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ESTIMATING MARYLAND CRITICAL AREA ACT'S IMPACT ON FUTURE NONPOINT POLLUTION ALONG THE RHODE RIVER ESTUARY[1]

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ABSTRACT: This paper presents the results of an investigation of the effects of the Maryland Critical Area Act on generation of nonpoint source loads of phosphorus, nitrogen, and sediment to the Rhode River estuary. The Simple Method model, the Marcus and Kearney regression model, and the CREAMS model were used to estimate annual loads under: (1) present conditions, (2) maximum land use development allowable under the Act, and (3) two sets of future land use conditions that might occur if the Act were not in place. Results indicate that the Critical Area Act can reduce the present generation of nonpoint nutrient and sediment loadings 20-30 percent from the regulated area. These reductions can occur while preserving agricultural lands and allowing limited residential and urban development. The decrease in nutrient loadings is primarily dependent upon implementation and enforcement of agricultural best management practices (BMPs). The BMPs could reduce present agricultural nutrient loadings by 90 percent to a level comparable to loadings from residential areas. The estimated effectiveness of the Critical Area Act is even greater when compared to potential future nutrient loadings if development in the area remains unregulated. Unrestricted residential and urban development could increase nutrient loadings by 200 percent to 1000 percent as compared to controlled development under Critical Area Act guidelines.The Critical Area Act primarily prevents these future increases by severely limiting woodland cutting, with lesser results obtained by requiring urban BMPs.

(KEY TERMS: Maryland Critical Area Act; nonpoint source pollution; land use planning; pollution modeling; watershed management; Chesapeake Bay; nutrients; erosion; water quality; Geographical Information System.)

INTRODUCTION

A significant and continuous decline in Chesapeake Bay water quality, fish and wildlife habitat, and commercial fisheries and waterfowl has occurred over the last 35 years (Chesapeake Executive Council, 1987). Nutrient over-enrichment, excessive sediment loadings, and toxic pollutants from increased urbanization and changing agricultural practices are responsible for many of the Bay's problems (Smullen *et al.*, 1982; USEPA, 1983). Nonpoint sources, particularly agricultural runoff, contribute on average an estimated 67 percent of the nitrogen and 39 percent of the phosphorus reaching the Bay from Maryland (Maryland Department of Environment, 1988).

The Maryland Critical Area Act was passed in 1984 in order to improve Chesapeake Bay water quality and natural resources while still accommodating population growth (State of Maryland, 1984). The Critical Area Act's jurisdiction includes all submerged land and waters of the Maryland portion of the Chesapeake Bay and tributaries, and all land within 305 meters beyond the landward boundary of tidal wetlands and the heads of tides (State of Maryland, 1984). The Critical Area Act regulates location, density, and type of development within this "critical area" in order to direct new development into already developed areas and preserve the remaining rural and undeveloped tracts of Chesapeake Bay shoreline (COMAR Section 14.15.02, 1986). The Act also requires existing farms within the Critical Area to control nutrient, animal waste, pesticide, and sediment runoff with best management practices (BMPs). Management responsibility in the Critical Area is shared between local jurisdictions and the State.

Controversy surrounds the Act, in part because its provisions were politically driven and not based on scientific data for decreasing nonpoint source pollutants (Gray, 1988; Hillyer, 1988; Perkel, 1988). The Act's most controversial provision restricts new development in nature-dominated environments and farmlands (Resource Conservation Areas) to

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approximately one dwelling unit per eight hectares (20 acres). This provision has been criticized as being overly restrictive and not based on scientific evidence that limiting development to one unit per eight hectares will improve the Chesapeake Bay water quality (Winegrad, 1986), although a "rationale" was published after the Act had been passed (Chesapeake Bay Executive Council, undated). Additionally, despite the fact that agriculture is the largest source of nutrients to the Chesapeake Bay, the Act protects agricultural lands in the Critical Area. This created further debate (USEPA, 1983; Perkel, 1988).

The objectives of this study are to model the potential effects of the Critical Area Act on the generation of nonpoint source loads of phosphorus, nitrogen, and sediment to the Rhode River estuary from the 305-meter "Critical Area;" and to investigate if preserving agricultural lands is consistent with the Act's goal to reduce nutrient and sediment loads from the Critical Area. Mathematical models were used to estimate annual loads under: (1) present conditions, (2) maximum land use development allowed by the Critical Area Act, and (3) two sets of future land use conditions that might occur if the Act were not in place. These models relate nutrient and sediment loads to rainfall and basin characteristics, including land use.

