Report for 2001MI3061B: Watershed Based Optimization Approach for Identification and Management of Non-Point Source Pollution

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Report Follows:

SYNOPSIS

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Title: Watershed Based Optimization Approach for Identification and Management of Non-Point Source Pollution / Sub-Title: Targeting Watershed Interventions for Reduction of Nonpoint Source Pollution
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Abstract:

Watershed protection and soil conservation programs offer targeted cost-sharing in an effort to induce farmers to promote conservation on vulnerable lands. Relatively little information is available about how effectively Federal programs to reduce agricultural soil erosion and water pollution achieve their objectives. These programs offer broad eligibility criteria, covering all land within a certain distance of waterways. They provide cost-sharing for a range of conservation practices, including filter strips but excluding no-till because it does not involve additional net costs for farmers. This study uses a soil erosion model to estimate soil erosion and sediment and phosphorous loading under alternative conservation practices and targeting approaches in Michigan's Stony Creek watershed. The analysis shows that promoting the use of no-till and targeting steeper areas within the riparian corridor can bring the greatest reduction in sedimentation and phosphorous loads. Around half of Stony Creek farmers use no-till; steps to encourage its expansion could yield greater soil conservation benefits than focusing only on filter strips.

Introduction

Federally-funded programs to reduce soil erosion and water pollution associated with agriculture have been in place for decades, but relatively little is known about how effectively they achieve their objectives. This lack of information stems mainly from the fact that nonpoint source pollution from agriculture is impossible to measure with existing technology (Horan and Ribaudo 1999). It is only possible to estimate the extent to which conservation programs have encouraged the adoption of certain practices or removed environmentally risky land from cultivation and then assess the likely reduction of erosion in probabilistic terms. Even so, data are not easily found regarding the percentage of eligible land that is enrolled in conservation programs and the associated likely reduction in water pollution.

Conservation programs offer targeted subsidies in an effort to induce farmers to promote conservation on vulnerable lands. Targeting follows broad eligibility guidelines; for example, under several conservation programs all land within a quarter mile of a waterway may be eligible for 75% cost-sharing of conservation practices. Little is known about how cost-effectively these guidelines generate additional conservation investment relative to alternative targeting approaches.

This study uses a soil erosion model to explore alternative possibilities for targeting conservation programs in order to reduce nonpoint source pollution as cost-effectively as possible. It first analyzes the cost-effectiveness of existing targeting designs and then explores possible alternatives.

Background and Review of the Literature

Agricultural NPS problems

In the last quarter century the United States has made substantial progress in reducing water pollution, especially from point sources and hazardous waste sites. However, according to the EPA (http://www.epa.gov/OWOW/watershed/framework.html), nearly 40% of surveyed waters remain too polluted for fishing, swimming and other uses. Attention has turned from controlling the major point source polluters to reducing nonpoint source pollution, or pollution from dispersed sources such as individual homes, farms, or construction sites.

The primary water quality problems from agricultural nonpoint source pollution are sediment and nutrients (particularly phosphorus). Contribution of nonpoint source pollution from agricultural land use has been estimated at 64% of total suspended sediment and 76% of total phosphorus (Duda and Johnson, 1985). Overenrichment of nutrients in freshwater stimulates algal and rooted aquatic plant growth, and results in oxygen depletion, fish kills, odor problem and consequently eutrophication (Lee, 1971). It is estimated that the economic damage to surface water quality caused by sediment and nutrients from agricultural cropland ranges from 2.2 to 7 billion dollars each year in the United States (Lovejoy et al., 1997).

Controlling nonpoint source pollution requires that numerous minor polluters coordinate their actions to reduce pollution, one at a time. Each individual polluter may not make a tangible impact on environmental quality, but all polluters together create severe problems. Likewise, changing the behavior of one polluter will not make much difference, but if many people change their polluting ways the difference can be substantial. Homeowners, for example, would need to avoid disposing of motor oil into street sewers and take steps to minimize lawn fertilizer runoff. Construction sites would need to install protection devices to reduce the erosion of bare soil. Farms would need to adopt tillage and cultivation practices that generate less runoff and erosion, and they would need to install land use measures such as grass filter strips that capture eroding soil before it can be deposited into waterways.

