



Prioritizing Vegetative Buffer Strip Placement in an Agricultural Watershed

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Abstract

In this study, the Agricultural Nonpoint Source Pollution Model (AGNPS) was used to determine locations of vegetative buffer strip effectiveness on reducing sediment load within the East Bad Creek (EBC) watershed, a 690 ha agricultural watershed located mid Michigan. Modeling scenarios consisted of simulating the hydrology and sediment transport throughout the EBC watershed on a baseline scenario (no buffer) and with a 30-meter vegetative buffer strip placed around each stream segment (buffer strip scenario). The model's results showed a 17% decrease in sediment load at the watershed's outlet for a 10yr-24hr storm. As a result, the placement of buffer strips within the watershed was prioritized on three different scales. The reduction of sediment due to buffer strips was analyzed on a stream segment level, a field boundary level, and on a cell-by-cell basis. The stream segment buffers and field buffers were ranked on their overall ability to reduce sediment load into the stream. The reduction in sediment yield from the stream segments and the fields varied from 3.49 to 58.54 tons and 0 to 19.31 tons respectively. The cell results were evaluated by highlighting 0.5 tons – 3.63 tons of sediment throughout the watershed, deeming those buffered cells efficient. The cell-by-cell evaluations highlighted specific critical areas of buffer efficiency on a 30-meter resolution where the stream segment and field evaluations identified specific stream segments and fields to target for buffer placement. The AGNPS model along with the Arcview Non-Point Source Model (AVNPSM) GIS interface demonstrates that agricultural watersheds can be quickly and efficiently evaluated to target locations of buffer placement. Therefore, helping watershed managers implement vegetative buffer strips in site-specific areas within the watershed to employ efficient implementation of conservation management programs.

Keywords: AGNPS, Buffer Strips, Sediment, GIS

Introduction

Pollutants such as soil erosion and sedimentation from agricultural and urban land, nutrients and organic materials from agricultural and livestock operations and storm water from urban areas are characterized as non-point source pollutants (Novotny and Olem, 1994). Non-point source pollution is the nation's number one source of water quality problems, where 40% of surface waters within the United States are contaminated to the degree where they cannot meet their basic use (U.S. EPA, 1990). Increased turbidity and eutrophication associated with sediment and sediment-bound nutrients decreases dissolved oxygen in stream and lake water. This dramatically impacts water quality for recreational and municipal uses and degrades aquatic habitat. The U.S. Environmental Protection Agency (EPA) noted that agricultural activities were responsible for more than 60% of surface water pollution where 64% of agricultural runoff is due to total suspended sediment (U.S. EPA, 1990).

For the past decade, research has determined that best management practices such as implementing vegetative buffer strips within agricultural watersheds will aid in the reduction of sedimentation into rivers or streams (Inamdar et al., 2001; Park et al., 1994). Vegetative buffer strips have been analyzed extensively in small-scale research plots for removing sediments caused by agricultural and urban runoff (Raffaella et al., 1997; Robinson et al., 1996; Dillaha et al., 1989). This research has demonstrated that vegetative buffer strips are effective for the removal of sediment from surface runoff if flow is shallow and uniform (Dillaha et al., 1989). Dillaha et al. (1989) specifies that in flatter regions of a watershed rather than hillier areas are where vegetative buffer strips reduce over half of the excess sediment yield that enters streams or rivers. Jin and Romvens (2001) similarly noted that sediment entrapment in vegetative buffer strips is characterized by vegetative characteristics, slope, flow rate, sediment type and sediment concentration. Magette et al. (1989) also indicated that when the ratio of vegetation to pollutant-originating areas decreased the efficacy of vegetative buffer strips also decreases. Thus, implying not all stream segments are candidates for adopting a buffer strip within a watershed. As a result, the effectiveness of a buffer strip is a complex function of the characteristics of the delivery area and the streamside area where the buffer is to be installed.

The installation of vegetative buffer strips has increased dramatically since 1997 when the USDA National Resource Conservation Service (USDA-NRCS) Buffer Initiative Program was established. The program has encouraged the use of vegetative buffer strips in agricultural watersheds by compensating landowners based on how many acres they invest in the program (SWCS, 2001). However, like most watershed programs the Buffer Initiative Program does not have an evaluation process to determine buffer effectiveness along every stream segment of any given watershed. Large-scale field evaluation procedures can be expensive and time consuming therefore better approaches to express buffer efficacy would be to incorporate a spatially distributed hydrologic/water quality model (Corwin et al. 1997). A model that would not only evaluate buffer effectiveness at the watershed outlet but also evaluate buffer efficacy on every stream segment throughout the watershed is needed.

Hydrologic water quality models such as CREAMS (Knisel 1980), EPIC (Williams et al., 1982), ANSWERS (Beasley et al., 1980), SWRRB (Williams et al., 1985) and AGNPS (Young et al., 1989) have been tested and validated on several watersheds within the United States. All of the models were formulated with different objectives in mind thus; simulated sediment results have varying degrees of accuracy (Bingner et al., 1989). With the capability of higher computing systems and the recent integration of geographic information systems (GIS), these models have gained widespread acceptance as accurate and cost-effective tools for evaluating agricultural best management practices such as vegetative filter strips (Tim and Jolly, 1994, Mitchell et al., 1993, Srinivasan and Arnold, 1994).

The AGNPS (Agricultural Non-point Source Pollution) model is an event-based distributed parameter model developed by the USDA-Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and Soil Conservation Service (Young et al., 1989). The model subdivides the watershed into uniform cells to capture the spatial variability of the physical characteristics of the watershed. The main objectives of the model are to simulate runoff, sediment and nutrient yields and to assess best management practices on surface water quality of agricultural watersheds ranging from a few hectares to 20,000 ha.

