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EPA

TMDL Case Study

Nomini Creek Watershed

Key Feature: Use of a geographic information system and watershed models to identify areas of critical nonpoint pollution.

Project Name: Nomini Creek Watershed GIS Study
Location: USEPA Region III/Westmoreland County, Virginia/Potomac River
Scope/Size: Small watershed, 1505 hectares
Land Type: Ecoregion 65, Southeastern plains
Type of Activity: Agriculture
Pollutants: Nutrients, sediment
TMDL Development: NPS
Data Sources: State, local, federal
Data Mechanisms: Modeling (SLOSS, PHOSPH); GIS (VirGIS)
Monitoring Plan: Yes, long-term BMP effectiveness monitoring
Control Measures: BMPs

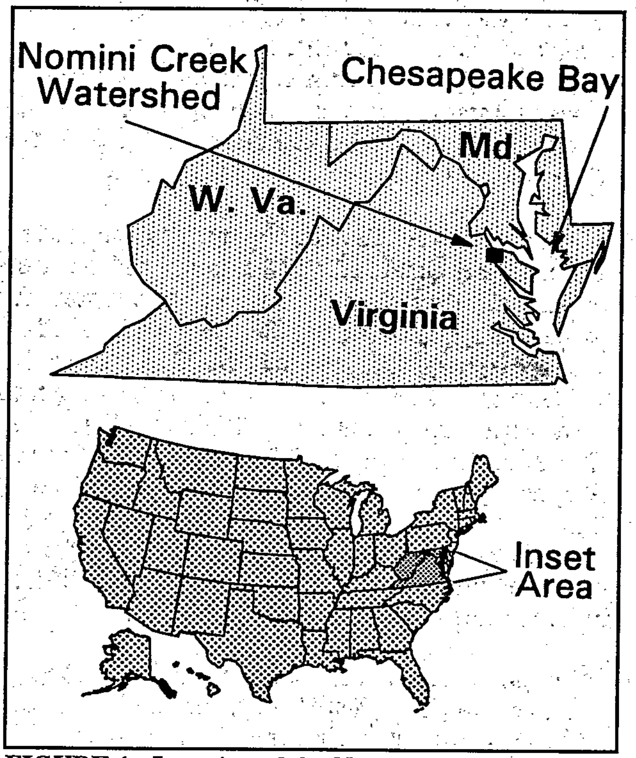

FIGURE 1. Location of the Nomini Creek watershed in Virginia

Summary: Using the Nomini Creek watershed (Figure 1), Virginia's Department of Conservation and Recreation and its Polytechnic and State University demonstrated how geographic information system (GIS) technology can be used to (1) prioritize and target waterbodies with multiple water quality concerns, and (2) target BMPs to critical nonpoint source loading areas to meet load allocations more effectively.

The Department of Conservation and Recreation selected the Nomini Creek watershed as an area in which to evaluate and monitor the effectiveness of best management practices (BMPs) for the Chesapeake Bay Program. To identify the critical phosphorus and sediment loading areas within the watershed so that BMPs could be sited effectively, the Division tested the feasibility of integrating VirGIS, a state-run GIS, with two simple pollutant yield models (SLOSS and PHOSPH). Because Virginia's data base was sufficiently large, VirGIS was able to provide the data required to run the models. The output from these models successfully identified critical areas of nonpoint source loading. BMPs were sited on these areas and an intensive water quality monitoring program is currently in place to evaluate BMP effectiveness and to verify the estimated pollutant loads.

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BACKGROUND

Programmatic Issues

EDITOR'S NOTE: Water quality management in the Chesapeake Bay employs the essential elements of a TMDL assessment. Stakeholders recognized water quality problems, identified the causes and sources of these problems, set an achievable target or endpoint, and then targeted controls for specific point and nonpoint pollution sources to decrease their contributions. Technical efforts to address difficulties or obstacles to effective water quality management in the Chesapeake basin therefore have a unique place within the TMDL Case Study series.

