THE OHIO STATE UNIVERSITY EXTENSION

Department of Agricultural, Environmental,
and Development Economics
Natural Resource and Environmental Economics
Research News
November, 1998

BENEFITS OF CONTROLLING SOIL EROSION IN THE MAUMEE RIVER BASIN

Brent Sohngen and Jonathan Rausch

The Maumee river basin drains approximately 4.2 million acres in northwest Ohio, northeast Indiana, and southeast Michigan. Within the basin, 3.1 million acres (75%) are predominately in row crop agriculture. Northwest Ohio contains 2.4 million acres (78%) of all agricultural land in the basin. Using the Universal Soil Loss Equation, annual soil loss from cropland has been estimated at 7.4 million tons for the entire basin. This amounts to average total soil loss from agriculture of 2.39 tons per acre per year.

Additional soil erosion in the Maumee river basin arises from streambank, geologic, gully, and urban erosion. Total soil erosion in the basin from all sources is estimated to be 10.3 million tons per year. Estimates of the disposition of soil erosion suggests that 83% of gross erosion remains in farm fields, 5% ends up in drainage ditches, 5% is deposited in the shipping channel in the Toledo Harbor, and 8% is deposited elsewhere in Lake Erie.

Because soil erosion has economic costs for water users downstream, it is possible to estimate the benefits of reducing soil erosion in the basin. This report presents estimates for three different downstream activities: harbor dredging, water treatment, and drainage ditch maintenance.

The Toledo harbor is a federal navigation channel, and the Army Corps of Engineers spends an average of $3.4 million each year dredging 468,000 tons of sediments in the harbor. Nearly 50% of dredged material must be confined due to suspected health hazards associated with contamination. Although the remaining material is disposed with open lake dumping, the Environmental Protection Agency has issued an order that all sediments must be confined after 1999.

Confining materials is an expensive proposition. Under current dredging rates and assuming no future open lake dumping, a new 20-year facility will need to be built after the turn of the century at a cost of nearly $100 million dollars. Avoiding or reducing this expenditure can provide substantial benefits for the U.S. Army Corps of Engineers. We estimate that the benefits of reducing dredging to be $0.87 per ton of reduced gross soil erosion. A 15% reduction in total gross soil erosion in the basin would reduce dredging and confining costs by $1.3 million per year.

Turning to water treatment plants, there are 17 such facilities in the basin in Ohio, serving approximately 230,000 people. Because the costs of water treatment depend on the amount of sediment in the water, these plants would benefit from reduced soil erosion. Estimates suggest that these benefits are approximately $0.05 per ton of gross soil erosion.

Soil erosion also affects the approximately 3000 miles of drainage ditches used by agricultural producers in the basin. Reducing soil erosion would reduce the annual maintenance costs for keeping these waterways free from debris and sediments. Estimates suggest that these benefits are $0.15 per ton of gross soil erosion.

Combining the three suggests that the benefits of reducing soil erosion are $1.07 per ton. Assuming a delivery ratio of 18% (sediments that actually enter the water), each ton of delivered sediments that can be kept on the land rather than allowed to enter the water creates a benefit of $5.94 downstream. While these benefits would not accrue directly to farmers, society would gain if soil erosion were reduced.

These estimates can be used by landowners to determine how reducing soil erosion would benefit society. An example using Hoytville-Nappanee-Blount soils is shown in table 1.

Conventional tillage and three alternative methods for reducing soil erosion -- conservation tillage, no tillage, and forested filter strips-- are shown. The first row presents the proportional reduction in soil erosion that arises when the practice is installed on a 50 acre field. Row 2 presents average annual soil erosion per acre, and row 3 is the total gross erosion for the field.

Row 4 presents the amount of sediments that move offsite (18% of annual gross erosion). The 5th row is the damage caused by this erosion moving offsite, which can be calculated as ($5.94 times Sediment Moving Offsite). Row 6 is the annual benefit of the three alternatives relative to conventional tillage methods, and row 7 provides the benefits per acre (row 6 divided by 50 acres).

While all three alternatives provide benefits relative to conventional tillage, forested filter strips provide the largest potential benefit. Forested filter strips reduce soil erosion entirely on 2.5 of the acres in the field, and they are 80% effective at keeping soil on the land over the remaining 47.5 acres.

The damages caused by soil erosion are small compared to the overall cash rents received by farmers. They are measureable, however, and when considered in total, they can be large. Farmers who are willing to adopt conservation tillage and filter strips can help reduce these downstream impacts.

For additional information on this and related research, please see:

http://www-agecon.ag.ohio-state.edu/Faculty/bsohngen/default.htm

Table 1: Comparison of conventional, conservation, no tillage, and forested filter strip sediment control on a 50 acre field of Hoytville, Nappanee, Blount soils in the Maumee river basin.

	Conventional Tillage	Conservation Tillage	No Tillage	2.5 acre Forest Filter Strip
(1) Reduction in soil erosion	0.00	0.50	0.68	0.80
(2) Annual Soil Erosion (tons/acre)	2.49	1.25	0.80	2.38
(3) Annual Gross Soil Erosion (tons for field)	125	63	40	119
(4) Annual Offsite Sediments (tons from field)	22.5	11.3	7.2	4.3
(5) Annual Damages (dollars for the field)	$ 133.75	$ 67.41	$ 42.80	$ 25.54
(6) Annual Benefit	--	$ 66.34	$ 90.95	$ 108.21
(7) Annual Benefit per acre	--	$ 1.33	$ 1.82	$ 2.16

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Department of Agricultural, Environmental,
and Development Economics
Natural Resource and Environmental Economics
Research News
September, 1998

THE COSTS OF RIPARIAN FOREST FILTER STRIPS FOR SOIL EROSION CONTROL

Megumi Nakao and Brent Sohngen

Economic estimates suggest that nearly $1.3 million in annual dredging and confining costs could be avoided by reducing soil erosion on farmland in the Maumee river basin. Unfortunately, little information exists to compare this benefit to the costs of soil conservation. This article reports on recent research into the costs of installing forested riparian filter strips along streams and drainage ditches in the Maumee river basin.

Because filter strips require owners to remove land from production, high land opportunity costs often discourage their adoption. When the potential for filter strips to remove sediments from run-off is considered along with land opportunity costs, however, the costs of filter strips in some soil types do not differ dramatically from the costs of conservation tillage. These costs, however, are likely to vary across the Maumee river basin in relation to soil characteristics, land opportunity costs, slope, drainage area, soil erosion rate, and the tillage system used on a field. When these factors are considered, it is possible to target financial cost share assistance to the lowest cost regions.

Because filter strips are installed for long periods of time (or even permanently), net present value analysis is used in this analysis. Only the private benefits for landowners are considered here, which include future harvesting of mature timber. Costs include establishment, maintenance, and land rent. Land rent is calculated from a sample of data from 334 land sales in 6 counties in northwest Ohio during 1996 and 1997.

Costs for reducing soil erosion with forested filter strips in 14 major soil associations in the basin are compared to costs for converting to conservation tillage in Table 1. Filter strip costs are calculated for representative 50 acre fields with 50' filter strips ranging from 60% to 95% effective at removing sediments. The filter strips are assumed to be composed of three zones: Unmanaged forest next to the stream, managed forest, and a grass area next to the field.

Table 1 shows that filter strip costs will vary dramatically across a large basin, even one like the Maumee river basin which is considered to be fairly homogeneous. Costs in the 95 % effectiveness case are nearly as low as those for conservation tillage, suggesting that filter strips can be a low cost alternative in many regions.

The study also explores how specific site characteristics affect costs. The most important site characteristic is the existing tillage system. Filter strips are found to be more expensive when the existing tillage system is "no till," as opposed to "conventional tillage," as shown in Table 2. Because no-till reduces gross soil erosion on a site below conventional tillage, filter strips on no till sites have a small incremental impact on reducing soil erosion. It is consequently more expensive to implement filter strips along fields that already use conservation or no tillage.

Second, the study explores how the shape of the field influences costs through the size of the filter strip and the drainage area protected. Filter strips protecting larger drainage areas cost less than those protecting a smaller drainage area, depending on effectiveness. The range of results considered in this research, however, suggest that effectiveness must decline more than 20% for each 1% loss in the ratio of filter strip size to field size for costs to rise as the field size increases.

For additional information on this and related research, please see:

http://www-agecon.ag.ohio-state.edu/Faculty/bsohngen/default.htm

Table 1: Ranking (high to low) of costs per ton for reducing soil erosion with filter strips, and comparison to the costs for converting to No Tillage Methods.

Soil Association	Average Soil Erosion	No Tillage	Riparian Filter Strip: Low Cost 95% Eff.	Riparian Filter Strip: Medium Cost	Riparian Filter Strip: High Cost 60% Eff.
	tons/acre/year	$$/ton/year	$$/ton/year		
Toledo	1.06	$ 1.60	$ 2.19	$ 4.87	$ 7.54
Genesee, Sloan, Shoals, Eel	1.37	1.24	1.73	3.86	6.00
Colwood, Kibbie, Bixler	1.68	1.01	1.48	3.30	5.11
Haskins, Haney, Rawson	1.64	1.03	1.47	3.27	5.07
Millgrove, Mermill, Haskin	1.68	1.01	1.42	3.17	4.91
Lenawee, Del Ray	2.49	0.68	0.97	2.15	3.33
Toledo, Fulton, Lenawee	2.39	0.71	0.94	2.09	3.23
Latty, Fulton	2.29	0.74	0.93	2.08	3.22
Hoytville, Nappanee, Blount	2.49	0.68	0.89	1.98	3.07
Paulding, Roselms	3.07	0.55	0.63	1.41	2.18
Blount, Oshtemo, Sloan	3.59	0.47	0.60	1.33	2.07
Wauseon, Ottokee, Spinks	3.41	0.50	0.58	1.28	1.99
Glynwood, Rawson, Blount	5.70	0.30	0.35	0.78	1.21
Blount, Glynwood, Pewamo	15.30	0.11	0.14	0.31	0.47

Table 2: Comparison of the costs of a forested riparian filter strip when the protected field is tilled with Conventional or No Tillage methods.

	Low Cost ($$/ton/year)	High Cost ($$/ton/year)
Toledo		
Conventional Tillage	$ 2.19	$ 7.54
No Tillage	6.81	23.51
Blount, Glynwood, Pewamo		
Conventional Tillage	0.14	0.47
No Tillage	0.43	1.48

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COSTS OF USING RIPARIAN FOREST BUFFERS FOR SOIL EROSION CONSTROL

A Thesis

Presented in Partial Fulfillment of the Requirement for

the Degree Master of Science in the

Graduate School of The Ohio State University

By

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* * * * *

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ABSTRACT

In recent years, the US. Army Corps of Engineers has began to consider soil conservation practices in the Maumee River basin as an alternative to dredging the Toledo Harbor in Lake Erie. Unfortunately little information exists on the likely costs of installing different soil conservation practices. This study examines the costs of riparian forest buffers as an alternative to the conservation tillage or no-tillage methods often employed. Riparian zones are interesting because in addition to the benefits of reducing soil erosion, they may provide other environmental benefits not considered in this study.

In order to calculate the costs of riparian forest buffer, a buffer strip that conforms to the existing literature is first designed. Because some of the costs of buffers differ over time, net present value analysis is conducted to determine current costs. Costs include establishment, maintenance, and land rent. Land rent is calculated for different soils with hedonic price analysis, using data on 334 land sales in 6 counties in NW Ohio. In addition to these costs, a timber harvest option is explored, where land owners offset costs with future timber sales.

The results show that costs vary dramatically across the region, ranging from \$0.44/ton to \$7.08/ton in parts of Wood County. The study additionally explored how

these costs vary by filed shape and size, effectiveness of buffers, tillage system, and timber revenue option.

This research provides several policy implications. First, it is possible to identify high and low cost regions for soil erosion reduction using riparian forest buffers. This information can be used to help target limited cost-share dollars. Second, costs are dramatically higher on fields where no-till systems are currently employed. While many researchers currently suggest that buffers and no-till should be used together, they may not be the most economically efficient proposition. Finally, costs are very sensitive to the relationship between the acre of protection and effectiveness of buffers, yet there is relatively little information on this relationship. Additional research could help policy makers design low cost riparian forest buffer programs more effectively.

ACKNOWLEDGEMENTS

I wish to thank my advisor, Dr. Brent Sohngen for his guidance and support throughout the time I spent in the graduate school. Without his support, it would have been impossible for me to complete the master's program at the Ohio State University.

I also would like to thank Dr. D. Lynn Forster for his helpful suggestions on this document.

Finally, I want to thank my best friend Stephen Spielman for his endless support and encouragement.

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INTRODUCTION

1.1 Sedimentation Problems

The sedimentation problem at the mouth of the Maumee River in Lake Erie has been forcing the U.S. Army Corps of Engineers to dredge in order to provide channels for shipping vessels since 1866. The Maumee River basin, which spreads into Indiana, Michigan, and Ohio, is the largest contributor of sediment and nutrients to lake Erie. The Corps dredges an average of 850,000 cubic yards of sediment and spends approximately 3.5 million dollars annually. The dredged material that contains heavy metals discharged from industries upstream is placed into Confined Disposal Facilities (CDFs), and less contaminated dredged materials are disposed of into the open lake. The disposal of sediments creates new issues such as acquiring new sites for CDFs and water contamination from resuspended heavy metals. In addition, as these problems increase, the cost of sedimentation removal increases as well (Toledo Harbor Planning Group 1995).

In order to resolve these issues, several governmental agencies, such as the Natural Resources Conservation Services (NRCS), started focusing on the reduction of soil erosion upstream rather than dredging at the harbor because they suspect that it can be done at a lower cost. The Corps has recently provided the NRCS with funds to provide incentives for farmers to adopt soil conservation practices.

Although a great number of practices are suggested, little attention has been paid to the economic benefits and costs of alternative practices. For example, conservation tillage has been adopted by many farmers throughout the US as a result of promotion efforts from many organizations (Nowak and Korsching 1985). However, the decision-makers who promote conservation tillage do not look at the economic efficiency of the practice, but only the financial benefits to the farmers. This research proposes to investigate the economic efficiency of an alternative practice, riparian forest buffers, which is a highly effective practice in reducing soil erosion and nutrient run off (Crowder and Young 1987).

While riparian forest buffers are costly and are only recommended if the sites are experiencing severe erosion (Lant 1991), riparian forest buffers not only reduce the erosion rate, but also offer other benefits. For example, grasses, trees, and shrubs provide cover for small birds and animals, provide essential habitat for fish and other aquatic organisms, keep streams from drying out during droughts by storing runoff, and prevent floods. In addition, root systems stabilize banks, and can reduce bank erosion; trees provide shade to the surface water so that the water temperature does not rise to a lethal level for fish (USDA[a] 1994, Miller 1993, Yoshimoto and Brodie 1994). Moreover, riparian forest buffers uptake nutrients such as phosphorous and nitrate from run off before it reaches streams, and from shallow groundwater as well (Welsch 1991). Although riparian forest buffers can be used for abatement of nutrient loadings, this study focuses on its effectiveness in reducing soil erosion.

1.2. Riparian Forest Buffers (RFBs)

1.2.1 Literature Review

Scientific and management interests in riparian ecosystem was brought to people's awareness by two publications in 1978. Karr and Schlosser reported that riparian ecosystems control stream environment. Also 55 reports on multifarious aspects of riparian ecosystem presented at a symposium were edited by McCormick in the same year (Chesapeake Bay Program 1995).

In the late 1970's studies on riparian ecosystems' role in controlling NPS pollution began. In 1980's much research on the roles of riparian ecosystems in nutrient retention were published. Peterjohn and Correl reported that riparian forest retained 89% of nitrogen, 80% of phosphorus (1984). They also investigated that the percentage of nutrient loss from cultivated fields and riparian forests through groundwater and surface runoff.

