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AN ECONOMIC ANALYSIS OF FILTER STRIPS FOR CONTROLLING AGRICULTURAL SOIL EROSION

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1. Introduction

Soil eroded from agricultural land can cause off-farm damages as well as damages on the farm. Surface water runoff carries eroded soil into waterways where it can be transported over farm boundaries. Off-farm damages stem from reductions in surface water quality and from sedimentation as suspended soil settles out of the water. These impacts affect water based recreation, fishing, boating, navigation, municipal and industrial water treatment, flooding and other water uses.

Effective control of agricultural erosion can result in improved water quality and substantial benefits to those who use water resources. Anglers may find their fishing opportunities enhanced by greater numbers of fish and more pleasing natural environments. Municipal and industrial water facilities may face lower treatment costs in making surface water suitable for use. Reduced sedimentation in shipping channels, water storage facilities, and drainage and irrigation ditches lowers dredging costs required to maintain these facilities.

Several estimates of the economic value of erosion control benefits exist. Clark, Haverkamp and Chapman (1985) estimated that the economic value of off-farm damages is about $2.2 billion annually. Ribaudo (1986) estimated erosion control benefits for each of ten national farm production regions (FPR's). The Lake States FPR includes Michigan, Wisconsin and Minnesota. He estimated control benefits for the Lakes States region of about $186 million annually. He also reported estimates of benefits per ton of erosion controlled. For the Lakes States region each ton of erosion that is abated results in an estimated $2.87 in off-farm benefits.

The 1990 Farm Bill addressed the issue of off-farm erosion control benefits. It further identified the Great Lakes Region as a conservation priority area. Part of the farm bill legislation, the Conservation Reserve Program (CRP), included a provision for filter strips. Filter strips are vegetative strips left along waterways. The purpose of filter strips is to affect the sediment delivery ratio (SDR). The SDR is defined as the percentage of eroded soil that is actually delivered to a specified point in a waterway. Most soil is redeposited before it reaches a stream. The amount that finally reaches a stream depends on physical factors of the watershed such as slope and vegetative cover. Filter strips are designed to increase the amount of soil that is deposited on land thereby decreasing the sediment delivery ratio.

Over the years much research has focused on specific components of the soil erosion problem. Soil scientists have developed soil erosion and transport models. Biologists and fisheries scientists have worked at identifying the effects of suspended soil particles on aquatic ecosystems. Economists have developed methods to measure the value of water quality improvements. Knowledge about each component is now sufficient to attempt rudimentary linkages between them. This program uses information from a variety of sources to link application of a specific water quality improvement practice (filter strips) to off-farm economic consequences. This ability is useful in program design and analysis.

The program serves two purposes. First, it is designed as a teaching tool that demonstrates the application of economic concepts and methods to environmental problems. Second, it brings together results from several research efforts and applies them to the economic evaluation of filter strips. By changing the parameters that drive the results program users can determine the estimated economic impacts of different levels of filter strip program enrollment. The sensitivity of results to the values assigned to various parameters can also be explored. A strength of the program is that the effects of parameter changes can be instantly calculated. This frees the user to concentrate on the economics of policy application while the computer handles the mathematics.

2. The Economics of Soil Erosion Control

Erosion control practices such as filter strips may be costly. Farmers receive a per acre payment for land enrolled in the filter strip program. In addition, the costs of constructing the filter strips are borne in part by the government. Filter strips are designed to reduce sediment delivery to surface water. The costs may thus be offset by benefits associated with water quality improvement. A relevant question for policy analysis is whether the benefits of control efforts outweigh the costs. This program demonstrates the use of economic methods to determine whether a program is economically justified and, if so, how large it should be. The analysis hinges on a comparison of program costs and benefits.

A farmer bears two types of costs to enroll land in filter strips. The first is the cost of constructing and maintaining the filter strip. The second is the lost crop revenues associated with withdrawing land from production. When a farmer decides to participate in the filter strip program the first acres enrolled will be those that are least valuable for crop production. As the level of participation increases more valuable land will be enrolled and per acre costs will rise. This leads to the upward slope of the marginal cost (MC) curve of Figure 1. Marginal costs are the incremental costs associated with enrolling an additional acre in the program.

Filter strips generate both private and social benefits. Privately, farmers derive long term benefits from maintaining soil productivity. Socially, the primary benefits of filter strips are those associated with improved water quality. Recent research indicates that benefits off the farm are much greater than on farm soil productivity benefits (Colacicco, Osborn and Alt, 1989). This analysis considers only the off farm benefits.

Social benefits are depicted by the downward sloping marginal benefit (MB) curve of Figure 1. Marginal benefits are the incremental benefits associated with enrolling an additional acre in the filter strip program. The downward slope of the MB curve implies that the benefits associated with incremental improvements in water quality are greater for dirty water than for relatively clean water.

In the absence of public programs to encourage the use of filter strips farmers have very little incentive to employ them. The farmer would bear the entire cost while the benefits would be spread over all people who are affected by surface water quality. Since farmers get little benefit from filter strips they will be unwilling to expend much to construct them. However, those who realize most of the benefits of improved water quality may prefer a greater level of filter strip use. One way to encourage farmers to employ filter strips is to compensate them, in the form of publicly funded filter strip contract payments, to provide improvements in water quality. The MC and MB curves of Figure 1 can be used to define the preferred level of public involvement.

