SAGINAW BAY INTEGRATED WATERSHED PRIORITIZATION AND MANAGEMENT SYSTEM

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Introduction

There are many reasons to develop a non-point source pollution prioritization system to determine which watersheds require the most attention. Once priority problem watersheds have been determined, an approach for directing specific actions is needed, i.e. targeting the specific areas of greatest potential erosion which can contribute to water quality degradation. Once targeted areas are identified, an optimizing management system can be used to examine trade-offs of the potential impacts from the implementation of various best management practice (BMP) options. The BMP's could be selected to minimize off-farm degradation of water quality and the farmers economic criteria.

This combined prioritization and targeting approach is being emphasized in the reauthorization of the Clean Water Act and the proposed 1995 Farm Bill. Also, watershed perspectives and critical assessment of best management practices are frequently referenced policy concepts. Multi-criteria decision making, integrated spatial information systems, and extensive digital spatial data are needed to assist with this process.

This paper summarizes a set of prioritization, targeting, and optimization developments at the state, watershed, and sub-watershed levels for selecting specific practices.

Prioritization of Watersheds

On a regional or state basis it is possible to cluster factors which have the highest priority for influencing non-point source pollution within watershed boundaries. Using geographic information systems (GIS) and digital data, these factors can be clustered within watershed to develop a prioritization indexing process. Such factors as animal numbers derived from census data clustered within zipcodes provides one index factor. Another might be an assessment of the land slope factor integrated over the watershed. Other factors could deal the erodibility characteristics of soils within the watershed and the amount of agricultural land devoted to row crops. The length of the reaches of rivers, streams, and open drains within the watershed is an additional factor.

These factors have been clustered in Michigan for a preliminary prioritization. Using this approach, the Saginaw Bay watershed has been designated as a high priority area of concern relative to non-point source pollution, in particular phosphorus loading to the Saginaw Bay. Also, the International Joint Commission (IJC) has classified the Saginaw Bay as one of the Great Lakes areas of concern primarily relative to non-point source phosphorus loading into the Bay.

With this prioritization approach, the Saginaw Bay was designated for additional funding from the EPA for the Saginaw Bay Watershed Initiative. One objective was to prioritize the many sub-watersheds within this 22 county watershed. Region 5 of the EPA undertook a study in cooperation with numerous agencies from U.S. Department of Agriculture, Natural Resources Conservation Service, Michigan Department of Agriculture, and local organizations to prioritize sub-watersheds within the Saginaw Bay watershed so that available dollars could be allocated to the highest priority areas.

Prioritization Within Watersheds

Given the significant investment of resources into the watershed, it was important to ensure that two critical objectives were being met regarding utilization of funds;

* facilitating implementation to achieve environmental benefits, and
* to ensure that funds were being directed to those areas where the rate of sediment delivery or erosion potential are the most concentrated.

The overall goal of the GIS project was to define and develop a methodology to determine overall sediment delivery and erosion potential within the Saginaw Bay watershed (Phillips, 1993). The project was designed to evaluate the conditions within the watershed and implement a methodology by:

* quantifying the physical characteristics in terms of land use/land cover, hydrography, soil characteristics, and topographic characteristics (land surface and shape);
* utilizing the Universal Soil Loss Equation (USLE) as a screening tool for ranking counties and sub-watersheds for sediment delivery and erosion potential;
* determining an overall unit area calculation which represents areas of greatest erosion potential or sediment delivery.

Methodology

Overview: GIS project requirements and technical issues surrounding data acquisition, data rectification, database creation, and spatial analytical routines required to meet the project objectives were developed initially in a technical approach plan prior to the start of the project.

The various GIS data layers used in the study were separated into discrete categories which could be classified as constant and variable factors. These constant and variable factors made up the components of the Universal Soil Loss Equation (USLE) which was used in this study to determine the erosion potential and sediment delivery within the Saginaw Bay watershed. The constant factors act as the initial screening tool, and the variable factors act as those factors which would further select and prioritize areas for erosion potential and sediment delivery.