In the early 1970s, water quality managers recognized that the water quality of the Chesapeake had become substantially degraded and prevented the Bay from fully meeting its designated uses. Subsequent studies of the Chesapeake Bay, sponsored by USEPA, identified nutrients as a primary cause of the depleted oxygen and other water quality problems. USEPA, the District of Columbia, and the states of Pennsylvania, Maryland and Virginia agreed that reducing total nutrient loads to the Bay by 40 percent was an achievable goal and would improve the health of the ecosystem. As the primary source of nutrients in the basin, agricultural activities were targeted for implementation of BMPs.

To begin to address these nonpoint source problems, Virginia, Maryland, Pennsylvania, and the District of Columbia have initiated watershed programs to demonstrate and monitor the benefits of various BMPs. The new information on BMP effectiveness will eventually be used to encourage more widespread use of BMPs throughout the Chesapeake drainage to achieve the 40 percent reduction in nutrient loads.

In 1985, the Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation (DCR-DSWC or the Division) selected the Nomini Creek watershed as an area in which to evaluate and monitor BMP effectiveness. The watershed was chosen because of its proximity to the Bay and because agriculture is its predominant land use activity. The watershed is also typical of row-cropped agricultural areas in the Virginia coastal plain. Agricultural loadings of nitrogen, phosphorus, and sediment from Nomini Creek enter the lower Potomac River, which is a main tributary to the Chesapeake Bay.

To site BMPs effectively, the Division sought to identify critical nutrient loading areas within the watershed. The Virginia Geographic Information System (VirGIS), in conjunction with simple pollutant loading models, was proposed to accomplish this task. Although the GIS was developed to facilitate these types of projects, no one had used it yet for this purpose. The Division and the Department of Agricultural Engineering at Virginia Polytechnic Institute and State University therefore conducted a sub-study to determine whether critical nutrient loading areas could be properly identified when VirGIS was linked with the models.

The Resource

The Nomini Creek watershed is located in Westmoreland County in eastern Virginia. Its 3,719 acre watershed is approximately 54 percent woodlands (there is a significant amount of commercial forestry), 43 percent croplands, and 3 percent homesteads and roads. There are no towns in the watershed. The primary agricultural activity in the watershed is row cropping of corn, barley, and wheat (USDA SCS, 1979). Twenty-five farmers cultivate the 1,646 acres of cropland in the watershed. Thirty-three percent (546 acres) of the farmland is farmed by the landowners/operators themselves, while the remaining 67 percent (1100 acres) is leased for others to farm (DCR-DSWC, 1986). One small beef cattle operation also exists in the watershed.

Nomini Creek currently meets all of its designated uses. Biological parameters indicate that water quality within the watershed is good; however, preliminary water quality sampling results indicate a high level of nutrients. In 1986, gross soil erosion was calculated at 7,920 tons/year for the study portion of the watershed. Approximately 1,584 tons of that sediment is delivered to Nomini Creek, along with 10,700 pounds of phosphorus. Eroding cropland is responsible for about 95 percent of the total sediment and phosphorus that is delivered to the creek (DCR-DSWC, 1986). The state, in conjunction with the Virginia Forestry Association, currently monitoring to determine how much forestry practices contribute to the pollution load.

Hydrologically, the watershed contains first- and second-order streams flowing through nearly level to gently sloping topography. The soils are mostly fine sandy loam to loam, with slopes that range from nearly level to 15 percent, except along stream banks where slopes range from 15 percent to 50 percent (USDA SCS, 1979). Approximately 40 percent of the cropland in the watershed is classified as highly erodible.

ASSESSING AND CHARACTERIZING PROBLEM AREAS

GIS and Modeling Tools

The data necessary for characterizing nutrient loading patterns within the Nomini Creek watershed were available on VirGIS, a state-run GIS. A GIS is a computerized system for storing and manipulating data that have a spatial component (i.e., data for which geographical location is important). VirGIS was initiated in 1985 by the Division as a tool for developing modeling and mapping procedures that could readily identify land areas with nonpoint source pollution potential.