Jacobs and Gilliam suggested that a substantial part of the nutrient was denitrified in the buffer strips in their study site which consists of poorly and very poorly drained soil covered by dense vegetation (1985[b]). Lowerance et al. reports that forest ecosystems function as a nutrient sink and buffer. They also found that riparian ecosystems serve as both short and long term nutrient filters and sinks if trees are periodically harvested (1984 and 1985).

In 1991, the US Department of Agriculture Forest Service published *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources.* This publication provides detailed information in regards to the functions, establishment, maintenance, and management of riparian forest buffers. In this publication, a riparian forest buffer is defined as:

> an area of trees and other vegetation located in areas adjoining and upgradiant from surface water bodies and designed to intercept surface runoff, waster water, subsurface flow and deeper groundwater flows from upland sources for the purpose of removing or buffering the effects of associated nutrients, sediment, organic matter, pesticides or other pollutants prior to entry into surface waters and groundwater recharge areas (Welsch 1991).

In contrast to scientific studies on riparian ecosystem, a limited number of economic studies have been conducted. Probably the first scientist who conducted an economic analysis on riparian ecosystems was William Mitsch (1978). In his study, he calculated the replacement value of a riparian swamp. The value of the riparian swamp was determined in terms of energy and money. He estimated that a society which was using a method other than a riparian ecosystem would require at least 5.5 barrels of oil per acre per year and $240 per acre per year to equal the amount of pollutant reduction that a riparian ecosystem would perform (1978).

Crowder and Young compared the cost per acre and effectiveness of eleven alternative conservation practices. They found that permanent vegetative cover was the most expensive practice. The total annual cost per acre of this practice was $150, however the effectiveness of pollutant reduction was among the highest (1987).

Some financial/economic studies have been done for farmers. Dillaha et al. found that the economic incentives play an important role in a farmer's decision as whether or not to install vegetative filter strips (Landry and Thurow 1997). Leeds et al. (1993) calculated internal rate of returns of vegetative filter strips. Their results are shown in table 1.1. Their results suggest that depending on the type of vegetation that farmer chooses, vegetative filter strips can be profitable.

	Types of VFS			
	Grass & Legume	Pasture	Hay	Timber
IRR	0	0	5%	4%
IRR with cost share	0	---	17%	6%

Table1.1: Internal Rate of Return for the use of Vegetative Filter Strips

Pritchart et al. compared the cost/ton of reduced sediment loading between a micro targeting program in which highly erodible land are removed from crop production, and vegetative filter strips. The micro targeting program reduced 31% of sediment loading at $80/ton, and vegetative filter strips reduced 26% of sediment loading at $91/ton (Landry and Thurow 1997).

1.2.2 Functions of Riparian Forest Buffers

The major functions of riparian forest buffers according to the Chesapeake Bay Program (1995) are

- Modifies stream temperature
- Control light quality and quantity
- Enhance habitat diversity
- Modifies channel morphology
- Enhance food web and species richness

In addition, forested buffer strips function as Filters, Transformers, and Sinks of nonpoint source pollutants (Welsch 1991). These functions can be used as a NPS pollution control.

Filters: The streamside forests remove sediments and sediment attached nutrient, such as phosphorus. Approximately 85% of phosphorus is bonded to soil particles that can be filtered by buffers, and the other 5% is bonded to soils too small to be filtered by buffers (Welsch 1996 and Kundt et al.1988).

Transformers: Forest buffers transform nitrate anion into nitrogen gas through denitrification and forms minerals. (Welsch 1991, CBP 1995, Kundt et al. 1988, Jacob and Gilliam 1985[b]). Nitrogen gases will be released into atmosphere and mineral forms of nitrate can be synthesized into proteins by plants and bacteria. Studies indicate that approximately 80% of nitrate can be removed from run off and shallow groundwater after passing through forest buffers. Stream side forests can also transform toxic chemicals to non toxic forms by microbial decomposition, oxidation, reduction, hydrolysis, solar radiation, and other biodegrading forces.(Welsch 1991).

Sink: Trees take up nutrients from run off, and these nutrients are sequestered in plant tissues, then stored for a long period of time (Welsch 1991 and Lowerance et al. 1984).

1.3. Researchable Problems

There are three related issues that need to be addressed when considering the costs of riparian forest buffers. First, the effectiveness on fields of riparian forest buffers verses other practices, such as the widely used conservation tillage method, in reducing sediment loading must be specified. Second, since other soil conservation practices on field are used in conjunction with riparian forest buffers, how these soil conservation practices affect additional reduction of soil erosion by riparian forest buffers needs to be specified.

Third, because land costs, which are closely related to soil types, are expected to be a major component of riparian forest buffers costs, the cost of riparian forest buffers may vary considerably across the basin. There are over 100 different soil types in the Maumee basin in Ohio, and each soil type has different characteristics. For instance, Mermill series have very high estimated average yields for corn, soybeans, wheat, and oats, whereas Seward series have one of the lowest estimated average yields for all crops. Mermill series are leveled and the wetness problem can be solved easily by installing artificial drainage. Seward series, on the other hand, are steep (2-18% slope), and have a severe erosion problem (Flesher, Jr. et al. 1974). These differences in soil characteristics may be reflected in the value of land. Therefore, how land costs vary with respect to soil types needs to be estimated.

1.4. Objectives

There are three main objectives in this study.

1. To estimate the value of land in different soil types using hedonic price analysis and data in agricultural land sale.
2. To develop an empirical model that shows how the costs of riparian forest buffers depend on a range of factors, including field size, field shape, buffer size, tillage system, effectiveness of riparian forest buffer, soil type, and revenue prospects.
3. To predict high and low cost regions for installing riparian forest buffers

By investigating these matters, we will have better ideas as to whether allocating funding for installation of riparian forest buffers rather than other soil conservation practices results in greater amount of reduced sedimentation in the Lake Erie at lower costs. In addition, regional comparisons within the Maumee basin provide information on regional targeting of resources for policy makers.

CHAPTER 2

METHOD

2.1 Introduction

This section outlines the methods used to calculate the costs of riparian forest buffers. These methods are employed to see how costs differ between alternative tillage practices, soil types, and field shapes. Different tillage practices have different effects on soil erosion rates on farms. Therefore, the costs of riparian forest buffer can be expected to vary depending on how much of soil erosion was already reduced by the tillage practices. Characteristics of soils vary among soil types. Some soils are more fertile or more erodible than others are, and these characteristics affect prices of lands in the market. Therefore, the method that will be used to study the cost of riparian forest buffers has to be able to incorporate the different soil characteristics. Shapes of fields are important because that determines the sizes of riparian forest buffers, and therefore the opportunity cost of the land used for buffers. In addition to these three factors, how the combinations of these three factors affect the costs of riparian forest buffer will be studied.

2.2 Design of Riparian Forest Buffers

Riparian forest buffers (RFBs) were designed based on the study done by the USDA Forest Services, the USDA Soil Conservatión Services, Stroud Water Research Center in Pennsylvania, Pennsylvania Department of Environmental Resources, Maryland Department of Natural Resources and U.S. Department of Interior Fish and Wildlife Services in 1991. The study results were published in a booklet, *Riparian Forest Buffers Function and Design for protection and Enhancement of Water Resources* (Welsch 1991). The Nutrient Subcommmittee of the Chesapeake Bay Program (CBP) exams the applicability of the riparian forest buffer system described in the booklet in Chesapeake Bay Watershed (CBP 1995).

The booklet by Welsch and the publication by the CBP suggest having three zones in designing riparian forest buffer.

1. Zone 1 is a 15-feet zone begins at the top of the stream bank to the cropland, and this zone is covered by the permanent woody vegetation. The purpose of Zone 1 is to stabilize ecosystem in the riparian area, and facilitate nutrient uptake by threes.
2. Zone 2 is a managed forest area, whose minimum width is specified as 60 feet. The primary purpose of this zone is to remove nitrate by denitrofication and plant uptake, degradation of organic pollutants.
3. Zone 3 is a runoff control area, and it is covered by grasses. The minimum width of this one is 20 feet. The grass filter removes sediment, some of nutrients, and converts concentrated flow to uniform, shallow, sheet flow.

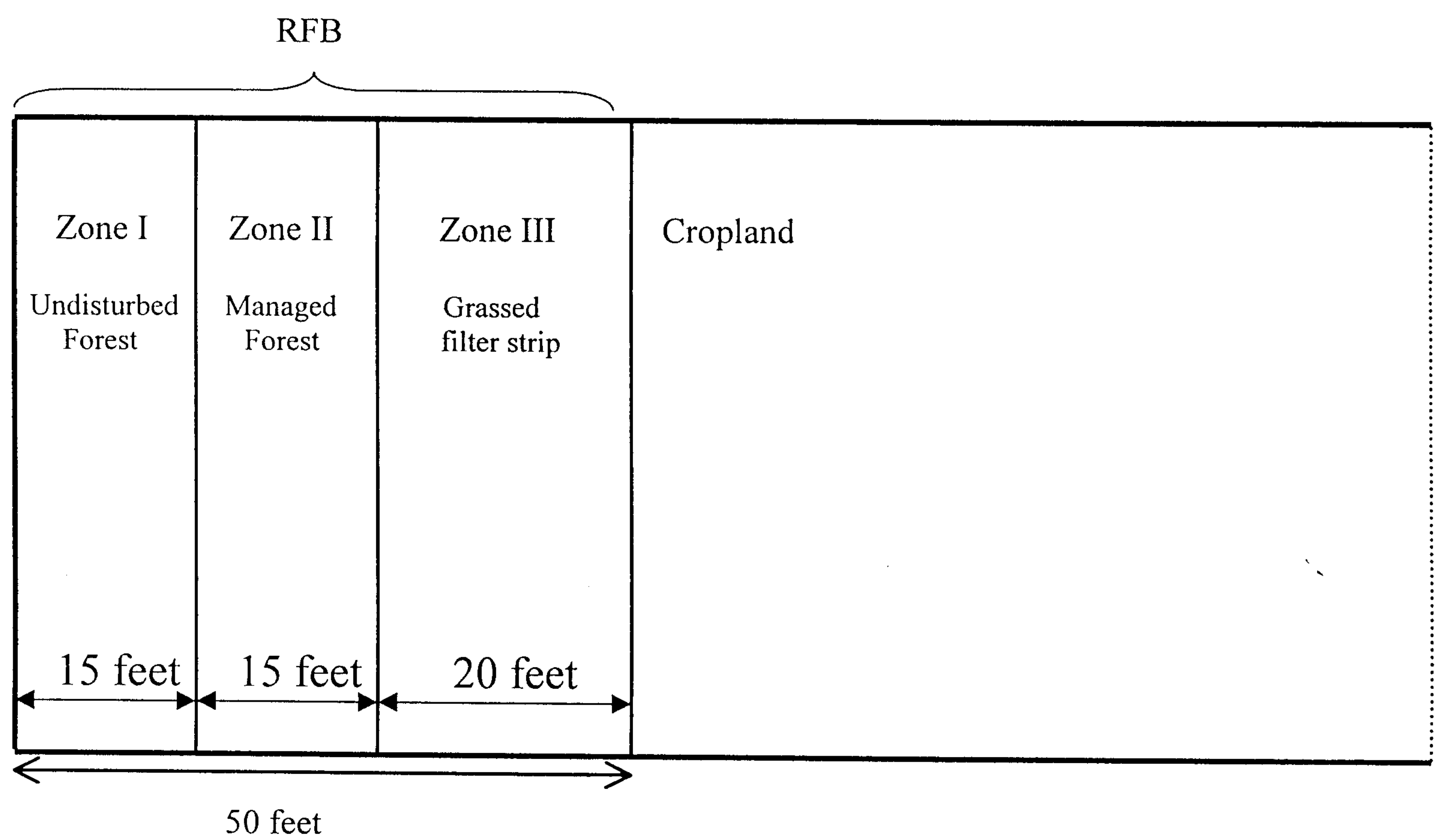

Figure 2.1: Design of a riparian forest buffer (RFB)

If we follow this recommendation strictly, at least 95 feet from the edge of a stream will be take out of crop production. This would be very costly to farmers. The riparian forest buffer used in this analysis were designed as described below.

Total width of 50 feet as recommended by the Ohio Department of Natural Resources, and it is divided into three zones I, II, and III (See figure 2.1)

- Zone I: Undisturbed forest (15 feet from the stream)
- Zone II: Managed forest (15feet)
- Zone III: Grassed filter strip (20 feet) Runoff control

2.3 Net Present Value (NPV)

In order to analyze the economic efficiency of riparian forest buffers, we need to estimate the cost of riparian forest buffers using the cost of shifting land use from cultivation to buffers.

$$Cost = C(0) + \int_{0}^{60} e^{-rt}\left[R(t) + M(t) - T(t)\right]dt \qquad (1)$$

C(t) : initial conversion costs, typically occurs only in year 0

R(t) : rent or opportunity cost of land

M(t): annual maintenance costs

T(t) : periodic revenue from timber

t : year

r : discount rate (r = 0.05)

The time horizon of this analysis is 60 years. Once a piece of land is converted into a riparian forest buffer, it will be there permanently unless the owner of land decides to change the use of the land. Because of discounting, present values of costs and benefits are small after year 60. Also, making an assumption of values of rents, maintenance costs, and stumpage prices after a certain period of time becomes very difficult.

2.3.1 Initial Outlay (Variable C(0))

Costs associated with converting land from crop production to riparian forest buffers are, soil preparation, equipment, labor, grass seeds, and tree seedlings costs. Typical costs of conversion in Ohio are $32.75/acre if conventional tillage system is used for planting, and it is $21/acre if No-till system is used (Leeds, Forster and Brown 1993). These figures include the costs of equipment and labor. It will be assumed that a farmer who uses conventional tillage system for crop production will also use conventional tillage system to convert a land to a riparian forest buffer. The same assumption will be made for no-till system as well. The cost of fertilizer is estimated as $25/acre (Leeds, Forster, and Brown 1993). The prices of grass seeds range from $0.75 to 5.10 per pound (Leeds, Forster and Brown 1993). According to the Ohio Department of Natural Resources (ODNR), tree seedlings cost about $0.35/seedling. Detailed information related to grass and trees is given later in the vegetation section (Berger 1998).

2.3.2 Land Opportunity Costs (Variable R)

The per acre opportunity cost of land, R, is expected to be the major component of costs of riparian forest buffers and to vary depending on the soil types on the parcel of land. The price of an asset such as a piece of land (one acre) can be calculated as the NPV of future profits or rent. For land, we assume:

Present Value of one acre of land (PV_L) = R/i,

where i is the assumed interest rate (Debertin 1992). Rent, in this case, is the annual opportunity cost of using land for riparian buffers. Rent can be determined as:

$R = PV_L*i$,

and this gives the value of rent for one acre of land. For this analysis, 5% will be used as the discount rate.

There are three methods to determine the present value of land.

1. Production function analysis
2. Hedonic pricing analysis
3. Obtain information from assessors

The production function analysis is a widely used method to determine values of land. Production function analysis determines land value by estimating the net present value of future profits. In the case of a riparian forest buffer, a portion of land will be taken out of crop production to install a riparian forest buffer. Therefore, the PV_L is the forgone profit from crop production on the land converted to a riparian forest buffer. Because this method uses the value of forgone production, results vary depending on production potential, crop rotation, and local crop market (Leeds, Forster, and Brown

1993). Because production function may shift over time as technology advances, or crop market prices change, this method may not capture correct land values.

The value of land (PV_L) can be also determined by hedonic price analysis. The hedonic pricing method, which was formalized by Rosen (1974), is the generalized form of Lancaster's model. It is hypothesized that goods are valued by the attributes that give utility to consumers (Rosen 1974). The hedonic pricing method can be used to study the relationship between price and characteristics of composite goods such as housing and its characteristics (Hite1995). Hedonic prices are not directly observable, but they can be estimated by regressing price of good against the level of its characteristics. The coefficients of regression are the willingness to pay of consumers for one additional unit of each characteristic.

