Water Resources Investigations Report
U.S. Department of the Interior, U.S. Geological Survey
WRIR-96-4273

STUDY OF NONPOINT SOURCE NUTRIENT LOADING IN THE PATUXENT RIVER BASIN, MARYLAND

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INTRODUCTION

Background

In 1985, the U.S. Geological Survey (USGS), in cooperation with the Maryland Department of the Environment (MDE) initiated a study of nonpoint source (NPS) nutrient loading in the Patuxent River watershed. The purposes of the study are to: (1) quantify NPS nutrient loading at various locations in the watershed; (2) gain further understanding of the relation between land use and water quality; and (3) evaluate the potential effectiveness of management practices. In order to achieve these goals, hydrologic, meteorologic, geographic, and water-quality data for the Patuxent watershed were collected and compiled. A model was then developed that allows simulation of the hydrology and water quality of the watershed and enables evaluation of various land-use alternatives on water quality.

The Patuxent watershed was selected for study because of its importance to the State of Maryland and because it is representative of other subbasins of the Chesapeake Bay. The Patuxent traverses the corridor between the two major metropolitan areas of Baltimore, Md., and Washington, D.C., and commercial, industrial, and residential development within the watershed has been substantial. Development in the Chesapeake Bay region is expected to continue, and the State has a strong interest in evaluating the effects of future growth on water quality and in defining methods for planning growth to minimize potential adverse effects.

Maryland's overall strategy for the study of nutrient loading in the Patuxent watershed calls for comprehensive monitoring, modeling, and research to reduce scientific uncertainty about nutrient loading and the response of the watershed to management actions. The monitoring program developed to meet the requirements of the Patuxent nutrient-reduction strategy includes both a tidal and nontidal water-quality sampling effort. The modeling component includes both watershed and estuarine water-quality models that are calibrated and verified with the appropriate monitoring data. Together, the data collection and modeling projects are used by the State to analyze alternative management strategies and to evaluate progress for meeting nutrient-load-reduction goals.

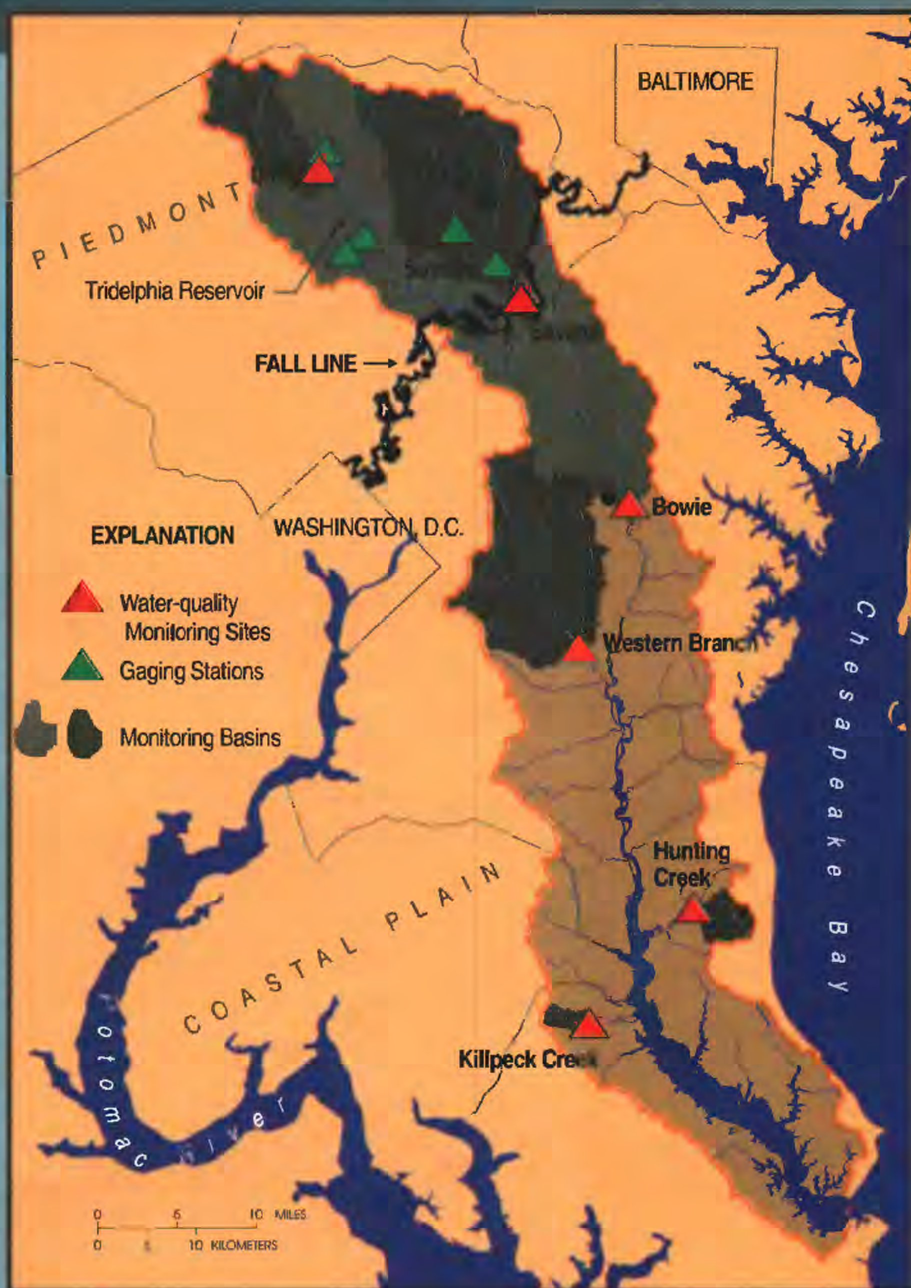

Figure 1. *The Patuxent River watershed, monitoring site locations and surrounding area.*

The USGS and the MDE have addressed the need for water-quantity and water-quality data in the nontidal part of the Patuxent by initiating a long-term study of the hydrology and water quality of the watershed. Water-quality data have been collected since September 1985. In July 1995, the primary responsibility for the study of nonpoint source nutrient loading in the State was transferred to the Maryland Department of Natural Resources (MDNR), and the USGS and MDNR have conducted the Patuxent study jointly since that date. The collection of water-quality data is expected to continue at least through September 1997.