A database consisting of 22 input parameters for every cell representing the watershed is required to run the AGNPS model. This distributed parameter approach allows the model to take into account the spatial variability of the landscape and also examine sedimentation, runoff or nutrients either for entire watershed (at the watershed's outlet) or on a cell-by-cell basis. The cell-by-cell analysis not only pinpoints areas of excessive sedimentation, it also is significant for evaluating areas where best management practices such as vegetative buffer strips are effective in reducing sediments.

The identifiable problems with this analysis is that it is very time consuming and labor intensive to develop the 22 input parameter database for every cell in a large watershed with high resolution. Previous research has concentrated on identifying a suitable cell size to adequately capture the variability within a watershed for increased accuracy (Mankin et al, 2001; Brannan and Hamlet, 1998). The model's estimates for runoff, sediment yield and nutrients are reasonably close to the measured data, where the coefficient of determinations are approximately 0.9 or above (Perrone et al., 1999; Lenzi, et al., 1995). The percent errors for sedimentation, runoff and nutrients have decreased since the adoption of GIS interfaces, and thus watershed analysis may be assessed on a finer level.

Over the years, there have been a number of AGNPS GIS interfaces developed (He et al., 2001; Tim and Jolly, 1994; He et al., 1993). These interfaces have been developed to aid in developing complex input databases for the AGNPS model. Thus, larger watersheds may be modeled at a higher resolution leading towards a more accurate physical representation of the watershed. Tim and Jolly (1994) demonstrated the use of an Arc/Info – AGNPS interface for assessing the effectiveness of best management practices. In their study, they demonstrated that by implementing a vegetative buffer strip around all of the stream segments in an agricultural watershed, sediment load was reduced by 41% at the

watershed outlet. Most recently, He et al. (2001) developed the Arcview Non-Point Source Model (AVNPSM), an Arcview GIS interface for AGNPS.

The objective of this study was to use the AGNPS model with the AVNPSM interface as a tool to efficiently prioritize areas adjacent to stream segments within a watershed where installing a buffer strip would significantly reduce sediment load into the stream. The large-scale analysis of identifying and prioritizing critical areas of buffer efficacy at high resolutions will help watershed managers recommend areas of buffer installation with less uncertainty, which in turn will help reach water quality goals.

Materials and Methods

Study Area

The East Bad Creek watershed, located in Clinton County, Michigan is a 690 ha subwatershed of Stoney Creek, which drains 45,452 ha and is a subbasin of the Grand River, a major tributary of Lake Michigan (Figure 1). The region receives on average 777 mm of rainfall each year with an average temperature of 8.2° C. Stoney Creek watershed has an extensive drainage network consisting of about 1350 km of surface water drains. These drains are primarily shallow upland drains installed to provide a conduit for removing surface runoff from agricultural fields. Recently, an environmental assessment of Stoney Creek identified water quality concerns caused by sediment as the primary pollutant in the watershed (NRCS, 2001). The sediment deposition that was assessed contributes to the degradation of habitat not only in Stoney Creek, but the Grand River and ultimately Lake Michigan. The damage of the eroded sediment is also reducing the life expectancy of roads, ditches, culverts and bridges throughout the watershed. An estimated 90,500 tons of sediment enters the stream each year, where damages are estimated at approximately \$15,000 per kilometer (NRCS, 2001).

Land use in the EBC watershed is 85% agricultural land consisting of corn, soybeans and wheat, as well as, more diverse crops such as mint, with the remaining 15% a mixture of farmsteads, shrubland and woodland (Figure 2). Agricultural land in this area was converted from forestland and soil types vary extensively, ranging from moderately loamy, well drained to poorly drained soils (Figure 3). The landscape is predominately flat but in some areas gentle slopes exist with the largest elevation change being approximately 5% (Figure 4).

Restoration efforts for Stoney Creek are being implemented in accordance with the Clinton Conservation District and the NRCS State and Federal grant projects. The Clinton Conservation District completed the implementation phase of the Clean Water Act Section 319 project in February 2000 (NRCS, 2001). Currently, riparian filter strips in the upper portion of the watershed are being restored, as well as preserving the remaining riparian forest conditions in the lower portion of the watershed. The Federal PL-566 Watershed grant implemented by the NRCS has also aided in restoring Stoney Creek by employing a cost-sharing program with landowners to implement best management practices that include

vegetative buffer strips. Under this program anyone within a quarter mile of the Stoney Creek or its tributaries can participate.



