

NONPOINT SOURCE (NPS) POLLUTION MODELING USING MODELS INTEGRATED WITH GEOGRAPHIC INFORMATION SYSTEMS (GIS)

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INTRODUCTION

Non-point source pollution problems cause an estimated tens of billions of dollars in damage in the U.S. each year (Committee on Conservation Needs and Opportunities, 1986). Identification of problem areas is often difficult because of the spatial, non-point source nature of the processes involved. Once a problem area and its severity are identified, a variety of techniques can be used to minimize impacts. To identify problem areas within watersheds and to evaluate the effectiveness of erosion and chemical movement control techniques, models and decision support systems are often used. The use of these models, and especially distributed parameter models, has often been limited as a result of their large data requirements. For example, both ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation) (Beasley and Huggins, 1982) and AGNPS (AGricultural Non-Point Source Pollution) (Young et al., 1987) typically use 1 hectare grid cell sizes (100 by 100 meters) with AGNPS requiring up to 22 data inputs for each grid cell. Data collection to run AGNPS or ANSWERS for a watershed of several thousand hectares usually requires several weeks to months. Once the data has been obtained, debugging data files can be problematic. In addition, results must be interpreted which is often a tedious task. Evaluation of alternatives requires editing of data files, running the model, and again interpreting results.

GIS, ANSWERS, AGNPS, AND SWAT

Geographic information systems (GIS) can be used to overcome some of the data requirement problems of distributed parameter non-point source pollution models. GIS are tools to collect, manage, store and display spatially varying data. Three non-point source pollution models, ANSWERS, AGNPS, and SWAT (Soil and Water Assessment Tool) (Arnold et al., 1993) have been integrated with the GRASS (Geographical Resources Analysis Support System) (U.S. Army, 1987) GIS tool.

ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation) was developed to simulate the behavior of watersheds having agriculture as their primary land use (Beasley and Huggins, 1982). ANSWERS uses a distributed parameter approach in data representation and modeling. A watershed being simulated is divided into a grid of square cells. Runoff, erosion, and sedimentation are computed for each cell and routed. ANSWERS is capable of assessing the effects of land uses, management schemes, and cultural practices on the quality of water leaving a watershed. Its primary applications are watershed planning for erosion and sediment control on complex watersheds, and water quality analysis associated with sediment associated chemicals. A variety of output data are produced by ANSWERS. The output includes: runoff and sediment yield hydrographs for the total watershed; individual element sediment loss/deposition and chemical movement masses; and sediment deposition for channel elements. For additional details concerning ANSWERS, consult Beasley et al. (1980) and Beasley and Huggins (1982).

The AGNPS (AGricultural Non-Point Source Pollution) model (Young et al., 1987) has been developed to analyze non-point source pollution in agricultural watersheds. It uses a distributed parameter approach similar to ANSWERS. Within this framework, runoff characteristics and transport processes of sediments and nutrients are simulated for each cell and routed. This permits the runoff, erosion, and chemical movement at any grid cell in the watershed to be examined. Thus, AGNPS is capable of identifying sources contributing to a potential problem and prioritizing those locations where remedial measures could be initiated to improve water quality. For more details concerning AGNPS, consult Young et al. (1987 and 1989).

SWAT is a continuous spatially distributed watershed model that operates on a daily time step (Arnold et al., 1993). SWAT provides several extensions to the SWRRB model (Arnold et al., 1990). Its primary uses are in assisting water resource managers in assessing water supplies and nonpoint source pollution on watersheds and large basins. SWAT provides considerable flexibility in watershed configuration and discretization allowing watersheds to be subdivided into cells and/or subwatersheds. SWAT is able to simulate runoff, sediment, nutrient, and pesticide movement through a watershed. For additional details concerning SWAT, see Arnold et al. (1993) and Arnold (1992).