The social problem confronting all types of pollution is that while the polluter enjoys exclusive benefits to the economic activity that causes pollution, the costs of that activity are shared with society at large in the form of pollution. By imposing the costs on others, the polluter has insufficient incentive to minimize pollution. With point source pollution, a combination of regulations or taxes can be imposed to change the polluter's behavior. Enforcing such arrangements is manageable because pollution sources can easily be identified and monitored. With nonpoint source pollution, on the other hand, the problem is more complex because the number of polluters is very high and each one's contribution is practically negligible. Enforcing elimination of pollution by every individual polluter becomes prohibitively costly.

Farm-level soil conservation adoption determinants

Agricultural pollution takes place primarily through runoff and soil erosion, which carries pollutants from agricultural chemicals off of farm fields and into drains, streams, and rivers. It has long been known that the costs of soil erosion in the United States are borne disproportionately off-farm. In other words, erosion has relatively little impact on agricultural production and its costs are manifested mainly in the form of soil erosion downstream (Crosson 1983).

Numerous studies in the 1980s aimed to identify factors that led some farmers to invest in soil conservation while others did not, with the hope that this information would facilitate the formation of policies that would encourage more widespread soil conservation (add citations.) Among other things, these studies found that perception of erosion was an important determinant of adoption of soil conservation measures (Ervin and Ervin 1982, Norris and Batie 1987, Gould et al. (1989). Better-educated farmers also invested more, other things being equal. Ervin and Ervin (1982) found that cost-sharing programs contributed to higher investment, but not necessarily on the lands that were most prone to erosion. Nielsen et al. (1989) also found that government programs contributed to investment, with one dollar in cost-sharing assistance yielding an additional fifty cents of private investment by the farmer. Set aside programs also contributed to private investment in soil conservation. While government programs did appear to generate conservation investment, Strohbehn et al. (1986) suggested that targeting them to lands with at least 15 tons per acre would yield more favorable benefit:cost ratios.

Targeting and incentives for cost effectiveness

If the benefits of soil conservation accrue primarily off-site and farmers have insufficient incentive to invest their own funds to generate those benefits, conservation programs must take steps to encourage investment. Several approaches are possible, including, either individually or in combination, imposing regulations requiring farmers to adopt conservation practices, subsidizing their cost, and appealing to farmers through education and moral suasion. The history of conservation programs in the United States and around the world shows elements of all of these approaches.

In the United States, programs have focused primarily on helping pay for the cost of conservation practices and paying for farmers to remove from cultivation land that bears a high risk of erosion. Programs are voluntary, although some farmers are required to participate in some ostensibly voluntary programs in order to be eligible for certain other attractive farm supports.

While there is widespread acceptance that farmers will need financial assistance to adopt soil conservation practices whose benefits will accrue only partially to them, there remain questions about how to design programs such that financial assistance will be as cost-effective as possible. Cost effectiveness entails achieving the greatest reduction in erosion at a given level of cost or, equivalently, achieving a given level of reduction in erosion at the least cost. Conceptually, this involves three interrelated goals:

- encouraging farmers to invest who would not have otherwise

- encouraging them to invest on land that is most vulnerable to erosion and nonpoint source pollution (as opposed to land where erosion problems are less severe).

- minimizing payments for conservation to farmers who would have invested even without payment.

Of course it is impossible to predict accurately where private investment might take place in the absence of special programs, and it is impossible to selectively subsidize those who would not have invested while asking others to invest on their own. The best that can be achieved is to intervene in a way that maximizes the likely reduction in erosion for the lowest cost. Horan and Ribaudo (1999) recommend incentive-based approaches as the most efficient way to encourage soil conservation.

Current programs select certain blunt eligibility targets for recruiting farmers to participate and for sharing investment costs with them. A common approach is to pay farmers 75% of the cost of approved conservation practices like buffer strips, grass waterways, and streambank protection. All land within one quarter mile of waterways is eligible for such cost sharing.

Specific programs and what they do, how they are targeted

Soil conservation programs date back to the 1930s, when they were developed in response to the dust bowl and the great depression. The Agriculture Conservation Program (ACP), which was introduced in 1936, offered farmers cost-sharing for land conservation measures. This program evolved over the years and was augmented and ultimately replaced by other programs. Today, several major programs help farmers make conservation investments. They are funded by a variety of sources but mainly the US Department of Agriculture and the Environmental Protection Agency.

