Application of C-CAP Protocol Land-Cover Data to Nonpoint Source Water Pollution Potential Spatial Models in a Coastal Environment

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Abstract

Nonpoint source water pollution is a gradual and often subtle hazard, especially to water quality. Custom-derived satellite imagery-based land-cover data have proven useful in the creation of nonpoint source water pollution potential models but are expensive and time consuming to create. This study examines the potential of an existing satellite-based (TM) land-cover data set (Coastal Change Analysis Program) in a rapidly developing coastal area. A comparison is made of generalized and detailed hydrologic soil groups in compiling permeability values. Two distance-to-water variables are also tested in the spatial model. Results indicate that C-CAP data can provide a useful land-cover database for such work. Both soil groupings may have utility, but weighted distance measures provide a more accurate representation of nonpoint source water pollution potential sources and spatial distribution.

Introduction

Nonpoint source water pollution has been defined as "the input to a receiving body of water, negatively impacting that water's beneficial uses, whose source is broad and diffuse pollution resulting from land runoff, precipitation, atmospheric deposition, drainage, and seepage" (Chandler, 1994). Nonpoint source water pollution is a major contributor to the degradation of water quality and is of critical relevance in the conservation of natural resources and environmental quality assessments. As water runoff moves over the land, pollutants resulting from human activity are picked up and deposited into rivers, lakes, and other bodies of water. Pollutants dissolved in the runoff are generally more biologically available in waterbodies than sediment-based fractions and can be potentially more harmful (DEC, 1990).

Nonpoint source water pollution is a subtle and indirect hazard to the environment. It is usually not an episodic event; rather, it contributes and produces a gradual deterioration of environmental conditions. For example, as a health hazard it contributes to fecal pollution and nutrient enrichment of water supplies (Byl *et al.*, 1996). The deterioration of water quality potentially endangers the quality and quantity of coastal wetlands which in turn adversely affects the susceptibility to flooding, shoreline erosion and rate and quality of underground aquifer recharge (Mitsch and Gosselink, 1993; Harbor, 1994). Nonpoint source water pollution affects our health, quality of life, economic well-being, and recreation, as well as the survival of fish and wildlife and ecosystems integral to natural resource preservation. Monitoring and managing water quality and the associated nonpoint source factors contributing to water pollution potential are of major importance in evaluating current and future urban development and non-urban land-use practices. This study reports on a spatial model designed to measure such nonpoint pollution attributes based on existing satellite-derived land-cover data.

People have traditionally settled near water because of a multitude of benefits and advantages: a ready supply of potable water, proximity to industry and power, easy access to transportation and commerce, increased soil fertility and agricultural productivity, safety, and even for waste disposal. Such human settlement has also resulted in loss of land and soil through erosion, degradation of water quality and wildlife habitat, and disruption of the natural ecosystem. Consequently, human use of water and its adjacent uplands has historically been one of the major factors responsible for water pollution and the subsequent decline in water quality. Urban, residential, and agricultural land use produce considerable disturbance of the natural habitat resulting in some of the highest potential for nonpoint source water pollution.

Coastal settlement areas, because of their dynamic nature, are particularly susceptible to environmental impacts of nonpoint source water pollution on shorelines and wetlands. In urban areas, pervious spaces such as vegetation and forested lands are converted to impervious rooftops, parking lots, streets, and sidewalks, increasing runoff volume and pollutant loadings. Runoff typical of urban areas includes sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, petroleum hydrocarbons, pathogenic bacteria, and viruses (EPA, 1993; DEC, 1990). Agricultural activity is considered by the Environmental Protection Agency (EPA) to be the nation's most widespread nonpoint source for water quality pollution through fertilizer, pesticide, and herbicide runoff; soil erosion; and animal and plant wastes (Jakubauskas *et al.*, 1992). Resulting pollutants include soluble nutrients and chemicals such as nitrogen, phosphorous, metals, and salts among others (EPA, 1993). Residential land use is somewhat a mixture of urban and agricultural land use, generating nonpoint source pollution components from both