The beneficiaries of improved water quality would be willing to support enrollment to the point where marginal costs equal marginal benefits. This is the level q^* in Figure 1. To understand why this level would be chosen consider a lower level of enrollment such as q^1. At this level the marginal benefits of enrolling an additional acre (p^1) exceed the marginal costs (p^2). It would be rational for society to bear costs of p^2 to reap benefits of p^1. This argument holds for any level of enrollment below q^*. Above q^* marginal costs exceed marginal benefits.

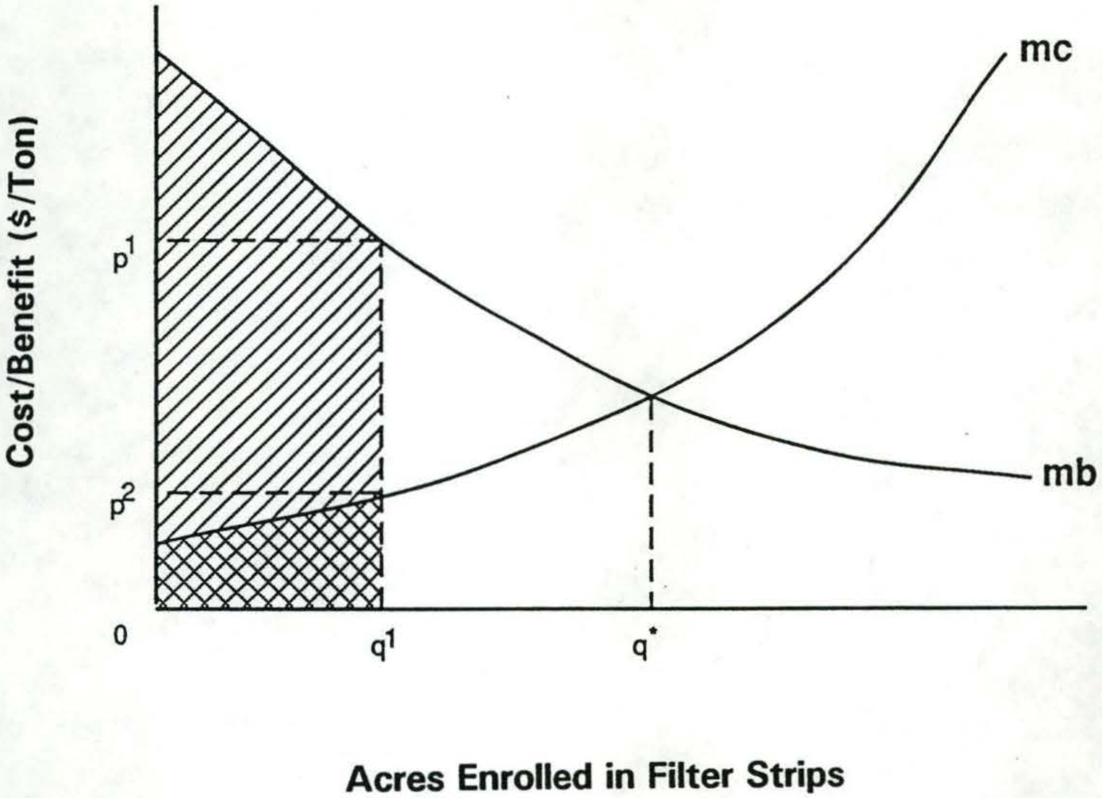
The equality of marginal costs and marginal benefits also implies maximum net benefits. Net benefits are total benefits minus total costs. Again consider the enrollment level q^1. Total benefits are given by the entire shaded area under the MB curve. Total costs are represented by the crosshatched area under the MC curve. As enrollment increases toward q^* total benefits increase faster than total costs. This implies that net benefits are increasing. At enrollment levels above q^* total costs increase faster than total benefits and net benefits decline. Thus maximum net benefits are found at enrollment level q^*. This level is also called the efficient level of filter strip enrollment.

The efficient level of enrollment depends on the position of the marginal benefit and marginal cost curves. These in turn depend on physical parameters of the watershed, the behavior of farmers in enrolling filter strips, and assumptions about the nature of benefits. For instance, the height of the marginal benefit curve depends on the proportion of eroded soil captured by filter strips and the benefits associated with each unit of captured soil. In general the greater the percent of eroded soil captured by filter strips and the greater the benefits of erosion control, the higher the marginal benefit curve. The marginal cost curve depends on the number of acres eligible for filter strips and the price at which farmers are willing to enroll them. The complex effects of parameter values on these curves is described in detail in Chapter 4.

This program sketches the marginal cost and marginal benefit curves illustrated in Figure 1. It also calculates exact numeric values corresponding to concepts illustrated by the graph. The program has two graphing options. The first option scales the horizontal axis in acres enrolled. The second considers the marginal costs and benefits of changes in the percent of eligible acres enrolled. The program allows the user to alter parameter values and quickly observe the effects of his or her choices on the position of the marginal cost and benefit curves. The efficient level of enrollment can then be compared with the level implied by the user's choice of a filter strip payment level. The marginal benefit curve shown in the program graphs differs from that of Figure 1. Research results to date do not permit estimation of changing benefits as increased amounts of sediment are controlled. The marginal benefit curve in the program is based on the assumption that benefits are the same for each ton of soil that is kept from entering streams. This assumption implies the horizontal MB curve seen in the program.

