VOLUME VI

WATERSHED LEVEL ECONOMIC ANALYSIS OF TILLAGE PRACTICES IN SOUTHWESTERN ONTARIO

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By:

Deloitte & Touche Management Consultants
Guelph, Ontario

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EXECUTIVE SUMMARY

This report contains the findings of the watershed modelling component of the Soil and Water Environmental Enhancement Program (SWEEP) for the Kettle Creek, Essex, and Pittock watersheds.

The watershed level analysis was undertaken to fulfil two main objectives. The first objective was to evaluate the farm level impact of conservation technologies on farmers' net income, choice of tillage method and resource use. Using a simulation model and a multi-period linear program it was found for the Kettle Creek, Essex and Pittock watersheds that maximum profits could be obtained by using conservation tillage for each of the 3 periods modelled. This result was due to the fact that no-till was not only environmentally sound but also more profitable than conventional mouldboard plough tillage. To contrast these 'unconstrained' solutions with the more common practice of using conventional tillage in the watershed, additional model runs were done which restricted the use of no-till technology to zero. The results showed a substantial reduction in overall profitability implying that failure to adopt conservation technology may be costly to some farmers.

The second objective was to evaluate the opportunity costs of conservation in terms of reducing soil and phosphorous run-off into surface water and reducing soil degradation through soil loss. The effect of imposing these environmental quality constraints was to reduce the total hectarage planted to more erosive crops such as continuous corn or soy-corn-soy in favour of a less erosive soy-wheat-corn rotation. However, there were many situations where land was left idle in order to satisfy the environmental quality constraints imposed. It was this idle land which established the opportunity costs of reduced revenue caused by the environmental quality constraints. Results showed that marginal costs of environmental quality constraints were never less than the average costs, implying an overall loss in allocative and economic efficiency could accrue to watershed farmers. However, opportunity cost of effluent restrictions was lower with conservation tillage practices relative to conventional tillage practices.

1.0 INTRODUCTION

This report contains the watershed level economic analysis component of the SWEEP program and is summarized in Section 4 of Volume I of this series.

1.1 STUDY BACKGROUND AND OBJECTIVES

The linkage between environmental quality degeneration and agricultural production decisions is well established and has been recognized as an important target for agricultural environmental policy in Canada and the United States. In Canada, for example, proactive policy guidelines call for an overall reduction in pesticide use of 50% by the year 2002 and a 50% reduction in soil and phosphate loading in surface water by the year 2000. In the United States, enabling legislation enacted under the 1985 farm bill established cross-compliance under the conservation reserve program; under the Water Quality Act of 1987 soil conservation districts will soon have to establish plans to control non-point-source pollution, including run-off from farms; there is evidence of increased use of legislation and civil penalty to curb pesticide misuse in Kansas; and the state of Iowa has the regulatory authority to impose soil loss and loading restrictions on individual farmers. Legislatures and courts now recognize that it is the responsibility of farmers to establish and maintain soil and water conservation practices as well as erosion control practices, and these practices are in the interest of the public good and within the domain of state power. Externalities motivating these initiatives are derived from food safety issues, recreational costs, water treatment costs, water transportation infrastructure, and increased risk of flooding.

This study uses economic analyses to determine which of various tillage technologies and crop rotations available to Kettle Creek ,Essex and Pittock watershed farmers provide the most benefits in terms of profitability and soil and phosphate effluent reduction. The specific objectives are:

1) To evaluate the farm level impact of conservation technologies on farmer's net farm income, choice of tillage method, and resource use; and,

2) To evaluate the opportunity costs of conservation in terms of reducing soil and phosphorous run-off into surface water and reducing soil degradation through soil loss.

1.2 ORGANIZATION OF REPORT

This report represents Volume VI of a seven volume series, consisting of:

Volume I: An Economic Evaluation of Soil Tillage Technologies: Summary Report

Volume II: Collection and Analysis of Field Data From Pilot Watersheds

Volume III: Field Level Economic Analysis of Changing Tillage Practices in Southwestern Ontario

Volume IV: An Economic Evaluation of the Tillage 2000 Program in Ontario

Volume V: An Economic Assessment of the Technology Evaluation and Development (TED) Program

Volume VI: Watershed Level Economic Analysis of Tillage Practices in Southwestern Ontario

Volume VII: Macro-Economic Impact Assessment of Soil Conserving Technologies

This document consists of six sections: Section 2.0 reviews data and methods employed, Section 3.0 reports the soil and phosphate losses and loadings results, Section 4.0 gives the economic impacts of the soil and phosphate loadings, Section 5.0 outlines the policy implications, and Section 6 summarizes the conclusions.

2.0 METHODOLOGY

2.1 METHODS

The method of analyses involves 3 steps and is outlined by the flow chart in Figure 1. The first step obtains primary data for each of the watersheds. These data include soil engineering data and production/economic data; the second is to obtain estimates of soil loading, soil loss, and phosphate loading. These are obtained using GAMESP, a simulation model; and the third step is to optimize among competing tillage technologies and crop rotations under various environmental quality constraints using a multi-period linear program.

2.2 DATA

Data requirements are broken down into 2 categories. Economic data relate to prices, yields and costs of alternative tillage practices and crop rotations, while engineering and environmental data relate to the input requirements for the GAMESP simulation model, and the watershed linear program.

Environmental data for the 3 watersheds are reported in Table 2.1. Kettle Creek, Essex and Pittock watersheds cover approximately 411, 435 and 359 hectares respectively. Although vegetables (e.g. peas), grains, and hay were also grown, the most common crops grown were corn, soybeans and wheat. Of these three crops the 3-year (1989-1991) averages reported in Table 2.1 show that Kettle Creek grew a mix of the three crops with corn being favoured most, whereas Essex grew proportionately more soybeans and Pittock proportionately more corn. Kettle Creek and Pittock, because they are slightly more rolling with fields of variable slope, were broken down into 365 and 203 field-size cells respectively. Essex on the other hand is relatively flat and homogenous so that 88 slightly larger cell sizes are used. For example, the average cell size in Essex is about 3.96 ha whereas the average sizes in Kettle Creek and Pittock are 1.12 ha and 1.77 ha respectively. It should also be noted that Kettle Creek and Pittock are characterised by fairly coarse loam-type soil whereas Essex is characterised by fairly light and particulate soil.

Figure 1. Methodology For Watershed Modelling Component of the SWEEP Analysis

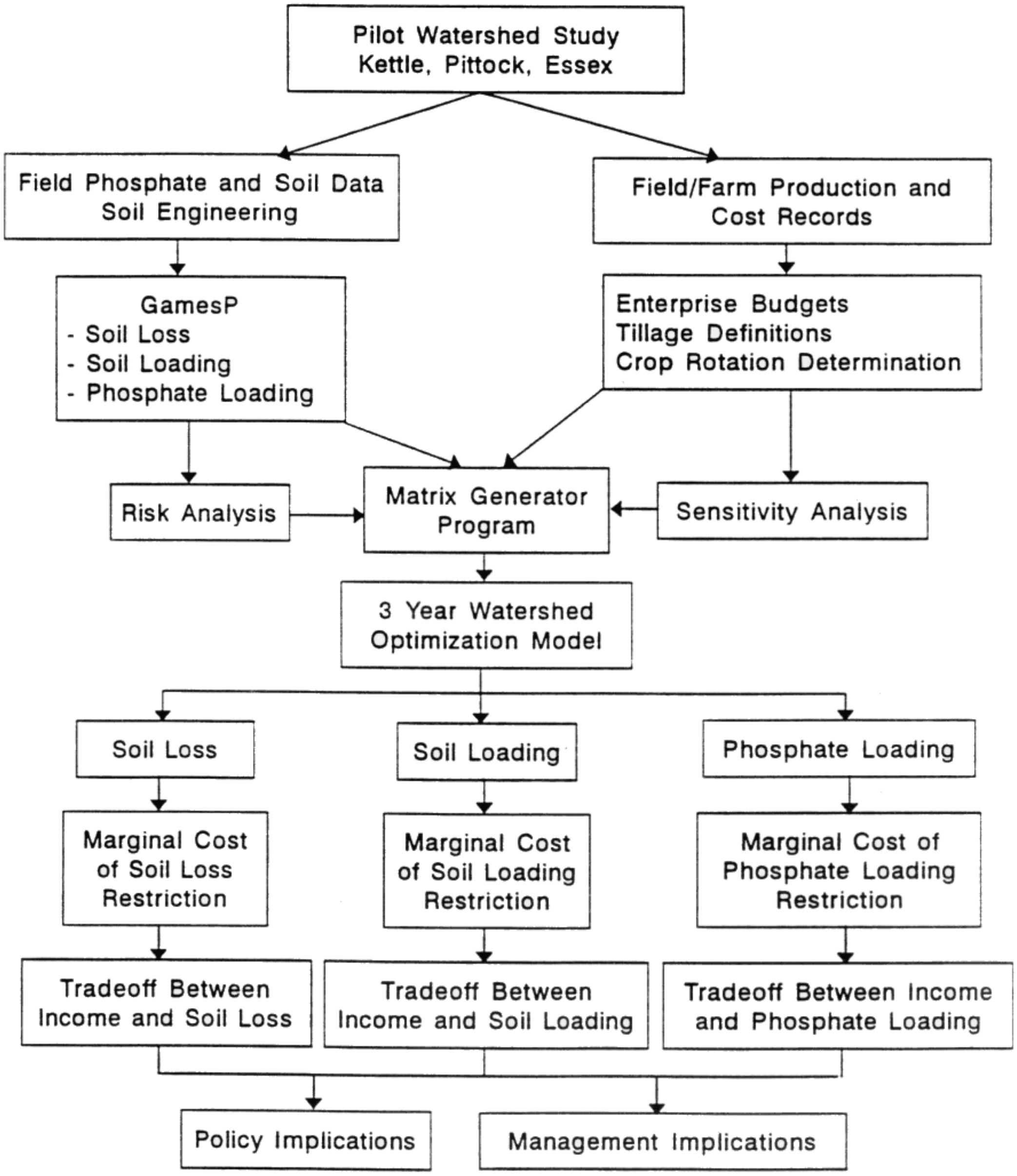


Table 2.1 Watershed Characteristics and Initial Conditions

	Kettle Creek	Essex	Pittock
Area (ha)	410.3	435.3	358.9
Number of cells	365	88	203
Rainfall factor	95	110	117
Soil loss (tonnes/year)	4,248	1,530	1,886.8
Soil loss (tonnes/ha)	10.4	3.5	5.3
Soil loading (tonnes/year)	46.8	1,361.2	46.1
Soil loading (tonnes/ha)	0.11	3.13	0.13
Phosphate loading (kg/year)	59.0	1,391.4	74.9
Phosphate loading (kg/ha)	0.14	3.20	0.21
% corn grown (3-year average)	48.6	15.4	78.2
% soybeans grown (3-year average)	33.0	70.6	8.9
% wheat grown (3-year average)	18.3	13.9	12.9

The economic data for the three watersheds is provided in Tables 2.2 and 2.3. Under each of conventional (mouldboard plough: Table 2.2) and no-till technologies (Table 2.3), 3 rotations consistent with current agronomic practices in Kettle creek and Pittock were selected for optimization; corn-corn-corn, soybean-corn-soybean, and soybean-wheat-corn. Essex did not include continuous corn since no farms in the watershed used this strategy.

For budgeting it is important to recognize that differences in yields and costs are conditional on the preceding crops. For example under conventional tillage for Kettle Creek the gross margin of corn following corn is $364.68/ha, whereas corn following wheat or soybeans yields approximately $379.79/ha. Differences between technologies are also reflected in the comparative data of Tables 2.2 and 2.3. For the Kettle Creek watershed it is revealed that no-till technology is sometimes more profitable, than conventional tillage.

For example conventionally tilled corn following corn yields a gross margin profit of $379.79/ha whereas the same planting under no-till yields a gross margin profit of $426.69/ha. However soybean following corn, which yielded net revenues of $241.99/ha under conventional tillage, yielded only $187.03/ha with no-till; similarly, conventionally-tilled soybean following corn in Pittock is higher ($214.42/ha) than its no-till counterpart ($142.36/ha) but corn following soy returns in the same watershed is higher ($417.72/ha) than that conventionally tilled ($394.71 /ha).

