catch per day. Estimates for the value or willingness to pay for a day of recreational fishing utilize surveys of fishermen which relate the cost of travelling to the fishing site to their total participation throughout the year (see Clawson and Knetsch, 1966). "A" value of $18 per angler day is used based on the value used by the Erosion and Sedimentation Control Committee, adjusted for inflation. This value is a conservative estimate since other studies (Charbonneau and Hay, 1978, and Vaughan and Russell, 1982b) have estimated average willingness to pay for a similar type of angler day at approximately $29.50 to $37.40. Using $18.00 per angler day, the dollar value of fishing, at previous catch rates, is shown in column (11). These values are used to calculate the increase in the value of fishing brought about by the increase in catch rates, as shown in column (12). Combining this increase in angler day value with the value of the increase in participation and summing for each species as in column (13),gives an estimate of approximately $35 million as the total benefits resulting from the elimination of excess sediment from streams and lakes in Southern Ontario.

Wall et al.(1972) estimated total sediment delivery from cropland and streambanks in Ontario to be 652.872 tonnes per year. Since this number included streambank erosion rates it was necessary to estimate streambank erosion based on research in southwestern Ontario by Knap et al. (1979). They measured streambank erosion at 0.223 tonnes per hectare in the Big Creek watershed. Streambank erosion at the Holiday Creek watershed, which is in the vicinity of the Stratford/Avon watershed and exhibits similar soils and cropping patterns was found to be 0.005 tonnes per hectare and this figure was used by this study as a close approximation for the Stratford/Avon watershed. Since no study was done at or near the Newbiggen Creek watershed streambank erosion was estimated to be 0.114 tonnes per hectare year, the mean of the other two estimates. Knap et al. also noted that 60 percent of streambank erosion was due to intensive agricultural practices and could potentially be controlled by the use of conservation tillage practices.

Table 13 illustrates the method used to calculate each watershed's share of the

Table 13: The Annual Value to Sport Fishing of Reduced Sediment Loading Under Conservation Tillage Practices in Selected Watersheds in Southwestern Ontario

Watershed	Rotation Tillage	(1) Cropland Sediment Delivery (tonnes)[1]	(2) Percentage Reduction of (1)	(3) Streamhank Erosion Rates[2] (tonnes/ha)	(4) Percentage Reduction of (3) [.6 x (2)]	(5) Total Streambank Erosion[3] (tonnes)
Big Creek	CS FPL	2,574	-	0.223	-	736
(3300 ha)	CS FCH	1,506	41.5	0.167	24.9	553
	CS RIPL	633	75.4	0.122	45.2	403
Newbiggen	CC FPL	826	-	0.114	-	302
Creek	CC FCH	444	46.2	0.082	27.7	218
(2647 ha)	CC RIPL	191	76.9	0.061	46.1	163
Stratford/	2C2A FPL	412	-	0.005	-	3
Avon	2C2A FCH	270	34.4	0.004	20.6	2
(537 ha)	2C2A NT	84	79.7	0.003	47.8	2

[1] Data from GAMES model simulations.

[2] Derived from Knap et al.(1979).

[3] Streambank erosion rates [column (3)] multiplied by the number of hectares in the watershed.

(Table 13 is continued on the next page)

Table 13 (continued)

Watershed	Rotation-Tillage	(6) Total Sediment Delivery (tonnes) [(1) + (5)]	(7) Cost to Fishing ($/tonne)[5]	(8) Total Cost to Fishing ($) [(6) x (7))	(9) Annual Value of Reducing Sediment Loading (total $)	(10) ($/ha)
Big Creek	CS FPl.	3,310	80.60	266,786	-	-
(3300 ha)	CS FCH	2,059	80.60	165,955	100,831	30.55
	CS RIPL	1,036	80.60	83,502	183,284	55.54
Newbiggen	CC FPL.	1,128	53.73	60,607	-	-
Creek	CC FCH	662	53.73	35,569	25,038	9.46
(2647 ha)	CC RIPL	354	53.73	19,020	41,587	15.71
Stratford/	2C2A FPL	415	26.87	11,151	-	-
Avon	2C2A FCH	272	26.87	7,309	3,842	7.15
(537ha)	2C2A NT	86	26.87	2,311	8,840	16.46

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

[5] Adjusted by damage factor based on type of soils and vicinity to area of damage as discussed in section 4.5.1.

total damages, and potential benefits arising from the adoption of conservation tillage practices. Columns (1)and (2) are data from the GAMES model simulation as reported in section 4.3. Column (3)illustrates streambank erosion rates as discussed above. Column (4)shows the percentage reduction in streambank erosion brought about by the conservation tillage practices in each watershed. This is simply the percentage reduction in sediment delivery predicted by the GAMES model, as in column (2)applied to 60 percent of streambank erosion, since that is the proportion which Knap et al. noted as controllable. These results applied to the total number of hectares in each watershed give the total amount of streambank erosion for each rotation-tillage combination as shown in column (5). Combining streambank and cropland sediment delivery, column (6) gives total sediment delivery for each management practice in each watershed.

The average cost of erosion to sport fishing in dollars per tonne of sediment delivered was found by dividing the total damage of excess sedimentation to sport fishing ($35,076.054) by the estimated total sediment delivery to streams and lakes in Southern Ontario (652,872 tonnes). The average cost of erosion to sport fishing was thus estimated to be $53.73 per tonne of sediment delivered and adjusted for each watershed as explained below.