Figure 1. Location of the East Bad Creek Watershed

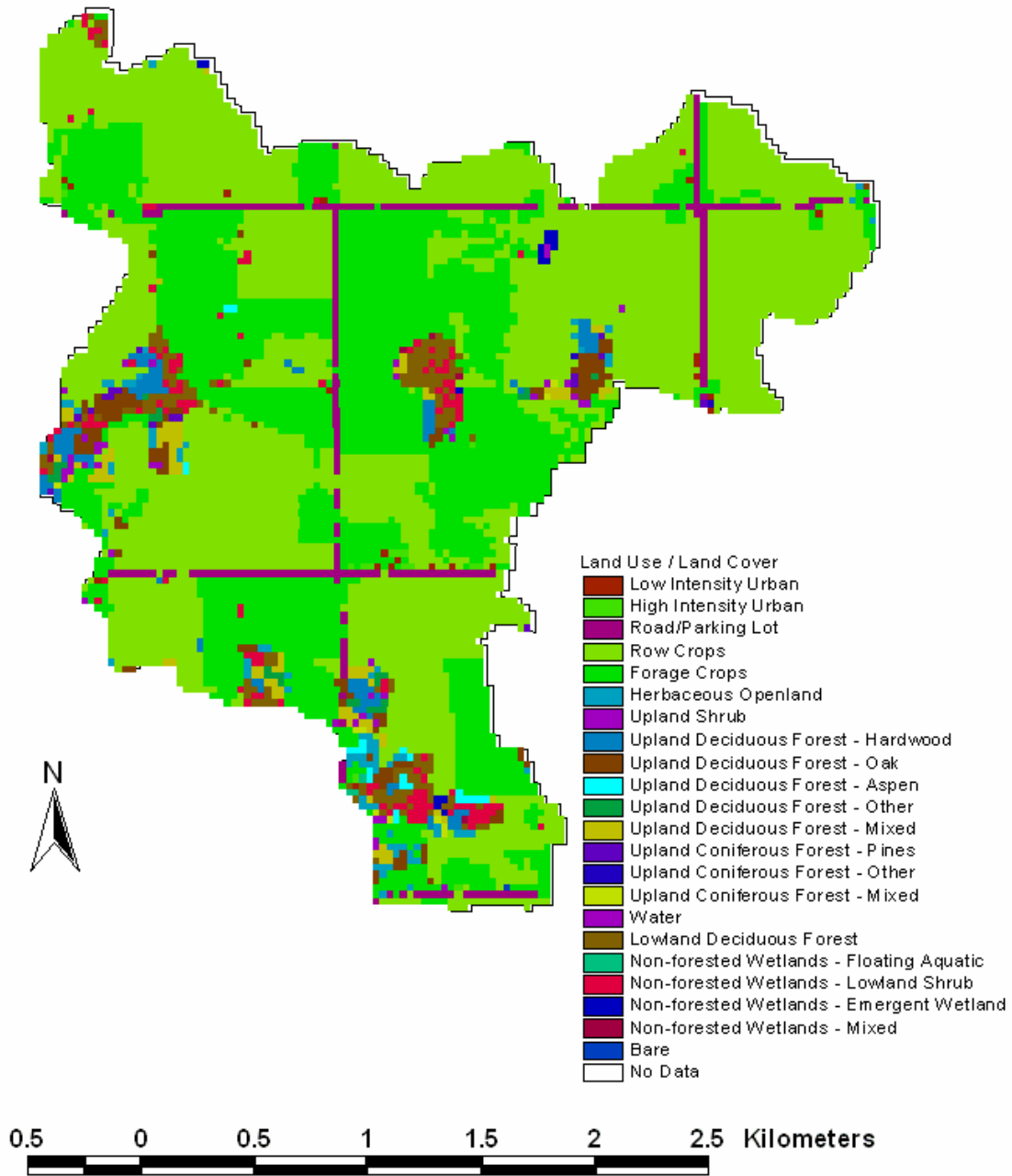


Figure 2. Land use in the East Bad Creek Watershed.