Table 2.2 Price, Yield, Cost and Soil Engineering Data for Conventional Tillage in Kettle Creek, Essex, and Pittock Watersheds

	Corn Follows Corn	Soybean Follows Corn	Corn Follows Soybeans	Wheat Follows Soybeans	Corn Follows Wheat
			Kettle Creek		
Yield (T/ha)	8.28	2.70	8.28	3.88	8.28
Price ($/T)	109.00	231.33	109.00	131.67	109.00
Costs ($/ha)	537.89	382.19	522.78	270.52	522.78
Net Revenues ($/ha)	364.68	241.95	379.79	240.84	379.79
			Essex		
Yield (T/ha)	-	2.69	8.16	3.87	8.16
Price ($/T)	-	231.33	109.00	131.67	109.00
Costs ($/ha)	-	434.87	495.47	328.82	495.47
Net Revenues ($/ha)	-	187.40	393.74	181.02	393.74
			Pittock		
Yield (T/ha)	8.36	2.84	8.36	4.08	8.36
Price ($/T)	109.00	231.33	109.00	131.67	109.00
Costs ($/ha)	545.97	442.08	517.05	286.68	517.05
Net Revenues ($/ha)	365.79	214.42	394.71	249.89	394.71
			GAMESP / USLE SOIL LOSS FACTORS		
USLE 'C' factor	0.42	0.29	0.42	0.32	0.41
USLE Mannings 'N'	0.014	0.014	0.014	0.029	0.014

Table 2.3 **Price, Yield, Cost and Soil Engineering Data for Zero Tillage in Kettle Creek, Essex and Pittock Watersheds**

	Corn Follows Corn	Soybeans Follows Corn	Corn Follows Soybeans	Wheat Follows Soybeans	Corn Follows Wheat
			Kettle Creek		
Yield (T/ha)	8.01	2.23	8.01	3.68	8.01
Price ($/T)	109.00	231.33	109.00	131.67	109.00
Costs ($/ha)	503.97	328.06	446.42	248.13	446.42
Net Revenues ($/ha)	369.14	187.03	426.69	236.53	426.69
			Essex		
Yield (T/ha)	-	2.22	7.89	3.67	7.89
Price ($/T)	-	231.33	109.00	131.67	109.00
Costs ($/ha)	-	389.58	432.60	303.86	432.60
Net Revenues ($/ha)	-	123.97	427.59	179.36	427.59
			Pittock		
Yield (T/ha)	8.09	2.34	8.09	3.86	8.09
Price ($/T)	109.00	231.33	109.00	131.67	109.00
Costs ($/ha)	507.20	399.44	464.27	242.95	464.27
Net Revenues ($/ha)	374.79	142.36	417.72	265.60	417.72
			GAMESP / USLE SOIL LOSS FACTORS		
USLE 'C' factor	0.23	0.25	0.34	0.18	0.23
USLE Mannings 'N'	0.027	0.013	0.027	0.03	0.027

3.0 RESULTS OF SOIL AND PHOSPHOROUS LOADING AND SOIL LOSS SIMULATIONS

3.1 GAMESP SIMULATIONS

For simulating soil and phosphorous loading and soil loss each of the watersheds were broken down into small field size cells (Table 2.1) each with a unique slope and erodibility factor. Soil loss quantities (tonnes/ha), soil loading quantities (tonnes/ha) and phosphate loading quantities (tonnes/ha) were obtained from the GAMESP Model (Guelph Model for Evaluating Effects of Agricultural Management Systems on erosion and sedimentation with phosphorous component) which describes and predicts soil loss by fluvial erosion and the delivery of soil and phosphates from field to stream using the universal soil loss equation (USLE). The USLE computes soil loss per unit area over a specified time. Estimates of soil and phosphate loading into surface water are obtained using a delivery ratio function. Soil loss is predicted on rainfall, soil erodibility factors, steepness of the slope in the field and length of slope, crop grown, and crop management (i.e. tillage) practice. In this study all factors except the crop 'C' factor and Manning's 'N' for tillage practice are held constant for each cell in the watershed. The USLE 'C' factors and Manning's 'N' are reported in Table 2.1. The USLE rainfall factor was 95 for Kettle Creek, 110 for Essex and 1 17 for Pittock.

The watershed models were run initially using real 1989 conditions and crops, including peas, white beans and other crops not covered in this study. This provides a base measure for a typical level of soil loss, soil load and phosphate load. The 1989 real conditions are also reported in Table 2.1. Although Kettle creek has by far the greatest potential for overall soil loss the rate at which soil is delivered to the stream is relatively low. For example of 4,248 tonnes of sediment eroded in the watershed only 46.8 tonnes was actually delivered to the stream for a delivery ratio of only 1.1%. Pittock's delivery ratio was approximately 2.4% with 46.1 tonnes of 1886.8 tonnes soil eroded being delivered to the stream. Essex contributes more to non-point water pollution than the other 2 watersheds. Of 1,530 tonnes soil eroded under the 1989 conditions 1,361 tonnes were delivered to the stream for an overall delivery ratio of about 89% .

Non-point phosphate pollution is the result of a reaction between phosphorous and the soil (e.g. iron) which results in a highly insoluble compound which, when transported to the stream via soil loading decomposes into a more soluble phosphorous compound. Since phosphates are transported to the water through soil erosion then it is not unreasonable to address the problems together. Phosphate loadings to the stream are reported in Table 2.1 for the real 1989 watershed conditions. Because it is transported by soil particles, phosphate loading is related to soil loading and this is reflected in the data in Table 2.1: Phosphate loading was lower for Kettle Creek with an average of 0.14 kg/ha, and Pittock with an average of 0.21 kg/ha than Essex with an average of 3.20 kg/ha.

Results from the GAMESP simulation run are presented in Table 3.1, for individual cropping activities and crop rotations. The data in Table 3.1 are based on an assumption that each of the crop enterprises are grown on the entire area of the watersheds. (It must be emphasised however that these numbers are only averages and do not reflect the contribution on margin that an acre would provide). In terms of overall soil loss, maximum erosion for Kettle Creek of 5,649 tonnes/year was found for continuous corn, and corn grown after soybeans in a corn-soybean rotation. The minimum soil loss was 2,421 tonnes/year through no-till wheat following soy in a corn-soy-wheat rotation. No-till corn in continuous corn and a corn-soy-wheat rotation was second lowest with 3,093 tonnes/year. Soil loading of 50.75 tonnes/year was highest with conventionally tilled corn in a continuous corn, and a corn-soybean rotation. These maxima correspond directly with effluent phosphate levels of 70.40 kg/year. Soil and phosphate loading was smallest at 9.30 tonnes/year and 14.38 kg/year, respectively for wheat following soy in a corn-soy-wheat rotation, and 13.38 tonnes/year and 2.89 kg/year for corn following corn in continuous corn, and corn following wheat in a corn-soybean-wheat rotation.

Table 3.1 Effluent Loss and Loadings for Alternative Management Systems in Kettle Creek, Essex, and Pittock Watersheds.

	Corn Follows Corn		Soybeans Follows Corn		Corn Follows Soybeans		Wheat Follows Soybeans		Corn Follows Wheat	
	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till
					Essex					
Soil Loss total T	-	-	1096.99	945.74	1588.71	1286.12	1210.47	680.88	1550.87	870.06
kg per/ha	-	-	2.52	2.17	3.65	2.95	2..78	1.56	3.56	1.99
Soil Load total T	-	-	982.57	851.63	1423.00	1087.70	1013.94	567.83	1389.12	735.12
kg per/ha	-	-	2.26	1.96	3.27	2.49	2.33	1.30	3.19	1.69
Phosphate Load total T	-	-	1109.86	986.73	1490.69	1197.86	1133.86	712.17	1468.06	880.25
kg per/ha	-	-	2.55	2.27	3.42	2.75	2.60	1.64	3.37	2.02
					Pittock					
Soil Loss total T	2743.76	1502.59	1894.52	1633.18	2743.76	2221.14	2090.49	1175.89	2678.46	1502.59
kg per/ha	7.65	4.19	5.28	4.55	7.65	6.19	5.83	3.28	7.47	4.19
Soil Load total T	85.45	27.59	58.99	53.98	85.45	40.78	36.23	19.84	83.41	27.59
kg per/ha	0.24	0.08	0.16	0.15	0.24	0.11	0.10	0.05	0.23	0.08
Phosphate Load total T	134.71	56.47	98.87	95.85	134.71	75.79	68.6	42.45	132.99	56.47
kg per/ha	0.38	0.16	0.28	0.27	0.38	0.21	0.19	0.12	0.37	0.16

	Corn Follows Corn		Soybeans Follows Corn		Corn Follows Soybeans		Wheat Follows Soybeans		Corn Follows Wheat	
	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till	Conventional	No-Till
	Kettle Creek									
Soil Loss total T	5649.08	3093.55	3900.53	3362.51	5649.08	4573.07	4304.03	2421.02	5514.54	3093.55
kg per/ha	13.72	7.51	9.47	8.17	13.72	11.11	10.45	5.88	13.39	7.51
Soil Load total T	50.75	13.38	35.05	32.08	50.75	19.76	17.18	9.30	49.54	13.38
kg per/ha	0.12	0.03	0.09	0.08	0.12	0.05	0.04	0.02	0.12	0.03
Phosphate Load total T	70.40	20.89	50.74	48.11	70.40	36.94	26.85	14.38	68.54	20.89
kg per/ha	0.17	0.05	0.12	0.12	0.17	0.09	0.07	0.03	0.17	0.05

Equivalent values for Essex and Pittock are also reported in Table 3.1 and are interpreted in a similar fashion to those for Kettle Creek. Of note is the order of magnitude that prevails with soil and phosphate loading in Essex. On a per hectare basis the average amount of soil delivered to the stream is more than 10 times that of Pittock and in most cases over 20 times that in Kettle Creek.

The results of the analyses are derived from Individual GAMESP simulations. Combined with the economic and yield data they show that, in general, the adoption of conservation tillage can increase profitability as well lead to a substantial reduction in non-point soil and phosphate pollution and overall soil erosion. However, simulation *per se* cannot provide an in depth assessment of optimum management strategies which simultaneously maximize profits while satisfying some specific environmental quality constraints. In the following sections the individual cell data (soil loss, soil loading and phosphate loading) are used in a 3 period linear programming model which maximizes watershed profits subject to constraints on the environmental parameters. By construction the model presumes a remedial targeting strategy in which the most erosive lands are the first to be assigned conservation strategies. For example each cell in each watershed has the opportunity to grow any of the crop rotations (corn-corn-corn; soybeans-corn-soybeans; and soybeans-wheat-corn) for either conventional or conservation tillage. Economic information is gained not only in obtaining the optimum combinations of the best management strategies but also in the provision of incremental (marginal) costs and the on-farm average costs associated with the environmental quality constraints.

4.0 ECONOMIC IMPACT OF ENVIRONMENTAL QUALITY CONSTRAINTS

4.1 THE LINEAR PROGRAM

A 3-year profit maximizing linear program was constructed using the economic data and the simulated GAMESP results. The objective was to maximize the 3-year profits subject to environmental quality constraints. The decision variables were to choose either of 3 rotations under a conventional or no-till technology. The 3 rotations were a) continuous corn, b) soybeans-corn-soybeans, and c) soybeans-wheat-corn. Each cell in the watershed was treated as a separate field so that any solution was available to it. However once a rotation was selected in year 1 there was no recourse in changing rotations for subsequent periods. For example if a particular cell was planted to soybeans in the first year of a corn-soybean-corn rotation then corn would have to be grown on that same hectarage in period 2 and soybeans again in period 3. Since corn was included in each rotation it was assumed in all cases that the crop preceding the choice of rotation in year 1 was corn. Furthermore since optimization permitted growing any crop or rotation on each cell, the procedure permitted a remedial targeting strategy to be investigated. Remedial targeting implies that conservation practices are applied first to the most erosive areas in the watershed.

The following sections proceed as follows; Watershed linear programming results are presented in detail for Kettle Creek, and then summarized in a comparative sense for Essex and Pittock. Then an a assessment of the effects of weather risk on total soil loss, and soil and phosphate loading are presented.

4.2 PROFITABILITY

The optimum solution to the 3-year linear program for Kettle Creek without environmental quality constraints was to grow 411.80 hectares of continuous corn using conservation tillage methods. Three year watershed profits were equal to $456,011. Soil loading into Kettle Creek over the 3 years equalled 40.13 tonnes, phosphate loading equalled 62.67 kg and overall soil loss equalled 9,280.65 tonnes.

From this optimum, restrictions were imposed on each of the 3 environmental factors by reducing the amount of effluent in increments of 10 percent, to a minimum total effluent discharge equal to 40 percent of the unconstrained maximum. To compare the impact of similar constraints on conventional tillage practices, the model was restricted to conventional tillage and equivalent effluent levels were imposed. By doing this, two things were accomplished:

1) By restricting the LP solution to conventional tillage, the impact on net watershed profits and environmental impact can be compared to the optimum solution of conservation tillage, without imposing soil loss constraints;
2) The impact of incremental effluent constraints under conventional and conservation tillage systems can be compared more easily.