Given the previously stated objectives, it was determined that a significant portion of the project would focus upon developing a series of Arc Macro Language (AML) and INFO programs for determining erosion potential, sediment delivery, and unit area consideration values.

This methodology was then applied to the entire Saginaw Bay Watershed.

Algorithm Development: The procedure utilized the universal soil loss equation (USLE) as the algorithm for estimating sediment delivery and erosion potential. This equation is frequently used to predict soil loss from a given area.

(1) SL = (R)(K)(LS)(C)(P)(SSF) where:
(SL) = soil loss
(R) = rainfall intensity
(K) = erodibility
(LS) = slope length
(C) = cover
(P) = practice
(SSF) = slope shape factor

Using this algorithm, the values obtained for soil loss were assumed to represent erosion potential. To develop values for sediment delivery, a zone of contribution was assumed within 1/4 mile of all perennial streams with a sediment delivery ratio of 1.0. This 1/4 mile contributing area was introduced as a stream distance factor (Sd) into the USLE. The resulting algorithm to evaluate sediment delivery was:

(2) SD = (R)(K)(LS)(C)(P) (Sd)(SSF):
(SD) = sediment delivery
(Sd) = stream distance

Ranking Procedure: In developing the final ranking of the hydrologic unit areas and counties, it was determined that all high and very high areas would be combined to give the ranking value for each hydrologic unit area or county.

In developing the ranking of the sediment delivery and erosion potential per unit area by sub-watershed and county USLE was employed. This utilized the combined value of the high and very high area of sediment delivery or erosion potential in relation to the total sub-watershed area or the county area within the watershed. The unit area analysis was used to identify those areas which had the highest concentration of sediment delivery or greatest erosion potential.

Results

The results of the screening analysis included sediment delivery for sub-watersheds, sub-watersheds per unit area, counties, and counties per unit area. This also included erosion potential for sub-watersheds, sub-watersheds per unit area, counties, and counties per unit area. The sub-watershed prioritization for erosion potential ranked Shiawassee River first, Cass River second, and the Pigeon/Wiscoggin Rivers third.

Regardless of missions, the study provides valuable information to resource managers from the variety of agencies working in the Saginaw Bay watershed. The screening procedure provided a tool to support the decision making process for various agencies for a variety of program objectives. The information generated by this procedure was used to direct the implementation of practices which can provide multiple benefits to the resource area.

Targeting Within a Sub-WatershedOverview

Once the priority sub-watersheds were identified, the next step was to assess specific areas within the sub-watershed that contribute the most to non-point source pollution and particularly non-point source pollution that impacts water quality. In this case a more detailed modelling approach was needed.

Approach

This study integrates GIS, LANDSAT imagery and AGNPS to estimate the loading potential of agricultural nonpoint sources and to evaluate the impact of agricultural runoff on water quality in the Cass River watershed, a large sub-watershed of Saginaw Bay (He, et al, 1994). The Agricultural Nonpoint Source Pollution Model (AGNPS) was used to estimate soil erosion potential by water and the amounts, origin and distribution of sediment, nitrogen (N), and phosphorus (P) in the watershed. LANDSAT imagery was used to derive the 1992 land use/cover and crop residue cover. Land use/cover maps of 1979 and 1992 were used in the AGNPS model to evaluate the effects of land use change on water quality. The Census of Agriculture data of 1987 were used to calculate the loading potential of animal manure by the 5-digit zip code. Estimates of fertilizers and pesticides uses for different crops at county level were used to compute agricultural chemical loading potential at the watershed level. Management scenarios were explored in the AGNPS model to minimize sedimentation and nutrient loading. In addition, areas vulnerable to erosion were identified for implementing best management practices.