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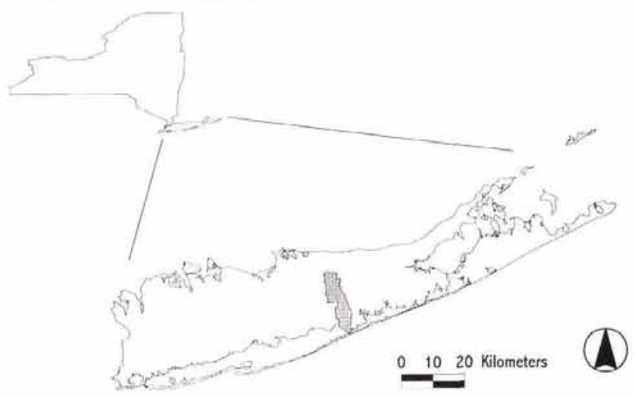

Figure 1. Location of Carmans River study area, Long Island, New York.

land-use types with variable levels of pollution concentrations.

State and federal governments have targeted the identification and control of nonpoint source water pollution runoff as a major goal for pollution abatement (Subra *et al.*, 1994). Among the most effective and economical controls are land-management techniques designed to modify or change present land-use activities and practices through financial incentives, voluntary compliance, or regulation (Rifai *et al.*, 1993). Because urban areas and the conversion of land to urban areas contribute heavily to nonpoint source water pollution, one way to implement such a management program is to focus on patterns of urbanization. But, to control and monitor these conditions, it is necessary to know what the current land uses are and how they are spatially distributed in the area(s) of concern, often at the parcel level. High quality spatial data requisite to support these data needs can be provided by geographic information systems (GIS) and remote sensing techniques (Jakubauskas *et al.*, 1992; Pelletier, 1985).

Several studies have illustrated the role of remote sensing and GIS in supplying data and information for assessing nonpoint source water pollution attributes and formulating land resource planning and management strategies. Newell *et al.*, (1992) created a ranking of nonpoint source water pollution loads in Galveston Bay, Texas, using eight land-use categories derived from Landsat TM data incorporated with soil run-off models, rainfall amounts, and water quality parameters. Subra and Waters (1993) examined an area of southwestern Louisiana to develop a prototype nonpoint source water pollution model using 15 land-cover types mapped from TM imagery, watershed, hydrography, slope, and soil type data. A Connecticut watershed was the focus of research by Nelson and Arnold (1995). Six categories of land cover were extracted from TM imagery and weighted by their percent of impervious area to produce current and future runoff values.

Each of these studies demonstrated the ability of satellite remote sensing, and Thematic Mapper imagery in particular, to generate land-cover information useful in nonpoint source water pollution potential analysis, but each study also generated its own customized land-cover categories by original analysis and classification of satellite imagery. While this procedure is useful, it is also somewhat time consuming and expensive compared to using a widely available existing land-cover database.

The National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (C-CAP) is a national program designed to inventory and monitor habitat change in the nation's coastal regions on a five-year basis using satellite imagery (Dobson *et al.*, 1995). The emphasis is on management of wetlands and their upland drainage basins, and their relationships and impacts on fisheries. The classification system focuses on land-cover classes that can be discriminated from satellite imagery in a hierarchical manner reflecting ecological conditions and relationships. Four categories of wetlands and seven types of upland land cover are specified initially, along with protocols for data format, map registration, and metadata documentation. When possible, the protocol recommends that the land-cover classes from this first hierarchical level be further subdivided into secondary levels. C-CAP data are to be disseminated in digital form to anyone wishing to incorporate them in geographic analysis. The spectral data comprising each land-cover class is provided with the metadata so that anyone wishing to modify or use the digital spectral data comprising each class as a GIS layer or other function may do so. The availability, quality, value, and consistency of this database make it extremely attractive for possible use in studies of nonpoint source water pollution potential as well as other applications.