The effects of reducing the amount of effluent under conventional and conservation tillage are reported in Tables 4.1, 4.2, and 4.3 for Kettle Creek. In general, profitability decreases with greater environmental quality constraints regardless of what those constraints are. Figures 2 to 10 illustrate the difference in overall watershed profitability with conventional and conservation tillage, and under various levels and types of constraints. Under all situations profitability was highest using no-till and furthermore the amount of effluent discharge per dollar of profit was lowest for no-till. It is worthwhile emphasizing this relationship with an example:

> If it is assumed that 411.8 ha of conventionally tilled continuous corn make up the solution then overall soil loss is 16,947 tonnes, whereas 411.8 ha of no-till continuous corn results in soil loss of 9,281 tonnes. Profitability of the conventionally tilled crop is $450,464. The results indicate that the most profitable alternative to watershed farmers is to adopt no-till strategies which ironically leads to an increase in profits of $5,547 and a reduction in soil loss of 7,666 tonnes. For conventionally tilled land to produce the same amount of soil loss as the optimal no-till solution, farmers would have to set aside 65.10 ha of land (i.e. grow only 346.7 ha continuous corn). As indicated in Tables 4.1 to 4.3 and Figures 2 to 4, this relationship between effluent reduction and increased profitability holds regardless of whether the environmental quality constraint is on soil loss, soil loading or phosphate loading.

4.3 MARGINAL AND AVERAGE COSTS

Marginal costs were obtained from the shadow price of the environmental quality constraint. The shadow price is interpreted as the incremental reduction in profits for one additional tonne (or kg) reduction in effluent. Average costs are defined as the reduction in profits (relative to no environmental quality constraints) per tonne (or kg) of effluent reduced. The marginal costs of soil-loss reduction tends to be higher for conventional tillage than no-till. For example, the marginal cost of reducing soil loss (Table 4.1) from 8,352 tonnes to 7,424 tonnes is approximately $11.30/tonne for conventional tillage, but only $10.46/tonne for no-till. To interpret, this implies that for farmers to achieve one additional tonne reduction in overall soil loss they would have to give up $11.30 or $10.46 of profit, presumably from requiring to set-aside additional land. The average cost of reducing soil loss to 7,424 tonnes is $10.46/tonne for no-till and $11.30/tonne for conventional tillage.

Table 4.1 Kettle Creek Watershed Optimization Results With Soil Loss Restrictions

	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
SOIL LOSS (TONNES)	SOIL LOAD (TONNES)	PHOS. LOAD (KG)	SOLUTION TYPE	SOLUTION AREA (HA)	PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($/T)	SOIL LOAD (TONNES	PHOS. LOAD (KG)	SOLUTION TYPE	SOLUTION AREA (HA)	PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($/T)
16947	152	211	CCC	412	450464	0	0	-	-	-	-	-	-	-
15252	90	147	CCC	404	442105	5	5	-	-	-	-	-	-	-
13558	71	125	CCC	394	431182	8	6	-	-	-	-	-	-	-
11863	64	113	CCC	380	415420	11	7	-	-	-	-	-	-	-
10168	52	95	CCC	360	393446	15	8	-	-	-	-	-	-	-
8474	44	80	CCC	333	364475	20	10	-	-	-	-	-	-	-
6778	39	71	CCC	300	328049	25	12	-	-	-	-	-	-	-
9281	48	88	CCC	347	379247	17	9	40	63	CCC	412	456011	0	0
8352	43	79	CCC	331	362115	20	10	24	41	CCC	404	447550	10	9
7424	41	74	CCC	313	342888	22	11	19	34	CCC	394	436586	15	10
6496	39	70	CCC	293	320878	25	12	17	30	CCC	380	420648	20	13
5568	33	59	CCC	270	295520	29	14	14	24	CCC	360	398421	27	16
4640	19	40	CCC	244	266495	37	15	12	20	CCC	333	369108	36	19
3712	15	32	CCC	208	226941	46	17	10	17	CCC	300	332237	46	22

Note: Constrained is the conventional tillage scenario and unconstrained is the no-tillage scenario.

Table 4.2 Kettle Creek Watershed Optimization Results With Soil Loading Restrictions

SOIL LOAD (TONNES	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOSS (TONNES	PHOS. LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($/T)	SOIL LOSS (TONNES	PHOS. LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($/T)
			TYPE	AREA (HA)						TYPE	AREA (HA)			
152	16945	211	CCC	412	450464	0	0	-	-	-	-	-	-	-
137	16800	199	CCC	408	449656	57	54	-	-	-	-	-	-	-
			SWC	3				-	-	-	-	-	-	-
122	16616	184	CCC	406	448652	80	60	-	-	-	-	-	-	-
			SWC	5				-	-	-	-	-	-	-
107	16292	168	CCC	406	447120	105	74	-	-	-	-	-	-	-
			SWC	5				-	-	-	-	-	-	-
91	15943	152	CCC	406	445519	105	81	-	-	-	-	-	-	-
			SWC	2				-	-	-	-	-	-	-
76	15632	136	CCC	405	443911	109	86	-	-	-	-	-	-	-
			SWC	1				-	-	-	-	-	-	-
61	15403	118	CCC	401	440487	385	110	-	-	-	-	-	-	-
			SWC	2				-	-	-	-	-	-	-
40	13938	86	CC	367	420318	1522	269	9280	63	CCC	412	456010	0	0
			SWC	23										
36	13579	79	CCC	362	413964	1718	315	9174	58	CCC	411	454910	342	275
			SWC	20										
32	13116	72	CCC	344	406458	2178	367	9017	53	CCC	410	453537	342	309
			SWC	35										
28	12768	65	CCC	340	397099	2660	430	8859	47	CCC	408	452161	342	321
			SWC	28										
24	11715	56	CCC	327	385281	3230	509	8701	42	CCC	407	450788	342	326
			SWC	32										
20	10867	48	CCC	318	371399	3800	599	8558	37	CCC	406	449257	654	338
			SWC	27										
16	10163	42	CCC	287	352713	5142	719	8399	31	CCC	402	445574	2279	435
			SWC	45										

Note: Constrained is the conventional tillage scenario and unconstrained is the no-tillage scenario.

Table 4.3 Kettle Creek Watershed Optimization Results With Phosphate Loading Restrictions

PHOS LOAD (KG)	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOAD (TONNES)	SOIL LOSS (KG)	SOLUTION		PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($/T)	SOIL LOAD (TONNES)	SOIL LOSS (TONNE)	SOLUTION		PROFIT ($)	MARG. COSTS ($/T)	AVE. COSTS ($WT)
			TYPE	AREA (HA)						TYPE	AREA (HA)			
211	152	16947	CCC	412	450464	0	0	....	....	....	....	....	....	....
190	128	16702	CCC	406	449142	64	63	....	....	....	....	....	....	....
			SWC	6				....	....	....	....	....	....	....
169	108	16313	CCC	406	447218	99	77	....	....	....	....	....	....	....
			SWC	4				....	....	....	....	....	....	....
148	88	15857	CCC	406	445125	99	85	....	....	....	....	....	....	....
			SWC	1				....	....	....	....	....	....	....
126	68	15574	CCC	403	442511	192	94	....	....	....	....	....	....	....
			SWC	2				....	....	....	....	....	....	....
106	54	14903	CCC	392	435015	578	147	....	....	....	....	....	....	....
			SWC	7				....	....	....	....	....	....	....
84	41	13831	CCC	354	419825	784	241	....	....	....	....	....	....	....
			SWC	38				....	....	....	....	....	....	....
63	33	12957	CCC	305	397791	1147	356	40	9280	CCC	412	456011	0	0
			SCS	49										
			SWC	29										
56	30	12611	CCC	292	390266	1232	388	35	9133	CCC	410	454548	264	209
			SCS	56										
			SWC	26										
50	27	12307	CCC	292	381409	1438	429	30	8943	CCC	409	452897	264	240
			SCS	56										
			SWC	16										
44	24	11104	CCC	290	371867	1823	471	25	8754	CCC	408	451244	264	251
			SCS	56										
			SWC	7										
38	20	10549	CCC	280	360314	2161	521	21	8564	CCC	406	449591	264	257
			SCS	55										
			SWC	7										
31	17	10158	CCC	280	346763	2161	576	16	8464	CCC	403	446328	1230	303
			SCS	40										
			SWC	7										
25	14	9665	CCC	225	332366	2314	635	14	8073	CCC	394	436392	1846	516
			SCS	38										
			SWC	62										

Note: Constrained is the conventional tillage scenario and unconstrained is the no-tillage scenario.

Figure 2

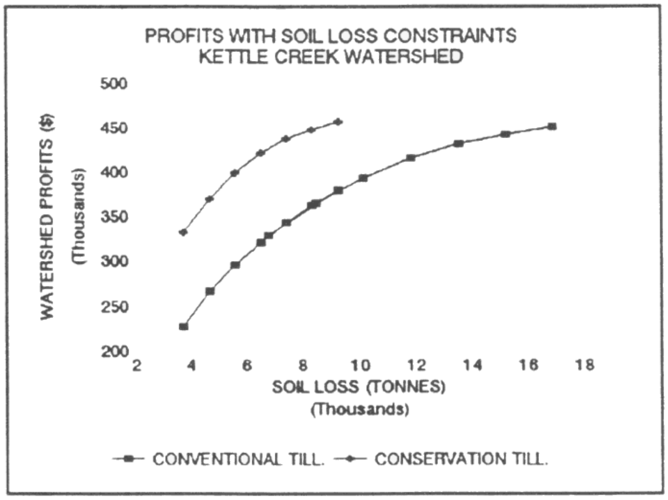


Figure 3

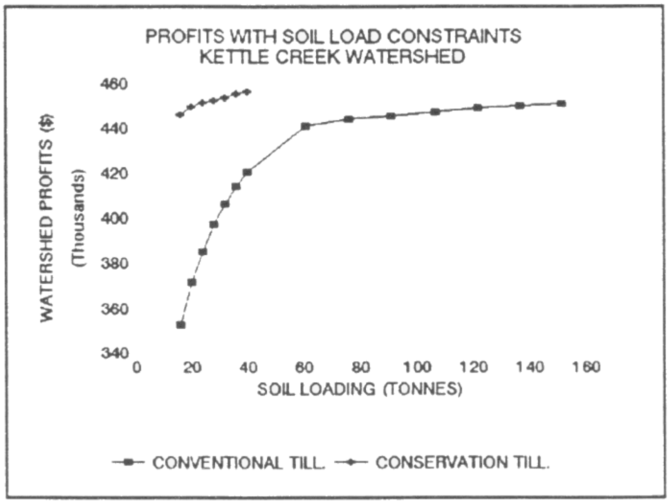
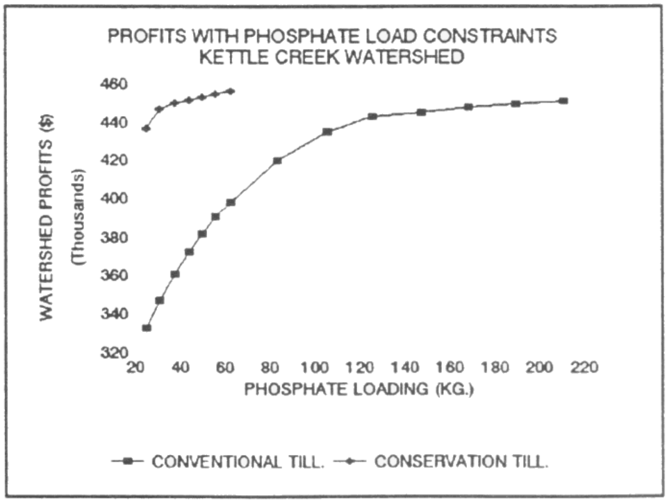


Figure 4



Note, however, that although average costs are similar between the two tillage practices their interpretation is quite different. For example, the average cost for conventional tillage is applied to all of the soil loss reduction (approximately 9,523 tonnes) whereas the average cost for no-till is applied only to approximately 1,857 tonnes. Similarly the marginal costs per unit of soil loss reduction are applied to a higher profit base for no-till (conservation tillage).

