Report for 2002MI4B: Develop a GIS-based Soil Erosion and Sediment Assessment System (SESAS)

- Articles in Refereed Scientific Journals:
    - J. Kerr, D. Ouyang, and J. Bartholic, 2003. Targeting Watershed Interventions for Reduction of Nonpoint Source Pollution. Submitted to Journal of Soil and Water Conservation.
- Conference Proceedings:
    - Da Ouyang, J. Bartholic, and J. Selegean. 2003. Soil Erosion and Sediment Assessment in the Great Lakes Basin. Presented at the 2003 Annual Conference of National Association of Environmental Professionals. San Antonio, TX.

Report Follows:

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Problem and Research Objectives:
Agricultural nonpoint source (NPS) pollution is considered the leading cause of water pollution in the United States. Sediment and phosphorus are two major contributors that are responsible for water pollution. While soil erosion degrades productivity, it also causes water quality problems through sediment and nutrients. Excessive fertilization, particularly from phosphorus, leads to eutrophication which deteriorates surface water quality. Efforts have been made to minimize agricultural nonpoint source pollution by, for example, implementing best management practices (BMP). Controlling agricultural nonpoint source pollution requires good information and knowledge for identifying the source areas and quantifying the pollutant loadings. A water monitoring program is helpful but costly. A scientifically based model can provide an alternative approach to provide a quantitative estimation on soil erosion, sediment and nutrient loadings, and to help identify the source areas.

The goal of this research is to investigate various agricultural nonpoint source pollution models, and develop a GIS based and spatially distributed approach to better estimate soil erosion, sediment and phosphorus loading in an agricultural watershed context.

Methodology:
A small agricultural watershed, Marshall Drain Watershed, was selected as the study area. This watershed is approximately 400 acres with 90 percent agricultural land use. It is a sub-watershed of the Sycamore Creek watershed, located in Ingham County, Michigan. Agricultural nonpoint source pollution, particularly sediments, have been identified as the major cause of water pollution in the watershed. A multi-year water quality and land use/tillage management monitoring program was been conducted in the watershed from 1990-1997. Data from this monitoring program are used in this study.

A Spatially Explicit Sediment Delivery Model (SEDMOD) and the Revised Universal Soil Loss Equation (RUSLE) are used in this study. These two models are integrated into Soil Erosion and Sediment Assessment System or SESAS. It is GIS based and capable of calculating soil erosion, sediment yield, and phosphorus loading. The results showed SESAS estimated sediment and phosphorus loading with an improved accuracy compared to other models. Input data required to run the model are minimum and readily available. The results of this research demonstrate the benefits of using a spatially explicit model combined with GIS technology. SESAS allows users to identify the source areas and estimate NPS loadings which may lead to cost-effective watershed planning and management for minimizing agricultural nonpoint source pollution.

The Revised Universal Soil Loss Equation (RUSLE) developed by the United States Department of Agriculture (USDA), is the most widely used erosion model. It estimates an annual average soil loss in tons per acre per year. The equation has a general format with the product of six factors:

$$A = R * K * LS * C * P$$

where A = estimated average soil loss in tons per acre per year
R = rainfall-runoff erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = support practice factor

SEDMOD is expressed as follows:

$$SDR = 39\,A^{-1/8} + \Delta DP$$

Where SDR = sediment delivery ratio
A = watershed area in square km
Δ DP = difference between the composite delivery potential and its mean value

Delivery Potential layer can determined as follows:

$$DP = (SG)r(SG)w + (SS)r(SS)w + (SR)r(SR)w + (SP)r(SP)w + (ST)r(ST)w + (OF)r(OF)w$$

Where SG = slope gradient
SS = slope shape
SR = surface roughness
SP = stream proximity
ST = soil texture
OF = overland flow index
r = parameter rating (1-100)
w = weighting factor (0-1)

After gross soil loss and sediment delivery ratio are determined, sediment load can be estimated as follows:

$$SY = A * SDR$$

Where SY = Sediment Yield
A = Gross Soil Loss
SDR = Sediment Delivery Ratio

Principle Findings and Significance:

Sediment Delivery Ratios

For a comparison study, two models were used to estimate sediment delivery ratio in the Marshall Drain Watershed. One is the newly developed spatially distributed model SEDMOD; the second was the spatially lumped empirical model equation. The reason for choosing this equation for comparison is that it was found in a previous study conducted in the Saginaw Bay watershed of Michigan. This model provides more accurate results than other spatially lumped statistical models that were tested in the study watershed (Ouyang and Bartholic 1997).