Very little is known about the transport of sediment after it enters the stream. Most researchers familiar with the soils and vicinity of the watersheds utilized in this study would agree that not all sediment delivered to streams from each watershed will make its way to Lake St. Clair. The Stratford/Avon watershed has heavier soils than the other watersheds and, although there is some fishing in the area, it is not very close to the lakes where most angler days occur. Suspended sediment from the Newbiggen Creek watershed will have some damaging effects on fishing since a larger proportion of it will travel to the sensitive spawning areas near the mouth of the Thames. Sediment delivered from the Big Creek watershed will have the largest effect on fishing since the soils are very fine, easily suspended and the watershed is very close to the sensitive fishing areas. For this reason it is assumed that approximately 100 percent, 67 percent and 33 percent of sediment from Big Creek, Newbiggen Creek and the Stratford/Avon watershed, respectively, will end up travelling to such areas as Lake St. Clair where the majority of damage occurs. In order that damage values correspond to the above assumption, damage factors were applied to the average costs for each watershed as follows:

Big Creek Watershed	+0.5
Newbiggen Creek Watershed	0.0
Stratford/Avon Watershed	-0.5

Since the average cost to fishing per tonne of suspended sediment is $53.73, applying these changes for each watershed sets the respective costs at:

Big Creek Watershed	$80.60/tonne
Newbiggen Creek Watershed	$53.73/tonne
Stratford/Avon Watershed	$26.87/tonne

These costs are recorded in column (7)of Table 13. Multiplying columns (6) and (7) provides the total cost to sport fishing caused by sediment delivery from the three watersheds under alternative tillage practices. The value of reducing sediment loading in total dollars per watershed and dollars per hectare are shown in column (9) and (10). The benefits range from $7.15 per hectare for adoption of fall chisel ploughing systems in the Stratford/Avon watershed to $55.54 per hectare for switching to ridge tillage systems in the

Big Creek watershed. Since cropland sediment loads may be an over-estimate of excess sedimentation, the benefits may accrue faster and in greater proportion than estimated above.

4.5.2 Water-Conveyance Costs

Sediment buildup in drainage ditches and municipal drains reduces the efficiency of the drainage system and must be periodically removed. The sediment that settles in drains will be a portion of gross on-farm sediment movement. Very little is known about the possible percentage of gross erosion that may settle in drains. Wall and Dickinson (1973) estimate annual spending on sediment removal from municipal drains at $11.2 million (in 1987 dollars). The Erosion and Sedimentation Control Committee (1983) reports that an additional $4.2 million (in 1987 dollars) is spent by the Ministry of Transportation and Communications on removing sediment from road ditches. Only a small portion of this sediment comes from sources other than cropland.

Areas with lower sediment delivery rates may have heavier soils that exhibit a higher tendency to settle, and areas with higher sediment delivery rates may have finer soils that exhibit a lower tendency to settle. Therefore, the share of total expenditures for each watershed should be calculated on a per hectare rather that: on a per tonne (of sediment loading) basis. Dividing the total expenditures of $15.4 million by the total improved cropland area in Ontario of 4,518,713 hectares (Ontario Ministry of Agriculture and Food. 1978a) reveals annual water-conveyance costs to be $3.41 per hectare, as shown in column

(1) of Table 14. Since the amount of sediment in drains will be related to gross erosion, rather than sediment delivery alone, this study has assumed that the damage to water-conveyance will decline in proportion with the percentage reduction in gross erosion as estimated by the GAMES model simulation reported in section 4.3. These percentage reductions are shown in column (2) of Table 14. Combining the information in columns (1) and (2) gives estimates for the total annual cost of erosion to water-conveyance systems for each rotation-tillage system in each watershed, as shown in column (3). The figures for costs under conventional tillage practices were checked with local superintendents at the municipal offices of Mersea. Tilbury West and Ekfrid Townships. The share of costs estimated for these watersheds turned out to be very close to actual 1987 expenditures in each case. These figures are conservative estimates of the total damage since not all sediment buildup is dredged. In fact, the persons in charge of maintenance in the townships mentioned above all asserted that more funds should be spent to clean the drainage networks.

The value of reducing sediment loading on a per watershed and per hectare basis are shown in columns (4)and (5). The estimated benefits range from $0.99 per hectare for a chisel ploughing system in the Stratford/Avon watershed to $2.27 per hectare for a ridge-tillage system in the Big Creek watershed.

4.5.3 Water-Treatment Costs

Many water treatment plants in Southern Ontario treat surface water from streams or lakes to be used for public drinking purposes. These plants utilize processes such as screening, sediment basins and filtration and treat approximately 1.4 billion gallons per day

Table 14: The Annual Value to Water Conveyance of Reduced Sediment Loading under Conservation Tillage Practices in Selected Watersheds in Southwestern Ontario

Watershed	Rotation-Tillage	(1) Maintenance Cost ($/ha)	(2) Percentage Reduction)	(3) Total Cost[2] ($)	(4) Annual Value of Reduced Sediment Loading (total $) [3]	(5) ($/ha) [4]
Big Creek	CS FPL	3.41	-	11,253	-	-
(3300 ha)	CS FCH	2.27	33.5	7,483	3,770	1.14
	CS RIPL	1.14	66.5	3,770	7,483	2.27
Newbiggen	CC FPL	3.41	-	9,026	-	-
Creek	CC FCH	2.28	33.0	6,047	2,979	1.13
(2647 ha)	CC RIPL	1.18	65.5	3,114	5,912	2.23
Stratford/	2C2A FPL	3.41	-	1,831	-	-
Avon	2C2A FCH	2.42	28.9	1,302	529	0.99
(537 ha)	2C2A NT	1.28	62.6	685	1,146	2.13

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard plougᶦing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

[1] The percentage reductions in sediment loading for conservation tillage practices is from GAMES model simulations.

[2] Maintenance cost [column (1)] multiplied by the number of hectares in each watershed.

[3] The total annual value of reduced sediment loading is calculated by comparing the total cost [column (3)] under conservation tillage practices to the total cost under conventional practices.

[4] Column (4) divided by the number of hectares in each watershed.

(Ministry of the Environment, 1986). Operational costs for such treatment are approximately 40 cents per thousand gallons treated[9]. The total operational costs for all these plants would be $560,000 per day or $204.4 M per year.