Marginal and average costs differ by constraint type. For example, with zero tillage a 50% reduction in soil loss (Table 4.1) to 4,640 tonnes implied a marginal cost of $36.05/tonne and an average cost of $18.73/tonne. In order to achieve such a large reduction in soil loss, only 333.32 ha of no-till continuous corn was grown. A 50 percent reduction in soil loading from the no-till maximum implied a maximum of 20 tonnes of soil loading was allowed (Table 4.2). The marginal cost at this point of reduction was $654.47/tonne with an average cost of $337.65/tonne. Hectares planted to continuous corn was 405.70 implying that 6.1 ha had to be set-aside in order to satisfy the constraints Finally, a 50% reduction in phosphate loading for the no-till solution implies maximum allowable phosphate loading of 31.50 kg (Table 4.3). This was achieved by reducing the area planted to no-till continuous corn from 411.8 ha to 403.06 ha. The marginal cost of phosphate reduction at this level is $1,230.40/kg and the average cost was $302.59/kg.

Marginal costs are never less than average costs. Marginal costs and average costs for each of the 3 types of restriction are illustrated in Figures 5 to 10. Both marginal costs and average costs tend to increase at an increasing rate. Although the marginal cost functions appear as discontinuous step functions, the average cost functions are continuous.

The same relationships hold for the conventionally tilled solutions. The greater the amount of effluent reduction the greater the marginal and average costs. It is of interest to note that when zero-tillage was disallowed the optimum conventional tillage practices were applied to different crop mixes, and there were differences in the crop mixes depending on the nature of the constraint. For example constraining soil loss (Table 4.1) resulted in setting

Figure 5

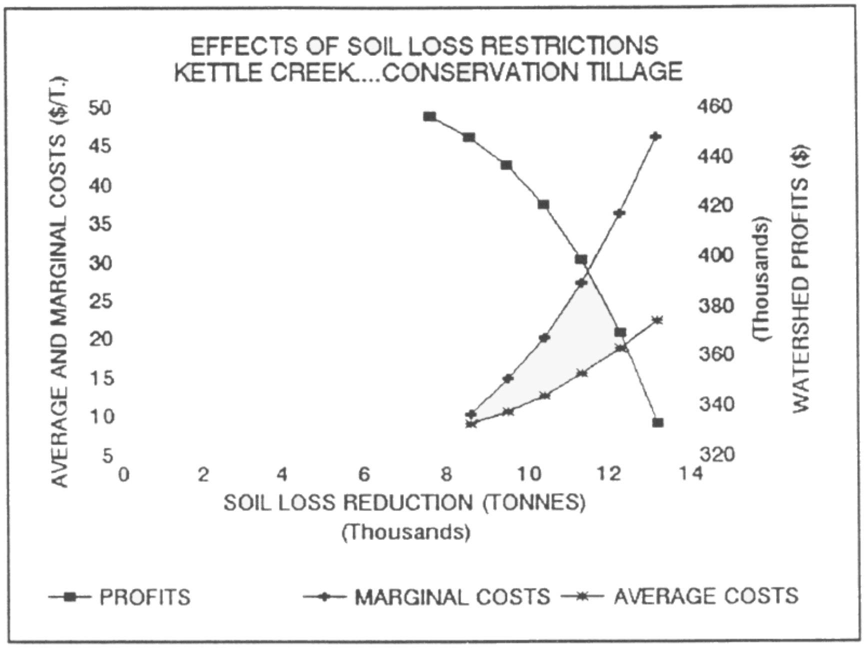


Figure 6

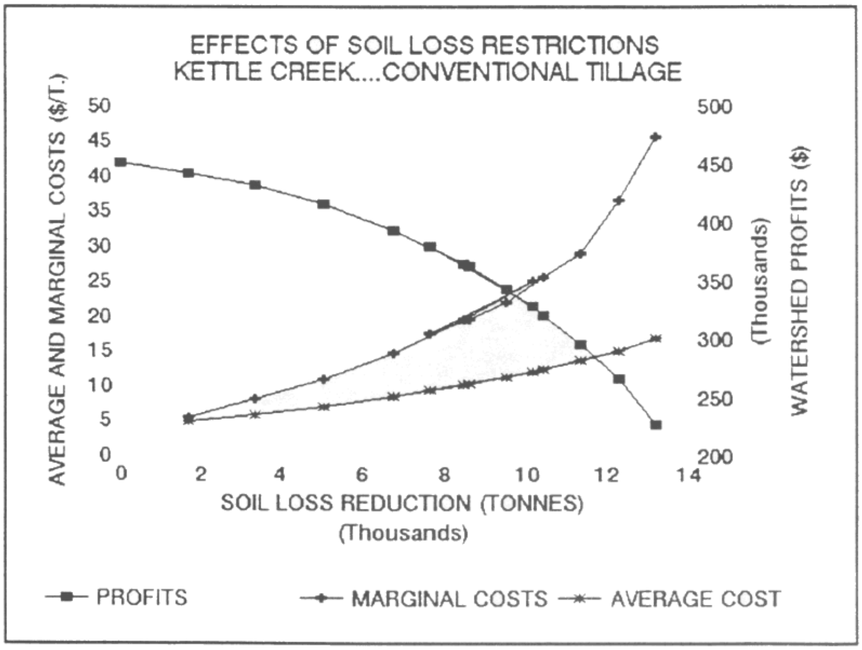


Figure 7

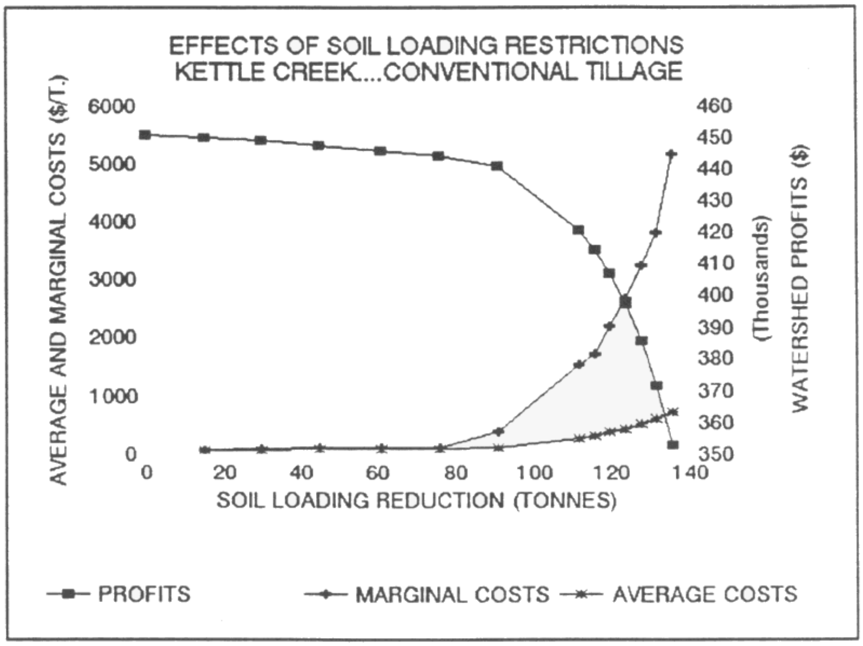


Figure 8

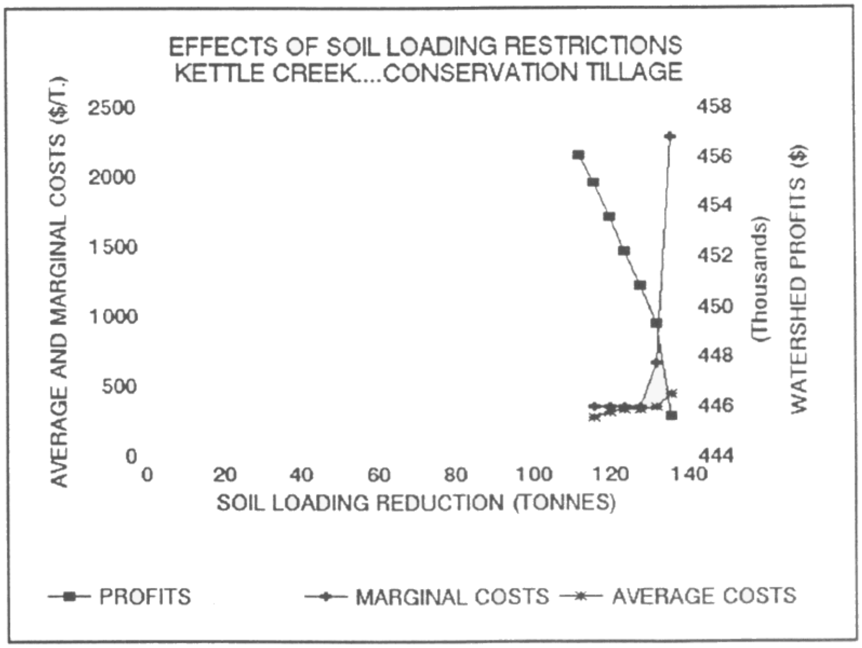


Figure 9

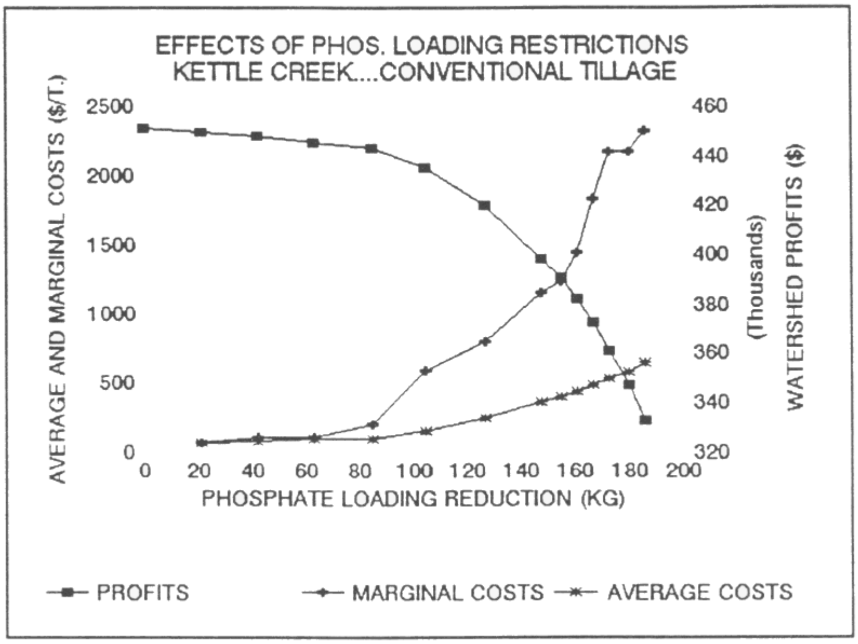
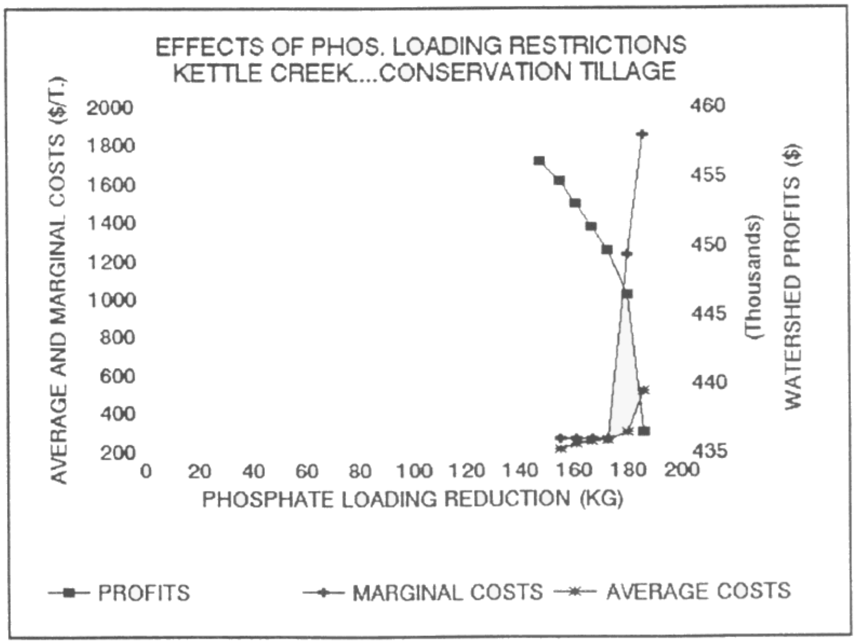


Figure 10



aside hectares and growing continuous corn on the remainder. However, as reported in Table 4.2, combinations of continuous corn and a soybean-wheat-corn rotation were employed to satisfy constraints on soil loading. Similarly, for conventional tillage, continuous corn, soy-wheat-corn and soy-corn-soy rotations were required to satisfy the environmental quality constraints on phosphate loading (Table 4.3).