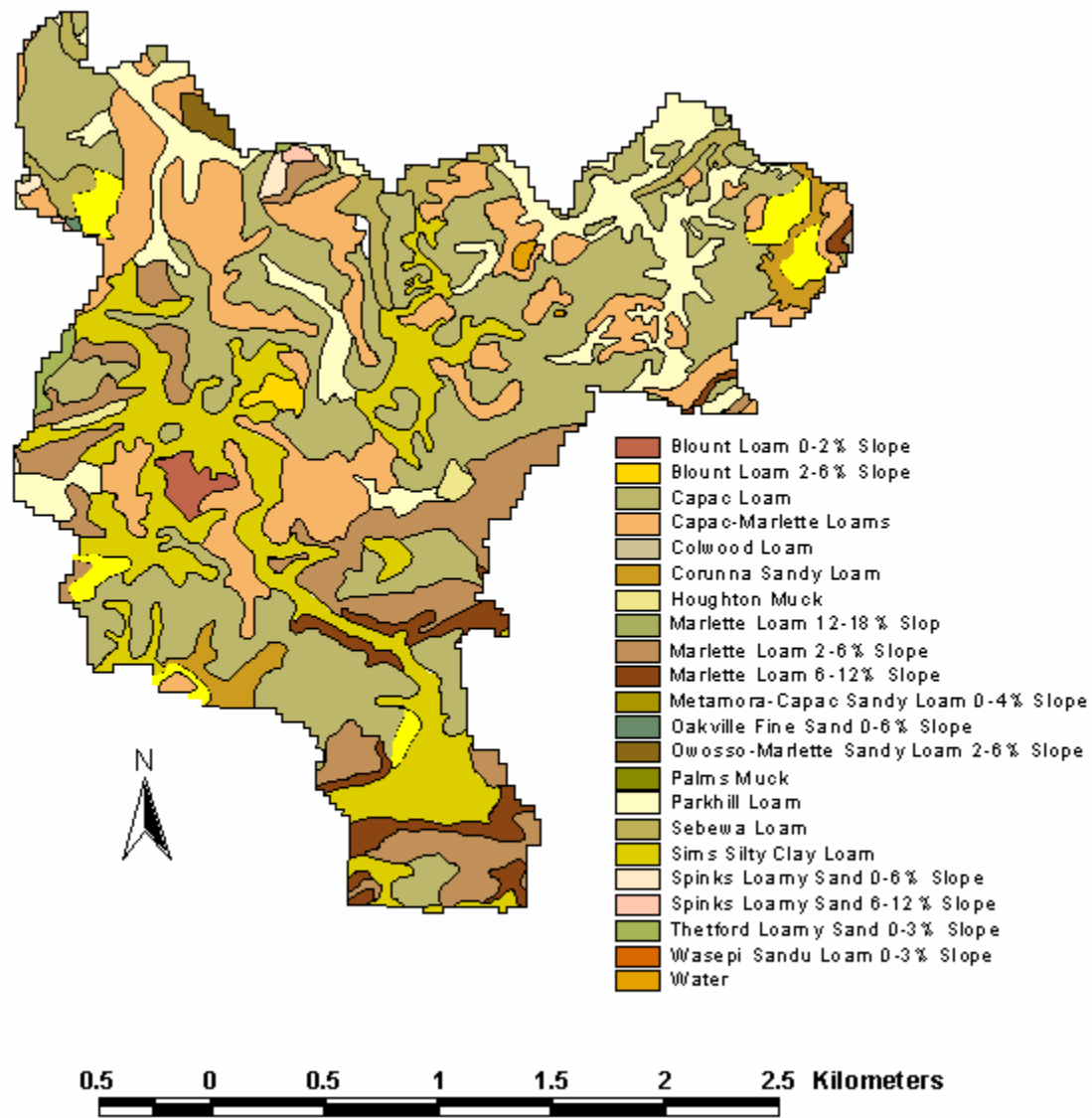


Figure 3. Soils of the East Bad Creek Watershed

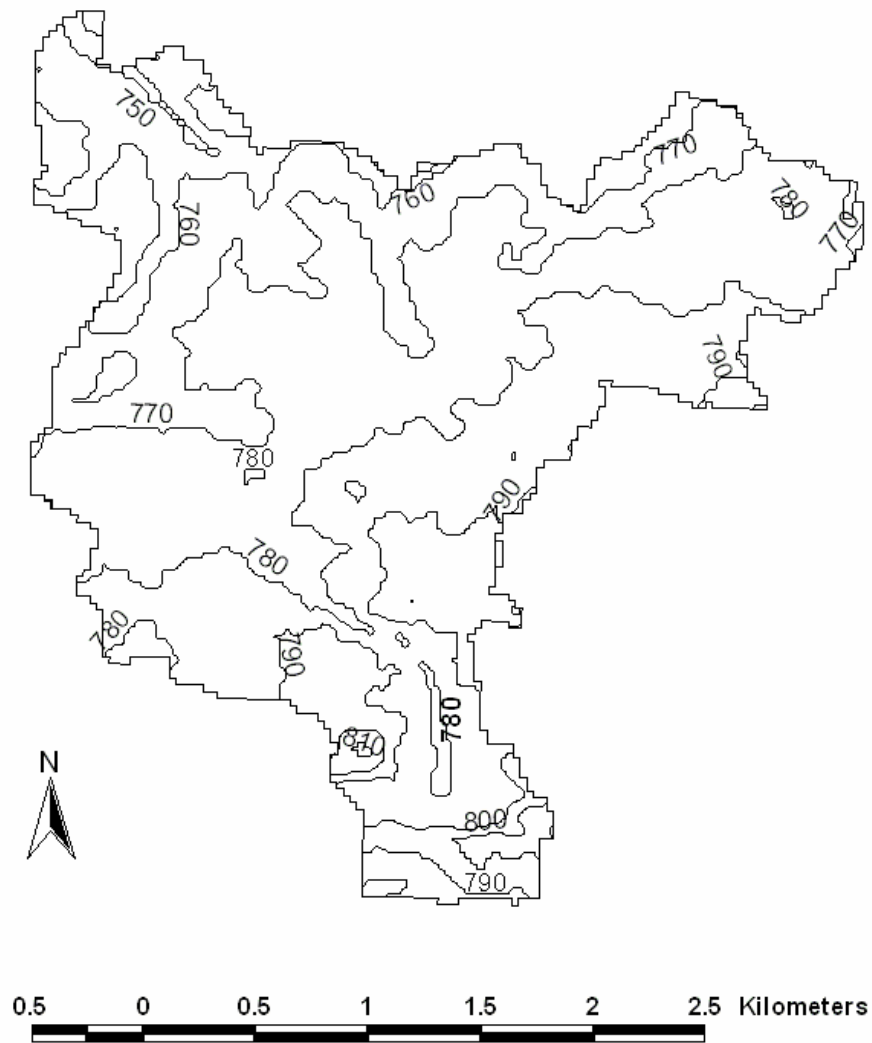


Figure 4. Elevation above mean sea level (m).

The problem with programs such as the ones described above is that they lack a watershed-scale evaluation process and can lead to inefficient implementation of conservation practices. Consequently, by the use of a non-point source pollution model called AGNPS, impacts of agricultural best management practices throughout the watershed can be evaluated. This study focuses on identifying and prioritizing areas of buffer efficacy based on sediment filtered within the EBC watershed.

AGNPS Modeling Scenarios

The AGNPS model operates on a grid cell basis where each homogeneous cell representing the watershed requires 22 input parameters called the AGNPS input database, which allows analysis at any point throughout the watershed. The EBC watershed was divided into 8,107 cells with a resolution of 30-

meters. Manually collecting the 22 input parameters for each cell is extremely labor intensive and time consuming. Therefore, an AGNPS GIS interface called the Arcview Non-Point Source Model (AVNPSM) was used to aid in the development of the AGNPS input database.