DESCRIPTION OF THE RHODE RIVER STUDY SITE

The Rhode River is a small sub-estuary in Anne Arundel County and is typical of the Chesapeake Bay's western shore (Figure 1). The Rhode River watershed covers 3,360 hectares in area and is drained by seven creeks (Correll *et al.*, 1977). The study site includes those portions of the Rhode River watershed that are subject to the Critical Area Act (i.e., land within 305 meters of mean high water or the landward edge of tidal wetlands). Land use in the 901 hectare study site consisted of approximately 59 percent forest and open space, 28 percent low density residential development, 7 percent agriculture, and 6 percent wetlands in 1984 (Ann Arundel Office of Planning and Zoning, 1984) (Figure 1). For purposes of this study, open space is defined as scrub areas, meadow or forest clearings, and abandoned agricultural land. The Ann Arundel Office of Planning and Zoning (1988) designated approximately 75 percent of the study site as Resource Conservation Area (RCA) which is the most restrictive category, 20 percent as Limited Development Area (LDA), and the remaining 5 percent as Intensely Developed Area (IDA) (Figure 2). Soils in the study site are a complex mix of sandy loams, fine sandy loams, and silt loams (USDA, 1973). The average annual precipitation is 100 cm and is evenly distributed throughout the year. High intensity rainfall events occur in the summer. The maximum and minimum annual precipitation recorded over a 12-year period (1976-1987) at the nearby and climatically similar University of Maryland Wye Research and Education Center are 136 cm and 61 cm, respectively. A rainfall of 5 cm per hour recurs about once in ten years.

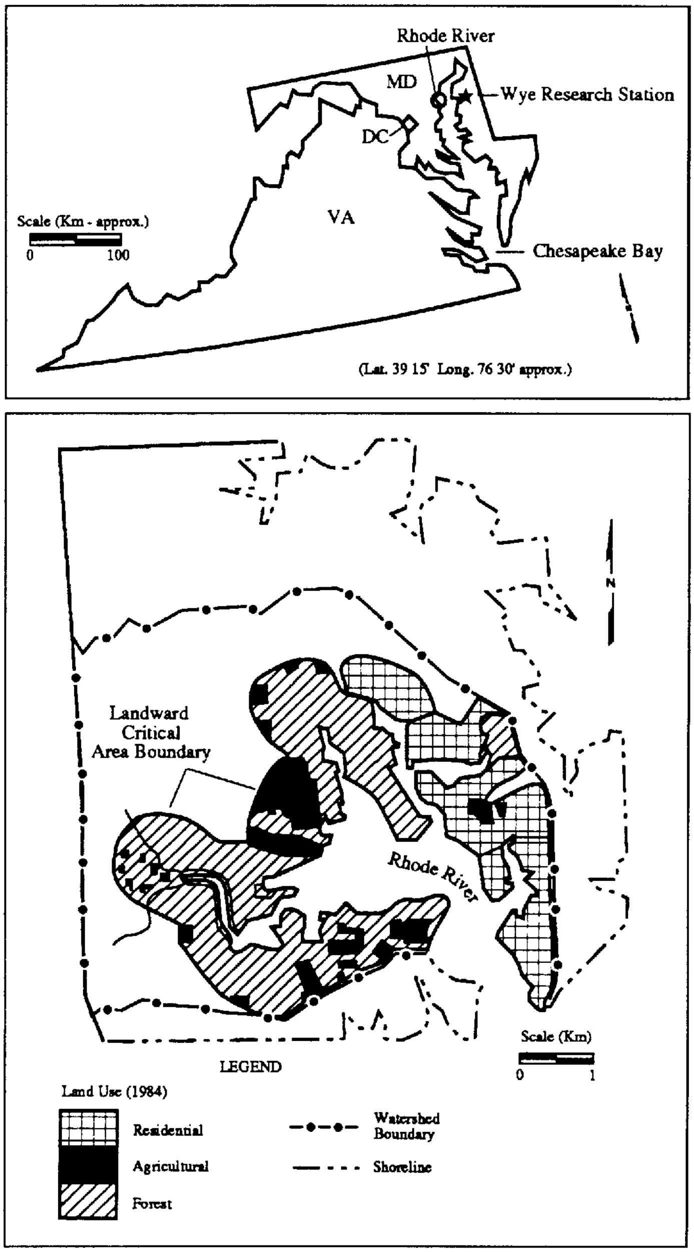

Figure 1. Regional Location and Land Use Within the Rhode River Critical Area.