That marginal costs are never less than average costs under any of the scenarios examined (Figures 5 to 10). This reflects the fact that production under environmental quality constraints is displaced from an optimum and efficient farm plan with non-increasing returns to scale to a less than profit maximizing watershed exhibiting decreasing returns to scale. This consequence of environmental quality constraints is predicated upon the observation that the ratio of marginal cost to average cost, a measure of output flexibility, is greater than 1. Decreasing returns to scale in this context implies overall technical and allocative inefficiency with respect to input use (i.e. land) and output (i.e. profits).

Results for the Essex and Pittock watersheds were not substantially different in terms of implication than the Kettle Creek results presented above. The results for Essex and Pittock are presented in Appendix A, in Tables A.1 to A.3 and Figures A.1 to A.9 for Essex, and Tables A.4 to A.6 and Figures A.10 to A.18 for Pittock. However, some aspects of the analyses are note worthy. First the level of effluent with Essex is substantially less in comparison to Kettle Creek and Pittock, and the optimum strategies are different. For example, the unconstrained profit maximizing solution for Essex grew a conventionally tilled soy-corn-soy rotation on all 436 hectares. However, as environmental quality constraints were imposed, the model grew increasing hectares of a soy-wheat-corn rotation under conservation tillage. Restricting the solution to conventional tillage resulted in lower profits and the adoption of a more erosive soy-corn-soy rotation for all levels of allowable effluent. An implication of this result, and one which is unique to Essex, is that adoption of conservation tillage practices is not a prerequisite to soil conservation; rather remedial targeting efforts can focus on using mixed conventional-conservation tillage strategies to meet environmental objectives. However a major result, and one which is common to all 3 watersheds is that failure to consider conservation tillage practices may, and most likely would, result in a reduction in maximum profit potential, when faced with meeting effluent restrictions.

Furthermore, a key observation is that tillage strategies among watersheds which differ in shape, topography, and soil texture should be approached differently. The issue of remedial targeting depends on these factors and strategies (recommendations) which are effective for one watershed may not be as effective in others. Moreover, targeting strategies should not exclude the economic information and the optimal use of resources in obtaining profits. Environmental quality constraints can be satisfied in a multitude of ways which are technically feasible but given an overall goal of profit maximization, not optimal.

4.4 ASSESSMENT OF RAINFALL RISK ON EFFLUENT LOADING

One of the major problems facing environmental regulators is in the definition and establishment of acceptable standards of soil loss, soil loading, and phosphate loading. In the above analyses it was presumed that average rainfall conditions prevailed and given those conditions the expected amount of effluent established. However, effluent is very much determined by weather conditions as well as the site-specific agronomic and topographical features. To address the issue of rainfall risk additional GAMESP simulation models were run with varying USLE rainfall factors. These rainfall factors were set 10 points above and below those stipulated in Table 2.1 and correspond to a high and low rainfall year respectively. A passive approach to risk assessment was used; that is it was assumed that all crop decisions were made based upon the average rainfall. This is not unrealistic. Farmers often make decisions which are irreversible when new information arises. For example, once a field has been planted it is very difficult to change the crop mix to satisfy environmental quality constraints when actual weather patterns deviate from the norm.

The additional GAMESP runs provided soil loss, soil loading and phosphate loading observations for high and low rainfall outcomes. Effluent at the cell levels were multiplied by the amount of planted crop in each cell, and for all cells, in each watershed and for all levels of environmental quality constraints. The resulting levels of effluent correspond directly to the difference in weather patterns given the initial planting decision. The results of this risk assessment are found in Table 4.4 for the three watersheds using the unconstrained models. The results show that a modest variance exists in the amount of effluent discharged. For example, growing 411.8 hectares of continuous corn in Kettle Creek yields an expected soil loss of 9,280 tonnes over the 3 year rotation, but if rainfall is higher than expected soil loss could increase to as much as 10,258 tonnes. Likewise, a reduction in rainfall reduces overall soil loss to as low as 8,304 tonnes. Similarly growing 436 hectares in a conventionally tilled soy-corn-soy rotation in Essex yields a range of soil loading from 3,080 tonnes to 3,696 tonnes and phosphate loading of 3,429 kg to 3,977 kg.

As would be expected the dispersion in effluent decreases with increased use of conservation tillage implying that not only does conservation tillage reduce the amount of effluent expected, but also the variability in this effluent due to changing weather conditions. For example, in Essex, targeting 106 hectares to a conventionally tilled soy-corn-soy rotation and 330 hectares to a soy-wheat-corn rotation reduces the range of soil loading to 2,521 tonnes and 2,587 tonnes, and phosphate loading from 2,589 kg and 2,999 kg.

Table 4.4 Sensitivity of Soil Loss, Soil Loading and Phosphate Loading to Rainfall Risk When Maximum Soil Loading is Restricted

Solution		Low Rain			Average Rain			High Rain		
Type	Hectares	Soil Loss	Soil Load	Phos-phate	Soil Loss	Soil Load	Phos-phate	Soil Loss	Soil Load	Phos-phate
Kettle										
CCC	411.80	8304	36	57	9280	40	63	10,258	44	57
CCC	410.81	8209	32	52	9174	36	58	10,140	40	63
CCC	409.57	8067	29	48	9017	32	53	9966	35	57
CCC	408.32	7926	25	43	8859	28	47	9791	31	51
CCC	407.08	7785	22	38	8701	24	42	9617	27	46
CCC	405.70	7657	18	33	8558	20	37	9459	22	40
CCC	402.37	7515	14	27	8399	16	31	9283	18	33
Essex										
SCS*	436	3438	3080	3429	3783	3388	3710	4127	3696	3077
SCS*/SWC	337/98	3145	2772	3161	3459	3049	3413	3773	3326	3663
SCS*/SWC	231/204	2839	2464	2883	3123	2711	3113	3407	2957	3341
SCS*/SWC	106/330	2521	2156	2589	2774	2372	2794	3025	2587	2999
SWC	418	2159	1847	2263	2375	2033	2443	2591	2218	2616
SWC	365	1851	1541	1906	2036	1695	2055	2221	1849	2202
SWC	312	1543	1232	1544	1697	1355	1663	1851	1479	1783
Pittock										
CCC	359	4122	76	160	83	4508	169	4893	89	180
CCC	355	4084	68	150	74	4466	158	4848	81	168
CCC	348	3958	61	137	66	4328	145	4698	72	153
CCC	338	3811	53	124	58	4167	131	4523	63	138
CCC	326	3668	45	112	50	4011	117	4354	54	122
CCC	312	3527	38	99	41	3857	103	4186	45	106
CCC	292	3282	30	83	33	3589	87	3896	36	88

* indicates a conventional tillage solution: CCC is continuous corn, SCS is a soy-corn-soy rotation, and SWC is soy-wheat-corn rotation.

5.0 POLICY IMPLICATIONS/RECOMMENDATIONS

The results of this study are indicative of the costs of environmental quality constraints which sometimes result in substantial opportunity costs and scale inefficiencies. Although in the context of social welfare, producer surplus would decrease with respect to environmental quality constraints, a social optimum would be obtained if the marginal costs to the farmer equalled the marginal benefits to society of clearing up the externality. For example, if it was determined that the social costs of phosphate loading from Kettle Creek were $263.66/kg, then the regulating authority could set restrictions to 56.70 kg. The cropping response would be to grow 410.48 ha of no-till continuous corn for watershed with profits of $454,548. However, if the social costs were higher, say $1,230.40/kg, then the regulating authority, to achieve a social optimum, would restrict phosphate loading to 50 percent of maximum (31 kg). Watershed farmers would have to reduce production to 403.06 ha, taking about 8.74 of the most erosive hectares out of production.

The opportunity cost per hectare can also be obtained from Tables 4.1 to 4.3. From a policy perspective, soil loading is the most likely candidate for which standards will be established. Indeed, as can be seen in the tables, setting limits on either of the effluent will also cause a reduction in the others. A problem, however, is in determining what the base level for effluent reduction is. From Table 4.2, soil loading from conventionally tilled land is maximized at 152 tonnes. A 20 percent reduction yields 122 tonnes, and watershed profits are reduced from $450,464 to $448,652 or approximately $1.47/ha/year. Likewise, the maximum soil load using no-till is 40 tonnes. A 20 percent reduction to 32 tonnes decreases watershed profits from $456,010 to $453,537, or approximately $2.00/ha/year. Equivalent values fora 20 percent reduction in Essex and Pittock are $37.96/ha/year and $10.82/ha/year for conventional tillage respectively, and $5.88/ha/year and $11.51/ha/year for conventional tillage respectively. Since these solutions represent the maximum erosion potential of the watershed and the solutions represent profit maximums, these values are likely to be the maximum per hectare/per year opportunity costs facing watershed farmers.

Hence, if the societal cost of off-site damage from the watershed exceeds these values then government intervention would be justified. Note here the importance of adopting reduced or minimal tillage: In all cases examined the adoption of no-till over conventional tillage leads to improved profits and this in turn lowers the opportunity costs which farmers would incur under environmental quality constraints.

Because optimal watershed planning strategies are based on remedial targeting efforts compensation, if any, should not be distributed on a per hectare basis equally to all watershed farmers. Using a remedial targeting strategy requires that only the most erosive land be taken out of production. For example, a 20 percent reduction in soil loading could be achieved by either revising the crop mix as in the conventional case in Table 4.2, or setting aside 2.23 hectares under the no-till case. Since substantial environmental benefits are achieved through such modest revisions of the farm strategies then compensation should be attributed to those hectares (farmers) affected.

From a more general perspective the results of this study indicate that a substantial extension effort is warranted. Farm profits for many farmers can be increased by adopting no-till technology and adjusting crop mixes or rotations. In addition to these immediate economic benefits substantial societal benefits can be realized, especially in the reduction of costs associated with non-point pollution.

5.1 JOINT RESTRICTIONS

The above discussions assume mutually exclusive restrictions on the environmental quality constraints. However it may be that multiple restrictions are imposed. For example, phosphate loading and soil loss may be treated by different legislations one limiting phosphate loading and the other limiting soil loss: The policies are not mutually exclusive and as a consequence marginal costs may increase due to multiple constraints.

To investigate the joint relationships the optimization model was run for multiple restrictions by holding 2 constraints constant while varying the third in parametric progression. Soil loss, and soil and phosphate loading were investigated through successive parameterization of the constraint limits from 100 percent to 40 percent in increments of 10 percent. In all, 216 additional linear programs covering all combinations of constraints (6x6x6) were run for each watershed. As anticipated no crop rotation/management practice other than those reported above was grown. The results, which are too numerous to report here, illustrated that contiguous standards on soil loss, soil loading and phosphate loading can jointly effect marginal costs and profitability. In essence the marginal cost structure of contiguous environmental policies obey the law of the minimum whereby the greatest opportunity costs accrue to the most restrictive constraint: Restrictions on 1 level of effluent become passive as increased restrictions on another level of effluent emerge and becomes most limiting.

These results suggest that multiple goal strategies for single watersheds may not be effective. Rather, establishing a single standard for the effluent deemed most important in terms of social costs would likely be the more effective policy. In targeting a single effluent, (e.g. soil loss, or soil/phosphate loading)the results from this research indicate that the remaining effluent would also be incrementally reduced. The extent of reduction is also reported in Tables 4.1 to 4.3.

6.0 CONCLUSIONS

This report addresses two objectives of the watershed modelling component of the Sweep Analysis Sub-program. The first objective was to evaluate the watershed level impact of conservation technologies on farmers' net income, choice of tillage method and resource use. Using a simulation model and a multi-period linear program it was found for the Kettle Creek watershed that maximum profits of $456,011 could be obtained by growing 411.8 ha of continuous corn, using conservation tillage for each of the 3 periods modelled. This result was due to the fact that, at least for Kettle Creek watershed farmers, no-till continuous corn was the most profitable of all management practices examined, and was also the least prone to soil and phosphate effluent loss and loading. At this maximum, total soil loading was 40 tonnes over 3 years. To contrast the results with a pure conventional (mouldboard plough) tillage system the optimization model was restricted to exclude conservation tillage. The constrained model grew 411.8 ha of continuous corn with 3-year profits of $450,464 and total soil loading of 152 tonnes. To achieve the same level of effluent as the conservation tillage strategy (i.e. 40 tonnes) watershed farmers would incur a reduction in profits to $420,318 or an average cost of $269.16/tonne. These costs are attributable to lower per hectare profitability of conventional tillage and a substantial set-aside requirement.