The AVNPSM, a Windows based ArcView (version 3.0a or later) GIS interface was developed to easily collect and manipulate the 22 input parameters needed for the AGNPS input database so multiple scenarios can be evaluated (He et al., 2001). The interface, which was written in ArcView Avenue scripts, uses three GIS layers to develop the database. These layers include soil, land use/cover and a digital elevation model (DEM).

AGNPS creates a tabular output that can easily be imported into ArcView for evaluation. The tabular output provides estimates of runoff volume (inches), peak runoff rate (cfs), sediment yield (tons), sediment concentration (ppm), upland erosion (tons/acre), amount of deposition (%), sediment generated within each cell (tons), mass of sediment attached and multiple chemical outputs associated with nitrogen, phosphorus and chemical oxygen demand (Young et al., 1989).

Modeling scenarios consisted of simulating the hydrology and sediment transport throughout the EBC watershed with a baseline scenario (no buffer) and with a 30-meter vegetative buffer strip placed around each stream segment (buffer strip scenario). Buffers were only simulated in agricultural areas, e.g. wooded streamside areas were not buffered. Thus, the entire buffered area within the watershed consisted of 660 cells, which resulted in approximately 59 ha. of buffer.

The scenarios were evaluated with AGNPS by simulating a 10-yr, 24-hr storm event with precipitation of 87.1mm and corresponding energy intensity of 70.47-ft*ton/acre-inch (Huff et al., 1992). Watershed evaluation procedures consisted of identifying and prioritizing areas of buffer efficacy based on sediment reduction. To determine the efficacy of a proposed buffer strip, the difference in sediment load moving into the stream system between the two scenarios was calculated. In this study, the placement of buffer strips was prioritized on three different scales within the watershed. The reduction of sediment due to buffer strips was analyzed on a stream segment level, a field boundary level, and on a cell level. On each scale, the separate analysis units (stream segment, field, and cell) were ranked on their ability to reduce sediment load into the stream.

Input Database

The data sets used for the study area were obtained from a variety of different sources outlined in Table 1. The NRCS county soil survey database (SSURGO) for Clinton County was used to identify the soil texture and soil erodibility factor (K) (Figure 2). A 30-meter DEM provided by the USGS identified slope, slope length, slope shape, and flow direction. The land use/cover database, digitized by using the 1992 USGS 1-meter digital orthophoto quadrangles (DOQ) for Clinton County, included woodland, shrubland, water, farmsteads and cropland. Each land cover class was assigned a value for the SCS curve number (CN), crop management factor (C), overland Manning's coefficient (n) value and surface condition constant (SC) based on the digitized land use/cover database (Table 2).

Table 1. AGNPS Cell Input Parameters

Parameter	Data Source	Data Type
1. Cell Number	Topography	30-meter (1:24,000) USGS DEM
2. Overland flow direction	Topography	30-meter (1:24,000) USGS DEM
3. Receiving Cell number	Topography	30-meter (1:24,000) USGS DEM
4. Average slope (%)	Topography	30-meter (1:24,000) USGS DEM
5. Average slope length	Topography	30-meter (1:24,000) USGS DEM
6. Slope shape factor	Topography	30-meter (1:24,000) USGS DEM
7. USLE K factor (K)	Soil	SSURGO county soil database
8. SCS curve number (CN)	Land use	MIRIS Public Land Survey
9. Mannings roughness coeff. (n)	Land cover/land use	MIRIS Public Land Survey
10. USLE C factor	Land use	MIRIS Public Land Survey
11. USLE P factor (P)	Land cover/land use	MIRIS Public Land Survey
12. Surface condition constant (SC)	Land use	MIRIS Public Land Survey
13. Chemical oxygen demand factor	Land use	MIRIS Public Land Survey
14. Soil texture	Soil	SSURGO county soil database
15. Fertilization incorporation	Assume none	-
16. Fertilization level	Assume none	-
17. Pest Indicator	Assume none	-
18. Point source indicator	Assume none	-
19. Gully source indicator	Topography	30-meter (1:24,000) USGS DEM
20. Impoundment factor	Assume none	-
21. Channel indicator	Hydrology	MIRIS Public Land Survey

Table 2. Land use parameters for the East Bad Creek watershed.

Land Cover Class	Area	Hydro Class	CN	C	P	n	SC
Cropland (90.07%)	1555.01	A	64	0.22	1	0.04	0.05
	-	B	75	0.22	1	0.04	0.05
	-	C	82	0.22	1	0.04	0.05
	-	D	85	0.22	1	0.04	0.05
Farmstead (0.66%)	11.29	B	74	0.20	1	0.137	0.01
	-	C	82	0.20	1	0.137	0.01
Shrubland (1.02%)	17.61	A	56	0.08	1	0.2	0.29
	-	C	70	0.08	1	0.2	0.29
	-	D	77	0.08	1	0.2	0.29
Water (0.094%)	1.63	-	100	0	0	0.99	0
Woodland (8.16%)	140.90	A	30	0.002	1	0.4	0.29
	-	B	55	0.002	1	0.4	0.29
	-	C	70	0.002	1	0.4	0.29
	-	D	77	0.002	1	0.4	0.29
Buffer	-	A	30	0.003	1	0.15	1
	-	B	48	0.003	1	0.15	1
	-	C	65	0.003	1	0.15	1
	-	D	73	0.003	1	0.15	1

Total 1726.44

Many of the 22 parameters were assumed for both scenarios. The USLE conservation practice factor (P) was assumed to be one to simulate worse case occurrences. The soil texture number (sand=1, silt=2, clay=3) for the EBC watershed was assumed a two which was the closest soil texture number simulating loam and silt loam soils. The fertilizer, pest, point source and impoundment factors were assumed to be zero, since the study did not focus on nutrient pollution.