VirGIS is a modular and highly interactive program that consists of a large database coupled with nearly 500 special-purpose programs that manipulate and display data. Basic data types, or layers, taken from 7.5-minute quadrangle maps, county soil surveys, National High Altitude Program color-infrared photos, and U.S. Geological Survey (USGS) digital elevation models include elevation, soils, land use, surface water, watersheds, and county boundaries. The data are stored primarily in raster form (i.e., as small areal units) with each unit, or cell, representing from 1/9 to 1 hectare. These units are joined to form data layers that cover areas ranging from 7.3 million hectares up to 10.1 million hectares (the entire State of Virginia). VirGIS can use the basic data layers to calculate "derived" data layers (Figure 2) for input parameters required by nonpoint source pollutant yield models.

Virginia Polytechnic and State University and the state developed two simple nonpoint source pollutant yield models, SLOSS and PHOSPH, to characterize the Nomini Creek watershed.

SLOSS is a simplified pollutant yield model designed to estimate soil loss and sediment delivery to a stream. It is based on the Universal Soil Loss Equation (USLE) and can be modified to estimate potential soil erosion for each hydrologically homogeneous cell in a watershed. For Nomini Creek, a cell size of 1/9 hectare was used.

Three main equations are used in SLOSS. The first equation computes soil loss per unit area of watershed (A_s). It is expressed as:

$$A_s=\sum_{i=1}^{n} K_i \times LS_i \times C_i \times P_i \qquad (1)$$

where

- n = maximum number of cells;
- K_i = soil erodibility factor;
- LS_i = topographic factor;
- C_i = land use/land cover management; and
- P_i = support practice factor.

The SLOSS model then calculates a sediment delivery ratio for each cell. This ratio relates the amount of sediment lost from a cell to the amount that will actually be delivered to the stream channel. The delivery ratio (DR) is expressed as:

$$DR_i=\exp[-(b_i Sf_i Lf_i)] \qquad (2)$$

where

- b = land cover factor;
- Lf = length of the flow path between cell i and the channel outlet; and
- Sf = slope function.