This investigation reports the outcome of a pilot study to create a nonpoint source water pollution potential model that incorporates and evaluates the utility of C-CAP-derived land-cover information for such models. It also examines the effect of generalized soils data on measurement of potential nonpoint source water pollution sources and the role of a distance-to-water variable. It is the first step in an effort to develop raster-based models which can produce pollution assessment information at a spatial level which relates to land-use parcel data. The research is part of a larger effort to examine the contribution of remote-sensing-derived information to New York's coastal environment resource management programs.

Study Area

Long Island New York is subject to a steep development gradient ranging from the boroughs of New York City through the heavily developed suburbs of Nassau County and western Suffolk County to the rural agricultural areas, woodlands, and small settlements characteristic of eastern Suffolk County and its North and South Forks. The population of eastern Long Island doubled each decade from 1960 to 1980. Surrounded by water and long a home to human populations, water-dependent industries, and recreation, water quality has always been a concern of Long Island. However, little discipline and inadequate planning over much of the three-hundred years since colonial settlement have led to a degradation of the environment and a recognition of the need to monitor and manage present land use and future growth (Kavenagh, 1980).

The Carmans River watershed, located in central Suffolk County and emptying into the Great South Bay, was selected as an appropriate study area for several reasons (Figure 1). It is one of Long Island's four major watersheds and home to several important finfish populations and related commercial and recreation activities. It is an area that is currently not heavily developed but is subject to steep development pressures from an expanding population with ready expressway transportation links to western Long Island and New York City. The area is also part of the South Shore Estuary Reserve, a major focus of coastal resource management by the State of New York. In contrast to the already extensively built-up and built-out areas of western Long Island, the Carmans River area largely awaits the impacts and effects of future development.

The 85-sq-km (20,995-acre) drainage basin contains a mix of land cover typical of Long Island—palustrine and estuarine wetlands, forests of predominantly oak-pines in various mixes, grasslands, some cultivated fields, bare ground, and a cross-section of developed land cover. The watershed is part of a deep aquifer recharge with shallow flow subsystems. Soils, comprised of sand, gravel, and clay deposits with coarse sediments, are generally deep and excessively drained.

Methodology

Imperviousness has been shown to be an effective and feasible (it can be calculated) vehicle for the measurement of nonpoint source water pollution potential (NSWPP). Imperviousness influences hydrologic changes in waterways, is a characteristic of land uses and land covers that are a major contributor to NSWPP, prevents percolation, and transports pollutants into waterways (Arnold and Gibbons, 1996). In this study C-CAP-derived land-cover type, hydrologic soils groups, soil permeability, and distance to water are used to calculate imperviousness, model NSWPP, determine NSWPP sources, and assess total NSWPP load in the watershed.

The Carmans River study area was delimited by drawing a half-mile buffer from the river. The half-mile boundary was selected based on underground aquifer characteristics of the area that effectively minimize the utility of traditional topographic boundary definition. Specifically, subsurface groundwater flow, a major contributor to river flow, does not follow contours because of the area's highly pervious sandy soils. The watershed boundary was then adjusted to include all of any split land-use parcels bridging the watershed boundary; roads were used to further adjust and refine the study boundary line. This process will permit the data from the study to be merged with land-use parcel data for use in a build-out analysis and subsequent refinement and expansion of the spatial model in progress.

A subset of the nine-category (Bare, Cultivated, Developed, Grassland, Water, Palustrine Wooded Wetland, Palustrine Emergent Wetland, Estuarine Emergent Wetland, and Wooded) C-CAP Long Island land-cover classification (Henderson *et al.*, 1998) was made of the Carmans River study area. Although these categories could have been used to test the C-CAP data, a decision was made to create sub-categories of the Developed class to provide more detailed input to land cover considered to have a great effect on NSWPP in urban areas. This step also employed the intended concept behind the C-CAP metadata concept. The spectral signatures for the Developed class were obtained from the C-CAP metadata. An unsupervised classification was performed on the spectral signatures comprising the Developed category to produce three sub-classes (High Intensity Developed, Medium Intensity Developed, and Low Intensity Developed). High Intensity Developed contained land cover such as highways and parking lots that were at least greater than 80 percent impervious; Medium Intensity Developed was land cover that was still primarily impervious (50 to 80 percent) but vegetation (grassland and wooded) and other cover types were present in the pixel; Low Intensity Developed was comprised of a mixture of land covers with 30 to 49 percent constructed materials. These categories were empirically defined using a combination of breakpoints in the spectral data, visual examination of NAPP photography, compatibility with TR-55 model classes Soil Conservation Service guidelines (SCS, 1986), and reference to categories defined by Ridd (1995). Accuracy tests indicated that each category was at least 90 percent accurate. These categories were then merged with the other eight C-CAP land-cover classes to produce the eleven-category land-cover map and data.

