Land Use and Water Resources Research

Development of TMDL watershed implementation plan using Annualized AGNPS

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Abstract

Section 319 of the amended Federal Clean 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 northern Louisiana. In this study, the AnnAGNPS was used to simulate the amount of water and sediment produced from each user-specified computational area within the watershed 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 targeted for effective non-point source pollution control. Alternative agricultural management options for reducing non-point source pollution and their impacts on water quality are also presented. Among these options, scenario G, 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.

Introduction

In 1987, when the US Federal Clean Water Act (CWA) was amended, Section 319 was added to address water quality issues related to non-point source (NPS) pollution. Agriculture has been long recognised as a major source of NPS pollution (Knisel, 1980; Baker, 1992; Phillips *et al*., 1993; USEPA, 1997; Borah *et al*., 2003; Stone *et al*., 2003). In recent years, the off-site transport of sediment and its pollutants from agricultural cropland has been identified as a major contributor to surface water impairment (USEPA, 1998). Excessive amounts of sediment 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

* 'watershed' is the American term for catchment or drainage basin. - *Ed.*

nutrients such as nitrogen and phosphorus; these materials may also enter streams with sediment which causes rapid algal growth. Algae decomposition depletes oxygen, which leads to low dissolved oxygen (DO) content. 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 in reducing NPS pollution from agriculture.

A significant amount of research has been conducted to identify management options to minimise NPS pollution (Loehr *et al*., 1979; Mueller *et al*., 1984; Robinson *et al*., 1996; Lowrance *et al*., 1997; Sheridan *et al*., 1999; Simon and Collision, 2002). Regulatory agencies promote best management practices (BMPs) for reducing NPS pollution. Under the Environment Quality Incentive Program (EQIP), cost-sharing schemes are available from government agencies to agricultural producers who voluntarily implement BMPs (NRCS, 2001). Section 319 of the CWA authorises the US Environmental Protection Agency (USEPA) to issue grants to states to assist in implementing management programmes 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 on this 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 is organic enrichment/low dissolved oxygen due to sediment. Required by the Louisiana Department of Environmental Quality (LDEQ), researchers at the USDA-Agricultural Research Service National Sedimentation Laboratory are responsible for outlining a TMDL implementation plan for Bayou LaFourche. This plan will be implemented with federal, state and local funds to reduce the amount of sediment entering Bayou LaFourche and thereby improve water quality to a level where the bayou meets its designated uses.

This paper presents a procedure used for developing an implementation plan for the Bayou LaFourche Watershed. In this study, AnnAGNPS was used to: (1) simulate water and sediment transported in the watershed; (2) identify the critical areas where potential sources of water pollution may be and problems which can most easily be corrected; and (3) evaluate watershed responses to alternative agricultural management practices.

Methods and procedures

AnnAGNPS model description

The Annualized Agricultural Non-point Source Pollution (AnnAGNPS) model is an advanced technological watershed evaluation tool that has been developed through a partnership between two USDA agencies — the Agriculture Research Service (ARS) and the Natural Resources Conservation Service (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).

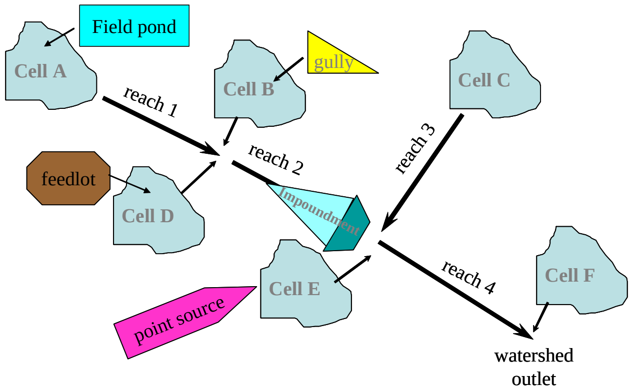

Figure 1. Processes simulated in AnnAGNPS

Within a watershed, spatial variability of soils, land use, and topography is accounted for by dividing the watershed into user-specified homogeneous drainage-area-determined-cells. Runoff, sediment and chemicals are routed from each cell through a channel network to the outlet of the watershed (Fig. 1). The model has the capability to identify the sources of pollutants at their origin and to track them as they move through the watershed system. From individual cells, runoff can be predicted from precipitation events that include rainfall, snowmelt and irrigation. Sheet and rill soil erosion within each cell is predicted based on the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997). A procedure based on sediment size distribution, surface 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).