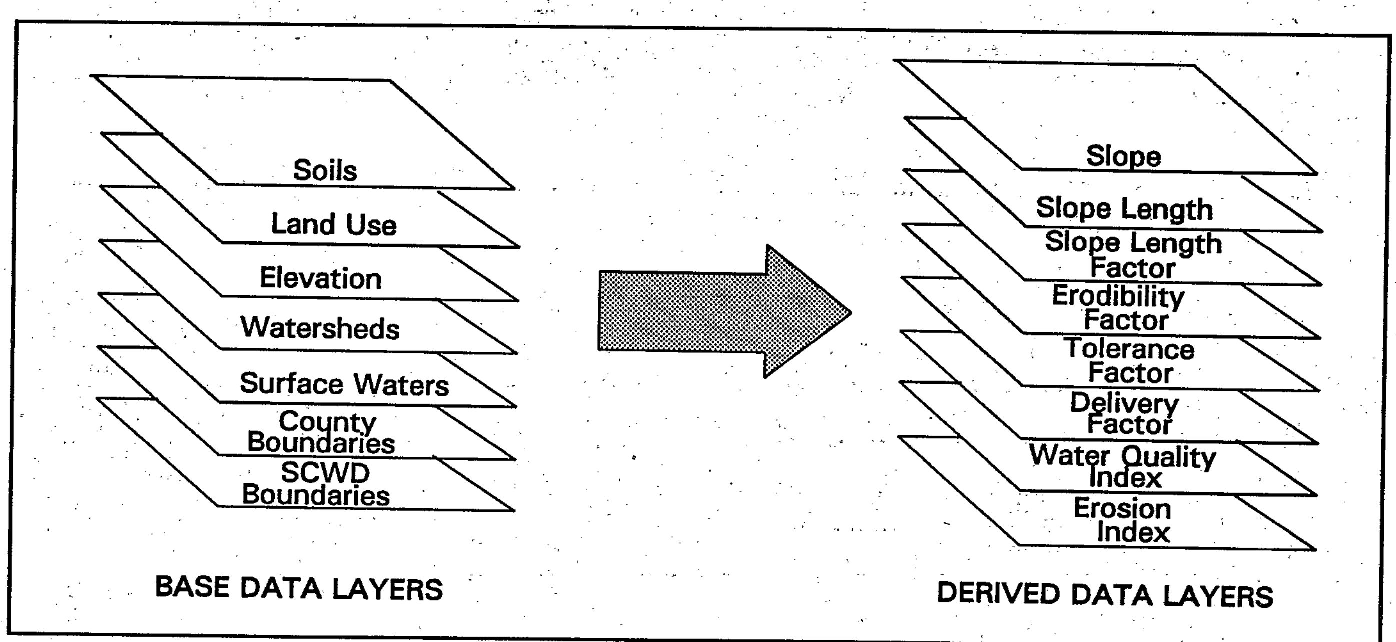

FIGURE 2. Basic and derived data layers used in the VirGIS database

Total sediment yield (L_s) is then calculated in the expression:

$$L_s=\sum_{i=1}^{n}(A_s)_i\times DR_i \qquad (3)$$

where the parameters are as previously defined.

PHOSPH is a simplified phosphorus loading model developed to circumvent the intense data requirements of more complex phosphorus models. The basic equation in PHOSPH is:

$$TP_s=\sum_{i=1}^{n}Pc_i\times(L_s)_i\times(ER_p)_i \qquad (4)$$

where

TP_s = total sediment-associated phosphorus delivered to the stream outlet;
Pc_i = average phosphorus content of the surface soil layer for soil in cell i;
L_s = sediment yield for each cell (eq. 3); and
ER_p = phosphorus enrichment ratio.

The phosphorus enrichment ratio is defined as the mass of phosphorus in the eroded sediment per unit mass of phosphorus in the surface soil layer. It is calculated in the equation:

$$ER_p=4.79\times\left[\frac{C_{max}+C_{min}}{2}\right]^{-0.29} \qquad (5)$$

where C_{max} and C_{min} are the maximum and minimum percent clay content of the soil in each cell.

Locating NPS Problem Areas

The first step in the modeling process was to obtain the necessary data layers from the VirGIS system. This was done by creating a data window for Nomini Creek to obtain only the relevant data from the much larger VirGIS data base. Once these data were extracted, several VirGIS programs were used to convert the information into parameters that would be accepted by the models (e.g., the topographic factor, LS, was determined from VirGIS slope information). The SLOSS model was then used with these parameters to estimate sediment loss. The sediment loss estimate then was passed to the PHOSPH model, which calculated sediment-associated phosphorus export. This process is summarized in Figure 3.

The spatial resolution of the VirGIS data for Nomini Creek was 1/9 hectare. In other words, each type of data was recorded for blocks of land 1/9 hectare in area. Consequently, individual sediment and phosphorus export values were calculated for each of approximately 33,470 individual cells within the watershed. The numerical results from both models were reprocessed by VirGIS into maps that allowed easy comparison of loadings throughout the watershed. Figure 4 shows the GIS-generated map for phosphorus yield in the watershed.

It was determined that estimated sediment yield exceeded the "high" threshold of 22.4 tons/hectare/year in approximately 15 percent (227 hectares) of the Nomini Creek watershed. Due to the lack of established values in the literature, the sediment threshold was arbitrarily