Exact numeric values corresponding to the graphs are displayed on the final screen of the parameter entry portion of the program. Marginal costs and benefits correspond to the height of the MC and MB curves at the level of enrollment implied by the filter strip payment level. Total costs and benefits correspond to the shaded areas of Figure 1 associated with the implied enrollment level. The point of maximum net benefits is the price and enrollment level defined by the intersection of the MC and MB curves.

Figure 1 - Marginal Costs and Benefits of Filter Strips



3. Using the Program

Software Requirements

The program provided with this package is a LOTUS 1-2-3 [1] worksheet. To use this worksheet you need to have a copy of LOTUS 1-2-3, version 2.0 or higher. The instructions assume that you have LOTUS 1-2-3 installed and configured for your hardware. A basic knowledge of the MS-DOS [2] or IBM-DOS [3] operating systems is also assumed.

Hardware Requirements

The program will run on any IBM compatible microcomputer running LOTUS 1-2-3, version 2.0 or higher. Since the program is distributed on a 5.25 inch, medium density floppy disk the computer should have a compatible drive installed.

Backing up Program Disks

Before you start it is recommended that you make a backup of the worksheet disk included with this package. Use the DOS copy command to copy all files on the original program disk onto a blank, formatted disk. Store your backup disk in a safe place.

Getting Started

To use the worksheet you must first load LOTUS 1-2-3. Once you are in LOTUS you need to retrieve the file named EROSION.WK1 from the program disk. To retrieve a file in LOTUS press the back slash (/) key. A menu will appear at the top of the screen. Choose FILE (F) and then RETRIEVE (R) from the bar menus at the top of the screen. At this point you will be prompted for a worksheet name. Enter the path and name for this worksheet. For instance, if the program disk is in drive A enter:

A:EROSION

Then press the **<RETURN>** key. Loading the worksheet may take a while. LOTUS will display a flashing WAIT message in the upper right corner of the screen while loading the worksheet. Once the worksheet is loaded the introductory screen shown in Figure 2 will appear. Follow the directions on screen to use the worksheet.

---

[1]LOTUS 1-2-3 is a registered trademark of Lotus Development Corp.
[2]MS-DOS is a registered trademark of Microsoft Corporation.
[3]IBM-DOS is a registered trademark of International Business Machines Corporation.

Figure 2. - Introductory Screen

```
****************************************************************
**                                                            **
**      AN ECONOMIC ANALYSIS OF SOIL EROSION CONTROL          **
**                  USING FILTER STRIPS                       **
**                                                            **
**                    Developed by:                           **
**                  Douglas J. Krieger                        **
**                  Dr. John P. Hoehn                         **
**                  Dr. Baxter Vieux                          **
**                                                            **
**                        For:                                **
**    The College of Agriculture and Natural Resources        **
**               Michigan State University                    **
**                East Lansing, Michigan                      **
**                                                            **
**                Press <RETURN> to begin                     **
**                                                            **
****************************************************************
```

Main Menu

When you press **<RETURN>** from the introductory screen as instructed the main worksheet menu shown in Figure 3 will appear. This menu has four choices and controls the flow through the worksheet. When you complete an operation you will be returned to this menu for another choice. To choose one of the operations press the corresponding number. Each menu choice is described below.

Figure 3 - Main Menu

```
****************************************************************
**                                                            **
**                        MAIN MENU                           **
**                                                            **
**              Choose a number to make a choice              **
****************************************************************
**                                                            **
**        1.    Enter Watershed Parameters                    **
**              and Calculate Physical and Economic           **
**              Values                                        **
**                                                            **
**        2.    Graph Results (Percentage)                    **
**                                                            **
**        3.    Graph Results (Acres)                         **
**                                                            **
**        4.    Exit the Program                              **
**                                                            **
****************************************************************
```

<u>Enter Watershed Parameters and Calculate Physical and Economic Values</u> - This option allows the user to alter the physical and economic parameters of the problem to determine what effect they have on the efficient level of filter strip enrollment. Each parameter is ini-

tially set at a default value that is typical for the state of Michigan or for the described watershed. Default values were chosen with the help of Soil Conservation Service agents familiar with Michigan agriculture.

When this option is chosen the first of four parameter choice screens appears. The **<PGUP>** and **<PGDN>** keys move between the four screens in this section. The **<HOME>** key allows you to return to the main menu from any screen. Each screen contains highlighted parameters that can be changed. The **<INSERT>** key moves the cursor to the these parameters and allows changes to be made. Use the cursor movement keys (arrows) to move among the highlighted parameters. As parameters are changed the effect on the calculated values will be displayed immediately. After using **<INSERT>** to edit parameters the **<RETURN>** key must be pressed to return the cursor to the bottom of the screen.

There are four types of values displayed by the program in the Watershed Parameter screens.