The U.S. Environmental Protection Agency (1979) and Bardos et al. (1987) both suggested that the cost of water treatment that is attributable to cropland erosion is approximately 4 to 17 cents (adjusted to 1987 Canadian dollars) per thousand (Imperial) gallons. The present study utilizes a conservative 2 cents per thousand gallons treated as the cost of sedimentation from cropland to water treatment. This represents approximately 5 percent of the total operational costs. Sediment from other sources, such as forestland may be partially responsible for the costs of sedimentation. The International Reference Group on Great Lakes Pollution from Land Use Activities (1978) estimates sediment delivery from sources other than cropland to be approximately 14 percent of the total. Using this figure and the estimate of sediment delivery by Wall et al. (1982) sets total sediment delivery in Southern Ontario at 759,153 tonnes per year. Five percent of total operational costs of surface water treatment is $10.2 million per year. Dividing this by the estimated sediment delivery gives an average cost to water treatment of $13.44 per tonne of suspended sediment. Again it is necessary to adjust this average value for each watershed based on the probability of the suspended sediment travelling to the Lake areas where all water treatment plants utilizing surface water are located. Again damage factors of +0.5, 0.0 and -0.5 were used for the Big Creek, Newbiggen Creek and Stratford/Avon watersheds, respectively.

Utilizing the estimated total sediment delivery estimates for each watershed (Table 13) and potential percentage reductions for each alternative tillage practice, as calculated for section 4.5.1, along with the adjusted cost of sedimentation to water treatment, the total annual cost to water treatment facilities is calculated and shown in column (3) of Table 15. Columns (4)and (5) illustrate the value of reducing sediment loading on a per watershed and per hectare basis, respectively. Considering the conservative nature of the estimating procedure the benefits turn out to be substantial in each case.

4.5.4 Other Damages of Soil Erosion in Southwestern Ontario

In order to stress the fact that the estimate given by this research is a very conservative one and to also give some direction for future research, this section will discuss many other damages occurring in southwestern Ontario which are directly related to erosion from cropland. Some damages, such as harbour dredging, were omitted since they did not pertain directly to the Thames River Basin, while for others. such erosion-related contaminants, there is evidence of damage but no research has been done to quantify the costs.

Other Sedimentation Damages

The sport fishing industry, discussed in section 4.5.1, accounts for only 13 percent of fish. by weight, caught in the Chatham district of the Ministry of Natural Resources (Ontario Ministry of Natural Resources. 1987). Thus, substantial benefits would likely accrue to the commercial fishery from sediment reduction in streams and lakes.

Flooding is a major problem near the mouth of the Thames River. For this reason large dams. such as the Fanshawe Dam near the City of London, have been constructed to

Table 15: The Annual Value to Water Treatment of Reduced Sediment Loading Under Conservation Tillage for Selected Watersheds

Watershed area in hectares)	Rotation-Tillage	(1) Total Sediment Delivery (tonnes)	(2) Adjusted Cost to Water Treatment) ($/tonne)	(3) Total Cost to Water Treatment. ($) [(1) x (2)]	(4) Annual Value of Reduced Sediment Loading (total $) [2]	(5) ($/ha) [3]
Big Creek	CS FPL	3,310	20.16	66,729	-	-
(3300 ha)	CS FCH	2.059	20.16	41,509	25,220	7.64
	CS RIPL	1,036	20.16	20,886	45,843	13.89
Newbiggen	CC FPL	1,128	13.44	15,460	-	-
Creek	CC FCH	662	13.44	8,897	6,263	2.37
(2617 ha)	CC RIPL	354	13.44	4.758	10,402	3.93
Stratford/	2C2A FPL	415	6.72	2,789	-	-
Avon	2C2A FCH	272	6.72	1,829	960	1.79
(537 ha)	2C2A NT	86	6.72	578	2,211	4.12

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no- tillage

[1] Adjusted by the damage factor based on type of soils and vicinity to area of damage as discussed in section 4.5.3.

[2] The total annual value of reduced sediment loading is calculated by comparing the total cost [column (3)] under conservation tillage practices to the total costs under conventional tillage practices.

[3] Column (4) divided by the number of hectares in the watershed.

control the flow of water from upstream areas. Much flooding continues to occur due to ice-jams in the main channel and at the mouth of the Thames River. Large sand bars caused by settling sediment at the mouth of the Thames River have been noted to impede the flow of ice from the river, thus causing the problem to increase in severity. For this reason $300,000 was spent in 1983 for dredging sediment from this area[10]. It has been suggested that at least $500,000 should be spent every 2 to 5 years[11].

The Erosion and Sedimentation Control Committee (1983) estimated that $7.5 million (in 1982 dollars) is spent annually to dredge sediment from commercial harbours in Ontario, and another $700,000 (in 1981 dollars) is spent annually to dredge sediment from small craft harbours. This type of damage was not estimated for the region in this study since no major commercial harbours are located in the Thames River Basin, however the potential benefits that may result from the adoption of conservation tillage practices are obvious.

The U.S. Coast Guard (1983) reported nearly $300 million in annual damages to commercial ships. About 2/3 of the total damage occured in inland waters such as the Great Lakes. for which Canada has shared responsibility with the U.S.. and approximately 1/2 of those damages could have been avoided if channels were deeper and wider. Based on this evidence they estimated that $20-100 million of annual damages were caused by sedimentation in the U.S.

Damages of Erosion-Related Contaminants

It is very important to note that damages caused by erosion-related contaminants are not estimated in this report. Many nutrients, pesticides and other contaminants such as phosphorus, are nonsoluble and are carried off of cropland while attached to eroded sediment. The damaging effects of these contaminants has been well documented in Canada (Sudar 1978, Muir 1981, and Canadian Federal/Provincial Phosphorus Task Force 1985), however the monetary value of these damages has not been estimated. One of the greatest problems in the Great Lakes is eutrophication (over-enrichment with nutrients), which is caused primarily by phosphorus loadings to streams and lakes. Researchers at Agriculture Canada and the Ontario Ministry of Agriculture and Food found that cropland was responsible for about 25 percent of the total phosphorus load to the Great Lakes in 1976 (Coote, 1980). The Canadian Federal/Provincial Phosphorus Task Force (1985) discussed the impact of phosphorus on water supplies, water treatment, commercial and recreational fisheries, and other forms of recreation, such as beach-going, swimming, and boating.