Because this model allows economists to analyze values of characteristics that are not observed in the market, the model has been used to estimate how the housing values are affected by environmental features. Ridker and Henning (1976) studied the effect of air pollution on residential properties, and they found that property values decline as air quality of the residential area deteriorates. Nelson, J. Genereux, and M. Genereux (1992) and Hite (1995) investigated effects of landfills on housing values. In both cases, the distance to a landfill site had positive effect on the housing values. Because the hedonic regression uses real land sale data, which capture future anticipated changes that would affect the asset prices (Randall 1987), it captures real willingness to pay for agricultural land by farmers in the study area. In addition, the hedonic regression allows us to see the effect of each characteristics of land, and therefore makes it easy to do a sensitivity analysis using different land sizes and characteristics.

The third method is to obtain information from assessors. While the value of land can be obtained from assessors in each county, assessors are interested in local market information. This research focuses on a broader region, so assessors' information may not be appropriate. Further, the costs of obtaining information from assessors could be high because it is private information and they are generally unwilling to give the data out to others.

In this paper, a hedonic pricing model is used to estimate the implicit price of land in different soils in Northwestern Ohio. Total land sale value is regressed on the acres of land in different soil types and other important variables such as square footage of dwellings. The resulting coefficients on each variable represent the additional acre of soil, or one additional unit of other characteristics.

2.3.3 Maintenance Costs (Variable M)

Maintenance costs will depend on the type of vegetative buffers. When grass is planted, it has to be mowed twice a year at an approximate cost of $7/acre for each mowing (Leeds, Forster, Brown 1993). There is no need to prune trees for the first 15 to 20 years. After the first pruning operation, pruning may be needed every 10 years. The cost of a pruning operation is approximately $85/acre (Leeds, Forster and Brown 1993). NPV calculation will be done with an assumption that there would be a minimal need for maintenance to maintain the effectiveness of riparian forest buffer. Therefore, if the buffer is damaged by storms or in any other way, or if sever weather occurs frequently, the owner has to spend more money and time for maintenance.

2.3.4 Net Revenue from Timber Production (Variable T)

In some circumstances, farmers may choose to offset the costs of vegetation buffer by harvesting trees. In order to estimate revenue from timber harvests, the stumpage prices of timber were used. In this study, trees will be planted in zone I and II, but trees will be harvested selectively from the buffer zone II. It is assumed that 2000 board feet of timber could be harvested every 15 years (Berger 1998).

2.4 Calculating Cost per ton of using Riparian Forest Buffers

After calculating the cost of a riparian forest buffer, cost/ton of reduced soil erosion will be calculated. NPV analysis gives the net discounted cost of riparian forest buffers over 60 years. In order to calculate the annual cost per ton of reduced soil erosion, the annual equivalent amounts (AEA) of the total costs need to be calculated. The AEA can be calculated by multiplying costs and the levelized cost factor (LCF).

$$LFC = \left[r * (1+r)^t\right] / \left[(1+r)^t - 1\right]$$

where r = 0.05 and t = 60

LCF in this study is 0.0528. Therefore, if the cost of shifting a portion of land into a riparian forest buffers is $1000, the AEA is $52.80 (= $1000*0.0528).

The cost per ton of reduced erosion can be obtained by dividing the AEA by the annual tons of retained soil erosion. Because riparian forest buffers protect many acres in addition to the acres with the buffer, the costs per ton of soil retained on the land must be calculated. The cost per ton of soil retained on the land is:

Cost/ton = AEA/(total acres of field* tons of reduced erosion per acre) (2)

It is very important that we calculate costs in terms of cost per ton of sediment loading reduction. Much of previous research has been done in terms of cost per acre. Costs per acre do not account for many factors. First, they ignore the effectiveness of conservation practices in reducing soil erosion. Cost per acre for a conservation practice tells us how much it costs for each acre for all across the region, but it does not account for the fact that the tons of reduced erosion will differ among farms. Therefore, choosing a practice on the basis of the lowest cost/acre does not guarantee a high degree of erosion abatement. On the other hand, if cost per ton of reduced erosion is used, costs of the same conservation practice vary depending on the characteristics of soils such as erodibility and location of the field. For example, assuming the cost of installing a new conservation practice are same for each acre, and the conservation practice removes a certain percentage of soil erosion, cost per ton of highly erodible land will be lower than that of non-erodible land. Because our primary goal is to reduce sedimentation in Lake Erie by reducing sediment loading from farmland, the effectiveness of each conservation practice needs to be incorporated into the cost calculation to help determine the lowest cost regions

Scientists calculate effectiveness of riparian forest buffers by using the difference between sediment input to a buffer and output after runoff go though the buffer. Therefore, if effectiveness of buffer is 90%, 90% of soil moving thorough the buffer will filtered out by the buffer, and 10% of soil leaves the field. Some researchers try to use the delivery ratio to estimate the amount of soil leaves a field, but the delivery ratio vary widely depending on the location. According to Lee at el. (1993) the delivery ratio for farmland varies from 1% to 40 % depending on the soil types, tillage direction, and slopes. Because of this wide range, it is difficult to make an assumption on the delivery ratios for the study area. Therefore, in this study, the Universal Soil Loss Equation (USLE), which is used to estimate sheet and rill erosion were used instead (Troeh, Hobbs, and Donahue 1991). Readers should keep in mind that the actual tons of reduced soil erosion by riparian forest buffers are lower than the numbers used in this study.

2.5 Factors that Influence NPVs and Costs

There are many factors that influence costs and benefits of riparian forest buffers. Some of the important factors will be discussed in this section.

2.5.1 Size and Shape of fields

Sizes of field vary parcel to parcel, but sizes of areas set aside for riparian forest buffers may not necessarily differ. For example, consider two parcel of lands A_1 (square field) and B_1 (rectangle field) that are both adjacent to a stream, and the same length of the fields (1000 feet) are facing the stream (table 2.1 and figure 2.2). The widths of vegetative buffer are set to 50 feet.

	Field Sizes (ft^2)	Buffer Sizes (acres)	Drainage area (acres)	Cost/ton
A_1	1000 x 1000	1.16	21.99	Higher
B_1	1000 x 2000	1.16	45.14	Lower

Table2.1: Effect of different sizes of fields on cost/ton

Because the length of the field facing the stream is the same for both A_1 and B_1, the size of the riparian forest buffers are the same as well. The only difference is the size of drainage area (land area draining into buffer). This difference will have a significant effect on cost/tons of reduced erosion. The costs will be high for A_1 because the denominator for A_1 is smaller than B_1, in other words, the amount of reduced erosion will be greater for B_1 because the drainage area is larger.

Similarly, shapes of the field will have an effect on the cost of buffers. Consider three plots of land A_2, B_2, and C_2 that are same in the size, 50 acres, but different in shape (table 2.2 and figure 2.3). The lengths of the fields facing the stream are 1469 ft, 1000 ft, and 2160 for A_2, B_2, and C_2 respectively.

	Sizes (ft^2)	Buffer Sizes (acres)	Drainage area (acres)	Cost/ton (ranking)[1]
C_2	2178 by 1000	2.5	47.5	1
A_2	1475.8 by 1475.8	1.69	48.31	2
B_2	1000 by 2178	1.147	48.823	3

1: For the ranking 1= most expensive, 3= least expensive

Table 2.2 Effect of different shapes of fields on cost/ton

In this case, the difference in drainage area is not so significant, so the amount of reduced erosion would not differ greatly. However, because rent would be the major component of costs, the larger the sizes of the buffer, the more expensive the practice is (assuming that all the lands consist of the same soil types).

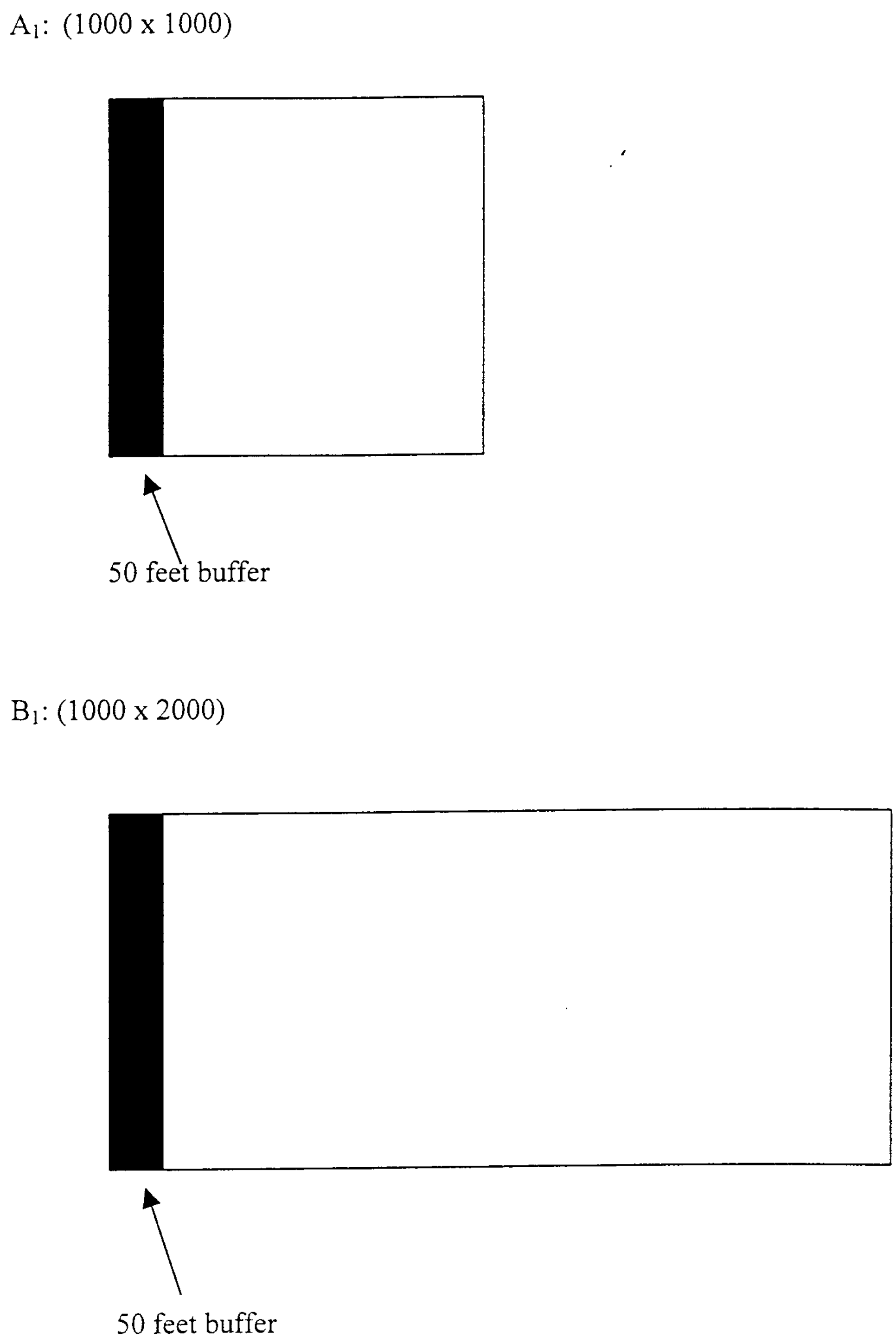

Figure 2.2: Different sizes of fields

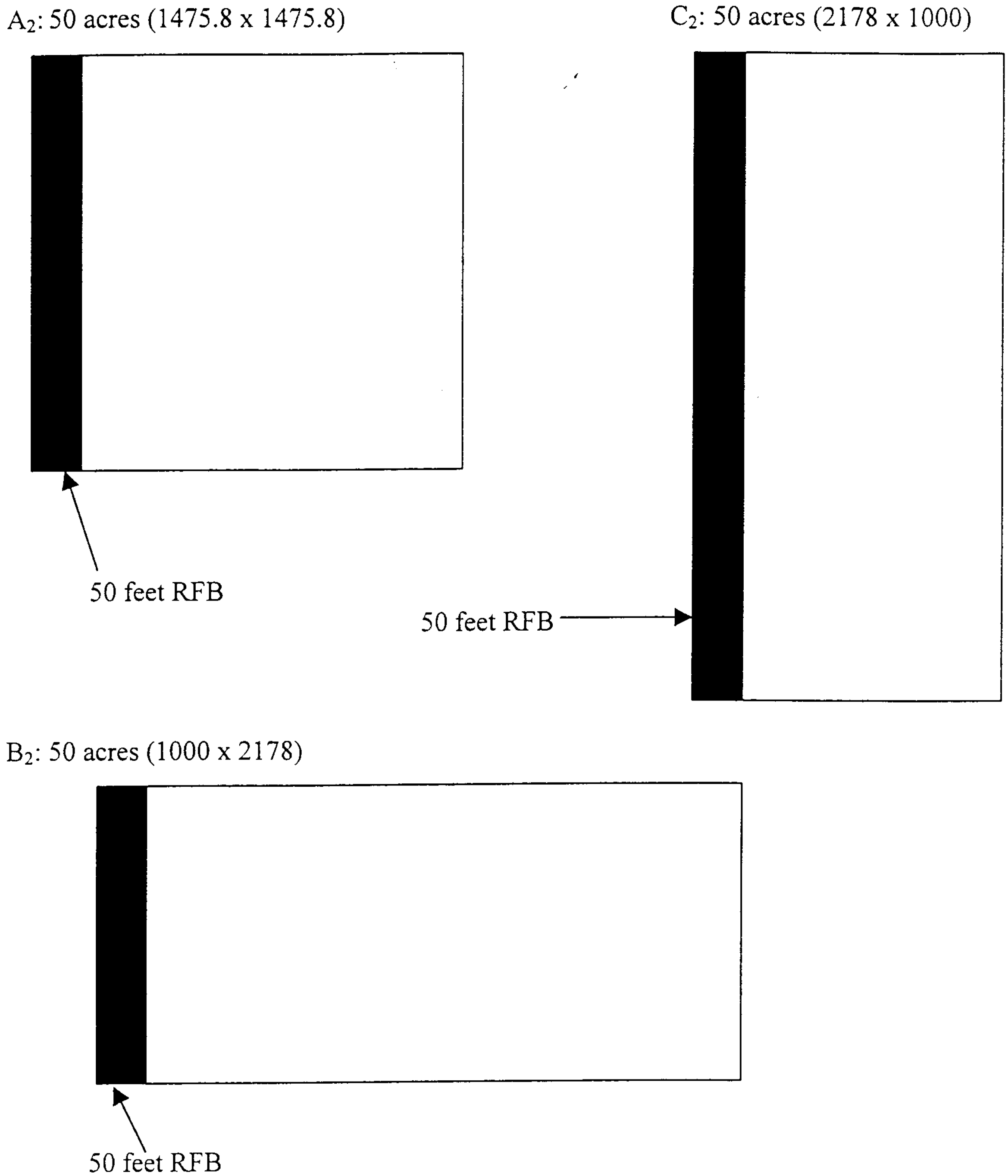

Figure 2.3: Different shapes of fields with 50 feet RFBs

2.5.2 Slope

Slopes will also affect the costs of riparian forest buffers because the effectiveness of the buffers may vary. Generally, it is suggested that for steeper land, the width of the buffer should be made wider. Robinson et al. compared the effectiveness of vegetative filter strips on 7% and 12% sloped cropland (1996). They found that the 12% slope had greater run off and soil losses than the 7% slope. Four percent more sediment was removed by the vegetative filter strips on the 12% slope cropland than the 7% slope, but more sediment was lost from the 12 % slope cropland. Therefore, if we decide to use the same width of buffers on different slope of land, a steeper land's cost/ton needs to be lower compared to a level land even though more sediments would be lost from the land. Effects of slopes on the costs of riparian forest buffers will not be examined because information on relationship between slopes and effectiveness of buffers are limited.

2.5.3 Tillage practices

Different tillage practices on the farm affect the erosion rates on the sites. Compared to conventional tillage, no-till operation reduces erosion rates by 68% (Crowder and Young 1987). Assuming the erosion rate of a farm is 2.4 tons/acre/year, which is the average erosion rate in the Maumee River basin (Sohngen and Rausch 1997), riparian forest buffers on farm with no-till practice will remove 1.632 tons/acre of sediment. On the other hand, riparian forest buffers reduce erosion rate by 95% (Crowder and Young 1987), so a riparian forest buffer on the edge of land with conventional tillage will reduce 2.28 tons/acre of erosion on the site. Table 2.3 shows the amount of reduced soil erosion on the site for each acre.