Purpose and Scope

This report provides an overview of the major components of the study of nutrient loading in the Patuxent watershed. The main focus of the joint USGS, MDE, and MDNR Patuxent study has been the collection of surface-water discharge and water-quality data from representative locations throughout the watershed. The data-collection effort has provided detailed hydrologic time-series data that are necessary for model development. A second major focus of the study has been the development of a detailed watershed model that has been used to evaluate various land-use and land-management alternatives. Water-quality synoptic studies were conducted by collecting a small number of samples over a broad spatial area. The synoptic studies were designed to provide information about spatial water-quality patterns in the watershed, and about the causes of those patterns. All of the components of the Patuxent watershed study are currently underway and are in various stages of completion. Detailed descriptions of the results of the study components have been presented to State and local agencies and will continue to be presented and published as the study continues.

LONG-TERM MONITORING

Purpose

Long-term surface-water discharge and water-quality data collection was implemented in the Patuxent watershed in order to provide the data necessary for evaluating various aspects of nutrient loading, including trend detection. Data collection was

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intended to be long-term because processes that control NPS nutrient loading can occur over an extended period of time, and the detection of water-quality changes related to land use may require observations over decades. Because of the need for long-term water-quality data, significant resources were expended to build monitoring-site housing and equipment configurations that would allow long-term or even permanent data collection.

In part, long-term water-quality data were collected to provide the statistical basis for documenting changes in water quality and relating those changes to land-use patterns. Stream nutrient and sediment loads have been estimated each year that data have been collected, and the estimates have been compared among the sites to investigate potential relations between the land-use patterns of the monitoring subbasins and loads. In addition, trend analysis has been planned to detect current trends in nutrient and sediment concentrations and loads. Future trend analyses have been planned to detect water-quality trends related to anticipated implementation of management practices.

Water-quantity and water-quality data were also collected to provide the data base necessary for calibration of a detailed watershed model. The watershed model was developed as a tool for relating land-use practices to water quality and for understanding the controls of water quality. The watershed model will also be useful for investigating the effects of potential land-use change and land-management alternatives on water quality, and to simulate hydrologic conditions and water quality in unmonitored parts of the watershed.

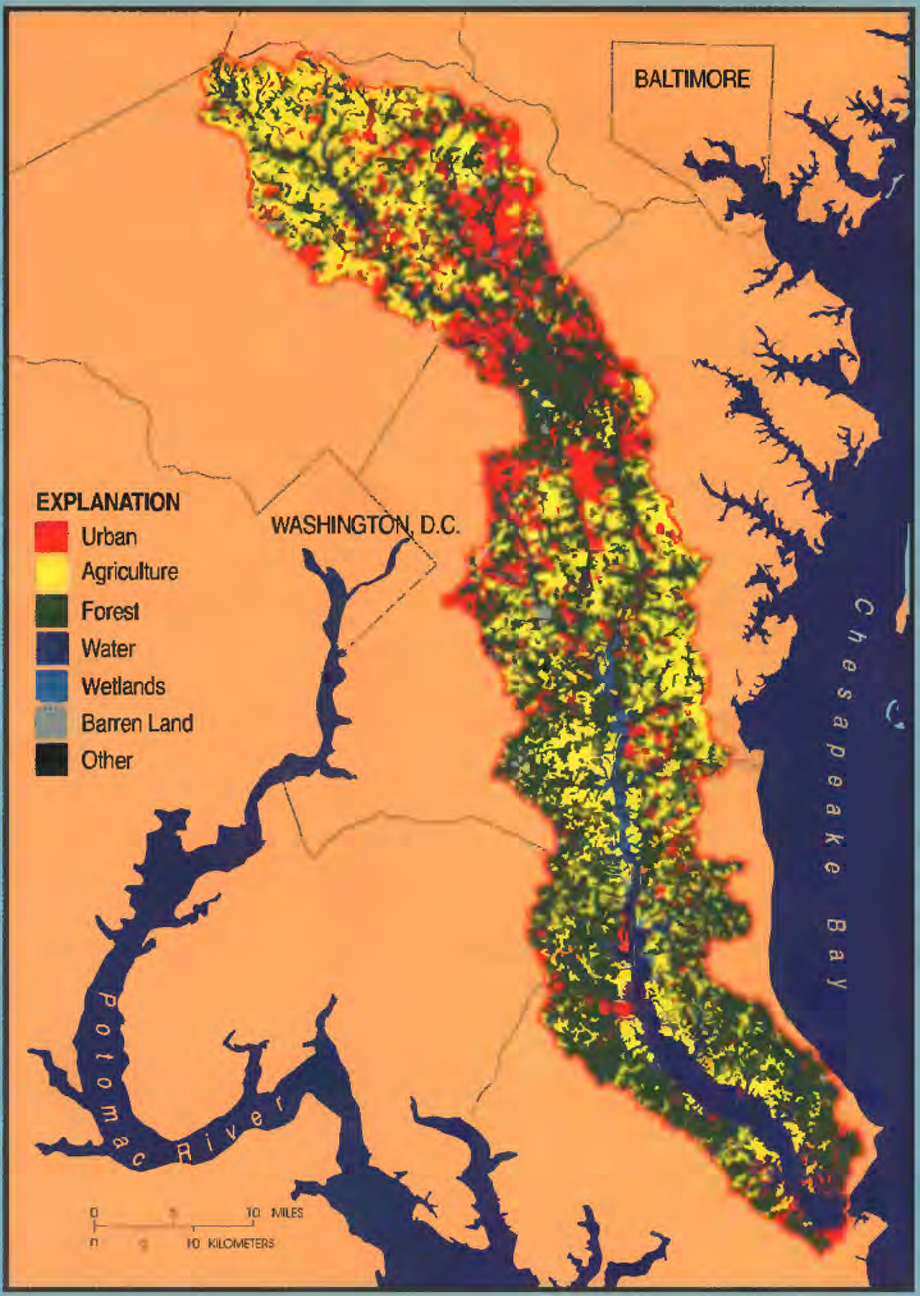

Figure 2. Land-use distribution in the Patuxent River watershed during 1985 (data from Maryland Office of Planning).