Damage from these types of contaminants has been evident at the Fanshawe Conservation Area in London, Ontario. In 1987 the beach at Fanshawe was closed for 25% of the season primarily due to pollution that originated from agricultural cropland and livestock operations (Upper Thames Conservation Authority, 1987). Since the beach use attendance for the rest of the season was approximately 80.000, an estimated 20,000 people may have been kept away by the closures. Usher et al. (1987) estimated the value of beach use in Ontario to be in the order of $20 per person per visit. Using this estimate would set the annual damage for Fanshawe alone at $400,000. In 1988 the Fanshawe Conservation Area is spending $300,000 to construct an ultra-violet treated swimming area to ensure that swimming is possible all summer long.

There are many other recreation areas in Ontario which exhibit similar problems (Upper Thames River Conservation Authority, 1988). In the U.S., Clark et al. (1985) estimated the costs of erosion damages to riparian property values, municipal and industrial water users and the preservation values of concerned individuals and groups. All these factors suggest that the off-farm benefits arising from the adoption of conservation tillage practices in three watersheds in southwestern Ontario are likely to be higher than the quantifiable estimates presented in this report.

4.6 The Total Annual Off-Farm Benefits of Adoption of Conservation Tillage Practices in Selected Watersheds in Southwestern Ontario

The annual off-farm benefits of erosion control are illustrated in Table 16. The benefits to sport fishing, water conveyance and water treatment are included in the estimated per hectare benefits of a reduction in sediment loading. The totals for each watershed, in dollars per hectare, illustrate that the annual off-farm benefits are significant for each watershed. The adoption of conservation tillage practices in southwestern Ontario looks very attractive from a social point of view.

Table 16: Total Annual Per Hectare Value of Reduced Sediment Loading Under Conservation Tillage Practices in Selected Watersheds In Southwestern Ontario

Watershed	Rotation	Tillage	Total Value[1] ($/ha)
Dig Creek	CS	FCH	39.33
	CS	RIPL	71.70
Newbiggen Creek	CC	FCH	12.86
	CC	RIPL	21.87
Stratford/ Avon	2C2A	FCH	9.93
	2C2A	NT	22.71

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

[1] The total per hectare value is calculated as the sum of the benefits of reduced sediment loading accruing to recreational fishing, water conveyance, and water treatment.

CHAPTER 5

5.0 CONCLUSION, IMPLICATIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusion

The distribution of annual costs and benefits arising from adoption of conservation tillage practices in the three watersheds is shown in Table 17. The off-farm benefits of adopting conservation tillage practices range from $9.93 per hectare for adopting a chisel ploughing system in the Stratford/Avon watershed to $71.70 per hectare for adopting a ridge tillage system in the Big Creek watershed. Forgone income, due to lower yields associated with conservation tillage, has been the major drawback to adoption rates in southwestern Ontario. Table 17 reveals that the conservation tillage practices considered in this study are not financially attractive to the average farmer. However, when the off-farm benefits are considered the adoption of conservation tillage practices becomes very attractive from a social point of view. Although the off-farm benefits of adopting conservation tillage practices are quite substantial for the Newbiggen Creek watershed, the net social benefits are negative due to the substantial sacrifice in net returns onthe farm. In the Stratford/Avon watershed the net social benefits are significant for both the fall chisel ploughing and no-tillage systems. The largest net social benefits accrue from adoption of conservation tillage in the Big Creek watershed. The large net social benefits in the Big Creek watershed were primarily due to high sediment delivery rates and the close proximity of this watershed to the location where the majority of estimated off-farm damages occur.

Table 17: A Comparison of the Annual Costs and Benefits Arising From Adoption of Conservation Tillage Practices in Selected Watersheds *in* Southwestern Ontario

Watershed	Rotation-Tillage Tillage	Annual Costs and Benefits: On-farm Costs[1] ($/ha)	Off-farm Benefits[2] ($/ha)	Net Social Benefit ($/ha)
Big Creek	CS FPL	base	base	-
	CS FCH	16.77	39.33	22.56
	CS RIPL	33.69	71.70	38.01
Newbiggen Creek	CC FPL	base	base	-
	CC FCH	17.64	12.86	-4.78
	CC RIPL	56.46	21.87	-34.59
Stratford/ Avon	2C2A FPL	base	base	-
	2C2A FCH	5.80	9.93	4.13
	2C2A NT	10.45	22.71	12.26

CC = continuous corn
CS = alternating corn and soybeans
2C2A = alternating 2 years corn and 2 years alfalfa
FPL = fall moldboard ploughing
FCH = fall chisel ploughing
RIPL = ridge planting
NT = no-tillage

[1] From Table 10 in section 4.2.3.

[2] From Table 16 in section 4.6.

5.2 Implications of The Distribution of Costs and Benefits in Relation to Current Efforts to Control Erosion in Southwestern Ontario

It is the responsibility of government to intervene in the affairs of private industry whenever the market fails to reflect the interests of society. For example, when a steel manufacturer located on the edge of a river emits its waste into the river, the market in which the company sells its goods would provide no incentive to induce the firm to reduce rate of pollution to the river. If society is adversely affected by the pollution, and the costs of private bargaining between the company and the affected agents are too high, it is the duty of government to see that the pollution is reduced.

The results of this study establish an argument for public intervention in factors affecting adoption of conservation tillage practices on cropland in southwestern Ontario. For example, farmers in the Big Creek watershed have no economic incentive to adopt conservation tillage practices. However, the magnitude of the off-farm benefits, which accrue to society, suggest that there are net gains to be made from adoption of conservation tillage practices in this area.

