DEVELOPMENT OF TMDL IMPLEMENTATION PLAN USING ANNAGNPS: A CASE STUDY

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ABSTRACT: Section 319 of the amended Federal Clear Water Act requires states to outline management plans for impaired water bodies to address non-point source pollution. When determining the priority for conservation measures within a watershed for non-point source pollution control, models are valuable tools that can provide clues as to where potential sources of water pollution may be and which problems can most easily be corrected. The USDA Annualized Agricultural Non-Point Source Pollution model (AnnAGNPS) is such a model which has been developed to aid in the evaluation of watershed response to agricultural management practices. This paper presents the processes used for developing an implementation plan for Bayou LaFourche, one of the impaired sub-segments of Ouachita River Basin in the northern Louisiana. In this study, the AnnAGNPS model was used to simulate amount of water and sediment generated from each user-specified computational area and their contributions to the watershed outlet; AnnAGNPS was also applied to simulate the impact of alternative agricultural management options on the water quality. Through AnnAGNPS simulations, high sediment producing areas were identified and those areas should be the targeted areas for effective non-point source pollution control. The alternative agricultural management options for reducing non-point source pollution and their simulated impacts on water quality are also presented in the paper. Among all the alternative agricultural management options, scenario E, which converts 25 percent of the highest eroding cropland in the watershed to grassland, would reduce sediment loads at the watershed outlet by 80 percent.

KEY TERMS: nonpoint source pollution; BMPs; management plan; AnnAGNPS; watershed modeling; critical areas.

INTRODUCTION

In 1987, when the Federal Clear Water Act (CWA) was amended, Section 319 was added to address water quality issues related to non-point source (NPS) pollution. Section 319 provides specific mandates for NPS pollution control. Agriculture has been long recognized as a major source of NPS pollution (Knisel, 1980; Baker, 1992; Phillips et al., 1993; USEPA, 1997; Stone et al., 2003; Borah et al., 2003). Transportation of excessive amount of sediment from agricultural cropland to water bodies can cause a plethora of water quality problems. Sediment directly damages water quality in streams and lakes. It impairs fish spawning areas, and reduces the amount of light reaching submerged vegetation, which decreases photosynthesis and consequently the amount of oxygen being released into the water. Sediment also increases water treatment costs, lowers recreational value, clogs channels and increases flooding. Furthermore, sediment is often rich in organic matter and nutrients such as nitrogen and phosphorous; those materials may also enter streams with sediment which causes rapid algae growth. Algae decomposition depletes oxygen, which leads to low dissolved oxygen (DO). Certain pesticides can attach to soil particles and be transported to water bodies, potentially harming aquatic species and human beings. Therefore, reducing soil erosion and sediment transport is of critical importance of reducing NPS pollutions.

A significant amount of research has been conducted to identify management options to minimize NPS pollution (Loehr et al., 1979; Mueller et al., 1984; Robinson et al., 1996; Lowrance et al., 1997; Sheridan et al., 1999; Simon and Collsion, 2002). Regulatory agencies promote that best management practices (BMPs) be adopted to reduce NPS pollution. Under the Environment Quality Incentive Program (EQIP), cost sharing is available from government agencies to agricultural producers who voluntarily implement BMPs (NRCS, 2001). Section 319 of the CWA authorizes the US Environmental Protection Agency

(USEPA) to issue grants to states to assist in implementing management programs to control NPS pollution.

The highest priority is to be given to water bodies included in the 303(d) List of Impaired Waters. A water body is entered onto the 303(d) list when it exceeds the water quality standard 10% of the time during an assessment period. Bayou LaFourche in the Ouachita River Basin in northern Louisiana was listed on the 303(d) list for Louisiana (USEPA, 2000) as not fully supporting the designated use for propagation of fish and wildlife. The cause for impairment cited in the 303(d) list is organic enrichment/low DO. Required by the Louisiana Department of Environmental Quality (LDEQ), researchers at the USDA-Agricultural Research Service-National Sedimentation Laboratory are responsible for outlining a management plan, which can be implemented with federal, state, and local funds, to reduce the amount of NPS pollution entering Bayou LaFourche and thereby improve water quality to a level where the bayou meets its designated uses.

The objective of this paper is to present the procedure used for developing an implementation plan for the Bayou LaFourche Watersheds. In the study, AnnAGNPS was used to help identify where potential sources of water pollution may be and which problems can most easily be corrected as well as simulate watershed responses to alternative agricultural management practices.