To simulate a buffer strip within AGNPS, four input parameters were manipulated on the streamside cells: the CN, C-factor, n value, and SC. These parameters were chosen by Tim and Jolly (1994) in their buffer strip analysis. The curve number for the buffer strip was defined as brush-weed-

grass mixture with good hydrologic condition (SCS, 1986). The C-factor for the buffer was assigned a value of 0.003 and represents a buffer with 95% vegetative density where 75% vegetative canopy is grass or grass like plants (Wischmeier and Smith, 1978). The overland Manning's value was set at 0.15 representing a grass pasture (SCS, 1979) and the surface condition constant was set to 1.0, an internal indicator in AGNPS for simulating a buffer strip (Young et al., 1994). These values are summarized in Table 2.

Results and Discussion

There was a significant difference in the predicted sediment loads at the watershed outlet between the baseline scenario and the buffer strip scenario. Sediment load at the watershed outlet was reduced by 17% (from 13.9 tons to 11.6 tons) by the incorporation of the buffer strip around all stream segments for the 10yr -24hr event.

In this study, the placement of buffer strips was prioritized on three different scales within the watershed. Stream segments, fields adjacent to the stream and individual streamside cells were analyzed to define critical areas of buffer placement. The stream system was separated into seven different stream segments, and identified by letters A-G (Figure 5). The buffer was assessed on the thirty-nine fields adjacent to the stream system owned by 14 different landowners. Finally, every 660-buffered cell was individually analyzed for increased sediment yield. Each analysis scale was assessed by totaling the amount of sediment filtered, where every buffered stream segment and field was ranked by determining the average reduced sediment per cell and then multiplying that value by 100. Therefore, a higher value represents greater buffer efficacy.

Stream Segment Results

The analysis of the seven-buffered stream segments within the EBC watershed is summarized in Table 3. For each stream segment, filtered sediment varied extensively ranging from 3.49 tons to 58.54 tons. The buffer surrounding stream segment F was found to be the most efficient with a ranking number of 43.6, however because of the small amount of agricultural land along that stream segment, one field was available to buffer (8 cells) and only filtering 3.49 tons. The second ranked stream segment D (rank=38.8), had 90-buffered cells and filtered 34.89 tons. The most amount of sediment filtered (58.54 tons) was on stream segment G. Stream segment G had the largest buffer consisting of 163 cells, with a rank of 11.7. Analyzing buffer efficacy on this scale allows for a quick assessment of sediment loads moving into a stream system. The analysis can be advantageous for focusing buffer strip placement in larger watersheds where identifying landowners is not an issue.