Highly Erodible Land Conservation (Sodbuster): This program, initiated as part of the 1986 Farm Bill, requires that farm program participants with highly erodible land adopt an approved soil conservation plan in order to remain eligible for certain other farm program benefits such as farm support payments. This program is voluntary, but when the agricultural economy is in hard times program benefits become very attractive and this program is effectively regulatory.

Conservation Reserve Program (CRP): This program, which dates back to the 1930s, focuses on land retirement both for the purpose of conservation and for reducing overproduction of agricultural commodities. The current version of the CRP was enacted in 1986 and reached 33.5 million acres through March, 2001, 2000 at a total cost of $1.5 billion (USDA 2001). USDA economists estimate that it generates far more savings than it costs. It is particularly attractive to farmers because, in addition to paying for 50% of the cost of installing conservation measures, it pays them up to 90% of the annual rental value of land taken out of production. Farmland is eligible for enrollment only if it meets strict eligibility requirements using a ranking of all applications throughout the country.

Environmental Quality Incentives Program (EQIP): This program provides cost-share for installation of any among about 250 conservation structures or practices. It does not involve land retirement but rather conservation farming on working farms. Farmers are asked to engage in five- or ten year contracts involving financial and technical assistance and education. EQIP was introduced with the 1996 Farm Act, updating and bringing under one umbrella a number of previous programs. It was initially funded at $200 million per year for 1997 through 2002, and then the total funding was raises to $325 million in 2001.

Small Watershed Program: Funded under Public Law 83-566 in 1954 and commonly referred to as PL-566 funding, the Small Watershed Program helps people in watersheds smaller than 250,000 acres to organize conservancy districts, develop plans to manage soil and water resources within the area, and receive cost-sharing funds to implement approved plans. It promotes watershed protection, flood prevention, and water quality improvements, including reduction of runoff, erosion, and sedimentation. The program pays for 75% of nonstructural measures like buffer strips and up to 100% of certain flood control structures.

Clean Water Act Section 319:

Section 319 of the Clean Water Act provides funds for reducing nonpoint source pollution in navigable waters. Local organizations establish the programs, which receive major funding from the Environmental Protection Agency. A local funding match is required.

Setting: the Stony Creek Watershed[1]

[1] Information in this section draws on the watershed plan document (NRCS 2001).

The current study draws on data from the Stony Creek Watershed in Central Lower Michigan, lying mostly in Clinton and Ionia Counties just north of Lansing. A PL-566 grant was recently implemented in the watershed, but farmers are also eligible for funding under the CRP and EQIP.

Stony Creek flows into the Maple River, which in turn is a major tributary of the Grand River. The watershed covers 113,600 acres, of which 80 percent is cropland, nine percent forest, and seven percent is urban or residential. At present rates of land conversion, development pressures from the Lansing area are likely to reduce cropped area to 74 percent by 2020. The present human population is around 15,500.

Corn, soybeans and alfalfa comprise almost 90 percent of cropped area in the watershed on farm sizes averaging about 250 hectares. More than half the farms are believed to have livestock and the total livestock population is relatively high with 41,000 head of cattle, 20,000 hogs, 2000 sheep and 1000 poultry. There are about 1200 acres of pasture in the watershed and animals have direct access to streams and drains in many areas.

Soil and water management problems in the watershed mainly concern runoff of nutrients and manure and sedimentation. Sheet and rill erosion on farmland are estimated to contribute over 80 percent of the sediment yield in the watershed, contributing approximately 153,000 pounds of phosphorous and 300,000 pounds of nitrogen annually. Livestock are the primary source of excessive nutrients and pathenogenic microorganisms in surface and groundwater. Nutrients and pathogens damage water quality for aquatic life and recreation; Stony Creek is a recognized warm water fishery and also a source of recreation with one of Clinton County's six public boat access sites. Sediment damages aquatic habitat by limiting oxygen availability, and it the capacity and life expectancy and raises maintenance costs of structures such as roads, ditches, culverts and bridges.

Urbanization can lead to its own watershed problems; residential areas are a source of nitrogen, phosphorus and pathogens (?) due to failed septic systems. An increase in pavement intensifies the amount of runoff.