In 1986, under federal-provincial agricultural agreements, it was announced that $62 million would be spent over a five year period to increase conservation tillage adoption rates. These resources will fund essential research needed to facilitate greater use of conservation practices, and also fund information transfer services, such as, extension agents and soil conservation technology demonstrations.

On September 1, 1987, the Ontario Ministry of Agriculture and Food (1987c) introduced a three-year, $30 million Land Stewardship Program which is being implemented in cooperation with the Ontario Soil and Crop Improvement Association. The program is designed to encourage crop rotations, adoption of conservation tillage practices, reforestation of fragile lands and further development of erosion control structures. Part of this program will supply grants of approximately $50 per hectare to farmers when at least 20 percent of the surface area is covered with residue immediately after planting. Up to 30 percent of the farmer's previous years acreage qualifies for this grant. In the past, the principal rationale for soil conservation policy in southwestern Ontario has been to preserve soil productivity. In fact, the Land Stewardship Program requires applicants to specify the damages of erosion to land ontheir farms when applying for grants for conservation tillage.[12] This would suggest that areas such as the Big Creek watershed, that exhibit low erosion-induced losses in productivity, would not be very high on the priority list to receive grants for conservation tillage. The results of the present study suggest that a shift in priority may be necessary in order to maximize the social benefits of conservation programs.

5.3 Recommendations for Future Research

There are many opportunities that arise for policy analysis when the off-farm impacts of soil erosion are considered. Dickinson (1982) utilized the GAMES model along with data from selected watersheds in southwestern Ontario and found that a significant portion of sediment delivered to streams and lakes often originates from specific areas within watersheds with variable topography. He also found that substantial reductions in sediment delivery could result by targeting buffer strips and forage crops to these areas. Future research could investigate the economic costs and benefits of a program aimed at identifying and targeting such areas for erosion control efforts.

Conservation tillage practices will generally lead to reductions in fuel and labour requirements but also require increased herbicides on cropland. Research should be done to investigate the potential impact of the increase in chemical application on groundwater. There may need to be tradeoffs between the control of pollution of surface waters and groundwater.

Economic data used in the SOILEC model could be updated as information on alternative tillage practices improves. Other conservation practices such as contour tillage, strip tillage and more alternative crop rotations could also be analysed in this framework. As discussed in section 4.5.4, there are a number of off-farm costs of erosion that this study was not able to investigate. What is most needed is the continuation of research which attempts to assign monetary values on the increasingly evident off-farm damages of sediment and other erosion-related contaminants.

FOOTNOTES

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** The authors are a graduate research assistant and an assistant professor in the Department of Agricultural Economics and Business, University of Guelph, Guelph, Ontario.

1 The following discussion is based on a simplification of a model developed by McConnell (1983).

2 Yield reductions were assumed for row cropland with slope limitations
that affect the agricultural capability of a soil as defined for the Canada Land Inventory by Environment Canada (1976). The yield reductions may be the result of many years of previous soil erosion and would not be fully restorable by any means.

3 A soil's capacity to absorb moisture increases as the percentage of clay content in the soil increases. The plant wilting point, which is lower than capacity also increases. The amount of soil water that is between the soil's capacity and the wilting point is available to the plant.

4 Bulk density is the weight per unit volume of oven dry soil, generally calculated in grams per cubic centimetre. Lower layers of soil horizons usually have a higher bulk density due to larger percentages of clay content.

5 In order for fertilizers to be effective in improving crop yields. farmers often need to correct the concentration of hydrogen ions in the soil. These concentrations are represented on a hydrogen potential (pH) scale.

6 Unless otherwise noted, discount rates, prices, and cost estimates will be used in real terms, that is, having been adjusted for the effects of inflation.

7. The ridge planting system, due to scraping of the top of ridges for planting, has worked well on generally flat soils such as those in the Big Creek and Newbiggen Creek watershed. No-tillage practices would be more effective on soils of variable topography such as those in the Stratford/Avon watershed.

8. Personal communication with Professor Murray H. Miller, Department of Land Resource Science, University of Guelph, Guelph, Ontario, 1988.

9 Information in a memo from Ann Vajdic, Supervisor, Policy and Assessment Unit, Drinking Water Section, Water Resources Branch, Ontario Ministry of the Environment.

10 Personal communication with John Trudgeon, superintendent, Dover Township, 1988.

11 Personal communication with Gerry Campbell, Lower Thames Conservation Authority, 1988.

12 Vern Spencer, Director, Soil and Water Management Branch, Ontario Ministry of Agriculture and Food, speaking at Ridgetown College Farmer's Week, January 1988.

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Appendix 1

For a number of decades in the U.S., researchers had been attempting to come up with a reliable soil loss prediction technique. In 1954, the U.S. Department of Agriculture established a National Runoff and Soil Loss Data Center to gather erosion-related data from numerous research stations. This collection of data culminated in the development of the Universal Soil Loss Equation.

The Universal Soil Loss Equation (USLE) is defined by Wischmeier and Smith {1978) as:

A= R K L S C P

where

"A" is the computed soil loss per unit area. expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute "A" in tons per acre per year, but other units can be selected (Wischmeier and Smith illustrate conversion to metric, for the USLE in an appendix).

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

K the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. which is defined as a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow.

L the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions.

S the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions.

C the cover and management factor, is the ratio soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P the support practice factor, is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight-row farming up and down the slope.