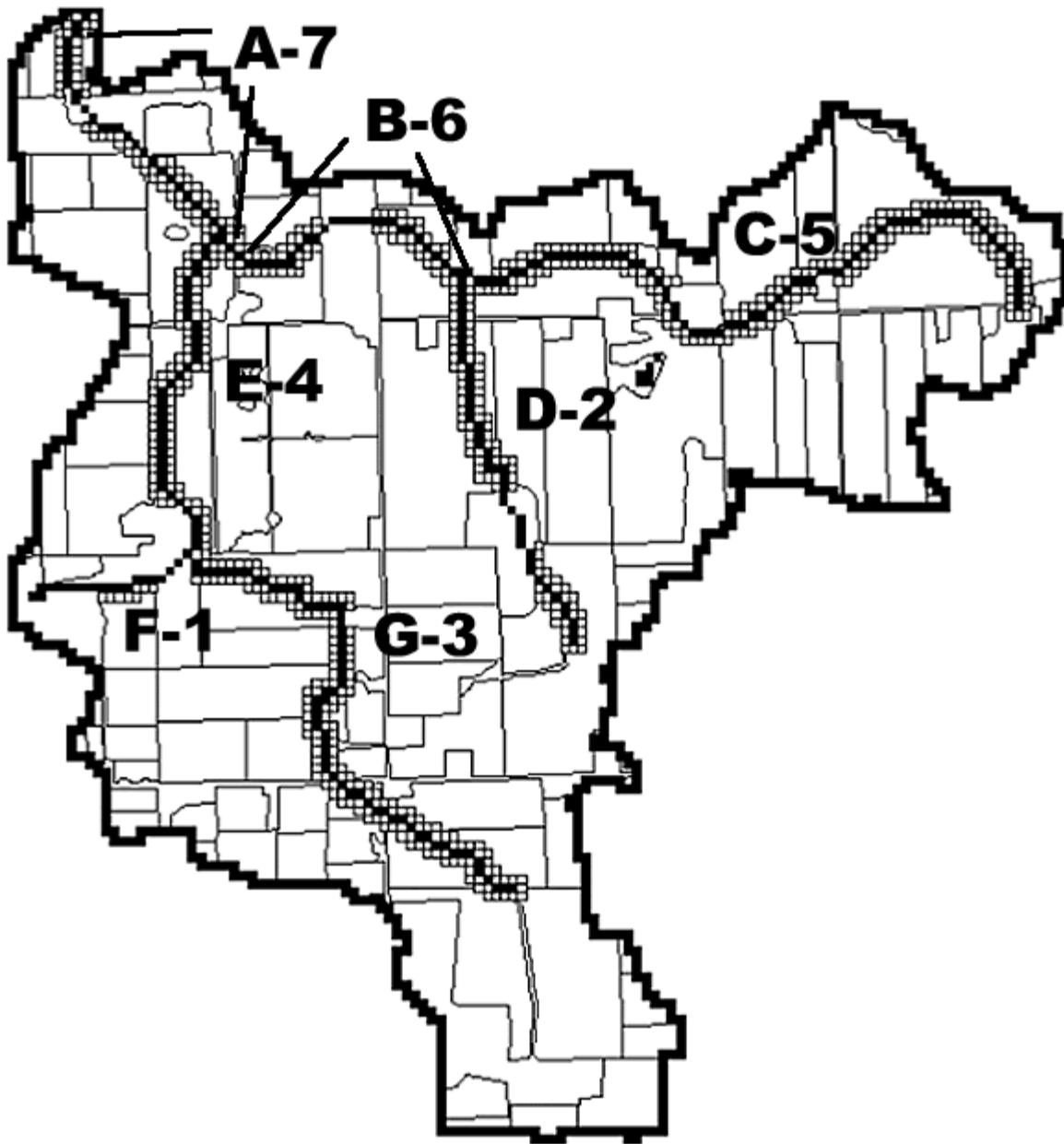


Figure 5. Stream segment's (A-F) ranked from 1-7 in order of buffer efficiency.

Field Results

The sediment reduction from the field buffers within the watershed varied from 0 to 19.3 tons (Table 4). As shown in Figure 6, the fields were numbered based on their buffer efficacy. Thus, if every cell does not reduce a certain amount of sediment then the average sediment per cell is low, indicating buffer inefficiency. Field buffers 1-14 were identified as reducing 55% of the total amount of sediment entering the stream, which resulted in buffering 60.5 acres (approximately 42% of the total buffer throughout the watershed). Therefore, a watershed manager would only have to target 5 landowners and

install buffers on a total of 14 fields. This analogy could also be used if a higher reduction percentage is desired.

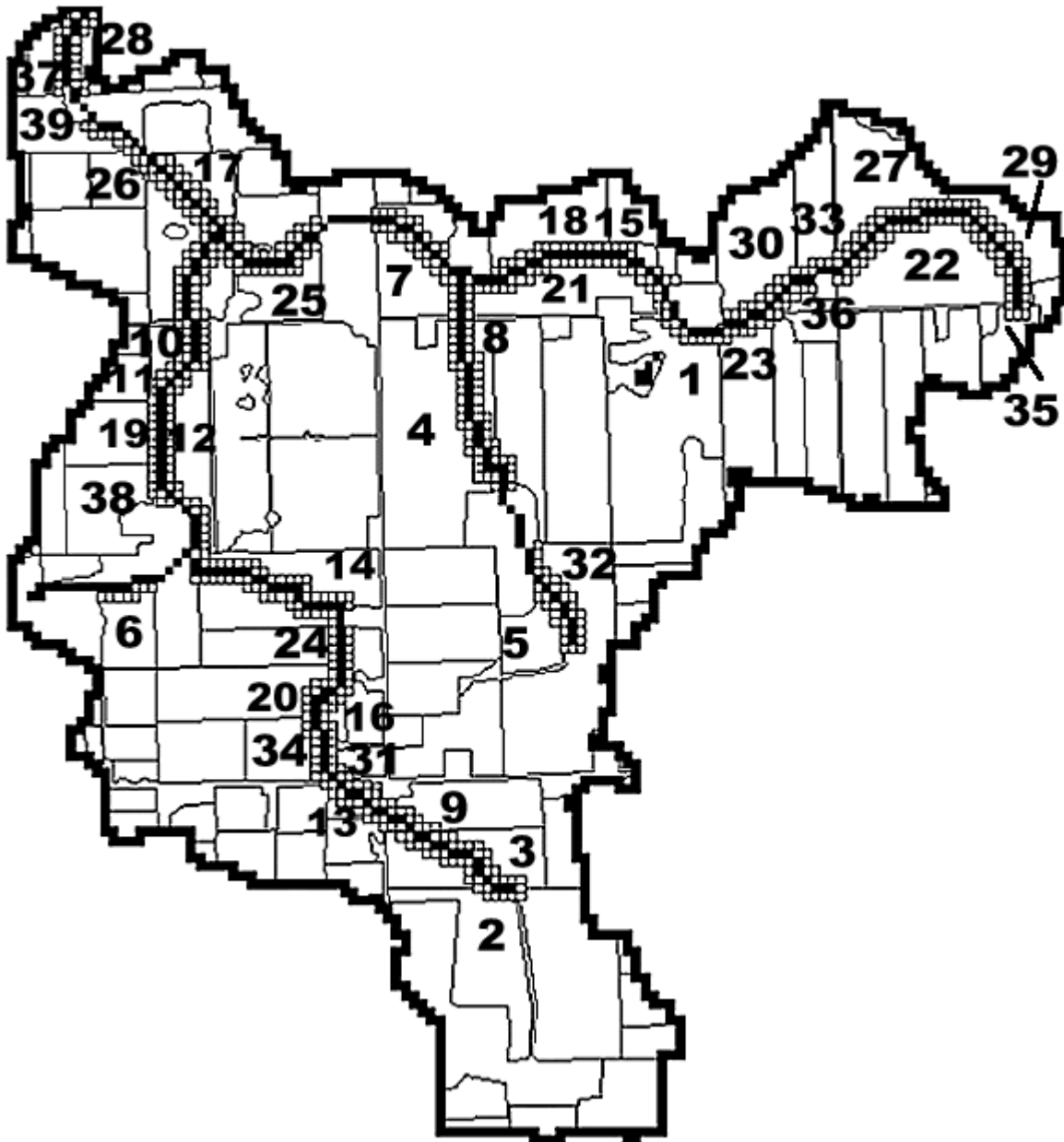


Figure 6. Fields ranked in order of buffer efficiency.