METHODS AND PROCEDURES

STUDY AREA AND HISTORICAL WATER QUALITY DATA

Bayou LaFourche (Fig. 1) is located approximately 8 km east of Monroe, LA in the Ouachita River Basin. The Ouachita River originates in the Ouachita Mountains of west central Arkansas. The River flows about 1000 km through northeastern Louisiana and joins with the Tensas River near Trinity, LA, where it forms the Black River. The drainage area for Bayou LaFourche is about 1461km^2 and majority of the land-use in the sub-segment is agricultural (60%). Cotton and soybeans are major crops in the watershed.

Monthly or bi-monthly grab water samples were collected at five locations in the subsegment (Fig. 1). Samples were usually taken at one meter depth. Then, samples were transported to the laboratory and water quality parameters including pH value, water temperature, DO, alkalinity, hardness, turbidity, total suspended solid, total dissolved solid, dissolved nitrogen, total nitrogen, total phosphorus were analyzed. Some sites have data as far back as 1978 (http://www.deq.state.la.us/surveillance). Since DO is the particular concern for the impaired water body, the mean of DO concentration and total suspended solid (TSS) over the monitoring period is presented in Table 1.

ANNAGNPS MODEL DESCRIPTION

AnnAGNPS is an advanced simulation tool that has been developed through a partnering project with the USDA-ARS and the NRCS to aid in the evaluation of watershed responses to agricultural management practices (Bingner and Theurer, 2001). AnnAGNPS is a continuous simulation, daily time step, pollutant loading model that includes significantly more advanced features than AGNPS (Young et al., 1989). Previous applications have proven that AnnAGNPS is capable of simulating long term runoff and sediment loadings from watersheds and the impact of BMPs on watershed water quality (Yuan et al., 2001; Yuan et al., 2002; Suttles et al., 2003). Within a watershed, spatial variability of soils, land use, and topography is accounted for by dividing the watershed into user-specified homogeneous drainage areas. From individual fields, runoff can be predicted from precipitation events that include rainfall, snowmelt and irrigation. Sheet and rill soil erosion within each field is predicted based on the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). A procedure based on sediment size distribution, runoff amount, and peak runoff rate is used to estimate sediment delivered beyond the edge of field and to link field soil erosion to sediment in the stream channel system (Bingner and Theurer, 2001).