This study develops strategies for integrating physically-based simulation models with geographic information systems (GISs) at the watershed scale to quantify the combined loadings of agricultural sedimentation, animal manure, and fertilizers and pesticides to surface water, and to identify the critical risk areas for implementation of water management programs. The specific objectives are to:

(1) estimate potential loadings of sediments, animal manure, and agricultural chemicals into surface water;
(2) identify the critical risk areas for implementation of water quality programs;
(3) explore management scenarios for minimizing soil erosion and nutrient runoff;
(4) verify the simulated results in the study areas; and,
(5) transfer the study results to management agencies in the Saginaw Bay watershed to facilitate use of simulation models and GISs for nonpoint source pollution control.

Procedures

Project Advisory Committee: In order to best serve the needs of management agencies in the Saginaw Bay watershed, a project advisory committee was established to prioritize the research objectives of this project. The committee consisted of representatives from the USDA Soil Conservation Service, Michigan Department of Natural Resources Bay City Office, Saginaw Bay National Watershed Initiative, Saginaw Bay Resource Conservation and Development Council, and the Cooperative Extension Service Saginaw County Office.

A number of methods are available for estimating soil erosion and sediment loading potential, including USLE (Wischmeier and Smith, 1978), ANSWERS (Beasley and Huggins, 1980). AGNPS (Agricultural Nonpoint Source Pollution Model, Young et al., 1989), and WEPP (USDA ARS-National Soil Erosion Research Laboratory, 1994). Considering the models' ability for estimating the soil erosion and sediment loading and their capacity for linking with GIS, AGNPS was used in this study to estimate the soil erosion and sediment potential. The model simulates runoff, sediment, and nutrient yields in surface runoff from primarily agricultural watersheds based on a single storm event. It operates on a cell basis and can be used to examine the runoff, sedimentation, and nutrient loading estimates either for the entire watershed (measured at the watershed outlet) or on a cell by cell basis. By comparing runoff estimates from individual cells, critical erosion areas within the watershed can be identified for implementation of best management practices.

AGNPS requires 22 input parameters, which include SCS curve number, slope length, Manning's roughness coefficient (surface roughness), cover and management factor (C-factor in USLE), support practice factor (P-factor in USLE), surface condition constant (makes adjustments for the time it takes channelization of overland runoff), receiving cell number (the cell into which most of the runoff drains), soil texture, soil hydrologic group, fertilization availability, and fertilization levels (Young et al., 1987). As AGNPS operates on a cell basis, the entire Cass River watershed was divided into 1,878 cells at 310-acre resolution in this study.

AGNPS provides estimates of runoff volume (inches), sediment yield (tons), sediment generated within each cell (tons), mass of sediment attached and soluble nitrogen in runoff (lbs/acre), and mass of sediment attached and soluble phosphorus in runoff (lbs/acre).

Manually imputing each of the 22 AGNPS parameters for the entire Cass River watershed (1,878 cells) is time consuming and inaccurate. This study used GRASS WATERWORKS; a GIS-model interface developed at the Institute of Water Research and Center for Remote Sensing, Michigan State University (Kang et al., 1992; Vieux et al., 1990; He et al., 1993) to derive the input parameters from GRASS (Geographic Resource Analysis and Support System, U.S. Army Corps of Engineers, 1987) and then fed them to AGNPS. GRASS WATERWORKS was written in shell scripts on the UNIX system. It allows users to derive all the 22 parameters from GIS data for AGNPS to use and also to geo-reference the output data for display and analysis within GIS.

The basic data sets required for the AGNPS model include land use/land cover, topography, water features (lakes, river, and drains), soils, and watershed boundary (He et al., 1993).

Land use/land cover, water resource features, and watershed boundaries were obtained from the Michigan Resource Information System (MIRIS) database.

Digital Elevation Model (DEM) was acquired from the U.S. Geological Survey to derive slope and aspect at 1:250,000 scale. The data were converted from Lambert Coordinate System to UTM and used at a resolution of 100m.

Soils data were obtained from USDA Soil Conservation Service's STATSGO database. Originally in ARC/INFO format, the data were converted to the UTM coordinate system exported to GRASS, and processed to a 100m resolution in GRASS raster format. The STATSGO database and County Soil Surveys were used to determine dominant texture, dominant hydrologic group, and weighted K values (soil erodibility factor) which are necessary to run the AGNPS model.