1. **Entered Values** are the parameters you can change. These are always highlighted.
2. **Suggested Values** are suggested parameter values that are consistent with the chosen watershed parameters. These values represent typical conditions for Michigan for the size of watershed chosen. You can use these suggested values or enter your own.
3. **Range** displays the allowable range for entered paramters when applicable.
4. **Calculated Values** are values calculated by the program for the described watershed.

Complete descriptions of each parameter and calculation can be found in section four titled **Reference to Program Operations**. The parameter entry screens with selected defaults are reproduced at appropriate points in the following text.

<u>Graph Results (Percentage)</u> - This option displays the marginal cost and benefit curves determined from the existing parameter set. Enrollment is represented in terms of the percentage of eligible land enrolled. The intersection of the marginal cost and marginal benefit curve represents the efficient level of erosion control. The corresponding percentage enrollment and marginal cost/benefit match those found on screen four of the editing operation. By locating the enrollment level implied by the chosen payment level you can observe the relationship between costs and benefits at that point relative to the point of maximum net benefits. Press the **<RETURN>** key to return to the main menu from the graph option.

<u>Graph Results (Acres)</u> - This option displays the marginal cost and benefit curves determined from the existing parameter set. Enrollment is represented in terms of total acres enrolled. The intersection of the marginal cost and marginal benefit curve represents the efficient level of erosion control. The corresponding acreage enrolled and marginal cost/benefit match those found on screen four of the editing operation. By locating the enrollment level implied by your chosen payment level you can observe the relationship between costs and benefits at that point relative to the point of maximum net benefits. Press the **<RETURN>** key to return to the main menu from the graph option.

<u>Exit the Program</u> - This option exits the program and LOTUS and returns the user to DOS.

4. Reference of Program Operations

Erosion

The rate of erosion depends on watershed characteristics, land use, and management factors. These include, rainfall energy, soil erodibility, cropping management, erosion control practices, and the slope and length of slope. The relationship between these factors is formalized in the Universal Soil Loss Equation (USLE). This worksheet employs the USLE to determine erosion rates based on entered watershed parameters. The USLE is estimated in metric units. Values in this worksheet are entered in english units and the program converts to metric units where necessary.

Screen One

```
CALCULATING EROSION USING THE UNIVERSAL SOIL LOSS EQUATION (UALE)
-----------------------------------------------------------------
                                Entered            Calculated
Parameter                        Values    Range     Values     Units
-----------------------------------------------------------------
Rainfall energy factor (R)         100    20 - 350              tons/acre
Soil erodibility factor (K)        0.4     0 -1
Cropping management factor (C)    0.4     0 -1
Erosion control practice (P)       .45     0 -1
Predominant slope (S)              1.5     0 -18                percent
Predominant slope length (L)       40                           yards
Watershed size                     500                          acres
   Erosion rate                                        1.37     tn/ac/yr
   Gross erosion                                        686     tons
-----------------------------------------------------------------

<HOME> -> main menu; <PGDN> -> next screen; <INS> -> edit
```

Rainfall Energy Factor - The rainfall energy factor (R) describes the erosive potential of rainfall. There is considerable regional and seasonal variation in the rainfall energy factor. Nationally, the magnitude of the factor varies from 20 to 350 tons/acre. The higher the factor the greater the erosive potential of rainfall. In Michigan the average annual rainfall energy factor is 100 tons/acre.

Soil Erodibility Factor - The soil erodibility factor (K) measures the erosion potential of particular soil types. It ranges in magnitude from zero to one. Soil erodibility factors can be calculated from five soil parameters, (1) percent silt and fine sand, (2) percent sand, (3) percent organic matter, (4) textural class, and (5) permeability. Based on these five factors typical values for the soil erodibility factor are given in Table 1.

Cropping Management Factor - The cropping management factor (C) accounts for the effects of ground cover conditions, soil conditions and general management practices on the erosion rate. It ranges in value from zero to one. Table 2 displays values of the cropping management factor for a variety of land uses.

Table 1 - Magnitude of Soil Erodibility Factor (K)

	K for organic matter content (%)		
Textural class	<0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.27	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13 - 0.2	

Source: Novotny, Vladimir and Gordon Chesters, *Handbook of Nonpoint Pollution: Sources and Management*, Van Nostrand Reinhold Company, 1981, pp. 180.

Table 2 - Cropping Management Factor Values

Land Cover or Land Use	Cropping Management Factor
Continuous fallow tilled up and down slope	1.0
Shortly after seeding or harvesting	0.3 - 0.8
For crops during main part of growing season	
Corn	0.1 - 0.3
Cotton	0.05 - 0.15
Soybeans	0.2 - 0.3
Meadow	0.01 - 0.02
For permanent pasture, idle land, unmanaged woodland	
Ground cover 95 - 100%	
As grass	0.003
As weeds	0.01
Ground cover 80%	
As grass	0.01
As weeds	0.04
Ground cover 60%	
As grass	0.04
As weeds	0.09
For managed woodland	
Tree canopy of 75 - 100%	0.001
40 - 75%	0.002 - 0.004
20 - 40%	0.003 - 0.01

Source: Novotny, Vladimir and Gordon Chesters, *Handbook of Nonpoint Pollution: Sources and Management*, Van Nostrand Reinhold Company, 1981, pp. 182.