Site Descriptions

Surface-water discharge and water quality were monitored at six stream sites that are representative of conditions in the Patuxent watershed (fig. 1). The area of the watershed is about 930 square miles, and land use or land cover in 1985 consisted of approximately 46 percent forest, 32 percent agriculture and 15 percent urban/residential (fig 2). The northern third of the watershed is in the Piedmont Physiographic Province and the remainder is in the Coastal Plain. The monitoring sites were selected to represent various subbasins, physiographic settings, and mixes of land uses in the watershed. Two of the sites are on the main stem of the Patuxent River, two are on major tributaries to the Patuxent, and two are on streams in small Coastal Plain subbasins that discharge directly to the Patuxent estuary. Five additional streamflow-gaging stations in the watershed are supported by other studies.

The farthest upstream site is near Unity, Md., immediately upstream from the Tridelphia Reservoir. The Unity site represents an area of rural land in the Piedmont part of the watershed. Land use in the Unity subbasin during the year that the study was initiated (1985) was primarily agriculture (64 percent) and forest (32 percent).

One site was selected to monitor the water quality of the Middle Patuxent and Little Patuxent Rivers, which are major tributaries of the Patuxent main stem. The site is south of Savage, Md., downstream of the confluence of the two tributaries. The area draining to the Savage site has received significant development pressure over the recent past so that the site represents a subbasin that has recently experienced a shift in much of its area from agricultural to urban and residential land uses. Land use in the Savage subbasin during 1985 was mostly agriculture (35 percent), but a large fraction of land area was urban and residential (31 percent).

A second main-stem monitoring site is located near Bowie, Md., downstream from the Fall Line and upstream from the tidal part of the Patuxent River. Data collected at the Bowie site are used by both the Patuxent study and a separate study of nutrient loads to the Chesapeake Bay, called the River Input Study (Zynjuk, 1995). The combined effort of the Patuxent and River Input studies has resulted in a more detailed data record at the Bowie site than at the other sites. Land use in the Bowie subbasin during 1985 was 44 percent forest, 30 percent agriculture, and 22 percent urban and residential. Several large sewage treatment plants are located immediately upstream of the Bowie site, and could have a significant effect on water quality at the site.

A water-quality-monitoring site was established on Western Branch at Upper Marlboro, Md., to represent an area of urbanization in the Coastal Plain. Western Branch is a relatively large stream that discharges directly to the Patuxent estuary. The Western Branch subbasin has received a substantial amount of development because of its location near Washington, D.C. Land use in the Western Branch subbasin in 1985 included 38 percent forest, 30 percent agriculture, and 24 percent urban and residential area.

Two monitoring sites were selected to represent the numerous small Coastal Plain subbasins along the Patuxent estuary. In Calvert County, the Hunting Creek subbasin was selected, and a monitoring site was established at the Md. Route 263 crossing. In St. Marys County, the Killpeck Creek subbasin was selected, and a monitoring site was established near Huntersville. In both subbasins, land use in 1985 was predominantly forest (63-76 percent) and agriculture (20 -26 percent), with the remainder being urban and residential.

Approach

Stream discharge and water-quality data are collected at each of the monitoring sites. Discharge data are collected using standard USGS streamflow-gaging procedures in which high-frequency stage measurements are converted to discharge using a rating curve (Buchanan and Somers, 1982). Water-quality samples are collected manually during low-flow conditions and automatically during high-flow events. Data on the concentration of nutrients during high-flow events are critical to the accuracy of nutrient loading estimates (Preston and Summers, in press) and significant effort has been expended to ensure reliable collection of high-flow samples.

To ensure the long-term reliability of sample collection, considerable resources were expended to establish and maintain stable infrastructure at the monitoring sites. The potential for damage from high, fast-flowing water and storms creates a large potential for failure of sampling equipment and the loss of important water-quality data. To minimize the potential for sample loss, the housing and equipment configurations at the monitoring sites were designed to withstand extreme weather and

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streamflow conditions. At each of the sites, semi-permanent housing was established to shelter data-collection equipment (fig. 3). Sampler intake lines were installed between the housing and the stream, and were stabilized to avoid damage during floods.

Water-quality samples were collected during low-flow and high-flow conditions to ensure sample coverage over the full range of discharge. Low-flow samples were collected monthly using the equal-

Figure 3. Housing was installed at each monitoring site to protect automatic sampling equipment and to allow automated water-quality sampling during high-flow events.

width-increment (EWI) method (Edwards and Glysson, 1988), which is designed to provide horizontally and vertically integrated samples that are representative of the entire stream cross section. High-flow samples were collected using automated sampling devices that initiated sampling as the stream stage reached a specified height that is indicative of surface-water runoff.

High-flow sampling equipment at each site includes a flow meter and an automatic sampler (fig. 4). The flow meter records the stream hydrograph and graphically indicates the time when samples are collected. The automatic sampler pumps water from the stream or mixing chamber and stores it in separate sample bottles. As many as 24 samples can be collected; however, large numbers of samples are usually composited to yield from one to five samples per storm. Automatic samplers are refrigerated at all sites to preserve the samples as they are collected. Samples are retrieved and processed for laboratory analysis within 48 hours of collection.

Storm samples are collected in proportion to flow rate by collecting a sample each time that a specific volume of flow is measured by the flow meter. Thus the sampling frequency is increased during high flows and the probability that samples will be collected during the highest flows is also increased. When necessary to minimize the number of samples, individual samples are composited to represent specific parts of the hydrograph, such as the rising and falling limbs, and the peak discharge.