Similar results are reported for Essex and Pittock watersheds. Maximum watershed profits of $334,699 in the 436 ha Essex watershed was achieved using a conventionally tilled corn-soybean rotation. Soil loading was 3,388 tonnes over the three years. However, optimal strategies for reducing effluent load were achieved through the adoption of conservation tillage. As with the other watersheds sole reliance on conventional tillage required higher set-aside needs and, consequently, higher average costs than reduced tillage strategies. The Pittock watershed model yielded an optimal strategy comprising 359 ha of no-till continuous corn for a 3 year profit of $403,312. Soil loading was 83 tonnes over the 3 years. To achieve an equivalent soil load using conventional tillage required substantial set-aside hectarage and average costs of $556/tonne.

The second objective was to evaluate the opportunity costs of conservation in terms of reducing soil and phosphorous run-off into surface water and reducing soil degradation through soil loss. The effect of imposing these environmental quality constraints was to reduce the total hectarage planted to corn. Land not planted was left idle in the model and it was this idle land which established much of the opportunity costs of the environmental quality constraints. Other contributions to these costs was a switch to less profitable crop rotations. Results showed that marginal costs of environmental quality constraints were never less than the average costs, implying an overall loss in allocative and economic efficiency could accrue to watershed farmers.

APPENDIX A

RESULTS FOR ESSEX AND PITTOCK

Table A.1 Essex Watershed Optimization Results with Soil Loss Restrictions

SOIL LOSS (TONNES)	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOAD (TONNES)	PHOSP LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)	SOIL LOAD (TONNES)	PHOSP LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)
			TYPE	AREA (HA)						TYPE	AREA (HA)			
3783	3388	3710	*SCS	436	334699	0	0	3388	3710	*SCS	436	334699	0	0
3411	3016	3326	*SCS	399	306674	77	75	3025	3390	*SCS	325	330545	11	11
										#SWC	110			
3032	2703	2983	*SCS	360	276953	79	77	2670	3069	*SCS	207	326085	12	11
										#SWC	229			
2653	2324	2582	*SCS	321	247030	79	78	2316	2732	*SCS	69	320930	15	12
										#SWC	366			
2274	2021	2251	*SCS	282	216524	81	78	1934	2331	#SWC	402	294141	110	27
1895	1688	1890	*SCS	242	185673	82	79	1610	1948	#SWC	344	251300	114	44
1516	1318	1491	*SCS	200	153666	89	80	1231	1509	#SWC	284	207684	117	56

* INDICATES CONVENTIONAL TILLAGE, # NO-TILLAGE

Table A.2 Essex Watershed Optimization Results with Soil Loading Loading Restrictions

SOIL LOAD (TONNES)	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOSS (TONNES)	PHOSP LOAD (KG)	SOLUTION		PROFIT ($)	MARG COST ($/T)	AVE. COST ($/T)	SOIL LOSS (TONNES)	PHOSP LOAD (KG)	SOLUTION		PROFIT ($)	MARG COST ($/T)	AVE. COST ($/T)
			TYPE	ACRES (HA)						TYPE	ACRES (HA)			
3388	3783	3710	*SCS	436	334699	0	0	3783	3710	*SCS	436	334699	0	0
3049	3517	3365	*SCS	239	311543	76	68	3459	3413	*SCS	337	331001	11	11
			*SWC	168						#SWC	98			
2711	3178	3010	*SCS	206	285051	79	73	3123	3113	*SCS	231	327014	13	11
			*SWC	166						#SWC	204			
2372	2839	2651	*SCS	171	258286	79	75	2774	2794	*SCS	106	322297	16	12
			*SWC	166						#SWC	330			
2033	2500	2292	*SCS	136	230934	81	77	2375	2443	#SWC	418	305207	110	22
			*SWC	166										
1695	2162	1929	*SCS	100	202847	86	78	2036	2055	#SWC	365	267114	114	40
			*SWC	166										
1355	1816	1564	*SCS	73	172206	92	80	1697	1663	#SWC	312	228089	117	52
			*SWC	152										

* INDICATES CONVENTIONAL TILLAGE, # NO-TILLAGE

Table A.3 Essex Watershed Optimization Results with Phosphate Loading Restrictions

PHOS LOAD (KG)	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOAD (TONNE)	SOIL LOSS (TONNE)	SOLUTION TYPE	SOLUTION ACRES (HA)	PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)	SOIL LOAD (TONNES)	SOIL LOSS (TONNES)	SOLUTION TYPE	SOLUTION ACRES (HA)	PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)
3710	3388	3783	*SCS	436	334699	0	0	3388	3783	*SCS	436	334699	0	0
3339	3027	3496	*SCS	234	309605	74	68	2966	3376	*SCS	312	330050	13	13
			*SWC	170						#SWC	124			
2968	2675	3144	*SCS	199	281972	75	71	2560	2967	*SCS	177	324982	14	13
			*SWC	170						#SWC	258			
2597	2324	2793	*SCS	163	254290	75	72	2172	2522	*SCS	12	318783	21	14
			*SWC	170						#SWC	423			
2226	1974	2442	*SCS	128	225929	77	73	1844	2186	*SCS	0	284054	99	34
			*SWC	167						#SWC	389			
1855	1627	2093	*SCS	94	196901	83	74	1522	1864	*SCS	0	247406	99	47
			*SWC	163						#SWC	338			
1484	1282	1739	*SCS	71	165326	88	76	1201	1543	*SCS	0	209920	103	56
			*SWC	146						#SWC	287			