Required input parameters for application of the model include climate data, watershed physical information and management information. Daily climate information, which includes daily precipitation, maximum and minimum temperatures, dew point temperature, sky cover and wind speed, 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 organised using the AnnAGNPS Input Editor, a graphical user interface developed to aid users in selecting appropriate input parameters. Much of the information needed to characterise crop characteristics, field operations, chemical characteristics, feedlots and soils can be obtained from databases imported from RUSLE (Renard *et al*., 1997) or from USDA-NRCS sources.

Output information produced in the model includes runoff, sediment, nutrient and pesticide at a temporal scale ranging from daily to yearly and at any desired location such as specific cells, stream reaches, feedlots, gullies, or point sources. The model also has the capability to provide source accounting information in terms of the fraction of a pollutant loading passing through any reach location that originated from an upstream watershed pollutant source area. More information on AnnAGNPS can be found in Bingner *et al*. (2003).

Previous applications have demonstrated 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, 2002; Suttles *et al.*, 2003). In a runoff and sediment validation study, Yuan *et al.* (2001) found that AnnAGNPS simulated monthly runoff and sediment were close to observed runoff and sediment with no calibrated parameters (R-square of 0.9 for runoff and 0.7 for sediment). A study by Suttles *et al*. (2003) concluded that AnnAGNPS simulated runoff and sediment matched observed runoff and sediment (100% of observed runoff, 106% of observed sediment) at the outlet of the Little River watershed in Georgia.

The Bayou LaFourche watershed

The Bayou LaFourche watershed is located in Ouachita River Basin in the northern part of Louisiana (Fig. 2). The watershed encompasses 146 104 hectares. Land use consists of 41% cropland, 15% grassland, 28% woodland, 6% urban, and 10% water and other land-uses. Cotton and soybeans are the predominant crops grown in the watershed and together account for an estimated 71% of the agricultural cropland in cultivation. Most soils in the Bayou LaFourche watershed are nearly level to gently sloping; silt loams with very slowly permeable subsoils are the dominant soil types in the western part of the watershed. The soils turn to clays towards the eastern part of the watershed. Common conservation practices adopted in the watershed include grassed waterways, conservation-tillage and no-tillage.

There are two US Geological Survey (USGS) gauging stations in the watershed along the Bayou LaFourche river. Daily mean discharges were maintained at one gauge and annual peak discharges were maintained at the other. However, flows in Bayou LaFourche are manually controlled. Many sections of the river have been hydraulically modified to accommodate barge traffic. In addition, Bayou LaFourche is often used as a diversion canal for a portion of an adjacent river (Boeuf River). The amount of water from the Bayou LaFourche watershed that actually contributes to the gauge is not known. The LDEQ has been collecting monthly or bi-monthly grab water samples since the 1980s. DO is one of the parameters analysed in the water sample and it was found that the DO was often below 5 mg L^{-1} in the summer months.

Input preparation of existing watershed conditions

The development of input parameters used for AnnAGNPS to describe the Bayou LaFourche condition 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 use of a Geographic Information System (GIS) is therefore