Tillage Practices	Tillage (tons)	**RFBs (tons)**	Total (tons)
A_3: Conventional	0.00	**2.28**	2.28
B_3: No-till	1.632	**0.73**	2.36

Table 2.3 Reduction of soil erosion rates per acre by tillage practices and RFBs

The difference in the amount of reduced erosion rate is only 0.08 tons. However, only the additional effectiveness of riparian forest buffers should be counted, so cost/ton of reduced erosion for a farm under no-till practice will be higher than the farm under conventional tillage system.

Different tillage practices on the croplands also affect the cost of maintenance. Accumulated sediments in the riparian forest buffers need to be removed periodically in order to remain effective. As we can see from table 2.3 that the amount of sediment accumulated for the riparian forest buffer on A_3 is approximately three times higher than the vegetative filter strip on B_3.

2.5.4 Vegetation

Types of vegetation that are planted affect both the costs and benefits of riparian forest buffers. Costs of seeds for some grasses are higher than the other seeds, and if trees are planted, the costs will be even higher. The benefits of using riparian forest buffers will be higher if landowner plants vegetation that can be sold in the market in later years. For example, if trees are planted, they can be sold in the market, or if a farmer plants only grasses, these grasses can be used as forage.

For the purpose of reducing soil erosion, cool-season grasses are recommended more than warm-season grasses, because cool season grasses grow vigorously when the erosion rates are high (Spring time). Also sod forming grasses are preferred to bunch grasses because sod forming grasses provide uniform ground cover (Leeds, Brown, Sulk and VanLieshout 1993). Legumes can be mixed with grasses, and the mixture of legumes and grasses are generally more satisfactory compared to pure grasses (Ohio Agronomy Guide 1995). Some of the benefits of mixture are:

1) Reduces the need for nitrogen fertilizer
2) Reduces the potential for nitrate poisoning and grass tetany
3) Reduces the damage from insect and disease pests

Table 2.4 shows the cool-season grasses mixtures and seeding rates (lb./acre) that are recommended. This table can be read, for example, in (a), 10 pounds of Alfalfa should be mixed with one of the four grasses and corresponding seeding rate listed to the right.

	Legumes	lb./acre	Grasses	lb./acre
a	Alfalfa	10	Timothy or	1-2 (fall) 4 (spring)
			Orchardgrass or	2-4
			Smooth Bromegrass or	5-7
			Perennial ryegrass	3-4
b	Alfalfa and	7	Timothy or	1-2 (fall) 4 (spring)
	Red clover	3	Orchardgrass or	2-4
			Smooth Bromegrass or	5-7
			Perennial ryegrass	3-4
c	Red clover	8	Timothy or	1-2 (fall) 4 (spring)
			Orchardgrass or	2-4
			Smooth Bromegrass or	5-7
			Perennial ryegrass or	3-4
			Reed canarygrass or	4-6
			Tall fescue	8-10
d	Red clover and	6	Orchardgrass or	2-4
	Ladino clover or	½-1	Perennial ryegrass or	3-4
	Alsike clover	2	Reed canarygrass or	5-7
			Tall fescue	8-10
			Garrison grass	4
e	Birdsfoot trefoil	6	Timothy or	2-4
			Orchardgrass or	2
			Smooth Bromegrass or	5-7
			Reed canarygrass	4-6
f	Birdsfoot trefoil	6	Kentucky bluegrass	2
g	Ladino clover	1	Orchardgrass or	6-8
			Tall fescue or	8-10
			Reed canarygrass or	8-10
			Smooth Bromegrass	6-8

(Source : Ohio Agronomy Guide 1995)

Table 2.4 Grass mixture and seeding rates

In the analysis later, mixture (f) will be used to estimate the cost of seeds. The mixture of Birdsfoot trefoil and Kentucky bluegrass was chosen because both have the desirable properties for sediment filtration. Birdsfoot trefoil is a deep rooted perennial legume. It is tolerant of low-pH soils and grows in moderate to somewhat poorly drain soil. Kentucky bluegrass is a long lived perennial grass that forms a dense tough sod under favorable conditions. It can tolerate a wide range of soil conditions and even mismanagement. The minimum adequate drainage required for acceptable growth is somewhat poorly drained (Ohio Agronomy Guide 1995).

Tree species suitable to the study area and the Ohio stumpage prices ($/thousand board feet) are shown in table 2.5. The stumpage prices for each species listed are the average values of mean fall and mean spring prices in 1996.

Species	Stumpage prices	Species	Stumpage Prices
Walnut	735.0	Ash	310.0
White Oak	425.0	Yellow Poplar	207.5
Red Oak	435.0	Basswood	145.0
Cherry	650.0	Hickory	102.5
Hard Maple	440.0	Pine	-----
Soft Maple	187.5	Other	72.5

(Source: Ohio Agricultural Statistic Service, 1997)

Table 2.5: Tree species and approximate stumpage prices ($ per thousand of feet)

Different trees are suitable to different soil associations. Therefore, the average stumpage values of mixed trees will be used in calculating NPVs.

CHAPTER 3

DATA

3.1 Study Area

The Maumee River drains 6,586 square miles, of which 74% (4,856 square miles) is in Ohio (Herdendorf et al. 1976 and Federal Water Pollution Control Administration 1966). The river empties into Maumee Bay at the Southwest tip of Lake Erie (figure 3.1). Approximately 73% of land in the basin are used for agricultural production. Table 5.1 shows the county summary of six studied counties.

Items	Defiance	Fulton	Henry	Paulding	Williams	Wood
[1]Total area (acres)	263680	260288	266240	266240	269312	395520
Number of fields	830	847	955	621	763	1089
Land in field (acres)	196759	205633	245049	219037	187175	302456
Average size of field (acres)	237	243	257	353	245	278
Total crop land (acres)	175451	191867	232281	205703	167430	288262
% of cropland	66.57	73.71	87.24	77.26	62.17	72.88

(Source: 1992 Census of Agriculture) 1: total acres are obtained from soil surveys

Table 3.1: County Summary Highlights: 1992

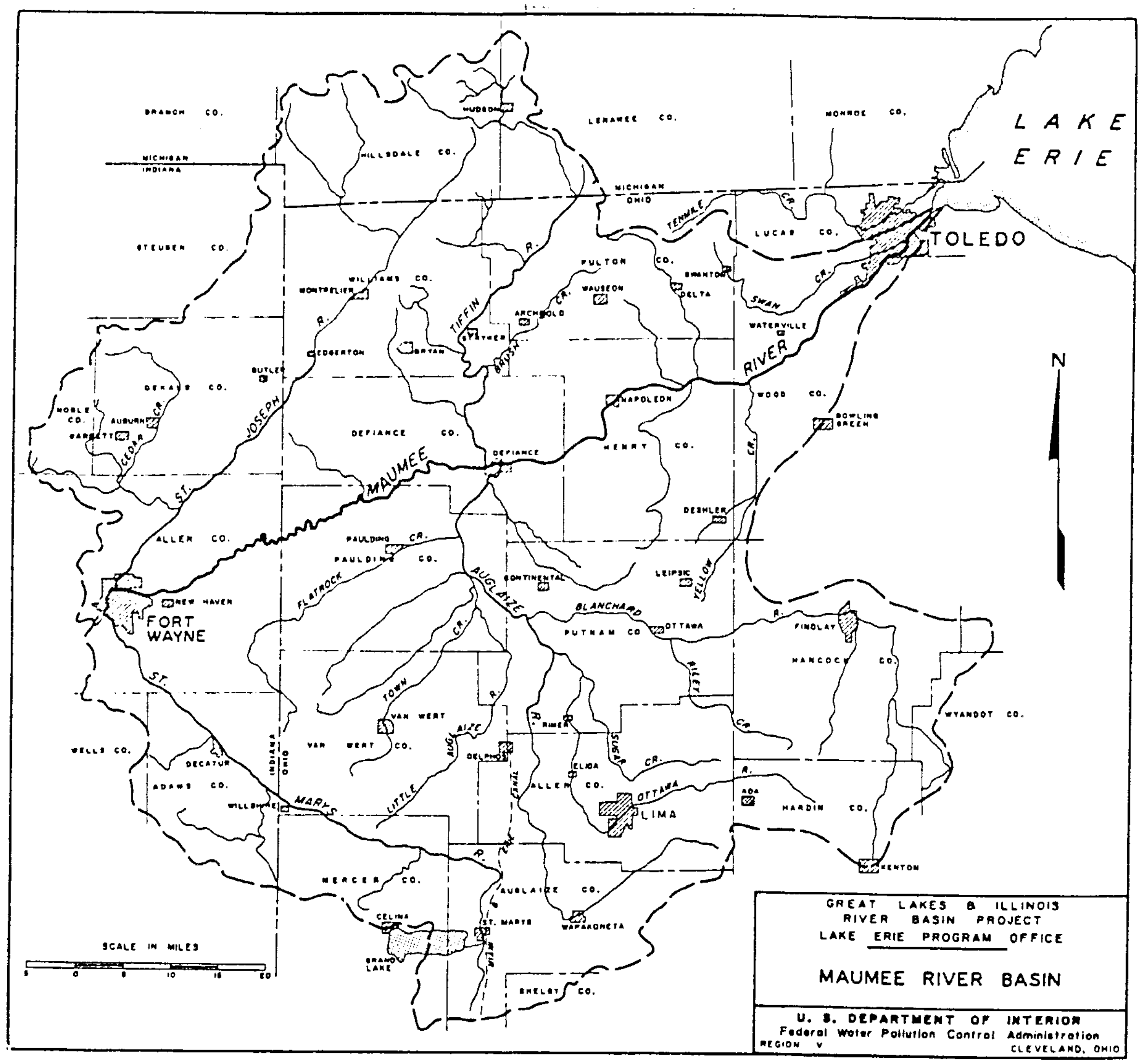

Figure 3.1: Map of Maumee River Basin

3.2 Collection of Information and Data

In order to estimate the cost of riparian forest buffers in reducing soil erosion, costs and effectiveness of riparian buffers need to be determined. The cost of a riparian buffer is the opportunity cost for the land use, the maintenance cost, the labor cost, the machinery cost, and the cost for seeds and trees.

The opportunity cost of land will be estimated using hedonic price analysis. This analysis requires data for the characteristics of land such as soil types and land size. Agricultural land sale data from 1995 to 1997 were collected from the Auditor's offices in Defiance, Fulton, Henry, Paulding, Wood, and Williams counties. The given information on the records are slightly different among the counties, but important information, such as total acre, prices of sale, cauv, building information, acres of different soil types in a parcel were obtained from all the counties. Descriptive analysis on land sale data is shown in table 3.2 and table 3.3. The average sale per acre of land is $1798.13/acre.

The effectiveness of vegetative buffer strips reported by the Ohio State University Extension ranges from 56% to 95% depending on the width of the buffer zones, soil types, and slopes (Leeds, Brown, Sulc, and VanLieshout 1993). For this study, some sensitivity analysis will be done by using different values for the effectiveness. The Ohio Department of Natural Resources (ODNR) recommends that the width of riparian buffers be at least 50 feet for the practice to be effective in sediment and nutrient removal (1991).

County	Number of observation	Average sale price[1] ($)	Average acre[2] (acres)
Defiance	79	71,904.65	53.20
Fulton	30	135,926.20	49.90
Henry	86	107,812.80	53.85
Paulding	45	71,073.34	53.58
Wood	52	106,056.40	48.56
Williams	42	71,745.62	59.76
Total	334	94086.50	53.14

1: Average of total sale prices which includes prices of everything sold with land such as housing, farm buildings and garage
2: Average size of acres sold

Table 3.2: Descriptive analysis on collected land sale data (N=334)

County	# of obs. with home	Average sale price[1] ($)	Ave. home price ($)
Defiance	15	108,540.00	40,384.67
Fulton	8	214,037.50	49,575.00
Henry	27	136,697.70	35,408.89
Paulding	8	82,283.60	32,062.50
Wood	6	138,583.30	59,683.33
Williams	8	113,375.00	30,600.00
Total	72	132,252.85	41,285.73

1: Average of total sale prices which includes prices of everything sold with land such as housing, farm buildings and garage

Table 3.3: Descriptive analysis on collected land sale data with housing (N=72)

3.3 Treatment of data

There are 193 different types of soil in the soil data obtained from county auditors, so they were aggregated into 5 different production levels. By using the productivity indices (PIs) of soil, individual soils are grouped into 5 different soil productivity levels based on an assumption that the values of soil differ depending on the productivity. The information on soil productivity was obtained from *Ohio Soils with Yield Data and Productivity Index* (Zobeck, Gerken, and Powell 1983). There were no indices for soils that are too steep for agricultural production, and these soils were omitted from the grouping of soils. Table 3.4 shows the grouping category and some descriptive analysis of aggregated soil data. Every PI value corresponding each soil were weighted equally.

PIs	Description	Average PI level*	Proportion (%)
PI 50	PI less than 59	52.214	5
PI 60	PI from 60 to 69	64.25	20
PI 70	PI from 70 to 79	73.821	30
PI 80	PI from 80 to 89	84.045	39
PI 90	PI greater than 90	84.857	6

*Every PI value corresponding each soil were weighted equally

Table 3.4: Descriptive analysis of productivity index soil groups

3.4 Soil Associations

One of the objectives of this research is to identify high and low costs regions within the study area. A regional comparison will be done based on soil associations. Soil Surveys from each county and the State Soil Geographic map were used to determine the number of soil associations and their locations (Baker et al. 1960, Flesher et al. 1984, Flesher et al. 1974, Rapparlie and Urban 1966, Stone and Michael 1984, Stone et al. 1978, and USDA 1994). Table 3.5 shows a list of the soil association and figure 3.2 shows the location of each soil association on the map.