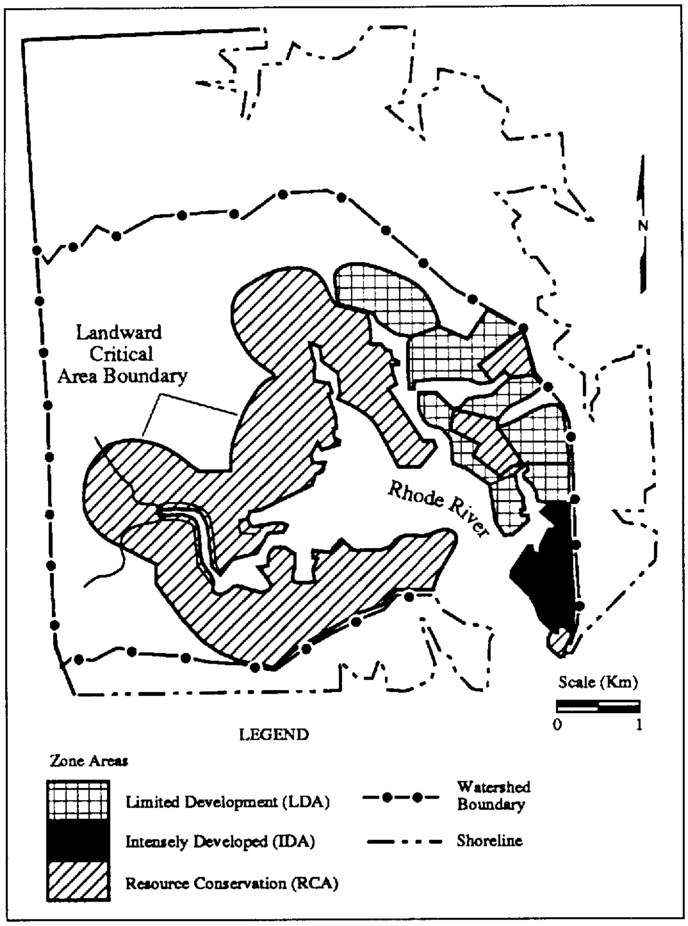

Figure 2. Critical Area Act Zoning in the Rhode River Critical Area (Anne Arundel County Department of Planning and Zoning, 1986).

METHODOLOGY

Overview

Three different nonpoint simulation models (CREAMS, Simple Method, and Marcus/Kearney regressions) were used to estimate the generation of annual areal nutrient and sediment loadings (kg/ha/-yr) in the Rhode River Critical Area under four different development scenarios. ARC/INFO, a Geographic Information System software package, was used to graphically represent the study site as well as store, analyze, and retrieve geographic and attribute data used as input to the models. Ideally, one model would be capable of estimating past and future nonpoint runoff loads from the different types of land use (e.g., agricultural, urban, forest, wetland), as well as the effect of agricultural and urban BMPs on nonpoint source load generation. Such a model does not exist. As a result, three different models were used.

The spatial land use distribution within the study area does not affect the results from the CREAMS, Simple Method, or Marcus/-Kearney models as used in this study. The location of land use relative to the estuary and other land use will impact the *delivery* of nonpoint source pollutants to the estuary. This study estimated the *generation* of nonpoint source pollution from different land uses. The relative position of land use does not affect the generation of nonpoint source pollution.