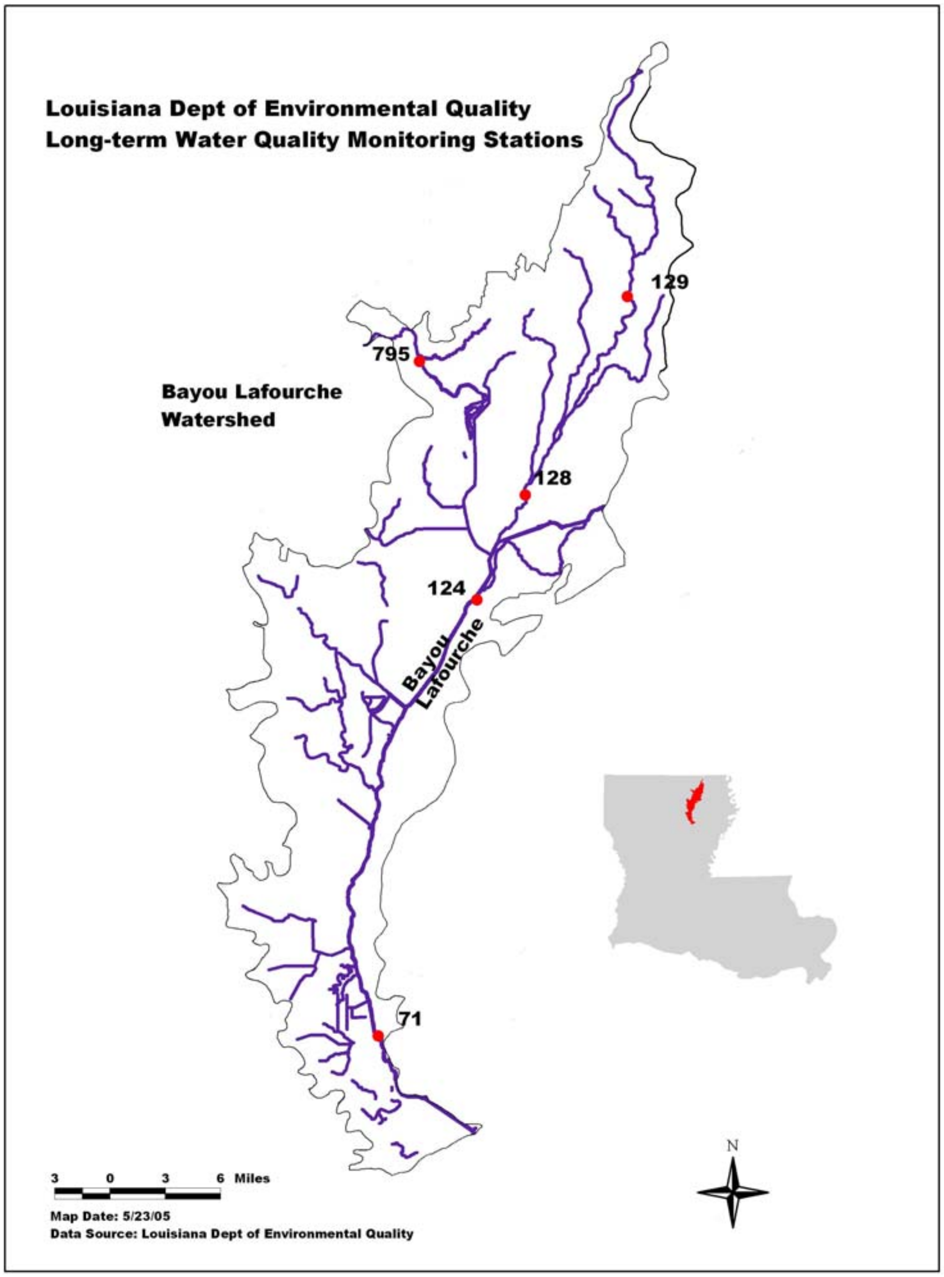


Figure 1 Bayou LaFourche sub-segment and its long-term monitoring locations

Table 1 Monitored mean of DO and TSS concentrations

Site Number	Mean of Monitored DO Conc. (mg/L)	Mean of Monitored T.S.S Conc. (mg/L)
71	6.5	103.9
124	7.7	92.7
128	5.0	86.6
129	6.2	88.2
795	2.6	49.0

Required input parameters for application of the model include climate data, watershed physical information, and management information. Daily climate information is needed to account for temporal variation in weather. Physical information, including watershed delineation, cell boundary, land slope, slope direction, and channel reach description can be generated by the AnnAGNPS data preparation tools (http://www.ars.usda.gov/Research/docs.htm?docid=5199). Management information can be organized using the AnnAGNPS Input Editor, a graphical user interface developed to aid users in selecting appropriate input parameters. Much information needed to characterize crop characteristics, field operations, chemical characteristics, feedlots, and soils can be obtained from databases imported from RUSLE or from NRCS sources. Climate data can be generated using the climate generator program (Johnson et al., 2000) based on climate stations located in the region surrounding the watershed. Output files include runoff, sediment, nutrient, and pesticide yield on a daily, monthly, or yearly basis. Output parameters can be specified for any desired watershed source location such as specific cells, reaches, feedlots, point sources, or gullies. More information on AnnAGNPS can be found in Bingner et al. (2003).

ANNAGNPS INPUT PREPARATION

The development of input parameters used for AnnAGNPS to describe the Bayou LaFourche conditions involved collecting many sources of available information, such as elevation maps, soil data, land-use and in field operation management practices as well as climate information. The compilation of the data into the form needed by AnnAGNPS was performed using the AGNPS Arcview Interface and the AnnAGNPS Input Editor (http://www.ars.usda.gov/Research/docs.htm?docid=5199). GIS data layers of the watershed include the digital elevation models (DEMs) to describe the topography; the land-use GIS layer to describe the vegetative cover; and soils GIS layer, which all together provide the spatial variation of the important characteristics of the watershed. Additional steps to further provide the model with the necessary inputs included developing the soil layer attributes to supplement the soil spatial layer, the different crop operation and management data, channel hydraulic characteristics, and climate data.