Tests were performed to verify that samples collected through the sampler intake were representative of the water in the stream (Koterba and others, 1994). As part of these tests, samples were collected manually in the stream and simultaneously using the automatic sampler. Comparison of the results indicated that the two methods provided data that were nearly equivalent throughout a range of discharges. Suspended sediment was the only constituent that exhibited slight differences between the two methods; suspended-sediment concentrations in samples collected by the automatic sampler were slightly lower than those in samples collected manually from the stream.

All laboratory analyses were performed by the Maryland Department of Health and Mental Hygiene laboratory, except for the suspended-sediment analyses, which were performed by the USGS sediment laboratories in Lemoyne, Pa., and Louisville, Ky. Data are reported annually in the USGS State report for Maryland, Delaware, and District of Columbia (for example, James and others, 1991). All data are stored electronically in the USGS National Water Information System (NWIS) data base.

Summary of Selected Long-Term Monitoring Data

Hydrologic and water-quality data were collected in the Patuxent watershed from October 1985 through September 1996. Data collection was temporarily discontinued at the Western Branch site because of construction during the period 1989-91. Data collection began in 1989 at the Hunting Creek site when the streamflow-gaging station was first installed.

Figure 4. Automatic sampling equipment at each site includes a flow meter for continuously recording discharge and a refrigerated automatic sampler for collecting and preserving water samples.

Selected hydrologic and water-quality data collected through September 1994 are summarized in table 1. Data summaries for mean daily discharge, suspended sediment, total phosphorus, total nitrogen and nitrate-nitrite are included in table 1 because of their importance in estimating and understanding nutrient loading. Summaries include the number of data values available, the mean, standard deviation, mean annual load and mean annual areal yield. Load estimation methods have been described by Preston and Summers (in press). Areal yield is simply the mean annual load divided by the subbasin size. Yields are more comparable than loads among the sites because variability due to subbasin size is eliminated.

Annual runoff (mean discharge divided by subbasin area) is a measure of the relative amount of water exported per unit area of the subbasin. Annual runoff is similar among the six sites. Slight differences at Western Branch and Hunting Creek may be due in part to differences in the periods of data collection. Slightly higher annual runoff at Killpeck Creek may be due to greater runoff caused by the steep terrain and incised valleys in the subbasin.

Suspended-sediment concentration is a measure of the particulate content of the water, and suspended-sediment load is a measure of the mass of sediment transported by the stream particularly during high discharge periods. Mean annual yield of suspended sediment was highest at the Savage, Western Branch, and Killpeck Creek sites. The subbasins represented by the Savage and Western Branch sites are the most urbanized. High suspended-sediment yields may reflect construction in those subbasins or particulate matter washed off impervious urban surfaces, such as roofs, roads, and parking lots. High suspended-sediment yield from the Killpeck Creek subbasin may be a reflection of streambank erosion caused by rapid runoff from steep slopes and ongoing valley incision.

Total phosphorus yields show a pattern similar to that observed for suspended sediment. Total phosphorus concentration is often related to suspended-sediment concentration because total phosphorus tends to be mostly in the particulate form. Consequently, phosphorus is readily transported by high discharge when particles are entrained and carried by rapidly flowing water. As with suspended-sediment yields, total phosphorus yields are highest at the Savage, Western Branch, and Killpeck Creek sites (fig. 5). These high total phosphorus yields may be related to sediment transport from construction areas, runoff from urban areas, and, in the case of Western Branch, the discharge from sewage-treatment plants.

Total nitrogen yields exhibit a spatial pattern that is different than that observed for suspended sediment and total phosphorus. Most of the nitrogen transport occurs through a different pathway than the other two constituents. Total nitrogen consists primarily of nitrate at most sites and nitrate is commonly transported to streams through ground water. As a result, geology or other natural factors may play an important role in the amount of nitrate that reaches the stream and is subsequently transported from the subbasin.

Total nitrogen and nitrate-nitrite yields were greatest at the Unity, Savage, and Bowie monitoring sites (fig. 5). Most of the area of these subbasins is in the Piedmont Physiographic Province; the other three subbasins are entirely within the Coastal Plain Physiographic Province. Some of the differences in nitrogen yield between the Piedmont and Coastal Plain sites are most likely due to the presence of point sources upstream (for example, the Bowie site). Some differences also may be due to land-use distribution and nonpoint sources. However, it is possible that geologic differences between the two physiographic provinces affect the

Table 1. Summary of discharge and selected water-quality constituent data collected at the Patuxent monitoring sites

	Unity	Savage	Bowie	Western Branch	Hunting Creek	Killpeck Creek
Mean Daily Discharge						
Number of data	3,286	3,286	3,286	2,221	2,429	3,286
Discharge - Mean (ft^3/s)	38.3	106	345	82.9	10.5	3.84
- Standard Deviation (ft^3/s)	59.7	167	421	134	15.2	4.62
Annual Runoff (in/yr)	14.9	14.6	13.5	12.5	15.2	16.0
Suspended Sediment						
Number of Data	175	173	273	145	127	176
Concentration - Mean (mg/L)	110	241	69.6	193	25.6	309
- Standard Deviation (mg/L)	287	468	89.1	275	29.5	575
Load (Mg/yr)	5170	34,400	22,100	16,400	286	987
Yield (g/m^2-yr)	57.4	135	24.6	70.5	11.8	117
Total Phosphorus						
Number of Data	252	163	551	285	114	147
Concentration - Mean (mg/L)	0.126	0.273	0.213	0.238	0.128	0.290
- Standard Deviation (mg/L)	0.265	0.404	0.163	0.419	0.155	0.0374
Load (Mg/yr)	7.55	35.0	60.1	31.2	1.27	1.06
Yield (g/m^2-yr)	0.084	0.137	0.067	0.134	0.052	0.126
Total Nitrogen						
Number of Data	2[illegible]9	153	465	276	108	140
Concentration - Mean (mg/L)	2.84	2.51	3.52	1.21	0.685	1.96
- Standard Deviation (mg/L)	0.923	0.868	1.54	0.686	0.627	0.691
Load (Mg/yr)	106	254	835	118	6.69	6.84
Yield (g/m^2-yr)	1.18	1.00	0.926	0.508	0.275	0.810
Nitrate / Nitrite						
Number of Data	238	159	547	270	114	146
Concentration - Mean (mg/L)	2.24	1.49	2.37	0.412	0.129	1.08
- Standard Deviation (mg/L)	0.602	0.591	1.21	0.244	0.095	0.566
Load (Mg/yr)	75.5	133	546	37.6	1.37	3.64
Yield (g/m^2-yr)	0.838	0.522	0.606	0.162	0.056	0.431