Watershed projects in Stony Creek

The Stony Creek watershed is the site of a PL 83-566 Small Watershed Program Grant that began in 2001 and will last seven years. The project calls for about $1.5 million in funds to install conservation practices on 27 percent of the land area. Stony Creek has already been the site of a Section 319 grant that operated in the 1990s; farmers in the watershed are also eligible for funding under EPIQ and CRP.

Under the 566 grant, lands within a quarter mile of drains and waterways are eligible for 75% cost sharing for erosion control practices. NRCS staff are responsible for providing technical assistance and education to farmers in an effort to recruit them to apply for cost-sharing funds. NRCS staff stress that although the funding for technical assistance comes from the 566 grant, they help raise awareness of other funding options through EPIQ and

CRP as well, helping farmers determine which source is best for them. This raises the total funds available for investing in the watershed.

Funds support a large number of land treatments including but not limited to filter strips, diversions, critical area plantings, grade stabilization structures, grassed watersways, stream bank protection, livestock exclusion mechanisms and the like. Additional management practices that are not eligible for cost sharing but for which staff members provide technical assistance include prescribed grazing, wildlife upland habitat management, nutrient management, pest management, and residue management.

Project officials estimate that investment in the Stony Creek Watershed through the 566 grant will have numerous favorable effects:

- reduce overall annual erosion rates by 45 percent
- improve water quality at recreational sites, raising the number of annual visitor days by an estimated 5,300.
- Reduce sedimentation into Stony Creek by 45,000 tons per year
- Improving fish habitat on 13 miles of the creek
- Reducing annual phosphorous and nitrogen loadings by 73,600 and 147,000 pounds, respectively
- Restoring and enhancing 150 acres of wetlands
- Improving wildlife habitat throughout the watershed

The question remains how well targeted the funded interventions will be for the purpose of reducing erosion and runoff as cost-effectively as possible. As mentioned above, all lands within a quarter of a mile of drains and streams are eligible for cost-shared treatments, with 75 percent cost sharing by the project.

NRCS analysts also considered alternatives to the selected treatment plan; one involved making all lands in the entire watershed eligible while the other would treat only the agricultural lands in the riparian corridor. All three treatments were compared to the option of no treatment at all. Cost-benefit analysis was conducted for each one. Based on an estimate that 27% of lands would be treated, the selected plan had the highest estimated benefit:cost ratio at 1.19. The total treatment plan was too expensive, providing treatment to lands that were responsible for too little of the erosion, while the latter had insufficient impact because it did not treat nonagricultural land in the steam corridor.

NRCS officials indicate that it is difficult to be more precise in selecting targeting mechanisms. Programs are voluntary, so participation rates can only be estimated. Also, eligibility criteria have to be published in advance and there is no way to be more selective than offering the program to all lands within the quarter mile distance from the stream. Some critical lands in that area are likely to be untreated while some less critical lands are likely to be treated.

Inquiries revealed that data are not systematically collected on the average percentage of area that farmers choose to treat or the extent to which local officials feel that existing targeting treatments have served them well or could be improved upon. Officials must work on the basis of certain rules of thumb generated by limited information from erosion models and intuition gained through their experience in the field.

Analysis

The present study aims to provide a small amount of additional information that may be helpful for targeting. Using an erosion/sediment delivery model, it analyzes likely erosion levels under alternative targeting options. The model focuses on the impact of altering the quarter mile treatment zone; it is not designed to address the question of how variations in the subsidy level will alter farmers' likely participation rate.

Simulation of alternative watershed management intervention approaches

The Revised Universal Soil Loss Equation (RUSLE) (Renard., et al. 1997) is chosen in this study to calculate soil loss under various conditions. The procedures to estimate soil erosion in Michigan are followed as per (Grigar and Davis, 1995). RUSLE computes the average annual soil loss by using a functional relationship of several factors, expressed in an equation as

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

where: A = computed spatial average soil loss and temporal average soil loss per unit of area. Usually, A is expressed in tons/acre/year (other units can also be used).

R = rainfall-runoff erosivity factor.

K = soil erodibility factor, i.e. the soil loss rate per erosion index unit for a specified soil as measured on a standard plot which is defined as a 72.6-ft (22.1 m) length of uniform 9% slope in continuous clean-tilled fallow.