Groups	Associations
S1	Wauseon, Ottokee, Spinks
S2	Hoytville, Nappanee, (Blount: Fulton)
S3	Toledo
S4	Millgrove, Mermill, Haskin, (Sloan: Fulton) (Brady: Fulton)
S5	Colwood, Kibbie, (Bixler: Fulton)
S6	Blount, Oshtemo, Sloan, (Genesee: Defiance)
S7	Toledo, Fulton, (Lenawee: Henry)
S8	Paulding, Roselms
S9	Blount, Glynwood, (Pewamo: Williams and Fulton)
S10	Lenewee, Del Ray
S11	Latty, Fulton
S12	Genesee, Sloan, Shoals, Eel
S13	Glynwood, Rawson, Blount
S14	Haskins, Haney, Rawson, (Mermill: Defiance), (Millgrove: Defiance)

Table 3.5: List of soil associations

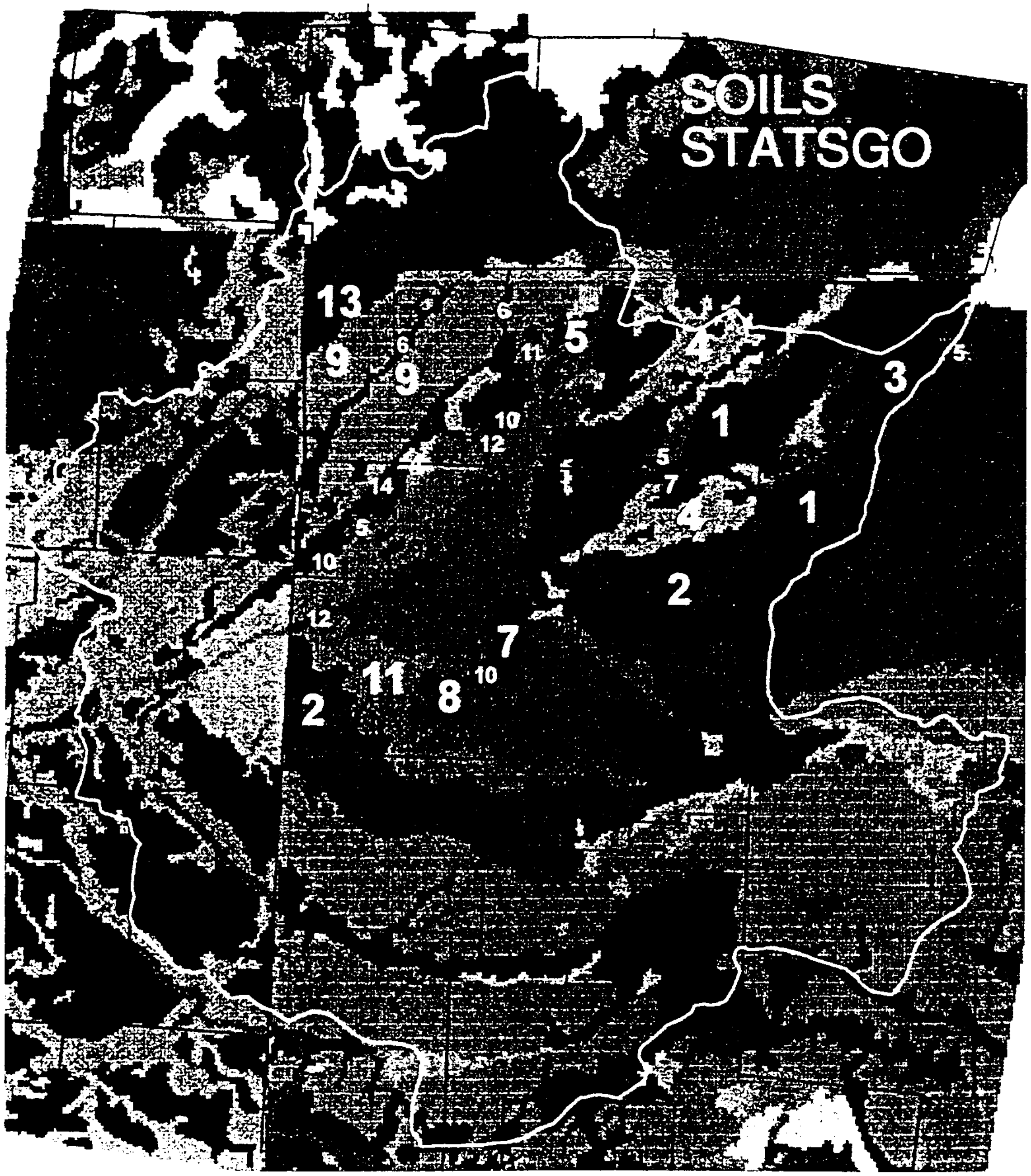

Figure 3.2: Soil Map

CHAPTER 4

ANAYSIS

4.1 Representative Fields

The costs of using riparian forest buffers for erosion control vary depending on the characteristics of buffers and fields. In this analysis, two 50-acre representative fields, F_A and F_B, which can be observed in the Maumee River basin will be used to estimate the NPV (table 4.1 and figure 4.1).

The field shapes are written in a way, so that the first number represents the length of field facing the stream, and the second number represents the length of field measured horizontally, perpendicular to the top of the stream bank.

Field Shapes	Representative fields	Size of buffers (acres)			
		Total	I	II	III
2178 x 1000	F_A	2.5	0.75	0.75	1.0
1000 x 2178	F_B	1.147	0.344	0.344	0.459

Table 4.1: Representative fields

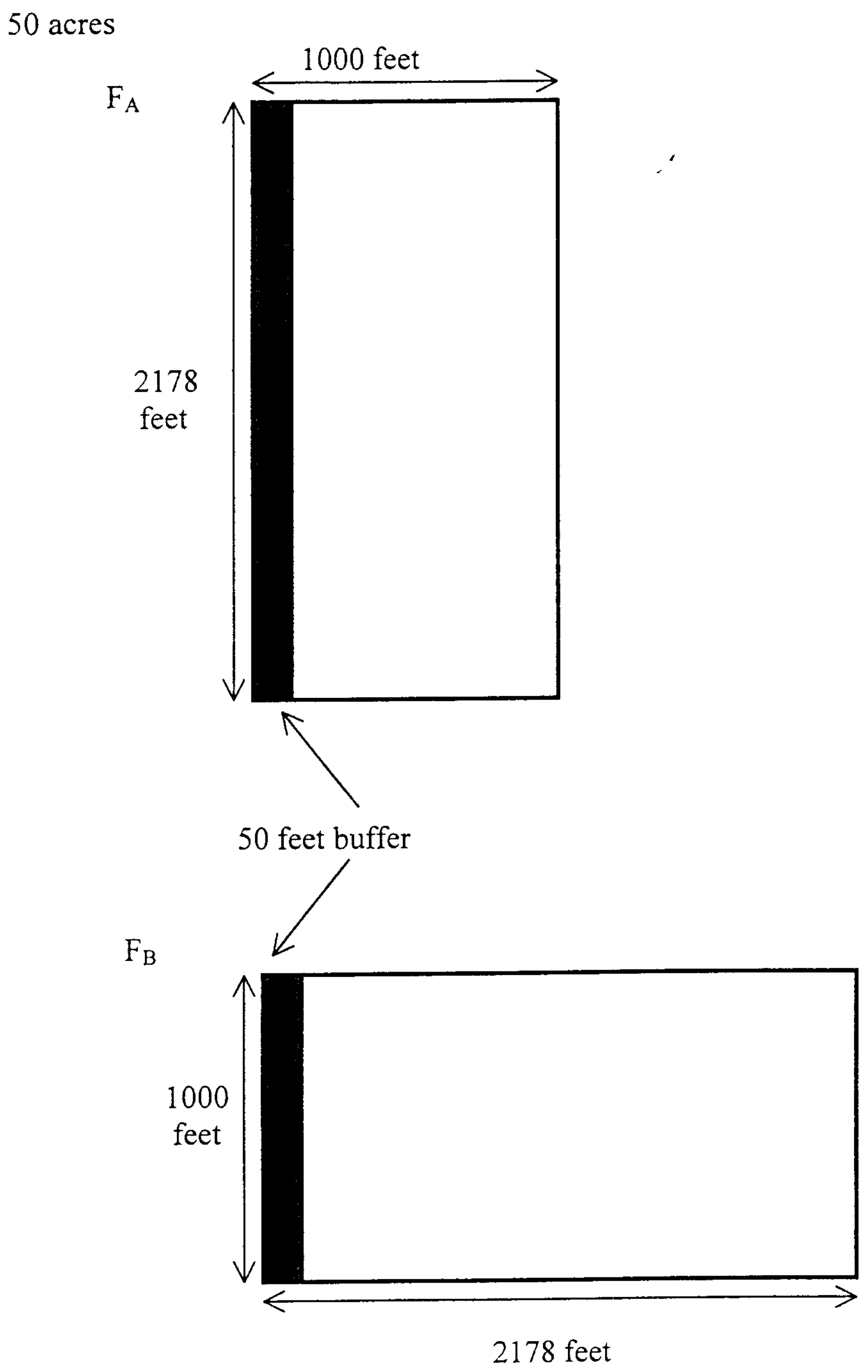

Figure 4.1: Representative Fields

4.2 Hedonic Pricing Analysis

Hedonic analysis was used to estimate land value. Weighet least square estimation was used for this hedonic regression because some test suggested the existence of heteroscedasticity. The model used for the analysis is:

$$Sale = \alpha_1 PI50 + \alpha_2 PI60 + \alpha_3 PI70 + \alpha_4 PI80 + \alpha_5 PI90 + \alpha_6 DW + \alpha_7 BD$$

Definitions of variables used in this analysis are shown in table 4.2.

Variables	**Definitions**
Sale	Total sale value ($)
PI50	Acres of soils with Productivity Index less than 59
PI60	Acres of soils with PI greater than 60, less than 69
PI70	Acres of soils with PI greater than 70, less than 79
PI80	Acres of soils with PI greater than 80, less than 89
PI90	Acres of soils with PI greater than 90
DW	Square feet of dwellings
BD	Dummy for field buildings

Table 4.2: Variable definitions

After the coefficients for PI50, PI60, PI70, PI80, and PI90 are obtained from regression analysis, these coefficients are plotted against the averages of each PI group. This allows estimation of different land values with all levels of PIs. The average PIs for

14 soil associations are used to estimate the value of soils. For example, if coefficient of PI50 is 1000 and PI60 is 1200, and also if the average PI of I50 is 55, and PI60 is 65, then a soil association with PI 60 will given a value $1100.

4.3 Modification of NPV Equation

Because there are three different zones in each Riparian forest buffers, NPVs of each zone were estimated. NPV equation (1) was modified as following for zone I, zone II, and Zone III.

Zone I $$Cost = C(0) + \int_0^{60} e^{-rt}\left[R(t)\right]dt \qquad (3)$$

Zone II $$Cost = C(0) + \int_0^{60} e^{-rt}\left[R(t) + M(t) - T(t)\right] \qquad (4)$$

Zone III $$Cost = C(0) + \int_0^{60} e^{-rt}\left[R(t) + M(t)\right] \qquad (5)$$

4.4 Values of Each Variable Used for the Analysis

Using the values for variables shown in table 4.3, NPVs for each zone were calculated. Values of costs that are consistent with all soil types are shown in terms of $/acre/year, so these numbers were adjusted for the sizes of riparian forest buffers. Maintenance included in this analysis are mowing and pruning only. Removing of soil and inspections of riparian forest buffers were not included because costs of these maintenance were not available.

Variables	$/year/acre	Notes
Grass seeds costs	19.90	mixture f, (Birdsfoot trefoil & Kentucky bluegrass)[3] ($2.55*6lb/ac)+($2.3*2lb/ac)
Trees seedling cost	238.35	($0.35/tree)*(681 trees)
Tree planting cost	204.30	($0.3/tree)*(681 trees)
Operation costs	CT[1]: 32.75 NT[2]: 21.00	Year(0) only These figures include soil preparation, seed planting, equipment, and labor costs.
Fertilizer	25.00	Year(0) only
Mowing	14.00	Annually ($7 each time and twice a year)
Pruning	85.00	Pruned in year 20, 30, 40, and 50

1: CT stands for conventional tillage
2: NT stands for No-tillage
3: The price of Birdsfoot trefoil is $2.25/lb., and we need 6lb/acre. The price of Kentucky bluegrass is $3.2/lb., and 2lb./acre of this grass need to be mixed with Birdsfoot trefoil.

Table 4.3 Values of variable used in NPV analysis.

Stumpage prices and erosion rates are calculated for each soil association. Tree species that grow in each soil association were obtained from soil surveys. The average prices of several of the most valuable trees are used for NPV calculations. Soil information obtained from county NRCS offices were used to calculate average USLE for each soil association. Table 4.4 shows the value of stumpage prices and erosion rates.

Soil Associations	Stumpage prices ($/1000 board feet)	USL4E (tons/acre)
S1	339.4	3.41
S2	358.0	2.49
S3	339.4	1.06
S4	313.0	1.68
S5	399.5	1.68
S6	314.0	3.59
S7	405.5	2.39
S8	248.8	3.07
S9	418.5	15.3
S10	356.0	2.49
S11	356.0	2.29
S12	360.0	1.37
S13	450.6	5.7
S14	422.5	1.64

Table 4.4: Stumpage prices and USLE for each soil association

4.5 Effectiveness of Riparian Forest Buffers

Very effective performance of riparian forest buffers has been reported by many scientists, yet the effectiveness can be influenced by many known and unknown factors. Because effectiveness of riparian forest buffers affects costs, how the costs will vary depending on the different effectiveness need to be studied. Ranges of effectiveness reported on literature are 59 to 95%. This wide range is results of different slopes, quality of vegetation on buffers, intensity of rainfalls, etc. In order to incorporate the effects of slopes and some other unknown factors on effectiveness of buffers, five different effectiveness of buffers, 60%, 70%, 80%, 90%, and 95% will be used.

4.6 Calculating Cost Per Ton of Reduced Soil Erosion

Costs per ton of reducing soil erosion are calculated for each soil association group using the formula (2) in section 2.4.

4.7 Sensitivity Analyses

In order to determine how the cost per ton of a riparian forest buffer vary depending on different circumstances, some sensitivity analyses need to be conducted.

One of the known factors that influences the effectiveness of the buffers is the size of the field or the drainage area. As a drainage area increases, the effectiveness of the buffer decreases. One method for keeping the effectiveness of buffers constant is to fix the proportion of buffers to the total drainage areas. In the case of 50-acre representative fields, F_A (2178 x 1000), the proportion of buffers is 5%. Therefore, when sensitivity analysis is done for larger acres of lands, and the proportion of buffer will be set to at 5%. Table 4.5 and figure 4.2 show the design of fields and buffers for three different sizes of lands.

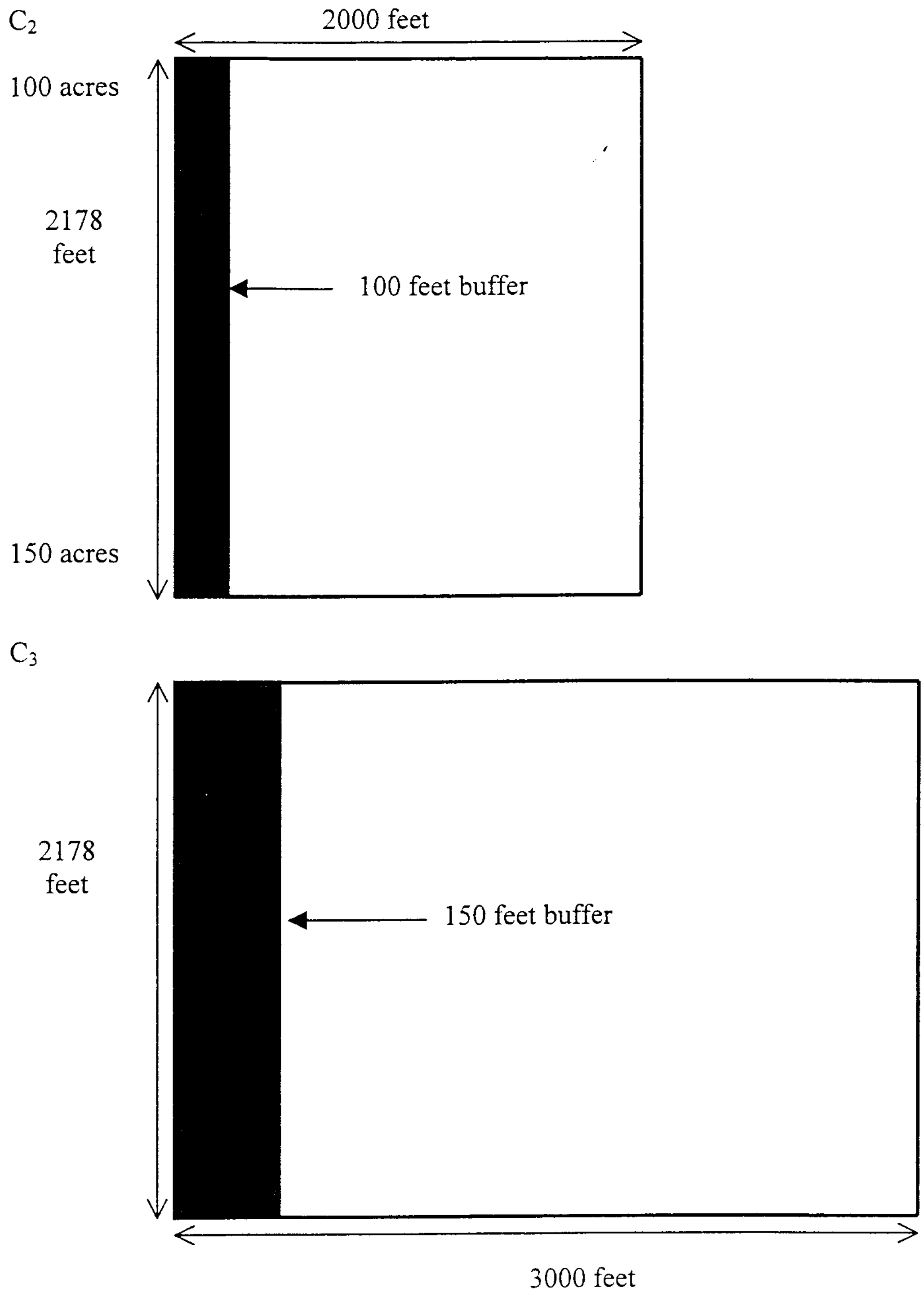

Figure 4.2: Designs of fields and RFBs

Cases	Field size (acres)	Field shapes	Riparian Forest Buffer Sizes				
			Widths (feet)	Total	I	II	III
C_1 (= F_A)	50	2178 x 1000	50	2.5	0.75	0.75	1.0
C_2	100	2178 x 2000	100	5.0	0.75	3.25	1.0
C_3	150	2178 x 3000	150	7.5	0.75	5.75	1.0

Table 4.5 Designs of lands and RFBs

No matter what the total width of buffers, the widths of zone I and III are set to 15 feet and 20 feet respectively. When the total width of a buffer is greater than 50 feet, such as C_2 and C_3, the width of zone II is adjusted to meet the total width of the buffer.