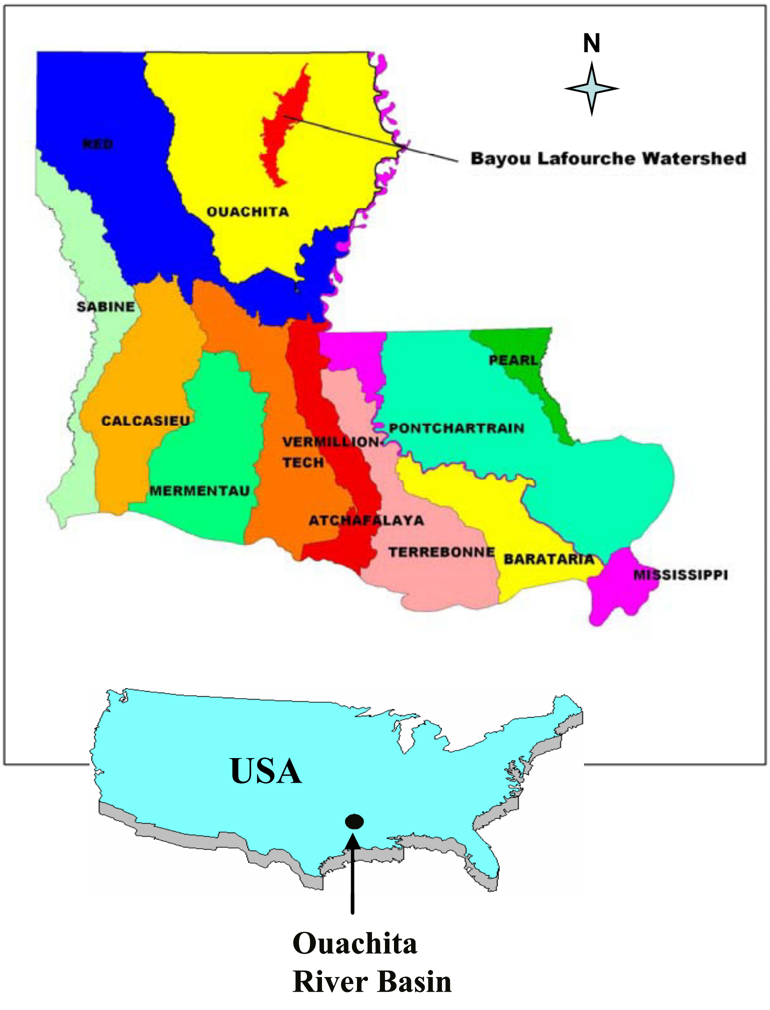

Figure 2. Louisiana major watershed basins. Ouachita River Basin is located in the northern part of the state and Bayou LaFourche is one of the subwatersheds of Ouachita river basin.

critical in gathering the needed data to perform simulations for a watershed of the size of LaFourche. The GIS data provide the vital link between the characteristics of the watershed and the parameters needed by the model. 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=5199H).

Using the GIS digital data layers of digital elevation model, soils and land use, most of the large data input requirements of AnnAGNPS were developed by using a customised ArcView GIS interface (http://www.ars.usda.gov/Research/docs.htm?docid=5199). Inputs developed from the ArcView GIS interface include physical information of the watershed and sub-watershed (AnnAGNPS cell), such as boundary and size, land slope and slope direction, and channel reach descriptions. The ArcView GIS interface also assigned a soil and land-use type to each cell by using the generated sub-watershed and the soil and land-use GIS data layers. Additional steps to provide the model with the necessary inputs included developing the soil layer attributes to supplement the soil spatial layer, establishing the different crop operation and management data, and providing channel hydraulic characteristics. Those inputs were organised using the AnnAGNPS Input Editor (http://www.ars.usda.gov/Research/docs.htm?docid=5199), a graphical user interface designed to aid users in selecting appropriate input parameters.

Climate data for AnnAGNPS simulation can be measured historically, generated synthetically using the climate generator program (Johnson *et al*., 2000), or created through a combination of the two. For this study, a combination of the historical climate information and synthetically generated climate information was used. AnnAGNPS requires daily precipitation, maximum and minimum temperatures, dew point temperature, sky cover and wind speed. Although there are several climate stations located in the watershed, daily recorded climate information includes only precipitation, maximum and minimum temperature; not dew point temperature, sky cover and wind speed. To complete the climate files needed by AnnAGNPS, several steps were involved. First, the USDA's GEM model (Johnson *et al.*, 2000) was used to generate daily precipitation, maximum and minimum temperature, and solar radiation for each climate station based on the latitude and longitude of the station. After this GEM file was produced, GEM-generated precipitation and maximum and minimum temperature were replaced with historically recorded precipitation and maximum and minimum temperature. Second, a monthly climate file for each location was built based on the climate Atlas data (www.ars.usda.gov/research/docs.htm?docid=5199). Finally, a complete_ climate model was run to produce the complete climate file needed by AnnAGNPS. This file included all six climate parameters required by AnnAGNPS. Complete information on weather generation can be found at the AGNPS website (www.ars.usda.gov/Research/docs.htm?docid=5199).

Spatially varied weather files were used for the Bayou LaFourche simulation. After climate files were completed for all climate stations, a Thiessen polygon was created based on all available climate locations in the study area; this was overlaid with the sub-watershed layer and climate files were assigned to cells based on this overlay. Cells that fell in the same polygon had the same climate file.