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

S = slope steepness factor, i.e. the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover-management factor, i.e. the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = support practice factor, i.e. the ratio of soil loss with a support practice such as contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

Digital soils and digital elevation model (DEM) data are used in this study. RUSLE factors are obtained from the technical guide provided by the State Office of NRCS in Michigan. Estimated sediment delivery ratio (0.288) based on the watershed size and phosphorus content in sediment are also used in estimating sediment and phosphorus loadings. In addition that sheet and rill erosions are estimated by RUSLE, streambank and gully erosions estimated by NRCS are used in this study.

Simulations have been conducted to evaluate the effects of crop rotations, tillage practices, slopes and the width of filter strips on sediment and phosphorus loadings.

Results and Discussion

At the outset it is important to keep in mind that the findings presented here are based on a modeling exercise, not actual measurements. The findings of the model are useful for indicating some broad areas of interest and concern.

Tillage practices

Different tillage practices can affect soil erosion and they are taken into account in the C factor in RUSLE. Table 1 displays total sheet and rill erosion, along with sediment and phosphorous loads for the entire watershed, for six different tillage practices. A corn-soybean cropping rotation is used as the baseline for these simulations.

Results in Table 1 demonstrate that implementing best management practices (BMPs) such as no till can greatly reduce erosion. In this case, no till can reduce sheet and rill erosion load by 85.7% and reduce sediment and phosphorus by 72% compared to fall plowing. These are effective practices that reduce erosion from its source – the field.

No till is currently practiced on about half of the land in the Stony Creek watershed, so the last column in the table reflects the existing situation. It offers a 41% reduction in erosion compared to fall plowing; this represents a major improvement thanks to the diffusion of no till over the last two decades. On the other hand, the results for 100% no till show clearly that major additional gains are possible.

Table 1. Soil erosion, sediment and phosphorus loading under different tillage practices (for corn-soybean)

	Fall Plow	Spring Plow	Mulch 10%	Mulch 20%	No till (100%)	No till (50%)
Sheet and Rill (tons)	241559.48	230056.68	184045.36	161039.65	34508.51	138034.00
Total erosion (tons)	257079.48	245576.68	199565.36	176559.65	50028.51	153554.00
Sediment (tons)	82282.13	78969.32	65718.06	59092.42	22651.45	52466.79
Phosphorus (tons)	175.26	168.20	139.98	125.87	48.25	111.75

Crop rotations

Simulations have been run for scenarios of different crop rotations including continuous corn and typical cropping patterns in Stony Creek Watershed such as corn-soybean, and soybean-wheat. Crops such as row crops and small grains have different effects on soil erosion. Table 2 lists the results of soil erosion, sediment and phosphorus loads for the entire watershed under different crop sequences. The baseline tillage system for this set of simulations is 50% no till as per the current situation in the watershed.

Table 2. Soil erosion, sediment and phosphorus loading under different crop sequences using current tillage practices (50% no till).

	Corn-Corn	Corn-Soybean	Soybean-Wheat
Sheet and Rill (tons)	166791.11	138034.00	51762.75
Total erosion (tons)	182311.11	153554.00	67282.75
Sediment (tons)	60748.84	52466.79	27620.67
Phosphorus (tons)	129.40	111.75	58.83

The results show that continuous corn generates the highest soil erosion rate and leads to a high sediment and phosphorus loading, followed by corn-soybean. Soybean-wheat has the lowest erosion rate and can reduce the sediment and phosphorus load by 55% compared to continuous corn.

Slopes

Since soil erosion is sensitive to slopes, different slopes have been analyzed in the watershed for the purpose of targeting cost-sharing for conservation practices. Table 3 lists the land coverage of different slopes and their contribution to total erosion under a corn-soybean system.

Table 3. Erosion for areas with different slopes

	Areas with slope ? 4%	Areas with slope ? 6%	Areas with slope ? 8%
Land Coverage (% of total area)	7.6	2.0	0.6

Erosion Contribution (% of total erosion)	12.1	3.5	1.1

Table 3 shows that Stony Creek watershed has a relatively flat topography. Areas with a slope greater than 4% account for only 7.6% of the buffer zone, and slopes greater than 6% cover only 2% of the area. Only a tiny percentage of the area has slopes of at least 8%.