amount of nitrate that reaches the stream through ground water. Synoptic sampling studies that have been carried out to expand the spatial extent of available data, confirm the differences observed among the long-term monitoring sites, and provide additional information for understanding the controls of stream nitrogen concentration.

WATERSHED MODELING

Purpose

Watershed modeling was implemented as part of the Patuxent study in order to provide a mathematical framework for integrating and extrapolating the collected information. The model was designed to simulate the hydrologic conditions and water quality of the watershed based on forcing functions such as precipitation, land use, nutrient sources, and other basin characteristics. Mathematical simulation of the related environmental processes provides a mechanism for improving the understanding of factors affecting nutrient loading and for predicting the effects of land-use changes.

The watershed model is being used to improve the understanding of the relative importance of environmental processes or sources for nutrient loading. Because many environmental processes affect nutrients as they pass through the watershed, it is difficult to quantify any one process independently to determine its relative importance. The watershed model integrates all of the major environmental processes and allows them to be quantified separately. Thus the model could be used to quantify the relative importance of nonpoint source and point source loading and the effects of urban and agricultural land use on loading.

The model also provides a tool for spatial extrapolation of available information. The model is first calibrated where data are available in order to determine the appropriate parameter values for a representative area. The model and parameter values defined by calibration at one site can then be applied to other nearby areas with similar characteristics. In that way, the entire watershed can be modeled and the relative importance of all nutrient source areas to the Patuxent can be determined.

The model can also be used to estimate the effects of changes in the watershed on nutrient loading. The relations between land use and nutrient loading are quantified by the model and these relations can be extrapolated to estimate nutrient loads under past or future land-use scenarios. Currently, MDE is applying the Patuxent watershed model to simulate nutrient loads under 100-percent forest cover to simulate pristine water-quality conditions, and under a hypothetical land-use pattern in the year 2000 to estimate future water-quality conditions. MDE is also using the model to determine the potential effects of management practices such as nutrient management and conservation tillage on nutrient loading.

Model Description

The Patuxent watershed model is a continuous simulation model that was designed to simulate water-quality constituent concentration or load on the basis of surface-water runoff, ground-water input, point-source input and instream processes.

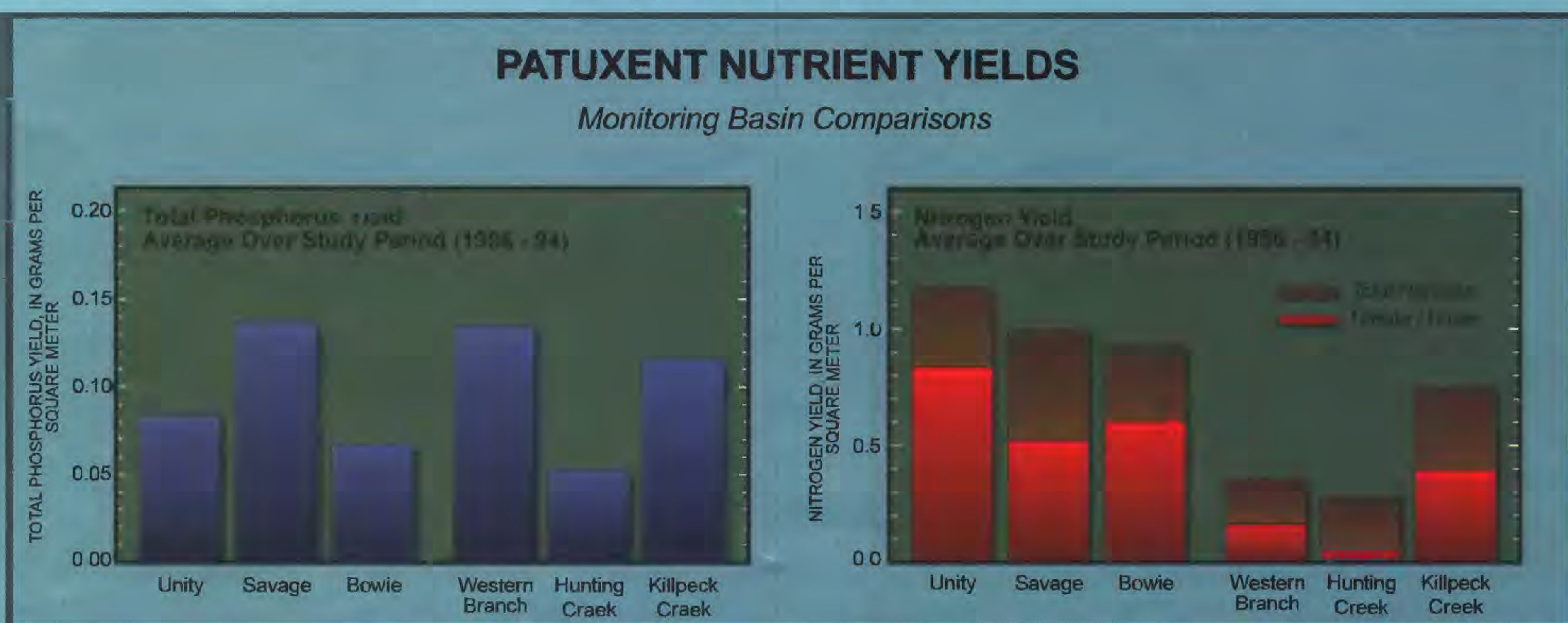

Figure 5. Nutrient loads at each site can be compared by calculating the nutrient yield (load divided by area). The differences among yields can then be related to differences in basin characteristics such as land use or the implementation of management practices.