Table 3 - Erosion Control Practice Factors for Agricultural Treatments

		Strip Cropping and Terracing	
Slope	Contouring	Alternate meadows	Closegrown crops
1.1-2.0	0.6	0.30	0.45
2.1-7.0	0.5	0.25	0.40
7.1-12.0	0.6	0.30	0.45
12.1-18.0	0.8	0.40	0.60
18.1-24.0	0.9	0.45	0.70

Source: Novotny, Vladimir and Gordon Chesters, *Handbook of Nonpoint Pollution: Sources and Management*, Van Nostrand Reinhold Company, 1981, pp. 184.

Erosion Control Practice - The erosion control practice factor (P) reflects the erosion control effectiveness of various soil conservation practices. Values of the erosion control practice factor for various farm practices are displayed in Table 3. Values of P for agriculture are generally smaller than one. For some construction practices, however, the value of P can be as high as 1.3.

Predominant Slope - This parameter refers to the predominant slope (S) of the land in the watershed. Slope is measured as a percentage which is calculated as:

(rise/run) x 100 = slope

Thus a field with a run of 100 yards and a vertical rise of 10 feet would have a slope of:

(10 feet/300 yards) x 100 = 3.33 percent

This worksheet allows only one slope parameter in the watershed. More detailed models divide the watershed into areas of equal slope and calculate erosion for each area separately. For illustrative purposes, however, this worksheet assumes equal slope over the entire watershed. The relationship between slope and erosion was originally calculated from data obtained on fields with a slope of less than 18 percent. **Using slopes of greater than 18 percent extrapolates beyond the estimated function and is not recommended.**

Predominant Slope Length - The predominant slope length (L) refers to the most common length of a slope before it changes or ends in a watercourse. Slope lengths of less than 109 yards were originally used to calculate the relationship between slope length and erosion. **Using lengths of over 109 yards extrapolates beyond the estimated function and is not recommended.**

Watershed Size - Watershed size is entered in acres. Factors such as predominant slope can vary considerably over a large watershed. This worksheet assumes a constant slope over the entire watershed. Suggested values calculated by the program are also estimated from small watersheds. **Using the program to analyze watersheds over 1,000 acres is not recommended.** A large watershed can be analyzed by breaking it up into smaller areas that are relatively homogneous with respect to the various factors that influence erosion (*i.e.* slope, cropping practices, etc.).

Erosion Rate - The rate of erosion is the tons of soil eroded per acre on an annual basis. The model used in this worksheet employs the Universal Soil Loss Equation (USLE) to estimate the erosion rate. The USLE can be stated as:

$$A = (R)(K)(LS)(C)(P), \tag{1}$$

where: A = annual soil loss in tonnes per hectare (converted to tons per acre in the program)
R = rainfall energy factor
K = soil erodibility factor
LS = slope-length factor
C = cropping management factor
P = erosion control practice factor.

This formulation estimates only soil lost to rainfall. Wind erosion is not estimated. The equation also does not estimate soil loss due to erosive effect of surface water runoff (*i.e.* gullies).

Each of the parameters in the USLE are entered directly into the worksheet with the exception of the LS parameter. The worksheet calculates the LS value from the entered values for Predominant Slope and Predominant Slope Length. The LS is defined as:

$$LS = L^{.5}(0.0138 + 0.00974\ S + 0.00138\ S^2). \tag{2}$$

As an example of calculating the erosion rate consider a watershed with the following attributes:

R = 100 tons/acre = 224 tonnes/hectare
K = .4
L = 40 yards = 36.7 meters
S = 1.5 percent
C = .4
P = .45.

The slope-length factor is given by:

$$\begin{aligned} LS &= (36.7)^{.5}\ [0.0138 + 0.00974\ (1.5) + 0.00138\ (1.5)^2] \\ &= 6.058\ [0.0138 + .0146 + .0031] \\ &= .1908. \end{aligned}$$

The erosion rate is given as:

$$\begin{aligned} A &= (224)\ (.4)\ (.1908)\ (.4)\ (.45) \\ &= 6.83 \text{ tonnes/hectare/year} = 1.37 \text{ tons/acre/year}. \end{aligned}$$

Gross Erosion - Gross erosion is the total erosion in the watershed. It is a function of the rate of erosion as calculated from the USLE and the size of the watershed. Using the example above for a watershed of 500 acres yields the following gross erosion estimate:

(1.37 tons/acre/year) (500 acres) = 686 tons/year.

Sediment Delivery Ratio

The sediment delivery ratio (SDR) is the proportion of upland erosion that eventually reaches the watershed outlet. These two quantities may not be the same because of redeposition between the source of erosion and the outlet. Factors affecting the sediment delivery ratio include, (1) the source of sediment, (3) climatic factors, (3) texture of the eroded material, (4) environments of redeposition, and (5) watershed characteristics.

For plausible results these parameters should be consistent with the watershed characteristics that determine erosion rates. The program thus calculates values for stream length, stream relief, and the bifurcation ratio based on watershed size. Ranges for these values are shown in the column titled **Suggested Values**. The relationships were derived from regression analysis based on an examination of maps of Michigan agricultural areas. The presented values represent state averages. The ranges reflect 90% confidence intervals for the parameters.