The characterization of the LaFourhce land-use, crop operation and management during the simulation period was critical in providing estimates of the nonpoint source loadings. AnnAGNPS has the capability of simulating watershed conditions with changing land-use over the simulation period. Unfortunately, the only land-use available is the land-sat satellite imagery taken in the summer of 1999. It is not know how land-use was changed before 1999 or after 1999. For crop operation and management, it is not known at the watershed level where the conservation tillage was specifically implemented and when the implementation started. Therefore, it is assumed that the 1999 GIS land-use layer represents the land-use for the period of 1971-2000; and at this watershed level, all fields were under reduced tillage operations during that period. This description of the watershed would reflect the current situation of the watershed. Additional management scenarios were simulated to look for strategies to reduce NPS pollution to achieve water quality goals. Information on field operation sequences under different tillage systems were collected from RUSLE 2.0 (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm).

BEST MANAGEMENT PRACTICES AND SIMULATIONS

Agricultural BMPs have been recommended to protect soil and water resources in the state of Louisiana. Management alternatives involve different tillage operations and/or land-use. A summary of the effectiveness of favorable BMPs is provided in Louisiana's Nonpoint Source Management Plan (LDEQ, 2000). Several different BMP treatment alternatives were modeled and run in the AnnAGNPS program as means to reduce soil erosion within the watershed and sediment load from the watershed. Those management alternatives were used to compare with the baseline existing condition (Table 2). Simulation runs were performed for scenarios A (all cropland with conventional tillage) and G (all cropland converted to no tillage) first to compare with reference conditions for the impact of tillage on soil erosion. Then, simulations were performed for the rest of the management scenarios listed in Table 2. The TMDLs (FTN, 2002) projected that the water quality standard for DO of 5.0 mg/L can be maintained if 80% reduction of manmade NPS pollution can be achieved. To target the TMDL reduction goal, trials and errors were performed to implement BMPs to critical areas to reduce manmade NPS pollution by 80% (scenario F).

Results and Discussion

Table 2 summarizes all simulation results. The soil erosion refers to amount of soil detached from the landscape; the sediment yield refers to amount of soil/sediment that moves through landscape and reaches the channel; and the sediment load refers to amount of soil/sediment that moves through stream channels and reaches the watershed outlet. The results shown in Table 2 are annual averages over a 30-year simulation period and the average annual rainfall for the 30-year simulation period was 1369 mm. Scenario B represents current situation of the watershed. This simulation resulted in the annual average erosion over the entire watershed of 1.632 tons per hectare per year. AnnAGNPS also produces the pollutant loading generated from each user-specified computational area. The amount of soil erosion generated from each user-specified computational area is displayed in Figure 2. Higher sediment producing areas can be targeted first to gain a better environmental benefit. For example, areas of soil erosion greater than 3.8 tons/ha/year, which account for about 17% of the watershed, are the first targeted area for management options (scenarios C and D) for this study. Then, second targeted areas are those producing soil erosion greater than 1.1 tons/ha/year (scenarios E and F).

Table 2 Summary of simulation results.

Scenario		Runoff Volume [mm]	Gross Soil Erosion [T/ha/yr]	Sediment Yield [T/ha/yr]	Sediment Loading at Outlet [T/ha/yr]
ID	Description				
A	All conventional	534	2.563	0.532	0.257
B	Current condition	526	1.632	0.346	0.178
C	16.6% of highest eroding cropland cells converted to no-till.	526	0.9	0.18	0.112
D	16.6% of highest eroding cropland cells converted to grass	505	0.451	0.079	0.062
E	25.2% of highest eroding cropland cells converted to no-till.	525	0.797	0.164	0.103
F	25.2% of highest eroding cropland cells converted to grass.	497	0.236	0.042	0.036
G	All cropland no-tilled.	525	0.708	0.149	0.092
H	All cropland converted to grass	483	0.025	0.005	0.005
I	All cropland converted to forestland.	453	0.024	0.005	0.005

Simulation of alternative management scenarios were used to compare with the baseline existing condition (Fig. 3). The fall plow simulation was thought to represent the worst case scenario for the existing land use within the watershed, whereas the all no-till simulation represented the best case scenario that could be obtained applying state of the art technology to each hectare of the existing land use within the watershed.