The characterisation of the Bayou LaFourche watershed land-use, crop operation, and management during the simulation period was critical in providing estimates of the sediment loadings. AnnAGNPS has the capability of simulating watershed conditions with changing land use and crop management over the simulation period. However, it was very difficult, at this watershed scale, for AnnAGNPS to characterise the annual changes, including land-use and field management practices, occurring in the watershed. The only land-use information available was Landsat satellite imagery taken in the summer of 1999: it is not known how land use changed before or after 1999. In addition, it is not known at the watershed level where conservation tillage was specifically implemented and when such implementation commenced. Therefore, it is assumed that the 1999 GIS land-use layer represents the land use for the period 1971–2000 when some parameters forming part of the required climate information were recorded; during that period, all fields were under reduced tillage operation management. Reduced tillage operation was assumed because NRCS field survey by parish found that the adoption of conservation tillage started in the 1970s and the area of adoption increased over the intervening period. By 2000, about 75% of the land was under conservation tillage which included reduced tillage and no-tillage. The AnnAGNPS parameter of curve numbers was selected based on the *National Engineering Handbook*, section 4 (SCS, 1985). Crop characteristics and field management practices were developed based on RUSLE (Renard *et al.*, 1997) guidelines and local RUSLE databases.

Development of alternative agricultural management scenarios

Agricultural BMPs have been recommended to protect soil and water resources. Management alternatives involve different tillage operations and/or land-use. A significant benefit in using watershed models in conservation planning is the capability to apply and evaluate various management practices on the same landscape. For the Bayou LaFourche watershed study, various alternative agricultural management scenarios were developed for simulation and evaluation as a means to reduce soil erosion within the watershed and sediment load from the watershed. A summary of the effectiveness of favourable BMPs is provided in Louisiana's Nonpoint Source Management Plan (LDEQ, 2000). Local NRCS personnel recommended that no-till conservation practices replace conventional and reduced tillage practices in agricultural producers' management schedules where they could be appropriately applied. Since no-till conservation practices may not be applied in every agricultural circumstance because of economic or local issues, various levels of no-till application throughout the watershed were evaluated. Using the existing watershed management (scenario A) as a baseline, all AnnAGNPS cells were sorted, based on their highest erosion rate and grouped into categories that represented 17% (scenario B) and 25% (scenario C) of the highest eroding cells in the watershed. No-till conservation practices were then defined for each cropland cell according to the existing conditions. While an evaluation of no-till conservation practices is important for NRCS, the Conservation Reserve Program (CRP), represented as grassland is also a key component of NRCS conservation efforts. Thus, CRP was also applied for each cropland cell according to the existing conditions (scenarios F and G).

In general, scenarios were considered that had a chance of being implemented based on NRCS conservation programmes (http://www.nrcs.usda.gov/programs/) and/or for which financial incentive programmes existed or could be developed. However, there were some scenarios evaluated which could not be realistically implemented, such as converting the watershed to 100% no-till (Scenario D) or converting all cropland to conventional tillage (Scenario E). Evaluating these less realistic scenarios provided results that served as benchmark information or helped in understanding model performance. The conventional tillage simulation (Scenario F) was thought to represent the worst case scenario for the existing conditions within the watershed, whereas the 100% no-till simulation (Scenario E) represented what was thought to be the best case scenario that could ever be obtained with the existing conditions in the watershed. In addition, converting the watershed to 100% grassland (Scenario H) or forest (I) was also evaluated as references.

Model simulations

AnnAGNPS simulation of the existing condition (baseline) was performed first; then, the various alternative agricultural management scenarios described above were simulated. Simulations of alternative agricultural management scenarios were then compared with the simulation of the baseline condition to evaluate their effects on erosion and sediment reduction in the watershed.

Results and discussion

Results of runoff, soil erosion, sediment yield, and sediment loading for alternative scenario simulations are given in Table 1. Soil erosion refers to the amount of soil detached from the landscape; sediment yield refers to the amount of soil/sediment that moves through the landscape and reaches the channel; and sediment loading refers to the amount of soil/sediment that moves through stream channels and reaches the watershed outlet. Sediment loadings for alternative agricultural management scenarios as percentages of existing conditions are also given in Table 1.