There is another way to analyze the sensitivity of both field size and effectiveness. In stead of holding the proportion of riparian forest buffer to the drainage area the same, one can hold the width of the buffer to 50 feet for any size of drainage ,and increase the drainage area . For instance, starting from a 50-acre field with the dimension of 2178 x 1000, size of the field will be increased by 5 acres—setting the dimension of the additional 5 acres to 2178 x 100 (figure 4.3). Therefore, the dimension of 55 acres is 2178 x 1100. In the same way, the dimension of 60 acres is specified to 2178 x 1200. As the size of field increase by 5 acres, the effectiveness of a riparian forest buffer is expected to decline, yet we do not know exactly by how much the effectiveness will be affected by the additional acres. In order to see the relationship between land sizes and effectiveness of buffers, 5 different percentage declines, (1%, 2%, 3%, 4%, and 5%), in the effectiveness as the size of field increases by 5 acres can be tested. By doing this analysis, how the costs of riparian forest buffer are effected by the declining effectiveness due to the increased field sizes can be tested.

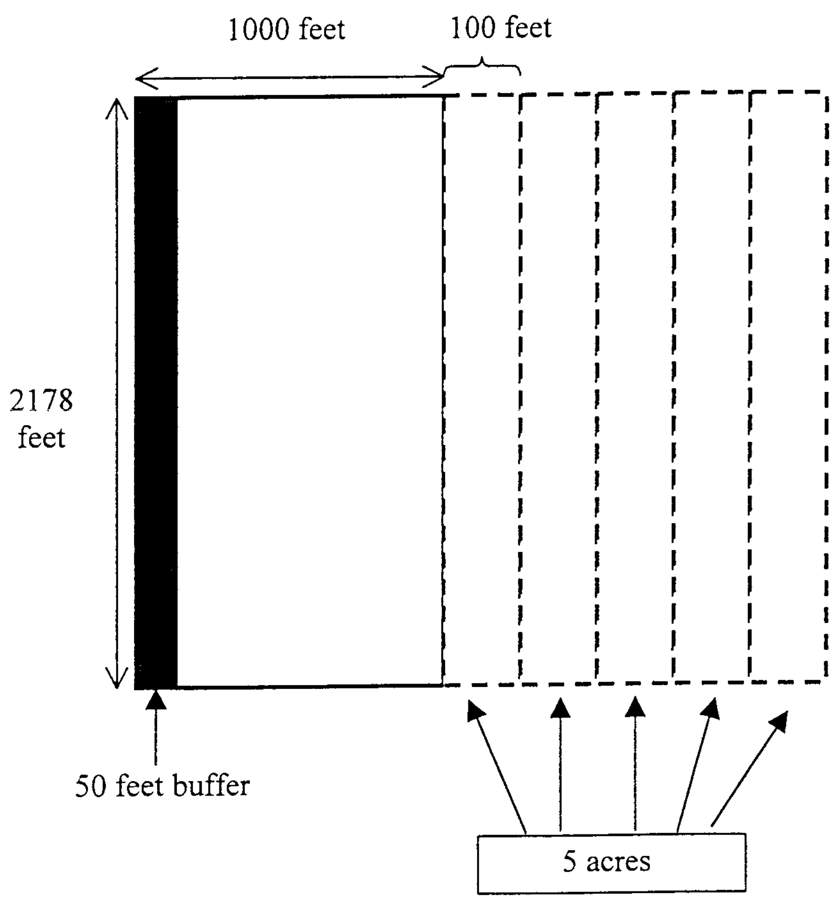

Figure 4.3: Design of different sizes of fields with a 50 Feet RFB

Last sensitivity analysis will be done for the option of tree harvesting. The value used in the basic analysis assumes optimal tree growth. One may actually have to wait 30 years to start harvesting trees, so one of options is to start harvesting trees from year 30 and after that harvest trees every 15 years. Also, if one desires, he or she does not have to harvest any trees. Therefore, how the costs will be affected if the owner decides not to harvest any trees on 50-acre representative fields will be also investigated. Tree harvesting options considered are:

1. Harvest every 15 years starting from year 15.
2. Harvest every 15 years starting from year 30.
3. No tree harvest.

CHAPTER 5

RESULTS

5.1 Hedonic Pricing Analysis and Rents

A linear regression model with no constant was used to estimate the coefficients of the independent variables. Because some tests suggested the existence of heteroscedasticity, weighted least square was used instead of the OLS estimation. Total acres of parcels were used as the weight. Table 5.1 shows the results of hedonic analysis.

Variables	Estimated coefficients	p-values
I50	1213.00	0.001
I60	1223.10	0.000
I70	1435.50	0.000
I80	1814.50	0.000
I90	2209.50	0.000
DW	17.48	0.000
DB	23168.00	0.003

(Adjusted R^2=0.4584)

Table 5.1: Regression results

Using the estimated coefficients for PIs, the marginal values and rents of 14 soil association were calculated. Table 5.2 shows the results.

Soil Associations	PI ranges	Mean PIs	Value ($)	Rents ($) r = 0.05
S1	54 - 84	66.83	1279.69	63.98
S2	60 - 85	75.00	1484.21	77.21
S3	75 - 77	77.00	1556.50	77.82
S4	59 - 100	78.20	1602.15	80.11
S5	69 - 98	81.42	1723.91	86.20
S6	52 - 84	72.75	1412.84	70.64
S7	68 - 84	76.33	1529.86	76.49
S8	50 - 69	53.37	1214.00	60.70
S9	56 - 83	73.58	1340.59	67.03
S10	72 - 84	79.00	1632.59	81.63
S11	68 - 80	73.30	1423.93	71.20
S12	73 - 84	78.63	1617.37	80.87
S13	56 - 77	70.58	1364.02	68.20
S14	70 - 100	81.10	1674.45	83.72

Table 5.2: Calculated values of marginal acres of land

Table 5.2 suggests that the S5: Colwood-Kibbie-(Bixer) association is the most valuable soil type, and that the S8: Paulding-Roselms association is the least valuable soil type on average in the study area. S5 can be found in small portions in northern Henry

County, northwest Fulton County, western Paulding County. S8 is one of the major soil types in the region spreading to the east half of Paulding county and a great portion of Defiance County (figure 3.2).

5.2 Total Costs

The costs of converting croplands to riparian forest buffers were calculated for all 14 soil associations. Total costs consist of three different components. Figure 5.1 shows the proportion of each components. As predicted, rent is the major part of the total costs followed by installment costs. Maintenance costs constitute only 7% of the total costs.

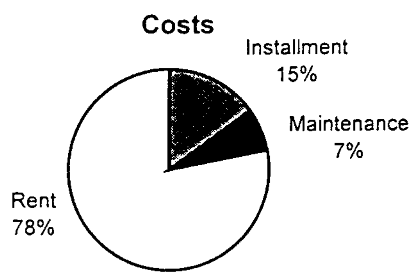

Figure 5.1: Components of Total cost

5.3 Representative fields

5.3.1 Soil Associations

In this section, the results of the most common soil associations in the study area, S2: Hoytville-Nappanee-(Blount), in NW Ohio will be discussed. This soil types covers approximately 34% of the study area, and it is used to produce corn and soybeans in most of the counties (figure 3.2). The characteristics of this association are: very poorly drained, nearly level to gently sloping, 2-6% (Flesher, Jr. et al. 1974). The results of all of the other soil associations are in Appendix A1. Equation (3), (4), and (5) from section 4.3 were used to calculate the cost of riparian forest buffers. All the values of variables in these equations are shown in table, 4.3, 4.4, and 5.2.

		Costs of Riparian Forest Buffer Zones ($)			
Fields	**Tillage types**	**I**	**II**	**III**	**Total**
F_A[1]	CT	1459.96	1402.28	1835.62	4337.85
	NT	1459.96	1402.28	1823.87	4326.10
F_B[2]	CT	669.63	478.06	842.55	1990.24
	NT	669.63	478.06	837.16	1984.85

1: F_A is (2178 x 1000) field
2: F_B is (1000 x 2178) field
CT: Conventional tillage
NT: No-till

Table 5.3: Costs of riparian forest buffers

Table 5.3 shows the results of discounted costs of riparian forest buffers. Differences between CT and NT for both F_A and F_B are seen only in zone III. The cost is lower when NT is used on the land to convert a cropland to a riparian forest buffer. The total NPV for F_B is 54.12% less than the total NPV of F_A. This difference resulted from the difference in total size of riparian forest buffer. Total size of buffer in F_B, 1.147 acres, is 54.12% less than the buffer size for F_A, which is 2.5 acres.

The total costs and AEA were used to obtain the cost/acre and cost/ton of using riparian forest buffers for five different effectiveness of buffers. The results are shown in table 5.4.

Fields	Tillage	Total Cost ($)	Cost/acre of total cost ($)	AEA* ($)	Cost/ton ($)				
					Effectiveness of RFBs				
					60%	70%	80%	90%	95%
F_A	CT	4337.85	1735.14	229.04	3.07	2.63	2.30	2.04	1.94
	NT	4326.10	1730.44	228.42	9.56	8.19	7.17	6.37	6.06
F_B	CT	1990.24	1735.17	105.09	1.41	1.21	1.06	0.94	0.89
	NT	1984.85	1730.47	104.80	4.38	3.76	3.29	2.92	2.77

*AEA stands for annual equivalent amount

Table 5.4: Costs per acre and costs per ton of reduced soil erosion on S2

Table 5.4 shows the cost/acre and cost/ton of riparian forest buffers in field F_A and F_B for both CT and NT. When the cost per acre is used to calculate costs of riparian forest buffer, there is only one value for each type of field can be obtained because this unit ignores the performance levels of the buffer. Results show that the costs per acre with CT system are greater than NT, and different shapes of field have no effect on costs per acre. On the other hand, when cost per ton is used, it can be calculated for different levels of effectiveness of buffer. Unlike the results from cost/acre, reducing soil erosion on fields that use NT system cost about 3 time as much as fields that use CT. This is because land with no-till system reduces the erosion rate by 68%, so additional erosion reduction by the buffer is only 30.4% of total erosion rate on the field. The shapes of buffer also affect costs. Both fields F_A and F_B set aside 50 feet for the riparian forest buffers, but because the total size of the buffer is greater for F_B, the cost/ton is higher.

Five different levels of effectiveness of riparian forest buffers were used to find out how effectiveness influences costs. As effectiveness dropped from 95% to 90%, cost/ton increased by 4.97% on the average. As effectiveness dropped from 90 to 80%, 80 to 70%, 70 to 60%, the average costs increased by 11.22%, 12.48%,14.28%, respectively. This result indicates that percent change in cost/ton is greater than the percent change in effectiveness of riparian forest buffers. See appendix A1 for changes in costs for all 14 soil associations.

5.3.2 Productivity Indices

The same analysis was done using the coefficients of each productivity indexes. This analysis shows ranges in costs of using riparian forest buffer for soil erosion abatement in the study area. Using the estimated coefficients for PIs, the marginal values and rents of 7 different levels of Productivity Indexes were calculated. Table 5.5 shows the calculated values of marginal acre of land and rents.

PI levels	Values ($)	Rents ($)
40	1202.76	60.14
50	1211.16	60.56
60	1219.56	60.98
70	1350.70	67.54
80	1670.64	83.53
90	2036.62	101.83
100	2392.80	119.64

Table 5.5: Calculated values of marginal acre of land and rents for different levels of Productivity Indexes

Because there is no specific erosion rate attached to the level of productivity indices, the average soil erosion rate, 3.439 ton/acre/year, and the average stumpage price, $371.5 per thousand board feet, are used for all the soil types. Table 5.5 shows the average costs per ton, (average of F_A-CT, F_A-NT, F_B-CT, and F_B-NT), of reduced soil erosion. This table will help to see the ranges of costs in using riparian forest buffers for soil erosion abatement.

PIs	Average total costs ($)	Average cost/acre ($)	Average AEF ($)	Average Cost/ton of reduced soil erosion ($)				
				Effectiveness of RFB				
				60%	70%	80%	90%	95%
40	2635.40	1445.25	139.15	$2.78	$2.38	$2.08	$1.85	$1.76
50	2650.67	1453.62	139.96	2.80	2.40	2.10	1.86	1.77
60	2665.93	1461.99	140.76	2.81	2.41	2.11	1.87	1.78
70	2904.22	1592.67	153.34	3.06	2.63	2.30	2.04	1.93
80	3485.57	1911.48	184.05	3.68	3.15	2.76	2.45	2.32
90	4150.57	2276.16	219.15	4.38	3.75	3.28	2.92	2.77
100	4797.77	2631.08	253.32	5.06	4.34	3.80	3.37	3.20

Table 5.6: Average Costs per ton of RFB for different levels of productivity indexes

5.4 Regional Differences

From appendix A1, the average costs of reduced soil erosion at 95% effectiveness were calculated for all 14 soil associations. Table 5.7 shows the results.

Using this table, we can identify regions with high and low costs of soil erosion abatement using riparian forest buffers. On the average, S3: Toledo association, is the soil type with the highest cost in reducing soil erosion using riparian forest buffers. S3 exists in the northern part of Wood County, right outside of the city of Toledo in Lucas County. The next expensive soil type is S12: Genesee-Sloan-Shoals-Eel associations. S12 can be found along the Maumee River in Defiance County and Paulding County. It can be also found along the Tiffin River in Williams County and Fulton County (figure 2.3).

Ranks*	Soil Associations	Average cost/ton ($)
1	S3	7.15
2	S12	5.69
3	S5	4.85
4	S14	4.81
5	S4	4.66
6	S10	3.17
7	S7	3.06
8	S11	3.05
9	S2	2.91
10	S8	2.07
11	S6	1.96
12	S1	1.89
13	S13	1.15
14	S9	0.45

*Ranks: 1 - most expensive, 14 - least expensive

Table 5.7: Average costs per ton of RFB for 14 soil associations

The lowest cost can be achieved in region with S9: Blount-Glynwood-(Pewamo). S9 spreads to the northwest side of the study area covering major part of Williams County and northwest Defiance County and Fulton County. S9 covers both sides of the St. Joseph River. Second lowest soil type is S13: Glynwood-Rawson-Blount association. S13 covers northwest part of Williams County (figure 3.2). It seems riparian forest buffers can be adopted at low costs in a majority part of Williams County.

Results based on costs per ton of reduced soil erosion can be compared to the results based on cost per acre to see if there are any differences. Table 5.8 shows the average costs per acre, (average of F_A-CT, F_A-NT, F_B-CT, and F_B-NT), for 14 soil associations.