These small areas contribute more than their share of erosion, but due to their small size the overall contribution is small. Areas of at least 4% slope contribute 12.1% of total erosion. Areas with 6% of slope contribute 3.5% of erosion.

This table shows that targeting on the basis of slope is important, and it would be even more important in a watershed with a greater area of sloping land. It is important to keep in mind that the program anticipates installing BMPs on 27% of the land in the riparian corridor. The 7.6% of the land with at least 4% slope constitutes 12.1% of total erosion, so good targeting for slope has the potential to maximize cost-effectiveness.

Filter strip width

Phosphorus reduction coefficients listed in Table 4 have been used to estimate the effects of various buffer strip widths on phosphorus loading. These data are obtained from other research projects conducted by the World Resource Institute.

The figures in Table 4 show that increasing the width of a grass filter strip reduces phosphorous loading (by reducing erosion), but the percentage of reduction gradually falls as the width of the filter strip increases. There is no difference at all in the effectiveness of a 100-foot and 120-foot filter strip. A filter strip containing timber, on the other hand, becomes much more effective when it reaches 75 feet, at which point it becomes much more effective than just a grass filter strip. Constructed wetlands and sediment basins can also contribute a great deal to erosion reduction.

Table 4. Phosphorus loading reduction through various buffering methods

	Width of filter strips				
	25 ft.	50 ft.	75 ft.	100 ft.	120 ft.
Filter strip (grass)	23%	33%	43%	53%	53%
Filter strip (multispecies timber)	23%	33%	70%	70%	70%
Constructed wetland	42%				
Sediment basin	50%				

Applying these coefficients to the Stony Creek Watershed gives the results shown in figures 1 and 2. Figure 1 shows the effectiveness of a grass filter strip of different widths and different tillage practices in reducing sediment load; figure 2 shows the effects on reduction of phosphorous. While the specific numbers differ, the relationships across different filter strip widths and tillage practices are very similar. For filter strips, a wider buffer strip can generally reduce more sediment and phosphorus. For corn-soybean crop rotations, a filter strip with 25-100 feet wide installed along the entire riparian corridor can reduce sediment and phosphorus by 23-53%.

As mentioned above, farmers are not required to join the watershed project, and according to the project document only about 27% of land in the riparian corridor is expected to be enrolled in the program. Figures 3 and 4 show the expected reduction in erosion when only 27% of the riparian corridor is under best management practices, including no till and filter strips. Instead of the 23-53% reduction in sediment and phosphorous under 100% coverage, the reduction is about 6-14%.

A more striking result in Figures 3 and 4 is that tillage practices can have a much greater impact on reduction of sediment and phosphorous loading than filter strips installed in a limited amount of areas (e.g. 27% of buffer zone). The difference in sediment and phosphorous loadings across the different tillage practices dwarfs that across differences in filter strip lengths. This suggests that the watershed project could have greater impact by promoting no till than filter strips. Another promising approach might be to promote no till everywhere and focus the filter strips only on the steepest land (above 4%).