The results shown in Table 1 are annual averages over a 30-year simulation period. The long-term annual average data were chosen for comparisons because the long-term annual average information accounts for the temporal variation of weather, land use and management practices, and thus reduces randomness. The average annual rainfall for the 30-year simulation period was 1369 mm. Scenario A, which represents the current land-use situation of the watershed, resulted in an annual average erosion over the entire watershed of 1.632 tons per hectare per year. The amount of soil erosion generated from each user-specified computational area is displayed in Fig. 3.

A targeted application of 17% no-till (scenario B) on the most erodible cropland (areas of soil erosion greater than 3.8 tons/ha/year, red area in Fig. 3) would achieve a 37% reduction in sediment loading at the mouth (Table 1). As expected, an increase in no-till application would achieve a higher sediment reduction. An application of 25% of no-till (scenario C) on the most erodible cropland (areas of soil erosion greater than 1.2 tons ha^{-1} $yr^{-}1$, pink area in Fig. 3) would achieve a 42% reduction, and converting all cropland to no-till (scenario D), which is about 40% application of no-till, would achieve a 48% reduction (Table 1). However, the increase in sediment reduction was not at the same pace as the increase in no-till application. The first 17% no-till application to the watershed would achieve a 37% reduction, an additional 8% increase of no-till from scenario B to scenario C resulted in an increase of 5% reduction, whereas another additional increase of 15% of no-till from scenario C to scenario D resulted in an increase of 6% reduction

Table 1. Summary of simulation results. The annual average rainfall is 896.6 mm.

Scenario ID	*Description*	*Runoff volume ([mm])*	*Total landscape erosion (T ha^{-1} yr^{-1})*	*Total sediment yield (T ha^{-1} yr^{-1})*	*Sediment loading at outlet (T ha^{-1} yr^{-1})*	*Percent of existing condition loading (%)*
A	Current condition.	526	1.632	0.346	0.178	100
B	16.6% of highest eroding cropland cells converted to no-till.	526	0.9	0.18	0.112	63
C	25.2% of highest eroding cropland cells converted to no-till.	525	0.797	0.164	0.103	58
D	All cropland no-tilled.	525	0.708	0.149	0.092	52
E	All conventional.	534	2.563	0.532	0.257	144
F	16.6% of highest eroding cropland cells converted to grass.	505	0.451	0.079	0.062	35
G	25.2% of highest eroding cropland cells converted to grass.	497	0.236	0.042	0.036	20
H	All cropland converted to grass.	483	0.025	0.005	0.005	3
I	All cropland converted to forestland.	453	0.024	0.005	0.005	3