Ranks*	Soil Association	Average cost/acre ($)
1	S5	1949.82
2	S14	1888.43
3	S10	1881.72
4	S4	1874.02
5	S12	1864.45
6	S3	1814.63
7	S7	1753.30
8	S2	1732.80
9	S6	1684.85
10	S11	1673.80
11	S9	1647.54
12	S13	1564.31
13	S1	1538.80
14	S8	1521.02

*Ranks: 1-most expensive, 14-least expensive

Table 5.8: Average costs per acres of RFB for 14 soil associations

The most expensive soil type using costs per acre is S5: Colwood-Kibbie-(Bixer) association. This soil is also the most valuable soil in the study area (table 5.2). The least expensive soil type is S8: Paulding-Roselms association. S8 is the least valuable soil type in the study area as well (table 5.2).

Although ranking of costs differ between costs per acre and costs per ton of reduced soil erosion, 7 high cost soil associations and 7 low cost soil associations were the same. The seven high cost soil associations are S3, S4, S5, S7, S10, S12, and S14, and the seven low cost soil associations are S1, S2, S6, S8, S9, S11, and S13, based on the results using both cost/acre and cost/ton. Therefore, if funding is allocated to 7 low cost regions, costs per acre and costs per ton do not result in different resource allocations. However, if only three region receive funding, uses of costs per acre lead to an inefficient resource allocation to S8 instead of S9.

5.5 Sensitivity Analyses

All of the sensitivity analysis was done for all soil associations, but the discussion here is focused on the S2: Hoytville-Nappanee-(Blount) association. In order to see the effects of widths and sizes of fields on costs, the costs of three different sizes of fields (50, 100, and 150 acres), for which 5% of total areas are set aside for riparian forest buffers were calculated (appendix A1 for 50 acres and A2 for 100, and A3 for 150 acres). Effectiveness of buffer was assumed to be 95%. The dimensions of fields and the size of each buffer zone are shown in table 4.5 in section 4.7. Table 5.9 shows the results on S2 soil.

Tillage	50 acres	100 acres	150 acres
CT	1.94	1.74	1.68
NT	6.04	5.44	5.24

(95% effectiveness)

Table 5.9: Costs per ton of S2 with different field sizes (95% effectiveness)

As the size of field becomes larger from 50 acres to 100 acres, cost/ton drops by 11.74% for CT and 11.03% for NT. An additional 50 acres lowers cost/ton by 3.57% for CT and 3.82 for NT. This result shows that even if the same percentage of land is used for riparian forest buffers, it costs less with a larger field. These results are only valid with the shape of field used in this sensitivity analysis. It would have had different results if the another shape of field was used. This result will be compared to the following sensitivity analysis.

Next, instead of changing the widths of riparian forest buffers, as a field becomes larger, the width of the buffer was kept to 50 feet. The same shape of field was used for this analysis to be able to make some comparisons with the preceding sensitivity analysis. Table 5.7 was created basting on the results of F_A-CT in table 5.4, which is a 50-acre field with S2 that uses conventional tillage for cultivation. Because the relationship between the size of the buffer and the total field size is not clear, five different cases in declining order of effectiveness, 1%, 2%, 3%, 4%, 5%, as field sizes increases by 5 acres were tested. Table 5.10 shows the sizes of fields, proportions of buffer, and costs per ton of reduced soil erosion as effectiveness of buffer decreases by 5 different percentages starting from 95%, as field sizes increase by 5 acres. The lowest cost/ton in each case is highlighted. If declines of effectiveness is 1%, costs of the buffer keep decreasing. When the effectiveness decreases by 2%, the costs decrease until the field size increases to 145 acres, but start increasing after that point. Although field size 135, 140, 145, 150 have the same cost, $1.11, at 145 acres the cost is lowest before the cost is rounded up. In the case of 3% effectiveness decline, the costs decrease until 105 acres, then the costs start going up as field size become bigger than 105 acres. If effectiveness decreases by 4%, a 50-foot riparian forest buffer should be used on an 85-acre field because the cost is the lowest before the costs were rounded up. When the effectiveness decreases by 5%, cost at 70 acres and 75 acres, exactly $1.75/ton, are the same and they are the lowest costs. Costs at 65 acres and 80 acres are the same as well, $1.77/ton. Therefore, cost would be the lowest at 72.5 acres. Costs start going up from 72.5 acres, rapidly increase from 120 acres.

These results can be compared with the results from appendix A3 which shows the costs of reduced soil erosion on 100 and 150 acres of lands of which 5% of their lands is used as riparian forest buffers.

Acres	Proportion of RFB (%)	Percent declines in effectiveness of RFBs									
		1%		2%		3%		4%		5%	
		$/ton	E*	$/ton	E*	$/ton	E*	$/ton	E*	$/ton	E*
50	5.00	1.94	95	1.94	95	1.94	95	1.94	15	1.94	95
55	4.55	1.78	94	1.80	93	1.82	92	1.84	19	1.86	90
60	4.17	1.65	93	1.68	91	1.72	89	1.76	23	1.80	85
65	3.85	1.54	92	1.59	89	1.65	86	1.70	27	1.77	80
70	3.57	1.44	91	1.51	87	1.58	83	1.66	31	**1.75**	75
75	3.33	1.36	90	1.44	85	1.53	80	1.64	35	**1.75**	70
80	3.13	1.29	89	1.39	83	1.49	77	1.62	39	1.77	65
85	2.94	1.23	88	1.34	81	1.46	74	**1.62**	43	1.80	60
90	2.78	1.17	87	1.29	79	1.44	71	1.62	47	1.86	55
95	2.63	1.13	86	1.26	77	1.42	68	1.64	51	1.94	50
100	2.50	1.08	85	1.23	75	1.42	65	1.67	55	2.04	45
105	2.38	1.04	84	1.20	73	**1.41**	62	1.72	59	2.19	40
110	2.27	1.01	83	1.18	71	1.42	59	1.78	63	2.39	35
115	2.17	0.98	82	1.16	69	1.43	56	1.86	67	2.67	30
120	2.08	0.95	81	1.14	67	1.45	53	1.97	71	3.07	25
125	2.00	0.92	80	1.13	65	1.47	50	2.10	75	3.50	20
130	1.92	0.90	79	1.12	63	1.51	47	2.28	79	4.18	15
135	1.85	0.87	78	1.12	61	1.55	44	2.52	83	6.81	10
140	1.79	0.85	77	1.11	59	1.60	41	2.86	87	13.14	5
145	1.72	0.83	76	**1.11**	57	1.67	38	3.34	91	-----	0
150	1.67	**0.82**	75	1.11	55	1.75	35	4.09	95	-----	0

*E stands for Effectiveness

Table 5.10: Changes in costs as field sizes increase by 5 acres

	Table 5.9*	Percent declines in effectiveness of RFBs				
		1%	2%	3%	4%	5%
RFB sizes (acres)	5.0	2.5	2.5	2.5	2.5	2.5
Proportion of RFB (%)	5.0	2.27	2.27	2.27	2.27	2.27
Cost/ton ($)	1.74	1.08	1.23	1.42	1.67	2.04
Effectiveness (%)	95	85	75	65	55	45

* Result from table 5.9 on 100 acres

Table 5.11: Comparison of costs at 100 acres

Table 5.11 shows the changes in cost/ton as effectiveness of a 2.5-acre buffer declines from 85% to 45%. We can compare this result to the cost/ton of a 100-acre field with a 5-acre buffer. From table 5.6, it costs $1.74/ton at 95% effectiveness. This means that on a 100-acre field, it is cheaper to have a 2.5-acre buffer with 55% effectiveness than a 5-acre buffer with 95% effectiveness. However, a 5-acre buffer with 95% effectiveness is cheaper than a 2.5-acre buffer with 45 % effectiveness. The same comparison can be done for 150 acres (table 5.12).

When the size of the field is 150 acres, a 5-acre buffer with 95% effectiveness is more expensive than a 2.5-acre buffer with 55% effectiveness, but it is cheaper than a 2.5-acre buffer with 35% effectiveness. These comparisons suggest that it is not necessarily economically efficient to install a larger size buffer in order to ensure a high effectiveness of riparian forest buffer.

150 acres	Table 5.9*	Percent declines in effectiveness of RFBs				
		1%	2%	3%	4%	5%
RFB sizes (acres)	7.5	2.5	2.5	2.5	2.5	2.5
Proportion of RFB (%)	5.0	1.67	1.67	1.67	1.67	1.67
Cost/ton	1.68	0.82	1.11	1.75	4.09	-----
Effectiveness (%)	95	75	55	35	15	0

* Results from table 5.9 on 150 acres

Table 5.12: Comparison of costs at 150 acres

Finally, sensitivity analysis is done for tree harvesting options using representative field F_A and F_B. The options are explained in section 4.7. Results shown here is on S2 table 5.13), and results for all different soil associations are shown in appendix A4.

On average, cost/ton increases 5.98% from option 1 to 2, when option 3 was chosen instead of 1, cost/ton increase by 11.01%. The cost per ton of option 3 is 4.74% more than option 2. Zone II is 30% of total riparian forest buffer area, 1.5% of total field size for F_A, and 0.696% of F_B. This analysis shows that management on zone II can affect costs of reduced soil erosion greatly even though it is a very small area.

Field	Tillage	Option 1	Option 2	Option 3
F_A	CT	$1.94	$2.05	$2.15
	NT	6.04	6.40	6.69
F_B	CT	0.89	0.94	0.98
	NT	2.77	2.93	3.07

(95% effectiveness of RFBs)

Table 5.13: Costs per ton for different timber harvest options

All these sensitivity analyses raise a need for more accurate information on effectiveness of riparian forest buffers. Also, because costs of reduced soil erosion are influenced by so many factors, costs should be calculated for each specific site.

5.6 Conclusion

Costs of soil erosion abatement using riparian forest buffers in six counties within Maumee River basin was estimated. Information provided in agricultural land sale sheets were used to estimate prices of land using hedonic pricing analysis. Results of hedonic pricing analysis were used to calculate rents of 14 soil associations. Costs of reduced soil erosion were calculated in terms of cost/ton to incorporate efficiency of riparian forest buffers.

Results of this research provide some useful information to policy makers. NPV analysis indicates that rent is the major component of riparian forest buffer costs, and values of rents vary across the Maumee River basin. The S5: Colwood-Kibbie-(Bixer) association is the most valuable soil type, and the S8: Paulding-Roselms association is the least valuable soil type in the study area.

Costs of riparian forest buffers are influenced by many factors. Tillage practices used on fields affect the costs of buffers. A riparian forest buffer on the edge of a field that is cultivated with the NT system costs approximately 3 times more than a field cultivated with the CT system. This is because soil erosion reduced by buffers on land with NT system is approximately 1/3 of the amount reduced by buffers on land with CT system. This results suggest that targeting resources to fields which are owned by farmers who have already adopted some kind of soil conservation practice is less efficient than targeting resources to field which is cultivated by CT system. Field shapes also affect the costs of buffers because that affect the proportion of the buffer to the total size of the field. Generally, it costs less if the proportion of the buffer to the field is smaller, provided that the effectiveness of buffers remains the same.

Regional comparison of costs revealed that installation of a riparian forest buffer on Toledo soil association is considerably expensive, whereas some practice on Blount-Glynwood-Pewamo association could be done at very low costs. The ranking of costs among soil association within the study area can be used to determine areas for targeting of funding.

The effectiveness of buffers is one of the most critical factors that influence the costs of buffers, yet the relationship between the effectiveness of a buffer and the characteristics of buffers, such as width and type of vegetation are ambiguous. Costs per ton of reduced soil erosion calculated with 5 different levels of effectiveness suggest that percent change in the costs is greater than percent change in the effectiveness of the buffer.

Sensitivity analysis on relationship between sizes of land and effectiveness indicated that a greater economic efficiency is not necessarily achieved with a large highly effective buffer. A greater economic efficiency can be achieved with a small riparian forest buffer at lower effectiveness on a certain size of field.

All these analyses indicate that cost/ton of reduced soil erosion using riparian forest buffers should be calculated for each specific site because many factors affect the outcomes.

APPENDIX

Soil[1] – Field[2] –Tillage[3]	Total costs ($)	AEA ($)	Cost per acre ($)	Cost per ton ($)				
				Effectiveness of RFB				
				60%	70%	80%	90%	95%
S1- F_A - CT	$3852.83	$203.43	$1541.13	$1.99	$1.70	$1.49	$1.33	$1.26
S1- F_A - NT	3841.08	202.81	1536.43	6.20	5.31	4.65	4.13	3.91
S1- F_B - CT	1767.71	93.34	1541.16	0.91	0.78	0.68	0.61	0.58
S1- F_B - NT	1762.32	93.05	1536.46	2.84	2.44	2.13	1.89	1.80
S2 - F_A - CT	4337.85	229.04	1735.14	3.07	2.63	2.30	2.04	1.94
S2 - F_A - NT	4326.10	228.42	1730.44	9.56	8.19	7.17	6.37	6.04
S2 - F_B - CT	1990.24	105.08	1735.17	1.41	1.21	1.06	0.94	0.89
S2 - F_B - NT	1984.85	104.80	1730.47	4.38	3.76	3.29	2.92	2.77
S3 - F_A - CT	4542.41	239.84	1816.97	7.54	6.46	5.66	5.03	4.76
S3 - F_A - NT	4530.66	239.22	1812.27	23.51	20.15	17.63	15.67	14.85
.S3 - F_B - CT	2084.09	110.04	1816.99	3.46	2.97	2.60	2.31	2.19
S3 - F_B - NT	2078.70	109.76	1812.29	10.79	9.24	8.09	7.19	6.81
S4 - F_A - CT	4690.89	247.68	1876.36	4.91	4.21	3.69	3.28	3.10
S4 - F_A - NT	4679.14	247.06	1871.66	15.32	13.13	11.49	10.21	9.67
S4 - F_B - CT	2152.21	113.64	1876.38	2.25	1.93	1.69	1.50	1.42
S4 - F_B - NT	2146.81	113.35	1871.68	7.03	6.02	5.27	4.69	4.44
S5 - F_A - CT	4880.38	257.68	1952.15	5.11	4.38	3.83	3.41	3.23
S5 - F_A - NT	4868.63	257.06	1947.45	15.94	13.66	11.95	10.63	10.07
S5 - F_B - CT	2239.16	118.23	1952.19	2.35	2.01	1.76	1.56	1.48
S5 - F_B - NT	2233.77	117.94	1947.49	7.31	6.27	5.48	4.88	4.62
S6 - F_A - CT	4217.96	222.71	1687.18	2.07	1.77	1.55	1.38	1.31
S6 - F_A - NT	4206.21	222.09	1682.48	6.44	5.52	4.83	4.30	4.07
S6 - F_B - CT	1935.23	102.18	1687.21	0.95	0.81	0.71	0.63	0.60
S6 - F_B - NT	1929.83	101.90	1682.50	2.96	2.53	2.22	1.97	1.87
S7 - F_A - CT	4389.09	231.74	1755.63	3.23	2.77	2.42	2.15	2.04
S7 - F_A - NT	4377.34	231.12	1750.93	10.07	8.63	7.56	6.72	6.36
S7 - F_B - CT	2013.75	106.33	1755.67	1.48	1.27	1.11	0.99	0.94
S7 - F_B - NT	2008.36	106.04	1750.97	4.62	3.96	3.47	3.08	2.92
S8 - F_A - CT	3808.42	201.08	1523.37	2.18	1.87	1.64	1.46	1.38
S8 - F_A - NT	3796.67	200.46	1518.67	6.80	5.83	5.10	4.53	4.30
S8 - F_B - CT	1747.32	92.26	1523.38	1.00	0.86	0.75	0.67	0.63
S8 - F_B - NT	1741.92	91.97	1518.68	3.12	2.67	2.34	2.08	1.97

(Continue)

1: Soil association
2: Field shapes
3: Tillage system

Table A.1: Costs of RFB for 14 soil associations

(Continued)