* INDICATES CONVENTIONAL TILLAGE, # NO-TILLAGE

Figure 1

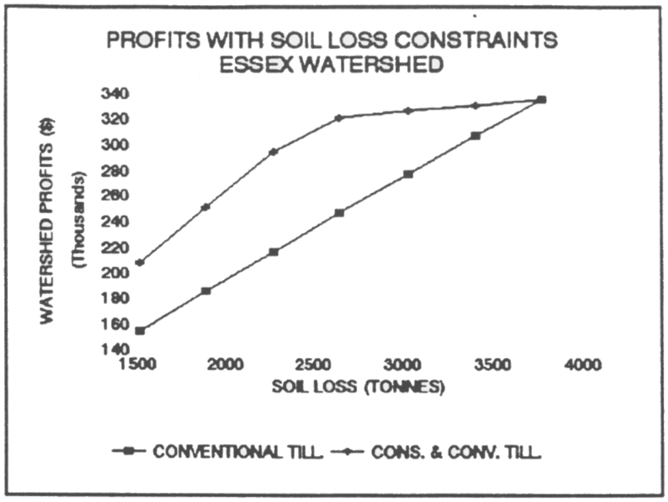


Figure 2

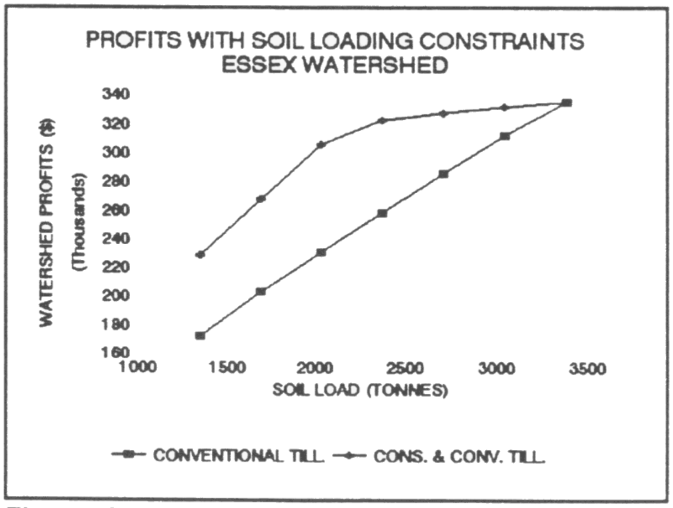


Figure 3

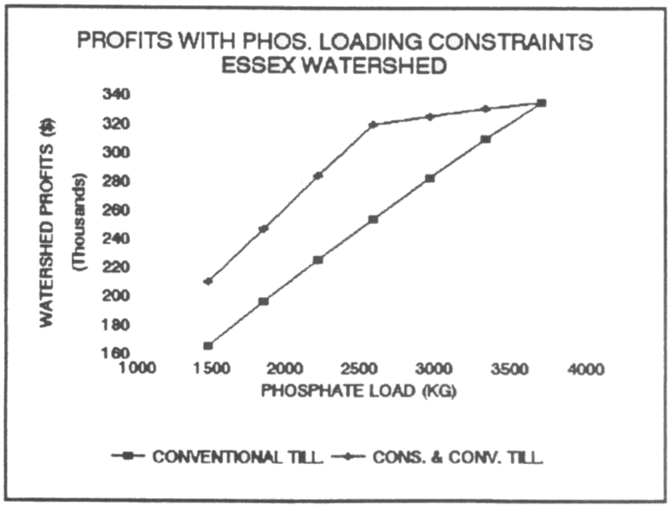


Figure 4

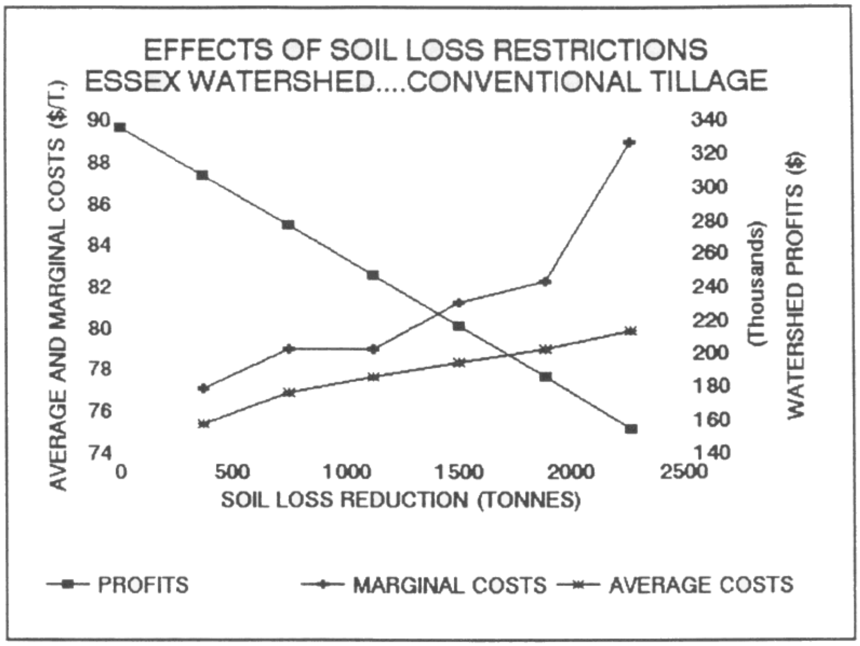


Figure 5

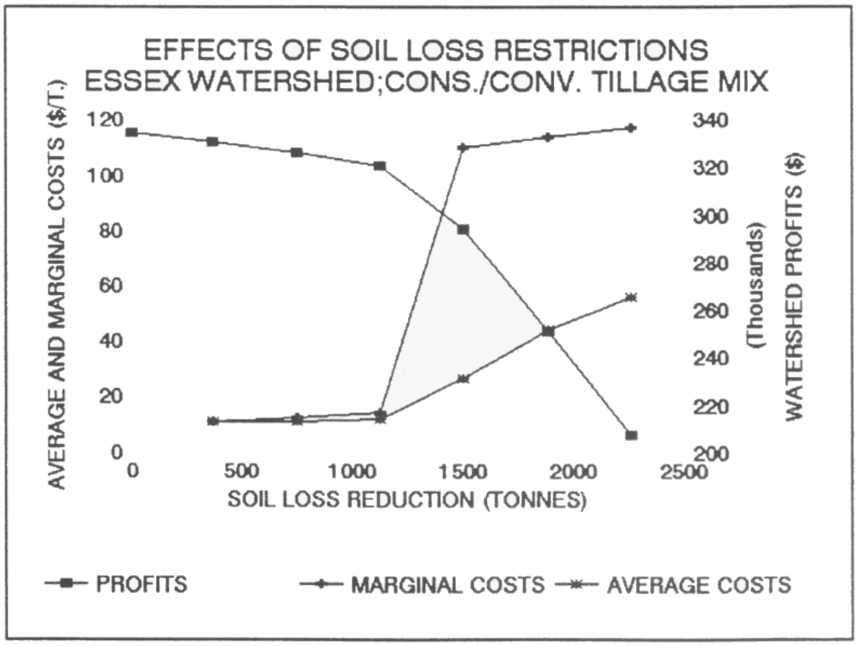


Figure 6

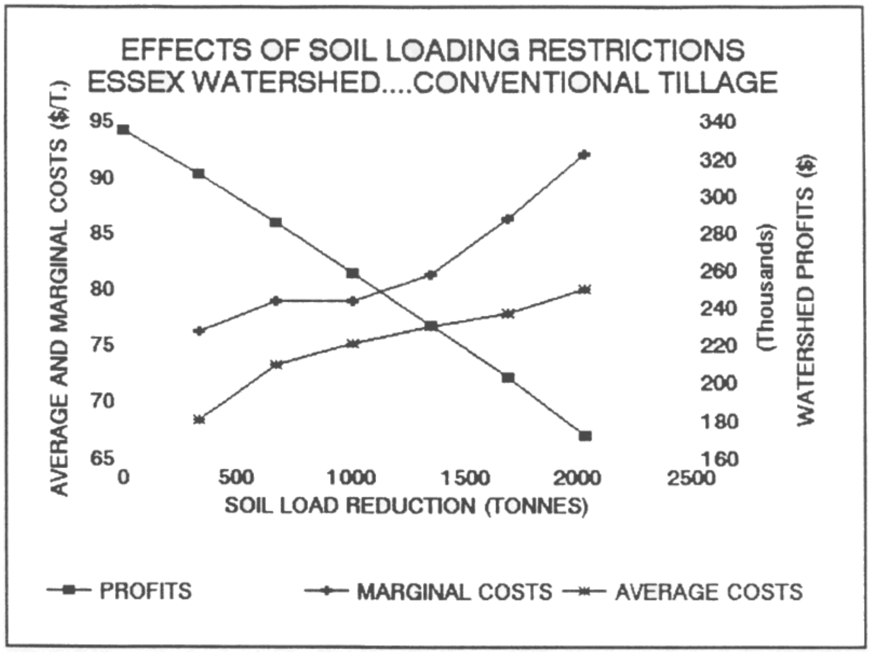


Figure 7

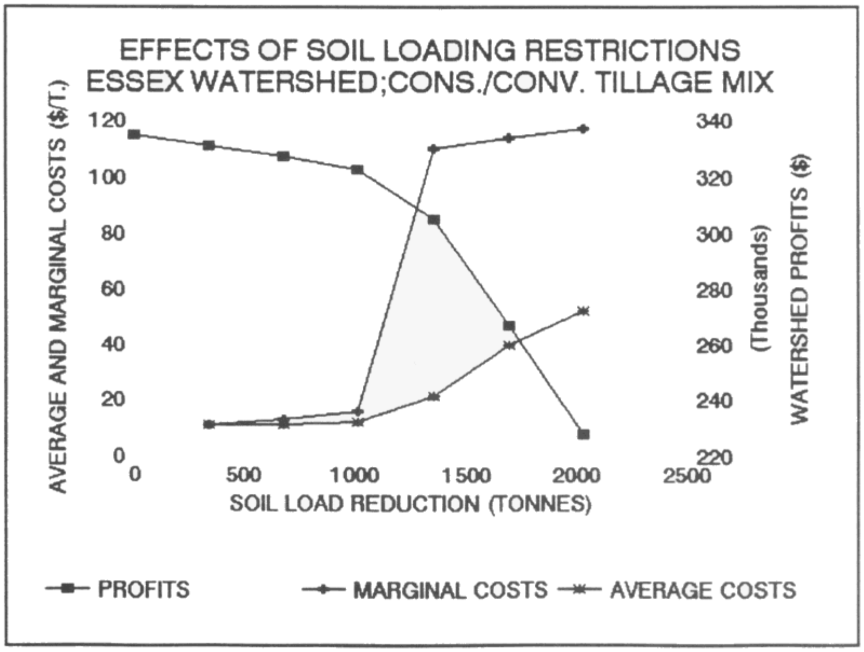


Figure 8

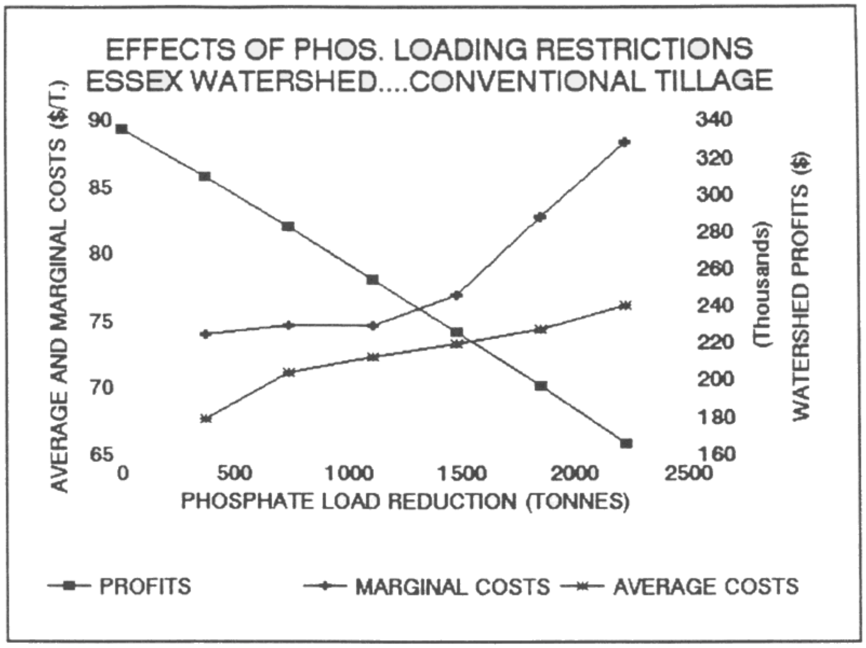


Figure 9

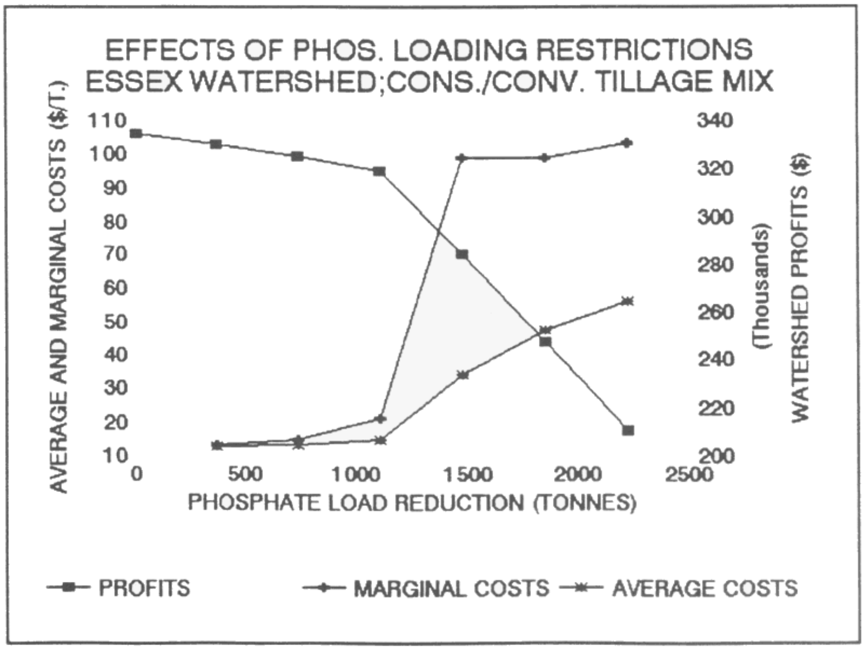


Table A.4 Pittock Watershed Optimization Results with Soil Loss Restrictions

SOIL LOSS (TONNES	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOAD (TONNES	PHOS. LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)	SOIL LOAD (TONNES	PHOS. LOAD (KG)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)
			TYPE	ACRE (HA)						TYPE	ACRE (HA)			
8231	256	404	CCC	359	393627	0		--	--	--	--	--	--	--
7408	222	358	CCC	340	373223	36	25	--	--	--	--	--	--	--
6585	211	336	CCC	311	341363	41	32	--	--	--	--	--	--	--
5762	193	305	CCC	279	306502	44	35	--	--	--	--	--	--	--
4939	180	281	CCC	245	269241	46	38	--	--	--	--	--	--	--
4116	159	245	CCC	210	230873	48	40	--	--	--	--	--	--	--
3293	134	205	CCC	173	189877	51	41	--	--	--	--	--	--	--
4508	171	264	CCC	227	249589	47	39	83	169	CCC	359	403312	0	
4057	153	237	CCC	208	228058	48	40	72	151	CCC	340	382412	67	46
3606	139	214	CCC	188	205875	50	41	68	143	CCC	311	349760	77	59
3155	130	198	. CCC	167	182840	51	42	62	129	CCC	279	314043	83	66
2705	113	174	CCC	145	159259	53	42	58	119	CCC	245	275862	85	71
2254	99	149	CCC	123	135171	53	43	47	98	CCC	210	236553	90	74
1803	71	108	CCC	101	110914	54	44	42	85	CCC	173	194547	96	77

Table A.5 Pittock Watershed Optimization Results with Soil Loading Restrictions

SOIL	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
LOAD (TONNES	SOIL LOSS (TONNES	PHOS. LOAD (KG)	SOLUTION TYPE	SOLUTION ACRE (HA)	PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)	SOIL LOSS (TONNES	PHOS. LOAD (KG)	SOLUTION TYPE	SOLUTION ACRE (HA)	PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)
256	8231	404	CCC	359	393627	0						....		
231	8158	377	CCC	351	389725	215	152							
205	7974	346	CCC	332	381969	335	227	....						
			SWC	21										
179	7660	311	CCC	319	372237	437	278							
			SWC	25				....						
154	7389	273	CCC	312	359542	515	332							
			SWC	19										
128	7045	236	CCC	299	343190	688	394							
			SWC	18										
103	6611	196	CCC	272	321507	985	469							
			SWC	26										
83	6134	164	CCC	245	297153	1497	556	4508	169	CCC	359	403312	0	0
			SWC	33										
74	5902	150	CCC	229	284277	1655	601	4466	158	CCC	355	398879	916	535
			SWC	38										
66	5615	135	CCC	214	270127	1766	650	4328	145	CCC	348	390916	1125	749
			SWC	41										
58	5281	121	CCC	173	253224	2255	708	4167	131	CCC	338	380071	1453	936
			SWC	74										
50	4839	106	CCC	155	232990	2557	777	4011	117	CCC	326	367084	1865	1095
			SWC	73										
41	4368	91	CCC	128	210235	2972	853	3857	103	CCC	312	350778	2357	1270
			SWC	81										
33	3819	73	CCC	97	184100	3369	939	3589	87	CCC	292	328108	3503	1514
			SWC	91										

Table A.6 Pittock Watershed Optimization Results with Phosphorus Loading Restrictions

PHOS LOAD (KG)	CONVENTIONAL TILLAGE							CONSERVATION TILLAGE						
	SOIL LOAD (TONNES)	SOIL LOSS (TONNES)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)	SOIL LOAD (TONNES	SOIL LOSS (TONNES)	SOLUTION		PROFIT ($)	MARG. COST ($/T)	AVE. COST ($/T)
			TYPE	ACRE (HA)						TYPE (KG)	ACRE (HA)			
404	256	8231	CCC	359	393627	0	0							
364	220	8048	CCC	345	386839	239	168							
			SWC	10										
323	191	7750	CCC	333	376245	298	215							
			SWC	13										
283	161	7449	CCC	315	362992	344	253							
			SWC	20										
242	134	7117	CCC	295	346693	477	290							
			SWC	27										
202	107	6690	CCC	287	325731	573	336							
			SWC	13										
162	84	6109	CCC	237	296251	795	402							
			SWC	42										
169	87	6221	CCC	263	302416	795	389	83	4508	CCC	359	403312	0	0
			SWC	16						SWC	0			
152	78	5973	CCC	220	288696	859	417	71	4416	CCC	352	395372	625	469
			SWC	55						SWC	0			
136	69	5675	CCC	220	272561	954	451	61	4221	CCC	341	383807	750	576
			SWC	36						SWC	0			
119	60	5323	CCC	160	253519	1192	491	51	4029	CCC	327	368147	937	692
			SWC	91						SWC	0			
102	52	4860	CCC	133	232921	1227	531	42	3833	CCC	310	349092	1249	800
			SWC	101						SWC	0			
85	43	4355	CCC	133	209336	1432	577	32	3532	CCC	288	323968	1874	937
			SWC	74						SWC	0			
68	34	3811	CCC	112	180102	1829	635	25	3225	CCC	260	292205	1874	1093
			SWC	66						SWC	0			