The factors affecting sediment delivery are not well understood. Thus there is much uncertainty about the calculated sediment delivery ratio (SDR). The program uses the values entered for stream length, stream relief, and bifurcation ratio to calculate a suggested SDR. This suggested value is displayed in the column titled **Suggested Values**. This value can be entered as the one used by the program or another value can be chosen. **The SDR is negatively related to watershed size. For large watersheds the suggested value of the SDR may be zero.**

Screen Two

```
         CALCULATING THE SEDIMENT DELIVERY RATIO (SDR)
--------------------------------------------------------------
                             Entered  Suggested Calculated
Parameter                    Values    Values    Values     Units
--------------------------------------------------------------
Stream length (L)               .93   0.3 - 1.6             miles
Stream relief (R)             10.93   0.0 - 21.9            feet
Bifurcation ratio (BR)         1.50   1.0 - 1.5
   Sediment delivery ratio    47.65   47.65                 percent

   Sediment delivered                               327     tons
--------------------------------------------------------------



--------------------------------------------------------------
 <HOME> -> main menu; <PGUP> -> previous screen; <PGDN> -> next
               screen; <INSERT> -> edit
```

Length of Stream - The length of the stream refers to the distance from the point where sediment enters the stream to the point where sediment loads are measured. Stream length is entered in miles. The suggested stream length values are derived from a regression equation based on stream length and watershed size observations in Michigan. The equation is

Length of Stream = .00186 x Watershed size (acres).

The displayed range is calculated using a standard deviation of .337 miles and a 90% confidence interval.

Relief of Stream - The relief of the stream is the difference in vertical elevation between the point where sediment enters the stream and the point of sediment measurement. Stream relief is entered in feet. The suggested stream relief values are derived from a regression equation based on stream relief and watershed size observations in Michigan. The equation is

Stream Relief = .017443 x Watershed size (acres)

The displayed range is calculated using a standard deviation of .278 feet and a 90% confidence interval.

Bifurcation ratio - The bifurcation ratio is the ratio of the number of streams in the watershed of any given order to the number in the next higher order. The suggested bifurcation ratio values are derived from a regression equation based on bifurcation ratio and watershed size observations in Michigan. The equation is

Bifurcation Ratio = .00079 x Watershed size (acres)

The displayed range is calculated using a standard deviation of .077 and a 90% confidence interval.

Sediment Delivery Ratio - Roehl (1962) developed the model of sediment delivery employed in the program. The log-log specification is:

$$\log DR = 3.59253 - 0.23043 \log W + 0.51022 \log R/L - 2.78594 \log BR, \quad (3)$$

where: DR = the delivery ratio in percent
W = watershed area in square kilometers (acres are entered in the worksheet)
R = stream relief
L = stream length
BR = bifurcation ratio.

As an example consider a 500 acre (2.023 square kilometers) watershed with the following characteristics:

L = .93 miles = 4,910 feet
R = 10.93 feet
BR = 1.5

The relief-length ratio is:

R/L = 10.93 feet / 4,910 feet = .00223

The sediment delivery ratio calculated for this watershed is:

$$\begin{aligned}
\log DR &= 3.59253 - 0.23043(\log 2.023) + 0.51022(\log .00223) - 2.78594(\log 1.5) \quad (4)\\
&= 3.59253 - 0.23043(3.06) + 0.51022(-2.6517) - 2.78594(.17609)\\
&= 1.678\\
DR &= 10^{1.678} = 47.70 \text{ percent.}
\end{aligned}$$

This implies that 47.7 percent of upland erosion in this watershed reaches the watershed outlet .93 miles downstream from the point where sediment enters the stream.

When changes are made to the three parameters that determine the SDR the change in the calculated SDR value is immediately displayed in column titled **Suggested Values**. If you choose to use the suggested values the suggested SDR will be used. If you wish to use a different SDR value it must be entered in the **Entered Values** column.

Gross Sediment Delivered - Gross sediment delivered to the stream outlet is the amount of gross upland erosion multiplied by the sediment delivery ratio. For the example above this would be:

(686 tons/year) (.4770) =327 tons/year.

Filter Strips

Filter Strip Efficiency - Filter strip efficiency refers to the percentage of eroded soil intercepted by the filter strip. Filter strip efficiency is measured as a percent. If 100 tons of soil enters the filter strip and 65 tons moves through the filter strip and enters the waterway then the filter strip efficiency is 35 percent. Filter strip efficiency has been reported to be around 54 percent in Indiana. Realistically, efficiencies are probably lower than this figure on average.