ANSWERS, AGNPS, and SWAT have been integrated with the GRASS GIS to overcome some of the difficulties in using these models as described previously. A toolbox rationale was utilized in providing a collection of GIS programs to assist with the data development and analysis requirements of the ANSWERS, AGNPS, and SWAT models. This allows a modular development approach that offers several benefits. Many of the modules required for integration of ANSWERS, AGNPS, and SWAT with GRASS can be used alone or with other hydrologic, erosion, and chemical movement process models. The tools that have been developed can be categorized as either input or output tools. These tools were written in the "C" language and thus are directly compatible with existing GRASS functions (also written in "C") and thus are very portable. Tools were developed to predict flow directions for grid cells from digital elevation maps (DEMs), eliminate flow direction problems from DEM derived data, determine slope lengths from DEM data, display cell flow direction, edit cell values, estimate SCS curve numbers for each cell, and develop soil property data layers from soil series layers by accessing the SOILS 5 database (Srinivasan and Engel, 1991a and 1991b; Rewerts and Engel, 1991; and Engel et al., 1992).

Once the GIS data layers required by the ANSWERS, AGNPS, and SWAT models are available, tools extract the spatial data and run the models. Once the models have been run, model results are used by the tools to build GIS data layers of results. Results can then be analyzed using the capabilities of the GIS including tools developed to help the user understand and analyze the model results (Srinivasan and Engel, 1991c; Rewerts and Engel, 1991). Once problem areas are identified, the input and output/visualization tools can be used to study the impact of proposed changes in land use, management, and structural practices.

APPLICATION OF GIS-MODELING SYSTEMS

The GIS, ANSWERS, AGNPS, and SWAT tools were applied to a watershed in the Indian Pine Natural Resources Field Station near Purdue University (West Lafayette, Indiana). The watershed selected for analysis encompasses 830 acres, has an average slope of approximately 1.5%, is characterized by row cropped agricultural land uses on silty clay loam soils, and is gauged at its outlet. This watershed is representative of much of the midwestern United States agricultural region.

Four rainfall events were chosen for the size of the hydrologic response with two of these events chosen for the availability of in situ measurements of suspended solids and phosphate and nitrate concentrations. The first three events took place on the 11th, 18th, and 23rd of May in 1991. There was no rain in the week before the first event and small amounts of rain the week before the second and third events. The fourth event on October 28th fell after a period of prolonged dryness and ended with short, but intense rainfall.

The ANSWERS, AGNPS, and SWAT input data were intentionally only roughly estimated based on suggested values for land uses, soils, and management practices. The models are capable of more closely estimating the actual response if additional data are available for calibration. However, these integrated models are

intended for the comparison of management and land use practices, and it is likely that the users will make only a best estimate of the a priori conditions to a storm event. The intention of this study is to demonstrate the quality of the simulated response for even only roughly estimated input parameters using the integrated GIS-modeling system.

The comparison of the simulated (ANSWERS) hydrograph response with the actual response was found to be quite good for all four events with correlation coefficients between .87 - .98 (Tables 1-4). The correlation is quite high in spite of the rough estimates for soil and land-use parameters. Figure 1 shows the observed and simulated (ANSWERS) hydrograph for event 3. Simulated and observed hydrographs for the other events were similar and can be found in Brown (1993).