Simple Method Model

The Simple Method model (Schueler, 1987) was used to estimate the generation of nitrogen and phosphorus loads from developed and forested areas. This model was chosen because it requires a minimum number of input parameters, and is calibrated to a wide variety of land uses in the Washington, D.C., and Baltimore, Mary-land, area. The Simple Method model is a modified Rational Equation (McCuen, 1989) with a mean runoff concentration parameter added. Pollutant export (L) is estimated by the following equation:

$$L = [(P)\,(P_j)\,(R_v)\,(C)\,(A)\,(10)] \qquad (1)$$

where L is pollutant export in kilograms per year; P is rainfall in centimeters; P_j corrects P for storms that produce no runoff; R_v is a runoff coefficient which expresses the fraction of rainfall which is converted into runoff; C is a flow-weighted mean concentration in mg/l of the pollutant in urban runoff; and A is the area of the development site in square kilometers. The coefficient 10 is a unit conversion factor. The 12-year rainfall record (1976-1987) from the University of Maryland Wye Research and Education Center (Figure 1) was used for precipitation data. The Simple Method does not consider baseflow runoff and associated pollutant loads (Schueler, 1987).

Modeling nutrient and sediment loads was complicated by the presence of approximately 50 hectares of wetlands within the study site. The Simple Method does not include a nutrient mean concentration value (C) for wetlands, and usable data on nutrient output from wetlands were not available. In compensation, a simplifying assumption was made that wetlands have the same nutrient mean concentration value as hardwood forests. This assumption probably increases the loadings from the study site; however, the small area of wetlands (5.5 percent of the study site) plus the relatively low nutrient mean concentration parameter from forests compared to other land uses should make the error small in relation to other loads. Also, orthophosphorus concentration is the only phosphorus value reported for central business districts by the Simple Model. This was used in place of total phosphorus measurements, underestimating total phosphorus loadings from central business districts since total phosphorus includes ortho-phosphorus and other forms of phosphorus.

Marcus / Kearney Regressions

Sediment erosion from non-agricultural lands was estimated using Marcus and Kearney's (1991) regressions for suspended sediment data derived from continuous suspended sediment samples collected at seven sites in the Rhode River between 1975 and 1987 (Correll *et al.*, 1989). They calculated average and maximum annual sediment yields and correlated basin area versus sediment discharge at six sites. Drainage basin areas ranged from 0.06 to 2.55 km^2. Land use within the basins was primarily forest and open space with some low to medium residential development and pasture land. The average annual sediment load was expressed as:

$$Q_s = 12.84A - 0.36 \quad (2)$$

(coefficient of determination (r^2) = 0.92, parametric variance (σ^2 = 4.67)

where Q_s is average annual sediment load in megagrams/km^2/yr, and A is basin area in km^2. Maximum annual sediment discharge (Q_m) was calculated from the highest annual values for the six sites during the period of record as follows:

$$Q_m = 37.26A - 2.03 \quad (3)$$

(coefficient of determination (r^2) = 0.87, parametric variance (σ^2) = 7.25)

The Marcus/Kearney regression models are not appropriate for estimating sediment loadings from watersheds containing large amounts of residential or commercial land use. Models for sediment loadings from urban and suburban watersheds are either site specific (e.g., Wolman and Schick, 1976; Ragan and Dietman, 1976) or have such large error components that they are not reliable measures of impacts of land use change (Driver and Tasker, 1990). As a result, potential sediment loadings from the two land use scenarios representing extensive suburban and urban development were not modeled.

CREAMS Model

The CREAMS model (Knisel, 1980) was used to model nitrogen, phosphorus, and sediment generated from farmland. CREAMS was chosen for its ability to model the relative impacts of agricultural BMPs on pollutant generation, and because it is a physically based model that does not need calibration (Knisel, 1985). CREAMS input requires data on soils, physical field characteristics, crop growth, cropping practices, and precipitation. Input data were gathered from ARC/INFO analysis, site visits and interviews with farmers, University of Maryland Agricultural Extension agents, and Anne Arundel County Soil Conservation Service staff. When actual field data were not available, default or recommended input parameters were used either following procedures described in the *User's Guide* (USDA, 1984) or using best professional judgment based on visits to nearby farms. When a range of values or dates were given, the midpoint or average value was used. The 12-year rainfall record (1976-1987) from the University of Maryland Wye Research and Education Center was used for precipitation data.

CREAMS models nonpoint source nutrient and sediment processes on a field-scale basis. To simplify modeling, average or typical physical field characteristics, soil type, crop, and cultivation practices were identified and used to create a "design" field that was used to model the effects of different BMPs.