Figure 10

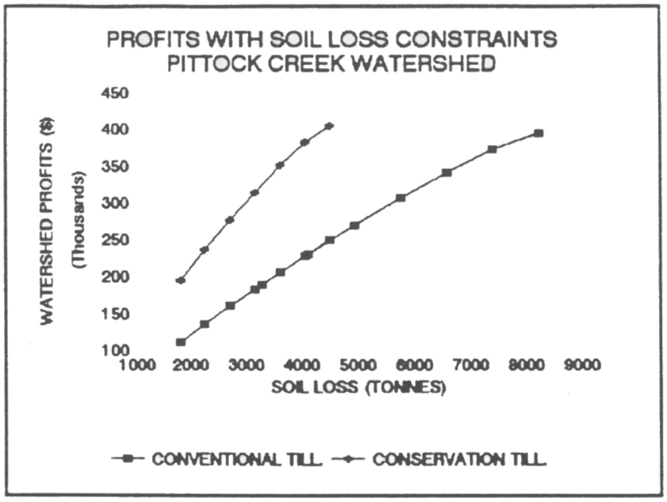


Figure 11

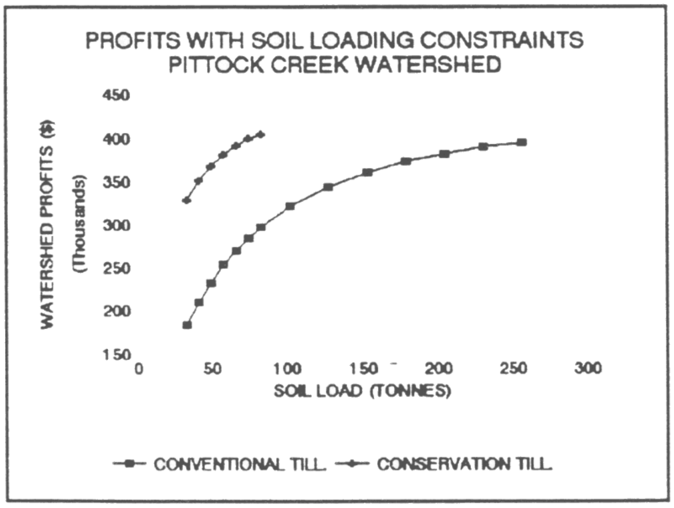


Figure 12

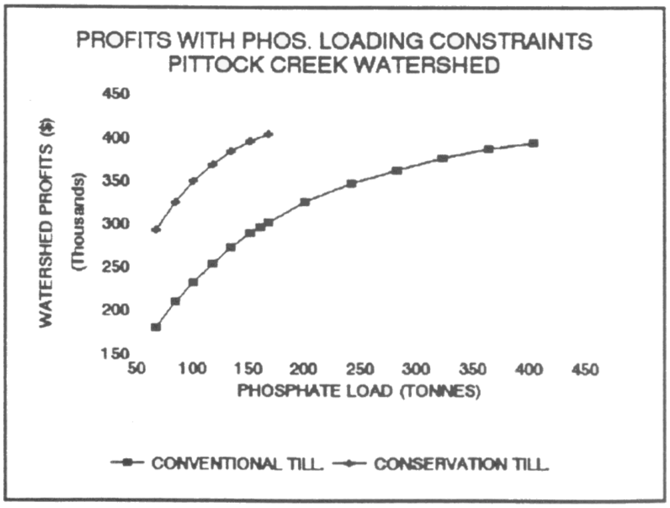


Figure 13

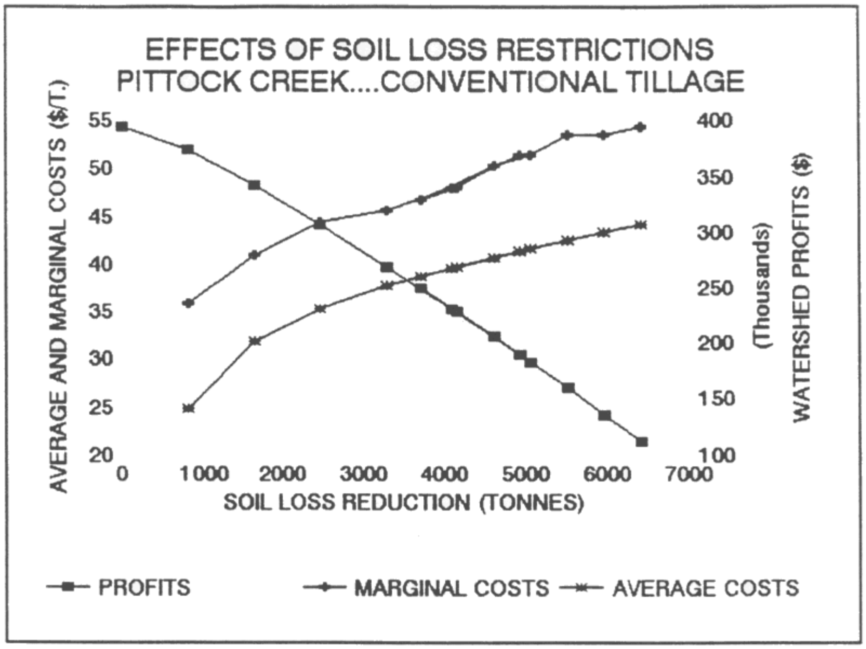


Figure 14

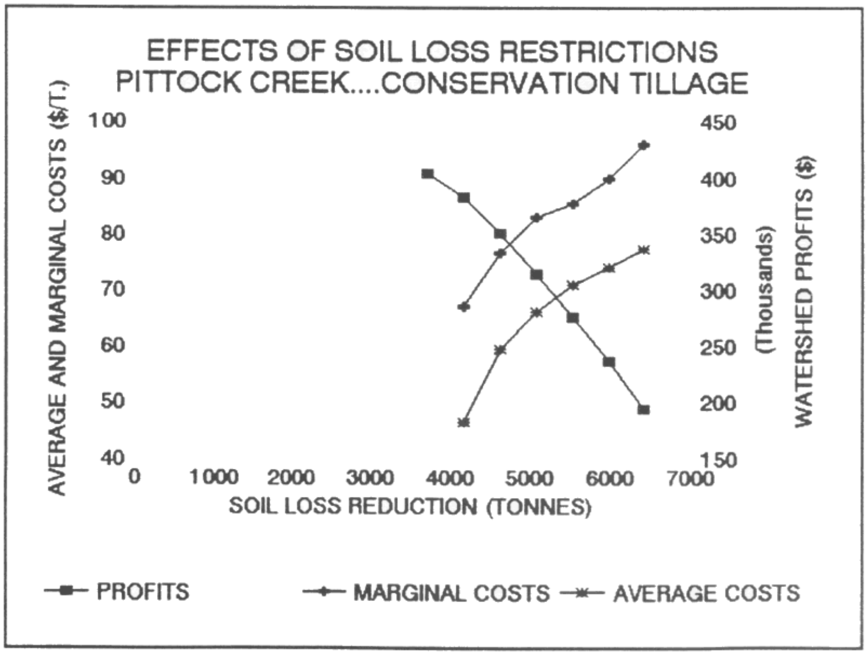


Figure 15

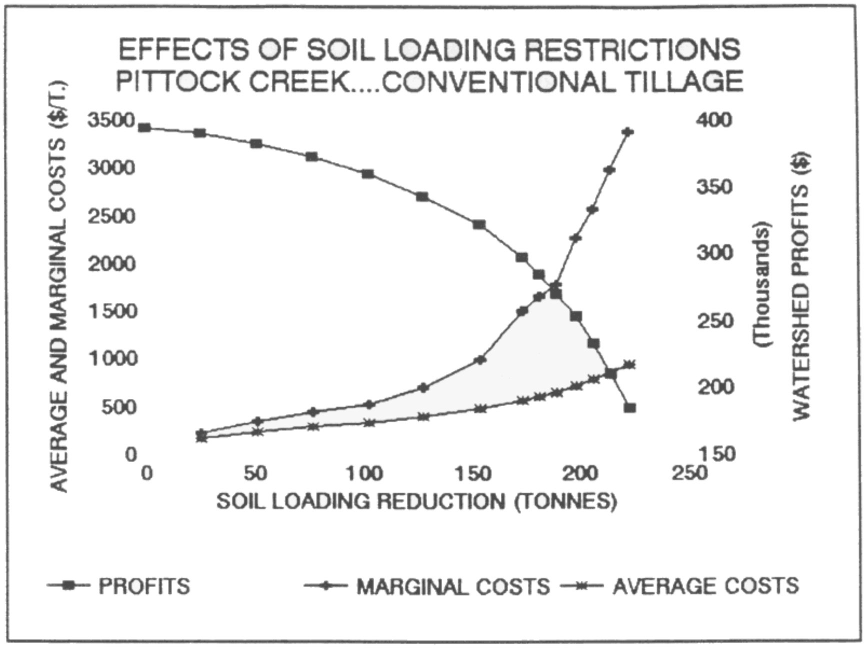


Figure 16

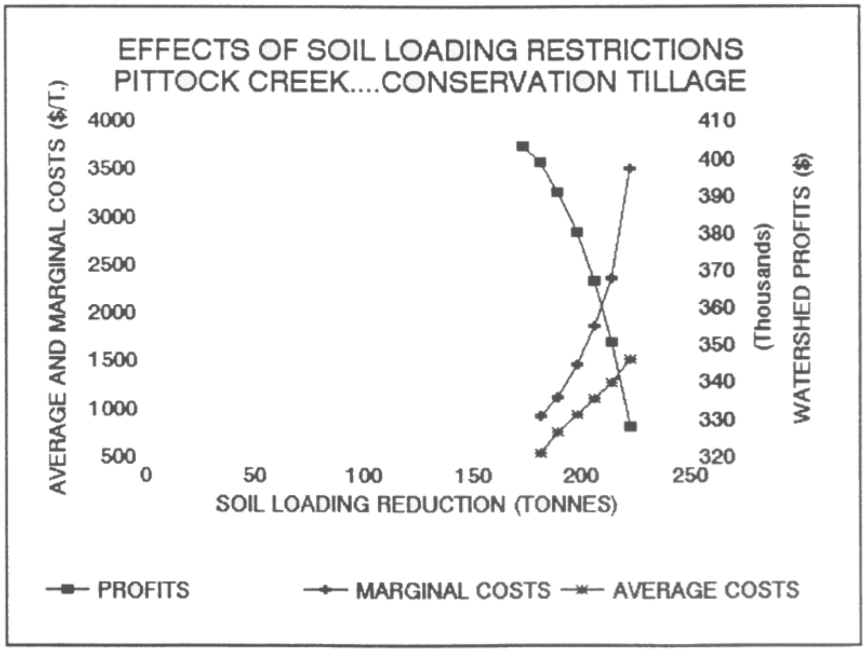


Figure 17

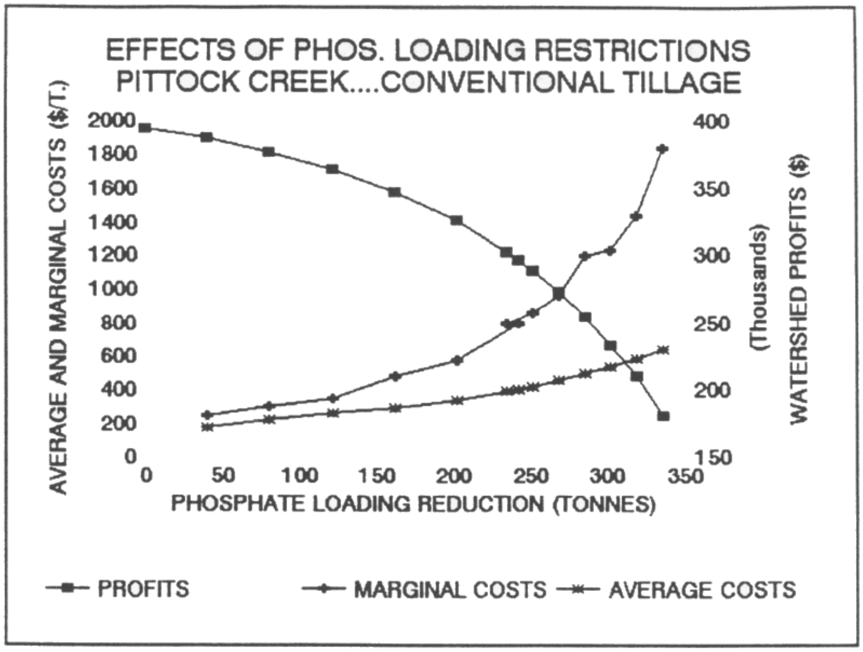


Figure 18