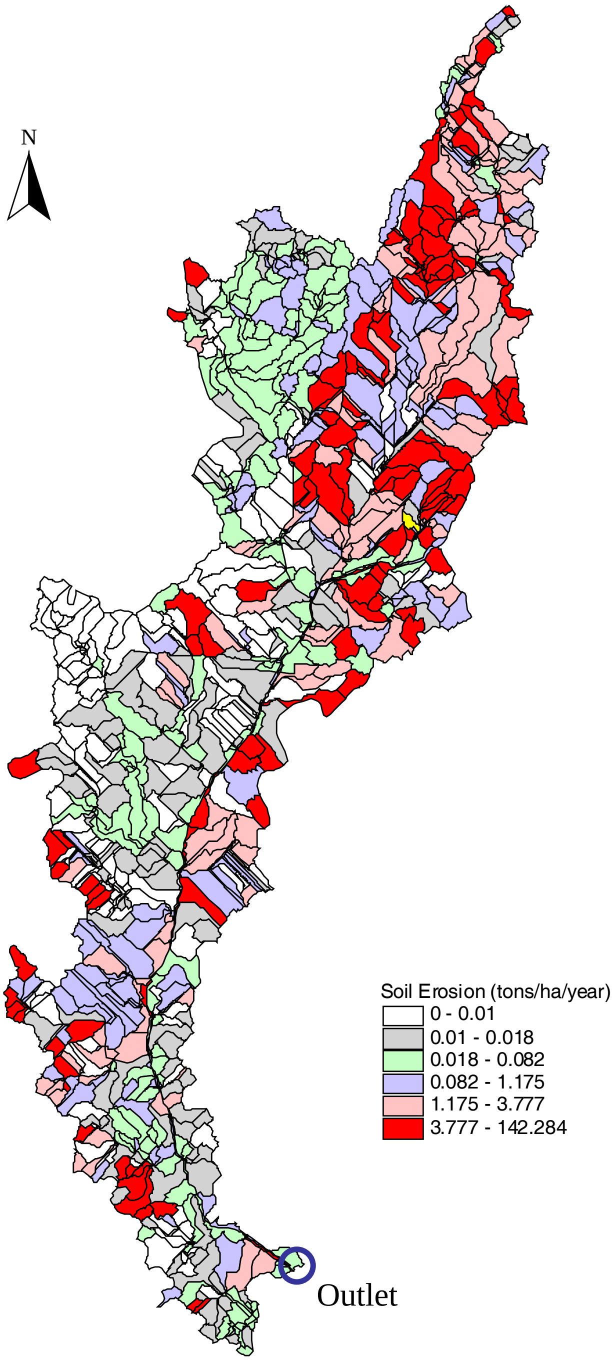

Figure 3. Soil erosion distribution map

(Table 1). Thus, it is important to target the critical areas which had serious erosion first so that cost/benefit can be maximised and non-point source pollution control can be achieved in the most efficient way.

A more efficient way to achieve sediment reduction is to convert cropland to grassland (Table 1). Scenario F, which converted 17% of the cropland to grassland, would achieve a 65% reduction in loading (Table 1). As expected, an increase in grassland application would achieve a higher sediment reduction; an application of 25% of grassland (scenario G) would achieve an 80% reduction in sediment loading, while converting all cropland to grassland (scenario H), which is about 64% increase in grassland, would achieve a 93% reduction (Table 1). Similarly, the increase in sediment reduction was not at the same pace as the increase in grassland application. The first 17% grassland application to the watershed predicted a 65% reduction, an additional 8% increase of grassland from scenario F to scenario G resulted in an increase of 15% reduction, whereas an additional 15% increase of grassland from scenario G to scenario H resulted in an increase of 17% reduction (Table 1).

Applications of both no-till and grassland would reduce landscape erosion, which in turn would reduce sediment yield and loading (Table 1). However, application of grassland areas would be more efficient than application of no-till areas in sediment reduction. A 17% grassland application (scenario F) would achieve a 65% reduction, whereas 17% of no-till application (scenario B) would achieve a 37% reduction (Table 1). Another comparison is that converting all cropland to no-till would have a reduction of 42%, whereas converting all cropland to grassland would have a 97% reduction in sediment loading. Converting all cropland to forest land would also achieve a 97% reduction in sediment loading (Table 1). The model as run for this project did not have a riparian buffer or filter strip component. The effectiveness of grass buffers captured in the model represented only the effect of land cover change on erosion and not the benefits that would accrue from any trapping efficiency when such practices took place adjacent to a stream. Thus the model may have underestimated the effects of these practices, which may provide additional reductions over the benefits stated.

Many combinations of alternative agricultural management practices which may have 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% of the highest eroding cropland to grass and 7% of the second highest eroding cropland to no tillage were not simulated. In addition to agricultural BMPs for crop land, effective BMPs available for construction activities include diversion dykes, seeding and mulching, hay bale dykes, silt fencing, sediment basins and sediment traps (http://nonpoint.deq.state.la.us/). Forest BMPs are also available to reduce NPS pollution. However, these BMPs for construction sites and forest were not modelled in this study because the model as run for this project did not have the capability. When an alternative agricultural management practice or a combination of practices is implemented, it is important to target the critical areas so that non-point source pollution control can be achieved more efficiently.

Neither calibration nor validation was performed for this watershed because of the lack of field observations. Long-term time series rainfall, runoff and sediment loadings are needed for model calibration and validation. However, such kind of monitoring information is not available in this study area. Although there are two USGS gauging stations in the LaFourche river, many sections of the river have been modified hydraulically to accommodate barge traffic. The LDEQ-maintained monthly or bimonthly sampling data were invaluable to identify water quality problems but not to calibrate or validate the model. In addition to long-term time series rainfall, runoff and sediment data, detailed land use, field management and field operations, including tillage, planting, harvesting and cover crop planting, are also important for model calibration and validation. Field operations that caused soil disturbance or land cover changes are especially important because of their impact on soil erosion and sediment loss. However, such data were not available either in this study area.