Screen Three

```
        CALCULATING THE IM[ACTS OF THE FILTER STRIP PROGRAM
-----------------------------------------------------------------
                                Entered  Suggested Calculated
Parameter                       Values    Values    Values    Units
-----------------------------------------------------------------
ECONOMICS OF FILTER STRIPS
  Filter strip efficiency       33                            percent
  Filter strip payments         54.00                         $/acre
  Acres eligible                14.88     14.88               acres
     Percent acres enrolled                         34.63     percent
     Acres enrolled                                  5.15     acres

PHYSICAL IMPACT OF FILTER STRIPS
     Sediment delivered without FS                      327 tons
     Sediment delivered with FS                         290 tons
     Sediment abated                                     37 tons
-----------------------------------------------------------------
<HOME> -> main menu; <PGUP> -> previous screen; <PGDN> ->
        next screen;  <INSERT> -> edit
```

Filter Strip Payments per Acre - Filter strip payment per acre measures the annual per acre payment to farmers to enroll land in filter strips. Average per acre payments across farm production regions (FPR's) in 1988 ranged from \$44.49 to \$71.73 with an average payment across all FPR's of \$54.22 per acre. The default value used in this worksheet is \$54.00.

Acres Eligible for Filter Strips - Land eligible for filter strip enrollment must meet four requirements.

1. The land must have been planted to agricultural commodities in at least two of the past five crop years.
2. The land must be in physical condition for continued crop management.
3. The land must be located adjacent and parallel to a continually flowing stream, creek, or river; a seasonal stream that flows only during a portion of the year (excluding gullies and grass waterways); or a lake or other permanent body of water, including wetlands, with a surface area of at least five acres.
4. The land, with the aid of a filter strip, must be capable of reducing the delivery of sediment to a stream or water body.

Filter strips must be no less than 66 feet and no more than 99 feet wide. The area eligible for filter strips is calculated by multiplying the length of the strip by its width at the narrowest point.

Eligible area is calculated in acres based on the total length of streams in the watershed. Total stream length is estimated from the watershed size. Filter strips are assumed to be 66 feet wide. Thus for each mile of stream (both sides) there will be:

2 x (66 feet) x (5,280 feet/mile) = 696,960 square feet/mile of stream.

There are 43,560 square feet in an acre, so there are:

(696,960 square feet/mile) / (43,560 square feet/acre) = 16 acres/mile of stream.

The watershed described in this example has .93 miles of stream and 14.88 acres eligible for filter strips.

Percent Acres Enrolled - The percent of acres enrolled is a function of the per acre payment made to farmers. This function is taken from the work of Purvis (1989). Purvis estimated a relationship between per acre filter strip payments and the percent of eligible acres enrolled for Southeast Michigan. Her estimated function was:

Percent acres enrolled = -45.097 + 19.986 ln (payment),

For a \$54 per acre payment the percent of eligible acres enrolled would be:

-45.097 + 19.986 ln (54)
-45.097 + 19.986 x (3.807)
=34.63 percent.

Acres Enrolled - The acres actually enrolled is the percent of eligible acres enrolled multiplied by the total number of eligible acres. For the watershed described here with 14.88 acres eligible for filter strips the number of acres enrolled is:

(14.88 acres) x (.3463) = 5.15 acres.

Physical Impact of Filter Strips

Sediment Delivered without Filter Strips - Sediment delivered to the outlet point without filter strips is calculated by applying the sediment delivery ratio to gross erosion. This figure is the same as that calculated in the previous screen.

Sediment Delivered with Filter Strips - Filter strips intercept soil that would otherwise enter a waterway. This amounts to a reduction in the amount of sediment delivered to the stream outlet. Thus, filter strips are modeled in the program as reducing the sediment delivery ratio. However, they affect sediment delivery only where they are applied. The total sediment delivered with filter strips in place is the sum of sediment from both land covered by filter strips and land that is not covered by strips.

This program assumes a direct relationship between the percentage of eligible acres enrolled in filter strips and the percentage of runoff that passes through filter strips. For example, if 29 percent of eligible land is enrolled, then the same percentage of total runoff is assumed to pass through a filter strip.

This program calculates the sediment delivered with filter strips by adjusting sediment delivery for, (1) acres covered by filter strips and, (2) filter strip efficiency. This is given by:

(Sediment delivered w/o strips) x (1 - (% acres covered) x (strip efficency))
= 327 x (1 - (.3463 x .33))
= 290 tons.

Sediment Abated by Filter Strips - The sediment abated by filter strips is merely the difference between sediment delivered with and without filter strips. For this example this is given by:

327 tons - 290 tons
= 37 tons abated.

Filter Strip Benefits

Erosion Control Benefits per Ton - Ribaudo (1986) estimated that off-farm erosion control benefits in the Lakes States region amounted to $2.87 per ton. These benefit values are in 1983 dollars. In 1990 dollars benefits per ton are $3.80. Ribaudo arrived at this figure by dividing total regional erosion by estimated off-farm benefits. While the use of this figure entails some simplifying assumptions about marginal benefits, it does provide a preliminary estimate of regional off-farm erosion control benefits.

Sediment Abated - The sediment abated value is taken directly from the previous screen.

Total Benefits of Filter Strips - The total benefits of filter strips are given by the benefits per ton of sediment abated multiplied by the quantity abated. For the example used here this is:

($3.80) x (37 tons) = $141.94.