The hydrologic component of the model is based on precipitation and other meteorologic variables, and directs water through multiple flow pathways to predict stream discharge. The water-quality component of the model simulates instream and land-surface biological and chemical processes such as plant nutrient uptake, denitrification, and sediment interactions.

The Patuxent watershed model is considered to be spatially detailed. The overall model is composed of segments among which input data and parameter values can vary. The model is composed of 39 segments that average approximately 20 square miles in size (fig. 6). Segmentation of the watershed was based upon many factors that affect the spatial variability of the model, such as data-collection locations, point-source locations and variations in basin characteristics such as land use.

The Patuxent watershed model was calibrated at all locations where load or discharge data were available. All of the long-term monitoring sites described above were used as hydrologic and water-quality calibration sites. In addition, data from five other stream-gaging stations were used for hydrologic calibration. The model was calibrated for various water-quality constituents including four forms of nitrogen, three forms of phosphorus, total suspended solids, dissolved oxygen, biological oxygen demand, and chlorophyll a.

Input to the model included meteorologic time series, point-source discharge time series, and geographic data. Hourly precipitation time series data were compiled from seven rainfall monitoring sites as input to the hydrologic component of the model. Discharge information from 33 point sources of nutrients in the watershed was included as input to stream reaches. Geographic information used in the model included land use, soils, and topography. Runoff from 20 types of land use, including 6 types of impervious area and 6 types of agricultural row crops, was simulated to predict nutrient inputs from nonpoint sources.

LOW-FLOW SYNOPTIC SAMPLING

Purpose and Approach

Synoptic sampling was performed to provide greater spatial detail on water-quality distributions in the Patuxent watershed. Differences were observed among the long-term monitoring sites, especially for nitrogen (fig. 5). To confirm these results, water-quality samples were collected at many sites in the Patuxent watershed at nearly the same time, but over a broad spatial scale (fig. 7).

Low-flow conditions were the primary emphasis of the Patuxent synoptic-sampling effort. Where point sources of nutrients are not present, low-flow conditions are generally indicative of ground-water input to streams (base flow). Spatial variations in base-flow water quality may be due to variations in ground-water quality that are also related to geologic, physiographic, or other environmental conditions. Low-flow synoptic sampling was intended to provide additional information for understanding the causes of water-quality spatial variations.

Samples were collected during August and September in each of water years 1993, 1994, and 1995. Summers are usually dry in the Patuxent watershed area and base flow usually dominates streamflow during August and September. During 1993, emphasis was placed on the Piedmont part of the watershed and most sampling locations were located in that physiographic province. During 1994 and 1995, emphasis was placed on the Coastal Plain part of the watershed and fewer streams were sampled in the Piedmont.

Selected Results of Nutrient Analyses

Results of nitrate analyses of samples collected during the synoptic sampling studies generally confirm the spatial patterns observed among the long-term monitoring sites. The nitrate distributions for each physiographic province and for each water year are shown in figure 8. As was observed for the long-term sites, nitrate values in the Piedmont part of the Patuxent watershed were consistently higher than those in the Coastal Plain. Median nitrate values were always more than 1.5 milligrams per liter (mg/L) in the Piedmont, but never exceeded 0.5 mg/L in the Coastal Plain. Nitrate exceeded 1.0 mg/L in 96 percent of the Piedmont samples and reached as high as 12 mg/L in one sample. Nitrate exceeded 1.0 mg/L in only 12 percent of the Coastal Plain samples and exceeded 2.0 mg/L in only 2 percent of the samples.

Several factors could cause the differences in nitrate concentrations between the two physiographic provinces. Land-use patterns differ and the percentage of agricultural land is higher in much of the Piedmont. The geology of the two provinces is also substantially different and ground-water flow and chemistry may differ as a result. Wetlands are more prevalent in the Coastal Plain and they may increase the potential for denitrification. Studies are underway to evaluate the potential causes of lower nitrate values in the Coastal Plain.

SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS

Study of nonpoint source (NPS) nutrient loading in Maryland has focused on the Patuxent River watershed because of its importance and representativeness. The evaluation of NPS nutrient loading in the watershed has been comprehensive and has included long-term monitoring, detailed watershed modeling, and synoptic sampling studies. A large amount of information has been compiled for the watershed and that information is being used to identify the primary controls of and efficient management strategies for NPS nutrient loading.

The Patuxent NPS studies have produced tools that will allow ongoing evaluations in the Patuxent River watershed and in the State of Maryland. The NPS evaluation tools generated by the Patuxent studies include extensive data bases and a detailed watershed model. These tools have provided information on the current status of water quality in the Patuxent watershed and on the controls of water quality and loads. The Patuxent data bases and watershed model have the potential to continue to provide information on water quality and nutrient loading. Thus, the cost of previous work in the Patuxent watershed represents an investment that can continue to aid the management of NPS nutrient loading in other areas of the State.