The complexity and expensive nature of laboratory and field observations necessitate the development and use of water quality models such as AnnAGNPS. Physically-based models have the potential to simulate the erosion processes or behaviour of sediment movement accurately, with little or no calibration of the parameters used. Using such models is significantly less expensive than large-scale monitoring of these processes in the field. AnnAGNPS is one such model which has been developed to utilise input parameters such as climate, soil and crop information taken from databases created by NRCS for any location in the U.S. This is meant to reduce users' effort in input data preparation and the need for calibration for ungauged watershed, where site-specific information is usually not available.

Although AnnAGNPS calibration or validation study was not performed in this watershed, many AnnAGNPS validation studies have been performed in the US and around the world (Yuan *et al*., 2001, 2003, 2005, 2006; Srivastava *et al.*, 2002; Baginska *et al*., 2003; Hong *et al*., 2005). Those studies have shown that AnnAGNPS is capable of simulating long-term runoff and sediment loadings from watersheds and is an effective tool for watershed conservation planning. AnnAGNPS is very powerful in that it can be used to identify critical areas where serious problems occur within a watershed and to demonstrate the impact of implementing various management options on water quality. As stated in the objectives, application of AnnAGNPS for this study was to identify critical areas and evaluate the impact of alternative land management scenarios for sediment reduction, thus comparisons of high or low sediment-producing areas within the watershed, as well as the impact of different management scenarios on sediment, can still be evaluated.

Summary and conclusion

To develop an implementation plan for a watershed size of 146 104 hectares as Bayou LaFourche to target non-point source pollution efficiently, the AnnAGNPS model was utilised to identify critical areas causing the most soil erosion and sediment and evaluate the impact of alternative management practices on soil erosion and sediment yield. The model indicated that an application to the watershed of various areas of no-till or grassland could reduce sediment loadings to a range of 3–63% of the existing condition. Converting the highest eroding cropland cells to grassland is more efficient in sediment reduction than converting the highest eroding cropland cells from reduced tillage to no tillage practice. However, as the land treatment programme relies on voluntary incentives, it is probably not politically feasible to convert the highest eroding cropland as recommended by the simulation; the actual reduction may well be lower on a voluntary basis. In addition, there are many combinations of alternatives which 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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References

Baginska, B., Milne-Home, W. and Cornish, P.S., 2003. Modelling nutrient transport in Currency Creek, NSW with AnnAGNPS and PEST. Environmental Model and Software 18:801–808.

Baker, L.A., 1992. Introduction to nonpoint source pollution in the United States and prospects for wetland use. *Ecol. Engng.*, **1**, 1–26.

Bingner, R.L. and Theurer, F.D., 2001. AnnAGNPS: Estimating sediment yield by particle size for sheet & rill erosion. Proc. Seventh Interagency Sedimentation Conference, Reno, NV, 25-29 March 2001. Vol. 1, 1–7.

Bingner, R.L., Theurer, F.D. and Yuan, Y., 2003. AnnAGNPS Technical Processes. Available at http://www.ars.usda.gov/Research/docs.htm?docid=5199. Accessed in May 2005.

Borah, D.K., Bera, M. and Shaw, S., 2003. Water, sediment, nutrient, and pesticide measurements in an agricultural watershed in Illinois during storm events. *Trans. ASAE,* **46**, 657–674.

Hong, H., Huang, J., Zhang, L. and Du, P., 2005. Modelling pollutant loads and management alternatives in Jiulong River watershed with AnnAGNPS. Environmental Science 26(4):63-69. The article is in Chinese. Available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=16212170&dopt=Abstract. Accessed on May 25, 2006.

Johnson, G.L., Daly, C., Taylor, G.H. and Hanson,C.L., 2000. Spatial variability and interpolation of stochastic weather simulation model parameters. *J. App. Meteorol.*, **39**,778–796.

Knisel, W.G. (Ed.), 1980. CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. *USDA Conservation Research Report No. 26*. Washington, D.C.: USDA-Agriculture Research Service.

LDEQ, 2000. Louisiana's Nonpoint Source Management Plan. Volume 6. State of Louisiana water Quality Management Plan. Louisiana Department of Environmental Quality, Office of Environmental Assessment.