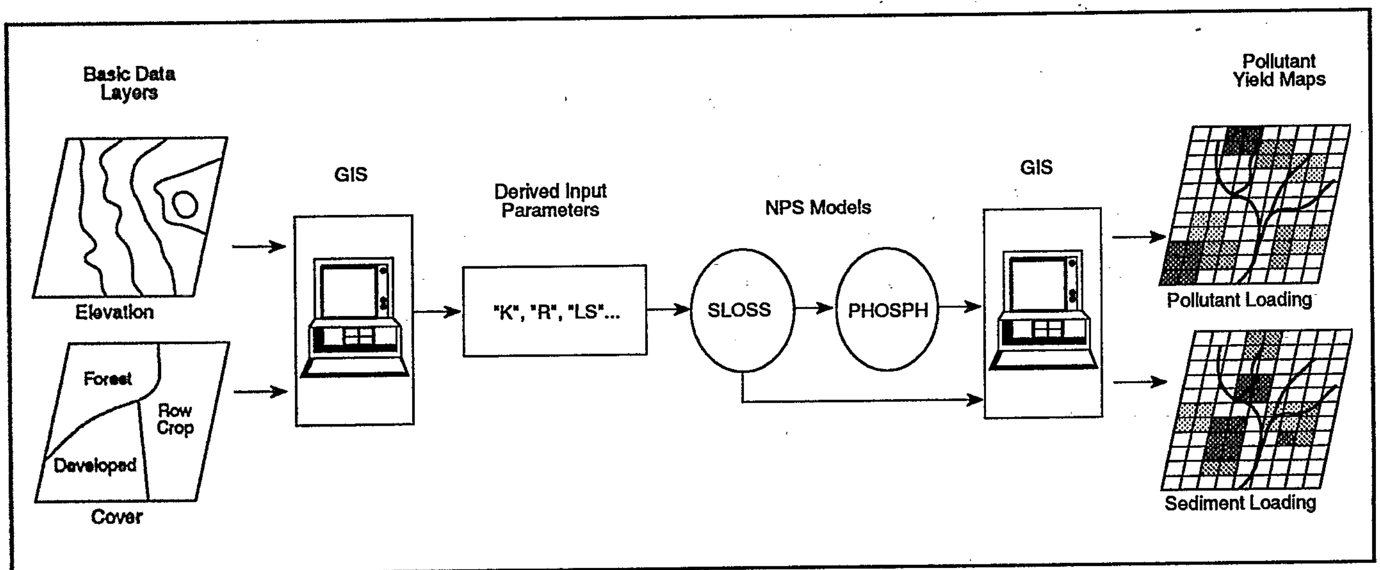

FIGURE 3. Conceptual framework for the integration of a GIS with water quality models

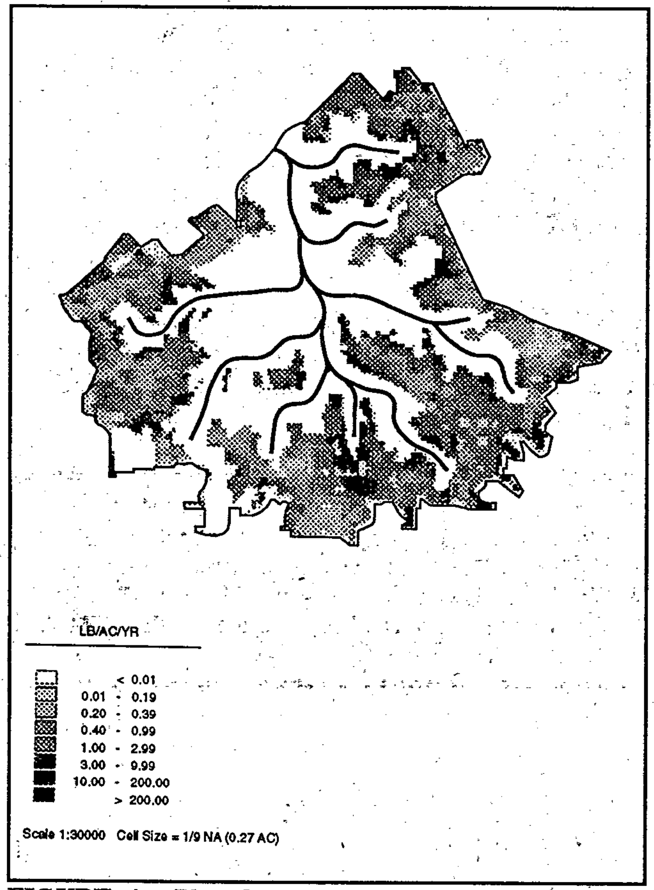

FIGURE 4. Phosphorus yield in the Nomini Creek watershed

determined in order to facilitate classification into high, medium, or low categories. For phosphorus, approximately 21 percent of the watershed (316 hectares) exceeded the high threshold value of 1.12 kg/hectare/year. The phosphorus threshold was obtained from extensive literature review.