The field results show the importance of knowing the efficiency of the buffer. In contrast, most watershed managers would want to install buffers based on the most amount of sediment each field buffer filtered. If this scenario is considered more acres would be buffered while reducing the same amount of sediment entering the stream. For example, buffers would have to be placed in 8 fields (fields:

17, 3, 14, 7, 4, 12, 22, 21) to reduce 53% of the sediment, which resulted in buffering 67.5 acres, approximately 7 more acres than buffering the 14 efficient field buffers.

Buffered Cell Results

Figure 7 shows the 30-meter cells that are filtering 0.5 tons of sediment or more are darkened. This identifies critical areas of buffer strip placement on a 30-meter resolution. Evaluating the buffered cells on this scale identifies why certain stream segments were efficient and especially pinpoints effective field buffers (Figure 6). If the 106 darkened cells were buffered (23 acres), 42% of the total amount of sediment entering the stream is filtered. This analysis suggests that a watershed manager could install buffer strips within these site-specific areas but it could be very time consuming and labor intensive. Thus, by identifying critical areas on a cell-by-cell basis will help watershed managers identify certain stream segments or fields for evaluating buffer strip placement. In the future, when the technology is available watershed managers may be able to install buffers in these site-specific areas. In comparison, Figure 4 shows the 14 buffered fields that reduced sediment entering the stream by 55% and also the cells that reduced 0.5 tons of sediment or more. It is important to assess efficiency on the fields that encompass the darkened cells because not all of the cells within the field buffers are filtering 0.5 tons of sediment or more.

The cell results did not show one or two distinct areas of buffer efficiency throughout the watershed that could easily be explained. Therefore, it was important to assess why buffered areas were performing well as apposed to other areas. As a result, the digital ortho photo quadrangles were evaluated and areas of channelized flow were identified and compared to the cell results. In most cases when one cell drains a large area of land and immediately enters the buffer (channelization), the buffered cell could not filter a lot of sediment as apposed to when the flow was uniform. Thus, on a primarily flat agricultural watershed, channelization does occur and should be considered when identifying areas of buffer effectiveness.

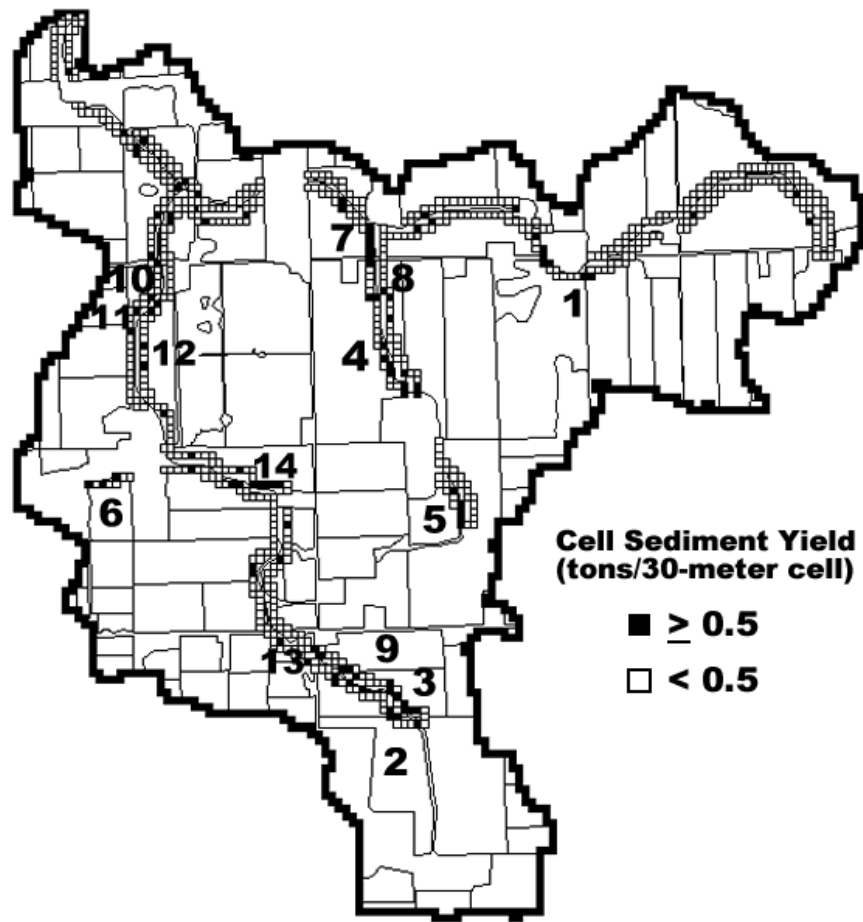


Figure 7. Sediment yield per cell with the 14 most efficient fields.

Conclusions

In conclusion, the AGNPS model proved to be an effective tool to help evaluate the efficiency of vegetative buffer strips within the East Bad Creek watershed. Areas with high buffer efficacy were established by evaluating the buffer around every stream segment throughout the watershed, on field boundaries along the stream and also comparing each buffered cell adjacent to the stream. Evaluating buffer efficiency on these three different scales will help watershed managers focus their efforts in areas where buffer strips will efficiently reduce the most amount of sediment. Perhaps, identifying critical areas of buffer efficiency on a cell-by-cell basis then recognizing stream segments of field boundaries where these critical areas reside may be the easiest way to assess buffer placement. As a result, the evaluation procedures discussed in this study will save watershed managers time and the extra expense of installing inefficient buffer strips while reducing the majority of the sediment load entering the stream.

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