Sediment delivery ratios were calculated for 1991 – 1997 using SEDMOD, which reflected the spatial variations and year-to-year different land uses. Table 1 lists the maximum, minimum, and mean sediment delivery ratios over the grid cells in the watershed. Although these statistical data for sediment delivery ratio were similar over the years, there are some spatial variations of sediment delivery ratios in watershed due to the changes in land use. Figure 1 shows sediment delivery ratios in the study watershed based on 1993 and 1996 data. The spatial distribution of sediment delivery ratios are slightly different from year to year due to land use change. Higher delivery ratios indicate areas that have potential to contribute more sediment.

Sediment delivery ratios were also calculated using an empirical model with drainage-area-based SDR which is a spatially and temporally lumped model. According to the equation, the calculated sediment delivery ratio is about 0.537 which is relatively high due to the small size of the watershed in which sediments have a short distance to travel to water systems.

Table 1. The Max/Min/Mean values of sediment delivery ratios in the study watershed

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Min.	0.23	0.25	0.25	0.24	0.22	0.21	0.21
Max.	1.00	1.00	1.00	1.00	1.00	1.00	0.99
Mean	0.365	0.364	0.364	0.364	0.365	0.365	0.365

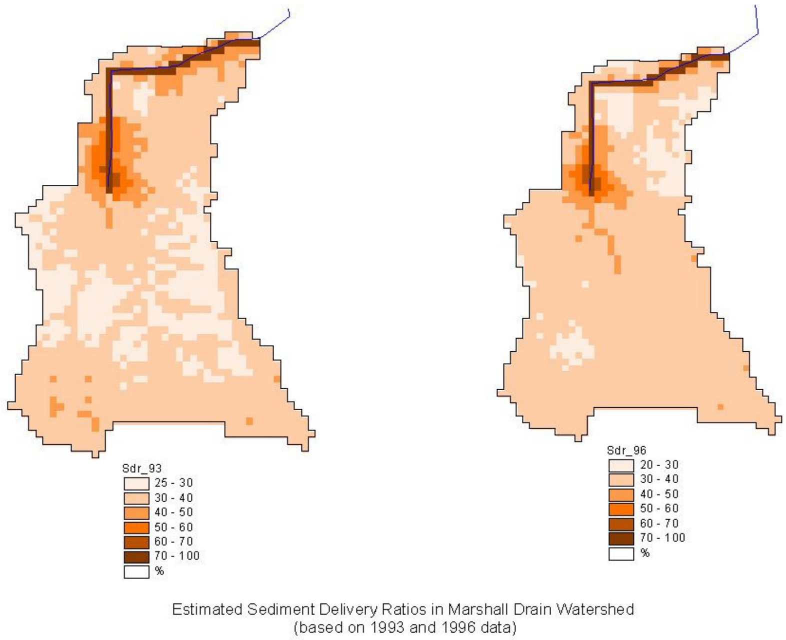

Figure 1. Sediment delivery ratios in the study watershed based on 1993 and 1996 data

Sediment Yield

With estimated soil erosion and sediment delivery ratios, the sediment yield can be determined. The model results and monitoring data are plotted in Figure 2. We used one of the most useful methods to evaluate the modeling results, which is called Model Efficiency (ME). Model efficiency was first used by Nash and Sutchliffe (1970) and later used by many researchers in water related modeling (Green and Stephenson, 1986; Risse et al. 1993; and Rapp et al. 2001). The value of ME for the model is 0.95, which is good. In the modeled and monitored data, the correlation coefficient is high ($R^2 = 0.95$) and with standard error SE = 0.85.

Once the sediment yield was calculated, one could estimate phosphorus loading based on sediment load and phosphorus-to-sediment ratio or phosphorus content in sediment. A previous study has shown that sediment attached phosphorus is a major form in phosphorus loading (Nelson and Logan, 1983). The estimated phosphorus load shows a similar pattern (see Figure 3).