SITING NPS CONTROLS

The critical area maps generated by VirGIS assisted in siting BMPs where they were needed in the watershed. The BMPs included no-till farming, nutrient management plans, grassed waterways, drop structures, diversions, pasture management, and the removal of land from production. The installation of the BMPs was accomplished through the Virginia Agricultural BMP Cost-Sharing Program, in cooperation with the U.S. Department of Agriculture's Soil Conservation Service and Agricultural Stabilization and Conservation Service, the Virginia Department of Forestry, the Cooperative Extension Service, and the Northern Neck Soil and Water Conservation District.

FOLLOW-UP MONITORING

Intensive water quality monitoring, which is the primary focus of the Division's efforts in the watershed, is continuing and will be used to verify the estimated loadings of sediment and phosphorus. This monitoring includes both storm event and ambient monitoring. Storm sampling is conducted whenever the stream level increases by 2/10 of a foot. Storm event parameters include total nitrogen, total phosphorus, nitrate, ammonia, phosphate, and total suspended solids. Ambient monitoring occurs on a monthly basis for protozoans, pesticides, and a suite of weather parameters. Coliform bacteria are sampled every 2 weeks, and land use data are collected twice per year. Monthly groundwater monitoring is also conducted for pesticides, nutrients, and water table depth.

MANAGEMENT CONSIDERATIONS

The maps produced by the modeling process are especially valuable as watershed management tools. First, they highlight the portions of a watershed that are critical in terms of their sediment and phosphorus loading potential. (The critical loading level can be set by the user based on literature review or professional judgment.) This feature provides managers with a readily understandable means for determining areas that are in need of control measures. For states, this information can assist in targeting areas to receive BMP cost-share funding, potentially increasing the cost-effectiveness of existing state cost-share programs.

In addition, GIS output maps are useful as an education tool. Landowner cooperation is sometimes a difficult obstacle in the implementation of BMP cost-share programs. These maps could be used by agricultural field personnel as visual means for promoting program cooperation.

Targeting high-priority waterbodies or watersheds for TMDL development often involves more than just technical factors. It may also involve the evaluation of factors related to recreational, economic, and ecological values such as the risk to human health and aquatic life; the degree of public interest and support in protecting a waterbody; the recreational, economic, and aesthetic importance of the waterbody; and its vulnerability or fragility as aquatic habitat. Many of these factors contain spatial components and can be displayed on maps. Overlaying these maps on maps of potential pollutant yield would illustrate which waterbodies are of special concern. Coupled with professional judgement, these maps could facilitate the prioritization and targeting of watersheds with the greatest need for TMDL development.

When sufficient data are collected, the Nomini Creek Study will provide useful information on the effectiveness of BMPs in reducing NPS pollution on an entire watershed in the coastal plain. Furthermore, if the statistical analyses show a significant instream phosphorus reduction, this experiment will have provided a new tool for managers to use in achieving the Chesapeake Bay 40 percent nutrient reduction goal. It is important to note, however, that the success of this technique in the coastal plain will not necessarily make it a viable modeling tool in other parts of the Chesapeake drainage. The ten-year monitoring period for Nomini Creek will be complete in 1995.

REFERENCES

DCR-DSWC. 1986. Nomini Creek Watershed Plan Westmoreland County, Virginia. Virginia Department of Conservation and Recreation, Division of Soil and Water Recreation. Revised 6/10/86.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77(1):118-125.

Shanholz, V.O., C.J. Desai, N. Zhang, J.W. Kleene, and C.D. Metz. 1990. *Hydrologic/water quality modeling in a GIS environment.* Written for presentation at the 1990 International Summer Meeting sponsored by the American Society of Agricultural Engineers, Columbus, OH, June 24-27, 1990. Paper No. 90-3033.

USDA SCS. 1979. *Westmoreland county soil survey.* Soil Conservation Service National Cooperative Soil Survey, U.S. Department of Agriculture, Washington, DC.

USEPA. 1991. *Guidance for water quality-based decisions: The TMDL process.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 440/4-91-001.

This case study was prepared by Research Triangle Institute, Research Triangle Park, NC, in conjunction with USEPA, Office of Office of Wetlands, Oceans, and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.