Results of the Patuxent NPS study components to date have identified many important aspects of NPS nutrient loading. Point sources of nutrients

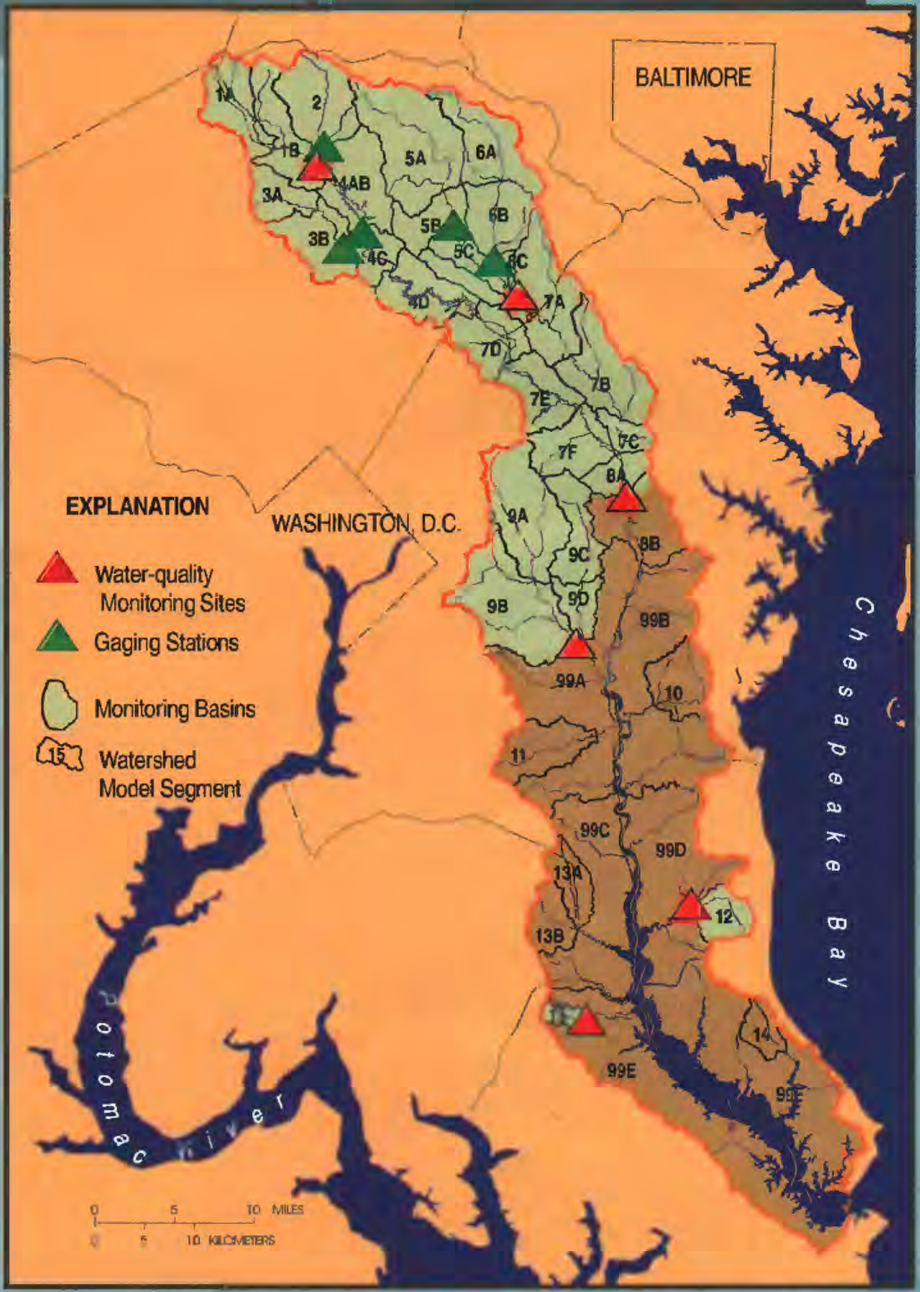

Figure 6. The Patuxent watershed model is designed to account for spatial variability in nutrient loading by dividing the basin into segments that can be calibrated seperately.

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control water quality of streams just above the point of tidal influence. However, land-use practices are most important at all other sampling locations. Sediment transport and ground-water discharge appear to be the most important mechanisms for phosphorus and nitrogen transport, respectively. Basin characteristics such as percentages of urban and agricultural areas, and type of geology affect those processes and are related to spatial variations identified by long-term and synoptic water-quality data-collection efforts. Ongoing evaluation of the collected data are expected to continue to provide information that will assist the management of NPS nutrient loading. In particular, ongoing evaluation of the watershed model output is expected to provide detailed information on the relative importance of nutrient sources and transport pathways.