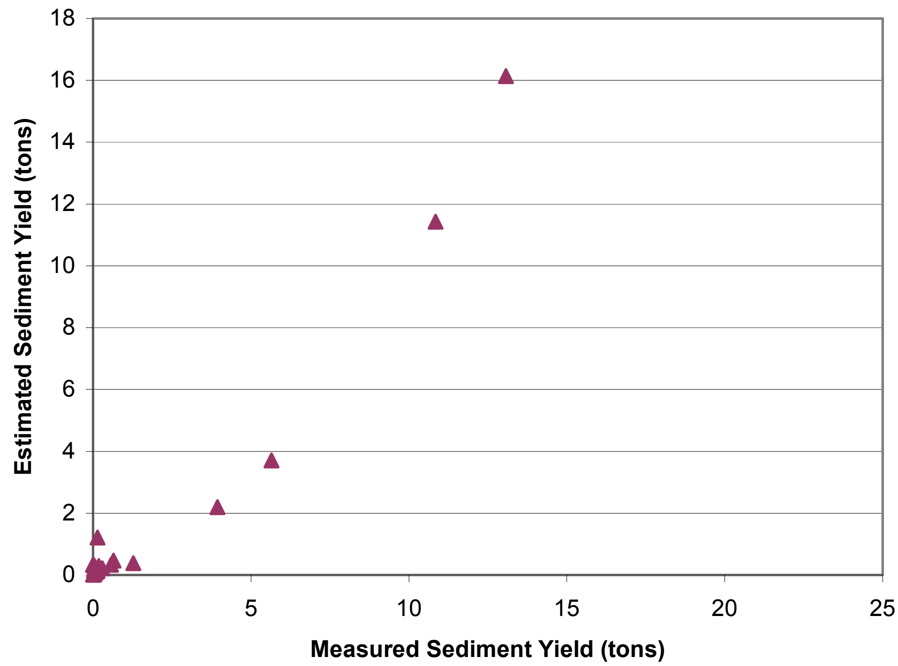

Figure 2. Monitoring sediment load and estimated sediment load from the model.

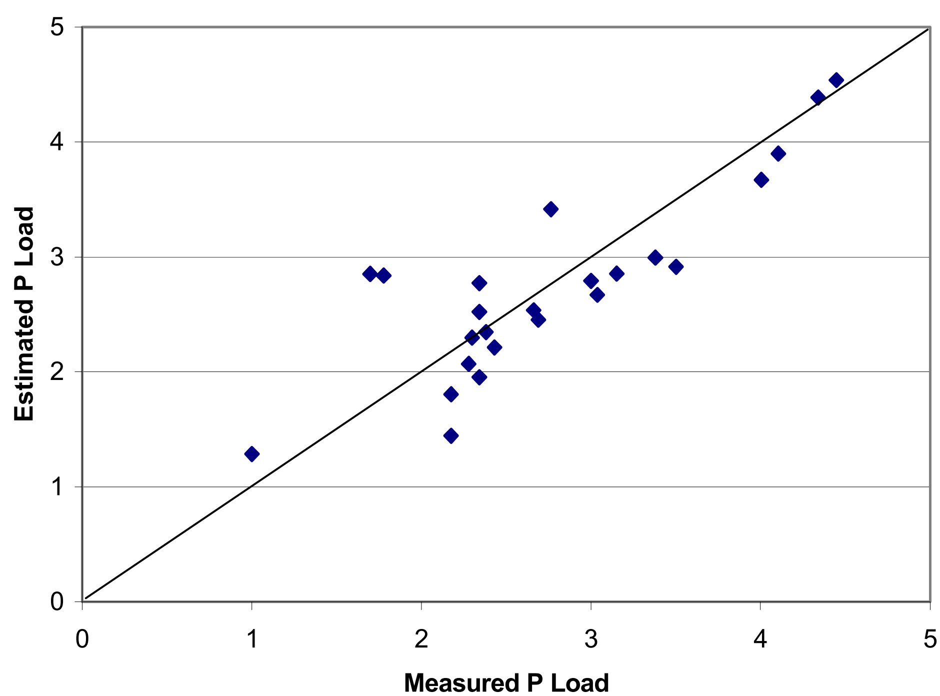

Figure 3. Monitoring phosphorus load and estimated load from the model.

Summary

In summary, the development of a GIS-Based Soil Erosion and Sediment Assessment System (SESAS) based on the spatially explicit sediment delivery model and the modified RUSLE, provides an easy-to-use tool for agricultural nonpoint source pollution assessment. The model estimates soil erosion, sediment delivery ratio, and sediment and phosphorus loading on a watershed basis with an improved accuracy. It has demonstrated the benefits of using spatially explicit models combined with GIS technology. This allows users to identify the source areas and estimate NPS loadings which may lead to a cost-effective watershed management plan for minimizing agricultural nonpoint source pollution.