The USDA Suffolk County Soils map of the study area was digitized and grouped according to Soil Conservation Service guidelines into four hydrologic soil groups (HSGs) based on precipitation runoff estimates derived from infiltration and transmission rates of saturated soils (SCS, 1986). The TR-55 model described in the Soil Conservation Service technical report *Urban Hydrology for Small Watersheds* (SCS, 1986) was then used to calculate estimates of permeability based on the 11 C-CAP land-cover types and four soils groups (Subra and Waters, 1993; Newell *et al.*, 1992; Nelson and Arnold, 1995). Land-cover classes from the C-CAP classification were compared and equated to corresponding SCS TR-55 model land-cover types. This procedure identified a runoff curve number (a unitless value ranging from 0 to 100) for each land-cover type based on the watershed's soils, plant cover, amount of impervious area, interception, and surface storage. The curve number, inversely proportional to permeability, provided a measure of impermeability. The percent of the total watershed occupied by each land-cover type was multiplied by its derived curve number and summed to determine the permeability/impermeability of the entire watershed.

Permeability calculations were completed in two stages to evaluate the value and merit of incorporating various soils data into the model. Stage one defined all soils in the study area as Group A. Group A soils consist mainly of deep, well-drained to excessively drained sands or gravelly sands and have a high filtration rate and high rate of water transmission. This soil group was the predominant soils group of Long Island and also depicted a best case (least surface runoff pollution potential) scenario. The second stage employed all four soil hydrology groups extant in the study area as derived and digitized from the USDA county soil maps. It provided an indication of the benefit and necessity of an expanded soils definition.

A distance-to-water buffer consisting of 100 pixels was created to incorporate a distance variable into the model that encompassed the entire watershed. Distance was inversely related to runoff potential. The distance-to-water variable in the model was examined using (1) an average value after that used by Subra and Waters (1993) and (2) a linear weighted distance value. In the average distance measure, the values for permeability (SCS curve numbers) and the distance values were summed and divided by two, placing equal weight on both variables. Distance values ranged from zero (low potential—far from water) to 100 (high potential—close to water).

The linear weighted distance variable assumes that land-cover type and distance are not equal. Rather, it assumes that the contribution of runoff from land cover far from water is less (due to absorption as it passes across intervening land cover) than the contribution of runoff from land cover close to the water body (i.e., a linear decline with distance). Sites with high pollution potential nearest to water are emphasized using this approach. The linear weighted distance values were calculated by multiplying the permeability and distance values together and dividing the product by 100 to create an output image with values again ranging from 0 to 100, indicating a low to high potential for nonpoint source pollution potential.

A spatial modeler was used to develop the NSWPP models. The input raster images were (1) permeability, based on the land cover and soil group curve values derived from SCS tables, and (2) the distance-to-water values. The first model derived permeability values based on land-cover type, Soils Group A, and an average distance-to-water measure. The second model used the same data but considered all four Soils Groups. Based on the results of these two models, the third model incorporated land-cover type, four Soils Groups, and a linear weighted distance-to-water factor.

Results and Analysis

The area and percent of the study area occupied by each land-cover type are listed in Table 1. The largest portion of land cover (49 percent) was Wooded while Low Intensity Developed was the second greatest segment (14 percent); each of the remaining nine categories comprised eight percent or less of the study area.