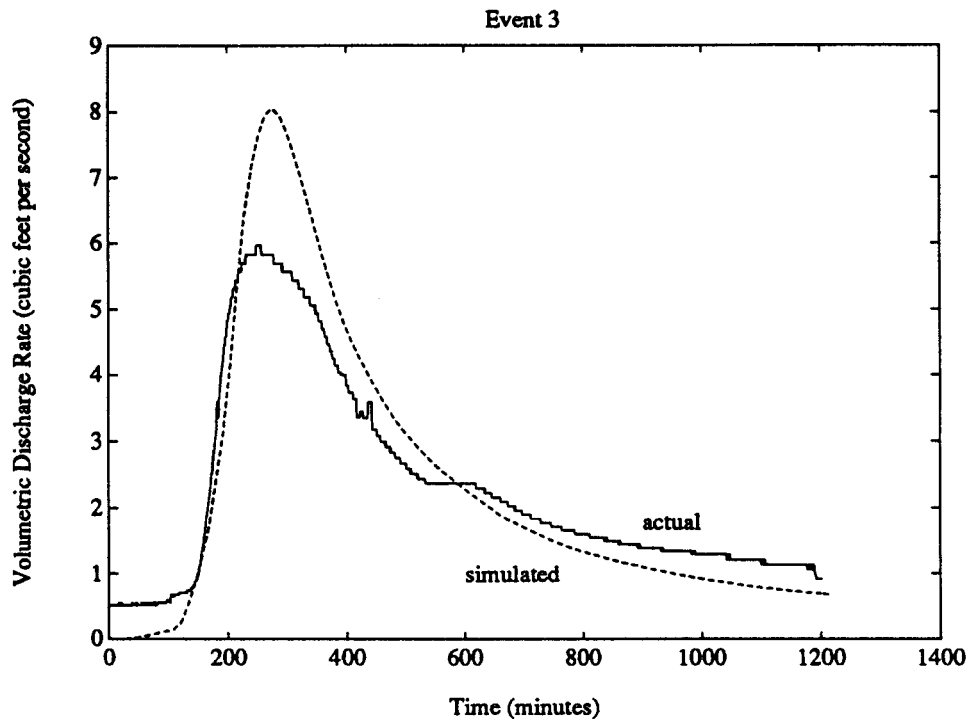


Table 1 Event 1 (May 11, 1991) Runoff Data

	Total Runoff (ft ³)	Peak Runoff Rate (ft ³ /sec)	Runoff Hydrograph Correlation Estimated to Actual
Estimated (AGNPS)	3,585	<1	
Estimated (ANSWERS)	17,407	1	.87
Estimated (SWAT)	81,500		
Actual	16,728	1	

Table 2 Event 2 (May 18, 1991) Runoff Data

	Total Runoff (ft ³)	Peak Runoff Rate (ft ³ /sec)	Runoff Hydrograph Correlation Estimated to Actual
Estimated (AGNPS)	290,400	47	
Estimated (ANSWERS)	228,178	8	.88
Estimated (SWAT)	317,900		
Actual	272,300	11	

Table 3 Event 3 (May 23, 1991) Runoff Data

	Total Runoff (ft ³)	Peak Runoff Rate (ft ³ /sec)	Runoff Hydrograph Correlation Estimated to Actual
Estimated (AGNPS)	113,525	10	.98
Estimated (ANSWERS)	215,476	8	
Estimated (SWAT)	55,900		
Actual	166,620	6	

Table 4 Event 4 (October 28, 1991) Runoff Data

	Total Runoff (ft ³)	Peak Runoff Rate (ft ³ /sec)	Runoff Hydrograph Correlation Estimated to Actual
Estimated (AGNPS)	290,400	57	.88
Estimated (ANSWERS)	163,250	8	
Estimated (SWAT)	549,700		
Actual	147,770	11.5	

In situ measurements of suspended solids and phosphate and nitrate concentrations were available for the May 23rd and October 28th events. Tables 5 and 6 show the observed and AGNPS estimates of nitrates, phosphates, and sediment delivered to the watershed outlet for events 3 and 4. The AGNPS estimates of nitrates and phosphates delivered to the outlet were significantly greater than observed values. This was in part due to differences in predicted and observed runoff. ANSWERS and SWAT estimates of sediment delivered to the watershed outlet are also shown in Tables 5 and 6.

Table 5 Event 3 (May 23, 1991) Nutrient and Sediment Data

	Nitrate (lb)	Phosphate (lb)	Sediment (lb)
Estimated (AGNPS)	288.1	65.8	10,600
Estimated (ANSWERS)			3,820
Estimated (SWAT)	14.6	2.1	300
Actual	109.8	6.3	17,435

Table 6 Event 4 (October 28, 1991) Nutrient and Sediment Data

	Nitrate (lb)	Phosphate (lb)	Sediment (lb)
Estimated (AGNPS)	165.0	68.0	42,000
Estimated (ANSWERS)			1,060
Estimated (SWAT)	145.1	20.9	14,300
Actual	51.7	10.0	6,760

CONCLUSION

The simulated watershed responses and observed data seem to match reasonably well. This is particularly true when one considers that inputs to the ANSWERS, AGNPS, and SWAT models were estimated using GIS data and have not been calibrated for this watershed. The integrated system allowed inputs for the models to be

quickly estimated and also allowed results from the models to be quickly understood. The limited number of observations should be expanded and additional comparisons to model results made. After additional validation, the integrated GIS-modeling system should prove a valuable tool for those responsible for controlling NPS pollution.

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