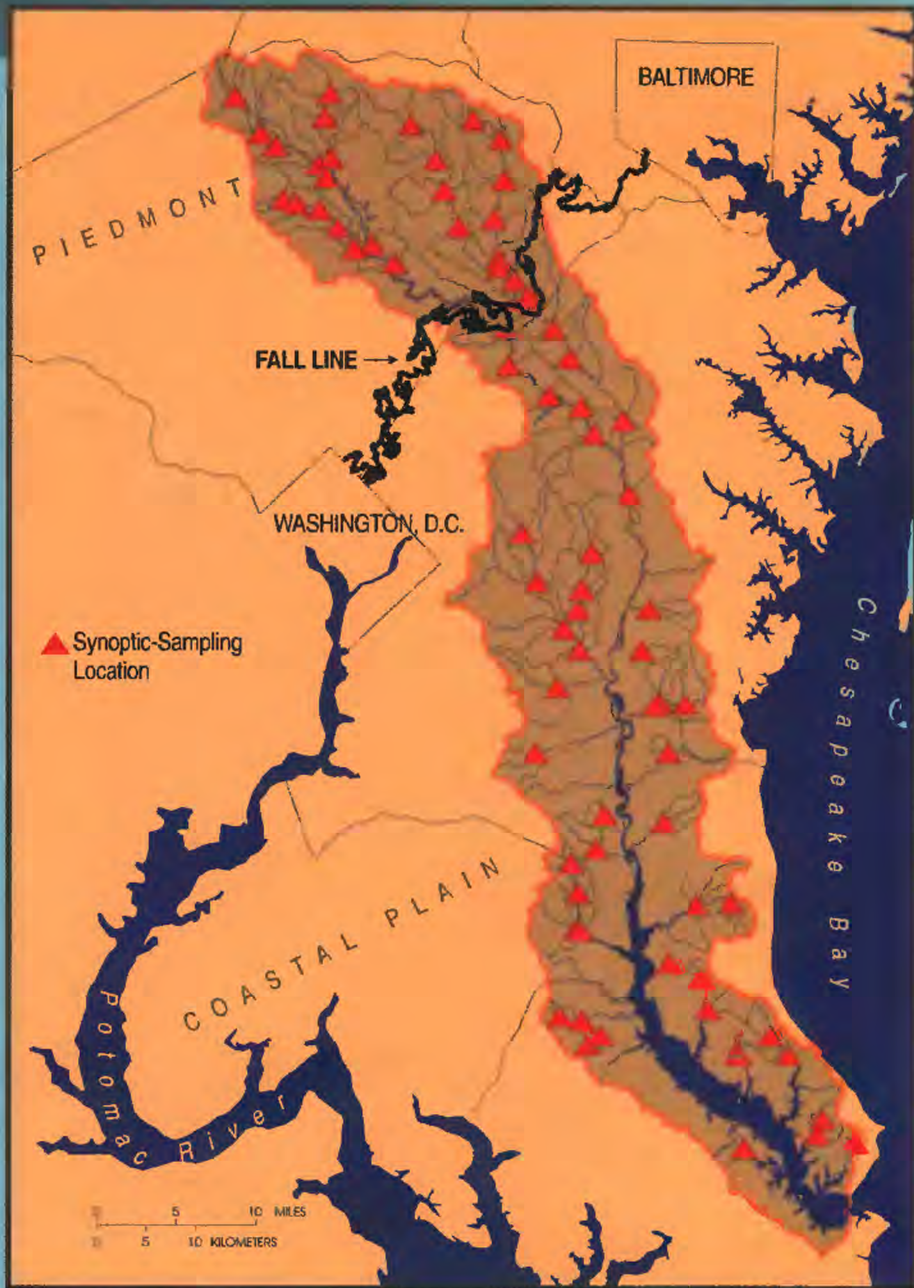

Figure 7. Low-flow synoptic sampling was performed at many sites across the Patuxent basin in order to detect spatial patterns in water quality.

Planned future directions of NPS evaluation in the State of Maryland include continued study of water quality in the Patuxent watershed and a shift in emphasis to a statewide approach. Long-term data collection in the Patuxent watershed is planned to continue in order to extend the data records for trend detection. However, future study will include other areas of the State to provide NPS information on a broader spatial scale. The statewide approach will eventually become the primary approach used by the State to evaluate NPS loading. The information gained in the Patuxent study and the tools developed will represent valuable assets in developing the statewide NPS assessment program.

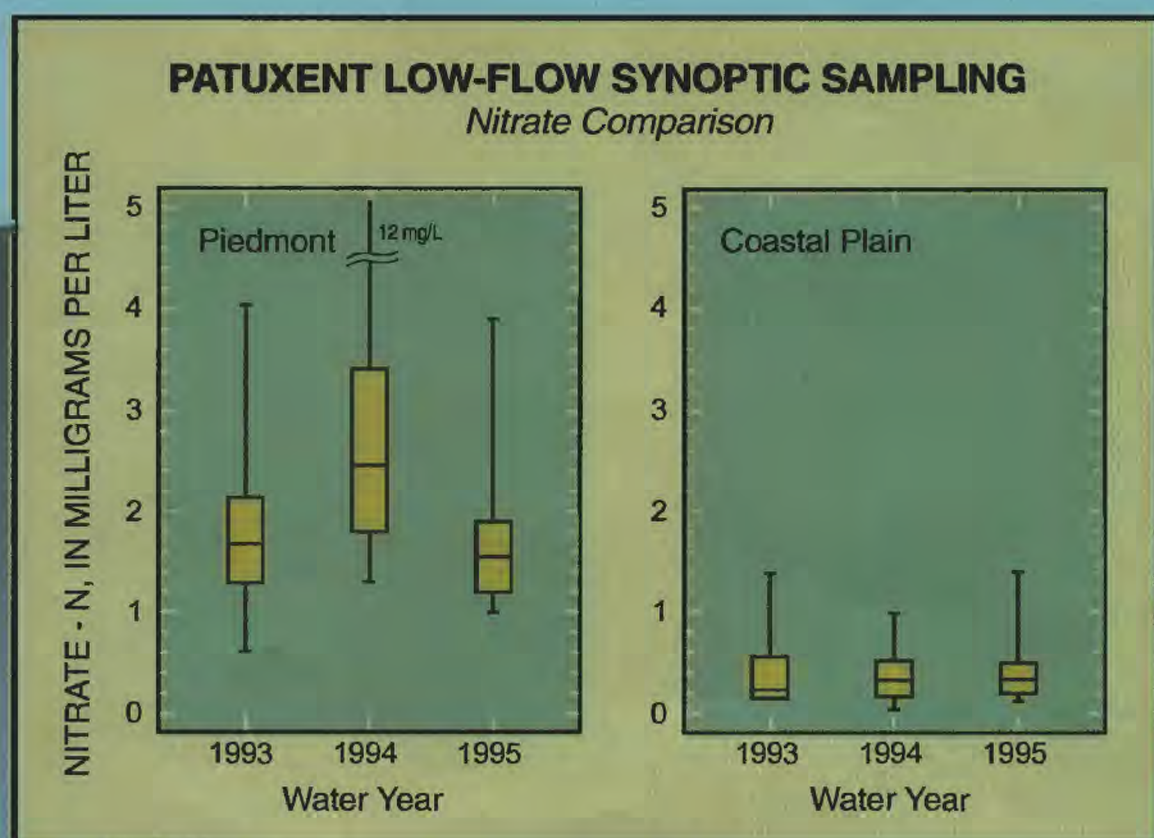

Figure 8. Base-flow nitrate concentrations tended to be lower at sites in the Coastal Plain than at sites in the Piedmont. The median nitrate value is illustrated as the centerline of each box and the 25th and 75th percentiles are illustrated as the top and bottom of each box. Lines extending above and below each box indicate the 90th and 10th percentiles, respectively.

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