A comparison was made of the NSWPP for the watershed using Soils Group A and an average distance-to-water variable, and the difference when four Soils Groups were used in the spatial model. In the first case, the total permeability of the watershed with the distance-to-water variable was determined to be 62.3. When the four soils groups were incorporated into the model, the permeability decreased to 53.4—an 8.9 percent increase in potential water runoff due to the inclusion of more specific soil type variables.

Table 2 provides an indication of the changes in NSWPP values as a result of incorporating additional soil type information. Using a single soil type, NSWPP values less than 40 (low pollution potential) occupy just over 19 percent of the study area, values between 40 and 70 (medium pollution potential) occupy about 59 percent, and values of 70 and above (high pollution potential) occupy a little over 22 percent of the watershed. When all four soils groups are employed in the model, the percent of high pollution potential area increases (22 to 39 percent) while the medium and low pollution values decrease (58.6 to 43.1 percent and 19 to 17.9 percent, respectively).

Table 3 provides a comparison of land-cover curve numbers and the four hydrologic soils groups. Water and wetland categories were excluded because their curve numbers (runoff potential) are 0. The amount of potential runoff (i.e., lower curve numbers for each category) would be underestimated using only Soil Group A. The influence of soil type information was largest for the Grassland and Wooded categories and Low Intensity Urban. Although Grassland and Wooded land covers occupy a considerable portion of the study area, the resulting increase in potential runoff is somewhat mitigated by the fact that their initial curve numbers (39 and 30) are low. The effect of soil groups data on Low Intensity Urban values is also evident. As the second largest land-cover class (after Wooded), the increase in curve number values from an initial moderate position (61) would have significant impact in calculating potential runoff for that category as well. Bare Ground and Cultivated land cover experience a slightly lower increase in potential runoff, but they also have a higher initial curve numbers (77 and 67). Adding soil group information for these two land covers has an important impact in calculating the revised potential runoff values but over a smaller portion of the study area. Bare ground is often also a transition or seasonal land cover for cultivated land. The addition of more soils information would not affect the Medium and High Intensity Urban land-cover runoff potential because large portions of these categories are already impervious surfaces.

Using only the Group A soils group afforded the opportunity to compare a best case scenario (minimum NSWPP) and the possibility of using a single soils type in the model; incorporation of the four soils groups permitted a comparison using data more reflective of actual conditions and variations. The use of one soil group might prove a useful indicator of NSWPP conditions when a large area (e.g., entire watershed or county) is being viewed at a regional perspective, and/or when the other soils groups are deemed minor in percent of total area occupied, are localized in occurrence, and/or are fragmented in distribution to small areal units. Still, the data here indicate that the amount of potential runoff would be underestimated if Group A curve numbers were used alone, particularly for Grassland, Wooded, and Low Intensity Urban land cover occurring over other soil types. Using all four soils groups allowed much more detail and finer discrimination of the spatial distribution of NSWPP throughout the study area, detail that would be lost if only a single soil group and its associated curve numbers were used in the model. The expanded model affords detailed analysis for resource-management decisions focused on a specific watershed or sub-region, or even individual parcels, increasing the spatial detail, precision, and functionality of the model for pollution-related analysis.

TABLE 1. LAND-COVER CLASSES PRESENT IN THE STUDY AREA

Land-Cover Type	Area (acres/hectares)	Percent of Study Area
Bare Ground	803/325	4
Cultivated	781/316	4
Grassland	1335/540	6
Water	1550/627	8
Palustrine Wooded Wetland	53/21	4
Palustrine Emergent Wetland	50/20	<1
Estuarine Emergent Wetland	946/383	5
Wooded	10211/4132	49
High Intensity Urban	795/322	4
Medium Intensity Urban	652/264	3
Low Intensity Urban	3019/1222	14