The physical field dimensions of the design field were based on ARC/INFO analysis and observations during site visits. The average field in the Rhode River Critical Area covers approximately 2 hectares, is rectangular in shape, and oriented with the long axis parallel to the shoreline. Field slope ranges from 2 to 5 percent with a complex mix of constant, concave, and convex profiles (USDA, 1972). A slope of $3^1/_2$ percent, the average slope, was assumed. A constant slope profile was chosen because this is midway between a concave slope with minimum erosion and hydrologic movement and a convex slope with maximum erosion and hydrologic potential. The surface water runoff pattern is a simple overland flow to channel configuration determined by observation during site visits, interpretation of aerial photographs of the study site (Anne Arundel Office of Planning and Zoning, 1984), and best professional judgment.

Soils in the study site are a complex mix of sandy loams, fine sandy loams, and silt loams (USDA, 1973). The three dominant soil series in the study site were modeled by CREAMS to determine the series with the highest and lowest nonpoint source pollution potential. Based on this analysis, the Colemantown series silt loam was found to generate the largest sediment loads. The Adelphia series sandy loam generated the lowest sediment loads.

Corn and soybean are the dominant crops grown in the region (Martin, 1990). CREAMS identified continuous corn as having the highest pollutant potential of soybean and corn crop rotations. Corn was therefore chosen for modeling the Act's impact on nitrogen, phosphorus, and sediment from agricultural land. This biases loads from agricultural lands toward the high estimate. Modeling the highest pollution crop provides a good test of whether preserving agricultural lands can be consistent with the Act's attempts to reduce nonpoint source loads to the Rhode River.

Cropping practices and planting, tilling, and fertilization dates were chosen based on interviews with agricultural extension agents, farmers in the watershed, and best professional judgment. The baseline cropping practices (i.e., farm practices commonly used in the Rhode River watershed that are the basis for comparing changes in loadings after instituting different BMPs) are conventional tillage, contour plowing, and two applications of commercial fertilizers per growing season. Contour plowing was chosen as a baseline practice because of the widespread use of this BMP in the study site (Martin, 1990).

GIS Data Base

ARC/INFO, a vector based GIS software, was used to create six different coverages from maps and aerial photographs (Table 1). Modifications to the drainage pattern, in particular by anthropogenic structures such as roads, were identified by observing runoff and drainage patterns during a site visit on the second day of a rain storm.

Data from ARC/INFO analysis were used as input to the different models. For example, the 1984 housing coverage was overlaid with the Critical Area Act zoning coverage to calculate the additional number of houses allowed by the Act in each land use category (e.g., within the LDA). This information was used in the Simple Method model to select the correct mean pollutant concentration value. Similarly, the 1984 land use coverage was overlayed on the soils coverage to quantify the amount of each soil type under cultivation and the average field size. This information was used in the CREAMS model.

Development Scenarios

Four development scenarios were modeled to show relative changes in generation of nutrient and sediment loads from the Rhode River Critical Area. The scenarios are 1984 land use, land use allowed by the Critical Area Act, and two scenarios portraying development without the Critical Area Act (Table 2). Development patterns that would exist without the restrictions of the Critical Area Act are uncertain, so two different scenarios were modeled: total urbanization representing an older urban waterfront; and suburban expansion into rural and woodland areas representing present development trends in the Chesapeake Bay region.

Scenario 1 – 1984 Land Use. The year 1984 was chosen as the baseline because it predates the Act's

TABLE 1. ARC/INFO Thematic Coverages.

Coverage	Source
1984 Land Use	Black and white aerial photographs (photo rectified), April 1984, Anne Arundel County Office of Planning and Zoning, scale 1:9600
1984 Housing Density	Black and white aerial photographs (photo rectified), April 1984, Anne Arundel County Office of Planning and Zoning, scale 1:9600
Critical Area Act Zoning	Official Critical Area Map, Anne Arundel County, 1989 Sheets # 26 and 27, scale 1:12000
Critical Area Landward Boundary	Official Critical Area Map, Anne Arundel County, 1989 Sheets #27 and 27, scale 1:12000
Rhode River Watershed Boundary	United States Geologic Survey 7-1/2 minute topographic quadrange sheets, Deale, Maryland (1975), and South River, Maryland (1978), scale 1:24000
Soils	Black and white aerial photographs, Soil Survey of Anne Arundel County Maryland, USDA Soil Conservation Service, 1972, scale 1:20000