The effect of conservation-tillage was evaluated by converting various areas to different levels of no-till crop production (management alternative Scenarios C, E, & G). No-till was applied by converting the highest eroding areas to no-till. A targeted application of 17 percent new no-till (Scenario C) on the highest eroding areas would achieve a 45 percent reduction in soil erosion (Figure 3). However, this is probably not politically or programmatically feasible to implement as a land treatment program which relies on voluntary incentives. A more realistic reduction may be lower than 45 percent by converting a percentage of areas to no-till on voluntary basis. As expected, reduction of soil erosion from scenario E and G are not as efficient as scenario C (Fig. 3). Increases in no-till areas reduced landscape erosion which in turn reduces sediment yield and load.

The effect of land use was evaluated by converting various areas to different levels of grass. Simulations were made to simulate the impact of conversion from cropland to grassland (management alternatives Scenarios D, F, & H). A targeted application of 17 percent new grass land (Scenario D) on the highest eroding areas would achieve a 73 percent reduction in soil erosion (Figure 3).

BMPs are widely used in the United States. Conservation tillage centered on the concept of reducing erosion within the watershed by increasing land cover as opposed to all row crops with a clean till (Conventional tillage). Conservation tillage requires selecting a combination of tillage and cropping systems that provide best protection of soil and water resources. Most systems considered in this study had a reasonable chance of being implemented and/or for which financial incentive programs existed or could be developed. However, there were some systems evaluated in this project which could not be realistically implemented (such as converting the watershed to 100 percent no-till or 100 percent trees). However, evaluating these systems provided a result that served as reference information and helped in understanding the model. Treating the watershed as 100% conventional tillage was also evaluated as a reference.

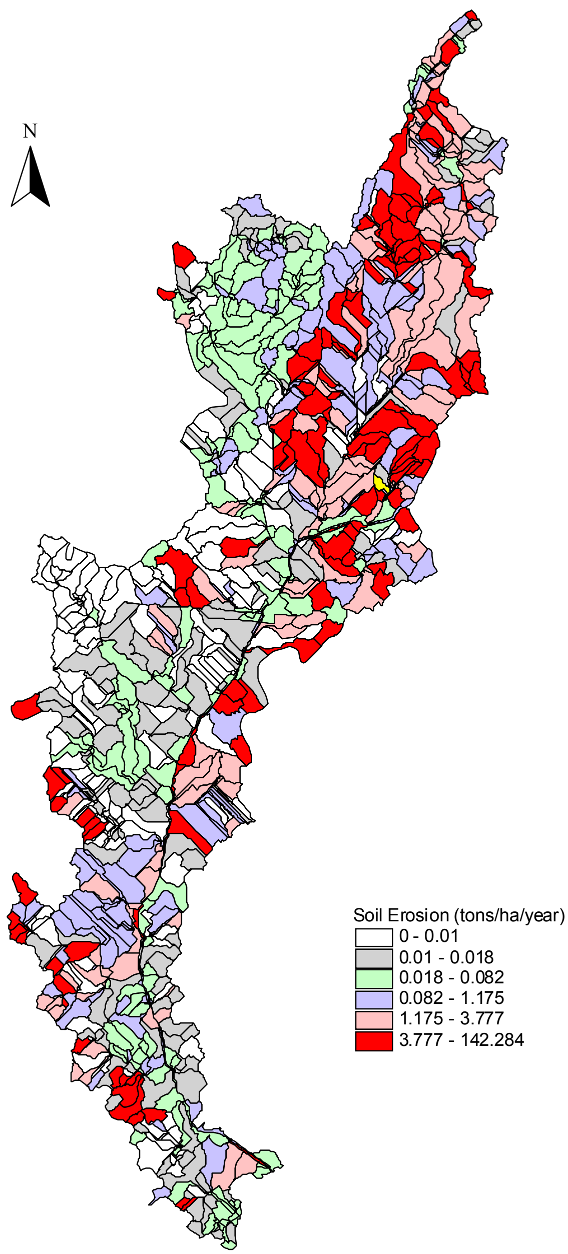
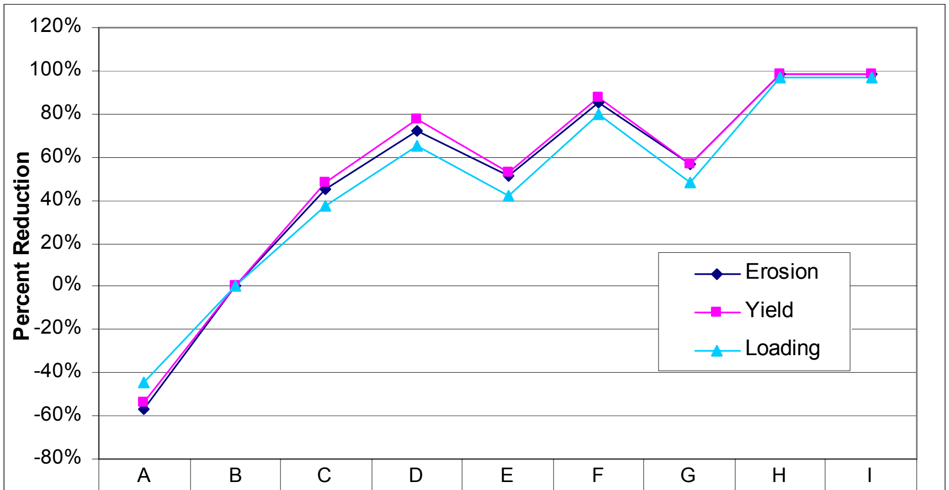