Screen Four

```
      TOTAL AND MARGINAL VALUES AT    54 DOLLARS PER ACRE
------------------------------------------------------------------
                                    Entered      Calculated
Parameter                            Values        Values       Units
------------------------------------------------------------------
Erosion control benefits per ton     3.8                        dollars
   Sediment abated                                    37        tons
   Total benefits of FS                           141.94        dollars
   Total program costs of FS                      138.64        dollars
   Net benefits of FS                               3.30        dollars

   Marginal costs of enrolling an acre             55.02        dollars
   Marginal benefit of enrolling an acre           27.55        dollars

MAXIMUM NET BENEFITS OCCUR AT...
   Marginal cost/benefit                           27.55        dollars
   Percent eligible land enrolled                  21.17        percent
   Acres enrolled                                   3.15        acres
------------------------------------------------------------------
<HOME> -> main menu; <PGUP> -> previous screen; <INSERT> ->edit
```

Total Program Costs of Filter Strips - The total program costs of filter strips are the total payments required to enroll the percentage of land actually enrolled. Enrollment is an increasing function of payment level. The total program cost is given by the area under the marginal cost curve. For this example with 14.88 percent of eligible land enrolled the total cost is $138.64. This is the area under to marginal cost curve and is not equal to per acre payments multiplied by acres enrolled.

Net Benefits of Filter Strips - The difference between program costs and benefits represents the net benefits of the filter strip program. For example, for the total costs and benefits given above, net benefits are:

$141.94 - $138.64 = $3.30.

Marginal Costs and Benefits

Marginal Costs of Enrolling an Acre - Purvis's results indicate a positive relationship between filter strip payment level and the percentage of eligible land enrolled. This implies that as the percentage enrolled rises so does the cost of enrolling an additional acre. The marginal cost of enrolling an acre is the payment required to bring one more acre into the filter strip program. The marginal cost of enrollment is approximately the given payment level.

Marginal Benefit of Enrolling an Acre - In this simplified analysis benefits are based on a constant measure of benefits per ton of erosion controlled. It is also assumed that each acre enrolled results in the abatement of the same quantity of eroded soil. The benefits associated with enrolling an acre are thus the same for every acre enrolled. This implies that the marginal benefits are constant and can be calculated as total benefits divided by acres enrolled. For the example used here this becomes:

(Total benefits)/(acres enrolled)
= 141.94 dollars / 3.15 acres
= 27.55 dollars/acre.

Maximum Net Benefits

Marginal Cost/Benefit - Maximum net benefits are defined where marginal cost equals marginal benefit. Marginal benefit in this simplified example is constant and given by the average benefit per acre. At the point of maximum net benefits marginal benefit is equal to marginal cost.

Percent Eligible Land Enrolled - The percent of eligible land enrolled refers to the level of enrollment at the point of maximum net benefits. This level may not be the same as that determined from the entered per acre filter strip payment. The marginal cost at the point of maximum net benefits is approximately equal to the per acre payment required to enroll enough land to equate marginal costs and benefits. This marginal cost, or per acre payment, is already known. The percentage of eligible land enrolled to achieve maximum net benefits is thus calculated from the results of Purvis. For this example this becomes:

$-45.097 + 19.986 \ln$ (marginal cost per acre)
$-45.097 + 19.986 \ln (27.55)$
$-45.097 + 19.986 \times (3.32)$
$= 21.17$ percent.

Acres Enrolled - Acres enrolled at the point of maximum net benefits is the total acres eligible multiplied by the percentage enrolled as determined above. For this example this is:

(total eligible acres) x (percent acres enrolled)
= 14.88 acres x .2117 = 3.15 acres.

Quick Reference

Starting the Program - To start the program enter LOTUS 123 [4] and retrieve the file titled EROSION. After a moment an introductory screen will appear. Press **<RETURN>** to advance to the main menu.

Main Menu - The main menu controls the flow of the program. Upon completion of any operation you will be returned to the main menu to choose another operation. The choices provided in this menu are:

1. Enter Watershed Parameters and Calculate Physical and Economic Values
2. Graph Results (Percentage)
3. Graph Results (Acres)
4. Exit the Program

To choose one of these operations press the corresponding number. Each menu choice is described below.

Enter Watershed Parameters and Calculate Physical and Economic Values - When this option is chosen the first of four parameter choice screens appears. The **<PGUP>** and **<PGDN>** keys move between the four screens in this section. The **<HOME>** key allows you to return to the main menu from any screen. Highlighted numbers on each screen are parameters that you can change. To edit parameters press **<INSERT>**. The cursor will then move to the highlighted cells. When editing is completed press **<RETURN>** to move the cursor to the bottom of the screen. The column labeled **Calculated Values** contains values that are calculated from the parameters. As parameters are changed the effect on the calculated values will be displayed immediately. These values are based on typical conditions in Michigan and are suggested values for the associated parameters.

Graph Results (Percentage) - This option displays the marginal cost and benefit curves determined from the existing parameter set. Enrollment is represented in terms of the percentage of eligible land enrolled. Press the **<RETURN>** key to return to the main menu from the graph option.

Graph Results (Acres) - This option displays the marginal cost and benefit curves determined from the existing parameter set. Enrollment is represented in terms of total acres enrolled. Press the **<RETURN>** key to return to the main menu from the graph option.

Exit the Program - This option exits the program and LOTUS and returns the user to DOS.

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[4] LOTUS 1-2-3 is a registered trademark of Lotus Development Corp.

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