Appendix 2

Figure 1A. The Future Path of Net Returns for Three Tillage Systems in the Big Creek Watershed

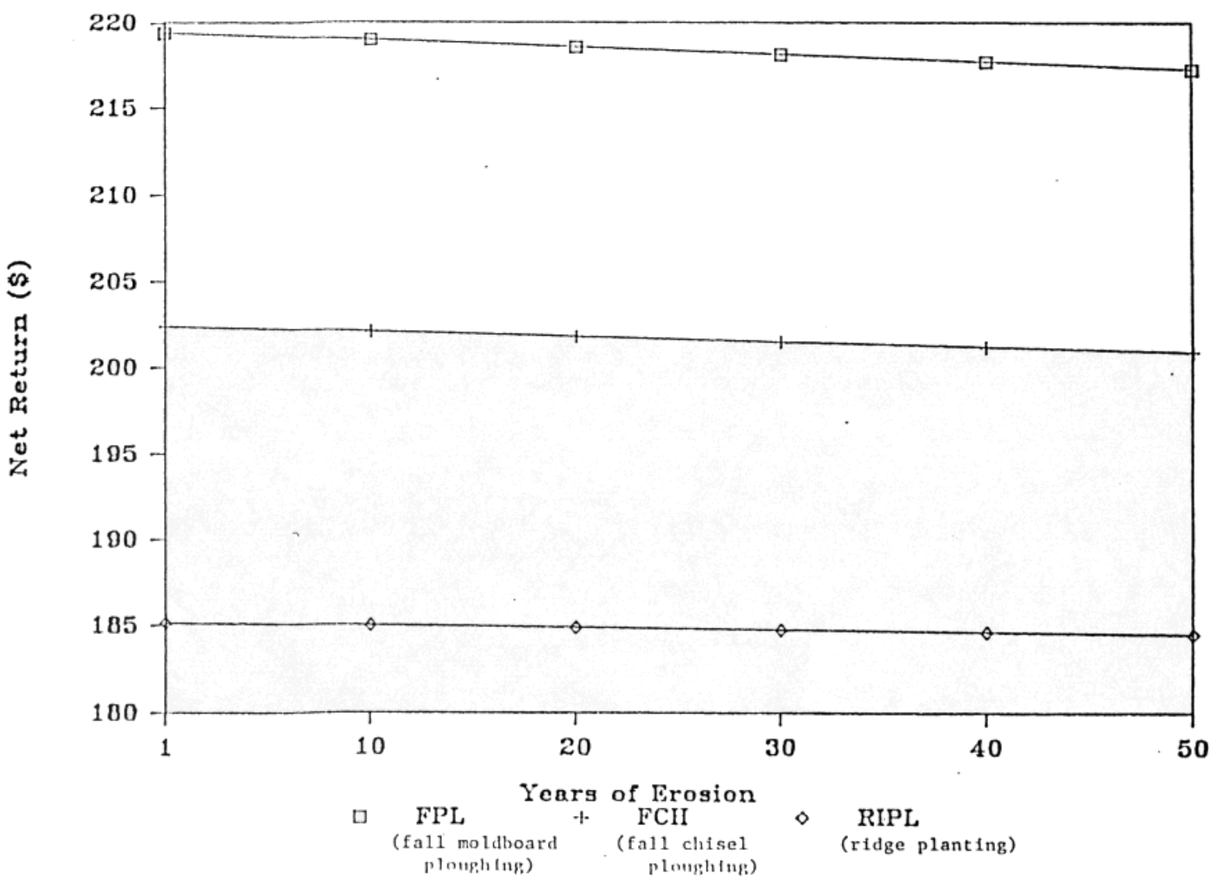

Figure 2A. The Future Path of Net Returns for Three Tillage Systems in the Newbiggen Creek Watershed

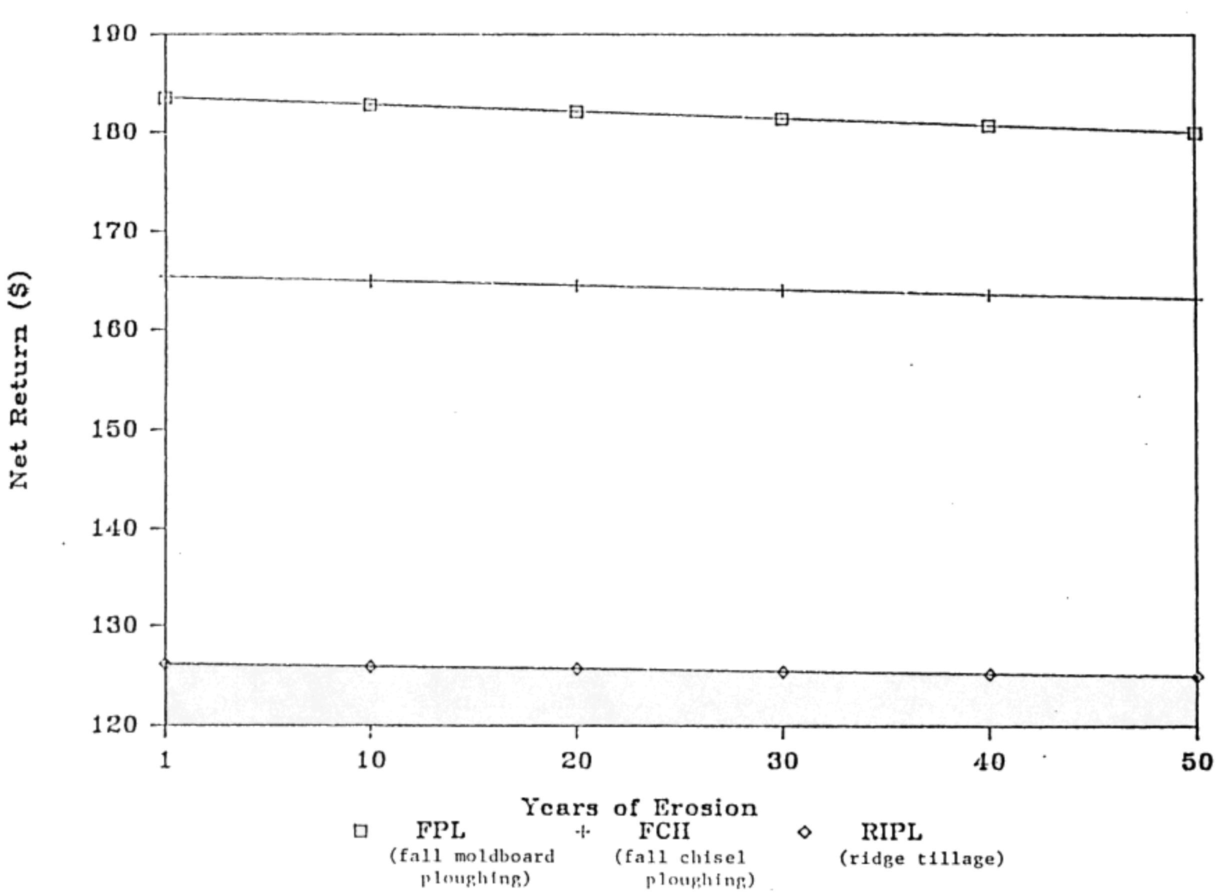

Figure 3A. The Future Path of Net Returns for Three Tillage Systems in the Stratford/Avon Watershed (Sub-Region 1)