Loehr, J.M., Haith, D.A. Walter, M.F. and Martin, C.S. (Eds), 1979. Best Management Practices for Agriculture and Silviculture. Ann Arbor Science, Ann Arbor, Michigan, 740pp.

Lowrance, R.R., Altier, L.S., Newbold, J.D., Schnabel, R.R., Groffman, P.M., Denver, J.M.,Correll, D.L., Gilliam, J.W., Robinson, J.L., Brinsfield, R.B., Staver, K.W., Lucas, W.C. and Todd, A.H., 1997. Water quality functions of riparian forest buffer systems in the Cheaspeake Bay Watersheds. *Environ. Manage*., **21**, 687–712.

Mueller, D.H., Wendt, R.C. and Daniel, T.C., 1984. Phosphorous losses as affected by tillage and manure application. *Soil Science Soc. Amer. J*., **48**, 901–905.

Natural Resources Conservation Service (NRCS). 2001. USDA Conservation Programs. http://www.nrcs.usda.gov/NRCSProg.html. Accessed in May 2005.

Phillips, D.L., Hardin, P.D., Benson, V.W. and Bagilo, J.V., 1993. Nonpoint source pollution impacts of alternative agricultural management practices in Illinois: A simulation study. *J. Soil Water Conserv*., **48**, 449–457.

Robinson, C.A., Ghaffarzadah, M. and Cruse, R.M., 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. *J. Soil Water Conserv*., **50**, 220–223.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C., coordinators. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* USDA Agriculture Handbook No. 703.

Sheridan, J.M., Lowrance, R.R. and Bosch, D.D., 1999. Management effects on runoff and sediment transport in riparian forest buffers. *Trans. ASAE*, **42**, 55–64.

Simon, A. and Collision, A.J.C., 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surf. Process. Landforms*, **27**, 527–546.

Srivastava, P., Hamlett, J.M., Robillard, P.D. and Day, R.L., 2002. Watershed optimization of best management practices using AnnAGNPS and a genetic algorithm. *Water Resour. Res*., **38**,1021.

Stone, K.C., Hunt, P.G., Novak, J.M. and Johnson, M.H., 2003. In-stream wetland design for non-point source pollution abatement. *Appl. Engng Agric*., **19**, 171–175.

Suttles, J.B., Vellidis, G., Bosch, D., Lowrance, R., Sheridan, J.M. and Usery, E.L., 2003. Watershed-scale simulation of sediment and nutrient loads in georgia coastal plain streams using the Annualized AGNPS model. *Trans. ASAE* ,**46**, 1325–1335.

USEPA, 1997. *National water quality inventory: 1996 report to United States Congress*. EPA841–R–97–005. Washington, D.C.: U.S. EPA.

USEPA, 1998. 1998 National Water Quality Inventory Section 305(5) Report to United States Congress. Available on internet http://www.epa.gov/305b/98report/.

USEPA, 2000. Modified Court Ordered 303(d) List for Louisiana. Downloaded from USEPA region 6 website (www.epa.gov/earth1r6/6wq/ecopro/latmdl/modifiedcourtorderedlist.xls).

Young, R.A., Onstad, C.A., Bosch, D.D. andAnderson, W.P. 1989. AGNPS: A Nonpoint-Source Pollution Model for Evaluating Agricultural Watersheds. *J. Soil Water Conserv*., **44**,168–173.

Yuan, Y., Bingner, R.L. and Rebich, R.A., 2001. Evaluation of AnnAGNPS on Mississippi Delta MSEA Watersheds. *Trans. ASAE*, **45**,1183–1190.

Yuan, Y., Dabney, S.M. and Bingner, R.L., 2002. Cost effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta. *J. Soil Water Conserv*., **57**, 259–267.

Yuan, Y., Bingner, R. L. and Rebich, R. A., 2003. Evaluation of AnnAGNPS Nitrogen Loading in an Agricultural Watershed. *J. Amer. Water Resour. Assn*., **39**, 457–466.

Yuan, Y., Bingner, R.L., Theurer, F.D., Rebich, R.A.and Moore, P.A., 2005. Phosphorus component in AnnAGNPS. *Trans. ASAE*, **48**, 2145–2154.

Yuan, Y., Bingner, R.L. and Theurer, F.D., 2006. Subsurface flow compoment for AnnAGNPS. *Appl. Engng Agric*., **22**, 231–241.