The next step compared the merits of the two distance-to-water values, average and linear weighted. Based on the results of the single versus multiple soils group comparison, four soils groups were used in the model. The result of using a linear weighted distance-to-water variable in the model and four soils groups can be seen in Plate 1 and Table 2. It is quite evident that linear distance weighting significantly reduces the overall NSWPP evaluation in the watershed. Compared to the equally valued, average water distance model, low potential values (0 to 39) in the linear weighted model have increased from 17.9 to 53.1, medium values (40 to 69) have decreased from 43.1 to 37.7, and high potential pollution values (70 to 99) have decreased from 39.0 to 9.2. This technique — a modification of that used by Subra and Waters (1993) where the NSWPP value was an average of the permeability value and the distance value — modified the distance variable and more precisely reflected the amount of potential water runoff that would enter into the waterbody from each land-cover type and location. That is, as the distance to water increased, the land-cover curve number (impermeability) was multiplied by a smaller number that reflected the decreasing possibility and rate at which water runoff from a particular land cover would actually enter directly into the river and bay. Conversely, sites with high water pollution potential nearest to water were emphasized; the

TABLE 2. POLLUTION POTENTIAL RESULTS

Pollution Potential	Percent of Study Area Using HSG A and Equally Valued Water Distance	Percent of Study Area with All HSGs and Equally Valued Water Distance	Percent of Study Area Using All HSGs and Weighted Water Distance
0–39	19	17.9	53.1
40–69	58.6	43.1	37.7
70–100	22.4	39.0	9.2

TABLE 3. CURVE NUMBERS BY LAND-COVER CLASS AND HYDROLOGIC SOIL GROUP

	Hydrologic Soil Group			
Land-Cover Class	A	B	C	D
Bare	77	86	91	94
Cultivated	67	78	85	89
Grassland	39	61	74	80
Wooded Land	30	55	70	77
High Intensity Urban	98	98	98	98
Medium Intensity Urban	89	92	94	95
Low Intensity Urban	61	75	83	87

Curve number for each land cover is derived from Soil Conservation Service (1986).

distance-to-water criterion accentuated the importance of such sources closer to water.

For each of the examined models, roads and other land cover with extensive impervious surfaces (e.g., commercial/industrial structures, parking lots, and strip development with little if any vegetated areas) had the highest NSWP potential; Low Intensity Development also retained a relatively high NSWP potential. Although Wooded land generally manifested the lowest NSWP potential, the model using the linear distance-to-water variable disproportionately identified Wooded land cover as a high potential pollution source when that land cover was found near water.

Summary and Conclusions

This study evaluated the potential of existing satellite-based land-cover data derived from C-CAP classification protocols to provide useful input to modeling nonpoint source water pollution potential in a complex coastal environment, the Carmans River watershed in eastern Long Island, New York. It also evaluated the alternatives of using different soils groups and distance-to-water scenarios in nonpoint source water pollution spatial models. A model was first created to merge the land-cover data with hydrologic soils group classes. Permeability/runoff values were derived from this information based on USDA Soil Conservation Service tables. These data were then merged with distance-to-water values in spatial models to create maps of nonpoint source water pollution potential for the watershed.

The C-CAP land-cover classification does provide a viable database for nonpoint source water pollution potential studies at a watershed or regional level. The information available from this satellite-based data set provides useful detailed information for such analysis, avoiding the time and expense of generating an original land-cover/land-use classification. Although the original nine land-cover categories could have been used in the model, the decision was made to also test the metadata concept of the C-CAP data and protocol. Eight land-cover categories were used as present in the original C-CAP classification and metadata. The Developed category was extracted from the metadata and the spectral signatures were reclassified into three more detailed land-cover categories reflecting the urban variation in the study area. The success of this step points to the utility of the data set in modifying the land-cover classification (within the spectral and spatial constraints of the data) to fit a user's particular needs without having to classify the entire area from original raw data.

Generalizing the contribution of soils type to the model by using a single soils group may provide useful information for regional assessment if the generalization conditions are acceptable to the user. However, the results of this study also point to the increased detail and precision that is attained with the curve numbers from four soils groupings; detail that was significant in determining the overall runoff potential in the study area and the spatial location of the contributors. A distance variable also added valuable spatial location information in evaluating nonpoint water pollution potential. Adoption of a linear weighted distance variable provided more spatially accurate information than did the use of an average distance variable. The enhanced identification of both spatial location and distribution of potential nonpoint water pollution sources increased the precision of the model and perhaps best reflects actual NSWP potential.