Soil[1] – Field[2] –Tillage[3]	Total costs ($)	AEA ($)	AEA ($)	Cost per ton ($)				
				Effectiveness				
				60%	70%	80%	90%	95%
S9 - F_A - CT	$4124.68	$217.78	1649:87	$0.47	$0.41	$0.36	$0.3	$0.30
S9 - F_A - NT	4112.93	217.16	1645.17	1.48	1.27	1.11	2	0.93
S9 - F_B - CT	1892.45	99.92	1649.91	0.22	0.19	0.16	0.99	0.14
S9 - F_B - NT	1887.05	99.64	1645.21	0.68	0.58	0.51	0.15	0.43
							0.45	
S10 - F_A - CT	4710.14	248.70	1884.06	3.34	2.87	2.51	2.23	2.11
S10 - F_A - NT	4698.39	248.07	1879.36	10.42	8.93	7.81	6.95	6.58
S10 - F_B - CT	2161.04	114.10	1884.08	1.53	1.31	1.15	1.02	0.97
S10 - F_B - NT	2155.65	113.82	1879.38	4.78	4.10	3.59	3.19	3.02
S11 - F_A - CT	4190.34	221.25	1676.13	3.22	2.76	2.42	2.15	2.03
S11 - F_A - NT	4178.59	220.63	1671.43	10.04	8.60	7.53	6.69	6.34
S11 - F_B - CT	1922.56	101.51	1676.16	1.48	1.27	1.11	0.99	0.93
S11 - F_B - NT	1917.17	101.23	1671.46	4.60	3.95	3.45	3.07	2.91
S12 - F_A - CT	4666.96	246.42	1866.78	6.00	5.14	4.50	4.00	3.79
S12 - F_A - NT	4655.21	245.80	1862.08	18.69	16.02	14.02	12.4	11.80
S12 - F_B - CT	2141.24	113.06	1866.81	2.75	2.35	2.06	6	1.73
S12 - F_B - NT	2135.84	112.77	1862.11	8.57	7.35	6.43	1.83	5.42
							5.72	
S13 - F_A - CT	3916.59	206.80	1566.64	1.21	1.04	0.91	0.81	0.76
S13 - F_A - NT	3904.84	206.18	1561.94	3.77	3.23	2.83	2.51	2.38
S13 - F_B - CT	1796.98	94.88	1566.68	0.55	0.48	0.42	0.37	0.35
S13 - F_B - NT	1791.59	94.60	1561.98	1.73	1.48	1.30	1.15	1.09
S14 - F_A - CT	4726.90	249.58	1890.76	5.07	4.35	3.80	3.38	3.20
S14 - F_A - NT	4715.15	248.96	1886.06	15.81	13.55	11.86	10.5	9.99
S14 - F_B - CT	2168.75	114.51	1890.80	2.33	1.99	1.75	4	1.47
S14 - F_B - NT	2163.35	114.22	1886.10	7.26	6.22	5.44	1.55	4.58
							4.84	

1: Soil association
2: Field shapes
3: Tillage system

PI^1 – $field^2$ – $tillage^3$	Total ($)	AEA ($)	$/acre	Costs per ton ($)				
				Effectiveness of RFBs				
				60%	70%	80%	90%	95%
40 - F_A- CT	$3618.96	$191.08	$1447.58	$1.85	$1.59	$1.39	$1.23	$1.17
40 - F_A- NT	3607.21	190.46	1442.88	5.77	4.94	4.33	3.85	3.64
40 - F_B- CT	1660.42	87.67	1447.62	0.85	0.73	0.64	0.57	0.54
40 - F_B- NT	1655.02	87.39	1442.91	2.65	2.27	1.99	1.76	1.67
50 - F_A- CT	3639.89	192.19	1455.95	1.86	1.60	1.40	1.24	1.18
50 - F_A- NT	3628.14	191.57	1451.25	5.80	4.97	4.35	3.87	3.66
50 - F_B- CT	1670.02	88.18	1455.99	0.85	0.73	0.64	0.57	0.54
50 - F_B- NT	1664.62	87.89	1451.28	2.66	2.28	2.00	1.77	1.68
60 - F_A- CT	3660.81	193.29	1464.33	1.87	1.61	1.41	1.25	1.18
60 - F_A- NT	3649.06	192.67	1459.63	5.84	5.00	4.38	3.89	3.69
60 - F_B- CT	1679.62	88.68	1464.36	0.86	0.74	0.64	0.57	0.54
60 - F_B- NT	1674.22	88.40	1459.65	2.68	2.30	2.01	1.79	1.69
70 - F_A- CT	3987.50	210.54	1595.00	2.04	1.75	1.53	1.36	1.29
70 - F_A- NT	3975.75	209.92	1590.30	6.36	5.45	4.77	4.24	4.02
70 - F_B- CT	1829.50	96.60	1595.03	0.94	0.80	0.70	0.62	0.59
70 - F_B- NT	1824.11	96.31	1590.33	2.92	2.50	2.19	1.94	1.84
80 - F_A- CT	4784.53	252.62	1913.81	2.45	2.10	1.84	1.63	1.55
80 - F_A- NT	4772.78	252.00	1909.11	7.63	6.54	5.72	5.09	4.82
80 - F_B- CT	2195.18	115.91	1913.84	1.12	0.96	0.84	0.75	0.71
80 - F_B- NT	2189.78	115.62	1909.14	3.50	3.00	2.63	2.33	2.21
90 - F_A- CT	5696.24	300.76	2278.50	2.92	2.50	2.19	1.94	1.84
90 - F_A- NT	5684.49	300.14	2273.80	9.09	7.79	6.82	6.06	5.74
90 - F_B- CT	2613.47	137.99	2278.53	1.34	1.15	1.00	0.89	0.84
90 - F_B- NT	2608.08	137.71	2273.83	4.17	3.58	3.13	2.78	2.63
100 - F_A- CT	6583.54	347.61	2633.42	3.37	2.89	2.53	2.25	2.13
100 - F_A- NT	6571.79	346.99	2628.72	10.51	9.01	7.88	7.01	6.64
100 - F_B- CT	3020.57	159.49	2633.45	1.55	1.33	1.16	1.03	0.98
100 - F_B- NT	3015.17	159.20	2628.75	4.82	4.13	3.62	3.21	3.05

1: Productivity Index level
2: Field shape
3: Tillage system

Table A.2: Costs of riparian forest buffer for 7 levels of productivity indexes

Soil[1] – Tillage[2]	Cost per ton ($)				
	Effectiveness				
	60%	70%	80%	90%	95%
S1-CT	$1.69	$1.45	$1.27	$1.13	$1.07
S1-NT	5.28	4.52	3.96	3.52	3.33
S2-CT	2.76	2.37	2.07	1.84	1.74
S2-NT	8.61	7.38	6.46	5.74	5.44
S3-CT	6.59	5.65	4.94	4.39	4.16
S3-NT	21.45	18.38	16.08	14.30	13.55
S4-CT	4.53	3.89	3.40	3.02	2.86
S4-NT	14.15	12.13	10.61	9.43	8.94
S5-CT	4.59	3.94	3.45	3.06	2.90
S5-NT	14.34	12.29	10.75	9.56	9.05
S6-CT	1.89	1.62	1.42	1.26	1.19
S6-NT	5.90	5.05	4.42	3.93	3.72
S7-CT	2.86	2.45	2.15	1.91	1.81
S7-NT	8.93	7.65	6.69	5.95	5.64
S8-CT	2.03	1.74	1.52	1.35	1.28
S8-NT	6.34	5.43	4.75	4.23	4.00
S9-CT	0.38	0.33	0.28	0.25	0.24
S9-NT	1.29	1.11	0.97	0.86	0.82
S10-CT	3.04	2.60	2.28	2.03	1.92
S10-NT	9.48	8.13	7.11	6.32	5.99
S11-CT	2.89	2.48	2.17	1.93	1.83
S11-NT	9.02	7.73	6.77	6.01	5.70
S12-CT	5.44	4.66	4.08	3.62	3.43
S12-NT	16.97	14.54	12.72	11.31	10.72
S13-CT	1.03	0.88	0.77	0.69	0.65
S13-NT	3.22	2.76	2.41	2.15	2.03
S14-CT	4.50	3.86	3.38	3.00	2.84
S14-NT	14.05	12.05	10.54	9.37	8.88

1: Productivity Index level
2: Tillage system

Table A.3: Costs of RFBs for 100 acre field with 5% of land used as RFB

Soil[1] – Tillage[2]	Cost per ton ($)				
	Effectiveness				
	60%	70%	80%	90%	95%
S1-CT	$1.71	$1.47	$1.28	$1.14	$1.08
S1-NT	5.34	4.58	4.01	3.56	3.37
S2-CT	2.66	2.28	1.99	1.77	1.68
S2-NT	8.30	7.12	6.23	5.53	5.24
S3-CT	6.31	5.41	4.74	4.21	3.99
S3-NT	19.71	16.90	14.78	13.14	12.45
S4-CT	4.41	3.78	3.31	2.94	2.78
S4-NT	13.76	11.80	10.32	9.17	8.69
S5-CT	4.42	3.79	3.32	2.95	2.79
S5-NT	13.80	11.83	10.35	9.20	8.72
S6-CT	1.83	1.57	1.37	1.22	1.16
S6-NT	5.71	4.90	4.28	3.81	3.61
S7-CT	2.74	2.35	2.05	1.82	1.73
S7-NT	8.54	7.32	6.41	5.70	5.40
S8-CT	1.98	1.70	1.49	1.32	1.25
S8-NT	6.18	5.30	4.64	4.12	3.91
S9-CT	0.39	0.34	0.30	0.26	0.25
S9-NT	1.23	1.05	0.92	0.82	0.78
S10-CT	2.94	2.52	2.20	1.96	1.85
S10-NT	9.17	7.86	6.88	6.11	5.79
S11-CT	2.78	2.38	2.09	1.85	1.76
S11-NT	8.68	7.44	6.51	5.79	5.48
S12-CT	5.25	4.50	3.94	3.50	3.32
S12-NT	16.41	14.06	12.31	10.94	10.36
S13-CT	0.97	0.83	0.73	0.65	0.61
S13-NT	3.04	2.60	2.28	2.02	1.92
S14-CT	4.31	3.70	3.23	2.88	2.72
S14-NT	13.47	11.54	10.10	8.98	8.50

1: Productivity Index level
2: Tillage system

Table A.4: Costs of RFBs for 150 acre field with 5% of land used as RFB

Soil[1] – Filed[2] – Tillage[3]	Cost per ton ($)			Percent increases in costs (%)		
	Options					
	1[4]	2[5]	3[6]	1 to 2[7]	2 to 3	1 to 3
S1 - F_A - CT	$1.26	$1.34	$1.40	6.36	4.92	11.59
S1 - F_A - NT	3.91	4.16	4.37	6.38	4.94	11.63
S1 - F_B - CT	0.58	0.61	0.64	6.35	4.92	11.59
S1 - F_B - NT	1.80	1.91	2.00	6.37	4.94	11.62
S2 - F_A - CT	1.94	2.05	2.15	5.95	4.63	10.86
S2 - F_A - NT	6.04	6.40	6.69	5.97	4.64	10.89
S2 - F_B - CT	0.89	0.94	0.98	5.95	4.63	10.86
S2 - F_B - NT	2.77	2.93	3.07	5.97	4.64	10.89
S3 - F_A - CT	4.76	4.98	5.23	4.61	5.00	9.83
S3 - F_A - NT	14.85	15.53	16.31	4.62	5.01	9.86
S3 - F_B - CT	2.19	2.29	2.40	4.60	4.99	9.83
S3 - F_B - NT	6.81	7.13	7.48	4.62	5.01	9.85
S4 - F_A - CT	3.10	3.25	3.38	4.81	3.78	8.78
S4 - F_A - NT	9.67	10.14	10.53	4.83	3.79	8.80
S4 - F_B - CT	1.42	1.49	1.55	4.81	3.78	8.78
S4 - F_B - NT	4.44	4.65	4.83	4.83	3.79	8.80
S5 - F_A - CT	3.23	3.42	3.58	5.91	4.59	10.77
S5 - F_A - NT	10.07	10.66	11.15	5.92	4.60	10.80
S5 - F_B - CT	1.48	1.57	1.64	5.90	4.59	10.77
S5 - F_B - NT	4.62	4.89	5.13	5.92	4.83	11.04
S6 - F_A - CT	1.31	1.38	1.43	5.37	4.20	9.80
S6 - F_A - NT	4.07	4.29	4.47	5.39	4.21	9.82
S6 - F_B - CT	0.60	0.63	0.66	5.37	4.20	9.79
S6 - F_B - NT	1.87	1.97	2.05	5.38	4.21	9.82
S7 - F_A - CT	2.04	2.18	2.29	6.67	5.15	12.16
S7 - F_A - NT	6.36	6.79	7.14	6.68	5.16	12.19
S7 - F_B - CT	0.94	1.00	1.05	6.66	5.15	12.15
S7 - F_B - NT	2.92	3.11	3.27	6.68	5.16	12.19

1: Productivity Index level

(Continue)

2: Field shape

3: Tillage system

4: Harvest every 15 years starting from year 15.

5: Harvest every 15 years starting from year 30.

6: No tree harvest

7: Percent change in cost as option changes from 1 to 2

Table A.4: Effects of timber harvest options on costs per ton

(Continued)

Soil[1] – Filed[2] – Tillage[3]	Cost per ton ($)			Percent increases in costs (%)		
	Options					
	1[1]	2[2]	3[3]	1 to 2[4]	2 to 3	1 to 3
S8 - F_A - CT	$1.38	$1.44	$1.50	4.71	3.71	8.60
S8 - F_A - NT	4.30	4.50	4.67	4.73	3.72	8.62
S8 - F_B - CT	0.63	0.66	0.69	4.71	3.71	8.59
S8 - F_B - NT	1.97	2.06	2.14	4.73	3.72	8.62
S9 - F_A - CT	0.30	0.32	0.34	7.32	5.62	13.35
S9 - F_A - NT	0.93	1.00	1.06	7.34	5.63	13.39
S9 - F_B - CT	0.14	0.15	0.16	7.32	5.62	13.35
S9 - F_B - NT	0.43	0.46	0.49	7.34	5.63	13.38
S10 - F_A - CT	2.11	2.23	2.32	5.45	4.26	9.95
S10 - F_A - NT	6.58	6.94	7.24	5.47	4.27	9.97
S10 - F_B - CT	0.97	1.02	1.06	5.45	4.26	9.94
S10 - F_B - NT	3.02	3.18	3.32	5.47	4.27	9.97
S11 - F_A - CT	2.03	2.16	2.26	6.13	4.76	11.18
S11 - F_A - NT	6.34	6.73	7.05	6.15	4.77	11.21
S11 - F_B - CT	0.93	0.99	1.04	6.13	4.76	11.18
S11 - F_B - NT	2.91	3.09	3.23	6.15	4.77	11.21
S12 - F_A - CT	3.79	4.00	4.17	5.57	4.34	10.15
S12 - F_A - NT	11.80	12.46	13.00	5.58	4.35	10.18
S12 - F_B - CT	1.74	1.83	1.91	5.56	4.34	10.15
S12 - F_B - NT	5.42	5.72	5.97	5.58	4.35	10.17
S13 - F_A - CT	0.76	0.83	0.88	8.30	6.31	15.14
S13 - F_A - NT	2.38	2.58	2.74	8.33	6.33	15.18
S13 - F_B - CT	0.35	0.38	0.40	8.30	6.31	15.13
S13 - F_B - NT	1.09	1.18	1.26	8.32	6.33	15.18
S14 - F_A - CT	3.20	3.41	3.58	6.45	4.99	11.76
S14 - F_A - NT	9.99	10.63	11.16	6.47	5.00	11.79
S14 - F_B - CT	1.47	1.56	1.64	6.45	4.99	11.76
S14 - F_B - NT	4.58	4.88	5.12	6.46	5.00	11.79

1: Productivity Index level
2: Field shape
3: Tillage system
4: Harvest every 15 years starting from year 15.
5: Harvest every 15 years starting from year 30.
6: No tree harvest
7: Percent change in cost as option changes from 1 to 2

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