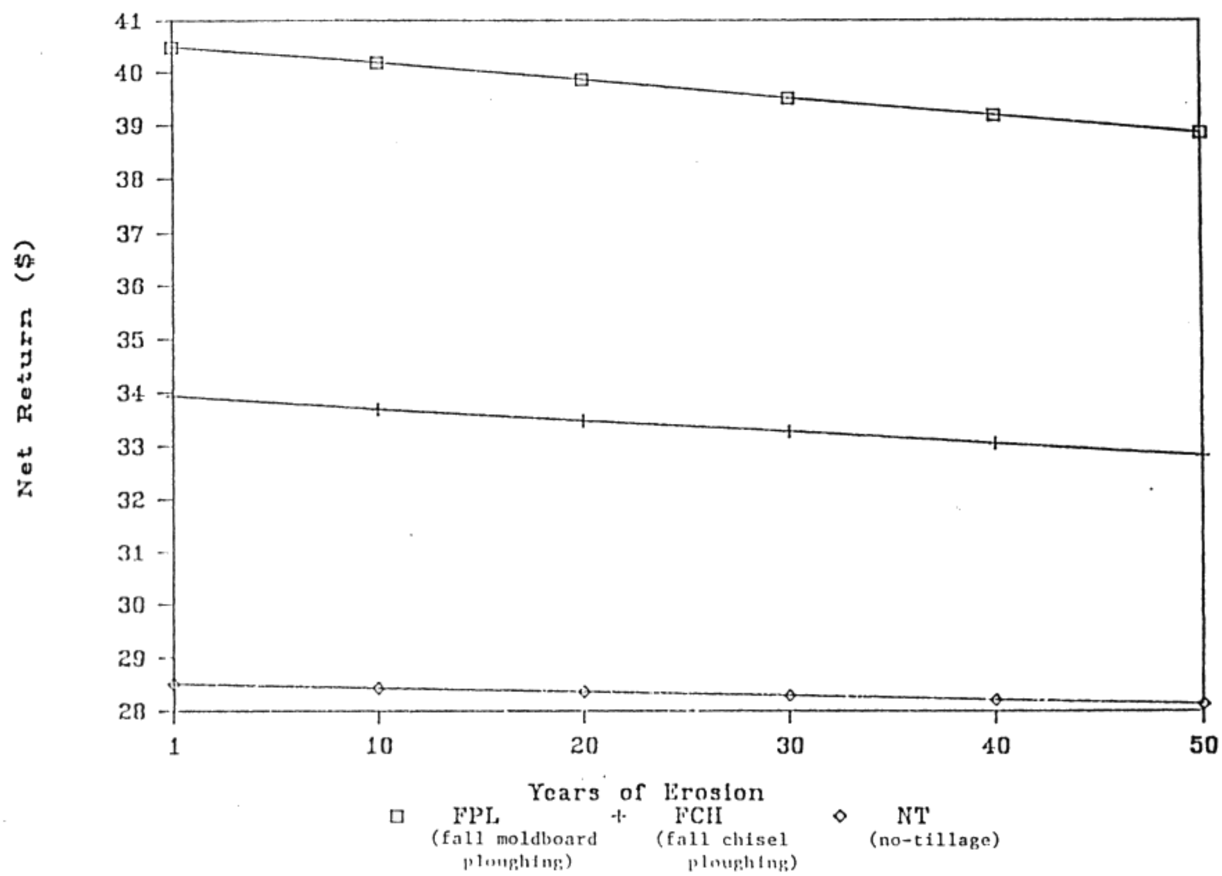

Figure 4A. The Future Path of Net Returns for Three Tillage Systems in the Stratford/Avon Watershed (Sub-Region 2)