The results of the final spatial model present the most detailed site-specific information on NSWPP for planning and management decisions. According to this model, it appears that a large portion of the Carmans River watershed currently has a relatively low potential for nonpoint source water pollution. The Wooded land cover possesses filtering capabilities that assist in runoff abatement and pollution control. At the same time, the red linear areas on the map (Plate 1) illustrate the high pollution potential of transportation arterials. Other areas noted by high NSWPP values in Plate 1 define land uses and land-cover conditions (e.g., high NSWPP values along the river) that merit monitoring.

These data represent current conditions; there are many other possibilities that will expand the usefulness of such a data set and spatial model. For example, a step in progress is to generate a refined spatial model that incorporates the effects of allowing 100 percent build-out of possible land use according to current zoning codes. The spatial model of the

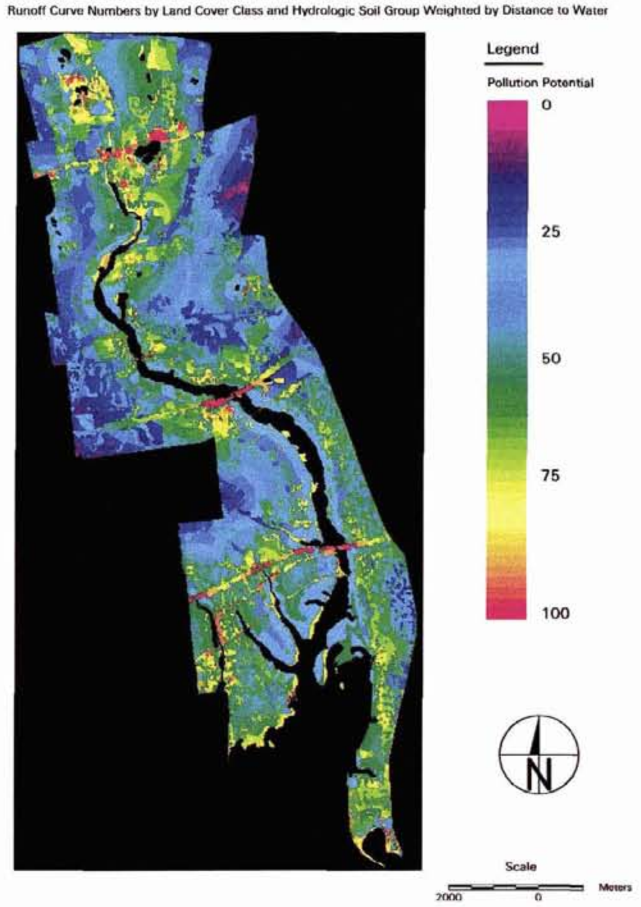

Plate 1. Nonpoint source pollution potential for the study area.

projected land-use/land-cover data weighted by soils data and distance-to-water factors would provide a recalculation of possible increases in NSWPP levels in the watershed; useful input for resource management decisions. The detail provided by the 25-m spatial resolution of the raster data would also permit detailed changes to be noted along with their spatial location, distribution, and frequency throughout the study area; data that could also be grouped to provide a single value for watershed comparison.

Other studies in other environments have used original analysis and land-cover classification of satellite-based land-cover data in creating water run-off models (Harbor, 1994; Newell *et al.*, 1992; Rifai *et al.*, 1993; Subra *et al.*, 1994). It is believed that the C-CAP data and spatial model described here could be substituted for such satellite data and classifications, saving much time, money, and effort in producing similar water pollution potential information.

The development of spatial models incorporating remote sensing data sets and other GIS data layers provide a useful tool not only for depiction of past and current nonpoint source water pollution potential conditions but also for the identification and location of areas at high risk of change and subsequent increase in nonpoint water pollution potential.

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