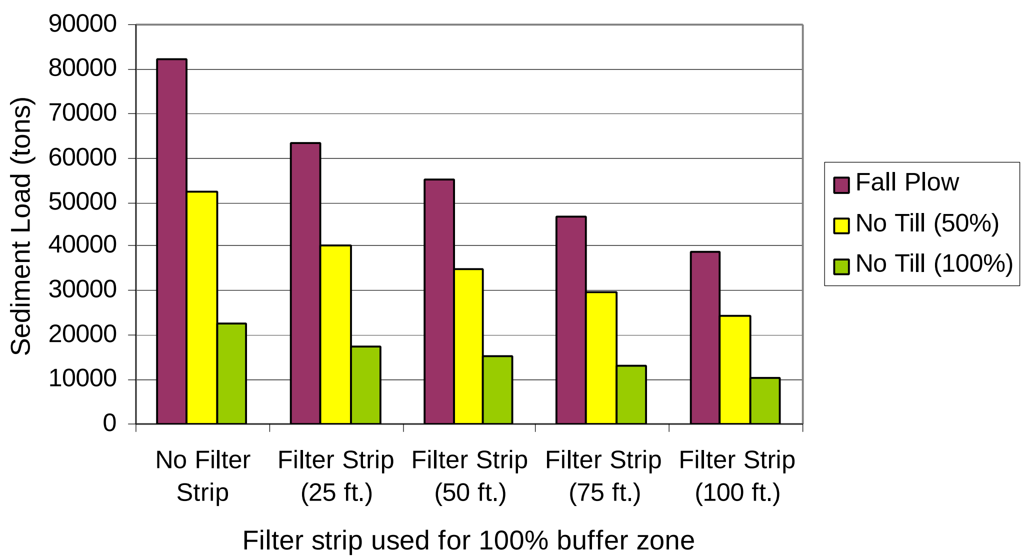
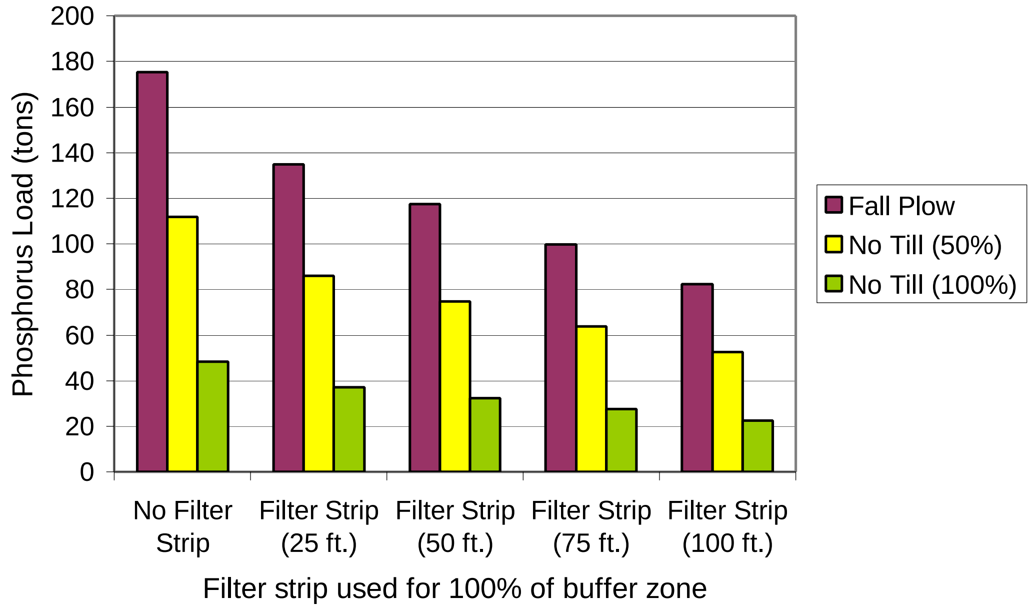


Figure 2. Sediment load under different tillage practices and different width of filter strips installed in 100% of buffer zone



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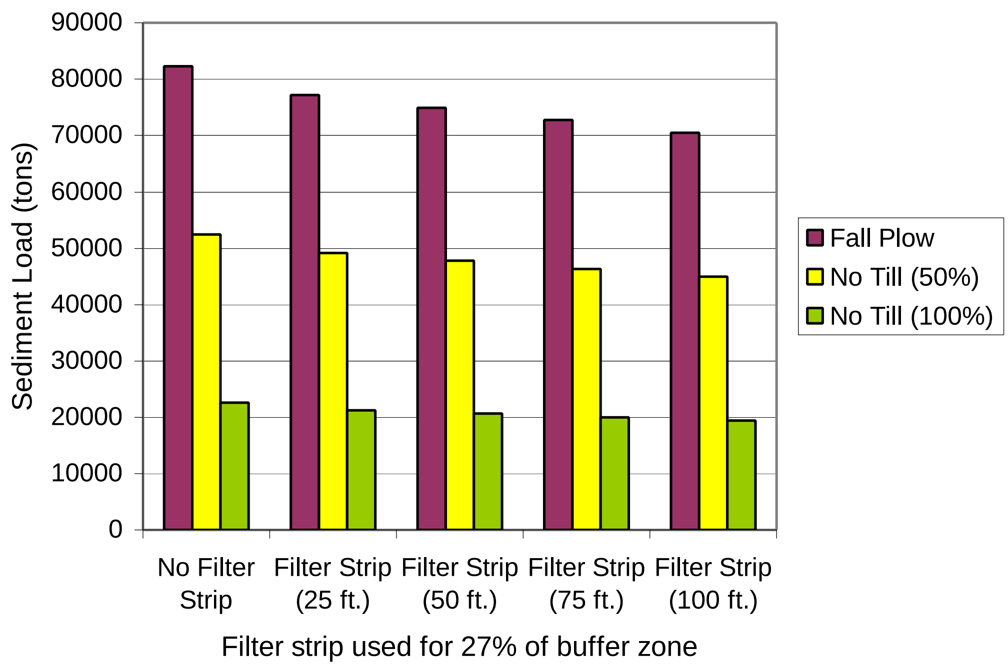