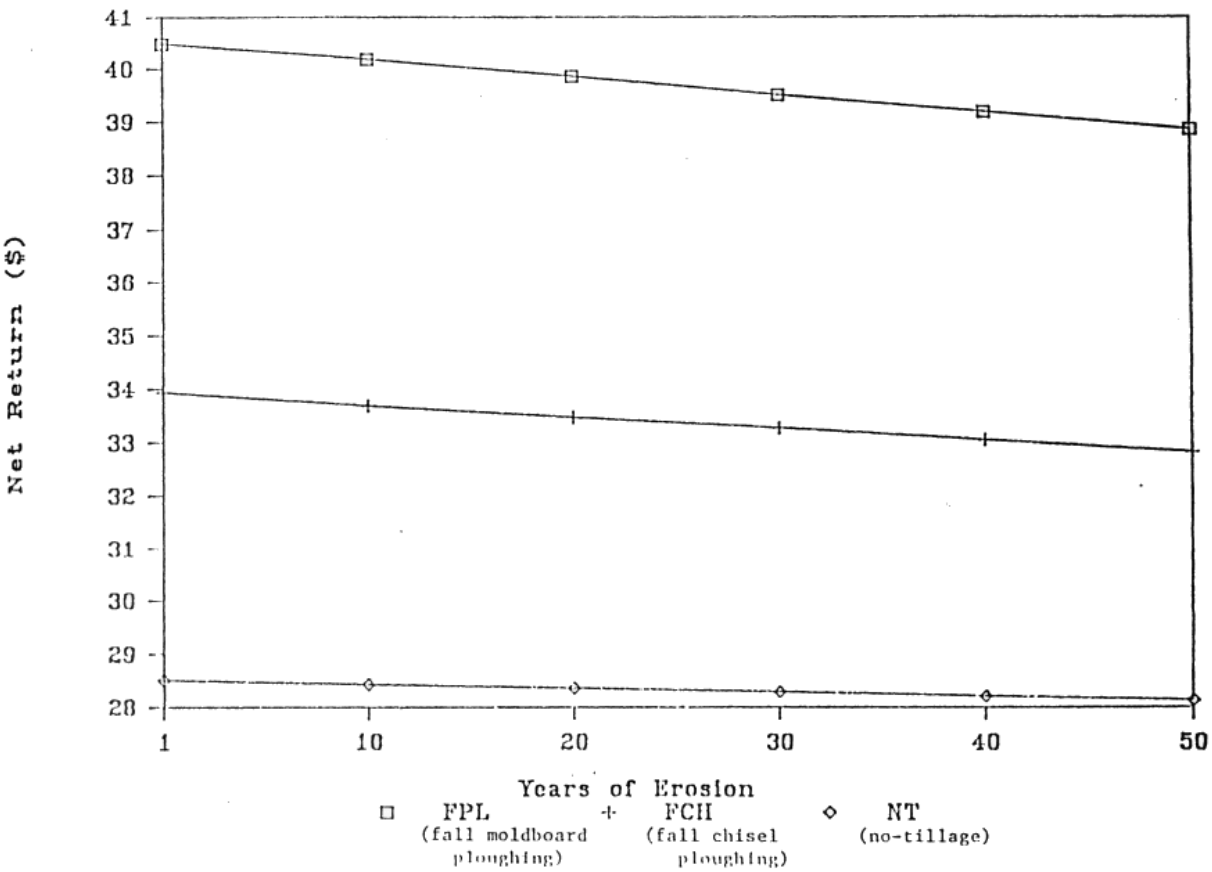

Figure 5.

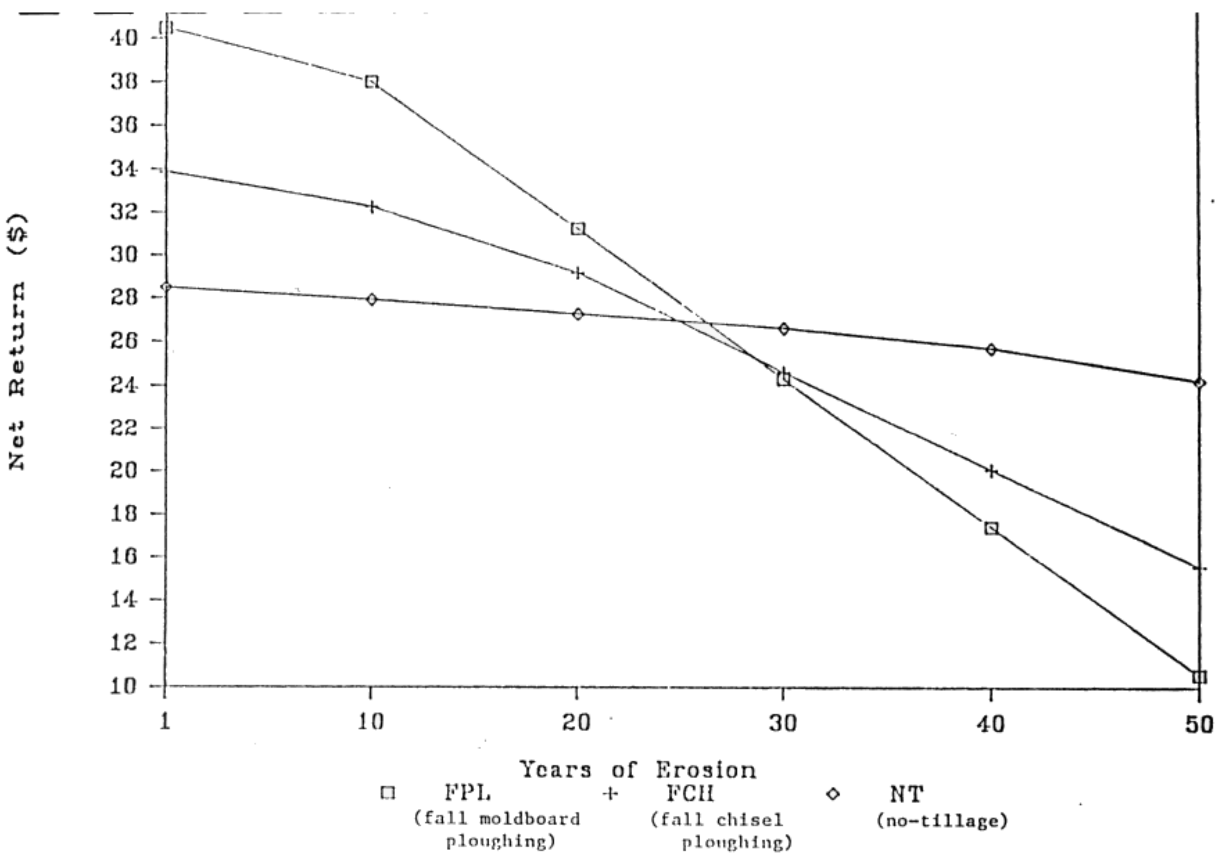
Net Return ($)
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
1
10
20
30
40
50
Years of Erosion
FPL
(fall moldboard ploughing)
FCH
(fall chisel ploughing)
NT
(no-tillage)

FIGURE 6 MISSING

Figure 7A. The Future Path of Net Returns for Three Tillage Systems in the Stratford/Avon Watershed (Sub-Region 5)