Figure 2 soil erosion distribution map



	A	B	C	D	E	F	G	H	I
Erosion	-57%	0%	45%	72%	51%	86%	57%	98%	99%
Yield	-54%	0%	48%	77%	53%	88%	57%	99%	99%
Loading	-44%	0%	37%	65%	42%	80%	48%	97%	97%

Figure 3 Percent reduction of soil erosion, sediment yield, and sediment loading from alternative scenarios

Many combinations of alternative agricultural management practices which had a reasonable chance of being implemented and can be used to reduce soil erosion and improve water quality were not simulated in this study. For example, converting 10% highest eroding cropland to grass and 7% second highest eroding cropland to no tillage were not simulated. In addition to agricultural BMPs for crop land, effective BMPs are available for construction activities include diversion dikes, seeding and mulching, hay bale dikes, silt fencing, vegetative cover, sediment basins, and sediment traps (http://nonpoint.deq.state.la.us/). Forest BMPs are also available to reduce the NPS pollution. However, BMPs for construction sites and forest were not modeled in this study because the model as run for this project did not have the capability.

Long term monitoring is needed to identify water quality problems as well as to calibrate the model for watershed evaluation. Continuous time series rainfall, runoff, and pollutant loadings are needed for model development, calibration, and validation. However, such kind of monitoring information is not available in this study area. The LDEQ maintained monthly or bimonthly sampling data is not enough for model calibration or validation. Although the simulated sediment load at monitoring sites can not be verified, application of AnnAGNPS for this study is to identify critical areas for nonpoint source pollution control. How accurate the AnnAGNPS simulation reflect real condition is not very critical. Instead, relative comparisons of results are more important in this study.

The need for more intensive monitoring can be seen from this project. In addition, it would be ideal that AnnAGNPS can be linked with a river water quality model so that DO concentration in the river as well as the impact of agricultural management practices on DO concentrations can be simulated. If such a model can be developed, the results presented in table 1 may be verified by linking AnnAGNPS with this river water quality model if land use and tillage practices on the watershed scale can be better defined. Linking nonpoint source pollution model with river water quality model and/or establish links between sediment load and biologic impairment/aquatic habitat maybe an ongoing or future challenge.

SUMMARY AND CONCLUSION

To develop an implementation plan for a watershed size of 1461 km^2 as Bayou LaFourche, AnnAGNPS model was used to identify critical areas causing the most soil erosion and sediment and simulate the impact of alternative management practices on soil erosion and sediment yield. For

AnnAGNPS simulations, considerable efforts were spent on input data preparations, which include collecting both spatial and nonspatial data from various sources and data analysis. Although few data were available to calibrate/validate the model, application of AnnAGNPS for this study is to identify critical areas for nonpoint source pollution control, thus, relative comparison of results is more important than real prediction. Simulations of alternative management practices show that converting 17% of highest eroding cropland cells from reduced tillage to no tillage practice would reduce soil erosion by 45%, a more efficient way is to convert 17% of highest eroding cropland cells to grass that would reduce soil erosion by 72%. However, the land treatment program relies on voluntary incentives, it is probably not politically feasible to convert highest eroding cropland as recommended by the simulation; the actual reduction may be lower on a voluntary basis. In addition, there are many combinations of alternatives were not simulated in this study. When it is time for the conservation practices to be implemented, alternative management practices should not be limited to the alternatives simulated in this study.

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