Figure 3. Sediment load under different tillage practices and different width of filter strips installed in 27% of buffer zone

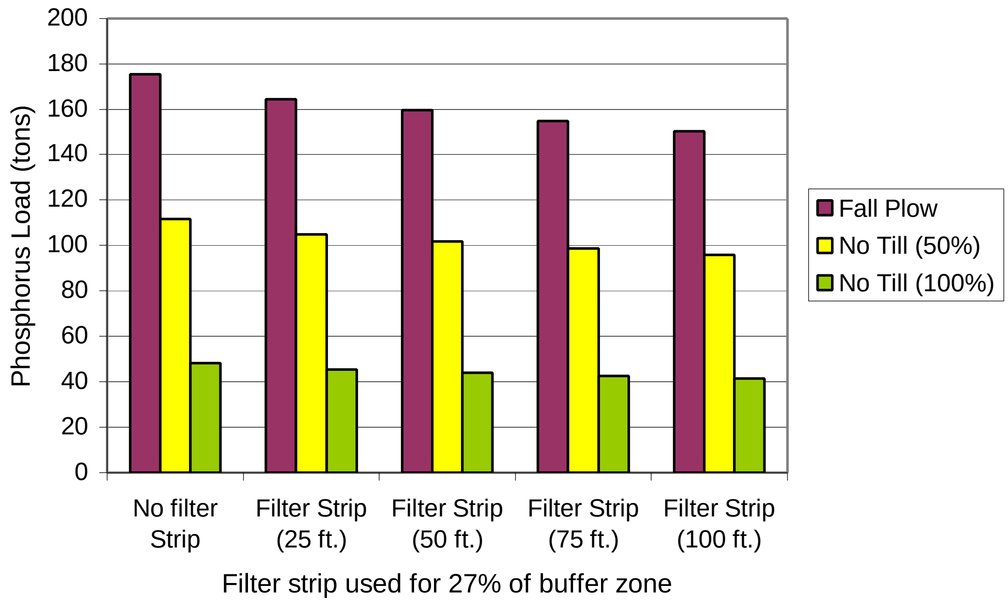

Figure 4. Phosphorus load under different tillage practices and different width of filter strips installed in 27% of buffer zone

Conclusion

It is important to stress that the findings presented here are based only on a model, not actual measurement in the watershed. The numbers should not be taken as precise, but rather as indicative of conditions under different management practices. The major findings can be summarized as follows:

1. Best management practices, particularly no till, can greatly reduce soil erosion and sediment/phosphorus loading. This "on-site" erosion control measure (which prevents erosion by keeping soil in place in the field) should be considered in combination of other "off-site" sediment/phosphorus reduction measures such as filter strip (which capture eroded soil before it can move into a waterway) in order to achieve the maximum benefits.

2. Targeting on the basis of slope can increase the cost-effectiveness per unit area covered. The Stony Creek Watershed is quite flat so the effects of this approach will not show a large magnitude in this particular case.

3. Regarding filter strips, key questions are both whether to install a filter strip at all and how wide it should be. Filter strips have a much larger quantitative impact on

reduction in erosion under fall plow than no till, even though the percentage reductions are similar. Filter strips are extremely important where fall plow is practiced, less so under no till. Perhaps a sensible targeting approach would be to focus as much as possible on encouraging no till and installing filter strips only on the steepest land. Determining the optimal width of a filter strip depends on the combination of how much erosion is reduced and what it costs; of course a wider strip costs more.

Publications

Kerr, John, Da Ouyang and Jon Bartholic. 2002. Targeting Watershed Interventions for Reduction of Nonpoint Source Pollution. Journal of Soil and Water Conservation. (In review).

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