Results

The results suggest that the Cass River watershed introduces large amounts of nutrients and sediment into the Saginaw River and Bay. Soil erosion was up to 3.5 tons per acre in some agricultural land areas after a single 24-hour storm of 3.7 inches with frequency of one in 25 years. The sediment yield was up to 145 tons per acre in the mouth of the watershed near Saginaw. Total nitrogen and phosphorus runoff was higher in agricultural land.

Management Within a Watershed

Overview

The assessment of management practices to optimally reduced off land impacts with limited dollar resources is the final step toward applying specific practices within critical areas of the watershed.

A system has been developed for integrating distributed simulation models, databases, Geographical Information Systems (GISs), and Expert Systems (ESs). It demonstrates a state of the art solution for the standard three-step nonpoint source pollution management procedure: (1) critical area identification, (2) Best Management Practices (BMPs) selection, and (3) comprehensive area-wide pollution control plan. A Graphical User Interface (GUI) is created for the integrated system to facilitate informed decision-making concerning agricultural nonpoint pollution control. The system has been used with the AGNPS distributed simulation model to demonstrate its usefulness (Kang & Bartholic, 1994).

Design, Development, and Implementation

System Design: The structure of the integrated system has four interfaces and two components. The *Basic Interface* contains basic GIS functionalities, such as display and statistics. The *Model Interface* helps the users derive model input data, run the AGNPS model, and create model outputs. The *Scenario Interface* provides utilities for users to analyze model outputs and create new alternatives. Finally, the *Decision-Making Interface* facilitates the users in making comprehensive management plans. Beside the above four interfaces, two other components, model base and database, are transparent to the users. The *Model Base* component stores the simulation model and optimization model. The *Database* component includes the GIS map data sets, the Soil-5 database, the AGNPS input and output data sets, the optimization model input and output data sets, and the information of user's comprehensive management plans. Interactions between interfaces are controlled by users through the GUI; however, interactions between interfaces and the database and model base components are controlled by the system itself. Users create a set of "project" files in the beginning set-up before each operation. Then, the system uses these project files to find where to store and extract data for specific tasks.

Discussion

First, the GUI of the integrated system provides a robust and user-friendly environment for the NPS pollution management. Navigation within the system is easy and clear by selecting menus and buttons. Users can perform simple GIS display to complex GIS analysis functions without knowing sophisticated GIS commands. Second, the tedious model data input process has been simplified through the integration of the spatial database georeferenced data sets. This integrated process not only reduces the time and efforts required to run the model, but also opens a wider view for model output analysis. Third, the inference utilities in the scenario interface allow the users to investigate possible alternatives by setting and testing users' own rules in the run time. Other spatial data can also be included into the reasoning process. Fourth, model output results can be presented in multiple formats (i.e. map, graph, and table), which help the users interpret data from different points of views. Finally, the system provides a comprehensive integration of data and information for decision makers in their reasoning and decision-making processes of the agricultural nonpoint source pollution control.

Results

The integrated system demonstrates a state of the art solution in facilitating agricultural nonpoint source pollution management. Through the integration of simulation models, GISs, databases, and ESs, we should be able to more efficiently and effectively use our limited resources. Future researches may focus on incorporating other models into the model base, merging other databases into the database, and exploring other spatial analyses to expand the system capability.

Summary

Society is limiting general government support and requires cost-benefit analysis and/or other approaches toward measuring effectiveness. This requires integrated spatial information systems for assisting agencies and private sector cooperators. It is now reasonable to refine development of prioritizing, targeting, and management approaches because key layers of spatial physical data for aspects of the land surface are becoming available. GIS systems are becoming more flexible and accessible, and spatial indexing approaches and models are better evaluated. Results from the integration of spatial data, GIS, and models can be closely linked to cooperating agencies who are involved in the process of allocating resources, and ultimately to farmers implementing practices.

This teaming of people and organizations with advanced information technology is yielding more efficient use of resources within problem watersheds to best protect water quality while maintaining economical use of the land.

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